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# Application Note

# Z8 Encore! XP® Based UPS Battery Charger

**AN030601-0910**

## Abstract

This Application Note describes the use of Z8 Encore! XP® based Uninterruptible Power Supply (UPS) Battery Charger. The battery used for this application is a Sealed Lead Acid (SLA) battery. The UPS Battery Charger (UBC) application uses the on-chip Internal Precision Oscillator (5 MHz) of the Z8 Encore! XP® MCU as System Clock, 16-bit timer blocks for Pulse Width Modulation (PWM), and an internal reference voltage of 2V applied to the ADC and Comparator Input peripheral of the Z8 Encore! XP® MCU.

The UBC is intended to show how a UPS battery charger design can be implemented with the Z8F082A Family. The UBC could be used to implement a standalone UPS design or integrated into other products such as a Set Top Box, DSL, Fiber communications equipment and other products that requires backup power source.

- The source code file associated with this application note, AN0306-SC01.zip, is available on www.zilog.com. This application note was tested and verified using ZDS II – Z8 Encore! V4.11.0.

## 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 microcontrollers. 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. Zilog's Z8 Encore! ® MCU's 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 ºC to +105 ºC. These devices include two enhanced 16-bit timer blocks, featuring Pulse Width Modulation (PWM) and 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 is 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® MCU's suitable for a variety of applications including motor control, security systems, home appliances, personal electronic devices, and sensors.

# Discussion

This section will discuss the functionality of the Z8 Encore! XP® based UPS Battery Charger application in detail.

## 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 (VSET) and current (ISET) 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 constant voltage mode, the converter voltage is compared with the voltage set point. While in 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 related documents provided under the References Section, “Electronics” topic.

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:

$$u(t) = \left(k1 \times e(t) + k2 \times \int e(t)dt\right)$$

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

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

where, C1 and C2 are constants.

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

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

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

$$u[k] - u[k-1] = (Kp \times e[k] + Ki \times e[k-1]) \quad \text{............Equation 3}$$

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 SLA batteries are charged using the constant current 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. It is therefore important to know when to terminate charging. In the SLA battery charger application, the battery parameters are constantly monitored, and the absolute battery voltage termination technique is used. In this way, the SLA battery charger ensures the safety of the battery.

# Developing the Application with the Z8 Encore! XP® MCU's

This section provides an overview of the functional architecture of the SLA battery charger implementation using the Z8 Encore! XP® Microcontroller.

## Hardware Architecture

Figure 1 illustrates hardware block diagram for the battery charger application. The Z8 Encore! XP® based SLA battery charger application features the following hardware blocks:

- Z8 Encore! XP® SLA Demo Board
- External power source (12 V, 8 A) and (16 V, 6 A)
- Step-down DC–DC (buck) converter
- Feedback section (analog design)
- SLA battery
- LOAD

## Basic Feature Set of the UPS Battery Charger demo board

1. Charge the 12VDC SLA battery up to 20A Hour.
2. Monitor for input power loss and switch the load to the battery and also monitor for restored power and switch off the battery to the load automatically.
3. Measure the battery condition by applying an artificial load to the battery and monitor the performance over a period of time by examining the voltage drop and current.
4. Four dip switches can be used during development and testing. Eventually these lines can be used by the user application for various purposes.
5. During backup mode, the battery can provide a maximum of 8 amperes.
6. 4 LED's indicator for different mode of operation (CHARGE, BACKUP, MEASURE, NORMAL)

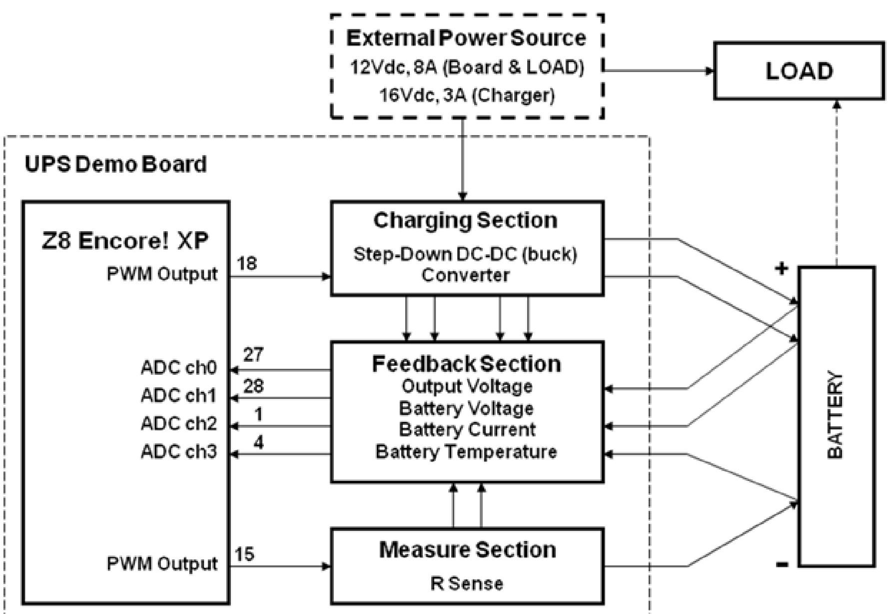



**Figure 1. Block Diagram of UPS Battery Charger**

The battery charger application uses Port B of the Z8 Encore! XP® MCU as ADC inputs to monitor the Feedback Section of the Output Voltage, Battery Current, Voltage and Temperature. Timer 0 is used as timer ticks for LED flashing and 10sec timer for updating the PWM needed for the PI controller. Timer 1 is used in PWM mode and the output is tapped at the PA7/T1OUT/PWM output pin 18 for CHARGE mode, while PA6/TIN/nPWM output pin 15 for the MEASURE mode. The system clock is derived from the 5.5296 MHz 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.

