User's Guide
SLUU369–September 2009

PMP3914 Evaluation Module

The PMP3914 evaluation module (EVM) is a complete charger module for evaluating up to 5s lithium-ion and 15s nickel metal hydride (or nickel cadmium) battery cell stacks. This user's guide provides a general description of the EVM, test summary, and software setup. Also included are the bill of materials, board layout, and schematic.

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1.1 EVM Features

- Evaluation module for bq24703 + MSP430F2012 for 5s#p Li-Ion, 15s#p NiMH / NiCad charging
- 100% duty cycle PMOS nonsynchronous buck charger with 300-kHz frequency
- 75-W ac/dc regulation using the UCC28600 Green-Mode Controller in Flyback Configuration
- MPS430F2002 charging and selection example code provided (written in C language)
- Flowchart of charging and fault-checking process
- Intended to operate with MSP430FETUIF tool
- Example code uses free IAR compiler
- LED indication for status signals.
- Test points for key signals available for testing purposes. Easy probe hook-up.
- Jumpers available. Easy-to-change connections.

1.2 General Description

The PMP3914 evaluation module is a complete charger module for evaluating up to 5s lithium-ion and 15s nickel metal hydride (or nickel cadmium) battery cell stacks. It is designed to deliver up to 3 A of charge current (~75 W). In this particular design, the charge current for lithium-ion battery is programmable to low (1.5 A) or high (3 A) setting by the MSP430 reading an external identification resistor, and for the NiMH battery the charging current is fixed at 1.5 A. All these settings can be changed and configured in the MSP430 C-code, as well as appropriate resistor value changes around the bq24703 multichemistry charger.

Offline regulation (108-132 Vac) is provided by a front-end UCC28600 Green-Mode controller in a flyback configuration. The MSP430F2002 is used to enable and disable charging, determine lithium or nickel chemistry, monitor temperature and charge current, determine and control low and high rate charging (lithium-ion battery only in this design), as well as flash a LED based on charging status.

For details, see the bq24703 data sheet (SLUS553), MSP430F2002 data sheet (SLAS491), and UCC28600 data sheet (SLUS646).

1.3 I/O Description

Table 1 describes the connectors and headers available on PMP3914.

Table 1. PMP3914 Connectors and Headers

Jack		Description
J3–1	Wall ac connector	AC adapter (108-132 Vac), LINE
J3–2		AC adapter (108-132 Vac), NTRL
J3–3		No connect
J1–1	MSP430	MSP430 pin 11
J1–2		MSP430 pin 10
J200–2	JTAG VCC	Vcc selection from MSP430 FET tool (VCC tool)
J200–4		Vcc selection from MSP430 FET tool (VCC target)
J200–7	MSP430 JTAG	Connection to J200-8 through R200 (see Section 2.6)
J200–8		Connection to MSP430 pin 11 (seeSection 2.6)
J201–1	JTAG VCC tool	Connection to J200-2 (VCC Tool)
J201–2		3.3 V provided by linear regulator U5
J201–3	JTAG VCC target	Connection to J200-4 (VCC target)
J202–1/2	RESID	R201 = 2.21-kΩ pulldown from RESID
J202–3/4		R203 = 3.32-kΩ pulldown from RESID
J202–5/6		R204 = 100-kΩ pulldown from RESID

Table 1. PMP3914 Connectors and Headers (continued)

Jack		Description
J202–7/8		R205 = 200-kΩ pulldown from RESID
J203–1/2	TEMP	R206 = 2.21-kΩ pulldown from TEMP
J203–3/4		R207 = 3.32-kΩ pulldown from TEMP
J203–5/6		R208 = 200-Ω pulldown from TEMP
J203–7/8		R209 = 10-kΩ pulldown from TEMP
J204–1	AC detect	Place jumper across J204-1/2 for normal operation.
J204–2		
J204–3	Transformer ac detect	Not used in design.

1.4 Controls and Key Parameters Setting

This section describes the function of the headers/jumpers used for testing PMP3914, as well as the default settings used in the step-by-step testing procedures described in this document.

Jack	Description	Factory Setting
J1	JTAG connection header to MSP430 1: MPS430 pin 11 test 2: MPS430 pin 10 SBWTDIO	Jumper OFF
J200	JTAG 14-pin connector to IAR FET tool	
J201	JTAG Vcc connection 1-2: VCC TOOL 2-3: VCC TARGET	Jumper on 1-2
J202	External resistor identification (lithium-ion) or thermistor connection (nickel chemistry) 1-2: Standard AT103 thermistor connection for nickel battery pack (2.21K test) 3-4: Standard AT103 thermistor connection for nickel battery pack (3.32K test) 5-6: 100K small lithium-ion pack identification. ISET from MSP430 set to High (1.5-A charge current) 7-8: 200K large lithium-ion pack identification. ISET from MSP430 set to Low (3-A charge current)	Jumper on 5-6 –Select small lithium-ion pack
J203	Thermistor Connection (lithium-ion chemistry) 1-2: Standard AT103 thermistor connection for lithium-ion battery pack (2.21K test) 3-4: Standard AT103 thermistor connection for lithium-ion battery pack (3.32K test) 5-6: Standard AT103 thermistor connection for lithium-ion battery pack (200Ω OUT OF BOUNDS) 7-8: Standard AT103 thermistor connection for lithium-ion battery pack (10kΩ OUT OF BOUNDS)	Jumper on 1-2 –Select temperature equating to 2.21K from Standard AT103 Thermistor
J204	AC detect connection to bq24703 battery charger. 1-2: Use for testing and normal operation. 2-3: Not used in this design.	Jumper on 1-2

1.5 Recommended Operating Conditions

The recommended operating range of PMP3914 devices is described below. Be sure to not exceed maximum recommend ratings of any semiconductor device for long-term reliability. Temperature is not included in the following table and must be evaluated during the design process.

Symbol	Description	Minimum	Typical	Maximum	Unit	Notes
Supply voltage, V_{IN} to UCC28600	Input voltage from ac adapter input	108	120	132	V	Standard 3-prong connector is provided for easy connection to wall outlet.
Supply voltage, V_{IN} to bq24703	Input voltage from dc adapter input	21.5	25.5	28	V	5s#p charging at 4.2 V/cell = 21 V minimum + overhead
Supply voltage, V_{IN} to MSP430F2002	Input voltage from linear regulator U5	3	3.3	3.6	V	TPS79733 (U5) linear regulator used to lower 5 V VREF provided from bq24703 to power MSP430
Supply current, I_{AC}	Maximum input current from ac adapter input	0		4	A	UCC28600 Offline Flyback stage is designed to 75 W at 25.5 V out
Charge current, I_{chrg}	Battery charge current	1.5	1.5 or 3	3	A	UCC28600 Offline Flyback stage is designed to 75 W at 25.5 V out

2 Test Summary

This section discusses PMP3914 hardware and software setup for both low-voltage (25 Vdc) and offline (120 Vac) testing. See *Installing IAR and the EZ430 Drivers* (4-15-2007)[1] and *MSP-FET430 Flash Emulation Tool (FET) (for Use With IAR Embedded Workbench Version 3+) User's Guide* (SLAU138) for creating an IAR Workspace and navigating through the provided example C-code. Also described in this section is JTAG connection and MSP430 Input/Output port setup.

(1) Find this document in the PMP3914 product folder on the TI Web site and associated with this user's guide.

2.1 Definitions

This procedure details how to configure the PMP3914 evaluation board. For the test procedure, the following naming conventions are followed. See the PMP3914 schematic for details. Assembly drawings have location for jumpers, test points, and individual components.

2.2 Equipment Required for Hardware Testing

This section describes the required equipment to test PMP3914 hardware.

2.2.1 Power Supplies

Power Supply 1 (PS1): a power supply capable of supplying 26 V at ~1.6 A is required (preferably, a greater than 3-A-capable power supply is desired for ISET of 3-A charge current). This power supply is used to power the input of the bq24703 for testing purposes. Connect to TP11 and TP13.

WARNING

A spark occurs when connecting to test points11/13; this is due to the offline-flyback output capacitors charging.

Power Supply 2 (PS2): an ac wall outlet power source capable or providing 120 Vac at 80 W is required.

2.2.2 Load 1

Use either (1) a power resistor decade box or (2) a 30-V (or above), 1.6-A (or above) electronic load that can operate at constant current or constant resistance mode. This load is used to simulate charge current to the battery cell stack.

2.2.3 Meters

Four Fluke 75 multimeters, (equivalent or better)
or
Two equivalent voltage meters and two equivalent current meters. The current meters must be capable of measuring ~2-A+ current.

Other options: use a combination of voltage and current meters, or an oscilloscope with voltage and current probes.

2.3 Equipment Setup Description for Hardware Testing

The low-voltage (25-Vdc) test setup and expected operation for PMP3914 hardware is listed as follows.

1. J204 (ACDET): ON 1-2, J1 (BYPASS): OFF, J201 (Vcc Tool): ON 1-2, J202 (RESID): ON 5-6 100 kΩ ISET:HIGH, J203 (TEMP): ON 1-2 2.21 kΩ TEMP:AT103 Thermistor simulation
2. Set PS1 for 25 V ±100 mVdc, 1.7 ±0.1 A current limit.
3. Connect a voltage meter across VBATT and GND (the output of the bq24703 battery charger).
4. Connect PS1 ground (TP13) and VDC (TP11). Warning: a spark occurs when connecting to test points11/13; this is due to the offline-flyback output capacitors charging.
5. Set Load 1 to approximately 120-Ω resistance and connect to VBATT and GND (the output of the bq24703 battery charger).
6. Note 25 Vin at ~220 mA and 25 Vout at ~210 mA
7. Change Load 1 to 17 Ω and note 25 Vin at ~1.5 A.
8. Measure → V(J201-2 3V3) = 3.3 ±0.1 V. This 3.3 V is provided from TPS79733 (U5) and fed from the integrated 5-V linear regulator on the bq24703.

The test setup for PMP3914 is shown in Figure 1 and Figure 2.

