CHAPTER 11

PRACTICAL APPLICATION OF TEST EQUIPMENT

One of the most important parts of the CT M training program is learning to use test equipment in all types of maintenance work. To be effective in this work, the CT M must become familiar not only with the common types of measuring instruments (like the ammeter, voltmeter, and ohmmeter) but also with the more specialized equipment like vector voltmeters, dual-trace oscilloscopes, power and frequency meters, and impedance bridges.

The purpose of this chapter is to 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 Also, outdated or specialized equipment for testing or servicing electronic equipment that is no longer aboard is of no value.

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 failure can be avoided by careful handling, proper use of the equipments, and proper stowage.

Much of the theory of operation and the practical application of the basic types of test instruments used in electric power and lighting circuits are included in *Basic Electricity*, NAVPERS 10086. A brief treatment of electronic test equipment is included in *Basic Electronics*, NAVPERS 10087. It is suggested that you review that material at this time. Additional practical information will be found in the instruction books that accompany the various equipments. Another very valuable source of information is *Standard General Purpose Electronic Test Equipment*, MIL-STD-1364C (NAVY).

MIL-STD-1364C lists the preferred electronic test equipment in current use by the Navy and gives the characteristics of each piece of equipment.

Some idea of the extent of the test equipment needed at an installation may be gained from the following list of equipments used for testing electronic equipment. The list is not complete; however, it is representative.

Electronic Digital Multimeter, 89536-8000A/BU
AC/DC Differential Voltmeter, 89536-893A
Tube Tester, AN/USM-118C
Oscilloscope, AN/USM-281A
Impedance Bridge, 11837-250DE
Audiofrequency Signal Generator, 28480-201C
Radiofrequency Signal Generator, 28480-8640B-001-003
Frequency Counter, AN/USM-207
Teletype Distortion Analyzer, AN/USM-329(V)
Semiconductor Test Set, AN/USM-206A
A/C Vacuum Tube Voltmeter, 28480-400E
Radiofrequency Power Meter, 70998-43
Vector Voltmeter, 28480-8405A
Wave Analyzer, 28480-310A
Time Domain Reflectometer, 28480-140A

TEST EQUIPMENT SAFETY PRECAUTIONS

The electrical measuring instruments included in portable test equipment are delicately constructed and require certain precautions when they are handled to avoid damaging them. In addition, there are precautions that must be observed while using portable test equipment to avoid injury to personnel.

Three precautions that apply to all electrical measuring instruments to avoid damage are as follows:

1. Avoid mechanical shock. Instruments contain permanent magnets, meters, etc., which are sensitive to shock. Heavy vibrations or shock can cause loss of calibration to the instruments.
2. Avoid exposure to strong magnetic fields. Strong magnetic fields may permanently impair the accuracy of an instrument by leaving residual magnetic effects in the magnet, iron parts, or in the magnetic materials used to shield the instruments. Locations subjected to strong magnetic fields include regions near the pole pieces of large motors and generators, degaussing coils, electrical propulsion cables, submarine main storage battery leads, and radar magnetrons.
3. Avoid excessive current flow. This includes various precautions, depending on the type of instrument. When in doubt, use the maximum scale range of the instrument. Connections should be made while the circuit is deenergized if possible and then all connections checked to ensure that the instrument will not be overloaded before energizing.

Other precautions to be observed to avoid instrument damage include the following:

1. Keep in mind that the coils of wattmeters, frequency meters, and power meters may be carrying excessive current even when the meter pointer is on scale.
2. Secondaries of current transformers should never be short-circuited when the primary is energized.
3. Secondaries of potential transformers should never be short-circuited when the primary is energized.
4. Ensure that meters in motor circuits can handle the motor starting current which may be as high as 6 or 8 times normal running current.
5. Never leave an instrument connected with its pointer off-scale or deflected in the wrong direction.
6. Never attempt to measure the internal resistance of a meter movement with an ohmmeter, as the movement may be damaged by the current required to operate the ohmmeter.
7. Never advance the intensity control of an oscilloscope to a position which causes an excessively bright spot on the screen or permits a sharply focused spot to remain stationary for any length of time.
8. When checking electron tubes with a tube tester always perform the inter-element short test first. If the tube is shorted, no further tests should be made.
9. Before measuring resistance, always discharge capacitors in the circuit to be tested. Note and record any points not having bleeder resistors or discharge paths for capacitors.
10. Always disconnect voltmeters from field circuits or other highly inductive circuits before the circuit is opened.

Situations can arise during the use of portable test equipments that are extremely dangerous to personnel. For example, you may have an oscilloscope plugged into one receptacle, and electronic voltmeter plugged into another, and a soldering iron in still another, using an extension cord, or many other combinations. Some of the hazards presented by situations such as these are coming into contact with live terminals or test leads, or accidentally knocking the equipments to the deck, which may possibly entangle personnel in the leads or cords and cause severe or fatal shock. In addition, the situation may be such that a potential difference exists between the metal cases of two or more instruments sufficient to cause harmful shock.

Wires attached to portable test equipment should extend from the back of the instruments away from the observer if possible. If this is not possible, they should be clamped to the bench or table near the instruments.

When used in places where vibration is present, the instruments should be placed on pads of folded cloth, felt, or similar material.

Precautions to be observed to avoid injury to personnel include the following:

1. Ensure that the metal cases of all instruments are grounded.

2. Ensure that one side of the secondary of external instrument transformers is also grounded.

3. If equipment must be energized for testing after removal from its normal rack or mounting, ensure that all parts normally at ground potential are securely grounded.

4. Avoid testing voltages in excess of 300 volts when holding test probes in the bare hands.

BASIC MEASUREMENTS

Basic electrical and electronic measurements involve the fundamental electrical quantities (voltage and current) and the inherent circuit characteristics (resistance, capacitance, and inductance).

VOLTAGE AND CURRENT

Voltage measurements, when compared with voltage charts, provided for a specific piece of equipment, are a valuable aid in locating trouble quickly and easily. However, if the sensitivity of the test voltmeter differs from that of the voltmeter used in preparing the chart, the voltage measurements must be evaluated before the true circuit conditions can be determined. It should be kept in mind that in certain cases a voltmeter, particularly one of low sensitivity used on a low range, may disturb some circuits to such a degree as to render them inoperative.

Since many troubles encountered in equipments and systems result from or cause abnormal voltages, voltage measurements are considered indispensable in locating trouble. Testing techniques that utilize voltage measurements have the advantage over other tests of not interrupting circuit operation. Point-to-point voltage measurement charts, which contain the normal operating voltages encountered in the various stages of the equipment, are available to the technician. These voltages are usually measured between the indicated points and ground, unless otherwise stated. When voltage measurements are taken, it is considered good practice to set the voltmeter on the highest range initially, so that any excessive voltages existing in a circuit will not cause overloading of the meter. To obtain increased accuracy, the voltmeter may then be set to the designated range for the proper comparison with the representative value given in the voltage charts. When checking voltages, it is important to remember that a voltage reading can be obtained across a resistance, even if that resistance is open. The resistance of the meter (and the multipliers) forms a circuit resistance when the meter prods are placed across the open resistance. Thus, the voltage across the part may appear to be approximately normal, as read on the meter, but may be abnormal when the meter is disconnected from the circuit. Therefore, to avoid unnecessary delay in troubleshooting, it is good practice to make a resistance check on a "cold" circuit (before applying power) to determine whether the resistance values are normal.

If the internal resistance of the voltmeter and multiplier is approximately comparable in value to the resistance of the circuit under test, it will indicate a considerably lower voltage than the actual voltage present when the meter is removed from the circuit. The sensitivity (in ohms-per-volt) of the voltmeter used to prepare the voltage charts is always given on those charts, therefore, if a meter of similar sensitivity is available, it should be used, so that the effects of loading will not have to be considered.

The following precautions are general safety measures, pertinent to the measurement of voltages, that you should follow when working with electronic equipment. You should constantly keep in mind that almost all voltages are dangerous and can possibly be fatal if contacted. When it is necessary to measure high voltages, the following precautions should be observed:

1. Connect the ground lead of the voltmeter first. While making measurements, place one hand in a pocket or behind the back.

2. If the voltage to be measured is less than 300 volts, place the end of the test probe on the point to be tested, which may be either positive or negative with respect to ground.

If the voltage to be measured is more than 300 volts, proceed as follows: shut off the circuit power, discharge any filter capacitors, and pulse-forming networks several times, and temporarily ground the point to be measured; then connect (clip on) the proper test lead to the high potential point, and move away from the voltmeter. Turn on the circuit power and read the voltmeter. Turn off the circuit power again and discharge any capacitors and pulse-forming networks several times before disconnecting the meter.

Current measurements, as a rule, are not often taken in the course of testing, unless the ammeter (or other current-measuring meter) is an integral part of the equipment being tested. Current measurements are infrequently used because in most cases the circuit must be opened (unsoldered) for the necessary series connection of the ammeter. Usually, a voltage measurement and a calculation by means of Ohm's law are sufficient to determine the circuit current. In a circuit of extremely high resistance, a current measurement is inadvisable because the current may be so low that it cannot be measured accurately with ordinary test equipment.

RESISTANCE

Resistance measurements are valuable in locating trouble. Hence, many maintenance handbooks contain resistance charts which are referenced to accessible points within the equipment. Without these charts, making resistance measurements in a complex circuit is a slow process, sometimes necessitating the unsoldering of one side of a particular resistor or group of resistors in order to prevent erroneous readings as a result of shunting circuits. It is important that the operation of ohmmeters and the calibration of their scales be understood, especially on the high ranges, since often it is impossible to attain reasonable accuracy when the meter is operated at its maximum range. For best results select a range that will indicate a near mid-scale reading on the meter.

For an ohmmeter to be used for troubleshooting, portability, convenience, and speed are considered of greater importance than extreme accuracy. Resistor tolerances vary so widely that approximate resistance readings are adequate for most jobs, with the exception of bridge circuits, voltage dividers, and balanced circuits. Two precautions to be observed when an ohmmeter is used are: (1) the circuit under test (including heaters of tubes) must be completely deenergized; and (2) any meters, tubes, or transistors which may be damaged by the ohmmeter current must be removed before any measurement is made. It is not practicable to measure very low values of resistance with an ohmmeter, because of the effect of lead and contact resistance and the possibility of damage to the electronic parts under test. For precision measurement of low values of resistance, a special type of bridge instrument must be used.

Multimeters

During troubleshooting, a technician is often required to measure voltage, current, and resistance. To eliminate the necessity of obtaining three or more meters, the multimeter is used. The multimeter contains a voltmeter, ammeter, and ohmmeter in one unit. Multimeters are of two types, electronic and nonelectronic.

NONELECTRONIC MULTIMETERS.—Nonelectronic multimeters combine the necessary circuitry for the measurement of a.c. voltages, d.c. voltages, d.c. currents, and resistances. These instruments are often called volt-ohm-milliammeters or VOM's.

One of the greatest advantages of a VOM is that no external power source is required for its operation and therefore no warmup period is necessary. Other advantages are its portability, versatility, and freedom from calibration errors due to aging tubes, line voltage variations, etc.

Some of the disadvantages of the VOM are its circuit loading characteristics, short scale, and danger of damage to the meter movement as a result of negligence in the testing procedures.

ELECTRONIC MULTIMETERS.—The introduction of any meter into a circuit will cause energy to be taken from that circuit. The amount of energy taken will depend upon the meter sensitivity. The extraction of energy cannot be avoided, and in some circumstances cannot be tolerated. For example, in extremely sensitive circuits (i.e., oscillator grid circuits, automatic volume control circuits, etc.,) disruption of normal circuit operation will occur, often resulting in failure to obtain a usable indication.

Primarily for this reason, an electron tube is often used in conjunction with a *nonelectric meter* to provide a very high shunting resistance across the circuit under test, and to increase the relative sensitivity of the instrument.

The use of electronic multimeters, often referred to as VTVM's, are therefore very practical in sensitive electronic circuits where only extremely small amounts of energy can be extracted without disturbing the circuits under test or causing them to become inoperative. The electronic multimeter has the disadvantage of requiring an external power source.

One example of an electronic multimeter which is in use within the Navy, is the Electronic Digital Multimeter 89536-8000A/BU shown in figure 11-1. The Electronic Digital Multimeter 89536-8000A/BU overcomes the disadvantage of requiring a continuous external power source by combining an external a.c. source with an internal rechargeable battery. The 89536-8000A/BU is in common use in the Navy as a replacement for both the nonelectronic and the conventional electronic multimeter.

AC/DC Differential Voltmeter

The AC/DC Differential Voltmeter is capable of being used as a conventional vacuum tube voltmeter or as a precision potentiometer. It can also be used to measure the excursions of a voltage about some nominal value. One feature

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Figure 11-1.—Electronic Digital Multimeter 89536-8000A/BU.

of a differential voltmeter is that no current is drawn from the unknown source for d.c. measurements when balance is attained. Thus the determination of the unknown d.c. potential is independent of its source resistance.

An unknown voltage is measured in this type of voltmeter by comparing the unknown voltage to a known adjustable reference voltage with the aid of a built-in null detector. An accurate standard for measurements is obtained by setting the reference power supply with a standard battery cell or Zener reference diode. The known adjustable reference voltage is provided by a high voltage d.c. power supply and Kelvin-Varley decade resistor strings that are set accurately by voltage readout dials. In this way, the output from the high voltage power supply can be precisely divided into increments as small as 10 microvolts. The unknown voltage is then simply read from the voltage dials.

