A Maxim Integrated Products Brand

78M661x Calibration Procedure

APPLICATION NOTE

AN_661x_037 **December 2010**

Introduction

Calibration for component tolerances may not be required when the system measurement accuracy requirement is looser than the cumulative tolerances of the sensing components. However, the reverse is typically true requiring board-level calibration. An effective calibration procedure reduces the cost of the sensing components by allowing the use of less precise, inexpensive components. The 78M661x firmware includes a simple and quick calibration procedure for the temperature, voltage and current measurements.

The document contains the following sections:

Measurement Accuracy Considerations

The 78M661x devices utilize either a voltage divider or a voltage transformer for sensing the line voltage. The current is typically sensed by means of resistive shunt or current transformer.

The voltage divider resistors tolerance is normally compensated through calibrations. However, the resistor temperature coefficient should be factored in the overall system tolerance and cannot be calibrated. The voltage divider generally utilize ±0.1% resistors, the reason is that typically the temperature coefficient is smaller than the equivalent ±1% resistor.

Figure 1 shows the voltage input circuitry with the critical elements circled.

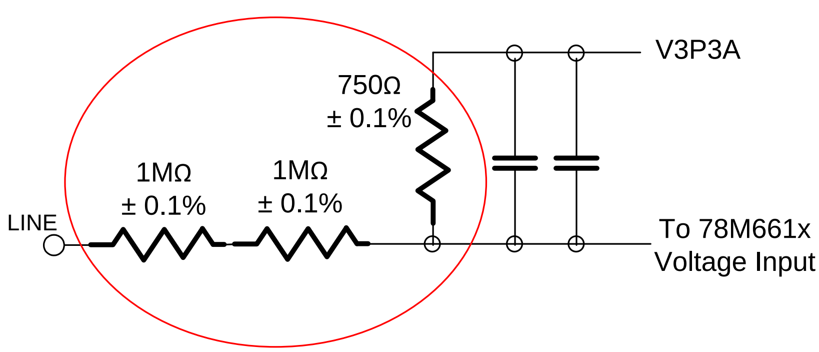

Figure 1: 78M661x Typical Voltage Input Schematic

The current shunt tolerance is typically 1%. The tolerance of the shunt is normally compensated by the calibration. The temperature coefficient of the shunt plays a critical role in the accuracy of the current measurement, since the shunt is subjected to self-heating with high currents.

For example, consider a 4mΩ shunt (surface mount) with a temperature coefficient of 50ppm/DegC mounted on a FR4 PCB. The calibration point has been set to 120Vrms and 1Arms.
At 10Arms the ΔTemperature (measured) versus 1Arms (calibration point) is 26DegC while at 15Arms the temperature raise versus 1Arms is 48DegC. The temperature difference from the calibration point influences the accuracy by 0.13% at 10A and 0.24% at 15A.

Figure 2 shows the typical circuitry for a shunt-based current input.

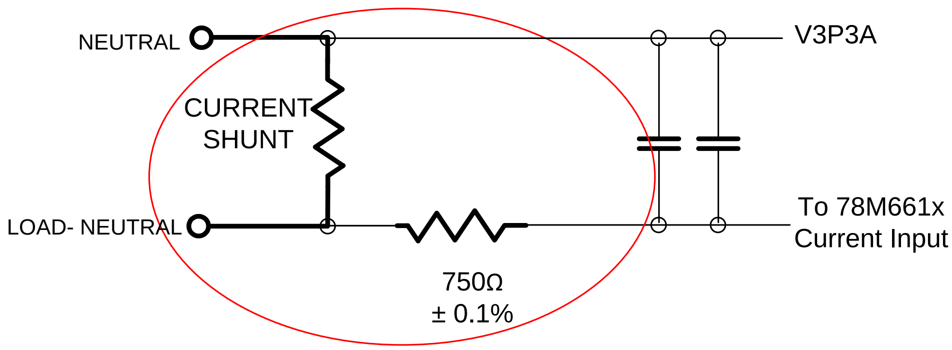

Figure 2: 78M661x Current Shunt Input Schematic

The current transformer (CT) selection should be based on the accuracy requirement and maximum load current. Figure 3 shows a typical current input circuitry utilizing a CT.

