CHAPTER 6

USE OF TEST EQUIPMENT

The purpose of this chapter and the next is to better acquaint the technician with the practical use of test equipment. A cabinet or room full of test equipment is of little value if the technicians are not familiar with its use. Also, outdated or specialized equipment for testing or servicing electronic equipment that is no longer aboard ship is of no value and takes up valuable space.

In the POMSEE books the necessary instruments for testing the electronic equipments are listed near the front, and the technician will do well to become familiar with these instruments.

The next most important thing, after learning how to use a test instrument, is to learn how to take the proper care of the instrument. Practically no test instrument will stand up under abuse. A damaged test instrument that reads incorrectly is, in many instances, worse than having no instrument at all. A large percentage of test equipment failures can be avoided by careful handling, proper use of the equipments, and proper stowage at sea.

REPRESENTATIVE EQUIPMENT

Some idea of the extent of the test equipment needed aboard ship may be gained from the following list of equipments used for testing electronic gear. The list is not complete; however, it is representative. It is compiled from the available maintenance manuals.

Audio Oscillator: The Signal Generator TS-382C/U series.

Echo Box: Echo Box TS-275/UP.

Frequency Meters: The LM-21 (heterodyne type), FR-4/U, AN/USM-29, and AN/URM-82 series. About 18 different frequency meters (including both the absorption and the heterodyne types) are included in Electronic Test Equipment Application Guide, NavShips 91727. Newer meters, such as the AN/USM-26, and/or CAQI-524D (Counter type), are rapidly replacing the older heterodyne frequency measuring meters.

Insulation Tester: The Insulation Test Set AN/PSM-2 and Navy Models OCW and 60089 Insulation Resistance Testers.

Microammeter: D-c Microammeter Navy Model 60107.

Multimeter (Electronic): The ME-25A/U series.

Electronic Voltmeters: The ME-6A/U series.

Multimeter (Nonelectronic): The AN/PSM-4 and TS-352/U series.

Oscilloscope: The OS-8/U series; AN/USM-24, 32, and 38 series; and TS-34A/AP series.

Synchroscope: There seems to be no clear line of distinction between synchroscopes and oscilloscopes. Actually, a synchroscope is a special type of oscilloscope. Several have already been listed under oscilloscopes—for example, the AN/USM-24 and 32, and TS-34A/AP series.

Range Calibrator: The TS-573/UP series. This equipment, part of Test Set AN/MPM-23, supersedes Range Calibrators TS-102/AP and TS-358/UP, as well as the range calibrator functions of Oscilloscopes OS-7/U and 60ACZ-1.

Power Meter: The TS-230B/AP series. About 14 power-measuring equipments are listed in NavShips 91727. They cover various frequency ranges and have various degrees of accuracy.

Signal Generator: The AN/URM-25B series. Over 30 signal generators are listed in NavShips 91727.

Wattmeter, R-F: AN/URM-43

Tube Tester: TV-7/U series. This equipment is a portable tube tester designed to test and measure mutual conductance values of electron tubes used in receivers and the smaller transmitters.

Transistor Tester: TS-1100/U. This equipment is a portable test set which operates on dry cells with a life expectancy of 1000 hours. The tester (using Technical Manual 93277) measures the amplification, or BETA, of a transistor without the need for removing the transistor from the circuit. In addition it will test for collector leakage current, with the transistor out of the circuit, and also for shorts.

CAPACITANCE-INDUCTANCE-RESISTANCE ANALYZER: Bridge ZM-11/U is a portable analyzer used in measuring and checking the characteristics of capacitors, resistors, inductors, and transformers to determine their value and condition. Capacitors are checked for leakage resistance, and inductors and transformers are checked for inductance.

COMBINATION TEST SETS: This type of test equipment permits more than a single characteristic to be checked, usually without switching. The following equipments are representative examples.

Analyzer TS-1074/TPM is a portable unit used in measuring or checking the frequency, wavelength, and power of radio transmitters, signal generators, and best-frequency oscillators. It will also measure the average power of CW, MCW, or pulsed radar sets and provide a video output signal for testing oscilloscopes.

Frequency-Power Meter TS-230B/AP is a portable radar test set used in measuring frequency and power of unmodulated and pulsed signals. It permits the detection of small percentages of rf power so that wave forms of pulsed signals can be displayed on an oscilloscope.

Test Set TS-146/UP is an F-M field unit used in measuring the power output and frequency of radar transmitters, as well as the sensitivity of radar receivers. In conjunction with an oscilloscope, this equipment is used in tuning radar receivers and TR boxes, measuring transmitter spectrum width and receiver bandwidth, determining TR box recovery time, checking magnetron pulsing and afc circuits, and tuning radar local oscillators.

Radar Test Set AN/UPM-99 was designed for maintaining and testing the Mark X and SIF type IFF equipment. The test set is comprised of a precision oscilloscope, trigger and suppressor pulse generators, Mark X and SIF code simulators, a pulsed RF signal generator and attenuator, a wavemeter, a demodulator, a pulse counter, and a calibrated video pulse generator. It operates through a range of RF inputs from 925 to 1225 mc. The following signal outputs are provided by the test set: triggers (zero time and delayed), suppressor pulses, Mark X and SIF interrogations and replies, internally or externally modulated RF pulses, and calibrated video pulses.

Radar Test Set AN/MPM-23 is a group of radar testing instruments required for maintenance at an advanced base. The test set is comprised of Power Supply PP-674/TPS-ID, Pulse Generator Set AN/UPM-15, Bridge Summation AN/URM-23, Signal Generators AN/URM-64, TS-452/U, and TS-497/URR, Electronic Multimeter ME-6/U, Motor Generator PU-20/C, Variable Power Transformer TF-171/USM, Fluxmeter TS-15/AP, Dummy Load TS-234/UP, Dummy Antenna TS-235/UP, Crystal Rectifier Test Set TS-268/U, Frequency Meter TS-328/U, and Range Calibrator TS-573/UP.

TYPES OF MEASUREMENTS

CURRENT, VOLTAGE, AND RESISTANCE MEASUREMENTS

The instruments and methods of making current, voltage, resistance, and power measurements in power and lighting circuits are included in Basic Electricity, NavPers 10086 (revised). It should be noted that the ETs will, in general, use multimeters in their work rather than separate instruments for measuring current, voltage, and resistance. For example, the AN/PSM-4 multimeter (nonelectronic) measures from 0 to 1000 volts a-c in 9 ranges, 0 to 4000 volts d-c in 10 ranges, 0 to 100 megohms in 5 ranges, and 0 to 10 amperes in 8 ranges. The ME-25/U multimeter (electronic) measures from 0 to 1000 volts a-c or d-c in 7 ranges, 0 to 1000 milliamperes in 6 ranges, and 0 to 1000 megohms in 6 ranges.

CAPACITANCE, INDUCTANCE, AND IMPEDANCE MEASUREMENTS

Combination capacitance, inductance, and resistance (impedance) measuring instruments commonly make use of some type of bridge arrangement employing standard units of capacitance, inductance, and resistance and some means (for example, a meter) of determining bridge balance. If C, L, and R are determined, X_C AND X_L, and Z may be computed for a chosen frequency. An elementary bridge circuit is treated in Basic Electronics, NavPers 10087 (revised).

The Capacitance-Inductance-Resistance Bridge, Type ZM-11/U can be used for measuring other quantities in addition to C, L, and R. It measures the turn ratios of transformers, the dissipation factor of inductors and capacitors, the storage factor (Q) of inductors at 1000 cps and insulation resistance of capacitors and other parts, as well as leakage in electrolytic capacitors when direct current is used. A brief description of the basic circuitry of the ZM-11/U (fig. 6-1) and the methods of making these measurements follows.

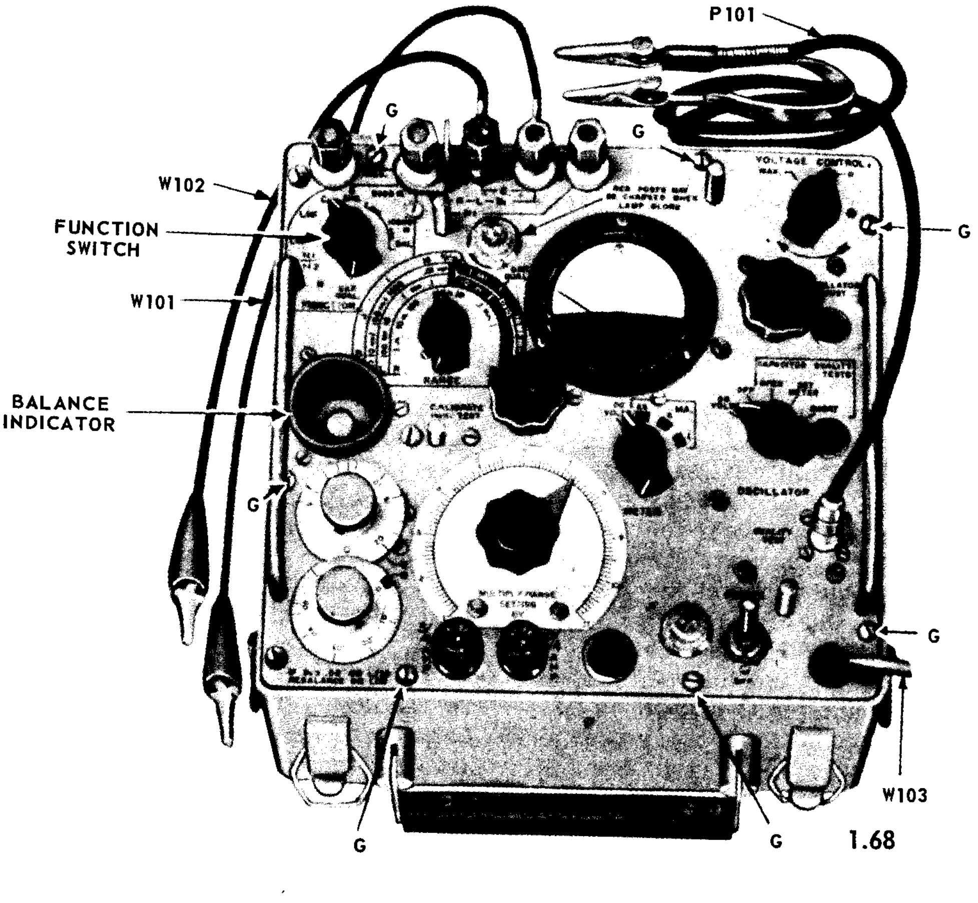
Note: Impedance measurements are included in all the following measurements except pure resistance.

Resistance Measurements

When the FUNCTION switch (upper left of figure 6-1) of the ZM-11/U is in the RESISTANCE (R) position, the circuit shown in simplified form in figure 6-2 is selected by the switch.

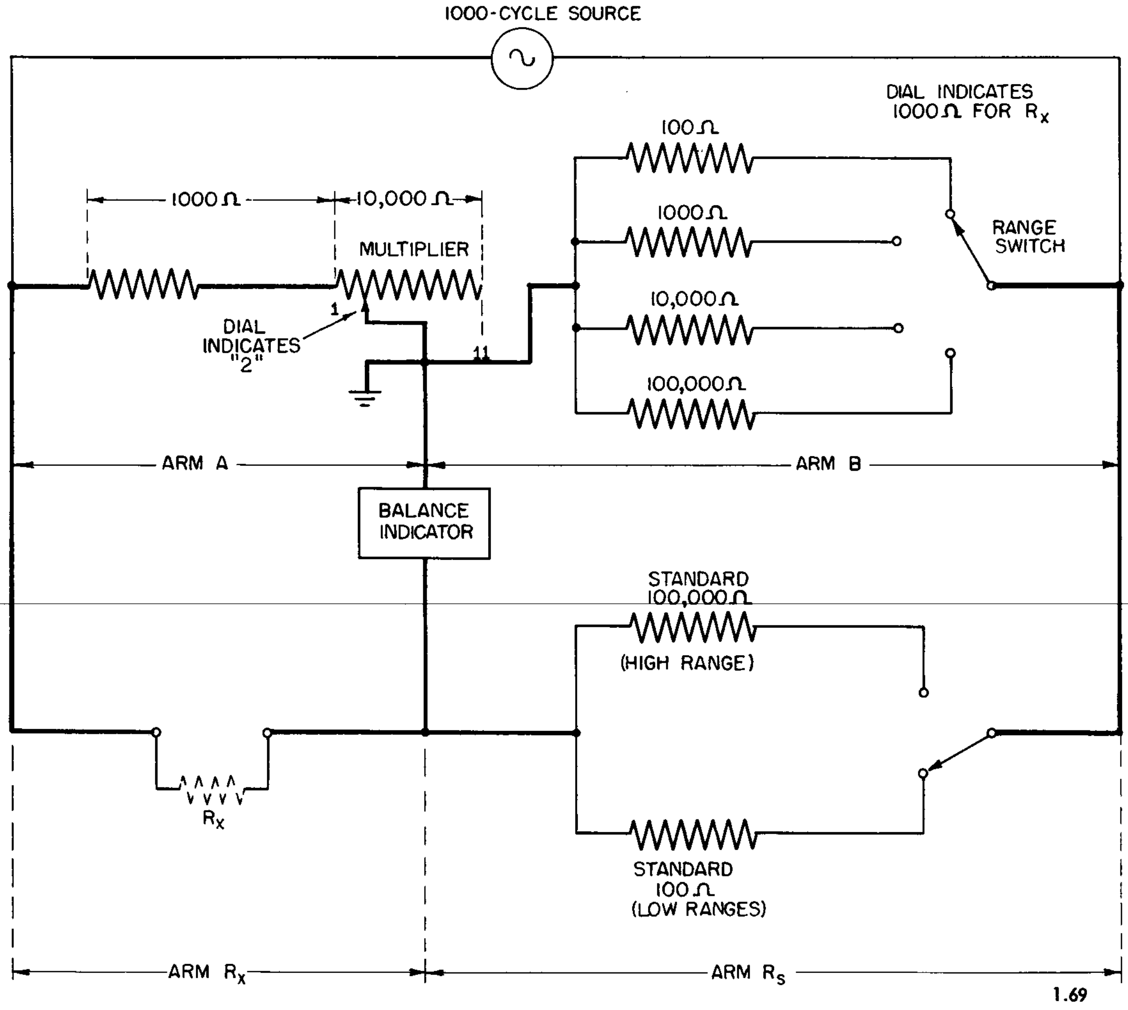
The four arms of the bridge are shown in the schematic diagram. Arm A contains the multiplier rheostat and a fixed resistor. When the multiplier rheostat is in position 1, arm A has a resistance of 1000 ohms; as it is moved to position 11, the resistance of arm A increases to 11,000 ohms. Arm B contains the range switch and the range resistors. Arm R_s contains one of the standard resistors; the correct standard resistor is connected into this arm by the range switch. The resistor of unknown resistance is connected in arm R_x.

