MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter Reference Design

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as "unbreakable."

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip's code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

QUALITY MANAGEMENT SYSTEM CERTIFIED BY DNV

═ ISO/TS 16949 ═

Trademarks

Printed on recycled paper.

ISBN: 978-1-62077-199-0

Microchip received ISO/TS-16949:2009 certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona; Gresham, Oregon and design centers in California and India. The Company's quality system processes and procedures are for its PIC® MCUs and dsPIC® DSCs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001:2000 certified.

Object of Declaration: MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter

EU Declaration of Conformity

This declaration of conformity is issued by the manufacturer.

The development/evaluation tool is designed to be used for research and development in a laboratory environment. This development/evaluation tool is not intended to be a finished appliance, nor is it intended for incorporation into finished appliances that are made commercially available as single functional units to end users. This development/evaluation tool complies with EU EMC Directive 2004/108/EC and as supported by the European Commission's Guide for the EMC Directive 2004/108/EC (8th February 2010).

This development/evaluation tool complies with EU RoHS2 Directive 2011/65/EU.

For information regarding the exclusive, limited warranties applicable to Microchip products, please see Microchip's standard terms and conditions of sale, which are printed on our sales documentation and available at www.microchip.com.

Signed for and on behalf of Microchip Technology Inc. at Chandler, Arizona, USA

Derek Carlson
VP Development Tools

02-MAY-12
Date

NOTES:

Table of Contents

NOTES:

Preface

NOTICE TO CUSTOMERS

All documentation becomes dated, and this manual is no exception. Microchip tools and documentation are constantly evolving to meet customer needs, so some actual dialogs and/or tool descriptions may differ from those in this document. Please refer to our web site (www.microchip.com) to obtain the latest documentation available.

Documents are identified with a "DS" number. This number is located on the bottom of each page, in front of the page number. The numbering convention for the DS number is "DSXXXXXA", where "XXXXX" is the document number and "A" is the revision level of the document.

For the most up-to-date information on development tools, see the MPLAB® IDE online help. Select the Help menu, and then Topics to open a list of available online help files.

INTRODUCTION

This chapter contains general information that will be useful to know before using the MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter Reference Design. Items discussed in this chapter include:

- Document Layout
- Conventions Used in this Guide
- Recommended Reading
- The Microchip Web Site
- Customer Support
- Document Revision History

DOCUMENT LAYOUT

This document describes how to use the MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter as a development tool to emulate and debug firmware on a target board. The manual layout is as follows:

- **Chapter 1. "Product Overview"** – Important information on using the MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter including a getting started section that describes wiring the line and load connections.
- **Chapter 2. "Hardware"** – Includes detail on the function blocks of the meter including the analog front-end and power supply design.
- **Chapter 3. "Calculation Engine and Register Description"** – This section describes the digital signal flow for all power output quantities such as RMS current, RMS voltage, active power, reactive power and apparent power. This section also includes the registers' detail.
- **Chapter 4. "Communication Protocol"**– Here is described the protocol used for accessing the registers. It includes commands that are used to interface to the meter.
- **Chapter 5. "Microchip Energy Meter Software"**– Describes the functionality of the Graphical User Interface (GUI) that runs on the PC.
- **Chapter 6. "Energy Meter Calibration"**– Information on calibration of the energy meter using the GUI.
- **Chapter 7. "Special Features"**– Describes the features developed in the MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter.
- **Appendix A. "Schematic and Layouts"** – Shows the schematic and layout diagrams
- **Appendix B. "Bill of Materials (BOM)"** – Lists the parts used to build the MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter.

CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

DOCUMENTATION CONVENTIONS

<table>
<tr><th>Description</th><th>Represents</th><th>Examples</th></tr>
<tr><td colspan="3">Arial font:</td></tr>
<tr><td rowspan="2">Italic characters</td><td>Referenced books</td><td>MPLAB® IDE User’s Guide</td></tr>
<tr><td>Emphasized text</td><td>...is the only compiler...</td></tr>
<tr><td rowspan="3">Initial caps</td><td>A window</td><td>the Output window</td></tr>
<tr><td>A dialog</td><td>the Settings dialog</td></tr>
<tr><td>A menu selection</td><td>select Enable Programmer</td></tr>
<tr><td>Quotes</td><td>A field name in a window or dialog</td><td>“Save project before build”</td></tr>
<tr><td>Underlined, italic text with right angle bracket</td><td>A menu path</td><td><u>File>Save</u></td></tr>
<tr><td rowspan="2">Bold characters</td><td>A dialog button</td><td>Click OK</td></tr>
<tr><td>A tab</td><td>Click the Power tab</td></tr>
<tr><td>N‘Rnnnn</td><td>A number in verilog format, where N is the total number of digits, R is the radix and n is a digit.</td><td>4‘b0010, 2‘hF1</td></tr>
<tr><td>Text in angle brackets < ></td><td>A key on the keyboard</td><td>Press <Enter>, <F1></td></tr>
<tr><td colspan="3">Courier New font:</td></tr>
<tr><td rowspan="7">Plain Courier New</td><td>Sample source code</td><td><code>#define START</code></td></tr>
<tr><td>Filenames</td><td><code>autoexec.bat</code></td></tr>
<tr><td>File paths</td><td><code>c:\mcc18\h</code></td></tr>
<tr><td>Keywords</td><td><code>_asm, _endasm, static</code></td></tr>
<tr><td>Command-line options</td><td><code>-Opa+, -Opa-</code></td></tr>
<tr><td>Bit values</td><td><code>0, 1</code></td></tr>
<tr><td>Constants</td><td><code>0xFF, ‘A’</code></td></tr>
<tr><td>Italic Courier New</td><td>A variable argument</td><td><code>file.o</code>, where <code>file</code> can be any valid filename</td></tr>
<tr><td>Square brackets [ ]</td><td>Optional arguments</td><td><code>mcc18 [options] file [options]</code></td></tr>
<tr><td>Curly brackets and pipe character: { | }</td><td>Choice of mutually exclusive arguments; an OR selection</td><td><code>errorlevel {0|1}</code></td></tr>
<tr><td rowspan="2">Ellipses...</td><td>Replaces repeated text</td><td><code>var_name [, var_name...]</code></td></tr>
<tr><td>Represents code supplied by user</td><td><code>void main (void)
{ ...
}</code></td></tr>
</table>

RECOMMENDED READING

This user's guide describes how to use MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources.

- **MCP3911 Data Sheet – *“3.3V Two-Channel Analog Front End”* (DS22286)**

This data sheet provides detailed information regarding the MCP3911 device.

- **PIC18F85K90 Family Data Sheet – *“64/80-Pin, High-Performance Microcontrollers with LCD Driver and nanoWatt XLP Technology”* (DS39957)**

This data sheet provides detailed information regarding the PIC18F85K90 device.

- **PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide (DS51964)**

This User's Guide describes the calibration registers and UART communication protocol used on the PIC18F87J72 Single-Phase Energy Meter Reference Design. Only some of the information applies to the MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter. The chapters recommended for reading will be specified in this document.

THE MICROCHIP WEB SITE

Microchip provides online support via our web site at www.microchip.com. This web site is used as a means to make files and information easily available to customers. Accessible by using your favorite Internet browser, the web site contains the following information:

- **Product Support** – Data sheets and errata, application notes and sample programs, design resources, user’s guides and hardware support documents, latest software releases and archived software
- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip consultant program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

CUSTOMER SUPPORT

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Field Application Engineer (FAE)
- Technical Support

Customers should contact their distributor, representative or field application engineer (FAE) for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in the back of this document.

Technical support is available through the web site at: http://www.microchip.com/support.

DOCUMENT REVISION HISTORY

Revision A (May 2013)

- Initial Release of this Document.

NOTES:

Chapter 1. Product Overview

1.1 INTRODUCTION

The MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter is a fully functional single-phase meter with enhanced capabilities, such as battery backup, RTC and anti-tamper features.

To detect the tamper condition, both currents (the neutral and the high-voltage line) must be monitored and compared to each other. The two current channels are measured with the MCP3911 device and the voltage channel is measured with the 12-bit SAR ADC integrated in the microcontroller.

This design has two sensors for the current measurements (a current transformer and a shunt). One is placed on the neutral and the other on the high-voltage line. The PIC18F85K90 microcontroller directly drives the LCD and communicates via UART with the MCP2200, offering an isolated USB connection for meter calibration and access to the device power calculations. The system calculates active and reactive energy, active, reactive and apparent power, power factor, RMS current, RMS voltage and the line frequency.

The Microchip Energy Meter Software is used to calibrate and monitor the system. The calibration can be done in closed loop or open loop.

FIGURE 1-1: *MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter Reference Design.*

1.2 WHAT THE MCP3911 AND PIC18F85K90 SINGLE-PHASE ANTI-TAMPER ENERGY METER KIT INCLUDES

This MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter kit includes:

- MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter (ARD00385)
- Important Information Sheet

1.3 GETTING STARTED

To describe how to use the MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter, the following example is given using a 2-wire single-phase, 220 VAC line voltage and connections using an energy meter calibrator equipment, or other programmable load source. The nominal current (I_N) is 5A, and the maximum current (I_{MAX}) is 60A.

To test a calibrated meter, the following connections apply for a 2-wire connection.

1.3.1 Step 1: Wiring Connections

Figure 1-2 is identifying the line and load connections of the MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter.

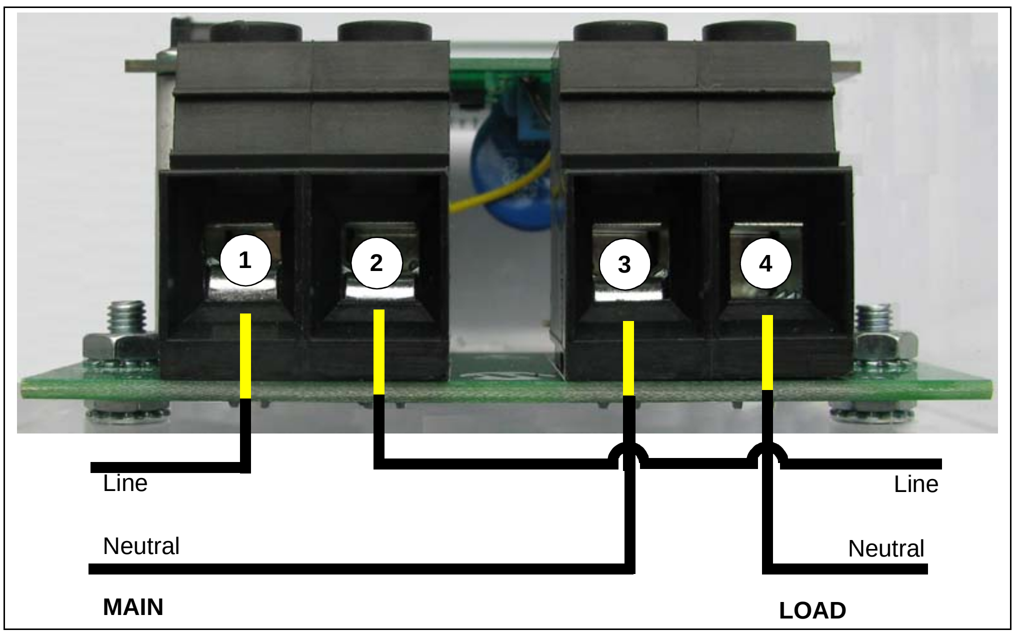


FIGURE 1-2: *Example Connections Using a 2-Wire System.*

1.3.2 Step 2: Turn On Line/Load Power to the Meter (Power the Meter)

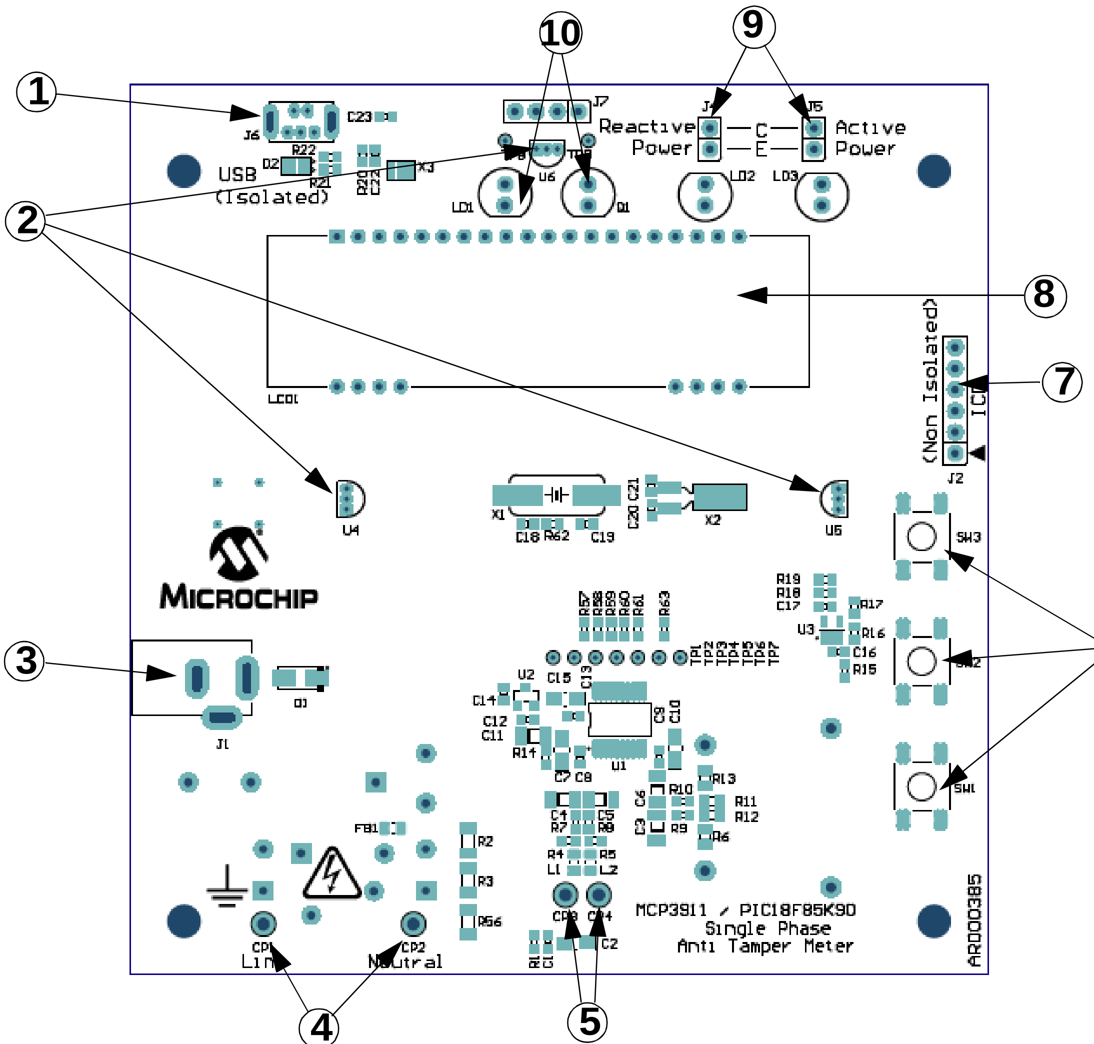
The meter will turn on when the line connection has 220V connected. The LCD display will show the total energy accumulated.

WARNING
The ICD header is non-isolated. In case of a potential difference between the ground of the user's PC and the ground of this meter, PC/device damage occurs. Before connecting to the ICD, make sure the PC is not earth-grounded, as this design employs a "hot-ground" system.

Chapter 2. Hardware

2.1 OVERVIEW

Figures 2-1 and 2-2 show the MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter hardware components:



Legend:

1	=	USB Connection (Isolated)	6	=	Push Button Switches
2	=	Magnetic Sensors	7	=	Non-Isolated ICD Programming Header
3	=	+9V DC Input (Non-Isolated)	8	=	9-digit LCD Display with Icons for kWh and kVARh
4	=	Connections to Line and Neutral	9	=	Pulse Outputs for Active and Reactive Energy (Isolated)
5	=	Connections to Shunt Current Sensing Resistor	10	=	IR Interface (not implemented in this design)

FIGURE 2-1: *Top View – Hardware Components.*

On the upper side, from left to right, there is the USB connection, IR transmitter and receiver (not implemented in this version of the firmware), and the isolated pulse outputs for reactive and active energy (each with an LED).

In the center of the board there is a 9-digit LCD display with icons for kWh and kVARh.

