

Measurements and Measuring Equipment

THE PROPER OPERATION of all but the very simplest of transmitters and receivers calls for the use of measuring instruments of various types. While the amateur station can be operated successfully with nothing more than a means for checking transmitter frequency and power input — and modulation, in the case of a 'phone transmitter — the progressive amateur is interested in instruments and measurements as an aid to better performance. The measure of the perfection of an amateur station, once a satisfactory transmitter and receiver have been provided, is the extent and utility of the auxiliary measuring and checking apparatus available.

Fundamentally, the process of measurement is that of comparing a quantity with a reference standard. Measuring equipment divides into two types: (1) fixed *standards* giving a reference point of known accuracy, used with associated equipment for making comparisons, and (2) direct-reading instruments or *meters* previously calibrated in terms of the quantity being measured.

Methods of making the measurements required in the amateur station will be discussed in this chapter, and representative types of the instruments used in making these measurements will be described.

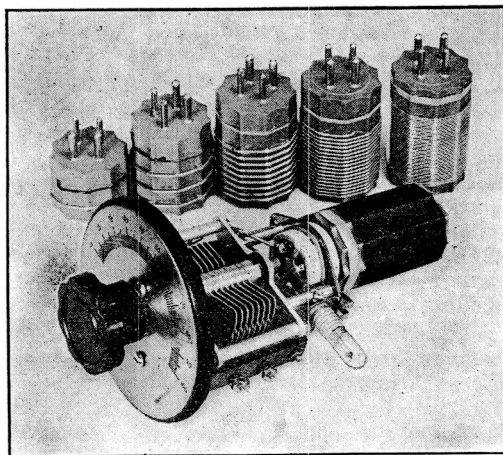


Fig. 1901 — Simple absorption frequency meter with plug-in coils covering the frequency range 1.1 to 120 Mc. with overlapping ranges. A link-coupled flashlight bulb is used as a resonance indicator. The dial plate is mounted on an insulating disc which serves as a handle. Coil forms are cut down to facilitate close coupling.

WWV SCHEDULES

All U. S. frequency calibration is based on the standard frequency transmissions from the National Bureau of Standards standard-frequency station, WWV. This station is on the air continuously, day and night, its radio frequencies of 5, 10 and 15 Mc. modulated by standard audio frequencies of 440 and 4000 cycles per second, the former, corresponding to A above middle C. In addition, there is a 0.005-second pulse every second, heard as a faint tick, which provides an accurate time interval for purposes of physical measurements.

The audio frequencies are interrupted on the hour and every five minutes thereafter for one minute to give the station announcement and to provide an interval for checking r.f. measurements. The station announcement is the call, WWV, sent in code, except on the hour and half hour when it is given by voice.

The accuracy of all frequencies is better than a part in 10,000,000. The 1-minute, 4-minute, and 5-minute intervals marked by the beginning and ending of the announcement periods are accurate to a part in 10,000,000. The beginnings of the periods when the audio frequencies are interrupted mark accurately the hour and the successive 5-minute periods.

Frequency Measurement

Dependable frequency-measuring apparatus is desirable in the amateur station for several closely related purposes:

- To insure that the transmitter is operated in the desired frequency band.
- To set the transmitter to a desired frequency (if a self-controlled oscillator is used).
- To determine the frequency of a received station, or to calibrate the receiver.
- To determine the harmonic at which a frequency multiplier stage operates.
- To determine the harmonic output of the transmitter.

Sec. 12.135 of the FCC Regulations states:

The licensee of an amateur station shall provide for measurement of the transmitter frequency and establish procedure for checking it regularly. The measurement of the transmitter frequency shall be made by means independent of the frequency control of the transmitter and shall be of sufficient accuracy to assure operation within the frequency band used.

Frequency (§ 2-7) is measured by counting the number of cycles or oscillations per second. Since this cannot be done directly, except at very low frequencies, in practice the measurement is made (a) by noting the response of a selective resonant device, such as a tuned cir-

cuit (absorption frequency meter, Wien bridge, etc.) or mechanical resonator (tuning fork, vibrating reed, etc.) previously calibrated in terms of frequency, or (b) comparing the unknown with a known frequency from a separate source, either matching it directly with a variable calibrated source (heterodyne frequency meter), or measuring the difference between it and a fixed source (frequency standard) the frequency of which is known with high precision, by interpolation.

Calibrated receiver—In the absence of more elaborate frequency-measuring equipment, a calibrated receiver may be used to indicate the approximate frequency of an oscillator. If the receiver is well-made and has good inherent stability, a bandsread dial calibration can be relied on to within perhaps 0.2 per cent. Some manufactured models having factory calibration may be used to even closer limits. For most accurate measurement the oscillator should be unmodulated and maximum response in the receiver indicated by a carrier-operated tuning indicator (§ 7-13), the receiver beat-oscillator being turned off.

When checking transmitting frequency the receiving antenna should be disconnected. If

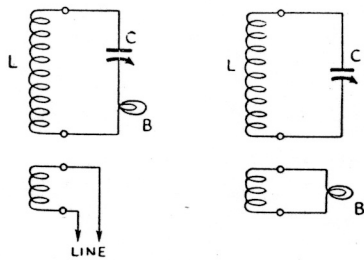


Fig. 1902—The simple absorption frequency meter circuit at left is used chiefly in transmitter checking, with link line coupling to the circuit being checked. Circuit at right uses a flashlight-bulb indicator loosely coupled to the tuned circuit, giving a sharper resonance point.

B—1.4-volt 50-ma. dial light.

C—150- μ fd. variable (Cardwell MR-150-BS).

L—Plug-in coils wound on 1½-inch diameter forms:

Freq. Range	Wire Size	Turns	Length	Link ¹
1.1–3.5 Mc. ²	No. 28 e.	81¾	17½"	17 turns
2.5–8.0 Mc. ²	No. 24 t.	37¾	15½"	11 "
4.5–14 Mc. ²	No. 20 t.	17¾	11½"	6 "
7.5–25 Mc. ²	No. 16 t.	8¾	1¼"	4 "
22–70 Mc.	No. 16 e.	2¾	1"	2 "
40–120 Mc.	No. 16 e.	¾	—	¾ "

¹ Closewound, No. 30 d.s.c., ¼-inch from primary.

² Available commercially (Hammarlund SWK-4).

the signal blocks the receiver, the transmitter frequency can be checked by listening to the oscillator, with the power amplifier turned off.

Absorption frequency meters—The simplest type of frequency meter consists of a coil and condenser, tunable over the frequency range desired (Figs. 1901–1902). A frequency meter of this type, when tuned to the frequency of the transmitter and loosely coupled to the tank coil, will extract a small amount of energy from the tank. This energy can be used to light

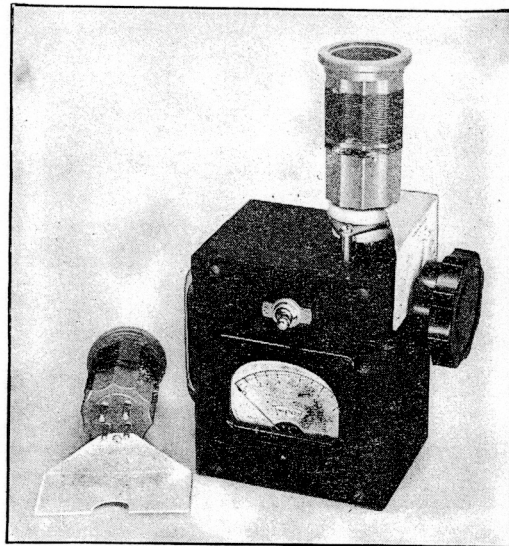


Fig. 1903—A sensitive absorption-type frequency meter with a crystal-detector rectifier and d.c. milliammeter indicating circuit. Individual calibration charts mounted directly on each coil form make the meter direct-reading. The toggle switch places a 10-ma. shunt across the 0–1 ma. meter; this range is used for preliminary readings, to avoid burning out meter or crystal. The meter gives indications at several feet from a low-power oscillator.

a small flashlight lamp. Maximum current will flow when the frequency meter is tuned exactly to the transmitter frequency; hence, the brightness of the lamp indicates resonance. A more accurate indication may be obtained by use of a thermogalvanometer or vacuum-tube voltmeter. A crystal detector may also be used (Figs. 1903–1904). (*Bib. 1.*)

Although this type of frequency meter is not well adapted to precise measurement of frequency, it is useful for checking (1) the fundamental frequency of an oscillating circuit, (2) presence and order of amplitude of harmonics, (3) frequency of parasitic oscillations, (4) neutralization of an amplifier, (5) field strength on a qualitative basis, (6) presence of r.f. in undesired places such as power wiring, or any other application where the detection of a small amount of r.f. and measurement of its frequency may provide useful information.

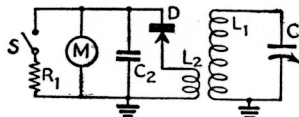


Fig. 1904—Indicating frequency-meter circuit diagram.

C₁—140- μ fd. variable (Hammarlund HFA-140-A).

C₂—0.001- μ fd. mica.

D—Fixed crystal detector (Philmore).

L₁, L₂—Same as in Fig. 1902.*

M—0.1 d.c. milliammeter (Triplett Model 321).

R₁—3-ohm shunt; see general data on meter shunts.

S—S.p.s.t. toggle switch.

If meter reads backwards, reverse crystal connections.

* Because the impedance of individual crystal detectors varies considerably, experiment with the number of turns on L₂ is necessary for maximum current indication.

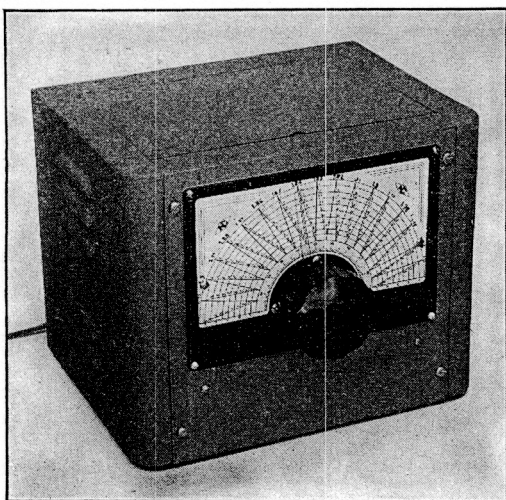


Fig. 1905 — Electron-coupled heterodyne frequency meter with harmonic amplifier and voltage regulator. The direct-reading dial is calibrated for every 10-kc. point from 1750 to 1900 kc. Axial lines passing through these points are intersected by ten semi-circular subdivision lines. Diagonal lines connecting the ends of adjacent 10-kc. lines, in conjunction with the subdivisions, enable reading the scale accurately to 1 kc. or better.

Calibration of the absorption frequency meter is most easily accomplished with a receiver of the regenerative type to which the coil in the meter can be coupled. With the detector oscillating weakly, the frequency meter should be brought near the detector coil and tuned over its range until a setting is found which causes the detector to stop oscillating. The coupling between meter and receiver should then be loosened until the stoppage of oscillation occurs at only one spot on the meter tuning dial. The meter is then tuned to the frequency at which the receiver is set. If the receiver is set on several stations of known frequency, a number of points for a calibration curve can be obtained for each coil.

The same method may be used with a super-heterodyne receiver, but it must be remembered that the oscillator frequency differs from the signal frequency by the intermediate frequency. For instance, if the receiver dial reads 6500 kc. and the receiver i.f. is 456, the oscillator frequency will be 6956 kc., which is the frequency which should be marked on the meter calibration scale. It is necessary to know whether the oscillator is on the high or low side of the incoming signal; in most receivers it is on the high side throughout, but in some it is shifted to the low side on the high-frequency ranges.

If the oscillator coils in the receiver are not accessible, the frequency meter may be capacity coupled through a few turns of insulated wire wrapped around the frequency-meter coil, one end of the wire being placed near the stator plates of the oscillator condenser.

For transmitter frequency checking a flash-light lamp or other indicator is not entirely necessary, since resonance will be indicated by

a change in the plate current of the stage being checked as the meter is tuned through resonance. However, for locating parasitic oscillations, determining amplitude of harmonics, checking neutralization, locating stray r.f. fields, etc., a sensitive indicator is indispensable.

The inherent errors in the absorption-type frequency meter ordinarily limit its useful accuracy to about 1 per cent.

Lecher wires — At very-high and ultra-high frequencies it is possible to determine frequency by actually measuring the length of the waves generated. The measurement is made by observing standing waves on a two-wire transmission line or Lecher-wire system. Such a line shows pronounced resonance effects, and it is possible to determine quite accurately the current loops (points of maximum current). The distance between two consecutive current loops is equal to one-half wavelength. Thus the wavelength can be read directly in meters (inches $\div$ 39.37 if a yardstick is used), or in centimeters for the very short wavelengths. Further details on the practical application of this system are given in Chapter Sixteen. (*Bib. 2.*)

Heterodyne frequency meters — For more accurate measurement of transmitter frequency, a heterodyne frequency meter is used. This is a small, completely shielded oscillator with a precise frequency calibration covering the lowest frequency band in use. It must be so designed and constructed that it can be accurately calibrated and will retain its calibration over long periods of time.

The signal from this oscillator (or a harmonic thereof) is fed into a receiver or simple detector together with the signal to be measured, and the two frequencies are heterodyned. When the frequency-meter oscillator is tuned to zero beat with the signal, its frequency or the harmonic multiple is the same as the unknown frequency, and the latter therefore can be read directly from the frequency-meter dial.

The oscillator used in the frequency meter must be very stable. Mechanical considerations are most important in its construction. No matter how good the instrument may be electrically, its accuracy cannot be depended upon if it is flimsily built. Inherent frequency stability can be improved by avoiding the use of phenolic compounds and thermoplastics (bakelite, polystyrene, etc.) in the oscillator circuit, and employing only high-grade ceramics for insulation. Plug-in coils or switches ordinarily are not acceptable; instead, a solidly built and firmly mounted tuned circuit should be permanently installed and the oscillator panel and chassis reinforced for rigidity.

To obtain high accuracy, the frequency meter must have a dial which can be read precisely to at least one part in 500; ordinary dials such as are used for transmitters and inexpensive receivers are not capable of such precision without the addition of vernier scales. Select a dial which has fine lines for division marks, and which preferably has an indicator close to the

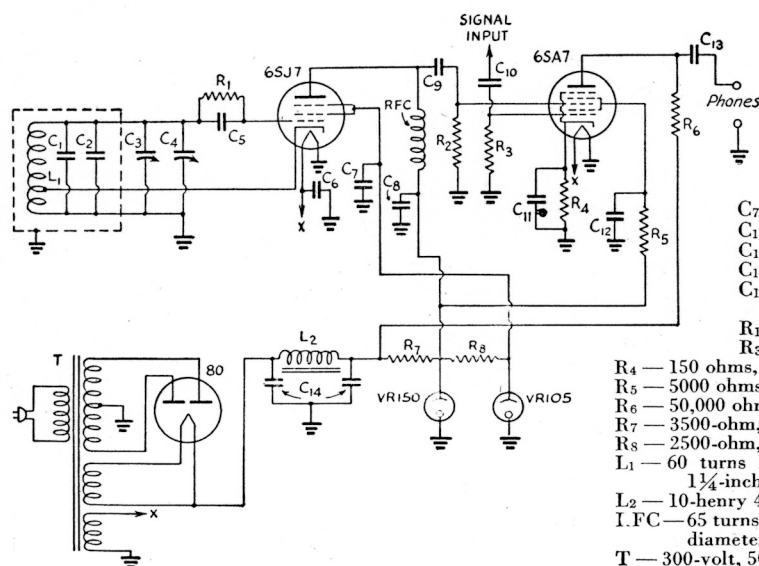


Fig. 1906 — Circuit diagram of the electron-coupled heterodyne frequency meter.

C₁ — 350-μfd. zero-drift.
C₂ — 40-μfd. negative temp.
C₃ — 100-μfd. midget.
C₄ — 50-μfd. trimmer.
C₅ — 100-μfd. silver-mica.
C₆, C₈ — 0.005-μfd. mica.
C₇, C₉, C₁₀ — 0.002-μfd. mica.
C₁₁ — 25-μfd. 25-volt electrolytic.
C₁₂ — 0.01-μfd. 400-volt paper.
C₁₃ — 0.5-μfd. 400-volt paper.
C₁₄ — Dual 8-μfd. 450-volt electrolytic.

R₁, R₂ — 1 megohm, 1/2-watt.
R₃ — 200,000 ohms, 1/2-watt.

