ANALOG DEVICES

AN-624
APPLICATION NOTE

One Technology Way • P.O. Box 9106 • Norwood, MA 02062-9106 • Tel: 781/329-4700 • Fax: 781/326-8703 • www.analog.com

Calibration of a 3-Phase Energy Meter Board on the ADE7754

By Etienne Moulin

INTRODUCTION

A 3-phase energy meter can interface with different services like 3-phase 4-wire, 3-phase 3-wire, and 3-phase 4-wire with 2½ elements. It can also provide active, reactive, and apparent energy calculations as well as power quality measurements, voltage rms, and current rms.

This application note describes the different steps to calibrate a 3-phase 4-wire, 3-element energy meter based on the ADE7754. It describes the software used with the ADE7754 evaluation board to perform the calibration.

The ADE7754 is comprised of six ADCs, a reference circuit, and all the signal processing necessary for the calculation of active energy, apparent energy, and rms value of the analog inputs. Circuitry is provided to null out various system errors including gain, phase, and offset errors. All registers of the ADE7754 are available through a 4-wire serial interface (SPI®). Please refer to the ADE7754 data sheet for a detailed description and the operation of the SPI interface.

3-PHASE ENERGY SERVICES

This section presents the different 3-phase services as well as the different meter architectures available in the field. Each of these solutions uses a different formula to calculate energy. The terms and descriptions of the services are taken from the US ANSI C12.1 standard.

3-Phase 4-Wire Wye Service

This service is comprised of three phases and one neutral conductor, as described in Figure 1. Each voltage phase is referred to the neutral and has ±120° phase difference with the other phases (see Figure 2). The energy measurement is done with three current sensors and two or three voltage sensors. A meter with two voltage sensors is generally called a 2½-element or 2-stator 4-wire wye meter. A meter with three voltage sensors is generally called a 3-element or 3-stator 4-wire wye meter.

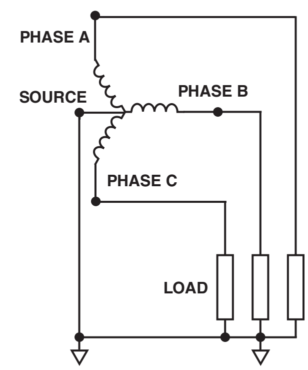

Figure 1. 3-Phase 4-Wire Wye Service

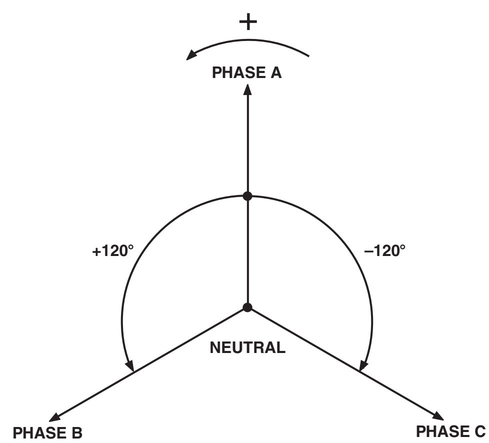

Figure 2. 3-Phase 4-Wire Wye Phasor Diagram

3-Stator 4-Wire Wye Meter

This 3-phase meter is comprised of three voltage sensors and three current sensors. The common point of the voltage sensors should be connected to the neutral conductor. The energy measurements are done based on the measurement of the six entities involved in the system. This method is accurate for all conditions of load (balanced and unbalanced), power factor, or voltage.

$$\text{Active Power} = V_{\phi A} \times I_{\phi A} + V_{\phi B} \times I_{\phi B} + V_{\phi C} \times I_{\phi C}$$

2-Stator 4-Wire Wye Meter

This 3-phase meter is comprised of two voltage sensors and three current sensors. The common point of the voltage sensors should be connected to the neutral conductor. According to Blondel's Theorem, if the voltages between each line and the neutral are balanced within acceptable limits, the accuracy is generally considered satisfactory. The energy measurements are done by combining the five entities (two voltages and three currents) of the system.

3-Phase 4-Wire Delta Service

This service is comprised of three phases and one neutral conductor (see Figure 3). The neutral conductor is formed by a tap to the midpoint of one of the phase windings (see Figure 4). The energy measurement is done with three current sensors and two or three voltage sensors. A meter with two voltage sensors is generally called a 2½-element or 2-stator 4-wire delta meter. A meter with three voltage sensors is generally called a 3-element or 3-stator 4-wire delta meter.

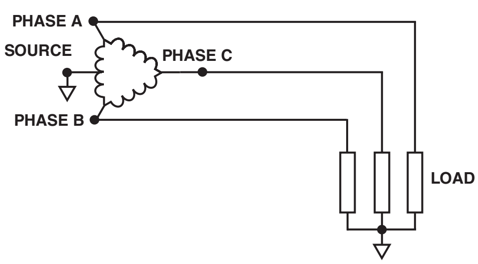

Figure 3. 3-Phase 4-Wire Delta Service

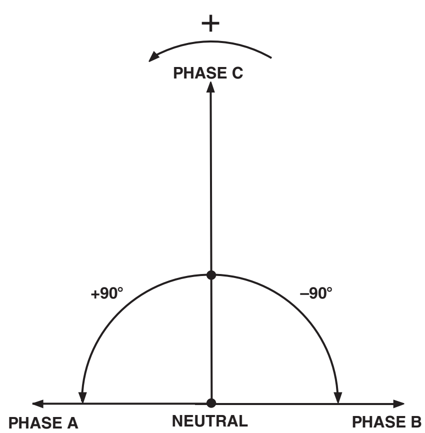

Figure 4. 3-Phase 4-Wire Delta Phasor Diagram

3-Stator 4-Wire Delta Meter

This 3-phase meter is comprised of three voltage sensors and three current sensors. The common point of the voltage sensors should be connected to the neutral conductor. The energy measurements are done based on the measurements of the six entities involved in the system. This method is accurate for all conditions of load (balanced and unbalanced), power factor, or voltage.

2-Stator 4-Wire Delta Meter

This 3-phase meter is comprised of two voltage sensors and three current sensors. The common point of the voltage sensors should be connected to the neutral conductor. If the neutral is a true midtap (voltages used to define the neutral are equal within acceptable limits), then only two voltage sensors need be used (2-stator). The energy measurements are done by combining the five entities (two voltages and three currents) of the system.

3-Phase 3-Wire Delta Service

This service is comprised of three phase conductors (see Figure 5 and 6). The energy measurements are done with three current sensors and two or three voltage sensors. A meter with two voltage sensors is generally called a 2½-element or 2-stator 4-wire delta meter. A meter with three voltage sensors is generally called a 3-element or 3-stator 4-wire delta meter.

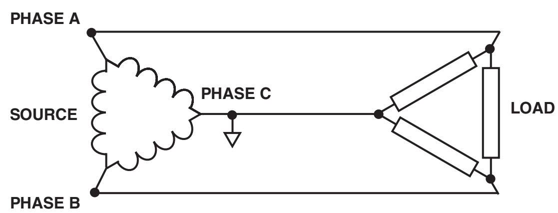

Figure 5. 3-Phase 3-Wire Delta Service

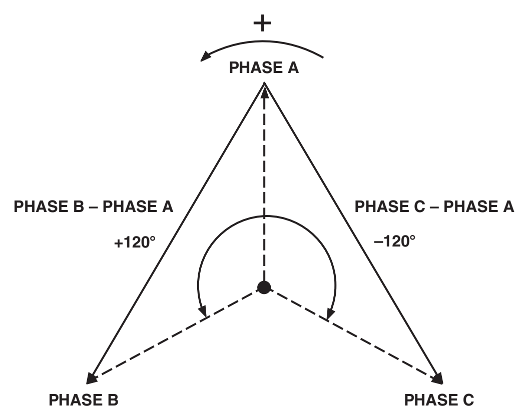

Figure 6. 3-Phase 3-Wire Delta Phasor Diagram

2-Stator 3-Wire Delta Meter

This 3-phase meter is comprised of two voltage sensors and two current sensors. The common point of the voltage sensors should be connected to one phase conductor. The current sensors are connected to the other two phase conductors.

CONFIGURATION OF ADE7754 FOR 3-PHASE ENERGY METERING

The ADE7754 provides several registers to configure the part depending on the meter connections and the desired results. Some registers are specific to the meter connections, but others are more generic and their values can be defined early in the design.

The OPMODE and GAIN registers define the general configuration of the ADE7754.

OPMODE (Address 0x0A)

Usually, the OPMODE register can be set to 0x00. With this value, the high-pass filters and low-pass filters are enabled and the pulse output proportional to active power, CF, is activated. The part can be reset to its default configuration by setting Bit 6 of this register to Logic 1. The default value of the OPMODE register after reset is 0x04. In this state, the CF pulse output is disabled.

GAIN (Address 0x18)

This register defines the PGA gain setting of both current and voltage channels, the mode of accumulation of the active powers (arithmetic sum or sum of the absolute values), and the application of a no-load threshold on the individual active powers.

The MMODE and WAVMODE registers configure the measurements processed by the ADE7754.

MMODE (Address 0x0B)

This register defines the phase input on which the period measurement and the peak detection are made. It also defines the phases used for counting the number of zero crossings in the line accumulation modes. This register can be set at a default value at initialization and changed during the meter operation.

WAVMODE (Address 0x0C)

This register defines the speed and the analog input used for waveform sampling. The value of this register can be defined at initialization and changed during the meter operation to access the different ADC outputs. This register also selects the accumulation of the reactive energy in the LAENERGY register if needed.

