BUILD A $25 HIGH-FREQUENCY VOLTMETER

Measures up to 90 volts from dc to beyond 20 MHz.

BY THOMAS H. SEAR

There has long been a need for an inexpensive, easy-to-use bench instrument that could measure the voltage levels of signals at frequencies into the MHz range. Now, for less than $25 you can build a broadband voltmeter that accurately measures from dc to frequencies over 20 MHz at amplitudes up to 90 volts in five overlapping voltage ranges.

The heart of this meter is a thermal converter similar to the type used in professional instruments to perform voltage calibrations to frequencies of 1 GHz. The converter is essentially a straight wire heater, which is connected in series with the current to be measured, and a thermocouple that measures the mid-point temperature of the heater. The thermocouple generates a dc voltage that is approximately proportional to the square of the current. (Fig. 1).

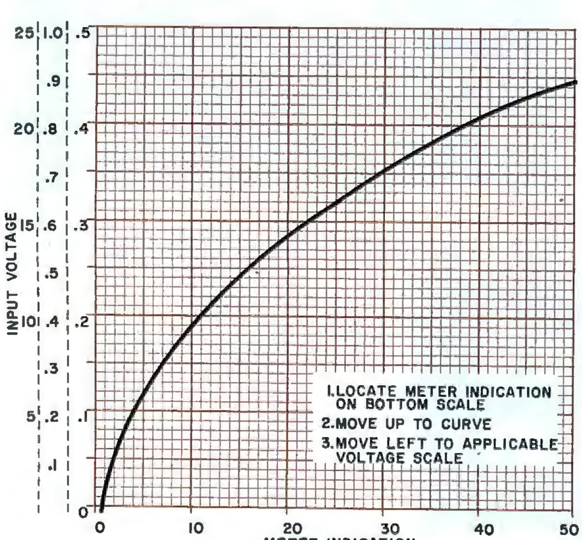

Fig. 1. Output of thermal converter varies with the square of the input. Use this curve to calibrate meter.

The important characteristic of the thermal converter is that its response is relatively independent of waveform and frequency variations. The unit used in this voltmeter is designed to operate between dc and 10 MHz with excellent accuracy and up to 65 MHz with only a 3% error. To get accurate results at, say, 65 MHz, a more sophisticated construction of the converter would be required.

How It Works. As shown in Fig. 2, *R1* through *R4* make up a voltage divider, with values selected to limit the voltage across *TC1*, the thermal converter, to 0.45 V. The dc output of *TC1* is connected to the noninverting input of operational amplifier *1C1*, which is connected as a dc amplifier. Resistors *R5* and *R6* determine the gain of *IC1*, whose output drives *M1* a 50-µA meter. Potentiometer *R7* is used to calibrate the circuit and the meter, while *R8* is adjusted to set the zero point of the meter movement.

Construction. With the exception of the circuit involving the input voltage divider and *TC1*, where r-f signals may be present, and all leads should be kept as short as possible, there are no special precautions to be observed in wiring the voltmeter. However, it is advisable to keep the r-f and dc portions separated as much as possible to avoid pickup.

The IC and resistors can be mounted on perforated phenolic board, with the five connectors, meter, switch, and two potentiometers on the front panel of a suitable enclosure. The resistors in the voltage divider are standard 5% units, *R1, R3,* and *R4* being made up of two resistors either in series or parallel, to obtain the required value. The closer you can come to the required value, the better the accuracy of the meter. A precision resistance measuring bridge can be used to get even better accuracy.

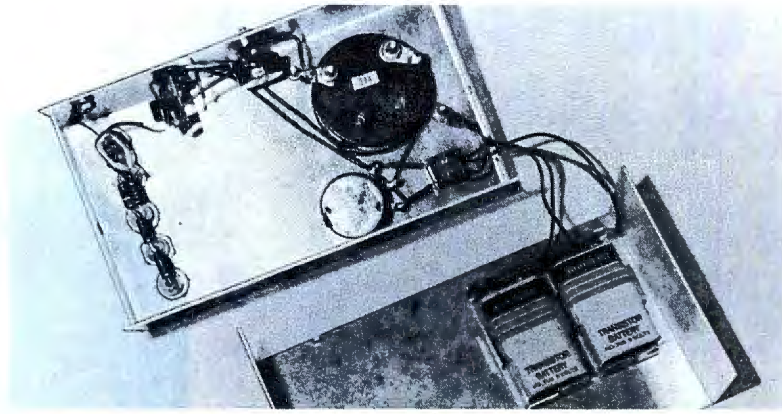

Photo of prototype shows layout of components.

