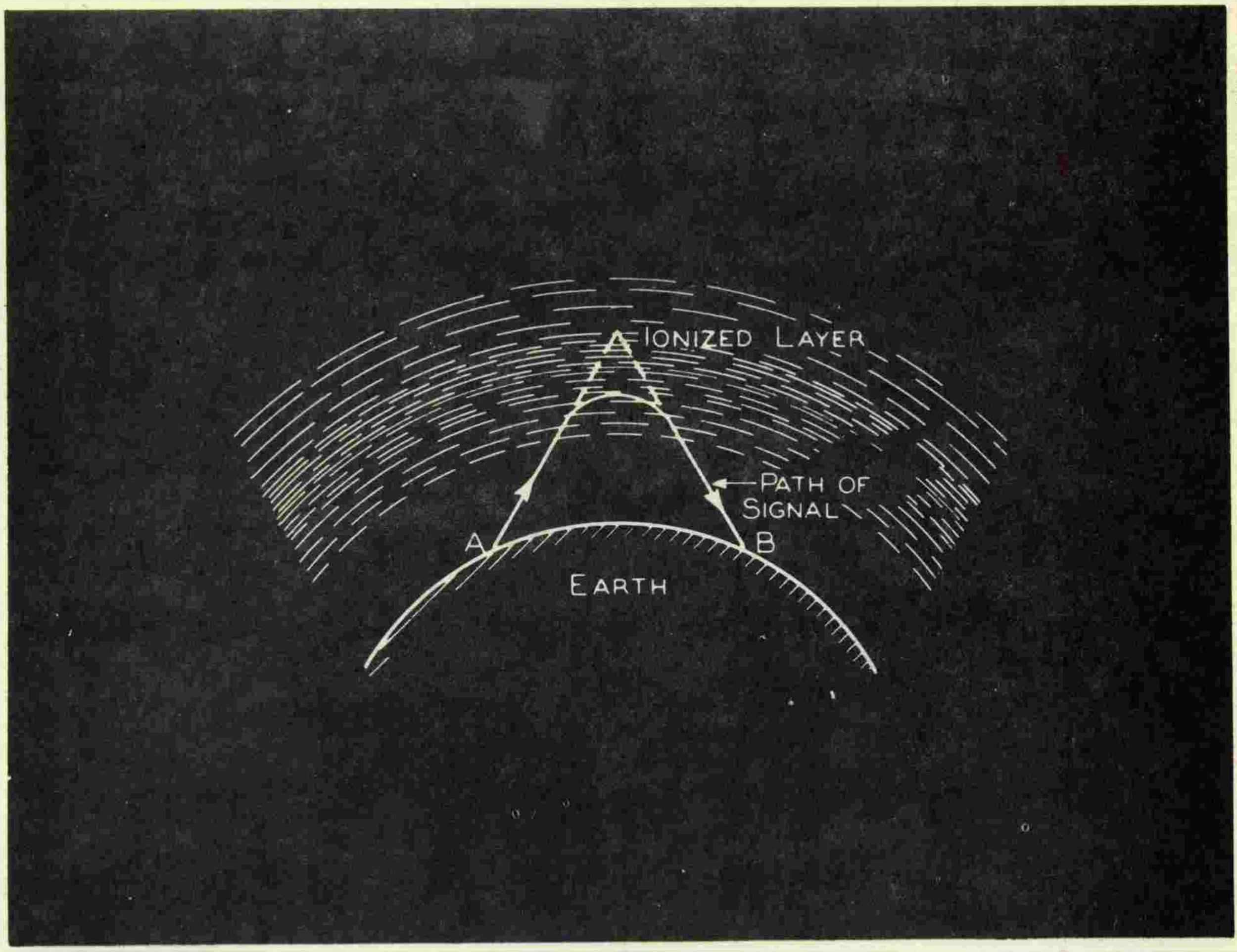

LESSON

69 RA

ANTENNA SYSTEMS

RADIO-TELEVISION TRAINING SCHOOL, INC.

5100 SOUTH VERMONT AVENUE • LOS ANGELES 37, CALIFORNIA, U. S. A.

ANTENNA SYSTEMS

The important characteristics of antenna systems for the transmission and reception of intelligence by radio with the least amount of distortion and electrical interference can best be understood when we know something about radio wave propagation through space. We will then be in a better position to select the type of antenna for a particular application.

Antenna systems differ in shape and size for the various applications and frequencies used for radio communication purposes. These frequencies range from 10,000 cycles to approximately 30,000 megacycles. In the propagation of radio waves from and to antenna systems, we find that the angle of radiation and the polarization of the waves may be of little importance on some antennas but may be very important on other types of antennas. We will also find that a particular type of antenna will work best for long distance communication and may not function satisfactorily for shorter distances. These are some of the reasons why an antenna system must be selected to give the maximum transfer of energy from the transmitting antenna to the receiving antenna. In analyzing some of the important characteristics of antenna systems, we must consider the following:

1. Polarization
2. Angle of radiation
3. Terminating impedance
4. Directional characteristics
5. Field strength

By the polarization of an antenna system, we refer, in particular, to the angle at which maximum energy may be transmitted from a member or a conductor of an antenna to the receiving antenna. For example: If we have a straight-wire antenna, we will find that the polarization will be of a horizontal nature when the wire is horizontally supported above the earth. If the straight-wire antenna was placed in a vertical position above the earth, the waves emitted from the antenna will be vertically polarized and can, therefore, be received with maximum efficiency on a receiving antenna that is held in a vertical position.

In studying the propagation of radio waves, we will find that more energy will be transmitted at a certain angle or angles, depending upon the surroundings as well as the design or arrangement of the antenna elements. For example: The height of the antenna above the ground and, in particular, whether the antenna is located in a valley, on a hill, or on a plain. The angle of radiation is generally measured from the vertical plane. A straight-wire antenna, which is mounted vertically and operating on or near its fundamental frequency, will transmit waves at low angles, that is, maximum energy will be directed at a low angle and along the surface of the earth.

The terminating impedance of an antenna is also a very important factor in obtaining maximum transfer of energy to the antenna from the transmitter and, likewise, from the antenna to the input of the receiver. The impedance value is expressed in ohms and is between a few thousand ohms and a few ohms. This value is often referred to as the load represented by the antenna system upon the transmitter or the source impedance to which a receiver is connected.

All antenna systems have directional characteristics, some of which are uniform, that is; circular, while others transmit more power in a given direction due to their design or natural surroundings. In many applications, the directional properties of the antenna system is utilized. In studying the directivity properties of an antenna system, we must consider the vertical plane, the horizontal plane, as well as the actual compass directions in which maximum radio wave propagation takes place. All three factors are important.

In general, the field strength produced by an antenna is proportional to the current flowing through it. Again, in many applications where there are variations in the current distribution throughout the length of the straight-wire antenna, those sections of the antenna that carry the greatest amount of current will have the greatest effect on the radiation pattern. For example: If the longest section of the antenna carrying the greatest current is vertical, the waves will be vertical-polarized and can, therefore, be received with the greatest of efficiency on a vertical straight-wire antenna. These statements apply to the simplest antenna systems.

