

## **Analog Devices Energy (ADE) Products: Frequently Asked Questions (FAQs)**

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### **INTRODUCTION**

This application note answers a series of frequently asked questions about Analog Devices, Inc., ADE products. This application note includes general questions and more specific questions, including product-specific questions, as well as meter configuration information and questions.

### **GENERAL**

#### ***How do I obtain samples of a preliminary product and evaluation board?***

Request samples of prereleased products (products with preliminary data sheets) through your local distributor or sales representative. The Analog Devices, Inc., Sales and Distributors listing is available [online](#). Be sure to mention that the product is prereleased. The preliminary data sheet, if available, should include the evaluation board part number in the Ordering Guide section.

#### ***Where do I find the evaluation tools and software pertaining to the evaluation board?***

The LabVIEW® executable file and microcontroller codes, along with the driver software, are included on a CD that comes with the evaluation board package. For newer ICs, most of this information is available online. Otherwise, codes can be sent separately to interested customers.

#### ***How can I obtain technical support on the use of ADE products?***

[Engineer Zone](#) is an Analog Devices online support community. Support for the ADE product family is found in the community named Energy Monitoring and Metering. Customers from all over the world can post questions, and view existing questions and answers as well as ongoing discussions in this community.

#### ***What are the different ADE products currently available in the market?***

The different ADE products currently available can be found [online](#). The site contains all the single-phase and poly-phase ADE products tabulated with different features for each of the solutions. New product releases and other up-to-date information about the ADE product family can be also found here.

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**REVISION HISTORY**

5/13—Revision 0: Initial Version

## METERING

### What are the pros and cons of using AFE over SOC?

Analog front-end (AFE) ICs provide flexibility to the energy meter manufacturers in terms of their microcontroller choice, interfacing, and selection of required features, whereas SOC include a microcontroller. AFE ICs also provide flexibility in regard to manufacturing cost, which can serve a wide range of customers and applications.

With increasing interest in developing communication capabilities of the meters, AFEs let the manufacturers select the microcontroller of their choice. In addition, when meter designers look to upgrade their microcontrollers, AFEs are the clear choice because SOC cannot be altered easily.

### What is the life span of a metering IC?

Tests such as autoclave (AC), biased HAST (HAST), high temperature storage life (HTSL), solder heat resistance (SHR), temperature cycling (TC), temperature humidity bias (THB), high temperature operating life (HTOL), electrostatic discharge (ESD), and latch-up tests are conducted to demonstrate the reliability of ADE ICs. More details on the tests conducted on each product and the durability of the ICs are provided in the [Reliability Handbook](#).

### What is the difference between active, reactive, and apparent energy?

Active energy is measured in kilowatt hours, while reactive and apparent energy are measured in VAR hours and VA hours, respectively. Figure 1 shows the relationship between active, reactive, and apparent energy. The relationship shown in Figure 1 holds true for pure sinusoids at the fundamental frequency. In the presence of harmonics, this relationship is not valid.

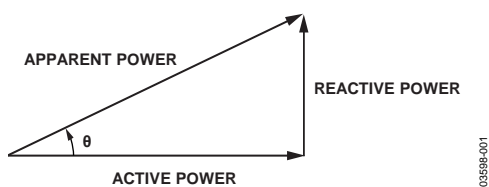


Figure 1. Power Triangle

The relationships are as follows:

$$\text{Active Power} = VI \cos \theta$$

$$\text{Reactive Power} = VI \sin \theta$$

$$\text{Apparent Power} = VI$$

$$\text{Power Factor} = \cos \theta$$

Utilities typically bill customers on active energy consumption only. When the load is purely resistive, only real or active energy is transferred. However, if the load is either capacitive (in the case of capacitive voltage transformers) or inductive (in the case of motors), reactive energy also flows. Utilities, however, care most about apparent power because even though the current associated with the reactive power does no work at the load, it heats the wires, wasting energy. Conductors, transformers, and generators must be sized to carry the total current, not just the current that does useful work.

### What is the power factor?

The quantity  $\cos(\theta)$  is known as the power factor, where  $\theta$  is the angle between active and apparent power vectors (and no harmonics are present). The general definition of power factor (PF) is, therefore, the ratio between real (or active) and apparent power.

$$PF = \frac{\text{Active Power}}{\text{Apparent Power}}$$

Some utilities charge a penalty for a low power factor. Common causes of a low power factor are induction motors and transformers. Reactance is introduced onto the line when current is displaced or shifted out of phase with the voltage by an angle  $\theta$ .

### What is creeping in regard to energy meters?

Creeping is the phenomenon in which the energy meter still shows some minimal energy consumption when there is no load attached to the meter. This is due to some inherent real world noise and it causes inconvenience to customers because they are billed even if they have not consumed any electricity. All ADE ICs have a no-load threshold at a minimum to prevent this phenomenon.

## CURRENT SENSORS AND INPUT SECTION

### What current sensor should I use with ADE ICs?

Analog Devices does not currently partner with or recommend any current sensor manufacturer. Meter manufacturers and other customers must perform their own evaluation and selection of current sensors. If the full dynamic range of ADE ICs' performance is desired, then care should be taken to use current sensors that have the desired accuracy over this range.

However, some of the benefits and drawbacks of the different current sensor technologies are provided in Table 1.

Table 1. Sensor Technologies

Sensor	Benefits	Drawbacks
Low Resistance Shunt	Very low cost, good linearity	Poor high current capability, dc offset, parasitic inductance
Current Transformer	Good high current performance, low power consumption	Hysteresis/saturation due to dc, phase shift, susceptible to external magnetic fields
Hall Effect Sensor	Good high current performance, wide dynamic range	Hysteresis/saturation, higher cost, temperature drift
Rogowski Coil (Air-Core CT)	Low cost, no saturation limit, low power consumption, immunity to dc offset, wide dynamic range, very low temperature range	Output is derivative of voltage signal—requires an analog (or digital) integrator. EMI sensitivity.

Many ADE ICs have a built-in digital integrator for easy interface with a Rogowski coil. In all cases, the integrator can be turned off to interface with a current transformer (CT) or shunt.

#### What are the considerations for selecting the shunt?

The following are several main considerations for the shunt:

- Thermal management consideration. For a large (high resistance) shunt, there will be significant temperature rise if the current is large.
- Shunt quality. The self-heating of the shunt can increase its resistance. The output signal can vary because of this, and affects the accuracy of the meter.
- Tampering consideration. The resistance of the shunt should be as close to a wire as possible to minimize the effect of any attempt to divert the current using an external wire.
- Signal level. The shunt should provide reasonable signal levels to the IC over the current operation range.
- Power consumption requirement. According to IEC 61036, the power consumption per channel cannot exceed 2 W. Larger shunts consume more power.

#### What are the considerations for selecting a current transformer (CT)?

Care should be taken to ensure that the dynamic range for current sensing with a given CT is large enough for the application. Current transformers can saturate under large dc or high current, and designers should choose CTs rated for their needs. CTs can introduce phase shift and should be chosen according to the designer's ability to compensate for this error. In addition, note that certain CTs introduce an inherent scaling error depending on the turns ratio selected and, thus, care must be taken to ensure that the current level at the secondary of the CT is the same as expected.

