MCP3909 and PIC18F85J90 Single Phase Energy Meter Reference Design

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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 on-line help. Select the Help menu, and then Topics to open a list of available on-line help files.

INTRODUCTION

This chapter contains general information that will be useful to know before using the MCP3909/PIC18F85J90 Single Phase 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 MCP3909/PIC18F85J90 Single Phase Energy Meter Reference Design 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 MCP3909 3-Phase Energy Meter Reference Design 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 design, phase lock loop circuitry, and power supply design.
- **Chapter 3. "PIC18F85J90 Calculation and Register Description"** – This section describes the digital signal flow for all power output quantities such as RMS current, RMS voltage, active power, and apparent power. This section also includes the calibration registers detail.
- **Chapter 4. "Meter Protocol and Timings"**– Here is described the protocol used for accessing the registers includes commands that are used to interface to the meter.
- **Chapter 5. "Meter Calibration"** – This chapter provides detail on how to calibrate the meter. The PC calibration software that is included with the meter automates the steps and calculations described in this chapter.
- .**Appendix A. "Schematic and Layouts"** – Shows the schematic and layout diagrams
- **Appendix B. "Bill of Materials"** – Lists the parts used to build the meter.

CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

DOCUMENTATION CONVENTIONS

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

	Represents code supplied by user	`void main (void)`
		`{ ...`
		`}`

RECOMMENDED READING

This user's guide describes how to use MCP3909/PIC18F85J90 Single Phase Energy Meter Reference Design. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources.

MCP3909 Data Sheet, *"Energy Metering IC with SPI Interface and Active Power Pulse Output"* (DS22025)

This data sheet provides detailed information regarding the MCP3909 device.

AN994 Application Note *"IEC61036 Meter Design using the MCP3905A/06A Energy Metering Devices"* (DS00994)

This application note documents the design decisions associated with using the MCP390X devices for energy meter design and IEC compliance.

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- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip consultant program member listing
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- Field Application Engineer (FAE)
- Technical Support

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

DOCUMENT REVISION HISTORY

Revision A (December 2009)

- Initial Release of this Document.

MCP3909/PIC18F85J90 SINGLE PHASE ENERGY METER REFERENCE DESIGN

Chapter 1. Product Overview

1.1 INTRODUCTION

The MCP3909/PIC18F85J90 Single Phase Energy Meter Reference Design is a fully functional single phase meter. The design is intended to be low cost and is transformerless. The design uses a half-wave rectified power supply circuit and a shunt current sensing element. A single MCP3909 acts as the analog front end measurement circuitry. The PIC18F85J90 directly drives the LCD glass and displays active energy consumption.

The meter design contains serially accessible registers and is intended to be flexible and upgraded to a variety of PIC® micro-based energy meter designs using the firmware presented herein. The “Single Phase Energy Meter Software” offers a functional and simple means to monitor and control the PIC18F85J90 and can be used to create custom calibration setups. In some situations, only a single point calibraton may be required. The energy meter software offers an automated step by step calibration process that can be used to quickly calibrate energy meters.

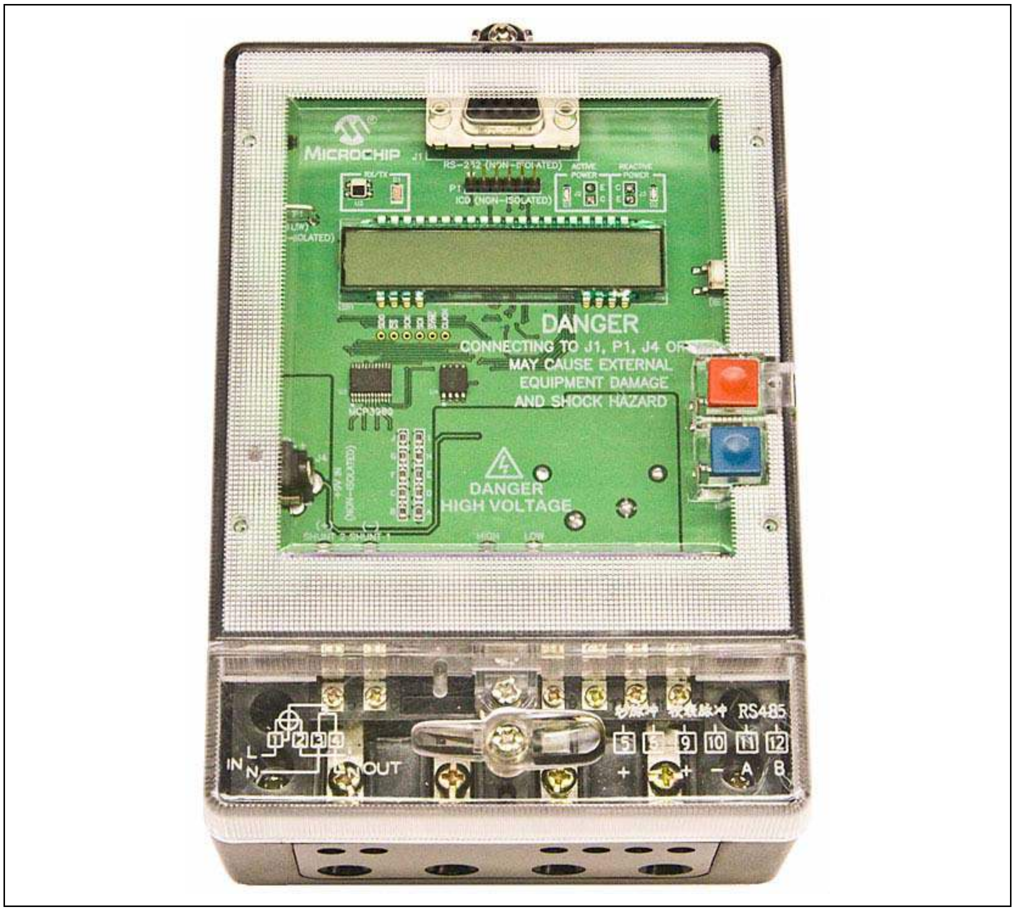


FIGURE 1-1: MCP3909/PIC18F85J90 Single Phase Energy Meter Reference Design.

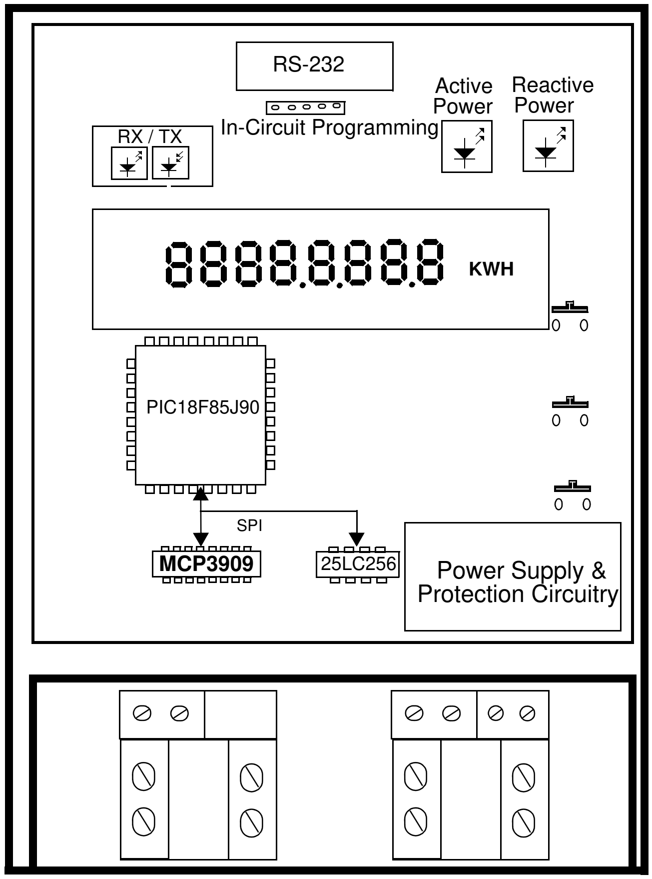


FIGURE 1-2: *Functional Block Diagram.*

1.2 WHAT THE MCP3909/PIC18F85J90 SINGLE PHASE ENERGY METER REFERENCE DESIGN KIT INCLUDES

This MCP3909/PIC18F85J90 Single Phase Energy Meter Reference Design Kit includes:

- MCP3909/PIC18F85J90 Single Phase Energy Meter Reference Design, 102-00130
- Important Information Sheet

1.3 GETTING STARTED

To describe how to use the MCP3909/PIC18F85J90 Single Phase Energy Meter Reference Design, the following example is given using a 2-Wire 1-phase, 220V AC line voltage and connections using an energy meter calibrator equipment or other programmable load source. The meter design uses a 5A load for calibration current and a maximum current (I_{MAX}) of 10A.

All connections described in this section are dependent on the choice of current sensing element and a secondary external transformer may be required in higher current meter designs.

For testing a calibrated meter, the following connections apply for a 4-wire connection.

1.3.1 Step 1: Wiring connections

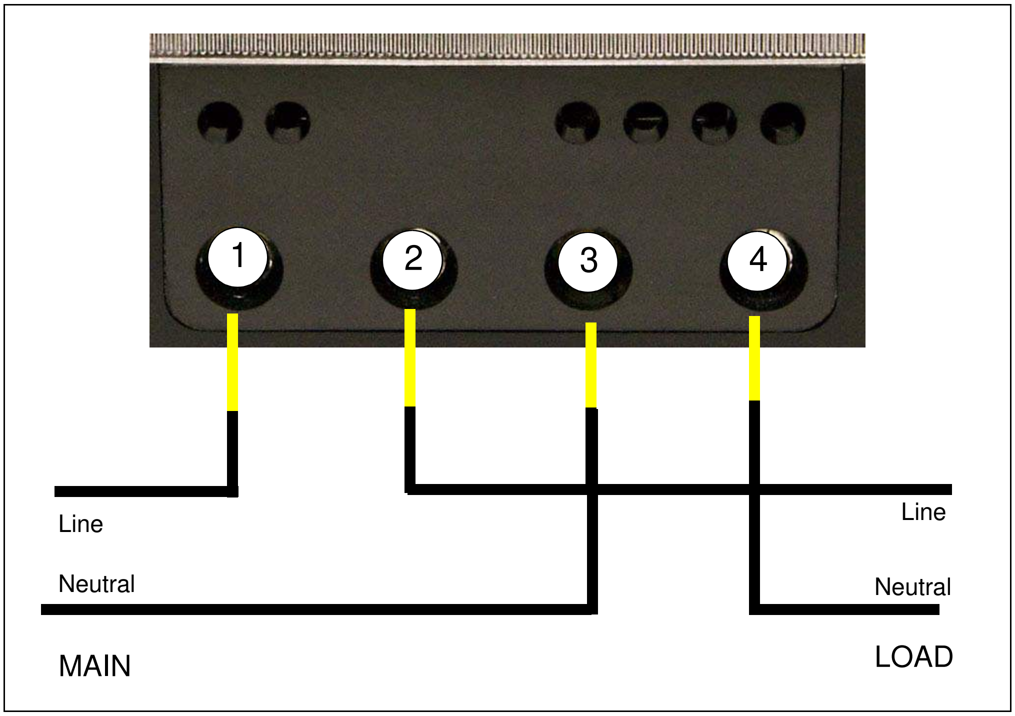


FIGURE 1-3: *Example Connections using a 4-Wire System.*

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 total energy accumulated.

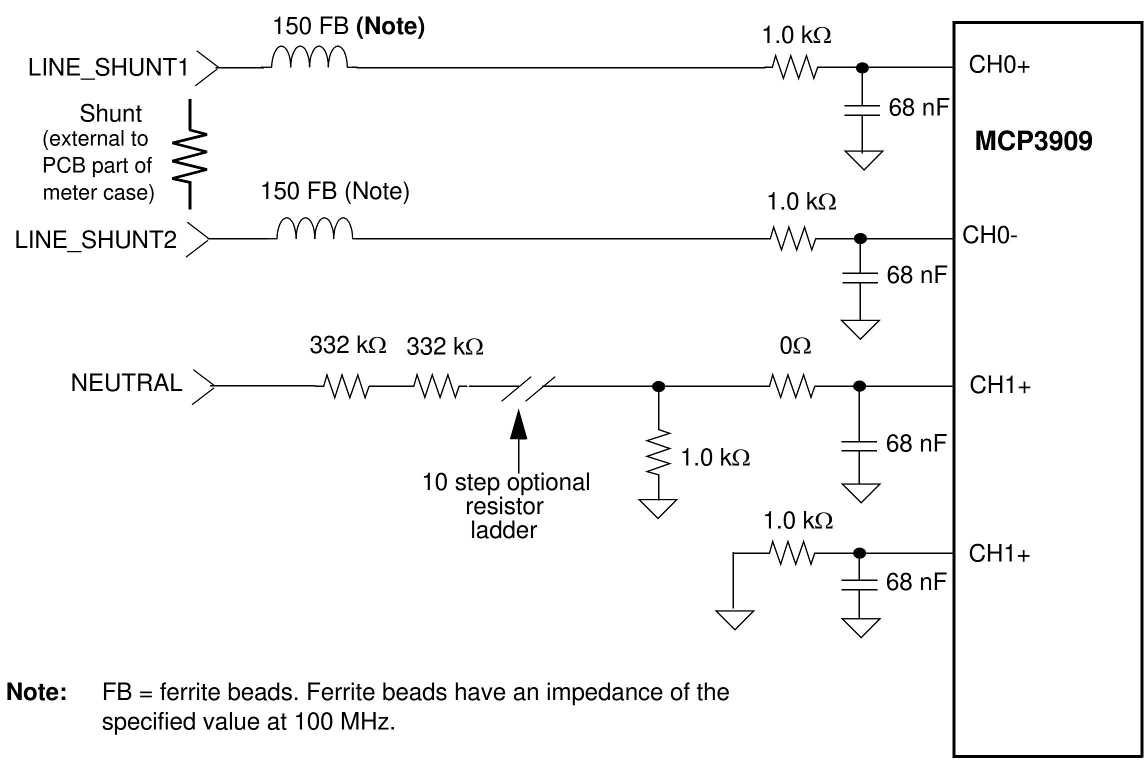
NOTES:

Chapter 2. Hardware

2.1 INPUT AND ANALOG FRONT END

This meter comes populated with components designed for 220V line voltage. At the bottom of the main board are the high voltage line and neutral connections. There are four total connections that are made from the PCB to the meter casing, labeled as LINE, NEUTRAL, SHUNT1 and SHUNT2. The shunt sits on the high or line side of a two wire system and the meter employes a hot or "live" ground. The wires going into the shunt to SHUNT1 and SHUNT2 should be twisted together. The wires going into the LINE and NEUTRAL side of the meter should also be twisted together and kept away from the SHUNT1 and SHUNT2 wires if possible.

