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

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ISBN: 978-1-61341-305-0

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# PIC18F87J72 SINGLE-PHASE ENERGY METER CALIBRATION USER'S GUIDE

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

## INTRODUCTION

This chapter contains general information that will be useful to know before using the Microchip Single-Phase Energy Meter Calibration Tool. Items discussed in this chapter include:

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

## DOCUMENT LAYOUT

This document describes how to use the Single Phase Energy Meter Calibration tool in energy meter design. The manual layout is as follows:

- **Chapter 1. Product Overview** provides a brief overview of the calibration tool, its features and uses.
- **Chapter 2. Meter Calibration** provides detail on calibration implementation and how to calibrate the meter. The PC calibration software, included with the reference design manual, automates the steps and calculations described in this chapter.
- **Chapter 3. Microchip Energy Meter Software** provides a detailed description of features of the calibration software tool, which is provided with the Single-Phase Energy Meter Calibration Reference Design User's Guide.
- **Chapter 4. Communication Protocol** provides the details on the protocol used to communicate with the meter for accessing the internal registers.

# PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide

## 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
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) { ... }

## RECOMMENDED READING

This user's guide describes how to use the Microchip Single-Phase Energy Meter Calibration Tool. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources:

### **User's Guide – “PIC18F87J72 Energy Meter Reference Design”(DS51931A)**

This user's guide contains the details of energy meters internal registers and hardware design descriptions.

### **PIC18F87J72 Family Data Sheet – “80-Pin, High-Performance Microcontrollers with Dual Channel AFE, LCD Driver and nanoWatt Technology” (DS39979)**

This data sheet provides detailed information regarding the PIC18F87J72 device.

### **AN994 – “IEC61036 Meter Design using the MCP3905A/06A Energy Metering Devices” (DS00994)**

This application note describes the design decisions related to the meter design using the MCP390X devices and IEC compliance. These are directly related to the PIC18F87J72 and other PIC<sup>®</sup> based energy meter designs.

## 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, and the Microchip consultant program member listing
- **Application and Market Support** – Specific information on Microchip's latest solutions for targeted vertical markets and hardware solutions, including ready-to-use application libraries to support the latest hardware
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, and distributors and factory representatives

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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://support.microchip.com>

# **PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide**

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## **DOCUMENT REVISION HISTORY**

### **Revision A (June 2011)**

Initial Release of this Document.



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## Chapter 1. Product Overview

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### 1.1 INTRODUCTION

Energy meters are part of electricity distribution networks, which measure electricity consumption. Usage of the energy meter in the electricity distribution network requires the energy meters to be adaptable to various configurations. This depends on the part of the distribution network and the type of end consumer for which the energy meters are installed. These configurations include a wide range of voltage and current, across which the meter should be functional, as per the specifications. The above requirements demand the metering engine to be adaptable, so that the transducers converting the input signal are selectable, depending on the specification, while still recording the actual values of the input line signal.

The meter design is comprised of many components, which may vary in their characteristics due to the various factors across the meter design.

The components that form part of the circuitry include:

- Current Transformer (CT) or Shunt used as a current transducer
- Resistive voltage divider as voltage transducer
- Resistors
- Capacitors
- Inductors

These variations in characteristics have an impact on measured signals, which may result in offset addition, amplitude alteration and change in signal phase.

Considering all the above factors, the standard value calibration needs to be carried out to achieve meter output. Calibration is the process where the line parameters are set to known values and the various signal conditioning parameters such as gain, offset compensation, and phase compensation factors are calculated.

The calibration process should be comprehensive. The process should aid meter design by selecting the various transducers, and should be fast enough to reduce the production line assembly time. The calibration should be accountable for the specifications like accuracy, class, and various parameters that need to be measured by the meter. The above requirements necessitate that the calibration process should be:

- Fast to aid production line calibration
- Achieve required meter specifications in one iteration
- Give information about the value of transducers required for a particular specification of the meter, aiding meter design
- Modular such that only required meter output parameter can be calibrated to desired level of accuracy

Different types of calibrations, considering all the above factors, are described in the following chapters.

# **PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide**

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## Chapter 2. Meter Calibration

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### 2.1 INTRODUCTION

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

### 2.2 TYPES OF CALIBRATION

Based on the type of meter accuracy class, and the stages of meter development, the different types of calibration options provided are:

- Closed Loop Calibration
- Multipoint Calibration
- Single Point Calibration

During the calibration process, the following register values are computed:

- Gain registers
  - GAIN\_V\_RMS
  - GAIN\_I\_RMS
  - GAIN\_POWER\_ACT
  - GAIN\_POWER\_REACT
  - GAIN\_NUMR\_ENERGY\_ACT
  - GAIN\_DENR\_ENERGY\_ACT
  - GAIN\_NUMR\_ENERGY\_REACT
  - GAIN\_DENR\_ENERGY\_REACT
- Offset registers
  - OFFSET\_I\_RMS
  - OFFSET\_V\_RMS
  - OFFSET\_POWER\_ACT
  - OFFSET\_POWER\_REACT
- Phase compensation register
  - PHASE\_COMPENSATION
- Creep threshold for No Load condition
  - CREEP\_THRSHOLD\_MINUTE
  - CREEP\_THRSHOLD\_SECOND

<p><b>Note:</b> For descriptions on these registers, refer to User's Guide – "PIC18F87J72 Energy Meter Reference Design"(DS51931)</p>
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The calibration flow charts, procedures and equation presented in this section are all automated using Microchip's "Single Phase Energy Meter Calibration Software", downloadable from the Energy Meter product page. The calibration software features multiple tabs, offering three different calibration processes.

## 2.2.1 Calibration Requirements

The calibration requirements for the Closed Loop, Multipoint and Single Point Calibration process are:

### • Requirement for Closed Loop Calibration

Closed loop calibration requires a reference meter. The reference meter is an accurate measurement source capable of measuring the line parameters and the output of the meter under calibration simultaneously, and gives the percentage difference. Calibration using a reference meter is common practice in the industry, which is adopted in the Closed Loop Calibration. To measure the output of the meter under calibration, the calibration pulse rate (CF pulse) is used, which is proportional to the energy accumulated by the meter. The rate of CF pulse of the meter and the reference meter are compared to calculate this percentage error (Error %). This Error % is used as feedback to calibrate the meter. The Closed Loop Calibration method reads the meter output as an average value over a period. Therefore, even if the line input is not from a highly accurate input source, it will not be a limitation during the closed loop calibration.

### • Requirement for Multipoint and Single Point Calibration

The accurate source that feeds the line parameters precisely is used in the multipoint and single point calibration. In this calibration process, the parameter under calibration is measured over a definite period, under the condition that the input is precisely set to a known value without any fluctuations. Based on this, various calibration register values are computed theoretically. As the calibration does not involve any feedback, the source feeding the line parameters must be highly accurate to achieve the desired accuracy class.

## 2.3 CLOSED LOOP CALIBRATION

The Closed Loop Calibration process involves taking feedback from the meter output and comparing it with the reference meter for the given parameter values. Error % in the meter output with respect to the standard reference meter is calculated, and the register values are adjusted until the desired level of accuracy is achieved.

Closed Loop Calibration includes two configurations, offered as a modular process:

- Power Calibration
- Energy Calibration

During these stages, various meter outputs are calibrated, and include:

- RMS Voltage
- RMS Current
- Active Power
- Reactive Power
- Apparent Power
- Active Energy
- Reactive Energy

All the above meter outputs can be calibrated independently, with the few dependencies based on the accuracy class of the meter under calibration.

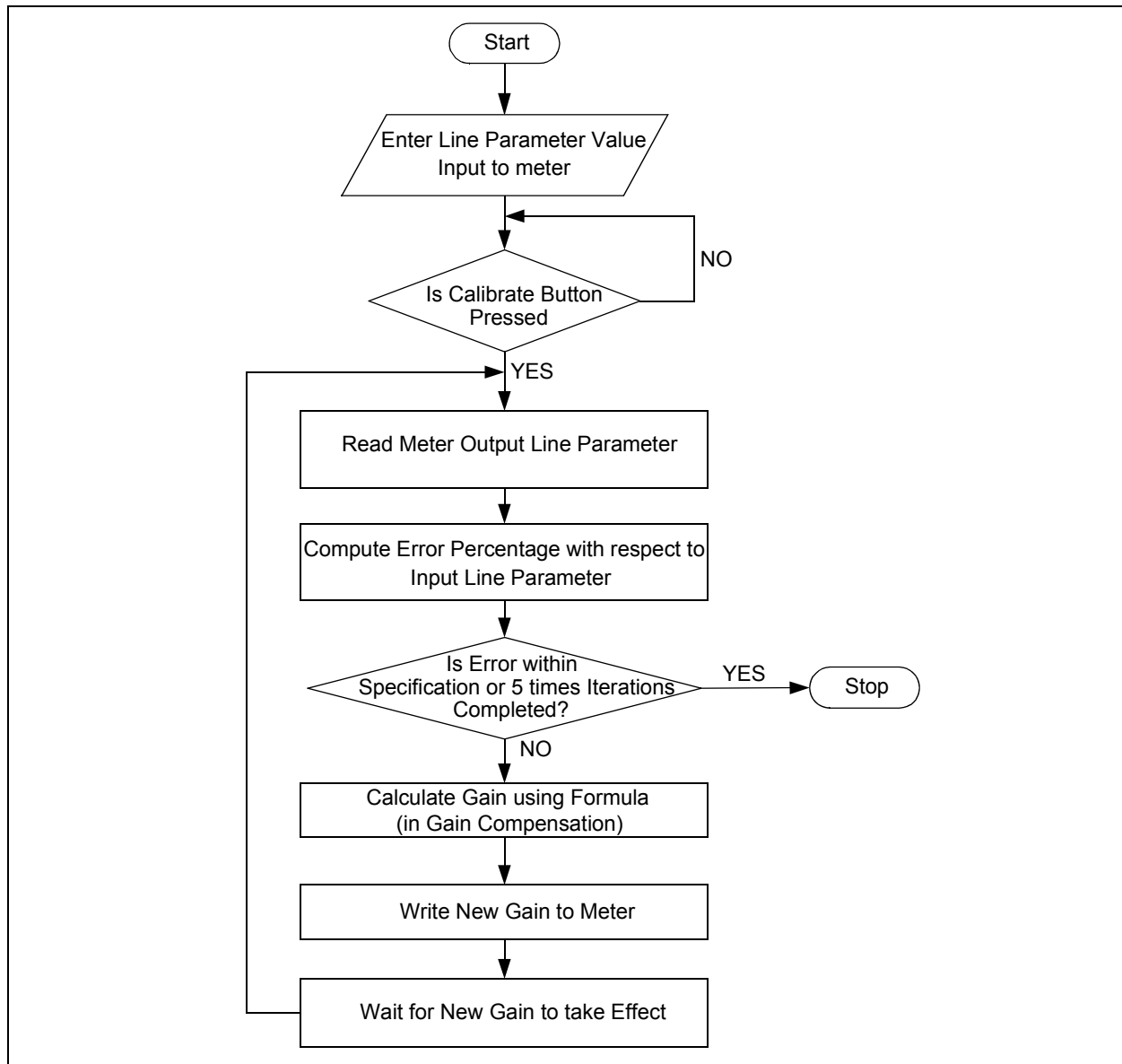
The method of calibrating these separate signal flows can be combined into five different stages in the power calibration tab, and three different stages in the energy calibration tab. These stages consist of supplying specific voltage and current at specific phase angles to the meter and input the Error % in energy registered in the reference meter.

Depending on the accuracy and the meter type, all calibration stages are not required to calibrate a meter completely. In some cases, only a few calibration stages are required. The software allows individual stages to be carried out independently, during the calibration flow.

## 2.3.1 Generic Flow chart for closed Loop calibration

Figure 2-1 represents the generic calibration process followed for:

- RMS Voltage
- RMS Current
- Active Power
- Reactive Power



**FIGURE 2-1:** Generic Flow Chart for Closed Loop Calibration.

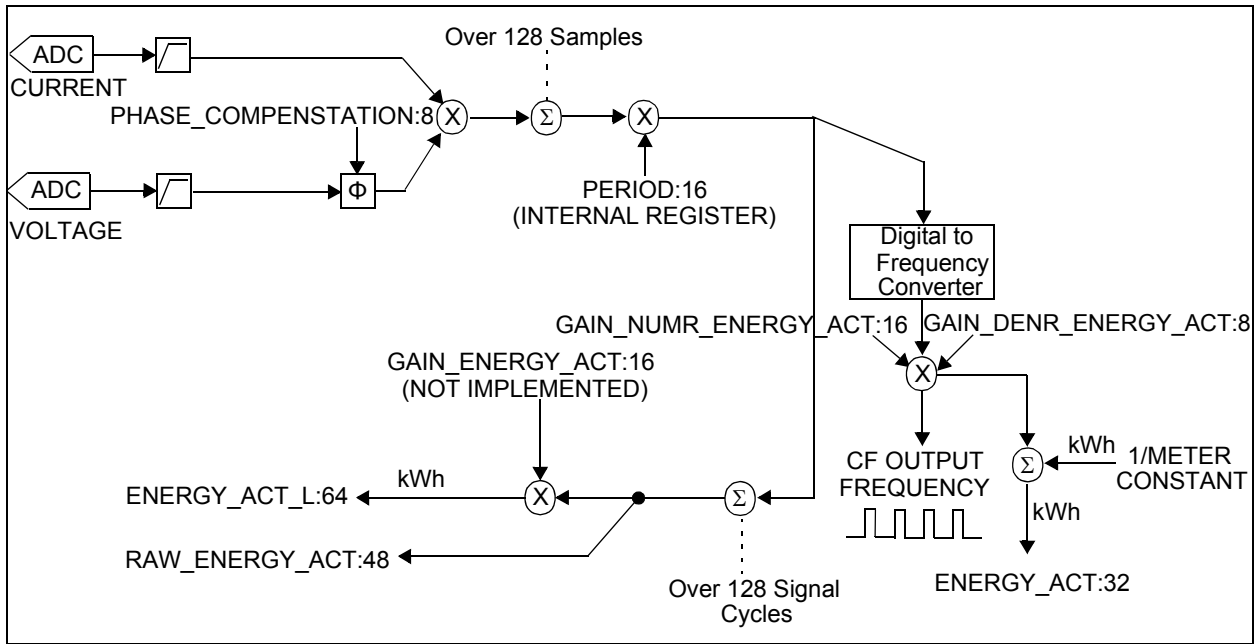
## 2.3.2 ENERGY CALIBRATION

In energy calibration, the calibration pulse rate, proportional to the energy measured by the meter, is used in the calibration. The calibration pulse output from the meter is probed to the reference meter. Any error registered in the energy meter is given by the reference meter, based on the difference in the blinking rate. This error percentage is entered as an input to the energy calibration. Depending upon the error, necessary corrections are made to the energy gain and phase compensation.

Energy calibration is carried out for active energy and reactive energy. Reactive energy calibration should always be preceded by the active energy calibration. In the two stages of active energy calibration, the phase compensation between voltage and current is computed, which is necessary for achieving good accuracy in reactive energy calibration.

### 2.3.2.1 ACTIVE ENERGY SIGNAL FLOW AND CALIBRATION

During the active energy calibration, the gain register `GAIN_NUMR_ENERGY_ACT`, `GAIN_DENR_ENERGY_ACT` and `PHASE_COMPENSATION` gets computed. Figure 2-2 shows the active energy calculation in the metering engine, the calibration gain and the phase compensation registers.



**FIGURE 2-2:** Active Energy Calculation Signal Flow.

## 2.3.2.2 ACTIVE ENERGY GAIN COMPUTATION

Active energy gain is computed as the percentage ratio of the error recorded against the previous gain. The Error % is the difference between the input line active energy and the meter output as recorded by the reference meter. Active energy gain is computed using Equation 2-1.

### EQUATION 2-1: ACTIVE ENERGY GAIN COMPUTATION

$$GAIN_{(NewValue)} = \frac{GAIN_{(OldValue)}}{\left(\frac{Error\%}{100}\right) + 1}$$

If  $GAIN > 65535$

Then,

$$GAIN\_NUMR\_ENERGY\_ACT_{(New\ Value)} = GAIN_{(New\ Value)} / 2$$

$$GAIN\_DENR\_ENERGY\_ACT_{(New\ Value)} = GAIN\_DENR\_ENERGY\_ACT_{(Old\ Value)} + 1$$

else,

$$GAIN\_NUMR\_ENERGY\_ACT_{(New\ Value)} = GAIN_{(New\ Value)}$$

$$GAIN\_DENR\_ENERGY\_ACT_{(New\ Value)} = GAIN\_DENR\_ENERGY\_ACT_{(Old\ Value)}$$

## 2.3.2.3 PHASE COMPENSATION

Due to reactive components in the signal flow path, the voltage and current may not be in phase at PF = 1.0. Therefore, the voltage and current samples measured will have a small phase offset, that may affect the energy accuracy. To rectify the offset, phase compensation is introduced, which shifts the voltage/current samples by corresponding angle through an interpolation method.

### 2.3.2.3.1 Phase Compensation Calculation

Equations 2-2 to 2-6 shows the calculation of different stages of phase compensation.

