MCP6L2 and PIC18F66J93 Energy Meter Reference Design
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Signed for and on behalf of Microchip Technology Inc. at Chandler, Arizona, USA

Derek Carlson
VP Development Tools

02-May-12
Date
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NOTICE TO CUSTOMERS

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

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

INTRODUCTION

This chapter contains general information that will be useful to know before using the MCP6L2 and PIC18F66J93 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
This document describes how to use the MCP6L2 and PIC18F66J93 Energy Meter as a development tool to emulate and debug firmware on a target board. The manual layout is as follows:

- **Chapter 1. “Product Overview”** – Important information on using the MCP6L2 and PIC18F66J93 Energy Meter including a Getting Started section that describes wiring the line and load connections.

- **Chapter 2. “Hardware”** – Includes details about the function blocks of the meter including the analog front-end and power supply design.

- **Chapter 3. “Calculation Engine and Register Description”** – This section describes the digital signal flow for all power output quantities such as RMS current, RMS voltage, active power, reactive power and apparent power. This section also includes the registers’ detail.

- **Chapter 4. “Communication Protocol”** – The protocol used for accessing the registers is described. It includes commands that are used to interface to the meter.

- **Chapter 5. “Microchip Energy Meter Software”** – Describes the functionality of the Graphical User Interface (GUI) that runs on the PC.

- **Chapter 6. “Energy Meter Calibration”** – Information on calibration of the energy meter using the GUI.

- **Appendix A. “Schematic and Layouts”** – Shows the schematic and layout diagrams

- **Appendix B. “Bill of Materials (BOM)”** – Lists the parts used to build the MCP6L2 and PIC18F66J93 Energy Meter.
CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

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

This user's guide describes how to use the MCP6L2 and PIC18F66J93 Energy Meter. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources.

• MCP6L2 Data Sheet – “2.8 MHz, 200 μA Op Amps” (DS22135)
  This data sheet provides detailed information regarding the MCP6L2 device.
• PIC18F66J93 Data Sheet – “64/80-Pin, High-Performance Microcontrollers with LCD Driver, 12-Bit A/D and nanoWatt Technology” (DS39948)
  This data sheet provides detailed information regarding the PIC18F66J93 device.
• PIC18F87J72 Single-Phase Energy Meter Calibration User’s Guide (DS51964)
  This User’s Guide describes the calibration registers and Universal Asynchronous Receiver/Transmitter (UART) communication protocol used on the PIC18F87J72 Single-Phase Energy Meter Reference Design. Only some of the information applies to the MCP6L2 and PIC18F66J93 Energy Meter Reference Design. The chapters recommended for reading will be specified later in this document.

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

DOCUMENT REVISION HISTORY

Revision A (August 2012)

• Initial Release of this Document.
Chapter 1. Product Overview

1.1 INTRODUCTION

The MCP6L2 and PIC18F66J93 Energy Meter is a fully functional single-phase meter that uses the 12-bit successive approximation analog-to-digital converter (SAR ADC) integrated in the microcontroller. This low-cost design has a shunt as the current sensor. The signal from the shunt is amplified by two external operational amplifiers and applied to the input of the ADC. The PIC18F66J93 directly drives the LCD and communicates via UART with the MCP2200, offering an isolated USB connection for meter calibration and access to the device power calculations. The system calculates active and reactive energy; active, reactive and apparent power; power factor; RMS current; RMS voltage, and line frequency.

The Microchip energy meter software is used to calibrate and monitor the system. The calibration can be done in closed loop or open loop. When connected to a stable source of voltage and current, the meter can do an auto-calibration by including the open loop calibration routine and formulas in the firmware.

FIGURE 1-1: MCP6L2 and PIC18F66J93 Energy Meter Reference Design.
1.2 WHAT DOES THE MCP6L2 AND PIC18F66J93 ENERGY METER KIT INCLUDE?

This MCP6L2 and PIC18F66J93 Energy Meter kit includes:
- MCP6L2 and PIC18F66J93 Energy Meter (ARD00370)
- Important Information Sheet

1.3 GETTING STARTED

To illustrate how to use the MCP6L2 and PIC18F66J93 Energy Meter, the following example is shown using a two-wire 1-phase, 220 VAC line voltage and connections using energy meter calibrator equipment, or other programmable load source. The nominal current ($I_N$) is 5A, and the maximum current ($I_{MAX}$) is 60A. The energy meter was designed for 50 Hz line systems.

All connections described in this section are dependent upon the choice of the current sensing element. A secondary external transformer may be required in higher current meter designs. To test a calibrated meter, the following connections apply for a two-wire connection.

1.3.1 Step 1: Wiring Connections

Figure 1-2 is identifying the line and load connections of the MCP6L2 and PIC18F66J93 Energy Meter.

![Example Connections using a Two-wire System.](image)

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 MCP6L2 and PIC18F66J93 Energy Meter:

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

Legend:

1. ICSP Programming header (non-isolated)
2. +9V DC input (non-isolated)
3. Connections to shunt current sensing resistor
4. Connections to Line and Neutral
5. Push-button switches
6. 9-digit LCD Display with icons for kWh and kVARh
7. Pulse Output for active and reactive energy (isolated)
8. USB connection (Isolated)
FIGURE 2-2: Bottom View – Hardware Components.

Legend:
9 = Opto-isolators for pulse outputs
10 = Power supply
11 = MCP6L2 and associated signal conditioning circuitry
12 = PIC18F66J93
13 = EEPROM for storing calibration constants and energy counters
14 = Isolation IC
15 = MCP2200 for USB connection
FIGURE 2-3: Digital Connections.
2.2 INPUT AND ANALOG FRONT END

The MCP6L2 and PIC18F66J93 Energy Meter comes populated with components designed for 220V line voltage. The high voltage line and neutral connections are at the bottom of the main board. The 200 µΩ shunt sits on the high or line side of a two-wire system, and the meter employs a hot or "live" ground.

The neutral side of the two-wire system goes into a resistor divider on the voltage channel input, along with a DC offset added from VDD. Anti-aliasing low-pass filters are included. The voltage channel uses three 100 kΩ resistors and one 820Ω resistor to achieve a divider ratio of 366:1. For a line voltage of 220 VRMS, the voltage channel input signal size will be 601 mVRMS, with a DC offset of 1.65V.

![Analog Front End - Voltage Measurement.](image-url)
To amplify the signal from the shunt, this energy meter design uses the two operational amplifiers from the MCP6L2 device to create two signal paths, with different gains: one for the low-current's range and one for the high-current's range, as shown in Figures 2-5 and 2-6:

**FIGURE 2-5:** Analog Input Circuitry for Current Measurement, LOW-Current's Range.

**FIGURE 2-6:** Analog Input Circuitry for Current Measurement, HIGH-Current's Range.

The low-current's range circuit (Figure 2-5) has a gain of 325 V/V. The high-current's range circuit (Figure 2-6) has a gain of 60 V/V. The firmware switches between the two gains with hysteresis between 4 and 5 A_{RMS}.

Note that all of the circuitry associated with the analog front-end is connected to the analog ground plane, AGND.
2.3 POWER SUPPLY CIRCUIT

The capacitive power supply circuit for the MCP6L2 and PIC18F66J93 Energy Meter uses a half-wave rectified signal and two +3.3V voltage regulators. One Low-dropout (LDO) supplies the analog side, and the other supplies the digital circuitry of the meter. There is an option to use only one LDO, by populating the R33 resistor and removing the U2 LDO. This will result in a lower cost meter, at the price of a decrease in accuracy.

