All-Electronic Power and Energy Meters

By Paul Daigle, Product Manager

The *AD775x family* of energy-measuring integrated circuits accepts voltage inputs representing local voltage and current in an electrical power system and converts them to digital using oversampling A/D converters. An on-chip digital processor continuously computes the product of the two signals, which is proportional to instantaneous power. Input conditioning, filtering, further processing, and other features, which are specific to each type within the AD775x family, provide metering solutions for a variety of power-system applications.

For example, the most general-purpose member of the family, the *AD7750* (Figure 1), low-pass filters the computed product, then uses digital-to-frequency conversion to output a complementary pair of pulse trains of frequency proportional to the instantaneous real power—for driving a counter or two-phase stepping motor—plus a higher-frequency output, suitable for calibration and test.

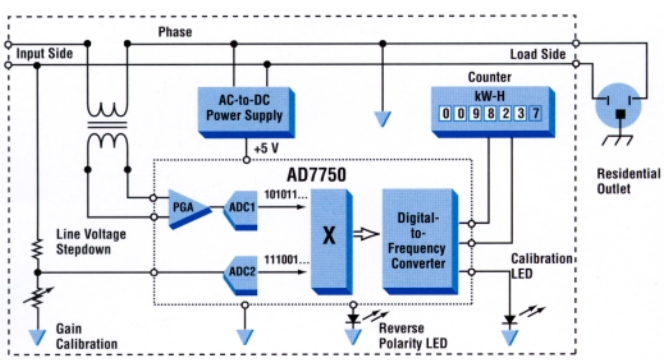

Figure 1. Functional block diagram of the AD7750 in a typical application measuring single-phase real power. Progress in power measurement.

Before continuing with a discussion of system applications and the features they give rise to, let us consider recent progress in power measurement in the electrical industry.

Electrical utilities, like many other heavy industries, have greatly increased their familiarity with sophisticated electronics in recent years. For example, the rate of replacement of long-used electromechanical meters by electronic devices is expected to quickly increase as decentralization in some countries and deregulation in others encourages customers to have a greater voice. Energy producers and consumers alike can benefit significantly from electronic energy meters.

A typical meter will convert signals proportional to instantaneous voltage and current to digital, then compute average and instantaneous real power, reactive power, active energy, etc., and transmit the information serially.

Customer service is improved through remote and automated meter reading and efficient data management. Besides receiving more credible utility bills, consumers benefit from more reliable power distribution. When customer meters are communicating through a network, power outages can be detected, identified, and corrected more quickly.

If the required ratio of peak power to average power in a system is reduced, the consequent reduction in required generating capacity will reduce environmental disturbance and pollution. The incentives provided by multiple-rate billing will help to greatly reduce peak usage despite population growth. Distribution cleanliness is maintained by monitoring the power-quality pollution (e.g., excessive reactive power, nonlinear loads, dc offsets) imposed by individual consumers. Consumers can benefit from lower electricity bills with the installation of smart card controlled energy meters that lower operational costs of providing service, reading meters, and processing data.

Electronic meters can compute power accurately irrespective of phase shifts and waveform distortion due to nonlinear loads; also, electromechanical meters are not able to accurately measure energy in the presence of phase-fixed load regulation schemes popular on distribution networks. Electronic measurements are thus more robust and accurate under these conditions.

Granted that electronic energy meters have outperformed the electromechanical meter in terms of functionality and performance, how do they stack up in cost and reliability? Two thumbs up! The entry to this field of companies like Analog Devices, with its excellent reputation for supplying analog, digital, and mixed-signal integrated circuits in large quantity for military, aerospace, and high-volume consumer products, promises the successful marriage between high reliability and low cost electronics that the industry has been waiting for. Recognizing the cost constraints of single-phase energy meters, ADI has identified an opportunity to help meter manufacturers meet their volume requirements, while reaching their cost targets and alleviating their reliability concerns.

Figure 2. When used with our reference designs, the AD775x family brings a new level of reliability to solid-state energy meters.

Such futuristic possibilities as automatic meter reading, smart card prepayment, and multiple rate billing will contribute importantly, but the actual accurate and reliable measurement of energy, both real and reactive, is the primary concern of progressive energy suppliers and distributors. Electronic measurement leads to reduced manufacturing investment, improved measurement accuracy and quality, and increased timely information, a combination of benefits that go well beyond the traditional rotor-plate energy meter design.

DSPs and Microcontrollers

The first attempts at electronic energy meters derived power by multiplying current and voltage in the analog domain, but the linearity over temperature and time proved to be no better than electromechanical meters. The stability, linearity, and accuracy provided by automatic error detection/correction of digital calculations has already swept across the communications industry and now has arrived at the door of electrical power metrology. Digital signal processing (DSP)-based products perform multiplication and other calculations on current- and voltage signals that have been digitized with on-chip analog-to-digital converters (ADCs). Processing the signals digitally provides stable and accurate calculations over time despite variations in the environment.

Although programmable DSPs are widely available at low cost and offer a degree of flexibility, what may turn out to be the most cost-effective form of processing electrical power measurements involves the use of a low-cost fixed-function (embedded) DSP, with on-chip A/D converters, for measurement and computation—and an associated microcontroller to handle programming tasks and simple calculations for communications and display. The DSP is continuously converting, sampling, and computing instantaneous and average power.

For example, during the past year many different energy meter designs have been manufactured using 4-MHz, 4-bit microprocessors. Such *microcontrollers* allow a limited degree of configurability while managing some house keeping functions, such as data encryption and demodulation, time stamping for multiple rate billing, and energy-delivery intelligence (power outage detection, remote disconnect, prepayment, load management). The microprocessor allows users to select the level of service they want, and the utility can remotely configure individual meters.

