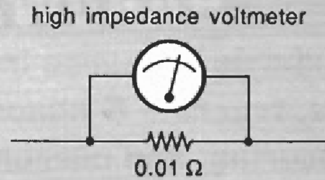
Current and current sensing

Accurately sensing or measuring an electrical current can get tricky. Especially when AC is involved or when breaking the primary circuit is a no-no. Let us do a quick review of several of the current-sensing fundamentals and see which hacking opportunities it leads us to.

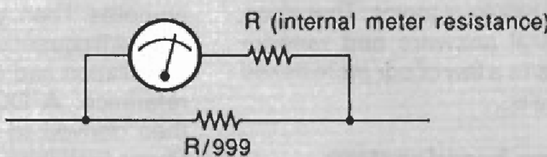
In general, there are two main methods of sensing current. With the *direct* method, you will place an appropriately low resistance or an impedance in series with your load and then measure the voltage drop across that impedance. With the *indirect* method, you try to accurately measure the strength of the magnetic field created by a conductor carrying your load current.

Figure 1 shows us three stock direct-current ammeter schemes. In 1-*a*, a low-value resistor known as a *shunt* is placed in series with the load. You then measure the voltage drop across it with a "perfect" high-impedance voltmeter. For instance, an 0.01-ohm shunt will give you a tenth of a volt out for ten amps in.

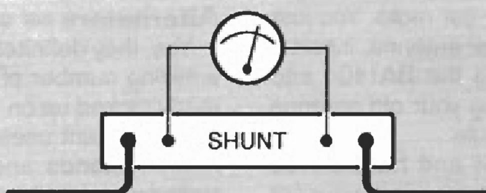
Shunts can be anything from a piece of paper clip (thank's to Steve Ciarcia) to precision and temperature-compensated devices. Sources of shunts include *Simpson*, *Triplett*, and various advertisers found in



(A) The standard way of measuring a DC current is to place a very small valued shunt resistor in series with your power load. The voltage drop across the shunt and Ohm's Law will tell you the current. In this example, an 0.01 Ohm shunt gives you a tenth of a volt out for a measured current of ten amperes.



(B) If an ordinary meter is used, its internal resistance must be included in the calculation of the shunt value. As shown here, to convert an 0-1 DC milliameter with an internal resistance of R into an 0-1 DC ammeter, you have to add an external shunt of R/999 Ohms. Note that the term "shunt" applies to the meter, and not to the load being measured.



(C) When ultra-low shunt values or high currents are involved, a four terminal Kelvin mesurement scheme should be used. This prevents unavoidable drops across the power connections from trashing your readings. Four terminal techniques are also used for remote load regulators and in superconductor research.

FIG. 1—SOME OF THE FUNDAMENTALS involved in DC current measurement.

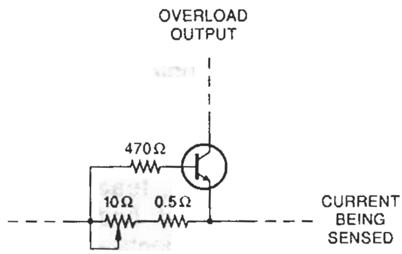


FIG. 2—THIS SIMPLE CURRENT LIMITER is adjustable over a 50-mA to 1-ampere range. Use the collector current to pull down a reference or otherwise reduce your input current or source voltage.

those *Measurement & Control* and *Sensors* trade journals.

It gets slightly trickier when you use a shunt to increase the range of an ordinary milliammeter, rather than a "perfect" high-impedance voltmeter. Details per Fig. 1-*b*. Say you have an 0–1 DC milliammeter of internal resistance R. Your shunt to convert it into a 0–1 DC ammeter should have a value of exactly R/999. Such that the combined parallel resistance of your shunt and the meter resistance ends up precisely R/1000.

The amount of voltage drop across your shunt will depend on the input current, your shunt resistance, and Ohm's law. The lower the R value of your meter, the less voltage drop you will get across your shunt when you measure high currents.

Since all high-current shunts are extremely low impedances, you have to be very careful that voltage drops across your meter and all your load connections do not inadvertently get included in your measurement.

That leads us to the *four terminal* or *Kelvin* connection shown in Fig. 1-*c*. You measure only the voltage drop across a precisely known *portion* of your shunt. That guarantees any external high-current connections are *outside* of the voltage drop being accurately measured.