For comparison purposes, radio engineers select an antenna that is a half-wave length long as a standard for the frequency upon which signal transmission or reception is to be made and the power gain of an antenna is the gain expressed in decibels over that normally obtained when using a half-wave antenna.

ANTENNA LENGTH

The electrical length of an antenna is expressed in wave length or the distance from the crest of a wave to the crest of the suceeeding wave in free space. This length can be found by using the following formula:

$$\text{Wave length} = \frac{300,000}{F}$$

Here the wave length is expressed in meters. A meter is equal to 39.37 inches. The frequency, F, is expressed in kilocycles per second.

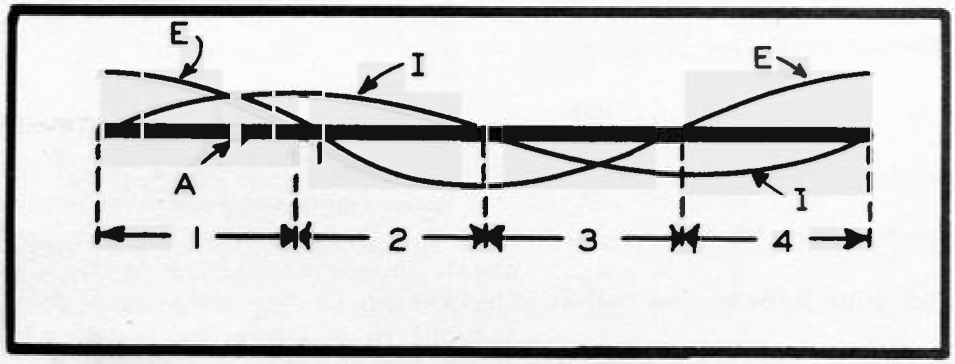

Fig. 1. A full-wave antenna is indicated by the complete current cycle as shown by the curve I.

Radiomen indicate the physical length of an antenna in multiples of the electrical wave length and of a straight-wire antenna having the form of a single conductor or wire. The radio frequency current shown by the curve I flowing at various points throughout the entire length of a straight-wire antenna A is a full-wave length long and varies as shown in Fig. 1. For practical purposes, there is zero current flow at the ends and center of this straight-wire antenna a full-wave length long. There will, however, be maximum values of voltage where the current is lowest. This is shown by the curve E in Fig. 1. This 90-degree phase displacement, between the current and the voltage in a straight-wave of an antenna or wire, is referred to as a standing wave. In general, but not in all antenna systems, we will find that radio waves will be propagated into space when there are standing waves present on conductors. This gradual increase and decrease of the radio frequency current flow throughout the length of the conductor of an antenna is attributed to the distributed capacity and inductance throughout the entire length, and, in actual practice, the length of the conductor is somewhat shorter than the theoretical value found by using the formula presented above. This is due to the fact that the waves do not propagate as fast through the conductor as they do through space. The difference is not, however, great but may reach a value of ten percent depending upon the relative shape of the conductor. For example: The wave will propagate at a slower rate through the length of a metal tower as shown in Fig. 2, than through a thin, long straight-wire.

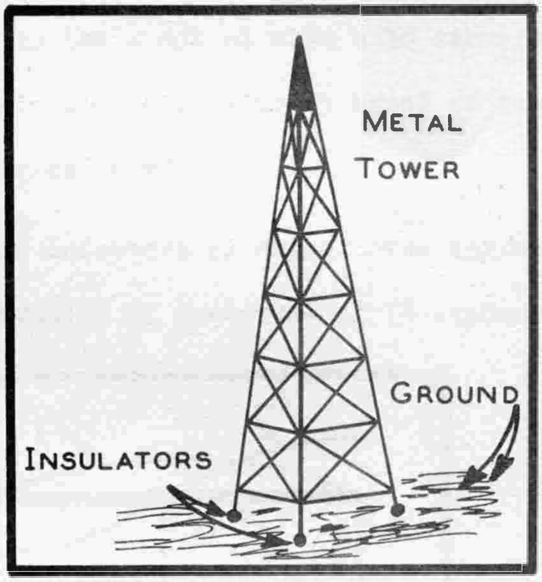

Fig. 2. Broadcast stations employ vertical steel towers supported by insulators above the ground as the antenna while a fan-like network of a large number of conductors, about the length of the tower, are planted several inches below the surface of the earth for a good ground connection.

The relative length of the conductors in an antenna system are always indicated in wave length or fractions of a full-wave length. This method and division is a practical way of indicating the tuning procedure of an antenna system among technical personnel. For example: Let us again refer to Fig. 1 and note that the length of the full-wave antenna is divided into four quarters. One-half of a full-wave antenna will be equal to two quarters of the length of a conductor that is full-wave in length.

Since the <u>shortest</u> <u>antenna</u> <u>conductor</u> that can be made to efficiently propagate radio waves into space must be one-half the wave length in electrical length, the voltage and current distribution will be as shown in Fig. 3. Note that maximum current flow is at the center and that there is maximum voltage at the ends of the antenna conductors as indicated by the curves I and E respectively. Careful examination of Fig. 1 and Fig. 3 will disclose to you that the half-wave antenna is equal to one-half the length of a full-wave antenna.

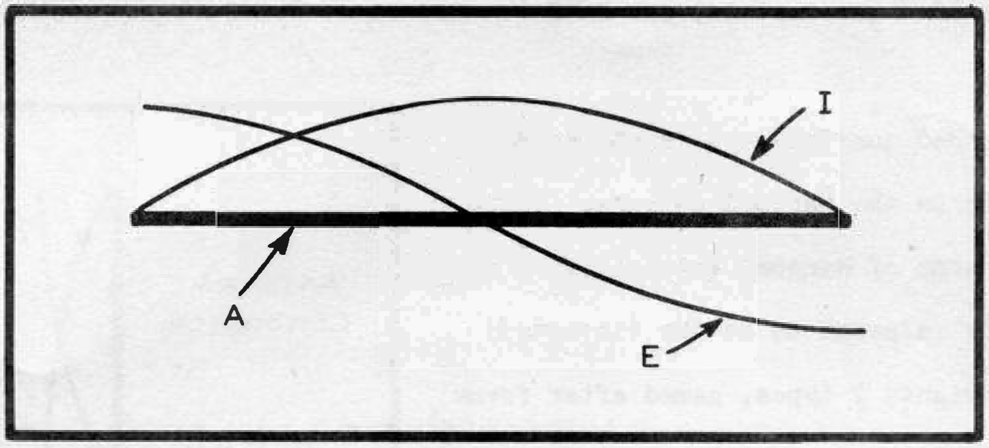

Fig. 3. The half-wave antenna A held in space and the voltage, as well as the current distribution, are shown in two separate curves.

If we were to cut the half-wave antenna shown in Fig. 3 in two parts and; at the center we were to find that its impedance to the flow of radio frequency current would be equal to approximately 70 ohms and it would be resistive rather than inductive or capacitive in nature.

