

Calibrating a Single-Phase Energy Meter Based on the ADE71xx/ADE75xx Family

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INTRODUCTION

This application note describes how to calibrate the ADE71xx/ADE75xx. The first section details the calibration procedure, providing equations and examples of how to calculate each constant. The second section of this document outlines how to use the LabVIEW™ calibration program that is designed to interact with the ADE71xx/ADE75xx reference design.

The ADE71xx/ADE75xx family of energy metering ICs integrates an 8052 microcontroller with an energy metering core to provide a fully integrated single-phase metering solution. This family of parts is the next generation of SPI interface energy metering ICs from Analog Devices, Inc. As a complete metering solution, the ADE71xx/ADE75xx family provides an internal LCD driver, battery switching, temperature ADCs, RTC, and communication peripherals.

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CALIBRATING THE ADE71xx/ADE75xx

To obtain accurate readings that do not reflect meter-to-meter variations in external components or the internal voltage reference, the ADE71xx/ADE75xx requires calibration. The energy measurements, current rms, and voltage rms need to be calibrated separately for accurate readings.

If a low resistance shunt is used as the current sensor, a watt gain calibration is required. If a current transformer is used, a phase calibration is also required to compensate for the phase shift added by the external sensor.

CALIBRATION METHODS

Two different methods can be used to successfully calibrate the ADE71xx/ADE75xx.

Reference Meter

The most popular method of calibration uses a pulse output and an external reference meter to determine the required compensation. The pulse output method is more commonly used because it allows the meter calibration to be verified by a utility using the calibration pulse output (CF). The CF output frequency can be configured to be proportional to the active, reactive, or apparent power or to the current rms. Calibration is achieved using a reference meter to obtain a percentage error in the output CF pulse. Using this percentage error, the corresponding compensation can be determined and applied to the internal registers.

Accurate Source

The second method uses the internal energy registers to accumulate energy over a specific period. Line cycle accumulation mode is used to accumulate energy over a specified number of line cycles. The energy obtained is compared to that expected and the corresponding compensation is applied to the internal calibration registers. For this method to be successful, an accurate source is required. Because this method does not use a pulse output, calibration verification must be performed via the internal registers. See the Calibrating Using an Accurate Source section for details on this calibration method.

ACTIVE ENERGY CALIBRATION

Configuring the ADE71xx/ADE75xx Meter

While performing the watt calibration, the CF pulse output should be configured to output active power. This is achieved by setting Bit 4 through Bit 7 of the MODE2 register. The signal chain for the ADE71xx/ADE75xx watt measurement is shown in Figure 1.

There are two steps required to calibrate the watt measurement on the ADE71xx/ADE75xx, and an additional two steps for advanced calibration:

- Set the CF output frequency
- Calibrate the watt gain
- Calibrate the watt phase (if required)
- Calibrate the watt offset (if required)

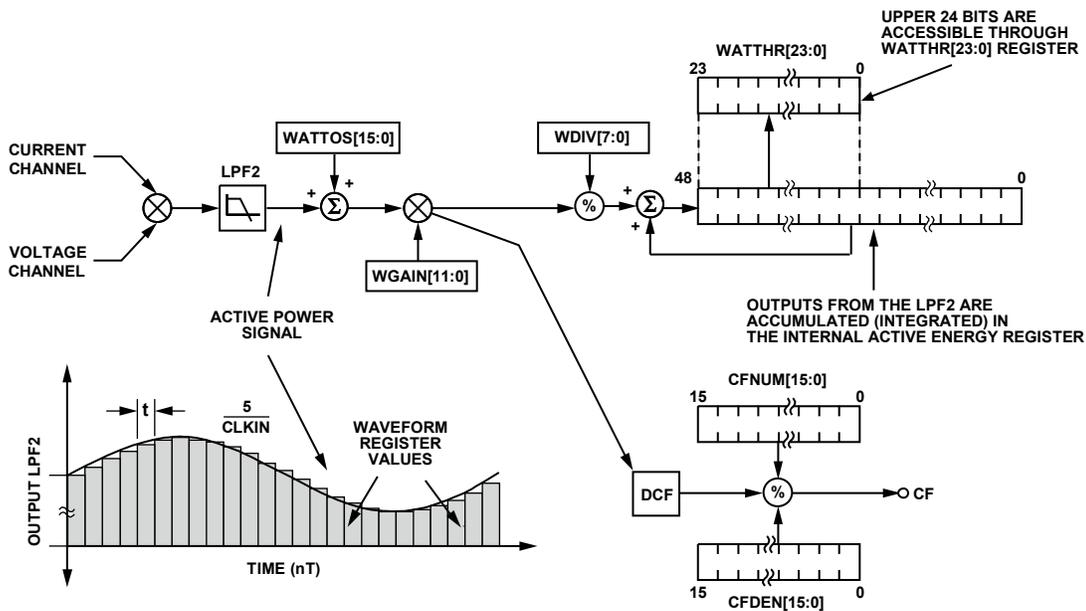


Figure 1. ADE71xx/ADE75xx Watt Signal Chain

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CF Output Frequency

Using the internal registers of the ADE71xx/ADE75xx, the CF pulse output can be configured so that each CF pulse represents a fraction of a kilowatt-hour. This is performed through a CF divider, composed of CFNUM and CFDEN. This divider is calculated based on the meter constant and the nominal scaling on the current and voltage channels.

$$\text{Meter Constant [imp/kWh]} = \frac{\text{CF[imp/sec]} \times 3600}{\text{Load[kW]}}$$

Assuming a meter constant of 3200 imp/kWh is required, the expected CF can be determined under a given load.

With a load of 220 V and 10 A at a power factor of 1, the expected CF output frequency is calculated to be 1.95556 Hz, as shown in the following equation:

$$\text{CF}_{\text{EXPECTED}} = \frac{\text{Meter Constant [imp/kWh]} \times \text{Load[kW]}}{3600 \text{ sec/h}} \times \cos(\phi)$$

$$\text{CF}_{\text{EXPECTED}} = \frac{3200 \text{ imp/kWh} \times 220\text{V} \times 10 \text{ A} / 1000}{3600 \text{ sec/h}} \times \cos(0)$$

$$= 1.95556 \text{ Hz}$$

The CFNUM and CFDEN ratio should be selected to obtain a frequency of 1.95556 Hz under the given load conditions.

Figure 2 shows the voltage channel inputs on the ADE71xx/ADE75xx reference design.

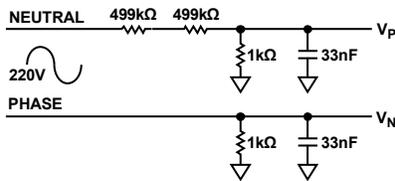


Figure 2. Voltage Channel Inputs

$$V_p = V_{\text{INPUT_MAX}} \times \frac{1 \text{ k}}{(2 \times 499 \text{ k}) + 1 \text{ k}}$$

$$= (220 \text{ V} \times \sqrt{2}) \times \frac{1}{(2 \times 499 + 1)} = 0.311 \text{ mV}$$

$$V_{\text{AS\% OF FULL SCALE}} = \frac{0.311}{0.5} \times 100 = 62.29\%$$

With a voltage channel amplitude of 220 V rms, the input is operating at 62.29% of full scale.

Figure 3 depicts the ADE71xx/ADE75xx default current channel configuration. With a current channel amplitude of 10 A rms and an internal gain of 16, the input is operating at 15.84% of full scale.

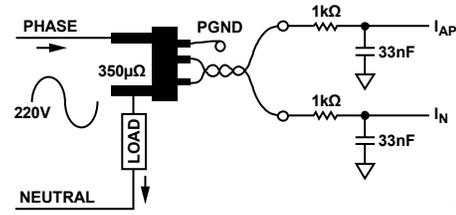


Figure 3. Current Channel Inputs

$$V_{\text{ACROSSHUNT}} = I \times R$$

$$= (10 \times \sqrt{2}) \times (350 \times 10^{-6}) = 0.0495 \text{ V}$$

$$= X \text{ Gain } 16 = 0.0495 \times 16 = 0.079 \text{ V}$$

$$I_{\text{AS\% OF FULL SCALE}} = \frac{0.079}{0.5} \times 100 = 15.84\%$$

From the ADE71xx/ADE75xx data sheet, the maximum CF output with full-scale ac inputs is 21.1 kHz. To obtain 1.9556 Hz with the given 220 V, 10 A input, the CF denominator should be set to 0x429, as shown in the following equation:

$$\text{CFDEN} = \frac{\text{Output Freq}_{\text{FULLSCALE}} \times V_{\text{OPERATING \%}} \times I_{\text{OPERATING \%}}}{\text{CF}_{\text{EXPECTED}}}$$

$$\text{CFDEN} = \frac{21.1 \text{ kHz} \times 62.29\% \times 15.84\%}{1.9556 \text{ Hz}} = 0x429$$

Note that CFNUM is fixed at 1.

