



Z8 Encore! XP[®]-Based Lithium Ion Battery Charger

AN021802-0708

Abstract

This Application Note describes Zilog's Z8 Encore! XP[®]-based Lithium (Li)-Ion battery charger. The battery charger application uses the internal clock of the Z8 Encore! XP MCU as the system clock. An internal reference voltage of 2 V is applied to the Analog-to-Digital Converter (ADC) peripheral of the Z8 Encore! XP MCU.

► **Note:** *The source code file associated with this Application Note (AN0218-SC01.zip), is available for download at www.zilog.com.*

Z8 Encore! XP F042A Series Flash Microcontrollers

Zilog's Z8 Encore![®] products are based on the Zilog's eZ8[™] CPU and introduce Flash Memory to Zilog's extensive line of 8-bit microcontrollers. The Flash Memory in-circuit programming capability allows for 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 F042A 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 PWM and Capture and Compare capabilities. An on-chip Internal Precision Oscillator (5 MHz/32 kHz) can be 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 can be written or read. The full-duplex UART, in addition to providing serial communications and IrDA encoding and decoding capability, also supports multidrop address processing in hardware.

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

Discussion

This section provides a detailed description of the the Z8 Encore! XP-based battery charger application. For more information on the Li-Ion and SLA battery technologies, see [Appendix D—Battery Technology](#) on page 15.

Theory of Operation

At the core of a battery charger is a step-down 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 can be viewed as 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 actual parameters such as current and voltage are controlled using the Pulse-Width Modulation (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 more information on battery controller, refer to related documents provided under the Electronics Books in [References](#) on page 9. 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 provided below:

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

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 can be expressed as follows:

Equation 1

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

In [Equation 1](#), C1 and C2 are constants.

[Equation 1](#) is known as the position algorithm. A better representation of [Equation 1](#) is shown in [Equation 2](#), as follows:

Equation 2

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

Subtracting [Equation 2](#) from [Equation 1](#) and rearranging the terms result in [Equation 3](#), represented as follows:

Equation 3

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

In [Equation 3](#), Kp and Ki are proportional and integral constants, respectively.

[Equation 3](#) is known as 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 Li-Ion and Sealed Lead Acid (SLA) batteries are charged using the constant voltage method.

An ON/OFF current limiter is required when performing constant voltage charging. 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. Therefore, it is important to know when to terminate the charging. In the Li-Ion battery charger application, the battery parameters are constantly monitored, and the absolute battery voltage termination technique is used. In this way, the Li-Ion battery charger ensures the safety of the battery. For more information on termination techniques associated with Li-Ion and SLA batteries, see [Appendix D—Battery Technology](#) on page 15.

Developing the Application with the Z8 Encore! XP[®] MCU

This section provides an overview of the functional architecture of the Li-Ion 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 Li-Ion battery charger application features the following hardware blocks:

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

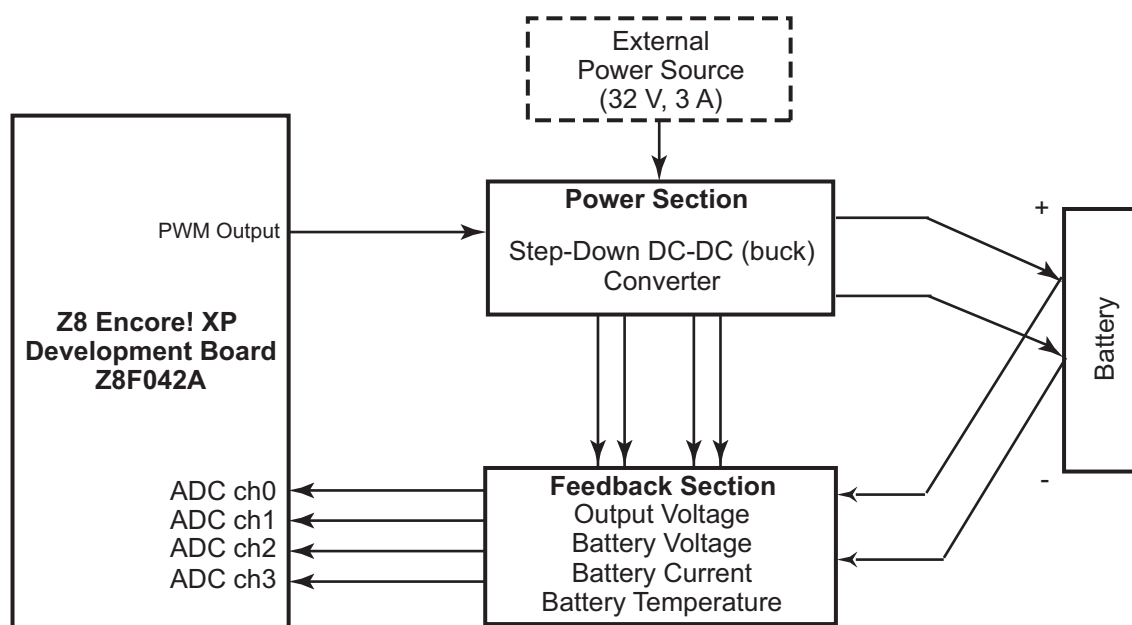


Figure 1. Block Diagram of Battery Charger Hardware

The battery charger application uses the Port B of the Z8 Encore! XP MCU as ADC inputs. Timer1 is used in the PWM mode and the output is tapped at the PC1/Timer1 output pin.

The system clock is derived from the Internal Precision Oscillator (IPO) of the Z8 Encore! XP MCU.

As the reference voltage required for the ADC is generated internally by the Z8 Encore! XP MCU, 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 Li-Ion battery. The buck converter modulates a higher voltage (from the external source) with a varying pulse width (Pulse-Width Modulation 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 the same. The fourth differential amplifier is used for temperature measurement in case of batteries featuring built-in temperature sensors.

For detailed schematic diagrams associated with the battery charger application, see [Appendix B—Schematics](#) on page 9.

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. Currently, these battery parameters are defined in the `charger.h` header file.

The safety and termination thresholds are calculated based on the battery parameters. Then, 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 a 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 also 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 known, 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 case of a device failure.

If all the actual values are within limits, the battery is tested for full charge. For Li-Ion batteries, the battery is considered to be completely charged if the measured charging current is below the threshold value. The charging is terminated after the battery is completely charged. If the battery is not completely charged, then the duty cycle required for maintaining the set points at the converter output is calculated by the control algorithm.

The control algorithm implements proportional plus integral (PI) control to derive the PWM output based on the equations provided 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 sent out 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.

The higher the frequency, the lesser the reload value and the lower the resolution in the pulse width variation; and vice versa. The timer ISR also updates the charge termination variables every 10 seconds.

For the flowcharts related to the battery charger application, see [Appendix C—Flowcharts](#) on page 13.

Testing

This section describes the setup, equipment used, and the procedure followed to test the Z8 Encore! XP[®]-based Li-Ion battery charger application.

Setup

Figure 2 displays the test setup for the Z8 Encore! XP-based Li-Ion battery charger application.

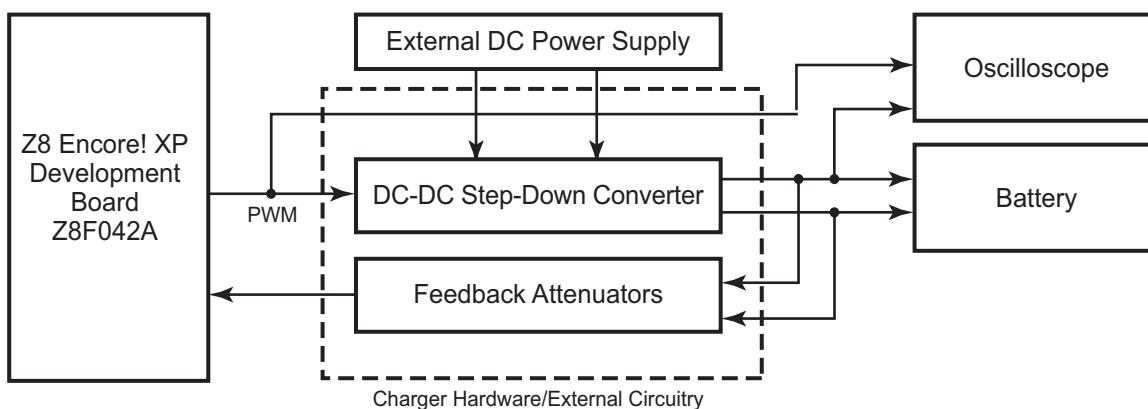


Figure 2. Battery Charger Test Setup

The test setup consists of a Z8 Encore! XP Development Board (Z8F042A), a Li-Ion battery to be charged, an oscilloscope, an external DC power supply, and a DC-DC step-down (buck) converter. A feedback circuit comprising of differential amplifiers/attenuators also form 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

Table 1 lists the equipment used to test the Z8 Encore! XP-based Li-Ion battery charger.