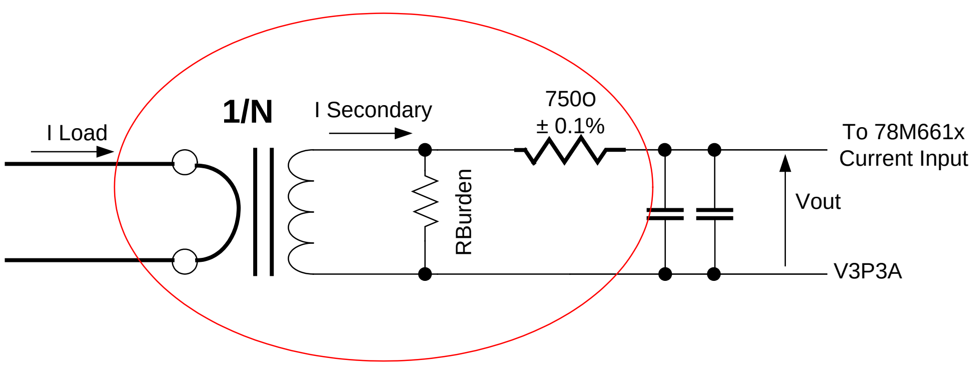

Figure 3: 78M661x Current Transformer Input Schematic

The accuracy or “Class” of the CT defines the current magnitude error from the calculated value expected by virtue of the CT ratio. The greater the number used to define the class, the greater the permissible “current error”.

The class of the CT specifies its accuracy:

- 0.1 or 0.2 for precision measurements.
- 0.5 for high grade kilowatt hour meters for commercial grade kilowatt hour meters.
- 3 for general industrial measurements.
- 3 or 5 for lower accuracy commercial measurements.

Teridian recommends use of class 0.5 or better for energy measurement.

The accuracy class also defines the permissible phase angle displacement between primary and secondary currents.

All current transformers include an inherent phase shift relative to the current measurement. This phase shift introduces an error in the power measurement. While at power factor approaching 1 the error in power calculation introduced by the CT's phase shift could be negligible, at lower power factor the error increases, as shown in Figure 4.

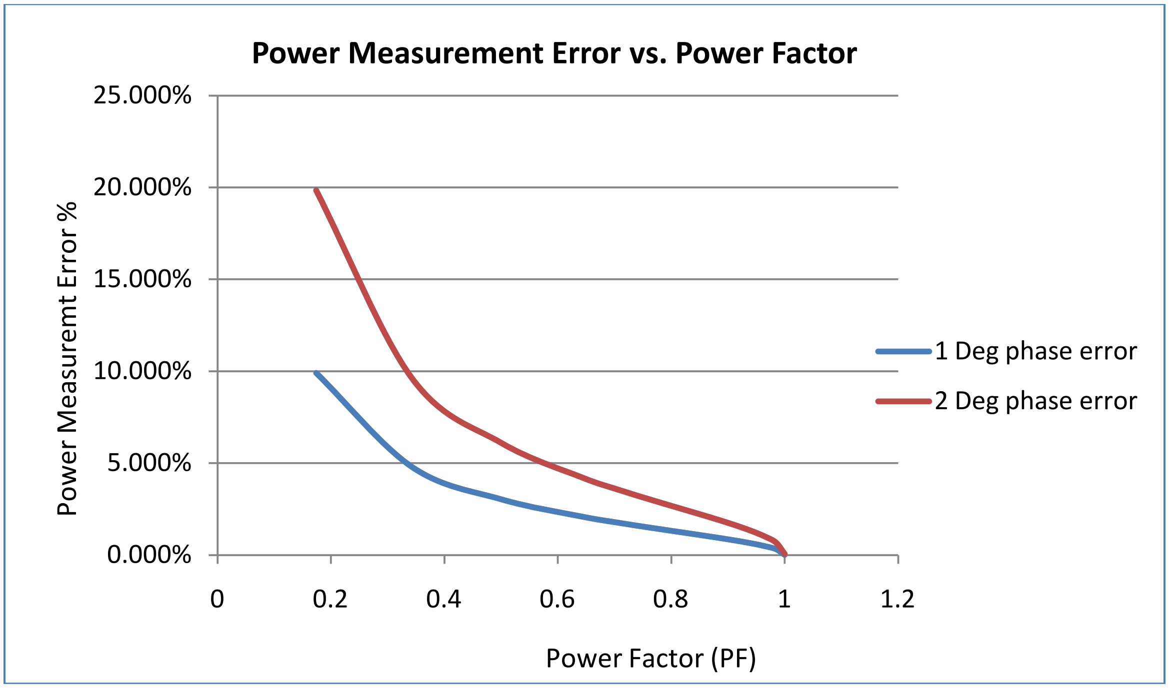

Figure 4: Power Measurement Error versus Power Factor

The phase error can be either compensated or calibrated.