Because the ADE71xx/ADE75xx reference design uses a 350 μΩ shunt, a gain of 16 is selected on the current channel. To set this gain, 0x04 should be written to the GAIN register.

Watt Gain

The purpose of the watt gain calibration is to compensate for small gain errors due to part-to-part variations in the design (variations in external components). Gain calibration is required on every meter and is performed at a power factor of 1. To determine the magnitude of compensation required the percentage error in the accumulation is determined using the following equation:

$$\% \text{Error} = \frac{\text{CF}_{\text{ACTUAL}} - \text{CF}_{\text{EXPECTED}}}{\text{CF}_{\text{EXPECTED}}}$$

$$\text{WGAIN} = \left(\frac{1}{(1 + \% \text{Error})} - 1 \right) \times 2^{12}$$

At 220 V and 10 A, the expected CF is 1.9556 Hz, as previously calculated. Assuming the actual measured CF is 2.2238 Hz, the measured percentage error is 13.71%.

To obtain the WGAIN value required to compensate for this variation, the percentage error is substituted into the WGAIN equation as follows:

$$WGAIN = \left(\frac{1}{(1 + 13.71\%)} - 1 \right) \times 2^{12} = 0xFE12 = -494$$

Note that as previously mentioned, if using a reference meter to perform the calibration, the percentage error can be read directly from the reference meter and does not need to be calculated.

Advanced Watt Calibration

Watt Phase—Optional

Phase calibration is required when using a current transformer to remove any phase shift introduced by the sensor. CTs can add significant phase shift that introduces large errors at low power factors. If using a different type of sensor, such as a low resistance shunt, phase calibration is not always required.

The phase calibration is performed with an inductive load at a power factor of 0.5. The following equation outlines how the phase compensation is determined:

$$PHCAL = - \left(\frac{\text{asin} \left(\frac{\%Error}{\sqrt{3}} \right)}{2\pi f_i \times 1.22 \times 10^{-6}} \right) + 0x40$$

where f_i is the line frequency.

Note that the preceding calculation should be performed in radians.

At 220 V and 10 A at a power factor of 0.5, the expected CF is exactly half of that previously calculated:

$$CF_{EXPECTED} = \frac{3200 \text{ imp/kWh} \times 220 \text{ V} \times 10 \text{ A} / 1000}{3600 \text{ sec/h}} \times \cos(60) = 0.9778 \text{ Hz}$$

Assuming the measured CF is 0.98 Hz, the percentage error can be calculated as follows:

$$\%Error = \frac{0.98 - 0.9778}{0.9778} = 0.2273\%$$

Note that if using a reference meter, the percentage error can be obtained directly from this device.

Finally, at a line frequency of 50 Hz, the PHCAL compensation can be determined as follows:

$$PHCAL = - \left(\frac{\text{asin} \left(\frac{0.2273\%}{\sqrt{3}} \right)}{2\pi \times 50 \times 1.22 \times 10^{-6}} \right) + 0x40 = 0x3D$$

For ADE71xx phase compensation, refer to the Antitamper Phase Calibration section for details of special considerations required when designing an antitamper meter.

Watt Offset—Optional

Watt offset calibration is only required if accuracy at low loads is outside the required specification before offset calibration.

To correct for any voltage to current channel crosstalk that may degrade the accuracy of the measurements at low current levels, watt offset calibration is performed. A low level current signal must be applied to allow the offset magnitude to be measured and then removed.

In this example, an input current of 100 mA is applied to perform the offset calibration. With a voltage channel input of 220 V at a power factor of 1, the expected CF output frequency is determined as before:

$$CF_{EXPECTED} = \frac{3200 \text{ imp/kWh} \times 220 \text{ V} \times 0.1 \text{ A} / 1000}{3600 \text{ sec/h}} \times \cos(0) = 0.0195556 \text{ Hz}$$

If the actual CF frequency is 0.020 Hz at 100 mA and 220 V, the percentage error due to offset is determined as follows:

$$\%Error = \frac{0.02000 - 0.0195556}{0.0195556} = 2.273\%$$

The offset in the watt measurement is corrected according to the following equation:

$$WATTOS = -\%ERROR \times CF_{EXPECTED} \times \frac{CFDEN}{\left(1 + \frac{WGAIN}{2^{12}}\right)} \times \frac{1}{819.2 \text{ kHz}} \times 2^{33}$$

$$WATTOS = -2.273\% \times 0.0195556 \times \frac{0x429}{\left(1 + \frac{0xFE12}{2^{12}}\right)} \times \frac{1}{819.2 \text{ kHz}} \times 2^{33} = 0xE9F5$$

Accumulating Watt-Hours in Software

The ADE71xx/ADE75xx provide an interrupt when a CF pulse is output so that the firmware can update the energy display synchronously with the CF output.

After calibrating the watt measurement, the CF output corresponds precisely to the meter constant, that is, 3200 imp/kWh. Energy accumulation in the ADE71xx/ADE75xx firmware can be based on the CF interrupt, so that once 3200 interrupts are counted, one kilowatt-hour is added to the running total. Similarly, for every 32 CF pulses, 10 watt-hours are added.

CURRENT AND VOLTAGE RMS

Calibrating the voltage and current rms is only required if the instantaneous rms readings are required. RMS calibration does not affect the performance of the active energy.

The rms calibration should be performed using the instantaneous rms register readings. The readings can be obtained from the energy measurement SFRs 0xD1 through 0xD6. The CF pulse output is not used for this calibration. The current and voltage rms readings on the ADE71xx/ADE75xx can be internally synchronized to the zero crossing, reducing the ripple in the resulting rms measurement. This functionality is an improvement on previous ADE parts where the synchronization had to be performed in software. This feature is enabled by setting the ZXRMS bit in the ADE MODE2 register. For increased accuracy, the zero crossing synchronization should be enabled throughout the calibration process and, if required, an average of multiple readings can be taken.

The current and voltage rms readings require gain calibration to compensate for any part-to-part variations. Offset calibration is also required on every meter to remove crosstalk that would degrade the accuracy of the readings at low signal inputs. There is not an internal gain calibration register for the rms readings and, therefore, the gain adjustment is performed in the firmware as shown in Figure 4.

RMS Gain

Both the current and voltage rms gain constants are calculated and implemented in firmware. Along with compensating for part-to-part gain variations, the rms gain constant converts the rms reading in LSBs into a reading in amps or volts. The voltage and current rms constants are determined under fixed load conditions by dividing the number of LSBs in the rms register by the amplitude of the input, as shown in the following equations:

$$V \text{ Constant [V/LSB]} = \frac{\text{Voltage Input [V]}}{\text{VRMS[LSBs]}}$$

$$I \text{ Constant [Amps/LSB]} = \frac{\text{Current Input [A]}}{\text{IRMS[LSBs]}}$$

Calculating RMS for Display Purposes

To maintain full resolution when the conversion is taking place in firmware, the voltage and current rms constants can be multiplied by a constant, k.

$$V \text{ Constant [V/LSB]} = \frac{\text{Voltage Input [V]}}{\text{VRMS[LSBs]}} \times k$$

$$I \text{ Constant [Amps/LSB]} = \frac{\text{Current Input [A]}}{\text{IRMS[LSBs]}} \times k$$

The use of a multiplication factor allows resolution to be maintained when converting and storing the rms readings as a hexadecimal number using fixed point multiplication. Converting the reading to the hexadecimal format is required prior to performing a hex to binary coded decimal conversion for display purposes.

An example of how the voltage rms register reading can be converted into a value in volts, maintaining resolution of two digits below the decimal point, is provided in the following equation. In this example, 220 V is applied, producing a VRMS register reading of 1089790d.

$$V \text{ Constant} = \frac{220 \text{ V}}{1,089,790} \times 100 \times 2^{16} = 1323$$

The volts/LSB constant is multiplied by a factor of 100×2^{16} to maintain accuracy when using fixed point multiplication. The V constant is 1323.

A further example showing the generation of the current rms gain constant is provided in the following equation. In this example, the resulting LCD display measurement is accurate to three digits below the decimal point. A current input of 10 A is applied, resulting in an IRMS reading of 317460d.

$$I \text{ Constant} = \frac{10 \text{ A}}{317,460} \times 1000 \times 2^{16} = 2064$$

The amps/LSB constant is multiplied by a factor of 1000×2^{16} to maintain the required accuracy during conversion. The resulting I constant is 2064.