The balance indicator is an electron-tube tuning indicator. The maximum possible opening of the pattern indicates balance. Balance is approached by proper positioning of the range switch, which connects the correct resistor in



1.68

Figure 6-1.—ZM-11/U bridge.



1.69

Figure 6-2.—Resistance bridge.

arm B and the correct standard resistor in arm R_S; balance is then completed by adjustment of the multiplier rheostat.

As the multiplier is moved through the point of balance, the balance indicator pattern increases to a maximum (point of balance) and then decreases again. This action results from the fact that the voltage across the indicator decreases to zero as the exact point of balance is reached and then it increases again as the multiplier is moved beyond the point of balance. The same reasoning may also be applied to capacitance and inductance measurements.

As a practical example of resistance measurement, assume that at balance the multiplier is at position 2 (the resistance of arm A is 2000 ohms), the range switch is in the position shown (100 ohms in arm B), and that 100 ohms standard is used in arm R_S. These positions are indicated in the figure.

Under conditions of balance,

$$\frac{A}{B} = \frac{R_X}{R_S},$$

where A is the resistance of arm A, B is the resistance of arm B, R_X is the resistance of the unknown resistance, and R_S is the resistance of the standard resistor.

Substituting the values previously given,

$$\frac{2000}{100} = \frac{R_X}{100}$$

$$R_X = \frac{2000 \times 100}{100} = 2000 \text{ ohms.}$$

On the instrument itself, the range switch (which has a calibrated dial) will indicate 1000 ohms, and the multiplier dial (which is also calibrated in units and tenths—from 1 to 11) will indicate 2; the reading will therefore be 2000 ohms. That is, 1000 ohms on the range switch multiplied by 2 on the multiplier dial is equal to 2000 ohms.

The same procedure is followed in making capacitance and inductance measurements. In each case the range switch indication is multiplied by the multiplier dial indication to determine the value of the unknown capacitor or inductor.

Capacitance Measurements

When the FUNCTION switch of the ZM-11/U is in the CAPACITANCE (C) position, the circuit shown in simplified form in figure 6-3 is selected by the switch.

Arm A contains the stray capacitor compensator. This compensator is used only on the lower capacitance ranges, and is automatically positioned by the range switch. Its function is to compensate for stray capacitance associated with the connecting leads in arm C_X. The error that would otherwise be introduced is significant only when small capacitances are measured, and the lead capacitance is of the same order of magnitude as that of the capacitor itself. Arm A also contains the multiplier resistor and a 1000-ohm fixed resistor. When the multiplier is in position 1, the resistance of arm A is 1000 ohms. The resistance increases to 11,000 ohms when the multiplier is moved to position 11.

Arm B contains the range switch and the range resistors, and arm C_X contains the capacitor of unknown capacitance.

Arm C_S contains a standard capacitor (one of two), which is selected automatically by the range switch, and the necessary dissipation control rheostat. The dissipation (D) dial associated with the rheostat indicates the dissipation factor (power factor) of the capacitor under test. Each of the two standard capacitors has its associated dissipation control rheostat. When the 1000 $\mu\mu$f standard is used, the 10,000-ohm rheostat is in the circuit. As the resistance of the rheostat is increased through the 10,000-ohm range, the D dial indicates a dissipation factor of from 0 to 0.06. When the 100 μf standard is used, the 100-ohm rheostat is in the circuit. As the resistance of the rheostat is increased through the 100-ohm range, the D dial again indicates a dissipation reading of from 0 to 0.06, but in this case, the reading must be multiplied by 10 to obtain the dissipation factor (0 to 0.6).

As a practical example, assume that at balance the controls are in the positions shown. Arm A has a resistance of 2000 ohms, arm B has a resistance of 100 ohms, arm C_S utilizes the 1000-$\mu\mu$f standard with a certain amount of resistance in series with it, and arm C_X contains the capacitor of unknown capacitance with its effective series resistance. Because the purpose of the dissipation rheostat is to make the power factor of arm C_S equal to the power factor of arm C_X to perfect the bridge balance, the resistance of the rheostat need not be considered in the following bridge equation:

Under conditions of balance,

$$\frac{A}{B} = \frac{C_X}{C_S}.$$

Performing the substitutions,

$$\frac{2000}{100} = \frac{C_X}{1000\,\mu\mu f}$$

$$C_X = \frac{2000 \times 1000}{100} = 20{,}000\,\mu\mu f = 0.02\,\mu f = 2 \times 10^{-8} \text{ fds}$$

Under conditions of balance, the power factor ($\cos \theta$ = D) of arm C_S is equal to the power factor of arm C_X. The calculations for the reactance and resistance of arms C_S and C_X for this example are

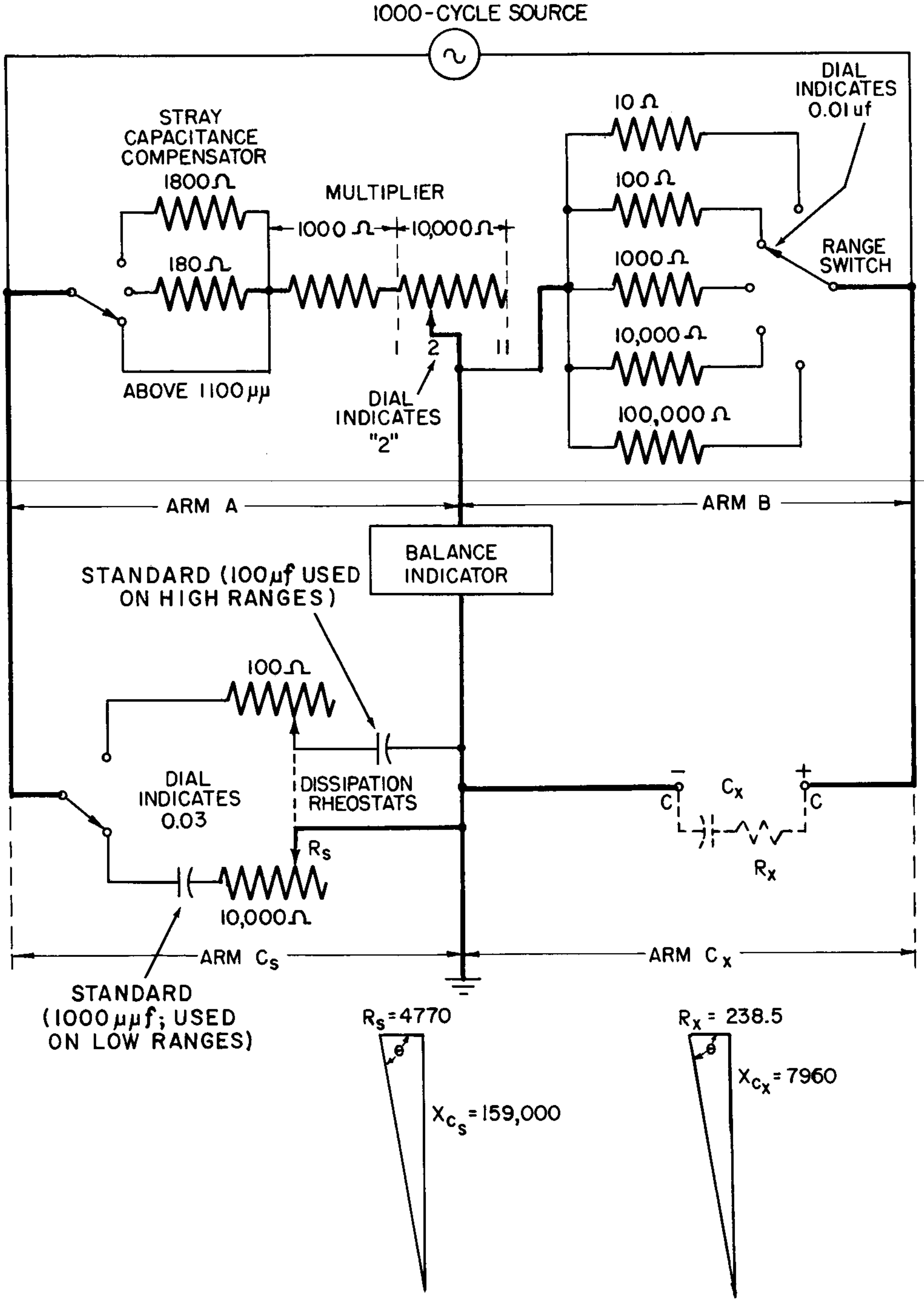
$$X_{CX} = \frac{1}{\pi\ fC_X} = \frac{1}{6.28 \times 10^3 \times 2 \times 10^{-8}} = 7950 \text{ ohms}$$

$$X_{CS} = \frac{1}{\pi\ fC_S} = \frac{10^{12}}{6.28 \times 10^3 \times 10^{-9}} = 159{,}000 \text{ ohms}$$

$$P_X = X_{C_X} \cos \theta = 7950 \times 0.03 = 238.5 \text{ ohms}$$

$$P_S = X_{C_S} \cos \theta = 159{,}000 \times 0.03 = 4770 \text{ ohms.}$$

Where the calibrated dissipation dial indicates a value of 0.03.



1.70

Figure 6-3.—Capacitance bridge.

The relation between resistance, reactance, and impedance in the capacitor arms of the bridge for the preceding example is represented by the two impedance triangles in the lower position of figure 6-3. The triangles are similar but not equal.

They are not drawn to scale; the length of the base lines is exaggerated in order to show clearly the effective series resistances, R_S and R_X, in their respective arms.

Because the power factor is low (0.03), θ is almost 90°, and the impedance (hypotenuse) is assumed to be equal to the reactance (altitude) of the right triangle. The base of the triangle represents the effective series resistance in each case.

On the instrument itself, the range switch will indicate 0.01 μf, and the multiplier dial will indicate 2; the reading will therefore be 0.02 μf. That is, 0.01μf on the range switch multiplied by 2 on the multiplier dial is equal to 0.02 uf. The calibrated dissipation dial will indicate some value—for example, 0.03 (or a 3% power factor). The larger the dissipation of the capacitor under test the larger will be the value of the dissipation rheostat resistance in series with the standard.

Inductance Measurements

When the FUNCTION switch of the ZM-11/U is in an INDUCTANCE position (either L (Q) or L (D) position), the circuit shown in simplified form in figure 6-4, A, is selected by the switch.

Because this circuit is somewhat more complex than those discussed previously, the circuit is further simplified into parts B and C.

The circuit shown in part B is selected when the FUNCTION switch is in the L (D) position. This circuit is used when the dissipation, D, is less than 0.05. Arm A contains the multiplier and a fixed resistor connected in series. Arm C_S contains one of the standard capacitors and its associated dissipation rheostat connected in series (capacitance standards are used in the inductance bridge to reduce the total number of standards needed). Arm B contains one of the range resistors, and arm L_X contains the inductor of unknown inductance. Arm L_X also contains R_X, the effective series resistance of arm L_X (R_X is, of course, a part of the impedance of arm L_X).

The circuit shown in part C is selected when the FUNCTION switch is in the L (Q) position. This circuit is used when the dissipation, D, is greater than 0.05. This circuit is essentially the same as the one shown in part B, except for arm C_S. In arm C_S the shunt rheostat, R_S shunts the standard capacitor, C_S. This rheostat is positioned by means of the Q dial. Q is the merit factor of a coil; it is the ratio of the inductive reactance (X_L) to the resistance (R). It is also the reciprocal of the dissipation factor — that is, $Q = \frac{1}{D}$. As stated above D = cos θ and from the impedance triangle (Fig. 6-3) $\cos\theta = \frac{R}{Z}$. Because R is small, for all practical purposes $Z = X_L$, therefore $\cos\theta = \frac{R}{X_L}$ and

$$Q = \frac{1}{\frac{R}{X_L}} = \frac{X_L}{R}.$$

As a practical example, assume that the inductance of a high-Q coil is being determined by means of the bridge circuit shown in part B. Assume that the inductor of unknown inductance is connected in arm L_X, that the resistance of arm A is 2000 ohms (multiplier dial in position 2) and that the 10,000-ohm range resistor is in arm B. Assume also that the dissipation rheostat connected to the D dial is adjusted to balance the bridge, and that the dial indicates 0.03, which is also the power factor of the inductor under test. The capacitance of the C_S arm is 1000 $\mu\mu$f. At balance,

$$\frac{Z_{armL_X}}{A} = \frac{B}{Z_{armC_S}}.$$

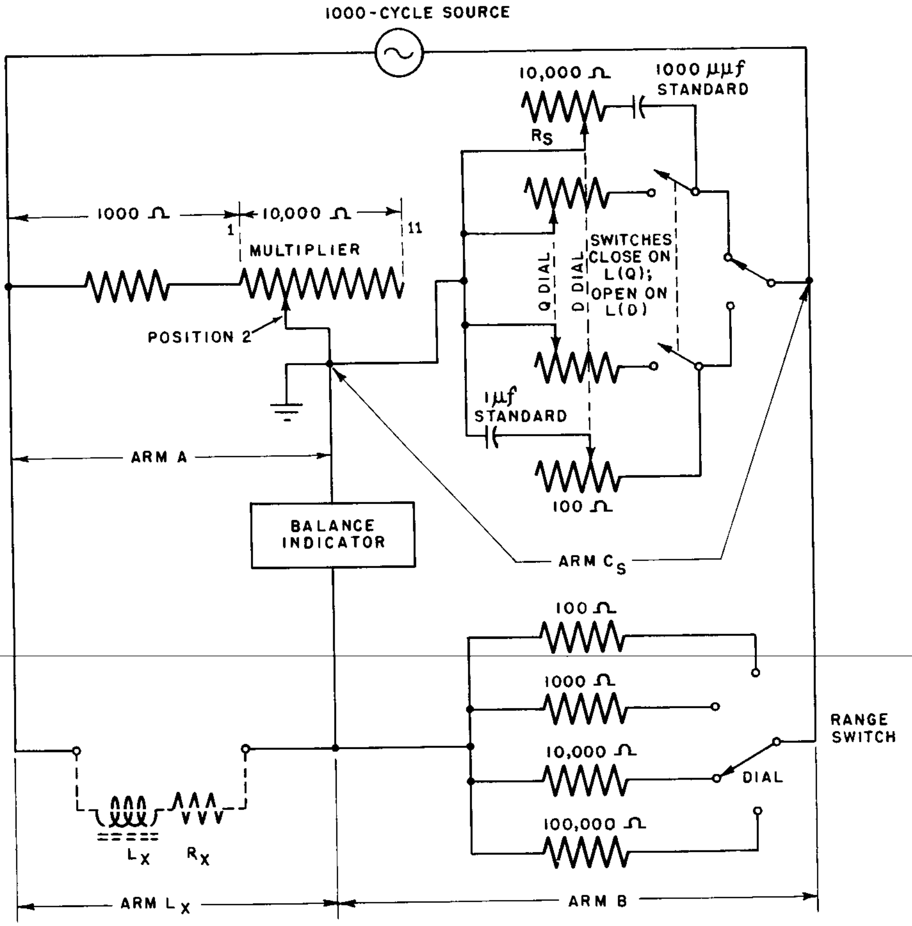
The impedance triangles shown in figure 7-5 will be helpful in illustrating how the reactance of L_X may be determined. For a power factor of 0.03, the phase angle is above 88° and so close to 90° that, for practical purposes, X_{L_X} is equal to $Z_{arm}X_L$, and X_{C_S} is equal to $Z_{arm}C_S$ in the figure. Therefore, the preceding equation may be written as