Interrupt Mask (Address 0x0F)

This register defines which event will drive the interrupt request pin ($\overline{IRQ}$) low. The detected events are:

- Active energy register half full
- Low voltage on any of the three voltage inputs (SAG)
- Missing zero-crossing on any of the three voltage inputs (ZXTOUT)
- Rising zero-crossing edge on any of the three voltage inputs (ZX)
- End of accumulation of energy over the LINCYC line cycles (LENERGY)
- High voltage on a selected voltage or current input (PKV and PKI)
- Sample available in the waveform sampling register (WFSM)
- Apparent energy register half full

The selection of the events for interruption depends on the functionality needed in the meter. It is recommended to select the interrupts for half-full energy (active and apparent) in order to avoid any information loss due to the overflow of these registers. The other interrupts should be selected depending on the need of the design. The configuration and operation of the SAG, ZXTOUT, VPEAK, and IPEAK interrupts are detailed in the ADE7754 data sheet.

ACTIVE POWER-ENERGY MEASUREMENTS

Theory of Operation

Electrical power is defined as the rate of energy flow from source to load. It is given by the product of the voltage and the current inputs. The resulting signal is called the instantaneous power signal and is equal to the rate of active energy flow at every instant of time. The unit of power is the watt or joules/sec. Equation 3 gives an expression for the instantaneous power signal in an ac system.

$$v(t) = \sqrt{2}V \sin(\omega t) \quad (1)$$

$$i(t) = \sqrt{2}I \sin(\omega t) \quad (2)$$

where V = rms voltage, I = rms current.

$$p(t) = v(t) \times i(t) \quad (3)$$
$$p(t) = VI - VI\cos(2\omega t)$$

The average power over an integral number n of line cycles is given by Equation 4.

$$P = \frac{1}{nT}\int_0^{nT} p(t)\,dt = VI \quad (4)$$

where T is the line cycle period.

P is referred to as the active or real power. Note that the active power is equal to the dc component of the instantaneous power signal p(t) in Equation 3, i.e., VI. This is the relationship used to calculate active power in the ADE7754 for each phase. Figure 7 shows the active power signal processing implemented in the ADE7754 for each phase.

Due to individual sensor characteristics, the active power calculation needs to be calibrated to correct for gain, phase, and offset errors for each phase independently (phase balancing).

Active Energy Accumulation

Besides the pulse output, which is used for calibration verification (see the Active Power Pulse Output section), a solid state energy meter requires some form of display. This display should show the amount of energy consumed in kWh (kilowatt hours). One convenient and simple way to interface the ADE7754 to a display or energy register is to use a microcontroller (MCU) that reads one of the active energy registers, e.g., AENERGY and LAENERGY. A full description of the functions of these registers can be found in the ADE7754 data sheet. The total active energy is accumulated in the ADE7754 by adding the average active powers from each phase and accumulating them into the active energy register (see Figure 8). The ADE7754 can be configured to execute the arithmetic sum of the three active powers, $W = W_{øA} + W_{øB} + W_{øC}$, or the sum of the absolute value of these powers, $W = |W_{øA}| + |W_{øB}| + |W_{øC}|$.

When the sum of the absolute values is selected, the active energy from each phase is always counted positive in the total active energy. It is particularly useful in a 3-phase 4-wire installation where the sign of the active power should always be the same. If the meter is misconnected to the power lines, i.e., CT is connected in the wrong direction, the total active energy recorded without this solution can be reduced by two-thirds. The sum of the absolute values assures that the active energy recorded represents the actual active energy delivered. In this mode, the reverse power information available in the CFNUM register is still detecting when negative active power is present on any of the 3-phase inputs.

To transform the active energy register reading into a usable form, a Wh/LSB conversion coefficient can be set. The calibration of this Wh/LSB constant is described later in this document.

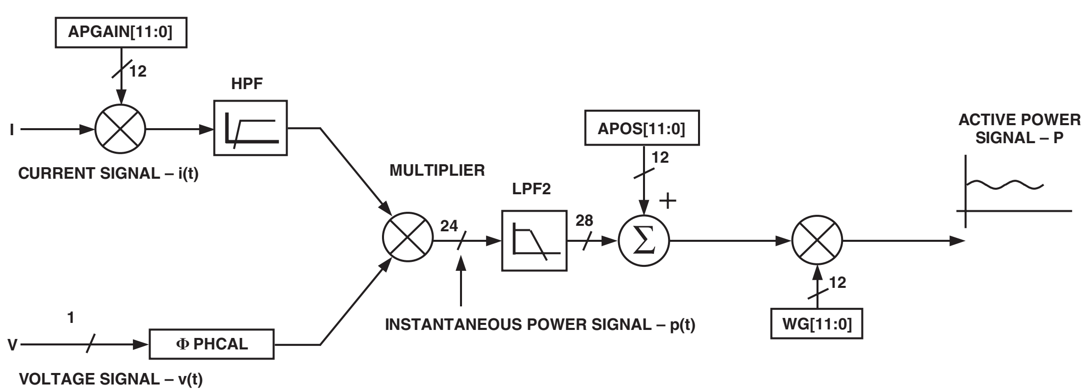

Figure 7. Active Power Signal Processing

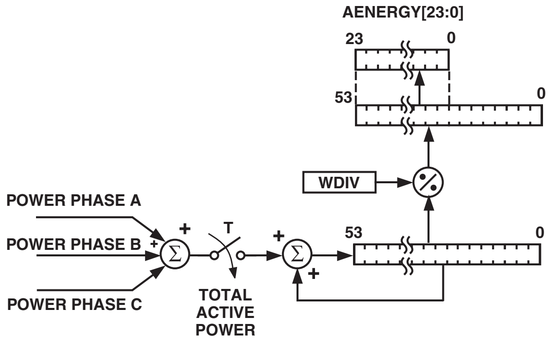

Figure 8. Active Energy Accumulation

Active Power Pulse Output (CF)

The ADE7754 provides a pulsed output, CF, whose frequency is proportional to the active power. It provides a simple, single-wire, optically isolated interface to external calibration equipment.

The energy-to-frequency conversion is accomplished by accumulating the total active power in a 54-bit wide register. An output pulse is generated each time the register value is greater than 2^{30} LSBs (see Figure 9).

The output frequency at CF, with full-scale ac signals on all six channel inputs and CFNUM = CFDEN = 0x000, is approximately 96 kHz. This can be calculated as follows: with all the gain registers set to 0x000 (APGAINs, WGAINs), the average value of the instantaneous active power on each phase is 0xD1B717 or 13743895d. For all three phases, the average value is 41231685d. An output frequency is generated on CF when the internal register accumulates 2^{30}. The accumulation rate is CLKIN/4.

$$CF\left(Hz\right)=\frac{Average\ Total\ \ Active\ Power\times CLKIN}{2^{30}\times 4} \quad (5)$$

In the ADE7754, the CF frequency can be adjusted by changing the different gain registers. As the ADE7754 is comprised of three independent inputs (phases), this calibration needs to be done for each input independently. CFNUM and CFDEN are meant for global coarse gain compensation and AWG, BWG, and CWG for fine gain adjustment per phase.

Active Power Measurement

A solid state energy meter requires the display of the active power in addition to the active energy. For 3-phase applications, the requirement is generally for the display of the active power per phase.

The ADE7754 does not provide a direct measurement of the active power as defined in Equation 4, but instead uses two accumulators for the active energy. Each accumulator can be configured independently to hold the active energy from a specific phase or the active energy sum of several phases. One of the accumulators (e.g., AENERGY) can be constantly used for the regular total active energy accumulation (e.g., billing) and the other accumulator (e.g., LAENERGY) can be used for average active power measurement by dividing the value read by the accumulation time.

Note: In the ADE7754, the average active power measurement per phase has to be processed one phase at a time by changing the phase selected in the LAENERGY accumulation. The switching between phases should follow the descriptions of Figure 10 by changing the MMODE and WATMODE register values.

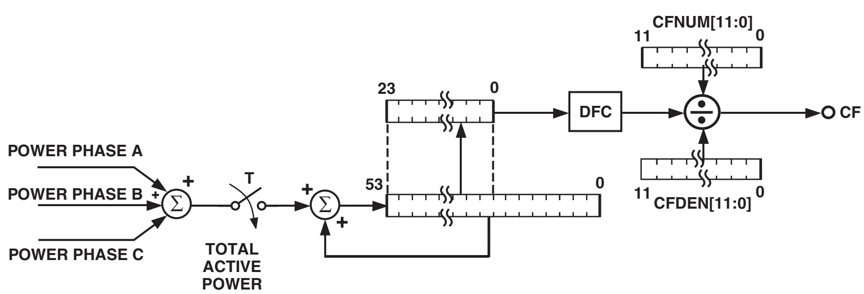

Figure 9. Energy-to-Frequency Conversion

ACTIVE ENERGY GAIN CALIBRATION USING THE LAENERGY REGISTER

The ADE7754 accumulates the active power synchronously to the line cycles. This mode is especially useful for calibration purposes as the ripple effect in the active energy accumulation is reduced to zero (see the Line Energy Accumulation section in the ADE7754 data sheet).

In this line accumulation mode, the ADE7754 accumulates the active power signal in the LAENERGY register for an integral number of half line cycles. The number of half line cycles, the phases selected to be accumulated, and the phases involved in the counting are specified in the LINCYC register, the LWATSEL bits of the WATMODE register (address 0x0D), and in the ZXSEL bits of the MMODE register (address 0x0B), respectively. Figure 10 describes how to set up the line accumulation mode in the ADE7754.