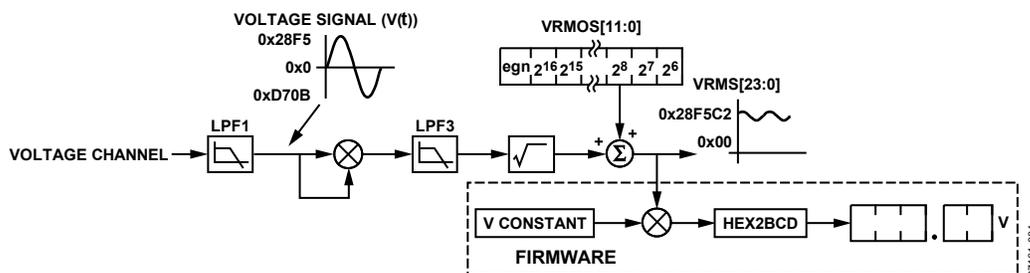


Figure 4. Voltage RMS Signal Chain

RMS Offset

To obtain accurate readings at low signal levels, the current and voltage rms offset needs to be calibrated. This calibration is done using the internal VRMSOS and IRMSOS registers. The compensation factor is determined by applying the following equations:

$$VRMSOS = \frac{VRMS_{EXPECTED} - VRMS_{ACTUAL}}{64}$$

$$IRMSOS = \frac{IRMS_{EXPECTED}^2 - IRMS_{ACTUAL}^2}{32,768}$$

The offset calibration should be performed at low signal levels where the offset is most apparent in the signal reading; this concept is illustrated in Figure 5.

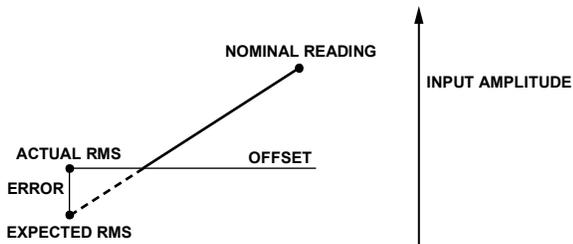


Figure 5. RMS Reading

The voltage rms measurement is specified over a dynamic range of 100:1 and the current rms measurement over a dynamic range of 1000:1. This is the minimum input level at which the measurement is accurate and, therefore, the minimum point at which the offset calibration should take place. In this example, the voltage rms offset is calibrated at 175 V and the current rms offset is calibrated at 100 mA. To determine the expected rms reading, a measurement should be taken at the nominal current and the nominal voltage. This reading should then be scaled down to obtain the expected value at the calibration point.

For example:

Reading at $I_{NOMINAL}$ (10 A) = 300,614
 Expected Reading at I_{CAL} (100 mA) = $(0.1/10) \times 300,614 = 3006$
 Actual Reading Obtained at I_{CAL} (100mA) = 3486

Therefore,

$$IRMSOS = \frac{3006^2 - 3486^2}{32,768} = 0xFFA1 = -95$$

The voltage rms offset is calibrated in a similar manner.

For example:

Reading at $V_{NOMINAL}$ (220 V) = 1064409
 Expected Reading at V_{CAL} (175 V) = $(175/220) \times 1,064,409 = 846,689$
 Actual Reading Obtained at V_{CAL} (175 V) = 900,833

Therefore,

$$VRMSOS = \frac{846,689 - 900,833}{64} = 0xFCB2 = -846$$

APPARENT ENERGY CALIBRATION

VA Gain

The VA gain calibration, similar to the watt gain calibration, must be performed on every meter to compensate for part-to-part variations. The VA gain register is also used to retain the meter constant established during the watt calibration. Because the apparent energy signal chain is not identical to the active energy signal chain, there is a scaling factor between the measurements. Details of this scaling factor can be found in the Energy Register Scaling section of the ADE71xx/ADE75xx data sheet.

The apparent energy calibration should also be performed at a power factor of 1 with nominal inputs, in this case 220 V and 10 A. Assuming a meter constant of 32000 imp/kVAh is also required for the apparent pulse output.

$$VACF_{EXPECTED} = \frac{Meter\ Constant\ [imp/kVAh] \times Load[kVA]}{3600\ sec/h}$$

$$VACF_{EXPECTED} = \frac{3200\ imp/kWh \times 220\ V \times 10\ A / 1000}{3600\ sec/h}$$

$$= 1.95556\ Hz$$

To determine the compensation required, the percentage error in the apparent energy reading must first be determined.

$$\%Error = \frac{VACF_{ACTUAL} - VACF_{EXPECTED}}{VACF_{EXPECTED}}$$

$$VAGAIN = \left(\frac{1}{(1 + \%Error)} - 1 \right) \times 2^{12}$$

At 220 V and 10 A, the expected CF is 1.9556 Hz, as previously calculated. Assuming the actual measured CF is 2.065 Hz, the percentage error is calculated as follows:

$$\%Error = \frac{2.065 - 1.95556}{1.95556} = 5.60\%$$

To obtain the VAGAIN value required to compensate for this variation, the percentage error is substituted into the VAGAIN equation as follows:

$$VAGAIN = \left(\frac{1}{(1 + 5.60\%)} - 1 \right) \times 2^{12} = 0xFF27 = -217$$

Note that as previously mentioned, if using a reference meter to perform the calibration, the percentage error can be read directly from the reference meter and does not need to be calculated.

Advanced Apparent Calibration

VA Offset—Optional

VA offset calibration is only required if accuracy at low loads is outside the required specification.

As the apparent energy is derived from the product of the instantaneous voltage and current rms readings, the removal of the apparent energy offset is achieved through calibration of the IRMS and VRMS offset compensation. Therefore, when an

accurate low load apparent energy reading is required, it is essential to calibrate the VRMSOS and IRMSOS registers.

REACTIVE ENERGY CALIBRATION

VAR Gain

The VAR gain calibration, similar to the watt gain calibration, must be performed on every meter to compensate for part-to-part variations. The VAR gain register is also used to retain the meter constant established during the watt calibration. Because the reactive energy signal chain is not identical to the active energy signal chain, there is a scaling factor between the measurements. Details of this scaling factor can be found in the Energy Register Scaling section of the ADE71xx/ADE75xx data sheet.

The reactive energy calibration should be performed at a power factor of 0 to obtain the maximum reactive energy output. Nominal inputs should once again be used, in this case 220 V and 10 A. Assuming a meter constant of 32000 imp/kVARh is also required for the reactive pulse output.

$$\begin{aligned} \text{VARCF}_{\text{EXPECTED}} &= \frac{\text{Meter Constant}[\text{imp/kVARh}] \times \text{Load}[\text{kVAR}]}{3600 \text{ s/h}} \times \sin(\theta) \\ &= \frac{32000 \text{ imp/kVARh} \times 10 \text{ kVAR}}{3600 \text{ s/h}} \times \sin(90) \\ &= 1.95556 \text{ Hz} \end{aligned}$$

$$\begin{aligned} \text{VARCF}_{\text{EXPECTED}} &= \frac{3200 \text{ imp/kVAh} \times 220 \text{ V} \times 10 \text{ A} / 1000}{3600 \text{ s/h}} \times \sin(90) \\ &= 1.95556 \text{ Hz} \end{aligned}$$

To determine the compensation required, the percentage error in the reactive energy reading must first be determined.

$$\% \text{Error} = \frac{\text{VARCF}_{\text{ACTUAL}} - \text{VARCF}_{\text{EXPECTED}}}{\text{VARCF}_{\text{EXPECTED}}}$$

$$\text{VARGAIN} = \left(\frac{1}{(1 + \% \text{Error})} - 1 \right) \times 2^{12}$$

At 220 V and 10 A, the expected CF is 1.9556 Hz, as previously calculated. Assuming the actual measured CF is 1.856 Hz, the percentage error is calculated as follows:

$$\% \text{Error} = \frac{1.856 - 1.95556}{1.95556} = -5.09\%$$

To obtain the VARGAIN value required to compensate for this variation, the percentage error is substituted into the VARGAIN equation as follows:

$$\text{VARGAIN} = \left(\frac{1}{(1 + (-5.09\%))} - 1 \right) \times 2^{12} = 0x\text{DC} = 220$$

Note that as previously mentioned, if using a reference meter to perform the calibration, the percentage error can be read directly from the reference meter and does not need to be calculated.

Advanced Reactive Calibration

VAR Offset—Optional

VAR offset calibration is only required if accuracy at low loads is outside the required specification.

The reactive power offset calibration corrects any small dc offsets that may degrade the accuracy of the measurement with small loads. This calibration procedure is performed with a small input current applied. The reactive offset calibration should be performed at a power factor of 0.

In this example, an input current of 100 A is applied to perform the offset calibration. With a nominal voltage input of 220 V, the expected VACF output frequency is determined as before.

$$\begin{aligned} \text{VACF}_{\text{EXPECTED}} &= \frac{3200 \text{ imp/kWh} \times 220 \text{ V} \times 0.1 \text{ A} / 1000}{3600 \text{ s/h}} \times \sin(90) \\ &= 0.0195556 \text{ Hz} \end{aligned}$$

If the actual CF frequency is 0.02050 Hz at 100 mA and 220 V, the percentage error due to offset is determined as follows:

$$\% \text{Error} = \frac{0.020500 - 0.0195556}{0.0195556} = 4.829\%$$

The offset in the reactive measurement is corrected according to the following equation:

$$\begin{aligned} \text{VAROS} &= \% \text{Error} \times \text{VARCF}_{\text{EXPECTED}} \times \left(\frac{\text{VARDIV}}{1 + \frac{\text{VARGAIN}}{2^{12}}} \right) \times \frac{1}{819.2 \text{ kHz}} \times 2^{33} \end{aligned}$$

$$\begin{aligned} \text{VAROS} &= 4.829\% \times 0.0195556 \times \left(\frac{0x426}{1 + \frac{0x\text{DC}}{2^{12}}} \right) \times \frac{1}{819.2 \text{ kHz}} \times 2^{33} = 0xD904 \end{aligned}$$

CALIBRATING USING AN ACCURATE SOURCE

The procedure for calibrating the ADE71xx/ADE75xx using an accurate source is very similar to that described in this document. Instead of using the CF output pulse to determine the percentage error in the signal, the line cycle accumulation register can be used.

