

Calibrating the **ADE7978** and **ADE7932/ADE7933** Isolated Metering Chipset

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INTRODUCTION

A 3-phase energy meter built around the **ADE7978** and **ADE7932/ADE7933** isolated metering chipset has the basic structure shown in Figure 1. One single 3.3 V supply is required to power the chipset. The Phase A, Phase B, and Phase C **ADE7932/ADE7933** isolated ADCs sense the phase currents using shunts and the phase to neutral voltages using resistor dividers.

The neutral line **ADE7932/ADE7933** senses the neutral line using a shunt and measures the neutral to earth voltage using a resistor divider. This is optional; not all three phase meters have to monitor the neutral line and the neutral to earth voltages.

A microcontroller manages the **ADE7978** using I²C or SPI communications. This application note explains the process of calibrating this meter. Although the configuration of this meter is 3-phase, 4-wire, the calibration flow does not change if other configurations are used.

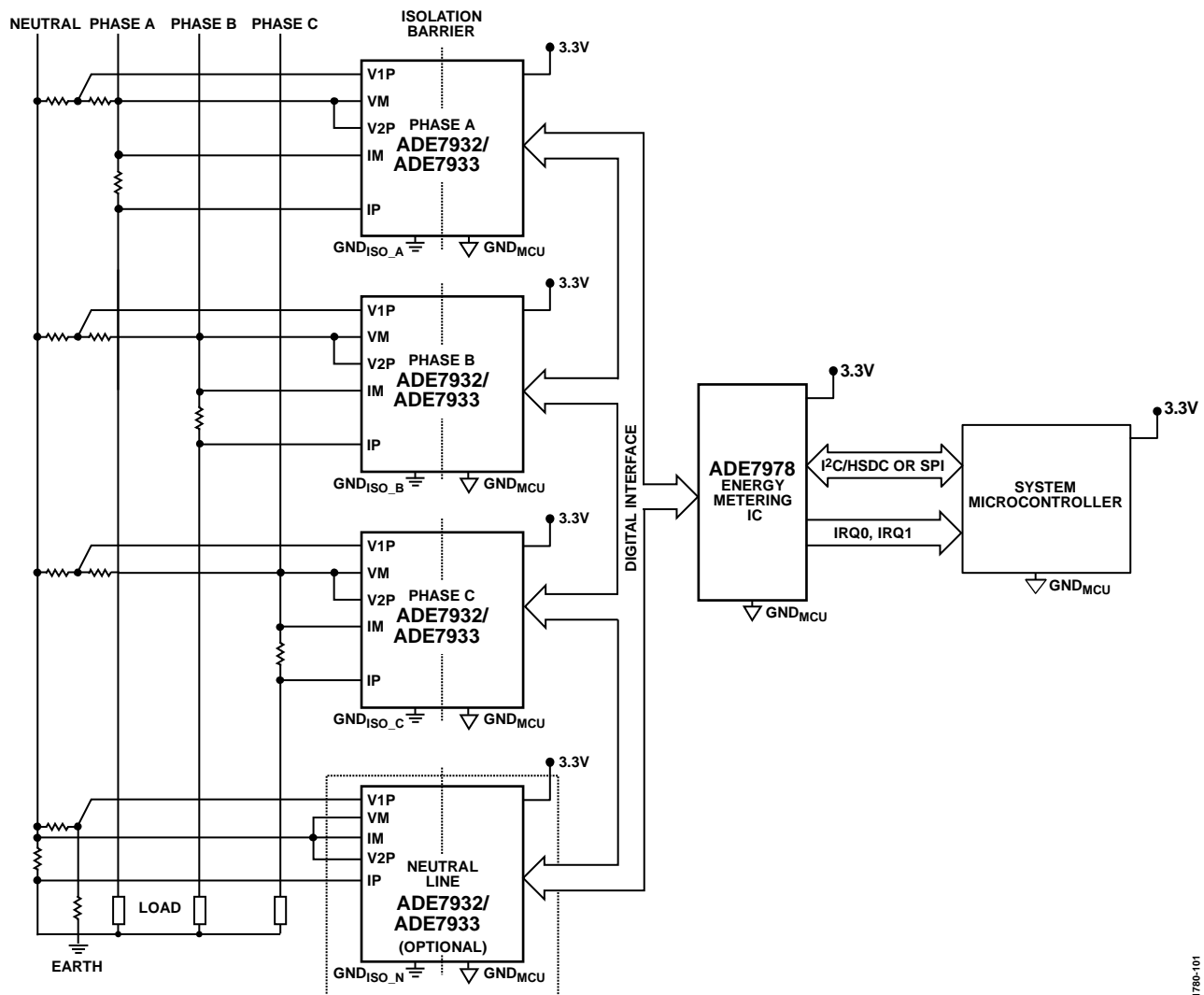


Figure 1. Three-Phase Energy Meter with Shunts Built Using the **ADE7978** and **ADE7932/ADE7933** Chipset

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REVISION HISTORY

11/13—Revision 0: Initial Version

CALIBRATION BASICS

To obtain accurate readings that do not reflect meter-to-meter variations in external components or the internal voltage reference, the [ADE7978](#) and [ADE7932/ADE7933](#) isolated metering chipset requires calibration. Calibration is required on every meter; however, it is a simple process that can be performed quickly.

CALIBRATION STEPS

When designing a meter using the [ADE7978](#) and [ADE7932/ADE7933](#) isolated metering chipset, a maximum of three calibration stages are required: gain, phase, and offset. Depending on the external configuration and meter class, one or more of these stages can be omitted. Table 1 provides guidance on which calibration steps are typically required for a particular configuration. Because the requirements and performance can differ on a design-by-design basis, use Table 1 only as a general guideline. The performance of the meter should be evaluated to determine whether any additional calibration steps are required.

CALIBRATION METHOD (CF OUTPUT OR REGISTERS)

The [ADE7978](#) and [ADE7932/ADE7933](#) isolated metering chipset can be calibrated by either reading the internal energy registers or measuring the external calibration frequency (CF)

output pulse. The relationship between these two measurements is shown in Figure 2.

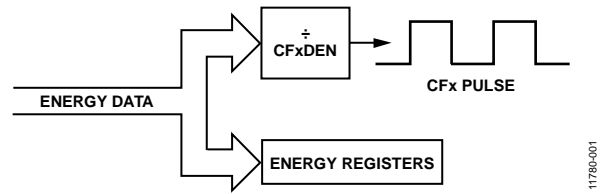


Figure 2. Accessing Energy Data

As shown in Figure 2, the energy register data and CFx output data are related by a factor of the CFxDEN register.

$$CFxOutput (Hz) = 1/CFxDEN \times Energy Register (Update Rate)$$

The decision of whether to calibrate using the CF or energy register depends on both the application and available calibration equipment (see the Calibration Setups section).

If the meter specification requires calibration to a particular meter constant, the CF output pin is typically used. If the CF output pin is not being used and no meter constant is specified by design, the register may be a more convenient method. Calibrating the energy registers result in accurate readings on the CF output pin and vice versa. Both methods result in the same level of accuracy.

