AN1151

PIC18F2520 MCP3909 3-Phase Energy Meter Reference Design - Meter Test Results and Adapting the Meter Design for other Requirements

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OVERVIEW

This application note shows how the PIC18F2520 MCP3909 3-phase energy meter performs under test as designed, and also how it can be easily modified for compatibility with a number of power measurement or energy meter designs.

This demo board is intended to be a fully functional 3-phase energy meter and is shipped calibrated as a 6400 imp/kWh 5(10)A / 220V meter. This document details the production calibration process, design limitations in terms of meter current, voltage, and accuracy.

Applying this energy meter to alternate designs such as single phase design, shunt based current measurement, and delta wiring will be discussed.

The accuracy results presented here were recorded against an industry power meter standard test equipment, the Fluke 6100A Electrical Power Standard. A description of the test setup will be initially presented, followed by a section describing the testing conditions.

Figure 1 shows the PIC18F2520 MCP3909 3-phase Energy Meter.

FIGURE 1: *PIC18F2520 With MCP3909 Meter Showing Line/load Connections To Test Equipment.*

A section detailing the current transformer selection, and the minimum/maximum current limitations that accompany this design choice will be a focus.

Test results will also be included that show how PCB layout and circuit grounding directly affects meter performance at low current input and channel to channel crosstalk both in-phase and between phases.

Note:	This application note includes test data from demo board hardware revision 2, which was the latest and current PCB revision at time of writing.

Meter Specifications

- Class 0.2 - 0.5 (see Figure 3 through Figure 5)
- Nominal Voltage: 3*220/380V
- Power Frequency: 50 Hz
- Nominal Current: 5A
- Maximum Current: 10(20)A
- Initiating current: 5 mA
- Error limits: (typical - see Figure 3 through Figure 5)
- Constant 6400 imp/kWh
- Power Consumption: 1.7W
- Voltage Dependence: ±10%
- Frequency Dependence: 45 Hz to 65 Hz

MICROCHIP'S DEMO BOARD CALIBRATION VS. PROPER METER CALIBRATION

It is important to note Microchip does not do a full calibration/test on each meter that we ship as demo boards. Steps have been taken to ensure you receive an energy meter 'out of the box' that performs to the above meter specifications, but the equipment and process we use during demo board production is not true energy calibration equipment, and any testing will reflect this.

The results shown here were taken from a shipped energy meter that was simply 're-calibrated' using the Fluke electrical power standard and the calibration software GUI that comes with the kit. No hardware 'tweaks', or firmware changes were done, only a true calibration using accurate energy meter calibration equipment.

Calibration used for this Application Note

Figure 2 describes the calibration and test setup used. The electrical power standard (Fluke 6100A) was configured to generate balanced loads for the meter, 3 x I_{CAL} for all calibration steps.

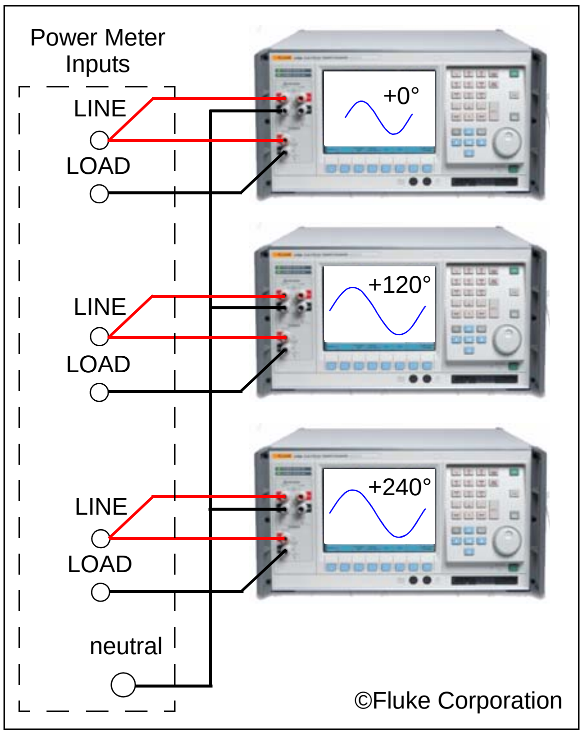

FIGURE 2: *Meter Calibration Setup.*

Meter Calibration

Each phase was calibration sequentially, starting with phase A.