The step-down DC–DC (buck) converter provides a voltage or current appropriate to the SLA 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: Converter Voltage (VOUT), Battery Voltage (VBATT), and the Battery Current (IBATT). The Battery Current and Converter Current are the same. The fourth differential amplifier is used for temperature measurement in case the SLA battery features built-in temperature sensors. (Temperature sensors are not implemented on the source code).

The two separate external power supplies (12V and 16V) allow flexibility for external power supplies to be easily connected to the charger board. Since this application is intended for a 12V actual load terminal, a 12V external power supply is provided. It also has another 16V external power supply to allow headroom for charging the 12V SLA battery.

The design also monitors for AC power loss by enabling an interrupt when CINP voltage < 0.6V (determined by the voltage divider across R9 and R12, see schematic). If a power loss is detected, battery power is supplied to the load by driving the BATT EN high.

The following Table shows the pin Signal States and LED status indicator. H and L correspond to the logic levels of pin.

**Table 1. Summary of Modes vs. Signal States**

| MODE | CINP (pin 23) | T1 (pin 18) | /T1 (pin 15) | BATT EN (pin 2) |
|---|---|---|---|---|
| NORMAL | H | PWM float charge | L | L |
| BACKUP | L | L | L | H |
| CHARGE | H | PWM | L | L |
| MEASURE | H | L | PWM | L |

**Table 2. Summary of LED Status**

| STATUS | LED-5 | LED-4 | LED-3 | LED-2 |
|---|---|---|---|---|
| NORMAL | ON | OFF | OFF | OFF |
| BACKUP | OFF | Flashing | OFF | OFF |
| CHARGE | OFF | OFF | Flashing | OFF |
| MEASURE | OFF | OFF | OFF | Flashing |
| NO BATT | Flashing | Flashing | Flashing | Flashing |
| TERMINATE | ON | ON | ON | ON |

**NORMAL mode**: The AC power is available and power to the load is provided by the AC power supplies. In NORMAL mode the SLA Battery is disconnected to the LOAD when fully charged, by PB4/(BATT_EN) (pin 2), and the T1 PWM (pin18) and should be providing a minimal **float** current of 100mA to the battery to keep it charged. If the battery's capacity is full, the firmware will TRICKLE CHARGE to maintain Constant Float Voltage mode according to battery data sheet recommendation. Otherwise, it will go into CHARGING MODE. For more information (see BB BP20-12 datasheet)

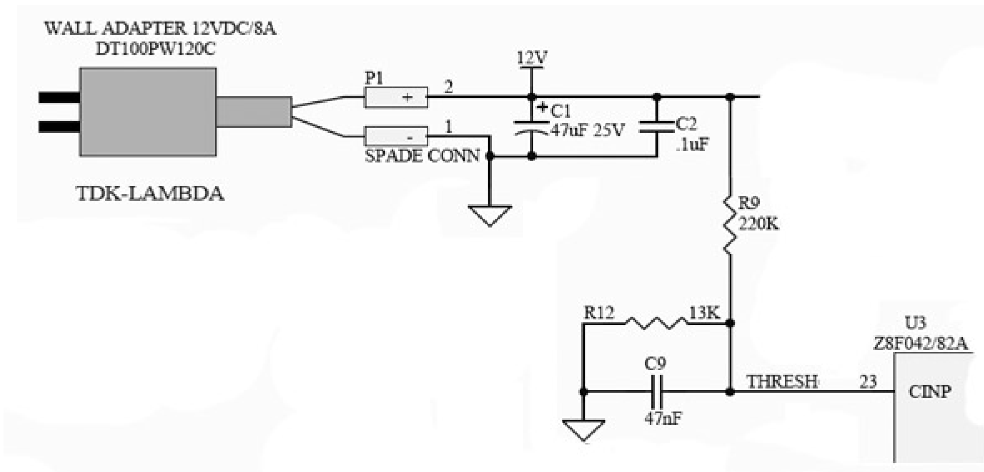



**Figure 2. Comparator Input Pin for Power Loss Detection**

**BACKUP mode:** During a complete AC power loss CINP will fall from a THRESH voltage of 0.6, the system will be in BACKUP mode. The board and the LOAD will draw power from the SLA battery through diode D2 (refer to Schematic). While in BACKUP MODE, the firmware will continuously monitor for AC power through CINP (Figure 2). When AC power is detected, the comparator interrupt will disable the BATT EN signal (refer to Schematic) and remove battery power to the load.