The neutral side of the 2-wire system goes into a resistor divider on the voltage channel input. Anti-aliasing low-pass filters will be included on both differential channels. The voltage channel uses two 332 kΩ resistors to achieve a divider ratio of 664:1. For a line voltage of 230 V_{RMS}, the channel 1 input signal size will be 490 mV_{PEAK}. The current channel of each phase uses current transformer with a turns ratio of 2000:1 and burden resistance of 56.4 kΩ. The resulting channel 0 signal size is 340 mV_{PEAK} for 20A, or twice the rated maximum current of the meter, still within the input range of the A/D converter of the MCP3909.



Note: FB = ferrite beads. Ferrite beads have an impedance of the specified value at 100 MHz.

FIGURE 2-1: *Analog Front End, Phase A Connections and Reference Designators shown.*

2.2 POWER SUPPLY CIRCUIT

The power supply circuit for the MCP3909/PIC18F85J90 Single Phase Energy Meter Reference Design uses a half wave rectified signal and a single +5V voltage regulator, and a 3.3V LDO.

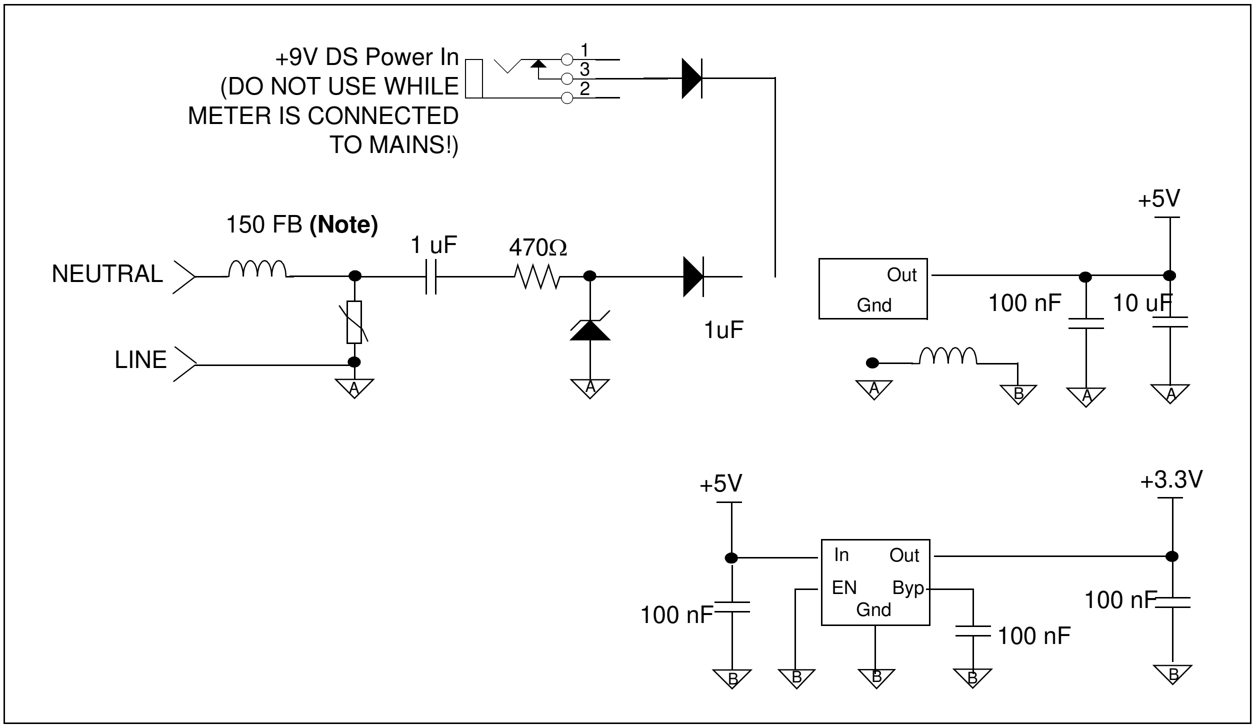


FIGURE 2-2: *Low-Cost Power Supply Circuit.*

2.3 MICROCONTROLLER CONNECTIONS

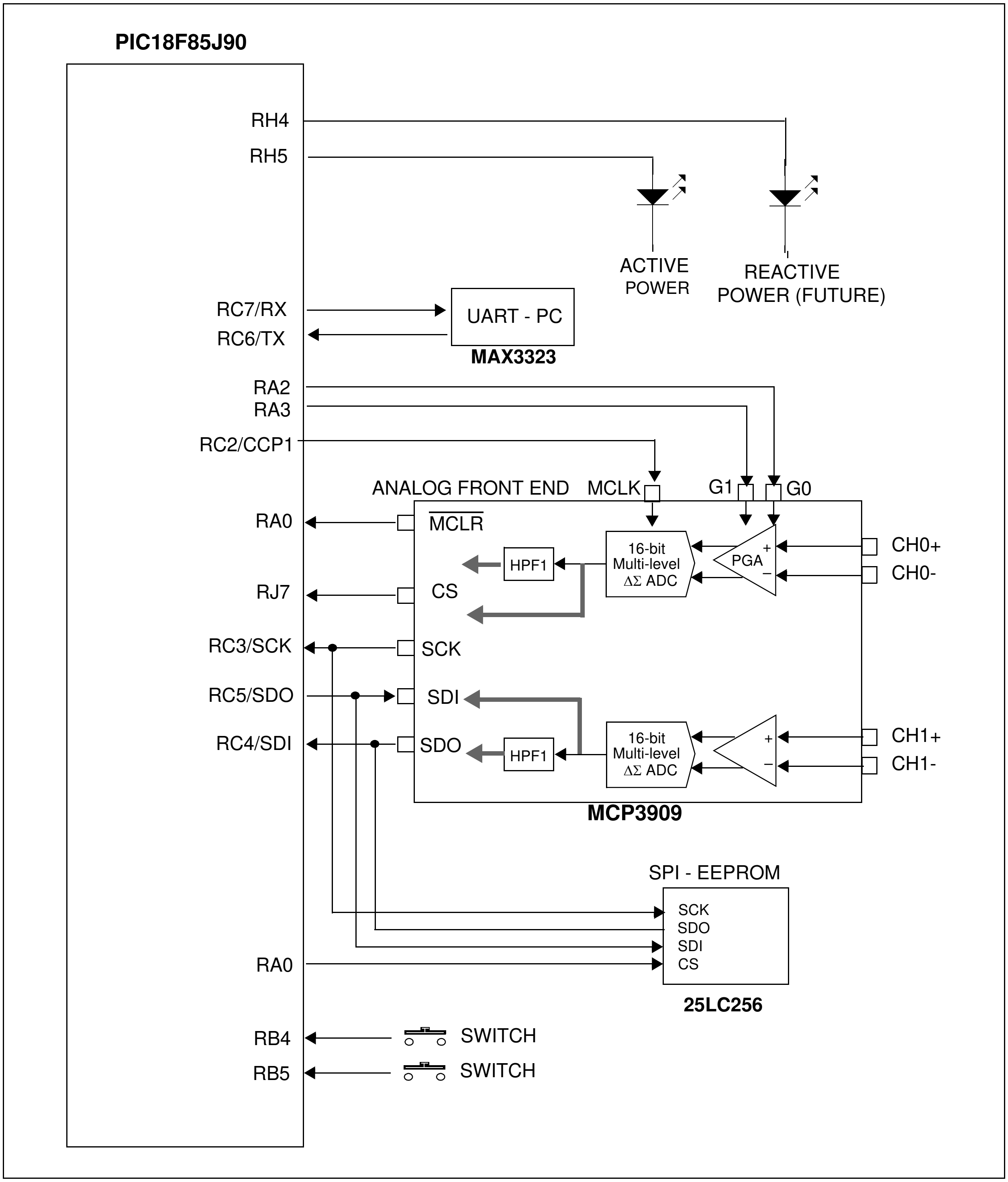


FIGURE 2-3: *MCP3909/PIC18F85J90 Digital Connections.*

NOTES:

Chapter 3. Calculation and Register Description

3.1 REGISTER OVERVIEW

The PIC18F85J90 contains registers that are used during calibration and registers that can be read through the UART. The registers are named to describe each phase, specific measurement, and in the case of the calibration registers, the calibration function.

The intent of the calibration process is to yield output registers that are decimal representation of the final energy, power, current or voltage value.

Instantaneous Power Registers

The PHy_W and PHy_VA registers contain the decimal representation of the active power (W) and apparent power (VA) post calibration. The reactive power calculation is not implemented at this time.

The final correction factors to convert these registers to units of energy are located in the _GLSB registers. These correction factors can be automatically calculated and loaded by using the PC calibration software. The exact representation depends on the meter values that are entered in the software. For example, at 10A and 220V, power in the PHy_W register is 0.1 mW/LSB.

Calibration Registers

The calibration registers fall into one of three categories: offset, gain, and LSB, denoted by _OFF, _GAIN and _GLSB register names.

In addition there are two registers, CFNUM and CFDEN, that calibrate the output pulse, CF.

3.2 ACTIVE ENERGY CALCULATION

Active Energy is described through the process described in Figure 3-1. The calibration registers for each calculation are shown as well as the output registers.

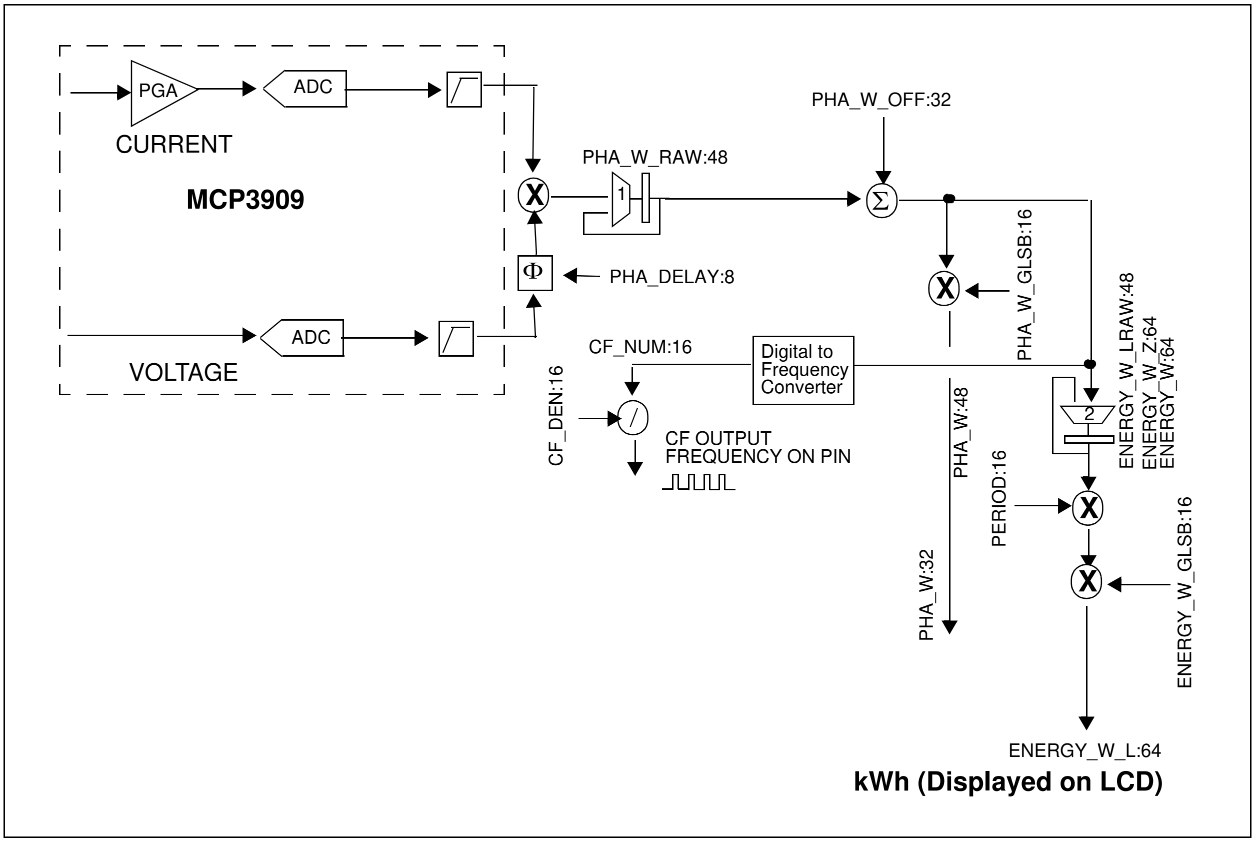


FIGURE 3-1: *Active Energy Calculation.*

3.3 COMPLETE REGISTER LIST

TABLE 3-1: INTERNAL REGISTER SUMMARY

Address	Name	Bits	R/W	Description
0x000	MODE1	16	R/W	Configuration register for operating mode of the meter
0x002	RESERVED	16	—	Reserved
0x004	STATUS1	16	R	Status Register
0x006	RESERVED	16	—	Reserved
0x008	CAL_CONTROL	16	R/W	Configuration register for calibration control
0x00A	LINE_CYC	16	R/W	2^{nd} number of line cycles to be used during energy accumulation
0x00C	LINE_CYC_CNT	16	R	Counter for number of line cycles
0x00E	RESERVED	16	—	Reserved
0x04F	RESERVED	8	—	Reserved
0x064	PHA_W_RAW	48	R	Raw phase A active power
0x076	PHA_W	32	R	Final Phase A active power, units in watts (W)
0x0A0	PHA_VAR_RAW	48	R	Not implemented
0x0B2	PHA_VAR	32	R	Not implemented
0x0BE	RESERVED	16	—	Not implemented
0x0C0	PERIOD	32	R	Period register
0x0C4	ENERGY_W	64	R	Total active energy accumulated
0x0CC	ENERGY_W_Z	64	R	Total active energy accumulated since last read of this register
0x0D4	ENERGY_W_L_RAW	48	R	Total energy accumulated over last LINE_CYC line cycles
0x0DA	ENERGY_W_L	32	R	Not implemented
0x0FE	RESERVED	16	—	Reserved
0x100	ENERGY_VAR	64	R	Not implemented
0x108	ENERGY_VAR_Z	64	R	Not implemented
0x116	ENERGY_VAR_L	32	R	Not implemented
0x11A	Reserved	272	—	Reserved
0x13C	Reserved	16	—	Reserved
0x13E	Reserved	16	—	Reserved
0x13F	End	—	—	End of PIC18F85J90 RAM
CALIBRATION REGISTERS				
0x140	PHA_DELAY	8	R/W	Phase A delay (delay between voltage and current, voltage is time shifted)
0x143	RESERVED	8	—	Reserved
0x170	PHA_W_OFF	32	R/W	Active power offset, Phase A
0x17C	PHA_W_GAIN	16	R/W	Active power gain adjust for Phase A, for CF matching
0x182	PHA_W_GLSB	16	R/W	Active power gain adjust for Phase A, to produce X W/LSB
0x194	PHA_VAR_GAIN	16	R/W	Not implemented
0x19A	PHA_VAR_GLSB	16	R/W	Not implemented
0x1A0	ENERGY_W_GLSB	16	R/W	Not implemented
0x1A4	ENERGY_VAR_GLSB	16	R/W	Not implemented
0x1A6	CREEP_THRESH	32	R/W	Not implemented
0x1AA	CF_PULSE_WIDTH	8	R/W	Defines CF pulse width from 0 to 255 * 1.25 ms for 50 Hz. For 60 Hz line 0 to 255 * 1.042 ms
0x1AB	RESERVED	8	—	Reserved
0x1AC	CFDEN	8	R/W	CF Calibration Pulse correction factor
0x1AD	RESERVED	8	—	Reserved
0x1AE	CFNUM	16	R/W	CF Calibration Pulse correction factor
0x1B0	MODE1DEF	16	R/W	Power Up Configuration Register
0x1B2	PHA_CAL_STATUS	16	R/W	Status of Phase A Calibration
0x1B8	STAND_W_RAW	48	R/W	Standard Phase Active Power Reading (place holder register used during calibration for gain matching)

3.4 CONFIGURATION AND OUTPUT REGISTERS

3.4.1 MODE1 Register

REGISTER 3-1: MODE1 REGISTER

Name	Bits	Address	Cof
MODE1	16	0x000	R/W

The mode register controls the operation of the energy meter. The bit functions are defined below.

