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**MCP3901 and PIC18F65J90  
Energy Meter Reference Design  
User's Guide**

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# **MCP3901 and PIC18F65J90 Energy Meter Reference Design**

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# MCP3901 AND PIC18F65J90 ENERGY METER REFERENCE DESIGN

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## Preface

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### 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](http://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 “DSXXXXA”, where “XXXX” 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 MCP3901 and PIC18F65J90 Energy Meter Reference Design User’s Guide. Items discussed in this chapter include:

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

# MCP3901 and PIC18F65J90 Energy Meter Reference Design

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## DOCUMENT LAYOUT

This document describes how to use the MCP3901 and PIC18F65J90 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 MCP3901 and PIC18F65J90 Energy Meter Reference Design including a Getting Started section that describes wiring the line and load connections.
- **Chapter 2. “Hardware”** – Includes details on the function blocks of the meter including the analog front end design, phase lock loop circuitry, 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, and apparent power. This section also includes the calibration register’s detail.
- **Chapter 4. “Meter Protocol and Timings”** – This chapter describes the protocol used for accessing the registers, including commands that are used to interface to the 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 MCP3901 and PIC18F65J90 Energy Meter Reference Design.



## CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

### DOCUMENTATION CONVENTIONS

Description	Represents	Examples
<b>Arial font:</b>		
Italic characters	Referenced books	<i>MPLAB<sup>®</sup> IDE User's Guide</i>
	Emphasized text	...is the <i>only</i> 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><i>File&gt;Save</i></u>
Bold characters	A dialog button	Click <b>OK</b>
	A tab	Click the <b>Power</b> 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>
<b>Courier New font:</b>		
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	<i>file.o</i> , where <i>file</i> can be any valid filename
Square brackets [ ]	Optional arguments	mcc18 [options] <i>file</i> [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) { ... }

# MCP3901 and PIC18F65J90 Energy Meter Reference Design

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## RECOMMENDED READING

This user's guide describes how to use the MCP3901 and PIC18F65J90 Energy Meter Reference Design. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources.

### **MCP3901 Data Sheet – “Two Channel Analog Front End” (DS22192)**

This data sheet provides detailed information regarding the MCP3901 device.

### **AN994 – “IEC Compliant Active-Energy Meter Design Using the MCP3905A/06A” (DS00994)**

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

## THE MICROCHIP WEB SITE

Microchip provides online support via our web site at [www.microchip.com](http://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
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- 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 (January 2012)**

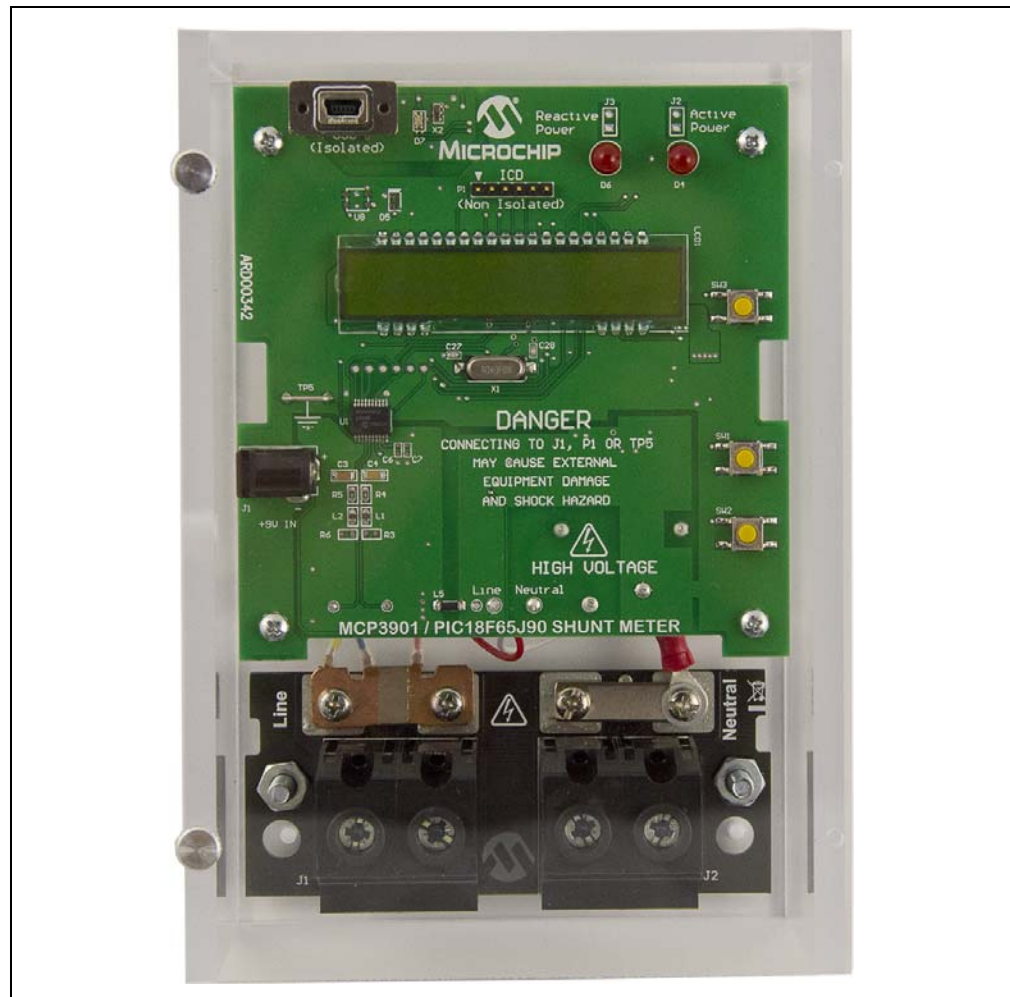
- Initial Release of this Document.

## Chapter 1. Product Overview

### 1.1 INTRODUCTION

The MCP3901 and PIC18F65J90 Energy Meter Reference Design is a fully functional IEC Class 0.5 compliant single-phase meter. This low-cost design does not use any transformers and requires few external components. The PIC18F65J90 directly drives the LCD, and includes both an isolated USB connection for meter calibration and access to the device power calculations. The system calculates active energy, active power, RMS current, RMS voltage, reactive energy, reactive power, apparent power and other typical power quantities.

The Microchip Energy Meter 1-Phase Software is used to calibrate and monitor the system, and can be used to create custom calibration setups. For some accuracy requirements, only a single point calibration may be needed. The energy meter software offers an automated step-by-step calibration process that can be used to quickly calibrate energy meters.



**FIGURE 1-1:** MCP3901 and PIC18F65J90 Single-Phase Energy Meter.

# MCP3901 and PIC18F65J90 Energy Meter Reference Design

## 1.2 WHAT THE MCP3901 AND PIC18F65J90 ENERGY METER REFERENCE DESIGN KIT INCLUDES

This MCP3901 and PIC18F65J90 Energy Meter Reference Design kit includes:

- MCP3901 and PIC18F65J90 Energy Meter Reference Design User's Guide
- Important Information Sheet

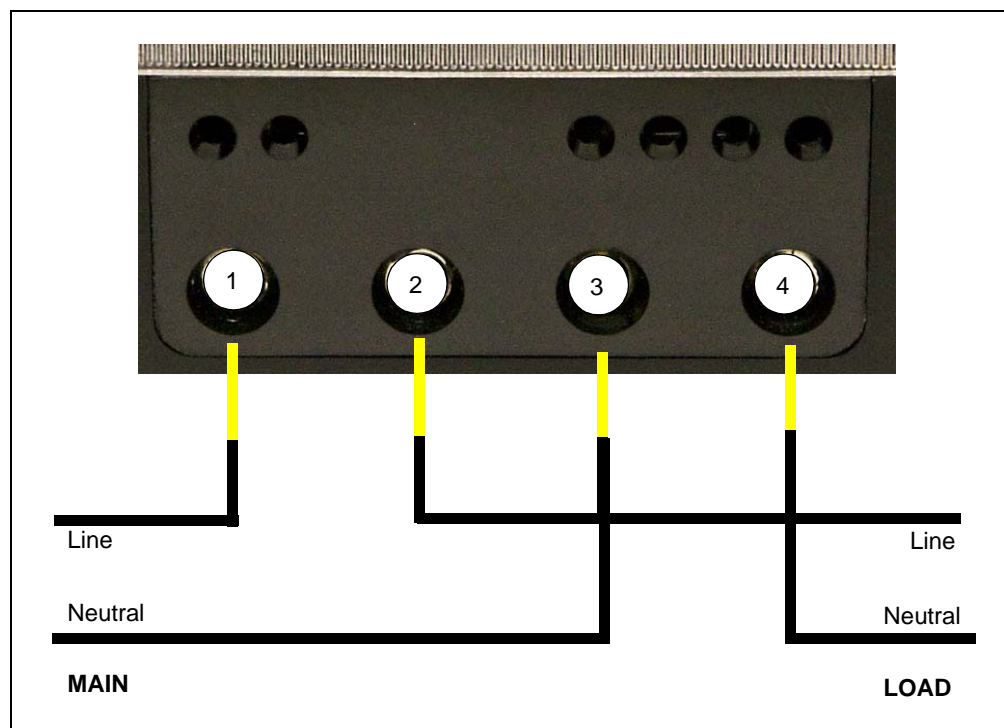
## 1.3 GETTING STARTED

To describe how to use the MCP3901 and PIC18F65J90 Energy Meter Reference Design, the following example is given using a two-wire 1-phase, 220 VAC line voltage and connections using 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 60A.

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

### 1.3.1 Step 1: Wiring Connections

Figure 1-2 identifies the line and load connections of the MCP3901 and PIC18F65J90 Energy Meter Reference Design.



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

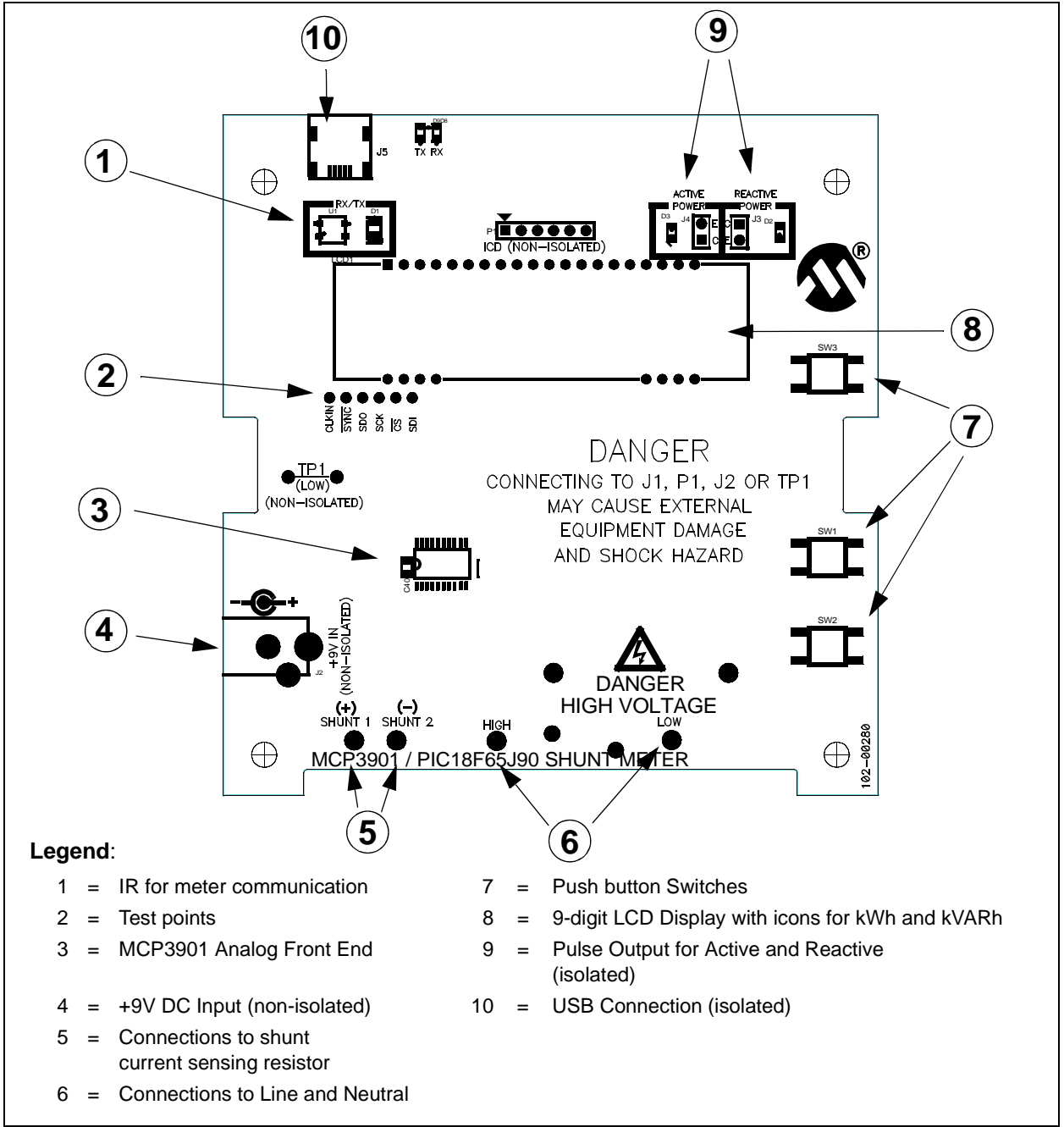
### 1.3.2 Step 2: Turn On Line/Load Power to the Meter (Power the Meter)