When used as an a.c. differential voltmeter the a.c. input voltage is converted to a d.c. voltage and measured in the same manner as an unknown d.c. voltage.

One example of an a.c./d.c. differential voltmeter which is in common usage within the Naval Security Group is the 89536-893A (figure 11-2).

The 89536-893A is a solid state differential voltmeter which provides nonloading d.c. voltage measurements of ± 10 microvolts to ±1100 volts. AC voltages of 0.001 to 1100 volts may be measured over a frequency range of 5 Hz to 100 kHz. It has four voltage readout dials which varies the resistance of the Kelvin-Varley divider assembly as described above.

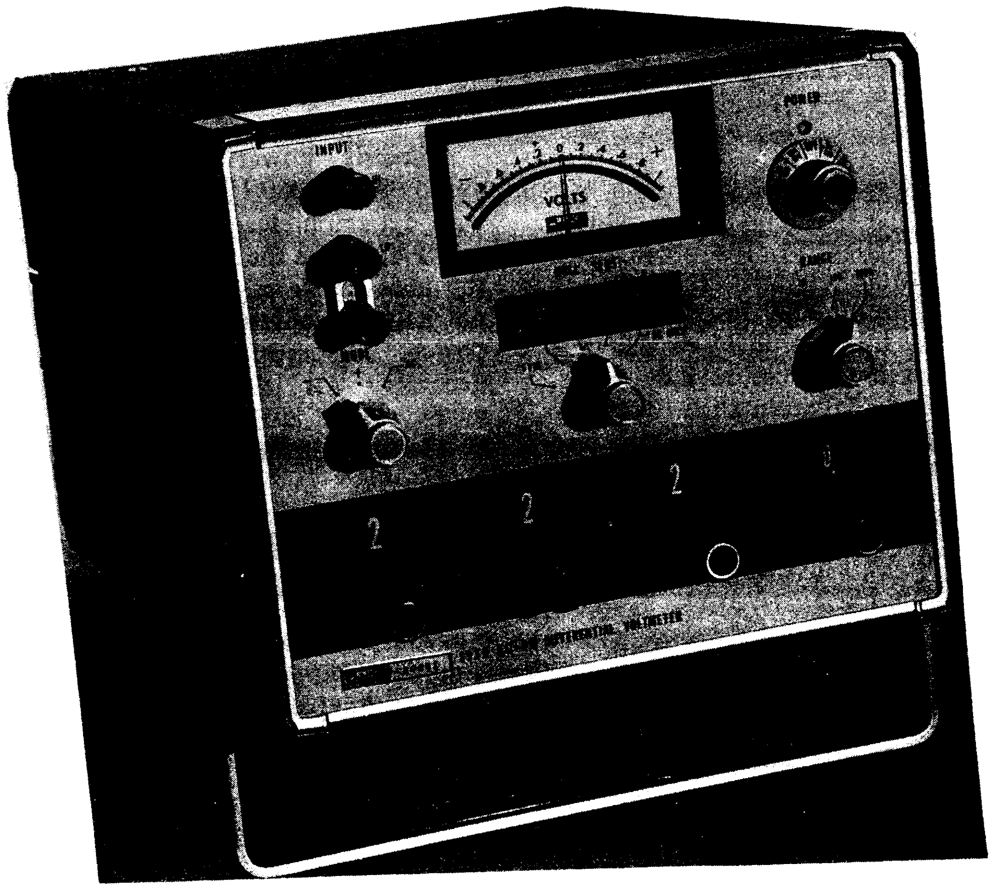

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Figure 11-2.–AC/DC Differential Voltmeter 89536-893A.

CAPACITANCE

Capacitance measurements are usually accomplished by either a bridge-type or a reactance-type capacitance meter. For accuracy, the former equipment is comparable to the resistance bridge, and the latter instrument is comparable to the ohmmeter. Capacitance tolerances vary even more widely than resistance tolerances, dependent upon the type of capacitor, the value of the capacitance, and the voltage rating. The results of capacitance tests must be evaluated to determine whether a particular capacitor will fulfill the requirements of the circuit in which it is used. The power factor of a capacitor is important because it is an indication of the various losses attributable to the dielectric, such as current leakage and dielectrical absorption. Current leakage is of considerable importance, especially in electrolytic capacitors. The measurement of capacitance is very simple; however, you must make the important decision of whether to reject or continue to use a certain capacitor after it has been tested.

INDUCTANCE

Inductance measurements are seldom required in the course of troubleshooting. However, in some cases inductance measurements are useful and instruments are available for making this test. Many capacitance test sets can be used to measure inductance. Most manufacturers of capacitance test sets furnish inductance conversion charts if the test equipment scale is not calibrated to read the value of inductance directly.

CAPACITANCE-INDUCTANCE-RESISTANCE BRIDGES

Capacitance, inductance, and resistance are measured for precise accuracy by alternating current bridges which are composed of capacitors, inductors, and resistors in a wide variety of combinations. These bridges operate on the principle of the Wheatstone bridge, in which an unknown resistance is balanced against known resistances. The unknown resistance is calculated in terms of the known resistance after the bridge has been balanced. One type of impedance bridge, the 11837-250DE, is shown in figure 11-3.

POWER MEASUREMENTS

It is often necessary to check the power consumption and the input and output signal power levels of communication and electronic equipment. The determination of d.c. power is comparatively simple; the unit of power (the watt) is the product of the potential in volts and the current in amperes.

As discussed in *Basic Electricity,* NAVPERS 10086, to make accurate a.c. power measurements, the phase angle of the voltage and current must be considered. The measurement of a.c. power is further complicated by the frequency limitations of various power meters. If there is no phase difference, a.c. power may be computed in the same manner as d.c. power; by determining the average value of the product of the voltage and current.

Electric power at a line frequency of approximately 60 Hz may be measured directly by a dynamometer-type wattmeter. This type of meter indicates the actual power, and, therefore, the phase angle of the voltage and current does not have to be determined. Normally, the exact power consumption of equipment is not necessary for maintenance, and a current measurement is sufficient to permit you to decide whether the power consumption is within reason.

In the audiofrequency range, power levels have to be determined in the course of routine checks and during corrective maintenance procedures. When working with audiofrequency amplifiers, it is ordinarily easier and more convenient to measure voltage, current, and impedance and then compute the power than it is to measure power directly. Power measurements for audiofrequency circuits are usually indicated in terms of decibels (dB), decibels referenced to one milliwatt (dBm), or volume units (vu). The power gain of an amplifier can be expressed in dB. The power level of a sinusoidal signal compared to a

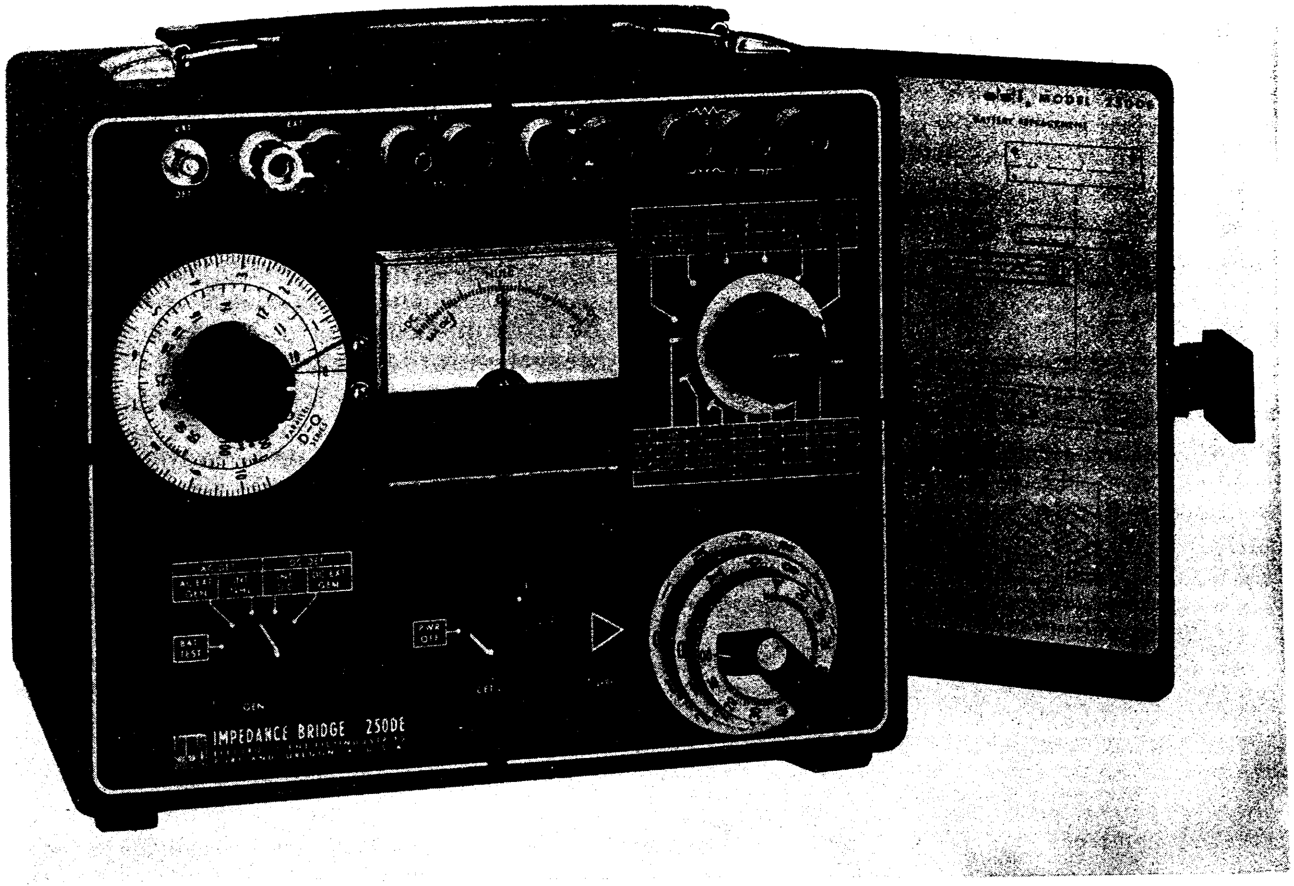

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Figure 11-3.—Impedance Bridge 11837-250DE.

1 milliwatt reference is indicated in dBm. The power level of a complex signal, such as voice, music, or multiplexed information, compared to a reference level of 1 milliwatt, is indicated in vu. Many a.c. voltmeters have scales calibrated in decibels or volume units. One such a.c. voltmeter in common usage is the 28480-400E (figure 11-4). The 28480-400E is suitable for measuring a.c. voltages over the frequency range from 10 Hz to 10 MHz. The meter responds well to the average value of the signal waveform, while the voltage scale is linear and calibrated to the rms value. Such meters are useful for making measurements where direct indication in decibels is desired. However, it must be remembered that these are voltmeters, and that power measurements are not meaningful unless the circuit impedance is known.

At radio frequencies below the UHF range, power is usually determined by voltage, current, and impedance measurements. One common method, used to determine the output power of RF oscillators and radio transmitters, consists of connecting a known resistance to the equipment output terminals, measuring the current flow through the resistance, and then calculating the power as the product of I^2R. Since the power is proportional to the current squared, the meter scale can be calibrated to indicate power units directly. A thermocouple ammeter is usually used for this measurement of RF current. The resistor used to replace the normal load is usually specially designed to have low reactance, and has the ability to dissipate the required amount of power. Such resistors are commonly called dummy loads or dummy antennas.

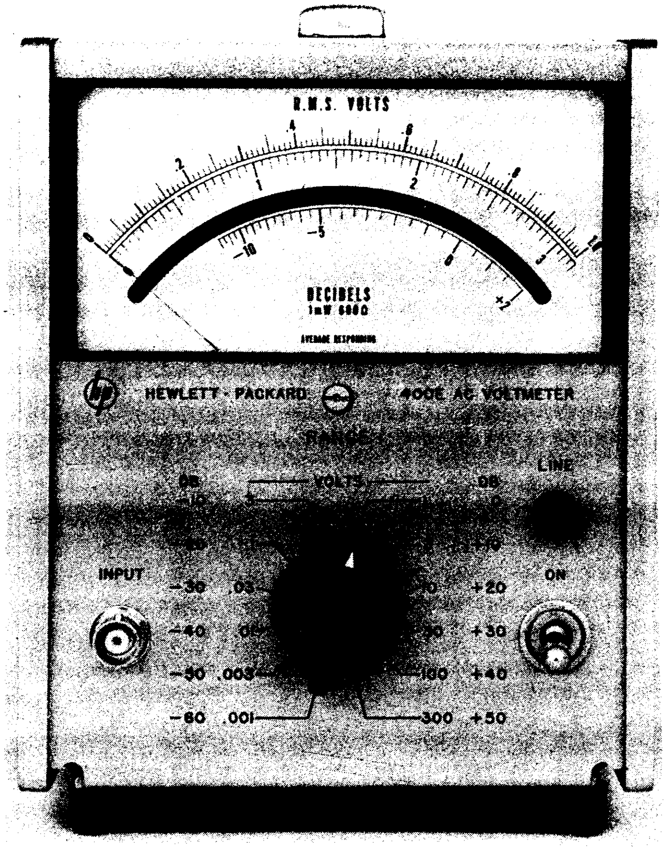

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Figure 11-4.—AC Voltmeter 28480-400E.