R₄ — 150 ohms, 1/2-watt.
R₅ — 5000 ohms, 1-watt.
R₆ — 50,000 ohms, 2-watt.
R₇ — 3500-ohm, 10-watt wire-wound.
R₈ — 2500-ohm, 5-watt wire-wound.
L₁ — 60 turns No. 24 d.c.c., close-wound on 1 1/4-inch diameter, tapped at 12 turns.
L₂ — 10-henry 40-ma. filter choke.
I.F.C. — 65 turns No. 28 e. close-wound, 1/16-inch diameter.
T — 300-volt, 50-ma. power transformer.

dial scale so that the readings will not appear different because of parallax when the dial is viewed from different angles.

A stable oscillator circuit suitable for use in a heterodyne frequency meter is the electron-coupled circuit (§ 4-2). The oscillation frequency is practically independent of moderate variations in supply voltages, provided the plate and screen voltages are properly proportioned, and it is possible to take output from the plate with but negligible effect on the frequency of the oscillator. A third feature is that strong harmonics are generated in the plate circuit, so that the meter is useful over a number of frequency bands. A typical electron-coupled frequency meter is shown in Figs. 1905-1907.

When the frequency meter is first turned on some little time is required for the tube to reach its final operating temperature; during this period the frequency of oscillation will drift slightly. Although the drift will not amount to more than two or three kilocycles on the 3500-kc. band and proportionate amounts on the other bands, it is desirable to allow the frequency meter to "warm up" for about a half hour before calibrating or before making measurements in which utmost accuracy is desired. Better still, it may be left on permanently. The power consumption is negligible, and the long-time stability will be vastly improved.

Although some frequency drift is unavoidable, it can be minimized by the use of voltage-regulator tubes in the power supply and low-drift silvered-mica or zero temperature-coefficient fixed condensers in the tuned circuit. A small negative temperature-coefficient capacity may be included to compensate for residual drift.

Calibration of the frequency meter is readily accomplished if a low-frequency standard (discussed later in this chapter) is available, the required calibration points being supplied by harmonics from the standard. The frequency meter is tuned to zero beat with these har-

monics, using either a built-in detector or the station receiver to combine the two signals to provide an audible beat. When a sufficient number of points have been established they may be marked on graph paper, and a calibration curve drawn. For maximum convenience, a direct-reading dial scale can be constructed.

If no frequency standard is available, calibration points may be obtained from other sources of known frequency, such as the transmitter crystal oscillator, harmonics of local broadcasting stations, etc. As many such points as possible should be secured, so that individual inaccuracies will average out.

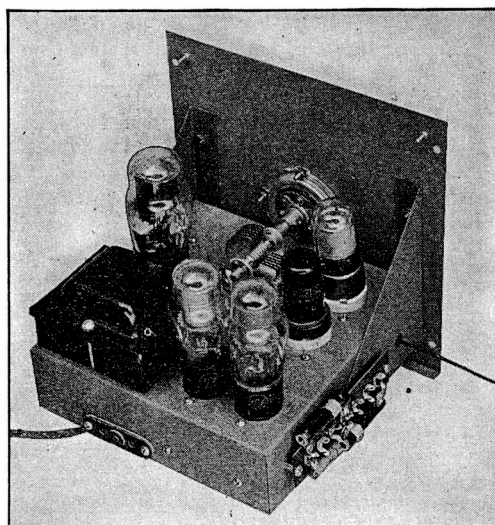


Fig. 1907 — Rear view of the electron-coupled heterodyne frequency meter. The 7 × 7 × 2-inch chassis is supported by two brackets for rigidity. It is raised sufficiently to accommodate the height of the coil shield underneath; this also enables mounting the tuning condenser directly on the chassis. The voltage-divider resistors are mounted outside to keep heat from the coil.

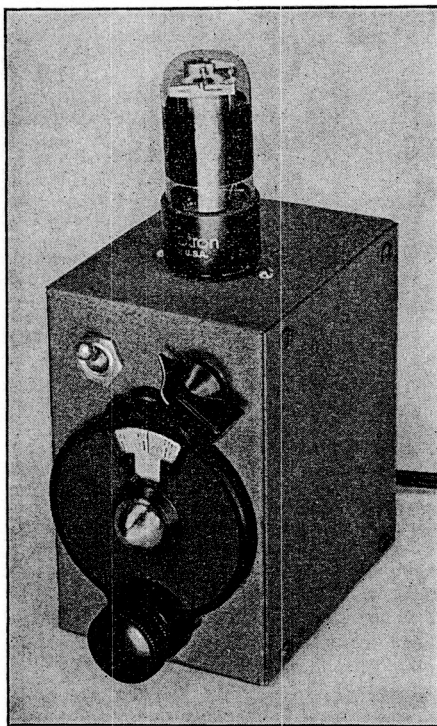


Fig. 1908 — A 50-, 100- and 1000-kc. electron-coupled frequency standard, using a dual-purpose 117L7GT tube which serves as both rectifier and oscillator. It is built up complete with transformerless power supply in a $3 \times 4 \times 5$ -inch metal box. The controls are the main tuning dial, power on-off switch, and frequency selector switch.

In use, the signal from the frequency meter may be fed into the receiver by connecting a wire from the plate of the oscillator through a very small capacity to the input of the receiver. The signal to be measured is then tuned in in the usual way and the frequency meter adjusted to zero beat.

For convenience in checking the frequency of the transmitter or other local oscillators which generate sufficiently strong signals, it is desirable to incorporate a detector in the frequency meter which will combine the signals

and deliver the audio beat-note output to headphones or to a visual zero-beat indicator. A frequency-converter tube such as the 6L7 or 6SA7 is especially suited for this purpose.

With a stable oscillator, a precision dial and frequent and careful calibration, an over-all accuracy of 0.05 to 0.1 per cent may be expected of the heterodyne frequency meter. The principal limiting factors are the precision with which the calibrated dial can be read and the "reset" stability of the tuned circuit.

Frequency standards — To make more precise frequency measurements, particularly of amateur-band limits, a secondary frequency standard is required. This is a highly stable low-frequency oscillator, usually operated at 50 or 100 kc., the harmonics of which are used

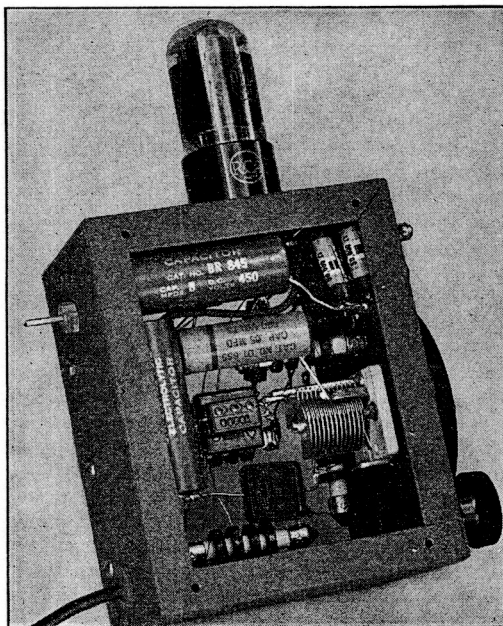


Fig. 1910 — Inside the e.c. frequency standard. Careful planning is necessary to get all parts in without crowding the inductances. Fine wire is used for all r.f. connections, to minimize vibration effects. The polystyrene bushing on the left side is the output connection.

Fig. 1909 — Wiring diagram of the 50-, 100- and 1000-kc. standard.

C₁ — 100- μ fd. midget variable (Hammarlund HF-100).

C₂ — 250- μ fd. mica.

C₃, C₄ — 0.02- μ fd. 400-volt paper.

C₅ — 500- μ fd. mica.

C₆ — 0.001- μ fd. mica.

C₇ — 0.002- μ fd. mica.

C₈ — 50- μ fd. mica.

C₉, C₁₀ — 8- μ fd. 450-volt electrolytic.

R₁, R₂ — 50,000 ohms, 1-watt.

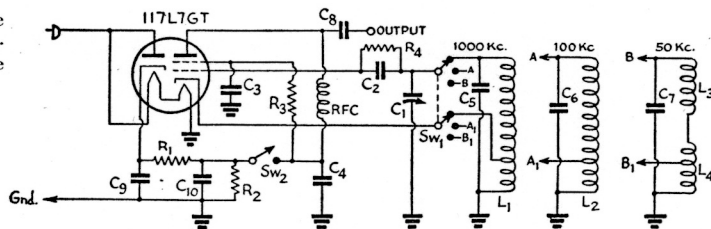
R₃, R₄ — 0.1 megohm, 1-watt.

RFC — 2.5-mh. r.f. choke.

S₁ — 3-position 2-circuit rotary switch (Mallory 3223J).

S₂ — S.p.s.t. toggle switch.

L₁ — 100 turns No. 34 d.c.c. close-wound on 9/16-inch



form. Cathode tap at 30th turn from ground.

L₂ — 2.5-mh. r.f. choke. Cathode tap is between first and second pies from ground.

L₃ — 2.5-mh. r.f. choke, at right angles to L₄.

L₁ — 2.5-mh. r.f. choke. Cathode tap between second and third pies from ground.

NOTE — Because of manufacturing tolerances in r.f. chokes and condensers, additional capacity may be required on the 50- and 100-kc. ranges. If C₁ does not tune to desired frequency, add 100 μ fd. to C₆ or C₇ as required. For additional output, decrease R₁ to 25,000 ohms. Single-wire power cord eliminates danger from shock with chassis connected to one side of line; plug must be correctly inserted or tube will not light. A ground connection is essential.

to provide reference points every 50 or 100 kc. throughout the spectrum. Since all amateur band edges fall at multiples of these frequencies, it is possible to establish band limits with extreme accuracy. A 1000-kc. frequency is often added to facilitate preliminary identification of frequency ranges, especially on v.h.f.

An electron-coupled oscillator built according to the principles previously outlined for frequency meters, with a tuned circuit for 50 or 100 kc., will serve as a simple and inexpensive standard. Such a unit is shown in Figs. 1908-1910. (Bib. 3.) A standard of this type is inherently more accurate than a heterodyne frequency meter because (a) the lower-frequency oscillator has better inherent stability and (b) the frequency setting once made is not thereafter changed, eliminating the reset and calibration errors. Even better long-time stability can be obtained from a crystal-controlled oscillator of the type shown in Figs. 1911-1913.

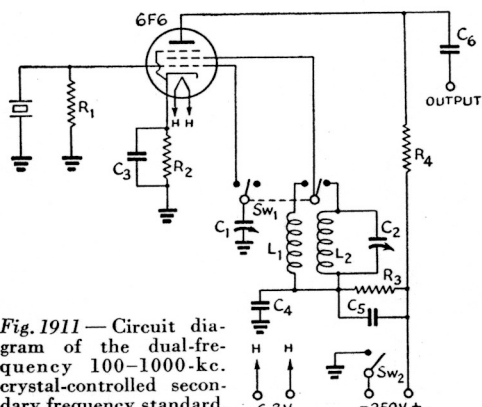


Fig. 1911 — Circuit diagram of the dual-frequency 100-1000-kc. crystal-controlled secondary frequency standard.

C₁ — 35- μ fd. midget variable (Hammarlund HF-35).
C₂ — 100- μ fd. mica trimmer (Hammarlund CTS-85).
C₃, C₄, C₅ — 0.1- μ fd. 400-volt paper.
C₆ — 0.001- μ fd. midget mica.
R₁ — 5 megohms, $\frac{1}{2}$ -watt.
R₂ — 500 ohms, $\frac{1}{2}$ -watt.
R₃ — 25,000 ohms, 1-watt.
R₄ — 0.25 megohm, $\frac{1}{2}$ -watt.
L₁ — 8-mh. r.f. choke (Meissner 1920-78).
L₂ — 2.5-mh. r.f. choke (all but one pie removed).
S₁ — D.p.d.t. toggle switch.
S₂ — S.p.s.t. toggle switch.
Crystal — Bliley SMC-100.

For highest accuracy in frequency measurement and calibration, the most suitable instrument is a precision crystal-controlled secondary standard, provided with a multivibrator (§3-7) for frequency division (Figs. 1914-1915) to mark 10-kc. intervals throughout the communications spectrum. The frequency of a signal can then be checked by noting its location with respect to two adjacent 10-kc. points on the dial of a calibrated receiver or heterodyne frequency meter and estimating the exact frequency by interpolation.

Although ordinary amateur practice does not require greater accuracy than is possible with this method, except at band edges, even more precise measurements can be made by the use of an interpolation oscillator. This is a

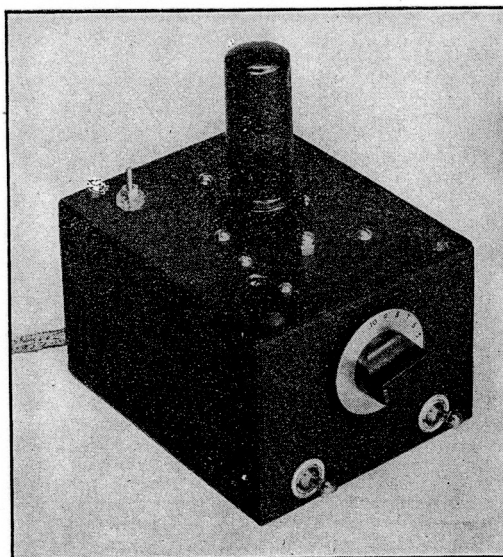


Fig. 1912 — A 100-1000-kc. crystal-controlled frequency standard. The special X-cut crystal oscillates at either of two frequencies, determined by its thickness (1000 kc.) and length (100 kc.). Either is selected by a switch which connects in a tuned circuit resonant at the desired frequency. A parallel trimmer across the crystal permits adjusting the frequency to precisely 100 kc. (provided natural crystal frequency is on the high side). Output is taken through insulated bushing at upper left.

calibrated audio oscillator used in the same manner as a heterodyne frequency meter; it is set at zero beat with the beat-note resulting from the combination of the unknown signal frequency with the nearest 10-kc. multivibrator harmonic. For example, if the "unknown" frequency is 3514 kc., it will produce a 4000-cycle beat with the 3510-kc. harmonic. When the audio oscillator is set at 4000 cycles it will zero-beat with this beat-note. Thus the frequency can be read direct from the dial of the a.f. oscillator to within a few cycles.

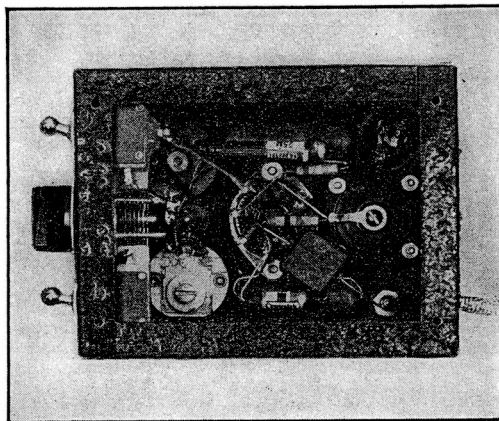


Fig. 1913 — Interior of the 100-1000-kc. standard. The crystal is mounted at right center, beside the socket. (If crystal does not oscillate on 1000 kc. when mounted in horizontal position, try other positions). Trimmer for 1000-kc. plate circuit is at lower left, near the crystal trimmer; the 8-mh. choke for 100-kc. is at upper left.

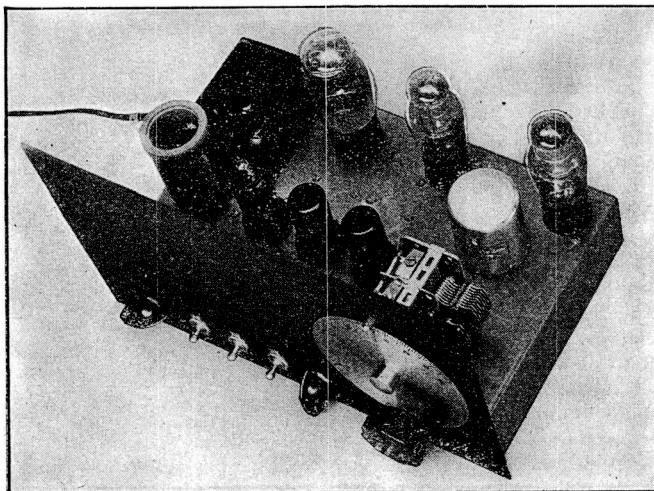


Fig. 1914—A secondary frequency standard, incorporating a 100-kc. low-drift crystal oscillator, a 10-kc. multivibrator, and a harmonic amplifier-modulator. The vernier dial is used for precise setting of crystal frequency. Controls along the bottom are, left to right: output tuning, C_{14} ; on-off switch, S_1 ; "B" switch, S_2 ; multivibrator switch, S_3 , and multivibrator control, R_8 . Power transformer, rectifier and regulator tubes are along the rear edge of the 7 × 12-inch chassis. The crystal oscillator is at the right, multivibrator tube in the center, and output circuit at the left. The output circuit is tuned to the band in use, with output taken either through C_{17} or a link winding. Output coupling is adjusted to give desired signal strength in the receiver. The crystal frequency can be adjusted to precisely 100 kc. by the vernier dial controlling C_1 . Switching the multivibrator section on or off will cause a frequency change of less than 1 part in a million.