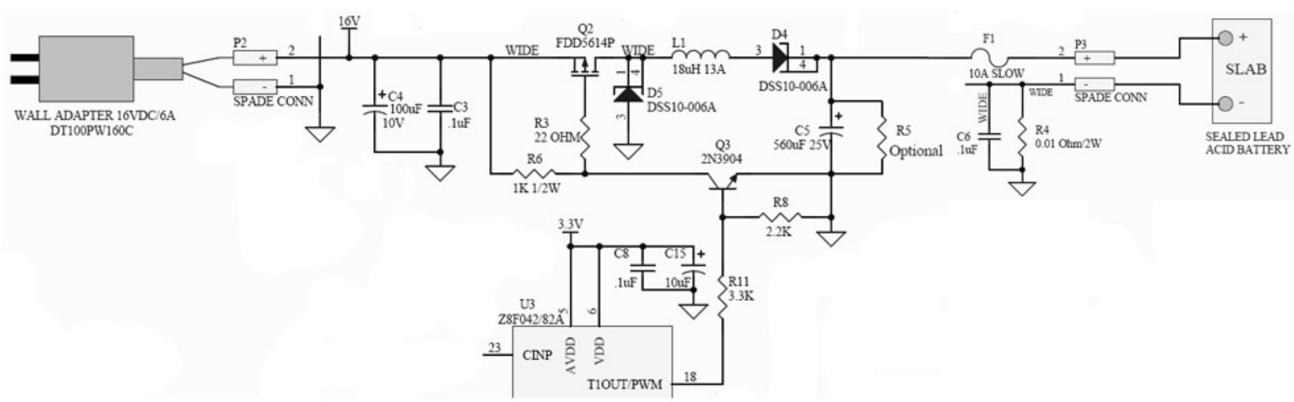



**Figure 3. Buck Converter Circuit**

**CHARGE mode:** During CHARGING MODE, AC power must be available to the LOAD. T1OUTPUT (PWM) is used to control the buck converter (Figure 3) charging functions. When the battery is fully charged, the charger will revert back to NORMAL MODE. The parameters used in this Application Note were designed for a 12V 20AH SLA battery. If a different battery is going to be used, the parameters Vset and Iset will need to change based on its own specification.

**MEASURE mode:** This user selectable mode is executed when the switch SW/PA0 (pin 7) is set to LOW. This mode will determine if a battery is installed. Another purpose of this feature is to perform a battery capacity measurement to determine if the battery still has a useful life that meets the product specifications. This mode will apply a load for 30 minutes of constant 2A load to the battery. The MCU analyze the voltage and current samples over this period of time and make some determination if the battery still conforms to its capacity rating. After completing the MEASURE mode (capacity measurement), the battery will go to CHARGE mode until the SLA battery is fully charged.

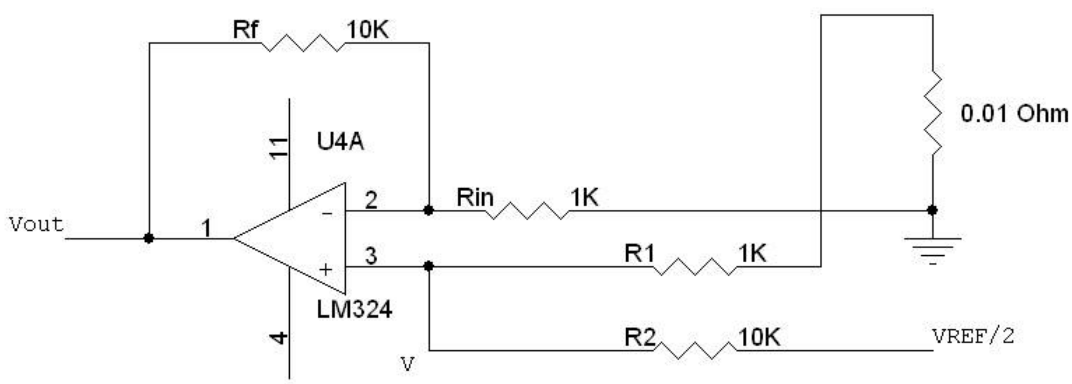



**Figure 4. Charge Current BATT (I) Feedback Circuit**

The battery current is measured through a sense resistor R4 (0.01 ohm). Another method to measure the battery current is to measure the voltage at the positive input to the op-amp U4A (Figure 4) which is biased to VREF/2 which is about 1V. When charging, the op-amp output will go positive with respect to the 1V reference. When the unit is on backup mode, the sense resistor voltage will become negative and the op-amp voltage will go negative with respect to the 1V reference (indicating current is being drawn from the battery). The gain of the op-amp is 11 (see computations below for circuit show in Figure 4).

Inputs:

I = current through 0.01 ohm
VREF = 1.90V
VREF/2 ~ 0.95V
G = (Rin+Rf) / Rin = (1K + 10K ) / 1K = 11
Vsense = I * 0.01 ohm

Outputs:

V = ((Vref – Vsense)/(R1+R2) * R1) + Vsense
Vout = V * G

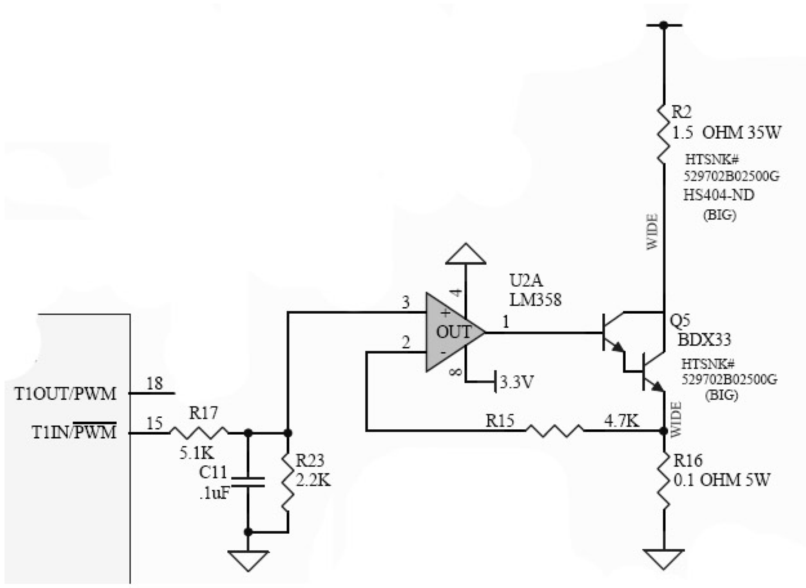



**Figure 5. Constant Current Source**

The constant current source (Figure 5) is used to vary the amount of artificial load to the battery during MEASURE MODE. The constant current source is made from a PWM filtered DC voltage from R17/C11 and this voltage determines the load current through the emitter of Q5. The load current on R16 (0.1 ohm) is determined by:

Current = PWM Voltage/0.1

With the voltage divider, the maximum voltage that can be applied to U2A voltage follower is 1V. This limits the load current to 10A. For this demo a load current of 2 Amps is applied.

PWM Voltage = 2A * 0.1 = 0.2 Volts.

This voltage sets the 20% PWM duty cycle. If a larger current is needed to speed up the measuring of battery capacity the heat sink requirements for R2 and Q5 should be reviewed before deciding to use a larger current for MEASURE MODE.

Figure 6 shows the set of discharge curves for the SLA Battery used in this application (BP20-12):

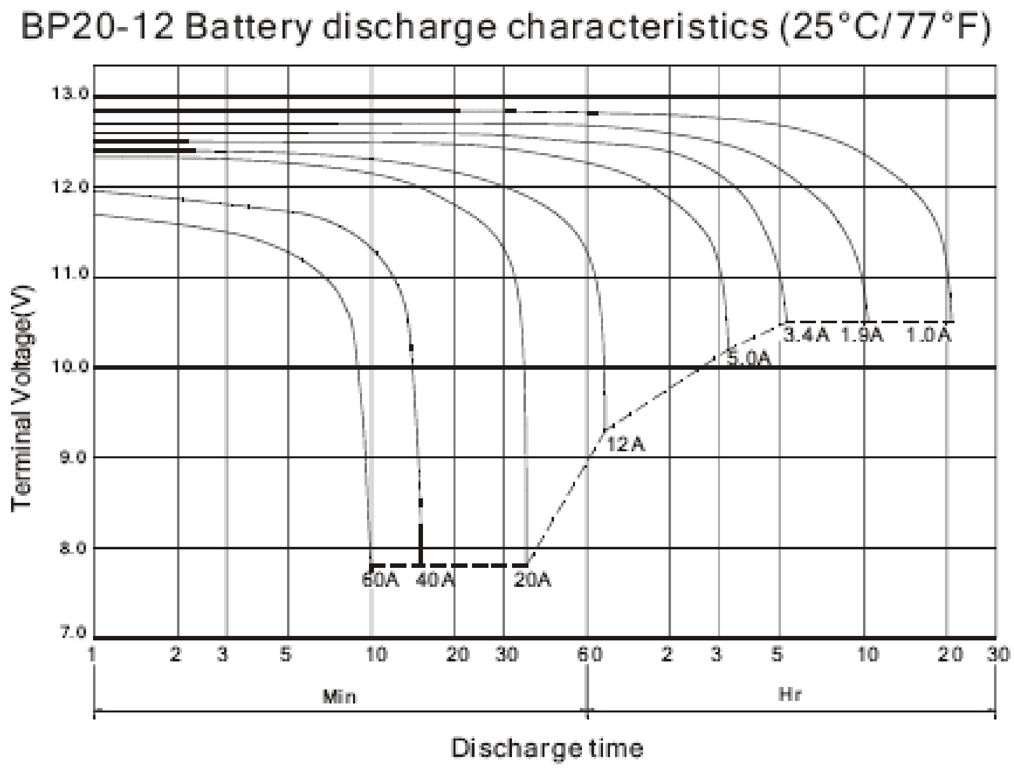



**Figure 6. BP20-12 Battery Discharge Characteristics**

For schematic diagrams associated with the battery charger application, see Appendix C — Schematic Diagrams.

## 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 SLA_charger.h header file.

The FW performs a quick battery test to the state of the battery. A measured voltage of greater than 14 could indicate one of the following:

1. the battery is fully charged
2. there is no battery
3. the battery has an open cell (defective)

The battery fault LED indicates a faulty or non-existent battery.
(See Table 2 for Summary of LED status)

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. The output voltage, the output current, and the battery voltage are the basic measurements. The current across the battery terminals is the 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 (VOUT, VBATT, and IBATT) 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 of the actual values are within limits, the battery is tested for full charge. For SLA 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, 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 presented in the Theory of Operation. The timer ISR of Timer 0 is invoked every 10 ms. The PWM value computed by the control algorithm is loaded into the PWM generators to be transmitted via the output pin. A lower frequency results in a higher reload value and a higher resolution in the pulse width variation.

A sample of the output response of the system with the PI controller is shown in figure 7. (Ziegler-Nichols turning method was used to gather this data).