### EQUATION 2-2: ENERGY WITH PHASE ERROR AT PF = 1.0

Energy at PF = 1.0 ( $\Phi = 0^\circ$ ):

$$E_{UPF} = V_{RMS} \times I_{RMS} \times \cos(\Phi + \beta) \times Period = V_{RMS} \times I_{RMS} \times \cos(\beta) \times Period$$

Where:

$\Phi$  = Input Phase between V and I

$\beta$  = Phase deviation between V and I,  $\beta \in [-90^\circ, +90^\circ]$

### EQUATION 2-3: ENERGY WITH PHASE ERROR AT PF = 0.5 LAG

Energy at PF = 0.5 lag ( $\Phi = 60^\circ$ ):

$$\begin{aligned} E_{PF0.5\_error} &= V_{RMS} \times I_{RMS} \times \cos(\Phi + \beta) \times Period \\ &= V_{RMS} \times I_{RMS} \times \cos(60 + \beta) \times Period \end{aligned}$$

Where:

$\Phi$  = Input Phase between V and I

$\beta$  = Phase deviation between V and I,  $\beta \in [-90^\circ, +90^\circ]$

## EQUATION 2-4: ENERGY WITHOUT PHASE ERROR AT PF = 0.5 LAG

*Actual Energy at PF = 0.5 lag (  $\Phi = 60^\circ$  ):*

$$\begin{aligned} E_{PF0.5} &= V_{RMS} \times I_{RMS} \times \text{Cos}(\theta) \times \text{Period} \\ &= V_{RMS} \times I_{RMS} \times \text{Cos}(60) \times \text{Period} \end{aligned}$$

Where:

$$\Phi = \text{Input Phase between V and I}$$

## EQUATION 2-5: PHASE COMPENSATION ANGLE CALCULATION

$$\text{Error} = (E_{PF0.5} - E_{PF0.5\_error}) * 100 / E_{PF0.5}$$

$$\text{Error}/100 = 1 - (E_{PF0.5\_error} / E_{PF0.5})$$

Substituting equations and simplify:

$$\begin{aligned} \text{Error}/100 &= 1 - (\text{Cos}(60 + \beta) / \text{Cos}(60)) \\ &= 1 - (\text{Cos}(60 + \beta) / 0.5) \end{aligned}$$

$$\text{Cos}(60 + \beta) = 0.5 \times (1 + \text{Error}/100) = n$$

$$\beta = [\text{COS}^{-1}(n) - 60] \text{ in degree is the phase compensation angle}$$

## EQUATION 2-6: PHASE COMPENSATION FACTOR CALCULATION

$$\begin{aligned} \text{PHASE\_COMPENSATION} &= \beta \times 128 / \text{Angle between samples} \\ &= \beta \times 128 / 5.529^\circ \end{aligned}$$

$$\begin{aligned} \text{Angle between samples} &= 360^\circ / \text{Samples per sine cycle} \\ &= 360^\circ / 65.1 \\ &= 5.529^\circ \end{aligned}$$

$$\begin{aligned} \text{Samples per sine cycle} &= \text{Sampling rate} / \text{Frequency of Signal} \\ &= 3906 / 60\text{Hz} \\ &= 65.1 \text{ samples per cycle} \end{aligned}$$

Magnitude of Phase compensation factor:

$$\begin{aligned} \text{PHASE\_COMPENSATION (magnitude)} &= |\text{PHASE\_COMPENSATION}| \\ &= \text{PHASE\_COMPENSATION} \times 2 \end{aligned}$$

**Note 1:** The Sign convention of Phase Compensation angle is:

- Positive, if the current leads voltage
- Negative, if the current lags voltage

### 2.3.2.3.2 Phase Compensation between Voltage and Current

To determine the state of the signal between the two successive samples, use the interpolation method.

If  $x(\Theta-N)$  and  $x(\Theta)$  are known, where, " $\Theta$ " is the phase of signal that can vary between  $0^\circ$  to  $360^\circ$  and " $N$ " is the angle between two successive samples =  $(360 * \text{frequency of signal/sampling rate})$ , then it is possible to determine the state of the signal at any interval between ' $\Theta-N$ ' and ' $\Theta$ ' with an assumption that signal varies linearly in the intermediate region as shown in Equation 2-7.

To apply this method to a line signal, the sampling rate has to be selected such that the interval between successive samples is small. This ensures that the above stated assumption holds true.



## EQUATION 2-7: CALCULATIONS WITH THE INTERPOLATION METHOD

Consider,  $X(\Theta)$  and  $X(\Theta - N)$  as known samples

$$X[\Theta + \beta] = X[\Theta] + (X[\Theta] - X[\Theta - N]) * PHASE\_COMPENSATION (magnitude)/256$$

Where:

$$\Theta - N \leq \Theta + \beta \leq \Theta$$

$\Theta$  = Varies between 0 and 360°

$N$  = Angle between successive samples = (360 \* frequency of signal / sampling rate)

PHASE\_COMPENSATION value is derived from **Equations 2-2 to 2-6**.

Equation 2-7 implements the linear interpolation on the previous sample of voltage for the phase compensation. The present or the previous sample of current is considered, depending on the voltage lag or lead condition respectively, as explained in Case 1 and Case 2, thus accounting to compensate phase by a maximum angle of  $\pm N/2$ .

### Case 1: Current Leads Voltage by Angle $\beta$

Phase correction factor "PHASE\_COMPENSATION" is calculated for the correction angle ' $\beta$ ' as explained in Equation 2-5 and Equation 2-6. In this case ' $\beta$ ' is positive, therefore "PHASE\_COMPENSATION" value will be positive as explained in Note 1.

As the current leads the voltage during phase compensation, the voltage sample needs to be given a lead by an angle ' $\beta$ '. From the interpolation method, it is possible to determine  $X(\Theta + \beta)$  from  $X(\Theta)$  and  $X(\Theta - N)$  and achieve a lead. The lead can only be applied to the previous sample, but not to the present sample.

Therefore, keeping the above argument in consideration to compensate the current lead:

- Phase compensation is carried out on the voltage sample, introducing a lead by using the present and the previous sample of voltage. This phase lead is applied to the previous sample of voltage.
- As the phase lead is applied to the previous sample of voltage, the corresponding previous sample of current is considered. This compensation brings voltage and current in synchronization.

### Case 2: Current Lags Voltage by Angle $\beta$

The phase correction factor "PHASE\_COMPENSATION", is calculated for the correction angle ' $\beta$ ' as explained in Equation 2-5 and Equation 2-6. In this case, ' $\beta$ ' is negative, therefore the "PHASE\_COMPENSATION" value will be negative as explained in Note 1.

As the current lags voltage during phase compensation, the voltage sample needs to be given a lead by angle ' $N-\beta$ '. From the interpolation method, it is possible to determine  $X[\Theta + N - \beta]$  from  $X(\Theta)$  and  $X(\Theta-N)$  as  $\Theta-N \leq \Theta + N - \beta \leq \Theta$  and achieve a lead. The lead can only be applied to the previous sample, but not to the present sample.

Therefore, keeping the above argument in consideration in order to compensate the current lag:

- Phase compensation is carried out on the voltage sample, introducing a lead by using the present and the previous sample of voltage. This phase lead is applied to the previous sample of voltage.
- As the phase lead is applied to the previous sample of voltage, the present sample of current is considered. This compensation brings voltage and current in synchronization.

# PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide

## 2.3.2.4 ACTIVE ENERGY CALIBRATION PROCEDURE

The active energy calibration (kWh) consists of two stages:

### STAGE 1

During Stage 1, the active energy gain compensation gets computed at PF = 1.0 lag. Depending on the type, value of voltage and current transducers, the value of gain compensation varies to measure the standard value of energy.

1. At PF = 1.0, the active energy calibration pulse output is probed. The Error % is entered into the Stage 1 calibration software, as shown in Figure 2-3.
2. Click **Calibrate** to proceed with the calibration. During this stage, the gain of the active energy will be calibrated.
3. After completion of the process, the active energy pulse output is probed and the Error % is recorded. If the meter output is within the specification, the active energy calibration Stage 1 can be stopped.

Microchip Energy Meter - 1 Phase

Energy Meter | Meter Parameters | **Energy Calibration** | Power Calibration

**Meter Detected**

**MICROCHIP**

Meter Specifications  
Meter Constant (imp/kWh) : 3200

Energy Calibration

**Active Energy Error %**

	Error % for Calibration	Previous Error %	
1. Error % at PF = 1.0 :	1.2	-20.2	Calibrate
2. Error % at PF = 0.5 LAG :	0.0	0.0	Calibrate

**Reactive Energy Error %**

	Error % for Calibration	Previous Error %	
3. Error % at PF = 0.5 LAG :	0.0	-19.83	Calibrate

Stage 1: Enter the Error % of Active Energy at UPF. This stage calibrates Active Energy Gain.  
Stage 2: After Stage 1 completion, enter the Error % of Active Energy at PF = 0.5 LAG. This Stage calibrates the Phase Compensation.  
Stage 3: After completion of Stage 2, enter the Error % of Reactive Energy at PF = 0.5 LAG. This stage calibrates Reactive Energy Gain

Save to EEPROM

**FIGURE 2-3:** Active Energy Calibration Stage 1.

## STAGE 2

During this stage, phase compensation will be computed at PF = 0.5 lag. Due to various components in the board design, there may be a phase delay between the voltage and the current.

1. To compensate for the phase delay, the meter line inputs are set at PF = 0.5 lag and the active energy calibration pulse output is probed.
2. The Error % registered in the reference meter is entered as an input to Stage 2 calibration. Click **Calibrate** to initiate the phase compensation calibration as shown in Figure 2-4.
3. After completion of the process, the meter active energy pulse output is probed and the Error % is recorded. To confirm accurate phase compensation, the active energy at various PF can be checked, during which the accuracy must be within the specification. If the meter output is within the specification, active energy calibration Stage 2 can be stopped.

**Meter Detected**

**MICROCHIP**

Meter Specifications  
Meter Constant (imp/kWh) : 3200

Energy Calibration

### Active Energy Error %

	Error % for Calibration	Previous Error %	
1. Error % at PF = 1.0 :	0.0	-20.2	Calibrate
2. Error % at PF = 0.5 LAG :	0.3	0.0	Calibrate

### Reactive Energy Error %

	Error % for Calibration	Previous Error %	
3. Error % at PF = 0.5 LAG :	0.0	-19.83	Calibrate

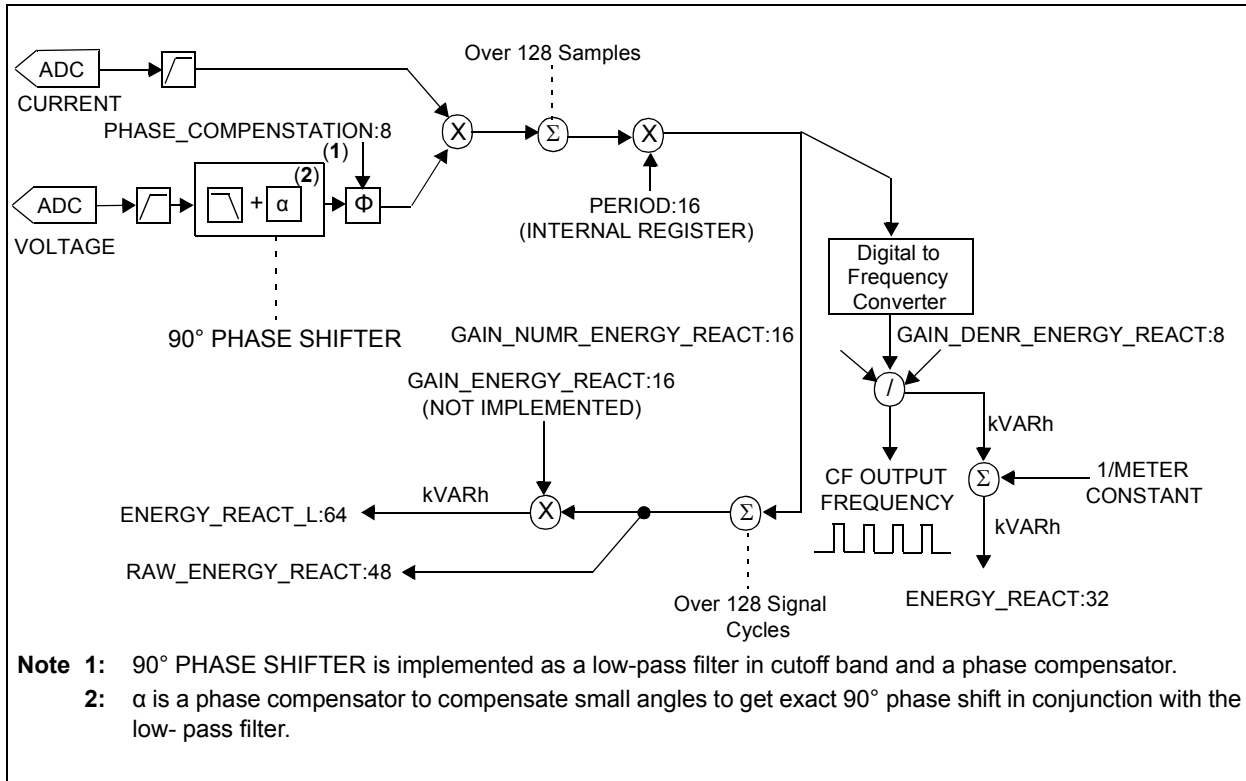
Stage 1: Enter the Error % of Active Energy at UPF. This stage calibrates Active Energy Gain.  
 Stage 2: After Stage 1 completion, enter the Error % of Active Energy at PF = 0.5 LAG. This Stage calibrates the Phase Compensation.  
 Stage 3: After completion of Stage 2, enter the Error % of Reactive Energy at PF = 0.5 LAG. This stage calibrates Reactive Energy Gain

Save to EEPROM

**FIGURE 2-4:** Active Energy Calibration Stage 2.

## 2.3.3 Reactive Energy Signal Flow and Calibration

During reactive energy calibration, the gain register `GAIN_NUMR_ENERGY_REACT`, `GAIN_DENR_ENERGY_REACT` gets computed. Figure 2-5 shows the reactive energy calculation in the metering engine and the calibration gain register.



**FIGURE 2-5:** Reactive Energy Calculation Signal Flow.

### 2.3.3.1 REACTIVE ENERGY GAIN COMPUTATION

Reactive energy gain is computed as a percentage ratio of the error recorded against the previous gain. The Error % is the difference between the input line reactive energy and the meter output, as recorded by the reference meter. Reactive energy gain is computed using Equation 2-8.

#### EQUATION 2-8: REACTIVE ENERGY GAIN COMPUTATION

$$GAIN_{(NewValue)} = \frac{GAIN_{(OldValue)}}{\left(\frac{Error\%}{100}\right) + 1}$$

If  $GAIN > 65535$

Then,

$$GAIN\_NUMR\_ENERGY\_REACT_{(New\ Value)} = GAIN_{(New\ Value)} / 2$$

$$GAIN\_DENR\_ENERGY\_REACT_{(New\ Value)} = GAIN\_DENR\_ENERGY\_REACT_{(Old\ Value)} + 1$$

else,

$$GAIN\_NUMR\_ENERGY\_REACT_{(New\ Value)} = GAIN_{(New\ Value)}$$

$$GAIN\_DENR\_ENERGY\_REACT_{(New\ Value)} = GAIN\_DENR\_ENERGY\_REACT_{(Old\ Value)}$$

## 2.3.3.2 REACTIVE ENERGY CALIBRATION PROCEDURE

In reactive energy calibration stage, the reactive energy calibration pulse output is probed and the percentage error (Error %) is entered as an input to the calibration software as shown in Figure 2-6. To calibrate the reactive energy, the phase compensation should be calibrated, which otherwise may be erroneous. The reactive energy calibration is similar to Stage 1 of active energy calibration, during which the gain of the reactive energy is calibrated.

1. At PF = 0.5 lag, the reactive energy calibration pulse output is probed and the percentage error (Error %) is entered as an input to the calibration software.
2. Click **Calibrate** to proceed with calibration. During this stage, the gain of the reactive energy is calibrated.
3. After the completion of the process, the meter reactive energy pulse output is probed and the error percentage is recorded, in comparison with the reference meter output. If the meter output is within the specification, the reactive energy calibration can be stopped.

**Microchip Energy Meter - 1 Phase**

Energy Meter | Meter Parameters | **Energy Calibration** | Power Calibration

**Meter Detected**

**MICROCHIP**

Meter Specifications  
Meter Constant (imp/kWh) : 3200

Energy Calibration

**Active Energy Error %**

	Error % for Calibration	Previous Error %	
1. Error % at PF = 1.0 :	0.0	-20.2	Calibrate
2. Error % at PF = 0.5 LAG :	0.0	0.0	Calibrate

**Reactive Energy Error %**

	Error % for Calibration	Previous Error %	
3. Error % at PF = 0.5 LAG :	1.4	-19.83	Calibrate

Stage 1: Enter the Error % of Active Energy at UPF. This stage calibrates Active Energy Gain.  
 Stage 2: After Stage 1 completion, enter the Error % of Active Energy at PF = 0.5 LAG. This Stage calibrates the Phase Compensation.  
 Stage 3: After completion of Stage 2, enter the Error % of Reactive Energy at PF = 0.5 LAG. This stage calibrates Reactive Energy Gain

Save to EEPROM

**FIGURE 2-6:** Reactive Energy Calibration.

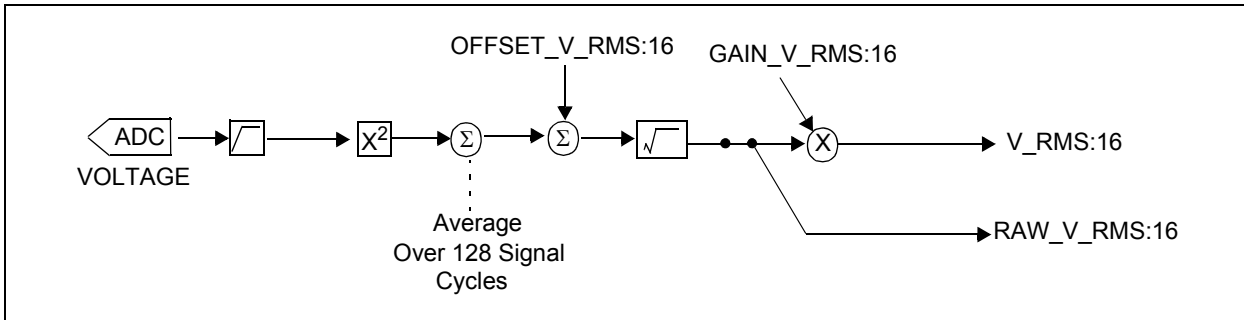
## 2.3.4 Power Calibration

In Power Calibration, the line parameter measured by the reference meter, is entered as an input to the calibration software. The difference between the output of the meter under the calibration, and the reference meter is computed. The Error % is used as feedback to adjust the calibration parameters accordingly.

