MOTOROLA OPTOELECTRONICS DEVICE DATA

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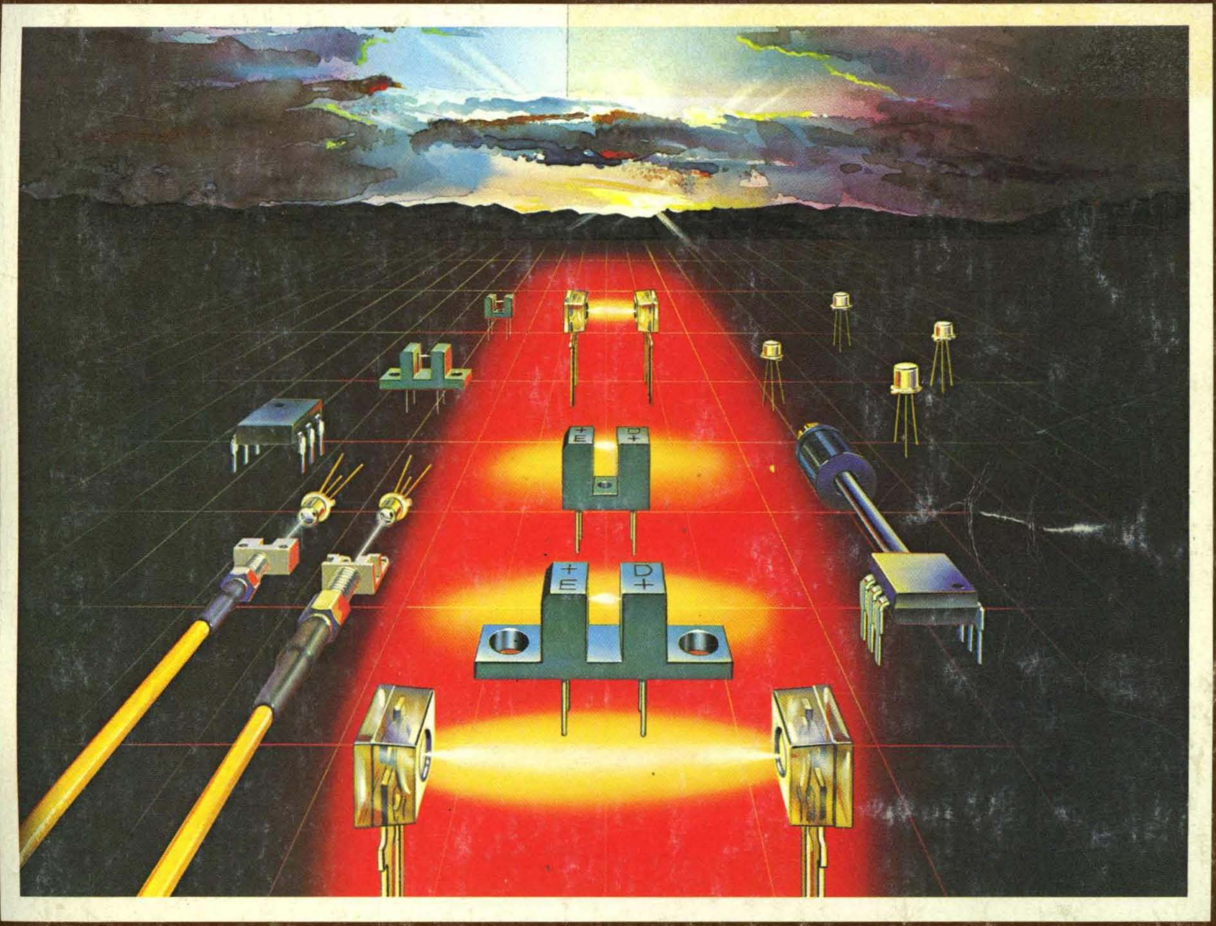

OPTOELECTRONICS DEVICE DATA

OPTOELECTRONICS

FIBER OPTICS

MOTOROLA
OPTOELECTRONIC DEVICE DATA

Prepared by
Technical Information Center

Motorola has concentrated on infrared, GaAs emitters, silicon detectors, high-technology optocoupler/isolators and an innovative approach to Fiber Optic components. This Optoelectronic Data Book contains up-to-date specifications on the complete product line.

The catalog is divided into the two major sections of Opto and Fiber Optics. The Table of Contents and Alphanumeric Index cover all products. Each section has its own General Information, Selector Guide, and Data Sheets.

All devices listed are available direct from Motorola and from Motorola's Authorized Distributors. Applications assistance and information on pricing and delivery are available from the nearest Motorola sales office.

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FIBER OPTICS

Alphanumeric Listing

This listing includes all devices in Motorola's Optoelectronics line. CTR, Current Transfer Ratio, is listed for each transistor and Darlington optocoupler to simplify locating a specific device in the Selector Guide where they are listed in order of ascending CTR.

Device	CTR %	Selector Guide Page #	Data Sheet Page #
Optocoupler, Transistor			
4N25	20	6	3-3
4N25A	20	6	3-3
4N26	20	6	3-3
4N27	10	6	3-3
4N28	10	6	3-3
Optocoupler, Darlington			
4N29	100	8	3-7
4N29A	100	8	3-7
4N30	100	8	3-7
4N31	50	8	3-7
4N32	500	8	3-7
4N32A	500	8	3-7
4N33	500	8	3-7
Optocoupler, Transistor			
4N35	100	7	3-11
4N36	100	7	3-11
4N37	100	7	3-11
Optocoupler, High Voltage Transistor			
4N38		9	3-15
4N38A		9	3-15
Optocoupler, SCR			
4N39		10	—
Optocoupler, Transistor			
CNY17-1	40	6	—
CNY17-2	63	6	—
CNY17-3	100	6	—
CNY17-4	160	6	—
H11A1	50	6	3-129
H11A2	20	6	3-129
H11A3	20	6	3-129
H11A4	10	6	3-129
H11A5	30	6	3-129
H11A520	20	6	3-129
H11A550	50	6	3-129
H11A5100	100	7	3-129
Optocoupler, AC Input, Transistor			
H11AA1		10	3-19
H11AA2		10	3-19
Optocoupler, Darlington			
H11B1	500	8	3-129
H11B2	200	8	3-129
H11B3	100	8	3-129
H11B255	100	8	3-129
Optocoupler, SCR			
H11C1		10	3-21
H11C2		10	3-21
H11C3		10	3-21
Optocoupler, High Voltage Transistor			
H11D1		9	3-24
H11D2		9	3-24
H11D3		9	3-24
H11D4		9	3-24
Optocoupler, Resistor Darlington			
H11G1		8	3-27
H11G2		8	3-27
H11G3		8	3-27
Optocoupler, Triac Driver			
H11J1		9	—
H11J2		9	—
H11J3		9	—
H11J4		9	—
H11J5		9	—
Optocoupler, Schmitt Trigger			
H11L1		10	3-31
H11L2		10	3-31

Device	CTR %	Selector Guide Page #	Data Sheet Page #
Slotted Coupler, Transistor			
H21A1		12	3-34
H21A2		12	3-34
H21A3		12	3-34
H22A1		12	3-34
H22A2		12	3-34
H22A3		12	3-34
Optocoupler, SCR			
H74C1		10	—
Optocoupler, Transistor			
IL1	20	6	3-129
IL12	10	6	3-129
IL74	12.5	6	3-129
Optocoupler, Darlington			
MCA230	100	8	3-129
MCA231	200	8	3-129
MCA255	100	8	3-129
Optocoupler, SCR			
MCS2		10	—
Optocoupler, Transistor			
MCT2	20	6	3-129
MCT2E	20	6	3-129
MCT26	6	6	3-129
MCT271	45	6	3-129
MCT272	75	7	3-129
MCT273	125	7	3-129
MCT274	225	7	3-129
MCT275	70	7	3-129
MCT277	40	6	3-129
MCT2200	20	6	—
MCT2201	100	7	—
Fiber Optics, Detector			
MFOD100		5	7-3
MFOD200		5	7-5
MFOD300		5	7-7
MFOD1100		5	7-9
MFOD2202		5	7-11
MFOD2302		5	7-13
MFOD2404		5	7-15
MFOD2405		5	7-17
Fiber Optics, Emitter			
MFOE200		5	7-19
MFOE1200		5	7-21
MFOE1201		5	7-23
MFOE1202		5	7-23
IRED			
MLED15		12	3-36
MLED71		12	3-38
MLED910		12	3-40
MLED930		12	3-42
Optocoupler, Darlington, No Base Connection			
MOC119		8	3-44
Optocoupler, VDE Transistor			
MOC601A		11	3-48
MOC602A		11	3-48
MOC603A		11	3-48
MOC604A		11	3-48
Optocoupler, VDE Darlington			
MOC622A		11	3-50
MOC623A		11	3-50
MOC624A		11	3-50
MOC625A		11	3-50
Optocoupler, VDE Darlington, No Base Connection			
MOC626A		11	3-50
MOC627A		11	3-50
MOC628A		11	3-50
MOC629A		11	3-50

Alphanumeric Listing (continued)

Device	CTR %	Selector Guide Page #	Data Sheet Page #
Optocoupler, VDE Triac Driver			
MOC633A		11	3-52
MOC634A		11	3-52
MOC635A		11	3-52
Optocoupler, VDE Triac Driver			
MOC640A		11	3-52
MOC641A		11	3-52
Optocoupler, Transistor			
MOC1005	20	6	3-54
MOC1006	10	6	3-54
Optocoupler, SCR			
MOC3002		10	3-58
MOC3003		10	3-58
MOC3007		10	3-58
Optocoupler, Triac Driver			
MOC3009		9	3-61
MOC3010		9	3-61
MOC3011		9	3-61
MOC3012		9	3-61
MOC3020		9	3-65
MOC3021		9	3-65
MOC3022		9	3-65
MOC3023		9	3-65
MOC3030		9	3-67
MOC3031		9	3-67
MOC3032		9	3-67
MOC3040		9	3-70
MOC3041		9	3-70
Optocoupler, Schmitt Trigger			
MOC5007		10	3-73
MOC5008		10	3-73
MOC5009		10	3-73
Optocoupler, AC Linear Amp.			
MOC5010		10	3-76
Slotted Coupler, Transistor			
MOC7811		12	3-78
MOC7812		12	3-78
MOC7813		12	3-78
MOC7821		12	3-78
MOC7822		12	3-78
MOC7823		12	3-78
Optocoupler, Darlington, No Base Connection			
MOC8020	500	8	3-80
MOC8021	1000	8	3-80
MOC8030	300	8	3-82
MOC8050	500	8	3-82
Optocoupler, Transistor			
MOC8100	50	6	3-86
Optocoupler, Transistor, No Base Connection			
MOC8111		7	3-90
MOC8112		7	3-90
MOC8113		7	3-90
Optocoupler, High Voltage Transistor			
MOC8204		9	3-94
MOC8205		9	3-94
MOC8206		9	3-94
Detector, Transistor			
MRD150		13	3-97
MRD300		13	3-100
MRD310		13	3-100
Detector, Darlington			
MRD360		13	3-104
MRD370		13	3-104

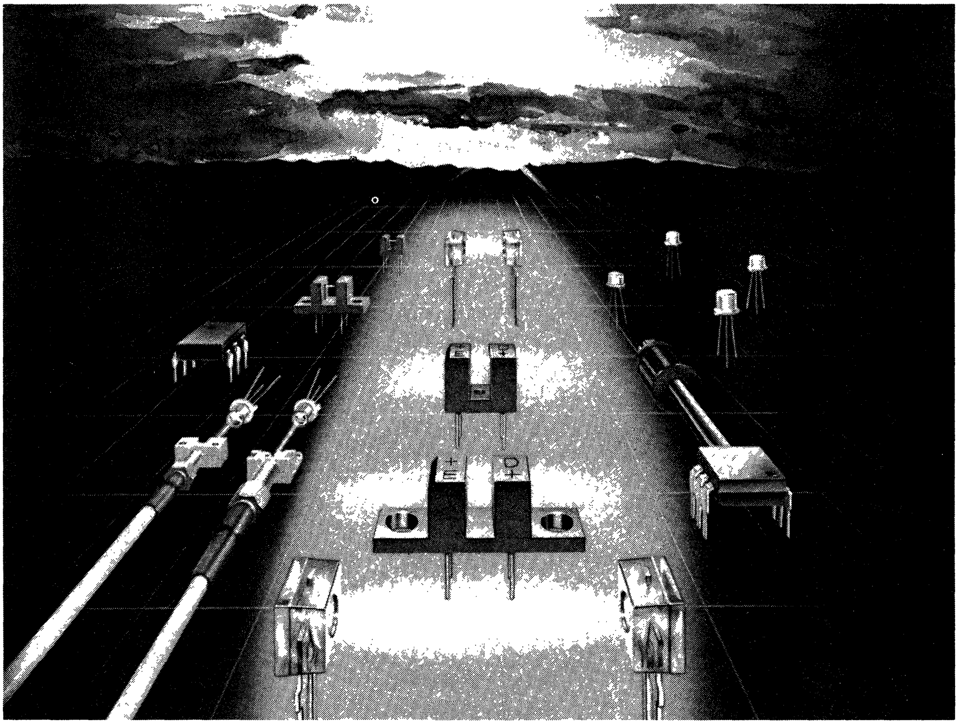
Device	CTR %	Selector Guide Page #	Data Sheet Page #
Detector, PIN			
MRD500		13	3-108
MRD510		13	3-108
Detector, Transistor			
MRD601		13	3-111
MRD602		13	3-111
MRD603		13	3-111
MRD604		13	3-111
MRD611		13	3-111
MRD612		13	3-111
MRD613		13	3-111
MRD614		13	3-111
MRD701		13	3-115
Detector, Resistor Darlington			
MRD711		13	3-117
Detector, PIN			
MRD721		13	3-119
Detector, Triac Driver			
MRD3010		14	3-122
MRD3011		14	3-122
Detector, Transistor			
MRD3050		13	3-125
MRD3051		13	3-125
MRD3054		13	3-125
MRD3055		13	3-125
MRD3056		13	3-125
Optocoupler, Transistor			
TIL111	8	6	3-129
TIL112	2	6	3-129
Optocoupler, Darlington			
TIL113	300	8	3-129
Optocoupler, Transistor			
TIL114	8	6	3-129
TIL115	2	6	3-129
TIL116	20	6	3-129
TIL117	50	6	3-129
Optocoupler, Transistor, No Base Connection			
TIL118		7	3-129
Optocoupler, Darlington, No Base Connection			
TIL119		8	3-129
Optocoupler, Transistor			
TIL124	10	6	3-129
TIL125	20	6	3-129
TIL126	50	6	3-129
Optocoupler, Darlington			
TIL127	300	8	3-129
Optocoupler, Darlington, No Base Connection			
TIL128		8	3-129
Optocoupler, Transistor			
TIL153	10	6	3-129
TIL154	20	6	3-129
TIL155	50	6	3-129
Optocoupler, Darlington			
TIL156	300	8	3-129
Optocoupler, Darlington, No Base Connection			
TIL157		8	3-129

OPTOELECTRONICS

General Information

Motorola Optoelectronic products include gallium arsenide infrared-emitting diodes, silicon photodetectors, optocouplers/isolators, and slotted coupler/interrupters. Fiber Optic components are presented in Sections 5 through 8. Motorola is a leader in high technology optocouplers as demonstrated in the 400 volt, zero-crossing triac drivers, the Schmitt trigger optocouplers, the 400 volt transistor optocouplers, and the isolation voltage of 7500 Vac peak, the highest available.

The broad optocoupler line includes nearly all the transistor, Darlington, SCR, triac driver, Schmitt trigger, high voltage transistor and linear output devices now available in the industry. All Motorola optocouplers are in the standard 6-pin DIP package. Each device is presented in the easy-to-use Selector Guide and is included in a detailed data sheet in a succeeding section.



The Motorola Spectrum of

OPTOELECTRONICS

INFRARED-LIGHT-EMITTING DIODES

The infrared-light-emitting diode emits radiation in the near infrared region when forward bias current (I_F) flows through the PN junction. The light output power (P_O) is a function of the drive current (I_F) and is measured in milliwatts.

Infrared-light-emitting diodes are used together with photosensors.

FIGURE 1

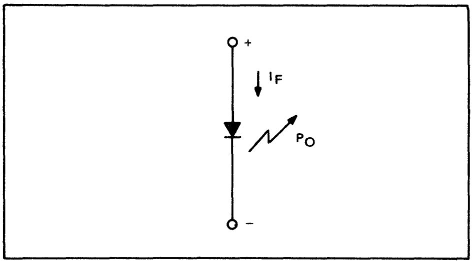
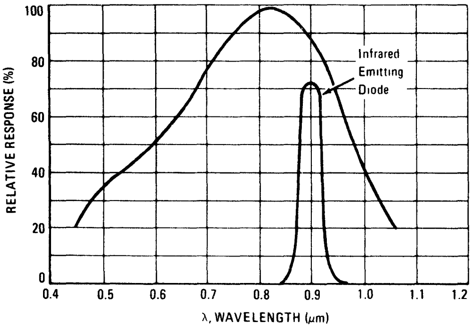


FIGURE 2 — Constant Energy Spectral Response



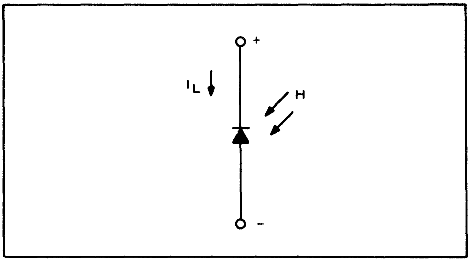
PHOTOSENSORS

Silicon photosensors respond to the entire visible radiation range as well as to the near infrared radiation range. The radiation response of a photosensor is a function of the material and the diffusion depth of the light-sensitive PN junction. All silicon photosensors (diodes, transistors, darlingtons, triacs) show the same basic radiation frequency response which peaks in the near infrared radiation range. Therefore, the sensitivity range of Motorola silicon sensors is ideally suited to Motorola infrared-emitting diodes.

Photodiodes

Radiation falling at the PN junction will generate hole electron pairs which cause the carriers to move, thus causing a current flow (I_L). The power density of the radiation H (measured in mW/cm^2) determines the current flow, I_L. At zero radiation, a small leakage current, called dark current (I_D) will remain.

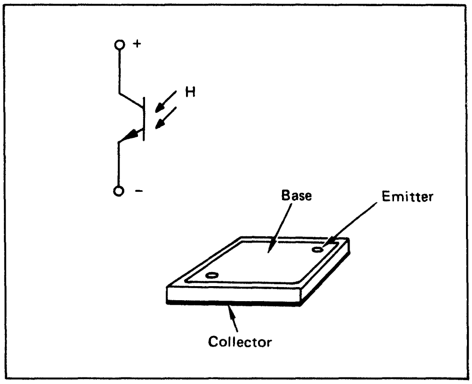
FIGURE 3



Phototransistors

The phototransistor is a light radiation controlled transistor. The collector base junction is enlarged and works as a reversed biased photodiode controlling the transistor. The collector current, I_L, depends on the radiation density (H) and the dc current gain of the transistor. Under dark condition, the transistor is switched off; the remaining leakage current, I_{CEO}, is called collector dark current.

FIGURE 4



Photodarlingtons

The photodarlington works on the same principle as a phototransistor. The collector base junction of the driver transistor is radiation sensitive and controls the driver transistor. The driver transistor controls the following transistor. The darlington configuration yields a high current gain which results in a photodetector with very high light sensitivity.

Phototriacs

The gate of the phototriac is radiation sensitive and triggers the triac at a certain specified radiation density (H). At dark condition, the triac is not triggered. The remaining leakage current is called peak blocking current (I_{DRM}). The device is bilateral and designed to switch ac signals.

FIGURE 5

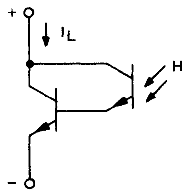
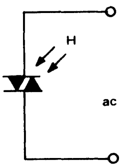


FIGURE 6



Optocouplers/Isolators

ISOLATORS

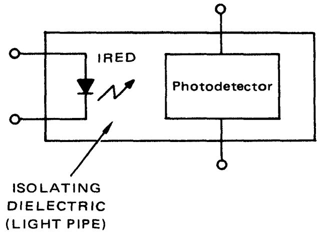
An optoelectronic isolator contains both an IRED and a photodetector in the same package, arranged so that energy radiated from the IRED is efficiently coupled to the detector through a clear, isolating dielectric. An opaque material surrounds the dielectric and provides ambient light protection.

Since there is no electrical connection between input and output, and since gallium-arsenide emitters and silicon detectors cannot reverse their roles, a signal is able to pass through the isolator in one direction only. To a degree determined by the package input-output capacitance and dielectric characteristics, the device is unresponsive to common mode input signals and provides input circuitry protection from the output circuit environment. Ground loop prevention, dc level shifting, and logic control of high voltage power circuitry are therefore typical areas where isolators are very useful.

The measure of an isolator's ability to efficiently pass a desired signal is most commonly referred to as Current Transfer Ratio (CTR). It is dependent upon the radiative efficiency of the IRED, the spacing between the IRED and the detector, the area and sensitivity of the detector, and the amplifying gain of the detector. It is subject to the nonlinearities (current, voltage, temperature) of both chips, causing a rather complex transfer function which should be evaluated closely when used at non-specified conditions.

The ability of an isolator to provide standoff protection is usually expressed as an Isolation Surge Voltage and is essentially a measure of the integrity of the package and the dielectric strength of the insulating materials.

FIGURE 7 – BASIC OPTO ISOLATOR (COUPLER)



ISOLATION VOLTAGE

The primary function of an optoelectronic isolator is to provide electrical separation between input and output, especially in the presence of high voltages. The amount of stress that an isolator can safely withstand and the stability of this protection varies considerably with package construction techniques used.

Figure 8 shows an older isolation technique, where the light transmission medium is a small amount of a clear, silicone-rubber type of material. Surrounding it is usually a black epoxy or phenolic compound. It has been found that the weakest point in this approach is the interface between the "light-pipe" and the overmold. It is a relatively short path between lead frames along this interface, and the two materials are dissimilar enough that the integrity of the interface is usually poor. This technique

ISOLATION VOLTAGE

FIGURE 8 — Standard

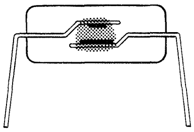
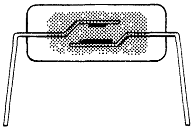


FIGURE 9 — Motorola



initially gives marginal standoff protection and stability under voltage stress is very poor.

Figure 9 shows Motorola's improved construction technique. The clear dielectric used here is a transfer-molded epoxy that encompasses a large volume of the interior of the package. The overmold is a transfer-molded opaque epoxy. The result is a much longer interface (typically ten times longer) between two very similar, electrically stable compounds. Minimum specified isolation voltage capability is 7500 volts ac peak on all Motorola isolators, and typical units provide in excess of 12,000 volts ac peak protection on a reliable, repeatable basis (in a clean and low humidity environment). External ambient conditions (humidity, cleanliness, etc.) tend to be the limiting factors when using Motorola isolators. Representative test data at typical applied voltages are shown below:

Test	No. of Units	Applied Voltage	Failure @ 1000 Hrs
A	100	1500 Vac peak	0
B	100	5000 Vdc peak	0

Isolation voltage has been specified in terms of both dc and ac conditions, sometimes with no associated test duration. In general, ac conditions are more severe than dc. Any imperfections or discontinuities in the isolating dielectric tend to have a lower dielectric constant than the surrounding areas and assume a disproportionate share of the total ac applied field, in the same manner that the smallest capacitance in a series string assumes the highest voltage drop under ac conditions. Microscopic ruptures can occur at these points, causing localized degradation and propagation of the weakened areas until large-scale puncture occurs. Dc fields tend to distribute more linearly. Additionally, ac fields are more effective in causing mobile impurities to align themselves and produce leakage paths.

Continuous ratings are therefore difficult to guarantee reliably as the result of individual unit testing or sorting. Instead, surge isolation voltage ratings should be specified with an associated test duration, while continuous ratings must be the result of a well-controlled, well-characterized assembly technique and realistic generic data. Since ac conditions are usually the most severe, it has become common to give them the most attention.

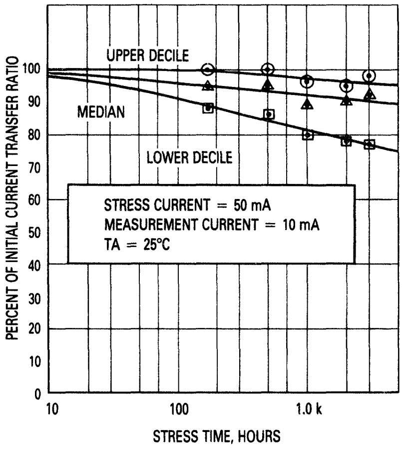
OPTOCOUPLER RELIABILITY

Motorola has demonstrated the reliability and quality of its optocouplers in the 6-pin DIP package. Details of an extensive evaluation are presented in "Reliability Report, Optocouplers," May 1981, and are summarized below.

IRED Life

The effectiveness of Motorola's approach to reliable and long-lived IREDs is monitored continuously by both routine weekly audits and long-term stress testing. Figure 10 shows the results of almost 1,500,000 device hours of accelerated testing. CTR lifetime projection exceeds 1 million hours based upon degradation of lower decile to 50% of initial value.

FIGURE 10 — Current Transfer Ratio versus Time



Optocoupler Environmental Stability

Stress tests have been performed on over 4000 optocouplers to characterize package performance under various environmental and mechanical conditions.

ENVIRONMENTAL TEST AND RESULTS

Test	No. of Units	No. of Rejects
Temperature Cycling Air-Air	1701	0
Thermal Shock Liquid	1400	0
Pressure Cooker	650	0
Impact Shock	130	0
Vibration Variable Frequency	130	0
Constant Acceleration	65	0

UNDERWRITERS' LABORATORIES RECOGNIZED

Most Motorola isolators are available under the Underwriters' Laboratories Component Recognition Program. It should be noted that applicable Motorola isolators are recognized for use in applications up to 240 Vac. Under the U.L. criteria, these devices must have passed isolation voltage tests at approximately 5000 volts ac peak for one second. In addition, Motorola tests every coupler to 7500 Vac peak for 5 seconds.

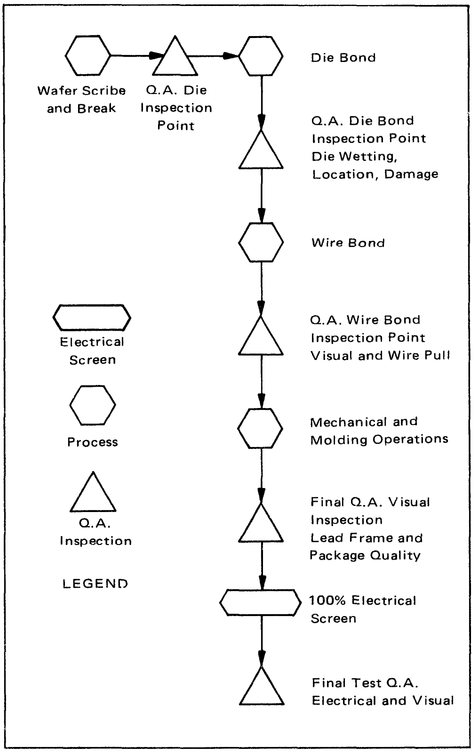
VDE APPROVED OPTOCOUPLERS

The Motorola MOC600A series of optocouplers has been approved by VDE per Test Certificate NR22762. They have passed the stringent safety requirement tests of the German VDE0883, an optocoupler standard which is accepted in most European countries. VDE guarantees the safety of this optocoupler family for applications up to 500 volts RMS line voltage. This family may be used in equipments per IEC380-VDE0806, IEC65-VDE860, IEC435-VDE0805 and per many other VDE equipment standards.

COUPLER PROCESS FLOW/QUALITY CHECK POINTS

Every optocoupler manufactured by Motorola undergoes extensive in-process checks for quality. After each process step (for example, die bond, encapsulation, electrical test, etc.) the product is randomly sampled. If the sample does not pass high-quality standards, the product flow is halted and corrective action is taken. In this manner, quality is built in at Motorola.

FIGURE 11 — Coupler Process Flow/Quality Check Points



SLOTTED COUPLERS/INTERRUPTERS

A slotted coupler consists of a gallium arsenide infrared emitting diode facing a silicon photodetector in a molded plastic housing. A slot in the housing between the emitter and the detector provides a means of interrupting the signal. Motorola offers several popular standard housings and has the capability to respond quickly to requirements for larger quantities of custom housings. These slotted couplers utilize emitters and detectors in the miniature, low profile Case 349. The combination of the wide selection of emitters and detectors and the number of different housings available presents a line of standard, off-the-shelf devices broad enough to meet most applications.

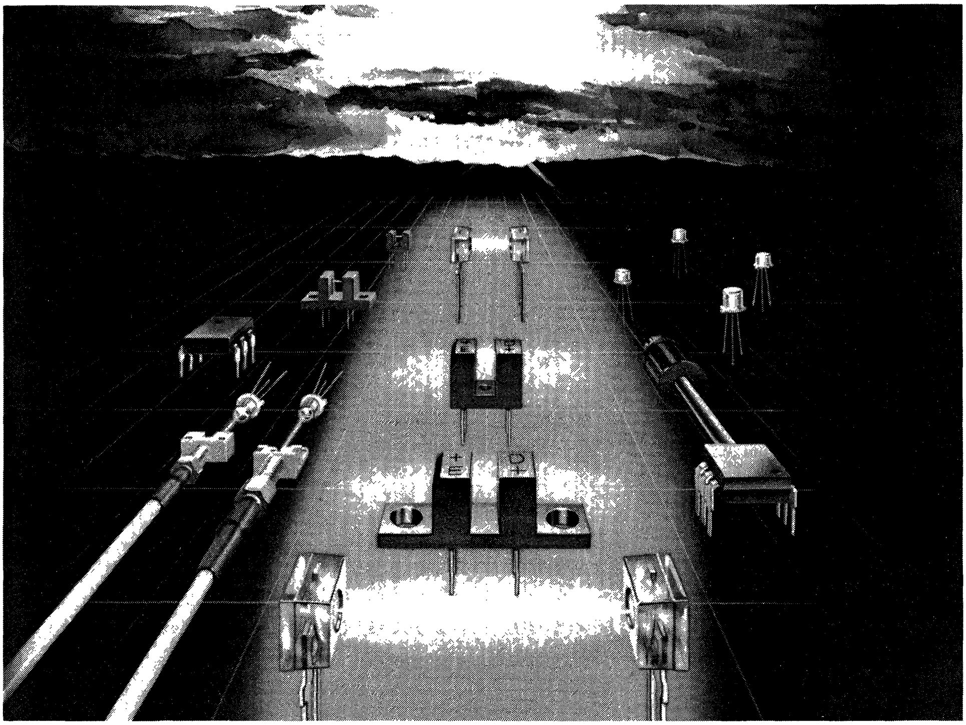
OPTOELECTRONIC DEFINITIONS, CHARACTERISTICS, AND RATINGS

CTR	Current Transfer Ratio — The ratio of output current to input current, at a specified bias, of an opto coupler.
dv/dt	Commutating dv/dt — A measure of the ability of a triac to block a rapidly rising voltage immediately after conduction of the opposite polarity. Coupled dv/dt — A measure of the ability of an opto thyristor coupler to block when the coupler is subjected to rapidly changing isolation voltage.
E	Luminous Flux Density (Illuminance) [lumens/ft.^{2} = ft. candles] — The radiation flux density of wavelength within the band of visible light.
H	Radiation Flux Density (Irradiance) [mW/cm^2] — The total incident radiation energy measured in power per unit area.
I_{CEO}	Collector Dark Current — The maximum current through the collector terminal of the device measured under dark conditions, (H ≈ 0), with a stated collector voltage, load resistance, and ambient temperature. (Base open)
I_D	Dark Current — The maximum reverse leakage current through the device measured under dark conditions, (H ≈ 0), with a stated reverse voltage, load resistance, and ambient temperature.
I_{FT}	Input Trigger Current — Emitter current necessary to trigger the coupled thyristor.
I_L	Collector Light Current — The device collector current measured under defined conditions of irradiance, collector voltage, load resistance, and ambient temperature.
R_s	Series Resistance — The maximum dynamic series resistance measured at stated forward current and ambient temperature.
SCR	Silicon Controlled Rectifier — A reverse blocking thyristor which can block or conduct in forward bias, conduction between the anode and cathode being initiated by forward bias of the gate cathode junction.
t_f	Photo Current Fall Time — The response time for the photo-induced current to fall from the 90% point to the 10% point after removal of the GaAs (gallium-arsenide) source pulse under stated conditions of collector voltage, load resistance and ambient temperature.
t_r	Photo Current Rise Time — The response time for the photo-induced current to rise from the 10% point to the 90% point when pulsed with the stated GaAs (gallium-arsenide) source under stated conditions of collector voltage, load resistance, and ambient temperature.
Triac	A thyristor which can block or conduct in either polarity. Conduction is initiated by forward bias of a gate-MTI junction.
T_{stg}	Storage Temperature
$V_{(BR)R}$	Reverse Breakdown Voltage — The minimum dc reverse breakdown voltage at stated diode current and ambient temperature.
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage — The minimum dc breakdown voltage, collector to base, at stated collector current and ambient temperature. (Emitter open and H ≈ 0)
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage — The minimum dc breakdown voltage, collector to emitter, at stated collector current and ambient temperature. (Base open and H ≈ 0)
$V_{(BR)ECO}$	Emitter-Collector Breakdown Voltage — The minimum dc breakdown voltage, emitter to collector, at stated emitter current and ambient temperature. (Base open and H ≈ 0)
V_{CBO}	Collector-Base Voltage — The maximum allowable value of the collector-base voltage which can be applied to the device at the rated temperature. (Base open)
V_{CEO}	Collector-Emitter Voltage — The maximum allowable value of collector-emitter voltage which can be applied to the device at the rated temperature. (Base open)
V_{ECO}	Emitter-Collector Voltage — The maximum allowable value of emitter-collector voltage which can be applied to the device at the rated temperature. (Base open)
V_F	Forward Voltage — The maximum forward voltage drop across the diode at stated diode current and ambient temperature.
V_{ISO}	Isolation Surge Voltage — The dielectric withstanding voltage capability of an optocoupler under defined conditions and time.
V_R	Reverse Voltage — The maximum allowable value of dc reverse voltage which can be applied to the device at the rated temperature.
λ_s(μm)	Wavelength of maximum sensitivity in micrometers.

OPTOELECTRONICS

Selector Guide and Cross-Reference

2



Optocoupler/Isolators

An optocoupler consists of a gallium arsenide infrared emitting diode, IRED, optically coupled to a monolithic silicon photodetector/output device in a light-shielding package. Motorola offers a wide array of standard devices in the popular 6-pin DIP

Transistor Output

Device Type	Current Transfer Ratio (CTR) % Min	@ I_F mA	V_{CE} Volts	V_{ISO} Volts ac Peak Industry	Motorola	$V_{CE(sat)}$ Volts Max	@ I_F mA	I_C mA	t_r, t_f/t_{on}, t_{off}* Typ μs	@ I_C mA	V_{CC} Volts	R_L Ω	I_F mA	$V_{(BR)CEO}$ Volts Min	V_F Volts Max	@ I_F mA	Case 730A-01 Style
TIL112	**2.0**	10	5.0	1500	7500	0.5	50	2.0	2.0	2.0	10	100		20	1.5	10	1
TIL115	**2.0**	10	5.0	2500	7500	0.5	50	2.0	2.0	2.0	10	100		20	1.5	10	1
MCT26	**6.0**	10	10	2500(R)	7500	0.3	20	0.25	2.0	2.0	10			30	1.5	20	1
TIL111	**8.0**	16	0.4	1500	7500	0.4	16	2.0	5.0	2.0	10	100		30	1.4	16	1
TIL114	**8.0**	16	0.4	2500	7500	0.4	16	2.0	5.0	2.0	10	100		30	1.4	16	1
4N27	**10**	10	10	1500	7500	0.5	50	2.0	2.0/8.0	10	10			30	1.5	10	1
4N28	**10**	10	10	500	7500	0.5	50	2.0	2.0/8.0	10	10			30	1.5	10	1
4N38,A	**10**	10	10	2500	7500	1.0	20	4.0	0.8/7.0	10	10			80	1.5	10	1
H11A4	**10**	10	10	1500	7500	0.4	10	0.5	2.0	2.0	10	100		30	1.5	10	1
IL-12	**10**	10	5.0	1000(D)	7500	0.5	50	2.0	2.0		10		10	20	1.5	10	1
MOC1006	**10**	10	10		7500	0.5	50	2.0	2.0/8.0	10	10			30	1.5	10	1
TIL124	**10**	10	10	5000	7500	0.4	10	1.0	2.0	2.0	10	100		30	1.4	10	1
TIL153	**10**	10	10	3540	7500	0.4	10	1.0	2.0	2.0	10	100		30	1.4	10	1
IL-74	**12.5**	16	5.0	1500(D)	7500	0.5	16	2.0	**6.0*/25***		**5.0***	**2.4k***	**16***	20	1.3	100	1
4N25,A	**20**	10	10	2500	7500	0.5	50	2.0	0.8/8.0	10	10			30	1.5	10	1
4N26	**20**	10	10	1500	7500	0.5	50	2.0	0.8/8.0	10	10			30	1.5	10	1
H11A2	**20**	10	10	1500	7500	0.4	10	0.5	2.0	2.0	10	100		30	1.5	10	1
H11A3	**20**	10	10	2500	7500	0.4	10	0.5	2.0	2.0	10	100		30	1.5	10	1
H11A520	**20**	10	10	5656	7500	0.4	20	2.0	**5.0***	**2.0***	**10***	**100***		30	1.5	10	1
IL-1	**20**	10	10	2500(D)	7500	0.5	16	1.6	6.0*/25*		5.0*	2.4k*	16*	30	1.5	60	1
MCT2	**20**	10	10	2500(R)	7500	0.4	16	2.0	**10*/30***		**5.0***	**2k***	**15***	30	1.5	20	1
MCT2E	**20**	10	10	3000(R)	7500	0.4	16	2.0	2.6	2.0	10	100		30	1.5	20	1
MCT2200	**20**	10	5.0	7500	7500	0.4	10	2.5	**6.0*/5.5***	**2.0***	**10***	**100***		30	1.5	60	1
MOC1005	**20**	10	10		7500	0.5	50	2.0	0.8/8.0	10	10			30	1.5	10	1
TIL116	**20**	10	10	2500	7500	0.4	15	2.2	5.0	2.0	10	100		30	1.5	60	1
TIL125	**20**	10	10	5000	7500	0.4	10	1.0	2.0	2.0	10	100		30	1.4	10	1
TIL154	**20**	10	10	3540	7500	0.4	10	1.0	2.0	2.0	10	100		30	1.4	10	1
H11A5	**30**	10	10	1500	7500	0.4	10	0.5	2.0	2.0	10	100		30	1.7	10	1
MCT277	**40**	16	0.4	3000(R)	7500				**15***	**2.0***	**5.0***	**100***		30	1.5	20	1
CNY17-1	**40–80**	10	5.0	7500	7500	0.4	10	2.5	**5.6*/4.1***		**5.0***	**75***	**10***	70	1.65	60	1
MCT271	**45–90**	10	10	3000(R)	7500	0.4	16	2.0	**4.9*/4.5***	**2.0***	**5.0***	**100***		30	1.5	20	1
MOC8100	**50**	1.0	5.0		7500	0.5	1.0	0.1	20*	2.0*	10*	100*		30	1.4	1.0	1
H11A1	**50**	10	10	2500	7500	0.4	10	0.5	2.0	2.0	10	100		30	1.5	10	1
H11A550	**50**	10	10	5656	7500	0.4	20	2.0	5.0*	2.0*	10*	100		30	1.5	10	1
TIL117	**50**	10	10	2500	7500	0.4	10	0.5	5.0	2.0	10	100		30	1.4	16	1
TIL126	**50**	10	10	5000	7500	0.4	10	1.0	2.0	2.0	10	100		30	1.4	10	1
TIL155	**50**	10	10	3540	7500	0.4	10	1.0	2.0	2.0	10	100		30	1.4	10	1
CNY17-2	**63–125**	10	5.0	5000	7500	0.4	10	2.5	**5.6*/4.1***		**5.0***	**75***	**10***	70	1.65	60	1

(R) = RMS (D) = DC *t_{on}, t_{off}

(Continued on next page)

package and encourages the use of special designs and selections for special applications. All Motorola optocouplers are UL Recognized per File Number 54915.

Transistor Output (continued)

Device Type	Current Transfer Ratio (CTR)			V_{ISO} Volts ac Peak		$V_{CE(sat)}$			t_r, t_f/t_{on}, t_{off}^* Typ					$V_{(BR)CEO}$ Volts Min	V_F		Case 730A-01
	% Min	@ I_F mA	V_{CE} Volts	Industry	Motorola	Volts Max	@ I_F mA	I_C mA	µs	@ I_C mA	V_{CC} Volts	R_L I_F	I_F mA		Volts Max	@ I_F mA	Style
MCT275	**70–210**	10	10	3000(R)	7500	0.4	16	2.0	**4.5*/3.5***	**2.0***	**5.0***	**100***		80	1.5	20	1
MCT272	**75–150**	10	10	3000(R)	7500	0.4	16	2.0	**6.0*/5.5**	**2.0***	**5.0***	**100***		30	1.5	20	1
4N35	**100**	10	10	3500	7500	0.3	10	0.5	**4.0***	**2.0***	**10***	**100***		30	1.5	10	1
4N36	**100**	10	10	2500	7500	0.3	10	0.5	**4.0***	**2.0***	**10***	**100***		30	1.5	10	1
4N37	**100**	10	10	1500	7500	0.3	10	0.5	**4.0***	**2.0***	**10***	**100***		30	1.5	10	1
H11A5100	**100**	10	10	5656	7500	0.4	20	2.0	**5.0***	**2.0***	**10***	**100***		30	1.5	10	1
MCT2201	**100**	10	5.0	7500	7500	0.4	10	2.5	**6.0*/5.5***	**2.0***	**10***	**100***		30	1.5	60	1
CNY17-3	**100–200**	10	5.0	5000	7500	0.4	10	2.5	**5.6*/4.1***		**5.0***	**75***	**10***	70	1.65	60	1
MCT273	**125–250**	10	10	3000(R)	7500	0.4	16	2.0	**7.6*/6.6***	**2.0***	**5.0***	**100***		30	1.5	20	1
CNY17-4	**160–320**	10	5.0	4000	7500	0.4	10	2.5	**5.6*/4.1***		**5.0***	**75***	**10***	70	1.65	60	1
MCT274	**225–400**	10	10	2500(R)	7500	0.4	16	2.0	**9.1*/7.9***	**2.0***	**5.0***	**100***		30	1.5	20	1

(R) = RMS (D) = DC $^*t_{on}$, t_{off}

Transistor Output with No Base Connection

Device Type	Current Transfer Ratio (CTR)			V_{ISO} Volts ac Peak		$V_{CE(sat)}$			t_r, t_f/t_{on}, t_{off}^* Typ					$V_{(BR)CEO}$ Volts Min	V_F		Case 730A-01
	% Min	@ I_F mA	V_{CE} Volts	Industry	Motorola	Volts Max	@ I_F mA	I_C mA	µs	@ I_C mA	V_{CC} Volts	R_L Ω	I_F mA		Volts Max	@ I_F mA	Style
TIL118	**10**	10	5.0	1500	7500	0.5	50	2.0	2.0	2.0	10	100		20	1.5	10	3
MOC8111	**20**	10	10		7500	0.4	10	0.5	**20*m**	**2.0***	**10***	**100***		30	1.5	10	3
MOC8112	**50**	10	10		7500	0.4	10	0.5	**20*m**	**2.0***	**10***	**100***		30	1.5	10	3
MOC8113	**100**	10	10		7500	0.4	10	0.5	**20*m**	**2.0***	**10***	**100***		30	1.5	10	3

$^*t_{on}$, t_{off}

Darlington Output

	Current Transfer Ratio (CTR)			V_{ISO} Volts ac Peak		$V_{CE(sat)}$			t_r, t_f/t_{on}, t_{off}* Typ					$V_{(BR)CEO}$ Volts Min	V_F		Case 730A-01
Device Type	% Min	@ I_F mA	V_{CE} Volts	Industry	Motorola	Volts Max	@ I_F mA	I_C mA	µs	@ I_C mA	V_{CC} Volts	R_L Ω	I_F mA		Volts Max	@ I_F mA	Style
4N31	**50**	10	10	1500	7500	1.2	8.0	2.0	**2*/25***	**50***	**10***		**200***	30	1.5	10	1
4N29,A	**100**	10	10	2500	7500	1.0	8.0	2.0	**2*/25***	**50***	**10***		**200***	30	1.5	10	1
4N30	**100**	10	10	1500	7500	1.0	8.0	2.0	**2*/25***	**50***	**10***		**200***	30	1.5	10	1
H11B3	**100**	1.0	5.0	2500	7500	1.0	1.0	1.0	**125*/100***	**10***	**10***	**100***		25	1.5	50	1
H11B255	**100**	10	5.0	1500	7500	1.0	50	50	**125*/100***	**10***	**10***	**100***		55	1.5	20	1
MCA230	**100**	10	5.0	4000(D)	7500	1.0	50	50	10/35		10	100	50	30	1.5	20	1
MCA255	**100**	10	5.0	4000(D)	7500	1.0	50	50	10/35		10	100	50	55	1.5	20	1
H11B2	**200**	1.0	5.0	2500	7500	1.0	1.0	1.0	**125*/100***	**10***	**10***	**100***		25	1.5	10	1
MCA231	**200**	1.0	1.0	4000(D)	7500	1.2	10	50	80	10	10	100		30	1.5	20	1
TIL113	**300**	10	1.0	1500	7500	1.0	50	125	300	125	15	100		30	1.5	10	1
TIL127	**300**	10	1.0	5000	7500	1.0	50	125	300	125	15	100		30	1.5	10	1
TIL156	**300**	10	1.0	3535	7500	1.0	50	125	300	125	15	100		30	1.5	10	1
4N32,A	**500**	10	10	2500	7500	1.0	8.0	2.0	**2*/60***	**50***	**10***		**200***	30	1.5	10	1
4N33	**500**	10	10	1500	7500	1.0	8.0	2.0	**2*/60***	**50***	**10***		**200***	30	1.5	10	1
H11B1	**500**	1.0	5.0	2500	7500	1.0	1.0	1.0	**125*/100***	**10***	**10***	**100***		25	1.5	10	1

Darlington Output with No Base Connection

	Current Transfer Ratio (CTR)			V_{ISO} Volts ac Peak		$V_{CE(sat)}$			t_r, t_f/t_{on}, t_{off}* Typ					$V_{(BR)CEO}$ Volts Min	V_F		Case 730A-01
Device Type	% Min	@ I_F mA	V_{CE} Volts	Industry	Motorola	Volts Max	@ I_F mA	I_C mA	µs	@ I_C mA	V_{CC} Volts	R_L Ω	I_F mA		Volts Max	@ I_F mA	Style
MOC119	**300**	10	2.0		7500	1.0	10	10	10/50	2.5	10	100		30	1.5	10	3
TIL119	**300**	10	2.0	1500	7500	1.0	10	10	300	2.5	10	100		30	1.5	10	3
TIL128	**300**	10	2.0	5000	7500	1.0	10	10	300	2.5	10	100		30	1.5	10	3
TIL157	**300**	10	2.0	3535	7500	1.0	10	10	300	2.5	10	100		30	1.5	10	3
MOC8030	**300**	10	1.5		7500				**13*/60***		**50***	**100***	**10***	80	2.0	10	3
MOC8020	**500**	10	5.0		7500				**13*/60***		**50***	**100***	**10***	50	2.0	10	3
MOC8050	**500**	10	1.5		7500				**13*/60***		**50***	**100***	**10***	80	2.0	10	3
MOC8021	**1000**	10	5.0		7500				**13*/60***		**50***	**100***	**10***	50	2.0	10	3

Resistor-Darlington Output

	Current Transfer Ratio (CTR)			V_{ISO} Volts ac Peak		$V_{CE(sat)}$			t_r, t_f/t_{on}, t_{off}* Typ					$V_{(BR)CEO}$ Volts Min	V_F		Case 730A-01
Device Type	% Min	@ I_F mA	V_{CE} Volts	Industry	Motorola	Volts Max	@ I_F mA	I_C mA	µs	@ I_C mA	V_{CC} Volts	R_L Ω	I_F mA		Volts Max	@ I_F mA	Style
H11G1	**1000**	10	1.0	3535	7500	1.0	1.0	1.0	**5.0/100**		**5.0**	**100**	**10**	100	1.5	10	1
H11G2	**1000**	10	1.0	3535	7500	1.0	1.0	1.0	**5.0/100**		**5.0**	**100**	**10**	80	1.5	10	1
H11G3	**200**	1.0	5.0	2125	7500	1.2	50	20	**5.0/100**		**5.0**	**100**	**10**	55	1.5	10	1

(R) = RMS (D) = DC *t_{on}, t_{off}

High Voltage Transistor Output

Device Type	Current Transfer Ratio (CTR) % Min	@ I_F mA	V_{CE} Volts	V_{ISO} Volts ac Peak Industry	Motorola	$V_{CE(sat)}$ Volts Max	@ I_F mA	I_C mA	t_r, t_f/t_{on}, t_{off}* Typ µs	@ I_C mA	V_{CC} Volts	R_L Ω	I_F mA	$V_{(BR)CEO}$ Volts Min	V_F Volts Max	@ I_F mA	Case 730A-01 Style
MOC8204	**20**	10	10		7500	0.4	10	0.5	**5.0***	**2.0***	**10***	**100***		400	1.5	10	1
MOC8205	**10**	10	10		7500	0.4	10	0.5	**5.0***	**2.0***	**10***	**100***		400	1.5	10	1
MOC8206	**5.0**	10	10		7500	0.4	10	0.5	**5.0***	**2.0***	**10***	**100***		400	1.5	10	1
H11D1	**20**	10	10	3500	7500	0.4	10	0.5	**5.0***	**2.0***	**10***	**100***		300	1.5	10	1
H11D2	**20**	10	10	2500	7500	0.4	10	0.5	**5.0***	**2.0***	**10***	**100***		300	1.5	10	1
H11D3	**20**	10	10	2500	7500	0.4	10	0.5	**5.0***	**2.0***	**10***	**100***		200	1.5	10	1
H11D4	**10**	10	10	2500	7500	0.4	10	0.5	**5.0***	**2.0***	**10***	**100***		200	1.5	10	1
4N38	**10**	10	10	1500	7500	1.0	20	4.0	0.8/7.0	10	10			80	1.5	10	1
4N38A	**10**	10	10	2500	7500	1.0	20	4.0	0.8/7.0	10	10			80	1.5	10	1
MCT275	**70–210**	10	10	3000(R)	7500	0.4	16	2.0	**4.5*/3.5***	**2.0***	**5.0***	**100***		80	1.5	20	1

Triac Driver Output

Device	Peak Blocking Voltage Min	LED Trigger Current-I_{FT} (V_{TM} = 3.0 V) mA Max	Zero Crossing Inhibit Voltage (at rated I_{FT}) Volts Max	Surge Isolation Voltage Vac pk Min Industry	Motorola	dv/dt V/µs Typ	Case 730A-01 Style
H11J1	250	10	—	5656	7500	12	6
H11J2	250	15	—	5656	7500	12	6
H11J3	250	10	—	3535	7500	12	6
H11J4	250	15	—	3535	7500	12	6
H11J5	250	25	—	2120	7500	12	6
MOC3009	250	30	—		7500	12	6
MOC3010	250	15	—		7500	12	6
MOC3011	250	10	—		7500	12	6
MOC3012	250	5.0	—		7500	12	6
MOC3020	400	30	—		7500	12	6
MOC3021	400	15	—		7500	12	6
MOC3022	400	10	—		7500	12	6
MOC3023	400	5.0	—		7500	12	6
MOC3030	250	30	25		7500	100	6
MOC3031	250	15	25		7500	100	6
MOC3032	250	10	25		7500	100	6
MOC3040	400	30	40		7500	100	6
MOC3041	400	15	40		7500	100	6

SCR Output

Device	Peak Blocking Voltage Min Volts	LED Trigger Current-I_{FT} (V_{AK} = 50 V) mA Max	Surge Isolation Voltage Vac pk Min Industry	Surge Isolation Voltage Vac pk Min Motorola	dv/dt V/µs Typ	Case 730A-01 Style
4N39	200	30	1500	7500	500 Min	7
H11C1	200	20	3535	7500	500 Min	7
H11C2	200	20	2500	7500	500 Min	7
H11C3	200	30	2500	7500	500 Min	7
H74C1	200	(TTL drive)	2500	7500		7
MCS2	200	14(V_{AK} = 100)	3000 RMS	7500		7
MOC3002	250	30		7500	500	7
MOC3003	250	20		7500	500	7
MOC3007	200	40		7500	500	7

Schmitt Trigger Output

Device	Threshold Current ON mA Max	Threshold Current OFF mA Min	$I_{F(off)}/I_{F(on)}$ Min	$I_{F(off)}/I_{F(on)}$ Max	V_{CC} Min	V_{CC} Max	t_r, t_f µs Typ	V_{ISO} Vac pk Min Industry	V_{ISO} Vac pk Min Motorola	Case 730A-01 Style
H11L1	1.6	0.3	0.5	0.9	3.0	15	0.1	3535	7500	5
H11L2	10	0.3	0.5	0.9	3.0	15	0.1	3535	7500	5
MOC5007	1.6	0.3	0.5	0.9	3.0	15	0.1		7500	5
MOC5008	4.0	0.3	0.5	0.9	3.0	15	0.1		7500	5
MOC5009	10	0.3	0.5	0.9	3.0	15	0.1		7500	5

AC Input — Transistor Output

Device Type	Current Transfer Ratio (CTR) % Min	@ I_F mA	V_{CE} Volts	V_{ISO} Volts ac Peak Industry	V_{ISO} Volts ac Peak Motorola	$V_{CE(sat)}$ Volts Max	@ I_F mA	I_C mA	$V_{(BR)CEO}$ Volts Min	V_F Volts Max	@ I_F mA	Case 730A-01 Style
H11AA1	**20**	±10	10	2500	7500	0.4	±10	0.5	30	1.5	±10	8
H11AA2	**10**	±10	10	2500	7500	0.4	±10	0.5	30	1.5	±10	8

AC Input — Linear Amplifier Output

Device	Transfer Gain (V_{CC} = 12 V) mV/mA Typ	Single Ended Distortion (V_{CC} = 12 V) (I_{sig} = 1.0 mA) % Typ	V_{ISO} Vac pk Min	Case 730A-01 Style
MOC5010	200	0.2	7500	5

VDE Approved Optocouplers

Transistor Output

Device Type	Current Transfer Ratio (CTR) % Min	@ I_F mA	V_{CE} Volts	V_{ISO} Volts ac Peak Industry	Motorola	$V_{CE(sat)}$ Volts Max	@ I_F mA	I_C mA	t_r, t_f/t_{on}, t_{off}* Typ µs	@ I_C mA	V_{CC} Volts	R_L Ω	I_F mA	$V_{(BR)CEO}$ Volts Min	V_F Volts Max	@ I_F mA	Case 730A-01 Style
MOC601A	**10**	10	10		7500	0.5	50	2.0	**8.0***	**2.0***	**10***	**100***		30	1.5	10	1
MOC602A	**20**	10	10		7500	0.5	50	2.0	**8.0***	**2.0***	**10***	**100***		30	1.5	10	1
MOC603A	**50**	10	10		7500	0.5	50	2.0	**8.0***	**2.0***	**10***	**100***		30	1.5	10	1
MOC604A	**100**	10	10		7500	0.5	50	2.0	**8.0***	**2.0***	**10***	**100***		30	1.5	10	1

Darlington Output

Device Type	Current Transfer Ratio (CTR) % Min	@ I_F mA	V_{CE} Volts	V_{ISO} Volts ac Peak Industry	Motorola	$V_{CE(sat)}$ Volts Max	@ I_F mA	I_C mA	t_r, t_f/t_{on}, t_{off}* Typ µs	@ I_C mA	V_{CC} Volts	R_L Ω	I_F mA	$V_{(BR)CEO}$ Volts Min	V_F Volts Max	@ I_F mA	Case 730A-01 Style
MOC622A	**100**	10	10		7500	1.0	8.0	2.0	**15*/60***	**50***	**10***	**100***	**200***	30	1.5	10	1
MOC623A	**300**	10	10		7500	1.0	8.0	2.0	**15*/60***	**50***	**10***	**100***	**200***	30	1.5	10	1
MOC624A	**500**	10	10		7500	1.0	8.0	2.0	**15*/60***	**50***	**10***	**100***	**200***	30	1.5	10	1
MOC625A	**1000**	10	10		7500	1.0	8.0	2.0	**15*/60***	**50***	**10***	**100***	**200***	30	1.5	10	1

Darlington Output with No Base Connection

Device Type	Current Transfer Ratio (CTR) % Min	@ I_F mA	V_{CE} Volts	V_{ISO} Volts ac Peak Industry	Motorola	$V_{CE(sat)}$ Volts Max	@ I_F mA	I_C mA	t_r, t_f/t_{on}, t_{off}* Typ µs	@ I_C mA	V_{CC} Volts	R_L Ω	I_F mA	$V_{(BR)CEO}$ Volts Min	V_F Volts Max	@ I_F mA	Case 730A-01 Style
MOC626A	**100**	10	10		7500	1.0	8.0	2.0	**15*/60***	**50***	**10***	**100***	**200***	30	1.5	10	3
MOC627A	**300**	10	10		7500	1.0	8.0	2.0	**15*/60***	**50***	**10***	**100***	**200***	30	1.5	10	3
MOC628A	**500**	10	10		7500	1.0	8.0	2.0	**15*/60***	**50***	**10***	**100***	**200***	30	1.5	10	3
MOC629A	**1000**	10	10		7500	1.0	8.0	2.0	**15*/60***	**50***	**10***	**100***	**200***	30	1.5	10	3

Triac Driver Output

Device	Peak Blocking Voltage Min	LED Trigger Current, I_{FT} (V_{TM} = 3.0 V) mA Max	Zero Crossing Inhibit Voltage (at rated I_{FT}) Volts Max	Surge Isolation Voltage Vac pk Min	dv/dt V/µs Typ	Case 730A-01 Style
MOC633A	400	30	—	7500	10	6
MOC634A	400	15	—	7500	10	6
MOC635A	400	10	—	7500	10	6
MOC640A	400	30	40	7500	1000	6
MOC641A	400	15	40	7500	1000	6

Slotted Couplers/Interrupter Modules

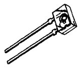
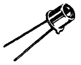
Slotted couplers consist of an infrared emitting diode facing a photodetector in a molded plastic housing. A slot in the housing between the emitter and the detector provides a means of interrupting the signal. A wide selection of standard and custom housings and detector functions is available. All IREDs and photodetectors in the miniature Case 349 (see Silicon Photodetectors) can be used in these housings.

Transistor Output ($V_{(BR)CEO}$ = 30 V)

		Current Transfer Ratio (CTR)			$V_{CE(sat)}$			t_{on}, t_{off} Typ				V_F	
Package	Device	% Min	@ I_F mA	V_{CE} Volts	Volts Max	@ I_F mA	I_C mA	μs	V_{CC} Volts	R_L Ω	I_F mA	Volts Max	@ I_F mA
354A-01 	H21A1	5.0	20	5.0	0.4	30	1.8	12/60	5.0	2.5K	30	1.7	60
	H21A2	10	20	5.0	0.4	20	1.8	12/60	5.0	2.5K	30	1.7	60
	H21A3	20	20	5.0	0.4	20	1.8	12/60	5.0	2.5K	30	1.7	60
354-01 	H22A1	5.0	20	5.0	0.4	30	1.8	12/60	5.0	2.5K	30	1.7	60
	H22A2	10	20	5.0	0.4	20	1.8	12/60	5.0	2.5K	30	1.7	60
	H22A3	20	20	5.0	0.4	20	1.8	12/60	5.0	2.5K	30	1.7	60
354A-01 	MOC7811	5.0	20	5.0	0.4	30	1.8	12/60	5.0	2.5K	30	1.8	50
	MOC7812	10	20	5.0	0.4	20	1.8	12/60	5.0	2.5K	30	1.8	50
	MOC7813	20	20	5.0	0.4	20	1.8	12/60	5.0	2.5K	30	1.8	50
354-01 	MOC7821	5.0	20	5.0	0.4	30	1.8	12/60	5.0	2.5K	30	1.8	50
	MOC7822	10	20	5.0	0.4	20	1.8	12/60	5.0	2.5K	30	1.8	50
	MOC7823	20	20	5.0	0.4	20	1.8	12/60	5.0	2.5K	30	1.8	50

Infrared Emitting Diodes

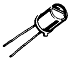
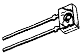
Motorola's infrared emitting diodes are made by the liquid phase epitaxial process for long life and stability. They provide high power output and quick response at 930 nm with low input drive current.

Package	Device	Power Output μW Typ	@ I_F mA	Emission Angle Typ	Peak Emission Wavelength nm Typ	Forward Voltage Max	@ I_F mA
 Actual Size  Case 173-01 Plastic Style 2	MLED15	1300	30	145°	930	1.5	30
 Actual Size  Case 349-01 Plastic Style 1	MLED71	2500	50	60°	940	1.8	50
 Actual Size  Case 81A-06 Metal Style 2	MLED910	150	50	30°	900	1.5	50
 Actual Size  Case 209-01 Metal Style 1	MLED930	650	100	30°	900	1.5	50

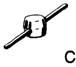
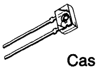
Silicon Photodetectors

A variety of silicon photodetectors are available, varying from simple PN diodes to complex, single chip 400 volt triac drivers. They are available in packages offering choices of viewing angle and size in either economical plastic cases or rugged, hermetic metal cans. They are spectrally matched for use with Motorola infrared emitting diodes.

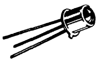
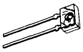
Photodiodes

Package	Type Number	Light Current μA Typ	@ V_R Volts	H mW/cm²	$V_{(BR)R}$ Volts Min	Dark Current nA Max	@ Volts	Response Time ns Typ
Actual Size   Case 209-02 Metal Convex Lens	MRD500	9.0	20	5.0	100	2.0	20	1.0
Actual Size   Case 210-01 Metal Flat Lens	MRD510	2.0	20	5.0	100	2.0	20	1.0
Actual Size   Case 349-01 Plastic, Style 1	MRD721	4.0	20	5.0	100	10	20	1.0

Phototransistors

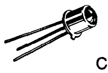
Package	Type Number	Light Current mA Typ	@ V_{CC}	H mW/cm²	$V_{(BR)CEO}$ Volts Min	t_r, t_f/t_{on}, t_{off}* μs	Typ @ V_{CC}	I_L μA
Actual Size   Case 173-01 Plastic, Style 1	MRD150	2.2	20	5.0	40	2.5/4.0	20	1000
 Case 82-05 Metal, Style 1 Actual Size 	MRD310	3.5	20	5.0	50	2.0/2.5	20	1000
	MRD300	8.0	20	5.0	50	2.0/2.5	20	1000
	MRD3050	0.1 Min	20	5.0	30	2.0/2.5	20	1000
	MRD3051	0.2 Min	20	5.0	30	2.0/2.5	20	1000
	MRD3054	0.5 Min	20	5.0	30	2.0/2.5	20	1000
	MRD3055	1.5 Min	20	5.0	30	2.0/2.5	20	1000
	MRD3056	2.0 Min	20	5.0	30	2.0/2.5	20	1000
Actual Size   Case 81A-06 Metal, Style 1* Case 81A-07 Metal, Style 1	MRD601, 611*	1.5	5.0	20	50	1.5/15	30	800
	MRD602, 612*	3.5	5.0	20	50	1.5/15	30	800
	MRD603, 613*	6.0	5.0	20	50	1.5/15	30	800
	MRD604, 614*	8.5	5.0	20	50	1.5/15	30	800
Actual Size   Case 349-01 Plastic, Style 2	MRD701	0.5	5.0	0.5	30	10/60*	5.0*	

Photodarlingtons

Package	Type Number	Light Current mA Typ	@ V_{CC}	H mW/cm²	$V_{(BR)CEO}$ Volts Min	t_r, t_f/t_{on}, t_{off}* μs	Typ @ V_{CC}	I_L μA
Actual Size   Case 82-05 Metal, Style 1	MRD370	10	5.0	0.5	40	15/40	5.0	1.0
	MRD360	20	5.0	0.5	40	15/65	5.0	1.0
Actual Size   Case 349-01 Plastic, Style 2	MRD711(1)	25	5.0	0.5	60	125/150*	5.0*	

(1)Photodarlington with integral base-emitter resistor.

Photo Triac Drivers

Package	Type Number	Latching Irradiance Level H_{FT} mW/cm² Max	On-State RMS Current mA Max	Off-State Output Terminal Voltage Volts Peak Min	Peak Blocking Current nA Typ
Actual Size   Case 82-05 Metal, Style 3	MRD3010	5.0	100	250	10
	MRD3011	2.0	100	250	10

CROSS-REFERENCE

The following cross-reference is meant to serve as a substitution guide for existing competitive devices to Motorola's optoelectronic product line.

Motorola's nearest equivalent devices are selected on the basis of general similarity of electrical characteristics and mechanical configuration. Interchangeability in particular applications is not guaranteed. Before using a substitute, please compare the detailed specifications of the substitute device to the data sheet of the original device.

In the event the device we recommend does not exactly meet your needs, we encourage you to refer to the Selector Guide for another device from the same line source which will have similar characteristics, or contact your nearest distributor or Motorola sales office for further information.

CODE

A = Direct Replacement
B = Minor Electrical Difference
C = Minor Mechanical Difference
D = Significant Electrical Difference
E = Significant Mechanical Difference

Cross-Reference

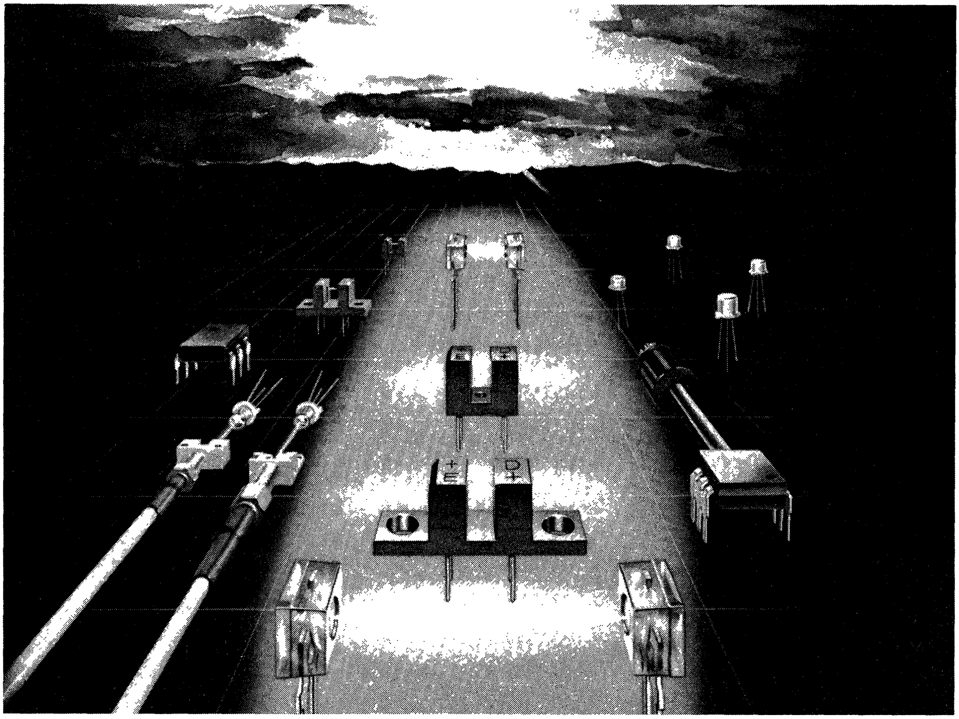
Industry Device	Motorola Equivalent	Code
BP101	MRD3050	C
BP102	MRD3050	C
BPW14	MRD300	A
BPW15	MRD602	A
BPW24	MRD701	E
BPW30	MRD360	A
BPX25A	MRD370	A
BPX25	MRD300	A
BPX29A	MRD370	A
BPX29	MRD310	A
BPX37	MRD300	A
BPX38	MRD3055	A
BPX43	MRD300	A
BPX58	MRD300	A
BPX59	MRD360	A
BPX62-1	MRD601	A
BPX62-2	MMD602	A
BPX62-3	MRD603	A
BPX62-4	MRD604	A
BPY62	MRD3055	A
CL100	MLED930	B
CL110	MLED930	A
CL110A	MLED930	A
CL110B	MLED930	B
CLI-2	4N38	B
CLI-3	4N35	B
CLI-5	4N26	A
CLI-10	4N33	B
CLR2050	MRD3050	A
CLR2060	MRD360	A
CLR2110	MRD310	A
CLR2140	MRD310	A
CLR2150	MRD300	A
CLR2160	MRD300	A
CLR2170	MRD370	A
CLR2180	MRD360	A
CLT3020	MRD601	A
CLT3030	MRD602	A
CLT3160	MRD603	A
CLT3170	MRD604	A
CLT4020	MRD601	E
CLT4030	MRD602	E
CLT4060	MRD603	E
CLT4070	MRD604	E
CNY17	CNY17	A
CNY18	4N25	A
CNY21	4N25	E
CQY10	MLED930	B
CQY11, B, C	MLED930	B
CQY12, B	MLED930	B
CQY13	4N26	B
CQY14	4N25	B
CQY15	4N26	B
CQY31	MLED930	B
CQY32	MLED930	B
CQY40, 41	4N26	A
CQY80	MOC1005	B
EP2	4N26	B
EPY62-1	MRD3055	A
EPY62-2	MRD3056	A
EPY62-3	MRD310	A
FCD810,A	4N28	A
FCD810, B, C, D	4N28	A
FCD820, A	TIL116	A
FCD820, B	TIL116	A
FCD820, C, D	TIL116	A
FCD825, A	TIL117	B
FCD825, B	TIL117	B
FCD825,C, D	TIL117	B
FCD830, A	TIL116	B
FCD830, B	TIL116	B
FCD830, C, D	TIL116	B
FCD831, A	TIL116	B
FCD831, B	TIL116	B
FCD831, C, D	TIL116	B
FCD836	4N28	B
FCD836, C, D	4N28	B
FCD850, C, D	4N29	B
FCD855, C, D	H11B255	A
FCD860, C, D	Special	
FPE100	MLED930	A
FPE410	MLED930	B
FPE500	MLED930	B
FPE520	MFOE200	D
FPT120, C	MRD300	B
FPT400	MRD360	A
FPT500, A	MRD300	A
FPT510	MRD3054	A
FPT510, A	MRD3055	A
FPT520	MRD300	A
FPT520A	MRD300	B
FPT530A	MRD300	A
FPT450A	MRD300	B
FPT550A	MRD300	B
FPT560	MRD300	B
FPT570	MRD360	A
GG686	MRD300	B
GS101	MRD601	A
GS103	MRD601	A
GS161	MRD601	A
GS163	MRD601	A
GS165	MRD604	A
GS167	MRD604	A
GS201	MRD601	E
GS203	MRD601	E
GS261	MRD601	E
GS263	MRD601	E
GS265	MRD604	E
GS267	MRD604	E
GS501	MRD604	E
GS503	MRD601	E
GS561	MRD601	E
GS567	MRD604	E
GS600, 3, 6, 9, 10	MRD300	A
GS612	MRD3050	A
GS670	MRD3050	A
GS680	MRD300	A
GS683	MRD300	A
GS686	MRD300	A
H11A1	H11A1	A
H11A2	H11A2	A
H11A3	H11A3	A
H11A4	H11A4	A
H11A5	H11A5	A
H11A520	H11A520	A
H11A550	H11A550	A
H11A5100	H11A5100	A
H74A1	4N26	B
H11AA1	H11AA1	A
H11AA2	H11AA2	A
H11B1	H11B1	A
H11B2	H11B2	A
H11B3	H11B3	A
H11B255	H11B255	A
H11C1, 2, 3	H11C1, 2, 3	A
H11C4, 5, 6	MOC3020	DE
H11D1, 2, 3, 4	H11D1, 2, 3, 4	A
H11G1, 2, 3	H11G1, 2, 3	A
H11J1	MOC3011/H11J1	A
H11J2	MOC3010/H11J2	A
H11J3	MOC3011/H11J3	A
H11J4	MOC3010/H11J4	A
H11J5	H11J5	A
H11L1	MOC5007/H11L1	A
H11L2	MOC5009/H11L2	A
H21A1	MOC7811/H21A1	A
H21A2	MOC7812/H21A2	A
H21A3	MOC7813/H21A3	A
H22A1	MOC7821/H22A1	A
H22A2	MOC7822/H22A2	A
H22A3	MOC7823/H22A3	A
H74C1	H74C1	A
H74C2	MOC3020	DE
IL1	IL1	A
IL5	4N25	B
IL12	IL12	A
IL15	IL15	A
IL16	IL16	A
IL74	IL74	A
IL250	H11AA1	A
ILA30	4N33	B
ILA55	4N33	B
ILCA2-30	MCA230	A
ILCA2-55	H11B255	A
IRL40	MLED930	B
L8, L9	MRD3011	D
L14F1	MRD360	A
L14F2	MRD370	A
L14G1	MRD300	A
L14G2	MRD310	A
L14G3	MRD310	A
L14H1	MRD701	DE
L14H2	MRD701	DE
L14H3	MRD701	DE
L14H4	MRD701	DE
L15E	MRD603	A
L15A	MRD602	A
L15AX601	MRD601	A
L15AX602	MRD602	A
L15AX603	MRD603	A

CROSS-REFERENCE (continued)

Industry Device	Motorola Equivalent	Code
L15AX604	MRD604	A
LED56, F	MLED930	A
MCA11G1	H11G1	A
MCA11G2	H11G2	A
MCA230	MCA230	A
MCA231	MCA231	A
MCA255	MCA255	A
MCP3009	MOC3009	A
MCP3010	MOC3010	A
MCP3011	MOC3011	A
MCP3020	MOC3020	A
MCP3021	MOC3021	A
MCP3022	MOC3022	A
MCS2	MCS2	A
MCS2400	MOC3020	DE
MCT2	MCT2	A
MCT2E	MCT2E	A
MCT26	MCT26	A
MCT271	MCT271	A
MCT272	MCT272	A
MCT273	MCT273	A
MCT274	MCT274	A
MCT275	MCT275	A
MCT277	MCT277	A
MCT2200	MOC602A	A
MCT2201	MOC604A	A
MFOD102F	MFOD1100	E
MFOD104F	MFOD1100	E
MFOD110F	MFOD1100	E
MFOD202F	MFOD2202	E
MFOD302F	MFOD2302	E
MFOD404F	MFOD2404	E
MFOD405F	MFOD2405	E
MFOE102F	MFOE1200	E
MFOE103F	MFOE1200	E
MFOE106F	MFOE1200	E
MFOE107F	MFOE1201	E
MFOE108F	MFOE1202	E
MLED92	MLED71	E
MLED93	MLED71	E
MLED94	MLED71	E
MLED95	MLED71	E
MOC1000	4N26	A
MOC1001	4N25	A
MOC1002	4N27	A
MOC1003	4N28	A
MOC1200	4N29	A
MRD14B	MRD711	E
OP123	MLED910	A
OP124	MLED910	A
OP130	MLED930	A
OP131	MLED930	A
OP600	MRD601	A
OP601	MRD601	A
OP602	MRD602	A
OP603	MRD603	A
OP604	MRD604	A
OP640	MRD601	A
OP641	MRD601	A
OP642	MRD602	A
OP643	MRD602	A
OP644	MRD603	A
OP800	MRD3055	A
OP801	MRD3050	A
OP802	MRD310	A
OP803	MRD300	A
OP804	MRD300	A
OP805	MRD300	A
OP830	MRD300	A
OPI110	MOC1005	DE
OPI2150	4N28	A
OPI2151	4N28	A
OPI2152	4N26	A
OPI2153	TIL117	A
OPI2250	4N28	A
OPI2251	4N28	A
OPI2252	4N26	A
OPI2253	TIL117	A
OPI2500	H11AA1	A
OPI3009	MOC3009	A
OPI3010	MOC3010	A
OPI3011	MOC3011	A
OPI3012	MOC3012	A
OPI3020	MOC3020	A
OPI3021	MOC3021	A
OPI3022	MOC3022	A
OPI3023	MOC3023	A
OPI3150	4N33	A
OPI3151	4N33	A
OPI3250	4N33	A
OPI3251	4N33	A
OPI4201	H11C1	A
OPI4202	H11C3	A
OPI5000	H11A520	A
OPI5010	H11A520	A
OPI6000	MOC8204	A
OPI6100	MOC8205	A
PC503	4N26	A
SCS11C1	H11C1	A
SCS11C3	H11C3	A
SD1440-1,-2,-3,-4	MRD3050	DE
SD2440-1	MRD601	A
SD2440-2	MRD602	A
SD2440-3	MRD603	A
SD2440-4	MRD604	A
SD2441-1	MRD602	A
SD2441-2	MRD603	A
SD2441-3	MRD604	A
SD2441-4	MRD604	B
SD3420-1,-2	MRD510	A
SD5400-1	MRD370	A
SD5400-2	MRD360	A
SD5400-3	MRD360	A
SD5420-1	MRD500	A
SD5440-1	MRD3052	A
SD5440-2	MRD3056	A
SD5440-3	MRD300	A
SD5440-4	MRD300	B
SD5442-1,-2,-3	MRD300	B
SE1450 series	MLED930	E
SE2450 series	MLED910	B
SE2460 series	MLED910	B
SE5450 series	MLED930	A
SE5451 series	MLED930	B
SG1001 series	MLED910	B
SPX2	4N35	A
SPX2E	4N35	A
SPX4	4N35	A
SPX5	4N35	A
SPX6	4N35	A
SPX26	4N27	A
SPX28	4N27	A
SPX35	4N35	A
SPX36	4N35	A
SPX37	4N35	A
SPX53	H11A550	A
SPX103	4N35	A
SPX1872-1	MOC7821/H22A1	C
SPX1872-2	MOC7821/H22A1	C
SPX1873-1	MOC7811/H21A1	C
SPX1873-2	MOC7811/H21A1	C
SPX1876-1	MOC7811/H21A1	C
SPX1876-2	MOC7811/H22A2	C
SPX2762-4	MOC7822/H22A2	C
SPX7271	CNY17-1	A
SPX7272	CNY17-2	A
SPX7273	CNY17-3	A
SSL4, F	MLED930	B
SSL34, 54	MLED930	B
STPT20	MRD604	A
STPT21	MRD601	A
STPT25	MRD603	A
STPT51	MRD3050	A
STPT53	MRD3056	A
STPT60 series	MRD601 series	A
STPT80	MRD3056	A
STPT81	MRD3052	A
STPT82	MRD3053	A
STPT83	MRD3054	A
STPT84	MRD3056	A
STPT260	MRD360	A
STPT300	MRD300	A
STPT310	MRD360	C
TIL23	MLED910	A
TIL24	MLED910	B
TIL31	MLED930	B
TIL33	MLED930	B
TIL34	MLED930	A
TIL63	MRD3050	A
TIL64	MRD3050	A
TIL65	MRD3052	A
TIL66	MRD3054	A
TIL67	MRD3056	A
TIL81	MRD300	A
TIL111	TIL111	A
TIL112	TIL112	A
TIL113	TIL113	A
TIL114	TIL114	A
TIL115	TIL115	A
TIL116	TIL116	A
TIL117	TIL117	A
TIL118	TIL118	A
TIL119	TIL119	A
TIL124	TIL124	A
TIL125	TIL125	A
TIL126	TIL126	A
TIL127	TIL127	A
TIL128	TIL128	A
TIL153	TIL153	A
TIL154	TIL154	A
TIL155	TIL155	A
TIL156	TIL156	A
TIL157	TIL157	A
TIL601	MRD601	A
TIL602	MRD602	A
TIL603	MRD603	A
TIL604	MRD604	A
TLP501	4N27	B
TLP503	4N25	B
TLP504	4N25	B
1N5722	MRD601	A
1N5723	MRD602	A
1N5724	MRD603	A
1N5725	MRD604	A
2N5777	MRD711	DE
2N5778	MRD711	DE
2N5779	MRD711	DE
2N5780	MRD711	DE
2N25, A	4N25, A	A
4N26	4N26	A
4N27	4N27	A
4N28	4N28	A
4N29, A	4N29, A	A
4N30	4N30	A
4N31	4N31	A
4N32, A	4N32, A	A
4N33	4N33	A
4N35	4N35	A
4N36	4N36	A
4N37	4N37	A
4N38, A	4N38, A	A
4N39	4N39	A
4N40	MOC3020	DE
5082-4203	MRD500	A
5082-4204	MRD500	A
5082-4207	MRD500	A
5082-4220	MRD500	A

OPTOELECTRONICS

Data Sheets



OPTOELECTRONIC DATA SHEETS

MOTOROLA

4N25, 4N25A
4N26
4N27
4N28

OPTO COUPLER/ISOLATOR

TRANSISTOR OUTPUT

NPN PHOTOTRANSISTORS AND PN INFRARED EMITTING DIODES

. . . gallium arsenide LED optically coupled to silicon phototransistors designed for applications requiring electrical isolation, high-current transfer ratios, small package size and low cost; such as interfacing and coupling systems, phase and feedback controls, solid-state relays and general-purpose switching circuits.

- High Isolation Voltage — V_{ISO} = 7500 V (Min)
- High Collector Output Current @ I_F = 10 mA —
  I_C = 5.0 mA (Typ) — 4N25,A,4N26
  2.0 mA (Typ) — 4N27,4N28
- Economical, Compact, Dual-In-Line Package
- Excellent Frequency Response — 300 kHz (Typ)
- Fast Switching Times @ I_C = 10 mA
  t_{on} = 0.87 μs (Typ) — 4N25,A,4N26
  2.1 μs (Typ) — 4N27,4N28
  t_{off} = 11 μs (Typ) — 4N25,A,4N26
  5.0 μs (Typ) — 4N27,4N28
- 4N25A is UL Recognized File Number E54915

*MAXIMUM RATINGS (T_A = 25°C unless otherwise noted).

Rating	Symbol	Value	Unit
INFRARED-EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	3.0	Volts
Forward Current — Continuous	I_F	80	mA
Forward Current — Peak Pulse Width = 300 μs, 2.0% Duty Cycle	I_F	3.0	Amp
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor	P_D	150	mW
Derate above 25°C		2.0	mW/°C
PHOTOTRANSISTOR MAXIMUM RATINGS			
Collector-Emitter Voltage	V_{CEO}	30	Volts
Emitter-Collector Voltage	V_{ECO}	7.0	Volts
Collector-Base Voltage	V_{CBO}	70	Volts
Total Device Dissipation @ T_A = 25°C Negligible Power in Diode	P_D	150	mW
Derate above 25°C		2.0	mW/°C
TOTAL DEVICE RATINGS			
Total Device Dissipation @ T_A = 25°C	P_D	250	mW
Equal Power Dissipation in Each Element Derate above 25°C		3.3	mW/°C
Junction Temperature Range	T_J	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)		260	°C

*Indicates JEDEC Registered Data.

FIGURE 1 — MAXIMUM POWER DISSIPATION

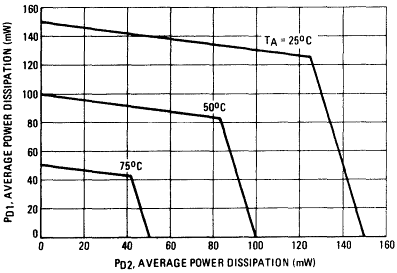


Figure 1 is based upon using limit values in the equation

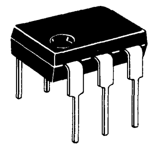
$T_{J1} - T_A = R_{\theta JA}(P_{D1} + K_\theta P_{D2})$

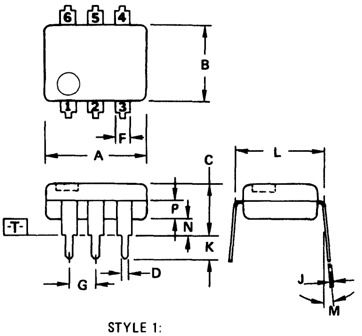
where:

T_{J1} Junction Temperature (100°C)
T_A Ambient Temperature
$R_{\theta JA}$ Junction to Ambient Thermal Resistance (500°C/W)
P_{D1} Power Dissipation in One Chip
P_{D2} Power Dissipation in Other Chip
K_θ Thermal Coupling Coefficient (20%)

Example

With P_{D1} = 90 mW in the LED @ T_A = 50°C, the transistor P_D (P_{D2}) must be less than 50 mW





STYLE 1:
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. BASE

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⊕ | Ø 0.13 (0.005) Ⓜ | T | A Ⓜ B Ⓜ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

LED CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
*Reverse Leakage Current (V_R = 3.0 V, R_L = 1.0 M ohms)	I_R	–	0.005	100	μA
*Forward Voltage (I_F = 10 mA)	V_F	–	1.2	1.5	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	–	40	–	pF

PHOTOTRANSISTOR CHARACTERISTICS (T_A = 25°C and I_F = 0 unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
*Collector-Emitter Dark Current (V_{CE} = 10 V, Base Open)	4N25, A, 4N26, 4N27 4N28	I_{CEO}	– –	3.5 –	50 100	nA
*Collector-Base Dark Current (V_{CB} = 10 V, Emitter Open)		I_{CBO}	–	–	20	nA
*Collector-Base Breakdown Voltage (I_C = 100 μA, I_E = 0)		$V_{(BR)CBO}$	70	–	–	Volts
*Collector-Emitter Breakdown Voltage (I_C = 1.0 mA, I_B = 0)		$V_{(BR)CEO}$	30	–	–	Volts
*Emitter-Collector Breakdown Voltage (I_E = 100 μA, I_B = 0)		$V_{(BR)ECO}$	7.0	8.0	–	Volts
DC Current Gain (V_{CE} = 5.0 V, I_C = 500 μA)		h_{FE}	–	325	–	–

COUPLED CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
*Collector Output Current (1) (V_{CE} = 10 V, I_F = 10 mA, I_B = 0)	4N25, A, 4N26 4N27, 4N28	I_C	2.0 1.0	5.0 2.0	– –	mA
Isolation Surge Voltage (2, 5)		V_{ISO}				Volts
(60 Hz Peak ac, 5 Seconds)			7500	–	–	
(60 Hz Peak)	*4N25, A		2500	–	–	
	*4N26, 4N27		1500	–	–	
	*4N28		500	–	–	
(60 Hz RMS for 1 Second) (3)	*4N25A		1775	–	–	
Isolation Resistance (2) (V = 500 V)		–	–	10^{11}	–	Ohms
*Collector-Emitter Saturation (I_C = 2.0 mA, I_F = 50 mA)		$V_{CE(sat)}$	–	0.2	0.5	Volts
Isolation Capacitance (2) (V = 0, f = 1.0 MHz)		–	–	0.5	–	pF
Bandwidth (4) (I_C = 2.0 mA, R_L = 100 ohms, Figure 11 (2)		–	–	300	–	kHz

SWITCHING CHARACTERISTICS

Characteristic	Conditions		Symbol	Min	Typ	Max	Unit
Delay Time	(I_C = 10 mA, V_{CC} = 10 V	4N25, A, 4N26 2N27, 4N28	t_d	– –	0.07 0.10	– –	μs
Rise Time	Figures 6 and 8)	4N25, A, 4N26 4N27, 4N28	t_r	– –	0.8 2.0	– –	μs
Storage Time	(I_C = 10 mA, V_{CC} = 10 V	4N25, A, 4N26 4N27, 4N28	t_s	– –	4.0 2.0	– –	μs
Fall Time	Figures 7 and 8)	4N25, A, 4N26 4N27, 4N28	t_f	– –	8.0 8.0	– –	μs

*Indicates JEDEC Registered Data
(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle ≤ 2.0%.
(2) For this test LED pins 1 and 2 are common and phototransistor pins 4, 5, and 6 are common.
(3) RMS Volts, 60 Hz. For this test, pins 1, 2, and 3 are common and pins 4, 5, and 6 are common.
(4) I_F adjusted to yield I_C = 2.0 mA and i_c = 2.0 mA p-p at 10 kHz.
(5) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

DC CURRENT TRANSFER CHARACTERISTICS

FIGURE 2 — 4N25,A,4N26

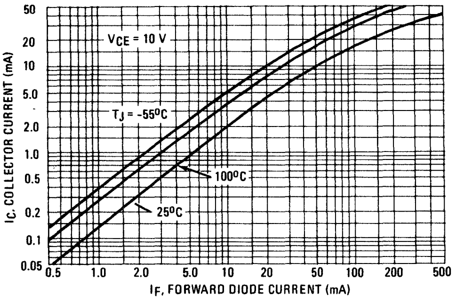
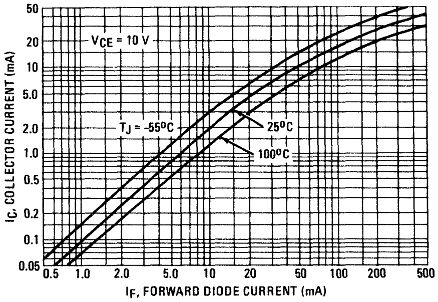


FIGURE 3 — 4N27,4N28



TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 4 — FORWARD CHARACTERISTICS

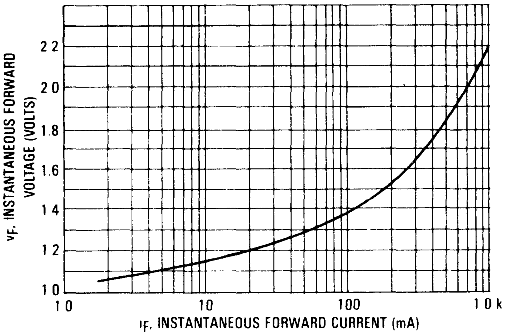


FIGURE 5 — COLLECTOR SATURATION VOLTAGE

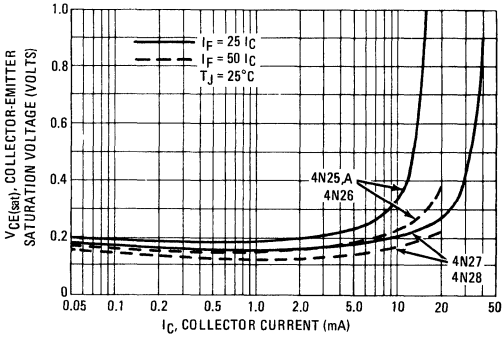


FIGURE 6 — TURN-ON TIME

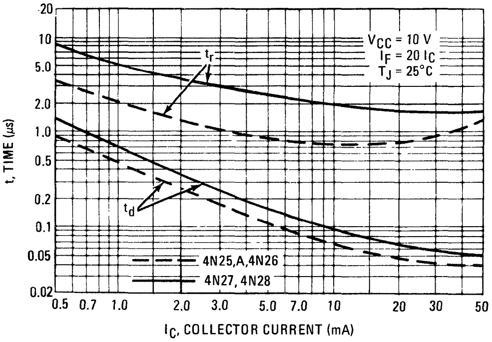


FIGURE 7 — TURN-OFF TIME

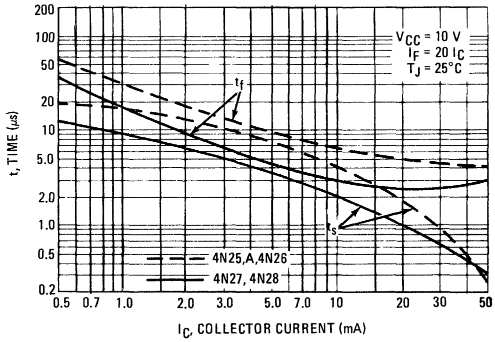


FIGURE 8 — SATURATED SWITCHING TIME TEST CIRCUIT

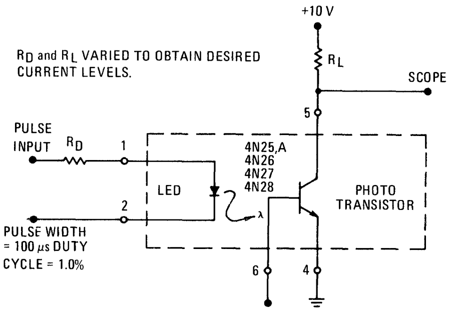


FIGURE 9 — DARK CURRENT versus AMBIENT TEMPERATURE

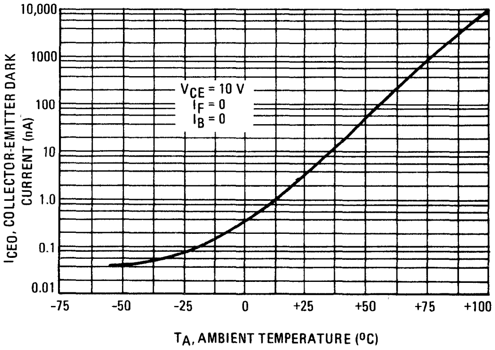


FIGURE 11 – FREQUENCY RESPONSE TEST CIRCUIT

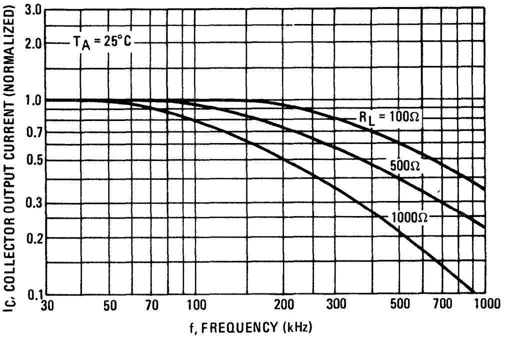
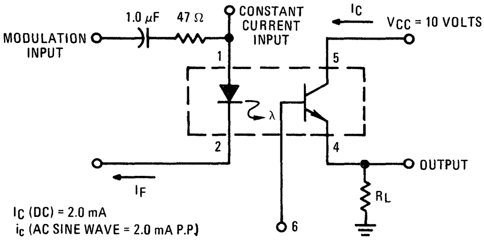


FIGURE 10 – FREQUENCY RESPONSE



TYPICAL APPLICATIONS

FIGURE 12 – ISOLATED MTTL TO MOS (P-CHANNEL) LEVEL TRANSLATOR

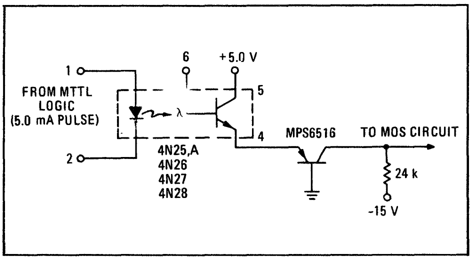


FIGURE 13 – COMPUTER/PERIPHERAL INTERCONNECT

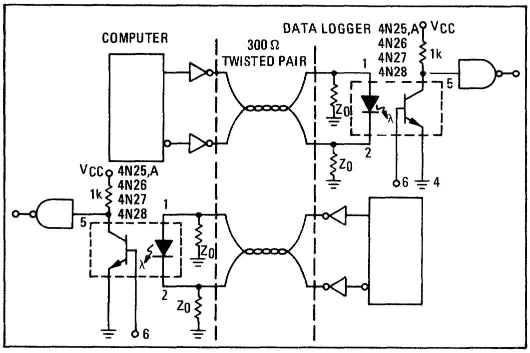


FIGURE 14 – POWER AMPLIFIER

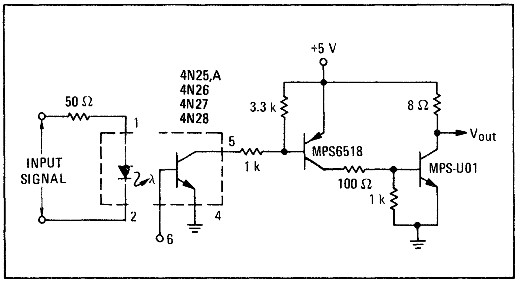
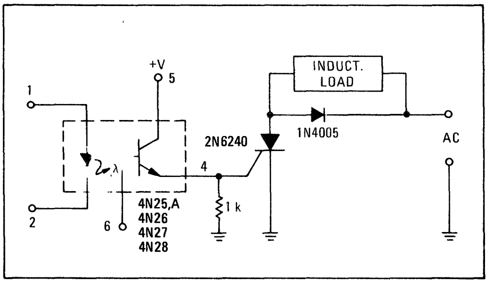


FIGURE 15 – INTERFACE BETWEEN LOGIC AND LOAD



MOTOROLA

4N29, 4N29A
4N30,4N31
4N32, 4N32A, 4N33

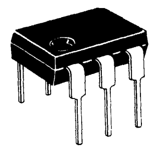
NPN PHOTODARLINGTONS AND PN INFRARED EMITTING DIODES

. . . gallium arsenide LED optically coupled to silicon photodarlington transistors designed for applications requiring electrical isolation, high-current transfer ratios, small package size and low cost; such as interfacing and coupling systems, phase and feedback controls, solid-state relays and general-purpose switching circuits.

- High Isolation Voltage — V_{ISO} = 7500 V (Min)
- High Collector Output Current @ I_F = 10 mA —
  I_C = 50 mA (Min) — 4N32,33
  10 mA (Min) — 4N29,4N30
  5.0 mA (Min) — 4N31
- Economical, Compact, Dual-In-Line Package
- Excellent Frequency Response — 30 kHz (Typ)
- Fast Switching Times @ I_C = 50 mA
  t_{on} = 2.0 μs (Typ)
  t_{off} = 25 μs (Typ) — 4N29,30,31
  60 μs (Typ) — 4N32,33
- 4N29A, 4N32A are UL Recognized — File Number E54915

OPTO COUPLER/ISOLATOR

DARLINGTON OUTPUT



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED-EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	3.0	Volts
Forward Current – Continuous	I_F	80	mA
Forward Current – Peak (Pulse Width = 300 μs, 2.0% Duty Cycle)	I_F	3.0	Amp
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	150 2.0	mW mW/°C
PHOTOTRANSISTOR MAXIMUM RATINGS			
Collector-Emitter Voltage	V_{CEO}	30	Volts
Emitter-Collector Voltage	V_{ECO}	5.0	Volts
Collector-Base Voltage	V_{CBO}	30	Volts
Total Power Dissipation @ T_A = 25°C	P_D	150	mW
Negligible Power in Diode Derate above 25°C		2.0	mW/°C
TOTAL DEVICE RATINGS			
Total Device Dissipation @ T_A = 25°C Equal Power Dissipation in Each Element Derate above 25°C	P_D	250 3.3	mW mW/°C
Operating Junction Temperature Range	T_J	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)	–	260	°C

FIGURE 1 – MAXIMUM POWER DISSIPATION

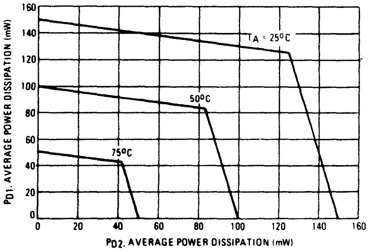


Figure 1 is based upon using limit values in the equation:

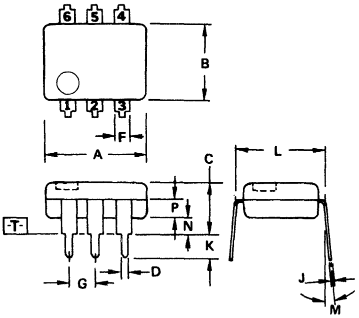
$$T_{J1} - T_A = R_{\theta JA} (P_{D1} + K_\theta P_{D2})$$

where

T_{J1}	Junction Temperature (100°C)
T_A	Ambient Temperature
$R_{\theta JA}$	Junction to Ambient Thermal Resistance (500°C/W)
P_{D1}	Power Dissipation in One Chip
P_{D2}	Power Dissipation in Other Chip
K_θ	Thermal Coupling Coefficient (20%)

Example

With P_{D1} = 90 mW in the LED @ T_A = 50°C, the Darlington P_D (P_{D2}) must be less than 50 mW.



STYLE 1:
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. BASE

NOTES:

1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
   ⌖ | ∅ 0.13 (0.005)Ⓜ | T | AⓂ BⓂ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

LED CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
*Reverse Leakage Current (V_R = 3.0 V, R_L = 1.0 M ohms)	I_R	–	0.005	100	µA
*Forward Voltage (I_F = 10 mA)	V_F	–	1.2	1.5	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	–	40	–	pF

PHOTOTRANSISTOR CHARACTERISTICS (T_A = 25°C and I_F = 0 unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
*Collector-Emitter Dark Current (V_{CE} = 10 V, Base Open)	I_{CEO}	–	8.0	100	nA
*Collector-Base Breakdown Voltage (I_C = 100 µA, I_E = 0)	$V_{(BR)CBO}$	50	110	–	Volts
*Collector-Emitter Breakdown Voltage (I_C = 100 µA, I_B = 0)	$V_{(BR)CEO}$	30	75	–	Volts
*Emitter-Collector Breakdown Voltage (I_E = 100 µA, I_B = 0)	$V_{(BR)ECO}$	5.0	8.0	–	Volts
DC Current Gain (V_{CE} = 5.0 V, I_C = 500 µA)	h_{FE}	–	15 K	–	–

COUPLED CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
*Collector Output Current (1) (V_{CE} = 10 V, I_F = 10 mA, I_B = 0)	4N32, 4N33 4N29, 4N30 4N31	I_C	50 10 5.0	80 40 –	– – –	mA
Isolation Surge Voltage (2, 5) (60 Hz ac Peak, 5 Seconds)	 *4N29, 4N32 *4N30, 4N31, 4N33	V_{ISO}	7500 2500 1500	– – –	– – –	Volts
Isolation Resistance (2) (V = 500 V)		–	–	10^{11}	–	Ohms
*Collector-Emitter Saturation Voltage (1) (I_C = 2.0 mA, I_F = 8.0 mA)	4N31 4N29, 4N30, 4N32, 4N33	$V_{CE(sat)}$	– –	0.8 0.8	1.2 1.0	Volts
Isolation Capacitance (2) (V = 0, f = 1.0 MHz)		–	–	0.5	–	pF
Bandwidth (3) (I_C = 2.0 mA, R_L = 100 ohms, Figures 6 and 8)		–	–	30	-	kHz

SWITCHING CHARACTERISTICS (Figures 7 and 9), (4)

Characteristic		Symbol	Min	Typ	Max	Unit
Turn-On Time (I_C = 50 mA, I_F = 200 mA, V_{CC} = 10 V)		t_{on}	–	2.0	5.0	µs
Turn-Off Time (I_C = 50 mA, I_F = 200 mA, V_{CC} = 10 V)	4N29, 30, 31 4N32, 33	t_{off}	– –	25 60	40 100	µs

*Indicates JEDEC Registered Data.
(1) Pulse Test: Pulse Width = 300 µs, Duty Cycle ≤ 2.0%.
(2) For this test, LED pins 1 and 2 are common and phototransistor pins 4, 5, and 6 are common.
(3) I_F adjusted to yield I_C = 2.0 mA and i_c = 2.0 mA P-P at 10 kHz.
(4) t_d and t_r are inversely proportional to the amplitude of I_F; t_s and t_f are not significantly affected by I_F.
(5) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

DC CURRENT TRANSFER CHARACTERISTICS

FIGURE 2 – 4N29, 4N30, 4N31

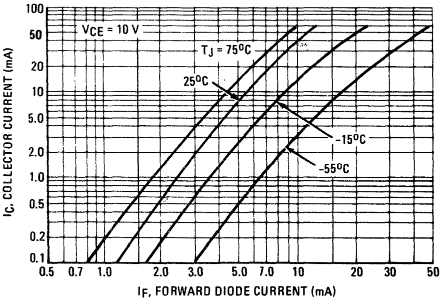
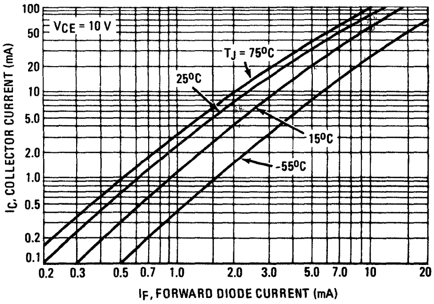


FIGURE 3 – 4N32, 4N33



TYPICAL ELECTRICAL CHARACTERISTICS

(Printed Circuit Board Mounting)

FIGURE 4 — DIODE FORWARD CHARACTERISTIC

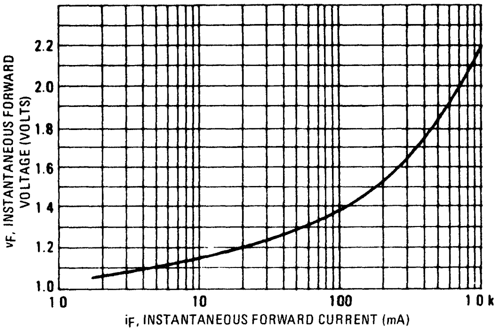


FIGURE 5 — COLLECTOR-EMITTER CUTOFF CURRENT

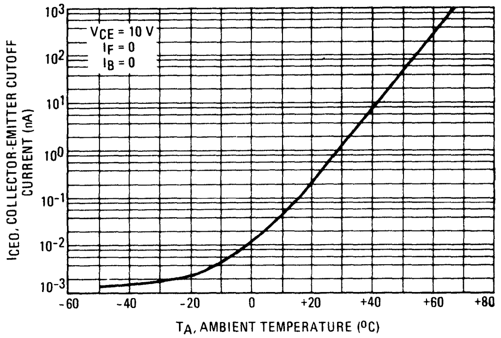


FIGURE 6 — FREQUENCY RESPONSE

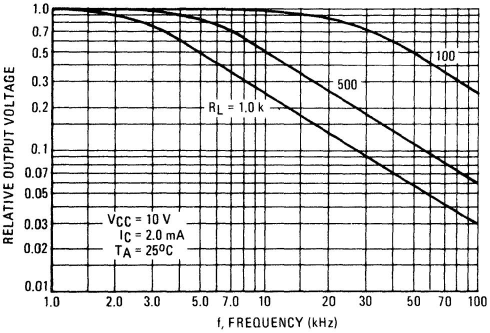


FIGURE 7 — SWITCHING TIMES

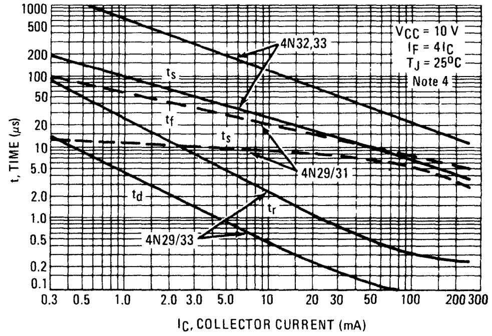


FIGURE 8 — FREQUENCY RESPONSE TEST CIRCUIT

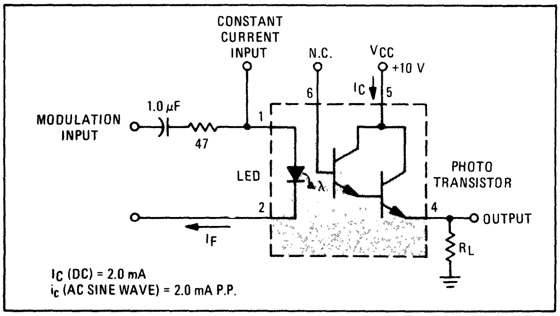
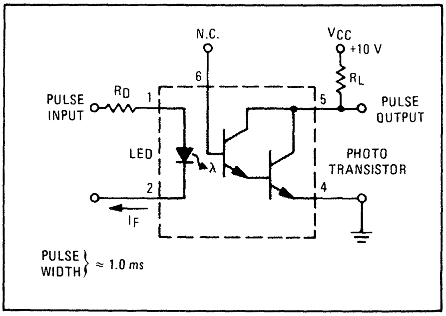


FIGURE 9 — SWITCHING TIME TEST CIRCUIT



TYPICAL APPLICATIONS

FIGURE 10 – VOLTAGE CONTROLLED TRIAC

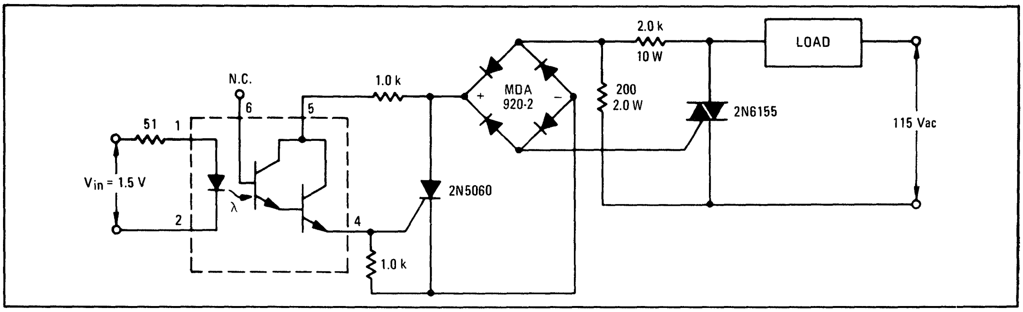


FIGURE 11 – AC SOLID STATE RELAY

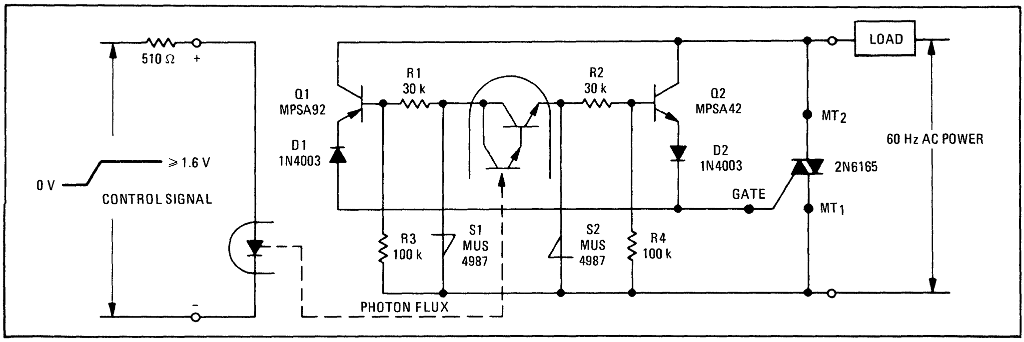


FIGURE 12 – OPTICALLY COUPLED ONE SHOT

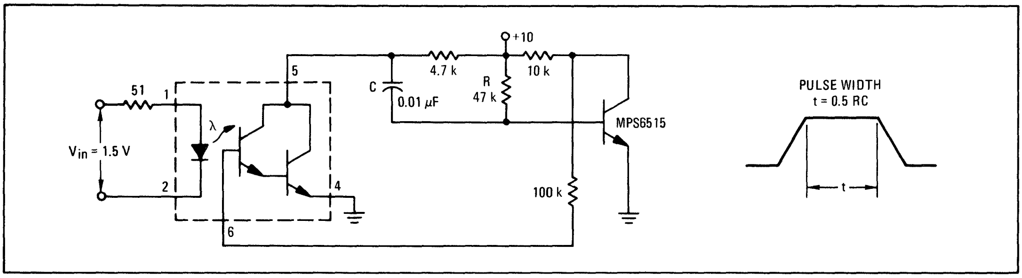
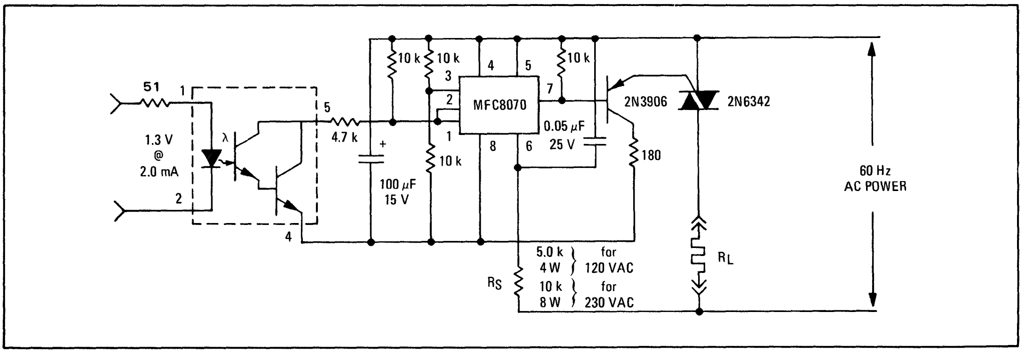


FIGURE 13 – ZERO VOLTAGE SWITCH



MOTOROLA

4N35
4N36
4N37

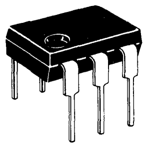
OPTO COUPLER/ISOLATOR

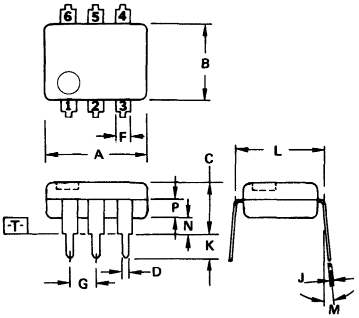
TRANSISTOR OUTPUT

NPN PHOTOTRANSISTORS AND PN INFRARED EMITTING DIODES

. . . gallium arsenide LED optically coupled to silicon phototransistors designed for applications requiring electrical isolation, high-current transfer ratios, small package size and low cost such as interfacing and coupling systems, phase and feedback controls, solid-state relays and general-purpose switching circuits.

- High Electrical Isolation V_{ISO} = 7500 V (Min)
- High Transfer Ratio —
  100% (min) @ I_F = 10 mA, V_{CE} = 10 V
- Low Collector-Emitter Saturation Voltage —
  $V_{CE(sat)}$ = 0.3 Vdc (max) @ I_F = 10 mA, I_C = 0.5 mA
- UL Recognized File Number E54915





STYLE 1.
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. BASE

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
   ⌖ | ∅ 0.13 (0.005)Ⓜ | T | AⓂ | BⓂ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
***INFRARED-EMITTER DIODE MAXIMUM RATINGS**			
Reverse Voltage	V_{RB}	6.0	Volts
Forward Current — Continuous	I_F	60	mA
Forward Current — Peak Pulse Width = 1.0 μs, 2.0% Duty Cycle	I_F	3.0	Amp
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	 100 1.3	mW mW/°C
***PHOTOTRANSISTOR MAXIMUM RATINGS**			
Collector-Emitter Voltage	V_{CEO}	30	Volts
Emitter-Base Voltage	V_{EBO}	7.0	Volts
Collector-Base Voltage	V_{CBO}	70	Volts
Output Current — Continuous	I_C	100	mA
Total Power Dissipation @ T_A = 25°C Negligible Power in Diode Derate above 25°C	P_D	 300 4.0	mW mW/°C
TOTAL DEVICE RATINGS			
*Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	300 4.0	mW mW/°C
Input to Output Isolation Voltage, Surge 60 Hz Peak ac, 5 seconds JEDEC Registered 4N35 = 3500 V Data @ 8 ms 4N36 = 2500 V 4N37 = 1500 V	V_{ISO}	7500	Volts V_{pk}
*Junction Temperature Range	T_J	−55 to +100	°C
*Storage Temperature Range	T_{stg}	−55 to +150	°C
*Soldering Temperature (10 s)	—	260	°C

*Indicates JEDEC Registered Data

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
LED CHARACTERISTICS (T_A = 25°C unless otherwise noted)					
*Reverse Leakage Current (V_R = 6.0 V)	I_R	–	0.005	10	μA
*Forward Voltage	V_F				Volts
(I_F = 10 mA)		0.8	1.2	1.5	
(I_F = 10 mA, T_A = –55°C)		0.9	–	1.7	
(I_F = 10 mA, T_A = 100°C)		0.7	–	1.4	
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	–	40	–	pF
***PHOTOTRANSISTOR CHARACTERISTICS** (T_A = 25°C and I_F = 0 unless otherwise noted)					
Collector-Emitter Dark Current	I_{CEO}				
(V_{CE} = 10 V, Base Open)		–	3.5	50	nA
(V_{CE} = 30 V, Base Open, T_A = 100°C)		–	–	500	μA
Collector-Base Dark Current (V_{CB} = 10 V, Emitter Open)	I_{CBO}	–	–	20	nA
Collector-Base Breakdown Voltage (I_C = 100 μA, I_E = 0)	$V_{(BR)CBO}$	70	–	–	Volts
Collector-Emitter Breakdown Voltage (I_C = 1.0 mA, I_B = 0)	$V_{(BR)CEO}$	30	–	–	Volts
Emitter-Base Breakdown Voltage (I_E = 100 μA, I_B = 0)	$V_{(BR)EBO}$	7.0	8.0	–	Volts
***COUPLED CHARACTERISTICS** (T_A = 25°C unless otherwise noted)					
Current Transfer Ratio	I_C/I_F				–
(V_{CE} = 10 V, I_F = 10 mA)		1.0	1.2	–	
(V_{CE} = 10 V, I_F = 10 mA, T_A = –55°C)		0.4	–	–	
(V_{CE} = 10 V, I_F = 10 mA, T_A = 100°C)		0.4	–	–	
Input to Output Isolation Current (2) (3)	I_{IO}				μA
(V_{io} = 3550 V_{pk}) 4N35		–	–	100	
(V_{io} = 2500 V_{pk}) 4N36		–	–	100	
(V_{io} = 1500 V_{pk}) 4N37		–	–	100	
Isolation Resistance (2) (V = 500 V)	R_{IO}	10^{11}	–	–	Ohms
Collector-Emitter Saturation Voltage (I_C = 0.5 mA, I_F = 10 mA)	$V_{CE(sat)}$	–	0.14	0.3	Volts
Isolation Capacitance (2) (V = 0, f = 1.0 MHz)	–	–	0.5	2.5	pF
***SWITCHING CHARACTERISTICS** (Figure 1)					
Turn-On Time (V_{CC} = 10 V, I_C = 2.0 mA, R_L = 100 Ω)	t_{on}	–	4.0	10	μs
Turn-Off Time (V_{CC} = 10 V, I_C = 2.0 mA, R_L = 100 Ω)	t_{off}	–	4.0	10	μs

*Indicates JEDEC Registered Data.

NOTES:
1. Pulse Test: Pulse Width = 300 μs, Duty Cycle ⩽ 2.0%.
2. For this test LED pins 1 and 2 are common and phototransistor pins 4, 5, and 6 are common.
3. Pulse Width ⩽ 8.0 ms.

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 1 – SWITCHING TIMES TEST CIRCUIT

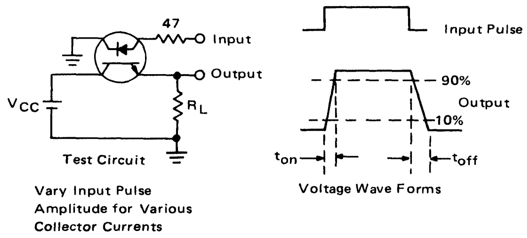


FIGURE 2 – FORWARD CHARACTERISTICS

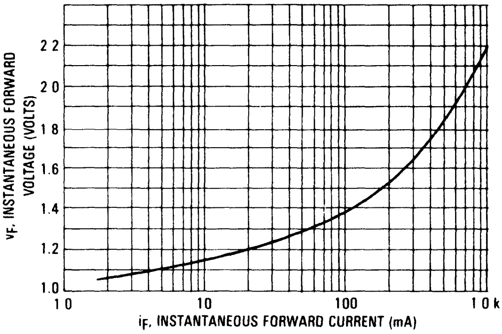


FIGURE 3 – COLLECTOR SATURATION REGION

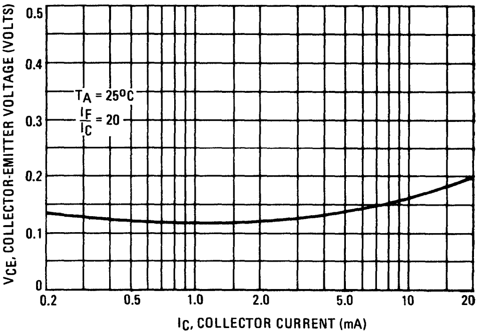


FIGURE 4 – COLLECTOR BASE CURRENT versus INPUT CURRENT

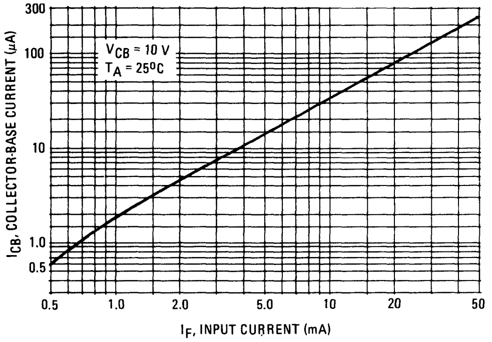


FIGURE 5 – COLLECTOR LEAKAGE CURRENT versus TEMPERATURE

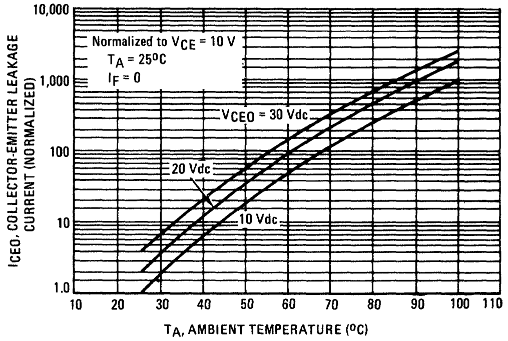
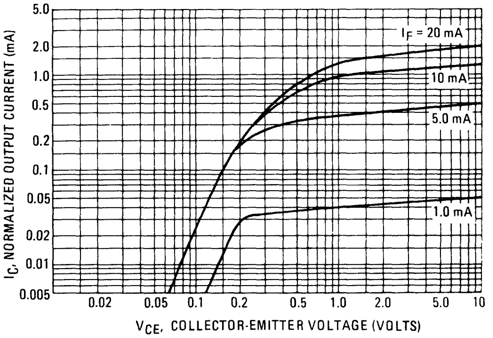


FIGURE 6 – COLLECTOR CHARACTERISTICS



TYPICAL APPLICATIONS

FIGURE 7 – ISOLATED MTTL TO MOS (P-CHANNEL) LEVEL TRANSLATOR

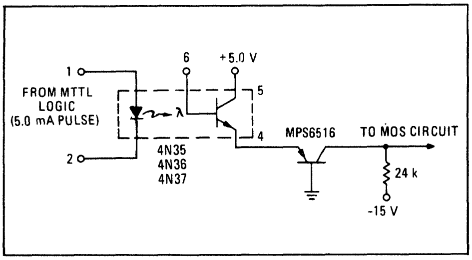


FIGURE 8 – COMPUTER/PERIPHERAL INTERCONNECT

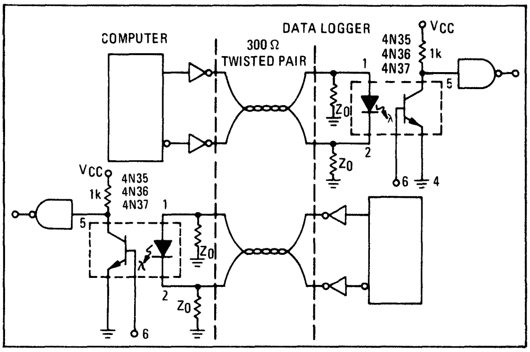


FIGURE 9 – POWER AMPLIFIER

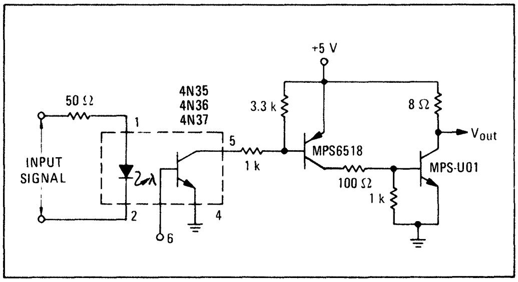
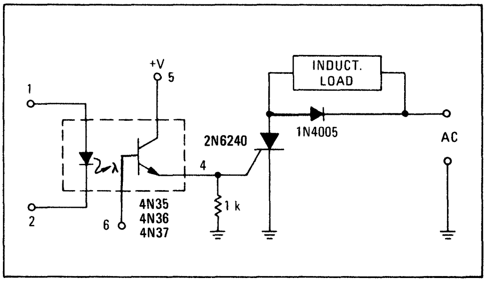


FIGURE 10 – INTERFACE BETWEEN LOGIC AND LOAD

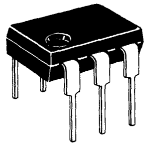


MOTOROLA

4N38
4N38A

OPTO COUPLER/ISOLATOR

TRANSISTOR OUTPUT



OPTICAL COUPLERS WITH NPN TRANSISTOR OUTPUT

. . . gallium-arsenide LED optically coupled to a silicon phototransistor. Designed for applications requiring electrical isolation, high breakdown voltage and low leakage such as teletypewriter interfacing, telephone line pulsing and driving high-voltage relays.

