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AN-639 APPLICATION NOTE

Frequently Asked Questions (FAQs) Analog Devices Energy (ADE) Products

By Rachel Kaplan

GENERAL

How do I get 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. For our Sales and Distributors listing, go to www.analog.com/salesdir/continent.asp. Please be sure to tell them that the product is prereleased. The preliminary data sheet, if available, should include the evaluation board part number in the Ordering Guide section.

METERING

Why are electronic meters (solid-state meters) better than electromechanical meters or analog electronic meters?

Electronic meters have high accuracy over a wide current dynamic range, are able to handle higher currents, have low power consumption, are reliable and robust (stable over time and temperature), and don't have gears that wear out or magnets that saturate with dc current. They do not require precision mechanics or have large tolerance variations over temperature. Electronic meters more easily enable new functionalities such as automatic meter reading (AMR), multitariff billing, tamper proofing, prepayment meters, load shedding, power outage detection, and power factor detection. Electronic meters offer flexibility of design, and can easily be reconfigured and updated (e.g., software update). They have easy and stable calibration without hardware adjustment and are simpler to manufacture, transport, and install. Electronic meters offer utilities a wider supply base of manufacturers—and the competitive environment helps keep the cost of this solution down.

What is the life span of a solid-state meter?

The ADE ICs have been tested using an accelerated life test. The results proved the ADE performance to be accurate and reliable for 60 years. The life span of the meter can be affected by the meter's design and component selection. The reference design described in the AN-559 and AN-563 Application Notes provide a proven meter solution, which is a good starting point for designing a solid-state energy meter.

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

Active energy is measured in kilowatt-hours, while reactive and apparent energy are VAR hours and VA hours, respectively. Figure 1 shows the relationship between active, reactive, and apparent energy. The relationship described in the figure holds true for pure sinusoids at the fundamental frequency. In the presence of harmonics, this relationship is not valid. See also the FAQ: What is power factor?

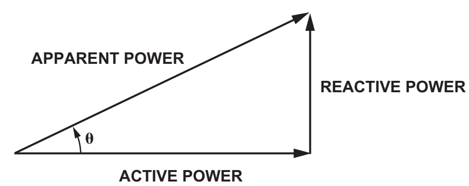

Figure 1. Power Triangle

The relationships are as follows:

Active Power = VI cos θ

Reactive Power = VI sin θ

Apparent Power = VI

Power Factor = cos θ

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What is power factor?

The quantity cos(θ) is known as power factor, where θ is the angle between active and apparent power vectors (and no harmonics are present). Power factor is, therefore, the ratio between real and apparent power. See Figure 1. Some utilities will charge a penalty for low power factor. Common causes of 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 θ.

CURRENT SENSORS

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 ADE77xx performance is desired, then care should be taken to use current sensors that have the desired accuracy over this range.

What are the benefits and drawbacks of the different current sensor technologies?

Sensor	Benefits	Drawbacks
Low Resistance Shunt	Very low cost, good linearity	Poor high current capability, dc offset, parasitic inductance
Current Transformer	High current performance, low power consumption	Hysteresis/saturation due to dc, phase shift
Hall Effect Sensor	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.

The ADE7753 and ADE7759 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 shunt selection:

Power consumption requirement: According to IEC 61036, the power consumption per channel cannot exceed 2 W. Larger shunts consume more power.

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.

The shunt should provide reasonable signal levels to the IC over the current operation range.

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.

How do I compensate for the phase shift of my current sensor (or phase mismatch between channels)?

For products such as ADE7751 and ADE7755 (single-phase) or ADE7752 (3-phase), the only way to compensate for phase mismatch is by hardware. The phase mismatch at 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 to offset the phase error from the CT. Application Note AN-563 has some detailed information about how to adjust the phase mismatch.

For products like the ADE7753, ADE7756, ADE7759 (single-phase), or ADE7754 (3-phase), you can use the internal PHCAL register to adjust the phase lead/lag. Adjusting the phase mismatch is a simple procedure of writing to the register. Refer to the data sheet of the respective product 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.

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.

$$y = \frac{Full\ Scale}{2} = \frac{500\ mV_{peak}}{2} = \frac{353.55\ mV_{rms}}{2}$$
$$= 176.8\ mV_{rms}$$

* Full Scale is 660 mV_{peak}, 500 mV_{peak}, or 1 V_{peak}, depending on the product. Refer to the product data sheet for specification.

The following equations apply:

$$\frac{I_{MAX}}{CTRN} = x \qquad \frac{y}{x} = 2R_B$$

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

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 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 ADI website in the technical article entitled "Current Sensing for Energy Metering."

Where can I find a Rogowski coil?

Currently, the ADE product development group is looking for an appropriate open-market Rogowski coil manufacturer. We will notify interested customers of our findings. If you would like this notification, send your contact information and request to energy.meter@analog.com. Meter manufacturers working with their proprietary sensors and ADE products are very happy with the performance of ADI's digital integrator and sensor interface.

How can I use one CT or Rogowski coil in a single-phase, 3-wire configuration (ANSI 2S)?

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 energy measurement ICs and two sensors are required. However, an approximation method (which is generally very close to the actual situation) can be used such that only one measurement IC and one current sensor is needed. The assumption in this case is that the amplitude of the two phase wires is the same (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. Here's the math:

Instantaneous Power on L1 = V1N × Current L1
Instantaneous Power on L2 = V2N × Current L2
Instantaneous Total Power = Power on L1 + Power on L2
= V1N × Current L1 + V2N × Current L2

Assuming *V1N = V2N = (V1N – V2N)/2*

Instantaneous Total Power
= V1N Current L1 + V2N Current L2
= V1N × Current L1 – V1N × Current L2
= ((V1N – V2N)/2) × (Current L1 – Current L2)

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.

ALL ADE PRODUCTS

Which metering standards do ADE products meet?

ADE ICs' performance meets the IEC 1036, IEC 61036, ANSI, and other derived specifications. Please refer to individual product specifications found on 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 ICs' performance over frequency (45 Hz to 70 Hz) can be seen in the Typical Performance Characteristics section of each data sheet.

Do I have to use the recommended CLKIN frequency?

ADI performs extensive testing using the recommended CLKIN frequency. The specified CLKIN frequency is the only frequency for which the product specifications and part performance are guaranteed. Changing the CLKIN frequency from 3.5 MHz (ADE7751, ADE7753, ADE7755, ADE7756, ADE7759) or 10 MHz (ADE7752, ADE7754) will change the constants given in the data sheet equations, as well as register resolutions, CF, F1, and F2 pulsewidths.

