

## Watt-Hour Meter Reference Design

## INTRODUCTION

The PICREF-3 Watt-Hour Meter (WHM) Reference Design shows the use of a mixed signal microcontroller in an AC power measurement application.

The traditional sensor signal processing chain consisting of sensor, signal conditioning electronics, A/D converter and microcontroller is abbreviated by the use of the mixed signal microcontroller with its on-board A/D converter.

The mixed signal microcontroller used is the Microchip PIC16C924. This microcontroller has five A/D channels, two of which are used to digitize voltage and current signals. The microcontroller features of pulse width modulation (PWM) and direct liquid crystal display (LCD) drive are utilized to further reduce cost and parts count.

The PWM output feature is used with a single pole RC filter to provide a comparator reference with 10 bits of resolution.

The direct LCD drive is used to drive an 8-digit, 7-segment LCD.

#### **MICROCONTOLLER BENEFITS**

The use of a PIC16C924 microcontroller in a power meter offers the following advantages:

- Real-Time Electrical Measurement and Power/Energy Calculations
- · Direct LCD Drive
  - Present Time
  - Total Watt-Hours (Whr)
  - Maximum or Cumulative Demand
- · Customization
- · Quick Time-to-Market

## PICREF-3 OVERVIEW

The WHM Reference Design provides a cost effective circuit capable of monitoring and displaying power and energy consumption on worldwide power mains in the 90V to 264V range.

The PIC16C924 microcontroller shows that the real-time events of sampling voltage and current waveforms can be interleaved with power and energy calculations. All measurements and calculations are performed once per second.

The current waveforms measured are linear for resistive and inductive loads and non-linear for switching power supplies. The current waveform is sampled during the positive current cycle with waveform symmetry assumed between positive and negative cycles (valid for the measured waveforms). A hardware method for full cycle current measurements and firmware methods for complex current waveform shapes are provided in the *Design Modifications* section.

#### **PICREF-3 KEY FEATURES**

- Accepts polarized and unpolarized worldwide power mains.
- Measures and displays AC Voltage (90V to 264V), Load Current and Power Factor.
- Measures power line frequency (47 Hz to 63 Hz).
- Calculates Watts, Watt-Hrs and cumulative Watt-Hrs and displays these values, as well as frequency and time.
- True RMS measurements.
- · Firmware control of triac load switch on/off state.
- · Real time clock during power-saving sleep mode.
- Hibernate mode to save on battery life during storage.
- · Battery back-up for microcontroller.

INFORMATION CONTAINED IN THIS PUBLICATION IS INTENDED THROUGH SUGGESTION ONLY AND MAY BE SUPERSEDED BY UPDATES. NO REPRESENTATION OR WARRANTY IS GIVEN AND NO LIABILITY IS ASSUMED BY MICROCHIP TECHNOLOGY INC. WITH RESPECT TO THE ACCURACY OR USE OF SUCH INFORMATION, OR INFRINGEMENT OF PATENTS ARISING FROM SUCH USE OF SUCH USE OF SUCH INFORMATION, OR INFRINGEMENT OF PATENTS ARISING FROM SUCH USE OR OTHERWISE. IT IS THE RESPONSIBILITY OF EACH USER TO ENSURE THAT EACH WATT-HOUR METER IS ADEQUATELY DESIGNED, SAFE, AND COMPATI-BLE WITH ALL CONDITIONS ENCOUNTERED DURING ITS USE. "TYPICAL" MUST BE VALIDATED FOR EACH CUSTOMER APPLICATION BY THE CUSTOMER'S TECHNICAL EXPERTS. USE OF MICROCHIP'S PRODUCTS AS CRITICAL COMPONENTS IN LIFE SUPPORT SYSTEMS IS NOT AUTHORIZED EXCEPT WITH EXPRESS WRITTEN APPROVAL BY MICROCHIP. NO LICENSES ARE CONVEYED, IMPLICITLY OR OTHERWISE, UNDER ANY INTELLECTUAL PROPERTY RIGHTS.

## TABLE OF CONTENTS

| System Overview                  | 3  |
|----------------------------------|----|
| Hardware Overview                | 4  |
| Firmware Overview                | 8  |
| Firmware Detail                  | 16 |
| Test Results                     | 21 |
| Calibration                      | 21 |
| Power Theory                     | 22 |
| Design Modifications             | 23 |
| App A: System Specifications     | 25 |
| App B: Schematics                | 26 |
| App C: Firmware Listing          | 37 |
| App D: PCB Layout & Fab Drawing  | 39 |
| App E: Bill of Materials (BOM)   | 40 |
| App F: Watt-Hour Meter Demo Unit | 45 |

## ACKNOWLEDGMENTS

#### Hardware Design and Firmware Development:

Dennis E. Coleman, Sr. Applications Engineer, Microchip Technology, Inc. dennis.coleman@microchip.com

**Documentation:** Beth McLoughlin, Applications Engineer, Microchip Technology, Inc.

## **System Overview**

The PICREF-3 Reference Design shows how to develop a cost-effective watt-hour meter (WHM). Using the PIC16C924 microcontroller, the WHM performs power line measurements, followed by power and energy calculations, once per second. System Specifications may be found in Appendix A.

The PICREF-3 can accept all worldwide power mains and is calibrated for both. Worldwide power mains can be either polarized or unpolarized. A polarized power main has a grounded neutral connection. Reversal of line and neutral on a polarized power main will create a power line fault. An unpolarized power main does not have a grounded neutral connection. Therefore, line and neutral can be connected at random without causing a power line fault.

Countries using polarized power mains include Australia, United Kingdom, Ireland, Denmark, India, Israel, Japan and Switzerland. Countries using unpolarized power mains include Germany, Austria, Norway, Sweden, France, Finland, the Netherlands, Belgium and Italy.

The PICREF-3 is limited to measuring a maximum current of 10 Amps. However, residential current loads are 200 Amps maximum. See *Design Modifications* for hardware design changes to scale the meter for 200A loads. Power line voltage (90V – 264V) is sensed by the high voltage AC electronics (Figure 1). Balanced input voltage and current signals are then provided to the Small Signal Analog/Digital Sense Electronics for input into the PIC16C924. The PIC16C924 uses the analog/digital voltage sense and analog/digital current sense to calculate the power and energy consumption of the load. The microcontroller then displays these calculations on the 8-digit LCD according to user pushbutton input.

The PIC16C924 controls the on/off state of the triac control circuit. The triac control circuit applies current to the power triac gate to effect on/off load current switching. (Triac switch included for demo purposes only.)

In addition, the pulse width modulation (PWM) output of the microcontroller is filtered and used as a variable reference to a comparator in the current sense circuitry.

A serial EEPROM is available to store the watt-hour count displayed at the time of a power outage. In addition, an RS-232 serial port is available for sending and receiving serial data. Firmware for these functions has not been implemented (See *Design Modifications*).

Linear power supply electronics provide general device power, voltage reference and battery backup.



## FIGURE 1: PICREF-3 WATT-HOUR METER (WHM) BLOCK DIAGRAM

The PIC16C924 source code is written in C. Firmware algorithms accomplish voltage and current measurements, voltage and current waveform phase shift measurements, real-time timekeeping, and calculation and display of power and energy consumption. In addition, there is code to display measurements on the LCD.

The Watt-Hour Meter (WHM) reference design has five (5) modes of operation, determined by the PIC16C924 firmware: Reset, Entry, Measurement, Sleep, and Hibernate. More information on each mode is presented in *Firmware Overview*.

## Hardware Overview

This section describes the PICREF-3 hardware and how it functions in the system. Hardware detail (schematics) may be found in Appendix B.

#### Microcontroller

The PIC16C924 (Figure 2) allows for the real-time interleaving of sampling voltage and current wave-forms, and power and energy calculations. Also, the PIC16C924 drives the display (LCD) and controls the triac and current sense input (for true RMS current measurements).



## FIGURE 2: PIC16C924 PINOUT

AC current also flows through a resistive voltage divider

The current sense transformer and resistive voltage

divider provide low-voltage analog waveforms which

replicate the large scale voltage and current waveforms

via the AC output.

at their respective sensor inputs.

#### **High Voltage AC Electronics**

AC voltage (90V - 264V) is applied to the AC input and a load is connected to the AC output (Figure 3).

AC current flow is from the AC input to the AC output and through the load. AC current continues through triac switch and current sense transformer back to the AC input.

FIGURE 3: HIGH-VOLTAGE AC ELECTRONICS DETAIL



## Small Signal Analog/Digital Sense Electronics – Voltage

The balanced input voltage signal from the resistive divider is amplified by an instrumentation amplifier (Figure 4). This amplifier accomplishes signal amplification and rejection of common mode noise.

The signal at the amplifier output swings above and below a negative reference potential. The amplifier output is connected to A/D converter input AN0 of the PIC16C924.

An unbalanced input voltage signal is tapped off of the balanced input voltage signal and connected to a comparator input. This comparator is used to compare the input signal to an analog ground reference.

The comparator output goes high when the input signal exceeds the ground reference. The output of the comparator provides digital voltage sense information and is connected to I/O line RG7 of the PIC16C924.

#### FIGURE 4: SMALL SIGNAL ANALOG/DIGITAL VOLTAGE SENSE ELECTRONICS DETAIL



## Small Signal Analog/Digital Sense Electronics – Current

The unbalanced input current signal from the sense transformer is amplified by an instrumentation amplifier (Figure 5). This amplifier accomplishes signal amplification and rejection of common mode noise.

The signal at the amplifier output swings above and below a ground reference potential. The amplifier output is connected to analog converter input AN1 of the PIC16C924.

