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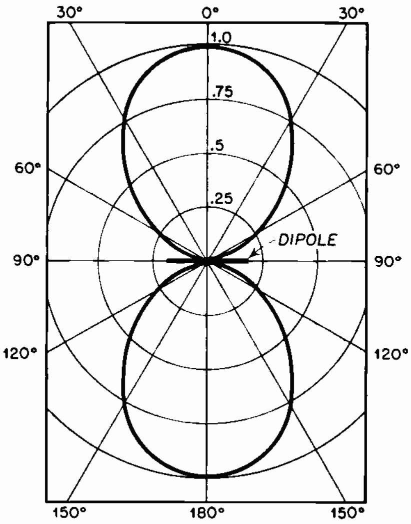
Simplified Antenna Pattern Measurements

By the Engineering Department, Aerovox Corporation

AS is well known, most of the characteristics of a *resonant* antenna are independent of its operating frequency. In other words, an antenna of a given design operating at 3000 Mc. will exhibit the same impedance, gain, radiation pattern, and certain other characteristics as an antenna of like design but 100 times larger in size and operating at 30 Mc. This fact has led to the important technique of employing scale models in the development of antennas of all types.

By this method, the performance of a large and elaborate experimental antenna array may be predetermined without the labor and expense of construction by first building a scale model which is reduced in size and operating wavelength by a factor of perhaps 1/100th. Under these conditions, measurements made on the model antenna will be fairly representative of those to be expected of the full-scale antenna. In addition, because of the small size and economy of the models, experiments may be made indoors, and many experimental variations can be tried for the price of building a single full-scale antenna. The modelling technique is therefore a valuable tool in the development of antennas. It is also a very effective method of demonstrating the properties of directional antennas for educational purposes.

The pattern measuring equipment used by commercial antenna development laboratories for determining the characteristics of model antennas is elaborate and costly. The results obtained, however, may be approximated by the amateur or experimenter with greatly simplified equipment. This issue of the AEROVOX RESEARCH WORKER describes the theory, construction, and use of such equipment.



CALCULATED POWER PATTERN OF HALF-WAVE DIPOLE
FIG.1

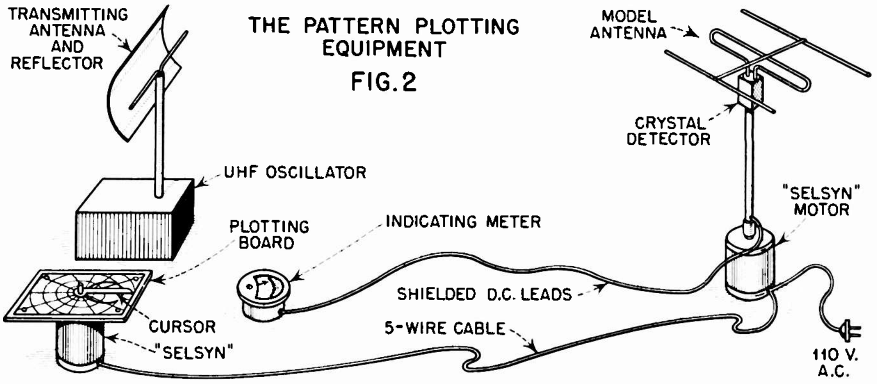
Pattern Plotting Techniques

The free-space directional characteristics and gain of a transmitting antenna may be determined by plotting the field intensity produced by the antenna as a function of the direction from it. Although the radiated fields surrounding the antenna are three-dimensional, sufficient information to evaluate the performance of the antenna may be obtained from a two-dimensional plot taken in the plane of greatest importance. A diagram made in this manner is, in reality, a cross-section of the three-dimensional solid radiation pattern of the antenna. Such plots are called "field patterns" or "radiation patterns" and are usually made on polar-coordinate graph paper.

Fig. 1 shows the theoretical power radiation pattern of a half-wave dipole antenna, taken in the plane containing its axis. The half-wave dipole is usually used as the standard antenna with which other antennas are compared. Thus, an antenna with "a gain of 7 db." usually means a gain of 7 db. over that of a half-wave dipole. The heavy line of Fig. 1 is a contour of equal radiated power, with the antenna located at the center of the diagram. It could be plotted in two ways; by allowing the radiating antenna to remain fixed in position and plotting points of equal power around it, or by rotating the antenna and plotting the variations of a power indicating meter located at a fixed spot some distance away.