Can I use a 3.3 V digital supply with ADE775x?

No, the digital supply is not supposed to work at 3.3 V.

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

Figure 2 demonstrates how to interpret the sign of the energy registers.

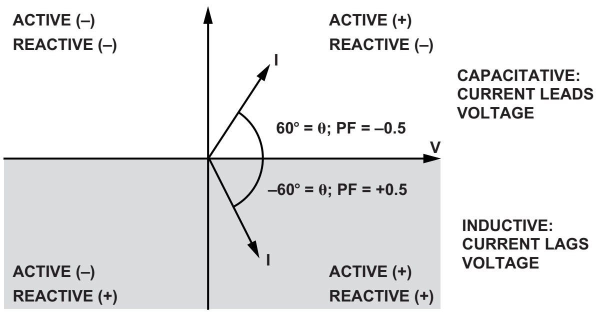

Figure 2. Sign of Reactive and Active Power in ADE ICs

Do ADE chips measure power or energy?

ADE energy measurement products have ADCs on the analog input channels that convert the ac voltage and current signals to digital bit streams. The voltage and current bit streams are multiplied in the digital domain; the product is instantaneous power. Internally, this power is accumulated over time. This is energy. Therefore, ADE chips measure energy and not power. The instantaneous power, if required, can be derived in our serial interface (SPI) parts (ADE7753, ADE7754, ADE7756, and ADE7759) by using the waveform sample register to read the bit streams.

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. The ADCs in the ADE775x family have a high sampling rate (approximately 800 kHz). As the Nyquist theory tells us, image frequencies near the sampling frequency can get folded back around half the sampling frequency (450 kHz) and end up in the band of interest (between 50 Hz and 60 Hz), causing distortion. A simple low-pass filter can attenuate the high frequencies (near 900 kHz) so they will not end up in the band of interest for metering (less than 2 kHz).

How do I design the antialiasing filters?

A simple RC low-pass filter is sufficient for antialiasing filters in this application. The AN-559 Application Note, the ADE7755 reference design documentation, explains how to design simple antialiasing filters for ADE77xx products.

Where did the factor of 3 in 3SRC come from in the formula $H(s) = 1/(S^2 \times R^2 \times C^2 + 3SRC + 1)$ for two RC filters in series (AN-559, Figure 12)?

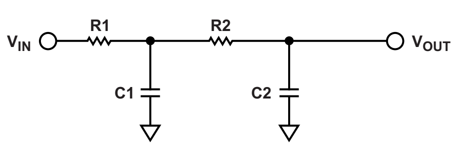

Figure 3. Two RC Filters in Series

For a filter network with two RC filters in series, the following equation applies:

$$H(s) = 1/((1 + sR1C1)(1 + sR2C2) + sR1C2)$$

with $R1 = R2$ and $C1 = C2$

An estimation of two filters in series is $H(s) = G(s) \times W(s)$ where G(s) and W(s) represent the transfer functions of the individual filters. This estimation would give the result (with R1 = R2 and C1 = C2) with a 2sRC term in the denominator.

This estimation neglects the "crossover" term sR1C2 that is seen in the more exact equation. You can prove this by deriving the transfer function from the circuit without estimation.

AN-559 explains how to use the pole location to calculate the resistor and capacitor values for phase matching and cancellation of parasitic shunt inductance.

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:

$$Error \approx Mismatch\,(Radians) \times \tan(\theta) \times 100\%$$

In the expression, θ represents the phase angle between the voltage and current. As one can see, a phase mismatch of 0.1° will result 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.

How do I calibrate the ADE metering IC?

For products such as ADE7751 and ADE7755 (single-phase) or ADE7752 (3-phase), calibration is done by hardware. These products require resistor divider networks on the voltage channel. See the related application notes and product data sheets for details.

For products like ADE7753, ADE7756, ADE7759 (single-phase) or ADE7754 (3-phase), calibration is done using the registers through the SPI interface. Refer to product data sheets and application notes for details.

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}).

Are there any differences internally between the ADE775x DIP, SSOP, or SOIC packages?

The difference is only in the package. The part's performance is not affected by its package.

There are both analog ground (AGND) and digital ground (DGND) on the ADE7755 and ADE7751. Why are both pins connected to the analog ground plane on the reference design?

The ADE7755 and ADE7751 do not produce significant digital noise. Therefore, the whole IC can be set on the quiet analog ground plane to minimize noise pickup from other sources. Furthermore, this arrangement enables a larger ground plane on the PCB. The key point here is to have the digital output pins (F1, F2, REVP, and CF) connect to the digital ground plane.

To which ground plane should the current sensing be connected?

The digital ground plane. This can not only reduce the noise from the noisy supply line entering the analog ground plane, but can also divert the energy away from the IC in an ESD event.

To which ground plane should the crystal oscillator be connected?

The digital ground plane.

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

The analog ground plane and digital ground plane should be physically separated from each other and should be connected only at one point (star ground configuration). Preferably, the two ground planes should be connected through a ferrite to minimize the noise from the digital ground plane entering the analog ground plane.

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

The following are 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 are 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.

ADE775x: SPI INTERFACE PRODUCTS

Can the ADE775x (ADE7753, ADE7754, ADE7756, ADE7759) handle bidirectional energy flow?

Yes, the ADE775x (ADE7753, ADE7754, ADE7756, ADE7759) can handle bidirectional energy flow. The energy registers are signed.

Can ADE775x (ADE7753, ADE7754, ADE7756, ADE7759) be used for dc energy measurement?

Yes, the ADE775x (ADE7753, ADE7754, ADE7756, ADE7759) can be used for dc energy measurement when the HPF in Channel 1 is turned off. Note, however, that there are dc offsets from the ADC in both Channels 1 and 2, so you need to perform a dc calibration to offset the error. You can achieve this by writing to the CH1OS, CH2OS, or APOS register to offset the error term CH1_OS1 × CH2_OS2.

Which products can be used with the Rogowski coil (air-core CT, di/dt sensor)?

The ADE7753 and ADE7759 are the single-phase products that can be used with a di/dt sensor. In all cases, the integrator that enables this direct interface can be disabled (refer to product data sheet for register maps) so that a current transformer (or shunt) can be used as the current sensor.