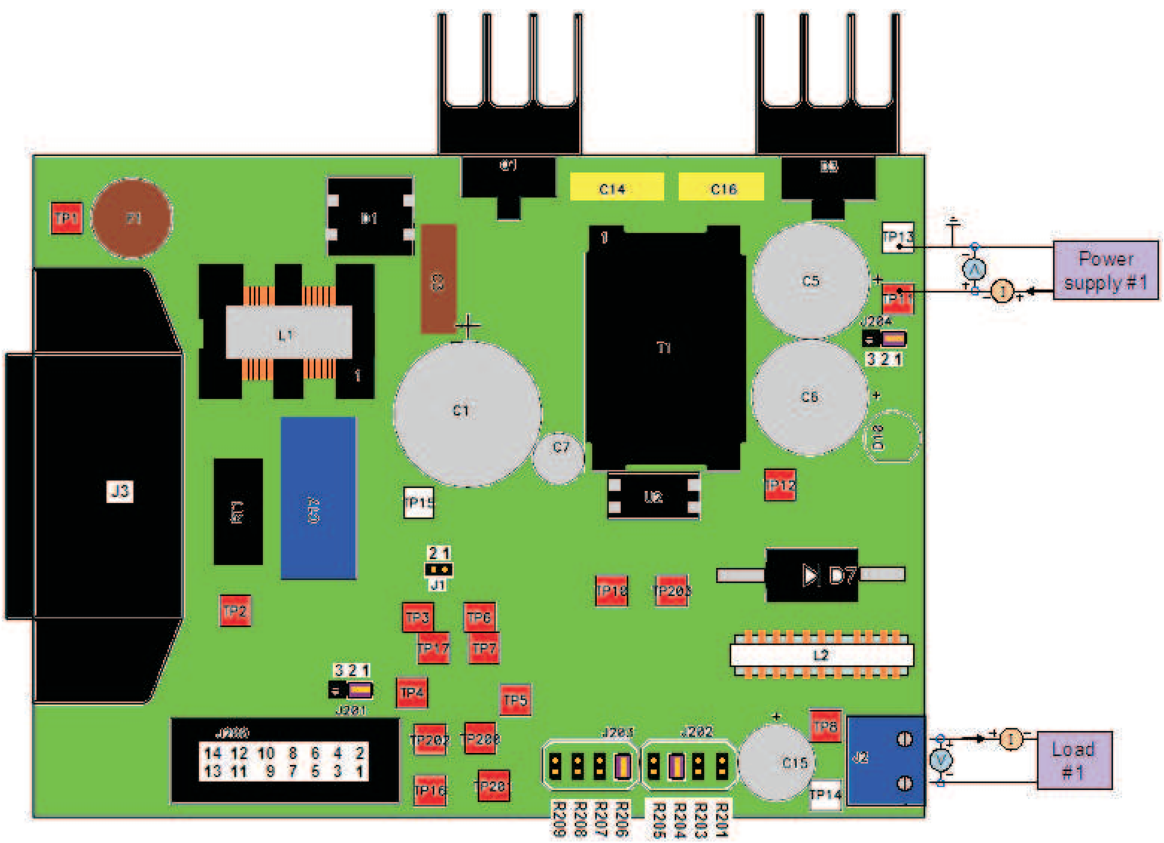


Figure 1. Low-Voltage Test Setup and Microcontroller Programming for PMP3914

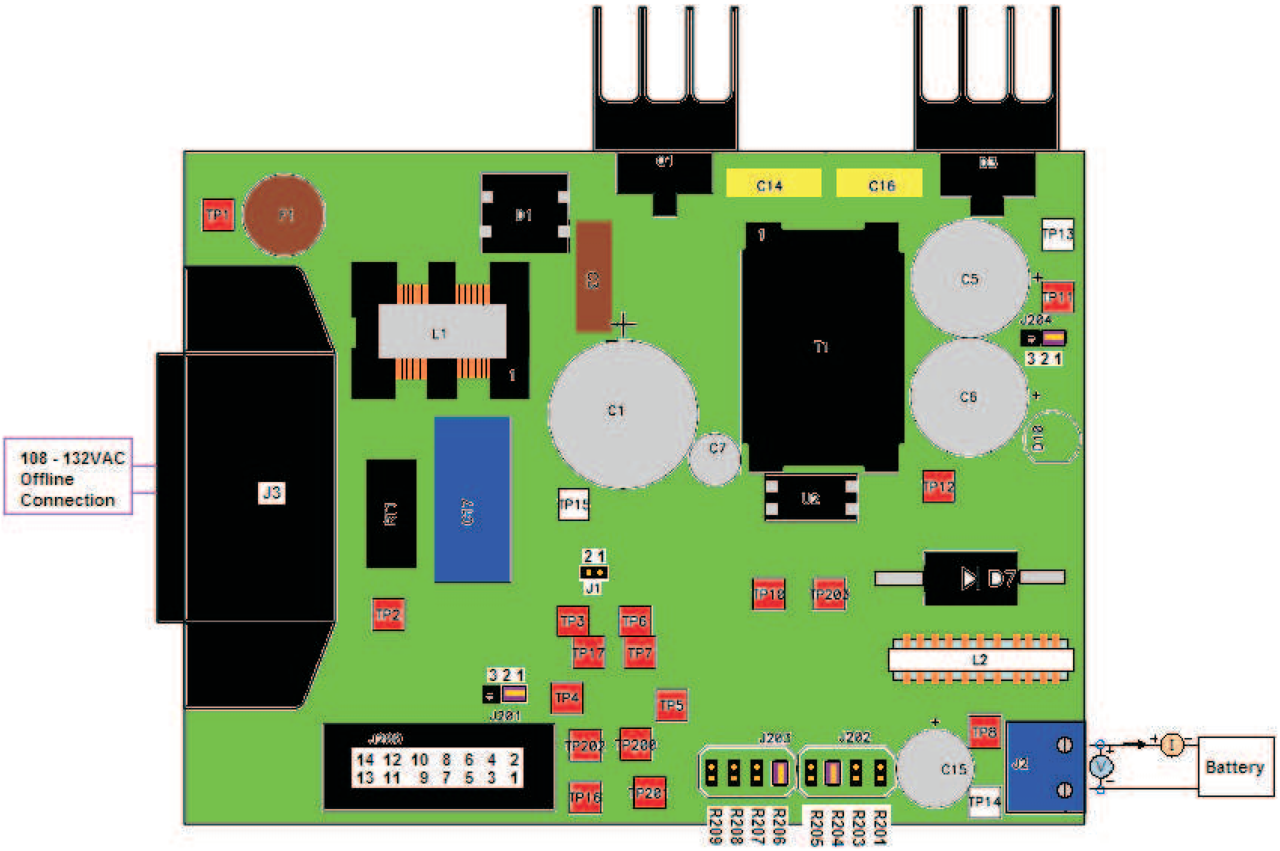


Figure 2. Offline Power Test Setup for PMP3914

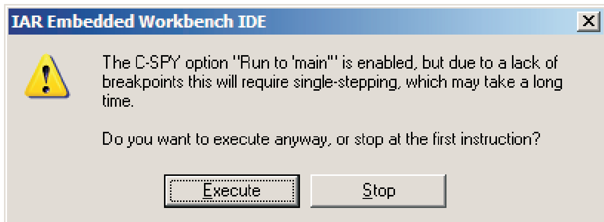
2.4 *Software Setup*

To properly evaluate the PMP3914 battery charger reference design, proper installation of the IAR Embedded Workbench software and creation of an IAR Workspace is required. Note that this section builds on the information included in *Installing IAR and the EZ430 Drivers* reference. Helpful tips on setting breakpoints and watch variables is shown.

2.4.1 IAR Software Download and Installation on your PC, and Loading Code into the MSP430

1. Connect J201 1-2 ON for Target Vcc power. PS1 is still connected to TP11 and TP13.
2. Follow the instructions found in *Installing IAR and the EZ430 Drivers* included in the PMP3914 Evaluation Module product folder. These instructions take you through the steps to set up a free version of the IAR compiler found on www.ti.com in the MSP430-FET430UIF product folder. Click on the Download & Register button for IAR-KickStart (zipped files, SLAC050).
3. Install the software drivers first before plugging in the MSP-FET430UIF USB communication box.
4. When following the 4-15-2007 instructions, make sure to delete the default main.c file. Also, select MSP430F2013 under General Options → Target → Device; even though a MSP430F2002 is used on PMP3914.
5. If asked to update the software on the target device, only do so if the communication process does not work. Select "continue" to any warnings you receive. Otherwise, if you are having problems, then update the firmware. The following screen appears.

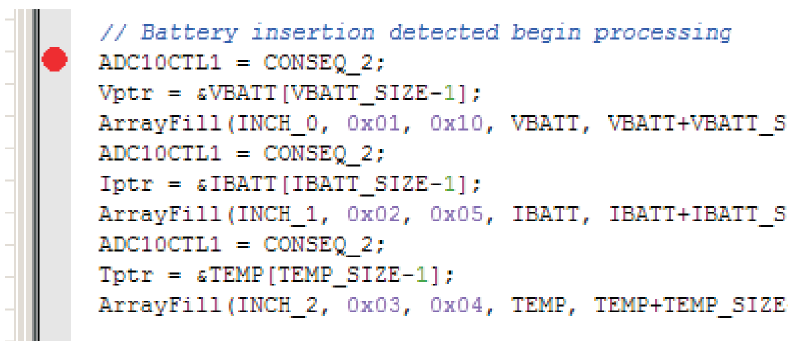
6. When asked if you want to execute from the first instruction, click Stop.



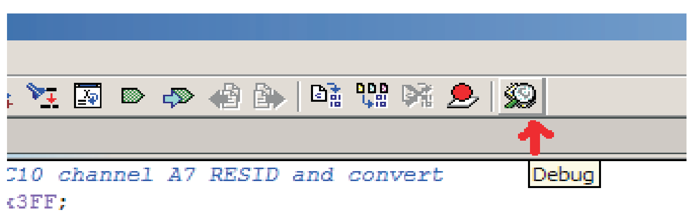
2.4.2 Navigating Through the Code

1. To begin, add a breakpoint to the code line:
   - // Battery insertion detected begin processing
   - ADC10CTL1 – CONSEQ_2

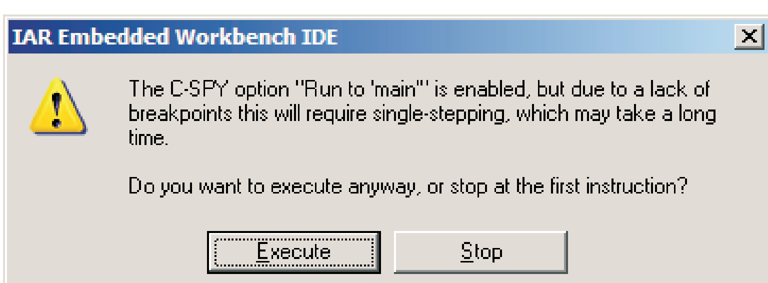
   by double-clicking in the gray separation bar to the left of the “Workspace” and the “.C” file.



2. Press the Debug button from the top right of the toolbars.

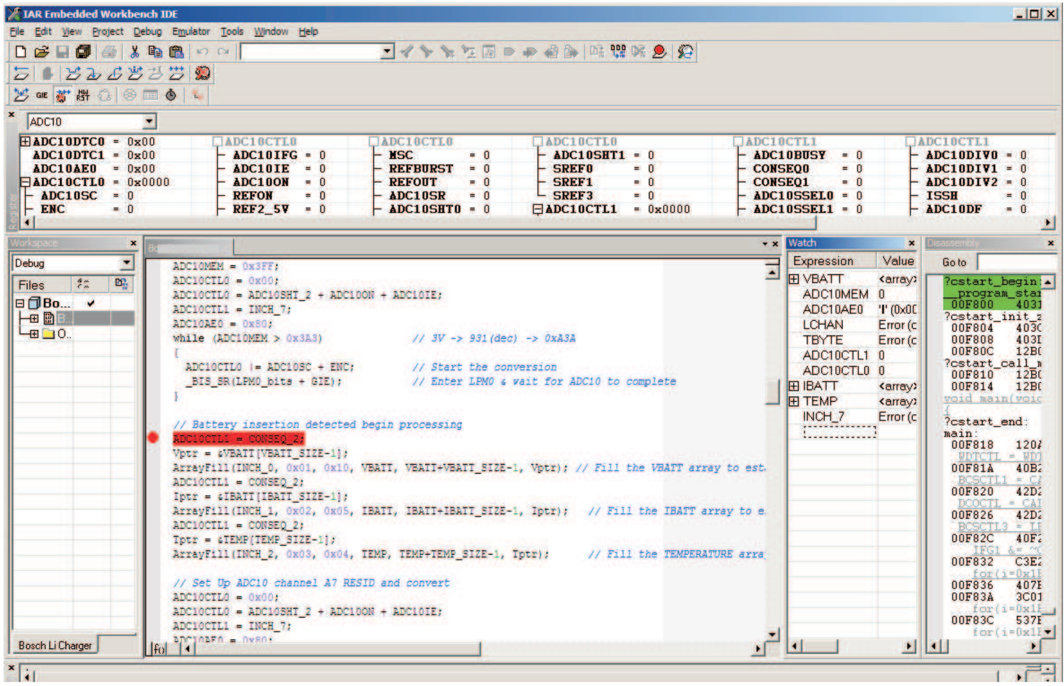


3. Choose to Stop execution at the first line of code.

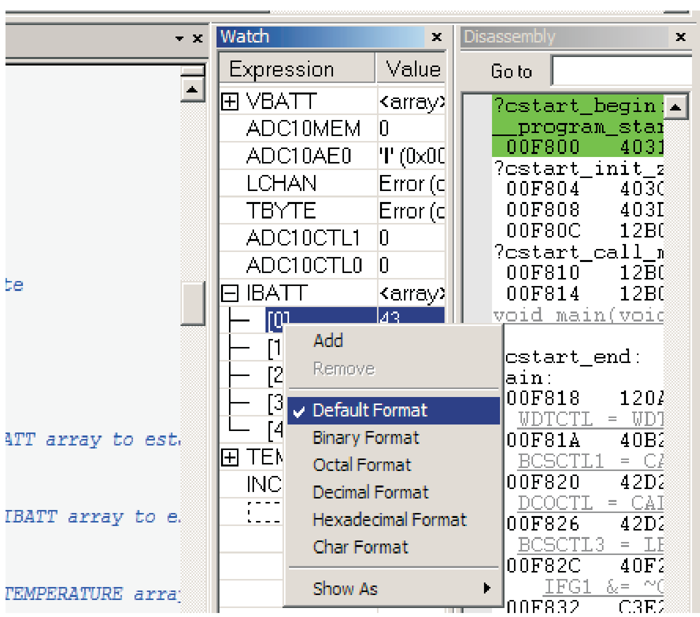


4. Step through the code by either pressing the F11 key for a single step, or click on the Run to breakpoint button to execute to the selected breakpoint.