- High Isolation Voltage — V_{ISO} = 7500 V (Min)
- High Collector Emitter Breakdown Voltage — $V_{(BR)CEO}$ = 80 V (Min)
- Economical Dual-in-Line Package
- 4N38A UL Recognized, File Number E54915

*MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED-EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	3.0	Volts
Forward Current — Continuous	I_F	80	mA
Forward Current — Peak Pulse Width = 300 µs, 2.0% Duty Cycle	I_F	3.0	Amp
Total Device Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	150 2.0	mW mW/°C
PHOTOTRANSISTOR MAXIMUM RATINGS			
Collector-Emitter Voltage	V_{CEO}	80	Volts
Emitter-Collector Voltage	V_{ECO}	7.0	Volts
Collector-Base Voltage	V_{CBO}	80	Volts
Total Device Dissipation @ T_A = 25°C Negligible Power in Diode Derate above 25°C	P_D	150 2.0	mW mW/°C
TOTAL DEVICE RATINGS			
Total Device Dissipation @ T_A = 25°C Equal Power Dissipation in Each Element Derate above 25°C	P_D	250 3.3	mW mW/°C
Junction Temperature Range	T_J	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)		260	°C

*Indicates JEDEC Registered Data.

FIGURE 1 — MAXIMUM POWER DISSIPATION

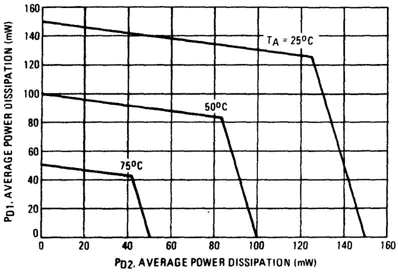


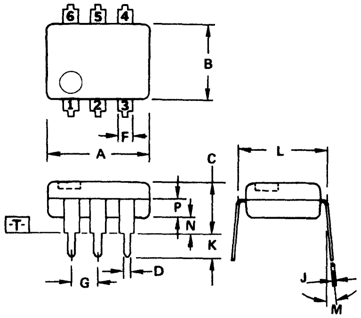
Figure 1 is based upon using limit values in the equation:

$$T_{J1} - T_A = R_{\theta JA}(P_{D1} + K_\theta P_{D2})$$

where:

T_{J1}	Junction Temperature (100°C)
T_A	Ambient Temperature
$R_{\theta JA}$	Junction to Ambient Thermal Resistance (500°C/W)
P_{D1}	Power Dissipation in One Chip
P_{D2}	Power Dissipation in Other Chip
K_θ	Thermal Coupling Coefficient (20%)

Example:
With P_{D1} = 90 mW in the LED @ T_A = 50°C, the transistor P_D (P_{D2}) must be less than 50 mW.



STYLE 1:
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. BASE

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⊕ | Ø 0.13 (0.005) Ⓜ | T | A Ⓜ B Ⓜ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

LED CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
*Reverse Leakage Current (V_R = 3.0 V)	I_R	–	0.005	100	μA
*Forward Voltage (I_F = 10 mA)	V_F	–	1.2	1.5	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	–	40	–	pF

PHOTOTRANSISTOR CHARACTERISTICS (T_A = 25°C and I_F = 0 unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
*Collector-Emitter Dark Current (V_{CE} = 60 V, Base Open)	I_{CEO}	–	3.5	50	nA
*Collector-Base Dark Current (V_{CB} = 60 V, Emitter Open)	I_{CBO}	–	–	–	nA
*Collector-Base Breakdown Voltage (I_C = 100 μA, I_E = 0)	$V_{(BR)CBO}$	80	120	–	Volts
*Collector-Emitter Breakdown Voltage (I_C = 1.0 mA, I_B = 0)	$V_{(BR)CEO}$	80	90	–	Volts
*Emitter-Collector Breakdown Voltage (I_E = 100 μA, I_B = 0)	$V_{(BR)ECO}$	7.0	8.0	–	Volts
DC Current Gain (V_{CE} = 5.0 V, I_C = 500 μA)	h_{FE}	–	250	–	–

COUPLED CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic		Symbol	Min	Typ	Max	Unit
Isolation Surge Voltage (2, 3)		V_{ISO}				Volts
(60 Hz Peak ac, 5 Seconds) (3)	4N38, A		7500	–	–	
*(60 Hz Peak ac)	*4N38		1500	–	–	
	*4N38A		2500	–	–	
*(60 Hz RMS for 1 second)	*4N38A		1775	–	–	
Isolation Resistance (2) (V = 500 V)		–	–	10^{11}	–	Ohms
*Collector-Emitter Saturation (I_C = 4.0 mA, I_F = 20 mA)		$V_{CE(sat)}$	–	–	1.0	Volts
Isolation Capacitance (2) (V = 0, f = 1.0 MHz)		–	–	0.5	–	pF

SWITCHING CHARACTERISTICS

Delay Time	(I_C = 10 mA, V_{CC} = 10 V)	t_d	–	0.07	–	μs
Rise Time	Figures 6 and 8	t_r	–	0.8	–	μs
Storage Time	(I_C = 10 mA, V_{CC} = 10 V)	t_s	–	4.0	–	μs
Fall Time	Figures 7 and 8	t_f	–	7.0	–	μs

*Indicates JEDEC Registered Data. (1) Pulse Test; Pulse Width = 300 μs, Duty Cycle ≤ 2.0%.

(2) For this test LED pins 1 and 2 are common and Photo Transistor pins 4, 5 and 6 are common.

(3) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

TYPICAL TRANSFER CHARACTERISTICS

FIGURE 2 – COLLECTOR-CURRENT versus DIODE FORWARD CURRENT

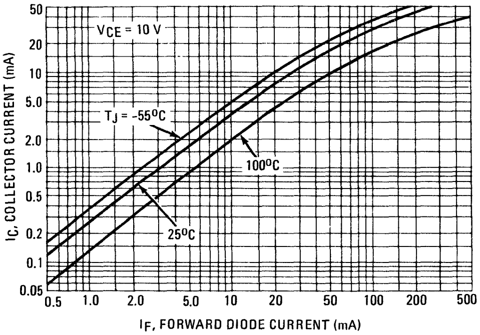
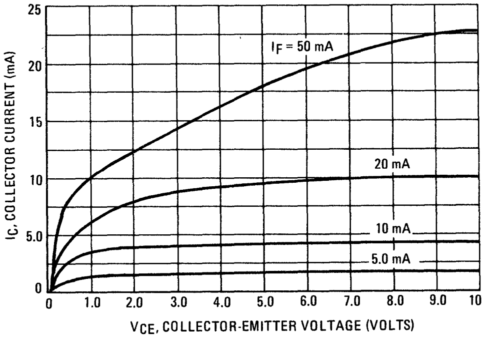


FIGURE 3 – COLLECTOR-CURRENT versus COLLECTOR-EMITTER VOLTAGE



TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 4 – FORWARD CHARACTERISTICS

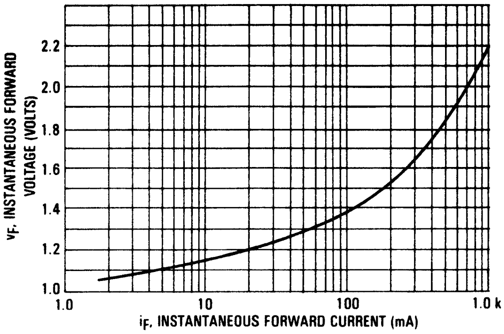


FIGURE 5 – COLLECTOR SATURATION VOLTAGE

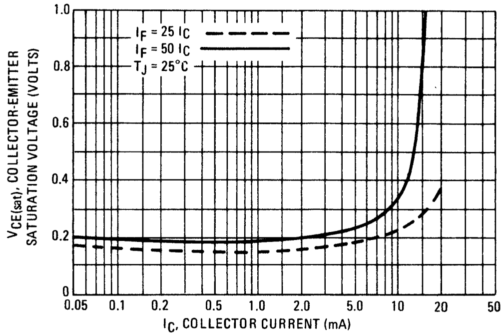


FIGURE 6 – TURN-ON TIME

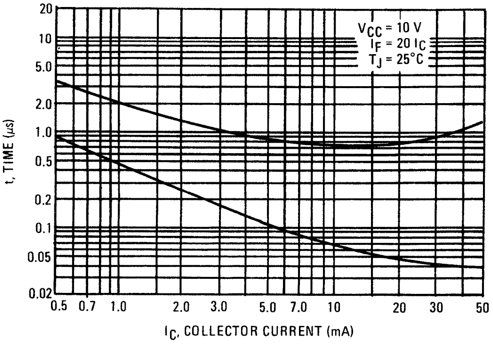


FIGURE 7 – TURN-OFF TIME

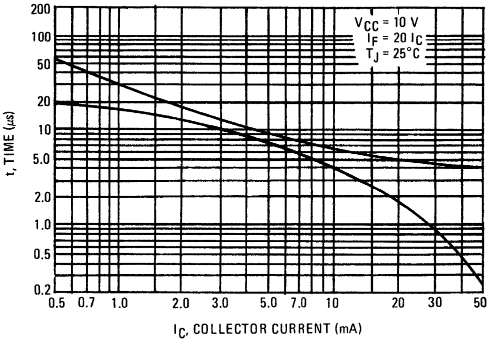
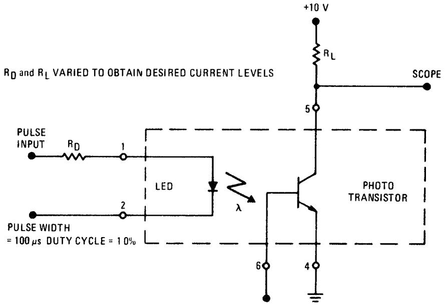


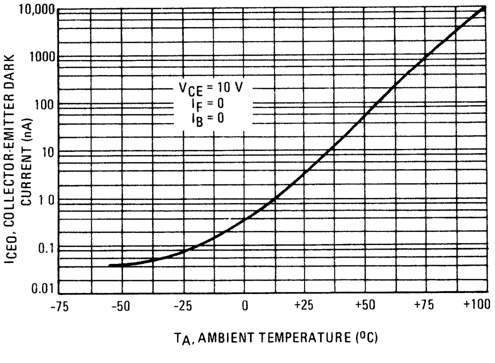
FIGURE 8 – SATURATED SWITCHING TIME TEST CIRCUIT



R_D and R_L VARIED TO OBTAIN DESIRED CURRENT LEVELS

PULSE WIDTH = 100 µs DUTY CYCLE = 10%

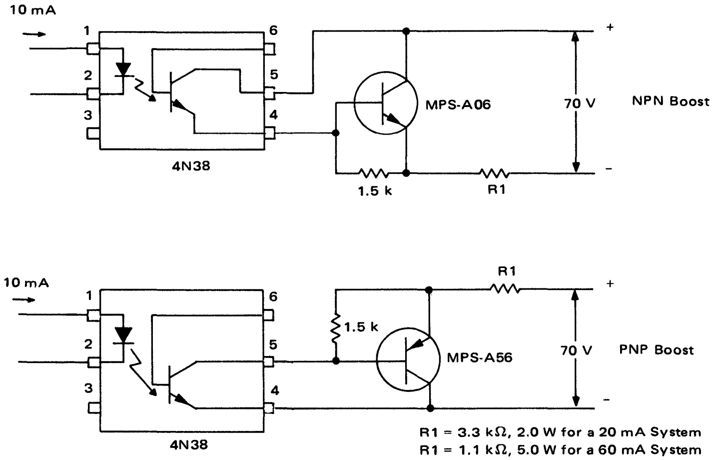
FIGURE 9 – DARK CURRENT versus AMBIENT TEMPERATURE



TYPICAL APPLICATIONS

The applications below utilize the 80 volt breakdown capability of the 4N38 and 4N38A eliminating the need for divider networks, zener diodes and the associated assembly costs.

FIGURE 10 – TYPICAL TELETYPE INTERFACE



R1 = 3.3 kΩ, 2.0 W for a 20 mA System
R1 = 1.1 kΩ, 5.0 W for a 60 mA System

FIGURE 11 – TELEPHONE LINE PULSE CIRCUIT

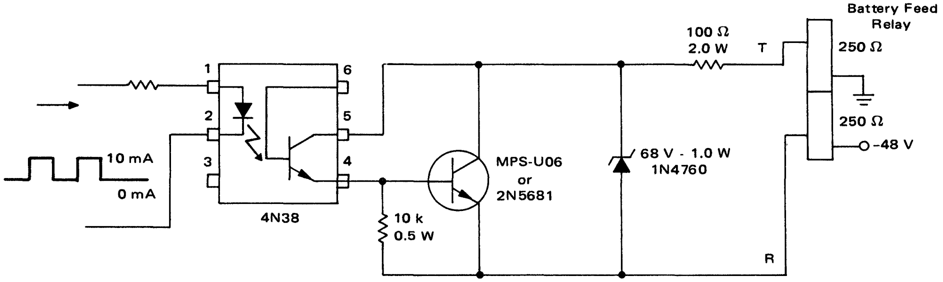
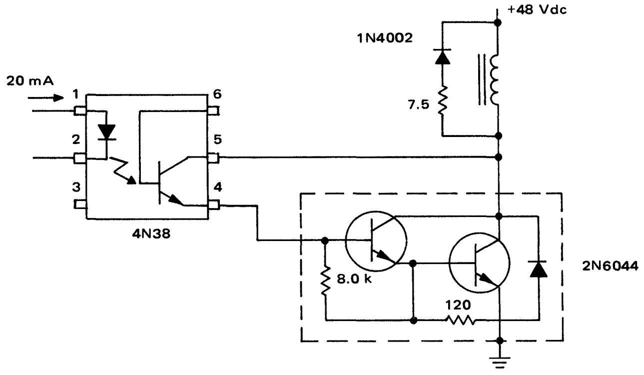


FIGURE 12 – 4-AMPERE SOLENOID DRIVER



MOTOROLA

H11AA1
H11AA2

AC INPUT TRANSISTOR OPTOCOUPLERS

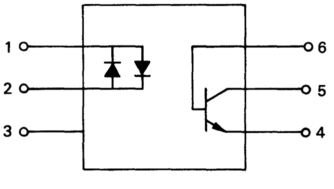
These devices consist of two gallium-arsenide infrared emitting diodes connected in inverse parallel, optically coupled to a silicon photo-transistor. They are designed for applications requiring detection or monitoring of ac signals.

- High Isolation Voltage, V_{ISO} = 7500 Vac (Min)
- Built-In Protection From Reverse Polarity
- Standard 6-Pin DIP Package
- UL Recognized, File Number E54915

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted).

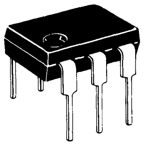
Rating	Symbol	Value	Unit
INFRARED-EMITTING DIODES MAXIMUM RATINGS			
Input Current — Continuous (RMS)	I_F	60	mA
Input Current — Peak Pulse Width = 1.0 µs, 330 pps	I_F	3.0	Amp
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	100 1.33	mW mW/°C
PHOTOTRANSISTOR MAXIMUM RATINGS			
Collector-Emitter Voltage	V_{CEO}	30	Volts
Emitter-Base Voltage	V_{EBO}	5.0	Volts
Collector-Base Voltage	V_{CBO}	70	Volts
Collector Current (Continuous)	I_C	100	mA
Total Device Dissipation @ T_A = 25°C Negligible Power in Diode Derate above 25°C	P_D	300 4.0	mW mW/°C
TOTAL DEVICE RATINGS			
Total Device Dissipation @ T_A = 25°C	P_D	250	mW
Equal Power Dissipation in Each Element Derate above 25°C		3.3	mW/°C
Operating Temperature Range	T_J	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)		260	°C
Surge Isolation Voltage (Input to Output)	V_{ISO}	7500	Vac(pk)

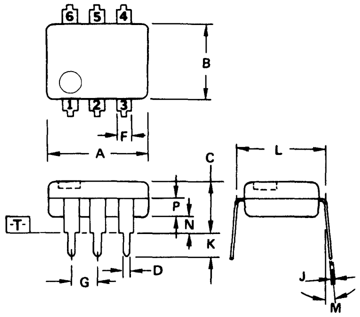
COUPLER SCHEMATIC



OPTO COUPLER/ISOLATOR

AC INPUT TRANSISTOR OUTPUT





STYLE 8:
PIN 1. LED 1 ANODE/LED 2 CATHODE
2. LED 1 CATHODE/LED 2 ANODE
3. NC
4. EMITTER
5. COLLECTOR
6. BASE

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⊕ | Ø 0.13 (0.005) Ⓜ | T | A Ⓜ B Ⓜ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

INFRARED EMITTING DIODES CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Input Voltage H11AA1 (I_F = ±10 mA) H11AA2	V_F	—	1.2 1.2	1.5 1.8	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	—	150	—	pF

PHOTOTRANSISTOR CHARACTERISTICS (T_A = 25°C and I_F = 0 unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector-Emitter Dark Current H11AA1 (V_{CE} = 10 V, Base Open) H11AA2	I_{CEO}	— —	1.0 1.0	100 200	nA
Collector-Base Breakdown Voltage (I_C = 100 μA)	$V_{(BR)CBO}$	70	—	—	Volts
Collector-Emitter Breakdown Voltage (I_C = 10 mA)	$V_{(BR)CEO}$	30	—	—	Volts
Emitter-Base Breakdown Voltage (I_E = 100 μA)	$V_{(BR)EBO}$	5.0	—	—	Volts
DC Current Gain (V_{CE} = 5.0 V, I_C = 1.0 mA)	h_{FE}	—	400	—	—

COUPLED CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Current Transfer Ratio H11AA1 (V_{CE} = 10 V, I_F = ±10 mA) H11AA2	CTR	20 10	— —	— —	%
Current Transfer Ratio Symmetry (1) (V_{CE} = 10 V) H11AA1 H11AA2	$\frac{\text{CTR } (I_F = +10 \text{ mA})}{\text{CTR } (I_F = -10 \text{ mA})}$	0.33 —	— —	3.0 —	—
Surge Isolation Voltage (Input to Output)^2 (Peak ac Voltage, 60 Hz, 5 sec.)	V_{ISO}	7500	—	—	Vac (pk)
Isolation Resistance (2) (V = 500 Vdc)	—	—	10^{11}	—	Ohms
Collector-Emitter Saturation (I_C = 500 μA, I_F = ±10 mA)	$V_{CE(sat)}$	—	0.15	0.40	Volts
Isolation Capacitance (2) (V = 0, f = 1.0 MHz)	—	—	2.0	—	pF

FIGURE 1 — INPUT VOLTAGE versus INPUT CURRENT

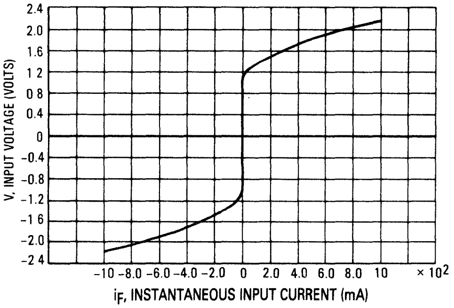


FIGURE 2 — COLLECTOR LEAKAGE CURRENT versus TEMPERATURE

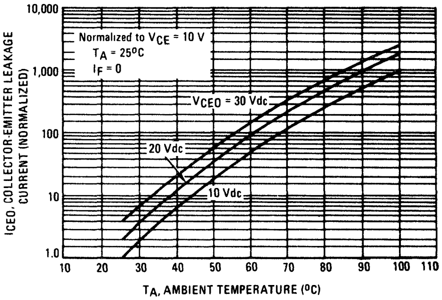
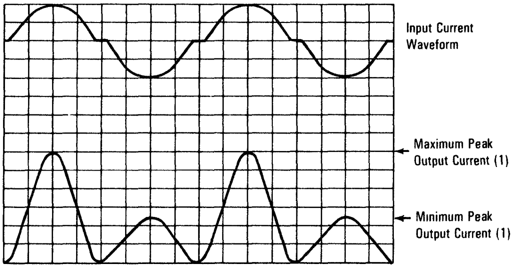


FIGURE 3 — OPERATING CHARACTERISTICS



NOTES:

(1) The H11AA1 specification guarantees the higher of the two CTR readings will be no more than three times the lower at I_F = 10 mA

(2) For this test LED Pins 1 and 2 are common and phototransistor Pins 4, 5, and 6 are common. Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

MOTOROLA

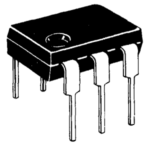
H11C1
H11C2
H11C3

200 V SCR OPTOCOUPLERS

These devices consist of a gallium-arsenide infrared emitting diode optically coupled to a photosensitive silicon controlled rectifier (SCR). They are designed for applications requiring high electrical isolation between low voltage circuitry, like integrated circuits, and the ac line.

- High Blocking Voltage of 200 V for 110 Vac Lines
- Very High Isolation Voltage: V_{ISO} = 7500 Vac (Min)
- All Parameters Other Than Isolation Voltage Pretested to the Originator's Specifications.
- Standard 6-Pin DIP
- UL Recognized, File Number E54915

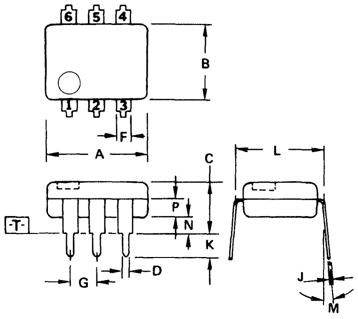
OPTO COUPLER/ISOLATOR
with
PHOTO SCR OUTPUT
200 VOLTS



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	7.0	Volts
Forward Current — Continuous	I_F	60	mA
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	100 1.33	mW mW/°C
OUTPUT DRIVER MAXIMUM RATINGS			
Peak Forward Voltage	V_{DM}	200	Volts
Forward RMS Current (Full Cycle, 50 to 60 Hz) T_A = 25°C	$I_{T(RMS)}$	300	mA
Peak Nonrepetitive Surge Current (PW = 10 ms)	I_{TSM}	3.0	A
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	400 5.33	mW mW/°C
TOTAL DEVICE MAXIMUM RATINGS			
Isolation Surge Voltage (1) (Peak ac Voltage, 60 Hz, 5 Second Duration)	V_{ISO}	7500 (2)	Vac
Junction Temperature Range	T_J	-40 to +100	°C
Ambient Operating Temperature Range	T_A	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)	—	260	°C

(1) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.
(2) Originator's Specifications are: H11C1 — 2500 V, H11C2 and H11C3 — 2100 V.

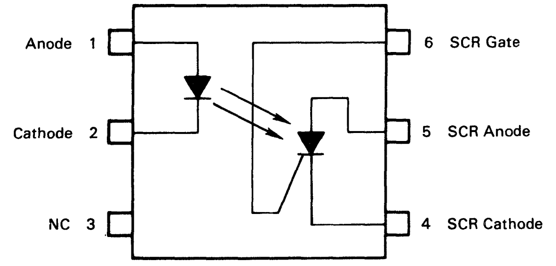


STYLE 7:
PIN 1. LED ANODE
2. LED CATHODE
3. NC
4. SCR CATHODE
5. SCR ANODE
6. SCR GATE

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS.
⊕ ∅ 0.13 (0.005) Ⓜ T A Ⓜ B Ⓜ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01



ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
LED CHARACTERISTICS						
Reverse Leakage Current (V_R = 3.0 V)		I_R	—	0.05	10	μA
Forward Voltage (I_F = 10 mA)		V_F	—	1.2	1.5	Volts
Capacitance (V = 0, f = 1.0 MHz)		C_J	—	50	—	pF
DETECTOR CHARACTERISTICS						
Peak Off-State Voltage (R_{GK} = 10 kΩ, T_A = 100°C)		V_{DM}	200	—	—	Volts
Peak Reverse Voltage (R_{GK} = 10 kΩ, T_A = 100°C)		V_{RM}	200	—	—	Volts
On-State Voltage (I_{TM} = 0.3 A)		V_{TM}	—	1.1	1.3	Volts
Off-State Current (V_{DM} = 200 V, T_A = 100°C)		I_{DM}	—	—	50	μA
Reverse Current (V_{RM} = 200 V, T_A = 100°C)		I_{RM}	—	—	50	μA
Capacitance (V = 0, f = 1.0 MHz)		C_J				pF
Anode - Gate			—	20	—	
Gate - Cathode			—	350	—	
COUPLED CHARACTERISTICS						
LED Current Required to Trigger		I_{FT}				mA
(V_{AK} = 50 V, R_{GK} = 10 kΩ)	H11C1, H11C2		—	10	20	
	H11C3		—	15	30	
(V_{AK} = 100 V, R_{GK} = 27 kΩ)	H11C1, H11C2		—	6.0	11	
	H11C3		—	8.0	14	
Isolation Resistance (V_{IO} = 500 Vdc)		R_{ISO}	100	—	—	GΩ
Capacitance Input to Output (V_{IO} = 0, f = 1.0 MHz)		C_{ISO}	—	—	2.0	pF
Coupled dv/dt, Input to Output (R_{GK} = 10 kΩ)		dv/dt	—	500	—	Volts/μs
Isolation Surge Voltage (Peak ac Voltage, 60 Hz, 5 Second Duration)		V_{ISO}	7500	—	—	Vac(pk)

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 1 — LED FORWARD VOLTAGE versus FORWARD CURRENT

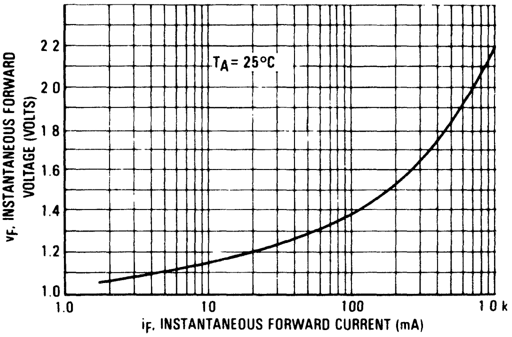


FIGURE 2 — ANODE CURRENT versus ANODE-CATHODE VOLTAGE

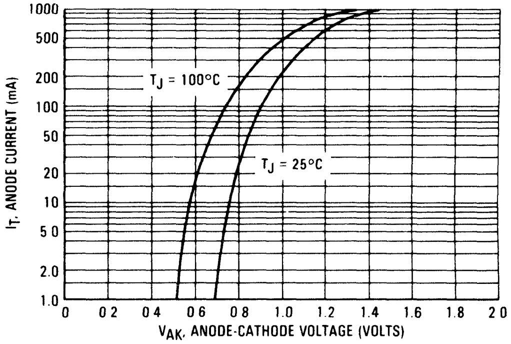


FIGURE 3 — LED TRIGGER CURRENT versus TEMPEATURE

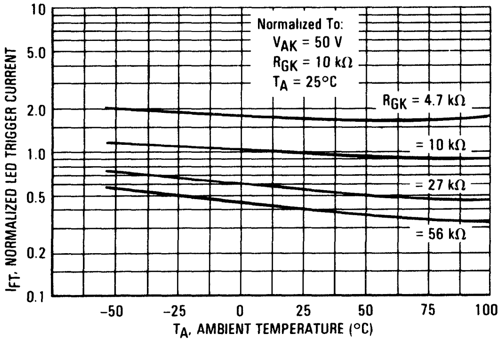
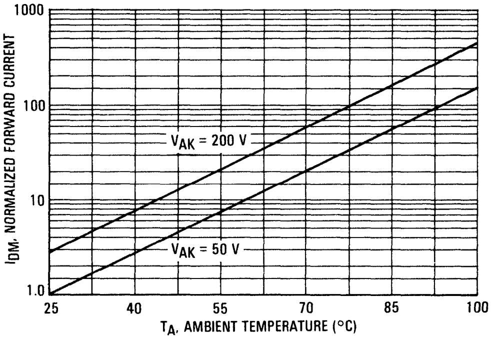


FIGURE 4 — FORWARD LEAKAGE CURRENT versus TEMPERATURE



MOTOROLA

H11D1
H11D2
H11D3
H11D4

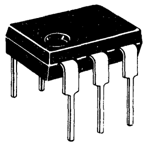
HIGH VOLTAGE TRANSISTOR OPTOCOUPLERS

. . . consist of gallium-arsenide infrared emitting diodes optically coupled to high voltage, silicon, phototransistor detectors in a standard 6-pin DIP package. They are designed for applications requiring high voltage output and are particularly useful in copy machines and solid state relays.

- High Voltage — H11D1,2 — 300 V
  — H11D3,4 — 200 V
- High Isolation Voltage — V_{ISO} = 7500 Vac pk (Min)
- Standard 6-Pin DIP Package
- UL Recognized, File Number E54915

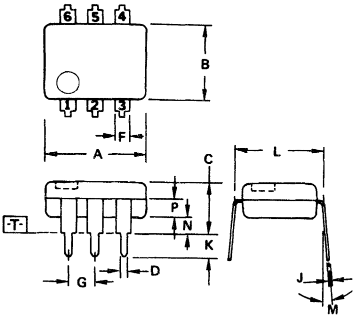
OPTO COUPLER/ISOLATOR

TRANSISTOR OUTPUT
200,300 VOLT



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted).

Rating	Symbol	Value	Unit
INFRARED-EMITTING DIODES MAXIMUM RATINGS			
Input Current — Continuous (RMS)	I_F	60	mA
Input Current — Peak Pulse Width = 1.0 μs, 330 pps	I_F	3.0	Amp
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	100 1.33	mW mW/°C
PHOTOTRANSISTOR MAXIMUM RATINGS			
Collector-Emitter Voltage H11D1,2 H11D3,4	V_{CER}	300 200	Volts
Emitter-Collector Voltage	V_{ECO}	7.0	Volts
Collector-Base Voltage H11D1,2 H11D3,4	V_{CBO}	300 200	Volts
Collector Current (Continuous)	I_C	100	mA
Total Device Dissipation @ T_A = 25°C Negligible Power in Diode Derate above 25°C	P_D	300 4.0	mW mW/°C
TOTAL DEVICE RATINGS			
Total Device Dissipation @ T_A = 25°C Equal Power Dissipation in Each Element Derate above 25°C	P_D	300 4.0	mW mW/°C
Operating Temperature Range	T_J	−55 to +100	°C
Storage Temperature Range	T_{stg}	−55 to +150	°C
Soldering Temperature (10 s)		260	°C
Surge Isolation Voltage (Input to Output)	V_{ISO}	7500	Vac(pk)



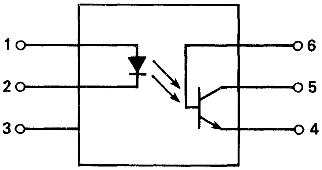
STYLE 1.
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. BASE

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⌖ | ∅ 0.13 (0.005) Ⓜ | T | A Ⓜ B Ⓜ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

COUPLER SCHEMATIC



ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
LED CHARACTERISTICS (T_A = 25°C unless otherwise noted)					
Reverse Leakage Current (V_R = 6.0 V)	I_R	—	—	10	μA
Forward Voltage (I_F = 10 mA)	V_F	—	1.2	1.5	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	—	50	—	pF
PHOTOTRANSISTOR CHARACTERISTICS (T_A = 25°C and I_F = 0 unless otherwise noted)					
Collector-Emitter Dark Current (R_{BE} = 1.0 MΩ) (V_{CE} = 200 V, T_A = 25°C) H11D1,2 (V_{CE} = 100 V, T_A = 25°C) H11D3,4 (T_A = 100°C) All Devices	I_{CER}	 — — —	 — — —	 100 100 250	 nA nA μA
Collector-Base Breakdown Voltage (I_C = 100 μA) H11D1,2 H11D3,4	$V_{(BR)CBO}$	 — —	 — —	 300 200	Volts
Collector-Emitter Breakdown Voltage (I_C = 1.0 mA, R_{BE} = 1.0 MΩ) H11D1,2 H11D3,4	$V_{(BR)CER}$	 — —	 — —	 300 200	Volts
Emitter-Base Breakdown Voltage (I_E = 100 μA)	$V_{(BR)EBO}$	7.0	—	—	Volts
COUPLED CHARACTERISTICS (T_A = 25°C unless otherwise noted)					
Current Transfer Ratio (V_{CE} = 10 V, I_F = 10 mA, R_{BE} = 1.0 MΩ) H11D1,2,3 H11D4	CTR	 20 10	 — —	 — —	%
Surge Isolation Voltage (Input to Output)(1) Peak ac Voltage, 60 Hz, 5 sec	V_{ISO}	7500	—	—	Volts
Isolation Resistance (1) (V = 500 V)	R_{IO}	—	10^{11}	—	Ohms
Collector-Emitter Saturation Voltage (I_C = 0.5 mA, I_F = 10 mA, R_{BE} = 1.0 MΩ)	$V_{CE(sat)}$	—	—	0.4	Volts
Isolation Capacitance (1) (V = 0, f = 1.0 MHz)	C_{IO}	—	2.0	—	pF
SWITCHING CHARACTERISTICS (T_A = 25°C)					
Turn-On Time (V_{CC} = 10 V, I_C = 2.0 mA, R_L = 100 Ω)	t_{on}	—	5.0	—	μs
Turn-Off Time (V_{CC} = 10 V, I_C = 2.0 mA, R_L = 100 Ω)	t_{off}	—	5.0	—	μs

NOTES: 1. For this test LED Pins 1 and 2 are common and phototransistor Pins 4, 5, and 6 are common.

FIGURE 1 — OUTPUT CURRENT versus LED INPUT CURRENT

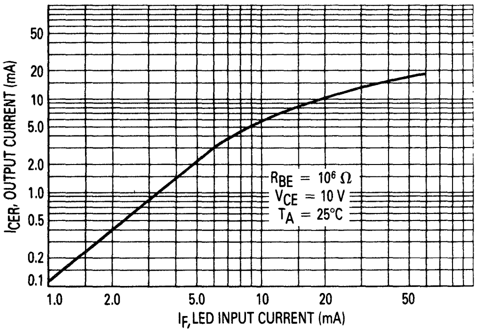
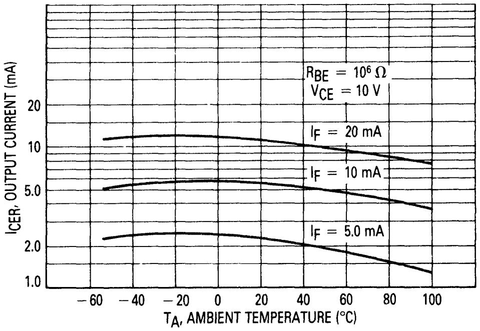


FIGURE 2 — OUTPUT CURRENT versus TEMPERATURE



TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 3 — OUTPUT CHARACTERISTICS

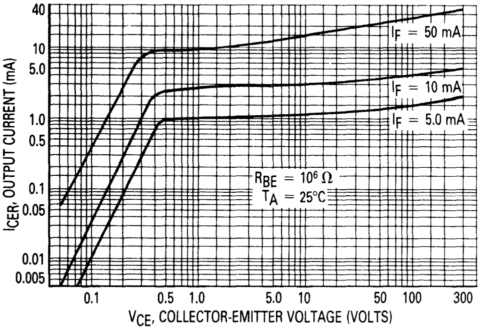


FIGURE 4 — FORWARD CHARACTERISTICS

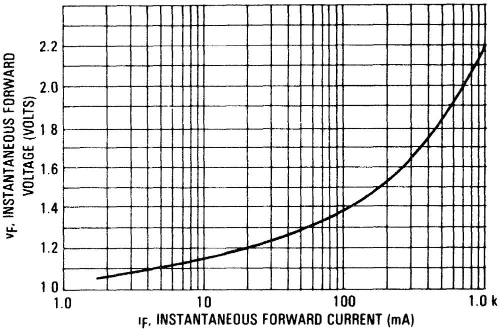


FIGURE 5 — COLLECTOR-BASE CURRENT versus TEMPERATURE

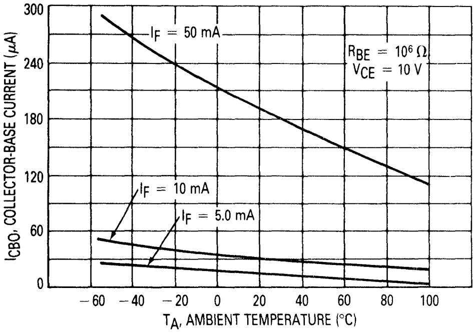
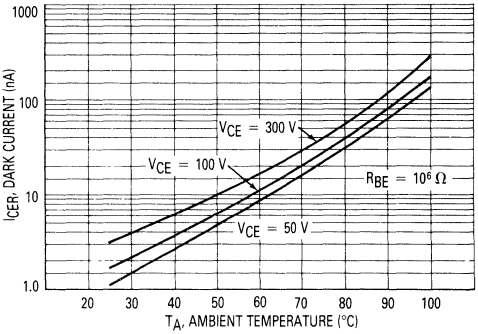


FIGURE 6 — DARK CURRENT versus TEMPERATURE



MOTOROLA

H11G1
H11G2
H11G3

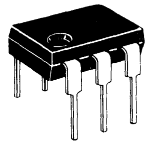
RESISTOR-DARLINGTON OPTOCOUPLER SERIES

. . . consists of a gallium arsenide IRED optically coupled to a silicon photodarlington detector which has an integral base-emitter resistor. The on-chip resistor improves higher temperature leakage characteristics. Designed with high isolation, high CTR, high voltage and low leakage, they provide excellent performance in interfacing and coupling systems, phase and feedback controls, solid state relays and general purpose switching circuits.

- High CTR, H11G1, H11G2 — 1000%
- High Isolation, V_{ISO} = 7500 Vac pk (Min)
- High $V_{(BR)CEO}$, H11G1 — 100 V, H11G2 — 80 V
- Standard, Economical, 6-Pin DIP Package
- UL Recognized — File No. E54915

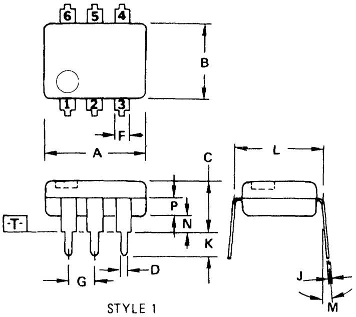
OPTO COUPLER/ISOLATOR

DARLINGTON OUTPUT



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED-EMITTING DIODE			
Reverse Voltage	V_R	6.0	Volts
Forward Current — Continuous	I_F	60	mA
Forward Current -- Peak Pulse Width = 300 μs, 2.0% Duty Cycle	I_F	3.0	Amp
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	100 1.33	mW mW/°C
PHOTO DARLINGTON TRANSISTOR			
Collector-Emitter Voltage H11G1 H11G2 H11G3	V_{CEO}	 100 80 55	Volts
Emitter-Base Voltage	V_{EBO}	7.0	Volts
Collector Current — Continuous	I_C	150	mA
Total Power Dissipation @ T_A = 25°C Negligible Power in Diode Derate above 25°C	P_D	150 2.0	mW mW/°C
TOTAL DEVICE			
Total Device Dissipation @ T_A = 25°C Equal Power Dissipation in Each Element Derate above 25°C	P_D	250 3.3	mW mW/°C
Operating Junction Temperature Range	T_J	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)	—	260	°C
Isolation Surge Voltage (Vac pk)	V_{ISO}	7500	Volts



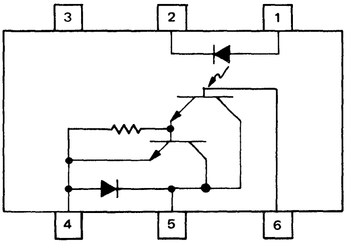
STYLE 1
PIN 1 ANODE
2 CATHODE
3 NC
4 EMITTER
5 COLLECTOR
6 BASE

NOTES
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS
⌖ | ∅ 0.13 (0.005)Ⓜ | T | AⓂ BⓂ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

FIGURE 1 — DEVICE SCHEMATIC



LED CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Leakage Current (V_R = 3.0 V)	I_R	—	0.05	10	μA
Forward Voltage (I_F = 10 mA)	V_F	—	1.1	1.5	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	—	50	—	pF

PHOTODARLINGTON CHARACTERISTICS (T_A = 25°C and I_F = 0 unless otherwise noted.)

Characteristic		Symbol	Min	Typ	Max	Unit
Collector -Emitter Breakdown Voltage (I_C = 1.0 mA, I_F = 0)	H11G1 H11G2 H11G3	$V_{(BR)CEO}$	100 80 55	— — —	— — —	Volts
Collector-Base Breakdown Voltage (I_C = 100 μA, I_F = 0)	H11G1 H11G2 H11G3	$V_{BR)CBO}$	100 80 55	— — —	— — —	Volts
Emitter-Base Breakdown Voltage (I_E = 100 μA, I_F = 0)		$V_{(BR)EBO}$	7.0	—	—	Volts
Collector-Emitter Dark Current (V_{CE} = 80 V) (V_{CE} = 80 V, T_A = 80°C) (V_{CE} = 60 V) (V_{CE} = 60 V, T_A = 80°C) (V_{CE} = 30 V)	 H11G1 H11G1 H11G2 H11G2 H11G3	I_{CEO}	 — — — — —	 — — — — —	 100 100 100 100 100	 nA μA nA μA nA
Capacitance (V_{CB} = 10 V, f = 1.0 MHz)		C_{CB}	—	6.0	—	pF

COUPLED CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic		Symbol	Min	Typ	Max	Unit
Collector Output Current (V_{CE} = 1.0 V, I_F = 10 mA) (V_{CE} = 5.0 V, I_F = 1.0 mA) (V_{CE} = 5.0 V, I_F = 1.0 mA)	 H11G1, 2 H11G1, 2 H11G3	I_C	 100 5.0 2.0	 — — —	 — — —	mA
Collector-Emitter Saturation Voltage (I_F = 1.0 mA, I_C = 1.0 mA) (I_F = 16 mA, I_C = 50 mA) (I_F = 20 mA, I_C = 50 mA)	 H11G1, 2 H11G1, 2 H11G3	$V_{CE(sat)}$	 — — —	 0.75 0.85 0.85	 1.0 1.0 1.2	Volts
Isolation Surge Voltage (1, 2) (60 Hz ac Peak, 5 Seconds)		V_{ISO}	7500	—	—	Volts
Isolation Resistance (1) (V = 500 Vdc)			—	10^{11}	—	Ohms
Isolation Capacitance (1) (V = 0 V, f = 1.0 MHz)			—	—	2.0	pF

SWITCHING CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Turn-On Time	(I_F = 10 mA, V_{CE} = 5.0 V, R_L = 100 Ω, Pulse Width ⩽ 300 μs, f ⩽ 30 Hz)	t_{on}	—	5.0	—	μs
Turn-Off Time		t_{off}	—	100	—	

(1) For this test LED Pins 1 and 2 are common and Phototransistor Pins 4 and 5 are common.

(2) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

FIGURE 2 — OUTPUT CURRENT versus INPUT CURRENT

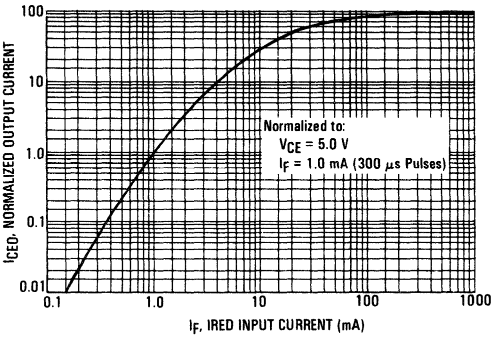


FIGURE 3 — OUTPUT CURRENT versus TEMPERATURE

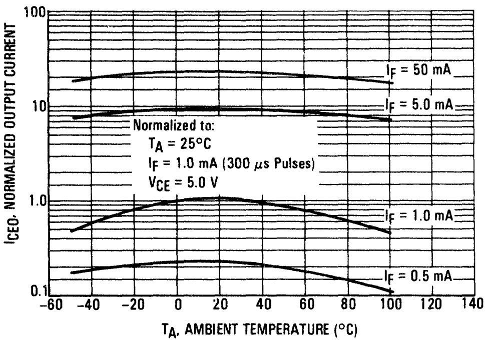


FIGURE 4 — OUTPUT CURRENT versus COLLECTOR-EMITTER VOLTAGE

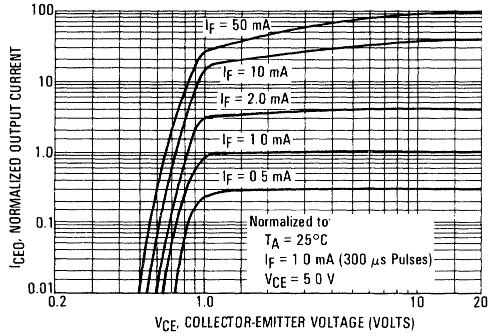


FIGURE 5 — LED FORWARD CHARACTERISTICS

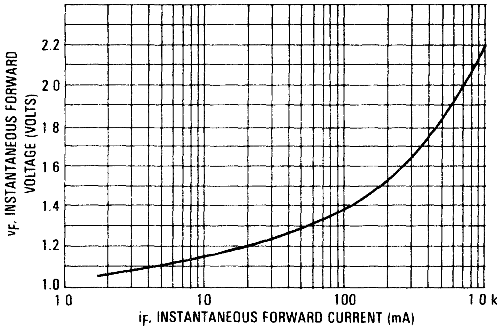


FIGURE 6 — COLLECTOR-EMITTER DARK CURRENT versus TEMPERATURE

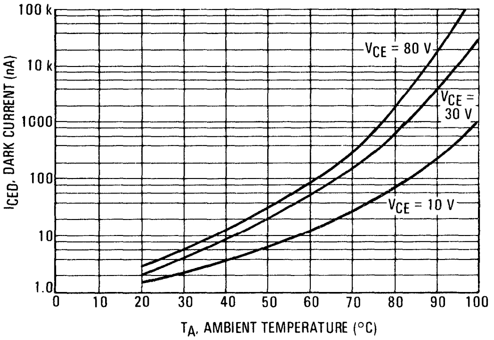
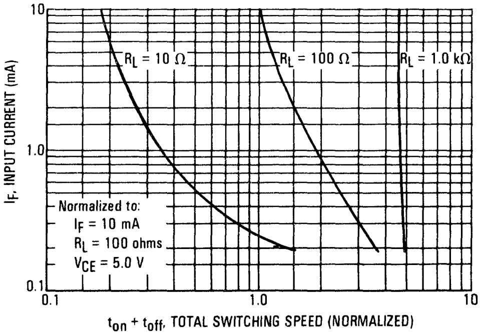
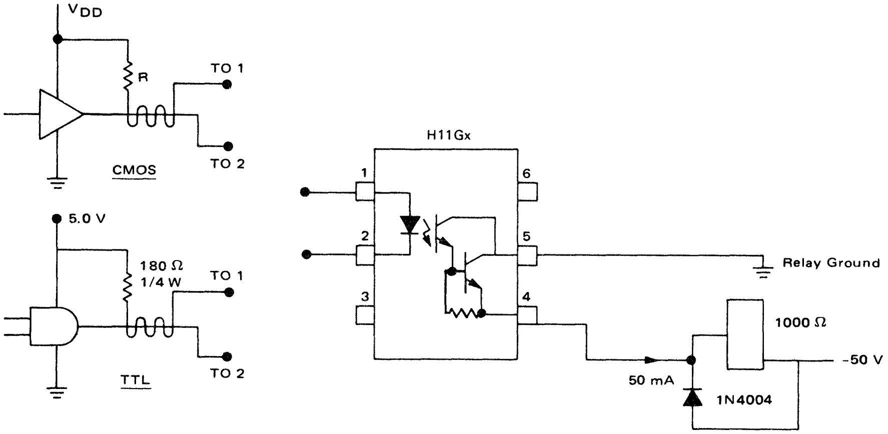


FIGURE 7 — INPUT CURRENT versus TOTAL SWITCHING SPEED



INTERFACING TTL OR CMOS LOGIC TO 50-VOLT, 1000-OHMS RELAY FOR TELEPHONY APPLICATIONS

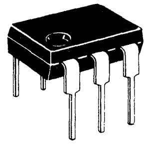
In order to interface positive logic to negative-powered electromechanical relays, a change in voltage level and polarity plus electrical isolation are required. The H11Gx can provide this interface and eliminate the external amplifiers and voltage divider networks previously required. The circuit below shows a typical approach for the interface.



MOTOROLA

H11L1
H11L2

OPTO COUPLER/ISOLATOR
SCHMITT TRIGGER OUTPUT



DIGITAL LOGIC COUPLERS

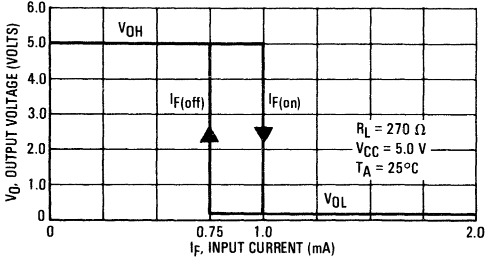
. . . gallium arsenide IRED optically coupled to high-speed integrated detectors with Schmitt trigger outputs. Designed for applications requiring electrical isolation, fast response time, noise immunity and digital logic compatibility such as interfacing computer terminals to peripheral equipment, digital control of power supplies, motors and other servo machine applications.

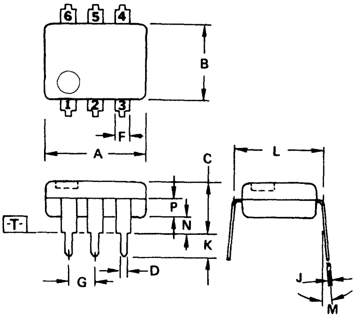
- High Isolation Voltage — V_{ISO} = 7500 Vac (Min)
- Guaranteed Switching Times
  $t_{on}, t_{off} < 4.0\ \mu s$
- Built-In ON/OFF Threshold Hysteresis
- Economical, Standard Dual-In-Line Plastic Package
- UL Recognized, File No. E54915

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	6.0	Volts
Forward Current — Continuous Peak Pulse Width = 300 μs, 2.0% Duty Cycle	I_F	60 0.5	mA Amp
Device Dissipation Negligible Power in C Derate above 25°C	P_D	100 1.33	mW mW/°C
DETECTOR MAXIMUM RATINGS			
Output Voltage Range	V_o	0–16	Volts
Supply Voltage Range	V_{CC}	0–16	Volts
Output Current	I_O	50	mA
Device Dissipation Negligible Power in Diode Derate above 25°C	P_D	150 2.0	mW mW/°C
TOTAL DEVICE RATINGS			
Total Device Dissipation	P_D	250	mW
Maximum Operating Temperature	T_A	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)		260	°C
Isolation Surge Voltage (Vac pk)	V_{ISO}	7500	Volts

FIGURE 1 — TRANSFER CHARACTERISTICS FOR H11L1





STYLE 5
PIN 1. ANODE
2. CATHODE
3. NC
4. OUTPUT
5. GROUND
6. V_{CC}

NOTES
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⌖ | ∅ 0.13 (0.005) Ⓜ | T | A Ⓜ B Ⓜ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

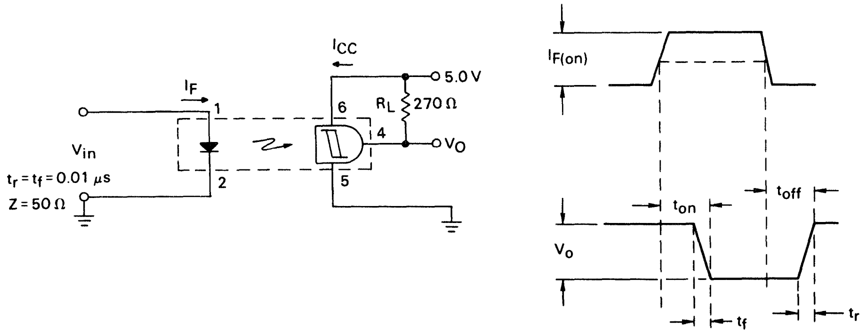
	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

Characteristic	Symbol	Min	Typ	Max	Unit
IRED CHARACTERISTICS (T_A = 0–70°C)					
Reverse Leakage Current (V_R = 3.0 V, R_L = 1.0 MΩ)	I_R	—	0.05	10	µA
Forward Voltage	V_F				Volts
(I_F = 10 mA)		—	1.2	1.5	
(I_F = 0.3 mA)		0.75	0.95	—	
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	—	50	—	pF
ISOLATION CHARACTERISTICS (T_A = 25°C)					
Isolation Voltage (1) 60 Hz, ac Peak, 5 s	V_{ISO}	7500	—	—	Volts
DETECTOR CHARACTERISTICS (T_A = 0–70°C)					
Operating Voltage	V_{CC}	3.0	—	15	Volts
Supply Current (I_F = 0, V_{CC} = 5.0 V)	$I_{CC(off)}$	—	1.0	5.0	mA
Output Current, High (I_F = 0, V_{CC} = V_o = 15 V)	I_{OH}	—	—	100	µA
COUPLED CHARACTERISTICS (T_A = 0–70°C)					
Supply Current (I_F = $I_{F(on)}$, V_{CC} = 5.0 V)	$I_{CC(on)}$	—	1.6	5.0	mA
Output Voltage, Low (R_L = 270 Ω, V_{CC} = 5.0 V, I_F = $I_{F(on)}$)	V_{OL}	—	0.2	0.4	Volts
Threshold Current, ON H11L1	$I_{F(on)}$	—	1.0	1.6	mA
(R_L = 270 Ω, V_{CC} = 5.0 V) H11L2		—	—	10	
Threshold Current, OFF H11L1	$I_{F(off)}$	0.3	0.75	—	mA
(R_L = 270 Ω, V_{CC} = 5.0 V) H11L2		0.3	—	—	
Hysteresis Ratio (R_L = 270 Ω, V_{CC} = 5.0 V)	$\frac{I_{F(off)}}{I_{F(on)}}$	0.5	0.75	0.90	
SWITCHING CHARACTERISTICS (T_A = 25°C)					
Turn-On-Time R_L = 270 Ω, V_{CC} = 5.0 V, I_F = $I_{F(on)}$	t_{on}	—	1.2	—	µs
Fall Time	t_f	—	0.1	—	
Turn-Off-Time	t_{off}	—	1.2	—	
Rise Time	t_r	—	0.1	—	

(1) For this test IRED Pins 1 and 2 are common and Output Gate Pins 4, 5, 6 are common.

FIGURE 2 — SWITCHING TEST CIRCUIT



TYPICAL CHARACTERISTICS

FIGURE 3 — THRESHOLD CURRENT versus SUPPLY VOLTAGE

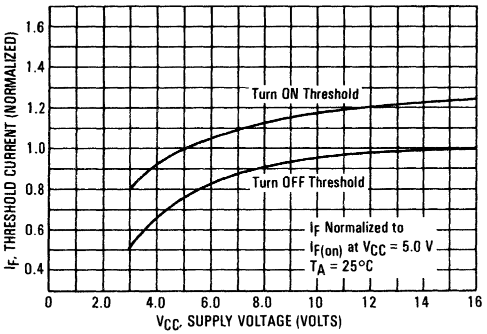


FIGURE 4 — THRESHOLD CURRENT versus TEMPERATURE

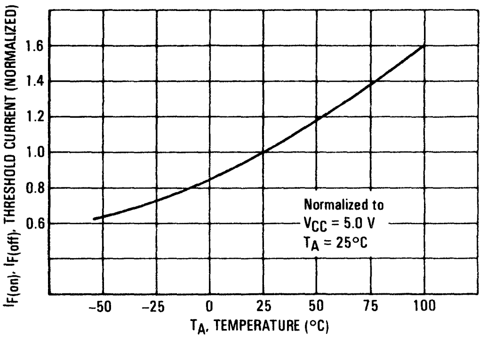


FIGURE 5 — OUTPUT VOLTAGE, LOW versus LOAD CURRENT

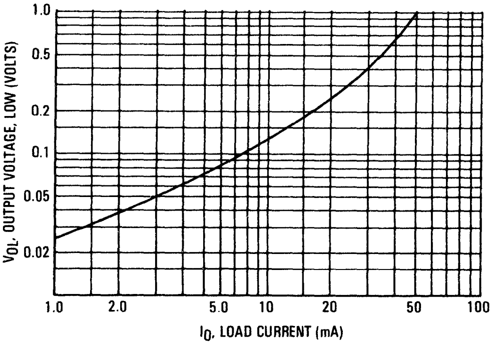
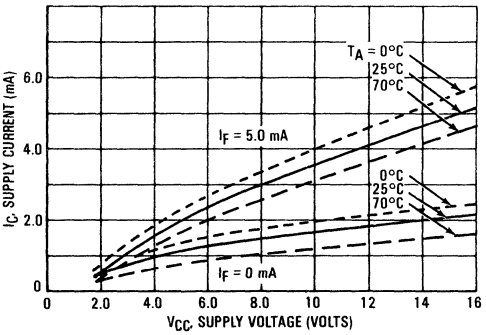


FIGURE 6 — SUPPLY CURRENT versus SUPPLY VOLTAGE



MOTOROLA

H21A1 H22A1
H21A2 H22A2
H21A3 H22A3

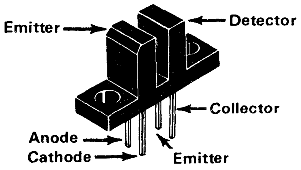
OPTO SLOTTED COUPLER/INTERRUPTER MODULES

These devices consist of a gallium arsenide infrared emitting diode facing a silicon NPN phototransistor in a molded plastic housing. A slot in the housing between the emitter and the detector provides a means of interrupting the signal. They are widely used in position and motion indicators, end of tape indicators, paper feed controls and arcless switches.

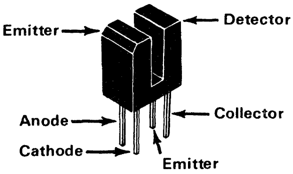
- 1.0 mm Aperture
- Easy PCB Mounting
- Cost Effective
- Industry Standard Configuration
- Uses Long-Lived LPE IRED

OPTO SLOTTED COUPLER

TRANSISTOR OUTPUT



(H21A1, 2, 3)
CASE 354A-01



(H22A1, 2, 3)
CASE 354-01

ABSOLUTE MAXIMUM RATINGS: (25°C)

Rating	Symbol	Value	Unit
TOTAL DEVICE			
Storage Temperature	T_{stg}	-55°C to +100°C	
Operating Temperature	T_J	-55°C to +100°C	
Lead Soldering Temperature (5 seconds maximum)	T_L	260°C	
INFRARED EMITTING DIODE			
Power Dissipation	P_D	100*	mW
Forward Current (Continuous)	I_F	60	mA
Reverse Voltage	V_R	6.0	V
PHOTOTRANSISTOR			
Power Dissipation	P_D	150**	mW
Collector-Emitter Voltage	V_{CEO}	30	V

*Derate 1.33 mW/°C above 25°C ambient
**Derate 2.0 mW/°C above 25° ambient.

INDIVIDUAL ELECTRICAL CHARACTERISTICS: (25°C) (See Note 1)

Characteristic	Symbol	Min	Typ	Max	Unit
EMITTER					
Reverse Breakdown Voltage (I_R = 100 μA)	$V_{(BR)R}$	6.0	—	—	V
Forward Voltage (I_F = 60 mA)	V_F	—	1.3	1.7	V
Reverse Current (V_R = 6.0 V, R_L = 1.0 MΩ)	I_R	—	50	—	nA
Capacitance (V = 0, f = 1 MHz)	C_i	—	25	—	pF
DETECTOR					
Breakdown Voltage (I_C = 10 mA, H ≈ 0)	$V_{(BR)CEO}$	30	—	—	V
Collector Dark Current (V_{CE} = 10 V, H ≈ 0)	I_{CEO}	—	—	100	nA

Note 1: Stray irradiation can alter values of characteristics. Adequate shielding should be provided.

COUPLED ELECTRICAL CHARACTERISTICS: (25°C) (See Note 1)

Conditions	Symbol	H21A1/H22A1			H21A2/H22A2			H21A3/H22A3			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
I_F = 5.0 mA, V_{CE} = 5.0 V	$I_{CE(on)}$	0.15	—	—	0.30	—	—	0.60	—	—	mA
I_F = 20 mA, V_{CE} = 5.0 V	$I_{CE(on)}$	1.0	—	—	2.0	—	—	4.0	—	—	mA
I_F = 30 mA, V_{CE} = 5.0 V	$I_{CE(on)}$	1.9	—	—	3 0	—	—	5.5	—	—	mA
I_F = 20 mA, I_C = 1 8 mA	$V_{CE(sat)}$	—	—	—	—	—	0 40	—	—	0.40	V
I_F = 30 mA, I_C = 1.8 mA	$V_{CE(sat)}$	—	—	0 40	—	—	—	—	—	—	V
V_{CC} = 5.0 V, I_F = 30 mA, R_L = 2.5 kΩ	t_{on}	—	12	—	—	12	—	—	12	—	μs
V_{CC} = 5.0 V, I_F = 30 mA, R_L = 2 5 kΩ	t_{off}	—	60	—	—	60	—	—	60	—	μs

Note 1 Stray irradiation can alter values of characteristics Adequate shielding should be provided

FIGURE 1 — OUTPUT CURRENT versus INPUT CURRENT

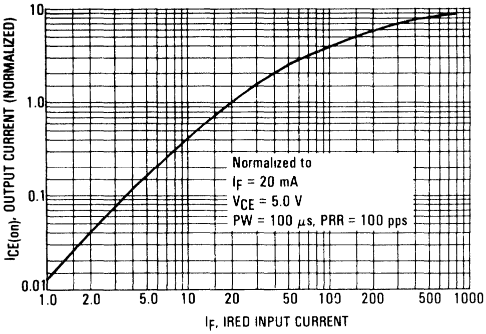


FIGURE 2 — t_{on}, t_{off} versus LOAD RESISTANCE

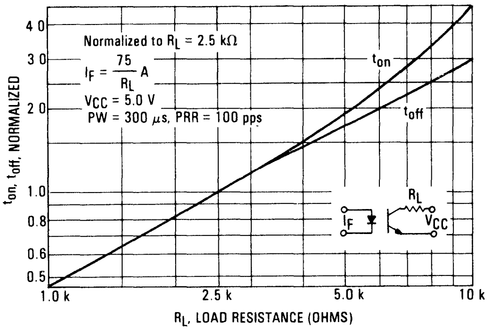
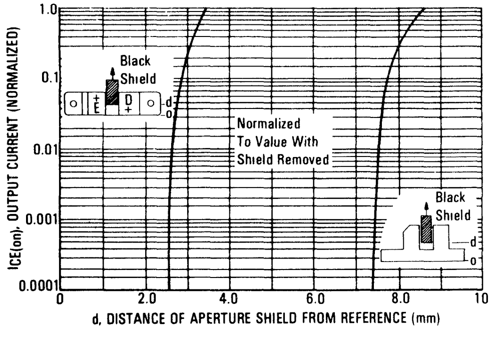
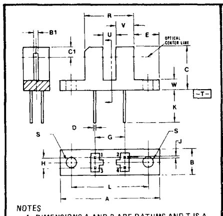


FIGURE 3 — OUTPUT CURRENT versus POSITION OF SHIELD COVERING APERTURE



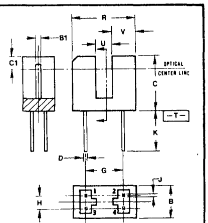


NOTES
1 DIMENSIONS A AND B ARE DATUMS AND T IS A DATUM SURFACE
2 POSITIONAL TOLERANCE FOR MOUNTING HOLES
| ⌖ | ⌀ 0 36 (0 014) Ⓜ | T | A Ⓜ | B Ⓜ |
3 POSITIONAL TOLERANCE FOR LEAD DIMENSION J
| ⌖ | 0 13 (0 005) Ⓜ | T | B Ⓜ |
4 POSITIONAL TOLERANCE FOR LEAD DIMENSION D
| ⌖ | 0 13 (0 005) Ⓜ | T | A Ⓜ | B Ⓜ |
5 DIMENSIONING AND TOLERANCING PER Y14 5, 1973

STYLE 1
PIN 1 CATHODE 3 ANODE
2 COLLECTOR 4 EMITTER

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	24 13	25 01	0 950	0 985
B	6 19	6 50	0 244	0 256
C	10 64	10 94	0 419	0 431
D	0 35	0 55	0 014	0 022
E	6 24	6 55	0 246	0 258
G	7 36 BSC		0 290 BSC	
H	2 54 BSC		0 100 BSC	
J	0 43	0 55	0 017	0 022
K	7 36	–	0 290	–
L	19 05 BSC		0 750 BSC	
R	11 98	12 19	0 472	0 480
S	3 24	3 37	0 124	0 133
U	3 07	3 32	0 115	0 129
V	4 36	4 52	0 172	0 178
W	2 38	2 69	0 094	0 106
B1	0 88	1 14	0 035	0.045
C1	2 54 NOM		0 100 NOM	

CASE 354A-01



STYLE 1
PIN 1 CATHODE 3 ANODE
2 COLLECTOR 4 EMITTER

NOTES
1 DIMENSIONS R AND B ARE DATUMS AND T IS A DATUM SURFACE
2 POSITIONAL TOLERANCE FOR LEAD DIMENSION J
| ⌖ | 0 13 (0 005) Ⓜ | T | B Ⓜ |
3 POSITIONAL TOLERANCE FOR LEAD DIMENSION D
| ⌖ | 0 13 (0.005) Ⓜ | T | R Ⓜ | B Ⓜ |
4 DIMENSIONING AND TOLERANCING ARE PER Y14 5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
B	6 19	6 50	0 244	0 256
C	10 64	10 94	0 419	0 431
D	0 35	0.55	0 014	0 022
G	7.36 BSC		0 290 BSC	
H	2 54 BSC		0 100 BSC	
J	0.43	0.55	0.017	0 022
K	7 36	–	0 290	–
R	11 98	12 19	0 472	0.480
U	3 07	3 32	0 115	0 129
V	4.36	4.52	0.172	0 178
W	2.38	2 69	0.094	0.106
B1	0.88	1.14	0 035	0 045
C1	2 54 NOM		0 100 NOM	

CASE 354 01

MOTOROLA

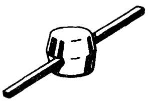
MLED15

INFRARED-EMITTING DIODE

. . . designed for applications requiring high-power output, low-drive power and very fast response time. This device is used in industrial processing and control, light modulators, shaft or position encoders, punched card and tape readers, optical switching, and logic circuits. It is spectrally matched for use with silicon detectors.

- High-Power Output of 1.3 mW (Typ) @ I_F = 30 mA
- Same Package as Popular MRD150 Photodetector
- Infrared-Emission — 930 nm (Typ)
- Low-Drive Current — Compatible with Integrated Circuits
- Broad Radiation Pattern
- Economical Plastic Package
- Small Size for High Density Mounting
- Easy Cathode Identification — Larger Flag

INFRARED-EMITTING DIODE
930 nm
PN GALLIUM ARSENIDE



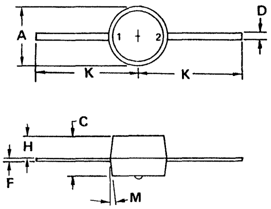
MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Reverse Voltage	V_R	6.0	Volts
Forward Current-Continuous	I_F	30	mA
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D(1)	50 0.67	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-40 to +100	°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance Junction to Ambient	$R_{\theta JA}$(1)	500	°C/W
Solder Temperature	260°C for 10 sec.		

(1)Printed Circuit Board Mounting



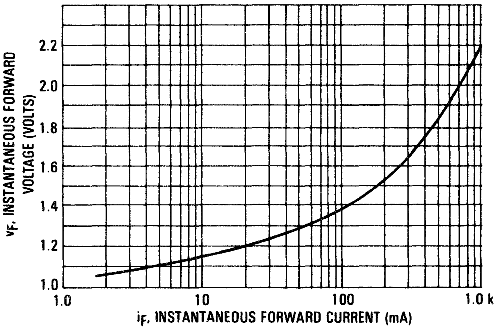
STYLE 2:
PIN 1. ANODE
2. CATHODE

NOTE:
1. INDEX BUTTON ON PACKAGE BOTTOM IS 0.25/0.51 mm (0.010/0.020) DIA & 0.05/0.13 mm (0.002/0.005) OFF SURFACE.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	1.98	2.34	0.078	0.092
C	1.22	1.47	0.048	0.058
D	0.25	0.41	0.010	0.016
F	0.10	0.15	0.004	0.006
H	0.51	0.76	0.020	0.030
K	4.06	—	0.160	—
M	3°	7°	3°	7°

CASE 173-01

FIGURE 1 — FORWARD CHARACTERISTICS



ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristics	Symbol	Min	Typ	Max	Unit
Reverse Leakage Current (V_R = 3.0 V, R_L = 1.0 Megohm)	I_R	—	0.05	100	μA
Reverse Breakdown Voltage (I_R = 100 μA)	$V_{(BR)R}$	6.0	—	—	Volts
Forward Voltage (I_F = 30 mA)	V_F	—	1.2	1.5	Volts
Total Capacitance (V_R = 0 V, f = 1.0 MHz)	C_T	—	50	—	pF

OPTICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristics	Symbol	Min	Typ	Max	Unit
Axial Radiant Intensity (I_F = 30 mA)	I_o	—	1000	—	μW/ Steradian
Power Output (I_F = 30 mA)	P_o	200	1300	—	μW
Peak Emission Wavelength	λ_P	—	930	—	nm
Spectral Line Half Width	$\Delta\lambda$	—	48	—	nm
Turn-On Time (I_F = 0 → 30 mA, P_o = 0 → 200 μW)	t_{on}	—	400	—	ns
Turn-Off Time (I_F = 30 mA → 0, P_o = max → 20 μW)	t_{off}	—	400	—	ns

FIGURE 2 — INSTANTANEOUS POWER OUTPUT

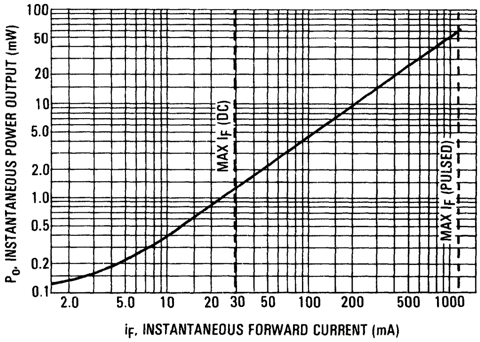
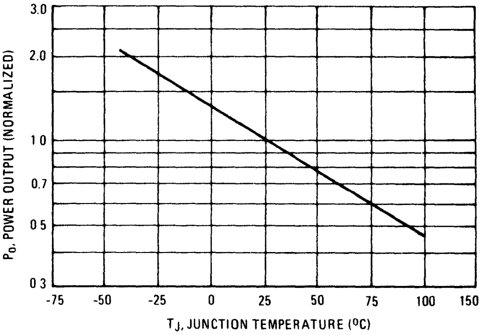


FIGURE 3 — POWER OUTPUT versus JUNCTION TEMPERATURE



Output saturation effects are not evident at currents up to 1 A as shown on Figure 2. However, saturation does occur due to heating of the semiconductor as indicated by Figure 3 To estimate output level, average junction temperature may be calculated from:

$$T_{J(AV)} = T_A + \theta_{JA} V_F I_F D$$

where D is the duty cycle of the applied current, I_F. Use of the above method should be restricted to drive conditions employing pulses of less than 10 μs duration to avoid errors caused by high peak junction temperatures.

FIGURE 4 — SPATIAL RADIATION PATTERN (I_o NORMALIZED)

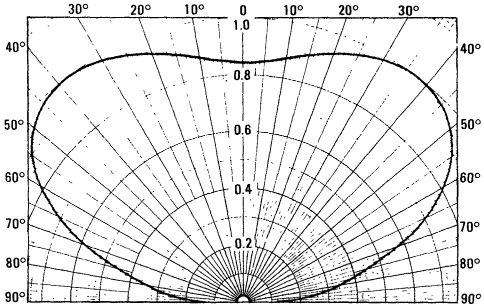
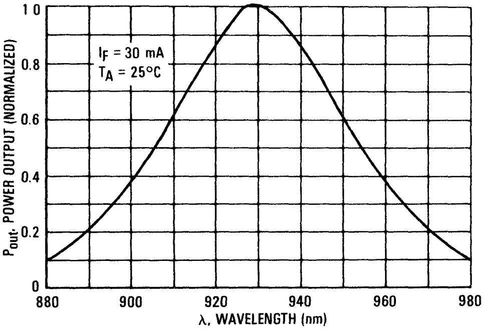


FIGURE 5 — RELATIVE SPECTRAL OUTPUT



MOTOROLA

MLED71

INFRARED-EMITTING DIODE

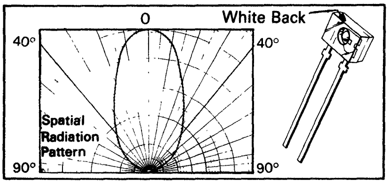
...designed for infrared remote control applications, for use with the MRD701 phototransistor in optical slotted coupler/interrupter module applications, and for industrial processing and control applications such as light modulators, shaft or position encoders, end of tape detectors.

- Continuous P_o = 2.5 mW (Typ) @ I_F = 50 mA
- Low Cost, Miniature, Clear Plastic Package
- Package Designed for Accurate Positioning
- Lens Molded into Package
- Narrow Spatial Radiation Pattern

INFRARED-EMITTING DIODE

PN GALLIUM ARSENIDE

940 nm



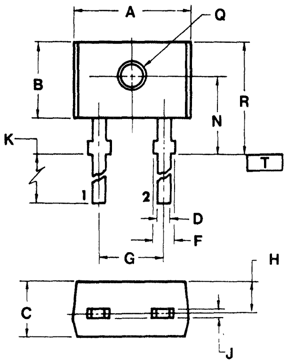
MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Reverse Voltage	V_R	6.0	Volts
Forward Current — Continuous	I_F	50	mA
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D(1)	150 2.0	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-40 to +100	°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance Junction to Ambient	$R_{\theta JA}$(1)	350	°C/W

(1)Measured with the device soldered into a typical printed circuit board



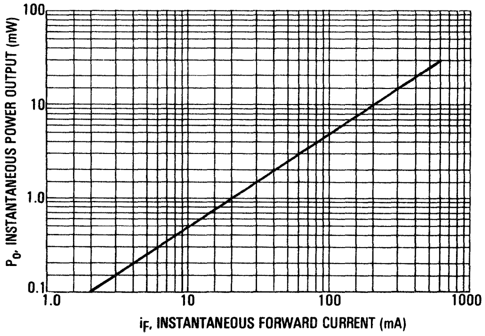
STYLE 1:
PIN 1. CATHODE
2. ANODE

NOTES:
1. DIMENSIONS A, B AND C ARE DATUMS.
2. POSITIONAL TOLERANCE FOR D DIMENSION:
   ⌖ .25 (0.010) Ⓜ -T- A Ⓜ C Ⓜ
3. POSITIONAL TOLERANCE FOR Q DIAMETER:
   ⌖ Ø.25 (0.010) Ⓜ A Ⓜ B Ⓜ
4. -T- IS SEATING PLANE.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	3.43	4.60	0.135	0.185
B	2.79	3.30	0.110	0.130
C	2.03	3.18	0.080	0.125
D	0.43	0.60	0.017	0.024
F	1.14	1.40	0.045	0.055
G	2.54 BSC		0.100 BSC	
H	1.52 BSC		0.060 BSC	
J	0.23	0.56	0.009	0.022
K	12.83	19.05	0.505	0.750
N	3.05	3.30	0.120	0.130
Q	0.76	1.52	0.030	0.060
R	3.81	4.60	0.150	0.185

CASE 349-01

FIGURE 1 — TYPICAL INSTANTANEOUS POWER OUTPUT



ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Unit
Reverse Leakage Current (V_R = 6.0 V, R_L = 1.0 Megohm)	—	I_R	—	50	—	nA
Reverse Breakdown Voltage (I_R = 100 μA)	—	$V_{(BR)R}$	6.0	—	—	Volts
Instantaneous Forward Voltage (I_F = 50 mA)	2	v_F	—	1.3	1.8	Volts
Total Capacitance (V_R = 0 V, f = 1.0 MHz)	—	C_T	—	25	—	pF

OPTICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Unit
Continuous Power Out, Note 1 (I_F = 50 mA)	—	P_O	2.0	2.5	—	mW
Instantaneous Power Out, Note 1 (I_F = 100 mA, 100 pps -100 μs pw)	1	P_O	—	5.0	—	mW
Radiant Intensity (I_F = 100 mA)		I_O	—	3.5	—	mW/st
Optical Turn-On Turn-Off Time	—	t_{on}, t_{off}	—	1.0	—	μs

Note 1. Power out measurements were made using a SPECTRA-1000 photometer with an integrated sphere.

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 2 — FORWARD CHARACTERISTICS

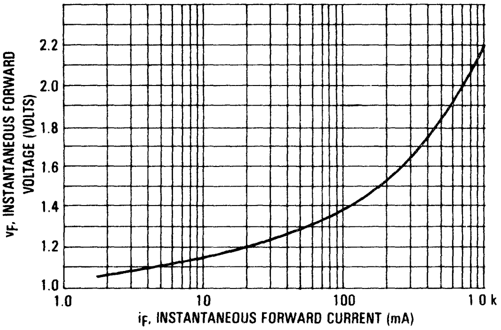
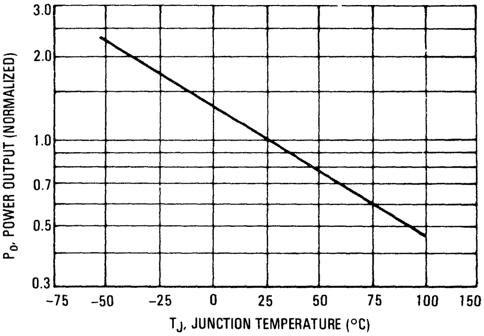


FIGURE 3 — POWER OUTPUT versus JUNCTION TEMPERATURE



TYPICAL COUPLED CHARACTERISTICS USING MLED71 EMITTER AND MRD701 PHOTOTRANSISTOR DETECTOR

FIGURE 4 — CONTINUOUS MRD701 COLLECTOR LIGHT CURRENT versus DISTANCE FROM MLED71

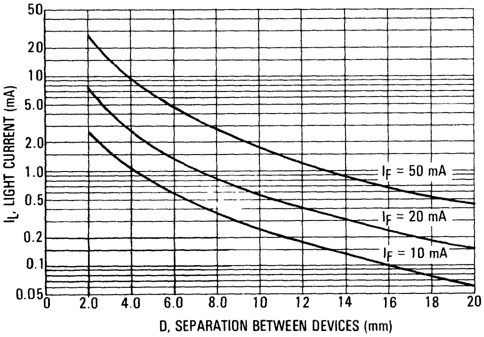
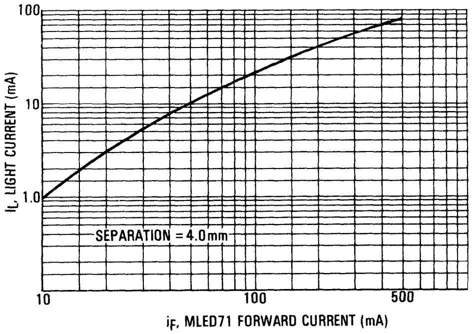


FIGURE 5 — INSTANTANEOUS MRD701 COLLECTOR LIGHT CURRENT versus MLED71 FORWARD CURRENT



MOTOROLA

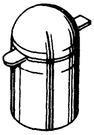
MLED910

INFRARED-EMITTING DIODE

. . . designed for applications requiring high density mounting, high power output, low drive power and very fast response time. This device is used in industrial processing and control, light modulators, shaft or position encoders, punched card and tape readers, optical switching, and logic circuits. It is spectrally matched for use with silicon detectors.

- High Power Output — 150 μW (Typ) @ I_F = 50 mA
- Infrared-Emission — 900 nm (Typ)
- Low Drive Current — 10 mA for 32 μW (Typ)
- Low Profile Pill Package Allows Printed Circuit Board Assembly
- Sub-Miniature Package for High Density Mounting

INFRARED-EMITTING DIODE
900 nm
PN GALLIUM ARSENIDE
350 MILLIWATTS



MAXIMUM RATINGS

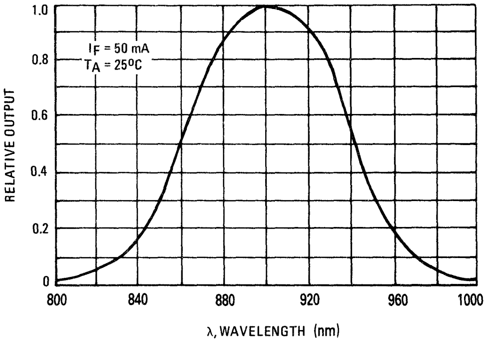
Rating	Symbol	Value	Unit
Reverse Voltage	V_R	3.0	Volts
Forward Current-Continuous	I_F	150	mA
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D(1)	350 3.5	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +125	°C

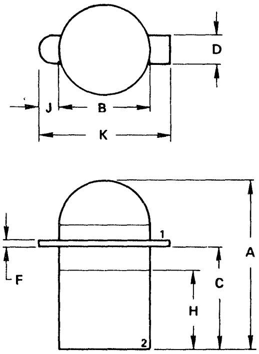
THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient	θ_{JA}	286	°C/W

(1) Thermal resistance, junction to case is typically 80°C/W. The mounting conditions determine the junction to ambient thermal resistance. For example, when soldered in a copper printed circuit board through a 1/8" diameter pad on the top to a 1/4" x 1/4" pad on the bottom surface, values of 160°C/W will occur. If both pads are 1/8" in diameter, thermal resistance is typically 250°C/W; the limit of 286°C/W is specified for the latter mounting condition.

FIGURE 1 — RELATIVE SPECTRAL OUTPUT





STYLE 1:
TERM 1. EMITTER
2. COLLECTOR

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	2.59	3.18	0.102	0.125
B	1.47	1.55	0.058	0.061
C	2.08	2.24	0.082	0.088
D	0.41	0.61	0.016	0.024
F	0.13	0.25	0.005	0.010
H	1.60	1.70	0.063	0.067
J	0.23	0.48	0.009	0.019
K	2.13	2.34	0.084	0.092

CASE 81A-06

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Unit
Reverse Leakage Current (V_R = 3.0 V, R_L = 1.0 Megohm)	–	I_R	–	50	–	nA
Reverse Breakdown Voltage (I_R = 100 μA)	–	$V_{(BR)R}$	3.0	–	–	Volts
Forward Voltage (I_F = 50 mA)	2	V_F	–	1.2	1.5	Volts
Total Capacitance (V_R = 0 V, f = 1.0 MHz)	–	C_T	–	150	–	pF

OPTICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Unit
Total Power Output (Note 1) (I_F = 50 mA)	3, 4	P_O	50	150	–	μW
Radiant Intensity (Note 2) (I_F = 50 mA)		I_O	–	0.66	–	mW/steradian
Peak Emission Wavelength	1	λ_P	–	900	–	nm
Spectral Line Half Width	1	$\Delta\lambda$	–	40	–	nm

NOTE:

1. Power Output, P_O, is the total power radiated by the device into a solid angle of 2π steradians. It is measured by directing all radiation leaving the device, within this solid angle, onto a calibrated silicon solar cell.
2. Irradiance from a Light Emitting Diode (LED) can be calculated by:

$H = \frac{I_o}{d^2}$ where H is irradiance in mW/cm², I_o is radiant intensity in mW/steradian; d is distance from LED to the detector in cm.

FIGURE 2 – FORWARD CHARACTERISTICS

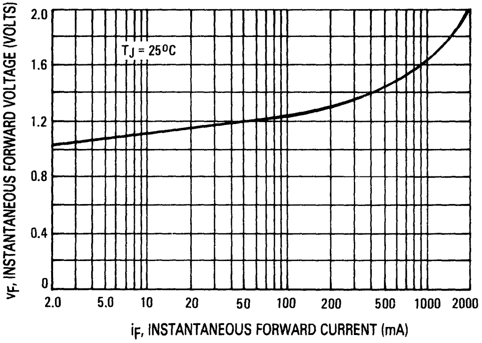


FIGURE 3 – POWER OUTPUT versus JUNCTION TEMPERATURE

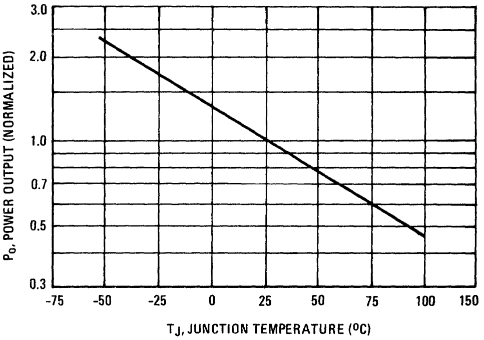


FIGURE 4 – INSTANTANEOUS POWER OUTPUT

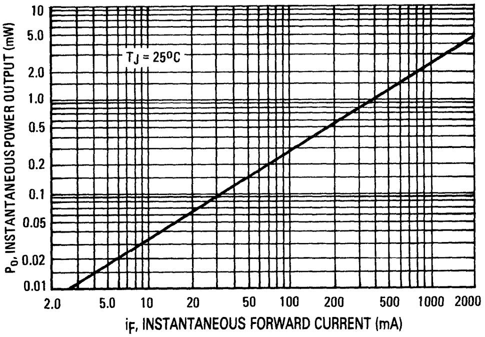
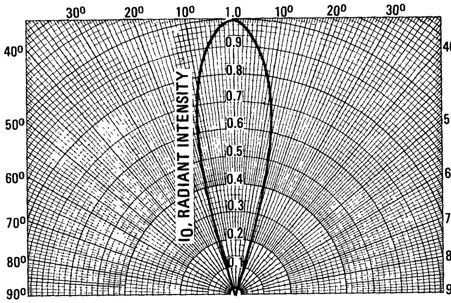


FIGURE 5 – SPATIAL RADIATION PATTERN



Output saturation effects are not evident at currents up to 2 A as shown on Figure 4. However, saturation does occur due to heating of the semiconductor as indicated by Figure 3. To estimate output level, average junction temperature may be calculated from:

$$T_{J(AV)} = T_A + \theta_{JA} V_F I_F D$$

where D is the duty cycle of the applied current, I_F. Use of the above method should be restricted to drive conditions employing pulses of less than 10 μs duration to avoid errors caused by high peak junction temperatures.

MOTOROLA

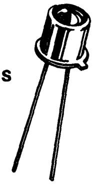
MLED930

INFRARED-EMITTING DIODE
900 nm
PN GALLIUM ARSENIDE
250 MILLIWATTS

INFRARED-EMITTING DIODE

. . . designed for applications requiring high power output, low drive power and very fast response time. This device is used in industrial processing and control, light modulators, shaft or position encoders, punched card readers, optical switching, and logic circuits. It is spectrally matched for use with silicon detectors.

- High-Power Output — 650 μW (Typ) @ I_F = 100 mA
- Infrared-Emission — 900 nm (Typ)
- Low Drive Current — 10 mA for 70 μW (Typ)
- Popular TO-18 Type Package for Easy Handling and Mounting
- Hermetic Metal Package for Stability and Reliability



CONVEX LENS

MAXIMUM RATINGS

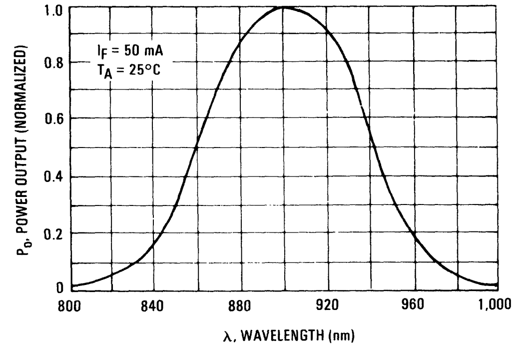
Rating	Symbol	Value	Unit
Reverse Voltage	V_R	6.0	Volts
Forward Current-Continuous	I_F	150	mA
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D(1)	250 2.5	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +125	°C

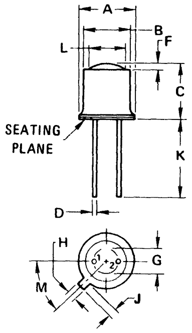
THERMAL CHARACTERISTICS

Characteristics	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient	θ_{JA}	400	°C/W

(1) Printed Circuit Board Mounting

FIGURE 1 — RELATIVE SPECTRAL OUTPUT





STYLE 1:
PIN 1. ANODE
PIN 2. CATHODE

NOTES:
1. PIN 2 INTERNALLY CONNECTED TO CASE
2. LEADS WITHIN 0.13 mm (0.005) RADIUS OF TRUE POSITION AT SEATING PLANE AT MAXIMUM MATERIAL CONDITION.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.52	4.95	0.178	0.195
C	5.08	6.35	0.200	0.250
D	0.41	0.48	0.016	0.019
F	0.51	1.02	0.020	0.040
G	2.54 BSC		0.100 BSC	
H	0.99	1.17	0.039	0.046
J	0.84	1.22	0.033	0.048
K	12.70	–	0.500	–
L	3.35	4.01	0.132	0.158
M	45° BSC		45° BSC	

CASE 209-01

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Unit
Reverse Leakage Current (V_R = 3.0 V)	—	I_R	—	2.0	—	nA
Reverse Breakdown Voltage (I_R = 100 μA)	—	$V_{(BR)R}$	6.0	20	—	Volts
Forward Voltage (I_F = 50 mA)	2	V_F	—	1.25	1.5	Volts
Total Capacitance (V_R = 0 V, f = 1.0 MHz)	—	C_T	—	150	—	pF

OPTICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Unit
Total Power Output (Note 1) (I_F = 100 mA)	3, 4	P_o	200	650	—	μW
Radiant Intensity (Note 2) (I_F = 100 mA)	—	I_o	—	1.5	—	mW/steradian
Peak Emission Wavelength	1	λP	—	900	—	nm
Spectral Line Half Width	1	Δλ	—	40	—	nm

NOTE:

1. Power Output, P_o, is the total power radiated by the device into a solid angle of 2π steradians. It is measured by directing all radiation leaving the device, within this solid angle, onto a calibrated silicon solar cell
2. Irradiance from a Light Emitting Diode (LED) can be calculated by:

$$H = \frac{I_o}{d^2}$$

where H is irradiance in mW/cm^2; I_o is radiant intensity in mW/steradian; d is distance from LED to the detector in cm.

FIGURE 2 — FORWARD CHARACTERISTICS

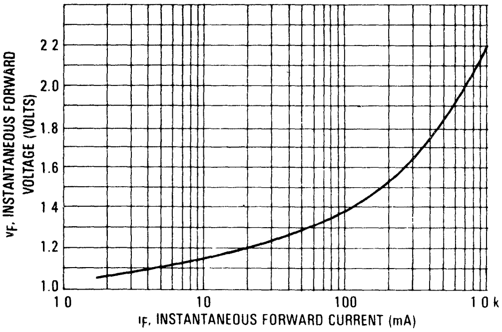


FIGURE 3 — POWER OUTPUT versus JUNCTION TEMPERATURE

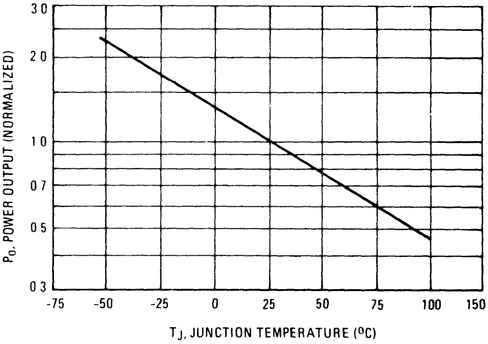


FIGURE 4 — INSTANTANEOUS POWER OUTPUT versus FORWARD CURRENT

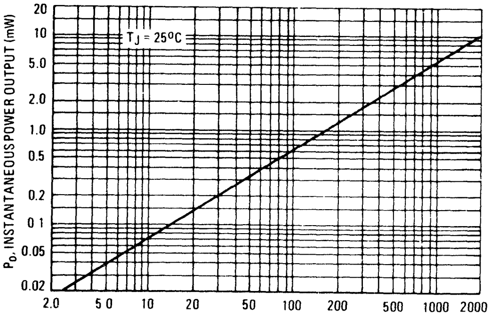
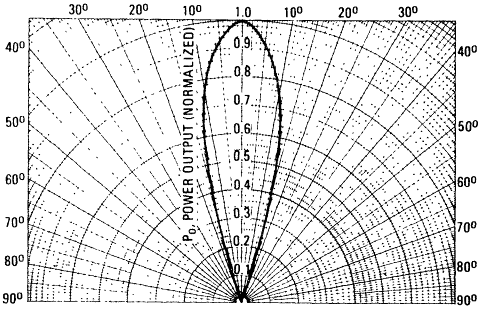


FIGURE 5 — SPATIAL RADIATION PATTERN



MOTOROLA

MOC119

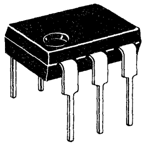
NPN PHOTODARLINGTON AND PN INFRARED EMITTING DIODE

. . . gallium arsenide LED optically coupled to a silicon photodarlington transistor designed for applications requiring electrical isolation, high-current transfer ratios, small package size and low cost; such as interfacing and coupling systems, phase and feedback controls, solid-state relays and general-purpose switching circuits.

- High Isolation Voltage — V_{ISO} = 7500 V (Min)
- High Collector Output Current @ I_F = 10 mA — I_C = 30 mA (Min)
- Economical, Compact, Dual-In-Line Package
- Base Not Connected
- Excellent Frequency Response — 30 kHz (Typ)
- Fast Switching Times @ I_C = 2.5 mA
  - t_r = 10 μs (Typ)
  - t_f = 50 μs (Typ)

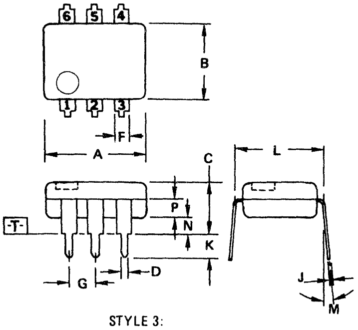
OPTO COUPLER/ISOLATOR

DARLINGTON OUTPUT



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED-EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	3.0	Volts
Forward Current – Continuous	I_F	100	mA
Forward Current – Peak (Pulse Width = 300 μs, 2.0% Duty Cycle)	I_F	3.0	Amp
Total Power Dissipation @ T_A = 25°C	P_D	150	mW
Negligible Power in Transistor Derate above 25°C		2.0	mW/°C
PHOTOTRANSISTOR MAXIMUM RATINGS			
Collector-Emitter Voltage	V_{CEO}	30	Volts
Emitter-Collector Voltage	V_{ECO}	7.0	Volts
Collector-Base Voltage	V_{CBO}	30	Volts
Total Power Dissipation @ T_A = 25°C Negligible Power in Diode Derate above 25°C	P_D	150 2.0	mW mW/°C
TOTAL DEVICE RATINGS			
Total Device Dissipation @ T_A = 25°C Equal Power Dissipation in Each Element Derate above 25°C	P_D	250 3.3	mW mW/°C
Operating Junction Temperature Range	T_J	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)	–	260	°C



STYLE 3:
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. NC

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:

⌖	∅ 0.13 (0.005)Ⓜ	T	AⓂ BⓂ

4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

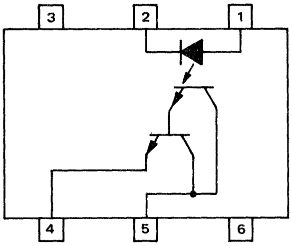


FIGURE 1 – DEVICE SCHEMATIC

LED CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Leakage Current (V_R = 3.0 V, R_L = 1.0 M ohms)	I_R	–	0.005	100	μA
Forward Voltage (I_F = 10 mA)	V_F	–	1.2	1.5	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	–	150	–	pF

PHOTOTRANSISTOR CHARACTERISTICS (T_A = 25°C and I_F = 0 unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector-Emitter Dark Current (V_{CE} = 10 V, I_F = 0)	I_{CEO}	–	8.0	100	nA
Collector-Emitter Breakdown Voltage (I_C = 100 μA, I_B = 0)	$V_{(BR)CEO}$	30	60	–	Volts
Emitter-Collector Breakdown Voltage (I_E = 10 μA, I_F = 0)	$V_{(BR)ECO}$	7.0	8.0	–	Volts

COUPLED CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector Output Current (1) (V_{CE} = 2.0 V, I_F = 10 mA)	I_C	30	70	–	mA
Isolation Surge Voltage (2, 5), 60 Hz ac Peak, 5 Second	V_{ISO}	7500	–	–	Volts
Isolation Resistance (2) (V = 500 V)	–	–	10^{11}	–	Ohms
Collector-Emitter Saturation Voltage (1) (I_C = 10 mA, I_F = 10 mA)	$V_{CE(sat)}$	–	0.8	1.0	Volts
Isolation Capacitance (2) (V = 0, f = 1.0 MHz)	–	–	1.0	–	pF

SWITCHING CHARACTERISTICS (Figures 4,5)

Characteristic	Symbol	Min	Typ	Max	Unit
Rise Time (V_{CC} = 10 V, I_C = 2.5 mA, R_L = 100 Ω)	t_r	–	10	–	μs
Fall Time (V_{CC} = 10 V, I_C = 2.5 mA, R_L = 100 Ω)	t_f	–	50	–	μs

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle ≤ 2.0%.

(2) For this test LED pins 1 and 2 are common and Photo Transistor pins 4 and 5 are common.

(3) I_F adjusted to yield I_C = 2.0 mA and i_c = 2.0 mA P-P at 10 kHz.

(4) t_d and t_r are inversely proportional to the amplitude of I_F; t_s and t_f are not significantly affected by I_F.

(5) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

DC CURRENT TRANSFER CHARACTERISTICS

FIGURE 2 – COLLECTOR CURRENT versus COLLECTOR-EMITTER VOLTAGE

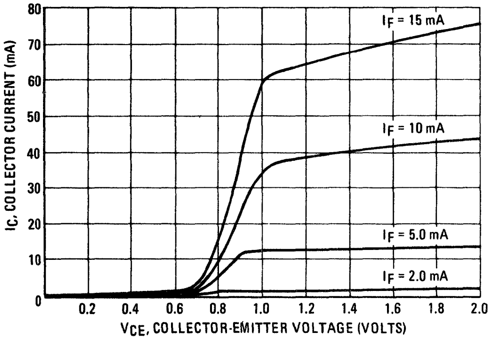
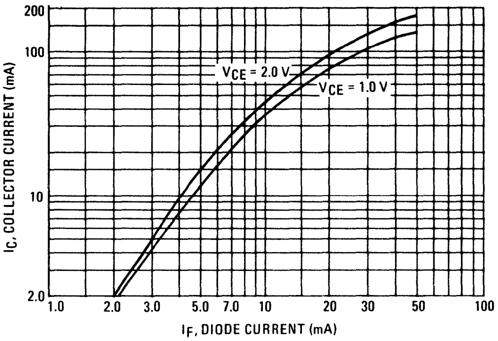


FIGURE 3 – COLLECTOR CURRENT versus DIODE CURRENT



SWITCHING CHARACTERISTICS

FIGURE 4 – SWITCHING TEST CIRCUIT

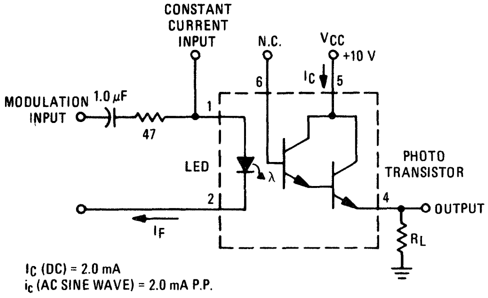


FIGURE 5 – VOLTAGE WAVEFORM

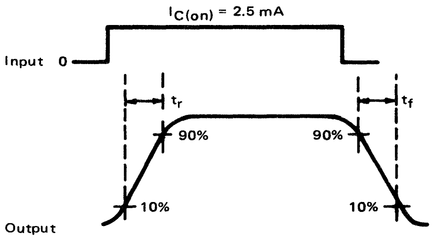
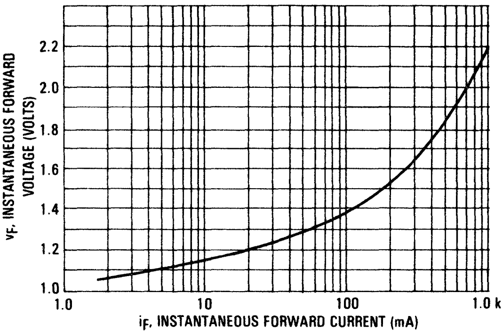


FIGURE 6 – FORWARD CHARACTERISTIC



TEMPERATURE CHARACTERISTICS

FIGURE 7 – COLLECTOR-EMITTER DARK CURRENT versus TEMPERATURE

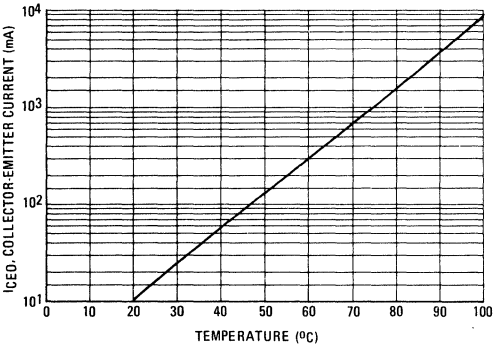
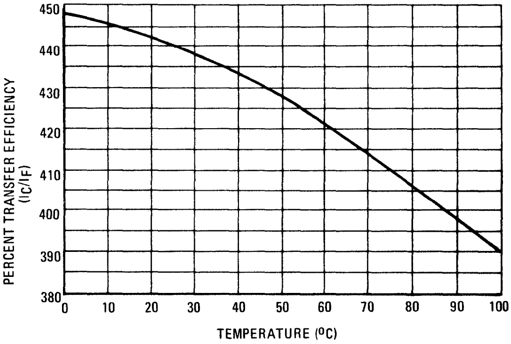


FIGURE 8 – TRANSFER EFFICIENCY versus TEMPERATURE



MOTOROLA

MOC601A
MOC602A
MOC603A
MOC604A

OPTOCOUPLER/ISOLATOR WITH TRANSISTOR OUTPUT

VDE approved per Component Standard 0883/6.80, Equipment Standard 0860, internal thickness through insulation 0.4 mm, and all equipment standards with similar or lower requirements.

These devices consist of a gallium-arsenide infrared-emitting diode optically coupled to a sensitive, silicon phototransistor in the standard 6-pin dual-in-line epoxy package.

- VDE Approved per Test Certificate Number 22762
- High Surge Isolation Voltage — 7500 Vac pk (Min)
- Low Degradation LPE IRED
- Standard 6-Pin, All Epoxy Package
- UL Recognized, File Number E54915

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	3.0	Volts
Forward Current — Continuous	I_F	60	mA
Forward Current — Peak Pulse Width = 30 μs, 2.0 % Duty Cycle	I_F	3.0	Amp
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	150 2.0	mW mW/°C
PHOTOTRANSISTOR MAXIMUM RATINGS			
Collector-Emitter Voltage	V_{CEO}	30	Volts
Emitter-Collector Voltage	V_{ECO}	7.0	Volts
Collector-Base Voltage	V_{CBO}	70	Volts
Total Power Dissipation @ T_A = 25°C Negligible Power in Diode Derate above 25°C	P_D	150 2.0	mW mW/°C
TOTAL DEVICE RATINGS			
Total Device Power Dissipation @ T_A = 25°C Equal Power Dissipation in Each Element Derate above 25°C	P_D	250 3.3	mW mW/°C
Junction Temperature Range	T_J	-55 to +100	°C
Ambient Operating Temperature Range	T_A	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)	—	260	°C

FIGURE 1 – MAXIMUM POWER DISSIPATION

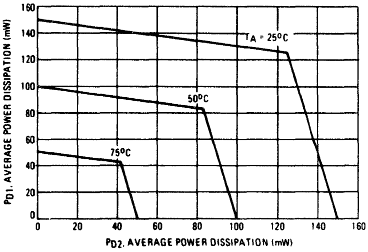


Figure 1 is based upon using limit values in the equation:

$T_{J1} - T_A = R_{\theta JA} (P_{D1} + K_\theta P_{D2})$

where:

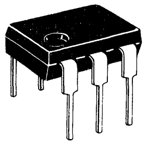
T_{J1}	Junction Temperature (100°C)
T_A	Ambient Temperature
$R_{\theta JA}$	Junction to Ambient Thermal Resistance (500°C/W)
P_{D1}	Power Dissipation in One Chip
P_{D2}	Power Dissipation in Other Chip
K_θ	Thermal Coupling Coefficient (20%)

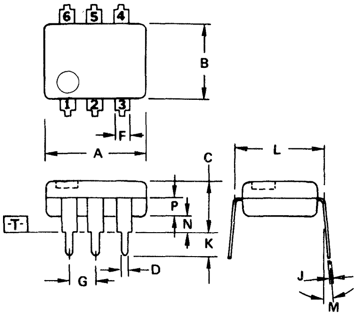
Example.

With P_{D1} = 90 mW in the LED @ T_A = 50°C, the Darlington P_D (P_{D2}) must be less than 50 mW.

VDE APPROVED
OPTO
COUPLER/ISOLATOR

TRANSISTOR OUTPUT





STYLE 1.
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. BASE

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS.
⌖ | ∅ 0.13 (0.005) Ⓜ | T | A Ⓜ B Ⓜ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

MOC601A, MOC602A, MOC603A, MOC604A

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

LED CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Leakage Current (V_R = 3.0 V, R_L = 1.0 M ohms)	I_R	—	0.05	100	μA
Forward Voltage (I_F = 10 mA)	V_F	—	1.2	1.5	Volts
Capacitance (V_R = 0 V,f = 1.0 MHz)	C	—	150	—	pF

PHOTOTRANSISTOR CHARACTERISTICS (I_F = 0 unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector-Emitter Dark Current (V_{CE} = 10 V, Base Open)	I_{CEO}	—	3.5	50	nA
Collector-Base Dark Current (V_{CB} = 10 V, Emitter Open)	I_{CBO}	—	—	20	nA
Collector-Base Breakdown Voltage (I_C = 100 μA, I_E = 0)	$V_{(BR)CBO}$	70	—	—	Volts
Collector-Emitter Breakdown Voltage (I_C = 1.0 mA, I_B = 0)	$V_{(BR)CEO}$	30	—	—	Volts
Emitter-Collector Breakdown Voltage (I_E = 100 μA, I_B = 0)	$V_{(BR)ECO}$	7.0	—	—	Volts
DC Current Gain (V_{CE} = 5.0 V, I_C = 500 μA)	h_{FE}	—	350	—	—

COUPLED CHARACTERISTICS

Characteristic		Symbol	Min	Typ	Max	Unit
Collector Output Current (1)		I_C				mA
(V_{CE} = 10 V, I_F = 10 mA, I_B = 0)	MOC601A		1.0	—	—	
	MOC602A		2.0	—	—	
	MOC603A		5.0	—	—	
	MOC604A		10	—	—	
Isolation Surge Voltage (2, 4) (60 Hz Peak ac, 5 Seconds)		V_{ISO}	7500	—	—	Volts
Isolation Resistance (2) (V = 500 V)		—	—	10^{11}	—	Ohms
Collector-Emitter Saturation Voltage (1) (I_C = 2.0 mA, I_F = 50 mA)		$V_{CE(sat)}$	—	0.2	0.5	Volts
Isolation Capacitance (2) (V = 0, f = 1.0 MHz)		—	—	1.3	—	pF
Bandwidth (3) (I_C = 2.0 mA, R_L = 100 ohms)		—	—	300	—	kHz

SWITCHING CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Turn-On Time (I_C = 2.0 mA, V_{CC} = 10 V, R_L = 100 Ω)	t_{on}	—	8.0	—	μs
Turn-Off Time (I_C = 2.0 mA, V_{CC} = 10 V, R_L = 100 Ω)	t_{off}	—	8.0	—	μs

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle ≤ 2.0%.

(2) For this test LED pins 1 and 2 are common and phototransistor pins 4, 5, and 6 are common.

(3) I_F adjusted to yield I_C = 2.0 mA and i_c = 2.0 mA p-p at 10 kHz.

(4) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

MOTOROLA

MOC622A MOC626A
MOC623A MOC627A
MOC624A MOC628A
MOC625A MOC629A

OPTOCOUPLER/ISOLATOR WITH DARLINGTON OUTPUT

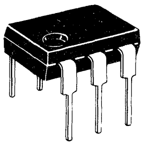
VDE approved per Component Standard 0833/6.80, Equipment Standard 0860, internal thickness through insulation 0.4 mm, and all equipment standards with similar or lower requirements.

These devices consist of a gallium-arsenide infrared-emitting diode optically coupled to a sensitive, silicon photodarlington transistor in the standard 6-pin dual-in-line epoxy package.

- VDE Approved Per Test Certificate Number 22762
- High Surge Isolation Voltage — 7500 Vac pk (Min)
- Low Degradation LPE IRED
- Standard 6-Pin, All Epoxy Package
- UL Recognized, File Number E54915
- Base NOT CONNECTED — MOC626A–629A (Case 730A-01, Style 3)

VDE APPROVED OPTO COUPLER/ISOLATOR

DARLINGTON OUTPUT



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	3.0	Volts
Forward Current — Continuous	I_F	60	mA
Forward Current — Peak Pulse Width = 300 μs, 2.0 % Duty Cycle	I_F	3.0	Amp
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	150 2.0	mW mW/°C
PHOTODARLINGTON MAXIMUM RATINGS			
Collector-Emitter Voltage	V_{CEO}	30	Volts
Emitter-Collector Voltage	V_{ECO}	5.0	Volts
Collector-Base Voltage	V_{CBO}	30	Volts
Total Power Dissipation @ T_A = 25°C Negligible Power in Diode Derate above 25°C	P_D	150 2.0	mW mW/°C
TOTAL DEVICE RATINGS			
Total Device Power Dissipation @ T_A = 25°C Equal Power Dissipation in Each Element Derate above 25°C	P_D	250 3.3	mW mW/°C
Junction Temperature Range	T_J	-55 to +100	°C
Ambient Operating Temperature Range	T_A	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)	—	260	°C

FIGURE 1 — MAXIMUM POWER DISSIPATION

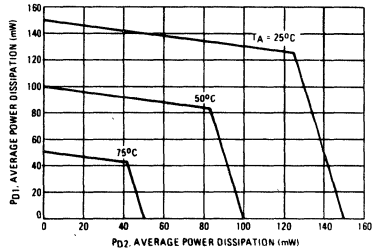


Figure 1 is based upon using limit values in the equation:

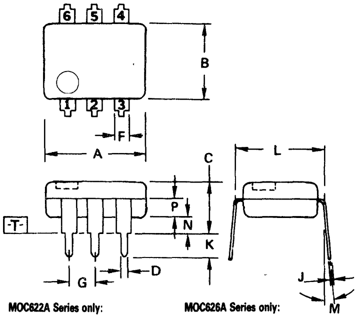
$$T_{J1} - T_A = R_{\theta JA}(P_{D1} + K_\theta P_{D2})$$

where:

T_{J1}	Junction Temperature (100°C)
T_A	Ambient Temperature
$R_{\theta JA}$	Junction to Ambient Thermal Resistance (500°C/W)
P_{D1}	Power Dissipation in One Chip
P_{D2}	Power Dissipation in Other Chip
K_θ	Thermal Coupling Coefficient (20%)

Example:

With P_{D1} = 90 mW in the LED @ T_A = 50°C, the Darlington P_D (P_{D2}) must be less than 50 mW.



MOC622A Series only:

STYLE 1:
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. BASE

MOC626A Series only:

STYLE 3:
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. NC

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⌖ | ∅ 0.13 (0.005)Ⓜ | T | AⓂ BⓂ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
LED CHARACTERISTICS						
Reverse Leakage Current (V_R = 3.0 V, R_L = 1.0 M ohms)		I_R	—	0.05	100	μA
Forward Voltage (I_F = 10 mA)		V_F	—	1.2	1.5	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)		C	—	150	—	pF
PHOTODARLINGTON CHARACTERISTICS (I_F = 0 unless otherwise noted)						
Collector-Emitter Dark Current (V_{CE} = 10 V, Base Open)		I_{CEO}	—	—	100	nA
Collector-Base Breakdown Voltage (5) (I_C = 100 μA, I_E = 0)		$V_{(BR)CBO}$	50	—	—	Volts
Collector-Emitter Breakdown Voltage (I_C = 100 mA, I_B = 0)		$V_{(BR)CEO}$	30	—	—	Volts
Emitter-Collector Breakdown Voltage (I_E = 100 μA, I_B = 0)		$V_{(BR)ECO}$	5.0	—	—	Volts
DC Current Gain (5) (V_{CE} = 5.0 V, I_C = 500 μA)		h_{FE}	—	10,000	—	—
COUPLED CHARACTERISTICS						
Collector Output Current (1) (5)		I_C				mA
(V_{CE} = 10 V, I_F = 10 mA, I_B = 0)	MOC622A/626A		10	—	—	
	MOC623A/627A		30	—	—	
	MOC624A/628A		50	—	—	
	MOC625A/629A		100	—	—	
Isolation Surge Voltage (2, 4) (60 Hz Peak ac, 5 Seconds)		V_{ISO}	7500	—	—	Volts
Isolation Resistance (2) (V = 500 V)		—	—	10^{11}	—	Ohms
Collector-Emitter Saturation Voltage (1) (I_C = 2.0 mA, I_F = 8.0 mA)		$V_{CE(sat)}$	—	—	1.0	Volts
Isolation Capacitance (2) (V = 0, f = 1.0 MHz)		—	—	0.8	—	pF
Bandwidth (3) (I_C = 2.0 mA, R_L = 100 ohms)		—	—	30	—	kHz
SWITCHING CHARACTERISTICS						
Turn-On Time (I_C = 50 mA, I_F = 200 mA, V_{CC} = 10 V, R_L = 100 Ω)		t_{on}	—	15	—	μs
Turn-Off Time (I_C = 50 mA, I_F = 200 mA, V_{CC} = 10 V, R_L = 100 Ω)		t_{off}	—	60	—	μs

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle ⩽ 2.0%.

(2) For this test LED pins 1 and 2 are common and phototransistor pins 4, 5, and 6 are common.

(3) I_F adjusted to yield I_C = 2.0 mA and i_c = 2.0 mA p-p at 10 kHz.

(4) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

(5) Base NOT CONNECTED in MOC626A–629A. See Case 730A-01, Style 3.

MOTOROLA

MOC633A MOC634A
MOC635A MOC640A
MOC641A

OPTICALLY ISOLATED TRIAC DRIVERS

VDE approved per Component Standard 0833/6.80, Equipment Standard 0860, internal thickness through insulation 0.4 mm, and all equipment standards with similar or lower requirements.

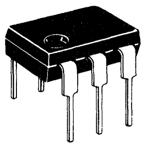
These devices consist of a gallium-arsenide infrared-emitting diode, optically coupled to a silicon bilateral switch. They are designed for applications requiring isolated zero and non-zero crossing triac triggering.

- VDE Approved Per Test Certificate Number 22762
- UL Recognized File Number E54915
- Output Driver Designed for Up to 240 Vac Line
- V_{ISO} Isolation Voltage of 7500 Vac Peak
- Standard 6-Pin Plastic DIP
- Zero Voltage Crossing — MOC640A, MOC641A
- Phase Controllable — MOC633A, MOC634A, MOC635A

VDE APPROVED
OPTO
COUPLER/ISOLATOR

TRIAC DRIVER OUTPUT

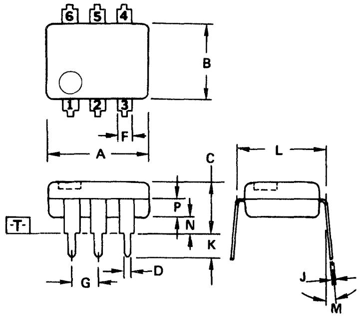
400 VOLTS



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	3.0	Volts
Forward Current — Continuous	I_F	60	mA
Total Power Dissipation @ T_A = 25°C Negligible Power in Triac Driver Derate above 25°C	P_D	100 1.33	mW mW/°C
OUTPUT DRIVER MAXIMUM RATINGS			
Off-State Output Terminal Voltage	V_{DRM}	400	Volts
On-State RMS Current T_A = 25°C (Full Cycle, 50 to 60 Hz) T_A = 70°C	$I_{T(RMS)}$	100 50	mA mA
Peak Nonrepetitive Surge Current (PW = 10 ms, DC = 10%)	I_{TSM}	1.2	A
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	300 4.0	mW mW/°C
TOTAL DEVICE MAXIMUM RATINGS			
Isolation Surge Voltage* (Peak ac Voltage, 60 Hz, 5 Second Duration)	V_{ISO}	7500	Vac
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	330 4.4	mW mW/°C
Junction Temperature Range	T_J	-55 to +100	°C
Ambient Operating Temperature Range	T_A	-55 to +70	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)	—	260	°C

*Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.



STYLE 6:
PIN 1. ANODE
2. CATHODE
3. NC
4. MAIN TERMINAL
5. SUBSTRATE
6. MAIN TERMINAL

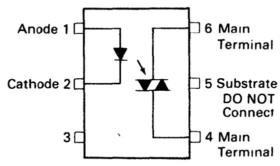
NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⊕ | ∅ 0.13 (0.005)Ⓜ | T | AⓂ BⓂ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

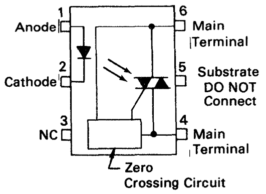
CASE 730A-01

COUPLER SCHEMATICS

MOC633A/634A/635A



MOC640A/641A



ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
LED CHARACTERISTICS						
Reverse Leakage Current (V_R = 3.0 V)		I_R	—	0.05	100	μA
Forward Voltage (I_F = 10 mA)		V_F	—	1.2	1.5	Volts
DETECTOR CHARACTERISTICS (I_F = 0 unless otherwise noted)						
Peak Blocking Current, Either Direction (Rated V_{DRM}, Note 1)	MOC633A/634A/635A MOC640A/641A	I_{DRM}	— —	10 2.0	100 100	nA
Peak On-State Voltage, Either Direction (I_{TM} = 100 mA Peak)	MOC633A/634A/635A MOC640A/641A	V_{TM}	— —	2.5 1.8	3.0 3.0	Volts
Critical Rate of Rise of Off-State Voltage, T_A = 70°C	MOC633A/634A/635A MOC640A/641A	dv/dt	— —	10 1000	— —	V/μs
COUPLED CHARACTERISTICS						
LED Trigger Current, Current Required to Latch Output (Main Terminal Voltage = 3.0 V, Note 2)	MOC633A/640A MOC634A/641A MOC635A	I_{FT}	— — —	15 8.0 5.0	30 15 10	mA
Holding Current, Either Direction	MOC633A/634A/635A MOC640A/641A	I_H	— —	100 200	— —	μA
ZERO CROSSING CHARACTERISTICS — MOC640A/641A						
Inhibit Voltage (I_F = Rated I_{FT}, MT1-MT2 Voltage above which device will not trigger.)		V_{IH}	—	15	40	Volts
Leakage in Inhibited State (I_F = Rated I_{FT}, Rated V_{DRM}, Off State)		I_{DRM2}	—	100	300	μA

Note 1. Test voltage must be applied within dv/dt rating.

2. All devices are guaranteed to trigger at an I_F value less than or equal to max I_{FT}. Therefore, recommended operating I_F lies between max I_{FT} and absolute max I_F (60 mA).

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 1 — ON-STATE CHARACTERISTICS

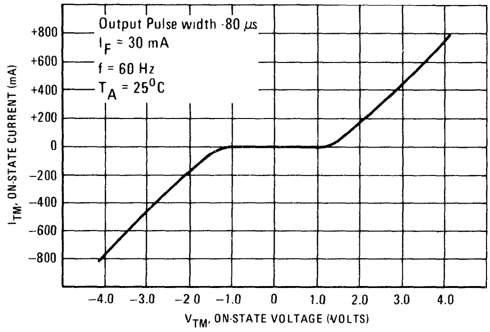
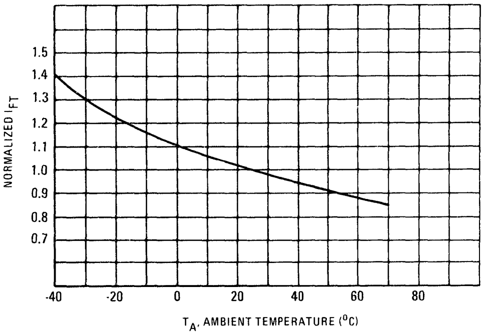


FIGURE 2 — TRIGGER CURRENT versus TEMPERATURE



MOTOROLA

MOC1005
MOC1006

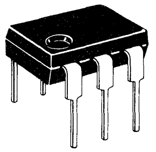
OPTO COUPLER/ISOLATOR

TRANSISTOR OUTPUT

HIGH ISOLATION COUPLER

. . . gallium arsenide LED optically coupled to a silicon phototransistor designed for applications requiring high electrical isolation, high transistor breakdown-voltage and low-leakage, small package size and low cost; such as interfacing and coupling systems, logic to power circuit interface, and solid-state relays.

