Smart Battery Charging with COP8ACC

INTRODUCTION

The availability of embedded controllers with increased functionality, and performance for fewer dollars has resulted in their tremendous proliferation in virtually every electronic gadget we own in our households today. Many of these applications require a high resolution A/D converter for precision measurements of analog signals from the real world. A rapid conversion is often a necessity to allow ample time for the controller to sort, sample, analyze, and transmit the continuously varying analog signals. In today's battery chargers, the temperature, voltage, and charge current are often monitored to determine the state of the charge, and consequently, how to charge the batteries. These batteries require precision charging, for a slight overcharge can significantly reduce battery life. National's COP8ACC microcontroller with high resolution, high speed, and single slope A/D converter is well suited for the battery charger application.

BATTERY CHARGING

In the past few years, many new battery technologies have emerged. High demand has driven the technology toward lighter weight batteries with higher capacities. This has resulted in the evolution of many new battery chemistries and their emergence in portable applications, making chargers increasingly complex. We often see one application using multiple chemistries. This added complexity has induced a migration from chargers based solely on discrete components to chargers with embedded intelligence in low-cost 8-bit microcontrollers.

Inherent nonlinear characteristics of battery chemistries impose significant challenges to charger designers. Researchers have developed various intelligent charging algorithms that accurately charge batteries, providing maximum capacity after each charge, and increased overall battery life (increased number of cycles). Charging time has been reduced significantly. These algorithms require the microcontroller to monitor charge status as well as battery parameters. These parameters include, but are not limited to, battery voltage, temperature, and charge current. This information is manipulated by the algorithm to determine the required charge current, and to terminate charging accurately. Accurate charge termination is critical, for premature termination means less usage time, and over-charge results in significant battery damage.

FEATURES OF COP8ACC

The COP8ACC integrates up to 6 channels of a high resolution, single slope A/D converter, a key feature for intelligent chargers. This device also offers a processor-independent PWM timer for easy, accurate control of the charge current. Up to 4 kbytes of program memory suffices to embed complex intelligent charge control algorithms. Often, chargers display the state of charge with LEDs. High sink/source capability on up to 4 pins provides that capability. The Microwire circuit allows simple serial communication to the battery pack's internal circuitry, or an EEPROM. Additionally, two low power-consumption modes (halt and idle) provide all the necessary ingredients for a battery charging application.

ANALOG TO DIGITAL CONVERSION

Figure 1 shows a block diagram of the single slope, comparator based A/D converter. Using this approach an A/D converter can be configured by using only a single external capacitor. This capacitor provides the designer flexibility in controlling the resolution and conversion time. The external capacitor should be grounded on one side, and the positive terminal should be reset to 0V by momentarily shorting the capacitor through software control. An internal $V_{CC}/2$ reference can be used to calibrate the A/D conversion. For a more accurate reference, the designer has the option to use one of the available analog input channels for this purpose, by supplying to it a known external voltage. At the beginning of a conversion cycle, the constant current source starts charging the capacitor. The voltage across the capacitor increases linearly. When this voltage exceeds the sampled voltage at the positive terminal of the comparator, the comparator output toggles to stop the capture timer. The value in the capture timer is analogous to the sampled voltage. The capture timer is clocked directly by CKI (the clock input of the COP8ACC) at up to 10 MHz frequency. This provides a high speed conversion time.

The slope of the increasing voltage can be controlled by controlling the size of the capacitor. This in turn controls the time it takes for the comparator output to toggle. Longer time to toggle translates to a more accurate or a higher resolution conversion.

The resolution of this A/D converter can be calculated by,

$Xres_{(min)} = \log_2 (CdV/ Imax\ tc)$, where C = value of capacitance (nF)   (2)

Imax = max. current from current source (A)

dV = range of channel input voltage (V)

tc = ext. clock cycle time or period (CKI = < 10 MHz) (sec)

Xres = resolution of conversion (bits)

Based on the above formulas, a minimum resolution of approximately 10 bits can be reached, when using 4 nF capacitor, with an external clock of 4 MHz, a dV of 2.5V, and a maximum current of 35 µA. The constant current on this device is specified to be in the range of 7 µA to 35 µA. A typical value for this current is about 20 µA. The conversion time for the above scenario can be calculated using the following formula,

$t_{conversion} = 2^{Xres(min)} \cdot tc$ (3)