First, the CF output frequency should be set up in the same manner as described in the CF Output Frequency section. When calibrating the gain, the percentage error can be determined using the line cycle accumulation reading. The following relationship can be assumed between the line accumulation energy registers and the CF output frequency:

$$LWATTHR \times \frac{CFNUM}{CFDEN} = CF \quad (\text{Assuming } WDIV = 0).$$

Using the preceding relationship and the $\text{CF}_{\text{EXPECTED}}$ equation in the CF Output Frequency section, the expected reading from the line cycle register is given by the following equation:

$$Line\ Cycle_{EXPECTED} = \frac{Meter\ Constant [imp/kWh] \times Load [kW] \times AccTime [sec] \times CFDEN}{3600\ s/h} \times \cos(\phi)$$

The actual reading from the line cycle accumulation register should then be obtained and the percentage error should be derived. The formula for WGAIN provided in the Watt Gain section can then be used to determine the required compensation. The same procedure should be followed for all energy readings to determine the required gain, phase, and offset calibration.

REAL-TIME CLOCK

For calibration of the RTC, see application note AN-949, *Compensating the ADE71xx/75xx Family RTC for Accurate Timekeeping*.

DESIGNING A TAMPER-PROOF METER

When designing a tamper-proof meter, additional calibration steps are required to ensure a properly calibrated output. The ADE71xx family of parts provide a second current input channel allowing the neutral current to be monitored. The ADE75xx series does not include this feature.

The ADE71xx series is designed to monitor both the phase and neutral current to detect for a fault. It can also be configured to detect a missing neutral condition and continue billing based only on the current channel input. These two features each require a separate calibration step to operate accurately.

Figure 6 shows the input configuration using a shunt resistor to monitor the current on the phase and a CT to monitor the current on the neutral.

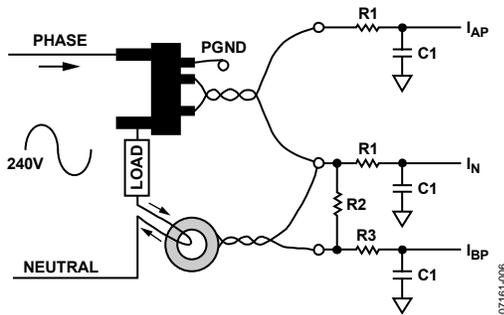


Figure 6. Antitamper Inputs

The calibration flow changes slightly when designing an antitamper meter. The flow diagram in Figure 7 outlines the steps involved when calibrating the watt measurement.

As shown in Figure 7, an extra calibration step, I_B gain calibration, is required when calibrating the watt measurement of an antitamper meter. The procedure for carrying out this calibration step is provided in the following section.

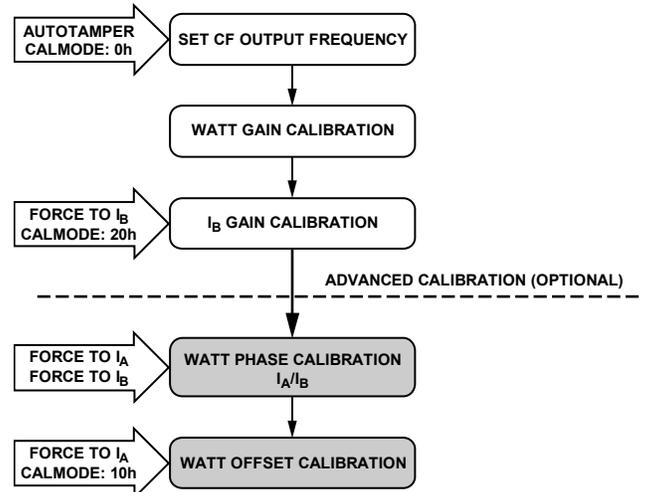


Figure 7. Antitamper Calibration Flow

I_B Gain Calibration

The purpose of the I_B gain calibration is to remove any small gain errors between the two current input channels. To perform calibration on I_B, the CALMODE register should be set to 0x20 to force the current channel to the I_B input. A signal should be applied to I_B, and I_A should have no current flowing through it.

I_B gain calibration should be performed with nominal current and voltage inputs, in this example, 10 A and 220 V. From previous calculations, the expected CF output frequency under these conditions is 1.95556 Hz. The percentage error in the I_B channel can be calculated as follows:

$$\%Error = \frac{CF_{I_B} - CF_{EXPECTED}}{CF_{EXPECTED}}$$

The value required in the IBGAIN register to compensate for this error can be calculated using the following equation:

$$I_B\ GAIN = \frac{-\%Error}{1 + \%Error} \times 2^{12}$$

For example, if the obtained CF output frequency is 2.275 Hz when using the I_B current channel, the IBGAIN register value required to ensure channel matching can be calculated as follows:

$$\%Error = \frac{2.275 - 1.95556}{1.95556} = 16.33\%$$

$$I_B\ GAIN = \frac{-0.1633}{1 + 0.1633} \times 2^{12} = -575d = 0xFDC1$$

Antitamper Phase Calibration

Care should be taken if performing a phase calibration on an antitamper meter. If one shunt and one CT are being used, the phase shifts differ from channel to channel. In this situation, two phase calibration constants should be determined, one for when the input signal is taken from I_A and another for when I_B is in use. The phase calibration is therefore performed twice, once with the input forced to I_A (CALMODE = 0x10) and once with the input forced to I_B (CALMODE = 0x20). Refer to the Watt Phase Calibration section for details on the phase calibration procedure. Alternatively, the phase shift inconsistency can be resolved by compensating using hardware.

Antitamper RMS Calibration

Calibration in antitamper mode follows the same procedure as described in the Current and Voltage RMS section. The input should be set to autotamper (CALMODE = 0x00) to perform the gain calibration. When performing rms offset calibration, the CALMODE register should be set to 0x10 to force the input to A and prevent noise induced switching.

Antitamper Apparent Energy Calibration

Calibration in antitamper mode follows the same procedure as described in the Apparent Energy Calibration section. The input should be set to autotamper (CALMODE = 0x00).

Antitamper Reactive Energy

Calibration in antitamper mode follows the same procedure as described in the Apparent Energy Calibration section. The input should be set to autotamper (CALMODE = 0x00). If reactive offset calibration is required, the CALMODE register should be set to 0x10 to force the input to A and prevent noise induced switching.

Missing Neutral Calibration

This calibration step is only required when designing an antitamper meter that is required to perform when the neutral connection is missing. Missing neutral calibration should be performed after the current rms measurement has been calibrated.

The missing neutral condition is entered when the voltage channel drops below a certain threshold. SAG and zero crossing

detection can be enabled to detect this event. Because there is no voltage going to the meter, no current should be consumed at this time. If current is consumed, there is a tamper situation. In this condition, the ADE71xx/ADE75xx can measure ampere-hour consumption and allows billing to continue based on this quantity. In this mode, the MODE2 register should be reprogrammed to output a CF pulse proportional to the instantaneous IRMS reading. To ensure that the CF pulse weight is maintained under these conditions, the CFNUM and CFDEN are modified to provide the correct meter constant.

When operating in missing neutral mode, the voltage amplitude and phase angle are unknown and therefore have to be assumed. The expected CF output frequency should once again be based on the meter constant determined in the previous calibration steps, in this case 3200 imp/kWh. For this example, an assumed voltage of 240 V with a phase angle of 30 degrees is used. The expected CF output frequency is determined as before.

$$CF_{EXPECTED} = \frac{\text{Meter Constant [imp/kWh]} \times \text{Load [kW]}}{3600 \text{ s/h}} \times \cos(\phi)$$

$$CF_{EXPECTED} = \frac{3200 \text{ imp/kWh} \times 240 \text{ V} \times 10 \text{ A} / 1000}{3600 \text{ s/h}} \times \cos(30)$$

$$= 1.84752 \text{ Hz}$$

In order to adjust the CF output frequency to obtain the missing neutral operating conditions, the CFDEN has to be scaled according to the new expected CF frequency.

$$\frac{CFNUM_{MN}}{CFDEN_{MN}} = \frac{CF_{EXPECTED}}{CF_{ACTUAL}} \times \frac{CFNUM}{CFDEN}$$

Note that CFNUM is forced to 1.

