Vol. 23 NOVEMBER - DECEMBER, 1958 No. 8

CORNELL-DUBILIER ELECTRIC CORP.
Hamilton Boulevard, South Plainfield, N. J.

POSTMASTER: If undeliverable for any reason, notify stating reason, on Form 3547 postage for which is guaranteed.

Sec. 34.66 P.L.&R.
U. S. POSTAGE
PAID
So. Plainfield, N. J.
Permit No. 1

FRANK EAMES
5 RICHARDSON AVE.
ATTLEBORO, MASS.

CRYSTAL VOLTMETER CIRCUITS

The crystal diode, first of all semiconductor devices is still one of the most uesful. During the past two generations, this simple, passive, circuit component has passed through many stages from the fragile crystal detector of early wireless to the stable diode of modern electronics. Its applications extend all the way from toy radio receivers to giant computers.

The point-contact germanium diode offers particular advantages as a meter rectifier. It is small in size (many recent designs having subsubminiature dimensions); free from contact potential, hum, and heat; instantaneous in operation; and two-terminal in nature. As a replacement for copper oxide and similar meter rectifiers, the germanium diode offers superior frequency response and higher rectification efficiency. Where a good-grade CuO rectifier, for example, might provide a-c meter operation up to a few tens of kilocycles, germanium diodes will extend the frequency range to many tens of megacycles. Thus, a simple rectifier-type a-c meter employing a germanium diode is suitable for radio-frequency as well as audio-frequency applications.

The small size and simplicity of the crystal voltmeter suit this device for inclusion in other instruments such as oscillators, signal generators, bridges, and receivers. Because the crystal voltmeter requires no power and no zero-set adjustment, it sometimes is preferred to the v-t voltmeter in such applications.

Instrument Circuit Configuration

A crystal voltmeter consists essentially of a point-contact diode and a sensitive direct current meter. Junction diodes seldom are used, because of their restricted frequency response. To the simple diode-meter combination may be added suitable multiplier resistors, coupling capacitor, and bypass capacitor, as required for the voltage and frequency ranges to be covered.

The versatility of the crystal diode is such that any meter circuit ordinarily employing vacuum-tube or CuO rectifiers may be duplicated (often with additional advantages), provided the voltage and power dissipation ratings of the crystal are not exceeded.

Typical Circuits

Typical, practical crystal voltmeter circuits are shown in the accompanying illustrations.

Simple Diode-Milliammeter Circuit. Figure 1 (A) shows the simplest basic circuit. This arrangement has found many applications where its sensitivity is adequate. Because this is a simple series-diode circuit, a d-c return path for the diode must be provided by the circuit under test. Thus, the A-C INPUT terminals may be connected across the ends of a voltage-carrying transformer winding, or similar "generator" having a conductive path between its output terminals. The output attenuator of an oscillator or signal generator would accommodate this meter successfully, provided the resistance included between the A-C

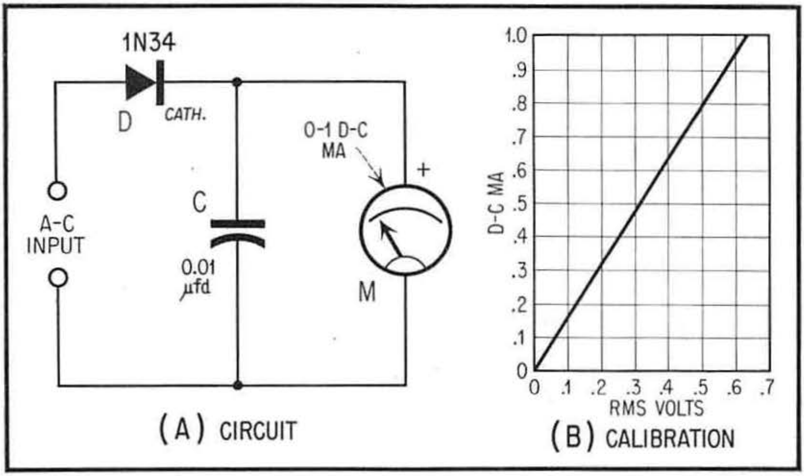

Fig. 1. Basic Single-Diode Circuit with Milliammeter.

