Vol. 18 AUGUST, 1953 No. 8

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MODERN V. T. VOLTMETERS

The vacuum-tube voltmeter has undergone a long and unhurried process of evolution. We might reason that the beginnings of this instrument go back to 1883 when Edison observed his celebrated "effect", since Edison contrived a diode tube from one of his early lamps and connected a galvanometer in series with the diode plate to show passage of electron current. Basically, this arrangement is no different from the configuration of any present-day diode v. t. voltmeter.

V. t. voltmeter circuits have applied numerous ingenious designs to suit general and special applications. Also, variations of standard designs have been made in order to permit the use of special measurements techniques. A review of the literature shows a surprisingly large number of such circuits.

The superiority of certain v. t. voltmeter circuits have secured their survival. These designs fall into discrete groups which categorize the modern instruments. It is advantageous that the electronic student and the instrumentation engineer recognize these categories and the conformation and characteristics of v. t. voltmeters which fall into the classifications.

This article groups the designs and describes the general features of modern v. t. voltmeter circuits. It may be used as the basis for acquiring a concept of the operation of these instruments. More detailed design data, when needed, then may be followed with better understanding when these data are located in more advanced engineering texts.

Single vs. Multi-tube Design

Except for special applications in laboratory tests and in the voltmeter channel in service-type signal analysts, the single-tube v. t. voltmeter circuit has disappeared from common use. The single tube refers, of course, to the active tube. A rectifier tube is also needed to supply power.

The single-tube v. t. voltmeter consisted of a triode with the indicating d. c. milliammeter connected either in the cathode return or in a balancing-bridge circuit in the plate output. The signal voltage to be measured was applied between grid and ground (circuit-negative). When used to measure d. c. potentials, the circuit usually was made highly degenerative through the use of a large cathode resistor to minimize the effects of tube characteristics and of supply voltage changes. For a. c. measurements, the single tube either was operated as a d. c. vacuum-tube voltmeter and preceded by a signal rectifier or the a. c. signal was applied directly to the grid-input circuit. In the latter type of operation, response of the circuit is approximately square-law, although the grid biasing affords various modes of operation. Behavior of the circuit usually could be described in terms of detection by grid rectification or plate rectification.

Some of the commercial instruments which for reasons of simplicity still incorporate single-tube v. t. voltmeter circuits include pH meters, amplitude modulation monitors, analyst-type radio signal tracers, test-bridge null detectors, and some field strength meters.

Advantages of the single-tube circuit are simplicity and low power requirements. Its one-time advantage of compactness disappeared with the availability of miniature dual tubes. Disadvantages which have resulted largely in the abandonment of this circuit include bad drift, insensitivity, and to some extent lack of linearity.

Modern v. t. voltmeter circuits employ two or more tubes in order to take advantage of one of several of the following desirable characteristics: higher amplification (sensitivity); balanced circuit operation; drift reduction or elimination; high-level degeneration for stability; improved linearity; increased frequency response; and the provision of certain special characteristics such as logarithmic response, frequency selectivity, and voltage expansion.

Direct-Reading vs. Manipulatory Arrangements

An early type of v. t. voltmeter was the slide-back circuit. This arrangement was used for both a. c. and d. c. voltage measurements. Peak a. c. values were obtained. In the slide-back circuit, the tube portion of the instrument served merely as a galvanometer with high-impedance input. An internal variable-voltage power supply was bucked against the voltage to be measured and its output adjusted for zero deflection of the meter. At this point, the adjustable bucking voltage (which then equalled the d. c. or peak a. c. signal input) was read from the scale of a self-contained voltmeter. Claims made for the method were high accuracy limited only by the accuracy of the indicating voltmeter, and near-zero loading of the circuit under test.

The fact that this slide-back type of circuit has to be manipulated, like a null bridge, in order to obtain a reading becomes inconvenient when the test voltage is fluctuating. Such an instrument could not be employed to monitor a continuously varying voltage. Furthermore, two meters must be read — the balance galvanometer and the voltmeter. In spite of its recommendations, the slide-back circuit has been abandoned in favor of low-current-drain v. t. voltmeters which require no manipulation.