R/W-0	R/W	R/W	R/W	R/W	U-0	U-0	U-0
APP2	APP1	APP0	ACT1	ACT0	—	—	—
bit 15							bit 8

R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
PGA1	PGA0	CF_C	CF_B	CF_A	ABSOLUTE	PHASE	CREEP
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 13-15 **APP:** Apparent Power Calculation Mode Bits (not implemented)

bit 11-12 **ACT:** Active Power Calculation Mode Bits (not implemented)

bit 8-10 **Unimplemented:** Read as ‘0’

bit 6-7 **PGA:** PGA Bits (not implemented)

bit 3-5 **CF Phase y:** Active Energy CF Phase Enable Bits
1 = Enabled to be accumulated into the total energy registers or CF pulse output
0 = Disabled and is not acculated into the total energy registers or CF pulse output

bit 2 **Absolute:** Positive Only Energy Accumulation Mode
1 = Positive Energy Only
0 = Both negative and positive energy accumulated (negative energy is subtracted)

bit 1 **Phase:** The Phase Bit
1 = Single Point Phase Correction
0 = Multi-Point Phase Correction (future)

bit 0 **CREEP:** No-Load Threshold Bit
1 = Enabled
0 = Disabled

3.4.2 STATUS1 Register

REGISTER 3-2: STATUS1 REGISTER

Name	Bits	Address	Cof
STATUS1	16	0x004	R

The STATUS1 register contains the operational status of the energy meter. The bit functions are defined below.

U-0	U-0	U-0	U-0	U-0	U-0	U-0	U-0
—	—	—	—	—	—	—	—
bit 15							bit 8

U-0	U-0	U-0	U-0	U-0	R	U-0	U-0
—	—	—	—	—	PHA_S	—	—
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 15-3 **Unimplemented:** Read as ‘0’

bit 2 **PHA_S:** Phase A Sign Bit. This is the sign bit of raw active power before absolute value taken (if enabled, see MODE1 bits).
- 1 = Negative active power, this may indicate the CT is wired in backwards
- 0 = Operation Normal

bit 1-0 **Unimplemented:** Read as ‘0’

3.4.3 CAL_CONTROL Register

REGISTER 3-3: CAL_CONTROL Register

Name	Bits	Address	Cof
CAL_CONTROL	16	0x008	R/W

This is the calibration mode control register. Bit 0 enables calibration mode. When bit 1 is set high, the energy accumulation registers are updated for LINE_CYC line cycles. After this time, bit 1 is set low by the PIC18F85J90 and the update of the energy accumulation registers will stop. This allows the calibration software to set bit 0, clear the registers, set bit 1, and then start reading the energy accumulation registers as well as this register to check the status of bit 1. When bit 1 goes low, then LINE_CYC lines cycles have passed and the energy accumulation registers are final. Note that bit 0 takes effect immediately and bit 1 will take effect on the very next line cycle. When bit 1 goes low, all energy accumulation registers will be ready to read. While in calibration mode, those registers that are used as part of the meter calibration and normally dependent on calibration registers will not be dependent while in calibration mode. For example, PHA_W_RAW is not dependent on PHA_W_OFF in calibration mode.

U-0	U-0	U-0	U-0	U-0	U-0	U-0	U-0
—	—	—	—	—	—	—	—
bit 15							bit 8

U-0	U-0	U-0	U-0	U-0	U-0	R/W-0	R/W-0
—	—	—	—	—	Reserved	CAL_Update	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

bit 15-3 **Unimplemented:** Read as ‘0’

bit 2 **Reserved:**

bit 1 **CAL_UPDATE:** Calbration Update Bit

Power and energy registers updated for LINE_CYC line cycles when set. Bit must be set for registers to begin updating, which starts on the next line cycle after bit is set.

1 = When CAL_MODE bit is set, set this bit to enable update of power and energy registers starting on next line cycle

0 = When CAL_MODE bit is set and this bit has been set, this bit will be cleared after LINE_CYC line cycles. At that point, all registers will be updated, and no further updates will be done until this bit is set again or CAL_MODE bit is cleared

bit 0 **CAL_MODE:** Calibration Mode Bit

This bit enables calibration mode.

1 = Calibration Mode Enabled

0 = Calibration Mode Disabled

3.4.4 LINE_CYC

REGISTER 3-4: LINE_CYC REGISTER

Name	Bits	Address	Cof
LINE_CYC	16	0x00A	R/W

Number of line cycles as a power of two. A setting of 0 indicates 2^0 or 1 line cycle. A setting of 1 is 2 line cycles (2^1), a setting of 2 is 4 lines cycles (2^2), up to a setting of 8 which is 256 line cycles. When written, this register will not take effect until the previous number of line cycles has been acquired.

3.4.5 LINE_CYC_CNT

REGISTER 3-5: LINE_CYC_CNT REGISTER

Name	Bits	Address	Cof
LINE_CYC_CNT	16	0x00C	R

This register counts from 0 and finishes at $2^{(LINE\_CYC)}$ -1 and then re-starts at 0, where LINE_CYC represents the value in the LINE_CYC register.

3.4.6 PHA_W_RAW

REGISTER 3-6: PHA_W_RAW REGISTER

Name	Bits	Address	Cof
PHA_W_RAW	48	0x064	R

These registers are the raw phase A active power as it represents the sum of each phase y current A/D value times phase y voltage A/D value results over LINE_CYC line cycles (each line cycle has 128 results). Each current times voltage multiplication results in a 32-bit word. There are up to 256 line cycles with each line cycle being 128 results and each result being 32-bit. Thus, a 48-bit register is needed. This is the register to be read during calibration for calculating the offset and gain values associated with active phase y power, PHy_W_OFF, PHy_W_GAIN, and PHy_W_GLSB. These registers are overwritten every line cycle, however if calibration is enabled, updates will stop once LINE_CYC line cycles have elapsed.

3.4.7 PHA_W

REGISTER 3-7: PHA_W REGISTER

Name	Bits	Address	Cof
PHA_W	32	0x076	R

These registers are the value for phase A active power. The goal of calibration is to get these registers values to equal X 0.1 mW/LSB. When displaying the active power for phase y, simply display the value in these registers with the decimal point one digit in from the right, in milli-watts. (Note this decimal point location, or LSB resolution of 0.1 mW, is specific for the 5(10)A, 220V rating that this meter is designed for). This register is overwritten every LINE_CYC line cycles (written only once if calibration is enabled).

3.4.8 PHA_VAR_RAW (NOT IMPLEMENTED)

REGISTER 3-8: PHA_VAR_RAW REGISTER

Name	Bits	Address	Cof
PHA_VAR_RAW	48	0x0A0	R

This is the raw phase A reactive power. This is the register to be read during calibration for calculating the gain values associated with reactive phase y power, PHA_VAR_GAIN and PHA_VAR_GLSB. This register is overwritten every LINE_CYC line cycles (written only once if calibration is enabled).

NOT IMPLEMENTED IN THIS FIRMWARE/SOFTWARE RELEASE.

3.4.9 PHA_VAR (NOT IMPLEMENTED)

REGISTER 3-9: PHA_VAR REGISTER

Name	Bits	Address	Cof
PHA_VAR	32	0x0B2	R

This is the value for phase A reactive power. The goal is to get this value to equal X VAR/LSB. This is done with the PHA_VAR_GLSB registers. When displaying the reactive power for phase A, simply display the value in these registers with the decimal point one digit in from the right, in milli-volt-amperes-reactive. (Note this decimal point location, or LSB resolution of 0.1 mVAR, is specific for the 5(10)A, 220V rating that this meter is designed for). This register is overwritten every LINE_CYC line cycles (written only once if calibration is enabled).

NOT IMPLEMENTED IN THIS FIRMWARE/SOFTWARE RELEASE.

3.4.10 PERIOD

REGISTER 3-10: PERIOD REGISTER

Name	Bits	Address	Cof
PERIOD	32	0x0C0	R

This 32-bit register represents the total number of clock ticks that elapsed over the most recent LINE_CYC line cycles. Each LSB represents 1.6 us with a 40 MHz clock on the microcontroller. This register is overwritten every LINE_CYC line cycles (written only once if calibration is enabled).

3.4.11 ENERGY_W_

REGISTER 3-11: ENERGY_W_ REGISTERS

Name	Bits	Address	Cof
ENERGY_W	64	0x0C4	R
ENERGY_W_Z	64	0x0CC	R
ENERGY_W_L	32	0x0DA	R
ENERGY_W_L_RAW	48	0x0D4	R

These four registers represent the total active energy accumulated. The ENERGY_W_L_RAW register is the total active energy accumulated over the previous LINE_CYC line cycles.

Accumulation is done every line cycle and is:

EQUATION 3-1:

$$ENERGY\_W = ENERGY\_W + \left[(PHA\_W\_RAW + PHA\_W\_OFF) \bullet \left(\frac{PHA\_W\_GAIN}{32768}\right) + (PHB\_W\_RAW + PHB\_W\_OFF) \bullet \left(\frac{PHB\_W\_GAIN}{32768}\right) + (PHC\_W\_RAW + PHC\_W\_OFF) \bullet \left(\frac{PHC\_W\_GAIN}{32768}\right)\right] \bullet \frac{PERIOD}{65536}$$

Where:

PERIOD = the period (in 1.6 µs clock ticks) for the most recent line cycle.

During calibration, ENERGY_W_Z, ENERGY_W, and ENERGY_W_L_RAW will all have the same value.

Also, during calibration, the PHA_W_OFF register additions are skipped and the PHA_W_GAIN values are all set to their default value of 0x4000 (16,384).

The ENERGY_W_L_RAW register is the register that should be read when calibrating CFNUM and CFDEN.

This register is updated every line cycle (updating ends once LINE_CYC line cycles have passed if calibration is enabled).

3.4.12 ENERGY_VA_

REGISTER 3-12: ENERGY_VA_ REGISTERS

Name	Bits	Address	Cof
ENERGY_VA	64	0x0DE	R
ENERGY_VA_Z	64	0x0E6	R
ENERGY_VA_L	32	0x0F4	R
ENERGY_VA_L_RAW	48	0x0EE	R

These four registers represent the total apparent energy accumulated so far. Energy from each LINE_CYC line cycles is:

EQUATION 3-2:

$$ENERGY\_VA = ENERGY\_VA + \Big[(PHA\_I\_RMS\_RAW \bullet PHA\_V\_RMS\_RAW) \bullet \left(\frac{PHA\_VA\_GAIN}{32768}\right)$$
$$+ (PHB\_I\_RMS\_RAW \bullet PHB\_V\_RMS\_RAW) \bullet \left(\frac{PHB\_VA\_GAIN}{32768}\right)$$
$$+ (PHC\_I\_RMS\_RAW \bullet PHC\_V\_RMS\_RAW) \bullet \left(\frac{PHC\_VA\_GAIN}{32768}\right)\Big] \bullet \frac{PERIOD \bullet 128}{65536}$$

Where:

PERIOD = the period (in 1.6 µs clock ticks) for the most recent LINE_CYC line cycles.

Note that during calibration, this value, ENERGY_VA_Z, and ENERGY_VA_L_RAW will all have the same value.

This register is updated every LINE_CYC line cycles (updating ends after first update if calibration is enabled).

3.4.13 ENERGY_VAR (NOT IMPLEMENTED)

REGISTER 3-13: ENERGY_VAR REGISTER

Name	Bit	Address	Cof
ENERGY_VAR	64	0x100	R
ENERGY_VAR_Z	64	0x108	R
ENERGY_VAR_L	32	0x116	R
ENERGY_VAR_L_RAW	48	0x110	R

NOT IMPLEMENTED IN THIS FIRMWARE/SOFTWARE RELEASE.

3.5 CALIBRATION REGISTERS

The calibration register set contains all of the offset, gain, LSB adjust, phase delay, and calibration output pulse adjustment settings. The values to be placed in these configuration registers come during meter calibration and can be automatically generated using the “3-Phase Meter Calibration Software” available for download on Microchip’s website.

3.5.1 PHA_DELAY

REGISTER 3-14: PHA_DELAY REGISTER

Name	Bit	Address	Cof
PHA_DELAY	8	0x140	R/W

Phase A delay, signed 8-bit value, ±2.8125 degrees (±130 µs for 60 Hz, ±156 µs for 50 Hz)

3.5.2 PHA_W_OFF

REGISTER 3-15: PHA_W_OFF REGISTER

Name	Bits	Address	Cof
PHA_W_OFF	32	0x170	R/W

Phase A active power offset (this is straight offset, not the square as with voltage and current). A much larger value is need because the power is a running sum. This is a 32-bit signed value.

3.5.3 PHA_W_GAIN

REGISTER 3-16: PHA_W_GAIN REGISTER

Name	Bits	Address	Cof
PHA_W_GAIN	16	0x17C	R/W

Phase A active power gain so that all results can be calibrated to produce equal CF pulses/watt-hour. The signed 16-bit number produces a change in the PHA_W_RAW value before being added to the energy registers. A value of 32,767 represents a 99.9939% increase while a value of 8192 represents a decrease of 50%.