In designing an energy measurement system some considerations and tradeoffs are necessary. For example, the required accuracy can be achieved by using components with better tolerance and avoiding the calibration. The required accuracy can also be achieved with lower cost components and having the calibration routine adjusting for the tolerance.

Also, if the system does not require the highest level of accuracy, entering built-in compensation coefficients might be sufficient. Table 1 shows typical calibration time versus system measurement accuracy. The **No Calibration** accuracy is based on 1% external components and a onetime pre-manufacturing calibration to determine the fixed coefficient values for the system board.

Table 1: Calibration Time versus Accuracy

Calibration	Time	Accuracy
Full Calibration	<15s	<0.5%
Current Only Calibration	<7.5s	< 1%
No Calibration (fixed coefficients)	0	< 2.5%

Calibration Bench Equipment Setup

Calibration of the 78M661x board requires external precision equipment in order to have stable reference sources for voltage and current. The 78M661x calibration procedure performs a single point calibration for each of the following: ambient temperature, load voltage and load current. The 78M661x calibrates against the following:

Target Calibration Temperature (Default = +22.0°C)
Target Calibration Voltage (Default = +120.000 VAC)
Target Calibration Current (Default = +1.000 Arms)
Target Calibration Phase Angle (Default = +0°)
Target Calibration Watts: (Default = +120.000)

Additionally, each of the above target parameters has a respective calibration tolerance. The calibration tolerance sets the threshold at which the calibration procedure closes-in on and then stops. The calibration procedure stops when the measured results fall within: Target Calibration ± Target Tolerance.

Target Temperature Tolerance: (Default = XXXXX°C)
Target Voltage Tolerance (Default = 0.010 mVAC)
Target Current Tolerance(Default = 0.010 Arms)
Target Phase Angle Tolerance (Default = +0°)
Target Watts Tolerance: (Default = XXXXX)

The target calibration and target tolerance parameters can be modified by the user. The time to complete the calibration is directly affected by the target tolerance. A tighter tolerance value will take longer to complete calibration. The target tolerance must be much larger than the reference source noise. Otherwise, the reference source noise will cause the calibration process to take longer or fail to calibrate.

The purpose of the calibration procedure is to adjust coefficients for temperature, voltage, load current and phase (Current Transformers). These coefficients are stored in the 78M661x's internal Flash memory. The coefficients provide gain compensation to accommodate for the initial tolerance of the external sensing components.

Refer to Appendix A for the respective register locations and descriptions of the target calibration parameters and target tolerance parameters.

In the calibration routines, the converted values for temperature, voltage, current etc. are compared against the known external source references (target calibration values) and the coefficients adjusted to match the external reference. Of course, the accuracy of the external sources directly affects the calibration results. For example the use of the line voltage (mains) is not recommended because of fluctuations in level and noise.

Figure 5 and Figure 6 show a typical calibration setup. The AC voltage source is generally a programmable AC source. The AC source should have a known and stable value, its accuracy should be higher than the system that is calibrating. The load can be either an AC electronic load or a set of power resistors. The current draw by the load should have a known and stable value, as the voltage source, its accuracy should be higher than the system that is calibrating. While the power resistors could be the lowest cost approach, it should be considered that the load resistors are subjected to self-heating during the calibration. Some time to allow their values (and therefore the current) to reach a steady state may be required, adding cost to the calibration.

