TRANSMITTER METERING

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For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in this same way.

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TRANSMITTER METERING

Meters in Transmitter Circuits

TRANSMITTER panels seem to the novice to have tremendous numbers of meters mounted on them. If you become a radio operator, very likely you will be dismayed at first by the quantity of meters you must read. You may feel that you can never hope to be able to interpret all the readings. Yet, in a few months, you will probably wish that there were even more meters—for you will have learned how much help they can be to you.

A radio operator has two chief jobs—to operate and maintain his transmitter efficiently, and to operate it so that it meets the specific requirements concerning power, frequency, and percentage of modulation set for it by the Federal Communications Commission. Meters are not merely helpful, but absolutely necessary, to him in performing both these tasks. In fact, the FCC requires that certain meters be incorporated in a broadcast transmitter so that the operator will be sure to have the basic equipment he needs to do his job.

Most transmitters have far more than the required number of meters, because experience has shown that extra meters speed the operator's work. An adequate metering arrangement places a meter at every point in the transmitter circuit that has a vital bearing upon the adjustment or performance. Not all transmitters have such an arrangement—as a matter of fact, small transmitters, like those used in 10-watt mobile police radio stations, may not have any meters—but practically all broadcast stations do.

It is the purpose of this Lesson to show you what meters are used in transmitters, what they indicate, and how they can help you in the operation and maintenance of a station. As the first step, let us learn what kinds of meters you will meet.

VOLTMETERS

First, let us consider the voltmeters. Both a.c. and d.c. voltmeters are used in transmitting stations. The a.c. voltmeters are generally used only to measure the power line voltage and the filament voltages of a.c.-operated tubes.

Measurements of the line voltage are important because fluctuations in this voltage are often prevalent at transmitter locations. These fluctuations are usually slow at land locations, where they generally occur because of intermittent industrial loads on the power line used by the transmitter. On shipboard the fluctuations are more pronounced because of the lower capacity of the ship's generator and distribution lines.

Almost always some means is provided at the transmitter for adjusting the line voltage to the desired value. Transmitters with powers up to 1 kilowatt are usually equipped with variable transformers for this purpose; in larger transmitters, automatic motor-operated voltage regulators are used.

The a.c. line voltmeter is, of course, connected across the line to be measured. In the case of three-phase a.c. supply systems, a transfer switch is provided for measuring the voltage of each phase.

D.C. voltmeters are used to measure the d.c. plate, screen, and grid bias voltages of the transmitter tubes. If

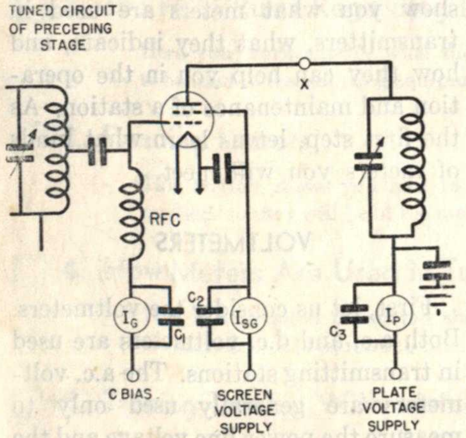


FIG. 1. This illustration shows how d.c. milliammeters may be connected to measure control grid current (I_G), screen grid current (I_{SG}), and plate current (I_P) in an r.f. stage.

the tubes are d.c.-operated, d.c. voltmeters are also used to measure their filament voltages.

Filament voltmeters, both a.c. and d.c., are connected across the filament leads of the tubes as close to the tube terminals as possible. This eliminates errors in the voltage measurement that might be introduced by the IR drop in the filament leads.

Filament voltmeters are now used only in the high-power stages of transmitters. All low-power tubes are designed to operate over a fairly wide range of filament voltages; they burn out faster if the voltage is above the rated one, but they are so relatively inexpensive that it is uneconomical to spend time keeping a close check on their voltages. With high-power and expensive tubes, however, tube life (and, therefore, transmitter operating cost) is so closely related to filament voltage that it is profitable to make a considerable effort to keep the voltage at or slightly under the proper value. Operation of the filament voltage 5% over the rated value will generally cut the tube life in half and not appreciably improve the tube's performance. On the other hand, operating the filament 5% under voltage will give a correspondingly longer life and will affect performance only slightly.

The series or multiplying resistor used with a voltmeter may be contained within the meter case itself or may be externally located. The voltage range of the meter usually determines which method is used: a voltmeter with a range of 300 volts or less generally has an internal resistor, one with a higher range usually has an external resistor. External multiplying resistors are used with high-voltage voltmeters for these reasons:

1. The resistor is usually too large to fit in the meter case.
2. The heat dissipated by the resistor would overheat the meter.
3. The problem of insulating the resistor from the meter case would be difficult.

The multiplying resistor is always connected to the high voltage side of the circuit so that the instrument itself is at ground potential. This protects operating personnel and makes it unnecessary to use high-voltage insulation between the meter and panel.

D.C. CURRENT METERS

D.C. ammeters and milliammeters are used to measure the *average* value of vacuum tube plate, screen, cathode, and grid currents. They are the most essential of all the meter types used in radio transmitters, for it is principally with their aid that the transmitter is adjusted and serviced. Voltmeters and r.f. meters are also essential, of course, but the majority of meters on a given transmitter are milliammeters or ammeters.

D.C. milliammeters are generally connected in a radio-frequency stage, as shown in Figs. 1 and 2.

Fig. 1 shows the connections for grid current, screen current, and plate current meters. Notice that in all these meter connections they are connected between the voltage supply and the vacuum tube circuit and are at r.f. ground potential. That is, there is no r.f. voltage between the meter and ground as there would be if the plate current meter, say, were connected between the vacuum tube plate and its oscillating circuit at point X in Fig. 1. However, when the meters are connected as shown in Fig. 1, there is high d.c. voltage between the meter and ground in each case. For this reason, all such meters must have adequate insulation to ground and adequate protection to prevent the operator from touching the meter and possibly receiving a shock.

The high r.f. impedance of the meter coil is the reason why a meter is invariably connected in the r.f. ground side of a transmitter circuit. Because of this high impedance, any r.f. current flowing through the meter would develop a high r.f. voltage across the terminals, and the meter would eventually be ruined. In fact, if the meters are located in the transmitter in any position in which they are subjected to an r.f. field or r.f. currents, they are almost certain to be destroyed in a

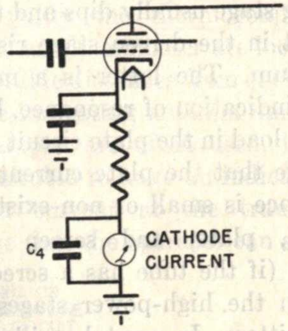


FIG. 2. How to connect a d.c. milliammeter to measure cathode current in an r.f. stage using a heater tube. Notice that the meter is at ground potential.

short time. To protect the meters from stray r.f. fields or currents, .001- to .01-mfd. r.f. by-pass condensers, such as C_1, C_2, and C_3 in Fig. 1, should be connected across them. To be effective, they must be connected directly across the meter terminals with the shortest possible leads.

Fig. 2 shows a cathode current meter connected in series with the cathode of the vacuum tube. This connection has the desirable feature of placing the meter at ground potential for both d.c. and r.f. That is, there is no d.c. or r.f. potential between the meter and ground.

Fig. 3 shows how the cathode current in a filament-type tube is measured. This connection has the same advantages as that shown in Fig. 2. However, when this circuit is used, a separate filament supply is required for each tube having a cathode current meter.

Optimum tuning of a driving stage can be indicated either by a meter that shows the current flow in the plate circuit of the stage or by a meter that measures the grid current in the driven stage. When the plate circuit is tuned to resonance, the plate current of the driving stage usually dips and the grid current in the driven stage rises to a maximum. The latter is a more reliable indication of resonance, because the r.f. load in the plate circuit may be so large that the plate current dip at resonance is small or non-existent.

Grid, plate, and screen current meters (if the tube has a screen) are used in the high-power stages of all transmitters. In crystal oscillator circuits, however, only one meter, either a grid current meter or a plate current meter, is used. Either will indicate oscillation: when the oscillator goes into oscillation, there is a rise in grid current and a dip in plate current.

The full-scale ranges of milliammeters and ammeters in various transmitters are interesting. In low-power transmitters and in low-power stages of high-power transmitters, plate current meters require ranges varying from a few milliamperes for the crystal oscillator stage to several hundred milliamperes for a driver stage. In high-power stages, the plate current meters have full-scale ranges of several amperes. Table 1 gives typical plate current values and plate current meter ranges for vacuum tubes of various power ratings. It can be seen from this table that ammeters are as commonplace in high-power transmitters as milliammeters are in low-power transmitters.

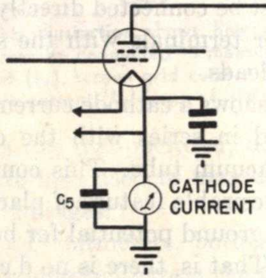


FIG. 3. Here's how to measure the cathode current in an r.f. stage using a filament-type tube.

TABLE 1

Tube Type	*Output Power (Class B)*	*Normal Plate Current*	*Range of Plate Current Meter*
RCA 807	12.5 watts	62 ma.	0-100 ma.
W.E. 357A	500 watts	380 ma.	0-500 ma.
W.E. 343A	2500 watts	1.2 amp.	0-1.5 amp.
GL-862	25,000 watts	3.2 amp.	0-5 amp.

R.F. ammeters are used generally in the tank circuits, transmission line circuits, and antenna circuits of transmitters where observance of the r.f. current is an aid in adjusting and maintaining the equipment. R.F. tank circuit ammeters are not used so extensively in late models of radio transmitters as they were in years gone by. These were used principally in broadcast transmitters where the exact adjustment of tank circuits was necessary. The modern technique is to use the radio-frequency bridge instead in adjusting the antenna coupling circuits and power amplifier tank circuits.

All radio transmitters except small, low-power, point-to-point or mobile transmitters have an antenna r.f. current ammeter. If the transmitter feeds into a transmission line, the meter is called a transmission line current meter.

Fig. 4 shows typical connections of tank circuit and antenna or transmission line current meters in an r.f. power amplifier stage.

The meter at A is the tank circuit meter and measures the current circulating in L_T and C_T. If the reactance of C_T or L_T is known, the root-mean-square value of the r.f. voltage across the tank circuit can be computed. ($E = I \times X_C$ or $I \times X_L$) This tank circuit voltage is an accurate indicator of the quality of the circuit adjustment, because this voltage should be a specific value for optimum operation in either modulated or unmodulated stages. When tank circuit ammeters are used in radio transmitters, the equipment instruction books give the proper values of tank circuit current for all conditions of operation.

The meter at B is the antenna or transmission line current meter, depending upon whether the transmitter is working into an antenna or transmission line. This meter is always placed in the circuit between the antenna or transmission line and the coupling line circuit as shown—*never* at a point, such as X, between the secondary inductance L_S and the coupling circuit. A meter at X will not indicate the true antenna or transmission line current because of the current losses in the coupling circuit. It is necessary to measure the true antenna or transmission line current so that the output power of the transmitter may be calculated from the current and the antenna or transmission line resistance.