Before adjusting a frequency standard, at least a 15-minute warm-up period should be allowed. For initial adjustment, couple its output into a broadcast receiver and adjust the oscillator to zero beat with a b.c. station operating on a multiple of 100 kc. If the oscillator is self-excited a second station 100-kc. away should be checked, to make sure it is working on 50 or 100 kc. rather than another frequency which gives an odd harmonic. Since broadcasting stations are required to stay within 20 cycles of assigned frequency, the maximum error will be less than 30 parts in one million.

For greatest accuracy the standard should be calibrated on the WWV transmissions (page 392), which are accurate to better than a part in 10 million. These transmissions may be tuned in on a receiver operating on 5 Mc. (the receiver beat oscillator being turned off) and the standard adjusted until its harmonic is exactly at zero beat with WWV. The calibration should be rechecked whenever precise measurements are to be made.

In adjusting the multivibrator, two adjacent 100-kc. points are first noted on the dial of a calibrated receiver. The multivibrator is

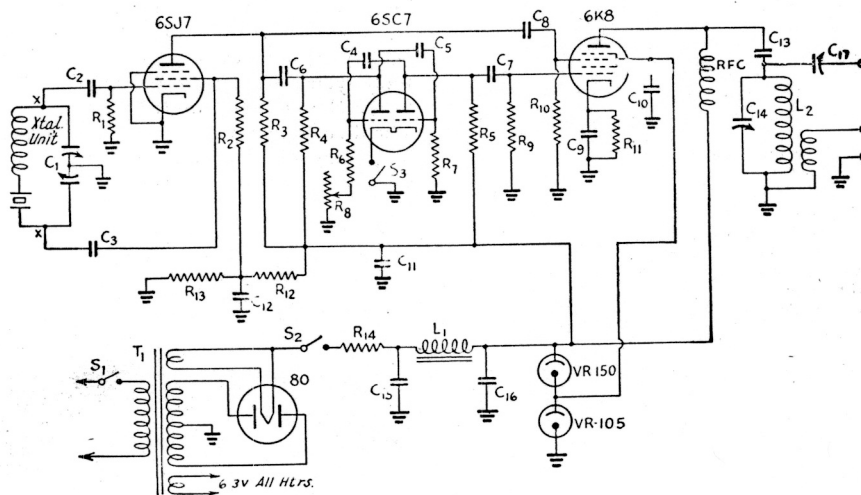
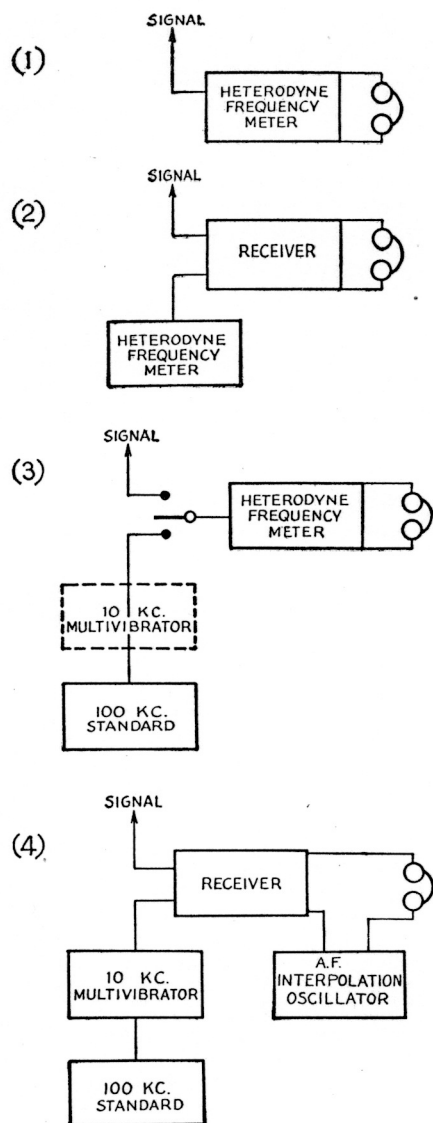


Fig. 1915—Circuit diagram of the precision low-drift crystal-controlled 100-kc. secondary frequency standard.

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|---|---|---|
| C_1 —Dual 365- μ fd. variable. | C_{17} —3-30- μ fd. trimmer. | R_{12} —25,000 ohms, 1-watt. |
| C_2, C_3 —0.01- μ fd., 400-volt paper. | R_1 —1 megohm, $\frac{1}{2}$ -watt. | R_{13} —50,000 ohms, 1-watt. |
| C_4, C_5 —0.001- μ fd. midget mica. | R_2, R_3 —0.5 megohm, 1-watt. | R_{14} —1500 ohms, 10-watt. |
| C_6, C_7 —10- μ fd. midget mica. | R_4, R_5 —50,000 ohms, 1-watt. | RFC—2.5 mh. r.f. choke. |
| C_8 —50- μ fd. midget mica. | R_6, R_7 —20,000 ohms, $\frac{1}{2}$ -watt. | S_1, S_2, S_3 —S.p.s.t. toggle. |
| $C_9, C_{10}, C_{11}, C_{12}$ —0.1- μ fd. 400-volt. | R_8 —15,000-ohm potentiometer. | T_1 —Power transformer, 250 volts, 40 ma. |
| C_{13} —0.002- μ fd. midget mica. | R_9 —0.3 megohm, $\frac{1}{2}$ -watt. | L_1 —7-henry, 40-ma. filter choke. |
| C_{14} —140- μ fd. variable. | R_{10} —0.1 megohm, $\frac{1}{2}$ -watt. | L_2 —Plug-in coil for band in use. |
| C_{15}, C_{16} —8- μ fd. 450-volt electrolytic. | R_{11} —800 ohms, $\frac{1}{2}$ -watt. | |

The crystal is a Bliley SOC-100 (supplied complete with oscillator coil in same mounting). For checking 1000-kc. points, a 150 microhenry coil (75 turns of No. 30 d.c.c. on a 1 $\frac{1}{2}$ -inch form) may be substituted for the crystal unit, connected between points X-X in the diagram. With C_1 near maximum capacity, the oscillator circuit will tune to 1000 kc.



then turned on, and its frequency control (R_8 in Fig. 1915) set at half-scale. The number of separate audio beats *between* the two marked 100-kc. points is then counted. If it is a number other than nine (indicating 10-kc. intervals), readjust R_8 until nine beats are observed. Mark this point. Note also the points on the R_8 scale where 8 and 10 beats occur, indicating approximately 11- and 9-kc. separation. The odd frequencies are occasionally useful in checking frequencies very close to the 10-kc. harmonics where the low beat-frequency makes it difficult to secure zero-beat, particularly when an interpolation oscillator is used.

The 100-kc. points usually can be identified because they are louder than the 10-kc. harmonics. This identification can be facilitated by applying audio modulation to the 100-kc. signal only, causing the modulated points to stand out because of the distinctive tone.

Fig. 1916 — Frequency measurement methods in common use. (1) A frequency meter (with built-in detector) used alone is the simplest arrangement for checking the frequency of local oscillators. (2) With a receiver, incoming received signals can be measured as well. (3) A heterodyne frequency meter can also be used as a linear interpolation oscillator in conjunction with a 100-kc. standard, with or without a 10-kc. multivibrator. The standard provides accurate check points on the frequency meter scale. Alternatively, a receiver (if adequately calibrated) may be substituted for the frequency meter. (4) For greatest precision, method is used with an interpolation audio oscillator having a linear scale. With careful design and construction, high precision can be attained with methods (3) and (4). Using (3), the accuracy can be 0.01 per cent (100 parts in a million). Method (4) is accurate to 10 parts in a million with ordinary equipment; when precision laboratory apparatus is used it is reliable to better than 1 part in a million.

Interpolation — When measuring exact frequencies with the aid of a frequency standard and multivibrator providing equi-spaced harmonic points, it is necessary to determine the exact location of the unknown frequency by interpolation between adjacent standard harmonics. This can be done (a) by use of a calibrated receiver or heterodyne frequency meter with a scale which is linear with frequency, or (b) by comparison of the audio beat frequency with a calibrated audio oscillator.

In method (a), the points at which the unknown frequency and the nearest lower and higher harmonics appear on the dial of the receiver or frequency meter are noted, as shown in Fig. 1917. Knowing the exact frequencies of the harmonic points, f_1 and f_2 , the unknown frequency, f_x , can be determined as follows:

$$f_x = f_1 + \frac{S_x - S_1}{S_2 - S_1} (f_2 - f_1)$$

where S_1 is the dial setting for f_1 , S_2 for f_2 and S_x for f_x .

Method (b) consists of beating the standard and unknown frequencies in a detector and measuring the resulting audio frequency by zero-beating with a calibrated audio oscillator having a linear frequency range covering half the difference between adjacent harmonics

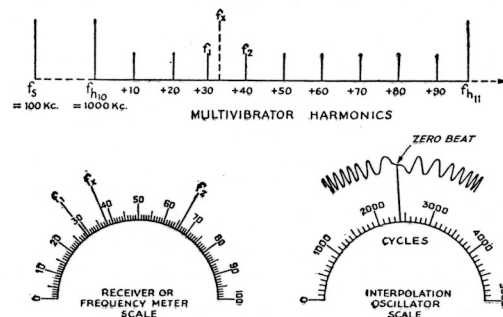


Fig. 1917 — Use of interpolation methods in measuring frequencies between standard harmonics. At the top is shown the relative location of the frequency-standard fundamental and harmonics in the spectrum, together with the multivibrator harmonics, as related to the unknown frequency under measurement (f_x). At the left is shown a small segment of this spectrum as it appears on the dial of a calibrated receiver or heterodyne frequency meter, and at right the appearance of the audio oscillator dial when using the comparison audio beat-note method.

(0-5000 cycles with a 10-kc. multivibrator), as shown in Fig. 1917. The measured frequency is then equal to the reading of the audio oscillator, added to or subtracted from the nearest standard harmonic. To determine whether to add or subtract this audio difference, it is necessary that the frequency be known within 5 kc. from the receiver (or auxiliary heterodyne frequency meter) calibration.

In addition to the beat note resulting from the nearest adjacent harmonic, f_1 , there will also be another higher beat from f_2 . However, by tuning the receiver midway between f_1 and f_2 , its adjacent-channel selectivity will discriminate against f_2 and reduce the higher beat note to a negligible level.

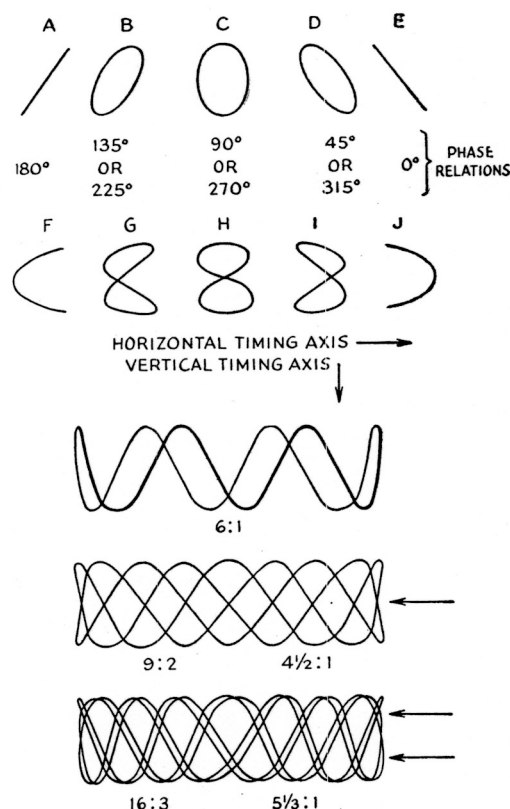


Fig. 1918 — Lissajou's figures as used in measuring audio frequencies by comparison with a known source on a cathode-ray oscilloscope. Figures A through E illustrate the pattern produced by different phase relationships when the two voltages have a 1:1 frequency ratio. Figures F through J show the same phase relationships with a 2:1 frequency ratio, the higher frequency being applied to the vertical plates. The next figure shows a ratio of 6:1, determined by counting the peaks of the waves in the horizontal plane (in this instance the higher frequency is applied to the horizontal plates). Complex ratios are identified by one or more cross-overs, as indicated by the arrows opposite the 9:2 and 16:3 figures. In principle, frequency ratios are determined by counting both horizontal and vertical peaks (number of cross-overs plus 1). Care must be taken not to confuse the back lines (return trace shown by light line in 6:1 figure) in counting cross-overs. This can be done by counting only those peaks which travel in the same direction across the screen when the frequency ratio is adjusted so that the pattern rotates slowly.

The interpolation audio oscillator should have a scale which reads linearly with frequency (as opposed to the logarithmic scale commonly found in laboratory oscillators). A beat-frequency oscillator with a straight-line-capacity tuning condenser in series with the correct value of fixed capacity can be made to have such a scale. A resistance-capacity oscillator also can be made with a nearly linear scale.

A suitable detector is a pentagrid converter (§ 7-9) with some form of zero-beat indicator in the plate circuit. The interpolation oscillator is connected to the oscillator grid and the audio beat note from the receiver to the signal grid.

Zero-beat indicators — Use of the heterodyne method of frequency comparison requires a means for determining when the known and unknown frequencies are synchronized; i.e., when they are at zero beat. The point at which zero beat occurs can be determined approximately by listening to the output of the receiver or detector in the headphones or loud-speaker. For greatest accuracy, however, some form of auxiliary visual zero-beat indicator is desirable. This may be a rectifier-type a.f. voltmeter with a copper-oxide or diode rectifier (§ 2-3), a neon-tube "flasher," or an electron-ray tube (§ 7-13) with its triode grid connected to the receiver output. Headphones still will be required for preliminary adjustments, since the visual indicator usually responds only to frequencies of less than about 25 cycles.

Audio-frequency measurement — The measurement of unknown audio frequencies also can be accomplished by either direct or comparison methods. Laboratory measurements are commonly made with a calibrated a.c. (Wien) bridge (§ 2-11).

Where a calibrated audio oscillator is available, measurements may be made by comparison as previously described in this chapter. If no electrical frequency standard is available, the audio frequency can be converted into sound through a power amplifier and loud-speaker and measured by aural comparison with a properly tuned piano, remembering that middle C is 256 cycles and each octave above or below doubles or halves the frequency. Intermediate points can be obtained by multiplying each successive half-note above C in any octave by 1.05946 (e.g., if C is 1, C# equals 1.05946, D equals 1.1225, etc.).

The cathode-ray oscilloscope (§ 3-9) is extremely useful in measuring frequencies by the comparison method when a reliable standard source is available. Applying voltages from the unknown and the standard to the opposite pairs of cathode-ray tube deflecting plates results in patterns of varying form termed Lissajou's figures. By proper interpretation of these figures, as shown in Fig. 1918, frequency ratios up to 10 to 1 can be obtained conveniently. Thus, with a 1000-cycle oscillator, calibration points between 100 and 10,000 cycles are available. A 60-cycle a.c. source similarly can be used up to 600 cycles or so.

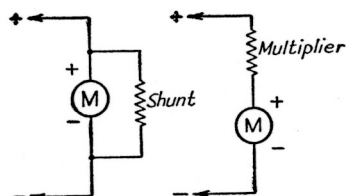
Measurement of Current, Voltage and Power

D.c. instruments — Instruments for measuring direct current (§ 2-6) are based on the d'Arsonval moving-coil principle, comprising an indicating pointer moving across a calibrated scale, actuated by the flow of current through a coil located in a constant magnetic field.

Ammeters and voltmeters are basically identical instruments, the difference being in the method of connection. An ammeter is connected in series with the circuit and measures the current flow. A voltmeter is a milliammeter (ammeter reading one-thousandth of an ampere) which measures the current through a high resistance connected across the source to be measured; its calibration is in terms of the voltage drop in the resistance or *multiplier*.

The ranges of both voltmeters and ammeters can be extended by the use of external resistors,

Fig. 1919 — How voltmeter multipliers and milliammeter shunts are connected to extend the range of a d.c. meter.



connected in series with the instrument in the case of a voltmeter or in shunt in the case of an ammeter. Fig. 1919 shows at the left the manner in which a shunt is connected to extend the range of an ammeter and at the right the connection of a voltmeter multiplier.

To calculate the value of a shunt or multiplier it is necessary to know the resistance of the meter. If it is desired to extend the range of a voltmeter, the value of resistance which must be added in series is given by the formula:

$$R = R_m (n - 1)$$

where R is the multiplier resistance, R_m the resistance of the voltmeter, and n the scale multiplication factor. For example, if the range of a 10-volt meter is to be extended to 1000 volts, n is equal to 1000/10 or 100.

