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Measuring Antenna Performance

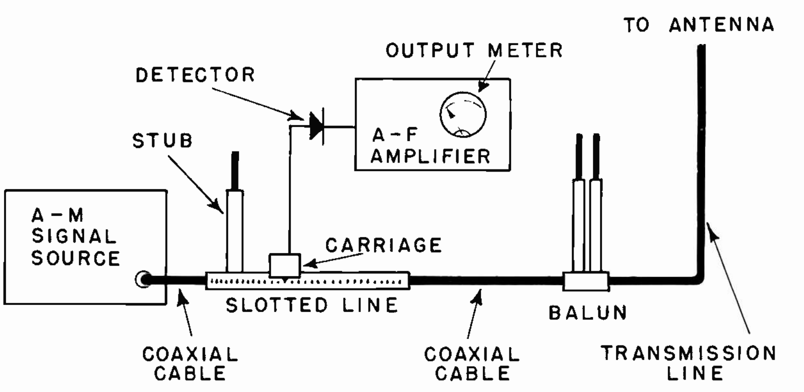
By the Engineering Department, Aerovox Corporation

QUANTITATIVE measurements of the characteristics of antennas and associated transmission lines remove all guesswork from antenna performance ratings. Many of the early antenna tests, which survived a surprisingly long time, were of an indirect sort based upon substitution techniques and some assumptions. Most present measurements, however, are direct in nature and require a minimum of calculations.

Some of the characteristics commonly measured are (1) voltage standing-wave ratio *VSWR*, (2) impedance, (3) resistance, (4) reactance, (5) field strength and radiation pattern (directivity), and (6) bandwidth. This article reviews briefly the techniques of measurement.

Voltage Standing-Wave Ratio

In the testing of uhf and microwave antennas, VSWR is measured with a slotted line. Figure 1 shows a typical test setup. Here, the input of the slotted line is connected to the r-f output of an amplitude-modulated signal source. The output of the slotted line is connected to the transmission line and antenna — through a balun if the impedance of the transmission line differs from



SLOTTED LINE SETUP FOR VSWR MEASUREMENTS

FIG. 1

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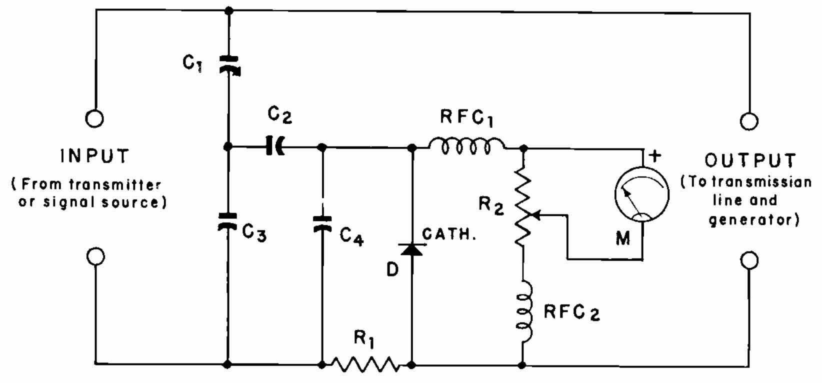
that of the slotted line (usually 50 ohms). When the test frequency is several thousand megacycles, the signal source usually is a klystron oscillator. The sliding carriage of the slotted line contains a crystal diode detector or a bolometer shown externally here for illustration. The audio output of this detector is presented to the a-f amplifier which terminates in a calibrated output meter. This meter reads directly in volts or relative units.

As the operator slides the carriage along the slotted line, the probe carried by the carriage and dipping into the interior of the chamber through the lengthwise slot samples the field and passes through maxima and minima of energy. The output meter accordingly indicates the strength of these points. A pointer attached to the carriage moves over a scale, usually graduated in centimeters, so that the positions of maximum and minimum points are indicated clearly.

After making required tuning adjustments of the stub, and of the balun if the latter is used, the carriage is slid along the line to a maximum point, as indicated by peak deflection of the meter, and the voltage is read from the meter as E_{max}. The carriage then is slid farther in the same direction to the next consecutive *minimum* point and the voltage here recorded as E_{min}. The standing-wave ratio then is calculated: VSWR $= E_{max}/E_{min}$.

