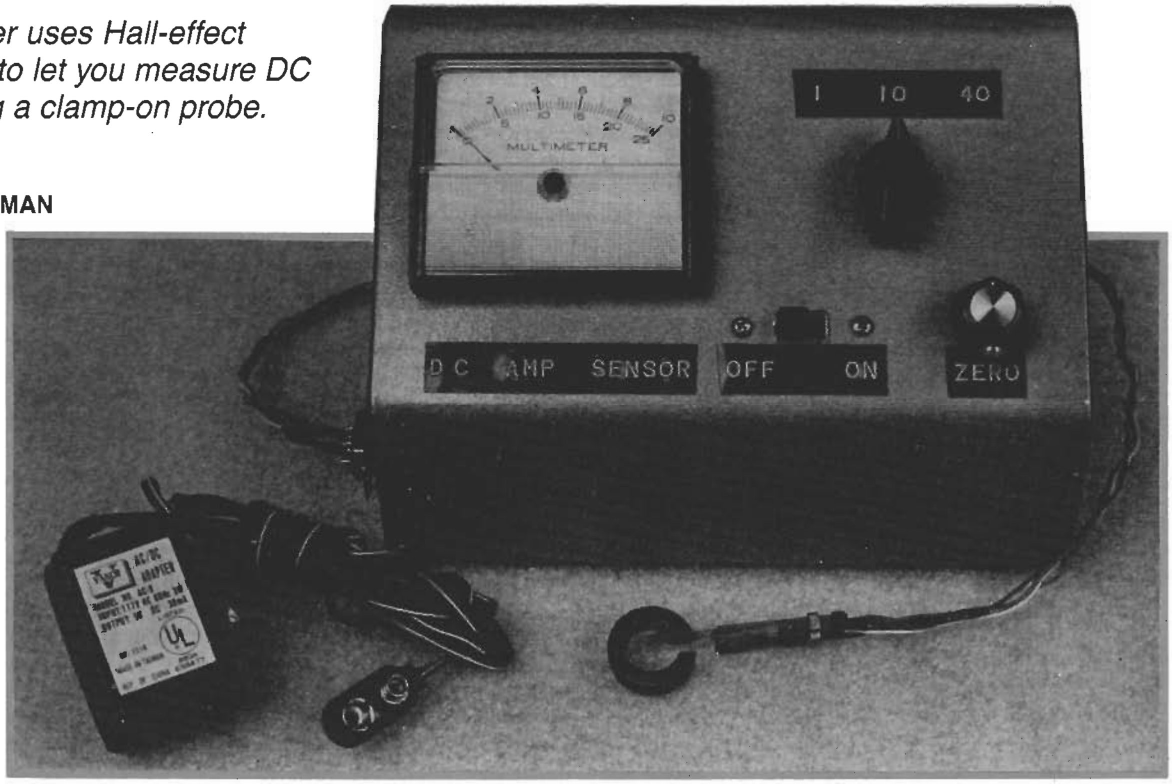
Clamp-on DC Ammeter

This ammeter uses Hall-effect transducers to let you measure DC current using a clamp-on probe.

HARDIN STRATMAN



THE CONVENTIONAL METHOD OF MEASURING direct current in a circuit is to connect an ammeter in series with the current flow, as shown in Fig. 1. That means that if you want to measure the circuit's current, you have to shut the current off before connecting or disconnecting the ammeter. If the point of current measurement is at a high voltage, the ammeter case must be insulated from ground to prevent arcing. And it also must be insulated from people who might come in contact with it.

Another problem with inserting a conventional ammeter in series with the current flow is that the internal resistance and inductance of the meter can alter some characteristics of the circuit under test in an undesirable manner. For example, it can add inductance in a video circuit or resistance in a high-current circuit. A remote meter-reading at any distance may be difficult to obtain.