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

**Chapter 2. Hardware**

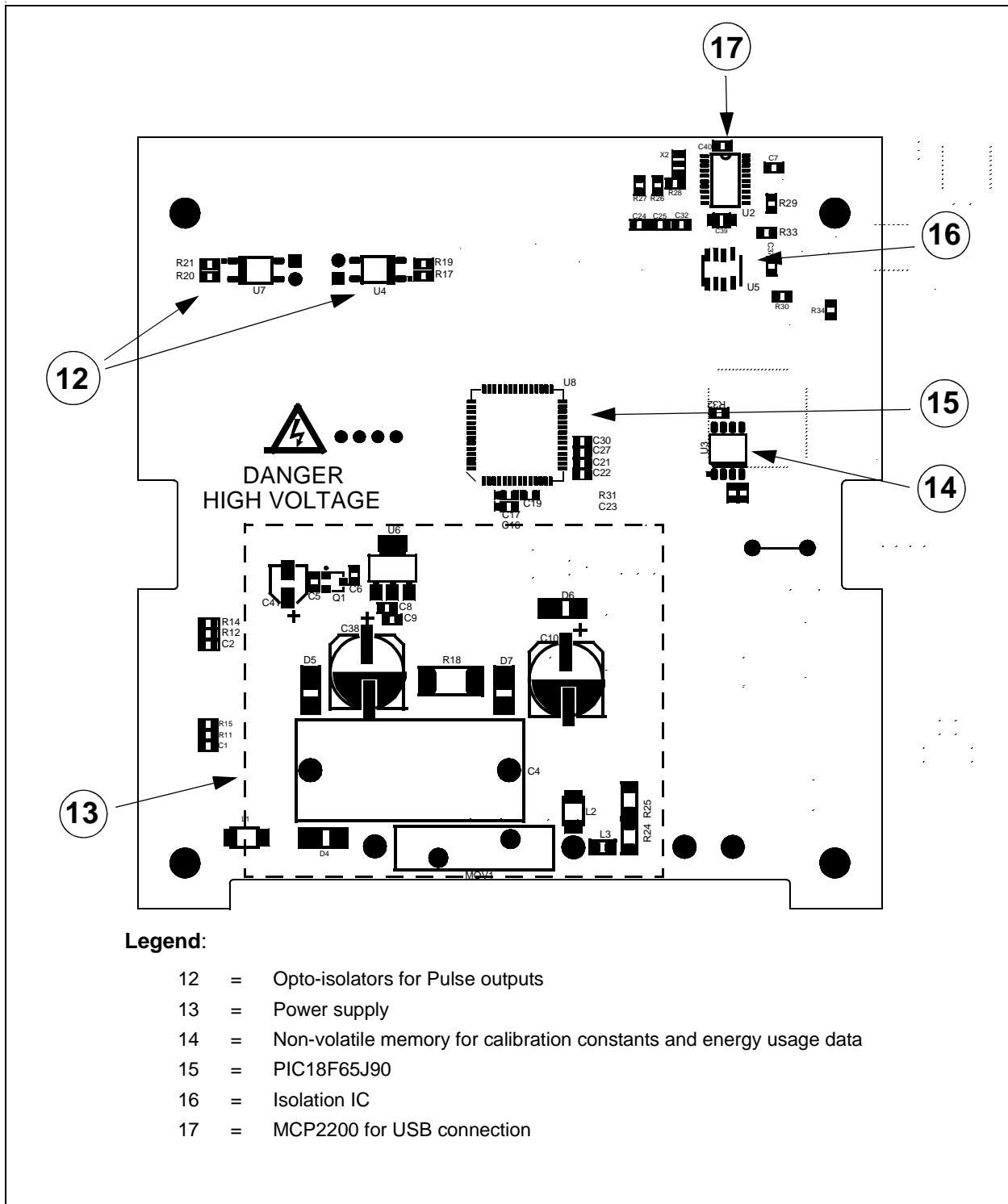
**2.1 OVERVIEW**

Figures 2-1 and 2-2 show the MCP3901 and PIC18F65J90 and Energy Meter Reference Design:

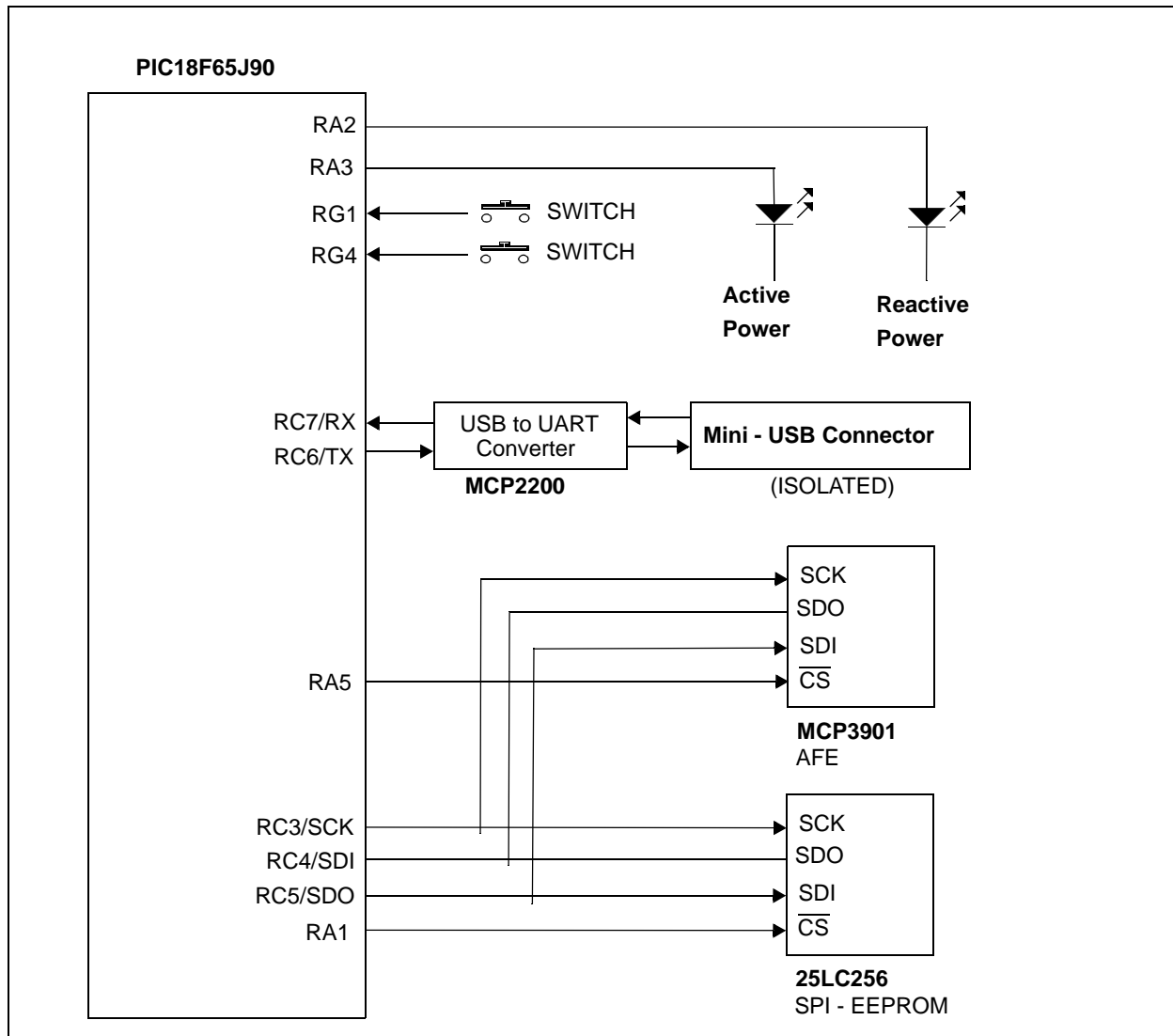


**FIGURE 2-1:** Top View – Hardware Components.

# MCP3901 and PIC18F65J90 Energy Meter Reference Design



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



**FIGURE 2-3:** Digital Connections.

# MCP3901 and PIC18F65J90 Energy Meter Reference Design

## 2.2 INPUT AND ANALOG FRONT END

The MCP3901 and PIC18F65J90 and Energy Meter Reference Design 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 connections that are made from the PCB to the meter casing. They are labeled LINE, NEUTRAL, SHUNT1, and SHUNT2. The shunt sits on the high or line side of a two-wire system and the meter employs 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 be twisted together, and also kept away from the SHUNT1 and SHUNT2 wires if possible.

The neutral side of the two-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<sub>RMS</sub>, the channel 1 input signal size will be 490 mV<sub>PEAK</sub>.

