Accurate measurement of real world ac power has long been the bane of beginning EE students. Especially ac power in the presence of phase shifts, harmonics, and nonlinear loads.

Power measurement difficulties also partly explain why "magic lamp" and other misinformed "free energy" pseudoscience scams still persist on the web. And why you probably have not yet done your own careful home power inventory to try and trim your personal power bill.

Thankfully, there's now bunches of new ways to accurately view and measure ac power. Before we look at these new happenings, let's once again go over some... AC Power Fundamentals

Work gets done any time you have any force actually move something through a distance. Energy is defined as the capacity for doing work. And power is the time rate of doing work. Electrical power is often measured in Watts or Kilowatts. Electrical energy is sold by the Kilowatt Hour.

Say you have a black box with two access terminals on it. Measure the instantaneous voltage across these terminals. Measure the instantaneous current that is going into one of the terminals. The instantaneous product of the voltage in volts and the current in amps should be your instantaneous power in watts.

If the current and voltage are both positive or are both negative, your instantaneous power is going into the black box. We say the black box acts as a load or a sink that is consuming power. Presumably, the input power is internally developing heat; moving something where it does not want to go; emitting light; altering chemical states; building up some electric or magnetic field; or otherwise doing some sort of work.

One watt of power over one hour equals one watt hour of energy. One thousand watts for one hour (or one watt for a thousand hours) gives you one kilowatt hour of energy.

For which you usually pay your power company a dime.

On the other hand, if the terminal voltage is positive and your current is negative or vice versa, we'll say the black box is a generator or a source which is now producing power. The generated power has to come from some other external energy source; by diminishing the strength of any previously built up internal electrical or magnetic fields; through chemical conversion to lower energy states; or by some other means that strictly and absolutely conserves total energy.

Minus, of course, the irreversible fraction always lost as unrecoverable low grade heat. Carnot always gets his cut. Mordita and Bakeesh.

The tricky thing about ac "loads" is that they sometimes are a source of energy and sometimes are a sink of energy. Thus, power flow in typical real world ac devices can be a two way street. In and out.

Let's use figure one to see some of the problems that power waveforms can cause for us.

In figure 1A, we have an ac source driving a linear resistive load. A hot...
In figure 1, we view the super important case of a typical motor. Here we have a lagging load that is mostly resistive, combined with the inductance of the motor winding. A power factor can be defined as the cosine of the phase angle. A common power factor of 0.8 implies a phase shift around 37 degrees. With such a lagging load, the current still goes both ways. Except the dominant flow this time is into the motor. Note the two brief and rather low power reversals in each line cycle.

I have purposely left the current waveforms out of this figure to keep things simple. I invite you to sketch all these in as an "exercise for the serious student". For there’s lots to be learned here.

Summing up: In pretty near any reasonable ac device you can think of, the power waveform will be more or less nonlinear. Typically, you’ll have a hard-to-measure average long term value overlain by some cyclic double frequency waveform. Thus, accurate ac power measurement all comes down to measurement of an arbitrary waveform that is formed by the product of two values. And these days, the best way to make any low frequency measurement is to...

Do It Digitally

Figure two shows you a good way to accurately calculate ac power. While you could dream up an analog multiplier circuit, such devices will quickly get into several crest factor problems. The crest factor is the ratio of your peak power to the average power. Analog solutions tend to get complex if the needed crest factor exceeds three or so.

Dimmers (figure 1D) and rectifiers (figure 1C) often exceed this value. Instead, the trick is to A/D convert your current and voltage waveforms, sampling them digitally at the same time, and then digitally multiply them together. How many samples? I’d vote for at least 100 per half cycle, or 12,000 per second. This sounds high at first glance, but with the often seen diode waveforms of figure 1C, this would only leave you with ten or so non-zero samples per half cycle. And an accuracy at best of five percent.

Note that any power measurement scheme either has to measure one full...
Fig. 3 – THE NEW MAXIM MAX125 lets you simultaneously sample voltage and current. This is a crucial first step in digital power measurement. A microcontroller does the actual multiplication.

cycle or else has to measure a "large number" of cycles. Otherwise errors are certain to happen when portions of cycles are unfairly or randomly represented. It does pay to lock your measurement scheme to the voltage or current zero crossings such that whole cycles are always measured.

Strong lowpass filtering of both voltage and current waveforms is a good idea to reduce high frequency noise. But it is super important that identical filters get applied to both voltage and current to prevent group delay problems.

The voltage and the current really should get measured at exactly the same time. But if your sample rate is high enough, you might get by taking the average of two sequential current measurements. For instance...

\[
\begin{align*}
&46 - \text{current} \\
&47 - \text{voltage} \\
&48 - \text{current} \\
&49 - \text{voltage} \\
&50 - \text{current}
\end{align*}
\]

...and then multiply #47 voltage times the average of current #46 and current #48. Similarly, multiply #49 voltage times the average of current #48 and current #50, and so on.

A PIC is your obvious choice for lowest cost ac power measurement calculations. Suitable current sensors might include a current transformer (Amecon is one better source), Hall effect sensors, clamp around probes, or measuring the voltage drop across a suitable small series resistor.

The New Stuff

As we already found out back in MUSE112.PDF, those ordinary cheap voltimeters and ammeters are totally useless to measure real ac power. Such meters measure average rather than true rms. They all lie like a rug, because their "answer" is so highly waveshape dependent.

Here are several of the latest new developments in low cost accurate ac power measurement...