FIGURE 2-7:  Power Supply Circuit.
Chapter 3. Calculation Engine and Register Description

3.1 COHERENT SAMPLING ALGORITHM

3.1.1 The Advantages of the Coherent Sampling in this Energy Metering Design

The outputs of an energy meter, power and RMS values are obtained by multiplying two AC signals, computing the average value and then multiplying it with a calibration gain. Ideally, these signals are sinusoids, with the frequency equal to the line frequency:

EQUATION 3-1:

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

The two signals (S1 and S2) can be the voltage and/or the current waveforms. The instantaneous power value is obtained by multiplication:

EQUATION 3-2:

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

The resultant signal has a continuous component and a sinusoidal component with a frequency equal to double the line frequency. Because the energy meter is computing the average power, only the continuous component is of interest, with the other requiring attenuation. If it is not properly attenuated, the indication of the energy meter will fluctuate in time. There are two methods to obtain efficient attenuation of the unwanted component: low-pass filtering and coherent sampling.

The instantaneous power signal can be applied to a low-pass filter with the cutoff frequency much lower than the double of the line frequency. If the energy meter must compute Active Power, Reactive Power, RMS Voltage, RMS Current (four instantaneous power computations, in total), it means that four low-pass filters must be applied.

In this particular energy meter design, with two current paths and gain switching controlled by the firmware, the problem is more complex with the low-pass filtering approach. This is because the low-pass filters have low-cutoff frequency, and consequently, high settling time. This affects the response of the meter outputs when the current gain is switched. In order to avoid this, the signals from the two current paths must be processed simultaneously, and low-pass filters must be applied on the instantaneous powers resulting from both paths. Therefore, three additional low-pass filters are required (for the instantaneous Active Power, Reactive Power and RMS Current on the other current channel). This means a total of seven low-pass filters are required for this energy meter design. Considering that the low-pass filter routines must be executed for each sample, the resulting processing time can be too long.
The coherent sampling approach solves this issue by eliminating the low-pass filters. Coherent sampling refers to the situation when the sampling frequency is a fixed integer multiple of the line frequency. The unwanted sinusoidal component from the instantaneous power signal is attenuated under coherent sampling conditions, if the averaging is computed over a number of samples corresponding to an integer number of line cycles.

### 3.1.2 Coherent Sampling Algorithm

Coherent sampling implies a dependency between the sampling frequency and the line frequency. Because the line frequency is not fixed, the sampling frequency needs to be adjustable. In the MCP6L2 and PIC18F66J93 Energy Meter design, based on the microcontroller’s internal successive approximation ADC (SAR ADC), the sampling period is controlled by a timer. At the beginning of the Interrupt Service Routine, the new timer value is set, and then the ADC samples are acquired and processed. The new timer value is computed based on the value of the line signal period.

In order to save hardware resources (timers), the line signal period is not measured directly in this design. Based on the amplitude of the acquired signal samples, the firmware detects the zero crossings on rising edges and tries to achieve a fixed integer number of samples between successive crossings, by adjusting the sampling period. The conditions for obtaining coherent sampling implemented in the firmware are:

- The number of samples between zero crossings must have a certain value (64 samples per line cycle in this design)
- The difference between the first sample after zero crossing and the corresponding sample from the previous line period, must be within certain limits (for more accurate locking on the line frequency).

A graphical representation of these conditions is shown in Figure 3-1.

![Figure 3-1: Conditions for Obtaining Coherent Sampling Implemented in the Firmware.](image)

These conditions are checked after every zero crossing on rising edge. If they are not met, then the corrections are applied to the sampling period.
The zero-crossing detection is done on the voltage channel, because it has much lower dynamic range than the current channel. To increase immunity to noise and distortions (harmonics), the acquired voltage samples are passed through a low-pass filter with a cutoff frequency lower than the line frequency, before being processed for zero-crossing detection.

3.2 CALCULATION ENGINE SIGNAL FLOW SUMMARY

RMS voltage, RMS current, Active Power, Reactive Power, Apparent Power and calibration output pulses are calculated through the process described in Figure 3-2. The calibration registers for each calculation are shown as well as the output registers.