#### How do I compensate for the phase shift of my current sensor?

The internal PHCAL register can be used in all ADE products (except ADE7761B, ADE7757A, ADE7768, ADE7769, ADE7751, ADE7755, ADE7762, and ADE7752A) to adjust the phase lead/lag. Adjusting the phase mismatch is a simple procedure of writing to the register. Refer to the specific data sheet for details. If the compensation range is beyond that of the PHCAL register, a combination of both hardware and software phase adjustment can be used. For example, you can use the hardware method to roughly compensate the default phase mismatch and use the PHCAL register as a fine adjustment in production. If a hardware method is required, the phase mismatch at the line frequency can be corrected by adjusting the corner frequency of the RC filter (used for antialiasing on the input channels) to create a phase shift that would offset the phase error. The AN-563 Application Note provides a detailed description of how to adjust the phase mismatch.

#### How do I calculate the burden resistor to use with my current transformer?

The burden resistor depends on the maximum current ( $I_{MAX}$ ), the input level to the ADC ( $y$ ), and the number of turns in the CT being used ( $CTRN$ ). At maximum current, the input signal at the current channel should be at half input full scale to allow headroom. The full scale can be 660 mV p-p, 500 mV p-p, or 1 V p-p, depending on the product. Refer to the product data sheet for specifications. Assuming that the 5750:1 CT is center-tapped as shown in the Figure 2, the burden resistor can be calculated as shown in Figure 2.

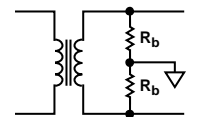


Figure 2. CT with Center-Tapped Burden Resistors

$$\begin{aligned}
 y &= \frac{\text{FullScale}}{2} = \frac{500 \text{ mV peak}}{2} \\
 &= \frac{353.55 \text{ mV rms}}{2} \\
 &= 176.8 \text{ mV rms}
 \end{aligned}$$

The following equations apply:

$$\begin{aligned}
 \frac{I_{max}}{CTRN} &= x \\
 \frac{y}{x} &= 2R_b
 \end{aligned}$$

where  $CTRN = 5750$ .

Solve for  $R_b$ . For example, if  $I_{MAX}$  is 113.1 A rms,  $R_b = 4.5 \Omega$ .

It is recommended to use a center-tapped burden as shown in Figure 2. If the burden resistor is not center-tapped as shown in

Figure 3, then the single burden resistor value connected would be twice the value of  $R_b$  calculated previously.

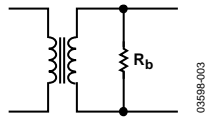


Figure 3. CT with a Single Burden Resistor

$$R_b = \frac{y}{x} = 9 \Omega$$

### How does the Rogowski coil work?

The basic operating principle of a Rogowski coil is to measure the primary current through mutual inductance.

When current passes through a conductor, a magnetic field forms around the conductor. The magnitude of the magnetic field is directly proportional to the current. The changes in the magnetic field induce an electromotive force (EMF) within a wire loop. The EMF is a voltage signal and is proportional to the changes in the magnetic field inside the loop. The output voltage of the loop is, therefore, proportional to the time differentiation ( $di/dt$ ) of the current.

A Rogowski coil is typically made with an air core, so, in theory, there is no hysteresis, saturation, or nonlinearity. Because the Rogowski coil relies on measuring the magnetic field, it makes this type of current sensor more susceptible to external magnetic field interference than the CT.

Details and equations can be found on the Analog Devices website in the technical article entitled [Current Sensing for Energy Metering](#).

### Where can I find a CT or a Rogowski coil?

There are many CT manufacturers and several Rogowski coil manufacturers around the world, and you can find a few listed here. Detailed information about the company and product is available online for each company. However, note that Analog Devices does not recommend or partner with any of these companies.

Rogowski coil manufacturers

- Taehwatrans Co., Ltd.
- Pulse Engineering, Inc.

Current transformer manufacturers

- Taehwatrans Co., Ltd.
- Vacuumschmelze GMBH Components
- CR Magnetics
- Shenzhen Belta Electronics Co.
- M/S Shah Electronics
- M/S Forbes Gokak Ltd.
- M/S Electro-Ohms

- Bicron Electronics Co.
- Magnetic GMBH

### How can I use one CT or Rogowski coil in a single-phase, 3-wire configuration?

In the United States (and some other locations), residential power is distributed in a single-phase, 3-wire configuration. Two wires, namely L1 and L2, have voltage signals that are 180° out of phase with each other and share a common neutral wire. In theory, two current and two voltage sensors are required. However, an approximation method (which is generally very close to the actual situation) can be used such that only one current sensor and one voltage sensor is sufficient. The assumption in this case is that the amplitude of the two-phase wires is the same and that they are 180° out of phase. One can simply use the voltage difference between L1 and L2 and multiply by the sum of the currents in L1 and reverse of L2.

$$\text{Instantaneous power on L1} = V1N \times \text{Current L1}$$

$$\text{Instantaneous power on L2} = V2N \times \text{Current L2}$$

$$\begin{aligned} \text{Instantaneous total power} &= \text{Power on L1} + \text{Power on L2} \\ &= V1N \times \text{Current L1} + V2N \times \text{Current L2} \end{aligned}$$

Assuming

$$V1N = -V2N = \frac{V1N - V2N}{2}$$

Instantaneous total power

$$\begin{aligned} &= V1N \times \text{Current L1} + V2N \times \text{Current L2} \\ &= V1N \times \text{Current L1} - V1N \times \text{Current L2} \\ &= (V1N - V2N/2) \times (\text{Current L1} - \text{Current L2}) \end{aligned}$$

The divide-by-2 factor is compensated for in the calibration process.

In the [AN-564](#) Application Note, the CT is used for summing the current properly. Use one CT with both L1 and L2 passing through in opposite directions to generate the sum of the two currents, or use two CTs to monitor individual phase currents and sum them externally (by connecting the two in parallel). Take care when using a single CT for the summation; the CT needs to be able to handle the total current in both phases. For example, if each phase wire has a maximum of 100 A, the CT needs to have a 200 A capability. In addition, in case of using two different CTs for summation, note that extra care needs to be taken to ensure that the phase shifts introduced by both CTs are the same.

### How is the performance of ADE ICs with Hall-effect sensors?

Hall-effect sensors can be used with ADE ICs for current sensing; however, they are not used often. Hall-effect sensors produce an output with a dc offset and it needs to be removed prior to applying the signal to the ADE. This can be done with a simple dc blocking capacitance in series with the signal. In addition, hall-effect sensors can be placement sensitive and this

creates challenges in mass producing meters with them. That being said, some customers do use them.

**Can I use a different crystal frequency than specified?  
What happens if I use the same crystal for multiple ICs?**

The specifications provided are for a particular crystal frequency. Analog Devices cannot guarantee the same results if a different crystal frequency is used. Crystals can be used for multiple ICs, but, if so, a buffer must be used. The CLKOUT of a crystal does not have enough drive strength to drive a second load, unless otherwise specified.

**Why do I need antialiasing filters on the input channels?**

Antialiasing filters are required for the ADCs at the input terminals of the ADE IC to prevent possible distortion due to the sampling in the ADC. According to the Nyquist theory, image frequencies near the sampling frequency can get folded back around half the sampling frequency and end up in the band of interest, causing distortion. A simple low-pass filter can attenuate the high frequencies, so they do not end up in the band of interest for metering (less than 2 kHz).