Standard Products

The growing family of standard products designed for energy measurement not only eliminates the high manufacturing investment associated with electromechanical energy meters; it also greatly reduces the need to develop ASICs (application-specific integrated circuits). Standard products incorporate the solutions of problems common to multitudes of different customers at a lower shared cost. Factors that manufacturers of electronic energy meters should consider when seeking to optimize overall cost-effectiveness of measurement choices include accuracy, hardware, software, development costs, time to market, and ease of implementation.

The following table shows how Analog Devices's growing family of fixed-function DSPs addresses the wide variation of system considerations worldwide. The choice of component from the family depends on the type of meter that is required for a given system.

Integrated Power Meter ICs

	AD7750	AD7751	AD7755	AD7756	Single Phase VA & VAR	Three Phase VA & VAR
PHASES						
Single Phase, 2-Wire	•	•	•	•	•	
Two Phase or Single Phase, 3-Wire	•		•	•	•	
Three Phase, 3- or 4-Wire (Wye or Delta Load)			•	•	•	•
INTERFACE						
Micro-ohm Shunts & Current Transformers		•	•	•	•	•
Milli-ohm Shunts & Current Transformers	•	•	•	•	•	•
OUTPUT						
High Frequency Pulse	•	•	•	•	•	•
Real Power	•	•	•	•	•	•
Low Frequency Complementary Pulse	•	•	•			
External Calibration	•	•	•			
Internal Calibration				•	•	•
Fault Tolerant Billing		•				
Zero Crossing Logic Output (Frequency)				•	•	•
Interrupt Request Output				•	•	•
Serial Port Interface				•	•	•
Apparent & Reactive Power, Voltage, Current					•	•
PACKAGE OPTIONS						
20-PDIP and 20-SOIC	•			•		•
24-PDIP and 24-SSOP		•	•		•	
SAMPLES	NOW	NOW	NOW	Aug '99	2000	Nov '99

NOTE: The first few AD775x standard products—designed to directly drive a stepper motor counter—precede a series of products with a serial port interface for bidirectional communication with a microprocessor. Analog Devices, Inc. will continue to assist in driving the cost of energy meters down by addressing the costs of the power supply, current transducer, oscillator, and external gain calibration. Ultimately, a highly integrated product can be designed to meet the aggressive cost targets while maintaining a great deal of functionality by close cooperation with both meter manufacturers and utilities. Contact our Power Measurement Group via email to begin developing a relationship.

The first in the family, the *AD7750*, is designed to directly drive a stepper motor counter to integrate power to energy. In terms of cost, the stepper motor counter is popular in developing countries because it is a practical way to build an inexpensive solid state energy meter. When power is lost, the counter simply stops turning. Other solutions, like light-emitting diode (LED) displays or liquid-crystal displays (LCDs), require high pin count drivers and a method to store the reading during power loss.

The next series of products have a serial port interface for bi-directional communication with a microprocessor. Products available soon will assist in driving the cost of energy meters down by addressing the costs of the power supply, current transducer, oscillator, and external gain calibration. Ultimately, close cooperation with meter manufacturers and utilities will lead to a highly integrated device designed to provide a great deal of functionality while meeting aggressive cost targets.

The AD7750 integrates two 16-bit analog-to-digital converters and the digital signal processing logic necessary to measure electrical energy. With the exception of the analog circuitry in the A/D converters and the reference circuit, all other signal processing (e.g., multiplication and filtering) is carried out in the digital domain. This approach provides superior stability and accuracy over extremes in environmental conditions and over time. The sigma-delta converters, operating at an oversampled rate of 900-kHz, which simplifies antialiasing, digitize the voltage signals from current and voltage transducers. The current channel has wide dynamic range and programmable gain to deal with direct connection to a variety of current-to-voltage transducers, which generally have low terminal voltage. A high-pass filter removes any dc from the current channel, eliminating inaccuracies that offset voltages might introduce into the calculation of real power.

Real power is calculated from the instantaneous power signal, which is generated by multiplying the current and voltage signals. A high-pass filter can be switched into the signal path of the current channel to remove any offsets. Low-pass filtering reduces the line-frequency harmonics and extracts the real power (in other words, dc) component. This approach calculates real power correctly, even with non-sinusoidal current and voltage waveforms and any power factor. The *digital* signal processing, (multiplication, filtering, etc.) ensures high stability over temperature and time.

The chip also contains two digital-to-frequency converters; one has a low-frequency output, the other, a high-frequency output. In both cases, the output pulse rate of the digital-to-frequency converters varies with value of real power dissipated over time. The chip offers a range of output frequencies, selectable by the designer, to accommodate most meters. The low-frequency output, because of its long accumulation time between pulses, has a frequency that is proportional to the average real power. The high-frequency output, with its shorter accumulation time, is proportional to the instantaneous real power. As a result, the high-frequency output is useful for calibrating the meter under steady load conditions.

Energy Metering IC with On-Chip Fault Detection

The *AD7751* is an accurate fault-tolerant electrical energy measurement IC intended for use in two-wire distribution systems. The part incorporates a novel fault-detection scheme, which both warns of fault conditions and allows the AD7751 to continue accurate billing despite a fault event. It does this by continuously monitoring both the phase and neutral (return) currents. A fault is indicated when these currents differ by more than 12.5%, and billing is continued using the larger of the two currents.

Energy Metering IC with Pulse Output

The AD7755 core is pin-compatible with the AD7751 but it does not include the fault-tolerant billing feature. It is also designed so that it can be used in systems with more than 2 wires, including 2- and 3-phase systems.