Are there any special considerations for SPI timing to interface with the MCU?

During a multibyte data transfer, there must be at least 4 μs between bytes (t_7 and t_{10} in the product data sheet). This includes writing to the communication register (the command byte that initiates SPI communication), i.e., the rising edge of SCLK should not occur until 4 μs after the falling edge of the write to the communication register. For a fast MCU, the transfer time could be fast enough to violate this timing specification.

Which ADE products give reactive energy?

ADE7753.

How does ADE77xx VAR (reactive energy) calculation work?

ADE energy measurement products calculate VAR using a single-pole low-pass filter with a constant 90° phase shift over frequency and attenuation of 20 dB/decade. The cut-off frequency of the low-pass filter is much lower than the fundamental frequency, so it provides a 90° phase shift at any frequency higher than the fundamental frequency and attenuates these frequencies by 20 dB/decade. This solution is susceptible to variations of the line frequency. However, a dynamic compensation of the gain attenuation with the line frequency can be achieved by evaluating the line period of the signal. The ADE products also have a period register that may be used for this compensation purpose (ADE7753). For a full description and comparison of VAR calculation methods, see the technical article entitled, "Measuring Reactive Power in Energy Meters," on the ADI website.

How many line cycles do I have to accumulate over to get a stable energy register reading from the ADE775x?

The reading will be stable in one half cycle, but the issue is the accuracy. The accuracy of the reading will be 1/n of LSB accumulated. This is similar to a quantization error in an ADC.

What is the smallest number of LINCYC to get a meaningful energy reading?

You can adjust the number of half line cycles and make a tradeoff between low current accuracy and the time it takes to read out each phase.

100 half cycles @ 60 Hz = 1.667 sec × 32 LSB/sec = 53.333 = 53 (due to rounding, and causes the error). The error in any measurement is going to be ± 0.5 LSB.

Therefore, the accuracy = 1 LSB of error/53 LSB = 1.875%.

The error due to this "quantization" will have a much smaller effect at larger currents (because you will accumulate more LSB). Therefore, the worst case occurs at small currents).

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

There are two main sources for the temperature drift: the internal voltage reference and the current sensor drift itself. The internal voltage reference drift is not predictable even though it has an "average" distribution, but it is not an indication of the individual part's performance. Unless the temperature drift is significant enough to warrant compensation (usually they are not), we don't recommend doing so. If you really need to do so, you should perform calibration over multiple temperatures.

How do I accommodate different 3-phase distribution configurations (3-wire, 4-wire, delta, and wye)?

The ADE7754 offers different modes for the calculation of energies. Depending on the service configuration, the appropriate formula should be selected. See the ADE7754 Data Sheet for details about the COMPMODE register.

Can I get a copy of the code that drives the evaluation board (EVAL-ADE775xEB)?

The code that is written is in LabVIEW™. It cannot be viewed without the LabVIEW software. The runtime engine included with the software can run only the executable. If the customer has access to LabVIEW software, we would be happy to send the files.

What is the difference between "read" and "read with reset" (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. The half full interrupt gives you the information when the internal register is half full. To read the accumulated active energy, you can read the internal register without reset and reset it when the half full interrupt is set, or always read the register with reset. In any case, you need to have an accumulator in your microprocessor that keeps track of the overall energy accumulated in the meter, and must add the AENERGY register value to it. The same description stands for VAENERGY and RVAENERGY.

What is the content of the internal registers of ADE775x after reset or power-up?

The content of the registers after reset are the default values stated in the data sheets. Calibration register contents should be stored in nonvolatile memory for reloading, if necessary. See also the FAQ: Do ADE775x have protection against power outages (voltage SAG)?

Do ADE775x have protection against power outages (voltage SAG)?

The registers of the ADE775x are volatile. For this reason, the calibration coefficients and energy register reading should be stored in the nonvolatile memory in the meter (e.g., EEPROM or FLASH memory). The ADE7753, ADE7754, ADE7756, and ADE7759 have a SAG detection function designed to warn the MCU ahead of time (when the supply voltage starts to drop). The voltage level at which this SAG detection occurs is configurable in the part registers. When this SAG detection occurs, it means that the 5 V power supply to the ADE775x is about to be interrupted. The MCU should back up the energy data, and when the line voltage (and 5 V supply) return, the calibration coefficients should be read from memory and then transferred to the ADE775x. Refer to Application Note AN-564 for details.

What is the sampling rate of the ADCs in the ADE7756, ADE7759, and ADE7753?

The ADCs in the ADE7756 have a sampling rate of 890 kHz. However, the input frequency bandwidth is smaller than the Nyquist frequency (445 kHz) because the ADCs have Σ-Δ architecture. The analog input bandwidth is then limited to 14 kHz in the ADE775x. It means that with 60 Hz signals, up to 233 harmonics can be digitized. You must also take into account the frequency bandwidth of the antialiasing filters in front of the ADCs that generally have lower cutoff frequencies.

How long can the IRMS/VRMS registers (ADE7753, ADE7754) hold data, and will it be erased after reading?

The IRMS/VRMS registers are updated continuously, so the registers are never really "holding" the data. The rms calculation in the ADE775x uses a low-pass filter to extract the rms value and has some associated settling time (approximately 700 ms). As a result, there will be some small delay in the updating of the register in accordance with the actual current/voltage event. On the RMS registers, we recommend sampling the register after a zero crossing of the voltage input to eliminate noise due to filtering. (You can use the zero crossing interrupt to indicate the occurrence of a zero crossing.)

How should I read and write signed registers that are not *n* bytes long?

With the SPI, you must always read and write in byte quantities. Here is an example of how to deal with registers that are not *n* bytes long: The PHCAL register is six bits; however, it is sign extended. Here you have to sign extend, placing the sign bit at the MSB. For a register such as PHCAL, Bit 7 is actually the sign bit. The five LSBs give you the register's numeric value. Bits 5 and 6 are "don't cares." When reading back a register that is sign extended, the don't cares will match the MSB (sign bit) regardless of the value written to these bit locations. This is the method for all of the registers that are signed 6- or 12-bit registers.

0	X	X	1	1	1	1	1	= +1F
7	6	5	4	3	2	1	0	

1	X	X	1	1	1	1	1	= –1F
7	6	5	4	3	2	1	0	

Figure 4. Writing Values to Sign Extended Registers

ADE775x: ANALOG CALIBRATION PRODUCTS

Can a potentiometer be used for the resistor calibration network in the analog calibrated parts?