Each phase calibration process was a 4(Note 2) step calibration. The steps are shown here with approximate calibration times (using 128 line cycle accumulation at 50 Hz)

GAIN (5A, 220V) - 2.5 seconds **(Note 1)**
DELAY (5A, 220V, PF = 0.5L) - 2.5 seconds **(Note 1)**
OFFSET for active power (0.005A, 220V, PF = 1) - 2.5 2.5 seconds **(Note 1)**
OFFSET for I_{RMS} (0.5A, 220V, PF=1) - 2.5 seconds **(Note 1, Note 2)**

Note 1: Important! The approach to calibration used by the PIC18F2520 firmware and Windows GUI ("energy meter software"), does not require accumulation of active power pulses to generate errors and resulting calibration correction factors for the meter. Instead, the software allows user input of the true current and voltage at each calibration step. The correction factors are then calculated by comparing this ideal to the measured active power after N line cycles, 128 line cycles in the results shown here. This approach greatly reduces meter production time.

2: This fourth calibration step can be skipped for active power only meters as it only applies to the RMS measurement.

Total Energy

When the meter is shipped the configuration of the output pulse is set such that the pulse frequency is proportional to the total active energy being consumed across all 3 phases. During meter calibration however, the firmware and software work together to ensure that 'phase to phase matching' is included. When calibrating all 3 phases, one of the phases is selected (normally Phase A) as the 'reference or 'standard' phase, and the other phases, when accumulating energy during the gain calibration step, or step 1, compare their accumulation to that recorded during phase A, thus phase to phase matching is included. For equations and signal flow, see the MCP3909 3-Phase Energy Meter Reference Design using PIC18F2520 User's Guide, (DS51643).

METER TEST RESULTS

Meter calibration was done using the automated calibration procedure performed by the USB “3-Phase Energy Meter Software”, and the 4 calibration steps were all performed.

The meter test results shown are at 20 points, from 100 mA to 20A, at power factors of 1 and 0.5L, and at both ends of the voltage and frequency dependence rated in Table 1. These results are from hardware revision 2. Differences in hardware revisions will be discussed later in this document.

Class 0.5 Compliance

The test results will show the meter performs better than 0.5% accurate from 100 mA to 20A, compliant to a class 0.5 meter, per IEC62053-22. No less than 0.3% margin of error exists for this compliance (see Table 1).

Class 0.2 Compliance

A class 0.2 meter, as required by the IEC specification, must not be more than 0.3% error at PF=0.5, and no more than 0.2% error at PF=1. The results from this meter tested would marginally pass these requirements and be class 0.2 compliant. However, it is the recommendation stated here that a volume production run using meters using this PIC18F/MCP3909 design should expect some yield to be outside of these limits, mainly due to variance in the current transformer phase response from meter to meter. The difference between the PF=1 and PF=0.5 performance (**FIGURE 5: “Meter Accuracy, Frequency Variation Testing.”**) are testament to this issue. Additional data using more expensive CTs with improved phase non-linearity will be presented later, including a more detailed explanation of these test results.

For reference, this table shows Class 0.5 and Class 0.2 limits as stated in the IEC62053-22 document.

TABLE 1: IEC ACCURACY LIMITS FOR CLASS 0.5 AND 0.2S ENERGY METERS

Current	Power Factor	Class 0.5	Class 0.2
$0.01\ I_N < I < 0.05\ I_N$	1	±1.0	±0.4
$0.1 I_N < I < I_{MAX}$	1	±0.5	±0.2
$0.02 I_N < I < 0.1\ I_N$	0.5L	±1.0	±0.5
	0.8C	±1.0	±0.5
$0.1 I_N < I < I_{MAX}$	0.5L	±0.6	±0.4
	0.8C	±0.6	±0.4

Results - Voltage Variation

Figure 3 shows the meter accuracy across the voltage variation tests.