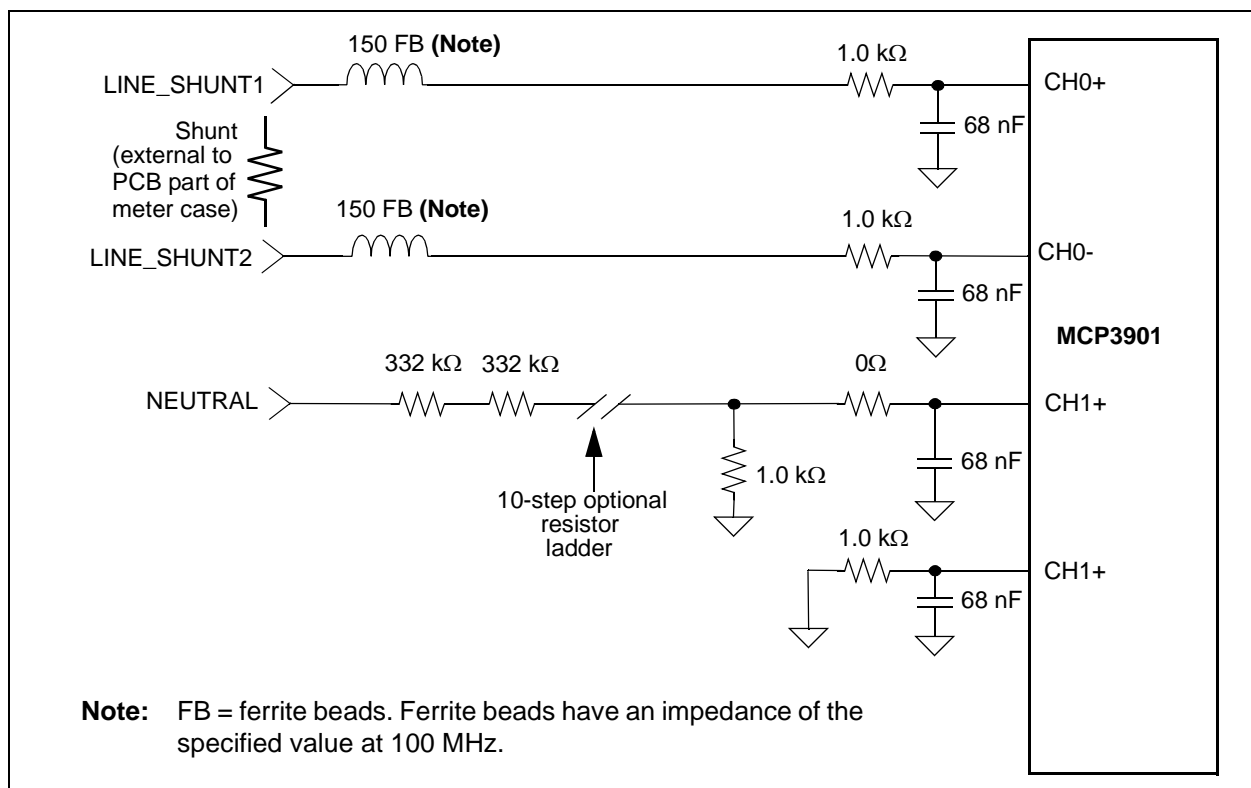


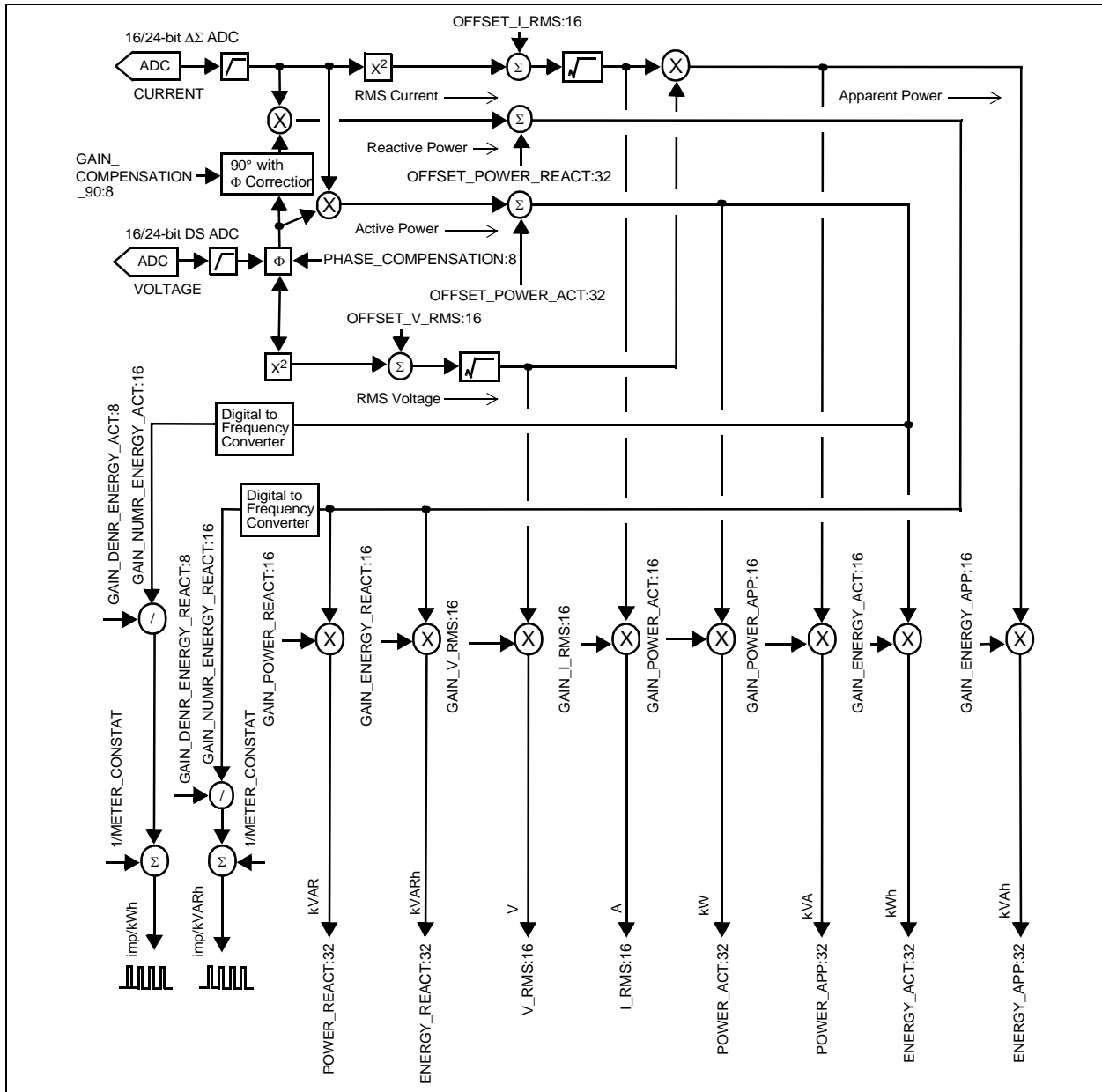
FIGURE 2-4: Analog Input Circuitry.



## Chapter 3. Calculation Engine and Register Description

### 3.1 CALCULATION ENGINE SIGNAL FLOW SUMMARY

RMS voltage, RMS current, Active Power, Reactive Power and Apparent Power, and the calibration output pulse are all calculated through the following process described in Figure 3-1. The calibration registers for each calculation are shown as well as the output registers.



**FIGURE 3-1:** PIC18F65J90 Calculation Engine Signal Flow

# MCP3901 and PIC18F65J90 Energy Meter Reference Design

## 3.2 REGISTER LIST

**Note:** Important! Not all registers and features are implemented in this version of firmware release.

**TABLE 3-1: INTERNAL REGISTER SUMMARY**

Name	Bits	R/W	Description
MODE	8	R/W	Configuration register for operating mode of the meter
STATUS	8	R	STATUS register
CAL_CONTROL	8	R/W	Configuration register for calibration control
LINE_CYC	16	R/W	2 <sup>n</sup> number of line cycles to be used during energy accumulation
LINE_CYC_CNT	16	R	Counter for number of line cycles
RAW2_I_RMS	64	R	Raw <sup>2</sup> RMS value from the current A/D converter in LSBs
RAW_I_RMS	16	R	Raw RMS value from the current A/D converter in LSBs
I_RMS	16	R	RMS value of the current, post Calibration
RAW2_V_RMS	64	R	Raw <sup>2</sup> RMS value from the voltage A/D converter in LSBs
RAW_V_RMS	16	R	Raw RMS value from the voltage A/D converter in LSBs
V_RMS	16	R	RMS value of the voltage, post Calibration
LINE_FREQUENCY	16	R	Line Frequency
RAW_POWER_ACT	64	R	Raw Active Power
POWER_ACT	32	R	Final Active Power, units in watts (W)
POWER_APP	32	R	Final Apparent Power, units in volt-amperes (VA)
RAW_POWER_REACT	64	R	Raw Reactive Power
POWER_REACT	32	R	Final Reactive Power, units in volt-amperes-reactive (VAR)
PERIOD	32	R	Period register
ENERGY_ACT	32	R	Final Active Energy accumulated
RAW_ENERGY_ACT	64	R	Raw Active Energy accumulated
ENERGY_APP	32	R	Final Apparent Energy accumulated
RAW_ENERGY_APP	64	R	Raw Apparent Energy accumulated
I_ABS_MAX	8	R	Not implemented
V_ABS_MAX	8	R	Not implemented
ENERGY_REACT	32	R	Final Reactive Energy accumulated
RAW_ENERGY_REACT	64	R	Raw Reactive Energy accumulated
PHASE_COMPENSATION	8	R/W	Phase compensation between voltage and current
OFFSET_I_RMS	16	R/W	Offset adjustment for RMS current reading
OFFSET_V_RMS	16	R/W	Offset adjustment for RMS voltage reading
GAIN_I_RMS	16	R/W	Gain adjustment for RMS current
GAIN_V_RMS	16	R/W	Gain adjustment for RMS voltage
OFFSET_POWER_ACT	32	R/W	Active Power offset
GAIN_POWER_ACT	16	R/W	Active Power gain adjust
OFFSET_POWER_REACT	32	R/W	Offset correction for Reactive Power
GAIN_POWER_REACT	16	R/W	Reactive Power gain adjust to produce X VAR/LSB
GAIN_ENERGY_ACT	16	R/W	Not implemented
GAIN_ENERGY_APP	16	R/W	Not implemented
GAIN_ENERGY_REACT	16	R/W	Not implemented
CF_PULSE_WIDTH	8	R/W	Defines CF pulse width from 0 to 255 x 0.8192 ms (0.209s)
GAIN_DENR_ENERGY_ACT	8	R/W	Active Energy Pulse Output correction factor

# Calculation Engine and Register Description

**TABLE 3-1: INTERNAL REGISTER SUMMARY (CONTINUED)**

Name	Bits	R/W	Description
GAIN_NUMR_ENERGY_ACT	16	R/W	Active Energy Pulse Output correction factor
MODE1_DEF	16	R/W	Power Up Configuration Register
CAL_STATUS	16	R/W	Calibration Status
MAXIMUM CURRENT	16	R/W	Maximum current of the meter ( $I_{MAX}$ )
CALIBRATION_VOLTAGE	16	R/W	Calibration Voltage of the meter ( $V_{CAL}$ )
CALIBRATION_CURRENT	16	R/W	Calibration Current of the meter ( $I_{CAL}$ )
CALIBRATION_FREQUENCY	16	R/W	Calibration Frequency of the meter
METER_CONSTANT	16	R/W	Meter Constant in imp/kWh or imp/kVARh
CALIBRATION_LINE_CYCLE	16	R/W	Number of line cycles for calibration
GAIN_DENR_ENERGY_REACT	8	R/W	Reactive Energy Pulse Output correction factor
GAIN_NUMR_ENERGY_REACT	16	R/W	Reactive Energy Pulse Output correction factor
PHASE_COMPENSATION_90	8	R/W	Phase delay for Reactive Power
CREEP_THRSHOLD_MINUTE	8	R/W	No Load threshold time (minutes)
CREEP_THRSHOLD_SECOND	8	R/W	No Load threshold time (seconds)
ENERGY_ACT	32	R/W	Active Energy
ENERGY_REACT	32	R/W	Reactive Energy

## 3.3 MODE

The MODE register controls the operation of the energy meter. The bit functions are defined by the table below.

**REGISTER 3-1: MODE REGISTER**

U-0	U-0	U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0
—	—	—	—	CF	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 7-4 **Unimplemented:** Read as '0'.

bit 3 **CF:** Active Energy CF Phase Enable bit

1 = Bit = 1 Phase is enabled to be accumulated into the total energy registers or CF pulse output

0 = Bit = 0 Phase is DISABLED and is not accumulated into the total energy registers or CF pulse output

bit 2 **ABSOLUTE** Positive Only Energy Accumulation Mode bit

1 = Bit = 1 Positive energy only

0 = Bit = 0 Both negative and positive energy accumulated (negative energy is subtracted)

bit 1 **PHASE:** Phase bit

1 = Single-Point Phase Correction

0 = Multi-Point Phase Correction (future)

bit 0 **CREEP:** No-Load Threshold bit

1 = Enabled

0 = Disabled

# MCP3901 and PIC18F65J90 Energy Meter Reference Design

## 3.4 STATUS

The STATUS register contains the operational status of the energy meter. The bit functions are defined in the table below.