The conversion time for this scenario turns can be calculated to be approximately 0.26 ms. *Table 1* shows various clock speeds versus conversion time, resolution, and achievable accuracy. The accuracy of the conversion depends on noise, drifting of RC clock, inaccuracies in the voltage reference, etc.

| TABLE 1. Clock Speed vs Resolution, Conversion Time, and Achievable Accuracy			
Clock Speed	**Resolution**	**Conversion Time**	**Achievable Accuracy**
10 MHz	12 Bits	0.410 ms	±2.0 LSB
10 MHz	8 Bits	0.026 ms	±1.0 LSB
5 MHz	13 Bits	1.640 ms	±2.5 LSB
4 MHz	10 Bits	0.260 ms	±1.5 LSB
2 MHz	11 Bits	1.300 ms	±1.5 LSB
1 MHz	12 Bits	4.100 ms	±1.5 LSB
1 MHz	10 Bits	1.025 ms	±1.0 LSB
1 MHz	8 Bits	0.260 ms	±1.0 LSB
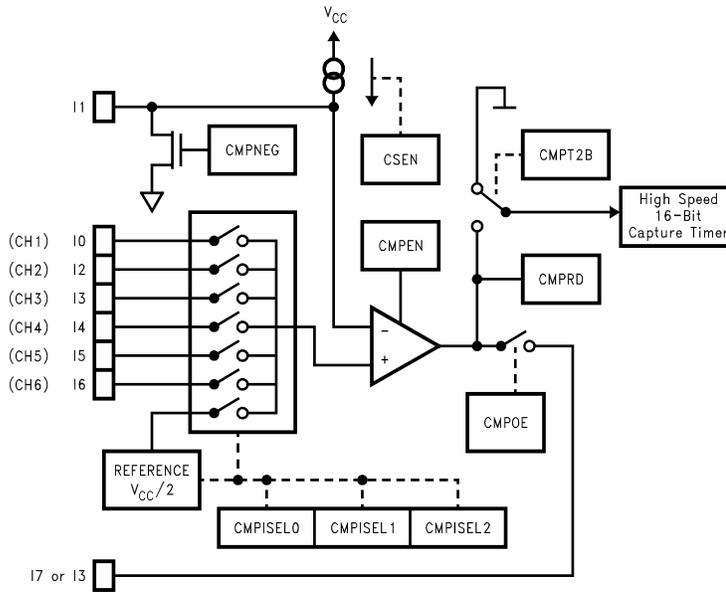
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FIGURE 1. Analog Function Block

USING THE COP8ACC IN A BATTERY CHARGER

Here we present a NiMH/NiCD dual chemistry charger as an example. The COP8ACC A/D channels monitor battery pack voltage, and temperature. These are two essential parameters used in most battery charging algorithms. A temperature sensor in the battery pack provides one of the inputs, and reading the battery terminal voltages provide the other. The rest of the analog input pins can optionally be used as general purpose digital inputs. Intelligent charge control algorithm can be embedded in the COP8ACC. Based on the current battery voltage and temperature, the COP8ACC controls the current source to feed the required amount of current into the battery pack. Both Ni based chemistries exhibit a drop in voltage and a sudden rise in temperature as the battery begins to over charge. The temperature effect is more pronounced in NiMH batteries. This slope of the voltage drop and/or the slope of the temperature rise can be monitored to determine the charge termination point. However, detection of such events signify that the battery is already in a state of overcharge, and some damage has been done. More advanced algorithms exist to determine more accurate termination points. Such algorithms are beyond the scope of this paper.

Up to four D port pins provide high source/sink capability to drive LEDs, which are often used to display the state of the charge. Various techniques exists to determine the state of the charge. These could range from a very crude determination based upon the battery voltage, or a more sophisticated mechanism where the sum of current into and out of the battery is monitored to determine a more accurate state. Often a mixture of these two parameters are used to determine very accurately how much charge is left in the battery.