INPUT terminals of the meter (by the attenuator arm included between them) is not too high.

Figure 1 (B) shows the voltage calibration of the circuit. Full-scale deflection of the 0-1 d-c milliammeter, M, is obtained for an input voltage of approximately 0.63 volt rms. Note that the response is non-linear, which means that a special voltage scale must be prepared for the meter.

The basic 0-6.3 v range of the meter may be extended by means of suitable series multiplier resistors. However, for low voltage values, the resistance of these multipliers cannot be calculated by the simple method used for d-c voltmeters. The reason for this is the non-linearity of the crystal diode at low forward current levels.

Figure 2 (A) shows the addition of a multiplier, R, to extend the instrument range to 0-1 v rms. This 500-ohm wire-wound rheostat may be adjusted for exact full-scale deflection of Meter M when a 1-volt rms signal is applied to the A-C INPUT terminals. Figure 2 (B) shows the voltage calibration of the circuit. Note that the response still is not linear but becomes a little more so in the upper half of this slightly higher voltage range. At ranges of 0-10 v and higher (corresponding to higher values of multiplier resistance, R), response becomes linear except in the lower 1/10 to ¼ of the scale (depending upon the voltage range) where the curvature approaches square law response.

While an inexpensive 1N34 diode is shown here and in several of the other circuits, succesful operation is not restricted to this single type. The maximum continuous reverse working voltage of the 1N34 is 60 v. The negative half-cycle of the voltage under test therefore must not exceed this value unless the IR drop in the

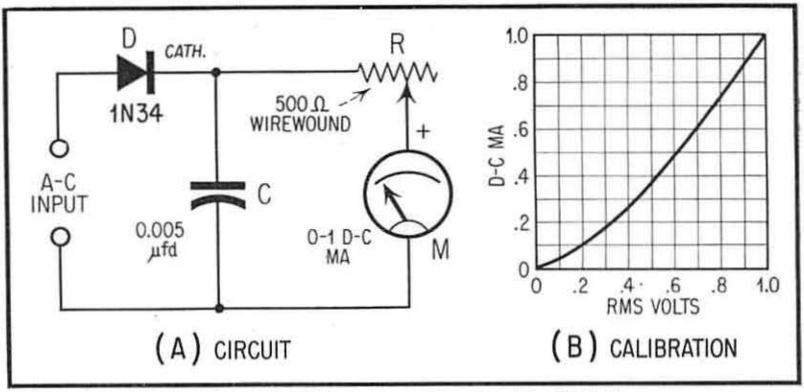

Fig. 2. Diode-Milliammeter Circuit with Multiplier.

multiplier resistor is sufficient to reduce the actual peak inverse diode voltage to -60 v. For higher-voltage applications, other diode types are available; e. g., 1N38 (100 v), 1N39 (200 v), and 1N59 (260 v).

Diode-Microammeter Circuit. The sensitivity of the basic crystal voltmeter may be increased by employing a more sensitive direct current meter in the circuit. Thus, substitution of a d-c microammeter for the 0-1 milliammeter will decrease the full-scale deflection value.

Figure 3 (A) shows a simple series-diode circuit, similar to the basic circuit of Figure 1 (A), but employing a 0-100 d-c microammeter. In all other respects, this circuit is similar to the diode-milliammeter circuit (Figure 1A) and all remarks made concerning the latter apply also