Balanced D. C. V. T. Voltmeter Circuit

Present d. c. vacuum-tube voltmeters take advantage of the symmetry of a balanced circuit. Obvious gains are reduction of both short- and long-term drift, and the ability to incorporate a large amount of stabilizing degeneration into the circuit in a simple manner. This type of circuit is used widely in v. t. voltmeters designed both for shop and laboratory service.

Figure 1 shows the basic arrangement of the balanced d. c. circuit. This essentially is a balanced d. c. amplifier with cathode degeneration.

The input d. c. voltage to be measured is applied to the grid of one of the triodes, V_1. The grid of the other tube, V_2, is grounded. Resistors R_1 to R_5 form a high-resistance input voltage divider which insures that the same small voltage will be applied through the range switch to the grid of V_1 regardless of the value of the voltage applied to the D. C. INPUT terminals.

Each tube has an independent cathode resistor (R_9 and R_{10}) and the junction of these two resistors is returned to a large resistance, R_{11}, which is in series with the fixed bias voltage. For simplicity, a bias battery is shown in Figure 1, but the positive voltage in a practical circuit is obtained from the plate-voltage power supply. The high resistance and degeneration of R_{11} causes this resistor to determine almost entirely the tube current. Fluctuations in tube characteristics and in small power supply voltages thus have negligible effect upon operation of the circuit.

The circuit operates in this manner. When a d. c. voltage is applied to the

INPUT terminals in the polarity shown, the grid of V_1 is driven positive. This increases the plate current of V_1, increasing the positive potential the meter circuit may be thrown to reverse the direction of the deflection and no changeover of the INPUT terminals is required.

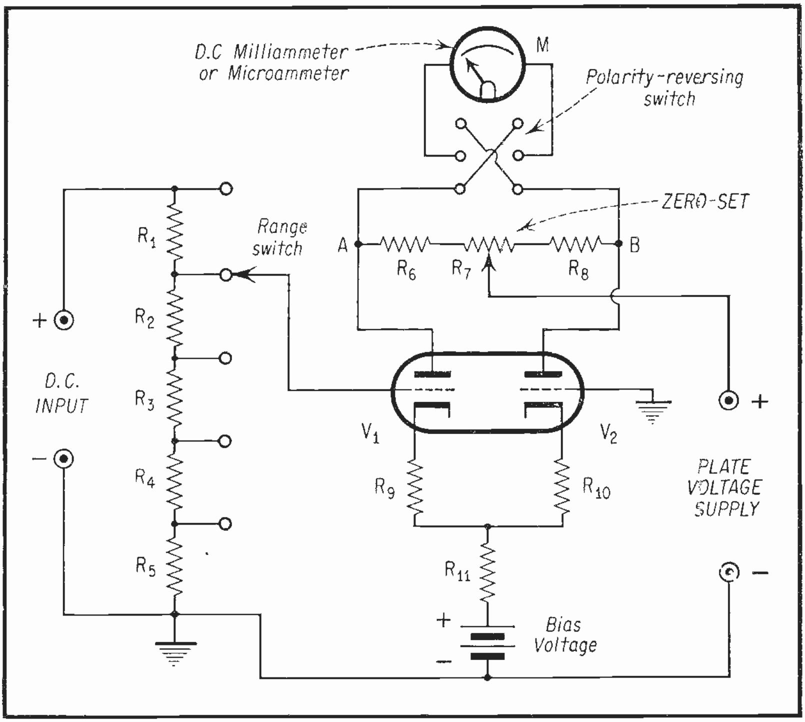

Fig. 1. Basic Circuit of Balanced D. C. V. T. Voltmeter.

at the top of R_{11}. This increased positive voltage makes the cathode of V_2 more positive at the same time and reduces the plate current in that tube. Point A of resistor R_6 is made more positive, and point B of resistor R_8 less positive, causing a current to flow through the meter, M. If the polarity of the input signal voltage is reversed, the opposite action takes place, and the meter is deflected downward. However, the polarity-reversing switch in

The input resistance of the v. t. voltmeter, which determines the amount of loading the instrument will impose upon a circuit under test, is equal to the total resistance of R_1 to R_5. In commercial instruments of this type, input resistance is constant and lies between 10 and 20 megohms, depending upon manufacturer and model. For very high input resistance at low-voltage input, the voltage divider string may be opened and the test voltage (negative) applied directly to the grid of V_1. For isolation against body capacitance and other stray coupling, the "high" input probe used with the d. c. vacuum-tube voltmeter usually contains a 1-megohm resistor.