In some commercial indicators, the output meter reads direct in VSWR. In using these instruments, the output of the signal source or the gain of the a-f amplifier, together with the line-circuit tuning, is adjusted such that the meter reads either zero or VSWR 1 (depending upon design of the instrument) at minimum points. The maximum swing then shows the VSWR value directly.



MICROMATCH -TYPE VSWR METER

FIG. 2

A simple circuit, called the *Micromatch*, is used by amateurs and experimenters for the measurement of VSWR up to several hundred megacycles. Such an instrument is shown in Figure 2. The INPUT terminals are connected to the output of the transmitter or other suitable r-f signal source, and the OUTPUT terminals to the transmission line and antenna.

This circuit includes a radio-frequency voltmeter (comprised of germanium diode D, r-f chokes RFC_1 and RFC_2, potentiometer R_2, and d-c milliammeter M) and an R-C bridge comprised by C_1, C_3, R_1, and the impedance of the transmission line and antenna (or other component) connected to the OUTPUT terminals of the instrument. Operation is based upon the fact that the transmission line and antenna appear as a pure resistance equal to the characteristic impedance of the line when the line and antenna are matched in impedance. If this is so, and the bridge previously has been balanced with this value of resistance (a non-inductive resistor) connected temporarily to the OUTPUT terminals, the meter will read zero (null) when the transmission line and antenna are substituted for the test resistor. The bridge may be balanced for different values of resistance connected to the OUTPUT terminals, by adjustment of variable capacitor C_1. The dial of this capacitor accordingly may be direct-calibrated in ohms.

In use, the bridge first is balanced with the non-inductive resistor at the OUTPUT terminals, having the same value as the line impedance. Next, the transmission line and antenna are connected to the OUTPUT terminals. If there is a match and the impedance of this load corresponds to the resistance of the resistor, the meter will read zero. If not, the deflection (E_1) is due to reflected energy. If a V_1 deflection is obtained, interchange the connections to the instrument (signal source now to the OUTPUT terminals, and

A complete field strength survey is made by means of intensity measurements made at many points in concentric circles around the antenna but at a sufficient distance from it to be clear of the induction field. For this purpose, the antenna is excited with r-f power from a steady source, and the field intensity is checked at as many outlying points as possible. The points at which readings are made may be recorded on a map of the area. Such a survey shows effectiveness of the transmitter throughout its service area.

In checking the radiation pattern (directivity) of an antenna, field strength measurements may be made in a single circle around the antenna, but outside of its induction field, and the signal-voltage points plotted on polar-coordinate graph paper to show microvolts vs geometric degrees with the antenna at the center. This plot will show the shape and intensity characteristics of the radiation pattern. The procedure may be repeated around a number of concentric circles. While the results of these tests show variation in field strength with respect to azimuth, measurements may be made where possible above the antenna and would serve to show field strength with respect to elevation.

Utilizing the principle of reciprocity, antenna engineers often mount a scale model of an antenna on a rotating turntable and transmit r-f energy, through the air, to it essentially in a straight line. The rotating antenna is connected to a detector and a sensitive graphic recorder. The record sheet in the recorder rotates in synchronism with the antenna. As the antenna rotates, picking up the signal successively on its various sides and ends, it thus will trace its own directional pattern on the polar-coordinate record sheet, as it receives more or less of the transmitted energy. This procedure requires that the test frequency be increased proportional to the reduction in size of the antenna model. For this reason, the measurement commonly is made at microwave frequencies for small-sized models of larger antennas.

Amateurs and others not interested in a complete radiation pattern often check the directivity of a beam antenna simply by comparing the field intensity in front of and behind the antenna. This front-to-back ratio is adequate for many practical purposes. There are two ways to make this test: (1) Place the field strength meter at a fixed distance from the antenna and outside of its induction field; and with the antenna excited with constant power, take one reading (front) with the antenna transmitting directly to the meter and then a second reading (back) with the antenna rotated 180 degrees. The front-to-back ratio is obtained by dividing by front-voltage reading by the back-voltage reading. (2) When the antenna is not rotatable, take the front-voltage reading directly in front of the antenna, but outside of its induction field, and the back-voltage reading at the same distance behind the antenna.

