Energy Measurement for Appliances

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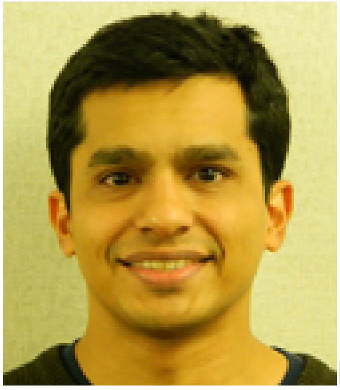

Energy consumption awareness is a crucial step in going green as an individual consumer. Real-time energy usage data aggregated at the home-level by smart meters is useful, but drilling down to the energy consumption of each major home appliance is even better and more actionable. Standards such as ENERGY STAR are undergoing revisions to include provisions for “connected” appliances. Appliances that meet the “connected” criteria can receive an extra allowance towards their energy use for ENERGY STAR qualification. Additionally, these appliances will be highlighted as “connected” on the ENERGY STAR qualified product list. One of the requirements for being “connected” includes the built-in capability of appliances to measure and report energy consumption. Low-cost components to perform energy measurement are key to enabling widespread integration of this functionality in appliances. Household appliances can be powered by gas or electricity, but since most are powered by electricity this discussion will focus on electricity measurement only.

The key components for energy measurement include voltage and current sensors, an analog front end (AFE) to interface with these sensors and a microcontroller to perform energy measurement calculations. The energy measurement results are then output to a LCD screen or sent over the serial bus to another device for wireless communication (Figure 1). Cost is a major consideration for products in the consumer market and it is important to design the energy measurement system with this consideration in mind. Since energy measurement on individual appliances is not used for billing purposes, the accuracy requirements are not as stringent as utility-grade meters. Additionally, the maximum currents to be measured are also smaller compared with utility meters. These factors enable choosing components that are not costly.