For all practical purposes, the pattern and gain of an antenna used for receiving are identical to those of the same antenna when used for transmitting. In the receiving case, the field pattern indicates the relative sensitivity of the antenna to signals arriving from various directions. Because of this *reciprocity* in antenna performance, patterns taken on a transmitting antenna also apply to receiving antennas of the same design, and conversely. Therefore, since the mechanical and electrical requirements are more conveniently satisfied, most pattern measuring systems, including the simplified method to be described here, use a receiving antenna as the model antenna under test. This receiving antenna is excited (or "illuminated") by a uniform r.f. field produced by a transmitting antenna operating at the resonant frequency of the test antenna and situated several wave-lengths away. A field-strength meter or other r.f. detecting device is coupled to the receiving antenna to indicate the relative intensity of the signal being received. The test model antenna is then rotated in the desired plane and the response, as indicated by the r.f. detector, is plotted as a function of the angular position of the antenna. The result is a radiation pattern of the test antenna.

In expensive systems, the pattern plotting is accomplished automatically by a recording pen which is actuated radially on the graph paper by the amplified output of the r.f. indicating device. The polar coordinate paper is rotated about its center or origin by means of a mechanical or



THE PATTERN PLOTTING EQUIPMENT
FIG. 2

electrical linkage which synchronizes its rotation with the angular position of the model antenna. As the system is rotated, the recording pen automatically records the angular response characteristic of the antenna.

The Equipment

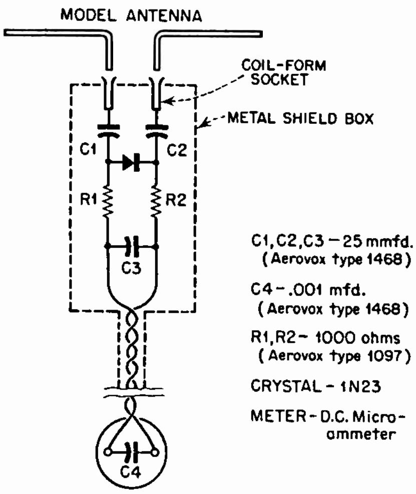
The pattern recording equipment which is the subject of this article is "semi-automatic" in nature, since several compromises have been made in the interests of simplicity and economy. It can be assembled at low cost from parts which should be readily available and is capable of producing power radiation patterns of experimental scale model antennas in less than two minutes. Since the system functions at ultra-high frequencies, the model antennas are quite small and may be fabricated at a cost of only a few cents each.

The essential elements of the system are illustrated in Fig. 2. The model antenna under test is mounted on a "mast" which consists of an 18 inch length of ¼ inch brass tubing. Both mast and antenna are rotated by a "selsyn" motor, which also acts as a base for the mast. If the frequency used is sufficiently high, almost any of the selsyns which have been abundant in war surplus will provide sufficient torque to rotate the model antennas. Motors of the "5G" size are very adequate.

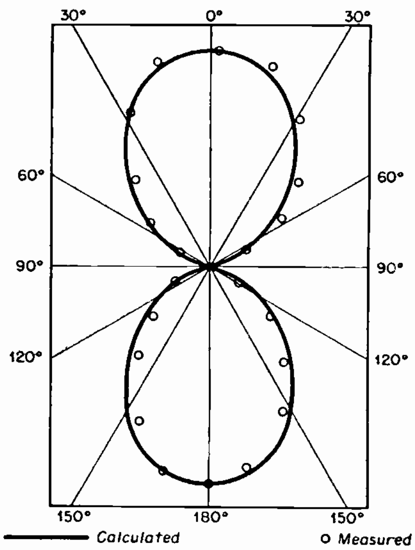
The test antenna is excited by the r.f. field produced by a stationary transmitting antenna placed about 10 wavelengths away, and fed by a stable r.f. oscillator. The frequency of operation may be any frequency above approximately 400 Mc., depending upon the availability of an oscillator. The best results are obtained in the 1000-1500 Mc. region since the model antenna sizes are convenient and reflections from near-by objects are less troublesome. Thus, it is possible to use the system indoors. The r.f. power required does not exceed one watt if the receiving device has sufficient sensitivity. The transmitting antenna should be provided with a small cylinderical parabolic reflector to increase the radiation in the direction of the receiving antenna under test.