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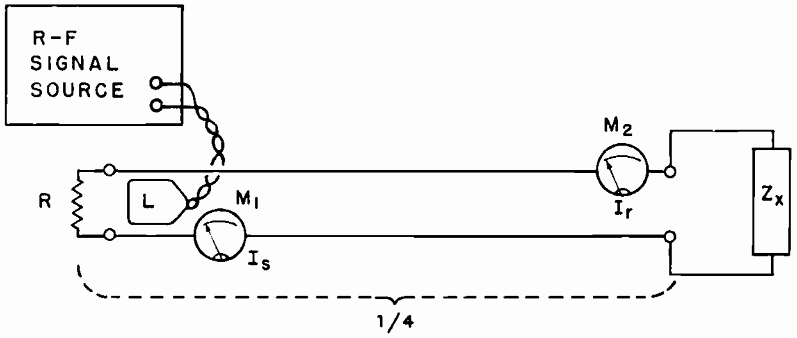
may be used as the null indicator even when the test signal is unmodulated.

The bridge has separate balance controls for reactance and resistance. It also has separate R and X initial balance controls for "zeroing" the bridge before making a measurement. The procedure for the initial balance differs with different bridge models.

The test procedure consists of the following steps: (1) Balance the bridge initially for R and X according to the operating instructions for the particular bridge used. (2) Connect the transmission line and antenna to the bridge "unknown" terminals. (3) Using the *Main* REACTANCE BALANCE and RESISTANCE BALANCE controls, balance the bridge for null, as indicated by the output meter of the receiver. Read the reactance (X) and resistance (R) values from the corresponding control dials according to bridge operating instructions. (4) Note whether the reactive component is capacitive or inductive according to instructions. (5) Calculate the impedance of the antenna and line from the relationship: $Z = \sqrt{R^2 + X^2}$. The receiver must be tuned sharply to the generator frequency, and the lowest practicable signal amplitude should be employed.

When it is possible to operate an antenna or other component through a quarter-wave section of transmission line, the r-f impedance may be determined with the setup shown in Figure 4. The transmiting end of the line (left end) is terminated with a non-inductive resistor, R, the resistance of which is equal to the characteristic impedance of the line (e. g., 600 Ω for a parallel-wire line of No. 12 wire spaced 6 inches apart). The unknown impedance, Z_x, is connected to the reflecting end (right end) of the line. The line is excited at the transmitting end by energy from the r-f signal source, coupled through the loop, L. The frequency must be that at which the line is ¼ wavelength long.



USE OF 1/4-WAVELENGTH LINE
TO MEASURE R-F IMPEDANCE

FIG. 4

Meters M_1 and M_2 are thermocouple-type r-f ammeters or milliammeters. M_1 is inserted in one wire as close as physically possible to the transmitting end of the line. M_2 is inserted in the opposite wire as close as physically possible to the reflecting end. The unknown impedance is calculated from the resistance of R and the deflections of meters M_1 and M_2 (i. e., I_s and I_r, respectively): $Z_x = R\ (I_s/I_r)$.

Field Strength and Directivity

In checking the field strength, or *field intensity*, of an antenna, r-f power of constant amplitude is supplied to the antenna under optimum conditions of tuning and loading. The intensity of the radiated field then is measured (in microvolts or millivolts), using a field strength meter at a distance sufficient to be outside of the induction field of the antenna.

Field strength measurements usually are made with the transmitter supplying normal operating power to the antenna, since the purpose of the measurement usually is to determine the effectiveness of the station at the location of measurement. The measurement may be made during regular operation of the station. The professional field strength meter is a specialized superheterodyne receiver having a self-contained output meter giving direct indications of the received-signal voltage. It employs a shielded loop antenna for sampling the electromagnetic component of the wave, and a whip antenna for the electrostatic component. Amateurs and others who do not require the accuracy and sensitivity of the professional field strength meter employ a simple instrument consisting of a whip antenna, tuned circuit, crystal diode rectifier, and d-c milliammeter.

transmission line to the INPUT terminals) and record the voltage now obtained as E_2. The standing-wave ration VSWR = $(E_2+E_1)/(E_2-E_1)$.