Frequently the thermocouple and meter of an r.f. ammeter are located at considerable distances from each other. Remote-indicating antenna ammeters, for example, are often used, because it is desirable to have an indication of antenna current at the transmitter house so that the operator can see how the antenna is working without making a trip to the antenna base, which may be several hundred feet away. The remote indication is secured by locating the meter in the transmitter house and the thermocouple at the base of the antenna and connecting the two with a suitable two-conductor cable. The combination must be calibrated with the equivalent resistance of the connecting line in the meter circuit.

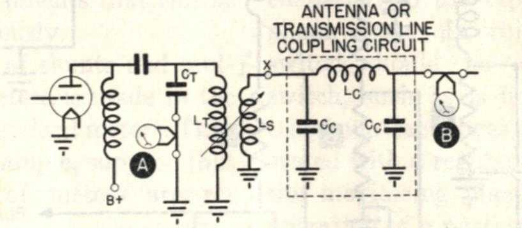


FIG. 4. How r.f. tank circuit and antenna or transmission line currents are measured in an r.f. power amplifier stage. Meter A measures tank circuit current, meter B measures the antenna or transmission line current.

THE TEST METER

Growing in popularity and in importance in radio transmitters is the so-called "test meter." One form of a test meter consists of a single standard 250-millivolt meter movement to which various shunts and multipliers are connected by a two-deck tap switch. The scale of the meter is calibrated for the ranges of the current shunts and voltmeter multipliers to be used with it. The current shunts and voltmeter multipliers are placed in the transmitter circuit in the places where d.c. milliammeters and d.c. voltmeters would normally be placed. When the meter movement is connected to these with the tap switch, the current or voltage at that point can be read. This method makes it possible to measure the current or voltage in 25 or 30 different circuits with one meter. The tap switch need only be set to the proper position to read any one of the currents and voltages.

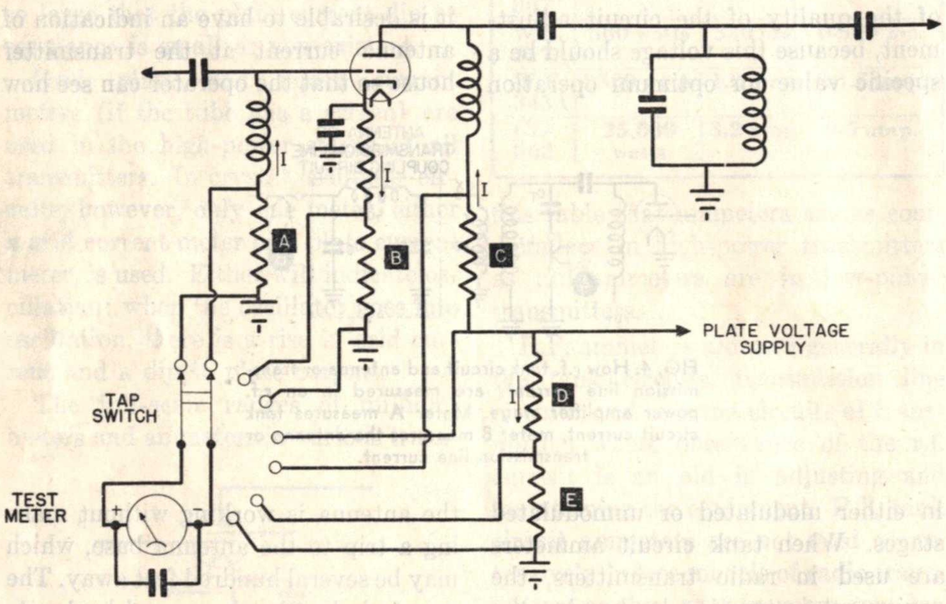


FIG. 5. Test meter connections. The switch connects the meter to shunt A for measuring grid current, to shunt B for measuring cathode current, to shunt C for measuring plate current, and to shunt E for measuring plate voltage. Resistor D is a voltmeter multiplier for this last measurement.

Fig. 5 shows the circuit of a test meter connected to several current shunts and voltage multipliers through a tap switch.

A is the current shunt for measuring the vacuum tube grid current; B, that for measuring the cathode current; C, that for measuring the plate current; and D and E are a voltmeter multiplier and meter shunt for measuring the plate voltage.

The current shunt C is used only when the plate voltage is a low value, say 300 volts maximum, and the tap switch and meter are designed to withstand that voltage. You will notice that all the other shunts are at ground potential, which makes the insulation problem very simple. Shunt C would be used only under extraordinary circumstances.

This method of combining many meter functions in one meter and tap switch is becoming popular for three reasons. First, it makes it more convenient for the operator to check the circuit voltages and currents, since he does not need to shift his attention over a panel filled with numerous meters. Second, it conserves panel space, a fact that is important in view of the tendency to build transmitters in smaller and smaller "packages." Third, it makes the transmitter cost less.

Generally, the lower-powered circuits are metered in this manner, and the line voltage, plate voltage, plate current, and r.f. meters for the power amplifier or power output stages are regular panel instruments that can be monitored continuously.

The calculation of shunts and multipliers for test meters is made in the same way as for standard meters. Taking Fig. 5 as an example, suppose that full-scale ranges of meters are required as follows:

A (grid current) 5 ma. full scale;

B (cathode current) 100 ma. full scale;

C (plate current) 100 ma. full scale;

D and E (plate voltage) 1000 volts full scale.

Suppose, further, that the test meter itself has a 0-.5 ma. full-scale range and an internal resistance of 500 ohms. This means the test meter will deflect full scale when .25 volts (250 millivolts) is impressed across its terminals.

The current shunts then must be designed so that there will be a voltage drop of .25 volt across the meter and shunt combination when the required full-scale current is flowing. Shunt A, it turns out, must be 55.6 ohms, shunts B and C must be 2.52 ohms.

In the case of the voltage multipliers, the shunt element at E can be made 500 ohms, making the resistance of the meter plus the shunt 250 ohms. The combination will then be equivalent to a meter with a 0-1 milliampere movement. The multiplier at D must then be 1 megohm.

A remote metering system can be very similar to the test meter circuits just described. When general metering of a remotely controlled and operated transmitter is undertaken, the current shunts, voltmeter multipliers, and the tap switch can be located at the transmitter location, and the test meter can be located at the monitoring place and connected to the tap switch by telephone lines. In this case, the tap switch should be a stepping type switch, such as is used in automatic telephone exchanges, that can be operated with a regular telephone dial at the monitoring place. To check the operation of a particular circuit in the remote transmitter, the operator can dial the number corresponding to the shunt or multiplier of that circuit; the selector switch will then step until it closes the circuit between the proper shunt and the test meter.

R.F. currents could be measured in a similar manner by switching the meter between several thermocouples. In remote metering of r.f. currents, one side of all shunts, multipliers, and thermocouples should be at ground potential so that no appreciable voltage will be applied to the telephone lines. If voltage is applied to the lines, it might break down cable insulation or become a hazard in the telephone system.

Multimeters and cathode-ray oscilloscopes, although they are not included in the normal complement of transmitter meters, are of such value that they should at least be mentioned in connection with the subject of transmitter metering. These instruments, with which you are already familiar, should be included in the maintenance equipment of every transmitting station.

CALCULATING CIRCUIT PERFORMANCE FROM METER READINGS

Often, in radio work, a meter reading is used merely as an indication of whether or not a circuit is operating normally. No attempt is made to read the meter accurately; the person reading it merely makes sure that the meter is indicating some value in about the right range. The operator of a transmitter, however, often finds it necessary to read meters accurately and make computations from his readings.

For example, the r.f. output power into the antenna is often calculated. The output power is $I_A^2 \times R_A$, where I_A is the antenna current in amperes and R_A is the antenna resistance in ohms. For this calculation to be accurate, the resistance must be measured at the same point in the antenna circuit as the location of the antenna ammeter. For broadcast stations, the Federal Communications Commission requires the measurement of output power to be made in this way. This is known as the "direct measurement" method of measuring output power.

Another important calculation is the input power to the final amplifier stage of a radio transmitter. This is equal to $I_p \times E_p$, where I_p is the final amplifier plate current in amperes and E_p is the plate voltage in volts. If the plate input power is multiplied by the plate circuit efficiency of the stage, the output power can be calculated; conversely, if the output power has already been measured by the direct measurement method, the plate efficiency can be calculated by dividing the output power by the plate input power. The efficiency figure derived by this method will include the losses in all apparatus, such as transmission lines and tuning circuits between the plate circuit and the antenna.

The FCC Rules Regarding Metering

The Federal Communications Commission makes two general kinds of rules regarding the metering of radio transmitters. The first kind, which apply particularly to stations in the broadcast service, are intended to insure uniform regulation of transmitter output power, modulation percentage, and frequency deviation. The second kind, which apply to stations in the ship and allied services, are intended to insure minimum standards of metering for maintenance and indication of normal operation.

Because there are so many broadcast stations, it is essential that the licensed power, frequency, and modulation of every transmitter be maintained to prevent disorder and confusion and to insure the maximum service to broadcast listeners. The rules set up by the Commission for the broadcast service that have a bearing on meters and measurements are as follows:

Frequency Monitoring. Each station in the broadcast service except relay broadcast stations must have installed at the transmitter location an approved frequency monitor with which the operator must periodically check the deviation of the transmitter frequency from the assigned frequency (Rules 2.75, 3.60, and 4.2). The Commission also prescribes that a reading of the frequency deviation shall be made at intervals of 30 minutes during the time of operation and a record shall be made of the deviation and of the crystal oven temperature if the ovens are equipped with thermometers. (Rules 3.404 and 4.264.) For standard broadcast stations in the 550-1600 kc. band, the frequency must be maintained within ±20 cycles of the assigned frequency. (Rule 3.59.) For high-frequency broadcast stations in the 88,000-108,000 kc. band (frequency modulation stations) the average frequency must be maintained within ±2000 cycles of the assigned frequency. (Rule 3.253.) The frequency of television stations must be maintained within 0.002% of the assigned frequency. (Rule 3.668.)

Modulation Monitor. All broadcast stations of every class must have installed at the transmitter location or under the observation of the operator an approved modulation meter with which the percentage modulation of the transmitter may be monitored. (Rules 3.55 and 3.244.) The Commission requires that all broadcast transmitters must be capable of at least 85% modulation at the authorized power output and that modulation percentage during transmission must be maintained as high as possible consistent with good quality of transmission. The modulation peaks must reach at least 85% but not more than 100%. (Rules 3.55 and 3.252.) These rules on minimum percentage of modulation are made in order that the maximum use will be made of the assigned broadcast facilities. With modulation monitors installed, there can be no excuse for the unsatisfactory service to the listener caused by continuously overmodulated or undermodulated transmitter carriers.

To abide by the above rules, the broadcast transmitter operator adjusts the gain or audio input control until the modulation peaks as indicated by the modulation monitor swing into the 85% to 100% region. Slight readjustments in the gain control are made from time to time as the character of the program changes to maintain the modulation peaks in this region.

Indicating Instruments. A transmitter being used in the broadcast service must be equipped with instruments for measuring the plate voltage of the final radio-frequency stage, the plate current of that stage, and the antenna current. These instruments must all be of an approved type (a license is not granted unless these meters meet with the Commission's approval) with suitable scales for the values to be measured. (Rules 3.58 and 3.246.)