**REGISTER 3-2: STATUS REGISTER**

U-0	U-0	U-0	U-0	U-0	U-0	R	U-0
—	—	—	—	—	—	PH_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 7-2      **Unimplemented:** Read as '0'

bit 1      **PH\_S:** Phase Sign bit  
             1 = CT may be in backward (if enabled)  
             0 = Operation normal

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

## 3.5 CAL\_CONTROL

This is the Calibration mode control register. Bit 0 enables the Calibration mode. In this mode, the power meter operates as normal, but no updates are made to the voltage, current, power or energy registers as long as bit 1 is low. When bit 1 is set high, the registers are updated for LINE\_CYC line cycles (only power and energy registers are updated). After this time, bit 1 is set low by the PIC18F65J90 and the update of the registers will stop. This allows the calibration software to set bit 0, clear the registers, set bit 1 and start reading the desired registers, as well as the CAL\_CONTROL register, to check the status of bit 1. When bit 1 goes low, the LINE\_CYC line cycles have passed and the 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 registers will be ready to read.

**REGISTER 3-3: CAL\_CONTROL REGISTER (NOTE 1)**

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 7-3      **Unimplemented:** Read as '0'

bit 2      **Reserved:**

# Calculation Engine and Register Description

## REGISTER 3-3: CAL\_CONTROL REGISTER (CONTINUED)(NOTE 1)

- bit 1      **CAL\_UPDATE:** Calibration Update bit  
Power and energy registers updated for LINE\_CYC line cycles when cleared. Bit must be set for registers to begin updating, which starts on the next line cycle after bit is set.
- 1 = When the CAL\_MODE bit is set, set the CAL\_UPDATE bit to enable update of power and energy registers starting on next line cycle. Bit = 1 Single Point Phase Correction.
  - 0 = When the CAL\_MODE bit is set and the CAL\_UPDATE bit has been set, the CAL\_UPDATE 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 the CAL\_UPDATE bit is set again, or the 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

**Note 1:** This register is used in Multi-Point and Single-Point Calibration modes only.

### 3.6 LINE\_CYC

Name	Bits	Cof
LINE_CYC	16	R/W

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

### 3.7 LINE\_CYC\_CNT

Name	Bits	Cof
LINE_CYC_CNT	16	R

This register counts from 0 and finishes at  $2^{(\text{LINE\_CYC} - 1)}$ . Then it restarts at 0, where LINE\_CYC represents the value in the LINE\_CYC register.

### 3.8 RAW2\_I\_RMS

Name	Bits	Cof
RAW2_I_RMS	64	R

This register is the square of the raw RMS value from the current A/D converter in LSBs. By definition, this register will always contain a positive value, including the situation where power is negative from a backwards CT or otherwise. This register is overwritten every LINE\_CYC line cycle and is written only once, if calibration is enabled.

# MCP3901 and PIC18F65J90 Energy Meter Reference Design

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## 3.9 RAW\_I\_RMS

Name	Bits	Cof
RAW_I_RMS	16	R

This register is the raw RMS value from the current A/D converter in LSBs (square root of the top 32-bits of RAW2\_I\_RMS + OFFSET\_I\_RMS). By definition, this register will always contain a positive value (even if the CT is in backwards). This register is overwritten every LINE\_CYC line cycle and is written only once, if calibration is enabled.

## 3.10 I\_RMS

Name	Bits	Cof
I_RMS	16	R

This register is the RMS value of phase A current in X A/LSB, as determined by the value in the GAIN\_I\_RMS register. When displaying the RMS current, multiply the (decimal) value in these registers by X to get the display value in amperes. This register is overwritten every LINE\_CYC line cycle (written only once if calibration is enabled).

## 3.11 RAW2\_V\_RMS

Name	Bits	Cof
RAW2_V_RMS	64	R

This register is the square of the raw RMS value from the voltage A/D converter in LSBs. By definition, it will always contain a positive value. This register is overwritten every LINE\_CYC line cycle (written only once if calibration is enabled).

## 3.12 RAW\_V\_RMS

Name	Bits	Cof
RAW_V_RMS	16	R

This is the raw RMS value from the voltage A/D converter in LSBs (square root of the top 32-bits of RAW2\_V\_RMS + OFFSET\_V\_RMS). By definition, this register will always contain a positive value. The register is overwritten every LINE\_CYC line cycle (written only once if calibration is enabled).

## 3.13 V\_RMS

Name	Bits	Cof
V_RMS	16	R

This register is the RMS value of the voltage, in X 0.01 V/LSB, as determined by the value in the GAIN\_V\_RMS register. When displaying the RMS voltage, assume a calibrated meter exists and multiply the (decimal) value in these registers by X to get the display value in volts. This register is overwritten every LINE\_CYC line cycle (written only once if calibration is enabled).

# Calculation Engine and Register Description

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## 3.14 LINE\_FREQUENCY

Name	Bits	Cof
LINE_FREQUENCY	16	R

This register holds the measured line frequency using the zero crossing technique.

## 3.15 RAW\_POWER\_ACT

Name	Bits	Cof
RAW_POWER_ACT	64	R

This register is the raw active power, as it represents the sum of current A/D value times 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, 48 bits are needed. This is the register to be read during calibration for calculating the offset and gain values associated with active power, OFFSET\_POWER\_ACT and GAIN\_POWER\_ACT. This register is overwritten every line cycle, however if calibration is enabled, the updates will stop once the LINE\_CYC line cycles have elapsed.

## 3.16 POWER\_ACT

Name	Bits	Cof
POWER_ACT	32	R

This register is the value for active power. The goal of the calibration is to get this register value to equal  $X$  W/LSB. This is done with the OFFSET\_POWER\_ACT and GAIN\_POWER\_ACT registers. When displaying the power, multiply the (decimal) value in this register by  $X$  to get the display value in watts. This register is overwritten every LINE\_CYC line cycle (written only once if calibration is enabled).

## 3.17 POWER\_APP

Name	Bits	Cof
POWER_APP	32	R

This is the value of the apparent power. The goal of the calibration is to get this value to equal  $X$  VA/LSB. This is done with the GAIN\_POWER\_APP registers. When displaying the power for phase A, multiply the (decimal) value in this register by  $X$  to get the display value in watts. This register is overwritten every LINE\_CYC line cycle (written only once if calibration is enabled).

# MCP3901 and PIC18F65J90 Energy Meter Reference Design

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## 3.18 RAW\_POWER\_REACT

Name	Bits	Cof
RAW_POWER_REACT	64	R

This is the raw reactive power. This register is read during the calibration for calculating the gain values associated with the reactive power and GAIN\_POWER\_REACT. This register is overwritten every LINE\_CYC line cycle (written only once if calibration is enabled). This register is accumulated on a line-cycle basis.

## 3.19 POWER\_REACT

Name	Bits	Cof
POWER_REACT	32	R

This is the value for reactive power. The goal is to get this value to equal X VAR/LSB. This is done with the GAIN\_POWER\_REACT register. When displaying the power, multiply the (decimal) value in this register by X to get the display value in watts. This register is overwritten every LINE\_CYC line cycle (written only once if calibration is enabled).

## 3.20 PERIOD

Name	Bits	Cof
PERIOD	32	R

This 32-bit register represents the total number of clock ticks that elapsed over the most recent LINE\_CYC line cycle. Each LSB represents 1.6  $\mu$ s with a 4 MHz clock on the microcontroller. This register is overwritten every LINE\_CYC line cycle (written only once if calibration is enabled).

## 3.21 ENERGY\_ACT

Name	Bits	Cof
ENERGY_ACT	32	R
RAW_ENERGY_ACT	64	R

The design updates the Energy register using the CF Pulse blink output count. In this method, the Energy registers increments every pulse by a value equal to  $1/(\text{METER\_CONSTANT})$ .

$$\text{ENERGY\_ACT} = \text{ENERGY\_ACT} + (1/\text{METER\_CONSTANT})$$

The gain calibration registers GAIN\_NUMR\_ENERGY\_ACT and GAIN\_DENR\_ENERGY\_ACT operate the same for this method also.



# Calculation Engine and Register Description

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## 3.22 ENERGY\_APP

Name	Bits	Cof
ENERGY_APP	32	R
RAW_ENERGY_APP	64	R

These two registers represent the total apparent energy accumulated so far.

## 3.23 I\_ABS\_MAX

Name	Bits	Cof
I_ABS_MAX	8	R

NOT IMPLEMENTED IN THIS FIRMWARE/SOFTWARE RELEASE.

## 3.24 V\_ABS\_MAX

Name	Bits	Cof
V_ABS_MAX	8	R/W

NOT IMPLEMENTED IN THIS FIRMWARE/SOFTWARE RELEASE.

## 3.25 ENERGY\_REACT

Name	Bits	Cof
ENERGY_REACT	32	R
RAW_ENERGY_REACT	64	R

The design updates the reactive energy register using the CF Pulse blink output. In this method, the Energy registers increment every pulse by a value equal to  $1/(\text{METER\_CONSTANT})$ .

$$\text{ENERGY\_REACT} = \text{ENERGY\_REACT} + (1/\text{METER\_CONSTANT})$$

The gain calibration registers GAIN\_NUMR\_ENERGY\_ACT and GAIN\_DENR\_ENERGY\_ACT operate the same for this method also.

## 3.26 PHASE\_COMPENSATION

Name	Bits	Cof
PHASE_COMPENSATION	8	R/W

Phase delay, signed 8-bit value, provides the phase compensation by sampling time/2.

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## 3.27 OFFSET\_I\_RMS

Name	Bits	Cof
OFFSET_I_RMS	16	R/W

Square of the offset for RMS current reading, signed 16-bit value. Note that this value should be similar to the ADC's noise squared. At a gain of 1, the noise will be about 1 LSB, 2 LSBs at a gain of 2, 6 LSBs at a gain of 8, 11 LSBs at a gain of 16, and 22 LSBs at a gain of 32. There may be other sources of noise. Using the square of the offset allows for higher accuracy. The value will be added before the square root is taken when calculating the final RMS value.

## 3.28 OFFSET\_V\_RMS

Name	Bits	Cof
OFFSET_V_RMS	16	R/W

Square of offset for RMS voltage reading, signed 8-bit value. Note that this value should be similar to the ADC's noise squared. For the voltage channel, the noise will be about 1 LSB. There may be other sources of noise. Using the square of the offset allows for higher accuracy. The value will be added before the square root is taken when calculating the final RMS value.

## 3.29 GAIN\_I\_RMS

Name	Bits	Cof
GAIN_I_RMS	16	R/W

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

## 3.30 GAIN\_V\_RMS

Name	Bits	Cof
GAIN_V_RMS	16	R/W

Voltage gain to produce 0.1 V/LSB in the V\_RMS register. The value is always less than one (for example,  $32,767 = 0.9999695$ ).

## 3.31 OFFSET\_POWER\_ACT

Name	Bits	Cof
OFFSET_POWER_ACT	32	R/W

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

# Calculation Engine and Register Description

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## 3.32 GAIN\_POWER\_ACT

Name	Bits	Cof
GAIN_POWER_ACT	16	R/W

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

## 3.33 OFFSET\_POWER\_REACT

Name	Bits	Cof
OFFSET_POWER_REACT	32	R/W

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

## 3.34 GAIN\_POWER\_REACT

Name	Bits	Cof
GAIN_POWER_REACT	16	R/W

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

## 3.35 GAIN\_ENERGY\_ACT

Name	Bits	Cof
GAIN_ENERGY_ACT	16	R/W

Active energy gain to produce X Wh/LSB. The value is always less than one (for example,  $32,767 = 0.9999695$ ).

## 3.36 GAIN\_ENERGY\_APP

Name	Bits	Cof
GAIN_ENERGY_APP	16	R/W

Apparent energy gain to produce X VAh/LSB. The value is always less than one (for example,  $32,767 = 0.9999695$ ).

## 3.37 GAIN\_ENERGY\_REACT

Name	Bits	Cof
GAIN_ENERGY_REACT	16	R/W

Reactive energy gain to produce X VARh/LSB. The value is always less than one (for example,  $32,767 = 0.9999695$ ).

# MCP3901 and PIC18F65J90 Energy Meter Reference Design

## 3.38 CF\_PULSE\_WIDTH

Name	Bits	Cof
CF_PULSE_WIDTH	8	R/W

Defines the CF pulse width from 0 to 255. Length of width is valued \* 8 \* (1/LINE\_FREQUENCY)/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.