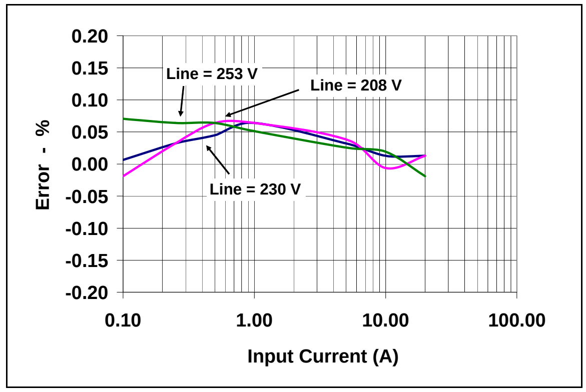

FIGURE 3: *Meter Accuracy, Voltage Variation Testing.*

Results - Frequency Variation

Figure 4 shows the meter accuracy across the frequency variation tests.

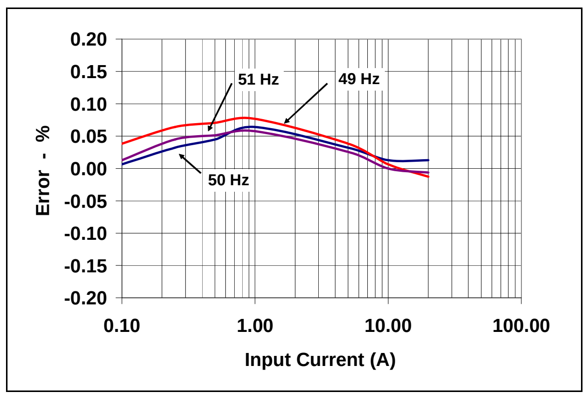

FIGURE 4: *Meter Accuracy, Frequency Variation Testing.*

Results at PF=0.5 (60 degrees Lead/Lag)

Figure 5 shows the meter accuracy across at PF=0.5. The graph also includes a PF=1 data series for comparison (dotted line marked “CONTROL”).

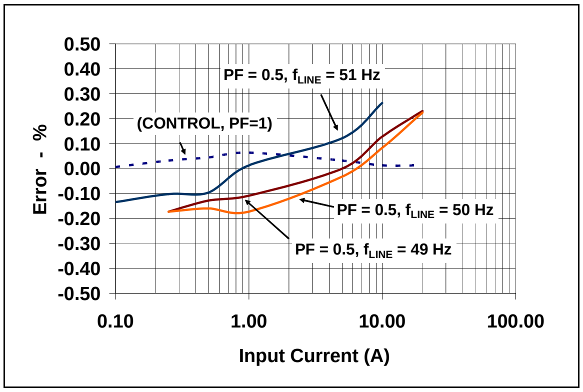

FIGURE 5: *Meter Accuracy, Frequency Variation Testing.*

Effects of Phase Non-linearity on Meter Performance

Any additional phase delay introduced to either the current or voltage signal will have a severe effect on the accuracy of the meter when the PF << 1. This is shown in Equation 1, where the additional phase delay introduced is represented by ϕ_e.

EQUATION 1:

$$\% \; Error = \left(\frac{\cos\phi - \cos(\phi + \phi_e)}{\cos\phi}\right) \bullet 100\%$$

If an additional delay of 0.2° is introduced, at PF=1, the effect is negligible. But, when PF=0.5, this 0.2° causes an additional 0.6% error, far from negligible for most meter designs.

MCP3909 PHASE RESPONSE

The MCP3909 device attributes less than 0.02% error due to phase error. In Figure 6, taken from the MCP3909 data sheet, shows active power measurement results used as characterization results and shown as typical performance curves.