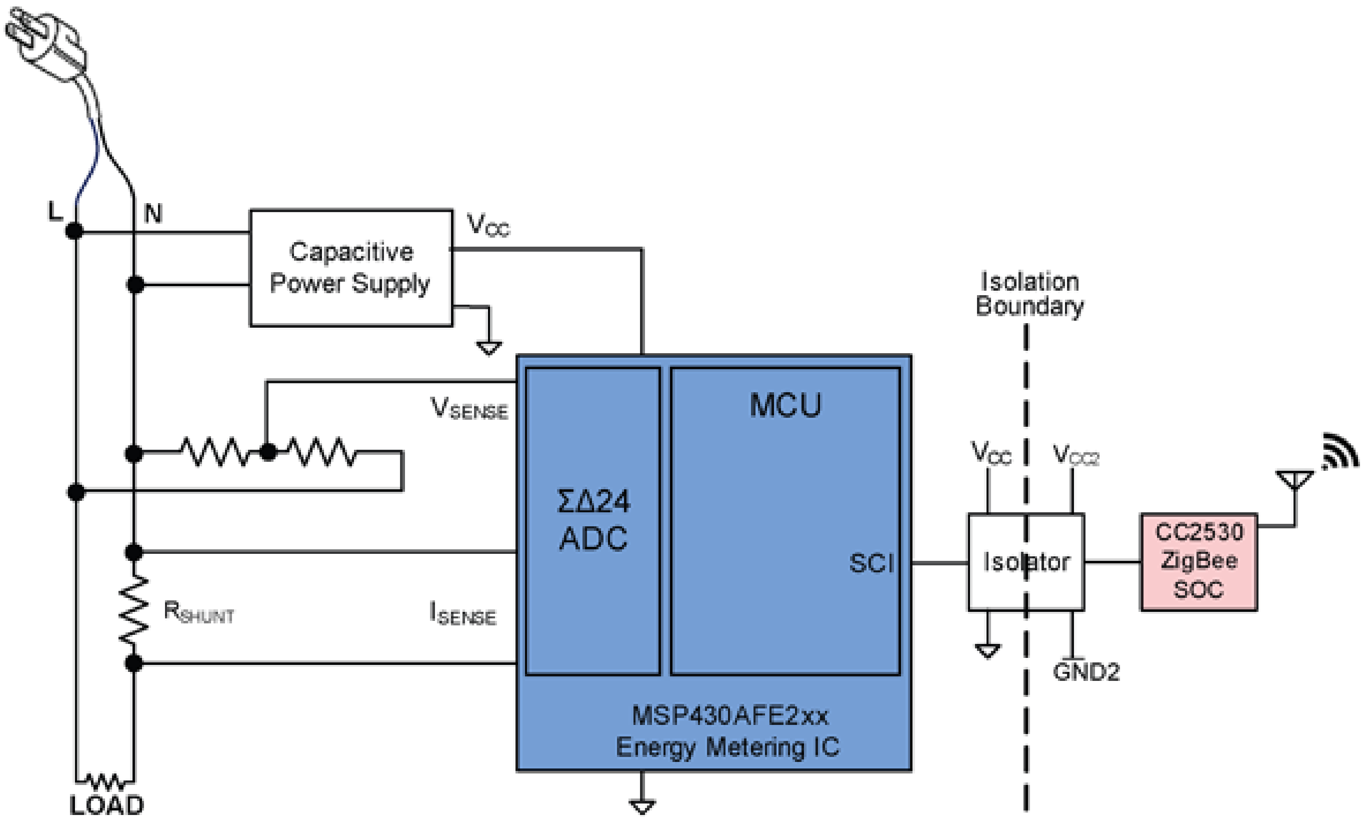

Figure 1. Block diagram of an energy measurement system

Electrical energy is power accumulated over time and is expressed in kilowatt-hours (kWh). Since power is the product of instantaneous voltage and current, the first step in energy measurement is to measure the incoming voltage and load current.

$$\text{Active Energy} = \frac{1}{N}\sum_{i=1}^{N} V_{samp}(i) * I_{samp}(i)$$

, where V_{samp} is Voltage Sample, I_{samp} is Current Sample

Simple resistor dividers can be used as voltage sensors. The resistor values are chosen such that the AC mains voltage is divided down to fit the input range of the analog-to-digital converter (ADC). The resistor-divider circuit (Figure 2a) divides down the input voltage by around 1000. Resistors have maximum voltage ratings that can cause arcing over the body of the resistor if exceeded. The use of discrete resistors (R1, R2, R3) in series instead of a single 1M? resistor allows the use of standard resistors without exceeding their maximum voltage ratings. An alternate choice of voltage sensors is potential transformers that can provide isolation from the high-voltage mains. However, they are expensive compared with discrete resistors.

The choice of current sensors depends on the type of incoming mains that the appliance uses. In the US, appliances such as refrigerators and washing machines run on single-phase 120V AC, whereas larger appliances such as clothes dryers and cooktops run on split-phase 240V AC. For single-phase applications, a low-resistance shunt can be inserted in the neutral line (Figure 2b) and the voltage drop across the shunt can be measured to calculate the current. Shunt resistors are low cost and easy to use, but they do not provide electrical isolation. For appliances such as clothes dryers and cooktops that use a split-phase supply, current transformers must be used on each of the two live wires, or a current transformer can be used on one live wire with a shunt resistor inserted in the neutral line. Current transformers provide electrical isolation, but cost more than shunts.