## 3.39 GAIN\_DENR\_ENERGY\_ACT

Name	Bits	Cof
GAIN_DENR_ENERGY_ACT	8	R/W

8-bit signed value. Represents the number of shifts for active power energy register ENERGY\_ACT before GAIN\_DENR\_ENERGY\_ACT is applied.

## 3.40 GAIN\_NUMR\_ENERGY\_ACT

Name	Bits	Cof
GAIN_NUMR_ENERGY_ACT	16	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).

## 3.41 MODE1\_DEF

Name	Bits	Cof
MODE1_DEF	16	R/W

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

## 3.42 CAL\_STATUS

The CAL\_STATUS register 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.

### REGISTER 3-4: CAL\_STATUS REGISTER

R/W-0	R/W-0	R/W-0	U-0	U-0	R/W-0	R/W-0	R/W-0
PHASE_COM PENSATION	OFFSET_I_ RMS	OFFSET_V_ RMS	—	—	GAIN_I_RMS	GAIN_V_RMS	OFFSET_PO WER_ACT
bit 15							bit 8
U-0	R/W-0	U-0	U-0	U-0	R/W-0	U-0	U-0
—	GAIN_POW ER_ACT	—	—	—	GAIN_POWE R_REACT	—	—
bit 7							bit 0

# Calculation Engine and Register Description

## REGISTER 3-4: CAL\_STATUS REGISTER (CONTINUED)

**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 15-0 **All bits:** Calibration Register Status bits

1 = This register has been calibrated

0 = This register is NOT calibrated

### 3.43 MAXIMUM CURRENT

Name	Bits	Cof
MAXIMUM_CURRENT	16	R/W

This register holds the maximum current for the meter ( $I_{MAX}$ ).

### 3.44 CALIBRATION\_VOLTAGE

Name	Bits	Cof
CALIBRATION_VOLTAGE	16	R/W

This register holds the calibration voltage of the meter ( $V_{CAL}$ ).

### 3.45 CALIBRATION\_CURRENT

Name	Bits	Cof
CALIBRATION_CURRENT	16	R/W

This register holds the calibration current of the meter ( $I_{CAL}$ ).

### 3.46 CALIBRATION\_FREQUENCY

Name	Bits	Cof
CALIBRATION_FREQUENCY	16	R/W

This register holds the calibration frequency of the meter.

### 3.47 METER\_CONSTANT

Name	Bits	Cof
METER_CONSTANT	16	R/W

This register holds the meter constant in imp/kWh or imp/kVARh.

# MCP3901 and PIC18F65J90 Energy Meter Reference Design

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## 3.48 CALIBRATION\_LINE\_CYCLE

Name	Bits	Cof
CALIBRATION_FREQUENCY	16	R/W

This register holds the number of line cycles used during the calibration.

## 3.49 GAIN\_DENR\_ENERGY\_REACT

Name	Bits	Cof
GAIN_DENR_ENERGY_REACT	8	R/W

8-bit signed value. Represents the number of shifts for reactive power energy register, before GAIN\_NUMR\_ENERGY\_REACT is applied.

## 3.50 GAIN\_NUMR\_ENERGY\_REACT

Name	Bits	Cof
GAIN_NUMR_ENERGY_REACT	16	R/W

Reactive power gain to produce a specified pulse per VAR-hour. The value is always less than one (for example,  $32,767 = 0.9999695$ ).

## 3.51 PHASE\_COMPENSATION\_90

Name	Bits	Cof
PHASE_COMPENSATION_90	8	R/W

Phase delay for reactive power, signed 8-bit value, sampling time/2.

## 3.52 CREEP\_THRSHOLD\_MINUTE

Name	Bits	Cof
CREEP_THRSHOLD_MINUTE	8	R/W

This 8-bit register holds the decimal representation of the creep threshold time in minutes (total creep is minutes + seconds register).

## 3.53 CREEP\_THRSHOLD\_SECOND

Name	Bits	Cof
CREEP_THRSHOLD_SECOND	8	R/W

This 8-bit register holds the decimal representation of the creep threshold time in seconds (total creep is minutes + seconds register).

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## Chapter 4. Meter Protocol and Timings

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### 4.1 PROTOCOL

The Universal Asynchronous Receiver/Transmitter (UART) of the PIC18F65J90 is used to access the register map of the meter. In addition to the reading and writing of the registers, there are also dedicated commands for clearing calibration registers, loading calibration registers and storing calibration registers to flash. The first byte UART 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: 'EABCDEFGHJKLMNOPQRSTUVWXYZ1234567890X'.

Returns: 'EABCDEFGHJKLMNOPQRSTUVWXYZ1234567890X'.

##### 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'.

# MCP3901 and PIC18F65J90 Energy Meter Reference Design

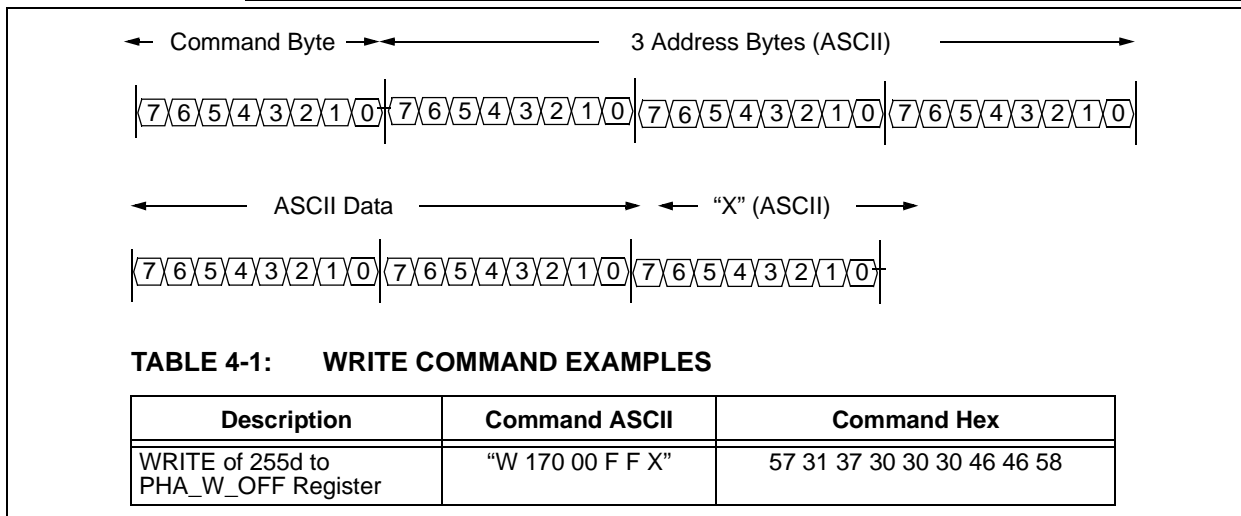
## 4.1.1.4 “W” WRITE: WRITE STARTING AT SPECIFIED ADDRESS

Write specified bytes.

Example: 'W030000102030405060708090A0B0C0D0E0FX'.

Returns: 'W030000102030405060708090A0B0C0D0E0FX'.

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



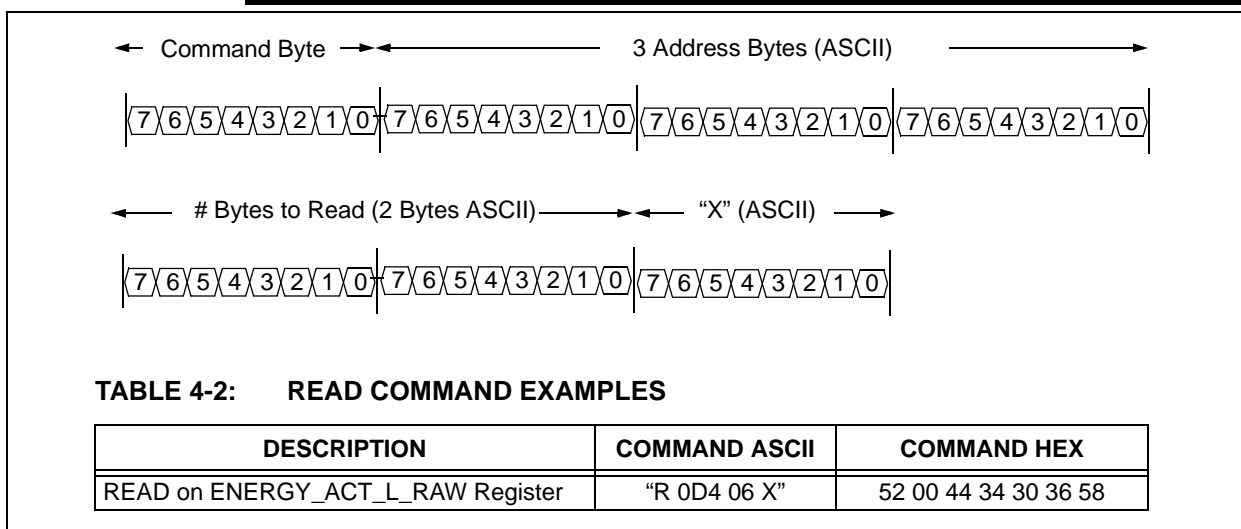
**FIGURE 4-1:** WRITE Command Protocol.

## 4.1.1.5 “R” READ: READ STARTING AT SPECIFIED ADDRESS

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

Returns: 'R030000102030405060708090A0B0C0D0E0FX'

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



**FIGURE 4-2:** Read Command Protocol.



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## Appendix A. Schematic and Layouts

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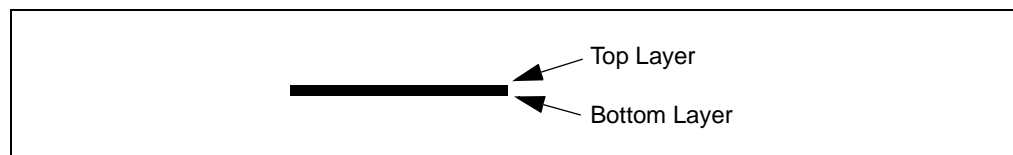
### A.1 INTRODUCTION

This appendix contains the following schematics and layouts for the MCP3901 and PIC18F65J90 Energy Meter Reference Design:

- Board – ADC Schematic
- Board – MCU Schematic
- Board – LCD and USB Schematic
- Board – Top Silk and Pads
- Board – Top Copper
- Board – Bottom Copper
- Board – Bottom Silk and Pads
- Board – Top 3D
- Board – Bottom 3D