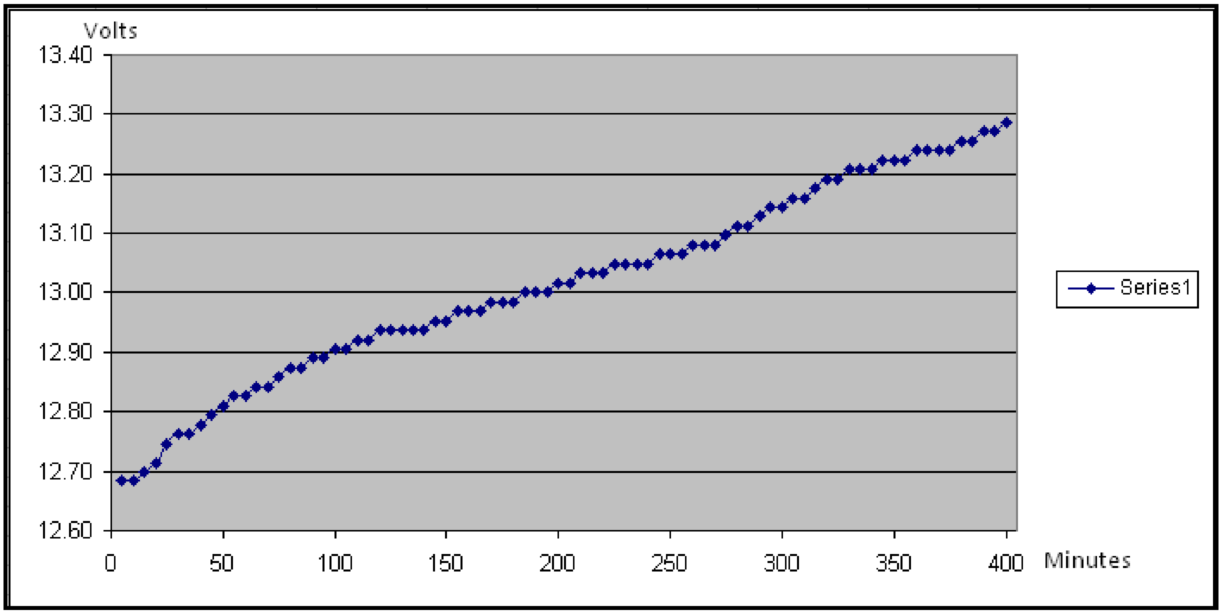



**Figure 7. Output Response of the System with the PI Controller**

Additionally, the timer ISR updates the charge termination variables every 10 sec.

For flowcharts related to the UPS Battery Charger application, see Appendix A — Flowcharts.

# Testing

This section discusses the setup, equipment used, and procedure followed to test the UPS Battery Charger application

## Setup

The test setup for the UPS Battery Charger application is illustrated in Figure 8.

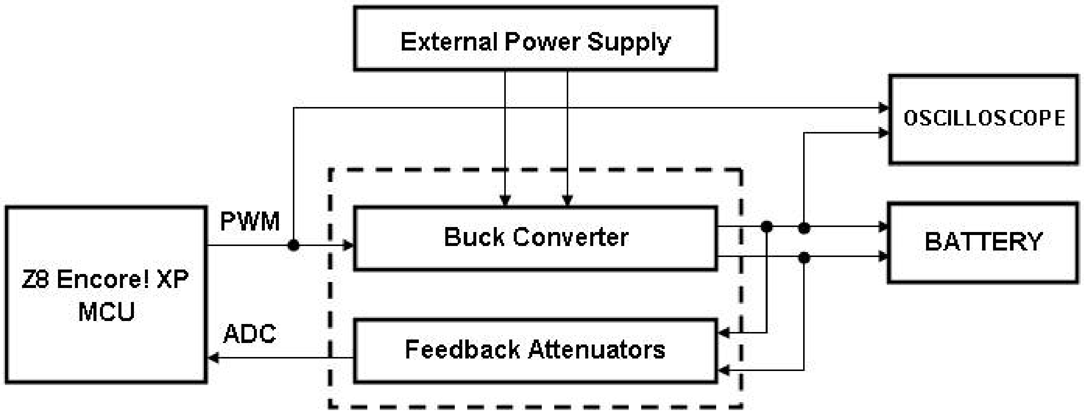



**Figure 8. UPS Battery Charger Test Setup**

The test setup consist of UPS Battery Charger demo hardware which has the circuit for (DC-DC buck converter, feedback circuit comprised of differential amplifiers), an SLA Battery (BP20-12) that must be charged, an Oscilloscope for PWM measurement, an External Power Supply for demo board and buck converter.

The External Power Supply provides two different voltages to the UBC circuit—the DC-DC Buck Converter and the UBC.

**Table 3. UPS Battery Charger Test Equipment**

| **Equipment used** | |
|---|---|
| Demo Hardware | UPS Battery Charger |
| External Power Supply | TDK-Lambda<br>- DT100PW120C (12VDC/8A)<br>- DT100PW160C (16VDC/6A) |
| Oscilloscope | Tektronix, Model: 3014B |
| Multimeter | Fluke, Model: 89 IV |
| SLA Battery | B.B.Battery, Model: BP20-12 (12V, 20AH) |

## Procedure to test the UPS Battery Charger application:

1. Download the AN0306-SC01.zip file from zilog.com. Extract its contents to a folder on your PC.
2. Launch ZDS II for Z8 Encore! 4.11.0.
3. Connect the battery to be charged across the provided battery terminals (see Appendix C — Schematic Diagrams).
   - ➢ Ensure that the external power supply is not yet connected to perform a proper firmware sequence upon startup.
4. Download the battery charger code to the Z8 Encore! XP® Flash memory, using the ZDS II IDE.
5. Execute the battery charger code.
   - ➢ All LEDS will flash once to perform firmware startup.