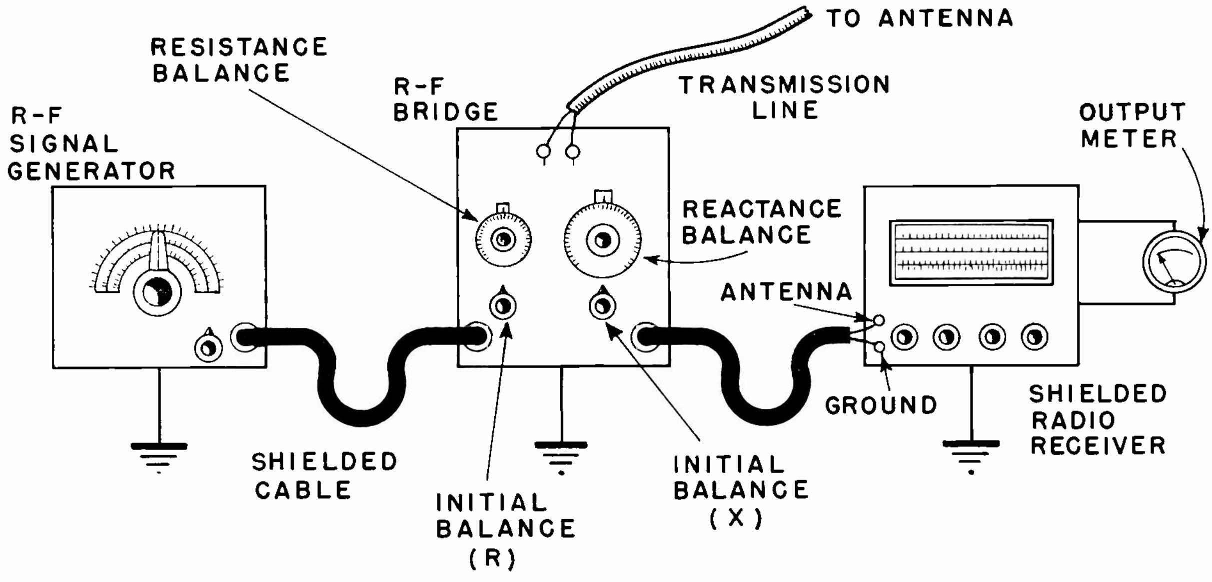
Common values for the circuit components are: C_1 15 μμfd, C_2 82 μμfd, C_3 220 μμfd, C_4 220 μμfd, R_1 1 ohm, R_2 5000 ohms wirewound, M 0-1 d-c milliammeter, RFC_1 2½ mh, and RFC_2 2½ mh. Since R_1 must be noninductive and should have a 10-watt power rating, it may consist of ten 1-ohm carbon resistors connected in parallel via the shortest possible leads.

Impedance

Impedance may be determined from a series of slotted-line measurements referred to a *Smith Chart.* However, since this method is beyond the scope of this article, interested readers are referred to Reference 3 in the bibliography at the end of this article.

The Micromatch-type VSWR meter (Figure 2) may be used for impedance measurement by first calibrating the dial of variable capacitor C_1 to read direct in ohms (as explained in the foregoing section) and then connecting the unknown impedance to the OUTPUT terminals, a suitable r-f signal source to the INPUT terminals, adjusting capacitor C_1 for null, and reading the impedance value from the C_1 dial. The measurement may be made at frequencies other than those at which the instrument was calibrated if resistor R_1 has excellent r-f characteristics. The simplest way to perform the calibration is by successive connection of a number of accurately-known, noninductive resistors to the OUTPUT terminals and adjusting variable capacitor C_1 for null with each. The r-f signal source employed for this operation may be any suitable generator with sufficient output to deflect meter M.

Well-shielded, laboratory-type radio-frequency bridges are available for use in the frequency range 400 kc to 60 Mc. A bridge of this type may be used to measure separately the resistive (R) and reactive (X) components of a transmission line and antenna, and the impedance (Z) determined from the vector sum: R + jX. Figure 3 shows an r-f bridge setup. The test signal is supplied by an amplitude-modulated r-f signal generator at the operating frequency of the antenna. The bridge detector is a well-shielded radio receiver tunable to the generator frequency, with its avc switched off, and provided with an output meter for indicating null. If the receiver is equipped with a built-in S-meter, the latter



RADIO-FREQUENCY BRIDGE SETUP

FIG. 3

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