A variation on the four-terminal technique can let you use a voltage regulator remote from its load. By feeding back your voltage-sensing leads, you could include your main current drops *inside* your regulator and get more precision results. The trick, of course, is to make absolutely certain that none of the load current travels through the sensing leads.

A simple *current limiter* is shown in Fig. 2. It's adjustable over a 50-milliampere to a 1-ampere range. It is based on a silicon NPN transistor needing a 0.6-volt drop before it conducts. Whenever your transistor starts conducting, its collector current gets used to pull down a regulator or whatever, thus safely limiting your current.

As Fig. 3 shows us, current sensors for *AC* circuits often use a *current transformer*. That is a special transformer with a very low-impedance primary and having a high step-up ratio. The AC voltage that is delivered to the load resistor is proportional to the primary current.

There are some very important rules for current-transformer use. The load must *never* be disconnected from a current transformer! Dangerous and possibly lethal voltages could result. Also obviously, you must never disconnect the primary in any live circuit. Only the specified load resistor can be used or calibration will suffer.

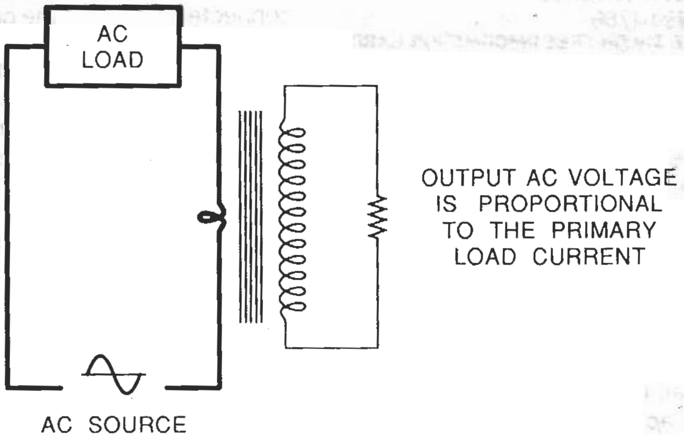


FIG. 3—A CURRENT TRANSFORMER is just a transformer that has a very low-impedance primary (often ONE turn or less) and a high step-up ratio. The voltage across the secondary is proportional to the primary current.

NAMES AND NUMBERS

Adobe Systems
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Mountain View, CA 94039
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Amecon
1900 Chris Lane
Anaheim, CA 92805
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Sausalito, CA 94965
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CR Magnetics
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Palo Alto, CA 94303
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(818) 792-5700
CIRCLE 306 ON FREE INFORMATION CARD

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Rockville, MD 20850
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2000 Sierra Point Parkway
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Home Automation USA
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Oklahoma City, OK 73123
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Ukiah, CA 95482
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Rohm
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Irvine, CA 92713
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Silicon Systems
14351 Myford Road
Tustin, CA 92680
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CIRCLE 313 ON FREE INFORMATION CARD

Statek
512 North Main Street
Orange, CA 92668
(714) 639-7810
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Synergetics
Box 809-RE
Thatcher, AZ 85552
(602) 428-4073
CIRCLE 315 ON FREE INFORMATION CARD

Texas Instruments
PO Box 809066
Dallas, TX 75380
(800) 336-5236
CIRCLE 316 ON FREE INFORMATION CARD

Toroid Corporation
608 Naylor Mill Road
Salisbury, MD 21801
(301) 860-0300
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Trade Winners
PO Box 2868
Vancouver WA 98668
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Often, the primary can simply be a single wire through the core of the transformer. If you do use a single wire, some care is needed to get an accurate and repeatable reading. The wire should go straight through the exact center of your current transformer. It should extend straight and normal for a few inches in either direction. It must not be allowed to move or vibrate.

On the other hand, sensitivity and accuracy can be improved by using several primary turns. But there may not be room in the core.

If the current-transformer core can be opened in some manner, you can connect or disconnect your current transformer without physically disconnecting the current-carrying load wire. That gets very important when making any service and test measurements. Or when you want to avoid an electrician.

A *snap around ammeter* is one example of an openable core. When you snap around your wire to be sensed, you are closing the core and completing a current-transformer magnetic circuit.

Two important points: You must snap around a *single* wire. If you snap around a wire and its return path at the same time, the two currents will largely cancel out, leading to a useless measurement. And the magnetic path must be identical for each snap. Thus, your core must snap together exactly and precisely. The same way each and every time.

I've found three good sources for low prices and eminently hackable current transformers. They include *Amecon, CR Magnetics*, and *Toroid Corporation*. The latter two offer toroidal current transformers, similar to Fig. 4. They are priced in the ten- to twenty-dollar range. Some models include built-in LED safety monitors.