### A.2 SCHEMATICS AND PCB LAYOUT

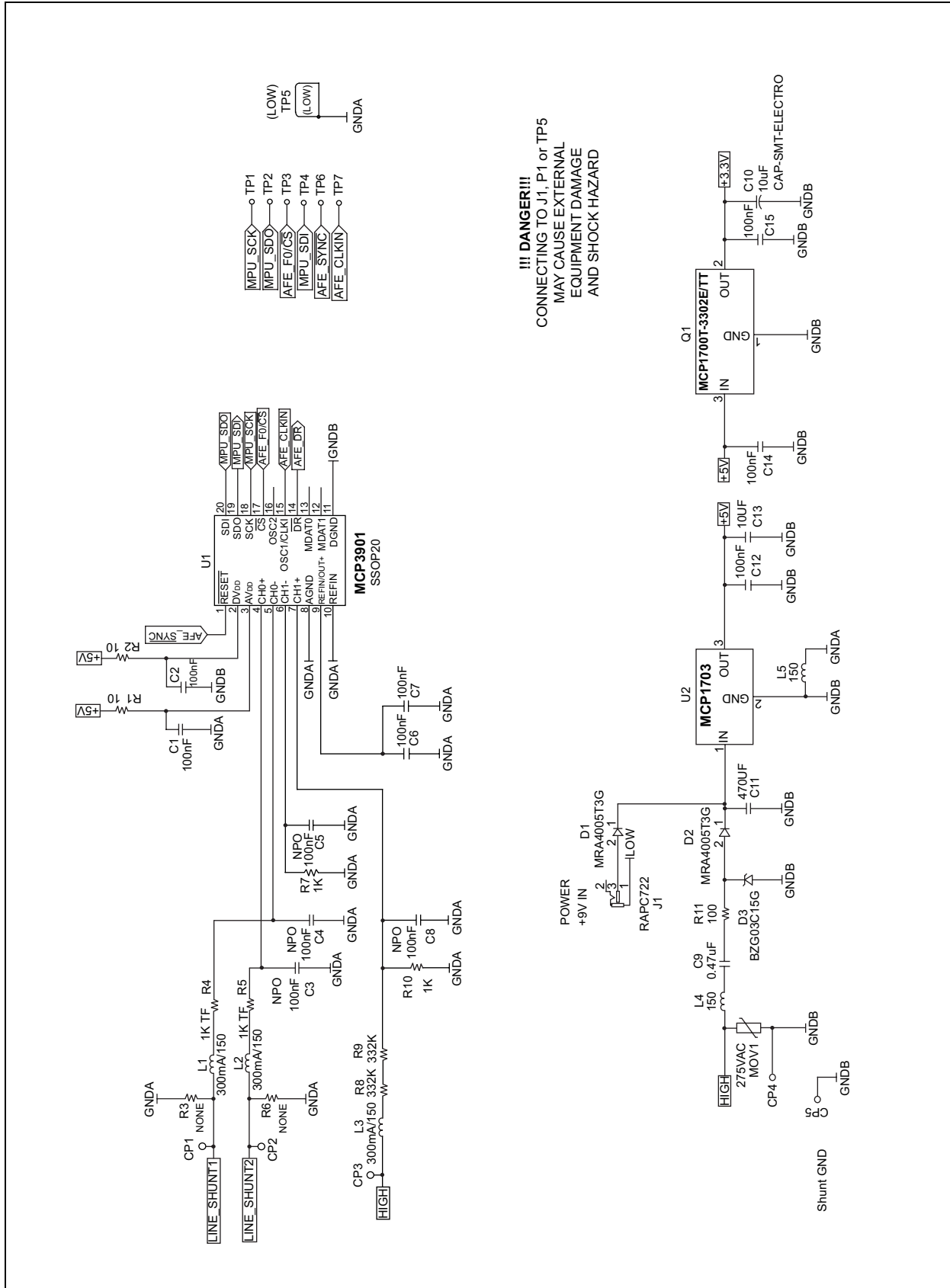
The layer order is shown in Figure A-1.