5. Note if jumper J202: ON 5-6 and J203: ON 1-2, then the output of the bq24703 charger is approximately 21 V ±1 V.



6. Adding watch variables.
CAUTION: some variables default to HEX, while others default to DECIMAL. This can be changed by right-clicking on the watch variable and making a different selection.



7. MSP430 analog-to-digital converter (ADC) conversions are based on VCC (3.3 V) as the reference and a 10-bit ADC. Full scale is 1023 decimal or 0x3FF hexadecimal.

```
///////////////////////////////////
// ADC Calculation Example       //
// 10 bit ADC, 0 - 1023          //
// Vref = VCC = 3.3V             //
// 3.3V / 1024 = 3.22mV per bit //
//   (full scale = 0x03FF)       //
//                               //
```

```
//////// 3.0V conversion /////////
// 3.0V / 3.22mV = ~931.7       //
// 932 (decimal) -> 0x03A3 hex  //
//////// 1.2V conversion /////////
// 1.2V / 3.22mV = ~372.7       //
// 373 (decimal) -> 0x0175 hex  //
//////////////////////////////////
```

2.5 AC → DC Test Procedure

After the example C-code has been loaded onto the MSP430 from the low-voltage test setup, the ac/dc power supply can be tested.

2.5.1 AC/DC Power Supply and bq24703 Onboard Linear Regulation

1. Be sure to follow the equipment setup steps listed in Section 2.3. See Figure 3.
2. Keep J204 jumper connected to 1-2.
3. Keep connection J201 ON 1-2 as before for MSP-FET430UIF Target power as before.
4. Instead of connecting PS1 to TP11 and TP13, connect J3 to the 120-Vac power through standard 3-prong connector. DANGER: high voltages are present on the evaluation module from the ac to dc regulation. Be very careful around components C17, L1, D1, C1, R1, R3, C3, R2, R3, D2, Q1, and T1.
   Measure → V(TP11/TP13 (VDC)) = 25.5 ±500 mV
   Measure → V(J201-2 (3V3)) = 3.3 ±0.1 V

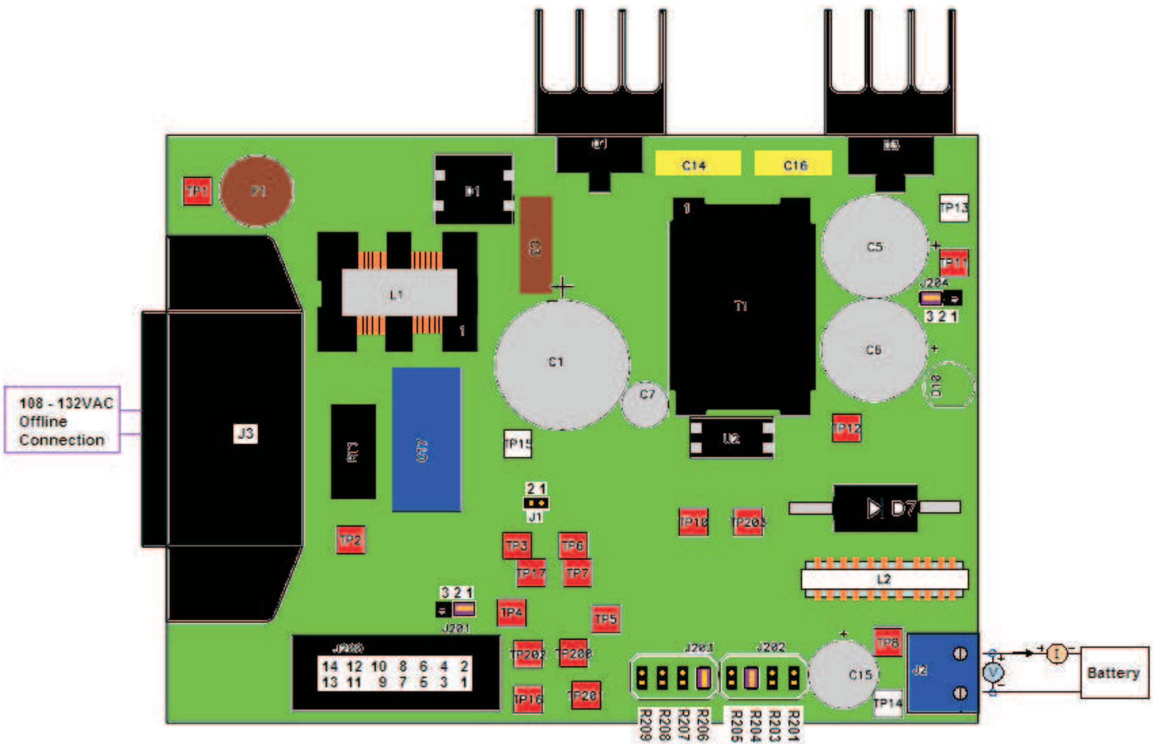


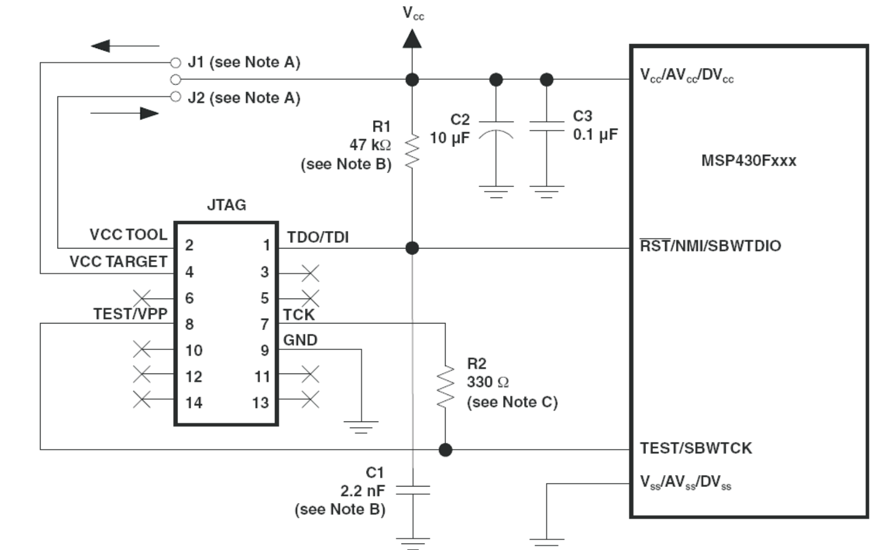
Figure 3. Offline Power Test Setup for PMP3914

2.5.2 Loading C-Code Into MSP430

1. If you were able to proceed beyond step 2.4.2.2 by clicking on Debug in the IAR code, then the example MSP430 code is loaded onto the MSP430.

2.6 MSP430 JTAG Connection

Figure 4 is borrowed from IAR FET User's Guide (SLAU138). These connections are provided by J1, J200, and J201 on PMP3914. Review Section 1.4 and Section 2.3 for default proper jumper settings during test.



A Make either connection J1 (if a local target power supply is used) or connection J2 (if powering the from the debug/programming adapter).

B Note that the device RST/NMI/SBWTDIO pin is used in 2-wire Spy-Bi-Wire mode for bi-directional debug communication with the device and that any capacitance attached to this signal may affect the ability to establish a connection with the device. The upper limit for C1 is 2.2 nF when using current TI FET Interface modules (USB FET).

C R2 is used to protect the JTAG debug interface TCK signal against the JTAG security fuse blow voltage that is supplied by the TEST/VPP pin during the fuse blow process. In the case that fuse blow functionality is not needed, R2 is not required (becomes 0 Ω) and the connection TEST/VPP must not be made.

Figure 4. Signal Connections for 2-Wire Spy Bi-Wire Communication

2.7 MSP430 Input/Output Port Setup

This section describes the Input/Output port setup used in the example C-code provided for RESID, ACPRES, ISET, CHEN, LED, TEMP, IBATT, and VBATT.

Pack Status

7	6	5	4	3	2	1	0
				OK	ISET	SPACK	NiCad

NiCad: 1 = Nicad Pack Present
0 = LiIon Pack Present

SPack: 1 = Small Pack Present
0 = Large Pack Present

ISET: 1 = TRUE
0 = FALSE

OK: 1 = Charging Complete
0 = Pack Removal/Restart Charge Cycle

Port1 Initial Conditions

	RESID	ACPRES	ISET	CHEN	LED	TEMP	IBATT	VBATT	
	7	6	5	4	3	2	1	0	
P1DIR	0	0	1	1	1	0	0	0	0x38
P1OUT	x	x	0	0	0	x	x	x	0x00
P1SEL	1	0	0	0	0	1	1	1	0x87
P1ES	x	0	x	x	x	x	x	x	0x00
P1IE	x	1	x	x	x	x	x	x	0x40
P1IFG	x	0	x	x	x	x	x	x	0x00

int VBATT[16]	32
Int IBATT[5]	10
Int TEMP[4]	8
Int *Vptr	2
Int *Iptr	2
Int *Tptr	2
Int *ptr	2
Int Charge_Timer	2
Int Fault_Register	2
Char PackStatus	1
Stack	50
Total Bytes	111

2.8 MSP430 C-Code

The following example code is provided for evaluating PMP3914 functionality.