$$\frac{X_{L_X}}{A} = \frac{B}{X_{C_S}}$$

$$\frac{\omega L_X}{A} = \frac{B}{\frac{1}{\omega C_S}}$$

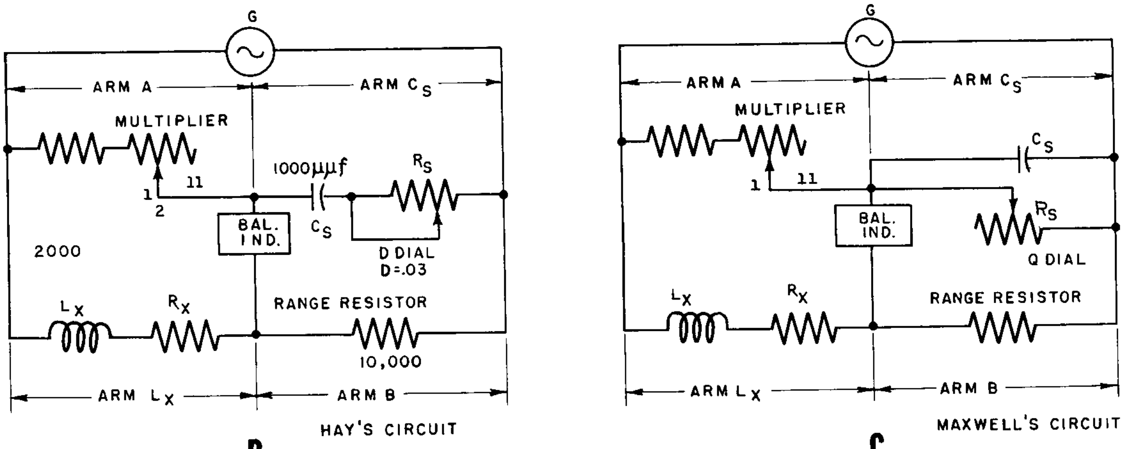
$$L_X = C_S BA.$$

Where $\omega = 2\pi f$.



A

BRIDGE CIRCUIT



B

FOR LOW-D OR HIGH-Q COIL
(FUNCTION SWITCH ON L (D))

C

FOR HIGH-D OR LOW-Q COILS
(FUNCTION SWITCH ON L(Q))

1.71

Figure 6-4.—Inductance bridge.

Substituting the known values,

$$L_X = 1000 \times 10^{-12} \times 10{,}000 \times 2000$$

$$2 \times 10^{-2} = 0.02 \text{ h.}$$

Converting to millihenries,

$$L_X = 0.02 \times 10^3 = 20 \text{ mh.}$$

On the meter itself the range switch will be on the 10-mh position, and the multiplier dial will indicate 2. The inductance of the unknown inductor will then be 10 mh x 2, or 20 mh. The dissipation will be 0.03, as previously stated.

The relationship between resistance, reactance, and impedance in the capacitance and inductance arms of the bridge for the preceding example is represented by the two impedance triangles of figure 6-5. The calculations are:

$$X_{L_X} = 2\pi fL = 6.28 \times 10^3 \times 2 \times 10^{-2} = 125.6 \text{ ohms}$$

$$X_{C_S} = \frac{1}{2\pi fC} = \frac{10^{12}}{6.28 \times 10^3 \times 10^3} = 159{,}000 \text{ ohms}$$

$$R_X = X_L \cos\theta = 125.6 \times 0.03 = 3.77 \text{ ohms}$$

$$R_S = X_{C_S} \cos\theta = 159{,}000 \times 0.03 = 4770 \text{ ohms.}$$

An alternate inductance measuring method known as the R-L and audio signal generator method can be used to determine the inductance of a coil (fig. 6-6). This method makes use of a coil, L (unknown value) and a resistor, R (of known value) in series across the output of an audio signal generator. Voltmeters are placed in the circuit to read the voltage drops E_s, E_l, and E_r. The resistor is 3 ohms. By a careful study of the impedance triangle of figure 6-6, it can be seen that

$$\frac{E_L}{E_r} = \frac{IX_L}{IR} = \frac{X_L}{R}, \text{ and therefore } \frac{E_L \times R}{E_r} = X_L.$$

For example assume that when a 1000 cycle voltage is applied the meters read E_s = 5v., E_r = 3v., and E_L = 4v. Substituting the values in the above formula, $X_L = \frac{E_L \times R}{E_r} = \frac{4 \times 3}{3}$ $= 4\Omega$ Thus $X_L = 4\Omega$.

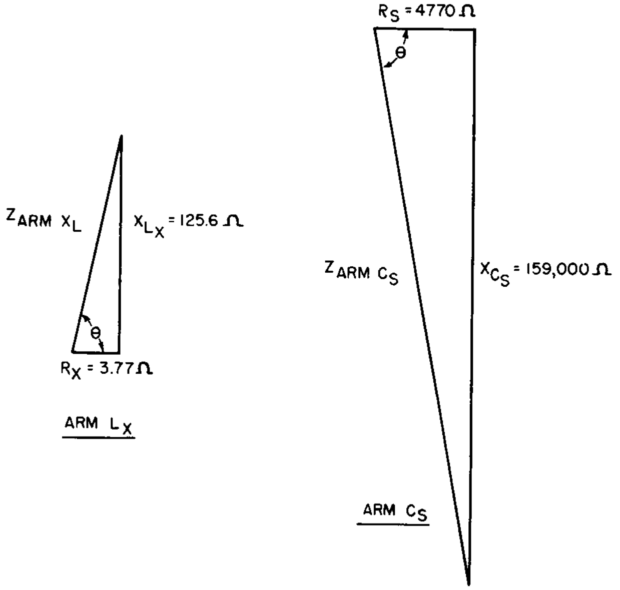
Substituting in the formula $X_L = \omega L$ and transposing for L, $L = \frac{X_L}{\omega} = \frac{4}{6.28 \times 10^3} = 0.64$mh. Thus for the unknown coil, L = 0.64mh, where f = 1000 cycles = 10^3.

POWER MEASUREMENTS

D-c power measurements and power measurements at power frequencies are treated in Basic Electricity, NavPers 10086 (revised) and will not be repeated in this training course.

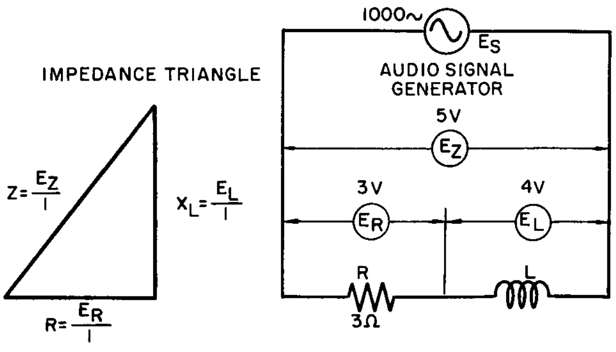
In the audio-frequency range, power-level measurements are usually expressed in decibels (db) or decibels with a reference level of one milliwatt (dbm). The technician must therefore become familiar with these units.

In the LF, MF, HF, and VHF bands, a dummy antenna and a thermocouple ammeter may be used to obtain reasonably accurate measurements of the power output of a transmitter.



1.72

Figure 6-5.—Impedance triangles.



70.30

Figure 6-6.—Alternate inductance measuring method.

In the UHF and higher portions of the r-f spectrum, special power-measuring equipments employing bolometers are used.

FREQUENCY MEASUREMENTS

It is necessary to make frequency measurements to ensure that electronic equipments remain on the assigned frequency.

Radio transmitters must be maintained on their assigned frequency (within the allowable deviation limits) in order not to interfere with other transmitters. It is also obvious that if the receiver is pretuned to a set frequency, and the transmitter is off frequency, communication may not be established. It is therefore important that a primary frequency standard be established so that frequency meters (secondary standards) may be accurately calibrated and used to keep the transmitters and receivers on frequency.

The primary frequency standard is supplied by station WWV in Washington and WWVH in Hawaii. Both stations are operated by the National Bureau of Standards. The schedule of services offered by these stations is published in Radio Navigation Aids, H.I. 205, issued by the USN Oceanographic officer.

To maintain its communication equipment on frequency, the Navy supplies good secondary frequency standards. These are discussed later in this chapter. Of course, the secondary frequency standard is of little value unless it is accurately calibrated against the primary standard.

Radar transmitters and receivers must likewise be maintained on the correct frequency if maximum use is to be made of the radar system. The components of a radar system are designed to be operated within certain frequency limits, and these frequency limits must be respected.

Interference could result if radars in the same area were operated on the same frequency; therefore, certain radars may be tuned to operate in different parts of a radar band. Except for beacon operation, a knowledge of the receiver frequency is not very important as long as the receiver is carefully tuned to the transmitter frequency.

Frequency measurements are also important in sonar testing.

FIELD-INTENSITY MEASUREMENTS

The field intensity, or strength, of a radio wave at a given point is, in most cases, a measure of the strength of the electric field component of the wave at that point. It is usually measured in terms of the number of millivolts or microvolts induced in an antenna one meter long.

Several types of test equipments for measuring field strength and interference are available to the technician. They are known generally as noise-field intensity meters. With this equipment, it is possible to measure either the RELATIVE or the ABSOLUTE magnitude of the field intensity produced by the energy radiated from an antenna. By the use of these instruments the directivity of an antenna may be determined, favorable antenna sites may be discovered, field patterns of an antenna may be plotted, and spurious radiation detected.

The measurement of relative field strength can be done with simple test equipment. It may consist of only a grid-dip meter or a pickup antenna, a tuner, a rectifier, and a microammeter.

For measuring the absolute field strength, more elaborate equipment is needed. These measurements are treated in more detail in the training courses, ET 2 and ET 1 and C.

INTERFERENCE MEASUREMENTS

A brief treatment of interference (and field-intensity) measurements is included in Basic Electronics, NavPers 10087 (revised). Instruments similar to those used in making field-intensity measurements are used. One of the simplest methods of locating the source of noise interference is to move about with the noise meter in the suspected area and listen to the audio output by means of a headset. It is often possible to locate the source of interference simply by walking in the direction that gives the largest volume of noise.

Two types of antennas are available for close work: the probe and the loop. The probe is a short wire antenna (approximately 1 ft in length) and operates by electrostatic induction; the loop (approximately 1 ft in diameter) operates by electromagnetic induction. These antennas will often permit the discovery of the individual item in an equipment that is causing the interference—for example, a sparking relay contact.

SENSITIVITY MEASUREMENTS

Receiver sensitivity measurements are made to determine whether or not the receiver is performing according to the required sensitivity specifications. The sensitivity is the value of signal voltage (in microvolts) fed to the receiver antenna terminals, which will produce a specified power output (for example, 6 mw) at the receiver output terminals when the signal-to-noise ratio is 10:1.

Receiver sensitivity measurements are very important in that they give a good indication of how well the receiver is performing its function. These measurements are made periodically aboard ship.

The details of how the measurements are made are given later in the chapter.

RADAR PERFORMANCE MEASUREMENTS

The power output of a radar transmitter may be measured in terms of relative values or absolute values. Relative values are useful in indicating CHANGES in output power. For this purpose a suitable rectifier (for example, a crystal) may be used in a suitable circuit with a d-c meter to indicate relative power in terms of needle deflection.

If the same meter and rectifier are used each time a measurement is made, and if no defect occurs in the setup, changes in power output will be indicated. On the basis of a change in power output, corrective maintenance may be undertaken.

There are obvious disadvantages in the use of relative values such as these. When the initial reading is taken, the equipment may be operating below the operational standards set for it. The readings may vary because of some defect in the crystal or meter or because of the way the technician makes the connections. Finally, the equipment is rated in watts by the manufacturer and by the engineer who set up the performance standards, and output power readings in watts are therefore more meaningful to the technician.

Before discussing the methods of making radar power measurements, it is necessary to have a clear understanding of what is meant by PEAK power and AVERAGE power. Because a radar transmitter generates r-f energy in the form of extremely short pulses and is turned off between pulses for comparatively long intervals, there is considerable difference between the peak power and the average power.

The relationship between peak and average power is treated in Introduction to Radar, of Basic Electronics, NavPers 10087 (revised).

An understanding of the use of the DECIBEL as a unit of power gain or loss is likewise necessary before a technician can acquire a clear understanding of the various methods of making radar power measurements. This subject is treated in Basic Electronics, NavPers 10087 (revised).

Methods of Sampling Radar Power

There are three common methods of taking a sample of radar power. They include the use of the R-F PROBE, the DIRECTIONAL COUPLER, and the TEST ANTENNA. For the purpose of this chapter, only the methods of extracting power and making power readings are given; the theory of operation is left to other courses of study in the ET series.

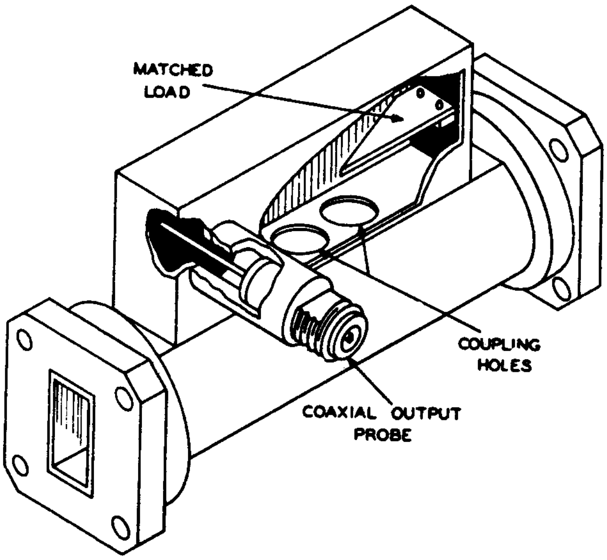
The R-F PROBE (in older radar systems) was used extensively for power sampling. It has been largely replaced by some form of directional coupler. The r-f probe consists of a small probe (or antenna) which when inserted into the waveguide or coaxial line extracts a small amount of power. The further the probe is pushed in, the greater the amount of power pickup. Most r-f probes provide 20 db or more attenuation between the main transmission line and the probe output.

