



Application Note

Z8 Encore! XP[®]-Based NiCd Battery Charger

AN022103-0608



Abstract

This Application Note describes Zilog's Z8 Encore! XP[®]-based Nickel Cadmium (NiCd) battery charger. The battery charger application uses the internal clock of the Z8 Encore! XP microcontrollers unit (MCU) as the system clock. An internal reference voltage of 2 V is applied to the ADC peripheral of the Z8 Encore! XP MCU.

- **Note:** *The source code file associated with this Application Note, AN0221-SC01.zip, is available on www.zilog.com.*

Z8 Encore! XP 4K Series Flash Microcontrollers

Zilog's Z8 Encore![®] products are based on the new eZ8[™] CPU and introduce Flash memory to Zilog's extensive line of 8-bit MCU. Flash memory in-circuit programming capability allows faster development time and program changes in the field. The high-performance register-to-register based architecture of the eZ8 core maintains backward compatibility with Zilog's popular Z8[®] MCU. Z8 Encore! MCUs combine a 20 MHz core with Flash memory, linear-register SRAM, and an extensive array of on-chip peripherals.

The Z8 Encore! XP 4K Series of devices support up to 4 KB of Flash program memory and 1 KB register RAM. An on-chip temperature sensor allows temperature measurement over a range of 40 °C to +105 °C. These devices include two enhanced 16-bit timer blocks featuring Pulse Width Modulation (PWM), Capture and Compare capabilities. An on-chip Internal Precision Oscillator (5 MHz/32 KHz) is used as a trimmable clock source requiring no external components. The Z8

Encore! XP devices include 128 bytes of Non Volatile Data Storage (NVDS) memory where individual bytes are written or read. The full-duplex UART, provides serial communications, Infrared Data Association (IrDA) encoding and decoding capability, and supports multidrop address processing in hardware.

The on-chip peripherals make the Z8 Encore! XP MCUs suitable for a variety of applications including motor control, security systems, home appliances, personal electronic devices, and sensors.

Discussion

This section discusses the functionality of the Z8 Encore! XP-based battery charger application in detail. For detailed information about NiCd battery technology, see [Appendix D—Battery Technology](#) on page 14.

Theory of Operation

At the core of a battery charger is the DC–DC converter (also known as a buck converter) that acts as a regulated power source. The charger hardware is capable of regulating the charger output in a number of modes, such as constant voltage, constant current, or constant voltage with a current limit. The charger is a control system in itself. The type and capacity of the battery determines the mode of operation of the battery controller—namely, a constant current source or a constant voltage source. The voltage (V_{SET}) and current (I_{SET}) set points are also determined by the type and capacity of the battery.

The parameters, current and voltage, are controlled using the PWM technique. In the PWM technique, the frequency of the signal is maintained constant,

and the width of the pulse or the duty cycle of the signal is varied. This variation is reflected as a change in voltage and/or current at the output. The switching regulator reads the parameters through a feedback circuit, and the battery controller operates based on the control algorithm.

The PWM output is obtained by comparing the actual value of the parameter under control with the corresponding set point. In the constant voltage mode, the converter voltage is compared with the voltage set point. In contrast, in the constant current mode, the voltage developed by the charging current across a sense resistor is compared with the current set point. The feedback loop maintains the converter voltage or the converter current constant depending on the selected mode of operation.

Controllers are differentiated based on the method of regulation of parameters in accordance with the corresponding set points. For detailed information about battery controllers, see the related document provided under the Electronics topic in [References](#) on page 6. In a proportional controller, the actual value and the set value are compared, and the resulting error value is used. The drawback of a proportional controller is the possibility of a steady state error. Adding an integral component to the control algorithm eliminates this error.

The equation for a proportional plus integral (PI) controller is:

$$x(t) = (k_1 \times e(t) + k_2 \times \int e(t)dt)$$

To be useful for a microcontroller-based (discrete) system, the integral is approximated by a running sum of the error signal. Therefore, an equation in the differential form is expressed as follows in Equation 1:

$$u[k] = \left(C1 \times e[k] + C2 \times \sum_{j=0}^{k-1} e[j] \right)$$

Where, C1 and C2 are constants.