Table 1. Typical Calibration Steps

Calibration Stage	Typical Requirement
Gain Calibration	It is always required.
Phase Calibration	It is not usually required because the shunts do not introduce any phase delay.
Offset Calibration	It is not usually required for meter designs. When looking for high accuracy over a large dynamic range, it is often required.

CALIBRATION SETUPS

Two calibration setups can be used to calibrate the [ADE7978](#) and [ADE7932/ADE7933](#) isolated metering chipset: a reference meter or an accurate source. When using a reference meter, the CF output method of calibrating must be used. When using an accurate source, either the CF output or energy register can be used. For additional information on the two calibration setups, see the Reference Meter section and the Accurate Source section.

Reference Meter

The most popular method of calibration uses an external reference meter to determine the required compensation. If using reference metering, the CF output must be used because the reference meter determines the error based on the CF pulse (see Figure 3). The reference meter should be more accurate than the desired specifications of the resulting meter.

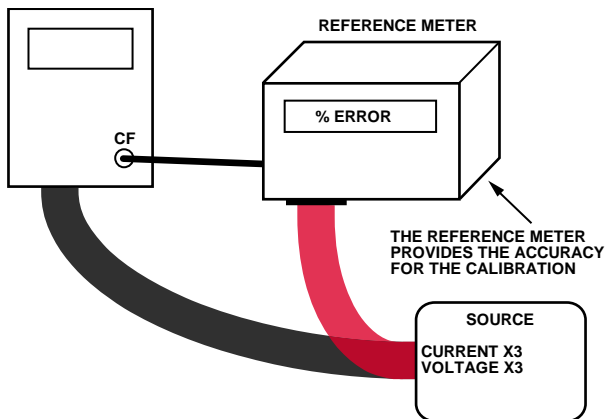


Figure 3. Reference Meter Configuration

When using a reference meter, a source is required to provide the required inputs to the meter; however, the accuracy of the source is not as critical because the reference meter determines the calibration result. Typically, reference meters are more cost effective than accurate sources; therefore, this is the most popular calibration method.

Accurate Source

The second calibration method is to use an accurate source to perform the calibration. If using an accurate source, either the CF output or the energy registers can be used to access the energy data. The accurate source must be able to provide a controllable voltage and current input with higher accuracy than that required in the resulting meter. Figure 4 shows a typical setup using an accurate source.

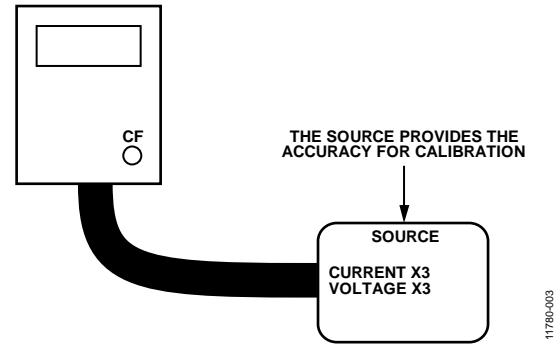


Figure 4. Accurate Source

An accurate source is typically more expensive than a reference meter and is, therefore, a less popular method of calibration.

CALIBRATION INPUTS

As shown in Table 1, a maximum of three calibration steps are required. Each calibration step requires a separate measurement to be taken and calculation to be performed. To allow the separate gain, phase, and offset errors to be extracted, three separate sets of input conditions are typically required. These are shown in Table 2.

Table 2. Typical Input Conditions

Calibration Step	Voltage Input	Current Input	Power Factor
Phase	Nominal	Nominal	0.5
Gain	Nominal	Nominal	1
Offset	Nominal	Minimum	1

The nominal voltage, V_n , is typically 110 V or 220 V.

The nominal current, I_n , is typically around 10 A, ten times lower than the maximum current, I_{max} , considered at 100 A.

The minimum current, I_{min} , is the minimum current specified in the meter while staying within the specification of the measurement for the [ADE7978](#) and [ADE7932/ADE7933](#) isolated metering chipset, such as 100 mA.

The chipset uses shunts to sense the currents. The shunts do not introduce any phase delay. Only the antialiasing filter in the current measurement hardware path introduces a small delay. However, because the same antialiasing filter is also used in the voltage measurement hardware path, no phase delay is introduced between the currents and voltage measurements. Thus, the phase calibration is not usually necessary when the [ADE7978](#) and [ADE7932/ADE7933](#) isolated metering chipset is used.

The gain calibration is performed at a power factor of 1.

If the phase calibration is still desired, then it is better to do it together with the gain calibration at a power factor of 0.5. This allows one single calibration point to be used for both the gain and phase calibration.

Table 3 shows the modified calibration conditions if the phase calibration is deemed necessary.

Table 3. Modified Input Conditions

Calibration Step	Voltage Input	Current Input	Power Factor
Phase	Nominal	Nominal	0.5
Gain	Nominal	Nominal	0.5
Offset	Nominal	Minimum	1

When using the input conditions shown in Table 3, it is important that the power factor used is as close to 0.5 as possible and that it is not varying. Note that an inductive or capacitive load can be used. This application note provides example calculations with the modified input conditions shown in Table 3.

Table 4. Default Registers Required Prior to Calibration

Register Address	Register Name	Register Description	Suggested Value	Comment
0xEA02	WTHR	Threshold used in phase total/fundamental active energy data path.	0x03	See the ADE7978/ADE7933/ADE7932 data sheet for details on modifying this constant.
0xEA03	VARTHR	Threshold used in phase total/fundamental reactive energy data path.	0x03	See the ADE7978/ADE7933/ADE7932 data sheet for details on modifying this constant.
0xEA04	VATHR	Threshold used in phase apparent energy data path.	0x03	See the ADE7978/ADE7933/ADE7932 data sheet for details on modifying this constant.
0x43A2	VLEVEL	Register used in the algorithm that computes the fundamental active and reactive powers.	0x58604A	See the ADE7978/ADE7933/ADE7932 data sheet for details on modifying this constant. Required for fundamental only readings. See the related note and equations in the Required Register Settings section.
0xE60E	COMPMODE, Bit 14 (SELFREQ)	50 Hz or 60 Hz selection for fundamental only measurement.	50 Hz 0 60 Hz 1	Required for fundamental active and reactive powers readings.

REQUIRED REGISTER SETTINGS

Prior to calibrating the [ADE7978](#) and [ADE7932/ADE7933](#) isolated metering chipset, it is important that a set of registers are configured. These registers are listed in Table 4. Refer to the [ADE7978/ADE7933/ADE7932](#) data sheet for details on these registers.

Note that regarding the VLEVEL default value, The [ADE7978/ADE7933/ADE7932](#) data sheet recommends using the following equation:

$$VLEVEL = \frac{V_{FS}}{V_n} \times 4 \times 10^6$$

For the [EVAL-ADE7978EBZ](#) evaluation board, $V_{FS} = 318.55$ V and $V_n = 220$ V, thus $VLEVEL = 5791818 = 0x58604A$.

CALIBRATING USING THE CF PULSE OUTPUT

When calibrating using the pulse output, the CFx pin must be configured to output the measurement and the channel that is being calibrated. For example, when calibrating active energy on Channel A, configure CF1, CF2, or CF3 to be proportional to the total active power on Channel A. This is achieved by setting Bit 0 through Bit 8 of the CFMODE register (Address 0xE610) as well as Bit 0 through Bit 8 of the COMPMODE register (Address 0xE60E). Any of the CF1, CF2, or CF3 pins can be used.