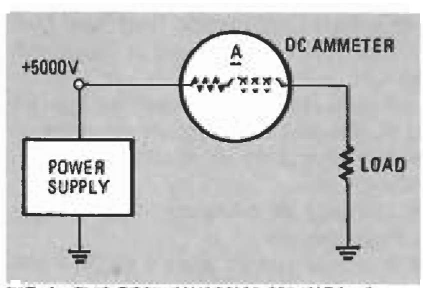


FIG. 1—THE CONVENTIONAL METHOD of measuring current can add undesirable resistance and inductance to the circuit. The ammeter case may also be at a dangerous voltage level.

The clamp-on ammeter

With clamp-on ammeters, there's no exposure to dangerous voltages when measuring current; there's no need to disturb the insulation; there's no inserted impedance. Clamp-on ammeters eliminate the undesirable characteristics of DC ammeters because they measure the current flowing in a wire without breaking the circuit connection, as shown in Fig. 2.

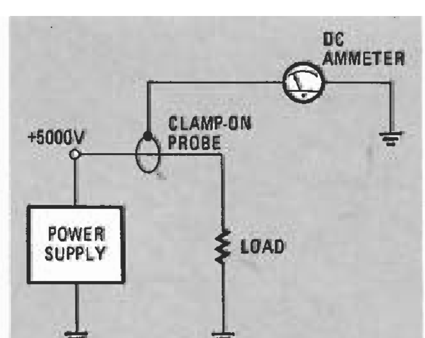


FIG. 2—THE CLAMP-ON AMMETER does not add inductance or resistance to the circuit, and it's isolated from high voltages.

Clamp-on ammeters for measuring alternating current have been around for a long time. Those devices are generally low cost, reasonably accurate, and easy to construct since they operate on a mutual-inductance principle the same as a transformer. But there have only been a limited number of DC clamp-on ammeters available. One example of a fine laboratory-type DC clamp-on ammeter is shown in Fig. 3: Hewlett Packard's *HP-428B*, which can measure current from 1 milliamp to 10 amps. Its list price is around $1800. The *HP-428B* first converts the magnetic field around the conductor to an AC voltage that is proportional to the DC current. If you connect a voltmeter or oscilloscope to a front-panel output, you can measure low-frequency (under 400 Hz) AC current, too. The unit's probe needs occasional de-gaussing.

Just recently, some DC clamp-on ammeters that make use of the *Hall effect* principle—as our ammeter will do—have become available. The list price of those instruments is about $200 to $500. Figure 4, for example, shows F.W. Bell's *Current Gun* model *CG-103A*. That is a clamp-on current probe that uses a Hall-effect gen-

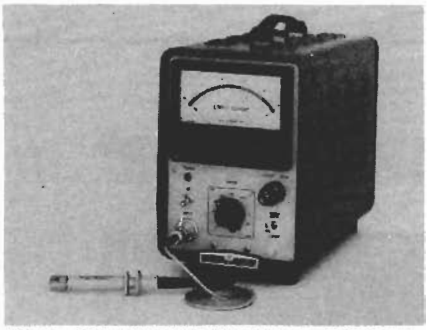


FIG. 3—ONE EXAMPLE OF a lab-type DC clamp-on ammeter: the *HP-428B*.

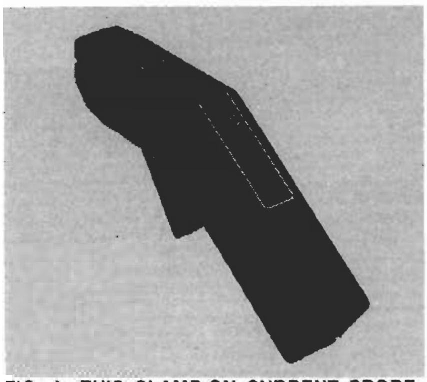


FIG. 4—THIS CLAMP-ON CURRENT PROBE uses Hall-effect sensors.

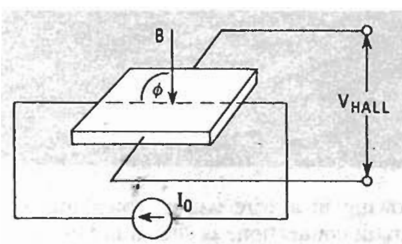


FIG. 5—IF A CURRENT-CARRYING conductor is placed in a magnetic field, a Hall voltage is generated that is perpendicular to both the current flow and the magnetic field.