- LED4 should be flashing to indicate the system status is in the BACKUP mode.

6. Apply the required voltages to the appropriate circuits, as described in the Setup section.
   - LED3 should be flashing to indicate the system status is in the CHARGE mode.
   - If the battery voltage is above 12.8V, the flashing of LED3 is bypassed, and LED5 should turn ON, showing that the battery is in the NORMAL mode. Skip to step 8.
7. Observe the PWM waveforms on the oscilloscope over a period of time when the battery is being charged.
8. After charging, the battery is in the NORMAL mode, and LED5 should turn ON.
   - PWM will stop once the battery is fully charged.
9. Please note that the UPS Battery Charger code is written from the point of view that the battery must be installed/connected to the Battery Charger first, and then the Battery Charger board must be powered up next. If this procedure is not followed, then the battery code will cause the Battery Charger to perform differently than described in the document.
   - In standalone mode without using the ZDS II to run the code, when the power is applied to the UPS Battery Charger board before the battery is connected, LEDs 2, 3, 4, and 5 will flash to warn that the battery is not connected. Subsequent connection of the battery to the UPS Battery Charger board will not change this condition. To exit this condition, the battery and the power to the UPS Battery Charger board must be removed; then connect the battery first.
   - Using ZDS II to run the code, the battery should always be connected and the 12-V & 16-V power supplies to the UPS Battery Charger board must be turned off until the code is actively executing in ZDS II. After the code is running, the power to the UPS Battery Charger board can be turned on. Both the 12-V and 16-V power supplies to the UPS Battery Charger board should be turned on. It does not matter which power supply is turned on first.

## References

Zilog's documents associated with Z8 Encore! XP® CPU and BP20-12 SLA Battery are provided below:

• eZ8 CPU User Manual (UM0128)

• Z8 Encore! XP® F082A Series Product Specification (PS0228)

• ZDS II-IDE Zilog Developer Studio II-Z8 Encore! User Manual (UM0130)

**Additional Sources**;
BP20-12 SLA Battery Performance Specification (http://www.bb-battery.com)

**Electronics**:

- 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

## Appendix A – Flowcharts

This appendix provides flowcharts for the UPS Battery Charger application described in this Application Note. Figure 9 explains flowchart of the main routine for the UPS Battery Charger application. The main routine shows the software flow for different modes of operation: BACKUP, CHARGE, NORMAL and MEASURE modes, the subroutine for the CHARGE mode involves reading of feedback values for battery voltage, charging current, and converter voltage, battery limits and PWM calculation.

