The AEROVOX Research Worker

The Aerovox Research Worker is a monthly house organ of the Aerovox Corporation. It is published to bring to the Radio Experimenter and Engineer authoritative, first hand information on capacitors and resistances for radio work.

VOL. 18, NO. 3 | MARCH, 1946 | 50c per year in U.S.A. 60c per year in Canada

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PART 1. INTRODUCTION

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The student or technician who of necessity has been out of close contact with technical radio progress during the war years now realizes that considerable microwave development has been carried on. The new F. C. C. allocations in the very-high, ultra-high, and super-high-frequency regions include sufficient provisions for old and new radio services to attest to the importance of these shorter waves. Above 500 Mc., the amateur alone has received a total of 2150 megacycles of new territory in five bands that extend as high as 22,000 Mc.

It is the purpose of this series of articles to present, for the benefit of such absentees who wish to catch up, the simplest picture of several important aspects of microwave operation. Such characteristic accessories as wave guides, resonant cavities, and special v. h. f. oscillators and tubes will be described. In order to keep reasonably close to a picture of physical operation, we will avoid the mathematical approach and, as nearly as possible with a subject of this kind, we will confine our references and descriptions to those physical phenomena and analogies with which a student of intermediate radio might have been expected to be familiar in 1940. From the elementary information given in this series, the reader should progress without delay to more quantitative explanations of the same topics and to further data not included in these papers. The books given in our reference lists are recommended for further study.

NOTES ON WAVES AND PROPAGATION

At the lower radio frequencies, we have kept in view certain well-established pictures of circuit operation, including current flow and the necessarily ever-present return circuit. When our attention is transferred to the microwaves, however, we find it important to visualize electromagnetic waves by themselves, without supporting wire circuits, and to "see" v. h. f. energy propagated in one direction, without return circuits. We can call upon our knowledge of reflections to clarify the picture of standing waves in space. At microwave frequencies, we find it practicable to transmit electromagnetic energy down hollow pipes and to secure resonance in hollow chambers. In order to avoid inevitable confusion in trying to understand these phenomena, it is necessary to turn aside from earlier wire-circuit pictures and to think in terms of the moving electromagnetic waves that carry microwave energy.

At microwave frequencies, the relation between operating wavelength and physical size of circuit components is an important consideration. At lower radio frequencies, we were not concerned with the ratio of wavelength to dimensions, but in this new case, it is seen early that the dimension of a component may equal one wavelength or a respectable fraction thereof. When wavelength and physical size are so closely related, devices dimensioned for operation at one frequency (or for propagation of energy in one specific fashion) may be found to operate instead — or simultaneously — at other frequencies or in unintended manners.

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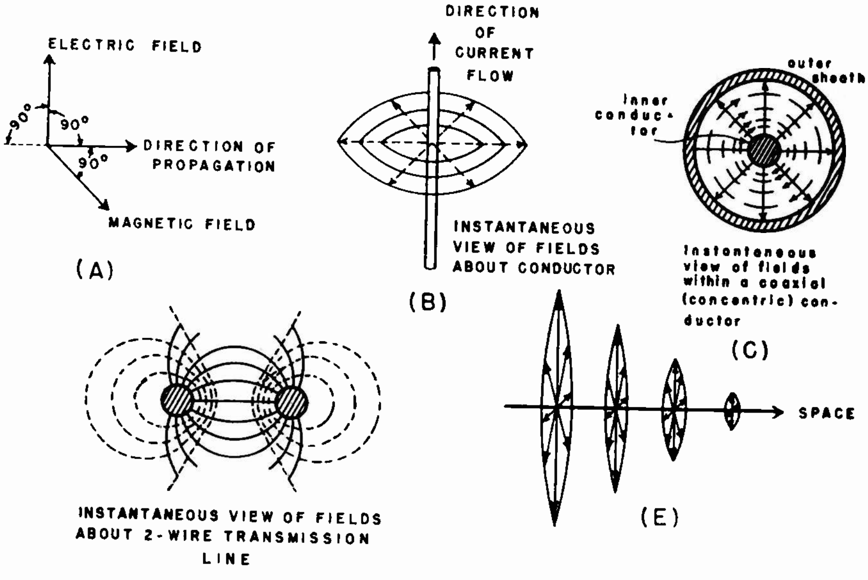