The exact requirements for meters to be used on transmitters operating in the standard broadcast band are fully described in Section 13 of the Federal Communications Commission's publication "Standards of Good Engineering Practice Concerning Standard Broadcast Stations." This section of that publication is reproduced here in full. These standards set up by the Commission should be regarded as good practice in regard to all the meters in a transmitter.

"13. INDICATING INSTRUMENTS PURSUANT TO SECTION 3.58 (FCC Rules and Regulations)

"Section 3.58 requires that each standard broadcast station shall be equipped with suitable indicating instruments of accepted accuracy to measure the antenna current, direct plate circuit voltage, and the direct plate circuit current of the last radio stage.

"The following requirements and specifications shall apply to indicating instruments used by standard broadcast stations in compliance with this rule:

A. Instruments indicating the plate current or plate voltage of the last radio stage (linear scale instruments), shall meet the following specifications:

(1) Length of scale shall be not less than 2 3/10 inches.

(2) Accuracy shall be at least 2 per cent of the full-scale reading.

(3) The maximum rating of the meter shall be such that it does not read off scale during modulation.

(4) Scale shall have at least 40 divisions.

(5) Full-scale reading shall not be greater than five times the minimum normal indication.

B. Instruments indicating the antenna current shall meet the following specifications:

(1) Instruments having logarithmic or square law scales.

(a) Shall meet same requirements as 1, 2, and 3 above for linear scale instruments.

(b) Full-scale reading shall not be greater than three times the minimum normal indication.

(c) No scale division above one-third full-scale reading (in amperes) shall be greater than one-thirtieth of the full-scale reading. (Example: An ammeter meeting requirement (a) above having full-scale reading of 6 amperes is acceptable for reading currents from 2 to 6 amperes, provided no scale division between 2 and 6 amperes is greater than one-thirtieth of 6 amperes, 0.2 ampere.)

(2) Radio frequency instruments having expanded scales.

(a) Shall meet same requirements as 1, 2, and 3 for linear scale instruments.

(b) Full-scale reading shall not be greater than five times the minimum normal indication.

(c) No scale division above one-fifth full-scale reading (in amperes) shall be greater than one-fiftieth of the full-scale-reading. (Example: An ammeter meeting the requirement (a) above is acceptable for indicating currents from 1 to 5 amperes, provided no division between 1 and 5 amperes is greater than one-fiftieth of 5 amperes, 0.1 ampere.)

(d) Manufacturers of instruments of the expanded scale type must submit data to the Commission showing that these instruments have acceptable expanded scales, and the type number of these instruments must include suitable designation.

(3) Remote reading antenna ammeters may be employed and the indications logged as the antenna current in accordance with the following:

(a) Remote reading antenna ammeters may be provided by:

1. Inserting second thermocouple directly in the antenna circuit with remote leads to the indicating instrument.

2. Inductive coupling to thermocouple or other device for providing direct current to indicating instrument.

3. Capacity coupling to thermocouple or other device for providing direct current to indicating instrument.

4. Current transformer connected to second thermocouple or other device for providing direct current to indicating instrument.

5. Using transmission line current meter at transmitter as remote reading ammeter. See paragraph (h) below.

6. Using indications of phase monitor for determining the ratio of antenna currents in the case of directional antennas, provided the indicating instruments in the unit are connected directly in the current sampling circuits with no other shunt circuits of any nature.

(b) A thermocouple type ammeter meeting the above requirements shall be permanently installed in the antenna circuit. (This thermocouple ammeter may be so connected that it is short-circuited or open-circuited when not actually being read. If open-circuited, a make-before-break switch must be employed.)

(c) The remote ammeter shall be connected at the same point in the antenna circuit as the thermocouple ammeter and shall be so connected and calibrated as to read in amperes within 2 per cent of this meter over the entire range above one-third or one-fifth full scale. See sections B 1(c) and B 2(c) above respectively.

(d) The regular antenna ammeter shall be above the coupling to the remote meter in the antenna circuit so it does not read the current to ground through the remote meter.

(e) All remote meters shall meet the same requirements as the regular antenna ammeter with respect to scale accuracy, etc.

(f) Calibration shall be checked against the regular meter at least once a week.

(g) All remote meters shall be provided with shielding or filters as necessary to prevent any feedback from the antenna to the transmitter.

(h) In the case of shunt excited antennas, the transmission line current meter at the transmitter may be considered as the remote antenna ammeter provided the transmission line is terminated directly into the excitation circuit feed line, which shall employ series tuning only (no shunt circuits of any type shall be employed), and insofar as practicable, the type and scale of the transmission line meter should be the same as those of the excitation circuit feed line meter (meter in slant wire feed line or equivalent).

(i) Remote reading antenna ammeters employing vacuum tube rectifiers are acceptable provided:

1. The indicating instruments shall meet all the above requirements for linear scale instruments.

2. Data are submitted under oath showing the unit has an over-all accuracy of at least 2 per cent of the full-scale reading.

3. The installation, calibration, and checking are in accordance with the above requirements.

(j) In the event there is any question as to the method of providing or the accuracy of the remote meter, the burden of proof of satisfactory performance shall be upon the licensee and the manufacturer of the equipment.

C. Stations determining power by the indirect method may log the transmission line current in lieu of the antenna current provided the instrument meets the above requirements for antenna ammeters, and further provided that the ratio between the transmission line current and the antenna current is entered each time in the log. In case the station is authorized for the same operating power for both day- and night-time operation, this ratio shall be checked at least once daily. Stations which are authorized to operate with night-time power different from the day-time power shall check the ratio for each power at least once daily.

D. No instruments indicating the plate current or plate voltage of the last radio stage, the antenna current or the transmission line current when logged in lieu of the antenna current, shall be changed or replaced without written authority of the Commission, except by instruments of the same make, type, maximum scale readings, and accuracy. Requests for authority to change an instrument may be made by letter or telegram giving the manufacturer's name, type number, serial number and full-scale reading of the proposed instrument and the values of current or voltage the instrument will be employed to indicate. Requests for temporary authority to operate without an instrument or with a substitute instrument may be made by letter or telegram stating the necessity therefor and the period involved.

E. No instrument, the seal of which has been broken, or the accuracy of which is questionable, shall be employed. Any instrument which was not originally sealed by the manufacturer that has been opened shall not be used until it has been recalibrated and sealed in accordance with the following: Repairs and recalibration of instruments shall be made by the manufacturer, by an authorized instrument repair service of the manufacturer or by some other properly qualified and equipped instrument repair service. In either case the instrument must be resealed with the symbol or trade mark of the repair service and a certificate of calibration supplied therewith.

F. Since it is usually impractical to measure the actual antenna current of a shunt excited antenna system, the current measured at the input of the excitation circuit feed line is accepted as the antenna current.

G. Recording instruments may be employed in addition to the indicating instruments to record the antenna current and the direct plate current and direct plate voltage of the last radio stage provided that they do not affect the operation of the circuits or accuracy of the indicating instruments. If the records are to be used in any proceedings before the Commission as representation of operation with respect to plate or antenna current and plate voltage only, the accuracy must be the equivalent of the indicating instruments and the calibration shall be checked at such intervals as to insure the retention of the accuracy.

H. The function of each instrument shall be clearly and permanently shown on the instrument itself or on the panel immediately adjacent thereto."

With the meters described above, the output power of the transmitter can be monitored and kept within the tolerances set by the Commission.

The Commission specifies three methods by which the operating or output power of all transmitters irrespective of class or service may be computed. (Rule 2.79.) These three methods are as follows:

1. Indirect measurement. This is accomplished by computing the input power to the final radio-frequency stage (plate voltage times plate current) and multiplying this power by the efficiency factor of the type of stage employed. These efficiency factors are discussed later in this Lesson.

2. Direct measurement. This is accomplished by making a measurement of the resistance component of the antenna impedance at the operating frequency, then multiplying this resistance by the square of the antenna current. This is a direct measurement of the power being supplied to the antenna.

3. Field intensity. This is accomplished by measuring the intensity of the radiated field within the area to be served by the transmitter and adjusting the transmitter power until a certain minimum field intensity over the area is obtained. The antenna or transmission line current at which the required service is obtained is noted and the transmitter is operated to maintain that current.

Standard broadcast stations are required to use the direct method of measurement exclusively, and high-frequency broadcast stations are required to use the field intensity method exclusively.

For stations in the broadcast service where the exact power is specified, the operating power is not allowed to exceed the specified power by more than 5% or to be under it by more than 10%. For stations whose maximum power is specified, the maximum power may not be exceeded by more than 5%. (Rule 2.8.)

To insure that the operating power and frequency of the transmitter are maintained within the prescribed limits, the Commission has ruled (Rule 3.404) that an entry of the following information in the transmitter operating log must be made at the beginning and end of each transmission and at intervals of 30 minutes during operation of transmitters in the broadcast service.

1. The operating constants of the last radio stage; i.e. plate voltage and plate current.
2. Antenna current.
3. Frequency deviation as read from the frequency meter.
4. Temperature of the crystal control chamber if a thermometer is used.

The rules of the Commission bearing on meters and measuring devices for all the other services are neither as specific nor voluminous as they are for broadcasting. The class of service in which the Commission is next most interested in metering is the ship service, where the quality of metering is a matter of safety of life.

Rule 8.142-d stipulates that the main transmitter shall be equipped with suitable instruments of approved accuracy to measure (1) the current in the antenna circuit, (2) the potential of the heating current (filament voltage) applied to the cathode or cathode heater of each electron tube or a potential directly proportional thereto, and (3) the anode current (plate current) of the radio frequency oscillator or oscillators and of each radio frequency amplifier stage containing one or more electron tubes.

Rule 8.144-d provides that the emergency transmitter shall be equipped with suitable indicating instruments of approved accuracy to measure (1) the current in the antenna circuit and (2) if completed by the manufacturer after January 1, 1944, the potential of the heating current applied to the cathode or cathode heater of each electron tube or a potential directly proportional thereto.

Rule 8.209 provides that portable lifeboat radio transmitters shall be equipped with a reliable visual indicator (such as a neon tube) to indicate when the antenna circuit is tuned to resonance at the operating frequency. Failure of this indicator shall not have any effect upon the actual operation of the transmitter.

Rule 8.233 requires, as necessary auxiliary equipment, one high-resistance direct current voltmeter having a resistance of at least 1000 ohms-per-volt and capable of measuring 2, 6, and 110 volts with an accuracy of at least 3%, except that on ships where the normal radio room power supply voltage is higher than 110 to 120 volts direct current, the voltmeter shall be capable of measuring this line voltage and 2 and 6 volts with an accuracy of at least 3%. This meter is intended for use in trouble shooting.

The licensee (owner) of each ship station is required to provide for measurement of each operating frequency of the station and to establish a procedure for regular measurement of each frequency. (Rule 8.97.) The rule stipulates that measurements must be made independently of the frequency control of the ship's transmitter and must be of an accuracy sufficient to detect deviations from the assigned frequency within one-half the authorized tolerance. (Tolerances are specified in Rule 8.96.) No other requirements about the measuring equipment are made; however, it is clear that the metering facilities prescribed by the above rules for ship service are considered the minimum acceptable.

The only reference to metering or measurements in radio services other than broadcast and ship services is in connection with the measurement and checking of transmitter frequencies. In general, for all these other services it is required that an acceptable schedule of checking transmitter frequencies be set up, and that the accuracy of the measuring equipment should be better than the allowed frequency tolerance of the transmitter.