For faster calibration, multiple different measurements or channels can be output on CF1, CF2, and CF3, simultaneously, with up to three calibrations performed in parallel. This allows all three phases to be calibrated simultaneously.

Figure 5 shows the calibration flow for the energy measurement. Use this flow to determine a calibration routine.

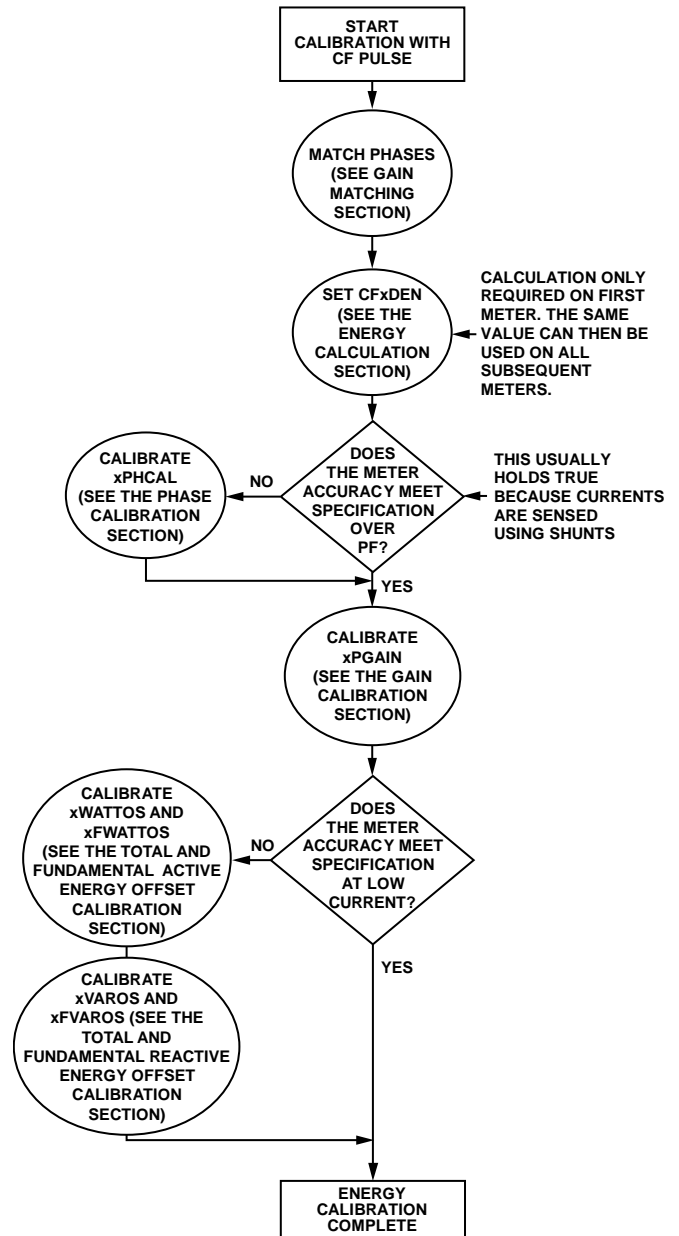


Figure 5. Energy Calibration Flow using CF Pulse Output

GAIN MATCHING

Table 5. xGAIN Registers for Gain Matching

Calibration Registers	Address
AIGAIN	0x4380
BIGAIN	0x4383
CIGAIN	0x4386
NIGAIN	0x4389
AVGAIN	0x4381
AV2GAIN (when ADE7933 is used)	0x4382
BVGAIN	0x4384
BV2GAIN (when ADE7933 is used)	0x4385
CVGAIN	0x4387
CV2GAIN (when ADE7933 is used)	0x4388
NVGAIN	0x438A
NV2GAIN (when ADE7933 is used)	0x438B

It is convenient to match all three phases prior to calibrating. Matching the phases results in easier computations because one pulse on the CF output has the same weight on each phase. It is recommended that phase matching be performed as the first calibration step.

To match phase current B, phase current C, and neutral current N to phase current A, apply the same fixed input current to all phase currents. Because the meter has not yet been calibrated, it is recommended that the amplitude of the applied signal be between full scale and 100:1. Usually, supplying the nominal current fulfills this condition. The current rms reading can then be used to determine if there is any error between the phase currents. This error can then be corrected using the BIGAIN register (Address 0x4383), the CIGAIN register (Address 0x4386), and the NIGAIN register (Address 0x4389).

The following equations describe how to adjust the BIRMS, CIRMS, and NIRMS readings to match those in AIRMS using the BIGAIN register, CIGAIN register, and NIGAIN register.

$$AIGAIN = 0x000000$$

$$BIGAIN = \frac{AIRMS}{BIRMS} - 1$$

$$CIGAIN = \frac{AIRMS}{CIRMS} - 1$$

$$NIGAIN = \frac{AIRMS}{NIRMS} - 1$$

The results are positive or negative fractional numbers. The actual values that are written into the BIGAIN and CIGAIN registers are the hexadecimal representations. In this section, all calibration registers are positive or negative fractional numbers, so the same rule is in effect. See the Computing the Hexadecimal Representation of a Signed Fractional Number section for details on how to compute the hexadecimal representations.

It is recommended to acquire the xIRMS measurements to ensure the stability of the results (x = A, B, C, or N) as follows:

- Read xIRMS rms registers at least once per line cycle over 1 sec.
- Average the readings to obtain the rms value.

The same procedure can then be used on the voltage channels to match the xVRMS and xV2RMS (when ADE7933 is used) readings. The voltage channels gain registers AV2GAIN (Address 0x4382), BVGAIN (Address 0x4384), BV2GAIN (Address 0x4385), CVGAIN (Address 0x4387), CV2GAIN (Address 0x4388), NVGAIN (Address 0x438A), and NV2GAIN (Address 0x438B) can be used to match the AV2RMS, BVRMS, BV2RMS, CVRMS, CV2RMS, NVRMS, and NV2RMS to the AVRMS measurement, respectively.

$$AVGAIN = 0x000000$$

$$AV2GAIN = \frac{AVRMS}{AV2RMS} - 1$$

$$BVGAIN = \frac{AVRMS}{BVRMS} - 1$$

$$BV2GAIN = \frac{AVRMS}{BV2RMS} - 1$$

$$CVGAIN = \frac{AVRMS}{CVRMS} - 1$$

$$CV2GAIN = \frac{AVRMS}{CV2RMS} - 1$$

$$NVGAIN = \frac{AVRMS}{NVRMS} - 1$$

$$NV2GAIN = \frac{AVRMS}{NV2RMS} - 1$$

Once this step is complete, all phase currents and all voltages will have the same weight.

ENERGY CALIBRATION

Table 6. CFxDEN Registers for Energy Calibration

Calibration Registers	Address
CF1DEN	0xE611
CF2DEN	0xE612
CF3DEN	0xE613

The CFx pulse output can be configured so that each pulse represents a fraction of a kilowatt hour (kWh). This relationship is known as the meter constant. Typically, design specifications require a particular meter constant to allow the utility to verify the accuracy of meters from multiple manufacturers. Typical meter constants are 1600 imp/kWh, 3200 imp/kWh, and 6400 imp/kWh. If designing a meter that does not require a specific meter constant, an arbitrary value can be chosen.