If a milliammeter is to be used as a voltmeter, the value of series resistance can be found by Ohm's law (§ 2-6):

$$R = \frac{1000 E}{I}$$

where E is the desired full-scale voltage and I the full-scale reading of the instrument in ma.

To increase the current range of a milliammeter, the resistance of the shunt is

$$R = \frac{R_m}{n - 1}$$

where R_m is the meter resistance as before.

Homemade milliammeter shunts can be constructed from any of the various special kinds of resistance wire, or from ordinary copper magnet wire if no resistance wire is available.

The Copper Wire Table on page 427 gives the resistance per 1000 feet for various sizes of copper wire. After computing the resistance required, determine the smallest wire size which will carry the full-scale current (at 250 circular mils per ampere). Measure off enough wire (pulled tight but not stretched) to provide the required resistance. Accuracy can be checked by causing a current to flow through the meter which makes it read full-scale without the shunt; connecting the shunt should then give the correct reading based on the new full-scale range.

Copper has an appreciable temperature coefficient of resistivity (actually, 0.00393/° C.), and therefore a change in temperature of only 5° F. will change the effective resistance of a copper-wire shunt about 1 per cent. The heating effect of the current through the shunt must be taken into account if high accuracy is desired, as must temperature rise in enclosed cabinets and even room-temperature variations.

The following table shows the minimum wire sizes which should be used for shunts required to carry typical values of current with reasonable temperature rise, together with the resistance per foot at temperatures of 20° C. (68° F.) and 25° C. (77° F.).

Current	Wire Size	Resistance in Ohms Per Foot	
		20° C.	25° C.
60 ma.	No. 38	0.6596	0.6726
100 "	" 36	0.4148	0.4295
150 "	" 34	0.2609	0.2660
250 "	" 32	0.1641	0.1673
400 "	" 30	0.1032	0.1052
600 "	" 28	0.06490	0.06617
1000 "	" 26	0.04082	0.04162

Precision wire-wound resistors used as voltmeter multipliers cannot readily be made by the amateur because of the much higher re-

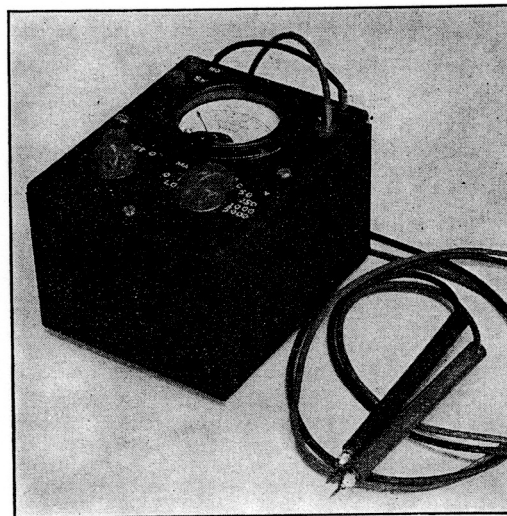


Fig. 1920 — An inexpensive multi-range volt-ohm-milliammeter housed in a standard 3 × 4 × 5-inch metal box. A bakelite panel is used. Ranges are marked with number dies, the impressions being filled with white ink.

sistance required (as high as several megohms). As an economical substitute, standard metalized fixed resistors may be used. Such resistors are supplied in tolerances of 5, 10 or 15 per cent $\pm$ the marked values. By obtaining matched pairs from the dealer's stock, one of which is, for example, 4 per cent low while the other is 4 per cent high, and using the pairs in parallel or series to obtain the required value of resistance, good accuracy can be obtained at small cost. High-voltage multipliers are preferably made up of several resistors in series; this not only raises the breakdown voltage but tends to average out errors in the individual resistors due to manufacturing tolerances.

A portable combination milliammeter-voltmeter-ohmmeter (often called a V-O-M, or multimeter) having several ranges is extremely useful for experimental purposes and for troubleshooting in receivers and transmitters. As a voltmeter such an instrument should have high resistance, so that very little current will be drawn in making voltage measurements. A low-resistance voltmeter will give inaccurate readings when connected across a high-resistance circuit. A resistance of 1000 ohms per volt is satisfactory for most uses; a 0-1 milliammeter or 0-500 microammeter (0-0.5 ma.) is the basis of most multi-range meters of this type. Microammeters having a sensitivity of 0-50 μ a., giving a voltmeter resistance of 20,000 ohms per volt, are found in units available at reasonable cost. Multipliers for the various ranges are selected by switches.

The various current ranges on a multi-range instrument are obtained by using a number of shunts individually switched in parallel with the meter. Particular care must be taken to minimize contact resistance in the switch.

A variety of mechanical and electrical arrangements may be used in a meter of this type. One simple and inexpensive version is shown in Figs. 1920-21. Using a 0-1 ma. meter, this unit provides five voltage ranges at 1000 ohms per volt: 0-10, 50, 250, 1000 and 5000 volts. The current ranges are 0-1, 10 and 100 ma. There are two ohmmeter ranges: a series range of 0-250,000 ohms and a shunt range of 0-500 ohms. The high-ohms scale is multiplied by 10 if the positive terminal of a 45-volt "B" battery is connected to the "Hi-Ohm" terminal as indicated (the unknown resistance being

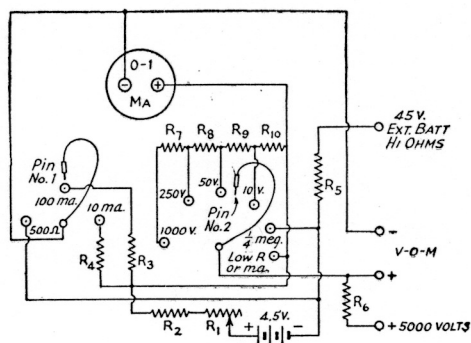


Fig. 1922 — Alternative V-O-M circuit employing pin-jack connectors. Except for the rotary switch, SW, all values are the same as in Fig. 1921. Voltage and high-resistance measurements are made with Pin No. 1 disconnected and Pin No. 2 in the appropriate jack. For measuring low resistances by the shunt method, Pin No. 1 is plugged into the 500-ohm jack and Pin No. 2 into the low-ohm-ma. jack. Leaving Pin No. 2 in this same position and removing Pin No. 1 to neutral, the 1-ma. range can be covered. To cover additional current ranges merely requires plugging Pin No. 1 into the 10- or 100-ma. jacks, while Pin No. 2 remains in the low-ohm-ma. jack.

connected between the negative battery terminal and the ohmmeter negative).

The circuit, based on the use of a multi-position rotary selector switch, is given in Fig. 1921. An alternative circuit for use where such a switch is not available, employing 'phone-tip and jack connectors, is shown in Fig. 1922.

When d.c. voltage and current are known, the power in a circuit can be stated by simple application of Ohm's law: $P = EI$ (§ 2-6). Thus the voltmeter and ammeter are also the instruments used in measuring d.c. power.

A.c. instruments — D.c. meters will not function on alternating current, and it is therefore necessary either to rectify the a.c. and measure the resulting d.c. or to use special instruments that will indicate on a.c. (§ 2-8).

A.c. ammeters and voltmeters utilize the moving iron-vane principle. Since the maximum sensitivity is 15 to 25 ma. (40 to 67 ohms per volt) iron-vane voltmeters consume substantial power. Thus they are suitable for measuring filament and line voltages, but cannot be used with circuits which are unable to sustain an appreciable measuring load. Moving iron-vane meters are not accurate at frequencies above a few hundred cycles.

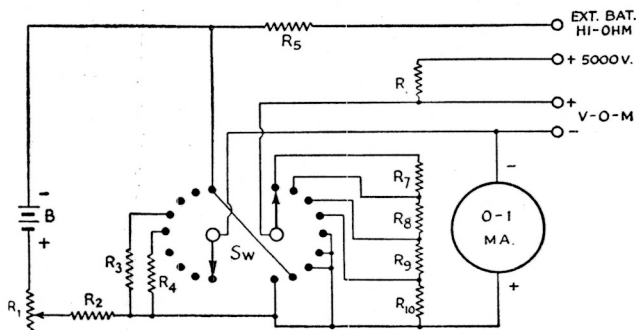


Fig. 1921 — Circuit of the low-cost V-O-M.

- R₁ — 2000-ohm wire-wound variable.
- R₂ — 3000 ohms, 1/2-watt.
- R₃ — 100-ma. shunt, 0.33 ohms (see text).
- R₄ — 10-ma. shunt, 3.6 ohms (see text).
- R₅ — 40,000 ohms, 1/2-watt.
- R₆ — 4 megohms, 4-watt (four 1-megohm 1-watt resistors in series).
- R₇ — 0.75 megohm, 1-watt (0.5 megohm and 0.25 megohm 1/2-watt in series).
- R₈ — 0.2 megohm, 1/2-watt.
- R₉ — 40,000 ohms, 1/2-watt.
- R₁₀ — 10,000 ohms, 1/2-watt.
- SW — 9-point 2-pole switch (Mallory-Yaxley 3109).
- B — 4.5 volts (Burgess 5360).

For measurements where iron-vane meters are not suitable, special devices enabling the use of d.c. movements are employed. The most common of these for the power- and audio-frequency range is the full-wave copper-oxide rectifier, which converts a low-resistance 0-1 ma. d.c. milliammeter into a high-resistance 0-0.909 ma. a.c. milliammeter, making possible the construction of a.c. voltmeters having a sensitivity of 1000 ohms per volt and an accuracy of about 5 per cent. The design of multipliers for such a voltmeter must allow for the fact that the rectifier resistance varies with current. Two scales are usually provided, one for use above 50 volts and one below. The frequency error averages 0.5 per cent per 1000 cycles.

A.c. power measurements are more complex than for d.c., the simple multiplication of current and voltage being in error unless the load is purely resistive. If the current and the a.c. impedance are known, the power is I^2Z . For ordinary amateur power calculations, such as the input to a power transformer, the product of a.c. voltage and current may be considered sufficiently accurate.

R.f. instruments — The measurement of high-frequency a.c. or r.f. quantities involves special problems. Practical instruments read in terms of d.c. from a conversion device.

R.f. current usually is measured by means of a thermoammeter. This is a sensitive d.c. microammeter connected to a thermocouple associated with a heater made of a short piece of resistance wire. Thermoammeters have been made with an r.f. sensitivity of 1 ma., but the ranges used by amateurs for measuring antenna current, etc., are from 0-0.5 ampere up.

The most suitable r.f. voltmeter is a peak-reading vacuum-tube voltmeter (Fig. 1923). When properly designed, its accuracy at r.f. is limited only by the variation of input resistance with frequency. The peak diode voltmeter has little error even at 60 Mc. The same is true of the self-biased and slide-back types, if tubes having low input capacity are used. The oscilloscope also can be used as an r.f. voltmeter where the potential is several volts or more.

R.f. power measurements can be made by measuring the current through a resistor or reactance of known value. Approximate power measurements can be made by using ordinary 115-volt light bulbs as a substitution or "dummy" load, connected either singly or in series-parallel to provide the required resistance and power rating. The approximate resistance of the bulb can be computed from its wattage rating at 60 cycles. Special non-inductive resistance units enclosed in vacuum bulbs mounted on standard tube bases, with resistances of 73 and 600 ohms at power ratings up to 100 watts, are available for this purpose. For higher power the units can be connected in series-parallel (§ 4-9).

Where the substitution load method is impractical, r.f. power can be measured by multiplying the current through a thermoammeter

in the circuit by the r.f. voltage across the circuit as indicated by an r.m.s. meter (or 70.7 per cent of the reading on a peak voltmeter).

Another method of measuring r.f. power is by the photometric method. In this method a calibrated light-sensitive cell (a photographer's exposure meter is suitable) is used to measure the relative brilliance of an electric light bulb as a substitution load compared with its normal brilliance on 115-volt 60-cycle supply.

Vacuum-tube voltmeters — The most generally useful instrument for the measurement of d.c., a.c. and r.f. voltages is the vacuum-tube voltmeter. Its chief advantages are (a) high input resistance (i.e., negligible power taken from the circuit under measurement), and (b) good accuracy over a wide range of frequencies extending, with some types, up into the ultrahigh-frequency region.

The vacuum-tube voltmeter operates by virtue of the change in plate current in a vacuum tube caused by a change in the voltage applied to the grid. Thus, by introducing the voltage which is to be measured into the grid circuit, the resulting plate-current change constitutes a measure of the applied voltage. In the case of a.c. the tube acts as a rectifier, and the measurement is in terms of rectified d.c.

Representative vacuum-tube voltmeter circuits are shown in Fig. 1923. The simple diode rectifier (A) can be almost any type of tube; in a triode or multi-grid type, all electrodes except the control grid are connected to cathode (or negative filament). A Type 30 or 1G4G tube with a flashlight cell for filament supply makes a convenient portable unit. Tubes with low input capacity (1N5G, 6T7G, 954, etc.) should be used for high frequencies. The frequency range is limited by the tube input capacity shunting the load resistance. The calibration will be linear above 2 or 3 volts, provided the load resistance exceeds 0.1 megohm. The meter, M , should be a sensitive microammeter (0-100 or 200 μ a.); however, a 0-1 ma. meter can be used with reduced sensitivity.

The peak diode voltmeter at B, shunt-connected to eliminate the necessity for a d.c. return in the measured circuit, reads peak a.c. voltage. The input resistance is comparable to that of the simple diode for equivalent sensitivity, but the high-frequency error is less. The time constant of the RC circuit should be at least 100 for the lowest frequency to be measured ($RCF < 100$). Typical values are 0.5 megohm and 0.5 μ fd. for audio frequencies and 0.1 megohm and 0.05 μ fd. (mica) for r.f. and i.f.

The grid-rectification circuit shown at C may be considered equivalent to the diode rectifier of B followed by a zero-bias triode amplifier. The sensitivity is greatly increased over the ordinary diode. The input resistance is low with small inputs (0.1 to 1.0 megohm) because of grid current. The plate current is at a maximum when idling and decreases with signal. This circuit is useful chiefly because it can be used with inexpensive meters. The in-

strument may be calibrated from a known 60-cycle source; the scale is square-law for small signals, becoming linear with increasing input. The value of R is non-critical. C should have a reactance small compared with R at the operating frequency; i.e., 0.01- μ fd. mica from 1 kc. up, 0.1- μ fd. paper for low a.f. For d.c., C is, of course, omitted. A high- μ tube is preferable, to reduce the idling or no-signal plate current.

The self-biased plate-rectification or reflex voltmeter at D has a very high input resistance and fair sensitivity. It is normally connected directly across the circuit to be measured; if no d.c. return is available, a coupling circuit must be added, as shown by the dotted lines ($C = 0.01 \mu$ fd; $R = 10$ meg-

ohms or more). A low- μ tube is preferable, to minimize contact potential and grid current. The cathode resistance, R_2 , controls the sensitivity; the higher its resistance, the more linear and stable will be the calibration. A range switch can be provided, connecting in various values of cathode resistance from 2000 ohms to 0.5 megohm to give full-scale ranges from about 2.5 to 250 volts. The plate and cathode by-passes may be 0.001- μ fd mica condensers, the cathode being shunted by a 10- μ fd. electrolytic for 60-cycle calibration and low audio-frequency measurements.

The no-signal plate current present in the circuits of C and D can be balanced out by bridge or bucking circuits, typical forms of which are shown at E. An auxiliary battery (or a section of the voltage divider in an a.c. power supply) is connected back to the meter through a variable resistor, providing a controllable opposite current flow which can be made to equal exactly the residual plate current of the tube. When used with C this balancing circuit allows the meter terminals to be reversed, thereby making the meter read forward instead of backward. The resistor, R , should have a value not less than ten times the internal resistance of the meter.

At the right in E an automatic balancing circuit is shown wherein a duplicate triode (usually the second section of a twin-triode tube) takes the place of the adjustable resistor, R . Current flow through R_1 and R_2 being equal and opposite with no signal, there is no potential across the meter and consequently no current flow. When a voltage is applied to the grid of the voltmeter triode this balance is disturbed, however, and the meter registers current flow. A small zero-setting resistor, R_3 , is provided to correct for any discrepancies in the tubes or resistors. The values for R_1 and R_2 depend on the plate-supply voltage available; the higher the resistances, the better the sensitivity and stability. The minimum value is several times the meter resistance.