Reading Meters

As we said earlier, it is often unnecessary to read meters carefully. When the readings are to be used in computations, however, they should be made accurately. Let's take a few moments to see how to do so.

In reading meters, the most common source of error is parallax, which is the error introduced when the line of sight of the person doing the reading is not perpendicular to the meter scale. The operator's head may be slightly to one side or the other of the plane of the pointer. This causes the pointer to *appear* to be slightly farther up the scale or slightly lower down on the scale than is its actual position and results in an inaccurate reading.

One way to prevent parallax is to make all readings with your preferred eye* lined up with the meter pointer so that a line between your eye and the scale directly under the pointer is exactly at right angles to the plane of the meter face. Finding the proper position to do this will take a little practice.

Another method is to make your readings by sighting along the pointer toward its outer end. This method is more awkward to use than the first, but is recommended when an accurate reading is to be made.

Portable precision meters are sometimes used in installing or adjusting equipment. A meter of this sort has a knife-edge pointer with a mirror behind it. To read this kind of meter correctly, line up the pointer and its mirror image, using your preferred eye, so that the pointer covers its image.

To make accurate meter readings, you must have a system for estimating fractions of divisions. One satisfactory system is to imagine the scale divisions divided into fourths. If the pointer comes a slight amount above the lower division mark, call it one-tenth of a division. If it is just a shade less than the imaginary one-quarter division point, call it two-tenths of a division; if it is just over the one-quarter division point, call it three-tenths. If it is more than three-tenths but less than the half division mark, call it four-tenths, and so forth.

Meter Accuracy. In using meters in the operation of transmitting equipment, you should keep the inherent accuracy of the meters in mind. Most panel instruments used in transmitters have guaranteed accuracies of ±2% of the full scale reading. If the meter

*To find your preferred eye, hold a pencil vertical at arm's length, directly in front of you and in such a position that it hides some distant object. Then close your eyes one at a time, keeping the pencil in the same position. When you close one eye, the pencil will appear to shift; when you close the other, the pencil will remain in the same position. The latter is your preferred eye. In a right-handed person, it is usually the right eye.

has a 100-ma. scale, the actual current flowing when the meter reads full scale may be anywhere within ±2 milliamperes of the indicated value, or somewhere between 98 and 102 milliamperes. On indications of less than full scale, say 10 milliamperes, the accuracy may still not be better than ±2 milliamperes, so the true reading may be anything from 8 to 12 milliamperes. Because of this inherent inaccuracy, don't bother to read any ordinary panel instrument to closer than 1% of the full-scale value. For example, a recorded reading within 1 ma. of the actual reading on a 100-ma. meter is close enough.

The only exception to the above suggestion is in the case where meter readings are being recorded for the purpose of determining a gradual change in transmitter performance or detecting a change from normal operation. Here the *relative* readings of the meters from day to day or hour to hour are what are desired, so the meter readings should be made and recorded as accurately as possible.

In practice, readings within the lower third of the meter scale are not regarded as accurate; therefore, meters are always selected so that normal readings will register in the upper two-thirds of the meter scale.

The preceding remarks about meter accuracy apply only to the usual panel meter. Precision meters, like those with mirrored scales mentioned earlier, are far more accurate and should be read with corresponding care if the readings are important. The length of scales of precision meters is several times that of ordinary panel instruments, so readings to an accuracy of ¼% of the full scale are easily made.

RECORDING METER READINGS

One of the most valuable maintenance practices that can be established at a radio transmitting station is that of keeping an accurate day-to-day record of the transmitter meter readings. It is from these records that present performance can be compared with past performance or with the transmitter's performance when first installed. (When the transmitter is first installed, acceptance tests are made that make the initial performance and adjustments a standard for future comparison.) The meter reading record also gives data with the aid of which a gradual change in characteristics can be detected. A gradual change in meter readings indicates that some component, generally a tube, is wearing out and will fail soon. For instance, if the grid current of an oscillator tube gradually decreases over a period of a month, say, it indicates that the tube is gradually losing its emission and soon will not oscillate at all. If close watch is kept on the trend of meter readings, it is often possible to anticipate and prevent failures of the transmitting equipment.

For a meter reading record to be of value, a system for taking and keeping the records must be set up and rigidly adhered to. A form (called a "log") upon which the meter readings are to be recorded should be prepared. Fig. 6 shows an example of a meter log. Each meter should have a column of its own. There should be a place for entering the date and the *time* when the readings are taken, and there should be ample space at the end of each line for remarks concerning unusual conditions that existed at the time the readings were taken. There should also be a

RADIO STATION XYZ
METER LOG

DATE	TIME	OSCILLATOR GRID CURRENT	OSCILLATOR PLATE CURRENT	BUFFER PLATE CURRENT	AMPLIFIER GRID CURRENT	AMPLIFIER PLATE CURRENT	ANTENNA CURRENT	OPERATOR AND REMARKS

FIG. 6. A typical page from a log of the kind used by radio stations to keep a record of meter readings.

space for the initials of the operator who made the readings, for it is important to know who made the readings when checking up on performance in case a question concerning the readings comes up.

Let's take a moment to study the procedure that should be used in making and recording the readings.

First, it is very important that the readings be made at the same time and under the same conditions each day. Select a convenient time, say an hour after the transmitter has been put on the air and thoroughly warmed up in the morning, and then again in the evening. Some broadcasting stations make a record of all meter readings each hour or every two hours as a means of keeping a tab on conditions. Stations that are in operation intermittently, such as police and marine stations, should not require a record to be made more than once a day. Remember that the readings should be made at the same time and as nearly as possible under the same conditions.

Before making the meter readings, make all the fine adjustments that are usually made during operation, such as adjustment of line voltage, fine adjustments in plate and grid circuit tuning, and fine adjustments of the antenna or output circuits. Make all these adjustments *before* beginning the meter readings and make no adjustments during the time it takes to make the readings. If it is necessary to make some circuit adjustments after starting to read the meters, start the readings over again from the beginning in order to avoid any discrepancies that might result from the change in the control.

All the readings of the transmitter should be made at the same time. That is, start at one end or the other of the transmitter circuit and record all meter readings consecutively through consecutive circuits to the other end of the transmitter circuit. You may find you have a clearer picture of what is happening in the transmitter if you start with the meters at the oscillator end and go straight through the transmitter to the antenna meter.

After the readings have been made, they should be compared with previous records. (A graphical method of recording readings for comparison will be discussed later in this Lesson.) This procedure will give a quick check of the day-to-day performance of the transmitter circuits and will instantly indicate any radical change. If a radical change in meter readings appears, it is a good practice to go back to the transmitter and check that reading again to be certain that an error in recording has not been made.

How Meters Are Used in Tuning a Transmitter

In other Lessons, the various types of transmitter stages and the tuning procedure to be used in adjusting each for best efficiency and maximum performance were discussed in detail. The parts of these Lessons that are concerned with the practice of adjustments should be reviewed at this time to correlate that information with what you are now going to learn about the use of meter readings in tuning a transmitter.

Let us go through the procedure of tuning a transmitter stage by stage, showing how meters are used in each stage. We will describe a *typical* tuning procedure that is followed in general in tuning commercial transmitters. (However, many transmitter circuits have special features that make their exact tuning procedure differ in some respects from this typical one. For this reason, you should never tune or adjust a strange transmitter without first reading the manufacturer's instruction book carefully, and you should follow his instructions to the letter.)

Transmitters are almost always tuned by tuning the oscillator stage first, then tuning each amplifying stage in sequence up to the antenna circuits. This is done because there is no excitation voltage on a particular stage unless all the preceding stages have been tuned up. The only exception to this procedure of starting at the oscillator stage occurs when radio frequency bridges are used to tune high efficiency power amplifier stages (such as the Doherty amplifier circuit) and some antenna tuning circuits.

Oscillators. The oscillator stage in a radio transmitter may be either a crystal oscillator or a self-excited LC oscillator. Very few commercial transmitters of recent design use self-excited oscillators, however.

Crystal oscillators and self-excited oscillators differ so in their functioning that different tuning procedures are used with each of them. A crystal oscillator oscillates at only one frequency and only when its plate or grid circuits are at the optimum adjustment for that frequency. That is, there is only one setting of the tuning control at which it will oscillate. Self-excited oscillators, on the other hand, will oscillate over the entire range of settings of the tuning control, so the tuning control must be adjusted according to the oscillator *frequency* desired. In both types of oscillators the presence of grid current is an indication of oscillation, the strength of oscillation increasing with increasing grid current. Lowered plate current is another indication of oscillation, the plate current tending to decrease with an increase in the strength of oscillation.

The solid curves in Fig. 7 show how the plate current, the grid current, and the r.f. output of a crystal oscillator vary as the capacity of the tuning condenser is increased from its minimum to its maximum value.

The plate current gradually *decreases* from point A to point C as the tuning capacity is increased. Notice that the tuned circuit goes through resonance at a point between these two tuning condenser settings. At C, oscillation stops very suddenly and the plate current goes up to D. The grid current starts from zero, gradually *increases* from A to C and suddenly decreases to zero again as point C is reached.

If the direction of rotation of the tuning condenser is reversed so that the capacity is *decreased* from maximum to minimum, oscillation does not start until point E is reached. This is indicated by the broken lines. Here the plate current decreases or dips to B as a minimum, then gradually increases to A, where the oscillations die out.

The region between B and C, although it is a region of very strong oscillation, is also a region of unstable operation and must be avoided. There are two requirements you must meet, then, when you tune a crystal oscillator: it should be tuned somewhere in the region between A and B for stability, and it should be tuned as near B as possible so that sufficient r.f. output will be obtained.

Self-excited oscillators are adjusted in conjunction with a wave-meter or shielded receiver to secure the correct frequency adjustment; then, when the final adjustments are made, the transmitter meters are used in addition to check the stability of the oscillator adjustments.

A stable adjustment of self-excited oscillators is indicated by the amount of oscillator grid current, by the amount of grid current in the succeeding amplifier stage, and by the amount of oscillator plate current. In general, the higher the grid current and the lower the plate current, the greater the stability of this type of oscillator. Stability will decrease as the loading on the oscillator is increased.

Therefore, when you adjust a self-excited oscillator, tune it for maximum grid current and minimum plate current, then adjust the output coupling so that only enough power is taken from the oscillator to excite the transmitter properly.

Amplifiers and Modulated Amplifiers. Amplifiers and modulated amplifiers are tuned in the same manner. There are two steps in the procedure: first the stage is neutralized, then the resonant circuits are tuned and the load is adjusted.

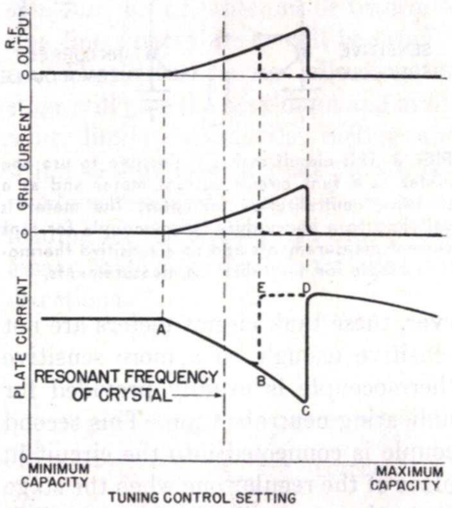


FIG. 7. How the r.f. output, grid current, and plate current of a crystal oscillator vary as the capacity of the tuning condenser is changed from minimum to maximum (solid lines) and from maximum to minimum (broken lines).