Equation 1 is the position algorithm. A better representation of Equation 1 is explained in Equation 2, as follows:

$$U[k-1] = \left(C1 \times e[k-1] + C2 \times \sum_{j=0}^{k-2} e[j] \right)$$

Subtracting Equation 2 from Equation 1 and rearranging the terms yields Equation 3, as follows:

$$u[k] - u[k-1] = (Kp \times e[k] + Ki \times e[k-1])$$

Where, Kp and Ki are the proportional and integral constants, respectively.

Equation 3 is the velocity algorithm, and is a convenient expression as only the incremental change in the manipulated variable is calculated.

The charging algorithms are designed based on the type of battery and the current state of charge for that battery. The basic charging methods are constant current and constant voltage charging. The NiCd and Nickel Metal Hydride (NiMH) batteries are charged using the constant current method.

In the constant current mode, fast charging occurs when the charging current equals the rated battery capacity, C. Fast charging requires constant monitoring of battery parameters and precise termination techniques. It is therefore important to know when to terminate charging. In the NiCd battery charger application, the battery parameters are constantly monitored, and the negative ΔV termination technique is used. As a result, the NiCd battery charger ensures the safety of the battery. For detailed information about termination techniques associated with NiCd batteries, see [Appendix D—Battery Technology](#) on page 14.

Developing the Application with the Z8 Encore! XP MCU

This section provides an overview of the functional architecture of the NiCd battery charger implementation using the Z8 Encore! XP MCU.

Hardware Architecture

Figure 1 displays a hardware block diagram for the battery charger application. The Z8 Encore! XP-based NiCd battery charger application features the following hardware blocks:

- Z8 Encore! XP Development Board
- External power source (32 V, 3 A)
- Step-down DC–DC (buck) converter
- Feedback section (analog design)
- NiCd battery

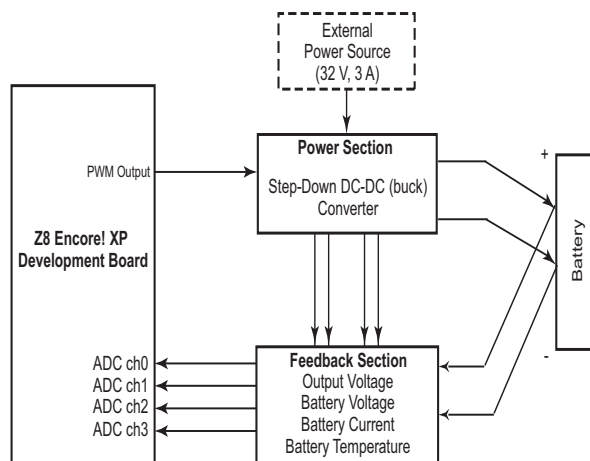


Figure 1. Block Diagram of Battery Charger Hardware

The battery charger application uses Port B on the Z8 Encore! XP MCU as ADC inputs. Timer 1 is used in PWM mode and the output is tapped at the PC1/Timer 1 output pin. The system clock is

derived from the internal precision oscillator of the Z8 Encore! XP MCU. The reference voltage required for the ADC is generated internally by the Z8 Encore! XP MCU, hence the external component requirement and the Bill of Material (BOM) cost is reduced.

The step-down DC–DC (buck) converter provides a voltage or current appropriate to the NiCd battery. The buck converter modulates a higher voltage (from the external source) with a varying pulse width (PWM method) to generate a lower voltage. The pulse width is controlled by the control algorithm based on the values obtained from the feedback section.

The feedback section consists of four differential amplifiers/attenuators. The parameters controlled by the first three amplifiers are the converter voltage (V_{OUT}), the battery voltage (V_{BATT}), and the battery current (I_{BATT}). The battery current and the converter current are same. The fourth differential amplifier is used for temperature measurement in the case of batteries featuring built-in temperature sensors.

For schematic diagrams associated with the battery charger application, see [Appendix B—Schematics](#) on page 8.

Software Implementation

All Z8 Encore! XP peripherals are initialized from their power-on state to the required mode of operation. After initialization, the battery parameters are loaded into the variables. These battery parameters are defined in the `charger.h` header file.

The safety and termination thresholds are calculated based on the battery parameters. The set points for the DC-DC step-down (buck) converter voltage, the current, and the current limit are calculated. After these one-time calculations are complete, the charger software enters into an infinite loop, which is broken only by a successful charge completion or a safety error.