Note: This code is provided for evaluation purposes only. TI makes no claims that this code is ready to go to production. Please evaluate and test carefully in your system.

```
//****************************************************************************
// LiIon 5s1p / 5s2p-Cell Charger
//  + NICAD 15s charger
// Pre release v1.2
// 8/29/2009
//
//
//
//
//
//                            MSP430F2012
//                          +--------------+
//                    VCC--1|              |14-Vss
//      VBATT AD0/P1.0--> 2|              |13-->P2.6/GPO UNUSED
//      IBATT AD1/P1.1--> 3|              |12--> P2.7/GPO NICD
//       TEMP AD2/P1.2--> 4|              |11-TEST
//        LED PWM/P1.3<-- 5|              |10-RST
//       CHEN GPO/P1.4<-- 6|              |9 <-- P1.7/A7 RESID
//       ISET GPO/P1.5<-- 7|              |8 <-- P1.6/A6 ACPRES
//                          +--------------+
//
//
//////////////////////////////////
// ADC Calculations             //
// 10 bit ADC, 0 - 1023         //
// Vref = VCC = 3.3V            //
// 3.3V / 1024 = 3.22mV per bit //
//   (full scale = 0x03FF)      //
// 3.0V / 3.22mV = ~931.7       //
// 932 (dec) -> 0x03A3          //
//////////////////////////////////

#include "msp430x20x2.h"

//  Constants
#define TRUE 1
#define FALSE 0
#define NiCad 0x01
#define SPack 0x02
#define ISET  0x04
#define OK    0x08
#define VBATT_SIZE 16
#define IBATT_SIZE 5
#define TEMP_SIZE 4

#define PreCharge_Fault       0x0001
#define NICADLowTemp_Fault    0x0002
#define NICADHighTemp_Fault   0x0004
#define LIIONLowTemp_Fault    0x0008
#define LIIONHighTemp_Fault   0x0010
#define FastChg_Fault         0x0020
#define OverViolation_Fault   0x0040
#define UnderViolation_Fault  0x0080
#define OverVoltNiCad_Fault   0x0100
#define UnderVoltNiCad1_Fault 0x0200
#define UnderVoltNiCad2_Fault 0x0400
#define I_Ave_Fault_Fault     0x0800
#define Proper_Termination    0x1000
#define ACPRES                0x40    // Port bit checking for AC pack present
#define CHEN                  0x10    // charge enable

// Global Variables
int VBATT[VBATT_SIZE];          // AD0   32 bytes
int IBATT[IBATT_SIZE];          // AD1   10 bytes
int TEMP[TEMP_SIZE];            // AD2    8 bytes
int *Vptr;                      // VBATT FIFO Pointer
```

```
int *Iptr;                    // IBATT FIFO pointer
int *Tptr;                    // TEMP FIFO pointer
int *ptr;                     // Discretionary pointer
int Charge_Timer;             // Keeps track of charge time one tick = ~333ms, 220 ticks = ~1
min
int FaultRegister = 0;
char PackStatus = 0;
int PROBE = 0x00;             // Debugging Register, NOTE: single-stepping in debugger can
cause problems / incorrect readings
int current_Vaverage = 0x0000;  // current average voltage of array
int last_Vaverage = 0x03FF;     // last average voltage of array (used in NICAD termination)

// Function Prototypes
int average(int *cptr,char,int *start,int *end);
void ArrayFill(int,int,int,int *start, int *end, int *cptr);

void main(void)
{
  char I;
  WDTCTL = WDTPW + WDTHOLD;             // Stop WDT
  BCSCTL1 = CALBC1_1MHZ;                // Set DCO to 1MHz
  DCOCTL = CALDCO_1MHZ;
  BCSCTL3 = LFXT1S_2 + XCAP_1;
  do{
    IFG1 &= ~OFIFG;
    for(I=0x1F; i>0;i--);
  }while(IFG1 & OFIFG);

  // Initialize the I/O
  P1SEL = 0x87;
  P1DIR = 0x38;
  P1OUT = 0x00;
  P2SEL = 0x00;
  P2DIR = 0x80;

  // Wait for battery insertion
  // Set up Timer to interrupt every ~333ms
  TACCR0 = 62500 - 1;             // 333ms period
  TACCTL0 = CCIE;                 // TACCR0 interrupt enable
  TACTL = TASSEL_2 + ID_2 + MC_1; // Start Timer, SMCLK/2, up mode

  // Set Up ADC10 channel A7 RESID and convert
  ADC10MEM = 0x3FF;
  ADC10CTL0 = 0x00;
  ADC10CTL0 = ADC10SHT_2 + ADC10ON + ADC10IE;
  ADC10CTL1 = INCH_7;                   // Read RESID P1.7
  ADC10AE0 = 0x80;
  while (ADC10MEM > 0x3A3)              // 3V -> 931(dec) -> 0xA3A
  {
    ADC10CTL0 |= ADC10SC + ENC;         // Start the conversion
    _BIS_SR(LPM0_bits + GIE);           // Enter LPM0 & wait for ADC10 to complete
  }

  // Battery insertion detected - begin processing by filling Voltage, Current & Temperature
Arrays
  ADC10CTL1 = CONSEQ_2;
  Vptr = &VBATT[VBATT_SIZE-1];
  ArrayFill(INCH_0, 0x01, 0x10, VBATT, VBATT+VBATT_SIZE-1, Vptr); // Fill the VBATT array to
establish Initial Conditions
  ADC10CTL1 = CONSEQ_2;
  Iptr = &IBATT[IBATT_SIZE-1];
  ArrayFill(INCH_1, 0x02, 0x05, IBATT, IBATT+IBATT_SIZE-1, Iptr);   // Fill the IBATT array to
establish Initial Conditions
  ADC10CTL1 = CONSEQ_2;
  Tptr = &TEMP[TEMP_SIZE-1];
  ArrayFill(INCH_2, 0x03, 0x04, TEMP, TEMP+TEMP_SIZE-1, Tptr);      // Fill the TEMPERATURE array
to establish Initial Conditions
```

```
    // Set Up ADC10 channel A7 RESID and convert
    ADC10CTL0 = 0x00;
    ADC10CTL0 = ADC10SHT_2 + ADC10ON + ADC10IE;
    ADC10CTL1 = INCH_7;
    ADC10AE0 = 0x80;
    ADC10CTL0 |= ADC10SC + ENC;          // Start the conversion
    _BIS_SR(LPM0_bits + GIE);            // Enter LPM0 & wait for ADC10 to complete
    // ADC10MEM now contains the RESID P1.7(A7) Voltage

    // Determine the battery and pack configuration
    if (TEMP[0] > 0x3A3)               // 3.0v NiCad_V; 3.0V/0.00322->931(dec)-> 0x3A3
    {
      PackStatus |= NiCad;    //  NICAD = TRUE;
  //    P2OUT |= BIT7;        // set NICAD output port to "1" - already set high by default - if
  change PCB to pull-down need to un-comment
    }
    else
    {
      PackStatus &= ~NiCad;   //  NICAD = FALSE;  (This is a LiIon Battery)
      P2OUT &= ~BIT7;         // set NICAD output port to "0" - LiIon Voltage Charging

      if (ADC10MEM <= 0x2E9)  // 2.4v SmallPack_V If true then have small LiIon Pack; 2.4V/0.00322 -
  > 745(dec) -> 0x2E9
      {
        P1OUT |= BIT5;        // set ISET P1.5 high for small pack
        PackStatus |= SPack + ISET;
      }
    } // end else

    // Set up Timer to interrupt every ~333ms
    TACCR0 = 62500 - 1;             // 333ms period
    TACCTL0 = CCIE;                 // TACCR0 interrupt enable
    TACTL = TASSEL_2 + ID_2 + MC_1; // Start Timer, SMCLK/2, up mode
    IFG1 = 0x00;
    IE1 |= WDTIE;

    //******** For Normal Operation, next line of code must be un-commented to start Watchdog
  ********
    //   WDTCTL = WDTPW + WDTIS0;    // Load WDT with max count

    P1OUT |= CHEN;                  // Enable the charge
    P1OUT |= BIT3;                  // Turn LED ON 100% DC
    // At this point a battery pack has been inserted, battery chemistry and
    // pack size have been determined.  Now, charge the battery.
    Charge_Timer = 0;               // Reset the charge timer counter

    do{  // Charging Loop Start
        _BIS_SR(LPM0_bits + GIE);     // Enter LPM0 & wait for Timer to continue

          //  refill arrays
          ADC10CTL1 = CONSEQ_2;
          Vptr = &VBATT[VBATT_SIZE-1];
          ArrayFill(INCH_0, 0x01, 0x10, VBATT, VBATT+VBATT_SIZE-1, Vptr); // Fill the VBATT array
  to establish Initial Conditions
          ADC10CTL1 = CONSEQ_2;
          Iptr = &IBATT[IBATT_SIZE-1];
          ArrayFill(INCH_1, 0x02, 0x05, IBATT, IBATT+IBATT_SIZE-1, Iptr);   // Fill the IBATT array
  to establish Initial Conditions
          ADC10CTL1 = CONSEQ_2;
          Tptr = &TEMP[TEMP_SIZE-1];
          ArrayFill(INCH_2, 0x03, 0x04, TEMP, TEMP+TEMP_SIZE-1, Tptr);      // Fill the TEMPERATURE
  array to establish Initial Conditions

        // Start Page 3 Flow Chart
        if ((Charge_Timer > 7000) && (*Vptr <= 0x165))  { //15V  -> 1.15V at MSP430  ~ 30min runtime
           FaultRegister |= PreCharge_Fault;  // Set Precharge Fault Condition
        }
```

```
 // ********** Start of NICAD Charging Loop **********
      if ((PackStatus & 0x01) == NiCad)    // Charging a NICAD battery
      {
 // sample NICAD Temperature (which is the RESID P1.7)
 // NOTE: TEMP from P1.2 is only used if LiIon Pack is present (and RESID is a large/small pack
detection)
        ADC10CTL0 = 0x00;
        ADC10CTL0 = ADC10SHT_2 + ADC10ON + ADC10IE;
        ADC10CTL1 = INCH_7;
        ADC10AE0 = 0x80;
        ADC10CTL0 |= ADC10SC + ENC;          // Start the conversion
        _BIS_SR(LPM0_bits + GIE);            // Enter LPM0 & wait for ADC10 to complete
        // RESID/ Temperature is now in ADC10MEM

        if (ADC10MEM >= 0x170)    // 0.5 volts ~ 10K thermistor reading / R53 = 49.9K
          FaultRegister |= NICADLowTemp_Fault;
        if (ADC10MEM <= 0x0020)   // 0.06volts ~1K thermistor reading / R53 = 49.9K

          FaultRegister |= NICADHighTemp_Fault;
        if (*Vptr >= 0x283)   // 27 volts [2.07V -> 643(dec) -> 0x283]
          FaultRegister |= OverVoltNiCad_Fault;
        if (*Vptr <= 0x0FA)   // 10.5 volts [0.805V -> 250(dec) -> 0x0FA]
          FaultRegister |= UnderVoltNiCad1_Fault;

        //  Looking for Voltage Droop which indicates a fully charged NICAD battery
        current_Vaverage = average(Vptr, VBATT_SIZE, VBATT, VBATT + VBATT_SIZE-1);       // check
what average value is
        // if Vbatt >=24.5V & looking for 9.66mV droop on NICAD indicating fully charged (due to
battery temp rise)
        if((*Vptr >= 0x0248) && (current_Vaverage <= (last_Vaverage-0x0003)))
        {
          FaultRegister |= Proper_Termination;
        }

        else
        {
          last_Vaverage = current_Vaverage; // store last Vaverage to compare with next
measurement
          if ((Charge_Timer > 30000) && (*Vptr >= 0x023B))  // >2 hour time & >24.0 volts
consider batt fully charged
          {
            FaultRegister |= Proper_Termination;
            // PROBE |= BIT0;  //  PROBE used for debug (BIT0 - BIT7 may be used)
          }
          if ((Charge_Timer > 30000) && (*Vptr <= 0x023A))  // >2 hours & batt voltage is too low
          {
              FaultRegister |= UnderVoltNiCad2_Fault;
          }
        }
      }  // ************ End of NICAD Battery loop ************

      // ************ LiIon Charging Loop ****************
      else  // Charging a LiION Battery
      {
        if (*Tptr >= 0x0136){  // 1.0v  [1V->310(dec)->0x136]
          FaultRegister |= LIIONHighTemp_Fault;
        }
        if (*Tptr <= 0x003E){  // 0.2v  [0.2V->62(dec)->0x03E]
          FaultRegister |= LIIONLowTemp_Fault;
        }
        if (Charge_Timer > 30000)  // >2 hour time Fast Charge Time Fault
        {
          FaultRegister |= FastChg_Fault;
        }
        if (*Vptr >= 0x20C)  // 22.0 volts [1.687V -> 524(dec) -> 0x20C]
        {
          FaultRegister |= OverViolation_Fault;
        }
        if (*Vptr <= 0x129)  // 12.5 volts [0.956V -> 297(dec) -> 0x129]
        {
          FaultRegister |= UnderViolation_Fault;
        }
        else
        {
```

```
                 if ((PackStatus & 0x04) == ISET) // ISET = TRUE ("small" pack and charging at 1.5A)
                 {
                     // detecting taper current threshold indicating battery is fully charged
                     if ((average(Iptr, IBATT_SIZE, IBATT, IBATT + IBATT_SIZE-1) <= 0x52))
                     {
                       FaultRegister |= Proper_Termination;
                     }
                 }
                 else {         // ISET = FALSE, large pack being charged at 3A
                     if ((average(Iptr, IBATT_SIZE, IBATT, IBATT + IBATT_SIZE-1) <= 0x70))  // looking
for taper current
                     {
                       FaultRegister |= Proper_Termination;
                     }
                 }
               }
    }  // ************** End LIION Charging ***************

    // End Page 3 Flow Chart

    // if charging current is >3.5A x 0.033 Rsense x 20V/V IBAT gain = 2.31V /0.0322 = 717d =
0x2CD, fault condition
      if (average(Iptr, IBATT_SIZE, IBATT, IBATT + IBATT_SIZE-1) > 0x2CD)
      {
        FaultRegister |= I_Ave_Fault_Fault;
      }

  }while(FaultRegister == 0x0000); // Charging Loop End - everything ok - no faults, don't
terminate


  if ((FaultRegister & 0x1000) == Proper_Termination)  // indicates proper termination
  {
    // Proper Termination
    P1OUT &= ~CHEN;       // Disable the Charge
    PackStatus |= OK;     // set pack status to OK
    P1OUT &= ~BIT3;       // Turn LED OFF 100% DC
    //    P1OUT |= BIT3;  // Turn LED ON 100% DC

    // Loop for Proper Termination wait for pack removal or voltage drop
    while ((PackStatus & 0x08) == OK)
    {
      _BIS_SR(LPM0_bits + GIE);          // Enter LPM0 & wait for timer
      // Set Up ADC10 channel A7 RESID and convert
      // Looking for pack removal
      ADC10CTL0 = 0x00;
      ADC10CTL0 = ADC10SHT_2 + ADC10ON + ADC10IE;
      ADC10CTL1 = INCH_7;
      ADC10AE0 = 0x80;
      ADC10CTL0 |= ADC10SC + ENC;         // Start the conversion
      _BIS_SR(LPM0_bits + GIE);           // Enter LPM0 & wait for ADC10 to complete
      if (ADC10MEM > 0x3A3)               // if statement is true, battery has been removed
        {PackStatus &= ~OK;}
    }
  }
  else // Fault Termination
  {
    P1OUT &= ~CHEN;                     //Disable the Charger
    // Set Up ADC10 channel A7 RESID and convert
    // Looking for pack removal by reading RESID pin
    ADC10CTL0 = 0x00;
    ADC10CTL0 = ADC10SHT_2 + ADC10ON + ADC10IE;
    ADC10CTL1 = INCH_7;
    ADC10AE0 = 0x80;
    while(1)
    {
      _BIS_SR(LPM0_bits + GIE);           // Enter LPM0 & wait for Timer
      P1OUT ^= BIT3;                      // flash LED
      ADC10CTL0 |= ADC10SC + ENC;         // Start the conversion
      _BIS_SR(LPM0_bits + GIE);           // Enter LPM0 & wait for ADC10 to complete
      if (ADC10MEM > 0x3A3)               // if statement is true, battery has been removed
        break;
    }
```

```
  }
  TACTL = 0x00; // Turn the timer off
  while(1) {}   // Wait to force WDT expiration and reboot
} // End Main

int average(int *cptr, char index, int *start, int *end)
{
  int sum = 0;
  char j = index;;

  do
  {
    while ((cptr > start) && (j > 0))
    {
      sum += *cptr;
      cptr--;
      j--;
    }
    cptr = end;
  }
  while (j > 0);
  return sum/index;
}

// LINCH = the input channel
// LCHAN = enable channel
// TBYTE = The number of 10-bit samples to transfer
// *cptr = pointer to the array index to begin the fill
void ArrayFill(int LINCH, int LCHAN, int TBYTE, int *start, int *end, int *cptr)
{
  cptr++;
  if (cptr > end)
    {cptr = start;}

  ADC10CTL0 &= ~ENC;
  while (ADC10CTL1 & BUSY);
  ADC10DTC1 = TBYTE;
  ADC10SA = (int)cptr;
  ADC10CTL1 &= ~0xF000;
  ADC10CTL1 |= LINCH;
  ADC10AE0 = LCHAN;
  ADC10CTL0 = ADC10SHT_2 + ADC10ON + ADC10IE + MSC;
  ADC10CTL0 |= ENC + ADC10SC;        // Start the conversion
  _BIS_SR(LPM0_bits + GIE);          // Enter LPM0 & wait for ADC10 IFG
  ADC10DTC1 = 0x0000;
  ADC10CTL1 = 0x0000;
  ADC10CTL0 = 0x0000;
}

// Interrupt routines

#pragma vector=TIMERA0_VECTOR
//#pragma vector=TIMER0_A0_VECTOR
__interrupt void TIMERA0_ISR(void)
{
  LPM0_EXIT;                      // ADC10 enable set
//******** For Normal Operation, next line of code must be un-commented to RESET Watchdog ********
//  WDTCTL =  WDTPW + WDTCNTCL;     // Reset Watchdog, need to un-comment for normal operation
  Charge_Timer++;
}

#pragma vector=ADC10_VECTOR
__interrupt void ADC10_ISR(void)
{
  LPM0_EXIT;
}

// Notes:
// 1) WDT needs to be enabled for normal operation
// 2) Next board spin, change P2.7 "NICAD" to pull-down (therefore start-up at lower voltage)
// 3) Next board spin, change P1.4 "CHEN" to pull-down (therefore charger defaults to off)
```