In the neutralization of a vacuum tube stage, the plate voltage is generally removed from the tube so that no amplification will take place through it. A sensitive r.f. milliammeter is connected in the plate tank circuit as an indicator by which to adjust the neutralization. Meter A in Fig. 4, for example, is an r.f. meter in the plate tank circuit that could serve as a neutralization indicator if it were sufficiently sensitive. Generally, how-

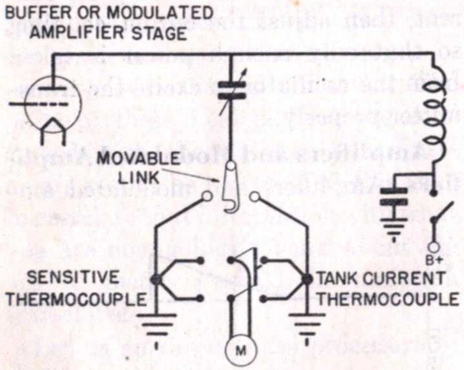


FIG. 8. This circuit makes it possible to use one meter as a tank circuit current meter and as a sensitive neutralization indicator. The meter is switched to a heavy-duty thermocouple for tank current measurements and to a sensitive thermocouple for neutralization measurements.

ever, these tank circuit meters are not sensitive enough, so a more sensitive thermocouple is usually provided for indicating neutralization. This second couple is connected into the circuit in place of the regular one when the stage is to be neutralized. Often a link switch and a d.p.d.t. switch are used for the purpose, as shown in Fig. 8.

To neutralize a stage having an indicator of this sort, first connect the sensitive thermocouple to the circuit with the link switch and the meter to the thermocouple with the d.p.d.t. switch. Then adjust the neutralizing control until a minimum r.f. current is indicated.

When thermocouple r.f. meters are not provided as neutralizing indicators, the grid current meter of the succeeding stage can be used as an equally effective indicator. In this case, increase the coupling between the stage being neutralized and the succeeding stage until a satisfactory grid current reading is obtained. Then adjust the neutralizing control for minimum grid current.

Another neutralizing indicator is that shown schematically in Fig. 9. Here a diode or multi-element tube is connected as a rectifier with a low-reading milliammeter in its cathode circuit. The diode converts a portion of any r.f. voltage appearing on the tank coil to d.c., which is measured by the cathode milliammeter.

A cathode ray oscilloscope makes a very effective neutralization indicator. The connections to the oscilloscope deflecting plates are shown schematically in Fig. 10. Notice that one vertical deflecting plate is connected to the plate tank circuit and the other is grounded.

The scope is made to sweep at any convenient frequency with its internal

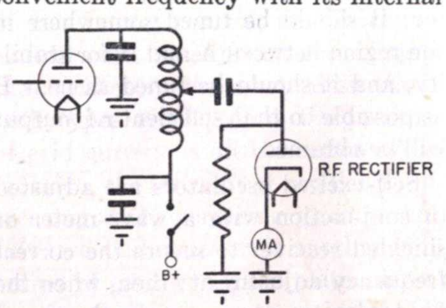


FIG. 9. Another neutralization indicator circuit. The milliammeter measures the d.c. passed by the r.f. rectifier. The resistor is used to allow some of the charge on the coupling condenser to leak off during the time the rectifier is not conducting. If this resistor were not used, the coupling condenser would remain fully charged at all times, and no current would flow through the rectifier and meter.

sweep generator. When r.f. is applied to the scope through the tap on the plate tank coil, the horizontal sweep line will expand vertically into a broad band. The tap on the tank coil is adjusted until this band is a convenient height, then the neutralizing control is adjusted until the band reaches a minimum depth.

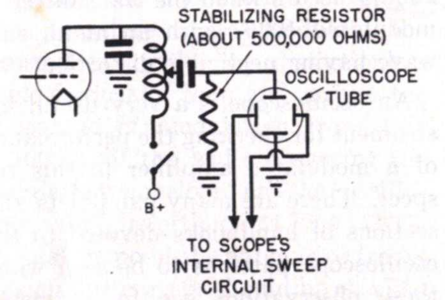


FIG. 10. How to connect a c.r.o. for use as a neutralization indicator.

The final tuning of intermediate amplifiers and modulated amplifiers is done mainly by adjusting their tank circuits until minimum plate current is produced or until maximum grid current is produced in the succeeding stage. As we said earlier, the load on the stage affects the sharpness of the plate current dip; if the load is great enough, the dip may not be noticeable. Fig. 11 shows the difference between the plate current dips in an unloaded and a loaded amplifier as the tuning control is adjusted through resonance.

The correct loading of amplifiers and modulated amplifiers is, in some cases, quite an important factor in the adjustment of transmitters. In the case of modulated amplifiers used for high quality program transmissions, the correct loading is necessary to produce full modulation and minimum distortion. In other cases, the correct loading is necessary to insure circuit stability.

Wherever loading is an important factor in the adjustment of circuits, most manufacturers of commercial transmitting equipment provide specific instructions for making the adjustments, and the transmitter stages involved will usually be equipped with enough indicating instruments to make the adjustments to the required accuracy.

The instruments most often used as indicators of the proper adjustment are the plate current meter of the amplifier being adjusted and a d.c. grid current meter in the grid circuit of the stage being driven. If the stage drives directly into an antenna or transmission line, an r.f. antenna or transmission line current meter will be provided. The directions for adjusting the stage will give the maximum and minimum limits for all the meters and will also show how to make the adjustments necessary to obtain the required loading for the circuit. All that is necessary to do a good job is to follow the directions.

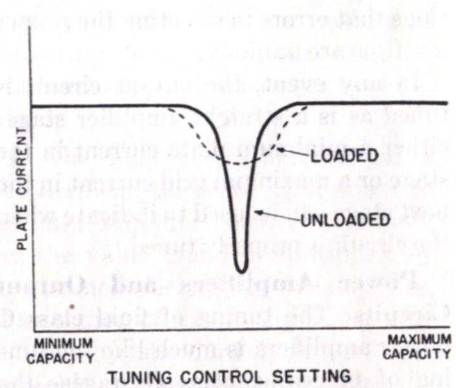


FIG. 11. Typical resonance dips in the plate current of an unloaded amplifier (solid line) and a loaded amplifier (broken line).

In this connection, we want to emphasize that if you are given the responsibility for the operation or maintenance of electrical equipment, one of your first duties should be to study the instruction books to familiarize yourself with all phases of its circuits, operation, and maintenance. If there are no instruction books available, manufacturers are usually eager to fill the void with instructional drawings or to replace the books if they have been lost or destroyed.

Doubler Stages. Frequency doubling stages are tuned in the same way as amplifier stages except that they do not have to be neutralized. Neutralization is unnecessary because their input and output circuits are not tuned to the same frequency and therefore they cannot go into self oscillation. In tuning the output circuit, it is necessary to ascertain by some means—wavemeter, frequency meter, or some other device—that the output frequency is the proper multiple of the input frequency. Charts are almost always provided with commercially built transmitters that show how to get the adjustment so close to the final settings that errors in selecting the proper multiple are unlikely.

In any event, the output circuit is tuned as is a straight amplifier stage; either a minimum plate current in the stage or a maximum grid current in the next stage can be used to indicate when the circuit is properly tuned.

Power Amplifiers and Output Circuits. The tuning of final class C power amplifiers is much like the tuning of preceding class C stages—the difference is in the adjustment of the amplifier loading. The circuit is tuned to produce a minimum plate current, and the coupling to the final amplifier tank is adjusted to produce maximum output, as indicated by the antenna or transmission line current meter.

Class B modulated amplifiers are tuned by tuning the plate tank to produce minimum plate current and adjusting the coupling to permit full modulation of the carrier. This coupling is such that an increase in antenna or transmission line current of 22½% occurs when the transmitter is modulated 100% with an audio sine wave having negligible distortion.

An oscilloscope is a very useful instrument for checking the performance of a modulated amplifier in this respect. There are many pamphlets and sections of handbooks devoted to the oscilloscope patterns to be seen when these observations are to be made. However, nothing concrete is generally said about the method of coupling the "scope" to the transmitter to get the desired pattern. Fig. 12 shows a simple method that is very effective. It consists of a low-capacity variable condenser connected directly to the antenna or transmission line post of the transmitter in series with another condenser of higher capacity that is connected to ground. This forms an r.f. voltage divider with the "scope" connected across the grounded condenser. The input to the scope is adjusted by means of the variable condenser until a satisfactory deflection is obtained. Naturally, the variable condenser must be a high voltage type with a voltage rating in accordance with the r.f. voltage impressed upon it. In moderate or high-power transmitters, the variable condenser can be replaced by a small flat plate held in the vicinity of the antenna post; this will provide adequate pickup. Some commercial broadcast transmitters come equipped with the required apparatus for using the oscilloscope to adjust the transmitter to optimum performance.

This use of an oscilloscope permits

the actual modulation envelope of the transmitter output to be seen and the quality of its output to be judged. Audio distortion amounting to but a few percent may be easily detected by observing the modulation envelope. The procedure is to modulate the transmitter with a distortionless single-frequency tone and adjust the percentage of modulation from zero to 100%, all the while observing the modulation envelope on the oscilloscope for distortion. At the 100% modulation point the antenna or transmission line current should be checked to see if the full 22½% increase is

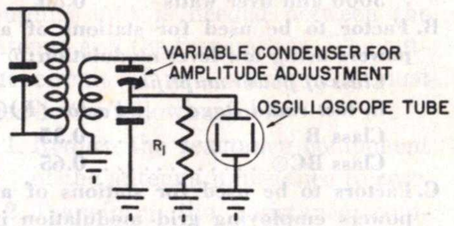


FIG. 12. This circuit can be used to check the modulation of a transmitter. R_1 is a high resistance (5 or 10 megohms) that is used to provide a d.c. path to ground.

obtained. If the modulation is 100% and the transmitter has low distortion, the antenna current increase should be no more or less than 22½%.

In the interesting case of "suppressed carrier" transmitters, in which only the modulation side bands are transmitted and the carrier itself has been filtered out, there is no antenna current until modulation occurs, and the antenna current will swing from zero to some maximum current value; the latter depends upon the amplitude of modulation and the energy in the modulation.

It should be emphasized here that the amount of coupling to the modulated amplifier is the governing factor in antenna current rise and in the efficiency of the amplifier.

At the same time the modulation percentage and distortion of the transmitter are being checked, the input power to the final amplifier or the antenna power should also be checked to be sure that the transmitter is operating with the power stipulated in the transmitter license. As we said in the section on FCC rules regarding meters, output power may be measured by either the direct or the indirect method. If the direct method is used, the antenna or transmission line impedance must have been measured and certified by a recognized engineer using approved methods and equipment. The direct power can then be computed by multiplying the squared antenna or transmission line current by the measured resistance. This method is the most accurate and reliable of all, and, as we said earlier, is the method of computing power that all standard broadcast stations must use, by FCC rule.