In the UHF and SHF portion of the radiofrequency spectrum, it is usually difficult to accurately measure the voltage, current, and impedance. These basic measurements may change greatly at slightly different points in a circuit, and are appreciably affected by small changes in the placement of parts in the vicinity of the tuned circuits. To measure the output of microwave radio or radar transmitters, test instruments which convert RF power to another form of energy, such as light or heat, can be used to indirectly measure the power. A method which measures the heating effect of a resistor load on a stream of passing air can be used. Accurate measurement of large-magnitude power can be achieved by measuring the temperature change of a water load. The most common type of power meter for use in this frequency range employs a bolometer. The bolometer is a loading device that undergoes changes of resistance as changes in the power dissipation occur. Resistance is measured before and after RF power is applied, and power can be determined by the change in resistance.

STANDING WAVE MEASUREMENTS

A transmission line which is not terminated in its characteristic impedance is subject to a condition known as "standing waves." Reflection of energy at the load end of a transmission line gives rise to a wave that travels toward the generator end. This reflected wave varies continuously in phase in much the same way that the incident wave varies in phase. At certain points, one half wave-length apart, the two waves are exactly in phase, and the resultant voltage is maximum. At points a quarter wave-length from the maximums, the two waves are in continuous opposition, and voltage nodes are produced. The ratio of maximum to minimum voltage at such points is called the "standing wave ratio" (SWR) or "voltage standing wave ratio" (VSWR). The ratio of maximum to minimum current along a transmission line will have the same value as the VSWR. A high SWR indicates that the characteristic impedance of a transmission line differs greatly from the terminating impedance, and a low SWR indicates that there is a good impedance match between a transmission line and the terminating impedance. If it is desired to terminate a transmission line in its characteristic impedance, a SWR of 1.0 is optimum.

Transmission line SWR measurements are often made during installation, tuning, and maintenance of communication equipment. Radio antenna transmission lines can be constructed to have the correct length and wire spacing to provide impedance matching for transmitter and receiver equipment. For maximum transfer of energy, the transmission line characteristic impedance should match the terminating impedance. However, unmatched (resonant) transmission lines are useful as impedance-matching devices. In many situations it is not necessary to determine the actual SWR. As an example, loading devices, such as antennas are often adjusted for the condition of minimum SWR. Absorption wavemeters or neon-lamp indicators are capable of providing a rough check of the SWR and the location of standing waves for an open-wire transmission line. Slotted coaxial lines or waveguides in conjunction with an indicator are used for standing-wave measurements in the VHF to SHF range.

TIME DOMAIN REFLECTOMETER (TDR), 28480-140A

The Time Domain Reflectometer (TDR), 28480-140A (figure 11-5) is an equipment which provides a fast, convenient technique for measuring the electrical characteristics of transmission systems. This measurement technique provides a display of the impedance profile of a system showing the magnitude, nature, and distance of discontinuities.

The TDR employs a step generator and an oscilloscope in a system best described as "closed-loop radar." A voltage step is propagated down the transmission line under investigation, and the incident and reflected voltage waves are monitored by the oscilloscope at a particular point on the line. This echo technique reveals at a glance the characteristic impedance of the line. Moreover, it shows both the position and the nature (resistive, inductive, or capacitive) of each discontinuity along the line. The TDR also demonstrates whether losses in a transmission system are series losses or shunt losses. All of this information is immediately available from the oscilloscope's display. The TDR is also useful for broadband reflection coefficient measurements of terminations; for broadband evaluation of individual components such as connectors and

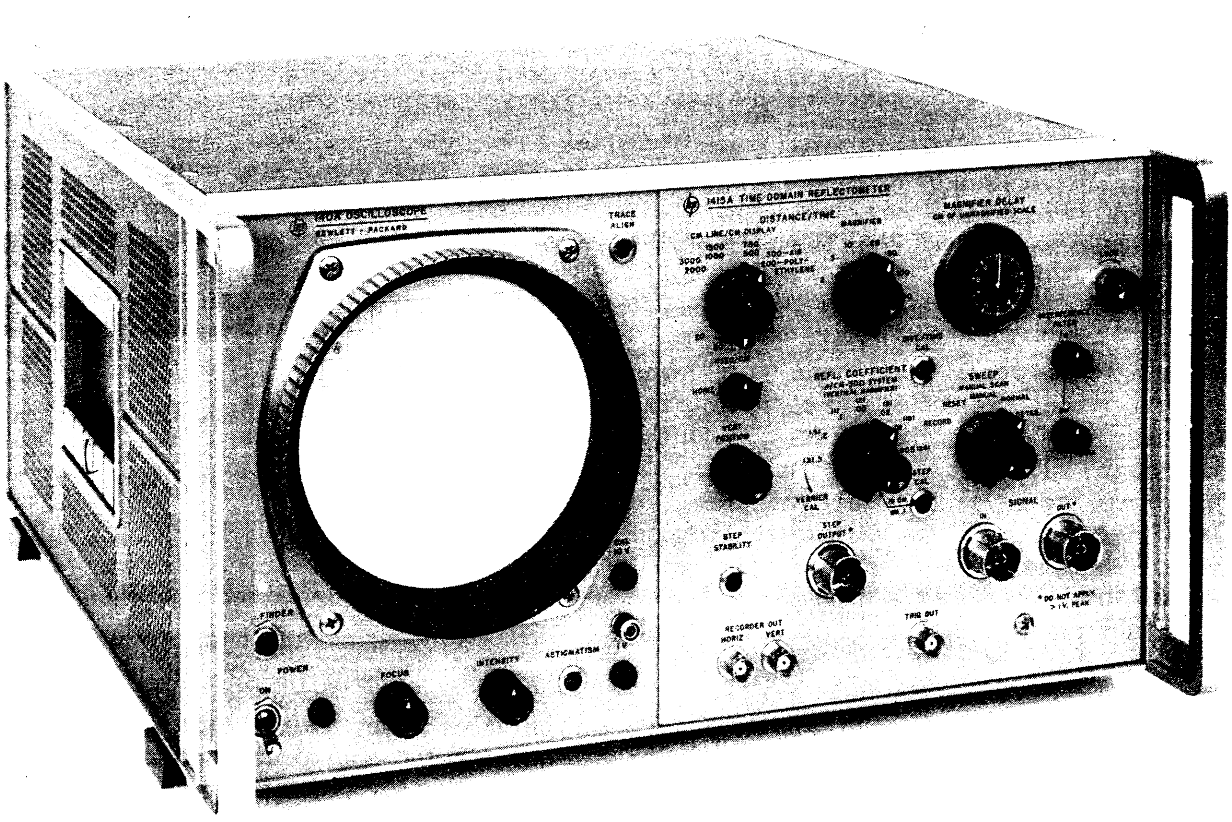

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Figure 11-5.–Time Domain Reflectometer (TDR) 28480-140A.

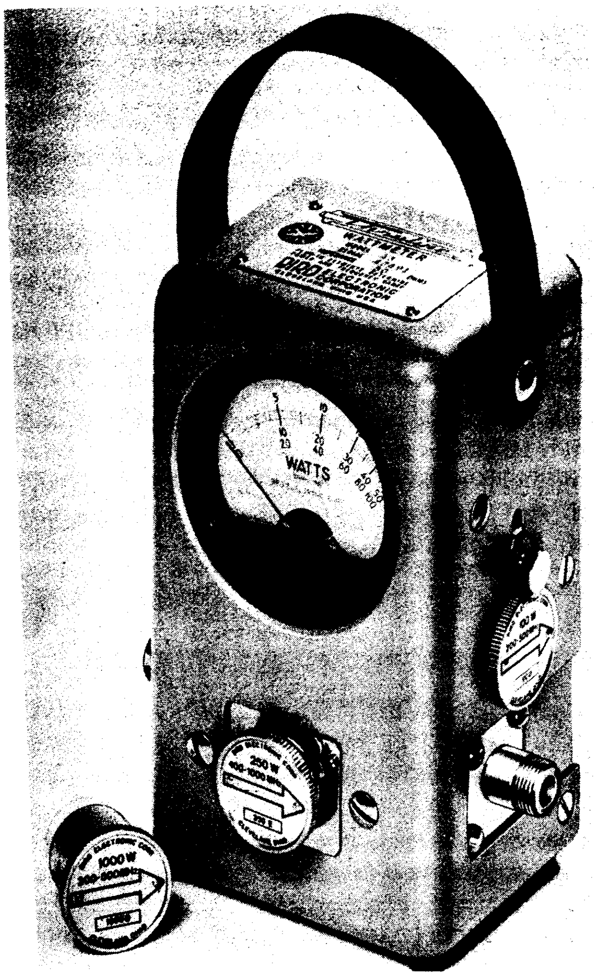
tees; and for determination of the broadband transmission quality of entire systems.

RF WATTMETER

Insertion Power Meter, 70998-43 (figure 11-6) is designed to measure incident and reflected RF power from 5 to 5000 watts with a frequency range of 2 to 500 MHz. Three coupler-detectors, each rated to cover a portion of the frequency and power ranges, are available with the wattmeter. Each coupler-detector has a knurled knob which projects through a hole in the wattmeter case as shown in figure 11-6. A nameplate on the knurled knob indicates the power range. Centered on the nameplate is the power range knob, which can be rotated 360° to any desired power range. The coupler-detector rotates only 180° along the coaxial primary line inside the metal case. Also located inside the metal case are the indicating meter and cable for interconnecting the meter to the coupler-detector.

Two female N-type connectors are located one on either side of the instrument case for connecting the wattmeter between the power source and the load. The upper and lower parts of the instrument are held together with quick action fasteners, which permit easy access to the coupler-detector, the coaxial primary line, and the indicating meter.

Power measurements are made by insertin[g] the proper coupler-detector and connecting th[e] wattmeter in the transmission line between the load and the RF power source. To determine incident power, the arrow on the coupler-detector knurled knob is rotated toward the load, and the power range knob is positioned for peak meter reading. To determine reflected power, the arrow is positioned toward the RF power source. In effect, rotation of the coupler-detector (which is a directional coupler) causes the coupler to respond only to a wave traveling in a particular direction while being unaffected by a wave traveling in the opposite direction. A diode rectifier in the coupler rectifies the energy picked up by the coupler, and this energy is measured across a known impedance to obtain the incident or reflected power.



Operation

Insert the proper coupler-detector for the RF power being measured into the wattmeter case. Remove the wire shunt from the meter terminals. Deenergize and tag the RF power source and connect the wattmeter in the transmission line, either at the load or the RF source. Ensure that all connections are tight.

Position the power range knob to a position higher than the rated power of the RF source. IF THE RATED POWER IS NOT KNOWN, PLACE THE POWER RANGE KNOB IN THE HIGHEST POWER POSITION BEFORE THE POWER SOURCE IS TURNED ON.

To measure incident power, rotate the coupler-detector so that the arrow indicating power flow points toward the load. Apply RF power to the transmission line under test. Rotate the power range knob to the proper range for measuring and observe the point at which the indicating meter peaks. This is the incident power.

Reflected power is measured in the same manner as described for incident power, except that the coupler-detector is rotated so that the arrow points toward the RF source. After power measurements have been completed, deenergize the RF source, disconnect the wattmeter from the transmission line, and replace the wire shunt on the meter terminals.

Interpreting Power Measurements

The RF power measurements made by the wattmeter are used to determine the VSWR of the load and the power absorbed by the load. The VSWR may be determined from a chart provided in the wattmeter technical manual, or it may be calculated by the following formula:

$$\mathrm{VSWR} = \frac{\sqrt{\mathrm{Pi}} + \sqrt{\mathrm{Pr}}}{\sqrt{\mathrm{Pi}} - \sqrt{\mathrm{Pr}}}$$

where Pi is the incident power and Pr is the reflected power as measured by the wattmeter.

The RF power absorbed by the load may be determined by subtracting the reflected power reading from the incident power reading.

VECTOR VOLTMETER

The addition of the vector voltmeter to the test equipment which is available to the technician filled a need that has existed as long as multicouplers and RF distribution system have been around. The vector voltmeter makes it possible for the technician to make accurate phase-relationship measurements of the fundamental components of two RF voltages. Prior to the development of the vector voltmeter, these measurements could only be made under strict laboratory conditions and therefore were impractical to perform at a field site.

One type of vector voltmeter in common usage within the Naval Security Group, is the Vector Voltmeter 28480-8405 (figure 11-7). The 28480-8405 measures both voltage and phase differences through its two channel capability over the frequency range of 1 Hz to 1000 MHz. It is possible to measure gain or loss in excess of 90 dB and phase measurement with 0.1 degree resolution over a 360 degree range.

As with all test equipment, the vector voltmeter is only as good as its operator.

WAVE ANALYZER, 28480-310A

The Wave Analyzer 28480-310A (figure 11-8) is a highly selective af/RF voltmeter, capable of accurate measurement of input signal components up to 1.5 MHz. Measurements may be made in calibrated values of volts and dBm or in relative values of percent and dB. A BFO mode of operation is provided, converting the instrument to a signal generator and a response meter, suitable for measuring characteristics of amplifiers or passive elements. In addition, signals containing single sideband or AM information may be detected and monitored.