Although the probe allows the radar equipment to be operated normally during tests, it has several disadvantages. The attenuation figure (and therefore the accuracy of the readings) is affected by line reflections and reflections from nearby objects. Other disadvantages may be summarized as follows: (a) The probe penetration is critical, (b) the probe is frequency sensitive, and (c) the attenuation figure depends on the type of load connected to the probe.

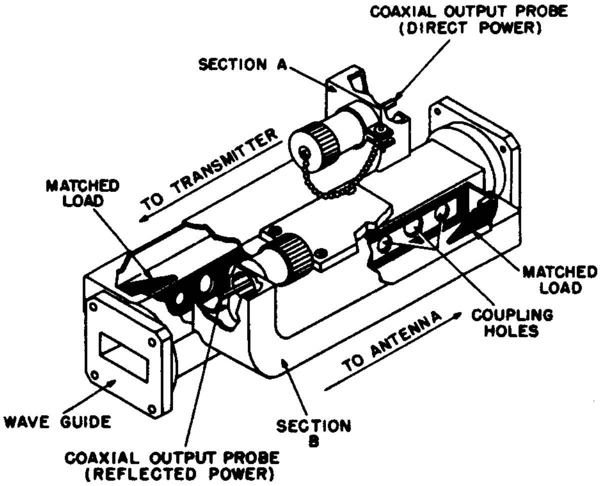
The DIRECTIONAL COUPLER couples, or samples, the energy traveling in one particular direction in a waveguide. A cutaway view of one type of directional coupler is illustrated in figure 6-7. If properly used, reflected power has little effect on the accuracy of the power measurements.

The amount of energy coupled from the waveguide to the coaxial output depends on the size of the two coupling holes. A small portion of the energy flow from right to left is coupled to the probe. However, energy flow from left to right is not coupled to the probe, but is largely dissipated in the matched load.

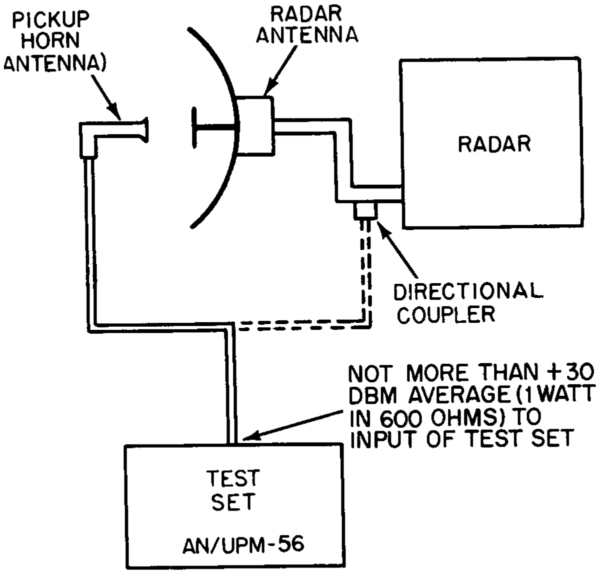
Generally, the power available at the probe is over 20 db down from the power level in the guide—that is, when the energy is moving from right to left through the directional coupler.



70.31
Figure 6-7.—Cutaway view of directional coupler.



70.32
Figure 6-8.—Cutaway view of bidirectional coupler.



70.33
Figure 6-9.—Simplified test arrangement employing pickup horn.

This loss in power is called the ATTENUATION, COUPLING FACTOR, or DIRECTIONAL COUPLER LOSS and is stamped on the coupler. The ability of the coupler to reject energy that moves through the guide in the reverse direction is called the DIRECTIVITY.

A BIDIRECTIONAL COUPLER is used to sample direct or reflected power. A cutaway view of a bidirectional coupler is shown in figure 6-8. It consists of a straight section of waveguide, with an enclosed section attached to each side along the narrow dimension. Each enclosed section contains an r-f pickup probe at one end and an impedance termination at the other end. The sections are supplied with energy from the main waveguide through coupling holes.

The TEST, or PICKUP, ANTENNA tunes broadly to the radar band being used. It may be placed in front of the radar antenna at a distance equal to the diameter of the radar antenna and so directed that it will pick up maximum energy. The space attenuation (output from pickup antenna compared to output from radar antenna) is then about 30 db; it is generally given, or will have to be determined.

A simplified test arrangement employing a pickup horn (pickup antenna) is shown in figure 6-9. The space loss of the pickup antenna is measured by comparison with the loss in the directional coupler. Once the space loss for a particular radar is determined, it is unlikely that the measurement will have to be repeated for each system of the same type, provided the same pickup antenna location is always used and the distance chosen is the least critical.

To ensure that the antenna is placed at the least critical location, the pickup antenna is positioned where a change in its position produces a minimum change in the amount of the meter reading on the test set. This usually occurs when the pickup antenna is placed from 3 to 5 ft from the radar antenna and at a maximum power point of the antenna pattern.

In the case of the test set used in this figure, care must be taken not to apply more than +30 dbm (1 watt in 600 ohms) to the r-f input/output connector. The test set is connected as shown, first using the directional coupler and then the pickup antenna. In each case the average power of the antenna is recorded.

The loss (space loss, plus antenna loss, transmission-line loss, etc.) for the pickup antenna in conjunction with the particular radar system is the difference between the dbm dial reading on the test set meter when the test set is connected to the directional coupler and the dbm dial reading when the test set is connected to the pickup antenna, added to the db (attenuation) value of the directional coupler.

MEASUREMENTS IN RADIO FREQUENCY CIRCUITS

In d-c circuits, power is the product of the current through a component and the voltage appearing across the component. Actually, if the resistance of the component is known, the power can be determined by the use of only one instrument (ammeter or voltmeter). The three basic power formulas are

$$P = E \times I$$
$$P = \frac{E^2}{R}$$
$$P = I^2R.$$

If the resistance is unknown, it may be determined by the use of an ohmmeter or a resistance bridge.

Below the UHF band, it is usually possible to measure the effect of a-c power directly in much the same manner as d-c measurements are made. In fact, modifications of this basic procedure utilizing the thermocouple ammeter are commonly used. The following power relationship is applicable:

$$P = I^2R,$$

where P is the power delivered by the transmitter, I is the r-f current in the antenna, and R is the effective resistance (principally radiation resistance) of the antenna.

A typical circuit for determining antenna input power is shown in figure 6-10. The meter may be calibrated to indicate the square of the current. The input power is equal to the product of the meter reading and the antenna effective resistance. Several methods are used for determining the effective resistance of the antenna. They include the VARIATION, SUBSTITUTION, and BRIDGE methods.

Antenna Resistance Measurements

BASIC VARIATION METHOD.—This method of making antenna resistance measurements is illustrated in figure 6-11A.

The antenna resistance at the natural frequency of the antenna (tuning network not used—that is, L and C in ZERO positions) is determined first. The antenna is connected to ground through the coupling coil and the milliammeter, A; the shorting switch is in the CLOSED position (R_S is out of the circuit). Care should be taken to ensure that no signal is coupled to the antenna except through the coupling coil.

The r-f oscillator is then tuned to the resonant frequency of the antenna system. There should be a gradual dip in the grid-circuit milliammeter (not shown in the figure), reaching a maximum at the resonant frequency of the antenna system. If the dip in grid current

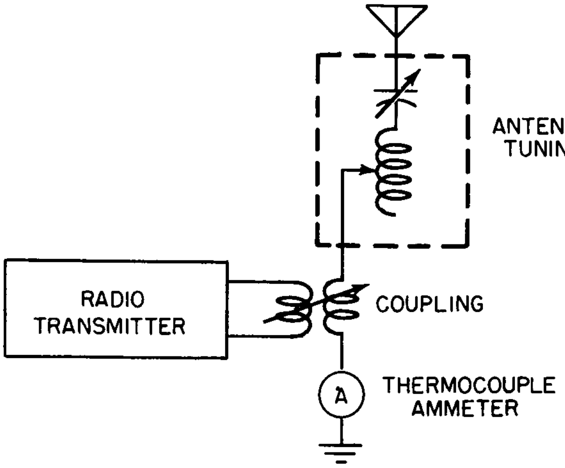
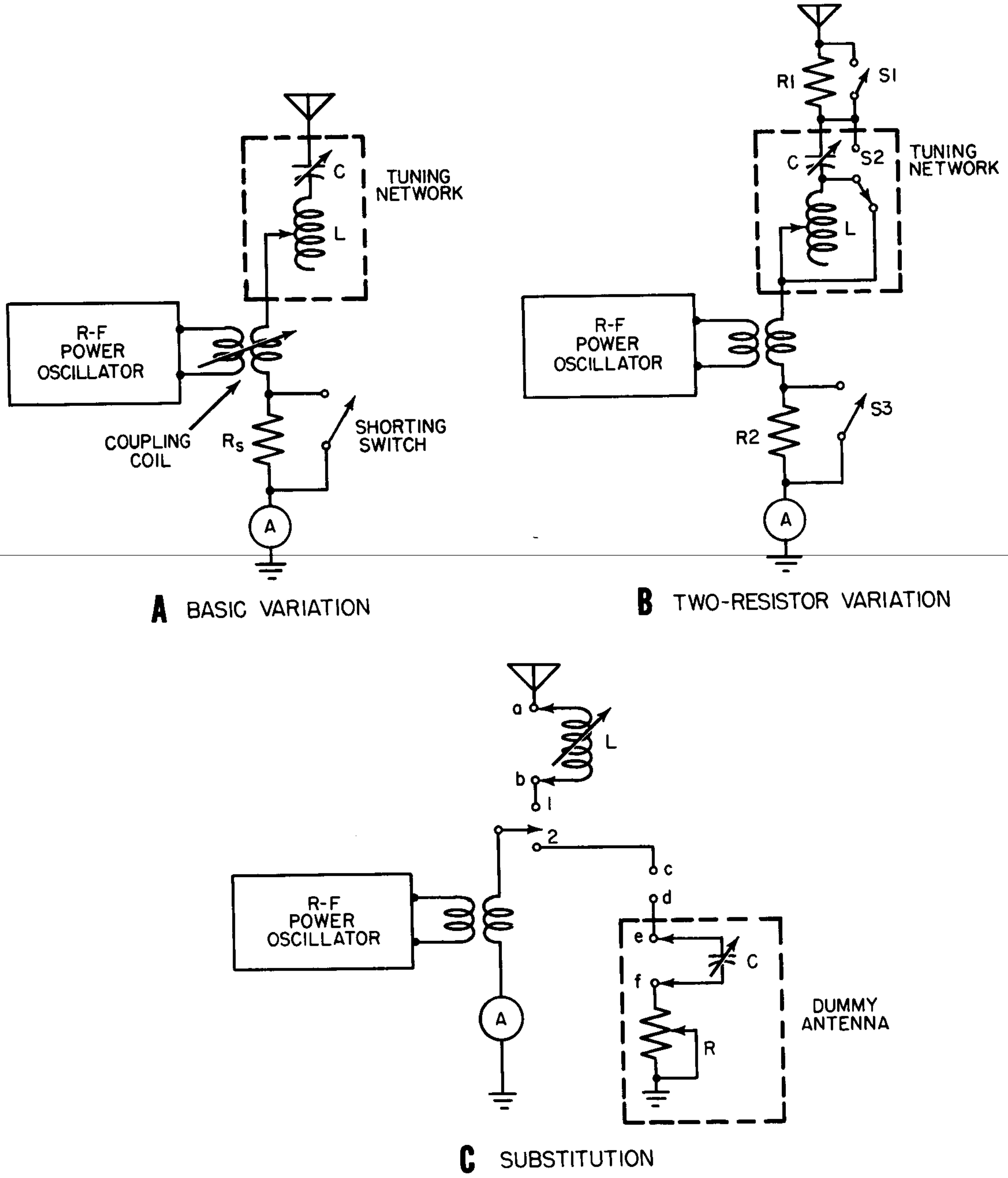


Figure 6-10. Typical circuit for measuring antenna input power.



1.80

Figure 6-11.—Methods of making antenna resistance measurements.

is too abrupt, the coupling should be reduced. At the instant of lowest grid-current reading, the antenna milliammeter reading (I_a) should be maximum. The precision resistor, R_S, is next inserted in the antenna circuit (by opening the shorting switch), and the antenna current, I_S, is again read. During these readings no adjustments should be made in the coupling (the voltage induced in the antenna secondary should be constant). The antenna resistance, R_a, is determined by the formula,

$$R_a = \left(\frac{I_s}{I_a - I_s}\right) R_s.$$

Example: Find the antenna resistance if the antenna current is reduced from 2.5 amperes to 1.0 ampere after inserting a standard resistance of 60 ohms.

$$R_a = \frac{1.00}{2.50 - 1.00}(60) = 40 \text{ ohms.}$$

The frequency of transmission is not necessarily the same as the natural frequency of the antenna.

The resistance of the antenna at the frequency of transmission is next determined. The tuning network is connected into the circuit to resonate the antenna to the frequency of transmission. The shielding eliminates stray coupling paths.

The antenna is tuned to resonance (by means of the tuning network) at the frequency of transmission, and the current readings are taken with R_s out of the circuit and with R_s in the circuit, as was done previously. R_a is computed the same as before.

The same procedure should be repeated for frequencies above and below the natural resonant frequency of the antenna and a graph (essentially a straight line) of antenna resistance vs frequency plotted. Antenna resistance without the tuning network should not vary greatly from the antenna resistance with the tuning network.

TWO-RESISTOR VARIATION METHOD.—This method of making antenna resistance measurements is helpful in determining if stray capacitive paths to ground are shunting the system. Although a variable inductor and capacitor are shown (fig. 6-11B), it is likely that only one or the other would be used. The inductor or capacitor should have calibrated dials. Two standard resistors are used instead of the single resistor that was used in the previous method. One resistor is located on the grounded side of the antenna transformer secondary; the other is located on the antenna side of the tuning network.