The unbalanced input current signal is also connected to a comparator input. This comparator is used to compare the input signal to a variable positive reference (PWM reference).

The comparator output goes high when the input signal exceeds the reference. The output of the comparator provides digital current sense information and is connected to I/O line RE7 of the PIC16C924.





#### Microcontroller I/O

The PIC16C924 is a "mixed-signal" microcontroller, or a microcontroller capable of analog and digital input/output (Figure 6). This capability is used by the PIC16C924 to control the functions of the PICREF-3.

#### <u>Input</u>

The on-board A/D converters of the PIC16C924 allow input of analog, as well as digital, voltage and current sense signals from the Small Signal Analog/Digital Sense Electronics (Figure 1). Depending on user pushbutton input (*Firmware Overview*), these signals may be used for display (LCD) or calculation and display. Pushbutton input is digital.

A +5V analog reference is provided for the A/D converters on the microcontroller. A +3V analog reference is also available for better A/D resolution.

Interrupt input is provided into microcontroller pin RB0/INT. The digital voltage sense line, digital current sense line, and serial communication input lines are each differentiated, by identical circuits, and wire-or'd together as input to RB0/INT. The differentiated digital voltage sense signal is used to wake the microprocessor from Sleep or Hibernate modes.

An A/C Input Balanced/Unbalanced Sense line provides the microcontroller with information on whether the input neutral line is grounded or ungrounded to support worldwide power main functionality of WHM.

## <u>Output</u>

The PIC16C924 feature of direct LCD drive makes display simple. The information displayed is determined by user pushbutton input (*Firmware Overview*).

Through the use of PWM and an RC filter, the PIC16C924 can vary the analog reference voltage to the current sense comparator (*Small Signal Analog/Digital Sense Electronics*) for use in true RMS current measurements (*Firmware Overview*).

The microcontroller controls the triac through triac control circuitry. The triac (*High Voltage AC Electronics*) may be turned on/off by pressing the START/STOP pushbutton. This will turn on/off current flowing to the load. (Triac switch included for demo purposes only.)

### Input/Output

A Serial EEPROM is provided to store data in the event of a power loss. In addition, an RS-232 serial port is provided for communication with a computer. Firmware for these functions has not been implemented (See *Design Modifications*).



#### FIGURE 6: MICROCONTROLLER I/O DETAIL

#### **Push Buttons**

PICREF-3 pushbuttons and functions are listed in Table 1. For more information on pushbutton functions, see *Firmware Overview*.

#### TABLE 1: PUSHBUTTONS

| Push-<br>button                 | Name              | Function  |  |
|---------------------------------|-------------------|---|--|
| S1                              | Start/Stop        | Turn on/off the current flow to the load.         |  |
| S2                              | Cancel*; $\Delta$ | Cancel: Quit w/o saving;<br>Δ: Increment          |  |
| S3                              | Enter;<br>Hiber   | Enter: Enter info;<br>Hiber: Enter hibernate mode |  |
| S4                              | CLR*; ∇           | Clr: Clear;<br>∇: Decrement                       |  |
| S5                              | MCLR              | Master Clear - Reset WHM                          |  |
| * This feature not implemented. |                   |   |  |

#### **Linear Power Supply Electronics**

The linear power supply provides the signals listed below.

- +5V digital
- +8V and -8 V analog
- Battery backup (4.5V to 5.5V) provides power to the microcontroller during AC power outages
- +5V analog reference provides an analog reference for the PIC16C924 on-board A/D converters
- +3V analog reference provides an analog reference for the PIC16C924 on-board A/D converters for higher-resolution measurements of signals less than 3V peak amplitude.

## **Firmware Overview**

The PIC16C924 firmware controls the Watt-Hour Meter operational modes and calculates power forms for display.

There are five (5) modes of operation for the PICREF-3:

- Reset
- Entry
- Measurement
- Sleep
- Hibernation

The 8-digit LCD is used to display information in each mode (Figure 7). Each digit has seven segments. Pushbuttons are used to control display output and set parameters.

There is a Watt-Hour Meter Demo Unit available to demonstrate the firmware. For a description of how to set up the demo unit, see Appendix F.

#### FIGURE 7: LCD AND PUSHBUTTONS



#### **Reset Mode**

The Reset mode occurs immediately after a power-on reset of the microcontroller. Power-on reset occurs when the microcontroller  $\overline{\text{MCLR}}$  pin is lowered to ground potential and then raised to VDD. Reset will occur when:

- 1. The first time that the battery is connected to the circuit with no AC input power;
- 2. The first time AC power is connected to the circuit when there is no battery, or;
- 3. Any time that the PICREF-3 MCLR button is pressed and released.

In Reset mode, the firmware version number is shown on digits 8, 6 and 5.

Firmware Version Number



**Note:** The Start/Stop pushbutton is <u>not</u> enabled during the Reset mode.

#### **Entry Mode**

Entry Mode occurs after Reset mode. In entry mode, the time must be set. Also, the cumulative Watt-Hours are cleared (Not implemented for this version of the document).

To set the time of the 24-hr clock, use the following procedure (maximum value is 24:00 before rolling over to 00.00):

• The display will show a "0" on digit 6 and colons separating hours/minutes/seconds. Digit 6 represents tens of hours.

Use the  $\Delta$  pushbutton to increase and the  $\nabla$  pushbutton to decrease this value. Pressing and releasing  $\Delta$  or  $\nabla$  will increase or decrease the value by one. Pressing and holding  $\Delta$  or  $\nabla$  will begin a scrolling increase or decrease in the value. Release the pushbutton to stop the scroll. Press the Enter pushbutton to select a value. Once a value is selected, digit 5 will display a "0."



 Digit 5 represents single hours. Use the ∆ pushbutton to increase and the ∇ pushbutton to decrease this value. Press the Enter pushbutton to select a value. Once a value is selected, digit 4 will display a "."

EX:

 Digit 4 represents tens of minutes. Use the ∆ pushbutton to increase and the ∇ pushbutton to decrease this value. Press the Enter pushbutton to select a value. Once a value is selected, digit 3 will display a "0."



 Digit 3 represents single minutes. Use the ∆ pushbutton to increase and the ∇ pushbutton to decrease this value. Press the Enter pushbutton to select a value.



• After the digit 3 value is selected, the selected time is shown on the LCD.

| X: |  |    | 1. 🗖 |    |  |
|----|--|----|------|----|--|
|    |  | İС | ÍΠ   | Π. |  |

#### Measurement Mode

Measurement mode occurs immediately after Entry mode.

When the unit is connected to line AC power, the load may be disconnected from the AC line power through power triac TR1. To start measuring power (from Reset Mode), press and release the START/STOP key (When the START/STOP key is released, the Triac receives gate trigger pulses). The triac is now enabled and the Load is now connected to the AC line voltage.

In one second, voltage, current and phase shift measurements are made and power factor, true power and watt-hour calculations are carried out.

#### Measurement Mode Display - No AC

If there is no AC input, the WHM goes into Sleep mode.

#### Measurement Mode Display - No Load

If there is no AC current flow to the load, the display shows Frequency, Voltage (= 0), Current ("A OFF" message) and Time. Each value is displayed for 3 seconds before the next parameter is displayed.

#### Measurement Mode Display - Current Flowing

If there is AC current flow to the load, the display shows Frequency, Voltage, Current, Power Factor, True Power and Watt-Hrs. Each value is displayed for 3 seconds before the next parameter is displayed.

Because a 7-segment per digit display is used, not all letters can be used for measurement parameter units. Therefore, the following abbreviations have been selected for each parameter:

Frequency - No letter displayed.

Range: Frequency is resolved to either 50 or 60 Hz.

| EX: |  |  |
|-----|--|--|
|     |  |  |

• Voltage - "V"

Range: 90V to 264V. Also 000.00 for voltages less than 90 V, or no load/no current.



· Current - "A". No numbers are displayed when current waveform shape is unknown. Range: 0A to 10 A



Power Factor - "PF"

Range: 0.199 to 0.999



• True Power in Watts - "P" Range: 0W to 2640W



Watt-Hrs - "Hr"

The maximum watt-hours displayed will be 999999, and will then roll over to 000000.

| EX: |  |
|-----|--|
|     |  |

To stop power measurement, press and release the START/STOP button.

#### Sleep Mode

Sleep Mode is entered when the microcontroller executes the SLEEP assembly instruction, located within the interrupt service routine of the sleep.c file. The interrupt service routine is called when AC voltage dropout is detected. The battery provides power to the microcontroller in Sleep Mode (Remove black heat shrink tubing from positive battery terminal for battery backup operation.). The processor clock is stopped at this time.

Disconnecting the AC line voltage at P1 at anytime will cause the unit to go into Sleep mode. In this mode, an "S" is displayed on digit 8 of the LCD.

The unit will maintain time for 5 minutes. If no AC line voltage is applied at P1, then, after 5 minutes, the unit will automatically enter Hibernate mode to conserve battery life. (Time keeping function in Sleep mode not implemented for this version of the document.)

The unit will automatically exit Sleep mode when AC line power is applied at P1 and return to Measurement mode.

#### Hibernate Mode

Hibernate mode is defined as a complete shutdown of all power consuming microcontroller peripherals prior to entering Sleep mode. The real-time clock is not updated during this mode.

When an AC power drop-out is detected, the display will flash "S." If the Hiber pushbutton is pressed while the "S" message is showing, the microprocessor will be put into hibernate mode and the display will first show "H" and then go blank.