For example, assuming that the measured CF in missing neutral mode is 1.954 Hz and from previous calculations, the current CFDEN = 0x429:

$$\frac{1}{CFDEN_{MN}} = \frac{1.84752}{1.954} \times \frac{1}{1065}$$

$$CFDEN_{MN} = 0x466$$

The missing neutral mode CFDEN should only be programmed into the CFDEN register when operating in missing neutral mode.

ADE71xx/ADE75xx CALIBRATION SOFTWARE

The ADE71xx/ADE75xx calibration software allows the user to calibrate the watt, VAR, current and voltage rms, and real time clock of the ADE71xx/ADE75xx reference design. This software program, developed in LabVIEW, communicates with the ADE71xx/ADE75xx reference design through an isolated serial port, using a protocol defined in *ADE7169 Based Energy Meter Program Structure* (found on the evaluation CD).

An ADE71xx/ADE75xx reference design is shipped with the reference design firmware in the Flash memory. Each reference design has been calibrated for watt, VAR, current and voltage rms, and RTC performance. The calibration constants required for the firmware and for the calibration registers in the ADE71xx/ADE75xx are stored in the EEPROM of the reference design. These values are also recorded on a sticker on each meter.

This section of the document describes how to install (if necessary) and use the LabVIEW software to obtain a calibrated reference meter.

DETERMINING THE ISOLATED COM PORT

To successfully communicate with the reference design, the PC COM port must be determined.

First, right click **My Computer** and select **Properties**.

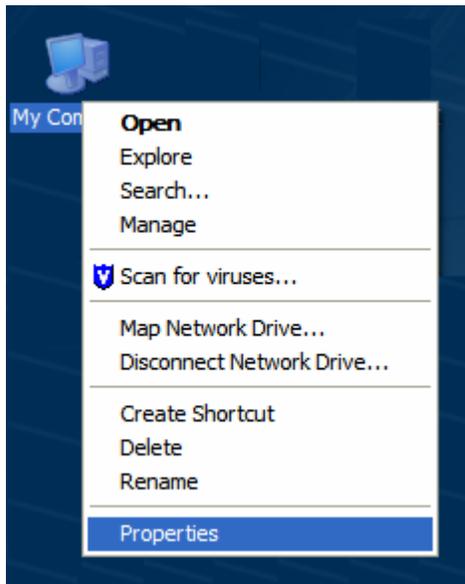


Figure 8. My Computer Properties

Then, select the **Hardware** tab and click the **Device Manager** button.

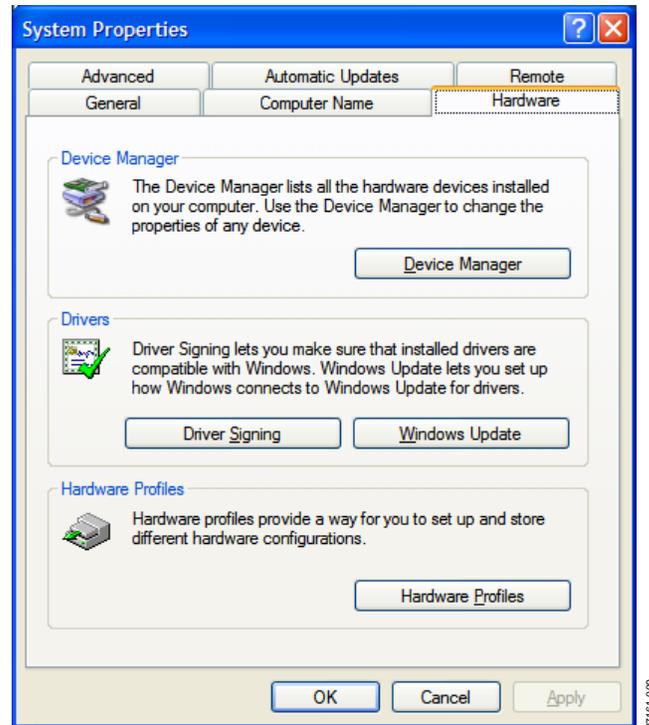


Figure 9. System Properties

The list of hardware devices is displayed. Click the + sign next to **Ports** and look for the port called **USB Serial Port with ISO**. Note the COM port number, as it is required when using the calibration software.

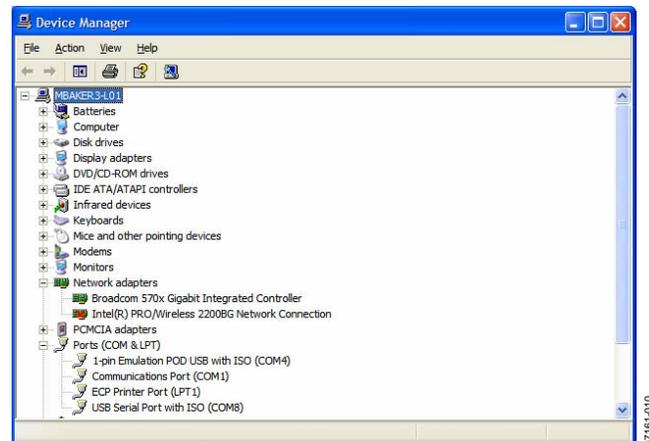


Figure 10. Device Manager

DOWNLOADING THE ADE71xx/ADE75xx REFERENCE DESIGN FIRMWARE

The reference design firmware should already be loaded into the Flash memory of the ADE71xx/ADE75xx. If this is the case, the LCD display blinks on and off every second. Once verified, proceed to the Calibration Software Start Screen section.

If the LCD display is not blinking, or if other code has been downloaded to the meter, redownload the reference design firmware by launching the **IAR Embedded Workbench** software and selecting **ADE7169_ref_design Project**. Configure the Analog Devices debugger to use the COM port found in the previous section with a baud rate of 57,600 and handshaking at 9600 baud. Then, put the ADE71xx/ADE75xx into serial download mode by holding down the SDEN button and pressing and releasing the reset button on the reference design. Download the code by clicking the magnifying glass. Stop the IAR tools by clicking the magnifying glass a second time. Press the reset button on the reference design to restart the firmware.

ADE71xx/ADE75xx REFERENCE DESIGN CALIBRATION CONSTANTS IN EEPROM

Table 1 lists the EEPROM addresses of the nonvolatile memory manipulated by the calibration software. This includes all of the ADE energy metering calibration constants as well as some constants used by the firmware, and the kilowatt-hour total. The data is stored in little-endian format, with less significant data at lower addresses.

Table 1. EEPROM Calibration Constants

Constant	EEPROM Address	# of Bytes
Kilowatt-Hour Total	0x00	5
Current Date (Weekday, Day of the Month, Month, Year)	0x17	4
PHCAL	0x3A	1
GAIN	0x3C	1
WGAIN	0x41	2
WATTOS	0x4A	2
IRMSOS	0x50	2
VRMSOS	0x53	2
CF1DEN	0x56	2
RTCCOMP	0x5C	1
I Constant	0x60	2
V Constant	0x63	2

If the reference design is going to be adapted or expanded, the EEPROM locations outlined in Table 1 should be reserved to prevent malfunction of the energy metering and calibration routines.

CALIBRATION SOFTWARE START SCREEN

Figure 11 shows the screen that appears when the ADE71xx/ADE75xx calibration software is launched.

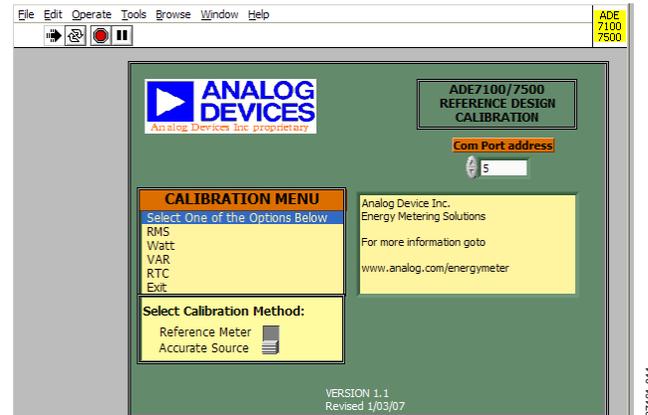


Figure 11. ADE71xx/ADE75xx Calibration Start Screen

To establish communication, enter the COM port number associated with the isolated serial port. The COM port number was previously identified in the Determining the Isolated COM Port section.

Next, select the calibration method as **Reference Meter** or **Accurate Source**, depending on your calibration setup. Select **Accurate Source** if the current and voltage source used is precisely calibrated. Otherwise, select **Reference Meter** if the energy meter calibration output is compared to a calibrated energy metering standard.

To begin calibration, select **Watt**, **VAR**, **RMS**, or **RTC** calibration from the calibration menu.

WATT CALIBRATION

Selecting watt calibration launches the screen shown in Figure 12. The tabs along the top allow you to select the aspects of the watt measurement that require calibration.