The CFx output is configured using the divider, CFxDEN ($x = 1, 2, \text{ or } 3$). This divider is calculated based on the meter constant and the nominal scaling on the current and voltage channels.

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

With a load of 220 V and 10 A at a power factor of 0.5, the CFx output frequency is calculated as follows:

$$CF_{EXPECTED} = \frac{\text{Meter Constant (imp/kWh)} \times \text{Load (kV)}}{3600 \text{ s/h}}$$

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

$$= 0.97778 \text{ Hz}$$

Select the CFxDEN to obtain a frequency of 0.97778 Hz under the given load conditions. This can be done by determining the scale on the input pins.

Figure 6 shows the voltage channel input network used on the EVAL-ADE7978EBZ evaluation board.

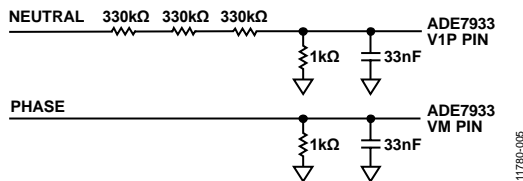


Figure 6. Voltage Channel Inputs

$$V_p = V_{INPUT_MAX} \times \frac{1 \text{ k}\Omega}{(990 + 1) \text{ k}\Omega} =$$

$$(220 \text{ V} \times \sqrt{2}) \times \frac{1}{991} = 314 \text{ mV}$$

$$V_{AS\%OF\ FULLSCALE} = \frac{0.314}{0.5} \times 100 = 62.8\%$$

With a voltage channel amplitude of 220 V rms, the input is operating at 62.8% of full scale. Figure 7 shows the current channel configuration.

Assuming a targeted full-scale current of 120 A, 20% greater than the maximum current $I_{max}=100 \text{ A}$, a shunt of

$$R_s = \frac{31.25 \times 10^{-3}}{\sqrt{2}} \times \frac{1}{120} \cong 180 \mu\Omega$$

must be used to sense the phase currents. This means I_n , the nominal current of 10 A, operates at 8.15% of full scale.

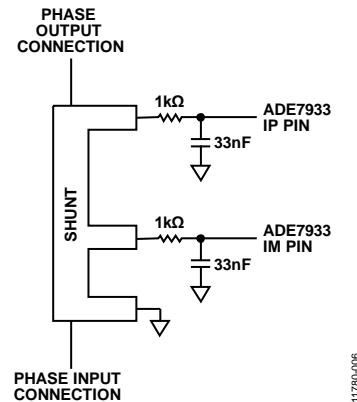


Figure 7. Current Channel Inputs

$$V_{ACROSS\ SHUNT} = 10 \times \sqrt{2} \times 180 \times 10^{-6} = 2.546 \text{ mV}$$

$$I_{AS\%OF\ FULLSCALE} = \frac{2.546 \times 10^{-3}}{31.25 \times 10^{-3}} \times 100 = 8.15\%$$

From the ADE7978/ADE7933/ADE7932 data sheet, the maximum CFx output with full-scale analog inputs is 68.8 kHz assuming WTHR = 3.

When a PF of 0.5 is applied, this reduces to 34.4 kHz. To obtain 0.9778 Hz with the given 220 V, 10 A, PF = 0.5 input, the CF denominator should be set to 0x709, as shown:

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

$$CFxDEN = \frac{34.4 \text{ kHz} \times 62.8 \times 10^{-2} \times 8.15 \times 10^{-2}}{0.97778 \text{ Hz}} = 1801 = 0x709$$

Remember, writing 0x709 to the CFxDEN register sets the CF output to around 0.97778 Hz for the conditions previously described. This CFxDEN setting can now be used on every meter. The gain calibration provides a finer resolution calibration that should be done on every meter to ensure that the 0.97778 Hz is precisely met.

PHASE CALIBRATION (OPTIONAL)

Note that because the ADE7932/ADE7933 uses shunts to sense the phase currents, there is usually no need to execute the phase calibration. The procedure is presented here as a reference for those instances where it is still necessary. Table 7 presents the registers that are used to calibrate the phase.

Table 7. xPHCAL Registers for Phase Calibration

Calibration Registers	Address
APHCAL	0xE614
BPHCAL	0xE615
CPHCAL	0xE616

The phase calibration is ideally performed with an inductive or capacitive load at a power factor of 0.5. If this load is not available, another power factor can be chosen. For best results, the power factor should be as close to 0.5 as possible. To perform phase calibration in one step with one reading, the active and reactive powers must be measured simultaneously. The following equation outlines how to determine the phase error in degrees:

$$Error(^{\circ}) = -\tan^{-1}\left(\frac{CF_{Active} \times \sin(\phi) - CF_{Reactive} \times \cos(\phi)}{CF_{Active} \times \cos(\phi) + CF_{Reactive} \times \sin(\phi)}\right)$$

where:

ϕ refers to the angle between the voltage and the current (in degrees).

Once the error in degrees is determined, the following formula can be used to determine the required phase compensation:

$$PhaseResolution = \left(\frac{360^{\circ} \times f}{1.024 \text{ MHz}}\right)$$

$$PhaseCompensation = abs\left(\frac{Error(^{\circ})}{PhaseResolution}\right)$$

where:

f refers to the line frequency.

Note that the format of the APHCAL register is such that if the value of the Error(degrees) is positive, then a value of 512d must be added to the calculated PhaseCompensation prior to writing to the APHCAL register.

$$APHCAL = \begin{cases} Error(^{\circ}) \leq 0, \Rightarrow APHCAL = PhaseCompensation \\ Error(^{\circ}) > 0, \Rightarrow APHCAL = PhaseCompensation + 512 \end{cases}$$

For example, at 220 V and 10 A at a power factor of 0.5, if the total active power CFx output frequency is 0.9709 Hz and the total reactive power CFx output frequency is 1.7347 Hz:

$$Error(^{\circ}) = -\tan^{-1}\left(\frac{0.9709 \times \sin(60) - 1.7347 \times \cos(60)}{0.9709 \times \cos(60) + 1.7347 \times \sin(60)}\right) = -0.76^{\circ}$$

Assuming that the line frequency is 50 Hz, the APHCAL compensation can be determined as

$$PhaseCompensation =$$

$$abs\left[\left(\frac{0.76}{360^{\circ} \times 50}\right) \times 1.024 \text{ MHz}\right] = 43 = 0x2B$$

$$APHCAL = PhaseCompensation = 43 = 0x2B$$

GAIN CALIBRATION

Table 8 presents the registers that are used to calibrate the gain of the energies.

Table 8. xPGAIN Registers for Gain Calibration

Calibration Registers	Address
APGAIN	0x4399
BPGAIN	0x439A
CPGAIN	0x439B

The purpose of the energy gain calibration is to compensate for small gain errors due to part-to-part variation in the internal and external components:

- ADE7933 ADC gain
- Shunt value
- Voltage divider value
- ADE7978 crystal frequency error

Gain calibration is required on every meter and is performed with nominal voltage and current inputs at a power factor of 0.5. The total and fundamental active and reactive powers as well as the apparent power are internally gain matched. One single gain calibration step is therefore required to calibrate all powers on a single phase.