Table 1. Battery Charger Test Equipment

Z8 Encore! XP [®] F042A Series Development Kit (Z8F042A28100KIT)			
External power supply			
Oscilloscope (Tektronix TDS 724D; 500 MHz/1 GSps)			
Multimeter			
Battery Used	Make	Type	Ratings
BP-T40	Sony	Sealed Lead Acid	4 V, 500 mAh

► **Note:** *As the SLA and Li-Ion batteries pursue similar charging (constant current followed by constant voltage) and termination algorithms, the SLA battery was charged during testing.*

Procedure

Follow the steps below to test the Z8 Encore! XP-based Li-Ion battery charger application:

1. Download the AN0218-SC01.zip file from www.zilog.com. Extract its contents to a folder on your PC.
2. Launch ZDS II-IDE for Z8 Encore![®].
3. Make the hardware connections as shown in [Figure 2](#) on page 5 and the schematics provided in [Appendix B—Schematics](#) on page 9.
4. Connect the battery to be charged across the provided battery terminals (see [Appendix B—Schematics](#) on page 9).
5. Apply the required voltages to the appropriate circuits as described in the [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. At a threshold specified by the manufacturer of the battery, the charging switched from the constant current mode to the constant voltage mode. In the constant voltage mode, the charging current was found to droop. The charging was terminated when the current value dropped below the set threshold.

Summary

This Application Note discusses a Li-Ion battery charger implementation using the Z8 Encore! XP MCU. The battery charger software accompanying this document 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 Pulse-Width Modulation technique facilitates an accurate DC-DC step-down converter (buck) implementation with excellent line/load regulation.

References

The documents associated with eZ8 CPU, Z8 Encore! XP Z8F042A MCU, and ZDS II available at www.zilog.com are provided below:

- eZ8[™] CPU User Manual (UM0128)
- Z8 Encore! XP[®] F082A Series Product Specification (PS0228)
- Z8 Encore! XP[®] F042A Series Development Kit User Manual (UM0166)
- Electronics books for reference:
 - 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
 - Digital Control Systems, Volume 1— Fundamentals, Deterministic Control;
Author: Rolf Isermann
ISBN: 0-387-50266-1
Publisher: Springer Verlag
- Panasonic Li-Ion Battery — <http://www.panasonic.com>
- ZDS II-IDE — Zilog Developer Studio II-Z8 Encore![®] User Manual (UM0130)

Appendix A—Glossary

Table 2 lists the definitions for terms and abbreviations used in this Application Note.

Table 2. Glossary

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

Appendix B—Schematics

Figure 3 displays the schematic diagram of the Z8 Encore! XP[®] MCU pin diagram.