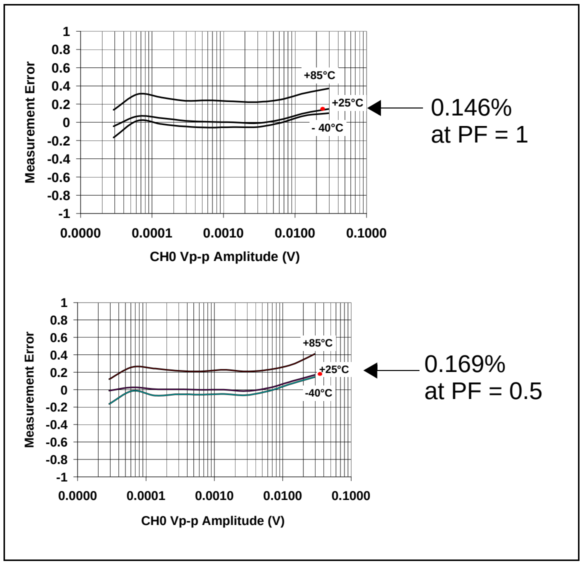

FIGURE 6: *As shown with these typical performance curves, the MCP3909 device does not contribute any appreciable additional phase error.*

TYPICAL SPECIFICED CT PHASE RESPONSE

The severe non-linearity of the current transformers is a major obstacle to overcome for most energy meter designs, and various methods exist to compensate for this error. The easiest method is to choose a more linear (and typically expensive) current transformer for your energy meter design. The CT used in our reference design changed from hardware revision 1 to hardware revision 2, and may be different depending on which meter design you have. Both CTs are from the same manufacturer (He Hua, Shanghai Electronics), the second with slightly better phase linearity performance.

TACKLING PHASE NON-LINEARITY THROUGH FIRMWARE CORRECTION

Other than buying a more expensive CT, a second method to compensate for this error is to calibrate at multiple points during phase delay calibration of the meter. As was shown, this meter design uses only a single point phase correction (at PF= 60 degrees lag).

Demo Board Rev 1 vs. Rev 2 Release Differences

The major changes in creating a revision 2 of the PCB was to improve the PCB grounding and layout. This helped to eliminate crosstalk between the voltage and current inputs of a given phase. In addition, a PIC18F2520 firmware bug was fixed that as receiving corrupt MCP3909 data. The graphs below show initial meter performance prior to fixing these bugs. The areas circled in red are the critical area of improvement where the meter performance was adjusted to be well below IEC62053 class 0.2S requirements.