In power calibration configuration, Active power, Reactive Power, RMS Voltage and RMS Current get calibrated.

### 2.3.4.1 VOLTAGE SIGNAL FLOW AND CALIBRATION

During voltage calibration, the gain register GAIN\_V\_RMS gets computed. Figure 2-7 shows the voltage calculation in the metering engine and the calibration gain register.



**FIGURE 2-7:** RMS Voltage Calculation Signal Flow.

#### 2.3.4.1.1 Voltage Gain Computation

Voltage gain is computed as a percentage ratio of the error, recorded against the previous gain. The Error % is the difference between the input line voltage and the meter output.

#### EQUATION 2-9: VOLTAGE GAIN COMPUTATION

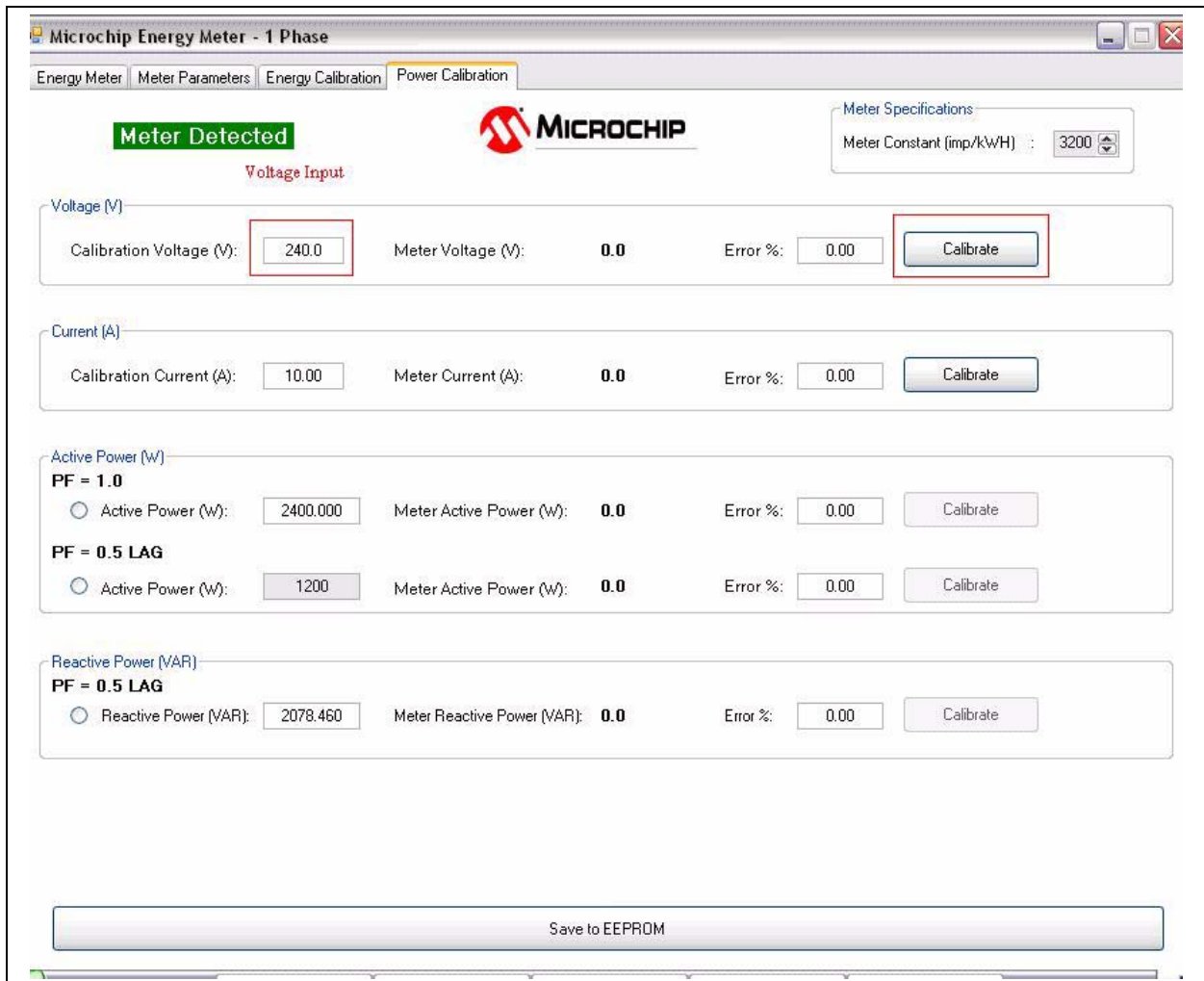
$$GAIN\_V\_RMS_{(NewValue)} = \frac{GAIN\_V\_RMS_{(OldValue)}}{\left(\frac{Error\%}{100}\right) + 1}$$

**Note:** The Error % is used as an input for the calibration software.

#### 2.3.4.1.2 Voltage Calibration Procedure

To calibrate the RMS voltage output of the meter, follow this procedure:

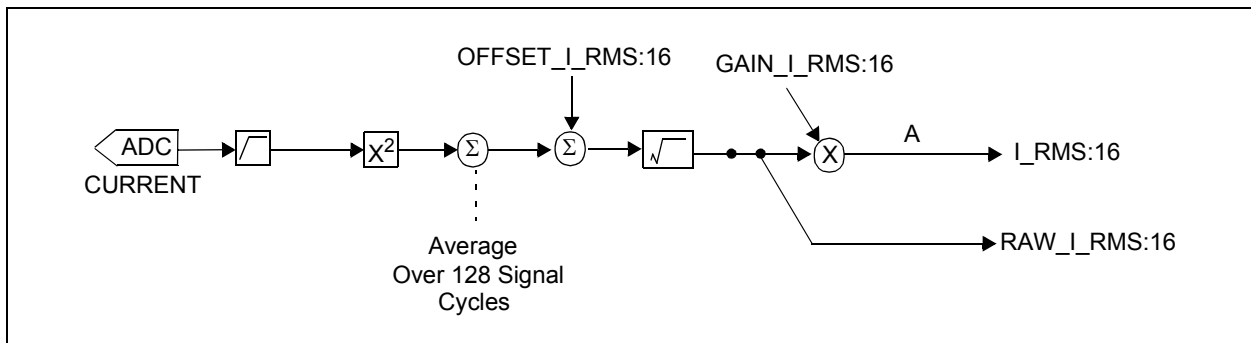
1. Enter the input line voltage value in “Calibration Voltage (V)” and click **Calibrate** to initiate the calibration, as shown in Figure 2-8.
2. After completion of the process, the meter output voltage will be displayed along with the Error % in comparison with the input line voltage.
3. If the meter output is within the specification, the voltage calibration can be stopped.



**FIGURE 2-8:** Voltage Calibration.

### 2.3.4.2 CURRENT SIGNAL FLOW AND CALIBRATION

During the current calibration, the gain register `GAIN_I_RMS` gets computed. Figure 2-9 shows the current calculation in the metering engine and the calibration gain register.



**FIGURE 2-9:** RMS Current Calculation Signal Flow.

# PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide

## 2.3.4.2.1 Current Gain Computation

Current gain is computed as a percentage ratio of the error recorded against the previous gain. The Error % is the difference between the input line current and the meter output.

### EQUATION 2-10: CURRENT GAIN COMPUTATION

$$GAIN\_I\_RMS_{(NewValue)} = \frac{GAIN\_I\_RMS_{(OldValue)}}{\left(\frac{Error\%}{100}\right) + 1}$$

## 2.3.4.2.2 Current Calibration Procedure

To calibrate the RMS current output of the meter, follow this procedure:

1. Enter the input line current value in "Calibration Current (A)" and click **Calibrate** to initiate the calibration, as shown in Figure 2-10.
2. After completion of the process, the meter output current will be displayed along with the Error % in comparison with the input line current.
3. If the meter output is within the specification, then the current calibration can be stopped.

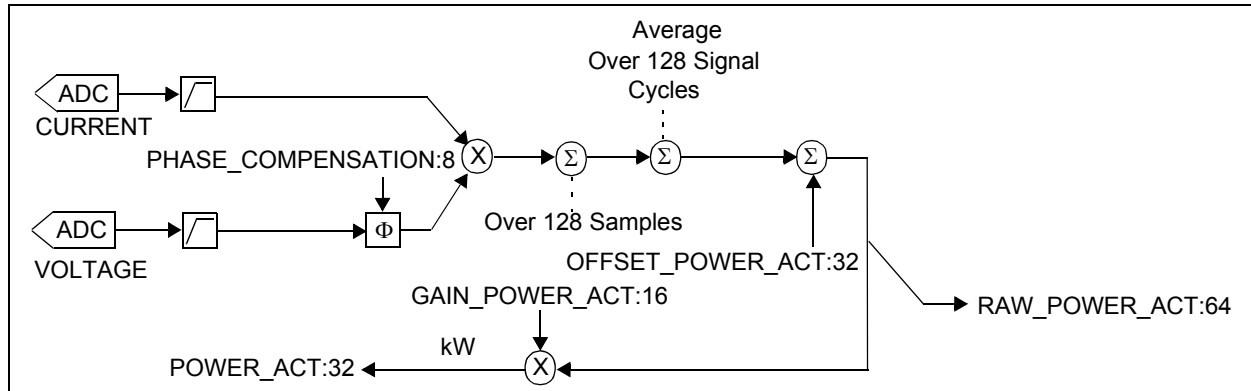
The screenshot shows the 'Microchip Energy Meter - 1 Phase' software interface. The 'Energy Calibration' tab is active. A green box says 'Meter Detected'. The 'MICROCHIP' logo is present. 'Meter Specifications' shows 'Meter Constant (imp/kWh) : 3200'. The 'Voltage [V]' section has 'Calibration Voltage (V): 240.0', 'Meter Voltage (V): 0.0', and 'Error %: 0.00'. The 'Current [A]' section, labeled 'Current Input', has 'Calibration Current (A): 10.00', 'Meter Current (A): 0.0', and 'Error %: 0.00'. The 'Active Power [W]' section has 'PF = 1.0' and 'Active Power (W): 2400.000'. The 'Reactive Power [VAR]' section has 'PF = 0.5 LAG' and 'Reactive Power (VAR): 2078.460'. A 'Save to EEPROM' button is at the bottom.

FIGURE 2-10: Current Calibration.



## 2.3.4.3 ACTIVE POWER SIGNAL FLOW AND CALIBRATION

During Active Power Calibration, the gain registers `GAIN_POWER_ACT` and `PHASE_COMPENSATION` get computed. Figure 2-11 shows the active power calculation in the metering engine, the calibration gain and the phase compensation registers.



**FIGURE 2-11:** Active Power Calculation Signal Flow

**Note:** Stage 2 of active power calibration includes the phase compensation factor calculation. This calibration is also included in the second stage of active energy calibration. If the meter configuration includes both active energy and power calibration, then it is suggested to calibrate the phase compensation factor in the energy calibration stage and skip this step during power calibration.

### 2.3.4.3.1 Active Power Gain Computation

Active Power Gain is computed as a percentage ratio of the error recorded against the previous gain. The Error % is the difference between the input line active power and the meter output, as shown in Equation 2-11.

**Note:** Phase compensation is explained in Stage 2 of Energy Calibration (Equations 2-2 to 2-6).

### EQUATION 2-11: ACTIVE POWER GAIN COMPUTATION

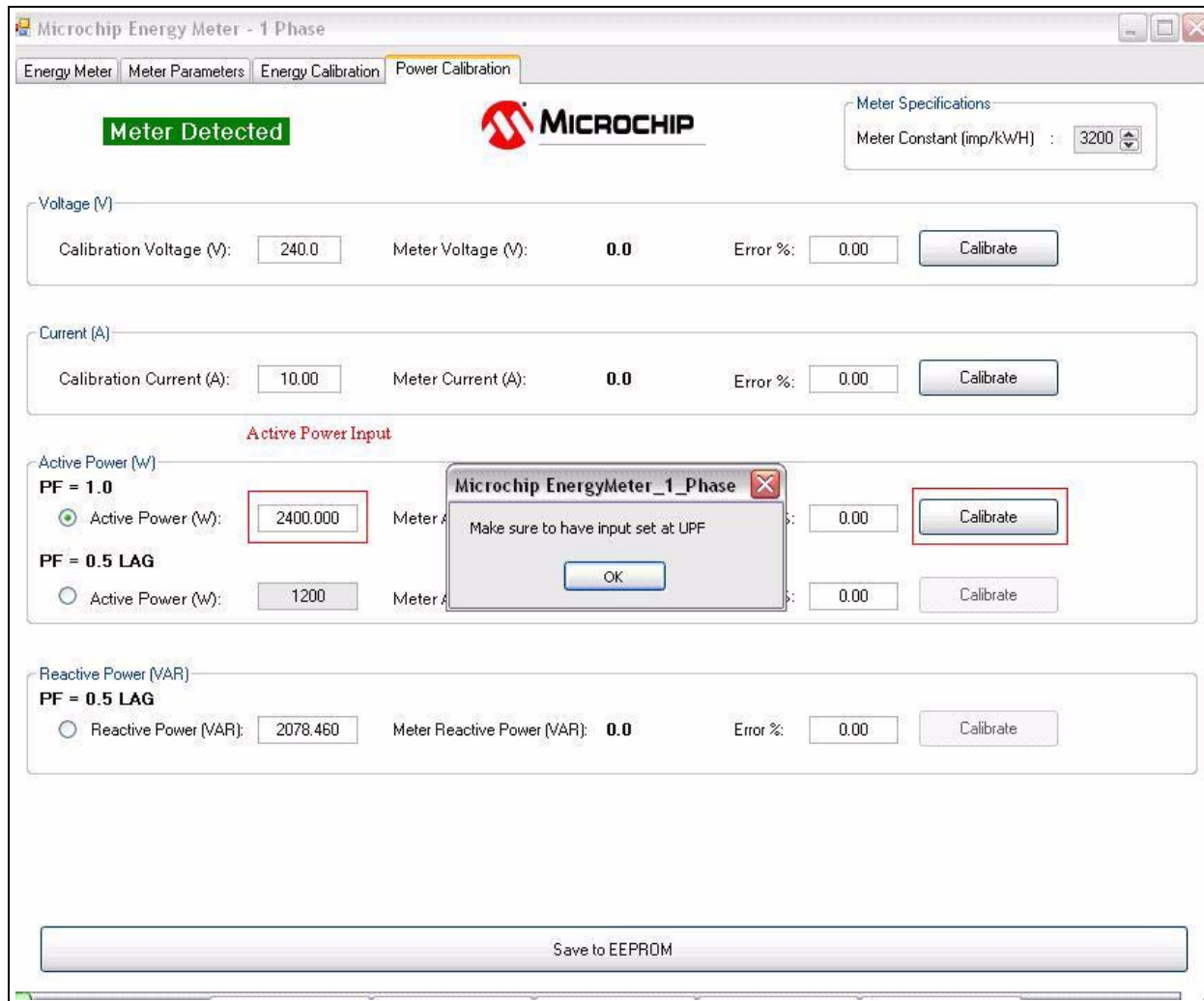
$$GAIN\_POWER\_ACT_{(NewValue)} = \frac{GAIN\_POWER\_ACT_{(OldValue)}}{\left(\frac{Error\%}{100}\right) + 1}$$

### 2.3.4.3.2 Active Power Calibration Procedure

The Active Power (W) calibration in the meter consists of two stages:

#### STAGE 1

1. During Stage 1 at PF = 1.0 lag, the active power read by the reference meter is entered as an input, and the active power calibration Stage 1 is selected as shown in Figure 2-12.
2. Click **Calibrate** to proceed with calibration. During this stage, the gain of the active power will be calibrated.
3. After the completion of the process, the meter active power output will be displayed along with the Error %, in comparison with the reference meter output. If the meter output is within the specification, the active power calibration Stage 1 can be stopped.