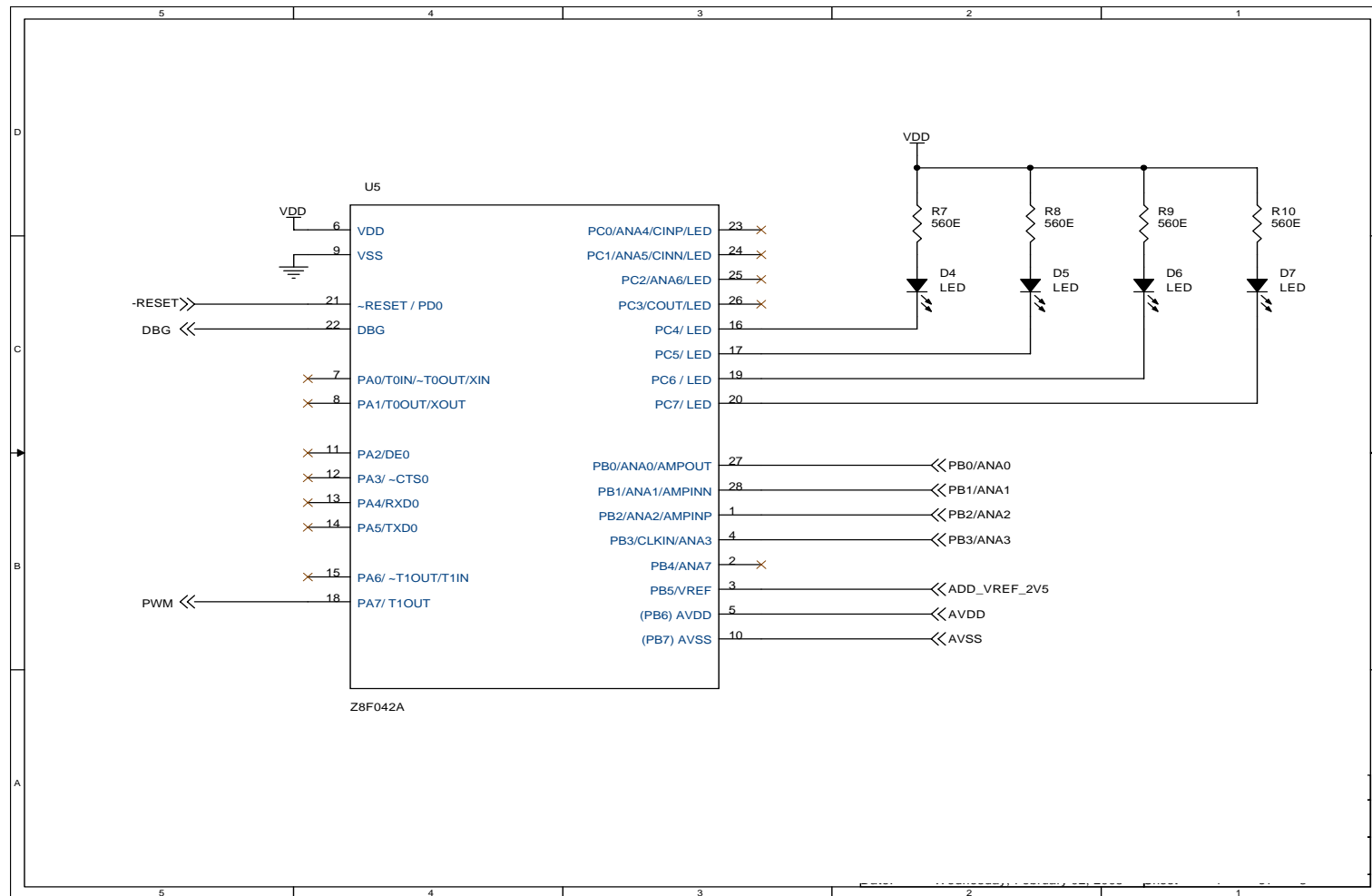


Figure 3. Z8 Encore! XP MCU Pin Diagram

Figure 4 displays the schematic diagram of the external circuitry for the battery charger application.