Antennas can be classified into two general groups. The Hertz types, which do not require a ground connection, and the Marconi types, which rely entirely upon a ground connection for proper operation. Both types are named after men who were pioneers in the use and application of the respective antenna types. There are, to be sure, a large number of other types of antennas in use, all of which operate upon principles in some form or other and involving one or both of these types.

The two antennas described in Fig. 1 and Fig. 3 are known as the Hertzian type. Now we shall learn about the operation of the Marconi type. The current and voltage distribution of the simplest form of this type is shown in Fig. 4. You will observe that the portion of the antenna conductor that extends above the earth or ground is equal to one-quarter of the length of the full-wave antenna shown in Fig. 1. There will be maximum voltage at the top end of this quarter-wave antenna while maximum current will be at the base or ground connection.

The earth serves as a good reflector for all the electrostatic and electromagnetic waves and will cause the impedance at the base of the antenna to be equal to approximately 30 ohms; that is, one-half the impedance found at the center of a half-wave antenna.

The grounded quarter-wave length antenna is referred to as the Marconi antenna. There are various forms of Marconi antennas such as those commonly referred to as the (inverted) L and the (upright) T types, named after forms taken by conductors.

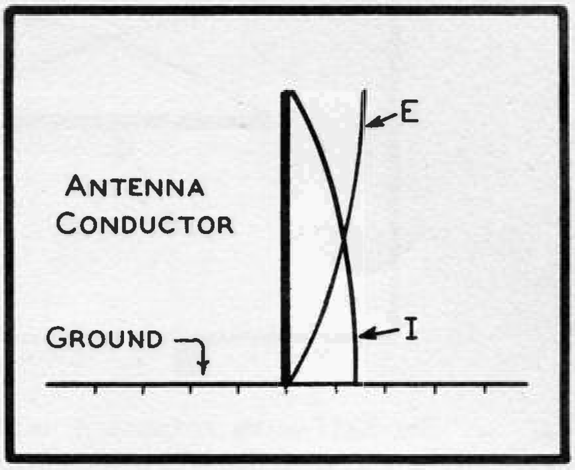

Fig. 4. Current and voltage distribution for a quarter-wave vertical antenna.

The L-type antenna shown in Fig. 5 functions very much like the quarter-wave antenna, however, the impedance at the base connection will be somewhat lower because additional distributed capacity has been added by the horizonal conductors. The horizontal section of the L-type antenna tends to raise current flow in the vertical section and has the effect of raising the height of the antenna. That is, the effective height of the antenna is increased even though supported on masts less than one-quarter wave long to nearly a quarter-wave, therefore, somewhat greater efficiency is obtained by using the L-type antenna than that available from a vertical antenna conductor which is shorter than a quarter-wave in length.

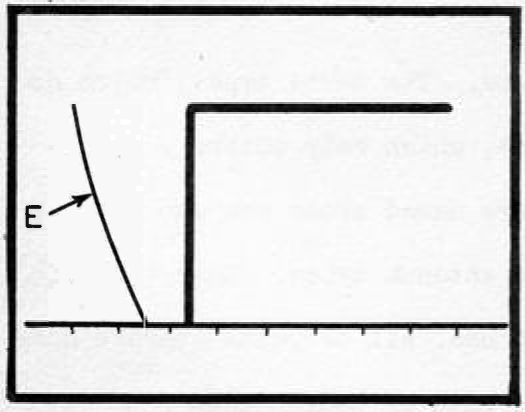

Fig. 5. Voltage distribution for the L-type antenna.

A further increase in the distributed capacity of the antenna system is obtained by using the T-type antennas shown in Fig. 6. This again means that the impedance between the base connection and ground will likewise be lower. Maximum voltage will again appear at the ends of the horizontal section of the T-type antenna and a greater current will flow in the vertical section with somewhat greater over-all efficiency than that obtained from the L-type antenna of the same height.

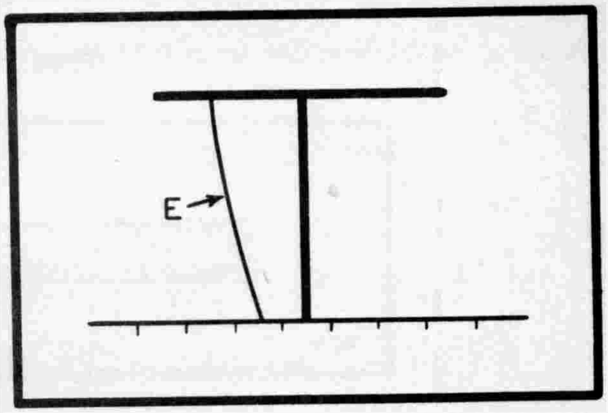

Fig. 6. Voltage distribution for the T-type antenna.

The efficiency of the three respective antennas shown in Fig. 4, Fig. 5 and Fig. 6 are very nearly equal providing the vertical sections are approximately the same length. However, if the vertical section of the T-type antenna is relatively short with respect to the over-all length of the horizontal section, we will find that the efficiency will be considerably lower. Maximum efficiency is obtained from an antenna when all the distributed capacitance and inductance is in the vertical section, in other words, when the antenna conductor is one-quarter wave in length and vertically mounted.

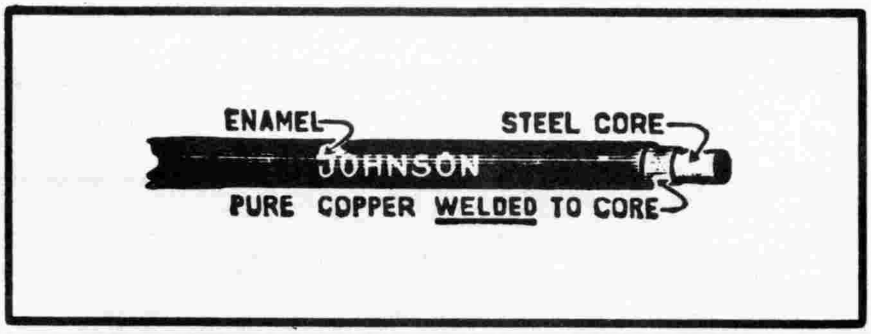

Fig. 7. A short length of enameled copperweld antenna wire is shown here.

Inasmuch as radio frequency currents travel over the surface of conductors rather than through them, we will find special antenna wire used in large antenna installations. That is, antenna systems for low radio frequency operation. This wire is often referred to as the enameled copperweld antenna wire. Such a wire has been especially made to specifications prepared by the engineers of the E. F. Johnson Company of Waseca, Minnesota. It is available in sizes 10, 12 and 14. As shown in Fig. 7, the wire has a steel core to which a pure copper covering is welded. To prevent excessive oxidation of the pure copper, a covering of enamel is used. This type of antenna wire has about three times the strength of hard drawn pure copper wire and, for that reason, can easily support itself as well as being able to withstand a considerable amount of wind and ice.