If the Hiber pushbutton is not pressed while the display shows "S," the processor will go into Sleep mode and the display will go blank. After 5 minutes in Sleep mode, Hibernate mode is entered automatically (Not implemented for this version of the document).

Applying AC line voltage at P1 will cause the unit to exit Hibernate mode and enter Entry mode.

## Voltage and Current Measurements

This section discusses the voltage and current measurements that are made by the PIC16C924 firmware during Measurement mode.

#### <u>Voltage</u>

A peak detect, RMS responding algorithm is used. The sinusoidal voltage waveform is sampled to determine the peak value.

Absolute calibration point data is stored for sinusoidal load voltages (see Voltage Sensor Calibration for list of calibration point values). At each calibration point, the whole and fractional part of the AC load voltage corresponding to a voltage A/D conversion are stored. An 8-bit integer representing hundreds and tens of millivolts (ex; 69 = 690mV) is stored. This stored value is the rate of change in mV/sample between the calibration point and the next higher calibration point. The increase in voltage resulting from the difference between the A/D conversion result and the A/D conversion result at the calibration point is calculated by multiplying the rate in mV/sample by the number of samples. The resulting difference voltage is added to the voltage stored at the calibration point to form the final load voltage result.

#### Current – True RMS Measurements

True RMS measurements are highly dependent on waveform shape. The watt-hour meter first determines waveform shape and then calculates true RMS values.

True RMS current calculations based on recognition of waveform shape and the use of constant RMS factors for these waveform shapes is a technically sound, low cost approach to true RMS current measurements.

The PICREF-3 provides algorithms for the fundamental shapes of linear resistive, linear inductive and narrow sinewave pulses.

More complex shapes will likely be combinations of these fundamental shapes and can be recognized through more complex algorithms based on the fundamental shape algorithm. (Complex combinations of waveform shapes are not implemented.)

The peak current waveform amplitude sample is first determined in order to ensure that comparator reference values do not exceed the waveform's peak amplitude. Current waveforms are then digitally scanned to determine waveform type.

The digital scan is accomplished by varying the reference voltage of the digital current sense comparator. The reference voltage is varied by filtering the modulated pulse width from the microcontroller's PWM output. As the comparator reference voltage is increased from ground to the maximum signal level (in varying step sizes), digital pulses synchronized with the analog waveform zero crossings are created. A count of when the pulses are low and high is kept to create the digital current scan.

The count numbers are applied to firmware algorithms which determine current waveform shape. Once the wave shape is determined, the appropriate true RMS algorithms are applied.

#### Current – Linear Loads

Linear loads are inductive and resistive. These loads create a variable 0° to 90° phase shift between the applied sinusoidal voltage waveform and the phase-shifted sinusoidal current waveforms. Figure 8 shows the voltage and current waveforms for a linear inductive load, a drill press. Figure 9 shows these waveforms and linear pulses.

A peak detect, waveform shape, RMS responding algorithm is used. The current waveform is sampled to determine the peak value.

Absolute calibration point data is stored for sinusoidal load currents (see *Current Sensor Calibration* for list of calibration point values). At each calibration point, the whole and fractional part of the current corresponding to a current A/D conversion are stored. An 8-bit integer representing hundreds and tens of milliamps (ex; 10 = 100mA) is stored. The rate of change in mA/sample between the calibration point and the next higher calibration point is also stored. Two integer numbers are used to store the current rate of change in mA/bit. One integer number represents tens and single milliamps (ex; 40 = 40mA) and the other integer number represents enths and hundredths of milliamps (ex: 80 = 0.80 mA).

The increase in current resulting from the difference between the A/D conversion result and the A/D conversion result at the calibration point is calculated by multiplying the rate in mA/sample by the number of samples. The resulting difference current is added to the current value stored at the calibration point to form the final current result.



#### Current - Non-linear Loads

Non-linear loads are created by active circuitry, such as switching power supplies. Figure 10 shows peak non-linear current pulses at peak voltage for a computer monitor load. Figure 11 shows logic pulses, developed by the watt-hour meter, as well as the waveforms of Figure 10. These pulses are synchronized to the current and voltage zero crossings.









The RMS value of the sine pulse current waveform varies as the square root of the inverse of the waveform's period. The RMS value of the current sine pulse, integrated over the half cycle of the exciting voltage waveform, is predicted by Equation 1.

## EQUATION 1: RMS CURRENT VALUE

$$RMS = \left| \frac{\sqrt{1/\tau} - \sqrt{1/T}}{\sqrt{1/\tau}} - 1 \right| \times 0.707$$

Where:

 $\tau =$  Current sine pulse width

T = Voltage waveform half cycle

0.707 = Peak-to-RMS ratio of a sine wave where the sine wave half cycle equals the integration period.

The firmware measures the current sine pulse width and the voltage waveform half cycle time. These numbers are then applied to Equation 1 to determine the RMS value of the sine pulse.

RMS factors resulting from Equation 1 for pulse widths ranging from 1 ms to 4.1 ms are stored in two arrays for 50 Hz and 60 Hz respectively. The number of tenths of ms is counted and used as an index number to access array elements. The arrays hold integer offset numbers which are added to an integer base number to form the calculation result of Equation 1.

The RMS factor is used to calculate true RMS current as follows. A constant representing the amount of current per A/D sample at an RMS value of 0.001 is multiplied by the number of samples found for the peak current. The result is then multiplied by the RMS factor found for the given pulse width which results in the true RMS current for the narrow pulse waveform.

#### **Power Calculations**

This section discusses the power calculations that are made by the PIC16C924 firmware from voltage and current measurements. For definitions of these power forms, see *Design Background*.

### **Apparent Power**

RMS voltage and RMS current, whole and fractional numbers are multiplied to obtain apparent power.

### Power Factor

Power factor is determined using a phase shift count and a look-up table.

Phase shift can be measured for current waveforms that are phase shifted from voltage waveforms by up to 78.5°. A firmware counter counts between rising edges of the voltage and current comparator outputs. The total phase shift count from two consecutive cycles in a one second measurement interval is divided by two to obtain an average phase shift count.

The average phase shift count is then applied to an algorithm which counts the number of 0.5 degree phase shift increments. The total number of increments is used to index into a cosine function offset look-up table. This table contains an integer offset which, when added to a long integer base number, yields a long integer cosine result of phase angles between 2° and 78.5°, which corresponds to power factors ranging from 0.999 to 0.199.

| Note: | If power factor of load is less than 0.199, |
|-------|---|
|       | the meter will display 0.199.               |

A rolling two-sample average is used to obtain an average power factor reading. Two power factor calculations from consecutive one second measurement intervals are averaged to determine the power factor displayed.

The firmware counter is a 16-bit integer variable which has a phase shift per count resolution of better than  $0.1^{\circ}$  degrees at all frequencies between 47 Hz and 63 Hz for the microcontroller oscillator operating at 8 MHz.

### True Power

True power in Watts (W) is found by multiplying the apparent power by the power factor.

#### **Energy Calculations**

This section discusses the energy calculations that are made by the PIC16C924 firmware from power calculations and time measurements.

#### Watt-Hours

A true power calculation is made once per second. Energy in joules is obtained by converting true power in joules/sec to joules. One watt-hour is obtained for each accumulation of 3600 joules.

## **Firmware Detail**

PIC16C924 firmware is written in C and consists of the following modules:

| main.c     | Main program. Contains INCLUDE<br>statements for all files listed below,<br>plus a modified header file,<br>16C924.h.             |
|------------|---|
| 16C924.h   | Modified header file. Redefined<br>some letters in standard header to<br>make code more readable for LCD<br>display instructions. |
| pf_table.c | Cosine table used for calculating power factor.   |
| sleep.c    | Put microprocessor to sleep.  |
| lcd_808.c  | LCD control.  |
| lcd_code.c | LCD display codes for numbers 0 through 9.  |
| message.c  | Contains LCD messages.  |
| time.c     | Real-time clock.  |
| int_serv.c | Interrupt service routines.   |
| pwrstate.c | Determine power state (on/off).   |
| triac.c    | Triac control (triac on/off).   |
| pwm.c      | Determine pwm for current digital scan.   |
| sample.c   | Sample current, voltage and neutral line.   |
| i_meas.c   | Current measurements.   |
| phase.c    | Determine phase difference<br>between current and voltage wave-<br>forms.   |
| shape.c    | Determine current waveform shape.   |
| freq.c     | Determine AC line voltage<br>frequency.   |
| power.c    | Power and energy calculations.  |
| v_meas.c   | RMS voltage and current calcula-<br>tion.   |
| v_table.c  | Look-up tables for absolute voltage calibration points and rates between calibration points.                                      |
| i_table.c  | Look-up tables for absolute current<br>calibration points and rates<br>between calibration points.                                |
| ac_sense.c | Determine neutral line state (grounded/ungrounded).   |
| inl_meas.c | finds pulsed current RMS values   |
| rms_nlp.c  | arrays holding integer offsets of<br>narrow pulse RMS factors at<br>50 and 60 Hz.   |

Program flow diagrams can be found on the following pages. Firmware listing information can be found in Appendix C.











FIGURE 16: MEASUREMENT MODE – DISPLAY LOOP







## **Test Results**

Results of PICREF-3 tests are listed below.

#### **Comparison Test**

PICREF-3 Watt-Hour Meter measurements were compared to the measurements of a commercial watt-hour meter, the Yokogawa WT2010 Digital Power Meter, which has a basic measurement accuracy of 0.03%.

The results of this comparison for several PICREF-3 demo units is TBD.

For individual WHM demo unit test results, see attached page(s).