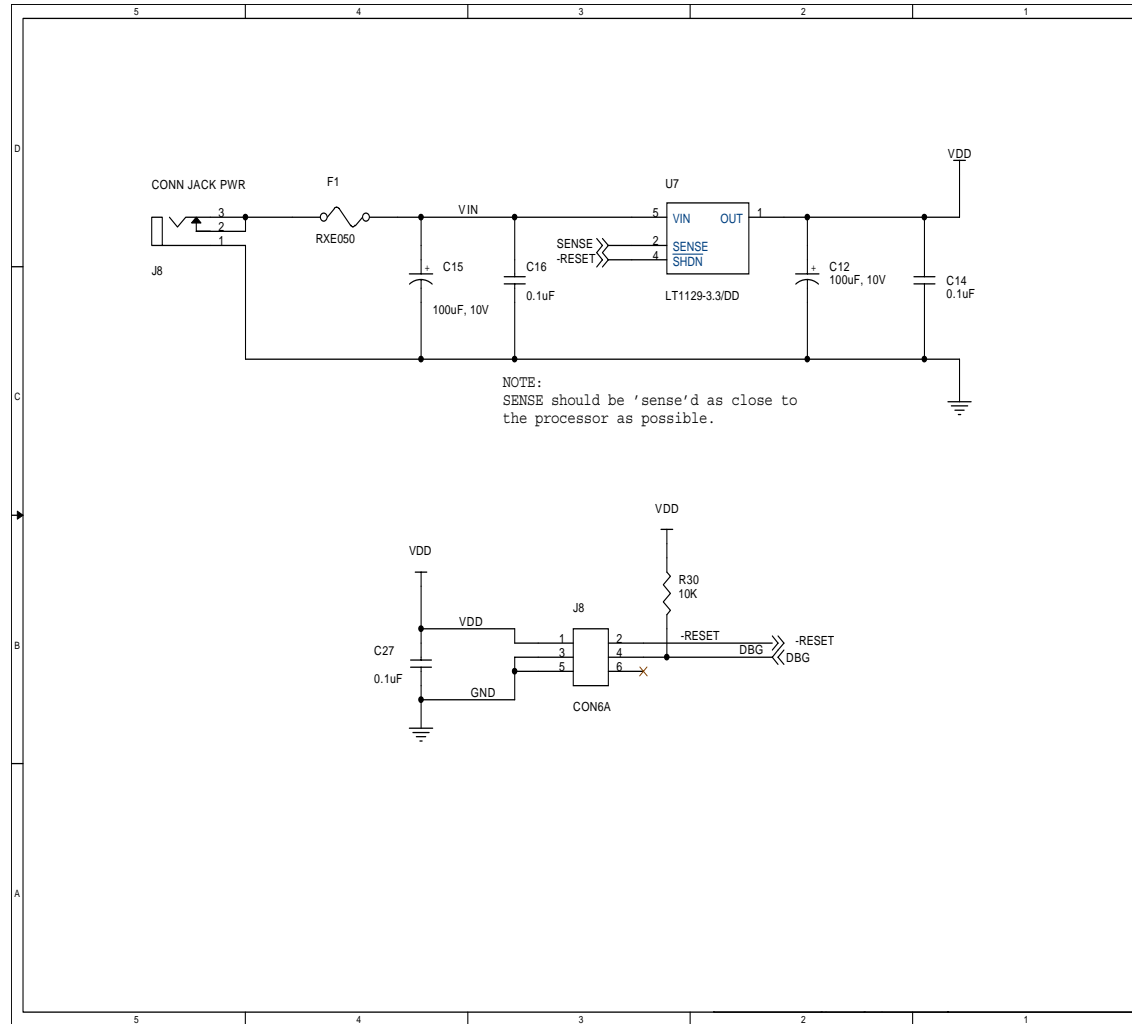


Figure 4. External Circuitry for the Battery Charger Application

Figure 5 displays the schematic diagram of the DC-DC step-down (buck) converter.