This section describes calibrating the gain using the total active energy; however, any of the other energy values can be output on the CFx output for calibration.

As discussed in the Energy Calibration section, the expected CF output is determined from the meter constant. The actual CF output is measured and the APGAIN register is used to adjust any error. The following formula describes this relationship:

$$APGAIN = \frac{CF_{EXPECTED}}{CF_{ACTUAL}} - 1$$

Using the previous example, at 220 V and 10 A, the expected CF is 0.97778 Hz. Assuming the CF actually measured is 0.9937 Hz, the APGAIN is calculated as

$$APGAIN = \frac{0.97778}{0.9937} - 1 = -0.016$$

In hexadecimal, APGAIN = 0xFDF3B6. See the Computing the Hexadecimal Representation of a Signed Fractional Number section for details on converting a fractional number into a hexadecimal number.

The BPGAIN and CPGAIN registers control the gain calibration for Phase B and Phase C, respectively. Assuming that the channels are correctly matched, as described in the Gain Matching

section, the previous procedure does not need to be repeated for Phase B or Phase C. Write the value calculated for APGAIN to BPGAIN and CPGAIN for accurate results. The total and fundamental reactive energies and the apparent energy are also effected by the xPGAIN calibration. Since all power calculations are internally gain matched, setting the xPGAIN registers will gain calibrate all energy measurements.

TOTAL AND FUNDAMENTAL ACTIVE ENERGY OFFSET CALIBRATION (OPTIONAL)

Table 9 presents the ADE7978 registers that are used to calibrate the total and fundamental active energy registers.

Table 9. xWATTOS Registers for Active Energy Offset Calibration

Calibration Registers	Address
AWATTOS	0x439C
BWATTOS	0x439D
CWATTOS	0x439E
AFWATTOS	0x43A3
BFWATTOS	0x43A4
CFWATTOS	0x43A5

Active energy offset calibration is only required if accuracy at low loads is outside the required specification prior to offset calibration.

To correct for any voltage-to-current channel crosstalk that may degrade the accuracy of the measurements at low current levels, perform an active energy offset calibration. Apply the minimum expected current signal to allow the offset magnitude to be measured and then removed. Do not perform offset calibration with grounded inputs because a low level signal is necessary to accurately measure the offset.

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 CFx output frequency is determined as

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

$$= 0.0195556 \text{ Hz}$$

If the actual CF frequency is 0.01947 Hz, the percentage error due to offset is determined as

$$\%Error = \frac{0.01947 - 0.0195556}{0.0195556} = -0.4377\%$$

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

$$AWATTOS = -\%Error \times CF_{EXPECTED} \times CFxDEN \times \frac{Threshold}{1.024 \text{ MHz}}$$

where *Threshold* is made up of the value in the 8-bit WTHR register joined to an internal 27 bits equal to 0.

If the WTHR is set to the default value of 3h, the threshold value would, therefore, be $3 \times 2^{27} = 402653184 = 0x18000000$.

$$AWATTOS = 0.004377 \times 0.0195556 \times 1801 \times \frac{402653184}{1024000} = 61 = 0x3D$$

The AFWATTOS register effects the fundamental only active energy offset in the same way as the AWATTOS register effects the total active energy offset. Typically, the same value that is calculated for the AWATTOS can be written to the AFWATTOS for accurate calculations.

Depending on the board layout and the crosstalk on the meter design, Phase B and Phase C may need separate offset calibration. This can be achieved through the BWATTOS and BFWATTOS registers for Phase B, and the CWATTOS and CFWATTOS registers for Phase C.

TOTAL AND FUNDAMENTAL REACTIVE ENERGY OFFSET CALIBRATION (OPTIONAL)

Typically, the value calculated for the xWATTOS register can be used in the xVAROS register for accurate results.

Table 10. xFVAROS Registers for Reactive Energy Offset Calibration

Calibration Registers	Address
AVAROS	0x439F
BVAROS	0x43A0
CVAROS	0x43A1
AFVAROS	0x43A6
BFVAROS	0x43A7
CFVAROS	0x43A8

Reactive energy offset calibration is only required if accuracy at low loads is outside the required specification prior to offset calibration.

To correct for any voltage-to-current channel crosstalk that may degrade the accuracy of the measurements at low current levels, perform a reactive energy offset calibration. A low level current signal at a power factor of 0 must be applied to allow the offset magnitude to be measured and then removed.

Similar to the total and fundamental active energy, the total and fundamental reactive energy offset is corrected according to the following equation:

$$AFVAROS = -\%Error \times CF_{EXPECTED} \times CFxDEN \times \frac{Threshold}{1.024 \text{ MHz}}$$

where *Threshold* is made up of the value in the 8-bit VARTH register joined to an internal 27 bits equal to 0. If the VARTH is set to the default value of 3h, the threshold value would, therefore, be 18000000h.

Depending on the board layout and the crosstalk on the meter design, Phase B and Phase C may need separate offset

calibration. This can be achieved through the BVAROS and BFVAROS registers for Phase B and CVAROS and CFVAROS registers for Phase C.

CURRENT AND VOLTAGE RMS

Calibrating the voltage and current rms is only required if the instantaneous rms readings are required.

Perform the rms calibration using the instantaneous rms register readings.

- The phase current readings can be obtained from the AIRMS register, the BIRMS register, the CIRMS register, and the NIRMS register.
- The phase voltage readings can be obtained from the AVRMS register, the BVRMS register, the CVRMS register, and the NVRMS register.
- The V2 channel rms readings can be obtained from the AV2RMS register, the BV2RMS register, the CV2RMS register, and the NV2RMS register.
- The fundamental rms values of phase currents and phase voltages can be obtained from the AFIRMS register (Address 0xE537), the BFIRMS register (Address 0xE539), the CFIRMS register (Address 0xE53B), the AFVRMS register (Address 0xE538), the BFVRMS register (Address 0xE53A), and the CFVRMS register (Address 0xE53C). The CFx pulse output is not used for this calibration.

It is recommended to acquire the xIRMS, xFIRMS, xVRMS, xFVRMS and xV2RMS (ADE7933 only) measurements to ensure the stability of the results as follows:

- Read xIRMS, xFIRMS, xVRMS, xFVRMS, and xV2RMS (ADE7933 only) rms registers at least once per line cycle over 1 sec.
- Average the readings to obtain the rms value.

RMS Gain

Assuming that the channel matching has been performed as described in the Gain Matching section, no further gain calibration should be required on the xIRMS, xFIRMS, xVRMS, xFVRMS, or xV2RMS (when ADE7933 is used) measurements. The readings from the xIRMS, xFIRMS, xVRMS, xFVRMS, and xV2RMS registers can be converted into current and voltage values in amps and volts using the V/LSB and Amps/LSB constants.