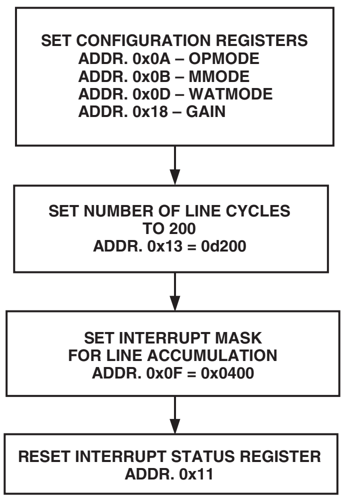

Figure 10. Line Accumulation Mode Setup

CF Frequency Gain Calibration

There is a direct relationship between CF frequency and the line active energy register value (see Equation 6).

$$CF\ (\text{Hz}) = \frac{LAENERGY}{4 \times Accumulation\ Time(s)} \times \frac{CFNUM}{CFDEN} \times WDIV \times \left(1 + \frac{WG}{2^{12}}\right) \tag{6}$$

where Accumulation Time is the period of time during which the active power has been accumulated in the LAENERGY register:

$$Accumulation\ Time(s) = \frac{LINCYC[15:0]}{2 \times Line\ Frequency \times No.\ of\ Phases\ Selected} \tag{7}$$

The number of phases selected is the number of ones in the ZXSEL bits of the MMODE register.

WDIV is a register used for scaling the active energy accumulations; it does not affect the CF frequency. It is introduced in Equation 6 to compensate its effect on the LAENERGY value.

When calculating the expected CF frequency with a LAENERGY reading and Equation 6, the actual ADE7754 register values used during the test should be used.

The CF frequency calibration has to be done for each phase individually. The gain correction carried by the CFNUM and CFDEN registers affects all three phases similarly and should be used as a coarse gain compensation. The WG registers should then be used to fine adjust the CF frequency to the expected frequency for each individual phase.

Note: If the active power is accumulated in both the active energy and line active energy registers during the same amount of time, the line active energy register value is four times the active energy register value.

Wh/LSB Constant Calibration

The active energy Wh/LSB constant and the CF frequency can be calibrated at the same time using the line accumulation mode. Equations 6 and 7 detail the relationship between the different parameters.

Under the steady load test condition, the watt power consumption, W, is known. The Wh/LSB constant for the AENERGY register is estimated using Equation 8:

$$\frac{Wh}{LSB}\,cst = \frac{W \times Accumulation\ Time(s)}{3600 \times \frac{LAENERGY}{4}} \tag{8}$$

It should be noted that once the CF frequency has been adjusted for each phase to the same value, the AENERGY and LAENERGY registers will give the same value from part to part and phase to phase under the same conditions. Therefore, the Wh/LSB coefficient is a constant that does not need to be calibrated. It can be estimated by design and stored as is in the MCU.

Line Period Measurement

The calibration of the CF frequency and the Wh/LSB constant with the line accumulation mode requires an estimation of the line frequency. A poor estimation of this quantity leads to errors in the calibration of the system. Some calibration systems do not provide the line frequency. The ADE7754 provides a measurement of the line period in the period register (address 0x07). The selection of the voltage input is done by Bits 0 and 1 of the measurement mode register (address 0x0B). As the resolution of the period register is 2.4 μs/LSB, the Line Frequency in Equation 7 can be replaced by:

$$Line\ Frequency\ (Hz) = \frac{1}{Period\ Register \times 2.4\ \mu s} \quad (9)$$

Note: When selecting a voltage input for the ADE7754 period measurement, the same phase must be selected for the zero-crossing detection (Bits 4 to 6 of the MMODE register).

Active Power Gain Calibration

As explained previously, the active power information per phase can be processed from the LAENERGY register and the accumulation time. The conversion of the LAENERGY register value to watts can be done by using the Wh/LSB constant and the accumulation time as:

$$Average\ Active\ Power\ (W) = \frac{\frac{LAENERGY}{4} \times 3600}{Accumulation\ Time(s)} \times Wh/LSB\ cst$$

As the phases' gains should be balanced, the only variables in this equation are the accumulation time (depending on the period register) and the actual reading from the LAENERGY register.

Note: In the ADE7754, the average active power measurement per phase has to be processed one phase at a time by changing the phase selected in the LAENERGY accumulation. The switching between phases should follow the descriptions of Figure 10 by changing the MMODE and WATMODE register values.

ACTIVE POWER OFFSET CALIBRATION USING THE LAENERGY REGISTER

An offset may exist in the power calculation due to cross- talk between channels on the PCB or the IC itself. The offset calibration allows the content of the active power to be maintained at zero when no power is being consumed.

To compensate for this error, a 2-point measurement is needed. The measurement at the test current can be used as well as another measurement at a lower current level, e.g., $I_{TEST}/100$. The APOS register is used to adjust the result at low current input to the expected value processed from the I_{TEST} value.

The calibration of the active power offset can be done using the line active energy accumulation mode similar to the gain calibration. If $LAENERGY_1$ and $LAENERGY_2$ are the accumulation of the active power in the LAENERGY register for two different current inputs (I_1 and I_2) under the same conditions, e.g., the same number of line cycles, frequency, voltage input, and gain, the offset to be compensated is:

$$Offset = \frac{LAENERGY_2 \times I_1 - LAENERGY_1 \times I_2}{I_1 - I_2} \quad (10)$$

The offset of Equation 10 is an active energy offset. It represents the number of LAENERGY LSBs that need to be corrected. This number depends on the duration of the accumulation.

An active power offset compensation is available in the ADE7754, e.g., AAPOS for Phase A. During the active energy accumulation, the value of this register is added to the active energy every CLKIN/4. If the active energy is accumulated during the accumulation time defined in Equation 7, the APOS register is added to the LAENERGY n times with:

$$n = \frac{Accumulation\ Time(s)}{4 \times T_{CLKIN}^{(S)}} \quad (11)$$

where T_{CLKIN} is the period of CLKIN.

The APOS offset is added to the 54-bit register displayed in Figures 8 and 9. An increment of one LSB in the LAENERGY register happens only when $n \times APOS > 2^{28}$.

From Equations 10 and 11, the APOS offset value can be set to:

$$APOS = -\frac{Offset}{n} \times 2^{28} \quad (12)$$

Note: If an error correction of 0.1% is desired, the active energy accumulated in the line accumulation mode should be greater than 1000 LSBs for both measurements.

PHASE CALIBRATION USING THE LAENERGY REGISTER

Phase matching between the current and voltage inputs of a phase is a critical issue. The errors induced by phase mismatch are minimal when PF = 1, but when PF = 0.5, a phase error as small as 0.5° causes a 1.5% error in the active power measurement.

Current transformers are very often used in 3-phase applications. By design, they generate phase shifts varying from around 0.5° for a standard CT to values as high as 5°. This phase shift must be compensated to reduce the reading error at low power factor. The ADE7754 has an internal phase compensation register for each phase input that can be used for this purpose. Each phase calibration register (APHCAL, BPHCAL, and CPHCAL) can introduce a delay in the voltage channel's signal path from –19.2 μs to +19.2 μs.

To calibrate this error, a 2-point measurement is needed. Measurements at the test current, unity power factor, and a lower power factor (e.g., 0.5) can be used. The PHCAL register is used to adjust the result at PF = 0.5 to the expected value processed from PF = 1.

The phase error is processed from the error between these two measurements:

$$Error = \frac{LAENERGY\ (PF = 0.5) - \frac{LAENERGY\ (PF = 1)}{2}}{\frac{LAENERGY\ (PF = 1)}{2}} \quad (13)$$

The phase error is then:

$$Phase\ Error\ (°) = -\ arc\ sin\left(\frac{Error}{\sqrt{3}}\right) \quad (14)$$

The phase register PHCAL is used to compensate for this error. The operation held by the PHCAL register is a time delay where one LSB is equivalent to 1.2 µs (CLKIN/12). Depending on the line frequency of the voltage input, the phase shift induced by the PHCAL register is different (see Equation 15).

$$Phase\ (°) = PHCAL\ Register \times 1.2\ \mu s \times 360° \times \frac{1}{PERIOD(s)} \quad (15)$$

where PERIOD is the reading from the ADE7754 period register for the specific phase.

From Equations 14 and 15, the value of the PHCAL register can be processed as:

$$PHCAL\ Register = arc\ sin\left(\frac{Error}{\sqrt{3}}\right)\frac{PERIOD \times 2.4\ \mu s}{360° \times 1.2\ \mu s} \quad (16)$$

Note: The equations above for phase calibration are only valid for a test at PF = 0.5 inductive load only. If a test at PF = 0.5 capacitive load is used, the sign of Equation 16 should be reversed.

Correction of Large External Phase Error

The PHCAL register can compensate only up to ±0.34° at 50 Hz and ±0.41° at 60 Hz. If larger corrections are required, the larger part of the correction can be made using external passive components. For example, the resistors in the antialias filter can be modified to shift the corner frequency of the filter so as to introduce more or less lag. The lag through the antialias filter with 1 kΩ and 33 nF is 0.56° at 50 Hz. Fine adjustments can be made with the PHCAL register. Note that, typically, CT phase shift does not vary significantly from part to part. If a CT phase shift is 1°, then the part-to-part variation should be only about ±0.1°. Therefore, the bulk of the phase shift (1°) can be cancelled with fixed component values at the design stage. The remaining small adjustments can be made in production using the PHCAL registers.

RMS MEASUREMENTS

Theory of Operation

Root mean square (rms) is a fundamental measurement of the magnitude of an ac signal. Its definition can be both practical and mathematical. Practically, the rms value assigned to an ac signal is the amount of dc required to produce an equivalent amount of heat in the same load.

Mathematically, the rms value of a continuous signal f(t) is defined as:

$$F_{RMS} = \sqrt{\frac{1}{T} \times \int_0^T f^2\ (t)\ dt} \quad (17)$$

For signals in discrete time, rms calculation involves squaring the signal, taking the average and then the square root:

$$F_{RMS} = \sqrt{\frac{1}{N} \times \sum_{i=1}^{N} f^2\ (i)} \quad (18)$$

The method used to calculate the rms value in the ADE7754 is to low-pass filter the square of the input signal (LPF3) and take the square root of the result (see Figures 11 and 12).