True rms meters – The costs for digital or analog meters with a true rms ability is dropping dramatically. Even Radio Shack now resells $79 digital voltmeters that can provide true rms. A true rms meter gives you
Inside you will find a pair of high multiplier, a digital-to-frequency chips and circuits. those new power factor correction why there is so much excitement over IEC  standard 555-2 is all about. And make them illegal. Which is what waveforms. The European method may not do all that great on stranger factors of two. Which suggests that it cycle-by-cycle measurements. The output frequencies of only a few drivers for a mechanical totalizer. The European 50 Hertz power meter. Their data sheet does mention crest NEED HELP? Phone or write all your US Tech Musings questions to: Don Lancaster Synergetics Box 809-EN Thatcher, AZ, 85552 (520) 428-4073 US email: don@tinaja.com Web page: www.tinaja.com Maxim MAX125— This is a brand new simultaneous multi-channel A/D converter. It is specifically designed for power meters, motor controls, and for power factor monitoring. There are eight analog inputs which can be routed to a 4PDT selector switch and then input to four simultaneous A/D converters. Fourteen bit conversion is provided in three microseconds, by using the circuit of figure three. An external clock is needed. Its typical value is 16 MHz. There are fourteen parallel data outputs, the lower four of which are used as bidirectional address inputs to program one of eight conversions plus a power down. The choices are A or B sides of one through four channels of conversion. It takes three microseconds to do the one-channel conversion and twelve microseconds for a four-channel conversion. There are four control inputs of chip select, read enable, write enable, and conversion start. There’s also a “conversion done” output normally used as an interrupt. After conversion is done, the first parallel data. The next one outputs channel 1 as parallel data. The next one outputs channel 2. Up to the fourth one that reads channel 4. For single phase power use, you normally only select a single side of channel one for current and two for voltage. The full four channels may be required for three phase power systems or exotic motor controls. Note that this chip only measures your input values for you, doing so accurately and simultaneously. Your host PIC or whatever has to do the actual multiplies for calculation of the instantaneous power. The interface to a PIC or other microcontroller is fairly simple. An external data latch may be needed in some systems. Evaluation kits and free chip samples are available. Maxim’s website can be found at www.maxim-ic.com. Digitest DT500— This is a unique home power monitor that I’ve been testing. In a $99 list package about the size of a box of cereal, you can monitor 120/240 volt ac appliances for your voltage, current, kilowatt hours, and duty cycle. And power costs in dollars and cents. You can plug an appliance or other load into the back of the unit, use an accessory snap-around current probe, or else directly input a custom test voltage that is related to current. You can very quickly find out that your refrigerator is costing you $19.37 per month to use. Around 3600 current and voltage samples per second are taken in this Intel 8751 based device. This pretty much follows most of figure two.
The DT500 certainly does what it claims to, and sure is a lot of fun to play with. Especially for doing your own home energy inventory. On the other hand, the ergonometrics aren’t all that great, the LCD desperately needs backlight, the cents per KWH cost entry is klutzy, and there’s zero I/O provision for data capture, record keeping, or for any history plotting. In addition, some sort of a wireless provision for data capture, record entry is klutzy, and there’s zero I/O needs backlit, the cents per KWH cost.

The Remote Measurement Systems Power Sentry—This is a neat little infrared sensor that sticks to the glass of an ordinary power meter and then counts every time the black mark on the disk comes around. Yes, the $79 device is not only allowed by certain power companies, but it is actually approved of and strongly encouraged. A companion ADC-1 interface and control software for Mac or PC lets you plot a month’s power use in half second intervals.

I’m trying to get one of these for further test and evaluation. I’m on good enough terms with our town’s power company that approval should not be much of a hassle. Once again, a wireless unit with a 35 foot range sure would be a lot more convenient.


I’ve gathered a few preliminary sources for ac power measurement and home energy management as this month’s resource sidebar. I’ll try to work up a more extensive survey for a future column. More on rms power measurement in MUSE112.PDF on my www.tinaja.com. New Tech Lit

From Logic Devices, a new Power of Signal Processing data book. You will find special video filter, alpha
mixer channel, and histogram chips here. From MuRata, a new RF and Microwave Products Catalog. You’ll find bunches of ceramic resonator and surface acoustic wave (SAW) devices in this manual.

From Texas Instruments, a pair of new CD ROM data books: Titled InfoNavigator and the Future of DSP Technology. Also through T.I., data sheets on their new low cost TSL253 light-to-voltage converter.

Use of DNA computing to solve a major math problem appears on pages 446-449 of Science for October 17, 1997. Volume 278.

A booklet on higher performance permanent magnets is available from Magnet Applications. Some low cost hygrometers are retailed by Klockit. Hydraulic bargains can be found at Roberts. Superb laser printer service seminars, and printer maint manuals are offered by Don Thompson.

Richard Grier has got a new Visual Basic Programmer’s Guide to Serial Communications, his useful text on low level Windows comm access. Published by Mabry. From Lindsay Publications, two volumes of their “new-old” 1906 reprint series titled Experimental Science; Elementary Practical and Experimental Physics.

Featured trade journals for this month are Data Storage for hard disk insiders, Forming & Fabricating for sheet metal, and Card Technology on smart cards.

The latest and finest version of Adobe Acrobat is newly available for $49 through the Academic Software division of Surplus Direct. Acrobat includes the powerful Distiller 3.01 program which makes an outstanding host based PostScript-as-language computer. More details on the power of raw PostScript computing can be found in DISTLANG.HTML and also in POSTFLUT.PDF on my Guru’s Lair at www.tinaja.com.

For nearly all individuals and all small scale startups most of the time, an involvement with patents is likely to end up as a net total loss of time, energy, money, and sanity. Find out why in my The Case Against Patents package. Included are my tested and proven real-world alternatives. Per my nearby Synergetics ad.

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