Even for a given battery chemistry, the batteries from different manufacturers show significantly different behavior. More advanced battery chargers store specific manufacturer or pack specific information to enable better charging. Manufacturer specific chemistry related information can be obtained by testing/characterizing many batteries from the same manufacturer. These parameters can be stored in an

external EEPROM as shown in the block diagram. The Microwire feature on the COP8ACC requires minimal software overhead to communicate with the EEPROM. Optionally, a reference for the A/D converter can be stored here for more accurate conversion. On the other hand, some battery packs contain intelligence in them to monitor its status. Battery abuse, battery age, and other parameters can be monitored by the battery itself.
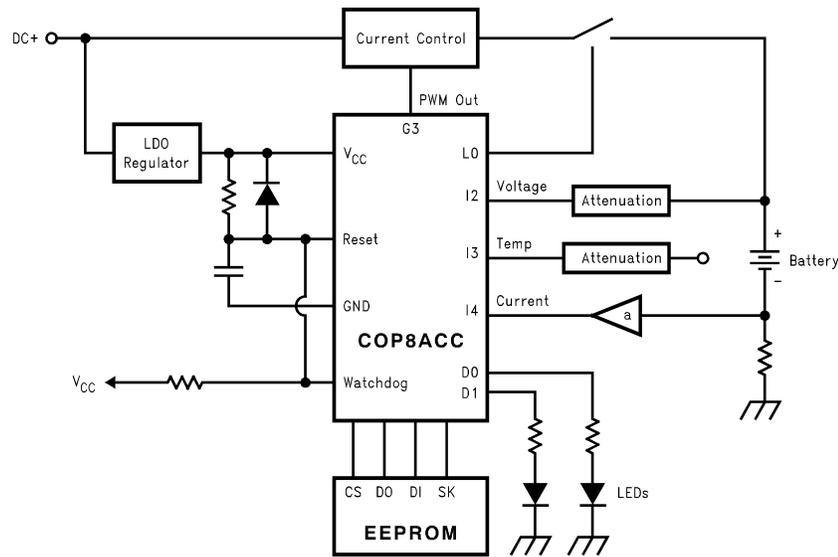

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FIGURE 2. Block Diagram of a Battery Charger Application