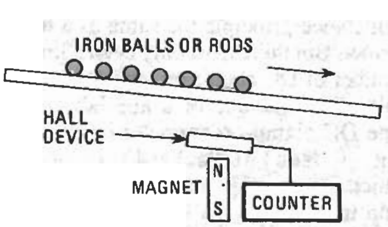


FIG. 6—BECAUSE THE OUTPUT of early Hall transducers varied widely with temperature and pressure variations, their use was limited to acting as switches. Here, the iron balls or rods concentrated the field from the magnet.

erator and lets you read DC and AC currents on a standard voltmeter or oscilloscope. The list price of that probe is about $220.

The Hall effect

The Hall effect is one of those great discoveries that had to wait for its time to come. Edward H. Hall, in 1879, found that if a current-carrying conductor is placed in a magnetic field that is perpendicular to the direction of current flow, a voltage is developed across the material in a direction perpendicular to both the initial current direction and the magnetic field, as shown in Fig. 5. That voltage is now known as the Hall voltage to commemorate the discoverer of the effect.

For close to 100 years, the Hall effect principle was little more than a note in some textbooks and a curiosity for experimenters. That's because there wasn't much practical use for it—the magnitude of the Hall voltage produced in metallic conductors is extremely small. However, experiments with semiconductors showed that some semiconductor materials exhibit a Hall voltage three or four orders of magnitude greater than that of metal. The advances in semiconductor technology permitted the construction of practical Hall transducers.

Early semiconductor Hall transducers had a tendency to drift considerably with vibration, pressure, and changes in temperature. That limited their use to acting as switches in counting devices. An example of how they could be used is shown in Fig. 6.

Using the Hall effect

We no longer have to limit the use of Hall transducers to switches. A useful DC clamp-on ammeter can be built using Hall-effect transducers.

If a Hall generator is placed near a current-carrying conductor, the Hall voltage that's developed is proportional to the magnitude of the magnetic field surrounding the conductor. Since that field is proportional to the current level, the Hall voltage is also proportional to the current level.

For our Hall-effect ammeter to be practical, it should meet some design criteria:

- It must perform accurately on a single, straight wire.
- It should be essentially free of high-voltage dangers.
- It should operate from a single 9-volt battery for a reasonable length of time.
- It should be simple to operate, calibrate, and "zero set".
- It should be fairly low-cost.

We can start with a simple design like that shown in Fig. 7. The voltage induced by the magnetic lines of force around wire generates a voltage that is amplified by the Hall transducer. However that type of circuit is not too practical: It can be used only if the current is extremely large. Figure 8 shows an improved simplified circuit. The first improvement is the use of a *concentrator core*, which increases the magnetic effects by about a factor of four. We'll talk more about that shortly. A second improvement is that two Hall transducers are used. Using two transducers, fastened back-to-back gives us two advantages: First, the Hall voltage is doubled. Second, drifting due to temperature and pressure changes is drastically reduced because each input of the differential op-amp will be effected similarly. The schematic of the final circuit is shown in Fig. 9.

When designing the meter, several Hall transducers were tried. Most of them drifted wildly. A 9SS-series transducer manufactured by the Micro Switch Company (Div. Honeywell, 11 W. Spring St., Freeport, IL) demonstrated considerable improvement over all others and was chosen for the final circuit. Figure 10 shows the Hall transducer.

The output voltage of the 9SS as a function of the magnetic field is linear over an input range of −400 to +400 gauss. The diagram in Fig. 11 shows the four blocks that make up the transducer: Hall-effect element, voltage regulator, amplifier, and output transistor. Its transfer function is:

$$V_{OUT} = (6.25 \times 10^{-4} B + 0.5)V_S$$

where V_S is the supply voltage and B is the magnetic flux density in gauss.

The flux concentrator

The flux density produced by low-level currents is usually not sufficient to allow the use of a Hall transducer to measure the current. However, if a toroidal is used to enclose the conductor and act as a flux concentrator, good results can be obtained, and the basic clamp-on circuit of Fig. 5 can be made into a practical and useful measuring instrument.