An IN23 crystal diode is used as the r.f. detector. It is mounted in a small shield box at the top of the mast and is connected directly to the test antenna, as is shown in Fig. 3. To facilitate changing model antennas for comparison purposes, a "plug-in" arrangement is used. A miniature polystyrene coil-form socket is mounted in the top of the crystal shield box and the feeding terminals of the antennas plug into the socket holes. The socket used makes a good connection to the No. 12 tinned copper wire of which the model antennas are constructed.

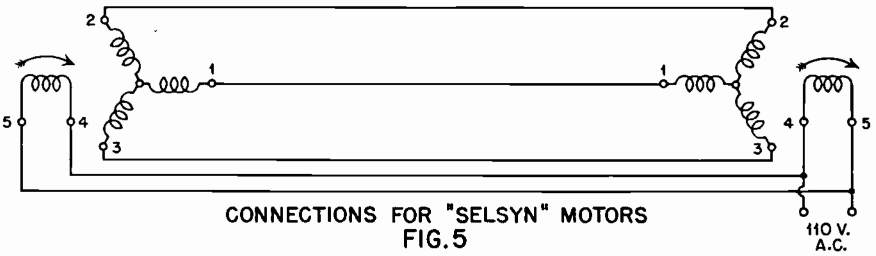
Since the crystal is assumed to present a load of about 300 ohms, antenna feeding systems which match this impedance are employed. Impedance matching is not extremely critical, however, since the crystal is



RECEIVER CIRCUIT DIAGRAM
FIG. 3



COMPARISON OF MEASURED POINTS WITH THEORETICAL DIPOLE POWER PATTERN
FIG. 4



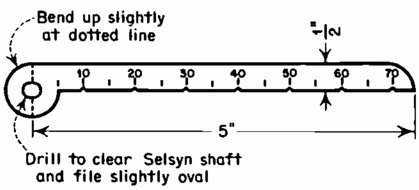
CONNECTIONS FOR "SELSYN" MOTORS
FIG. 5

connected to the antenna without intervening transmission line. An impedance mismatch of 2:1 will cause only about 10% error in the relative power indicated. Such mismatches do not change the shape of the radiation pattern indicated, but do cause errors in comparing the power gains of various antenna models unless the degree of mismatch is the same for each. For instance, valid comparisons may be made between the gains and patterns of complex arrays having 72 ohm feeding impedance and a center-fed half-wave dipole having the same feeding, impedance, although both mismatch the detector by 4:1.

The rectified d.c. from the crystal "receiver" is connected to a remote current meter (preferably a low range microammeter) by two flexible wires which run down the inside of the brass tube supporting the test antenna. If the current is less than about one milliampere, the reading of the remote indicating meter will be approximately proportional to power received by the test antenna, since the crystal is a square-law detector in the low current portion of its characteristic. The power response of the crystal may be checked by comparing a measured half-wave dipole pattern with the theoretical dipole power pattern of Fig. 1. A typical comparison is shown in Fig. 4.

The selsyn motor which rotates the model antenna is controlled by a second selsyn coupled to it by leads about 15 feet long. The standard connections of a selsyn system are given in Fig. 5. A plotting board, consisting of a 9 by 12-inch piece of ¼-inch plywood, is mounted on the drive selsyn. The selsyn shaft protrudes through the plotting board and through the center of the polar coordinate paper, which is thumb-tacked to the board. A radial scale, or *cursor*, is fastened to the selsyn drive shaft to act as an indicator of the angular position of the model antenna, so that as the cursor is rotated on the graph paper, the selsyns synchronize the rotation of the antenna with it. Thus, the angle of the polar diagram is automatically determined. The other coordinate, the *radius vector*, is read directly from the power indicating meter, and is plotted in arbitrary units from the center of the graph. Plotting an antenna pattern polar diagram is then merely a matter of rotating the cursor and plotting sufficient points, as defined by the angle of the cursor and the radius indicated on the meter, to determine its shape.

The details of the cursor are given in Fig. 6. It is made of thin aluminum or brass, and may be graduated with a scale similar to that of the meter used. This simplifies converting meter readings to radial distances from the center of the plotting paper. It is also helpful to put small notches in the cursor arm at the positions of the major scale divisions, as this facilitates locating these positions with the pencil point. The cursor should be easily removable to facilitate changing graph paper. One simple



DETAILS OF CURSOR
FIG. 6

way of accomplishing this is to drill the hole in the cursor large enough to clear the selsyn shaft, but file it slightly oval (Fig. 6). Then, if the cursor is bent upward a few degrees at the dotted line, it will grip the shaft firmly when held down against the paper, but is easily removed.