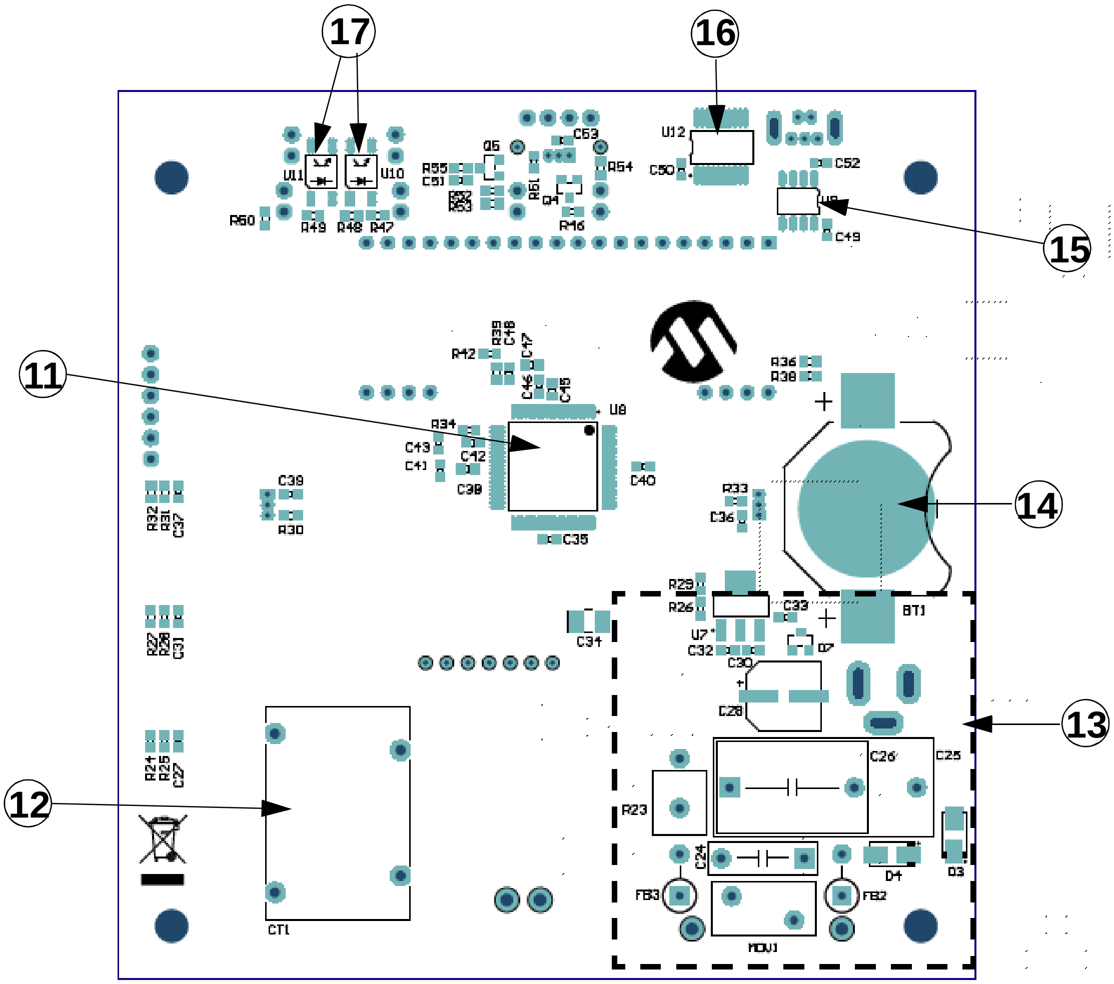
Three magnetic sensors are placed in the middle of the board, for detecting a perturbing exterior magnetic field.

On the left side, there is a 9V DC input jack connector, for powering the meter when the mains supply is missing.

On the right we can see the non-isolated ICD programming header and three push button switches:

SW1 is the tamper switch. SW2 is not used in this firmware implementation. SW3 is the MCU hardware reset.

On the bottom, there are connections to the shunt current sensing resistor and to the line and neutral mains input wires.



Legend:

11	=	PIC18F85K90
12	=	Current Transformer
13	=	Capacitive Power Supply
14	=	3V Backup Battery
15	=	Isolation IC
16	=	MCP2200 for USB Connection
17	=	Optoisolators for Pulse Outputs

FIGURE 2-2: *Bottom View – Hardware Components.*

2.2 INPUT AND ANALOG FRONT END

The MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter is designed for a 220V line voltage. At the bottom of the main board are the high-voltage line and neutral connections. The 200 µΩ shunt sits on the high or line side of a 2-wire system, and the meter employs a hot or "live" ground, while the current transformer is used on the neutral side.

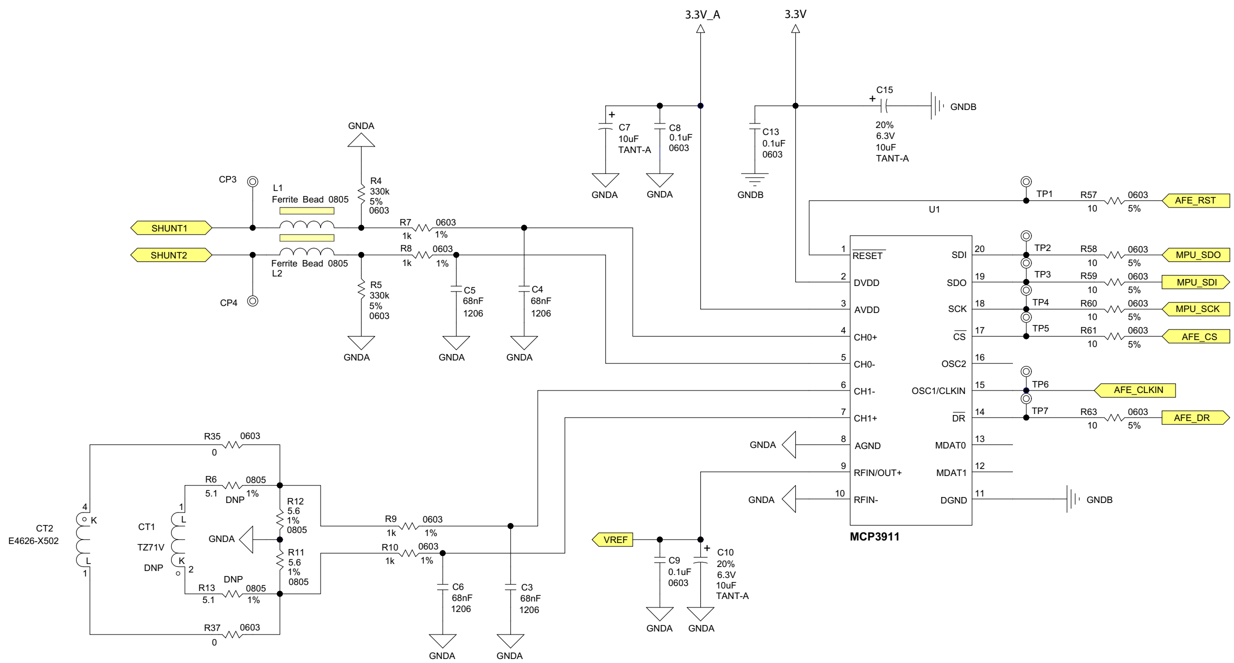


FIGURE 2-3: *Current Channels.*

There are two current channels to be measured, connected to the external 16-bit two-channel ADC (MCP3911). Channel 0 measures the voltage on the shunt, while Channel 1 measures the output voltage of the current transformer.

Anti-aliasing low-pass filters are placed on both current channels and also on the voltage channel.

Special care has been taken in the design of the analog ground. There are two analog grounds (one for MCP3911, the other for the voltage channel), separated from each other and the digital ground, but connected in a single point in a star connection.

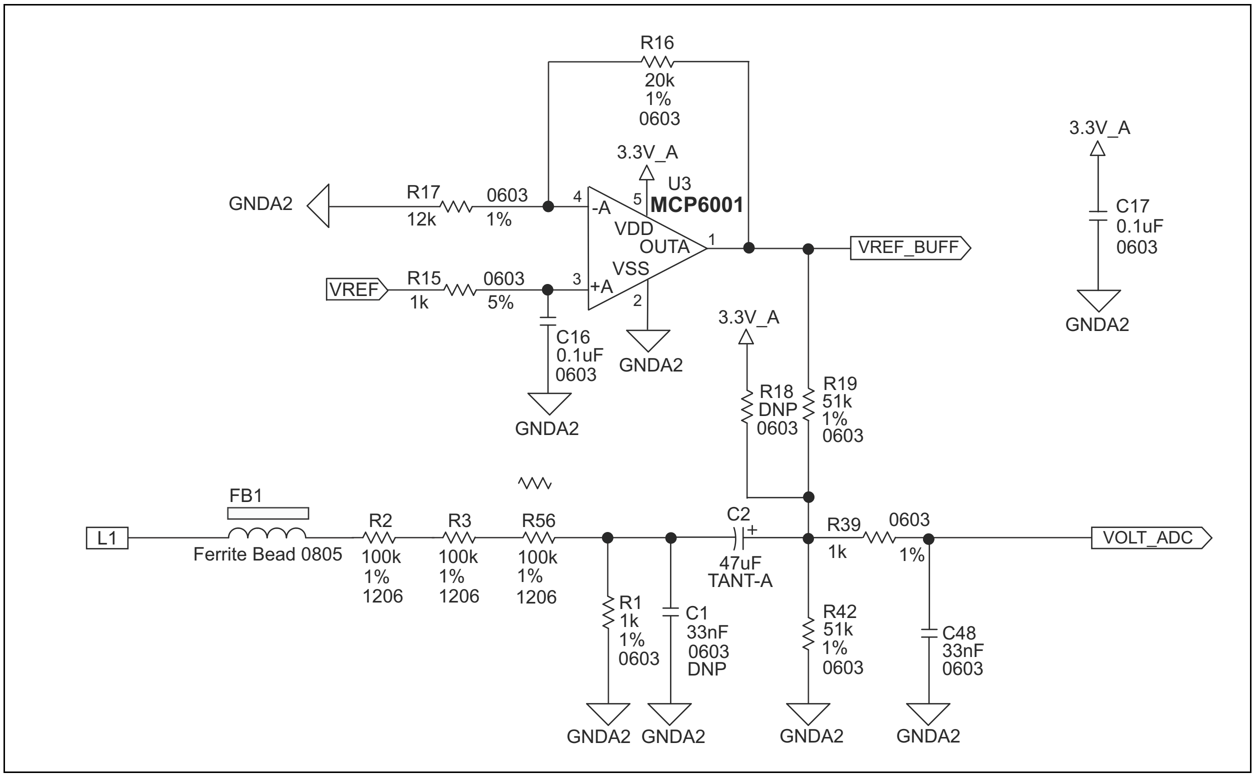


FIGURE 2-4: *Voltage Channel.*

The neutral side of the 2-wire system goes into a resistive divider and a high-pass filter to remove the input DC offset, and then a very stable DC offset is added to shift the signal into the correct input voltage range of the 12-bits internal ADC.

The voltage channel resistive divider uses three 100 kΩ resistors in series and one 1 kΩ resistor connected to ground, to achieve a divider ratio of 301:1. For a line voltage of 220 V_{RMS}, the voltage channel input signal size will be 731 mV_{RMS}.

This DC offset of 1.5V is generated from the MCP3911 very low drift internal voltage reference (1.2V typical is multiplied by a factor of 2.5 with a low-cost op amp in a non-inverting amplifier configuration, and then divided by 2, with two equal-value resistors).

The output of the operational amplifier is also used as the external-voltage reference for the 12-bits internal ADC.

2.3 POWER SUPPLY CIRCUIT

The capacitive power supply circuit for the MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter uses a half-wave rectified signal and two +3.3V LDO voltage regulators. One LDO supplies the analog side and the other the digital circuitry of the meter. This separation between analog and digital power supplies ensures the best accuracy.

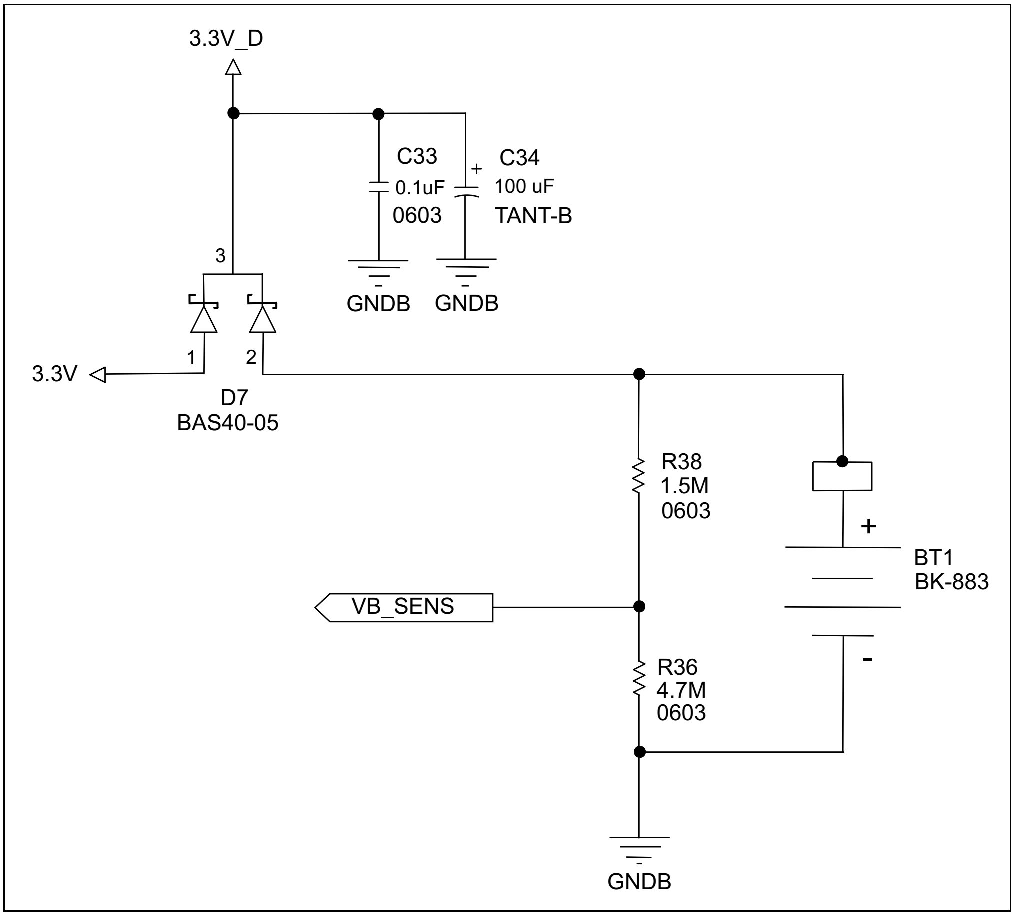


FIGURE 2-5: *MCU Digital Power Supply Circuit with Battery Backup and Battery Voltage Monitoring.*

A 3V backup battery is also provided, connected only to the MCU, ensuring the proper functionality of the clock, even in the absence of the mains power supply.

The battery voltage is monitored and a tamper event is written in the LOG, in case the battery is missing or the voltage is too low.

When the meter is disconnected from mains supply, the battery is automatically switched on and the MCU goes into Sleep mode, for the lowest current consumption. In this mode, only the real time clock module from inside the MCU is active.

Chapter 3. Calculation Engine and Register Description

3.1 PROCESSING ADC SAMPLES

The samples from the current sensors and from the voltage channel are passed through digital high-pass filters, with the purpose of removing the DC component of the input signals.

Phase compensation is necessary to remove any phase difference between the three channels. To do that, two-phase compensation coefficients are employed:

- One phase compensation register implemented in MCP3911's hardware, which will remove the phase difference between current channels
- The other removes the difference between the voltage channel and one of the current channels, based on the interpolation method (which channel is selected doesn't matter, since the current channels are in-phase after calibration). For more details on the interpolation method, see *"PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide"* (DS51964).

The phase-compensated samples of the currents and voltage are used in computations, from which all the required values (RMS, Active/Reactive Power/Energy) are determined.

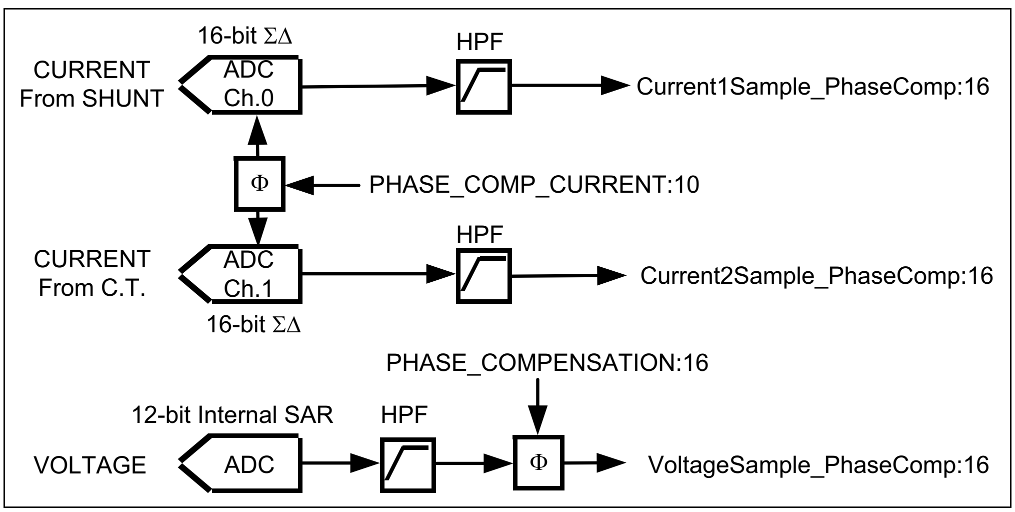


FIGURE 3-1: *Samples Processing.*

3.1.1 RMS Computation

The RMS values of the currents and voltage are calculated by multiplying the samples by themselves, accumulating the result during the full measurement cycle, applying the square root to the sum and then performing the gain calibration.

The current channel priority selection is made based on an algorithm that compares the two RMS currents, selecting the bigger one as priority channel.

At startup, the current channel connected to the current transformer is selected as the main channel.

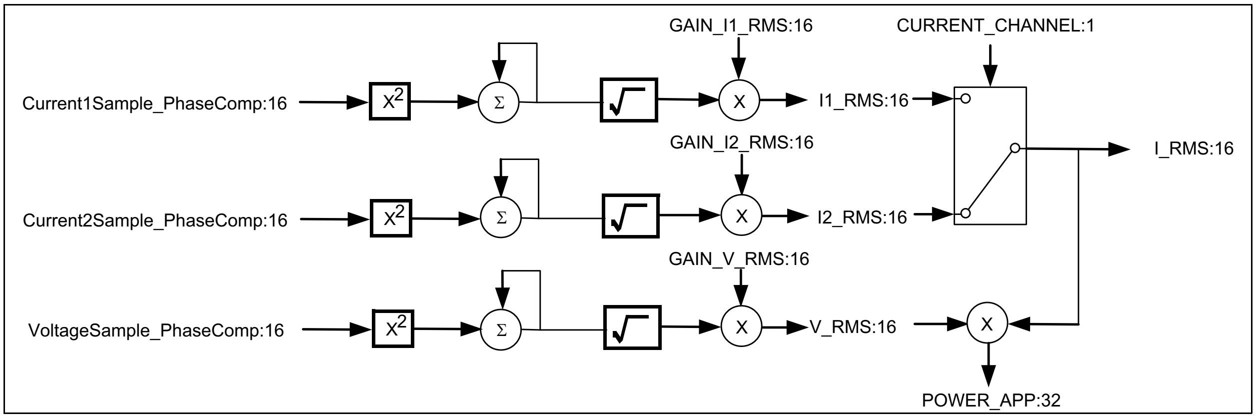


FIGURE 3-2: *RMS Computation.*

3.1.2 Active Power and Energy Computation

The Active Power and Energy values are obtained by multiplying two AC signals (Equation 3-1), computing the average value and then multiplying it with a calibration gain. Ideally, these signals are sinusoids, with the frequency equal to the line frequency:

EQUATION 3-1:

$$S_1(t) = A_1 cos(\omega t)$$
$$S_2(t) = A_2 cos(\omega t + \phi)$$

The two signals (S_1 and S_2) can be the voltage and/or the current waveforms. The instantaneous power value is obtained by multiplication, as shown in Equation 3-2:

EQUATION 3-2:

$$P(t) = S_1(t) \times S_2(t) = \frac{A_1 \times A_2}{2} \times cos(\phi) + \frac{A_1 \times A_2}{2} \times cos(2\omega t + \phi)$$

The resulting signal has a continuous component and a sinusoidal component with a frequency equal to the double of the line frequency. Because the energy meter is computing the average power, only the continuous component is of interest, the other requiring attenuation. If not properly attenuated, the indication of the energy meter will fluctuate in time.