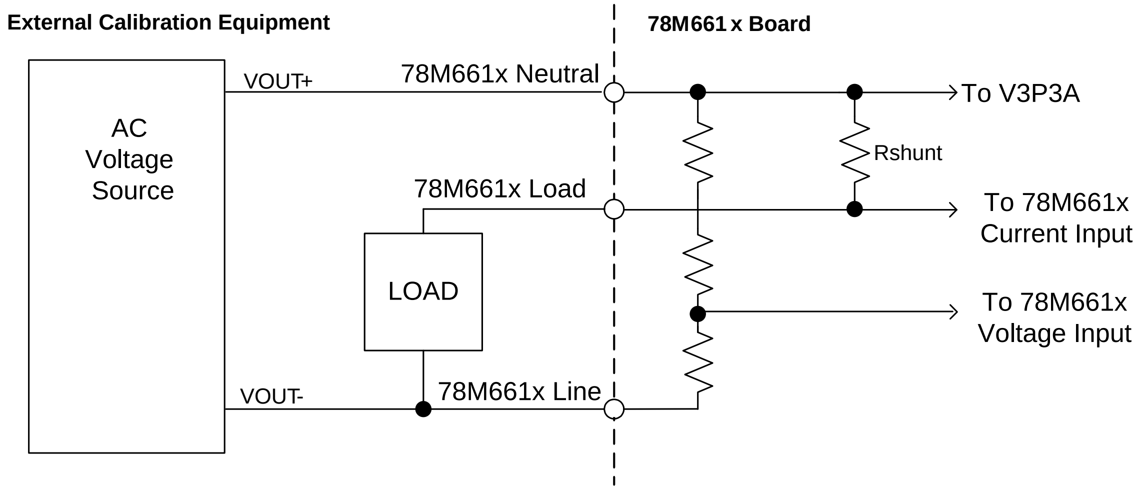

Figure 5: Shunt Voltage Source and Load Resistor Calibration Setup

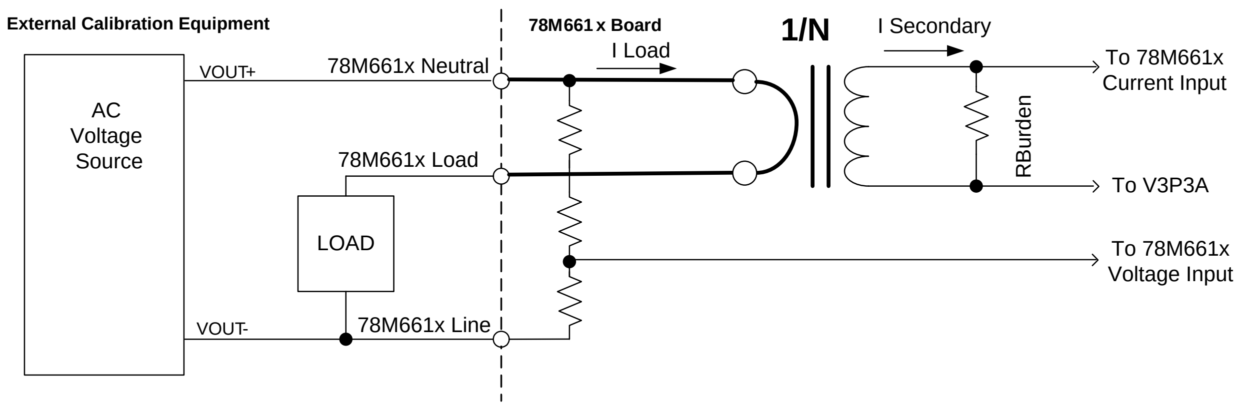

Figure 6: CT Voltage Source and Load Resistor Calibration Setup

Setup with a Precision Power Meter

To minimize the cost of the equipment, the user could utilize a precision power meter and a stable (but not necessarily accurate) AC source and load.