3 PCB Layout Guidelines

1. Care must be taken in the ac/dc power routing to provide adequate isolation on the high-voltage lines.
2. The control stage and the power stage must be routed separately. PMP3914 is designed to have surface-mount devices on the bottom-side and throughhole devices on top-side.
3. The dynamic power path feature of the bq24703 is not used in this stand-alone design (with ACN/ACP pulled high to Vcc). However, if this feature is desired, the ac current sense resistor must be connected to ACP and ACN with a Kelvin contact. The area of this loop must be minimized. The decoupling capacitors for these pins must be placed as close to the IC as possible.
4. The charge current sense resistor must be connected to SRP, SRN with a Kelvin contact. The area of this loop must be minimized. The decoupling capacitors for these pins must be placed as close to the IC as possible.
5. Decoupling capacitors for VCC, and VREF must be placed next to, or immediately underneath, the IC (on the second and third layers) and make the interconnections to the IC as short as possible.
6. Decoupling capacitors for Q2 are required (C32, C33, and C34) and must be placed close to the corresponding IC pins and make the interconnections to the IC as short as possible.
7. High current switching components (Q2, L2, D7, C18, and C15) must be separated from sensitive analog circuitry.

4 Bill of Materials, Board Layouts and Schematics

4.1 Bill of Materials

Table 2. Bill of Materials

Count	RefDes	Value	Description	Size	Part Number	Mfr
1	C1	100μF	Capacitor, Aluminum, 200V, 20%	16 × 25 mm	EEUEB2D101	Panasonic
7	C10, C11, C20, C23, C24, C200, C201	0.1μF	Capacitor, Ceramic, 50V, X7R, 10%	0603	C1608X7R1H104K	TDK
2	C14, C16	1500pF	CAP, CERM DISC Y1, 250Vac, 20%	.500 × .310	ECKDNA152ME	Panasonic
1	C15	220μF	Capacitor, Aluminum, 35V	0.315 inch	35V ZL 220uF 8 X 16	Rubycon
1	C17	0.33μF	CAP 305VAC EMI SUPPRESSN	0.354 x 0.709 inch	B32922A2334M	Epcos
2	C21, C28	1μF	Capacitor, Ceramic, 16V, X7R, 20%	0603	C1608X7R1C105M	TDK
2	C22, C27	4.7μF	Capacitor, Ceramic, 16V, X5R, 15%	0805	Std	Std
1	C29	10μF	Capacitor, Ceramic, 16V, X5R, 15%	0805	Std	Std
1	C3	0.01μF	Capacitor, Polyester, .01uF, 630V, 10%	0.472 x 0.177 inch	ECQE6103KF	Panasonic
3	C32, C33, C34	3.3μF	Capacitor, Ceramic, 50V, X7R, 15%	1210	Std	Std
5	C35, C36, C37, C38, C39	0.01uF	Capacitor, Ceramic, 50V, X7R, 10%	0603	C1608X7R1H103K	TDK
3	C4, C13, C18	1μF	Capacitor, Ceramic, 50V, X7R, 15%	1206	Std	Std
2	C5, C6	1000μF	Capacitor, Aluminum Electrolytic, 35V	0.492 inch	35V ZL 1000uF 12.5 X 25	Rubycon
1	C7	27μF	Capacitor, Aluminum Electrolytic, 25V	0.200 × 0.435 inch	25V ZL 27uF 5 X 11	Panasonic
5	C8, C12, C25, C26, C202	100pF	Capacitor, Ceramic, 50V, X7R, 10%	0603	C1608X7R1H101K	TDK
1	C9	0.047μF	Capacitor, Ceramic, 50V, X7R, 10%	0603	C1608X7R1H473K	TDK
1	D1	DF1504M	Diode, Bridge, 1.5-A, 400-V	DIP6	DF1504M	Diodes Inc
1	D10	DNP	Do Not Populate	T1-3/4	N/A	N/A
1	D2	MURA160T3	Diode, Rectifier, 1A, 600V	SMA	MURA160T3	ON Semiconductor
1	D201	3.6V	Diode, Zener, 3.6-V	SOT23	BZX84C3V6LT1	ON Semiconductor
1	D3	MBR10H100CT	Diode, Dual Schottky, 10A, 100-V	TO220	MBR10H100CT	On Semi
3	D4, D5, D200	MMSD914	Diode, Switching, 100-V, 200-mA, 225-mW	SOD-123	MMSD914T1	On Semi
1	D6	LTST-C190GKT	Diode, LED, Green, 2.1-V, 20-mA, 6-mcd	0603	LTST-C190GKT	Lite On
1	D7	MBR340	Diode, Schottky, 3A, 40V	DO-201AD	MBR340	On Semi
1	D8	13V	Diode, Zener, 13-V	SOT23	BZX84C13LT1	ON Semiconductor
1	D9	DNP	Do Not Populate	SOD-123	N/A	N/A
1	F1	2.5A/250V	Fuse, TR5 Series, 2.5A, 250V	0.335	3701250041	Wickmann

Table 2. Bill of Materials (continued)

Count	RefDes	Value	Description	Size	Part Number	Mfr
2	HS1, HS2	{Value}	Heatsink, TO-220/218 vertical	0.640 x 0.640	STD	STD
1	J1	PTC36SAAN	Header, Male 2-pin, 100mil spacing, (36-pin strip)	0.100 inch x 2	PTC36SAAN	Sullins
1	J2	D120/2DS	Terminal Block, 2-pin, 15-A, 5.1mm	0.40 x 0.35 inch	D120/2DS	OST
1	J200	103308-2	Header, Latch Assy 2x7, Low Profile	1.000 x 0.360 inch	103308-2	AMP
2	J201, J204	PTC36SAAN	Header, Male 3-pin, 100mil spacing, (36-pin strip)	0.100 inch x 3	PTC36SAAN	Sullins
2	J202, J203	PTC36DAAN	Header, Male 2x4-pin, 100mil spacing (36-pin strip)	0.20 x 0.40 inch	PTC36DAAN	Sullins
1	J3	703W-00/54	Connector, AC Board mount, 9mm	1.97 x 0.79 inch	703W-00/54	Qualtek Electronics
1	L1	1mH	Inductor, 1A, 0.4 Ω	0.670 x 0.748 inch	UU10.5V-102LF	GCI
1	L2	22 uH	Inductor, Through hole, 7A	0.860 x 0.450 inch	2105-V	JWMiller
1	Q1	IRFB9N60A	MOSFET, N-ch, 600-V, 9.2-A, 0.75-Ω	TO-220V	IRFB9N60A	Vishay
2	Q2, Q8	FDS4435	MOSFET, Pch, -30V, -8.8A, 20-mΩ	SO8	FDS4435	Fairchild
7	Q3, Q4, Q6, Q7, Q9, Q10, Q11	2N7002	MOSFET, N-ch, 60-V, 115-mA, 1.2-Ω	SOT23	2N7002	Diodes
1	Q5	BSS84	MOSFET, Pch, -50V, –0.13A, 10 Ω	SOT23	BSS84	Infineon
2	R1, R3	499k	Resistor, Chip, 1/4W, 5%	1210	Std	Std
1	R12	11.8k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R13	1.5k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R14	1.05k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
4	R15, R16, R17, R18	1	Resistor, Chip, 1/8W, 5%	0805	Std	Std
1	R19	0.033	Resistor, Metal Film, 1/2W, 5%	2010	Std	Std
2	R2, R100	200k	Resistor, Chip, 1W, 5%	2512	Std	Std
4	R20, R23, R36, R38	301k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R200	332	Resistor, Chip, 1/16W, 1%	0603	Std	Std
2	R201, R206	2.21k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
2	R203, R207	3.32k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R204	100k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R205	200k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R208	200	Resistor, Chip, 1/16W, 1%	0603	Std	Std
2	R22, R62	1k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
2	R24, R25	30.9k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
12	R28, R30, R32, R40, R41, R42, R43, R44, R48, R51, R59, R61	150k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
2	R29, R35	15k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R31	4.99k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R34	100	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R37	18.7k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R39	24.9k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
2	R4, R7	10	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R47	2.21k	Resistor, Chip, 1/4W, 5%	1210	Std	Std
3	R49, R53, R300	49.9k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
3	R5, R45, R50	0	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R52	69.8k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R6	34.8k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	R60	249k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
2	R8, R10	2k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
5	R9, R11, R33, R54, R209	10k	Resistor, Chip, 1/16W, 1%	0603	Std	Std
1	RT1	2.5 Ω	Thermistor, NTC, 2.5 Ω, 6.5-A	0.590 × 0.276	B57237S0259M000	Epcos
1	T1	PA2624NL	Transformer, Custom, Flyback	0.690 × 1.100 inch	PA2624NL	Pulse
17	TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP10, TP11, TP12, TP16, TP17, TP200, TP201, TP202, TP203	5000	Test Point, Red, Thru Hole Color Keyed	0.100 x 0.100 inch	5000	Keystone

Table 2. Bill of Materials (continued)

Count	RefDes	Value	Description	Size	Part Number	Mfr
3	TP13, TP14, TP15	5001	Test Point, Black, Thru Hole Color Keyed	0.100 x 0.100 inch	5001	Keystone
1	U1	UCC28600D	IC, Quasi-Resonant Flyback Green Mode Controller	SO8	UCC28600D	Texas Instruments
1	U2	H11A817A	IC, Optocoupler, 5300-V, 80-160% CTR	0.380 x 0.180 inch	H11A817A	Fairchild
1	U3	TL431AIDBZ	IC, Precision Adjustable Shunt Regulator	SOT23-3	TL431AIDBZ	TI
1	U4	bq24703PW	IC, Battery Charge Controller/Selector w/DPM	TSSOP24	bq24703PW	TI
1	U5	TPS79733DCK	IC, Regulator, LDO, Micropower	SOP-5 (DCK)	TPS79733DCK	TI
1	U6	MSP430F2012IPW	IC, Mixed Signal Microcontroller	TSSOP-14	MSP430F2012IPW	TI

4.2 Board Layout

The PMP3914 PCB is a four-layer board. The assembly drawings for all four layers appear in the following illustrations.