At the beginning of the test, both resistors are shorted out of the circuit, and the antenna circuit is tuned to the frequency of transmission (to the frequency of the oscillator). The oscillator output is then adjusted to produce the desired deflection, I_a, on the r-f milliammeter in the antenna circuit. No readjustment of the output should be made during the remainder of the test.

Switch S1 is then opened to insert R1 into the antenna circuit, and the antenna current, I_a, noted.

The antenna resistance, R_a, is computed by the formula that was given previously.

Next, S1 is closed to short out R1, and S3 is opened to place R2 in the antenna circuit. The antenna resistance, R_a, is again computed by means of the formula.

If the two values of R_a do not agree, there is appreciable stray capacitance between the measuring circuit and ground or elsewhere. Proper grounding, shielding, and arrangement of the components will permit the two readings to be essentially the same.

The reactance of the antenna at the frequency of transmission may be determined by noting the value of L or C that is required to resonate the system. If C is required, the reactance of the capacitor will be

$$X_c = \frac{1}{2\pi fC}$$

The antenna reactance, X_L, will have the same magnitude as X_c. If L is required to resonate the system, the reactance of the inductor will be

$$X_L = 2\pi fL.$$

The antenna reactance, in this case, X_c, will have the same magnitude as X_L.

Substitution Method.—This method of making antenna resistance measurements is illustrated in figure 6-11C. In this method, the antenna is replaced by equivalent amounts of reactance and resistance (a dummy antenna). Before making the resistance measurements, the antenna system is made resonant at the operating frequency. The oscillator should be well shielded and a fairly high energizing current should flow in the antenna circuit.

After these conditions are established, the adjustment of the antenna tuning element must not be disturbed throughout the remainder of the measurement procedure.

The antenna current is noted when the switch is in position 1. The switch is then placed in position 2. If a coil is used to resonate the antenna, as indicated in the figure, a capacitor will be used in the dummy antenna. If a capacitor is used to resonate the antenna, an inductor will be used in the dummy antenna. The antenna tuning element (inductor in this case) is then connected between points C and D, and the capacitor is tuned to resonance, as indicated by a maximum deflection of the milliammeter. The resistance of R is then varied until the meter reads the same as it did when the antenna was connected in the circuit. The resistance of R is equal to the antenna resistance, and the reactance of C is equal to the reactance of the antenna circuit (with the coil shorted out) at the resonant frequency.

The R-F BRIDGE METHOD (previously discussed) may be used in determining the impedance of an antenna. This method is both rapid and accurate, (if shielding is sufficient and if the connections are properly made). The exact method of making the measurements with a bridge depends on the type of bridge used.

Antenna Circuit Power Measurements

R-F POWER METERS may be used to obtain a direct reading of the power output of a transmitter when a high degree of accuracy is not required and the power output is less than 500 w. With proper termination of the transmission line, the standing-wave ratio will be negligible, and essentially all of the power will be absorbed in the power meter.

There are several indirect methods of measuring r-f power—for example, the lamp-load, resistor-load, and bolometer methods.

In the LAMP-LOAD METHOD a pair of identical lamps are placed side by side. One lamp is fed by the r-f source, and the other is fed by a d-c source through a potentiometer. An ammeter is connected in series with the lamp fed by the d-c source, and a voltmeter is connected across the lamp.

The potentiometer is varied until the lamp fed from the d-c source has the same brilliancy as that of the lamp fed from the r-f source. The d-c and r-f power dissipated in the lamps are then equal. All that is necessary to determine the power dissipated in the lamp connected to the r-f source is to multiply the ammeter reading by the voltmeter reading.

To make the readings more accurate, a photoelectric cell and a sensitive meter photographic exposure meter) may be used to determine when the lamps have the same brilliancy. It is assumed, of course, that the transmission line feeding the r-f energy to the lamp is properly terminated in the lamp.

In the RESISTOR-LOAD METHOD of measuring r-f power the temperature rise of a noninductive resistor fed by the r-f power is determined by means of thermocouples placed in a stream of air that is blown over the resistor. This method is somewhat involved in that the rate of air flow and the temperature rise must be determined before the power dissipation can be calculated.

BOLOMETER METHODS of measuring r-f energy, especially in the UHF range, are becoming standard procedure. The bolometer is a loading device that changes in resistance as the power dissipated in it changes. The two main types of bolometers are the thermistor and the barretter. Their changes in resistance with temperature change are opposite. When the thermistor dissipates more power (increased temperature) its resistance decreases; when the barretter dissipates more power, its resistance increases. (The use of the thermistor in making power measurements is described in Chapter 7.

Regardless of which type of bolometer is used, the method of making power measurements is essentially the same. The resistance of the bolometer is measured before and after the application of r-f power. A d-c source of power, which may be varied, is then connected to the bolometer, and the power is adjusted to give the same change in bolometer resistance as was obtained when r-f power was applied. The readily measured d-c power is equal to the r-f power. A bridge arrangement calibrated in units of power is commonly used along with the necessary attenuation devices. The thermistor is more widely used because of the high degree of precision that can be obtained, especially when compensating thermistors are used.

Because of the low power that the thermistor is capable of dissipating (1 mw is standard), the power must be attenuated before it is applied to the thermistor bridge. The amount of attenuation must be accurately known before the r-f power being measured can be determined.

Frequency Measurements

RADAR.—frequency measurements involve transmitter frequency and receiver frequency measurements.

The radar transmitter must operate within its assigned band of frequencies because radar beacon stations will respond only to signals within an assigned frequency range, and because the waveguide tuning adjustments cover only a limited range of frequencies. Also, two radar transmitters operating in the same band could cause serious interference.

The radar receiver must operate at the same frequency as the transmitter. A knowledge of the receiver frequency is not so important as long as the receiver is tuned exactly to the transmitter frequency.

Radar transmitter frequency measurements are often made with a combination frequency and power meter—for example, Frequency-Power Meter TS-230B/AP, a functional block diagram of which is shown in Chapter 7, figure 7-28A. An exploded view of the wavemeter is shown in part B, and the r-f assembly is shown in part C. The open-circuited coaxial transmission line (in the wavemeter) is coupled to the waveguide in the meter by means of a probe antenna. The micrometer FREQ control (fig. 7-28) varies the length (and thus the resonant frequency) of the resonant coaxial line comprising the wavemeter (fig. 7-28B). The motion of the drive can be accurately calibrated in terms of resonant frequency. When the wavemeter is in resonance, more energy is extracted from the waveguide, leaving less to be absorbed by the power thermistor; thus, there is a decrease in the meter, M, reading. (The bridge approaches a balance when the thermistor absorbs the least r-f energy.) The setting of the micrometer can then be translated into frequency by reference to the calibration chart inside the front cover of the meter.

This meter is designed to measure the frequency of unmodulated and pulsed signals in the range from 8500 to 9600 mc. It is suitable for use in a temperature range between -40°F and +131°F.

The following is a brief summary of the procedure for making a frequency measurement, using the Frequency-Power Meter TS-230B/AP. The meter is turned on, adjusted, and calibrated as outlined in the instruction book. It is not necessary to have the meter adjusted to precisely zero when frequency alone is being measured. The ADJ zero control is next set to the position that makes the meter read close to zero, and the meter is connected to the radar system by means of the connector or adapter furnished with the meter.

The radar transmitter is then turned on, and the input attenuation control is adjusted to give a meter reading between 50 and 100 μa at M (fig. 7-28A).

The FREQ control is moved to an initial setting of 9600; then it is turned slowly clockwise until the meter reads the exact minimum. This should be done slowly because there is a slight time lag in the change in resistance of the thermistor in the bridge circuit.

The FREQ setting is recorded, and the calibration curve is used to obtain the frequency in megacycles corresponding to the micrometer (FREQ dial) setting.

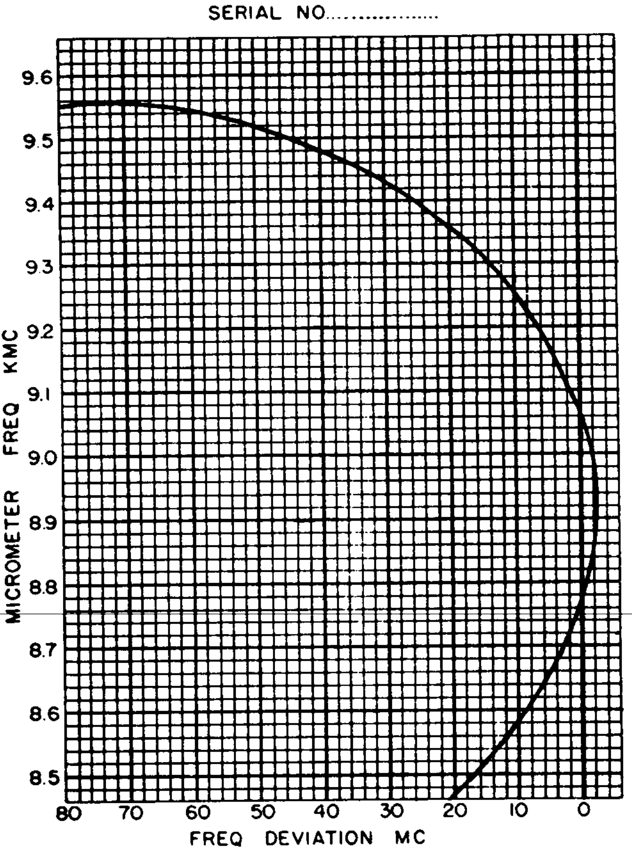
The following sample calculation is taken from the instruction book. For purposes of illustration, the micrometer setting at resonance is assumed to be 8555.0. From the sample calibration chart (fig. 6-12) the point on the curve corresponding to 8555 mc (8.555 kmc) corresponds to 13 mc on the frequency deviation axis. The frequency is calculated by adding 13 mc to 8555 mc to give 8568 mc. Frequency measurements are also included under the section on echo box in the next chapter.

RADIO.—It is very important to keep Navy transmitters on their assigned frequencies. To aid the technician or operator in keeping the transmitters within the frequency tolerances, the Navy provides accurate frequency meters. These meters must be calibrated periodically against the primary standard frequencies transmitted by the U. S. Bureau of Standards. These primary frequency standards are transmitted continuously, day and night.

Where extreme accuracy is not of prime importance, as in making preliminary adjustments or for general experimental work, rapid frequency checks may be made with the simple resonant-circuit wavemeter of the absorption type.

The ABSORPTION-TYPE WAVEMETER, the grid dip meter, and secondary frequency standards are discussed in Basic Electronics NavPers 10087 (revised).

A REACTION-TYPE WAVEMETER may also be used. In this type of wavemeter the indicating device is in the circuit under test; otherwise, the setup is essentially the same as that used



70.34
Figure 6-12.—Sample calibration chart.

with the absorption-type wavemeter. The reaction-type wavemeter absorbs very little energy from the source and is therefore advantageous when the frequency of low-power sources is being measured.

Where great accuracy is needed, oscillating frequency standards (FREQUENCY METERS) are used. These instruments are similar to signal generators, but are more stable and accurate; however, they have lower output than a signal generator. The frequency meter is used to measure frequency and to tune transmitters and receivers to the desired frequency. As has been mentioned, they must be compared with the primary frequency standard transmissions of WWV (Washington) or WWVH (Hawaii) at frequent intervals.

A HETERODYNE type frequency meter (one of the LM series) used extensively on small craft is shown in figure 6-13. Several models of this meter have been built. These models are similar except for the power supply and some minor mechanical differences. The LM-21 frequency meter covers the band of frequencies from 125 to 20,000 kc. This equipment has accuracies within 0.02 percent in the 125- to 2000-kc band and within 0.01 percent in the 2000- to 20,000-kc band.

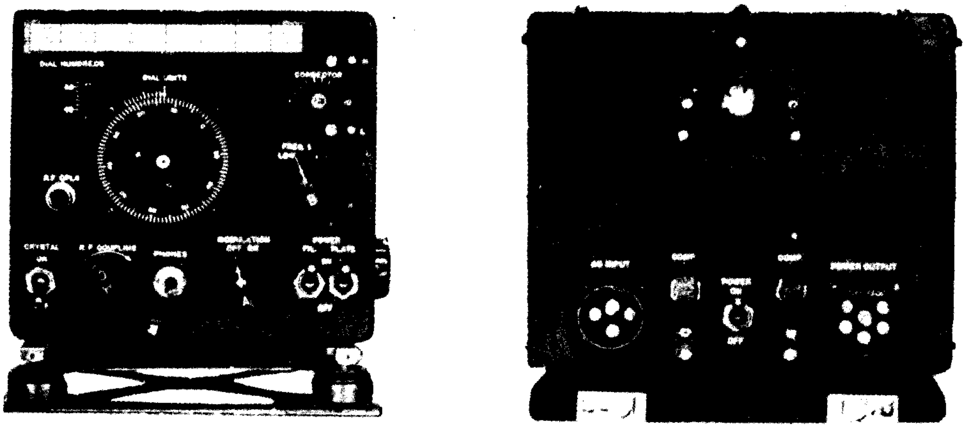
Two oscillators are used: (1) crystal oscillator and (2) heterodyne oscillator. The crystal oscillator is used to calibrate the heterodyne oscillator at several different points over the entire band covered by the frequency meter. The LM-21 also contains an a-m detector, an audio amplifier, and a modulator.

The fundamental frequency of the crystal oscillator is 1000 kc. However, the oscillator output has a high harmonic content. A small trimmer capacitor is placed across the crystal so that if the crystal frequency changed, an adjustment can be made to keep the crystal frequency close to 1000 kc. Most of the frequency-determining components, including the crystal, are hermetically sealed to keep out moisture and dirt.

The band of frequencies measured by the LM-21 is covered in two ranges. The heterodyne oscillator has two continuously variable ranges that may be selected by the frequency band switch. In the LOW position a fundamental range of 125 to 250 kc is used. By calibrating the first, second, fourth, and eighth harmonics of this range, continuous coverage from 125 to 2000 kc is obtained. In the HIGH position of the switch, the fundamental range of 2000 to 4000 kc is calibrated over the first, second, fourth harmonics, and part of the fifth harmonic to provide continuous coverage through the range of 2000 to 20,000 kc.