**FIGURE 3-2:** MCP6L2 and PIC18F66J93 Calculation Engine Signal Flow.
### 3.3 COMPLETE REGISTER LIST

<table>
<thead>
<tr>
<th>Address</th>
<th>Register Name</th>
<th>Bits</th>
<th>R/W</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x000</td>
<td>METER_VERSION_ID</td>
<td>8</td>
<td>R</td>
<td>Hardware and firmware version identification register</td>
</tr>
<tr>
<td>0x001</td>
<td>METER_STATUS</td>
<td>8</td>
<td>R</td>
<td>Contains information regarding the operational status of the meter</td>
</tr>
<tr>
<td>0x002</td>
<td>CAL_CONTROL</td>
<td>8</td>
<td>R/W</td>
<td>Configuration register for calibration control</td>
</tr>
<tr>
<td>0x003</td>
<td>RAW_I_RMS</td>
<td>16</td>
<td>R</td>
<td>Raw RMS value of the current channel</td>
</tr>
<tr>
<td>0x005</td>
<td>I_RMS</td>
<td>16</td>
<td>R</td>
<td>RMS value of the current channel, post calibration</td>
</tr>
<tr>
<td>0x007</td>
<td>RAW_V_RMS</td>
<td>16</td>
<td>R</td>
<td>Raw RMS value of the voltage channel</td>
</tr>
<tr>
<td>0x009</td>
<td>V_RMS</td>
<td>16</td>
<td>R</td>
<td>RMS value of the voltage channel, post calibration</td>
</tr>
<tr>
<td>0x00B</td>
<td>FREQUENCY</td>
<td>16</td>
<td>R</td>
<td>Line frequency indication</td>
</tr>
<tr>
<td>0x00D</td>
<td>POWER_ACT</td>
<td>32</td>
<td>R</td>
<td>Active Power indication</td>
</tr>
<tr>
<td>0x011</td>
<td>POWER_REACT</td>
<td>32</td>
<td>R</td>
<td>Reactive Power indication</td>
</tr>
<tr>
<td>0x015</td>
<td>POWER_APP</td>
<td>32</td>
<td>R</td>
<td>Apparent Power indication</td>
</tr>
<tr>
<td>0x019</td>
<td>POWER_FACTOR</td>
<td>16</td>
<td>R</td>
<td>Power factor indication</td>
</tr>
<tr>
<td>0x01B</td>
<td>PHASE_COMPENSATION</td>
<td>8</td>
<td>R</td>
<td>Phase delay between voltage and current channels</td>
</tr>
<tr>
<td>0x01C</td>
<td>GAIN_I_RMS</td>
<td>16</td>
<td>R</td>
<td>Gain adjustment for current channel RMS</td>
</tr>
<tr>
<td>0x01E</td>
<td>GAIN_POWER_ACT</td>
<td>16</td>
<td>R</td>
<td>Active Power Gain adjust</td>
</tr>
<tr>
<td>0x020</td>
<td>GAIN_POWER_REACT</td>
<td>16</td>
<td>R</td>
<td>Reactive Power Gain adjust</td>
</tr>
<tr>
<td>0x022</td>
<td>GAIN_NUMR ENERGY_ACT</td>
<td>16</td>
<td>R</td>
<td>Active Power Pulse Output correction factor</td>
</tr>
<tr>
<td>0x024</td>
<td>GAIN_DENR ENERGY_ACT</td>
<td>8</td>
<td>R</td>
<td>Active Power Pulse Output correction factor</td>
</tr>
<tr>
<td>0x025</td>
<td>GAIN_NUMR ENERGY.REACT</td>
<td>16</td>
<td>R</td>
<td>Reactive Power Pulse Output correction factor</td>
</tr>
<tr>
<td>0x027</td>
<td>GAIN_DENR ENERGY.REACT</td>
<td>8</td>
<td>R</td>
<td>Reactive Power Pulse Output correction factor</td>
</tr>
<tr>
<td>0x028</td>
<td>PHASE_COMPENSATION_LOW</td>
<td>8</td>
<td>R/W</td>
<td>Phase-delay between voltage and low region current channels</td>
</tr>
<tr>
<td>0x029</td>
<td>PHASE_COMPENSATION_HIGH</td>
<td>8</td>
<td>R/W</td>
<td>Phase-delay between voltage and high region current channels</td>
</tr>
<tr>
<td>0x02A</td>
<td>GAIN_V_RMS</td>
<td>16</td>
<td>R/W</td>
<td>Gain adjustment for voltage RMS</td>
</tr>
<tr>
<td>0x02C</td>
<td>GAIN_I_RMS_LOW</td>
<td>16</td>
<td>R/W</td>
<td>Gain adjustment for low region current RMS</td>
</tr>
<tr>
<td>0x02E</td>
<td>GAIN_I_RMS_HIGH</td>
<td>16</td>
<td>R/W</td>
<td>Gain adjustment for high region current RMS</td>
</tr>
<tr>
<td>0x030</td>
<td>GAIN_POWER_ACT_LOW</td>
<td>16</td>
<td>R/W</td>
<td>Low-region Active Power gain adjust</td>
</tr>
<tr>
<td>0x032</td>
<td>GAIN_POWER_ACT_HIGH</td>
<td>16</td>
<td>R/W</td>
<td>High-region Active Power gain adjust</td>
</tr>
<tr>
<td>0x034</td>
<td>GAIN_NUMR ENERGY_ACT_LOW</td>
<td>16</td>
<td>R/W</td>
<td>Low-region Active Power Pulse Output correction factor</td>
</tr>
<tr>
<td>0x036</td>
<td>GAIN_NUMR ENERGY_ACT_HIGH</td>
<td>16</td>
<td>R/W</td>
<td>High-region Active Power Pulse Output correction factor</td>
</tr>
<tr>
<td>0x038</td>
<td>GAIN_DENR ENERGY_ACT_LOW</td>
<td>8</td>
<td>R/W</td>
<td>Low-region Active Power Pulse Output correction factor</td>
</tr>
<tr>
<td>0x039</td>
<td>GAIN_DENR ENERGY_ACT_HIGH</td>
<td>8</td>
<td>R/W</td>
<td>High-region Active Power Pulse Output correction factor</td>
</tr>
<tr>
<td>0x03A</td>
<td>GAIN_POWER_REACT_LOW</td>
<td>16</td>
<td>R/W</td>
<td>Low-region Reactive Power gain adjust</td>
</tr>
<tr>
<td>0x03C</td>
<td>GAIN_POWER_REACT_HIGH</td>
<td>16</td>
<td>R/W</td>
<td>High-region Reactive Power gain adjust</td>
</tr>
<tr>
<td>0x03E</td>
<td>GAIN_NUMR ENERGY.REACT_LOW</td>
<td>16</td>
<td>R/W</td>
<td>Low-region Reactive Power Pulse Output correction factor</td>
</tr>
</tbody>
</table>
3.4 METER_VERSION_ID

This register contains a constant that is hard-coded in the firmware, giving information regarding the hardware and firmware version running on the energy meter.

3.5 METER_STATUS

The register contains information regarding the operational status of the energy meter.
3.6 CAL_CONTROL

This register controls the calibration process.

REGISTER 3-2: CAL_CONTROL REGISTER

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAL_CONTROL</td>
<td>8</td>
<td>0x002</td>
<td>R/W</td>
</tr>
</tbody>
</table>

| bit 7-5               | Unimplemented: Read as ‘0’ |
| bit 4                 | AUTOCAL_FIRST_LINE_CYCLE: Flag used in the auto-calibration routine.  
  1 = The actual line cycle is the first after the current region has been changed in the auto-calibration routine.  
  0 = The actual line cycle is not the first after the current region has been changed in the auto-calibration routine. |
| bit 3                 | CURRENT_REGION_SELECTED: Current region set by the external device via UART, during the calibration procedure  
  1 = Low Current Region  
  0 = High Current Region |
| bit 2                 | FORCE_CURRENT_REGION: This bit is set by the external device via UART, before the calibration procedure.  
  1 = Automatic current region selection is bypassed. The current region is set by the "CURRENT_REGION_SELECTED" bit.  
  0 = The current region is set automatically, based on current RMS indication. |
| bit 1                 | Unimplemented: Read as ‘0’ |
| bit 0                 | CAL_MODE: Activates the auto-calibration procedure.  
  1 = Auto-calibration procedure has been activated.  
  0 = Auto-calibration procedure is not enabled. |

3.7 RAW_I_RMS

This register is the raw current RMS value, before the multiplication with the calibration register GAIN_I_RMS.
3.8  **I_RMS**

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>I_RMS</td>
<td>16</td>
<td>0x005</td>
<td>R</td>
</tr>
</tbody>
</table>

This register is the current RMS indication, in amperes, after the multiplication with the calibration register GAIN_I_RMS. The decimal point is placed after three digits, for low-current region, or two digits, for high-current region. For example: if the meter is in the low region and the read value is $I_{RMS} = 5000$ (in decimal), it means that the current is 5.000A. But if the same value is read when the meter is in the high-current region, it means that the current is 50.00A.

3.9  **RAW_V_RMS**

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAW_V_RMS</td>
<td>16</td>
<td>0x007</td>
<td>R</td>
</tr>
</tbody>
</table>

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

3.10 **V_RMS**

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_RMS</td>
<td>16</td>
<td>0x009</td>
<td>R</td>
</tr>
</tbody>
</table>

This register is the voltage RMS indication, in volts, after the multiplication with the calibration register GAIN_V_RMS. The decimal point is placed after the first digit. For example: a read value of $V_{RMS} = 2200$ means 220.0V.

3.11 **FREQUENCY**

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>FREQUENCY</td>
<td>16</td>
<td>0x00B</td>
<td>R</td>
</tr>
</tbody>
</table>

This register is the line frequency indication, in hertz. The decimal point is placed after three digits. For example: a read value of $FREQUENCY = 50000$ means 50.000 Hz.