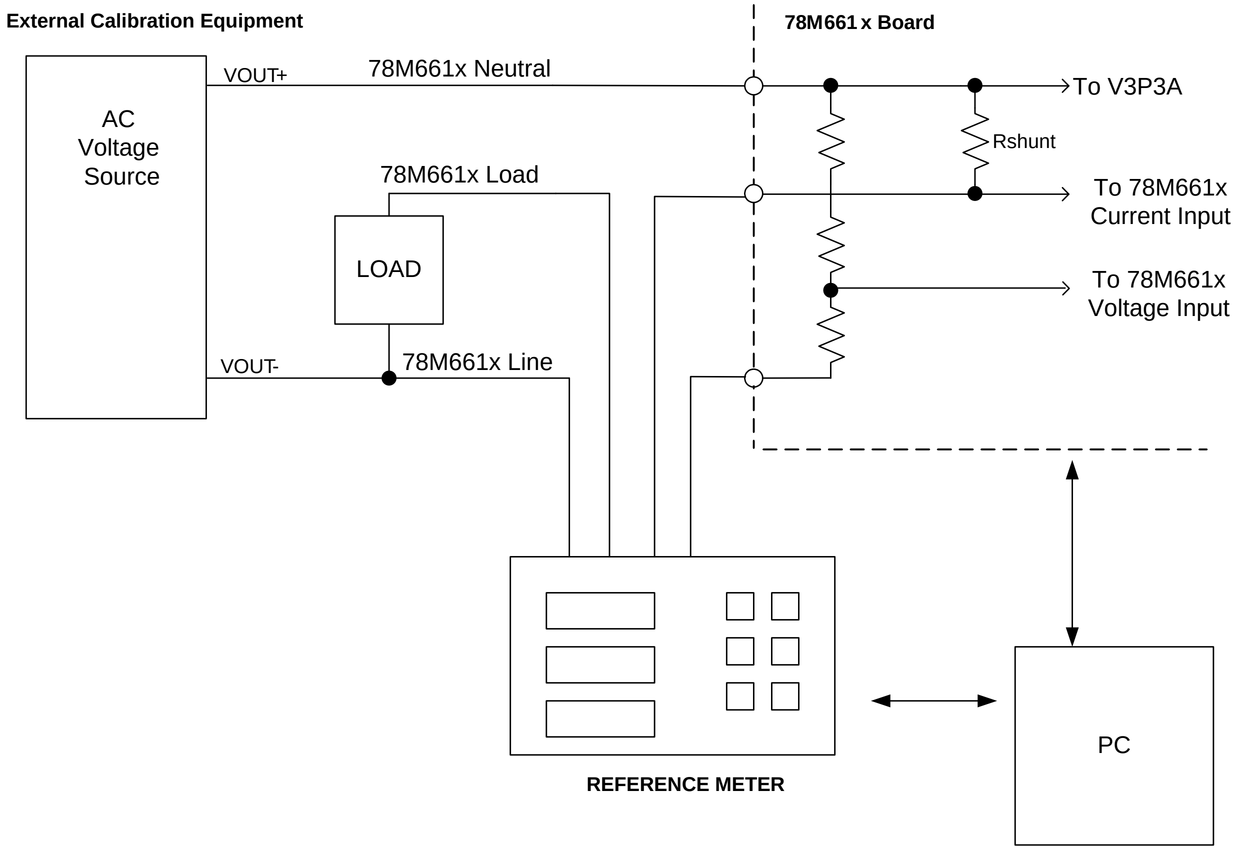

Figure 15: Calibration Setup with a Precision Power Meter

A PC that is usually issuing the calibration command can perform the following sequence.

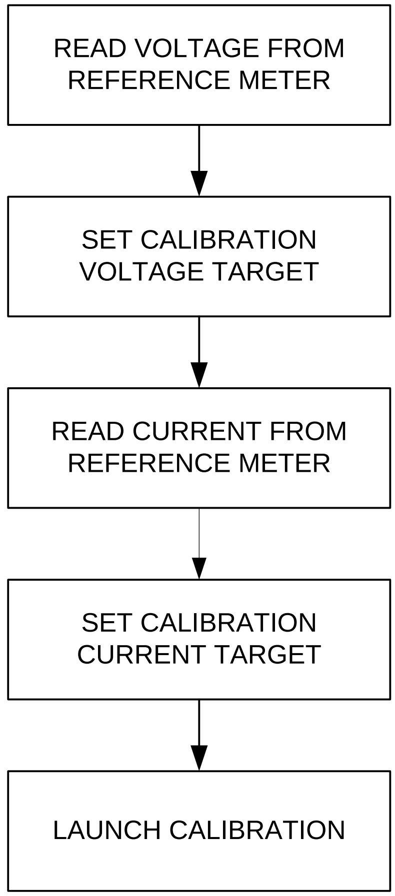

Figure 16: Calibration Sequence

This application note presents a straightforward 78M661x calibration procedure. The built-in calibration commands also provide flexibility to meet different application requirements (other than the default settings) where the 78M661x might be deployed. When high accuracy is needed, precision voltage and current sources must be used with the calibration procedure. These precision sources assure that the calibration results are most accurate and reliable. Regardless what precision is needed, the built-in calibration procedures allow the user to perform complete calibrations without any firmware modification and accommodate different user environments.

CLI Calibration Procedure

The 78M661x standard firmware provides a Command Line Interface (CLI) that allows the user to interface the device through any terminal emulation SW, via UART interface.

The CLI provides commands for calibrating a 78M661x board. There are combination calibration commands (temperature+voltage+current) and individual parameter calibration commands. Refer to the applicable Firmware Description Document User Guide for a complete description of all the various calibration commands. Refer to Appendix B for a summary of the CLI calibration commands. The following discussion presents the CLI calibration commands typically used in a manufacturing calibration procedure. The remaining (not discussed) calibration commands are useful for device characterization and system debug.

The 78M6612 supports one or two outlet configurations. For both configurations, the combination calibration command ***"CAL"*** is used to calibrate the temperature, voltage and "IA" load current coefficients. For two outlet boards, the second load current "IB" can be calibrated using the load current only calibration command ***"CLI1***" after the combination calibration command has completed successfully.

If the board utilizes a relay, the relay must be turned "on" before starting calibration. Refer to the applicable Firmware Description Document for the appropriate TC relay commands.