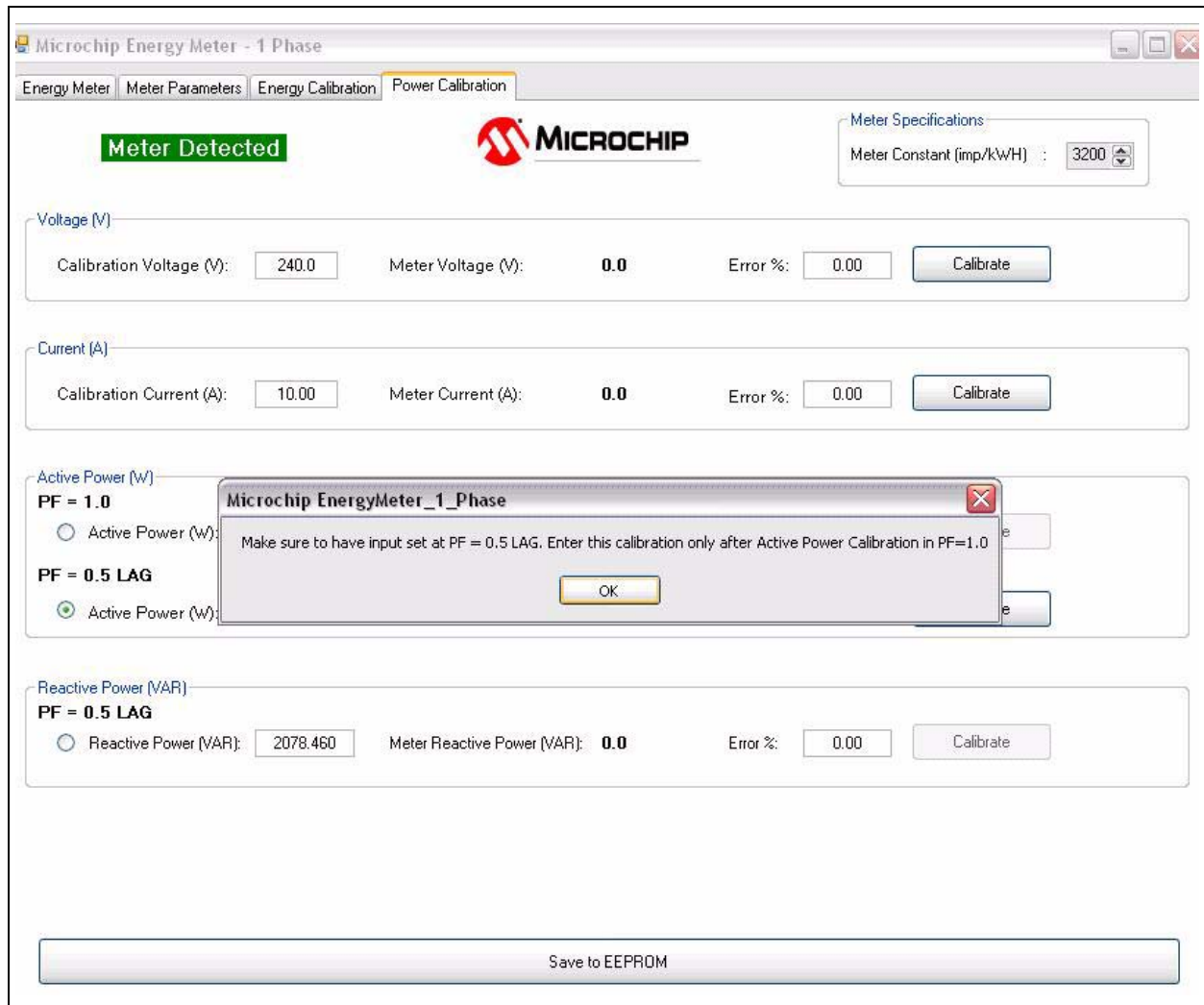


**FIGURE 2-12:** Active Power Phase 1 Calibration.

## STAGE 2

During this stage, phase compensation will be computed at PF = 0.5 lag.

1. During Stage 2, meter line inputs are set at PF = 0.5 lag, with the active power being exactly half of PF = 1.0.
2. The phase compensation calibration is initiated by selecting Stage 2 of the active power calibration, as shown in Figure 2-13.
3. Click **Calibrate** to proceed with the calibration.
4. After the completion of this process, the meter active power output will be displayed along with the Error %, in comparison with that of the reference meter output. After the calibration, the meter output should be exactly half of the active power value that was calibrated at the Stage 1. If the meter output is within the specification, active power calibration Stage 2 can be stopped.

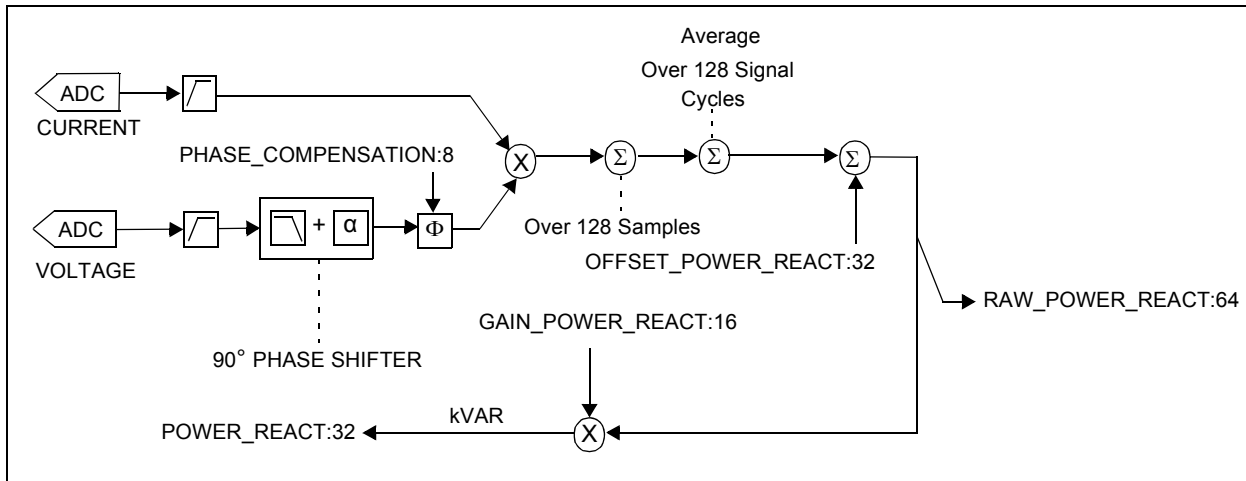


**FIGURE 2-13:** Active Power Phase 2 Calibration.

# PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide

## 2.3.4.4 REACTIVE POWER SIGNAL FLOW AND CALIBRATION

During Reactive Power Calibration, the gain register `GAIN_POWER_REACT` gets computed. Figure 2-14 shows the reactive power calculation metering engine and the calibration gain register.



**FIGURE 2-14:** Reactive Power Calculation Signal Flow.

### 2.3.4.4.1 Reactive Power Gain Computation

Reactive Power Gain is computed as the percentage ratio of the error recorded against the previous gain. The Error % is the difference between the input line reactive power and the meter output, as shown in Equation 2-12.

#### EQUATION 2-12: REACTIVE POWER GAIN COMPUTATION

$$GAIN\_POWER\_REACT_{(NewValue)} = \frac{GAIN\_POWER\_REACT_{(OldValue)}}{\left(\frac{Error\%}{100}\right) + 1}$$


### 2.3.4.4.2 Reactive Power Calibration Procedure

Reactive Power Calibration mode is entered by selecting the Reactive Power (VAR) calibration. To calibrate reactive power, phase compensation should be calibrated, which otherwise may be erroneous. Therefore, the software does not allow users to calibrate reactive power unless the phase compensation in Stage 2 of the active power is calibrated. The Reactive Power Calibration is similar to Stage 1 of the active power calibration, during which the gain of the reactive power will be calibrated (see Figure 2-15).

1. Enter the reactive power value read by the reference meter as an input at PF = 0.5 lag. The reactive power calibration is selected as shown in Figure 2-15.
2. Click **Calibrate** to proceed with the calibration. During this stage, the gain of reactive power will be calibrated.
3. After completion of the process, the meter reactive power output will be displayed along with the Error %, in comparison with the reference meter output. If the meter output is within the specification, the Reactive Power Calibration can be stopped.

Microchip Energy Meter - 1 Phase

Energy Meter | Meter Parameters | Energy Calibration | **Power Calibration**

**Meter Detected** 

Meter Specifications  
Meter Constant (imp/kWh) : 3200

**Voltage (V)**  
Calibration Voltage (V): 240.0    Meter Voltage (V): 0.0    Error %: 0.00    **Calibrate**

**Current (A)**  
Calibration Current (A): 10.00    Meter Current (A): 0.0    Error %: 0.00    **Calibrate**

**Active Power (W)**  
PF = 1.0  
 Active Power (W)  
PF = 0.5 LAG  
 Active Power (W)

**Microchip EnergyMeter\_1\_Phase**  
Make sure to have input set at PF = 0.5 LAG. Enter this Calibration only after Active Power Calibration with both PF  
**OK**

**Reactive Power Input**

**Reactive Power (VAR)**  
PF = 0.5 LAG  
 Reactive Power (VAR): 2078.460    Meter Reactive Power (VAR): 0.0    Error %: 0.00    **Calibrate**

Save to EEPROM

**FIGURE 2-15:** Reactive Power Calibration.

## 2.4 MULTIPOINT CALIBRATION

Multipoint Calibration calculates the gain and offset theoretically, based on the input line parameters. The line parameters are set to defined values, which are entered as an input to the calibration software. This calibration is suitable for the development process, to get an insight on gain and offset to the gain and offset calculations for signal conditioning.

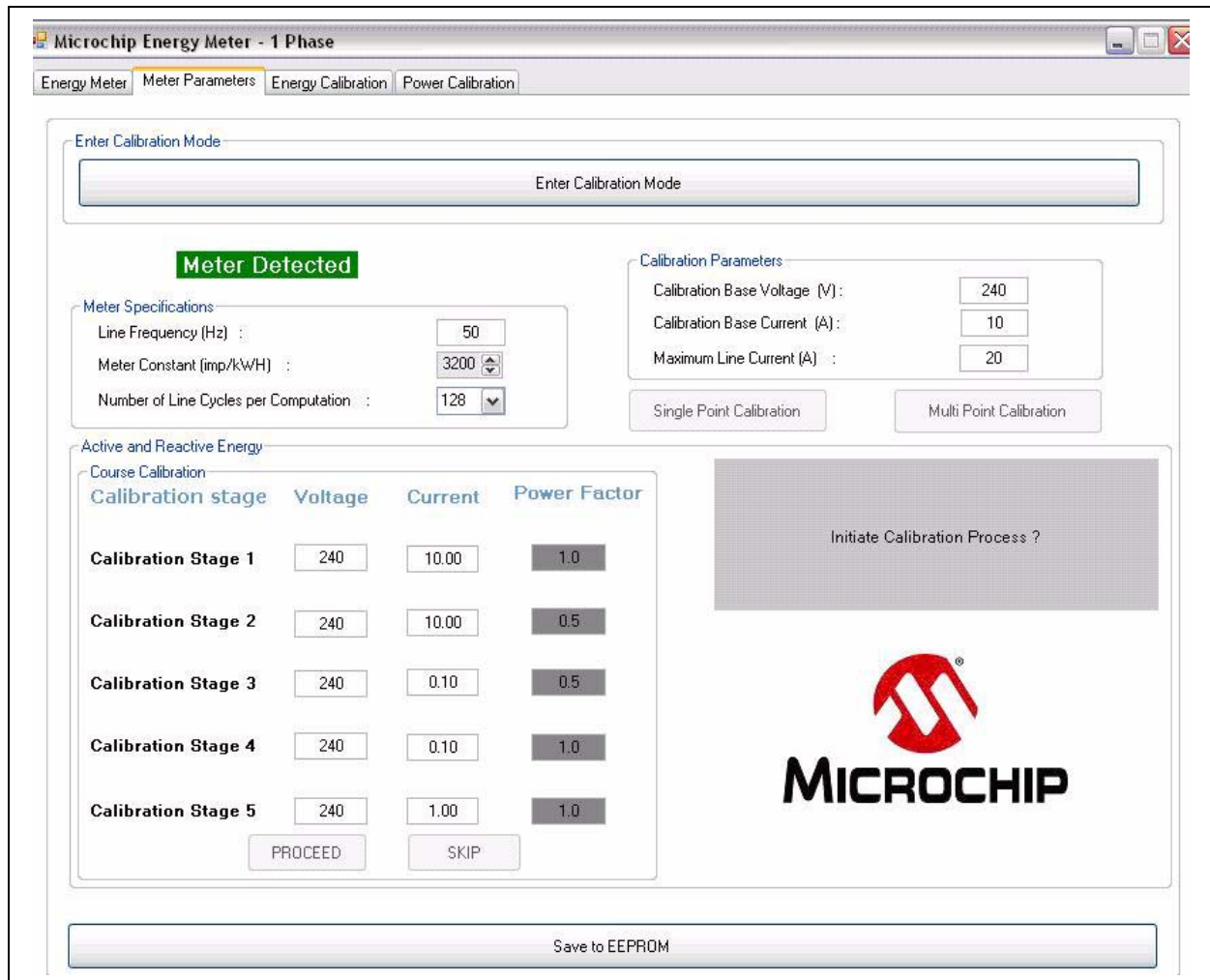
### 2.4.1 $I_B$ , $V_B$ , Meter Constant and Calibration Configurations

The calibration of the single phase energy meter involves up to five different configurations, as shown in Figure 2-16.

#### EXAMPLE 2-1:

Meter design with base operational condition is 5(10)A, $I_B = 5$ , $I_{MAX} = 10$ A.
---

1. **Calibration Stage C1:** Active Power, Energy and RMS Voltage Gain Calibration, Gain – Basic voltage  $V_B$  and basic current  $I_B$  at a power factor of 1. For example, 220V and 5A.
2. **Calibration Stage C2:** Phase Compensation, Reactive Power and Energy Gain Calibration – Basic 220V and 5A voltage  $V_B$  and basic current  $I_B$  at a power factor of 0.5 lag.
3. **Calibration Stage C3:** Reactive Power Offset – Base voltage  $V_B$  and 1/100 of base current  $I_B$  at PF = 0.5 lag at 220V and 50 mA.
4. **Calibration Stage C4:** Active Power Offset – Basic voltage  $V_B$  and 1/100 of  $I_B$  at a power factor of 1. For example, 220V and 50 mA.
5. **Calibration Stage C5:** Current Gain and Offset Calibration – Mid-range – Basic voltage  $V_B$  and 1/10 of  $I_B$  at a power factor of 1. For example, 220V and 500 mA.



**FIGURE 2-16:** Multipoint/Single Point Calibration Screen.

These calibration configurations are sequential steps. Configuration C1 is always the most important stage of calibration, and must be executed in the beginning. The other configurations require values obtained from configuration C1, but are not dependent on the values obtained from the other configurations. In other words, C1 is the first step, while the other configurations are optional, depending on the meter type.

The meter constant is typically measured in units of impulses per kilowatt-hour or impulses per kilovar-hour. For example, the calibration output frequency of the calibration frequency,  $METER\ CONSTANT = 3200\ imp/kWh$  or  $imp/kVARh$ ,  $6400\ imp/kWh$  or  $imp/kVARh$ .

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

## 2.4.2 Active Power and Energy Signal Flow and Calibration

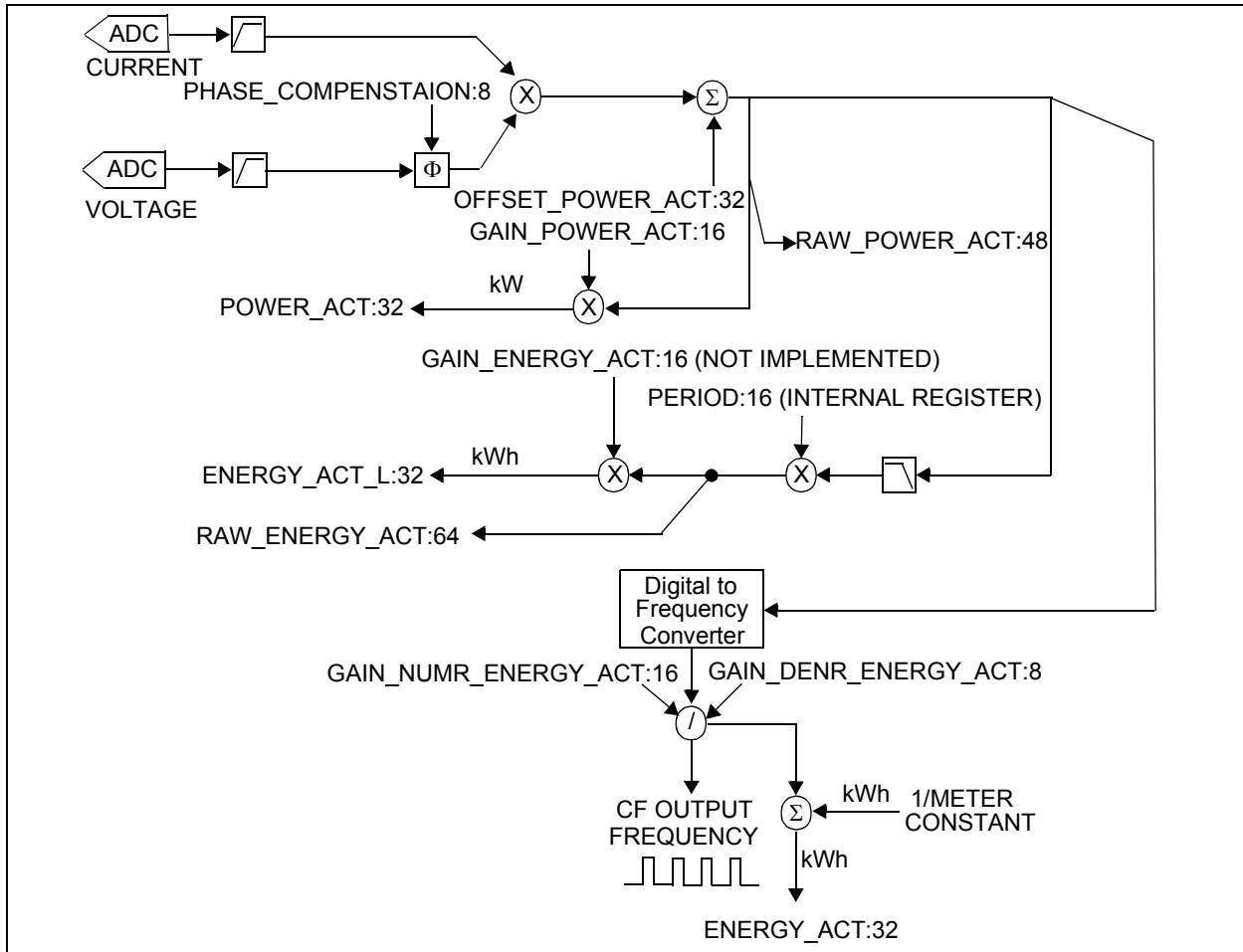
The active power and energy signal flow leads to the CF output pulse frequency, which is proportional to the total active energy measured by the energy meter as shown in Figure 2-17.