For the analog calibration parts (ADE7751, ADE7752, ADE7755, ADE7757) to ensure the accuracy of the meter over time and temperature, a potentiometer is not recommended.

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 (AV_{DD}) falls below 4 V, the chip will reset itself. 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 $X_C = 1/(2\pi fC)$. The current through the capacitor is I_C = Line Voltage × ($2\pi fC$). Because the power supply uses half-wave rectification, supply current is half of the current passing through the capacitor $I_P = I_C/2$.

SINGLE-PHASE PRODUCTS

ADE7751/ADE7755

How do I determine the gain calibration range?

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

If you use the equation in the data sheet that calculates the frequency output,

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

you can estimate overall error based on all of the parameters. F_{1-4} contributes nearly no error, as 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, V2 plus twice the reference error. Assuming 1% resistors, this gives

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

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

Can the ADE7755 be used with a current transformer?

Yes. See the ADE7755 Data Sheet.

What is the starting current for a ADE7751 or ADE7755 based meter?

The following calculation is based on a meter with F1, F2 output set to 100 imp/kWh and F_{1-4} is 3.4 Hz (S1 = 0, S0 = 1). Similar calculation can be easily done by other settings:

The output frequency

$$F1, F2 = \frac{100 \frac{imp}{kWh}}{3600 \frac{sec}{hr}} \approx 0.0277 \frac{Hz}{kW}$$

The ADE7755 has a minimum output frequency of 0.0014% of F_{1-4}. The minimum output frequency from F1, F2 is:

$$0.0014\%(3.4\ Hz) \approx 0.0000476\ Hz$$

The equivalent power is:

$$\frac{0.0000476\ Hz}{0.0277 \frac{Hz}{kW}} = 1.72\ W$$

The corresponding starting current (at 220 V line voltage) is 1.72 W/220 V = 7.8 mA

How big is EVAL-ADE7755EB?

EVAL-ADE7755EB is approximately 6 inches × 5 inches.

Can the EVAL-ADE7755EB be used with a 120 V source?

Yes. The board is designed to have a 220 V voltage source, but the voltage divider's values can be changed proportionately to be used with a 120 V source. Please refer to the related application note and evaluation board documentation. You can preserve the corner frequency matching at 4.8 kHz as stated in the application note only by changing the values of resistors R53 and/or R54 on the evaluation board. In this case, because you want to reduce the voltage source, either R53 or R54 or both should increase. This is true for other ADE775x evaluation boards as well.

How do I calculate power consumption in the circuit in the ADE7755 Application Note (AN-559)?

The power dissipation is calculated based on the worst-case scenario. On the power supply side, the main load is the 470 nF capacitor in series with the 470 Ω resistor. At 50 Hz, the magnitude of the impedance is about 6.8 kΩ. If the nominal current going through the load is 32.4 mA, the apparent power is then:

$$(220\ V)(32.4\ mA) = 7\ VA$$

The real power (dissipated by the resistor) for the power supply is:

$$(470\ \Omega)(32.4\ mA)^2 = 0.5\ W$$

The other major source of active power consumption comes from the shunt. Being a resistive element, it consumes power when there is current passing through it. At 40 A, the power consumption of the shunt is:

$$(350\ \mu\Omega)(40\ A)^2 = 0.56\ \text{W}$$

Therefore, the total power consumption is:

$$0.5\ W + 0.56\ W = 1.06\ W$$

In the AN-559 reference design, what is the effect of replacing the 7805 voltage regulator with a Zener diode?
The Zener diode does not have equivalent power supply rejection (PSR) as the regulator. This means the meter could have a large error at light load due to ripple from the power supply if a Zener diode is used in place of the regulator.

What is the function of the 10 μF tantalum capacitor at the REFIN/OUT pin suggested in the ADE7751/ADE7755 reference design?
Along with a dielectric capacitor, the two capacitors are used to stabilize the reference voltage and to ensure high accuracy.

What is the tolerance of the input impedance of inputs V1P and V1N for the ADE7755?
The input impedance is stated as a minimum value, 390 kΩ. The nominal value is higher but the minimum value must be known to design for the worst-case scenario.

ADE7757

What is the difference between ADE7755 and ADE7757?
The ADE7757 is a pin-reduced version of the ADE7755 with an integrated oscillator to eliminate the cost of the external crystal oscillator. EVAL-ADE7757EB is available for purchase. Due to the similarities between the ADE7755 and ADE7757, you can use the same application note (AN-559) as a starting point of your design. The performance of the ADE7757 is very similar to ADE7755. Refer to the product data sheets for details.

Can I use an external crystal oscillator with the ADE7757?
The ADE7757 has an internal oscillator and cannot be used with an external crystal oscillator.

Do I have to use the resistor specified in the data sheet?
The data sheet specifications and constants are for a certain CLKIN value determined by the resistor used. If the recommended resistor is not used in the design, we cannot guarantee part performance, and data sheet constants will change.

Are the F1, F2, and CF pulses synchronous in the ADE7757?
In the ADE7757, CF and F1–F2 pulses are synchronous, as in the ADE7755.

ADE7753

Is there a fixed relationship between the AENERGY, VAENERGY, and VARENERGY registers on the ADE7753?
Yes. The AENERGY, VARENERGY, and VAENERGY registers will not match due to differences in the signal path, but there is a fixed ratio between them. They should scale with your inputs accordingly.

Integrator off (50 Hz line frequency):

$$VA = 0.810 \times W,\ VA = 2.796 \times VAR,\ W = 3.453 \times VAR$$

Integrator on (50 Hz line frequency):

$$VA = 0.870 \times W,\ VA = 1.186 \times VAR,\ W = 1.363 \times VAR$$

How do I find the relationship between the VAENERGY, AENERGY, and VARENERGY registers?
Verify the relationship between the energy registers by taking active, VA, and VAR measurements at 90° phase shift and 0° phase shift. The ratio of VA to watts will be LVAENERGY at 90° phase shift divided by LAENERGY at 0° phase shift.

How do I get the power factor from the ADE7753?
The power factor is the ratio between the active power and the apparent power.

Active power is usually expressed as VI cos(θ) for signals with no harmonics where V and I are the voltage and current rms, respectively. The apparent power is VI. To get this information in the ADE7753, use the LAENERGY and LVAENERGY registers. Even though they are energies, you can usually make the assumption that the power is constant. Because the accumulation time is the same for both energies, the ratio will give you the same result.