FIG 1

Electromagnetic Wave Components. Each electromagnetic wave comprises an electrostatic and an electromagnetic component. These are *fields of force.* The electrostatic component often is termed simply the *electric field.* Similarly, the electromagnetic component is termed the *magnetic field.* The two components act at right angles to each other, and both are at right angles to the direction of propagation of the wave, as shown in Figure 1-A. The energy of the wave alternates between the two fields.

Figure 1-B depicts the arrangement of electric and magnetic fields about a conductor carrying current. Electrons constituting the current flow move in the direction of the arrow. Electrostatic lines of force, represented by the dotted arrows, radially around the conductor, pointing outward perpendicular to the lengthwise axis of the conductor. Their length is determined by the strength of the current. The electromagnetic field, associated with the electric field, takes the form of whorls concentric to the conductor. One of these whorls is shown as a solid circle in Figure 1-B. Note how the angular relationship of the two fields and the direction of propagation satisfies the diagram of Figure 1-A.

Figure 1-C shows the ideal arrangement of the electric and magnetic fields in a coaxial cable, viewed in radial cross section. It is assumed that current is being carried by the central conductor in the direction represented by going into the page from the surface. Figure 1-D shows field distribution about the two parallel wires of an ordinary transmission line. Note that in both of the illustrations, the whorls of the magnetic field are more closely spaced near the conductors, and that both fields in the coaxial line terminate at the outer sheath.

The diagrams of Figures 1-B, C, and D represent the conditions of electric and magnetic field intensities and direction taken at one particular point along the conductor. This point of observation is represented as a perpendicular plane passed through the conductor at that point. If the wave is assumed to exist in space rather than along a conductor, the plane might be regarded as representing a particular point in space. Note that in any such plane the strength of the magnetic field at a given point depends upon the strength of the electric field at the same point. If the components are varying in intensity, as is true of all alternating fields, the two wave components will undergo a corresponding series of intensity values. Also, where the initiating currents are alternating, the field directions will reverse in accordance with the cyclic variations in current. If we visualize a *standing wave* in space, we see that planes passed through the fields perpendicular to, and at various points along the space (distance) axis (See Figure 1-E) will show variations in field size, as depicted by arrow length and circle diameter. However, observe from Figure 1 that if we take any *single* such plane, the electric intensity values and the magnetic intensity values will be the same along equal radii anywhere in that plane.

Radiation and Plane Waves. To explain the exact nature of the radiation of electromagnetic waves without the aid of Maxwell's equations is difficult. The experienced radio technician is in possession of simple concepts which, although not altogether quantitative, will however give him some notion of the mechanics of the phenomenon. Our purpose here is to clarify that picture rather than confuse it with material at present out of his grasp. We will begin by mentioning that it is well known that in the case of electromagnetic waves having frequencies starting just beyond the upper limit of the audio-frequency spectrum, energy is not returned by the electric and magnetic fields entirely to the conductor carrying the initiating currents. But a portion of such energy is radiated into space. It already has been pointed out in this article that propagation is in a direction perpendicular to both fields. Furthermore, it has been established that, neglecting the distorting and absorbing effects of the earth's surface and intervening bodies, waves leaving the initiating conductor, or *antenna,* take the shape of concentric spheres which move away from the source by "growing" outward in all directions. This may be visualized in a simple manner by imagining the originating antenna as a point at the exact center of a sphere. The surface of the sphere then would represent the ideal wave at a given point in space, any point on the surface being at the same distance from the center as all other points. Any area on the surface would contain both electric and magnetic field components perpendicular to each other and at the same time perpendicular to the radius representing the direction of propagation. This is shown in Figure 2-A. *Any* radius would represent the direction of propagation of this spherical wave.