In the indirect method of power measurement, the plate input power to the final amplifier stage is measured, and the value found is multiplied by the assumed efficiency of the amplifier. This method of computing power may be used by standard broadcast stations only in emergencies involving the damage or loss of the licensed antenna or antenna ammeter. The assumed efficiencies of various types of amplifier stages authorized by the FCC (Rule 3.52) are shown in Table 2. Factor (F) is the assumed efficiency.

The final amplifier plate input power (the plate current read on the plate current meter multiplied by the plate voltage read on the final amplifier plate voltmeter) is multiplied by the applicable efficiency factor from the table to obtain the assumed output power. You will note that we say "assumed output power." This is because the efficiencies of the various output stages are not exactly as shown in the table, although those given are fair averages for average transmitter design practice. Any particular amplifier may have an efficiency of a few percent more or a few percent less than that given in the table, so the actual power output may be more or less than that calculated by the indirect method of power measurement.

Antennas and Coupling Units. Most present-day antennas for commercial transmitter installations are located at a point remote from the transmitter itself to prevent interference from the transmitter housing structure. This requires the use of an antenna coupling unit separate from the transmitter and a transmission line to connect the transmitter to the coupling unit.

Coupling circuits between transmission lines and antennas are required for the following purposes:

1. To transform the resistance component of the antenna impedance to a value equal to the characteristic impedance of the transmission line.
2. To reduce the reactive component of the antenna impedance to zero.

In general, antenna coupling units are equipped with two meters (Fig. 13), one to measure the antenna current and one to measure the incoming transmission line current. In some cases, the unit may be equipped with one meter that has detachable leads or links with which it may be inserted in either circuit.

Most antenna coupling circuits are designed so that they can be adjusted using only the meters and components provided with the unit. However, a more precise adjustment can be made with an r.f. bridge, which permits measurement of the impedance (resistance and reactance components) of the antenna and makes it possible to adjust the coupling circuits to match this impedance to that of the transmission line. The use of an r.f. bridge for these purposes is described elsewhere in your Course.

TABLE 2

Assumed Efficiencies of Amplifier Stages

A. Factor to be used for stations employing plate modulation in the last radio stage:①

Maximum rated carrier power of transmitter②	**Factor (F)④**
100-1000 watts	**0.70**
5000 and over watts	**0.80**

B. Factor to be used for stations of all powers using low level modulation:①

Class of power amplifier in last radio stage	**Factor (F)④**
Class B	**0.35**
Class BC③	**0.65**

C. Factors to be used for stations of all powers employing grid modulation in the last radio stage:①

Type of tube in last radio stage	**Factor (F)④**
Table C①	**0.25**
Table D①	**0.35**

① See Power Rating of Vacuum Tubes in F.C.C. Standards of Good Engineering Practice Concerning Standard Broadcast Stations, Section 8.

② The maximum rated carrier power must be distinguished from the operating power.

③ All linear amplifier operation where efficiency approaches that of Class C operation.

④ Factor to be used in determining the operating power from the plate input power.

Many transmitter installations, especially marine radio installations, are arranged so that the antenna lead

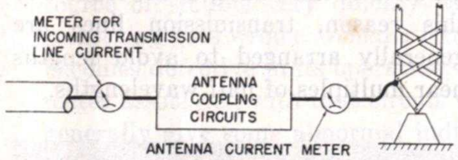


FIG. 13. Typical arrangement for metering an antenna-coupling unit.

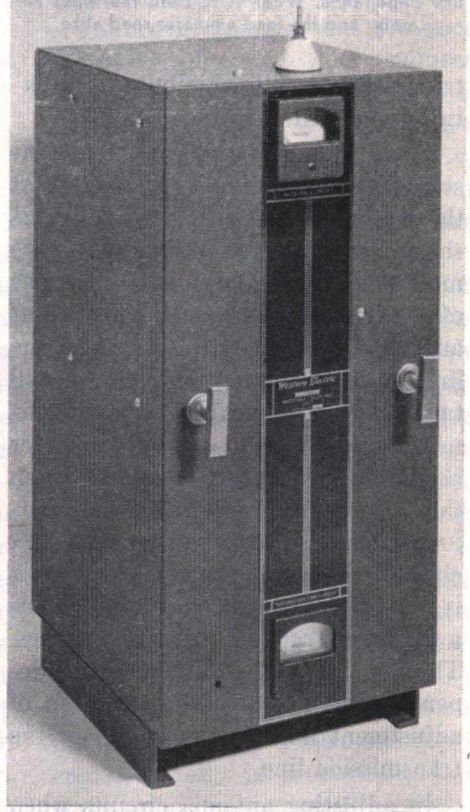
comes directly through the roof or wall of the transmitter house to the transmitter. If the output circuit of such a transmitter is suitably designed, no coupling unit is needed between the antenna and the transmitter. The output circuit of the transmitter must then do the following jobs:

1. Reduce the reactance component of the antenna impedance to zero.
2. Transform the resistance component of the antenna impedance into a suitable resistance value to couple satisfactorily into the tank circuit of the transmitter's final r.f. stage.

For any particular antenna being excited at a particular frequency, the power radiated is proportional to the square of the antenna current. Therefore, an operator who is adjusting his transmitter for maximum power output will naturally strive for the highest antenna current that is consistent with stability and with any other factors he must consider.

This does not mean, however, that the relative antenna currents of two transmitters can be used as a basis for comparing their radiated power outputs. Two transmitters having the same antenna currents may have widely different power outputs if their operating frequencies or the impedances of their antennas differ — or, conversely, two transmitters having the same power outputs will differ in antenna currents if their operating frequencies or antenna impedances are different. Therefore, output powers measured by the direct method form the only basis on which the outputs of two transmitters can be compared.

Transmission Lines. Transmission lines connecting the transmitter with the antenna do not require any adjust-



Courtesy Western Electric

A commercial version of the antenna-coupling unit shown in diagram form in Fig. 13. The meter at the bottom measures the transmission line current, the meter at the top shows the current fed to the antenna.

ment. However, it is important that the impedance of the load that terminates the transmission line be as close as possible to the transmission line's characteristic impedance so that standing waves on the line will be at a minimum. Large standing-wave ratios will contribute to flashover in concen-

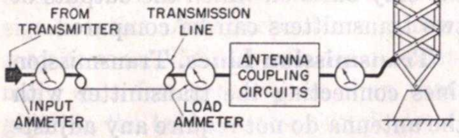


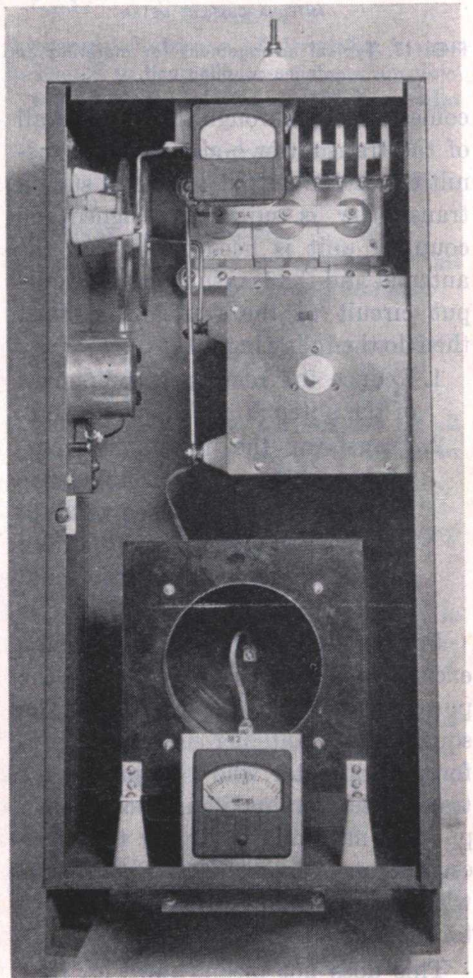
FIG. 14. This metering arrangement makes it possible to tell when the load is matched to the line impedance. When it is, both the input ammeter and the load ammeter read alike.

tric lines and will contribute to radiation from open-wire lines.

There should be an ammeter installed at the input end and another at the load end of a transmission line as shown in Fig. 14. With these two meters, failures and misterminations of the line may be readily checked at any time. Whatever the length of the line (with one exception that we will take up in a moment), the input ammeter and the load current ammeter should have identical readings when the load on the transmission line is adjusted to the same value as the line's characteristic impedance. If the load is not properly adjusted, there will be a difference between the two readings. The amount of the difference will depend on the amount the load is out of adjustment and on the length of the transmission line.

In adjusting antenna circuits when transmission lines are used, make sure that the input ammeter and the load ammeter give the same reading.

This does not hold for transmission lines that are multiples of half wavelengths long, because, in such lines, the input ammeter will always indicate the same current as the load ammeter regardless of the tuning of the load. For this reason, transmission lines are generally arranged to avoid lengths near multiples of half wavelengths.



Courtesy Western Electric

This is the interior of the antenna-coupling unit shown on the preceding page. The components are used to match the transmission line impedance to that of the antenna.

Tracing Trouble With Meters

One reason why transmitter meters are valuable is that they often make it possible for the operator to locate the source of trouble very quickly when something goes wrong. When a circuit becomes defective in its operation, the meter associated with that circuit will generally give some abnormal indication. An experienced man who is thoroughly familiar with the meter panel can often tell almost at once from such an indication what the difficulty is, or at least what two or three possible defects exist. Let's learn how he does it.

Failures in transmitters are most apt to occur in the following order:

1. Failure of fuses.
2. Failure of vacuum tubes.
3. Failure of components.
4. Failure of wiring.

Fuses are, of course, supposed to fail when the circuit current gets dangerously high. Often the failure of a fuse indicates that something else has gone wrong. If so, you will find the fact out when you replace the fuse, because the new one will fail at once or soon.

However, fuses in many cases seem to fail without cause. When they are replaced, normal operation is resumed with no hint of further trouble. Any one of a number of things might cause such an occurrence—a defect in the original fuse, perhaps, or an intermittent defect in the circuit, or an arc caused by some transient condition.

Vacuum tubes always wear out eventually, and may fail at any time if they are accidentally overloaded. Therefore, a bad tube is almost always a possibility when the operation of a radio transmitter becomes defective.

Failure of components, like failure of tubes, we must expect, but not on the same scale. Most low-power components of a transmitter, such as small condensers and resistors in low-power circuits, should last indefinitely in a well-made transmitter. Components handling high currents and particularly high voltages, however, may need replacing occasionally. In these components the insulation sometimes deteriorates from the effects of the high dielectric stresses.

Failure of wiring should never occur in a well-designed and engineered transmitter unless it has been subjected to some mechanical or chemical action outside the control of the manufacturer. Such actions do occur, however, so an occasional wiring failure is to be expected.

Any of these failures will, of course, be reflected in the meter readings of a transmitter. An abrupt failure, such as a blown fuse, will cause an immediate change in meter indications. A gradual failure, such as the wearing out of a vacuum tube or the gradual burning up of a resistor, will cause a gradual change in meter indications.

When trouble occurs in one stage of a transmitter, the operation of all succeeding stages is affected. If the r.f. output of one stage decreases for some reason, the r.f. outputs of all succeeding stages and the transmitter also decrease, usually in proportion. If one stage stops functioning altogether, the r.f. outputs of the succeeding stages and of the transmitter drop to zero. This chain effect will be apparent in the meter readings of the ailing stage and succeeding stages. If the succeeding stages are all class B or class C, their plate currents will be low if the trouble has decreased the output of the defective stage; if the stage has stopped functioning altogether, their plate currents will be zero. If a failure in a grid bias supply has occurred, on the other hand, the stages biased by that supply will have abnormally high plate currents.