In commercial service-type vacuum-tube voltmeters, an ohmmeter function is added. This is obtained by using the meter to measure the voltage drop across a standard resistor when an unknown resistor is connected in series with it.

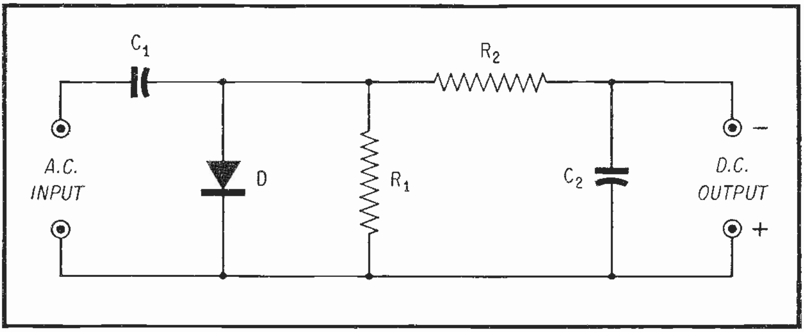

Fig. 2. A. C. Rectifier for D. C. V. T. Voltmeter.

Rectifier-Amplifier V. T. Voltmeter

A. C. voltages may be measured with the d. c. vacuum-tube voltmeter, provided they first are rectified. This usually is accomplished with a simple rectifier probe which may be plugged into the instrument input terminals. The resulting arrangement is a rectifier-amplifier circuit, which is one of the basic v. t. voltmeter categories.

Figure 2 shows the circuit of a signal rectifier probe. The shunt-diode circuit is used, since it does not recuire . d. c. return path through the voltmeter input circuit. The input capacitor, C_1, is chosen high so as to charge approximately to the peak value on positive half-cycles of signal voltage when the diode conducts. This capacitor serves also as a block to protect the diode from any damaging d. c. component in the circuit under test. R_1 is the diode load resistor which is chosen high for minimum circuit loading. It is of the order of 10 to 20 megohms. Resistor R_2 and capacitor C_2 form a filter to remove any signal component escaping the diode.

The d. c. vacuum-tube voltmeter with the probe will read the peak value of the a. c. signal voltage if the filter resistor R_2 is small compared with the total input resistance of the v. t. voltmeter (total resistance of R_1 to R_6 in Figure 1). However, by proper choice of R_2 with respect to the instrument input resistance, the d. c. meter may be made to read r. m. s. values.

The diode, D, may be either a tube or a germanium diode. Advantages of the diode are small size, simplicity, no heating, no contact potential to be bucked out, operation up to more than 100 megacycles, and no warmup time. The crystal is limited, however, to input signal amplitudes not in excess of about 21 volts r. m. s. for the 1N34 and about 53 volts r. m. s. for