The "slide-back" voltmeter at F is a comparison instrument in which the peak value of an a.c. or r.f. voltage is read in terms of a d.c. substitution voltage; the voltmeter tube and the milliammeter, M , merely indicate when the two voltages are equal. With the input terminals shorted and R_1 set so that V reads zero, the tube is biased nearly to cut-off by adjustment of R_2 . The residual plate current becomes the reference current ($I_{ref.}$) or "false zero." When an a.c. voltage, E , is applied across the input terminals, plate rectification of the positive peaks causes the plate current to rise. By adjustment of R_1 , additional bias voltage is introduced to balance out the a.c. voltage. The additional bias required to bring the plate current back to the reference value ($I_{ref.}$) is equal to the peak value of the voltage being measured. In operation, R_1 should be adjusted (after setting $I_{ref.}$) so that all of E_1 is in the circuit, to avoid burning out the milliammeter

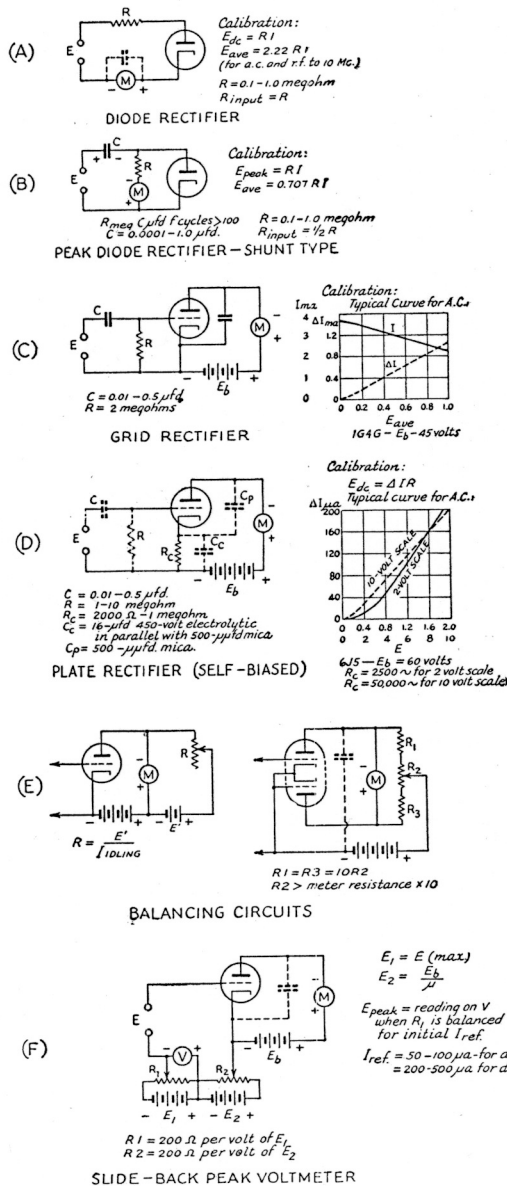


Fig. 1923—Fundamental vacuum-tube voltmeter circuits.

when the signal is applied. After the unknown voltage has been connected, the bias is reduced by R_1 until the reference current is reached. The slide-back voltmeter is capable of high accuracy and has the advantage of requiring no a.c. calibration; it is, therefore, particularly useful for a temporary set-up.

Oscilloscopes — Perhaps the most useful of all measuring devices is the cathode-ray oscilloscope (§ 3-8, 3-9). Although relatively expensive, its applications are so numerous that it can replace a number of other less satisfactory types of measuring equipment. It can be used on d.c., a.c. and r.f., and is particularly suited to a.f. and r.f. measurements because of the high input resistance and small frequency error.

The oscilloscope is, in effect, a complex voltmeter capable of measuring any two voltages simultaneously by the deflection of a weightless electron-beam pointer. Moreover, because this pointer projects its indication on a retentive luminous screen, the measurements include the additional factor of time. It is possible, therefore, to see the actual form of one or more repetitive cycles of an a.c. voltage by means of the oscilloscope, and to measure thereby not only the amplitude of the voltage but also its frequency and waveform (§ 3-9).

A simple cathode-ray oscilloscope is shown in Figs. 1924-25. It employs a type 902, an inexpensive 2-inch cathode-ray tube, which is mounted, together with the associated rectifier tube and other components, in a cabinet made of a standard $3 \times 5 \times 10$ -inch steel chassis with bottom plate. The shielding provided by this box is highly desirable for prevention of stray-field interference in the patterns obtained.

In building the unit, the cathode-ray tube must be placed so that the alternating magnetic field from the transformer has no effect on the electron beam. The transformer should be mounted directly behind the base of the tube, with the axes of the transformer windings and the tube on a common line.

If trouble is experienced in getting a pattern from a high-power transmitter because of r.f. voltage on the 115-volt supply line, two blocking condensers (0.01 or 0.1 μ fd.) may be connected in series across the primary of the power transformer in the oscilloscope, with the common connection grounded to the case.

Fig. 1925 — Circuit of the 2-inch oscilloscope.

C — 2- μ fd. 900-volt electrolytic (dual 4- μ fd. 450-volt with sections in series).

R_1 — 100,000-ohm potentiometer.

R_2 — 50,000 ohms, 1-watt.

R_3 — 200,000 ohms, 2-watt.

R_4 — 100,000-ohm potentiometer.

RFC — 2.5-mh. 125-ma. r.f. choke (optional; used when needed to correct leaning patterns because of r.f. coupling).

SW₁ — S.p.d.t. toggle switch, 250-volt 1-ampere.

SW₂ — S.p.s.t. switch (on R_4).

T — Receiver-type power transformer delivering 325-0-325 volts a.c. at 40 ma., 5 volts at 3 amperes, and 6.3 volts at 2 amperes.

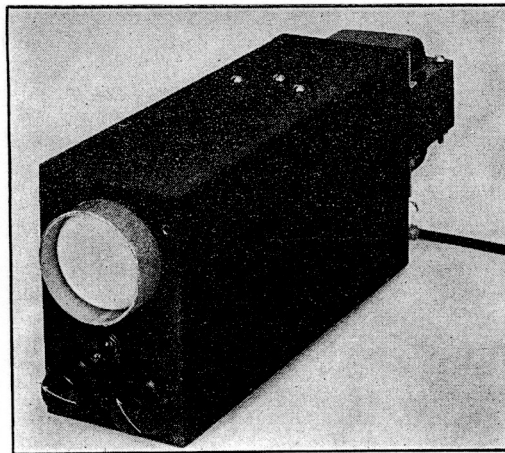
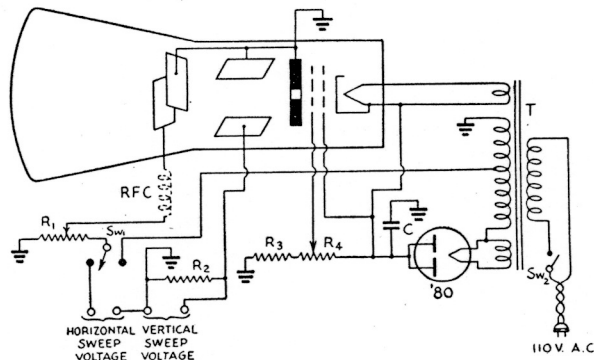


Fig. 1924 — A c.r. oscilloscope using a 902 2-inch tube, housed in a $5 \times 10 \times 3$ -inch chassis with bottom plate. Two small feed-through insulators serve as terminals for external horizontal- and vertical-sweep connections. Note the location of the power transformer; it is placed not only outside the steel shield chassis but also directly behind the cathode-ray tube, with the axis of the transformer winding along the axis line of the tube.

It is important that provision be included for switching off the electron beam, reducing the spot intensity, or swinging the beam to one side of the screen with d.c. bias when no signal voltage is being applied. A pattern that is a thin, bright line or a spot of high intensity will "burn" the screen of the cathode-ray tube.

Horizontal sweep voltage may be obtained either from an audio-frequency source (such as the modulator stage of the transmitter) or from the 60-cycle a.c. line. Using an a.f. horizontal sweep, the pattern appearing on the screen will be in the form of a trapezoid or triangle (depending on the percentage of modulation) when checking transmitter performance.

For actual studies of waveform, the use of a sweep circuit having a linear time base is necessary (§ 3-9). The sweep circuit proper usually employs a grid-controlled gaseous discharge tube (the 884 and 885 are especially designed for this purpose), operating as a relaxation oscillator. In operation, the sweep circuit is connected to the horizontal-deflection plates of the existing oscilloscope. The voltage under observation is connected to the vertical-deflec-



tion plates, and the resulting picture is an accurate representation of the waveshape of the voltage being examined.

An example of a linear sweep circuit and wide-range amplifiers applied to a 902 2-inch cathode-ray tube is shown in Fig. 1926. The circuit elements in the center of the diagram comprise the sweep circuit. The 884 generates a saw-tooth sweep voltage and the 6J7 acts as a current-limiting tube to ensure linearity.

The high-gain vertical and horizontal amplifiers using 6J7s have inductance compensation in their plate circuits to extend the frequency range. The amplifier input and output leads should be direct and placed well clear of other components, to avoid frequency distortion and unwanted pick-up. For r.f., the input is applied directly to the deflection plates.

The panel controls are the intensity control, R_2 ; focusing control, R_3 ; horizontal and vertical spot-positioning controls, R_7 and R_8 ; sweep-amplitude control, R_{14} ; sweep-frequency vernier, R_{17} ; synchronization control, R_{18} ; direct-input controls, R_{19} and R_{20} ; and the amplifier input controls, R_{23} .

For the 902 power supply, a replacement-type transformer may be used with a half-wave rectifier. (Bib. 5.)

The cathode-ray oscilloscope is useful in the measurement of almost any quantity involving amplitude or waveform. Elsewhere in this *Handbook* are described methods for using the

oscilloscope for measuring audio frequencies (p. 400), adjusting vibrator power supplies (p. 363), and checking and adjusting modulation percentage in 'phone transmitters, (§ 5-10).

When used for measuring voltage, the signal is applied to the vertical plates and its amplitude measured in terms of the height of the resulting trace. Approximate measurements can be made by calibrating the sensitivity of the cathode-ray tube in volts per inch. The sensitivity varies with the anode voltage and type of tube; typical figures for small tubes are 25 to 75 volts per inch, peak-to-peak. The initial calibration can be made with a variable d.c. voltage source and a comparison voltmeter.

Impedance can be measured at any frequency by connecting the circuit or component under measurement in series with a non-reactive resistor across a source of signal voltage of the required frequency. The relative deflection as the oscilloscope is connected across first the resistor and then the impedance will give the value of impedance with respect to the known value of resistance.

Transformer turns ratios and gain ratios, as well as the gain of amplifier stages, can be determined by applying a signal of appropriate frequency from an audio oscillator or r.f. signal generator to the primary or input, measuring the amplitude at this point, and then measuring the relative amplitude across the secondary or output (§ 2-9).

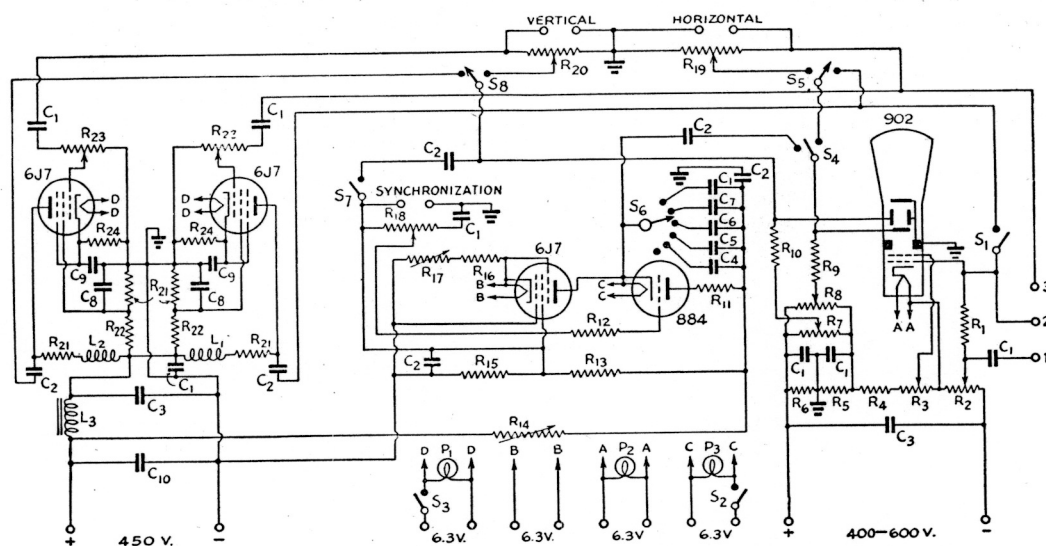


Fig. 1926 — Circuit diagram of a complete cathode-ray oscilloscope with sweep circuit and voltage amplifiers.

C_1 — 0.1- μ fd. 600-volt paper.
 C_2 — 0.25- μ fd. 600-volt paper.
 C_3 — 8- μ fd. 500-volt electrolytic.
 C_4 — 0.0001- μ fd. 400-volt paper.
 C_5 — 0.001- μ fd. 400-volt paper.
 C_6 — 0.005- μ fd. 400-volt paper.
 C_7 — 0.025- μ fd. 400-volt paper.
 C_8 — 0.01- μ fd. 400-volt paper.
 C_9 — 5- μ fd. 25-volt electrolytic.
 C_{10} — 16- μ fd. (dual 8-8 in parallel) 500-volt electrolytic.
 R_1 — 300,000 ohms, $\frac{1}{2}$ -watt.
 R_2 — 25,000 ohms, 1-watt.

R_3 — 50,000 ohms, 1-watt.
 R_4 — 75,000 ohms, 1-watt.
 R_5, R_6 — 30,000 ohms, 1-watt.
 R_7, R_8 — 1-megohm potentiometer.
 R_9, R_{10} — 5 megohms, $\frac{1}{2}$ -watt.
 R_{11} — 1000 ohms, 1-watt.
 R_{12} — 300,000 ohms, 1-watt.
 R_{13} — 40,000 ohms, 1-watt.
 R_{14} — 50,000-ohm wire-wound rheostat.
 R_{15} — 6000 ohms, 2-watt.
 R_{16} — 1500 ohms, 1-watt.
 R_{17} — 50,000-ohm rheostat.

R_{18} — 500,000-ohm potentiometer.
 R_{19}, R_{20} — 5-megohm potentiometer.
 R_{21} — 100,000 ohms, 1-watt.
 R_{22} — 150,000 ohms, 1-watt.
 R_{23} — 500,000-ohm potentiometer.
 R_{24} — 1000 ohms, $\frac{1}{2}$ -watt.
 S_1, S_2, S_3 — S.p.s.t. toggle switch.
 S_4, S_5, S_8 — S.p.d.t. toggle switch.
 S_6 — 6-contact selector switch.
 S_7 — Snap switch, mounted on R_{18} .
 L_1, L_2 — 25-mh. r.f. choke.
 L_3 — 30-henry 15-ma. filter choke.
 P_1, P_2, P_3 — Jeweled pilot lamps.

Ⓜ R, Z, C, L and Q Measurements

It is frequently necessary to measure values of components used in the construction of amateur equipment — resistors, condensers, coils, etc. — both as a means of identification and in checking accuracy. The advanced amateur will also be interested in measuring impedances and the characteristics of devices of his own construction or under other than rated conditions.

Resistance — The volt-ammeter, ohmmeter and Wheatstone bridge methods are commonly used in measuring resistance. In the volt-ammeter method, the resistance is determined from Ohm's Law by measuring the current through the resistor when a known d.c. voltage is applied. The resistance can be determined with a voltmeter alone, when

$$R = \frac{eR_m}{E} - R_m$$

where R is the resistance under measurement, E is the voltage read on the meter, e is the series voltage applied, and R_m is the internal resistance of the meter (full-scale reading $\times$ ohms-per-volt).

The ohmmeter is a practical application of this method, with a low-current d.c. voltmeter and a source of voltage (usually dry cells) connected in series with the unknown resistance. If the meter reads full-scale with the connecting leads shorted, insertion of the resistance under measurement will cause the reading to decrease in proportion to the resistance inserted. The scale thus can be calibrated in ohms.

In Fig. 1927-A, the series resistance is adjusted until the milliammeter reads full-scale when the test leads are shorted. When the meter reading changes as the battery ages the series resistance is reduced to compensate for the change. In B, the series resistance is kept constant but the sensitivity of the meter is varied to compensate for the changing voltage. The circuit of C is useful for measuring resistances below a few hundred ohms. The unknown resistance is connected as a shunt across the meter, reducing the current reading. Values of a fraction of an ohm can be read in this way.

The ratio of resistances which can be measured on a single ohmmeter range averages about 100 to 1, or from one-tenth to ten times the center-scale value.