3.12 **POWER_ACT**

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>POWER_ACT</td>
<td>32</td>
<td>0x00D</td>
<td>R</td>
</tr>
</tbody>
</table>

This register is the active power indication, in watts. The decimal point is placed after five digits for low-current region or four digits for high-current region. For example: if the meter is in the low region and the read value is $POWER\_ACT = 110000000$ (in decimal), it means that the active power is 1100.0000W. If the same value is read when the meter is in the high-current region, it means that the active power is 11000.0000W.
3.13 POWER_REACT

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>POWER_REACT</td>
<td>32</td>
<td>0x011</td>
<td>R</td>
</tr>
</tbody>
</table>

This register is the reactive power indication, in VAR. The decimal point is placed after five digits, for low-current region, or four digits, for high-current region. For example: if the meter is in the low region and the read value is POWER_REACT = 11000000 (in decimal), it means that the active power is 1100.00000 VAR. If the same value is read when the meter is in the high-current region, it means that the active power is 11000.0000 VAR.

3.14 POWER_APP

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>POWER_APP</td>
<td>32</td>
<td>0x015</td>
<td>R</td>
</tr>
</tbody>
</table>

This register is the apparent power indication, in VA. The decimal point is placed after five digits, for low-current region, or four digits, for high-current region. For example: if the meter is in the low region and the read value is POWER_APP = 110000000 (in decimal), it means that the active power is 1100.00000 VA. If the same value is read when the meter is in the high-current region, it means that the active power is 11000.0000 VA.

3.15 POWER_FACTOR

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>POWER_FACTOR</td>
<td>16</td>
<td>0x019</td>
<td>R</td>
</tr>
</tbody>
</table>

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

3.16 PHASE_COMPENSATION

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE_COMPENSATION</td>
<td>8</td>
<td>0x01B</td>
<td>R</td>
</tr>
</tbody>
</table>

This register contains the phase compensation value between the voltage and the current channels, used by the metering engine at the moment of reading. It is a copy of one of the calibration registers: PHASE_COMPENSATION_LOW or PHASE_COMPENSATION_HIGH, depending on the actual current region.

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

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_I_RMS</td>
<td>16</td>
<td>0x01C</td>
<td>R</td>
</tr>
</tbody>
</table>

This register contains the gain value for the current RMS indication, used by the metering engine at the moment of reading. It is a copy of one of the calibration registers: GAIN_I_RMS_LOW or GAIN_I_RMS_HIGH, depending on the actual current region.

3.18 GAIN_POWER_ACT

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_POWER_ACT</td>
<td>16</td>
<td>0x01E</td>
<td>R</td>
</tr>
</tbody>
</table>

This register contains the gain value for the active power indication, used by the metering engine at the moment of reading. It is a copy of one of the calibration registers: GAIN_POWER_ACT_LOW or GAIN_POWER_ACT_HIGH, depending on the actual current region.

3.19 GAIN_POWER_REACT

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_POWER_REACT</td>
<td>16</td>
<td>0x020</td>
<td>R</td>
</tr>
</tbody>
</table>

This register contains the gain value for the reactive power indication, used by the metering engine at the moment of reading. It is a copy of one of the calibration registers: GAIN_POWER_REACT_LOW or GAIN_POWER_REACT_HIGH, depending on the actual current region.

3.20 GAIN_NUMR_ENERGY_ACT

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_NUMR_ENERGY_ACT</td>
<td>16</td>
<td>0x022</td>
<td>R</td>
</tr>
</tbody>
</table>

This register contains the active energy gain value necessary to produce the specified number of impulses per kilowatt-hour (the meter constant), used by the metering engine at the moment of reading. It is a copy of one of the calibration registers: GAIN_NUMR_ENERGY_ACT_LOW or GAIN_NUMR_ENERGY_ACT_HIGH, depending on the actual current region.
3.21 GAIN_DENR_ENERGY_ACT

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_DENR_ENERGY_ACT</td>
<td>8</td>
<td>0x024</td>
<td>R</td>
</tr>
</tbody>
</table>

This register contains the number of left bit shifts for the raw active power, used by the metering engine at the moment of reading. It is a copy of one of the calibration registers: GAIN_DENR_ENERGY_ACT_LOW or GAIN_DENR_ENERGY_ACT_HIGH, depending on the actual current region.

3.22 GAIN_NUMR_ENERGY.REACT

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_NUMR_ENERGY.REACT</td>
<td>16</td>
<td>0x025</td>
<td>R</td>
</tr>
</tbody>
</table>

This register contains the reactive energy gain value necessary to produce the specified number of impulses per kVArh (the meter constant), used by the metering engine at the moment of reading. It is a copy of one of the calibration registers: GAIN_NUMR_ENERGY.REACT_LOW or GAIN_NUMR_ENERGY.REACT_HIGH, depending on the actual current region.

3.23 GAIN_DENR_ENERGY.REACT

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_DENR_ENERGY.REACT</td>
<td>8</td>
<td>0x027</td>
<td>R</td>
</tr>
</tbody>
</table>

This register contains the number of left bit shifts for the raw reactive power, used by the metering engine at the moment of reading. It is a copy of one of the calibration registers: GAIN_DENR_ENERGY.REACT_LOW or GAIN_DENR_ENERGY.REACT_HIGH, depending on the actual current region.

3.24 PHASE_COMPENSATION_LOW

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE_COMPENSATION_LOW</td>
<td>8</td>
<td>0x028</td>
<td>R/W</td>
</tr>
</tbody>
</table>

This calibration register contains the phase compensation value between the voltage and the low-current region channel.

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

This calibration register contains the phase compensation value between the voltage and the high-current region channel.

For more information related to phase compensation implementation in firmware please refer to Chapter 2.3.2.3 from “PIC18F87J72 Single-Phase Energy Meter Calibration User’s Guide” (DS51964).

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE_COMPENSATION_HIGH</td>
<td>8</td>
<td>0x029</td>
<td>R/W</td>
</tr>
</tbody>
</table>

3.26 **GAIN_V_RMS**

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

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_V_RMS</td>
<td>16</td>
<td>0x02A</td>
<td>R/W</td>
</tr>
</tbody>
</table>

3.27 **GAIN_I_RMS_LOW**

This calibration register contains the gain value for the current RMS indication in the low-current region.

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_I_RMS_LOW</td>
<td>16</td>
<td>0x02C</td>
<td>R/W</td>
</tr>
</tbody>
</table>

3.28 **GAIN_I_RMS_HIGH**

This calibration register contains the gain value for the current RMS indication in the high-current region.

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_I_RMS_HIGH</td>
<td>16</td>
<td>0x02E</td>
<td>R/W</td>
</tr>
</tbody>
</table>

3.29 **GAIN_POWER_ACT_LOW**

This calibration register contains the gain value for the active power indication in the low-current region.

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_POWER_ACT_LOW</td>
<td>16</td>
<td>0x030</td>
<td>R/W</td>
</tr>
</tbody>
</table>
### 3.30 GAIN_POWER_ACT_HIGH

This calibration register contains the gain value for the active power indication in the high-current region.

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_POWER_ACT_HIGH</td>
<td>16</td>
<td>0x032</td>
<td>R/W</td>
</tr>
</tbody>
</table>

### 3.31 GAIN_NUMR_ENERGY_ACT_LOW

This calibration register contains the active energy gain value necessary to produce the specified number of impulses per kWh (the meter constant) in the low-current region.

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_NUMR_ENERGY_ACT_LOW</td>
<td>16</td>
<td>0x034</td>
<td>R/W</td>
</tr>
</tbody>
</table>

### 3.32 GAIN_NUMR_ENERGY_ACT_HIGH

This calibration register contains the active energy gain value necessary to produce the specified number of impulses per kWh (the meter constant) in the high-current region.