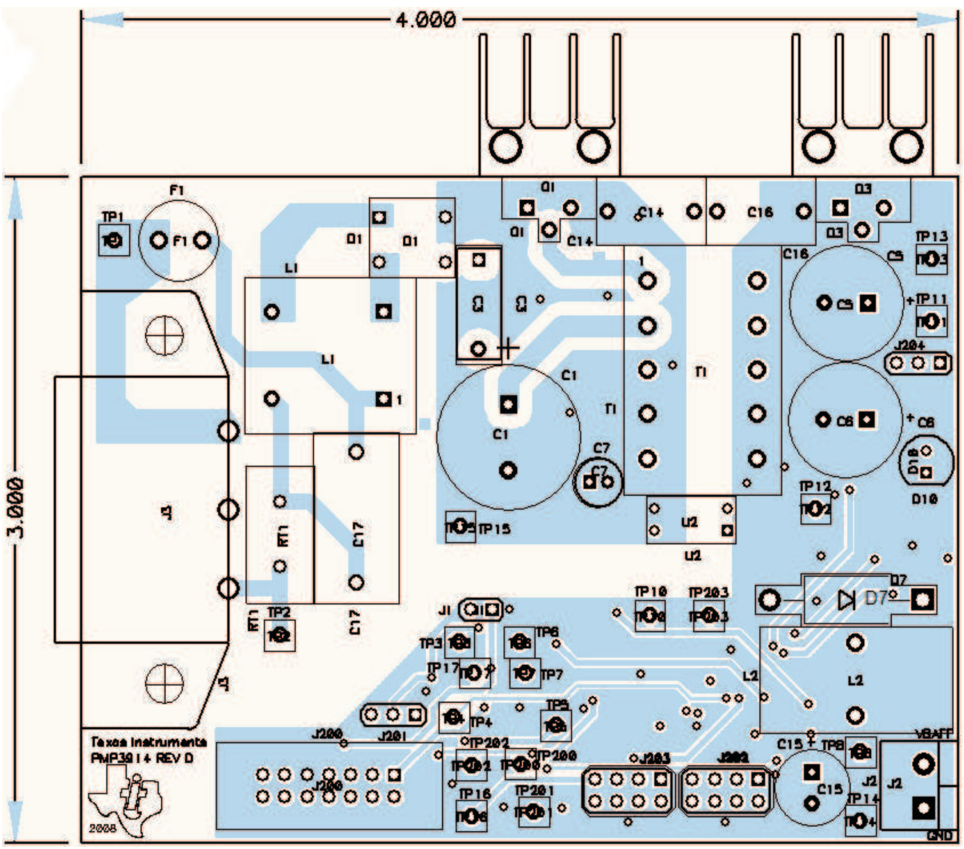


Figure 5. Top, Silkscreen Layer

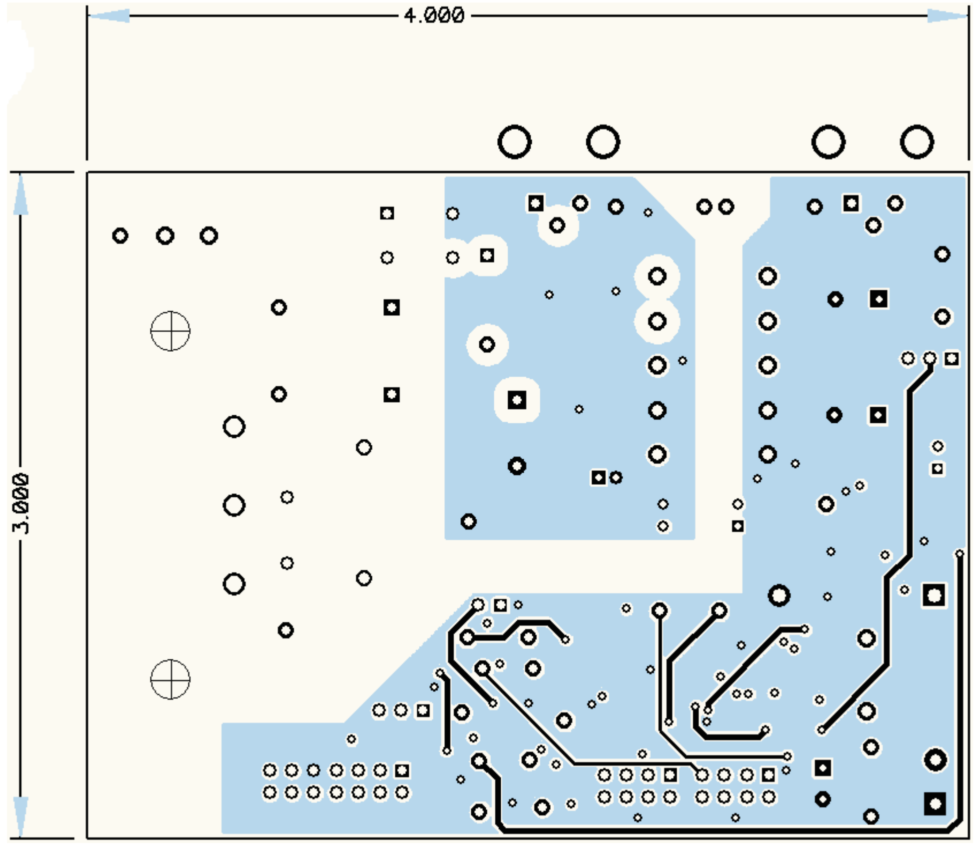


Figure 6. Second Layer

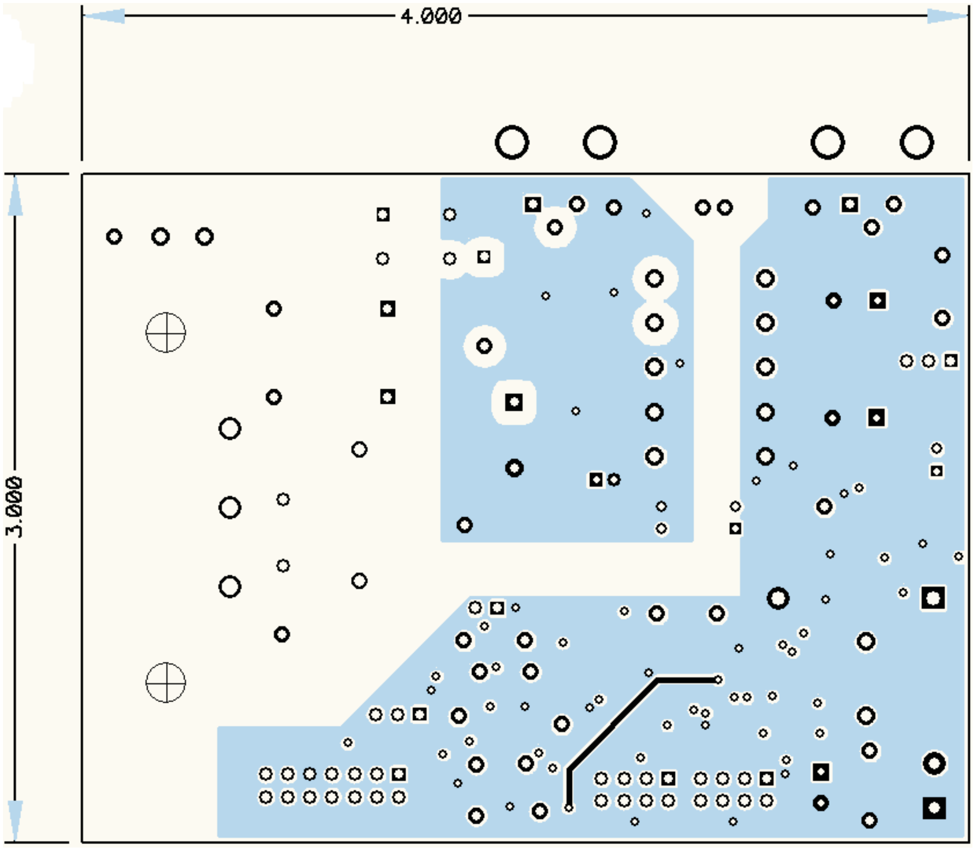


Figure 7. Third Layer

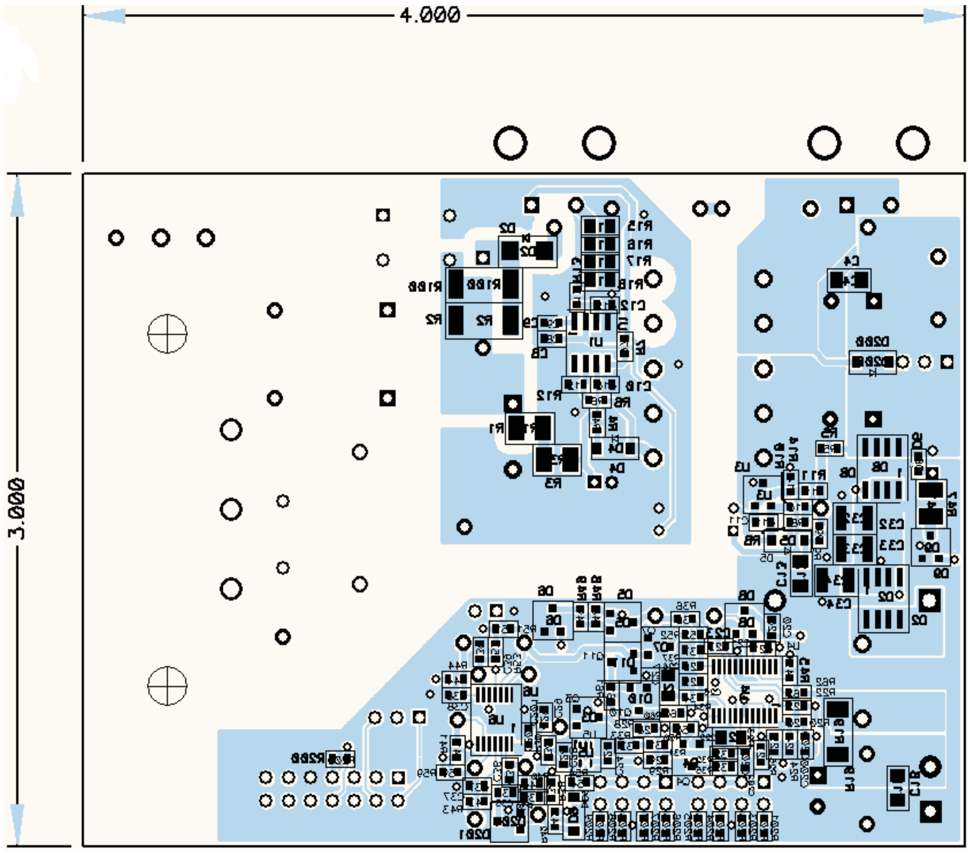


Figure 8. Bottom Layer

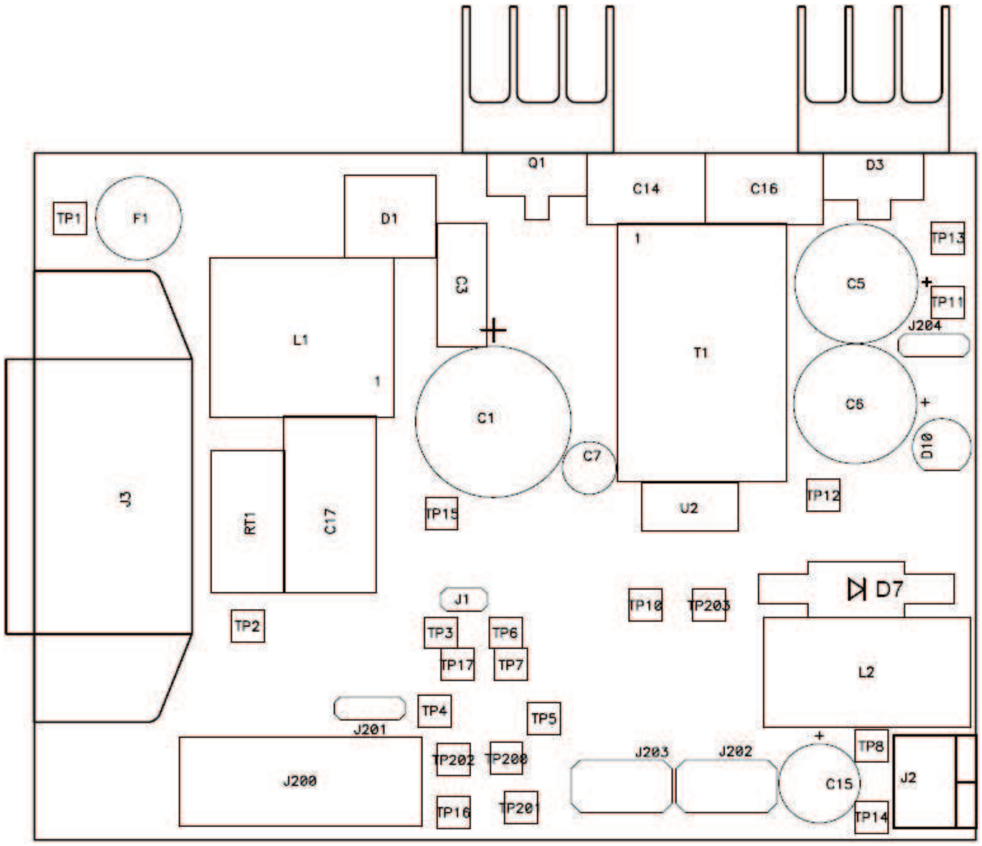


Figure 9. Top Assembly Drawing

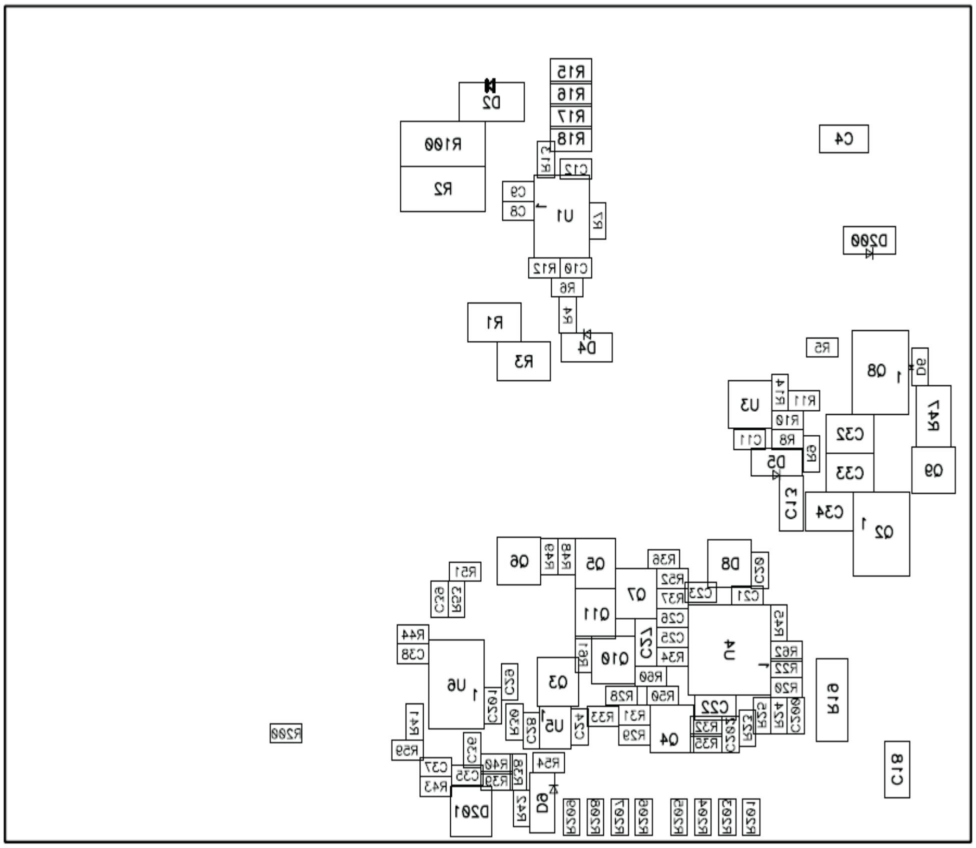