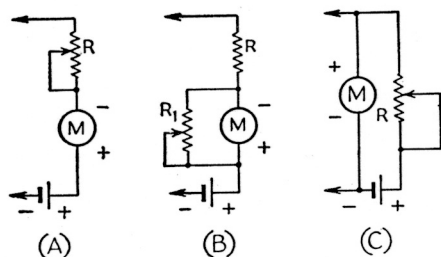


Fig. 1927 — Basic ohmmeter circuits. (A) Series-type ohmmeter with series compensation. (B) Series-type ohmmeter with shunt compensation. (C) Shunt-type ohmmeter used for measuring low values of resistance.

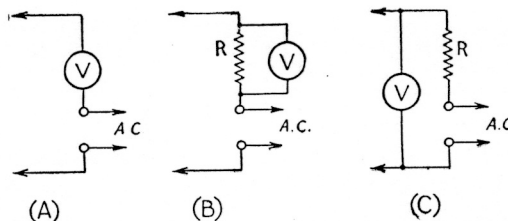


Fig. 1928 — Reactance-meter circuits for checking C and L .

Only approximate measurements can be made with an ohmmeter. For greater accuracy, the unknown resistor may be compared with a standard resistance of known accuracy by means of a Wheatstone bridge (§ 2-11). If resistance measurements only are to be made, the bridge can be powered from a battery and a milliammeter used for the balance indicator. If reactances also are to be measured, an a.c. source is required (Fig. 1929).

Capacity and inductance — The capacity of condensers and the inductance of coils can be measured (a) in terms of their reactance, (b) by comparison with a standard, or (c) by substitution methods.

The reactance method is simplest but least accurate. The method is similar to the d.c. ohmmeter, except that impedance is measured instead of resistance. In Fig. 1928-A, the unknown reactance is placed in series with an a.c. rectifier-type voltmeter across the 115-volt a.c. line. With a 1000-ohms-per-volt meter, capacities can be identified from approximately 0.001- μ fd. to 0.1- μ fd. At B the reactance is connected in series with a 1000-ohm resistance; the proportionate voltage drop across this resistance indicates the reactance of condensers from 0.1 μ fd. to 10 μ fd. and of inductances from 0.5 henry to 50 henries, when Q is greater than 10. Because the lower end of the scale of a rectifier-type meter is somewhat crowded, a better reading can be had by using the connection at C for large reactances. Approximate calibrations for each connection may be made by checking typical condensers and coils of known values and drawing calibration curves for the voltmeter in use.

The reactance method at best gives only approximate indications of inductance and capacity. For accurate measurements, an a.c. bridge must be used.

A simple bridge for the measurement of R , C and L is shown in Fig. 1929. Its accuracy will depend on the precision of the standards, the sensitivity of the detector or balance indicator, the voltage and frequency of the a.c. source, and the ratio of the unknown value to the standard. The signal source can be a 1000-cycle audio oscillator with low harmonic content and the detector a pair of headphones. A "magic-eye" tube can be used as a detector.

For maximum accuracy the ratio of the unknown to the standard should be kept small, so that R is read near the center of its scale. The ratio can be as high as 10 to 1 in either direction with good accuracy, and an indication can

be had even at 100 to 1. Additional standards may be included for other ranges if desired.

The potentiometer, R , must be calibrated as accurately as possible in terms of the ratio of resistance on either side of its mid-point, which may be arbitrarily marked 10. If the potentiometer is next set at 500 ohms, the ratio of resistances is 1 to 10 and the scale may be marked 1. The corresponding point on the other end of the scale is marked 100. Intermediate points are similarly marked according to the resistance ratios. These ratios will then correspond with the ratio of the unknown resistance, inductance or capacity to the standard in use, when the bridge has been balanced for a null indication on the detector.

Since direct current flowing through a coil changes its inductance, allowance must be made for this effect when measuring choke coils and transformers carrying d.c.

Condensers should be checked for leakage as well as for capacity. This check must be made with the rated d.c. voltage applied, a microammeter being connected in series with the high voltage source. The resistance of good paper condensers should be above 50 megohms per microfarad, that of mica condensers above 100.

The condition of electrolytic condensers can be checked roughly with an ohmmeter. With the positive terminal of the condenser connected to the positive of the ohmmeter battery, high-voltage electrolytics should show a resistance of 0.5-megohm or so; low-voltage cathode by-pass condensers should be over 0.1 megohm. Electrolytics can also be checked by measuring the leakage current when the rated d.c. polarizing voltage is applied. It should read about 0.1 ma. per μfd . The maximum for a useful unit is about 0.5 ma. per μfd . Low leakage current also indicates a faulty unit. Electrolytic condensers which have lain idle on the shelf will show leakage currents as high as 2 ma. per μfd . per 100 volts. After "aging" for a few minutes with rated d.c. voltage applied they should return to normal, however.

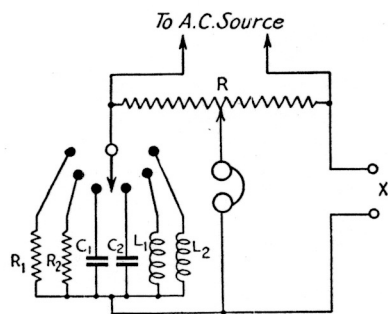


Fig. 1929 — Simple a.c. bridge for measuring R , C and L .

- C_1 — 0.01- μfd . mica.
- C_2 — 1.0- μfd . paper.
- R — 10,000-ohm linear wire-wound potentiometer.
- R_1 — 100 ohms, wire-wound (1 per cent accuracy).
- R_2 — 10,000 ohms, wire-wound (1 per cent accuracy).
- L_1 — 125-millihenry powdered-iron-core r.f. choke.
- L_2 — 12-henry iron-core choke (Thordarson T-49C91).

The measurement of small capacities under 0.001 μfd . is not possible with a bridge of the type previously described because stray reactances affect the accuracy. A more accurate bridge for measurement of small capacities is shown in Fig. 1930. It is of the substitution type with a calibrated air condenser, C_1 , for the variable arm. C_2 is a fixed reference capacity.

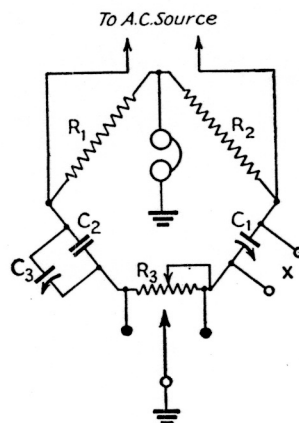


Fig. 1930 — A substitution-type capacity bridge.

- C_1 — 100- μfd . straight-line-capacity condenser (may be dual 500- μfd . with sections in parallel).
- C_2 — 900- μfd . silver-mica.
- C_3 — 100- μfd . variable trimmer.
- R_1, R_2 — 500-ohm wire-wound (1 per cent accuracy).
- R_3 — 1000-ohm wire-wound potentiometer.

C_3 is used to balance out stray capacity including that of the leads to C_x . The bridge is first balanced by adjusting C_3 , with C_1 at maximum capacity and the leads to C_x in place. C_x is then connected and the bridge again balanced by adjusting the capacity of C_1 to compensate for C_x . The difference in capacity (ΔC) of C_1 between its new setting and maximum capacity is the capacity of C_x .

It is impossible to get a zero null indication from the detector unless the resistance as well as the capacity of the two condensers being compared are equal. R_3 is therefore included to aid in achieving a resistive balance. Generally speaking, R_3 will be in the C_2 leg when measuring a mica condenser and in the C_1 leg for an air condenser. The bridge is brought into balance by alternately varying the standard capacity, C_1 , and equalizing the power factor by means of R_3 until zero indication is obtained.

The bridge can be made direct-reading in μfd . by using a dial with 100 divisions and a 10-division vernier (such as the National Type N), installed so that 0 on the dial corresponds to maximum capacity on C_1 . Then, as the capacity of C_1 is decreased to compensate for the addition of C_x , ΔC is numerically equal to the dial reading times 10. The true capacity of C_1 will depart from linearity with the dial setting as it nears zero, but the percentage error remains small up to at least .90 on the dial ($C_x < 900 \mu\text{fd}$). The over-all accuracy can be made better than 1 per cent.

Neon-Tube Parts Checker — A useful instrument for measuring resistance and capacity and even voltage which does not require a meter is the neon-tube parts checker shown in Figs. 1931–1934. (*Bib. 4.*) By making use of the fact that the extinction voltage of a neon or argon tube is constant within close limits, this device measures voltage, resistance and capacity over a useful range of values. The tube is shunted across the variable portion of a voltage divider and the divider adjusted to bring the neon-tube voltage just to the extinction point. The values are read directly from a calibrated scale associated with the voltage divider.

With the insulation and resistances used, d.c. voltages between 70 and 1500 and a.c. voltages between 50 and 800 can be measured fairly accurately. Resistances from 0 to 500,000 ohms and capacities between 0.0025 μ fd. and 4 μ fd. also can be measured.

Referring to Fig. 1932, the transformer, T , with its associated switch, S_1 , and potentiometer, R_1 , provides a means of adjusting the voltage across the voltage divider, R_2 to R_6 (including the unknown resistance or capacitive reactance to be measured), to approximately the 96 volts required, regardless of the line voltage. For a line voltage of 120 volts, the secondary voltage of the bell-ringing transformer must be increased to 24 volts (the nominal secondary voltage is 10) in order to reduce the voltage to 96. This requires the addition of some 240 turns of No. 28 enameled wire to the secondary of the bell-ringing transformer, T . The secondary voltage must equal the difference between 96 volts and the highest voltage encountered on the a.c. line. In practice, with S_1 in the "low" position, R_3 , R_4 and R_6 at minimum and the test leads shorted, adjusting R_1 should extinguish the neon lamp.

R_2 and R_6 are current-limiting resistors which permit measuring low-wattage resistors safely. R_6 , being in series with one side of the a.c. power line, protects the line against a short circuit in case of accidental contact via a test lead to a grounded chassis. The terminal to which R_6 is connected should be marked "Ground." To insure that this terminal is on the "cold" side of the line reverse the power plug until the neon lamp glows when a test lead from the terminal connected to R_5 is touched to an actual ground connection, such as a radiator or water pipe.

R_3 , R_4 and R_5 are the adjustable part of the voltage divider, and, when adjusted to the point where the neon glow is just extinguished, equal the resistance being measured. These resistors are calibrated in terms of resistance and capacity. For voltage measurements, the variable resistors may be calibrated in terms of applied voltage. Voltages below the value required to make the lamp glow — in general, somewhat higher than the extinction voltage — cannot be measured, but for a.c. voltages above 50 and d.c. voltages from 70 volts upward the method is quite satisfactory.

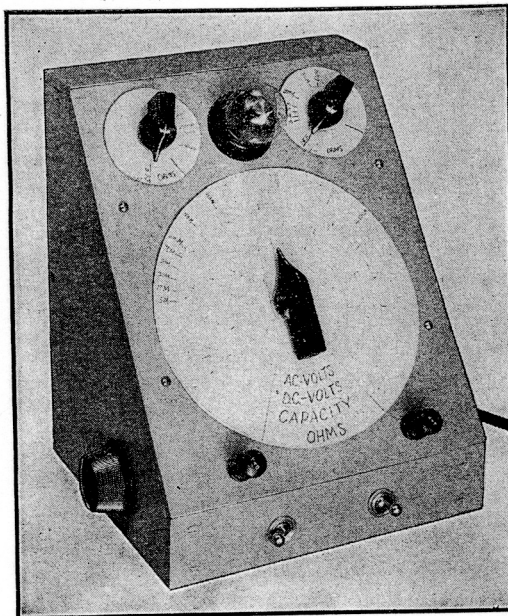


Fig. 1931 — Front view of the neon-tube parts checker, showing the main calibrated dial in the center, the 0–5,000-ohm resistance scale, upper left, and the 0–50,000-ohm resistance scale, upper right. The small knob on the left-hand side is the line-voltage compensator control.

S_2 , when thrown to the right, connects the voltage-divider system to the a.c. power source, and also at the same time connects the rotary arm of R_5 to the upper test lead. These connections are for making resistance or capacity measurements. For voltage measurements S_2 is thrown to the left, disconnecting the internal power source, breaking the connection of the rotary arm of R_5 to the upper test lead, and connecting R_6 to R_2 . For all voltage measurements below 500 this checker draws less current than the common 1000-ohms-per-volt meter.

For accurate reading the variable potentiometers (R_3 , R_4 and R_5) should have a useful rotational arc as great as possible. Actually, no resistor of this type is absolutely linear for every degree of dial rotation. Good resistors are, however, linear from approximately 25 to 87 per cent of their total rotation. The actual mid-point of the total resistance comes at approximately 56 per cent of the total rotation (clockwise); 36 per cent of total rotation is required to give one-quarter total resistance, while three-fourths of the resistance is covered by 78 per cent of the total rotation.

Four initial calibration points may thus be obtained. Additional points can be secured by subdividing. The same procedure is followed in calibrating the other two potentiometers.

If an ohmmeter is available, the individual potentiometers, whether linear or tapered, can be accurately calibrated. A voltmeter will give a voltage calibration as accurate as is the original meter. For capacity calibration, readings can be taken on groups of 1- μ fd., 0.5- μ fd.,

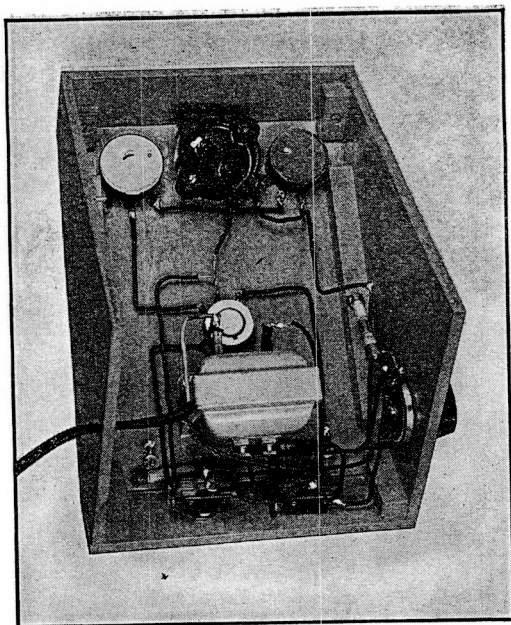


Fig. 1932 — Interior view of the neon-tube checker showing the general arrangement of the "meterless meter" and the method of assembling the plywood cabinet.

0.25- μ fd., 0.1- μ fd., 0.01- μ fd., etc., condensers, averaging the readings for each group.

If a voltmeter is not available for voltage calibration, the scale can be calculated as follows. The total resistance across the external voltage is always 500,000 ohms (within the limits of resistor accuracy) and for d.c. the extinction voltage across the neon lamp must be dropped to 62 volts, while for a.c. it must go down to 48 volts. The resistance needed across the neon lamp to reduce the external voltage to the extinction point of the lamp is, for a.c., equal to $48 \times 500,000$ divided by the external voltage; for d.c. the resistance across the lamp equals $62 \times 500,000$ divided by the external voltage. The resistance of R_6 can be ignored.

Before making measurements, the neon lamp should be given an initial two-minute warm-up. To do this, plug in the power cord, snap S_1 to the high position, snap S_2 to the right or ohms-capacity position, turn the main dial to the maximum resistance position, and short the binding posts with a test lead.

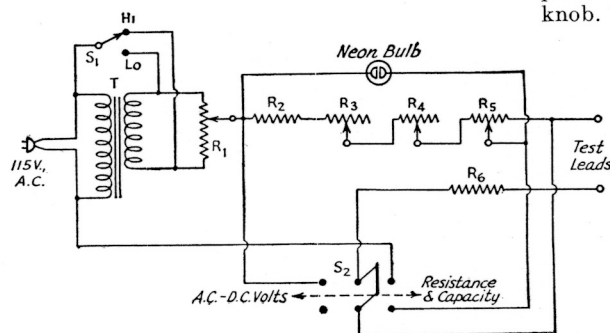


Fig. 1933 — Circuit of the neon-tube checker.

- R_1 — 300-ohm potentiometer, wire-wound (Centralab V125).
- R_2, R_6 — 2,000 ohms, 2-watt.
- R_3 — 5,000-ohm potentiometer (Centralab 72-110).
- R_4 — 50,000-ohm potentiometer (Electrad 205).
- R_5 — 500,000-ohm potentiometer (Centralab 72-106 or N118).
- S_1 — S.p.d.t. toggle switch.
- S_2 — D.p.d.t. toggle switch.
- T — Bell-ringing transformer.

Line-voltage adjustment is the next step. Leave the binding posts shorted and, after turning all front-panel dials to zero, attempt to extinguish the neon glow by turning the dial of R_1 (mounted on the left side). If this fails, snap S_1 to the low position and again turn R_1 until the glow is just extinguished. It must first be possible to light the neon lamp and then extinguish it with R_1 . If it is neither possible to light nor extinguish the indicator lamp with any combination of R_1 and S_1 , there are not enough turns on the secondary of transformer.