The 28480-310A is primarily used to measure harmonic or intermodulation products in active circuits. The 28480-310A also measures the response of amplifiers, passive networks, and transmission systems. The 28480-310A can also be used in accomplishing a variety of recorder and receiver alignments.

FREQUENCY MEASUREMENTS

Frequency measurements are an essential part of preventive and corrective maintenance for electronics equipment. Frequency measurements for radio equipment are made during tuning, preventive maintenance, and corrective maintenance procedures. The type of test equipment selected depends on the frequency to be measured and the required accuracy. Signal frequencies of radio transmitters which operate in the low-frequency to the very-high frequency range are normally measured by absorption-type wavemeters, reaction-type wavemeters, heterodyne-type frequency meters, or calibrated radio receivers. Where accuracy is not of prime importance, in making preliminary adjustments, or for general

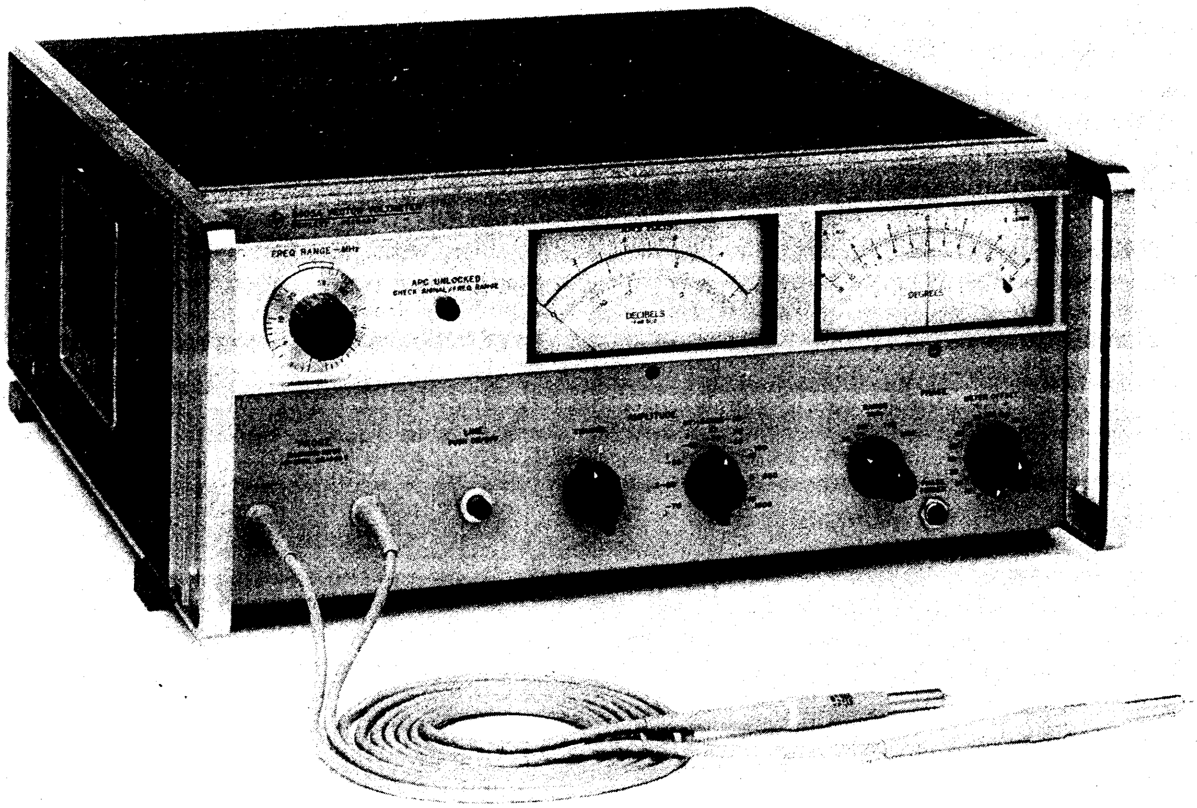


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Figure 11-7.—Vector Voltmeter 28480-8405.

experimental work, rapid frequency checks may be made by the absorption-type wavemeter. Since the wavemeter is relatively insensitive, it is very useful in determining the fundamental frequency in a circuit generating multiple harmonics.

The signal frequencies of radio and radar equipment which operate in the ultra-high frequency and super-high frequency range can be measured by resonant-cavity-type wavemeters, resonant-coaxial-line-type wavemeters, or Lecher-wire devices. When properly calibrated, resonant-cavity and resonant-coaxial-line wavemeters are more accurate and have better stability than wavemeters used for measurements in the low-frequency to very-high frequency range. These frequency-measuring instruments are often furnished as part of communication and electronic equipment, but are also available as general-purpose test sets.

Frequency measuring equipment and devices, particularly those used to determine radio frequencies constitute a distinct class of test equipment because of the important and critical nature of such measurements. The requirement of precise calibration is extremely important in all frequency measuring work. In order to provide accurate measurements, every type of frequency meter must be calibrated against some frequency standard.

Frequency standards were discussed in Chapter 3.

FREQUENCY COUNTER AN/USM-207

The AN/USM-207 (figure 11-9) is a portable, solid-state electronic counter for precisely

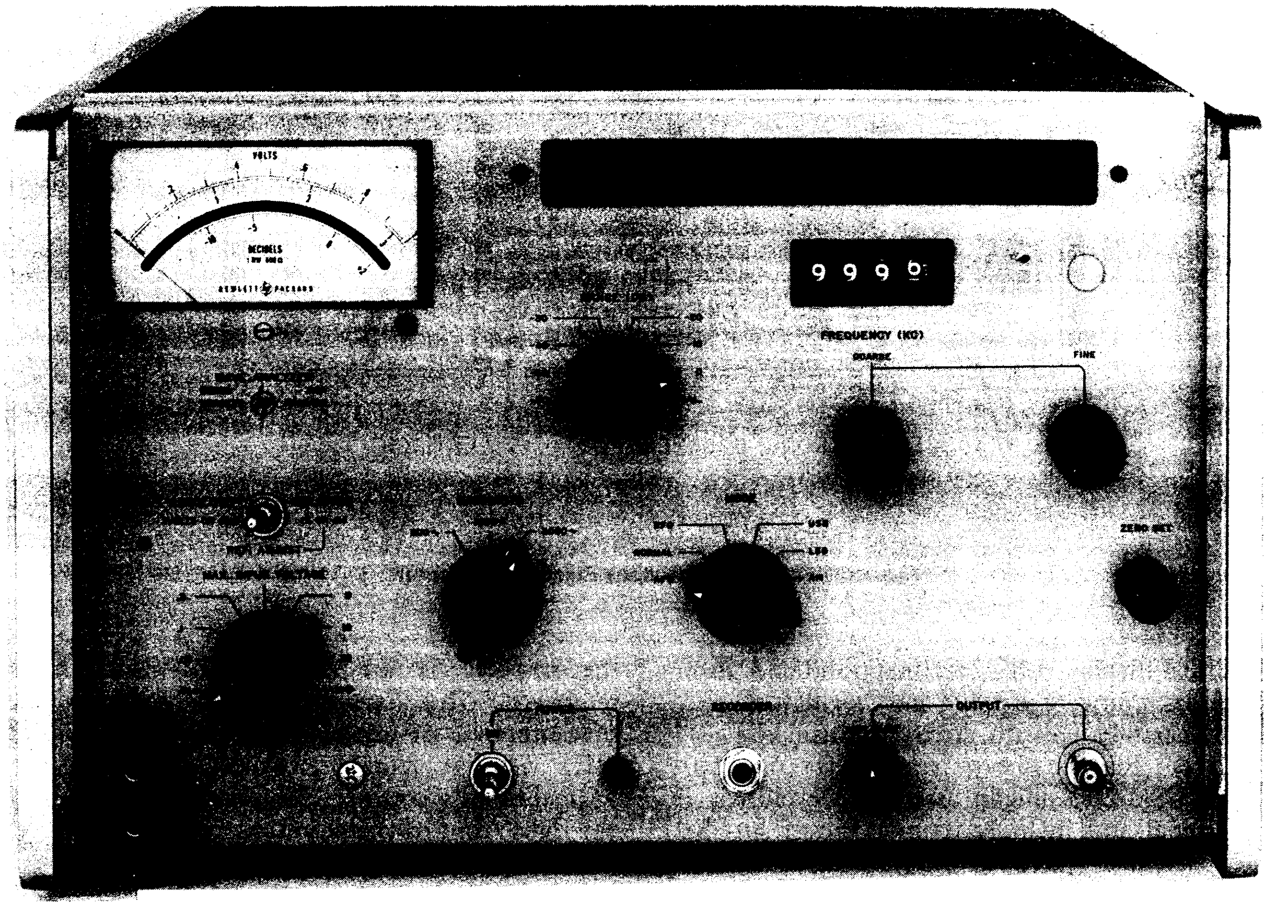

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Figure 11-8.—Wave Analyzer 28480-310A.

measuring and displaying on an 8-digit numerical readout the frequency and period of a cyclic electrical signal, the frequency ratio of two signals, the time interval between two points on the same or different signals, and the total number of electrical impulses (totalizing). The counter also provides the following types of output signals:

1. Standard signals from 0.1 Hz to 10 MHz in decade steps derived from a 1 MHz frequency standard, frequency dividers, and a frequency multiplier
2. Input signals divided in frequency by factors from 10 to 10^8 by a frequency divider
3. Digital data of the measurement in four-line binary-coded-decimal form with decimal point and control signals for operation of printers, data recorders, or control devices
4. A 1 MHz output from a frequency standard.

General Description

The AN/USM-207 (figure 11-9) consists of a major counter assembly, two plug-in assemblies installed in recesses on the front and rear panel, and a group of accessory cables and connectors stored in the detachable front cover.

The major assembly Digital Readout Electronic Counter CP-814/USM-207 contains the input amplifiers, gate control, display, reset and transfer control, frequency multipliers, time base dividers, decade and readout boards,

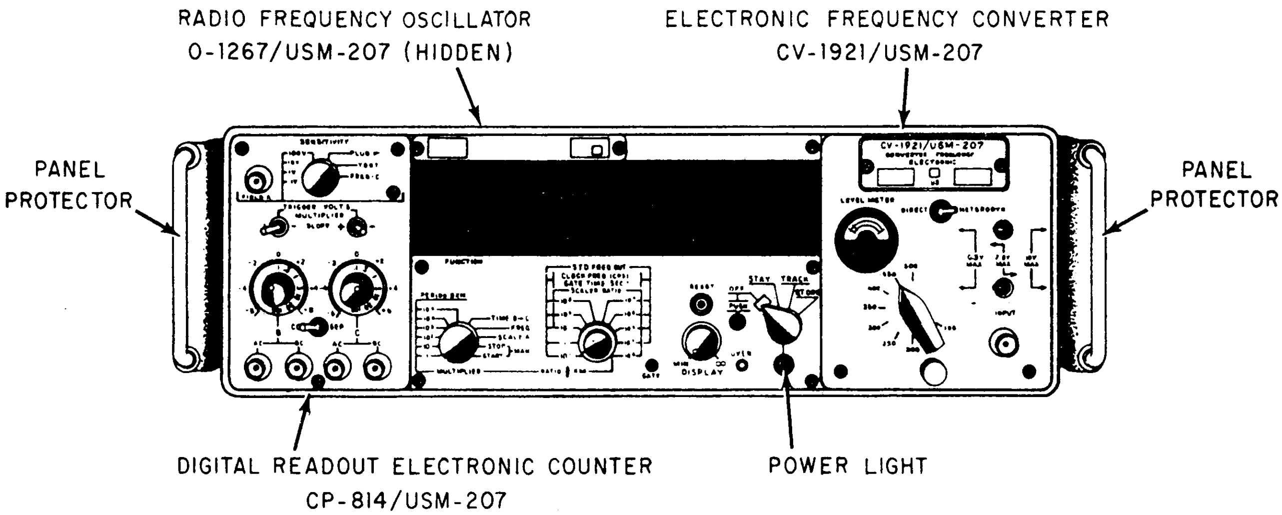

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Figure 11-9.—Digital Readout Electronic Counter.

numerical display tubes, decimal point and units indicators, power supply and regulator, and controls associated with these circuits.

The Radiofrequency Oscillator 0-1267/USM-207 plug-in assembly develops a 1 MHz signal and includes its own power supply. The oscillator includes the 1 MHz output receptacle which may be used as a source of that frequency when the oscillator is connected to a.c. power through the basic counter or when connected to the power line independently of the counter. The counter may be operated without the oscillator in totalizing, scaling the input signal, time interval with external clock, and frequency ratio measurements. For other measurements the counter does not require the oscillator when a separate external 100 kHz or 1 MHz signal is connected. In either of these two situations, the oscillator may be left in the counter or removed. The oscillator plugs into the right rear of the counter.

The Electronic Frequency Converter CV-1921/USM-207 plug-in assembly permits measurement of frequencies up to 500 MHz, using the heterodyne principle. The unit consists of the broadband amplifier, mixer, multiplier, and controls and indicators associated with these circuits. When measurements other than heterodyne frequency measurements are made, the converter is not required, but need not be removed. The converter also permits the measurement of signals from 35 MHz to 100 MHz with a greater sensitivity than available with the basic counter. The converter plugs into the right front of the counter.