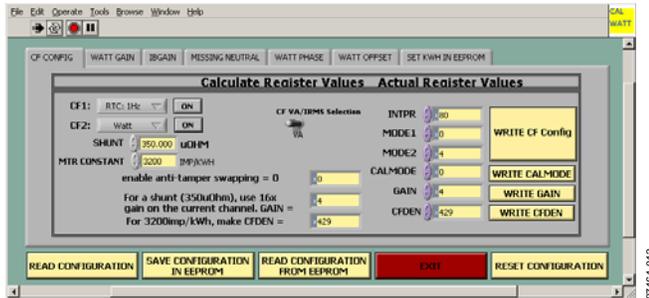


Figure 12. Watt Calibration Window

When the watt calibration is launched, a reset calibration command is performed. During the reset, the watt calibration registers WGAIN, PHCAL, and WATTOS are restored to power-on defaults. In addition, values specific to the ADE71xx/ADE75xx reference design are written to the CALMODE, GAIN, and CFDEN registers. See the CF Output Frequency section for more information on how these values are calculated.

To calibrate the watt measurement, the error in accumulated energy has to be determined by measuring the CF output. See the Active Energy Calibration section. To power the isolated CF output, apply an isolated 5 V or 3.3 V power supply to EXPWR and EXGND, Pin 1 and Pin 4 on the header P5, indicated by the arrow in Figure 13. Measure the isolated CF1 and CF2 on Pin 2 and Pin 3 of the header.

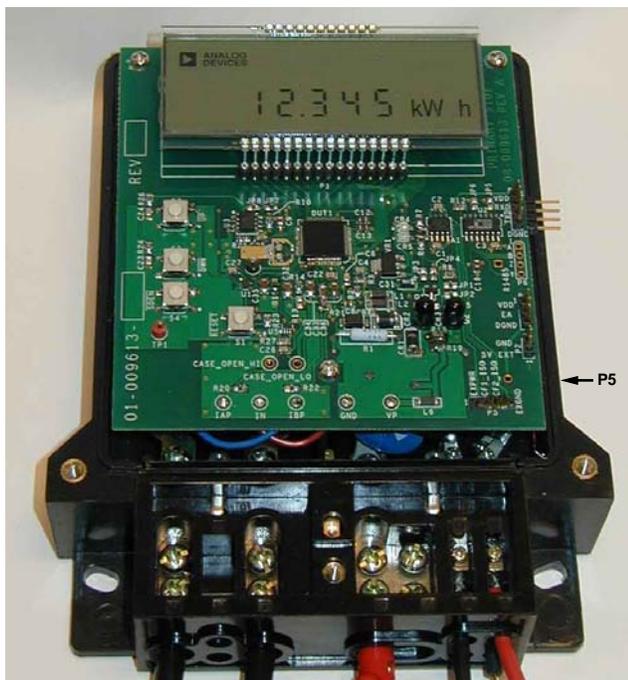


Figure 13. Reference Design with Isolated Terminal P5 Indicated by Arrow

Watt Gain Calibration

To calibrate the watt gain, select the **WATT GAIN** tab at the top of the watt calibration screen.

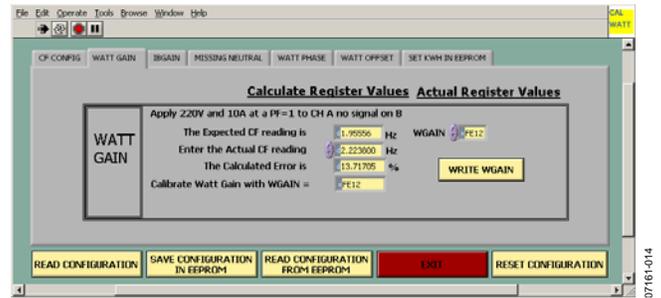


Figure 14. Watt Gain Calibration Window

To perform a watt gain calibration, apply 220 V and 10 A to the meter. Enter the actual CF reading into the box shown in Figure 14. Then enter the **Calibrate Watt Gain with WGAIN** value into the WGAIN box and click **WRITE WGAIN**. Verify that the new WGAIN value brings the measurement into the desired error range. If additional adjustment is required, modify the WGAIN value and click **Write WGAIN**.

Note that the **Calibrate Watt Gain with WGAIN** value is based on the default WGAIN setting. To retry the calibration, write WGAIN = 0x00 and then reenter the actual CF reading to obtain a new suggested WGAIN value.

Watt Phase Calibration

To calibrate the watt phase, select the **WATT PHASE** tab at the top of the watt calibration screen.

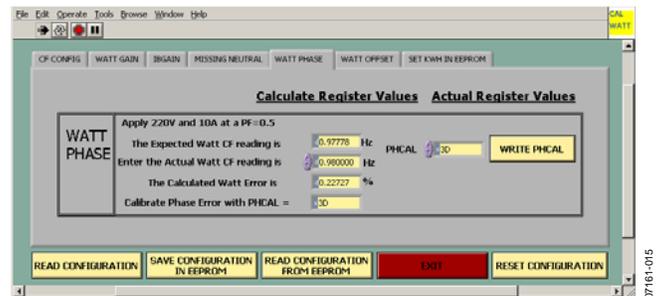


Figure 15. Watt Phase Calibration Window

To perform a phase calibration, apply 220 V and 10 A at a power factor of 0.5 inductive to the meter. Enter the actual watt CF reading into the box shown in Figure 15. Then enter the **Calibrate Phase Error with PHCAL** value into the PHCAL box and click **WRITE PHCAL**. Verify that the new PHCAL value brings the measurement into the desired error range. If additional adjustment is required, modify the PHCAL value and click **WRITE PHCAL**.

Note that the **Calibrate Phase Error with PHCAL** value is based on the default PHCAL setting. To retry the calibration, write PHCAL = 0x40 and then reenter the actual watt CF reading to obtain a new suggested PHCAL value.

Watt Offset Calibration

To calibrate the watt offset, select the **WATT OFFSET** tab at the top of the watt calibration screen.

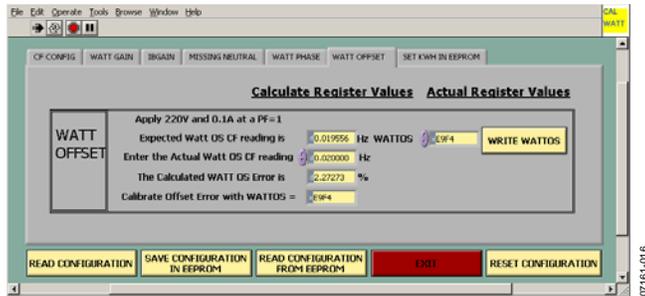


Figure 16. Watt Offset Calibration Window

To perform an offset calibration, apply 220 V and 0.1 A at a power factor of 1 to the meter. Enter the actual watt offset CF reading into the box shown in Figure 16. Then enter the **Calibrate Offset Error with WATTOS** value into the WATTOS box and click **WRITE WATTOS**. Verify that the new WATTOS value brings the measurement into the desired error range. If additional adjustment is required, modify the WATTOS value and click **WRITE WATTOS**.

Note that the **Calibrate Offset Error with WATTOS** value is based on the default WATTOS setting. To retry the calibration, write WATTOS = 0 and then reenter the actual CF reading to obtain a new suggested WATTOS value.

Saving the Watt Calibration

Once calibration of the watt is complete, it may be desirable to reset the internal energy counters and restart the accumulation from 0. If this is the case, click on the **SET KWH IN EEPROM** tab.

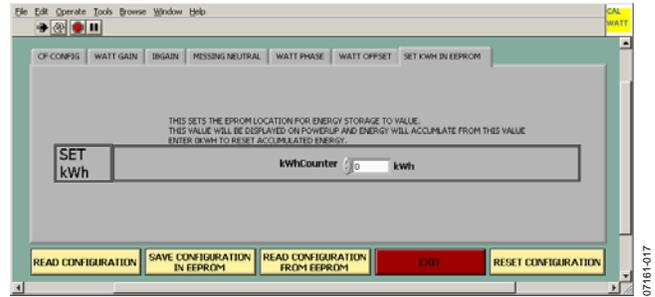


Figure 17. Set kWh Calibration Window

To change the kilowatt-hour total displayed on the LCD, write a value into the **kWhCounter** box shown in Figure 17. Then click **SAVE CONFIGURATION IN EEPROM** to update the values in the EEPROM with those in the WGAIN, PHCAL, and WATTOS boxes, as well as in the kWhCounter. Press the reset button on the ADE71xx/ADE75xx reference design to see the kWh total updated with the new value.

Click **READ CONFIGURATION FROM EEPROM** to update the WGAIN, PHCAL, and WATTOS registers with values from the EEPROM. Press the reset button on the reference design board to see the effect of the calibration. The kWh total should now be set to the user-defined default.

READ CONFIGURATION allows the user to read the current values in all the registers on the screen. **RESET CONFIGURATION** resets CALMODE, GAIN, and CFDEN to the suggested values and restores the watt calibration registers to their power-on defaults.