ADE7756

Can I calculate rms current or rms voltage with the ADE7756 or ADE7759?
Yes. Refer to the AN-578 Application Note for details on how to calculate rms current and voltage with the ADE7756 and ADE7759. The ADE7753 supplies IRMS and VRMS directly in registers.

How do I detect a power failure (voltage SAG) with the ADE7756?
The ADE7756 has a very useful mode that enables you to detect if there is any dropout on the line voltage (SAG detection). You can set up this detection to give you an interrupt when the line voltage is below a configurable threshold for more than a (configurable) number of half line cycles. This feature gives you an early indication that your 5 V power supply from the main will probably drop soon and that you need to back up your data immediately.

The SAG pin does not reliably catch a power failure event. The IRQ pin should be used for failure detection. For the IRQ pin to show a SAG event, the SAG bit (Bit 1) in the interrupt enable register should be set high. The default for this bit is logic low.

Settings: MODE = 0x0000; IRQEN = 0x02

What is the power consumption of the ADE7756 in suspend mode? How can I halt the digital circuitry if there is a 3.57 MHz crystal at the CLK inputs? What is power consumption in this case?

In suspend mode (Bit 4 of the mode register set to 1), the analog section is turned off, and the current consumption on AV_{DD} is below 0.3 mA. The digital power supply consumption can be reduced only by shutting down the clock input and tying CLKIN to GND or V_{DD} (CLKOUT open). The power consumption is then close to 0 mA on DV_{DD}.

If you drive the ADE7756 from a microprocessor, you can hold the CLK input to logic 1 or 0 in standby mode. If your microprocessor clock is at 8 MHz, you can run the ADE7756 at 4 MHz without any problem. Otherwise, a mechanism to disconnect the crystal needs to be implemented to reduce the DV_{DD} current.

How can I detect reverse active power with the ADE7756 or ADE7759?

For the ADE7756 or ADE7759, you can detect reverse power by reading the multiplier waveform from the waveform register. The sign of the average value can be interpreted by the MCU.

How can I measure the active power with the ADE7756?

The signal at the output of the LPF after the multiplication (average active power) should be around 0xCCCD when both inputs (current and voltage) are at full-scale ac signal (±1 V peak differential). This signal is accessible by reading the waveform register with multiplier output selected (WAVSEL bits of MODE register = 00).

How do I calculate the power factor or get the sign of the reactive energy with ADE7756?

In the ADE7756, you can't know if the reactive energy is capacitive or inductive. You need the ADE7753 for that. To determine the power factor with the ADE7756, you will need to process the VRMS and IRMS from the waveform samples as detailed in the AN-578 Application Note. Then, you can get the power factor as the ratio of Active Power/(VRMS × IRMS). Calculating power factor is much easier with the ADE7753 because it provides active and apparent energies directly.

ADE7759

Are all eight bits of IRQEN (ADE7753, ADE7756, ADE7759) supposed to be writable? When I write 0x00 to IRQEN, I get 0x40 back.

What you are reading is correct. The default value of the IRQEN register is 0x40 with the reset bit (6) high. This enable bit has no function in the interrupt enable register, meaning that this status bit is set at the end of a reset, but cannot be enabled to cause an interrupt. The rest of the bits in the IRQEN register are default zero. When set to logic high, if a corresponding event is detected in the STATUS register, an interrupt will be generated on the IRQ pin. The reset bit in the IRQEN is not writable because it has no function.

How do I calculate the constant that relates the active energy register to kilowatt-hours?

You can calculate the kWh/LSB constant using your calibration *kW*:

$$kW = \frac{(Volts_{CAL})(Current_{CAL})}{1000}$$

and the amount of energy you accumulated during the accumulation time, t_{ACC}, where your accumulation time is

$$t_{ACC} = \frac{LINECYC}{(2)(Line\ Freq)}$$

The 2 comes from the fact that it is half line cycles the LINECYC register counts. The equation is:

$$\frac{kWh}{LSB} = \frac{\frac{(t_{ACC})(kW)}{3600}}{Energy}$$

where *Energy* is the amount of energy accumulated during the calibration cycle.

POLYPHASE PRODUCTS

In a 3-phase system, how do I calculate the voltage between phases if I have the voltage of each phase?

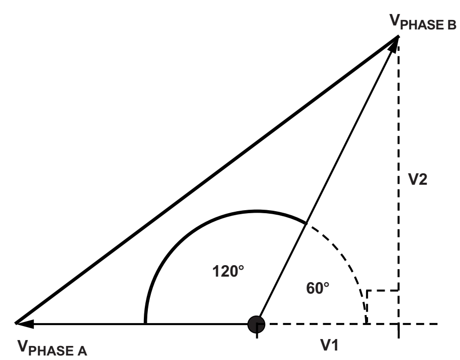

Figure 5. Three Phase Voltages

$$V_1 = V_{PHASE\,B} \times \cos(60°)$$

$$V_2 = V_{PHASE\,B} \times \sin(60°)$$

$$(V_{PHASE\,A} - V_{PHASE\,B})^2 = (V_1 + V_{PHASE\,A})^2 + V_2^2$$

If you assume that the three voltages are balanced (120° between them), Figure 5 shows how you can tell the phase-to-phase voltage.

You can fine tune this equation by using the phase-to-phase phase difference. This phase difference can be derived from the zero-crossing detection (and interrupt) from each phase and the period measurement of the ADE7754.

ADE7752

How does the no-load threshold relate to the current input signal?

The no-load threshold for the ADE7752 is specified to be 0.005% of the full-scale output frequency, or equivalently, 0.005% of the maximum power. Because there is a fixed relationship between the output frequency and the input signals (given in the data sheet), one can relate this back to the current input. The following equation assumes that V = VA = VB = VC and I = IA = IB = IC:

$$Freq = \frac{3.922 \times 3(VI) \times F_{1-7}}{V_{REF}^{2}}$$

The no-load threshold is 0.005% of the output frequency. This means that if the voltage channel is 100% of full scale, the no-load threshold is 0.005% of the current channel. But if the voltage channel is only 50% of full scale, the threshold is 0.01% of the current channel input.

ADE7754

Why are there three active energy registers on the ADE7754?

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.