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_NUMR_ENERGY_ACT_HIGH</td>
<td>16</td>
<td>0x036</td>
<td>R/W</td>
</tr>
</tbody>
</table>

### 3.33 GAIN_DENR_ENERGY_ACT_LOW

This calibration register contains the number of left bit shifts for the raw active power in the low-current region.

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_DENR_ENERGY_ACT_LOW</td>
<td>8</td>
<td>0x038</td>
<td>R/W</td>
</tr>
</tbody>
</table>

### 3.34 GAIN_DENR_ENERGY_ACT_HIGH

This calibration register contains the number of left bit shifts for the raw active power in the high-current region.

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_DENR_ENERGY_ACT_HIGH</td>
<td>8</td>
<td>0x039</td>
<td>R/W</td>
</tr>
</tbody>
</table>

### 3.35 GAIN_POWER_REACT_LOW

This calibration register contains the gain value for the reactive power indication in the low-current region.

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_POWER_REACT_LOW</td>
<td>16</td>
<td>0x03A</td>
<td>R/W</td>
</tr>
</tbody>
</table>
3.36 **GAIN_POWER_REACT_HIGH**

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_POWER_REACT_HIGH</td>
<td>16</td>
<td>0x03C</td>
<td>R/W</td>
</tr>
</tbody>
</table>

This calibration register contains the gain value for the reactive power indication in the high-current region.

3.37 **GAIN_NUMR_ENERGY_REACT_LOW**

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_NUMR_ENERGY_REACT_LOW</td>
<td>16</td>
<td>0x03E</td>
<td>R/W</td>
</tr>
</tbody>
</table>

This calibration register contains the reactive energy gain value necessary to produce the specified number of impulses per kVArh (the meter constant) in the low-current region.

3.38 **GAIN_NUMR_ENERGY_REACT_HIGH**

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_NUMR_ENERGY_REACT_HIGH</td>
<td>16</td>
<td>0x040</td>
<td>R/W</td>
</tr>
</tbody>
</table>

This calibration register contains the reactive energy gain value necessary to produce the specified number of impulses per kVArh (the meter constant) in the high-current region.

3.39 **GAIN_DENR_ENERGY_REACT_LOW**

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_DENR_ENERGY_REACT_LOW</td>
<td>8</td>
<td>0x042</td>
<td>R/W</td>
</tr>
</tbody>
</table>

This calibration register contains the number of left bit shifts for the raw reactive power in the low-current region.

3.40 **GAIN_DENR_ENERGY_REACT_HIGH**

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIN_DENR_ENERGY_REACT_HIGH</td>
<td>8</td>
<td>0x043</td>
<td>R/W</td>
</tr>
</tbody>
</table>

This calibration register contains the number of left bit shifts for the raw reactive power in the low-current region.
3.41 METER_CONSTANT

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>METER_CONSTANT</td>
<td>16</td>
<td>0x044</td>
<td>R/W</td>
</tr>
</tbody>
</table>

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

3.42 PULSE_WIDTH

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>PULSE_WIDTH</td>
<td>8</td>
<td>0x046</td>
<td>R/W</td>
</tr>
</tbody>
</table>

This register contains the width of the active/reactive energy pulse in milliseconds. The maximum pulse width that can be set in the existing firmware release is 65 milliseconds. If higher values are required, then the corresponding code portion in the firmware must be modified.

3.43 NO_LOAD_THRESHOLD_I_RMS

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO_LOAD_THRESHOLD_I_RMS</td>
<td>8</td>
<td>0x047</td>
<td>R/W</td>
</tr>
</tbody>
</table>

This register contains the current RMS indication (I_RMS value) in the low-current region below which the energy accumulation is disabled.

3.44 LINE_CYC

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>LINE_CYC</td>
<td>8</td>
<td>0x048</td>
<td>R/W</td>
</tr>
</tbody>
</table>

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

\[
\text{Computation\_cycle\_duration} = 2^n \times \text{line\_cycle\_duration}
\]

The computation cycle contains a number of \(2^n\) line cycles. The indication registers are updated every computation cycle. The value of LINE_CYC register sets the update rate of the indication registers.

In this software release LINE_CYC = 4. The energy meter was designed for 50 Hz systems, so a line cycle has a period of 20 milliseconds. It results in a computation cycle of:

\[
\text{Computation\_cycle\_duration} = 2^4 \times 20 = 320 \text{ milliseconds}
\]
3.45 ENERGY_ACT

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY_ACT</td>
<td>32</td>
<td>0x100</td>
<td>R/W</td>
</tr>
</tbody>
</table>

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

3.46 ENERGY_REACT

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Address</th>
<th>Cof</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY_REACT</td>
<td>32</td>
<td>0x104</td>
<td>R/W</td>
</tr>
</tbody>
</table>

This energy counter register contains the accumulated reactive energy in kVArh. The decimal point is after two digits. For example: an indication of ENERGY_REACT = 1234 means that the value of the accumulated active energy is 12.34 kVArh.
Chapter 4. Communication Protocol

4.1 PROTOCOL

The UART of the PIC Microcontroller is used to communicate with the meter. In addition to the reading and writing of the registers, there are also dedicated commands for clearing, loading 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, R, C or A.

- E – Request for Echo Response to which meter responds with “Q” as acknowledgment
- L – Load Calibration Registers from Flash (LOAD)
- S – Store Calibration Registers (STORE)
- W – Write Bytes (WRITE)
- R – Read Bytes (READ)
- C – Load Default Calibration Values
- A – Run Auto-calibration Routine

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

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

Example: ‘EX’.
Returns: ‘QX’

4.1.1.2 “L” LOAD: LOAD CALIBRATION REGISTERS FROM FLASH

Example: ‘LX’.
Returns: ‘LX’.

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

4.1.1.3 “S” STORE: STORE CALIBRATION REGISTERS INTO FLASH

The Store command writes all the calibration values to the 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, 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: 'W03000102030405060708090A0B0C0D0E0FX'.
Returns: 'W03000102030405060708090A0B0C0D0E0FX'.

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

<table>
<thead>
<tr>
<th>Command Byte</th>
<th>3 Address Bytes (ASCII)</th>
<th>ASCII Data</th>
<th>&quot;X&quot; (ASCII)</th>
</tr>
</thead>
<tbody>
<tr>
<td>76543210</td>
<td>76543210</td>
<td>76543210</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 4-1: WRITE COMMAND EXAMPLE**

<table>
<thead>
<tr>
<th>Description</th>
<th>Command ASCII</th>
<th>Command Hex</th>
</tr>
</thead>
<tbody>
<tr>
<td>WRITE 40000d to GAIN_V_RMS Register</td>
<td>&quot;W 02A 9C40 X&quot;</td>
<td>57 30 32 41 39 43 34 30 58</td>
</tr>
</tbody>
</table>

**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: 'R03000102030405060708090A0B0C0D0E0FX'.

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

<table>
<thead>
<tr>
<th>Command Byte</th>
<th>3 Address Bytes (ASCII)</th>
<th># Bytes to Read (2 Bytes ASCII)</th>
<th>&quot;X&quot; (ASCII)</th>
</tr>
</thead>
<tbody>
<tr>
<td>76543210</td>
<td>76543210</td>
<td>76543210</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 4-2: READ COMMAND EXAMPLE**