RMS CALIBRATION

Selecting rms calibration launches the screen shown in Figure 18.

To calibrate the rms measurements, current and voltage gain and offset coefficients should be determined, as described in the Current and Voltage RMS section.

VRMS and IRMS Gain Calibration

To perform an rms gain calibration, apply 220 V and 10 A to the meter. Then click the **READ VRMS** and **READ IRMS** buttons shown in Area 1 in Figure 18. Suggested V constant and I constant values will be calculated. Enter these values into the V constant and I constant boxes in Area 1 in Figure 18. Then click **SAVE CONFIGURATION IN EEPROM**.

Press the reset button on the reference design. Verify that VRMS and IRMS are displayed as 220 V and 10 A on the LCD. If additional adjustment is required, modify the V constant or I constant value and click **SAVE CONFIGURATION IN EEPROM**.

VRMS and IRMS Offset Calibration

To perform an rms offset calibration, apply 175 V and 0.1 A to the meter. Then click the **READ VRMS** and **READ IRMS** buttons in Area 2 in Figure 18. Suggested VRMSOS and IRMSOS values will be calculated. Enter these values into the VRMSOS and IRMSOS boxes in Area 2 in Figure 18. Then click the **WRITE VRMSOS** and **WRITE IRMSOS** buttons. Click **SAVE CONFIGURATION IN EEPROM**.

Press the reset button on the reference design. Verify that VRMS and IRMS are displayed as 175 V and 0.100 A on the LCD. If additional adjustment is required, modify the VRMSOS or IRMSOS value, click **WRITE VRMSOS** or **WRITE IRMSOS**, respectively and then click **SAVE CONFIGURATION IN EEPROM**.

Note that the **Calibrate VRMS Offset with VRMSOS** and **Calibrate IRMS Offset with IRMSOS** values are based on the default VRMSOS and IRMSOS settings. To retry the calibration, write VRMSOS and IRMSOS = 0x00 and then click **READ VRMS** and **READ IRMS** to get new suggested values.

Saving the RMS Calibration

Click **SAVE CONFIGURATION IN EEPROM** to update the values in the EEPROM with those in the V constant, I constant, VRMSOS, and IRMSOS boxes.

Click **READ CONFIGURATION FROM EEPROM** to update the V constant and I constant boxes and the VRMSOS and IRMSOS registers with values from the EEPROM. Press the reset button on the reference design board to see the effect of the calibration. The voltage and current RMS values should correspond to the voltage and current inputs, respectively.

READ CONFIGURATION allows the user to read the current values in all the registers on the screen. **RESET CALIBRATION** resets MODE2 to the suggested value and restores the rms calibration registers to their power on defaults.

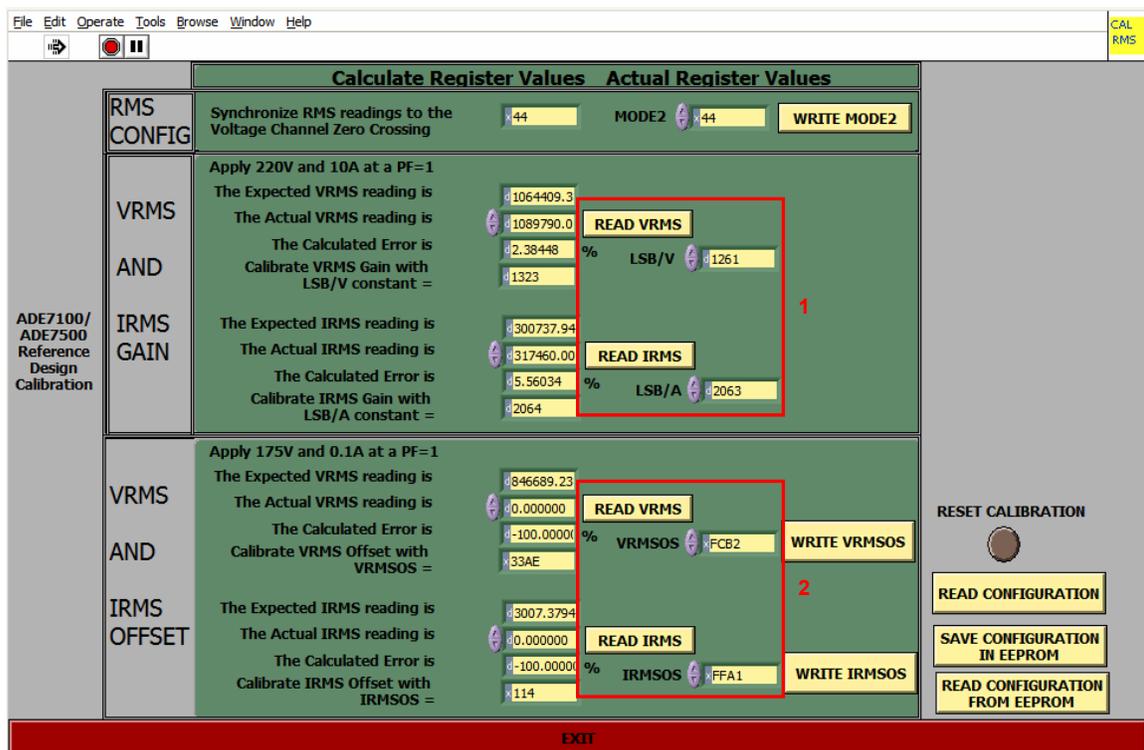


Figure 18. RMS Calibration Window

VAR CALIBRATION

Selecting VAR calibration launches the screen shown in Figure 19. The tabs along the top allow you to select the aspects of the VAR measurement that require calibration.

Similarly to the watt calibration, when the VAR calibration is launched, a reset calibration command is performed. During the reset, the VAR calibration registers VARGAIN and VAROS are restored to power-on defaults. In addition, values specific to the ADE71xx/ADE75xx reference design are written to the CALMODE, GAIN, and CFDEN registers. The CF2 output should be configured to output a pulse proportional to the reactive energy by selecting **VAR** from the CF2 pull-down menu.

Once again, the isolated CF output pulse is required for calibration; this output should be powered with an isolated supply (see Figure 13).

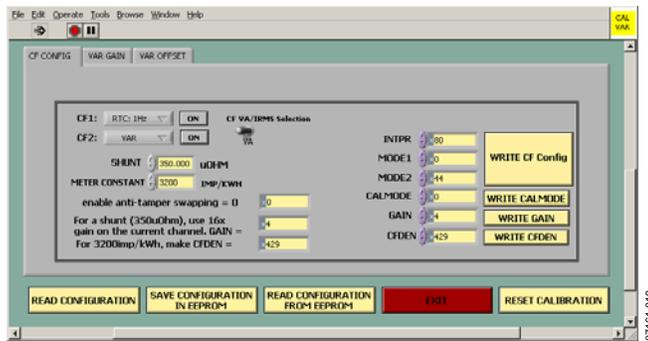


Figure 19. VAR Calibration Window

VAR Gain Calibration

To calibrate the VAR gain, select the **VAR GAIN** tab at the top of the VAR calibration screen.

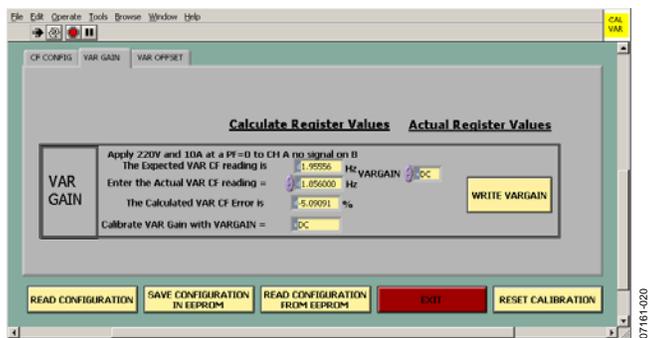


Figure 20. VAR Gain Calibration Window

To perform a VAR gain calibration, apply 220 V and 10 A at a power factor of 0 to the meter. Enter the actual CF reading into the appropriate box (see Figure 20). Then enter the appropriate value into the **Calibrate VAR Gain with VARGAIN** box and click **WRITE VARGAIN**. Verify that the new VARGAIN value brings the measurement into the desired error range. If addi-

tional adjustment is required, modify the VARGAIN value and click **WRITE VARGAIN**.

Once complete, click **SAVE CONFIGURATION IN EEPROM**.

Note that the **Calibrate VAR Gain with VARGAIN** value is based on the default VARGAIN setting. To retry the calibration, write VARGAIN = 0x00 and then reenter the actual CF reading to obtain a new suggested VARGAIN value.

VAR Offset Calibration

To calibrate the VAR phase, select the **VAR OFFSET** tab at the top of the VAR calibration screen.