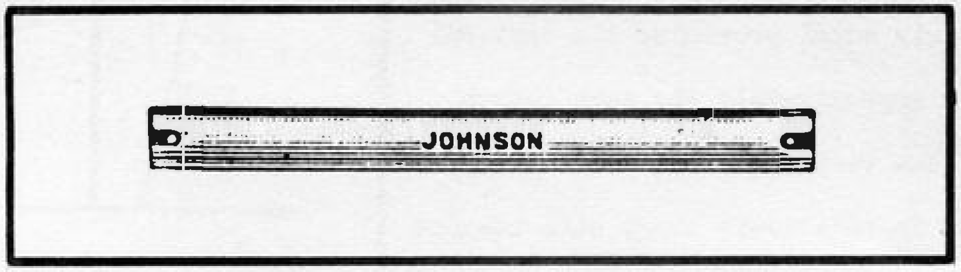

Fig. 8. Low power transmitting antenna insulators make excellent receiving antenna insulators.

Insulators used for the purpose of supporting antenna elements and antenna wire are especially designed to withstand great strength and provide long leakage paths with low end-to-end capacity. The insulator shown in Fig. 8 is available in lengths of 4, 7 and 12 inches and is capable of withstanding a pull up to 400 pounds. These insulators are of genuine wet process porcelain with smooth white glazing and about one inch in diameter. The glazed surface prevents moisture absorption.

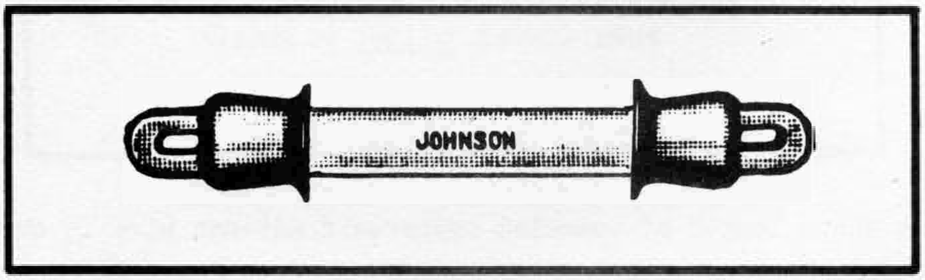

Fig. 9. A high-power, high-voltage, high-leakage type of transmitting antenna insulator is shown here. The E. F. Johnson Company manufactures a complete line of antenna equipment.

The large, high-voltage, commercial type insulator shown in Fig. 9 is one and one-half inches in diameter and is provided with non-corrosive aluminum alloy end pieces. The insulator is available in lengths of 8, 12 and 20 inches and is capable of withstanding a pull up to 5,000 pounds. Again glazed porcelain is used as the insulating material.

Marconi antennas are most efficient at radio frequencies below 3,000 kilocycles while the Hertzian antenna is very efficient at frequencies above this value. The efficiency of these two types of antennas is dependent largely upon the behavior of radio waves. That is, their propagation characteristics differ.

At relatively low radio frequencies from 10,000 to 300,000 cycles, we find that the wave propagation is not materially affected by the time of day or the relative contour of the terrain at and between the transmitting and receiving antenna systems.

As we increase the frequency range of operation from 300,000 to 3,000,000 cycles, the intermediate radio frequency range; the effects of the relative height of hills, buildings, and other objects at an near both the transmitting and receiving antennas begin to become apparent. These waves are reflected easier; that is, the ground begins to act more like a perfect reflector and tends to direct the waves off the surface of the earth and send them to the outer ionized layers thirty to one-hundred and fifty miles above the earth where they are again reflected and returned to the earth many miles away. Then they bounce off the earth again and strike the ionized layer again as if they were light waves being reflected by a mirror until the power in the wave is completely dissipated. Although it is less costly to erect efficient antenna systems for these frequencies because of the relative length and height of antennas for these frequencies, we encounter another problem and that is the skipping of the wave or signal over the receiving antenna. The shortest distance between the transmitting antenna <u>A</u> and the receiving antenna <u>B</u> will be as shown on the front cover of this lesson. The area between the useful ground wave, the wave that travels directly from the transmitting antenna <u>A</u> to the receiving antenna by the line-of-sight, and the beginning of the ionospheric wave point <u>B</u> is called the skip zone and commonly referred to as the skip distance. This skip distance depends on the height of the ionized layer in which refraction takes place. The higher layers give longer skip distances for the same wave angle.

If the height of the ionized layer should change and if the receiving antenna should be near the skip distance zone, we may experience fading; that is, a continual changing of the intensity of the signal.

Between the frequency range of 3,000,000 cycles and 10,000,000 cycles, better referred to as 3 to 10 megacycles, the high radio frequency range, more and more of the wave is reflected by the earth and conveyed to the receiving antenna by reflection from the ionized layers above the earth. The relative height of the short antenna above the earth has little, or rather less effect on the efficient transmission or propagation of the radio wave to the receiving antenna. With increased antenna efficiencies at both the transmitter and receiver locations, a lower amount of power is required for a reliable signal although the relative height of the ionized layers will change with the time of day.

The height of these heaviside layers, named after Mr. Heaviside (the man who discovered their presence), changed with the active rays leaving the sun.

The very high radio frequencies, generally referred to as those frequencies between 10 and 100 megacycles, are even reflected to a greater degree by the earth's surface and by man-made objects than any of the other frequencies. Waves at the high frequency end of the range tend to reflect in a vertical plane off the earth and start to penetrate the ionized layer; that is, go right through it rather than be reflected by it.

Radio frequencies above 100 megacycles are referred to as ultra-high frequencies and seldom are propagated over the horizon. That is, they behave like light rays. Reception will be consistently good when the respective antennas are in the line-of-sight. As already pointed out, these waves penetrate the ionized layers and are not reflected back to earth. Since the maximum distance of transmission is the line-of-sight, satisfactory communication is limited due to the curvature of the earth or approximately 7.5 miles with normal antenna heights of 30 feet as shown by the chart in Fig. 10. This chart is based strictly on line-of-sight coverage. The formula $D = 1.23 \sqrt{H}$ was used in preparing the chart. Here <u>H</u> is the height in feet while <u>D</u> is the distance in miles.

In view of the fact that high frequency antennas must be erected high above the earth to cause efficient transmission of radio signals, we encounter the problem of efficient transfer of the radio frequency signal from the transmitter to the antenna and the antenna to the receiver. This is done by using a transmission line capable of conveying the signal without loss and without the introduction of noise or distortion in the signal.