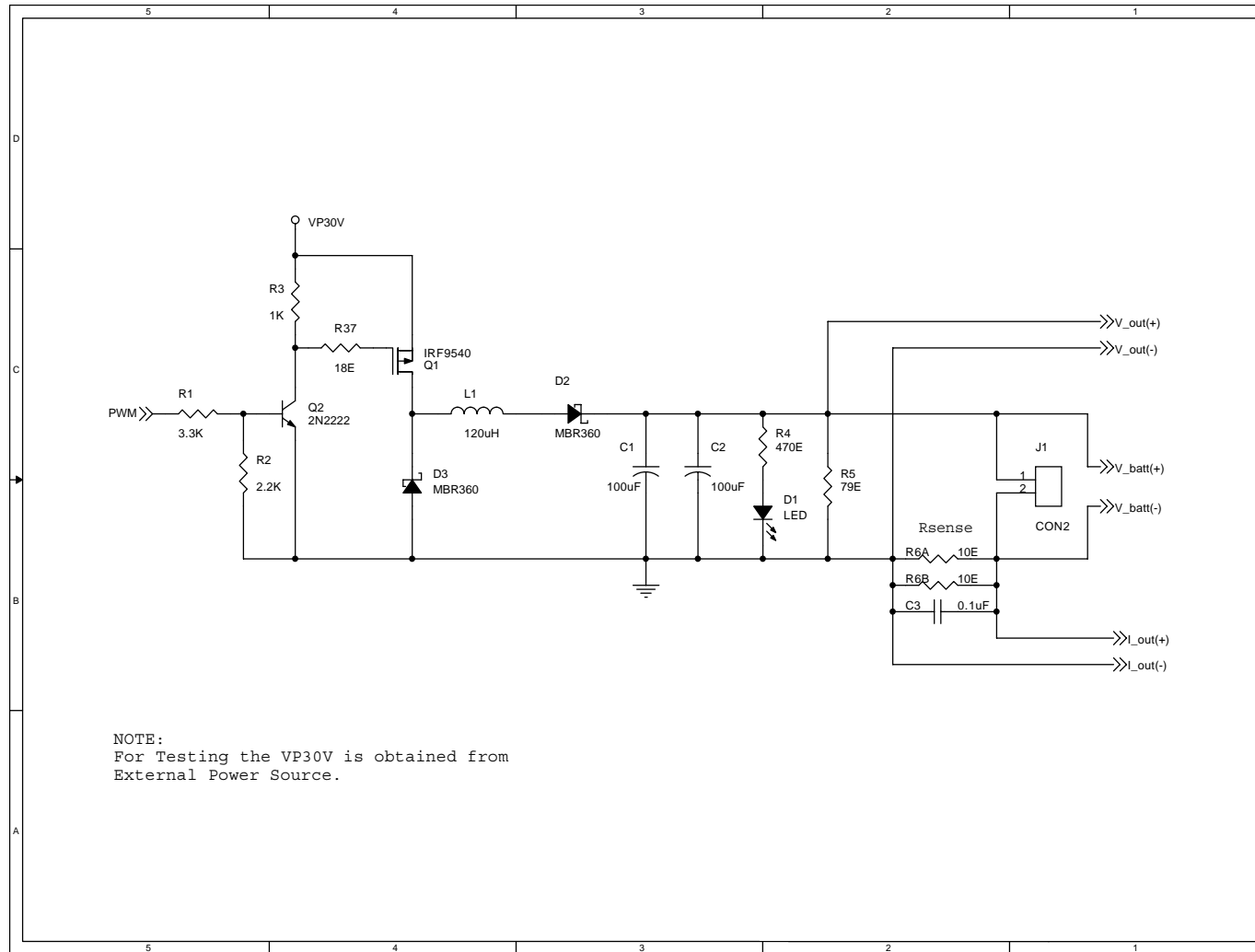


Figure 5. DC-DC Step-Down (Buck) Converter

Figure 6 displays the schematic diagram of the feedback circuits for the battery charger application.