With $V(t) = \sqrt{2}V \sin(\omega t)$, then

$$V(t) \times V(t) = V_{RMS}^2 - V_{RMS}^2 \times \cos(2\omega t)$$

The low-pass filter (LPF3) attenuates the 2ω component of $V^2(t)$ and provides an average output proportional to the square of the rms input (V_{RMS}^2). The square root operation then provides V_{RMS}. The rms calculation is simultaneously processed on the six analog input channels. Each result is available in a separate register.

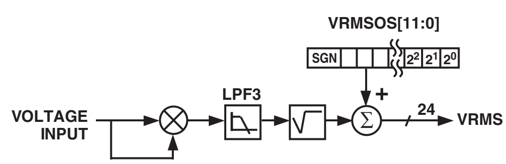

Figure 11. ADE7754 Voltage RMS Signal Processing

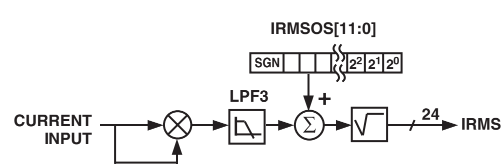

Figure 12. ADE7754 Current RMS Signal Processing

ADE7754 RMS Register Readings

As described earlier, the ADE7754 provides an rms measurement for each analog input every CLKIN/4. As the low-pass filtering (LPF3) is not perfect, a ripple noise coming from the 2ω component is present in the rms output (see the rms calculation in the ADE7754 data sheet). To minimize the effect of this noise in the readings, it is recommended to synchronize the rms readings with the zero-crossing of the three input phases. Figure 13 describes how to configure the ADE7754 for this operation on Phase A.

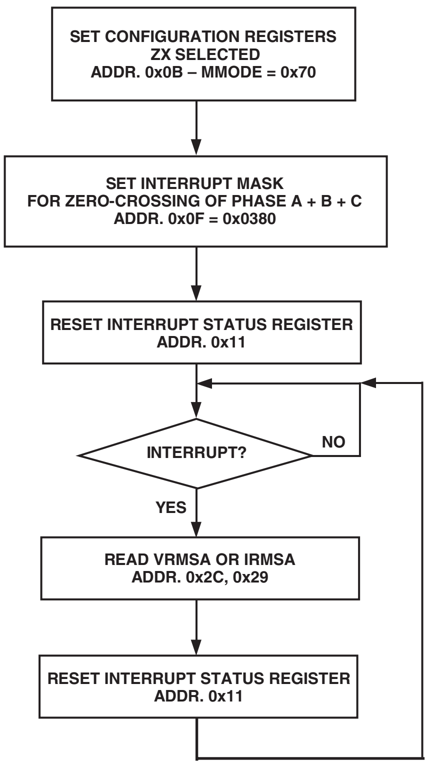

Figure 13. ADE7754 RMS Reading Setup for Phase A

ADE7754 RMS OFFSET COMPENSATION

The rms calculation integrates any noise during its signal processing. This noise contributes to the rms value as a dc offset. The ADE7754 provides an offset compensation register for each rms measurement as described in Figures 11 and 12.

To calibrate out this error, two nonzero measurements are needed. As the dynamic range on the voltage channels and the current channels are different, these two points are different. The voltage rms calculation provided in the ADE7754 is linear from full scale to full scale/20 and the current rms calculation from full scale to full scale/100. The two point measurements for the voltage rms calculation can be $V_{NOMINAL}$ and $V_{NOMINAL}/10$. For the current rms measurement, I_{TEST} and $I_{MAX}/100$ can be selected.

The VRMS and IRMS offset registers (VRMSOS and IRMSOS) are used to adjust the low level input to match the expected value derived from the high level value. As the offset correction is implemented in a different way for the voltage and current rms measurements (see Figures 11 and 12), the processing of the adequate correction is different for each channel.

Voltage Inputs RMS Offset Compensation

In the ADE7754, the voltage rms offset compensation is performed after the square root as described in Figure 11 and Equation 19.

$$V_{RMS} = V_{RMS0} + 64 \times VRMSOS \quad (19)$$

The voltage rms offset compensation (VRMSOS) can be processed from two nonzero measurements (see Equation 20).

$$VRMSOS = \frac{1}{64} \times \frac{V_1 \times V_{RMS2} - V_2 \times V_{RMS1}}{V_2 - V_1} \quad (20)$$

where V_{RMS1} and V_{RMS2} are the rms register values without offset correction for input V_1 and V_2, respectively. V_1 and V_2 must be expressed in any similar unit.

Current Inputs RMS Offset Compensation

In the ADE7754, the current rms offset compensation is performed before the square root as described in Figure 12 and Equation 21.

$$I_{RMS}^{\;2} = I_{RMS0}^{\;2} + 32768 \times IRMSOS \quad (21)$$

The current rms offset compensation (IRMSOS) can be processed from two nonzero measurements (see Equation 22).

$$IRMSOS = \frac{1}{32768} \times \frac{I_1^2 \times I_{RMS2}^{\;2} - I_2^2 \times I_{RMS1}^{\;2}}{I_2^2 - I_1^2} \quad (22)$$

where I_{RMS1} and I_{RMS2} are the rms register values without offset correction for input I_1 and I_2, respectively. I_1 and I_2 must be expressed in any similar unit.

SCALING OF ADE7754 RMS READINGS

A solid state energy meter requires the display of the rms value of the analog inputs in a meaningful format, e.g., amperes for current inputs and volts for voltage inputs.

Therefore, the rms calculations processed in the ADE7754 need to be converted to volts or amperes by applying a constant, e.g., V/LSB or A/LSB.

Due to sensor differences, the three analog inputs of the same channel (voltage or current) do not generally provide the same rms register value under the same conditions. For this reason, each input rms measurement needs a specific calibration parameter. As the ADE7754 does not provide individual gain calibration registers, the conversion constant as well as the gain adjustment need to be held in the MCU.

MCU RMS Scaling Adjustment Implementation

The ADE7754's rms register value for a full-scale ac signal is around 1,848,772d. If 220 V represents half scale of the analog input, the conversion constant is: 220/924,386 = 2.38×10^{-4} V/LSB. The implementation of this gain compensation can be done by multiplying the rms register value from the ADE7754 by a 16-bit register representing $2.38 \times 10^{-4} \times 2^{24}$ = 3993d. The result of this multiplication is then divided by 2^{24} (shift right by 24 bits) to provide the voltage rms value in volts (see Figure 14).

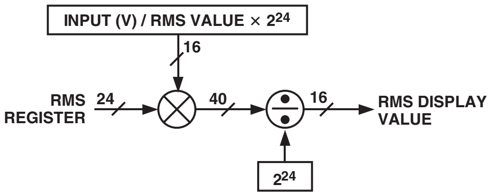

Figure 14. Conversion of the RMS Register in a Displayable Value

APPARENT POWER-ENERGY MEASUREMENTS

The apparent power is defined as the maximum active power that can be delivered to a load. As V_{RMS} and I_{RMS} are the effective voltage and current delivered to the load, the apparent power (AP) is defined as $V_{RMS} \times I_{RMS}$. Figure 15 shows the apparent power signal processing implemented in the ADE7754 for each phase.

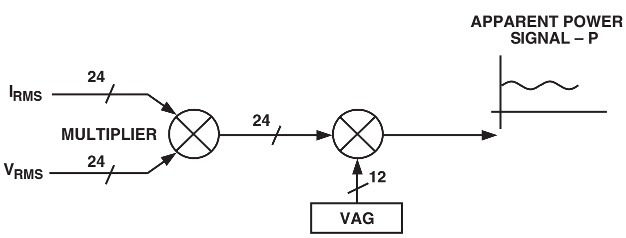

Figure 15. Apparent Power Signal Processing

Apparent Energy Accumulation

A solid state energy meter very often requires the display of the amount of apparent energy consumed in kVAh. When the ADE7754 is interfaced to a microcontroller (MCU), the MCU can read one of the apparent energy registers, e.g., VAENERGY and LVAENERGY. A full description of the functions of these registers can be found in the ADE7754 data sheet. The total apparent energy is accumulated in the ADE7754 by adding the apparent powers from each phase and accumulating them into the apparent energy register (see Figure 16).

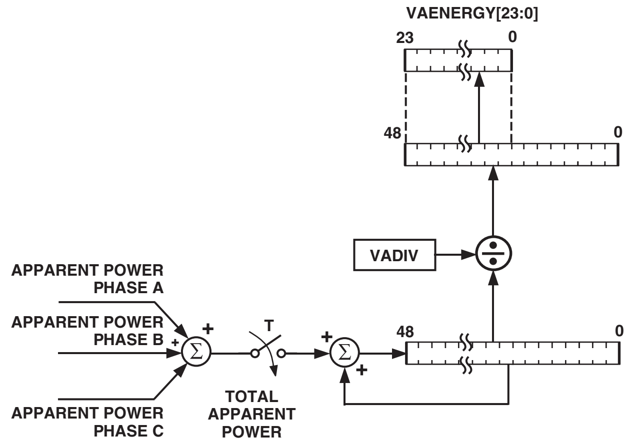

Figure 16. Apparent Energy Accumulation

A VAh/LSB coefficient converting the value of the VAENERGY or LVAENERGY registers to VAh should be set. The calibration of this VA/LSB constant is described in the Apparent Energy Gain Calibration Using LVAENERGY section.

Apparent Power Measurement

A solid state energy meter may require the display of the apparent power per phase.

The ADE7754 does not provide a direct measurement of the apparent power as defined by $V_{RMS} \times I_{RMS}$, but it provides two accumulators for the apparent energy. Each accumulator can be configured independently to hold the apparent energy from a specific phase or the apparent energy sum of several phases. One of the accumulators (e.g., VAENERGY) can be constantly used for the regular total apparent energy accumulation (e.g. billing) and the other accumulator (e.g., LVAENERGY) can be used for the apparent power measurement by dividing the value read by the accumulation time.