- High Isolation Voltage — V_{ISO} = 7500 Vac pk (Min)
- High Collector-Emitter Breakdown Voltage — $V_{(BR)CEO}$ = 80 V (Typ) @ I_C = 1.0 mA
- High Collector Output Current @ I_F = 10 mA —
  I_C = 5.0 mA (Typ) — MOC1005
  = 3.0 mA (Typ) — MOC1006
- Economical, Compact, Dual-In-Line Plastic Package



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted).

Rating	Symbol	Value	Unit
INFRARED-EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	3.0	Volts
Forward Current — Continuous	I_F	80	mA
Forward Current — Peak Pulse Width = 300 μs, 2.0% Duty Cycle	I_F	3.0	Amp
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	150 2.0	mW mW/°C
PHOTOTRANSISTOR MAXIMUM RATINGS			
Collector-Emitter Voltage	V_{CEO}	30	Volts
Emitter-Collector Voltage	V_{ECO}	7.0	Volts
Collector-Base Voltage	V_{CBO}	70	Volts
Total Power Dissipation @ T_A = 25°C Negligible Power in Diode Derate above 25°C	P_D	150 2.0	mW mW/°C
TOTAL DEVICE RATINGS			
Total Power Dissipation @ T_A = 25°C Equal Power Dissipation in Each Element Derate above 25°C	P_D	250 3.3	mW mW/°C
Junction Temperature Range	T_J	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)		260	°C

FIGURE 1 — MAXIMUM POWER DISSIPATION

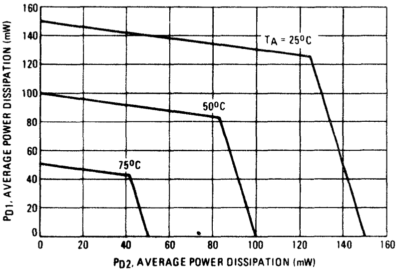


Figure 1 is based upon using limit values in the equation:

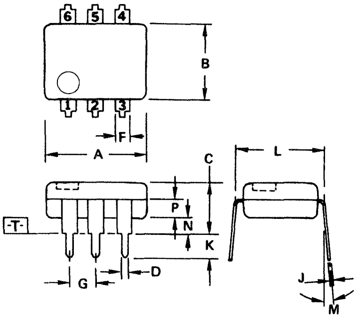
$$T_{J1} - T_A = R_{\theta JA} (P_{D1} + K_\theta P_{D2})$$

where

T_{J1}	Junction Temperature (100°C)
T_A	Ambient Temperature
$R_{\theta JA}$	Junction to Ambient Thermal Resistance (500°C/W)
P_{D1}	Power Dissipation in One Chip
P_{D2}	Power Dissipation in Other Chip
K_θ	Thermal Coupling Coefficient (20%)

Example

With P_{D1} = 90 mW in the LED @ T_A = 50°C, the transistor P_D (P_{D2}) must be less than 50 mW.



STYLE 1:
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. BASE

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⌖ | ∅ 0.13 (0.005) Ⓜ | T | A Ⓜ B Ⓜ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

LED CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Leakage Current (V_R = 3.0 V)	I_R	—	0.005	100	μA
Forward Voltage (I_F = 10 mA)	V_F	—	1.2	1.5	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	—	30	—	pF

PHOTOTRANSISTOR CHARACTERISTICS (T_A = 25°C and I_F = 0 unless otherwise noted)

Collector-Emitter Dark Current (V_{CE} = 10 V, Base Open)	I_{CEO}	—	3.5	50	nA
Collector-Base Dark Current (V_{CB} = 10 V, Emitter Open)	I_{CBO}	—	—	20	nA
Collector-Base Breakdown Voltage (I_C = 100 μA, I_E = 0)	$V_{(BR)CBO}$	70	100	—	Volts
Collector-Emitter Breakdown Voltage (I_C = 1.0 mA, I_B = 0)	$V_{(BR)CEO}$	30	80	—	Volts
Emitter-Collector Breakdown Voltage (I_E = 100 μA, I_B = 0)	$V_{(BR)ECO}$	7.0	—	—	Volts
DC Current Gain (V_{CE} = 5.0 V, I_C = 500 μA)	h_{FE}	—	250	—	—

COUPLED CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Collector Output Current (1) (V_{CE} = 10 V, I_F = 10 mA, I_B = 0)	MOC1005 MOC1006	I_C	2.0 1.0	5.0 3.0	— —	mA
Isolation Surge Voltage, (1) (Peak ac Voltage, 60 Hz, 6.0 s)		V_{ISO}	**7500**	**—**	—	**Vac**
Isolation Resistance (4) (V = 500 V)		—	—	10^{11}	—	Ohms
Collector-Emitter Saturation (I_C = 2.0 mA, I_F = 50 mA)		$V_{CE(sat)}$	—	0.2	0.5	Volts
Isolation Capacitance (4) (V = 0, f = 1.0 MHz)		—	—	1.3	—	pF
Bandwidth (5) (I_C = 2.0 mA, R_L = 100 Ohms, Figure 11)		—	—	300	—	kHz

SWITCHING CHARACTERISTICS

Delay Time	(I_C = 10 mA, V_{CC} = 10 V) Figures 6 and 8	MOC1005	t_d	—	0.07	—	μs
		MOC1006		—	0.10	—	
Rise Time		MOC1005	t_r	—	0.8	—	μs
		MOC1006		—	2.0	—	
Storage Time	(I_C = 10 mA, V_{CC} = 10 V) Figures 7 and 8	MOC1005	t_s	—	4.0	—	μs
		MOC1006		—	2.0	—	
Fall Time		MOC1005	t_f	—	8.0	—	μs
		MOC1006		—	8.0	—	

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle ≤ 2.0%

(2) Peak DC Voltage — 1.0 Minute

(3) Nonrepetitive Peak AC Voltage — 1 Full Cycle, Sine Wave, 60 Hz

(4) For this test LED pins 1 and 2 are common and Photo Transistor pins 4, 5 and 6 are common.

(5) I_F adjusted to yield I_C = 2.0 mA and i_c = 2.0 mA p-p at 10 kHz

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 2 – MOC1005

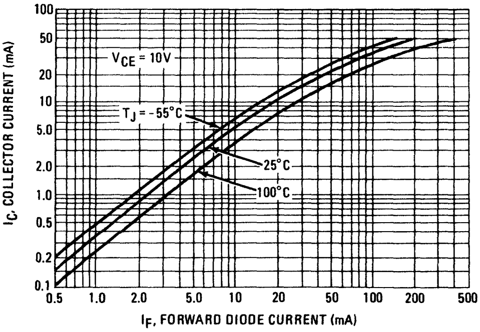
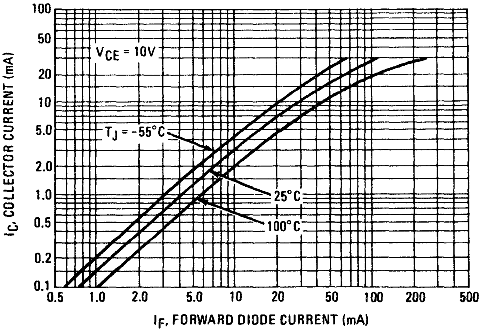


FIGURE 3 – MOC1006



TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 4 — FORWARD CHARACTERISTICS

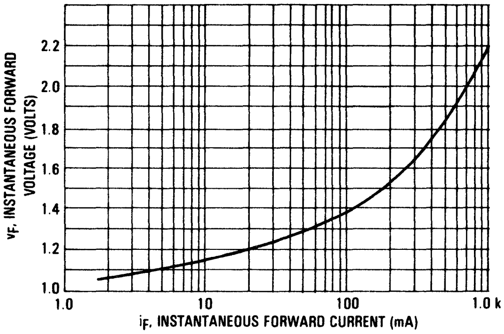


FIGURE 5 — COLLECTOR SATURATION VOLTAGE

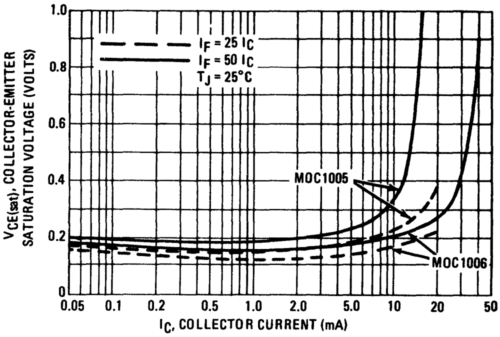


FIGURE 6 — TURN-ON TIME

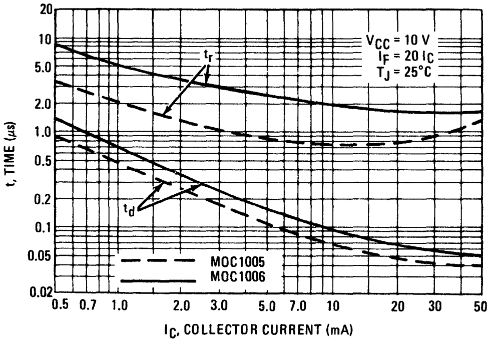


FIGURE 7 — TURN-OFF TIME

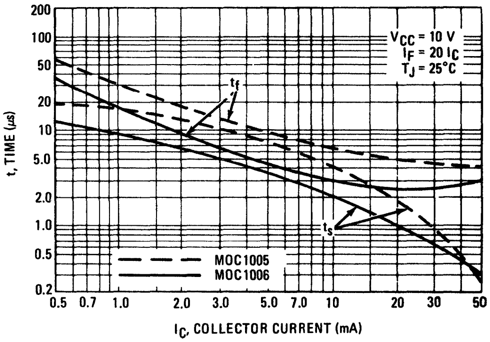


FIGURE 8 — SATURATED SWITCHING TEST CIRCUIT

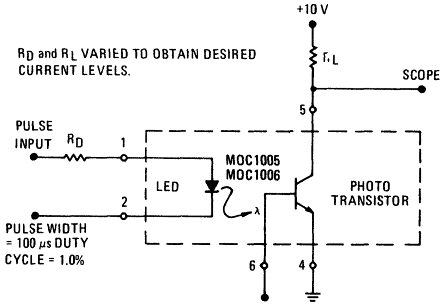


FIGURE 9 — DARK CURRENT versus AMBIENT TEMPERATURE

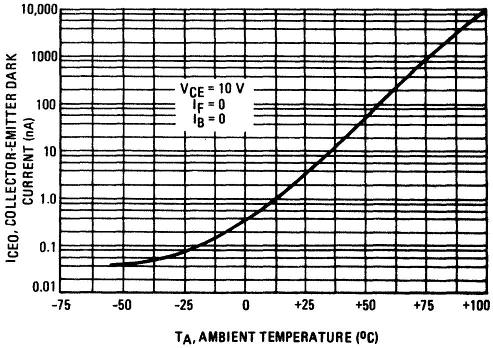


FIGURE 10 – FREQUENCY RESPONSE

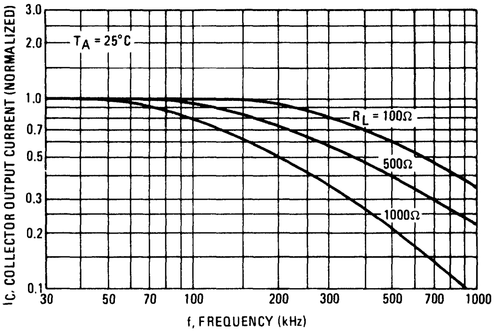


FIGURE 11 – FREQUENCY RESPONSE TEST CIRCUIT

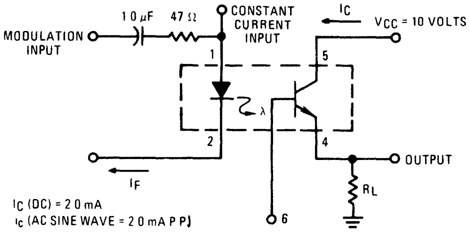


FIGURE 12 – POWER AMPLIFIER

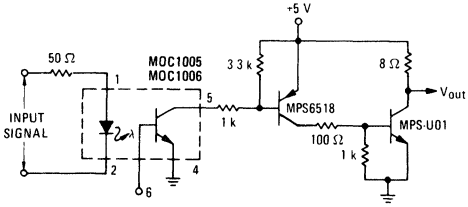


FIGURE 13 – INTERFACE BETWEEN LOGIC AND LOAD

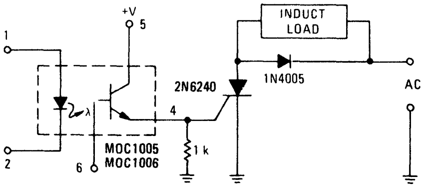


FIGURE 14 – UNIVERSAL CMOS LOGIC TRANSLATOR

(Programmable Constant Current Drive)

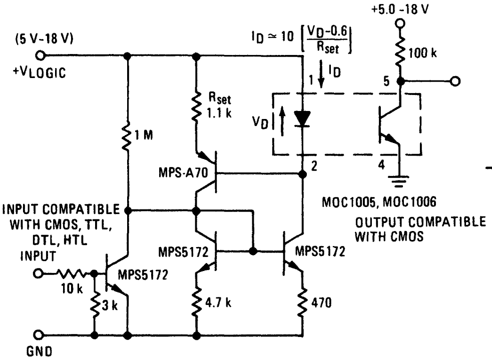
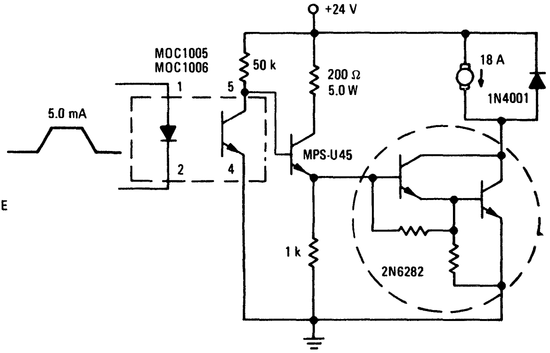


FIGURE 15 – ISOLATED DC MOTOR CONTROLLER



MOTOROLA

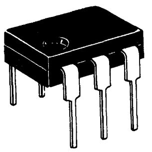
MOC3002
MOC3003
MOC3007

OPTO SCR COUPLERS

These devices consist of gallium-arsenide infrared-emitting diodes optically coupled to photosensitive silicon controlled rectifiers (SCR). They are designed for applications requiring high electrical isolation between low voltage circuitry, like integrated circuits, and the ac line.

- High Blocking Voltage
  MOC3002, 3003 — 250 V for 110 Vac Lines
  MOC3007 — 200 V for 110 Vac Lines
- Very High Isolation Voltage
  V_{ISO} = 7500 V Min
- Standard 6-Pin DIP
- UL Recognized, File Number E54915

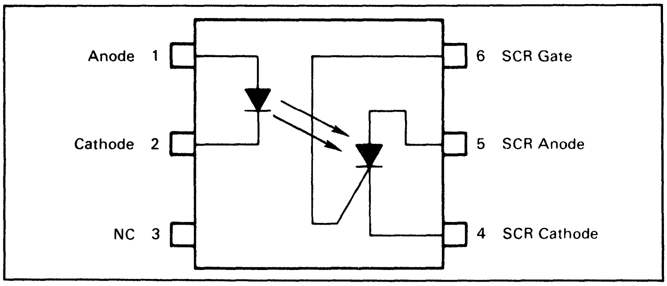
OPTO
COUPLER/ISOLATOR
with
PHOTO SCR OUTPUT
250 and 200 VOLTS

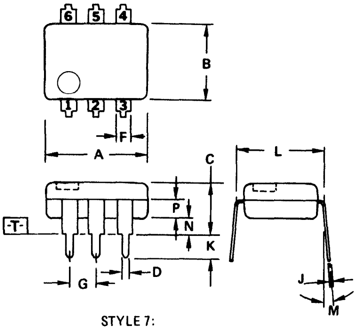


MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	7.0	Volts
Forward Current — Continuous	I_F	60	mA
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	100 1.33	mW mW/°C
OUTPUT DRIVER MAXIMUM RATINGS			
Peak Forward Voltage MOC3002, 3 MOC3007	V_{DM}	250 200	Volts
Forward RMS Current (Full Cycle, 50 to 60 Hz) T_A = 25°C	$I_{T(RMS)}$	300	mA
Peak Nonrepetitive Surge Current (PW = 10 ms, dc = 10%)	I_{TSM}	3.0	A
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	400 5.33	mW mW/°C
TOTAL DEVICE MAXIMUM RATINGS			
Isolation Surge Voltage (1) (Peak ac Voltage, 60 Hz, 5 Second Duration)	V_{ISO}	7500	Vac
Junction Temperature Range	T_J	-40 to +100	°C
Ambient Operating Temperature Range	T_A	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)	—	260	°C

(1) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.





STYLE 7:
PIN 1. LED ANODE
2. LED CATHODE
3. NC
4. SCR CATHODE
5. SCR ANODE
6. SCR GATE

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⌖ | Ø 0.13 (0.005)Ⓜ | T | AⓂ BⓂ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
LED CHARACTERISTICS					
Reverse Leakage Current (V_R = 3.0 V)	I_R	—	0.05	10	µA
Forward Voltage (I_F = 10 mA)	V_F	—	1.2	1.5	Volts
Capacitance (V = 0, f = 1.0 MHz)	C_J	—	50	—	pF
DETECTOR CHARACTERISTICS					
Peak Off-State Voltage (I_{DM} = 50 µA) MOC3002, 3003	V_{DM}	250	—	—	Volts
(R_{GK} = 10 kΩ, T_A = 100°C, I_{DM} = 100 µA) MOC3007		200	—	—	
Peak Reverse Voltage (I_{RM} = 50 µA) MOC3002, 3003	V_{RM}	250	—	—	Volts
(R_{GK} = 10 kΩ, T_A = 100°C, I_{RM} = 100 µA) MOC3007		200	—	—	
On-State Voltage MOC3002, 3003	V_{TM}	—	1.1	1.3	Volts
(I_{TM} = 0.3 A) MOC3007		—	1.2	1.5	
Off-State Current	I_{DM}				µA
(V_{DM} = 250 V, R_{GK} = 10 kΩ, T_A = 100°C) MOC3002, 3003		—	—	50	
(V_{DM} = 200 V, R_{GK} = 10 kΩ, T_A = 100°C) MOC3007		—	—	100	
Reverse Current	I_{RM}				µA
(V_{RM} = 250 V, R_{GK} = 10 kΩ, T_A = 100°C) MOC3002, 3003		—	—	50	
(V_{RM} = 200 V, R_{GK} = 10 kΩ, T_A = 100°C) MOC3007		—	—	100	
Capacitance (V = 0, f = 1.0 MHz)	C_J				pF
Anode - Gate		—	20	—	
Gate - Cathode		—	350	—	
COUPLED CHARACTERISTICS					
LED Current Required to Trigger	I_{FT}				mA
(V_{AK} = 50 V, R_{GK} = 10 kΩ) MOC3002		—	15	30	
MOC3003		—	10	20	
MOC3007		—	20	40	
(V_{AK} = 100 V, R_{GK} = 27 kΩ) MOC3002		—	8.0	14	
MOC3003		—	6.0	11	
MOC3007		—	12	22	
Isolation Resistance (V_{IO} = 500 Vdc)	R_{ISO}	100	—	—	GΩ
Capacitance Input to Output (V_{IO} = 0, f = 1.0 MHz)	C_{ISO}	—	—	2.0	pF
Coupled dv/dt, Input to Output (R_{GK} = 10 kΩ)	dv/dt	—	500	—	Volts/µs
Isolation Surge Voltage (Peak ac Voltage, 60 Hz, 5 Second Duration)	V_{ISO}	7500	—	—	Vac

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 1 — LED FORWARD VOLTAGE versus FORWARD CURRENT

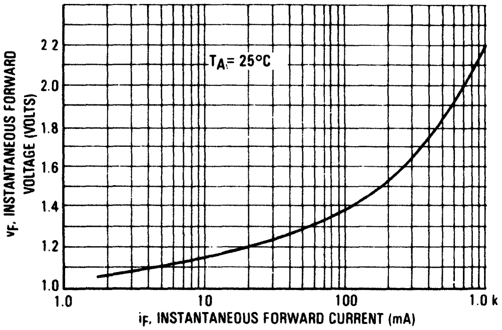


FIGURE 2 — ANODE CURRENT versus ANODE-CATHODE VOLTAGE

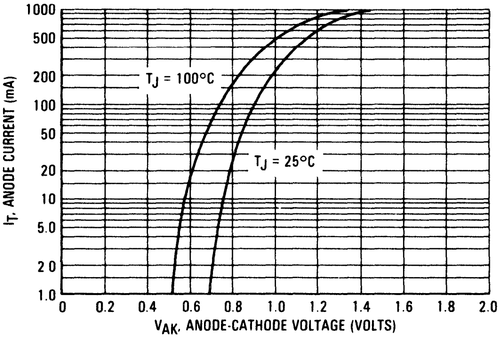


FIGURE 3 — LED TRIGGER CURRENT versus TEMPEATURE

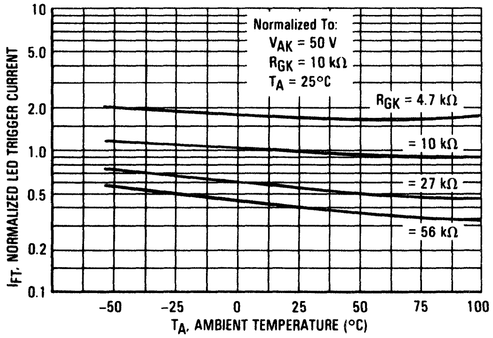
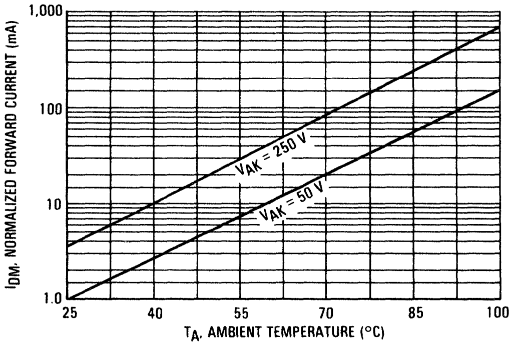


FIGURE 4 — FORWARD LEAKAGE CURRENT versus TEMPERATURE



MOTOROLA

MOC3009
MOC3010
MOC3011
MOC3012

OPTICALLY ISOLATED TRIAC DRIVERS

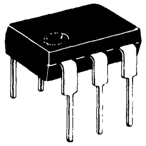
These devices consist of gallium-arsenide infrared-emitting diodes optically coupled to silicon bilateral switches and are designed for applications requiring isolated triac triggering, low-current isolated ac switching, high electrical isolation (to 7500 V peak), high detector standoff voltage, small size, and low cost.

- UL Recognized File Number 54915
- Output Driver Designed for 115 Vac Line
- Standard 6-Pin DIP

OPTO
COUPLER/ISOLATOR

PHOTO TRIAC DRIVER
OUTPUT

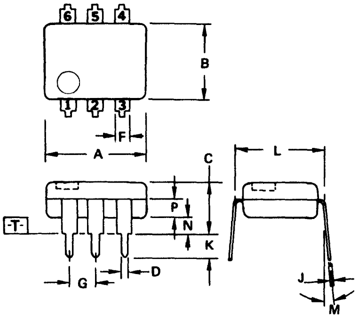
250 VOLTS



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	3.0	Volts
Forward Current — Continuous	I_F	50	mA
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	100 1.33	mW mW/°C
OUTPUT DRIVER MAXIMUM RATINGS			
Off-State Output Terminal Voltage	V_{DRM}	250	Volts
On-State RMS Current T_A = 25°C (Full Cycle, 50 to 60 Hz) T_A = 70°C	$I_{T(RMS)}$	100 50	mA mA
Peak Nonrepetitive Surge Current (PW = 10 ms, DC = 10%)	I_{TSM}	1.2	A
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	300 4.0	mW mW/°C
TOTAL DEVICE MAXIMUM RATINGS			
Isolation Surge Voltage (1) (Peak ac Voltage, 60 Hz, 5 Second Duration)	V_{ISO}	7500	Vac
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	330 4.4	mW mW/°C
Junction Temperature Range	T_J	-40 to +100	°C
Ambient Operating Temperature Range	T_A	-40 to +70	°C
Storage Temperature Range	T_{stg}	-40 to +150	°C
Soldering Temperature (10 s)	–	260	°C

(1) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

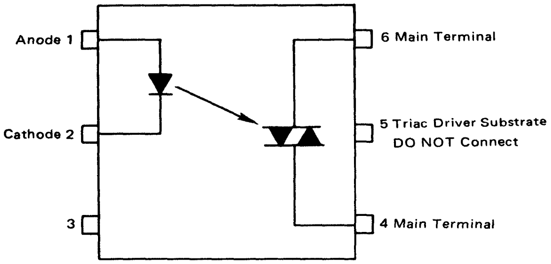


STYLE 6:
PIN 1. ANODE
2. CATHODE
3. NC
4. MAIN TERMINAL
5. SUBSTRATE
6. MAIN TERMINAL

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⊕ | ∅ 0.13 (0.005)Ⓜ | T | AⓂ BⓂ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01



ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
LED CHARACTERISTICS					
Reverse Leakage Current (V_R = 3.0 V)	I_R	–	0.05	100	μA
Forward Voltage (I_F = 10 mA)	V_F	–	1.2	1.5	Volts
DETECTOR CHARACTERISTICS (I_F = 0 unless otherwise noted)					
Peak Blocking Current, Either Direction (Rated V_{DRM}, Note 1)	I_{DRM}	–	10	100	nA
Peak On-State Voltage, Either Direction (I_{TM} = 100 mA Peak)	V_{TM}	–	2.5	3.0	Volts
Critical Rate of Rise of Off-State Voltage, Figure 3	dv/dt	–	12	–	V/μs
Critical Rate of Rise of Commutation Voltage, Figure 3 (I_{load} = 15 mA)	dv/dt	–	0.15	–	V/μs
COUPLED CHARACTERISTICS					
LED Trigger Current, Current Required to Latch Output (Main Terminal Voltage = 3.0 V) MOC3009	I_{FT}		15	30	mA
MOC3010		–	8.0	15	
MOC3011		–	5.0	10	
MOC3012		—	—	5.0	
Holding Current, Either Direction	I_H	–	100	–	μA

Note 1. Test voltage must be applied within dv/dt rating.
2. Additional information on the use of the MOC3009/3010/3011 is available in Application Note AN-780A.

TYPICAL ELECTRICAL CHARACTERISTICS
T_A = 25°C

FIGURE 1 – ON-STATE CHARACTERISTICS

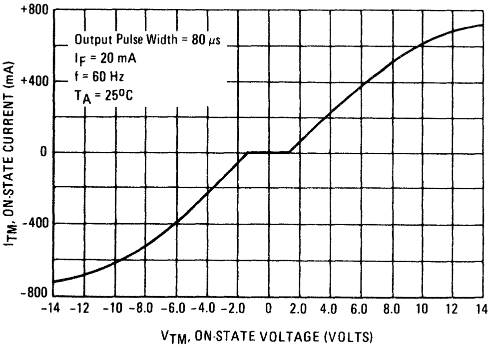


FIGURE 2 – TRIGGER CURRENT versus TEMPERATURE

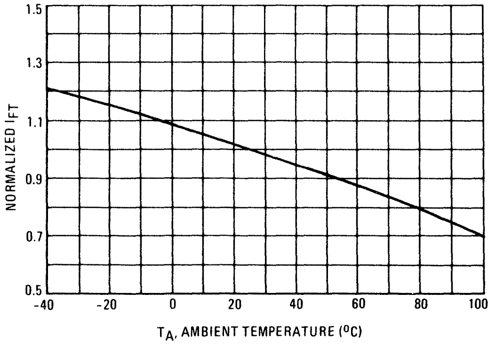


FIGURE 3 – dv/dt TEST CIRCUIT

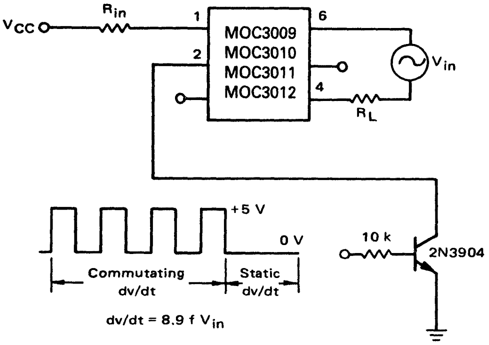


FIGURE 4 – dv/dt versus LOAD RESISTANCE

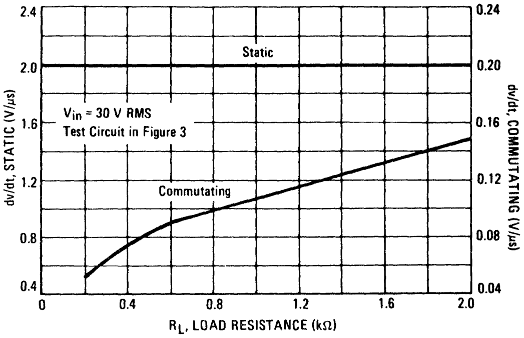


FIGURE 5 – dv/dt versus TEMPERATURE

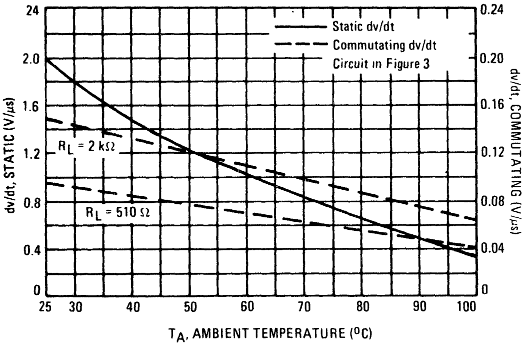


FIGURE 6 – COMMUTATING dv/dt versus FREQUENCY

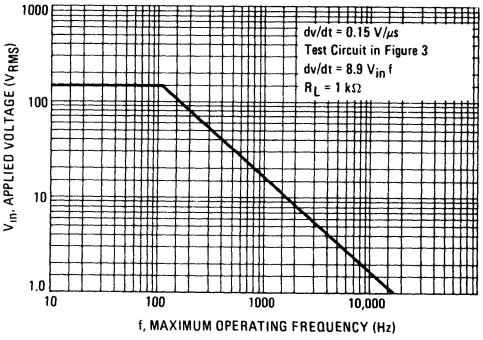
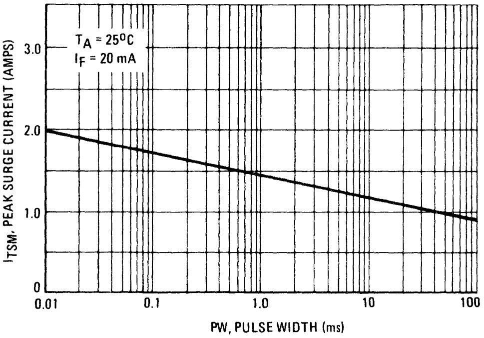


FIGURE 7 – MAXIMUM NONREPETITIVE SURGE CURRENT



TYPICAL APPLICATION CIRCUITS

FIGURE 8 — RESISTIVE LOAD

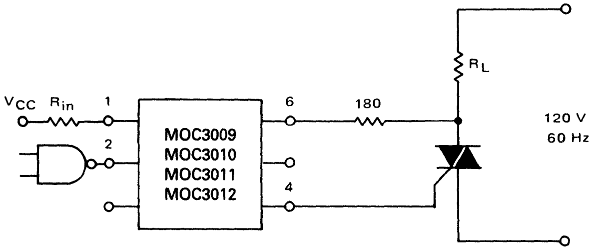


FIGURE 9 — INDUCTIVE LOAD WITH SENSITIVE GATE TRIAC
($I_{GT} \leq 15$ mA)

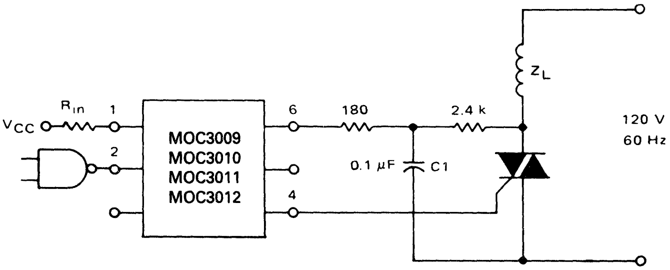
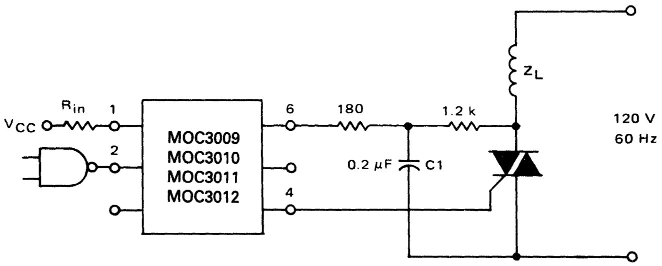


FIGURE 10 — INDUCTIVE LOAD WITH NON-SENSITIVE GATE TRIAC
(15 mA < I_{GT} < 50 mA)



MOTOROLA

MOC3020
MOC3021
MOC3022
MOC3023

OPTO COUPLER/ISOLATOR

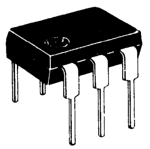
PHOTO TRIAC DRIVER OUTPUT

400 VOLTS

OPTICALLY ISOLATED TRIAC DRIVERS

These devices consist of gallium-arsenide infrared-emitting diodes, optically coupled to silicon bilateral switches. They are designed for applications requiring isolated triac triggering.

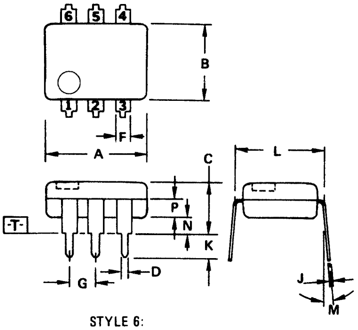
- UL Recognized File Number E54915
- Output Driver Designed for 220 Vac Line
- V_{ISO} Isolation Voltage of 7500 V Peak
- Standard 6-Pin Plastic DIP



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	3.0	Volts
Forward Current — Continuous	I_F	50	mA
Total Power Dissipation @ T_A = 25°C Negligible Power in Triac Driver Derate above 25°C	P_D	100 1.33	mW mW/°C
OUTPUT DRIVER MAXIMUM RATINGS			
Off-State Output Terminal Voltage	V_{DRM}	400	Volts
On-State RMS Current T_A = 25°C (Full Cycle, 50 to 60 Hz) T_A = 70°C	$I_{T(RMS)}$	100 50	mA mA
Peak Nonrepetitive Surge Current (PW = 10 ms, DC = 10%)	I_{TSM}	1.2	A
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	300 4.0	mW mW/°C
TOTAL DEVICE MAXIMUM RATINGS			
Isolation Surge Voltage (1) (Peak ac Voltage, 60 Hz, 5 Second Duration)	V_{ISO}	7500	Vac
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	330 4.4	mW mW/°C
Junction Temperature Range	T_J	-40 to +100	°C
Ambient Operating Temperature Range	T_A	-40 to +70	°C
Storage Temperature Range	T_{stg}	-40 to +150	°C
Soldering Temperature (10 s)	–	260	°C

(1) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

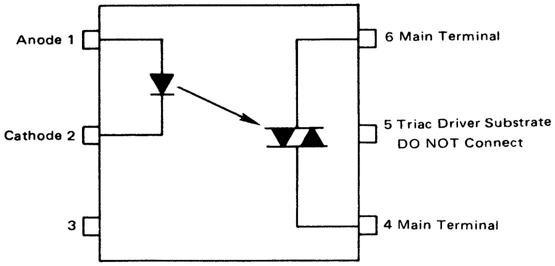


STYLE 6:
PIN 1. ANODE
2. CATHODE
3. NC
4. MAIN TERMINAL
5. SUBSTRATE
6. MAIN TERMINAL

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⌖ | ∅ 0.13 (0.005)Ⓜ | T | AⓂBⓂ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01



ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
LED CHARACTERISTICS					
Reverse Leakage Current (V_R = 3.0 V)	I_R	–	0.05	100	μA
Forward Voltage (I_F = 10 mA)	V_F	–	1.2	1.5	Volts
DETECTOR CHARACTERISTICS (I_F = 0 unless otherwise noted)					
Peak Blocking Current, Either Direction (Rated V_{DRM}, Note 1)	I_{DRM}	–	10	100	nA
Peak On-State Voltage, Either Direction (I_{TM} = 100 mA Peak)	V_{TM}	–	2.5	3.0	Volts
Critical Rate of Rise of Off-State Voltage, T_A = 85°C	dv/dt	–	12	–	V/μs
COUPLED CHARACTERISTICS					
LED Trigger Current, Current Required to Latch Output (Main Terminal Voltage = 3.0 V, Note 2) MOC3020	I_{FT}	–	15	30	mA
MOC3021		–	8.0	15	
MOC3022		—	—	10	
MOC3023		—	—	5.0	
Holding Current, Either Direction	I_H	–	100	–	μA

Note 1. Test voltage must be applied within dv/dt rating.

2. All devices are guaranteed to trigger at an I_F value less than or equal to max I_{FT}.

TYPICAL ELECTRICAL CHARACTERISTICS
T_A = 25°C

FIGURE 1 — ON-STATE CHARACTERISTICS

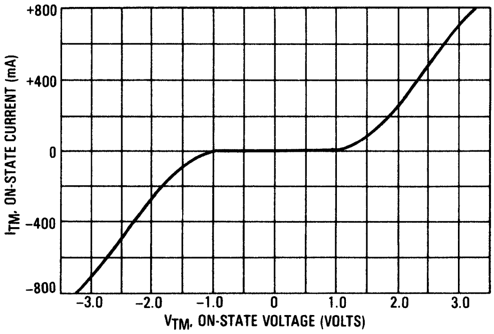


FIGURE 2 — TRIGGER CURRENT versus TEMPERATURE

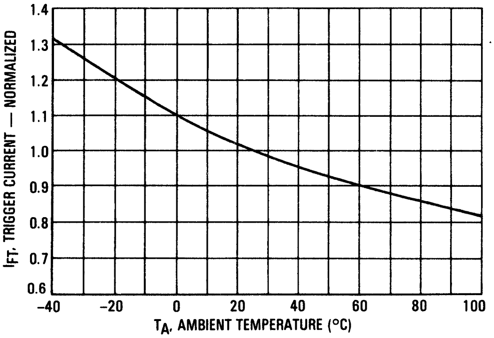
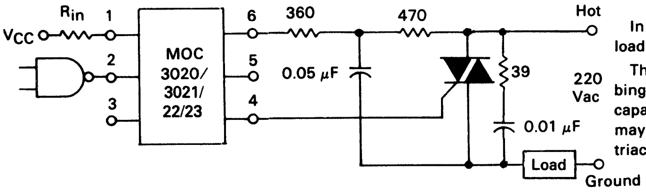


FIGURE 3 — TYPICAL APPLICATION CIRCUIT



In this circuit the "hot" side of the line is switched and the load connected to the cold or ground side.

The 39 ohm resistor and 0.01 μF capacitor are for snubbing of the triac, and the 470 ohm resistor and 0.05 μF capacitor are for snubbing the coupler. These components may or may not be necessary depending upon the particular triac and load used.

Additional information on the use of optically coupled triac drivers is available in Application Note AN-780A.

MOTOROLA

MOC3030
MOC3031
MOC3032

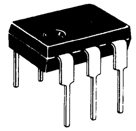
OPTO COUPLER/ISOLATOR
ZERO CROSSING TRIAC DRIVER
250 VOLTS

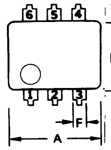
ZERO VOLTAGE CROSSING OPTICALLY ISOLATED TRIAC DRIVERS

These devices consist of gallium-arsenide infrared-emitting diodes optically coupled to monolithic silicon detectors performing the functions of a Zero Voltage crossing bilateral triac drivers.

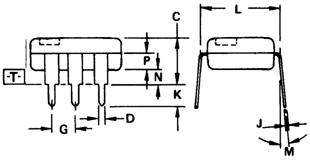
They are designed for use with a triac in the interface of logic systems to equipment powered from 115 Vac lines, such as teletypewriters, CRTs, printers, motors, solenoids and consumer appliances, etc.

- Simplifies Logic Control of 110 Vac Power
- Zero Voltage Crossing
- High Breakdown Voltage: V_{DRM} = 250 V Min
- High Isolation Voltage: V_{ISO} = 7500 V Min
- Small, Economical, 6-Pin DIP Package
- Same Pin Configuration as MOC3010/3011
- UL Recognized, File No. E54915
- dv/dt of 100 V/μs Typ





NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
   ⊕ | ∅ 0.13 (0.005)Ⓜ | T | AⓂ BⓂ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.



DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

STYLE 6.
PIN 1. ANODE
2. CATHODE
3. NC
4. MAIN TERMINAL
5. SUBSTRATE
6. MAIN TERMINAL

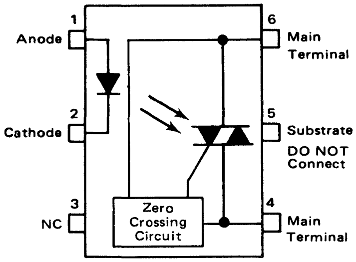
CASE 730A-01

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	3.0	Volts
Forward Current — Continuous	I_F	50	mA
Total Power Dissipation @ T_A = 25°C Negligible Power in Output Driver Derate above 25°C	P_D	120 1.33	mW mW/°C
OUTPUT DRIVER MAXIMUM RATINGS			
Off-State Output Terminal Voltage	V_{DRM}	250	Volts
On-State RMS Current T_A = 25°C (Full Cycle, 50 to 60 Hz) T_A = 85°C	$I_{T(RMS)}$	100 50	mA mA
Peak Nonrepetitive Surge Current (PW = 10 ms)	I_{TSM}	1.2	A
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	300 4.0	mW mW/°C
TOTAL DEVICE MAXIMUM RATINGS			
Isolation Surge Voltage (1) (Peak ac Voltage, 60 Hz, 5 Second Duration)	V_{ISO}	7500	Vac
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	330 4.4	mW mW/°C
Junction Temperature Range	T_J	-40 to +100	°C
Ambient Operating Temperature Range	T_A	-40 to + 85	°C
Storage Temperature Range	T_{stg}	-40 to +150	°C
Soldering Temperature (10 s)	—	260	°C

(1) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

COUPLER SCHEMATIC



ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
LED CHARACTERISTICS					
Reverse Leakage Current (V_R = 3.0 V)	I_R	–	0.05	100	μA
Forward Voltage (I_F = 30 mA)	V_F	–	1.3	1.5	Volts
DETECTOR CHARACTERISTICS (I_F = 0 unless otherwise noted)					
Peak Blocking Current, Either Direction (Rated V_{DRM}, Note 1)	I_{DRM}	–	10	100	nA
Peak On-State Voltage, Either Direction (I_{TM} = 100 mA Peak)	V_{TM}	–	1.8	3.0	Volts
Critical Rate of Rise of Off-State Voltage	dv/dt	–	100	–	V/μs

COUPLED CHARACTERISTICS

Characteristic		Symbol	Min	Typ	Max	Unit
LED Trigger Current, Current Required to Latch Output (Main Terminal Voltage = 3.0 V, Note 2)	MOC3030 MOC3031 MOC3032	I_{FT}	– – –	– – –	30 15 10	mA
Holding Current, Either Direction		I_H	–	100	–	μA

ZERO CROSSING CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Inhibit Voltage (I_F = Rated I_{FT}, MT1-MT2 Voltage above which device will not trigger.)	V_{IH}	–	15	25	Volts
Leakage in Inhibited State (I_F = Rated I_{FT}, Rated V_{DRM}, Off State)	I_R	–	100	200	μA

Note 1. Test voltage must be applied within dv/dt rating.

2. All devices are guaranteed to trigger at an I_F value less than or equal to max I_{FT}.

TYPICAL ELECTRICAL CHARACTERISTICS
T_A = 25°C

FIGURE 1 – ON-STATE CHARACTERISTICS

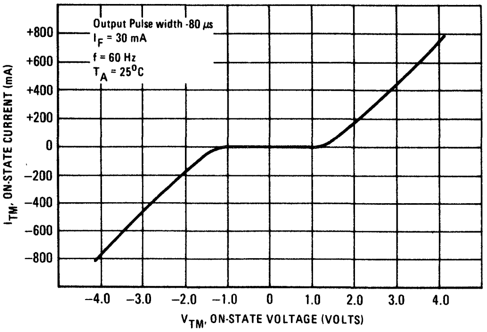


FIGURE 2 – TRIGGER CURRENT versus TEMPERATURE

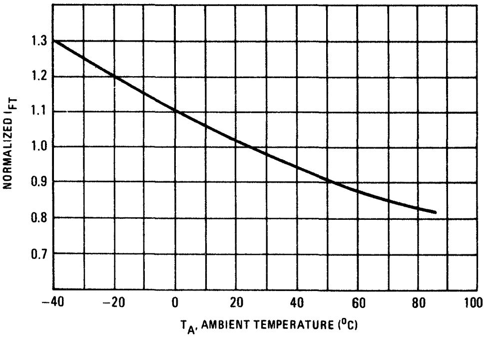
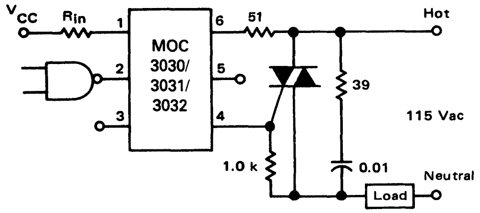
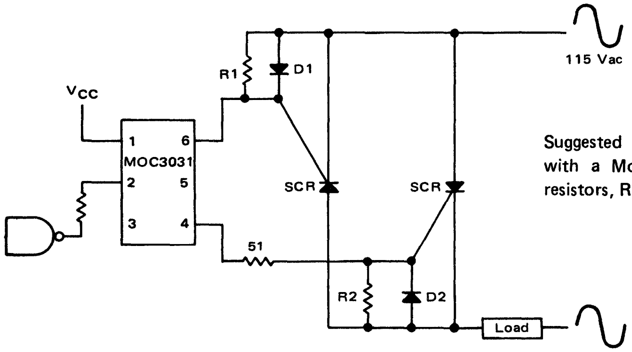


FIGURE 3 – HOT-LINE SWITCHING APPLICATION CIRCUIT



Typical circuit for use when hot line switching is required. In this circuit the "hot" side of the line is switched and the load connected to the cold or neutral side. The load may be connected to either the neutral or hot line.
The 39 ohm resistor and 0.01 μF capacitor are for snubbing of the triac and may or may not be necessary depending upon the particular triac and load used.

FIGURE 4 – INVERSE-PARALLEL SCR DRIVER CIRCUIT



Suggested method of firing two, back-to-back SCR's, with a Motorola triac driver. Diodes can be 1N4001; resistors, R1 and R2, are optional 1 k ohm.

MOTOROLA

MOC3040
MOC3041

OPTO COUPLER / ISOLATOR ZERO CROSSING TRIAC DRIVER

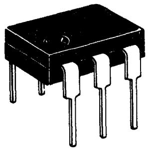
400 VOLTS

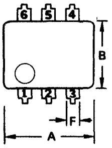
ZERO VOLTAGE CROSSING OPTICALLY ISOLATED TRIAC DRIVERS

These devices consist of gallium-arsenide infrared-emitting diodes optically coupled to monolithic silicon detectors performing the functions of Zero Voltage Crossing bilateral triac drivers.

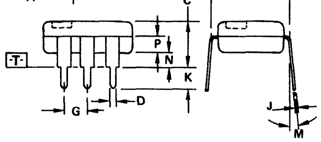
They are designed for use with a triac in the interface of logic systems to equipment powered from 220 Vac lines, such as solid-state relays, industrial controls, motors, solenoids and consumer appliances, etc.

- Simplifies Logic Control of 220 Vac Power
- Zero Voltage Crossing
- High Breakdown Voltage: V_{DRM} = 400 V Min
- High Isolation Voltage: V_{ISO} = 7500 Vac (Min)
- Small, Economical, 6-Pin DIP Package
- Same Pin Configuration as MOC3020/3021
- UL Recognized, File No. E54915
- dv/dt of 100 V/μs Typ





NOTES.
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
   ⌖ | Ø 0.13 (0.005) Ⓜ | T | A Ⓜ | B Ⓜ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.



DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

STYLE 6:
PIN 1. ANODE
2. CATHODE
3. NC
4. MAIN TERMINAL
5. SUBSTRATE
6. MAIN TERMINAL

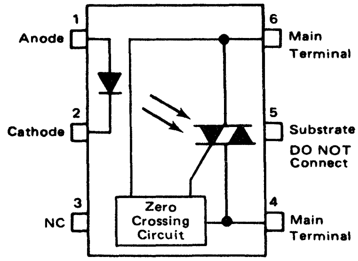
CASE 730A-01

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	6.0	Volts
Forward Current – Continuous	I_F	50	mA
Total Power Dissipation @ T_A = 25°C Negligible Power in Output Driver Derate above 25°C	P_D	120 1.33	mW mW/°C
OUTPUT DRIVER MAXIMUM RATINGS			
Off-State Output Terminal Voltage	V_{DRM}	400	Volts
On-State RMS Current T_A = 25°C (Full Cycle, 50 to 60 Hz) T_A = 70°C	$I_{T(RMS)}$	100 50	mA mA
Peak Nonrepetitive Surge Current (PW = 10 ms)	I_{TSM}	1.2	A
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	300 4.0	mW mW/°C
TOTAL DEVICE MAXIMUM RATINGS			
Isolation Surge Voltage (1) (Peak ac Voltage, 60 Hz, 5 Second Duration)	V_{ISO}	7500	Vac
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	330 4.4	mW mW/°C
Junction Temperature Range	T_J	-40 to +100	°C
Ambient Operating Temperature Range	T_A	-40 to +70	°C
Storage Temperature Range	T_{stg}	-40 to +150	°C
Soldering Temperature (10 s)	–	260	°C

(1) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

COUPLER SCHEMATIC



ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
LED CHARACTERISTICS					
Reverse Leakage Current (V_R = 6.0 V)	I_R	–	0.05	100	μA
Forward Voltage (I_F = 30 mA)	V_F	–	1.3	1.5	Volts
DETECTOR CHARACTERISTICS (I_F = 0 unless otherwise noted)					
Peak Blocking Current, Either Direction (Rated V_{DRM}, Note 1)	I_{DRM1}	–	2.0	100	nA
Peak On-State Voltage, Either Direction (I_{TM} = 100 mA Peak)	V_{TM}	–	1.8	3.0	Volts
Critical Rate of Rise of Off-State Voltage	dv/dt	–	100	–	V/μs

COUPLED CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
LED Trigger Current, Current Required to Latch Output (Main Terminal Voltage = 3.0 V, Note 2)	I_{FT}				mA
MOC3040		–	–	30	
MOC3041		–	–	15	
Holding Current, Either Direction	I_H	–	200	–	μA

ZERO CROSSING CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Inhibit Voltage (I_F = Rated I_{FT}, MT1-MT2 Voltage above which device will not trigger.)	V_{IH}	–	15	40	Volts
Leakage in Inhibited State (I_F = Rated I_{FT}, Rated V_{DRM}, Off State)	I_{DRM2}	–	100	300	μA

Note 1. Test voltage must be applied within dv/dt rating.

2. All devices are guaranteed to trigger at an I_F value less than or equal to max I_{FT}. Therefore, recommended operating I_F lies between max I_{FT} (30 mA for MOC3040, 15 mA for MOC3041) and absolute max I_F (50 mA).

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 1 – ON-STATE CHARACTERISTICS

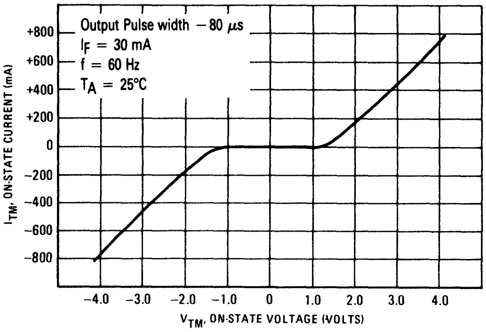


FIGURE 2 – TRIGGER CURRENT versus TEMPERATURE

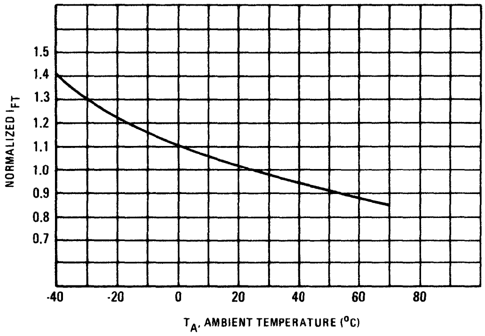
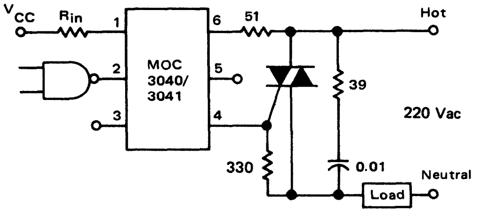


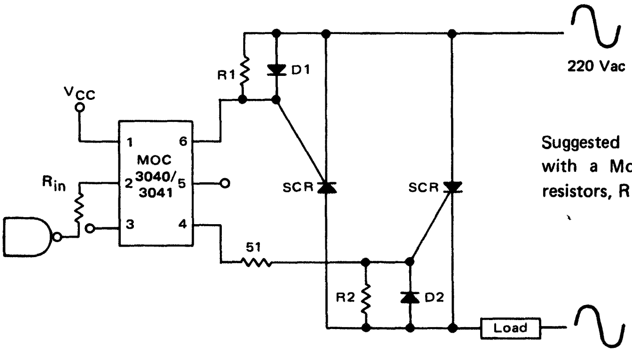
FIGURE 3 – HOT-LINE SWITCHING APPLICATION CIRCUIT



Typical circuit for use when hot line switching is required. In this circuit the "hot" side of the line is switched and the load connected to the cold or neutral side. The load may be connected to either the neutral or hot line.

R_{in} is calculated so that I_F is equal to the rated I_{FT} of the part, 15 mA for the MOC3041 or 30 mA for the MOC3040. The 39 ohm resistor and 0.01 µF capacitor are for snubbing of the triac and may or may not be necessary depending upon the particular triac and load used.

FIGURE 4 – INVERSE-PARALLEL SCR DRIVER CIRCUIT



Suggested method of firing two, back-to-back SCR's, with a Motorola triac driver. Diodes can be 1N4001; resistors, R1 and R2, are optional 330 ohms.

MOTOROLA

MOC5007
MOC5008
MOC5009

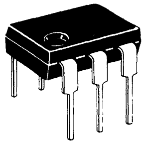
DIGITAL LOGIC COUPLERS

. . . gallium arsenide IRED optically coupled to high-speed integrated detectors with Schmitt trigger outputs. Designed for applications requiring electrical isolation, fast response time, noise immunity and digital logic compatibility such as interfacing computer terminals to peripheral equipment, digital control of power supplies, motors and other servo machine applications.

- High Isolation Voltage — V_{ISO} = 7500 Vac (Min)
- Guaranteed Switching Times t_{on}, t_{off} < 4.0 μs
- Built-In ON/OFF Threshold Hysteresis
- Economical, Standard Dual-In-Line Plastic Package
- UL Recognized, File No. E54915

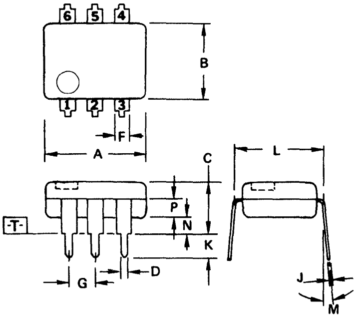
OPTO COUPLER/ISOLATOR

SCHMITT TRIGGER OUTPUT



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	6.0	Volts
Forward Current — Continuous Peak Pulse Width = 300 μs, 2.0% Duty Cycle	I_F	60 1.2	mA Amp
Device Dissipation Negligible Power in C Derate above 25°C	P_D	100 1.33	mW mW/°C
DETECTOR MAXIMUM RATINGS			
Output Voltage Range	V_O	16	Volts
Supply Voltage Range	V_{CC}	16	Volts
Output Current	I_O	50	mA
Device Dissipation Negligible Power in Diode Derate above 25°C	P_D	150 2.0	mW mW/°C
TOTAL DEVICE RATINGS			
Total Device Dissipation	P_D	250	mW
Maximum Operating Temperature	T_A	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)		260	°C
Isolation Surge Voltage (Vac pk)	V_{ISO}	7500	Vac



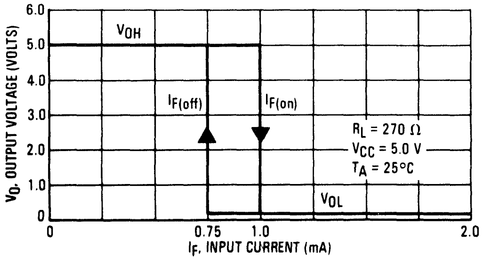
STYLE 5:
PIN 1. ANODE
2. CATHODE
3. NC
4. OUTPUT
5. GROUND
6. V_{CC}

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
   | ⊕ | Ø 0.13 (0.005) Ⓜ | T | A Ⓜ B Ⓜ |
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

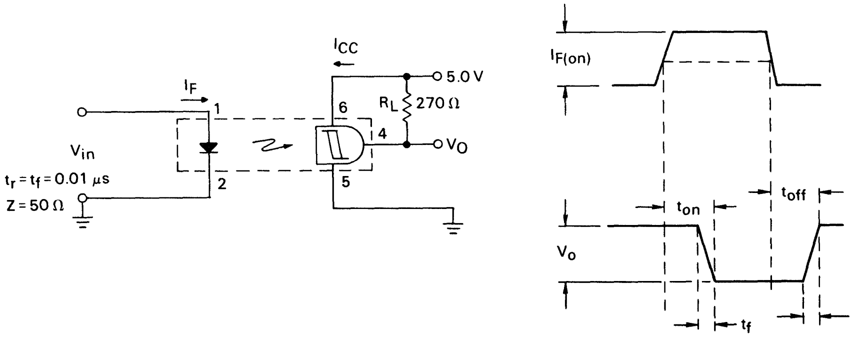
FIGURE 1 — TRANSFER CHARACTERISTICS FOR MOC5007



Characteristic	Symbol	Min	Typ	Max	Unit
IRED CHARACTERISTICS (T_A = 0-70°C)					
Reverse Leakage Current (V_R = 3.0 V, R_L = 1.0 MΩ)	I_R	—	0.05	10	μA
Forward Voltage (I_F = 10 mA) (I_F = 0.3 mA)	V_F	 — 0.75	 1.2 0.95	 1.5 —	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	—	50	—	pF
ISOLATION CHARACTERISTICS (T_A = 25°C)					
Isolation Voltage (1) 60 Hz, ac Peak, 5 s	V_{ISO}	7500	—	—	Volts
DETECTOR CHARACTERISTICS (T_A = 0-70°C)					
Operating Voltage	V_{CC}	3.0	—	15	Volts
Supply Current (I_F = 0, V_{CC} = 5.0 V)	$I_{CC(off)}$	—	1.0	5.0	mA
Output Current, High (I_F = 0, V_{CC} = V_o = 15 V)	I_{OH}	—	—	100	μA
COUPLED CHARACTERISTICS (T_A = 0-70°C)					
Supply Current ($I_F = I_{F(on)}$, V_{CC} = 5.0 V)	$I_{CC(on)}$	—	1.6	5.0	mA
Output Voltage, Low (R_L = 270 Ω, V_{CC} = 5.0 V, $I_F = I_{F(on)}$)	V_{OL}	—	0.2	0.4	Volts
Threshold Current, ON — MOC5007 (R_L = 270 Ω, V_{CC} = 5.0 V) — MOC5008 MOC5009	$I_{F(on)}$	— — —	1.0 — —	1.6 4.0 10	mA
Threshold Current, OFF — MOC5007 (R_L = 270 Ω, V_{CC} = 5.0 V) — MOC5008, 5009	$I_{F(off)}$	0.3 0.3	0.75 —	— —	mA
Hysteresis Ratio (R_L = 270 Ω, V_{CC} = 5.0 V)	$\frac{I_{F(off)}}{I_{F(on)}}$	0.5	0.75	0.90	
SWITCHING CHARACTERISTICS (T_A = 25°C)					
Turn-On-Time R_L = 270 Ω, V_{CC} = 5.0 V, $I_F = I_{F(on)}$	t_{on}	—	1.2	4.0	μs
Fall Time	t_f	—	0.1	—	
Turn-Off-Time	t_{off}	—	1.2	4.0	
Rise Time	t_r	—	0.1	—	

(1) For this test IRED Pins 1 and 2 are common and Output Gate Pins 4, 5, 6 are common

FIGURE 2 — SWITCHING TEST CIRCUIT



TYPICAL CHARACTERISTICS

FIGURE 3 — THRESHOLD CURRENT versus SUPPLY VOLTAGE

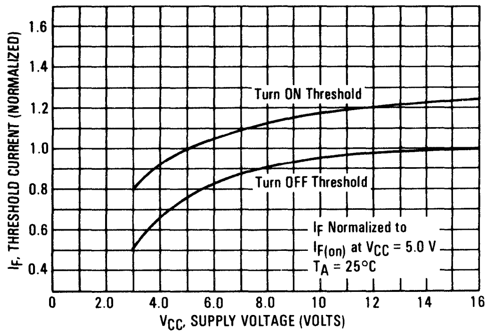


FIGURE 4 — THRESHOLD CURRENT versus TEMPERATURE

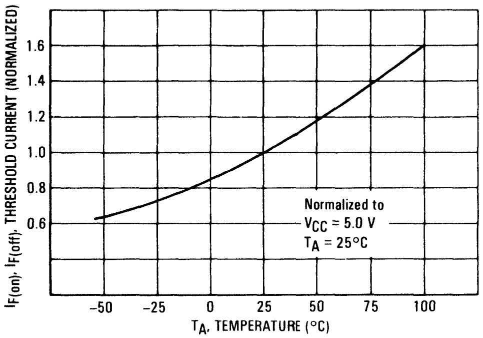


FIGURE 5 — OUTPUT VOLTAGE, LOW versus LOAD CURRENT

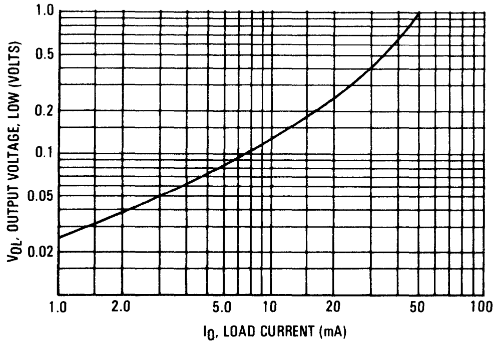
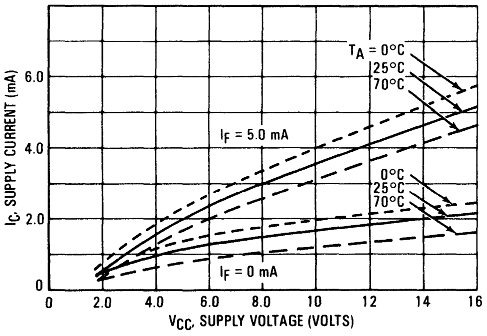


FIGURE 6 — SUPPLY CURRENT versus SUPPLY VOLTAGE



MOTOROLA

MOC5010

OPTICALLY ISOLATED AC LINEAR COUPLER

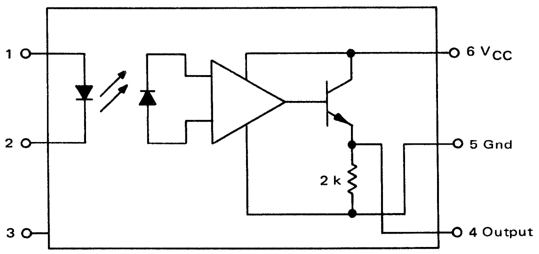
. . . gallium arsenide IRED optically-coupled to a bipolar monolithic amplifier. Converts an input current variation to an output voltage variation while providing a high degree of electrical isolation between input and output. Can be used for line coupling, peripheral equipment isolation, audio, medical, and other applications.

- 250 kHz Bandwidth
- Low Impedance Emitter Follower Output: $Z_O < 200\ \Omega$
- High Voltage Isolation: $V_{ISO} = 7500$ V (Min)
- UL Recognized, File Number E54915

MAXIMUM RATINGS ($T_A = 25^\circ C$ unless otherwise noted)

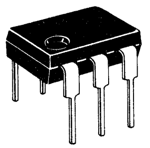
Rating	Symbol	Value	Unit
INFRARED EMITTING DIODE			
Reverse Voltage	V_R	3.0	Volts
Forward Current — Peak Pulse Width = 300 μs, 20% Duty Cycle	I_F	50	mA
Device Dissipation @ $T_A = 25^\circ C$ Negligible Power in IC Derate above 25°C	P_D	100 2.0	mW mW/°C
AC AMPLIFIER			
Supply Voltage	V_{CC}	15	Volts
Supply Current @ $V_{CC} = 12$ V	I_{CC}	13	mA
Device Dissipation @ $T_A = 25^\circ C$ Negligible Power in Diode	P_D	200	mW
TOTAL DEVICE			
Device Dissipation @ $T_A = 25^\circ C$	P_D	200	mW
Maximum Operating Temperature	T_A	85	°C
Storage Temperature Range	T_{stg}	−55 to +100	°C

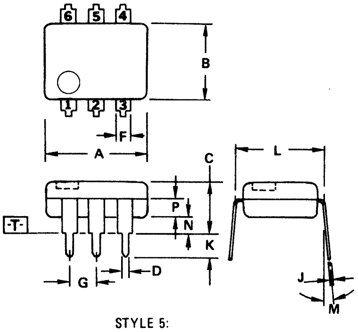
FIGURE 1 — COUPLER SCHEMATIC



OPTO COUPLER/ISOLATOR

AC LINEAR AMPLIFIER





STYLE 5:
PIN 1. ANODE
2. CATHODE
3. NC
4. OUTPUT
5. GROUND
6. V_{CC}

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⌖ | ∅ 0.13 (0.005)Ⓜ | T | AⓂ BⓂ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

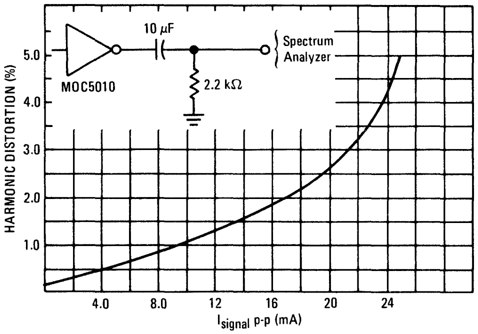
CASE 730A-01

Characteristic		Symbol	Min	Typ	Max	Unit
IRED CHARACTERISTICS (T_A = 25°C unless otherwise noted)						
Reverse Leakage Current (V_R = 3.0 V, R_L = 1.0 MΩ)		I_R	–	0.05	10	µA
Forward Voltage (I_F = 10 mA)		V_F	–	1.2	1.5	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)		C	–	100	–	pF
ISOLATION CHARACTERISTICS (T_A = 25°C)						
Isolation Voltage (1) 60 Hz, ac Peak		V_{ISO}	7500	–	–	Volts
Isolation Resistance (V = 500 V) (1)		–	–	10^{11}	–	Ohms
Isolation Capacitance (V = 0, f = 1.0 MHz) (1)		–	–	1.3		pF
DEVICE CHARACTERISTICS (T_A = 25°C)						
Supply Current (I_F = 0, V_{CC} = 12 V)		I_{CC}	2.0	6.0	10	mA
Transfer Resistance — Gain I_{sig} = 1.0 mA p-p, I_{Bias} = 12 mA	(V_{CC} = 6.0 V) (V_{CC} = 12 V)	G_R	– 100	100 200	– –	mV/mA
Output Voltage Swing — Single Ended	(V_{CC} = 12 V)	V_O	–	4.0	–	Volts
Single-Ended Distortion (2)		THD	See Figure 2			
Step Response		t	–	1.4	–	µs
DC Power Consumption	(V_{CC} = 6.0 V) (V_{CC} = 12 V)	P	– –	30 72	– –	mW
Bandwidth		BW	100	250	–	kHz
DC Output Voltage (I_{LED} = 0), V_{CE} = 12 V		V_O	0.2	1.0	6.0	Volts

(1) For this test IRED pins 1 and 2 are common and Output Gate pins 4, 5, 6 are common.

(2) Recommended I_F = 10 to 15 mA at V_{CC} = 12 V.

FIGURE 2 — TYPICAL TOTAL HARMONIC DISTORTION



Typical total harmonic distortion @ 25°C (for units with gain of 200 mV/mA at I_{Bias} = 12 mA, V_{CC} = 12 V, f = 50 kHz, Load = [See Insert]).

FIGURE 3 — NORMALIZED FREQUENCY RESPONSE

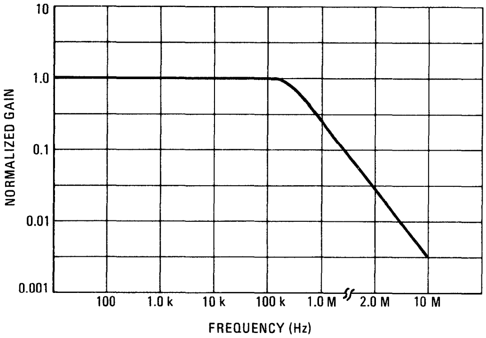
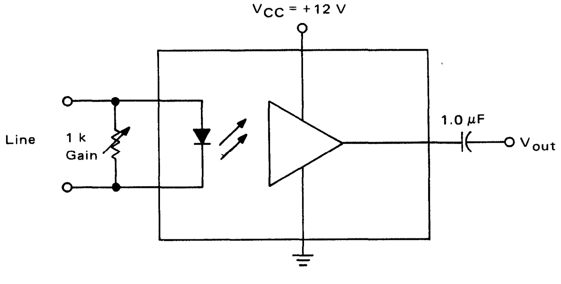


FIGURE 4 — TELEPHONE COUPLER APPLICATION



MOTOROLA

MOC7811 MOC7821
MOC7812 MOC7822
MOC7813 MOC7823

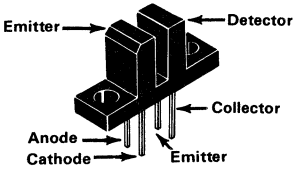
OPTO SLOTTED COUPLER/INTERRUPTER MODULES

These devices consist of a gallium arsenide infrared emitting diode facing a silicon NPN phototransistor in a molded plastic housing. A slot in the housing between the emitter and the detector provides a means of interrupting the signal. They are widely used in position and motion indicators, end of tape indicators, paper feed controls and arcless switches.

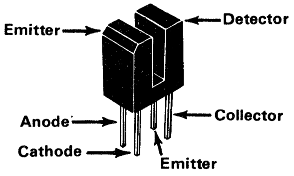
- 1.0 mm Aperture
- Easy PCB Mounting
- Cost Effective
- Industry Standard Configuration
- Uses Long-Lived LPE IRED

OPTO
SLOTTED COUPLER

TRANSISTOR OUTPUT



(MOC7811, 12, 13 only)
CASE 354A-01



(MOC7821, 22, 23 only)
CASE 354-01

ABSOLUTE MAXIMUM RATINGS: (25°C)

Rating	Symbol	Value	Unit
TOTAL DEVICE			
Storage Temperature	T_{stg}	-40 to +100	°C
Operating Temperature	T_J	-40 to +100	°C
Lead Soldering Temperature (5 seconds maximum)	T_L	260	°C
INFRARED EMITTING DIODE			
Power Dissipation	P_D	150*	mW
Forward Current (Continuous)	I_F	50	mA
Reverse Voltage	V_R	6.0	V
PHOTOTRANSISTOR			
Power Dissipation	P_D	150**	mW
Collector-Emitter Voltage	V_{CEO}	30	V

*Derate 2.0 mW/°C above 25°C ambient.
**Derate 2.0 mW/°C above 25° ambient.

INDIVIDUAL ELECTRICAL CHARACTERISTICS: (25°C) (See Note 1)

Characteristic	Symbol	Min	Typ	Max	Unit
EMITTER					
Reverse Breakdown Voltage (I_R = 100 μA)	$V_{(BR)R}$	6.0	—	—	V
Forward Voltage (I_F = 50 mA)	V_F	—	1.3	1.8	V
Reverse Current (V_R = 6.0 V, R_L = 1.0 MΩ)	I_R	—	50	—	nA
Capacitance (V = 0, f = 1 MHz)	C_i	—	25	—	pF
DETECTOR					
Breakdown Voltage (I_C = 10 mA, H ≈ 0)	$V_{(BR)CEO}$	30	—	—	V
Collector Dark Current (V_{CE} = 10 V, H ≈ 0)	I_{CEO}	—	—	100	nA

Note 1: Stray irradiation can alter values of characteristics. Adequate shielding should be provided.

COUPLED ELECTRICAL CHARACTERISTICS: (25°C) (See Note 1)

Characteristics	Symbol	MOC7811/7821			MOC7812/7822			MOC7813/7823			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
I_F = 5.0 mA, V_{CE} = 5.0 V	$I_{CE(on)}$	0.15	—	—	0.30	—	—	0.60	—	—	mA
I_F = 20 mA, V_{CE} = 5.0 V	$I_{CE(on)}$	1.0	—	—	2.0	—	—	4.0	—	—	mA
I_F = 30 mA, V_{CE} = 5.0 V	$I_{CE(on)}$	1.9	—	—	3.0	—	—	5.5	—	—	mA
I_F = 20 mA, I_C = 1.8 mA	$V_{CE(sat)}$	—	—	—	—	—	0.40	—	—	0.40	V
I_F = 30 mA, I_C = 1.8 mA	$V_{CE(sat)}$	—	—	0.40	—	—	—	—	—	—	V
V_{CC} = 5.0 V, I_F = 30 mA, R_L = 2.5 kΩ	t_{on}	—	12	—	—	12	—	—	12	—	μs
V_{CC} = 5.0 V, I_F = 30 mA, R_L = 2.5 kΩ	t_{off}	—	60	—	—	60	—	—	60	—	μs

Note 1: Stray irradiation can alter values of characteristics. Adequate shielding should be provided.

FIGURE 1 — OUTPUT CURRENT versus INPUT CURRENT

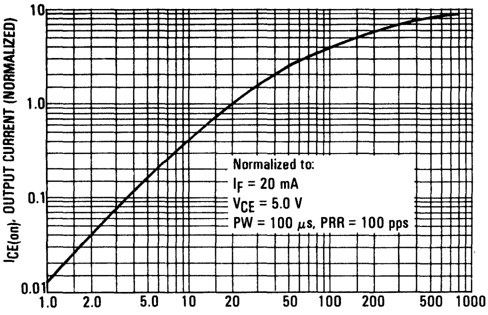


FIGURE 2 — t_{on}, t_{off} versus LOAD RESISTANCE

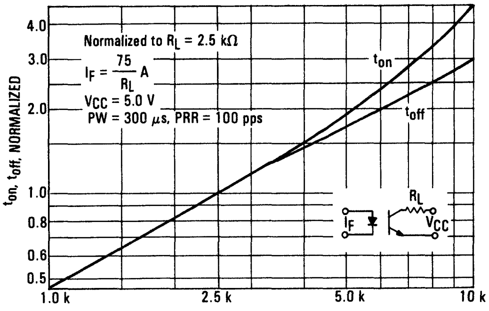
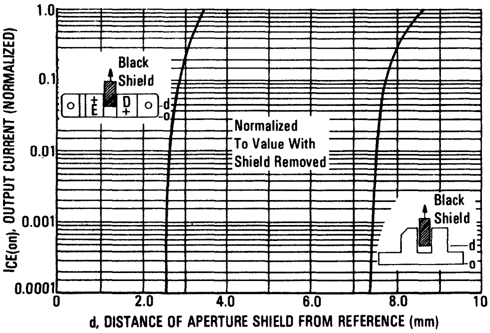
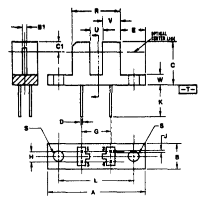


FIGURE 3 — OUTPUT CURRENT versus POSITION OF SHIELD COVERING APERTURE

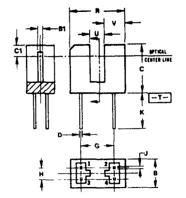




NOTES
1 DIMENSIONS A AND B ARE DATUMS AND T IS A DATUM SURFACE
2 POSITIONAL TOLERANCE FOR MOUNTING HOLES
⌖ | Ø 0.36 (0.014) Ⓜ | T | A Ⓜ | B Ⓜ
3 POSITIONAL TOLERANCE FOR LEAD DIMENSION J
⌖ | 0.13 (0.005) Ⓜ | T | B Ⓜ
4 POSITIONAL TOLERANCE FOR LEAD DIMENSION D
⌖ | 0.13 (0.005) Ⓜ | T | A Ⓜ | B Ⓜ
5 DIMENSIONING AND TOLERANCING PER Y14.5, 1973

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	24.13	25.01	0.950	0.985
B	6.19	6.50	0.244	0.256
C	10.64	10.94	0.419	0.431
D	0.35	0.55	0.014	0.022
E	6.24	6.55	0.246	0.258
G	7.36 BSC		0.290 BSC	
H	2.54 BSC		0.100 BSC	
J	0.43	0.55	0.017	0.022
K	7.36	–	0.290	–
L	19.05 BSC		0.750 BSC	
R	11.98	12.19	0.472	0.480
S	3.24	3.37	0.124	0.133
U	3.07	3.32	0.115	0.129
V	4.36	4.52	0.172	0.178
W	2.38	2.69	0.094	0.106
B1	0.88	1.14	0.035	0.045
C1	2.54 NOM		0.100 NOM	

CASE 354A-01



NOTES
1 DIMENSIONS R AND B ARE DATUMS AND T IS A DATUM SURFACE
2 POSITIONAL TOLERANCE FOR LEAD DIMENSION J
⌖ | 0.13 (0.005) Ⓜ | T | B Ⓜ
3. POSITIONAL TOLERANCE FOR LEAD DIMENSION D
⌖ | 0.13 (0.005) Ⓜ | T | R Ⓜ | B Ⓜ
4 DIMENSIONING AND TOLERANCING ARE PER Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
B	6.19	6.50	0.244	0.256
C	10.64	10.94	0.419	0.431
D	0.35	0.55	0.014	0.022
G	7.36 BSC		0.290 BSC	
H	2.54 BSC		0.100 BSC	
J	0.43	0.55	0.017	0.022
K	7.36	–	0.290	–
R	11.98	12.19	0.472	0.480
U	3.07	3.32	0.115	0.129
V	4.36	4.52	0.172	0.178
W	2.38	2.69	0.094	0.106
B1	0.88	1.14	0.035	0.045
C1	2.54 NOM		0.100 NOM	

CASE 354-01

MOTOROLA

MOC8020
MOC8021

OPTO COUPLER/ISOLATOR

DARLINGTON OUTPUT

HIGH CTR DARLINGTON COUPLERS

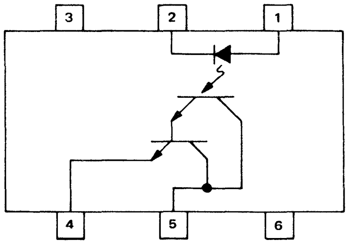
. . . gallium arsenide LED optically coupled to silicon photodarlington transistors designed for applications requiring electrical isolation, high breakdown voltage, and high current transfer ratios. Provides excellent performance in interfacing and coupling systems, phase and feedback controls, solid state relays, and general purpose switching circuits.

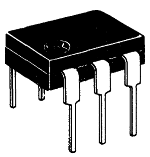
- High Transfer Ratio
  500% — MOC8020 1000% — MOC8021
- High Collector-Emitter Breakdown Voltage— $V_{(BR)CEO}$ = 50 Vdc (Min)
- High Isolation Voltage — V_{ISO} = 7500 Vac Peak
- UL Recognized, File No. E54915
- Economical Dual-In-Line Package
- Base Not Connected

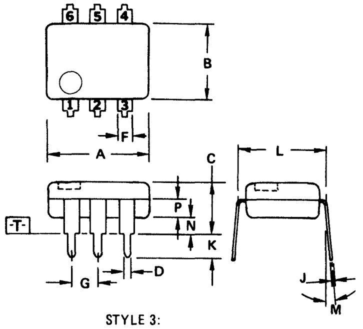
MAXIMUM RATINGS (T_A = 25°C unless otherwise noted.)

Rating	Symbol	Value	Unit
INFRARED-EMITTING DIODE			
Reverse Voltage	V_R	3.0	Volts
Forward Current — Continuous	I_F	50	mA
Forward Current — Peak Pulse Width = 300 μs, 2.0% Duty Cycle	I_F	3.0	Amp
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	150 2.0	mW mW/°C
PHOTO DARLINGTON TRANSISTOR			
Collector-Emitter Voltage	V_{CEO}	50	Volts
Emitter-Collector Voltage	V_{ECO}	5.0	Volts
Collector Current — Continuous	I_C	150	mA
Total Power Dissipation @ T_A = 25°C Negligible Power in Diode Derate above 25°C	P_D	150 2.0	mW mW/°C
TOTAL DEVICE			
Total Device Dissipation @ T_A = 25°C Equal Power Dissipation in Each Element Derate above 25°C	P_D	250 3.3	mW mW/°C
Operating Junction Temperature Range	T_J	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)	—	260	°C

FIGURE 1 — DEVICE SCHEMATIC







STYLE 3:
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. NC

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
   ⌖ | ∅ 0.13 (0.005) Ⓜ | T | A Ⓜ | B Ⓜ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

LED CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Leakage Current (V_R = 3.0 V)	I_R	–	0.005	10	μA
Forward Voltage (I_F = 10 mA)	V_F	–	1.2	2.0	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	–	100	–	pF

PHOTODARLINGTON CHARACTERISTICS (T_A = 25°C and I_F = 0, unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector-Emitter Dark Current (V_{CE} = 10 V)	I_{CEO}	–	8.0	100	nA
Collector-Emitter Breakdown Voltage (I_C = 1.0 mA)	$V_{(BR)CEO}$	50	60	–	Volts
Emitter-Collector Breakdown Voltage (I_E = 100 μA)	$V_{(BR)ECO}$	5.0	8.0	–	Volts

COUPLED CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector Output Current (V_{CE} = 5.0 V, I_F = 10 mA) MOC8020 MOC8021	I_C	50 100	90 150	– –	mA
Isolation Surge Voltage (1, 2), Vac 60 Hz Peak ac, 5 Second	V_{ISO}	7500	–	–	Volts
Isolation Resistance (1) (V = 500 V)	–	–	10^{11}	–	Ohms
Isolation Capacitance (1) (V = 0, f = 1.0 MHz)	–	–	0.8	–	pF

SWITCHING CHARACTERISTICS

Turn-On Time (I_F = 10 mA, V_{CE} = 50 V, R_2 = 100 Ω)	t_{on}	–	13	–	μs
Turn-Off Time (I_F = 10 mA, V_{CE} = 50 V, R_2 = 100 Ω)	t_{off}	–	60	–	μs

(1) For this test LED pins 1 and 2 are common and Photodarlington pins 4 and 5 are common.
(2) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 2 — FORWARD CHARACTERISTICS

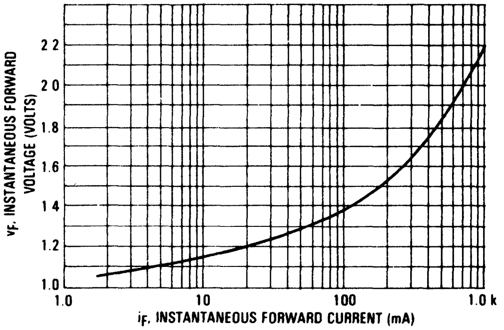
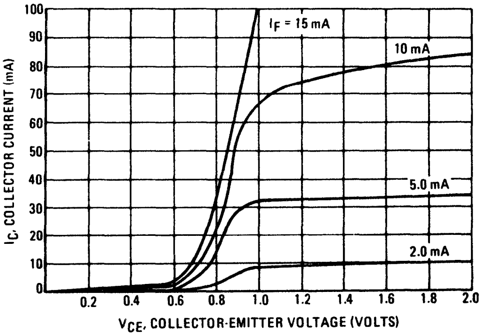


FIGURE 3 — COLLECTOR CURRENT versus COLLECTOR-EMITTER VOLTAGE (MOC8020)



MOTOROLA

MOC8030
MOC8050

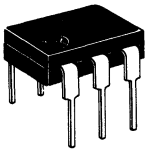
80-VOLT DARLINGTON COUPLERS

. . . gallium arsenide LED optically coupled to silicon photodarlington transistors designed for applications requiring electrical isolation, high-current transfer ratios, small package size and low cost; such as interfacing and coupling systems, phase and feedback controls, solid-state relays and general-purpose switching circuits.

- High Transfer Ratio @ Output = 50 mA —
  300% — MOC8030 500% — MOC8050
- High Collector-Emitter Breakdown Voltage —
  $V_{(BR)CEO}$ = 80 Vdc (Min)
- High Isolation Voltage —
  V_{ISO} = 7500 Vac Peak
- Excellent Stability Over Temperature
- Economical Dual-In-Line Package
- Base Not Connected

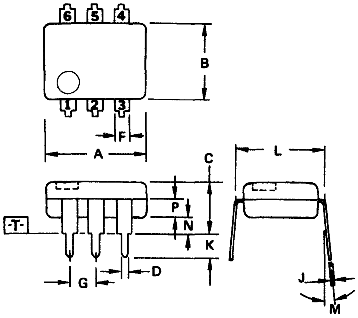
OPTO COUPLER/ISOLATOR

DARLINGTON OUTPUT



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted.)

Rating	Symbol	Value	Unit
INFRARED-EMITTING DIODE			
Reverse Voltage	V_R	3.0	Volts
Forward Current — Continuous	I_F	80	mA
Forward Current — Peak Pulse Width = 300 μs, 2.0% Duty Cycle	I_F	3.0	Amp
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor	P_D	150	mW
Derate above 25°C		2.0	mW/°C
PHOTO DARLINGTON TRANSISTOR			
Collector-Emitter Voltage	V_{CEO}	80	Volts
Emitter-Collector Voltage	V_{ECO}	5.0	Volts
Collector Current — Continuous	I_C	150	mA
Total Power Dissipation @ T_A = 25°C	P_D	150	mW
Negligible Power in Diode Derate above 25°C		2.0	mW/°C
TOTAL DEVICE			
Total Device Dissipation @ T_A = 25°C Equal Power Dissipation in Each Element	P_D	250	mW
Derate above 25°C		3.3	mW/°C
Operating Junction Temperature Range	T_J	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)	—	260	°C



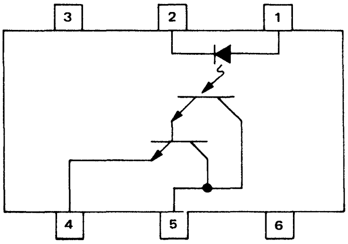
STYLE 3:
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. NC

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⌖ | Ø 0.13 (0.005)Ⓜ | T | AⓂ BⓂ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

FIGURE 1 — DEVICE SCHEMATIC



LED CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Leakage Current (V_R = 3.0 V)	I_R	–	0.005	10	μA
Forward Voltage (I_F = 10 mA)	V_F	–	1.2	2.0	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	–	100	–	pF

PHOTO DARLINGTON CHARACTERISTICS (T_A = 25°C and I_F = 0, unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector-Emitter Dark Current (V_{CE} = 60 V)	I_{CEO}	–	25	1000	nA
Collector-Emitter Breakdown Voltage (I_C = 1.0 mA)	$V_{(BR)CEO}$	80	95	–	Volts
Emitter-Collector Breakdown Voltage (I_E = 100 μA)	$V_{(BR)ECO}$	5.0	8.0	–	Volts

COUPLED CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector Output Current	I_C				mA
(V_{CE} = 1.5 V, I_F = 10 mA) MOC8050		50	100	–	
MOC8030		30	50	–	
Isolation Surge Voltage (1, 2), Vac 60 Hz Peak ac, 5 Second	V_{ISO}	7500	–	–	Volts
Isolation Resistance (1) (V = 500 V)	–	–	10^{11}	–	Ohms
Isolation Capacitance (1) (V = 0, f = 1.0 MHz)	–	–	0.8	–	pF

SWITCHING CHARACTERISTICS

Turn-On Time (I_F = 10 mA, V_{CE} = 50 V, R_2 = 100 Ω)	t_{on}	–	13	–	μs
Turn-Off Time (I_F = 10 mA, V_{CE} = 50 V, R_2 = 100 Ω)	t_{off}	–	60	–	μs

(1) For this test LED pins 1 and 2 are common and Photodarlington pins 4 and 5 are common.
(2) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 2 – FORWARD CHARACTERISTICS

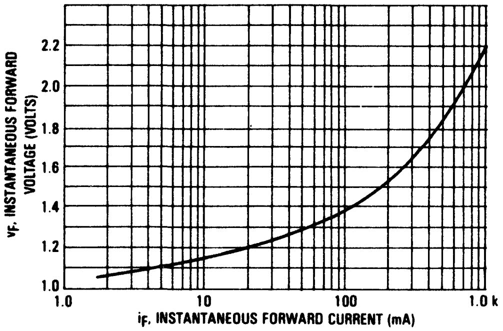
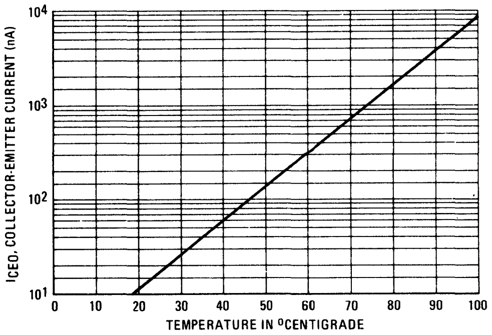


FIGURE 3 – COLLECTOR-EMITTER DARK CURRENT versus TEMPERATURE



TYPICAL ELECTRICAL CHARACTERISTICS

COLLECTOR CURRENT versus COLLECTOR-EMITTER VOLTAGE

FIGURE 4 – MOC8050

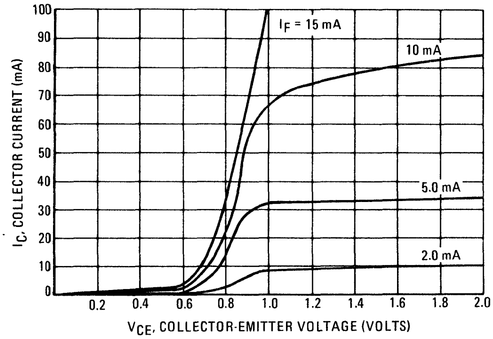
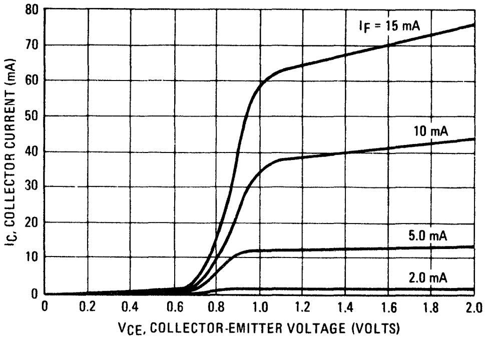


FIGURE 5 – MOC8030



COLLECTOR CURRENT versus COLLECTOR-EMITTER VOLTAGE (at 25° and 70°C)

FIGURE 6 – MOC8050

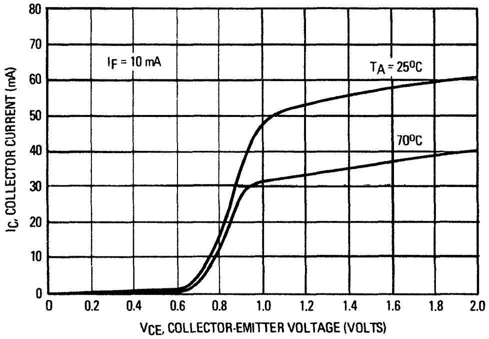
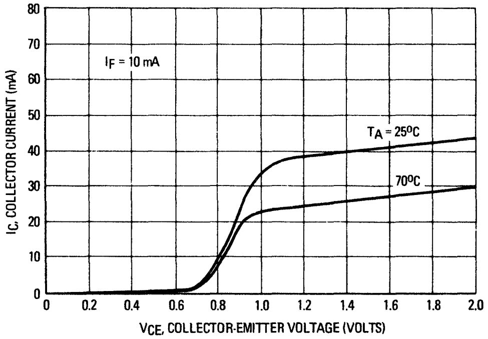


FIGURE 7 – MOC8030



COLLECTOR CURRENT versus DIODE CURRENT

FIGURE 8 – MOC8050

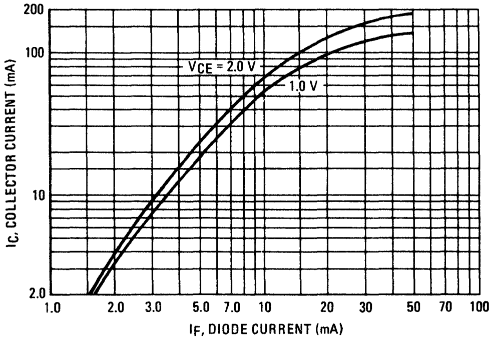
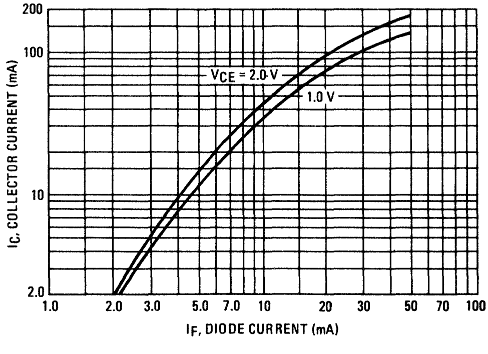
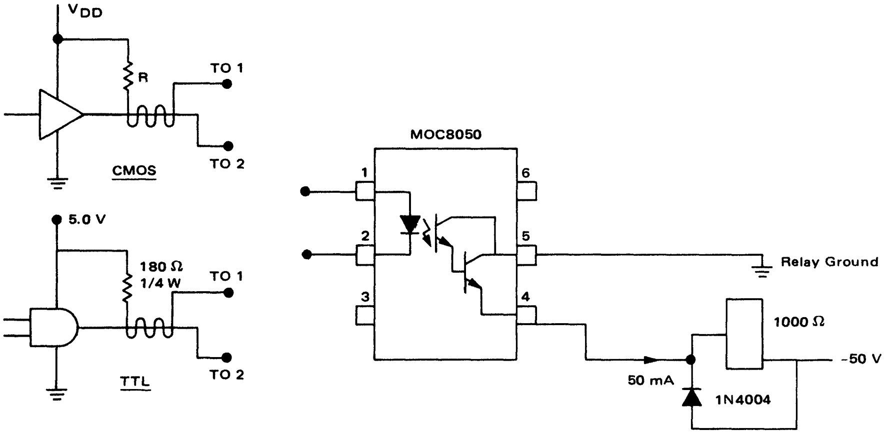


FIGURE 9 – MOC8030



INTERFACING TTL OR CMOS LOGIC TO 50-VOLT, 1000-OHMS RELAY FOR TELEPHONY APPLICATIONS

In order to interface positive logic to negative-powered electromechanical relays, a change in voltage level and polarity plus electrical isolation are required. The MOC8050 can provide this interface and eliminate the external amplifiers and voltage divider networks previously required. The circuit below shows a typical approach for the interface.

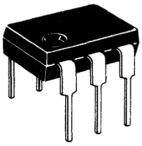


MOTOROLA

MOC8100

OPTO COUPLER/ISOLATOR

TRANSISTOR OUTPUT



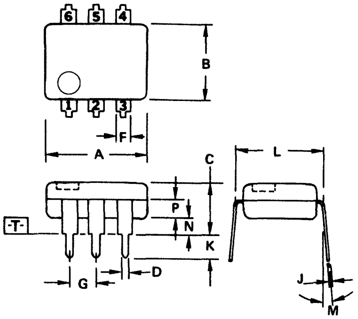
LOW LED DRIVE OPTOCOUPLER WITH TRANSISTOR OUTPUT

. . . gallium-arsenide IRED optically coupled to a silicon phototransistor designed for applications requiring low LED drive current, high electrical isolation, small package size and low cost such as interfacing and coupling systems, phase and feedback controls, solid-state relays and general-purpose switching circuits.

- High Transfer Ratio with Low LED Drive 50% (Min) @ I_F = 1.0 mA, V_{CE} = 5.0 V
- High Electrical Isolation — V_{ISO} = 7500 V (Min)
- Low Collector-Emitter Saturation Voltage — $V_{CE(sat)}$ = 0.5 Vdc (Max) @ I_F = 1.0 mA, I_C = 100 μA
- UL Recognized File Number E54915

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INFRARED-EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	6.0	Volts
Forward Current — Continuous	I_F	60	mA
Forward Current — Peak Pulse Width = 1.0 μs, 2.0% Duty Cycle	I_F	1.2	Amp
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	 100 1.3	 mW mW/°C
PHOTOTRANSISTOR MAXIMUM RATINGS			
Collector-Emitter Voltage	V_{CEO}	30	Volts
Emitter-Base Voltage	V_{EBO}	7.0	Volts
Collector-Base Voltage	V_{CBO}	70	Volts
Output Current — Continuous	I_C	100	mA
Total Power Dissipation @ T_A = 25°C Negligible Power in Diode Derate above 25°C	P_D	 300 4.0	 mW mW/°C
TOTAL DEVICE RATINGS			
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	300 4.0	mW mW/°C
Isolation Voltage, Surge 60 Hz Peak ac, 5 seconds	V_{ISO}	7500	Volts
Junction Temperature Range	T_J	−55 to +100	°C
Storage Temperature Range	T_{stg}	−55 to +150	°C
Soldering Temperature (10 s)	—	260	°C



STYLE 1:
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. BASE

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⊕ | ∅ 0.13 (0.005) Ⓜ | T | A Ⓜ B Ⓜ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

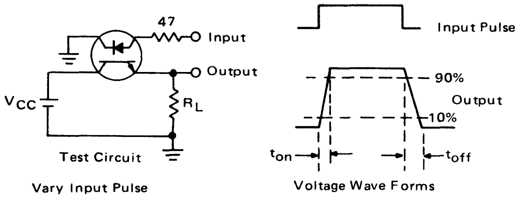
ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
LED CHARACTERISTICS (T_A = 25°C unless otherwise noted)					
Reverse Leakage Current (V_R = 6.0 V)	I_R	—	0.05	10	μA
Forward Voltage (I_F = 1.0 mA, T_A = 0°C to 70°C)	V_F	0.7	1.1	1.4	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	—	150	—	pF
PHOTOTRANSISTOR CHARACTERISTICS (T_A = 25°C and I_F = 0 unless otherwise noted)					
Collector-Emitter Dark Current	I_{CEO}				
(V_{CE} = 5.0 V, Base Open)		—	1.0	25	nA
(V_{CE} = 30 V, Base Open, T_A = 70°C)		—	—	50	μA
Collector-Base Dark Current (V_{CB} = 5.0 V, Emitter Open)	I_{CBO}	—	—	10	nA
Collector-Base Breakdown Voltage (I_C = 100 μA, I_F = 0)	$V_{(BR)CBO}$	70	—	—	Volts
Collector-Emitter Breakdown Voltage (I_C = 1.0 mA, I_B = 0)	$V_{(BR)CEO}$	30	—	—	Volts
Emitter-Base Breakdown Voltage (I_E = 100 μA, I_B = 0)	$V_{(BR)EBO}$	7.0	—	—	Volts
COUPLED CHARACTERISTICS (T_A = 25°C unless otherwise noted)					
Current Transfer Ratio	I_C/I_F				%
(V_{CE} = 5.0 V, I_F = 1.0 mA)		50	—	—	
(V_{CE} = 5.0 V, I_F = 1.0 mA, T_A = 0 to +70°C)		30	—	—	
Isolation Resistance (1) (V = 500 V)	R_{IO}	10^{11}	—	—	Ohms
Isolation Voltage, Surge, 60 Hz pk ac, 5 sec. (1)	V_{ISO}	7500	—	—	Volts
Collector-Emitter Saturation Voltage (I_C = 100 μA, I_F = 1.0 mA)	$V_{CE(sat)}$	—	—	0.5	Volts
Isolation Capacitance (1) (V = 0, f = 1.0 MHz)	—	—	1.3	2.5	pF
SWITCHING CHARACTERISTICS (Figure 1)					
Turn-On Time (V_{CC} = 10 V, I_C = 2.0 mA, R_L = 100 Ω)	t_{on}	—	—	20	μs
Turn-Off Time (V_{CC} = 10 V, I_C = 2.0 mA, R_L = 100 Ω)	t_{off}	—	—	20	μs

NOTES: 1. For this test LED pins 1 and 2 are common and phototransistor pins 4, 5, and 6 are common.

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 1 — SWITCHING TIMES TEST CIRCUIT



Vary Input Pulse
Amplitude for Various
Collector Currents

FIGURE 2 — DIODE FORWARD CHARACTERISTICS

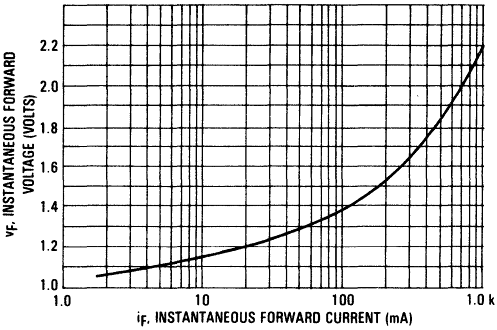


FIGURE 3 — COLLECTOR SATURATION REGION

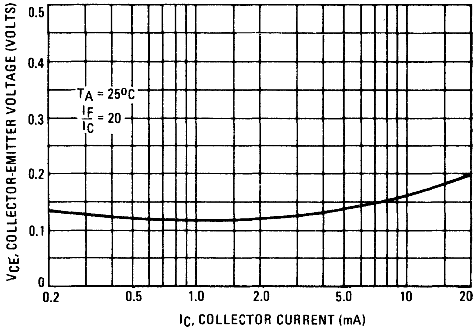


FIGURE 4 — COLLECTOR BASE CURRENT versus INPUT CURRENT

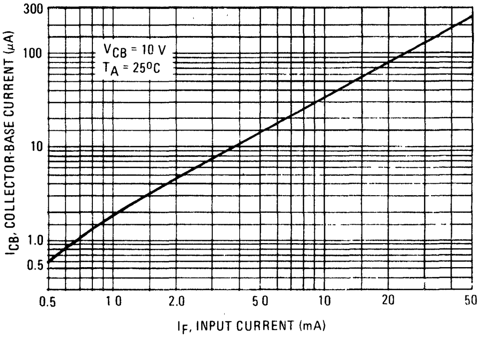


FIGURE 5 — COLLECTOR LEAKAGE CURRENT versus TEMPERATURE

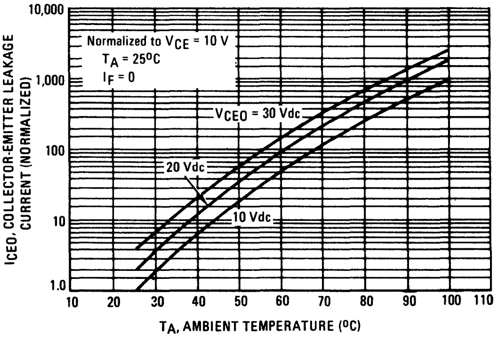
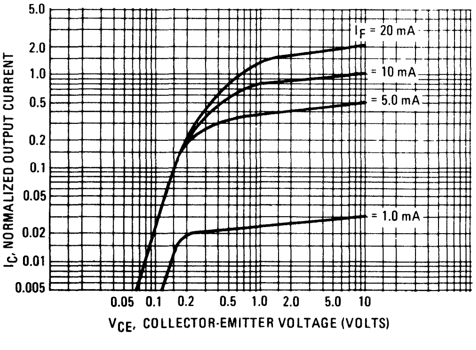


FIGURE 6 — COLLECTOR CHARACTERISTICS



TYPICAL APPLICATIONS

FIGURE 7 — ISOLATED MTTL TO MOS (P-CHANNEL) LEVEL TRANSLATOR

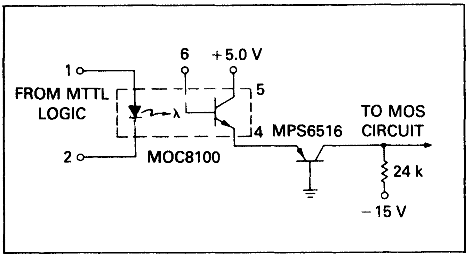


FIGURE 8 — COMPUTER/PERIPHERAL INTERCONNECT

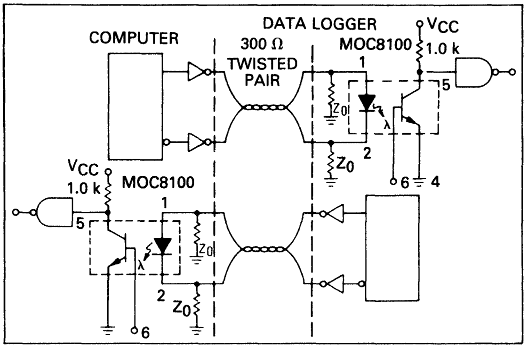


FIGURE 9 — POWER AMPLIFIER

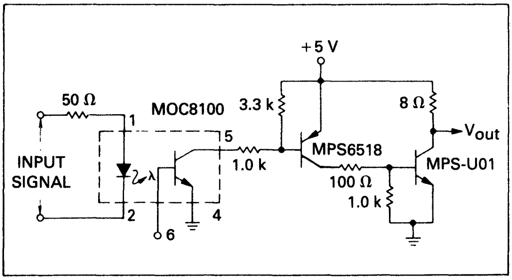
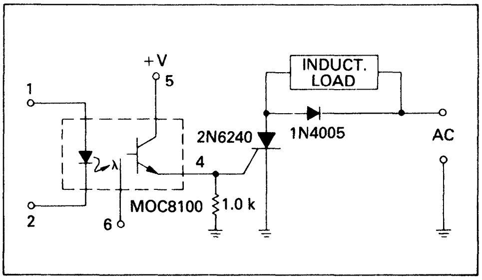


FIGURE 10 — INTERFACE BETWEEN LOGIC AND LOAD



MOTOROLA

MOC8111
MOC8112
MOC8113

TRANSISTOR OUTPUT OPTOCOUPLERS WITH NO BASE CONNECTION

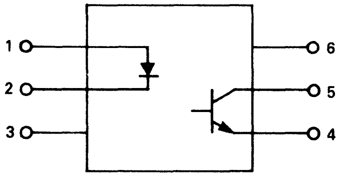
... gallium arsenide LED optically coupled to silicon phototransistors designed for applications requiring improved noise immunity, high electrical isolation, small package size and low cost, such as interfacing and coupling systems, solid-state relays and general-purpose switching circuits.

- High Isolation Voltage — V_{ISO} = 7500 Vac (Min)
- No Base Connection for Better Noise Immunity
- UL Recognized; File Number E54915
- Economical, Compact, Dual-In-Line Package

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

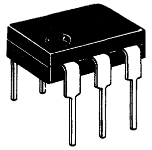
Rating	Symbol	Value	Unit
INFRARED-EMITTING DIODE MAXIMUM RATINGS			
Reverse Voltage	V_R	6.0	Volts
Forward Current — Continuous	I_F	60	mA
Forward Current — Peak (Pulse Width = 1.0 μs, 330 pps)	I_F	1.2	Amp
Total Power Dissipation @ T_A = 25°C	P_D	100	mW
Negligible Power in Transistor Derate above 25°C		1.3	mW/°C
PHOTOTRANSISTOR MAXIMUM RATINGS			
Collector-Emitter Voltage	V_{CEO}	30	Volts
Emitter-Collector Voltage	V_{ECO}	7.0	Volts
Output Current — Continuous	I_C	100	mA
Total Power Dissipation @ T_A = 25°C Negligible Power in Diode Derate above 25°C	P_D	300 4.0	mW mW/°C
TOTAL DEVICE RATINGS			
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	300 4.0	mW mW/°C
Input to Output Isolation Voltage, Surge 60 Hz Peak ac, 5 seconds	V_{ISO}	7500	Vac
Operating Junction Temperature Range	T_J	−55 to +100	°C
Storage Temperature Range	T_{stg}	−55 to +150	°C
Soldering Temperature (10 s)	—	260	°C

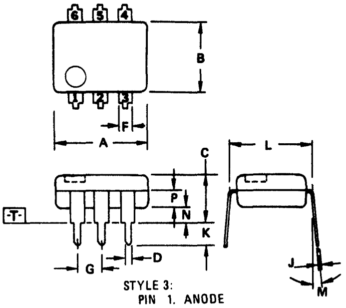
COUPLER SCHEMATIC



OPTO COUPLER/ISOLATOR

TRANSISTOR OUTPUT





STYLE 3:
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. NC

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⌖ | ∅ 0.13 (0.005) Ⓜ | T | A Ⓜ B Ⓜ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

LED CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Leakage Current (V_R = 6.0 V)	I_R	—	0.05	10	μA
Forward Voltage (I_F = 10 mA)	V_F	—	1.2	1.5	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	—	150	—	pF

PHOTOTRANSISTOR CHARACTERISTICS (T_A = 25°C and I_F = 0 unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector-Emitter Dark Current (V_{CE} = 10 V, I_F = 0)	I_{CEO}	—	2.0	50	nA
Collector-Emitter Breakdown Voltage (I_C = 1.0 mA, I_B = 0)	$V_{(BR)CEO}$	30	50	—	Volts
Emitter-Collector Breakdown Voltage (I_E = 100 μA, I_F = 0)	$V_{(BR)ECO}$	7.0	—	—	Volts

COUPLED CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

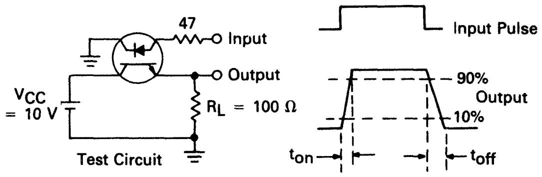
Characteristic	Symbol	Min	Typ	Max	Unit
Current Transfer Ratio	I_C/I_F				%
(V_{CE} = 10 V, I_F = 10 mA) MOC8111		20	50	—	
MOC8112		50	100	—	
MOC8113		100	150	—	
Isolation Surge Voltage (1), 60 Hz ac Peak, 5 Second	V_{ISO}	7500	—	—	Volts
Isolation-Resistance (2) (V = 500 V)	—	—	10^{11}	—	Ohms
Collector-Emitter Saturation Voltage (I_C = 500 μA, I_F = 10 mA)	$V_{CE(sat)}$	—	—	0.4	Volts
Isolation Capacitance (2) (V = 0, f = 1.0 MHz)	—	—	1.0	—	pF

SWITCHING CHARACTERISTICS (Figure 1)

Characteristic	Symbol	Min	Typ	Max	Unit
Turn-On Time (V_{CC} = 10 V, I_C = 2.0 mA, R_L = 100 Ω)	t_{on}	—	7.0	20	μs
Turn-Off Time (V_{CC} = 10 V, I_C = 2.0 mA, R_L = 100 Ω)	t_{off}	—	7.0	20	μs

NOTES: (1) For this test LED Pins 1 and 2 are common and Phototransistor Pins 4 and 5 are common.
(2) Isolation Surge Voltage, V_{ISO}, is an internal device dielectric breakdown rating.

FIGURE 1 — SWITCHING TIMES TEST CIRCUIT



Test Circuit

Voltage Wave Forms

Vary Input Pulse
Amplitude for
Collector Current
of 2.0 mA

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 2 — FORWARD CHARACTERISTICS

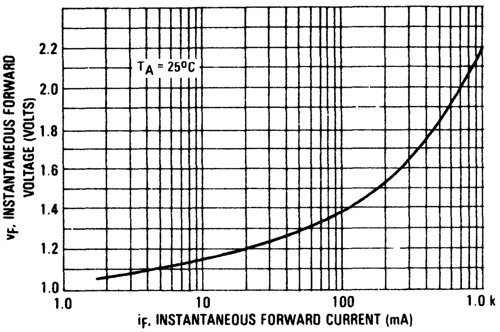


FIGURE 3 — COLLECTOR SATURATION REGION

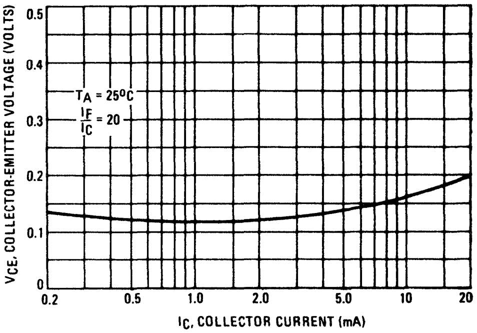


FIGURE 4 — COLLECTOR LEAKAGE CURRENT versus TEMPERATURE

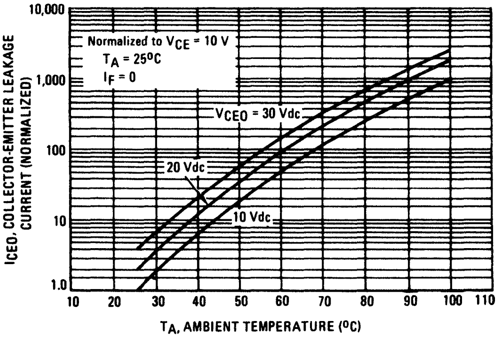
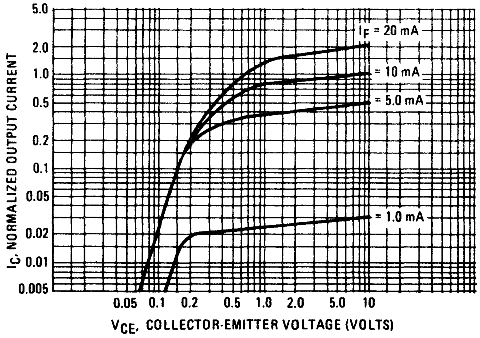


FIGURE 5 — COLLECTOR CHARACTERISTICS



TYPICAL APPLICATIONS

FIGURE 6 — ISOLATED MTTL TO MOS (P-CHANNEL) LEVEL TRANSLATOR

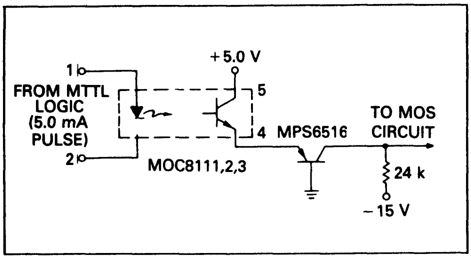


FIGURE 7 — COMPUTER/PERIPHERAL INTERCONNECT

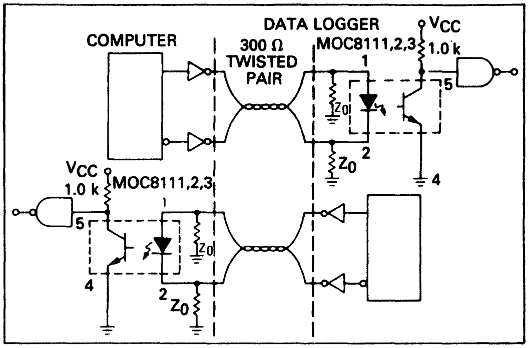


FIGURE 8 — POWER AMPLIFIR

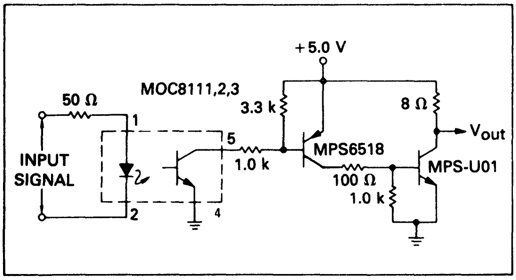
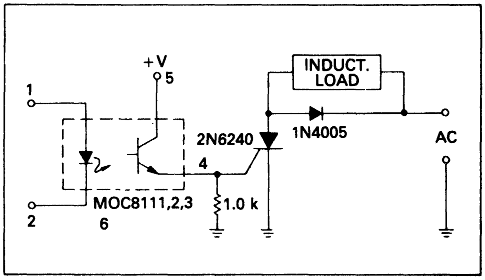


FIGURE 9 — INTERFACE BETWEEN LOGIC AND LOAD



MOTOROLA

MOC8204
MOC8205
MOC8206

HIGH VOLTAGE TRANSISTOR OPTOCOUPLERS

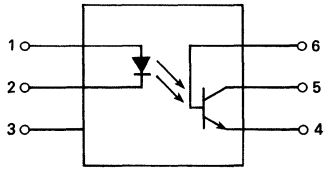
. . . consists of gallium-arsenide infrared-emitting diodes optically coupled to high voltage, silicon, phototransistor detectors in a standard 6-pin DIP package. They are designed for applications requiring high voltage output and are particularly useful in copy machines and solid state relays.

- High Voltage — 400 V
- High Isolation Voltage — V_{ISO} = 7500 Vac pk (Min)
- Standard 6-Pin DIP Package
- UL Recognized, File Number E54915

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted).

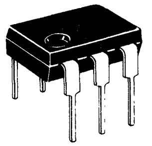
Rating	Symbol	Value	Unit
INFRARED-EMITTING DIODES MAXIMUM RATINGS			
Input Current — Continuous (RMS)	I_F	60	mA
Input Current — Peak Pulse Width = 1.0 μs, 330 pps	I_F	1.2	Amp
Total Power Dissipation @ T_A = 25°C Negligible Power in Transistor Derate above 25°C	P_D	100 1.33	mW mW/°C
PHOTOTRANSISTOR MAXIMUM RATINGS			
Collector-Emitter Voltage	V_{CER}	400	Volts
Emitter-Collector Voltage	V_{ECO}	7.0	Volts
Collector-Base Voltage	V_{CBO}	400	Volts
Collector Current (Continuous)	I_C	100	mA
Total Device Dissipation @ T_A = 25°C Negligible Power in Diode Derate above 25°C	P_D	300 4.0	mW mW/°C
TOTAL DEVICE RATINGS			
Total Device Dissipation @ T_A = 25°C Equal Power Dissipation in Each Element Derate above 25°C	P_D	300 4.0	mW mW/°C
Operating Temperature Range	T_J	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Soldering Temperature (10 s)		260	°C
Surge Isolation Voltage (Input to Output)	V_{ISO}	7500	Vac(pk)

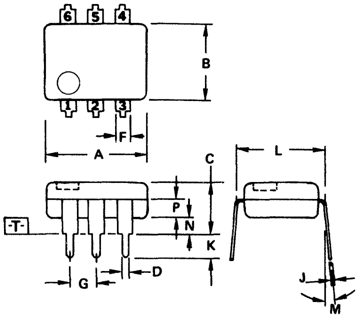
COUPLER SCHEMATIC



OPTO
COUPLER/ISOLATOR

TRANSISTOR OUTPUT
400 VOLT





STYLE 1:
PIN 1. ANODE
2. CATHODE
3. NC
4. EMITTER
5. COLLECTOR
6. BASE

NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
⌖ | ∅ 0.13 (0.005)Ⓜ | T | AⓂ BⓂ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
LED CHARACTERISTICS (T_A = 25°C unless otherwise noted)					
Reverse Leakage Current (V_R = 6.0 V)	I_R	—	—	10	μA
Forward Voltage (I_F = 10 mA)	V_F	—	1.2	1.5	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	—	50	—	pF
PHOTOTRANSISTOR CHARACTERISTICS (T_A = 25°C and I_F = 0 unless otherwise noted)					
Collector-Emitter Dark Current (R_{BE} = 1.0 MΩ) (V_{CE} = 300 V) TA = 25°C TA = 100°C	I_{CER}	— —	— —	100 250	nA μA
Collector-Base Breakdown Voltage (I_C = 100 μA)	$V_{(BR)CBO}$	400	—	—	Volts
Collector-Emitter Breakdown Voltage (I_C = 1.0 mA, R_{BE} = 1.0 MΩ)	$V_{(BR)CER}$	400	—	—	Volts
Emitter-Base Breakdown Voltage (I_E = 100 μA)	$V_{(BR)EBO}$	7.0	—	—	Volts
COUPLED CHARACTERISTICS (T_A = 25°C unless otherwise noted)					
Current Transfer Ratio (V_{CE} = 10 V, I_F = 10 mA, R_{BE} = 1.0 MΩ) MOC8204 MOC8205 MOC8206	CTR	20 10 5.0	— — —	— — —	%
Surge Isolation Voltage (Input to Output)(1) Peak ac Voltage, 60 Hz, 5 sec	V_{ISO}	7500	—	—	Volts
Isolation Resistance (1) (V = 500 V)	R_{IO}	—	10^{11}	—	Ohms
Collector-Emitter Saturation Voltage (I_C = 0.5 mA, I_F = 10 mA, R_{BE} = 1.0 MΩ)	$V_{CE(sat)}$	—	—	0.4	Volts
Isolation Capacitance (1) (V = 0, f = 1.0 MHz)	C_{IO}	—	2.0	—	pF
SWITCHING CHARACTERISTICS (T_A = 25°C)					
Turn-On Time — V_{CC} = 10 V, I_C = 2.0 mA, R_L = 100 Ω	t_{on}	—	5.0	—	μs
Turn-Off Time — V_{CC} = 10 V, I_C = 2.0 mA, R_L = 100 Ω	t_{off}	—	5.0	—	μs

NOTES: 1. For this test LED Pins 1 and 2 are common and phototransistor Pins 4, 5, and 6 are common.