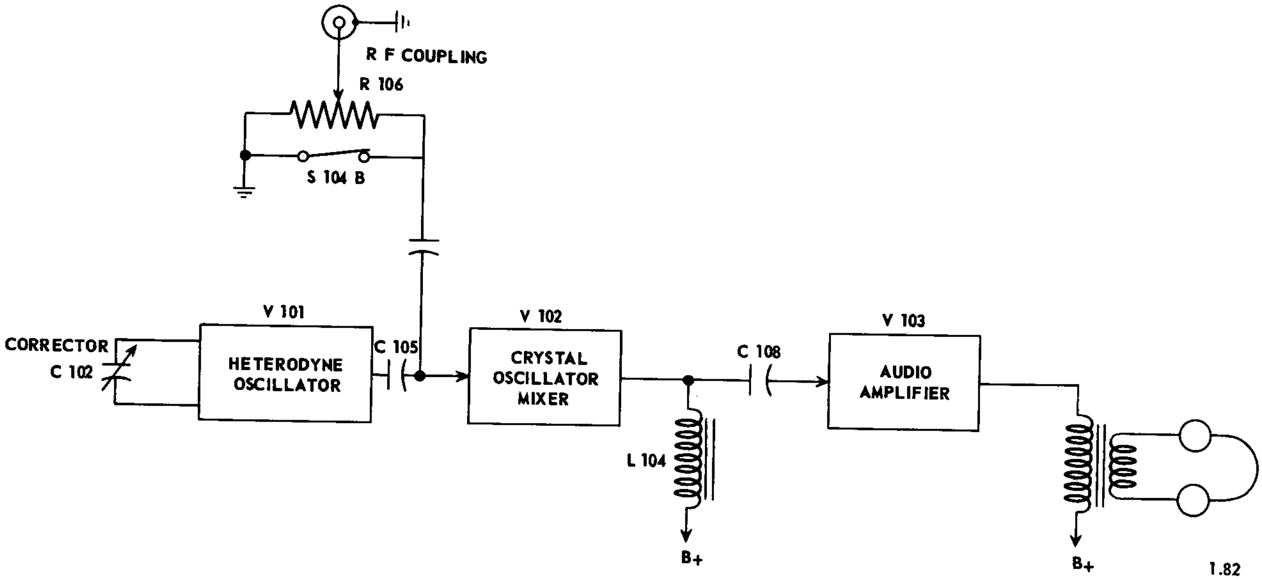
The LM-21 frequency meter can be used to tune transmitters and receivers (both c-w and m-c-w) and to determine the frequency of a received signal. Figure 6-14 shows a block diagram of the frequency meter when it is used to calibrate the heterodyne oscillator with the crystal oscillator.

The output of the heterodyne oscillator is coupled to the grid of V102. Tube V102 is used as a crystal oscillator and mixer. The two oscillator frequencies beat together and the difference frequency is developed across choke L104. An audio amplifier, V103, amplifies the beat note and supplies it to a set of headphones. If a beat note is heard, the corrector, C102, is adjusted until a zero beat is obtained. Thus the heterodyne oscillator is corrected to the crystal



1.81

Figure 6-13.—LM-21 frequency meter.



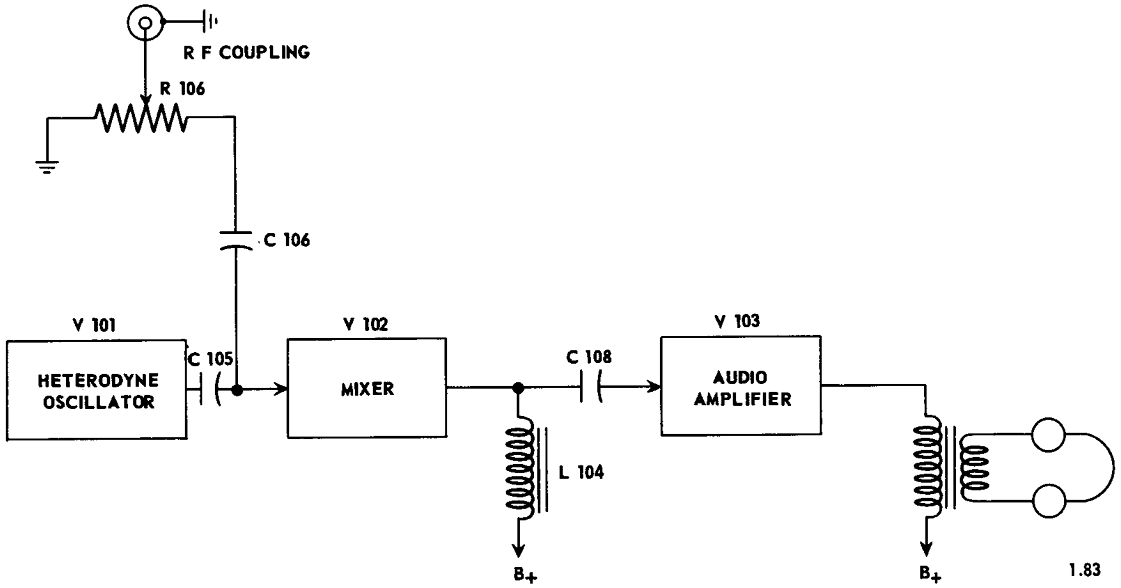
1.82

Figure 6-14.—Block diagram of LM-21 frequency meter when calibrating the heterodyne oscillator.

check point nearest the frequency to be measured, as shown in the calibration book. During the calibration procedure, r-f coupling R106 is grounded by a section of S104 to prevent interference from external r-f signals.

Figure 6-15 is a block diagram of the LM-21 frequency meter when it is used to tune a receiver or a transmitter to a given frequency. The modulation and crystal switches are in the OFF position for this operation. When a receiver is tuned, the heterodyne oscillator output is coupled through capacitors C105, C106, and potentiometer R106 to the receiver. The beat-frequency oscillator of the receiver is turned on, and the receiver is tuned until a zero beat is heard in the output of the receiver (not shown in the figure). It is assumed that the beat-frequency oscillator frequency is centered in the r-f band pass before the receiver tuning is accomplished.

When a transmitter is tuned, a portion of the transmitter oscillator signal is coupled into the

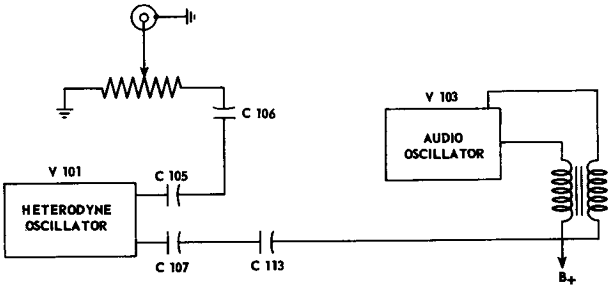


1.83

Figure 6-15.—Block diagram of the LM-21 frequency meter when tuning a transmitter or a receiver.

frequency meter through R106 and C106 to the mixer tube, V102. This signal from the transmitter is mixed with the output of the heterodyne oscillator. The difference frequency is developed across L104 and amplified by V103. The output of V103 may be fed to a phone jack in the switching system for convenience because the transmitter may be located at a distance from the frequency meter. A zero beat occurs when the transmitter frequency is the same as the frequency of the heterodyne oscillator.

Figure 6-16 shows a block diagram of the LM-21 frequency meter when it is used to tune an m-c-w receiver. The modulation switch is ON and the crystal switch is OFF. In this arrangement, the crystal oscillator-mixer is not used in the circuit. When the modulation switch is ON, the audio amplifier, V103, becomes a 500-cycle audio oscillator. The output of the audio oscillator is fed to the suppressor grid of the heterodyne oscillator where it modulates the r-f signals generated by this tube. The output is fed to the m-c-w receiver (not shown in the figure). No zero beat is heard. Instead, the receiver is tuned for maximum output of the 500-cycle modulating signal. The r-f coupling control, R106, is adjusted to produce the desired output signal.



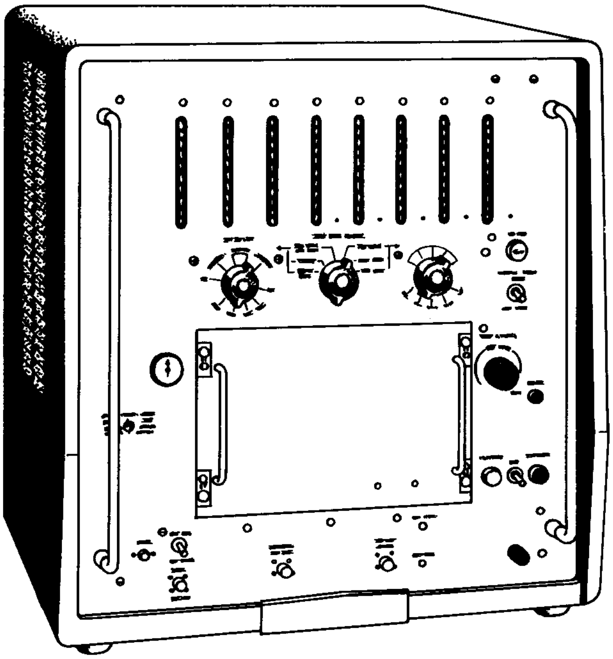
1.84

Figure 6-16.—Tuning an m-c-w receiver with the LM-21 frequency meter.

The power supply is a separate unit. This unit supplies the a-c filament voltage and the relatively high d-c plate voltage. The plate voltage is regulated so that the output frequency is stable, regardless of variations of the line voltage to the power supply.

Other types of heterodyne frequency meters are the LR, the OCP, the TS-186/UP, and the TS-535/U.

A COUNTER type frequency meter (fig. 6-17), Electronic Counter 524C/D (Hewlett-Packard), can measure frequencies from 10 cps



70.35

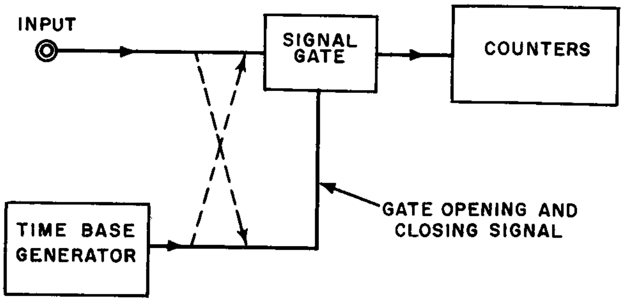
Figure 6-17.—Electronic counter, 524D.

to 10.1 megacycles and display the readings in digital form on an eight-place indicating system. In addition to making direct frequency measurements, the counter can measure periods (0 cps to 100 kc), frequency ratios and total events. A self-check feature enables an operator to verify instrument operation for most types of measurements. The internal oscillator is stable within 5 parts of 10^8 per week. Thus these counters make good secondary frequency standards.

To increase the range of measurement, seven accessory plug-in units (not shown) are available. Frequency Converter Units, Models 525A, B, and C, increase the frequency range from 10.1 to 100 mc, 100 to 220 mc, and 100 to 510 mc respectively. Video Amplifier unit 526A increases the basic set sensitivity to 10 mv in the range of from 10 cps to 10.1 mc; Time Interval unit 526B permits measuring time intervals from 1 μsec to 10^7 seconds; Period Multiplier unit 526C extends the period measurement range up to 10,000 periods of unknown frequency; and Phase unit 526D permits measuring phase angle with an accuracy approaching ±0.1°. In addition to the plug-ins, the Model 540B Transfer Oscillator extends, as a companion instrument, the frequency range up to 12.4 megacycles (10^9).

Measuring Frequency—The basic circuit arrangement of the Electronic counter is shown in figure 6-18. For frequency measurement the signal is fed through a Signal Gate to a series of digital type counters. A precision time interval obtained from the Time Base Section opens and closes the Signal Gate for an extremely accurate period of time, for example, 1 second. The counters count the number cycles entering through the gate during the 1-second interval and then display the total. The answer is read directly as the number of kilocycles occurring during the 1-second interval. The period of time the Signal Gate remains open is set by the FREQUENCY UNIT switch (not shown). For each position of the FREQUENCY UNIT switch the illuminated decimal point is automatically positioned so that the answer is always read directly in kilocycles. The answer is automatically displayed for a period of time determined by gate time or the setting of the DISPLAY TIME control on the front panel, whichever is greater.

Measured Period—To measure a period or time interval the application of the two signals reverses as shown by the doted lines in figure 6-18. The period or time interval to be measured is connected to open and close the Signal Gate while one of the standard frequencies from the Time Base Section is passed through the Signal Gate to the counters. When measuring period, one cycle of the incoming signal opens the gate, the next cycle closes it. The number of cycles of the standard frequency from the Time Base that occurred during the period are then indicated on the counters. The standard



70.36

Figure 6-18.—Basic diagram of the 524D.

frequencies obtained from the Time Base have been selected so that the answer to the measured period will always be displayed in direct-reading units of time: seconds, milliseconds, or microseconds.

Provision is also made in the circuit to permit measurement of the average of 10 periods of the unknown frequency. Higher accuracy can thus be obtained than with single period measurements.

The accuracy of frequency measurements is determined by an internal oscillator and by a possible error of ± 1 count that is inherent in the gate and counter type of instrument. At low frequencies, greater accuracy can be obtained by measuring the period of the signal than by measuring the frequency directly.

The block diagram (fig. 6-19A) shows the circuit arrangement of the basic counter when measuring frequencies in the range of 10 cps to 10.1 mc. To measure frequencies up to 510 mc, one of three frequency converter units is required (fig. 6-19B). As stated above, the 525C Frequency Converter unit is used between 100 and 510 mc. In these frequency converters the input signal is mixed with a harmonic of 10 mc so that the difference between the signal and the harmonic is not more than 10.1 mc. The difference frequency is counted and displayed by adding the count displayed by the counter to the known 10 mc harmonic.

All three frequency converters have tuning systems to indicate the correct mixing frequency. However, if the mixing frequency is within 1 mc of the unknown frequency, there is a possibility of two answers, for you may not know whether to add or subtract the displayed reading from the mixing frequency. In such cases, make additional measurements using the two adjacent mixing frequencies to determine the unknown frequency. When making the final measurement choose a mixing frequency which is at least 100 kc away from the unknown.

When measuring frequency, the counter will count sine waves, rectangular waves, and positive pulses. To measure the frequency of negative pulses, adjustment of a FREQUENCY sensitivity control is necessary. This control is a screwdriver adjustment located on the front panel.

When the counter is set for PERIOD measurements, the time base and the signal input circuits are interchanged from their frequency measurement positions (fig. 6-19C). With the circuits so connected, the counters count the output of the time base for the period of the unknown input signal. Thus the standard frequencies generated in the time base are used as units of time to measure the unknown period in terms of microseconds, milliseconds, or seconds.