Single Outlet 78M6612

Figure 7 shows the calibration command invocation (line item beginning with ">") and the expected results for each calibration step for a single outlet shunt board.

```
>cal
CalStatus - 00
 T:OK
 V:OK
 I:OK
```

Figure 7: 78M6612 Single Shunt Calibration Command and Results

After successfully completing the board calibration, it is recommended that the resultant calibration coefficients be recorded in a manufacturing log along with the board's serial number. If in the future the firmware is updated, the recorded calibration coefficients can be restored (i.e. – remotely in the field) without having to return the board to the calibration bench. Enter the CLI command string ***"]8????"*** to read-back the two load current and two voltage coefficients**.** Figure 9 shows the read-back of these four coefficients.

```
>]8????
+13635 +13873 +16567 +16567
```

Figure 8: Read-back of 78M6612 Coefficients after Single Shunt Calibration

The coefficients are restored using the following CLI command sequence:

1. CE0 Disable CE
2.]8=+”*IA coefficient*” =+”*IB coefficient*” =+”V*A coefficient*” =+”VB *coefficient*”
   Write IA, IB, VA, VB coefficients
3.]U Save to internal Flash
4. CE1 Enable CE

```
>CE0
>]8=+13635=+13873=+16567=+16567

>]U

>CE1
```

Figure 9: Saving Coefficients to Internal Flash

Dual Outlet 78M6612

A two outlet shunt board adds one extra calibration step. After moving the external load resistor to the second load connector, use the CLI command ***“CLI2”*** to calibrate the second load current measurement. Figure 10 shows the CLI command sequence for a two outlet 78M6612 board calibration.

```
>cal
CalStatus - 00
 T:OK
 V:OK
 I:OK
>cli2
CalStatus - 00
 I:OK
```

Figure 10: 78M6612 Dual Shunt Calibration Commands and Results

The two outlet coefficients are read-back from the same CE locations as with the single outlet configuration.

```
>]8????
+13632 +13627 +16567 +16567
```

Figure 11: Read-back of 78M6612 Coefficients after Dual Shunt Calibration

Use the same CLI commands presented above for the single shunt calibration to restore the four dual shunt calibration coefficients.

8 Outlet 78M6618

Calibration of the 78M6618 eight outlet shunt board is similar to the two outlet shunt board with the addition of calibrating the additional outlets. Figure 12 shows the CLI calibration command sequence and expected results.

```
>cal
TCal OK
VCal OK:
ICal 1 OK:
>cli2
ICal 2 OK:
>cli4
ICal 3 OK:
>cli8
ICal 4 OK:
>cli10
ICal 5 OK:
>cli20
ICal 6 OK:
>cli40
ICal 7 OK:
>cli80
ICal 8 OK:
```

Figure 12: 78M6618 Eight Shunt Calibration Commands and Results

Similarly, the 78M6618 calibration coefficients (ten coefficients: 8 current + 2 voltage coefficients) can be read out and later restored to internal Flash.

Current Transformer Calibration

Phase calibration is normally performed after the voltage and current calibrations.

The phase calibration does not affect the voltage and current measurements. Phase calibration corrects for the inherent phase shift introduced by the current transformer.

```
>)c3=+30

>clp
CalStatus - 00
 P:OK
>clp2
CalStatus - 00
 P:OK
```

Figure 13: 78M6612 CT Calibration Commands and Results

Similarly, the phase calibration coefficients (one for each outlet current) can be read out and later restored to internal Flash.

M-API Calibration Commands

The 78M661x M-API interface provides calibration libraries to perform each of the CLI calibration functions. Figure 14 shows a calibration sequence for a two outlet shunt board. The first M-API command performs a temperature, watts and voltage calibration on outlet 1. The second M-API command performs a current calibration on outlet 2.

```
>mcc.13.1
Cal: GOOD!
>mcc.4.2
Cal: GOOD!
```

Figure 14: M-API Calibration Commands and Results

The M-API libraries do not have an equivalent function to read CE locations. Use the CLI "]" command to read and write the calibration coefficients. After the coefficients have been restored, use the following M-API commands to save the new coefficients to Flash.

```
>mce0
>muc
MAPI_UpdateCE - Good!
>mce1
```

Figure 15: M-API Saving Coefficients to Internal Flash

Table 2 provides a summary of the M-API calibration libraries and CE controls. Refer to the *78M661x M-API Library User Guide* for the latest M-API calibration library information.