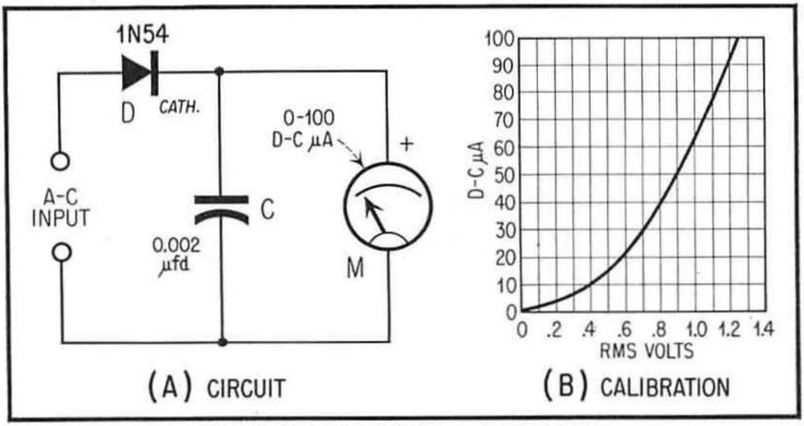

Fig. 3. Series Diode-Microammeter Circuit.

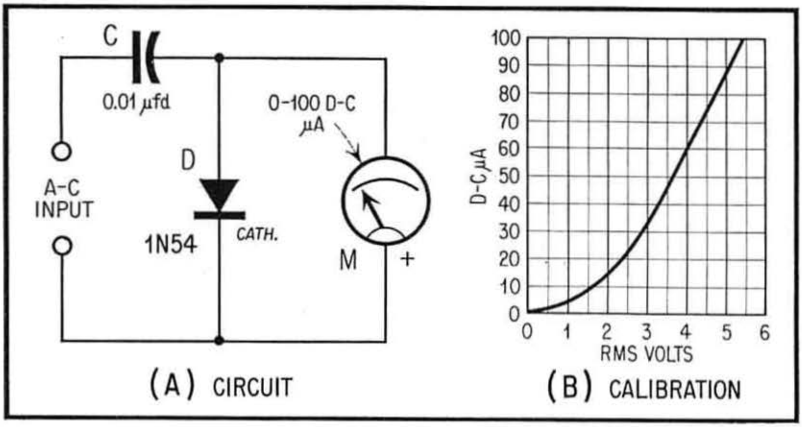

Fig. 4. Shunt Diode-Microammeter Circuit.

to this circuit. Figure 3 (B) shows the voltage calibration. Note that the 0.125 v rms full-scale deflection obtained with the microammeter circuit makes this arrangement approximately twice as sensitive as the milliammeter circuit.

Shunt-Diode Circuit. When the voltage source under test does not provide a d-c return path for the voltmeter diode (or when there is present in the voltage source a d-c component against which the voltmeter circuit must be protected), a shunt-diode meter rectifier may be employed and a blocking capacitor included in the instrument circuit. This arrangement is shown in Figure 4 (A). Coupling capacitor C isolates the diode (D) and microammeter (M) from any d-c component reaching the A-C INPUT terminals and which might affect the calibration or damage the diode or meter.

Figure 4 (B) shows the voltage calibration of the shunt-diode circuit. From this plot, note that the shunt-diode circuit is considerably less sensitive than the series-diode circuit (Figure 3A) employing the same components, over four times as much input voltage being required by the shunt circuit for full-scale deflection.

Multi-Range Voltmeter Circuit. The principle, illustrated in Figure 2, of adding a multiplier resistor to the basic crystal voltmeter circuit may be extended to provide a multi-range ac-rf voltmeter.

Figure 5 shows an example of a multi-range circuit. Separate multiplier resistors (R_1 to R_5) for the voltage ranges E_1 to E_5 also may be used instead of the series combination shown here.

Two diodes, D_1 and D_2, are employed. Diode D_1 provides a high-resistance shunt path for the positive half-cycle of signal voltage, while supplying an easy bypass for the negative half-cycle around the meter circuit, D_2-M. This two-diode arrangement is used in many a-c meters