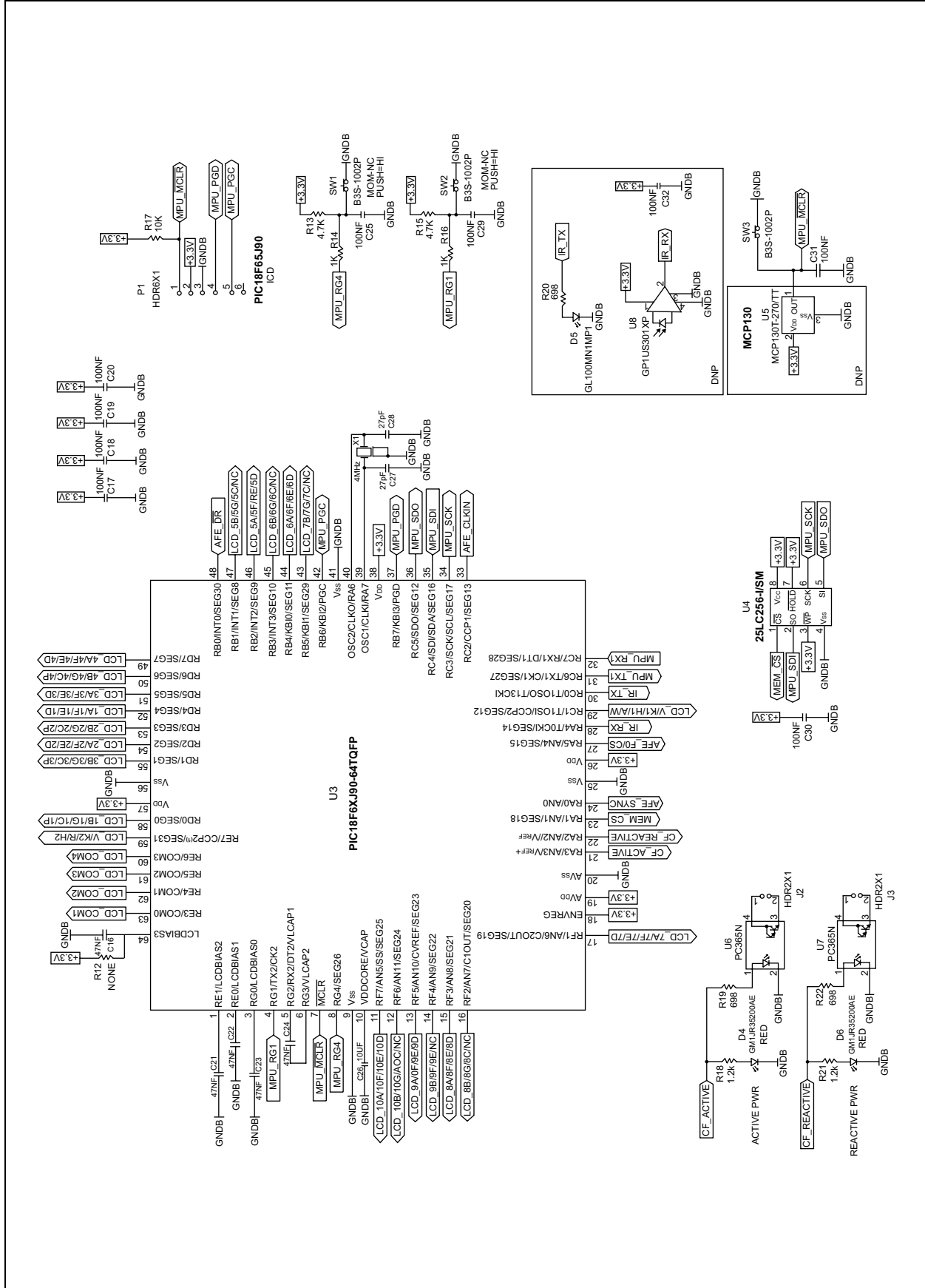
**FIGURE A-1:** *Layer Order.*

# MCP3901 and PIC18F65J90 Energy Meter Reference Design

## A.3 BOARD – ADC SCHEMATIC

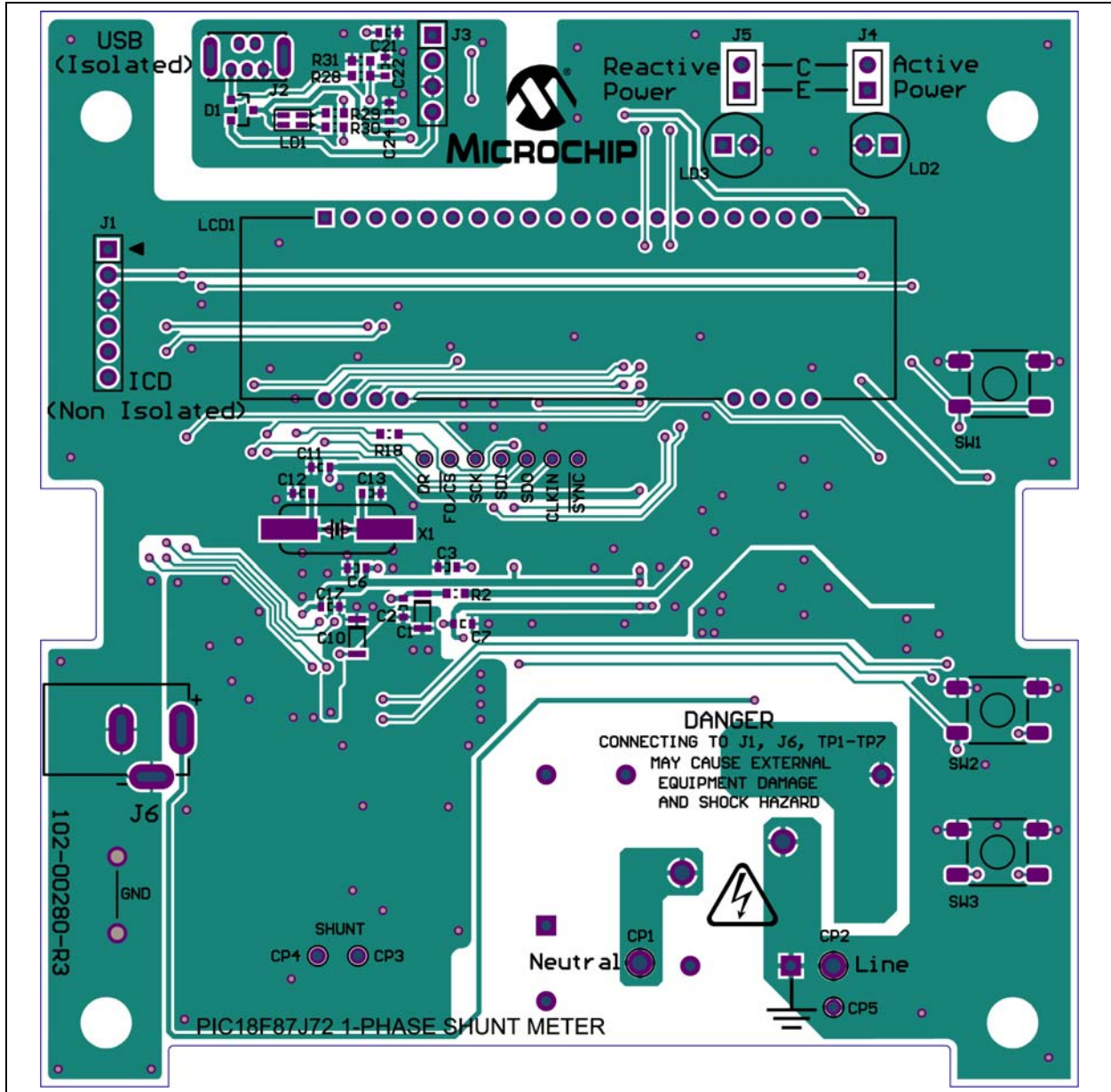


## A.4 BOARD – MCU SCHEMATIC



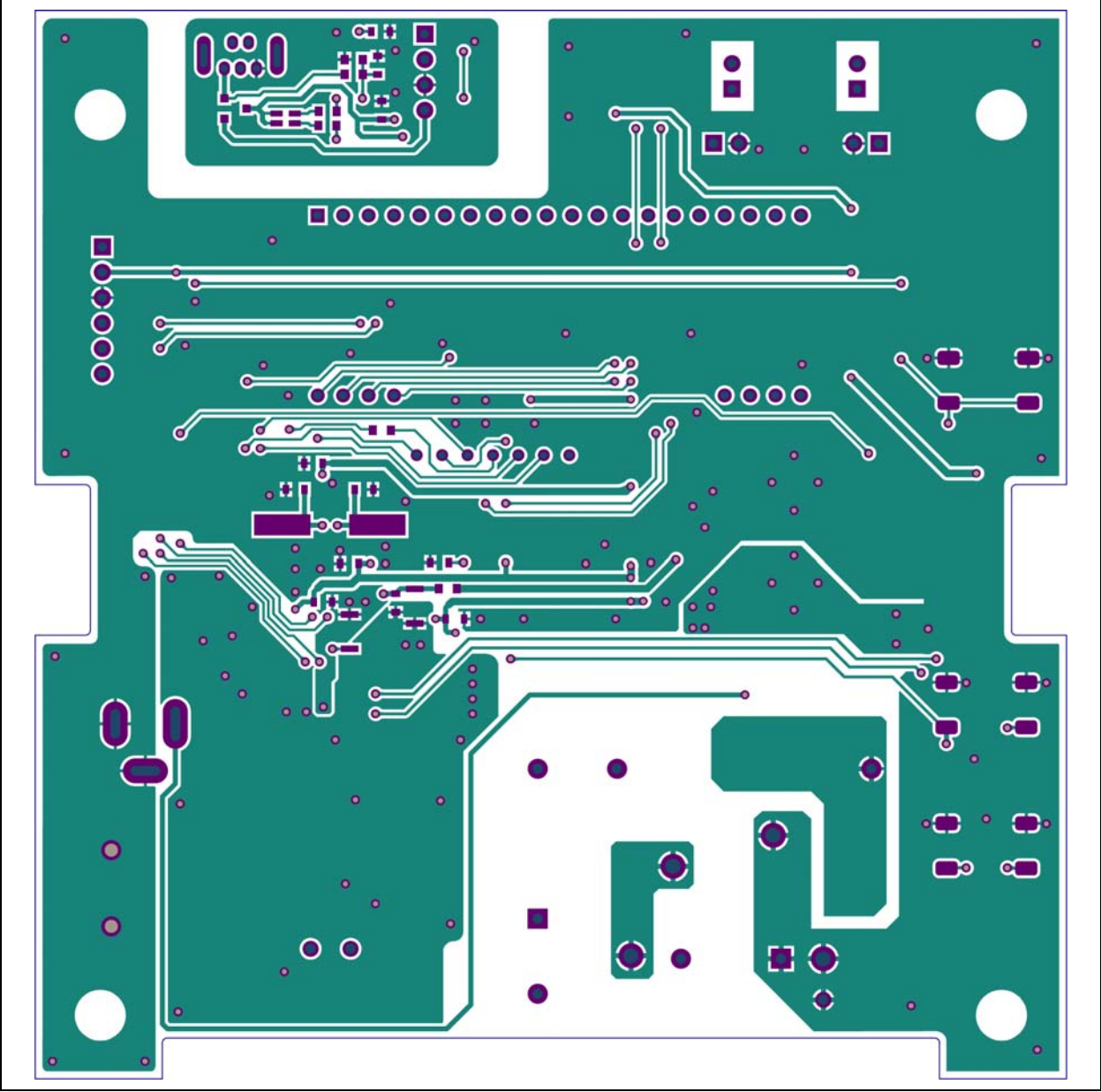


## A.6 BOARD – TOP SILK AND PADS

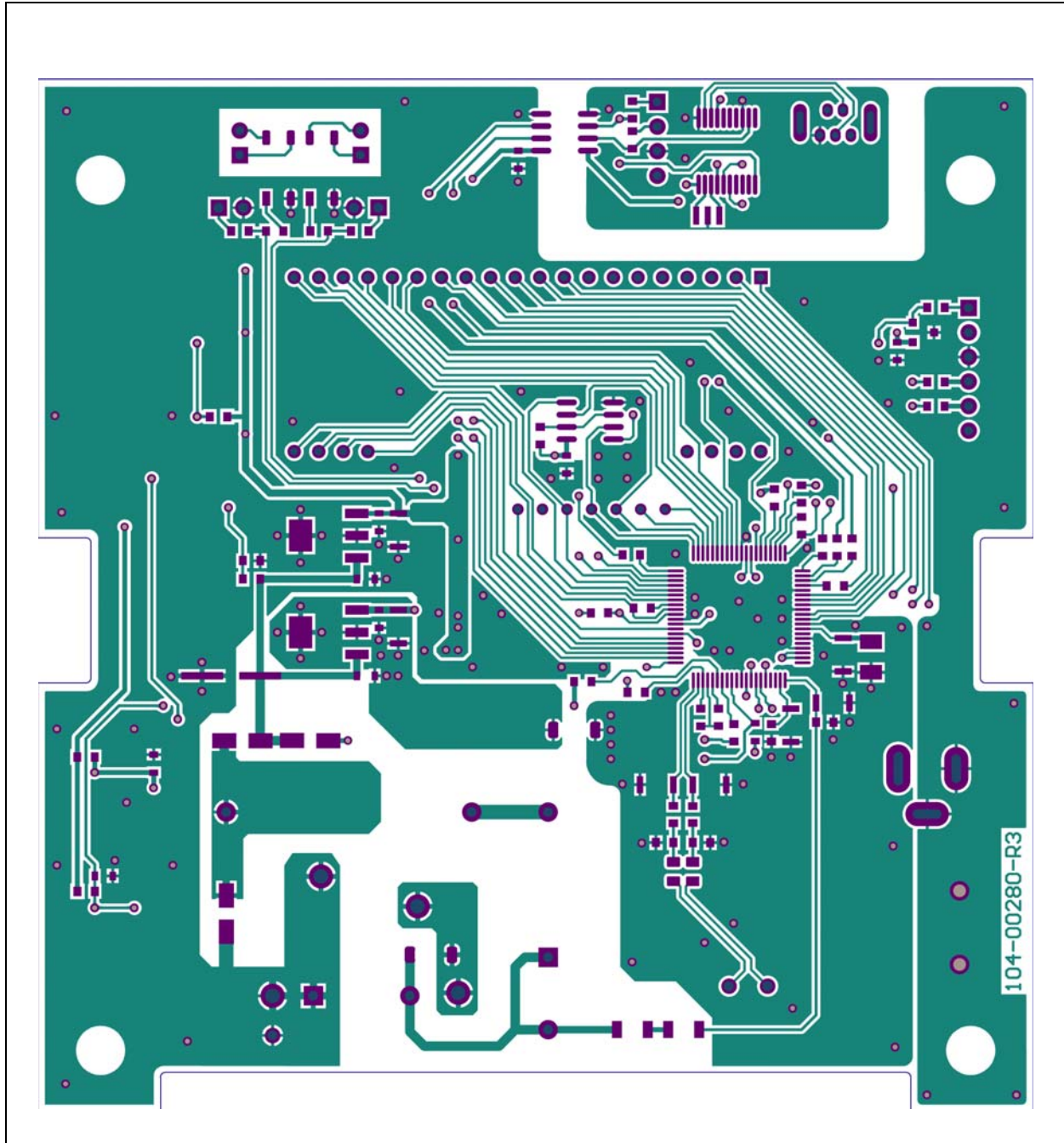


# MCP3901 and PIC18F65J90 Energy Meter Reference Design

## A.7 BOARD – TOP COPPER

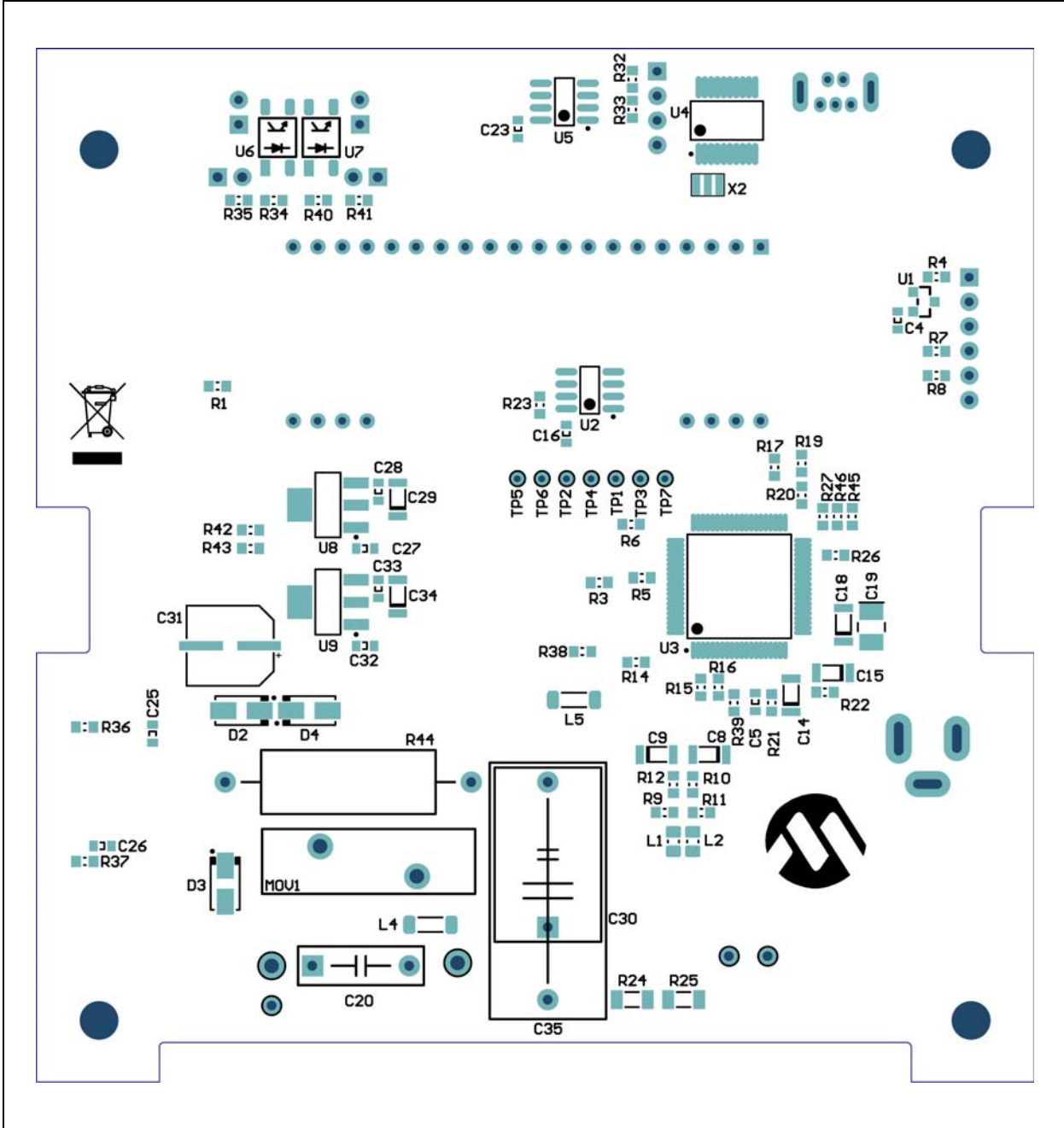


## A.8 BOARD – BOTTOM COPPER



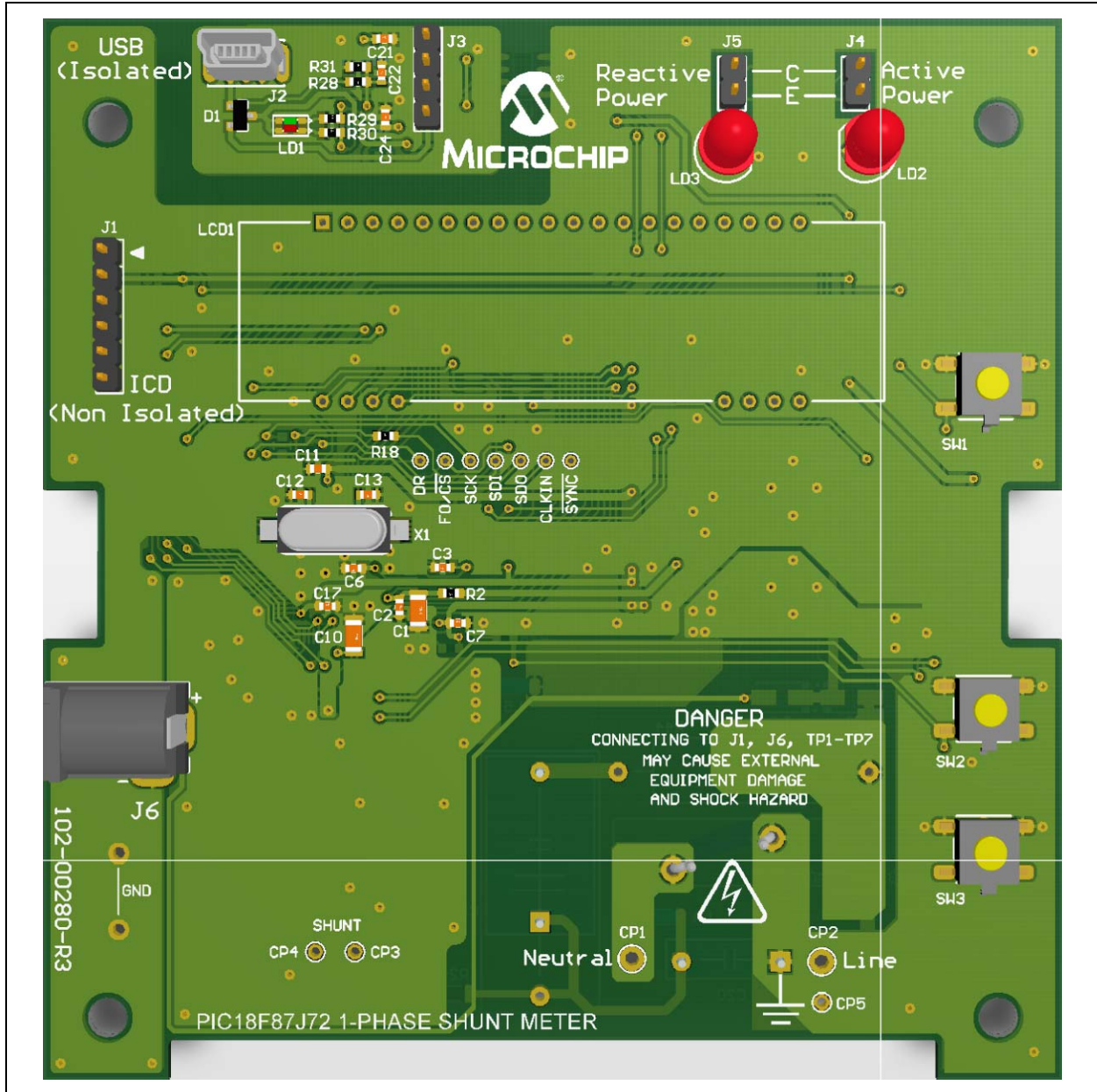
# MCP3901 and PIC18F65J90 Energy Meter Reference Design