#### Linear Resistive Load Tests

Halogen lamps of different wattage were tested with the PICREF-3 at 50 and 60 Hz.

- 120V: Wattages from 60W to 1100W
- 240V: 1000W, 2000W

#### **Linear Inductive Load Tests**

Fractional horsepower motors used with PICREF-3 are listed below. Start-up and steady state currents are also shown.

- 115V, 1/2 HP, 2-speed motor at 60Hz, 120V
  - High speed start-up current: 11.5A
  - High speed steady state current: 8.8A
  - Low speed start-up current: 10.9A
  - Low speed steady state current: 4.2A
- 115V, 1/3 HP, 2-speed motor at 60Hz, 120V
  - High speed start-up current: 17.3A
  - High speed steady state current: 7.0A
  - Low speed start-up current: 12.5A
  - Low speed steady state current: 4.25A
- 230V, 1/2 HP, 2-speed motor at 60Hz, 220V
  - High speed start-up current: 8.8A
  - High speed steady state current: 2.1A
  - Low speed start-up current: 2.7A
  - Low speed steady state current: 1.4A
- 230V, 1/2 HP, 2-speed motor at 50Hz, 220V
  - High speed start-up current: 7.5A
  - High speed steady state current: 3A
  - Low speed start-up current: 5.6A
  - Low speed steady state current: 1.75A
- 115V/230V, 1/6 HP, motor at 60Hz, 120V
  - Start-up current: 5A
  - Steady state current: 2.9A
- 115V/230V, 1/6 HP, motor at 50Hz, 120V
  - Start-up current: 7.5A
  - Steady state current: 4A
- 115V/230V, 1/6 HP, motor at 60Hz, 220V
  - Start-up current: 3.7A
  - Steady state current: 1.2A

- 115V/230V, 1/6 HP, motor at 50Hz, 220V
  - Start-up current: 4.9A
  - Steady state current: 1.7A

#### Non-Linear Load Tests

A Mitsubishi Color Display Monitor (Model # FW6405ATK) was tested with the PICREF-3 at 50 Hz and 60 Hz.

## Calibration

This section describes the calibration procedure and equipment used.

The signal source used was a Hewlett Packard 6814B AC Power Source/Analyzer. The measurement reference used was a Yokogawa WT2010 Digital Power Meter.

#### Voltage Sensor Calibration

90 VAC is applied to P1. A  $200\Omega$  load is connected and the triac is turned on. Resistors R4, R25 and R37 are adjusted to provide an A/D conversion result of "1" of an ungrounded neutral line and "4" for a grounded neutral line.

For an ungrounded neutral line, there is one voltage sensor curve, and for a grounded neutral line, there is another. These voltage sensor curves, developed at R26, are viewed as piecewise linear curves with absolute calibration points at 90V, 100V, 110V, 120V, 130V, 150V, 200V, 210V, 220V, 230V, 240V and 260V AC. Calibration of the voltage sensor is frequency independent.

A volt/sample rate is used to calculate voltage in between absolute voltage calibration points.

#### **Current Sensor Calibration**

A resistive load is connected to P2 and voltage is applied to P1. Resistors R5 and R38 are adjusted to provide an A/D conversion result of 0xFB at the load current of 10A.

Separate current sensor curves are stored for 50Hz and 60Hz. The current sensor curves, developed at R9, are viewed as piecewise linear curves with absolute calibration points at 0.5A, 0.7A, 1.0A, 2.5A, 3.5A, 5.00A and 10.00A. The calibration of the current sensor is independent of the state of the neutral line. The current sensor calibration is frequency dependent.

A mA/bit rate is used to calculate currents in between absolute current calibration points.

#### **Phase Sensor Calibration**

The phase shift between the digital voltage sense waveform at R27 and the digital current sense waveform at R44 is adjusted with the phase shift capacitor at U5-5. Inductive loads with power factors between 1 and 0.2 are connected to P2. The phase shift capacitor is adjusted to cause the WT2010 power meter phase and the circuit phase difference to match at a frequency of 50Hz. The circuit phase difference is monitored with a digital storage oscilloscope. Inductive loads with power factors spanning the specified measurement range are connected to P2.

Absolute phase calibration points are obtained at or close to 2.5°, 25°, 50°, 70°, 75° and 78°. A phase degree/sample rate is used to calculate phase shifts in between absolute phase calibration points. The phase sensor calibration is frequency dependent. Four piecewise linear phase curves are stored for the following conditions:

- 60 Hz neutral line grounded
- · 60 Hz neutral line not grounded
- · 50 Hz neutral line grounded
- 50 Hz neutral line not grounded

A calibration point at a power factor of 0.999 is obtained for each condition.

## **Power Theory**

An example of how to implement a watt-hour meter using microcontrollers has been described in the previous sections. However, if a customer wishes to change part or all of this design, then an understanding of why the design was developed as it was, i.e., an understanding of power theory, is essential.

#### **Components of Power**

Residential loads are primarily inductive and resistive. These loads can be represented by a series RL circuit.



FIGURE 18: SERIES RL CIRCUIT

The components of power delivered by the AC generator to the R, L series load can be represented on a vector diagram.

#### FIGURE 19: COMPONENTS OF POWER



The three components are apparent power, true power and reactive power.

Apparent Power This is the value that would be found if a voltmeter and ammeter were used to measure circuit voltage and current and then these measured values were multiplied together.

$$VA = \sqrt{P^2 + VARs^2}$$

True Power This is the pure resistive component measured in watts.

$$P = \sqrt{VA^2 + VARs^2}$$

ł

**Reactive Power** This is the pure reactive component measured in VARs.

$$VARs = \sqrt{VA^2 + P^2}$$

The true power, in watts, can be obtained by multiplying the apparent power by the cosine of the angle between the apparent power and true power.

The cosine of the angle between apparent power and true power is known as the power factor.

The angle between apparent power and true power is equal to the angular displacement between the voltage and current waveforms.

FIGURE 20: TRUE POWER DEFINITION



Solid state watt-hour meters now in use measure and display energy based on the time accumulation of true power by default but also provide for the selection of the alternate energy measurements of VARh and VAh.

## **Design Modifications**

This reference design is for guidance only, and it is anticipated that customers will modify parts of it. With this in mind, this section suggests modifications that the customer may wish to make to the design.

• Full Cycle Current Measurements:

A hardware method for full cycle current measurements involves an additional current sensor channel. This channel would consist of instrumentation amplifier U14 with current sensor input connections reversed with respect to instrumentation amplifier U2. The output of amplifier U14 is then 180 degrees out-of-phase with U2. A switching circuit/device would be needed to switch the RA1 input between U2 and U14.

200A Max Current:

This design may be modified to accommodate 200A Max residential loads by doing the following: (1) remove the triac from the circuit, and (2) use a higher-rated (200A) current sense transformer.

• Serial EEPROM for Power Outage Data Storage

A Serial EEPROM is provided to store data in the event of a power loss. Additional firmware must be written to accomplish this function.

Disconnecting the AC line voltage at P1 at any time will cause the unit to go into Sleep mode. At this time, the microcontroller should write the sum of the last calculated watt-hour value and the last cumulative watt-hour value to Serial EEPROM memory. When power is restored, this data should be read back into the microcontroller.

For more information on interfacing a serial EEPROM and a PICmicro, see *AN567* - *Interfacing the 24LCXXB Serial EEPROMs to the PIC16C54*.

RS-232 Communications Port

An RS-232 serial port is provided for communication with a computer. Additional firmware must be written to accomplish this function.

For more information on a software serial port, see *AN593–Serial Port Routines Without Using Timer0*.

Five Meters in One

The PICREF-3 may be thought of as 5 meters in one. This design may be used as a guideline for the designs of other meters, namely:

- Volt Meter
- Current Meter
- Power Factor Meter
- True Power Watt Meter
- Time Integrating Watt-Hour Meter

NOTES:

## APPENDIX A: SYSTEM SPECIFICATIONS

| Parameter                  | Condition  | Value  |
|----------------------------|--|--|
| AC Input Frequency         |  | 47 Hz to 63 Hz   |
| Maximum Load Current       |  | 10 Amp AC  |
| Current Range              | Current below 0.5A is displayed as 0A  | 0.5A - 10 A AC   |
| AC Input Voltage           | Voltage below 90V is displayed as 0V   | 90V to 264V  |
| Voltage                    |  | 1% of reading  |
| Current                    |  | 1% of reading  |
| Laging Power Factor        | Inductive Loads  | 0.199 – 1.000  |
| Leading Power Factor       | Capacitve Loads  | 1.000  |
| Power Measurement Accuracy | Linear resistive loads; power factor = 1.000;<br>crest factor of voltage and current waveforms = | 1.0% of average reading plus 0.2% of full scale                      |
|                            | 1.414.   | Option 1: 1.0% of reading<br>with current automatic<br>gain control. |
|                            | Linear inductive loads;<br>crest factor of voltage and current waveforms =<br>1.414.             | 1.0% of average reading plus 0.2% of full scale                      |
| Maximum Power Consumption  |  | 3.5 W @ 240V<br>0.54W @ 120V<br>0.43W @ 100V                         |
| Maximum Battery Current    | Sleep Mode   | 16 μA  |
| Nominal Battery Current    | Hibernate Mode   | 60 nA  |
| Minimum Battery Life       | Based on current in Hibernate mode   | 10 yrs   |

Visio is a registered trademark of Visio Corporation.

## **APPENDIX B: SCHEMATICS**

Watt-hour meter schematics are shown on the following pages. These schematics may be obtained electronically on the Microchip BBS and WWW site (Visio<sup>®</sup> format).