Different materials, sizes, and shapes

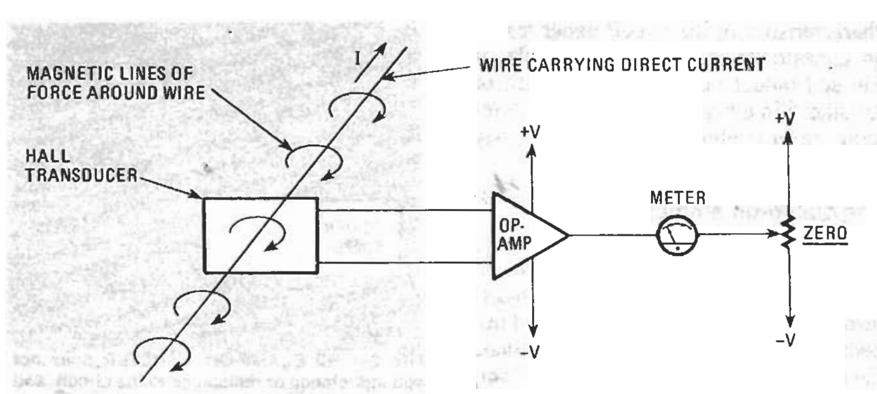


FIG. 7—SIMPLIFIED HALL-EFFECT DC ammeter.

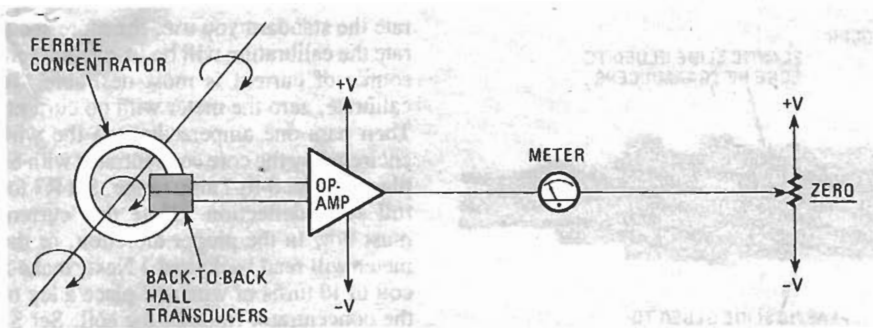


FIG. 8—THIS IMPROVED HALL-EFFECT-AMMETER circuit uses two back-to-back Hall transducers and a ferrite concentrator core.

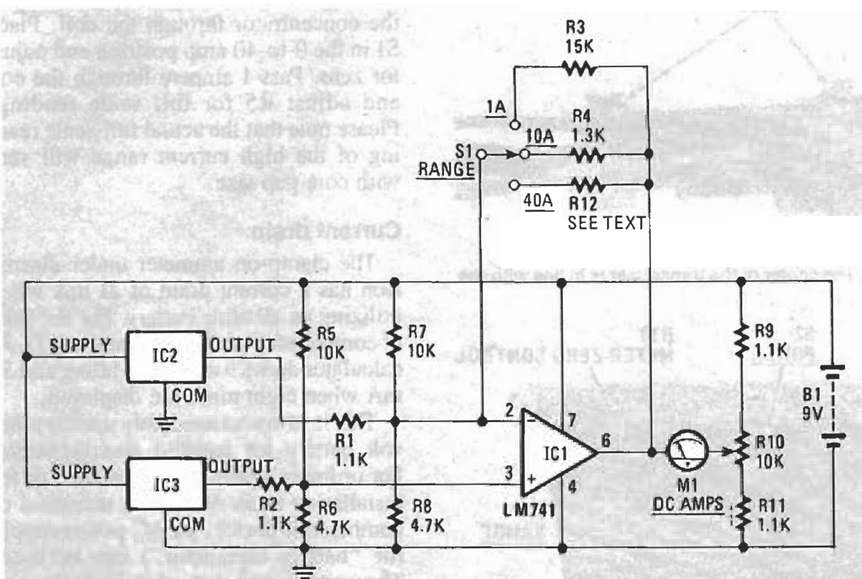


FIG. 9—COMPLETE AMMETER SCHEMATIC. Parts values are not critical, but for more accurate calibration, use variable resistors for R3, R4 (and R12, if you don't use a jumper).