3.5.4 PHA_W_GLSB

REGISTER 3-17: PHA_W_GLSB REGISTER

Name	Bits	Address	Cof
PHA_W_GLSB	16	0x182	R/W

Phase A active power gain to produce X W/LSB. The value is always less than one (for example, 32,767 = 0.9999695).

3.5.5 PHA_VAR_GAIN (NOT IMPLEMENTED)

NOT IMPLEMENTED IN THIS FIRMWARE/SOFTWARE RELEASE.

3.5.6 PHA_VAR_GLSB (NOT IMPLEMENTED)

NOT IMPLEMENTED IN THIS FIRMWARE/SOFTWARE RELEASE.

3.5.7 ENERGY_W_GLSB (NOT IMPLEMENTED)

REGISTER 3-18: ENERGY_W_GLSB REGISTER

Name	Bits	Address	Cof
ENERGY_W_GLSB	16	0x1A0	R/W

NOT IMPLEMENTED IN THIS FIRMWARE/SOFTWARE RELEASE.

3.5.8 ENERGY_VAR_GLSB (NOT IMPLEMENTED)

REGISTER 3-19: ENERGY_VAR_GLSB REGISTER

Name	Bits	Address	Cof
ENERGY_VAR_GLSB	16	0x1A4	R/W

NOT IMPLEMENTED IN THIS FIRMWARE/SOFTWARE RELEASE.

3.5.9 CREEP_THRESH (NOT IMPLEMENTED)

REGISTER 3-20: CREEP_THRESH REGISTER

Name	Bits	Address	Cof
CREEP_THRESH	32	0x1A6	R/W

NOT IMPLEMENTED IN THIS FIRMWARE/SOFTWARE RELEASE.

3.5.10 CF_PULSE_WIDTH

REGISTER 3-21: CF_PULSE_WIDTH REGISTER

Name	Bits	Address	Cof
CF_PULSE	8	0x1AA	R/W

Defines CF pulse width from 0 to 255. Length of width is value * 8 * (1/LINEFREQ) / 128) ms. A maximum of 0.266 seconds for 60 Hz and 0.319 seconds for 50 Hz.

If the value is 0, no CF pulse is produced.

3.5.11 CFDEN

REGISTER 3-22: CFDEN REGISTER

Name	Bits	Address	Cof
CF_DEN	16	0x1AC	R/W

8-bit signed value. Represents the number of shifts for active power energy register ENERGY_W_L before CFNUM is applied.

3.5.12 CFNUM

REGISTER 3-23: CFNUM REGISTER

Name	Bits	Address	Cof
CF_NUM	16	0x1AE	R/W

Active power gain to produce a specified pulses per watt-hour. The value is always less than one (for example, 32,767 = 0.9999695).

3.5.13 MODE1_DEF

REGISTER 3-24: MODE1_DEF REGISTER

Name	Bits	Address	Cof
MODE1_DEF	16	0x1B0	R/W

Mode 1 default power-up settings. On power-up, this register will be read and placed into the MOD1 register.

3.5.14 PHA_CAL_Status Register

REGISTER 3-25: PHA_CAL_STATUS REGISTER

Name	Bits	Address	Cof
PHA_CAL_STATUS	16	0x1B2	R/W

The PHASE_A CAL_STATUS registers holds the calibration status for each individual phase. Broken down by phase, these are the values that can be calibrated. Each bit has the status of ‘0’ = Not calibrated, ‘1’ = Calibrated.

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
DELAY	I_RMS_OFF	V_RMS_OFF	I_RMS_GAIN	V_RMS_GAIN	I_RMS_GLSB	V_RMS_GLSB	W_OFF
bit 15							bit 8

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	U-0	R/W-0
W_GAIN	W_GLSB	VA_GAIN	VA_GLSB	VAR_GAIN	VAR_GLSB	—	STANDARD
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 15-2 **CALIBRATION REGISTER:** Calibration register status for offset, gain, LSB, and phase delay
1 = This register has been calibrated
0 = This register is NOT calibrated

bit 1 **Unimplemented:** Read as ‘0’

bit 0 **STANDARD:** Standard Phase Bit
1 = Standard Phase is THIS phase
0 = This phase is NOT the standard phase

3.5.15 STANDARD_W_RAW

REGISTER 3-26: STANDARD_W_RAW REGISTER

Name	Bits	Address	Cof
STANDARD_W_RAW	48	0x1B8	R/W

This calibration register holds the energy value that was accumulated during the standard phase measurement under calibration configuration C1. The software will read this value when performing phase to phase gain matching during active power calibration.

NOTES:

Chapter 4. Meter Protocol and Timings

4.1 PIC18F85J90 PROTOCOL

The RS-232 port of the PIC18F85J90 is used to access the register map of the meter. In addition to reading and writing of registers, there are also dedicated commands for clearing calibration registers, loading calibration registers, and storing calibration registers to flash. The first byte RS-232 data is an ASCII character that represents the command, and each command has a specific protocol. Each command ends with the ASCII character “X”.

4.1.1 Command Description

The first byte of the data (byte 0) is an ASCII character E, L, S, W and R.

- E - Echo All Data Received (ECHO)
- L - Load Calibration Registers from Flash (LOAD)
- S - Store Calibration Registers (STORE)
- W - Write Bytes (WRITE)
- R - Read Bytes (READ)

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 additional data in lieu of the number of bytes.

4.1.1.1 “E” ECHO: - ECHO ALL DATA RECEIVED

Example: 'EABCDEFGHIJKLMNOPQRSTUVWYZ1234567890X'.

Returns: 'EABCDEFGHIJKLMNOPQRSTUVWYZ1234567890X'.

4.1.1.2 “L” LOAD: LOAD CALIBRATION REGISTERS FROM FLASH.

Example: 'LX'.

Returns: 'LX'.

This command is used to verify that the calibration values were actually written into flash (or EEPROM). Once the software executes a 'SX' command, it should verify that the values were stored by issuing an 'LX' command and then reading the calibration values with a 'R' command.

4.1.1.3 “S” STORE: STORE CALIBRATION REGISTERS INTO FLASH

Note that the store command will write all calibration values to internal EEPROM and this function takes some time. During that time, the meter is not functional. The store command should only be used after calibrating the meter and not while it is in actual use.

Example: 'SX'.

Returns: 'SX'.

4.1.1.4 “W” WRITE: WRITE STARTING AT SPECIFIED ADDRESS

Write specified bytes.

Example: 'W030000102030405060708090A0B0C0D0E0FX'.

Returns: 'W030000102030405060708090A0B0C0D0E0FX'.

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

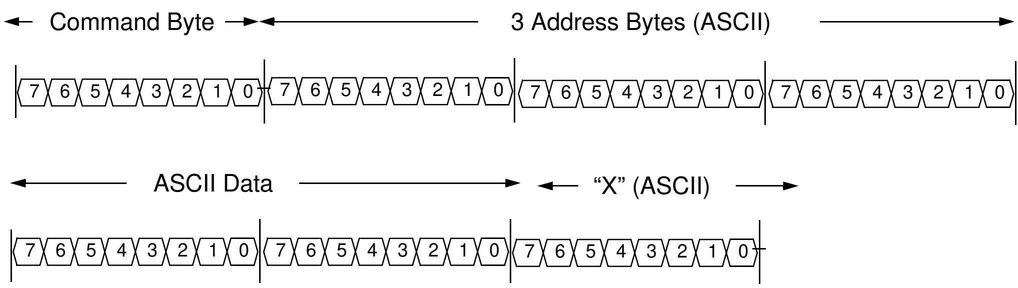


TABLE 4-1: WRITE COMMAND EXAMPLES

Description	Command ASCII	Command Hex
WRITE of 255d to PHA_W_OFF Register	“W 170 00 F F X”	57 31 37 30 30 30 46 46 58

FIGURE 4-1: *WRITE Command Protocol.*

4.1.1.5 “R” READ: READ STARTING AT SPECIFIED ADDRESS

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

Returns: 'R0300001020304050607080 90A0B0C0D0E0FX'

> **Note:** For 16 bytes, there are 32 ASCII characters returned or two characters per byte.

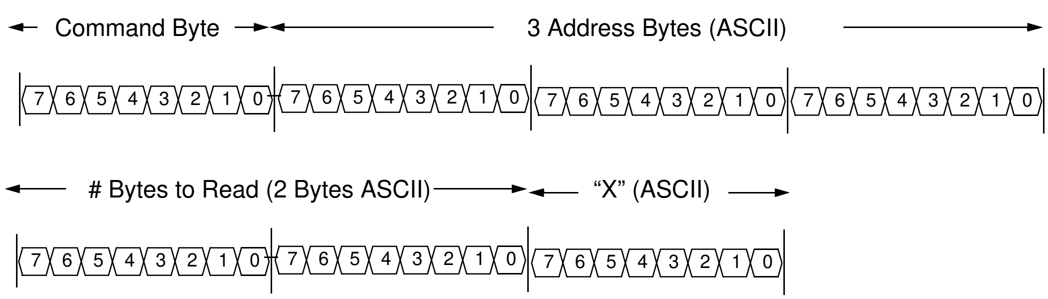


TABLE 4-2: READ COMMAND EXAMPLES

DESCRIPTION	COMMAND ASCII	COMMAND HEX
READ on ENERGY_W_L_RAW Register	“R 0D4 06 X”	52 00 44 34 30 36 58

FIGURE 4-2: *Read Command Protocol.*

Chapter 5. Meter Calibration

5.1 CALIBRATION OVERVIEW

The method to calculate the values for the calibration registers in **"Chapter 3. "PIC18F85J90 Calculation and Register Description"** are described in this chapter. These registers are used to remove offset, set gain and phase adjustments, and include (units)/LSB adjustments for the meter outputs. The calibration flow charts and equations presented in this section are all automated using Microchip's "Single Phase Energy Meter Calibration Software", downloadable from Microchip's energy metering web site. The following calibration routines are described in this chapter.

- Active Power Calibration
- RMS Current and Voltage Calibration
- Apparent Power Calibration

The method of calibrating these three separate signal flows can be combined into 4 different calibration configurations. These configurations consist of supplying specific voltages and currents at specific phase angles to the meter during calibration.

Depending on the accuracy and meter type, not all 4 calibration configurations are required to fully calibrate a meter. In some cases only a single point calibraton is required. The software allows individual configurations to be turned on or off when going through the calibration flow.

5.1.1 I_B, V_B, Meter Constant and Calibration Configurations

Calibration of the single phase energy meter involves up to four different test configurations.

For example, meter design example 5(10)A, $I_B = 5$, $I_{MAX} = 10A$.

The four different test configuraitons are listed here: :

1. **Configuration C1: Gain** - Basic voltage V_B and basic current I_B at a power factor of 1.
   For example, 220V and 5A.
2. **Configuration C2: Phase** - Basic voltage V_B and basic current I_B at a power factor of 0.5.
3. **Configuration C3: Offset** - Basic voltage V_B and 1/100 of I_B at a power factor of 1.
   For example, 220V and 50 mA.
4. **Configuration C4: Mid-range** - 1/10 of Basic voltage V_B and 1/10 of I_B at a power factor of 1.
   For example, 22V and 1A.

These calibration configurations are typically steps in a sequence. Almost always, configuration C1 is the most important and must be done first. The other configurations require values obtained from configuration C1, but are not dependent on values obtained from the other configurations. In other words, C1 is probably the first step, while the other configurations can be done in any order, and are optional depending on the meter type.

The meter constant is typically given in units of impulses per kilo-watt hour. As an example, the calibration output frequency of CF, METER_CONSTANT =
3200 imp/kWh or **6400 imp/kWh**.

5.2 ACTIVE POWER SIGNAL FLOW AND CALIBRATION

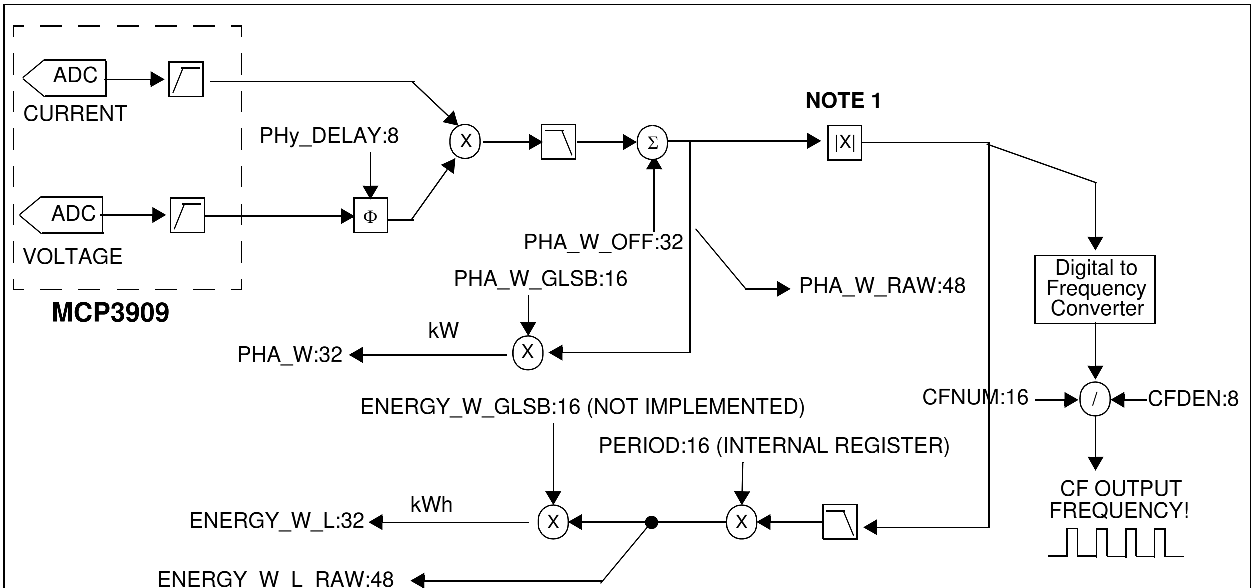
5.2.1 Active Power Calibration Overview and Signal Path

The active power signal flow leads to the CF output pulse frequency, which is proportional to the total active power being measured by the energy meter, the active energy registers, which are in units of kWh and can also be phase gated using the MODE1 register, and the active power output register (PHA_W).

Table 5-1 represents the registers being set during active power calibration.

TABLE 5-1: CALIBRATION REGISTERS GENERATED THROUGH THIS ROUTINE

Register Name	Equations	Configurations Needed
CFDEN	**Section 5.3.3**	C1 ONLY
CFNUM	**Section 5.3.3**	C1 ONLY
PHA_DELAY	**Section 5.3.5**	C1, C2
PHA_W_OFF	**Section 5.3.7**	C1, C3
PHA_W_GLSB	**Section 5.3.3**	C1 ONLY
ENERGY_W_GLSB	Not Implemented	C1 ONLY



Note 1: This absolute value is controlled by the MODE1 register. See **Section 3.4.1** for more information.