Functional Description

Figure 11-10 is the overall functional block diagram of the AN/USM-207 counter. To make a measurement requires two types of information; a count signal, and a gate control signal. These two signals may be generated within the instrument, or they may be supplied from outside sources. The type of measurement the counter will make depends upon the relationship of these two signals. In any function the instrument counts the count signal for a period of time determined by the gate control signal. Routing of these signals within the instrument is accomplished by logic circuits. These logic circuits are controlled by means of the front panel controls.

The radio frequency oscillator (0-1267/USM-207) generates a signal of precise frequency for use throughout the counter or to provide a precise 1 MHz signal for use outside the equipment.

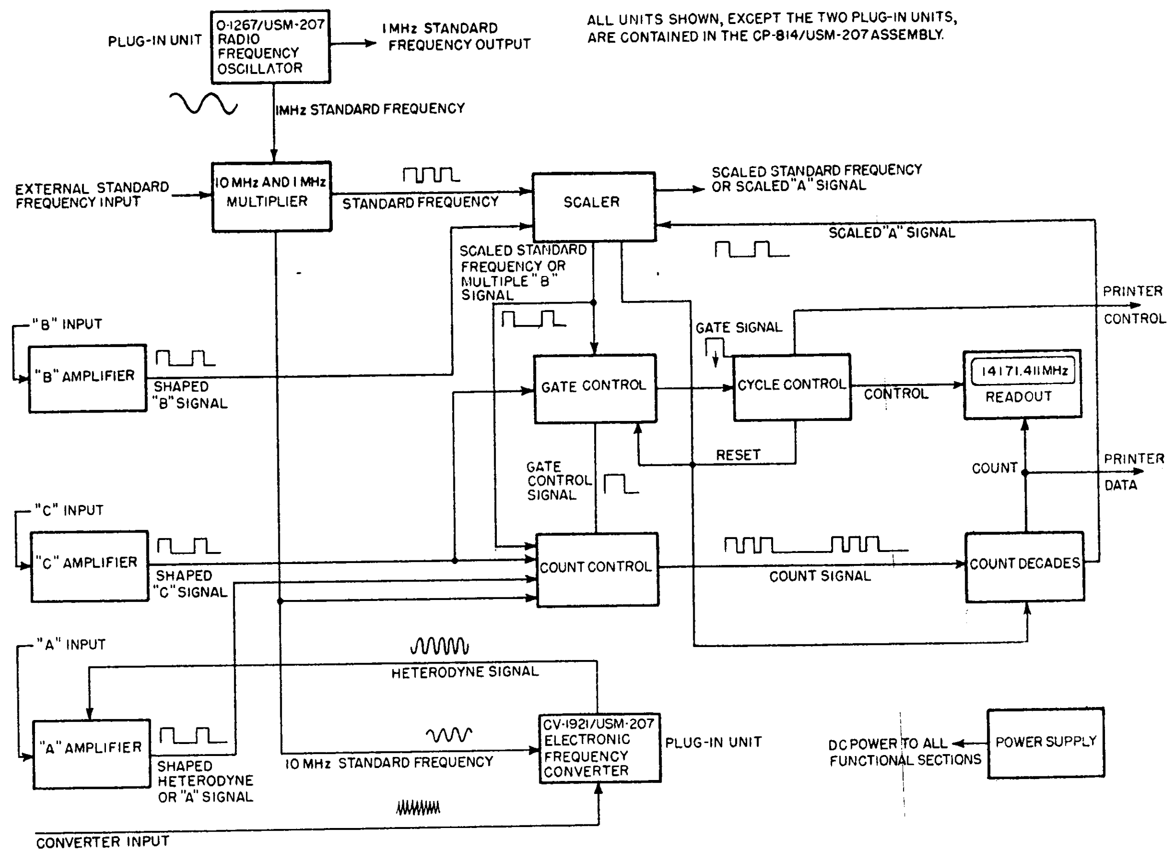

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Figure 11-10.–Digital Readout Electronic Counter Overall Block Diagram.

The electronic frequency converter accepts radio frequencies between 100 MHz and 500 MHz and converts them to radio frequencies between 5 MHz and 100 MHz for measurement by the basic counter.

The "A", "B", and "C" amplifiers amplify and shape the respective input signals for use throughout the counter.

The 10 MHz and 1 MHz multiplier multiplies the frequency and shapes the signal generated by the radio frequency oscillator. It also provides precise timing signals to the various functional sections of the basic counter and to the frequency converter.

The scaler consists of a series of decade dividers and gating systems which provide divided standard frequencies and control signals depending on the type of measurement the instrument is making.

The gate control generates the gate control signal. This signal determines the length of time that the count decades will count the count signal.

The count control provides the proper count signal to the count decades, as selected by the setting of the front-panel switches.

The cycle control produces all signals necessary to display the measurement results on the readout and to recycle the counter.

The count decades count the count signal when permitted to do so by the gate control.

The result of their counting becomes the final reading displayed by the readout at the end of each measurement.

The readout receives binary-coded-decimal (BCD) data from the count decades, decodes this data into decimal form and drives the readout indicator tubes. The readout also contains memory circuits which function when the counter is operated in the "Store" mode.

The power supply supplies all d.c. power required by the basic instrument and the converters and consists of seven d.c. supplies. Five of these supplies (+18 volts, +12 volt, +6 volt, -6 volt, and -12 volt) are regulated, and two (+180 volt and +45 volt) are unregulated.

TESTING ELECTRON TUBES

Electron tube failures are responsible for a large percent of troubles that occur in electronic tube type equipments or systems. However, if a particular system uses a great number of tubes, it is obviously impracticable, as well as poor policy, for you to attempt to locate faults by general tube checking. Only when the fault has been traced to a particular stage should any tubes be tested, and then only those associated with the improperly functioning circuits.

The condition of a tube can be determined by substituting a tube known to be good for the questionable one. However, indiscriminate substitution of tubes is to be avoided, as detuning of circuits may result. In addition, a tube may not operate properly in a high-frequency circuit, although it performs well in a low-frequency circuit. Therefore, if you are to service electronic equipment, a knowledge of tube-testing devices and their limitations, as well as correct interpretation of the test results obtained, is indispensable for accurate and rapid job performance.

TYPES OF TESTS

In order to determine the condition of an electron tube, some method of testing is necessary. Because the operating capabilities (and design features) of a tube are shown by its electrical characteristics, a tube is tested by measuring its characteristics and comparing them with representative values established as standard for that type of tube. Tubes which read abnormally high or low with respect to the standard are subject to suspicion. Practical considerations, which take into account the limitations of the tube test in predicting actual tube performance in a particular circuit, make it unnecessary to employ complex and costly test equipment having laboratory accuracy. For most applications the testing of a single tube characteristic suffices to determine whether a tube is performing satisfactorily.

Testing the emission characteristic of the cathode or filament is perhaps the simplest method of determining the condition of a tube. Since emission normally decreases as the tube ages, low emission is indicative of the end of tube serviceability. This test, however, is subject to limitations, because it tests the tube under static conditions and does not consider the actual circuit operation of the tube. Furthermore, coated cathodes or filaments may develop highly emissive spots, so that the relatively small grid area adjacent to these spots cannot control the electron stream. Under these conditions, testing the total emission may indicate the tube to be satisfactory, while in reality it is defective.

The transconductance (Gm) of a tube used in an amplifier stage is normally a more useful characteristic to measure than the emission. Transconductance is the change of plate current which results from a change in grid voltage; this characteristic, therefore, indicates the ability of the tube to amplify a.c. signals. The most common military tube testers provide dynamic transconductance measurements, although some of the testers are limited to static measurements of this characteristic.

It should be kept in mind that a tube testing device only compares the characteristic of a given tube with a standard for that particular type of tube. Since the operating conditions imposed upon a tube may vary over wide limits, it is not possible for the tube tester to evaluate a tube in terms of performance capability for all applications. Therefore, the tube tester is not considered the final authority in deciding whether or not a tube is always satisfactory. Substituting a good tube in the equipment, and observing the performance of the equipment, provides the most reliable evidence concerning the condition of the tube in question. Substitution is also the only method by which you may test many high-power tubes used for transmitter applications. Nevertheless, the tube tester plays a very important function, since in most cases it provides a quick and satisfactory check on tube serviceability.

TUBE TESTER AN/USM-118C

A representative field type electron tube tester designed to test all common low power tubes is shown in figure 11-11. The tube test conditions (which are as close as possible to the actual tube operating conditions) are programmed on a prepunched card. The card switch (S101, figure 11-11) automatically programs the tube test conditions when it is actuated by a card. A card compartment on the front panel of the tester provides storage for the most frequently used cards. The cover of the tester (not shown) contains operating instructions, brackets for storing the technical manual, the power cord, a calibration cell for checking the meter and short tests, calibration cards, blank cards, and a steel hand punch.

Front Panel

When a prepunched card is fully inserted into the card switch (S101), a microswitch is actuated which energizes a solenoid, causing the card switch contacts to complete the circuit. The card switch has 187 single-pole single-throw switches arranged in 17 rows with 11 switches in each row. The card is used to push the switches closed; thus, the absence of a hole in the card is required to actuate a switch.

The meter (M301 figure 11-11) contains four scales. The upper scale is graduated from zero to 100 for direct numerical readings. The three lower scales, numbered 1, 2, and 3, are read for LEAKAGE, QUALITY, and GAS respectively. Each numbered scale includes green and red areas marked GOOD and REPLACE. Inside a shield directly in front of the meter are five neon lamps (DS301 through DS305), which indicate shorts between tube elements.

The number 2 pushbutton (MP6) is used for transconductance, emission, and other quality tests described later. The number 3 pushbutton (MP7) is used to test for the presence of gas in the tube envelope. The number 4 pushbutton (MP8) is used for tests on dual tubes. A neon lamp (DS203) lights when pushbutton number 4 is to be used. Eleven tube test sockets are located on the panel plus tube pin straighteners for the 7 and 9-pin miniature tubes.

The power ON-OFF spring-return toggle switch (S105) turns the tester on by energizing a line relay. Pilot light (DS107) lights when this relay closes. Above the power ON-OFF switch are five fuses. Fuses F101, F201, and F202 protect circuits in the tester not protected by other means and have neon lamps to indicate when they have blown. Fuses F102 and F103 protect both sides of the power line.

Auxiliary Compartment

A group of auxiliary controls covered by a hinged panel are used for special tests and for calibration of the tester. Two of these controls labeled SIGNAL CAL (R152 and R155, figure 11-12) are used with special test cards for adjusting the regulation and amplitude of the signal voltage. A pushbutton labeled CATH ACT (S302D) is used for making cathode activity tests. When this button is pressed, DS106 on the front panel (figure 11 - 11) lights, and the filament voltage of the tube under test is reduced by 10 percent. Results of the test are read as a change in reading on the numerical meter scale.

Pushbutton S302E and potentiometers R401 and R405 (figure 11-12) are used for balancing the Gm bridge circuit under actual tube operating current. Pressing S302E removes the grid signal and allows a zero balance to be made with one potentiometer or the other, depending upon whether the tube under test is passing high or low plate current. Lamp DS108 on the front panel lights when S302E is pressed. Pushbutton S302C is used for checking grid to cathode shorts at a sensitivity much higher than the normal tests. Results of this test are

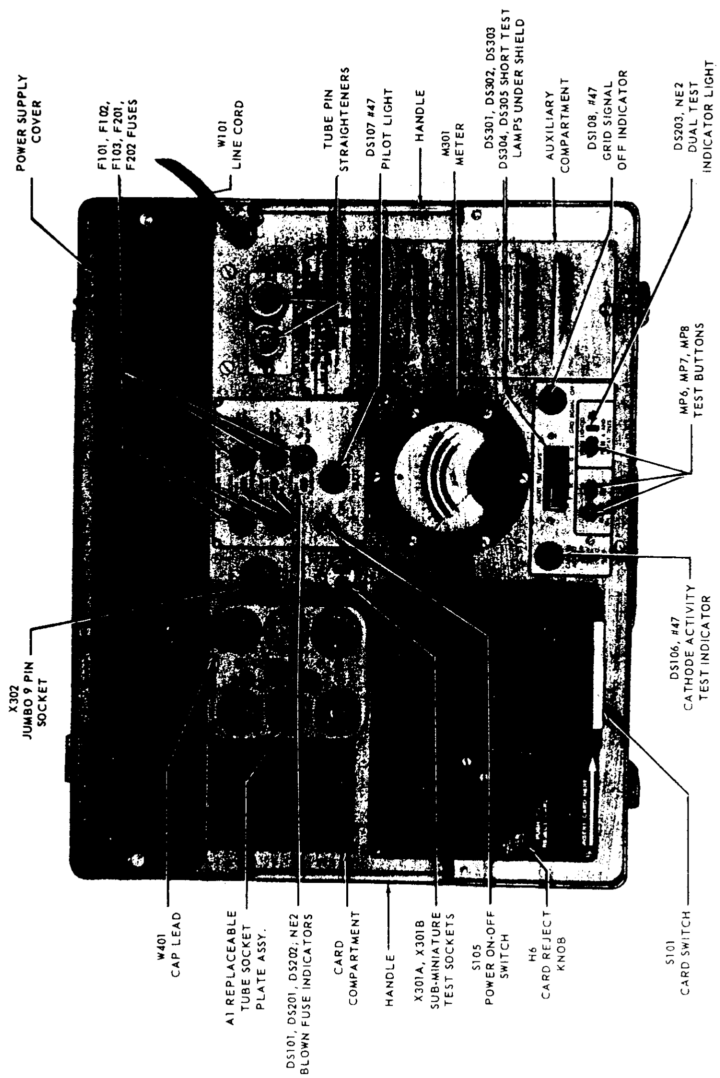

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Figure 11-11.—Electronic Tube Tester AN/USM-118C.