**SYSTEM-LEVEL QUESTIONS**

**What are the considerations for designing the ground plane on an energy meter PCB?**

From the PCB designer's standpoint, analog ground (AGND) and digital ground (DGND) pins of the ADE IC should be tied together outside the chip with the lowest impedance connection possible. They are not connected within the chip because the noise present in the digital channel might enter the analog circuitry and affect its performance. Thus, when they are tied together outside the chip, they must be connected to the analog ground plane of the system. All the other circuitry, such as current sensor circuit, crystal oscillator circuit, and the microcontroller, must be grounded to the digital plane of the system.

The analog ground plane and the digital ground plane should be physically separated from each other and should be connected only at one point (star ground configuration), preferably beneath the chip or the shortest route possible. It is recommended that the AGND and DGND pins of the ADE IC be connected exactly at the same point as this star ground connection beneath the chip.

Figure 4 and Figure 5 provide an example of a PCB layout proposal for the [ADE7878](#) with two layers that have components placed only on top of the board. Following these layout guidelines helps to create a low noise design with higher immunity to EMC influences. Note that only the connections pertaining to the decoupling capacitors, the crystal, and its load capacitors are shown here; the remainder of the pins that are dependent on the particular application are not shown.

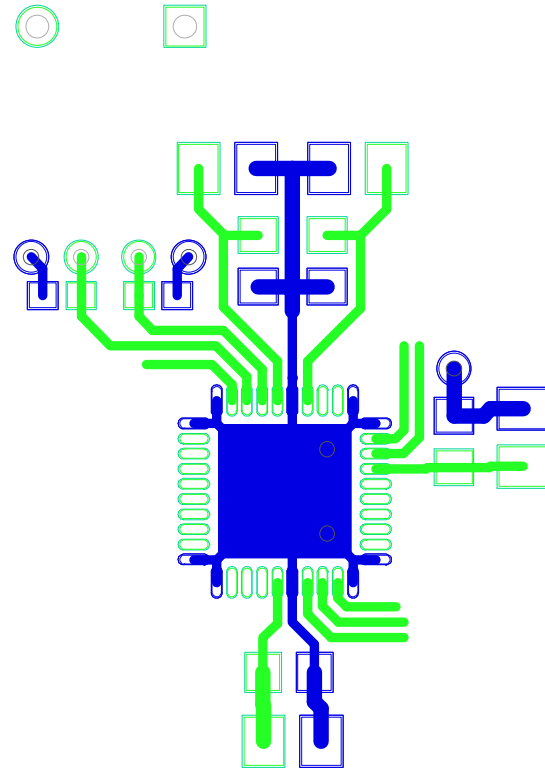


Figure 4. [ADE7878](#) Top Layer Printed Circuit Board

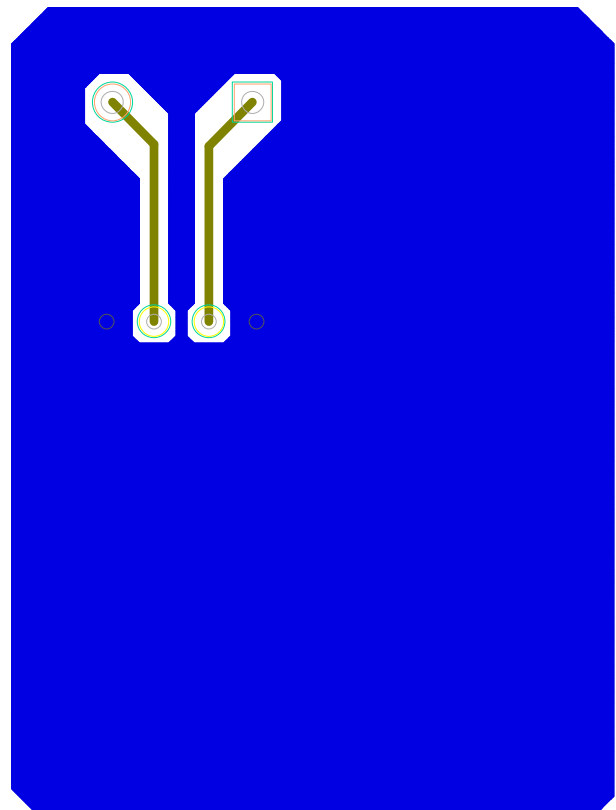


Figure 5. [ADE7878](#) Bottom Layer Printed Circuit Board

The VDD, AVDD, DVDD, and REF<sub>IN/OUT</sub> pins each have two decoupling capacitors, one of  $\mu\text{F}$  order and a ceramic one of 220 nF or 100 nF. These ceramic capacitors need to be placed closest to the ADE7878 because they decouple high frequency noise, while the microfarad capacitors can be placed in close proximity. Place the crystal load capacitors closest to the ADE7878, while the crystal can be placed in close proximity. The exposed pad of the ADE7878 is soldered to an equivalent pad on the PCB. The AGND and DGND traces of the ADE7878 are then routed directly into the PCB pad. The bottom layer is composed mainly of a ground plane surrounding as much as possible the crystal traces.

These recommendations can be extended to all ADE ICs. Note the exposed PCB pad is not present for some of the older ICs.

### What are the system design considerations for electrical fast transient (EFT) burst testing?

The following list provides some useful tips:

- Use ferrites at points where the meter is connected to the line.
- Use a metal oxide varistor (MOV) and shunt capacitor between the line wires.
- Maximize the physical distance between the areas with possible high voltage to avoid sparks.

### What are the system design considerations for electromagnetic interference (EMI) testing?

The following list provides some useful tips:

- The ground plane should be made as large as possible.
- Use a short signal path on the analog portion of the PCB.
- Eliminate ground loops.
- Use short and tight twisted-pair wires.
- Consider physical shielding.

### If the kit is not responding, how do I systematically find where the problem is?

Many users run into situations where the kit does not respond or function as expected. This could be due to a variety of simple errors.

Follow these steps to debug the issue:

1. Check if the device is operational. To verify
  - Check if the VDD pin is powered up by the power supply.
  - Check the VREF pin. If it is not high, then the part is not powered up.
  - Check the PM1 and PM2 registers for mode select (when using ADE78xx or ADE7878).
  - Ensure that the crystal or clock is attached.
2. If Step 1 is complete yet problems remain, then check the COMS by following the bulleted items listed in Step 1.
  - Check if the evaluation software is running and the COM port is found.

- Use a scope to follow the signals from the PC through the microcontroller to the ADE. Check if the signals reach the ADE chip.
- Check if the ADE is responding.

3. Ensure that you can read and write to the registers.

Following these steps when encountering a problem helps distinguish the root cause of the problem easily.

### Can ADE ICs be used with Linux drivers? Are there any example codes available?

Analog Devices currently does not support Linux-based drivers. ADE software has been built and tested only for the Windows® operating system.

## CHIP-LEVEL QUESTIONS

### Which metering standards do ADE products meet?

The latest ADE IC performance meets the IEC 62053-21, IEC 62053-22, IEC 62053-23, EN 50470-1, EN 50470-3, ANSI C12.20, and IEEE1459 specifications. Refer to individual product specifications found on the relevant product data sheets for details or confirmation of compliance with other metering specifications.

### Can ADE ICs be used in both 50 Hz and 60 Hz environments?

Yes. ADE IC performance over frequency (45 Hz to 70 Hz) is shown in the Typical Performance Characteristics section of each data sheet.

### How do I interpret the sign of the reactive or active power in the ADE ICs?

Figure 6 demonstrates how to interpret the sign of the energy registers.