Inside the infinite loop, the ADC reads the actual values for the converter output voltage, the battery voltage, the current, and the temperature (temperature is measured only if the battery features a temperature sensor). The ADC measures the output voltage and the output current of the DC–DC converter as feedback to the controller. The ADC also measures the voltage at the battery terminals as an input to determine the charge termination. Measurement of the output voltage, the output current, and the battery voltage are the basic measurements. The current across the battery terminals is same as the measured converter output current. For batteries featuring built-in temperature sensors, the charger reads the battery temperature in addition to the basic measurements. The temperature measurement is significant from the safety point of view.

After the actual values (V_{OUT} , V_{BATT} , and I_{BATT}) are determined, they are checked for safety limit compliance. The safety routine is responsible for the overall safety features associated with the battery charger. The charger ensures safety by comparing the actual converter voltage, the battery voltage, and the battery temperature with the calculated thresholds. Crossing these thresholds switches off the PWM output, which turns off the converter output and terminates charging functions. Such termination protects the batteries in the case of a device failure.

If all the actual values are within limits, the battery is tested for full charge. NiCd batteries are considered to be completely charged if the voltage level, as indicated by [Figure 2](#), produces a distinctive rise over a period of time, then a decrease.

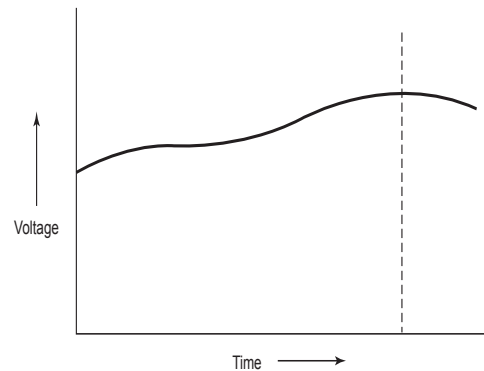


Figure 2. Voltage Levels as a Function of Time

The dashed line in [Figure 2](#) represents where a decrease in voltage occurs. At this point, maximum charge has been reached; charging then terminates. If, however, the battery is not completely charged, the duty cycle required for maintaining the set-points at the converter output is calculated by a control algorithm.

This control algorithm implements PI control to derive a PWM output based on the equations presented in the [Theory of Operation](#) on page 1. The timer ISR is invoked every 5 ms. The PWM value computed by the control algorithm is loaded into the PWM generators to be transmitted via the output pin. The 16-bit timer PWM mode offers a programmable switching frequency based on the reload value. This flexibility allows you to trade off between accuracy and frequency of the PWM switching signal. A lower frequency results in a higher reload value and a higher resolution in the pulse width variation. The reverse is also true. The timer ISR also updates the charge termination variables every 10 s.

For flowcharts related to the battery charger application, see [Appendix C—Flowcharts](#) on page 12.

Testing

This section discusses the setup, equipment used, and procedure followed to test the Z8 Encore! XP-based NiCd battery charger application.

Setup

The test setup for the Z8 Encore! XP-based NiCd battery charger application is described in [Figure 3](#).

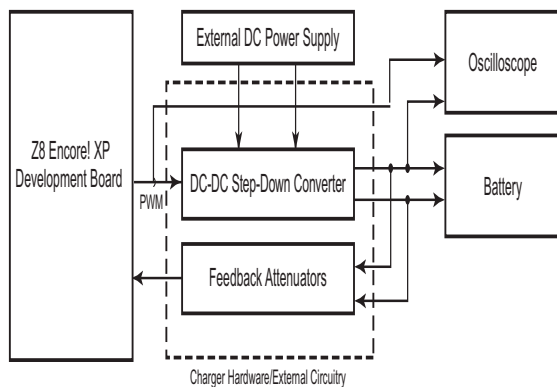


Figure 3. Battery Charger Test Setup

The test setup comprises of a Z8 Encore! XP Z8F042A Development Board, a NiCd battery that must be charged, an oscilloscope, an external DC power supply, and a DC-DC step-down (buck) converter. A feedback circuit comprised of differential amplifiers or attenuators also forms a part of the test setup.

The external DC power supply provides two different voltages to the charger circuits—the DC–DC step-down converter and the feedback attenuators. The operational amplifier-based feedback attenuator circuits are fed with a 12 V supply. The DC–DC converter works on a 8 V to 12 V DC input for the batteries tested. The control algorithm provides the necessary line regulation to sustain the voltage variation at the input.