To read the accumulated active energy, you can read and reset the internal register when the half full interrupt is set. You need to have an accumulator in your microprocessor that keeps track of the overall energy accumulated in the meter, and should add the AENERGY register value to it when the half full interrupt occurs.

The third active energy register is the LANERGY register, which accumulates active energy over the specified (LINECYC) number of line cycles. This register can be used for calibration purposes. See the AN-624 Application Note for details.

The VAENERGY and RVAENERGY registers behave in the same manner.

How do I interface ADE7754 with current transformers and what accuracy is required for CTs?

The ADE7754 can be interfaced to a current transformer very easily. The two wires from the CT can be connected directly to the current input of the ADE7754. Two burden resistors should also be connected to the two CT outputs and to the analog ground. The value of the burden resistors should be chosen to accommodate the analog input full scale of the ADE7754 (0.5 V peak differential with PGA = 1). See also the FAQ: How do I calculate the burden resistor for my CT?

The accuracy of the CT dictates the accuracy of the meter itself so you should choose CTs that have the same or better accuracy than your intended meter accuracy. See also the FAQ: What are the considerations for selecting a current transformer (CT)?

How do I write the values in the ADE7754 (ADE7753) evaluation board software windows to the part?

In most of the windows of this software, the configuration of the window is written to the part only when you click the "Write configuration" button.

Can I read per-phase information from the ADE7754?

Yes. Per-phase information may be obtained by using the LINECYC mode and the WATMODE register to select the phase that is accumulated.

Setup

Configure the part:

- Select the line accumulation mode.
- Mask the line accumulation interrupt (0x0F, Bit 10).
- WATMODE register (0x0D, Bits 0–2)—Select Phase A.
- MMODE register (0x0B, Bits 4–6)—Select the zero-crossing phase.

LOOP

1. Wait for LAENERGY interrupt.
2. Write LINECYC (0x13) to small value.
3. Write WATMODE to select Phase B.
4. Write MMODE to select Phase B for zero crossings (ZX).
5. Read LAENERGY register (Phase A value).
6. Reset the interrupt (0x11).
7. Wait for LAENERGY interrupt.
8. Write LINECYC to normal value. (Must be performed before first ZX.)
9. Reset the Interrupt (0x11).

   Note: There is no reason to read the LAENERGY register as the value was accumulated from both Phase A (time between Step 1 and Step 3) and Phase B (time from Step 3 to Step 7).
10. Repeat from Step 1 for each phase.

The value of the LINECYC in Step 2 should be long enough to allow the LAENGERY register to accumulate at least one bit and to allow enough time to perform all the register reads and writes (Steps 3 through 5).

How can I get active power information from ADE7754?

The ADE7754 gives active energy in the registers, which is the accumulation of the average active power. You don't have the ability in the ADE7754 to read the active power waveform in the waveform register as in the ADE7756. To estimate the active power, you can read the LAENERGY register and extract the active power by dividing the LAENERGY register by the accumulation time. You won't get this information before accumulating the active energy.

How do I get power factor from the ADE7754?
The power factor is the ratio between the active power and the apparent power.

Active power is usually expressed as VI cos(θ) for signals with no harmonics where V and I are the voltage and current rms, respectively. The apparent power is VI. To get this information in the ADE7754, you can use the LAENERGY and LVAENERGY registers. Even though they are energies, you can usually make the assumption that the power is constant and, because the accumulation time is the same for both energies, the ratio will give you the same result.

How do I get the sign of the power factor?
For the sign of the power factor, use the LAENERGY configured for reactive measurement (Bit 5, WAVMODE register). This measurement is not accurate for the actual reactive energy measurement but will give you its sign as well as the sign of the power factor.

Can I make a meter that can be used in both 3-wire delta and 4-wire wye configurations?
Your design will have to be calibrated for both configurations and the microprocessor should load the different calibration parameters (gain, for example) in each situation. There are two ways to implement the detection of the grid configuration. You can have your microprocessor autodetect with software (look for zero crossings on each phase, find out which phase is present, look at voltage level in waveform sampling) and disable the input for the phase you are not using. Or, to be more accurate, you could have hardware switches.

How can I monitor neutral to ground voltage as well as all three phases in a 4-wire system using the ADE7754?
If you have a 4-wire situation, you can estimate that VA + VB + VC = VN and you can find VA + VB + VC by toggling through the phases and using waveform sampling. A more accurate option is to add one dedicated ADC or single-phase metering IC to the system.

Why do I get accumulation in the VAENERGY register when no current and voltage are present? Is there a no-load threshold for the VAENERGY register?
We did not implement a no-load threshold on VA. You will need to ignore any accumulation in your microprocessor from this register when the voltage and current are zero. You should be able to tell when the voltage is zero by using the SAG interrupts or by monitoring the accumulation in the AENERGY register.

Why can't I use the reactive energy register in the ADE7754?
ADE7753 and ADE7754 have reactive energy registers. However, the ADE7754 has a design error: in the reactive energy calculation, there is an internal phase shift of the current by 89° instead of 90°. This error will cause the reactive energy to be nonzero at PF of 1 and have a large error at PF = 0.5. This means that the reactive energy register in the ADE7754 cannot be used directly for billing or even for information. The method we recommend in the ADE7754 to get the reactive energy is to use the active and apparent energies. The power triangle approach will give the reactive energy as:

$$reactive = \sqrt{(apparent)^2 - (active)^2}$$

The ADE7754's reactive energy register can be used to determine the sign of the reactive energy, as the result from the power triangle calculation method is unsigned.

ADE7753 has reactive energy registers that can be used directly for accurate billable quantities.

The period register of the ADE7754 does not seem to be working. What is different about this register?
If you disable a phase in the ZXSEL part of the MMODE register, the period register will not work for that phase. The period register works by counting the time between ZX of the phase you selected. The ZXSEL register controls a MUX that is in the beginning of the data path. Therefore, if you disable a phase in the ZXSEL register and then in the PERIOD block, you will not get any ZX to count between for that phase.

The other issue you might be seeing is that without any ZX, the period register will not be updated. It also does not get cleared when you switch phases in the PERDSEL register. If you are testing by applying 60 Hz to Phase A and no input to Phase B, then when you switch to Phase B after testing Phase A, you will continue to read the last value in the period register (which would be the value from Phase A).