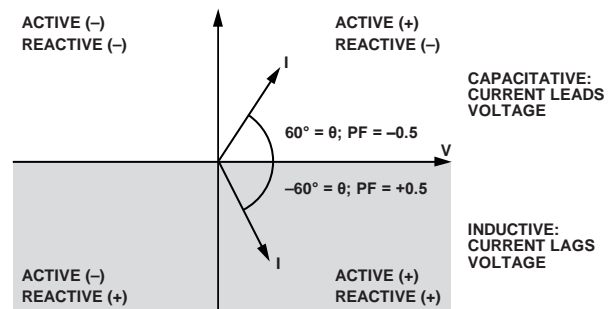


Figure 6. Sign of Reactive and Active Power in ADE ICs

### What is the effect of phase mismatch in the voltage and current channels?

The percentage measurement error in active power caused by any phase mismatch between the voltage and current signal paths can be approximated by the following formula:

$$\text{Error} \approx \text{Mismatch (radians)} \times \tan\theta \times 100\%$$

In this expression,  $\theta$  represents the phase angle between the voltage and current. A phase mismatch of 0.1 results in about 0.3% error at a power factor of 0.5. Therefore, special care needs

to be taken to ensure phases are precisely matched between the internal signal paths for the voltage and current. A large error can occur at a low power factor with even a small phase mismatch.

#### **At what test current do I calibrate my meter?**

Meters are typically calibrated at a specified base current ( $I_B$ ). This current is usually 10% of the maximum current ( $I_{MAX}$ ). Do not calibrate the meter at analog full-scale input level as that may cause problems in the event of spikes.

#### **What are the different serial port communication options available when using ADE ICs for meters?**

ADE ICs offer up to four different serial port communication options: I<sup>2</sup>C, SPI, UART, and high speed data capture (HSDC). Selection of which serial port interface to use depends on the application purpose and requirements.

I<sup>2</sup>C implementation requires only two pins; however, because they are bidirectional, this is expensive to isolate, and also cannot address devices individually. This is available in the [ADE7953](#), [ADE7878](#), and [ADE7880](#).

SPI implementation provides a faster communication and offers a chip select pin for communicating with multiple devices. However, it uses four wires, which must be isolated for some meters. SPI ports can be found in most of the ADE ICs.

UART is used in the [ADE7953](#). There are two unidirectional pins and thus isolation becomes easier, but the communication is fairly slow. The HSDC port, which is used in the [ADE7878](#) and [ADE7880](#), is a dedicated high speed interface that can be used in conjunction with I<sup>2</sup>C interface to access ADC outputs and to obtain real-time power information.

#### **Can the ADE7758 measure active power of nonlinear electrical loads?**

Yes, it can. In fact, all ADE ICs can measure active power for all kinds of loads as long as they are measured within the bandwidth specified in the specifications table. The ADE ICs capture all the data, including the harmonic content, within the bandwidth of interest and helps to measure active power. Look for the -3 dB bandwidth specification in the data sheet to see the frequency limits for which the harmonic measurements are made.

Figure 7 shows a sample waveform of a nonlinear load signal. This is the typical signal for dimmer switch applications. The proportion of time that the sine wave is ON is determined by the dimmer. This is an example of a nonlinear application where ADE ICs can be used.

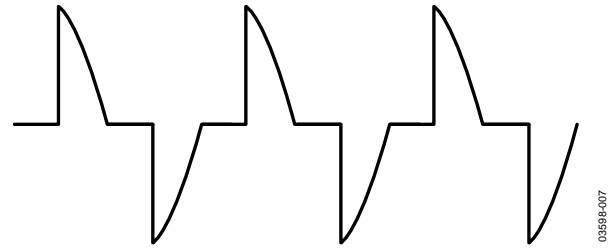


Figure 7. Sample Waveform of a Nonlinear Load Signal

#### **What does accuracy of 0.1% over 1000:1 mean?**

0.1% accuracy over 1000:1 means that the particular measurement of the energy metering IC has a typical accuracy of 0.1% over the range of current signals from the full-scale reading to as low as 1000 times smaller than that. For example, the specifications table in the [ADE7878](#) data sheet shows that the accuracy of total active power is 0.1% over a dynamic range of 1000:1, which means that even if the input is reduced to 0.5 mV, the measurement of total active power does not typically have an error of more than 0.1% (the full-scale input is 500 mV). Remember that the accuracy specification is typical because it is a result of several other external measurement factors that must be accurate as well. Note that the accuracy measurement is done on a system level, after calibrating the chip.

#### **I am applying 5 A and reading the IRMS register. How to I convert this reading into amps?**

To convert the reading in LSBs into amps, calibrate the gain.

The basic procedure is

1. Apply a known current to the current channel.
2. Read the rms register and note the value.
3. Determine the amps/LSB constant: it is the ratio of applied current to the rms register reading.
4. Store this constant in the microcontroller and use it to convert all readings to real world values.

#### **What is the difference between “read” and “read with reset”, that is, AENERGY register vs. RAENERGY register (or VAENERGY and RVAENERGY)?**

The two registers (AENERGY and RAENERGY) are actually reading the same internal register. When you read AENERGY, it reads the internal register. When you read RAENERGY, it reads the internal register and resets it to 0.

It is recommended to read the energy registers with reset and have an accumulator in the microprocessor to keep track of the overall energy accumulated in the meter. The same description applies to VAENERGY and RVAENERGY.

#### **Can the ADE energy meters measure dc power?**

Yes. DC power can be measured using ADE ICs. To do so, the high-pass filter has to be disabled. However, the dc energy accuracy error is expected to be around 1% over a 100:1 dynamic range.



**Can ADE ICs be used for four-quadrant metering?**

Four-quadrant metering is the ability to measure all four quadrants of the energy spectrum as illustrated in Figure 6. The ADE family of devices measure both positive and negative active energy. Many of the devices also measure both positive and negative reactive energy, allowing all four quadrants to be recorded.

Most of ADE devices contain status bits and interrupts that provide the power polarity information. For example in the [ADE7953](#), the REVP and sign indication features can be used to determine the polarity of the active and reactive power being accumulated at any time (see the [ADE7953](#) data sheet, specifically the Indication of Power Direction section). This allows an external microcontroller to accumulate the positive and negative energy separately when required.

**What is the minimum number of line cycles that I have to accumulate in order to get an accurate reading?**

The minimum number of line cycles you must accumulate before taking an energy measurement is one line cycle. However, there is always an accuracy vs. accumulation time tradeoff. The number of LSBs accumulated in a register determines the resolution. The larger the LSB count, the better the resolution and thus the accuracy.

Two factors, signal level and accumulation time, play a main role in increasing the number of accumulated LSBs. Increasing either factor results in a higher number of accumulated LSBs. Therefore, for a full-scale current signal, one can get an accurate reading in less time compared to a smaller signal. The smaller the signal gets, the more time one needs to accumulate, to obtain the same accuracy. This also applies over different power factors. Because of the angle between the current and voltage, the entire signal power is split up as active and reactive power, accordingly, and thus the number of accumulated LSBs is smaller for the same current signal level and accumulation time. Use the following procedure to determine the minimum number of line cycles to obtain the required accuracy.