were tried for the concentrator for the external probe. The standard of comparison was to pass one ampere of current through a single wire surrounded by the core under test. Ordinary steel, power-transformer steel, silicon steel and "mu" metal all retained enough residual magnetism after the passage of 1 ampere through the wire to upset the zero calibration of the meter after removal of current. The only materials that retained no measurable residual magnetism were ferrite and a special nickel core.

Different core sizes from .5 to 1 inch in diameter were used with no measurable difference in results. Changing the core gap size caused the instrument sensitivity to vary in a linear manner. If the gap size was doubled, the meter reading was reduced to one-half.

The final probe constructed by the writer used a ⅞-inch outside-diameter ferrite core with a 3/16-inch gap.

Building the ammeter

You can build the DC ammeter for less than $60, including the case. In addition to being used as an ammeter, you can use the instrument as a gaussmeter—it will

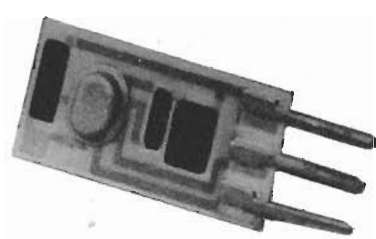


FIG. 10—THE HALL-EFFECT SENSOR from Micro Switch, the *LOHET* (*Linear Output Hall Effect Transducer*).

indicate the presence, relative intensity, and polarity of an external magnetic field.

The probe is the most difficult part of the instrument to build. In the prototype, the Hall transducers were first glued back-to-back with epoxy glue and plastic slides were glued on the sides of the transducers, as shown in Fig. 12. The core was then glued to a piece of 1/32-inch fiberglass which slid into the side pieces. That permits the Hall transducers to move into the the gap in the ferrite after the wire has been passed through. When the transducers are properly positioned, their centers should be in line with the core. The closed probe is shown in Fig. 13.

When you build your clamp-on ammeter, you may want to use your imagination when constructing a probe for the device. The one shown here works, but is not necessarily the most elegant. You may want to build the entire ammeter into a handheld probe. For example, F.W Bell Inc. (6120 Hanging Moss Rd., Orlando, FL 32807) sells such a meter. They simply added a digital meter to the probe that was shown in Fig. 4.

Cores for the probe should be purchased with a precut gap, because cutting

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted.
R1,R2,R9,R11—1100 ohms
R3—15,000 ohms
R4—1300 ohms
R5,R7—10,000 ohms
R6,R8—4700 ohms
R10—10,000 ohms, potentiometer
R12—see text
Semiconductors
IC1—LM741 op-amp
IC2, IC3—Hall transducer, sensitivity 3 mV/gauss (Micro Switch 91SS12-2)
Other components
M1—Meter, 100 microamperes movement. (Note that meters with movements up to 1 mA may be used.)
S1—Three-position rotary switch
S2—SPDT toggle or slide switch
B1—Battery, 9 volts, transistor type

Miscellaneous: Concentrator cores, case, wire, solder. Concentrator cores with a permeability of 2500 or greater all performed equally well. It appears that a permeability greater than 2500–3000 fails to capture any additional magnetic flux lines.

The core used in the probe shown in the pictures is a Stackpole 57-3336 type 24B material with a permeability of 5000 and a 0.187-inch gap. These may be obtained from Permag Central Corp., 1213 Estes Ave., Elk Grove Village, IL 60007. The single-unit price is $11 postpaid (IL residents add 7% sales tax).

A pair of Hall-effect transducers (Micro Switch 91SS12-2) is available from Peerless Radio Corporation, 19 Wilbur Street, Lynbrook, NY 11563, for $16 postpaid. (NY residents add 8% sales tax).