The first step in finding trouble in a transmitter is to localize it by stages.

First, all supply voltages are checked for normal output. A glance at the supply voltage voltmeters takes care of this. Second, the plate current meters of each stage are checked, starting with the final amplifier and working back toward the oscillator. The stage in which trouble is located is the last one having abnormal meter readings.

For example, if the antenna current falls to zero, indicating no output, a quick check of power supply voltages is made first to be sure that voltages are O.K. Next, the plate and grid currents of all tubes are examined, starting with the final amplifier and going back toward the oscillator. Let us say, to continue with our example, that all these are normal except for the final amplifier plate current, which is almost zero. The trouble then must be in the final amplifier circuit some place —perhaps in the grid drive or in the plate circuit. Perhaps the vacuum tube has failed.

This procedure has localized the trouble to a stage. The next step is to locate the defect within that stage. This is done by checking each of the possible causes of failure in the order of probability of occurrence that we gave earlier.

Since fuses are most apt to fail, any fuses or overloaded devices that may directly affect the stage in which the trouble has been localized are checked first. Second, the vacuum tube is tested or changed—usually the latter if it can be done quickly. Third, the grid driving circuit or the preceding stage is checked to be sure that grid driving power is available. If grid drive is available and a replacement vacuum tube does not cure the trouble, it is assumed that the failure has been in the circuit components or the wiring. From this point on, a volt-ohmmeter and a schematic of the circuit are used in the final isolation of the trouble.

As you can see from this quick sketch, the procedure followed in isolating trouble is to check the most likely causes of trouble first and in such a sequence that the transmitter can be put back on the air with the minimum loss of time. It would take only two minutes, for example, to place the transmitter back on the air if this procedure were followed and if the cause of the trouble were the failure of a vacuum tube, allowing 15 seconds to check all power supply voltages, another 15 seconds to check plate currents and localize the stage in which the trouble occurred, 45 seconds to replace the vacuum tube, and 45 seconds to warm up filaments and switch on the high voltage.

Some defects, of course, may take longer to remedy, some less time; the point we want to make is that if you follow a logical procedure, you can locate defects quickly and minimize the time the transmitter is off the air.

Preventive Maintenance

Preventive maintenance is the art of maintaining and operating any kind of machinery or apparatus in such a way that possible causes of failure are remedied before they can cause actual failures of the equipment.

Preventive maintenance is important for many reasons. It is, of course, of supreme importance in ship and aircraft services, where the breaking down of a transmitter may be a danger to life. It is also important in broadcasting and commercial services, because in these an interruption in radio service costs money, both in loss of revenue and in expense for repairs. If a broadcasting station is off the air during the time of the commercial announcement in a sponsored program, even though the rest of the program is transmitted satisfactorily, a large portion of the revenue from that program must be rebated to the sponsor. If a commercial communications service transmitter is off the air, the revenue from messages that might have been transmitted is lost.

A further consideration on this matter of costs is that it is usually far easier and cheaper to prevent failures than it is to repair the equipment after the failure has occurred. For example, inspecting and maintaining the brushes of a generator and replacing them when they get too short costs very little in time and money. Failure to do so, however, may mean that the commutator will have to be repaired or replaced at considerable expense after the brushes have failed and damaged it from arcing.

We are particularly interested in preventive maintenance in this Lesson because the meters of radio transmitters are one of the most valuable means by which an impending failure in the transmitter may be recognized.

Preventive maintenance involves more than metering and adjusting the transmitter, however. In a transmitting station, it involves the cleanliness and orderliness of the station, the quality of management exercised by the chief in charge of the station, the accessibility and availability of tools and replacement parts, the morale and discipline of the personnel of the station, and the expertness with which the operating and servicing routines are set up.

Of the above, the morale and discipline of the station personnel are perhaps the most important, because a group of people in good spirits, interested and proud of the apparatus that is in their charge, and mindful of their duty can perform miracles of maintenance and emergency repair work without any of the facilities mentioned. Further, with morale and discipline present in a group, cleanliness and orderliness are certain to be in evidence or shortly to appear.

It is not hard to see that the ingredients of successful preventive maintenance are interlocking in character and more complex than mere operating routines. The use of meters to check transmitter performance is but a step in the carrying out of the maintenance procedure. However, it is an important one.

To use meters with maximum success in a preventive maintenance procedure, you must be thoroughly familiar with the transmitter circuit and its operating characteristics, and you must establish a satisfactory routine for checking the transmitter performance with the meters provided. If you are not familiar with every phase of the electronic circuits and mechanical assembly of any transmitter you operate, it is very difficult, if not impossible, for you either to detect approaching trouble or to be prompt in preventing or repairing the trouble.

Naturally, it takes time to become thoroughly familiar with all the important features of a transmitter. To shorten this period as much as possible, you should follow some logical plan in studying the equipment. We suggest the following program:

1. Study all the electronic circuits in detail. Make sure you understand every feature.
2. Study each meter in the equipment, learn what it measures, and memorize its normal range of readings.
3. Learn the location and purpose of each fuse and circuit breaker.
4. Study the mechanical location and construction of each circuit component and each mechanical feature of the transmitter installation.
5. Learn the location of all power lines and transmission lines.
6. Study all the auxiliary equipment. Learn what it is used for and how to use it.
7. Learn the maintenance procedures for the transmitter and all its auxiliary equipment.

All radio stations should maintain complete files of instruction books and maintenance instructions from the manufacturers of every piece of equipment used. These should include complete schematic and wiring diagrams and complete apparatus lists. This information is the source on which you can base your studies.

The purpose of making these studies is, of course, to enable you to locate and remedy trouble quickly. By all means, do study the equipment *before* the trouble appears so that you may go into action immediately. Do not wait until the emergency is upon you to make the effort to learn. The spectacle of a person feverishly studying the instruction book of a transmitter after it has broken down is entirely too common an occurrence.

METER CHECKING ROUTINE

A meter checking routine provides a day-to-day indication of the performance of the transmitter from which the condition of the transmitter can be checked. The method and procedure of logging meter readings has been discussed previously in the section on reading meters.

A metering routine must be regularly and conscientiously carried out to be of real value. As we suggested earlier, the routine should occur at the same time of day and under the same circumstances so that consistent readings may be made. Readings of the same meter at different times of the day and under different circumstances will be slightly different. A log of meter readings and also of tuning control settings should be kept as suggested.

Exactly when the meter reading routine for preventive maintenance records should be made is a matter for the person in charge of maintenance to decide. It is a good procedure, however, for each operator as he comes on watch to make the rounds of the station and equipment, making specific inspections of possible trouble points, observing the general condition of the equipment, and making a record of the meter readings. Under this procedure, the man making the observations is not fatigued, so errors in readings are less likely.

The data and inspection made by the man coming on watch should include the following:

1. Complete check of all meter readings and control settings.
2. Check of the bearing temperatures of all rotating machinery by feeling.
3. Check of the temperatures and pressures in the water cooling systems.
4. Check of the antenna tuning unit compartment if accessible.
5. Check of the operation of the tower obstruction lighting and the emergency lighting circuits.
6. Inspection of the state of charge of the battery banks.
7. Inspection and trial of the auxiliary power system.

The above inspections may require a half hour or more of the operator's time, depending upon the size of the station and the kind of equipment installed. It should be considered time well spent in safeguarding the continuous operation of the transmitter. The list of specific items to be inspected should form a part of the log, which the person making the inspection can checkmark as each inspection is made. This will enable him to be sure he has not missed any point that should be checked.

The inspection data sheets must, of course, be systematically studied and analyzed to be useful. By comparing today's records with yesterday's, last week's, or last month's records, you can notice slight trends of change that are imperceptible in the day-to-day operation of the transmitter. From these slight trends, you can often tell in advance when a tube or some other component will need replacement.

A convenient way of quickly comparing meter readings is by means of graphs. Fig. 15 shows a graph of oscillator grid current meter readings taken over a period of eight months. The readings on which this plot was based were made and recorded daily, but, for clarity, we have shown only 5-day in-

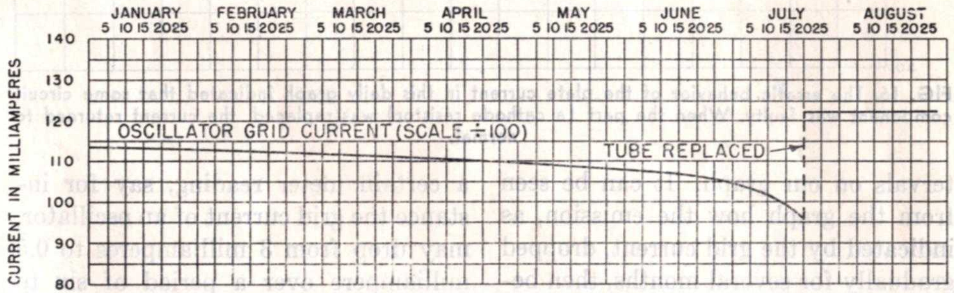


FIG. 15. The sudden dip in this day-to-day graph of oscillator grid current showed that it was time to replace the tube.

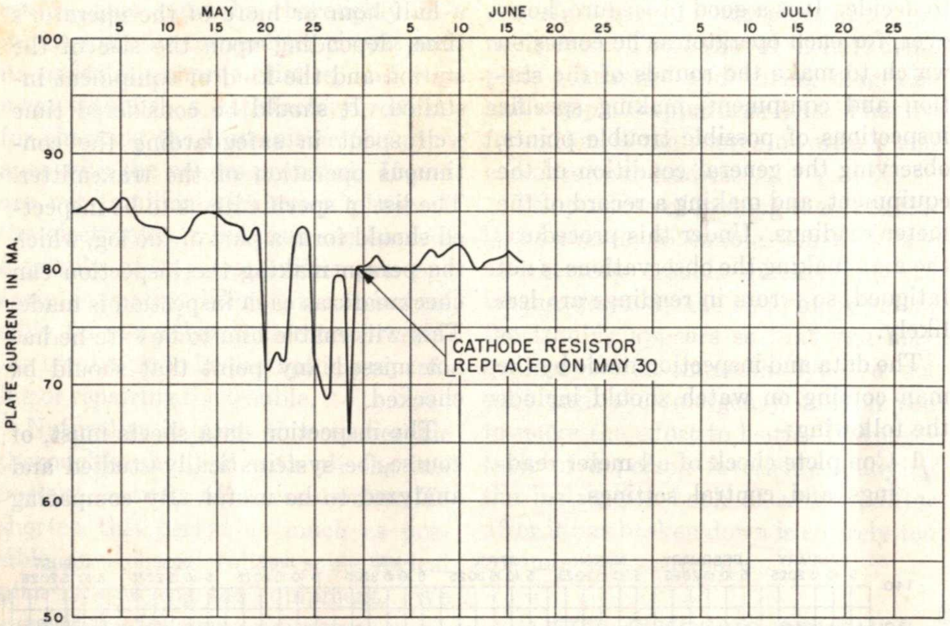


FIG. 16. The erratic behavior of the plate current in this daily graph indicated that some circuit component was faulty. When the part (a cathode resistor) was replaced, the current returned to normal.

tervals on our graph. It can be seen from the graph how the emission, as indicated by the grid current, dropped gradually for several months, then began to drop sharply in July. The tube may have been capable of operating a month longer, but the danger of its causing a transmitter outage indicated that the wise thing to do was to replace it. If this chart had not been kept, the decrease in grid current might not have been noticed until danger of failure was imminent. A day-to-day graph like this one should be kept as a check on each metered circuit and stage in the transmitter.

