Measure Weak Direct Currents with the Sensitive Micro Meter

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Low-cost op-amp system can measure solar-cell output and currents in other low-level circuits.

IF YOU PLAN to measure the output of a solar cell under low-light conditions, to work with micropower ICs, or otherwise experiment with weak-current circuits, you'll need a sensitive current meter. The Sensitive μ Meter presented here will allow you to measure direct currents as small as a fraction of a microampere. Moreover, it is not subject to the disadvantages associated with standard panel microammeters—high cost, fragile movements, and relatively high internal resistance.

The project employs an operational amplifier to increase the sensitivity and effectively decrease the input impedance of a moderately priced, readily available 0-to-50 microammeter. It has three switch-selected scales; 0 to 0.5 μ A; 0 to 5 μ A; and 0 to 50 μ A. The circuit can be powered by a supply furnishing as little as ±2 or +4 V, and can be constructed for about $15.

Circuit Operation. A simple circuit for current-measuring applications is shown in Fig. 1. When an input current *I* is applied to the inverting input of the op amp, an inverted output signal is generated by the op amp. If the gain of the operational amplifier is very high, we can consider that the entire input current flows through feedback resistor *R*. An output voltmeter *M*, which is calibrated in terms of *I*, measures the product *IR*. The voltage drop across the operational amplifier is practically zero (the output voltage divided by the op amp's open-loop gain).

The schematic of the Sensitive μ Meter is shown in Fig. 2. Switch *S2* selects the range and determines the feedback resistance of the stage. When the switch is in its center (off) position, the feedback resistance is *R3*, one megohm. An input current of 0.5 μ A will cause the output of the op amp to be 0.5 volt above ground when only *R3* is in the feedback loop.

This output voltage will cause full-scale deflection of 0-to-50-microammeter *M1* if the effective resistance between the output terminal of the operational amplifier and the negative terminal of the meter is 10,000 ohms. The internal resistance of the meter specified in the parts list is 1620 ohms, so the balance of the required resistance is supplied by *R4*. This trimmer potentiometer is adjusted for full-scaie deflection of the meter movement when the op amp output is at +0.5 volt.

The project is most sensitive when *S2* is in its center (off) position and the feedback resistance is one megohm. In this operating mode, full-scale deflection of the meter corresponds to an input current of 0.5 μ A. Higher-current ranges are obtained by shunting *R3* with other resistors to lower the overall feedback resistance. This is accomplished by placing *S2* in one of its two other positions. When the range switch is placed in its 5 μ A position, the parallel combination of *R1* and *R3* causes the meter to deflect to full scale if the input current is five microamperes. Similarly, placing *S2* in its 50 μ A position shunts *R3* with *R2* and causes full-scale deflection of the meter movement when an input current of fifty microamperes exists.

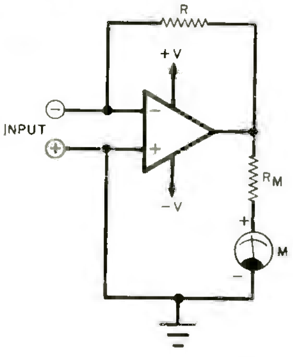

Fig. 1. Schematic of simple current-measuring circuit.

Two shorting switches are included in the circuit. Switch *S1* shorts the input of the project. It is used in conjunction with potentiometer *R5* to zero the meter movement. The other switch (*S3*) is used to short the terminals of *M1* when the meter is not being used. This minimizes mechanical shocks to the meter movement when the project is being transported. Diodes *D1* and *D2* protect the project from excessive input voltages. Jack *J2* provides access to *M1* so that the meter can be used in isolation from the rest of the project.

You might wonder why the circuit provides for a 0-to-50-microampere scale when meter movement, *M1*, covers this range on its own. The following exercise performed by the author will illustrate the need for such a scale. A solar cell was connected across input jack *J1* and illuminated so that the Sensitive μ Meter indicated a current of 50 μ A. The cell was then connected to *J2* and its output current measured using *M1* alone. It indicated a current of 1 μ A.

The reason for this discrepancy between the two readings is that *M1* presents a higher resistance to the solar cell when it is used independently than the project as a whole does. It is desirable to keep the internal impedance of a current-measuring instrument as low as possible. Thus, it is better to employ the project as a whole (as opposed to *M1* or a similar meter alone) in the measurement of currents up to 50 μ A.

There is another significant advantage to the use of the Sensitive μ Meter as opposed to a microammeter alone. Due to the clipping action of protective diodes *D1* and *D2*, the maximum output voltage of the op amp on any of the three ranges is