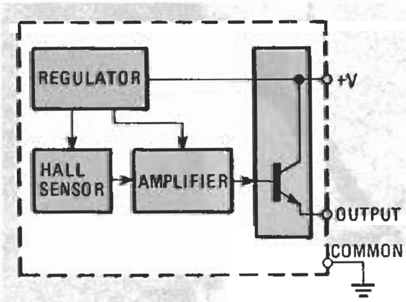


FIG. 11—BLOCK DIAGRAM of Micro Switch's LOHET 91SS12-2.

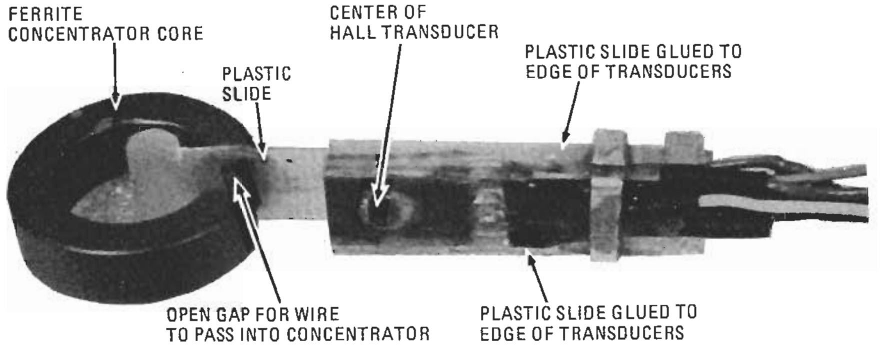


FIG. 12—THE CLAMP-ON PROBE is shown with the gap open.

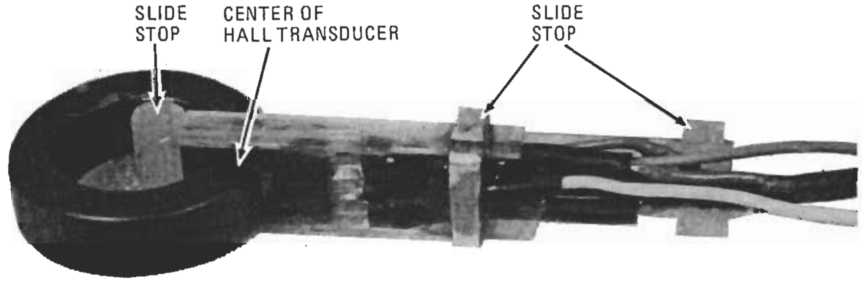


FIG. 13—THE CLAMP-ON PROBE is show here closed. The center of the transducer is in line with the ferrite core.