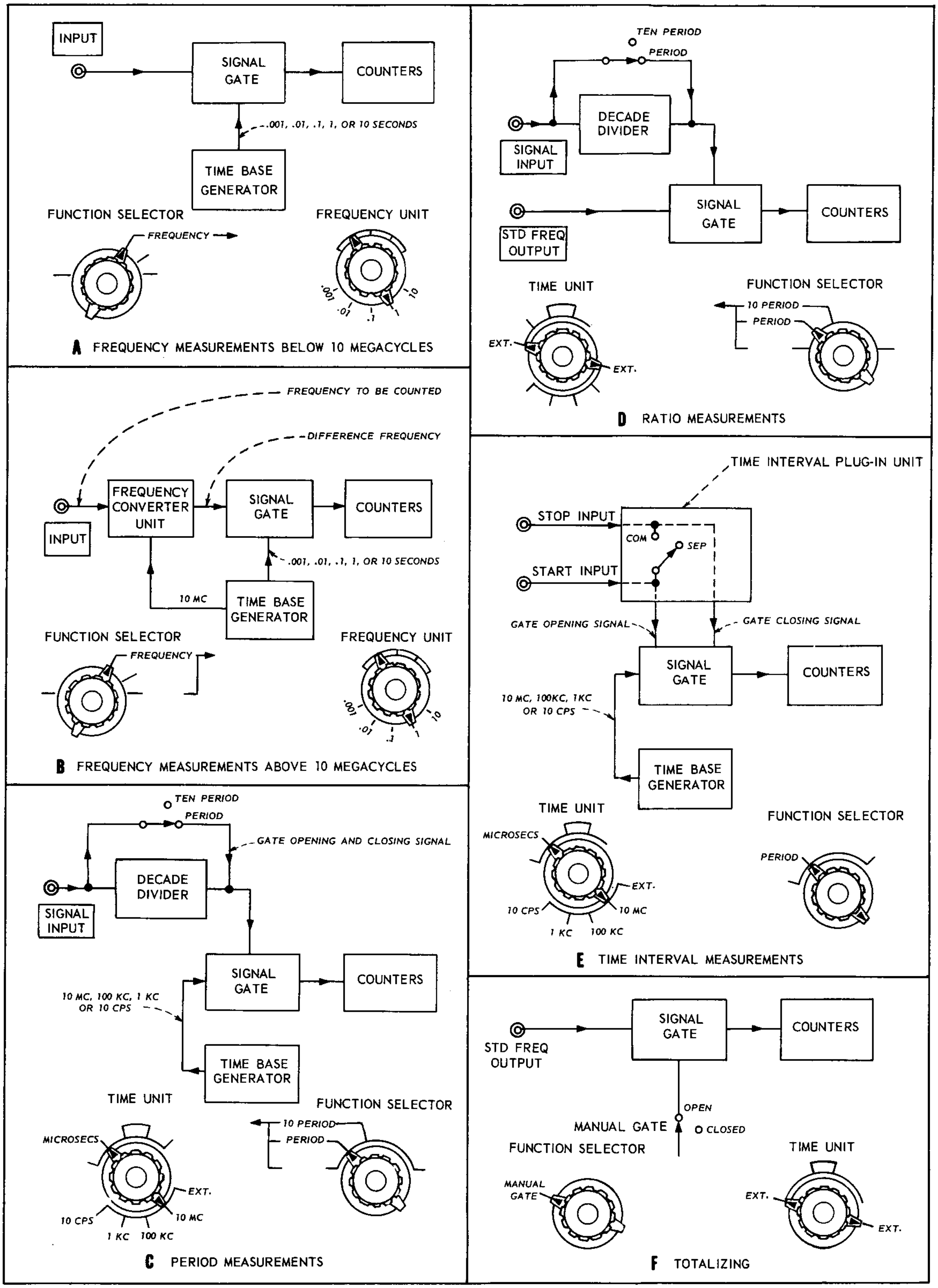
The accuracy of period measurements is largely determined by the accuracy with which triggering occurs at the same point on consecutive cycles of signal voltages having a slow rate-of-rise. Nore that when the signal-to-noise ratio improves, the triggering accuracy also improves. Averaged over ten periods, the single-period error is reduced by a factor of ten. If you use the 526C Period Multiplier unit, the error is reduced an additional factor of ten for each factor of ten you extend the measurement. The accuracy of triggering is considerably improved when the waveforms being measured have a fast rise time. For example, you can obtain a significant reduction in error if you apply square waves instead of sine waves to the input.

In order to follow the slowest-changing waveforms, the period measurement input circuits are direct-coupled and are adjusted to trigger at the zero-volt crossing of a negative-going voltage. Thus any d-c component in the input signal will shift the triggering level so that the maximum slope no longer occurs at the zero-volt level, resulting in a loss of accuracy. If the d-c component is large enough, there may be no triggering at all. An external generator can be used in place of the time base generator for period measurements.

The counter can be used to measure the RATIO of two frequencies. The higher frequency is passed through the signal gate to the counters and is counted for a period of time determined by either one period or ten periods of the lower frequency, which controls the opening and closing of the gate (fig. 6-19D).

Ratio measurement accuracy is determined by the same factors as period measurement accuracy: consistency of triggering by the lower input frequency and the inherent error of ± 1 count of the higher frequency. The 526C Period Multiplier unit is used to reduce the error by extending the number of periods of the lower frequency over which the measurement is made. For each factor of ten the measurement is extended, the error is decreased by a factor of ten.

Although the time base generator is not used during ratio measurements, you cannot make



70.37

Figure 6-19.—Test measurements, block diagram.

ratio measurements if the time base generator is not operating. The counter has a holdoff circuit which disables the signal gate if the time base generator fails.

To make TIME INTERVAL measurements (fig. 6-19E), the 526B Time Interval unit must be installed. Time interval measurements are similar to period measurements except that the points on the signal waveforms at which the measurement starts and stops are adjustable. The adjustable threshold feature allows you to make measurements from one part of the same waveform or to use separate waveforms as start and stop signals.

As in the case of period measurements, the input signals control the opening and closing of the gate while the standard frequencies are passed to the counters (fig. 6-19E). Thus the accurate frequencies generated in the time base are used as units of time to measure the unknown interval in terms of microseconds, milliseconds, or seconds.

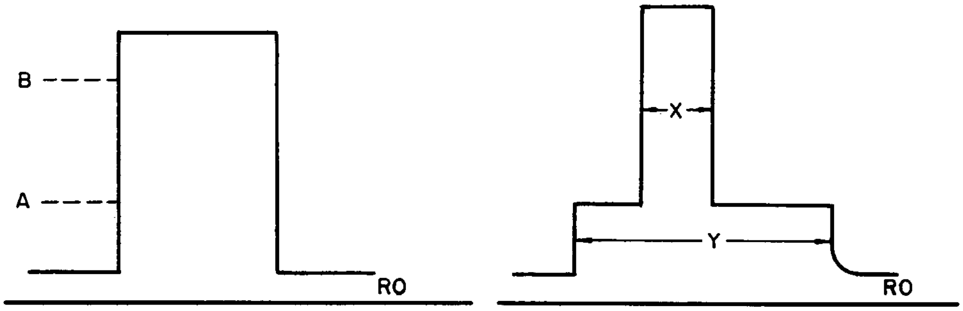
The threshold-selecting controls adjust the start and stop channels so that they will be actuated only by signals of predetermined polarity, amplitude, and slope. Time interval measurements begin when the start signal crosses the selected start threshold value in the selected direction and end when the stop signal crosses the selected stop threshold value in the selected direction. The threshold controls are only approximately calibrated, and in some applications you will have to take special precautions in order to obtain the desired interval.

If you use an uncomplicated waveform as the start and/or stop signal, the setting of the threshold controls is not critical. For example, if you use a sharp pulse like that shown in figure 6-20A, there will be little difference whether the measurement begins at point A or B. However, if you use a more complex waveform like that shown in fig. 6-20B to measure the interval X, set the threshold controls near zero as a preliminary adjustment. As you adjust first the start and then the stop threshold controls, you will notice definite changes in the measured time interval. Thus you know that the start and stop thresholds are above the step and that the indicated time interval is actually X.

It is highly desirable to examine both start and stop signals on a d-c coupled oscilloscope before you attempt a measurement. In this way you can determine that no spurious signals exist, and you will know how carefully you must set the threshold controls.

The 526B Time Interval unit may also be used as a high-speed totalizer capable of counting at a maximum rate of 10.1 million events per second. The basic circuit arrangement is indicated in figure 6-19F.

With a 526D Phase unit plugged into the counter, the phase angle between two signals of identical frequency, in the range from 1 cps to 20 kc, may be measured. This unit is useful for investigating, at various points in a circuit, the phase a signal has with respect to the phase it had at the input. Connect the reference signal to the REFERENCE INPUT, and the signal whose



A SIMPLE WAVEFORM SHOWING TWO POSSIBLE VOLTAGE LEVELS AT WHICH A TIME INTERVAL MEASUREMENT MAY BE STARTED

B TWO POSSIBLE TIME INTERVAL MEASUREMENTS OF A SINGLE COMPLEX WAVEFORM

70.38

Figure 6-20.—Time interval waveforms.

phase is under investigation to the UNKNOWN INPUT. If the frequency of the signal is 400 cps ±4 cps, phase angle is read directly in tenths of a degree. For a signal of some other frequency in the rated range, the information is read in time units, with resolution up to 0.1 μsec. For all phase measurements, set the phase unit PHASE/PERIOD switch to PHASE, the REFERENCE LEAD/LAG switch to the type of measurement desired, and the counter FUNCTION SELECTOR to PERIOD.

In general, circuit action for a phase measurement is similar to that for a time interval measurement. Trigger circuits in the Phase unit supply the pulses which open and close the signal gate in the counter. Arrangement of the circuits will be similar to that shown in figure 6-19E, for time interval measurements.

A recommended method of TUNING RADIO RECEIVERS USING A FREQUENCY COUNTER has been included in the EIB, No. 569. This method will soon become the accepted procedure for all such tuning.

The latest recommended frequency standard AN/URQ-9 (not shown) consists of three fixed frequencies. This frequency standard is a highly stable, multiple-purpose frequency standard designed for continuous-duty use aboard ship and at shore facilities. It provides three output frequencies, 5.0 mc, 1.0 mc, and 100 kc, and a regulated power output of 26.5 volts d-c at 0.5 amp for use by other equipment. The set can be used for laboratory frequency measurements and to drive precision timing devices such as a time comparator.

Receiver Sensitivity Measurements

RADAR.—The loss of radar receiver sensitivity has the same effect on reducing the range as a decrease in transmitter power. For example, a 6-db loss in receiver sensitivity shortens the effective range of a radar just as much as a 6-db decrease in transmitter power. Such a drop in transmitter power may be easily detected, but a comparable drop in receiver sensitivity is not so easy to detect unless accurate measurements are made.

A sensitive receiver is one that can pick up weak signals. The minimum discernible signal (MDS) is the weakest signal that produces a visible receiver output above the noise level of the receiver.

In the microwave range of operation, virtually all of the noise originates within the receiver. Atmospheric and manmade noise or static is normally too small to be considered.

Not all receiver noise originates in electron tubes. For example (because of the heat in the circuit conductors) there are certain amounts of random motion of the electrons other than the motion associated with the signal current. These motions produce voltages within the conductor that likewise vary in a random manner. The frequencies with which these voltages vary are distributed throughout the r-f spectrum and appear as noise in the receiver.

The power in watts developed by this form of noise is given by

$$\text{noise power} = KT\Delta F,$$

where K is Boltsmann's constant (1.37×10^{-23} watt-seconds per degree Kelvin), T is the temperature in degrees Kelvin (C° + 273), and ΔF is the bandwidth ($f_2 - f_1$) in cycles per seconds. Frequencies f_2 and f_1 are the upper and lower noise frequency limits (frequencies at which the noise voltage falls to 0.7 of the maximum).

This formula shows that thermal-agitation noise varies directly as the temperature and the bandwidth. In a theoretically perfect receiver having no noise except thermal-agitation noise, this noise could be considered as a voltage across the antenna terminals, and the power represented could be calculated on the basis of temperature and bandwidth.

In practice, the noise generated in a receiver is not limited to thermal-agitation noise. Additional noise sources are carbon resistors, which generate noise when current flows through them; crystal mixers; and electron tubes. Electron tubes generate noise because of random variations in electron emission from the cathode, random variations in current division between plate and screen, etc. In general, the more grids a tube has the more noise it generates.

The term, NOISE FIGURE (NF), indicates the amount of noise that is to be expected for a given receiver. It is the ratio of measured noise to calculated noise and may be expressed as a power ratio or in decibels. There are, however, variations in the way the noise figure may be expressed.

The three main sources of noise in a radar receiver are: first, the crystal mixer; second, the i-f preamplifier; and third, the local oscillator.

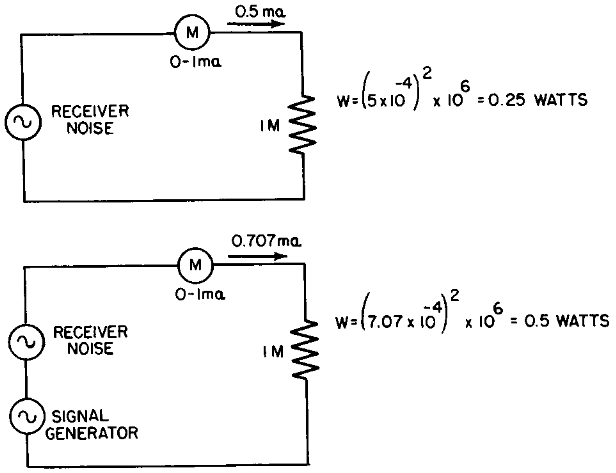
If the noise in a certain radar receiver becomes too high, something must be done to reduce it. First of all, another crystal mixer is substituted; in practice, several may be used in turn and the one with the lowest noise chosen. The same precedure is used for the i-f preamplifier tubes. If the noise is still high, the local oscillator tube is replaced. It should be noted that the noise of a reflex klystron is much greater than normal when the tube is tuned off the center of a mode (a proper operating frequency).

The noise figures of early radars were in excess of 20 db, but modern receivers have noise figures between 6 and 18 db.

The noise figure of a radar receiver may be determined by the use of a noise generator or a c-w signal generator. The noise-generator method is more accurate.

A practical example will illustrate how a noise generator may be used to determine the noise figure of a radar receiver. The following are the steps that are involved in making the measurement:

1. A 0-1 milliammeter is connected in series with the diode load resistor of the second detector.
2. The receiver input is grounded, and the receiver gain control adjusted to produce a 0.5-ma reading. This reading is due to the internal noise alone.
3. The input ground is removed and the noise generator connected to the input of the receiver.
4. The output of the noise generator is adjusted until the meter reads 0.707 ma—that is (1.4 X 0.5 ma). The receiver gain control is NOT adjusted after the initial adjustment in step (2).
5. If in step (4) a further increase in noise input does not cause a corresponding increase in meter reading, the receiver is limiting and the readings will not be accurate. The procedure is to start with step (2) again and to reduce the receiver gain-control setting until the meter reads less than 0.5 ma. For example, reduce the reading to 0.3 ma. In step (4) the output of the noise generator should be adjusted to make the meter read 0.42 ma—that is (1.4 X 0.3 ma).
6. The noise-generator power output is now equal to the receiver noise power. This may be understood from the following. The resistance of the diode load resistor remains constant, and therefore the power dissipated in it varies as the square of the current, as read on the meter.