Figure 10. Bottom Assembly Drawing

4.3 Schematics

The schematics are shown in Figure 11 and Figure 12.

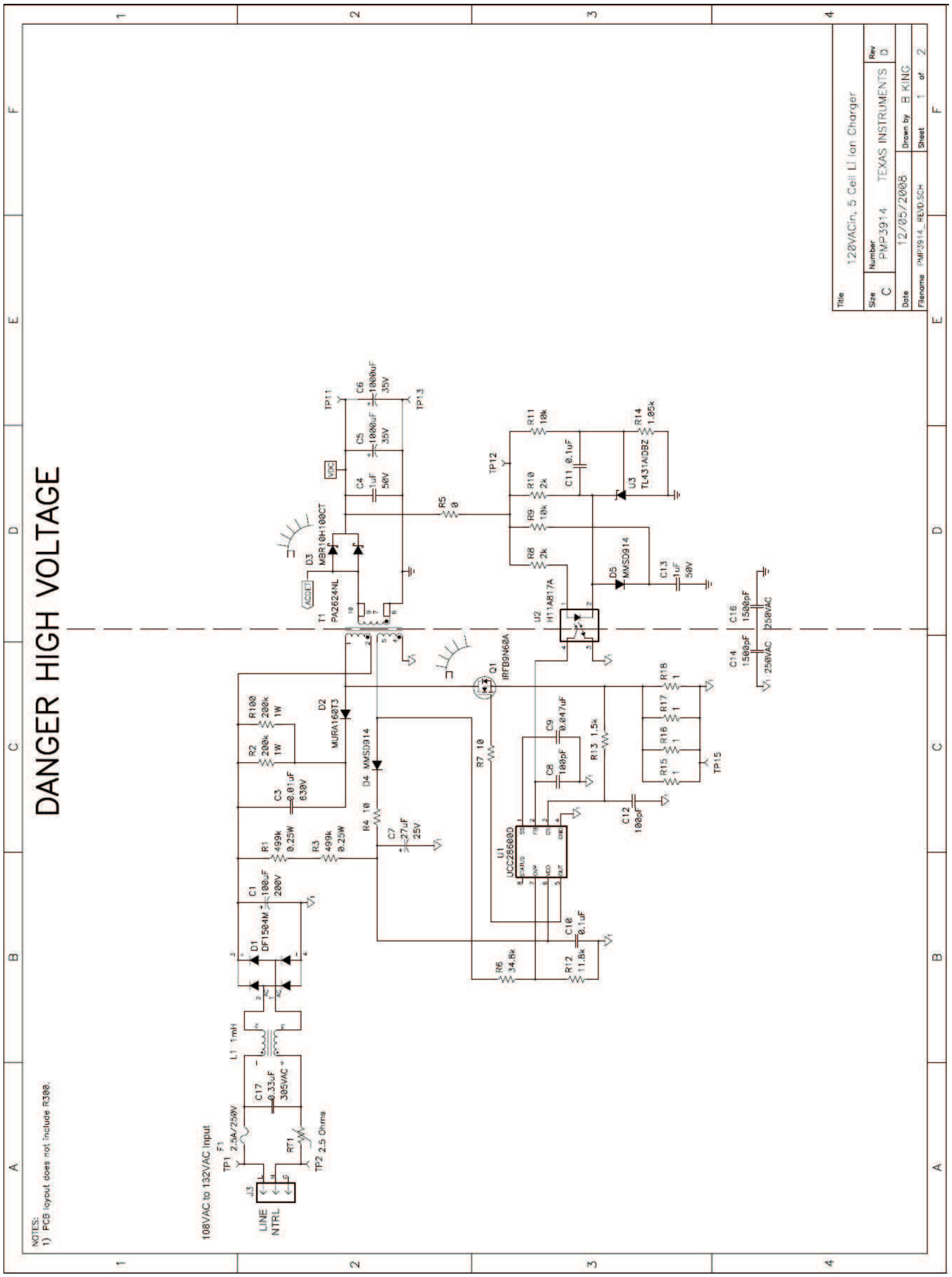


Figure 11. UCC28600 Offline Flyback Converter from 108-132 Vac to 25.5 Vdc Isolated.

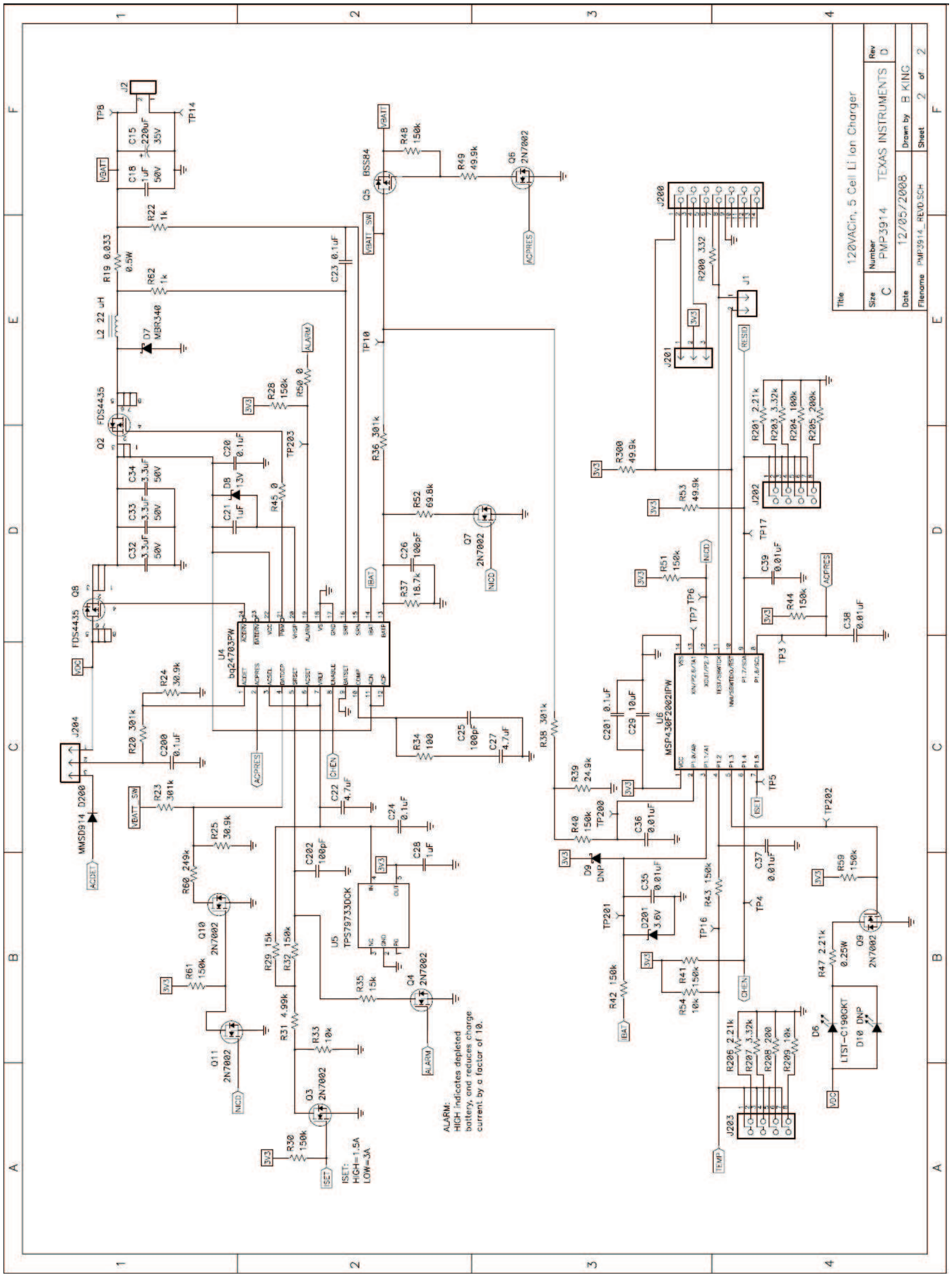


Figure 12. bq24703 Multichemistry Charger with MSP430F2012 Control and Monitoring

Appendix A Flowchart

The following flowchart shows...