### B.1 PCB Functional Overview

A functional layout of the PICREF-3 PCB is shown in Figure B-1. The board functions relate to the overall functions as follows.

AC Input/Output: AC Input/Output from *High Voltage AC Electronics.* 

DC Power Supply: From *Linear Power Supply Electronics*.

Voltage Sense: Includes the Resistive Voltage Divider from *High Voltage AC Electronics* and the voltage sense amplifier and comparator from *Small Signal Analog/Digital Sense Electronics*.

Current Sense: Includes the Current Sense Transformer from *High Voltage AC Electronics* and the current sense amplifier and comparator from *Small Signal* 

Analog/Digital Sense Electronics. Also included is the RC filter used, with the PIC16C924 PWM, to produce a variable reference to the current sense comparator for true RMS current measurements (*Microcontroller I/O*).

Phase Sense: Includes the Voltage Sense and Current Sense circuitry.

Power Triac: From *High Voltage AC Electronics*. (Triac switch included for demo purposes only.)

Triac Control: Triac control circuitry from *Microcontroller I/O*.

LCD Control: Includes the 8-digit LCD, PIC16C924 microcontroller and pushbuttons from *Microcontroller I/O*.

Remote Communication: Includes the serial (RS-232) communications interface and port from *Microcontroller I/O*.

Battery Backup: Includes the Serial EEPROM from *Microcontroller I/O* and the Battery Backup from *Linear Power Supply Electronics*.

Interrupt: From Microcontroller I/O.



FIGURE B-1: PCB FUNCTIONAL BLOCK DIAGRAM

## B.2 <u>AC Input/Output</u>

AC voltage is applied to AC power line connector P1 and a load is connected to AC outlet P2. Alternating current flows from P1 to P2.

### B.3 Voltage Sense

A resistive ladder (R2A, R2B, R3, R35, R36A and R36B) is used as a voltage sensor. A differential voltage develops on R3,R35 that has a 1000:1 divide-down ratio.

#### B.3.1 ANALOG VOLTAGE SENSE

The voltage signal from resistive divider R3/R35 is amplified by U1. The U1 amplifier accepts a balanced input and has a minimum common mode rejection ratio (CMRR) of 93 dB. The signal at the amplifier output U1-6 swings above and below a negative volt reference potential.

The output of U1-6 is connected to the anode of Schottky diode D10. The cathode of D10 is connected to analog converter input AN0 of the PIC16C924. The analog voltage sense signal is developed across R26 and C22 at the cathode of diode D10.

#### B.3.2 DIGITAL VOLTAGE SENSE

Comparator U5 is a dual comparator integrated circuit. Half of U5 compares an analog ground reference at U5-2 to the single-ended voltage sensor signal developed across R3 at U5-3. The output of U5 at U5-1 switches to a logic high level of 5V when the voltage sensor signal exceeds the analog ground reference.

The comparator output at U5-1 is applied to the anode of Schottky diode D11. The cathode of D11 is connected to the digital input line RG7 of the PIC16C924. The digital voltage sense signal is developed across R27 at the cathode of D11.

#### B.3.3 AC INPUT BALANCED/UNBALANCED SENSE LINE

The AC Input Balanced/Unbalanced Sense Line is used to determine whether the AC input neutral line is grounded or ungrounded.

The RA5 microcontroller input is set in firmware as an analog input and the voltage across resistors R36A and R35 is sampled. If the voltage is positive, the neutral line from the P1 AC input is not grounded. If the voltage is zero, the neutral line is grounded.

After the microcontroller determines the neutral line state, the RA5 input is set in firmware to be digital.

## B.4 Current Sense

Current flows through triac TR1 and current sense transformer T2. A voltage is developed across burden resistor R1B that is proportional to the current flow.

#### B.4.1 ANALOG CURRENT SENSE

The current signal from the current sense transformer is amplified by U2. The U2 amplifier accepts a balanced input and has a minimum common mode rejection ratio (CMRR) of 93 dB. The signal at the amplifier output of U2-6 swings above and below a 0V (ground) reference potential.

The output at U2-6 is connected to the anode of Schottky diode D2. The cathode of D2 is connected to analog converter input AN1 of the PIC16C924. The analog current sense signal is developed across R9 and C26 at the cathode of D2.

#### B.4.2 DIGITAL CURRENT SENSE

Comparator U5 is a dual comparator integrated circuit. Half of U5 is used to compare the sensed analog current signal (U5-5) to a variable positive reference (U5-6). The digital current sense output (U5-7) goes high when the sensed current signal exceeds the reference.

The comparator output at U5-7 is connected to the anode of Schottky diode D12. The cathode of D12 is connected to digital input RE7 of the PIC16C924. The digital current sense signal is developed across R44 at the cathode D12.

#### B.4.3 PWM REFERENCE RC FILTER

The PWM output of the microcontroller at RC2 has a frequency of 7.81 kHz. The waveform duty cycle has a 10-bit resolution resulting in a single step pulse width of 125 ns. The pulses are filtered by R29, 470 $\Omega$ , and C28, 2.2 $\mu$ F. These components form a low pass filter with a break frequency of 967 Hz. The low pass filtered PWM signal is applied to the current sense comparator reference at U5-6.

## B.5 Phase Sense

Phase Sense is the combination of Voltage Sense and Current Sense circuitry, plus phase shift circuitry at U5-5. The phase shift between the digital voltage sense waveform at R27 and the digital current sense waveform at R44 is adjusted with the phase shift low-pass filter at U5-5. The phase shift circuitry is adjusted for calibration purposes.

## B.6 LCD Control

The heart of the LCD Control electronics is the PIC16C924 microcontroller, U4.

The microcontroller receives analog and digital current and voltage sense signals. Depending on user pushbutton input (S1 to S4), these signals may be used for LCD display or calculation and LCD display. The LCD is an eight-digit, seven segment per digit, display. Additional segments make up the periods and colons necessary for decimal and time display. The LCD has a total of 71 segments. Three commons are used in a multiplexing drive scheme.

The LCD part, VIM-808-DP, is manufactured by V.L. Electronics Inc.

### B.6.1 LCD CONTRAST ADJUSTMENT

A charge pump for the LCD is formed by resistors R24, R47 and capacitors C7, C8, C9, and C10. The charge pump consists of a 10 $\mu$ A constant current source, internal to U4, which sources current into R24. The voltage developed across R24 is applied to C10 at VLCD1. the charge pump boosts VLCD1 into VLCD2 = 2 \* VLCD1 at C8, and VLCD3 = 3 \* VLCD1 at C9. By varing R24, the LCD contrast can be adjusted.

#### B.6.2 PUSHBUTTONS - MCLR

A processor reset signal can be manually applied to U4 at U4-2, the master clear (MCLR) input.

The reset signal originates at the node of resistor R17 (10k $\Omega$ ) and capacitor C14 (0.1 $\mu$ F). R17 is connected to the 5V digital line causing C14 to charge to 5V. The R17/C14 node is tied to pushbutton S5. S5 is a momentary pushbutton which is in a normally open position. Depressing S5 and then releasing causes the voltage level at U4-2 to drop to ground and then return to 5V. The low-going logic pulse at U4-2 resets the processor's program counter to the beginning of the firmware program.

### B.6.3 CLOCK INPUT

The clock input is an 8MHz frequency set by an external three-terminal resonator designated as XTAL1. The 8MHz resonator, manufactured by Panasonic (EF0-EC8004A4), has a nominal center frequency of 8.00MHz and has built-in phase shift capacitors.

The resonator element connects to the OSC1 and OSC2 pins at U4-24 and U4-25. The PIC16C924 microcontroller has an internal inverter connected between the OSC1 and OSC2 pins. This internal inverter combined with the 8MHz resonator establish the clock input frequency.

### B.6.4 TIMER1

A 32kHz crystal, a Panasonic EF0-EC8004A4 designated as XTAL2, is connected between U4's pin 26 and pin 27. Capacitors C16 and C17, both 33pF, are connected to U4-26 and U4-27. These components combine with an inverter internal to microcontroller U4, between pins 26 and 27, to form a 32kHz oscillator. This oscillator clocks Timer 1, a 16-bit counter. Timer 1 is used to measure one second time intervals. A 22M $\Omega$  resistor is connected across each of the 33pF capaci-

tors, C16 and C17. The purpose of these resistors is to rapidly discharge C16 and C17 when Timer 1 is turned off prior to entering Hiber mode.

#### B.7 Remote Communications

The serial interface circuit (Q1 and Q2) is provided for RS-232 communication between a computer and the PICREF-3. Serial port connection is provided by P3. Firmware for this function has not been implimented (See *Design Modifications*).

#### B.8 Triac and Triac Control Circuit

Triac switch included for demo purposes only.

The triac control circuit is comprised of U13 (MOC3042), a triac output opto-coupler with zero crossing detect circuitry. Resistor R10 limits forward current to 10mA to U13's infrared LED when the RA4 control line is pulled low. Resistor R6 limits current to the gate of the power triac TR1 (*High Voltage AC Electronics*) when U13 fires.

Microcontroller I/O pin RA4 is toggled in response to pressing the START/STOP button. Action is taken to change the ON/OFF state of the triac after the first zero crossing of the released START/STOP button.

### B.9 Battery Backup

The battery backup section consists of two 3V batteries, B1 and B2, in series with diodes D9A and D9B, and U3, a Serial EEPROM.

#### B.9.1 BATTERIES

In the event of an AC line voltage dropout, the microcontroller is powered by the 6V series battery combination, which provides voltages in the range of 4.5V to 5.5V at the cathode of D9B.