Figure 3 shows the flow chart of the embedded software for a battery charging application.

```
        ┌─────────┐
        │  start  │
        └─────────┘
             │
             ▼
    ┌──────────────────┐
    │  read battery    │
    │    voltage       │
    └──────────────────┘
             │
             ▼
    ┌──────────────────┐
    │ calculate battery│
    │  voltage slope   │
    └──────────────────┘
             │
             ▼
    ┌──────────────────┐
    │  read battery    │
    │   temperature    │
    └──────────────────┘
             │
             ▼
    ┌──────────────────┐
    │ calculate battery│
    │ temperature slope│
    └──────────────────┘
             │
             ▼
         ╱ charge ╲
        ╱termination╲    Yes    ┌──────────────┐
       ╱   point     ╲─────────▶│  terminate   │
       ╲  reached?   ╱          │   charging   │
        ╲           ╱           └──────────────┘
         ╲  No     ╱
             │
             ▼
    ┌──────────────────┐
    │ calculate required│
    │  charge current  │
    └──────────────────┘
             │
             ▼
    ┌──────────────────┐
    │   Adjust PWM     │
    │ output to adjust │
    │  charge current  │
    └──────────────────┘
             │
             ▼
        ┌───────────┐
        │ go to start│
        └───────────┘
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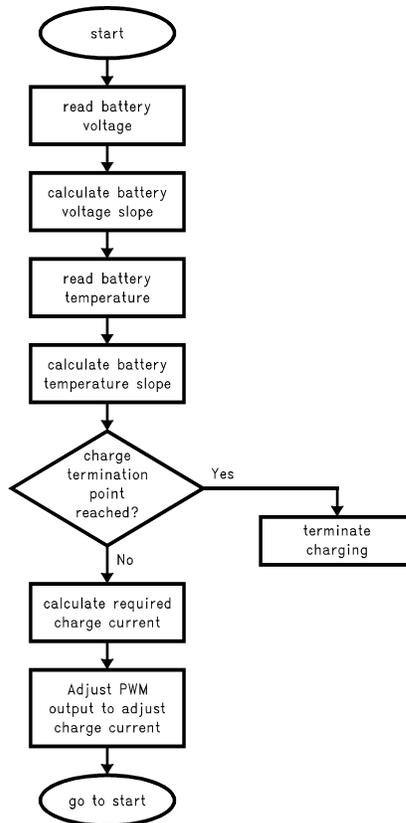
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FIGURE 3. Flow Chart of The Software for A Battery Charger Application

CONCLUSION

The features of the COP8ACC were tailored for intelligent battery charging applications. The A/D converter provides a highly efficient, high resolution, cost effective A/D conversion required for such applications. Many algorithms exists for charging the various chemistries available. These algorithms offer various tradeoffs to the application engineer. However, a growing demand for long battery life and faster charge times have spawned new research for more intelligent algorithms. These algorithms are often more complex and require sufficient programming space. The 4k ROM space can be used to embed various intelligent algorithms.
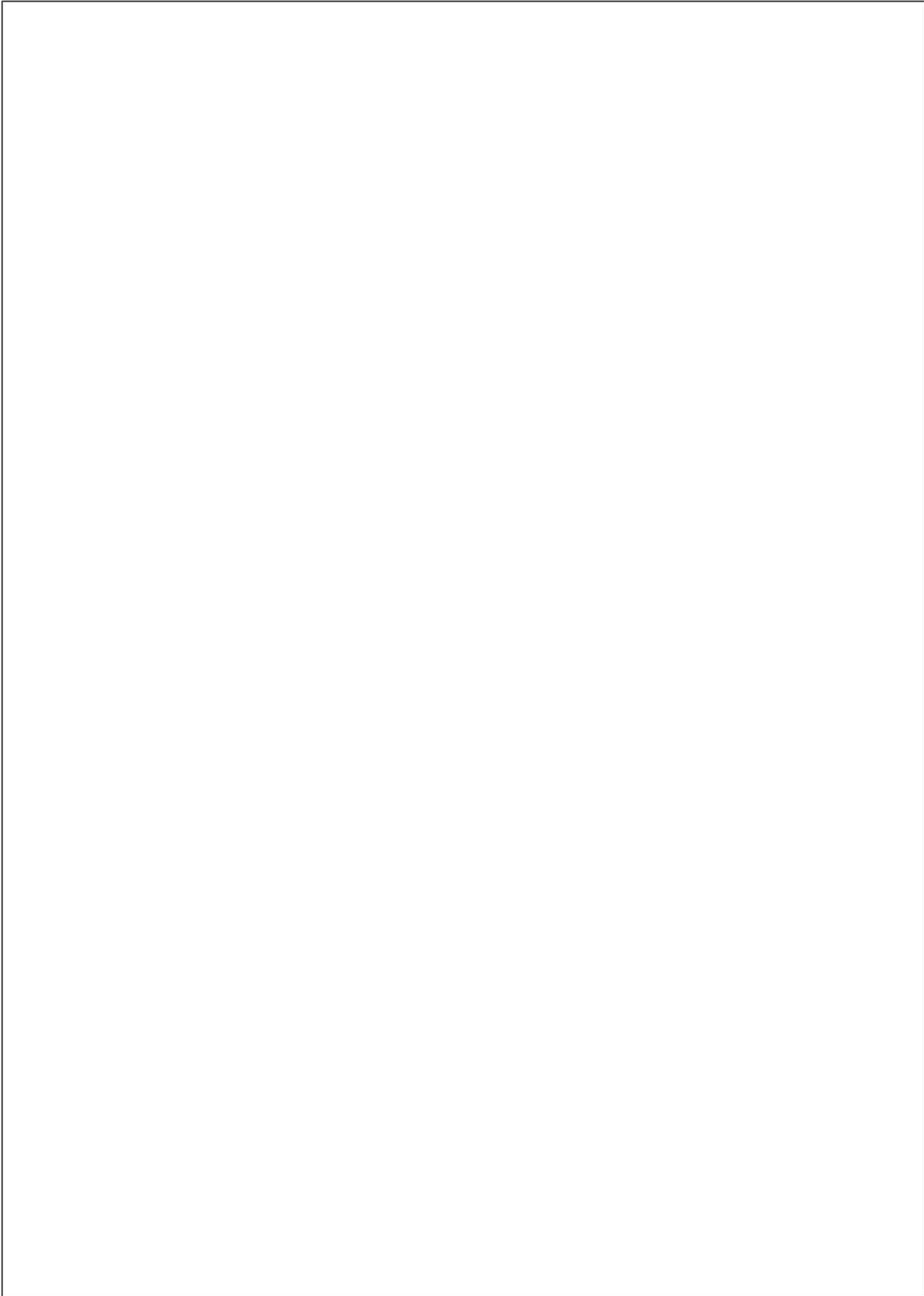
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