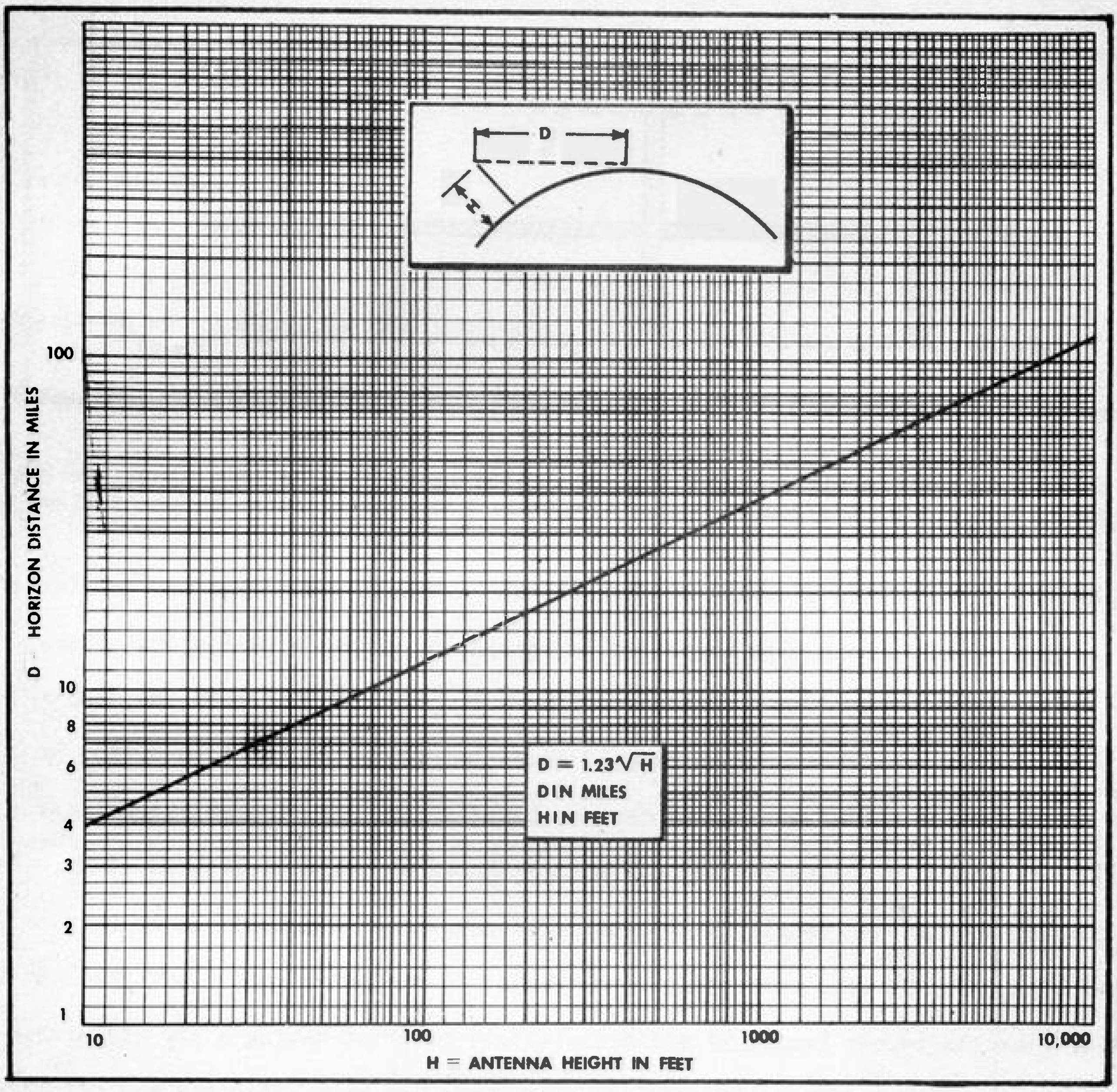

Fig. 10. Line-of-sight transmission distance for ultra-short wave propagation.

TRANSMISSION LINES

The subject of antenna systems would not be complete without discussing the electrical characteristics of transmission lines. Unlike antenna elements, transmission lines, when properly terminated, do not radiate or accept radio signals. As pointed out, the transmission line serves only to convey the signal with the least loss and without the introduction of noise or distortion. A transmission line may consist of two parallel wires or one wire supported by insulators within a hollow conductor. This latter line is known as a concentric line. For transmission purposes, the center conductor is usually supported or held concentric with the outer conductor by thin ceramic discs spaced several inches as shown in Fig. 11. Transmission lines used for reception purposes may employ what is known as solid dielectric lines, semi-flexible conductors,and usually with a center conductor of stranded number 14 pure copper wire which is held concentric with respect to the outer conductor (the latter made of flexible copper braid) by solid dielectric material having a low dielectric constant. Transmission lines of the concentric type are very efficient and completely eliminate the pickup of interference along the line although they cost relatively more than the open or parallel wire type lines.

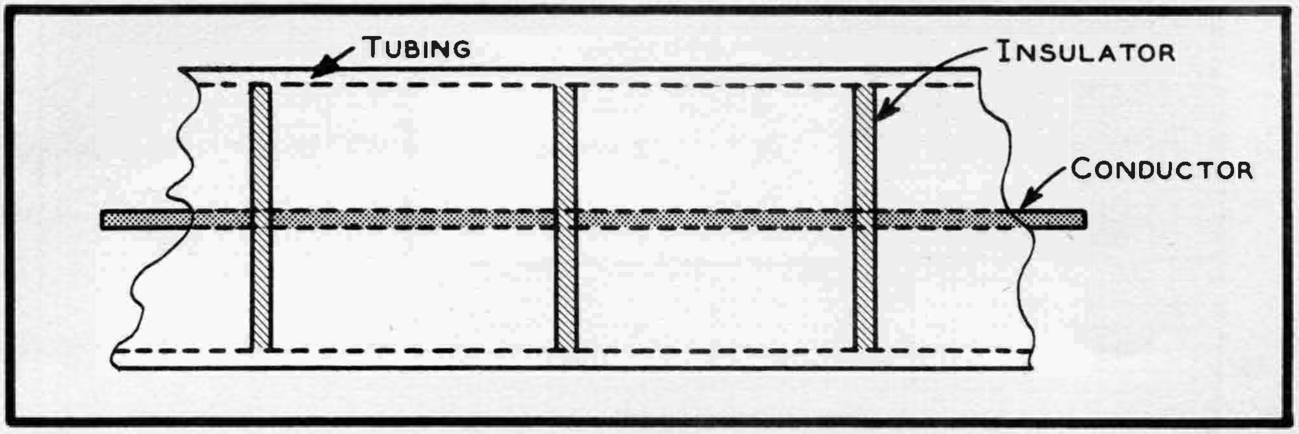

Fig. 11. A concentric air dielectric transmission line using ceramic discs for the purpose of supporting the center copper conductor and a metal outer copper tubing.

Transmission lines can be divided into two general groups; the tuned and untuned types, or those with and without standing waves, respectively. The concentric lines employing untuned lines, have their terminating impedance matched by employing suitable transformers or selecting conductor sizes that will cause the characteristic impedance of the line to equal the circuits to which they are connected. The chart shown in

Fig. 12 indicates the impedance for different sizes of transmission lines. Note the outside diameter of the center conductor and the inside diameter of the outer conductor and how they affect the impedance value of the transmission line. Furthermore, observe the fact that the smaller the wire, the higher the impedance.