FIGURE 1 — OUTPUT CURRENT versus LED INPUT CURRENT

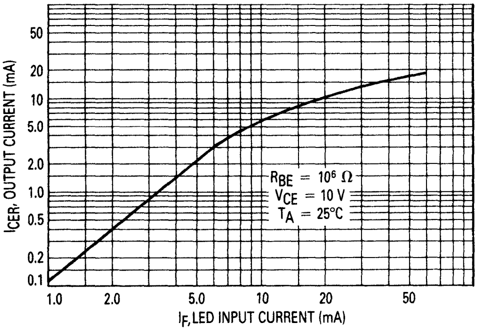


FIGURE 2 — OUTPUT CURRENT versus TEMPERATURE

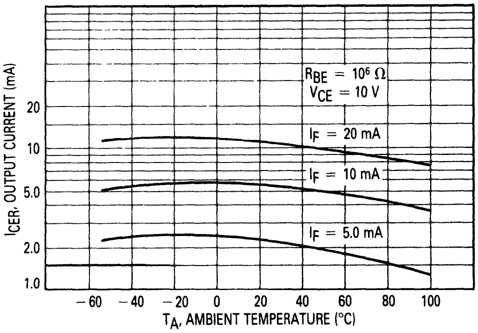


FIGURE 3 — OUTPUT CHARACTERISTICS

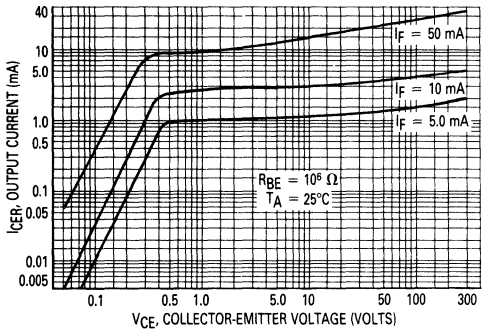


FIGURE 4 — FORWARD CHARACTERISTICS

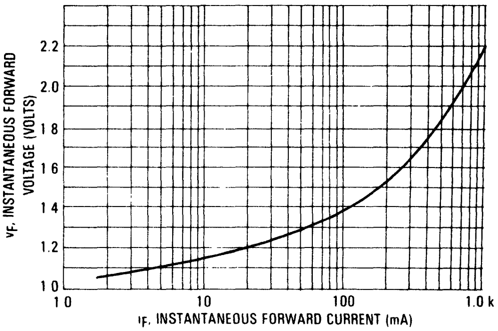


FIGURE 5 — COLLECTOR-BASE CURRENT versus TEMPERATURE

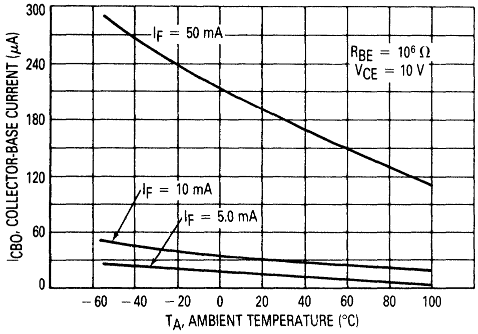
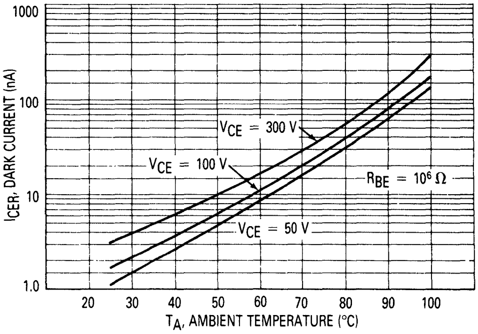


FIGURE 6 — DARK CURRENT versus TEMPERATURE

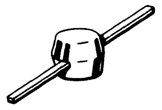


MOTOROLA

MRD150

40 VOLT
MICRO-T
PHOTOTRANSISTOR
NPN SILICON

50 MILLIWATTS



PLASTIC NPN SILICON PHOTOTRANSISTOR

. . . designed for application in punched card and tape readers, pattern and character recognition equipment, shaft encoders, industrial inspection processing and control, counters, sorters, switching and logic circuits, or any design requiring radiation sensitivity, stable characteristics and high-density mounting.

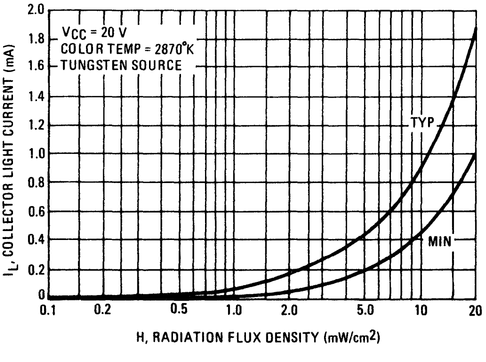
- Economical Plastic Package
- Sensitive Throughout Visible and Near Infrared Spectral Range for Wide Application
- Small Size for High-Density Mounting
- High Light Current Sensitivity (0.20 mA) for Design Flexibility
- Annular Passivated Structure for Stability and Reliability

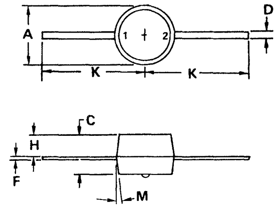
MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	40	Volts
Emitter-Collector Voltage	V_{ECO}	6.0	Volts
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	50 0.67	mW mW/°C
Operating and Storage Junction Temperature Range	T_J(1),T_{stg}	-40 to +100	°C

(1) Heat Sink should be applied to leads during soldering to prevent Case Temperature from exceeding 85°C.

FIGURE 1 – COLLECTOR-EMITTER SENSITIVITY





STYLE 1:
PIN 1. EMITTER
2. COLLECTOR

NOTE:
1. INDEX BUTTON ON PACKAGE BOTTOM IS 0.25/0.51 mm (0.010/0.020) DIA & 0.05/0.13 mm (0.002/0.005) OFF SURFACE.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	1.98	2.34	0.078	0.092
C	1.22	1.47	0.048	0.058
D	0.25	0.41	0.010	0.016
F	0.10	0.15	0.004	0.006
H	0.51	0.76	0.020	0.030
K	4.06	–	0.160	–
M	3°	7°	3°	7°

CASE 173-01

STATIC ELECTRICAL CHARACTERISTICS (T_A = 25°C unless noted)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Units
Collector Dark Current (V_{CC} = 20 V; Base Open) (Note 2) T_A = 25°C T_A = 85°C	–	I_{CEO}	 – –	 – 5.0	 0.10 –	μA
Collector-Emitter Breakdown Voltage (I_C = 100 μA; Base Open; Note 2)	–	$V_{(BR)CEO}$	40	–	–	Volts
Emitter-Collector Breakdown Voltage (I_E = 100 μA; Base Open; Note 2)	–	$V_{(BR)ECO}$	6.0	–	–	Volts

OPTICAL CHARACTERISTICS (T_A = 25°C unless noted)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Units
Collector Light Current (V_{CC} = 20 V; R_L = 100 ohms; Base Open) (Note 1)	1	I_L	0.20	0.45	–	mA
Photo Current Rise Time (Note 3)	2 and 3	t_r	–	2.5	–	μs
Photo Current Fall Time (Note 3)	2 and 3	t_f	–	4.0	–	μs
Wavelength of Maximum Sensitivity	9	$\lambda_{s(typ)}$	–	0.8	–	μm

NOTES:

1. Radiation Flux Density (H) equal to 5.0 mW/cm^2 emitted from a tungsten source at a color temperature of 2870°K.
2. Measured under dark conditions. ($H \approx 0$).
3. For unsaturated response time measurements, radiation is provided by a pulsed GaAs (gallium-arsenide) light-emitting diode (λ = 0.9 μm) with a pulse width equal to or greater than 10 microseconds (see Figure 2 and Figure 3).

FIGURE 2 – PULSE RESPONSE TEST CIRCUIT

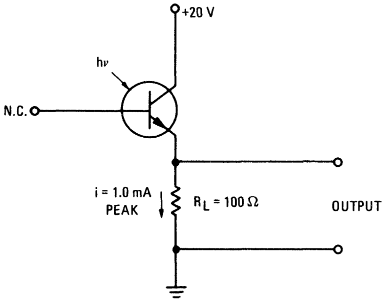
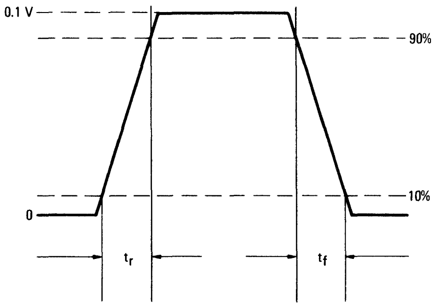


FIGURE 3 – PULSE RESPONSE TEST WAVEFORM



TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 4 – COLLECTOR-EMITTER CHARACTERISTICS

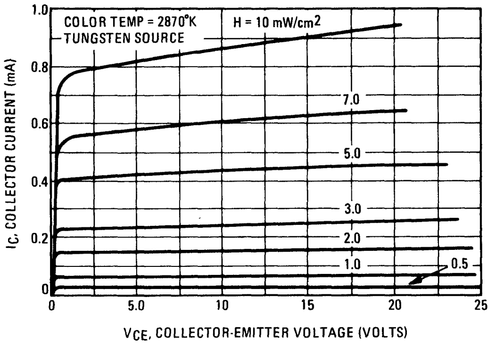


FIGURE 5 – COLLECTOR SATURATION CHARACTERISTICS

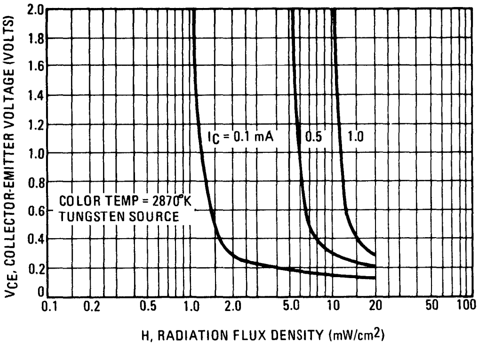


FIGURE 6 – DARK CURRENT versus TEMPERATURE

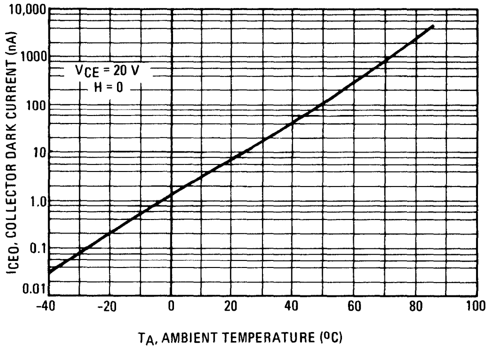


FIGURE 7 – DARK CURRENT versus VOLTAGE

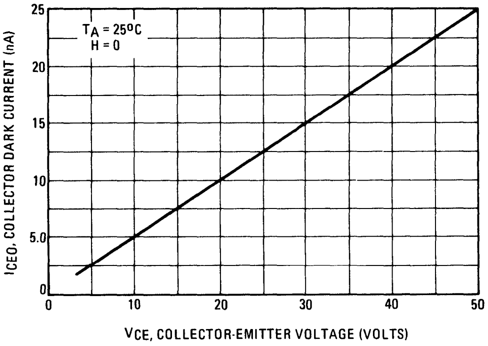


FIGURE 8 – ANGULAR RESPONSE

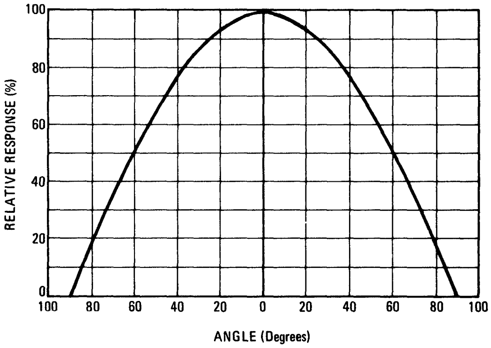
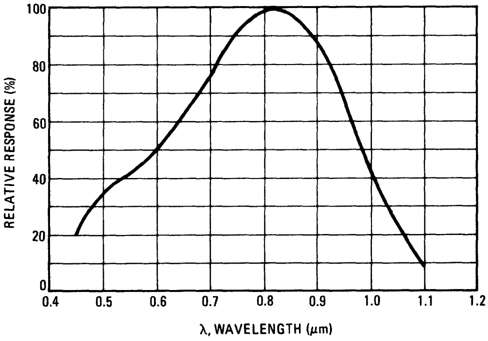


FIGURE 9 – CONSTANT ENERGY SPECTRAL RESPONSE



MOTOROLA

MRD300
MRD310

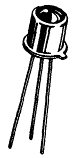
50 VOLT PHOTOTRANSISTOR NPN SILICON

250 MILLIWATTS

NPN SILICON HIGH SENSITIVITY PHOTOTRANSISTORS

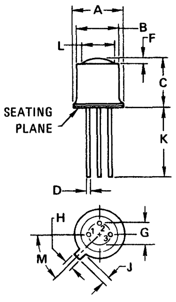
. . . designed for application in industrial inspection, processing and control, counters, sorters, switching and logic circuits or any design requiring radiation sensitivity, and stable characteristics.

- Popular TO-18 Type Package for Easy Handling and Mounting
- Sensitive Throughout Visible and Near Infrared Spectral Range for Wider Application
- Minimum Light Current 4 mA at H = 5 mW/cm$_2$ (MRD300)
- External Base for Added Control
- Annular Passivated Structure for Stability and Reliability



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating (Note 1)	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	50	Volts
Emitter-Collector Voltage	V_{ECO}	7.0	Volts
Collector-Base Voltage	V_{CBO}	80	Volts
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	250 1.43	mW mW/°C
Operating Junction and Storage Temperature Range	T_J, T_{stg}	-65 to +200	°C



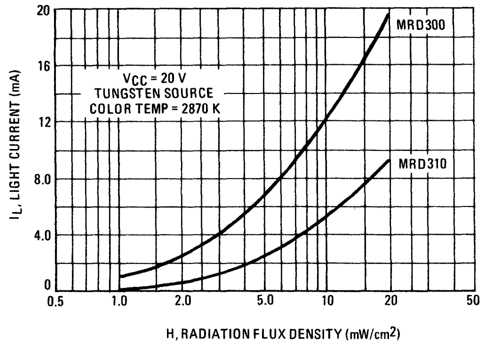
STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

NOTES:
1. LEADS WITHIN .13 mm (.005) RADIUS OF TRUE POSITION AT SEATING PLANE, AT MAXIMUM MATERIAL CONDITION.
2. PIN 3 INTERNALLY CONNECTED TO CASE.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.52	4.95	0.178	0.195
C	4.57	6.48	0.180	0.255
D	0.41	0.48	0.016	0.019
F	–	1.14	–	0.045
G	2.54 BSC		0.100 BSC	
H	0.99	1.17	0.039	0.046
J	0.84	1.22	0.033	0.048
K	12.70	–	0.500	–
L	3.35	4.01	0.132	0.158
M	45° BSC		45° BSC	

CASE 82-05

FIGURE 1 – LIGHT CURRENT versus IRRADIANCE



STATIC ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector Dark Current	I_{CEO}				
(V_{CC} = 20 V, H≈0) T_A = 25°C		–	5.0	25	na
T_A = 100°C		–	4.0	–	μA
Collector-Base Breakdown Voltage (I_C = 100 μA)	$V_{(BR)CBO}$	80	120	–	Volts
Collector-Emitter Breakdown Voltage (I_C = 100 μA)	$V_{(BR)CEO}$	50	85	–	Volts
Emitter-Collector Breakdown Voltage (I_E = 100 μA)	$V_{(BR)ECO}$	7.0	8.5	–	Volts

OPTICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Device Type	Symbol	Min	Typ	Max	Unit
Light Current (V_{CC} = 20 V, R_L = 100 ohms) Note 1	MRD300	I_L	4.0	8.0	–	mA
	MRD310		1.0	3.5	–	
Light Current (V_{CC} = 20 V, R_L = 100 ohms) Note 2	MRD300	I_L	–	2.5	–	mA
	MRD310		–	0.8	–	
Photo Current Rise Time (Note 3) (R_L = 100 ohms I_L = 1.0 mA peak)		t_r	–	2.0	2.5	μs
Photo Current Fall Time (Note 3) (R_L = 100 ohms I_L = 1.0 mA peak)		t_f	–	2.5	4.0	μs

NOTES:

1. Radiation flux density (H) equal to 5.0 mW/cm^2 emitted from a tungsten source at a color temperature of 2870 K.
2. Radiation flux density (H) equal to 0.5 mW/cm^2 (pulsed) from a GaAs (gallium-arsenide) source at λ≈0.9 μm.
3. For unsaturated response time measurements, radiation is provided by pulsed GaAs (gallium-arsenide) light-emitting diode (λ ≈ 0.9 μm) with a pulse width equal to or greater than 10 microseconds (see Figure 6) I_L = 1.0 mA peak.

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 2 – COLLECTOR-EMITTER SATURATION CHARACTERISTIC

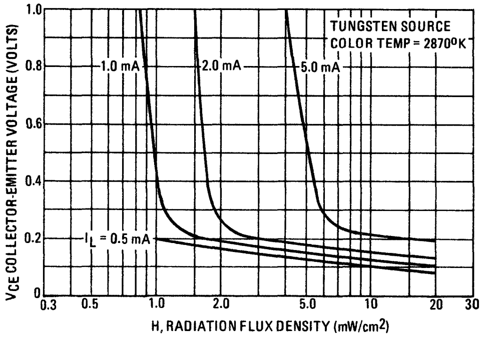


FIGURE 3 – NORMALIZED LIGHT CURRENT versus TEMPERATURE

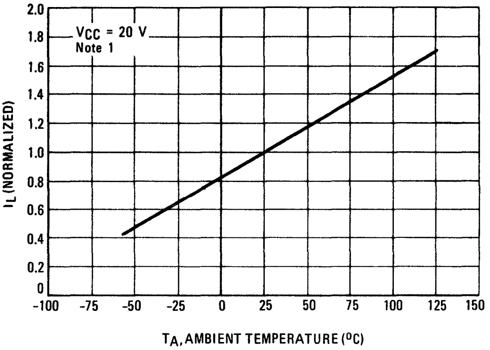


FIGURE 4 – RISE TIME versus LIGHT CURRENT

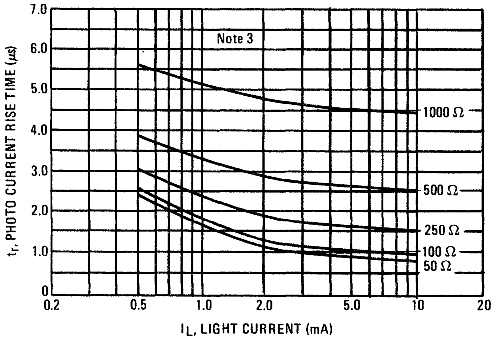


FIGURE 5 – FALL TIME versus LIGHT CURRENT

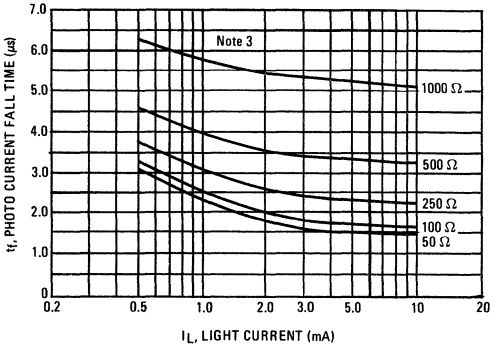


FIGURE 6 – PULSE RESPONSE TEST CIRCUIT AND WAVEFORM

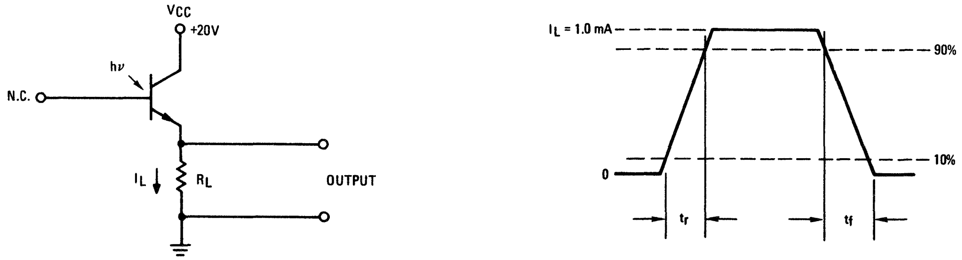


FIGURE 7 — DARK CURRENT versus TEMPERATURE

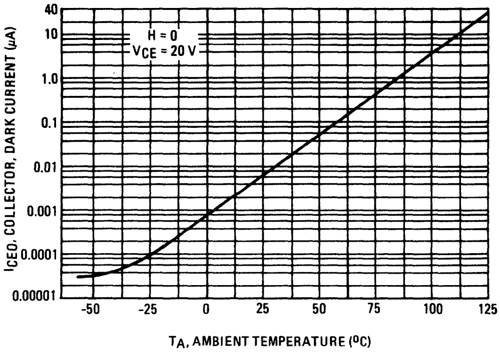


FIGURE 8 — CONSTANT ENERGY SPECTRAL RESPONSE

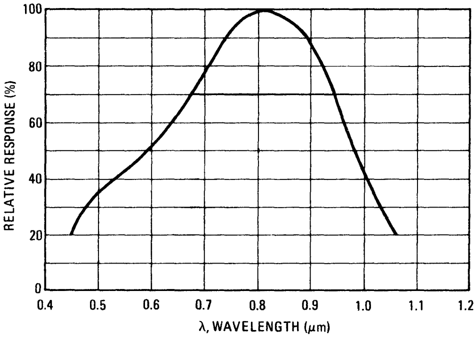
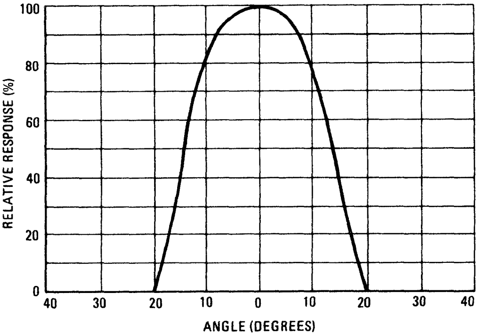


FIGURE 9 — ANGULAR RESPONSE



MOTOROLA

MRD360
MRD370

NPN SILICON HIGH SENSITIVITY PHOTODARLINGTON TRANSISTORS

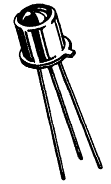
. . . designed for application in industrial inspection, processing and control, counters, softers, switching and logic circuit or any design requiring very high radiation sensitivity at low light levels.

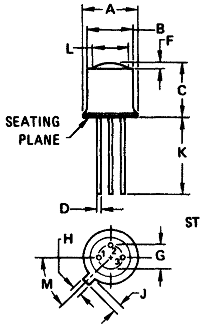
- Popular TO-18 Type Hermetic Package for Easy Handling and Mounting
- Sensitive Throughout Visible and Near Infrared Spectral Range for Wider Application
- Minimum Light Current 12 mA at H = 0.5 mW/cm^2 (MRD360)
- External Base for Added Control
- Switching Times —
  - t_r @ I_L = 1.0 mA peak = 15 μs (Typ) — MRD370
  - t_f @ I_L = 1.0 mA peak = 40 μs (Typ) — MRD370

PHOTODARLINGTON TRANSISTORS NPN SILICON

40 VOLTS

250 MILLIWATTS





STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

NOTES:
1. LEADS WITHIN .13 mm (.005) RADIUS OF TRUE POSITION AT SEATING PLANE, AT MAXIMUM MATERIAL CONDITION.
2. PIN 3 INTERNALLY CONNECTED TO CASE.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.52	4.95	0.178	0.195
C	4.57	6.48	0.180	0.255
D	0.41	0.48	0.016	0.019
F	–	1.14	–	0.045
G	2.54 BSC		0.100 BSC	
H	0.99	1.17	0.039	0.046
J	0.84	1.22	0.033	0.048
K	12.70	–	0.500	–
L	3.35	4.01	0.132	0.158
M	45° BSC		45° BSC	

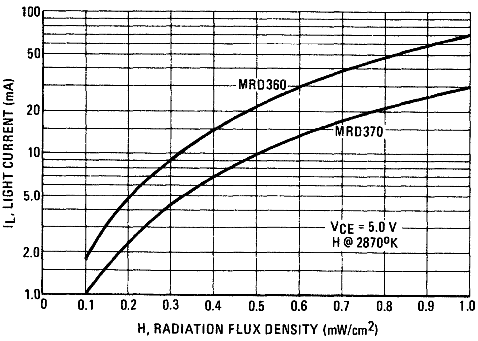
CASE 82-05

TO-18 Type

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted).

Rating (Note 1)	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	40	Volts
Emitter-Base Voltage	V_{EBO}	10	Volts
Collector-Base Voltage	V_{CBO}	50	Volts
Light Current	I_L	250	mA
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	250 1.43	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +200	°C

FIGURE 1 – LIGHT CURRENT versus IRRADIANCE



STATIC ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector Dark Current (V_{CE} = 10 V, H ≈ 0) T_A = 25°C	I_{CEO}	–	10	100	nA
Collector-Base Breakdown Voltage (I_C = 100 μA)	$V_{(BR)CBO}$	50	100	–	Volts
Collector-Emitter Breakdown Voltage (I_C = 100 μA)	$V_{(BR)CEO}$	40	80	–	Volts
Emitter-Base Breakdown Voltage (I_E = 100 μA)	$V_{(BR)EBO}$	10	15.5	–	Volts

OPTICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic	Device Type	Symbol	Min	Typ	Max	Unit
Light Current V_{CC} = 5.0 V, R_L = 10 Ohms (Note 1)	 MRD360 MRD370	I_L	 12 3.0	 20 10	 – –	mA
Collector-Emitter Saturation Voltage (I_L = 10 mA, H = 2 mW/cm^2 at 2870°K)		$V_{CE(sat)}$	–	0.6	1.0	Volts
Photo Current Rise Time (Note 2) (R_L = 100 ohms I_L = 1.0 mA peak)	MRD360 MRD370	t_r	– –	15 15	100 100	μs
Photo Current Fall Time (Note 2) (R_L = 100 ohms I_L = 1.0 mA peak)	MRD360 MRD370	t_f	– –	65 40	150 150	μs

NOTES:

1. Radiation flux density (H) equal to 0.5 mW/cm^2 emitted from a tungsten source at a color temperature of 2780°K.
2. For unsaturated response time measurements, radiation is provided by pulsed GaAs (gallium-arsenide) light-emitting diode (λ ≈ 0.9 μm) with a pulse width equal to or greater than 500 microseconds (see Figure 6) I_L = 1.0 mA peak.

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 2 – COLLECTOR-EMITTER SATURATION CHARACTERISTIC

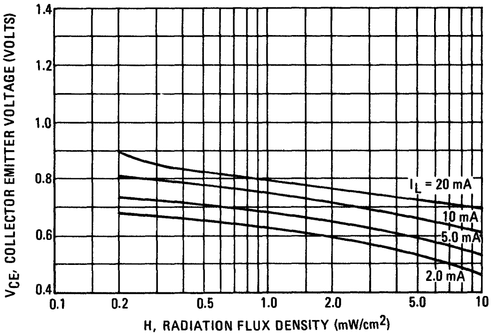


FIGURE 3 – COLLECTOR CHARACTERISTICS

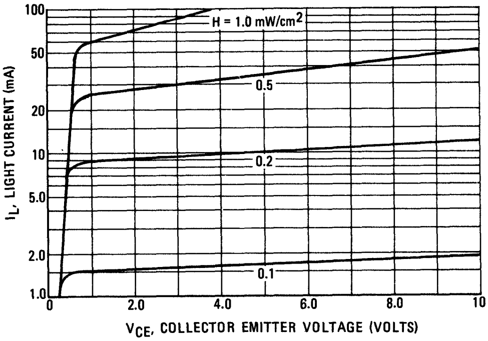


FIGURE 4 – NORMALIZED LIGHT CURRENT versus TEMPERATURE

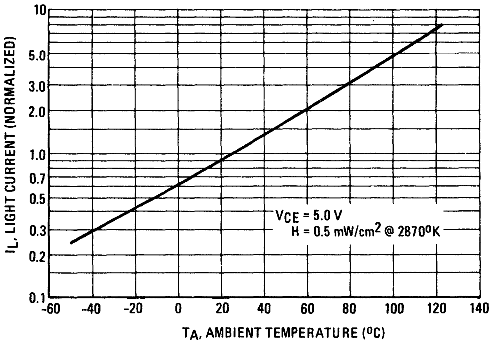


FIGURE 5 – DARK CURRENT versus TEMPERATURE

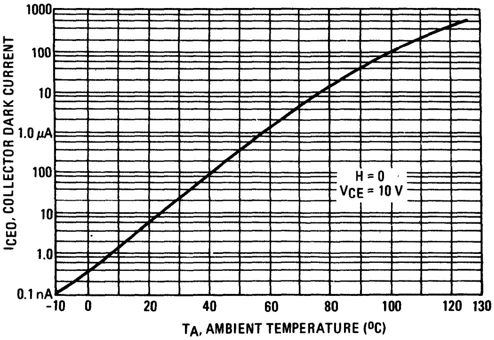


FIGURE 6 – PULSE RESPONSE TEST CIRCUIT AND WAVEFORM

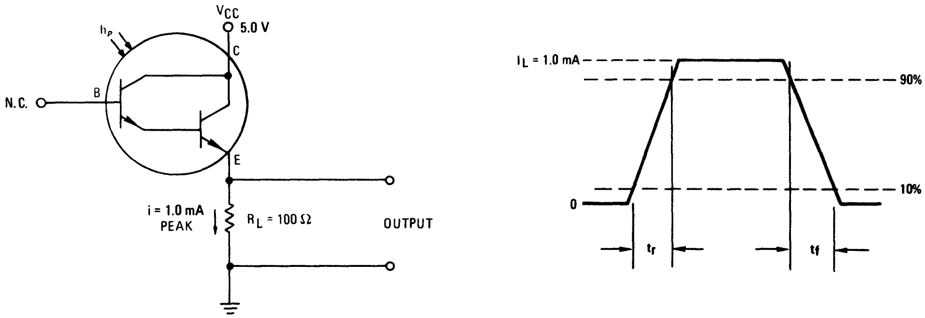


FIGURE 7 – CONSTANT ENERGY SPECTRAL RESPONSE

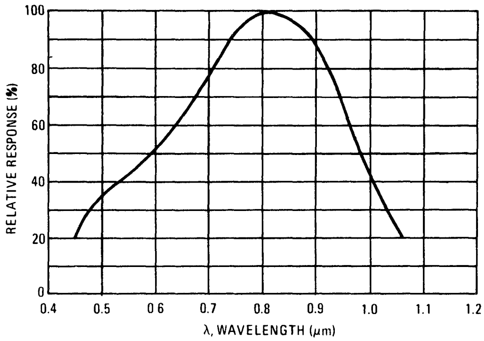
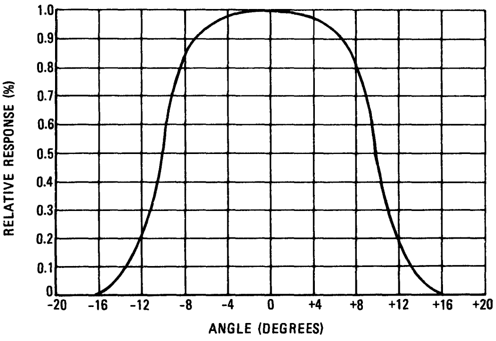


FIGURE 8 – ANGULAR RESPONSE



MOTOROLA

MRD500
MRD510

PIN SILICON PHOTO DIODES

. . . designed for application in laser detection, light demodulation, detection of visible and near infrared light-emitting diodes, shaft or position encoders, switching and logic circuits, or any design requiring radiation sensitivity, ultra high-speed, and stable characteristics.

- Ultra Fast Response – (<1.0 ns Typ)
- High Sensitivity – MRD500 (1.2 μA/mW/cm^2 Min)
  MRD510 (0.3 μA/mW/cm^2 Min)
- Available With Convex Lens (MRD500) or Flat Glass (MRD510) for Design Flexibility
- Popular TO-18 Type Package for Easy Handling and Mounting
- Sensitive Throughout Visible and Near Infrared Spectral Range for Wide Application
- Annular Passivated Structure for Stability and Reliability

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Reverse Voltage	V_R	100	Volts
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	100 0.57	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +200	°C

FIGURE 1 – TYPICAL OPERATING CIRCUIT

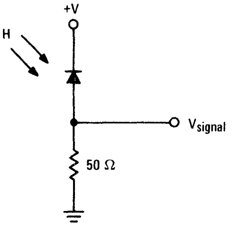
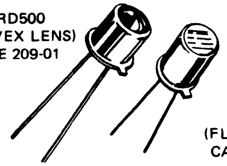
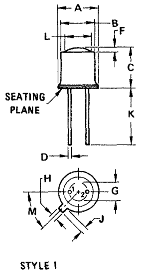


PHOTO DIODES
PIN SILICON

100 VOLTS

100 MILLIWATTS



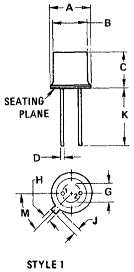


NOTES:
1. PIN 2 INTERNALLY CONNECTED TO CASE
2. LEADS WITHIN 0.13 mm (0.005) RADIUS OF TRUE POSITION AT SEATING PLANE AT MAXIMUM MATERIAL CONDITION

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.52	4.95	0.178	0.195
C	5.08	6.35	0.200	0.250
D	0.41	0.48	0.016	0.019
F	0.51	1.02	0.020	0.040
G	2.54 BSC		0.100 BSC	
H	0.99	1.17	0.039	0.046
J	0.84	1.22	0.033	0.048
K	12.70	–	0.500	–
L	3.35	4.01	0.132	0.158
M	45° BSC		45° BSC	

STYLE 1
PIN 1 ANODE
PIN 2 CATHODE

CASE 209-01



NOTES:
1. PIN 2 INTERNALLY CONNECTED TO CASE
2. LEADS WITHIN 0 13 (0.005) RADIUS OF TRUE POSITION AT SEATING PLANE AT MAXIMUM MATERIAL CONDITION.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.52	4.95	0.178	0.195
C	4.57	5.33	0.180	0.210
D	0.41	0.48	0.016	0.019
G	2.54 BSC		0.100 BSC	
H	0.99	1.17	0.039	0.046
J	0.84	1.22	0.033	0.048
K	12.70	–	0.500	–
M	45° BSC		45° BSC	

STYLE 1
PIN 1 ANODE
2 CATHODE

CASE 210-01

STATIC ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Unit
Dark Current (V_R = 20 V, R_L = 1.0 megohm; Note 2)		I_D				nA
T_A = 25°C	4 and 5		–	–	2.0	
T_A = 100°C			–	14	–	
Reverse Breakdown Voltage (I_R = 10 μA)	–	$V_{(BR)R}$	100	300	–	Volts
Forward Voltage (I_F = 50 mA)	–	V_F	–	0.82	1.1	Volts
Series Resistance (I_F = 50 mA)	–	R_s	–	1.2	10	ohms
Total Capacitance (V_R = 20 V; f = 1.0 MHz)	6	C_T	–	2.5	4	pF

OPTICAL CHARACTERISTICS (T_A = 25°C)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Unit
Radiation Sensitivity (V_R = 20 V, Note 1)		S_R				μA/mW/cm²
MRD500	2 and 3		1.2	3.0	–	
MRD510			0.3	0.42	–	
Sensitivity at 0.8 μm (V_R = 20 V, Note 3)		$S(\lambda = 0.8\ \mu m)$				μA/mW/cm²
MRD500	–		–	6.6	–	
MRD510	–			1.5	–	
Response Time (V_R = 20 V, R_L = 50 ohms)	– –	$t_{(resp)}$		1.0		ns
Wavelength of Peak Spectral Response	7	λ_s	–	0.8	–	μm

NOTES:

1. **Radiation Flux Density (H) equal to 5.0 mW/cm² emitted from a tungsten source at a color temperature of 2870°K.**
2. **Measured under dark conditions. (H≈0).**
3. **Radiation Flux Density (H) equal to 0.5 mW/cm² at 0.8 μm.**

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 2 – IRRADIATED VOLTAGE – CURRENT CHARACTERISTIC FOR MRD500

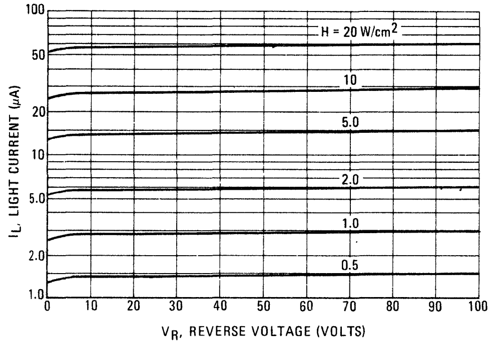


FIGURE 3 – IRRADIATED VOLTAGE – CURRENT CHARACTERISTIC FOR MRD 510

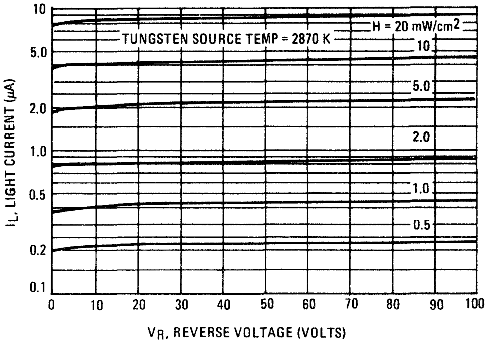


FIGURE 4 – DARK CURRENT versus TEMPERATURE

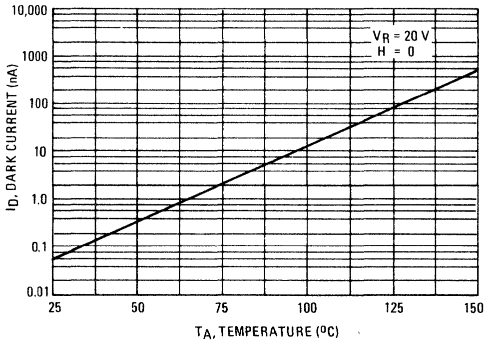


FIGURE 5 – DARK CURRENT versus REVERSE VOLTAGE

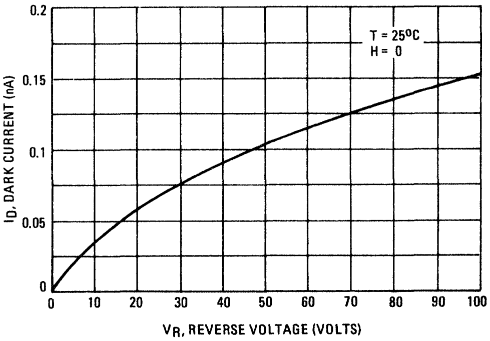


FIGURE 6 – CAPACITANCE versus VOLTAGE

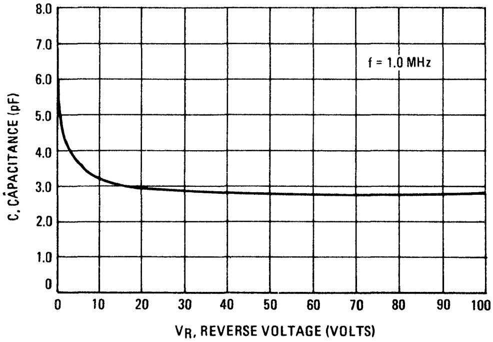
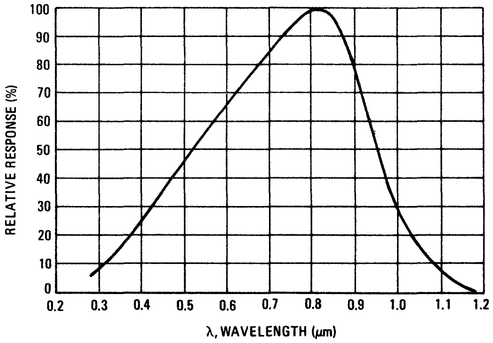


FIGURE 7 – RELATIVE SPECTRAL RESPONSE



MOTOROLA

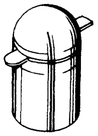
MRD601 MRD611*
MRD602 MRD612*
MRD603 MRD613*
MRD604 MRD614*

NPN SILICON PHOTO DETECTORS

. . . designed for application in card and tape readers, pattern and character recognition, and shaft encoders, or any design requiring radiation sensitivity, stable characteristics, and high-density mounting.

- Low Profile Lens Reduces Optical Cross-Talk
- Pill Package Designed for PC Board Insertion
- Wide Range of Output Currents
- Excellent Match to Tungsten and Gallium-Arsenide Sources
- Sensitive Throughout Visible and Near Infrared Spectral Range for Wider Application
- Rugged Hermetic Package
- Annular Passivated Structure for Stability and Reliability

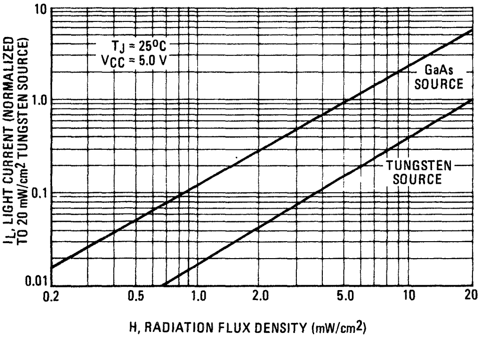
50 VOLT
NPN SILICON
PHOTO DETECTOR
50 MILLIWATTS

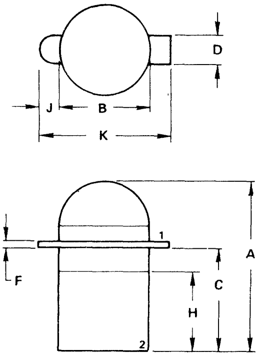


MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	50	Volts
Emitter-Collector Voltage	V_{ECO}	7.0	Volts
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	 50 0.5	 mW mW/°C
Operating Junction Temperature Range	T_J	-65 to +125	°C
Storage Temperature Range	T_{stg}	-65 to +150	°C
Soldering Temperature (10 s)		240	°C

FIGURE 1 – NORMALIZED LIGHT CURRENT versus RADIATION FLUX DENSITY





STYLE 1:
TERM 1. EMITTER
2 COLLECTOR

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	2.59	3.18	0.102	0.125
B	1 47	1.55	0.058	0.061
C	2.08	2.24	0.082	0.088
D	0.41	0.61	0.016	0.024
F	0.13	0.25	0 005	0.010
H	1.60	1.70	0.063	0.067
J	0.23	0.48	0.009	0.019
K	2.13	2.34	0.084	0.092
* A	2.87	3.50	0.113	0.138

CASE 81A-06
***CASE 081A-07**

STATIC ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic (Note 1)	Symbol	Min	Typ	Max	Unit
Collector Dark Current (V_{CC} = 30 V, H = 0) T_A = 25°C	I_{CEO}	–	–	25	nA
T_A = 100°C		–	1.0	–	μA
Collector-Emitter Breakdown Voltage (I_C = 100 μA, H = 0)	$V_{(BR)CEO}$	50	–	–	Volts
Emitter-Collector Breakdown Voltage (I_E = 100 μA, H = 0)	$V_{(BR)ECO}$	7.0	–	–	Volts

ELECTRO-OPTICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Light Current (V_{CC} = 5.0 V, R_L = 100 ohms, H = 20 mW/cm^2 MRD601,611	I_L	0.5	1.5	–	mA
MRD602,612		2.0	3.5	–	
MRD603,613		4.0	6.0	–	
MRD604,614 (Note 1 – Figure 1)		7.0	8.5	–	
Light Current (V_{CC} = 5.0 V, R_L = 100 ohms, H = 0.5 mW/cm^2) MRD601,611	I_L	–	0.08	–	mA
MRD602,612		–	0.18	–	
MRD603,613		–	0.30	–	
MRD604,614 (Note 2 – Figure 1)		–	0.45	–	
Collector-Emitter Saturation Voltage (I_C = 0.5 mA, H = 20 mW/cm^2) (Note 1 – Figure 2)	$V_{CE(sat)}$	–	0.13	–	Volts
Rise Time (V_{CC} = 30 V, I_L = 800 μA, R_L = 1000 ohms) (Note 3 – Figure 10)	t_r	–	1.5	–	μs
Fall Time (V_{CC} = 30 V, I_L = 800 μA, R_L = 1000 ohms) (Note 3 – Figure 10)	t_f	–	15	–	μs
Rise Time (V_{CC} = 30 V, I_L = 800 μA, R_L = 100 ohms) (Note 4 – Figure 10)	t_r	–	2.0	–	μs
Fall Time (V_{CC} = 30 V, I_L = 800 μA, R_L = 100 ohms) (Note 4 – Figure 10)	t_f	–	2.8	–	μs

NOTES:

1. Radiation Flux Density (H) equal to 20 mW/cm^2 emitted from a tungsten source at a color temperature of 2870°K.
2. Radiation Flux Density (H) equal to 0.5 mW/cm^2 emitted from a GaAs (gallium-arsenide) source at $\lambda \approx 900$ nm.
3. For this response time measurement, radiation is provided by a pulsed xenon arc lamp with a pulse width of approximately 1.0 μs (see Figure 10).
4. For this response time measurement, radiation is provided by a pulsed GaAs (gallium arsenide) light emitting diode ($\lambda \approx 900$ nm) with a pulse width equal to or greater than 10 μs (see Figure 10), I_L = 800 μA.

TYPICAL CHARACTERISTICS

COLLECTOR-EMITTER SATURATION VOLTAGE versus RADIATION FLUX DENSITY

FIGURE 2 – SATURATION CHARACTERISTICS WITH TUNGSTEN SOURCE

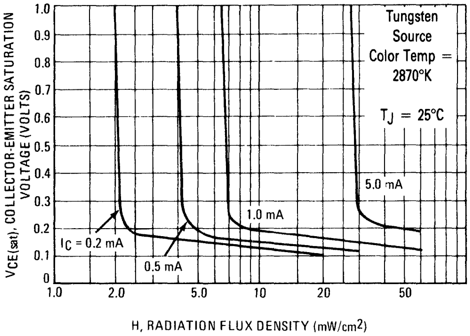
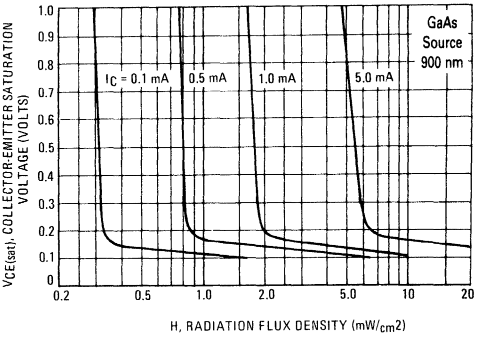


FIGURE 3 – SATURATION CHARACTERISTICS WITH GaAs SOURCE



COUPLING CHARACTERISTICS WITH GaAs SOURCE

FIGURE 4 – CONTINUOUS LIGHT CURRENT versus DISTANCE

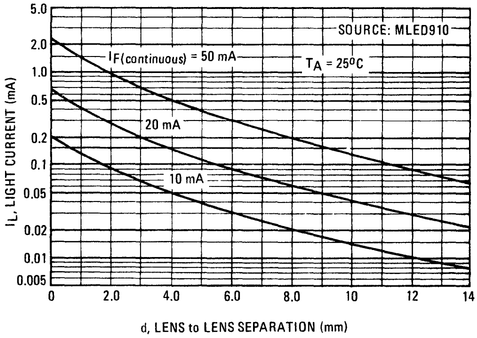


FIGURE 5 – PULSED LIGHT CURRENT versus DISTANCE

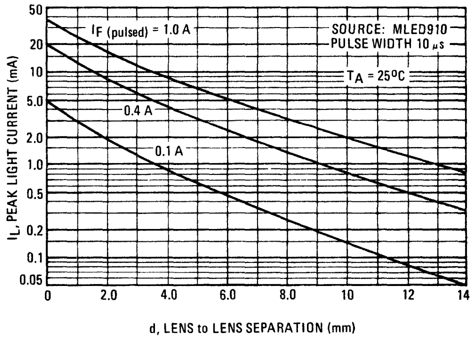


FIGURE 6 – DARK CURRENT versus TEMPERATURE

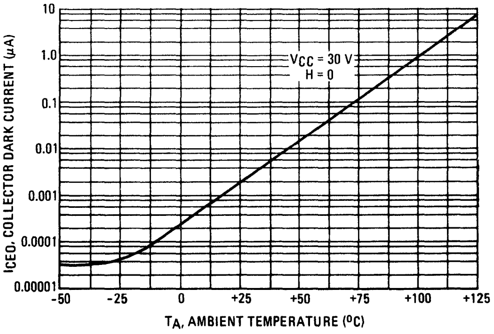


FIGURE 7 – NORMALIZED LIGHT CURRENT versus TEMPERATURE

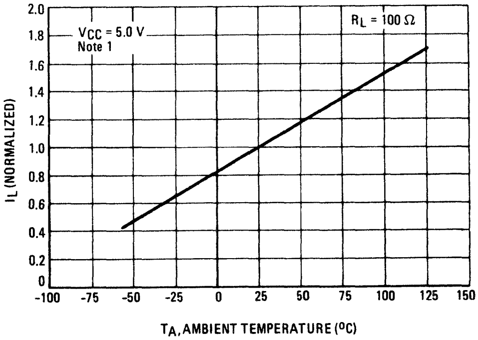


FIGURE 8 – RISE TIME versus LIGHT CURRENT

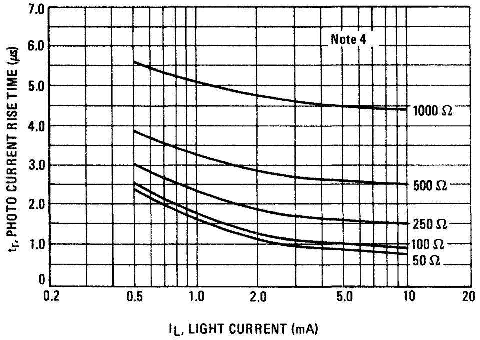


FIGURE 9 – FALL TIME versus LIGHT CURRENT

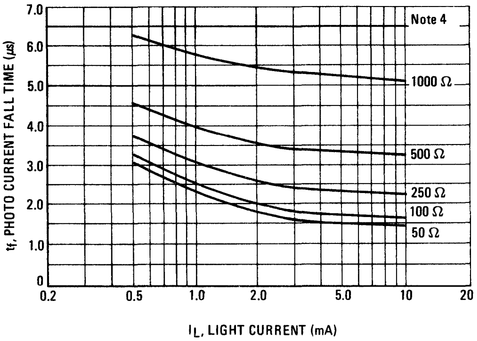


FIGURE 10 – PULSE RESPONSE TEST CIRCUIT AND WAVEFORM

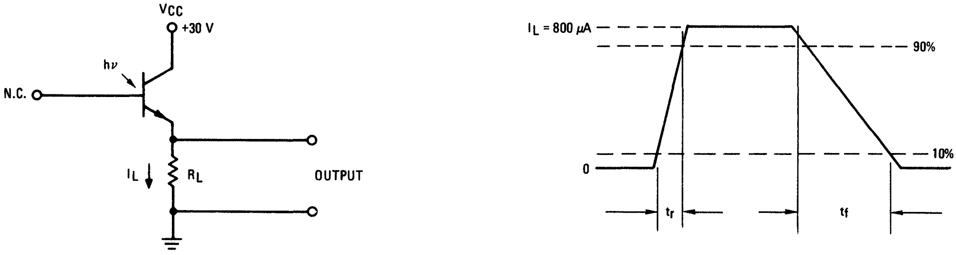


FIGURE 11 – ANGULAR RESPONSE

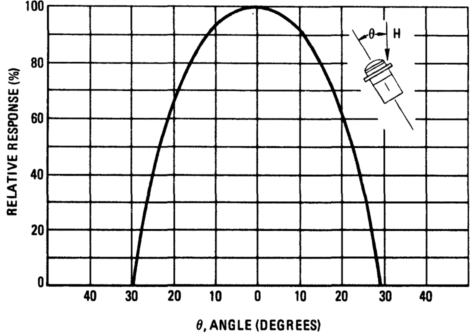
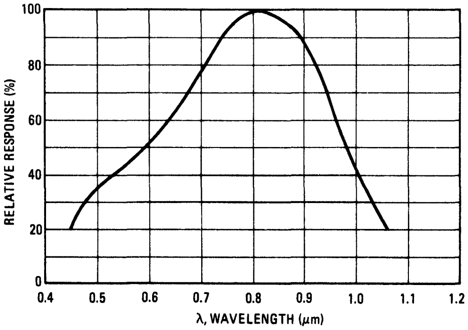


FIGURE 12 – CONSTANT ENERGY SPECTRAL RESPONSE



MOTOROLA

MRD701

PLASTIC NPN SILICON PHOTOTRANSISTORS

. . . designed for industrial processing and control applications such as light modulators, shaft or position encoders, end of tape detectors. The MRD701 is designed to be used with the MLED71 infrared emitter in optical slotted coupler/interrupter applications.

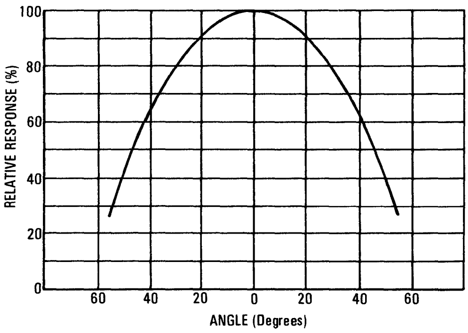
- Economical, Miniature Plastic Package
- Package Designed for Accurate Positioning
- Lens Molded into Package

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	30	Volts
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D(1)	150 2.0	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-40 to +100	°C

(1)Measured with the device soldered into a typical printed circuit board

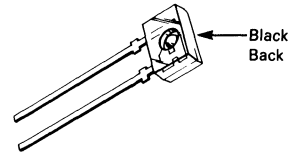
FIGURE 1 — ANGULAR RESPONSE

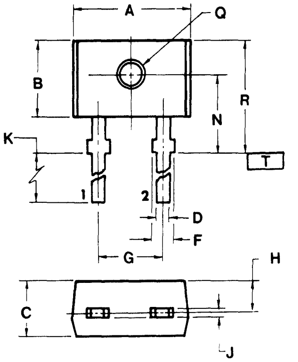


30 VOLT

PHOTOTRANSISTOR

NPN SILICON





STYLE 2:
PIN 1. EMITTER
2. COLLECTOR

NOTES:

1. DIMENSIONS A, B AND C ARE DATUMS.
2. POSITIONAL TOLERANCE FOR D DIMENSION:
   ⌖ | .25 (0.010) Ⓜ | -T- | A Ⓜ | C Ⓜ
3. POSITIONAL TOLERANCE FOR Q DIAMETER:
   ⌖ | Ø.25 (0.010) Ⓜ | A Ⓜ | B Ⓜ
4. -T- IS SEATING PLANE.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	3.43	4.60	0.135	0.185
B	2.79	3.30	0.110	0.130
C	2.03	3.18	0.080	0.125
D	0.43	0.60	0.017	0.024
F	1.14	1.40	0.045	0.055
G	2.54 BSC		0.100 BSC	
H	1.52 BSC		0.060 BSC	
J	0.23	0.56	0.009	0.022
K	12.83	19.05	0.505	0.750
N	3.05	3.30	0.120	0.130
Q	0.76	1.52	0.030	0.060
R	3.81	4.60	0.150	0.185

CASE 349-01

STATIC ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector Dark Current (V_{CE} = 10 V, H ≈ 0)	I_D	—	—	100	nA
Collector-Emitter Breakdown Voltage (I_C = 10 mA, H ≈ 0)	$V_{(BR)CEO}$	30	—	—	Volts

OPTICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
Collector Light Current (V_{CE} = 5.0 V, H = 500 μW/cm^2 at 2870°K Tungsten Source)		I_L	100	500	—	μA
Turn-On Time	H = 5.0 mW/cm^2, V_{CC} = 5.0 V R_L = 2400 Ω	t_{on}	—	10	—	μs
Turn-Off Time		t_{off}	—	60	—	μs
Saturation Voltage (H = 5.0 mW/cm^2, I_C = 2.0 mA)		$V_{CE(sat)}$	—	0.25	0.4	Volts

TYPICAL COUPLED CHARACTERISTICS USING MLED71 EMITTER AND MRD701 PHOTOTRANSISTOR DETECTOR

FIGURE 2 — CONTINUOUS MRD701 COLLECTOR LIGHT CURRENT versus DISTANCE FROM MLED71

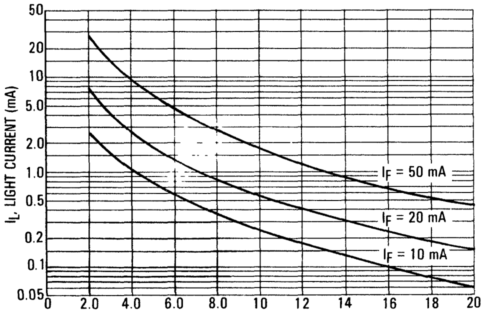
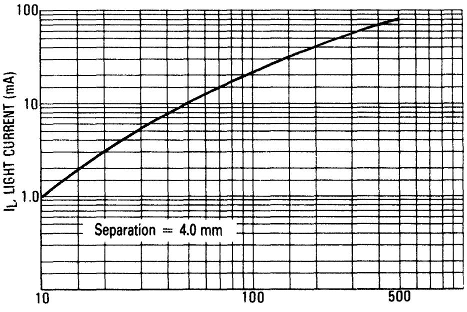


FIGURE 3 – INSTANTANEOUS MRD701 COLLECTOR LIGHT CURRENT versus MLED71 FORWARD CURRENT



MOTOROLA

MRD711

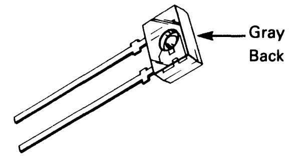
PLASTIC NPN SILICON PHOTODARLINGTON

. . . designed for a wide variety of industrial processing and control applications requiring a sensitive detector. The chip has an integral base-emitter resistor to improve higher temperature characteristics The MRD711 is in an identical package and is designed for use with the MLED71 infrared emitter

- Miniature, Low Profile, Clear Plastic Package
- Designed for Automatic Handling and Accurate Positioning
- Side Looking, with Molded Lens
- High Volume, Economical

PHOTODARLINGTON DETECTOR

NPN SILICON
60 VOLT



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	60	Volts
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D(1)	150 2.0	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-40 to +100	°C

(1)Measured with the device soldered into a typical printed circuit board

SCHEMATIC

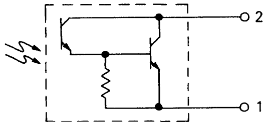
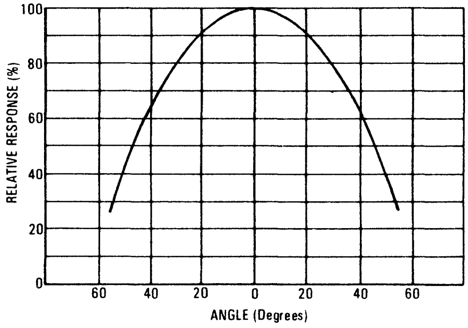
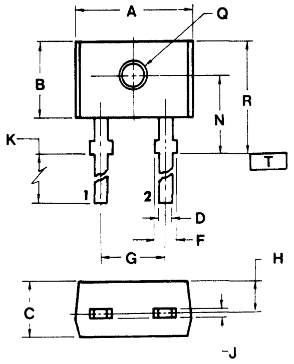


FIGURE 1 — ANGULAR RESPONSE





STYLE 2:
PIN 1. EMITTER
2. COLLECTOR

NOTES:
1. DIMENSIONS A, B AND C ARE DATUMS.
2. POSITIONAL TOLERANCE FOR D DIMENSION:
⌖ .25 (0.010) Ⓜ -T- A Ⓜ C Ⓜ
3. POSITIONAL TOLERANCE FOR Q DIAMETER:
⌖ Ø.25 (0.010) Ⓜ A Ⓜ B Ⓜ
4. -T- IS SEATING PLANE.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	3.43	4.60	0.135	0.185
B	2.79	3.30	0.110	0.130
C	2.03	3.18	0.080	0.125
D	0.43	0.60	0.017	0.024
F	1.14	1.40	0.045	0.055
G	2.54 BSC		0.100 BSC	
H	1.52 BSC		0.060 BSC	
J	0.23	0.56	0.009	0.022
K	12.83	19.05	0.505	0.750
N	3.05	3.30	0.120	0.130
Q	0.76	1.52	0.030	0.060
R	3.81	4.60	0.150	0.185

CASE 349-01

STATIC ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector Dark Current (V_{CE} = 10 V, H ≈ 0)	I_D	—	—	100	nA
Collector-Emitter Breakdown Voltage (I_C = 1.0 mA, H ≈ 0)	$V_{(BR)CEO}$	60	—	—	Volts
Capacitance (V_{CC} = 5.0 V, f = 1.0 MHz)	C_{ce}	—	12	—	pF

OPTICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
Collector Light Current (V_{CE} = 5.0 V, H = 500 μW/cm^2, λ = 940 nm)		I_L	5.0	25	—	mA
Turn-On Time	H = 500 μW/cm^2, V_{CC} = 5.0 V R_L = 100 Ω	t_{on}	—	125	—	μs
Turn-Off Time		t_{off}	—	150	—	μs
Saturation Voltage (H = 500 μW/cm^2, λ = 940 nm, I_C = 2.0 mA, V_{CC} = 5.0 V)		$V_{CE(sat)}$	—	0.75	1.0	Volts

TYPICAL COUPLED CHARACTERISTICS USING MLED71 EMITTER AND MRD711 DARLINGTON TRANSISTOR DETECTOR

FIGURE 2 — CONTINUOUS MRD711 COLLECTOR LIGHT CURRENT versus DISTANCE FROM MLED71

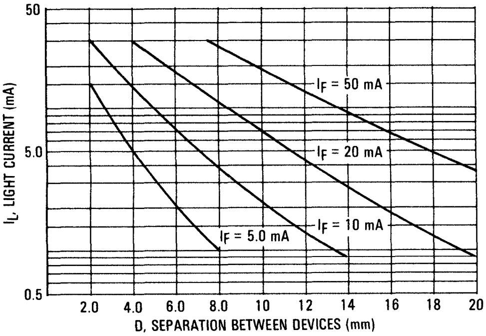
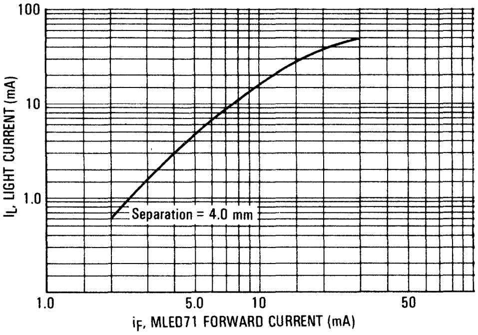


FIGURE 3 — INSTANTANEOUS MRD711 COLLECTOR LIGHT CURRENT versus MLED71 FORWARD CURRENT



MOTOROLA

MRD721

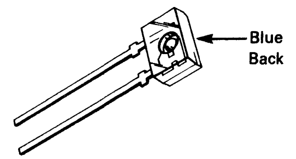
PIN PHOTO DIODE

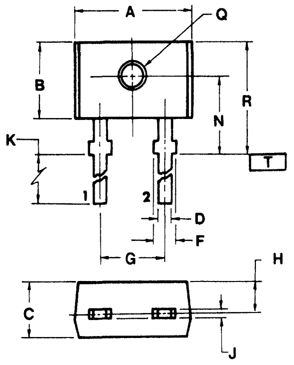
100 VOLT

PIN SILICON PHOTO DIODE

. . . designed for application in laser detection, light demodulation, detection of visible and near infrared light-emitting diodes, shaft or position encoders, switching and logic circuits, or any design requiring radiation sensitivity, ultra high-speed, and stable characteristics.

- Ultra Fast Response — (<1.0 ns Typ)
- Sensitive Throughout Visible and Near Infrared Spectral Range for Wide Application
- Annular Passivated Structure for Stability and Reliability
- Economical, Low Profile, Miniature Plastic Package
- Lense Molded Into Package
- Designed for Automatic Handling and Accurate Positioning





STYLE 1:
PIN 1. CATHODE
2. ANODE

NOTES:
1. DIMENSIONS A, B AND C ARE DATUMS.
2. POSITIONAL TOLERANCE FOR D DIMENSION:
⌖ .25 (0.010) Ⓜ -T- A Ⓜ C Ⓜ
3. POSITIONAL TOLERANCE FOR Q DIAMETER:
⌖ Ø.25 (0.010) Ⓜ A Ⓜ B Ⓜ
4. -T- IS SEATING PLANE.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

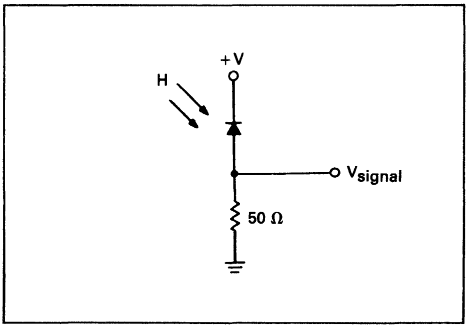
DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	3.43	4.60	0.135	0.185
B	2.79	3.30	0.110	0.130
C	2.03	3.18	0.080	0.125
D	0.43	0.60	0.017	0.024
F	1.14	1.40	0.045	0.055
G	2.54 BSC		0.100 BSC	
H	1.52 BSC		0.060 BSC	
J	0.23	0.56	0.009	0.022
K	12.83	19.05	0.505	0.750
N	3.05	3.30	0.120	0.130
Q	0.76	1.52	0.030	0.060
R	3.81	4.60	0.150	0.185

CASE 349-01

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Reverse Voltage	V_R	100	Volts
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	100 1.33	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-40 to +100	°C

FIGURE 1 — TYPICAL OPERATING CIRCUIT



STATIC ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Unit
Dark Current (V_R = 20 V, R_L = 1.0 MΩ; Note 2)		I_D				nA
T_A = 25°C	3 and 4		—	0.06	10	
T_A = 100°C			—	14	—	
Reverse Breakdown Voltage (I_R = 10 μA)	—	$V_{(BR)R}$	100	200	—	Volts
Forward Voltage (I_F = 50 mA)	—	V_F	—	—	1.1	Volts
Series Resistance (I_F = 50 mA)	—	R_s	—	8.0	—	ohms
Total Capacitance (V_R = 20 V; f = 1.0 MHz)	5	C_T	—	3.0	—	pF

OPTICAL CHARACTERISTICS (T_A = 25°C)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Unit
Light Current (V_R = 20 V, Note 1)	2	I_L	1.5	4.0	—	μA
Sensitivity (V_R = 20 V, Note 3)						μA/mW/cm^2
	—	S(λ = 0.8 μm)	—	5.0	—	
	—	S(λ = 0.94 μm)	—	1.2	—	
Response Time (V_R = 20 V, R_L = 50 Ω)	—	$t_{(resp)}$	—	1.0	—	ns
Wavelength of Peak Spectral Response	6	λ_s	—	0.8	—	μm

NOTES: 1. Radiation Flux Density (H) equal to 5.0 mW/cm^2 emitted from a tungsten source at a color temperature of 2870 K.

2. Measured under dark conditions. (H ≈ 0).

3. Radiation Flux Density (H) equal to 0.5 mW/cm^2

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 2 — IRRADIATED VOLTAGE — CURRENT CHARACTERISTIC

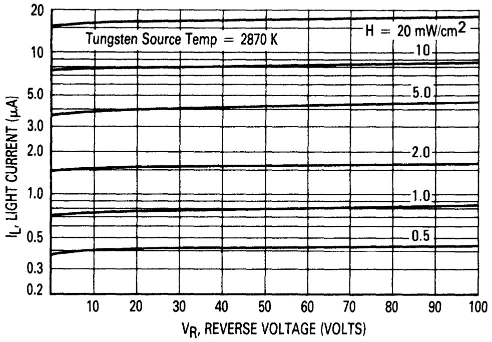


FIGURE 3 — DARK CURRENT versus TEMPERATURE

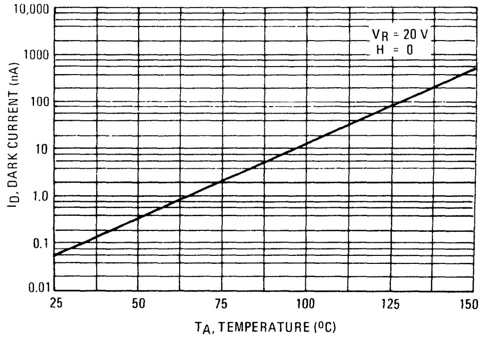


FIGURE 4 — DARK CURRENT versus REVERSE VOLTAGE

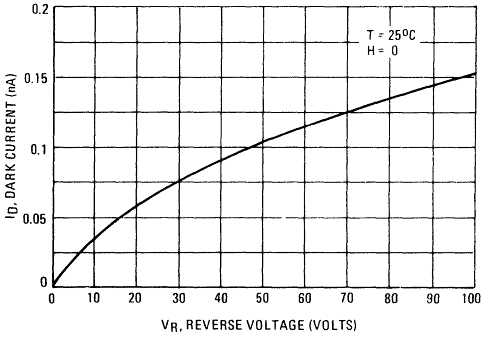


FIGURE 5 — CAPACITANCE versus VOLTAGE

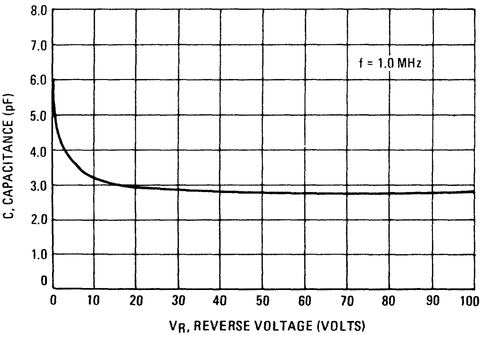
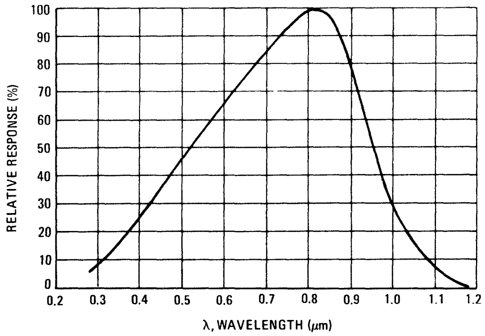


FIGURE 6 — RELATIVE SPECTRAL RESPONSE



MOTOROLA

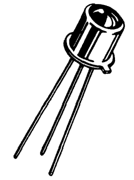
MRD3010
MRD3011

250 V PNP SILICON PHOTO TRIAC DRIVERS

. . . designed for applications requiring light and infrared LED TRIAC triggering, small size, and low cost.

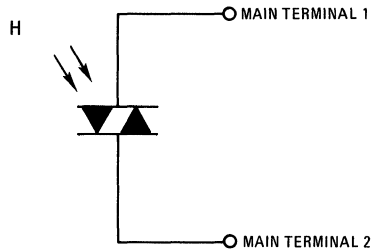
- Hermetic Package at Economy Prices
- Popular TO-18 Type Package for Easy Handling and Mounting
- High Trigger Sensitivity
  H_{FT} = 0.5 mW/cm^2 (Typ-MRD3011)

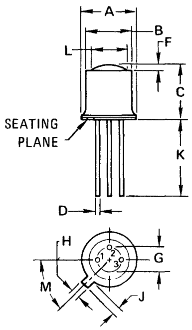
OPTICALLY TRIGGERED TRIAC DRIVERS



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Off-State Output Terminal Voltage	V_{DRM}	250	Volts
On-State RMS Current T_A = 25°C (Full Cycle, 50 to 60 Hz) T_A = 70°C	$I_{T(RMS)}$	100 50	mA mA
Peak Nonrepetitive Surge Current (PW = 10 ms, DC = 10%)	I_{TSM}	1.2	A
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	400 2.28	mW mW/°C
Operating Ambient Temperature Range	T_A	−40 to +70	°C
Junction Temperature Range	T_J	−40 to +100	°C
Storage Temperature Range	T_{stg}	−40 to +150	°C
Soldering Temperature (10 s)	–	260	°C





STYLE 3:
PIN 1. MAIN TERMINAL
2. MAIN TERMINAL
3. SUBSTRATE
(do not connect)

NOTES:
1. LEADS WITHIN .13 mm (.005) RADIUS OF TRUE POSITION AT SEATING PLANE, AT MAXIMUM MATERIAL CONDITION.
2. PIN 3 INTERNALLY CONNECTED TO CASE.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.52	4.95	0.178	0.195
C	4.57	6.48	0.180	0.255
D	0.41	0.48	0.016	0.019
F	–	1.14	–	0.045
G	2.54 BSC		0.100 BSC	
H	0.99	1.17	0.039	0.046
J	0.84	1.22	0.033	0.048
K	12.70	–	0.500	–
L	3.35	4.01	0.132	0.158
M	45° BSC		45° BSC	

CASE 82-05

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
DETECTOR CHARACTERISTICS (I_F = 0 unless otherwise noted)					
Peak Blocking Current, Either Direction (Rated V_{DRM}, Note 1)	I_{DRM}	—	10	100	nA
Peak On-State Voltage, Either Direction (I_{TM} = 100 mA Peak)	V_{TM}	—	2.5	3.0	Volts
Critical Rate of Rise of Off-State Voltage, Figure 3	dv/dt	—	2.0	—	V/μs
Critical Rate of Rise of Commutation Voltage, Figure 3 (I_{load} = 15 mA)	dv/dt	—	0.15	—	V/μs
OPTICAL CHARACTERISTICS					
Maximum Irradiance Level Required to Latch Output (Main Terminal Voltage 3.0 V, R_L = 150 Ω) MRD3010 Color Temperature = 2870°K MRD3011	H_{FT}	—	1.0 0.5	5.0 2.0	mW/cm²
Holding Current, Either Direction Initiating Flux Density = 5.0 mW/cm²	I_H	—	100	—	μA

NOTE 1. Test voltage must be applied within dv/dt rating.

FIGURE 1 — ON-STATE CHARACTERISTICS

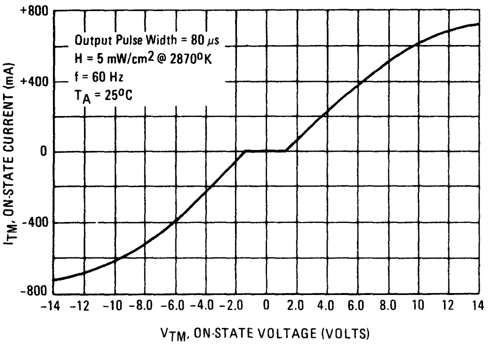


FIGURE 2 — dv/dt TEST CIRCUIT

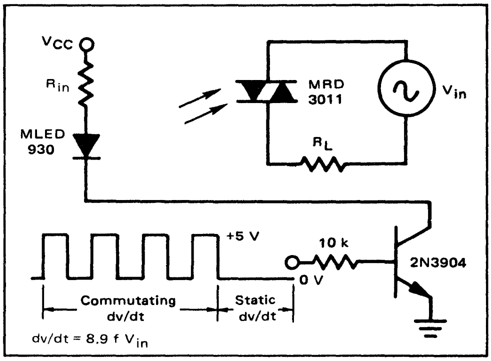


FIGURE 3 — dv/dt versus LOAD RESISTANCE

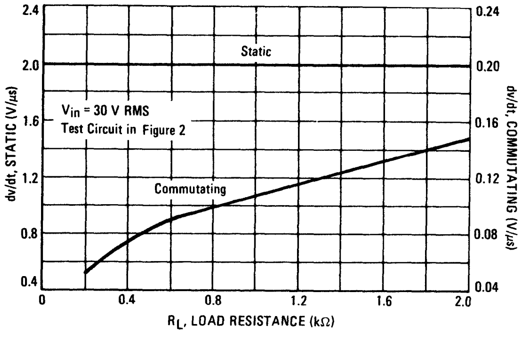


FIGURE 4 — dv/dt versus TEMPERATURE

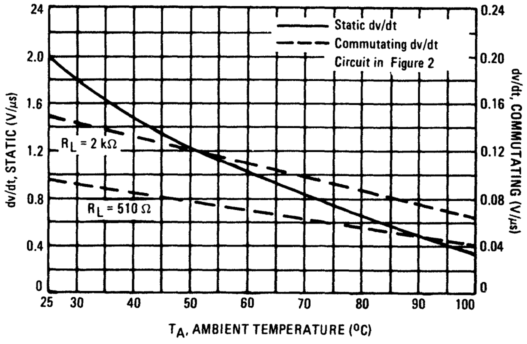


FIGURE 5 — COMMUTATING dv/dt versus FREQUENCY

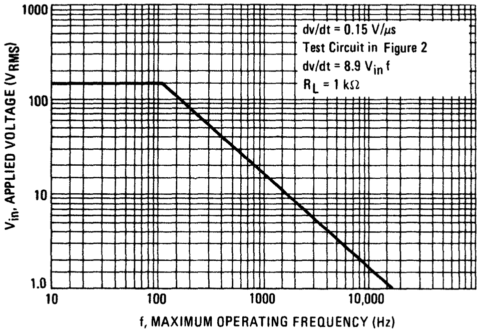
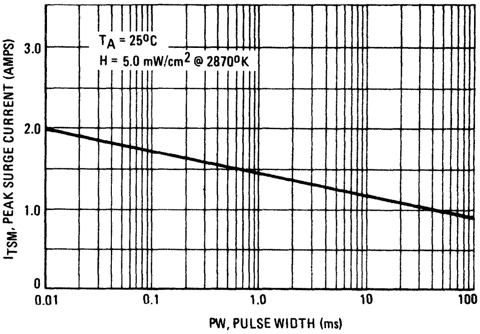
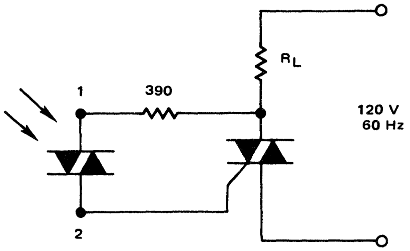


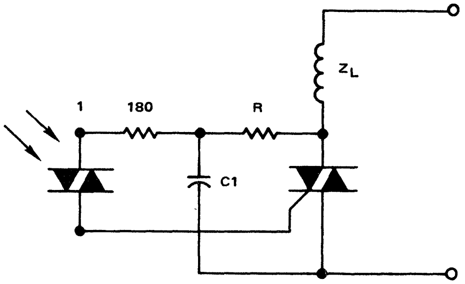
FIGURE 6 — MAXIMUM NONREPETITIVE SURGE CURRENT



RESISTIVE LOAD



INDUCTIVE LOAD



TRIAC I_{GT} < 15 mA
R = 2.4 k
C1 = 0.1 μF
TRIAC I_{GT} > 15 mA
R = 1.2 kΩ
C1 = 0.2 μF

MOTOROLA

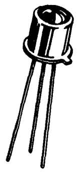
MRD3050,MRD3051,
MRD3054,
MRD3055,MRD3056

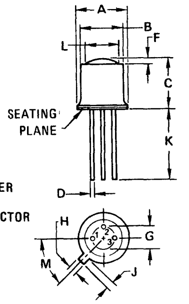
NPN SILICON PHOTOTRANSISTORS

. . . designed for application in industrial inspection, processing and control, counters, sorters, switching and logic circuits or any design requiring radiation sensitivity, and stable characteristics.

- Hermetic Package at Economy Prices
- Popular TO-18 Type Package for Easy Handling and Mounting
- Sensitive Throughout Visible and Near Infrared Spectral Range for Wider Application
- Range of Radiation Sensitivities for Design Flexibility
- External Base for Added Control
- Annular Passivated Structure for Stability and Reliability

30 VOLT
PHOTOTRANSISTORS
NPN SILICON





STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

NOTES:
1. LEADS WITHIN .13 mm (.005) RADIUS OF TRUE POSITION AT SEATING PLANE, AT MAXIMUM MATERIAL CONDITION.
2. PIN 3 INTERNALLY CONNECTED TO CASE.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.52	4.95	0.178	0.195
C	4.57	6.48	0.180	0.255
D	0.41	0.48	0.016	0.019
F	–	1.14	–	0.045
G	2.54 BSC		0.100 BSC	
H	0.99	1.17	0.039	0.046
J	0.84	1.22	0.033	0.048
K	12.70	–	0.500	–
L	3.35	4.01	0.132	0.158
M	45° BSC		45° BSC	

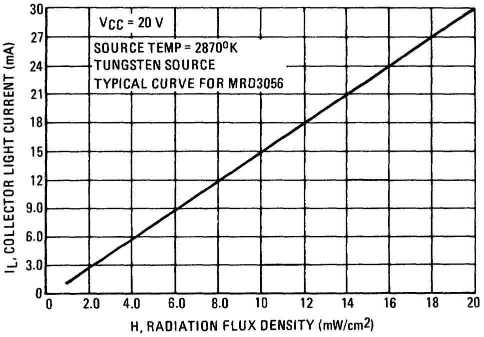
CASE 82-05

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	30	Volts
Emitter-Collector Voltage	V_{ECO}	5.0	Volts
Collector-Base Voltage	V_{CBO}	40	Volts
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	400 2.28	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +200	°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	438	°C/W



STATIC ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector Dark Current	I_{CEO}				μA
(V_{CC} = 20 V, R_L = 1.0 Megohm, Note 2) T_A = 25°C		–	0.02	0.1	
T_A = 85°C		–	5.0	–	
Collector-Base Breakdown Voltage (I_C = 100 μA)	$V_{(BR)CBO}$	40	100	–	Volts
Collector-Emitter Breakdown Voltage (I_C = 100 μA)	$V_{(BR)CEO}$	30	75	–	Volts
Emitter-Collector Breakdown Voltage (I_E = 100 μA)	$V_{(BR)ECO}$	5.0	8.0	–	Volts

OPTICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Unit
Collector-Light Current	1	I_L				mA
(V_{CC} = 20 V, R_L = 100 ohms, Note 1) MRD3050			0.1	–	–	
MRD3051			0.2	–	–	
MRD3054			0.5	–	–	
MRD3055			1.5	–	–	
MRD3056			2.0	8.0	–	
Photo Current Saturated Rise Time (Note 3)	4	$t_{r(sat)}$	–	1.0	–	μs
Photo Current Saturated Fall Time (Note 3)	4	$t_{f(sat)}$	–	1.0	–	μs
Photo Current Rise Time (Note 4)	4	t_r	–	2.0	–	μs
Photo Current Fall Time (Note 4)	4	t_f	–	2.5	–	μs
Wavelength of Maximum Sensitivity	–	λ_s	–	0.8	–	μm

NOTES:

1. Radiation flux density (H) equal to 5.0 mW/cm^2 emitted from a tungsten source at a color temperature of 2870°K.
2. Measured under dark conditions. (H≈0).
3. For saturated switching time measurements, radiation is provided by a pulsed xenon arc lamp with a pulse width of approximately 1.0 microsecond (see Figure 4).
4. For unsaturated switching time measurements, radiation is provided by a pulsed GaAs (gallium-arsenide) light-emitting diode (λ≈0.9 μm) with a pulse width equal to or greater than 10 microseconds (see Figure 4).

TYPICAL ELECTRICAL CHARACTERISTICS

FIGURE 2 – COLLECTOR EMITTER CHARACTERISTICS – MRD3056

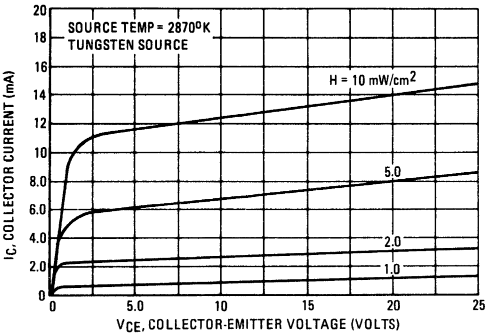


FIGURE 3 – PHOTO CURRENT verus TEMPERATURE

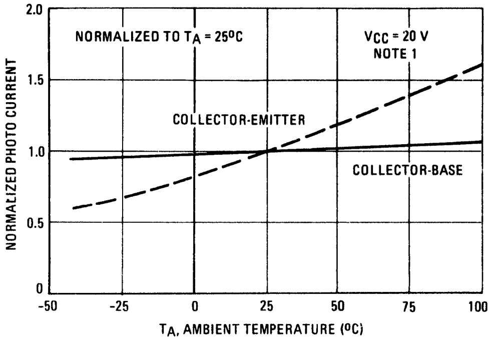


FIGURE 4 – PULSE RESPONSE TEST CIRCUIT AND WAVEFORM

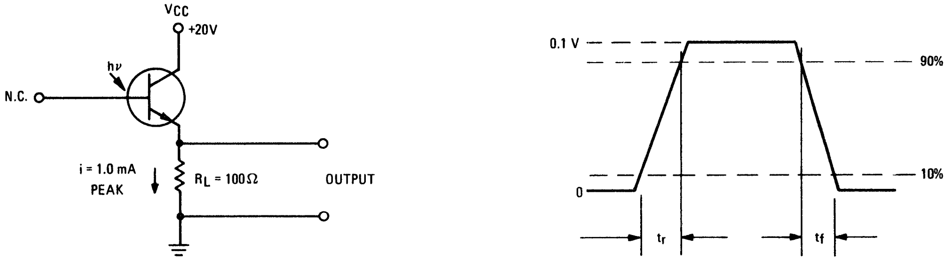
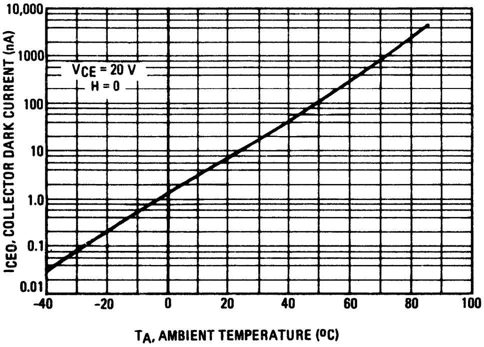


FIGURE 5 – DARK CURRENT versus TEMPERATURE



TYPICAL CIRCUIT APPLICATIONS

(Extracted from Motorola Application Note AN-508, "Applications of Phototransistors in Electro-Optic Systems")

FIGURE 6 – STROBEFLASH SLAVE ADAPTER

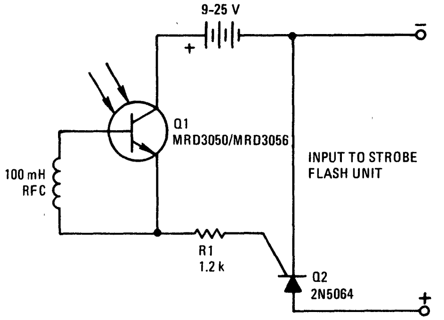


FIGURE 7 – LIGHT OPERATED SCR ALARM USING SENSITIVE-GATE SCR

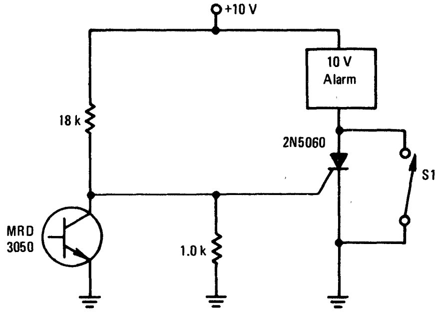
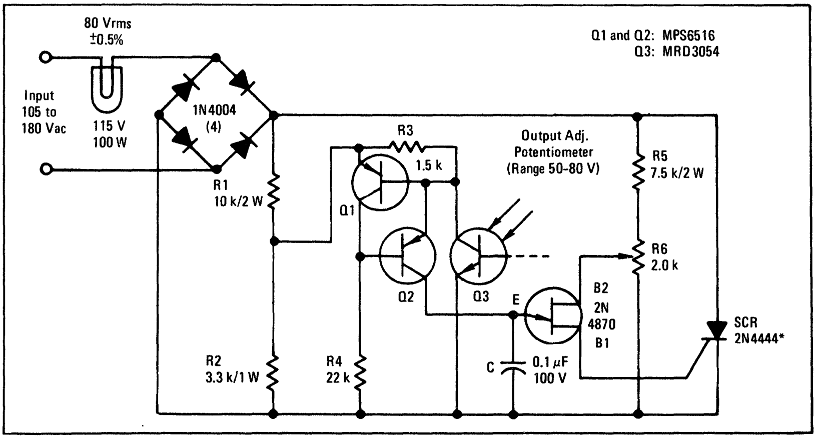


FIGURE 8 – CIRCUIT DIAGRAM OF VOLTAGE REGULATOR FOR PROJECTION LAMP.



*2N4444 to be used with a heat sink.

MOTOROLA

OPTO COUPLERS/ISOLATORS

PHOTOTRANSISTOR AND PHOTODARLINGTON OPTOCOUPLERS

Extensive series of popular industry couplers in the standard dual-in-line plastic package.

- **High Isolation Voltage — 7500 V**
  All Motorola couplers are specified at 7500 Vac peak (5 seconds). This usually exceeds the originator's specification.
- **Specifications Correspond to Originator's Specifications**
  All parameters other than isolation voltages are tested to the originator's specifications (both condition and limits), including parameters which may not be shown on this data sheet.
- **UL Recognition, File No. E54915**
  All Motorola devices shown here are UL Recognized.

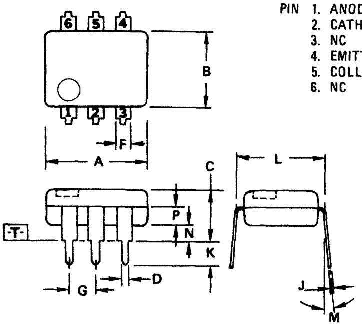
Transistor Couplers

H11A1, 2, 3, 4, 5
H11A520, 550, 5100
IL1, 12, 74
MCT2, 2E, 26
MCT271, 272, 273
MCT274, 275, 277
TIL111, 112, 114, 115
TIL116, 117, 118
TIL124, 125, 126
TIL153, 154, 155

Darlington Couplers

H11B1, 2, 3, 255
MCA230, 231, 255
TIL113, 119, 127, 128
TIL156, 157

TIL118,119, 128 157 ONLY	ALL OTHERS
STYLE 3:	STYLE 1:
PIN 1. ANODE	PIN 1. ANODE
2. CATHODE	2. CATHODE
3. NC	3. NC
4. EMITTER	4. EMITTER
5. COLLECTOR	5. COLLECTOR
6. NC	6. BASE

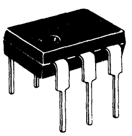


NOTES:
1. DIMENSIONS A AND B ARE DATUMS.
2. -T- IS SEATING PLANE.
3. POSITIONAL TOLERANCES FOR LEADS:
   ⌖ | Ø 0.13 (0.005) Ⓜ | T | A Ⓜ B Ⓜ
4. DIMENSION L TO CENTER OF LEADS WHEN FORMED PARALLEL.
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	8.13	8.89	0.320	0.350
B	6.10	6.60	0.240	0.260
C	2.92	5.08	0.115	0.200
D	0.41	0.51	0.016	0.020
F	1.02	1.78	0.040	0.070
G	2.54 BSC		0.100 BSC	
J	0.20	0.30	0.008	0.012
K	2.54	3.81	0.100	0.150
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.38	2.54	0.015	0.100
P	1.27	2.03	0.050	0.080

CASE 730A-01

PLASTIC PACKAGE



CASE 730A-01

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

PARAMETER	Current Transfer Ratio			Isolation Voltage (1)	Saturation Voltage			Collector Dark Current		Collector-Emitter Breakdown Voltage		LED Forward Voltage	
TEST CONDITION	I_F and V_{CE} as shown			Input to Output	I_F and I_C as shown			$I_F = 0$ V_{CE} as shown		$I_F = 0$ I_C as shown		I_F as shown	
SYMBOL	CTR			V_{ISO} Volts Peak	$V_{CE(SAT)}$ Volts			I_{CEO} nA		$V_{(BR)CEO}$ Volts		V_F Volts	
Device Type	% Min	@ I_F mA	V_{CE} Volts	Min	Max	@ I_F mA	I_C mA	Max	@ V_{CE} Volts	Min	@ I_C µA	Max	@ I_F mA
H11A1	50	10	10	7500	0.4	10	0.5	50	10	30	10	1.5	10
H11A2	20	10	10	7500	0.4	10	0.5	50	10	30	10	1.5	10
H11A3	20	10	10	7500	0.4	10	0.5	50	10	30	10	1.5	10
H11A4	10	10	10	7500	0.4	10	0.5	50	10	30	10	1.5	10
H11A5	30	10	10	7500	0.4	10	0.5	100	10	30	10	1.7	10
H11A520	20	10	10	7500	0.4	20	2.0	50	10	30	10	1.5	10
H11A550	50	10	10	7500	0.4	20	2.0	50	10	30	10	1.5	10
H11A5100	100	10	10	7500	0.4	20	2.0	50	10	30	10	1.5	10
H11B1*	500	1.0	5.0	7500	1.0	1.0	1.0	100	10	25	10	1.5	10
H11B2*	200	1.0	5.0	7500	1.0	1.0	1.0	100	10	25	10	1.5	10
H11B3*	100	1.0	5.0	7500	1.0	1.0	1.0	100	10	25	10	1.5	50
H11B255*	100	10	5.0	7500	—	—	—	100	10	55	0.1	1.5	20
IL1	20	10	10	7500	0.5	16	1.6	50	10	30	1.0	1.5	60
IL12	10	10	5.0	7500	—	—	—	250	5.0	20	1.0	1.5	10
IL74	12.5	16	5.0	7500	0.5	16	2.0	500	5.0	20	1.0	1.75	10
MCA230*	100	10	5.0	7500	1.0	50	50	100	10	30	0.1	1.5	20
MCA231*	200	1.0	1.0	7500	1.2	10	50	100	10	30	1.0	1.5	20
MCA255*	100	10	5.0	7500	1.0	50	50	100	10	55	0.1	1.5	20
MCT2	20	10	10	7500	0.4	16	2.0	50	10	30	1.0	1.5	20
MCT2E	20	10	10	7500	0.4	16	2.0	50	10	30	1.0	1.5	20
MCT26	6.0	10	10	7500	0.5	60	16	100	5.0	30	1.0	1.5	20
MCT271	45	10	10	7500	0.4	16	2.0	50	10	30	1.0	1.5	20
MCT272	75	10	10	7500	0.4	16	2.0	50	10	30	1.0	1.5	20
MCT273	125	10	10	7500	0.4	16	2.0	50	10	30	1.0	1.5	20
MCT274	225	10	10	7500	0.4	16	2.0	50	10	30	1.0	1.5	20
MCT275	70	10	10	7500	0.4	16	2.0	50	10	30	1.0	1.5	20
MCT277	100	10	10	7500	—	—	—	50	10	30	1.0	1.5	20
TIL111	8.0	16	0.4	7500	0.4	16	2.0	50	10	30	1.0	1.4	16
TIL112	2.0	10	5.0	7500	0.5	50	2.0	100	5.0	20	1.0	1.5	10
TIL113*	300	10	1.0	7500	1.0	125	50	100	10	30	1.0	1.5	10
TIL114	8.0	16	0.4	7500	0.4	16	2.0	50	10	30	1.0	1.4	16
TIL115	2.0	10	5.0	7500	0.5	50	2.0	100	5.0	20	1.0	1.5	10
TIL116	20	10	10	7500	0.4	15	2.2	50	10	30	1.0	1.5	60
TIL117	50	10	10	7500	0.4	10	0.5	50	10	30	1.0	1.4	16
TIL118*[2]	10	10	5.0	1500	0.5	50	2.0	100	5.0	20	1.0	1.5	10
TIL119*[2]	300	10	2.0	7500	1.0	10	10	100	10	30	1.0	1.5	10
TIL124	10	10	10	7500	0.4	10	1.0	50	10	30	1.0	1.4	10
TIL125	20	10	10	7500	0.4	10	1.0	50	10	30	1.0	1.4	10
TIL126	50	10	10	7500	0.4	10	1.0	50	10	30	1.0	1.4	10
TIL127*	300	10	1.0	7500	1.0	50	125	100	10	30	1.0	1.5	10
TIL128*[2]	300	10	2.0	7500	1.0	10	10	100	10	30	1.0	1.5	10
TIL153	10	10	10	7500	0.4	10	1.0	50	10	30	1.0	1.4	10
TIL154	20	10	10	7500	0.4	10	1.0	50	10	30	1.0	1.4	10
TIL155	50	10	10	7500	0.4	10	1.0	50	10	30	1.0	1.4	10
TIL156*	300	10	1.0	7500	1.0	50	125	100	10	30	1.0	1.5	10
TIL157*[2]	300	10	2.0	7500	1.0	10	10	100	10	30	1.0	1.5	10

*Darlington

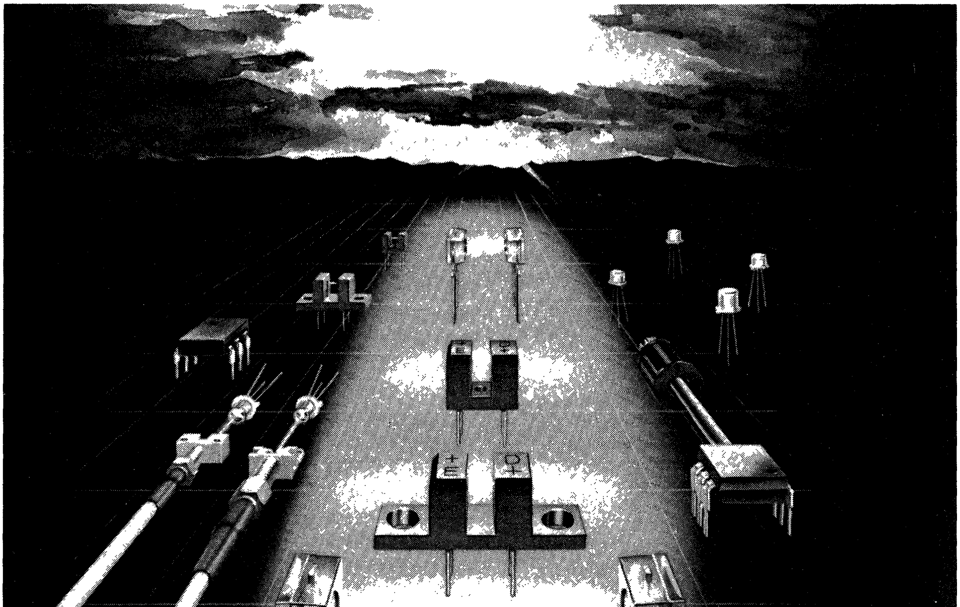
(1) Isolation Surge Voltage V_{ISO}, is an internal device dielectric breakdown rating.
For this test LED pins 1 and 2 are common and phototransistor pins 4, 5, and 6 are common.

(2) See Case 730A-01, Style 3.

OPTOELECTRONICS

Applications Information

4



VDE TESTING INFORMATION

The MOC600A series optocouplers have been approved by VDE per Test Certificate NR22762 to Component Standard VDE0883/6.80 and Equipment Standards VDE0860/8.81 and IEC65, and to all VDE Standards of Electric and Electronic Equipment with similar or lower requirements such as VDE0805 — IEC345/83 and VDE0806 — IEC380 with the VDE decision to use VDE0805 clause 2.9.7 for potted components.

The 0.4 mm separation between internal conductors is accomplished by reinforced insulation for Insulation Group C and Safety Class I and II equipment per VDE0110 and VDE0110B/2.79.

VDE RATINGS

Rating	Symbol	Value	Unit
Ambient Operating Temperature Range	T_A	-55 to +100	°C
Storage Temperature Range	T_{stg}	-55 to +150	°C
Climatic Test Class		55/100/21	
DC Isolation Voltage at 100°C for 1 Minute	$V_{ISO(pk)}$	4.4	kVdc
Nominal Operating Isolation Voltage for Isolation Group C According to VDE0110B	$V_{ISO(nom)}$	500 600	Vac Vdc
Isolation Creepage Path	L_{ICP}	8.5 Min	mm
Isolation Clearance	L_{ICL}	7.9 Min	mm
Internal Thickness Through Insulation	—	0.4 Min	mm
Creepage Current Stability of Insulation According to VDE303 Part 1/10.76	Overmold Undermold	KB100 Min KB600 Min	— —
Surge Isolation Voltage According to IEC65 or VDE0860/8.81	50 Discharges of 10 kV charged 1 nF 12 Discharges Max at 1 Minute		

ENVIRONMENTAL TEST

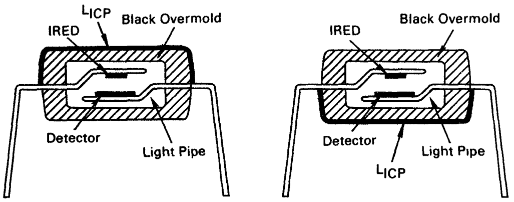
Environment Test Per VDE0883	Kind of Test	Application	Condition	Duration
Solderability Per DIN 40046 Part 18 or IEC 68-2-20	Ta1 Tb1	Solder Bath Solder Iron 3 mm TIP	260°C 260°C	5 ± 1 sec 5 ± 1 sec
Temperature Cycling Per DIN 40046 Part 14 or IEC 68-2-18	Na	5 Cycles	-55°C/+100°C	Dwell 3 Hrs Transfer 3 Min
Dry Heat Per DIN 40046 Part 4 or IEC 68-2-2	Ba		100°C	16 Hrs
Humid Heat Cycling Per DIN 40046 Part 31 or IEC 68-2-30	Db	6 Cycles	25°C/40°C RH 95%	Dwell 6 Hrs
Cold Per DIN 40046 Part 3 or IEC 68-2-1	Aa		-55°C	16 Hrs
Humid Heat (Long Term) Per DIN 40046 Part 5 or IEC 68-2-3	Ca		40°C RH 95%	21 Days
Vibration Per DIN 40046 Part 8 or IEC 68-2-6	Fc		55 Hz — 2 kHz 10 g	90 Min

ISOLATION CREEPAGE PATH

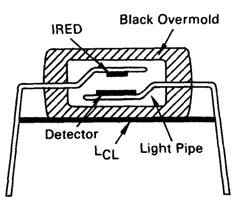
Denotes the shortest path between two conductive parts measured along the surface of the insulation. i.e., on the optocouplers, it is the shortest distance on the surface of the package between the input and output leads. On the circuit board in which the coupler is mounted, it is the shortest distance across the surface on the board between the solder eyes of the coupler input/output leads. Coupler and circuit board creepage path have to meet the minimum specified distances for the individual VDE equipment norms. (See application section.)

CLEARANCE

Denotes the shortest distance between two conductive parts or between a conductive part and the bonding surface of the equipment, measured through air. (See application sections.)



Topside Creepage Path L_{ICP} A = 8.5 mm Minimum
Underside Creepage Path L_{ICP} B = 8.5 mm Minimum



Clearance L_{CL} = 7.9 mm Minimum as Supplied

APPLICATION OF THE MOTOROLA VDE OPTOCOUPLERS

The VDE approval of the Motorola Optocoupler Family is of great importance since VDE follows the wide spread safety recommendations of the International Electrotechnical Commission (IEC) which is accepted and adopted by many European and other countries. The intent of these safety standards is to prevent injury or damage due to electrical shock, fire, energy — mechanical — heat — radiation and chemical hazards. The IEC recommendations provide an ever increasing unifying control over most national standards worldwide. The US and Canada have similar standards and there is a trend to harmonize their standards with the IEC recommendations. This short application note is able to mention only some VDE/IEC equipment safety standards whose primary objective is to enable designers to realize safety requirements at an early design stage and build them into the equipment while incorporating the relevant requirements of these standards.

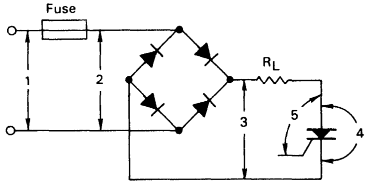
CIRCUIT BOARD LAYOUT DESIGN RULES

The most demanding and stringent safety requirements are on interfaces between a safety low-voltage circuit [SELV] and a hazardous voltage (240 V power line). The requirements for creepage path and clearance dimensioning are different for each individual equipment norm and also depend on the isolation group and safety class of the equipment and the circuit boards resistance to tracking. Isolation materials are classified for their resistance to tracking creepage current stability from KB 100 to KB ≤ 600 (see VDE 303). On circuit board materials with a low KB value, the creepage path distance requirements are higher than for materials with a high KB value. In the following examples we therefore show creepage path dimensions for KB 100, the lowest value which is easily met by most circuit board materials.

The least stringent requirements on optocouplers, as well as printboard layouts, are within and inbetween SELV or ELV loops or circuits. (ELV = Electrical Low Voltage which does not meet the safety low voltage requirements.)

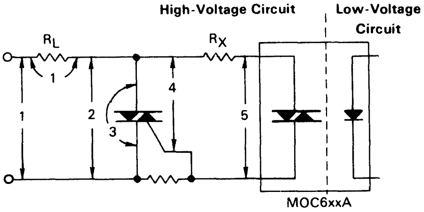
In studying the individual equipment norms, the designer will discover that optocouplers are not mentioned in most of these norms. He has to use the requirements for transformers or potted components instead.

Spacing requirements between two live tracks on a PC board within a low or high voltage loop (circuit) should generally meet the VDE requirements for minimum clearance and creepage path dimensions. If they do not, the circuit has to show some sort of current limiting (fuse, high-impedance, etc.) which prevents fire hazard due to an eventual short or sparkover between the two tracks. The VDE testing institute will conduct, in this case, a shorting test and a tracking test (arcing). See VDE 804. Classical cases are rectifiers, thyristors, high-voltage transistors which, sometimes due to their close pinout, might not meet the VDE equipment requirements at a certain voltage.



1 — Clearance and creepage path **must** meet min requirements
2 — Current limited due to fuse
3, 4 — Current limited due to R_L and fuse
5 — Current limited due to I_{GT}, R_L and fuse

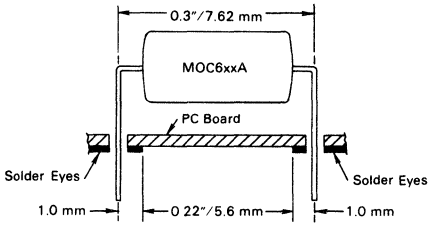
2, 3, 4, 5 — Clearance and creepage path may be smaller than VDE min requirements but **must** meet fire hazard requirements due to short and arcing between the tracks There shall be no flames or explosion during the test.



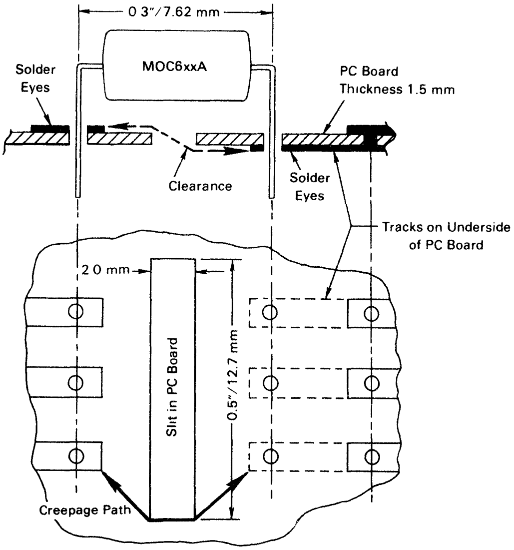
1 Clearance and creepage path **must** meet min requirements
2 Current limited due to R_L
3 Current limited due to R_L
4 Current limited due to I_{GT}
5 Current limited due to I_{GT} and R_X

COUPLER MOUNTING ON A CIRCUIT BOARD

Clearance and Creepage Path Between Input and Output for Optocouplers on a PC Board

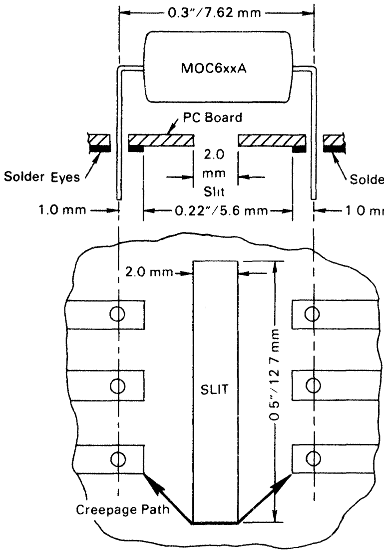


Input/Output Leads — L = 0.3″/7.62 mm
Clearance Limited Due to PC Board
Solder Eyes — 0.22″/5.6 mm
Creepage Path on PC Board — 0.22″/5.6 mm



If a clearance of 0.23″/6.0 mm and a creepage path of minimum 8.0 mm is required, this is a possible solution.

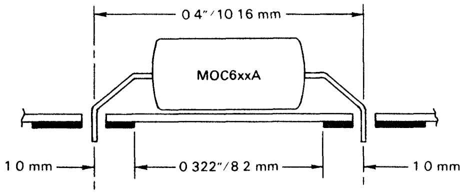
Slit — 0.5″/12.7 mm long, 2.0 mm wide
PC Board Thickness — 1.5 mm
Clearance — 6.0 mm Min
Creepage Path — 8.0 mm Min



Slit punched out 2.0 mm wide, 12 mm long

VDE equipment norms demanding longer creepage path than 0.22″/5.6 mm can be accomplished by a slit in the PC board between the coupler input and output solder eyes of 2.0 mm width

Input/Output Leads — L = 0.3″/7.62 mm
Clearance on PC Boards — 0.22″/5.6 mm Min
Creepage Path on PC Board — 0.31/8.0 mm Min



Where the equipment norms demand a clearance and creepage path of 8.0 mm Min, the coupler input and output leads should be bent to 0.4″/10.16 mm and the printboard layout should be as shown

Safety Coupler Mounting with Spacing — L = 0.4″/10.16 mm
Clearance on PC Board — 0.322″/8.2 mm
Creepage Path on PC Board — 0.322″/8.2 mm

PRINTED CIRCUIT BOARD LAYOUT FOR SELV-POWER INTERFACES

The circuit board layout examples shown here are dimensioned so that they provide a safe electrical isolation between metal parts carrying line voltage (called Power Interface) and conductors connected to a SELV circuit.

The required thickness through insulation for the optocoupler can be found in the individual VDE equipment norms. (See examples for safety applications of the MOC600A family at the end of this article.)

Many Class I equipment norms permit the use of parts (modules, PC boards) which meet the Safety Class II dimension and isolation requirements. This enables the designer to take advantage of the less complex and space demanding design of the Class II PC board layout also in Class I classified equipment.

Optocoupler Mounting on PC Boards for Safety Class I

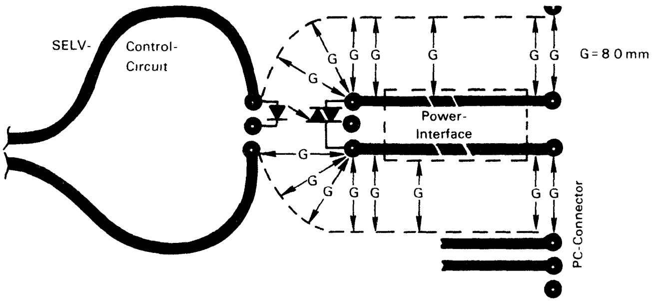
SELV transformers for Class I equipment have a Faraday shield which is connected to earth ground between primary and secondary windings. This is **not** applicable to optocouplers, but creepage path and clearance requirements from safety Class II can be applied. Class I also demands an earth ground track on the circuit board between SELV — and power circuit. Applying the Class I rules, this earth ground track should be between the coupler input and output. However, this cannot be done without violating the minimum creepage path and clearance requirements. A possible solution is found on page 4-6.

The earth ground track itself has to show a minimum distance to the equipment body (i.e., frame, circuit board enclosure) or to any inactive, active or hazardous track on the circuit board. According to many VDE equipment norms, this creepage path distance for 250 V Max is 4.0 mm. A mechanically unsecured circuit board which can be plugged in and out without a tool and is electrically connected through a standard PC board connector, has to show an isolation of the earth ground track to Class II, which is 8.0 mm. This is because a standard PC connector does not guarantee earthing contact **before** there is termination of the life 220 V tracks on the circuit board when plugged in. Another reason for increased spacing is when the circuit board metal enclosure is not securely earth grounded. This is the case when the connection is done with the PC module mounting screws through lacquer or oxide layers to a grounded rack or frame. PC board designs account for these possibilities and therefore show dimensions M, N and A, B and D as 8.0 mm instead of 4.0 mm.

OPTOCOUPLER MOUNTING ON PC BOARDS FOR SAFETY CLASS II WITH CREEPAGE PATH AND CLEARANCE

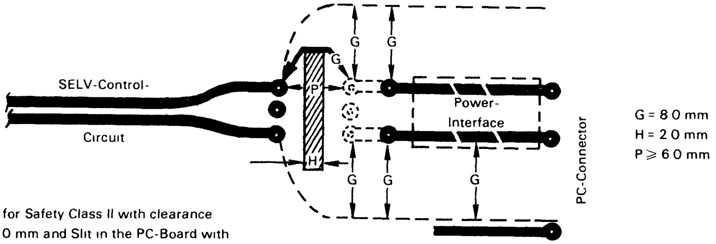
Applicable for

VDE 0113
VDE 0160 Part 1 and 2
VDE 0804 and 0804d
VDE 0831/0832/0833
VDE 0860
VDE 110b
VDE 0805
VDE 0806



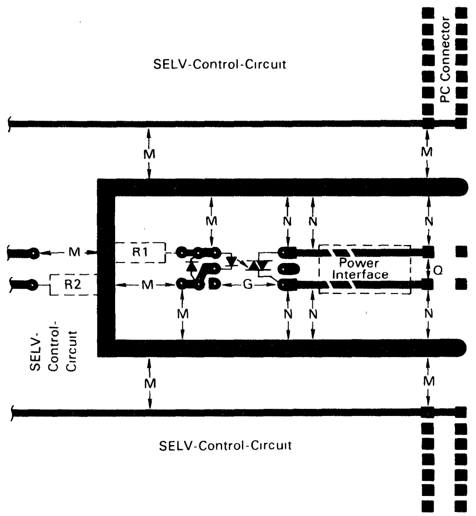
OPTOCOUPLER MOUNTING ON PC BOARDS FOR SAFETY CLASS II WITH CLEARANCE

Applicable for
with Slit — VDE 0860
without Slit — VDE 0804d
with/without Slit — VDE 0110b



Optocoupler Mounting on PC-Boards for Safety Class II with clearance P ⩾ 6 0 mm and creepage path G = 8 0 mm and Slit in the PC-Board with Slit length = 12 7 mm and Slit thickness H = 2 0 mm

OPTOCOUPLER MOUNTING ON PC BOARD ACCORDING TO SAFETY CLASS I WITH ONLY ONE PC BOARD PLUG CONNECTION

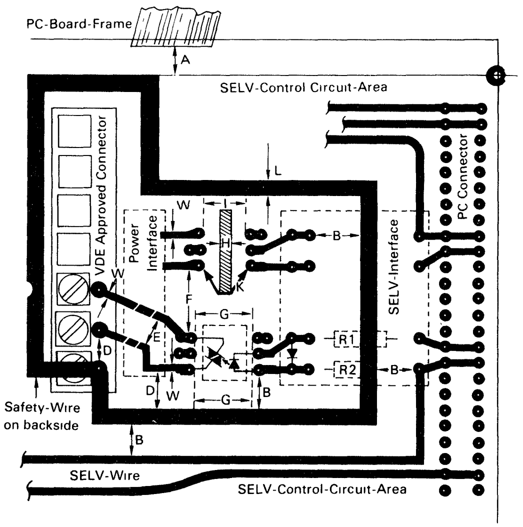


G = 8.0 mm
M = 8.0 mm
N = 8.0 mm

Applicable for

VDE 0113
VDE 0160P1
VDE 0160P2
VDE 0804
VDE 0804d
VDE 0831
VDE 0832
VDE 0833
VDE 0860
VDE 0110b
VDE 0805
VDE 0806

OPTOCOUPLER MOUNTING ON PC BOARD ACCORDING TO SAFETY CLASS I WITH ONE PLUG CONNECTION FOR THE SELV-CONTROL CIRCUIT AND ONE SCREW-CONNECTION FOR THE POWER-INTERFACE



G = 8.0 mm
K = 8.0 mm
A = 8.0 mm
B = 8.0 mm
D = 8.0 mm
H = 2.0 mm
I = 5.6 mm

E, L, W depends on the Application

Applicable for

VDE 0804 without Slit
VDE 0110b with/without Slit

EXAMPLES FOR SAFETY APPLICATIONS OF THE MOC600A FAMILY

The VDE approval of the MOC600A family covers many VDE standards for electrical and electronic equipment.

EXAMPLE 1.

Safety of data processing equipment IEC435/85 – VDE0805

Subclause 2.9.2
Clearance 8.0 mm Less for printed circuit boards
Creepage 8.0 mm with conformal coating
Subclause 2.9.7 Potted Components
Subclause 5.3.3 V_{ISO} 3750 Vac RMS 1 Minute

EXAMPLE 2.

Safety of electrically energized office machines IEC380 – VDE0806 In connection with the VDE decision to use IEC435/85 – VDE0805

Subclause 2.9.7 for Potted Components:
Subclause 29.1.1
Clearance 8.0 mm
Creepage 8.0 mm
Subclause 2.9.7 (VDE0805) Potted Components
Subclause 5.3.3 V_{ISO} 3750 Vac RMS 1 Minute

EXAMPLE 3.

Safety requirements for mains operated electronic and related apparatus for household and similar use (Radio, TV, Electronic Organs):

VDE 0860/8.81 and IEC65, 4 Edition 1976 inclusive amendments 12B (co) 133/134/135/138/139
Clause 10
Subclause 10.1 and Figure 7A
Surge Isolation Voltage
50 Discharges of 10 kV charged 1.0 nF
12 Discharges Max at 1 minute
Subclause 10.3 and Figures 15:
Isolation Resistance higher than 4 MΩ
Isolation voltage higher 4240 Vdc at 1 minute and at T_A = 100 degrees Celsius
Subclause 9.3.8
Minimum thickness through isolation 0.4 mm
Subclause 9.3.4 and 9.3.5 and 4.3.1 and Table 2 and Clause 13 and Figure 13:
Clearances and creepage distance higher than 6.0 mm at 354 V Curve B

EXAMPLE 4.

VDE Specifications for the electrical equipment of manufacturing and processing machines with rated voltage up to 1000 V (Individual controls) VDE 0113/12.73 and IEC 204

Subclause 4.1.1
Clearances 8.0 mm
Creepage Distance 8.0 mm

Clause 15
Isolation Resistance 1.0 MΩ
Isolation Voltage 1.5 kVac

EXAMPLE 5.

Requirements for electrical trains: VDE 0115/3.65 and VDE 0115A/8.75

Clause 15
Isolation Voltage 2.5 kVac for the VDE 0115-Isolation Group D
Subclause 15A according VDE 110
Clearance 8.0 mm
Creepage Distance 8.0 mm

EXAMPLE 6.

VDE Specifications for the electrical equipment of electrical power installations with electronic devices:

VDE 0160 Part 1/7.71 and VDE 0160 Part 1B/5.76
Clause 13
Subclause 13B and Subclause 24D
Isolation Resistance 1 MΩ
Clause 14 and Subclause 28C
Clearances 8.0 mm
Creepage Distances 8.0 mm
Clause 24
Isolation Voltage 2.7 kVac at 1 minute for the nominal — Operation Isolation Voltage or Working Isolation Voltage of $V_{ISO(nom)}$ = 250 Vac or 300 Vdc

EXAMPLE 7.

VDE 160 Part 2/10.75
Subclause 3.10 and 3.11
Clearance 8.0 mm
Creepage Distance 8.0 mm
Subclause 3.10 and 4.4
Isolation Voltage 3.6 kVdc at 1 minute = for $V_{ISO(nom)}$ = 500 Vac or 600 Vdc
Isolation Resistance 1.0 MΩ

EXAMPLE 8.

Specifications for telecommunications apparatus including data processing equipments:

VDE 0804/5.72 and VDE 0804/2.80
Clause 9
Clearance 8.0 mm
Creepage Distance 8.0 mm
Clause 14
Isolation Voltage 2.5 kVac at 1 minute for $V_{ISO(nom)}$ = 250 Vac
Clause 18
Subclause 18C
Isolation Voltage 2.5 kVac at 1 minute for $V_{ISO(nom)}$ = 250 Vac
Subclause 18D
Isolation Resistance 2.0 MΩ

EXAMPLE 9.

Electric signal systems for railroads:

VDE 0831/2.80
Clause 4.5 according VDE 110
Clearances 8.0 mm
Creepage Distance 8.0 mm
Clause 4.5 and Subclause 5.9.3
Isolation Voltage 2.0 kVac at 1 minute for $V_{ISO(nom)}$ = 250 Vac

EXAMPLE 10.

Road traffic signal systems:

VDE 832/7.81
Subclause 5.2 and 9.2.4
Isolation Voltage according VDE 804 Subclause 14, 2.5 kVac at 1 minute for $V_{ISO(nom)}$ = 250 Vac
Subclause 9.2 according VDE 110
Clearances 8.0 mm
Creepage Distance 8.0 mm
Subclause 9.2.1 according VDE 804

EXAMPLE 11.

Jeopardy alarm systems for fire, hold-up and intrusion general requirements:

VDE 0833 Part 1/11.78 and VDE 0833 Part 1A/3.80
Subclause 4.1 according VDE 804
Isolation Voltage 2.5 kVac at 1 minute for $V_{ISO(nom)}$ = 250 Vac
Isolation Resistance 2.0 MΩ at 1 minute
Clearance 8.0 mm
Creepage Distance 8.0 mm

THEORY AND CHARACTERISTICS OF PHOTOTRANSISTORS

Prepared By:
John Bliss

INTRODUCTION

Phototransistor operation is based on the sensitivity of a pn junction to radiant energy. If radiant energy of proper wave-length is made to impinge on a junction, the current through that junction will increase. This optoelectronic phenomenon has provided the circuit designer with a device for use in a wide variety of applications. However, to make optimum use of the phototransistor, the designer should have a sound grasp of its operating principles and characteristics.

HISTORY

The first significant relationships between radiation and electricity were noted by Gustav Hertz in 1887. Hertz observed that under the influence of light, certain surfaces were found to liberate electrons.

In 1900, Max Planck proposed that light contained energy in discrete bundles or packets which he called photons. Einstein formulated this theory in 1905, showing that the energy content of each proton was directly proportional to the light frequency:

$$E = hf, \qquad (1)$$

where E is the photon energy,
h is Planck's constant, and
f is the light frequency.