Equipment Used

The equipment used to test the Z8 Encore! XP-based NiCd battery charger are listed in [Table 1](#).

Table 1. Battery Charger Test Equipment

System Equipment	
Z8 Encore! XP 4K Series Development Kit	(Z8F042A28100KIT)
External power supply	Make: Aplab, Model: LQ 6324
Test Equipment	
Oscilloscope	Make: Tektronix, Model: TDS 724D; 500 MHz / 1 GSps
Multimeter	Make: Motwane, Model: DM3750
Batteries Used for Testing	
BP–T16	Make: Sony, Type: NiCd, Ratings: 3.6 V, 270 mAh

Procedure

To test the Z8 Encore! XP-based NiCd battery charger application, perform the following steps:

1. Download the AN0221-SC01.zip file from www.zilog.com. Extract its contents to a folder on your PC.
2. Launch ZDS II for Z8 Encore!.
3. Make the hardware connections as described in [Figure 3](#) and the schematics provided in [Appendix B—Schematics](#) on page 8.
4. Connect the battery to be charged across the provided battery terminals (see [Appendix B—Schematics](#) on page 8).
5. Apply the required voltages to the appropriate circuits as described in the section [Setup](#) on page 5.
6. Download the battery charger code to the Z8 Encore! XP Flash memory using ZDS II–IDE.
7. Execute the battery charger code.

8. Observe the PWM waveforms on the oscilloscope.

Results

The charging of the battery began in the constant current mode with the charging current equal to 1 C. The charging is terminated when the battery voltage increases to a peak and then decreases (negative ΔV termination technique).

Summary

This Application Note discusses a NiCd battery charger implementation using the Z8 Encore! XP MCU. The battery charger software provides fast charging algorithms. Fast recharge is possible due to the accurate monitoring of the charging rendered by the 10-bit accuracy of the ADC. Monitoring the charging mechanism facilitates the accurate termination of charging. Therefore, overcharging is prevented, resulting in a longer battery life. Additionally, the PWM technique facilitates an accurate DC-DC (buck) step-down converter implementation with excellent line/load regulation.

References

The documents associated with Z8 Encore! XP[®], eZ8[™], and ZDS II available on www.zilog.com and electronics references are provided below:

- Digital Control Systems, Volume 1—Fundamentals, Deterministic Control; Author: Rolf Isermann, ISBN: 0-387-50266-1, Publisher: Springer Verlag
- Zilog Developer Studio II-Z8 Encore![®] User Manual (UM0130)
- eZ8[™] CPU User Manual (UM0128)
- Z8 Encore! XP[®] F082A Series Product Specification (PS0228)
- Z8 Encore! XP[®] F042A Series Development Kit User Manual (UM0166)
- Power Electronics Design Handbook: Low Power Components and Applications; Author: Nihal Kularatna, ISBN: 0-7506-7073-8, Publisher: Oxford: Newnes, 1998
- High Frequency Switching Power Supplies: Theory and Design; Author: George Chryssis, ISBN: 0-07-010949-4, Publisher: McGraw-Hill Book Company

Appendix A—Glossary

Definitions for terms and abbreviations used in this Application Note that are not commonly used are listed in [Table 2](#).

Table 2. Glossary

Term/Abbreviation	Definition
1C	A charging current rate equal to the A-hr rating of the battery
ADC	Analog-to-Digital Converter
ISR	Interrupt Service Routine
Li-Ion	Lithium Ion
mAh	milli-Ampere-hour: the unit of battery capacity
NiCd	Nickel Cadmium
NiMH	Nickel Metal Hydride
PI	Proportional and Integral
PWM	Pulse Width Modulation
SLA	Sealed Lead Acid



Appendix B—Schematics

The schematics in Figure 4 displays the Z8 Encore! XP MCU pin diagram.