The test leads are now clipped across an unknown external resistance. Turn the main dial, R_6 , to the right until the neon glows, then back it off until the glow is extinguished and note the reading on the ohms scale. If the lamp does not glow with R_6 at maximum, the unknown resistor is more than 500,000 ohms.

Although the main 500,000-ohm potentiometer is capable of measuring resistances as low as 100 ohms with fair accuracy, the other two dials are added to provide "calibration spread" for the 0-5000-ohm and 0-50,000-ohm scales, respectively. Whenever one of the three front dials is in use, the other two must remain at their zero settings.

Electrolytic condensers cannot be measured with this checker, as a.c. is present across the test leads. All other condensers are measured in the same manner as resistors. With all front panel dials at zero, clip the test leads across the unknown capacity, turn the main dial until the lamp glows, back it off to the extinction point, and read the value on the capacity scale. The same procedure is followed in making voltage measurements, S_2 being switched to the "A.C.-D.C. Volts" position.

As shown in Fig. 1934, the cabinet is made from a piece of $\frac{1}{4}$ -inch plywood $32\frac{3}{8}$ inches long and $6\frac{3}{4}$ inches wide. Full dimensions are given in the drawing. Wooden dowels, $\frac{1}{2}$ -inch square, are used in the corners. The transformer and the neon-lamp socket are mounted on the back of the front panel by machine screws which are self-threaded into undersized holes drilled to a depth of $\frac{3}{16}$ inch into the plywood.

The main dial chart is a $5\frac{1}{2}$ -inch diameter paper circle, bearing four circular scales spaced $\frac{3}{8}$ -inch apart. The pointer is made from a piece of celluloid, cemented to the bakelite knob. The other dials are 2-inch paper circles.

L, C and Q measurements at r.f. — The low-frequency a.c. bridge method of measuring inductance is of value only for the high-inductance coils used at power and audio frequencies. I.f. and r.f. coils must be measured at the frequencies at which they are used.

The method commonly employed is to determine the frequency at which the coil resonates when connected across a capacity of known value. This may be done (1) by connecting the coil-condenser combination in a two-terminal oscillator (§ 3-7) and observing the resulting oscillation frequency on a calibrated receiver, or (2) by connecting the coil to a calibrated condenser, supplying the circuit with r.f. power from a suitable oscillator, and tuning the condenser until resonance is indicated by maximum indication on a vacuum-tube voltmeter (Fig. 1935). With the capacity known in $\mu\text{mfd.}$ and the resonant frequency in kc., the apparent inductance of the coil in microhenries can be computed:

$$L = \left(\frac{159,160}{f} \right)^2 \frac{1}{C}$$

The apparent inductance thus computed is in error, however, in that it also includes the distributed capacity of the coil. This will be discovered if a similar measurement is made at another frequency (for example, the harmonic of f_1), for it will be found that a different value of inductance results. However, by combining the two measurements the true inductance can be found (*Bib. 6.*):

$$L = \frac{10^{12}}{13.15 f_2^2} \times \frac{1}{C_1 - C_2}$$

when f_2 is the second harmonic of f_1 , C_1 is the

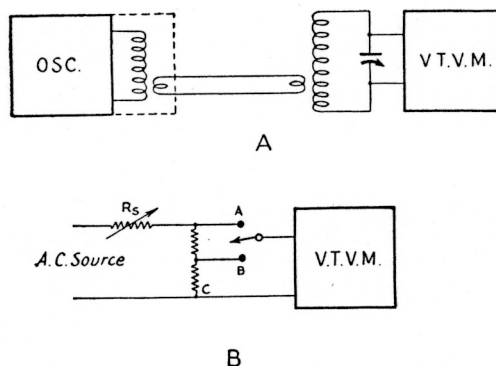


Fig. 1935 — (A) Circuit used for measuring inductance, capacity and Q at r.f. The calibrated variable-frequency oscillator should have a tuning range in excess of 2-to-1. (B) Circuit for calibrating the v.t.v.m. for Q measurements from 60-cycle a.c. R_{BC} is 70.7 per cent of R_{AC} . With the switch in position A, R_s is adjusted to give a voltmeter deflection near the upper part of its scale; this is the peak-deflection reference point. The switch is then turned to position B, and the new reading noted. By making a number of measurements with different initial input levels, a graph can be plotted showing both peak and 70.7 per cent readings for a wide range of inputs.

capacity required to tune to f_1 , and C_2 the capacity required to tune to f_2 .

A convenient source of r.f. power for the two-frequency method of inductance measurement is the transmitter exciter unit, provided it has good second harmonic output. The oscillator output and link circuit (shown inside dashed lines in Fig. 1935) should be either shielded or sufficiently remote from the measuring circuit so that the vacuum-tube voltmeter shows no indication when there is no coil in the circuit. The calibrated condenser must, of course, have sufficient capacity to tune over a 2-to-1 frequency range. This condenser may be calibrated by means of a bridge such as the substitution-type capacity bridge of Fig. 1930.

The resonance method can also be used for accurate measurement of capacity. A standard coil of suitable inductance must be provided; the exact value is not important. The standard condenser, C_1 , is first tuned to resonance with the oscillator frequency. The unknown capacity, C_x , is then added in parallel and the capacity of C_1 reduced until the circuit again resonates at the oscillator frequency. The difference between the two settings (ΔC) represents the capacity of C_x .

The arrangement of Fig. 1935 is additionally useful in that it can be used as a Q meter, and thus can be used for measuring r.f. resistance and impedance.

As is shown by Fig. 1936, resistance in a tuned circuit broadens the resonance curve. Measuring the frequency difference between the two points at which the output voltage equals 70.7 per cent of the peak voltage (where the resistance in the circuit equals its reactance), will give the Q of coils and condensers.

There are two methods of determining these points. One involves the use of a calibrated variable frequency oscillator to de-

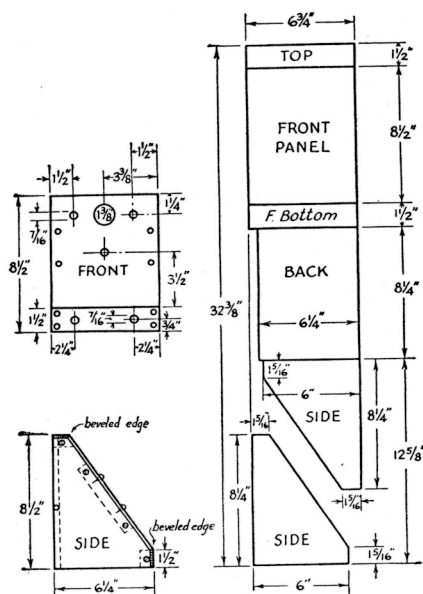


Fig. 1934 — Dimensions of the parts-checker cabinet.

termine the band-width in terms of frequency change and the other a calibrated variable condenser to measure the capacity change.

When the calibrated variable oscillator and v.t.v.m. are used, the frequency and r.f. voltage at resonance are first noted. The oscillator frequency is then varied on either side of resonance until the v.t.v.m. reads 70.7 per cent of its initial value. Then Q is equal to the frequency divided by the band-width:

$$Q = \frac{f_r}{\Delta f}$$

where Δf is the difference between f_1 and f_2 .

When the frequency of the oscillator is fixed and a calibrated variable condenser is used, the capacity at resonance (C_r) is noted, as well as that on either side at which the meter reads 70.7 per cent of maximum. Then

$$Q = \frac{2 C_r}{C_2 - C_1}$$

The foregoing applies to measurement of the Q coils. Actually, the figure of Q thus derived is not that of the coil alone but of the tuned circuit as a whole, including the condenser. The Q of the standard condenser must, therefore, be kept high. An efficient air condenser with steatite or mycalex insulation is required; it should be operated near maximum capacity. Use short, heavy leads and keep the stray capacities as low as possible.

The Q of other air condensers and of mica condensers can be determined by first measuring the Q of the circuit with a standard coil in place, and then connecting C in parallel with C and again measuring the Q . The Q of the unknown condenser is

$$Q_x = \frac{(C_1 - C_2) Q_1 Q_2}{C_1 (Q_1 - Q_2)}$$

Low- Q mica and paper condensers ($Q < 1000$) can be measured by inserting the unknown in series with L and C . Q_1 is measured with a shorting bar across the unknown; the bar is then removed and Q_2 determined. Then

$$Q_x = \frac{(C_2 - C_1) Q_1 Q_2}{C_1 Q_1 - C_2 Q_2}$$

If C_2 is larger than C_1 , the reactance is inductive rather than capacitive; i.e., the "con-

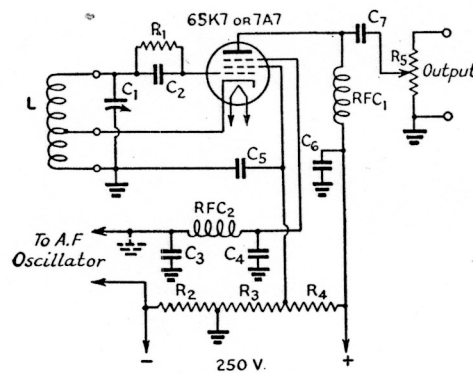
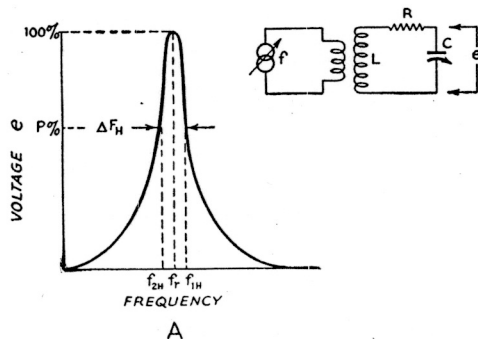


Fig. 1937 — Simple i.f. test oscillator circuit diagram. C_1 — 100- μ fd. variable with 200- μ fd. fixed silver-mica zero-drift in parallel.

C_2 — 100- μ fd. midget mica.

C_3, C_4 — 250- μ fd. midget mica.

C_5 — 0.005- μ fd. mica.

C_6 — 0.1- μ fd. 400-volt paper.

C_7 — 500- μ fd. midget mica.

R_1 — 50,000 ohms, $\frac{1}{2}$ -watt.

R_2 — 2000 ohms, $\frac{1}{2}$ -watt.

R_3 — 20,000 ohms, 1-watt.

R_4 — 20,000 ohms, 2-watt.

R_5 — 500-ohm carbon potentiometer.

L — 440–510 kc.: 140 turns No. 30 e. close-wound on $1\frac{1}{2}$ -inch diameter plug-in form. Cathode tap 35 turns from ground end.

1400–1550 kc.: 42 turns No. 20 d.s.c. on $1\frac{1}{2}$ -inch diameter form, tapped 10 turns.

4500–5500 kc.: 11 turns No. 18-e. on $1\frac{1}{2}$ -inch diameter form, spaced wire diameter, tapped 3 turns.

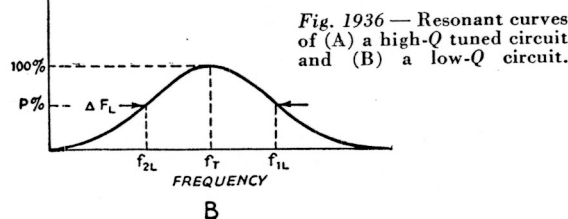
RFC_1 — 2.5-mh. r.f. choke.

RFC_2 — 25-mh. r.f. choke.

denser" is actually an inductance at the measurement frequency.

The r.f. resistance, reactance and impedance of other components can be measured by the same methods. If an external r.f. impedance (such as an antenna or transmission line or an r.f. choke) is inserted in a coil-condenser circuit, it will both detune the circuit and broaden its resonance curve. By observing the capacity required to bring the circuit back to resonance and measuring the additional resistance introduced, by re-measuring the Q , the reactive and resistive components of the external impedance can be computed.

Using a standard coil and condenser suitable for the operating frequency, connect the unknown quantity across C_1 (for high resistances) or in series with L and C (for low resistances), and proceed as previously outlined. If C_1 must be increased to restore resonance, the reactance of the unknown is inductive; if it must be decreased, the reactance is capacitive.



Receiver Characteristics

Measurements in connection with receiving equipment come under two heads: (1) over-all performance, and (2) servicing and alignment. The measurement of receiver performance requires precision laboratory equipment beyond the scope of the average amateur. Sufficient apparatus for servicing receivers should be

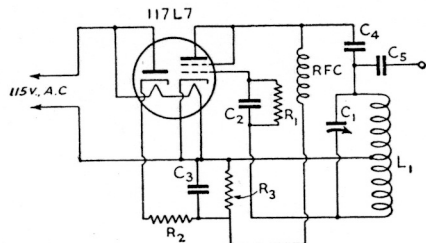


Fig. 1938 — Simple test oscillator for receiver alignment.

C_1 — 350- μ fd. variable.
 C_2, C_5 — 250- μ fd. mica.
 C_3 — 40- μ fd. 250-volt electrolytic.
 C_4 — 0.001 to 0.005 μ fd. mica.
 R_1 — 0.1 megohm, $\frac{1}{2}$ -watt.
 R_2, R_3 — 50,000 ohms, $\frac{1}{2}$ -watt.
 L_1 — See Fig. 1937.
 RFC — 10 mh. or larger r.f. choke.

available in every amateur station, however. This may be as little as a multi-range volt-ohm-milliammeter, a test-signal source of some description, and a few spare tubes.

For the alignment of tuned circuits a simple test oscillator is required, preferably one that can be modulated by a 400-cycle audio oscillator. A rectifier-type voltmeter may be used for the output meter.

A heterodyne frequency meter is a suitable signal source for r.f. alignment, provided the harmonic amplitude on the higher frequencies is great enough. A harmonic amplifier and output attenuator are useful in this application.

The i.f. test oscillator circuit shown in Fig. 1937 consists of a simple e.c.o. with plug-in coils. The output level is controlled by a potentiometer so connected as to present a constant input resistance to the receiver. The oscillator should be shielded so that direct pick-up is minimized. Make all ground returns to a heavy copper strap connected to the cabinet at the output ground terminal. The plug-in coil should be separately shielded.

The test oscillator may be suppressor-grid modulated by applying approximately 10 volts of audio (for 50 per cent modulation), as shown in the diagram. The suppressor-grid is biased 10 volts negative for modulated use; if an unmodulated signal is desired, the upper terminal may be grounded as indicated. This will increase the output from the oscillator. Conversely, if the output potentiometer does not attenuate the signal sufficiently additional d.c. negative bias may be applied between the modulation terminals.

An even simpler test oscillator requiring no external power supply is shown in Fig. 1938. The tetrode section of the 117L7 is connected

as a triode in a simple Hartley circuit, while the rectifier supplies plate voltage through a resistance-capacity filter. Output is taken from C_5 .

The i.f. test oscillator may be calibrated by beating harmonics against signals of known frequency in the b.c. band. Frequencies between 465 kc. and 275 kc. can be spotted by using the second harmonic of the oscillator, while the remainder of the range to 175 kc. can be checked by using the third harmonic.

Ordinarily, however, precise calibration is not required. Most communications receivers are equipped with a crystal filter and for i.f. alignment the oscillator frequency is set to correspond with the crystal response (§ 7-17). If the receiver contains no crystal filter the oscillator should be set at the design i.f. as closely as its calibration will permit.

For use with an unmodulated test signal, the output indicator may be the "S"-meter in the receiver, a microammeter in the detector or a.v.c. circuit, or a vacuum-tube voltmeter. It is not advisable to use the receiver beat oscillator to generate an audible note for output indications. When a modulated test signal is used, the output indicator may be a copper-oxide rectifier-type voltmeter which reads the a.f. voltage across the rated output load resistance. Power output can be computed by Ohm's Law.

The a.f. modulating source for the test oscillator can be any audio oscillator capable of delivering 10 to 20 volts at the standard receiver-checking frequency of 400 cycles.

A useful audio oscillator circuit is shown in Fig. 1939. It is a two-terminal or "transitron" oscillator (§ 3-7) using a pentagrid tube. A frequency of approximately 400 cycles is generated with the tuned-circuit values shown. A variable-frequency oscillator can be made by inserting a resistance, R , in the tuned circuit, between L and ground. The highest frequency available is determined by L and C alone. Increasing R will decrease the frequency. If R is made 5000 ohms, a frequency ratio of about 5 to 1 can be obtained. A good-quality wire-wound variable resistor should be used. If difficulty is had making the tube oscillate over the entire range, try other values of R_1 and C_2 .

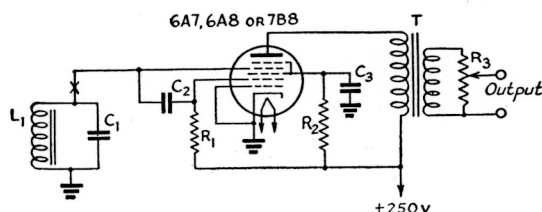


Fig. 1939 — Simple negative-resistance audio oscillator.