Planck theorized that a metal had associated with it a work function, or binding energy for free electrons. If a photon could transfer its energy to a free electron, and that energy exceeded the work function, the electron could be liberated from the surface. The presence of an electric field could enhance this by effectively reducing the work function. Einstein extended Planck's findings by showing that the velocity, and hence the momentum of an emitted electron, depended on the work function and the light frequency.

PHOTO EFFECT IN SEMICONDUCTORS

Bulk Crystal

If light of proper wavelength impinges on a semiconductor crystal, the concentration of charge carriers is found to increase. Thus, the crystal conductivity will increase:

$$\sigma = q\,(\mu_e\, n + \mu_h\, p), \qquad (2)$$

where σ is the conductivity,
q is the electron charge,
μ_e is the electron mobility,
μ_h is the hole mobility,
n is the electron concentration, and
p is the hole concentration.

The process by which charge-carrier concentration is increased is shown in Figure 1. The band structure of the semiconductor is shown, with an energy gap, or forbidden region, of Eg electron volts. Radiation from two light sources is shown striking the crystal. Light frequency f_1 is sufficiently high that its photon energy, hf_1, is slightly greater than the energy gap. This energy is transferred to a bound electron at site one in the valence band, and the electron is excited to a higher energy level, site one in the conduction band, where it is free to serve as a current carrier. The hole left behind at site one in the valence band is also free to serve as a current carrier.

The photon energy of the lower-frequency light, hf_2, is less than the band gap, and an electron freed from site two in the valence band will rise to a level in the forbidden region, only to release this energy and fall back into the valence band and recombine with a hole at site three.

The above discussion implies that the energy gap, Eg, represents a threshold of response to light. This is true, however, it is not an abrupt threshold. Throughout the photo-excitation process, the law of conservation of mo-

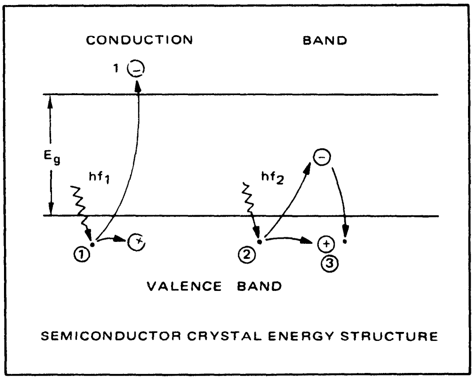


FIGURE 1 – Photoeffect in a Semiconductor

mentum applies. The momentum and density of hole-electron sites are highest at the center of both the valence and conduction bands, and fall to zero at the upper and lower ends of the bands. Therefore, the probability of an excited valence-band electron finding a site of like momentum in the conduction band is greatest at the center of the bands and lowest at the ends of the bands. Consequently, the response of the crystal to the impinging light is found to rise from zero at a photon energy of Eg electron volts, to a peak at some greater energy level, and then to fall to zero again at an energy corresponding to the difference between the bottom of the valence band and the top of the conduction band.

The response is a function of energy, and therefore of frequency, and is often given as a function of reciprocal frequency, or, more precisely, of wave length. An example is shown in Figure 2 for a crystal of cadmium-selenide. On the basis of the information given so far, it would seem reasonable to expect symmetry in such a curve; however, trapping centers and other absorption phenomena affect the shape of the curve[1].

The optical response of a bulk semiconductor can be modified by the addition of impurities. Addition of an acceptor impurity, which will cause the bulk material to become p-type in nature, results in impurity levels which lie somewhat above the top of the valence band. Photoexcitation can occur from these impurity levels to the conduction band, generally resulting in a shifting and reshaping of the spectral response curve. A similar modification of response can be attributed to the donor impurity levels in n-type material.

PN Junctions

If a pn junction is exposed to light of proper frequency, the current flow across the junction will tend to increase. If the junction is forward-biased, the net increase will be relatively insignificant. However, if the junction is reverse-biased, the change will be quite appreciable. Figure 3 shows the photo effect in the junction for a frequency well within the response curve for the device.

Photons create hole-electron pairs in the crystal on both sides of the junction. The transferred energy promotes the electrons into the conduction band, leaving the holes in the valence band. The applied external bias provides an electric field, $\mathcal{E}$, as shown in the figure. Thus the photo-induced electrons in the p-side conduction band will flow down the potential hill at the junction into the n-side and from there to the external circuit. Likewise, holes in the valence band of the n-side will flow across the junction into the p-side where they will add to the external current.

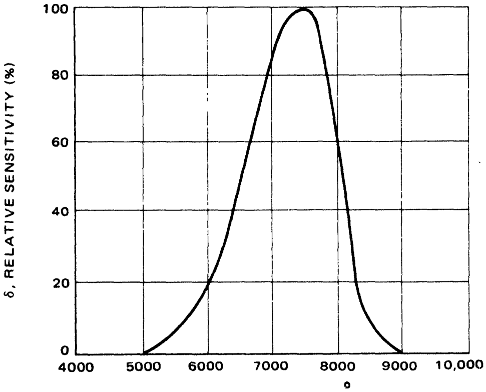


FIGURE 2 – Spectral Response of Cadmium Selenide

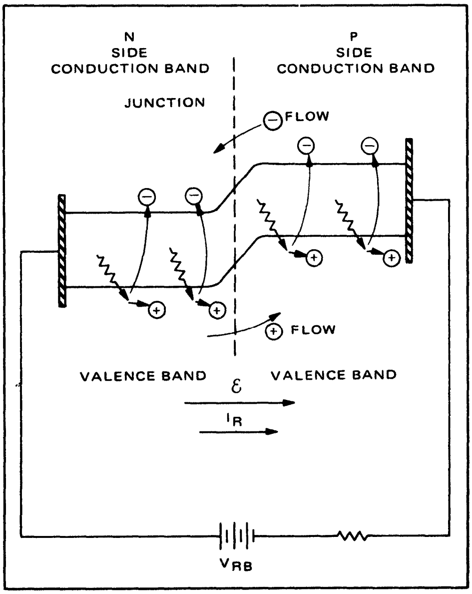


FIGURE 3 – Photo Effect in a Reverse-Biased PN Junction

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[1] See references for a detailed discussion of these.

Under dark conditions, the current flow through the reverse-biased diode is the reverse saturation current, I_o. This current is relatively independent of the applied voltage (below breakdown) and is basically a result of the thermal generation of hole-electron pairs.

When the junction is illuminated, the energy transferred from photons creates additional hole-electron pairs. The number of hole-electron pairs created is a function of the light intensity.

For example, incident monochromatic radiation of H (watts/cm^2) will provide P photons to the diode:

$$P = \frac{\lambda H}{hc}, \tag{3}$$

where λ is the wavelength of incident light,

h is Planck's constant, and

c is the velocity of light.

The increase in minority carrier density in the diode will depend on P, the conservation of momentum restriction, and the reflectance and transmittance properties of the crystal. Therefore, the photo current, I_λ, is given by

$$I_\lambda = \eta F q A, \tag{4}$$

where η is the quantum efficiency or ratio of current carriers to incident photons,

F is the fraction of incident photons transmitted by the crystal,

q is the charge of an electron, and

A is the diode active area.

Thus, under illuminated conditions, the total current flow is

$$I = I_o + I_\lambda. \tag{5}$$

If I_λ is sufficiently large, I_o can be neglected, and by using the spectral response characteristics and peak spectral sensitivity of the diode, the total current is given approximately by

$$I \approx \delta S_R H, \tag{6}$$

where δ is the relative response and a function of radiant wavelength,

S_R is the peak spectral sensitivity, and

H is the incident radiation.

The spectral response for a silicon photo-diode is given in Figure 4.

Using the above relations, an approximate model of the diode is given in Figure 5. Here, the photo and thermally generated currents are shown as parallel current sources. C represents the capacitance of the reverse-biased junction while G represents the equivalent shunt conductance of the diode and is generally quite small. This model applies only for reverse bias, which, as mentioned above, is the normal mode of operation.

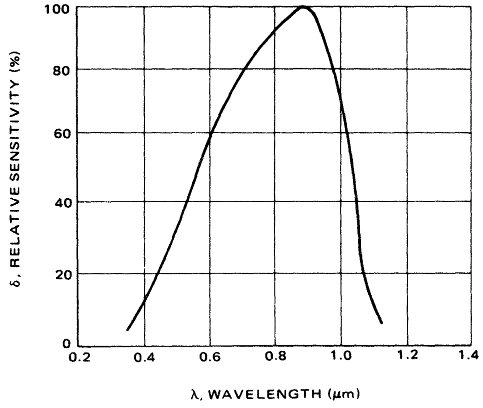


FIGURE 4 – Spectral Response of Silicon Photodiode

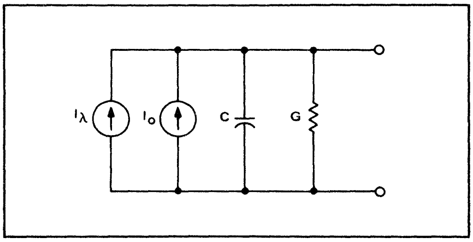


FIGURE 5 – Approximate Model of Photodiode

Photo Transistor

If the pn junction discussed above is made the collector-base diode of a bipolar transistor, the photo-induced current is the transistor base current. The current gain of the transistor will thus result in a collector-emitter current of

$$I_C = (h_{fe} + 1)\, I_\lambda, \tag{7}$$

where I_C is the collector current,

h_{fe} is the forward current gain, and

I_λ is the photo induced base current.

The base terminal can be left floating, or can be biased up to a desired quiescent level. In either case, the collector-base junction is reverse biased and the diode current is the reverse leakage current. Thus, photo-stimulation will result in a significant increase in diode, or base current, and with current gain will result in a significant increase in collector current.

The energy-band diagram for the photo transistor is shown in Figure 6. The photo-induced base current is returned to the collector through the emitter and the external circuitry. In so doing, electrons are supplied to the base region by the emitter where they are pulled into the collector by the electric field $\mathcal{E}$.

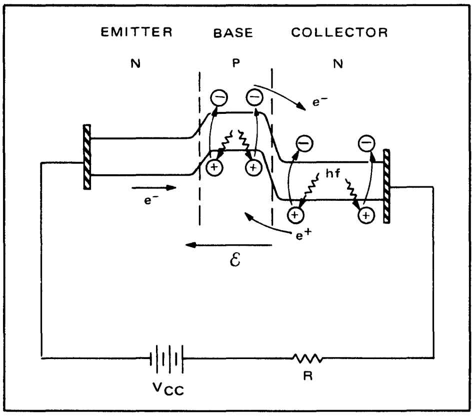


FIGURE 6 – Photoeffect in a Transistor

The model of the photo diode in Figure 5 might also be applied to the phototransistor, however, this would be severely limited in conveying the true characteristics of the transistor. A more useful and accurate model can be obtained by using the hybrid-pi model of the transistor and adding the photo-current generator between collector and base. This model appears in Figure 7.

Assuming a temperature of 25°C, and a radiation source at the wave length of peak response (i.e., $\delta = 1$), the following relations apply:

$$I_\lambda \approx S_{RCBO} \cdot H, \qquad (8a)$$

$$gm = 40\, i_c, \text{ and} \qquad (8b)$$

$$r_{be} = h_{fe}/g_m, \qquad (8c)$$

where S_{RCBO} is the collector-base diode radiation sensitivity with open emitter,

g_m is the forward transconductance,

i_c is the collector current, and

r_{be} is the effective base-emitter resistance.

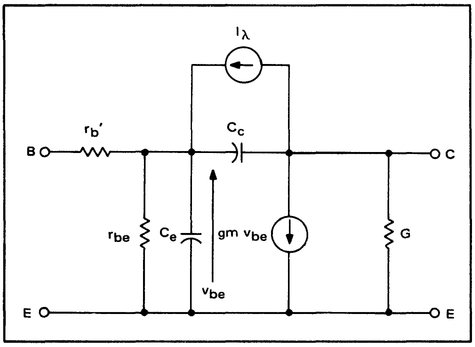


FIGURE 7 – Hybrid-pi Model of Phototransistor

In most cases $r'_b \ll r_{be}$, and can be neglected. The open-base operation is represented in Figure 8. Using this model, a feel for the high-frequency response of the device may be obtained by using the relationship

$$f_t \approx \frac{g_m}{2\pi C_e}, \qquad (9)$$

where f_t is the device current-gain-bandwidth product.

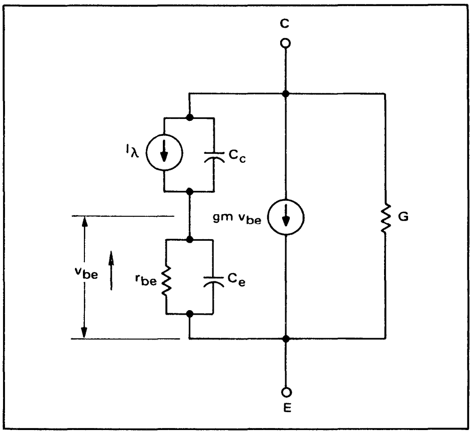


FIGURE 8 – Floating Base Approximate Model of Phototransistor

STATIC ELECTRICAL CHARACTERISTICS OF PHOTOTRANSISTORS

Spectral Response

As mentioned previously, the spectral response curve provides an indication of a device's ability to respond to radiation of different wave lengths. Figure 9 shows the spectral response for constant energy radiation for the Motorola MRD300 phototransistor series. As the figure indicates, peak response is obtained at about 8000 Å (Angstroms), or 0.8 μm.

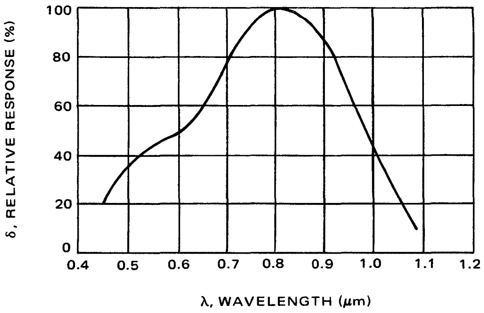


FIGURE 9 – Constant Energy Spectral Response for MRD300

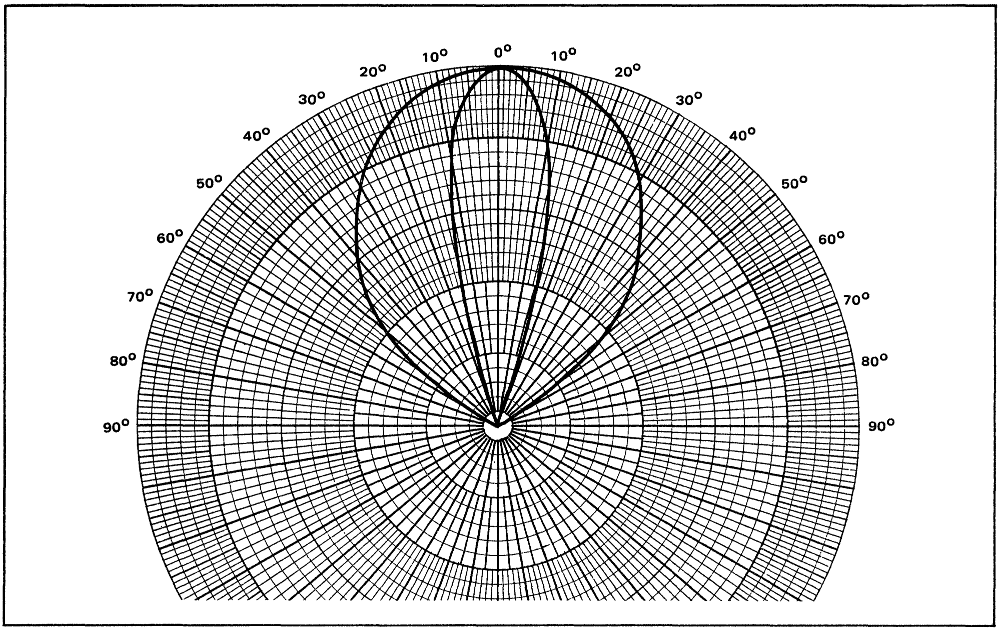


FIGURE 10 – Polar Response of MRD300. Inner Curve with Lens, Outer Curve with Flat Glass.

Angular Alignment

Lambert's law of illumination states that the illumination of a surface is proportional to the cosine of the angle between the normal to the surface and the direction of the radiation. Thus, the angular alignment of a phototransistor and radiation source is quite significant. The cosine proportionality represents an ideal angular response. The presence of an optical lens and the limit of window size further affect the response. This information is best conveyed by a polar plot of the device response. Such a plot in Figure 10 gives the polar response for the MRD300 series.

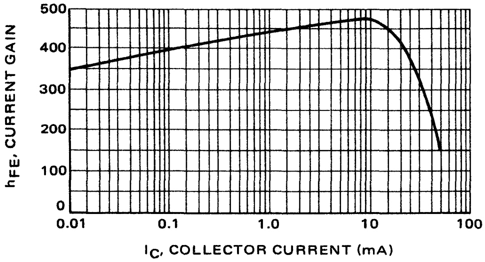


FIGURE 11 – DC Current Gain versus Collector Current

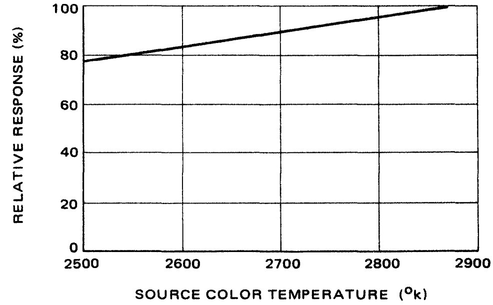


FIGURE 12 – Relative Response of MRD300 versus Color Temperature

DC Current Gain

The sensitivity of a photo transistor is a function of the collector-base diode quantum efficiency and also of the dc current gain of the transistor. Therefore, the overall sensitivity is a function of collector current. Figure 11 shows the collector current dependence of dc current gain.

Color Temperature Response

In many instances, a photo transistor is used with a broad band source of radiation, such as an incandescent lamp. The response of the photo transistor is therefore dependent on the source color temperature. Incandescent sources are normally operated at a color temperature of 2870°K, but, lower-color-temperature operation is not uncommon. It therefore becomes desirable to know the result of a color temperature difference on the photo sensitivity. Figure 12 shows the relative response of the MRD300 series as a function of color temperature.

Temperature Coefficient of Ip

A number of applications call for the use of phototransistors in temperature environments other than normal room temperature. The variation in photo current with temperature changes is approximately linear with a positive slope of about 0.667%/°C.

The magnitude of this temperature coefficient is primarily a result of the increase in h_{FE} versus temperature, since the collector-base photo current temperature coefficient is only about 0.1%/°C.

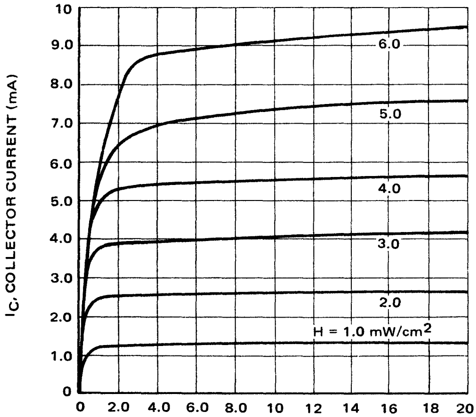


FIGURE 13 – Collector Characteristics for MRD300

Collector Characteristics

Since the collector current is primarily a function of impinging radiation, the effect of collector-emitter voltage, below breakdown, is small. Therefore, a plot of the $I_C–V_{CE}$ characteristics with impinging radiation as a parameter, are very similar to the same characteristics with I_B as a parameter. The collector family for the MRD300 series appears in Figure 13.

Radiation Sensitivity

The capability of a given phototransistor to serve in a given application is quite often dependent on the radiation sensitivity of the device. The open-base radiation sensitivity for the MRD300 series is given in Figure 14. This indicates that the sensitivity is approximately linear with respect to impinging radiation. The additional capability of the MRD300 to be pre-biased gives rise to interest in the sensitivity as a function of equivalent base resistance. Figure 15 gives this relationship.

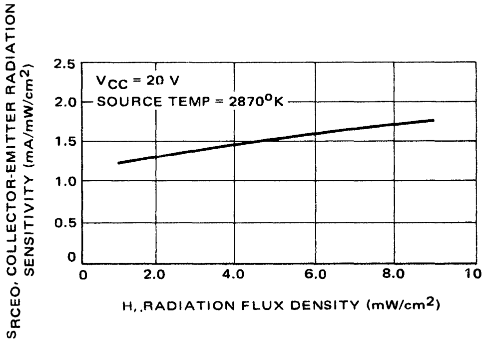


FIGURE 14 – Open Base Sensitivity versus Radiation for MRD300

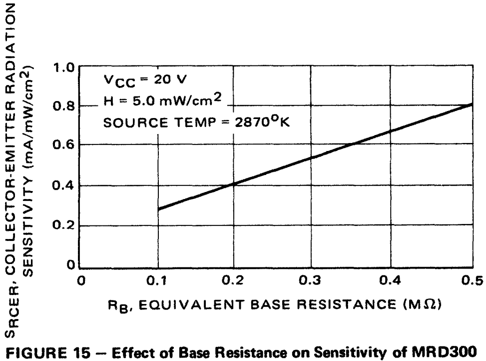


FIGURE 15 – Effect of Base Resistance on Sensitivity of MRD300

Capacitance

Junction capacitance is the significant parameter in determining the high frequency capability and switching speed of a transistor. The junction capacitances of the MRD300 as a function of junction voltages are given in Figure 16.

DYNAMIC CHARACTERISTICS OF PHOTOTRANSISTORS

Linearity

The variation of h_{FE} with respect to collector current results in a non-linear response of the photo transistor over

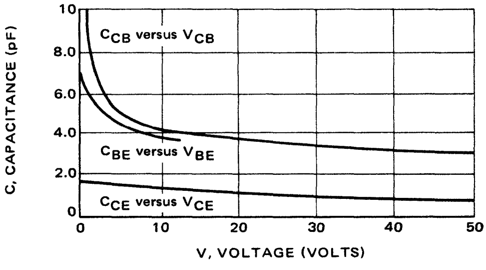


FIGURE 16 – Junction Capacitances versus Voltage for MRD300

large signal swings. However, the small-signal response is approximately linear. The use of a load line on the collector characteristic of Figure 13 will indicate the degree of linearity to be expected for a specific range of optical drive.

Frequency Response

The phototransistor frequency response, as referred to in the discussion of Figures 7 and 8, is presented in Figure 17. The device response is flat down to dc with the rolloff frequency dependent on the load impedance as well as on the device. The response is given in Figure 17 as the 3-dB frequency as a function of load impedance for two values of collector current.

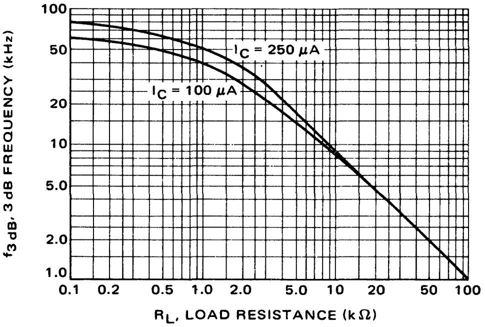


FIGURE 17 — 3 dB Frequency versus Load Resistance for MRD300

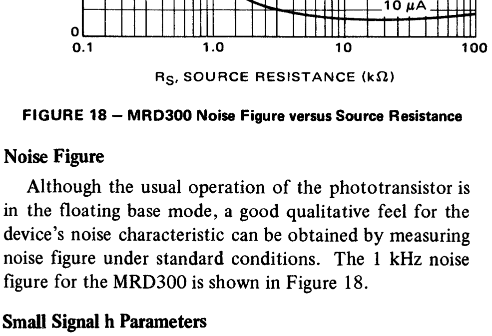


FIGURE 18 — MRD300 Noise Figure versus Source Resistance

Noise Figure

Although the usual operation of the phototransistor is in the floating base mode, a good qualitative feel for the device's noise characteristic can be obtained by measuring noise figure under standard conditions. The 1 kHz noise figure for the MRD300 is shown in Figure 18.

Small Signal h Parameters

As with noise figure, the small-signal h-parameters, measured under standard conditions, give a qualitative feel for the device behavior. These are given as functions of collector current in Figure 19. With this information, the device can be analyzed in the standard hybrid model of Figure 20(a); by use of the conversions of Table I, the equivalent r-parameter model of Figure 20(b) can be used.

TABLE I — Parameter Conversions

$$h_{fb} = \frac{h_{fe}}{1 + h_{fe}}$$

$$r_c = \frac{h_{fe} + 1}{h_{oe}}$$

$$r_e = \frac{h_{re}}{h_{oe}}$$

$$r_b = h_{ie} - \frac{h_{re}(1 + h_{fe})}{h_{oe}}$$

SWITCHING CHARACTERISTICS OF PHOTOTRANSISTORS

In switching applications, two important requirements of a transistor are:

(1) speed
(2) ON voltage

Since some optical drives for phototransistors can provide fast light pulses, the same two considerations apply.

Switching Speed

If reference is made to the model of Figure 8, it can be seen that a fast rise in the current I_λ will not result in an equivalent instantaneous increase in collector-emitter current. The initial flow of I_λ must supply charging current to C_{CB} and C_{BE}. Once these capacitances have been charged, I_λ will flow through r_{be}. Then the current generator, $g_m \cdot v_{be}$, will begin to supply current. During turn-off, a similar situation occurs. Although I_λ may instantaneously drop to zero, the discharge of C_{CB} and C_{BE} through r_{be} will maintain a current flow through the collector. When the capacitances have been discharged, V_{be} will fall to zero and the current, $g_m \cdot V_{be}$, will likewise drop to zero. (This discussion assumes negligible leakage currents). These capacitances therefore result in turn-on and turn-off delays, and in rise and fall times for switching applications just as found in conventional bipolar switching transistors. And, just as with conventional switching, the times are a function of drive. Figure 21 shows the collector current (or drive) dependence of the turn-on delay and rise times. As indicated the delay time is dependent on the device only; whereas the rise-time is dependent on both the device and the load.

If a high-intensity source, such as a xenon flash lamp, is used for the optical drive, the device becomes optically saturated unless large optical attenuation is placed between source and detector. This can result in a significant storage time during the turn off, especially in the floating-base mode since stored charge has no direct path out of the

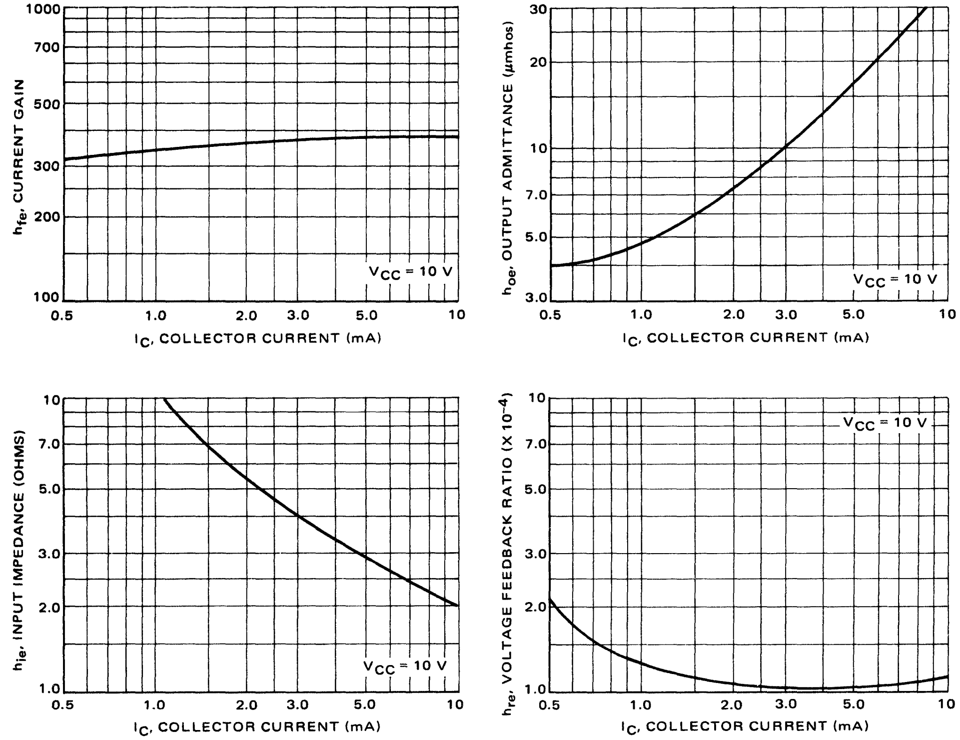
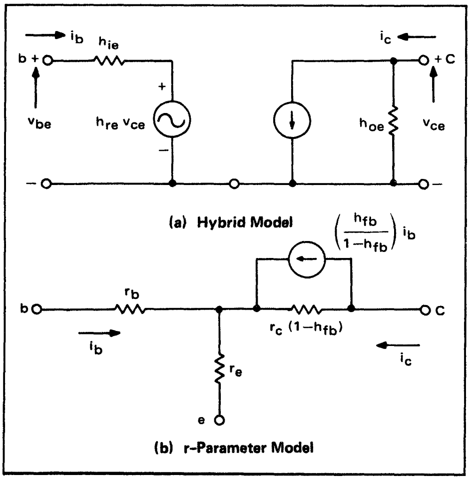


FIGURE 19 — 1 kHz h-Parameters versus Collector Current for MRD300



(a) Hybrid Model

(b) r-Parameter Model

FIGURE 20 — Low Frequency Analytical Models of Phototransistor Without Photo Current Generator

base region. However, if a non-saturating source, such as a GaAs diode, is used for switching drive, the storage, or turn-off delay time is quite low as shown in Figure 22.

Saturation Voltage

An ideal switch has zero ON impedance, or an ON voltage drop of zero. The ON saturation voltage of the MRD300 is relatively low, approximately 0.2 volts. For a given collector current, the ON voltage is a function of drive, and is shown in Figure 23.

APPLICATIONS OF PHOTOTRANSISTORS

As mentioned previously, the phototransistor can be used in a wide variety of applications. Figure 24 shows two phototransistors in a series-shunt chopper circuit. As Q_1 is switched ON, Q_2 is OFF, and when Q_1 is switched OFF, Q_2 is driven ON.

Logic circuitry featuring the high input/output electrical isolation of photo transistors is shown in Figure 25.

Figure 26 shows a linear application of the phototransistor. As mentioned previously, the linearity is obtained for small-signal swings.

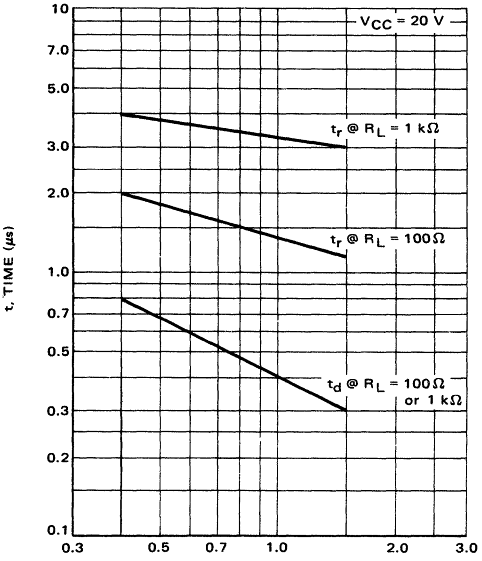


FIGURE 21 – Switching Delay and Rise Times for MRD300

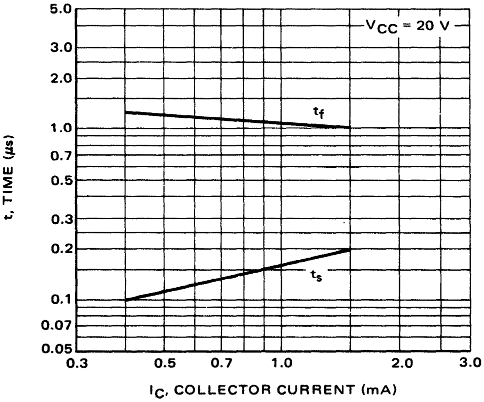


FIGURE 22 – Switching Storage and Fall Times for MRD300

A double-pole, single-throw relay is shown in Figure 27.

In general, the phototransistor can be used in counting circuitry, level indications, alarm circuits, tachometers, and various process controls.

Conclusion

The phototransistor is a light-sensitive active device of moderately high sensitivity and relatively high speed. Its response is both a function of light intensity and wavelength, and behaves basically like a standard bipolar transistor with an externally controlled collector-base leakage current.

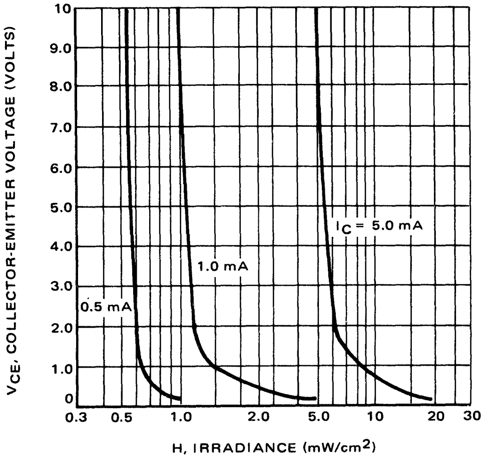


FIGURE 23 – Collector Emitter Saturation Voltage as a Function of Irradiance for MRD300

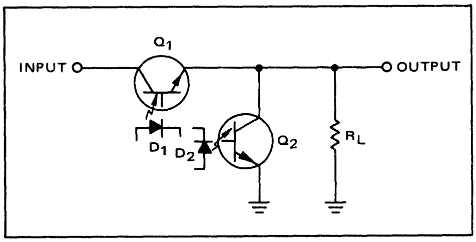


FIGURE 24 – Series-Shunt Chopper Circuit Using MRD300 Phototransistors and GaAs Light Emitting Diodes (LEDs)

APPENDIX I

Radiant energy covers a broad band of the electromagnetic spectrum. A relatively small segment of the band is the spectrum of visible light. A portion of the electromagnetic spectrum including the range of visible light is shown in Figure I-1.

The portion of radiant flux, or radiant energy emitted per unit time, which is visible is referred to as luminous flux. This distinction is due to the inability of the eye to respond equally to like power levels of different visible wavelengths. For example, if two light sources, one green and one blue are both emitting like wattage, the eye will perceive the green light as being much brighter than the blue. Consequently, when speaking of visible light of varying color, the watt becomes a poor measure of brightness. A more meaningful unit is the lumen. In order to obtain a clear understanding of the lumen, two other definitions are required.

The first of these is the standard source (Fig. I-2). The standard source, adopted by international agreement, con-

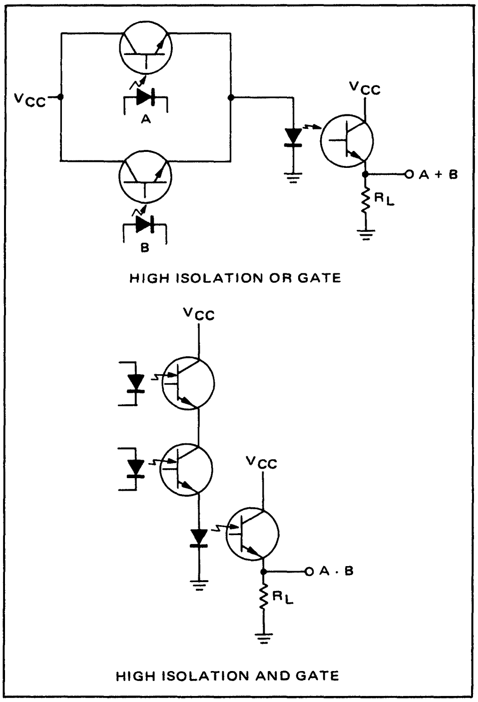


FIGURE 25 – Logic Circuits Using the MRD300 and LEDs

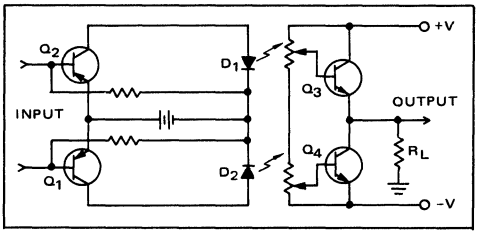


FIGURE 26 – Small Signal Linear Amplifier Using MRD300 and LEDs

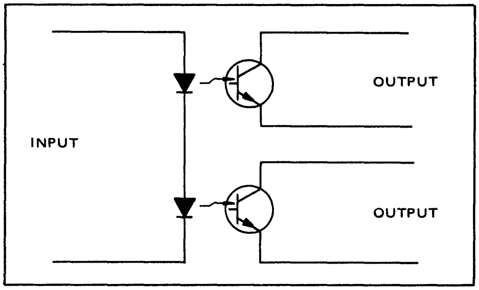


FIGURE 27 – DPST Relay Using MRD300s and LEDs

sists of a segment of fused thoria immersed in a chamber of platinum. When the platinum is at its melting point, the light emitted from the chamber approximates the radiation of a black body. The luminous flux emitted by the source is dependent on the aperture and cone of radiation. The cone of radiation is measured in terms of the solid angle.

The concept of a solid angle comes from spherical geometry. If a point is enclosed by a spherical surface and a set of radial lines define an area on the surface, the radial lines also subtend a solid angle. This angle, ω, is shown in Figure I-3, and is defined as

$$\omega = \frac{A}{r^2}, \qquad \text{(I-1)}$$

where A is the described area and r is the spherical radius.

If the area A is equal to r^2, then the solid angle subtended is one unit solid angle or one steradian, which is nothing more than the three-dimensional equivalent of a radian.

With the standard source and unit solid angle established, the lumen can be defined.

A lumen is the luminous flux emitted from a standard source and included within one steradian.

Using the concept of the lumen, it is now possible to define other terms of illumination.

Illuminance

If a differential amount of luminous flux, dF, is impinging on a differential area, dA, the illuminance, E, is given by

$$E = \frac{dF}{dA}. \qquad \text{(I-2)}$$

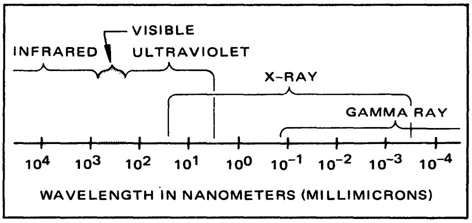


FIGURE I–1 – Portion of Electromagnetic Spectrum

Illuminance is most often expressed in lumens per square foot, or foot-candles. If the illuminance is constant over the area, (I-2) becomes

$$E = F/A. \qquad \text{(I-3)}$$

Luminous Intensity

When the differential flux, dF, is emitted through a differential solid angle, dω, the luminous intensity, I, is given by

$$I = \frac{dF}{d\omega}. \qquad \text{(I-4)}$$

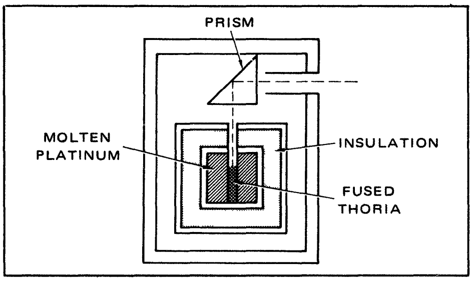


FIGURE I–2 – International Standard Source

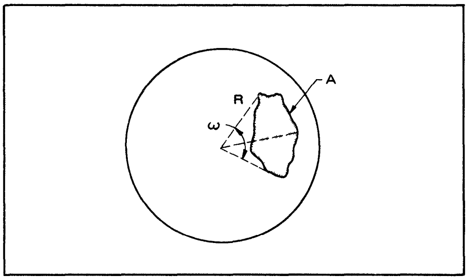


FIGURE I–3 – Solid Angle, ω

Luminous intensity is most often expressed in lumens per steradian or candela. If the luminous intensity is constant with respect to the angle of emission, (I-4) becomes:

$$I = \frac{F}{\omega}. \qquad \text{(I-5)}$$

If the wavelength of visible radiation is varied, but the illumination is held constant, the radiative power in watts will be found to vary. This again illustrates the poor quality of the watt as a measure of illumination. A relation between illumination and radiative power must then be specified at a particular frequency. The point of specification has been taken to be at a wavelength of 0.555 μm, which is the peak of spectral response of the human eye. At this wavelength, 1 watt of radiative power is equivalent to 680 lumens.

APPENDIX II
OPTOELECTRONIC DEFINITIONS

F, Luminous Flux: Radiant flux of wavelength within the band of visible light.

Lumen: The luminous flux emitted from a standard source and included within one steradian (solid angle equivalent of a radian).

H, Radiation Flux Density (Irradiance): The total incident radiation energy measured in power per unit area (e.g., mW/cm^2).

E, Luminous Flux Density (Illuminance): Radiation flux density of wavelength within the band of visible light. Measured in $lumens/ft^2$ or foot candles. At the wavelength of peak response of the human eye. 0.555 μm (0.555×10^{-6}m), 1 watt of radiative power is equivalent to 680 lumens.

S_R, Radiation Sensitivity: The ratio of photo-induced current to incident radiant energy, the latter measured at the plane of the lens of the photo device.

S_I, Illumination Sensitivity: The ratio of photo-induced current to incident luminous energy, the latter measured at the plane of the lens of the photo device.

Spectral Response: Sensitivity as a function of wavelength of incident energy. Usually normalized to peak sensitivity.

Constants

Planck's constant: $h = 4.13 \times 10^{-15}$ eV-s.
electron charge: $q = 1.60 \times 10^{-19}$ coulomb.
velocity of light: $c = 3 \times 10^{8}$ m/s.

Illumination Conversion Factors

Multiply	By	To Obtain
$lumens/ft^2$	1	ft. candles
$lumens/ft^{2*}$	1.58×10^{-3}	mW/cm^2
candlepower	4π	lumens

*At 0.555 μm.

BIBLIOGRAPHY AND REFERENCES

1. Fitchen, Franklin C., Transistor Circuit Analysis and Design, D. Van Nostrand Company, Inc., Princeton 1962.
2. Hunter, Lloyd P., ed., Handbook of Semiconductor Electronics, Sect 5., McGraw-Hill Book Co., Inc., New York 1962.
3. Jordan, A.G. and A.G. Milnes, "Photoeffect on Diffused PN Junctions with Integral Field Gradients", IRE Transactions on Electron Devices, October 1960.
4. Millman, Jacob, Vacuum-tube and Semiconductor Electronics, McGraw-Hill Book Co., Inc., New York 1958.
5. Sah, C.T., "Effect of Surface Recombination and Channel on PN Junction and Transistor Characteristics", IRE Transactions on Electron Devices, January 1962.
6. Sears, F.W. and M.W. Zemansky, University Physics, Addison-Wesley Publishing Co., Inc., Reading, Massachusetts 1962.
7. Shockley, William, Electrons and Holes in Semiconductors, D. Van Nostrand Company, Inc., Princeton 1955.

APPLICATIONS OF PHOTOTRANSISTORS IN ELECTRO-OPTIC SYSTEMS

INTRODUCTION

A phototransistor is a device for controlling current flow with light. Basically, any transistor will function as a phototransistor if the chip is exposed to light, however, certain design techniques are used to optimize the effect in a phototransistor.

Just as phototransistors call for special design techniques, so do the circuits that use them. The circuit designer must supplement his conventional circuit knowledge with the terminology and relationships of optics and radiant energy. This note presents the information necessary to supplement that knowledge. It contains a short review of phototransistor theory and characteristics, followed by a detailed discussion of the subjects of irradiance, illuminance, and optics and their significance to phototransistors. A distinction is made between low-frequency/steady-state design and high-frequency design. The use of the design information is then demonstrated with a series of typical electro-optic systems.

PHOTOTRANSISTOR THEORY[1]

Phototransistor operation is a result of the photo-effect in solids, or more specifically, in semiconductors. Light of a proper wavelength will generate hole-electron pairs within the transistor, and an applied voltage will cause these carriers to move, thus causing a current to flow. The intensity of the applied light will determine the number of carrier pairs generated, and thus the magnitude of the resultant current flow.

In a phototransistor the actual carrier generation takes place in the vicinity of the collector-base junction. As shown in Figure 1 for an NPN device, the photo-generated holes will gather in the base. In particular, a hole generated in the base will remain there, while a hole generated in the collector will be drawn into the base by the strong field at the junction. The same process will result in electrons tending to accumulate in the collector. Charge will not really accumulate however, and will try to evenly distribute throughout the bulk regions. Consequently, holes will diffuse across the base region in the direction of the emitter junction. When they reach the junction they will be injected into the emitter. This in turn will cause the emitter to inject electrons into the base. Since the emitter injection efficiency is much larger than the base injection effeciency, each injected hole will result in many injected electrons.

It is at this point that normal transistor action will occur. The emitter injected electrons will travel across the base and be drawn into the collector. There, they will combine with the photo-induced electrons in the collector to appear as the terminal collector current.

Since the actual photogeneration of carriers occurs in the collector base region, the larger the area of this region, the more carriers are generated, thus, as Figure 2 shows, the transistor is so designed to offer a large area to impinging light.

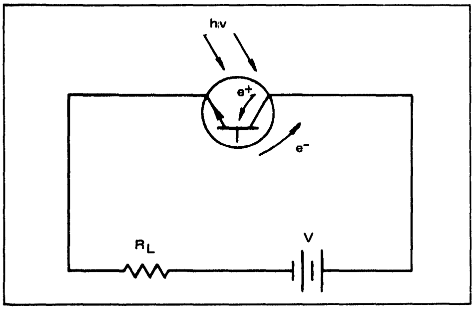


FIGURE 1 – Photo-Generated Carrier Movement in a Phototransistor

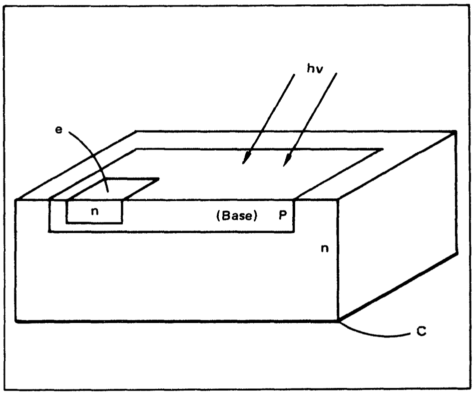


FIGURE 2 – Typical Double-Diffused Phototransistor Structure

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[1] For a detailed discussion see Motorola Application Note AN-440, "Theory and Characteristics of Phototransistors."

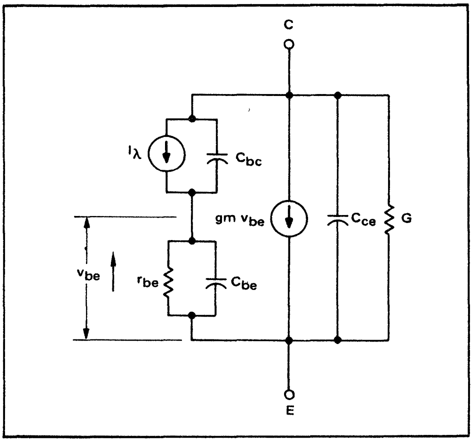

FIGURE 3 – Floating Base Approximate Model of Phototransistor

PHOTOTRANSISTOR STATIC CHARACTERISTICS

A phototransistor can be either a two-lead or a three-lead device. In the three-lead form, the base is made electrically available, and the device may be used as a standard bipolar transistor with or without the additional capability of sensitivity to light. In the two-lead form the base is not electrically available, and the transistor can only be used with light as an input. In most applications, the only drive to the transistor is light, and so the two-lead version is the most prominent.

As a two-lead device, the phototransistor can be modeled as shown in Figure 3. In this circuit, current generator I_λ represents the photo generated current and is approximately given by

$$I_\lambda = \eta F q A \qquad (1)$$

where

η is the quantum efficiency or ratio of current carriers to incident photons,

F is the fraction of incident photons transmitted by the crystal,

q is the electronic charge, and

A is the active area.

The remaining elements should be recognized as the component distribution in the hybrid-pi transistor model. Note that the model of Figure 3 indicates that under dark conditions, I_λ is zero and so v_{be} is zero. This means that the terminal current $I \approx g_m v_{be}$ is also zero.

In reality there is a thermally generated leakage current, I_o, which shunts I_λ. Therefore, the terminal current will be non-zero. This current, I_{CEO}, is typically on the order of 10 nA at room temperature and may in most cases be neglected.

As a three lead device, the model of Figure 3 need only have a resistance, r_b', connected to the junction of C_{bc} and C_{be}. The other end of this resistance is the base terminal. As mentioned earlier, the three lead phototransistor is less common than the two lead version. The only advantages of having the base lead available are to stabilize the device operation for significant temperature excursions, or to use the base for unique circuit purposes.

Mention is often made of the ability to optimize a phototransistor's sensitivity by using the base. The idea is that the device can be electrically biased to a collector current at which h_{FE} is maximum. However, the introduction of any impedance into the base results in a net decrease in photo sensitivity. This is similar to the effect noticed when I_{CEO} is measured for a transistor and found to be greater than I_{CER}. The base-emitter resistor shunts some current around the base-emitter junction, and the shunted current is never multiplied by h_{FE}.

Now when the phototransistor is biased to peak h_{FE}, the magnitude of base impedance is low enough to shunt an appreciable amount of photo current around the base-emitter. The result is actually a lower device sensitivity than found in the open base mode.

Spectral Response – As mentioned previously, a transistor is sensitive to light of a proper wavelength. Actually, response is found for a range of wavelengths. Figure 4 shows the normalized response for a typical phototransistor series (Motorola MRD devices) and indicates that peak response occurs at a wavelength of 0.8 µm. The warping in the response curve in the vicinity of 0.6 µm results from adjoining bands of constructive and destructive interference in the SiO_2 layer covering the transistor surface.

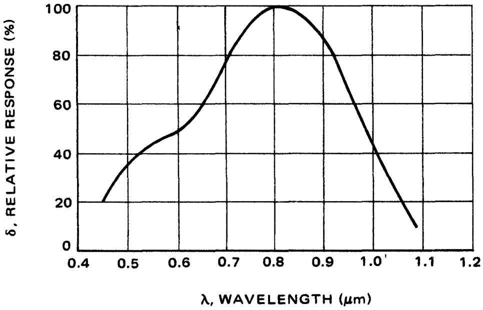

FIGURE 4 – Constant Energy Spectral Response for MRD Phototransistor Series

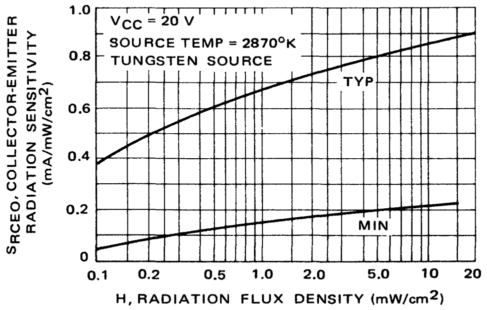

FIGURE 5 — Radiation Sensitivity for MRD450

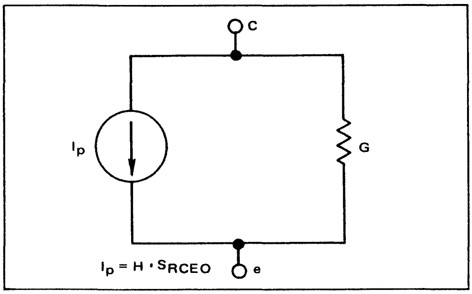

FIGURE 6 — Low-Frequency and Steady-State Model for Floating-Base Phototransistor

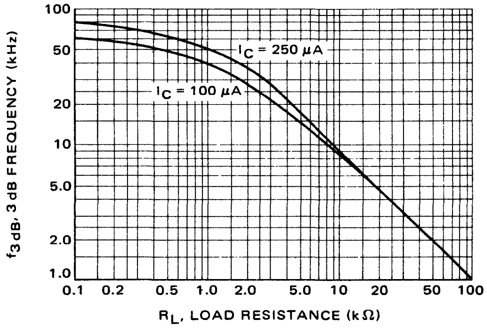

FIGURE 7 — 3 dB Frequency versus Load Resistance for MRD Phototransistor Series

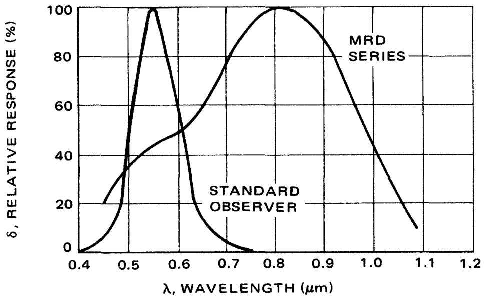

FIGURE 8 — Spectral Response for Standard Observer and MRD Series

Radiation Sensitivity — The absolute response of the MRD450 phototransistor to impinging radiation is shown in Figure 5. This response is standardized to a tungsten source operating at a color temperature of 2870°K. As subsequent discussion will show, the transistor sensitivity is quite dependent on the source color temperature.

Additional static characteristics are discussed in detail in AN-440, and will not be repeated here.

LOW-FREQUENCY AND STEADY-STATE DESIGN APPROACHES

For relatively simple circuit designs, the model of Figure 3 can be replaced with that of Figure 6. The justification for eliminating consideration of device capacitance is based on restricting the phototransistor's use to d.c. or low frequency applications. The actual frequency range of validity is also a function of load resistance. For example, Figure 7 shows a plot of the 3 dB response frequency as a function of load resistance.

Assume a modulated light source is to drive the phototransistor at a maximum frequency of 10 kHz. If the resultant photo current is 100 μA, Figure 7 shows a 3-dB frequency of 10 kHz at a load resistance of 8 kilohms. Therefore, in this case, the model of Figure 6 can be used with acceptable results for a load less than 8 kilohms. For larger loads, the hybrid-pi model must be used.

For the remainder of the discussion of low frequency and steady state design, it is assumed that the simplified model of Figure 6 is valid.

RADIATION AND ILLUMINATION SOURCES

The effect of a radiation source on a photo-transistor is dependent on the transistor spectral response and the spectral distribution of energy from the source. When discussing such energy, two related sets of terminology are available. The first is radiometric which is a physical system; the second is photometric which is a physiological system.

The photometric system defines energy relative to its visual effect. As an example, light from a standard 60 watt-bulb is certainly visible, and as such, has finite photometric quantity, whereas radiant energy from a 60-watt resistor is not visible and has zero photometric quantity. Both items have finite radiometric quantity.

The defining factor for the photometric system is the spectral response curve of a standard observer. This is shown in Figure 8 and is compared with the spectral response of the MRD series. The defining spectral response of the radiometric system can be imagined as unit response for all wavelengths.

A comparison of the terminology for the two systems is given in Table I.

There exists a relationship between the radiometric and photometric quantities such that at a wavelength of 0.55 µm, the wavelength of peak response for a standard observer, one watt of radiant flux is equal to 680 lumens of luminious flux. For a broadband of radiant flux, the visually effective, or photometric flux is given by:

$$F = K \int P(\lambda)\,\delta(\lambda)\,d\lambda \qquad (2a)$$

where

K is the proportionality constant (of 680 lumens/-watt),

P (λ) is the absolute spectral distribution of radiant flux,

δ(λ) is the relative response of the standard observer,

and

dλ is the differential wavelength,

A similar integral can be used to convert incident radiant flux density, or irradiance, to illuminance:

$$E = K \int H(\lambda)\,\delta(\lambda)\,d\lambda \qquad (2b)$$

In Equation(2b)if H (λ) is given in watts/ cm^2, E will be in lumens/ cm^2. To obtain E in footcandles (lumens/-ft^2), the proportionality constant becomes

$K = 6.3 \times 10^5$ footcandles/mW/cm^2

Fortunately, it is usually not necessary to perform the above integrations. The photometric effect of a radiant source can often be measured directly with a photometer.

Unfortunately, most phototransistors are specified for use with the radiometric system. Therefore, it is often necessary to convert photometric source data, such as the candle power rating of an incandescent lamp to radiometric data. This will be discussed shortly.

GEOMETRIC CONSIDERATIONS

In the design of electro-optic systems, the geometrical relationships are of prime concern. A source will effectively appear as either a point source, or an area source, depending upon the relationship between the size of the source and the distance between the source and the detector.

Point Sources – A point source is defined as one for which the source diameter is less than ten percent of the distance between the source and the detector, or,

$$\alpha < 0.1r, \qquad (3)$$

where

∝ is the diameter of the source, and

r is the distance between the source and the detector.

Figure 9 depicts a point source radiating uniformly in every direction. If equation (3) is satisfied, the detector area, A_D, can be approximated as a section of the area of a sphere of radius r whose center is the point source.

The solid angle, ω, in steradians[2] subtended by the detector area is

$$\omega = \frac{A_D}{r^2} \qquad (4)$$

Since a sphere has a surface area of $4\pi r^2$, the total solid angle of a sphere is

$$\omega_S = \frac{4\pi r^2}{r^2} = 4\pi \text{ steradians.}$$

Table II lists the design relationships for a point source in terms of both radiometric and photometric quantities.

The above discussion assumes that the photodetector is alligned such that its surface area is tangent to the sphere with the point source at its center. It is entirely possible that the plane of the detector can be inclined from the

TABLE I – Radiometric and Photometric Terminology

Description	Radiometric	Photometric
Total Flux	Radiant Flux, P, in Watts	Luminous Flux, F, in Lumens
Emitted Flux Density at a Source Surface	Radiant Emittance, W, in Watts/cm^2	Luminous Emittance, L. in Lumens/ft^2 (footlamberts), or lumens/ cm^2 (Lamberts)
Source Intensity (Point Source)	Radiant Intensity, I_r, in Watts/Steradian	Luminous Intensity, I_L, in Lumens/Steradian (Candela)
Source Intensity (Area Source)	Radiance, Br, in (Watts/Steradian) /cm^2	Luminance, B_L, in (Lumens/Steradian) /ft^2 (footlambert)
Flux Density Incident on a Receiver Surface	Irradiance, H, in Watts/cm^2	Illuminance, E, in Lumens/ft^2 (footcandle)

TABLE II – Point Source Relationships

Description	Radiometric	Photometric
Point Source Intensity	I_r, Watts/Steradian	I_L, Lumens/Steradian
Incident Flux Density	H(Irradiance) = $\frac{I_r}{r^2}$, watts/ distance^2	E(Illuminance) = $\frac{I_L}{r^2}$, lumens/distance^2
Total Flux Output of Point Source	$P = 4\pi I_r$ Watts	$F = 4\pi I_L$ Lumens

TABLE III – Design Relationships for an Area Source

Description	Radiometric	Photometric
Source Intensity	B_r, Watts/cm^2/steradian	B_L, Lumens/cm^2/ steradian
Emitted Flux Density	$W=\pi B_r$, Watts/cm^2	$L=\pi B_L$, Lumens/cm^2
Incident Flux Density	$H = \frac{B_r A_S}{r^2+(\frac{d}{2})^2}$, Watts/$cm^2$	$E = \frac{B_L A_S}{r^2+(\frac{d}{2})^2}$, Lumens/$cm^2$

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[2] Steradian: The solid equivalent of a radian.

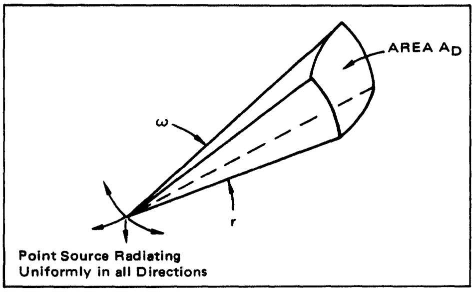


FIGURE 9 — Point Source Geometry

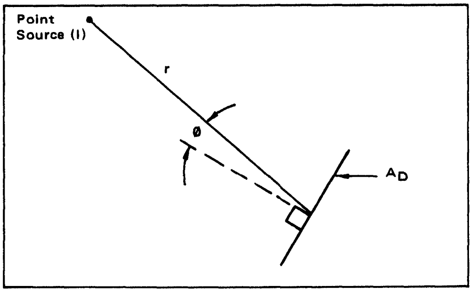


FIGURE 10 — Detector Not Normal to Source Direction

tangent plane. Under this condition, as depicted in Figure 10, the incident flux density is proportional to the cosine of the inclination angle, ϕ. Therefore,

$$H = \frac{I_r}{r^2} \cos\phi, \text{ and} \tag{5a}$$

$$E = \frac{I_L}{r^2} \cos\phi. \tag{5b}$$

AREA SOURCES

When the source has a diameter greater than 10 percent of the separation distance,

$$\alpha \geqslant 0.1r, \tag{6}$$

it is considered to be an area source. This situation is shown in Figure 11. Table III lists the design relationships for an area source.

A special case that deserves some consideration occurs when

$$\frac{\alpha}{2} >> r, \tag{7}$$

that is, when the detector is quite close to the source. Under this condition,

$$H = \frac{B_r A_s}{r^2 + \left(\frac{\alpha}{2}\right)^2} \approx \frac{B_r A_s}{\left(\frac{\alpha}{2}\right)^2}, \tag{8}$$

but, the area of the source,

$$A_s = \pi\left(\frac{\alpha}{2}\right)^2, \tag{9}$$

Therefore,

$$H \approx B_r \pi = W, \tag{10}$$

That is, the emitted and incident flux densities are equal. Now, if the area of the detector is the same as the area of the source, and equation (7) is satisfied, the total incident energy is approximately the same as the total radiated energy, that is, unity coupling exists between source and detector.

LENS SYSTEMS

A lens can be used with a photodetector to effectively increase the irradiance on the detector. As shown in Figure 12a, the irradiance on a target surface for a point source of intensity, I, is

$$H = I/d^2, \tag{11}$$

where d is the separation distance.

In Figure 12b a lens has been placed between the source and the detector. It is assumed that the distance d′ from the source to the lens is approximately equal to d:

$$d' \approx d, \tag{12}$$

and the solid angle subtended at the source is sufficiently small to consider the rays striking the lens to be parallel.

If the photodetector is circular in area, and the distance from the lens to the detector is such that the image of the source exactly fills the detector surface area, the radiant flux on the detector (assuming no lens loss) is

$$P_D = P_L = H' \pi r_L^2, \tag{13}$$

where

P_D is the radiant flux incident on the detector,

P_L is the radiant flux incident on the lens,

H’ is the flux density on the lens, and

r_L is the lens radius.

Using equation (12),

$$H' = I/d^2 = H. \tag{14}$$

The flux density on the detector is

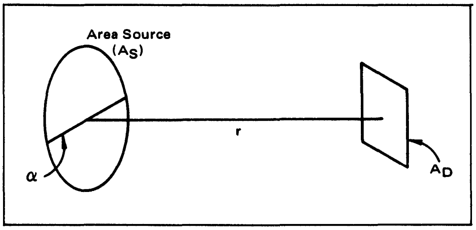


FIGURE 11 – Area Source Geometry

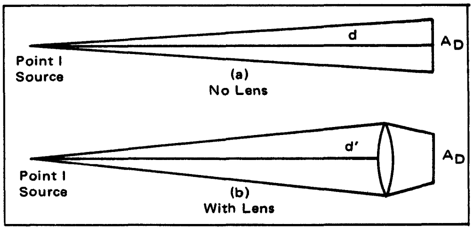


Figure 12 – Use of a Lens to Increase Irradiance on a Detector

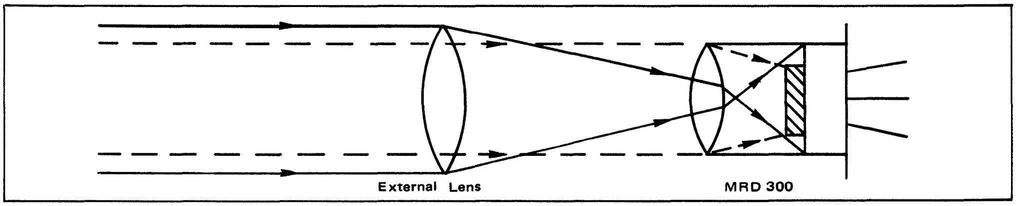


FIGURE 13 – Possible Misalignment Due to Arbitrary Use of External Lens Dotted Rays Indicate Performance Without External Lens

$$H_D = P_D/A_D, \qquad (15)$$

where A_D is the detector area, given by

$$A_D = \pi r_d^2. \qquad (16)$$

Using (13), (14), and (16) in (15) gives

$$H_D = \frac{I}{d^2}\left(\frac{r_L}{r_d}\right)^2. \qquad (17)$$

Now dividing (17) by (11) gives the ratio of irradiance on the detector with a lens to the irradiance without a lens.

$$\frac{H_D}{H} = \frac{\frac{I}{d^2}\left(\frac{r_L}{r_d}\right)^2}{I/d^2} = \left(\frac{r_L}{r_d}\right)^2. \qquad (18)$$

As (18) shows, if the lens radius is greater than the detector radius, the lens provides an increase in incident irradiance on the detector. To account for losses in the lens, the ratio is reduced by about ten percent.

$$R = 0.9\left(\frac{r_L}{r_d}\right)^2 \qquad (19)$$

where R is the gain of the lens system.

It should be pointed out that arbitrary placement of a lens may be more harmful than helpful. That is, a lens system must be carefully planned to be effective.

For example, the MRD300 phototransistor contains a lens which is effective when the input is in the form of parallel rays (as approximated by a uniformly radiating point source). Now, if a lens is introduced in front of the MRD300 as shown in Figure 13, it will provide a non-parallel ray input to the transistor lens. Thus the net optical circuit will be misaligned. The net irradiance on the phototransistor chip may in fact be less than without the external lens. The circuit of Figure 14 does show an effective system. Lens 1 converges the energy incident on its surface to lens 2 which reconverts this energy into parallel rays. The energy entering the phototransistor lens as parallel rays is the same (neglecting losses) as that entering lens 1. Another way of looking at this is to imagine that the phototransistor surface has been increased to a value equal to the surface area of lens 1.

FIBER OPTICS

Another technique for maximizing the coupling between source and detector is to use a fiber bundle to link the phototransistor to the light source. The operation of fiber optics is based on the principle of total internal reflection.

Figure 15 shows an interface between two materials of different indices of refraction. Assume that the index of refraction, n, of the lower material is greater than that, n', of the upper material. Point P represents a point source of light radiating uniformly in all directions. Some rays from P will be directed at the material interface.

At the interface, Snell's law requires:

$$n \sin \theta = n' \sin \theta', \qquad (20)$$

where

θ is the angle between a ray in the lower material and the normal to the interface,

and

θ' is the angle between a refracted ray and the normal.

Rearranging (20),

$$\sin\theta' = \frac{n}{n'}\sin\theta. \qquad (21)$$

By assumption, n/n′ is greater than one, so that

$$\sin\theta' > \sin\theta. \qquad (22)$$

However, since the maximum value of sin θ' is one and occurs when θ' is 90°, θ' will reach 90° before θ does. That is, for some value of θ, defined as the critical angle, θ_C, rays from P do not cross the interface. When $\theta > \theta_C$, the rays are reflected entirely back into the lower material, or total internal reflection occurs.

Figure 16 shows the application of this principle to fiber optics. A glass fiber of refractive index n is clad with a layer of glass of lower refractive index, n′. A ray of light entering the end of the cable will be refracted as shown. If, after refraction, it approaches the glass interface at an angle greater than θ_C, it will be reflected within the fiber. Since the angle of reflection must equal the angle of incidence, the ray will bounce down the fiber and emerge, refracted, at the exit end.

The numerical aperature, NA, of a fiber is defined as the sin of the half angle of acceptance. Application of Snell's law at the interface for θ_C, and again at the fiber end will give

$$NA \equiv \sin\phi = \sqrt{n^2 - n'^2}. \qquad (23)$$

For total internal reflection to occur, a light ray must enter the fiber within the half angle ϕ.

Once a light ray is within the fiber, it will suffer some attenuation. For glass fibers, an absorption rate of from five to ten per cent per foot is typical. There is also an entrance and exit loss at the ends of the fiber which typically result in about a thirty per cent loss.

As an example, an illuminance E at the source end of a three-foot fiber bundle would appear at the detector as

$$E_D = 0.7\,Ee^{-\alpha L} = 0.7\,Ee^{-(0.1)(3)} = 0.51\,E, \qquad (24)$$

where E is the illuminance at the source end,

E_D is the illuminance at the detector end,

α is the absorption rate, and

L is the length.

This assumes an absorption loss of ten percent per foot.

TUNGSTEN LAMPS

Tungsten lamps are often used as radiation sources for photodetectors. The radiant energy of these lamps is distributed over a broad band of wavelengths. Since the eye and the phototransistor exhibit different wavelength-dependent response characteristics, the effect of a tungsten lamp will be different for both. The spectral output of a tungsten lamp is very much a function of color temperature.

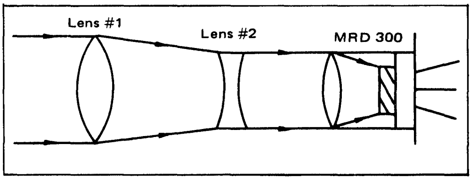


FIGURE 14 – Effective Use of External Optics with the MRD 300

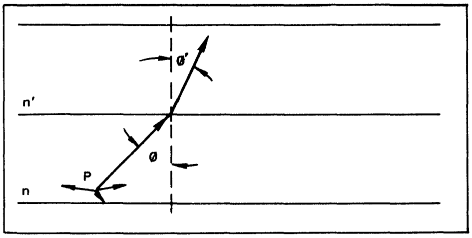


FIGURE 15 – Ray Refraction at an Interface

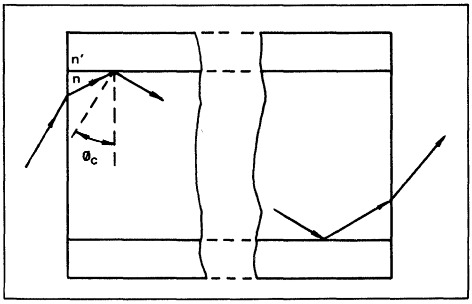


FIGURE 16 – Refraction in an Optical Fiber

Color temperature of a lamp is the temperature required by an ideal blackbody radiator to produce the same visual effect as the lamp. At low color temperatures, a tungsten lamp emits very little visible radiation. However, as color temperature is increased, the response shifts toward the visible spectrum. Figure 17 shows the spectral distribution of tungsten lamps as a function of color temperature. The lamps are operated at constant wattage and the response is normalized to the response at 2800°K. For comparison, the spectral response for both the standard observer and the MRD phototransistor series are also plotted. Graphical integration of the product of the standard observer response and the pertinent source distribution from Figure 17 will provide a solution to equations (2a) and (2b).

Effective Irradiance – Although the sensitivity of a photodetector to an illuminant source is frequently provided, the sensitivity to an irradiant source is more common. Thus, it is advisable to carry out design work in

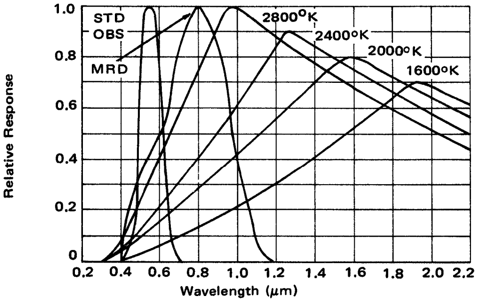


FIGURE 17 – Radiant Spectral Distribution of Tunsten Lamp

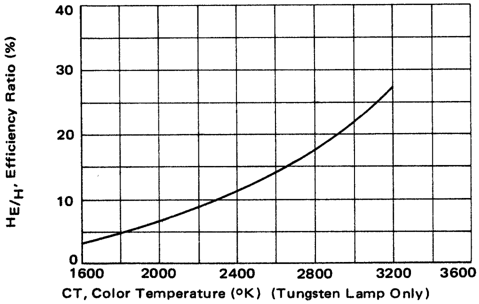


FIGURE 18 – MRD Irradiance Ratio versus Color Temperature

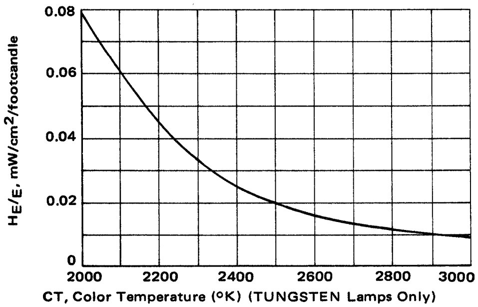


FIGURE 19 – MRD Irradiance/Illuminance Ratio versus Color Temperature

terms of irradiance. However, since the spectral response of a source and a detector are, in general, not the same, a response integration must still be performed. The integral is similar to that for photometric evaluation.

$$P_E = \int P(\lambda)\, Y(\lambda)\, d\lambda \qquad (25)$$

where

P_E is the effective radiant flux on the detector, $P(\lambda)$ is the spectral distribution of source flux

and

$Y(\lambda)$ is the spectral response of the detector.

Again, such an integration is best evaluated graphically. In terms of flux density, the integral is

$$H_E = \int H(\lambda)\, Y(\lambda)\, d\lambda \qquad (26)$$

where H_E is the effective flux density (irradiance) on the detector

and $H(\lambda)$ is the absolute flux density distribution of the source on the detector.

Graphical integration of equations (2b) and (26) has been performed for the MRD series of phototransistors for several values of lamp color temperature. The results are given in Figures 18 and 19 in terms of ratios. Figure 18 provides the irradiance ratio, H_E/H versus color temperature. As the curve shows, a tungsten lamp operating at 2600°K is about 14% effective on the MRD series devices. That is, if the broadband irradiance of such a lamp is measured at the detector and found to be 20 mw/cm², the transistor will effectively see

$$H_E = 0.14\,(20) = 2.8 \text{ mW/cm}^2 \qquad (27)$$

The specifications for the MRD phototransistor series include the correction for effective irradiance. For example, the MRD450 is rated for a typical sensitivity of 0.8 mA/mW/cm². This specification is made with a tungsten source operating at 2870°K and providing an irradiance at the transistor of 5.0 mW/cm². Note that this will result in a current flow of 4.0 mA.

However, from Figure 18, the effective irradiance is

$$H_E = (5.0)(.185) = 0.925 \text{ mW/cm}^2 \qquad (28)$$

By using this value of H_E and the typical sensitivity rating it can be shown that the device sensitivity to a monochromatic irradiance at the MRD450 peak response of 0.8 μm is

$$S = \frac{I_C}{H_E} = \frac{4.0 \text{ mA}}{0.925 \text{ mW/cm}^2} = 4.33 \text{ mA/mW/cm}^2 \qquad (29)$$

Now, as shown previously, an irradiance of 20 mW/cm² at a color temperature of 2600°K looks like monochromatic irradiance at 0.8μm of 2.8 mW/cm² (Equation 27). Therefore, the resultant current flow is

$$I = S\, H_E\, (4.33)(2.8) = 12.2 \text{ mA} \qquad (30)$$

An alternate approach is provided by Figure 20. In this figure, the relative response as a function of color temperature has been plotted. As the curve shows, the response is down to 83% at a color temperature of 2600°K. The specified typical response for the MRD450 at 20mW/cm² for a 2870°K tungsten source is 0.9 mA/mW/cm². The current flow at 2600°K and 20 mW/cm² is therefore

$$I = (0.83)(0.9)(20) = 14.9 \text{ mA} \qquad (31)$$

This value agrees reasonably well with the result obtained in Equation 30. Similarly, Figure 19 will show that a current flow of 6.67 mA will result from an illuminance of 125 foot candles at a color temperature of 2600°K.

Determination of Color Temperature – It is very likely that a circuit designer will not have the capability to measure color temperature. However, with a voltage measuring capability, a reasonable approximation of color temperature may be obtained. Figure 21 shows the classical variation of lamp current, candlepower and lifetime for a tungsten lamp as a function of applied voltage. Figure 22 shows the variation of color temperature as a function of the ratio

$$\rho = \frac{\text{MSCP}}{\text{WATT}} \qquad (32)$$

where

MSCP is the mean spherical candlepower at the lamp operating point and WATT is the lamp IV product at the operating point.

As an example, suppose a type 47 indicator lamp is used as a source for a phototransistor. To extend the lifetime, the lamp is operated at 80% of rated voltage.

Lamp	Rated Volts	Rated Current	MSCP
47	6.3V	150 mA	0.52 approx

Geometric Considerations – The candlepower ratings on most lamps are obtained from measuring the total lamp output in an integrating sphere and dividing by the unit solid angle. Thus the rating is an average, or mean-spherical-candlepower. However, a tungsten lamp cannot radiate uniformly in all directions, therefore, the candlepower varies with the lamp orientation. Figure 23 shows the radiation pattern for a typical frosted tungsten lamp. As shown, the maximum radiation occurs in the horizontal direction for a base-down or base-up lamp. The circular curve simulates the output of a uniform radiator, and contains the same area as the lamp polar plot. It indicates that the lamp horizontal output is about 1.33

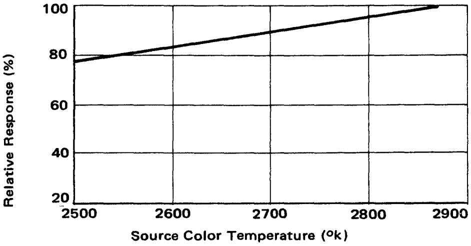


FIGURE 20 – Relative Response of MRD Series versus Color Temperature

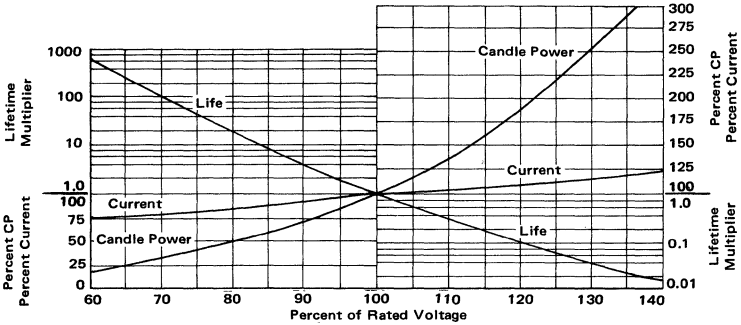


FIGURE 21 – Tungsten Lamp Parameter Variations versus Variations about Rated Voltage

From Figure 21 for 80% rated voltage,

(Rated Current) (Percent current) = (.15)(0.86) = 0.129 ampere

(Rated CP) (Percent CP) = (0.5)(0.52) = 0.26 CP

(Rated Voltage) (Percent Voltage) = (6.3)(0.8) = 5.05 V

$$\text{WATTS} = (5.05)(0.129) = 0.65$$

$$\rho = \frac{0.26}{0.65} = 0.4,$$

From Figure 22, for p = 0.4,

CT = 2300°K,

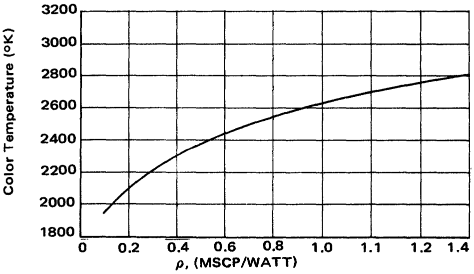


FIGURE 22 – Color Temperature versus Candle Power/Power Ratio

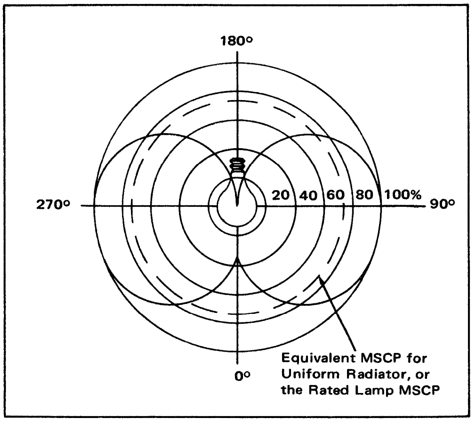


FIGURE 23 – Typical Radiation Pattern for a Frosted Incandescent Lamp

times the rated MSCP, while the vertical output, opposite the base, is 0.48 times the rated MSCP.

The actual polar variation for a lamp will depend on a variety of physical features such as filament shape, size and orientation and the solid angle intercepted by the base with respect to the center of the filament.

If the lamp output is given in horizontal candlepower (HCP), a fairly accurate calculation can be made with regard to illuminance on a receiver.

A third-form of rating is beam candlepower, which is provided for lamps with reflectors.

In all three cases the rating is given in lumens/steradian or candlepower.

SOLID STATE SOURCES

In contrast with the broadband source of radiation of the tungsten lamp, solid state sources provide relatively narrow band energy. The gallium arsenide (GaAs) light-emitting-diode (LED) has spectral characteristics which make it a favorable mate for use with silicon photodetectors. LED's are available for several wavelengths, as shown in Figure 24, but as the figure shows, the GaAs diode and the MRD phototransistor series are particularly compatible. Application of Equation (26) to the GaAs response and the MRD series response indicates that the efficiency ratio, H_E/H, is approximately 0.9 or 90%. That is, an irradiance of 4.0 mW/cm^2 from an LED will appear to the phototransistor as 3.6 mW/cm^2. This means that a typical GaAs LED is about 3.5 times as effective as a tungsten lamp at 2870°K. Therefore, the typical sensitivity for the MRD450 when used with a GaAs LED is approximately

$$S = (0.8)(3.5) = 2.8 \text{ mA/mW/cm}^2. \qquad (33)$$

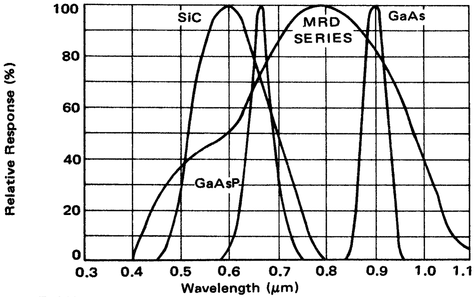


FIGURE 24 – Spectral Characteristics for Several LED's Compared with MRD Series

An additional factor to be considered in using LED's is the polar response. The presence of a lens in the diode package will confine the solid angle of radiation. If the solid angle is θ, the resultant irradiance on a target located at a distance d is

$$H = \frac{4P}{\pi\theta^2 d^2} \text{ watts/cm}^2, \qquad (34)$$

where

P is the total output power of the LED in watts
θ is the beam angle
d is the distance between the LED and the detector in cm.

LOW FREQUENCY AND STEADY STATE APPLICATIONS

Light Operated Relay – Figure 25 shows a circuit in which presence of light causes a relay to operate. The relay used in this circuit draws about 5 mA when Q2 is in saturation Since h_{FE} (min) for the MPS3394 is 55 at a collector current of 2mA, a base current of 0.5 mA is sufficient to ensure saturation. Phototransistor Q1 provides the necessary base drive. If the MRD300 is used, the minimum illumination sensitivity is 4 μA/footcandle, therefore,

$$E = \frac{I_C}{S_{ICEO}} = \frac{0.5 \text{ mA}}{4\text{X}10^{-3} \text{mA/footcandle}} \qquad (35)$$

$$E = 125 \text{ footcandles}$$

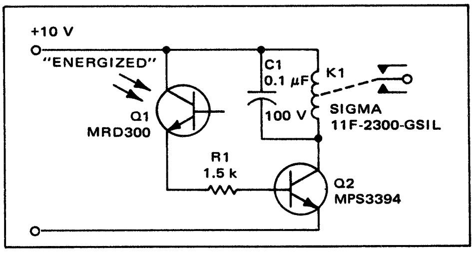


FIGURE 25 – Light-Operated Relay

This light level can be supplied by a flashlight or other equivalent light source.

The equivalent irradiance is obviously that value of irradiance which will cause the same current flow. Assume the light source is a flashlight using a PR2 lamp. The ratings for this lamp are

Lamp	Rated Volts	Rated Current	MSCP
PR2	2.38	0.50 A	0.80

If the flashlight has new batteries the lamp voltage is

$$V_L = 2(1.55) = 3.1 \text{ volts} \qquad (36)$$

This means that the lamp is operated at 130 per cent of rated voltage. From Figure 21 for 130% rated voltage,

(Rated Current) (Percent Current) = (0.5)(1.15) = 0.575 ampere

(Rated CP) (Percent CP) = (0.80)(2.5) = 2 CP

(Rated Voltage) (Percent Voltage) = (2.38)(1.3) = 3.1 volts.

Therefore, the MSCP/watt rating is 1.12. From Figure 22, the color temperature is 2720°K.

Now, from Figure 20, the response at a color temperature of 2720°K is down to 90% of its reference value. At the reference temperature, the minimum S_{RCEO} for the MRD300 is 0.8 mA/mW/cm², so at 2720°K it is

$$S_{RCEO\ (MIN)} = (0.9)(0.8) = 0.72 \text{ mA/mW/cm}^2 \qquad (37)$$

and

$$H_E = \frac{I_C}{S_{RCEO}} = \frac{0.5}{0.72} = 0.65 \text{ mW/cm}^2 \qquad (38)$$

However, sensitivity is a function of irradiance, and at 0.695 mW/cm² it has a minimum value (at 2720°K) of about 0.45 mA/mW/cm², therefore

$$H_E = \frac{0.5}{0.45} = 1.11 \text{ mW/cm}^2 \qquad (39)$$

Again, we note that at an irradiance of 1.11 mW/cm², the minimum S_{RCEO} is about 0.54 mA/mW/cm². Several applications of the above process eventually result in a convergent answer of

$$H_E \approx 1.0 \text{ mW/cm,}^2 \qquad (40)$$

Now, from the MRD450 data sheet, $S_{RCEO\ (min)}$ at an irradiance of 1.0 mW/cm² and color temperature of 2720°K is

$$S_{RCEO} = (0.15)(0.9) = 0.135 \text{ mA/mW/cm}^2 \ (41)$$

At 1.0 mW/cm², we can expect a minimum I_C of 0.135 mA. This is below the design requirement of 0.5 mA. By looking at the product of $S_{RCEO\ (min)}$ and H on the data sheet curve, the minimum H for 0.5 mA for using the MRD450 can now be calculated.

$$\frac{H}{H_E} = \frac{3.0}{1.0} = \frac{I\ (\text{MRD450})}{I\ (\text{MRD300})} = \frac{I\ (\text{MRD450})}{125} \qquad (42)$$

or

$$I\ (\text{MRD450}) = 375 \text{ footcandles} \qquad (43)$$

This value is pretty high for a two D-cell flashlight, but the circuit should perform properly since about 200 footcandles can be expected from a flashlight, giving a resultant current flow of approximately

$$I = \frac{220}{275}\,(0.5 \text{ mA}) = 0.293 \text{ mA} \qquad (44)$$

This will be the base current of Q2, and since the relay requires 5 mA, the minimum h_{FE} required for Q2 is

$$h_{FE}\ (Q2) = \frac{5}{0.293} = 17. \qquad (45)$$

This is well below the $h_{FE\ (min)}$ specification for the MPS3394 (55) so proper circuit performance can be expected.

A variation of the above circuit is shown in Figure 26. In this circuit, the presence of light deenergizes the relay. The same light levels are applicable. The two relay circuits can be used for a variety of applications such as automatic door activators, object or process counters, and intrusion alarms. Figure 27, for example, shows the circuit of Figure 26 used to activate an SCR in an alarm system. The presence of light keeps the relay deenergized, thus denying trigger current to the SCR gate. When the light is interrupted, the relay energizes, providing the SCR with trigger current. The SCR latches ON, so only a momentary interruption of light is sufficient to cause the alarm to ring continuously. S1 is a momentary contact switch for resetting the system.

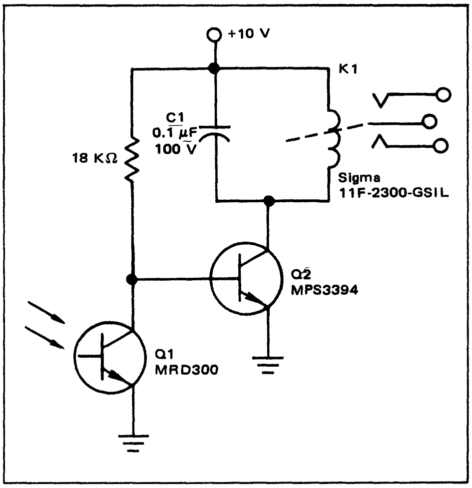


FIGURE 26 — Light De-energized Relay

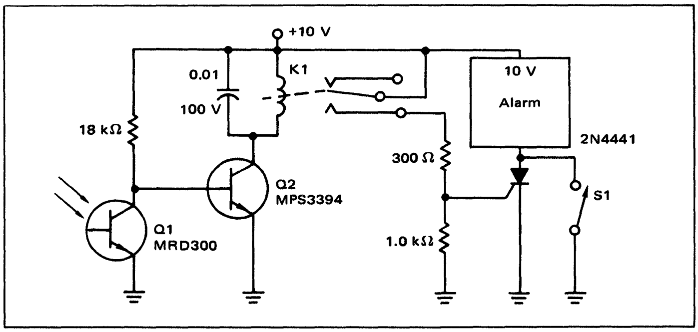


FIGURE 27 – Light-Relay Operated SCR Alarm Circuit

If the SCR has a sensitive gate, the relay can be eliminated as shown in Figure 28. The phototransistor holds the gate low as long as light is present, but pulls the gate up to triggering level when the light is interrupted. Again, a reset switch appears across the SCR.

Voltage Regulator – The light output of an incandescent lamp is very dependent on the RMS voltage applied to it. Since the phototransistor is sensitive to light changes, it can be used to monitor the light output of a lamp, and in a closed-loop system to control the lamp voltage. Such a regulator is particularly useful in a projection system where it is desired to maintain a constant brightness level despite line voltage variations.

Figure 29 shows a voltage regulator for a projection lamp. The RMS voltage on the lamp is set by the firing angle of the SCR. This firing angle in turn is set by the unijunction timing circuit. Transistors Q1 and Q2 form a constant-current source for charging timing capacitor C.

The magnitude of the charging current, the capacitance, C, and the position of R6 set the firing time of the UJT oscillator which in turn sets the firing angle of the SCR. Regulation is accomplished by phototransistor Q3. The brightness of the lamp sets the current level in Q3, which diverts current from the timing capacitor. Potentiometer R6 is set for the desired brightness level.

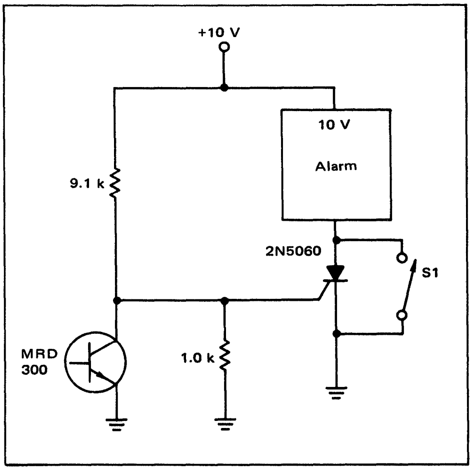


FIGURE 28 – Light Operated SCR Alarm Using Sensitive-Gate SCR

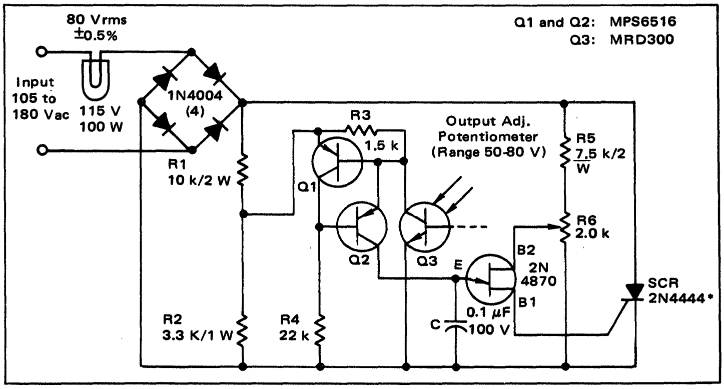


FIGURE 29 – Circuit Diagram of Voltage Regulator for Projection Lamp.

*2N4444 to be used with a heat sink.

If the line voltage rises, the lamp tends to become brighter, causing an increase in the current of Q3. This causes the unijunction to fire later in the cycle, thus reducing the conduction time of the SCR. Since the lamp RMS voltage depends on the conduction angle of the SCR, the increase in line voltage is compensated for by a decrease in conduction angle, maintaining a constant lamp voltage.

Because the projection lamp is so bright, it will saturate the phototransistor if it is directly coupled to it. Either of two coupling techniques are satisfactory. The first is to attenuate the light to the phototransistor with a translucent material with a small iris. The degree of attenuation or translucency must be experimentally determined for the particular projection lamp used.

The second coupling technique is to couple the lamp and phototransistor by a reflected path. The type of reflective surface and path length will again depend on the particular lamp being used.

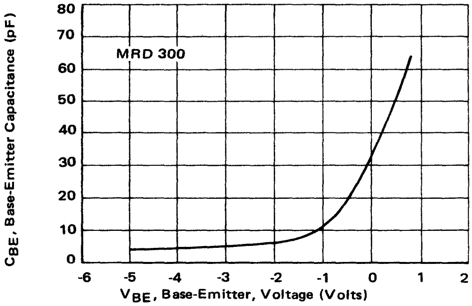


FIGURE 30 — MRD300 Base-Emitter Junction Capacitance versus Voltage

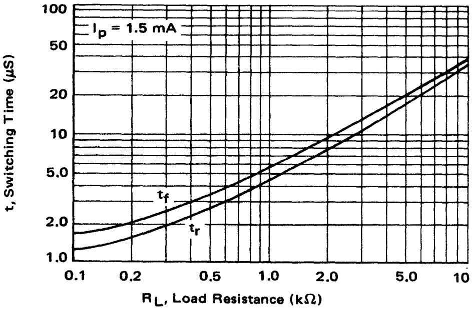


FIGURE 31 — MRD300 Switching Times versus Load Resistance

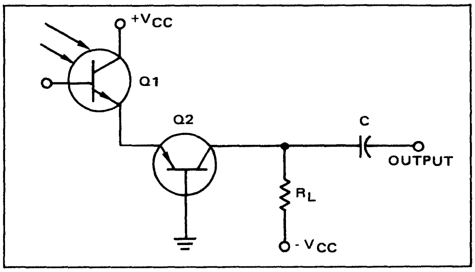


FIGURE 32 — Improved Speed Configuration for Phototransistor

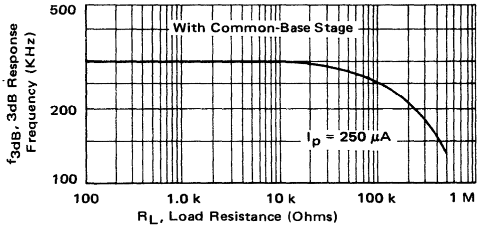


FIGURE 33 — 3dB Frequency Response for Speed-up Circuit

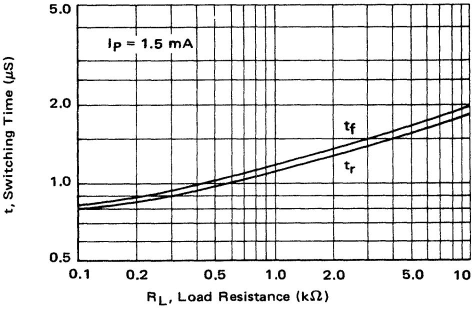


FIGURE 34 — Switching Times with Speed-up Circuit

HIGH FREQUENCY DESIGN APPROACHES

It was shown in Figure 7 that the frequency response of the MRD phototransistor series is quite dependent on the load. Depending on the load value and the frequency of operation, the device can be modled simply as in Figure 6, or else in the modified hybrid-pi form of Figure 3.

While the hybrid-pi model may be useful for detailed analytical work, it does not offer much for the case of simplified design. It is much easier to consider the transistor simply as a current source with a first-order transient response. With the addition of switching characteristics to the device information already available, most design problems can be solved with a minimum of effort.

Switching Characteristics – When the phototransistor changes state from OFF to ON, a significant time delay is associated with the r_{be} C_{be} time constant. As shown in Figure 30, the capacitance of the emitter-base junction is appreciable. Since the device photocurrent is g_m v_{be} (from Figure 3), the load current can change state only as fast as v_{be} can change. Also, v_{be} can change only as fast as C_{be} can charge and discharge through the load resistance. Figure 31 shows the variations in rise and fall time with load resistance. This measurement was made using a GaAs light emitting diode for the light source. The LED output power and the separation distance between the LED and the phototransistor were adjusted for an ON phototransistor current of 1.5 mA. The rise time was also measured for a short-circuited load and found to be about 700 ns.

The major difficulty encountered in high-frequency applications is the load-dependent frequency response. Since the phototransistor is a current source, it is desirable to use a large load resistance to develop maximum output voltage. However, large load resistances limit the useful frequency range. This seems to present the designer with a tradeoff between voltage and speed. However, there is a technique available to eliminate the need for such a tradeoff.

Figure 32 shows a circuit designed to optimize both speed and output voltage. The common-base stage Q2 offers a low-impedance load to the phototransistor, thus maximizing response speed. Since Q2 has near-unity current gain, the load current in R_L is approximately equal to the phototransistor current. Thus the impedance transformation provided by Q2 results in a relatively load-independent frequency response.

The effect of Q2 is shown in Figures 33 and 34. In Figure 33, the 3-dB frequency response as a function of load is shown. Comparing this with Figure 7, the effect of Q2 is quite evident. Comparison of Figures 31 and 34 also demonstrates the effect of Q2.

Remote Strobeflash Slave Adapter – At times when using an electronic strobe flash, it is desirable to use a remote, or "slave" flash synchronized with the master. The circuit in Figure 35 provides the drive needed to trigger a slave unit, and eliminates the necessity for synchronizing wires between the two flash units.

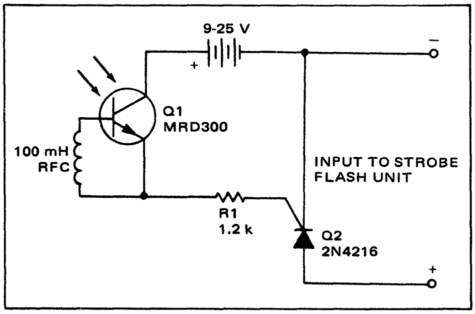


FIGURE 35 – Strobeflash Slave Adapter

The MRD300 phototransistor used in this circuit is cut off in a V_{CER} mode due to the relatively low dc resistance of rf choke L1 even under high ambient light conditions. When a fast-rising pulse of light strikes the base region of this device, however, L1 acts as a very high impedance to the ramp and the transistor is biased into conduction by the incoming pulse of light.

When the MRD300 conducts, a signal is applied to the gate of SCR Q2. This triggers Q2, which acts as a solid-state relay and turns on the attached strobeflash unit.

In tests this unit was unaffected by ambient light conditions. It fired up to approximately 20 feet from strobe-light flashes using only the lens of the MRD300 for light pickup.

CONCLUSION

The phototransistor provides the circuit or system designer with a unique component for use in dc and linear or digital time-varying applications. Use of a phototransistor yields extremely high electrical and mechanical isolation. The proper design of an electro-optical system requires a knowledge of both the radiation source characteristics and the phototransistor characteristics. This knowledge, coupled with an adequately defined distance and geometric relationship, enables the designer to properly predict the performance of his designs.

REFERENCES

1. Motorola Application Note AN-440, *Theory and Characteristics of Phototransistors.*
2. Francis W. Sears, *Optics,* Addison-Wesley Publishing Company, Inc., 1948.
3. *IES Lighting Handbook,* 3rd Edition, Illuminating Engineering Society, 1959.

ISOLATION TECHNIQUES USING OPTICAL COUPLERS

Prepared by
Francis Christian

INTRODUCTION

The optical coupler is a new device that offers the design engineer new freedoms in designing circuits and systems. Problems such as ground loop isolation, common mode noise rejection, power supply transformations, and many more problems can be solved or simplified with the use of an optical coupler.

Operation is based on the principle of detecting emitted light. The input to the coupler is connected to a light emitter and the output is a photodetector, the two elements being separated by a transparent insulator and housed in a light-excluding package. There are many types of optical couplers; for example, the light source could be an incandescent lamp or a light emitting diode (LED). Also, the detector could be photovoltaic cell, photoconductive cell, photodiode, phototransistor, or a light-sensitive SCR. By various combinations of emitters and detectors, a number of different types of optical couplers could be assembled.

Once an emitter and detector have been assembled as a coupler, the optical portion is permanently established so that device use is only electronic in nature. This eliminates the need for the circuit designer to have knowledge of optics. However, for effective application, he must know something of the electrical characteristics, capabilities, and limitations, of the emitter and detector.

COUPLER CHARACTERISTICS

The 4N25 is an optical coupler consisting of a gallium arsenide (GaAs) LED and a silicon phototransistor. (For more information on LEDs and phototransistors, see References 1 and 2).

The coupler's characteristics are given in the following sequence: LED characteristics, phototransistor characteristics, coupled characteristics, and switching characteristics. Table I shows all four for the 4N25 series.

INPUT

For most applications the basic LED parameters I_F and V_F are all that are needed to define the input. Figure 1 shows these forward characteristics, providing the necessary information to design the LED drive circuit. Most circuit applications will require a current limiting resistor in series with the LED input. The circuit in Figure 2 is a typical drive circuit.

The current limiting resistor can be calculated from the following equation:

$$R = \frac{V_{IN} - V_F}{I_F},$$

where V_F = diode forward voltage
I_F = diode forward current

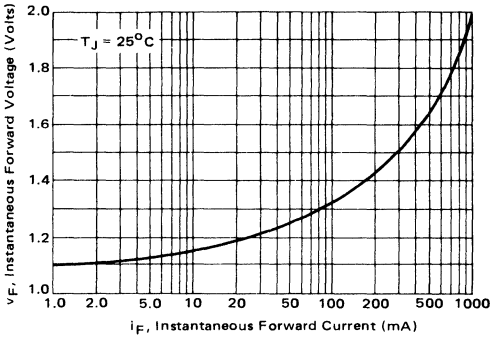


FIGURE 1 – Input Diode Forward Characteristic

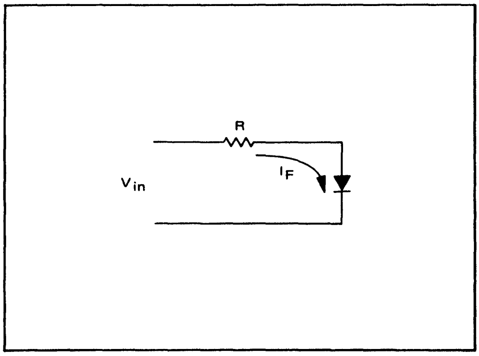


FIGURE 2 – Simple Drive Circuit For An LED

TABLE I

LED CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
*Reverse Leakage Current (V_R = 3.0 V, R_L = 1.0 M ohms)	I_R	–	0.05	100	μA
*Forward Voltage (I_F = 50 mA)	V_F	–	1.2	1.5	Volts
Capacitance (V_R = 0 V, f = 1.0 MHz)	C	–	150	–	pF

PHOTOTRANSISTOR CHARACTERISTICS (T_A = 25°C and I_F = 0 unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
*Collector-Emitter Dark Current (V_{CE} = 10 V, Base Open)	4N25, 4N26, 4N27 4N28	I_{CEO}	– –	3.5 –	50 100	nA
*Collector-Base Dark Current (V_{CB} = 10 V, Emitter Open)		I_{CBO}	–	–	20	nA
*Collector-Base Breakdown Voltage (I_C = 100 μA, I_E = 0)		$V_{(BR)CBO}$	70	–	–	Volts
*Collector-Emitter Breakdown Voltage (I_C = 1.0 mA, I_B = 0)		$V_{(BR)CEO}$	30	–	–	Volts
*Emitter-Collector Breakdown Voltage (I_E = 100 μA, I_B = 0)		$V_{(BR)ECO}$	7.0	–	–	Volts
DC Current Gain (V_{CE} = 5.0 V I_C = 500 μA)		h_{FE}	–	250	–	–

COUPLED CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
*Collector Output Current (1) (V_{CE} = 10 V, I_F = 10 mA, I_B = 0)	4N25,4N26 4N27,4N28	I_C	2.0 1.0	5.0 3.0	– –	mA
*Isolation Voltage (2)	4N25 4N26,4N27 4N28	V_{ISO}	2500 1500 500	– – –	– – –	Volts
Isolation Resistance (2) (V = 500 V)		–	–	10^{11}	–	Ohms
*Collector-Emitter Saturation (I_C = 2.0 mA, I_F = 50 mA)		$V_{CE(sat)}$	–	0.2	0.5	Volts
Isolation Capacitance (2) (V = 0, f = 1.0 MHz)		–	–	1.3	–	pF
Bandwidth (3) (I_C = 2.0 mA, R_L = 100 ohms, Figure 11)		–	–	300	–	kHz

SWITCHING CHARACTERISTICS

Delay Time	(I_C = 10 mA, V_{CC} = 10 V) Figures 6 and 8	4N25,4N26 4N27,4N28	t_d	– –	0.07 0.10	– –	μs
Rise Time		4N25,4N26 4N27,4N28	t_r	– –	0.8 2.0	– –	μs
Storage Time	(I_C = 10 mA, V_{CC} = 10 V) Figures 7 and 8	4N25,4N26 4N27,4N28	t_s	– –	4.0 2.0	– –	μs
Fall Time		4N25,4N26 4N27,4N28	t_f	– –	7.0 3.0	– –	μs

*Indicates JEDEC Registered Data (1) Pulse Test Pulse Width = 300 μs, Duty Cycle ≤ 2.0%
(2) For this test LED pins 1 and 2 are common and Photo Transistor pins 4, 5 and 6 are common
(3) I_F adjusted to yield I_C = 2.0 mA and i_c = 2.0 mA p-p at 10 kHz

OUTPUT

The output of the coupler is the phototransistor. The basic parameters of interest are the collector current I_C and collector emitter voltage, V_{CE}. Figure 3 is a curve of $V_{CE(sat)}$ versus I_C for two different drive levels.

COUPLING

To fully characterize the coupler, a new parameter, the dc current transfer ratio or coupling efficiency (η) must be defined. This is the ratio of the transistor collector current to diode current I_C/I_F. Figures 4A and 4B show the typical dc current transfer functions for the couplers at V_{CE} = 10 volts. Note that η varies with I_F and V_{CE}.

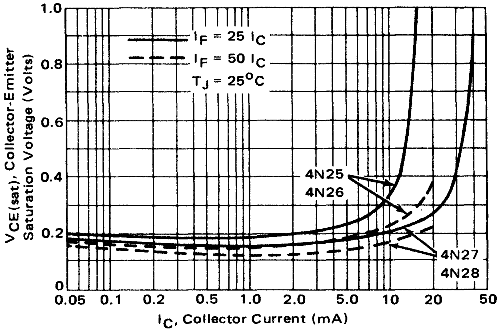


FIGURE 3 – Collector Saturation Voltage

Once the required output collector current I_C is known, the input diode current can be calculated by

$$I_F = I_C/\eta,$$

where I_F is the forward diode current
I_C is the collector current
η is the coupling efficiency or transfer ratio.

4N25, 4N26

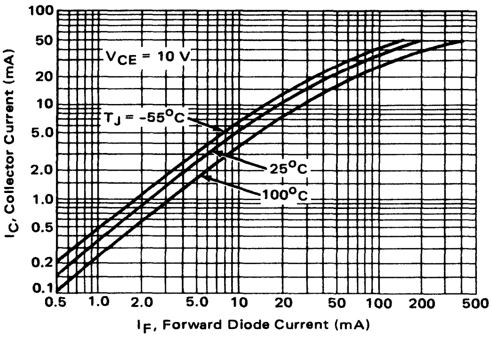


FIGURE 4A — DC Current Transfer Ratio

4N27, 4N28

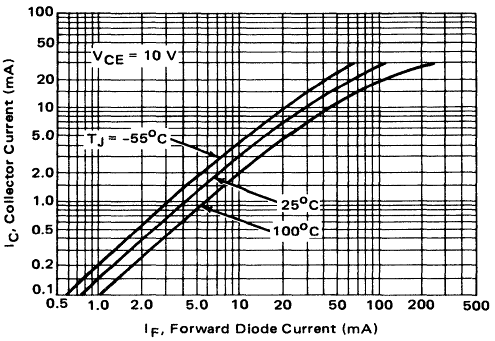


FIGURE 4B — DC Current Transfer Ratio

RESPONSE TIME

The switching times for the couplers are shown in Figures 5A and 5B. The speed is fairly slow compared to switching transistors, but is typical of phototransistors because of the large base-collector area. The switching time or bandwidth of the coupler is a function of the load resistor R_L because of the R_LC_O time constant where C_O is the parallel combination of the device and load capacitances. Figure 6 is a curve of frequency response versus R_L.

TURN-ON TIME

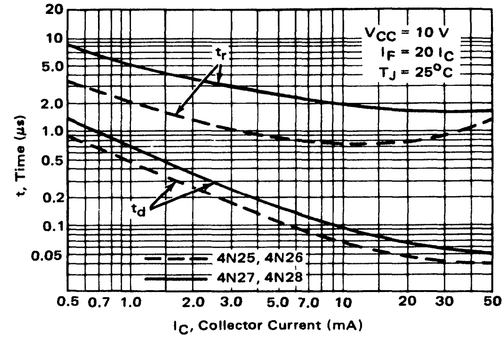


FIGURE 5A — Switching Times

TURN-OFF TIME

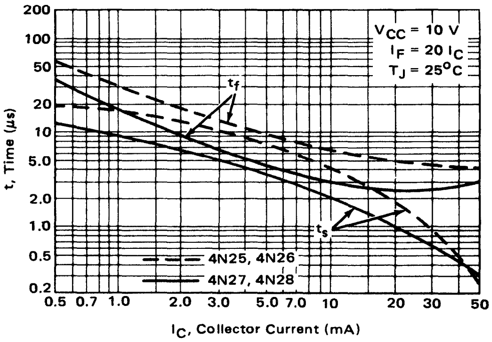


FIGURE 5B — Switching Times

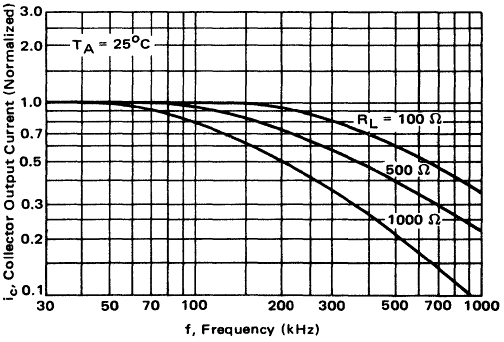


FIGURE 6 — Frequency Response

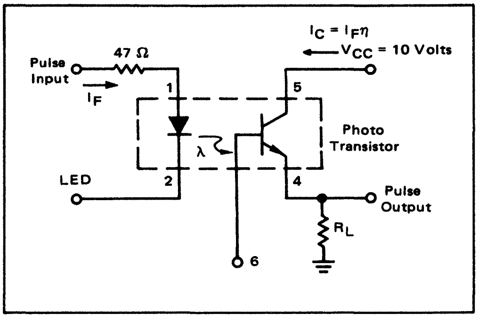


FIGURE 7 – Pulse Mode Circuit

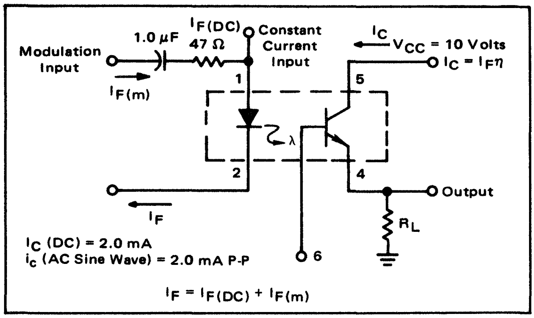


FIGURE 8 – Linear Mode Circuit

OPERATING MODE

The two basic modes of operation are pulsed and linear. In the pulsed mode of operation, the LED will be switched on or off. The output will also be pulses either in phase or 180° out of phase with the input depending on where the output is taken. The output will be 180° out of phase if the collector is used and in phase if the emitter is used for the output.

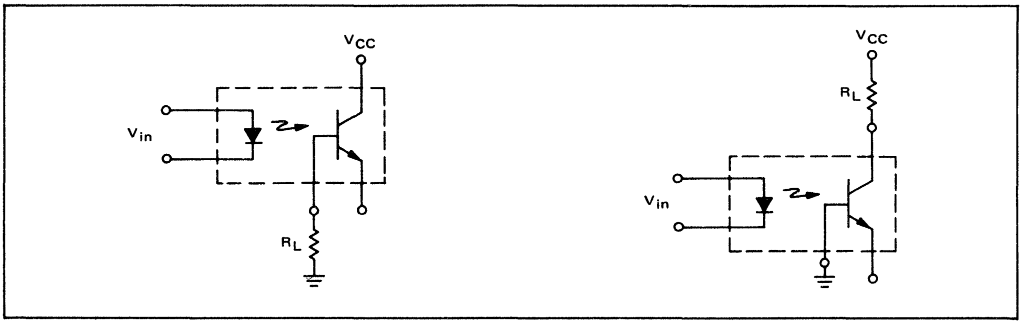


FIGURE 9 – Circuit Connections for Using the 4N26 As a Diode-Diode Coupler

In the linear mode of operation, the input is biased at a dc operating point and then the input is changed about this dc point. The output signal will have an ac and dc component in the signal.

Figures 7 and 8 show typical circuits for the two modes of operation.

THE 4N26 AS A DIODE-DIODE COUPLER

The 4N26 which is a diode-transistor coupler, can be used as a diode-diode coupler. To do this the output is taken between the collector and base instead of the collector and emitter. The circuits in Figure 9 show the connections to use the coupler in the diode-diode mode.

The advantage of using the 4N26 as a diode-diode coupler is increased speed. For example, the pulse rise time for a diode-transistor coupler is in the order of 2 to 5 μs, where the diode-diode coupler is 50 to 100 ns. The one disadvantage with the diode-diode coupler is that the output current is much lower than the diode-transistor coupler. This is because the base current is being used as signal current and the β multiplication of the transistor is omitted. Figure 10 is a graph of I_B versus I_F using the coupler in the diode-diode mode.

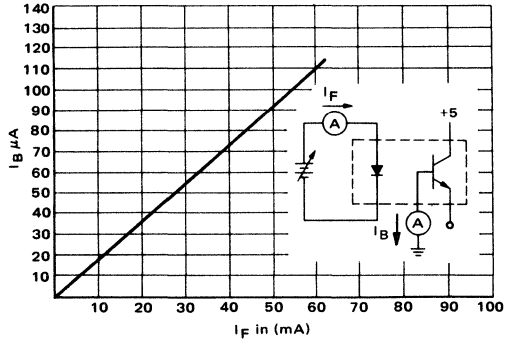


FIGURE 10 – I_B versus I_F Curve for Using the 4N26 As a Diode-Diode Coupler

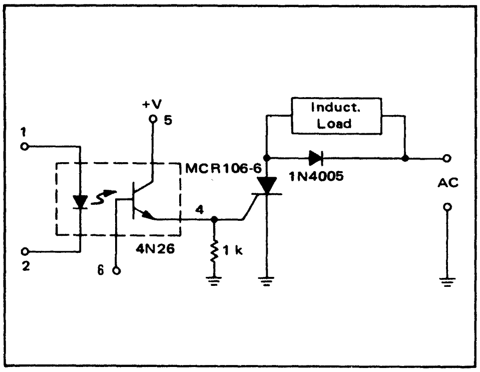


FIGURE 11 – Coupler-Driven SCR

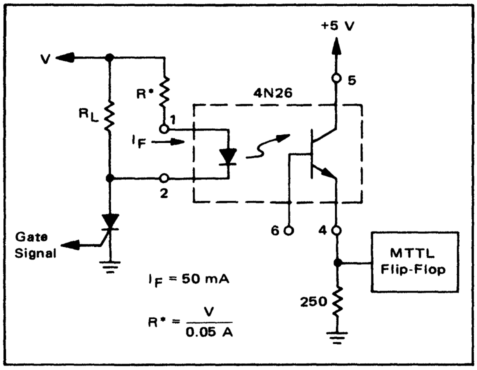


FIGURE 12 – Opto Coupler In A Load To Logic Translation

APPLICATIONS

The following circuits are presented to give the designer ideas of how the 4N26 can be used. The circuits have been bread-boarded and tested, but the values of the circuit components have not been selected for optimum performance over all temperatures.

Figure 11 shows a coupler driving a silicon controlled rectifier (SCR). The SCR is used to control an inductive load, and the SCR is driven by a coupler. The SCR used is a sensitive gate device that requires only 1 mA of gate current and the coupler has a minimum current transfer ratio of 0.2 so the input current to the coupler, I_F, need only be 5 mA. The 1 k resistor connected to the gate of the SCR is used to hold off the SCR. The 1N4005 diode is used to supress the self-induced voltage when the SCR turns off.

Figure 12 is a circuit that couples a high voltage load to a low voltage logic circuit. To insure that the voltage to the MTTL flip-flop exceeds the logic-one level, the coupler output current must be at least 10 mA. To guarantee 10 mA of output current, the input current to the LED must be 50 mA. The current limiting resistor R can be calculated from the equation $R = \frac{V - V_F}{0.05}$. If the power supply voltage, V, is much greater than V_F, the equation for R reduces to $R = \frac{V}{0.05}$.

The circuit of Figure 13 shows a coupler driving an operational amplifier. In this application an ac signal is passed through the coupler and then amplified by the op amp. To pass an ac signal through the coupler with minimum distortion, it is necessary to bias the LED with a dc current. The ac signal is summed with the dc current so the output voltage of the coupler will have an ac and a dc component. Since the op amp is capacitively coupled to the coupler, only the ac signal will appear at the output.

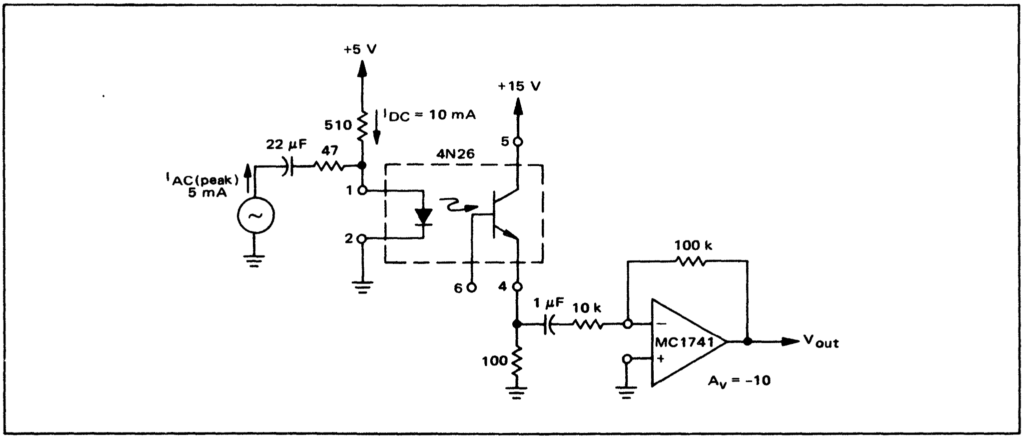


FIGURE 13 – Coupling An AC Signal to an Operational Amplifier

The circuit of Figure 14 shows the 4N26 being used as a diode-diode coupler, the output being taken from the collector-base diode. In this mode of operation, the emitter is left open, the load resistor is connected between the base and ground, and the collector is tied to the positive voltage supply. Using the coupler in this way reduces the switching time from 2 to 3 μs to 100 ns.

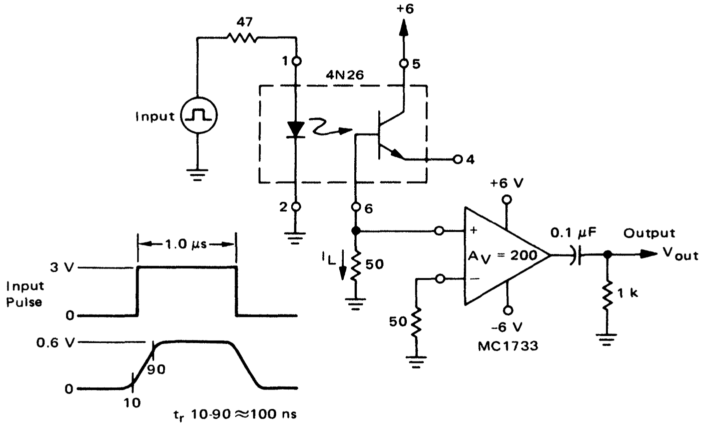


FIGURE 14 – Using the 4N26 as a Diode-Diode Coupler

The circuit of Figure 15 is a standard two-transistor one-shot, with one transistor being the output transistor of the coupler. The trigger to the one-shot is the LED input to the coupler. A pulse of 3 μs in duration and 15 mA will trigger the circuit. The output pulse width (PW_O) is equal to 0.7 RC + PW_I + 6 μs where PW_I is the input pulse width and 6 μs is the turn-off delay of the coupler. The amplitude of the output pulse is a function of the power supply voltage of the output side and independent of the input.