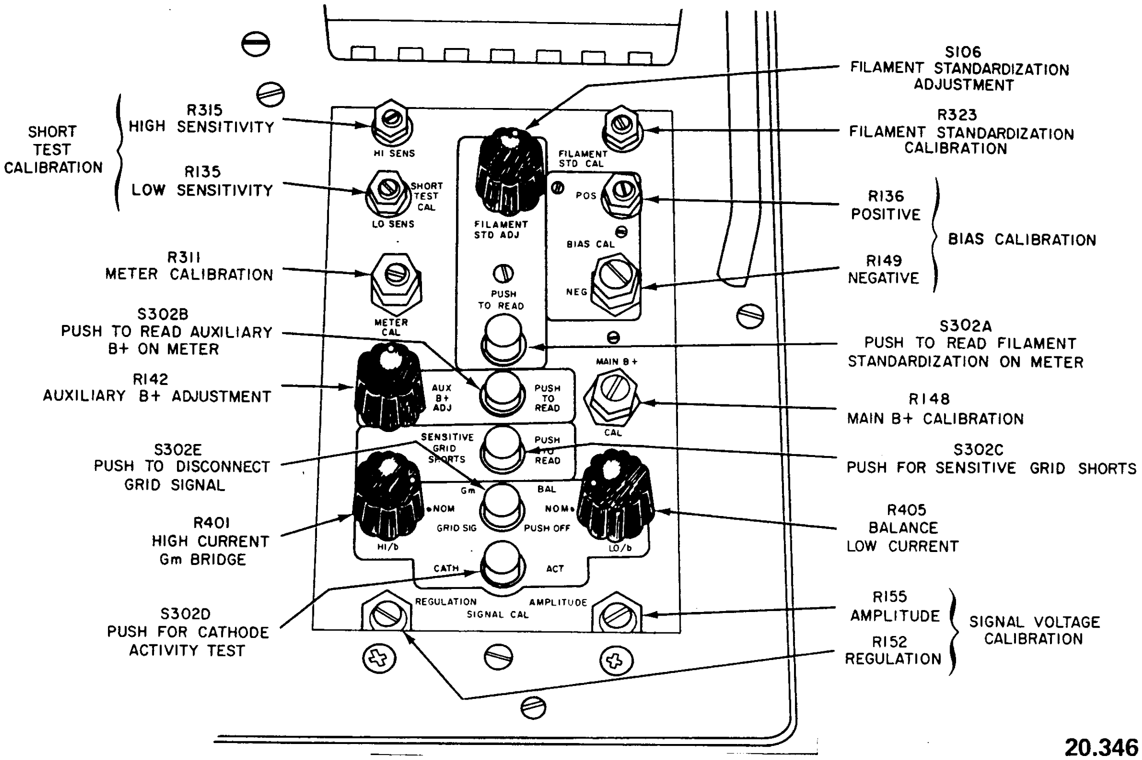

Figure 11-12.–Auxiliary Compartment.

indicated by the short test lamps on the front panel.

Certain special tests require the use of a continuously adjustable auxiliary power supply. By pressing pushbutton S302B, meter M301 may be used to read the voltage of the auxiliary power supply. This voltage may be adjusted by the use of potentiometer R142. The rest of the potentiometer controls are calibration controls and are adjusted by the use of special calibration cards and a calibration test cell.

All circuits in the tester except the filament supply are electronically regulated to compensate for line voltage fluctuations. The filament supply voltage is adjusted by pressing pushbutton S302A and rotating the filament standardization adjustment switch S106 until meter M301 reads midscale.

Program Cards

As stated previously, the circuits to be used in testing are selected by a prepunched card. These cards are made of a tough vinyl plastic material. The tube numbers are printed in color on the tabs of the cards and also at the edge of the card for convenience in filing. A special card is provided to use as a marker when a card is removed for use. Blank cards are provided so that additional test cards may be punched for new tubes that are developed or to replace cards that have become unserviceable (figure 11-13).

Operation

Before operating for the first time, and periodically thereafter, the tester should be calibrated using the calibration test cards as described in the equipment technical manual.

NORMAL TEST.–The tester is equipped with a three-conductor power cord, one wire of which is chassis ground. It should be plugged into a grounded 105-125 volt 50-400 Hz outlet.

Before operating the tester, open the auxiliary compartment (figure 11-12) and ensure

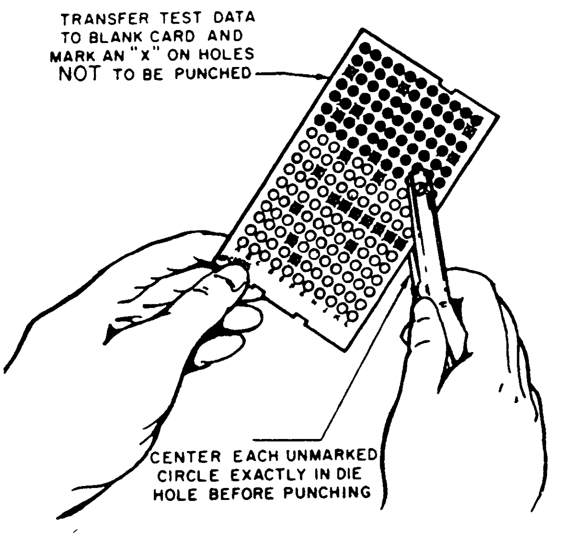

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Figure 11-13.—Punching New or Replacement Tube Test Code Cards.

that the FILAMENT STD ADJ, and the Gm BAL knobs are in the NOM position. The GRID SIG and CATH ACT buttons (S302E and S302D) should be up and lamps DS108 and DS106 on the front panel out.

Turn on the tester and allow it to warm up for five to ten minutes, then press the PUSH TO REJECT CARD knob (figure 11-11) down until it locks. If a nontest card is installed in the card switch, remove it. This card is used to keep the switch pins in place during shipment and should be inserted before transporting the tester.

Plug the tube to be tested into its proper socket. (Use the pin straighteners before plugging in 7 and 9-pin miniature tubes.) Select the proper card or cards for the tube to be tested. Insert the card selected into the slot in the card switch until the PUSH TO REJECT knob pops up. The card will operate the tester only if it is fully inserted, and the printing is up and toward the operator. DO NOT put paper or objects other than program cards into the card switch as they will jam the switch contacts. If the overload shuts off the tester when the card is inserted in the switch, check to see that the proper card is being used for the tube under test, and if the tube under test has a direct interelectrode short.

As soon as the card switch is actuated, the tube under test is automatically subjected to an interelement short test and a heater to cathode leakage test. A blinking or steady glow of any of the short test lamps is an indication of an interelement short. If the short test lamps remain dark, no interelement shorts exist within the tube. If a short exists between two or more elements, the short test lamp or lamps connected between these elements will remain dark, and the remaining lamps will light. The abbreviations for the tube elements are located on the front panel just below the short test shield so that the neon lamps are between them. This enables the operator to tell which elements are shorted. Heater to cathode shorts are indicated as leakage currents on the #1 meter scale. If the meter reads above the green area, the tube should be replaced. A direct heater to cathode short will cause the meter to read full scale.

To make the QUALITY test, push the number 2 button (figure 11-11) and read the number 2 scale on meter M301 to determine if the tube is good. (This test may be one of various types, such as transconductance, emission, plate current, or voltage drop, depending upon the type of tube under test.)

To test the tube for GAS, press the number 3 button and read the number 3 meter scale. The number 2 button also goes down when number 3 is pressed. If a dual tube having two identical sections is being tested, the neon lamp (DS203) will light, indicating that both sections of the tube may be tested with one card. To do this, check the tube for shorts, leakage, quality, and gas as described previously, then hold down button number 4 and repeat these tests to test the second section of the tube. Dual tubes with sections that are not identical require two cards for testing. A second card is also provided to make special tests on certain tubes.

AUXILIARY TESTS.—As mentioned previously, two special tests (cathode activity and sensitive grid shorts) may be made by use of controls located in the auxiliary compartment (figure 11-12). The cathode activity test (CATH ACT) is used as an indication of the amount of useful life remaining in the tube. By reducing the filament voltage by 10 percent and allowing the cathode to cool off slightly, the ability of the cathode as an emitter of electrons can be estimated. This test is made in conjunction with the normal quality test.

To make the CATH ACT test, allow the tube under test to warm up, press button number 2 (figure 11-11) and note the reading of scale number 2 on meter M301. Note also the numerical scale reading on M301. Next, lock down the CATH ACT button (figure 11-12), wait for about 1.5 minutes, then press button number 2 (figure 11-11) again and note the numerical and number 2 scale readings on meter M301. The tube should be replaced if the numerical reading on M301 differs from the first reading by more than 10 percent, or if the reading is in the red area on the number 2 scale.

It is sometimes desirable to check certain tubes for shorts at a sensitivity greater than normal. To make the SENSITIVE GRID SHORTS test, push S302C (figure 11-12) and note if any short test lamps (figure 11-11) light.

TESTING SEMICONDUCTOR DEVICES

Because of the reliability of semi-conductor devices, servicing techniques developed for transistorized equipment differ from those normally used for electron tube circuits. Electron tubes are usually considered to be the circuit component most susceptible to failure, and are, therefore, normally the first components to be tested. Transistors, however, are capable of operating in excess of 30,000 hours at maximum rating without failure and are often soldered in the circuit in much the same manner as resistors and capacitors.

Substitution of a semiconductor diode or transistor known to be in good condition is a simple-method of determining the quality of a questionable semiconductor device. This technique should be used only after you have made voltage and resistance measurements to make certain that there is no circuit defect that might damage the substitution semi-conductor device. If more than one defective semiconductor is present in the equipment section where trouble has been localized, this method becomes cumbersome, since several semiconductors may have to be replaced before the trouble is corrected. To determine which stages failed and which semiconductors are not defective, all of the removed semiconductors must be tested. This can be accomplished by observing whether the equipment operates correctly as each of the removed semiconductor devices is reinserted into the equipment.

TESTING DIODES

Semiconductor diodes, such as general purpose germanium and silicon diodes, power silicon diodes, and microwave silicon diodes may be tested most effectively only under actual operating conditions. However, crystal rectifier testers are available to determine direct-current characteristics which provide an indication of crystal diode quality.

A common type of crystal diode test set is a combination ohmmeter-ammeter. Measurements of forward resistance, back resistance, and reverse current may be made with this equipment. The condition of the diode under test can then be determined by comparison with typical values obtained from test information furnished with the test set or from the manufacturer's data sheets. A check which provides a rough indication of the rectifying property of a diode is the comparison of the diode's back and forward resistance at a specified voltage. A typical back-to-forward resistance ratio is on the order of 10:1, and a forward-resistance value of 50 to 80 ohms is common.

Testing With Ohmmeter

A convenient test for a semiconductor diode requires only an ohmmeter. The forward and back resistance can be measured at a voltage determined by the battery potential of the ohmmeter and the resistance range at which the meter is set. When the test leads of the ohmmeter are connected to the diode, a resistance will be measured which is different from the resistance indicated if the leads are reversed. The smaller value is called the forward resistance, and the larger value is called the back resistance. If the ratio of back-to-forward resistance is greater than 10:1, the diode should be capable of functioning as a rectifier. However, you should keep in mind that this is a very limited test that does not take into account the action of the diode at voltages of different magnitudes and frequencies.

Testing With An Oscilloscope

An oscilloscope can be used to graphically display the forward and back resistance characteristics of a crystal diode. A circuit used in conjunction with an oscilloscope to make this test, is shown in figure 11-14. This circuit uses the oscilloscope line test voltage as the test signal. A series circuit composed of rheostat R1 and the internal resistance in the line test circuit decreases the 3-volt open circuit test voltage to a value of approximately 2 volts, peak to peak. The test signal applied to the crystal diode is also connected to the horizontal input of the oscilloscope. The horizontal sweep will then represent the voltage applied to the diode under test. The voltage developed across current-measuring resistor R2 is applied to the vertical input of the oscilloscope. Since this voltage is proportional to the current through the diode under test, the vertical deflection will indicate crystal current. The resulting oscilloscope trace for a normal diode will be similar to the curve shown in figure 11-15.

To test Zener diodes, a higher voltage than the oscilloscope line test signal must be used. This test can be made with a diode test set or with the circuit shown in figure 11-16. In this circuit, rheostat R1 is used to adjust the input voltage to a suitable value for the Zener diode being tested, and resistor R2 limits the current through the diode. The signal voltage applied to the diode is also connected to the horizontal input of the oscilloscope. The voltage developed across current-measuring resistor R3 is applied to the vertical input of the oscilloscope. Therefore, the horizontal sweep will represent the applied voltage, and the vertical deflection will indicate the current through the diode under test. Figure 11-17 shows the characteristic pattern of a Zener diode; note the sharp increase in current at the Zener voltage (avalanche) point. For the Zener diode to be acceptable, this voltage must be within the limits specified by the manufacturer.