Table 2: 78M6612 M-API Calibration Commands

Command	Format	Example	M-API Used	Note
Calibration Features	M**CC**.z.x	M**CC**.6.01, M**CC**.6.81, M**CC**.13.FF	**MAPI_Calibrate** Calibrate V & I on channel 1. Calibrate V & I on channels 1 and 8. Calibrate Temp, Volt & Watt on all channels.	z = calibration type such as: C_WATT = 0x01, C_VOLT = 0x02, C_CURRENT = 0x04, C_PHASE = 0x08, C_TEMP = 0x10.
	M**CS**.**T**.P=#.I=#.W=#.V=#	M**CS**.T.P=+0.2.I=+.007.W=+.008.V=+.009	**MAPI_CalSetGet**	Set Calibration **T**olerance parameters as follows: Phase Angle=0.2, Current = 7mA, Watt = 8mA, Volt = 9mV. The order of P, I, W and V is NOT sensitive. The '#' with a '+' indicates a decimal value and without a '+' indicates a hex value.
	M**CS**.**R**.P=#.I=#.W=#.V=#.T=#	M**CS**.R.I=+.33.V=+115.P=+.1.W=+40.T=+35	**MAPI_CalSetGet**	Set Calibration **R**eferenced parameters as follows: Phase Angle=0.1, Current = 33mA, Watt = 40A, Volt = 115V, Temp = 35 degrees. The order of P, I, W, T and V is NOT sensitive. The '#' with a '+' indicates a decimal value and without a '+' indicates a hex value.
	M**CG**	M**CG**	**MAPI_CalSetGet**	Get current calibration parameters.
Get **S**tatus	M**S**C	M**SC**	**MAPI_CalStatus**	Get Calibration Status
Update/Save CE data	M**UC**	M**UC**	**MAPI_UpdateCE**	Save CE data permanently in Flash.
CE Control	M**CE**.y	M**CE**.0 or M**CE**.1	**MAPI_CEOn** **MAPI_CEOff**	When y=1, turn on CE. When y=0, turn off CE.

Appendix A – MPU Calibration Parameter Registers

Table 3 summarizes the 78M6612 MPU calibration parameter registers. Refer to the *6612_OMU_S2_URT_V1_13 Firmware Description Document* for the latest CLI calibration parameter register information.

Table 3: 78M6612 MPU Calibration Parameters

MPU Parameter	Location (hex)	LSB	Default	Comment	Example
Target Calibration Voltage	C1	1mVrms	+120.000	Target line voltage (rms) used for calibration.	If the target line voltage for calibration is 220V, enter the following: >)C1=+220<CR>
Target Calibration Current	C2	1mArms	+1.000	Target load current (rms) used for calibration.	If the target load current for calibration is 2A, enter the following: >)C2=+2<CR>
Target Calibration Temperature	CE	0.1°C	+22.0	Target nominal temperature for calibration.	If the user desires the target nominal temperature to be 25°C, then set as follows: >)CE=+25.0<CR>
Target Calibration Watts	CF	mW	+120.000	Target Watts used for calibration.	If the target Watts for calibration is 240, enter the following: >)CF=+240.000<CR>
Target Calibration Phase	C3	0.1°	+0	Target Phase (voltage to current). Normally set to zero.	If the target Phase for calibration is +30°, enter the following: >)C3=+30<CR>
Tolerance on Voltage	C4	1mVrms	+0.010V (10mV)	Measured value to fall within this set tolerance of the target value (Calibration Voltage entry) for the calibration to be complete.	If the tolerance to the target voltage is desired to within 0.1V, the user can enter the following: >)C4=+0.100<CR>
Tolerance on Current	C5	1mArms	+0.010A (10mA)	Measured value to fall within this set tolerance of the target value (Calibration Current entry) for the calibration to be complete.	If the tolerance to the target current is desired to within 0.1A, the user can enter the following: >)C5=+0.100<CR>
Tolerance on Phase	BF	0.001°	0.100°	Measured value to fall within this set tolerance of the target value (Calibration Current entry) for the calibration to be complete.	If the tolerance to the target phase is desired to within 0.5°, the user can enter the following: >)BF=+0.500<CR>
Tolerance on Watts	CA	1mW	+0.010	Measured value to fall within this set tolerance of the target value (Calibration Voltage multiplied by the Calibration Current entries) for the calibration to be complete.	If the tolerance to the target power is desired to be within 0.1W, the user can enter the following: >)CA=+0.100<CR>
Average Count for Voltage	C6	1	+3	Number of voltage measurements taken and averaged to be compared to the target value (Calibration Voltage entry).	If the amount of averaging for the voltage measurement is desired to be 10, enter the following: >)C6=+10<CR>