The 3V batteries are lithium ion cell batteries, CR2032, manufactured by Panasonic. The batteries have a 180 mAh rating.

Diodes D9A and D9B, 1N4150, are in series with B1 and B2. The cathode of D9B is connected to the cathodes of D8, D15 and D13 in a wire-or'd configuration.

#### B.9.2 SERIAL EEPROM

The Serial EEPROM is available to provide non-volatile storage for key parameters during AC line voltage dropouts. Firmware for this function has not been implimented (See *Design Modifications*). Firmware should function as described below.

The microcontroller should provide power to the Serial EEPROM by setting the RB3 line as an output and writing a logic "1" to the RB3 line. The last calculated watt-hour value should be added to the last cumulative watt-hour value previously written to the Serial EEPROM. The resulting sum should be written to the

Serial EEPROM. The microcontroller should then write a logic "0" to the RB3 line to reduce battery current drain.

The Serial EEPROM, 24AA16/P, is manufactured by Microchip Technology. The Serial EEPROM is a 16-Kbit electrically erasable PROM that operates down to 1.8V. Resistor R22 is a pull-up resistor to Vcc for the open drain SDA terminal of the Serial EEPROM.

Resistor R23 provides isolation between Vcc and the SCL line of the Serial EEPROM. Vcc is provided by the RB3 line to the microcontroller.

## B.10 DC Power Supply

The DC power supply provides the following power forms:

- + 5V digital
- + 5V analog reference
- + 8V analog
- 8V analog
- +3V analog reference

The AC Input at P1 is applied to step-down transformer T1, MagneTek P30-200. The output of T1 is full wave rectified by bridge rectifier BR1, General Instruments W005G-ND. The full wave rectified waveform from BR1 is applied to capacitors C1 and C2, which charge to positive and negative DC supply rails. Zener diodes Z2, Z3 and Z4, 18V 1N4746, and 68 $\Omega$  R30 provide a shunt path for current from capacitor C1. The current flow through Z2, Z3, Z4 and R30 reduce the positive supply rail to a voltage less than 26V, which is the maximum input voltage for 5V regulator IC U10. IC U8, New Japan Radio Co. NJM78LO8A-ND, and U9, New Japan Radio Co. NJM79LO8A-ND, provide +8 and -8 volt regulated output voltages.

U10, LM2932AZ-5.0, is a low drop-out 5.0V regulator manufactured by National Semiconductor.

Diode D6, in series with diode D1, increases the virtual ground point for regulator U10 by one schottky diode drop.

Diode D1 provides a virtual ground point for regulator U10 which is one diode drop above ground potential. The regulated output of U10 adds to the diode drop at the U10 GND terminal.

Diode D8, 1N4150, D15, 1N4150, and diode D9, 1N5817, provide a wired-or scheme for the switching of either 5V digital from the output of U8 or 4.5V - 5.5V from batteries B1 and B2.

Diode D13, 1N4150, limits voltage undershoot at the output of 5V regulator U10 when the AC input voltage drops out. Clamping the U10 output at ground potential prevents the regulator from sensing a negative output voltage and entering an output shutdown mode when AC input voltage returns.

Battery operation requires D8 and D13 to have a low reverse current specification. These diodes are switching diodes which have a reverse leakage current of 200 nA at maximum reverse peak voltage.

U11, LM4040AIZ-5.0, is a precision 5V reference diode with a +/- 0.1% accuracy. U11 receives bias current from R40. The 5V reference voltage is buffered by U12, LM358A. The output of U12 (U12-7) is applied to the anode of D14, 1N4150. The cathode of D14 is tied back to the input terminal of U12 and to U4-21, the analog input reference line of the PIC16C924 microcontroller. Diode D14 blocks current flow from U4-21 during battery backup operation.

Resistors R41, R33 and R34 provide an optional 3V reference to buffer amplifier U12. The 5V analog reference can be divided down to 3 V at the R41/R33 node. The 3V ladder reference is applied to U12-3. The output of U12-1 is applied to U4-9. The PIC16C924 microcontroller can select U4-9 as an analog reference input. In this design, R41 is a zero ohm wire and R23 is a 22 M $\Omega$  resistor. The values of R41 and R33 affect battery current in Sleep and Hibernate modes. Battery currents in this document are based on a value of 22M $\Omega$  for R33.

### B.11 Interrupt

Interrupt input is provided into microcontroller pin RB0/INT. The digital voltage sense line, digital current sense line and serial communication input lines are each differentiated, by identical circuits, and wire-or'd together as input to RB0/INT, U4-13 (Figure B-2). The differentiated digital voltage sense signal is used to wake the microprocessor from Sleep or Hibernate modes.

The digital voltage sense signal is differentiated by the circuit consisting of C11, R45 and D3.

The digital current sense signal is differentiated by the circuit consisting of C12, R46 and D4.

The serial communication input signal is differentiated by the circuit consisting of C15, R8 and D5.

The cathodes of D3, D4 and D5 are wire-or'd together and connected to U4-13, the RB0/INT interrupt.



#### FIGURE B-2: INTERRUPT DIFFERENTIATOR BLOCK DIAGRAM





WATTHOUR - METER REFERENCE DESIGN, 50/60 Hz, 90 - 264 V, 10 A





WATTHOUR - METER REFERENCE DESIGN, 50/60 Hz, 90 - 264 V, 10 A

FIGURE B-5: MICROCONTROLLER AND LCD



## FIGURE B-6: DC POWER SUPPLY

WATTHOUR - METER REFERENCE DESIGN, 50/60 Hz, 90 - 264 V, 10 A



## FIGURE B-7: DC POWER SUPPLY AND BATTERY BACKUP





kwhr\_v1.vsd 11/14/97 Page 5

FIGURE B-8: OPTION 1: CURRENT MEASUREMENT AUTOMATIC GAIN CONTROL

WATTHOUR - METER REFERENCE DESIGN, 50/60 Hz, 90 - 264 V, 10 A

**OPTION 1: CURRENT MEASUREMENT AUTOMATIC GAIN CONTROL** 



kwhr\_v1.vsd 11/14/97 Page 6

## **APPENDIX C: FIRMWARE LISTING**

PIC16C924 firmware source code was written in C and was compiled using MPLAB-C.

Source code, and future updates, may be obtained electronically on the Microchip BBS and WWW site.

NOTES:

## APPENDIX D: PCB LAYOUT & FAB DRAWING

The top silk screen drawing for the WHM unit is shown in Figure D-1. The dimensions listed are, with respect to the orientation of this page; (horizontal dimension x vertical dimension). Figure D-1 is the WHM unit generic silk screen and as-built schematics should be consulted for accurate information concerning the components of each unit. As-built schematics are provided with each unit shipped, as calibration may alter the components used.

This drawing may be obtained electronically on the Microchip BBS or WWW site



FIGURE D-1: WATT-HOUR METER TOP SILK SCREEN

## APPENDIX E: BILL OF MATERIALS (BOM)

This appendix lists the Bill of Materials (BOM) for the WHM PCB. WHM schematics may be found in Appendix B.

## TABLE E-1: WATT-HOUR METER (PICREF-3) BOM

| Item | Description                                  | Component | Part #, Manufacturer,<br>Contact #   | Distrib #, Distributor       |
|------|--|-----------|--|------------------------------|
| 1    | Instrumentation Amplifier                    | U1, 2     | AD620AN, Analog Devices,<br>(617) 329-4700   | Newark                       |
| 2    | Serial EEPROM                                | U3        | 24AA16/P,<br>Microchip Technology,<br>(602) 786-7200                                     | N/A                          |
| 3    | Microcontroller (8MHz)                       | U4        | PIC16C924 - 08I/L,<br>Microchip Technology,<br>(602) 786-7200                            | N/A                          |
| 4    | PLCC Socket                                  | U4-Socket | PLCC 68P-T-2, McKenzie,<br>(510) 651-2700  | 978-2220, Allied             |
| 5    | Dual Comparator                              | U5        | LM393N,<br>National Semiconductor,<br>(408) 712-5800<br>(800) 272-9959 (USA Only)        | LM393N-ND, DigiKey           |
| 6    | LCD, Multiplexed Display                     | U7        | VIM-808-DP-RC-S-HV,<br>VL Electronics, Inc.,<br>(213) 738-8700                           | 10995-ND, DigiKey            |
| 7    | 3-Terminal Regulator, 8.0V,<br>TO-92 Pkg     | U8        | NJM78L08A, JRC,  | NJM78L08A-ND,<br>DigiKey     |
| 8    | 3 Terminal Regulator, Neg 8.0V,<br>TO-92 Pkg | U9        | NJM79L08A, JRC,  | NJM79L08A-ND,<br>DigiKey     |
| 9    | Positive 5.0V Regulator, TO-92<br>Pkg        | U10       | LM2931AZ-5.0,<br>National Semiconductor,<br>(408) 712-5800<br>(800) 272-9959 (USA Only)  | LM2931AZ-5.0-ND,<br>DigiKey  |
| 10   | Reference Diode, 0.1%, 5V                    | U11       | LM4040AIZ-5.0,<br>National Semiconductor,<br>(408) 712-5800<br>(800) 272-9959 (USA Only) | LM4040AIZ-5.0-ND,<br>DigiKey |
| 11   | Dual Operational Amplifier                   | U12       | LM358A,<br>National Semiconductor,<br>(408) 712-5800<br>(800) 272-9959 (USA Only)        | LM358AN-ND,<br>DigiKey       |
| 12   | Triac Output Optoisolator                    | U13       | MOC3042, Isocom,<br>(214) 423-5521   | MOC3042IS-ND,<br>DigiKey     |
| 13   | Metal Film Resistor,<br>20 Ω, 1%, 1/8 W      | R1B       | 20E0MF1/4W-B 1%, Yageo,<br>886-2-917-7555  | 20.0XBK, Digikey             |
| 14   | Metal Film Resistor, 1 MΩ, 1%                | R2, 36    | 5043ED1M000F, Philips,<br>(914) 246-2811<br>(800) 234-7381 (USA only)                    | 50F8317, Newark              |
| 15   | Metal Film Resistor, 1 kΩ, 1%                | R3, 35    | 5043ED1K000F, Philips,<br>(914) 246-2811<br>(800) 234-7381 (USA only)                    | 50F8302, Newark              |
| 16   | Select Resistor, Alignment                   | R4        | RN60C 68.1K 1%, Dale,<br>(402) 563-6506  | 58F006R 68.1K,<br>Newark     |
| 17   | Metal Film Resistor, 6.2 kΩ, 1%              | R5        | Generic  |                              |