A plane passed through the sphere perpendicular to the surface would give a cross-sectional view of field distribution similar to Figure 2-B. These magnetic lines of force, represented by the dotted circles, and the electric lines of force, represented in end view by the dots within circles, must be visualized as moving outward in continually growing circles. The magnetic field growth is in the direction parallel to the surface of the page, while that of the electric field is perpendicular to the page.

With the preceding picture of the sphere in mind, it may be seen that any practical portion of a wave (represented by an area on the surface of the sphere) approaches a true plane as the radius of the sphere approach-

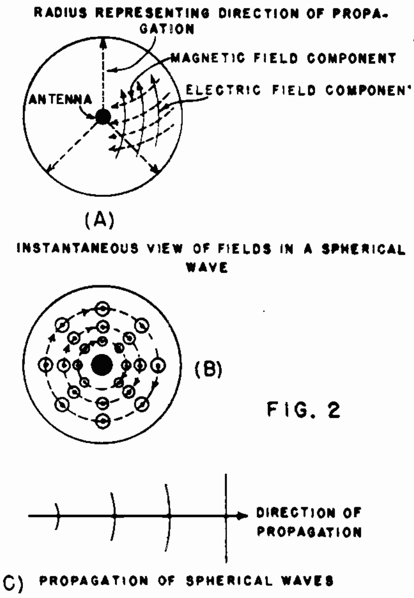

FIG. 2

es infinity. That is, the sphere radius increases as the distance from the initiating source increases with the movement of the spherical wave through space. This approach to a true plane is depicted by Figure 2-C. The waves reaching a receiving antenna are essentially plane waves when the distance between transmitting and receiving is large.

Velocity, Reflection, and Standing Waves. Radio waves behave in a manner similar to that of light waves. They travel at high velocity and may be polarized, reflected, and refracted. In fact, it is reasonable to conclude that light is a form of electromagnetic wave motion. Radio microwaves appear to resemble light waves more closely than low frequency radio emanations because their shortness permits easy manipulation of directing devices and facilitates observation of transmission phenomena. For these reasons, these waves have been referred to as quasi-optical.

If we examine propagation along any one radius of the sphere used for illustration in the preceding section, we note that propagation, with respect to that radius, is in a straight line from the source. This is shown in Figure 3-A. The velocity of travel along the radius is identical with that of light, 300 million meters (approximately 186,000 miles) per second, assuming that the propagation is through empty space or air. Propagation through dielectric materials is somewhat slower, depending upon the physical properties of the materials.

It is of course well understood by students of intermediate radio that electromagnetic waves striking an intervening body, especially a flat surface, as shown in Figure 3-B, will be reflected, the angle of reflection being equal to the angle of incidence. In most cases, the greater amount of energy will be reflected by metal surfaces. Waves likewise may be reflected successively by two parallel surfaces, as in Figure 3-C, so that the resultant direction of propagation is at some angle to the original direction of travel. This principle has been utilized in the *wave guide.*

It is well understood too that waves are reflected by the open-circuited or very high-impedance ends of transmission lines. When such a line is excited by high-frequency voltage, the varying phase relationship between transmitted and reflected currents give rise to maxima and nulls along the line. Both current and voltage undergo these variations along the line, giving rise to the phenomena known as *standing waves.* Reflections are essential to standing waves.

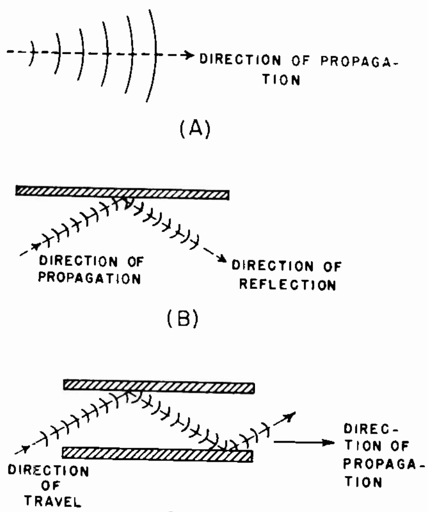

FIG. 3

Two waves in space likewise may combine to form *standing wave in space.* In microwave practice, wave reflections are combined with the original wave for this very purpose. The mechanics are analagous to the formation of standing waves along a transmission line — alternate cancellations (zero field) and reinforcements (maximum field) of the original wave by the reflected wave set up maxima and nulls in space. Thus, reflections between two parallel surfaces, as shown in Figure 3-C, may produce standing waves between the surfaces as field components in original and reflected waves combine in various phase relationships.