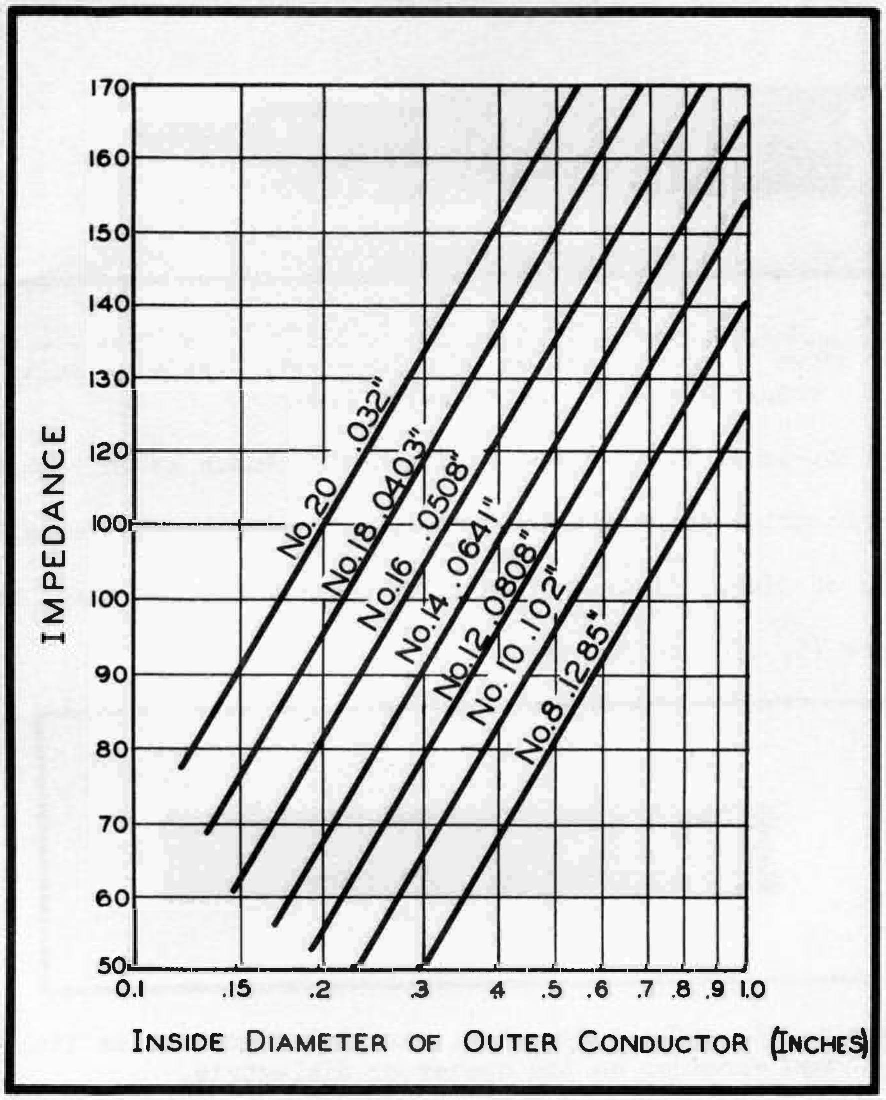

Fig. 12. This chart shows the characteristic impedance values obtained when using air-insulated, ceramic disc, or equivalent spaced insulators, concentric-type lines.

In Fig. 13 is shown a high frequency cable employing a stranded copper wire as a center conductor and a flexiable copper braid as the outer conductor. This line is referred to as a solid dielectric. The outside protecting cover of the copper braid is either made of vinyl or polyethelene. This transmission line is available having terminal impedance values ranging from 50 to 75 ohms.

Not all untuned lines are concentric lines. Many transmission lines employ parallel wire, that is, two wires that are held in position by the use of spacers, referred to as spreaders. It is not at all unusual to find two parallel wires supported by a ribbon-like, low-loss, solid dielectric material known as polyethelene as shown in Fig. 14. This material is unaffected by weather and will give excellent service over a long period of time. It is available in three different sizes or impedance values and they are 75, 150 and 300 ohms.

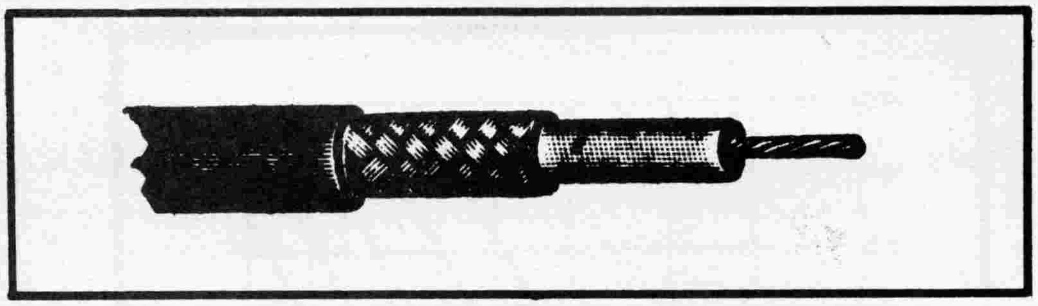

Fig. 13. Here is shown the construction of a low-loss, flexible, solid dielectric concentric R.F. transmission line.

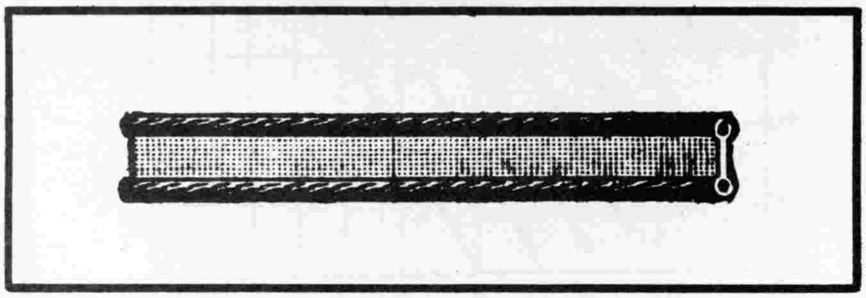

Fig. 14. This is a section of the two-wire, parallel transmission line using a ribbon spreader as the spacer or dielectric.

Whenever using parallel, two-wire, transmission lines for receiving purposes, having an impedance greater than 300 ohms, it is common practice to transpose; that is, cross the lines every few feet throughout the length of the line to prevent one side of the line from picking up more noise than the other. The transposition of the parallel leads causes equal and opposing noise voltages to be picked up, thereby preventing the line from introducing a strong line noise which may be generated near the line on its way to the input of the receiver.

Special transmission line insulators are available for transposing parallel lines. A typical efficient insulator of this type is shown in Fig. 15. It is made of glazed porcelain and provides a two inch separation of the number 14 or 12 wire conductors.

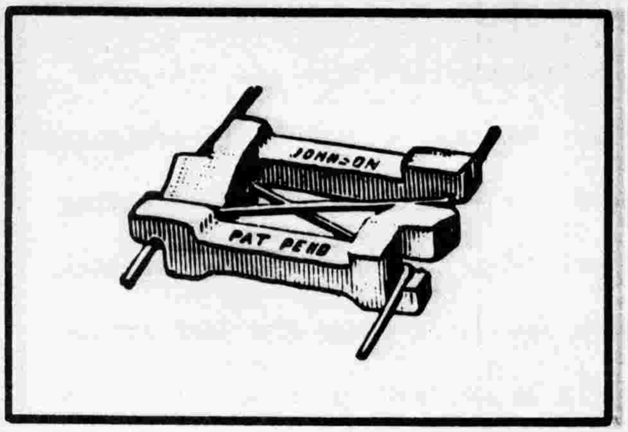

Fig. 15. This special glazed porcelain transposition insulator has been especially designed for open two-wire transmission lines.