The instantaneous power signal can be applied to a low-pass filter with the cutoff frequency much lower than the double of the line frequency.

In this particular energy meter design, the signals from the two current paths must be processed simultaneously, and low-pass filters are applied on the instantaneous power resulting from both of them.

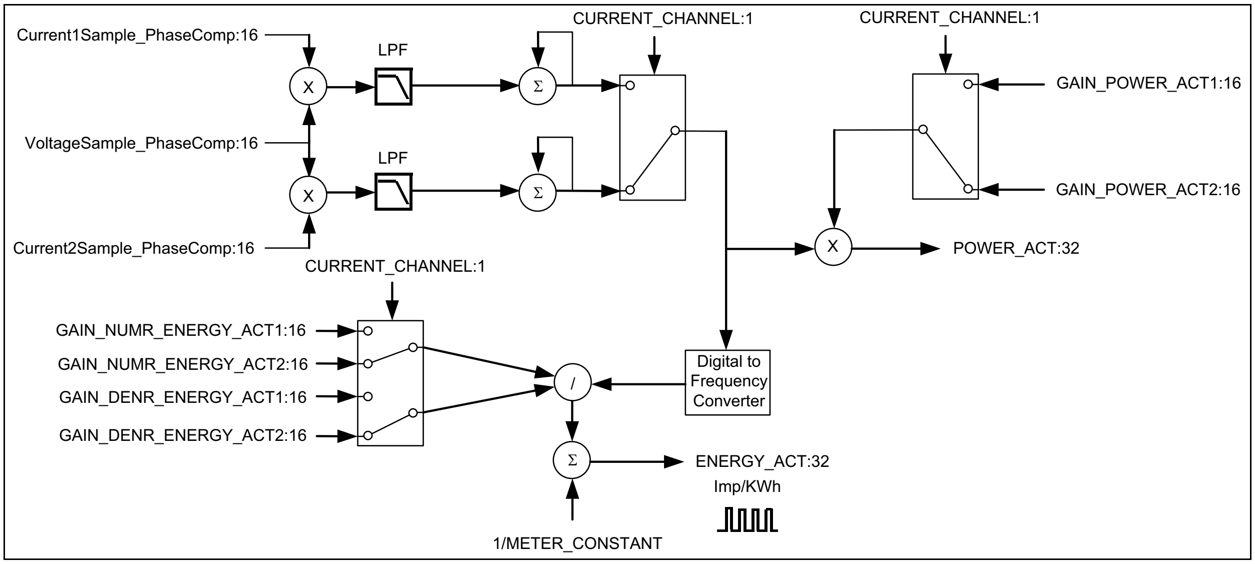


FIGURE 3-3: *Active Power and Energy Computation.*

3.1.3 Reactive Power and Energy Computation

The reactive power and energy values are computed in the same way as the active values, with the exception that there is a precisely 90 degree delay applied to the voltage phase-compensated samples, and also a phase correction with frequency in the range of 45 to 65 Hz.

The frequency of the input signal is determined by zero-crossing detection, done on the voltage channel, because it has much lower dynamic range than the current channels. In fact, to increase the immunity to noise and distortions (harmonics), the 90 degree delayed voltage samples computed for the reactive values are used for this purpose.

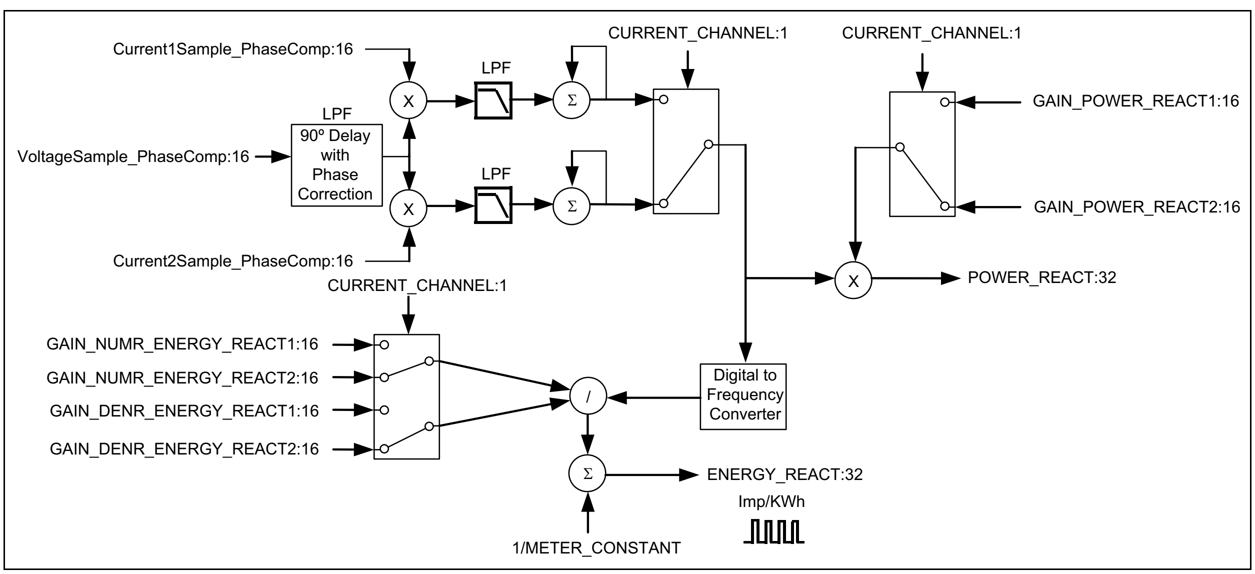


FIGURE 3-4: *Reactive Power and Energy Computation.*

3.2 REGISTERS LIST

TABLE 3-1: INTERNAL REGISTER SUMMARY

Name	Address	Data Type	R/W	Description
CAL_CONTROL	0x202	u8	R/W	Configuration register for calibration control
LINE_CYC	0x203	u16	R/W	It is "n" from the formula: Computation cycle = 2^n number of line cycles
RAW_I1_RMS	0x205	u16	R	Raw RMS value of the current Channel 0
RAW_I2_RMS	0x207	u16	R	Raw RMS value of the current Channel 1
I1_RMS	0x209	u16	R	RMS value of the current Channel 0, post calibration
I2_RMS	0x20B	u16	R	RMS value of the current Channel 1, post calibration
I_RMS	0x20D	u16	R	RMS value of the current channel selected, post calibration
RAW_V_RMS	0x20F	u16	R	Raw RMS value of the voltage channel
V_RMS	0x211	u16	R	RMS value of the voltage channel, post calibration
FREQUENCY	0x213	u16	R	Line frequency indication
PERIOD	0x215	u32	R	Period register
POWER_ACT	0x219	u32	R	Active Power indication
POWER_APP	0x21D	u32	R	Apparent Power indication
POWER_FACTOR	0x221	u16	R	Power factor indication
POWER_REACT	0x223	u32	R	Reactive Power indication
TAMPER_INDICATION	0x227	u8	R	Tamper register
BATTERY_VOLTAGE	0x228	u16	R	12-bit value of battery voltage
MAGNET_VOLTAGE_CH_X	0x22A	u16	R	12-bit value of the X-axis magnetic sensor output voltage
MAGNET_VOLTAGE_CH_Y	0x22C	u16	R	12-bit value of the Y-axis magnetic sensor output voltage
MAGNET_VOLTAGE_CH_Z	0x22E	u16	R	12-bit value of the Z-axis magnetic sensor output voltage
PHASE_COMPENSATION	0x230	s16	R/W	Phase delay between voltage and current channels
PHASE_COMP_CURRENT	0x232	s16	R/W	Phase delay between current Channels 0 and 1
GAIN_I1_RMS	0x234	u16	R/W	Gain adjustment for current Channel 0 RMS
GAIN_I2_RMS	0x236	u16	R/W	Gain adjustment for current Channel 1 RMS
GAIN_V_RMS	0x238	u16	R/W	Gain adjustment for voltage RMS.
GAIN_POWER_ACT1	0x23A	u16	R/W	Active Power gain adjust for Channel 0
GAIN_POWER_ACT2	0x23C	u16	R/W	Active Power gain adjust for Channel 1
GAIN_NUMR_ENERGY_ACT1	0x23E	u16	R/W	Active Power Pulse Output correction factor for Channel 0
GAIN_NUMR_ENERGY_ACT2	0x240	u16	R/W	Active Power Pulse Output correction factor for Channel 1
GAIN_DENR_ENERGY_ACT1	0x242	u8	R/W	Active Power Pulse Output correction factor for Channel 0
GAIN_DENR_ENERGY_ACT2	0x243	u8	R/W	Active Power Pulse Output correction factor for Channel 1
GAIN_POWER_REACT1	0x244	u16	R/W	Reactive Power gain adjust for Channel 0

Note 1: u*n* = unsigned, s*n* = signed, where *n* is the register's number of bits.

TABLE 3-1: INTERNAL REGISTER SUMMARY (CONTINUED)

Name	Address	Data Type	R/W	Description
GAIN_POWER_REACT2	0x246	u16	R/W	Reactive Power gain adjust for Channel 1
GAIN_NUMR_ENERGY_REACT1	0x248	u16	R/W	Reactive Power Pulse Output correction factor for Channel 0
GAIN_NUMR_ENERGY_REACT2	0x24A	u16	R/W	Reactive Power Pulse Output correction factor for Channel 1
GAIN_DENR_ENERGY_REACT1	0x24C	u8	R/W	Reactive Power Pulse Output correction factor for Channel 0
GAIN_DENR_ENERGY_REACT2	0x24D	u8	R/W	Reactive Power Pulse Output correction factor for Channel 1
MAGNET_THRESHOLD_LOW_CH_X	0x24E	u16	R/W	Low-threshold value for X-axis magnetic sensor
MAGNET_THRESHOLD_LOW_CH_Y	0x250	u16	R/W	Low-threshold value for Y-axis magnetic sensor
MAGNET_THRESHOLD_LOW_CH_Z	0x252	u16	R/W	Low-threshold value for Z-axis magnetic sensor
MAGNET_THRESHOLD_HIGH_CH_X	0x254	u16	R/W	High-threshold value for X-axis magnetic sensor
MAGNET_THRESHOLD_HIGH_CH_Y	0x256	u16	R/W	High-threshold value for Y-axis magnetic sensor
MAGNET_THRESHOLD_HIGH_CH_Z	0x258	u16	R/W	High-threshold value for Z-axis magnetic sensor
METER_CONSTANT	0x25A	u16	R/W	Meter Constant in imp/kWh
CF_PULSE_WIDTH	0x25C	u8	R/W	Defines CF pulse width in milliseconds
NO_LOAD_THRESHOLD_I_RMS	0x25D	u8	R/W	Below this Current RMS indication, the energy accumulation is disabled
PHASE_COMPENSATION_90	0x262	s8	R/W	Phase delay for Reactive Power
LOG_INDEX	0x263	u16	R/W	Address in EEPROM where the next event will be stored
LOG_EVENTS_NUMBER	0x265	u8	R/W	Number of events stored in the LOG of events (up to 100)
READ_LOG_ADDRESS	0x266	u16	R/W	Address of event in LOG
ENERGY_ACT	0x300	u32	R/W	Active Energy Counter
ENERGY_REACT	0x304	u32	R/W	Reactive Energy Counter

Note 1: u*n* = unsigned, s*n* = signed, where *n* is the register's number of bits.

3.3 CAL_CONTROL

Name	Address	Data Type	Cof
CAL_CONTROL	0x202	u8	R/W

This register controls the calibration process.

REGISTER 3-1: CAL_CONTROL REGISTER

U-0	U-0	U-0	R/W-0	R/W-0	U-0	R/W-0	R/W-0
—	—	—	FORCE_CHANNEL	CURRENT_CHANNEL	—	CAL_MAG_SENSORS	CAL_MODE
bit 7							bit 0

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

REGISTER 3-1: CAL_CONTROL REGISTER (CONTINUED)

bit 7-5 **Unimplemented:** Read as '0'

bit 4 **FORCE_CHANNEL:** This bit is set by the external device via UART, during the calibration procedure.
1 = The automatic current channel selection is bypassed. The current channel is selected by the "CURRENT_CHANNEL" bit
0 = The main current channel is set automatically, based on current RMS indication.

bit 3 **CURRENT_CHANNEL:** Current channel set by the external device via UART, during the calibration procedure.
1 = Current Channel 1
0 = Current Channel 0

bit 2 **Unimplemented:** Read as '0'

bit 1 **CAL_MAG_SENSORS:** This bit activates the initial reading of the voltage when no magnetic field is applied for the magnetic sensors.
1 = Initial reading of the magnetic sensors has been activated.
0 = Initial reading of the magnetic sensors has been completed.

bit 0 **CAL_MODE:** Activates the auto-calibration procedure.
1 = Auto-calibration procedure has been activated.
0 = Auto-calibration procedure is not enabled.

3.4 LINE_CYC

Name	Address	Data Type	Cof
LINE_CYC	0x203	u16	R/W

This register contains the value of "n" from the formula:

EQUATION 3-3:

$$Computation\_cycle\_duration = 2^{n} \times line\_cycle\_duration$$

The computation cycle contains a number of 2^n line cycles. The indication registers are updated every each computation cycle. The value of LINE_CYC register sets the update rate of the indication registers. In this software release, LINE_CYC = 4.

3.5 RAW_I1_RMS

Name	Address	Data Type	Cof
RAW_I1_RMS	0x205	u16	R

This register is the raw current RMS value of Channel 0, before the multiplication with the calibration register GAIN_I1_RMS.

3.6 RAW_I2_RMS

Name	Address	Data Type	Cof
RAW_I2_RMS	0x207	u16	R

This register is the raw current RMS value of Channel 1, before the multiplication with the calibration register GAIN_I2_RMS.

3.7 I1_RMS

Name	Address	Data Type	Cof
I1_RMS	0x209	u16	R

This register is the current RMS indication of Channel 0 (in Amperes), after the multiplication with the calibration register GAIN_I1_RMS. The decimal dot is placed after three digits. For example, if the read value is I_RMS = 5000 (in decimal), it means that the current is 5.000A.

3.8 I2_RMS

Name	Address	Data Type	Cof
I2_RMS	0x20B	u16	R

This register is the current RMS indication of Channel 1 (in Amperes), after the multiplication with the calibration register GAIN_I2_RMS. The decimal dot is placed after three digits. For example, if the read value is I_RMS = 5000 (in decimal), it means that the current is 5.000A.

3.9 I_RMS

Name	Address	Data Type	Cof
I_RMS	0x20D	u16	R

This register is the current RMS indication of the meter. Its value is equal to I1_RMS or I2_RMS, depending on the current channel selected as priority channel.

3.10 RAW_V_RMS

Name	Address	Data Type	Cof
RAW_V_RMS	0x20F	u16	R

This register is the raw voltage RMS value, before the multiplication with the calibration register GAIN_V_RMS.

3.11 V_RMS

Name	Address	Data Type	Cof
V_RMS	0x211	u16	R

This register is the voltage RMS indication, in volts, after the multiplication with the calibration register GAIN_V_RMS. The decimal dot is placed after one digit. For example, a read value of V_RMS = 2200 means 220.0 V.

3.12 FREQUENCY

Name	Address	Data Type	Cof
FREQUENCY	0x213	u16	R

This register is the line frequency indication, in hertz. The decimal dot is placed after two digits. For example: a read value of FREQUENCY = 5000 means 50.00 Hz.

3.13 PERIOD

Name	Address	Data Type	Cof
PERIOD	0x215	u32	R

This register contains the total number of clock ticks that elapsed over the entire measurement cycle (which in this design is a constant).

3.14 POWER_ACT

Name	Address	Data Type	Cof
POWER_ACT	0x219	u32	R

This register is the active power indication, in watts. The decimal point is placed after four digits. For example, if the meter read value is POWER_ACT = 11000000 (in decimal), it means that the active power is 1100.0000W.

3.15 POWER_APP

Name	Address	Data Type	Cof
POWER_APP	0x21D	u32	R

This register is the apparent power indication, in VA. The decimal dot is placed after four digits. For example, if the meter read value is POWER_APP = 11000000 (in decimal), it means that the active power is 1100.0000 VA.

3.16 POWER_FACTOR

Name	Address	Data Type	Cof
POWER_FACTOR	0x221	u16	R

This register is the power factor indication. The power factor value is obtained by dividing the register value to 65535. For example: a read value of POWER_FACTOR = 32767 means that the power factor is 0.5.

3.17 POWER_REACT

Name	Address	Data Type	Cof
POWER_REACT	0x223	u32	R

This register is the reactive power indication, in VAR. The decimal dot is placed after four digits. For example: if the meter read value is POWER_ACT = 11000000 (in decimal), it means that the active power is 1100.0000 VAR.

3.18 TAMPER_INDICATION

Name	Address	Data Type	Cof
TAMPER_INDICATION	0x227	u8	R

This register holds the bits corresponding to each tamper event detected (the bit is '1' when the condition is active, and '0' when the condition has been removed).