But by far the most hackable current transformer I have ever seen is the *Amecon* LD-50 load detector. That beauty costs under three dollars in quality. Samples are available.

Now for the unusual part. Their LD-50 comes apart so you can install it snap-around style, without breaking your primary load wire. Wires of #8 size or smaller are acceptable.

With a 50-ohm load, the LD-50 produces 50 millivolts per ampere and is useful over a 5- to 50-ampere range. Which is ideal for most home power monitoring uses.

Home energy monitoring

Most people can save hundreds of dollars a year on their power bills, simply by finding out what electricity gets used when and by whom. And then attacking the worst of the power gobblers in a logical and a cost effective way. Step number one in this process is one or more current sensors connected to your home computer or microcontroller.

Probably the one single greatest obstacle to wide acceptance and use of home energy monitoring involves the hassles of current sensing. You do not want to rewire your house, hire an electrician, or go to any expensive and fully approved devices.

Figure 5 shows you one home energy monitor scheme that I call the *isopod*. A fully insulated and split tennis-ball shaped pod gets snapped around one insulated line of a power cable. Inside the pod is a current transformer and some black magic chips. Possibly from such outfits as *Dallas Semiconductor, Maxim, LSI,* or one of the other good guys.

The isopod derives all the power it needs from the sensed current. A separate control receiver/transmitter is located a safe few feet away. The control box uses a lower-frequency radio waveform to interrogate your isopod. If properly addressed, the isopod responds by returning a high-frequency code burst equal to the current presently being measured. Finally, the control box intercepts the data burst and converts the sensed current into standard serial data that a computer can understand.

As shown, the isopod would only measure and monitor current. That should be good enough for typical home energy monitoring uses. But, by carefully synchronizing the start of your data burst to the a positive-going current zero crossing, your control box could measure its *own* voltage to determine the lag or lead and your actual real and reactive power.

Several channels could be made available by using different isopod addresses. That solves the dilemma of simultaneously monitoring both legs of the normal 220-volt, center-ground home power system. Or of monitoring individual breaker lines.

You can probably snap the pod directly onto your incoming power leads *ahead* of the meter—up on the roof where they are easily open and accessible. The tiny extra power "stolen" from your utility would add half a cent to a $200 monthly power bill. And the potential utility benefits in load shedding and load leveling would be much higher.

I can think of lots of other uses for a cheap and fully isolated, snap-on current sensor. Safely measuring high-voltage industrial systems can be one obvious use. Getting info onto or off of a rotating shaft or moving machine is a second.

And last summer I had a slightly but infuriatingly intermittent frost sensor in my heat pump. It sometimes insisted on switching over to high emergency heat during the middle of an Arizona desert summer afternoon.

The several wasted service calls and the perfectly good parts that were unnecessarily replaced could have been eliminated by several snap-on isopods that monitored and recorded what was going down.

But why don't you tell me instead? For this month's contest, just tell me

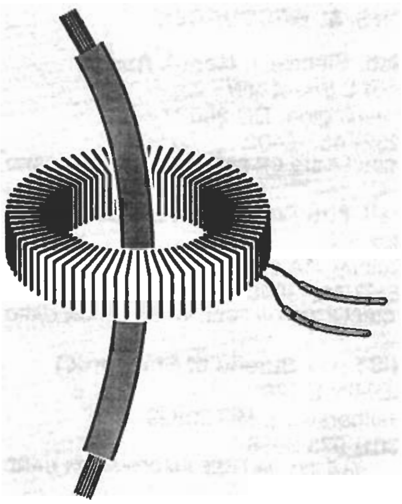

FIG. 4—A TOROIDAL CURRENT transformer is economical and accurate. It is also self-shielding. But you physically have to disconnect and thread the primary wire through the core center.

what you would do with one or more isopods. Or else contribute somehow to our home-energy dialog. There will be all of those usual newly revised *Incredible Secret Money Machine* books going to the dozen best entries, with an a great expense-paid (FOB Thatcher, AZ) *tinaja quest* for two going to the best of all. Be sure to send your written entries directly to me at *Synergetics,* and *not* to **Radio-Electronics** editorial.