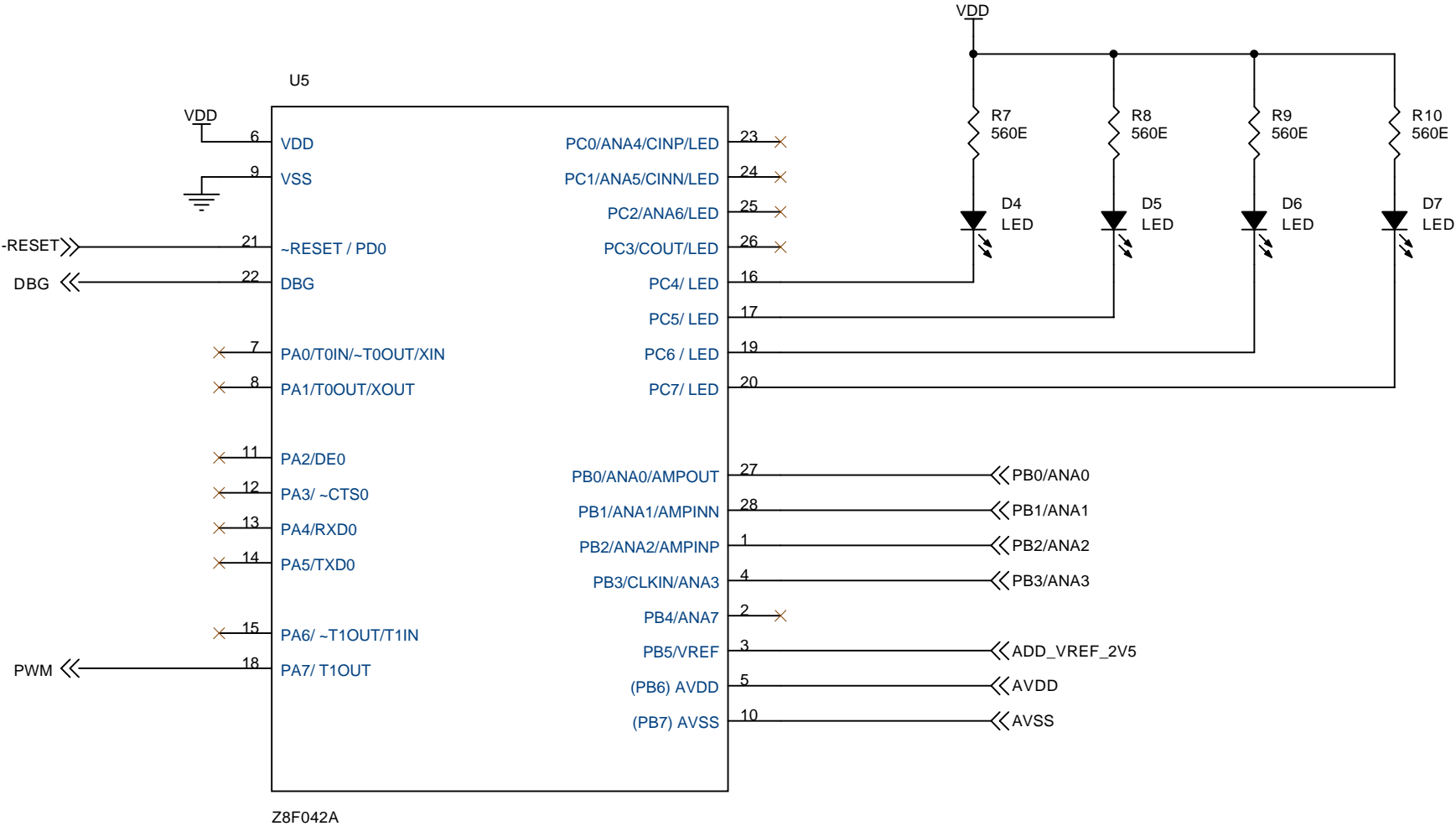


Figure 4. Schematic Displaying the Z8 Encore! XP MCU Pin Diagram

The schematic diagram in [Figure 5](#) displays the external circuitry for the battery charger application.