REGISTER 3-2: CAL_CONTROL REGISTER

R-0	R-0	R-0	R-0	R-0	R-0	R-0	R-0
LOW_ BATTERY	LOG_FULL	NEUTRAL_ DISURBANCE	MISSING_ NEUTRAL	MAGNETIC_ FIELD	CH2_CUR- RENT_LOW	CH1_CUR- RENT_LOW	POWER_ REVERSE
bit 7							bit 0

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as ‘0’	
-n = Value at POR	‘1’ = Bit is set	‘0’ = Bit is cleared	x = Bit is unknown

bit 7 **LOW_BATTERY:** Backup battery voltage is too low or the battery is missing
bit 6 **LOG_FULL:** The LOG is full, next event will overwrite the first event in the circular buffer
bit 5 **FREQUENCY_DISTURBANCE:** The signal frequency is outside of permitted range of 45 to 65Hz
bit 4 **SWITCH_OPENED:** The tamper switch is opened
bit 3 **MAGNETIC_FIELD:** A potentially disturbing magnetic field has been detected
bit 2 **CH2_CURRENT_LOW:** I2_RMS < I1_RMS
bit 1 **CH1_CURRENT_LOW:** I1_RMS < I2_RMS
bit 0 **POWER_REVERSE:** The sign of active power does not match on the two channels

3.19 BATTERY_VOLTAGE

Name	Address	Data Type	Cof
BATTERY_VOLTAGE	0x228	u16	R

This register holds the 12-bits ADC readings of the backup battery voltage.

3.20 MAGNET_VOLTAGE_CH_X

Name	Address	Data Type	Cof
MAGNET_VOLTAGE_CH_X	0x22A	u16	R

This register holds the 12-bits ADC readings of the X-axis magnetic sensor output.

3.21 MAGNET_VOLTAGE_CH_Y

Name	Address	Data Type	Cof
MAGNET_VOLTAGE_CH_Y	0x22C	u16	R

This register holds the 12-bits ADC readings of the Y-axis magnetic sensor output.

3.22 MAGNET_VOLTAGE_CH_Z

Name	Address	Data Type	Cof
MAGNET_VOLTAGE_CH_Z	0x22E	u16	R

This register holds the 12-bits ADC readings of the Z-axis magnetic sensor output.

3.23 PHASE_COMPENSATION

Name	Address	Data Type	Cof
PHASE_COMPENSATION	0x230	u16	R/W

This register contains the phase compensation value between the voltage and the current channels, used by the metering engine at the moment of reading.

For more information related to phase compensation implementation in firmware, refer to **Chapter 2.3.2.3** from *"PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide"* (DS51964).

3.24 PHASE_COMP_CURRENT

Name	Address	Data Type	Cof
PHASE_COMP_CURRENT	0x232	u16	R/W

This register contains the phase compensation value between the current Channel 0 and the current Channel 1, written in the PHASE register of the MCP3911 device.

3.25 GAIN_I1_RMS

Name	Address	Data Type	Cof
GAIN_I1_RMS	0x234	u16	R/W

This register contains the gain value for the current RMS indication of Channel 0.

3.26 GAIN_I2_RMS

Name	Address	Data Type	Cof
GAIN_I2_RMS	0x236	u16	R/W

This register contains the gain value for the current RMS indication of Channel 1.

3.27 GAIN_V_RMS

Name	Address	Data Type	Cof
GAIN_V_RMS	0x238	u16	R

This calibration register contains the gain value for the voltage RMS indication.

3.28 GAIN_POWER_ACT1

Name	Address	Data Type	Cof
GAIN_POWER_ACT1	0x23A	u16	R

This register contains the gain value for the active power indication of current Channel 0.

3.29 GAIN_POWER_ACT2

Name	Address	Data Type	Cof
GAIN_POWER_ACT2	0x23C	u16	R

This register contains the gain value for the active power indication of current Channel 1.

3.30 GAIN_NUMR_ENERGY_ACT1

Name	Address	Data Type	Cof
GAIN_NUMR_ENERGY_ACT1	0x23E	u16	R

This register contains the active energy gain value necessary to produce the specified number of pulses per kilowatt-hour (the meter constant) for current Channel 0.

3.31 GAIN_NUMR_ENERGY_ACT2

Name	Address	Data Type	Cof
GAIN_NUMR_ENERGY_ACT2	0x240	u16	R

This register contains the active energy gain value necessary to produce the specified number of pulses per kilowatt-hour (the meter constant) for current Channel 1.

3.32 GAIN_DENR_ENERGY_ACT1

Name	Address	Data Type	Cof
GAIN_DENR_ENERGY_ACT1	0x242	u8	R

This register contains the number of left bit shifts for the raw active power for current Channel 0.

3.33 GAIN_DENR_ENERGY_ACT2

Name	Address	Data Type	Cof
GAIN_DENR_ENERGY_ACT2	0x243	u8	R

This register contains the number of left bit shifts for the raw active power for current Channel 1.

3.34 GAIN_POWER_REACT1

Name	Address	Data Type	Cof
GAIN_POWER_REACT1	0x244	u16	R

This register contains the gain value for the reactive power indication for current Channel 0.

3.35 GAIN_POWER_REACT2

Name	Address	Data Type	Cof
GAIN_POWER_REACT2	0x246	u16	R

This register contains the gain value for the reactive power indication for current Channel 1.

3.36 GAIN_NUMR_ENERGY_REACT1

Name	Address	Data Type	Cof
GAIN_NUMR_ENERGY_REACT1	0x248	u16	R

This register contains the reactive energy gain value necessary to produce the specified number of pulses per KVArh (the meter constant) for current Channel 0.

3.37 GAIN_NUMR_ENERGY_REACT2

Name	Address	Data Type	Cof
GAIN_NUMR_ENERGY_REACT2	0x24A	u16	R

This register contains the reactive energy gain value necessary to produce the specified number of pulses per KVArh (the meter constant) for current Channel 1.

3.38 GAIN_DENR_ENERGY_REACT1

Name	Address	Data Type	Cof
GAIN_DENR_ENERGY_REACT1	0x24C	u8	R

This register contains the number of left bit shifts for the raw reactive power for current Channel 0.

3.39 GAIN_DENR_ENERGY_REACT2

Name	Address	Data Type	Cof
GAIN_DENR_ENERGY_REACT2	0x24D	u8	R

This register contains the number of left bit shifts for the raw reactive power for current Channel 1.

3.40 MAGNET_THRESHOLD_LOW_CH_X

Name	Address	Data Type	Cof
MAGNET_THRESHOLD_LOW_CH_X	0x24E	u16	R

This register contains the threshold value of the voltage that triggers a tamper event. This value should be calibrated with an external magnetic field of a certain strength.

As an example, the threshold value considered in this firmware version is 5% less than the 12-bits ADC readings of the X-axis magnetic sensor output voltage when no magnetic field is present (during initialization).

3.41 MAGNET_THRESHOLD_LOW_CH_Y

Name	Address	Data Type	Cof
MAGNET_THRESHOLD_LOW_CH_Y	0x250	u16	R

This register represents the threshold value of the voltage that triggers a tamper event. This value should be calibrated with an external magnetic field of a certain strength.

As an example, the threshold value considered in this firmware version is 6.25% less than the 12-bits ADC readings of the Y-axis magnetic sensor output voltage when no magnetic field is present (during initialization).

3.42 MAGNET_THRESHOLD_LOW_CH_Z

Name	Address	Data Type	Cof
MAGNET_THRESHOLD_LOW_CH_Z	0x252	u16	R

This register contains the threshold value of the voltage that triggers a tamper event. This value should be calibrated with an external magnetic field of a certain strength.

As an example, the threshold value considered in this firmware version is 6.25% less than the 12-bits ADC readings of the Z-axis magnetic sensor output voltage when no magnetic field is present (during initialization).

3.43 MAGNET_THRESHOLD_HIGH_CH_X

Name	Address	Data Type	Cof
MAGNET_THRESHOLD_HIGH_CH_X	0x254	u16	R

This register contains the threshold value of the voltage that triggers a tamper event. This value should be calibrated with an external magnetic field of a certain strength.

As an example, the threshold value considered in this firmware version is 6.25% more than the 12-bits ADC readings of the X-axis magnetic sensor output voltage when no magnetic field is present (during initialization).

3.44 MAGNET_THRESHOLD_HIGH_CH_Y

Name	Address	Data Type	Cof
MAGNET_THRESHOLD_HIGH_CH_Y	0x256	u16	R

This register contains the threshold value of the voltage that triggers a tamper event. This value should be calibrated with an external magnetic field of a certain strength.

As an example, the threshold value considered in this firmware version is 6.25% more than the 12-bits ADC readings of the Y-axis magnetic sensor output voltage when no magnetic field is present (during initialization).

3.45 MAGNET_THRESHOLD_HIGH_CH_Z

Name	Address	Data Type	Cof
MAGNET_THRESHOLD_HIGH_CH_Z	0x258	u16	R

This register contains the threshold value of the voltage that triggers a tamper event. This value should be calibrated with an external magnetic field of a certain strength.

As an example, the threshold value considered in this firmware version is 6.25% more than the 12-bits ADC readings of the Z-axis magnetic sensor output voltage when no magnetic field is present (during initialization).

3.46 METER_CONSTANT

Name	Address	Data Type	Cof
METER_CONSTANT	0x25A	u16	R/W

This register contains the meter constant in pulses/kWh. It must be a multiple of 100.

3.47 CF_PULSE_WIDTH

Name	Address	Data Type	Cof
CF_PULSE_WIDTH	0x25C	u16	R/W

This register contains the width of the active/reactive energy pulse. In this firmware release CF_PULSE_WIDTH = 29, equivalent to a pulse width of approximately 90 ms.

3.48 NO_LOAD_THRESHOLD_I_RMS

Name	Address	Data Type	Cof
NO_LOAD_THRESHOLD_I_RMS	0x25D	u16	R/W

This register contains the current RMS indication (I_RMS value) below which the energy accumulation is disabled. Its value represents tens of mA.

In this firmware release, NO_LOAD_THRESHOLD_I_RMS = 30 (mA).

3.49 PHASE_COMPENSATION_90

Name	Address	Data Type	Cof
PHASE_COMPENSATION_90	0x262	s8	R/W

This register contains a compensation value of the phase delay for Reactive Power.

3.50 LOG_INDEX

Name	Address	Data Type	Cof
LOG_INDEX	0x263	u16	R/W

This register holds the address in EEPROM where the next event is going to be stored. The LOG of events is designed as a circular buffer. Only the latest 100 events are stored, the older events being overwritten.

3.51 LOG_EVENTS_NUMBER

Name	Address	Data Type	Cof
LOG_EVENTS_NUMBER	0x265	u8	R/W

This register represents the number of events stored in LOG. When the LOG is full, the value remains unchanged and is equal to the maximum number of events (which is 100 in this firmware release). Its value is reset only when the LOG is cleared.

3.52 READ_LOG_ADDRESS

Name	Address	Data Type	Cof
READ_LOG_ADDRESS	0x266	u16	R/W

This register is used by the software interface to specify the address of the event to be read from LOG, using the command 'N'.

3.53 ENERGY_ACT

Name	Address	Data Type	Cof
ENERGY_ACT	0x300	u32	R/W

This energy counter register contains the accumulated active energy in kWh. The decimal point is after two digits. For example: an indication of ENERGY_ACT = 1234 means that the value of the accumulated active energy is 12.34 kWh.

3.54 ENERGY_REACT

Name	Address	Data Type	Cof
ENERGY_REACT	0x304	u32	R/W

This energy counter register contains the accumulated reactive energy in kVArh. The decimal point is after two digits. For example, an indication of ENERGY_REACT = 1234 means that the value of the accumulated active energy is 12.34 kVArh.

Chapter 4. Communication Protocol

4.1 PROTOCOL

The UART communication protocol is an improved version of the protocol implemented on PIC18F87J72 Energy Meter Reference Design (see DS51964 for reference).

4.1.1 Command Description

The first byte of the data (byte `0`) is an ASCII character representing the command.

- E – Request for Echo Response to which meter responds with “Q” as acknowledgment
- L – Load Calibration Registers
- S – Store Calibration Registers
- W – Write Bytes
- R – Read Bytes
- T – Set RTC time and date
- G – Get RTC time and date
- N – Read event from LOG
- C – Clear Log of Events

The last data byte is always an ‘X’ character. All commands will result in the same command being returned. The exception is the ‘R’ (READ) command which will return the data being read in lieu of the number of bytes.

4.1.1.1 “E” ECHO: - TO DETECT THE METER CONNECTION

Example: ‘EX’.

Returns: ‘QX’

4.1.1.2 “L” LOAD: LOAD CALIBRATION REGISTERS FROM EEPROM

Example: ‘LX’.

Returns: ‘LX’.

4.1.1.3 “S” STORE: STORE CALIBRATION REGISTERS INTO EEPROM

Example: ‘SX’.

Returns: ‘SX’.

The Store command writes all the calibration values to the internal EEPROM. This function takes some time and during that time, the meter is not functional. The Store command should only be used after calibrating the meter, not while it is in actual use.

4.1.1.4 “W” WRITE: WRITE STARTING AT SPECIFIED ADDRESS INTO RAM

This command writes the specified bytes at the specified address into the RAM.

Example: ‘W0300000102030405060708090A0B0C0D0E0FX’.

Returns: ‘W0300000102030405060708090A0B0C0D0E0FX’.

Note:	If the number of data characters is odd, the last character (the one just prior to the 'X') will be ignored.

4.1.1.5 “R” READ: READ STARTING AT SPECIFIED ADDRESS

This command reads the specified number of bytes.

Example: 'R03010X' (read 16 bytes starting at address 30h).

Returns: 'R0300000102030405060708090A0B0C0D0E0FX'

4.1.1.6 “T” SET: SET TIME AND DATE

Example: ‘T21441101050612X' (meaning 21 seconds, 44 minutes, 11 hours, day 1, weekday 5, month 6, year 2012).

Returns: 'T21441101050612X

4.1.1.7 “G” GET: GET TIME AND DATE

Example: 'GX'

Returns: 'G25441101050612X' (meaning 25 seconds, 44 minutes, 11 hours, day 1, weekday 5, month 6, year 2012).

4.1.1.8 “N” READ: READ EVENT FROM LOG

This command reads the event data at the address specified by the register READ_LOG_ADDRESS.

Example: 'NX'

Returns: 'N12010611442102X' (meaning year 2012, day 1, month 6, 11 hours, 44 minutes, 21 seconds and the event code '02', which is 'Meter Time Set').

4.1.1.9 "C" CLEAR: CLEAR LOG OF EVENTS

This command resets the values of the LOG_INDEX and LOG_EVENTS_NUMBER registers, initializing the circular buffer of the LOG.

The previously stored events cannot be retrieved from GUI after the command 'C' has been given.

Example: ‘CX’

Returns: ‘CX’

Chapter 5. Microchip Energy Meter Software

5.1 OVERVIEW

The Microchip Energy Meter Software is a Graphical User Interface (GUI) that runs on a PC. It enables the meter to be monitored, debugged and calibrated during development phase.

5.2 THE MAIN SCREEN

The main screen contains four tabs:

- **Energy Meter**: This tab contains the instantaneous meter output display and a debug window, which enables access to all the internal registers of the meter.
- **Energy Calibration**: This tab contains a calibration tool for closed loop calibration.
- **Power Calibration**: This tab contains a calibration tool for open loop calibration.
- **Special Features**: This tab contains an interface for setting the time and date, to read and clear the LOG of events and an interface to save or load the factory default calibration values.

The calibration procedures are presented in detail in **Chapter 6. "Energy Meter Calibration"**.

The COM port selection on the top of the window is used to select a serial port or a serial port emulator (the energy meter must be connected to the PC via the USB interface and powered up).

The status of the meter connection to the computer is displayed on the top of the window (see Figure 5-1). If connected, this status displays the text "Meter Detected" in green; when disconnected, it changes the status to "Meter Disconnected", in red. The status is present across all tabs.

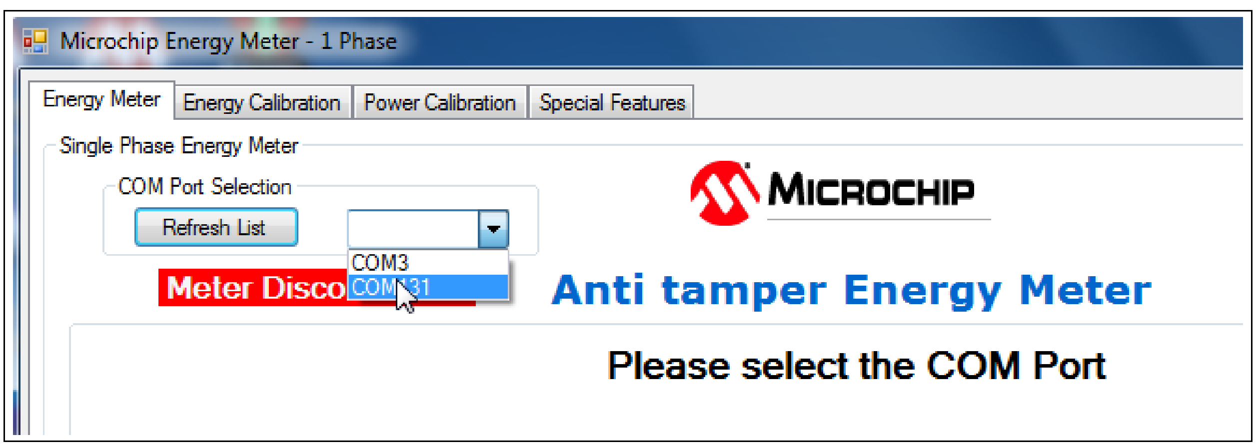


FIGURE 5-1: Energy Meter GUI – COM Port Selection.

The tool has a feature to display the instantaneous parameters from the meter, updated in real time (see Figure 5-2). The “Instantaneous Parameters” field contains the recent meter output parameters: RMS Voltage, RMS Current, Line Frequency, Active Power, Reactive Power, Apparent Power and Power Factor. The corresponding registers are continuously collected and refreshed on the PC side periodically.