This procedure is performed by the microcontroller and the resulting constants must be saved in the microcontroller. These constants can be calculated using the following formulas:

$$V \text{ Constant (V/LSB)} = \frac{\text{Voltage Input (V)}}{\text{VRMS(LSBs)}}$$

$$I \text{ Constant (V/LSB)} = \frac{\text{Current Input (A)}}{\text{IRMS(LSBs)}}$$

V Constant works for both xVRMS, xFVRMS, and xV2RMS registers, while I Constant works for both xIRMS and xFIRMS registers.

Since all phases on all meters are matched, the same constant can be used for all current rms and voltage rms readings on all meters. This constant should be stored in the microcontroller. If this constant is not convenient for storing or a different constant is required, then the xIGAIN, xVGAIN, and xV2GAIN (when ADE7933 is used) registers can be used to adjust the constant. Note that in this case, xIGAIN and xVGAIN registers compensate the gain errors introduced in the active and reactive energies data paths by the ADE7932/ADE7933 ADC gain, the shunt and the voltage divider values. Therefore, the energy calibration needs to compensate only for the ADE7978 crystal frequency error. Execute the energy calibration after adjusting the xIGAIN or xVGAIN registers.

$$xVGAIN = \frac{\text{Voltage Input (V)} \times 2^{23}}{V \text{ Constant (Volts / LSB)} \times xVRMS(\text{LSBs})}$$

$$xV2GAIN = \frac{\text{Voltage Input (V)} \times 2^{23}}{V \text{ Constant (Volts / LSB)} \times xV2RMS(\text{LSBs})}$$

$$xIGAIN = \frac{\text{Current Input (I)} \times 2^{23}}{I \text{ Constant (Amp / LSB)} \times xIRMS(\text{LSBs})}$$

RMS Offset

To obtain accurate readings at low signal levels, the current and voltage rms offset may have to be calibrated. This calibration is done using the internal xIRMSOS, xFIRMSOS, xVRMSOS, xFVRMSOS, and xV2RMSOS registers (when ADE7933 is used) that apply an offset prior to the square root function.

Table 11. xRMSOS Registers for RMS Offset Calibration

Calibration Registers	Address
AIRMSOS	0x438C
AVRMSOS	0x438D
AV2RMSOS (when ADE7933 is used)	0x438E
BIRMSOS	0x438F
BVRMSOS	0x4390
BV2RMSOS (when ADE7933 is used)	0x4391
CIRMSOS	0x4392
CVRMSOS	0x4393
CV2RMSOS (when ADE7933 is used)	0x4394
NIRMSOS	0x4395
NVRMSOS	0x4396
NV2RMSOS (when ADE7933 is used)	0x4397
AFIRMSOS	0x43A9
BFIRMSOS	0x43AA
CFIRMSOS	0x43AB
AFVRMSOS	0x43AC
BFVRMSOS	0x43AD
CFVRMSOS	0x43AE

The compensation factor is determined by applying the following equations:

$$xIRMSOS = \frac{xIRMS_{EXPECTED}^2 - xIRMS_{ACTUAL}^2}{128}$$

$$xFIRMSOS = \frac{xFIRMS_{EXPECTED}^2 - xFIRMS_{ACTUAL}^2}{128}$$

$$xVRMSOS = \frac{xVRMS_{EXPECTED}^2 - xVRMS_{ACTUAL}^2}{128}$$

$$xFVRMSOS = \frac{xFVRMS_{EXPECTED}^2 - xFVRMS_{ACTUAL}^2}{128}$$

$$xV2RMSOS = \frac{xV2RMS_{EXPECTED}^2 - xV2RMS_{ACTUAL}^2}{128}$$

As illustrated in Figure 8, the rms offset calibration is based on two points, where the expected reading is derived from the rms measurement with nominal inputs.

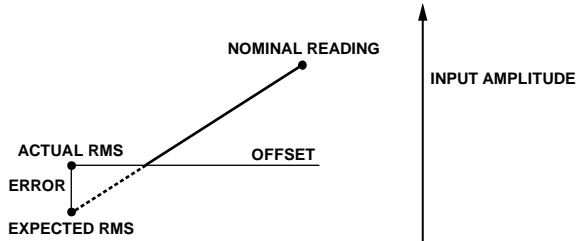


Figure 8. RMS Reading

The rms measurements are specified over a dynamic range of 1000:1. This is the minimum input level at which the measurement is accurate and, thus, the minimum point at which the offset calibration should take place. In this example, the voltage

rms offset is calibrated at 22 V, and the current rms offset is calibrated at 100 mA. To determine the expected rms reading, take a measurement 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, on Phase A:

Reading the AIRMSOS register at $I_{NOMINAL}$ (10 A) = 315184

Expected reading at I_{CAL} (100 mA) = $(0.1/10) \times 315184 = 3152$

Actual AIRMS reading obtained at I_{CAL} (100 mA) = 3907

Therefore,

$$AIRMSOS = \frac{3152^2 - 3907^2}{128} = -41637 = 0xFF5D5B$$

The voltage rms offset is calibrated in a similar manner.

For example, on Phase A:

Reading the AVRMS register at $V_{NOMINAL}$ (220 V) = 2391362

Expected reading at V_{CAL} (22 V) = $(22/220) \times 2391362 = 239136$

Actual AVRMS reading obtained at V_{CAL} (22 V) = 239153

Therefore,

$$AVRMSOS = \frac{239136^2 - 239153^2}{128} = -63523 = 0xFF07DD$$

CALIBRATING USING THE ENERGY REGISTERS

This section explains the calibration procedure and calculations used with the internal energy registers. The internal energy registers provide access to energy metering measurements via the SPI or I²C interface (see the [ADE7978](#) and [ADE7932/ADE7933](#) data sheet for more details).

When calibrating using the internal energy registers, use an accurate source. Calibration via the internal registers is typically performed when the CF pulse is not required in the final meter design. Figure 2 shows the relationship between the CF output

and energy registers. Figure 9 shows the calibration flow for the energy measurements. Use the flowchart in Figure 9 to determine a calibration routine.

Calibrating the voltage and current rms is only required if the instantaneous rms readings are required. Perform the rms calibration using the instantaneous rms register readings. See the Current and Voltage RMS section for full details on calibrating the current and voltage rms.