Many open wire R.F. transmission lines are held in position by spreaders of the type shown in Fig. 16. Here the insulators are held at right angles to the transmission line wires and the wires run in grooves at each end of the insulator. Then a short length of wire is used in holdiñg the transmission line wire in the groove. These insulators have a 3/8" X 1/2" cross section and are available in lengths of 2", 4" and 6". They are made of high grade, low absorption porcelain and silicone impreganted to repel water.

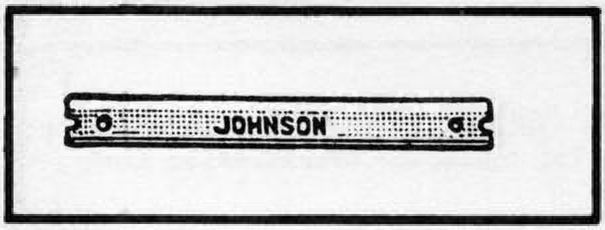

Fig. 16. Special porcelain insulators are provided for the purpose of keeping the parallel transmission line wires separated.

It is common practice to use these special transmission line insulators or spreaders every few feet throughout the entire length of the line. If the line is tuned; that is, has standing waves on it, then they are more closely spaced along the line and a greater number is employed when the spacing is but a few inches.

Open wire transmission lines employing two parallel wires are very efficient and reliable as long as the insulation between them is adequate and in good condition. These lines have somewhat higher terminating impedance, as can be seen in the chart shown in Fig. 17.

Whenever using transmission lines of the concentric or parallel open wire types for receiving or transmitting purposes in commercial installations, every attempt is made to keep the standing wave ratio down to a low value. In other words, the line is properly terminated so that there are practically no losses along the line. There are, however, many applications of the open transmission line and, in particular, for the purpose of transmitting energy to an antenna or for receiving signals from the ends of the antenna. These open wire lines are used extensively by amateur radio operators in feeding radio frequency to the ends of Hertzian antennas.

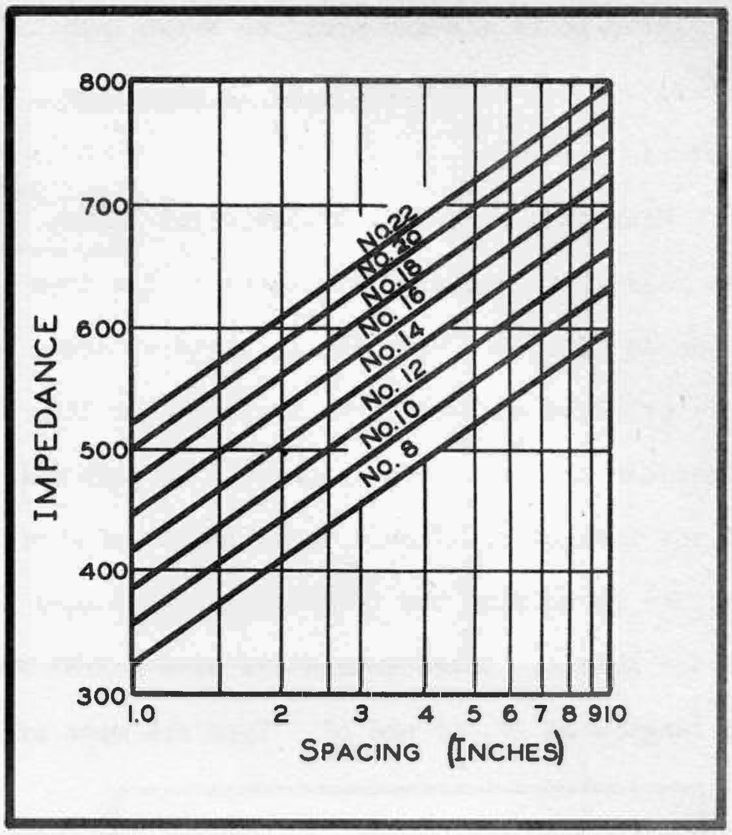

Fig. 17. This chart shows the impedance of parallel conductor transmission lines.

The current and voltage distribution along the length of an open wire quarter-wave transmission line is shown in Fig. 18 when it is is not terminated with equal impedance values. Note that the maximum current is at the transmitter end of the line where the coupling coil is located. The current distribution is identical in both wires of the lines, however, the phase of the voltage is opposite; that is, the end of one wire at one instant is negative while the other is positive. A line of this length may be connected to one end of a half-wave antenna as shown in Fig. 19. Note that the points

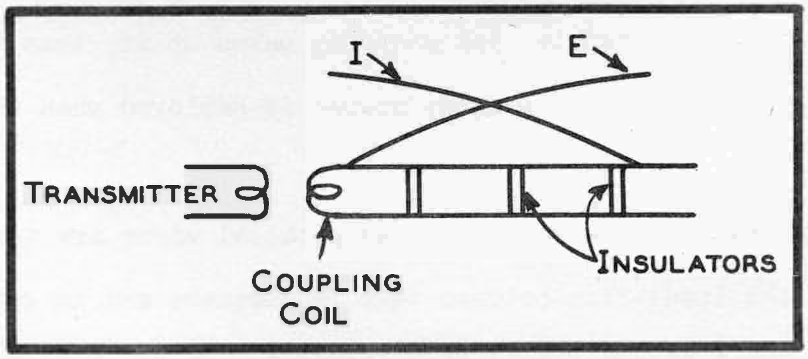

Fig. 18. A quarter-wave open wire transmission showing its current I and voltage E distribution.

of maximum voltage are connected together for an efficient transfer of energy from the transmission line to the antenna. We can also feed high voltage to a full-wave antehna as shown in Fig. 1 because points of maximum voltage are of high impedance.

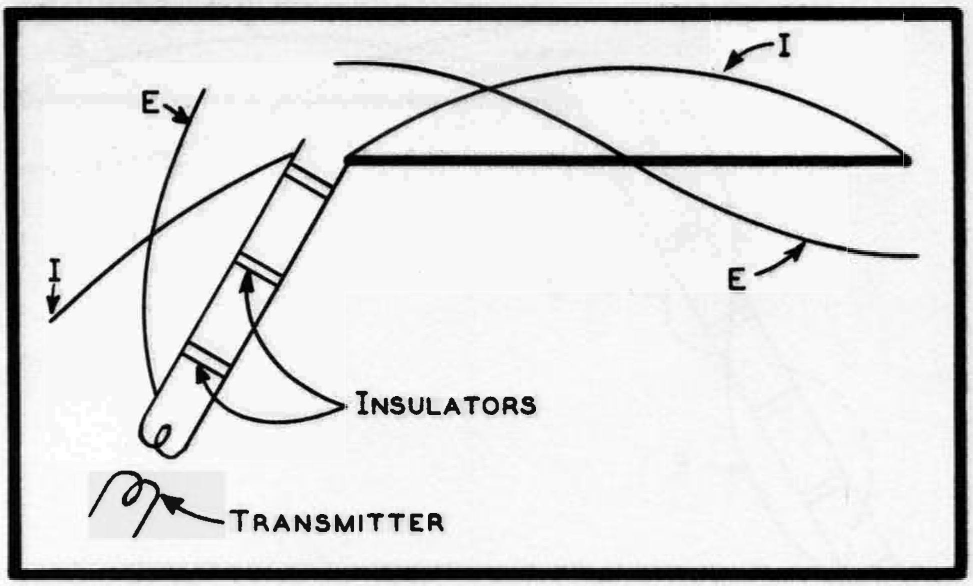

Fig. 19. A quarter-wave tuned transmission line is connected to a half-wave antenna.