FIGURE 5-1: *Active Power Signal Path showing Output and Calibration Registers.*

5.3 RMS CURRENT, RMS VOLTAGE, APPARENT POWER SIGNAL FLOW AND CALIBRATION

5.3.1 RMS Current, RMS Voltage, and Apparent Power Overview and Signal Path

The RMS current and voltage outputs require a two point calibration reading at configurations C1 and C4. The automated USB software performs these calibrations suggested on the calibration values entered in the text boxes on the meter design window.

The following table represents the registers being set for RMS Current and Voltage calibration.

TABLE 5-2: RMS CURRENT, RMS VOLTAGE, AND APPARENT POWER CALIBRATION REGISTERS

Register	Equation	Configurations Needed
PHA_V_RMS_OFF	**Section 5.3.9**	C1, C4
PHA_I_RMS_OFF	**Section 5.3.9**	C1, C4
PHA_V_RMS_GLSB	**Section 5.3.9**	C1, C4
PHA_I_RMS_GLSB	**Section 5.3.9**	C1, C4
PHA_VA_GLSB	**Section 5.3.3**	C1 ONLY
ENERGY_VA_GLSB	Not Implemented	C1 ONLY

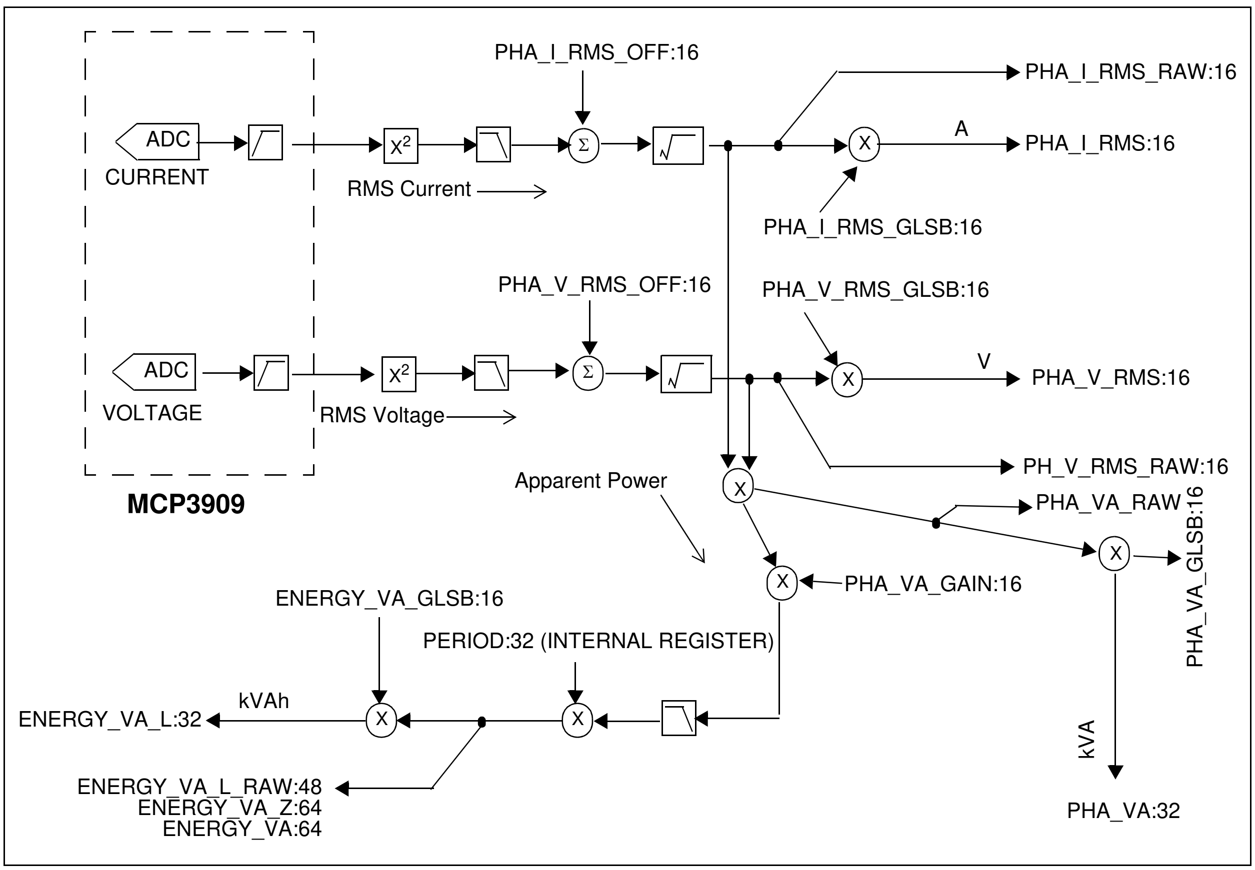


FIGURE 5-2: *RMS Current, Voltage, and Apparent Power Flow.*

5.3.2 Main Flow Chart for Calibration Configuration C1

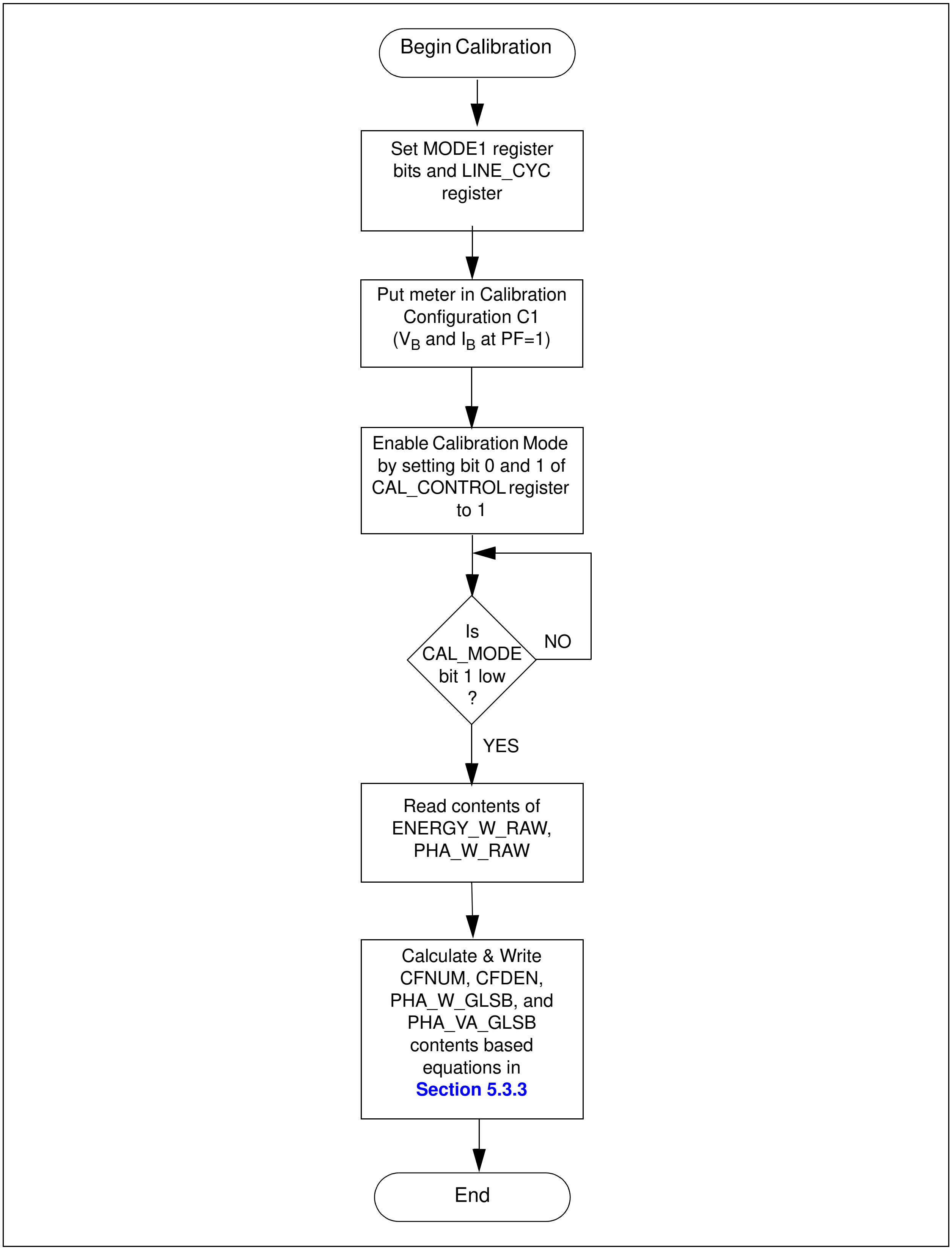


FIGURE 5-3: *Main Calibration Flow Chart.*

5.3.3 Equations for Configuration C1 Calibration

The following equations represent the proper method for calculating the calibration and correction factors after configuration C1. The PC calibration software handles these calculations automatically.

The following equations only apply when calibrating a standard phase.

The first four equations apply for calculating the proper output frequency of the CF output. See Figure 5-3 for meter input conditions.

EQUATION 5-1:

$$CF\_IMP\_S = \frac{Meter\ Constant}{3600} \bullet \frac{V_B I_B}{1000}$$

EQUATION 5-2:

$$LINE\_CYC\_NUM = 2^{LINE\_CYC}$$

EQUATION 5-3:

$$CFDEN = \frac{LOG\left[\frac{2^{32} \bullet CF\_IMP\_S}{Line\ Freq \bullet 128}\right]\left[\frac{LINE\_CYC\_NUM \bullet 256}{ENERGY\_W\_L\_RAW}\right]}{LOG(2)} + 1$$

Note: Convert to 8-bit signed integer for compatibility with PIC18F2520 register and firmware calculations.

EQUATION 5-4:

$$CFNUM = \frac{\left(\frac{2^{32} \bullet CF\_IMP\_S}{Line\ Freq \bullet 128}\right)}{\left(\frac{ENERGY\_W\_L\_RAW}{LINE\_CYC\_NUM \bullet 256}\right)} \bullet 2^{CFDEN} \bullet 32768$$

Note: Convert to 16-bit signed integer for compatibility with PIC18F2520 register and firmware calculations.

The gain matching registers for the standard phase need to be set to the following values when calibrating a standard phase:

EQUATION 5-5:

$$PHA\_W\_GAIN = 16,384$$

The following equations apply for calculating the proper GLSB registers when calibrating both a standard phase, and a non-standard phase. See flow chart for meter input conditions.

EQUATION 5-6:

$$PLSB = \text{Value from Table 5-4 based on } V_B \text{ and } I_{MAX} \text{ values}$$

EQUATION 5-7:

$$PHA\_W\_GLSB = \frac{\left(\frac{V_B \bullet I_B}{PLSB}\right)}{\left(\frac{PHA\_W\_RAW}{64 \bullet LINE\_CYC\_NUM}\right)} \bullet 32768$$

Note:	Convert to 16-bit signed integer for compatibility with PIC18F85J90 register and firmware calculations.

The calculation for PHA_VA_GLSB is identical except that it uses the PHA_VA_RAW register instead of PHA_W_RAW:

EQUATION 5-8:

$$PHA\_VA\_GLSB = \frac{\left(\frac{V_B \bullet I_B}{PLSB}\right)}{\left(\frac{PHA\_VA\_RAW}{64 \bullet LINE\_CYC\_NUM}\right)} \bullet 32768$$

Note:	Convert to 16-bit signed integer for compatibility with PIC18F85J90 register and firmware calculations.

5.3.4 Configuration C2 Flow Chart - Phase Delay

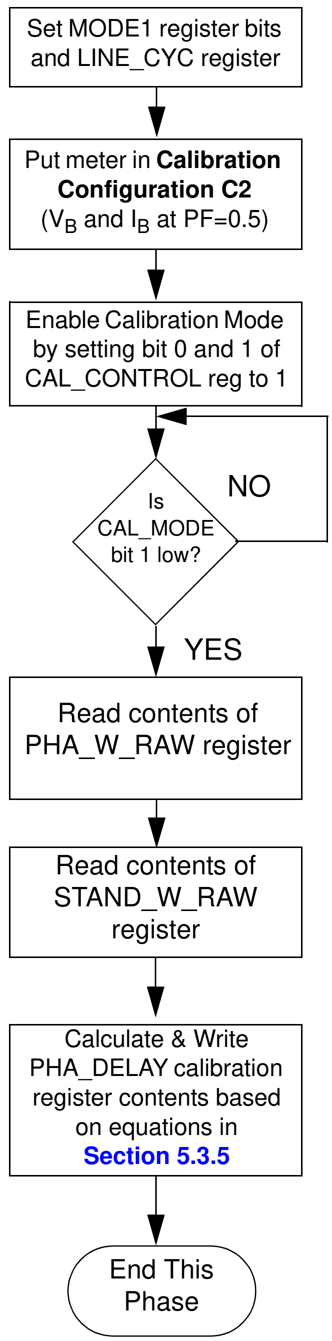


FIGURE 5-4: *Configuration C2 Flow Chart. - Phase Delay.*

5.3.5 Configuration C2 Equations - Phase Delay

For active power the following equations apply for calculating the time shift delay for a given phase.

EQUATION 5-9:

$$W1 = PHA\_W\_RAW\ @\ PF = 1,\ Configuration\ C1$$

EQUATION 5-10:

$$W2 = PHA\_W\_RAW\ @\ PF = 0.5,\ Configuration\ C2$$

EQUATION 5-11:

$$LINE\_CYC\_NUM\_1 = LINE\_CYC\_NUM\ @\ PF = 1,\ Configuration\ C1$$

EQUATION 5-12:

$$LINE\_CYC\_NUM\_2 = LINE\_CYC\_NUM\ @\ PF = 0.5,\ Configuration\ C2$$

EQUATION 5-13:

$$PHA\_DELAY = \frac{\left[COS^{-1}\left(\frac{W2 / LINE\_CYC\_NUM2}{W1 / LINE\_CYC\_NUM1}\right) \times \frac{180}{PI}\right] - 60}{2.8125} \bullet 128$$

Note 1: Convert to 8-bit signed integer for compatibility with PIC18F2520 register and firmware calculations.

2: Since 60 degrees (default) is being subtracted from the measured quantity, the current should lag the voltage under configuration C2.