Instructions for constructing a simple in-circuit semiconductor diode and transistor

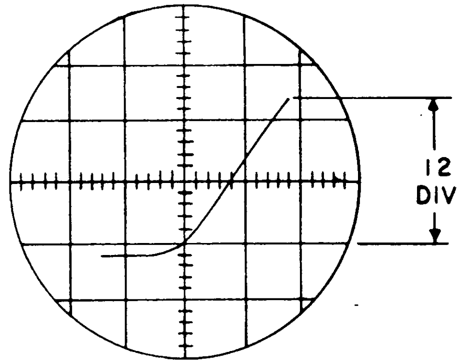

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Figure 11-15.—Characteristic Curve of a Semiconductor Diode.

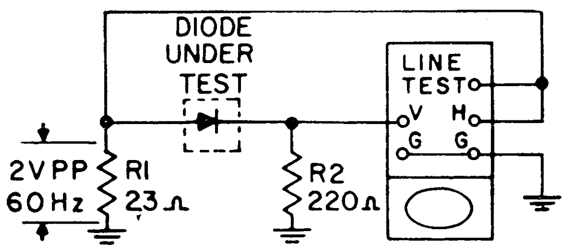

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Figure 11-14.—Testing Semiconductor Diode With Oscilloscope.

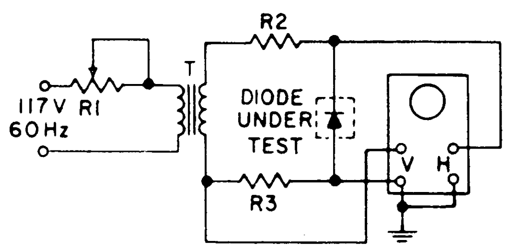

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Figure 11-16.—Testing a Zener Diode.

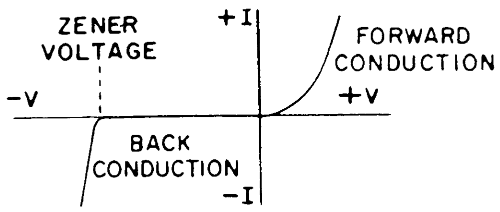

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Figure 11-17.–Zener Diode Characteristics Curve.

tester (used in conjunction with an oscilloscope) are contained in EIB 815 of 15 November 1971.

TESTING TRANSISTORS

When trouble occurs in transistorized equipment; power supply voltage measurement, waveform checks, signal substitution or signal tracing methods are normally the first tests made. If a faulty stage is isolated by one of these test methods; voltage, resistance, and current measurements can be made to locate defective parts. When making these measurements, you must make certain that the voltmeter resistance is high enough to have no appreciable effect upon the voltage being measured, and that current from the ohmmeter will not damage the transistor. If the transistors are not soldered into the equipment, it is usually advisable to remove the transistors from their sockets during a resistance test. Transistors should be removed from or reinserted into their sockets only after power has been removed from the stage, since damage by surge currents may otherwise result.

Transistor circuits other than pulse and power amplifier stages are usually biased so that the emitter current is from 0.5 to 3 milliamperes, and the collector voltage is from 3 to 15 volts. The emitter current can be measured by opening the emitter connector and inserting a milliammeter. When making this measurement, you should expect some change in bias due to the meter resistance. The collector current can often be determined by measuring the voltage drop across a resistor in the collector circuit and calculating the current. If the transistor itself is suspected, it can be tested with an ohmmeter or transistor tester as described in the following paragraphs.

Resistance Test

An ohmmeter can be used to test transistors by measuring the emitter-collector, base-emitter, and base-collector forward and back resistances. A back-to-forward resistance ratio on the order of 500:1 should be obtained for the collector-to-base and emitter-to-base measurements. The forward and back resistances between the emitter and collector should be nearly equal. All three measurements should be made for each transistor tested, since experience has shown that transistors can develop shorts between the collector and emitter and still have good forward and reverse resistances for the other two measurements.

Because of shunting resistances in transistor circuits, you will normally have to disconnect at least two transistor leads from the associated circuit for this test. You must exercise caution during this test to make certain that current during the forward resistance tests does not exceed the rating of the transistor. Ohmmeter ranges which require a current of more than 1 milliampere should not be used for testing transistors. Many ohmmeters are designed so that on the RX1 range 100 milliamperes or more can flow through the electronic part under test.

Transistor Tester

Laboratory transistor test sets are used in experimental work to test all characteristics of transistors. For maintenance and repair, however, it is not necessary to check all of the transistor parameters. A check of two or three performance characteristics is usually sufficient to determine whether a transistor needs to be replaced. Two of the most important parameters used for transistor testing are the transistor current gain (Beta) and the collector leakage or reverse current (Ico). These are discussed in *Basic Electronics, Vol. 1,* NAVPERS 10087.

Semiconductor test set AN/USM-206A (figure 11-18) is a rugged field type tester designed to test transistors and semiconductor diodes. The set will measure the Beta of a transistor, the resistance appearing at the electrodes and the reverse current of a transistor or semiconductor diode, a shorted or open condition of a diode, the forward trans-conductance of a field effect transistor, and the condition of its own batteries.

In order to assure that accurate and useful information is gained from the transistor tester, the following preliminary checks of the tester should be made prior to testing any transistors:

With the POLARITY switch (figure 11-18) in the OFF position the meter pointer should indicate exactly zero. (When required, rotate meter adjust screw on front of meter to fulfill this requirement). The POLARITY switch must always be left in the OFF position, when measurements are not actually being made, to prevent battery drain.

Always check the condition of the test set batteries by disconnecting the test set power cord, placing the POLARITY switch in the PNP position and placing the FUNCTION switch first to BAT.(1) then to BAT.(2). In both BAT

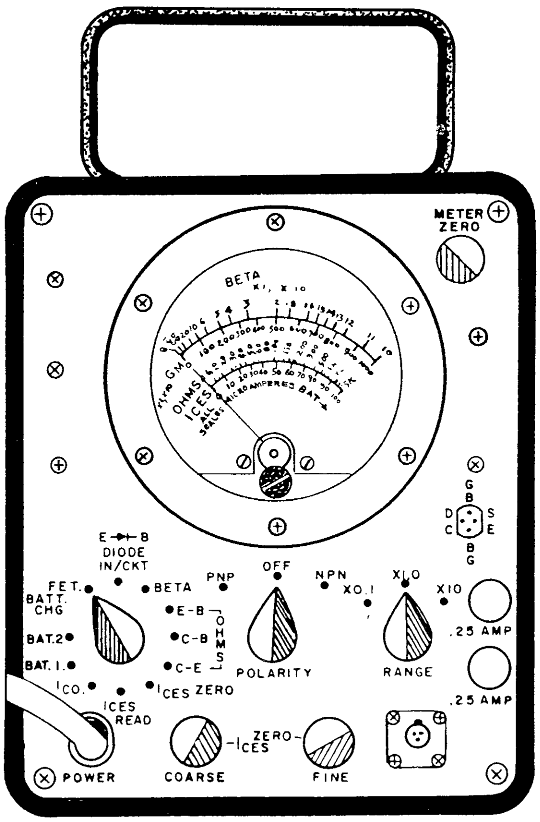

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Figure 11-18.—Semiconductor Test Set AN/USM-206A.

positions the meter pointer should move so as to indicate within the red BAT range.

BETA MEASUREMENTS.—If the transistor is to be tested out of the circuit, plug it into the test jack located on the right hand side below the meter shown in figure 11-18. If the transistor is to be tested in the circuit it is imperative that at least 300 OHMS exists between E-B, C-B, and C-E for accurate measurement. Initial setting of the test set controls is:

1. FUNCTION switch to BETA
2. POLARITY switch to PNP or NPN (dependent on type of transistor under test.)
3. RANGE switch to X10
4. Adjust meter zero for zero meter indication (transistor disconnected.)

NOTE: The POLARITY switch should remain OFF while transistor is connected to or disconnected from the test set. If it is determined that the Beta reading is less than 10, reset the RANGE switch to X1 and reset the meter to zero.

After connecting the yellow test lead to the emitter, the green test lead to the base, and the blue test lead to the collector; plug the test probe (not shown) into the jack located at the lower right hand corner of the test set. When testing grounded equipment, unplug the 115 VAC line cord and use battery operation. Beta reading is attained by multiplying the meter reading times the RANGE switch setting. Refer to the transistor characteristics book provided with the tester to determine if the reading is normal for the type of transistor under test.

ELECTRODE RESISTANCE MEASUREMENTS.—Connect the in-circuit probe test leads to the transistor with the yellow lead to the emitter, the green lead to the base, and the blue lead to the collector. Set the FUNCTION switch to the OHMS E-B position and read the resistance between the emitter and base electrode on the center scale of the meter.

To read the resistance between the collector and base and the collector and emitter, set the FUNCTION switch to OHMS C-B and OHMS C-E. These in-circuit electrode resistance measurements are used to correctly interpret the in-circuit beta measurements. The accuracy of the BETA X1, X10 range is ±15% only when the emitter to base load is equal to or greater than 300 ohms.

ICO MEASUREMENTS.–Adjust METER ZERO control for zero meter indication. Plug the transistor to be tested into the jack or connect test leads to the device under test. Set the PNP/NPN switch to correspond with the transistor under test. Set the FUNCTION switch to ICO, the RANGE switch to X0.1, X1 or X10 as specified by the transistor data book for allowable leakage. Read leakage on bottom scale, and multiply by the range setting figure as required.

DIODE MEASUREMENTS.–Diode qualitative in-circuit measurements are attained by connecting the green test lead to the cathode and the yellow test lead to the anode. Set the FUNCTION switch to DIODE IN/CKT and the RANGE switch to X1. (Insure that the meter has been properly zeroed on this scale). If the meter reads down scale reverse the POLARITY switch. If the meter reads less than mid-scale the diode under test is either open or shorted. The related circuit impedance of this test is less than 25 ohms.

PRECAUTIONS.–Transistors, although generally more rugged mechanically than electron tubes, are susceptible to damage by excessive heat and electrical overload. The following precautions should be taken in servicing transistorized equipment:

1. Test equipment and soldering irons must be checked to make certain that there is no leakage current from the power source. If leakage current is detected, isolation transformers must be used.

2. Ohmmeter ranges which require a current of more than 1 milliampere in the test circuit should not be used for testing transistors.

3. Battery eliminators should not be used to furnish power for transistor equipment because they have poor voltage regulation and, possibly, high ripple voltage.

4. The heat applied to a transistor, when soldered connections are required, should be kept to a minimum by using a low-wattage soldering iron and heat shunts (such as longnose pliers) on the transistor leads.

5. All circuits should be checked for defects before a transistor is replaced.

6. The power should be removed from the equipment before replacing a transistor or other circuit part.

7. When working on equipment with closely spaced parts, conventional test probes are often the cause of accidental short circuits between adjacent terminals. Momentary short circuits, which rarely cause damage to an electron tube, may ruin a transistor. To avoid accidental shorts, the test probes can be covered with insulation for all but a very short length of the tips.

SIGNAL GENERATORS

In the maintanance of electronic equipment, it is often necessary to employ standard sources of a.c. energy, both audiofrequency and radiofrequency. These sources are called signal generators. They are used in testing and aligning radio transmitters, receivers, and amplifiers; they are also used when troubleshooting various electronic devices, and sometimes for measuring frequency.

The principal function of a signal generator is the production of an alternating voltage of the desired frequency and amplitude which has the necessary modulation for the test or measurement concerned. It is very important that the amplitude of the generated signal be correct. In many generators, output meters are included in the equipment so that the output may be adjusted and maintained at a standard level over a wide range of frequencies.

When using the generator, the output test signal is coupled into the circuit being tested, and its progress through the equipment is traced by the use of high-impedance indicating devices such as vacuum tube voltmeters or oscilloscopes. In many signal generators, calibrated networks of resistors (called attenuators) are provided. These are used to regulate the voltage of the output signal and also provide correct impedance values for matching the input impedance of the circuit under test. Accurately calibrated attenuators are used, as the signal strength must be regulated to avoid overloading the circuit receiving the signal.

There are many types of signal generators. They may be classified roughly by frequency into audio generators, video signal generators, radiofrequency generators, frequency-modulated RF generators, and special types which combine all of these frequency ranges.

AUDIO AND VIDEO SIGNAL GENERATORS

Audio signal generators produce stable audiofrequency signals used for testing audio equipment. Video signal generators produce signals which include the audio range and extend considerably further into the RF range. These generators are used in testing video amplifiers and other wideband circuits. In both audio and video generators, the major components include a power supply, an oscillator (or oscillators), one or more amplifiers, and an output control. Voltage regulation circuits are necessary to insure stability of the oscillator in generators which derive power from 115-volt, a.c. sources. In portable generators, battery power supplies are usually used, and these require no voltage regulation.

In the audio and video generators of the beat-frequency type, the output frequency is produced by mixing the signals of two radiofrequency oscillators, one of which is fixed in frequency and the other variable. The difference in frequency of the two is equal to the desired audio or video frequency.

Audio signal generators often include RC oscillators in which the audiofrequency is directly produced. In these, a resistance-capacitance circuit is the frequency determining part of the oscillator. The frequency varies when either the resistance or the capacitance is changed in value. In commercial generators, however, the capacitance alone is often chosen as the variable element. The change in frequency which can be produced by this method is limited, and it is usually necessary to cover the entire range of the generator in steps. This is accomplished by providing several RC circuits, each corresponding to a portion of the entire range of frequency values. The circuits in the oscillator are switched one at a time to give the desired portion of the audio range.