Calibration. Before turning on the power, be sure that the meter needle is at its zero mark, using the mechanical zero adjustment on the meter itself if necessary. Set *R7* to its center position, turn on the power *(S1), and* wait a few minutes for the circuit to stabilize. Then adjust *R8* to set the meter pointer to zero.

Because *TC1* is a thermal device, it will generate a slight output due to the ambient temperature. It will also indicate above zero following each measurement until it returns to the ambient temperature. For this reason, *R8* should not be used to adjust the zero after each measurement. Use *R8* only after the temperature has stabilized for 5 or 10 minutes.

With the power on and the meter zeroed, connect a known dc voltage to the appropriate input jack. The 22.5-volt input *(J2)* is recommended because calibrating on that range will distribute the voltage divider errors more evenly. Wait about 10 seconds for *TC1* to stabilize. Then adjust *R7* to obtain the correct meter reading as determined by the graph in Fig. 1. The calibration will be as good as the degree to which the input voltage is known. (Three fresh 1.5-volt dry cells will provide a calibration voltage very close to 4.8 volts.)

PARTS LIST

B1,B2—9-volt battery
IC1—709 op amp
J1 to J5—BNC female connector (Amphenol UG-1094/U or similar)
M1—0-50-µA meter (Radio Shack 22-051 or similar)
R1—13,500-ohm, ½-W, 5% resistor (select 56,000 and 18,000 ohms in parallel)
R2—3600-ohm, ½-W, 5% resistor
R3—720-ohm, ½-W, 5% resistor (680 and 39 ohms in series)
R4—90-ohm, ½-W, 5% resistor (68 and 22 ohms in series)
R5—1000-ohm, ½-W, 5% resistor
R6—1-megohm, ½-W, 5% resistor
R7—250,000-ohm miniature potentiometer
R8—50,000-ohm potentiometer
S1—Dpst switch
TC1—Thermal converter (Best Products, Ltd., Model S-7. Available from Best Electrics Div., 1211 E. Denny Way, Seattle, WA 98122 at $10.30 each, plus postage.)
Misc.—Battery holder (2), suitable enclosure (LMB 138), knob (2), mounting hardware, etc.

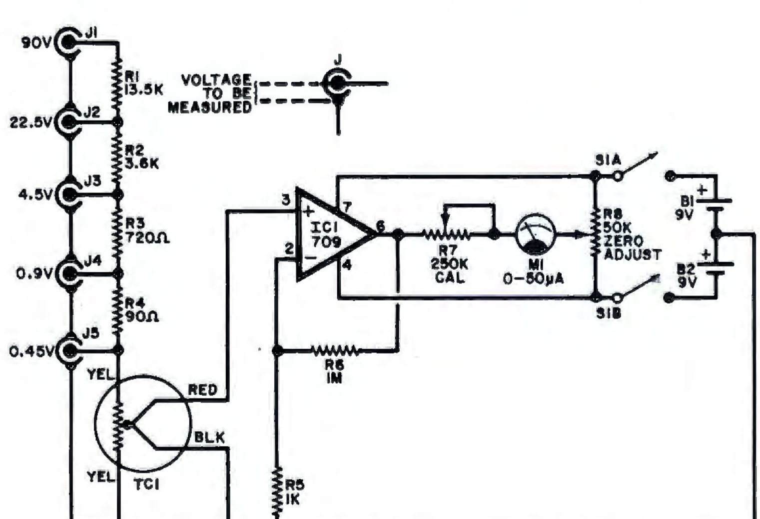

Fig. 2. Schematic of the voltmeter. Select and combine resistors to obtain proper values as given in Parts List.

Caution. Although the circuit is conservatively designed to protect *TC1*, the device can be easily damaged by excessive current. Even brief currents of 5 mA or more in the input divider circuit can burn out *TC1*. Always start measurements using the 90-V range and move down to the lower ranges only if the meter indication is 5 divisions or less. Never connect a voltage to an input jack when you know the voltage is higher than the range for that jack. Also, never change the amplitude or frequency of the input signal without first reducing it to zero since transients could damage the thermal converter.

Use. Always remember to allow the voltmeter to warm up for a few minutes.

Keep in mind that the meter's repeatability may be an order of magnitude better than most instruments to which you may compare it. To avoid confusion, set this meter to a reference indication and then compare it to another instrument. This voltmeter is very sensitive in the upper third of the scale, and a small voltage change that may not be noticed on a conventional multimeter can amount to several divisions on this meter. ◈