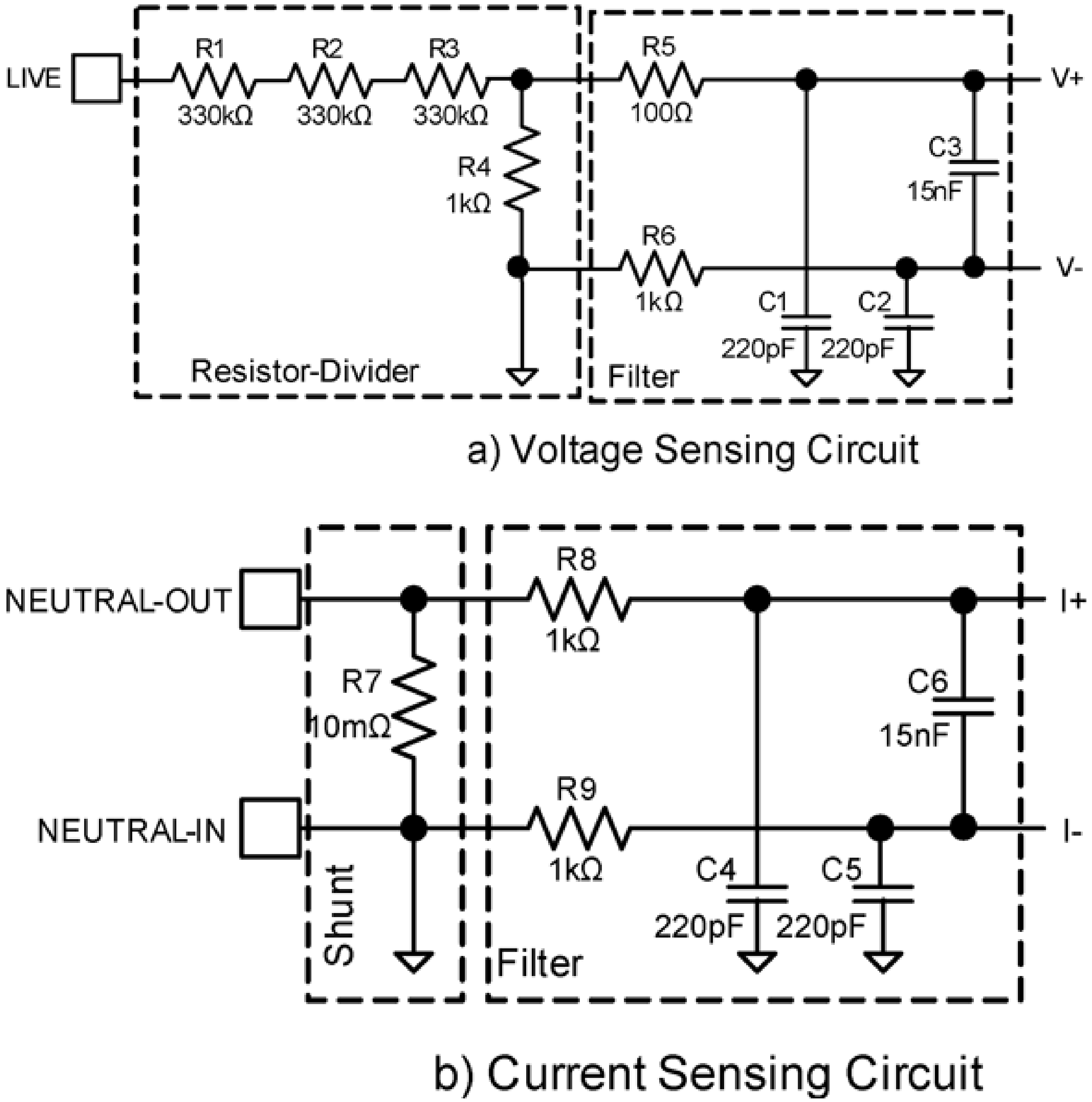

Figure 2a and 2b. Voltage and current sensing circuits for energy measurement

The sensing stage is followed by passive interface circuitry that further conditions the input signals before being fed into the ADC. The circuitry includes a filter to remove spurious wideband noise that can lead to inaccurate measurements. An additional level-shifter (not shown) might be needed to ensure that the voltage and current comply with input specs of the ADC. For a single-phase appliance such as a refrigerator, two ADCs are needed: one to measure the voltage and another to measure the current. For clothes dryers and cooktops, four ADCs are needed to measure two voltages and two currents. ADCs with 16-bit or 24-bit resolution and simultaneous sampling capability are typically used to generate accurate energy measurement results.

The microcontroller performs energy calculations with data received from the ADC. To compute active energy, reactive energy or apparent energy, microcontrollers must have good math libraries for common functions such as square root, square, and division. Once the data has been processed, it can be displayed on a LCD on the appliance or on a remote terminal. The microcontroller can be interfaced with LCD drivers or wireless communication modules via serial communication. If non-isolating sensors such as shunts and voltage dividers are used or if the AFE and microcontroller are referenced to the mains, it is critical to isolate any connection to other devices or systems that use a different reference voltage. Optocouplers or capacitive isolation ICs can be used to implement this data isolation.

Energy metering ICs available today integrate many of the components described above to enable low-cost solutions with minimal part count. The MSP430AFE2xx energy metering IC from Texas Instruments Incorporated (TI) includes multiple 24-bit sigma-delta ADCs, programmable gain amplifiers, serial peripherals and TI’s MSP430 Energy Library software suite to enable simple, low-cost implementations of energy measurement circuitry. Data can be sent to a LCD driver or a wireless device such as TI’s CC2530 ZigBee® network processor over a standard serial interface such as SPI or UART. Software-programmable solutions such as the MSP430AFE2xx provide flexibility to the system designer to tailor the solution to specific application needs. For example, implementing a non-standard communication protocol to send energy consumption data to a host processor. Low-power consumption of the MSP430AFE2xx microcontroller is important in being able to employ a low-cost capacitive supply to power the microcontroller.

Appliances with built-in energy measurement will help increase energy awareness among consumers so they can take actions to reduce their energy bills and contribute to a greener environment. Low-cost sensors and highly integrated energy measurement ICs enable low-cost implementations of energy measurement systems that can be widely adopted in appliances.

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