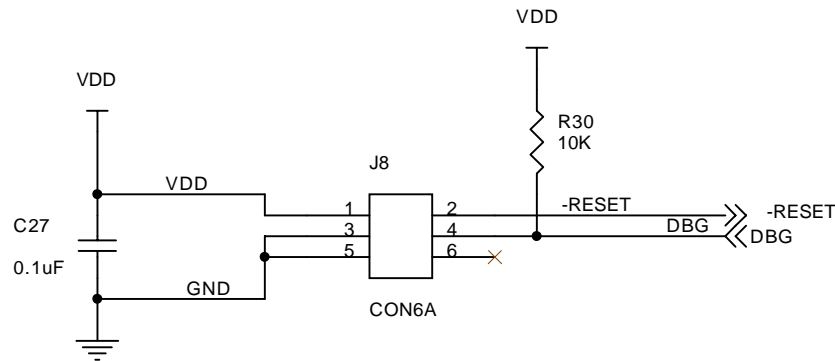
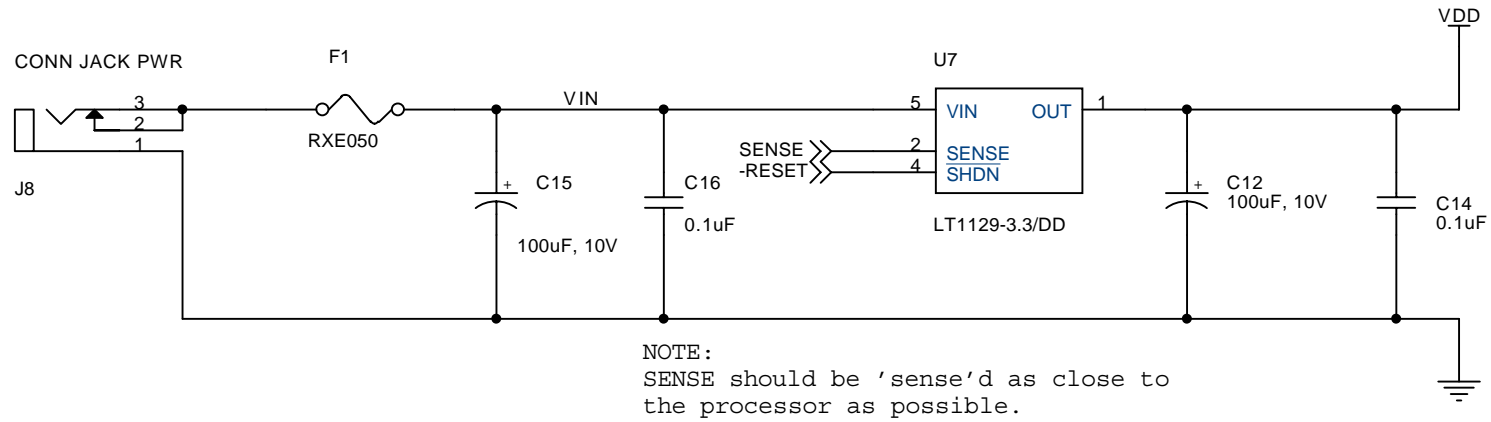
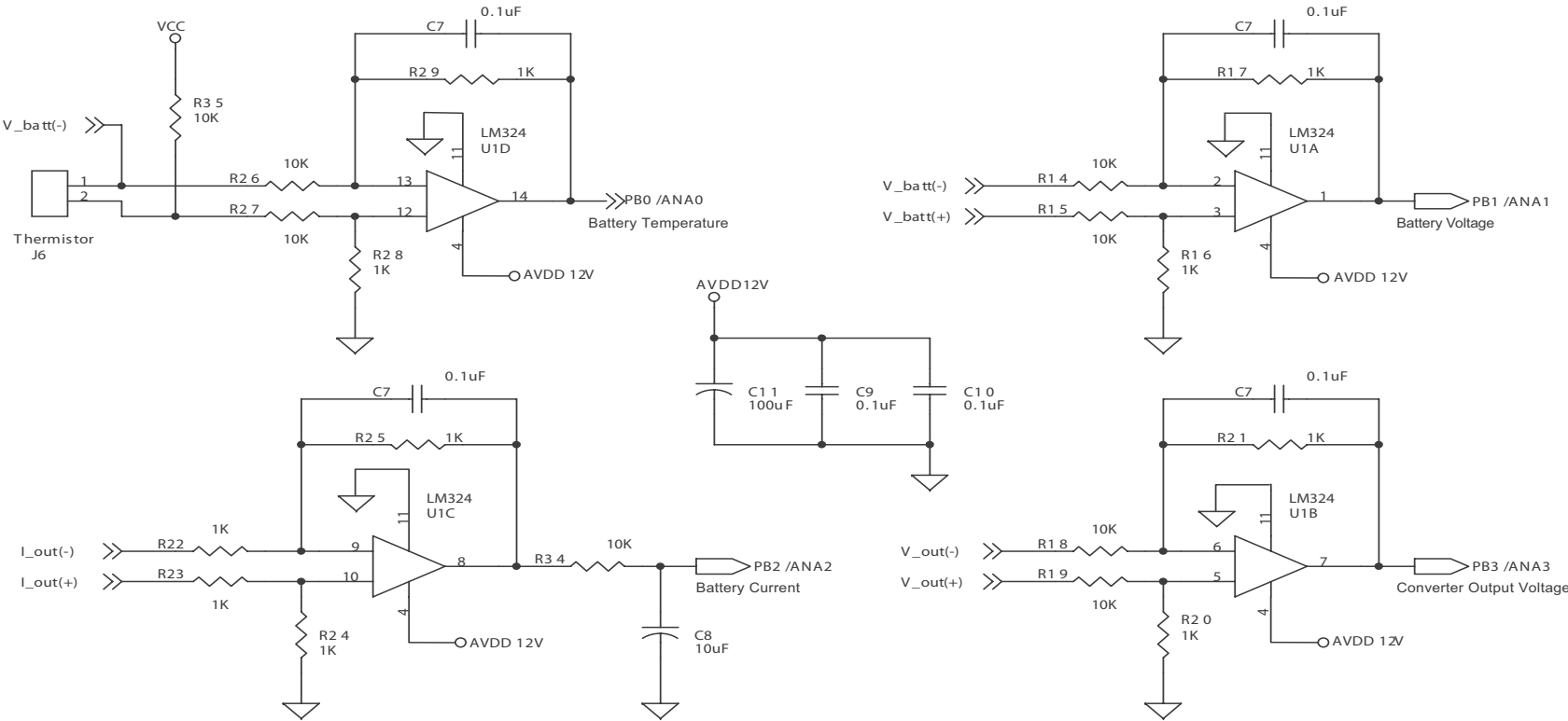