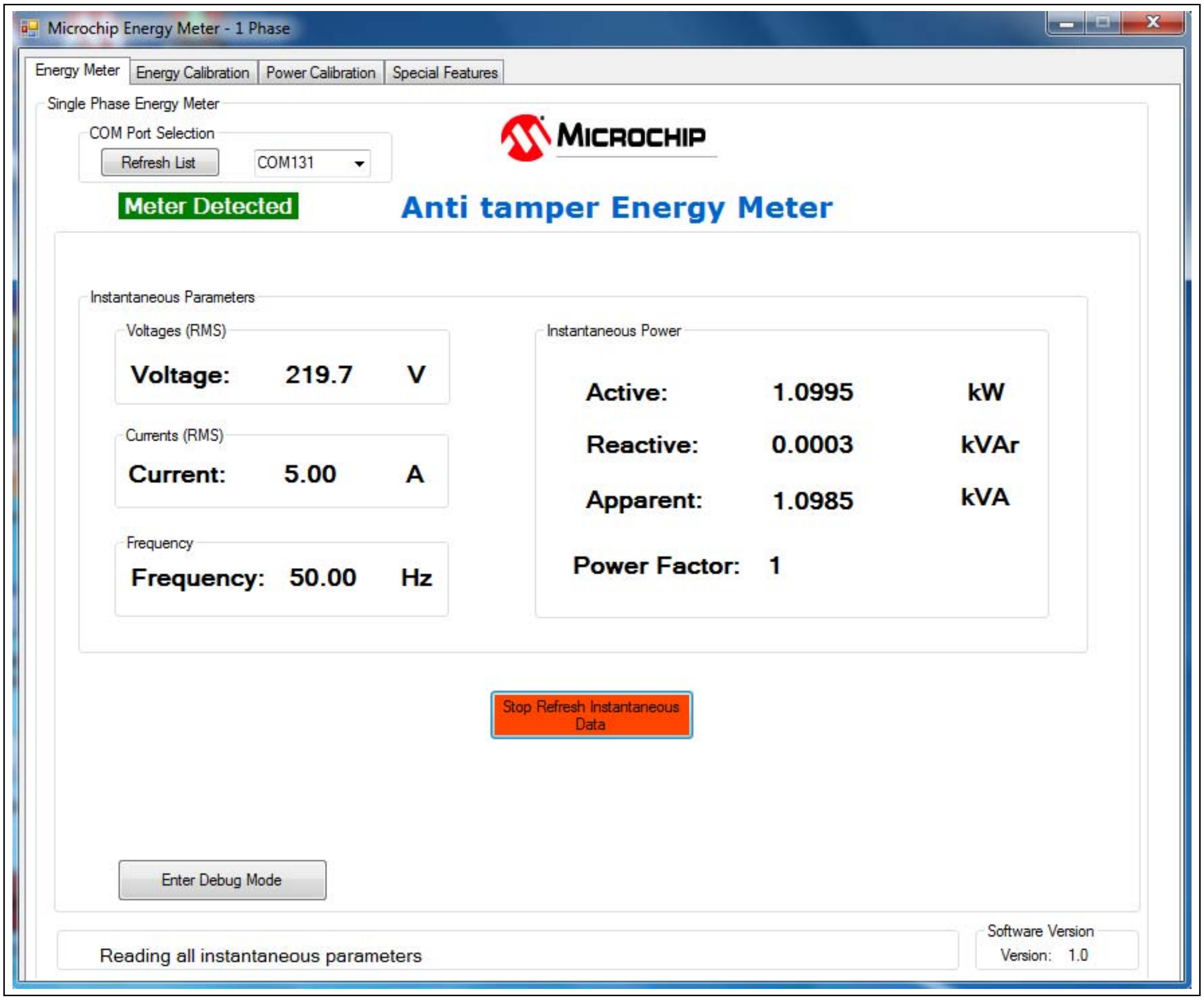


FIGURE 5-2: *Energy Meter GUI – Instantaneous Parameters Display.*

5.3 DEBUG MODE

The Debug mode feature enables access to all the internal registers of the meter. From the **Energy Meter** tab, click on the **Enter Debug Mode** button in the lower right corner of the window. The Debug mode screen appears ready for use.

Debug mode displays the complete list of the internal registers of the meter in details: address, name, attribute, register length and value.

Each register is available for read and write in real time, when the meter is computing.

5.3.1 Refreshing Registers Status

To update all the internal registers, click the **Refresh Meter Registers** button at the bottom of the window, as shown in Figure 5-3. This will update the registers only once per click.

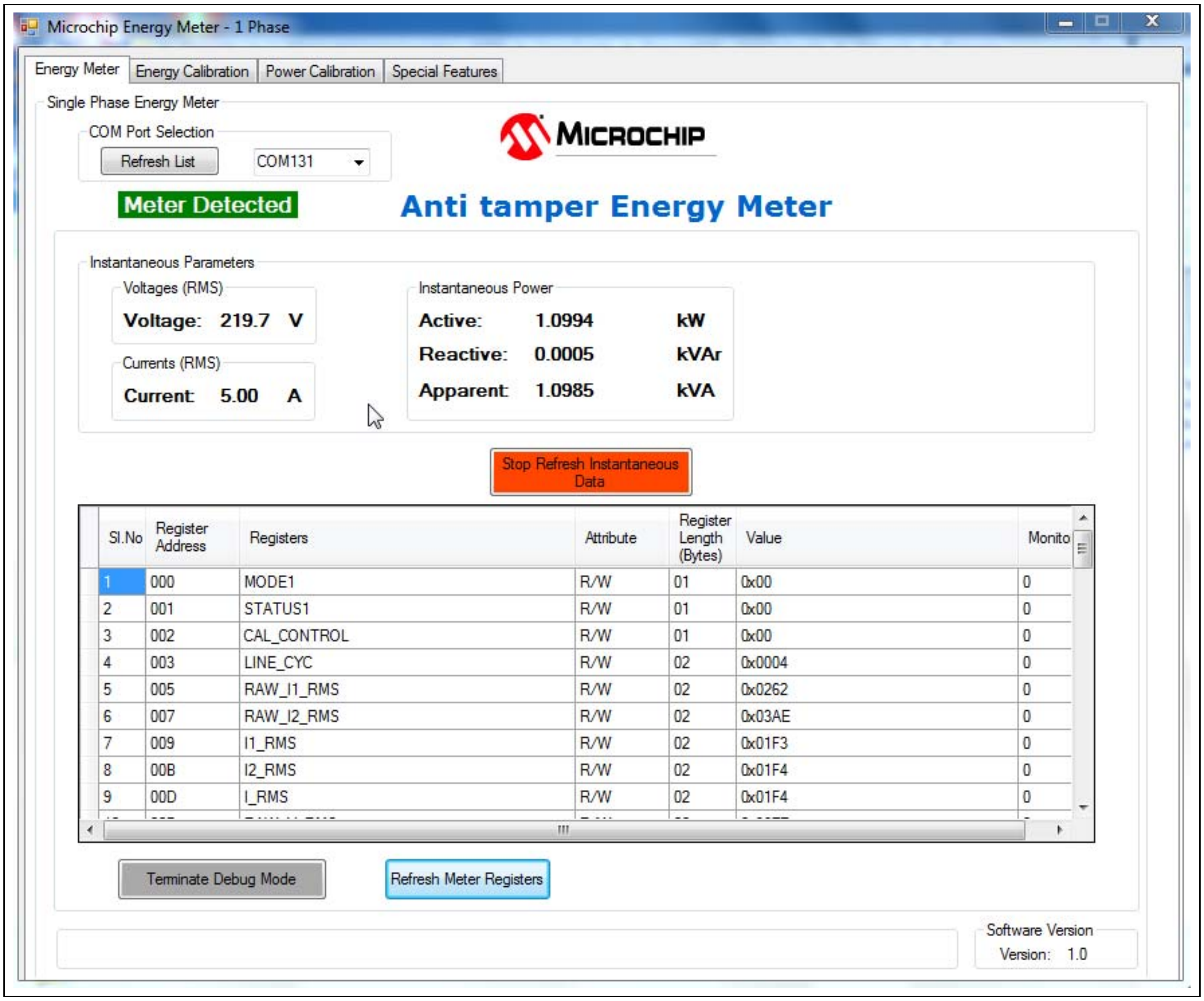


FIGURE 5-3: Energy Meter GUI – Debug Mode.

5.3.2 Writing to Individual Registers

For testing certain limiting conditions and manual tuning the calibration registers, the software offers the possibility to write to individual registers. To write a register, enter the value in HEX format (as stored in the registers) in the "Value" column across that particular register and press <Enter> from the keyboard to initiate the write process.

NOTES:

Chapter 6. Energy Meter Calibration

6.1 INTRODUCTION

This chapter describes the methods to calculate calibration parameters. It includes various types of calibration suitable for different stages of meter design.

6.2 CALIBRATION REGISTERS

The registers that need to be calibrated include the following:

- Gain registers
  - GAIN_V_RMS
  - GAIN_I1_RMS
  - GAIN_I2_RMS
  - GAIN_POWER_ACT1
  - GAIN_POWER_ACT2
  - GAIN_NUMR_ENERGY_ACT1
  - GAIN_NUMR_ENERGY_ACT2
  - GAIN_DENR_ENERGY_ACT1
  - GAIN_DENR_ENERGY_ACT2
  - GAIN_POWER_REACT1
  - GAIN_POWER_REACT2
  - GAIN_NUMR_ENERGY_REACT1
  - GAIN_NUMR_ENERGY_REACT2
  - GAIN_DENR_ENERGY_REACT1
  - GAIN_DENR_ENERGY_REACT2
- Phase compensation registers:
  - PHASE_COMPENSATION
  - PHASE_COMP_CURRENT

All the calibration registers, except GAIN_V_RMS, have one set of values for current Channel 0 and one for current Channel 1. Each current channel must be calibrated separately, starting with Channel 0. For this purpose, the mechanism that switches automatically between the two current channel can be bypassed by setting the bit called `FORCE_CHANNEL`, in the CAL_CONTROL register. In this mode, the main current channel is set by the value of the `CURRENT_CHANNEL` bit, in the same register.

6.3 ENERGY CALIBRATION/CLOSE LOOP CALIBRATION

6.3.1 Closed Loop Calibration Principle

For this type of calibration, the energy meter to be calibrated must be connected to a calibration device, consisting of a source with configurable RMS Voltage, RMS Current, Power Factor and a Reference Meter. By reading the values indicated by the Reference Meter and those indicated by the meter to be calibrated, the calibration gain can be computed:

EQUATION 6-1:

$$New\_gain = Existing\_gain \times \frac{Indication\_from\_Reference\_Meter}{Indication\_from\_Meter\_to\_be\_calibrated}$$

The indication can be Voltage RMS, Current RMS, Active/Reactive Power, Active/Reactive Energy Pulses, but in this design only energy pulses are calibrated using this method.

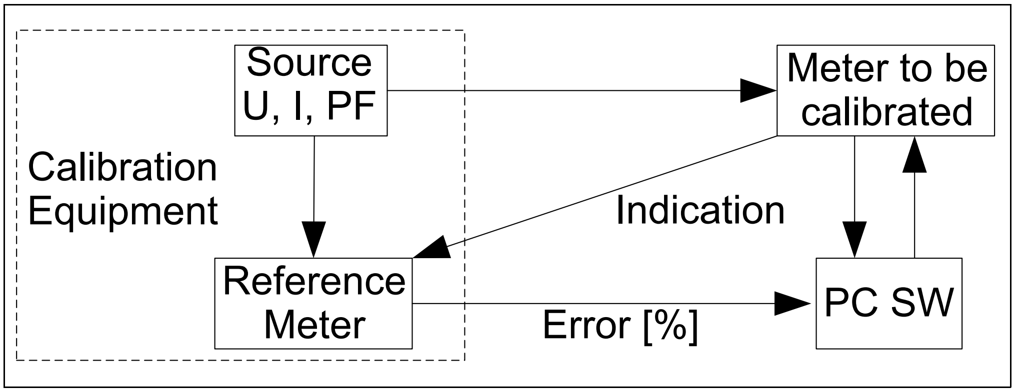


FIGURE 6-1: *Closed Loop Calibration Setup.*

In the case of energy pulses, the calibration equipment can indicate the error between the period of the pulses from its Reference Meter and the meter to be calibrated. In this case, the previous formula is applied in this form:

EQUATION 6-2:

$$New\_gain = \frac{Existing\_gain}{\frac{Error[\%]}{100} + 1}$$

The above formulas apply to gain calibration. They are computed for a power factor of 1, except for the Reactive Energy and power gains, which are computed at a different power factor (usually 0.5).

The information for phase compensation is extracted from the indication of the Active Power at a power factor different than 1 (usually 0.5), after Active Power Gain has been previously computed at the power factor of 1. For more information related to phase compensation calibration, refer to **Section 2.3.2.3 - Phase Compensation** from the *“PIC18F87J72 Single-Phase Energy Meter Calibration User’s Guide (DS51964)”*.

6.3.2 Energy Calibration with Microchip Energy Meter Software

Select **Energy Calibration** tab. The screen from Figure 6-2 appears.

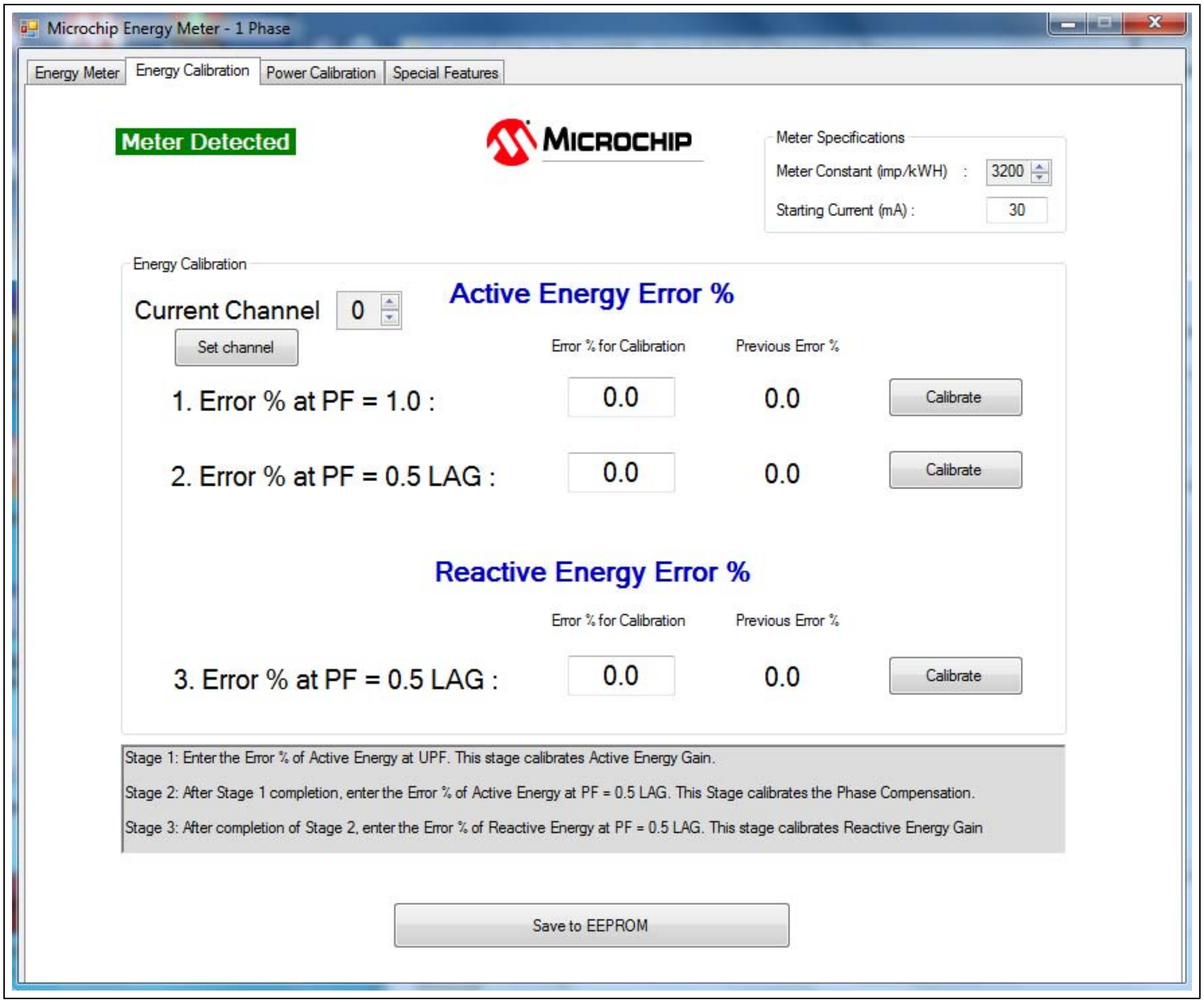


FIGURE 6-2: *Energy Calibration Screen.*

Before the actual calibration, the user can modify the default values of the energy pulse parameters. The software sets the corresponding registers:

- Meter Constant (imp/kWh) – METER_CONSTANT (default is 3200)
- No Load Threshold (mA) – NO_LOAD_THRESHOLD_I_RMS (default is 30mA)

After the modification, press the **Save Parameters** button to store the values into the EEPROM.

The user will enter the values indicated by the Reference Meter in the “Calibration Parameters” fields. The recommended calibration values are 220V line voltage, 5A current.

To start calibrating the current Channel 0, set the checkbox to “0” and press the **Set channel** button from below the checkbox. The GUI will configure the corresponding register in the meter and force it to select the current channel 0.

6.3.3 Energy Calibration - Current Channel 0

The calibration of each current channel consists of three stages that must be performed in a specified order. In each stage, the user will proceed with the following steps:

1. Configure the Power Factor from the source.
2. Obtain the indication of the energy pulse error in percentage format from the Reference Meter .
3. Write the error value in the corresponding text box from the screen.
4. Press the corresponding **Calibrate** button.

When **Calibrate** is pressed, the software computes the new values of the following calibration registers:

- **Step 1:** GAIN_NUMR_ENERGY_ACT1, GAIN_DENR_ENERGY_ACT1
- **Step 2:** PHASE_COMPENSATION
- **Step 3:** GAIN_NUMR_ENERGY_REACT1, GAIN_DENR_ENERGY_REACT1

After the calibration of the Current Channel 0 is complete, the user needs to set the checkbox to “1” and press **Set channel** again. The software will configure the corresponding register in the meter and force it to select the **current channel** 1.