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>COMMAND ASCII</th>
<th>COMMAND HEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>READ on POWER_ACT Register</td>
<td>&quot;R 00D 04 X&quot;</td>
<td>52 30 30 44 30 34 58</td>
</tr>
</tbody>
</table>

**FIGURE 4-2: Read Command Protocol.**
4.1.1.6 "A" AUTOCALIBRATION: RUN AUTO-CALIBRATION ROUTINE

Example: "AX"

Returns: "DX" or "BX"

This command enables the auto-calibration routine only if it is present in the firmware and returns "DX". If not, it returns "BX", indicating that the auto-calibration routine is not present in the firmware (the statement "#define AUTOCALIBRATION_ENABLE" is missing).
Chapter 5. Microchip Energy Meter Software

5.1 OVERVIEW

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

5.2 THE MAIN SCREEN

The main screen contains four tabs:

- **Energy Meter**: This tab contains the instantaneous meter output display and a debug window, which enables access to all the internal registers of the meter.
- **Closed Loop Calibration**: This tab contains a calibration tool for closed loop calibration.
- **Open Loop Calibration**: This tab contains a calibration tool for open loop calibration.
- **Auto Calibration**: This tab contains an interface for auto calibration.

The calibration procedures are presented in details in Chapter 6. “Energy Meter Calibration”.

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

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

![FIGURE 5-1: Energy Meter GUI – COM Port Selection.](image)
The tool has a feature to display the instantaneous parameters from the meter, updated in real time (see Figure 5-2). The “Instantaneous Parameters” field contains the recent meter output parameters: RMS Voltage, RMS Current, Line Frequency, Active Power, Reactive Power, Apparent Power and Power Factor. The corresponding registers are continuously collected and periodically refreshed on the PC side.

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

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

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

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

5.3.1 Refreshing Registers Status

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

![Energy Meter GUI – Debug Mode](image)

**FIGURE 5-3:** Energy Meter GUI – Debug Mode.
5.3.2 Monitoring Individual Registers

The tool enables the selected registers to be monitored for their real-time updates. Monitoring can be enabled by writing “1” to the column “Monitor” across a particular register, as shown in Figure 5-4. By enabling the monitoring feature, once the Start Refresh Instantaneous Data button is pressed, the GUI reads the register periodically, showing the real-time status. Unless monitoring is enabled, the register status is not updated after every instantaneous refresh.

![Image of Energy Meter GUI - Monitoring Individual Registers in Debug Mode]

**FIGURE 5-4:** Energy Meter GUI – Monitoring Individual Registers in Debug Mode.

5.3.3 Writing to Individual Registers

For testing certain limiting conditions and manual tuning the calibration registers, the software offers the option to write to individual registers. To write to a register, enter the value in HEX format (as stored in the registers) in the “Value” column across that particular register and press <Enter> from the keyboard to initiate the write process.
Chapter 6. Energy Meter Calibration

6.1 INTRODUCTION

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

6.2 CALIBRATION REGISTERS

This registers that need to be calibrated include the following:

- Gain registers:
  - GAIN_V_RMS
  - GAIN_I_RMS_LOW
  - GAIN_I_RMS_HIGH
  - GAIN_POWER_ACT_LOW
  - GAIN_POWER_ACT_HIGH
  - GAIN_NUMR_ENERGY_ACT_LOW
  - GAIN_NUMR_ENERGY_ACT_HIGH
  - GAIN_DENR_ENERGY_ACT_LOW
  - GAIN_DENR_ENERGY_ACT_HIGH
  - GAIN_NUMR_ENERGY_REACT_LOW
  - GAIN_NUMR_ENERGY_REACT_HIGH
  - GAIN_DENR_ENERGY_REACT_LOW
  - GAIN_DENR_ENERGY_REACT_HIGH

- Phase compensation registers:
  - PHASE_COMPENSATION_LOW
  - PHASE_COMPENSATION_HIGH

All the calibration registers, except GAIN_V_RMS, have one set of values for the low-current region and one for the high-current region. Each current region must be calibrated separately. For this purpose, the mechanism that switches automatically between the two current regions can be bypassed by setting the bit called FORCE_CURRENT_REGION, in CAL_CONTROL register. In this mode, the current region is set by the value of the CURRENT_REGION_SELECTED bit, in the same register.
6.3 CLOSED LOOP CALIBRATION

6.3.1 Closed Loop Calibration Principle

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

**EQUATION 6-1:**

\[
\text{New_gain} = \frac{\text{Existing_gain} \times \text{Indication_from_Reference_Meter}}{\text{Indication_from_Meter_to_be_calibrated}}
\]

The indication can be Voltage RMS, Current RMS, Active/Reactive Power, or Active/Reactive Energy Pulses.

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

**EQUATION 6-2:**

\[
\text{New_gain} = \frac{\text{Existing_gain}}{\text{Error[\%]} + 1}
\]

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

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

Select the Closed Loop Calibration tab. The screen from Figure 6-2 appears.

![Closed Loop Calibration Screen](image)

**FIGURE 6-2:** Closed Loop Calibration Screen.

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

- Pulse Width (ms) – PULSE_WIDTH
- Meter Constant (imp/kWh) – METER_CONSTANT
- No Load Threshold (mA) – NO_LOAD_THRESHOLD_I_RMS

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

Enter the values indicated by the Reference Meter in the “Calibration Parameters” fields. The recommended calibration values are 220V line voltage, 20A for the high-current region and 3A for the low-current region.
To start calibrating the high-current region, configure the source to provide the specified high-region calibration current and select the “Enable High Current Region” check box. The software will configure the corresponding register in the meter and force it to work in the high-current region only. The screen will change, as shown in Figure 6-3.

**FIGURE 6-3:** *Closed Loop Calibration – High-Current Region.*

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

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

When Calibrate is pressed, the software computes the new values of the following calibration registers, and saves them to EEPROM:

- **High Region, Step 1**: GAIN_V_RMS, GAIN_I_RMS_HIGH, GAIN_POWER_ACT_HIGH, GAIN_NUMR_ENERGY_ACT_HIGH, GAIN_DENR_ENERGY_ACT_HIGH
- **High Region, Step 2**: PHASE_COMPENSATION_HIGH
- **High Region, Step 3**: GAIN_POWER_REACT_HIGH, GAIN_NUMR_ENERGY_REACT_HIGH, GAIN_DENR_ENERGY_REACT_HIGH
To calibrate the low-current region, configure the source to provide the specified low-region calibration current and select the “Enable Low Current Region” check box. The software will configure the corresponding register in the meter and force it to work in the low-current region only. The screen will change, as shown in Figure 6-4.

**FIGURE 6-4:** Closed Loop Calibration – Low-Current Region.

The user must perform the calibration in the same manner as for the high region. When the *Calibrate* button is pressed, the software computes the new values of the following calibration registers, and saves them to EEPROM:

- **Low Region, Step 1**: GAIN_I_RMS_LOW, GAIN_POWER_ACT_LOW, GAIN_NUMR_ENERGY_ACT_LOW, GAIN_DENR_ENERGY_ACT_LOW
- **Low Region, Step 2**: PHASE_COMPENSATION_LOW
- **Low Region, Step 3**: GAIN_POWER_REACT_LOW, GAIN_NUMR_ENERGY_REACT_LOW, GAIN_DENR_ENERGY_REACT_LOW.