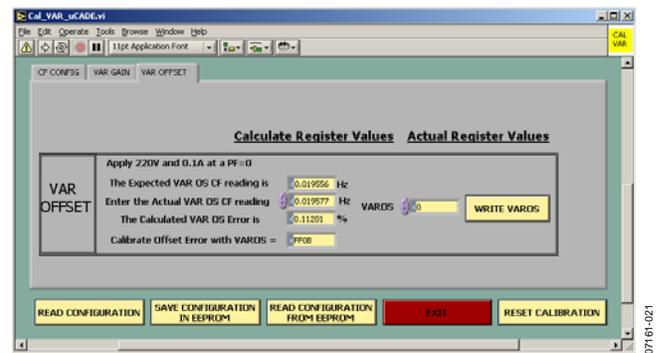


Figure 21. VAR Offset Calibration Window

To perform an offset calibration, apply 220 V and 0.1 A at a power factor of 0 to the meter. Enter the actual VAR offset CF reading into the appropriate box (see Figure 21). Then enter the appropriate value into the **Calibrate Offset Error with VAROS** box and click **WRITE VAROS**. Verify that the new VAROS value brings the measurement into the desired error range. If additional adjustment is required, modify the VAROS value and click **WRITE VAROS**.

Once complete, click **SAVE CONFIGURATION IN EEPROM**.

Note that the **Calibrate Offset Error with VAROS** value is based on the default VAROS setting. To retry the calibration, write VAROS = 0 and then reenter the actual CF reading to obtain a new suggested VAROS value.

Antitamper Calibration—ADE71xx Meters Only

When designing an antitamper meter, care should be taken to ensure that the input channels are configured correctly. Prior to performing offset calibration, the CALMODE register, accessible from the **CF CONFIG** tab, should be written to 0x10 to force the current input to Channel A. The CALMODE register should be set to autotamper (0x00) for all other calibration steps. Refer to the *Designing a Tamper-Proof Meter* section for further details on the setup.

I_B Gain Calibration

Before performing I_B gain calibration, the current channel input should be configured so that it is forced to Channel B. This can be achieved in the CF CONFIG tab by writing 0x20 to the CALMODE register. To calibrate the gain error on the second current channel, select the IBGAIN tab on the watt calibration screen.

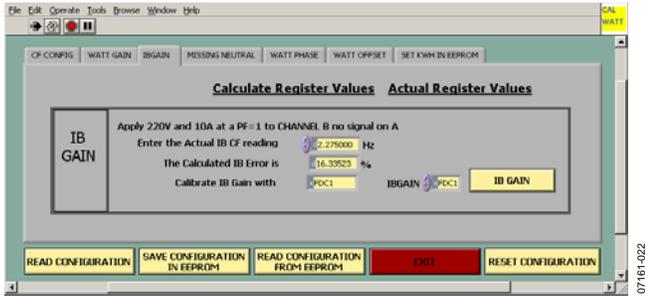


Figure 22. IBGAIN Calibration Window

To perform I_B gain calibration, apply 220 V and 10 A at a power factor of 1 to the meter. Enter the actual I_B CF reading into the box shown in Figure 22. Then enter the **Calibrate IB Gain with** value into the box and click **IB GAIN**. Verify that the new I_B gain value brings the measurement into the desired error range. If additional adjustment is required, modify the I_B gain value and click **IB GAIN**.

Note that the **Calibrate IB Gain** value is based on the default I_B gain setting. To retry the calibration, write **IBGAIN** = 0x00 and then reenter the actual I_B gain CF reading to obtain a new suggested I_B gain value.

After performing I_B gain calibration, the input configuration should be returned to autotamper mode by writing 0x00 to the CALMODE register.

Missing Neutral Calibration

To configure the meter to produce a calibrated CF output based on the IRMS reading in the case of a missing neutral condition, select the MISSING NEUTRAL tab. Missing neutral calibration should be performed after the IRMS has been calibrated.

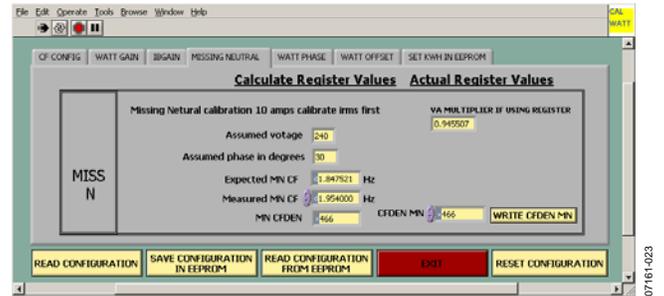


Figure 23. Missing Neutral Calibration Window

To perform missing neutral calibration, apply 10 A with an assumed voltage of 240 V at a power factor of 0.866 inductive. Enter the measured MN CF reading into the appropriate box (see Figure 23). Enter the MN CFDEN value into the appropriate box and click **WRITE CFDEN MN**. Verify that the new CFDEN value brings the measurement into the desired error range. If additional adjustment is required, modify the CFDEN value and click **WRITE CFDEN MN**.

RTC CALIBRATION

The theory behind the RTC calibration procedure is described in detail in AN-949, *Compensating the ADE71xx/ADE75xx Family RTC for Accurate Timekeeping*. Note that the software allows the nominal crystal frequency to be calibrated; it does not perform the calibration over temperature.

Selecting RTC calibration launches the window shown in Figure 24.

RTC calibration involves determining the error in the 32.768 kHz crystal input by measuring a 1 Hz output generated from this clock and the output on CF2.

Apply an isolated 5 V or 3.3 V power supply to EXPWR and EXGND, Pin 1 and Pin 4 on the header P5, indicated by the arrow on a picture of the reference design in Figure 13. Measure the isolated CF1 and CF2 on Pin 2 and Pin 3 of the header.

Compensating for the Crystal Frequency

Enter the actual frequency on the CF2 pin into the **The Actual CF2 frequency is** box in Figure 24.

Then enter the suggested RTCCOMP value into the **RTCCOMP** box in Figure 24. Click **WRITE RTCCOMP** to see the effect of the correction. The frequency on CF2, averaged over a 30.5 second window, should now be $1 \text{ Hz} \pm 2 \text{ ppm}$.

Setting the Date and Time

Click the **WRITE RTC WITH PC TIME** button to write the RTC hundredths, seconds, minutes, and hours timekeeping registers with the PC time. Clicking this button also saves the date into the EEPROM.

Saving the RTC Calibration

Click **SAVE CONFIGURATION IN EEPROM** to update the value in the EEPROM with that in the **RTCCOMP** box.

Click **READ CONFIGURATION FROM EEPROM** to update the **RTCCOMP** register with the value from the EEPROM. Press the reset button on the reference design board to see the effect of the calibration: the time and date should now be displayed properly on the LCD.

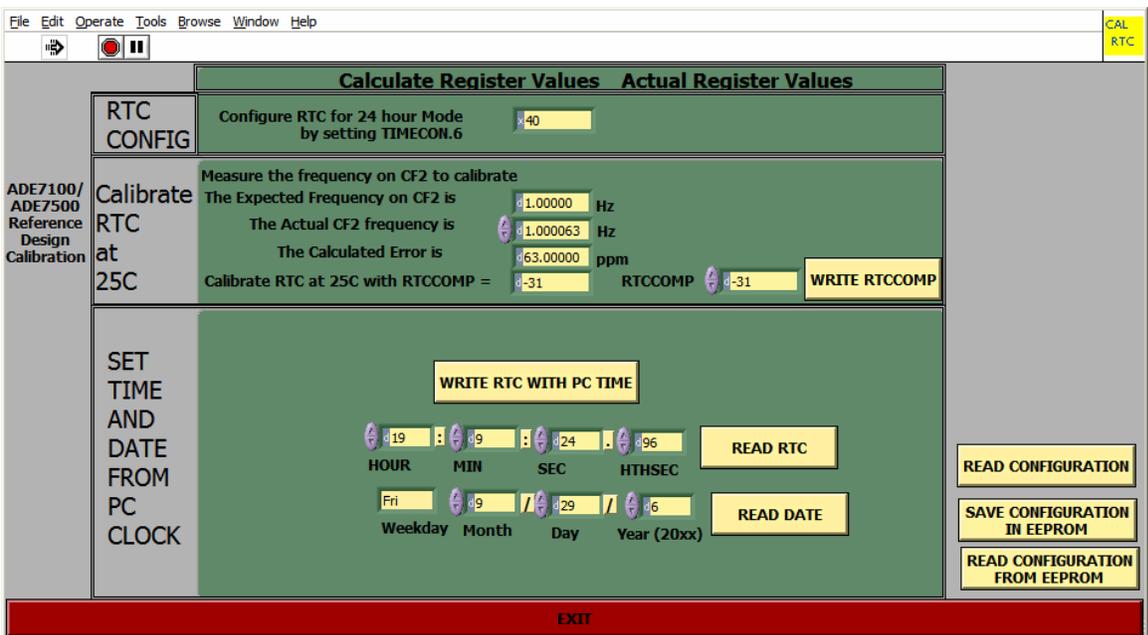


Figure 24. RTC Calibration Window

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