Table 3: 78M6612 MPU Calibration Parameters (continued)

MPU Parameter	Location (hex)	LSB	Default	Comment	Example
Average Count for Current	C7	1	+3	Number of current measurements taken and averaged to be compared to the target value (Calibration Current entry).	If the amount of averaging for the current measurement is desired to be 10, enter the following: >)C7=+10<CR>
Average Count for Watts	CB	1	+3	Number of wattage measurements taken and averaged to be compared to the target value (Calibration Wattage entry).	If the amount of averaging for the power measurement is desired to increase to 10 enter the following: >)CB=+10<CR>
Max Iteration for Voltage	C8	1	+10	Number of attempts to reach the target value (Target Calibration Voltage entry) within the programmed tolerance.	If maximum number of iterations to be tried for obtaining the target value of voltage within the set tolerance (at C4) is to be 5, then enter: >)C8=+5<CR>
Max Iteration for Current	C9	1	+10	Number of attempts to reach the target value (Target Calibration Current entry) within the programmed tolerance.	If maximum number of iterations to be tried for obtaining the target value of power within the set tolerance (at C5) is to be 5, then enter: >)C9=+5<CR>
Max Iteration for Watts	CC	1	+10	Number of attempts to reach the target value (Calibration Voltage multiplied by the Target Calibration Current entries) within the programmed tolerance.	If maximum number of iterations to be tried for obtaining the target value of power within the set tolerance (at CA) is to be 5, then enter: >)CC=+5<CR>

Changes to the above MPU parameters can be saved to the internal Flash using the following CLI command sequence:

CE0
)U
CE1

Appendix B – MPU Calibration Commands

The following tables summarize the 78M6612 MPU calibration commands. Refer to the 78M6612 applicable Firmware Description Document for the latest CLI calibration command information.

Table 4 lists the Combination Calibration Commands which integrate multiple individual (atomic) parametric calibrations into a single CLI command.

Table 4: 78M6612 Combination Calibration Commands

CALx	**Combination Calibration Commands**	
Description	Allows the user to Calibrate the IC.	
Usage	CAL	Calibrates temperature, then voltage, and finally current for Outlet 1.
	CAL2	Calibrates temperature, then voltage, and finally current for Outlet 2.
	CAL3	Calibrates temperature, then voltage, and finally current for both Outlet1 and Outlet 2.
	CALW	Calibrates temperature, then voltage, and finally power for Outlet 1.
	CALW2	Calibrates temperature, then voltage, and finally power for Outlet 2.
	CALW3	Calibrates temperature, then voltage, and finally power for both Outlet1 and Outlet 2.

Table 5 lists the Atomic Calibration Commands. These individual parametric calibration commands are useful for device characterization or for system debug research.

The CLWn command must be used after the CAL or CLIn command for the same outlet. The CAL or CLIn load current calibration must be performed prior to invoking the CLWn calibration to first establish the load current coefficients.

If multiple outlets are calibrated at the same time, then all load outlets must have their voltage and current references active at the time of calibration.

All outlet numbers are entered in hex format for the calibration commands.

The 78M661x devices are single phase energy measurement devices. There is one AC voltage for all load current outlets. Therefore, the voltage only needs to be calibrated once, typically with the first outlet calibration. The second load current calibration does not require repeating the voltage calibration.

The 78M661x reports separate voltage results for narrowband and wideband energy measurements. The narrowband (MPU locations 0x06 and 0x46 for 78M6612) and wideband (MPU locations 0x26 and 0x66 for 78M6612) voltage results are the same and do not have separate calibration commands.

Table 5: 78M6612 Atomic Calibration Commands

CLxx	**Atomic Calibration Commands**	
Description	Allows the user to Calibrate individual sections of the IC.	
Usage	CLV	Calibrates voltage only.
	CLI1	Calibrate current on Outlet 1 only.
	CLI2	Calibrate current on Outlet 2 only.
	CLI3	Calibrate for current on both Outlet 1 and Outlet 2 only.
	CLW1	Calibrate for power on Outlet 1 only.
	CLW2	Calibrate for power on Outlet 2 only.
	CLW3	Calibrate for power on both Outlet 1 and Outlet 2.
	CLP	Calibrate for phase on Outlet 1 only. Generally only used when using current transformers.
	CLP2	Calibrate for phase on Outlet 2 only. Generally only used when using current transformers.
	CLP3	Calibrate for phase on both Outlet 1 and Outlet 2. Generally only used when using current transformers.
	CLT	Calibrate temperature only.

Revision History

Revision	Date	Description
1.0	12/15/2010	First publication.