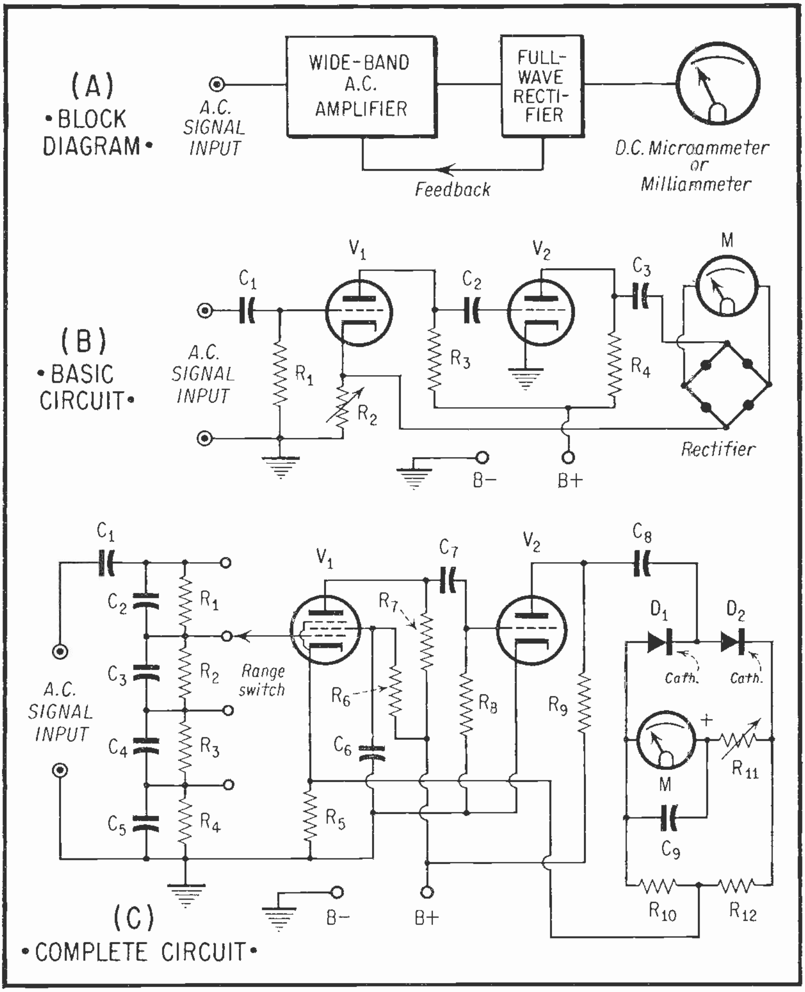

Fig. 3. Amplifier-Rectifier V. T. Voltmeter.

the 1N55. Tube diodes have the disadvantages of requiring heater voltage and of delivering a contact potential, but they permit operation at voltages up to 1000 volts r. m. s. in commercial rectifier-amplifier-type v. t. voltmeters.

Amplifier-Rectifier V. T. Voltmeter

Another important v. t. voltmeter arrangement is the **amplifier-rectifier** circuit. This instrument, which is illustrated by Figure 3, is used principally for the measurement of small audio-frequency voltages, although some commercial types have upper frequency limits of 1 and 2 megacycles.

Referring to Figure 3 (A), a small a. c. signal voltage is stepped-up by the input amplifier which is a wide-band channel with sufficient output capability to drive a full-wave rectifier and d. c. indicating milliammeter or microammeter. This arrangement thus makes possible the measurement of small voltages in the millivolt region by first amplifying the latter to the level required to operate the rectifier-type meter. Stability; freedom from tube, component, and power supply variations; and linearization of response are secured by means of negative feedback from the meter circuit to the input circuit of the amplifier. Deflection of the meter is proportional to the average value of the applied a. c. signal voltage.

Various arrangements have been used successfully in amplifier-rectifier-type v. t. voltmeters. Where wide frequency response is not required, it is possible to use a small conventional resistance - capacitance - coupled audio voltage amplifier having a low-power output stage followed by a crystal rectifier and d. c. milliammeter. Video amplifiers have been employed for higher-frequency operation.

Figure 3 (B) shows the basic circuit employed in several commercial amplifier-rectifier instruments. Tube V_1 is a high-gain voltage amplifier, while V_2 essentially is a current amplifier. The output of V_2 is coupled through a large capacitance, C_3, to a full-wave bridge rectifier which actuates milliammeter M. The greater amount of signal gain must be provided by V_1. The frequency response of the circuit also will be dependent upon the characteristics of the input amplifier stage. Degenerative voltage, derived from the meter rectifier circuit, is applied across a low resistance, R_2, in the cathode of V_1. When this resistor is made adjustable, it serves as a calibration control.

Figure 3 (C) shows a typical complete 2-tube circuit. Resistors R_1 to R_4 form an input voltage divider for switching the instrument ranges. Each resistor in the string is shunted by a trimmer capacitor (C_2 to C_5) employed for frequency compensation. The first tube, V_1, is a high-gain pentode voltage amplifier. The second tube, V_2, is a high-mu triode current amplifier. The meter rectifier is a full-wave half-bridge comprised of germanium diodes D_1 and D_2 and resistors R_{10} and R_{12}. The meter series rheostat, R_{11}, serves as a calibration control. Degenerative feedback voltage is applied from the meter circuit across cathode resistor R_5 which usually is of the order of 10 to 20 ohms.