5.3.6 Configuration C3 Flow Chart - Offset

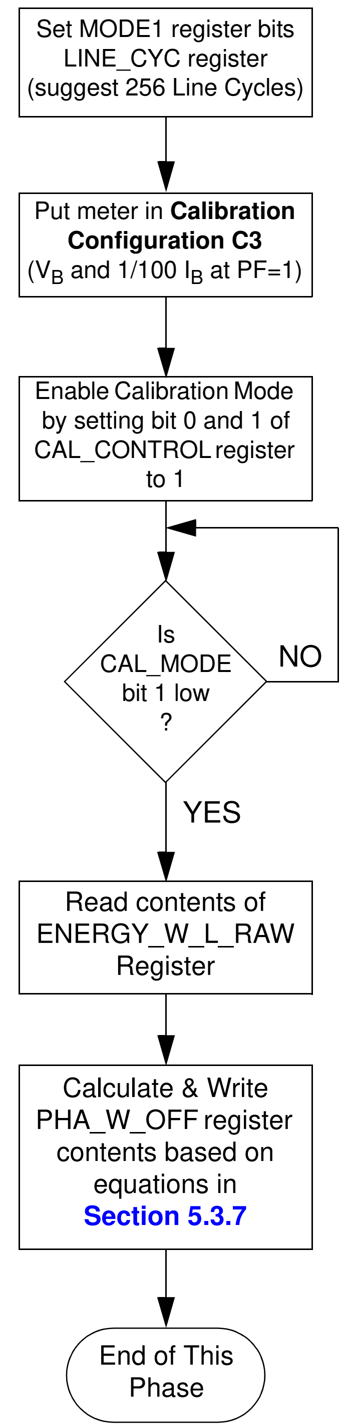


FIGURE 5-5: *Configuration C3 Flow Chart - Active Power Offset .*

5.3.7 Configuration C3 Equations - P_A Offset

For active power offset, the following equations apply for a given phase. W1 corresponds to the PHA_W_RAW register obtained during configuration C1. LINE_CYC_W1 corresponds to the LINE_CYC during this measurement.

W2 corresponds to the PHA_W_RAW register obtained during configuration C3. LINE_CYC_W2 is the LINE_CYC during this measurement.

EQUATION 5-14:

$$W1 = PHA\_W\_RAW \mathbin{@} I_{B,} \text{ Configuration } C1$$

EQUATION 5-15:

$$W2 = PHA\_W\_RAW \mathbin{@} 1/100\ I_B,\ \text{Configuration } C3$$

EQUATION 5-16:

$$LINE\_CYC\_NUM\_1 = LINE\_CYC\_NUM \text{ in Configuration } C1$$

EQUATION 5-17:

$$LINE\_CYC\_NUM\_2 = LINE\_CYC\_NUM \text{ in Configuration } C3$$

EQUATION 5-18:

$$PHA\_W\_OFF = \left[\frac{W1/100}{LINE\_CYC\_NUM\_W1}\right] - \left[\frac{W2}{LINE\_CYC\_NUM\_W2}\right]$$

Note: Convert to 32-bit signed integer for compatibility with PIC18F85J90 register and firmware calculations

The PHA_W_OFF registers hold a signed 32-bit value. However, the math in the microcontroller could overflow for some values near the limits. Limit check the resulting value to make sure the value is between -2,130,706,432 and 2,130,706,431 (inclusive). Values less than -2,130,706,432 should be set to -2,130,706,432 while values greater than 2,130,706,431 should be set to 2,130,706,431. If the value is limited, the user should be aware that the meter could not completely correct the offset.

It is expected that this value will always be negative. If the value is positive, it may indicate that the user has not provided a large enough number of line cycles for configuration C4 (where the number of line cycles should be set to a larger value such as 64 or 128). This may also be true if offset does not contribute a large enough percentage to W2 (for example, 10% to 50% or more).

5.3.8 Configuration C4 Flow Chart - Mid-Range

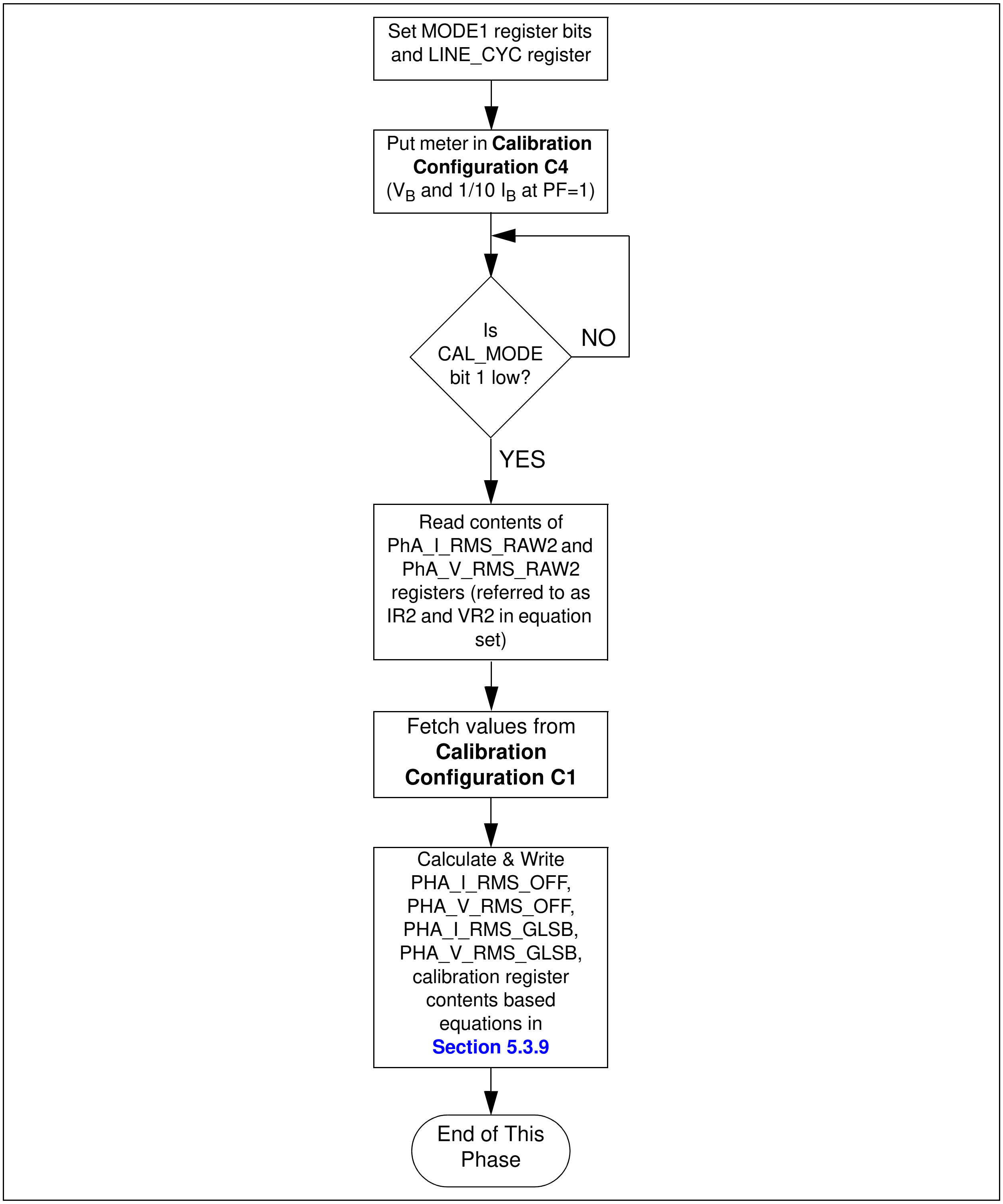


FIGURE 5-6: *Flow Chart for RMS Calibration.*

5.3.9 Equations for RMS Calibration

The following equations represent the proper method for calculating the calibration and correction factors for the RMS current and RMS voltage. The PC calibration software handles these calculations automatically.

Typically, the V_{MIN} and I_{MIN} voltages and currents will be 1/10 of the V_B and I_B values.

For RMS Offset, the following equations apply:

EQUATION 5-19:

$$IR1 = PHA\_I\_RMS\_RAW2 \text{ @ } I_B, \text{ Configuration } C1$$

EQUATION 5-20:

$$VR1 = PHA\_V\_RMS\_RAW2 \text{ @ } I_B, \text{ Configuration } C1$$

EQUATION 5-21:

$$IR2 = PHA\_I\_RMS\_RAW2 \text{ @ } I_B, \text{ Configuration } C4$$

EQUATION 5-22:

$$VR2 = PHA\_V\_RMS\_RAW2 \text{ @ } I_B, \text{ Configuration } C4$$

EQUATION 5-23:

$$I_G = \frac{I_B \text{ @ } C1}{I_B \text{ @ } C4}$$

EQUATION 5-24:

$$V_G = \frac{V_B \text{ @ } C1}{V_B \text{ @ } C4}$$

EQUATION 5-25:

$$PHA\_I\_RMS\_OFF = \frac{\left(\frac{IR1 - IR2}{IG \bullet IG - 1}\right) - IR_2}{65536}$$

Note:	Convert to 16-bit signed integer for compatibility with PIC18F85J90 register and firmware calculations

EQUATION 5-26:

$$PHA\_V\_RMS\_OFF = \frac{\left(\frac{VR1 - VR2}{VG \bullet VG - 1}\right) - VR_2}{65536}$$

> **Note:** Convert to 16-bit signed integer for compatibility with PIC18F85J90 register and firmware calculations

For RMS LSB correction, the following equations apply:

EQUATION 5-27:

ILSB = Value from Table 5-3 *based on* I_{MAX} *value*

EQUATION 5-28:

VLSB = Value from Table 5-5 *based on* V_B *value*

EQUATION 5-29:

$$PHA\_I\_RMS\_GLSB = \frac{\left(\frac{I_B}{ILSB}\right)}{\sqrt{\frac{IR_1}{65536} + PHA\_I\_RMS\_OFF}} \bullet 32768$$

> **Note:** Convert to 16-bit signed integer for compatibility with PIC18F85J90 register and firmware calculations

EQUATION 5-30:

$$PHA\_V\_RMS\_GLSB = \frac{\left(\frac{V_B}{VLSB}\right)}{\sqrt{\frac{VR_1}{65536} + PHA\_V\_RMS\_OFF}} \bullet 32768$$

> **Note:** Convert to 16-bit signed integer for compatibility with PIC18F85J90 register and firmware calculations

TABLE 5-3: CURRENT RESOLUTION TABLE

Maximum Current Less than or Equal To (A)	LSB Resolution (A)
8.1	0.001
81	0.01
810	0.1
8,100	1

TABLE 5-4: POWER RESOLUTION TABLE

Maximum Wattage Less than or Equal To (W - I_{MAX} times VCAL)	LSB Resolution (mW)
125	0.001
1,250	0.01
12,500	0.1
125,000	1
1,250,000	10
12,500,000	100

TABLE 5-5: VOLTAGE RESOLUTION TABLE

Maximum Voltage Less than or Equal To (V)	LSB Resolution (V)
ALL	0.1

Note that the decimal point location in the reading frame is updated whenever the V_{CAL}, I_{CAL}, or I_{MAX} values are changed.

NOTES:

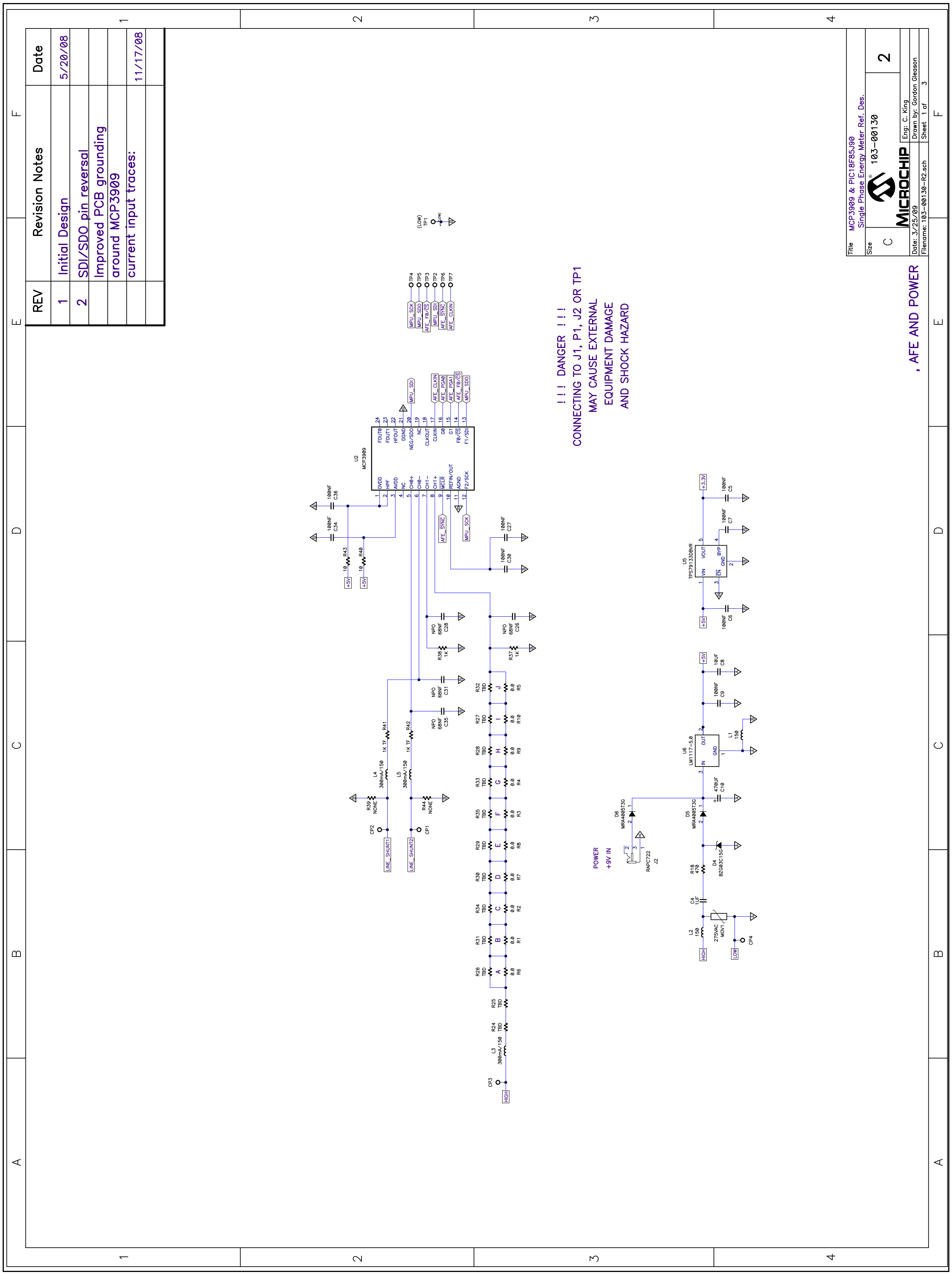
Appendix A. Schematic and Layouts

A.1 INTRODUCTION

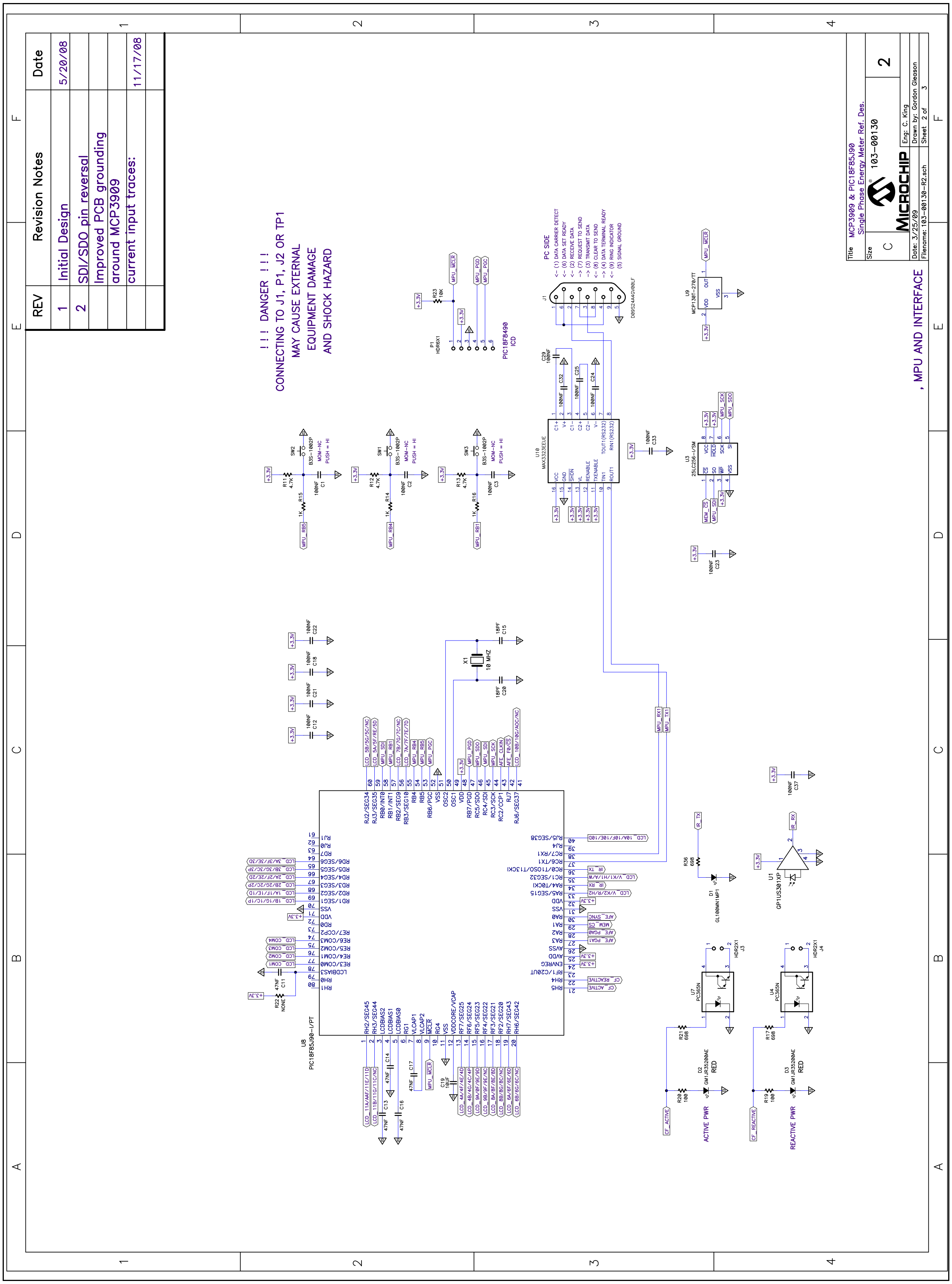
This appendix contains the following schematics and layouts of the MCP3909/PIC18F85J90 Single Phase Energy Meter Reference Design:

- Board Schematic - Page 1
- Board Schematic - Page 2
- Board Schematic - Page 3
- Board - Top Layer and Silk-screen
- Board - Top Copper
- Board - Bottom Layer and Silk-screen
- Board - Bottom Copper