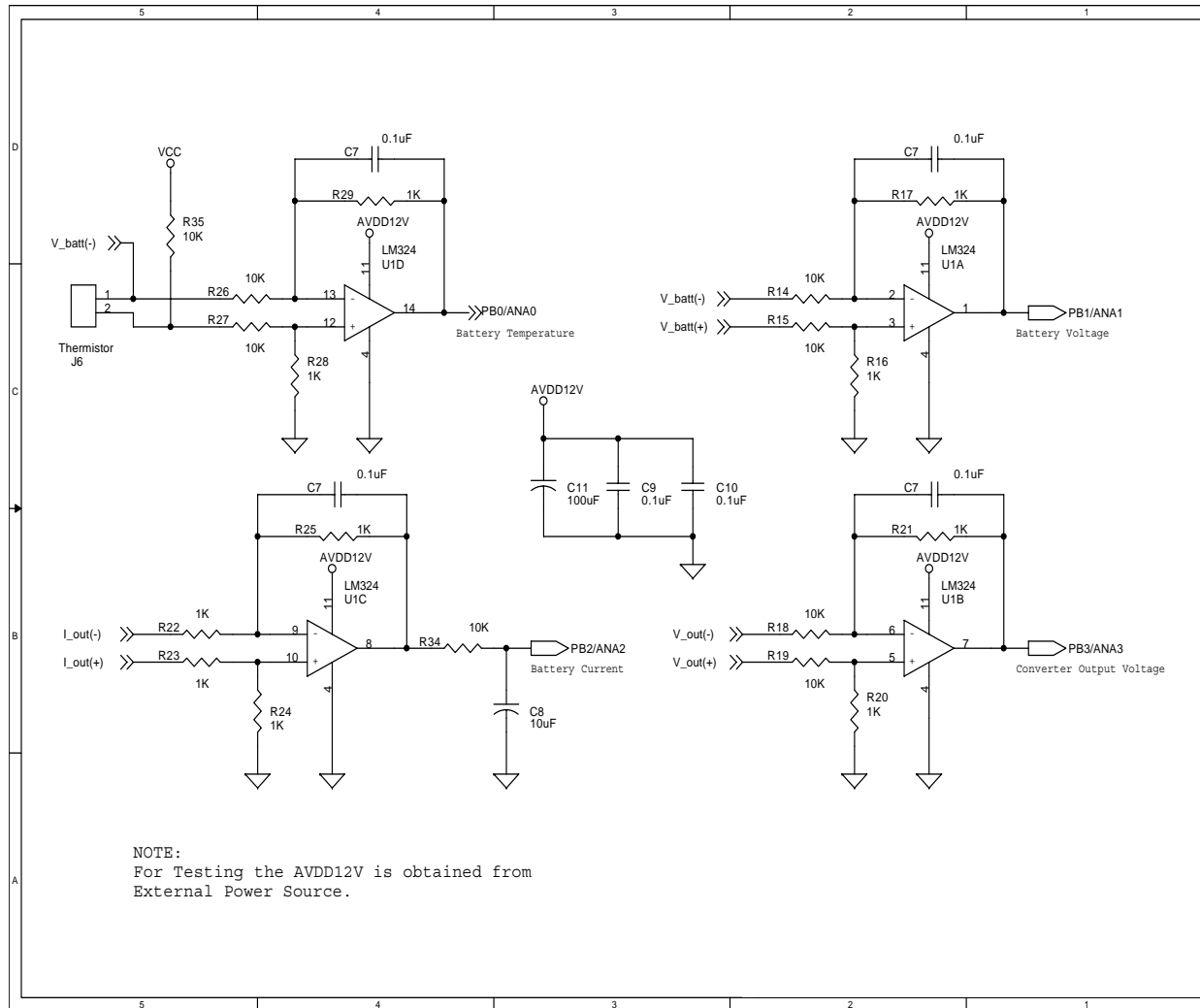


Figure 6. Feedback Circuits

Appendix C—Flowcharts

This appendix provides flowcharts for the battery charger application.

Figure 7 displays the flowchart for the main routine. The main routine involves calculation of safety limits, thresholds, duty cycle, reading of feedback values for battery voltage, charging current, and converter voltage.