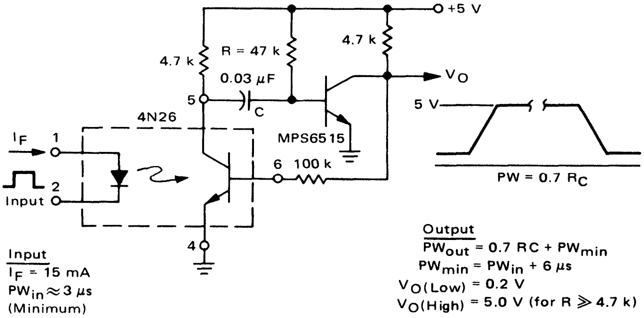


FIGURE 15 – Pulse Stretcher

The circuit of Figure 16 is basically a Schmitt trigger. One of the Schmitt trigger transistors is the output transistor of a coupler. The input to the Schmitt trigger is the LED of the coupler. When the base voltage of the coupler's transistor exceeds V_e+V_{be} the output transistor of the coupler will switch on. This will cause Q2 to conduct and the output will be in a high state. When the input to the LED is removed, the coupler's output transistor will shut off and the output voltage will be in a low state. Because of the high impedance in the base of the coupler

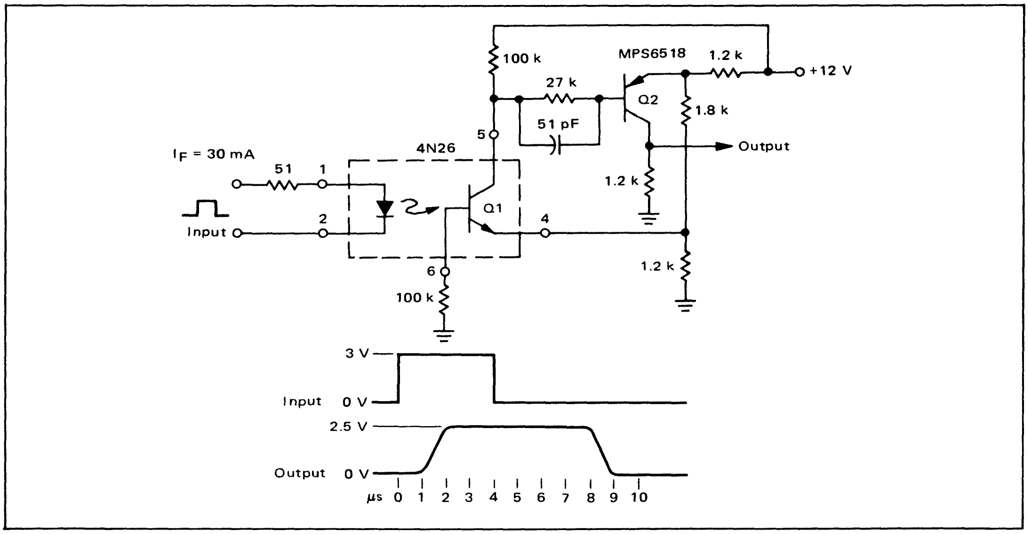


FIGURE 16 – Optically Coupled Schmitt Trigger

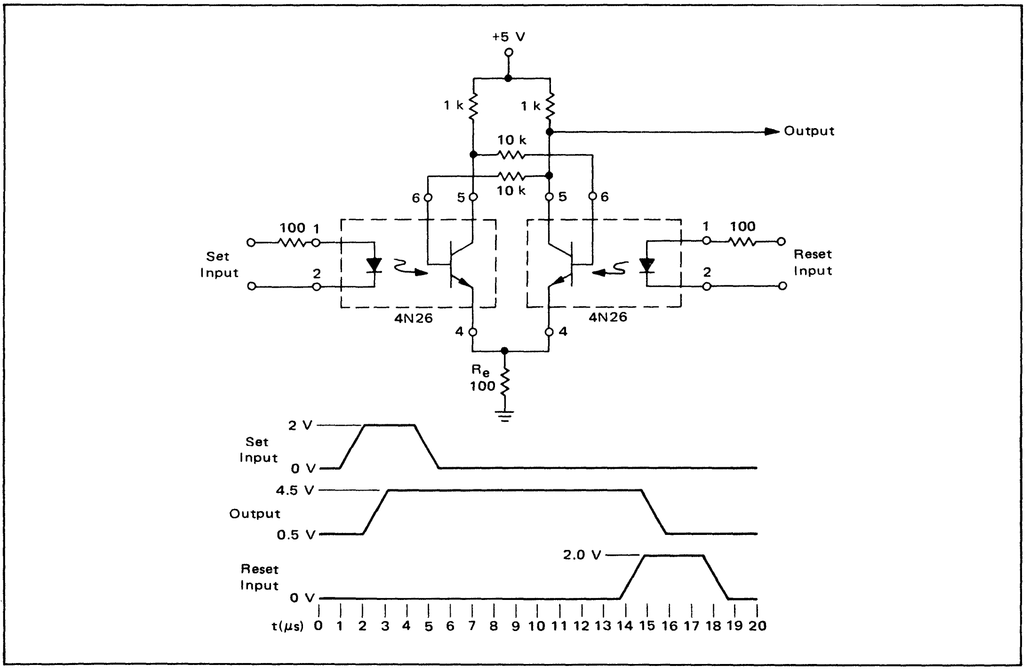


FIGURE 17 – Optically Coupled R-S Flip-Flop

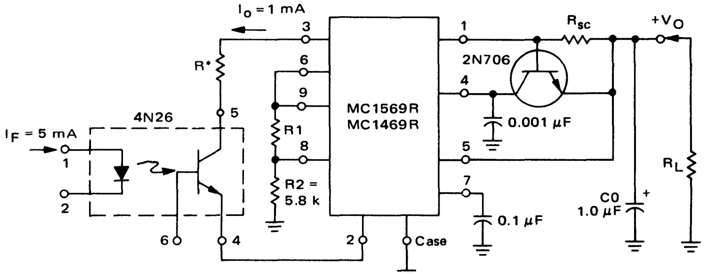
transistor, the turn-off delay is about 6 µs. The high base impedance (100 k ohms) represents a compromise between sensitivity (input drive required) and frequency response. A low value base resistor would improve speed but would also increase the drive requirements.

The circuit in Figure 17 can be used as an optically coupled R-S flip-flop. The circuit uses two 4N26 couplers cross coupled to produce two stable states. To change the output from a low state to a high state requires a positive 2 V pulse at the set input. The minimum width of the set pulse is 3 µs. To switch the output back to the low state needs only a pulse on the reset input. The reset-operation is similar to the set operation.

Motorola integrated voltage regulators provide an input for the express purpose of shutting the regulator off. For large systems, various subsystems may be placed in a stand-by mode to conserve power until actually needed. Or the power may be turned OFF in response to occurrences such as overheating, over-voltage, shorted output, etc.

With the use of the 4N26 optically coupler, the regulator can be shut down while the controlling signal is isolated from the regulator. The circuit of Figure 18 shows a positive regulator connected to an optical coupler.

To insure that the drive to the regulator shut down control is 1 mA, (the required current), it is necessary to drive the LED in the coupler with 5 mA of current, an adequate level for logic circuits.



R* = |V_{in} −1.7 V| kΩ

FIGURE 18 – Optical Coupler Controlling the Shut Down of MC1569 Voltage Regulator

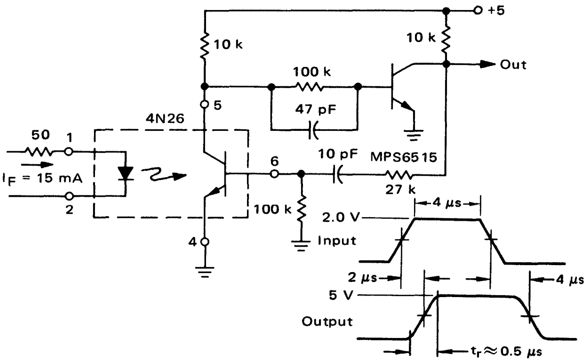


FIGURE 19 – Simple Pulse Amplifier

The circuit in Figure 19 is a simple pulse amplifier using positive, ac feedback into the base of the 4N26. The advantage of the feedback is in faster switching time. Without the feedback, the pulse rise time is about 2.0 µs, but with the positive feedback, the pulse rise time is about 0.5 µs. Figure 17A shows the input and output wavefroms of the pulse amplifier.

REFERENCES

1. "Theory and Characteristics of Phototransistors," Motorola Application Note AN-440.
2. "Motorola Switching Transistor Handbook."
3. Deboo, G.J. and C.N. Burrous, Integrated Circuits and Semiconductor Devices Theory and Application, McGraw-Hill, 1971.

AN-780A

APPLICATIONS OF THE MOC3011 TRIAC DRIVER

Prepared by:
Pat O'Neil

4

DESCRIPTIONS OF THE MOC3011

Construction

The MOC3011 consists of a gallium arsenide infrared LED optically exciting a silicon detector chip, which is especially designed to drive triacs controlling loads on the 115 Vac power line. The detector chip is a complex device which functions in much the same manner as a small triac, generating the signals necessary to drive the gate of a larger triac. The MOC3011 allows a low power exciting signal to drive a high power load with a very small number of components, and at the same time provides practically complete isolation of the driving circuitry from the power line.

The construction of the MOC3011 follows the same highly successful coupler technology used in Motorola's broad line of plastic couplers (Figure 1). The dual lead frame with an epoxy undermold provides a stable dielectric capable of sustaining 7.5 kV between the input and output sides of the device. The detector chip is passivated with silicon nitride and uses Motorola's annular ring to maintain stable breakdown parameters.

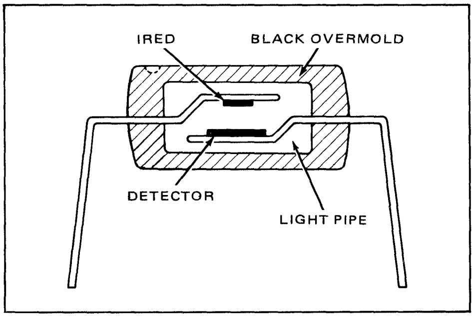


FIGURE 1 — Motorola Double-Molded Coupler Package

Basic Electrical Description

The GaAs LED has nominal 1.3 V forward drop at 10 mA and a reverse breakdown voltage greater than 3 V. The maximum current to be passed through the LED is 50 mA.

The detector has a minimum blocking voltage of 250 Vdc in either direction in the off state. In the on state, the detector will pass 100 mA in either direction with less than 3 V drop across the device. Once triggered into the on (conducting) state, the detector will remain there until the current drops below the holding current (typically 100 μA) at which time the detector reverts to the off (non-conducting) state. The detector may be triggered into the on state by exceeding the forward blocking voltage, by voltage ramps across the detector at rates exceeding the static dv/dt rating, or by photons from the LED. The LED is guaranteed by the specifications to trigger the detector into the on state when 10 mA or more is passed through the LED. A similar device, the MOC3010, has exactly the same characteristics except it requires 15 mA to trigger.

Since the MOC3011 looks essentially like a small optically triggered triac, we have chosen to represent it as shown on Figure 2.

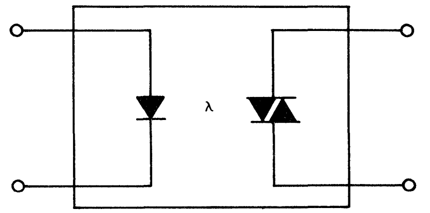
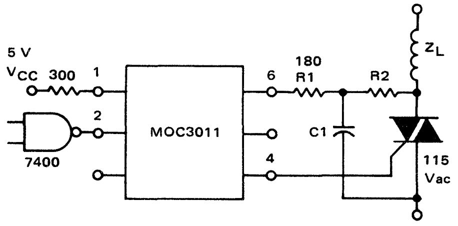


FIGURE 2 – Schematic Representation of MOC3011 and MOC3010



NOTE: Circuit supplies 25 mA drive to gate of triac at V_{in} = 25 V and $T_A \leqslant 70^{\circ}C$.

TRIAC		
I_{GT}	R2	C
15 mA	2400	0.1
30 mA	1200	0.2
50 mA	800	0.3

FIGURE 4 – Logic to Inductive Load Interface

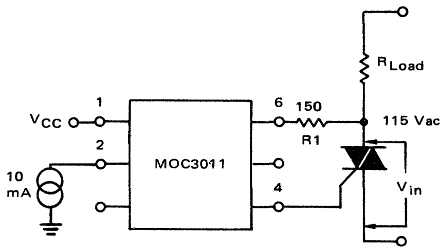


FIGURE 3 – Simple Triac Gating Circuit

USING THE MOC3011 AS A TRIAC DRIVER

Triac Driving Requirements

Figure 3 shows a simple triac driving circuit using the MOC3011. The maximum surge current rating of the MOC3011 sets the minimum value of R1 through the equation:

$$R1\,(\text{min}) = V_{in}(\text{pk})/1.2\ A$$

If we are operating on the 115 Vac nominal line voltage, $V_{in}(\text{pk})$ = 180 V, then

$$R1(\text{min}) = V_{in}(\text{pk})/1.2\ A = 150\ \text{ohms.}$$

In practice, this would be a 150 or 180 ohm resistor. If the triac has I_{GT} = 100 mA and V_{GT} = 2 V, then the voltage V_{in} necessary to trigger the triac will be given by $V_{inT} = R1 \cdot I_{GT} + V_{GT} + V_{TM} = 20$ V.

Resistive Loads

When driving resistive loads, the circuit of Figure 3 may be used. Incandescent lamps and resistive heating elements are the two main classes of resistive loads for which 115 Vac is utilized. The main restriction is that the triac must be properly chosen to sustain the proper inrush loads. Incandescent lamps can sometimes draw a peak current known as "flashover" which can be extremely high, and the triac should be protected by a fuse or rated high enough to sustain this current.

Line Transients–Static dv/dt

Occasionally transient voltage disturbance on the ac line will exceed the static dv/dt rating of the MOC3011. In this case, it is possible that the MOC3011 and the associated triac will be triggered on. This is usually not a problem, except in unusually noisy environments, because the MOC3011 and its triac will commute off at the next zero crossing of the line voltage, and most loads are not noticeably affected by an occasional single half-cycle of applied power. See Figure 5 for typical dv/dt versus temperature curves.

Inductive Loads–Commutating dv/dt

Inductive loads (motors, solenoids, magnets, etc.) present a problem both for triacs and for the MOC3011 because the voltage and current are not in phase with each other. Since the triac turns off at zero current, it may be trying to turn off when the applied current is zero but the applied voltage is high. This appears to the triac like a sudden rise in applied voltage, which turns on the triac if the rate of rise exceeds the commutating dv/dt of the triac or the static dv/dt of the MOC3011.

Snubber Networks

The solution to this problem is provided by the use of "snubber" networks to reduce the rate of voltage rise seen by the device. In some cases, this may require two snubbers–one for the triac and one for the MOC3011. The triac snubber is dependent upon the triac and load used and will not be discussed here. In many applications the snubber used for the MOC3011 will also adequately protect the triac.

In order to design a snubber properly, one should really know the power factor of the reactive load, which is defined as the cosine of the phase shift caused by the load. Unfortunately, this is not always known, and this makes snubbing network design somewhat empirical. However a method of designing a snubber network may be defined, based upon a typical power factor. This can be used as a "first cut" and later modified based upon experiment.

Assuming an inductive load with a power factor of PF = 0.1 is to be driven. The triac might be trying to turn off when the applied voltage is given by

$$V_{to} = V_{pk}\sin\phi \approx V_{pk} \approx 180\ \mathrm{V}$$

First, one must choose R1 (Figure 4) to limit the peak capacitor discharge current through the MOC3011. This resistor is given by

$$R1 = V_{pk}/I_{max} = 180/1.2\ \mathrm{A} = 150\ \Omega$$

A standard value, 180 ohm resistor can be used in practice for R1.

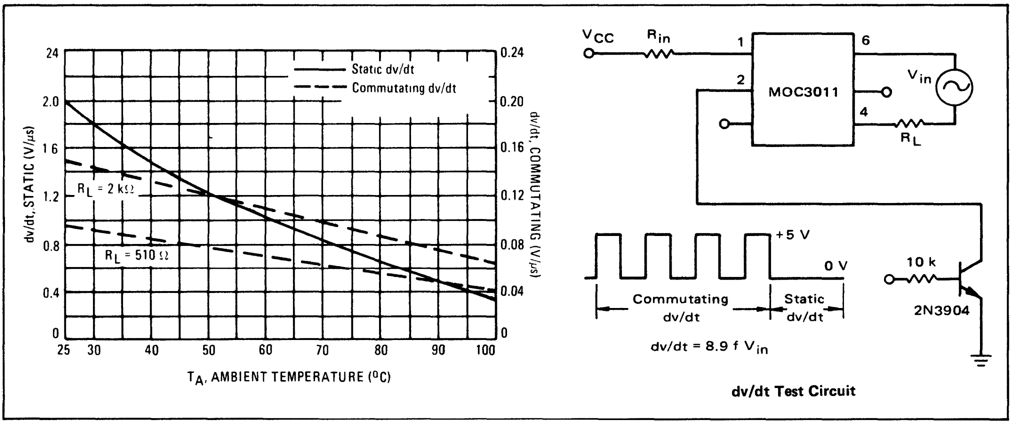
It is necessary to set the time constant for $\tau = R_2C$. Assuming that the triac turns off very quickly, we have a peak rate of rise at the MOC3011 given by

$$dv/dt = V_{to}/\tau = V_{to}/R_2C$$

Setting this equal to the worst case dv/dt (static) for the MOC3011 which we can obtain from Figure 5 and solving for R_2C:

$$dv/dt(T_J = 70^{\circ}C) = 0.8\ V/\mu s = 8 \times 10^5$$

$$R_2C = V_{to}/(dv/dt) = 180/(8 \times 10^5) \approx 230 \times 10^{-6}$$



dv/dt Test Circuit

FIGURE 5 — dv/dt versus Temperature

The largest value of R2 available is found, taking into consideration the triac gate requirements. If a sensitive gate triac is used, such as a 2N6071B, I_{GT} = 15 mA @ -40°C. If the triac is to be triggered when $V_{in} \leqslant 40$ V

$$(R1 + R2) \approx V_{in}/I_{GT} \approx 40/0.015 \approx 2.3 \text{ k}$$

If we let R2 = 2400 ohms and C = 0.1 μF, the snubbing requirements are met. Triacs having less sensitive gates will require that R2 be lower and C be correspondingly higher as shown in Figure 4.

INPUT CIRCUITRY

Resistor Input

When the input conditions are well controlled, as for example when driving the MOC3011 from a TTL, DTL, or HTL gate, only a single resistor is necessary to interface the gate to the input LED of the MOC3011. This resistor should be chosen to set the current into the LED to be a minimum of 10 mA but no more than 50 mA. 15 mA is a suitable value, which allows for considerable degradation of the LED over time, and assures a long operating life for the coupler. Currents higher than 15 mA do not improve performance and may hasten the aging process inherent in LED's. Assuming the forward drop to be 1.5 V at 15 mA allows a simple formula to calculate the input resistor.

$$R_i = (V_{CC} - 1.5)/0.015$$

Examples of resistive input circuits are seen in Figures 2 and 6.

Increasing Input Sensitivity

In some cases, the logic gate may not be able to source or sink 15 mA directly. CMOS, for example, is specified to have only 0.5 mA output, which must then be increased to drive the MOC3011. There are numerous ways to increase this current to a level compatible with the MOC3011 input requirements; an efficient way is to use the MC14049B shown in Figure 6. Since there are six such buffers in a single package, the user can have a small package count when using several MOC3011's in one system.

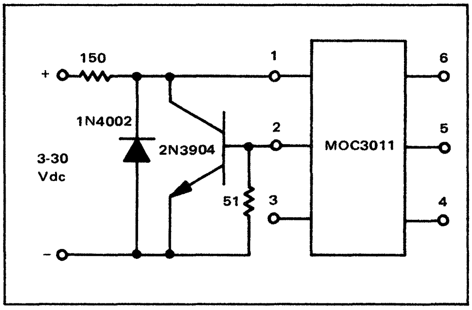
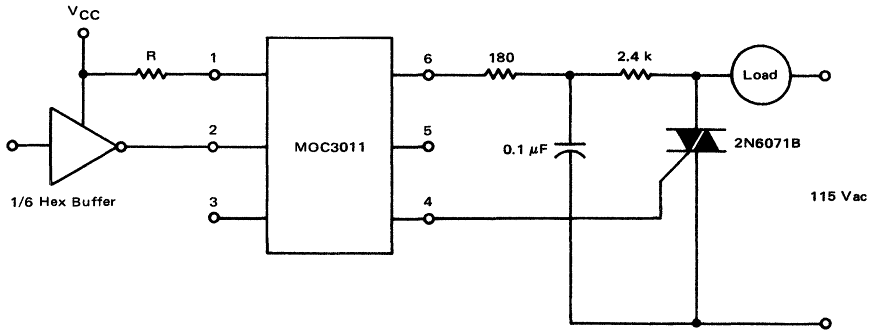


FIGURE 7 — MOC3011 Input Protection Circuit



V_{CC}	R	HEX BUFFER
5.0 V	220 Ω	MC75492
10 V	600 Ω	MC75492
15 V	910 Ω	MC14049B

FIGURE 6 — MOS to ac Load Interface

Input Protection Circuits

In some applications, such as solid state relays, in which the input voltage varies widely the designer may want to limit the current applied to the LED of the MOC3011. The circuit shown in Figure 7 allows a non-critical range of input voltages to properly drive the MOC3011 and at the same time protects the input LED from inadvertent application of reverse polarity.

LED Lifetime

All light emitting diodes slowly decrease in brightness during their useful life, an effect accelerated by high temperatures and high LED currents. To allow a safety margin and insure long service life, the MOC3011 is actually tested to trigger at a value lower than the specified 10 mA input threshold current. The designer can therefore design the input circuitry to supply 10 mA to the LED and still be sure of satisfactory operation over a long operating lifetime. On the other hand, care should be taken to insure that the maximum LED input current (50 mA) is not exceeded or the lifetime of the MOC3011 may be shortened.

APPLICATIONS EXAMPLES

Using the MOC3011 on 240 Vac Lines

The rated voltage of a MOC3011 is not sufficiently high for it to be used directly on 240 Vac line; however, the designer may stack two of them in series. When used this way, two resistors are required to equalize the voltage dropped across them as shown in Figure 8.

Remote Control of ac Voltage

Local building codes frequently require all 115 Vac light switch wiring to be enclosed in conduit. By using a MOC3011, a triac, and a low voltage source, it is

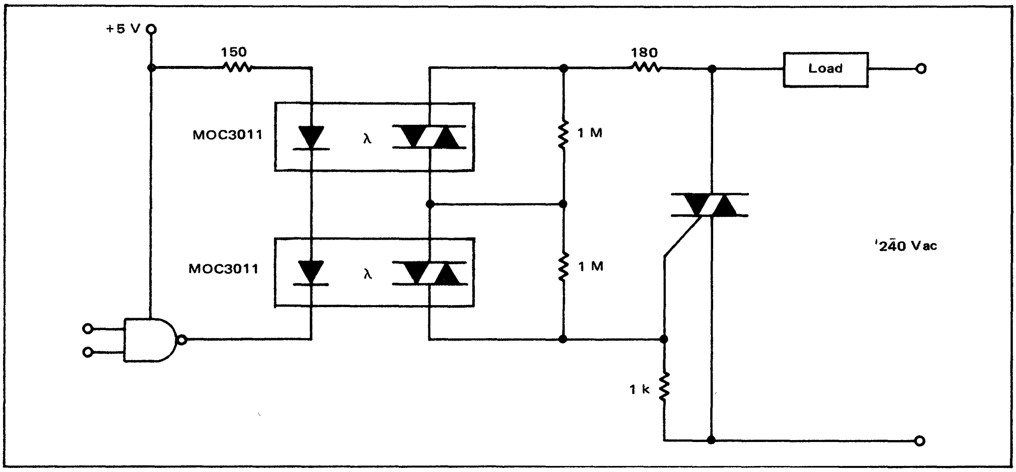


FIGURE 8 — 2 MOC3011 Triac Drivers in Series to Drive 240 V Triac

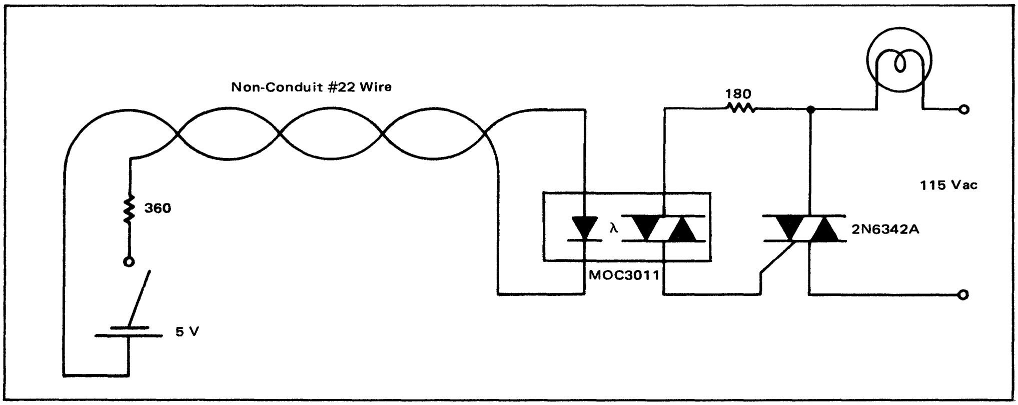


FIGURE 9 — Remote Control of ac Loads Through Low Voltage Non-Conduit Cable

possible to control a large lighting load from a long distance through low voltage signal wiring which is completely isolated from the ac line. Such wiring usually is not required to be put in conduit, so the cost savings in installing a lighting system in commercial or residential buildings can be considerable. An example is shown in Figure 9. Naturally, the load could also be a motor, fan, pool pump, etc.

Solid State Relay

Figure 10 shows a complete general purpose, solid state relay snubbed for inductive loads with input protection. When the designer has more control of the input and output conditions, he can eliminate those components which are not needed for his particular application to make the circuit more cost effective.

Interfacing Microprocessors to 115 Vac Peripherals

The output of a typical microcomputer input-output (I/O) port is a TTL-compatible terminal capable of driving one or two TTL loads. This is not quite enough to drive the MOC3011, nor can it be connected directly to an SCR or triac, because computer common is not normally referenced to one side of the ac supply. Standard 7400 series gates can provide an input compatible with the output of an MC6820, MC6821, MC6846 or similar peripheral interface adaptor and can directly drive the MOC3011. If the second input of a 2 input gate is tied to a simple timing circuit, it will also provide energization of the triac only at the zero crossing of the ac line voltage as shown in Figure 11. This technique extends the life of incandescent lamps, reduces the surge current strains on the triac, and reduces EMI generated by load switching. Of course, zero crossing can be generated within the microcomputer itself, but this requires considerable software overhead and usually just as much hardware to generate the zero-crossing timing signals.

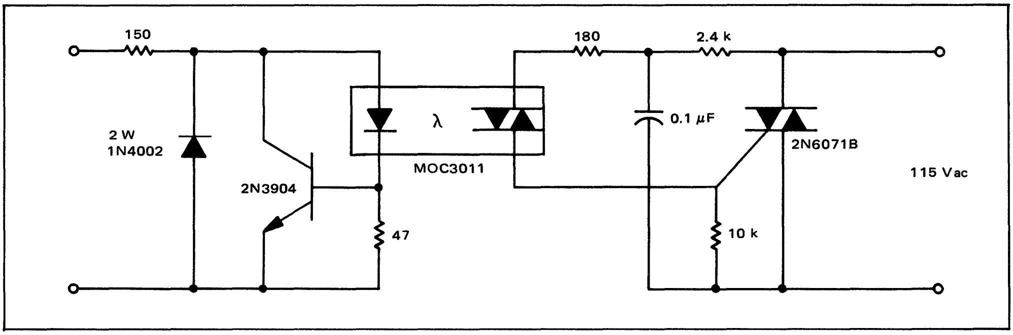
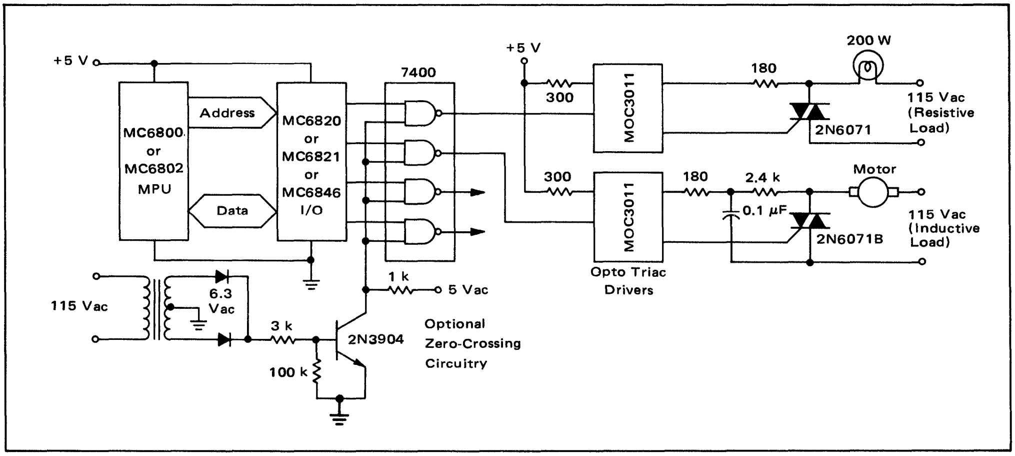
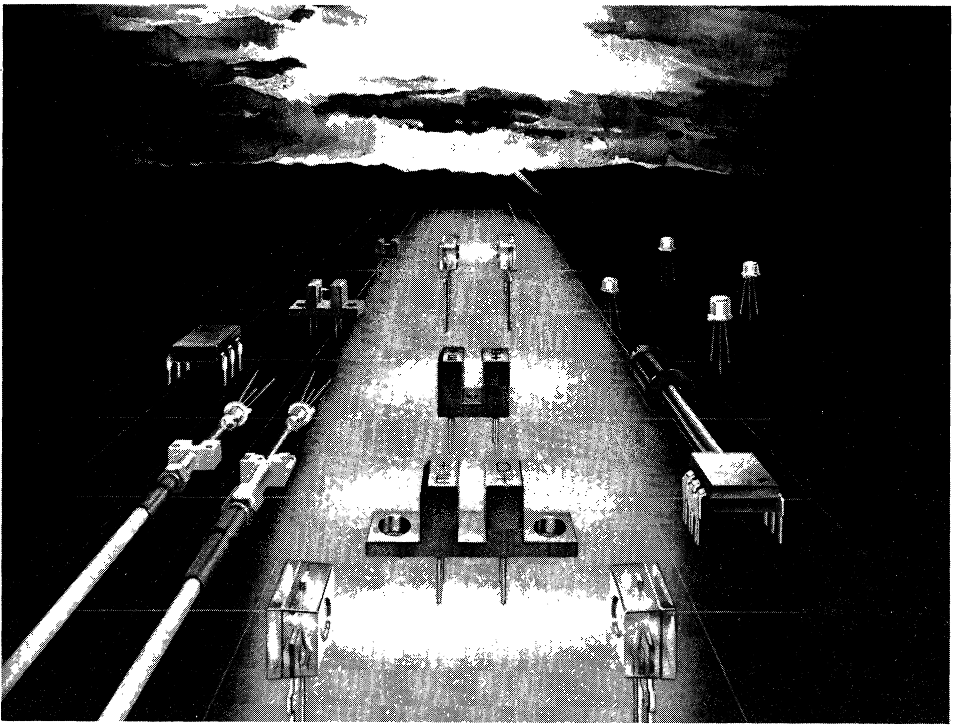


FIGURE 10 — Solid-State Relay



FIBER OPTICS



General Information

The Motorola Fiber Optic product portfolio is intended principally to address fiber optic communications systems in the computer, industrial controls, medical electronics, consumer and automotive applications.

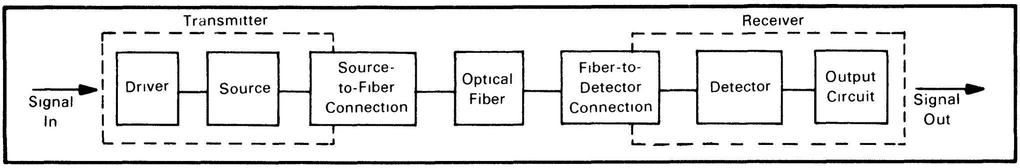
Analog and digital modulation schemes at bandwidths through 100 MHz and system lengths through several kilometers may be achieved using Motorola fiber optic semiconductor devices.

The semiconductors are housed in packages suitable for high-volume production and low cost. Most important, however, the packages are standardized, permitting interchangeability, speedy field maintenance, and easy assembly into systems.

FIBER OPTICS . . .

a new method of cabled communication and data transmission using modulated light through an optical cable.

Basic Fiber-Optic Link



Fiber optic systems offer many advantages in terms of performance and cost over traditional electrical, coaxial or hard-wired transmission systems.

Fiber optic systems inherently provide:

- Ability to transmit a great deal of data on a single fiber
- Electrical isolation
- EMI/RFI noise immunity, no electromagnetic coupling
- No signal radiation or noise emission
- No spark or fire hazard
- Short circuit protection, no current flow
- Transmission security
- Lightweight, small diameter cable
- Lightning surge current and transient immunity
- Cost effectiveness

Replacements for Discontinued FOAC Devices

The theory and applications sections refer to or were written around the FOAC emitters and detectors. The FOAC devices were in a ferruled plastic package and have been discontinued in favor of a standard, TO-206AC (TO-52) hermetic package.

In the following descriptive sections the equivalent TO-206AC (TO-52) device can be substituted for the FOAC device without any circuit modifications. The TO-206AC (TO-52) emitters do have faster switching capability.

FOAC	TO-206AC (TO-52)
MFOD102F MFOD104F	MFOD1100
MFOD202F MFOD302F MFOD402F MFOD404F MFOD405F	MFOD2202 MFOD2302 MFOD2405 MFOD2404 MFOD2405
MFOE102F MFOE103F MFOE106F	MFOE1200
MFOE107F MFOE108F	MFOE1201 MFOE1202

BASIC CONCEPTS OF FIBER OPTICS AND FIBER OPTIC COMMUNICATIONS

Prepared By
John Bliss
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Introduction

This note presents an introduction to the principles of fiber optics. Its purpose is to review some basic concepts from physics that relate to fiber optics and the application of semiconductor devices to the generation and detection of light transmitted by optical fibers. The discussion begins with a description of a fiber optic link and the inherent advantages of fiber optics over wired systems.

A Fiber Optic Link

Webster gives as one definition of a link "something which binds together or connects." In fiber optics, a link is the assembly of hardware which connects a source of a signal with its ultimate destination. The items which comprise the assembly are shown in Figure 1. As the figure indicates, an input signal, for example, a serial digital bit stream, is used to modulate a light source, typically an LED (light emitting diode). A variety of modulation schemes can be used. These will be discussed later. Although the input signal is assumed to be a digital bit stream, it could just as well be an analog signal, perhaps video.

The modulated light must then be coupled into the optical fiber. This is a critical element of the system. Based on the coupling scheme used, the light coupled into the fiber could be two orders of magnitude less than the total power of the source.

Once the light has been coupled into the fiber, it is attenuated as it travels along the fiber. It is also subject to distortion. The degree of distortion limits the maximum data rate that can be transmitted through the fiber.

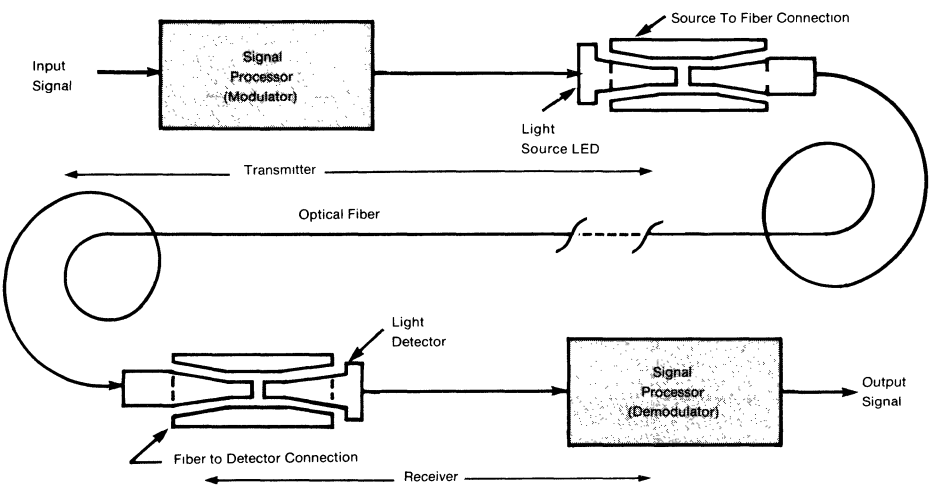

FIGURE 1. A FIBER OPTIC LINK

At the receive end of the fiber, the light is coupled into a detector element (like a photo diode). The coupling problem at this stage, although still of concern, is considerably less severe than at the source end. The detector signal is then reprocessed or decoded to reconstruct the original input signal.

A link like that described in Figure 1 can be fully transparent to the user. That is, everything from the input signal connector to the output signal connector can be prepackaged. Thus, the user need only be concerned with supplying a signal of some standard format and level (like NRZ T^2L) and extracting a similar signal. Such a T^2L in/T^2L out system obviates the need for a designer to understand fiber optics. However, by analyzing the problems and concepts internal to the link, the user is better prepared to apply fiber optics technology to his sytem.

Advantages of Fiber Optics

There are both performance and cost advantages to be realized by using fiber optics over wire.

Greater Bandwidth. The higher the carrier frequency in a communication system, the greater its potential signal bandwidth. Since fiber optics work with carrier frequencies on the order of 10^{13}-10^{14} Hz as compared to radio frequencies of 10^6-10^8 Hz, signal bandwidths are theoretically 10^6 times greater.

Smaller size and weight. A single fiber is capable of replacing a very large bundle of individual copper wire. For example, a typical telephone cable may contain over 1,000 pairs of copper wire and have a cross-sectional diameter of seven to ten centimeters. A single glass fiber cable capable of handling the same amount of signal might be only one-half centimeter in diameter. The actual fiber may be as small as 50 μ-meters. The additional size is the jacket and strength elements. The weight reduction in this example should be obvious.

Lower attenuation. Length for length, optical fiber exhibits less attenuation than does twisted wire or coaxial cable. Also, the attenuation of optical fibers, unlike that of wire, is not signal frequency dependent.

Freedom from EMI. Unlike wire, glass does not pick up nor generate electro-magnetic interference (EMI). Optical fibers do not require expensive shielding techniques to desensitize them to stray fields.

Ruggedness. Glass is 20 times stronger than steel and since glass is relatively inert, corrosive environments are of less concern than with wired systems.

Safety. In many wired systems, the potential hazard of short circuits between wires or from wires to ground, requires special precautionary designs. The dielectric nature of optic fibers eliminates this requirement and the concern for hazardous sparks occurring during interconnects.

Lower Cost. Optical fiber costs are continuing to decline while the cost of wire is increasing. In many applications today, the total system cost for a fiber optic design is lower than for a comparable wired design. As time passes, more and more systems will be decidedly less expensive with optical fibers.

Physics of Light

The performance of optical fibers can be fully analyzed by application of Maxwell's Equations for electromagnetic fields. However, these are necessarily complex and, fortunately, can be bypassed for most users by the application of geometric ray tracing and analysis. When considering LEDs and photo detectors, the particle theory of light is used. The change from ray to particle theory is fortunately a simple step.

Over the years, it has been demonstrated that light (in fact, all electromagnetic energy) travels at approximately 300,000 km/second in free space. It has also been demonstrated that in materials denser than free space, the speed of light is reduced. This reduction in the speed of light as it passes from free space into a denser material results in refraction of the light. Simply

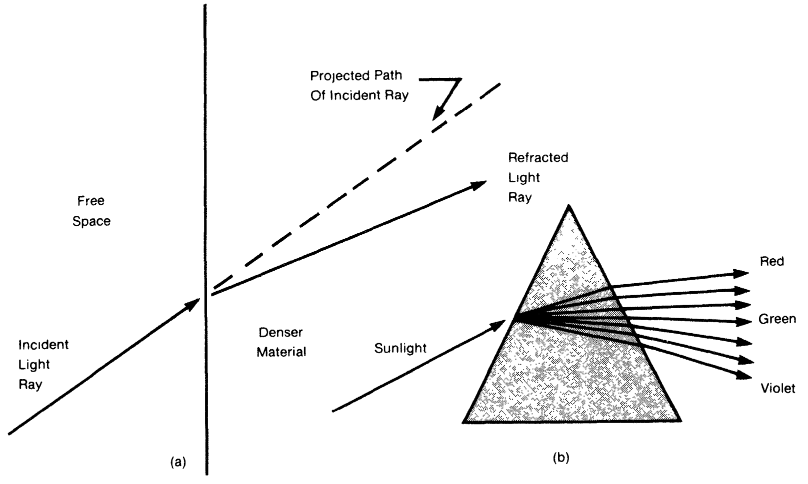

FIGURE 2. REFRACTION OF LIGHT:
a. Light refraction at an interface; b. White light spectral separation by prismatic refraction.

stated, the light ray is bent at the interface. This is shown in Figure 2a. In fact, the reduction of the speed of light is different for different wavelengths; and, therefore, the degree of bending is different for each wavelength. It is this variation in effect for different wavelengths that results in rainbows. Water droplets in the air act like small prisms (Figure 2b) to split white sunlight into the visible sprectrum of colors.

The actual bend angle at an interface is predictable and depends on the **refractive index** of the dense material. The **refractive index**, usually given the symbol n, is the ratio of the speed of light in free space to its speed in the denser material:

$$n = \frac{\text{speed of light in free space}}{\text{speed of light in given material}} \qquad (1)$$

Although n is also a function of wavelength, the variation in many applications is small enough to be ignored and a single value is given. Some typical values of n are given in Table 1:

Table 1
Representative Indices of Refraction

Vacuum	1.0
Air	1.0003 (1.0)
Water	1.33
Fused Quartz	1.46
Glass	1.5
Diamond	2.0
Silicon	3.4
Gallium-Arsenide	3.6

It is interesting to consider what happens to a light ray as it meets the interface between two transmissive materials. Figure 3 shows two such materials of refractive indices n_1 and n_2. A light ray is shown in material 1 and incident on the interface at point P. Snell's law states that:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad (2)$$

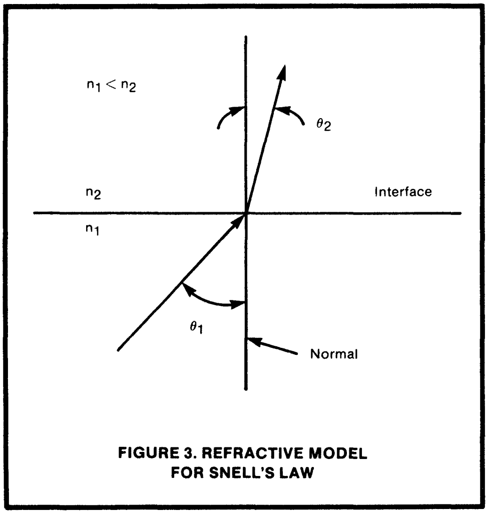

FIGURE 3. REFRACTIVE MODEL FOR SNELL'S LAW

The angle of refraction, θ_2, can be determined:

$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1 \qquad (3)$$

If material 1 is air, n_1 has the value of 1; and since n_2 is greater than 1, θ_2 is seen to be less than θ_1; that is, in passing through the interface, the light ray is refracted (bent) toward the normal.

If material 1 is not air but still has an index of refraction less than material 2, the ray will still be bent toward the normal. Note that if n_2 is less than n_1, θ_2 is greater than θ_1, or the ray is refracted away from the normal.

Consider Figure 4 in which an incident ray is shown at an angle such that the refracted ray is along the interface or the angle of refraction is 90°. Note that $n_1 > n_2$. Using Snell's law:

$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1 \qquad (4)$$

or, with θ_2 equal to 90°:

$$\sin\theta_1 = \frac{n_2}{n_1} = \sin\theta_c \qquad (5)$$

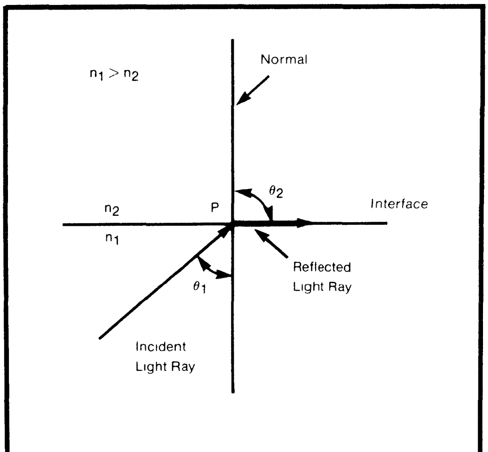

FIGURE 4. CRITICAL ANGLE REFLECTION

The angle, θ_c, is known as the critical angle and defines the angle at which incident rays will not pass through the interface. For angles greater than θ_c, 100 percent of the light rays are reflected (as shown in Figure 5), and the angle of incidence equals the angle of reflection.

This characteristic of reflection for light incident at greater than the critical angle is a fundamental concept in fiber optics.

Optical Fibers

Figure 6 shows the typical construction of an optical fiber. The central portion, or core, is the actual propagating path for light. Although the core is occasionally constructed of plastic, it is more typically made of glass. The choice of material will be discussed later. Bonded to the core is a cladding layer — again,

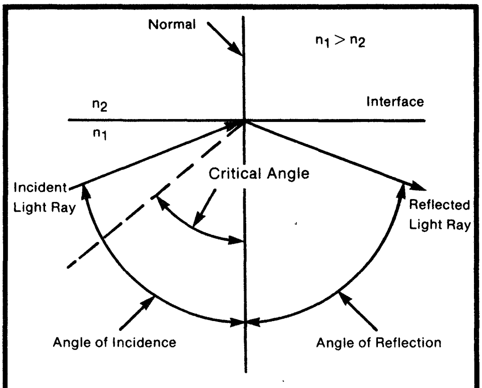

FIGURE 5. LIGHT INCIDENT AT GREATER THAN CRITICAL ANGLE

usually glass, although plastic cladding of glass core is not uncommon. The compositon of glass can be tailored during processing to vary the index of refraction. For example, an all-glass, or silica-clad fiber, may have the compositions set so that the core material has an index of refraction of 1.5; and the clad has an index of refraction of 1.485. To protect the clad fiber, it is typically enclosed in some form of protective rubber or plastic jacket. This type of optical fiber is called a "step index multimode" fiber. Step index refers to the profile of the index of refraction across the fiber (as shown in Figure 7). The core has an essentially constant index n_1. The classification "multimode" should be evident shortly.

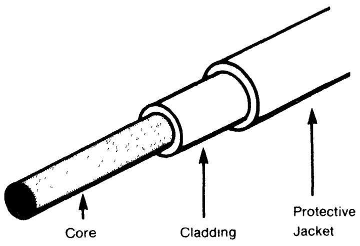

FIGURE 6. SINGLE FIBER CONSTRUCTION

Numerical Aperture

Applying the concept of total internal reflection at the n_1 n_2 interface, we can now demonstrate the propagation of light along the fiber core and the constraint on light incident on the fiber end to ensure propagation. Figure 8 illustrates the analysis. As the figure shows, ray propagation results from the continuous reflection at the core/clad interface such that the ray bounces down the fiber length and ultimately exits at the far end. If the principle of total internal reflection is applied at point P, the critical angle value for θ_3 is found by Snell's law:

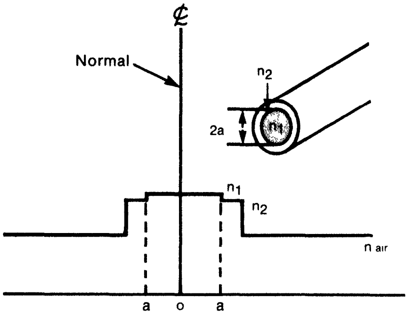

FIGURE 7. INDEX PROFILE FOR A STEP INDEX FIBER

$$\theta_c = \theta_3\,(\min) = \sin^{-1}\frac{n_2}{n_1} \qquad (6)$$

Now, since θ_2 is a complementary angle to θ_3,

$$\theta_2\,(\max) = \sin^{-1}\frac{(n_1{}^2 - n_2{}^2)^{1/2}}{n_1} \qquad (7)$$

Again applying Snell's law at the entrance surface (recall $n_{air} = 1$),

$$\sin\theta_{in}\,(\max) = n_1 \sin\theta_2\,(\max) \qquad (8)$$

Combining (7) and (8),

$$\sin\theta_{in}\,(\max) = (n_1{}^2 - n_2{}^2)^{1/2} \qquad (9)$$

θ_{in} (max) represents the largest angle with the normal to the fiber end for which total internal reflection will occur at the core/clad interface. Light rays entering the fiber end at angles greater than θ_{in} (max) will pass through the interface at P and be lost. The value $\sin\theta_{in}$ (max) is one of the fundamental parameters for an optical fiber. It defines the half-angle of the cone of acceptance for light to be propagated along the fiber and is called the "numerical aperture", usually abbreviated N.A.

$$\text{N.A.} = \sin\theta_{in}\,(\max) = (n_1{}^2 - n_2{}^2)^{1/2} \qquad (10)$$

There are several points to consider about N.A. and equation (10). Recall that in writing (8), we assumed that the material at the end of the fiber was air with an index of 1. If it were some other material, (8) would be written with n_3 representing the material):

$$n_3 \sin\theta_{in}\,(\max) = n_1 \sin\theta_2\,(\max) \qquad (11)$$

and, combining (7) and (11),

$$\sin_{in}\,(\max) = \frac{(n_1{}^2 - n_2{}^2)^{1/2}}{n_3}\ \text{N.A.} \qquad (12)$$

That is, the N.A. would be reduced by the index of refraction of the end material. When fiber manufacturers specify N.A., it is usually given for an air interface unless otherwise stated.

The second point concerns the absoluteness of N.A. The analysis assumed that the light rays entered the fiber, and in propagating along it, they continually passed through the

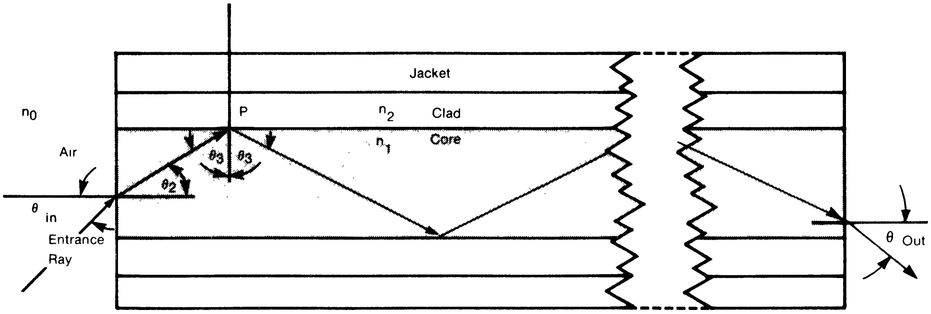

FIGURE 8. RAY PROPAGATION IN A FIBER

central axis of the fiber. Such rays are called "meridional" rays. It is entirely possible that some rays may enter the fiber at such an angle that in passing down the fiber, they never intercept the axis. Such rays are called "skew" rays. An example is shown in both side and end views in Figure 9.

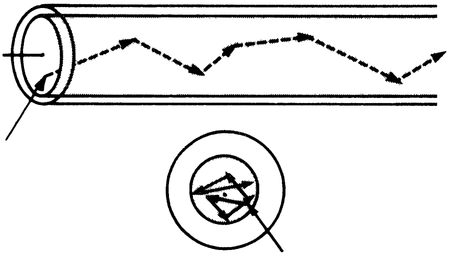

FIGURE 9. SKEW RAY PATH

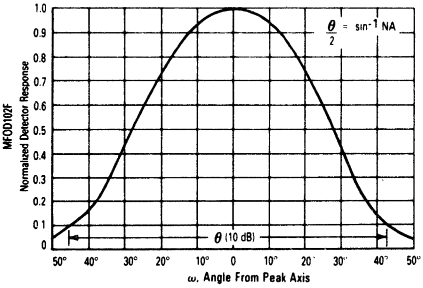

FIGURE 10. GRAPHICAL DEFINITION OF NUMERICAL APERTURE

Also, some rays may enter at angles very close to the critical angle. In bouncing along the fiber, their path length may be considerably longer than rays at shallower angles. Consequently, they are subject to a larger probability of absorption and may, therefore, never be recovered at the output end. However, for very short lengths of fiber, they may not be lost. These two effects, plus the presence of light in the cladding for short lengths, results in the N.A. not cutting off sharply according to equations (10) and (12) and of appearing larger for short lengths. It is advisable to define some criteria for specifying N.A. At Motorola, N.A. is taken as the acceptance angle for which the response is no greater than 10 dB down from the peak value. This is shown in Figure 10. Figure 11 shows a typical method of measuring a fiber's N.A. In the measurement, a sample to be measured (at least 1 meter to allow the attenuation of clad and high order modes[1]) is connected to a high N.A. radiometric sensor, such as a large-area photodiode. The power detected by the sensor is read on a radiometer power meter. The other end of the fiber is mounted on a rotatable fixture such that the axis of rotation is the end of the fiber. A collimated light source is directed at the end of the fiber. This can be a laser or other source, such as an LED, at a sufficient distance to allow the rays entering the fiber to be paraxial. The fiber end is adjusted to find the peak response position. Ideally, this will be at zero degrees; but manufacturing variations could result in a peak slightly offset from zero. The received power level is noted at the peak. The fiber end is then rotated until the two points are found at which the received power is one-tenth the peak value. The sine of half the angle between these two points is the N.A.

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[1] High order modes refers to steep angle rays.

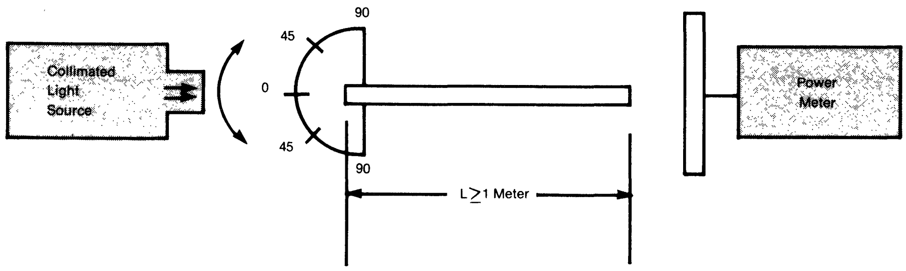


FIGURE 11. MEASUREMENT OF FIBER NUMERICAL APERTURE

The apparent N.A. of a fiber is a function of the N.A. of the source that is driving it. For example, Figures 12a and 12b are plots of N.A. versus length for the same fiber. In (12a) the source has a large N.A. (0.7), while in (12b) the source N.A. is 0.32. Note that in both cases, the N.A. at 100m is about 0.31; but at 1 meter, the apparent N.A. is 0.42 in (12a) but 0.315 in (12b). The high order modes entering the fiber from the 0.7 N.A. source take nearly the full 100 meters to be stripped out by attenuation. Thus, a valid measurement of a fiber's true N.A. requires a collimated, or very low, N.A. source or a very long-length sample.

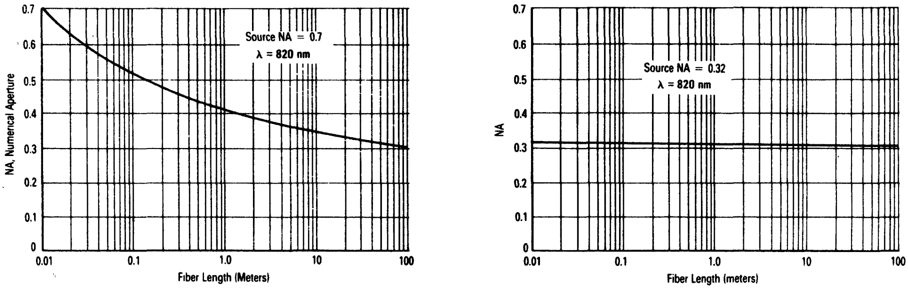
Fiber Attenuation

Mention was made above of the "stripping" or attenuation of high order modes due to their longer path length. This suggests that the attenuation of power in a fiber is a function of length. This is indeed the case. A number of factors contribute to the attenuation: imperfections at the core/clad interface; flaws in the consistency of the core material; impurities in the composition. The surface imperfections and material flaws tend to affect all wavelengths. The impurities tend to be selective in the wavelength they affect. For example, hydroxl molecules (OH^-) are strong absorbers of light at 900 nm. Therefore, if a fiber manufacturer wants to minimize losses at 900 nm, he will have to take exceptional care in his process to eliminate moisture (the source of OH^-). Other impurities are also present in any manufacturing process. The degree to which they are controlled will determine the attenuation characteristic of a fiber. The cumulative effect of the various impurities results in plots of attentuation versus wavelength exhibiting peaks and valleys. Four examples of attenuation (given in dB/km) are shown in Figure 13.

Fiber Types

It was stated at the beginning of this section that fibers be made of glass or plastic. There are three varieties available today:

1. Plastic core and cladding;
2. Glass core with plastic cladding — often called 'PCS' (plastic-clad silica);
3. Glass core and cladding — silica-clad silica.



(a) (b)

FIGURE 12. FIBER NUMERICAL APERTURE versus LENGTH FOR TWO VALVES OF SOURCE N.A.

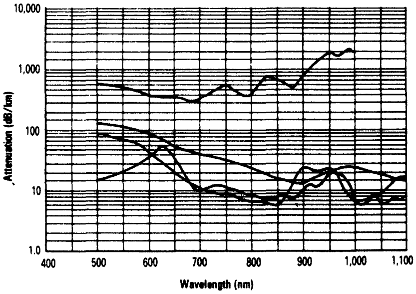


FIGURE 13. FIBER ATTENUATION versus WAVELENGTH

All plastic fibers are extremely rugged and useful for systems where the cable may be subject to rough day-after-day treatment. They are particularly attractive for benchtop interconnects. The disadvantage is their high attenuation characteristic.

PCS cables offer the better attenuation characteristics of glass and are less affected by radiation than all-glass fibers.[2] They see considerable use in military-grade applications.

All glass fibers offer low attenuation performance and good concentricity, even for small-diameter cores. They are generally easy to terminate, relative to PCS. On the down side, they are usually the least rugged, mechanically, and more susceptible to increases in attenuation when exposed to radiation.

The choice of fiber for any given application will be a function of the specific system's requirements and trade-off options.

So far, the discussion has addressed single fibers. Fibers, particularly all-plastic, are frequently grouped in bundles. This is usually restricted to very low-frequency, short-distance applications. The entire bundle would interconnect a single light source and sensor or could be used in a fan-out at either end. Bundles are also available for interconnecting an array of sources with a matched array of detectors. This enables the interconnection of multiple discrete signal channels without the use of multiplex techniques. In this type of cable, the individual fibers are usually separated in individual jackets and, perhaps, each embedded in clusters of strength elements, like Kevlar. In one special case bundle, the fibers are arrayed in a ribbon configuration. This type cable is frequently seen in telephone systems using fiber optics.

In Figure 7, the refractive index profile was shown as constant over the core cross-section with a step reduction at the core/clad interface. The core diameter was also large enough that many modes (low and high order) are propagated along its path. In Figure 14, a section of this fiber is shown with three discrete modes shown propagating down the fiber. The lowest order mode is seen traveling parallel to the axis of the fiber. The middle order mode is seen to bounce several times at the interface. The total path length of this mode is certainly greater than that of the mode along the axis. The high order mode is seen to make many trips across the fiber, resulting in an extremely long path length.

The signal input to this fiber is seen as a step pulse of light. However, since all the light that enters the fiber at a fixed time does not arrive at the end at one time (the higher modes take longer to traverse their longer path), the net effect is to stretch or distort the pulse. This is characteristic of a multimode, step-index fiber and tends to limit the range of frequency for the data being propagated.

Figure 15 shows what this pulse stretching can do. An input pulse train is seen in (15a). At some distance (say 100 meters), the pulses (due to dispersion) are getting close to running together but are still distinquishable and recoverable. However, at some greater distance (say 200 meters), the dispersion has resulted in the pulses running together to the degree that they are indistinquishable. Obviously, this fiber would be unusable at 200 meters for this data rate. Consequently, fiber specifications usually give bandwidth in units of MHz-km — that is, a 200 MHz-km cable can send 200 MHz data up to 1.0 km or 100 MHz data up to 2.0 km etc.

To overcome the distortion due to path length differences, fiber manufacturers have developed graded index fiber. An example of multimode, graded-index fiber is shown in Figure 16.

In the fiber growth process, the profile of the index of refraction is tailored to follow the parabolic profile shown in the

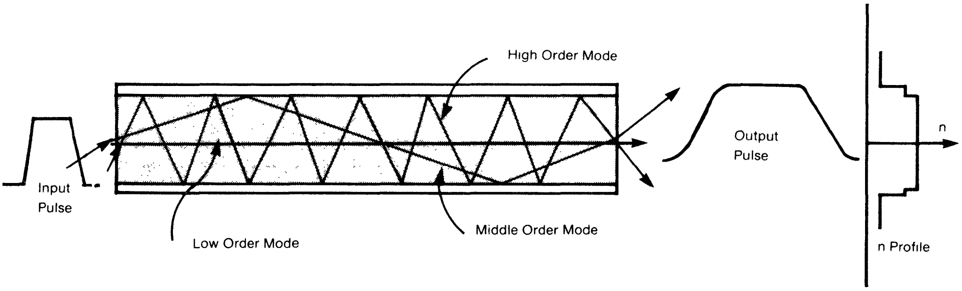


FIGURE 14. PROPAGATION ALONG A MULTIMODE STEP INDEX FIBER

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[2] It should be noted that the soft clad material should be removed and replaced by a hard clad material for best fiber core-to connector termination.

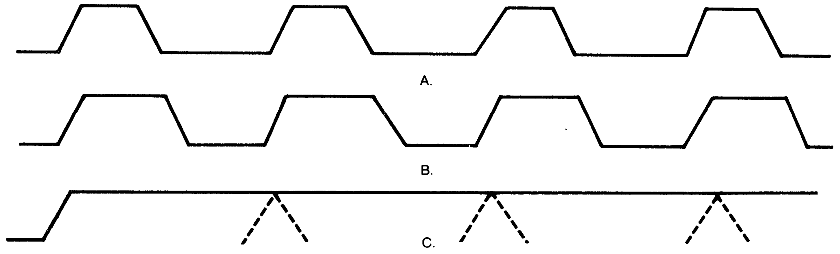

FIGURE 15. LOSS OF PULSE IDENTITY DUE TO PULSE WIDTH DISPERSION

A. Input B. Signal at 100 Meters C. Signal at 200 Meters

figure. This results in low order modes traveling through a constant density material. High order modes see lower density material as they get further away from the axis of the core. Thus, the velocity of propagation increases away from the center. The result is that all modes, although they may travel different distances, tend to cover the length of the fiber in the same amount of time. This yields a fiber with higher bandwidth capability than multimode stepped index.

One more fiber type is also available. This is the single mode, step-index fiber shown in Figure 17. In this fiber, the core is extremely small (on the order of just a few micrometers). This type accepts only the lowest order mode and suffers no modal dispersion. It is an expensive fiber and requires a very high-power, highly-directional source like a laser diode. Consequently, applications for this type of fiber are the very high data rate, long-distance systems.

As a final statement on fiber properties, it is interesting to compare optical fiber with coax cable. Figure 18 shows the loss versus frequency characteristics for a low-loss fiber compared with the characteristics of several common coax cables. Note that the attentuation of optical fiber is independent of frequency (up to the point where modal dispersion comes into play).

Active Components For Fiber Optics

Propagation through fiber optics is in the form of light or, more specifically, electromagnetic radiation in the spectral range of near-infrared or visible light. Since the signal levels to be dealt with are generally electrical in nature (like serial digital logic at standard T^2L levels), it is necessary to convert the source signal into light at the transmitter end and from light back to T^2L at the receive end. There are several components which can accomplish these conversions. This discussion will concentrate on light emitting diodes (LEDs) as souces and PIN photo diodes and Integrated Detector Preamplifiers (IDPs) as sensors.

Light Emitting Diodes

Most people are familiar with LEDs in calculator displays. Just as they are optimized geometrically and visually for the function of displaying characters, some LEDs are specifically designed and processed to satisfy the requirements of generating light, or near infrared for coupling into fibers. There are several criteria of importance for LEDs used with fibers:

1. Output power;
2. Wavelength;
3. Speed;
4. Emission pattern.

Output power. Manufacturers are continually striving to increase the output power or efficiency of LEDs. The more efficient an LED, the lower its drive requirements, or the greater

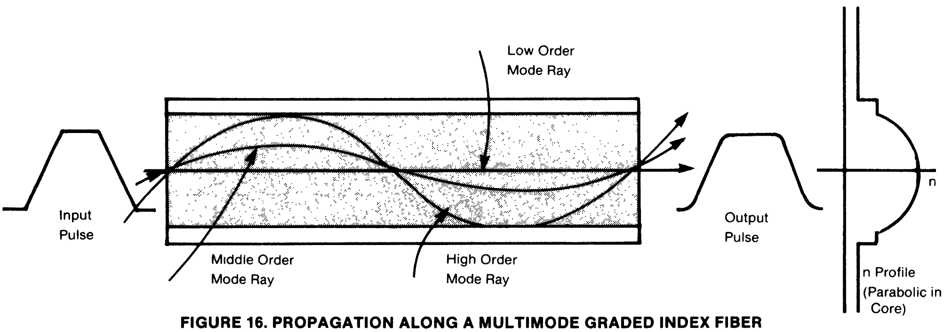

FIGURE 16. PROPAGATION ALONG A MULTIMODE GRADED INDEX FIBER

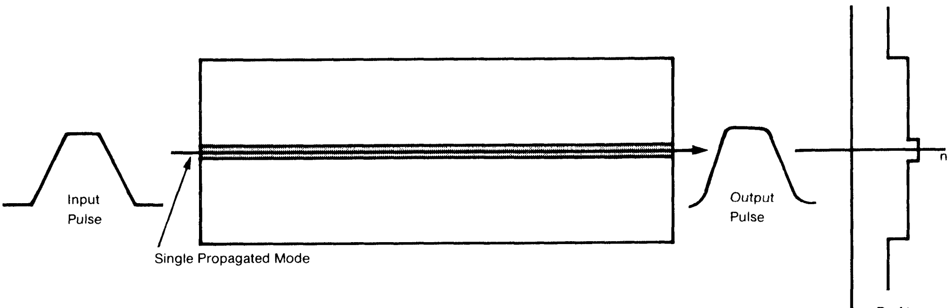

FIGURE 17. PROPAGATION ALONG A SINGLE MODE STEP INDEX FIBER

the losses that can be accomodated elsewhere in the system. However, total power emitted by an LED is not the whole picture (see **Emission Pattern**).

Wavelength. As shown earlier, optical fibers exhibit an attenuation characteristic that varies with wavelength. Figure 19 is a repeat of one of the sample curves from Figure 13. If this fiber were to be used in a system, the desired wavelength of operation would be about 875 nm where the attenuation is down to about 7.0 dB/km. The most undesirable wavelength for use in this fiber's range is 630 nm where the loss is about 600 dB/km. Therefore, all other considerations being satisfied, an LED with a characteristic emission wavelength of 875 nm would be used.

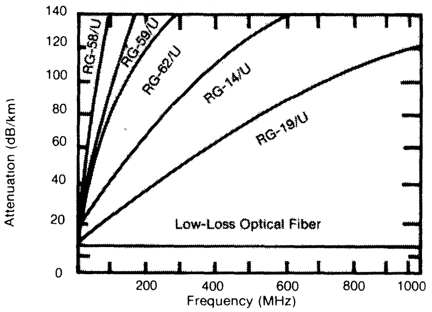

FIGURE 18. COMPARATIVE ATTENUATION versus FREQUENCY FOR OPTICAL FIBER AND COAX CABLE

Speed. LEDs exhibit finite turn-on and turn-off times. A device with a response of 100 ns would never work in a 20 MHz system. (In general, the 3.0 dB bandwidth is equal to 0.35 divided by the risetime.) In a symmetrical RTZ system (see data encoding later in this paper), the pulse width for a single bit would be 25 ns. A 100 ns LED would hardly have begun to turn on when it would be required to turn off. There is often a trade-off between speed and power, so it would not be advisable to select the fastest diode available but rather the fastest required to do the job, with some margin designed in.

Emission Pattern. In typical data communications systems the light from the LED is coupled into a fiber with a core diameter of 100 to 200 μm. If the emission pattern of a particular LED is a collimated beam of 100 μm or less diameter, it might be possible to couple nearly all the power into the fiber. Thus, a 100 μW LED with such an emission pattern might be a better choice than a 5.0 mW LED with a lambertian[3] pattern.

Light Generation

Light is emitted from an LED as a result of the recombining of electrons and holes. Electrically, an LED is just a P-N junction. Under forward bias, minority carriers are injected across

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[3] Lambertian: The spatial pattern of reflected light from a sheet of paper, e.g. The intensity of light in any direction from a plane lambertian surface is equal to the intensity in the direction of the normal to the surface times the cosine of the angle between the direction and the normal.

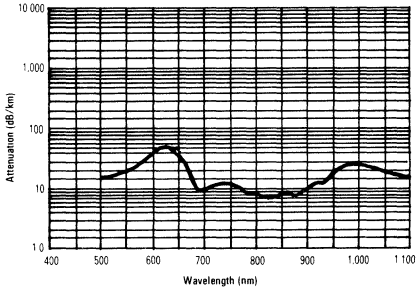


FIGURE 19. ATTENUATION versus WAVELENGTH FOR A SAMPLE FIBER

the junction. Once across, they recombine with majority carriers and give up their energy in the process. The energy given up is approximately equal to the energy gap for the material. The same injection/recombination process occurs in any P-N junction; but in certain materials, the nature of the process is typically radiative — that is, a photon of light is produced. In other materials (silicon and germanium, for example), the process is primarily non-radiative and no photons are generated.

Light emitting materials do have a distribution of non-radiative sites — usually crystal lattice defects, impurities, etc. Minimizing these is the challenge to the manufacturer in his attempt to produce more efficient devices. It is also possible for non-radiative sites to develop over time and, thus, reduce efficiency. This is what gives LEDs finite lifetimes, although 10^5 to 10^6-hour lifetimes are essentially infinite compared with some other components of many systems.

The simplest LED structures are homojunction, epitaxially-grown devices and single-diffused devices. These structures are shown in Figure 20.

The epitaxially-grown LED is generally constructed of silicon-doped gallium-arsenide. A melt of elemental gallium containing arsenic and silicon dopant is brought in contact at high temperature with the surface of an n-type gallium-arsenide wafer. At the initial growth temperature, the silicon atoms in the dopant replace some of the gallium atoms in the crystal lattice. In so doing, they contribute an excess electron to the bond. This results in the grown layer being n-type. During the growth, the temperature is systematically reduced. At a certain critical temperature, the silicon atoms begin to replace some of the arsenic atoms in the crystal. This removes an electron from the bond, resulting in the formation of a p-type layer. As a finished diode, the entire surface, as well as the four sides, radiate light. The characteristic wavelength of this type of device is 940 nm, and it typically radiates a total power of 3.0 mW at 100 mA forward current. It is relatively slow with turn-on and turn-off times on the order of 150 ns. The non-directionality of its emission makes it a poor choice as a light source for use with optical fibers.

The planar diffused LED is formed by controlled diffusions of zinc into a tellurium-doped n-gallium-arsenide wafer. A finished diode has a typical power output of 500 μW at a wavelength of 900 nm. Turn-on and turn-off times are usually around 15-20 ns. The emission pattern is lambertian, similar to the grown junction LED above.

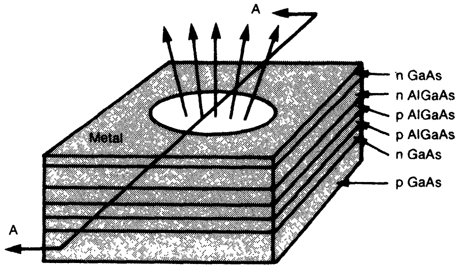
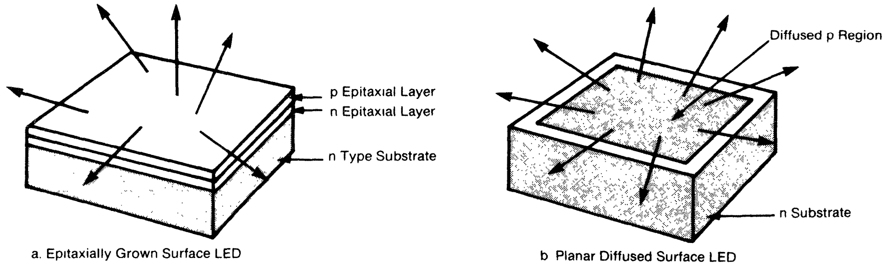


FIGURE 21. PLANAR HETEROJUNCTION LED

Both of the above structures, although they can be used in fiber optics, are not optimized for the purpose of coupling into small fibers. Several variations of LED structures are currently used to improve the efficiency of light coupling into fibers. The two basic structures for fiber optic LEDs are surface emitting and edge emitting. Surface-emitting devices are further broken down to planar and etched-well devices. The material used for these devices could be gallium-arsenide or any material which exhibits efficient photon-generating ability. The most common material in use today is the ternary crystal aluminum-gallium-arsenide. It is used extensively because it results in very efficient devices and has a characteristic wavelength around 820 nm[4] at which many fibers give lowest attenuation. (Many fibers are even better around 1300 nm, but the materials technology for LEDs at this wavelength — InGaAsP — is still on the front end of the learning curve; and devices are very expensive.)

Planar Fiber Optic LED

The planar heterojunction LED is somewhat similar to the grown junction LED of Figure 20a. Both utilize the liquid-phase epitaxial process to fabricate the device. The LED shown in



a. Epitaxially Grown Surface LED

b Planar Diffused Surface LED

FIGURE 20. SIMPLE LED STRUCTURES

a Epitaxially Grown

b. Planar Diffused

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[4] This is adjustable by varying the mix of aluminum in the aluminum-gallium-arsenide crystal.

Figure 21 is a heterojunction aluminum-gallium-arsenide structure. The geometry is designed so that the device current is concentrated in a very small area of the active layer. This accomplishes several things: (1) the increase in current density makes for a brilliant light spot; (2) the small emitting area is well suited to coupling into small core fibers; and (3) the small effective area has a low capacitance and, thus, higher speed.

In Figure 21, the device appears to be nothing more than a multilayer version of the device in Figure 20a with a top metal layer containing a small opening. However, as the section view of AA shows in Figure 22, the internal construction provides some interesting features. To achieve concentration of the light emission in a small area, a method must be incorporated to confine the current to the desired area. Since the individual layers are grown across the entire surface of the wafer, a separate process must be used to confine the current. First an n-type tellurium-doped layer is grown on a zinc-doped p-type substrate. Before any additional layers are grown, a hole is etched through the n-layer and just into the substrate. The diameter of the hole defines the ultimate light-emitting area. Next, a p-type layer of AlGaAs is grown. This layer is doped such that its resistivity is quite high; this impedes carrier flow in a horizontal direction, but vertical flow is not impeded since the layer is so thin. This ensures that current flow from the substrate will be confined to the area of the etched hole. The next layer to be grown is the p-type active layer. The aluminum-gallium mix of this layer gives it an energy gap corresponding to 820 nm wavelength photons. The actual P-N junction is then formed by growth of n-type tellurium-doped aluminum-gallium-arsenide. The doping and aluminum-gallium mix of this layer is set to give it a larger energy gap than the p-layer just below it. This makes it essentially transparent to the 820 nm photons generated below. A final cap layer of gallium-arsenide is grown to enable ohmic contact by the top metal. The end result is an 820 nm planar LED of small emission area. The radiation pattern is still lambertian, however.

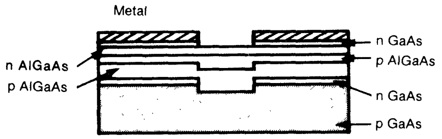

FIGURE 22. SECTION AA OF PLANAR HETEROJUNCTION LED

If a fiber with a core equal in area to the emission area is placed right down on the surface, it might seem that all the emitted light would be collected by the fiber; but since the emission pattern is lambertian, high order mode rays will not be launched into the fiber.

There is a way to increase the amount of light coupled. If a spherical lens is placed over the emitting area, the collimating effect will convert high order modes to low order modes (see Figure 23).

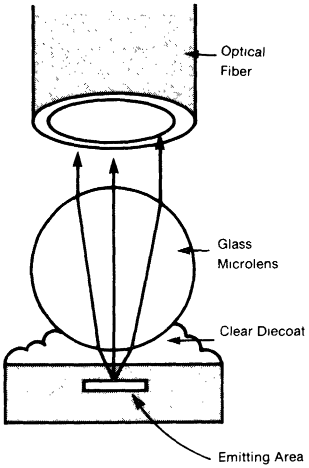

FIGURE 23. INCREASING LIGHT COUPLING WITH A MICROSPHERE

Etched-Well Surface LED

For data rates used in telecommunications (100 MHz), the planar LED becomes impractical. These higher data rates usually call for fibers with cores on the order of 50-62 μm. If a planar LED is used, the broad emission pattern of several hundred micro-meters will only allow a few percent of the power to be launched into the small fiber. Of course, the emission area of the planar device could be reduced; but this can lead to reliability problems. The increase in current density will cause a large temperature rise in the vicinity of the junction, and the thermal path from the junction to the die-attach header (through the confining layer and substrate) is not good enough to help draw the heat away from the junction. Continuous operation at higher temperature would soon increase the non-radiative sites in the LED and the efficiency would drop rapidly. If the chip is mounted upside down, the hot spot would be closer to the die-attach surface; but the light would have to pass through the thick substrate. The photon absorption in the substrate would reduce the output power significantly. A solution to this problem was developed by Burris and Dawson, of Bell Labs. The etched-well, or "Burrus" diode, is shown in Figure 24.

The thick n-type substrate is the starting wafer. Successive layers of aluminum-gallium-arsenide are grown epitaxially on the substrate. The layer functions (confinement, active, window) are essentially the same as in the planar structure. After the final p-type layer (contact) is grown, it is covered with a layer of SiO_2. Small openings are then cut in the SiO_2 to define the active emitting area. Metal is then evaporated over the wafer and contacts the p-layer through the small openings. The final processing consists of etching through the substrate. The

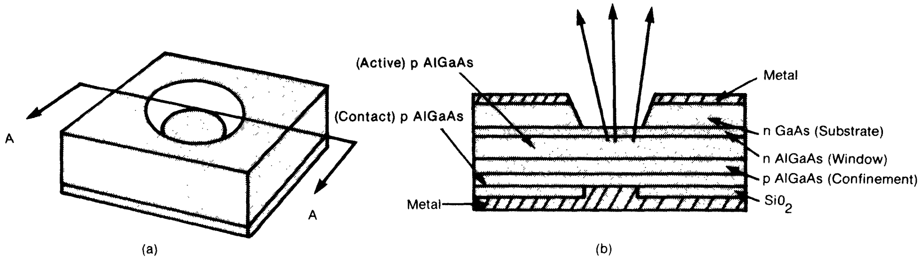

FIGURE 24. BURRUS, OR ETCHED WELL, LED:
(a) Device (b) Crossection at AA

etched wells are aligned over the active areas defined by the SiO_2 openings on the underside of the wafer and remove the heavily-photon-absorptive substrate down to the window layer. As an indication of the delicacy of this operation, it requires double-sided alignment on a wafer about 0.1 mm thick with a final thickness in the opening of about 0.025 mm.

The radiation pattern from the Burrus diode is still lambertian. However, it has a remarkably-small emitting area and enables coupling into very small fibers (down to 50 μm). The close proximity of the hot spot (0.005 mm) to the heat sink at the die attach makes it a reliable structure.

Several methods can be used for launching the emitted power into a fiber. These are shown in Figure 25.

The Burrus structure is superior to the planar for coupling to small fibers (<100 μm) but considerably more expensive due to its delicate structure.

Edge-Emitting LED

The surface structures discussed above are lambertian sources. A variation of the heterojunction family that emits a more directional pattern is the edge-emitting diode. This is shown in Figure 26. The layer structure is similar to the planar and Burrus diodes, but the emitting area is a stripe rather than a confined circular area. The emitted light is taken from the edge of the active stripe and forms an elliptical beam. The edge-emitting diode is quite similar to the diode lasers used for fiber optics. Although the edge emitter provides a more efficient source for coupling into small fibers, its structure calls for significant differences in packaging from the planar or Burrus.

Photo Detectors

PIN Photodiodes. Just as a P-N junction can be used to generate light, it can also be used to detect light. If a P-N junction is reverse-biased and under dark conditions, very little current flows through it. However, when light shines on the device, photon energy is abosorbed and hole-electron pairs are created. If the carriers are created in or near the depletion region at the junction, they are swept across the junction by the electric field. This movement of charge carriers across the junction causes a current flow in the circuitry external to the diode. The

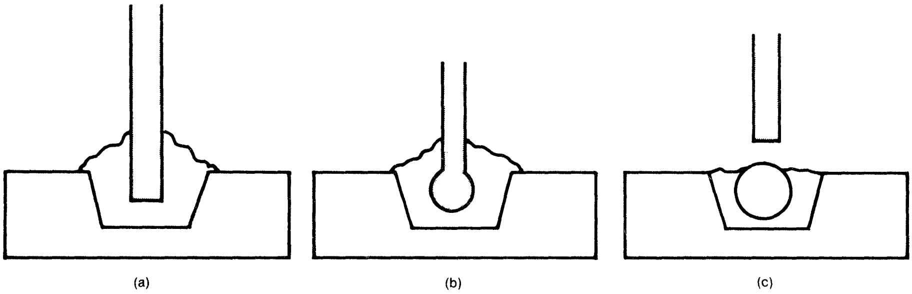

FIGURE 25. FIBER COUPLING TO A BURRUS DIODE

(a) Standard Fiber Epoxied In Well
(b) Fiber With Balled End Epoxied In Well.
(c) Microlens Epoxied In Well.

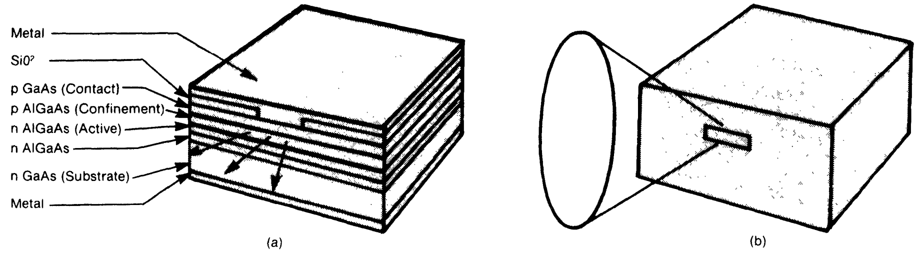

FIGURE 26. EDGE EMITTING LED

(a) Stucture
(b) Beam Pattern

magnitude of this current is proportional to the light power absorbed by the diode and the wavelength. A typical photodiode structure is shown in Figure 27, and the IV characteristic and spectral sensitivity are given in Figure 28.

In Figure 28a, it is seen that under reverse-bias conditions, the current flow is a noticeable function of light power density on the device. Note that in the forward-bias mode, the device eventually acts like an ordinary forward-biased diode with an exponential IV characteristic.

Although this type of P-N photodiode could be used as a fiber optic detector, it exhibits three undesirable features. The noise performance is generally not good enough to allow its use in sensitive systems; it is usually not fast enough for high-speed data applications; and due to the depletion width, it is not sensitive enough. For example, consider Figure 29. The depletion is indicated by the plot of electric field. In a typical device, the p-anode is very heavily doped; and the bulk of the depletion region is on the n-cathode side of the junction. As light shines on the device, it will penetrate through the p-region toward the junction. If all the photon absorption takes place in the depletion region, the generated holes and electrons will be accelerated by the field and will be quickly converted to circuit current. However, hole-electron pair generation occurs from the surface to the back side of the device. Although most of it occurs within the depletion region, enough does occur outside this region to cause a problem in high-speed applications. This problem is illustrated in Figure 30. A step pulse of light is applied to a photodiode. Because of distributed capacitance and bulk resistance, an exponential response by the diode is expected. The photocurrent wave form shows this as a ramp at turn-on. However, there is a distinct tail that occurs starting at point "a." The initial ramp up to "a" is essentially the reponse within the depletion region. Carriers that are generated outside the depletion region are not subject to acceleration by the high electric field. They tend to move through the bulk by the process of diffusion, a much slower travel. Eventually, the carriers reach the depletion region and are sped up. The effect can be eliminated, or at least substantially reduced by using a PIN structure. This is shown in Figure 31, and the electric field distribution is shown in Figure 32. Almost the entire electric

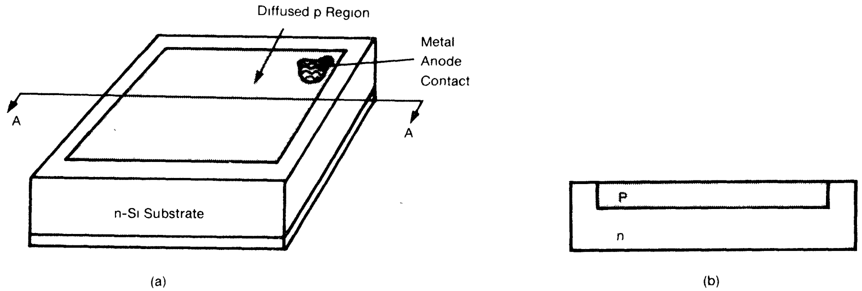

FIGURE 27. PN PHOTODIODE

(a) Device
(b) Section View At AA

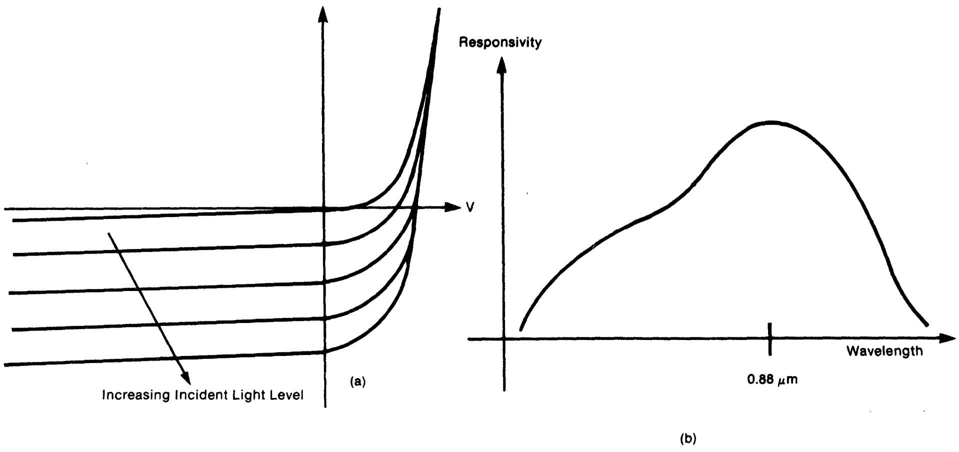

FIGURE 28. CHARACTERISTICS OF A PN PHOTODIODE
(a) I-V Family
(b) Spectral Sensitivity

field is across the intrinsic (I) region and very few photons are absorbed in the p- and n-region. The photocurrent response in such a structure is essentially free of the tailing effect seen in Figure 30.

In addition to the response time improvements, the high resistivity I-region gives the PIN diode lower noise performance.

The critical parameters for a PIN diode in a fiber optic application are:

1. Responsivity;
2. Dark current;
3. Response speed;
4. Spectral response.

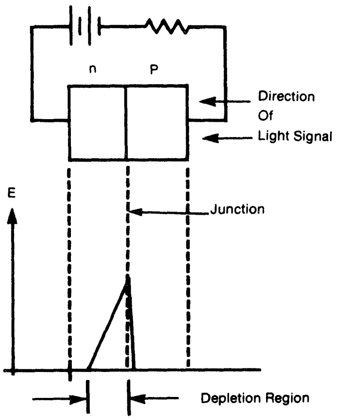

FIGURE 29. ELECTRIC FIELD IN A REVERSE-BIASED PN PHOTODIODE

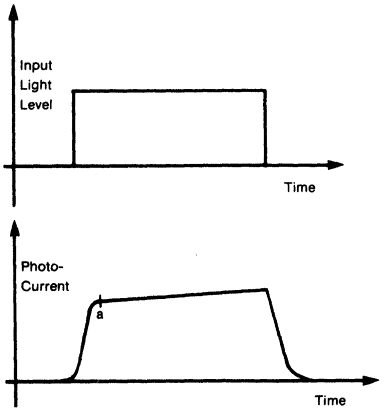

FIGURE 30. PULSE RESPONSE OF A PHOTODIODE

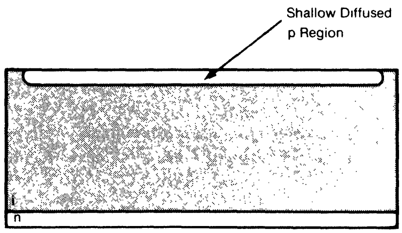

FIGURE 31. PIN DIODE STRUCTURE

Responsivity is usally given in amps/watt at a particular wavelength. It is a measure of the diode output current for a given power launched into the diode. In a system, the designer must then be able to calculate the power level coupled from the system to the diode (see AN-804, listed in Bibliography).

Dark current is the thermally-generated reverse leakage current in the diode. In conjunction with the signal current calculated from the responsivity and incident power, it gives the designer the on-off ratio to be expected in a system.

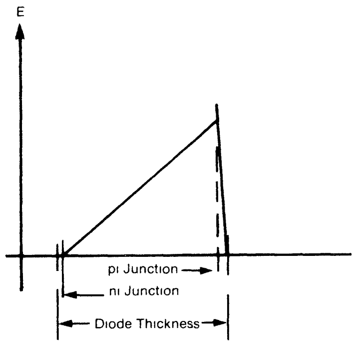

FIGURE 32. ELECTRIC FIELD DISTRIBUTION IN A PIN PHOTODIODE

Response Speed determines the maximum data rate capability of the diode; and in conjunction with the response of other elements of the system, it sets the maximum system data rate.[5]

Spectral Response determines the range, or system length, that can be achieved relative to the wavelength at which responsivity is characterized. For example, consider Figure 33. The responsivity of the MFOD102F is given as 0.15 A/W at 900 nm. As the curve indicates, the response at 900 nm is 78 percent of the peak response. If the diode is to be used in a system with an LED operating at 820 nm, the response (or system length) would be:

$$R_{(820)} = \frac{0.98}{0.78} R_{(900)} = 1.26R_{(900)} = 0.19 \text{ A/W} \qquad (13)$$

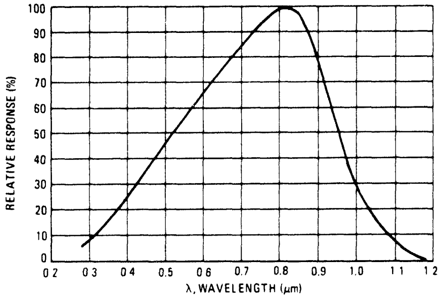

FIGURE 33. RELATIVE SPECTRAL RESPONSE MFOD102F PIN PHOTODIODE

Integrated Detector Preamplifiers. The PIN photodiode mentioned above is a high output impedance current source. The signal levels are usually on the order of tens of nanoamps to tens of microamps. The signal requires amplification to provide data at a usable level like T^2L. In noisy environments, the noise-insensitive benefits of fiber optics can all be lost at the receiver connection between diode and amplifier. Proper shielding can prevent this. An alternative solution is to integrate the follow-up amplifier into the same package as the photo diode. This device is called an integrated detector preamplifier (IDP). An example of this is given in Figure 34.

Incorporating an intrinsic layer into the monolithic structure is not practical with present technology, so a P-N junction photodiode is used. The first two transistors form a transimpedance amplifier. A third stage emitter follower is used to provide resistive negative feedback. The amplifier gives a low impedance voltage output which is then fed to a phase splitter. The two outputs are coupled through emitter followers.

The MFOD404F IDP has a responsivity greater than 230 mV/μW at 820 nm. The response rise and fall times are 50 ns maximum, and the input light power can go as high as 30 μW before noticeable pulse distortion occurs. Both outputs offer a typical impedance of 200 Ω.

The IDP can be used directly with a voltage comparator or, for more sophisticated systems, could be used to drive any normal voltage amplifier. Direct drive of a comparator is shown in Figure 35.

A Fiber Optics Communication System

Now that the basic concepts and advantages of fiber optics and the active components used with them have been discussed, it is of interest to go through the design of a system. The system will be a simple point-to-point application operating in the simplex[6] mode. The system will be analyzed for three aspects:

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[5] Device capacitance also impacts this. See "Designer's Guide to Fiber-Optic Data Links" listed in Bibliography.

[6] In a simplex system, a single transmitter is connected to a single receiver by a single fiber. In a half duplex system, a single

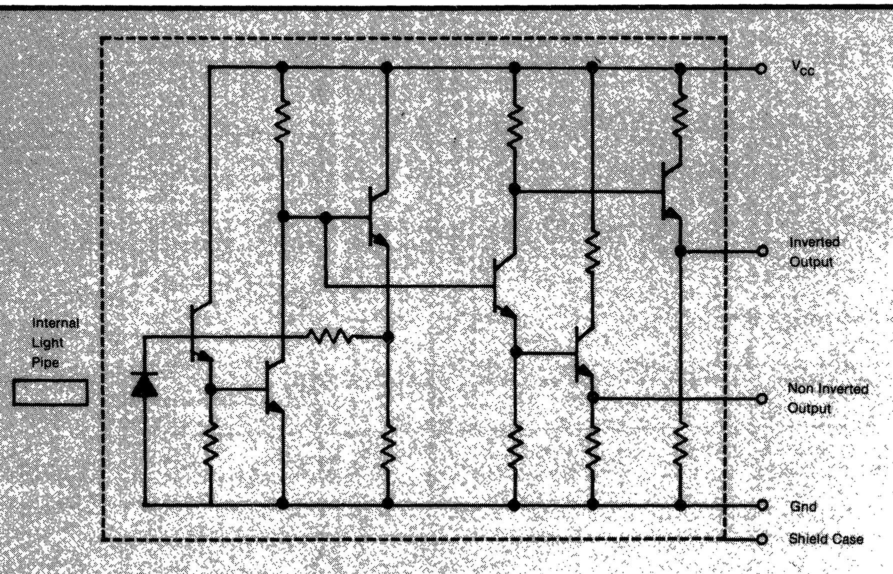


FIGURE 34. INTEGRATED DETECTOR PREAMPLIFIER

1. Loss budget;
2. Rise time budget;
3. Data encoding format.

Loss Budget. If no in-line repeaters are used, every element of the system between the LED and the detector introduces some loss into the system. By identifying and quantifying each loss, the designer can calculate the required transmitter power to ensure a given signal power at the receiver, or conversely, what signal power will be received for a given transmitter power. The process is referred to as calculating the system loss budget.

This sample system will be based on the following individual characteristics:

Transmitter: MFOE107F/108F, characteristics as in Figure 36.

Fiber: Silica-clad silica fiber with a core diameter of 200 μm; step index multimode; 20 dB/km attenuation at 820 nm; N.A. of 0.35, and a 3.0 dB bandwidth of 5.0 MHz-km.

Receiver: MFOD404F, characteristics as in Figure 37.

The system will link a transmitter and receiver over a distance of 1000 meters and will use a single section of fiber (no splices).

Some additional interconnect loss information is required.[7]

1. Whenever a signal is passed from an element with an N.A. greater than the N.A. of the receiving element, the loss incurred is given by:
   $$\text{N.A. Loss} = 20 \log (\text{NA1}/\text{NA2}) \qquad (14)$$
   where; NA1 is the exit numerical aperture of the signal source;
   where NA2 is the acceptance N.A. of the element receiving the signal.
2. Whenever a signal is passed from an element with a cross-sectional area greater than the area of the receiving element, the loss incurred is given by:
   $$\text{Area Loss} = 20 \log (\text{Diameter 1}/\text{Diameter 2}) \qquad (15)$$
   where: Diameter 1 is the diameter of the signal source (assumes a circular fiber port);
   where: Diameter 2 is the diameter of the element receiving the signal.
3. If there is any space between the sending and receiving elements, a loss is incurred. For example: an LED with an exit N.A. of 0.5 will result in a gap loss of 1.5 dB if it couples into a fiber over a gap of 0.15 mm.
4. If the source and receiving elements have their axes offset, there is an additional loss. This loss is also dependent on the separation gap. For an LED with an exit N.A. of 0.5, a gap with its receiving fiber of 0.15 mm, and an axial misalignment of 0.035 mm, there will be a combined loss of 1.8 dB.

---

[6]cont

fiber provides a bidirectional alternate signal flow between a transmitter/receiver pair at each end. A full duplex system would consist of a transmitter and receiver at each end and a pair of fibers connecting them.

[7] For a detailed discussion of all these loss mechanisms, see AN-804.

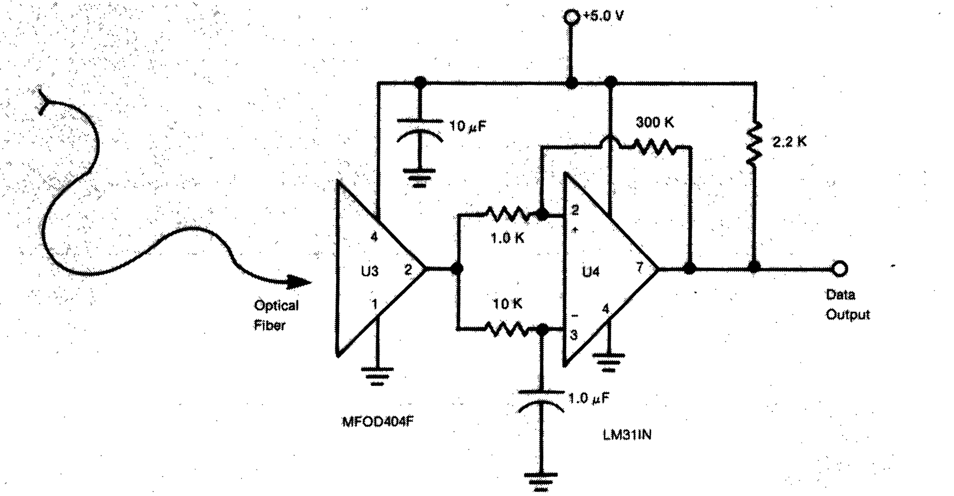


FIGURE 35. SIMPLE F/O DATA RECEIVER USING IDP AND A VOLTAGE COMPARATOR

5. If the end surfaces of the two elements are not parallel, an additional loss can be incurred. If the non-parallelism is held below 2-3 degrees, this loss is minimal and can generally be ignored.
6. As light passes through any interface. some of it is reflected. This loss, called Fresnel loss, is a function of the indices of refraction of the materials involved. For the devices in this example, this loss is typically 0.2 dB/interface.

The system loss budget is now ready to be calculated. Figure 38 shows the system configuration. Table II presents the individual loss contribuiton of each element in the link.

TABLE II
Fiber Optic Link Loss Budget

	Loss Contribution
MFOE107F to Fiber N.A. Loss	3.10 dB
MFOE107F to Fiber Area Loss	0
Transmitter Gap and Misalignment Loss (see text)	1.80 dB
Fiber Entry Fresnel Loss	0.20 dB
Fiber Attenuation (1.0 km)	20.00 dB
Fiber Exit Fresnel Loss	0.20 dB
Receiver Gap and Misalignment Loss	1.20 dB
Detector Fresnel Loss	0.20 dB
Fiber to Detector N.A. Loss	0
Fiber to Detector Area Loss	0
Total Path Loss	26.70 dB

Note that in Table II no Fresnel loss was considered for the LED. This loss, although present, is included in specifying the output power in the data sheet.

In this system, the LED is operated at 100 mA. Figure 36 shows that at this current the instantaneous output power is typically 1100 µW. This assumes that the junction temperature is maintained at 25°C. The output power from the LED is then converted to a reference level relative to 1.0 mW:

$$P_O = 10 \log \frac{1.1 \text{ mW}}{1.0 \text{ mW}} \quad (16)$$

$$P_O = 0.41 \text{ dBm} \quad (17)$$

The power received by the MFOD404F is then calculated:

$$P_R = P_O - \text{loss} \quad (18)$$

$$\begin{aligned} &= 0.41 - 26.70 \\ &= -26.29 \text{ dBm} \end{aligned} \quad (19)$$

This reference level is now converted back to absolute power:

$$P_R = 10(-26.29)\text{mW} = 0.0024 \text{ mW} \quad (20)$$

Based on the typical responsivity of the MFOD404F from Figure 37, the expected output signal will be:

$$V_O = 35 \text{ mV}/\mu\text{W}) (2.4\ \mu\text{W}) = 84 \text{ mV} \quad (21)$$

As shown in Figure 37, the output signal will be typically two hundred times above the noise level.

In many cases, a typical calculation is insufficient. To perform a worst-case analysis, assume that the signal-to-noise ratio at the MFOD404F output must be 20 dB. Figure 37 shows the maximum noise output voltage is 1.0 mV. Therefore, the output signal must be 10 mV. With a worst-case responsivity of 20 mV/µW, the received power must be:

$$P_R = \frac{V_O}{R} = \frac{10 \text{ mV}}{23 \text{ mV}/\mu\text{W}} = 0.43\ \mu\text{W} \quad (22)$$

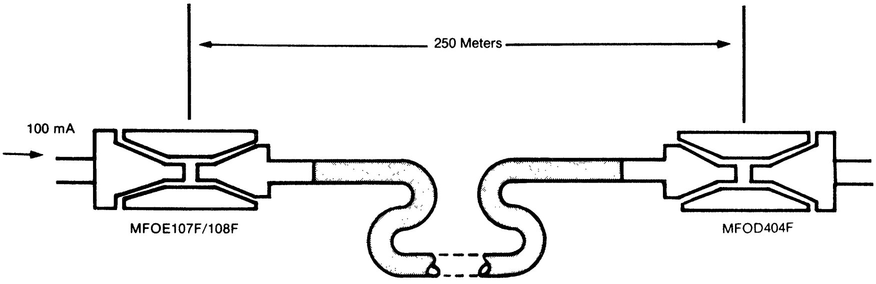


FIGURE 38. SIMPLEX FIBER OPTIC POINT TO POINT LINK

$$P_R = 10 \log \frac{0.00043\text{ mW}}{1.0\text{ mW}} = -34\text{ dBm} \qquad (23)$$

It is advisable to allow for LED degradation over time. A good design may include 3.0 dB in the loss budget for long-term degradation.

The link loss was already performed as worst case, so:

$$P_0\text{ (LED)} = -34\text{ dBm} + 3.0\text{ dB} + 20.62\text{ dB} = -4.38\text{ dBm} \qquad (24)$$

$$P_0 = 10(-4.38)\text{ mW} = 0.365\text{ mW} = 365\ \mu\text{W} \qquad (25)$$

Based on the Power Output versus Forward Current curve in Figure 36, it can be seen that the drive current (instantaneous forward current) necessary for 365 μW of power is about 30 mA.

Figure 36 also includes a Power Output versus Junction Temperature curve which, when used in conjunction with the thermal resistance of the package enables the designer to allow for higher drive currents as well as variations in ambient temperatures.

At 30 mA drive, the forward voltage will be less than 2.0 V worst case. Using 2.0 V will give a conservative analysis:

$$P_D = (30\text{ mA})\,(2.0\text{ V}) = 60\text{ mW} \qquad (26)$$

This is well within the maximum rating for operation at 25°C ambient. If we assume the ambient will be 25°C or less, the junction temperature can be conservatively calculated. Installed in a compatible metal connector:

$$\Delta T_J = (175^\circ\text{C/W})\,(0.06\text{ W}) = 11^\circ\text{C} \qquad (27)$$

If we are transmitting digital data, we can assume an average duty cycle of 50% so the ΔT_J will likely be less than 6°C. This gives:

$$T_J = T_A + \Delta T_J = 32^\circ\text{C} \qquad (28)$$

The power output derating curve shows a value of 0.9 at 32°C. Thus the required dc power level needs to be:

$$P_0\text{ (dc)} = \frac{365}{0.9} = 406\ \mu\text{W} \qquad (29)$$

As Figure 36 indicates, increasing the drive current to 40 mA would provide greater than 500 μW power output and only increase the junction temperature 1°C. This analysis shows the link to be more than adequate under the worst case conditions.

Rise Time Budget. The cable for this system was specified to have a bandwidth of 5.0 MHz-km. Since the length of the system is 1.0 km, the system bandwidth, if limited by the cable, is 5.0 MHz. Data links are usually rated in terms of a rise time budget. The system rise time is found by taking the square root of the sum of the squares of the individual elements. In this system the only two elements to consider are the LED and the detector. Thus:

$$t_{R_S} = \sqrt{(t_{R\text{-LED}})^2 + (t_{R\text{-detector}})^2} \qquad (30)$$

Using the typical values from Figures 36 and 37:

$$t_{R_S} = \sqrt{(15)^2 + (35)^2 = 38\text{ ns}} \qquad (31)$$

Total system performance may be impacted by including the rise time of additional circuit elements. Additional considerations are covered in detail in AN-794 and the Designer's Guide mentioned earlier (see Bibliography).

Data Encoding Format. In a typical digital system, the coding format is usually NRZ, or non-return to zero. In this format, a string of ones would be encoded as a continuous high level. Only when there is a change of state to a "0" would the signal level drop to zero. In RTZ (return to zero) encoding, the first half of a clock cycle would be high for a "1" and low for a "0." The second half would be low in either case. Figure 39 shows an NRZ and RTZ waveform for a binary data stream. Note between a-b the RTZ pulse rate repetition rate is at its highest. The highest bit rate requirement for an RTZ system is a string of "1's". The highest bit rate for an NRZ system is for alternating "1's" and "0's," as shown from b-c. Note that the highest NRZ bit rate is half the highest RTZ bit rate, or an RTZ system would require twice the bandwidth of an NRZ system for the same data rate.

However, to minimize drift in a receiver, it will probably be ac coupled; but if NRZ encoding is used and a long string of "1's" is transmitted, the ac coupling will result in lost data in the receiver. With RTZ data, data is not lost with ac coupling since only a string of "0's" results in a constant signal level; but that level is itself zero. However, in the case of both NRZ and RTZ, any continuous string of either "1's" or "0's" for NRZ or

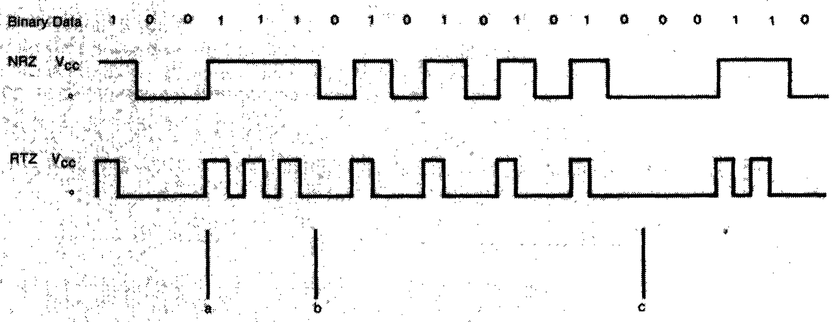


FIGURE 39. NRZ AND RTZ ENCODED DATA

or "0's" for RTZ will prevent the receiver from recovering any clock signal.

Another format, called Manchester encoding, solves this problem, by definition, in Manchester, the polarity reverses once each bit period regardless of the data. This is shown in Figure 40. The large number of level transitions enables the receiver to derive a clock signal even if all "1's" or all "0's" are being received.

In many cases, clock recovery is not required. It might appear that RTZ would be a good encoding scheme for these applications. However, many receivers include automatic gain control (AGC). During a long stream of "0's", the AGC could crank the receiver gain up; and when "1's" data begin to appear, the receiver may saturate. A good encoding scheme for these applications is pulse bipolar encoding. This is shown in Figure 41. The transmitter runs at a quiescent level and is turned on harder for a short duration during a data "0" and is turned off for a short duration during a data "1."

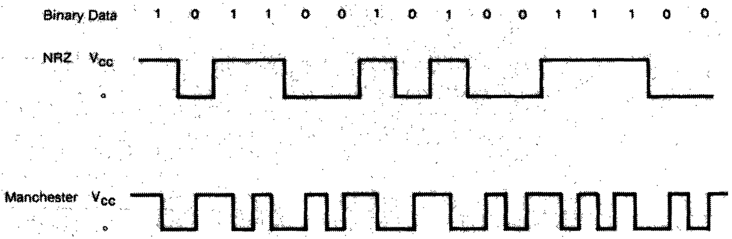


FIGURE 40. MANCHESTER DATA ENCODING

Additional details on encoding schemes can be obtained from recent texts on data communications or pulse code modulation.

Summary

This note has presented the basic principles that govern the coupling and transmission of light over optical fibers and the design considerations and advantages of using optical fibers for communication information in the form of modulated light.

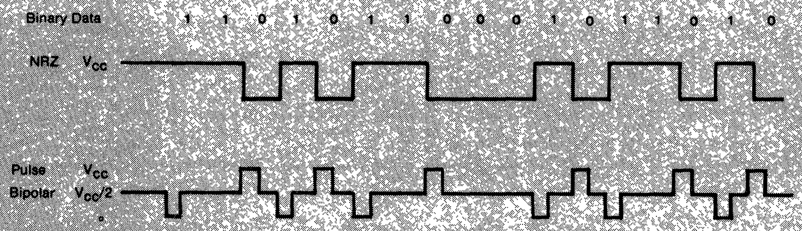


FIGURE 41. PULSE BIPOLAR ENCODING

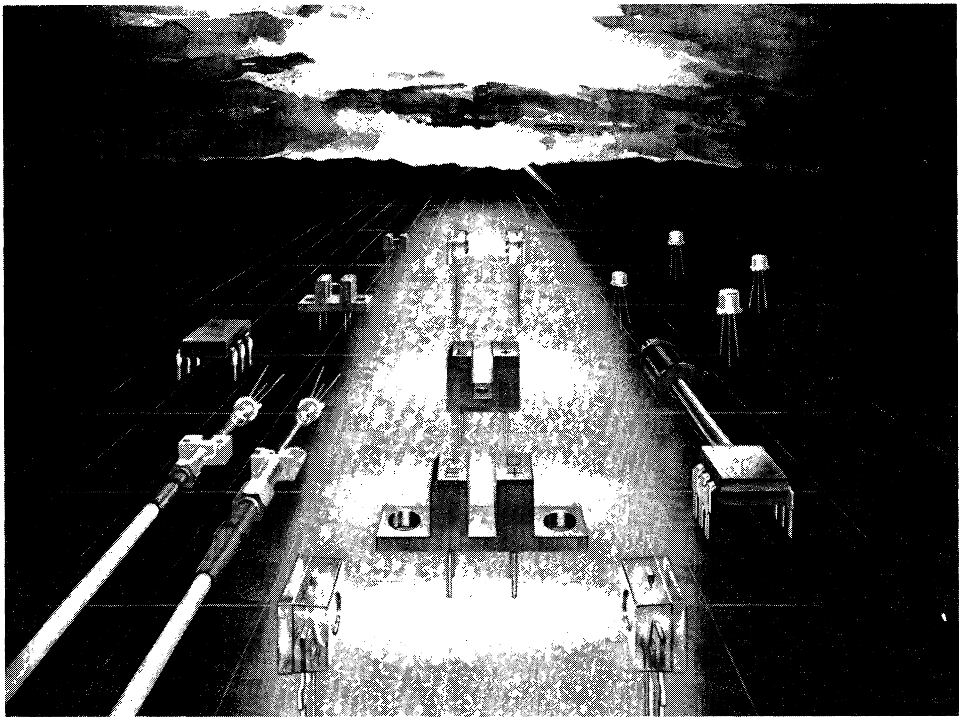
Biblography

1. Gempe, Horst: "Applications of Ferruled Components to Fiber Optic Systems," Motorola Application Note AN-804; Phoenix, Arizona; 1980.
2. Mirtich, Vincent L.; "A 20-M Baud Full Duplex Fiber Optic Data Link Using Fiber Optic Active Components." Motorola Application Note AN-794; Phoenix, Arizona, 1980.
3. Mirtich, Vincent L.; "Designer's Guide to: Fiber-Optic Data Links." Parts 1, 2, & 3; EDN June 20, 1980; August 5, 1980; and August 20, 1980.

BASIC FIBER OPTIC TERMINOLOGY

FIBER:	The glass, plastic-clad silica or plastic medium by which light is conducted or transmitted. Can be multi-mode (capable of propagating more than one mode of a given wavelength) or single-mode (one that supports propagation of only one mode of a given wavelength).
CABLE:	The jacketed combination of fiber or fiber bundles with cladding and strength reinforcing components.
CLADDING:	A covering for the core of an optical fiber that provides optical insulation and protection. Generally fused to the fiber, it has a low index of refraction.
CORE:	The light transmitting portion of the fiber optic cable, It has a higher index of refraction than the cladding.
ACCEPTANCE ANGLE:	A measure of the maximum angle within which light may be coupled from a source or emitter. It is measured relative to the fiber's axis.
NUMERICAL APERTURE (NA):	A number that indicates a fiber's ability to accept light and shows how much light can be off-axis and still be accepted by the fiber.
FRESNEL LOSS:	Reflection losses which occur at the input and output interfaces of an optical fiber and are caused by differences in the index of refraction between the core material and immersion media.
INDEX OF REFRACTION:	Compares the velocity of light in a vacuum to its velocity in a material. The index or ratio varies with wavelength.
EMITTER:	Converts the electrical signal into an optical signal. Lasers or LED's are commonly used.
DETECTOR:	Converts light signals from optical fibers to electrical signals that can be further amplified to allow reproduction of the original signal.

FIBER OPTICS



Selector Guide

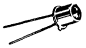
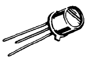
6

Fiber Optic Devices

Fiber Optic devices available from Motorola include photoemitters (IREDs) and photodetectors compatible with existing standard fiber optic cables and fit directly into standard OPTIMATE and SMA fiber optic connector systems. The devices are small and rugged. They are designed to simplify efficient optical coupling with fiber cable. Typical applications include computer, M6800 microprocessor systems, industrial controls, security systems, medical electronics and peripheral equipment, etc.

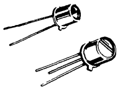
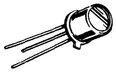
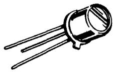
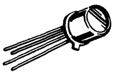
Infrared Emitters

Designed as infrared sources for fiber optic systems. MFOE200 is compatible with AMP #227015; MFOE1200, MFOE1201 and MFOE1202 are compatible with AMP #227846-1 and Amphenol #905-138-5001 receptacles.

Package	Device Type	Total Power Output mW Typ	@ I_F mA	t_{on}/t_{off} ns Typ	λ nm Typ
 Case 209-02 Style 1	MFOE200	3.0	100	25	940
 Case 210A-01 TO-206AC (TO-52) Style 1	MFOE1200 MFOE1201 MFOE1202	0.9 1.5 2.4	100 100 100	(>70 MHz bw) (>100 MHz bw) (>100 MHz bw)	820 820 820

Photodetectors

Designed for detection of infrared radiation in fiber optic systems and provide a variety of output configurations. The MFOD100/200/300 are compatible with AMP connector #227015. The MFOD1100 thru 2405 are compatible with AMP #227846-1 and Amphenal #905-138-5001 receptacles.

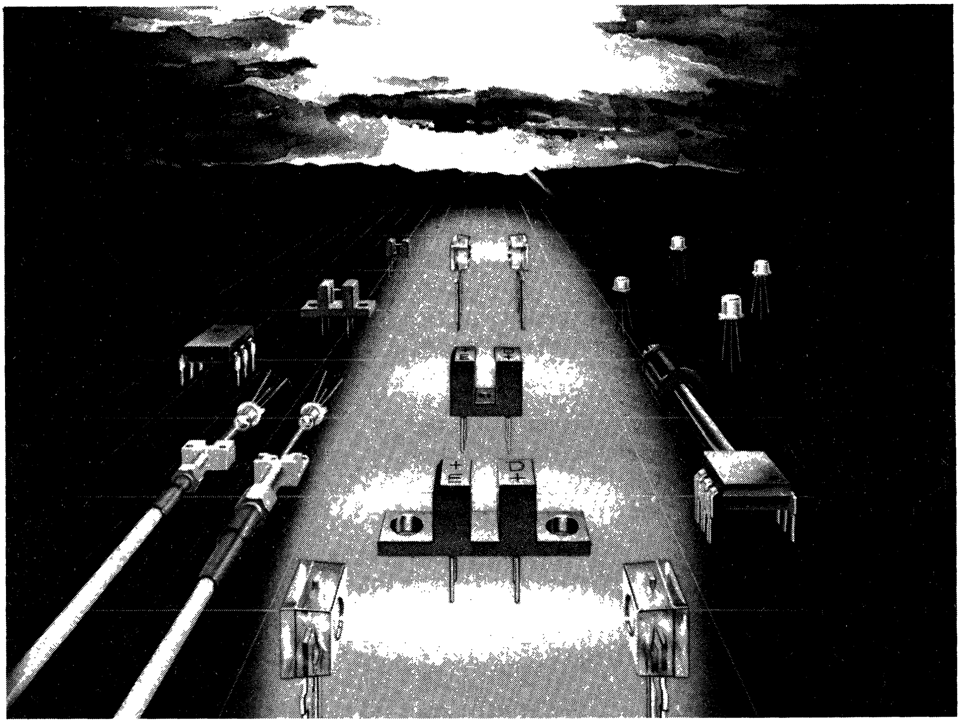
Package	Device	Responsivity μA/μW Typ	@ λ nm	Response Time μs Typ t_{on}* t_r	t_{off}* t_f	$V_{(BR)}$ Volts Min
 Case 209-02 Style 1	**Photo PIN Diodes** MFOD100	0.5	900	1.0*ns	1.0*ns	100
Case 210A-01 TO-206AC (TO-52) Style 1	MFOD1100	0.4	820	0.5ns	0.5ns	50
 Case 82-04 Style 1	**Phototransistors** MFOD200	18	900	2.5	4.0	30
Case 210C-01 TO-206AC (TO-52) Style 1	MFOD2202	110	820	2.5	4.0	40
 Case 82-04 Style 1	**Photodarlington** MFOD300	500	900	40	60	30
Case 210C-01 TO-206AC (TO-52) Style 1	MFOD2302	4000	820	40	60	30
 Case 210D-01 Style 1	**Monolithic IDP** MFOD2404	mV/μW 35	820	0.035	0.035	V_{CC} Range 4.0–6.0
(TO-52 Type)	MFOD2405	4.5	820	0.010	0.010	4.0–6.0

Replacements for Discontinued Devices

The ferruled plastic fiber optics package is being replaced by the standard, hermetic TO-206AC (TO-52) package. Direct functional replacements for the discontinued devices are shown below.

Discontinued Device	Replacement	Discontinued Device	Replacement
MFOD104F	MFOD1100	MFOD405F	MFOD2405
MFOD110F	MFOD1100	MFOE106F	MFOE1200
MFOD202F	MFOD2202	MFOE107F	MFOE1201
MFOD302F	MFOD2302	MFOE108F	MFOE1202
MFOD404F	MFOD2404		

FIBER OPTICS



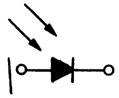
Data Sheets

FIBER OPTIC DATA SHEETS

MOTOROLA

MFOD100

FIBER OPTICS
PIN PHOTO DIODE



PIN PHOTO DIODE FOR FIBER OPTICS SYSTEMS

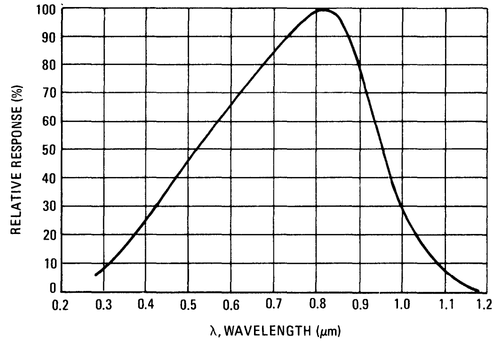
. . . designed for infrared radiation detection in short length, high frequency Fiber Optics Systems. Typical applications include: medical electronics, industrial controls, M6800 Microprocessor systems, security systems, etc.

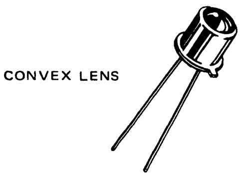
- Spectral Response Matched to MFOE 200
- Hermetic Metal Package for Stability and Reliability
- Ultra Fast Response — 1.5 ns typ
- Very Low Leakage
  I_D = 2.0 nA (max) @ V_R = 20 Volts
- Compatible with AMP Mounting Bushing #227015

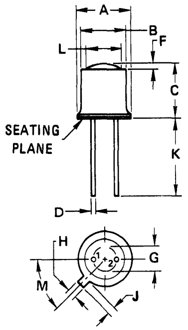
MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Reverse Voltage	V_R	150	Volts
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	100 0.57	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−55 to +175	°C

FIGURE 1 — RELATIVE SPECTRAL RESPONSE







STYLE 1:
PIN 1. ANODE
PIN 2. CATHODE

NOTES:
1. PIN 2 INTERNALLY CONNECTED TO CASE
2. LEADS WITHIN 0.13 mm (0.005) RADIUS OF TRUE POSITION AT SEATING PLANE AT MAXIMUM MATERIAL CONDITION.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.52	4.95	0.178	0.195
C	6.22	6.98	0.245	0.275
D	0.41	0.48	0.016	0.019
F	1.19	1.60	0.047	0.063
G	2.54 BSC		0.100 BSC	
H	0.99	1.17	0.039	0.046
J	0.84	1.22	0.033	0.048
K	12.70	–	0.500	–
L	3.35	4.01	0.132	0.158
M	45° BSC		45° BSC	

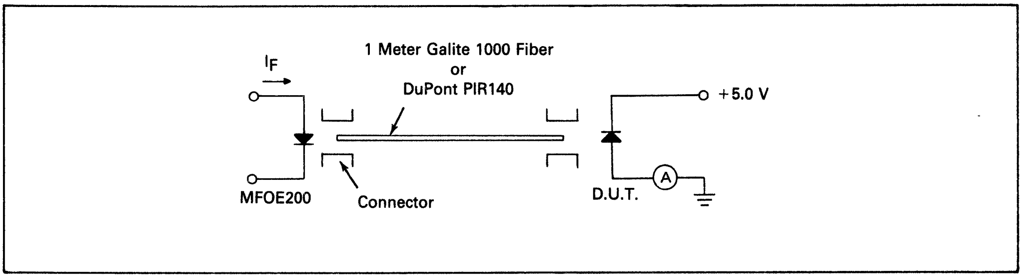
CASE 209-02

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Dark Current (V_R = 20 V, R_L = 1.0 M, Note 1)	I_D				nA
T_A = 25°C		–	1.0	10	
T_A = 100°C		–	14	–	
Reverse Breakdown Voltage (I_R = 10 µA)	$V_{(BR)R}$	100	200	–	Volts
Forward Voltage (I_F = 50 mA)	V_F	–	–	1.1	Volts
Series Resistance (I_F = 50 mA)	R_s	–	–	10	ohms
Total Capacitance (V_R = 20 V, f = 1.0 MHz)	C_T	–	–	4.0	pF
Responsivity (Figure 2)	R	0.4	0.5	–	µA/µW
Response Time (V_R = 20 V, R_L = 50 ohms)	t_{on} t_{off}	– –	1.0 1.0	– –	ns ns

1. Measured under dark conditions. H = 0

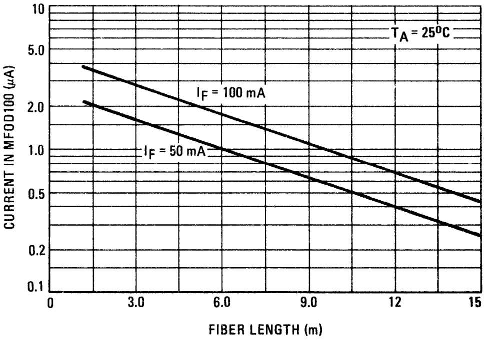
FIGURE 2 – RESPONSIVITY TEST CONFIGURATION



TYPICAL CHARACTERISTICS

COUPLED SYSTEM PERFORMANCE versus FIBER LENGTH*

FIGURE 3 — MFOE200 SOURCE

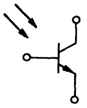


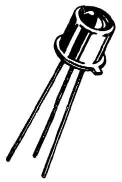
*0.045" Dia. Fiber Bundle, N.A. ≃ 0.67, Attenuation at 900 nm ≃ 0.6 dB/m

MOTOROLA

MFOD200

FIBER OPTICS
NPN SILICON
PHOTOTRANSISTOR





PHOTOTRANSISTOR FOR FIBER OPTICS SYSTEMS

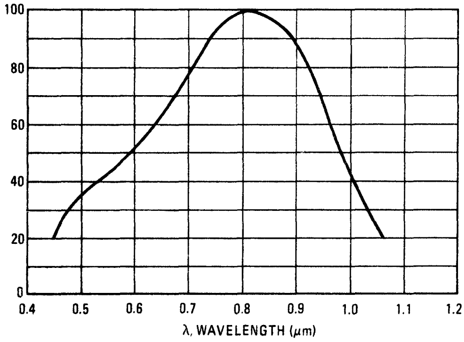
. . . designed for infrared radiation detection in medium length, medium frequency Fiber Optic Systems. Typical applications include: medical electronics, industrial controls, security systems, M6800 Microprocessor systems, etc.