## A.9 BOARD – BOTTOM SILK AND PADS



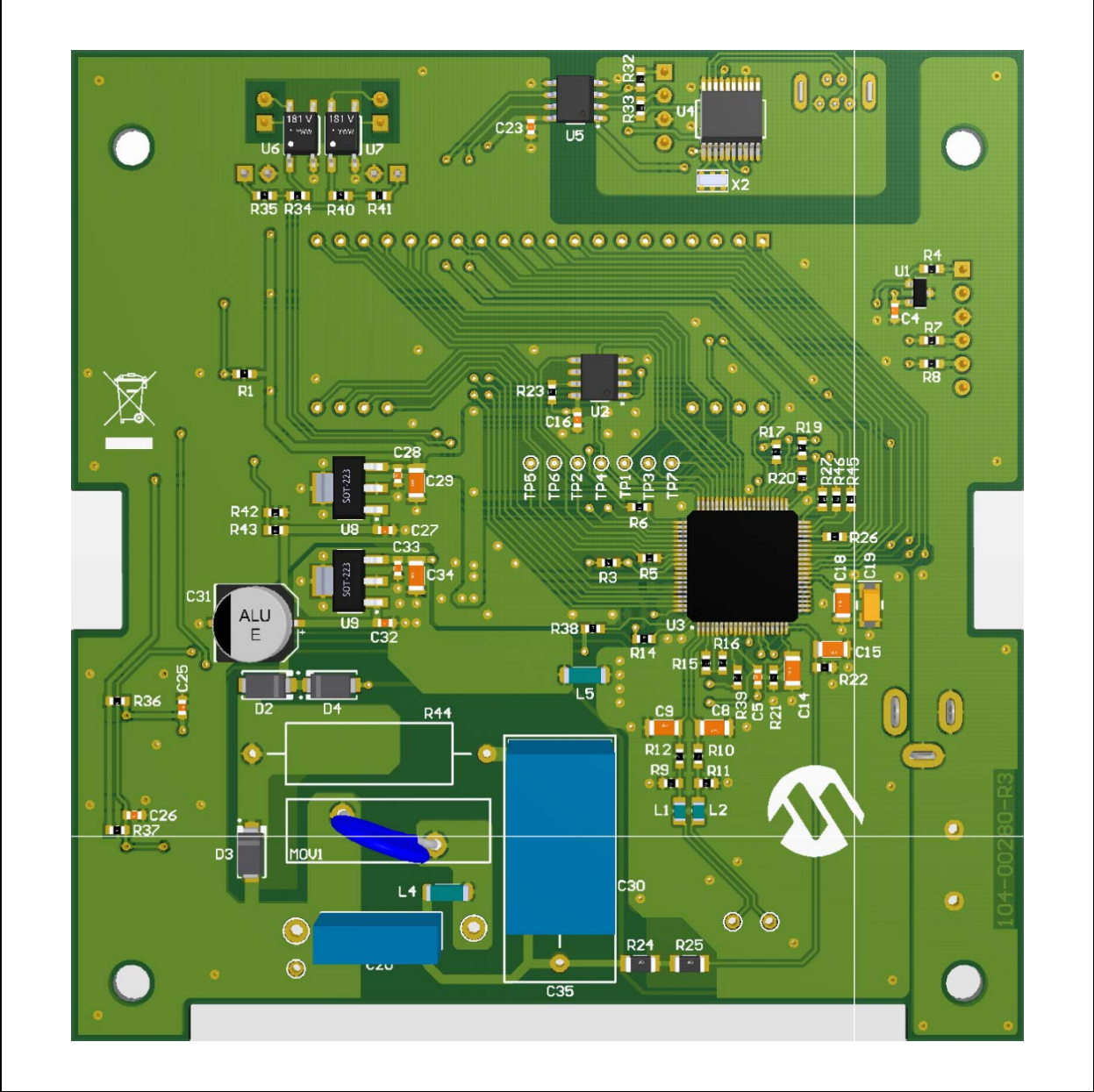


## A.10 BOARD – TOP 3D



# MCP3901 and PIC18F65J90 Energy Meter Reference Design

## A.11 BOARD – BOTTOM 3D



## Appendix B. Bill of Materials (BOM)

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

Qty	Reference	Description	Manufacturer	Part Number
20	C1, C2, C5, C6 C7, C8, C12, C14, C15, C17, C18, C19, C20, C25, C29, C30, C31, C33, C34, C35	CAP CER .1UF 25V 10% X7R 0603	Murata Electronics®	GRM188R71E104KA01D
2	C3, C4	CAP CER .1UF 25V X7R 1206 FO	KEMET®	C1206F104K3RACTU
1	C9	CAP .47UF 305VAC Lead Spacing 22.5 mm, WxHxL = 10.5 x 16.5 x 26.5	EPCOS Inc.	B32933B3474K000
1	C10	CAP 10UF 16V ELECT FC SMD	Panasonic® - ECG	EEE-FC1C100R
1	C11	CAP 470UF 25V ELECT FC SMD	Panasonic - ECG	EEE-FC1E471P
2	C13, C26	CAP CER 10UF 6.3V X5R 0603	Murata Electronics	GRM188R60J106ME47D
5	C16, C21, C22, C23, C24	CAP CER 47000PF 25V 10% X7R 0603	Murata Electronics	GRM188R71473KA01D
2	C27, C28	CAP CER 27PF 50V 5% C0G 0603	TDK Corporation	C1608C0G1H270J
2	D1, D2	DIODE SCHOTTKY 40V 1A SMB	ON Semiconductor®	MBRS140T3G
1	D3	DIODE ZENER 15V 1.5W SMA	ON Semiconductor	BZG03C15G
2	D4, D6	LED 1.6X0.8MM 625NM RED CLR SMD	Kingbright Corp.	APT1608EC
1	D7	LED 2X1.2MM RD/GN WTR CLR SMD	Kingbright Corp.	APHBM2012SURKCGKC
1	J1	CONN POWERJACK MINI R/A T/H	CUI Inc.	PJ-102B
3	L1, L2, L3	FERRITE 300MA 150 OHM 1806 SMD	Laird-Signal Integrity Products	LI1806C151R-10
2	L4, L5	FERRITE 300MA 150 OHM 1806 SMD	Laird-Signal Integrity Products	LI1806C151R-10
1	LCD1	Energy Meter LCD Display	Deepakshi Display Devices	DP-093
1	MOV 1	VARISTOR 275V RMS 20MM RADIAL	EPCOS Inc.	S20K275E2
1	P1	6 X 1 Header 2.54 mm on center 6 mm/2.5 mm	Samtec	TSW-106-07-G-S
1	PCB	RoHS Compliant Bare PCB, MCP3901 PIC18F65J90 Shunt Meter Ref Des	—	104-00342
1	Q1	IC REG LDO 3.3V 250MA SOT23-3	Microchip Technology Inc.	<b>MCP1700T-3302E/TT</b>
2	R1, R2	RES 10.0 OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF10R0V
4	R4, R5, R7, R10	RES 1.00K OHM 1/8W 1% 0805 SMD	Panasonic - ECG	ERJ-6ENF1001V
2	R8, R9	RES 332K OHM 1/4 1% 1206 SMD	YAGEO Corp.	RC1206FR-07332KL

**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.

# MCP3901 and PIC18F65J90 Energy Meter Reference Design

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

Qty	Reference	Description	Manufacturer	Part Number
1	R11	RES 100 OHM 1W 5% 2512 SMD	Panasonic - ECG	ERJ-1TNF1000U
2	R13, R15	RES 4.70K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF4701V
2	R14, R16	RES 1.00K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1001V
1	R17	RES 10.0K OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1002V
2	R18, R21	RES 100 OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF1000V
2	R19, R22	RES 698 OHM 1/10W 1% 0603 SMD	Rohm Semiconductor	MCR03EZPF6980
3	R23, R24, R25	RES 470 OHM 1/10W 1% 0603 SMD	Panasonic - ECG	ERJ-3EKF4700V
3	SW1, SW2, SW3	SWITCH TACT 6MM 230GF H=4.3MM	Omron Electronics	B3S-1002P
1	TP5	Wire Test Point 0.3" Length	Component Corporation	PJ-202-30
1	U1	IC ENERGY METER SSOP-20	Microchip Technology Inc.	<b>MCP3901AO-I/SS</b>
1	U2	IC REG LDO 5V 250MA SOT-223-3	Microchip Technology Inc.	<b>MCP1703-5002E/DB</b>
1	U3	64/80-Pin, High-Performance Microcontrollers with LCD Driver and nanoWatt Technology TQFP-64	Microchip Technology Inc.	<b>PIC18F65J90-I/PTY</b>
1	U4	256K SPI Bus Serial EEPROM SOIC-8	Microchip Technology Inc.	<b>25LC256-I/SN</b>
2	U6, U7	PHOTOCOUPLER DARL OUT 4-SMD	Sharp@ Electronic Corp.	PC36NJ0000F
1	U9	CONN RUGGED USB RCPT VERT MINI B	Amphenol Commercial	MUSBB55104
1	U10	IC USB TO UART SSOP-20	Microchip Technology Inc.	<b>MCP2200-I/SS</b>
1	U11	IC ISOLATOR DIGITAL DUAL 8-SOIC	Analog Devices Inc.	ADUM1201CRZ-RL7
1	X1	CRYSTAL 4.000 MHZ 18PF SMD	Abrakon Corporation	ABLS-4.000MHZ-B4-T
1	X2	CER RESONATOR 12.0MHZ SMD	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 (COMPONENTS NOT INSTALLED)**

Qty	Reference	Description	Manufacturer	Part Number
1	C32	CAP CER .1UF 25V 10% X7R 0603	—	—
1	D5	DO NOT INSTALL	—	—
2	J2, J3	DO NOT INSTALL	—	—
2	R3, R6	DO NOT INSTALL	—	—
1	R12	DO NOT INSTALL	—	—
1	R20	RES 698 OHM 1/10W 0603 SMD	—	—
1	U5	Microcontroller Supervisory Circuit with Open Drain Output SOT23-3	—	—
1	C32	CAP CER .1UF 25V 10% X7R 0603	—	—

**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





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