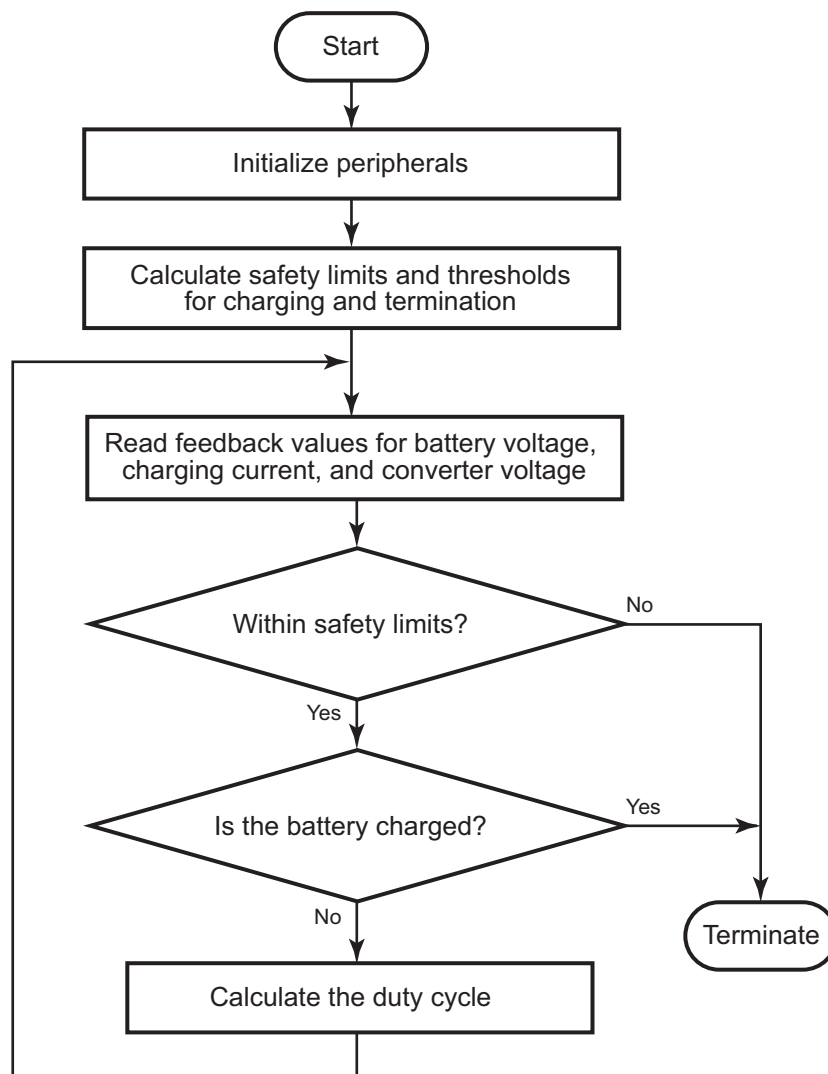


Figure 7. Main Routine

Figure 8 displays the flowchart illustrating the Interrupt Service Routine (ISR) to reload the PWM value and update the charge termination data.

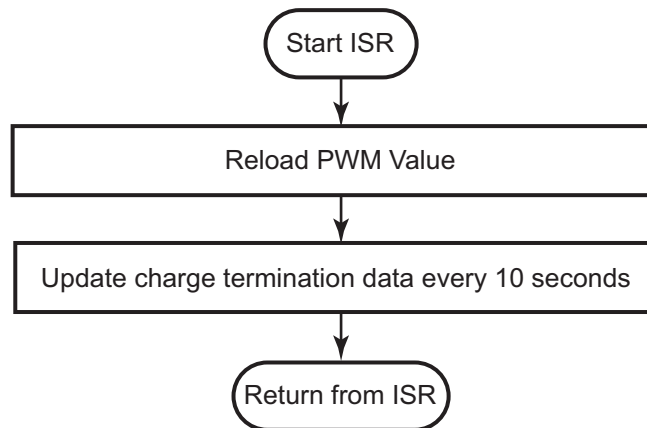


Figure 8. ISR Return Routine

Appendix D—Battery Technology

The four mainstream battery technology discussed in this Application Note feature different charging and discharging characteristics. Long-term battery life and performance depends on how the batteries are charged. Therefore, it is important to charge the batteries with a mechanism specific to their requirements.

It is also important to know when to terminate charging as overcharging of a battery invariably results in poor performance and can damage the battery in extreme cases. The different battery types function differently near the full charge condition. 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 include:

- [Lithium Ion \(Li-Ion\)](#)
- [Sealed Lead Acid \(SLA\)](#)

These battery types are briefly discussed below. For additional references, see [References](#) on page 9.

Lithium Ion (Li-Ion)

The Li-Ion batteries are lighter in weight than NiCad and NiMH batteries. This feature makes Li-Ion high-energy density batteries. They exhibit flat discharge characteristics and are free from memory effect.

If the starting voltage of these batteries is initially too low, a small constant current is applied until the battery reaches a certain threshold specified by the manufacturer. The battery is charged with constant voltage when this threshold is crossed. Charging is terminated when the charging current drops below the threshold in the constant voltage mode.

Sealed Lead Acid (SLA)

The SLA batteries are commonly seen in automobiles. The single cell voltage for SLA is 2 V. According to the use, several such cells are connected in series to get higher voltages such as 12 V/24 V.

SLA batteries are usually charged with a constant voltage supply of 2.45 V per cell. For the application described in this document, 4.90 V is used as the charging voltage for the 4V SLA battery.

At the start of charging, depending on their state of charge, SLA batteries require huge amounts of current. If this current uptake is not controlled, the battery electrolyte boils, producing gases inside the battery. Therefore, it is necessary to limit the charging current. As soon as the battery reaches a particular level of charge, the current is limited and constant voltage charging is enforced. The charge termination mechanism is simple and is achieved as battery voltage reaches the charging voltage. At the same time, there is a corresponding drop in charging current.



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