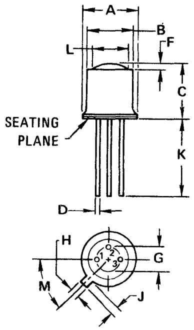
- Spectral Response Matched to MFOE200
- Hermetic Metal Package for Stability and Reliability
- High Sensitivity for Medium Length Fiber Optic Control Systems
- Compatible with AMP Mounting Bushing #227015

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted).

Rating (Note 1)	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	40	Volts
Emitter-Base Voltage	V_{EBO}	10	Volts
Collector-Base Voltage	V_{CBO}	70	Volts
Light Current	I_L	250	mA
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	250 1.43	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-55 to +175	°C

FIGURE 1 – CONSTANT ENERGY SPECTRAL RESPONSE





STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

NOTES:
1. LEADS WITHIN .13 mm (.005) RADIUS OF TRUE POSITION AT SEATING PLANE, AT MAXIMUM MATERIAL CONDITION.
2. PIN 3 INTERNALLY CONNECTED TO CASE.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.52	4.95	0.178	0.195
C	6.22	6.98	0.245	0.275
D	0.41	0.48	0.016	0.019
F	1.19	1.60	0.047	0.063
G	2.54 BSC		0.100 BSC	
H	0.99	1.17	0.039	0.046
J	0.84	1.22	0.033	0.048
K	12.70	–	0.500	–
L	3.35	4.01	0.132	0.158
M	45° BSC		45° BSC	

CASE 82–04

STATIC ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

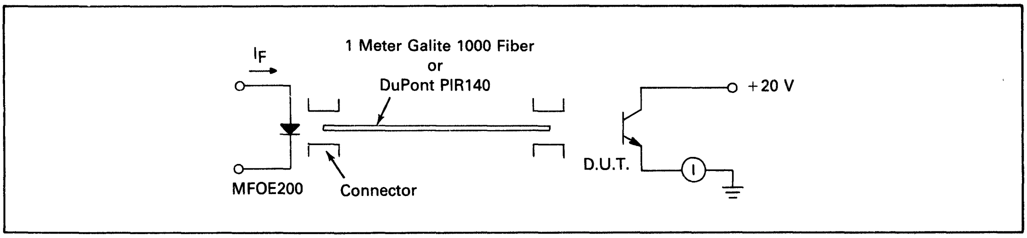
Characteristic	Symbol	Min	Typ	Max	Unit
Collector Dark Current (V_{CC} = 20 V, H≈0) T_A = 25°C T_A = 100°C	I_{CEO}	– –	– 4.0	25 –	na µA
Collector-Base Breakdown Voltage (I_C = 100 µA)	$V_{(BR)CBO}$	50	–	–	Volts
Collector-Emitter Breakdown Voltage (I_C = 100 µA)	$V_{(BR)CEO}$	30	–	–	Volts
Emitter-Collector Breakdown Voltage (I_E = 100 µA)	$V_{(BR)ECO}$	7.0	–	–	Volts

OPTICAL CHARACTERISTICS (T_A = 25°C)

Characteristic	Symbol	Min	Typ	Max	Unit
Responsivity (Figure 2)	R	14.5	18	–	µA/µW
Photo Current Rise Time (Note 1) (R_L = 100 ohms)	t_r	–	2.5	–	µs
Photo Current Fall Time (Note 1) (R_L = 100 ohms)	t_f	–	4.0	–	µs

Note 1. For unsaturated response time measurements, radiation is provided by pulsed GaAs (gallium-arsenide) light-emitting diode (λ ≈ 900 nm) with a pulse width equal to or greater than 10 microseconds, I_C = 1.0 mA peak.

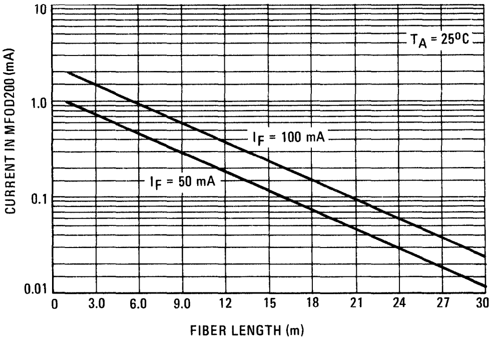
FIGURE 2 — RESPONSIVITY TEST CONFIGURATION



TYPICAL CHARACTERISTICS

COUPLED SYSTEM PERFORMANCE versus FIBER LENGTH*

FIGURE 3 — MFOE200 SOURCE



*0.045″ Dia. Fiber Bundle, N.A. ≅ 0.67, Attenuation at 900 nm ≅ 0.6 dB/m

MOTOROLA

MFOD300

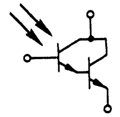
PHOTODARLINGTON TRANSISTOR FOR FIBER OPTICS SYSTEMS

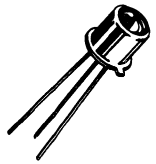
. . . designed for infrared radiation detection in long length, low frequency Fiber Optics Systems. Typical applications include: industrial controls, security systems, medical electronics, M6800 Microprocessor Systems, etc.

- Spectral Response Matched to MFOE200
- Hermetic Metal Package for Stability and Reliability
- Very High Sensitivity for Long Length Fiber Optics Control Systems
- Compatible With AMP Mounting Bushing #227015

FIBER OPTICS

NPN SILICON PHOTODARLINGTON TRANSISTOR

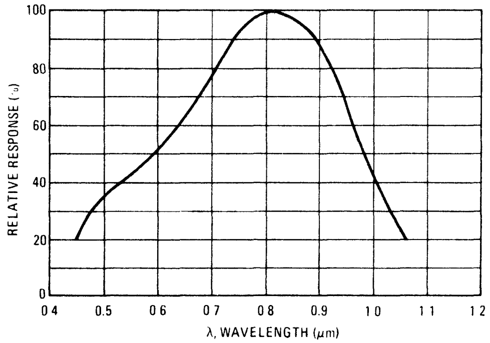


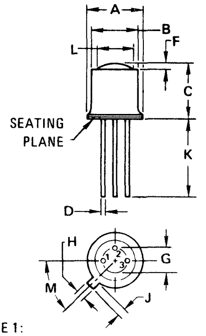


MAXIMUM RATINGS (T_A = 25°C unless otherwise noted).

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	40	Volts
Emitter-Base Voltage	V_{EBO}	10	Volts
Collector-Base Voltage	V_{CBO}	70	Volts
Light Current	I_L	250	mA
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	250 1.43	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−55 to +175	°C

FIGURE 1 — CONSTANT ENERGY SPECTRAL RESPONSE





STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

NOTES:
1. LEADS WITHIN .13 mm (.005) RADIUS OF TRUE POSITION AT SEATING PLANE, AT MAXIMUM MATERIAL CONDITION.
2. PIN 3 INTERNALLY CONNECTED TO CASE.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.52	4.95	0.178	0.195
C	6.22	6.98	0.245	0.275
D	0.41	0.48	0.016	0.019
F	1.19	1.60	0.047	0.063
G	2.54 BSC		0.100 BSC	
H	0.99	1.17	0.039	0.046
J	0.84	1.22	0.033	0.048
K	12.70	–	0.500	–
L	3.35	4.01	0.132	0.158
M	45° BSC		45° BSC	

CASE 82–04

STATIC ELECTRICAL CHARACTERISTICS ($T_A = 25°C$)

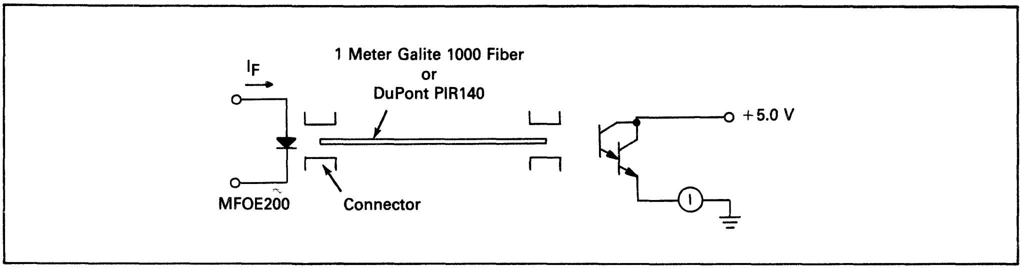
Characteristic	Symbol	Min	Typ	Max	Unit
Collector Dark Current ($V_{CE} = 10$ V, $H \approx 0$)	I_{CEO}	–	10	100	nA
Collector-Base Breakdown Voltage ($I_C = 100\ \mu A$)	$V_{(BR)CBO}$	50	–	–	Volts
Collector-Emitter Breakdown Voltage ($I_C = 100\ \mu A$)	$V_{(BR)CEO}$	30	–	–	Volts
Emitter-Base Breakdown Voltage ($I_E = 100\ \mu A$)	$V_{(BR)EBO}$	10	–	–	Volts

OPTICAL CHARACTERISTICS ($T_A = 25°C$)

Characteristic	Symbol	Min	Typ	Max	Unit
Responsivity (Figure 2)	R	400	500	–	μA/μW
Photo Current Rise Time (Note 1) ($R_L = 100$ ohms)	t_r	–	40	–	μs
Photo Current Fall Time (Note 1) ($R_L = 100$ ohms)	t_f	–	60	–	μs

Note 1. For unsaturated response time measurements, radiation is provided by pulsed GaAs (gallium-arsenide) light-emitting diode ($\lambda \approx 900$ nm) with a pulse width equal to or greater than 500 microseconds, $I_C = 1.0$ mA peak.

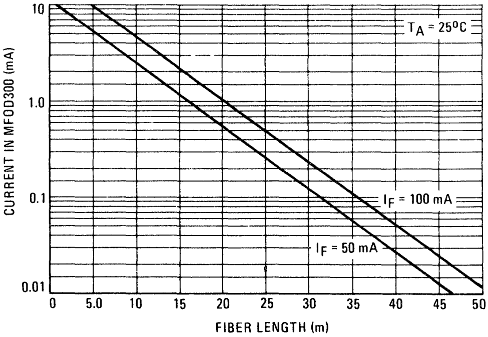
FIGURE 2 – RESPONSIVITY TEST CONFIGURATION



TYPICAL CHARACTERISTICS

COUPLED SYSTEM PERFORMANCE versus FIBER LENGTH*

FIGURE 3 — MFOE200 SOURCE

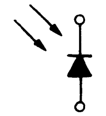


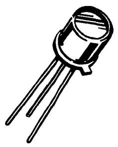
*0.045″ Dia. Fiber Bundle, N.A. ≃ 0.67, Attenuation at 900 nm ≃ 0.6 dB/m

MOTOROLA

MFOD1100

FIBER OPTICS
PIN PHOTO DIODE





PIN PHOTO DIODE FOR FIBER OPTIC SYSTEMS

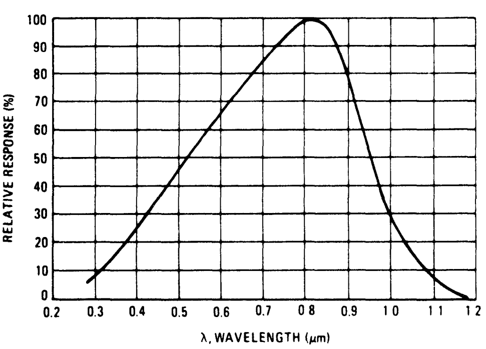
. . . designed for infrared radiation detection in high frequency Fiber Optic Systems. It is packaged in Motorola's hermetic TO-206AC (TO-52) case, and it fits directly into standard fiber optic connectors. The metal connectors provide excellent RFI immunity. Major applications are: CATV, video systems, M68000 microprocessor systems, industrial controls, computer and peripheral equipment, etc.

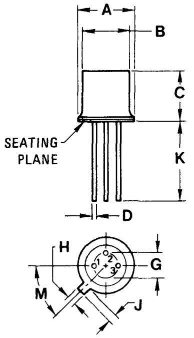
- Fast Response — 1.0 ns Max @ 5.0 Volts
- May be used with MFOExxx Emitters
- Hermetic Package
- Compatible with AMP #227846-1 and Amphenol 905-138-5001 Receptacles

MAXIMUM RATINGS (T_A = 25°C Unless otherwise noted)

Rating	Symbol	Value	Unit
Reverse Voltage	V_R	50	Volts
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	50 0.50	mW mW/°C
Operating Temperature Range	T_A	−65 to +125	°C
Storage Temperature Range	T_{stg}	−65 to +150	°C

FIGURE 1 — RELATIVE SPECTRAL RESPONSE





STYLE 1·
PIN 1. ANODE
2. CATHODE
3. CASE

NOTES:
1. PIN 3 INTERNALLY CONNECTED TO CASE.
2. LEAD POSITIONAL TOLERANCE AT SEATING PLANE:
⌖ Ø 0.36 (0.014) Ⓜ T A Ⓜ H Ⓜ
3. DIMENSIONS A AND H ARE DATUMS AND T IS A DATUM PLANE.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.65	4.70	0.183	0.185
C	3.12	3.28	0.123	0.129
D	0.41	0.48	0.016	0.019
G	2.54 BSC		0.100 BSC	
H	0.99	1.17	0.039	0.046
J	0.84	1.22	0.033	0.048
K	12.70	–	0.500	–
M	45° BSC		45° BSC	

CASE 210A-01
TO-206AC
(TO-52)

ELECTRICAL CHARACTERISTICS (T_A = 25°C)

Characteristic	Symbol	Min	Typ	Max	Unit
Dark Current (V_R = 5.0 V, R_L = 1.0 M, H ≈ 0)	I_D	—	—	1.0	nA
Reverse Breakdown Voltage (I_R = 10 μA)	$V_{(BR)R}$	50	—	—	Volts
Forward Voltage (I_F = 50 mA)	V_F	—	0.70	1.0	Volts
Total Capacitance (V_R = 5.0 V, f = 1.0 MHz)	C_T	—	—	2.5	pF
Noise Equivalent Power	NEP	—	50	—	$fW/\sqrt{Hz}$

OPTICAL CHARACTERISTICS (T_A = 25°C)

Characteristic	Symbol	Min	Typ	Max	Unit
Responsivity @ 820 nm (V_R = 5.0 V, P = 10 μW)	R	0.35	0.40	—	μA/μW
Response Time @ 820 nm (V_R = 5.0 V)	t_r, t_f	—	0.5	1.0	ns
Numerical Aperture of Input Port, 10 dB (300 μm [12 mil] diameter spot)	NA	—	0.40	—	—

TYPICAL CHARACTERISTICS

FIGURE 2 — RESPONSIVITY TEST CONFIGURATION

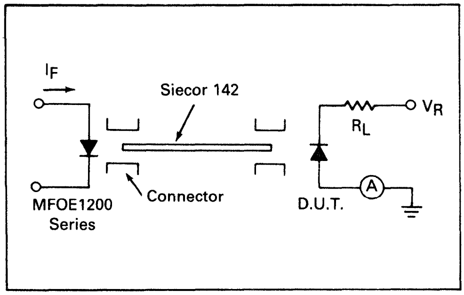
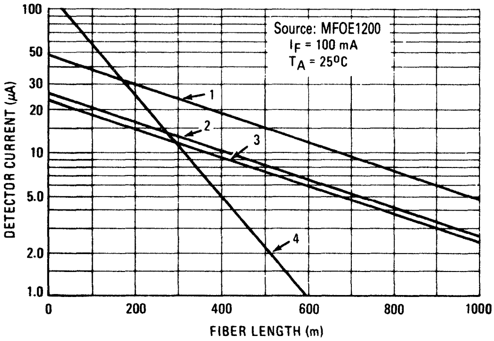


FIGURE 3 — DETECTOR CURRENT versus FIBER* LENGTH

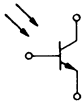


Fiber Type:
1. Times LC10
2. ITT 1320
3. Siecor 142
4. Siecor 155

MOTOROLA

MFOD2202

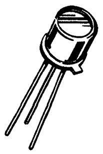
FIBER OPTICS
NPN SILICON PHOTOTRANSISTOR



PHOTOTRANSISTOR FOR FIBER OPTIC SYSTEMS

. . . designed for infrared radiation detection in medium frequency Fiber Optic Systems. It is packaged in Motorola's hermetic TO-206AC (TO-52) case, and fits directly into standard fiber optic connectors. These metal connectors provide excellent RFI immunity. Typical applications include medical electronics, industrial controls, security systems, computer and peripheral equipment, etc.

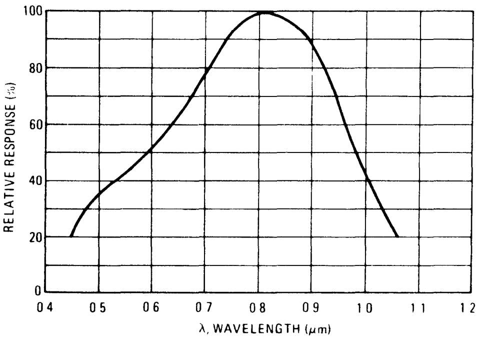
- High Sensitivity for Medium Frequency Fiber Optic Systems
- May be used with MFOExxx Emitters
- Hermetic Package
- Compatible with AMP #227846-1 and Amphenol 905-138-5001 Receptacles
- 300 μm, 12 mil, Diameter Optical Spot

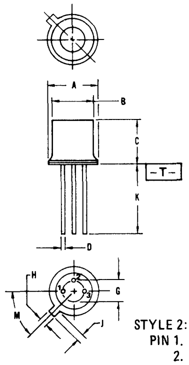


MAXIMUM RATINGS (T_A = 25°C unless otherwise noted).

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	50	Volts
Emitter-Base Voltage	V_{EBO}	10	Volts
Collector-Base Voltage	V_{CBO}	70	Volts
Light Current	I_L	250	mA
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	150 1.5	mW mW/°C
Operating Temperature Range	T_A	−65 to +125	°C
Storage Temperature Range	T_{stg}	−65 to +150	°C

FIGURE 1 — CONSTANT ENERGY SPECTRAL RESPONSE





STYLE 2:
PIN 1. EMITTER
2. BASE
3. COLLECTOR/CASE

NOTES:
1. DIMENSIONS A AND H ARE DATUMS AND T IS A DATUM SURFACE.
2. LEAD POSITIONAL TOLERANCE AT SEATING PLANE:
⌖ | Ø 0.036 (0.014) Ⓜ | T | A Ⓜ | H Ⓜ
3. DIMENSIONING AND TOLERANCING PER Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.30	5.38	0.209	0.212
B	4.64	4.69	0.183	0.185
C	3.42	3.60	0.135	0.142
D	0.40	0.48	0.016	0.019
G	2.54 BSC		0.100 BSC	
H	0.91	1.16	0.036	0.046
J	0.83	1.21	0.033	0.048
K	12.70	–	0.500	–
M	45° BSC		45° BSC	

CASE 210C-01
TO-206AC
(TO-52)

STATIC ELECTRICAL CHARACTERISTICS (T_A = 25° unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector Dark Current T_A = 25°C V_{CC} = 20 V, H ≈ 0) T_A = 100°C	I_{CEO}	— —	— 4.0	25 —	nA μA
Collector-Base Breakdown Voltage (I_C = 100 μA)	$V_{(BR)CBO}$	50	—	—	Volts
Collector-Emitter Breakdown Voltage (I_C = 100 μA)	$V_{(BR)CEO}$	40	—	—	Volts

OPTICAL CHARACTERISTICS (T_A = 25°C)

Characteristic	Symbol	Min	Typ	Max	Unit
Responsivity (V_{CC} = 20 V, R_L = 10 Ω, λ ≈ 820 nm, P = 1.0 μW*)	R	80	110	—	μA/μW
Photo Current Rise Time (R_L = 100 Ω)	t_r	—	2.5	—	μs
Photo Current Fall Time (R_L = 100 Ω)	t_f	—	4.0	—	μs
Numerical Aperture of Input Port (300 μm [12 mil] diameter spot)	NA	—	0.70	—	—

*Power Launched into Optical Input Port. The designer must account for interface coupling losses.

TYPICAL CHARACTERISTICS

FIGURE 2 — RESPONSIVITY TEST CONFIGURATION

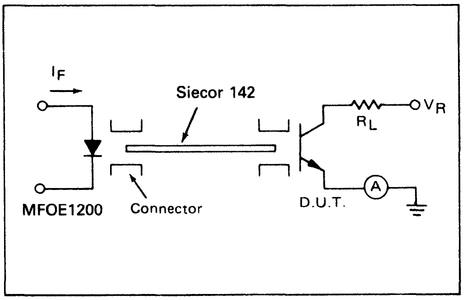
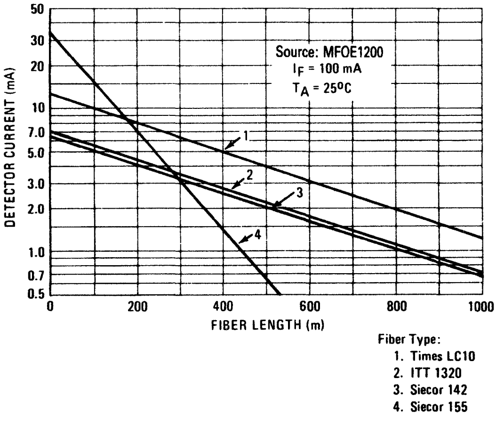


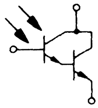
FIGURE 3 — DETECTOR CURRENT versus FIBER* LENGTH

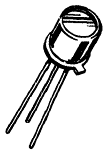


MOTOROLA

MFOD2302

FIBER OPTICS
NPN SILICON PHOTODARLINGTON TRANSISTOR





PHOTODARLINGTON TRANSISTOR FOR FIBER OPTIC SYSTEMS

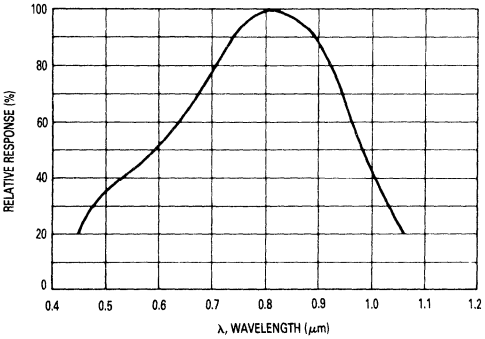
. . . designed for infrared radiation detection in medium frequency Fiber Optic Systems. It is packaged in Motorola's hermetic TO-206AC (TO-52) case, and it fits directly into standard fiber optic connectors. These metal connectors provide excellent RFI immunity. Typical applications include medical electronics, industrial controls, security systems, computer and peripheral equipment, etc.

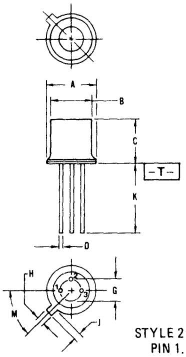
- High Sensitivity for Low Frequency, Long Length Fiber Optic Control Systems
- May be used with MFOExxx Emitters
- Hermetic Package
- Compatible with AMP #227846-1 and Amphenol 905-138-5001 Receptacles
- 300 μm, 12 mil, Diameter Optical Spot

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted).

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	40	Volts
Emitter-Base Voltage	V_{EBO}	10	Volts
Collector-Base Voltage	V_{CBO}	70	Volts
Light Current	I_L	250	mA
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	150 1.5	mW mW/°C
Operating Temperature Range	T_A	−65 to +125	°C
Storage Temperature Range	T_{stg}	−65 to +150	°C

FIGURE 1 — CONSTANT ENERGY SPECTRAL RESPONSE





STYLE 2:
PIN 1. EMITTER
2. BASE
3. COLLECTOR/CASE

NOTES:
1. DIMENSIONS A AND H ARE DATUMS AND T IS A DATUM SURFACE.
2. LEAD POSITIONAL TOLERANCE AT SEATING PLANE:
⌖ | Ø 0.036 (0.014) Ⓜ | T | A Ⓜ | H Ⓜ
3. DIMENSIONING AND TOLERANCING PER Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.30	5.38	0.209	0.212
B	4.64	4.69	0.183	0.185
C	3.42	3.60	0.135	0.142
D	0.40	0.48	0.016	0.019
G	2.54 BSC		0.100 BSC	
H	0.91	1.16	0.036	0.046
J	0.83	1.21	0.033	0.048
K	12.70	–	0.500	–
M	45^0 BSC		45^0 BSC	

CASE 210C-01
TO-206AC
(TO-52)

STATIC ELECTRICAL CHARACTERISTICS (T_A = 25°C)

Characteristic	Symbol	Min	Typ	Max	Unit
Collector Dark Current (V_{CC} = 12 V, H ≈ 0, T_A = 25°C)	I_{CEO}	—	10	100	nA
Collector-Base Breakdown Voltage (I_C = 100 μA)	$V_{(BR)CBO}$	50	—	—	Volts
Collector-Emitter Breakdown Voltage (I_C = 100 μA)	$V_{(BR)CEO}$	30	—	—	Volts
Emitter-Base Breakdown Voltage (I_E = 100 μA)	$V_{(BR)EBO}$	7.0	—	—	Volts

OPTICAL CHARACTERISTICS (T_A = 25°C)

Characteristic	Symbol	Min	Typ	Max	Unit
Responsivity (V_{CC} = 5.0 V, R_L = 10 Ω, λ ≈ 820 nm, P = 1.0 μW*)	R	2300	4000	—	μA/μW
Photo Current Rise Time (R_L = 100 ohms)	t_r	—	40	—	μs
Photo Current Fall Time (R_L = 100 ohms)	t_f	—	60	—	μs
Numerical Aperture of Input Port (300 μm [12 mil] diameter spot)	NA	—	0.70	—	—

*Power launched into Optical Input Port. The designer must account for interface coupling losses.

TYPICAL CHARACTERISTICS

FIGURE 2 — RESPONSIVITY TEST CONFIGURATION

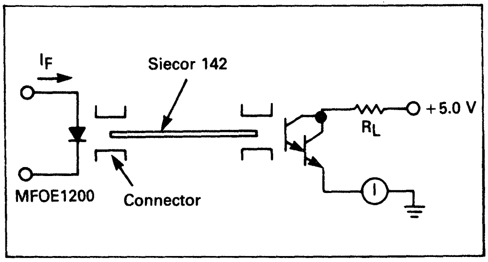
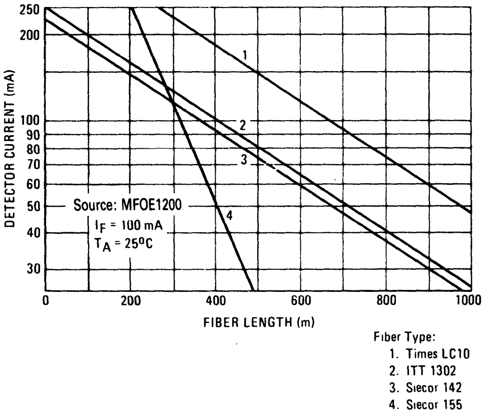


FIGURE 3 — DETECTOR CURRENT versus FIBER* LENGTH



MOTOROLA

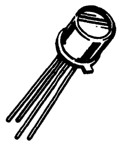
MFOD2404

FIBER OPTICS
INTEGRATED DETECTOR PREAMPLIFIER

INTEGRATED DETECTOR/PREAMPLIFIER FOR FIBER OPTIC SYSTEMS

. . . designed as a monolithic integrated circuit containing both detector and preamplifier for use in medium bandwidth, medium distance systems. It is packaged in Motorola's hermetic TO-52 type case, and fits directly into standard fiber optic connectors which also provide excellent RFI immunity. The output of the device is low impedance to provide even less sensitivity to stray interference. The MFOD2404 has a 300 μm (12 mil) fiber input with a high numerical aperture.

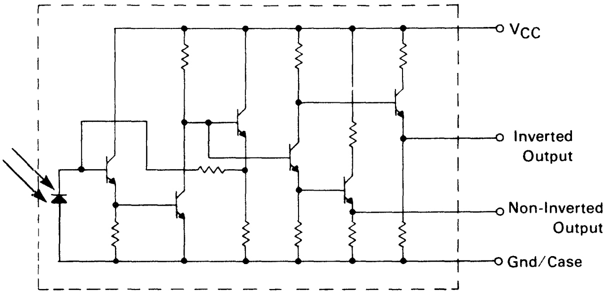
- Usable for Data Systems up to 10 Megabaud
- Dynamic Range Greater than 100:1
- RFI Shielded in AMP #227846-1 and Amphenol 905-138-5001 Receptacles.
- May be used wth MFOExxx Emitters
- Hermetic Package
- 300 μm (12 mil) Diameter Optical Spot

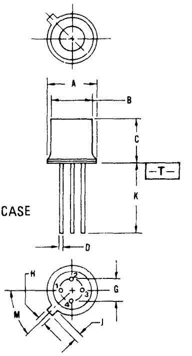


MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Supply Voltage	V_{CC}	7.5	Volts
Operating Temperature Range	T_A	-65 to +125	°C
Storage Temperature Range	T_{stg}	-65 to +150	°C

FIGURE 1 — EQUIVALENT SCHEMATIC





STYLE 1.
PIN 1. $-V_{OUT}$
2. $+V_{OUT}$
3. GROUND/CASE
4. $+V_{CC}$

NOTES.
1. DIMENSIONS A AND H ARE DATUMS AND T IS A DATUM SURFACE.
2. LEAD POSITIONAL TOLERANCE AT SEATING PLANE:
⌖ | Ø 0.036 (0.014) Ⓜ | T | A Ⓜ | H Ⓜ
3. DIMENSIONING AND TOLERANCING PER Y14.5, 1973.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.30	5.38	0.209	0.212
B	4.64	4.69	0.183	0.185
C	3.42	3.60	0.135	0.142
D	0.40	0.48	0.016	0.019
G	2.54 BSC		0.100 BSC	
H	0.91	1.16	0.036	0.046
J	0.83	1.21	0.033	0.048
K	12 70	–	0.500	–
M	45° BSC		45° BSC	

CASE 210D-01

ELECTRICAL CHARACTERISTICS (V_{CC} = 5.0 V, T_A = 25°C)

Characteristics	Symbol	Conditions	Min	Typ	Max	Units
Power Supply Current	I_{CC}	Circuit A	3.0	3.5	5.0	mA
Quiescent dc Output Voltage (Non-Inverting Output)	V_q	Circuit A	0.5	0.6	0.7	Volts
Quiescent dc Output Voltage (Inverting Output)	V_q	Circuit A	2.7	3.0	3.3	Volts
Output Impedance	z_o		—	200	—	Ohms
RMS Noise Output	V_{NO}	Circuit A	—	0.4	1.0	mV

OPTICAL CHARACTERISTICS (T_A = 25°C)

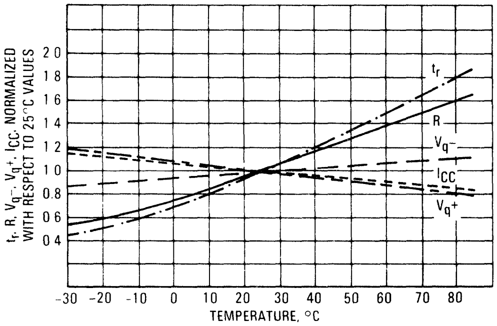
Characteristics	Symbol	Conditions	Min	Typ	Max	Units
Responsivity (V_{CC} = 5.0 V, P = 2.0 µW*) λ = 900 nm λ = 820 nm	R	Circuit B	20 23	30 35	50 58	mV/µW
Sensitivity (10 Mb/s NRZ, BER = 10^{-9})	S		0.10	—	—	µW
Pulse Response	t_r, t_f	Circuit B	—	35	50	ns
Numerical Aperture of Input Port (300 µm [12 mil] diameter spot)	NA		—	0.70	—	—
Signal-to-Noise Ratio @ P_{in} = 1.0 µW peak*	S/N		—	35	—	dB
Maximum Input Power for Negligible Distortion in Output Pulse*			—	—	30	µW

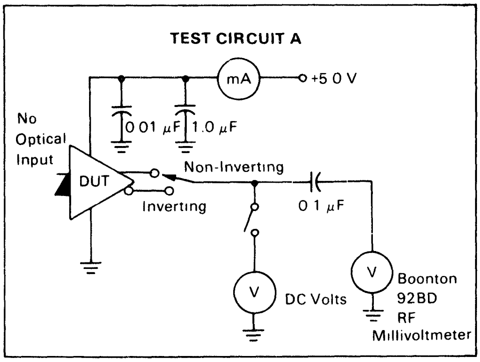
RECOMMENDED OPERATING CONDITIONS

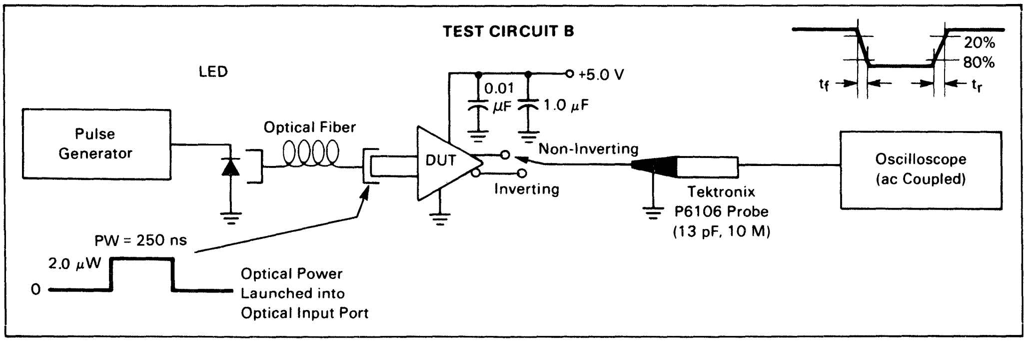
Characteristics	Symbol	Conditions	Min	Typ	Max	Units
Supply Voltage	V_{CC}		4.0	5.0	6.0	Volts
Capacitive Load	C_L		—	—	100	pF
Input Wavelength	λ		—	820	—	nm

*Power launched into Optical Input Port. The designer must account for interface coupling losses.

FIGURE 2 — TYPICAL PERFORMANCE OVER OPERATING TEMPERATURE RANGE




TEST CIRCUIT A


TEST CIRCUIT B

MOTOROLA

MFOD2405

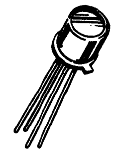
INTEGRATED DETECTOR/PREAMPLIFIER FOR FIBER OPTIC SYSTEMS

. . . designed as a monolithic integrated circuit containing both detector and preamplifier for use in computer, industrial control, and other communications systems.

Packaged in Motorola's hermetic TO-52 type case, the device fits directly into standard fiber optic connectors which also provide excellent RFI immunity. The output of the device is low impedance to provide even less sensitivity to stray interference. The MFOD2405 has a 300 μm (12 mil) fiber input with a high numerical aperture.

- Usable for Data Systems Through 40 Megabaud
- Dynamic Range Greater than 100:1
- RFI Shielded in AMP #227846-1 and Amphenol 905-138-5001 Receptacles.
- May be used wth MFOExxx Emitters
- Hermetic Package
- 300 μm (12 mil) Diameter Optical Spot

FIBER OPTICS
INTEGRATED DETECTOR PREAMPLIFIER



MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Supply Voltage	V_{CC}	7.5	Volts
Operating Temperature Range	T_A	-65 to +125	°C
Storage Temperature Range	T_{stg}	-65 to +150	°C

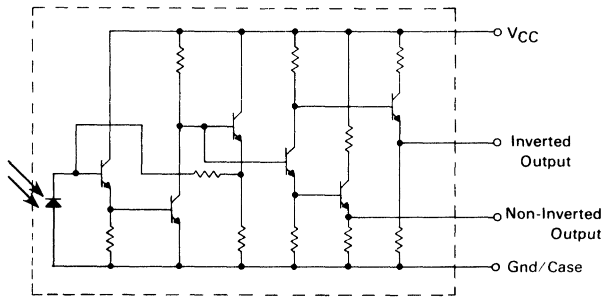
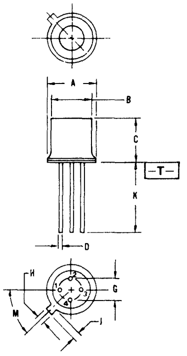


FIGURE 1 — EQUIVALENT SCHEMATIC



STYLE 1:
PIN 1. $-V_{OUT}$
2. $+V_{OUT}$
3. GROUND/CASE
4. $+V_{CC}$

NOTES:
1. DIMENSIONS A AND H ARE DATUMS AND T IS A DATUM SURFACE.
2. LEAD POSITIONAL TOLERANCE AT SEATING PLANE:
⌖ | Ø 0.036 (0.014) Ⓜ | T | A Ⓜ | H Ⓜ
3. DIMENSIONING AND TOLERANCING PER Y14.5, 1973.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	5.30	5.38	0.209	0.212
B	4.64	4.69	0.183	0.185
C	3.42	3.60	0.135	0.142
D	0.40	0.48	0.016	0.019
G	2.54 BSC		0.100 BSC	
H	0.91	1.16	0.036	0.046
J	0.83	1.21	0.033	0.048
K	12.70	–	0.500	–
M	45° BSC		45° BSC	

CASE 210D-01

ELECTRICAL CHARACTERISTICS (V_{CC} = 5.0 V, T_A = 25°C)

Characteristics	Symbol	Conditions	Min	Typ	Max	Units
Power Supply Current	I_{CC}	Circuit A	3.0	4.5	6.0	mA
Quiescent dc Output Voltage (Non-Inverting Output)	V_q	Circuit A	0.6	0.7	0.8	Volts
Quiescent dc Output Voltage (Inverting Output)	V_q	Circuit A	2.7	3.0	3.3	Volts
Output Impedance	z_o		—	200	—	Ohms
RMS Noise Output	V_{NO}	Circuit A	—	0.5	1.0	mV

OPTICAL CHARACTERISTICS (T_A = 25°C)

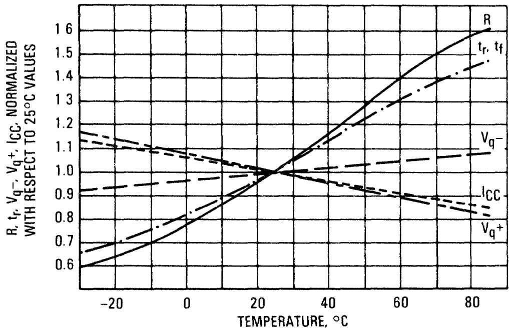
Responsivity (V_{CC} = 5.0 V, λ = 820 nm, P = 10 μW*)	R	Circuit B	3.0	4.5	7.0	mV/μW
Sensitivity (40 Mb/s NRZ, BER = 10^{-9})	S		0.8	—	—	μW
Pulse Response	t_r, t_f	Circuit B	—	10	15	ns
Numerical Aperture of Input Port (300 μm [12 mil] diameter spot)	NA		—	0.70	—	—
Signal-to-Noise Ratio @ P_{in} = 2.0 μW peak*	S/N		—	24	—	dB
Maximum Input Power for Negligible Distortion in Output Pulse*		Circuit B	—	—	120	μW

RECOMMENDED OPERATING CONDITIONS

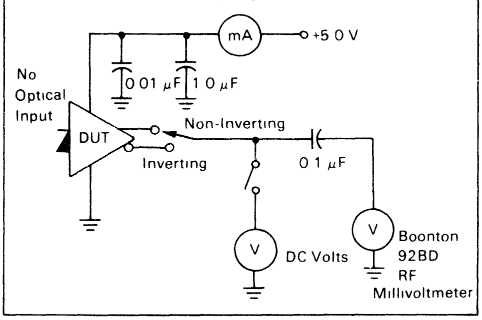
Supply Voltage	V_{CC}		4.0	5.0	6.0	Volts
Capacitive Load (Either Output)	C_L		—	—	100	pF
Input Wavelength	λ		—	820	—	nm

*Power launched into Optical Input Port The designer must account for interface coupling losses

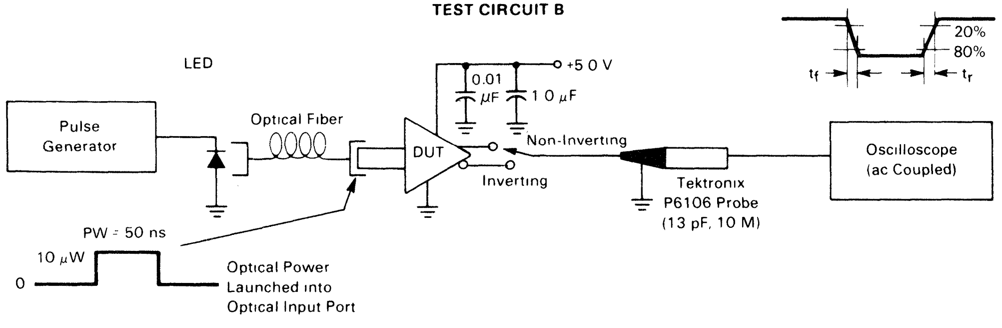
FIGURE 2 — TYPICAL PERFORMANCE OVER OPERATING TEMPERATURE RANGE



TEST CIRCUIT A



TEST CIRCUIT B



MOTOROLA

MFOE200

FIBER OPTICS

HIGH-POWER IR-EMITTING DIODE

INFRARED-EMITTING DIODE FOR FIBER OPTICS SYSTEMS

. . . designed as an infrared source in low frequency, short length Fiber Optics Systems. Typical applications include: medical electronics, industrial controls, M6800 Microprocessor systems, security systems, etc.

- High Power Output Liquid Phase Epitaxial Structure
- Spectral Response Matched to MFOD100, 200, 300
- Hermetic Metal Package for Stability and Reliability
- Compatible With AMP Mounting Bushing #227015

MAXIMUM RATINGS

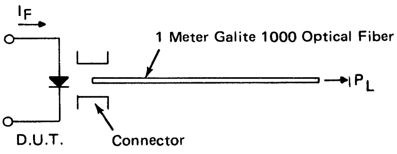
Rating	Symbol	Value	Unit
Reverse Voltage	V_R	3.0	Volts
Forward Current—Continuous	I_F	100	mA
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D(1)	250 2.5	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−55 to +125	°C

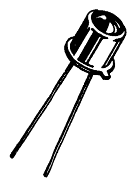
THERMAL CHARACTERISTICS

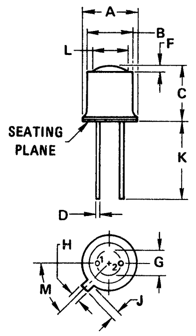
Charactersitics	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient	θ_{JA}	400	°C/W

(1) Printed Circuit Board Mounting

FIGURE 1 — LAUNCHED POWER TEST CONFIGURATION







STYLE 1:
PIN 1. ANODE
2. CATHODE

NOTES:
1. PIN 2 INTERNALLY CONNECTED TO CASE.
2. LEADS WITHIN 0.13 mm (0.005) RADIUS OF TRUE POSITION AT SEATING PLANE AT MAXIMUM MATERIAL CONDITION.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.52	4.95	0.178	0.195
C	6.22	6.98	0.245	0.275
D	0.41	0.48	0.016	0.019
F	1.19	1.60	0.047	0.063
G	2.54 BSC		0.100 BSC	
H	0.99	1.17	0.039	0.046
J	0.84	1.22	0.033	0.048
K	12.70	–	0.500	–
L	3.35	4.01	0.132	0.158
M	45° BSC		45° BSC	

CASE 209-02

ELECTRICAL CHARACTERISTICS ($T_A = 25^\circ C$)

Characteristic	Fig. No.	Symbol	Min	Typ	Max	Unit
Reverse Leakage Current ($V_R = 3.0$ V, $R_L = 1.0$ Megohm)	–	I_R	–	50	–	nA
Reverse Breakdown Voltage ($I_R = 100$ μA)	–	$V_{(BR)R}$	3.0	–	–	Volts
Forward Voltage ($I_F = 100$ mA)		V_F	–	1.5	1.7	Volts
Total Capacitance ($V_R = 0$ V, f = 1.0 MHz)	–	C_T	–	150	–	pF

OPTICAL CHARACTERISTICS ($T_A = 25^\circ C$)

Total Power Output (Note 1) ($I_F = 100$ mA, $\lambda \approx 940$ nm)	1, 2	P_o	2.0	3.0	–	mW
Power Launched (Note 2) ($I_F = 100$ mA)	3	P_L	35	45	–	μW
Optical Turn-On and Turn-Off Time	–	t_{on}, t_{off}	–	250	–	ns

1. Total Power Output, P_o, is defined as the total power radiated by the device into a solid angle of 2π steradians.
2. Power Launched, P_L, is the optical power exiting one meter of 0.045" diameter optical fiber bundle having NA = 0.67, Attenuation = 0.6 dB/m @ 940 nm, terminated with AMP connectors. (See Figure 1.)

TYPICAL CHARACTERISTICS

FIGURE 2 – INSTANTANEOUS POWER OUTPUT versus FORWARD CURRENT

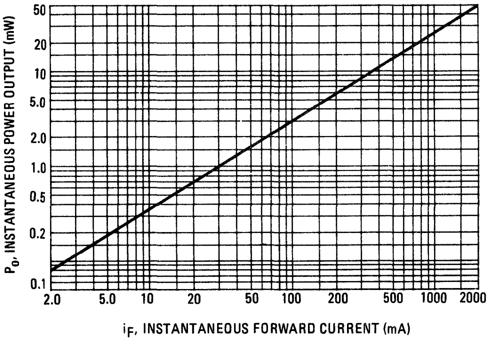
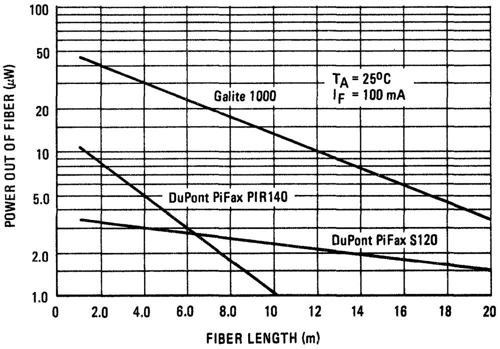


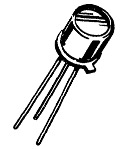
FIGURE 3 – POWER OUT OF FIBER versus FIBER LENGTH



MOTOROLA

MFOE1200

FIBER OPTICS
HIGH-POWER
AlGaAs LED



AlGaAs FIBER OPTIC EMITTER

. . . designed for fiber optic applications requiring high power and fast response time. It is spectrally matched to the minimum attenuation region of most fiber optic cables. Motorola's package fits directly into standard OPTIMATE and SMA fiber optic connector systems. Applications are broad, and include industrial controls, computer systems, CATV, military and others.

- Fast Response – >70 MHz Bandwidth
- 250 μm Diameter Spot Size
- Hermetic Package
- Internal Lensing Enhances Coupling Efficiency
- Complements All Motorola FO Detectors
- Compatible With AMP #227846-1 and Amphenol #905-138-5001 Receptacles

MAXIMUM RATINGS

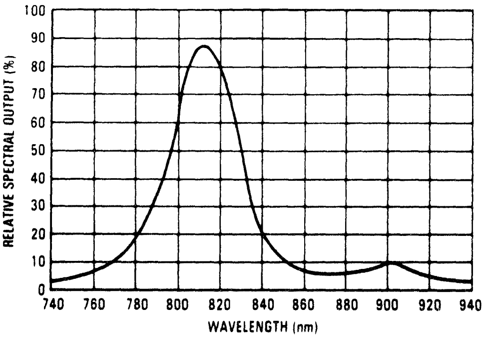
Rating	Symbol	Value	Unit
Reverse Voltage	V_R	3.0	Volts
Forward Current-Continuous	I_F	200	mA
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	400 4.0	mW mW/°C
Operating Temperature Range	T_A	−65 to +125	°C
Storage Temperature Range	T_{stg}	−65 to + 150	°C

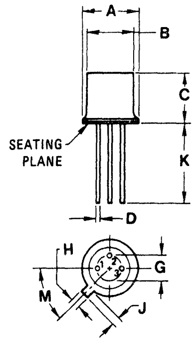
THERMAL CHARACTERISTICS

Characteristics	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient	θ_{JA}	250 175*	C/W

*Installed in compatible metal connector housing.

FIGURE 1 — SPECTRAL OUTPUT versus WAVELENGTH





STYLE 1:
PIN 1. ANODE
2. CATHODE
3. CASE

NOTES:
1. PIN 3 INTERNALLY CONNECTED TO CASE.
2. LEAD POSITIONAL TOLERANCE AT SEATING PLANE:

⌖	Ø 0.36 (0.014) Ⓜ	T	A Ⓜ	H Ⓜ

3. DIMENSIONS A AND H ARE DATUMS AND T IS A DATUM PLANE.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.65	4.70	0.183	0.185
C	3.12	3.28	0.123	0.129
D	0.41	0.48	0.016	0.019
G	2.54 BSC		0.100 BSC	
H	0.99	1.17	0.039	0.046
J	0.84	1.22	0.033	0.048
K	12.70	–	0.500	–
M	45° BSC		45° BSC	

CASE 210A-01
TO-206AC
(TO-52)

ELECTRICAL CHARACTERISTICS (T_A = 25°C)

Characteristics	Symbol	Min	Typ	Max	Unit
Forward Voltage (I_F = 100 mA)	V_F	—	1.8	2.5	Volts
Total Capacitance (V_R = 0 V, f = 1.0 MHz)	C_T	—	70	—	pF

OPTICAL CHARACTERISTICS (T_A = 25°C)

Total Power Output From 250 μm Optical Spot (I_F = 100 mA, λ ≈ 820 nm)	P_o	900	—	—	μW
Numerical Aperture of Output Port (at −10 dB) (250 μm [10 mil] diameter spot)	NA	—	0.30	—	—
Wavelength of Peak Emission (I_F = 100 mAdc)	—	—	820	—	nm
Spectral Line Half Width	—	—	50	—	nm
Electrical Bandwidth (I_F = 100 mAdc)	BWE	70	—	—	MHz

TYPICAL CHARACTERISTICS

FIGURE 2 — POWER OUTPUT versus JUNCTION TEMPERATURE

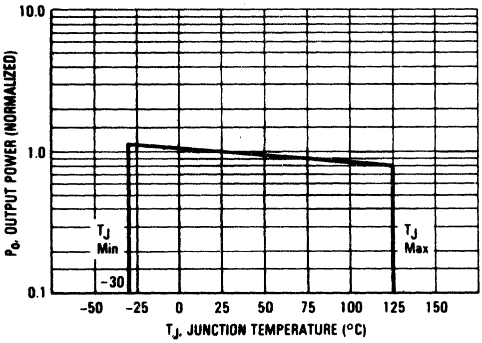
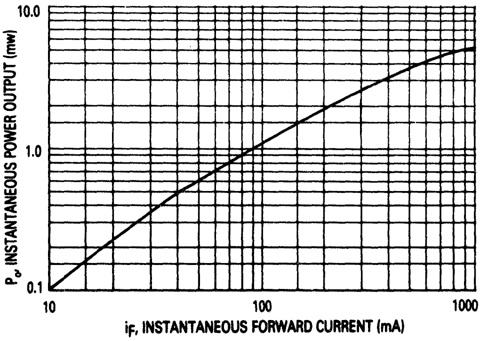


FIGURE 3 — POWER OUTPUT versus FORWARD CURRENT



MOTOROLA

MFOE1201
MFOE1202

AlGaAs FIBER OPTIC EMITTER

. . . designed for fiber optic applications requiring high power and fast response time. It is spectrally matched to the minimum attenuation region of most fiber optic cables. Motorola's package fits directly into standard OPTIMATE and SMA fiber optic connector systems. Applications are broad, and include industrial controls, computer systems, CATV, military and others.

- Fast Response — 3.0 ns Typ
- 100 MHz Bandwidth
- 250 μm Diameter Spot Size
- Hermetic Package
- Internal Lensing Enhances Coupling Efficiency
- Complements All Motorola FO Detectors
- Compatible With AMP #227846-1 and Amphenol #905-138-5001 Receptacles

MAXIMUM RATINGS

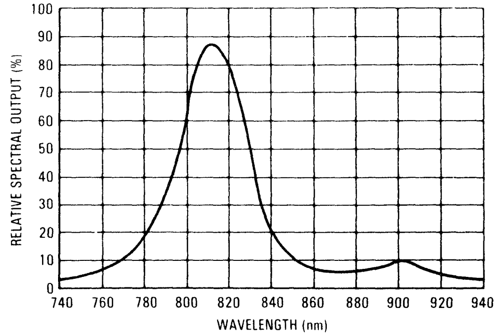
Rating	Symbol	Value	Unit
Reverse Voltage	V_R	3.0	Volts
Forward Current-Continuous	I_F	200	mA
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	400 4.0	mW mW/°C
Operating Temperature Range	T_A	−65 to +125	°C
Storage Temperature Range	T_{stg}	−65 to + 150	°C

THERMAL CHARACTERISTICS

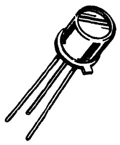
Characteristics	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient	θ_{JA}	250 175*	°C/W

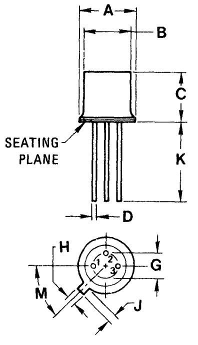
*Installed in compatible metal connector housing.

FIGURE 1 — SPECTRAL OUTPUT versus WAVELENGTH



FIBER OPTICS
HIGH-POWER AlGaAs LED





STYLE 1:
PIN 1. ANODE
2. CATHODE
3. CASE

NOTES:
1. PIN 3 INTERNALLY CONNECTED TO CASE.
2. LEAD POSITIONAL TOLERANCE AT SEATING PLANE:

⌖	Ø 0.36 (0.014) Ⓜ	T	A Ⓜ	H Ⓜ

3. DIMENSIONS A AND H ARE DATUMS AND T IS A DATUM PLANE.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.65	4.70	0.183	0.185
C	3.12	3.28	0.123	0.129
D	0.41	0.48	0.016	0.019
G	2.54 BSC		0.100 BSC	
H	0.99	1.17	0.039	0.046
J	0.84	1.22	0.033	0.048
K	12.70	–	0.500	–
M	45° BSC		45° BSC	

CASE 210A-01
TO-206AC
(TO-52)

ELECTRICAL CHARACTERISTICS (T_A = 25°C)

Characteristics	Symbol	Min	Typ	Max	Unit
Reverse Breakdown Voltage (I_R = 100 μA)	$V_{(BR)R}$	2.0	4.0	—	Volts
Forward Voltage (I_F = 100 mA)	V_F	1.5	1.8	2.0	Volts
Total Capacitance (V_R = 0 V, f = 1.0 MHz)	C_T	—	70	—	pF

OPTICAL CHARACTERISTICS (T_A = 25°C)

Characteristics	Symbol	Min	Typ	Max	Unit
Total Power Output From 250 μm Optical Spot (I_F = 100 mA, λ ≈ 820 nm) MFOE1201 MFOE1202	P_o	 1000 1750	 1500 2400	 2000 3500	μW
Total Power Output From 250 μm Optical Spot (I_F = 100 mA, λ ≈ 820 nm) MFOE1201 MFOE1202	P_o	 0.00 2.43	 1.76 3.80	 3.01 5.44	dBm
Numerical Aperture of Output Port (at −10 dB) (250 μm [10 mil] diameter spot)	NA	—	0.30	—	—
Wavelength of Peak Emission @ 100 mAdc	—	—	820	—	nm
Spectral Line Half Width	—	—	50	—	nm
Optical Rise and Fall Times (I_F = 100 mAdc)	t_r, t_f	—	3.0	—	ns
Electrical Bandwidth (I_F = 100 mAdc)	BWE	100	—	—	MHz

TYPICAL CHARACTERISTICS

FIGURE 2 — POWER OUTPUT versus JUNCTION TEMPERATURE

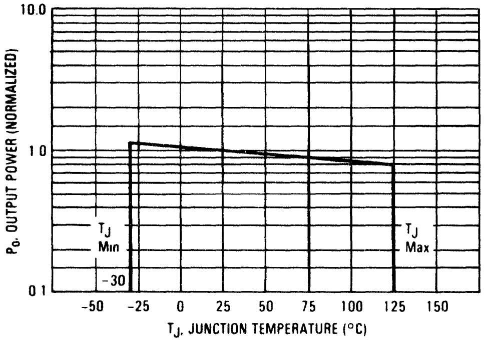
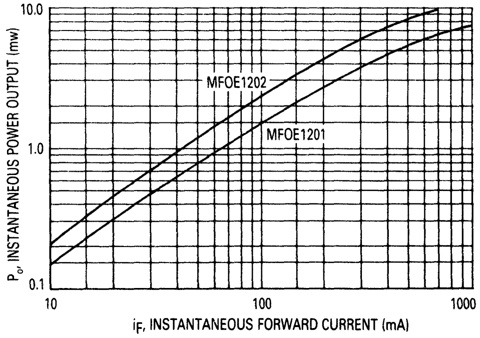
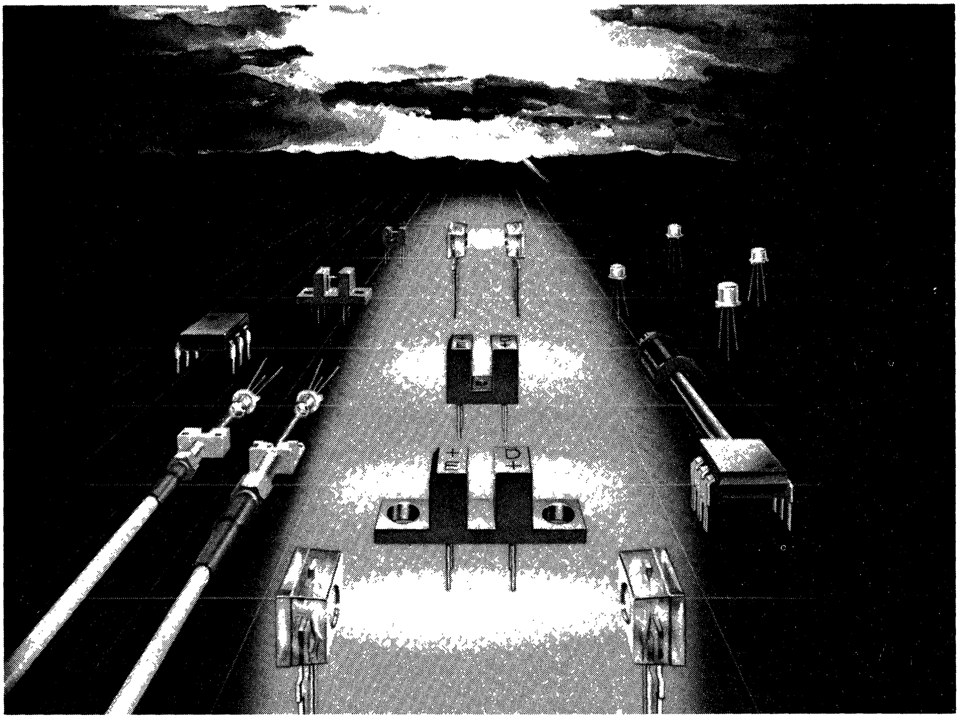


FIGURE 3 — POWER OUTPUT versus FORWARD CURRENT



FIBER OPTICS



For discontinued FOAC devices, see page 5-2 for TO-206AC (TO-52) replacements.

Applications Information

A 20-MBAUD FULL DUPLEX FIBER OPTIC DATA LINK USING FIBER OPTIC ACTIVE COMPONENTS

Prepared By:
Vincent L. Mirtich

INTRODUCTION

This application note describes an optical transceiver which is designed to be used in a full duplex data communications link. Its electrical interface with the outside world is TTL. The optical interface between modules consists of separate transmit and receive ports, which use the Motorola Fiber Optic Active Component (FOAC) for the optical to electrical transducers. Two modules can optically communicate via either two separate fibers or via an optical duplexer such as a three-port directional coupler and a single fiber. The data rate can be anything from 20 Mbaud on down as long as the transmitter input rise times are compatible with TTL specifications. For NRZ data where one baud per bit is required, data can be transferred at rates up to 20 Mbits. For RZ data where 2 bauds per bit are required, data can be transferred at rates up to 10 Mbits. The small-signal 3.0 dB bandwidth of the system is 10 MHz minimum. The unit can also be configured as an optical repeater by connecting the receiver electrical output to the transmitter electrical input.

The receiver is edge coupled and therefore places no constraints on data format. Since the edge coupling removes the data base line variation, there is no base line tracking required. Consequently, there is no limit on the length of a string of ones or zeroes. The receiver latches and remembers the polarity of the last received data edge. The use of the Motorola FOAC for the transmitter and receiver transducers greatly simplifies the optical interface. It eliminates the handling of delicate fiber pigtails, the need for terminating and polishing such pigtails, and is compatible with the AMP connector system.

This application note will follow the following format:

- I. Transmitter Description
  - A. Block diagram and functional description
  - B. Schematic diagram and design considerations
  - C. Transmitter performance
- II. Receiver Description
  - A. Functional block diagram and design considerations
  - B. Amplitude detector coupling and required S/N
  - C. Schematic diagram and circuit implementation
  - D. Receiver performance
- III. Building the Boards
  - A. Parts list and unique parts
  - B. Working with FOACs and AMP connectors
  - C. Shielding requirements
- IV. Testing the Boards
  - A. Test equipment required
  - B. Looping transmitter to receiver. Caution with LED
  - C. Waveform analysis
  - D. Setting hysteresis
- V. System Performance
  - A. Interpreting fiber, emitter, and detector specifications
  - B. Calculating system performance. Loss budget, dispersion limit.

TRANSMITTER DESCRIPTION

Transmitter Block Diagram and Functional Description

Figure 1 shows the functional block diagram of the optical transmitter. The first block is the **logic interface**. Since the transmitter is intended for use in data communications applications, it has to interface a common logic family and provide some standard load and input signal requirements. Also, since it is intended for use at data rates of up to 20 Mbaud, TTL is a good choice for the logic family. The logic interface function then could be implemented by one of the standard TTL gates, inverters, etc., to provide an electrical port which can be driven from any TTL output.

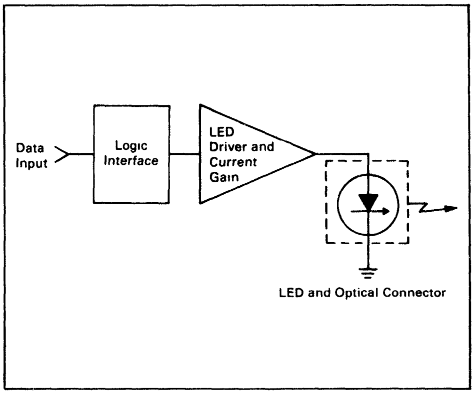


FIGURE 1 — Optical Transmitter Functional Block Diagram

The second block in Figure 1, **the LED Driver** and **Current Gain**, has several functions. First, it must provide the forward current required by the LED for the particular optical output power desired. Secondly, it must switch that current on and off in response to the input data with rise and fall times consistent with the maximum baud rate expected. Third, it must provide enough current gain to amplify the limited source and sink current of the logic interface block up to the needed LED current.

The third block, **the LED** and **Optical Connector** could be broken into two separate functions, as is usually the case. However, through the use of a well thought out and economically advantageous approach to the electrical to optical fiber translation, the electrical to optical transducer and the fiber coupling functions have been addressed in concert. The electro/optical transducer is an LED which emits pulses of optical energy in response to the data input. In this case, the optical energy is near infrared which is invisible to the unaided eye. The LED package, a FOAC, efficiently couples as much emitted energy as possible into a short internal pre-polished pigtail fiber. The coupler or connector then mounts the FOAC so that its optical port is aligned with the core of the system fiber. In this way, the percentage of emitted optical power that is launched into the system fiber is maximized without any special preparation of the transducer by the user. Refer to Figure 2.

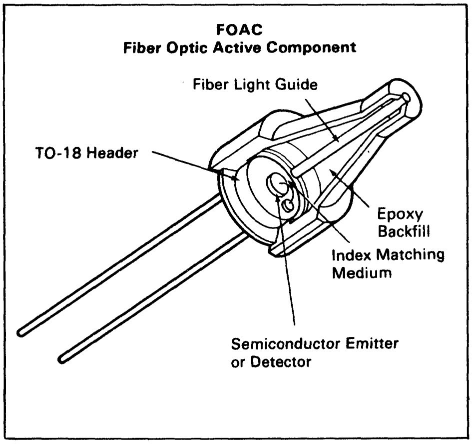


FIGURE 2 — FOAC Construction

In addition to these functions, it would be nice if the transmitter had the following features. It would be convenient if the LED current were easily set to whatever value was desired. It would be desirable if the LED current were not influenced greatly by power supply fluctuations or temperature variations. Since this transmitter is to be operating beside a receiver operating on the same power supply, it would greatly simplify transmitter/receiver isolation if the transmitter didn't cause large supply current variations which modulated the power supply lines. Finally, it would be useful if the transmitter could easily be gated off by another logic signal so that the LED did not respond to the data input.

Transmitter Schematic and Design Considerations

Figure 3 shows the transmitter circuit schematic and indicates which portion of the circuit performs each of the previously mentioned functions.

The **logic interface** has been implemented using the two sections of the SN74LS40 dual four input NAND gate in cascade. The LS40 was chosen as the particular part because of its buffered output. Since it can sink 24 mA instead of the normal 8.0 mA (typical LS output) and still provide 0.5 V for a low output, it puts less of a current gain requirement on the following circuitry. The reason two sections were used in cascade rather than one is that every TTL gate introduces some differential prop delay. This is a difference in propagation times through the gate for positive and negative transitions. It is primarily a function of the gates' output transistor configuration and how hard they are driven by internal circuitry. In some instances, it can be very near zero, and in other parts it can be as high as 10 ns. However, on a particular chip, all sections will tend to have differential prop delays of the same polarity and very nearly equal. If two inverting functions on the same chip are then cascaded, the differential prop delay through the pair will tend to null to zero since both polarities of incoming data edges are processed as positive transitions by one gate and as negative transitions by the other gate.

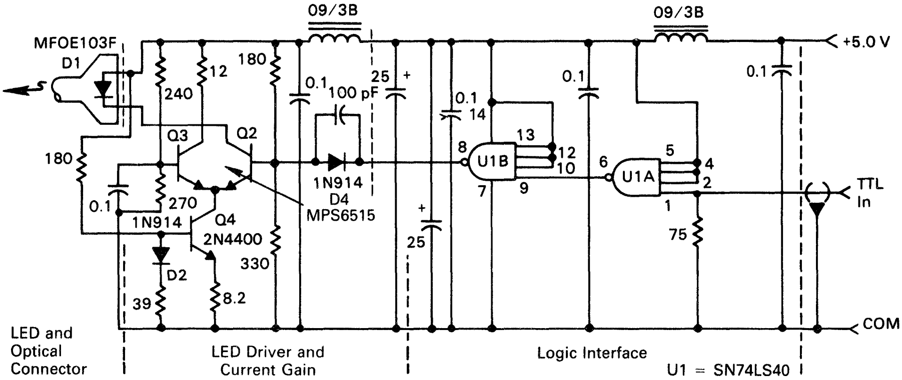


FIGURE 3 — Transmitter Schematic

The effect of a 10 ns longer propagation delay for high to low transitions on a 20 Mbaud squarewave is shown in Figure 4. It will be noted that processing the distorted signal through a second gate having prop delays equal to those of the first gate corrects the duty cycle distortion at the expense of a little higher absolute prop delay. The distorted waveform is delayed by t_{PHL} only whereas the undistorted waveform is delayed by $t_{PHL} + t_{PLH}$. This slight increase in absolute prop delay is usually insignificant compared to the absolute prop delay through the transmission medium. It will also be noted that if the distortion is not corrected, then the waveform applied to the LED driver is of a higher baud rate, thus requiring wider system bandwidth.

The cascading of two identical inverting gates also provides a way of balancing their power supply currents and avoids putting transients on the +5.0 V power line. The schematic shows different loads on the two NAND gate sections so that the currents are not equal for the two logic input levels. However, if additional power supply decoupling were needed to further reduce transmitter and receiver crosstalk, putting a 430 Ω pull-up resistor from Pin 6 of U1A to +5.0 V would improve the balance of transmitter power supply current between the two logic states at the expense of another 10 mA or so in transmitter current drain.

The gating function mentioned earlier is also not shown in the schematic but can be easily implemented by tying one of Pins 2, 4, or 5 of U1A to +5.0 V through a suitable pull-up resistor and then providing this pin to the outside world for a logic low to gate off the data. This data off condition would also produce an LED off condition.

The 75 Ω termination across the data input is to terminate an expected 75 Ω coaxial cable. If data rates significantly lower than 20 Mbaud are transmitted

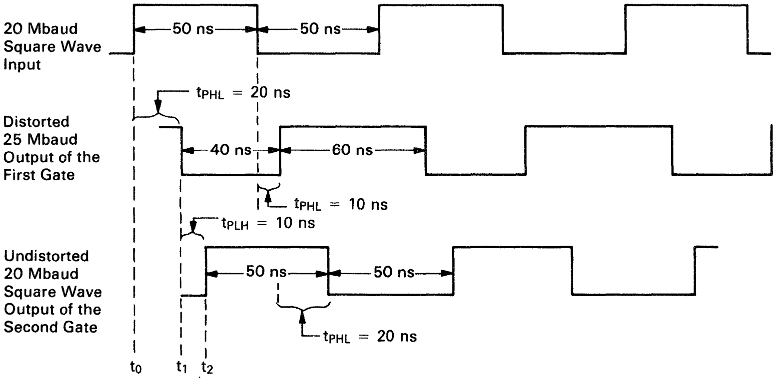


FIGURE 4 — Correction of Duty Cycle Distortion Caused by Gate Differential Prop Delay

then a coaxial cable may not be necessary and a different termination can be used. The reader is cautioned, however, that an unshielded data line into the transmitter could cause crosstalk to the receiver and thereby destroy the system error rate performance. Therefore, if an unshielded lead-in is desired, it should be implemented while monitoring bit errors in the receive channel.

The **LED driver** and **current gain** function is implemented with a discrete current limited differential amplifier with the LED as one of the collector loads. The amplifier's emitter coupled configuration is well known for providing fast switching speeds. Its non-saturating characteristic prevents any stored charge accumulation in the transistor base region and the corresponding degradation in turn off time. Therefore, rise and fall times of this driver are fast and very nearly the same. Since these driver transistors don't saturate, they also preserve their high small-signal current gain and consequently minimize base drive requirements.

The current source, Q4, is biased so that its collector current is equal to the peak LED current desired. The emitter resistor of Q4 sets the current and the component values shown in Figure 3 bias Q4 at 100 mA. Diode D2 matches the thermal drift in the emitter voltage of Q4 which holds its collector current constant over temperature.

Once this current is fixed, the logic state at Pin 8 of U1B determines if it flows through Q2 and the LED or through Q3 and the 12 Ω resistor. A logic high at Pin 8 reverse biases D4 and allows the Q2 base current to be supplied by the resistor divider network and consequently turns on the LED. A logic low at Pin 8 biases Q2 and the LED off.

The required logic condition at the TTL input to turn on the LED can easily be switched 180° by driving the LED with the opposite side of the differential amplifier. It should be pointed out that this is the preferred way of switching the transmitter phase rather than adding another stage of logic inversion which would introduce differential prop delay and hence duty cycle distortion.

The use of a differential driver does cause the transmitter current drain to be relatively constant even when the LED is off. However, the disadvantage of higher standby drain is far outweighed by the reduction in power line transients on the +5.0 V line due to no significant power supply current switching. This greatly enhances the isolation between the transmitter and receiver.

The **LED** and **connector** used is the MFOE103F in the ferruled package and the AMP 227240-1 connector. This LED has a maximum rise time of 22 ns and a typical power out of 70 μW at 50 mA drive current.

Transmitter Performance

Figure 5 shows the calculated exit power expected for six different fibers when driven from the transmitter. This chart can be used to determine which fiber delivers the most exit power for a given path length.

Figure 6 shows the variation in LED current and transmitter output power over temperature. This was measured at the end of a 20 foot length of the Seicor cable, with the LED biased for continuous operation.

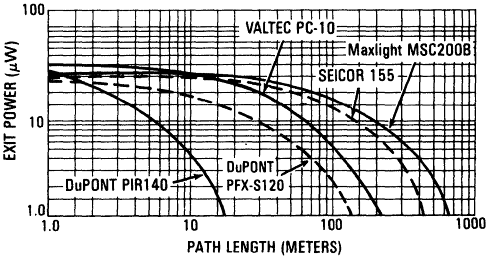


FIGURE 5 — Calculated Peak Exit Power versus Fiber Path

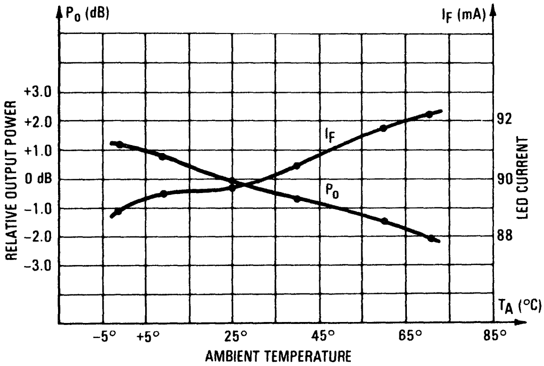


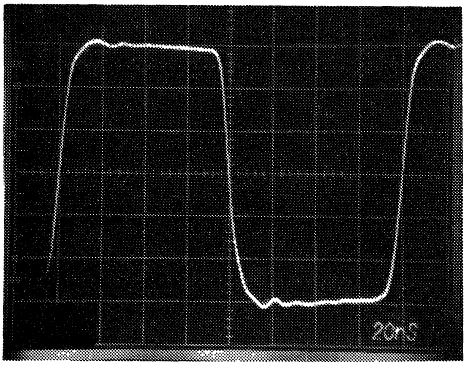
FIGURE 6 — Optical Output Power and LED Current versus Temperature

Figure 7 displays the duty cycle distortion introduced by the transmitter logic interface and LED driver. Figure 7(a) shows a 50% duty cycle squarewave at the transmitter TTL input and Figure 7(b) shows the corresponding LED current waveform measured with a high frequency current probe. It will be noted that the current waveform exhibits an indiscernible amount of duty cycle distortion.

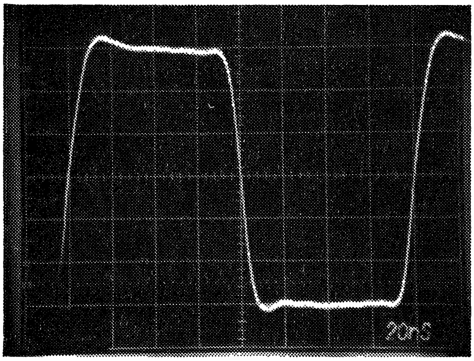
The biasing of the base of Q2 in both logic states relative to the bias at the base of Q1 can be another source of duty cycle distortion. If this is critical to the application and must be held to less than a couple of nanoseconds, these resistors may be selected to tighter tolerances. Also, replacing the LS40 NAND gate with an S40 (standard Schottky) NAND gate will reduce distortion contributed by that source.

Figure 8 shows the absolute prop delay through the transmitter. It will be noted that both positive and negative transitions are delayed about 43 ns.

Figure 9 shows the 10%–90% rise and fall times of the LED current waveform to be about 17 ns and 13 ns respectively.



(a) Transmitter TTL Input



(b) LED Current

FIGURE 7 — Transmitter Duty Cycle Distortion

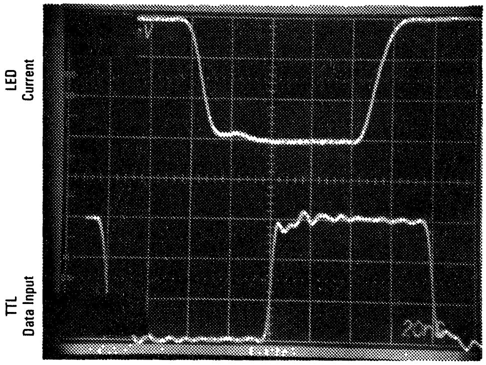


FIGURE 8 — Transmitter Absolute Prop Delay

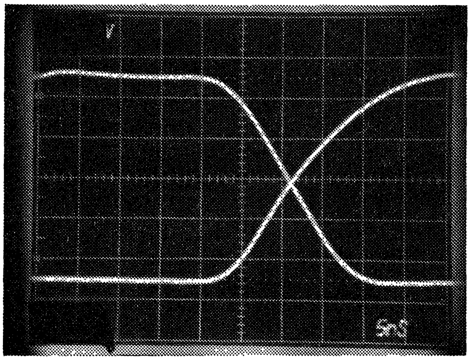


FIGURE 9 — LED Current Rise and Fall Time

RECEIVER DESCRIPTION

Functional Block Diagram and Design Considerations

Figure 10 shows the receiver functional block diagram.

The first element is the **optical detector** which receives pulses of optical energy emanating from the end of a fiber. It typically looks like a current source (see Figure 11) whose magnitude is dependent on the incident optical energy and a parallel capacitor whose value is dependent on device design and the magnitude of reverse bias across it. This capacity adds in parallel with any external load capacity to form a net load capacity which must be charged and discharged by the minute photo current from the detector. Because this detector output is a high impedance source and its signal is very small, it is a difficult point to interface without introducing noise, RFI, and reactive loads which degrade the signal quality.

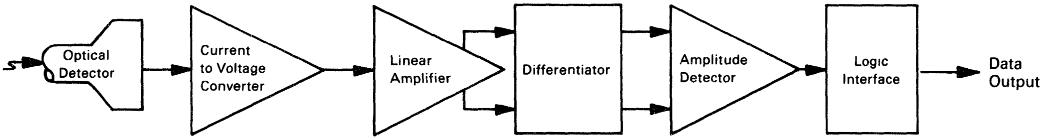


FIGURE 10 — Optical Receiver Functional Block Diagram

For this reason, the second element shown in the block diagram, **the current to voltage converter**, is usually coupled as closely as possible to the optical detector and very often this interface is then shielded from outside interference. This converter is typically a transimpedance amplifier circuit built from an op amp or other high gain amplifier with negative current feedback. This circuit does three things. First, it provides signal gain by producing an output voltage proportional to the input current. Second, by virtue of its high open loop gain and negative feedback, it provides a low output impedance. Third, it provides a virtual ground at its signal input. That is to say, it has a very low input impedance. Because of this, there is little or no voltage swing at its input. Since the capacitive load on the optical detector has to be charged by the photo current, the relationship of

$$I = C\frac{\Delta V}{\Delta t} \tag{1}$$

$$\Delta t = C\frac{\Delta V}{I} \tag{2}$$

holds true. This says that for a capacitor C, being charged by a constant current I, the change in voltage across it, ΔV, will occur in time interval Δt. Thus, for the model in Figure 11,

$$\begin{aligned} \text{if } I &= 50\text{ nA} \\ C &= 10\text{ pF} \\ \Delta V &= 1.0\text{ mV} \\ \text{then } \Delta t &= 200\text{ ns} \end{aligned}$$

Naturally, if the virtual ground input of the current to voltage converter reduces ΔV to very nearly zero, the transition time, Δt, also approaches zero and much faster rise times can be recovered. Also, by reducing the capacitance, C, one can improve the rise time.

This capacitance is the parallel equivalent of the optical detector capacitance, the amplifier input capacitance, and parasitic capacitance of the printed circuit board. An integrated detector/preamp (IDP) reduces the component capacitances to a minimum and completely eliminates the PCB capacitance, thereby minimizing rise time and providing a low impedance voltage source to which interfacing is easily accomplished.

Now that the optical signal has been converted into a voltage pulse coming from a low source impedance and having fast rising and falling edges, it can be processed by more conventional means. For this reason, the third element in the block diagram is a linear **voltage amplifier**. This amplifier should have sufficient gain to amplify the expected noise from the current to voltage converter up to the minimum level detectable by the amplitude detector. The reason for this will be seen later.

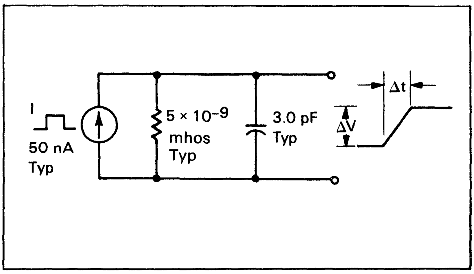


FIGURE 11 — Practical Photo Detector Model

With this consideration in mind, the minimum gain of the voltage amplifier can then be defined as

$$A_{v_{min}} = \frac{\text{Amplitude Detector Threshold } (V_{pp})}{\text{I to V Converter Noise Output } (V_{pp})} \tag{3}$$

Having more gain than this merely amplifies signal and noise together beyond the minimum amplitude detector threshold and accomplishes nothing but a higher required detector threshold. Thus, it would behoove the designer to have a voltage gain block whose gain tracked detector threshold from unit to unit or else a voltage gain and detector threshold which did not vary significantly from unit to unit. The latter is much easier to accomplish.

The next characteristic of the linear amplifier that must be considered is its bandwidth or rise time. Rise time will be considered here because data links are usually characterized by a rise time budget rather than a bandwidth budget. The system rise time is defined as the rise time of the signal appearing at the amplitude detector input which in this case is the voltage amplifier's output. For reasons explained later, a well designed system has its bandwidth determined in the optical detector and preamp so the voltage gain block's rise time should not degrade system rise time by more than 10%. Rise time contributions through the system add as the square root of the sum of the squares. System rise time is exhibited by the output waveform of the voltage amplifier. It is usually determined by contributions from the current to voltage converter and the voltage amplifier such that:

$$t_{R_{SYS}} = \sqrt{(t_{R_{IDP}})^2 + (t_{R_{A_v}})^2} \tag{4}$$

where $t_{R_{SYS}}$ is the system rise time desired at the voltage amplifier's output

$t_{R_{IDP}}$ is the rise time of the integrated detector preamp

$t_{R_{A_v}}$ is the required rise time of the voltage amplifier

This is only true if all other rise times in the system, such as the LED driver, the LED, and the fiber dispersion, are fast enough so as not to contribute significantly to the system rise time.

Now, if the voltage amplifier rise time should not degrade the well designed system by more than 10%, then using equation (4)

$$t_{R_{SYS}} \leq (1.1)\, t_{R_{IDP}}$$

$$\sqrt{(t_{R_{IDP}})^2 + (t_{R_{A_v}})^2} \leq 1.1\, t_{R_{IDP}}$$

$$\text{and} \quad t_{R_{A_v}} \leq (0.458) t_{R_{IDP}} \tag{5}$$

There is also a lower limit on this voltage amplifier's rise time which precludes it from having as fast a rise time as is available. That is, as the noise from each noise source in the receiver is added, its relative contribution is a function of its bandwidth. For example, if the IDP is characterized as having a noise bandwidth B_1, an input noise of e_{n1} V/$\sqrt{\text{Hz}}$, and a gain of A_{V1} and if the voltage amplifier similarly has equivalent parameters of B_2, e_{n2}, and A_{V2}, then the noise presented to the amplitude detector in volts is

$$e_{nDET} = [e_{n1} \sqrt{B_1}\, A_{v1} + e_{n2} \sqrt{B_2}]\ A_{v2} \qquad (6)$$

From equation (6) it can be seen that if the voltage amplifier's noise bandwidth, B_2, is too large in relation to the IDP's bandwidth, B_1, its noise contribution can be significant or even dominant in which case a much wider noise spectrum and higher noise levels are available at the amplitude detector to degrade S/N. The upper limit on the voltage amplifier's bandwidth then is the point at which the noise contribution of the voltage amplifier is about 50% of the IDP noise. This will enable the IDP noise to still determine amplitude detector threshold.

$$e_{n1} \sqrt{B_1}\, A_{v1} A_{v2} = 2e_{n2} \sqrt{B_2}\ A_{v2}$$

$$B_2 = B_1 \left[\frac{(A_{v1}) \cdot (e_{n1})}{2e_{n2}}\right]^2$$

To sum up the characteristics of the voltage gain block, it should have sufficient gain to amplify the IDP noise up to minimum amplitude detector threshold as well as gain which doesn't vary more than amplitude detector threshold from unit to unit. It should have a rise time fast enough so as not to degrade system rise time by more than 10% but not so fast a rise time that its noise bandwidth contributes significantly to system noise.

The next component in the block diagram of Figure 10 is the **differentiator**. As was mentioned in the Introduction, this edge coupled receiver strips off the base line variations with duty cycle from the data stream. This is the function of the differentiator and there are a few considerations to be made in picking the values of R and C. Figure 12 compares the waveforms through an ac coupling network with those through a differentiator. Figures 12(a) and 12(b) each show a 20% duty cycle pulse train and an 80% duty cycle pulse train as two possible extremes in data format for a particular system. When passed through the ac coupling network shown in Figure 12(c), the resulting waveforms will have the levels shown in 12(e). Note the 3.0 V variation in "logic 1" levels and the same variation in "logic 0" levels as the duty cycle varies from 20% to 80%. In practice, an even wider range in duty cycle is often encountered, thereby making the lowest "logic 1" and the highest "logic 0" even less distinguishable from one another. As a result, if a level detector such as a comparator is used to decide whether a "logic 1" or a "0" is present, it must compare the data stream to a floating reference which tracks the reference level of the data stream so that it is always centered between the peaks. For best noise immunity, this reference would have to be at the midpoint of the peak to peak amplitude of the data. Under this condition, the noise immunity would be equal to the amplitude of the data pulses. If the data should lapse for a period of time,

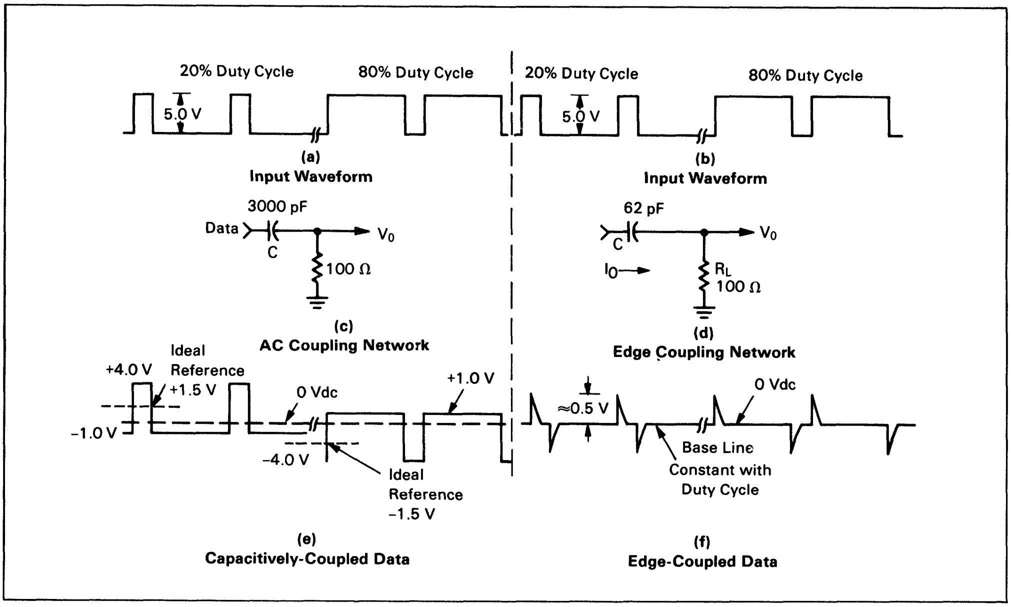


FIGURE 12 — Comparison of Data Stream Waveforms Through AC-Coupled and Edge-Coupled Systems

this floating reference would decay to its appropriate limit for minimum or maximum duty cycle. Once transmission resumed, depending on the initial duty cycle, the first few bits of data could be missed until the reference returned to its proper level.

A much more versatile system which is tolerant of any duty cycle from continuous "logic 1's" to continuous "logic 0's" is the edge coupled system. As can be seen from Figures 12(b), (d), and (f), only the edges of the data pulses are passed by the coupling network. These pass at reduced amplitude and then the recovery or discharge of the network occurs before the next data edge comes along. Since the V_O out of the network in Figure 12(d) is the drive signal for the amplitude detector, it should be maximized. Since V_O is the product of the load resistor and the capacitor current, I_O should be maximized. Therefore,

$$\text{since} \quad V_0 = R_L I_0$$

$$\text{and} \quad I_0 = C\frac{dV_C}{dt}, \qquad (7)$$

$$V_0 = R_L \bullet C \bullet \frac{dV_C}{dt}$$

where V_C is the voltage across the differentiator capacitors. Hence, the R_LC time constant should be maximized to provide maximum amplitude detector drive. If the input waveform to the edge coupling network appears as Figure 13(a), V_O will appear as that shown in 13(b).

However, in maximizing the R_LC time constant, it cannot be increased without limit. As can be seen from Figure 13(b), within the minimum bit time, the differentiator must be allowed to recover fully. Allowing 4 time constants (4 R_LC) after the system rise time $t_{R_{SYS}}$ has occured will permit sufficient recovery. Hence the minimum bit time, T, is given by

$$T = t_{R_{SYS}} + 4\,R_LC \text{ max}$$

$$\text{and } R_LC \text{ max} = \frac{T - t_{R_{SYS}}}{4} \qquad (8)$$

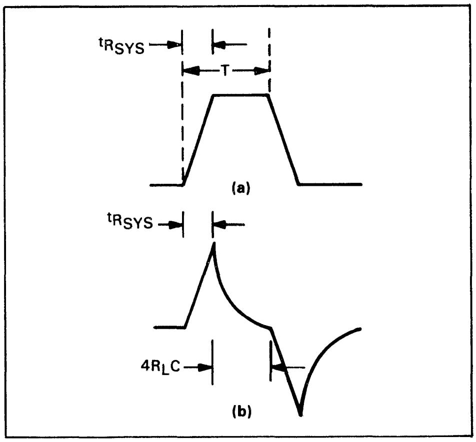


FIGURE 13 — Differentiator Waveforms

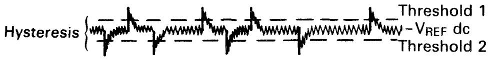
There is an implication here that may not be obvious. That is, to provide the required input to the amplitude detector, two requirements must be satisfied. The differentiator input signal must have adequate amplitude and it must have an adequately fast rise time. Looking back at equation 7, it will be noted that it is $\frac{dV_C}{dt}$ which determines V_O and therefore there is a myriad of combinations of amplitude and rise time which will provide adequate results. However, if the transition height of the input waveform is so small that its peak value is below detector threshold, or if the rise time is so slow that the R_LC time constant decays significantly before the transition is complete, then the pulse will go undetected. An example of this occurs if the fiber link is disrupted during the transmission of an LED "ON" condition ("logic 1"). That disruption generates so slow a transition that it will not couple through the differentiator and the receiver will indicate that the LED is still on until the link is restored and a fast LED "OFF" transition is received.

There is another subtlety implied here and that is that all coupling capacitor time constants ahead of the differentiator must be long enough so as not to decay, during a long string of ones or zeroes, so fast as to generate an edge that is differentiable. A coupling time constant of one or two orders of magnitude longer than the differentiator time constant is suitable.

From a practical point of view the output impedance level of the differentiator should be kept low so that measurements with scope probes can be made without destroying the waveshape of the differentiator output signal. It was found that an R value of 500 Ω or less was needed to keep a conventional 10X, 7.0 pF probe from severely loading differentiators having time constants in the 5 to 20 ns range.

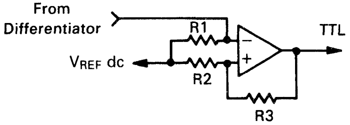
With the data stream now differentiated, the next block in Figure 10, the **amplitude detector** can be considered. Refer to Figure 14. Since each differentiated edge returns to the reference voltage level from

(a)
Transmitter Input Data



(b)
Amplitude Detector Input Data and Noise

(c)
Receiver Output Data



(d)
Amplitude Detector Implementation

FIGURE 14 — Edge Detector Operation

either polarity of pulse, what is required is an amplitude detector with two thresholds, one above the reference voltage and one below; in essence a Schmitt Trigger function which has hysteresis and whose threshold is dependent on the output state. Looking at the next block of Figure 10 and noting that it must generate a logic interface, in this case a TTL interface, it can be seen that both blocks can be accomplished by using a comparator or line receiver with positive feedback as the amplitude detector. Figure 14 describes the operation and implementation of this amplitude detector with hysteresis. As can be seen, when a positive edge crosses threshold 1, the output switches low and the feedback to the non-inverting input causes threshold 2 to now apply. Since the positive edge decays back to V_{REF}, threshold 2 is not crossed and the output is latched low. The next edge to come along must be negative and when it occurs it crosses threshold 2 causing the output to switch high. Similarly, it latches in this state and reinstates threshold 1.

In order for the hysteresis to be symmetrical about V_{REF}, it must be centered between the limits of the TTL output swing. That is,

$$V_{REF} = \frac{V_{OH} + V_{OL}}{2} \tag{9}$$

Referring to Figure 14(d), the hysteresis is determined by:

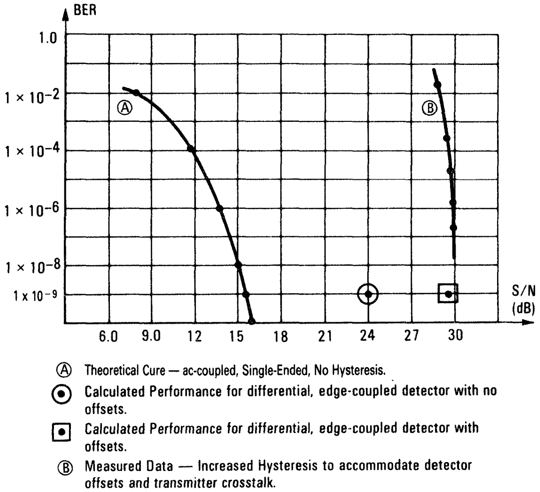
$$H = (V_{OH} - V_{OL})\left(\frac{R2}{R2 + R3}\right) \tag{10}$$

R1 is made equal to R2 so as not to introduce voltage offsets due to the input current of the amplitude detector. In practice, R1 and R2 should be made fairly low values so that the actual input voltages do not have a step between the two states due to the voltage drop of these resistors and the amplitude detector input current. Because they are low values, 100–500 Ω is typical, R1 also becomes the load of the differentiator.

As can be seen from Figure 14(b), the hysteresis must be made greater than the peak-to-peak noise riding on the data stream. The amplitude detector used in this 20-Mbaud system is similar to this but is driven differentially. To afford a better understanding of why this type of amplitude detector was chosen, a discussion of different amplitude detector implementations and their relative merits follow.

Amplitude Detector Coupling and Required S/N

Just how much larger than the noise the hysteresis must be depends on the probability of error one is willing to accept. That probability, or Bit Error Rate performance, directly relates to the required signal-to-noise ratio. These two parameters of BER and S/N have been related by Curve A shown in Figure 15. This curve is derived by evaluating the error function for a normal distribution which defines the probability of a noise pulse being some factor, N, times the rms noise level for various values of N. However, this curve is only applicable to amplitude detector performance if certain assumptions are made. The first is that the amplitude detector threshold or decision level is always midway between the two extremes of the data stream level. The second assumption is either that during the absence of data it is acceptable for noise crossing threshold to cause output transitions or else that data is never absent. The third is that there is no hysteresis around the threshold. The expected waveforms are shown in Figure 16(a).



Ⓐ Theoretical Cure — ac-coupled, Single-Ended, No Hysteresis.

⊙ Calculated Performance for differential, edge-coupled detector with no offsets.

▣ Calculated Performance for differential, edge-coupled detector with offsets.

Ⓑ Measured Data — Increased Hysteresis to accommodate detector offsets and transmitter crosstalk.

FIGURE 15 — BER versus S/N Performance

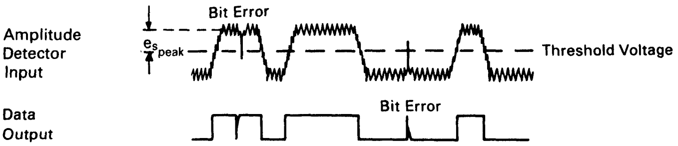
This S/N versus BER curve and the waveforms of Figure 16(a) apply to both ac-coupled as well as dc-coupled systems as long as the above assumptions prevail. However, because of the difficulty of controlling the amplified thermal drifts in a dc-coupled system, ac coupling is usually used in an optical data transmission system. Therefore dc-coupled systems will not be considered here.

Referring to Figure 16(a), as long as the waveform is above threshold the data bit is labeled a "logic 1" and if the waveform is below threshold, the data bit is labeled a "logic 0." As long as data is always present, that is idle channel condition is marked with a flag, a squarewave or some other recognizable pattern, the only time an error will occur is when a noise pulse is large enough to reach threshold. Looking at Figure 16(a) it can be seen that when the noise peak equals or exceeds the threshold voltage, a bit error is made. The amplitude to which noise peaks will rise only once in 1×10^{-9} attempts is 6.15 times the rms noise amplitude. Therefore, the required peak signal amplitude for a 1×10^{-9} BER is 6.15 times the rms noise. If the signal is any smaller than that, a noise pulse riding on the data which is large enough to cross threshold and cause a bit error will occur more often and the BER will be less than 1×10^{-9}. Expressing this in more conventional terms then, the required S/N ratio for a 1×10^{-9} BER is:

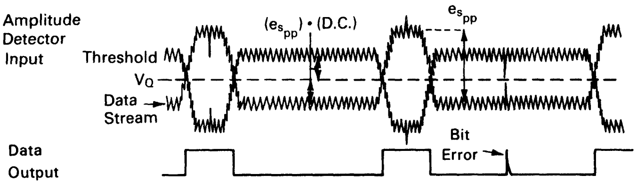
$$S/N = 20 \log \left(\frac{e_{s_{peak}}}{e_{n_{rms}}}\right) = 20 \log \left(\frac{6.15\, e_{n_{rms}}}{e_{n_{rms}}}\right)$$

$$S/N = 15.8 \text{ dB}$$

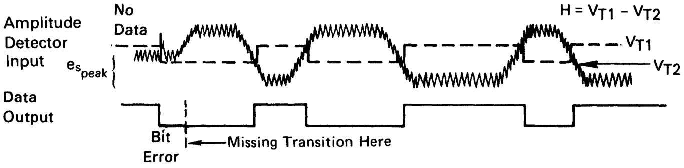
This can be seen to lie on Curve A in Figure 15. This S/N is not a true power ratio but merely 20 times the log of a ratio of a peak voltage to an rms voltage.



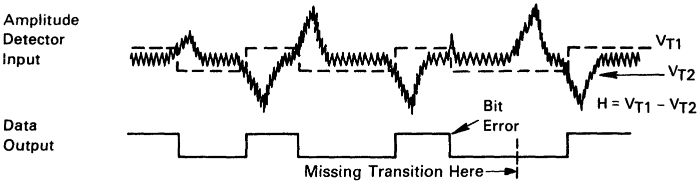
(a)
Single-Ended ac-Coupled Data and Noise with Fixed Threshold at 50% Level



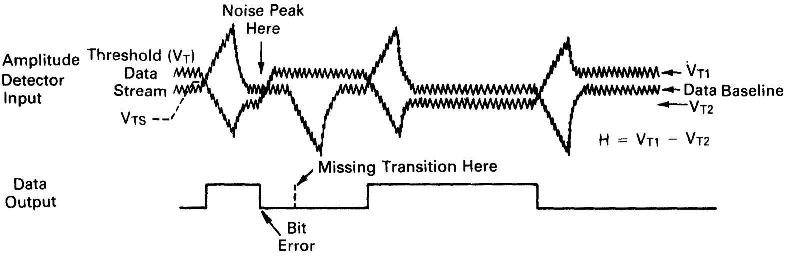
(b)
Differential ac-Coupled Data and Noise



(c)
Single-Ended ac-Coupled Data and Noise with Threshold Hystersis (H) around 50% Level



(d)
Single-Ended Edge-Coupled Data and Noise with Threshold Hysteresis (H)



(e)
Differential Edge-Coupled Data and Noise

FIGURE 16

However, by convention these units are called dBs of signal-to-noise.

If the data in Figure 16(a) drives the detector differentially, then the waveforms of Figure 16(b) apply. Here, rather than comparing data to a fixed noise free threshold centered between the voltage extremes of the data stream, the data is compared to a threshold voltage which is different for a logic one bit than it is for a logic zero bit. This threshold is the data stream inverted. That is, it is data plus noise which is equal in amplitude to the data stream data plus noise, but opposite in phase. Since both the data stream and the threshold are capacitively coupled, their base lines float to maintain an average value of zero. Thus, referring to Figure 16(b), the data stream and threshold levels are separated from each other by a voltage difference which is a function of the incoming duty cycle (D.C.). The amplitude of noise this system can tolerate without making bit errors is, therefore, a function of duty cycle. This means the peak signal to rms noise required by this system to insure a 1×10^{-9} BER is also a function of duty cycle.

Looking at Figure 16(b) it can be seen that the data stream is in a logic one state for a small percentage of the time and in a logic zero state the rest of the time. This represents a low duty cycle pulse train. As the duty cycle is increased so that the data stream remains in a logic one state for a longer percentage of the time, the entire data stream waveform will float downward, so that the logic zero voltage level will move farther from and the logic one voltage level will move closer to the quiescent bias level V_Q. As this happens the threshold waveform on the other hand will remain in the logic zero state for the same increased percentage of time and the waveform will move upward a corresponding amount. Thus, the two waveforms will be close to one another and noise immunity will be relatively low for large duty cycles as well as for low duty cycles and their separation from each other and the noise immunity will be maximized when the duty cycle is 50%.

Thus, the promimity of the threshold and data stream waveforms depends on the limit of incoming duty cycle furthest from 50%. If this limit is less than 50%, the value of D.C. to be used in equation (11) is equal to the decimal equivalent of the duty cycle itself. If the limit of duty cycle is greater than 50%, then the value of D.C. is the decimal equivalent of 100% minus the duty cycle.

That is

$$(e_{s_{p\text{-}p}}) \cdot (\text{D.C.}) = 6.15(e_{n_{rms}})$$

$$2(e_{s_{peak}}) = \frac{6.15\,(e_{n_{rms}})}{\text{D.C.}} \qquad (11)$$

$$(e_{s_{peak}}) = \frac{6.15\,(e_{n_{rms}})}{2(\text{D.C.})}$$

for a square wave or 50% duty cycle,

$$e_{s_{peak}} = 6.15\,(e_{n_{rms}})$$

or $\quad S/N = 15.8\text{ dB}$

For a 20% to 70% variation in duty cycle, the limit is 20% and the value of D.C. is 0.2.

$$e_{s_{peak}} = \frac{6.15\,(e_{n_{rms}})}{2(.2)}$$

or $\quad S/N = 20\log\left[\dfrac{e_{s_{peak}}}{e_{n_{rms}}}\right]$

$$S/N = 23.7\text{ dB}$$

For a 30% to 80% variation in duty cycle, the limit is 80% and the value of D.C. is 1.00 -0.8 = 0.2.
Hence,

$$e_{s_{peak}} = \frac{6.15\,(e_{n_{rms}})}{2(.2)}$$

and $\quad S/N = 20\log\left[\dfrac{e_{s_{peak}}}{e_{n_{rms}}}\right]$

$$S/N = 23.7\text{ dB}$$

for the general case and a 1×10^{-9} BER requirement,

$$S/N = 20\log\left[\frac{6.15}{2(\text{D.C.})}\right] = 20\log\left[\frac{(6.15)(.5)}{(\text{D.C.})}\right]$$

$$S/N = 15.8\text{ dB} + 20\log\left(\frac{.5}{\text{D.C.}}\right) \qquad (12)$$

where D.C. is always $\leqslant 0.5$.

The added benefit of differential drive is the common mode rejection of extraneous signals being radiated or conducted into the amplitude detector inputs.

The idle channel pattern is not always a continuation of constant amplitude transitions. In some cases it is a continuous logic state and in such cases idle channel noise can be rejected by hystersis in the amplitude detector. Such is the case in Figure 16(c). In this case the data stream is compared to a threshold which is different for a logic one output than it is for a logic zero output. This threshold is not generated by inverting the data stream. It is generated by feeding back a portion of the output data signal to the non-inverting input of the amplitude detector. Since the threshold is not a linear function of the input data stream, there is no noise riding on it. The difference in threshold voltage for the two states is called the hysteresis. The hysteresis must be wide enough to reject all noise spikes of amplitudes which occur more often than once in 10^9 when no data is present. That is to maintain a BER of 1×10^{-9},

$$H \geqslant 2\,e_{n_{peak}} \text{ or } 2\,(6.15\,e_{n_{rms}})$$

Once this condition is satisfied a detection will occur every time the peak signal plus noise exceeds one-half the hysteresis. However, if this is all that is required, there will be much greater edge ambiguity or jitter in this system than in the previous ones because of the increased proximity between the noise and the amplitude detector threshold. Therefore, in order for this edge jitter to be no worse than before, the peak signal must exceed the threshold by the same amount as it did before or,

$$e_{s_{peak}} = \tfrac{1}{2} H + e_{n_{peak}}$$
$$e_{s_{peak}} = 6.15 e_{n_{rms}} + 6.15\ e_{n_{rms}}$$
$$e_{s_{peak}} = 12.3 e_{n_{rms}}$$

In other words, imposing the condition of idle channel noise rejection has caused a degradation in system sensitivity for the same BER performance. The signal-to-noise ratio required for this idle channel noise rejection is,

$$S/N = 20 \log \left(\frac{e_{s_{peak}}}{e_{n_{rms}}}\right) = 20 \log \left(\frac{12.3\ e_{n_{rms}}}{e_{n_{rms}}}\right)$$

$$S/N = 21.8 \text{ dB}$$

This system is 6.0 dB less sensitive than those previously discussed. Its benefit is freedom from data format constraints such as the maximum length of a string of ones or zeroes or having to present an appropriate idle channel pattern for noise rejection.

The effect of edge coupling or differentiation rather than ac coupling can be examined by referring to Figure 16(d). The first thing to be noticed is that the data is compared to the same type of threshold as in the previous case; that is a two state threshold generated by feedback from the amplitude detector output to non-inverting input. The difference between these two thresholds is the hysteresis H. Referring to Figure 16(d), it will be noticed that after the edge or transition is coupled through to the detector, the differentiation network immediately begins to discharge according to its time constant. This forces the amplitude detector input to return to its base line level midway between the two threshold levels during every bit cell. Because of this, the hysteresis H must once again be greater than the peak to peak noise level for the required probability of error regardless of the idle channel condition. Otherwise noise would toggle the detector during almost every bit interval after the network discharge was complete. Since this system should have no more jitter than the others, the signal should exceed threshold by the same amount as before or $e_{n_{peak}}$. Thus the required signal level at the amplitude detector input is

$$e_{s_{peak}} = \frac{H}{2} + e_{n_{peak}} = 6.15\ e_{n_{rms}} + 6.15\ e_{n_{rms}}$$
$$e_{s_{peak}} = 12.3\ e_{n_{rms}}$$

Since this is after the differentiation, the effect of the differentiator on the signal to noise ratio must be taken into account in order to compare sensitivities at the same point in the circuit. It has been experimentally determined that the loss of the differentiator is 8.2 dB for the rms noise. When measuring the differentiators loss to the signal, it must be remembered that the differentiators peak output transition is the response to the peak to peak input transition. The amplitudes of those two transitions have been compared and it has been determined that the input was 10.4 dB larger than the output. Therefore, the S/N has been degraded by 10.4 dB less 8.2 dB or 2.2 dB. Therefore, the required S/N ratio into the differentiator for a BER of 1×10^{-9} is

$$S/N = 2.2 \text{ dB} + 20 \log \left(\frac{e_{s_{peak}}}{e_{n_{rms}}}\right) = 2.2 \text{ dB} + 20 \log (12.3)$$

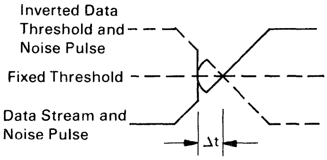
$$S/N = 24.0 \text{ dB}$$

This relatively high signal to noise requirement is 8.2 dB higher than the originally proposed approach of Figure 16(a) but this loss of sensitivity buys the freedom from idle channel noise and simplicity of no base line variation with duty cycle.

Finally, the edge coupled system differentially driven will be examined. Refer to Figure 16(e). Once again as in the case described in Figure 16(b), the threshold for this differentially driven edge coupled case is generated by inverting the incoming data stream plus noise. However, unique to this case, is the fact that there is hysteresis in the threshold as well. This hysteresis limits the levels to which the threshold can decay after the inverted data edges couple through the differentiator network. This hysteresis, H, is the difference between the two threshold levels, V_{T1} and V_{T2}. These levels can be seen clearly in Figure 16(e) only if the data edges are separated in time long enough to allow the RC differentiators to discharge completely. The noise on these threshold levels can also be noticed. Assuming the data base line is centered between V_{T1} and V_{T2}, the hysteresis must be

$$H = 2\,(e_{n_{peak}} + e_{n_{peak}}) = 4\ e_{n_{peak}}$$

to insure that noise doesn't toggle the output. As can be seen from the inset below, a noise pulse riding on the data stream will cause the same ambiguity in zero crossing (i.e. Δt) whether the threshold is fixed or is inverted data plus noise.



In order to keep edge jitter the same in this system as it was in previous systems then, the peak signal must exceed threshold by the same amount or $e_{n_{peak}}$. Therefore referring to Figure 16(e) the peak signal required is

$$e_{s_{peak}} = V_{TS} + e_{n_{peak}}$$

where V_{TS} is the threshold at the time of switching.

However, the threshold doesn't remain at V_{T1} but starts moving in opposite phase with the data edge with the same rise time as the data edge. Because of this, the data edge and threshold edge will cross each other and thereby cause an output transition when they have traversed equal voltage increments. Since the data stream baseline is assumed to be centered between V_{T1} and V_{T2}, this crossover will occur halfway between V_{T1} and the baseline and so the actual threshold voltage level will be V_{T1} or 1/2 H less 1/4 (H). That is

$$V_{TS} = (\tfrac{1}{2}H - \tfrac{1}{4}H) = \tfrac{1}{4}H$$

therefore $$e_{s_{peak}} = \tfrac{1}{4}H + e_{n_{peak}}$$

$$e_{s_{peak}} = e_{n_{peak}} + e_{n_{peak}}$$

$$e_{s_{peak}} = 2\, e_{n_{peak}}$$

and for a BER = 1×10^{-9}

$$S/N = 20 \log \left(\frac{e_{s_{peak}}}{e_{n_{rms}}}\right) = 20 \log\ 2\left(\frac{6.15\, e_{n_{rms}}}{e_{n_{rms}}}\right)$$

$$S/N = 21.8 \text{ dB}$$

Once again this is out of the differentiator and to translate it to the differentiator input an additional degradation in S/N of 2.2 dB must be taken into account. Therefore for the differentially driven edge coupled detector the S/N ratio required for a 1 × 10^{-9} BER is

$$S/N = 21.8 \text{ dB} + 2.2 \text{ dB}$$
$$S/N = 24.0 \text{ dB}$$

Table I below summarizes the pros and cons of these amplitude detector approaches.

It can be seen looking at Table I that the differentially driven edge coupled detector accommodates the most variation in data format and idle channel signalling. In addition it provides common mode rejection of extraneous signals thereby providing better performance under full duplex conditions. For these reasons it was chosen as the detector for this receiver which needed such flexibility. The price for this versatility is about 8.2 dB in S/N sensitivity. Certainly this is not insignificant and if the data format and idle channel signalling in a particular application permitted, the system designer would do well to consider the ac coupled approaches.

One practical factor not considered here is that the amplitude detector device itself will have input offset specifications which vary from unit to unit. This means that in all of the amplitude detectors described, a certain amount of additional signal will be required to insure that threshold is always crossed regardless of the offset for a particular unit. For the device used here, the MC75107, a potential difference of 25 mV or greater between inputs must exist to guarantee states. This directly affects the required hysteresis. The two amplitude detector inputs which are separated by H/2 volts must now be separated by 2 $e_{n_{peak}}$ + 25 mV rather than by 2 $e_{n_{peak}}$ in the previous comparison. Similarly, the peak signal must now exceed the reference level, V_T, by 2 $e_{n_{peak}}$ + 25 mV.

That is: $$e_{s_{peak}} = V_T + (2\, e_{n_{peak}} + 25 \text{ mV})$$

and $$V_T = \tfrac{1}{2}H - e_{s_{peak}}$$

Therefore $$e_{s_{peak}} = 2e_{n_{peak}} + 25 \text{ mV}$$

for a BER of 1 × 10^{-9}

$$e_{s_{peak}} = 12.3e_{n_{rms}} + 25 \text{ mV}$$

The value of $e_{n_{rms}}$ was experimentally determined to be 2.4 mV rms. Since 25 mV is 10.4 times the 2.4 mV rms measured at the detector input,

$$e_{s_{peak}} = 12.3\, e_{n_{rms}} + 10.4\, e_{n_{rms}}$$

$$e_{s_{peak}} = 22.7\, e_{n_{rms}}$$

$$20 \log \left(\frac{e_{s_{peak}}}{e_{n_{rms}}}\right) = 27.1 \text{ dB}$$

Taking into account the 2.2 dB degradation in S/N due to the differentiator, the required S/N is

$$S/N = 27.1 \text{ dB} + 2.2 \text{ dB}$$
$$S/N = 29.3 \text{ dB}$$

to accommodate all MC75107 detector chips. This point is also plotted on Figure 15.

The remaining function in the block diagram of

TABLE I

DETECTOR APPROACH	S/N SENSITIVITY FOR 1X10^{-9} BER	ADVANTAGES	DISADVANTAGES
Single Ended ac Coupled. No hysteresis	15.8 dB	Maximum sensitivity.	Requires continuous idle channel pattern and duty cycle limits to reject noise as well as a reference voltage that tracks data base line. No common mode rejection.
Differential ac Coupled	* 15.8 dB $+ 20 \log \left(\frac{0.5}{D.C.}\right)$	No base line tracking required. Common mode rejection.	Requires continuous idle channel pattern and duty cycle limits to reject noise. Sacrifice in sensitivity dependent on duty cycle limits.
Single Ended ac Coupled with hysteresis	21.8 dB	Doesn't require continuous idle pattern and duty cycle limits for noise rejection.	Sacrifices 6 dB in sensitivity. Requires threshold which tracks data stream base line. No common mode rejection.
Single Ended Edge Coupled with hysteresis	24.0 dB	Doesn't require idle channel pattern or duty cycle limits to reject noise. Doesn't require tracking reference voltage.	Sacrifices 8.2 dB in sensitivity. No common mode rejection.
Differential Edge Coupled with hysteresis	24.0 dB	Doesn't require idle channel pattern or duty cycle limits. Doesn't require tracking reference voltage. Offers common mode rejection.	Sacrifices 8.2 dB in sensitivity.

*See text for definition of D.C.

Figure 10 is the **logic interface**. Its purpose is to generate a standard logic level and provide sufficient drive capability for simple interfacing. The TTL logic level in this receiver is actually generated by the amplitude detector. However, in order to buffer the amplitude detector's output, another line receiver section is used for isolation and the interface to the TTL world. In addition, an emitter follower provides the needed drive for a 75 Ω coaxial line to the external test equipment.

Receiver Schematic Diagram and Circuit Implementation

Figure 17 shows the receiver schematic and indicates which portions perform each of the functions outlined in the functional block diagram description.

The first active component in the receiver schematic is the MFOD402F integrated detector preamp (IDP). It performs both the **optical detector** and **current to voltage converter** functions described earlier. It also affords all the isolation advantages of the integrated structure that were outlined in a previous section. Its transfer function is typically 1.0 mV of output amplitude per μW of optical input power. Output impedance is specified as 200 Ω typical and although its maximum real and reactive loads are also specified, it was found that these loads caused excessive ringing of the IDP output. Therefore, in this circuit, the real load was kept above 500 Ω and the capacitive load was minimized by careful printed circuit layout. The output rise time of the MFOD402F is specified as typically 20 ns and that is about what appears at the output of the linear amplifier where the signal is sufficiently large in amplitude to measure. The supply voltage of +15 V was chosen so that operation on the flat portion of the IDP's $\frac{\Delta t_R}{\Delta V_{CC}}$ curve was guaranteed. Below 10 V, the IDP's rise time begins to degrade rapidly.

The shield over the optical connector and IDP is required for isolation from the receivers own TTL output and the crosstalk of the transmitter. Its contribution to performance may only be measurable in terms of improved bit error rate.

The noise out of the IDP is specified as 300 μV rms typical, and is a good number to use in calculating the amplitude detector hysteresis required.

Linear Amplifier

The MC1733 was chosen as the linear amplifier primarily because of its wide gain bandwidth and its reasonably low noise. It was used at a gain of 100 because that provides sufficient gain to amplify the IDP noise up to minimum amplitude detector threshold, as will be seen later, and it also allows the simple strapping of Pins 3 and 12 together using a

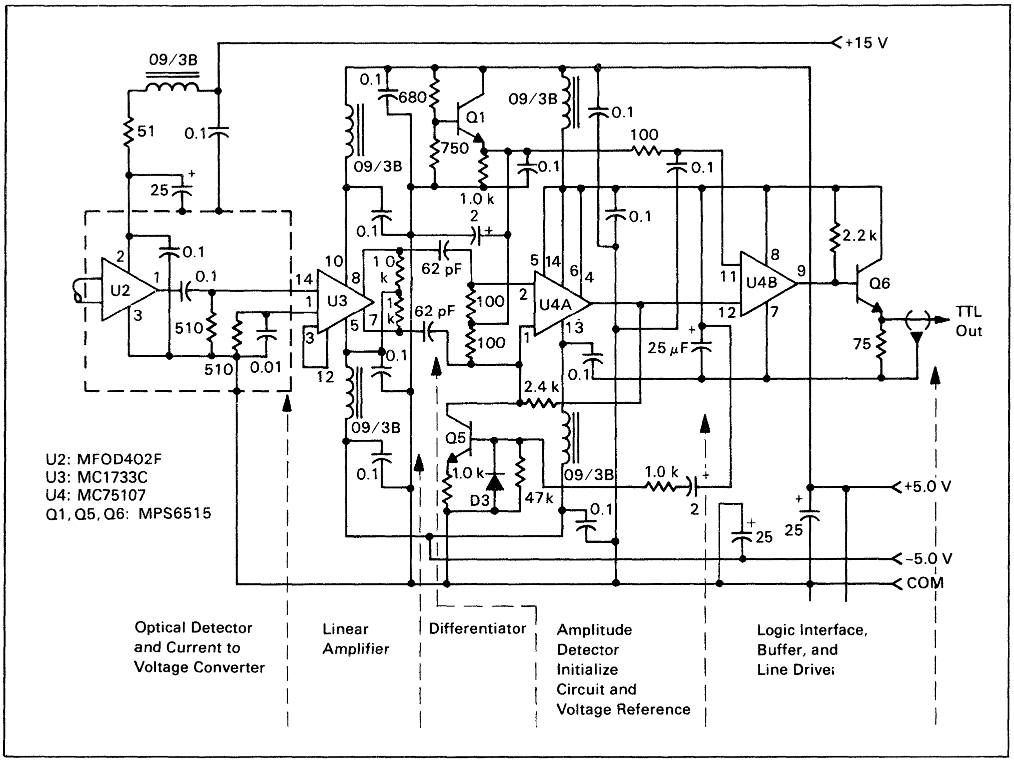


FIGURE 17 — Receiver Schematic

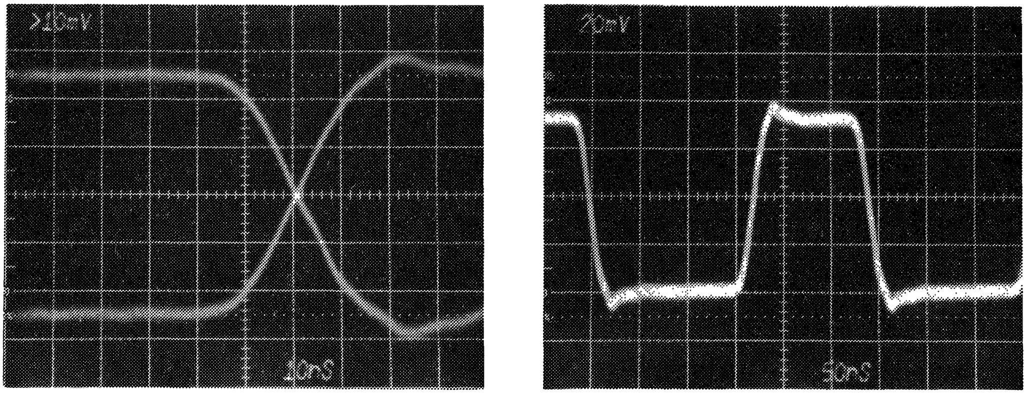
foil runner beneath the chip itself. This proved simpler than bringing Pins 4 and 11 out around the chip and tying them together with an external gain setting resistor. Pins 4 and 11 are the emitters of the input differential amplifier and proved very susceptible to the injection of noise and positive feedback from the TTL output.

Output Pins 7 and 8 provide the data stream waveforms which are the vital signs of the system. They provide information about the system signal to noise ratio, the system rise and fall time, and an indication of received signal level. See Figure 18. With the MC1733 strapped for a differential gain of 100, each output will deliver a single ended signal 50 times larger than the IDP output.

With this gain strapping on the MC1733, the rise time out of this amplifier is typically 10 ns when driven from a fast pulse generator. The input bias resistors were chosen to be as low as the IDP could drive so as to enhance gain stability of the MC1733.