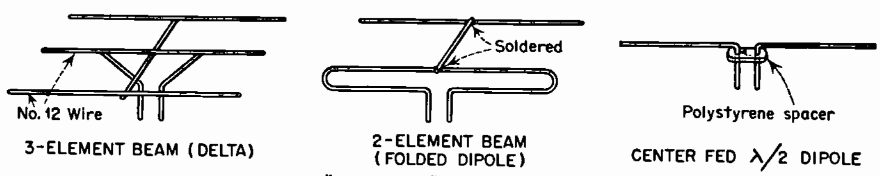
The Model Antennas

According to scaling theory, a model antenna will perform exactly like its full-scale prototype in free-space if the element lengths, diameters, and spacings are divided by a given factor (called the "scale-factor"), and the operating frequency and element conductivity are multiplied by the same factor. Conductivity scaling is usually ignored, however, since the metals used for elements can be assumed to be perfectly conducting.

As an example, suppose that it is desired to determine the characteristics of an antenna designed for the amateur 10-meter band, say at 28.5 Mc. Assuming that the pattern measuring equipment operates in the amateur band at 1220 Mc., the ratio of the frequencies, and hence the scale-factor, is 1220/28.5 or 42.75. This is the number by which all of the dimensions of the 28.5 Mc. antenna must be divided to result in a model which will give comparable performance at 1220 Mc. The dimensions of any impedance matching system associated with the antenna should be scaled in the same proportion.

Having determined the dimensions of the model antenna, the construction is relatively simple. The "plumber's delight" type of construction may be used to advantage, since a piece of wire may be used as the "boom", and the radiating elements soldered to it. Fig. 7 illustrates the construction of several typical model antennas. As mentioned above, only antennas having equal feeding impedances may be compared directly for power gain. Impedance matching systems of the folded-dipole, delta, and "T" types may be used.

In using the pattern measuring equipment, the operator should be located at a remote spot, well out of the path between the transmitting and receiving antennas. If the transmitting antenna has a good reflector, the plotting board and meter may be located back of this, where a relatively field-free region exists. In this way, movements made by the operator will not upset the pattern being measured. In making pattern measurements indoors, reflections from walls or other objects directly behind the model antenna are sometimes troublesome. These reflections can be prevented by placing a large piece of sheet-metal at a 45-degree angle behind the test antenna to deflect the waves upward.



TYPICAL "PLUG-IN" MODEL ANTENNAS
FIG. 7

You haven't seen this before!

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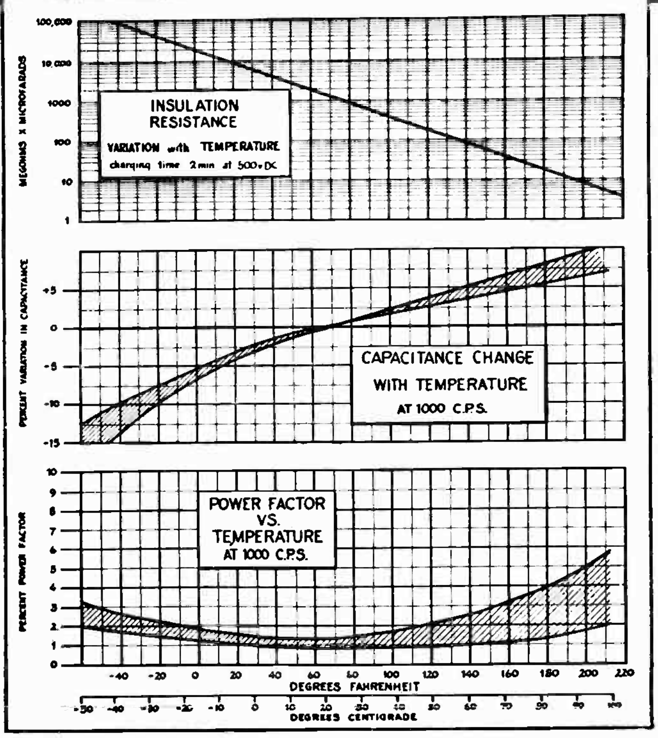

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- Dielectric strength maintained at elevated temperatures. Rated voltages based on 212°F. operation.
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- Unimpaired by sub-zero operation. Capacitance increases slightly with temperature rise.
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