C_1 — 0.15- μ fd. 400-volt paper.
 C_2, C_3 — 0.1- μ fd. 400-volt paper.
 C_3 — 0.25- μ fd. 200-volt paper.
 R_1, R_2 — 50,000 ohms, 1-watt.
 R_3 — 50,000-ohm volume control.
 L_1 — 1.2-henry choke (Thordarson T-14C61 with iron core removed).
 T — Output transformer (interstage audio, 1:3 ratio).

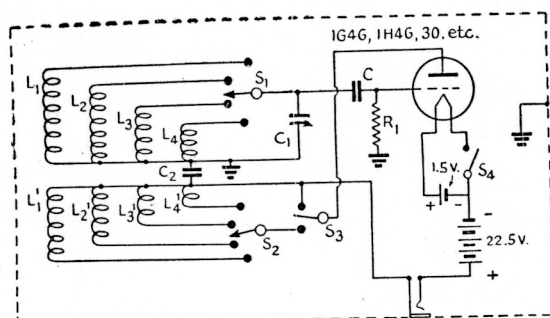


Fig. 1940 — Simple monitor for c.w. and 'phone.

C₁ — 50-μfd. midget variable.
 C₂ — 0.002-μfd. midget mica.
 C₃ — 100-μfd. midget mica.
 R₁ — 1 megohm, 1/2-watt.
 S₁-S₂ — 2-section 4-position rotary band switch.
 S₃ — S.p.d.t. low-capacity switch.
 S₄ — Toggle switch.

Band	L	L'
1.7 Mc.	90 turns No. 30 e.	24 turns
3.5 Mc.	50 turns No. 30 d.c.c.	16 turns
7 Mc.	30 turns No. 22 d.c.c.	10 turns
14 Mc.	10 turns No. 22 d.c.c.	7 turns

All coils close-wound on 1-inch forms, adjacent coils at right angles. L and L' spaced 1/4-inch apart.

Transmitter Characteristics

The transmitter characteristics ordinarily requiring measurement are d.c., a.c. and r.f. voltages and currents, keying and modulation quality, and modulation percentage. Instruments for the measurement of voltages and currents have been discussed. Keying and modulation checks may be made by several methods; the two commonly used by amateurs are aural checks with monitors, and visual checks with the oscilloscope (§ 5-10).

Monitors — A monitor is a miniature receiver, usually having only a single tube, enclosed with its batteries in some sort of metal box which serves as a shield. The requirements for a satisfactory monitor for checking c.w. signals are not difficult to satisfy. It should oscillate steadily over the bands on which the station is to be active; the tuning should not be excessively critical, although the degree of bandspread ordinarily considered desirable for receivers is not essential; the shielding should be complete enough to permit the monitor to be placed near the transmitter and still give a good beat note when tuned to the fundamental frequency of the transmitter (this is often impossible with the receiver because the pick-up is too great); and it should be constructed solidly, so that it can be moved around the station without the necessity for retuning while listening to a signal.

The circuit of a simple monitor with band-switching, covering four amateur bands, is shown in Fig. 1940. Any 1.5- or 2-volt filament triode can be used, as well as any batteries of a size that will fit into the container selected.

A plate-tickler switch (S₃) is provided to make the monitor non-oscillating when checking 'phone signals. If desired, a regeneration control could be incorporated (§ 7-4).

Any type of simple detector with a means for picking up a small amount of r.f. from the transmitter can be used as a 'phone monitor. A satisfactory monitor circuit using a simple diode rectifier and an untuned pick-up coil is shown in Fig. 1941-A. Headphones are plugged into the jack for listening checks. The monitor may also be employed as an overmodulation indicator by use of the 0-1 milliammeter, M. The pick-up coil is loosely coupled to the tank circuit of the final r.f. amplifier until the milliammeter reads approximately 0.9 ma. The speech amplifier is supplied with a 400-cycle sine-wave tone from an audio oscillator, such as that shown in Fig. 1939, and its gain control turned up. When the monitor meter starts to rise, overmodulation is indicated.

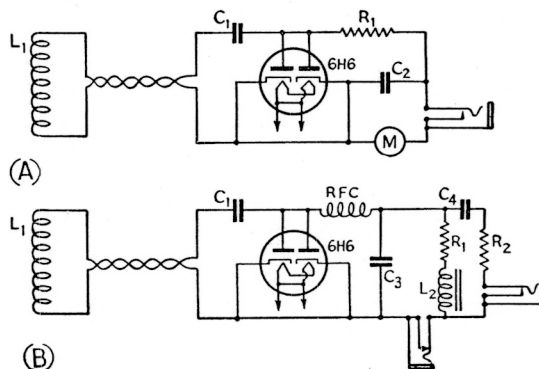
The circuit of Fig. 1941-B indicates the percentage of modulation directly. The a.c. milliammeter is first plugged into the left-hand jack and the pick-up coupling adjusted to give a full-scale meter reading on the unmodulated carrier. Then the meter is plugged into the right-hand jack and the transmitter modulated by a tone or speech signal. The modulation percentage will be 140 times the reading of the meter; e.g., with 100 per cent modulation the meter will read approximately 0.7 ma. When measuring percentage of speech modulation, the inertia of meter will cause it to undershoot on peaks; the swing should, therefore, be limited to somewhat less than 0.7 ma. (Bib. 7.)

Fig. 1941 — (A) Circuit diagram for a combination 'phone monitor and overmodulation indicator.

C₁ — 0.005-μfd. midget mica.
 C₂ — 0.01-μfd. paper.
 R₁ — 0.15 megohm, 1/2-watt.
 L₁ — Pick-up coil (enough turns of hook-up wire to give 1 ma. deflection on the meter when the pick-up coil is loosely coupled to the final amplifier tank circuit).
 M — 0-1 ma. d.c. milliammeter.

(B) Circuit for a modulation percentage indicator.

C₁, R₁ and L₁ — Same as above.
 C₃ — 0.005-μfd. midget mica.
 C₄ — 1.0-μfd. paper.
 R₂ — 0.25 megohm, 1/2-watt.
 L₂ — 30 to 50 henry iron-core choke.
 A 0-1 ma. a.c. milliammeter (d.c. movement with copper-oxide rectifier) also will be required.



Antenna Measurements

Antenna measurements are made for the purpose (a) of securing maximum transfer of power to the antenna from the transmitter, and (b) of adjusting directional antennas to conform with design conditions. Measurements are therefore made of the current (power) in the antenna, voltage and current relationships, resistance, and radiated field intensity. Related to measurements of the antenna proper is the measurement of transmission line characteristics, chiefly involving impedance and resistance.

The instruments described for r.f. measurement (thermocouple ammeter, vacuum-tube voltmeter, L , C and Q meter) all are applicable to antenna measurement.

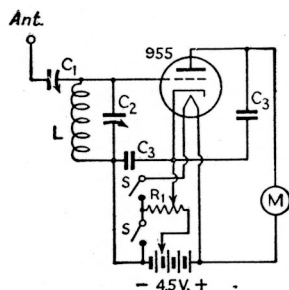


Fig. 1942 — Acorn-tube field-intensity meter for v.h.f.

- C_1 — 3–30- μ fd. mica trimmer.
- C_2 — 35- μ fd. midget variable.
- C_3 — 250- μ fd. midget mica.
- R_1 — 1000-ohm potentiometer.
- L — 50–80 Mc.: 7 turns No. 14 tinned wire, $\frac{1}{2}$ -inch diameter 1 inch long.
- 25–40 Mc.: 10 turns No. 14 tinned wire, $\frac{3}{4}$ -inch diameter 1 inch long.
- 12–20 Mc.: 20 turns No. 16 enamel wire, close-wound on $\frac{3}{4}$ -inch diameter tubing.
- 6–10 Mc.: 37 turns No. 22 enamel wire, close-wound on $\frac{3}{4}$ -inch diameter tubing.
- M — 0–200 μ a. d.c. microammeter.

Field-intensity meters — In adjusting antenna systems for maximum radiation and in determining radiation patterns, use is made of field-intensity meters. Fundamentally the field-intensity meter is a vacuum-tube voltmeter provided with a tuned input circuit. It is used to indicate the relative intensity of the radiation field under actual *radiating* conditions. It is particularly useful on the very-high frequencies and in adjusting directional antennas. Field-intensity checks should be made at points several wavelengths distant from the antenna and at heights corresponding with the desired angle of radiation.

The absorption frequency meter shown in Figs. 1903–1904 may be used as a field strength meter if it is provided with a pick-up antenna. This can be short length of brass rod or an automotive-type antenna mounted on a stand-off insulator and connected to the stator of the tuning condenser through a small trimmer. The crystal detector is not linear, and a given increase in rectified current does not indicate a directly proportional increase in field strength.

A simple field intensity meter particularly suitable for work in the v.h.f. region is shown in Fig. 1942. Essentially, it consists of an acorn triode operated with very low plate voltage and biased to cut-off, constituting a linear detector. When a signal is tuned in rectification occurs, and the plate-current increment is read on the microammeter. The microammeter scale will read approximately linearly with voltage, a characteristic which is advantageous when making certain types of comparative measurements. Radiated power variations will, of course, be as the square of the field-voltage indication.

A more sensitive field-intensity meter of use in examining the field-strength patterns of lower-frequency antenna systems, employing a diode rectifier and d.c. amplifier in the same envelope, is shown in Fig. 1943. The initial plate current reading is about 1.4 ma.; with signal input, the current dips downward. The scale reading is linear with signal voltage.

Power gain in antenna systems usually is expressed in terms of decibels. A field-intensity meter which reads directly in db. is shown in Fig. 1944. It consists of self-biased linear triode voltmeter followed by a variable- μ d.c. amplifier tube. Because of the logarithmic grid-voltage/plate-current characteristic of this tube, a 0–1 ma. milliammeter in its plate circuit can be calibrated arbitrarily with a linear db. scale, as shown. For extreme accuracy an individual calibration should be made on a.c., but the arbitrary scale shown will be found sufficiently accurate to be useful.

The scale covers approximately 25 db. and is linear over a range of about 20 db. At very small signals it departs from linearity, and therefore 0 db. is placed at 90 per cent of the scale. A variable meter shunt compensates for variations in tubes and battery voltages. In use, the balancing resistor is adjusted to give a full-scale reading of 1 ma. The signal pick-up is then made such as to cause the meter to indi-

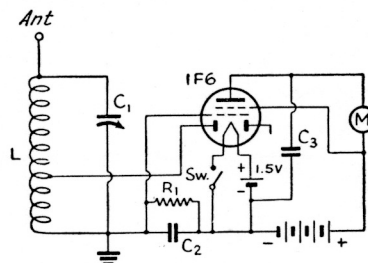


Fig. 1943 — Sensitive diode-triode field-intensity meter.

- C_1 — 50- μ fd. midget variable.
- C_2 — 250- μ fd. midget mica.
- C_3 — 0.002- μ fd. midget mica.
- R_1 — 1 megohm, $\frac{1}{2}$ -watt.
- L — 1.5–Mc.: 58 turns No. 28 d.s.c., close-wound.
- 3–6 Mc.: 29 turns No. 20 e., close-wound.
- 6–12 Mc.: 15 turns No. 20 e., spaced.
- 11–22 Mc.: 8 turns No. 20 e., spaced.
- 20–40 Mc.: 4 turns No. 20 e., spaced.

All wound on $1\frac{1}{2}$ -inch coil forms, winding length 1 $\frac{1}{2}$ inches; diode tap in center of coil.
 M — 0–500 μ a. d.c. microammeter.

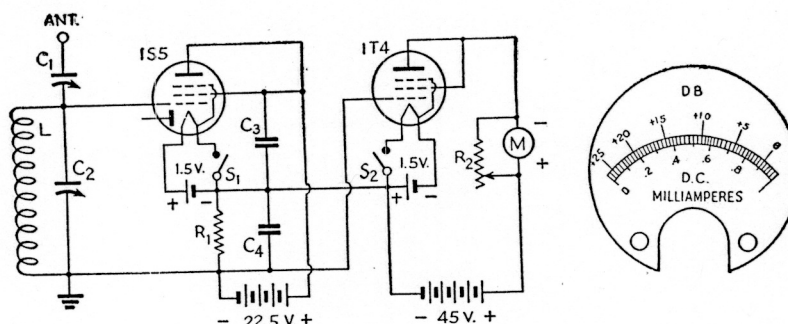


Fig. 1944 — A logarithmic field-intensity meter with db. calibration, employing a variable- μ d.c. amplifier tube.
 C₁ — 3–30- μ fd. mica trimmer. R₁ — 10 megohms, $\frac{1}{2}$ -watt. L — See coil data under Figs. 1942 and 1943.
 C₂ — 50- μ fd. midget variable. R₂ — 1000-ohm wire-wound. M — 0–1 ma. d.c. milliammeter.
 C₃, C₄ — 500- μ fd. midget mica. S₁, S₂ — Toggle switches or d.p.s.t.

cate 0 db. Alternatively, the initial reading may be set arbitrarily at 10 db.; adjustments will then be indicated as losses or gains in relation to that figure.

The range may be extended to +45 db. by inserting a 2-point tap switch in the lead to the 1T4 amplifier from the self-biasing resistor R_1 and tapping that resistor at 1 megohm to provide a 10-to-1 multiplier. Add 20 db. to all readings when the multiplier is used.

Tube Characteristics

The best check on a receiving or transmitting tube is by a direct comparison in its own socket with a new tube of known quality under actual operating conditions. Any other test falls short of an actual performance test.

For convenience, however, an auxiliary tube checker is desirable. A number of commercial tube checkers of the type used by servicemen are on the market. In purchasing one, the following qualifications should be sought: (1) complete facilities for checking shorts between any pair of electrodes; (2) a transconductance rather than an "emission" test (the emission of a tube may vary widely with no effect on its performance, while genuinely faulty tubes may show rated emission); (3) provision for checking plate and screen currents under typical conditions (at rated voltages); (4) gas and noise tests.

The construction of a comprehensive tube-checker is an elaborate project. However, for

an occasional need the amateur can assemble a circuit using an existing power source in accordance with Fig. 1945 to make a reasonably accurate standard transconductance test. A pentode tube is shown; for other types omit or add electrode connections as required. The voltages applied should correspond with those listed under "Typical Operating Conditions" in the tables of Chapter Twenty-One. They should be accurate to within 5 per cent (especially grid voltage, plate voltage for triodes and screen voltage for pentodes). With the switch in No. 2 position, the plate and screen currents should be near the rated values; wide variations from normal indicate a defective tube.

To make the transconductance test, note the plate current with the grid switch alternately on positions 3 and 1, which changes the bias from exactly 0.5 volt less than rated bias to exactly 0.5 volt more. The resulting plate current change multiplied by 1000 equals the transconductance in micromhos. This value should be checked against the tables. Tubes usually will operate satisfactorily until the transconductance falls to 70 per cent of rating.

Pentagrid and heptode frequency converters can be checked by this method if the rated d.c. electrode voltages are applied. The oscillator section can be checked separately by noting the oscillator-anode current change.

Diodes can be checked by applying 50 volts of 60-cycle a.c. between plate and cathode, in series with a 0.25-megohm load shunted by a 2- μ fd. condenser, and reading the rectified current on a 0–1 ma. d.c. meter. A reading of 0.2 to 0.25 ma. indicates a satisfactory tube.

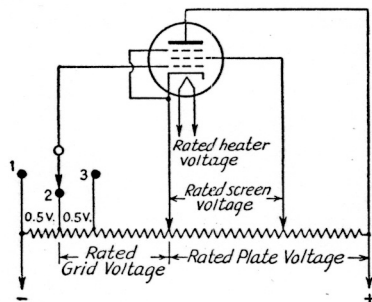


Fig. 1945 — Circuit for measuring vacuum-tube transconductance, used for checking condition of tubes.

BIBLIOGRAPHY

- ¹ Grammer, *QST*, July, 1941, "A Sensitive Absorption Wavemeter."
- ² Grammer, *QST*, October, 1941, "A Lecher Wire System for U. H. Frequency Measurement."
- ³ Goodman, *QST*, September, 1941, "A 50-, 100- and 1000-Kc. Oscillator for Band-Edge Spotting."
- ⁴ Bradley, *QST*, October, 1942, "A Neon-Tube Parts Checker."
- ⁵ Greek, *QST*, October, 1940, "A Complete Oscilloscope Using the 902."
- ⁶ Stafford, *QST*, January, 1940, "Q Measurements."
- ⁷ Poor, *QST*, June, 1940, "A Simple Modulation Monitor and Percentage Indicator."