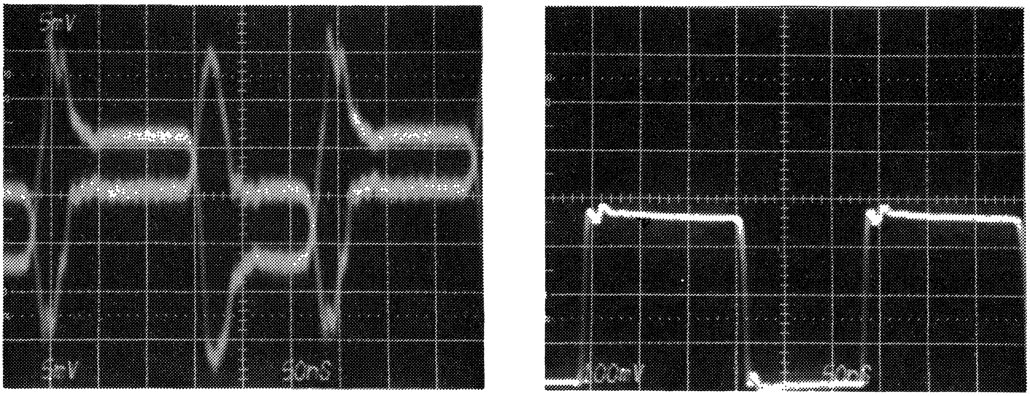
The **differentiators** consist of the 62 pF capacitors and the 100 Ω resistors for the amplitude detector's input bias. Since the output of the MC1733 is taken differentially, there are two such networks required. The impedance of these networks was made low so as to minimize the voltage step at the detector input pins caused by the drop across the 100 Ω resistors. This step results from the change in base current of the amplitude detector between the ON and OFF states. Specified as a total worst case base current change of 80 μA, the 100 Ω differentiator will cause an 8.0 mV step at Pin 2 of the amplitude detector and a subtracting of 8.0 mV from the hysteresis at Pin 1 of the amplitude detector. Another reason to keep the differentiator impedance low is to prevent instrument loading. A 10X scope probe, for example, will load a 1000 Ω differentiator enough so as to make time constant measurements meaningless and waveform analysis unreliable.

As mentioned earlier, in equation (8), the differenti-



(a)
System Rise and Fall Time at Pin 8 of MC1733

(b)
System S/N at Pin 8 of MC1733 for a BER of $<1 \times 10^{-9}$



(c)
Typical Waveforms at Amplitude Detector Inputs
Pins 1 and 2 of MC75107

(d)
Amplitude Detector Output

FIGURE 18 — Receiver Waveforms

ator time constant is controlled by the minimum bit time and the system rise time. From equation (8)

$$4R_L C_{max} = T - t_{R_{SYS}}$$

where T is the minimum bit time and $t_{R_{SYS}}$ is the system rise time. Assuming for now that the system rise time, that which is measured at the MC1733 output is 30 ns worst case, the maximum RC time constant consistent with a 20 Mbaud bit cell is

$$R_L C_{max} = \frac{T - t_{R_{SYS}}}{4} = \frac{50\ \text{ns} - 30\ \text{ns}}{4}$$

$$R_L C_{max} = 5.0\ \text{ns}$$

The values used are 62 pF and 100 Ω giving a time constant of 6.2 ns. This hedging by 1.2 ns means that the required transition height from the MC1733 will have to be slightly higher to be detected for transitions spaced 50 ns apart than they will be if spaced by 55 ns or greater.

The MC75107 line receiver is the **amplitude detector** and Q1 and Q5 perform the voltage reference and initialize functions, respectively. The amplitude detector is basically a high speed comparator with positive feedback to perform a Schmitt Trigger function. Its output swing is 0.1 to 3.6 Vdc, limited by the active pullup. With that output swing the hysteresis is 130 mV. With this output swing, the optimum reference voltage is using equation (9)

$$V_{REF} = \frac{V_{OH} + V_{OL}}{2} = \frac{3.6\ \text{V} + 0.1\ \text{V}}{2}$$

$$V_{REF} = +\ 1.85\ \text{V}$$

As was mentioned previously, the 100 Ω input bias resistors were that low to minimize the voltage step at the amplitude detector inputs when the output changed state. Similarly, to reduce the step in reference voltage when the output switches, the current in the reference transistor, Q1, has been set to 4.0 mA and its base to ground impedance (r_b) has been lowered to about 360 Ω. This makes the voltage reference output impedance approximately

$$R_O = r_e + \frac{r_b}{H_{FE}} \quad \text{or} \quad \frac{26\ \Omega\text{ - mA}}{4.0\ \text{mA}} + \frac{360\ \Omega}{150}$$

$$R_O = 8.9\ \Omega$$

To evaluate the step change in reference voltage when the data output changes states, the amount of current that the voltage reference, Q1, must source and sink must first be found.

$$I_{SOURCE} = \frac{V_{REF} - V_{OL}}{R_H} = \frac{1.85 - 0.1}{2.5\ \text{k}} = 0.7\ \text{mA}$$

where R_H is the sum of the feedback resistor and bias resistor for the amplitude detector. From Figure 21, $R_H = R_{11} + R_{10} = 2.4\ \text{k} + 100\ \Omega = 2.5\ \text{k}$. Similiarly,

$$I_{SINK} = \frac{V_{OH} - V_{REF}}{R_H} = \frac{3.6 - 1.85}{2.5\ \text{k}} = 0.7\ \text{mA}$$

Thus, the total change in reference current between logic states is 1.4 mA. With $R_O = 8.9\ \Omega$, the step in V_{REF} = 12.5 mV. This step is almost completely a common mode signal which is about 0.6% of V_{REF} and thus insignificant. The voltage divider formed by the 2.4 k hystersis resistor and the 100 Ω bias resistor does introduce a differential signal of 1/25 of this step in reference voltage. Therefore, the differential signal at the amplitude detector input resulting from this 12.5 mV step in V_{REF} is only 0.5 mV. Refer to Figure 18 for typical waveforms at the amplitude detector input and output.

The sensitivity specification on the MC75107 is ±25 mV over temperature and unit to unit variations. It will be noted from Figure 18(c) that the hysteresis must be large enough so as to keep the voltage difference between the data base line and the threshold always greater than 25 mV, including the noise peaks, except during transitions. When the absolute difference between these two inputs to the MC75107 falls below 25 mV, the output state is not defined and thus errors can be made. Consequently, the hystersis was empirically set to 130 mV to insure this 25 mV separation between inputs at all points on the waveform. Only when this is accomplished does the BER approach 1×10^{-9} or less as was discussed in the section on amplitude detectors.

The **initializing circuit**, Q5, which does not appear on the simplified block diagram of Figure 10, merely injects a pulse of approximately 250 μs in duration into the amplitude detector during power up to insure that the output always turns on to the low state in the absense of optical transitions. By pulling down on the positive input of the amplitude detector a logic high at Pin 4 of the MC75107 is inhibited. After the discharge of C16, the leakage current and depletion capacity of the Q5 collector base junction are inconsequential to the performance of the circuit.

The **logic interface, buffer,** and **line driver** have been implemented using the other section of the MC75107 and Q6. The MC75107 section regenerates the TTL level already at Pin 4 but isolates the positive feedback from the external loading conditions. Q6 provides the additional drive required to the 75 Ω cable used in the test set up. At 20 Mbaud, the shielding of this lead is essential. Since the error detector used provided a 75 Ω coaxial interface, RG-59 cable was selected.

Receiver Performance

Figure 18, once again, shows the typical waveforms one should expect at key points in the receiver, as well as system rise time and the S/N ratio required for good BER performance.

Figure 15, Curve B, shows the typical BER versus S/N at the differentiator input. Curve B represents performance that can be expected when amplitude detector input offsets and transmitter crosstalk are accounted for. Figure 19 relates S/N to optical input power for this 20 Mbaud receiver. This curve was generated by measuring S/N and then calculating backwards from the measured signal level out of the MC1733 amplifier through the receiver gain of 50 mV/μW.

The dynamic range of the receiver is precisely defined as the ratio of the amplitude of the maximum usable signal detected to the amplitude of the minimum usable signal detected. There the precision ends, however, because what is usable in one application is not in another. The minimum usable signal can be picked off of the curve in Figure 19 for whatever S/N is required to achieve the desired BER. The maximum usable signal is where distortion gets to be prohibitive. Duty cycle distortion versus output level of the MC1733 is plotted in Figure 20.

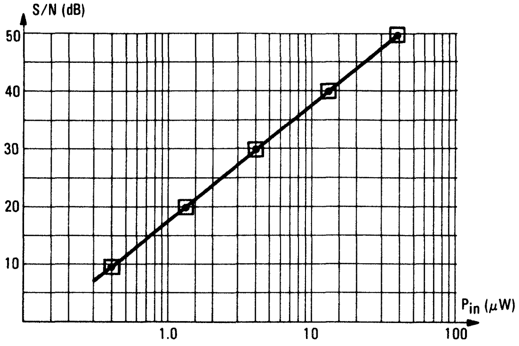


FIGURE 19 — Signal-to-Noise versus Optical Input Power

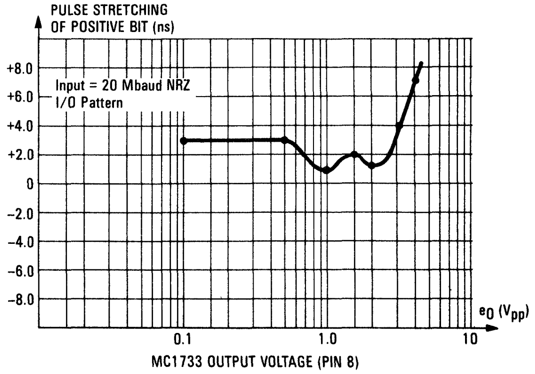


FIGURE 20 — Receiver Overload Characteristic

This curve was measured by simulating high level optical inputs with a pulse generator in place of the IDP and having equivalent output impedance and transition times. The distortion occurs in the MC1733 output before the IDP overloads and thus this is a valid test. The dynamic range can be deduced then by dividing the optical input power needed to cause an intolerable level of distortion, say 5.0 ns, by the optical input power needed to provide the required BER, say 1×10^{-9}, and taking 10 log of the ratio. To find the optical input power that causes overload, refer to Figure 20 and divide the output voltage in mV by 50 mV/μW. To find the optical input power required for a 1×10^{-9} BER, refer to Figure 15, Curve B, and then use that S/N ratio to find optical power required from Figure 19. For this example then, the dynamic range would be

$$\text{Dynamic Range} = 10 \log \left(\frac{70\ \mu W}{4.0\ \mu W}\right)$$

$$\text{Dynamic Range} = 12.4\ \text{dB}$$

Temperature testing indicated that over the 0°C to 70°C temperature range, no significant degradations in performance occurred. Nominal drifts in detector offsets did not cause any significant changes in sensitivity.

BUILDING THE BOARDS

In building the boards, the last components to be inserted should be the optical transducers and mounting bushings. This will reduce their handling and thus the probability of scratching or contaminating the optical ports with particles commonly found in a work bench environment.

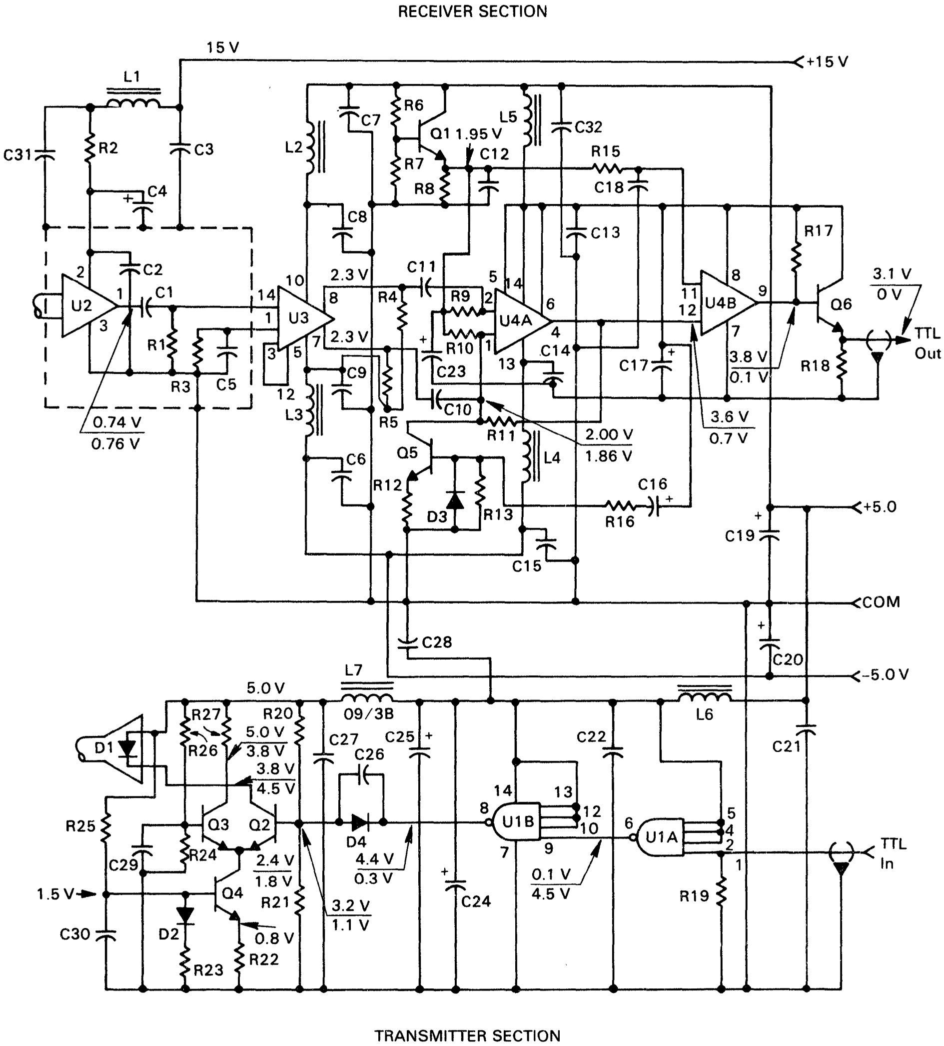
To begin building the boards, refer to the parts list and complete schematic (Figure 21), the component overlay (Figure 22) and the photograph of the completed board (Figure 27). It is recommended that the IC sockets mentioned in the part list be used at least on the first pair of boards to allow looking at system performance versus tolerances in device parameters and to allow for the misfortune of damaging an IC during construction. The decoupling chokes should be available from Ferroxcube. When installing them, care should be taken so as to position them so that the turns protruding from the ends of the ferrite are not shorted together. When ordering electrolytic capacitors to fit the board layout, the approximate dimensions on the parts list should be used as a guide. Where there is ground foil on the component side of the board, care must be used when inserting all components so that no leads are shorted to ground.

It will be noted in the schematic of Figure 21 and in the parts list, that a shield can is specified for shielding the receiver optical transducer. This is to prevent the sensitive receiver input from picking up energy radiating from the receivers TTL output as well as from the transmitter circuitry. The can part number listed must be notched out to fit over the AMP mounting bushing and then sweat soldered down to the ground foil pattern on the component side of the board. Refer to Figure 24 for details of shield preparation. Without the shield, there will probably be more ringing in the waveform at the detector input and the bit error rate will be significantly degraded. To accommodate this shield, capacitor C4 may have to be installed on the solder side of the board depending on the vintage of the actual board used. Before any components are installed, it is recommended that the holes for the BNC connectors first be enlarged to a 0.375 inch diameter and the holes for the +5.0 V, -5.0 V, and ground wires be enlarged to about a 0.070 inch diameter in order to accommodate #18 AWG stranded wire.

After all other components are mounted to the PCB, and before the receiver shield is put on, the FOAC's and their bushings must be assembled.

It will be noted that the FOAC, shown in Figure 23(a), has a flat spot on the circumference of the ferrule and this flat spot affords it a stable position on the PC board. Therefore, when assembling the FOAC and bushing, refer to Figure 23(b), the FOAC is first inserted into the connector so that the flat spot is facing down toward the PC board. Large coupling losses will be encountered if the FOAC is not seated properly in the bushing. To eliminate the uncertainty of whether or not these parts are seated properly, the distance between the back of the FOAC and plane "A" of the bushing, shown in Figure 23(b), can be measured. It should be no greater than 0.130 inches. The plastic retention plate puts sufficient tension on the FOAC's so as to maintain proper seating.

Once the FOAC is properly seated, its leads can be formed to fit the foot print on the PC board. The



Voltage measurement shown: Receiver Section $\frac{\text{Value when optical input is present}}{\text{Value when optical input is not present}}$

Transmitter Section $\frac{\text{Value when TTL input is high}}{\text{Value when TTL input is low}}$

FIGURE 21 — Complete Transceiver Schematic

PARTS LIST

Reference Symbol	Description
	Capacitors
C1, C2, C3, C6, C7, C8, C9, C12, C13, C14, C15, C18, C21, C22, C27, C28, C29, C30, C31, C32	0.1 μF — ≥50 V Ceramic Capacitors, 0.250" lead spacing, Mallory C25C104M101CA
C5	0.01 μF — 50 V Disk Ceramic Capacitors, 0.250" lead spacing, 290" OD, Sprague UK50-103
C10, C11	62 pF 5% Dipped Mica Capacitor
C16, C23	2.0 μF, 25 W Vdc — 0.250" OD × 9/16" long, Sprague TE-1201
C4, C17, C19, C20, C24, C25	25 μF, 25 W Vdc, 0.25" OD × 0.625", Mallory TT25X25B
C26	100 pF 5% Dipped Mica Capacitor
	Diodes
D1	MFOE103F, Infrared LED
D2, D3, D4	1N914, High-Speed Switching Diode
	Chokes
L1, L2, L3, L4, L5, L6, L7	Ferroxcube VK200-09/3B
	Transistors
Q1, Q2, Q3, Q5, Q6	MPS6515 General-Purpose High-Gain NPN Transistor
Q4	2N4400, Low $V_{CE\,(sat)}$ Switching Transistor
	Resistors (1/4 W, 5%, Carbon composition)
R1, R3	510 Ω
R2	51 Ω
R4, R5, R8, R12, R16	1 kΩ
R6	680 Ω
R7	750 Ω
R9, R10	100 Ω
R11	2.4 kΩ
R13	47 kΩ
R17	2.2 kΩ
R15	100 Ω
R18, R19	75 Ω
R20, R25	180 Ω
R21	330 Ω
R22	8.2 Ω
R23	39 Ω
R24	270 Ω
R26	240 Ω
R27	12 Ω
	Integrated Circuits
U1	SN74LS40B, Dual 4-Input Buffered NAND Gate
U2	MFOD402F, Integrated Photodetector Preamp
U3	MC1733, Wide Band Linear Video Amp
U4	MC75107, Dual TTL Line Receiver
	Non-Referenced Items
	3 Low Profile IC Sockets, AMP #530177-1
	1 Shield Can, Hudson Tool & Die Co., #HU5655, 0.734" long, steel
	2 BNC Bulkhead Connectors, UG1094/U Female
	2 Active Device Mounting Kits, AMP Part #227240-1

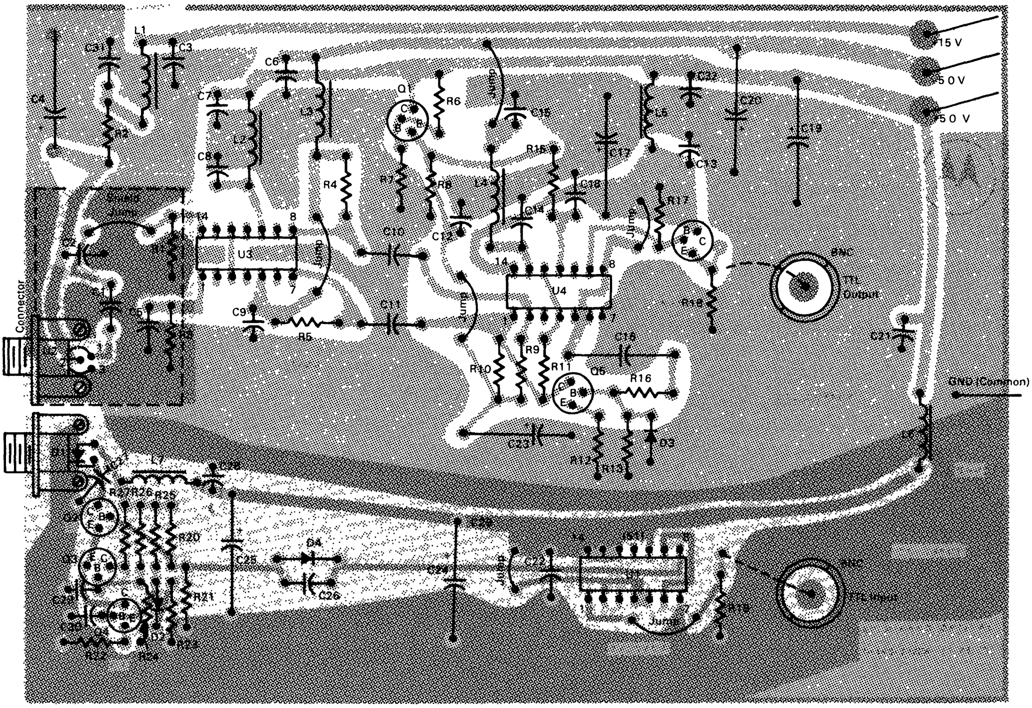


FIGURE 22 — PCB Component Overlay

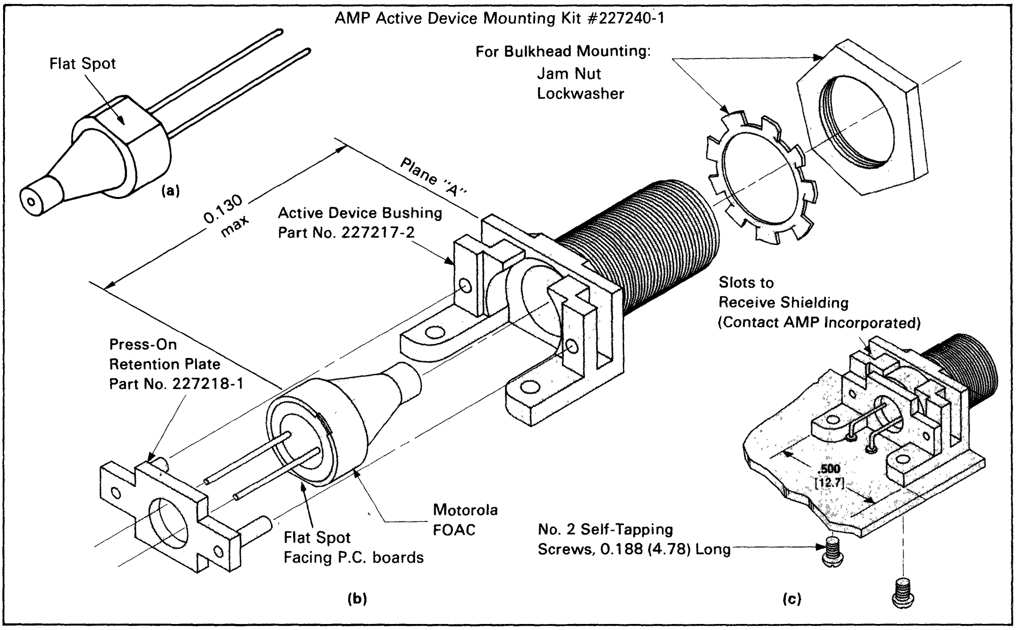


FIGURE 23 — Assembly of the FOAC and Connector

bushing is then fastened down to the PC board using the two self-tapping screws included with it, and the leads appropriately soldered. See Figure 23(c).

The bushing, retention plate, self-tapping screws, lockwasher, and jam nut are available as kit #227240 -1 from AMP, Inc. Additional FOAC's i.e., the MFOE103F and MFOD402F, are available through Motorola distributors.

Once the MFOD402F is mounted in its bushing and the assembly is mounted on the PC board, the shield can be mounted over the receiver front end. The cover specified in the parts list must be notched as shown in Figure 24 in order to fit over the AMP bushing. Once it is notched it can be sweat soldered at the corners to the component side ground foil provided for this purpose.

If more printed circuit boards are required, it should be kept in mind that the PC layout with its bus ground structure and component side shielding is an integral part of the circuit. Any deviation from this layout can be expected to cause changes in isolation between the receiver TTL output and the receiver input as well as between the transmitter and receiver. Figure 30 shows the full size artwork which can be used to make a photomaster in order to duplicate the boards.

The artwork shown is positive with the emulsion side down so that a photo negative of this should provide the proper photomaster. Alignment of the two photomasters can be achieved by drilling through the photomasters and the board at the hole locations for the optical connector mounting screws and the +5.0 V and the -5.0 V power connection pads.

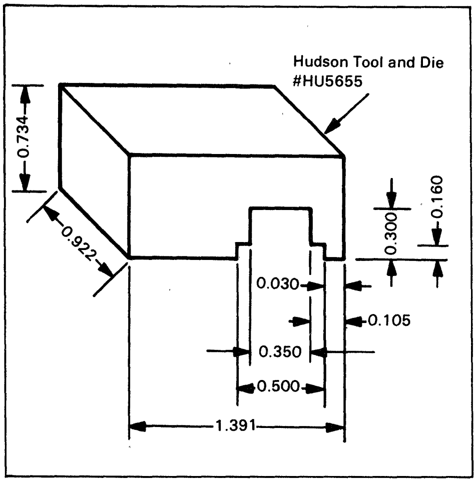


FIGURE 24 — Shield Preparation

TESTING THE BOARDS

To test the completed boards to their full capability, the following equipment is required:

1. One known-good 1 meter fiber of 200 μm core (See Figure 28 for suggested types).
2. Tektronix 475 oscilloscope or equivalent with two 10X, 7.0 pF probes.
3. Two compliments of power supplies each consisting of:
   1-HP 6205 dual power supply, or equivalent, for ± 5.0 V
   1-HP 6218A power supply, or equivalent, for +15 V
4. One Tektronix 6042 DC to 50 MHz current probe, or equivalent
5. One HP 3780A Pattern Generator/Error Detector, or equivalent
6. One E.H. Research Labs Model 139 Pulse Generator, or equivalent
7. One Wavetek Model 142 Function Generator, or equivalent
8. Assorted RG-59 coaxial cables, 1-4 ft. long, and two 75 Ω BNC terminations
9. DC Multimeter General Purpose type 100 kΩ/volt or greater
10. Two system fibers (see section on System Performance)
11. One Photodyne Model 22 XL Optical Power meter, or equivalent

If the two boards in the kit are built correctly, and connected as shown in Figure 25, with appropriate lengths of the system fiber chosen, then a 1×10^{-9} BER or better should be measurable in both directions.

It must be kept in mind that this receiver is sensitive to electrical signal variations at the interface to the electro/optic transducer, regardless of their source. Because of this, the unshielded receiver is sensitive to EMI.

Before any attempt at measuring system performance is made, each module should be given a cursory check by comparing dc voltage levels to those typical dc voltages shown on the schematic in Figure 21.

CAUTION

> An inadvertent short from the LED cathode or Q2 collector to ground will place a momentary 5.0 V of forward bias across the LED and DESTROY IT. Care should be taken in probing this portion of the circuit. Probing the collector of Q3 rather than Q2 will provide an indication of proper switching without the danger of shorting the LED.

If meaningful BER measurements are to be made, either a shielded enclosure for the receiver or a shielded environment such as a screen room will be required. The latter enables lower bit error rates to be measured because it allows the pattern generator/error detector which is also sensitive to EMI and line transients to be shielded as well.

If the above BER performance is not achieved, then some troubleshooting must be done. Each module should be first checked out individually by looping a transmitter back to its own receiver with the known-good 1 meter fiber. The testing sequence listed below can be used.

TROUBLE SHOOTING TEST SEQUENCE

1. Test Module A in loop mode with 1 meter fiber. If data output is good proceed to Step 2. If bad, follow module troubleshooting tree to locate problem and retest.
2. Test Module B in loop mode with 1 meter fiber. If data output is good, proceed to Step 3. If bad, follow module troubleshooting tree to locate problem and then retest.

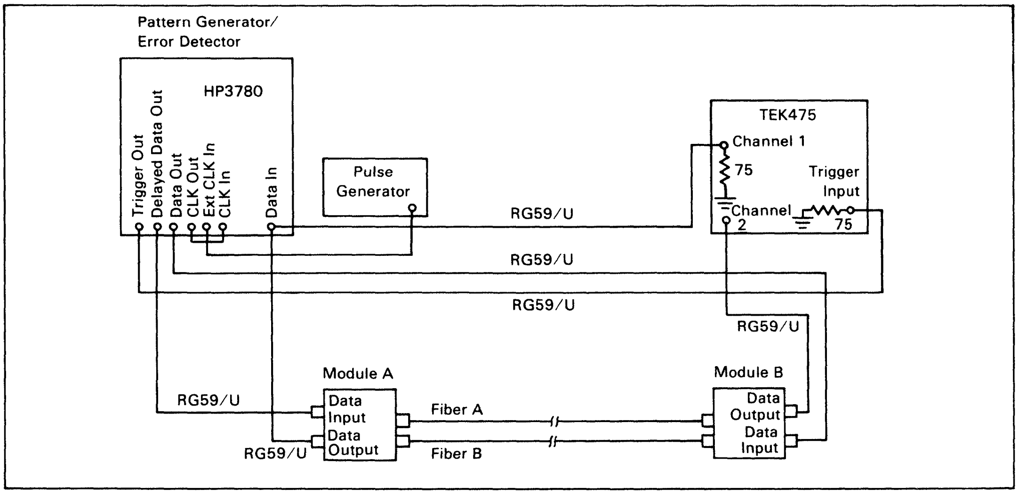


FIGURE 25 — BER Test Setup

3. Test Module A in loop mode with system fiber A. Examine recovered signal at MC1733 Pin 8. Amplitude should be ⩾ 500 mVpp. If not, enter module troubleshooting tree at Box #3.
4. Test Module A in loop mode with system fiber B. Examine recovered signal at MC1733 Pin 8. Amplitude should be ⩾ 500 mVpp. If not, system fiber B exhibits too much loss.
5. Test Module B with system fiber B. Examine recovered signal at MC1733 Pin 8. Amplitude should be ⩾ 500 mVpp. If not, enter module troubleshooting tree at Box #3.
6. With both modules working and both system fibers functioning, retest duplex link in configuration shown in Figure 25.

EXIT POWER TABLE

FIBER CORE DIAMETER	EXIT POWER REQUIRED (Pe)
150 μm	10 μW
200 μm	16 μW
250 μm	25 μW
400 μm	63 μW

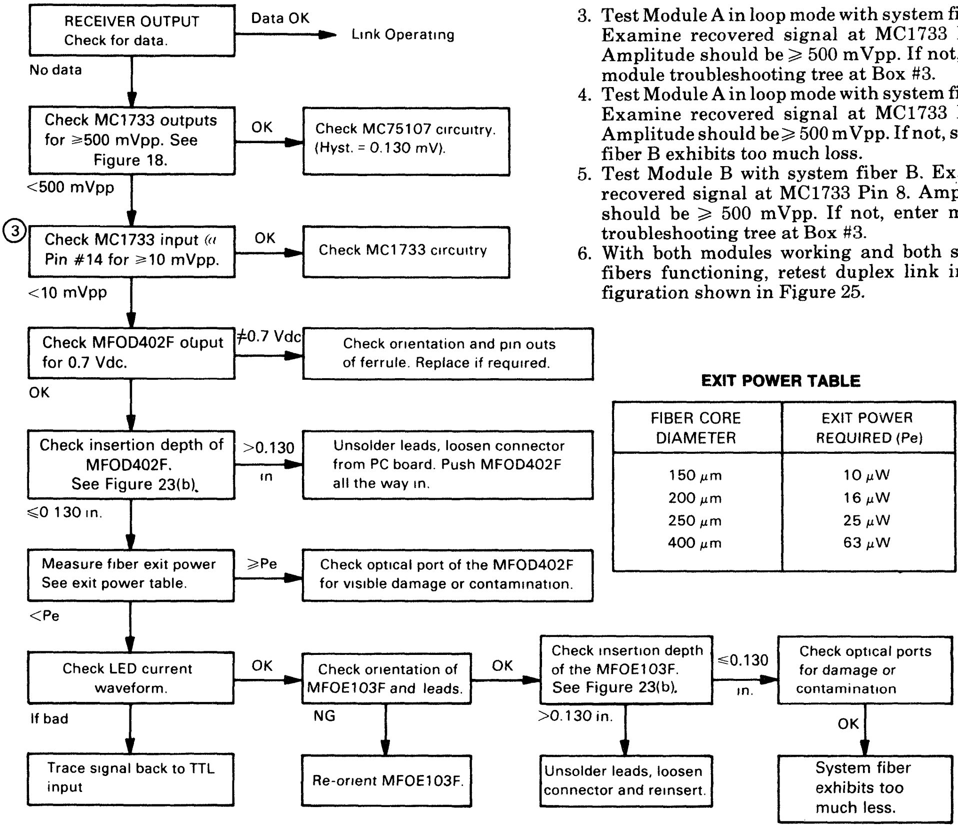


FIGURE 26 — Module Troubleshooting Tree

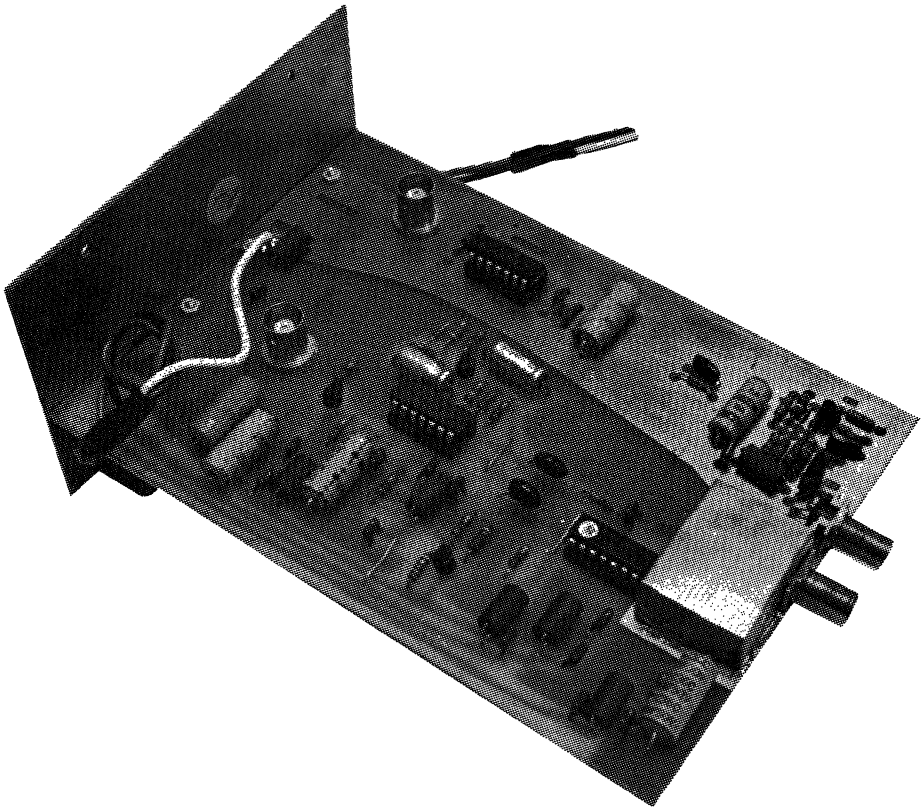


FIGURE 27 — The Completed Transceiver

SYSTEM PERFORMANCE

Before system performance is calculated, the elements of system loss will be reviewed. (Refer to Figure 28.)

L_{CM} is clad mode loss which reflects the portion of the LED's measured output that exits from the clad of the FOAC and is essentially unusable.

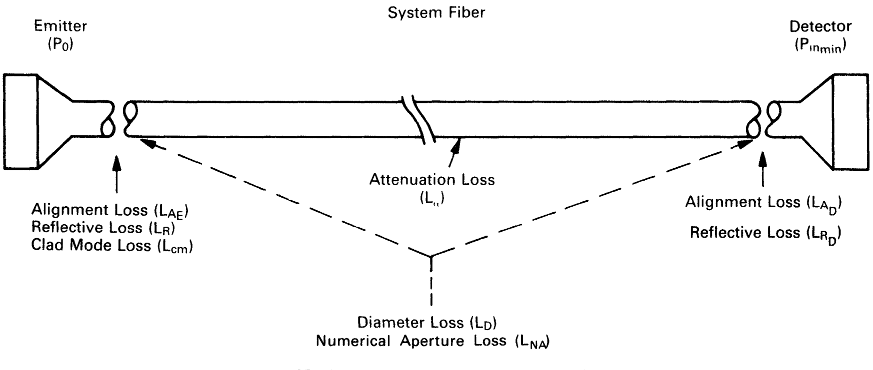


FIGURE 28 — Components of Loss Budget

L_D is the diameter loss which is the portion of light lost when the system fiber has a different core diameter than the 200 μM core of the FOAC.

L_{AE} and L_{AD} are the alignment losses at the emitter and detector respectively due to mechanical tolerances of the connector and ferrule.

L_R is the reflective loss at the interface between two fiber ends.

L_{NA} is the NA loss incurred when the system fiber NA, which is a function of fiber length, is different from the NA of the FOAC.

$L\alpha$ is the signal attenuation loss due to the attenuation of the fiber per unit length.

These loss components will be evaluated in a sample calculation using Maxlight MSC200B fiber.

First, the clad mode loss has been measured experimentally. For very short systems using 200 μM core fibers or systems having fiber core diameters of 250 μM or more, the clad mode loss would be ignored since light exiting the clad of the FOAC would be usable. In most systems, however, this is not the case. Therefore, the power out of the LED must be reduced by 5% which is the amount of the FOAC output that exits from the clad. Therefore, the clad mode loss is given by:

$$L_{CM} = 10 \log \left(\frac{P_{o_{core}}}{P_{o_{total}}}\right) = 10 \log \left(\frac{(0.95\ P_{o_{total}})}{P_{o_{total}}}\right)$$

$$L_{CM} = 0.2 \text{ dB}$$

L_D, or diameter loss, is proportional to the relative cross sectional areas of the system fiber core and the FOAC core. If the system fiber is of a smaller core diameter than the FOAC, the diameter loss will be incurred at the emitter/fiber interface. If the system fiber is of a larger core diameter than the FOAC, the diameter loss will be incurred at the fiber/detector interface. The loss across this type of diameter step is given by:

$$L_D = 10 \log \left(\frac{\text{larger diameter}}{\text{smaller diameter}}\right)^2$$

for MSC200B fiber,

$$L_D = 10 \log \left(\frac{200\ \mu\text{m}}{200\ \mu\text{m}}\right)^2$$

$$L_D = 0.0 \text{ dB}$$

L_A, or alignment loss, is incurred at each interconnect whether that is between two fibers, a fiber and a FOAC, or two FOAC's. It is due to finite tolerances in the mechanical dimensions of the mounting bushing, the ferrule, and the FOAC. These tolerances allow some axial and angular misalignment as well as some longitudinal tip to tip separation between the fiber and the FOAC. Measurements indicate that this loss component is typically 2 dB at the emitter/fiber interface and 1 dB at the detector/fiber interface. The reason it is less at the receive end is that the cone of light exiting the fiber subtends a smaller solid angle than the cone of light exiting the LED FOAC. Therefore, the fiber/detector interface is more tolerant of longitudinal tip to tip separation. Thus, the values of alignment loss are:

$$L_{AE} = 2 \text{ dB}$$

$$L_{AD} = 1 \text{ dB}$$

L_R, the reflective loss, is due to the loss of light incurred by the reflection off of the surface of the fiber core at both the emitter and detector interfaces. These losses amount to about 0.5 dB for each interface. However, where the IDP is used as the photo detector component, its transfer function in mV per μW already includes the reflective loss at its optical port, so that a receiver sensitivity calculation includes this loss. Therefore, with that type of detector the reflective loss need only be accounted for at the emitter interface. With other detectors, namely the PIN photo diode, photo transistor, or photo darlington, reflective loss has to be accounted for at both ends of the system. For this system using the IDP then,

$$L_R = 0.5 \text{ dB}$$

L_{NA} is the loss incurred when light emitted from an LED or fiber subtends a larger solid angle then the acceptance cone of the mating fiber or detector. If the LED source has a numerical aperture (NA) larger than the NA of the system fiber, then the loss will occur at the LED end of the system. If on the other hand the system fiber has an NA larger than the LED and photo detector, then all of the light emitted by the LED will be accepted by the system fiber but the NA loss will occur at the fiber/detector interface.

A complicating facet of NA loss is that fiber NA decreases as fiber length increases and each fiber has a different characteristic. Some fiber manufacturers plot it as a function of length and others specify it only at a kilometer. Some fibers have a slow variation of NA over path length and others apparently vary exponentially. The path length must be known so that the fiber NA can be defined by the fiber manufacturer. Once the NA is defined, the NA loss can be calculated from:

$$L_{NA} = 10 \log \left(\frac{\text{larger NA}}{\text{smaller NA}}\right)^2$$

The NA's used here are the 10% intensity NA's for the FOAC and fiber. The 10% NA's provide much closer correlation to measured results than do the 50% NA's. This formula is based on certain assumptions and provides a good first order approximation to the actual NA loss. In this example, the component of NA loss will be left undefined until later.

Next, L_α, the signal attenuation loss, is merely the product of the cable attenuation factor in dB per unit length and the path length needed. It is expressed by:

$$L_\alpha = \left(\alpha \text{ in } \frac{\text{dB}}{\text{m}}\right) \bullet (\ell \text{ in meters})$$

For MSC200B fiber, the attenuation factor is typically 18 dB/KM.

Finally, the last component of the loss budget is the system gain margin. This is the amount of excess signal desired at the receiver input. Some amount of signal above sensitivity level should be supplied to the receiver to insure that the system still performs well through out the LED aging and expected variations in ambient conditions. For this example a gain margin of 3 dB will be assumed. That is:

$$GM = 3 \text{ dB}$$

The sum of all of these loss components is the system loss budget. That is:

$$\text{Loss Budget} = \text{L.B.} = L_{CM} + L_D + L_{AE} + L_{AD} + L_{RE} + L_{RD} + L_{NA} + L_\alpha + GM$$

For MSC200B fiber then:

$$\text{L.B.} = 0.2\text{ dB} + 0\text{ dB} + 2\text{ dB} + 1\text{ dB} + 0.5\text{ dB} + 0\text{ dB} + L_{NA} + L_\alpha + 3\text{ dB}$$

$$\text{L.B.} = 6.7\text{ dB} + L_{NA} + L_\alpha$$

This loss budget must now be compared to the difference in power levels between the transmitter output power and the receiver minimum input power. This difference in power levels is called system gain. If the loss budget exceeds this system gain then there is no excess system gain and the desired performance cannot be obtained. Either a shorter path length must be used or less Gain Margin must be specified or the transmitter output power or receiver input sensitivity must be increased. If, on the other hand, the loss budget doesn't exceed the system gain, then there will be excess system gain and the desired performance will be obtained.

The output power of the transmitter described here can be taken from the MFOE103F data sheet. At 100 mA, the typical output power is 125 μW. Referenced to 1 mW, this is -9.0 dBm. The receiver input sensitivity is defined by the measure of BER performance required. From Figure 15, curve B, a S/N ratio of about 30 dB is required for a BER of 1×10^{-9}. From Figure 19, a S/N ratio of 30 dB requires an optical input power of 4 μW. Referenced to 1 mW, this is -24.0 dBm. Therefore, the system gain is:

$$G_{sys} = P_o - P_{in_{min}} = 9\text{ dBm} - (-24\text{ dBm})$$

$$G_{sys} = 15\text{ dB}$$

If a specific path length is known, the NA loss and signal attenuation loss can be evaluated. For example, assume 100 feet or 31 meters is the desired path length. From the Maxlight MSC200B data sheet,

at 31 meters, the NA $\simeq$ 0.40.

therefore, from eq. (13) $\quad L_{NA} = 10 \log \left(\frac{0.63}{0.40}\right)^2$

$$L_{NA} = 3.9\text{ dB}$$

It will be noted that 0.63 was used for the NA of the FOAC. This is the 10% NA which, as explained earlier, must be used in this formula. What appears on the present MFOE103F data sheet is the 50% NA of 0.48. Use of this 50% NA will give erroneous results for the NA loss. Now that L_{NA} has been evaluated, L_α can be determined.

$$L_\alpha = (18\text{ dB/kM}) \cdot (0.031\text{ kM})$$

$$L_\alpha = 0.6\text{ dB}$$

Now the loss budget for this fiber is found using equation (14).

$$\text{L.B.} = 6.7\text{ dB} + 3.9\text{ dB} + 0.6\text{ dB}$$

$$\text{L.B.} = 11.2\text{ dB}$$

Now the excess system gain can be found. It is given by:

$$\Delta G_{sys} = G_{sys} - \text{L.B.}$$

For this 31 meter system,

$$\Delta G_{sys} = 15\text{ dB} - 11.2\text{ dB}$$

$$\Delta G_{sys} = 3.8\text{ dB}$$

Since ΔG_{sys} is a positive number, the system will perform better than expected. If ΔG_{sys} were zero, the system would perform as expected with typical connectors and components. If ΔG_{sys} were negative, the system would not have performed as expected or may not have performed at all if ΔG_{sys} were a large negative number.

Since a ΔG_{sys} was positive, that 3.8 dB of excess system gain can be spent in a variety of ways. One way is that the fiber path length can be increased by an amount which will cause L_{NA} plus L_α to increase the loss budget by 3.8 dB. Another way is that a splice can be inserted in the system fiber path which will use up about 2.5 dB of the 3.8 dB. A third way of spending the 3.8 dB of excess system gain is to reduce LED current until the P_o drops 3.8 dB and thereby increase LED reliability. Or the 3.8 dB can be left unspent and allowed to provide extra gain margin for less susceptibility to disruption of communications.

In this example the path length was known and the loss budget was easily calculated in order to determine excess system gain. Very often the path length is the unknown and the maximum path length is what needs to be determined. In this case a re-iterative calculation is necessary. This is done by assuming a path length such as the length that has been calculated already and then calculating the ΔG_{sys}. If ΔG_{sys} turns out to be positive, as in this example, the fiber length can be increased until the L_{NA} and L_α increase by an amount equal to ΔG_{sys} according to the fiber manufacturers plots of NA and L_α vs. length. If on the other hand this guess at path length yields a negative ΔG_{sys}, then the length should be reduced until the sum of L_{NA} and L_α is reduced by an amount equal to ΔG_{sys}. Once this second guess at fiber length has been made, a recalculation of ΔG_{sys} is made and should be much closer to zero. When ΔG_{sys} is essentially zero, then that path length is L_{MAX}.

For example, since a 31m length of MSC200B fiber yielded a ΔG_{sys} of 3.8 dB, a second guess of path length of 200 m will be made in order to find L_{MAX}. When the length is increased from 33 m to 200 m, the NA drops from 0.40 to 0.36 according to the fiber data sheets. That means the new value of L_{NA} is:

$$L_{NA} = 10 \log \left(\frac{0.63}{0.36}\right)^2 = 4.9\text{ dB}$$

The signal attenuation loss is also increased to:

$$L_\alpha = (18\text{ dB/kMo}) \cdot (0.2\text{ kM}) = 3.6\text{ dB}$$

Therefore, the new loss budget using equation 14 is:

$$\text{L.B.} = 6.7\text{ dB} + 4.9\text{ dB} + 3.6\text{ dB} = 15.2\text{ dB}$$

Using equation 15, the excess system gain for 200 meters is:

$$\Delta G_{sys} = 15\text{ dB} - 15.2\text{ dB}$$

$$\Delta G_{sys} = -0.2\text{ dB}$$

That is 200 meters is slightly longer than the maximum path length that will provide the desired performance. Reducing this new path length sufficiently to reduce the loss budget by 0.2 dB will cause an insignificant decrease in L_{NA}. Therefore, this 0.2 dB can be spent by shortening the system by approximately:

$$\Delta \ell = \frac{0.2\text{ dB}}{18\text{ dB/kM}} = 11\text{m}$$

In other words, with Maxlight MSC200B fiber and typical characteristics for connectors, transmitter and receiver, the maximum path length that will allow 1×10^{-9} BER performance with a 3 dB gain margin is:

$$L_{MAX} = 189\text{ meters}$$

Figure 29 summarizes similar calculations for a variety of other fibers.

All of these calculations assume that the system under consideration is attentuation limited. But there is another limitation relating to the maximum data rate that can be transmitted over a given distance. The source of this limitation is a transit time phenomenon of fiber propagation called modal dispersion.

Because of the relatively short system path lengths summarized in Figure 28, modal dispersion is not a factor in these systems. At what path length modal dispersion in a particular fiber begins to degrade system rise time can be calculated if the pulse spreading specification or dispersion for the fiber is known. For example, Valtec PC-10 has a pulse broadening specification of 40 ns/km. This represents the pulse width at the 50% points of a pulse exiting the fiber in response to a sub-nanosecond wide pulse being launched into the fiber. Since the pulse exiting the fiber is Gaussian in shape, the 10%-90% rise time is about 72% of this 50% pulse width. Therefore, if the short system rise time of this 20-Mbaud system is 30 ns, the rise time of the fiber for less than 10% degradation due to modal dispersion is:

$$t_{R_{SYS(long)}} \leqslant 1.1\, t_{R_{SYS(short)}}$$

$$\sqrt{(30\text{ ns})^2 + (t_{R_{fiber}})^2} \leqslant 1.1\,(30\text{ ns})$$

$$900\text{ ns}^2 + (t_{R_{fiber}})^2 \leqslant 1089\text{ ns}^2$$

$$(t_{R_{fiber}})^2 \leqslant 189\text{ ns}^2$$

$$t_{R_{fiber}} \leqslant 13.7\text{ ns}$$

The length of PC-10 which will cause this much degradation is given by:

$$t_{R_{fiber}}(\text{ns}) = (0.72)\,(\text{Dispersion}\,\frac{\text{ns}}{\text{km}})\times(\text{length})$$

$$\text{length} = \frac{t_{R_{fiber}}}{0.72(\text{Disp})}\text{ km} = \frac{13.7\text{ ns}}{0.72\,(40\text{ ns/km})}$$

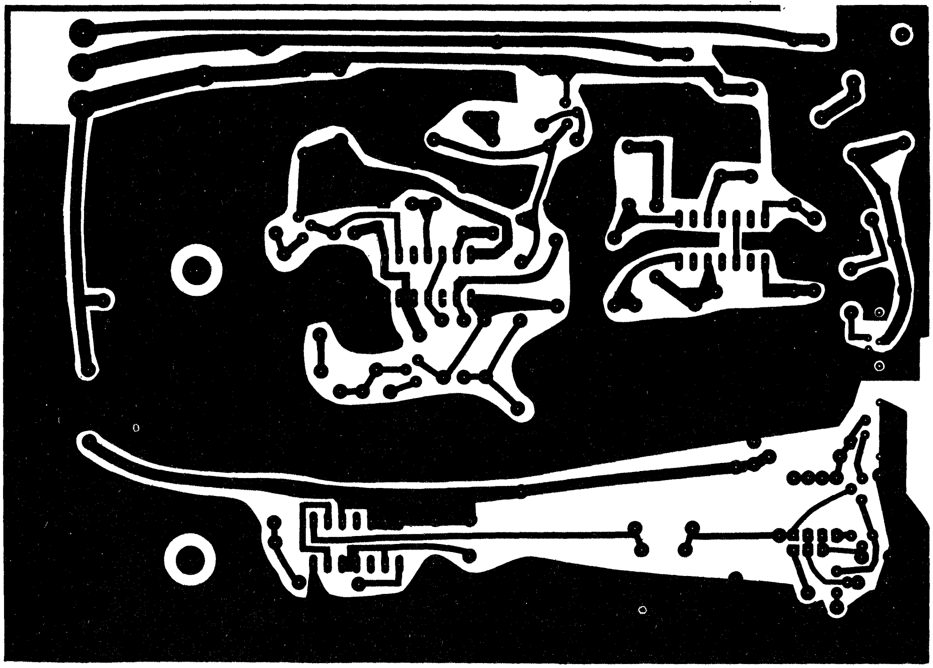
$$\text{length} = 476\text{ meters}$$

In other words, if a 10% degradation in system performance is all that is tolerable and improvements in this 20-Mbaud system extend the use of PC-10 to beyond 476 meters, then 476 meters will remain as the maximum allowable path length. The system will no longer be attenuation limited but will now be dispersion limited.

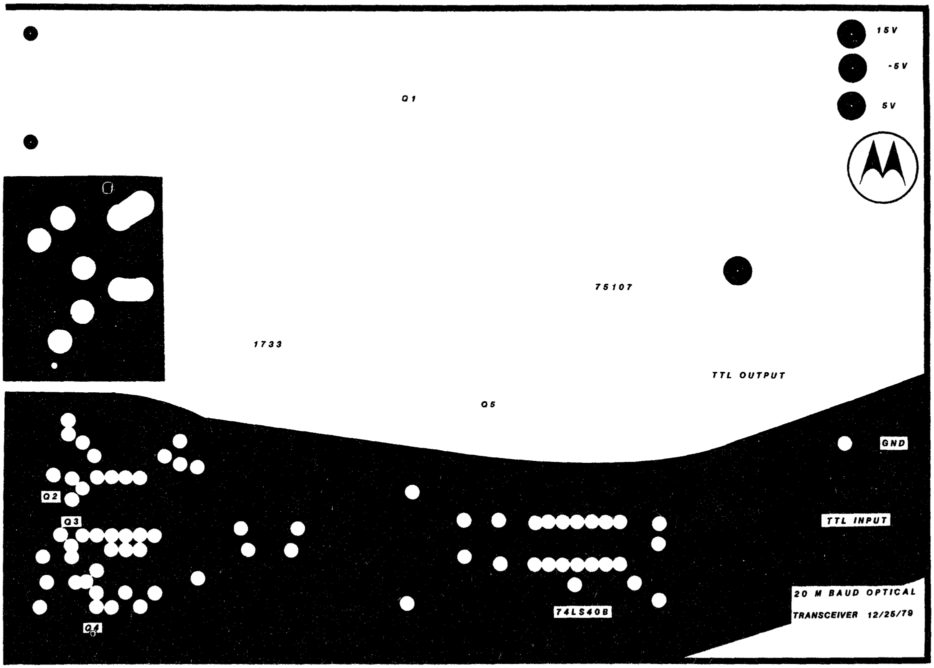
Fiber/System Parameters	Maxlight MSC200B	Seicor 155	Valtec[1] PC-08	Valtec[1] PC-10	DuPont[1] PIR 140	DuPont[1] S-120 Type 30
Fiber Core Diameter	200 μm	200 μm	200 μm	250 μm	368 μm	200 μm
Clad Mode Loss (L_{CM})	0.2 dB	0.2 dB	0.2 dB	0.0 dB	0.0 dB	0.2 dB
Diameter Loss (L_D)	0.0 dB	0.0 dB	0.0 dB	1.9 dB	5.3 dB	0.0 dB
Alignment Loss ($L_{AE} + L_{AD}$)	3.0 dB	3.0 dB	3.0 dB	0.5 dB	0.5 dB	3.0 dB
Reflective Loss (L_R) (Using IDP)	0.5 dB	0.5 dB	0.5 dB	0.5 dB	0.5 dB	0.5 dB
Loss Budget (L.B.') without L_{NA} or L_α including 3 dB G.M.	6.7 dB	6.7 dB	6.7 dB	5.9 dB	9.3 dB	6.7 dB
Fiber NA @ ℓ_{max}	0.36	0.40	0.38	0.38	0.44	0.38
NA Loss (L_{NA})	4.9 dB	3.9 dB	4.4 dB	4.4 dB	3.1 dB	4.4 dB
Allowable Attenuation Loss (L_α) (15 dB — L.B.' — L_{NA})	3.4 dB	4.4 dB	3.9 dB	4.7 dB	2.6 dB	3.9 dB
Fiber Attenuation Factor (α)	18 dB/kM	35 dB/kM	70 dB/kM	70 dB/kM	950 dB/kM	95 dB/kM
Maximum Path Length (ℓ_{max})	189 m	126 m	55 m	67 m	2.7 m	41 m

[1] Calculations for this fiber are based on measured NA versus length data which is available from the fiber manufacturer but is as yet unpublished.

FIGURE 29 — Maximum Path Length Calculations with 15 dB of System Gain



(a) Solder Side



(b) Component Side

FIGURE 30 — Printed Circuit Artwork

SUMMARY

The fiber optic data link described herein is quite versatile. With a TTL interface, no data format constraints, 0-20 Mbaud capability, and full duplex operation, it can be inserted into almost any system as a transparent link for the purpose of evaluating the contribution of fiber optics to improved system performance. In addition, it can be configured as a simplex optical repeater by strapping the receiver data output to the transmitter data input.

This application note has also introduced the reader to the Motorola Fiber Optic Active Component, or FOAC, and some of the mechanical and optical considerations involved in its proper use. The necessary functional blocks as well as some of the desirable characteristics of an optical data transmitter and receiver have also been discussed. The text and waveform diagrams dealing with signal detection schemes should offer insight into whether or not edge coupling is appropriate for a particular application.

The data shown here on transmitter, receiver, and system performance was generated from measurements on two units in a system. It should be considered typical performance and normal variations around these values should be expected.

ACKNOWLEDGEMENTS

The author would like to acknowledge the laboratory assistance of John Toney in gathering data and generating several interations of printed circuit board design.

APPLICATIONS OF FERRULED COMPONENTS TO FIBER OPTIC SYSTEM

Prepared By:
Horst Gempe

THE MOTOROLA FERRULED LED

Construction and Optical Characteristics

This device is constructed by assembling an infrared light emitting diode (LED) in a package suitably configured to mate with and become an integral part of a fiber optic connector. This active connector concept is illustrated in Figure 1(a). The ferruled semiconductor and its exploded view are illustrated in Figures 1(b) and 1(c).

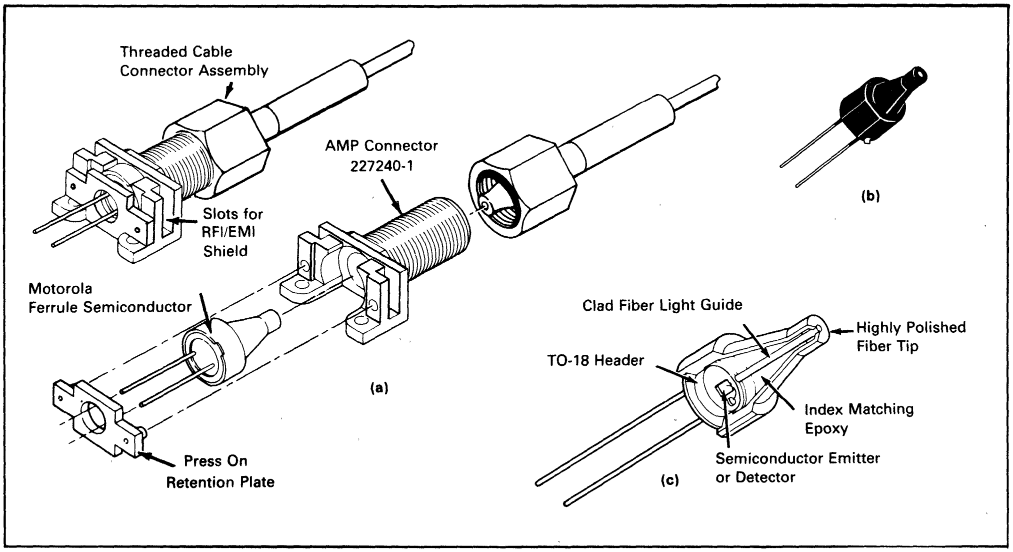


FIGURE 1 — Motorola Fiber Optic Active Component (FOAC)
(a) Package/Connector Concept
(b) External View of FOAC
(c) Exploded View of FOAC

A depiction of the light emission pattern of the LED is shown in Figure 2. The fiber cladding carries less than five percent of the total output power since most clad modes are absorbed by the high index of refraction epoxy.

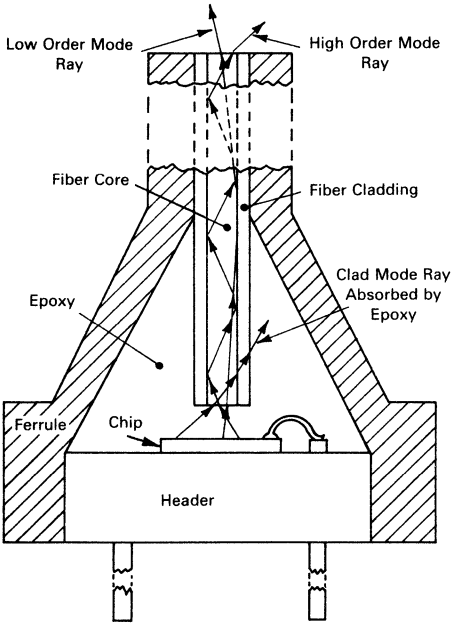


FIGURE 2 — Light Ray Patterns in FOAC LED

The core carries high- and low-order modes with the distribution of total energy as shown in Figure 3. The presence of high-order modes makes the effective numerical aperture (NA) greater than would be found for a fiber length longer than about one meter.

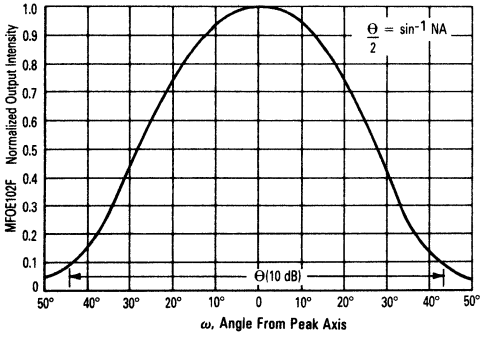


FIGURE 3 — Light Emission Pattern for FOAC LED

Measurement of Output Power

There are several methods currently in use for measuring the output of F/O sources.

The integrating sphere method shown in Figure 4 collects the power radiated from the source in all directions and directs it to the silicon detector cell of a radiometer. It is the most repeatable technique of measurement since it is effectively independent of geometry. However, since it is not sensitive to the NA of the source, it does not enable the user to predict the amount of the measured power that can be coupled from the source into a fiber.

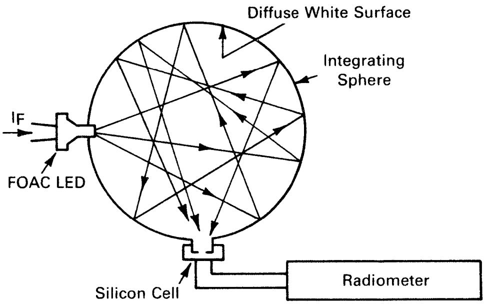


FIGURE 4 — Integrating Sphere/Radiometer Measurement Method

The barrel method, Figure 5, simulates the condition of coupling into a fiber. Only the power that passes through the aperture is measured. Repeatability requires exact duplication of the aperture size, the distance between the source and the silicon cell, and the accurate positioning of the source orthogonal to the direction between source and cell.

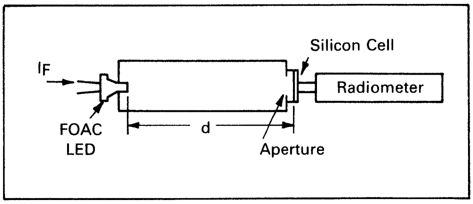


FIGURE 5 — Barrel/Radiometer Measurement System

As an example of measurement difference between the integrating sphere and barrel methods, a device was measured under like-drive conditions in the integrating sphere of a PhotoResearch PR 1000 Radiometer and a barrel type Photodyne Radiometer. The results are given in Table I.

TABLE I

Measurement Method	MFOE102F Measured Power
Integrating Sphere (PR 1000)	73 microwatts
Barrel (Photodyne)	67 microwatts

For the MFOE102F (NA = 0.7) the correction factor between the barrel and the integrating sphere is 0.91. Devices with smaller NAs will have a correction factor approaching 1.0.

THE MOTOROLA FERRULED DETECTOR

Construction and Optical Characteristics

The detector members of the FOAC family utilize the same construction as the LED. Again, because of the short length of the fiber in the ferrule, the effective NA is larger than found for longer sections of the same type of fiber. The angular response for the detector is similar to the emission pattern for the LED, Figure 6.

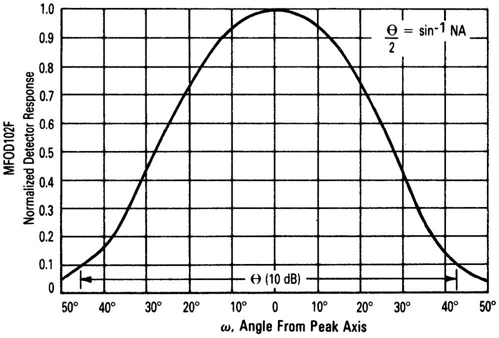


FIGURE 6 — Light Response Pattern for FOAC Detector

Measurement of Responsivity

The response of the detectors is given in output voltage or current per unit of optical power coupled into the detector's input port. It does not include losses (see Fresnel and connector losses later in this bulletin) between the power source and the input port since these are a function of each individual system's variables.

The FOAC detector responsivity is measured by connecting a FOAC LED to a one meter length of fiber that is connected to a simulated detector ferrule, see Figure 7. The power launched from the simulated ferrule is measured in an integrating sphere, and is a true measure of the actual power coupled into a ferrule detector. The power measured by the sphere/radiometer is recorded.

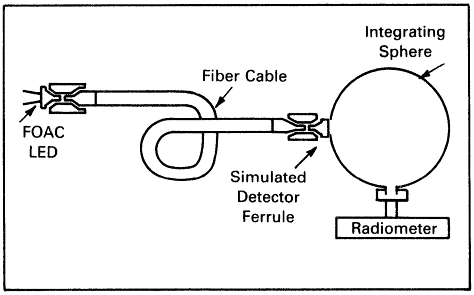


FIGURE 7 — Calibration of Light Source for Detector Responsivity Measurement

The detector to be measured is then connected to the fiber in place of the simulated ferrule, Figure 8, and the output voltage or current is noted. The responsivity for the detector is taken as the ratio of the output voltage or current to the power as measured by the integrating sphere.

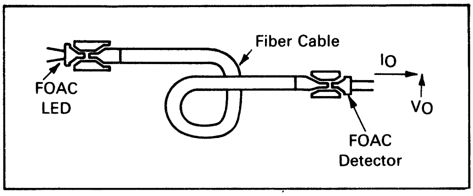


FIGURE 8 — Detector Responsivity Measurement

OPTICAL FIBERS

To calculate the total losses for a system, it is important to know and understand the parameters of the system fiber. The two most critical parameters are:

1. Output NA of the fiber
2. Fiber attenuation

Output NA of a Fiber

The output NA of a fiber is a function of its length, as shown in Figure 9. Most fiber manufacturers specify NA. If it is not available for a particular fiber, it can be measured as shown later in this bulletin.

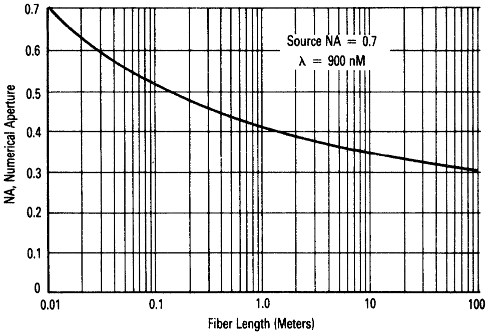


FIGURE 9 — NA versus Length for a Sample Fiber

Fiber Attenuation

The attenuation characteristic of a fiber is usually specified in dB per meter or dB per kilometer. If it is given as a single value, the manufacturer will specify the wavelength of measurement. Usually the attenuation is given graphically as a function of wavelength. Figure 10 shows several examples. The specified attenuation does not contain losses due to NA changes, since

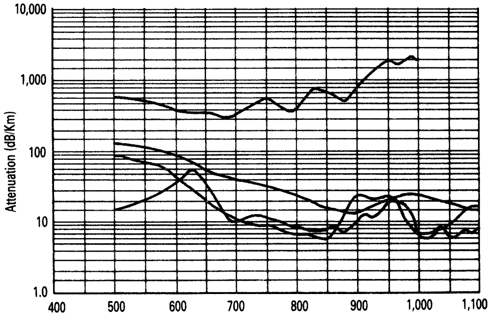


FIGURE 10 — Attenuation versus Wavelength for Several Fibers

it is usually measured with a very narrow angle (small NA) source. In many applications, the NA of the system source is greater than the NA of the system fiber. This means additional loss is incurred which will have to be added to the total attenuation loss when calculating a system flux budget.

THE MEASUREMENT OF NA

Source NA

The measurement of NA for an LED source can be made as shown in Figure 11(a). The power from the source is measured by a silicon cell/radiometer through a very small aperture. The peak power level is measured and recorded. The source is rotated and the angle between the two points at which the power level drops to one tenth the peak power level (−10 dB) is noted. Signifying this angle as Θ, the source NA is calculated:

$$\text{NA (source)} = \sin(\Theta/2) \qquad (1)$$

Detector NA

The NA for a detector is measured in a similar arrangement, see Figure 11(b). The silicon cell/radiometer is replaced by a stable light source. The peak detector response is measured and recorded, and the angle between the two points at which the response is one tenth the peak (−10 dB) is noted. Again signifying this angle as Θ:

$$\text{NA (detector)} = \sin(\Theta/2) \qquad (2)$$

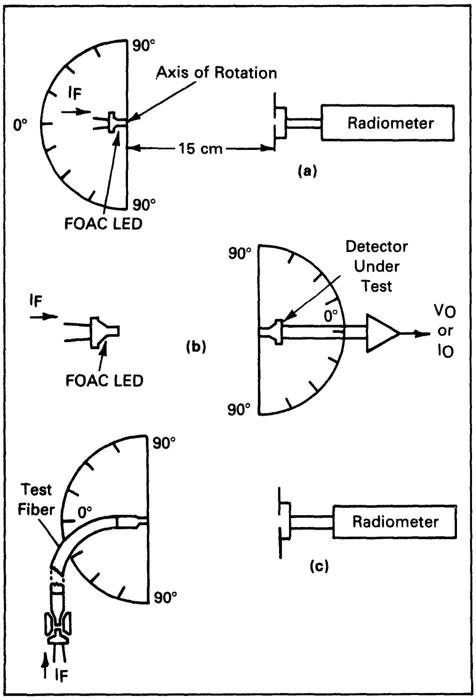


FIGURE 11 — NA Measurement
(a) For FOAC LED
(b) For FOAC Detector
(c) For Fiber

Fiber NA

If the NA of a fiber is not known, it can be measured. The fiber to be tested is terminated in standard cable connectors (AMP Part #530954). One end of the fiber to be measured is connected to a FOAC LED. The other end of the fiber is directed at a silicon cell/radiometer, Figure 11(c). The peak power level from the fiber is recorded. The end of the fiber is then rotated and the angle between the points at which the power level is one tenth the peak (−10 dB) is noted. Again, using this angle, Θ:

$$\text{NA (fiber)} = \sin(\Theta/2) \qquad (3)$$

CONNECTOR LOSSES

There are a variety of losses that can occur in the interconnections in a system. These are:

- NA loss
- Diameter loss
- Gap loss
- Axial misalignment loss
- Fresnel loss
- Angular loss

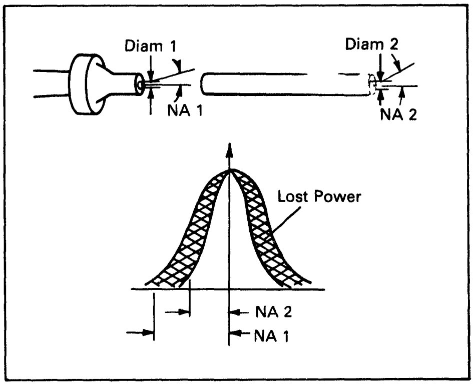


FIGURE 12 — NA Loss

NA Loss

It was shown earlier that presence of high order modes in the FOAC LED give it an effective NA higher than a long length of the same type of fiber, Figure 9. As shown in Figure 12, the difference in the two areas of the spatial patterns represents lost power due to different NAs. The magnitude of this loss is given by:

$$\text{NA Loss} = 20 \log (\text{NA1}/\text{NA2}) \qquad (4)$$

Note that in the case of coupling from a small NA fiber to a larger NA fiber, no energy is lost due to NA difference so that the loss in equation 4 becomes zero. (Example: coupling from a system fiber into a FOAC detector)

Diameter Loss

If two fibers of different diameters are coupled, an additional loss may be incurred. It is given by:

$$\text{Diameter Loss} = 20 \log (\text{Dia1}/\text{Dia2}) \qquad (5)$$

Again, if the receiving fiber has a diameter greater than the source fiber, Figure 12, the diameter loss reduces to zero.

Gap Loss

Ideally, two fibers would be joined such that no gap exists between them. In practice a small gap is intentionally introduced to prevent mechanical damage to the fiber surfaces. The Motorola FOAC devices and AMP connector bushings are designed to hold this gap to about 0.1 mm. The result of variations in the gap for several sample NAs is given in Figure 13.

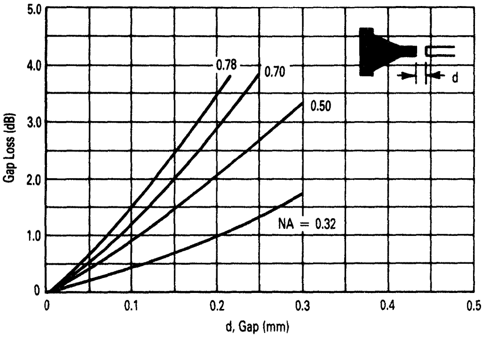


FIGURE 13 — Gap Loss

Axial Misalignment Loss

If two connected fibers are not concentric there will be an obvious loss of power. The effect of this misalignment for several NAs is shown in Figures 14(a), 14(b), and 14(c). The effect of gap separation is also included in these graphs.

FIGURE 14(a)

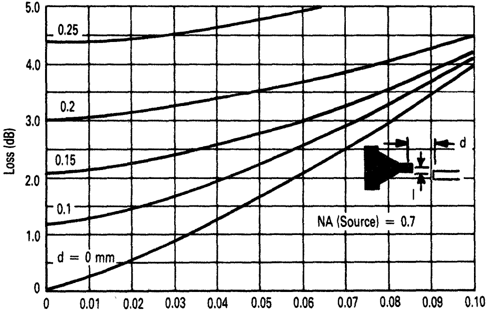


FIGURE 14(b)

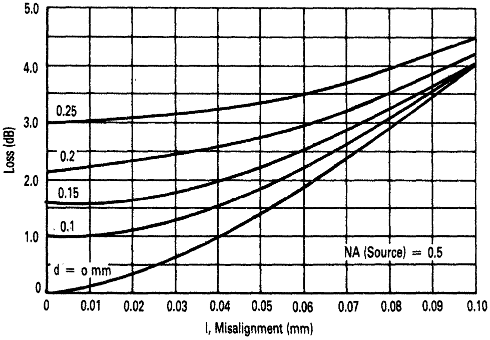


FIGURE 14(c)

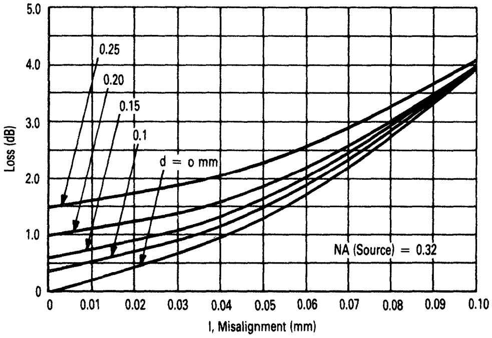


FIGURE 14 — Misalignment Loss

Fresnel Loss

As light passes through any interface, some energy is transmitted and some reflected. The amount of energy lost is a function of the indices of refraction of the materials forming the interface. For the FOAC family of devices and glass core fibers this loss is a fairly consistent 0.2 dB per interface.

Angular Loss

If the surfaces of the two connected fiber ends are not parallel, an additional loss is incurred. The magnitude of this is shown in Figure 15.

FLUX BUDGET

Once the various losses in a system have been identified and quantified, it is a relatively simple exercise to calculate the total system loss and thus predict system performance. To illustrate this, and to highlight a major loss element in systems, two examples will be considered. In each case an MFOE102F LED is used for the source and an MFOD102F PIN diode as the detector. System A uses a 50 meter length of cable, while system B uses two 50 meter lengths joined by a fiber/fiber splice.

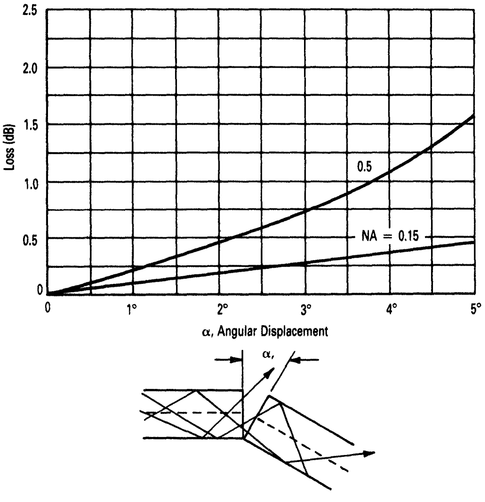


FIGURE 15 — Angular Loss

System A Flux Budget

System A is shown in Figure 16. A proper flux budget should consider all significant losses. These include:

1. Connector losses: gap, misalignment and Fresnel (angular losses are usually quite small so the very low loss that results will be ignored).
2. Numerical aperture loss
3. Fiber attenuation
4. Diameter loss — the two systems being analyzed will use the same diameter fiber throughout so that diameter loss can be considered to be zero.

The following specifications apply:

MFOE102F: $P_O = 125\ \mu W$ @ 100 mA
NA (10 dB effective) = 0.7
Core diameter = 200 μM
Wavelength = 900 nM
MFOD102F: R = 0.4 μA/μW @ 900 nM
NA (10 dB effective) = 0.7
Core diameter = 200 μM
I(dark) = 2.0 nA @ 25°C
Fiber: Length = 50 M
Attenuation = 25 dB/Km @ 900 nM, Figure 10
NA @ 50 M = 0.32
Core diameter = 200 μM
Connectors: Gap = 0.15 mm typical
Misalignment = 0.05 mm typical

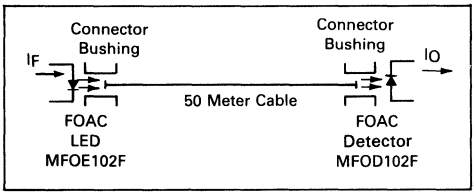


FIGURE 16 — 50 Meter F/O System

The total system loss can now be calculated:

LED to Fiber Connector Loss, Figure 14(a)	2.7 dB
LED to Fiber Fresnel Loss	0.2 dB
LED to Fiber NA Loss {20 log |NA(LED)/ NA(FIBER)|}	6.79 dB
Fiber Attenuation (50 Meters)	1.25 dB
Fiber to Detector Connector Loss, Figure 14(c)	1.5 dB
Fiber Exit Fresnel Loss	0.2 dB
Detector Entry Fresnel Loss	0.2 dB
Total System A Loss	12.84 dB

(Note that no NA loss was included at the detector end since the detector NA is greater than the fiber NA. Also, no LED exit Fresnel loss was considered since it is already accounted for in the P_O specification for the LED).

To determine total system performance we can construct a table. For this analysis we will use power units in dBm similar to the volume units (vu) used in audio work. We will define a power unit of zero dBm for an optical power of one milliwatt. For any power level we then have:

$$\text{dBm} = 10 \log (P/1\ \text{mW}) \tag{6}$$

$$\text{dBm} = 10 \log P(\text{mW}) \tag{7}$$

The table for system analysis now becomes:

TABLE II

Point in the System	Power Units (dBm)	P (μW)
P1: LED @ 100 mA	−9.03	125
P2: Power in Fiber (P1 — Connector loss — Fresnel loss)	−11.93	
P3: Power from Fiber (P2 — NA loss — Attenuation — exit Fresnel)	-20.17	
P4: Power into Detector (P3 — Connector loss — entry Fresnel)	-21.87	6.5

Of course, this could have just as easily been calculated from the total system loss of 12.6 dB:

$$\text{System Loss} = 10 \log [P(\text{in})/P(\text{out})] \tag{8}$$

$$12.84 = 10 \log [125\ \mu W/P(\text{out})] \tag{9}$$

$$P(\text{out}) = 6.50\ \mu W \tag{10}$$

However, partitioning the power level at any point in the system, as in Table II, enables us to plot the power level over the system as shown in Figure 17.

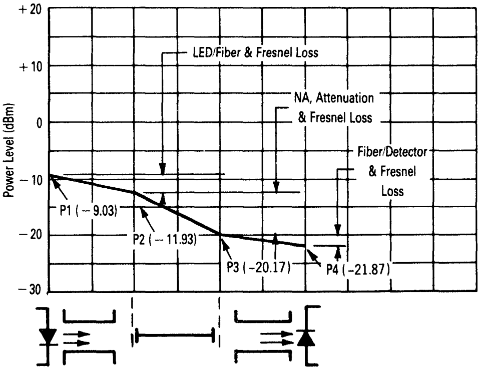


FIGURE 17 — Power Level Along System A

Using the detector responsivity, the output signal current can now be determined:

$$I_O = P(\text{in})(\text{detector}) \times R \tag{11}$$

$$I_O = 6.5\ \mu W \times 0.4\ \mu A/\mu W \tag{12}$$

$$I_O = 2.60\ \mu A \tag{13}$$

Since the detector dark current, I_d, of the MFOD102F is 2.0 nA at 25°C, the signal-to-noise ratio is:

$$\text{SNR} = 10 \log (2.60/0.002) \tag{14}$$

$$\text{SNR} = 31.1\ \text{dB} \tag{15}$$

System B Flux Budget

System B is shown in Figure 18. It is identical to System A except for the addition of a second 50 meter length of fiber and a fiber/fiber splice.

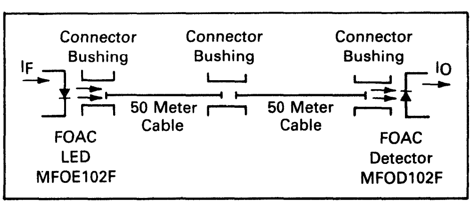


FIGURE 18 — 100 Meter, 2 Cable System

In calculating system losses it is important to note that the NA of 100 meters of fiber is 0.31, per Figure 9. It is independent of the presence of the splice at the midpoint, since the second 50 meters continues to strip high order modes. Another way of looking at it is to consider a replot of Figure 9. This is shown in Figure 19. The difference is that the NA at zero is the NA of the source, in this case the 0.32 exit NA of the first 50 meter length. At long distances the cable will still approach the same asymptotic value as in Figure 9. In Figure 19 it can be seen that the curve passes through 0.31 at 50 meters. So a 50 meter cable with a beginning NA of 0.32, and a 100 meter cable starting with an NA of 0.7 will both have an exit NA of 0.31. (This is true of course only for this particular cable)

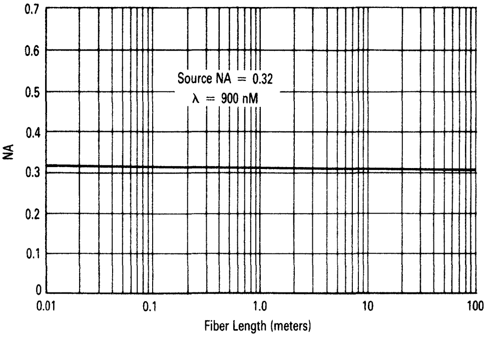


FIGURE 19 — NA versus Length for a Sample Fiber

Calculating system loss:

LED to Fiber Connector Loss, Figure 14(a)	2.7 dB
Fiber 1 Entry Fresnel Loss	0.2 dB
LED to Fiber 1 NA Loss	6.79 dB
Fiber 1 Attenuation	1.25 dB
Fiber 1 Exit Fresnel Loss	0.2 dB
Fiber/Fiber Connector Loss	1.50 dB
Fiber 2 Entry Fresnel Loss	0.2 dB
Fiber 1/Fiber 2 NA Loss	0.28 dB
Fiber 2 Attenuation	1.25 dB
Fiber 2 Exit Fresnel Loss	0.2 dB
Fiber to Detector Connector Loss	1.5 dB
Detector Entry Fresnel Loss	0.2 dB
Total System B Loss	16.27 dB

The power level system analysis is:

TABLE III

Point in the System	Power Units (dBm)	P (μW)
P1: LED @ 100 mA	−9.03	125
P2: Power in Fiber 1 (P1 — Connector Loss — Fresnel Loss)	−11.93	
P3: Power from Fiber 1 (P2 — NA loss — Attenuation — Fresnel Loss)	−20.17	
P4: Power in Fiber 2 (P3 — Connector Loss — Fresnel Loss)	−21.87	
P5: Power from Fiber 2 (P4 — NA Loss — Attenuation — Fresnel Loss)	−23.60	
P6: Power into Detector (P5 — Connector Loss — Fresnel Loss)	−25.30	2.95

The power level along System B is plotted in Figure 20.

The output signal is now calculated:

$$I_O = 2.95\ \mu W \times 0.4\ \mu A/\mu W \quad (16)$$

$$I_O = 1.18\ \mu A \quad (17)$$

The SNR for System B is:

$$SNR = 10 \log (1.18/0.002) \quad (18)$$

$$SNR = 28\ dB \quad (19)$$

It is now of interest to compare the losses in System A with those in System B. At first thought, it might seem that doubling the system length should approximately double the system loss. If the dominant loss mechanism were fiber attenuation, this might be true.

However, as Figures 17 and 20 show, the greatest loss occurs in the first 50 meters of fiber. Since the Fiber attenuation and Fresnel loss for any 50 meter length of this cable is essentially constant at fixed wavelength, the major loss has to be a result of the NA loss from the FOAC LED to the fiber. As shown in the analysis of the two systems this loss is 6.79 dB. As a percentage of the total loss in the two systems, it represents 53% in System A and 42% in System B.

Therefore, in designing a system, the greatest loss will usually be incurred at the front end of the system where the LED couples to the system fiber. One way to combat this is to select fibers with large NAs. However, this will reduce the high frequency capability of the system by increasing pulse dispersion distortion, so the designer is faced with making a tradeoff between system length, or SNR and high-frequency performance.

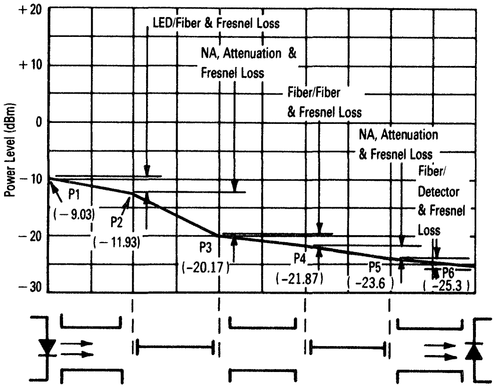


FIGURE 20 — Power Level Along System B

SUMMARY

The packaging concept used in the Motorola FOAC line of products enables the user to quickly design and assemble an F/O system. A full understanding of the device characteristics and the characteristics of cables and connectors used with FOACs, gives the designer the capability to perform a flux budget analysis of his system and thus predict performance.

Specific conclusions drawn from this study are:

LED — in most cases not all power as specified on typical data sheets is usable due to NA differences.

Fiber — NA is not constant in short lengths of fiber when used with high NA sources.

Connectors — Connector losses are dependent upon the NA conditions combined with the mechanical tolerances.

Detector — Detector responsivity is specified as a function of the actual power launched into the optical input port.

BIBLIOGRAPHY

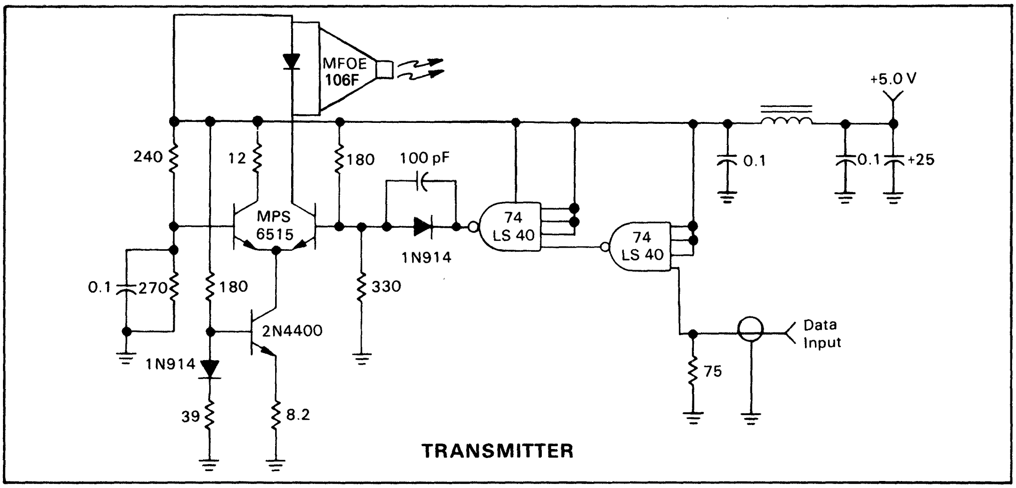
1. Barnoski, Michael K., ed., *Fundamentals of Optical Fiber Communications,* Academic Press, Inc., New York, 1976.

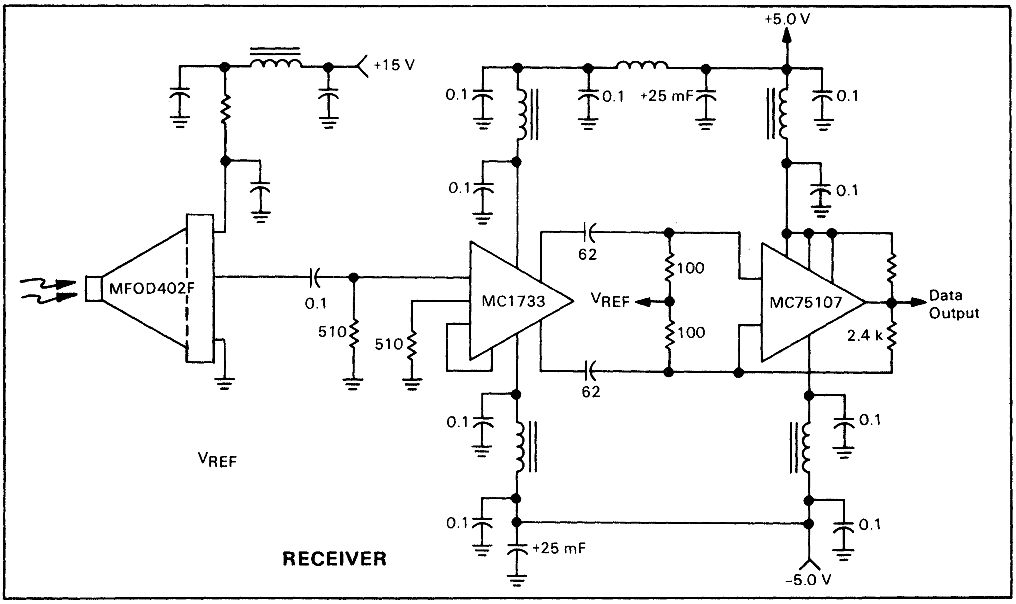
2. "Introduction to Fiber Optics and AMP Fiber-Optic Products," HB5444, AMP, Inc., Harrisburg, PA, 1979.

3. Mirtich, Vince, "A 20-MBaud Full Duplex Fiber Optic Data Link Using Fiber Optic Active Components," Motorola Application Note AN-794, Phoenix, AZ, 1980.

FIBER OPTIC CIRCUIT IDEAS

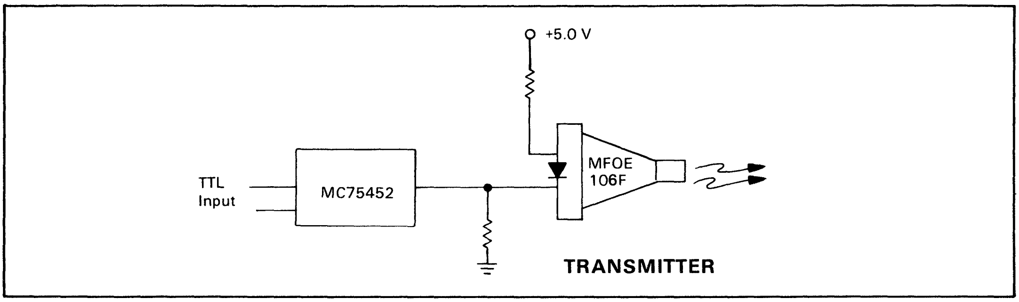
20 MBaud Data Link
Emitter — MFOE106F
Detector — MFOE402F

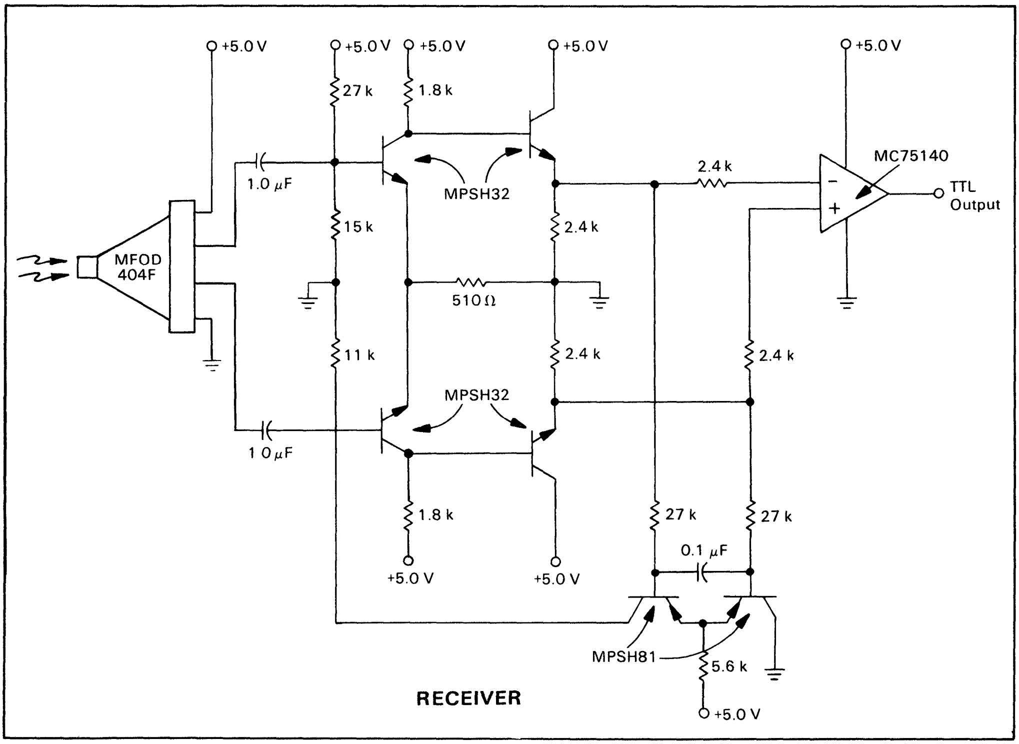




FIBER OPTIC CIRCUIT IDEAS

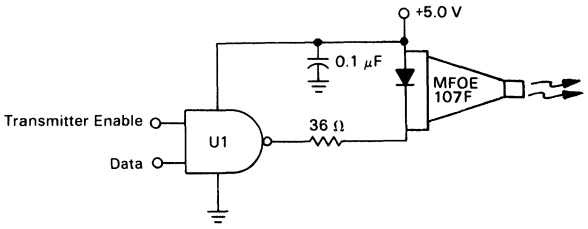
10 MBaud Data Link
Emitter — MFOE106F
Detector — MFOD404F



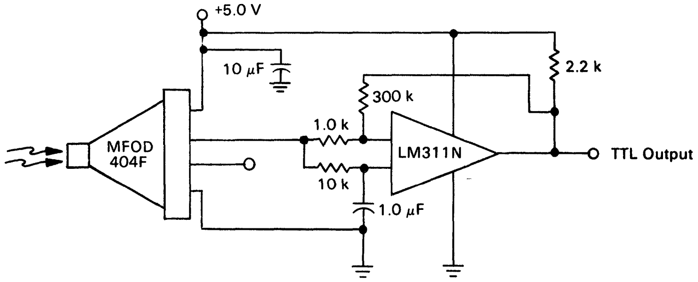


FIBER OPTIC CIRCUIT IDEAS

2.0 MBaud Data Link
Emitter — MFOE107F
Detector — MFOD404F



TRANSMITTER



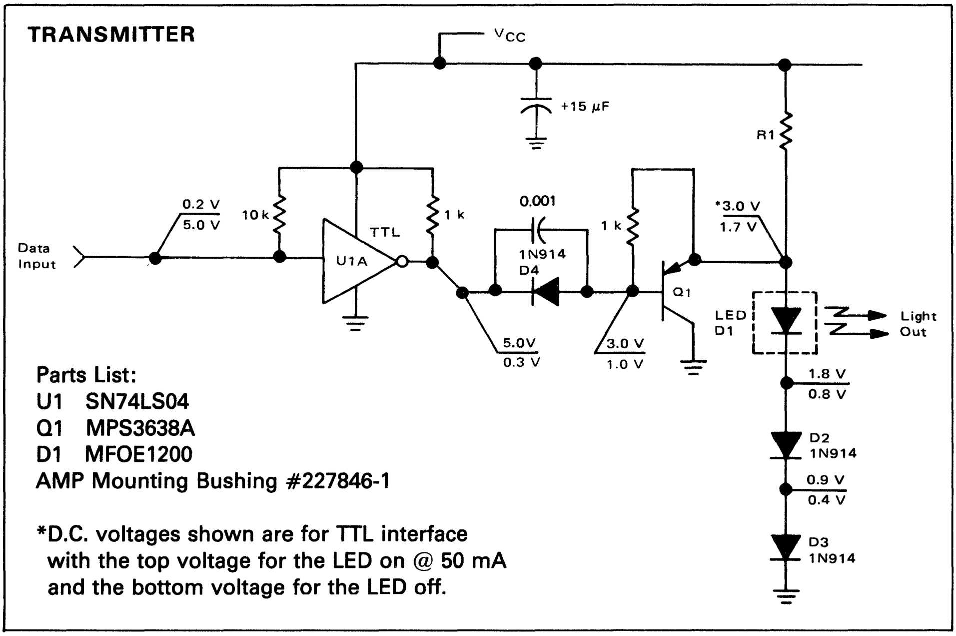
RECEIVER

FIBER OPTIC CIRCUIT IDEAS

1.0 MEGABIT SYSTEM

Microcomputer and microprocessor data links may be constructed using fiber optics. These data links offer all the advantages of fiber optics (transient/surge current immunity, high voltage isolation, no ground loops, RFI/EMI isolation, etc.) The links have been demonstrated in point of sale terminals, microprocessor controlled industrial controls, petro chemical applications, RS232 and many other areas. Full duplex links with system lengths greater than 1 Km have been constructed.

The transmitter and receiver circuits are depicted below with recommended parts list:



Parts List:
U1 SN74LS04
Q1 MPS3638A
D1 MFOE1200
AMP Mounting Bushing #227846-1

*D.C. voltages shown are for TTL interface with the top voltage for the LED on @ 50 mA and the bottom voltage for the LED off.

TRANSMITTER:

This fiber optic transmitter handles NRZ data rates to 10 Mbits or square wave frequencies to 5 MHz, and is TTL compatible.

Powered from +5V supply for TTL operation, the transmitter requires only 150 mA total current.

The LED drive current may be adjusted by resistor R1, and should be set for the proper LED power output level needed for system operation. (see LED data sheets.)

Resistor (R1) value may be calculated as follows:

$$\frac{R1 + V_{CC} - 3.0\text{ V}}{I_F}\ \text{ohms}$$

Where: V_{CC} = Power Supply Voltage
I_F = Desired LED forward current

FIBER OPTIC CIRCUIT IDEAS

1.0 MEGABIT SYSTEM — Cont.

The LED is turned off when transistor Q1 is driven on. Diodes D2 and D3 are used to assure the turn-off.

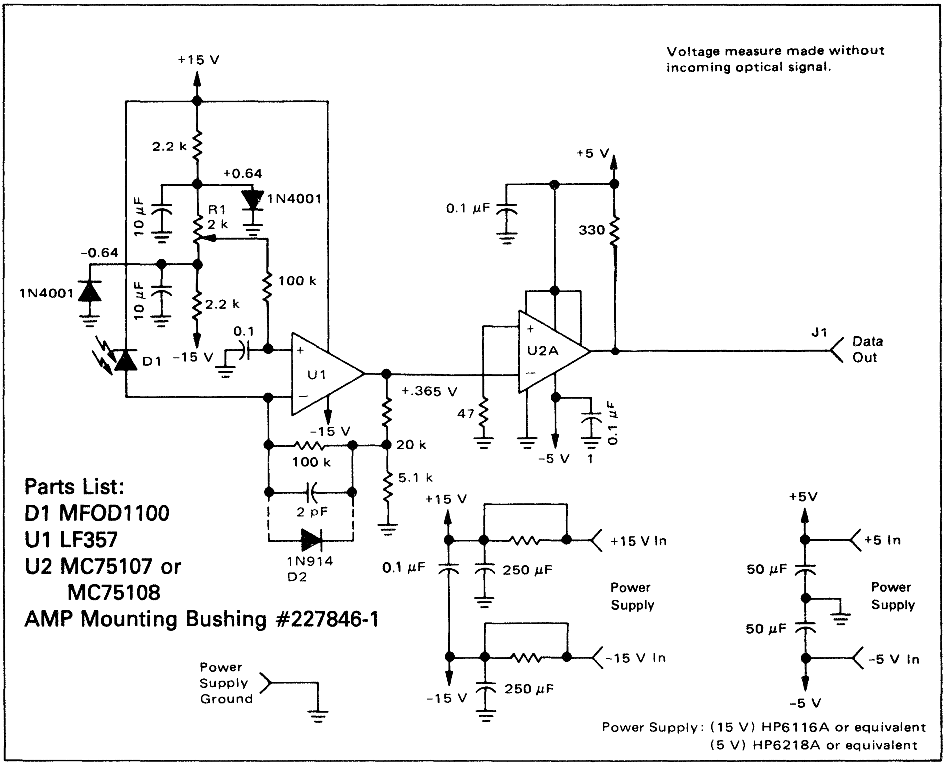
Diode D4 prevents reverse bias breakdown (base-emitter) of transistor Q1 when the integrated circuit U1 output is high. The transmitter requires a power supply voltage of +5 ±0.25V.

RECEIVERS

The receiver uses an MFOD1100 PIN photodiode as an optical detector. The detector diode responds linearly to the optical input over several decades of dynamic range. The PIN detector output current is converted to voltage by integrated circuit U1 (Operational amplifier LF357). The minimum photocurrent required to drive U1 is 250 nA. Receiver dynamic range is extended with diode D2 to prevent U1 from saturating at large optical power inputs.

Integrated circuit U2 acts as a voltage comparator. Its worst case sensitivity of 50 mV determines the size of the pulse required out of U1. U2 detects, inverts, and provides standard TTL logic level to the output.

Offset adjustment R1 should be set to accurately reproduce a 1 MHz 50% duty cycle square wave at the receiver output.



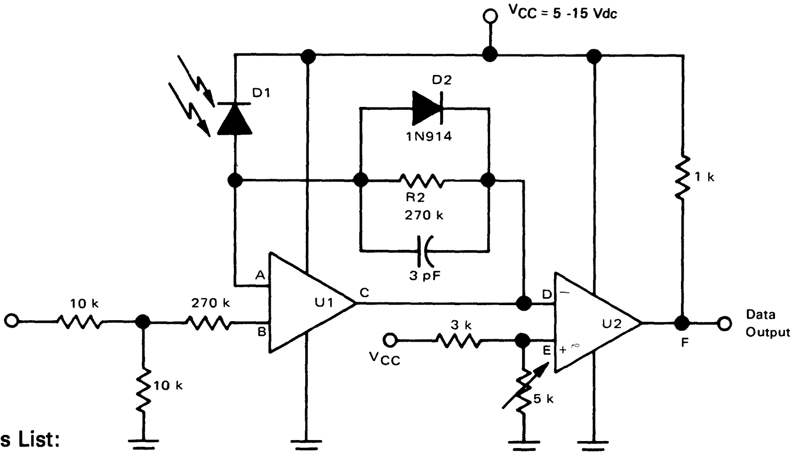
Parts List:
D1 MFOD1100
U1 LF357
U2 MC75107 or
MC75108
AMP Mounting Bushing #227846-1

Power Supply: (15 V) HP6116A or equivalent
(5 V) HP6218A or equivalent

FIBER OPTIC CIRCUIT IDEAS

100 KILOBIT RECEIVER

This is a two-IC four-channel receiver. An operational amplifier, U1 (MC3403) translates the PIN detector Photo current into a voltage level. The U1 output voltage is used by open collector comparator U2 (MC3302) to generate TTL or CMOS compatible signal levels at the receiver output. One channel is shown below.



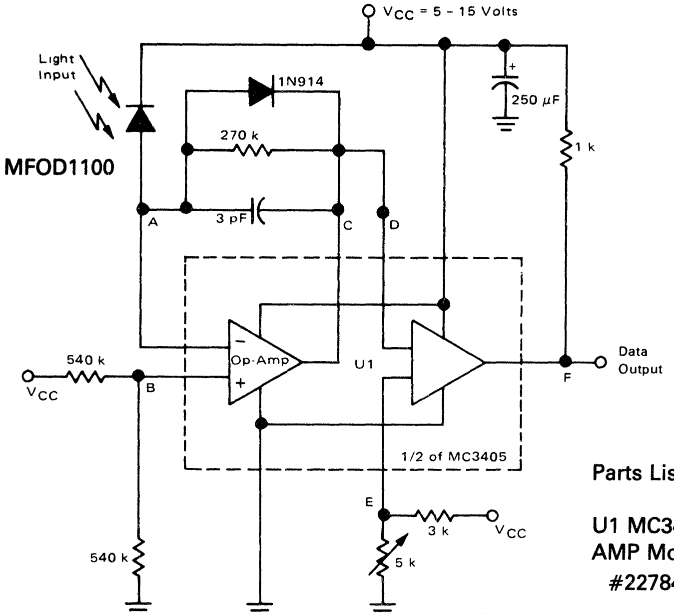
Parts List:
U1 MC3403 (1/4)
U2 MC3302 (1/4)
D1 MFOD1100
D2 1N914
AMP Mounting Bushing #227846-1

Power Supply: HP6218A or equivalent

FIBER OPTIC CIRCUIT IDEAS

1/10/100 KILOBIT RECEIVER

This is a single IC two-channel receiver, using an MC3405, which contains two op-amps and two comparators. The receiver is TTL of CMOS compatible and operates up to 100 Kilo-bit data rate.



Parts List:

U1 MC3405
AMP Mounting Bushing
#227846-1

Power Supply: HP6218A or equivalent

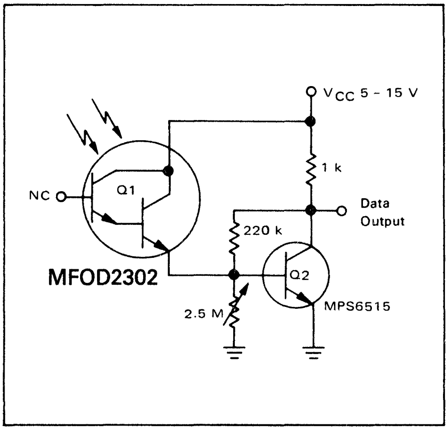
FIBER OPTIC CIRCUIT IDEAS

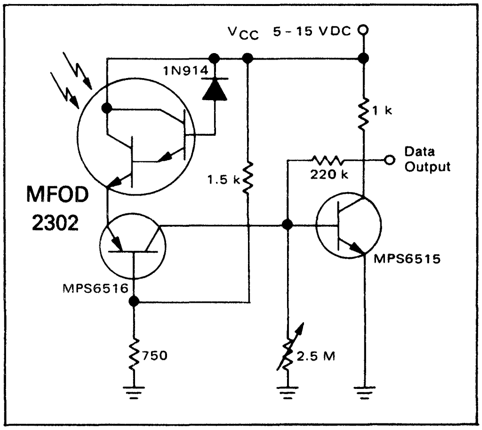
DARLINGTON RECEIVER

Discrete Low Speed Circuits

A simple photodarlington receiver may be used in a dc control or low frequency system. The output of the MFOD2302 drives a signal (MPS6515) transistor common emitter amplifier. This circuit operates from a +5 to +15 volt power supply, and its output is TTL and CMOS compatible.

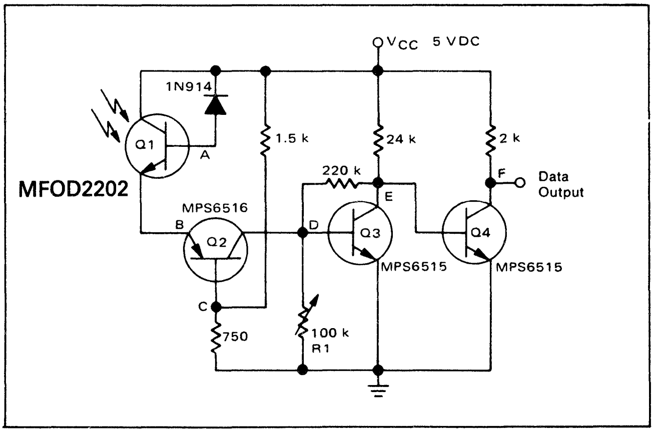
By the addition of a second transistor, the circuit described below may be extended in frequency from one Kilo-bit to two Kilo-bit.





PHOTOTRANSISTOR RECEIVER

The phototransistor receiver circuit shown below may be used for data rates up to 20 kilo-bit. The receiver sensitivity at 10 kilo-bits is 4.7 μW.



A MICROCOMPUTER DATA LINK USING FIBER OPTICS

The performance capability of fiber optics now offers the designer a practical, advantageous alternative to wire for data communications. The advantages of optical fibers over twisted pair or coax wire are easily enumerated:

1. *Bandwidth.* Standard optical fiber cable on the market today has bandwith up to several hundred MHz, and a few available cables are good up to several GHz.
2. *EMI Immunity.* Optical fibers neither radiate nor pick up electromagnetic interference. Thus, crosstalk and RFI-induced errors are eliminated. Optical fibers can be installed alongside high-voltage or high-current-carrying cables or in close proximity to EMI or RFI-intensive systems with no fear of interference. Recently proposed FCC regulations restricting the magnitude of EMI generation in data communication systems create no concern for users of fiber optics.
3. *Security.* Optical fibers are difficult to tap. Either the fibers must be broken to insert a tap or the cladding stripped to allow another fiber to contact the core and draw off some of the signal. Both methods are difficult to implement and easily detectable, so that optical-fiber-transmitted data is relatively secure.
4. *Size and Weight.* A one-kilometer reel of optical fiber cable of equal, and often greater data handling ability, weighs about one-tenth that of comparable coax cable. The optical fiber is considerably smaller, also, allowing significantly more signal-handling capability in the same cross-sectional area of a conduit or cable trough.
5. *Cost.* The price of optical fiber cable continues to drop while that of wire is seen to be facing a future of increasing cost. Even with optical fiber costing more than wire, the overall system cost with fiber optics is often lower.

This article describes a data communication system designed to demonstrate the ability to interconnect a series of microcomputer terminals with a fiber optic link.

System Hardware Requirements

The basic system in this example is illustrated in Figure 5. It uses a cost-effective transmitter and receiver design in a full-duplex, two-terminal arrangement using a pair of fibers for interconnect purposes. The basic system is easily expandable to multiple terminals, however, in a looping configuration shown in Figure 1. Here, the central control, or primary terminal, initiates data flow. The data then passes serially through the secondary terminals and returns back to the primary. Note that this loop arrangement results in any one terminal operating in a half-duplex, one-direction mode. Each secondary serves as a repeater network; that is, the received optical data is fed to the terminal and also retransmitted to the next terminal in the loop. As the data passes around the loop, any secondary recognizing its address in the address field of the Information Frame reads that frame and acts on it. The data continues to pass down the loop whether a terminal has acted on it or not. Secondary stations are given an opportunity to transmit local data when the central terminal transmits a "POLL" command. If a secondary desires loop control, it is granted by the primary by a "GO AHEAD" flag following a "POLL" command. Error detection and recovery are also governed by a full set of rules.

The Motorola EXORterm 220 M6800 development system serves as the basis for the system hardware. The EXORterm 220 is an intelligent CRT display terminal featuring an integral development facility that provides a motherboard and card cage capable of holding up to eight microprocessor modules. Each station is composed of standard M6800 microprocessor modules including an M6800 MPU Module, an MEX6816-22 16K Static RAM Module, an MEX68RR 8K ROM Module, and an MEX6850 ACIA Module interfaced to the CRT terminal. An MEX6854 Advanced Data Link Controller (ADLC) Module with fiber optic transmitter and receiver on-board provides the interface to the fiber optic link. This is shown in Figure 2.

The MC6854 ADLC performs the complex interface function between the MPU data bus and a synchronous communications channel employing a Bit-Oriented-Protocol. It is an NMOS LSI intelligent peripheral device that automatically performs many of the functions required by the communications protocol, thus reducing the amount of software required and increasing the data throughput rate.

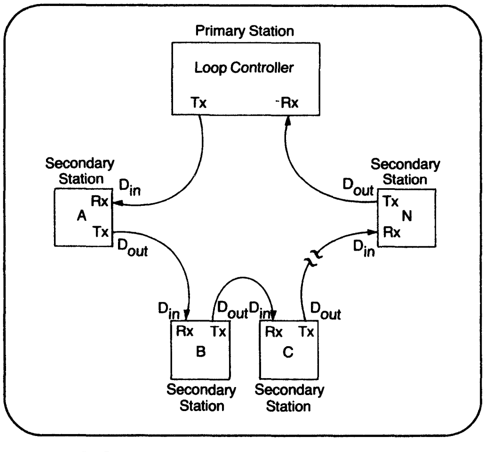


FIGURE 1 — Loop Configuration

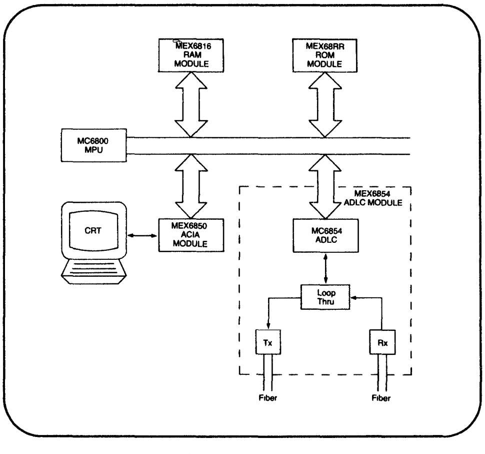


FIGURE 2 — Micromodule complement of an EXORterm 220, used as an intelligent CRT display terminal

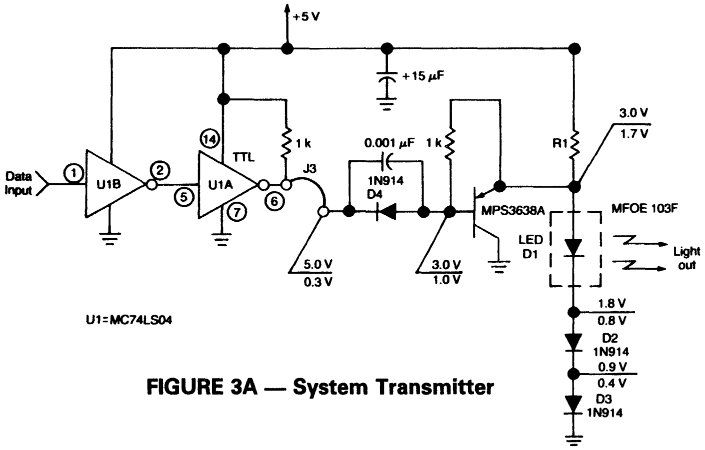


FIGURE 3A — System Transmitter

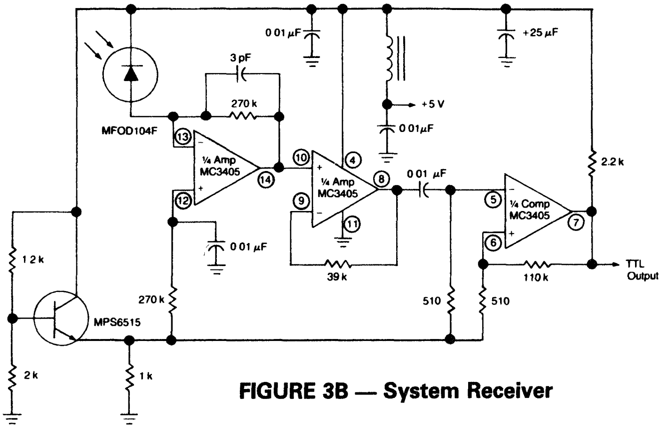


FIGURE 3B — System Receiver

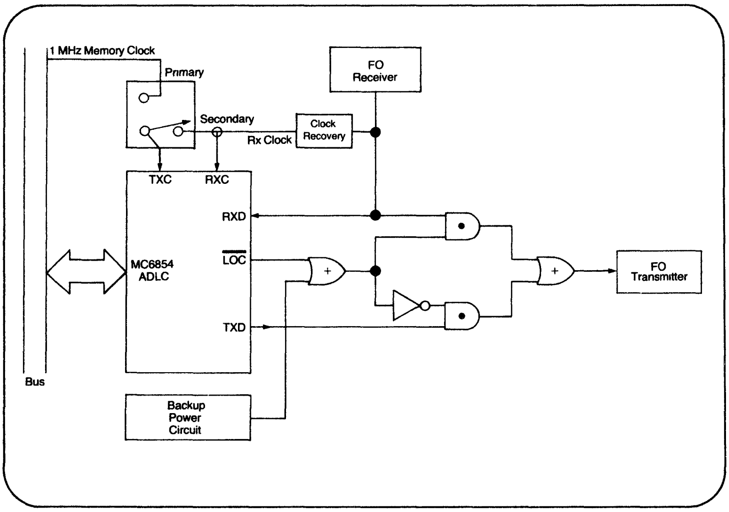
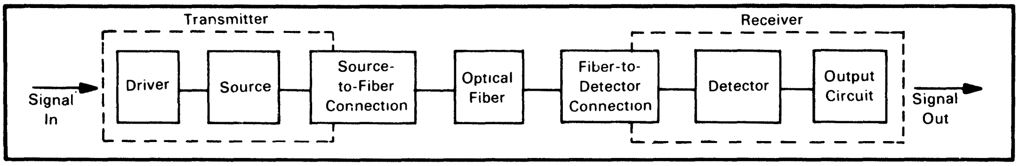


FIGURE 4 — Clock Recovery and Loop Through Circuit

FIGURE 5 — Basic Fiber Optic Link



Fiber Optic Transmitter and Receiver

The transmitter and receiver modules are built around the Motorola Fiber Optic Active Component (FOAC) products.[1] The transmitter uses an MFOE103F light emitting diode (LED). The receiver component is an MFOD104F PIN diode. The FOAC family and a compatible connector are joint developments of Motorola and AMP Inc. The concept (Figure 1) allows the user to efficiently interface to any of the many types and sizes of optical fibers on the market.

As shown in Figure 3, the transmitter and receiver are mounted directly to the ADLC Module. The driver circuit for the transmitter uses an MC74LS04 inverter and one discrete driver transistor. This circuit is capable of driving the LED at a 1-Mbit/second data rate.

Although the optical fiber is impervious to EMI, the actual receiver circuit is not. It is shielded, therefore, to prevent noise pickup. At 100 kHz, the receiver is capable of reception with a bit-error-rate of 10^{-9}.

The receiver sensitivity, transmitter power, and system losses (e.g., fiber attenuation) determine the maximum usable distance between terminals. This system was operated with a pair of 70-meter Siecor 155 cables, but was designed to operate up to 120 meters. System length and data rate might be increased with higher receiver sensitivity or increased transmitter power.

Transmitter and receiver are interfaced to the ADLC as shown in the clock recovery and loop-through circuit of Figure 4. The clock recovery circuit synchronizes a 1-MHz oscillator (divided down to the 62.5-kHz data rate) to the incoming data from the receiver. Both the data and the separated clock information are presented to the ADLC. The data rate clock is then also used to route data back to the transmitter so it can be sent to the next downstream station. In the event that power is lost to any terminal on the loop (power failure or maintenance operation), there is a provision for a separate power supply or battery pack to operate the receiver and transmitter circuits. The loop-through control then routes the receiver output directly to the transmitter input line so that repeater performance is maintained during terminal power-down.

System Software

Connecting a series of terminals together requires a well-defined and efficient communications protocol to manage the data link. For this system, a Bit-Oriented-Protocol — known as Synchronous Data Link Control (SDLC)[3] — was used. This protocol provides an efficient method for establishing and terminating the conversation between terminals, identifying senders and receivers, acknowledging received information, and error recovery.

A transmit sequence from the primary station to a secondary station starts with the transmission of the Information Frame (I-Frame) containing the address of the intended secondary station in the address field. When a secondary receives an I-Frame with its address, it reads that frame and stores it in a receive buffer. In SDLC, all frames contain a 16-bit error checking code which precedes the closing flag. The receiving station checks this error code to validate transmission accuracy and responds with the appropriate acknowledge or not-acknowledge frame when it sees a "GO AHEAD" flag. A secondary is permitted to suspend the repeater function and go "on loop" and transmit a frame only when it receives the "GO AHEAD" flag from the primary station.

In the two-terminal demonstration system, the M6800 MPU data throughput capability at 1-MHz operation limited the maximum data rate to about 75-kbit/second. By using an MC6844 Direct Memory Access Controller to reduce the amount of processor overhead in data handling, and by incorporating a receiver designed for higher bandwidth, data rates up to 1 Mbaud have been demonstrated. Since the optical fiber possesses such high bandwidth capability, the existing cable easily handles increased data rates or system upgrading. This demonstrates one of the big cost advantages of fiber optic communications.

Conclusion

A practical, cost-effective alternative solution to a specific applications problem has been discussed. As higher power LED's and more sensitive detectors and directional fiber couplers or splitters are introduced, even more flexibility will be in the hands of the system designer.

1. The FOAC line of components is described in Application Note AN-804, "Applications of Ferruled Components to Fiber Optic Systems." The Note is available from your Motorola sales representative or distributor.
2. AMP Bulletin HB5444, "Fundamentals of Fiber Optics."
3. IBM SDLC Document No. GA27-3093-1
4. Motorola Application Note AN-794, "A 20-Mbaud Full Duplex Fiber Optic Data Link Using Fiber Optic Active Components." Available late August from your Motorola sales representative or distributor.

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