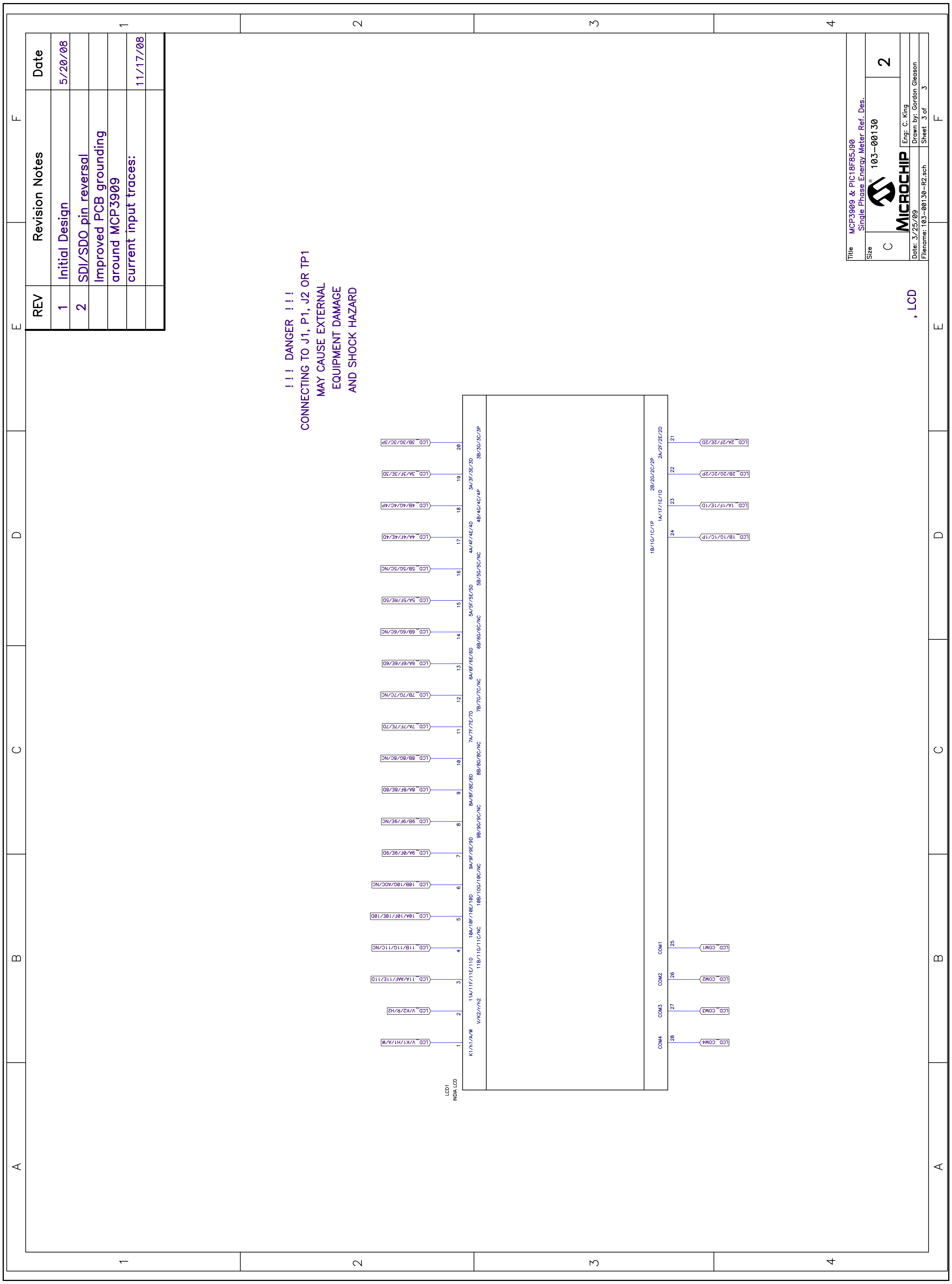
A.2 BOARD SCHEMATIC - PAGE 1



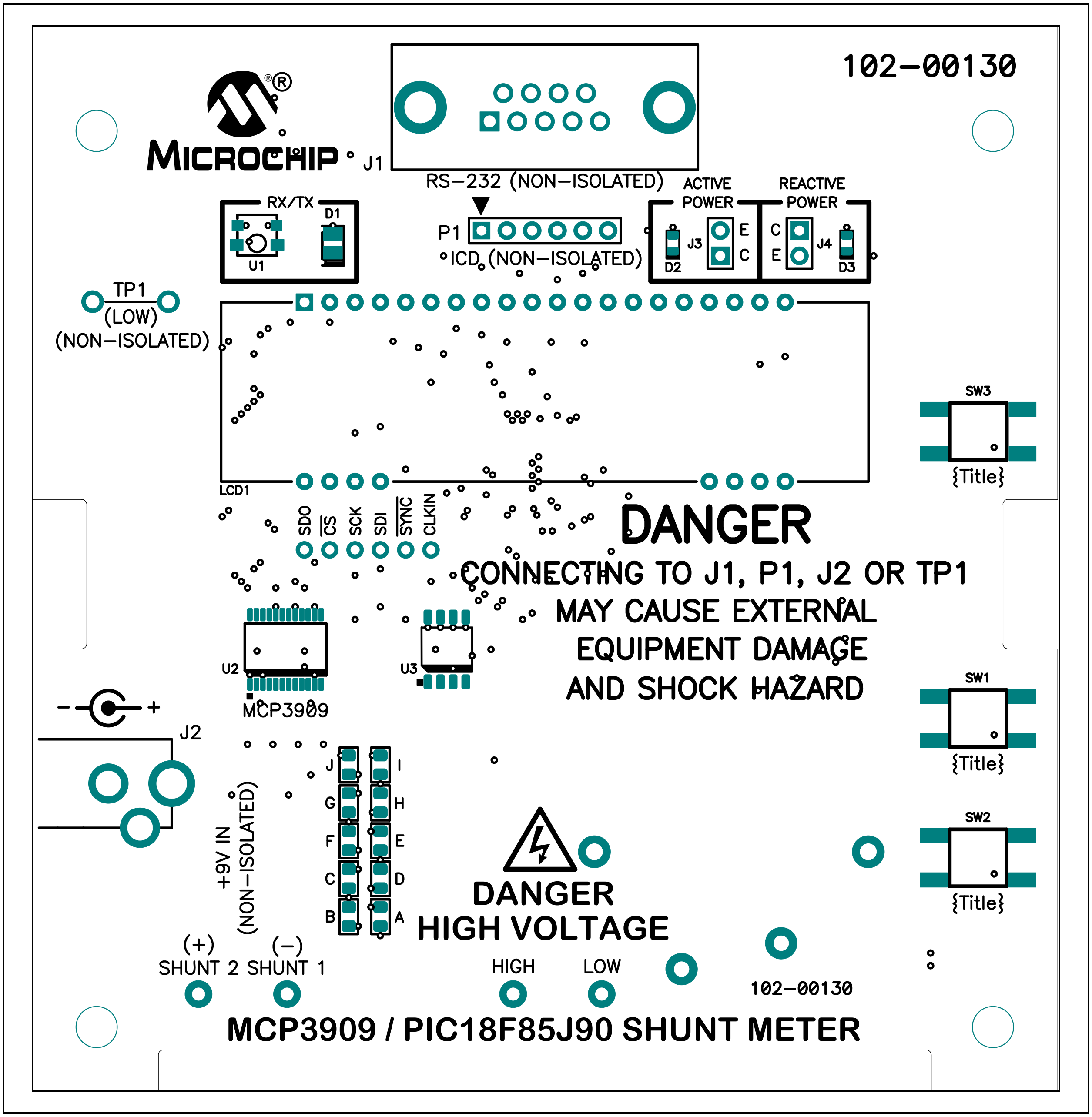
A.3 BOARD SCHEMATIC - PAGE 2



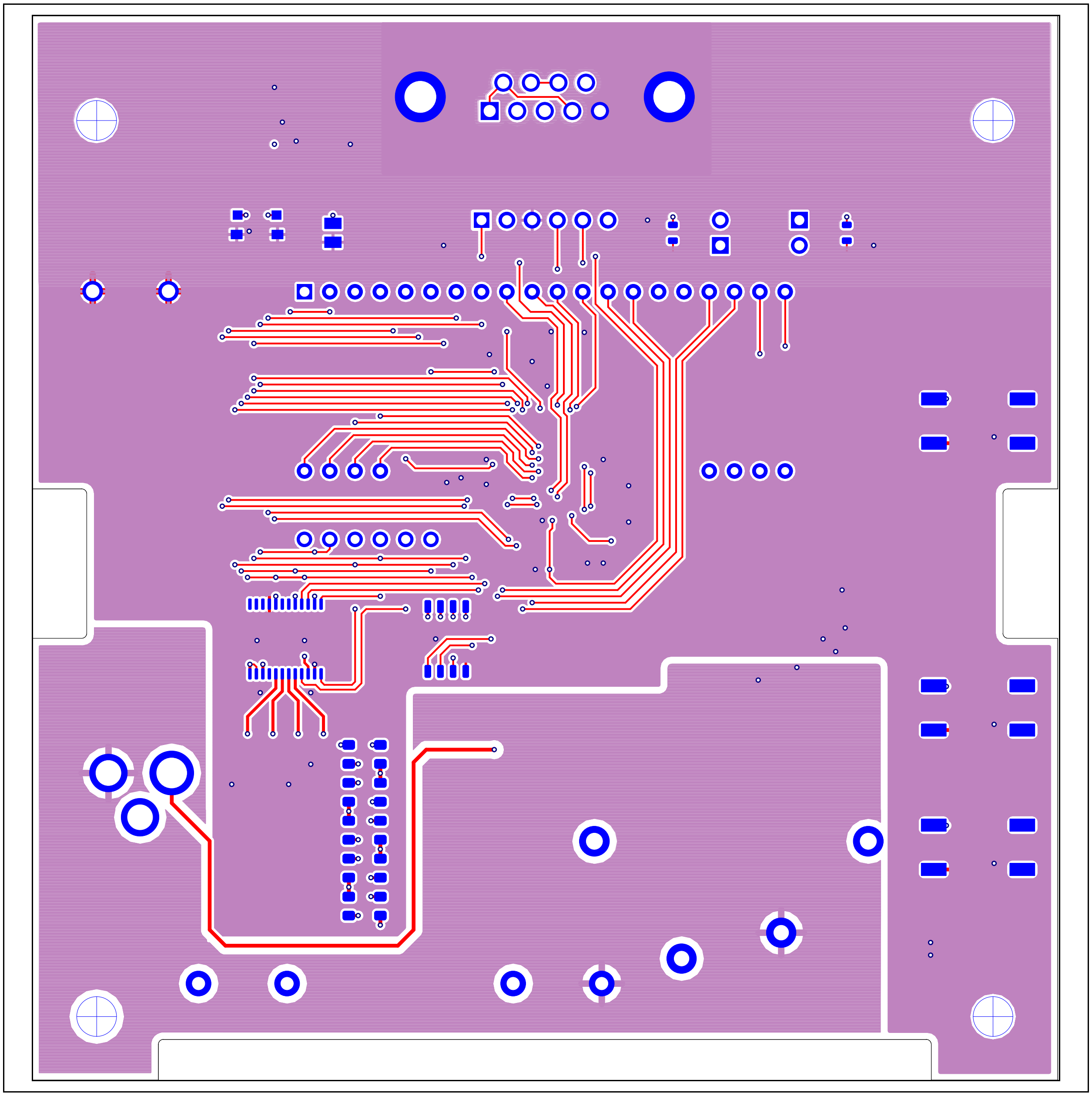
A.4 BOARD SCHEMATIC - PAGE 3



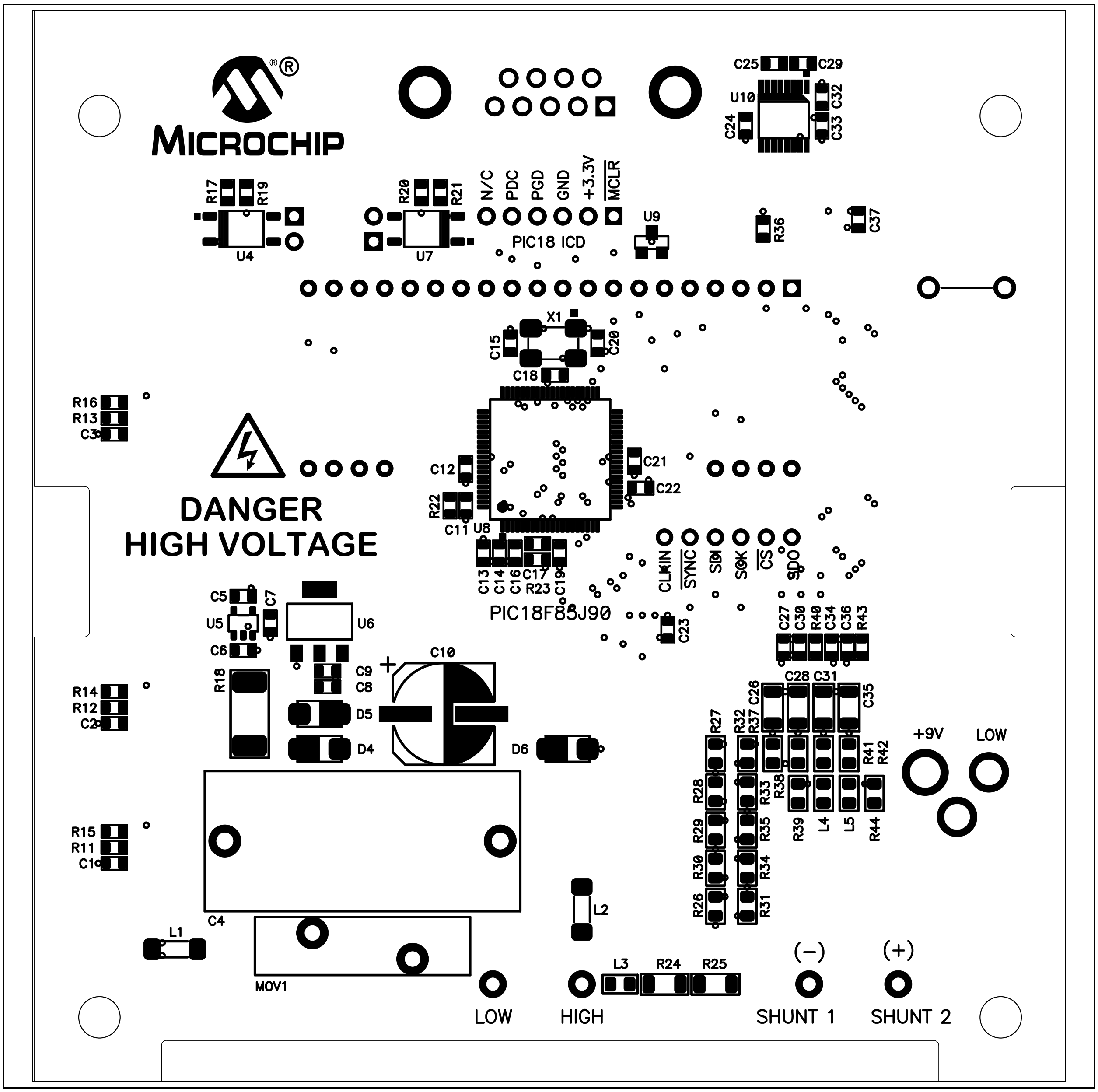
A.5 BOARD - TOP LAYER AND SILK-SCREEN



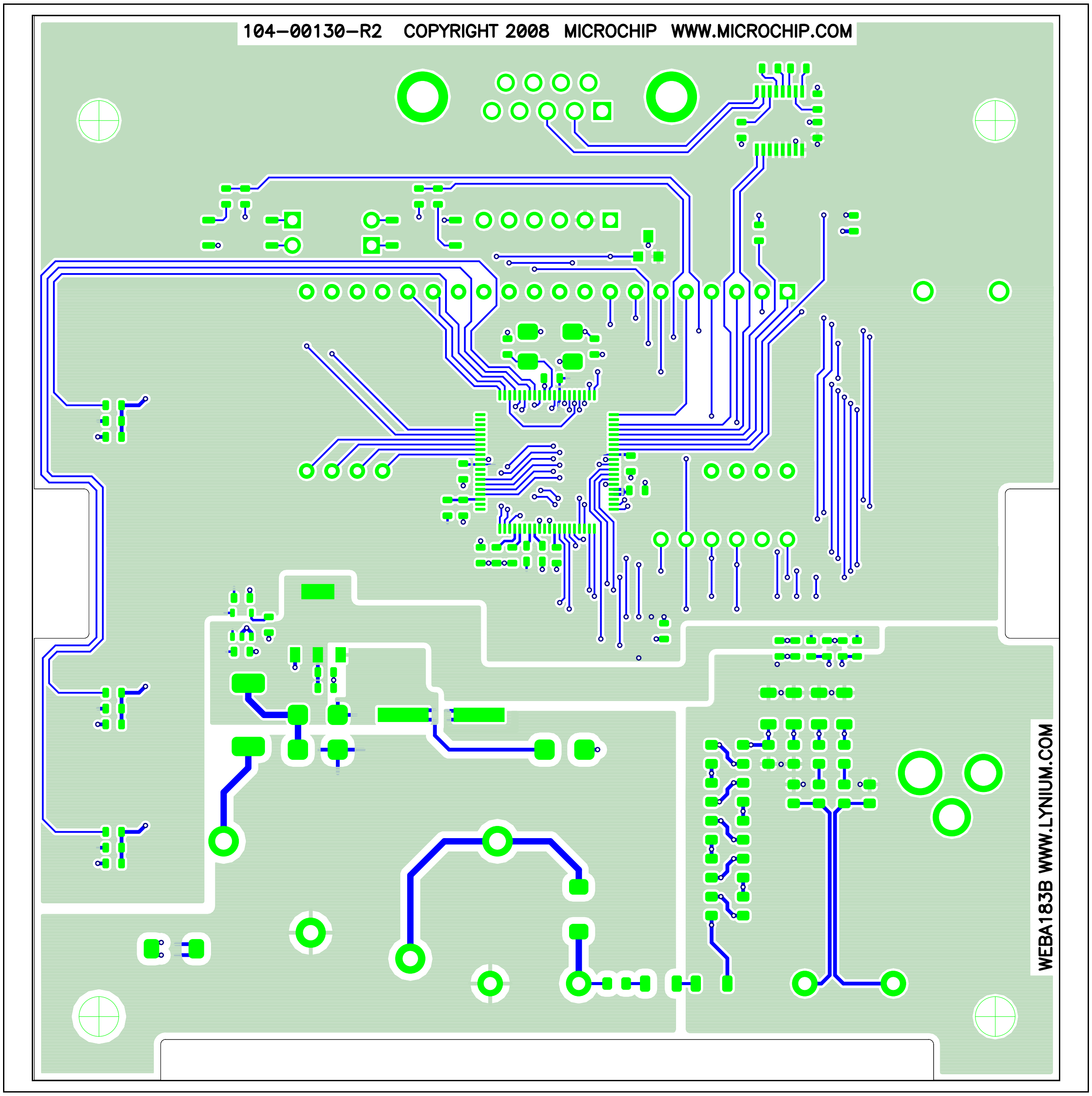
A.6 BOARD - TOP COPPER



A.7 BOARD - BOTTOM LAYER AND SILK-SCREEN



A.8 BOARD - BOTTOM COPPER



Appendix B. Bill of Materials

TABLE B-1: BILL OF MATERIALS (BOM)

Qty	Reference	Description	Manufacturer	Part Number
22	C1, C2, C3, C5, C6, C7, C9, C12, C18, C21, C22, C23, C24, C25, C27, C29, C30, C32, C33, C34, C36, C37	CAP CER .1UF 25V 10% X7R 0603	Murata Electronics®	GRM188R71E104KA01D
1	C4	CAP 1.0UF 630V METAL POLYPRO	EPCOS	B32614A6105J008
2	C8, C19	CAP CER 10UF 6.3V X5R 0603	Murata Electronics	GRM188R60J106ME47D
1	C10	CAP 470UF 25V ELECT FC SMD	Panasonic® - ECG	EEE-FC1E471P
5	C11, C13, C14 C16, C17	CAP CER 47000PF 25V 10% X7R 0603	Murata Electronics	GRM188R71E473KA01D
2	C15, C20	CAP CER 18PF 50V 5% C0G 0603	Murata Electronics	GRM1885C1H180JA01D
4	C26, C28, C31, C35	CAP CER 6800PF 50V 5% C0G 1206	Murata Electronics	GRM3195C1H682JA01D
1	D1	IRED 940NM TOP MNT SMD	Sharp® Microelectronics	GL100MN0MP
2	D2, D3	LED 1.6X0.8MM 625NM RED CLR SMD	Kingbright Corporation	APT1608EC
1	D4	DIODE ZENER 600W 15V 40A SMA	ON Semiconductor®	BZG03C15G
2	D5, D6	DIODE STD REC 1A 600V SMA	ON Semiconductor	MRA4005T3G
2	L1, L2	Chip Ferrite Beads / EMI Filters 150ohms 100MHz .3A Monolithic 1806 SMD	Steward	LI1806C151R-10
3	L3, L4, L5	Chip Ferrite Beads / EMI Filters 150ohms 100MHz .8A Monolithic 0805 SMD	Steward	LI0805H151R-10
1	LCD	LCD Glass size 65.00 x 18.00	Xiamen Ocular Optics Co., Ltd.	DP076P
1	J1	CONN DSUB RCPT 9POS STR PCB SLD	FCI	D09S24A4GV00LF
1	J2	CONN POWERJACK MINI R/A T/H	Switchcraft®	RAPC722X
2	J3, J4	DO NOT INSTALL	—	—
1	MOV1	VARISTOR 275V RMS 20MM RADIAL	EPCOS	S20K275E2
1	P1	6 X 1 Header 2.54mm on center 6 mm/2.5mm	Samtec	TSW-106-07-G-S
1	PCB	RoHS Compliant Bare PCB, MCP3909/PIC18F85J90 Single Phase Energy Meter Reference Design	Microchip Technology Inc.	104-000130
10	R1-R10	RES 0.0 OHM 1/8W 5% 0805 SMD	Rohm Co., Ltd	MCR10EZHJ000
3	R11, R12, R13	RES 4.70K OHM 1/10W 1% 0603 SMD	Rohm Co., Ltd	MCR03EZPFX4701
3	R14, R15, R16	RES 1.00K OHM 1/10W 1% 0603 SMD	Rohm Co., Ltd	MCR03EZPFX1001
3	R17, R21, R36	RES 698 OHM 1/10W 1% 0603 SMD	Rohm Co., Ltd	MCR03EZPFX6980
1	R18	RES 470 OHM 1W 5% 2512 SMD	Panasonic - ECG	ERJ-1TYJ471U
2	R19, R20	RES 100 OHM 1/10W 1% 0603 SMD	Rohm Co., Ltd	MCR03EZPFX1000
1	R22	DO NOT INSTALL	—	—
1	R23	RES 10.0K OHM 1/10W 1% 0603 SMD	Rohm Co., Ltd	MCR03EZPFX1002

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	R24, R25	1206 Precision Thin Film Chip Resistors 1/4watt 332Kohms .1% 25ppm	Vishay® Intertechnology Inc.	TNPW1206332KBETY
2	R37, R38	RES 1.00K OHM 1/8W 1% 0805 SMD	Rohm Co., Ltd	MCR10EZHF1001
2	R40, R43	RES 10.0 OHM 1/10W 1% 0603 SMD	Rohm Co., Ltd	MCR03EZPFX10R0
2	R41, R42	RES 1.0K OHM .1% 1/4W 0805 SMD	Susumu Co Ltd	RGH2012-2E-P-102-B
3	SW1, SW2, SW3	SWITCH TACT 6MM 230GF H=4.3MM	Omron Electronics	B3S-1002P
1	TP1	Wire Test Point 0.3" Length	Component Corporation®	PJ-202-30
1	U1	Sensors 3V 38 kHz Surface Mount	Sharp Microelectronics	GP1US301XP
1	U2	Energy Metering IC with SPI Interface and Active Power Pulse	Microchip Technology Inc.	MCP3909T-I/SS
1	U3	SPI Serial EEPROM Family	Microchip Technology Inc.	25LC256-I/SN
2	U4, U7	PHOTOCOUPLER DARL OUT 4-SMD	Sharp Microelectronics	PC365NJ0000F
1	U5	n IC 3.3V 100MA LDO REG SOT-23-5	Texas Instruments Inc.	TPS79133DBVR
1	U6	IC REG LDO 800MA 5.0V SOT-223	National Semiconductor	LM1117MP-5.0/NOPB
1	U8	PIC18F Microcontroller with 32K bytes of Flash, 2048 bytes of RAM	Microchip Technology inc.	PIC18F85J90-I/PT
1	U9	MCP130 is a voltage supervisory device	Microchip Technology Inc.	MCP130T-270I/TT
1	U10	±15kV ESD-Protected, RS-232 Transceivers	Maxim	MAX3323EEUE+
1	X1	CRYSTAL 10.0000MHZ 10PF SMD	Abracon™ Corporation	ABM3B-10.000MHZ-10-1-U-T

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.

NOTES:

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