Figure 5. Schematic Displaying the External Circuitry for the Battery Charger Application



The schematic diagram in Figure 7 displays the feedback circuits for the battery charger application.



NOTE:
For Testing the AVDD12V is obtained from External Power Source.

Figure 7. Schematic Displaying the Feedback Circuits

Appendix C—Flowcharts

This appendix provides flowcharts for the battery charger application described in this document. [Figure 8](#) explains a flowchart of the main routine for the battery charger application. The main routine involves calculation of safety limits, thresholds, duty cycle, reading of feedback values for battery voltage, charging current, and converter voltage.

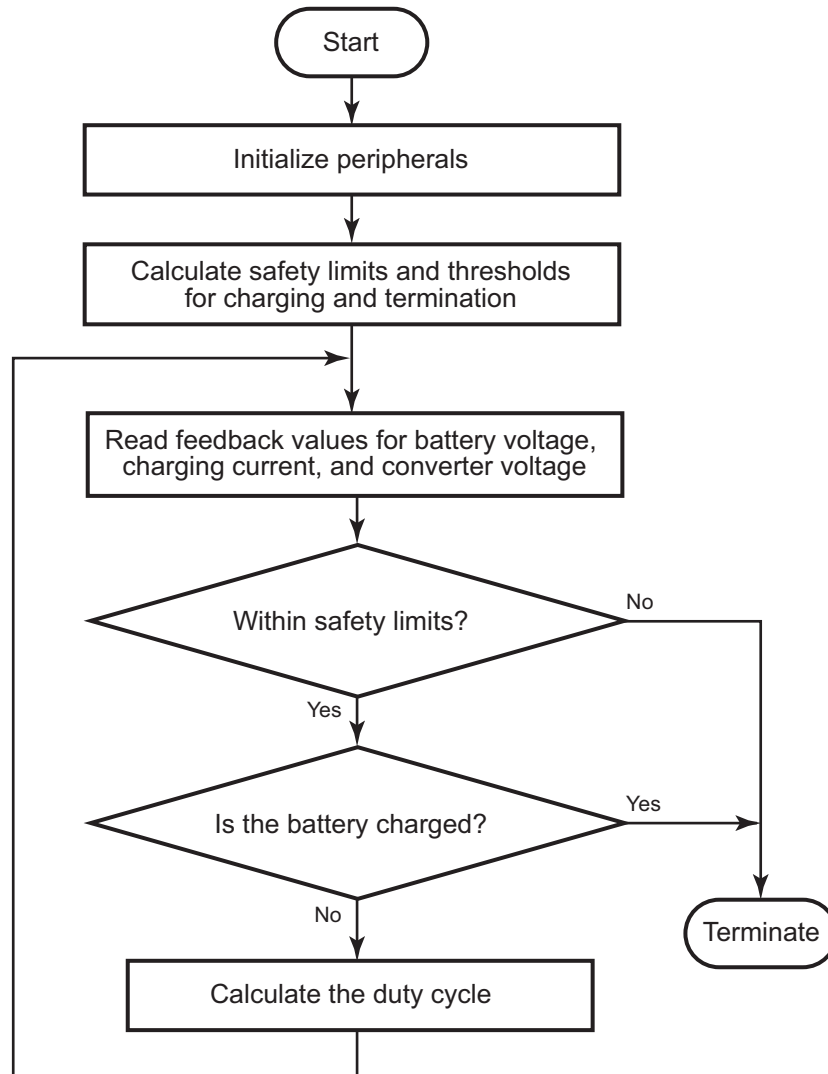


Figure 8. The Main Routine

Figure 9 presents a flowchart of the Interrupt Service Routine (ISR) for reloading the PWM value and updating the charge termination data.

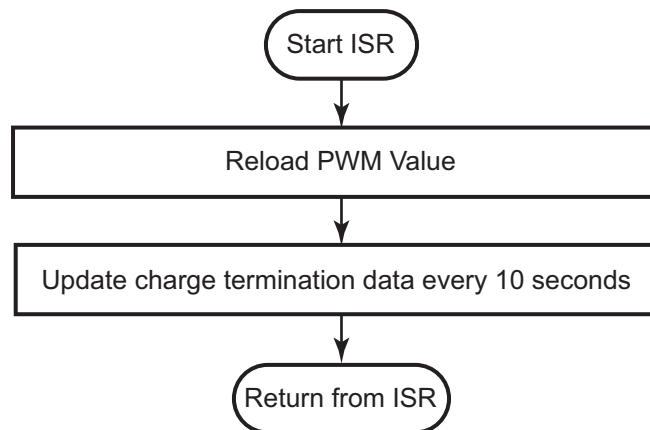


Figure 9. The ISR Return Routine

Appendix D—Battery Technology

The four mainstream battery chemistries (NiCd, NiMH, SLA, and Li-Ion) feature different charging and discharging characteristics. Long-term battery life and performance are critically dependent up on how batteries are charged. Therefore, it is important to charge batteries with a mechanism specific to their requirements.

It is also important to know when to terminate charging, because overcharging of a battery invariably results in poor performance and can damage the battery in extreme cases. Moreover, different battery types function differently near full charge condition, and therefore require specific charge termination techniques. During charging, all batteries exhibit a marked rise in voltage above the rated battery voltage.