Commercial amplifier-rectifier v. t. voltmeters are available with full-scale deflections as low as 1 millivolt r. m. s. These meters give a deflection proportional to the average value of the applied signal voltage, although their scales are graduated in r. m. s. values. Such a combination suffers less signal harmonic error than do either the peak-type (e. g., rectifier-amplifier circuit) or the true r. m. s.-actuated instruments.

One laboratory instrument employing the amplifier-rectifier circuit (the Hewlett-Packard Model 400C v. t. voltmeter) employs a multistage high-gain amplifier and provides operation up to 2 Mc. It achieves this wide-band response by means of a unique method of bypassing the tube screens. The bypassing is ineffective at low frequencies with the tubes operating as triodes with high load impedances, but is effective at high frequencies where they operate as pentodes with low load impedances.

Logarithmic V. T. Voltmeters

Logarithmic-response v. t. voltmeters are of particular interest to audio engineers and to others who work with comparative voltage and power levels, since logarithmic response permits a linear scale for decibel readings.

The most practical logarithmic v. t. voltmeters have been those which utilize the amplifier rectifier arrangement. Various methods have been employed to secure the final result.

A common layout for logarithmic v. t. voltmeters is shown in Figure 4(A). Here, a conventional linear rectifier-type milliammeter or microammeter circuit is driven by an a. c. signal amplifier having logarithmic response. Logarithmic action may be obtained through the use of variable-mu pentodes operated with correct parameters. An instrument of this type would, of course, require a special voltage scale for the indicating meter, but a db scale would be linear.

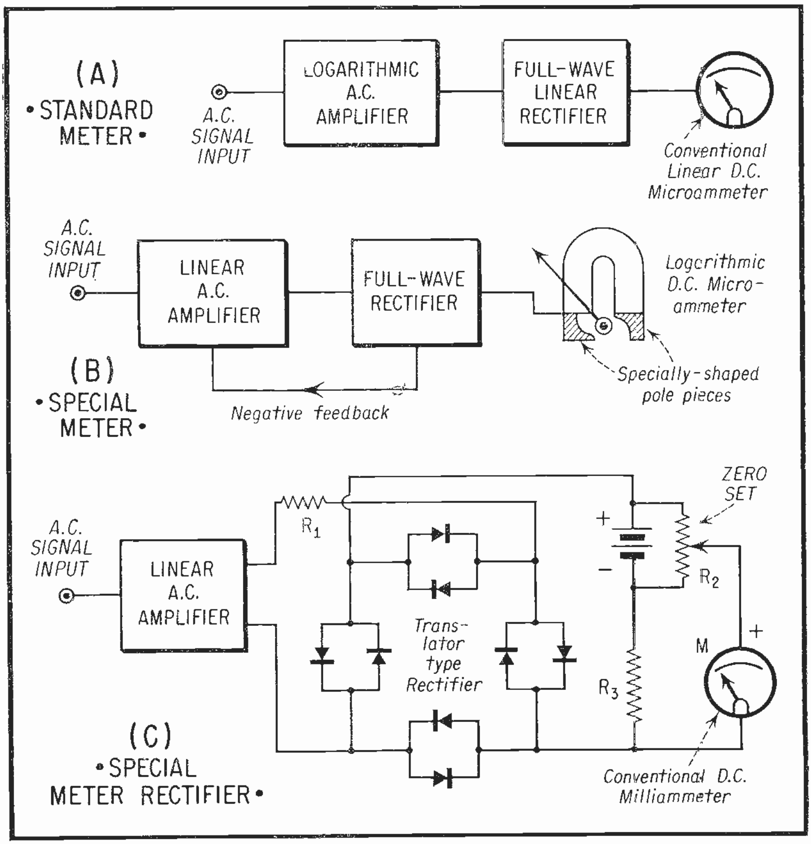

Fig. 4. Logarithmic V. T. Voltmeters.