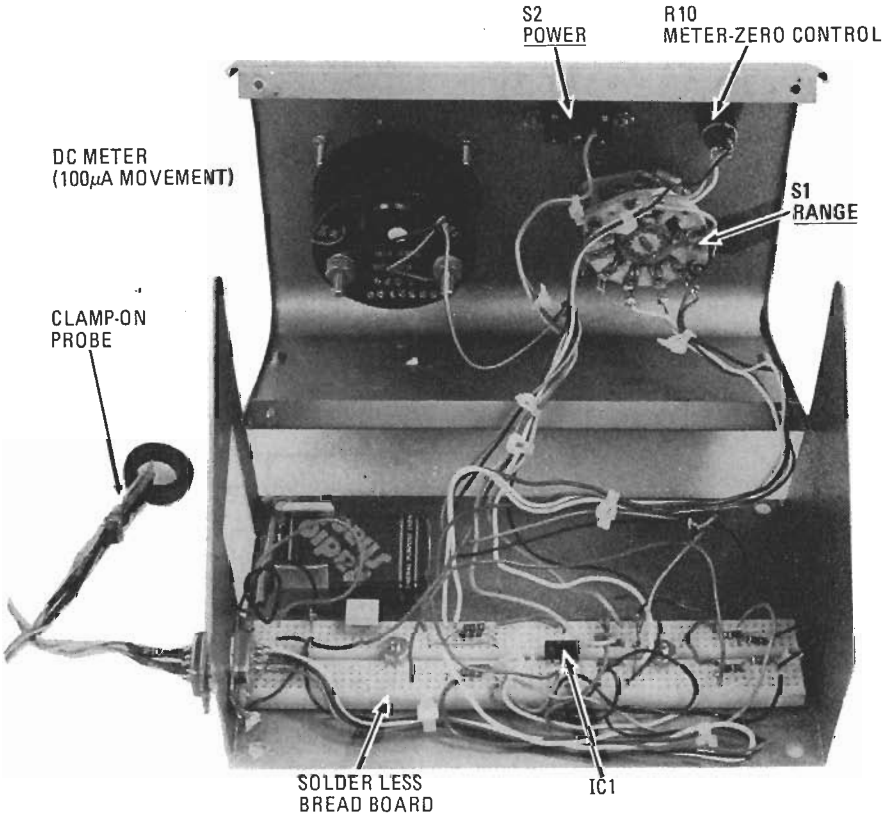


FIG. 14—THE AUTHOR'S PROTOTYPE. The construction method is obviously not critical.

through ferrite material without special tools is extremely difficult.

We won't go into detail on the construction of the rest of the instrument. It is rather straightforward and is not critical. We'll leave it to the ability of the persons wanting to build a clamp-on ammeter. As you can see in Fig. 14, the author's prototype simply used a solderless breadboard for the op-amp circuit.

Calibration procedures

Calibration of the ammeter is determined mainly by the size of feedback resistors R3, R4, and R12 and by the concentrator-core gap. Resistor R12 will generally be zero (a jumper) for the highest current range desired.

Potentiometers should be substituted for R3 and R4 to increase the calibration accuracy. And, of course, the more accurate the standard you use, the more accurate the calibration will be. A one-ampere source of current is most desirable. To calibrate, zero the meter with no current. Then pass one ampere through the wire encircled by the core concentrator with S1 placed in the 0-to-1 amp range. Set R3 for full scale deflection. (Note that current must flow in the proper direction, or the meter will read backward.) Next, make a coil of 10 turns of wire and place a leg of the concentrator through the coil. Set S1 to the 0 to 10 ampere range and zero the meter. Pass 1 ampere through the coil. Set R4 to full scale deflection. Construct a coil of 40 turns of wire and place a leg of the concentrator through the coil. Place S1 in the 0-to-40 amp position and adjust for zero. Pass 1 ampere through the coil and adjust R5 for full scale reading. Please note that the actual full-scale reading of the high current range will vary with core gap size.

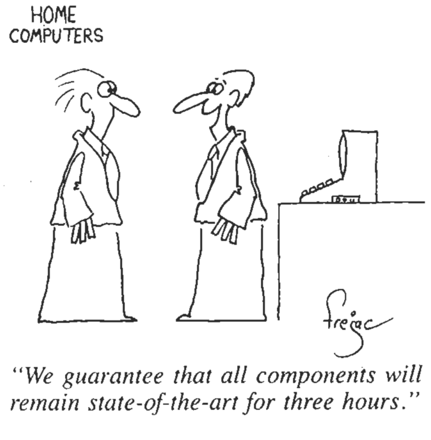
Current drain

The clamp-on ammeter under discussion has a current drain of 21 mA when utilizing an alkaline battery. For the sake of comparison, we'll mention that a *TI-30* calculator draws 9 mA when idling and 50 mA when eight nines are displayed.

This instrument need only use the nine-volt battery for isolated measurements. For ordinary bench measurements, or for installation in an AC driven industrial or commercial device, an AC power-supply (or "battery eliminator") can be used. Those small, low-cost, plug-in devices are capable of delivering 30 to 40 mA. But for best results and drift-free measurements, use a regulated supply.

High voltage warning

One of the advantages of a clamp-on ammeter is the ability to indicate current in a high voltage circuit without insulating the measuring meter. However, the safety factor is only as good as the wire insulation involved. When using the instrument to measure current in a high-voltage circuit make sure the wire insulation has an adequate safety factor to prevent arcing or danger to the operator. **R-E**



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