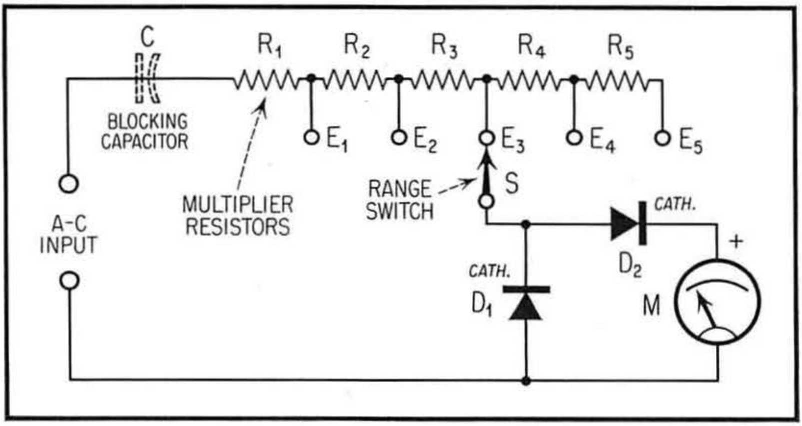

Fig. 5. Multi-Range Voltmeter.

employing CuO rectifiers. The coupling capacitor (C), when needed, serves to block d-c components from the meter circuit where they might upset the meter calibration or damage the components. The capacitance of C must be chosen such that the corresponding reactance at the lowest operating frequency is appreciably lower than the highest multiplication resistance $(R_1+R_2+R_3+R_4+R_5)$ in Figure 5.

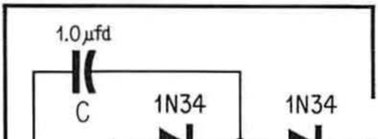

Fig. 6. Full-Wave Meter Rectifier Circuit.

Full-Wave Meter Rectifier. Because a full-wave rectifier circuit supplies unidirectional current to a load during both half-cycles of applied a-c voltage, greater sensitivity with a given indicating meter is obtained with bridge rectification than with simple half-wave arrangements in crystal meter circuits.

Figure 6 shows a meter circuit employing a bridge rectifier composed of four 1N34 diodes, D_1 to D_4. Full-scale deflection of the 0-1 d-c milliammeter, M, is obtained with an input signal of 0.20 volt rms. This is approximately three times the sensitivity of the simple half-wave circuit (Figure 1A) employing the 0-1 milliammeter. Coupling capacitor, C, serves to block any d-c component present in the voltage source, and thus to protect the meter circuit components and calibration.

If a higher full-scale voltage than the basic 0.2 v value is required, a suitable calibration rheostat, R, should be included in the circuit. This rheostat is set for exact full-scale deflection with the desired input voltage (e. g., 1 volt rms) applied to the A-C INPUT terminals.

Transistorized Crystal Voltmeters. For the measurement of potentials in the millivoltage region, an amplifier may be operated ahead of a crystal voltmeter. Such amplifier-rectifier arrangements are widely used in audio engineering. For this purpose, transistorized amplifiers are convenient because of their small size and low d-c power requirements.

Figure 7 shows the circuit of a bridge-type crystal meter circuit operated from an RC-coupled, single-transistor, a-f amplifier. Full-scale deflection of the 0-100 d-c microammeter, M, corresponds to a signal voltage of 150 millivolts rms applied to the A-C INPUT terminals. The CALIBRATION CONTROL rheostat, R_4, may be set for exact full-scale deflection when this voltage value is applied.

The circuit has an input impedance of approximately 25,000 ohms at 1000 cps. This high value results from degenerative feedback obtained by means of the unbypassed emitter resistor, R_2. Current drain from the 22½-volt battery (B) is approximately 600 microamperes dc. For compact construction, the coupling capacitors, C_1 and C_2, may be subminiature tantalum electrolytics, such as Cornell-Dubilier Type TAN59A.

For higher sensitivity, additional amplification may be employed. Thus, in Figure 8, two transistor amplifier stages ahead of the bridge-type crystal meter provide a full-scale sensitivity of 50 millivolts rms. Input impedance is approximately 30,000 ohms at 1000 cps. Total current drain from the 22½-volt battery, B, is approximately 1 milliampere dc. In all other respects, the circuit is similar to the single-stage unit given in Figure 8. Frequency response is reasonably flat from 50 cps to 25 kc.