| TARI E E-1. | WATT-HOUR ME | TER (PICREE-3 | BOM | (CON'T) |  |
|-------------|--------------|---------------|-----|---------|--|
| TADLE L-T.  |              | IER (FICREF-J |     |         |  |

| ltem | Description                                | Component                             | Part #, Manufacturer,<br>Contact #                                    | Distrib #, Distributor      |
|------|--|---------------------------------------|---|-----------------------------|
| 18   | Carbon Film Resistor, 360Ω, 1%, 1/4W       | R6                                    | Yageo,<br>886-2-917-7555  | 360QBK-ND, DigiKey          |
| 19   | Carbon Resistor, 100 k $\Omega$ , 5%       | R7, 29                                | Yageo,<br>886-2-917-7555  | 100KQBK-ND,<br>DigiKey      |
| 20   | Carbon Resistor, 2.2 kΩ, 5%, 1/4W          | R9, 26                                | Yageo,<br>886-2-917-7555  | 2.2KQBK-ND, DigiKey         |
| 21   | Carbon Resistor, 470Ω, 5%, 1/4W            | R10, 29                               | Yageo,<br>886-2-917-7555  | 470QBK-ND, DigiKey          |
| 22   | Carbon Resistor,<br>4.7 kΩ, 10%, 1/4W      | R13, 16, 18                           | Yageo,<br>886-2-917-7555  | 4.7KQBK-ND, DigiKey         |
| 23   | Metal Film Resistor, 1 kΩ, 1%              | R14                                   | 5063JD1K000F, Philips,<br>(914) 246-2811<br>(800) 234-7381 (USA only) | 50F8359, Newark             |
| 24   | Carbon Resistor, 10 kΩ, 5%                 | R17, 22, 23,<br>27, 28, 32,<br>39, 44 | Yageo,<br>886-2-917-7555  | 10KQBK-ND, DigiKey          |
| 25   | Carbon Resistor,<br>910 kΩ, 10%, 1/4W      | R19                                   | Yageo,<br>886-2-917-7555  | 910QBK-ND, DigiKey          |
| 26   | Carbon Resistor,<br>180 kΩ, 10%, 1/4W      | R20                                   | Yageo,<br>886-2-917-7555  | 180QBK-ND, DigiKey          |
| 27   | Carbon Resistor,<br>12 kΩ, 10%, 1/4W       | R21                                   | Yageo,<br>886-2-917-7555  | 12KQBK-ND, DigiKey          |
| 28   | Trimmer Potentiometer, 250 k $\Omega$      | R24                                   | 3352E-1-254, Bourns,<br>(909) 781-5500                                | 3352E-1-254, DigiKey        |
| 29   | Metal Film Resistor, 63.4 k $\Omega$ , 1%  | R25                                   | RN60C 63.4k 1%, Dale,<br>(402) 563-6506                               | 58F006R 63.4k, New-<br>ark  |
| 30   | Carbon Resistor, 68Ω, 5%, 1W               | R30                                   | Generic   |                             |
| 31   | Metal Film Resistor, 1%, 1/4W              | R33                                   | Generic   |                             |
| 32   | Metal Film Resistor, 1%, 1/4W              | R34                                   | Generic   |                             |
| 33   | Metal Film Resistor, 3.83 k $\Omega$ , 1%  | R37                                   | 3K83MF-1/4W-B 1%, Yageo,<br>886-2-917-7555                            | 3.83KXBK, Digikey           |
| 34   | Select Resistor, Alignment                 | R38                                   | Generic   |                             |
| 35   | Carbon Resistor, 5.1 kΩ, 5%, 1/4W          | R40                                   | Yageo,<br>886-2-917-7555  | 5.1QBK-ND, DigiKey          |
| 36   | Metal Film Resistor, 1%, 1/4W              | R41                                   | Generic   |                             |
| 37   | Carbon Resistor, 100 Ω, 5%, 1/4W           | R48                                   | Yageo,<br>886-2-917-7555  | 100QBK-ND, DigiKey          |
| 38   | 8-pin SIP resistor network, $470\Omega$    | RN1                                   | CTS,<br>(219) 293-7511  | 770-83-R 470-ND,<br>DigiKey |
| 39   | Fast Acting Fuse,<br>AGC 0.25 x 1.25, 12 A | F1                                    | AGC-12, Cooper,<br>(414) 549-5000                                     | 94F2182, Newark             |
| 40   | PCB 3AG Fuse Clips                         | F1-Clips                              | 102074, Little Fuse,<br>(847) 824-0400                                | 27F1086, Newark             |
| 41   | NPN Transistor, TO-92 pkg                  | Q1                                    | 2N3904, Motorola,<br>(602) 244-6900                                   | 2N3904-ND, DigiKey          |
| 42   | PNP Transistor, TO-92 pkg                  | Q2                                    | 2N4403, Motorola,<br>(602) 244-6900                                   | 2N4403-ND, DigiKey          |

## TABLE E-1: WATT-HOUR METER (PICREF-3) BOM (CON'T)

| Item | Description   | Component                             | Part #, Manufacturer,<br>Contact #                                    | Distrib #, Distributor |
|------|---|---------------------------------------|---|------------------------|
| 43   | MOV, 420V AC  | Z1                                    | V420LA10, Harris,<br>(407)724-7000<br>(800) 4 HARRIS (USA Only)       | V420LA10, Newark       |
| 44   | Zener diodes, 18V, 1W                               | Z2, 3, 4                              | 1N4746A, Motorola,<br>(602) 244-6900                                  | 1N4746A-ND, DigiKey    |
| 45   | High Speed Switching Diode,<br>0.5W, D0-35          | D1, 3, 4, 5,<br>8, 9A, 9B,<br>13, 15  | 1N4150, Diodes Inc.,<br>(805) 446-4800                                | Sterling               |
| 46   | Schottky Barrier Rectifier,<br>DO-41 Pkg            | D2, 6, 10,<br>11, 12                  | 1N5817, Diodes Inc.,<br>(805) 446-4800                                | Newark                 |
| 47   | 8 MHz Ceramic Resonator/w built in caps             | XTAL1                                 | EF0-EC8004A4, Panasonic,<br>(714) 373-7366                            | PX800-ND, DigiKey      |
| 48   | 32 kHz Crystal Resonator                            | XTAL2                                 | C-001R 32.768K-A, Epson,<br>(310) 787-6300                            | SE3201-ND, DigiKey     |
| 49   | PC Mount Transformer                                | T1                                    | PF30-200, MagneTek,<br>(219) 297-3111                                 | DigiKey                |
| 50   | Current Sense Transformer                           | T2                                    | CSE187-L, MagneTek,<br>(219) 297-3111                                 | 10515-ND, DigiKey      |
| 51   | Bridge Rectifier                                    | BR1                                   | W005G-ND,<br>General Instrument,<br>(516) 847-3000                    | W005G-ND, DigiKey      |
| 52   | Aluminum Electrolytic Capacitor,<br>470 uF, 35W VDC | C1, 2                                 | 515D477M035CG6A, Sprague,<br>(603) 224-1961                           | 50F072, Newark         |
| 53   | Ceramic Capacitor, 0.01 $\mu$ F                     | C3, 6, 15,<br>22, 23, 24,<br>26,11,12 | 1C10Z5U103M050B, Sprague,<br>(603) 224-1961                           | 81F2060, Newark        |
| 54   | Tantalum Capacitor,<br>100 uF, 10W VDC              | C4                                    | 199D107X0010EE2, Sprague,<br>(603) 224-1961                           | 17F2029, Newark        |
| 55   | Ceramic Capacitor, 0.1 µF                           | C5, 13, 14,<br>18, 19, 20,<br>21      | 1C10Z5U104M050B, Sprague,<br>(603) 224-1961                           | 81F2061, Newark        |
| 56   | Monolithic Ceramic Capacitor, 0.47 uF               | C7, 8, 9, 10                          | ECU-S1J474MEB, Panasonic,<br>(714) 373-7366                           | P4919-ND, DigiKey      |
| 57   | Ceramic Capacitor,<br>0.001 uF, 500 VAC             | C9A, C10A                             | 125LD10, Sprague,<br>(603) 224-1961                                   | 46F5228, Newark        |
| 58   | Ceramic Capacitor, 33 pF                            | C16, 17                               | 1C10C0G330J050B, Sprague,<br>(603) 224-1961                           | 95F7168, Newark        |
| 59   | Tantalum Capacitor, 2.2 μF, 25W<br>VDC              | C27, 28                               | 199D225X0025AA1, Sprague,<br>(603) 224-1961                           | 17F2041, Newark        |
| 60   | 3V Lithium Battery, PCB Termi-<br>nal Coin Type     | B1, 2                                 | CR2032, Panasonic,<br>(714) 373-7366                                  | P189-ND, DigiKey       |
| 61   | 20mm Coin Cell Lithium PC Bat-<br>tery Holder       | B1, 2-Holder                          | 1026, Keystone,<br>(718) 956-8900<br>(800) 379-3943 (USA only)        | 1026K-ND, DigiKey      |
| 62   | AC Power Line Connector -<br>Input                  | P1                                    | GSP1.3101.1, Schurter,<br>(707) 778-6311<br>(800) 848-2600 (USA only) | 509-1269, Allied       |
| 63   | AC Power Line Connector -<br>Output                 | P2                                    | 4300.0251, Schurter,<br>(707) 778-6311<br>(800) 848-2600 (USA only)   | 509-1271, Allied       |