Tuned transmission lines must, for efficient operation, be definite multiples of quarter-waves in length. For example: Fig. 20 shows the tuned open wire transmission line which is three quarter-waves in length and connected to feed power to a half-wave antenna. In both the arrangements shown in Fig. 19 and 20, the terminating impedance at the transmitter end of the transmission is the same and of a low value of approximately 30 ohms. The voltage distribution<u>E</u> is shown for the antenna and the transmission line in each case.

You will recall the important characteristic of a half-wave and full-wave antenna; that is, there is always a condition of maximum voltage at the ends of antennas of this length. If we stop to consider, we will find that a half-wave antenna of a specified length for a given fundamental frequency of 3,000 kc. will actually be a full-wave antenna when the transmitting frequency is 6,000 kc. This is represented by the dotted curve, EF2, shown in Fig. 20. Therefore, a Hertzian antenna can be operated on multiple frequencies of the fundamental, however, the transmission line must be fed from a high voltage source because the line was originally three-quarter waves in length. For operation on twice its original frequency (its second harmonic), we must have an odd quarter-wave in the transmission line to give us a low voltage; that is, low impedance coupling at the transmitter end. We could introduce power into the line which is now six quarter-waves in length by connecting the transmitter end of the line to the terminals of a resonant circuit as this would give us maximum voltage. This is why the output impedance of many low powered transmitters is adjustable so that they are capable of supplying power to low and high impedance lines and antennas of different lengths.

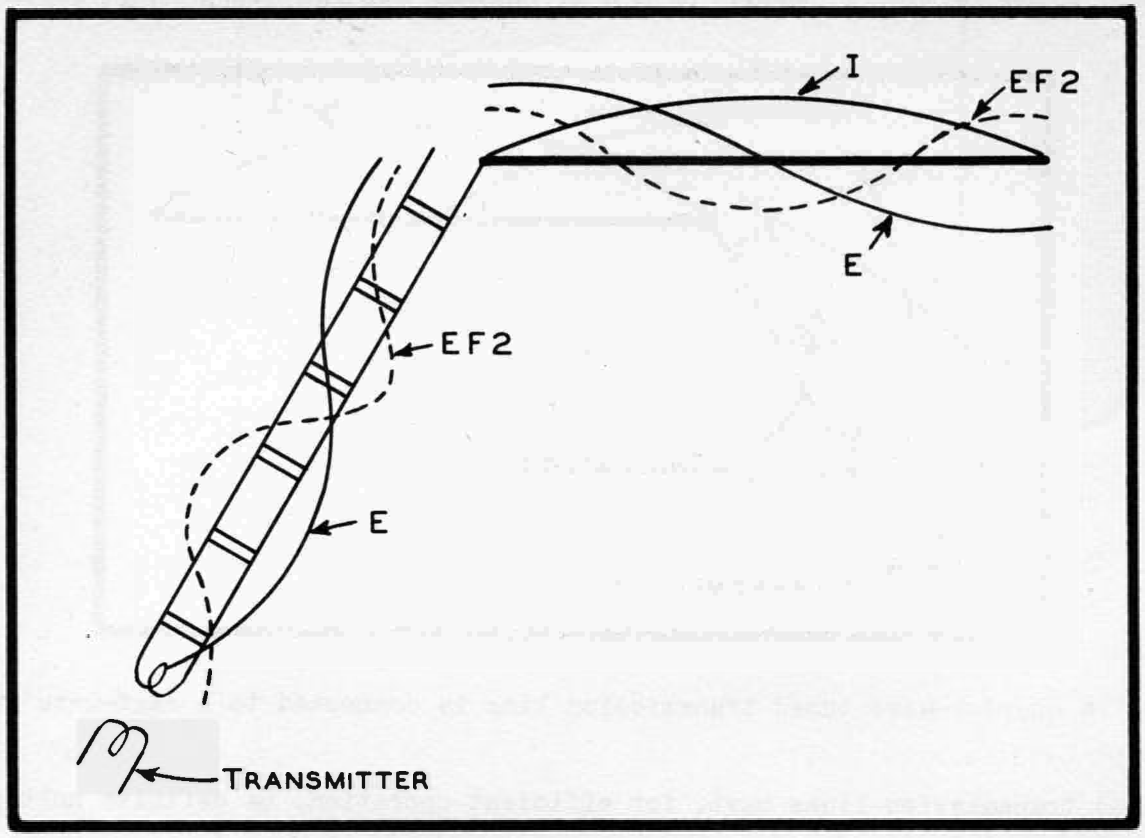

Fig. 20. The voltage distribution is shown for the fundamental frequency and the second harmonic when using a Hertzian antenna.

It is also possible to cause an efficient transfer of R.F. power from an untuned open wire transmission line by connecting the line to the antenna at points which will reflect an equal impedance. This may be done by employing the connections indicated in Fig. 21. Here the end of the transmission line is spread out into the form of a V.

The line insulators are removed a short distance from the antenna, thereby giving a gradual increase in the terminating impedance of the line. When using an untuned line, the current will be essentially the same throughout the parallel sections of the line.

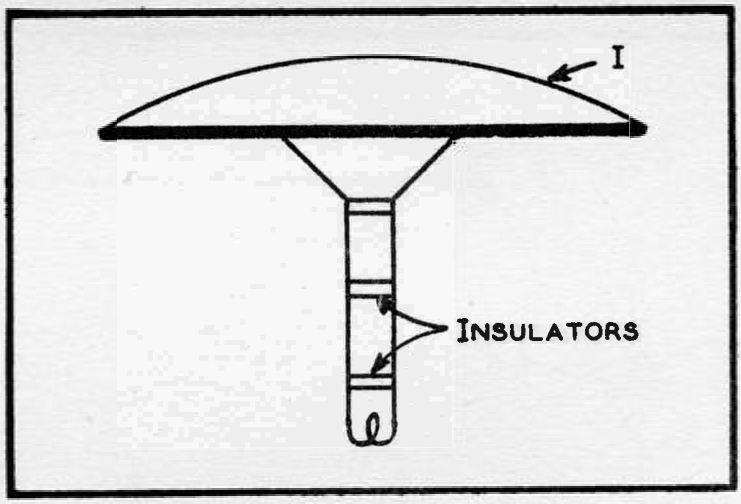

Fig. 21. This is how an untuned line may be coupled to a half-wave antenna for operation on one frequency.

EXAM QUESTIONS ON FOLLOWING PAGE