After the last calibration step, the software will automatically deselect the “Enable Low Current Region” check box, and the automatic current region selection mechanism from the energy meter will be reactivated.
6.4 OPEN LOOP CALIBRATION

6.4.1 Open Loop Calibration Principle

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

![FIGURE 6-5: Open Loop Calibration Setup.](image)

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

The calibration is done at a single power factor, different than 1 (to include the phase compensation calibration). Usually, this power factor is 0.5.

The calibration parameters are computed differently, depending on the parameter type, as follows:

- **Voltage/Current RMS Gains**: The software running on the PC reads the meter output (RMS indication) and the existing calibration gain. It calculates the new calibration gain with the following formula:

\[
\text{New RMS gain} = \text{Existing RMS gain} \times \frac{\text{Expected RMS indication}}{\text{Read RMS indication}}
\]

- **Active/Reactive Energy and Power Gains**: The software running on the PC computes these values directly, based on the assumption they are proportional to the Voltage and Current RMS gains:

\[
\text{Energy(Power) gain} = \text{Voltage RMS gain} \times \text{Current RMS gain} \times k
\]

The proportionality factors, noted with “k” in the above formula, are hard-coded in the software. They can be computed by knowing all the operations applied in the signal processing chain (bit shifts, number of samples per line cycle, number of cycles per computation cycle), or by the simpler way, computing them from the readings of the RMS and energy/power gains on a calibrated meter.

- **Phase Compensation**: The software on the PC reads the indicated Active Power from the energy meter. By knowing the expected Active Power (since the voltage, current and the applied power factor are already known), it computes the phase compensation. For more information related to phase compensation calibration, refer to Section 2.3.2.3 - Phase Compensation in “PIC18F87J72 Single-Phase Energy Meter Calibration User’s Guide (DS51964)”.

Source

Known V, I, PF

Meter to be calibrated

PC SW

Read RMS indication

Expected RMS indication

New RMS gain

Existing RMS gain

\( \times \)

\( \times \)

\( k \)
6.4.2 Open Loop Calibration with Energy Meter GUI

When the Open Loop Calibration tab is selected, the screen in Figure 6-6 will appear.

**FIGURE 6-6:** Open Loop Calibration Screen.

The source must be configured with the parameters specified in the “Calibration Parameters” box. The recommended calibration values are 220V line voltage, 20A for the high-current region, and 3A for the low-current region. The user can modify these values, but it is recommended to have the high-region calibration current higher than 5A, and the low-region calibration current lower than 5A.
To start calibrating the high-current region, configure the source to provide the specified high-region calibration current, at power factor of 0.5, and select the “Enable High Current Region” check box. The software will configure the corresponding register in the meter and force it to work in the high-current region only. The following window will appear:

![Open Loop Calibration – High Current Region](image)

**FIGURE 6-7:** *Open Loop Calibration – High Current Region*

Press **Calibrate**. The GUI sends a confirmation message when the calibration is complete and the new registers are saved to EEPROM.

At this step, the GUI calibrates all the registers related to the high-current region and the GAIN_V_RMS register. The energy gain registers are calibrated for a meter constant of 3200 imp/kWh.
To calibrate the low-current region, configure the source to provide the specified low-region calibration current, at power factor of 0.5, and select the “Enable Low Current Region” check box. The software will configure the corresponding register in the meter and force it to work in the low-current region only. The following window will appear:

![Image of calibration window](image)

**FIGURE 6-8:** Open Loop Calibration – Low-Current Region.

Press **Calibrate**. A confirmation message will be sent when the calibration is complete and the new registers are saved to EEPROM.

At this step, the GUI calibrates all the registers related to the low-current region. The energy gain registers are calibrated for a meter constant of 3200 imp/kWh.
6.5 AUTO-CALIBRATION

6.5.1 Auto-Calibration Principle

Auto Calibration is considered to be the open loop calibration routine implemented into the energy meter’s firmware. Communication with the PC is not required during this procedure.

The Auto-Calibration routine can be triggered by external events, such as I/O pin state change (from push-button, jumper or other MCU), or UART command (as in this design).

When the trigger event is received, the meter enters into Auto-Calibration mode: it acquires data, computes the calibration parameters and saves them to EEPROM. Then it returns back to Normal mode.

Because the calibration routine occupies a significant size of the program memory, the user has the option to remove it from the code by commenting the statement `#define AUTOCALIBRATION_ENABLE` in the file `Config_EnergyMeter.c`. If the size of the program memory becomes a limitation in the user’s custom design, the user may create two firmware versions: one for the calibration, with a reduced set of features, and one with the auto-calibration routine removed and the complete set of features.

The auto-calibration method implemented in this design requires only one current level. Both low- and high-current regions are calibrated at 5A. This value was selected to be in the range of both regions.

The execution time of the auto calibration routine includes the following components:

- the duration of two line cycles (one for the high-current region and one for the low-current region)
- calibration registers calculation time (it is much lower than the duration of a line cycle so it can be neglected)
- the necessary time to store the calibration registers to EEPROM
6.5.2 Auto-Calibration with Energy Meter GUI

When the Auto Calibration tab is selected, the following screen appears:

The source must be configured with the parameters specified in the text above the Calibrate button.

After Calibrate is pressed, three possible messages can appear:

• An error message indicating that the auto-calibration routine is not present in the meter code, because the firmware was compiled with the statement `#define AUTOCALIBRATION_ENABLE` commented or missing.
• “Auto Calibration Complete”
• “Communication error. Calibration not done.” — this means the GUI did not receive feedback from the energy meter.

In the current firmware version, the energy gain registers are computed for a meter constant of 3200 imp/kWh.

FIGURE 6-9: Auto-Calibration Screen.

The calibration parameters are hardcoded in the PW (Voltage 220V, Current 5A, Power Factor 0.5 lag). For different values, please modify the PW.

Before pressing “Calibrate”, please check that the meter is connected to the calibration equipment configured with the parameters specified above.
Appendix A. Schematic and Layouts

A.1 INTRODUCTION

This appendix contains the following schematics and layouts of the MCP6L2 and PIC18F66J93 Energy Meter:

- Board – Schematic – Analog-to-Digital Converter
- Board – Schematic – Microcontroller
- Board – Schematic – LCD - USB
- Board – Top Silk
- Board – Top Copper
- Board – Top Silk and Copper
- Board – Bottom Silk
- Board – Bottom Copper
- Board – Bottom Silk and Copper

A.2 SCHEMATICS AND PCB LAYOUT

The layer order is shown in Figure A-1.