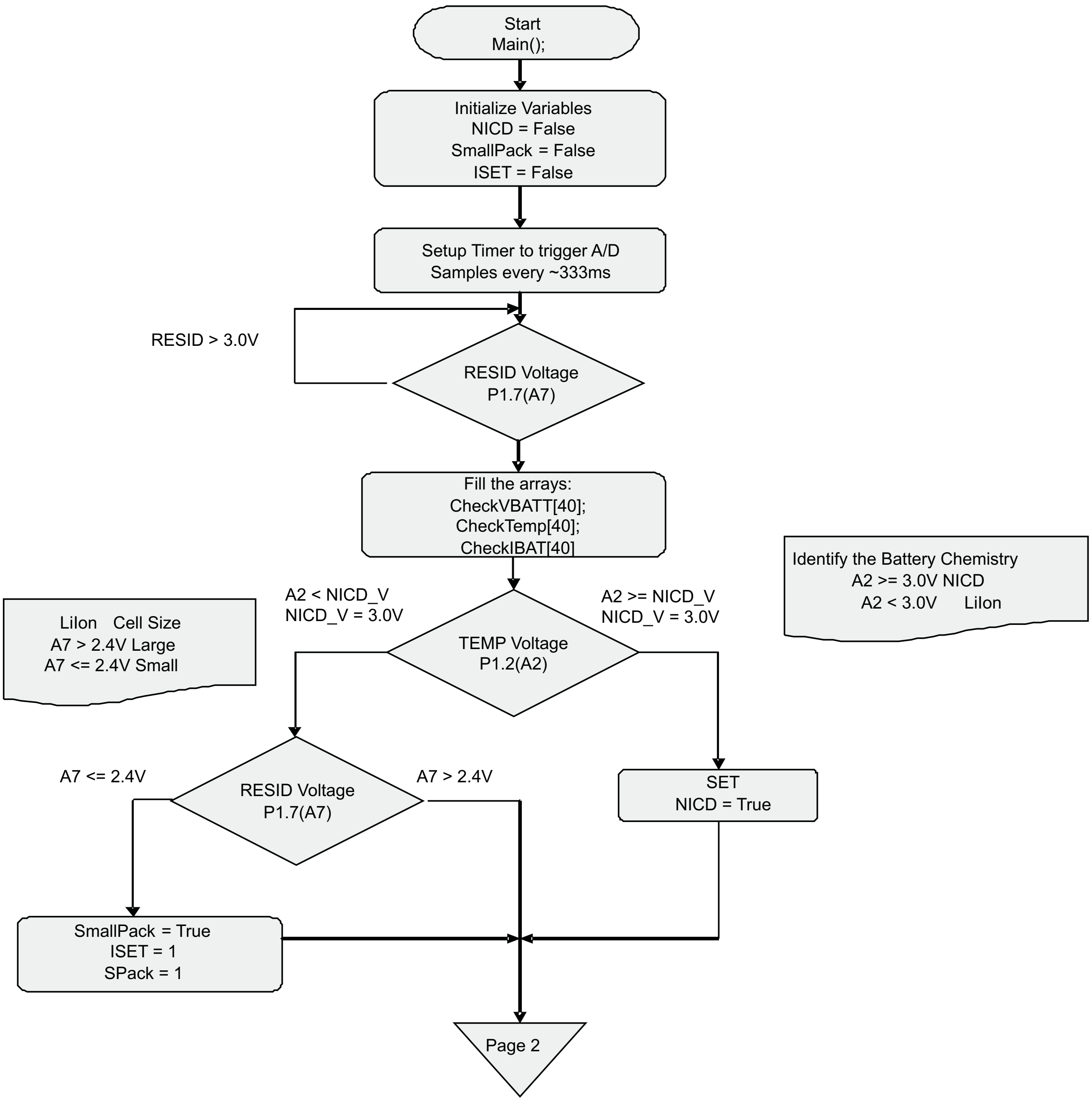


Figure A-1. Flowchart, Sheet 1

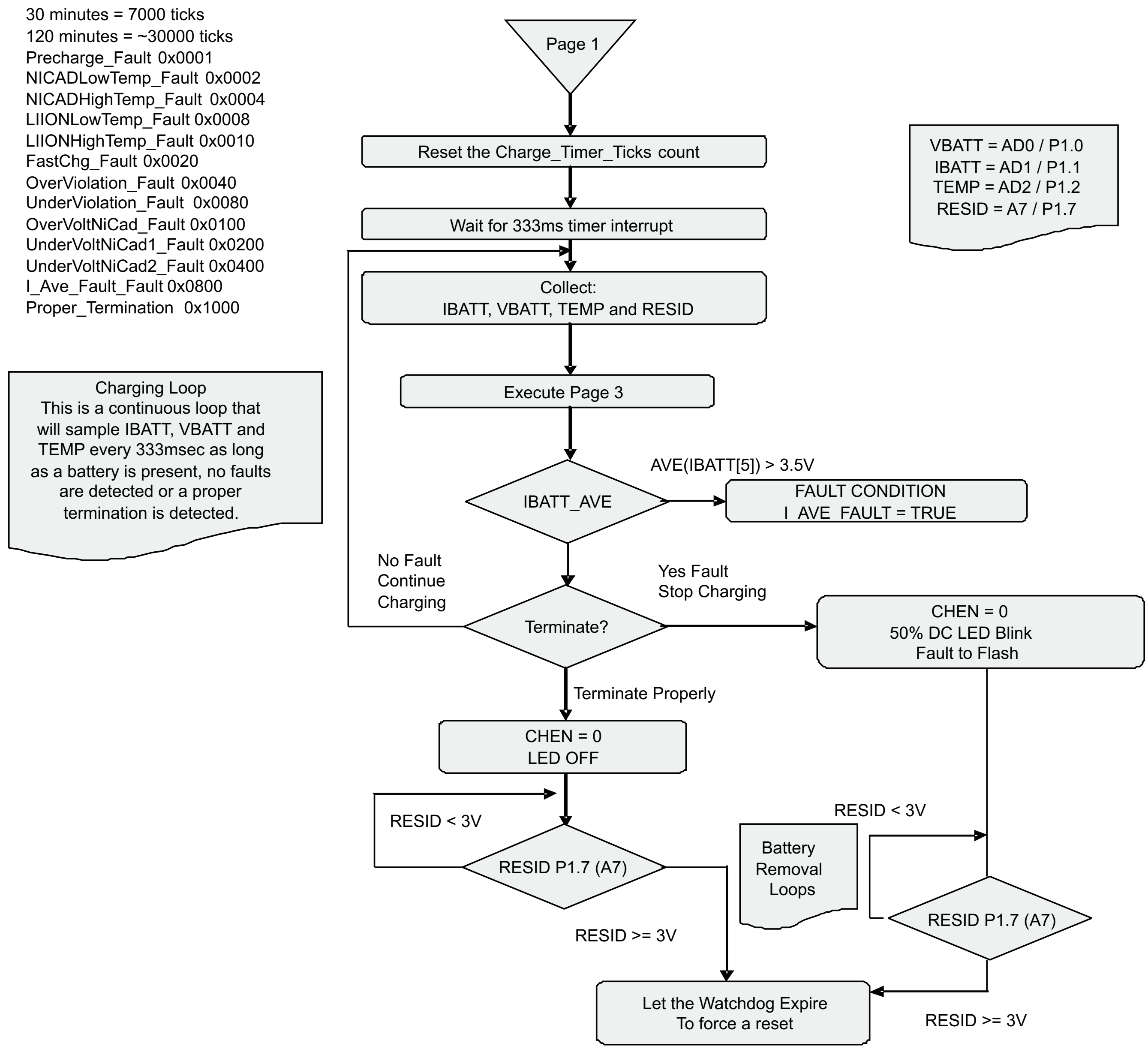


Figure A-2. Flowchart, Sheet 2

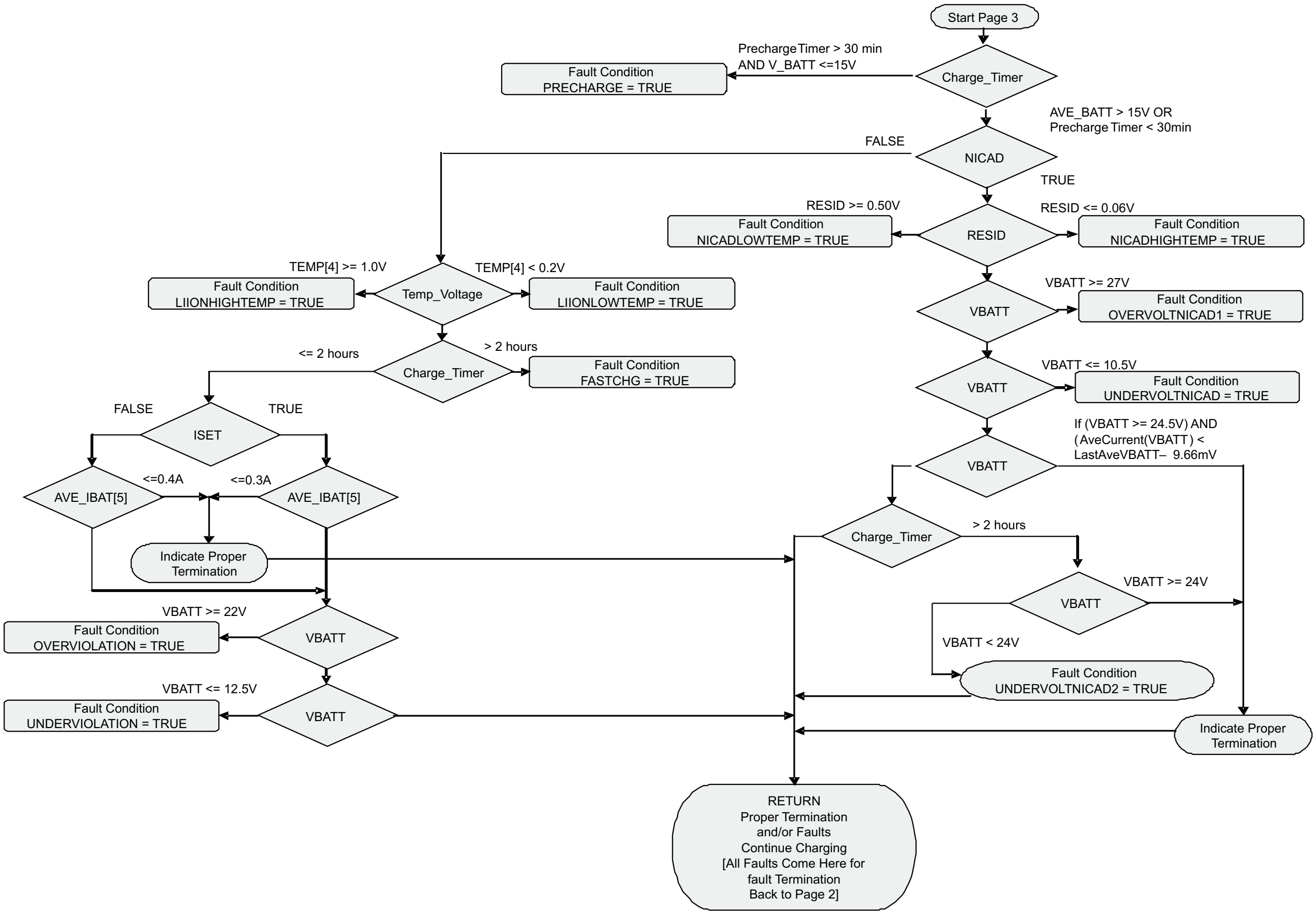


Figure A-3. Flowchart, Sheet 3

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EVM WARNINGS AND RESTRICTIONS

It is important to operate this EVM within the input voltage range of 108 V and 132 V and the output voltage range of 0 V and 25.6 V, with a microcontroller input and output voltage range between 0 V and 3.3 V .

Exceeding the specified input range may cause unexpected operation and/or irreversible damage to the EVM. If there are questions concerning the input range, please contact a TI field representative prior to connecting the input power.

Applying loads outside of the specified output range may result in unintended operation and/or possible permanent damage to the EVM. Please consult the EVM User's Guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative.

During normal operation, some circuit components may have case temperatures greater than 70°C. The EVM is designed to operate properly with certain components above 70°C as long as the input and output ranges are maintained. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors. These types of devices can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during operation, please be aware that these devices may be very warm to the touch.

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