6.3.4 Energy Calibration - Current Channel 1

The user must perform the calibration in the same manner as for the Current Channel 0. When the **Calibrate** button is pressed, the software computes the new values of the following calibration registers:

- **Step 1**: GAIN_NUMR_ENERGY_ACT2, GAIN_DENR_ENERGY_ACT2
- **Step 2**: PHASE_COMP_CURRENT
- **Step 3**: GAIN_NUMR_ENERGY_REACT2, GAIN_DENR_ENERGY_REACT2.

After all calibration steps for both current channels are complete, press **Save to EEPROM** to complete the calibration.

6.4 POWER, RMS CALIBRATION/OPEN LOOP CALIBRATION

6.4.1 Open Loop Calibration Principle

The meter to be calibrated is connected to a source delivering stable, known values of RMS Voltage, RMS Current and Power Factor. This type of calibration does not require a Reference Meter and feedback from the calibration device.

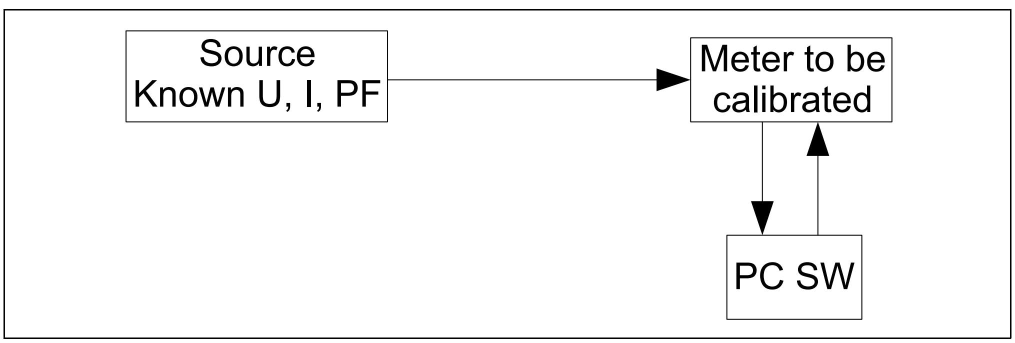


FIGURE 6-3: *Open Loop Calibration Setup.*

The calibration software running on the PC computes the calibration coefficients based on the values indicated by the meter and the known parameters of the source.

The calibration parameters are computed using the following formula:

EQUATION 6-3:

$$New\_gain = Existing\_gain \times \frac{Expected\_indication}{Read\_indication}$$

6.4.2 Power Calibration with Energy Meter GUI

When the **Power Calibration** tab is selected, the screen in Figure 6-4 will appear.

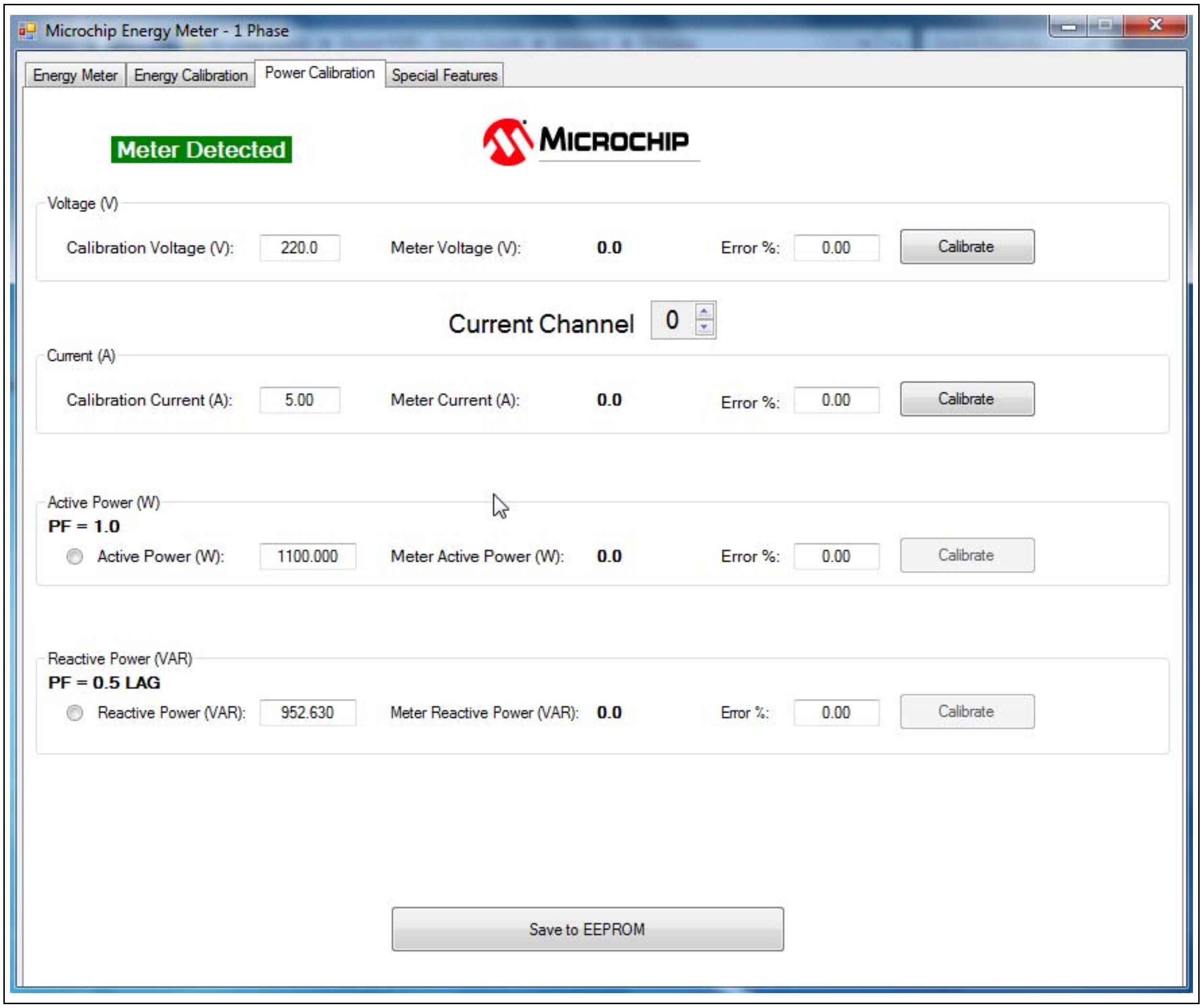


FIGURE 6-4: *Power Calibration Screen.*

The source must be configured with the parameters specified in the “Calibration Parameters” box. The recommended calibration values are 220V line voltage and 5A current. The user can modify these values.

To start calibrating the voltage, press **Calibrate**. The software computes the value of GAIN_V_RMS register.

To start calibrating the Current Channel 0, select ”0” in the check box to configure the corresponding register in the meter and force it to select the Current Channel 0 during the following calibration steps.

6.4.2.1 POWER CALIBRATION - CURRENT CHANNEL 0

CAUTION
At this step, make sure the energy calibration is performed, so the phase compensation parameters are already computed.

The calibration of each current channel consists of three steps that must be performed in a specified order. At each step the user will have to configure the power factor of the source accordingly, and then simply press the **Calibrate** button:

- **Current calibration at PF=1**: the GUI computes the value of GAIN_I1_RMS register
- **Active power calibration at PF=1**: the GUI computes the value of GAIN_POWER_ACT1 register
- **Reactive power calibration at PF=0.5**: the GUI computes the value of GAIN_POWER_REACT1 register

6.4.2.2 POWER CALIBRATION - CURRENT CHANNEL 1

The user must perform the calibration in the same manner as for the Current Channel 0, but first the Current Channel checkbox needs to be filled with a value of “1”.

During the calibration, the GUI computes the values of GAIN_I2_RMS, GAIN_POWER_ACT2 and GAIN_POWER_REACT2 registers.

After all the calibration steps for both current channels are complete, the user is required to **Save to EEPROM**.

Chapter 7. Special Features

7.1 ANTI TAMPER

The anti-tamper features are designed to detect exterior conditions that can alter the functionality of the meter.

There are five conditions detected:

- The difference between RMS currents measured simultaneously on the two current channels:
  - the RMS current is monitored both on LINE and NEUTRAL; any difference between channels larger than a threshold value (which in this design is 1.5625% of the value measured by the main current channel) will trigger a tamper condition.
  - the difference between the currents is also used in automatically selecting the main current channel (the channel measuring the biggest RMS current gets selected as the main current channel, used in all the power and energy computations afterwards)
- Current Circuit Reversal:
  - the sign of the instantaneous active power is monitored on both current channels
  - if the two signs do not match, the Current Reversal tamper condition is detected
  - to avoid false alarms, there is a threshold for minimum RMS currents
- Magnetic field:
  - there are three magnetic sensors on the board, placed to be sensitive to the corresponding axis (X, Y and Z) of an exterior magnetic field
  - in this firmware, the low and high threshold values have been chosen for detecting small magnetic fields, for evaluation purposes
- Switch opening detection:
  - any change in SW1 push button's state generates a tamper event
- Frequency disturbance:
  - when the line frequency is outside the acceptable range of 45 to 65 Hz, a tamper event is generated

7.2 LOG OF EVENTS

A tamper event is generated both when the tamper condition is detected and also when the condition is removed, with a stamp of time and date and the code of the event.

All tamper events are saved in EEPROM in the LOG of events.

TABLE 7-1: EVENTS CODES LIST

Code	Event
00	Default Calibration Loaded
01	Meter Calibration Saved
02	Meter Time Set
03	LOG is full
04	LOG Cleared
05	Power Reversed Detected
06	Power Reversed Removed
07	Frequency Disturbance Detected
08	Frequency Disturbance Removed
09	Channel 0 Low Current Detected
10	Channel 0 Current Restored
11	Channel 1 Low Current Detected
12	Channel 1 Current Restored
13	Magnetic Field Detected
14	Magnetic Field Removed
15	Low Backup Battery
16	Backup Battery Replaced
17	Calibration Loaded OK
18	Tamper switch opened
19	Tamper switch closed
20	Power Down
21	Power Up

The LOG is designed as a circular buffer of 100 events in the internal EEPROM of the microcontroller.

Each event is stored using 8 bytes, in the following format:

TABLE 7-2: 8 BYTES FORMATTING

Byte Number	Format
0	Event code
1	Year (only the two lower digits, the first two are ‘20’)
2	Day
3	Month
4	Hour
5	Minute
6	Second
7	Checksum of previous bytes

After saving the event, the LOG_INDEX and LOG_EVENTS_NUMBER registers are updated automatically. An event is generated when the LOG is full or cleared. The LOG can be read or cleared in GUI.

The detected tamper conditions are also displayed on the LCD. During active tamper conditions, the total energy is displayed on the LCD for 10 seconds (5 seconds active energy, 5 seconds reactive energy). Then a special message appears on the screen, describing the tamper conditions one-by-one in a cyclic manner. The message displayed is `Err t`<n>, where <n> is a number between 0 and 7, representing the tamper event as follows:

TABLE 7-3:

Tamper Condition Code	Description
`t0`	Current circuit reversal (active power is positive on one channel and negative on the other)
`t1`	Channel 1 current lower than Channel 2
`t2`	Channel 2 current lower than Channel 1
`t3`	External magnetic field detected
`t4`	Switch opened
`t5`	Frequency disturbance
`t6`	LOG of events is full
`t7`	Low (or missing) battery

7.3 FACTORY CALIBRATION

Before attempting to calibrate the meter, it is recommended to **Save Factory Calibration** values from the EEPROM into a PC file, stored in the same directory as the software. If required, the user can later restore the factory calibration parameters (stored in the saved file) by pressing the **Load Factory Calibration** button.

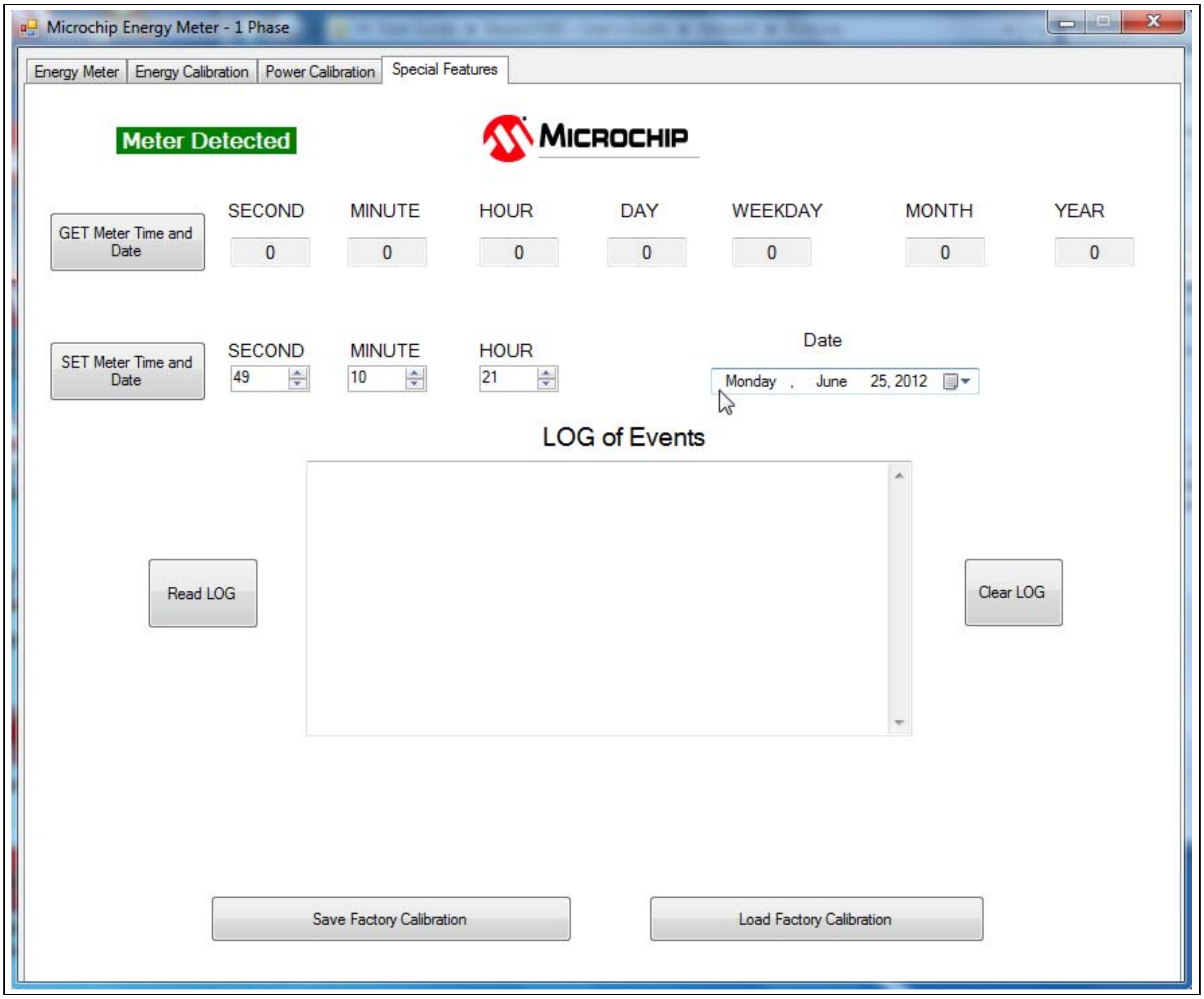


FIGURE 7-1: Special Features Screen.

Appendix A. Schematic and Layouts

A.1 INTRODUCTION

This appendix contains the following layouts of the MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter:

- Board – Top Silk
- Board – Top Copper
- Board – Top Silk and Copper
- Board – Bottom Silk
- Board – Bottom Copper
- Board – Bottom Silk and Copper

The latest evaluation board schematics can be found on the ARD00385 board page at www.microchip.com.

A.2 SCHEMATICS AND PCB LAYOUT

The layer order is shown in Figure A-1.