The two major rechargeable battery types—NiCd and NiMH, are briefly discussed below. For more information, see [References](#) on page 6.

Nickel Cadmium

NiCd batteries are used in camcorders, walkmans, and other portable consumer electronic equipment. The voltage/cell ratio for a NiCd battery is 1.2 V. NiCd batteries are charged using the constant current charging method. If the voltage crosses the full-charge point during charging, the charging current drops to 15 mV/cell. This voltage drop represents the full-charge condition. Charging is terminated when the battery is in full-charge condition. NiCd batteries use the negative ΔV charge termination technique. During charging, the battery voltage rises to 1.65 V/cell. Therefore, the battery must be discharged periodically to ensure that the battery functions efficiently. This is memory effect.

Nickel Metal Hydride

NiMH batteries exhibit high power density compared to NiCd batteries. The voltage/cell ratio for a NiMH battery is 1.2 V. NiMH batteries are charged using the constant current charging method. If the voltage crosses the full-charge point during charging, the charging current drops but this drop in charging current is not as low as that in the case of NiCd batteries. Therefore, the negative ΔV charge termination technique is not recommended for NiMH batteries. NiMH batteries exhibit plateau characteristics after a minimal drop in the voltage. This flat region of the battery characteristics represents the full-charge condition. Therefore, the charge termination technique used in NiMH batteries is termed as zero ΔV . NiMH batteries do not exhibit memory effect, these batteries are used in consumer durables such as cell phones. NiMH batteries are more expensive compared to NiCd batteries as they are lighter in weight and are not prone to memory effect.



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