1. Apply full-scale inputs and accumulate for one line cycle.
2. Measure the energy reading and determine its accuracy.

3. Aim for an accuracy  $10\times$  better than what is required to account for noise and interference effects. For example, if an accuracy of 0.1% is required, find the number of line cycles required to obtain 0.01% accuracy. A minimum of 10000 LSBs is necessary to achieve the resolution required to get an accuracy of 0.01%, as 0.01% is  $1/10000$ . So, aim at accumulating at least 10000 LSBs. Then, increase the number of line cycles on a step-by-step basis to obtain the minimum number of line cycles with full-scale inputs, LINECYCFS, required to get this accuracy level. The LSB count at this level can be considered as  $y$ .
4. Scale LINECYCFS linearly for lower amplitude signals to get the same accuracy at that signal level. Assuming the requirement is to get the same results at 1000:1 input level, accumulate for 1000 times LINECYCFS line cycles to get the same accuracy. This increase in accumulation time is necessitated due to the fact that the number of accumulated LSBs per LINECYCFS line cycles for 1000:1 signal is  $y/1000$ .

**What are the different types of calibration that have to be done on the chip to get accurate and reliable results?**

The gain compensation is always executed. The phase compensation is done only when the current sensor introduces a phase delay, that is, in the case of the current transformers and Rogowski coils. The offset compensation is done when large dynamic ranges are required. Table 2 presents the conditions where these compensations are executed.

**Table 2. Calibration Conditions**

Calibration Steps	Typical Requirement
Gain	$V = V_n, I = I_n, \cos \theta = 1$
Phase	$V = V_n, I = I_n, \cos \theta = 0.5$
Offset	$V = V_n, I = I_{min}, \cos \theta = 1$

The performance of the meter should be evaluated to determine whether any additional calibration steps are required.

In any case, if phase calibration is required, it is done first followed by gain calibration. Offset calibration, if needed, is done as the final calibration step.

### How are the rms measurements taken, and what is the settling time?

Every rms reading in an ADE IC is a running average and not a windowed measurement. For some of the products, such as the [ADE7753](#), [ADE7763](#), [ADE7754](#), [ADE7758](#), ADE75xx, and [ADE5169](#), ADE71xx, and [ADE5569](#), the V rms measurement is the mean absolute value and not the true rms measurement. However, in newer ICs, V rms denotes the true rms value.

Because these measurements are running averages, they take some time to settle down to an accurate value. Consider the [ADE7953](#) for an example. Whenever the current level increases from, say, 0 V to full scale, it take about 200 ms to settle to the accurate value.

Figure 8 shows the trade-off if you choose to wait for less time before taking the reading. Based on the accuracy required for the application, you can select your wait time appropriately.

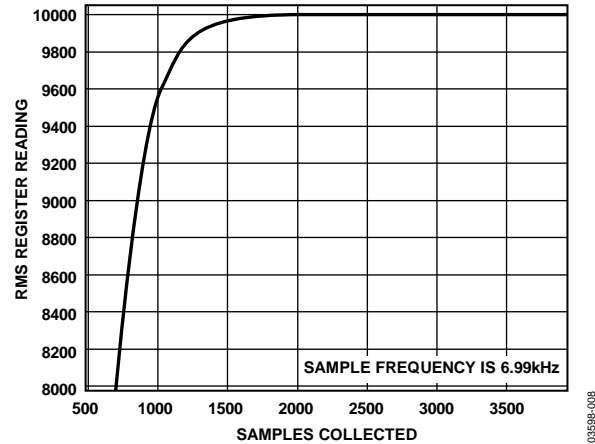


Figure 8. Accuracy vs. Wait Time Trade-Off

Refer to the specific product data sheet for rms settling times.

## PRODUCT-SPECIFIC QUESTIONS

### ADE77xx PRODUCTS

#### Can I use the temperature sensor in the ADE77xx for reference drift compensation?

There are two main sources for the meter temperature drift: the internal voltage reference and the current sensor circuitry. The internal voltage reference drift of every single ADE77xx is not specified in the data sheet. Unless the temperature drift is significant enough to warrant compensation (usually they are not), it is not recommended to do so. If the temperature compensation is required, then calibration of every meter over temperature has to be done. Then the temperature sensor can be used to implement a temperature compensation scheme.

#### What is the consideration when selecting the capacitors used in the power supply unit for the ADE7751/ADE7755 reference design?

Because ADE7751/ADE7755 have an internal power supply monitoring function, if the supply voltage at analog voltage supply pin (AVDD) falls below 4 V, the chip goes into reset. To ensure that the meter operates properly at voltage SAG, the capacitor used in the capacitor divider network should be made larger. One should also choose a larger dielectric capacitor for noise filtering. The impedance of the capacitor used in the voltage divider network is

$$X_C = \frac{1}{2\pi fC}$$

The current through the capacitor is

$$I_C = \text{line voltage} \times 2\pi fC$$

Because the power supply uses half-wave rectification, supply current is half of the current passing through the capacitor

$$I_P = I_C/2$$

#### How do I determine the gain calibration range in the ADE7751/ADE7755?

The attenuation network should allow a calibration range of at least  $\pm 30\%$  to allow for shunt tolerances and the on-chip reference tolerance of  $\pm 8\%$ .

Using the equation in the data sheet that calculates the frequency output,

$$\text{Freq} = \frac{\text{Constant} \times V1 \times V2 \times \text{Gain} \times F_{1-4}}{V_{REF}^2}$$

one can estimate the overall error based on all parameters. Note that  $F_{1-4}$  is a notation for one of four possible frequencies. contributes nearly no error because the error is only dependent on the crystal.

To estimate the overall error in this way, add the typical gain error given in the data sheet (7%), and add errors in V1 and V2 plus twice the reference error.

Assuming 1% resistors, this gives

$$\text{Error} \approx 1\% + 1\% + 7\% + 2(8\%) \approx 25\%$$

The ADE7755 reference design errs on the conservative side, recommending a 30% calibration range.

### ADE78xx PRODUCTS

#### How are the ADE78xx products different from one another in the group?

ADE7854, ADE7858, ADE7868, and ADE7878 are three-phase analog front ends (AFEs) that are pin-for-pin compatible and share the same architecture. Some of the factors that separate them from one another are shown in Table 3.

Table 3. AFE Comparison

Part No.	WATT	VAR	IRMS, VRMS, and VA	di/dt	Fund. WATT and VAR	Tamper Detect and Low Power Modes
ADE7878	Yes	Yes	Yes	Yes	Yes	Yes
ADE7868	Yes	Yes	Yes	Yes	No	Yes
ADE7858	Yes	Yes	Yes	Yes	No	No
ADE7854	Yes	No	Yes	Yes	No	No

For a complete list of all capabilities of the product, refer to the product data sheet. A single data sheet is available for these products and a single Evaluation board can be used to evaluate all these chips.

#### How is the ADE7880 different from the ADE7878?

The ADE7880 is also a three-phase AFE, pin-to-pin compatible with the ADE7878. However, there are quite a few software and hardware differences between them. The AN-1127 Application Note explains these differences. One of the few unique features of the ADE7880 is its harmonic analysis capability.

#### What is 3.21 signed format in the ADE7880?

The 3.21 signed format is a representation by which the 24-bit register is viewed as described herein. The most significant three bits are assigned to the integer value of the decimal number. The less significant 21 bits constitute the fractional component. The most significant bit of the integer portion is the sign bit. Thus, the maximum value that is possible to represent in this format (0x7FFFFFFF) is  $3 + 1 - 1/2^{21} = +3.9999$ .

On a simpler note, get the actual value of the register by dividing the register value by  $2^{21}$ .