It was not possible in a Lesson of this kind to give specific directions as to what steps to follow as a result of specific data from a particular meter. This is something you will have to learn from experience with the transmitter you operate. You may find that a certain meter reading, say for instance the grid current of an oscillator, may drop from 3 milliamperes to 0.5 milliampere over a period of six to nine months without being necessary to replace the tube. Or, on the other hand, you may find from experience that after the grid current drops to 2 milliamperes, the tube is ineffective and must be replaced. After you have discovered the point at which to replace the tube, the proper moment to replace it can be predicted from your charts and records.

Or you may find from experience that a certain peculiar action of the readings of a meter always precedes the short-circuiting of a condenser or the opening of a resistor, and your records and charts again will be able to tell you when to replace the component to prevent an outage. The usefulness of the data taken in the routine meter

check will be limited only by your resourcefulness in putting it to work for you.

Fig. 16 shows a graph of the plate current of a buffer amplifier that began to show signs of developing trouble on May 20 with an abrupt drop in plate current followed by erratic readings of the plate meter. Work was immediately started to determine the cause. The circuit of the preceding stage was investigated. Tubes were replaced, wiring checked, and the circuit of the next stage checked for a high resistance in its grid. The trouble was finally found to be in a defective cathode resistor in the buffer amplifier stage. This was replaced on May 30. The graph shows that operation was normal again after the resistor was replaced. This example illustrates how defective components as well as defective tubes can be detected by these graphs before serious trouble develops.

Special Meters in Use at Transmitting Stations

In addition to the d.c., a.c., and r.f. meters mentioned in the first part of this Lesson, there are several instruments classified as meters that are used for making measurements in transmitting stations. These instruments are in general composed of electronic circuits and are used to measure quantities that cannot be measured with meters alone. The important meters of this kind will be described for your general information.

Frequency Monitors. Frequency monitors are instruments with which the deviation from the assigned operating frequency of a transmitter may be checked. All broadcast stations, including television stations, must have a frequency monitor installed at the transmitter to comply with

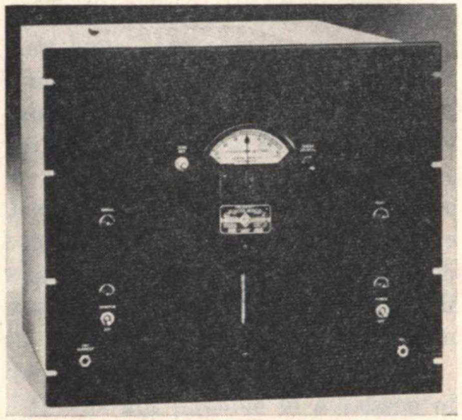


FIG. 17. General Radio type 1181-A frequency deviation monitor. This instrument is generally used to indicate the frequency deviation of standard a.m. broadcast stations and the dial is marked from —30 to +30 cycles. Under normal operating conditions its stability is better than one part in one million, that is, less than 1½ cycles for any standard a.m. station.

Federal Communications Commission rules.

Other stations, such as marine, ship and aviation stations, are not required to have a monitor installed at the transmitter, but must provide for the periodic measurement of frequencies regularly used and establish a procedure for regular checking of the transmitter frequency. The measurements are sometimes made by a company specializing in that service that tunes in on the transmitter at regular periods and measures the frequency to within 0.1 cycle. The measurements are also sometimes made by a serviceman using a portable frequency meter of the required accuracy who visits the transmitter on a regular schedule for that purpose.

Fig. 17 shows a General Radio type 1181-A frequency monitor that has been approved by the Federal Communications Commission for use in standard broadcast stations. Its accuracy is within five cycles out of a million cycles and adjustments are provided by means of which a higher degree of accuracy may be maintained if the instrument is periodically checked against an external frequency standard.

Checks of the transmitter frequency every 30 minutes during the operating day are made with this instrument and are entered in a log.

Modulation Monitors. Modulation monitors are instruments with which the instantaneous modulation level of a transmitter may be measured. These instruments are required by the Federal Communications Commission to be installed at all standard and high frequency broadcast transmitters and at television transmitters. Fig. 18 shows a General Radio type 1931-A

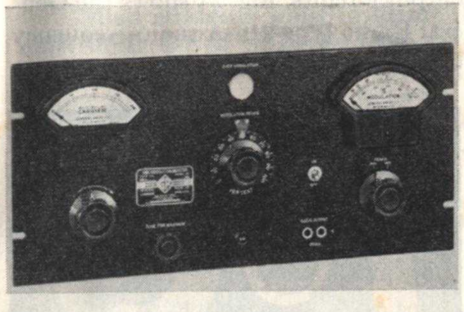


FIG. 18. General Radio type 1931-A amplitude-modulation monitor. This monitor will indicate the instantaneous modulation on either positive or negative peaks of a.m. stations for any one carrier between 0.5 and 60 megacycles. It also has a warning light that will flash at any pre-set value of modulation.

modulation monitor that has been approved by the FCC for installation at standard and high-frequency broadcast stations. The right-hand meter reads directly the percentage of modulation up to 110%. A warning light is provided that will flash if modulation exceeds a predetermined level, which the operator can select by using the dial in the center of the instrument.

Field Intensity Meters. Field intensity meters are instruments with which the strength of the radiated energy from the transmitter may be measured. Field intensity meters give field strengths in terms of the voltage that exists between two points in the air one meter apart; this is expressed in units of volts per meter. Fig. 19 shows an RCA Model 308-A field intensity set. The loop antenna is the means used to pick up the signal to be measured.

Directional Antenna Phase Meters. Phase meters are instruments used in connection with directional antenna arrays to monitor the phase relationships and amplitudes of the currents in the various elements of the array. This instrument lets the operator make sure the directional array is functioning properly. Fig. 20 shows a Western Electric model 2A phase meter for use with standard broadcast stations. This instrument will give relative antenna current and phase measurements for arrays having any number of elements or antennas. The top row of meters gives relative indi-

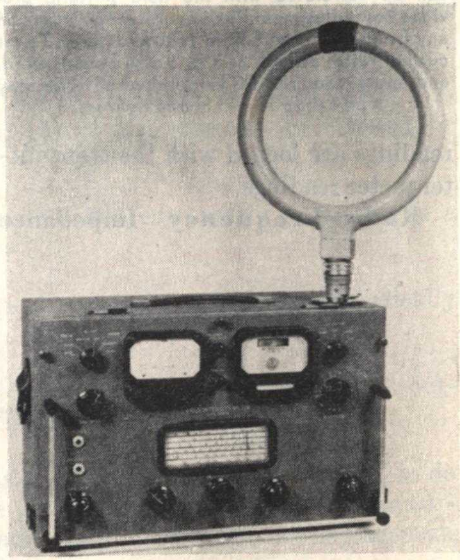


FIG. 19. RCA model 308-A field intensity meter. This instrument is used in determining the horizontal field intensity pattern of a broadcast station as required by the FCC in all standard low-frequency a.m. broadcast station applications.

cations of antenna current. The dial at the center of the instrument gives the phase angle in degrees between the current in a reference antenna and any of the other antennas in the array. The relative antenna currents and phase

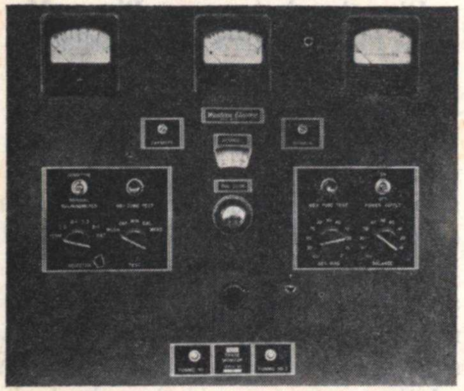


FIG. 20. Front panel view of the Western Electric 2A phase monitor, an instrument for measuring the phase and amplitude relations of the currents in the antenna elements of radio broadcast directive antenna arrays so that these relations can be correlated with the field pattern, provides for adjustment for accurate operation on any frequency from 540 to 1600 kilocycles. Tower current ratios as high as 5 to 1 may be measured, and angles required for established patterns may be set up to within one degree.

readings are logged with the transmitter meter readings.

Radio-Frequency Impedance Bridge. The radio-frequency bridge is an instrument used to measure the resistance and reactance components of the impedances of antennas and transmission lines, and to adjust antenna coupling circuits and power amplifier output circuits. Fig. 21 shows the General Radio type 916-A radio-frequency bridge.

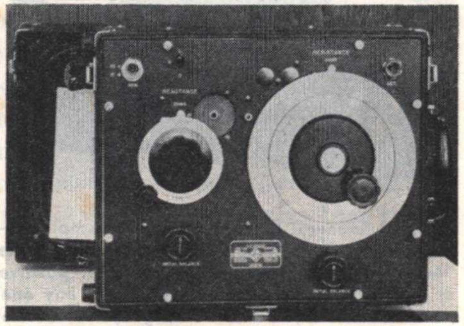


FIG. 21. General Radio type 916-A radio-frequency bridge. The characteristics input reactance and resistance of transmission lines and antennas in the range of 400 kc. to 60 mc. may be determined by this instrument.

Lesson Questions

Be sure to number your Answer Sheet 40RC.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next Lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of Lessons before new ones can reach you.

1. When a driving stage is tuned to resonance, what happens to the grid current of the next, or driven, stage?

2. The FCC rules regarding the metering of broadcast transmitters are intended to insure uniform regulation of three characteristics. What are these three?

3. What frequency deviation is permitted by the FCC in the operating frequency of: (a) a broadcast station; (b) an f.m. station; (c) a television station?

4. The FCC requires that one voltage and two currents be measured in a broadcast transmitter. What are they?

5. For what three reasons are meter readings made and logged periodically during each operating day?

6. What two factors must be measured or known to determine the power output of a transmitter by the direct measurement method?

7. If it is desired to replace, without asking the permission of the FCC to do so, any instrument used to measure the antenna current or the plate current or plate voltage of the last radio stage, how must the replacement meter compare with the original one?

8. If fine tuning adjustments must be made on a transmitter, should meter readings be made before the adjustments are made or after the adjustments are made—or is the matter of no importance?

9. At 100% modulation, assuming the transmitter has low distortion, should the antenna current be 10%, 22½%, or 35% higher than it is at zero modulation?

10. Suppose a transmitter has broken down. All plate supply voltages are normal. What meters should you check next to localize the defective stage?

KEEPING PROMISES

To have the reputation for always meeting obligations and paying debts is a most valuable asset in social as well as professional life. If you owe money, pay promptly when payment is due. If you owe allegiance to a person or organization, grant it. If you have given your promise to some one, keep it. To hedge on any type of obligation is to start a moral disintegration which may eventually ruin your chances for enjoying life and its successes. Failure to keep an obligation is a sin which has resulted in many failures in life itself.

J. E. SMITH