Note: In the ADE7754, the average apparent power measurement per phase has to be processed one phase at a time by changing the phase selected in the LVAENERGY accumulation. The switching between phases should follow the descriptions of Figure 10 by changing the MMODE and VAMODE (instead of WATMODE) register values.

APPARENT ENERGY GAIN CALIBRATION USING THE LVAENERGY REGISTER

The ADE7754 accumulates the apparent power synchronously to the line cycles. This mode is especially useful for calibration purposes as the ripple effect in the apparent energy accumulation is reduced to zero (see the Line Energy Accumulation section in the ADE7754 data sheet).

In this line accumulation mode, the ADE7754 accumulates the apparent power signal in the LVAENERGY register for an integral number of half line cycles. The number of half line cycles, the phases selected to be accumulated, and the phases involved in the counting are specified in the LINCYC, the LWATSEL[2:0] bits of the VAMODE register (address 0x0E), and in the ZXSEL[6:4] bits of the MMODE register (address 0x0B), respectively. Figure 10 describes how to set up the line accumulation mode in the ADE7754 for the VA calculation. The configuration of the WATMODE register can be replaced by the configuration of the VAMODE register for the calibration of the apparent energy. The procedure to calibrate Phase A is described in Figure 17.

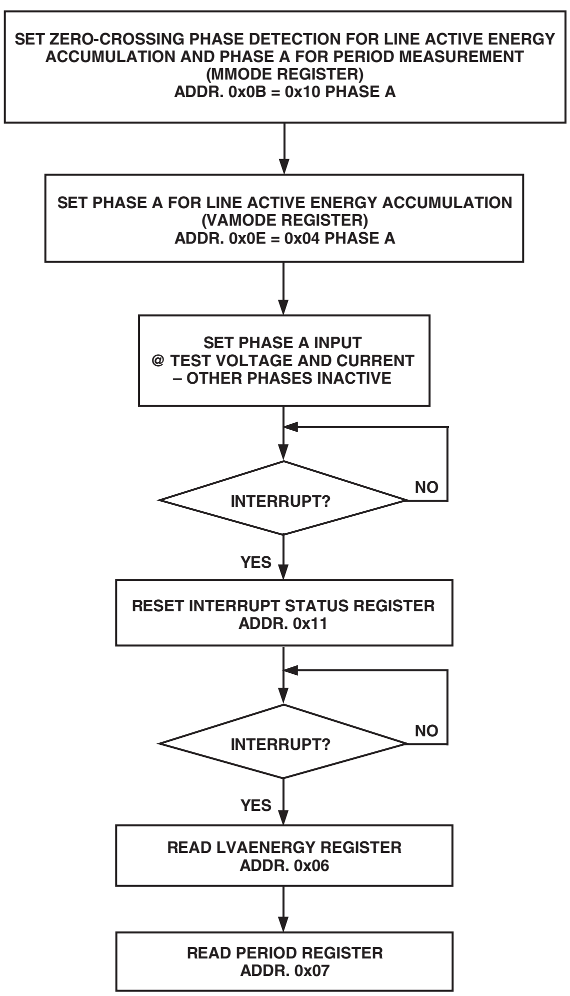

Figure 17. Apparent Energy Gain Calibration Procedure for Phase A

VAh/LSB Constant Calibration

The apparent energy VAh/LSB constant can be calibrated using the line accumulation mode. This constant can be set by default to a nominal value. The nominal value is determined during the design by experiment. The purpose of the calibration is to adjust the VADIV and VAG registers to get the same predetermined LVAENERGY accumulation from all three phases.

Under the steady load test condition, the apparent power consumption, VA, is known. The VAh/LSB constant is estimated using Equation 23:

$$\frac{VAh}{LSB}\,cst = \frac{VA \times Accumulation\,Time(s)}{3600 \times LVAENERGY} \tag{23}$$

where Accumulation Time is given in Equation 7. As for the active energy gain calibration, the accumulation time in the line accumulation mode depends on the line period (see the Line Period Measurement section).

The apparent gain calibration has to be done for each phase individually. The gain correction carried by the VADIV register affects all three phases similarly and should be used as a coarse gain compensation. The VAG registers should then be used to adjust the LVAENERGY register to the expected value for each individual phase (see Equation 24).

$$LVAENERGY = LVAENERGY_0 \times \frac{1}{VADIV} \times \left(1 + \frac{VAG}{2^{12}}\right) \tag{24}$$

where $LVAENERGY_0$ is the line apparent energy accumulation without gain calibration, e.g., WG = VADIV = 0.

Apparent Power Gain Calibration

As explained previously, the apparent power information per phase can be processed from the LVAENERGY register and the accumulation time. The conversion of the LVAENERGY register value to VA can be done by using the VAh/LSB constant and the accumulation time as:

$$Average\ Apparent\ Power\,(W) = \frac{LVAENERGY}{Accumulation\,Time} \times VAh/LSB\,cst$$

As the phase gains should be balanced, the only variables in this equation are the accumulation time, depending on the period register, and the actual reading from the LVAENERGY register.

Note: In the ADE7754, the apparent power measurement per phase has to be processed one phase at a time by changing the phase selected in the LVAENERGY accumulation. The switching between phases should follow the descriptions in Figure 10 by changing the MMODE and VAMODE register values.

ADE7754 CALIBRATION SOFTWARE

The ADE7754 calibration software is supported by Windows® based software that allows the user to calibrate the watt, rms, and VA measurements of the ADE7754. The software is designed to communicate with the ADE7754 evaluation board via the parallel port of a PC.

Installing the ADE7754 Calibration Software

The ADE7754 calibration software is supplied on one CD. The minimum requirements for the PC are Pentium® II 233 MHz, 32 MB RAM, 10 MB free HD space, and at least one PS/2 or ECP parallel port. To install the software, place the CD in the CD drive and double-click **setup.exe**. This launches the setup program that automatically installs all the software components, including the uninstall program, and creates the required directories. When the setup program has finished installing the "ADE7754Cal" program, instructions prompt the user to install the National Instruments run-time engine. This software was developed using National Instruments' LabView™ software; the runtime engine is required to run the ADE7754Cal program. Follow the on-screen instructions to complete the installation. To complete the installation, the computer will need to be rebooted.

To launch the software, go to **Start→Programs→ADE7754 menu** and select **ADE7754Cal**.

Uninstalling the ADE7754 Calibration Software

Both the ADE7754Cal program and the NI runtime engine are easily uninstalled by using the Add/Remove Programs facility in the Control Panel. Select the program to uninstall and click the Add/Remove button.

When installing a new version of the ADE7754 calibration software, the previous version should be uninstalled.

Default Mode

When the software is launched, the user has the choice to set the configuration of the meter to either nominal voltage, nominal current, line frequency, maximum current, minimum current, or meter constant for active power pulse output (see Figure 18).

When the calibration is launched, each phase is calibrated for active power gain, offset, phase mismatch, rms offsets, and apparent power gain. One phase is calibrated completely before going to the next phase. This software should be used in conjunction with the ADE7754 data sheet.

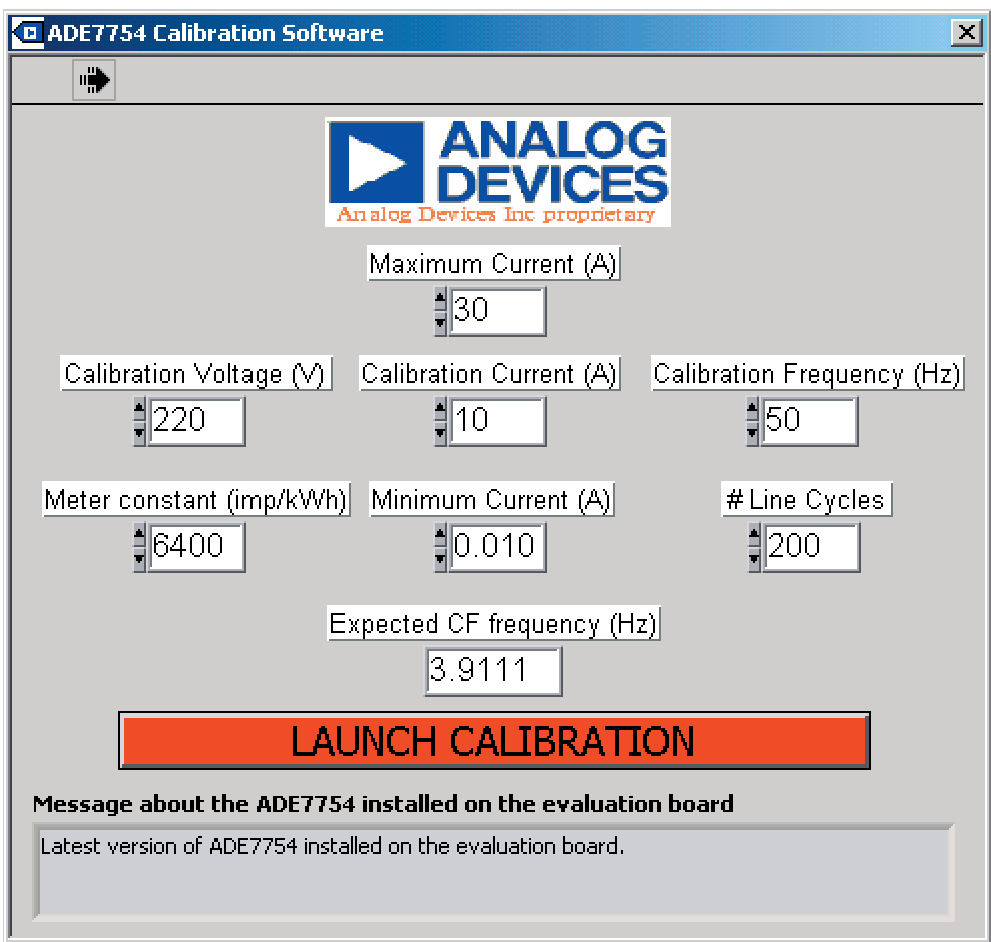

Figure 18. ADE7754 Calibration Default Window

ACTIVE ENERGY CALIBRATION

The ADE7754 calibration software manages the setup of the ADE7754 and the calibration procedure. When launched, a description of the next operation to perform or of the operation executed by the software is provided. The new message is framed in a red box. Carefully read each message before going to the next step of the calibration. The next step is carried out after clicking the green Next button (see Figure 19).