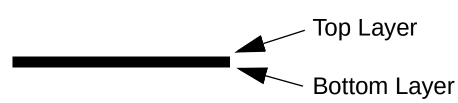
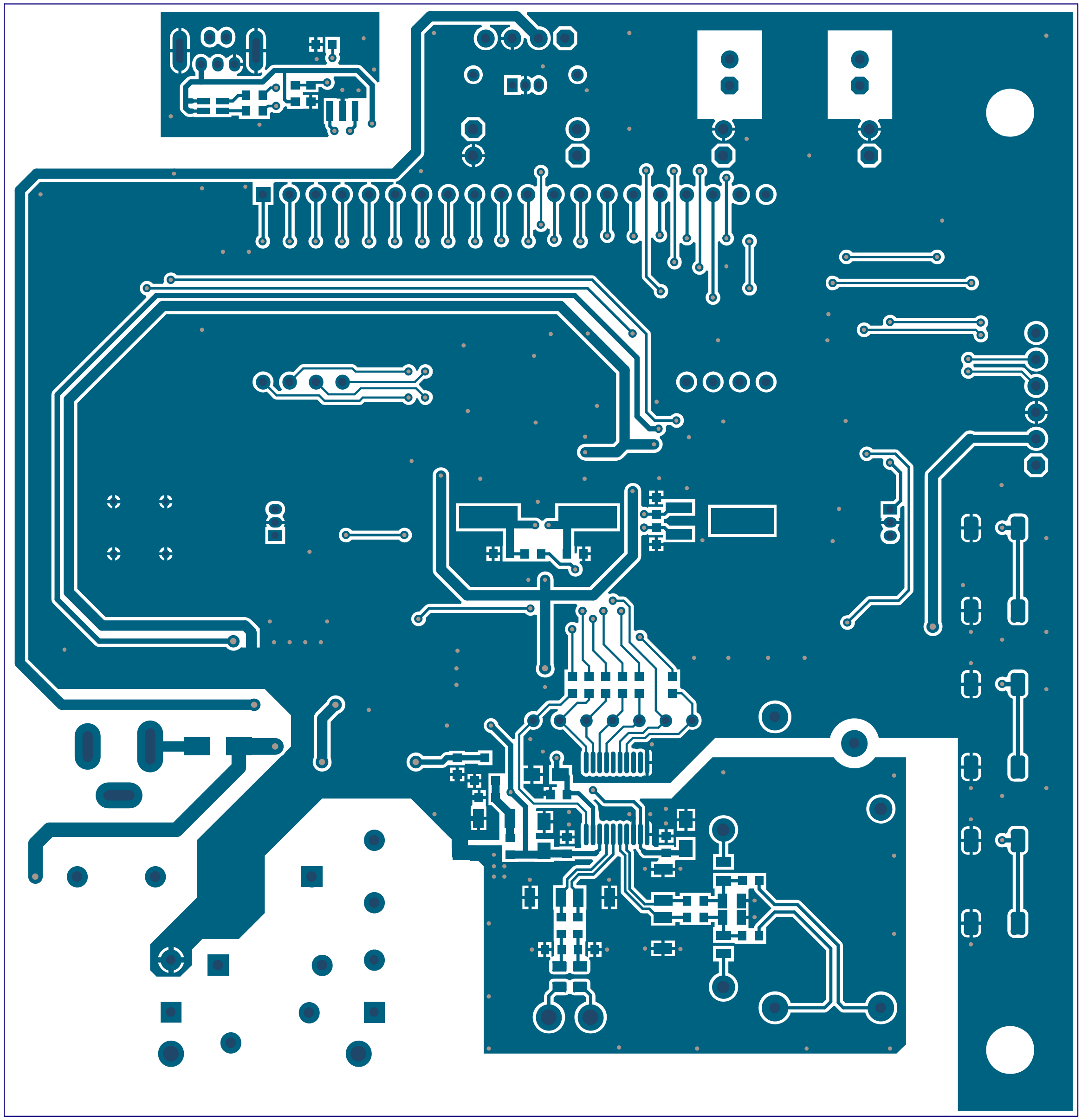
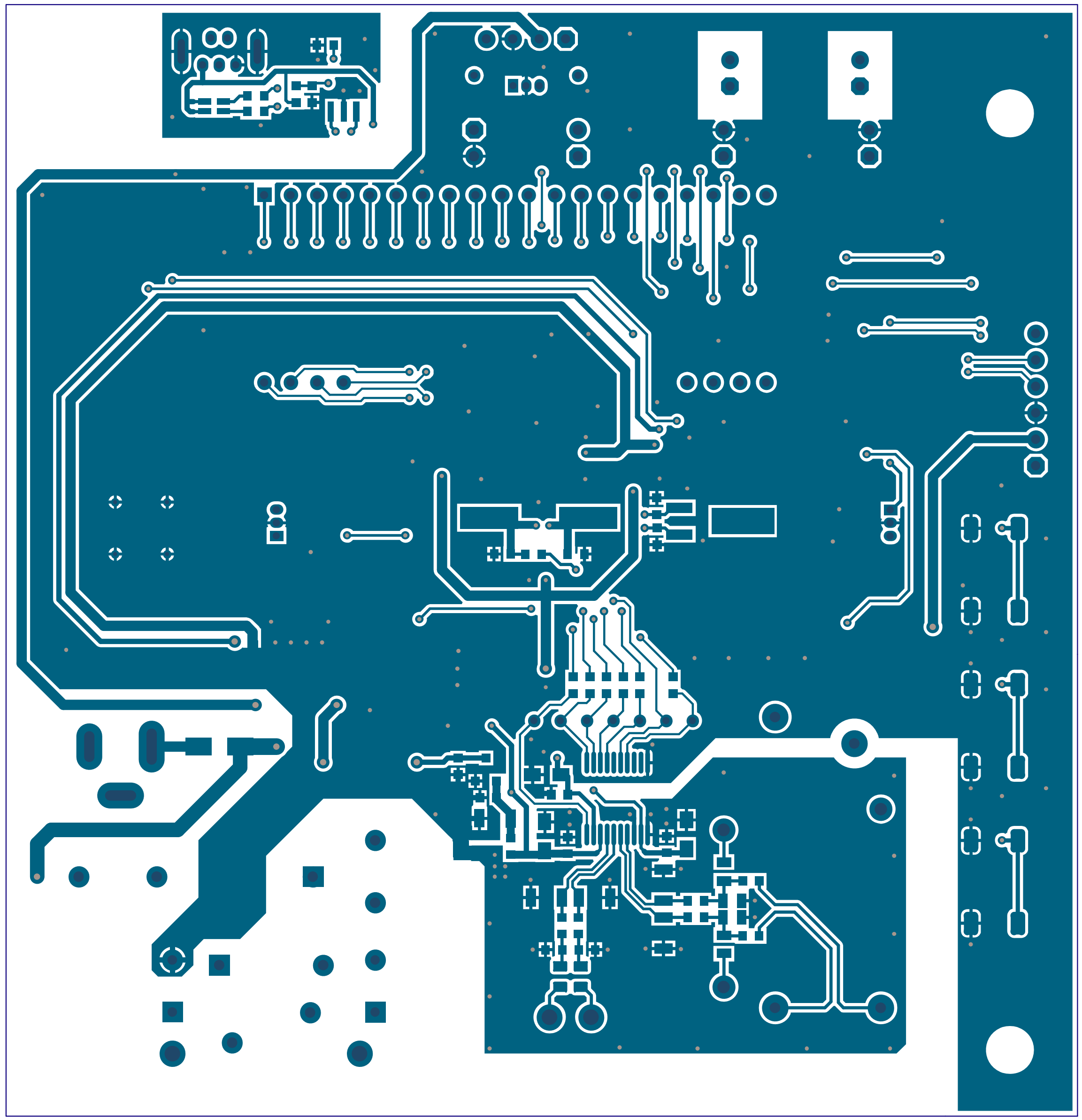