#### How is ADE7816 different from other ADE ICs?

The ADE7816 is a multi-channel energy metering IC that can measure up to six current channels and one voltage channel simultaneously. It is suitable for a variety of metering applications that require the monitoring of more than three different loads that share the same voltage, like Smart electricity meters, power distribution units, and in-home energy monitors, to name a few. Application Notes AN-1152 provides the calibration steps involved and Application Note AN-1137 describes the theory of operation of ADE7816, in detail.

**Should I change the phase calibration register values in the ADE7816 after power-up?**

Yes. Phase calibration is executed differently in the ADE7816 when compared with other ADE ICs. Based on the frequency of operation (50 Hz or 60 Hz), the phase calibration registers, along with a few other registers, need to be set manually by the user to predefined values, after power-up. The register settings and the sequence to be followed are elaborated in the product data sheet.

**How do I change my power modes in the ADE7878? If problems occur when handling data in different power modes, how do I manage them?**

In the ADE7878, there are four power modes: PSM0, PSM1, PSM2, and PSM3. The bits in the PM registers (PM1 and PM0) can set the corresponding power mode. Refer to the appropriate table in the data sheet to set the bits in the registers. A common mistake while handling power modes is trying to take readings from the chip when it is still in sleep mode. Though it is easy to miss this step, remember that the IC has to be brought back to either PSM0, PSM1, or PSM2 modes before performing any other operations. There are various reasons and advantages for operating the IC in each of these modes, which are described in the Power Management section of the data sheet.

**ADE71xx/ADE51xx/ADE75xx/ADE55xx PRODUCTS****Do any ADE ICs have a built-in microcontroller?**

Yes. All ADE71xx/51xx/75xx/55x products, such as the ADE5569, ADE7518, ADE5169, ADE7116, ADE7156, ADE7166, ADE7169, ADE7569, and ADE7566 have an on-chip MCU, RTC, and a LCD driver.

**Is it possible to measure the power factor using the ADE71XX/51XX IC?**

It is possible to calculate the power factor from the energy readings, though it cannot be measured directly from the ADE71xx/ADE51xx IC. The power factor is obtained by dividing the active power by the apparent power.

The energy calculations are done within the chip through line cycle accumulation mode, if enabled by the user. The line cycle accumulation mode accumulates the power over a fixed time and synchronizes that with the zero-crossing of the voltage signals. In this way, power is accumulated in half line cycles for a specific amount of time, which varies from one ADE IC to another.

Note that some of the recent ICs, including ADE7880 and ADE7953, have an option to measure the power factor directly.

**Can I compensate RTC temperature drift using the ADE51xx/ ADE71xx/ADE55xx/ADE75xx ICs?**

The ADE51xx/71xx/55xx/75xx ICs have a RTC crystal compensation circuitry, which can be used to compensate the RTC over temperature variations. The AN-949 Application Note describes in detail about how to compensate the RTC of ADE ICs in this family, for accurate timekeeping.

**ADE7953****How can I tell if the ADE7953 is fully powered and ready for communication?**

The power-up procedure described in the data sheet addresses this concern. Typically, the microcontroller can be made to wait for a specific time period before beginning the communication with the chip. The typical total delay for the chip to be completely ready for communication is about 66 ms. Thus, a time-out can be set for about 100 ms before communication begins. However, a better approach is to track the reset flag in the IRQSTATA register (Address 0x22D and Address 0x32D). This flag is set once the chip is ready to communicate and thus the microcontroller can effectively determine when the chip is ready.

**What is the purpose of the second current channel in the ADE7953?**

The ADE7953 has two current channels, which are identical in terms of internal architecture, except for a few changes in the PGA section. The second channel (Channel B) was provided to measure neutral current. This measurement can help detect tamper conditions. However, in applications where two separate current measurements need to be made, Channel B can be viewed as yet another current channel similar to Channel A. The differences in full-scale level and PGA gain settings between the channels are elaborated in the section of the data sheet that discusses analog inputs.

**What is the accuracy specification for active and reactive energy measurements in ADE7953?**

The typical error in measurement is less than 0.1% over a dynamic range of 3000:1.

## METER CONFIGURATIONS

In this section, the most commonly used single-phase and three-phase configurations are illustrated, from a generic system perspective. For detailed information on the antialiasing filter, attenuation network, or any other protective circuitry that might be required for a design involving a particular IC, refer to the evaluation board user guide for the specific product.

### SINGLE-PHASE CONFIGURATIONS

This is the most basic single-phase connection configuration. It just has two wires: a phase and a neutral. Figure 9 shows a resistive shunt used as a current sensor. However, any current sensor can be used for such a configuration.

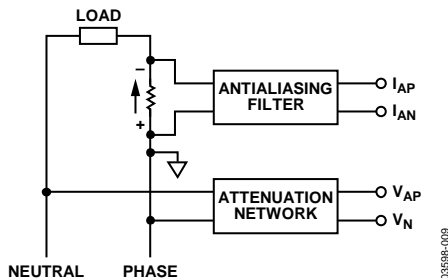


Figure 9. Single-Phase, One Current Sensor

Figure 10 shows an anti-tamper connection diagram, which uses a current transformer (CT) for tamper detection. Generally in these cases, at least one of the sensors, must be a CT or a Rogowski coil for isolation purposes.

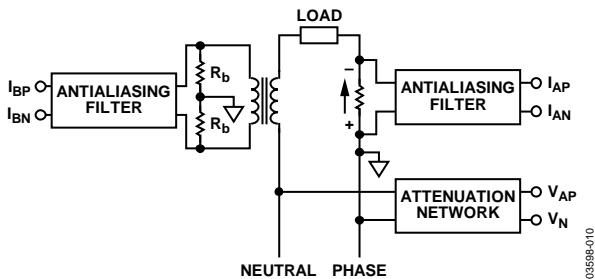


Figure 10. Single-Phase, Two Current Sensors

In certain single-phase applications, it might be required to measure power from two loads and thus sense two current signals. Such applications are called split-phase applications and ADE ICs can be used in such split-phase configurations. If the total power is desired, then any single-phase ADE IC can be used and it can be set up in a configuration as shown in Figure 11.

A single current transformer can be used as a current sensor with inputs from both lines connected in opposite directions. The voltage difference between the lines L1 and L2 is fed into the attenuation network. Also, refer to the How can I use one CT or Rogowski coil in a single-phase, 3-wire configuration? section.

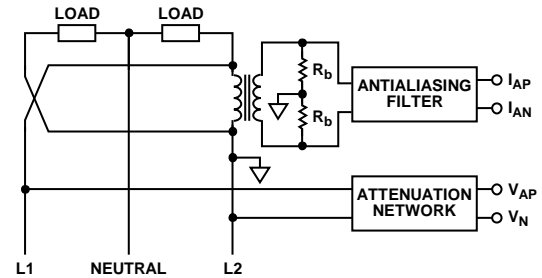


Figure 11. Split-Phase, One Current Sensor

If individual load powers need to be measured, then a single-phase ADE IC with a neutral channel can be used. Ideally, the purpose of the neutral channel measurement is to detect tamper conditions, but the neutral channel is exactly the same internally as the other current channel and, thus, the IC can be visualized as having two identical current channels. The meter can be connected as shown in Figure 12 to achieve this. However, this can only be done on the assumption that both line voltages are exactly the same. Therefore, the voltage difference between the neutral line and one of the line voltages is fed into the attenuation network.