Getting standards info

Where do you go to get a copy of EIA standard RS-232? Two obvious places to start include the *Encyclopedia of Associations* on the reference shelf of your local library. Or, for government standards, the

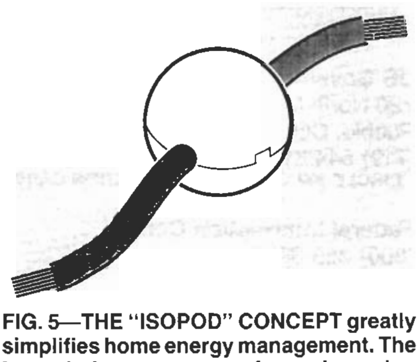

FIG. 5—THE "ISOPOD" CONCEPT greatly simplifies home energy management. The Isopod clamps on one of your incoming power cables. Inside is a current transformer and some micropower electronics. On any addressable VLF radio inquiry from a nearby control module, the isopod returns your present current consumption as a UHF radio signal. Response is synchronized to current zero crossings so that both real and reactive power can be remotely measured.

STANDARDS ASSOCIATIONS & RESOURCES

Am. National Standards Inst.
11 West 42nd Street, 13th Floor
New York City, NY 10036
(212) 642-4900
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AM. Soc. Testing & Materials
1916 Race Street
Philadelphia, PA 19103
(215) 299-5400
CIRCLE 320 ON FREE INFORMATION CARD

American Radio Relay League
225 Main Street
Newington, CT 06111
(203) 666-1541
CIRCLE 321 ON FREE INFORMATION CARD

Assoc. Computing Machinery
11 West 42nd Street, 3rd Floor
New York City, NY 10036
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Compliance Engineering
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Boxborough, MA 01719
(508) 264-4208
CIRCLE 323 ON FREE INFORMATION CARD

Electronic Industries Assoc.
2001 Pennsylvania Avenue NW
Washington, DC 20006
(202) 457-4900
CIRCLE 324 ON FREE INFORMATION CARD

IEEE Electronic Engineers
345 East 47th Street
New York City, NY 10017
(212) 705-7900
CIRCLE 325 ON FREE INFORMATION CARD

Int. Standards Organization
1 Rue Varembe Case post 56
CH1211 GENEVE 20 Switzerland
41-22-749-0111
CIRCLE 326 ON FREE INFORMATION CARD

MIL Spec Order Desk
700 Robbins Avenue B4 Sect. D
Philadelphia, PA 19111
(215) 697-2179
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Natl. Assoc. of Broadcasters
1771 N Street NW
Washington, DC 20036
(202) 429-5300
CIRCLE 328 ON FREE INFORMATION CARD

Natl. Electrical Manuf. Assoc.
2101 L Street NW
Washington, DC 20037
(202) 457-8400
CIRCLE 329 ON FREE INFORMATION CARD

Natl. Fire Protection Assoc.
Box 9101
Quincy, MA 02269
(617) 770-3000
CIRCLE 330 ON FREE INFORMATION CARD

NIST (US Bureau of Standards)
ADMIN E-128
Gaithersburg, MD 20899
(301) 975-3058
CIRCLE 331 ON FREE INFORMATION CARD

National Standards Assoc.
1200 Quince Orchard Blvd.
Gaithersburg, MD 20878
(800) 638-8094
CIRCLE 332 ON FREE INFORMATION CARD

Soc. of Automotive Engineers
400 Commonwealth Drive
Warrendale, PA 15096
(412) 776-4841
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Soc. Mot. Pic. & TV Engineers
595 West Hartsdale Avenue
White Plains, NY 10607
(914) 761-1100
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Standards Engineering Society
P.O. Box 2307
Dayton, OH 45401
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Underwriters Laboratories
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Northbrook, IL 60062
(708) 272-8800
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US Government Bookstore
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Pueblo, CO 81003
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Federal Information Center
(800) 359-3997

main *Federal Information Center* phone number of (800) 359-3997.

To make things easier for you, I've gathered up most of the standards associations and resources of hacker interest together for you into our resource sidebar for this month.

Two quick notes. *ANSI* is just the American arm of the international *ISO*. They are pretty much one in the same. And the *US National Bureau of Standards* has long ago changed their name over to the *National Institute of Science and Technology*, or NIST.

Actually, RS232 has been largely replaced by the MacDonald interface. Jerome R. MacDonald is the senior member of a design team in the dairy science division of the *US*

Department of Agriculture who came up with a fast, convenient, error-free, and fully networkable serial communication setup.

The great MacDonald interface is presently up for *Electronic Industries Evaluationary (EIE)* status. Thus, the old MacDonald farm interface is now an EIE I/O.