FIGURE A-1: *Layer Order*

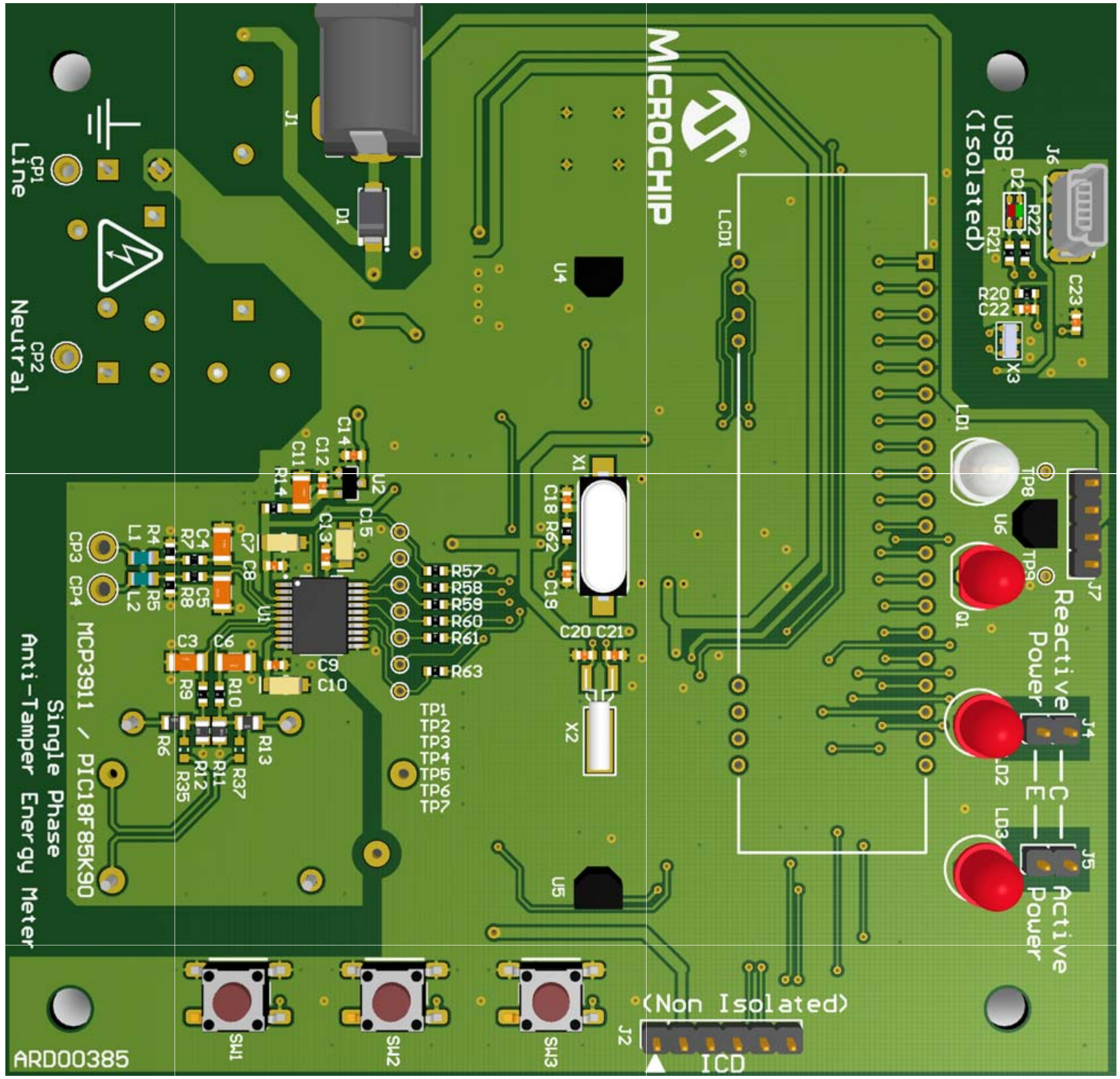
A.3 BOARD – TOP SILK



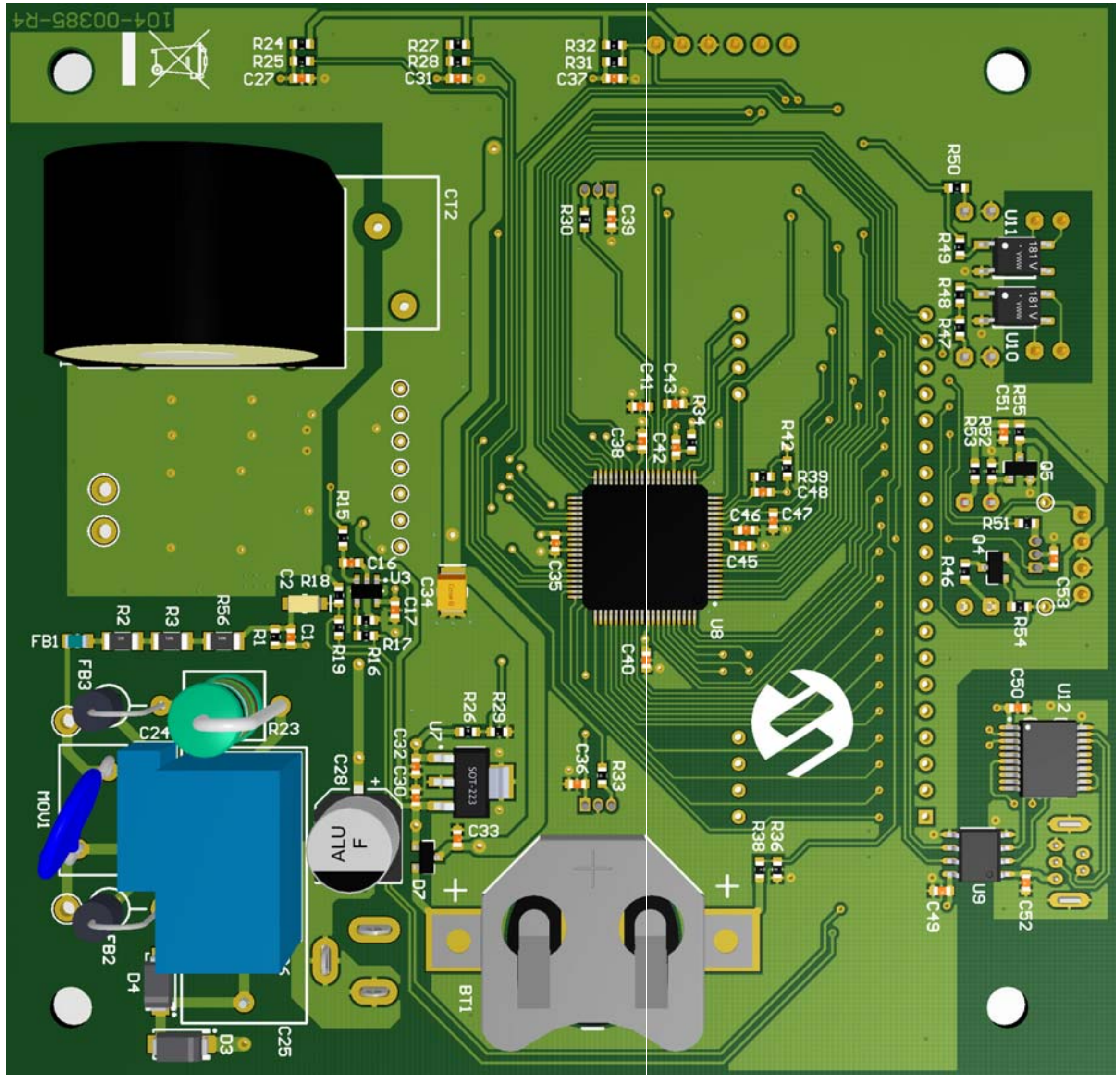
A.4 BOARD – TOP COPPER



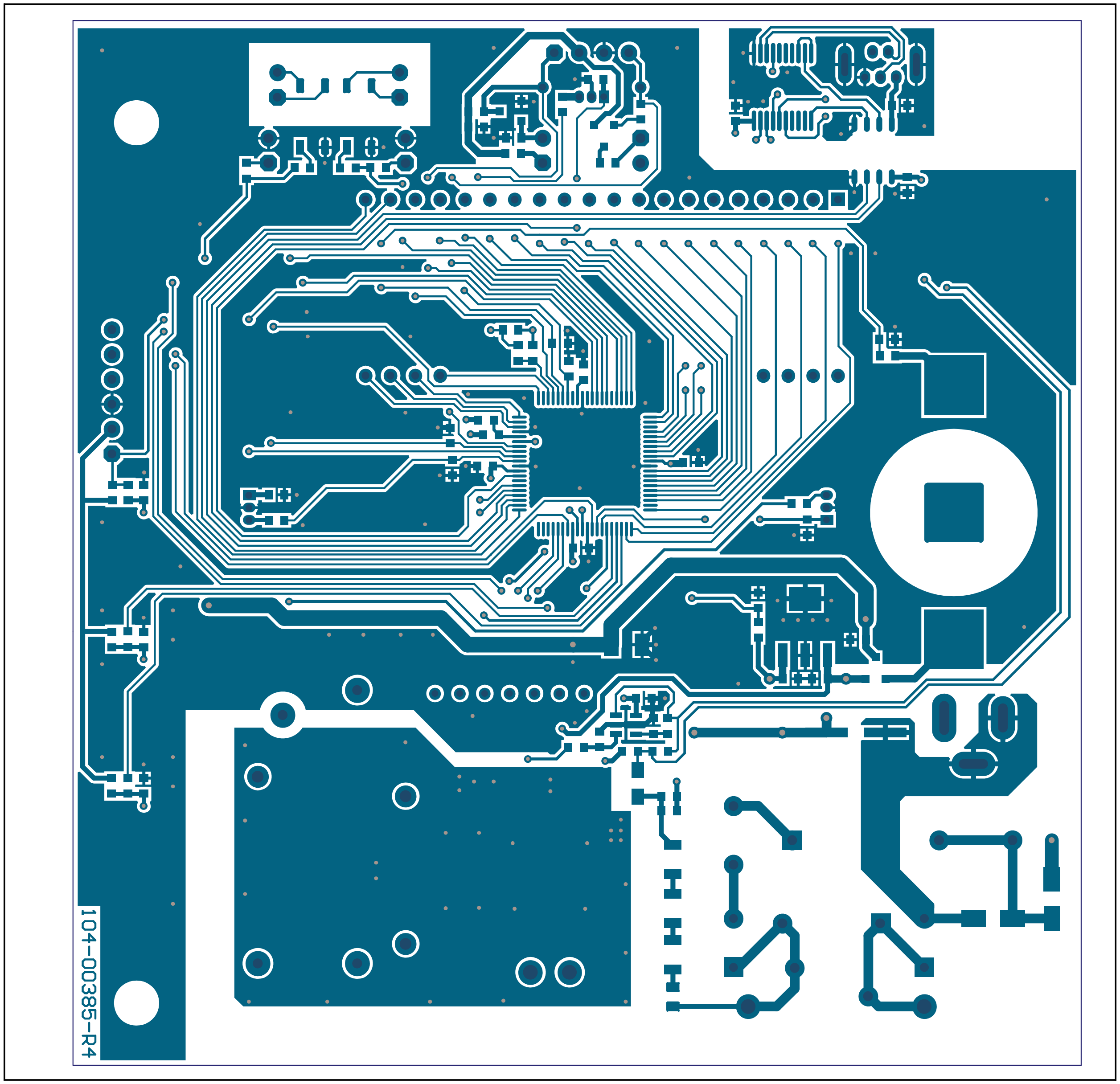
A.5 BOARD – TOP SILK AND COPPER



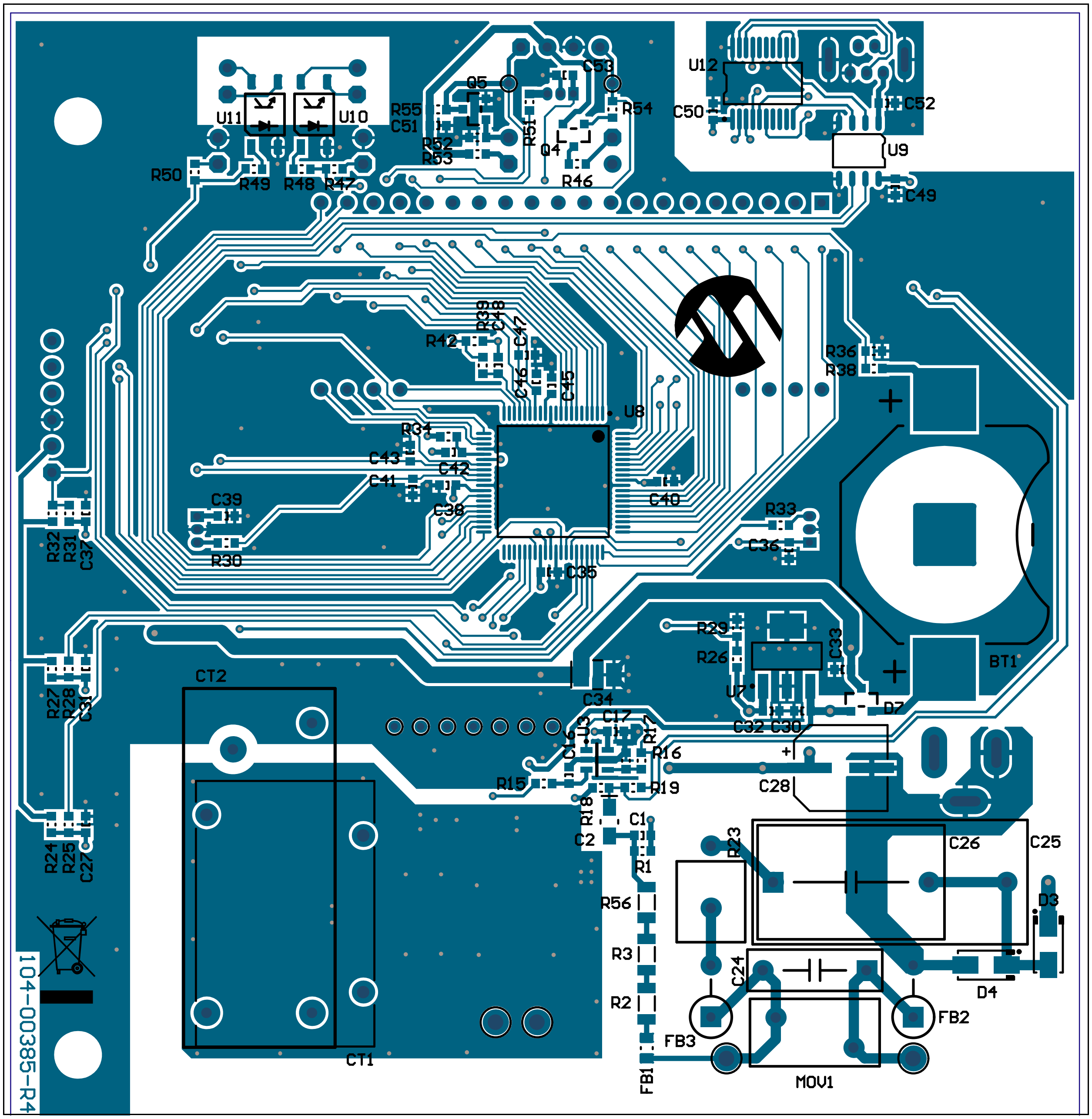
A.6 BOARD – BOTTOM SILK



A.7 BOARD – BOTTOM COPPER



A.8 BOARD – BOTTOM SILK AND COPPER



NOTES:

Appendix B. Bill of Materials (BOM)

TABLE B-1: BILL OF MATERIALS (BOM)

Qty	Reference	Description	Manufacturer	Part Number
1	BAT1	Battery Lithium Coin. 3V CR2032	Panasonic® - BSG	CR2032
1	BT1	Holder Coin. cell. 2032 SMD	MPD – Memory Protection Devices, Inc.	BK-883-TR
1	C1	Cap. Cer. 33 nF 50V 10% X7R 0603 - **DO NOT POPULATE**	TDK Corporation	C1608X7R1H333K
1	C2	Cap. Tant. 47 uF 4V 10% Size A	AVX Corporation	TAJA476K004RNJ
4	C3, C4, C5, C6	Cap. Cer. 68 nF 50V 5% C0G 1206	Murata Electronics®	GRM31C5C1H683JA01L
3	C7, C10, C15	Cap. Tant. 10 uF 6.3V 20% 300m Ohm Size A	AVX Corporation	TCJA106M006R0300
28	C8-9, C12-13, C16-17, C22-C23, C27, C31, C33, C35-43, C45-47, C49-53	Cap. Cer. 0.1 uF 16V 10% X7R 0603	TDK Corporation	C1608X7R1C104K
1	C11	Cap. Cer. 10uF 10V X7R 20% 1206	TDK Corporation	C3216X7R1A106M
3	C14, C30, C32	Cap. Cer. 1uF 16V 10% X7R 0603	TDK Corporation	C1608X7R1C105K
2	C18, C19	Cap. Cer. 27 pf 50V C0G 5% 0603	TDK Corporation	C1608C0G1H270J
2	C20, C21	Cap. Cer. 10 pF 50V 5% C0G 0603	Murata Electronics	GRM1885C1H100JA01D
1	C24	Cap. Film. .01 uF 330 vac. Suppress.	EPCOS AG	B32911A3103M
1	C25	Cap. Film. 1 uF 305 vac. power supply	EPCOS AG	B32933A3105M000
1	C26	Cap. Film. 0.47 uF 305 vac. power supply - **DO NOT POPULATE**	EPCOS AG	B32932A3474M
1	C28	Cap. Elect. 470 uF 16V 20% VS Size F	Panasonic - ECG	EEE-1CA471UP
1	C34	Cap. Tant. Loesr 100 UF 6.3V 10% Size B	AVX Corporation	TPSB107K006R0400
1	C48	Cap. Cer. 33 nF 50V 10% X7R 0603	TDK Corporation	C1608X7R1H333K
1	CT1	Current Transformer PCB mount 2500/1 128 Ohm 300A - **DO NOT POPULATE**	Taehwatrans Co. Ltd.	TZ71V
1	CT2	Current Transformer 100A	VACUUMSCHMELZE GmbH & Co. KG	T60404-E4626-X502
2	D1, D3	Diode Std. Rec. 1A 600V SMA	ON Semiconductor®	MRA4005T3G
1	D2	LED 2X1.2 mm RD/GN Wtr. Clr. SMD	Kingbright Corporation	APHBM2012SURKCGKC
1	D4	Diode Zener 15V 3W SMA	Micro Commercial Components Corp.	3SMAJ5929B-TP
1	D7	Diode Schotky SS 40V 200 mA SOT-23-3	Vishay Intertechnology, Inc.	BAS40-05-V-GS08
3	FB1, L1, L2	Ferrite 800 MA 150 mOhm 0805 SMD	Laird Technologies®	LI0805H151R-10

Note 1: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

TABLE B-1: BILL OF MATERIALS (BOM) (CONTINUED)

Qty	Reference	Description	Manufacturer	Part Number
2	FB2, FB3	Bead Core Single 10 mOhm 7A 3.8X5.3mm radial	Panasonic - ECG	EXC-ELSR35S
1	J1	Conn. power jack male 2.5 MM CLSD	CUI Inc.	PJ-002B
1	J2	Conn. header 6 Pos. .100 Str. 30 AU	FCI	68001-106HLF
2	J4, J5	Conn. header 2 Pos. vert. T/H	FCI	77311-118-02LF
1	J6	Conn. Recept. USB TH vert. 5 Pos.	Molex® Connector Corporation	500075-1517
1	J7	Conn. header male .100 1x4 Pos. vert. - **DO NOT POPULATE**	TE Connectivity, Ltd.	HDR M 1x4 Vertical
1	LCD1	LCD glass size 65.00 x 18.00	Xiamen Ocular Optics Co., Ltd.	DP076P
1	LD1	IR Emitter GaAlAs 880 nm 5 mm radial	OSRAM Opto Semiconductors GmbH.	SFH 484-2
2	LD2, LD3	LED 5mm Red 640 nm 20 mcd 2 mA	Kingbright Corporation	WP7113LSRD
1	MOV1	Varistor 420V RMS 10 mm radial	EPCOS AG	S10K420
1	Q1	Phototransistor 880 nm 5mm radial	OSRAM Opto Semiconductors GmbH.	SFH 300 FA-3/4
1	Q4	Trans. PNP 40V 200 mA 300 mW SOT-23-3	Diodes® Incorporated	MMBT3906-7-F
1	Q5	Trans. NPN 40V 200 mA 350 mW SOT-23-3	Diodes Incorporated	MMBT3904-7-F
1	PCB	Printed Circuit Board – MCP3911 and PIC18F85K90 Single-Phase Anti-Tamper Energy Meter Reference Design	—	104-00385
6	R1, R7, R8, R9, R10, R39	Res. 1k Ohm 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1001V
3	R2, R3, R56	Res. 100k Ohm 1/4W 1% 1206 SMD	Panasonic - ECG	ERJ-8ENF1003V
2	R4, R5	Res. 330k Ohm 1/10W 5% 0603 SMD	Panasonic - ECG	ERJ-3GEYJ334V
2	R6, R13	Res. 5.1 Ohm 1/8W 1% 0805 SMD - **DO NOT POPULATE**	Vishay Intertechnology, Inc.	CRCW08055R10FKEA
2	R11, R12	Res. 5.6 Ohm 1/8W 1% 0805 SMD	Vishay Intertechnology, Inc.	CRCW08055R60FKEA
9	R14, R34, R57, R58, R59, R60, R61, R62, R63	Res. 10 Ohm 1/10W 5% 0603 SMD	Panasonic - ECG	ERJ-3GEYJ100V
9	R15, R21, R22, R25, R28, R30, R31, R33, R51	Res. 1k Ohm 1/10W 5% 0603 SMD	Panasonic - ECG	ERJ-3GEYJ102V
1	R16	Res. 18k Ohm 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1802V
1	R17	Res. 12k Ohm 1/10W 1% 0603 SMD	Yageo	RC0603FR-0712KL
1	R18	Res. 51k Ohm 1/10W 1% 0603 SMD - **DO NOT POPULATE**	Panasonic - ECG	ERJ-3EKF5102V
2	R19, R42	Res. 51k Ohm 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF5102V
1	R20	Res. 4.7k Ohm 1/10W 5% 0603 SMD	Panasonic - ECG	ERJ-3GEYJ472V
1	R23	Res. MO 100 3W 5% Axial	Stackpole Electronics Inc.	RSMF3JT100R
2	R24, R27	Res. TKF 2.2M 5% 1/10W SMD 0603	Yageo	9C06031A2204JLHFT

Note 1: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

TABLE B-1: BILL OF MATERIALS (BOM) (CONTINUED)

Qty	Reference	Description	Manufacturer	Part Number
1	R26	Res. 20k Ohm 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF2002V
1	R29	Res. 10k Ohm 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1002V
1	R32	Res. 47k Ohm 1/10W 5% 0603 SMD	Panasonic - ECG	ERJ-3GEYJ473V
2	R35, R37	Res. 0 Ohm 1/10W 0603 SMD	Panasonic - ECG	ERJ-3GEY0R00V
1	R36	Res. 4.7M Ohm 1/10W 1% 0603 SMD	Yageo Corporation	RC0603FR-074M7L
1	R38	Res. 1.50M Ohm 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1504V
1	R46	Res. 499 Ohm 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF4990V
5	R47, R48, R49, R50, R53	Res. 2k Ohm 1/10W 5% 0603 SMD	Panasonic - ECG	ERJ-3GEYJ202V
2	R52, R54	Res. 10k Ohm 1/10W 5% 0603 SMD	Panasonic - ECG	ERJ-3GEYJ103V
1	R55	Res. 20k Ohm 1/10W 5% 0603 SMD	Panasonic - ECG	ERJ-3GEYJ203V
3	SW1, SW2, SW3	Switch Tact. 6 MM 160 GF H=4.3MM	Omron Electronics LLC – EMC Division	B3S-1000P
3	U4, U5, U6	Sensor SS Hall Effect Linear	Honeywell International Inc.	SS49E
1	U9	Optocoupler Bidirectional 3.3V 5V SOIC-8	Fairchild Optoelec-tronics Group	FOD8012
2	U10, U11	Photocoupler Darl. Out 4-SMD	Sharp Corporation	PC365NJ0000F
1	X1	Crystal 7.3728 MHz 18 pF HC49-SMD-B	Abracon® Corporation	ABLS-7.3728MHZ-B4-T
1	X2	Crystal 32.768 KHz 12.5 pF Cyl. SMD	Abracon Corporation	AB26TRB-32.768KHZ-T
1	X3	Resonator Cer. 12.0 MHz CSTCE_G	Murata Electronics	CSTCE12M0G55-R0

Note 1: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

TABLE B-2: BILL OF MATERIALS – MICROCHIP CONSIGNED PARTS

Qty	Reference	Description	Manufacturer	Part Number
1	U1	IC AFE 16/24 Bit 125 Ksps SPI SSOP-20	Microchip Technology Inc.	**MCP3911A0-E/SS**
1	U2	IC Reg. LDO 3.3V 250 mA SOT-23-3	Microchip Technology Inc.	**MCP1703T-3302E/CB**
1	U3	IC Op Amp SGL 1.8V 1 MHZ SOT-23-5	Microchip Technology Inc.	**MCP6001T-E/OT**
1	U7	IC Reg. LDO 250 mA 3.3V SOT-223-3	Microchip Technology Inc.	**MCP1703-3302E/DB**
1	U8	MCU PIC 32K FLASH XLP TQFP-80	Microchip Technology Inc.	**PIC18F85K90-I/PTRSL**
1	U12	IC USB to UART SSOP-20	Microchip Technology Inc.	**MCP2200-I/SS**

Note 1: The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

Worldwide Sales and Service

AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200
Fax: 480-792-7277
Technical Support:
http://www.microchip.com/support
Web Address:
www.microchip.com

Atlanta
Duluth, GA
Tel: 678-957-9614
Fax: 678-957-1455

Boston
Westborough, MA
Tel: 774-760-0087
Fax: 774-760-0088

Chicago
Itasca, IL
Tel: 630-285-0071
Fax: 630-285-0075

Cleveland
Independence, OH
Tel: 216-447-0464
Fax: 216-447-0643

Dallas
Addison, TX
Tel: 972-818-7423
Fax: 972-818-2924

Detroit
Farmington Hills, MI
Tel: 248-538-2250
Fax: 248-538-2260

Indianapolis
Noblesville, IN
Tel: 317-773-8323
Fax: 317-773-5453

Los Angeles
Mission Viejo, CA
Tel: 949-462-9523
Fax: 949-462-9608

Santa Clara
Santa Clara, CA
Tel: 408-961-6444
Fax: 408-961-6445

Toronto
Mississauga, Ontario,
Canada
Tel: 905-673-0699
Fax: 905-673-6509

ASIA/PACIFIC

Asia Pacific Office
Suites 3707-14, 37th Floor
Tower 6, The Gateway
Harbour City, Kowloon
Hong Kong
Tel: 852-2401-1200
Fax: 852-2401-3431

Australia - Sydney
Tel: 61-2-9868-6733
Fax: 61-2-9868-6755

China - Beijing
Tel: 86-10-8569-7000
Fax: 86-10-8528-2104

China - Chengdu
Tel: 86-28-8665-5511
Fax: 86-28-8665-7889

China - Chongqing
Tel: 86-23-8980-9588
Fax: 86-23-8980-9500

China - Hangzhou
Tel: 86-571-2819-3187
Fax: 86-571-2819-3189

China - Hong Kong SAR
Tel: 852-2943-5100
Fax: 852-2401-3431

China - Nanjing
Tel: 86-25-8473-2460
Fax: 86-25-8473-2470

China - Qingdao
Tel: 86-532-8502-7355
Fax: 86-532-8502-7205

China - Shanghai
Tel: 86-21-5407-5533
Fax: 86-21-5407-5066

China - Shenyang
Tel: 86-24-2334-2829
Fax: 86-24-2334-2393

China - Shenzhen
Tel: 86-755-8864-2200
Fax: 86-755-8203-1760

China - Wuhan
Tel: 86-27-5980-5300
Fax: 86-27-5980-5118

China - Xian
Tel: 86-29-8833-7252
Fax: 86-29-8833-7256

China - Xiamen
Tel: 86-592-2388138
Fax: 86-592-2388130

China - Zhuhai
Tel: 86-756-3210040
Fax: 86-756-3210049

ASIA/PACIFIC

India - Bangalore
Tel: 91-80-3090-4444
Fax: 91-80-3090-4123

India - New Delhi
Tel: 91-11-4160-8631
Fax: 91-11-4160-8632

India - Pune
Tel: 91-20-2566-1512
Fax: 91-20-2566-1513

Japan - Osaka
Tel: 81-6-6152-7160
Fax: 81-6-6152-9310

Japan - Tokyo
Tel: 81-3-6880- 3770
Fax: 81-3-6880-3771

Korea - Daegu
Tel: 82-53-744-4301
Fax: 82-53-744-4302

Korea - Seoul
Tel: 82-2-554-7200
Fax: 82-2-558-5932 or
82-2-558-5934

Malaysia - Kuala Lumpur
Tel: 60-3-6201-9857
Fax: 60-3-6201-9859

Malaysia - Penang
Tel: 60-4-227-8870
Fax: 60-4-227-4068

Philippines - Manila
Tel: 63-2-634-9065
Fax: 63-2-634-9069

Singapore
Tel: 65-6334-8870
Fax: 65-6334-8850

Taiwan - Hsin Chu
Tel: 886-3-5778-366
Fax: 886-3-5770-955

Taiwan - Kaohsiung
Tel: 886-7-213-7828
Fax: 886-7-330-9305

Taiwan - Taipei
Tel: 886-2-2508-8600
Fax: 886-2-2508-0102

Thailand - Bangkok
Tel: 66-2-694-1351
Fax: 66-2-694-1350

EUROPE

Austria - Wels
Tel: 43-7242-2244-39
Fax: 43-7242-2244-393

Denmark - Copenhagen
Tel: 45-4450-2828
Fax: 45-4485-2829

France - Paris
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79

Germany - Munich
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

Italy - Milan
Tel: 39-0331-742611
Fax: 39-0331-466781

Netherlands - Drunen
Tel: 31-416-690399
Fax: 31-416-690340

Spain - Madrid
Tel: 34-91-708-08-90
Fax: 34-91-708-08-91

UK - Wokingham
Tel: 44-118-921-5869
Fax: 44-118-921-5820

11/29/12