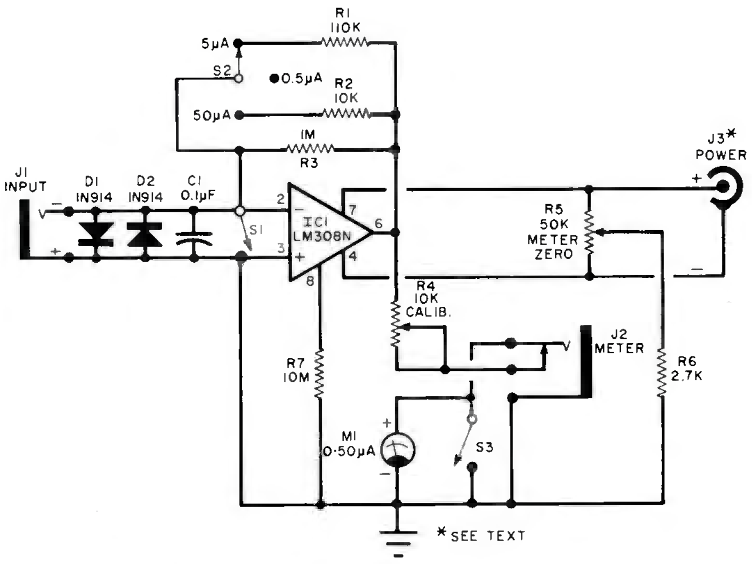

Fig. 2. The gain of the operational amplifier and, hence, the range of the meter are determined by the amount of resistance in the feedback circuit.

PARTS LIST

C1—0.1-μF disc ceramic
D1,D2—1N914 diode
IC1—LM308N operational amplifier
J1—Open-circuit miniature phone jack
J2—Closed-circuit subminiature phone jack
J3—Phono jack (must be insulated from project enclosure)
M1—0-to-50-μA meter movement (Radio Shack No. 22-051 or equivalent)
The following are ¼-watt, 5%-tolerance carbon-composition fixed resistors, unless otherwise specified:
R1—110,000 ohms (can be a series connection of 100,000 ohms and 10,000 ohms)
R2—10,000 ohms
R3—1 megohm
R4—10,000-ohm, linear-taper trimmer potentiometer
R5—50,000-ohm linear-taper potentiometer
R6—2700 ohms
R7—10 megohms
S1,S3—Spst toggle switch
S2—Spdt toggle switch with center-off position
Misc.—Suitable enclosure, perforated or printed circuit board, IC socket, circuit board spacers, machine hardware, control knob, hookup wire, solder, etc.

approximately 0.7 volt. This corresponds to less than a 50% overload of meter movement *M1*, one that is highly unlikely to cause any permanent damage to the movement. An unprotected microammeter, on the other hand, can easily be "zapped" by the inadvertent application of high current overloads, a fact to which more than one electronics experimenter can ruefully attest.

Power for the circuit is furnished by an external supply via phono jack *J3*. Note that the shell of this power jack must be insulated from chassis ground. The operational amplifier specified for use as *IC1* is an LM308, a precision op amp that can be used with supply voltages ranging from ±2 to ±20 volts. Accordingly, a supply capable of furnishing bipolar voltages within these extremes (or a single-ended one rated at 4 to 40 V) should be employed to power the Sensitive μ Meter. Potentiometer *R5* is connected across the supply to allow zeroing of the meter movement under no-input conditions (*S1* closed) for any suitable supply voltage.

Construction. The project is relatively simple, so the use of a perforated board and point-to-point wiring is an acceptable assembly technique. Alternatively, the project can be constructed using wrapped-wire or printed circuit connections. The author housed his prototype in a 4" × 2" × 1½" (10.2 × 5.1 × 3.8 cm) aluminum utility box. A Radio Shack No. 22-051 0-to-50-microammeter was used for *M1*. This meter fits the enclosure with only a slight amount of overlap at the edges. Of course, a larger enclosure can be employed if it is preferred over the one selected by the author.

An LM307 operational amplifier can be used for *IC1* in place of an LM308 if pin 3 is connected to project ground through the parallel combination of a 30,000-ohm resistor and a 0.1-μF disc ceramic capacitor. This op amp will provide performance comparable to that of the LM308 if the circuit is modified as just described. Other operational amplifiers can also be used if variations in pinouts and possible compensation requirements are taken into account.

Calibration and Use. Connect a suitable power supply to *J3*, observing polarities. Then close *S1*, place *S2* in its 0.5 μA position, and open *S3*. Set the wiper of *R4* halfway between the two extremes of its travel and adjust potentiometer *R5* for a zero reading on meter movement *M1*. Then open *S1* and place *S2* in its 50 μA position. Connect a suitable source of weak dc current to the input jack of the project using a length of shielded cable terminated with a miniature phone plug. A 1.5-volt battery and a series-connected 1-megohm potentiometer can be used as a source of low-level dc.

Depending on the capabilities and sensitivity of the test equipment available to you, monitor either the current at *J1* or the voltage at the output of the operational amplifier. Adjust the amplitude of the input current so that it equals 50 μA. Alternatively, monitor the output voltage of the op amp and adjust the amplitude of the input current until the voltmeter reads +0.500 volt. Then adjust trimmer potentiometer *R4* to obtain a full-scale (50 μA) reading on *M1*.

The Sensitive μ Meter is now calibrated and ready for use. In view of its high sensitivity, it is a remarkably stable instrument. At the start of each measuring session, the meter should be zeroed by adjusting potentiometer *R5*. It should not be necessary to continually touch up this adjustment if a battery or regulated line-powered supply is used in conjunction with the project.

Thanks to the protective action of *D1* and *D2*, the meter movement is relatively immune from damage caused by current overloads. Overloads should still be avoided, however, especially severe ones that could damage the protective diodes. Finally, remember that it is good practice to keep shorting-switch *S3* closed when the project is not being used. This will damp the meter movement and minimize the effects of physical shock upon it.