Active Energy Gain Calibration

As explained, the first step for calibration is to adjust the CF frequency to a predetermined constant. On a 3-phase product, this gain calibration has to be done on each phase separately to ensure correct gain balance between phases. It is assumed in the following that Phase A of the test equipment is connected to Phase A of the ADE7754; the same is true for Phases B and C.

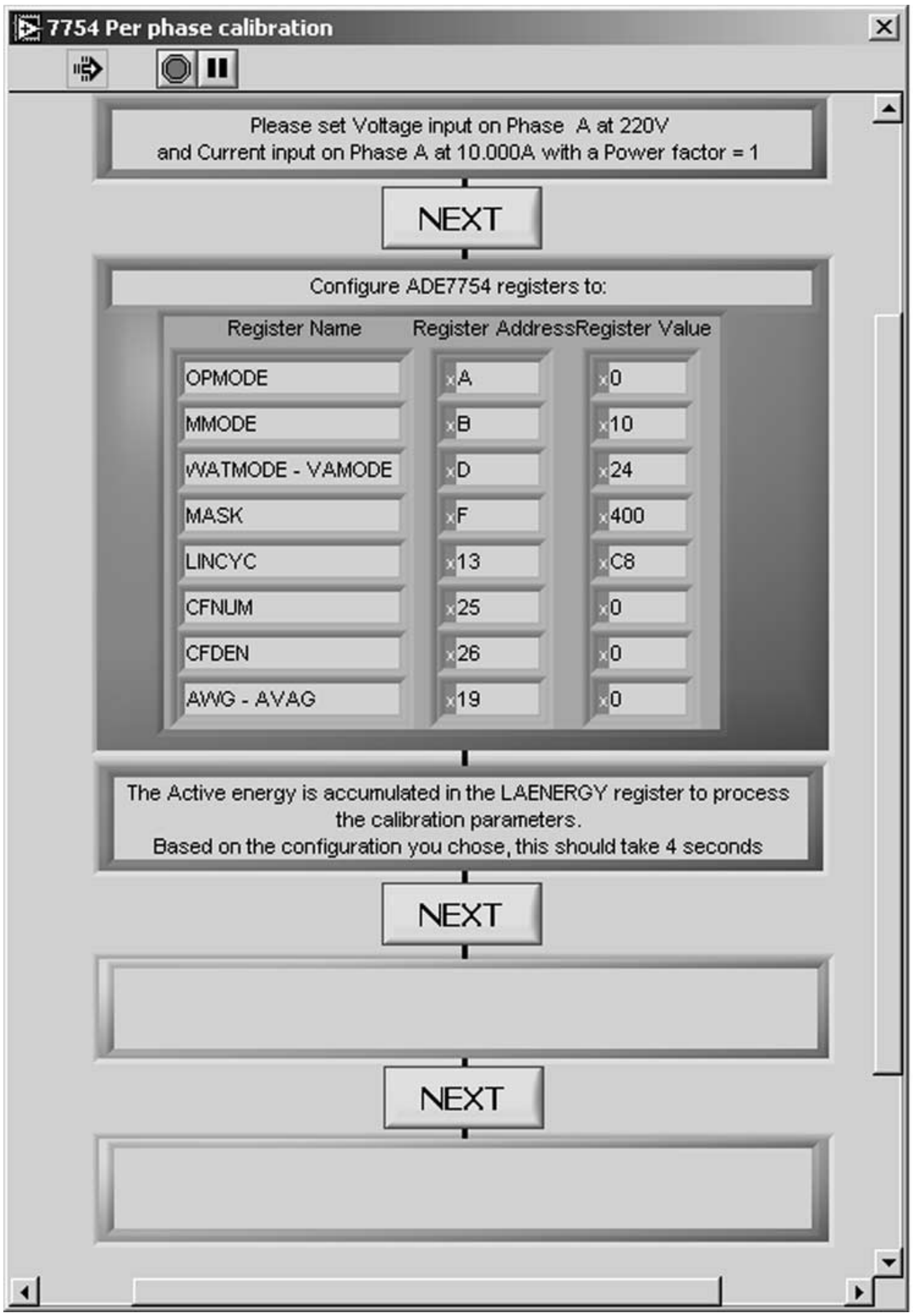

Figure 19. ADE7754 Calibration

The meter used as an example in this calibration procedure has three voltage sensors and three current sensors. The gain calibration can be done with only one test point. For a 220 V–30 A max meter, the test point chosen is 220 V and 10 A. The meter constant is 6400 imp/kWh. The expected CF frequency in this case is 220 × 10 × 6400/(1000 × 3600) = 3.911 Hz. The line frequency in this example is 50 Hz.

The ADE7754 should be set in MODE0 for the active energy calculation (WATMOD[7:6] = 00). Figure 20 shows the total active energy signal processing. The gain calibration will be done by adjusting the AWG, BWG, CWG, WDIV, CFNUM, and CFDEN registers. AAPGAIN, BAPGAIN, and CAPGAIN are not used for calibration in this mode.

WDIV and CFDEN are coarse gain adjustments for the total active energy and CF pulsed output. AWG, BWG, and CWG are fine gain adjustments for gain balancing.

For each phase, the active energy is accumulated over 200 half line cycles in the LAENERGY register (address 0x04). Only the calibrated phase is selected for line counting (WATMOD[2:0] = 1, 2, or 4 depending on the phase to calibrate).

Phase A: Active Energy Gain Calibration

All the registers are set to their default values, CFDEN is set to 0, the MMODE register is set to 0x10, the WATMODE register is set to 0x24, and Phase A current and voltage inputs are active. Phase B and Phase C inputs can be active as their contribution to the active energy is disabled inside the part during this test. Active energy is accumulated for 200 half lines cycles and 38760d is read from the LAENERGY register. A value of 8336d is read from the period register. Then, using Equation 2, the CF frequency under this load is calculated as:

$$CF\,(Hz) = \frac{38760 \times 2 \times \dfrac{1}{8336 \times 2.4 \times 10^{-6}} \times 1}{4 \times 200}$$

$$= 4843.45\ Hz$$

where WDIV = CFNUM = CFDEN = 0; accumulation time = 2.0006 seconds.

Note: When WDIV, CFNUM, or CFDEN is equal to zero, they are replaced by 1 in the calculation (see the ADE7754 data sheet).

The desired frequency output under the test point chosen is 3.911 Hz. Therefore, the CF frequency must be divided by 4843.45/3.911 = 1238.4d. This is achieved by loading the CFDEN register with 1238d. This coarse adjustment is valid for the calibration of all three channels.

The fine adjustment of Phase A can be made using the AWG register (address 0x19). CF varies with AWG as described in:

$$CF = CF_{INITIAL} \times \left(1 + \frac{AWG}{2^{12}}\right) \times \frac{CFNUM}{CFDEN}$$

With $CF_{INITIAL}$ = 4843.45 Hz, CFNUM = 0, and CFDEN = 1238d, AWG should be set to correct the mismatch between the target frequency (3.911 Hz) and the initial frequency. In this example, AWG should be set to –1d or 0xFFF.

In this example, the Wh/LSB can be processed using Equation 8:

$$\frac{Wh}{LSB} = \frac{4 \times 220 \times 10 \times 2.0006}{3600 \times 38760 \times \left(1 - \dfrac{1}{2^{12}}\right)} = 1.262 \times 10^{-4}$$

This constant is the same for all three phases. It should be noted that the resolution of the AENERGY register can be changed with the WDIV register. Increasing WDIV will reduce the reading out of the AENERGY register and, therefore, increase the Wh/LSB constant proportionally.

The procedure to calibrate Phase A is described in Figure 21.