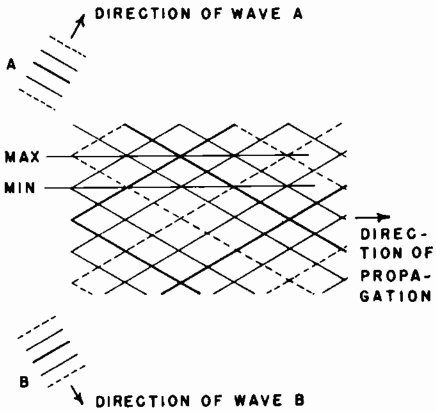

FIG. 4

The large pattern in Figure 4 shows how standing waves might be set up in space in the manner just mentioned. The two waves, A and B, are assumed to move in the directions indicated by the arrows opposite their patterns. Each of these patterns in Figure 4 may be thought of as a top view of a sine wave representing field intensity in space — the dotted lines representing negative peaks, the light lines zero points, and the heavy lines positive peaks. The wave would resemble a corrugated area, such as shown in Figure 5. The large pattern shows how interference of the two travelling waves sets up the standing wave. The nulls correspond to intersections of dissimilar peaks, while the maxima are intersections of similar peaks. The troughs and crests of the standing wave accordingly run from top to bottom in the Figure, and the direction of propagation is the resultant of the independent directions of the contributing waves.

For maximum reflection of energy from conducting surfaces, the angle of incidence must be such that the electric field is perpendicular to the reflecting wall, or zero at every point of incidence. If the electric field has

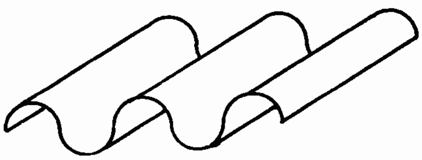

FIG. 5

a component parallel to the wall at the point of contact, or at some angle other than 90 degrees (assuming ideal conductivity in the wall), current will flow in the wall.

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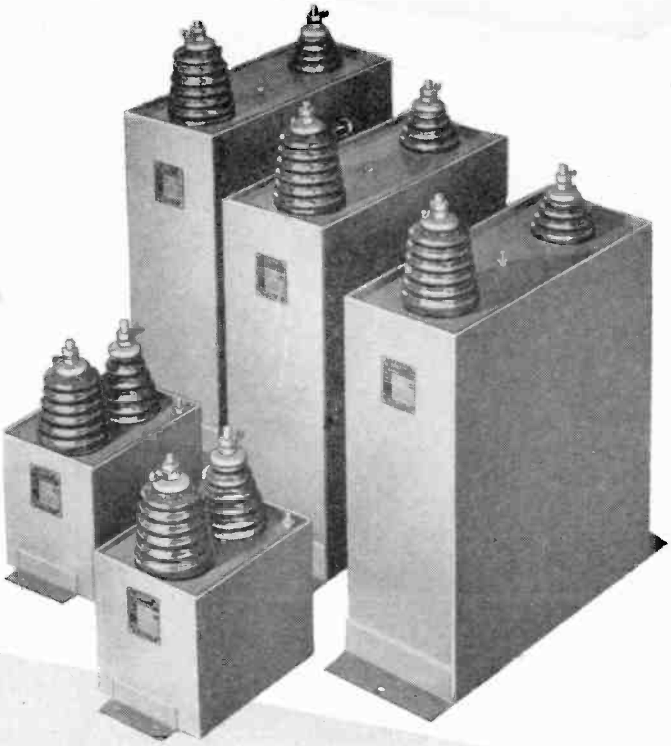

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