Table 2-1 represents the registers that are set for active power and energy calibration.

# PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide

**TABLE 2-1: CALIBRATION REGISTERS GENERATED THROUGH THIS ROUTINE**

Register Name	Equations	Configurations Required
GAIN_DENR_ENERGY_ACT	Section 2.4.4.1 "Equations for Configuration C1 Calibration – Active Energy and Active Power"	C1 ONLY
GAIN_NUMR_ENERGY_ACT	Section 2.4.4.1 "Equations for Configuration C1 Calibration – Active Energy and Active Power"	C1 ONLY
PHASE_COMPENSATION	Section 2.4.7.1 "Equations for Configuration C2 Calibration – Phase Delay"	C1, C2
OFFSET_POWER_ACT	Section 2.4.9.1 "Equations for Configuration C4 Calibration – Active Power Offset"	C1, C4
GAIN_POWER_ACT	Section 2.4.4.1 "Equations for Configuration C1 Calibration – Active Energy and Active Power"	C1 ONLY
GAIN_ENERGY_ACT	Not Implemented	Not Implemented



**FIGURE 2-17:** Active Power and Energy Signal Path Showing Output and Calibration Registers.



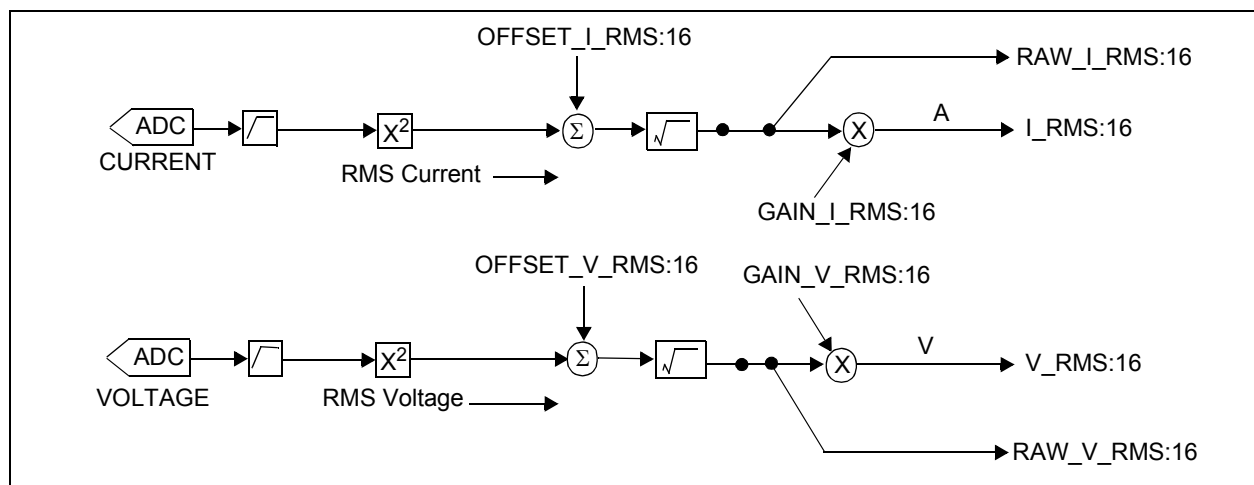
## 2.4.3 RMS Current, RMS Voltage, Signal Flow and Calibration

The RMS current and voltage outputs require a two-point calibration at configurations C1 and C5. The automated software performs these calibrations, suggested on the calibration values entered in the text boxes, as shown in Figure 2-16.

Table 2-2 and Figure 2-18 represent the registers that are set for RMS current and voltage calibration.

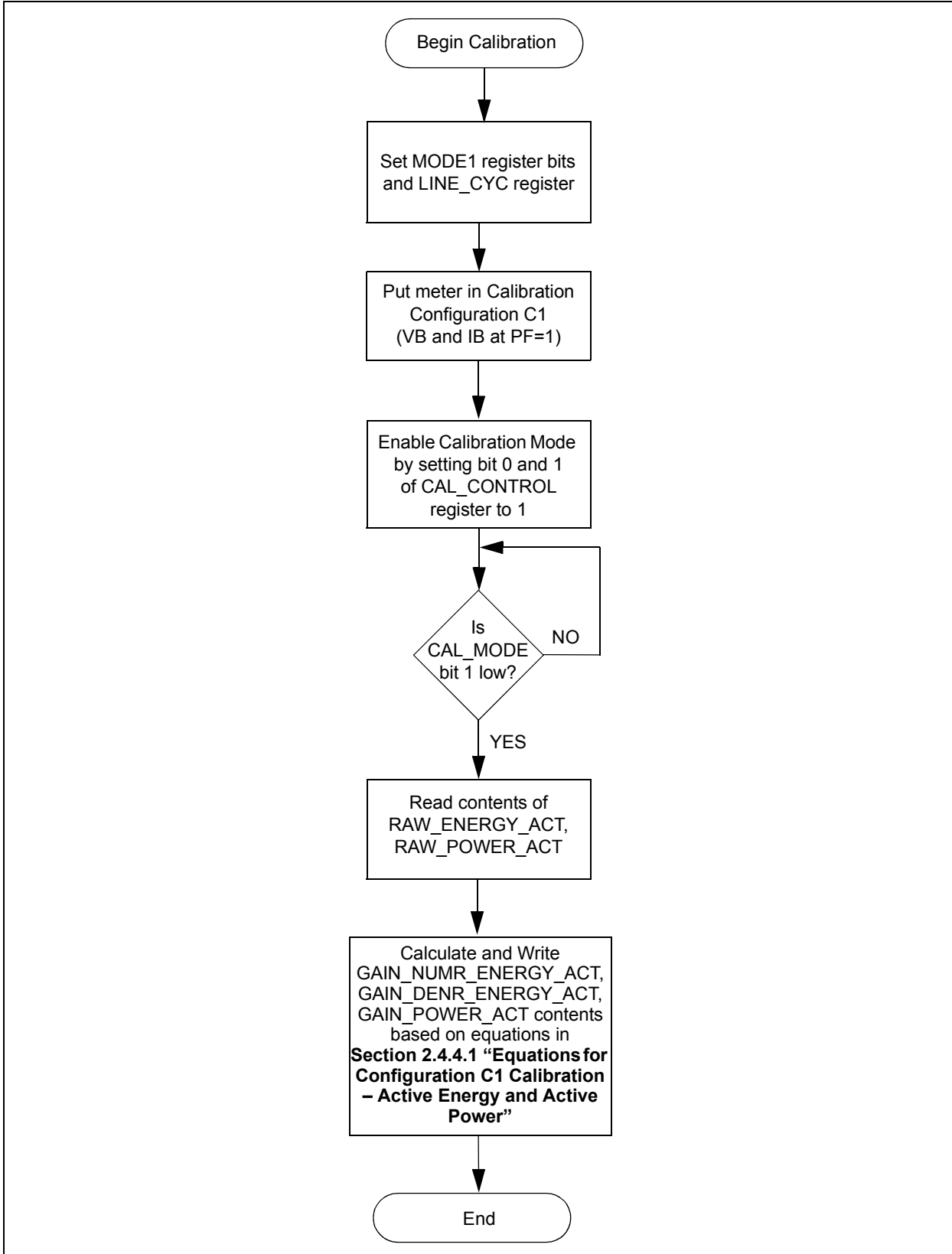
**TABLE 2-2: RMS CURRENT, RMS VOLTAGE, CALIBRATION REGISTERS**

Register	Equation	Configurations Required
OFFSET_V_RMS	Section 2.4.10.1 “Equations for Configuration C5 Calibration – RMS Voltage and Current”	C1, C5
OFFSET_I_RMS	Section 2.4.10.1 “Equations for Configuration C5 Calibration – RMS Voltage and Current”	C1, C5
GAIN_V_RMS	Section 2.4.10.1 “Equations for Configuration C5 Calibration – RMS Voltage and Current”	C1 ONLY
GAIN_I_RMS	Section 2.4.10.1 “Equations for Configuration C5 Calibration – RMS Voltage and Current”	C1 ONLY



**FIGURE 2-18:** RMS Current and Voltage Flow.

## 2.4.4 Flow Chart for C1 Configuration – Active Energy, Active Power Gain



## 2.4.4.1 EQUATIONS FOR CONFIGURATION C1 CALIBRATION – ACTIVE ENERGY AND ACTIVE POWER

Equations 2-13 to 2-17 represent the method for calculating the calibration, and the correction factors after configuration C1. The PC calibration software processes these calculations automatically.

Equations 2-13 to 2-16 apply for calculating the proper output frequency of the CF output. See **Section 2.4.4 “Flow Chart for C1 Configuration – Active Energy, Active Power Gain”** for the meter input conditions.

### EQUATION 2-13:

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

### EQUATION 2-14:

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

### EQUATION 2-15:

$$GAIN = \frac{\left( \frac{2^{32} \cdot CF\_IMP\_S}{Line\ Freq \cdot Samples\ per\ Cycle} \right)}{\left( \frac{RAW\_ENERGY\_ACT}{LINE\_CYC\_NUM \cdot 256} \right)} \cdot 32768$$

If  $GAIN > 65535$

Then,

$$GAIN\_NUMR\_ENERGY\_ACT = GAIN / 2$$

$$GAIN\_DENR\_ENERGY\_ACT = GAIN\_DENR\_ENERGY\_ACT + 1$$

else,

$$GAIN\_NUMR\_ENERGY\_ACT = GAIN$$

$$GAIN\_DENR\_ENERGY\_ACT = GAIN\_DENR\_ENERGY\_ACT$$

**Note:** Convert to a 16-bit unsigned integer for compatibility with the energy meter register and firmware calculations.

Equations 2-16 and 2-17 are used for calculating the proper Gain/LSb registers in calibration.

### EQUATION 2-16:

$$PLSb = \text{Value from Table 2-7 based on } V_B \text{ and } I_{MAX} \text{ values}$$

### EQUATION 2-17:

$$GAIN\_POWER\_ACT = \frac{\left( \frac{V_B \cdot I_B}{PLSb} \right)}{\left( \frac{RAW\_POWER\_ACT}{64 \cdot LINE\_CYC\_NUM} \right)} \cdot 32768$$

**Note:** Convert to a 16-bit unsigned integer for compatibility with the energy meter register and firmware calculations.

# PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide

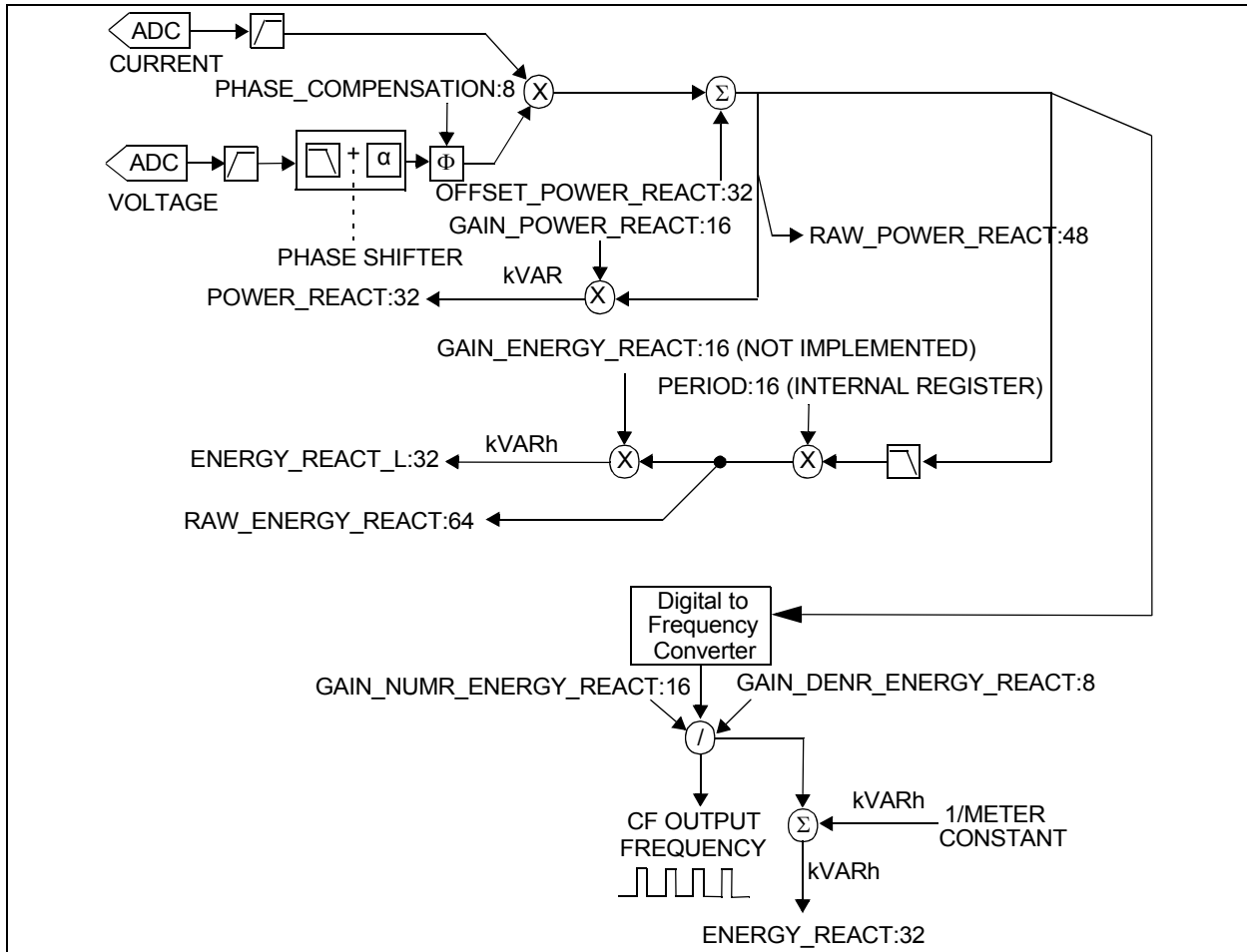
## 2.4.5 Reactive Power and Energy Signal Flow and Calibration

The reactive power and the energy signal flow leads to the CF output pulse frequency, which is proportional to the total reactive energy, measured by the energy meter as shown in Figure 2-19.

Table 2-3 represents the registers being set during the reactive power and energy calibration.