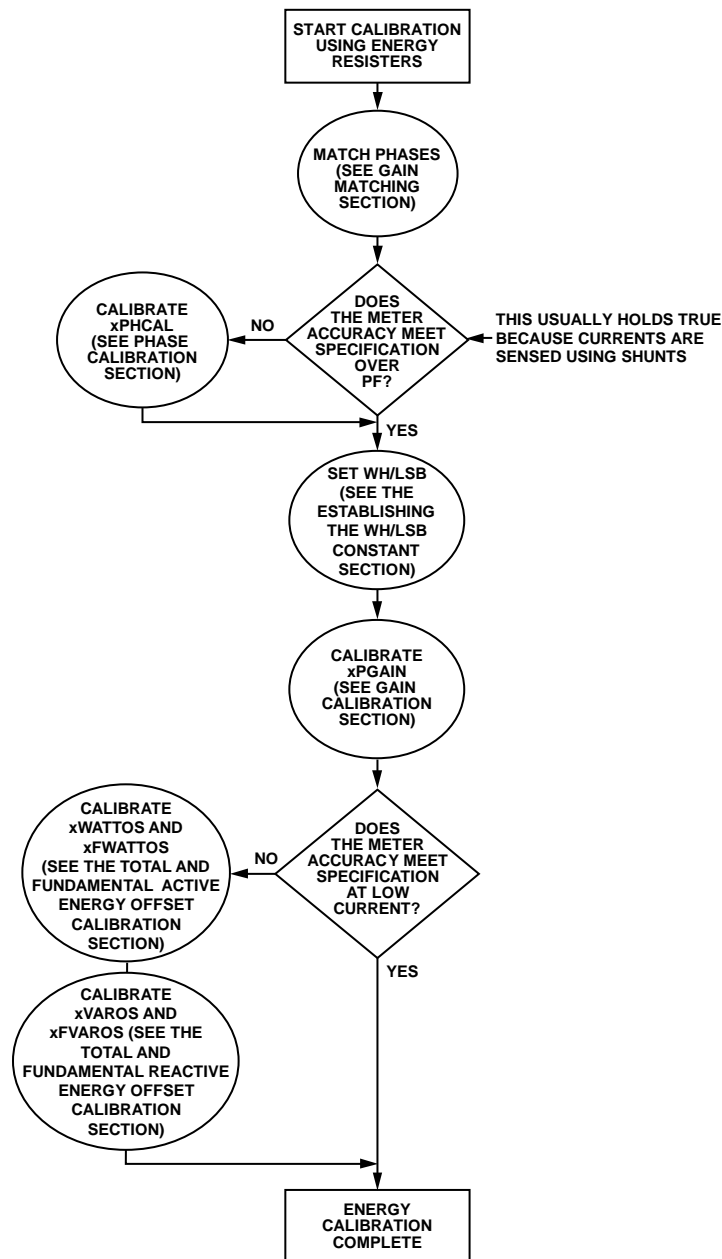


Figure 9. Energy Calibration Flow using Energy Registers

11780-008

GAIN MATCHING

It is convenient to match all three phases prior to calibrating. Matching the phases results in easier computations because one bit in the energy has the same weight on each phase. It is recommended to perform phase matching as the first calibration step. See the Gain Matching section for details on matching the phases.

PHASE CALIBRATION (OPTIONAL)

Note that because the ADE7932/ADE7933 use shunts to sense the phase currents, there is usually no need to execute the phase calibration. The procedure is presented here as a reference, in case it is still necessary. Table 12 presents the registers that are used to calibrate the phase.

Table 12. xPHCAL Registers for Phase Calibration

Calibration Registers	Address
APHCAL	0xE614
BPHCAL	0xE615
CPHCAL	0xE616

The phase calibration is ideally performed with an inductive or capacitive load at a power factor of 0.5. If this load is not available, another power factor can be chosen. For best results, the power factor should be as close to 0.5 as possible. To perform phase calibration in one step with one reading, the active and reactive powers must be measured simultaneously. The following equation outlines how to determine the phase error in degrees:

$$Error(^{\circ}) = -\tan^{-1}\left(\frac{AWATTHR \times \sin(\varphi) - AVARHR \times \cos(\varphi)}{AWATTHR \times \cos(\varphi) + AVARHR \times \sin(\varphi)}\right)$$

where:

φ refers to the angle between the voltage and the current (in degrees).

Once the error in degrees is determined, the following formula can be used to determine the required phase compensation:

$$PhaseResolution = \left(\frac{360^{\circ} \times f}{1.024 \text{ MHz}}\right)$$

$$PhaseCompensation = \text{abs}\left(\frac{Error(^{\circ})}{PhaseResolution}\right)$$

where:

f refers to the line frequency.

Note that the format of the APHCAL register is such that if the value of the Error(degrees) is positive, then a value of 512d must be added to the calculated PhaseCompensation prior to writing to the APHCAL register.

APHCAL =

$$\left(\begin{array}{l} Error(^{\circ}) \leq 0, \Rightarrow APHCAL = PhaseCompensation \\ Error(^{\circ}) > 0, \Rightarrow APHCAL = PhaseCompensation + 512 \end{array}\right)$$

For example, if, at 220 V and 10 A at a power factor of 0.5, the AWATTHR value is 3384 and the AVARHR is 5663, the error in degrees can be calculated as follows:

$$Error(^{\circ}) = -\tan^{-1}\left(\frac{3384 \times \sin(60) - 5663 \times \cos(60)}{3384 \times \cos(60) + 5663 \times \sin(60)}\right) = -0.86^{\circ}$$

Assuming the line frequency is 50 Hz, the APHCAL compensation can be determined as

$$PhaseCompensation = \text{abs}\left[\left(\frac{-0.86}{360^{\circ} \times 50}\right) \times 1.024 \text{ MHz}\right] = 0 \times 31$$

$$APHCAL = PhaseCompensation = 0 \times 31$$

ESTABLISHING THE WH/LSB CONSTANT—FIRST METER ONLY

When calibrating the first meter, the Wh/LSB must be determined. The Wh/LSB constant is used to set the weighting of each LSB in the active energy register. This constant allows the energy register readings to be converted into real world values.

Once established, the same Wh/LSB meter can be used for each subsequent meter. The weighting of each LSB in the energy register is often stated in the specifications of the design. If no specification is provided, then the user can select the weighting. To determine the Wh/LSB constant, the following formula can be used:

$$Wh/LSB = \frac{Load(W) \times AccumulationTime(sec)}{xWATTHR \times 3600}$$

where:

AccumulationTime is the line cycle accumulation time.

xWATTHR is the energy register reading after this time has elapsed.

For example, if a line cycle value of 100 has been set and the frequency of the input signal is 50 Hz, the accumulation time will be 1 second ($0.5 \times (1/50) \times 100$) assuming that only one phase is selected for the zero crossing detection (LCYCMODE Bits[3:5]). With a load of 220 V and 10 A with a power factor of 0.5, this produces an AWATTHR reading of 3299. The Wh/LSB constant can be calculated as follows:

$$Wh/LSB = \frac{220 \text{ V} \times 10 \text{ A} \times \cos(60) \times 1 \text{ sec}}{3299 \times 3600} = 9.262 \times 10^{-5}$$

Should the user wish to adjust the constant to meet a particular specification or make the constant a rounder number for storing purposes, the APGAIN register can be used. The APGAIN register can be used to modify the Wh/LSB constant by $\pm 100\%$. The APGAIN register affects the AWATTHR register is shown in the following formula:

$$APGAIN = \frac{AWATTHR_{EXPECTED}}{AWATTHR_{ACTUAL}} - 1$$

To achieve a different meter constant, the AWATTHR reading must be altered based on the desired Wh/LSB.

$$AWATTHR_{Expected} = \frac{Load(W) \times AccumulationTime(sec)}{Wh/LSB \times 3600}$$

For example, to alter the previously calculated Wh/LSB constant of 9.6262×10^{-5} to 9×10^{-5} for storing purposes, the desired AWATTHR reading is

$$AWATTHR_{Expected} = \frac{220V \times 10A \times \cos(60) \times 1sec}{9 \times 10^{-5} \times 3600} = 3395d$$

The required APGAIN value is then

$$APGAIN = 2^{23} \times \left(\frac{3395}{3299} - 1 \right) = 244106 = 0x3B98A$$

ENERGY GAIN CALIBRATION

The purpose of the energy gain calibration is to compensate for small gain errors due to part-to-part variation in the internal and external components:

- ADE7933 ADC gain
- Shunt value
- Voltage divider value
- ADE7978 crystal frequency error

Table 13. xPGAIN Registers for Energy Gain Calibration

Calibration Registers	Address
APGAIN	0x4399
BPGAIN	0x439A
CPGAIN	0x439B

Gain calibration is required on every meter and is performed with nominal voltage and current inputs at a power factor of 0.5. The total and fundamental active, and reactive powers and the apparent power are internally gain matched. One single gain calibration step is thus required to calibrate all powers on a single phase.