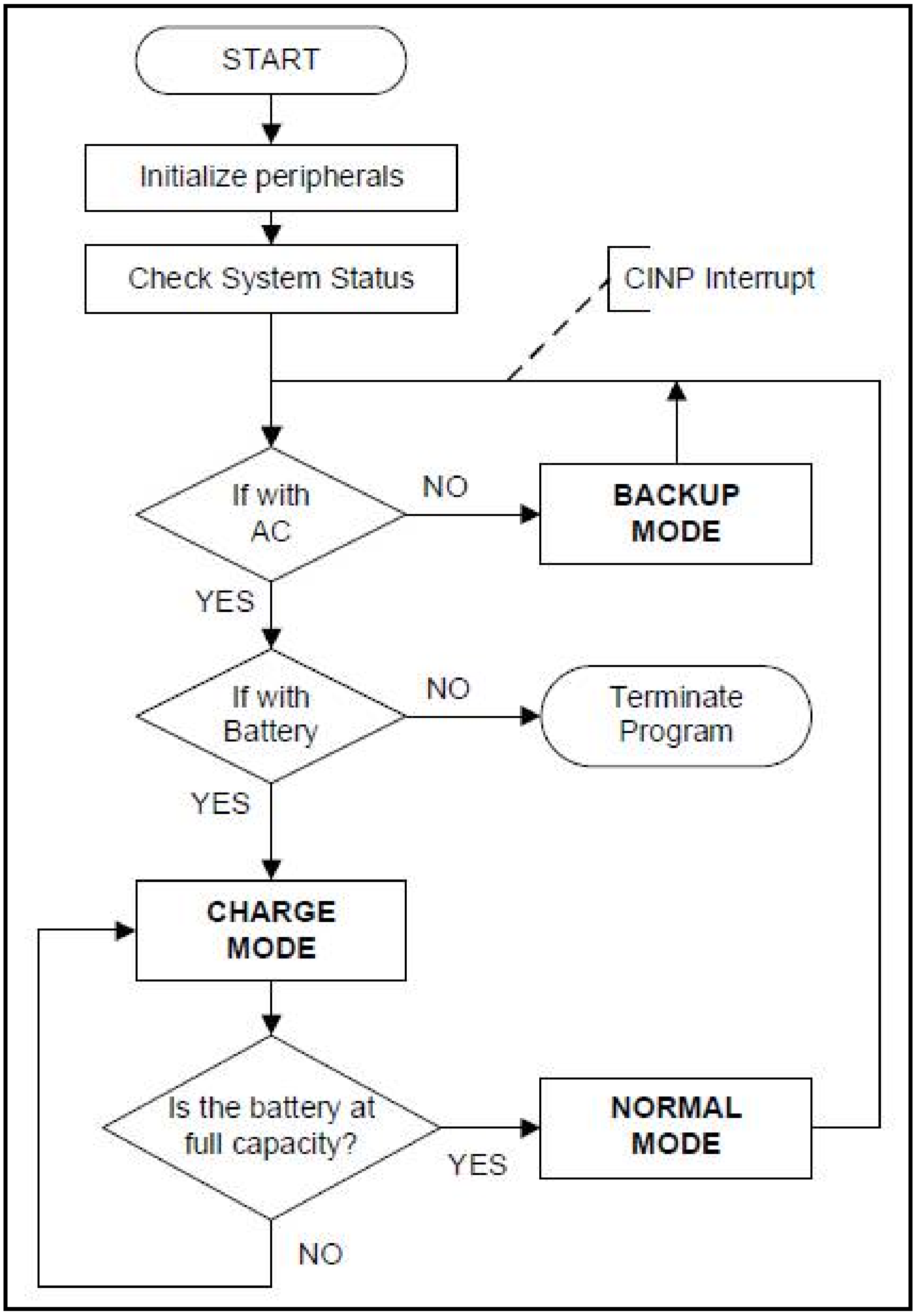



**Figure 9. UPS Battery Charger Main Routine**

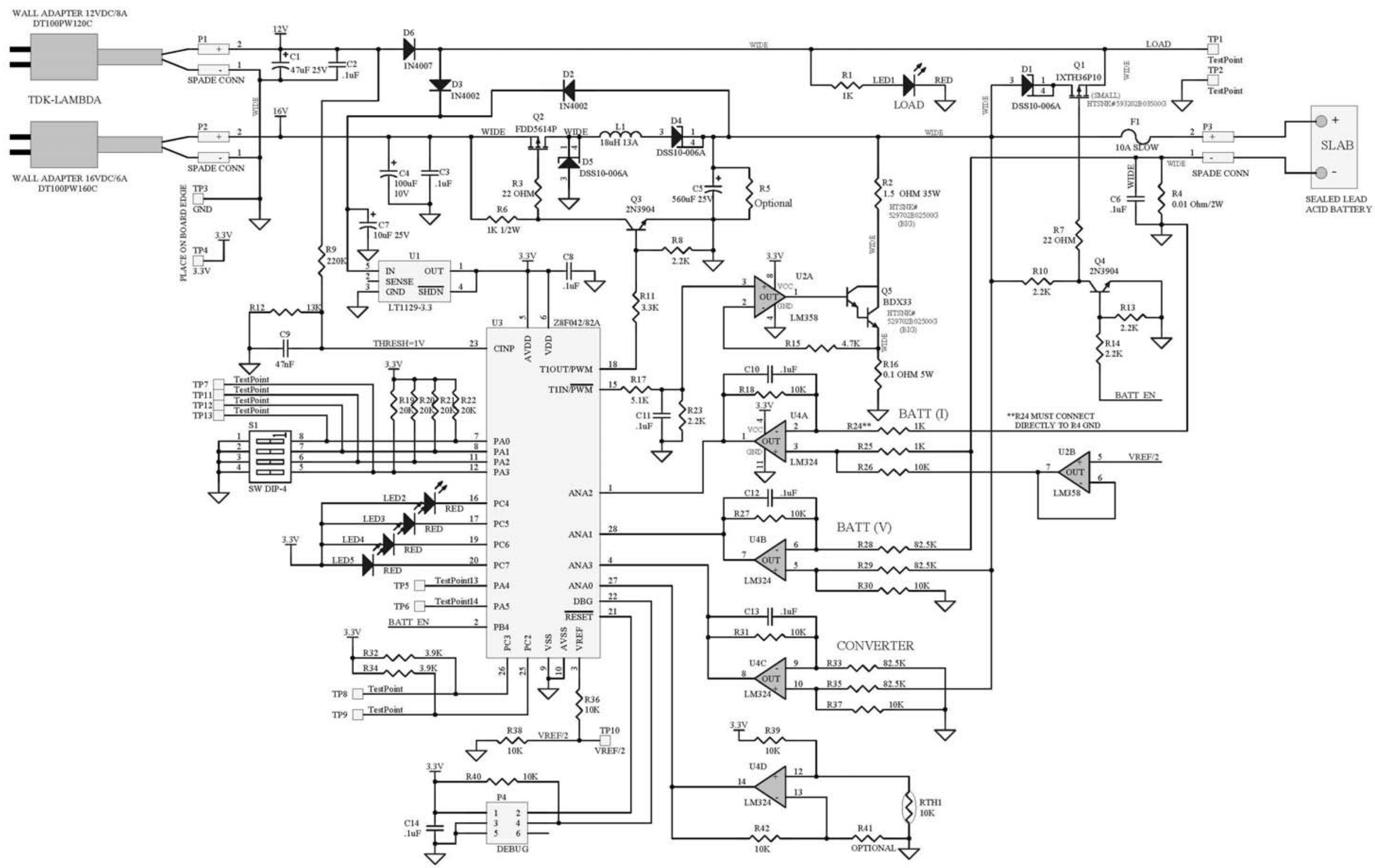
# Appendix B – Raw Data of System Response Time

This appendix provides the raw data of the system response time using Ziegler-Nichols method to find the system parameters.