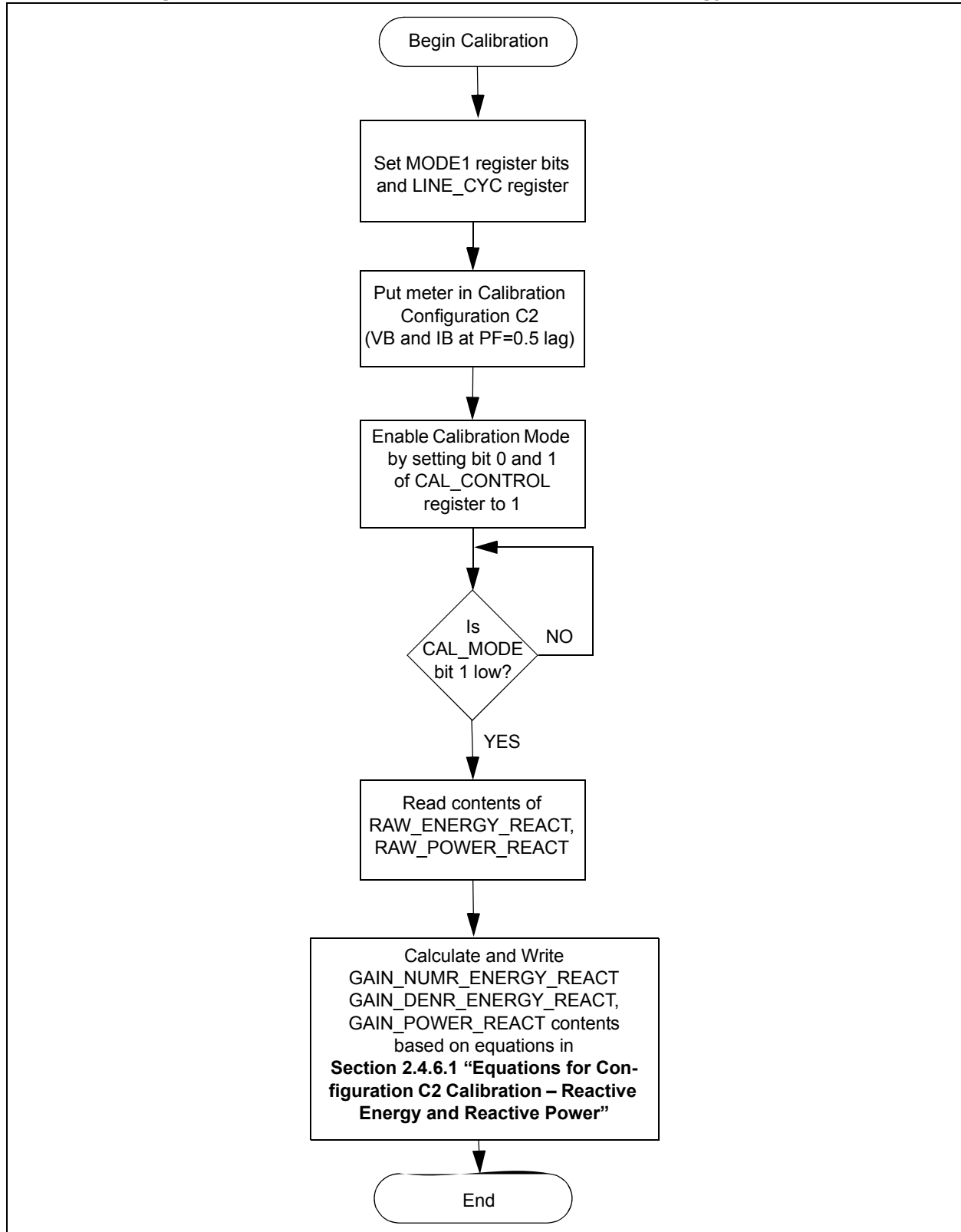
**TABLE 2-3: CALIBRATION REGISTERS GENERATED THROUGH THIS ROUTINE**

Register Name	Equations	Configurations Required
GAIN_DENR_ENERGY_REACT	Section 2.4.6.1 "Equations for Configuration C2 Calibration – Reactive Energy and Reactive Power"	C2 ONLY
GAIN_NUMR_ENERGY_REACT	Section 2.4.6.1 "Equations for Configuration C2 Calibration – Reactive Energy and Reactive Power"	C2 ONLY
OFFSET_POWER_REACT	Section 2.4.8.1 "Equations for Configuration C3 Calibration – Reactive Power Offset"	C2, C3
GAIN_POWER_REACT	Section 2.4.6.1 "Equations for Configuration C2 Calibration – Reactive Energy and Reactive Power"	C2 ONLY
GAIN_ENERGY_REACT	Not Implemented	Not Implemented



**FIGURE 2-19:** Reactive Power and Energy Signal Path Showing Output and Calibration Registers.

2.4.6 Configuration C2 Flow Chart – Reactive Power and Energy



# PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide

## 2.4.6.1 EQUATIONS FOR CONFIGURATION C2 CALIBRATION – REACTIVE ENERGY AND REACTIVE POWER

Equations 2-18 to 2-22 represent the method for calculating the calibration and the correction factors after configuration C2. The PC calibration software processes these calculations automatically.

Equations 2-18 to Equation 2-21 applies for calculating the proper output frequency of the CF output. See **Section 2.4.6 “Configuration C2 Flow Chart – Reactive Power and Energy”** for the meter input conditions.

### EQUATION 2-18:

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

### EQUATION 2-19:

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

### EQUATION 2-20:

$$GAIN = \frac{\left( \frac{2^{32} \cdot CF\_IMP\_S \cdot SIN(60)}{\text{Line Freq} \cdot \text{Samples per Cycle}} \right)}{\left( \frac{RAW\_ENERGY\_REACT}{LINE\_CYC\_NUM \cdot 256} \right)} \cdot 32768$$

If  $GAIN > 65535$

Then,

$$GAIN\_NUMR\_ENERGY\_REACT = GAIN / 2$$

$$GAIN\_DENR\_ENERGY\_REACT = GAIN\_DENR\_ENERGY\_REACT + 1$$

else,

$$GAIN\_NUMR\_ENERGY\_REACT = GAIN$$

$$GAIN\_DENR\_ENERGY\_REACT = GAIN\_DENR\_ENERGY\_REACT$$

**Note:** Convert to a 16-bit unsigned integer for compatibility with the energy meter register and firmware calculations.

Equations 2-21 and 2-22 are used for calculating the proper Gain/LSb registers in calibration.

### EQUATION 2-21:

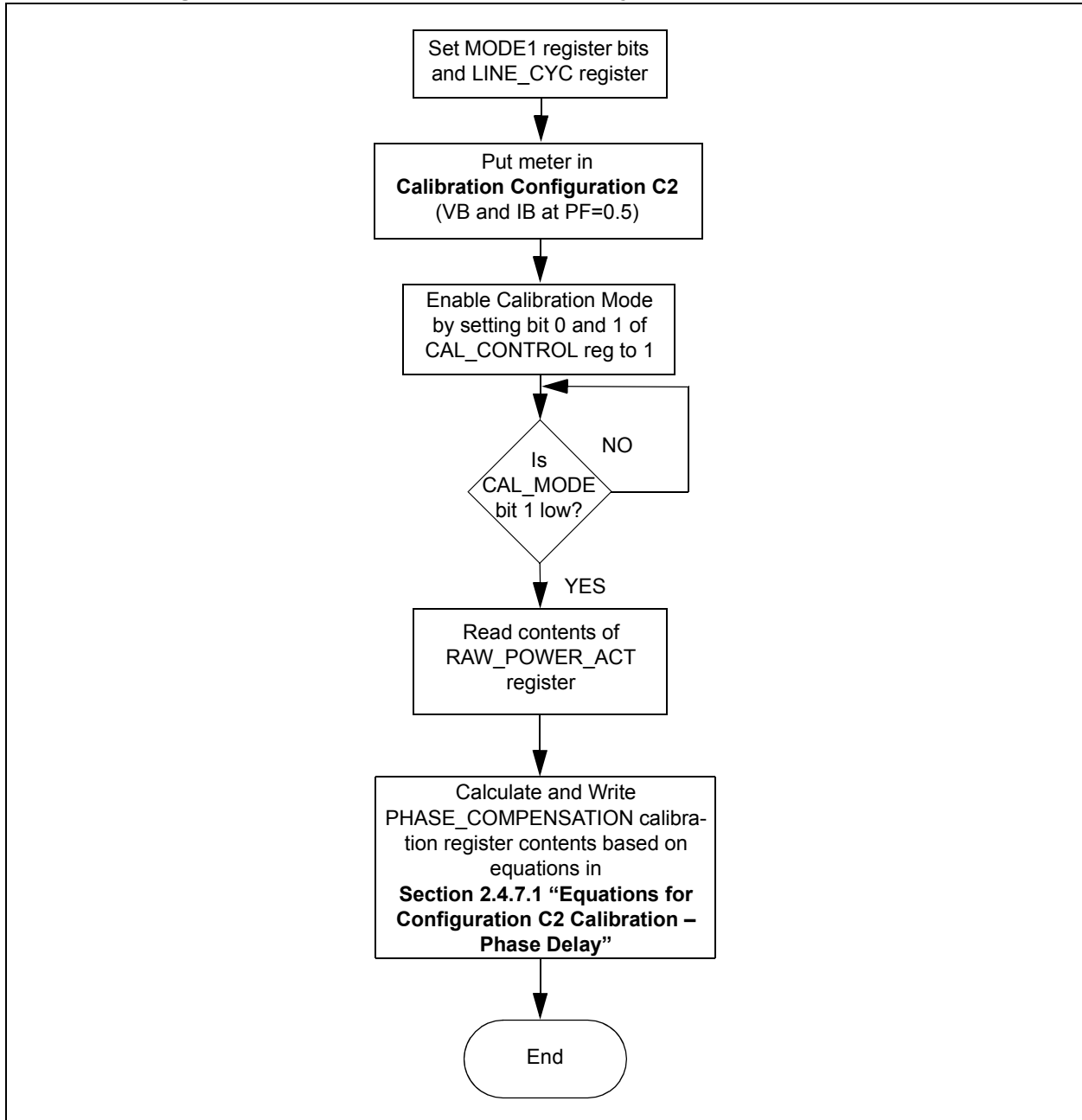
$$PLSb = \text{Value from Table 2-7 based on } VB \text{ and } IMAX \text{ values}$$

### EQUATION 2-22:

$$GAIN\_POWER\_REACT = \frac{\left( \frac{V_B \cdot I_B \cdot SIN(60)}{PLSb} \right)}{\left( \frac{RAW\_POWER\_REACT}{64 \cdot LINE\_CYC\_NUM} \right)} \cdot 32768$$

**Note:** Convert to a 16-bit unsigned integer for compatibility with the energy meter register and firmware calculations.

2.4.7 Configuration C2 Flow Chart – Phase Delay,



# PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide

## 2.4.7.1 EQUATIONS FOR CONFIGURATION C2 CALIBRATION – PHASE DELAY

For active power, Equations 2-23 to 2-27 are used to calculate the time shift delay for a given phase.

### EQUATION 2-23:

$$W1 = \text{RAW\_POWER\_ACT@PF} = 1, \text{ Configuration C1}$$

### EQUATION 2-24:

$$W2 = \text{RAW\_POWER\_ACT@PF} = 0.5, \text{ Configuration C2}$$

### EQUATION 2-25:

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

### EQUATION 2-26:

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

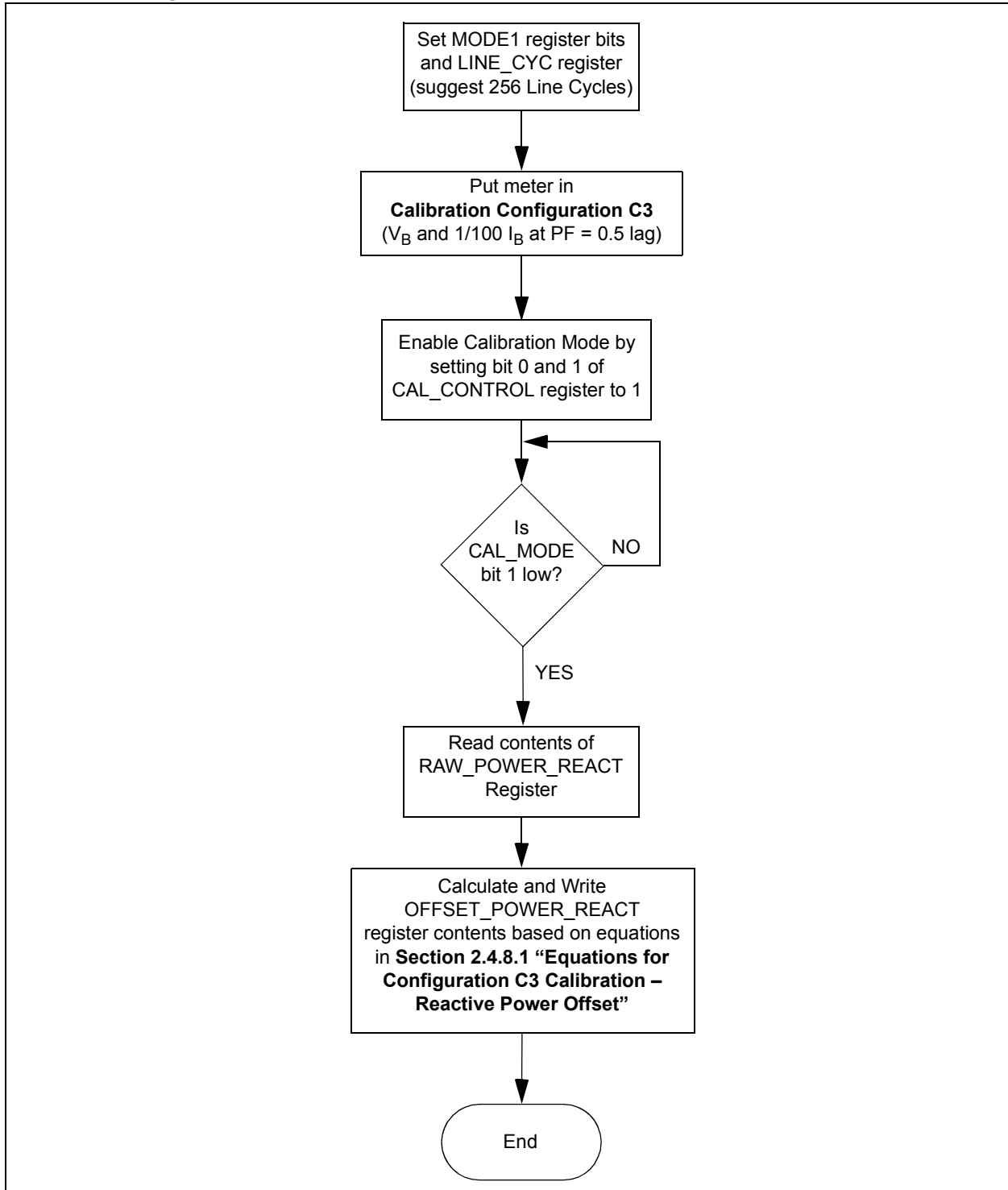
### EQUATION 2-27:

$$\text{PHASE\_COMPENSATION} = \frac{\left[ \cos^{-1} \left( \frac{(W2)/(LINE\_CYC\_NUM2)}{(W1)/(LINE\_CYC\_NUM1)} \cdot \frac{180}{\pi} \right) \right] - 60}{\frac{\text{DEGREE}}{\text{SAMPLE}}} \cdot 128$$

- Note 1:** Convert to an 8-bit signed integer for compatibility with the energy meter register and firmware calculations.
- 2:** Since the 60° (default) is being subtracted from the measured quantity, the current should lag the voltage under configuration C2.
- 3:** In the reference design, with a sampling rate of 3906 samples/sec, Degree/Sample value will be equal to 5.529.



## 2.4.8 Configuration C3 Flow Chart – Reactive Power Offset



# PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide

## 2.4.8.1 EQUATIONS FOR CONFIGURATION C3 CALIBRATION – REACTIVE POWER OFFSET

For reactive power offset, Equations 2-28 to 2-32 apply for a given phase. W1 corresponds to the RAW\_POWER\_REACT register obtained during configuration C2. LINE\_CYC\_NUM\_W1 corresponds to the LINE\_CYC during this measurement.

W2 corresponds to the RAW\_POWER\_REACT register obtained during configuration C3. LINE\_CYC\_NUM\_W2 is the LINE\_CYC during this measurement.

### EQUATION 2-28:

$$W1 = \text{RAW\_POWER\_REACT} @ I_B, \text{ Configuration C2}$$

### EQUATION 2-29:

$$W2 = \text{RAW\_POWER\_REACT} @ 1/100 I_B, \text{ Configuration C3}$$

### EQUATION 2-30:

$$\text{LINE\_CYC\_NUM\_W1} = \text{LINE\_CYC\_NUM in Configuration C2}$$

### EQUATION 2-31:

$$\text{LINE\_CYC\_NUM\_W2} = \text{LINE\_CYC\_NUM in Configuration C3}$$

### EQUATION 2-32:

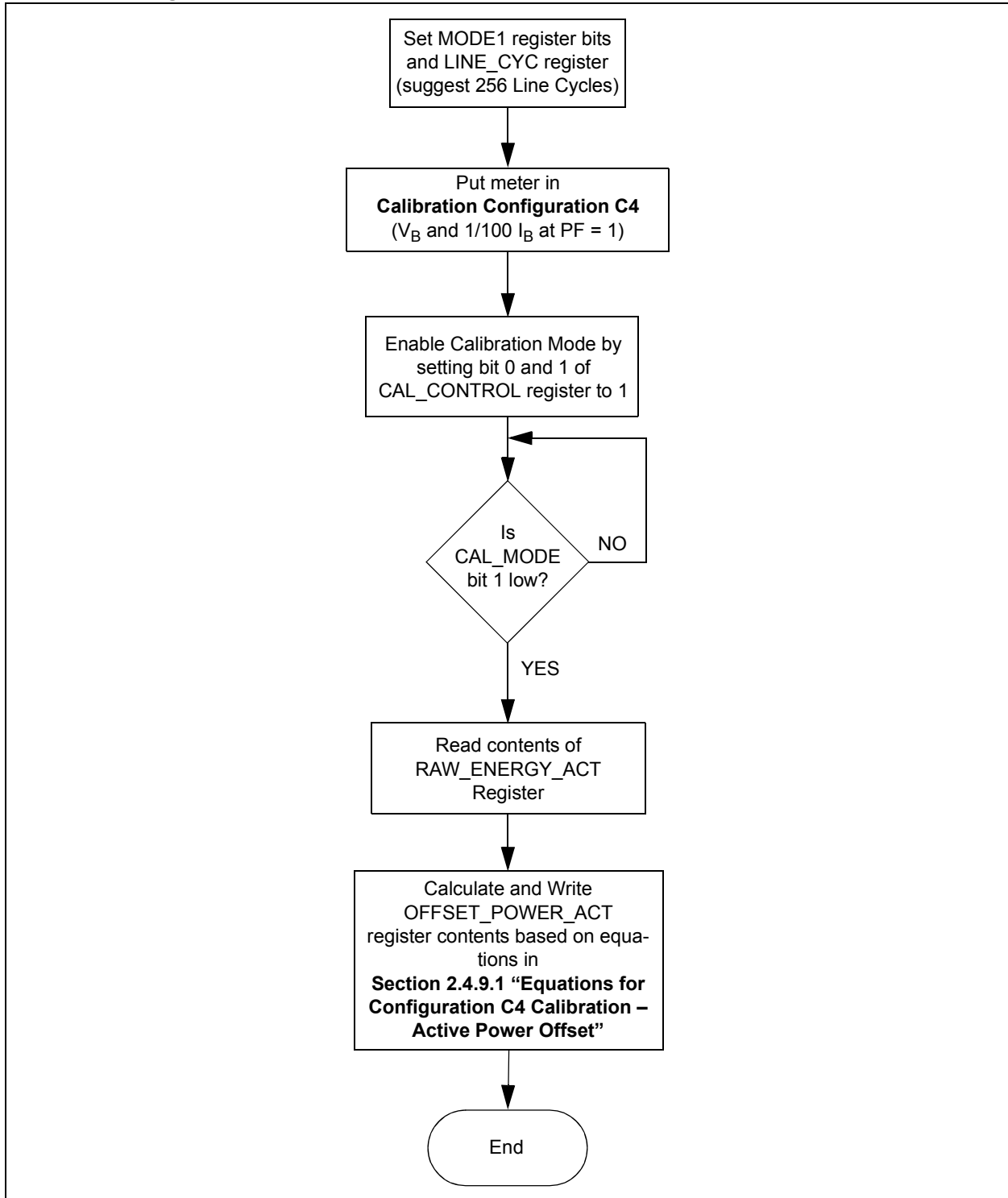
$$\text{OFFSET\_POWER\_REACT} = \left[ \frac{(W1)/(100)}{\text{LINE\_CYC\_NUM\_W1}} \right] - \left[ \frac{W2}{\text{LINE\_CYC\_NUM\_W2}} \right]$$

**Note:** Convert to a 32-bit signed integer for compatibility with the energy meter register and firmware calculations.

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

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

2.4.9 Configuration C4 Flow Chart - Active Power Offset



# PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide

## 2.4.9.1 EQUATIONS FOR CONFIGURATION C4 CALIBRATION – ACTIVE POWER OFFSET

For active power offset, Equations 2-33 to 2-37 apply for a given phase. W1 corresponds to the RAW\_POWER\_ACT register obtained during configuration C1. LINE\_CYC\_NUM\_W1 corresponds to the LINE\_CYC during this measurement.