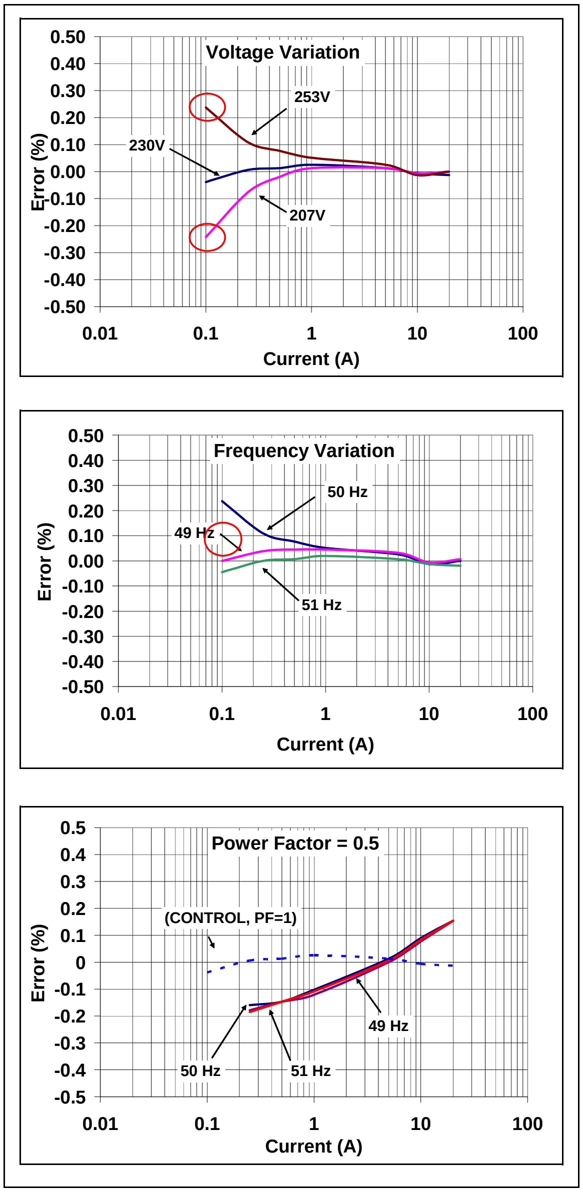

FIGURE 7: *Hardware and Firmware Improvements Fixed the Areas of Concern (circled in red). This data is from meter revision 1.*

ADAPTING TO WIDER CURRENT RANGES

There are 3 design decisions to be made when changing this meter to operate at current ranges other than the 5(10)A range chosen.

- CT selection
- Bias resistor value for CT circuit
- MCP3909 CH0 Gain (PGA Setting)

The MCP3909 input voltage range on channel zero (current channel input), is specified across a 1000:1 range at all gain settings (1,2,8,16). In addition the device offers ~82 dB across this entire range at a gain of 1, or ~76 dB for G=16. This highly accurate ADC and PGA allows for extremely wide current ratings such as 5(40)A, 5(60)A, 10(100)A, or 1(10)A meters.

For the 5(10)A design, the approach taken to the design decisions above took into consideration over-current situations and current signals with higher harmonic content, or crest factors, such that the peak-to-peak value of the signal would be greater than the 0.707 * IRMS expected for a pure sine wave. A conservative approach was taken here, with the goal to be only at half of the input range of the MCP3909 ADC when the input current of the meter is at I_{MAX}. This leaves much room for over-current and greatly reduces the chance of any signal clipping at the ADC.

Revision 1 of the energy meter uses an 20/80A CT (SCT220B, He Hua, Shanghai Electronics) and was designed to a I_{MAX} of 20A. with over range up to $2I_{MAX}$ or 40A. This CT has a 1000:1 turns ratio, resulting in signal of approximately the full scale input range of the ADC at twice I_{MAX}. A PGA gain of 2 was selected to match this signal size.

Revision 2 of the energy meter uses a 6/20A CT (SCT954) and was designed to an IMAX of 10A, with over range up to $2I_{MAX}$ or 20A. This CT has a 2000:1 turns ratio, resulting in a signal of approximately the full scale range of the ADC at 20A, or twice the maximum current. A PGA gain of 2 was selected to match this signal size.

Thus, to adapt this meter to wider current ranges, it is suggested to target signal size at I_{MAX} to be around half of the full scale input range of the ADC on the MCP3909 (allowing over-range and signals with high crest factors).

SUMMARY

The meter performs better than 0.5% accurate from 100 mA to 20A, compliant to a class 0.5 meter, per IEC62053-22. A simple current transformer change along with burden resistor and gain changes could increase the maximum current well above 100A. Although the data presented here is also class 0.2 compliant, it is marginal at PF=0.5, solely due to the current transformer selection, and the method of phase correction used, single point. A class 0.2 meter, as required by the IEC specification, must not be more than 0.3% error at PF=0.5, and no more than 0.2% error at PF=1. The results from this meter tested would marginally pass these requirements and be class 0.2 compliant.

Migrating the PIC18F2520 “calculation core” used in this design, to a customer specific energy meter design, perhaps using another PICmicro controller, allows accuracy results to be consistent with those presented here.

REFERENCES

1. Figure 2: Meter Calibration Setup photo from Fluke Corporation ©2002.

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