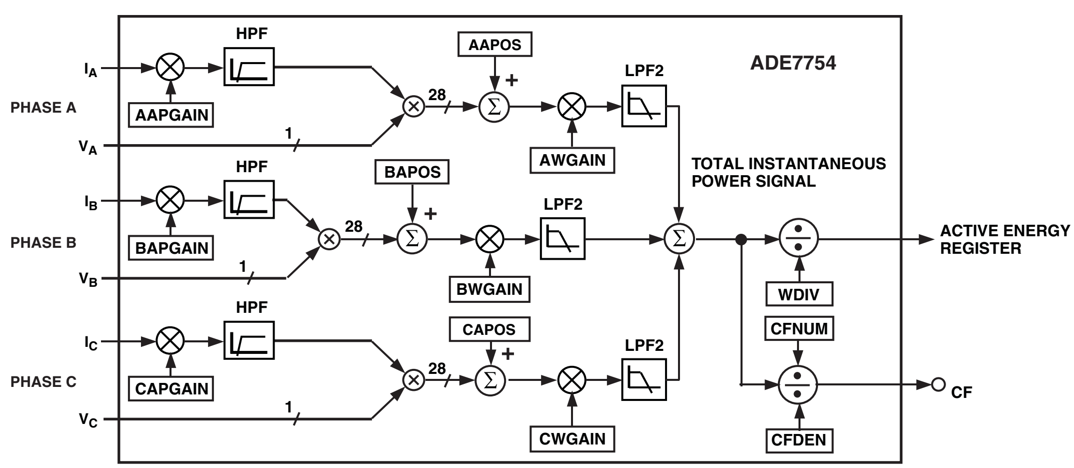

Figure 20. Total Active Energy Calculation

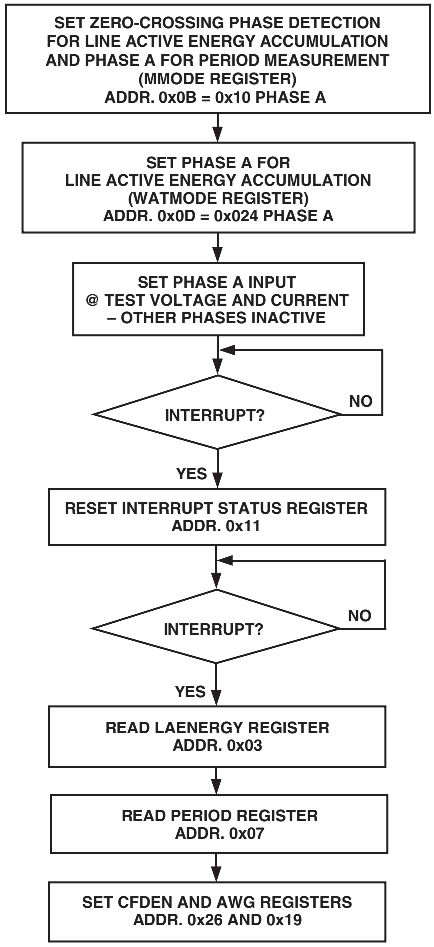

Figure 21. Active Energy Gain Calibration Procedure for Phase A

Phase B: Active Energy Gain Calibration

All the registers are set to their default values, CFDEN is set to 1238d, the WATMODE register is set to 0x12, the MMODE register is set to 0x21, and Phase B current and voltage inputs are active. Phase A and Phase C inputs can be active because their contribution to the active energy is disabled inside the part during this test. Active energy is accumulated for 200 half line cycles and 38631d is read from the LAENERGY register. A value of 8336d is read from the period register. Then, using Equation 6, the CF frequency under this load is calculated as:

$$CF\ (Hz) = \frac{38631 \times 2 \times \dfrac{1}{8336 \times 2.4 \times 10^{-6}} \times 1}{4 \times 200} \times \frac{1}{1238}$$

$$= 3.8993\ Hz$$

where CFNUM = 0 and CFDEN = 1238d.

The desired frequency output is 3.911 Hz with Phase B active only.

The fine adjustment of the output frequency can be made using the BWG register (address 0x1A). CF varies with BWG as described in Equation 4, replacing AWG by BWG.

With $CF_{INITIAL}$ = 3.8993 Hz, CFNUM = 0, and CFDEN = 1238d, BWG should be set to correct the mismatch between the target frequency (3.911 Hz) and the initial frequency. BWG should be set to 13d or 0x000D in this example.

Phase C: Active Energy Gain Calibration

All the registers are set to their default values, CFDEN is set to 1238d, the WATMODE register is set to 0x09, the MMODE register is set to 0x42, and Phase C current and voltage inputs are active. Phase A and Phase B inputs can be active because their contribution to the active energy is disabled inside the part during this test. Active energy is accumulated for 200 half lines cycles and 38687d is read from the LAENERGY register. Following the same procedure as for Phase B, the CWG register should be adjusted to 7d to reach the expected CF frequency.

Active Power Offset Calibration

As explained previously, the calibration of the active power offset can increase the performance of the energy meter over the current dynamic range. In the example used in this document, the minimum current is 10 mA for a maximum current of 30 A and a reference current of 10 A.

Phase A: Active Power Offset Calibration

Using the previous setup as a reference, 38760d is read from the LAENERGY register at I_{REF} (10 A) with 200 half line cycles. At 10 mA under the same conditions, the accumulation in the LAENERGY register would be around 38d if no offset were present. A value of 38d is too small to make an accurate offset compensation calculation where an accuracy of at least 0.1% is needed. With 38d, the resolution error is already 2.6%/LSB in the reading itself. It is necessary to use a larger number of half line cycles to get a larger value from the LAENERGY accumulation at low current.

To get enough resolution for the active power offset compensation, a lower limit of 2000d for the LAENERGY accumulation at low current is fixed in the ADE7754 calibration software, i.e., resolution of 0.05%/LSB.

In our example, the number of half line cycles necessary to get this value is: LINCYC = 2000/(38760/10 × 0.01) × 200 = 10320. The accumulation time in this case is roughly 10320/2/50 = 103 seconds.

Under the same conditions as for the Phase A gain calibration with LINCYC = 10320d, the LAENERGY accumulation read from the ADE7754 is 2041d.

As the two line active energy accumulations use different accumulation time and the second measurement is done after gain calibration, it is necessary to scale the first measurement (at 10 A) to the value it would be with LINCYC = 10320 and to AWG = –1:

$LAENERGY1 = 38760 \times 10320 \times (1 - 1/2^{12})/200 = 1999528d.$

$I_1 = 10$; $I_2 = 0.01$; $LAENERGY_2 = 2041d$; PERIOD = 8336d

From Equation 10: Offset = 41d

From Equation 11: n = 258082560d

then AAPOS = –43d = 0xFD5.

Figure 22 shows the active energy accuracy performances of a meter with and without watt offset compensation.

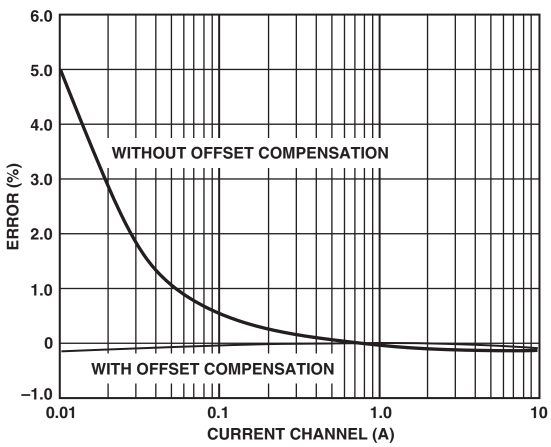

Figure 22. Active Energy Linearity Errors

Note: This calibration step can take a large amount of time due to the accumulation time needed for an accurate measurement of the active energy at low current. The user can decide the minimum current in the first window of the ADE7754 calibration software. This minimum current is used as the low end point of the active energy offset calibration. Increasing this value will reduce the calibration time. Depending on the resolution needed at low current, a minimum of 2000 LSB for the LAENERGY accumulation might not be necessary. In the ADE7754 calibration software, the user can change the number of line cycles for the next LAENERGY accumulation (Figure 23). The value proposed in the window correspond to an approximate LAENERGY accumulation of 2000 LSB under the conditions specified.

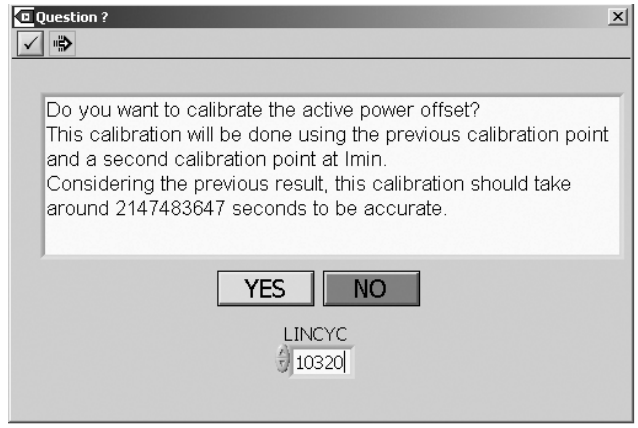

Figure 23. Change LINCYC Register for Offset Calibration

Phase B and C: Active Power Offset Calibration

The watt offset calibration of Phase B and Phase C can be done the same way using the ADE7754 calibration software. The configuration of the ADE7754 for each phase is the same as the one used for the gain calibration for the same phase.

Phase Calibration

As explained previously, phase mismatch between voltage and current inputs can create a large error in the watt measurement at low power factor. In the ADE7754 calibration software, the phase error calibration is done by using the first measurement collected for watt gain calibration and by doing another measurement at PF = 0.5 with inductive load (voltage leading current).

As for the watt gain calibration, the active energy is accumulated over 200 half line cycles in the LAENERGY register (address 0x04) for each phase. Only the calibrated phase is selected for line counting (WATMOD[2:0] = 1, 2, or 4, depending on the phase to calibrate).

Phase A: Phase Calibration

The setup is the same as for the Phase A gain calibration. Phase A current and voltage inputs are active with a PF = 0.5 (inductive load). Active energy is accumulated for 200 half line cycles and 19442d is read from the LAENERGY register. A value of 8336d is read from the period register. As the first measurement (for gain calibration) has been done without gain compensation and the second measurement with it (AWG = –1), the first measurement has to be compensated for this change: $38760 \times (1 - 1/2^{12}) = 38750.5$.

The error given by Equation 13 is then 0.344% or 0.11°.

Using Equation 16, the phase calibration register (APHCAL) is calculated as:

$$APHCAL = -0.11 \times \frac{8336 \times 2.4\ \mu s}{360° \times 1.2\ \mu s} = -5$$

Phase B and C: Phase Calibration

The phase calibration of Phase B and Phase C can be done the same way, using the ADE7754 calibration software. The configuration of the ADE7754 for each phase is the same as the one used for the gain calibration for the same phase.

RMS CALIBRATION

The ADE7754 provides six rms measurements for the six analog inputs. These rms calculations have to be calibrated for offset to give an accurate measurement at low levels. The ADE7754 provides rms offset correction registers for each rms measurement.