70.39

Figure 6-21.—Simple power analogy.

A simple analogy is shown in figure 6-21. As may be seen in the figure, when the current increases from 0.5 ma to 0.707 ma, the power is doubled. When the output of the noise generator is added to the receiver noise, and the output across the 1M resistor is doubled, the output of the noise generator is equal to that developed by the receiver noise. A chart is usually furnished with the instrument for converting the dial reading to power for various load resistances.

7. The noise figure (NF) is determined as follows:

$$\text{NF (db)} = 10 \log \frac{\text{power measured}}{\text{power calculated}} \cdot$$

Noise energy (calculated) has already been given as

$$\text{NP} = 4\ \text{KT}\ \Delta f.$$

Assume that the temperature is 20°C and that the receiver bandwidth is 4×10^6 cycles $(f_2 - f_1)$.

$$\begin{aligned}\text{NP} &= 4(1.37 \times 10^{-28}) \times (20 + 273) \times (4 \times 10^6) \\ &= 6422.56 \times 10^{-17} \\ &= 0.06423\ \mu\mu\text{W}.\end{aligned}$$

Assume that the measured noise power of the receiver is $1.018\ \mu\mu$W. The noise figure in db is then

$$\begin{aligned}\text{NF (db)} &= 10 \log \frac{1.018}{0.0642} \\ &= 10 \log 15.86 \\ &= 10 \times 1.2 \\ &= 12\ \text{db}.\end{aligned}$$

Overall radar system sensitivity measurements are included in the following chapter under the treatment of the echo box.

RADIO.—The one measurement that provides maximum information about receiver condition in field operation is that of sensitivity.

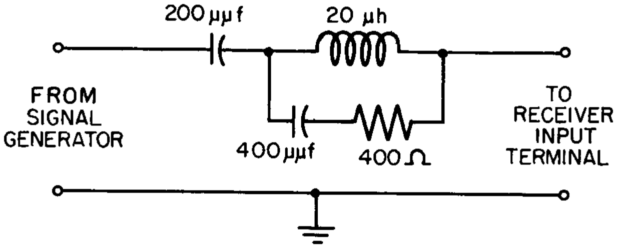
The sensitivity of a radio receiver is an indication of its ability to give a satisfactory output with a weak signal input. Although there may be some variation in the exact wording of the definition, sensitivity is the value of input carrier voltage that must be fed from the signal generator to the receiver input to develop a specified output power. The settings of the various controls are specified as well as the modulation frequency and percentage of modulation.

In many Navy receivers, sensitivity is the magnitude of signal voltage (in microvolts) that must be fed to the receiver antenna terminals in order to produce a standard output of 6 mw across a 600-ohm noninductive resistance substituted for the headphones or other device at the receiver output terminals. A signal-to-noise ratio of 10:1 is maintained for this test.

This measurement ordinarily requires the application of a calibrated input signal voltage to the antenna terminals of the receiver through an impedance, which approximates that of the antenna with which the receiver is to be used. This impedance is usually known as a DUMMY antenna. The dummy antenna ensures that the signal current in the input circuit of the receiver is the same as would appear with the calibrated signal voltage induced in an ideal receiving antenna. It also ensures that the input circuit of the receiver is "loaded" the same as it would be by an ideal antenna.

A dummy antenna that may be used with high-impedance input receivers is shown in figure 6-22. In the case of low-impedance input receivers of 50 to 70 ohms nominal impedance, a signal generator with a 50-ohm output, may be directly connected without the use of an external dummy antenna. Other generator impedances may require special dummy-antenna networks to load the generator and the receiver properly.

For sensitivity measurements, the receiver is adjusted for the type of reception desired. Controls, such as AGC, silencer, noise limiter, etc, are set according to the instructions in the instruction book. The power-line voltage and frequency applied to the receiver should be within the recommended operating range. The



1.65

Figure 6-22.—Dummy antenna circuit.

receiver output terminals should be properly loaded by substituting for the headphone or audio-line termination a 600-ohm noninductive resistor capable of dissipating the maximum output power (approximately 6 mw for this test).

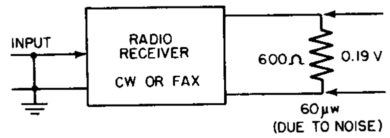
High-impedance headphones may be used in shunt with the load for monitoring the output. Low-impedance headphones would load the output appreciably. The output voltage is measured with a high-impedance audio voltmeter capable of accurate indication from 0.1 v to 100 v. Although some receivers are equipped with audio output meters, their meters may not indicate the required standard noise levels with sufficient accuracy.

Detailed instructions for making sensitivity measurements are included in the instruction book that accompanies a particular receiving equipment. In some of these instruction books detailed information for making sensitivity checks for the various sections of the receiver are given. In other instruction books instructions for making sensitivity tests are included in receiver final testing.

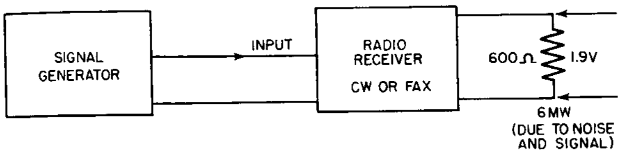
A general idea of one method of making sensitivity measurements on c-w and facsimile receivers may be obtained from the following considerations. The test setup is shown in figure 6-23.

In part A, no signal is applied (input grounded), and the r-f gain control is adjusted to produce 60 μw (0.06 mw) of noise at the output—that is, 0.19 v across 600 ohms. This is the power developed by the noise. No further adjustment of the gain controls (either r-f or a-f) is made during the remainder of the test.

If a db meter is used to obtain this indication of noise level, the meter reading will be in decibels. For example, if the total resistance of the load is 600 ohms, and zero db is equivalent to 1 db (1 mw in 600 ohms), the indication of



A MEASUREMENT OF INTERNAL NOISE POWER



B MEASUREMENT OF SIGNAL & NOISE POWER

70.40

Figure 6-23.—One method of making radio receiver sensitivity measurements.

the output meter will be $10 \log \frac{0.06 \times 10^{-3}}{1 \times 10^{-3}}$, or -12.2 db.

In part B, the unmodulated carrier signal is applied. The c-w oscillator frequency (receiver BFO) control is adjusted to produce a 1000 cps beat note. The input signal voltage to the receiver from the signal generator is then adjusted to produce an output of 6 mw. The value of voltage across 600 ohms required to produce this output may be calculated as follows:

$$\begin{aligned} E &= \sqrt{PR} \\ &= \sqrt{0.006 \times 600} \\ &= 1.9 \text{ V} \end{aligned}$$

If the same db meter is used to obtain this indication, the signal generator output is adjusted so that the meter reading will be

$$10 \log \frac{6 \times 10^{-3}}{1 \times 10^{-3}}, \text{ or } 7.78 \text{ db.}$$

The output signal-to-noise ratio (actually the signal-plus-noise to noise ratio), using the output voltages, is

$$\text{signal-to-noise ratio} = \frac{1.9 \text{ volts}}{0.19 \text{ volts}} = 10,$$

or a 10: 1 ratio; the power ratio is 100:1. The signal-to-noise ratio in db in terms of the power ratio is

$$\text{db} = 10 \log \frac{6 \times 10^{-3}}{60 \times 10^{-6}} = 20 \text{ db.}$$

The receiver sensitivity, in terms of input signal voltage in microvolts, is obtained from the signal-generator voltage calibration chart. For the example being considered, the input signal voltage is approximately 5 μv. Thus, the receiver sensitivity is expressed as 5 μv input to produce an output of 6 mw when the signal-to-noise ratio is 10 to 1. The correct sensitivity will appear in the Performance Standards Book for the receiver as a part of the data provided with the receiver.

MEASUREMENTS IN TRANSISTOR CIRCUITS

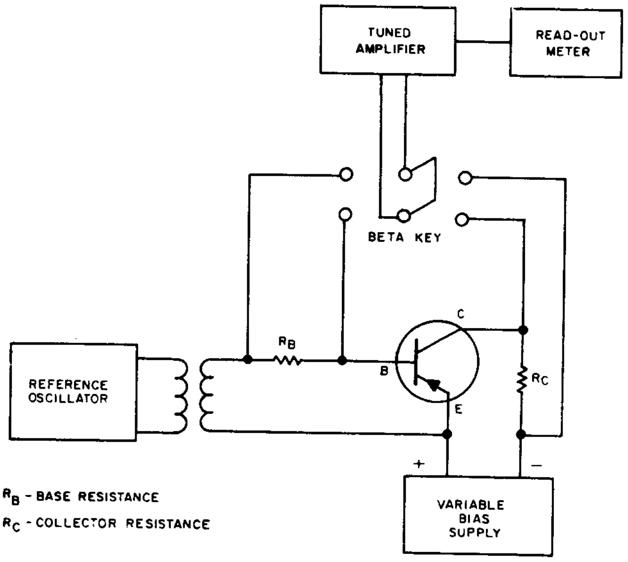
The many types of transistor base connection arrangements (discussed later in this training course) require that the leads be properly identified to secure correct hookup to the tester. The TS-1100/U test socket arrangement is compatible with some transistor types, but not all types. If the leads are long enough, it is generally possible to effect proper hookup by bending them. If the leads are too short, it will be necessary to use the test cable and alligator clips provided with the tester. In all cases, however, the transistor leads should be identified and then matched up with the tester connections.

The great advantage of the TS-1100/U lies not only in its accuracy and simplicity, but also in its use of a-c as the testing current. This eliminates interference from any d-c currents and voltages that may be present and permits measurement of the gain of a transistor in-circuit, thus making it unnecessary to unsolder or disconnect the transistor for this test. This is particularly advantageous where the transistor is mounted on a module printed wiring board.

The a-c testing current is provided by means of a built-in oscillator and amplifier. To avoid possible interference from other frequencies, the amplifier is sharply peaked for a single frequency, 2250 cycles per second. The test current is then rectified and read on a microammeter which has a full-scale deflection of 50 microamperes. The test is also provided with a variable bias supply. The method of determining beta for a given transistor is shown in figure 6-24. When the proper adjustments are made according to the instructions in the instruction book, the value of beta will be indicated directly on the meter.

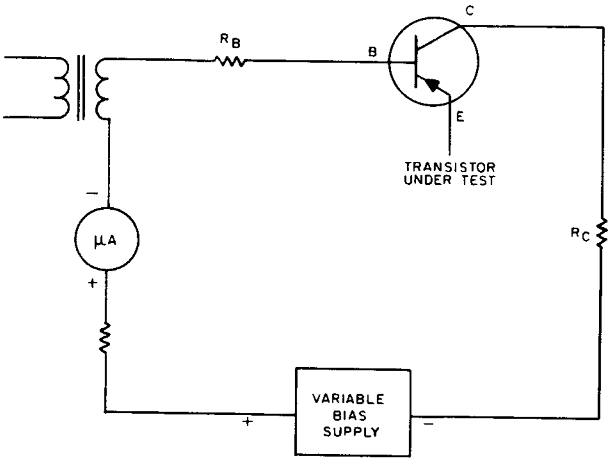
TS-1100/U is also designed to measure collector leakage current, I_{CO}, which is read directly on the meter. The circuit arrangement is shown in figure 6-25. The technical manual for the test set provides information concerning the collector bias to be applied for a particular transistor and the maximum permissible collector leakage current.

However, since this current is d-c, the reading may be affected by other d-c potentials in the circuit. For this reason it is necessary to remove the transistor from the circuit in order to obtain an accurate measurement of collector leakage current.



70.41

Figure 6-24.—Measuring beta, using Transistor Test Set TS-1100/U.



70.42

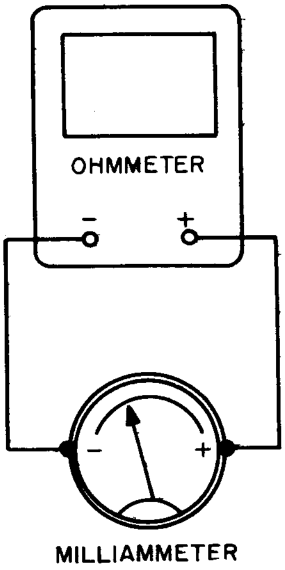
Figure 6-25.—Measuring collector leakage current, Ico, using Transistor Test Set TS-1100/U.

The test set is also equipped to indicate a short between any two of the three elements of the transistor under test. With the transistor in-circuit, it will also indicate a short if the circuitry between any two of the transistor elements has a resistance of 500 ohms or less. To determine whether the short is in the transistor itself or in the associated circuit, it is necessary to remove the transistor from the circuit.

The test set has the following additional features: a switch marked PNP-NPN, which selects the proper bias polarity for the type of transistor under test; a temperature alarm indicator lamp, which will light when the ambient temperature surrounding the equipment exceeds 50°C; and a switch marked TEST, which checks the test set battery output.

In conjunction with the transistor test set, multimeters, when used for voltage measurements should have a sensitivity of 20,000 ohms per volt or better on all voltage ranges. Meters with a lower sensitivity will draw too much current from the circuit under test when used in their low-voltage ranges. A VOM (20,000 ohms-per-volt) or an electronic voltmeter (VTVM) with an input resistance of 11 megohms or higher on all voltage ranges is preferred. However, a VTVM should be used with an isolating transformer between the VTVM and the power line.

Ohmmeter circuits which pass a current of more than 1 milliampere through the circuit under test cannot be used safely in testing transistor circuits. Many electronic voltmeters have ohmmeter circuits which exceed this safe value of 1 milliampere. High-sensitivity multimeters often are shunted on ohmmeter ranges, so that they also pass a current of more than 1 ma through the circuit under test. Before using any ohmmeter on a transistor circuit, the circuit it passes under test should be checked on all ranges. Do not use any range which passes more than 1 ma. To check the current, adjust the ohmmeter for resistance measurements; then connect a milliammeter in series with the test leads (fig. 6-26), and observe the indication on the milliammeter. The meter used should have a low resistance such as contained in Multimeter TS-352A/U or equivalent.



70.43

Figure 6-26.—Measuring current passed by ohmmeter.