W2 corresponds to the RAW\_POWER\_ACT register obtained during configuration C4. LINE\_CYC\_NUM\_W2 is the LINE\_CYC during this measurement.

### EQUATION 2-33:

$$W1 = \text{RAW\_POWER\_ACT} @ I_B, \text{ Configuration C1}$$

### EQUATION 2-34:

$$W2 = \text{RAW\_POWER\_ACT} @ 1/100 I_B, \text{ Configuration C4}$$

### EQUATION 2-35:

$$\text{LINE\_CYC\_NUM\_W1} = \text{LINE\_CYC\_NUM in Configuration C1}$$

### EQUATION 2-36:

$$\text{LINE\_CYC\_NUM\_W2} = \text{LINE\_CYC\_NUM in Configuration C4}$$

### EQUATION 2-37:

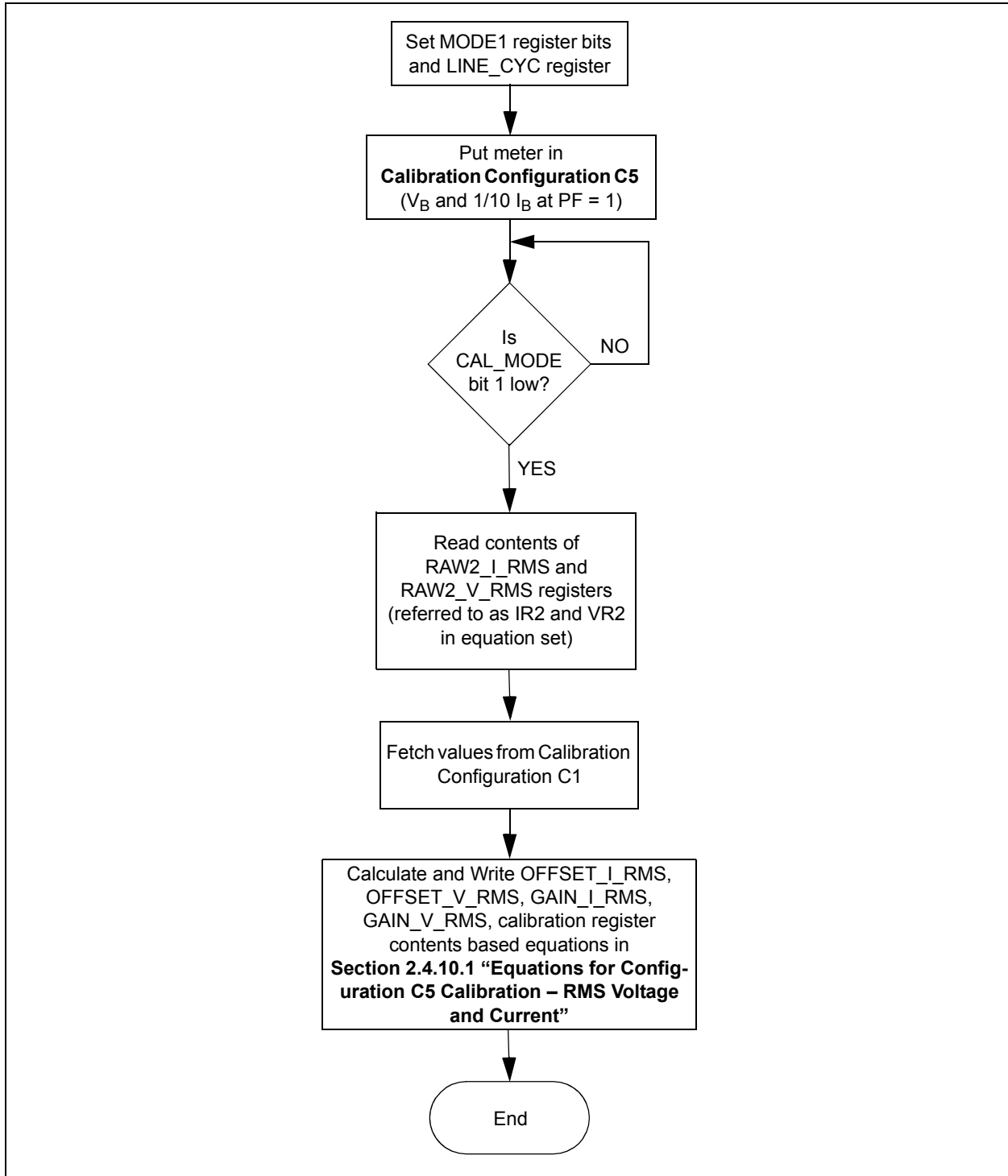
$$\text{OFFSET\_POWER\_ACT} = \left[ \frac{(W1)/(100)}{\text{LINE\_CYC\_NUM\_W1}} \right] - \left[ \frac{W2}{\text{LINE\_CYC\_NUM\_W2}} \right]$$

**Note:** Convert to a 32-bit signed integer for compatibility with the energy meter register and firmware calculations.

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

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

2.4.10 Flow Chart for RMS Calibration



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## 2.4.10.1 EQUATIONS FOR CONFIGURATION C5 CALIBRATION – RMS VOLTAGE AND CURRENT

Equations 2-38 to 2-49 represent the method for calculating the calibration and correction factors for the RMS current and RMS voltage. The PC calibration software processes these calculations automatically.

Typically, the  $V_{\min}$  and  $I_{\min}$  voltages and currents will be 1/10 of the  $V_B$  and  $I_B$  values. For RMS Offset, apply Equations 2-38 to 2-45:

### EQUATION 2-38:

$$IR1 = RAW2\_I\_RMS @ I_B, \text{ Configuration C1}$$

### EQUATION 2-39:

$$VR1 = RAW2\_V\_RMS @ I_B, \text{ Configuration C1}$$

### EQUATION 2-40:

$$IR2 = RAW2\_I\_RMS @ I_B, \text{ Configuration C5}$$

### EQUATION 2-41:

$$VR2 = RAW2\_V\_RMS @ I_B, \text{ Configuration C5}$$

### EQUATION 2-42:

$$I_G = \frac{I_B @ C1}{I_B @ C5}$$

### EQUATION 2-43:

$$V_G = \frac{V_B @ C1}{V_B @ C5}$$

### EQUATION 2-44:

$$OFFSET\_I\_RMS = \frac{\left(\frac{IR1 - IR2}{IG \cdot IG - 1}\right) - IR2}{65536}$$

**Note:** Convert to a 16-bit signed integer for compatibility with the energy meter register and firmware calculations.

## EQUATION 2-45:

$$OFFSET\_V\_RMS = \frac{\left(\frac{VR1 - VR2}{VG \cdot VG - 1}\right) - VR_2}{65536}$$

**Note:** Convert to a 16-bit signed integer for compatibility with the energy meter register and firmware calculations.

For RMS LSb correction, apply Equations 2-46 to 2-49.

## EQUATION 2-46:

$$ILSb = \text{Value from Table 2-6 based on } I_{MAX} \text{ value}$$

## EQUATION 2-47:

$$VLSb = \text{Value from Table 2-8 based on } V_B \text{ value}$$

## EQUATION 2-48:

$$GAIN\_I\_RMS = \frac{\left(\frac{I_B}{ILSb}\right)}{\sqrt{\frac{IR_I}{65536} + OFFSET\_I\_RMS}} \cdot 32768$$

**Note:** Convert to a 16-bit unsigned integer for compatibility with the energy meter register and firmware calculations.

## EQUATION 2-49:

$$GAIN\_V\_RMS = \frac{\left(\frac{V_B}{VLSb}\right)}{\sqrt{\frac{VR_I}{65536} + OFFSET\_V\_RMS}} \cdot 32768$$

**Note:** Convert to a 16-bit unsigned integer for compatibility with the energy meter register and firmware calculations.

# PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide

## 2.5 SINGLE POINT CALIBRATION

Single Point Calibration is a subset of multipoint calibration, with the omission of a few calibration register value calculations. With the omission, the number of stages in calibration are reduced, thus speeding the calibration process. Single Point Calibration can be carried out if the meter accuracy class is achieved, even with the omission of a few calibration parameter calculations, such as offset.

Single Point Calibration includes only two stages of calibration, as listed below:

1. **Calibration Stage C1:** Active power, energy and RMS voltage, current gain calibration, gain - basic voltage  $V_B$  and basic current  $I_B$  at a power factor of unity. For example, 220V and 5A at PF = 1.0.

The calibration parameters calculated in this stage include:

**TABLE 2-4: CALIBRATION REGISTERS GENERATED THROUGH THIS ROUTINE**

Register Name	Equations	Configurations Required
GAIN_POWER_ACT	Section 2.4.4.1 "Equations for Configuration C1 Calibration – Active Energy and Active Power"	C1 ONLY
GAIN_NUMR_ENERGY_ACT	Section 2.4.4.1 "Equations for Configuration C1 Calibration – Active Energy and Active Power"	C1 ONLY
GAIN_DENT_ENERGY_ACT	Section 2.4.4.1 "Equations for Configuration C1 Calibration – Active Energy and Active Power"	C1 ONLY
GAIN_V_RMS	Section 2.4.10.1 "Equations for Configuration C5 Calibration – RMS Voltage and Current"	C1 ONLY
GAIN_I_RMS	Section 2.4.10.1 "Equations for Configuration C5 Calibration – RMS Voltage and Current"	C1 ONLY

2. **Calibration Stage C2:** Phase compensation and reactive power and energy gain calibration - basic 220V and 5A voltage  $V_B$  and basic current  $I_B$  at a power factor of 0.5 lag.

The calibration parameters calculated in this stage include:

**TABLE 2-5: CALIBRATION REGISTERS GENERATED THROUGH THIS ROUTINE**

Register Name	Equations	Configurations Required
GAIN_POWER_REACT	Section 2.4.6.1 "Equations for Configuration C2 Calibration – Reactive Energy and Reactive Power"	C2 ONLY
GAIN_NUMR_ENERGY_REACT	Section 2.4.6.1 "Equations for Configuration C2 Calibration – Reactive Energy and Reactive Power"	C2 ONLY
GAIN_DENT_ENERGY_REACT	Section 2.4.6.1 "Equations for Configuration C2 Calibration – Reactive Energy and Reactive Power"	C2 ONLY



## 2.6 CREEP THRESHOLD CALIBRATION

Creep threshold represents a state below which the energy accumulation will be suppressed. Due to external noise, even under No Load condition, the meter may register a very small value of energy. To inhibit registering of this unwanted energy, the meter needs to be calibrated for creep threshold. Creep Threshold Calibration also accounts for the threshold starting current, above which the energy needs to be registered.

In Creep Threshold Calibration, maximum-rated operational voltage, threshold starting current and Meter Constant of the meter are used to compute the creep threshold timer value. Using these parameters, the time for energy accumulation equivalent to 1/METER CONSTANT at threshold starting current, is calculated. If the energy accumulation is less than 1/METER CONSTANT during this creep threshold time, it represents either a No Load condition, or load current less than the threshold starting current. In such a case, the incremental energy accumulation will be flushed, suppressing energy accumulation.

### 2.6.1 Creep Threshold Computation

To accumulate energy equal to 1/METER CONSTANT at the above specified line input, time taken is as shown in Equation 2-50.

#### EQUATION 2-50:

$$Time = (1kWh) / (METERCONSTANT \cdot MAX\_VOLTAGE \cdot LEAST\_CURRENT\_DETECT)$$

Time is converted to equivalent minutes + seconds

$CREEP\_THRESHOLD\_MINUTE = Creep\ Threshold\ time\ in\ minutes$

$CREEP\_THRESHOLD\_SECOND = Creep\ Threshold\ time\ in\ seconds$

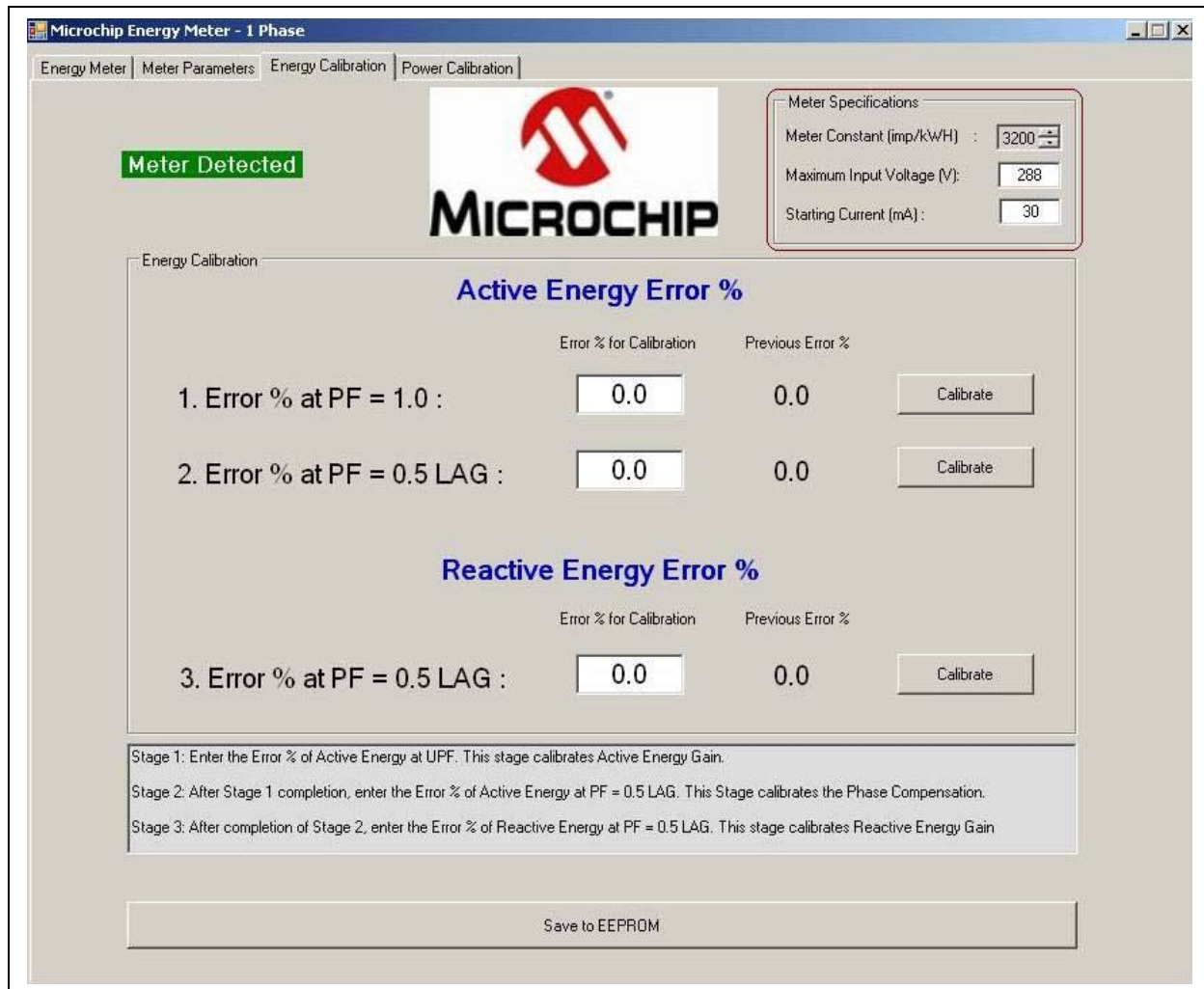
### 2.6.2 Creep Threshold Calibration procedure

Apply the following procedure for Creep Threshold Calibration:

1. Enter the maximum rated voltage of the meter in “Maximum Input Voltage (V)” field, as shown in Figure 2-20.
2. Enter the least detectable current the of meter in “Starting Current”.
3. Set the “Meter Constant”.
4. Click **Save to EEPROM** to save the calibration data to EEPROM. During this process, creep threshold values get computed and saved in the meter.