| TABLE E-1: | WATT-HOUR METER (PICREF-3) BOM (CON'T) |  |
|------------|--|--|
|            |  |  |

| Item                | Description                        | Component        | Part #, Manufacturer,<br>Contact #                                     | Distrib #, Distributor |
|---------------------|------------------------------------|------------------|--|------------------------|
| 64                  | Right Angle, DB9,<br>PCB Connector | P3               | DEKL-09SAT-F2, Cinch,<br>(708) 981-6000                                | 95F4128, Newark        |
| 65                  | Triac, 10 amps                     | TR1              | Q4010L5, Teccor,<br>(214) 580-1515                                     | Q4010L5-ND, DigiKey    |
| 66                  | TO-220 Heat Sink, Extruded Pins    | TR1-Heat<br>Sink | 531002B02500, AAVID,<br>(603) 528-3400                                 | HS190-ND, DigiKey      |
| 67 Momentary Switch |                                    | S1, 2, 3, 4, 5   | EVQ-PAD04M, Panasonic,<br>(714) 373-7366                               | P8007S, DigiKey        |
| 68                  | Circuit Board Test Points          | TP1, 2           | 131-5031-00, Tektronix,<br>(503) 627-5000<br>(800) 426-2200 (USA only) | N/A                    |

NOTES:

## APPENDIX F: WATT-HOUR METER DEMO UNIT

This Demo Unit was designed to showcase the PIC16C924 microcontroller in a watt-hour meter application.

## F.1 Demo Unit Specifications

The specifications for this demo are stated in Appendix A.

## FIGURE F-1: DEMO ASSEMBLY - TOP

## F.2 Demo Unit Assembly



A Watt-Hour Meter demo unit top view is shown in the figure below.







Follow these steps to set up the PICREF-3 Demo Unit:

 Plug the receptacle end of a power cord into the Demo Unit "AC Input". Plug the pronged end of the power cord into an AC wall socket. The AC Input will accept voltages in the 90 - 264V range.

Note: A grounded AC power cord MUST be used for proper operation of the meter.

 Plug the load into the Demo Unit "AC Output" socket. Steady state load currents in the 0.5 -10A range can be measured. Surge currents of up to 17A have been applied to the unit without

## FIGURE F-2: DEMO ASSEMBLY - SIDE

damage.

 Display the desired power and energy information on the LCD display by pressing the push buttons (See *Firmware Overview*).

#### F.4 Recommended Loads

The following loads are recommended:

Linear Resistive Loads (Halogen lights):

- 90W
- 180W
- 250W
- 500W
- 1000W
- 2000W

Linear Inductive Loads (Fractional horsepower motors):

- 230 V; 1/2 HP
- 115V; 1/2, 1/3, 1/6 HP

Non-linear Loads:

· Computer monitor



NOTES:



## WORLDWIDE SALES AND SERVICE

## AMERICAS

#### Corporate Office

Microchip Technology Inc. 2355 West Chandler Blvd. Chandler, AZ 85224-6199 Tel: 602-786-7200 Fax: 602-786-7277 Technical Support: 602 786-7627 Web: http://www.microchip.com

#### Atlanta

Microchip Technology Inc. 500 Sugar Mill Road, Suite 200B Atlanta, GA 30350 Tel: 770-640-0034 Fax: 770-640-0307

#### Boston

Microchip Technology Inc. 5 Mount Royal Avenue Marlborough, MA 01752 Tel: 508-480-9990 Fax: 508-480-8575

#### Chicago

Microchip Technology Inc. 333 Pierce Road, Suite 180 Itasca, IL 60143 Tel: 630-285-0071 Fax: 630-285-0075

#### Dallas

Microchip Technology Inc. 14651 Dallas Parkway, Suite 816 Dallas, TX 75240-8809 Tel: 972-991-7177 Fax: 972-991-8588

#### Dayton

Microchip Technology Inc. Two Prestige Place, Suite 150 Miamisburg, OH 45342 Tel: 937-291-1654 Fax: 937-291-9175

#### Detroit

Microchip Technology Inc. 42705 Grand River, Suite 201 Novi, MI 48375-1727 Tel: 248-374-1888 Fax: 248-374-2874

#### Los Angeles

Microchip Technology Inc. 18201 Von Karman, Suite 1090 Irvine, CA 92612 Tel: 714-263-1888 Fax: 714-263-1338

#### New York

Microchip Technology Inc. 150 Motor Parkway, Suite 202 Hauppauge, NY 11788 Tel: 516-273-5305 Fax: 516-273-5335

#### San Jose

Microchip Technology Inc. 2107 North First Street, Suite 590 San Jose, CA 95131 Tel: 408-436-7950 Fax: 408-436-7955

## **AMERICAS** (continued)

#### Toronto

Microchip Technology Inc. 5925 Airport Road, Suite 200 Mississauga, Ontario L4V 1W1, Canada Tel: 905-405-6279 Fax: 905-405-6253

## ASIA/PACIFIC

#### Hona Kona

Microchip Asia Pacific RM 3801B, Tower Two Metroplaza 223 Hing Fong Road Kwai Fong, N.T., Hong Kong Tel: 852-2-401-1200 Fax: 852-2-401-3431

#### India

Microchip Technology Inc. India Liaison Office No. 6, Legacy, Convent Road Bangalore 560 025, India Tel: 91-80-229-0061 Fax: 91-80-229-0062

#### Japan

Microchip Technology Intl. Inc. Benex S-1 6F 3-18-20, Shinyokohama Kohoku-Ku, Yokohama-shi Kanagawa 222-0033 Japan Tel: 81-45-471- 6166 Fax: 81-45-471-6122

#### Korea

Microchip Technology Korea 168-1, Youngbo Bldg. 3 Floor Samsung-Dong, Kangnam-Ku Seoul, Korea Tel: 82-2-554-7200 Fax: 82-2-558-5934

#### Shanghai

Microchip Technology RM 406 Shanghai Golden Bridge Bldg. 2077 Yan'an Road West, Hong Qiao District Shanghai, PRC 200335 Tel: 86-21-6275-5700 Fax: 86 21-6275-5060

## **ASIA/PACIFIC** (continued)

#### Singapore

Microchip Technology Singapore Pte Ltd. 200 Middle Road #07-02 Prime Centre Singapore 188980 Tel: 65-334-8870 Fax: 65-334-8850

#### Taiwan, R.O.C

Microchip Technology Taiwan 10F-1C 207 Tung Hua North Road Taipei, Taiwan, ROC Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

### EUROPE

#### United Kingdom

Arizona Microchip Technology Ltd. 505 Eskdale Road Winnersh Triangle Wokingham Berkshire, England RG41 5TU Tel: 44-1189-21-5858 Fax: 44-1189-21-5835 Franco

Arizona Microchip Technology SARL Zone Industrielle de la Bonde 2 Rue du Buisson aux Fraises 91300 Massy, France Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

#### Germany

Arizona Microchip Technology GmbH Gustav-Heinemann-Ring 125 D-81739 Müchen, Germany Tel: 49-89-627-144 0 Fax: 49-89-627-144-44

#### Italv

Arizona Microchip Technology SRL Centro Direzionale Colleoni Palazzo Taurus 1 V. Le Colleoni 1 20041 Agrate Brianza Milan, Italy Tel: 39-39-6899939 Fax: 39-39-6899883

7/7/98

**DNV Certification. Inc** DNV MSC USA The Netherla Accredited by the ByA ED 8 c ı Ø -2 ANSI-RAB C ø **ISO 9001** REGISTERED FIRM

Microchip received ISO 9001 Quality System certification for its worldwide headquarters, design, and wafer fabrication facilities in January, 1997. Our field-programmable PICmicro™ 8-bit MCUs, Serial EEPROMs, related specialty memory products and development systems conform to the stringent quality standards of the International Standard Organization (ISO).

All rights reserved. © 1998, Microchip Technology Incorporated, USA. 7/98 💭 Printed on recycled paper.

Information contained in this publication regarding device applications and the like is intended for suggestion only and may be superseded by updates. No representation or warranty is given and no liability is assumed by Microchip Technology incorporated with respect to the accuracy or use of such information, or infringement of patents or other intellectual property rights arising from such use or otherwise. Use of Microchip By products as critical components in life support systems is no authorized except with express written approval by Microchip. No licenses are conveyed, implicitly or otherwise, under any intellectual property rights. The Microchip logo and name are registered trademarks of Microchip Technology Inc. in the U.S.A. and other countries. All rights reserved. All other trademarks mentioned herein are the property of their respective companies.