For simplicity, it is recommended that all meters be calibrated to use the same Wh/LSB value, and this should be set up in the first meter as explained in the Establishing the Wh/LSB Constant—First Meter Only section. Use the following formula to determine the expected reading in the AWATTHR register:

$$AWATTHR_{EXPECTED} = \frac{Load(W) \times AccumulationTime(sec)}{Wh/LSB \times 3600s/h}$$

The actual value can then be read from the AWATTHR register and the APGAIN register can be used to correct any errors. The following formula shows how APGAIN can be used to adjust the AWATTHR reading:

$$APGAIN = \frac{AWATTHR_{EXPECTED}}{AWATTHR_{ACTUAL}} - 1$$

Using the previous example, at 220 V and 10 A, the expected AWATTHR reading is 3395d. Assuming that the actual AWATTHR reading is 3380d, APGAIN is calculated as

$$APGAIN = 2^{23} \times \left(\frac{3395}{3380} - 1 \right) = 37228 = 0x916C$$

Note that the gain calibration for Phase B and Phase C is controlled by the BPGAIN and CPGAIN registers, respectively. Assuming that the channels are correctly matched, as described in the Gain Matching section, the previous procedure does not need to be repeated for the other channels.

Write the value calculated for APGAIN to BPGAIN and CPGAIN for accurate results. Since all power calculations are internally gain matched, setting the xPGAIN registers gain calibrates all energy measurements.

TOTAL AND FUNDAMENTAL ACTIVE ENERGY OFFSET CALIBRATION (OPTIONAL)

Total and fundamental active energy offset calibration is only required if accuracy at low loads is outside the required specification prior to offset calibration.

Table 14. xWATTOS Registers for Active Energy Offset Calibration

Calibration Registers	Address
AWATTOS	0x439C
BWATTOS	0x439D
CWATTOS	0x439E
AFWATTOS	0x43A3
BFWATTOS	0x43A4
CFWATTOS	0x43A5

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

When performing offset calibration, it is often required to increase the accumulation time to minimize the resolution error. As the line-cycle accumulation mode accumulates energy over a fixed time, the result is accurate to ± 1 LSB. If the number of bits accumulated in the xWATTHR register is small after this time, the ± 1 LSB error can result in a large error in the output.

For example, if xWATTHR=10, the resolution error is 10%. Increasing the number of accumulation bits to xWATTHR = 1000 reduces the resolution error to 0.1%.

In the following example, a LINECYC of 5000 half-line cycles is set, and an input current of 100 mA is applied. With a voltage channel input of 220 V at a power factor of 1, the expected AWATTHR reading is determined as

$$AWATTHR_{EXPECTED} = \frac{220V \times 0.1A \times \cos(0) \times 50sec}{9 \times 10^{-5} \times 3600} = 3395$$

If the actual AWATTHR register reading is 3380 at 100 mA, the percentage error due to offset is determined as

$$\%Error = \frac{3380 - 3395}{3395} = -0.44\%$$

The offset in the watt measurement is corrected according to

$$AWATTOS = -\%Error \times \frac{AWATTHR_{EXPECTED}}{AccumulationTime(sec)} \times \frac{Threshold}{1.024 MHz}$$

where:

Threshold is made up of the value in the 8-bit WTHR register joined to an internal 27 bits equal to 0. If WTHR is set to the default value of 3h, the threshold value would, therefore, be 0x18000000 = 402653184.

$$AWATTOS = 0.0044 \times \frac{3395}{50} \times \frac{402653184}{1024000} = 117 = 0x75$$

The AFWATTOS register effects the fundamental active energy offset in the same way as the AWATTOS register effects the total active energy offset. Typically, the same value that was calculated for the AWATTOS can be written to the AFWATTOS for accurate calculations.

Depending on the board layout and the crosstalk on the meter design, Phase B and Phase C may need separate offset calibration. This can be achieved through the BWATTOS and BFWATTOS registers for Phase B, and the CWATTOS and CFWATTOS registers for Phase C.

TOTAL AND FUNDAMENTAL REACTIVE ENERGY OFFSET CALIBRATION

Fundamental reactive energy offset calibration is only required if accuracy at low loads is outside the required specification prior to offset calibration.

Table 15. xFVAROS Registers for Reactive Energy Offset Calibration

Calibration Registers	Address
AVAROS	0x439F
BVAROS	0x43A0
CVAROS	0x43A1
AFVAROS	0x43A6
BFVAROS	0x43A7
CFVAROS	0x43A8

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

¹C refers to a communications protocol originally developed by Philips Semiconductors (now NXP Semiconductors).

When performing offset calibration, it is often required to increase the accumulation time to minimize the resolution error. Because the line-cycle accumulation mode accumulates energy over a fixed time, the result is accurate to ± 1 LSB. If the number of bits accumulated in the xVARHR register is small after this time, the ± 1 LSB error can result in a large error in the output.

For example, if xVARHR = 10, the resolution error is 10%. Increasing the number of accumulation bits to xVARHR = 1000 reduces the resolution error to 0.1%. The expected xVARHR reading is determined as

$$AVARHR_{EXPECTED} = \frac{Load(var) \times AccumulationTime(sec)}{var\ hr / LSB \times 3600\ s/h}$$

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

$$AVAROS = -\%Error \times \frac{AVARHR_{EXPECTED}}{AccumulationTime(sec)} \times \frac{Threshold}{1.024 MHz}$$

where:

Threshold is made up of the value in the 8-bit VARTH register joined to an internal 27 bits equal to 0.

If the VARTH is set to the default value of 3h, the threshold value would therefore be 18000000h.

The AFVAROS register effects the fundamental reactive energy offset in the same way as the AVAROS register effects the total reactive energy offset. Typically, the same value that was calculated for the AVAROS can be written to the AFVAROS for accurate calculations.

Depending on the board layout and the crosstalk on the meter design, Phase B and Phase C may need separate offset calibration. This can be achieved through the BVAROS and BFVAROS registers for Phase B, and the CVAROS and CFVAROS registers for Phase C.

COMPUTING THE HEXADECIMAL REPRESENTATION OF A SIGNED FRACTIONAL NUMBER

Many calibration registers of the [ADE7978](#) are 24-bit signed numbers. The hexadecimal representation *X* of a positive number *x* lower than 1 is

$$X = x \times 2^{23}$$

The hexadecimal representation of a negative number greater than -1 is

$$X = 2^{24} + (x \times 2^{23})$$