The accuracy of the period register in our simulations is about 5% error after 1 second, and would fully settle to <2 LSB error in about 2.5 seconds due to a filter in the period register data path. The simulation was run from no input to a 60 Hz sine wave input.

Is the meter constant on output CF defined?
There is no meter constant defined for the ADE7754 CF frequency. If all six analog inputs are at full scale ac level, the CF frequency will be approximately 96 kHz. You can use the CFDEN register in the ADE7754 to scale the CF frequency to the value corresponding to your meter constant and input values (220 V, 10 A, for example).

Is there a fixed relationship between the AENERGY and VAENERGY registers on the ADE7754?
Yes. The AENERGY and VAENERGY registers will not match due to differences in the signal path, but there is a fixed relationship between them. They should scale with your inputs accordingly.

At 50 Hz line frequency:

$$VA = W/3.657$$

What are the connections for 3-phase 4-wire wye service (with three voltage sensors)?

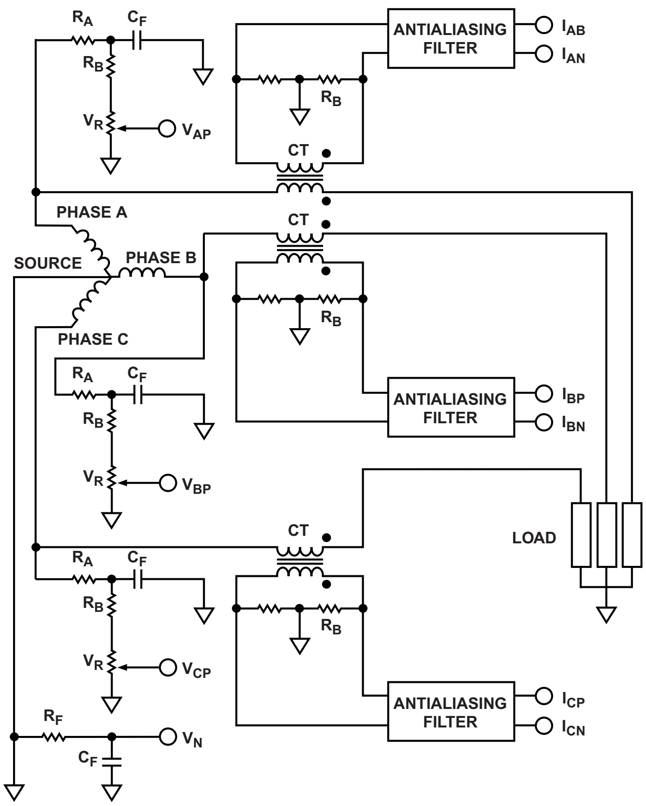

Figure 6. 4-Wire Wye Service Connections with Three Voltage Sensors

$$Active\ Power = (V_{AP} - V_N) \times (I_{AP} - I_{AN}) + (V_{BP} - V_N) \times (I_{BP} - I_{BN}) + (V_{CP} - V_N) \times (I_{CP} - I_{CN}) = (V_{\phi A} \times I_{\phi A}) + (V_{\phi B} \times I_{\phi B}) + (V_{\phi C} \times I_{\phi C})$$

To select this calculation mode in the ADE7754, the WATMOD register should be 00x00 and WATSEL = 0x00 according to the ADE7754 Data Sheet.

What are the connections for 3-phase 4-wire wye service (with two voltage sensors)?

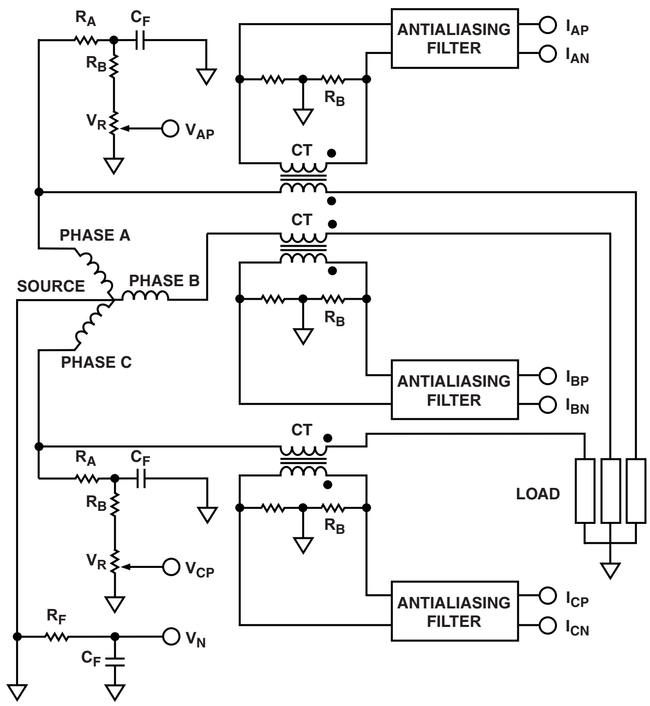

Figure 7. 4-Wire Wye Connections with Two Voltage Sensors

$$Active\ Power = (V_{AP} - V_N) \times ((I_{AP} - I_{AN}) - (I_{BP} - I_{BN})) + (V_{CP} - V_N) \times ((I_{CP} - I_{CN}) - (I_{BP} - I_{BN})) = V_{\phi A} \times (I_{\phi A} - I_{\phi B}) + V_{\phi C} \times (I_{\phi C} - I_{\phi B})$$

To select this calculation mode in the ADE7754, the WATMOD register should be 0x01 and WATTSEL = 0x07.

What are the connections of the analog inputs in 3-phase 3-wire delta service?

For 3-phase 3-wire systems, only two voltage inputs are connected to the ADE7754. One phase is used as a reference (connected to V_N of the ADE7754) and the other two phases are referred to this phase. In 3-phase 3-wire connection, you cannot get V_{AB} and I_C directly. For measuring I_C, you need an additional CT. For V_{AB}, the ADE7754 actually measures V_{BC} and V_{AC}. V_{AB} can be calculated from these two values assuming a constant phase difference between the three phases (120°). To select this calculation mode in the ADE7754, the WATTMOD register should be 0x00 and WATTASEL = 0x3, 0x5, or 0x6.