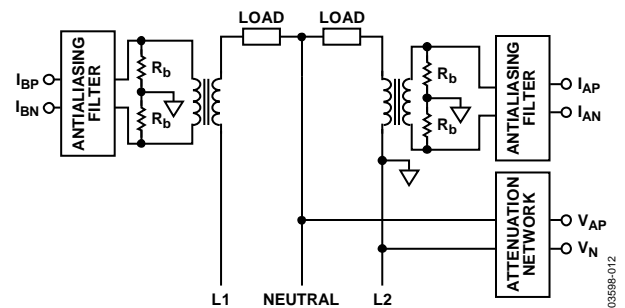


Figure 12. Split-Phase, Two Current Sensors

### THREE-PHASE CONFIGURATIONS

Figure 13 shows a 4-wire Wye with three voltage sensors.

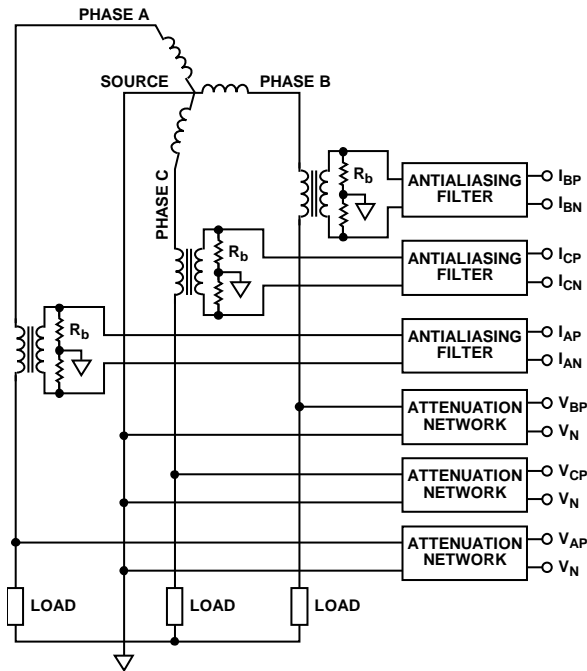


Figure 13. 4-Wire Wye with Three Voltage Sensors

Three voltage sensors are used in this configuration; one for each phase. Since all three phase currents and voltages can be measured, calculating power is simple enough. This is the default configuration setting in all ADE ICs.

$$\begin{aligned} \text{Active Power} &= V_A \times I_A + V_B \times I_B + V_C \times I_C \\ &= (V_{AP} - V_N) \times (I_{AP} - I_{AN}) + (V_{BP} - V_N) \times \\ &\quad (I_{BP} - I_{BN}) + (V_{CP} - V_N) \times (I_{CP} - I_{CN}) \end{aligned}$$

The cumulative reactive power and apparent power computations in this configuration can also be explained based on the same logic.

Figure 14 shows a 4-wire Wye with two voltage sensors.

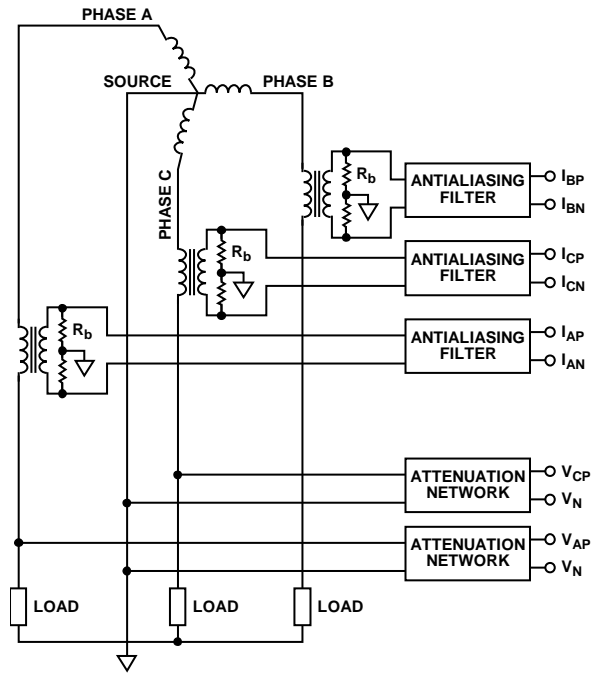


Figure 14. 4-Wire Wye with Two Voltage Sensors

This configuration differs from the earlier one because it does not measure the voltage of one of the phases. Figure 14 shows that voltage for Phase B is not measured, but still the power calculations can be done using the other values obtained. Refer to the product data sheet to determine the proper register setting enabling this configuration.

Ideally,  $V_A + V_B + V_C = 0$ . So, assume  $V_B = -V_A - V_C$ .

$$\begin{aligned} \text{Active Power} &= V_A \times I_A + V_B \times I_B + V_C \times I_C \\ &= V_A \times I_A + (-V_A - V_C) \times I_B + V_C \times I_C \\ &= V_A \times (I_A - I_B) + V_C \times (I_C - I_B) \\ &= (V_{AP} - V_N) \times ((I_{AP} - I_{AN}) - (I_{BP} - I_{BN})) + \\ &\quad (V_{CP} - V_N) \times ((I_{CP} - I_{CN}) - (I_{BP} - I_{BN})) \end{aligned}$$

The cumulative reactive power computations of three-phase ADE ICs can be proven correct, based on the same logic. For certain products, correct apparent power computations are made available in the concerned registers by computing Phase B voltage from Phase A and Phase C voltages as described here. However, this is based on the assumption that the system is symmetrical and balanced.

Figure 15 shows a 3-wire delta configuration.

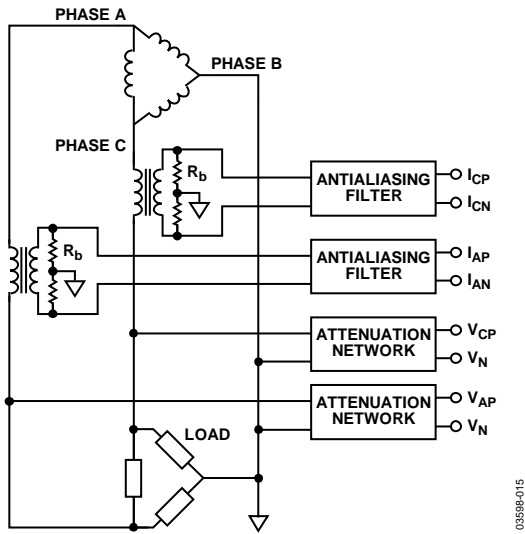


Figure 15. 3-Wire Delta Configuration

This delta configuration takes one of the phases to be the reference and the measurements are made in the other phases with respect to this reference. In most of the newer ICs, it is mandatory to choose Phase B as the reference. Refer to the product data sheet to determine the proper register setting enabling this configuration.

Because of the closed loop,  $I_A + I_B + I_C = 0$ .