| Time (minutes) | ANA1-ADC (Dec) | ANA1-ADC (Hex) | Op-Amp Voltage | Battery Voltage |
|---|---|---|---|---|
| 5 | 798 | 31e | 1.565 | 12.683 |
| 10 | 798 | 31e | 1.565 | 12.683 |
| 15 | 799 | 31f | 1.567 | 12.699 |
| 20 | 800 | 320 | 1.569 | 12.715 |
| 25 | 802 | 322 | 1.573 | 12.747 |
| 30 | 803 | 323 | 1.575 | 12.762 |
| 35 | 803 | 323 | 1.575 | 12.762 |
| 40 | 804 | 324 | 1.577 | 12.778 |
| 45 | 805 | 325 | 1.579 | 12.794 |
| 50 | 806 | 326 | 1.581 | 12.810 |
| 55 | 807 | 327 | 1.583 | 12.826 |
| 60 | 807 | 327 | 1.583 | 12.826 |
| 65 | 808 | 328 | 1.585 | 12.842 |
| 70 | 808 | 328 | 1.585 | 12.842 |
| 75 | 809 | 329 | 1.587 | 12.858 |
| 80 | 810 | 32a | 1.589 | 12.874 |
| 85 | 810 | 32a | 1.589 | 12.874 |
| 90 | 811 | 32b | 1.591 | 12.890 |
| 95 | 811 | 32b | 1.591 | 12.890 |
| 100 | 812 | 32c | 1.593 | 12.905 |
| 105 | 812 | 32c | 1.593 | 12.905 |
| 110 | 813 | 32d | 1.594 | 12.921 |
| 115 | 813 | 32d | 1.594 | 12.921 |
| 120 | 814 | 32e | 1.596 | 12.937 |
| 125 | 814 | 32e | 1.596 | 12.937 |
| 130 | 814 | 32e | 1.596 | 12.937 |
| 135 | 814 | 32e | 1.596 | 12.937 |
| 140 | 814 | 32e | 1.596 | 12.937 |
| 145 | 815 | 32f | 1.598 | 12.953 |
| 150 | 815 | 32f | 1.598 | 12.953 |
| 155 | 816 | 330 | 1.600 | 12.969 |
| 160 | 816 | 330 | 1.600 | 12.969 |
| 165 | 816 | 330 | 1.600 | 12.969 |
| 170 | 817 | 331 | 1.602 | 12.985 |
| 175 | 817 | 331 | 1.602 | 12.985 |
| 180 | 817 | 331 | 1.602 | 12.985 |
| 185 | 818 | 332 | 1.604 | 13.001 |
| 190 | 818 | 332 | 1.604 | 13.001 |
| 195 | 818 | 332 | 1.604 | 13.001 |
| 200 | 819 | 333 | 1.606 | 13.017 |
| 205 | 819 | 333 | 1.606 | 13.017 |

| | | | | |
|---|---|---|---|---|
| 210 | 820 | 334 | 1.608 | 13.033 |
| 215 | 820 | 334 | 1.608 | 13.033 |
| 220 | 820 | 334 | 1.608 | 13.033 |
| 225 | 821 | 335 | 1.610 | 13.049 |
| 230 | 821 | 335 | 1.610 | 13.049 |
| 235 | 821 | 335 | 1.610 | 13.049 |
| 240 | 821 | 335 | 1.610 | 13.049 |
| 245 | 822 | 336 | 1.612 | 13.064 |
| 250 | 822 | 336 | 1.612 | 13.064 |
| 255 | 822 | 336 | 1.612 | 13.064 |
| 260 | 823 | 337 | 1.614 | 13.080 |
| 265 | 823 | 337 | 1.614 | 13.080 |
| 270 | 823 | 337 | 1.614 | 13.080 |
| 275 | 824 | 338 | 1.616 | 13.096 |
| 280 | 825 | 339 | 1.618 | 13.112 |
| 285 | 825 | 339 | 1.618 | 13.112 |
| 290 | 826 | 33a | 1.620 | 13.128 |
| 295 | 827 | 33b | 1.622 | 13.144 |
| 300 | 827 | 33b | 1.622 | 13.144 |
| 305 | 828 | 33c | 1.624 | 13.160 |
| 310 | 828 | 33c | 1.624 | 13.160 |
| 315 | 829 | 33d | 1.626 | 13.176 |
| 320 | 830 | 33e | 1.628 | 13.192 |
| 325 | 830 | 33e | 1.628 | 13.192 |
| 330 | 831 | 33f | 1.630 | 13.207 |
| 335 | 831 | 33f | 1.630 | 13.207 |
| 340 | 831 | 33f | 1.630 | 13.207 |
| 345 | 832 | 340 | 1.632 | 13.223 |
| 350 | 832 | 340 | 1.632 | 13.223 |
| 355 | 832 | 340 | 1.632 | 13.223 |
| 360 | 833 | 341 | 1.634 | 13.239 |
| 365 | 833 | 341 | 1.634 | 13.239 |
| 370 | 833 | 341 | 1.634 | 13.239 |
| 375 | 833 | 341 | 1.634 | 13.239 |
| 380 | 834 | 342 | 1.636 | 13.255 |
| 385 | 834 | 342 | 1.636 | 13.255 |
| 390 | 835 | 343 | 1.638 | 13.271 |
| 395 | 835 | 343 | 1.638 | 13.271 |
| 400 | 836 | 344 | 1.640 | 13.287 |

# Appendix C – Schematic Diagrams



**Warning: DO NOT USE IN LIFE SUPPORT**

## LIFE SUPPORT POLICY

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### As used herein

Life support devices or systems are devices which (a) are intended for surgical implant into the body, or (b) support or sustain life and whose failure to perform when properly used in accordance with instructions for use provided in the labeling can be reasonably expected to result in a significant injury to the user. A critical component is any component in a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system or to affect its safety or effectiveness.

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