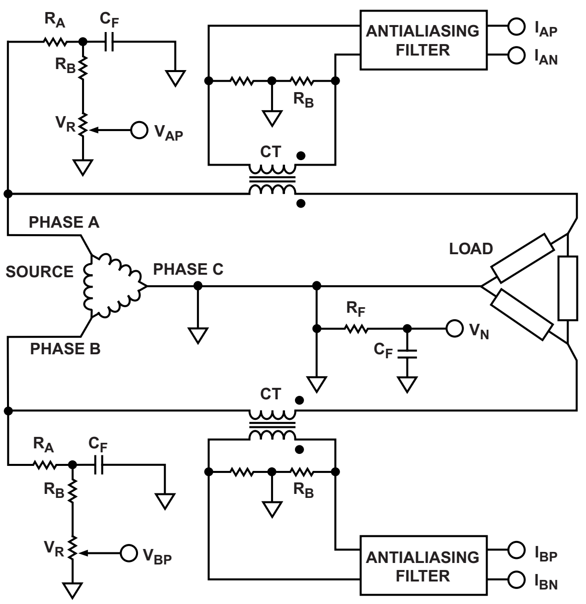

Figure 8. 3-Wire Delta Connections

$$\begin{aligned} Active\ Power &= (V_{AP} - V_N) \times (I_{AP} - I_{AN}) \\ &+ (V_{BP} - V_N) \times (I_{BP} - I_N) \\ &= (V_{\phi A} - V_{\phi B}) \times I_{\phi A} + (V_{\phi B} - V_{\phi C}) \times I_{\phi B} \end{aligned}$$

What are the connections for 3-phase 4-wire delta service?

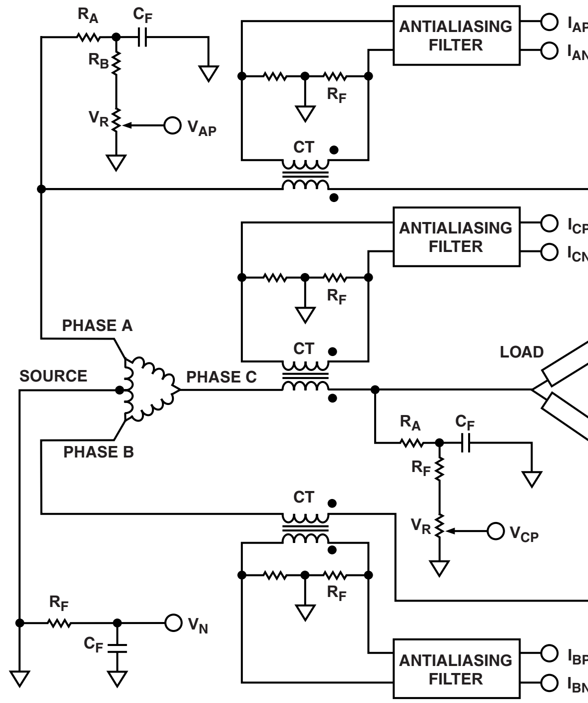

Figure 9. 4-Wire Delta Connections

To select this calculation mode in the ADE7754, the WATTMOD register should be 0x02 and WATTSEL = 0x07.

$$\begin{aligned} Active\ Power &= (V_{AP} - V_N) \times ((I_{AP} - I_{AN}) - (V_{BP} - I_{BN})) \\ &+ (V_{CP} - V_N) \times (I_{CP} - I_N) \\ &= V_{\phi A} \times (I_{\phi A} - I_{\phi B}) + V_{\phi C} \times I_{\phi C} \end{aligned}$$

Is there a time delay between the zero crossing on analog inputs of the voltage channel and the falling of IRQ at 50 Hz?

The zero-crossing detection has an inherent time delay from the low-pass filter. This time delay is approximately 0.6 ms as stated in the ADE7754 Data Sheet.

What is the error and dynamic range of the rms measurement (registers) in the ADE7754?

The error on the rms measurement depends on the level and type of input (current or voltage). On the voltage side, we recommend synchronizing the Vrms reading with the zero crossing of this phase to reduce the ripple noise in the VRMS register. By doing that, you can get errors below 1% in the range of FS to FS/20 with offset correction. On the current channel, the error can be below 1% in the range of FS to FS/100 with offset correction.

How do I calibrate the rms offset in the ADE7754?

You can correct the rms values with negative offsets by writing negative, twos complement values in the IRMSOS and VRMSOS registers. A value of 0xF800 is equivalent to –2048d and 0xFFFF is equivalent to –1d. The effect of these registers on the rms values is listed in the ADE7754 Data Sheet. For these offset calibrations, we recommend processing the offset correction with two nonzero values. If you use the rms value with no (zero) input to process the rms offset correction, the compensation will not be accurate. The reason is that the rms calculation integrates all the noise. This noise contribution becomes predominant in the rms register value and corrupts the reading well before the no-signal level. To avoid this problem, the offset correction should be done between V_{MAX} and $V_{MAX}/10$ for the voltage inputs and I_{MAX} and $I_{MAX}/100$ for the current inputs. DC offset appears more likely on the voltage input as there is no high-pass filter before the rms calculation, unlike on the current input.

Why should I read the rms register synchronous to zero crossings?

The rms calculation in the ADE7754 uses a low-pass filter to extract the rms value. This low-pass filter is not perfect and does not reject the 50 Hz and 100 Hz frequencies of the ac input. This "ripple" noise can be high and sampling the RMS register after a zero crossing of the corresponding voltage input (the ADE7754 has interrupts for zero crossing) to eliminate this noise is recommended.

Do the rms measurement registers of the ADE7754 include the harmonics?

In the ADE7754, the rms measurements include all the frequencies up to 10 kHz for the current channel, and up to 260 Hz for the voltage channel.

How do I implement 2-quadrant and 4-quadrant measurement in ADE7754?

The 2-quadrant calculation or sum of absolute values can be selected in the ADE7754 by setting Bit 2 of the GAIN register to logic 1. Regular, 4-quadrant, or arithmetic sum is selected by setting this bit to logic 0.

How can I reduce the power consumption of ADE7754?

One way to reduce the power consumption is to reduce the CLKIN frequency (10 MHz). All constants listed in the data sheet will be different but the part should work fine. The CF pulsewidth may also be affected by this change. Analog Devices tests to ensure high performance of its products before shipment. These tests are performed at 10 MHz only and performance for other CLKIN frequencies is not guaranteed.

Can we expect that power consumption will be reduced on the ADE7754 in the future?

No power consumption reduction is planned on the ADE7754. Future products in the ADE product family are being designed with power consumption reduction as a key design goal.

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