The amplifier section of the block diagram (in figure 11-19) usually consists of a voltage amplifier and one or two power amplifiers. These are coupled by means of RC networks, and the output of the final power amplifier is often coupled to the attenuator, or output control, by means of an output transformer.

The output control section provides a means of matching the output signal to the input of the equipment under test and regulating the amplitude of the signal. Figure 11-20 is one example of an audiofrequency signal generator.

RADIOFREQUENCY SIGNAL GENERATORS

A typical radiofrequency signal generator (see figure 11-21) contains, in addition to the necessary power supply, three main sections; an oscillator circuit, a modulator, and an output control circuit. The internal modulator modulates the radio frequency signal of the oscillator. In addition, most RF generators are provided with connections through which an external source of modulation of any desired waveform may be applied to the generated signal. Metal shielding surrounds the unit to prevent the entrance of signals from the oscillator into the circuit under test by means

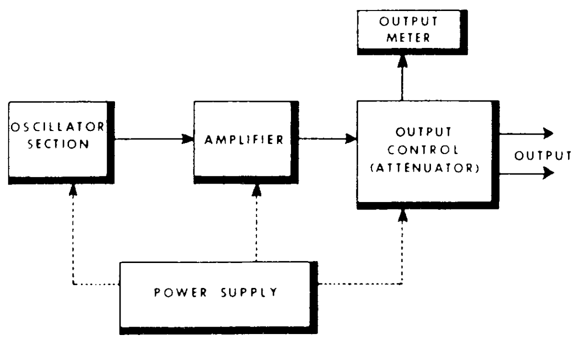

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Figure 11-19.—Block Diagram of Audio or Video Signal Generator.

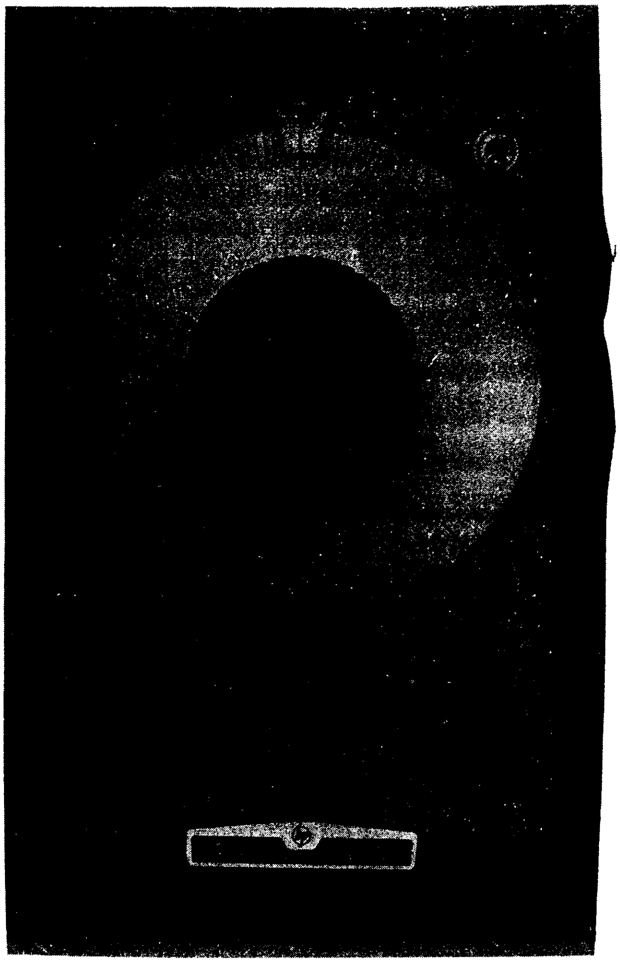

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Figure 11-20.–Audiofrequency (af) Signal Generator 28480-201C.

other than through the output circuit of the generator.

A block diagram of a representative RF signal generator is shown in figure 11-22. The function of the oscillator stage is to produce a signal which can be accurately set in frequency at any point in the range of the generator. The type of oscillator circuit used depends on the range of frequencies for which the generator is designed. In low-frequency signal generators, the resonating circuit consists of one of a group of coils combined with a variable capacitor. One of the coils is selected with a range selector switch which attaches it to the capacitor to provide an LC circuit which has the correct range of resonant frequencies.

The function of the modulating circuit is the production of an audio (or video) voltage which can be superimposed on the RF signal produced by the oscillator. The modulating signal may be provided by an audio oscillator within the generator (internal modulation), or it may be derived from an external source. In some signal generators, either of these methods of modulation may be employed. In addition, a means of disabling the modulator section is used whereby the pure unmodulated signal from the oscillator can be used when it is desired.

The type of modulation used depends on the application of the particular signal generator. The modulating voltage may be either a sine wave, a square wave, or pulses of varying duration. In some specialized generators, provision is made for pulse modulation in which the RF signal can be pulsed over a wide range of repetition rates and at various pulse widths.

Usually the output circuit of the generator contains a calibrated attenuator and often an output level meter. The output level meter gives an indication of, and permits control of, the output voltage of the generator by indicating arbitrary values of output read in tenths through the value of one. The attenuator selects the amount of this output. The attenuator, a group of resistors forming a voltage-dropping circuit, is controlled by a knob which is calibrated in microvolts. When the control element is adjusted so that the output meter reads unity (1.0), the reading on the attenuator knob gives the exact value (no multiplication factor) of the output in microvolts. If output voltage is desired at a lower value, the control is varied until the meter indicates some decimal value less than one, and this decimal is multiplied by the attenuator reading to give the output in microvolts.

Frequency-modulated RF signal generators are widely used for testing frequency-modulated receivers and for visual alignment (using an oscilloscope) of AM receivers. A frequency-modulated signal is an alternating voltage in which the frequency varies above and below a given center frequency value. The overall frequency change is called the frequency swing.

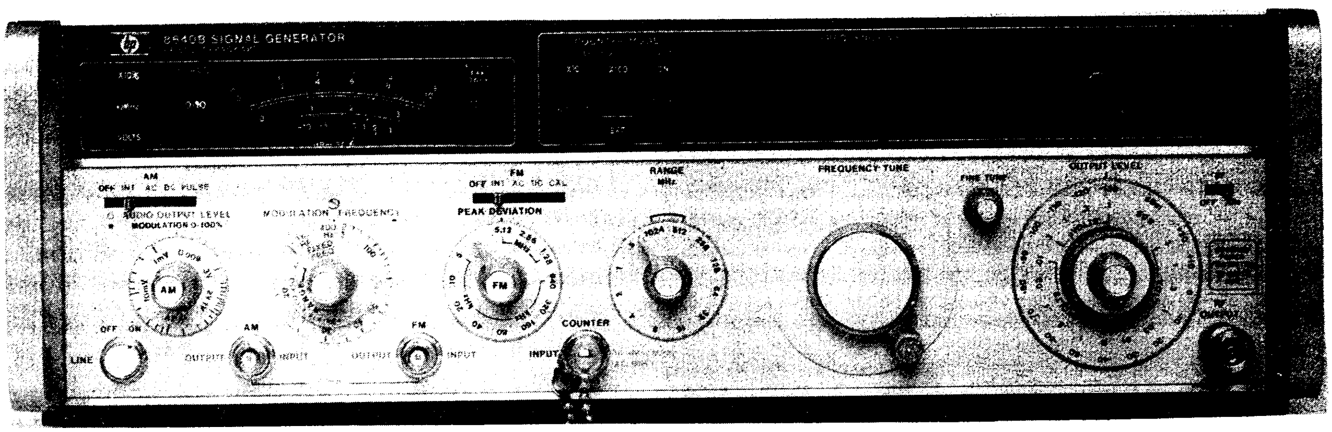

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Figure 11-21.—Radiofrequency (RF) Signal Generator 28480-8640B.

There are several methods by which the frequency of the oscillator in the signal generator may be frequency modulated. In one type of FM generator, use is made of a vibrating plate which forms one of the elements of the tuning capacitor of the oscillator to be modulated. The plate is driven by a device similar to a magnetic loudspeaker. The audio modulating voltage is applied to the driving coil which moves in the field of a permanent magnet and vibrates the plate of the capacitor at the applied audiofrequency. Movement of the plate causes variation of the capacitance in the oscillator tuning circuit with the result that the frequency of the oscillator is periodically raised or lowered.

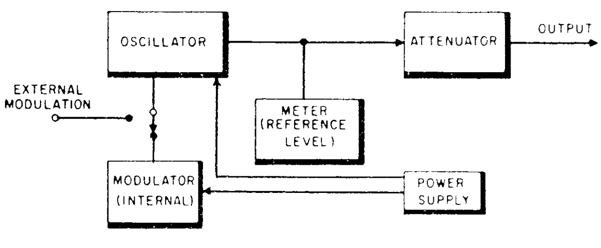

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Figure 11-22.—Block Diagram of RF Signal Generator.

Another method of producing frequency modulation is based on the action of a reactance tube which is connected in parallel with the tuning circuit of the oscillator to be modulated.

In signal generators of microwave frequencies, frequency modulation is accomplished in the oscillator by applying the modulating voltage to the repeller plate of the reflex klystron tube, which is usually employed in these generators.

OSCILLOSCOPES

One of the most widely used pieces of test equipment for both installation and maintenance is the oscilloscope. Many electronic equipment types include an oscilloscope built into the chassis of a unit and pickup loops or probes at the input circuits of key units, which are wired to a switch at the oscilloscope for instant or constant observation. A chart is also furnished with optimum waveform shape, voltage in height and time in length. The actual shape and measurements may vary in different installations; therefore, maintenance personnel responsible for the equipment should check for true operating waveforms.

The voltage or current waveform is normally represented in a graphically displayed two-dimensional (horizontal and vertical) plane with no depth involved. The horizontal ("X") axis on the oscilloscope will represent elapsed time or waveform duration in either whole or parts of a second. The vertical ("Y") axis will represent amplitude, quantity, or intensity of the subject waveform in either whole or parts of volts or amperes. Any portion of the waveform extending above the present horizontal (zero amplitude) reference line is considered positive, while any portion below the horizontal reference line is considered negative (opposite to the positive portion of the subject waveform).

Most oscilloscopes consists of a major unit and any one of several plug-in units. The major unit contains the power supplies, sweep circuits, calibration circuits, cathode-ray tube (CRT), and the controls associated with these circuits. The plug-in units are single-channel, multichannel or special feature preamplifiers and are selected depending on the display desired; i.e., a multichannel plug-in unit provides two separate traces on the CRT and thus allows two functions to be displayed simultaneously. An instruction manual is provided with each plug-in unit that gives detailed instructions for operating that specific plug-in unit in conjunction with the oscilloscope.

The AN/USM-281A Oscilloscope, illustrated in figure 11-23, is an example of the type of oscilloscope presently in use throughout the fleet. The AN/USM-281A is a direct coupled, wideband oscilloscope that provides a visual display of simple and complex waveforms. In addition to displaying waveforms, the oscilloscope provides the user with the capability of accurately measuring rise time of a waveform, waveform magnitude, time difference between any two points on a displayed waveform and accurate time comparison of two separate waveforms. This oscilloscope consists of essentially three operating units, the oscilloscope assembly mainframe, a dual trace plug-in unit (bottom left) and a time base and delay plug-in unit (bottom right). Oscilloscopes are treated in greater detail in *Basic Electronics, Vol. 1* NAVPERS 10087.

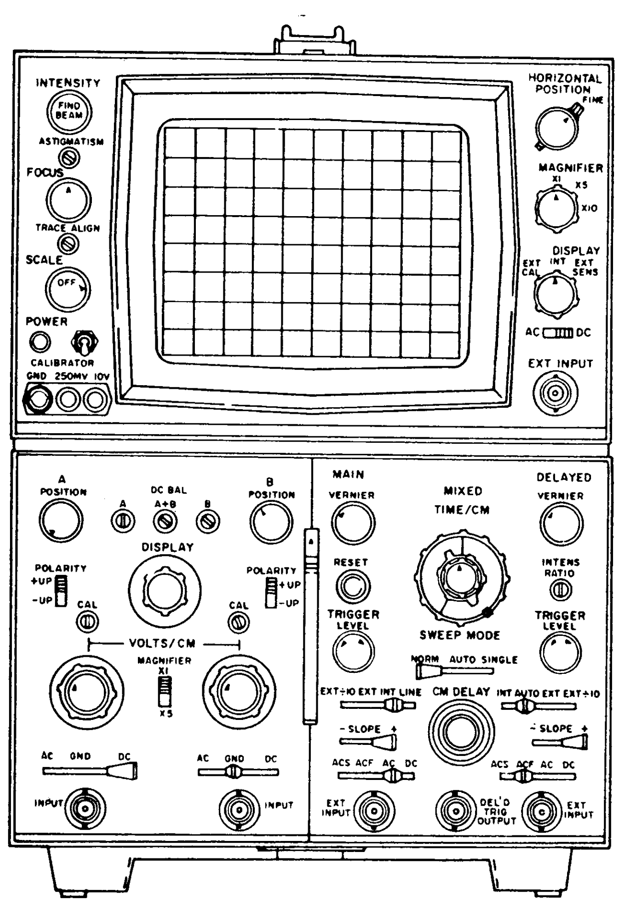

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Figure 11-23.—AN/USM-281A Front Panel.