A familiar arrangement, such as is used in the Ballantine laboratory-type v. t. voltmeters, is shown in block diagram in Figure 4(B). In this instance, a linear signal amplifier and rectifier are used, but the d. c. microammeter has specially-shaped pole pieces which serve to give the meter itself logarithmic response. Logarithmic movement of the moveable coil of the meter is secured by so shaping the pole pieces of the magnet that the air gap is varied continuously in a logarithmic manner as the coil rotates.

An interesting possibility for a logarithmic v. t. voltmeter for use at frequencies not exceeding 20 kc. is illustrated in Figure 4 (C). This application involves the use of a linear signal amplifier to drive a special meter rectifier circuit which has been found to have logarithmic response. The special oxide-type rectifier is an 8-section Translator which has been described by Conant (See "Rectifying Without Rectifiers" by H. B. Conant; RADIO-ELECTRONICS, July, 1952, p. 61). This arrangement will permit readings of 1-10-100, 10-100-1000, etc., on the milliammeter scale, with the center value at half-scale of the meter. Ranges may be changed by switching-in appropriate values for the multiplier resistor, R_1, or this resistor may be maintained at a fixed value and the range switching accomplished by means of a conventional input voltage divider in the amplifier.

Tuned V. T. Voltmeters

A tuned v. t. voltmeter is a special adaptation of the amplifier-rectifier circuit in which the amplifier has been provided with the selectivity necessary to accept or reject certain frequencies. Such instruments can be fixed-tune or tuneable. At radio frequencies, the Chanalyst type of tuneable signal tracer is an example of such a tuned v. t. voltmeter. At audio frequencies, the wave analyzer, in any one of its several forms, is a classic example.

The subject of wave analyzers and tuned amplifiers has been covered completely in previous issues of the C-D CAPACITOR and will not be re-introduced here. For reference, see the following issues: August 1951, September 1951, November 1952, February 1953, and March 1953.

Transistor Possibilities

With the transistor in the forefront at present and threatening to take over some of the functions of the vacuum tube, the question arises naturally as to the possibility of using this new component in electronic voltmeters. The low current drain, high efficiency, and long life of the transistor are attractive indeed.

At the present state of the art, however, immediate application of the transistor to electronic voltmeter circuits does not appear likely. One important consideration is that of input impedance. The major virtue of the v. t. voltmeter has been its extremely high input impedance. The best figure obtainable with present transistors appears to be about ½ megohm for the grounded-collector amplifier using a junction transistor. Frequency response and rather annoying temperature dependence also are important.

Even within the present limitations of the transistor, however, it is possible to conceive of a practical audio-type amplifier-rectifier voltmeter-millivoltmeter using (1) a grounded-collector input stage for highest possible input impedance, (2) several cascaded grounded-emitter amplifier stages for voltage gain, and (3) a grounded-collector output stage to drive a rectifier-type milliammeter.

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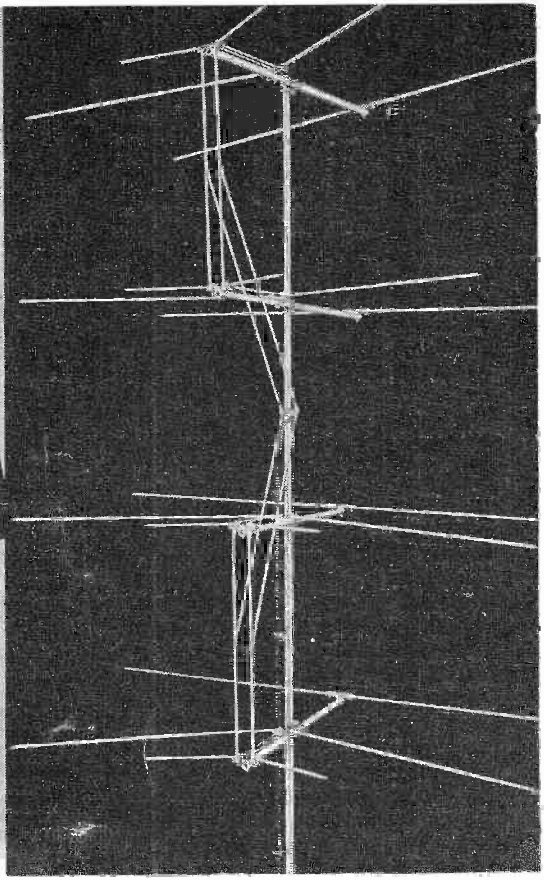