**Note:** Creep Threshold Calibration needs to be done irrespective of the type of above mentioned calibration process.

# PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide



**FIGURE 2-20:** Creep Threshold Calibration.

## 2.7 METER SPECIFICATIONS AND CALIBRATION PARAMETERS

This section contains the editable options for the meter design.

The resolution of the output registers are determined from these three parameters, and are set based on the information in Table 2-6–Table 2-8.

These tables are important and are applied to calculate the resolution values used when calculating the GAIN/LSb registers, that occur while calibrating the meter. These values are also used to place the decimal point in the reading or results frame.

The resolutions shown in the below tables are based on the assumption that the  $I_{MAX}$  and  $V_{CAL}$  voltages will be at approximately 50% of the input voltage to the A/D converters. To change the headroom of the A/D input, simply change the maximum current number, and the GAIN/LSb registers will scale accordingly.

**TABLE 2-6: CURRENT RESOLUTION TABLE**

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

**TABLE 2-7: POWER RESOLUTION TABLE**

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

**TABLE 2-8: VOLTAGE RESOLUTION TABLE**

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

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

# **PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide**

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## **Chapter 3. Microchip Energy Meter Software**

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### **3.1 INTRODUCTION**

The energy meter software is a Graphical User interface (GUI) that enables the meter to be monitored and debugged in the development phase. It also provides the calibration tool used to precisely calibrate the meter.

### **3.2 MAIN SCREEN**

The main screen contains four tabs:

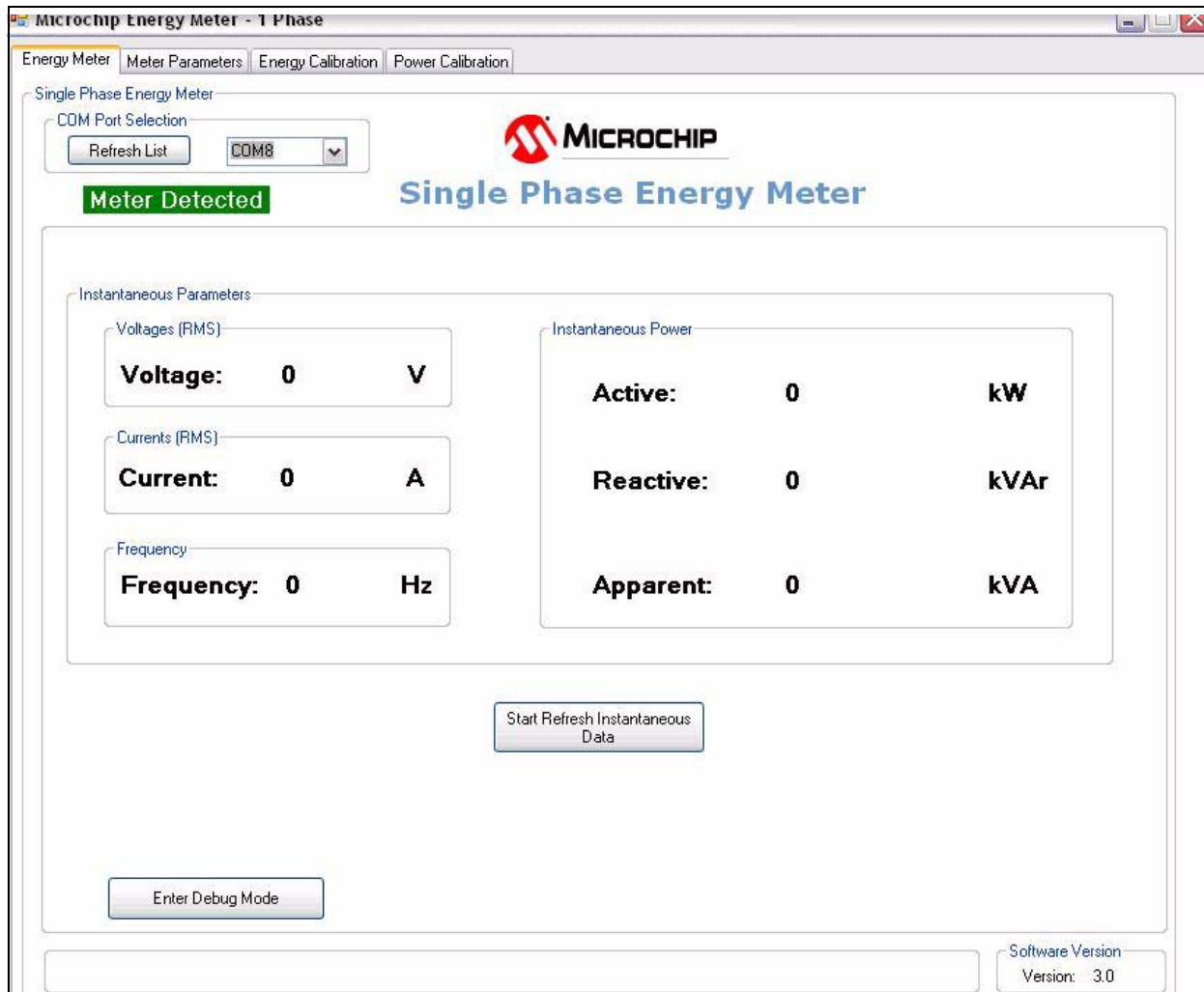
- **Energy Meter:** This tab contains the instantaneous meter output display and a debug window, which enables access to all the internal registers of the meter.
- **Meter Parameters:** This tab contains a calibration tool for Multipoint and Single Point Calibration.
- **Power Calibration:** This tab is used for feedback calibration of voltage, current and power.
- **Energy Calibration:** This tab is used for feedback calibration of energy.

The COM port selection option on top of the window is used to select a serial port or a serial port emulator.

The status of the meter connection with the computer is displayed at the top of the window. This status displays the text "Meter Detected" in green if connected, and changes its status to "Meter Disconnected" in red, if disconnected. This status is present across all the tabs.

The tool has a feature to display the "Instantaneous Parameters", updated in real time (see Figure 3-1).

# PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide



**FIGURE 3-1:** Main Screen with Active Results Frame.

The “Instantaneous Parameters” field contains the recent meter output parameters, such as Active Power, Reactive Power, Apparent Power, RMS Current, RMS Voltage and Frequency. The registers in this frame are continuously collected and refreshed on the PC side periodically.

Table 3-1 shows examples of the meter readings.

**TABLE 3-1: REGISTERS READINGS OF THE METER**

Meter Reading	Register	Example
Active Power	POWER_ACT	101.44W
Reactive Power	POWER_REACT	17.2371 VAR
Apparent Power	POWER_APP	102.894 VA
RMS Current Phase A	I_RMS	0.45A
RMS Voltage Phase A	V_RMS	220.6V
Frequency	FREQUENCY	50 Hz

## 3.2.1 Decimal Point Location

The location of the decimal point, i.e., the resolution of the power quantities, is determined by the values introduced in the “Calibration Parameters” field on the **Calibration** tab. When the meter is calibrated using the calibration methods available with this software, the proper GAIN/LSb correction factor is calculated to ensure the Least Significant bit (LSb), which represents the least significant digit for a given quantity. For example, if the PHA\_I\_RMS register, which represents the RMS current, contains the decimal value 4523, and the ILSb is defined to be 0.01 based on the meter design entry, this value represents exactly 45.23A.

Another example for active power is shown in Table 3-1, where the POWER\_ACT register contains the value 101.44. For this example, the power resolution is 0.1 mW. Therefore, this register represents exactly 101.44W.

## 3.3 DEBUG MODE

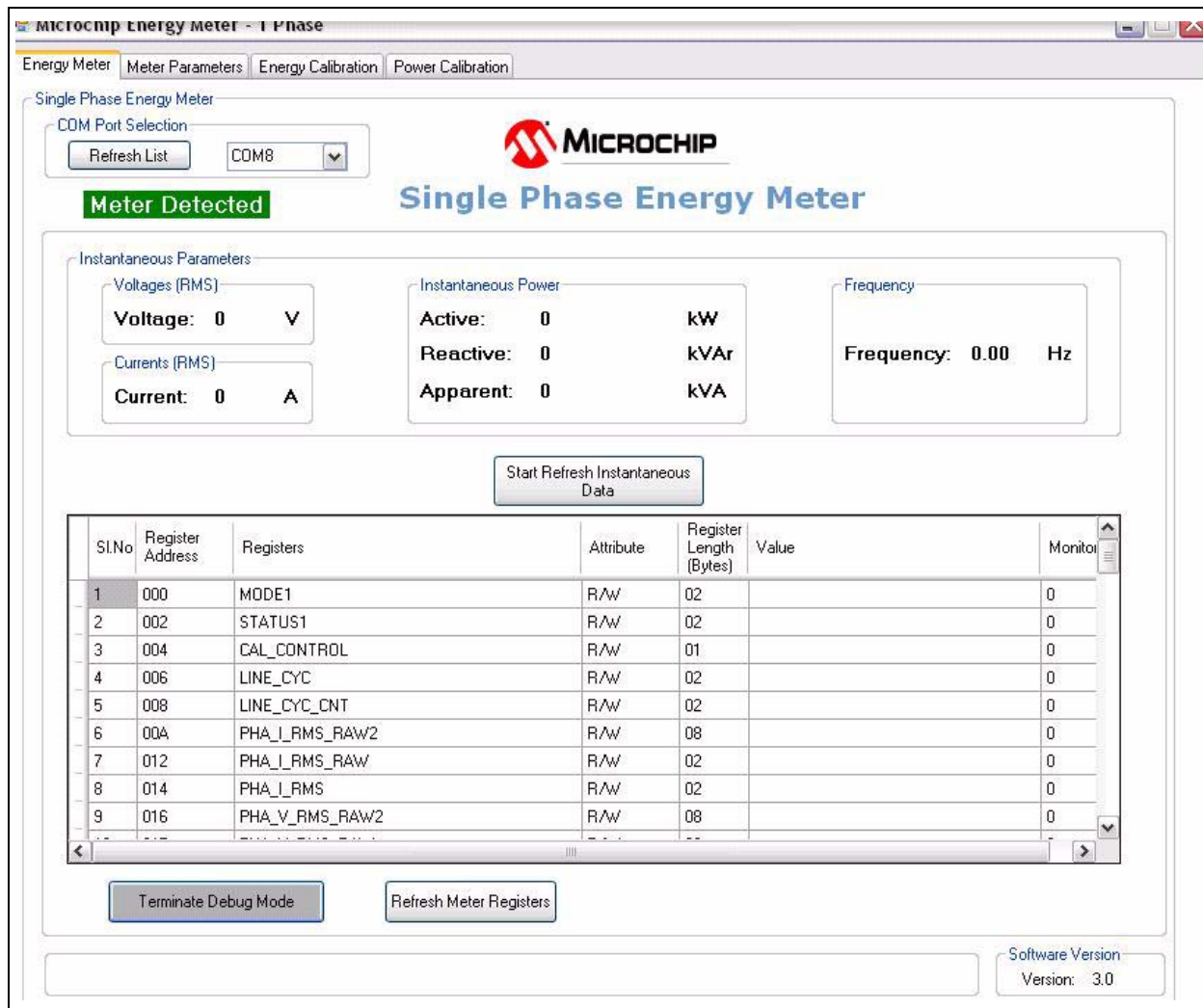
The Debug mode feature enables access to all the internal registers of the meter. From the **Energy Meter** tab, click on **Enter Debug Mode** on the lower right corner of the tool. The Debug mode screen appears as shown in Figure 3-2.

Debug mode displays a complete list of all the internal registers of the meter with their address, name, attribute, register length and value.

Each register is available for read and write in real time, when the meter is computing. This is a convenient tool for debugging operations, giving complete access to all internal details of the meter.

### 3.3.1 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 column “Monitor” across a particular register, as shown in Figure 3-2. By enabling this, the GUI reads the register periodically by bringing the real-time status. Unless monitoring is enabled, the register status is not updated with every instantaneous refresh.



**FIGURE 3-2:** Debug Mode in Main Screen Showing Internal Registers.



### 3.3.2 Refreshing Registers Status

To update all the internal registers, click **Refresh Meter Registers** at the lower right corner, as shown in Figure 3-2. However, this will update the registers only once per click.

### 3.3.3 Writing to Individual Registers

It is possible to write to individual registers for testing certain limiting conditions and fine tuning the calibration 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, as shown in Figure 3-2, and press **Enter** to initiate the write process.

<p><b>Note:</b> “Value” and “Monitor” are the only two user editable columns. The remaining sections are read only.</p>
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# PIC18F87J72 Single-Phase Energy Meter Calibration User's Guide

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NOTES:

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## Chapter 4. Communication Protocol

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### 4.1 PROTOCOL

The Universal Asynchronous Receiver and Transmitter (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 and R.

- 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

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 a 'SX' command, it should verify that the values were stored by issuing a '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'.

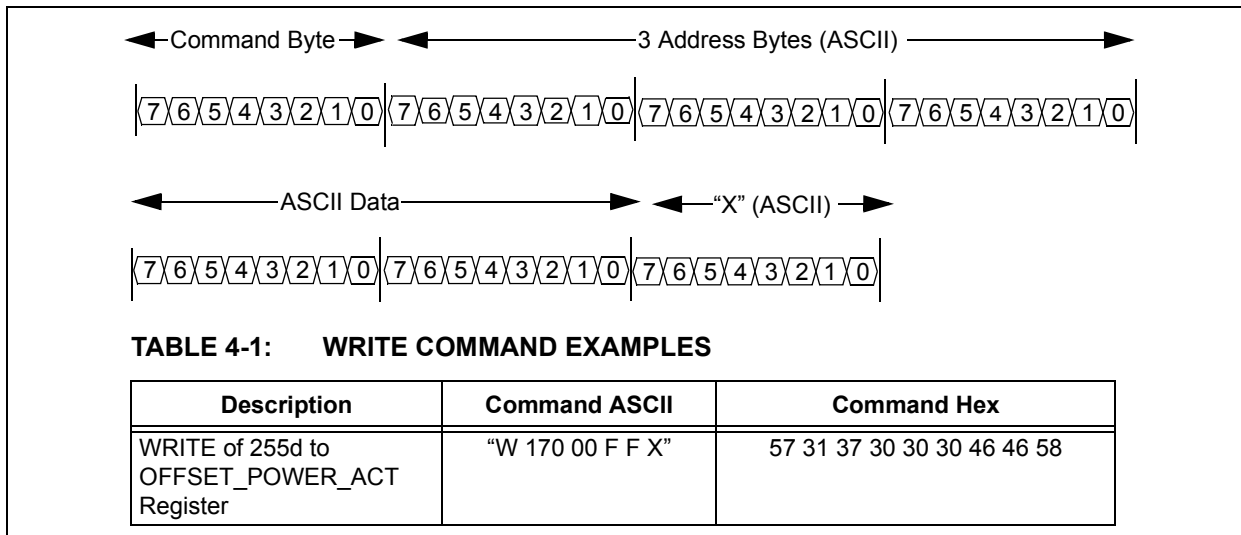
### 4.1.1.4 “W” WRITE: WRITE STARTING AT SPECIFIED ADDRESS

Write the 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.



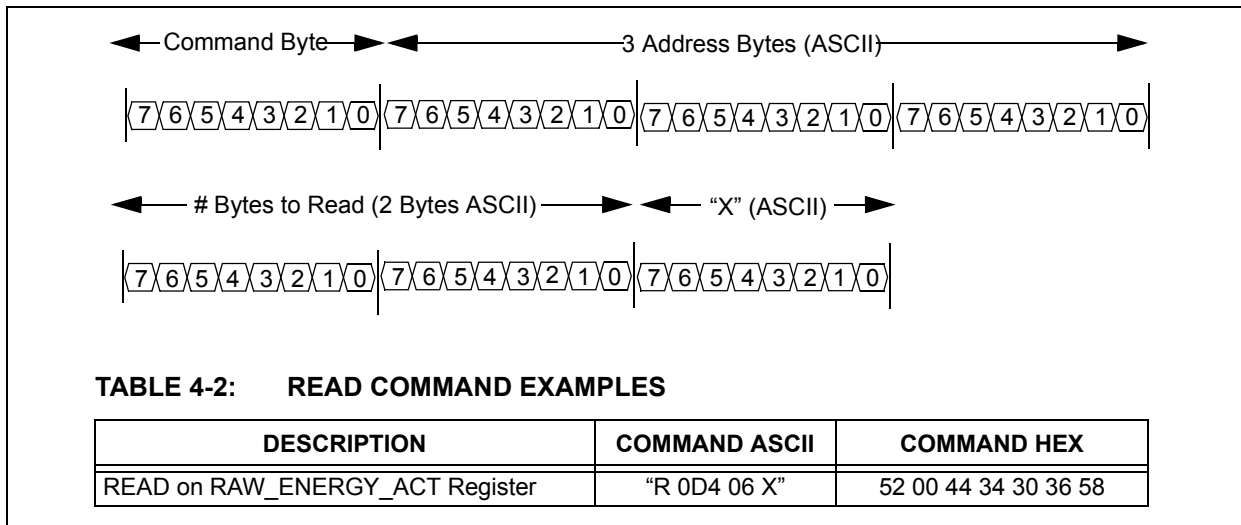
**FIGURE 4-1:** WRITE Command Protocol.

### 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.

NOTES:



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