The ADE7754 does not provide rms gain correction. As explained before, the rms gain calibration has to be done in the MCU. The ADE7754 calibration software provides the calibration constants (V/LSB and A/LSB) that can be used in the MCU for conversion of the rms register values to the actual inputs.

Figures 24 and 25 show the difference with and without rms offset compensation for the voltage and current inputs.

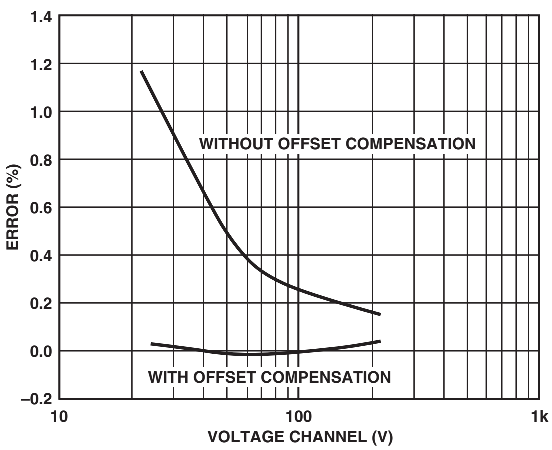

Figure 24. Voltage RMS Linearity Errors

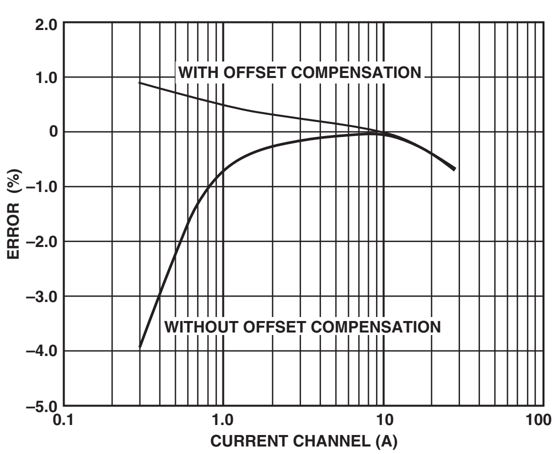

Figure 25. Current RMS Linearity Errors

RMS Offset Calibration

Phase A: RMS Offset Calibration

All the registers are set to their default values, except CFDEN, AWG, APHCAL, and AAPOS, which are set to their calibrated values. The MMODE register is set to 0x70 (ZXSEL Phase A, Phase B, and Phase C enabled), the MASK register is set to 0x0380 (ZXA, ZXB, ZXC interrupts enabled only).

Phase A current input is set to its reference value (10 A) and Phase A voltage input is set to its nominal value (220 V). Voltage and current rms Phase A registers (address 0x2C and 0x29, respectively) are read as described in Figure 13 and averaged over 500 samples: VRMS1 = 1019627d and IRMS1 = 436988d.

Note: In the ADE7754 calibration software, these measurements are done during the watt gain calibration.

Under the same conditions, the voltage and current inputs are changed to $V_{NOMINAL}/10$ (22 V) and $I_{MAX}/100$ (0.3 A). The voltage and current rms phase A registers are read as described in Figure 13 and averaged over 500 samples: V_{RMS2} = 102246d and I_{RMS2} = 14059d.

Based on these measurements, the voltage rms offset and current rms offset register values can be processed using Equation 20 and 22:

$$AVRMSOS = \frac{1}{64} \times \frac{220 \times 102246 - 22 \times 1019627}{22 - 220} = -5$$

$$AIRMSOS = \frac{1}{32768} \times \frac{10^2 \times 14059^2 - 0.3^2 \times 436988^2}{0.3^2 - 10^2} = -788$$

The V/LSB and A/LSB constant can be processed from the measurements at 220 V and 10 A:

Phase A V/LSB = 220/1019627 = 2.158×10^{-4}

Phase A A/LSB = 10/436988 = 2.288×10^{-5}

Phase B: RMS Offset Calibration

All the registers are set to their default values, except CFDEN, BWG, BPHCAL, and BAPOS, which are set to their calibrated values. The MMODE register is set to 0x71 (ZXSEL Phase A, Phase B, and Phase C enabled). The MASK register is set to 0x0380 (ZXA, ZXB, ZXC interrupts enabled only).

The two measurements at 220 V–10 A and 22 V–0.3 A can be done in the same manner as for Phase A and will lead to the calculation of BIRMSOS, BVRMSOS, Phase B V/LSB, and Phase B A/LSB values.

Phase C: RMS Offset Calibration

All the registers are set to their default values, except CFDEN, CWG, CPHCAL, and CAPOS, which are set to their calibrated values. The MMODE register is set to 0x72 (ZXSEL Phase A, Phase B, and Phase C enabled). The MASK register is set to 0x0380 (ZXA, ZXB, ZXC interrupts enabled only).

The two measurements at 220 V–10 A and 22 V–0.3 A can be done in the same manner as for Phase A and will lead to the calculation of CIRMSOS, CVRMSOS, Phase C V/LSB, and Phase C A/LSB values.

APPARENT ENERGY GAIN CALIBRATION

As explained in the ADE7754 data sheet, each component of the apparent calculation (V_{RMS} and I_{RMS}) is offset calibrated, so the apparent power measurement does not need to be offset calibrated.

The gain calibration of the apparent power measurements has two steps:

1. Calibrate the apparent power to a nominal value determined by design.
2. Calibrate the apparent power per phase to the same value (phase balancing).

In the ADE7754 calibration software, no predetermined value is set. The software will select the first apparent energy value read from the first phase calibrated as a reference and will change the VAG registers of the other phases to match this value. This method differs from the gain calibration for the active power where a predetermined value is set by the meter constant imp/kWh.

The ADE7754 should be set in MODE0 for the apparent energy calculation (VAMOD[7:6] = 00). Figure 26 shows the total apparent energy signal processing. The gain calibration will be done by adjusting the AVAG, BVAG, CVAG, and VADIV registers. AAPGAIN, AVAGAIN, BAPGAIN, BVGAIN, CAPGAIN, and CAVGAIN are not used for calibration in this mode.

VADIV is the coarse gain adjustment for the total apparent energy. AVAG, BVAG, and CVAG are fine gain adjustments for gain balancing.

For each phase, the apparent energy is accumulated over 200 half line cycles in the LVAENERGY register (address 0x06). Only the calibrated phase is selected for line counting (VAMOD[2:0] = 1, 2, or 4, depending on the phase to calibrate).

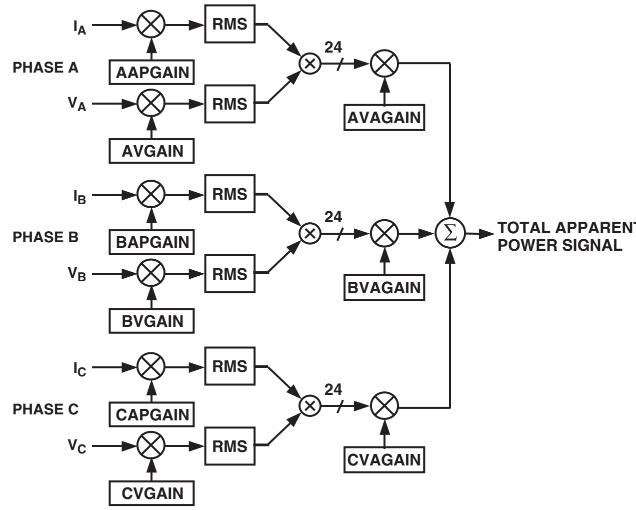

Figure 26. Total Apparent Energy Application

Phase A: Apparent Energy Gain Calibration

All the registers are set to their default values, the MMODE register is set to 0x10, the VAMODE register is set to 0x24, and only Phase A current and voltage inputs are active. Phase B and Phase C inputs can be active since their contribution to the apparent energy is disabled inside the part during this test. Apparent energy is accumulated for 200 half line cycles and 10582d is read from the LVAENERGY register. A value of 8336d is read from the period register. The value from the LVAENERGY register is used as the reference value for the gain calibration.

Accumulation time = 2.0006 seconds.

In this example, the VAh/LSB constant can be processed using Equation 23:

$$\frac{VAh}{LSB}cst = \frac{220 \times 10 \times 2.0006}{3600 \times 10582} = 1.1554 \times 10^{-4}$$

This constant is the same for all three phases. It should be noted that the resolution of the VAENERGY register can be changed with the VADIV register. Increasing VADIV will reduce the reading out of the VAENERGY register and, therefore, increase the VAh/LSB constant proportionately.

Phase B: Apparent Energy Gain Calibration

All the registers are set to their default values, the VAMODE register is set to 0x12, the MMODE register is set to 0x21, and only Phase B current and voltage inputs are active. Phase A and Phase C inputs can be active because their contribution to the apparent energy is disabled inside the part during this test. Apparent energy is accumulated for 200 half line cycles and 10558 is read from the LVAENERGY register. A value of 8336d is read from the period register. The expected value for this register is 10582 (from Phase A measurement). The fine adjustment of the LVAENERGY register value can be made using BVAG register (address 0x1D). The LVAENERGY register value varies with BVAG as described in Equation 24.

With LVAENERGY0 = 10558, VADIV = 0, BVAG should be set to correct the mismatch between the target register value (10582) and the actual measurement. BVAG should be set to 9d or 0x0009 in this example.

Phase C: Apparent Energy Gain Calibration

CVAG (address 0x1E) is set to its default value, the VAMODE register is set to 0x09, the MMODE register is set to 0x42, and only Phase C current and voltage inputs are active. Phase A and Phase B inputs can be active as their contribution to the apparent energy is disabled inside the part during this test. Apparent energy is accumulated for 200 half lines cycles and 10571d is read from the LVAENERGY register. Following the same procedure as for Phase B, the CVAG register should be adjusted to 4d to reach the expected LVAENERGY register value.

E03546–0–4/03(0)