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FOR SALE—NRI comm. course, complete, including NRI meter (less mike); Precision 612C tube tester; Superior CA-12 sig. tracer, all $125 f.o.b. Stephen Plauski, 425-3rd St, Brooklyn 15, N. Y.

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WANTED—Heath model TS-2 TV sig. gen. in exc. cond. and properly calibrated. Col. J. N. Cole, AFF Board No. 2, Ft. Knox, Ky.

SELL—Prism binoculars; unused 8x30 I. F. Skyline Magna, finest Japanese make, coated, $40 p.p. Used 6x20 C. F. Havelock $25 p.p. Both pocket size. Floyd Donbar, 6305 Flushing Rd. Flushing, Mich.

FOR SALE—Audio Oscillator, model 710, The Ferret, made by Coastwise Electronics Co., Inc., exc. cond., complete with instruction manual $50 plus postage. Jules d'Hemecourt, 52 Drolla Park, Harahan Branch, New Orleans 23, La.

FOR SALE—Webster 156-27 changer, GE pickup, $15 f.o.b.; Consumers Research Triode Amplifier with 6J5, 6SC7, two 6SN7GT, two 6B4G, 5U4G, build-in preamplifier, Thordarsen Transformers and choke, $50 f.o.b. Both like new. Don Bagren, 9418 Gregory St., Rockford, Ill.

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WANTED—Late model tube tester for cash or trade for Zenith AM-FM console radio with single speed automatic record changer with Cobra tone arm. Exc. cond. P. S. Dover, 4609 N. Avers Ave., Chicago 25, Ill.

FOR SALE—Model 650 Supreme Scope, A1 cond., all leads and instruction manual, $27.50 f.o.b. Jacks Radio Hospital, 8234 So. Campbell Ave., Chicago 29, Ill.

SELL OR SWAP—Like new tube checker, 6 v. power supply, VOMA, tubes, condensers, filters, tools, vibrators, books. Want car, pick up, or cash. Raymond T. Holdman, 204 Jackson St., Bonne Terre, Mo.

FOR SALE—Proc. IRE 1947-1952 incl., Electronics, 1947-1950 incl., 1951 and 1952 less Sept., all copies in very good cond. Prefer local purchaser. Robert K. Shnitzler, 11 Bilodeau Rd. Dorchester, Mass.

FOR SALE—Make offer for Riders 1 thru 14, good cond.; Jackson 650A condenser tester; Meissner Analyst; RCA Voltohmyst; Precision series E-200 sig. gen. George H. Coole, Jr., 1001 Carpenter St., Brunswick, Ga.

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SWAP OR SELL—Garrard single-speed phono changer, RC 60/D16. Exc. cond., very heavy duty motor and turntable. Wesley Wray, 2630 N. Moreland Blvd., Cleveland, Ohio.

FOR SALE—Jackson model 580 tube tester and analyzer. All OK except the condenser test, $25. G. S. Bennage, Marionville, Mo.

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FOR SALE—Pilot tuner IF stage $20; TV booster EV3010, 4 stages 6J6, $25. Harry's Radio, 5232 France Ave., So., Minneapolis, Minn.

FOR SALE—FM tuner, high-fidelity speakers, audio equip., reasonably priced. Send for list, prices. Maxwell Strange, 673 Colrain Rd., Greenfield, Mass.

WANTED—35 mm. camera, with flash and case, new cond., only, brand name. Quality electronic equip. and items to swap, cash difference. References available. R. H. Ives, Route 1, Box 109, Lynnhaven, Va.

SELL OR TRADE—Teletone 7" TV., Al cond., table model, wood cabinet, $35. Want wire recorder. Earl Kloenhamer, Route 7, St. Wendel Rd., Evansville, Ind.