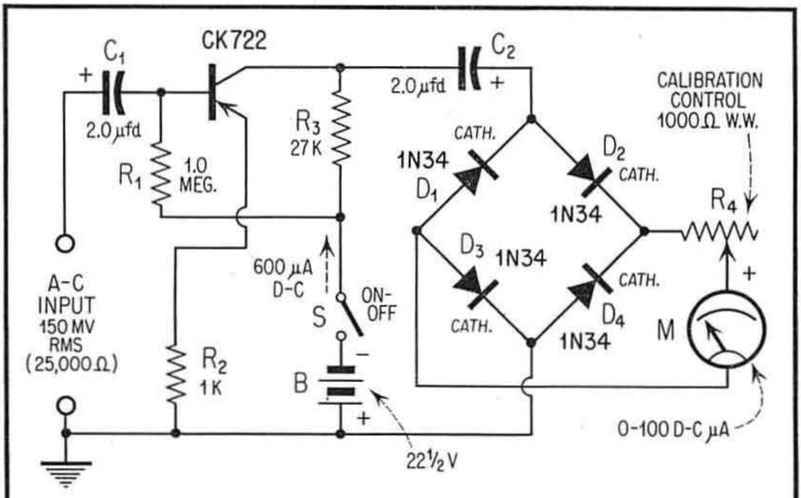

Fig. 7. Single-Stage Transistor-Diode Meter.

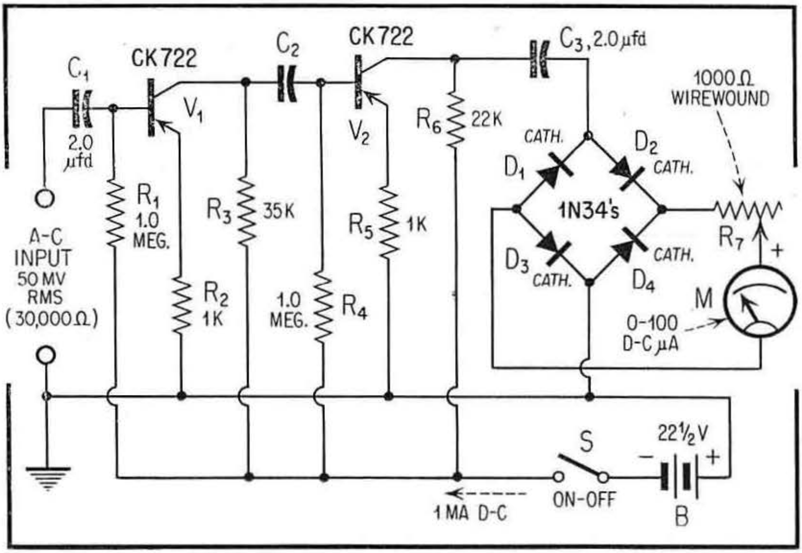

Fig. 8. Two-Stage Transistor-Diode Voltmeter.

Transformer-Coupled Millivoltmeter. When extreme simplicity is demanded and millivolt measurements are to be made across very low impedances, and preferably at a single audio frequency, a step-up transformer, instead of an amplifier, may be operated ahead of a crystal voltmeter as shown in Figure 9. Varying degrees of success are obtained, depending upon such factors as the impedance level involved and the step-up ratio of the transformer. A sensitive d-c microammeter is best, and the primary winding of the transformer should have optimum impedance for the impedance of the circuit under test. While a simple series-diode circuit is shown here, a 2-diode circuit (Figure 5) or bridge (Figure 6) might also be used.

The basic voltage range of the meter circuit is not exactly multiplied by the turns ratio of the transformer, T, because of the loading of the secondary by the diode-meter circuit. For this reason, a special voltage calibration of the circuit must be made. Nevertheless, considerable sensitivity is obtainable by means of this potential-transformer arrangement, provided the highest usable turns ratio is employed.

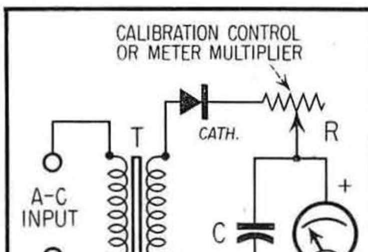

Fig. 9. Transformer-Coupled Diode Millivoltmeter.