![Layer Order](image)

**FIGURE A-1:** Layer Order.
A.7 BOARD – TOP COPPER
A.11 BOARD – BOTTOM SILK AND COPPER
## Appendix B. Bill of Materials (BOM)

<table>
<thead>
<tr>
<th>Qty.</th>
<th>Reference</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>C1, C5, C9, C12</td>
<td>Cap. ceramic 2.2 uF 6.3V 10% X7R 0603</td>
<td>TDK Corporation</td>
<td>C1608X7R0J225K</td>
</tr>
<tr>
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<td>C2, C3, C6, C10, C11, C13</td>
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<td>TDK Corporation</td>
<td>C1608X7R1A224K</td>
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<td>TAJA476K004RNJ</td>
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<td>C1608X7R1C154K</td>
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<td>C1608X7R1H333K</td>
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<td>16</td>
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<td>C1608X7R1C104K</td>
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<tr>
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<td>C3216X7R1A106M</td>
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<tr>
<td>1</td>
<td>C18</td>
<td>Cap. film 0.47 uF 305V AC power supply</td>
<td>EPCOS AG</td>
<td>B32932A3474M</td>
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<tr>
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<td>C19</td>
<td>Cap. film .01 uF 330V AC suppress</td>
<td>EPCOS AG</td>
<td>B32911A3103M</td>
</tr>
<tr>
<td>1</td>
<td>C20</td>
<td>Cap. elect. 470 uF 16V 20% VS size F</td>
<td>Panasonic®- ECG</td>
<td>EEE-1CA471UP</td>
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<tr>
<td>2</td>
<td>C25, C27</td>
<td>Cap. ceramic 1 uF 10V X7R 20% 0603</td>
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<td>C1608X7R1A105M</td>
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<tr>
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<td>Cap. ceramic 22 pF 50V 5% C0G. 0603</td>
<td>TDK Corporation</td>
<td>C1608CG1H220J</td>
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<tr>
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<td>D1, D2</td>
<td>Diode STD REC 1A 600V SMA.</td>
<td>ON Semiconductor®</td>
<td>MRA4005T3G</td>
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<tr>
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<td>D3</td>
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<td>Fairchild Semiconductor®</td>
<td>1N4744A</td>
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<td>J1</td>
<td>Conn. power jack male 2.5 mm clsd.</td>
<td>CUI Inc</td>
<td>PJ-002B</td>
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<tr>
<td>1</td>
<td>J2</td>
<td>Conn. recept. USB TH. vert. 5 pos.</td>
<td>Molex®</td>
<td>500075-1517</td>
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<tr>
<td>1</td>
<td>J3</td>
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<td>TE Connectivity, Ltd.</td>
<td>HDR M 1x6 Vertical</td>
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<tr>
<td>2</td>
<td>J4, J5</td>
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<td>TE Connectivity, Ltd.</td>
<td>HDR M 1x2 Vertical</td>
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<td>Ferrite 800 MA 150 mOhm 0805 SMD.</td>
<td>Laird Technologies®</td>
<td>LIO805H151R-10</td>
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<tr>
<td>2</td>
<td>L3, L4</td>
<td>Bead core single 3.8 X 5.3 mm axial</td>
<td>Panasonic - ECG</td>
<td>EXC-ELSA35</td>
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<td>LD1</td>
<td>LED 2 X 1.2mm rd/gn wrt. clr. SMD.</td>
<td>Kingbright Corporation</td>
<td>APHBM2012SURKCGKC</td>
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<td>LED 5mm RED 640 nm 20 mcd 2 mA</td>
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<td>WP7113LSRD</td>
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<td>MOV1</td>
<td>Varistor 420 V RMS 20 mm radial</td>
<td>EPCOS AG</td>
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</table>

**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)

<table>
<thead>
<tr>
<th>Qty</th>
<th>Reference</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Part Number</th>
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<tbody>
<tr>
<td>1</td>
<td>PCB</td>
<td>Printed Circuit Board – MCP6L2 and PIC18F66J93 Energy Meter Reference Design</td>
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<td>104-00370</td>
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<tr>
<td>8</td>
<td>R1, R2, R12, R18, R19, R21, R28, R32</td>
<td>Res. 681 kOhm 1/10W 1% 0603 SMD.</td>
<td>Panasonic - ECG</td>
<td>ERJ-3EKF6813V</td>
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<td>Panasonic - ECG</td>
<td>ERJ-3EKF49R9V</td>
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<tr>
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<td>Res. 499 Ohm 1/10W 1% 0603 SMD.</td>
<td>Panasonic - ECG</td>
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<tr>
<td>1</td>
<td>R6</td>
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<td>Panasonic - ECG</td>
<td>ERJ-3EKF6800V</td>
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<td>Vishay Intertechnology, Inc.</td>
<td>CRCW06032R49FKEA</td>
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<td>R11, R22</td>
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<td>Res. 0 Ohm 1/10W 0603 SMD.</td>
<td>Panasonic - ECG</td>
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<td>ERJ-3EKF3401V</td>
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<td>ERJ-3EKF8200V</td>
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<td>Panasonic - ECG</td>
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<td>R35</td>
<td>Res. 47 kOhm 1/10W 5% 0603 SMD.</td>
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<td>R45, R46, R47</td>
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<td>R48, R52</td>
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<tr>
<td>2</td>
<td>R51, R54</td>
<td>Res. 3.3 kOhm 1/10W 5% 0603 SMD.</td>
<td>Panasonic - ECG</td>
<td>ERJ-3GEYJ332V</td>
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<td>SW1, SW2, SW3</td>
<td>Switch tact. 6 mm 160 GFH = 4.3 mm</td>
<td>Omron Electronics</td>
<td>B3S-1000P</td>
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<tr>
<td>1</td>
<td>U5</td>
<td>Isolator HS dual digital SOIC-8</td>
<td>NVE Corporation</td>
<td>IL721-3E</td>
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<tr>
<td>2</td>
<td>U8, U9</td>
<td>Photocoupler Darl. Out 4-SMD.</td>
<td>Sharp Corporation</td>
<td>PC365N1000F</td>
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<tr>
<td>1</td>
<td>X1</td>
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<td>Murata Electronics</td>
<td>CSTCE12MOG55-R0</td>
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<tr>
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<td>Crystal 8 MHz 18 pF SMD.</td>
<td>Abracon Corporation</td>
<td>ABLS-8.000MHZ-B4-T</td>
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</table>

**Note 1:** The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.
### TABLE B-2: BILL OF MATERIALS – MICROCHIP CONSIGNE PARTS

<table>
<thead>
<tr>
<th>Qty</th>
<th>Reference</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Part Number</th>
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</thead>
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<tr>
<td>1</td>
<td>LCD1</td>
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<td>Xiamen Ocular Optics Co., Ltd.</td>
<td>DP076P</td>
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<td>MCP6L2T-E/SN</td>
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<td>1</td>
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<td>Microchip Technology Inc.</td>
<td>24FC256-I/SN</td>
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**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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http://www.microchip.com/support
Web Address:
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Fax: 905-673-6509

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Suits 3707-14, 37th Floor
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Fax: 86-25-8473-2470

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Fax: 86-532-8502-7205

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Fax: 86-21-5407-5066

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Fax: 86-24-2334-2393

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Fax: 86-756-3210049

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Fax: 91-80-3090-4123

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Fax: 91-11-4160-8632

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

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Tel: 81-66-152-7160
Fax: 81-66-152-9310

#### Japan - Yokohama
Tel: 81-45-471-6166
Fax: 81-45-471-6122

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

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

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

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

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

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Fax: 65-6334-8850

#### Taiwan - Hsin Chu
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Fax: 886-3-5770-955

#### Taiwan - Kaohsiung
Tel: 886-7-536-4818
Fax: 886-7-330-9305

#### Taiwan - Taipei
Tel: 886-2-2500-6610
Fax: 886-2-2508-0102

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

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

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

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

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

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

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

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

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

11/29/11