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SERVICE FOR SALE—Trouble with your Healthkit TV sweep generator? Can change circuits to make it work like $200 gen. for $45. Guaranteed. Will buy a few. Write for details. John Zimmerly, 909 S. Madison St., Bloomington, Ind.

FOR SALE—500 tubes, Rider's instruments, tools, and 1000 other articles, also TV tubes, misc. of all kinds, condensers, a few radios, $400. Mrs. Shirley Rivers, 1533 S. 53rd St., W. Philadelphia 43, Pa.

SERVICE FOR SALE—Kits: assembled, wired, tested and guaranteed! Heath, Eico, Viking, WRL, Meissner, etc. Low cost service. Write for price on your kit. R. W. Wetherald, 128 Chestnut Hill Dr., Rochester 17, N. Y.

TRADE—Two sig. Xformers; Lionel train complete; sander and polishing machine; plastic seat covers for radio and TV late type test equip. E. W. Taylor, 110 W. Missouri St., Dallas, Tex.

WANTED—TV and radio servicemen with experience and own hand tools. Permanent job, no floaters wanted. State experience and salary expected. Butler Electric Co., Box 431, Eustis, Fla.

FOR SALE—Radio-TV Appliance business (sales and service). Est. present owner 1942. Good stock, test equip. Grossing about $2500 mo. with one serviceman. Located town of 6000. -Very reasonable. W. J. Wyatt, 951 Truman Boyd Manor, Long Beach 10, Calif.

WANTED—In good cond., 901, 902 or 2002 CRO tube. State price and cond. Chas. B. Shaw, 4172 Paxton Woods Lane, Cincinnati 9, Ohio.

FOR SALE OR SWAP—Bargains @ $15 ea. plus 75c postage; Philco sig. gen.; Rider amplifier Vol 1; Sterling tube tester; Heath sig. gen.; NRI advance radio course Agostino, 223 S. Winebiddle Ave, Pittsburgh 24, Pa.

FOR SALE—18" full range P.M. speaker, 40 w., modern, walnut cabinet 35" x 35" x 16" O.D. Exc cond. Best offer over $60 f.o.b. Will demonstrate locally. GE floor model sun lamp with type S-1 bulb, $10 f.o.b. N. Hulemark, 130-75th St. Brooklyn 9, N. Y.

SELL—De-TVI'ed Viking. Super Pro with extra set new tubes. 100' ea. 72 ohm twin-lead and RG-8U. Best offer over $400. Herb Spingeld, 35-50 78th St., Jackson Heights, N. Y.

TRADE—1941 Harley Davidson "80" less than 3000 miles since rebore, transmission rebuilt, Buddy seat and saddle bags. Will drive within 250 miles of Baltimore Swap for good comm. rcvr. worth $300. Joseph F. Bauer, 565 Carrington Dr., Fullerton P. O., Md.

FOR SALE—Rider's 13 vols. Radio Service Manuals including all charts, indexes; other technical data and books in good cond., $60 f.o.b. Al Fiess, 3224 Midland Ave., Syracuse 7, N. Y.

FOR SALE—Nomograph for solving equivalent resistance of parallel resistors or equivalent capacitance of series capacitors. 50c p.p. with full instructions. Lakeview Laboratories, 146 Lakeview Ave., Waltham, Mass.

SELL OR TRADE—SCR-284A transmitter-receiver, hand gen., remote control unit, misc. parts, instruction manual. In working order, range: 3800 to 5800 kc., $45 prepaid express, or trade for TV set in working cond. Milo G. Burston, 320 Tawas St., Alpena, Mich.

FOR SALE—UHF Standard coil strips, $13.90 ea., send old VHF strip and $9.40 for any UHF channel and series. New strip sent p.p. Ben's TV, Nash near Pearce, No. Tonawanda 2, N. Y.

TRADE OR SALE—30.06 model 1917 Rem. rifle convered to sporter; battery elim. for car radio repair; Heath VOM; oscilloscope and TV alignment gen. Want 110 AC power plant or 6 v. portable units. John Chazick, 1360 Cleveland Ave., Flint 3, Mich.

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