So, assume  $I_B = -I_A - I_C$

$$\begin{aligned} \text{Active Power} &= V_A \times I_A + V_B \times I_B + V_C \times I_C \\ &= V_A \times I_A + V_B \times (-I_A - I_C) + V_C \times I_C \\ &= (V_A - V_B) \times I_A + (V_C - V_B) \times I_C \end{aligned}$$

As Phase B is taken as the reference here,  $V_A$  is  $V_{AB}$  and  $V_C$  is  $V_{CB}$

$$= (V_{AP} - V_N) \times (I_{AP} - I_{AN}) + (V_{CP} - V_N) \times (I_{CP} - I_{CN})$$

On a similar note, the cumulative reactive power generated by a three-phase ADE IC can also be proved correct, for this configuration. However, the apparent power results would be incorrect, because the line-to-line voltages will be treated as phase voltages by the ICs, in this configuration. Certain ICs compute Phase B voltage as the difference between Phase A and Phase C voltages, assuming the system is balanced. The Phase B current assumption, as explained above, must also be considered. The equivalent wye configuration apparent power can be obtained by dividing the obtained result by  $\sqrt{3}$ .

Figure 16 shows a 4-wire delta configuration.

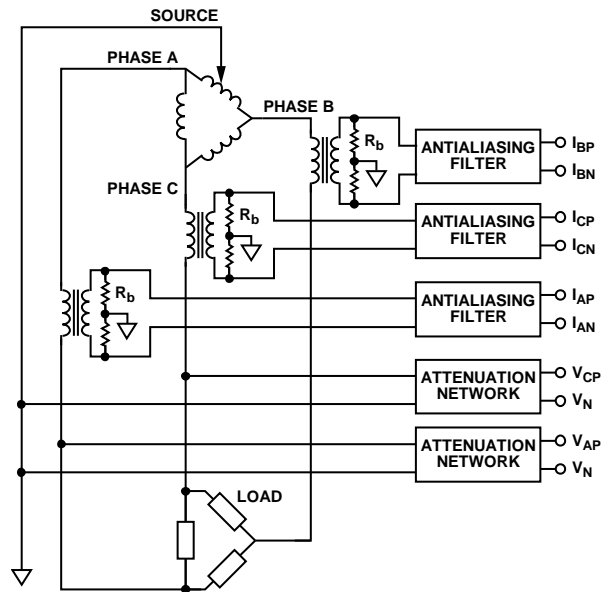


Figure 16. 4-Wire Delta Configuration

This is the delta configuration with current measurements made on all three phases. A separate neutral terminal is also present here. In addition, Phase B voltage is not measured. It is considered as equal in magnitude, but opposite in sign, to that of Phase A, since neutral is taken between Phases A and B. Refer to the product data sheet to determine the proper register setting enabling this configuration.

So, assume  $V_B = -V_A$

$$\begin{aligned} \text{Active Power} &= V_A \times I_A + V_B \times I_B + V_C \times I_C \\ &= V_A \times I_A - V_A \times I_B + V_C \times I_C \\ &= V_A \times (I_A - I_B) + V_C \times I_C \\ &= (V_{AP} - V_N) \times ((I_{AP} - I_{AN}) - (I_{BP} - I_{BN})) + (V_{CP} - V_N) \times (I_{CP} - I_{CN}) \end{aligned}$$

On a similar note, the cumulative reactive power generated by a three-phase ADE IC can also be proved correct, for this configuration. However, the apparent power results would be incorrect, because the line-to-line voltages will be treated as phase voltages by the ICs, in this configuration. Certain ICs assume Phase B voltage is equal in magnitude and opposite in direction to Phase A voltage, assuming the system is symmetrical and balanced. The equivalent wye configuration apparent power can be obtained by dividing the obtained result by  $\sqrt{3/2}$  for Phase A and Phase B and  $3/2$  for Phase C.

If you wish to reconfigure the meter setup from one configuration to another, recalibrate the ADE IC for the new setup if accurate results are desired.

APPLICATIONS

Can a three-phase ADE IC be used for a single-phase application?

Yes. It is possible to use a three-phase ADE IC for a single-phase application though not recommended. Three-phase ADE ICs are designed and tested for three-phase applications only.

However, if you do need to use it for a single-phase application, then it is important to consider a few points. If only one channel is to be used, then make sure that no signal enters through the other channels by grounding the inputs along with antialias filters. If all three channels are going to be used to monitor three individual loads at the same time, then it has to be understood that you will provide a common terminal for the voltage channels.

Can three single-phase ADE ICs be used for a three-phase application?

Yes. It is possible to use three single phase ICs for a three-phase application. Single-phase ADE ICs are designed and tested for single-phase applications only. However, if you do need to use three such ICs for a three-phase application, then note that to read the phase angle between different phases you will have to measure the time difference between zero-crossings. If more sophisticated power quality information is required, it is recommended to use a three-phase ADE IC. Also, make sure to provide proper isolation between channels, for example, by using current transformers as current sensors. If shunts are used, take special care to provide sufficient isolation as shown in Figure 17.

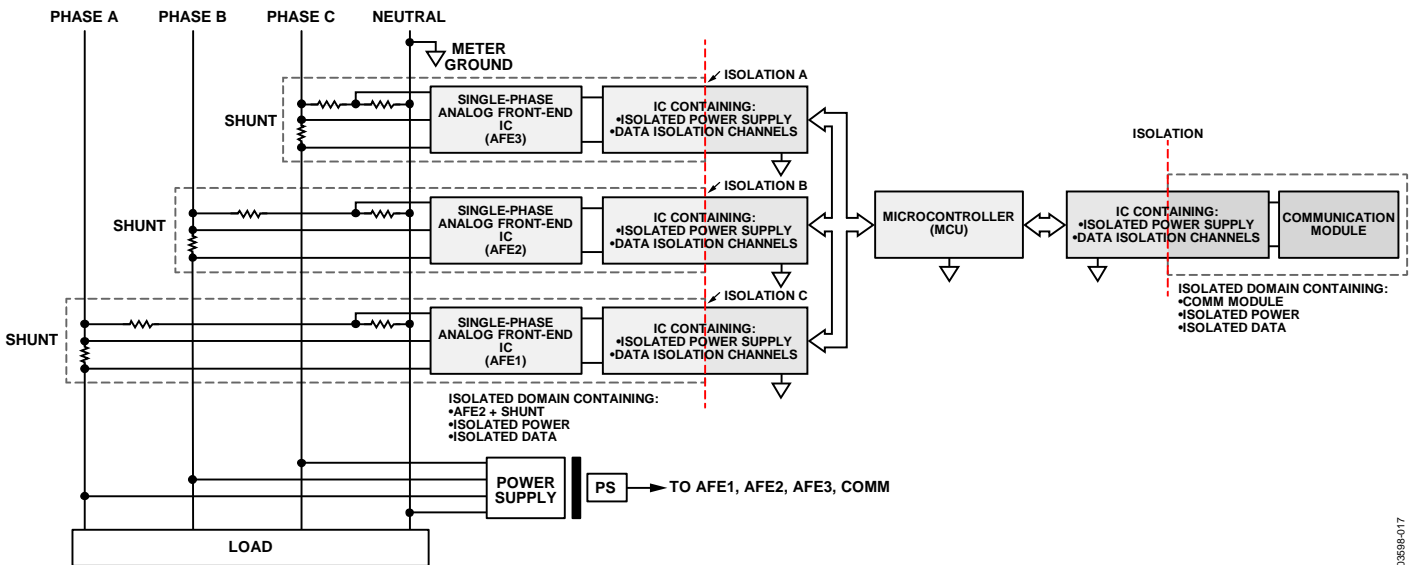


Figure 17. Single-Phase ADE ICs in a Three-Phase Application

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<sup>1</sup>I<sup>2</sup>C refers to a communications protocol originally developed by Philips Semiconductors (now NXP Semiconductors).