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CHAPTER I

Introduction

1.1 Introduction. In the communication between two points, antennas are used to transmit and receive modulated carriers which is, in general, linearly polarized wave. The receiving antennas must be placed parallel to the direction of electric field to pick up the modulated carriers. In some cases, such as moving antenna, its orientation sometimes is not parallel to the electric field direction. The antennas are then developed to produce circularly polarized wave which the direction of electric field rotates around the direction of propagation so that receiving antennas can arbitrarily oriented.

1.2 Elliptical Polarization. The plane of polarization, or simply the polarization of radio wave, is defined by the direction in which the electric vector is aligned during the passage of at least one full cycle. In the general case, both the magnitude and the pointing of the electric vector will vary during each cycle and the electric vector will map out an ellipse in the plane normal to the direction of propagation at the point of observation. In this general case the polarization of the wave is said to be elliptical.

It is convenient to consider linear polarization and circular polarization as special case of elliptical polarization. The electric field vectors for a linearly polarized wave are shown in Fig. 1-1a. The magnitude and direction of the electric field E are indicated as a function of distance for a given instant to time. In Fig. 1-1b the wave is viewed from the direction of the positive Z axis (wave

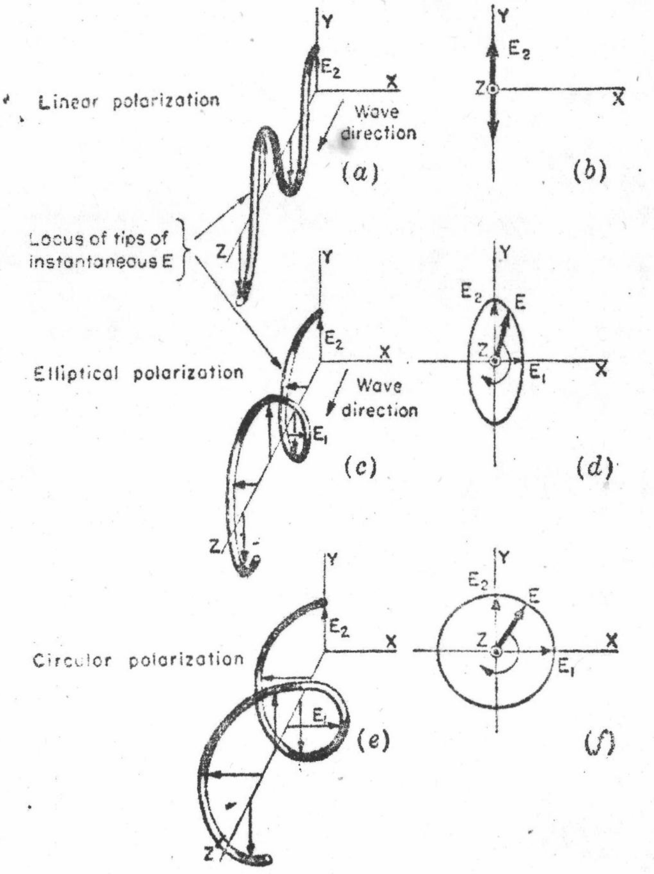

Fig. 1-1 Linear, elliptical and circular polarization.

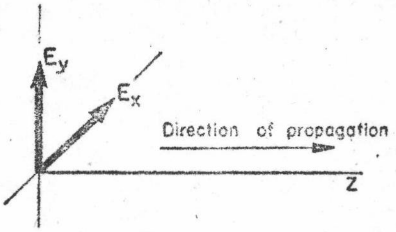

Fig. 1-2 Linearly polarized components of an elliptically polarized wave.

approaching reader). The electric field E varies in magnitude between positive and negative E_2, the direction of E being confined to the Y direction. In Fig. 1-1c the instantaneous space distribution of E is presented for an elliptically polarized wave traveling in the positive Z direction. As viewed from the positive z axis, the tip of the electric field vector E at a fixed positive z describes an ellipse with major and minor semiaxes E_2 and E_1 as shown in Fig. 1-1d. The special case of the linearly polarized wave of Fig. 1-1a and b accurs when $E_1 = 0$. On the other hand, when $E_1 = E_2$ the ellipse becomes a circle and we have another special case of elliptical polarization called circular polarization. The variation of E for a circularly polarized wave is illustrated by Fig. 1-1e and f.

An elliptically polarized wave may be regarded as the resultant of two linearly polarized waves of the same frequency. Assume that both waves are traveling in the positive Z direction and that the plane of polarization of one wave is in the X direction and the other in the Y direction as in Fig. 1-2. If X is horizontal, the wave with E in the X direction may also be called a horizontally polarized wave and the wave with E in the Y direction a vertically pollarized wave.

Let the instantaneous electric field of the horizontally polarized wave be designated E_x and the instantaneous electric field of the vertically polarized wave be designated as E_y. Then as a function of time and distance,

$$E_x = E_1 \sin(wt-\beta z) \qquad (1)$$

and $$E_y = E_2\sin(wt-\beta z+\delta) \tag{2}$$

where E_1 = amplitude of horizontally polarized wave

E_2 = amplitude of vertically polarized wave

δ = time-phase angle by which E_y leads E_x (the horizontally polarized wave is then as the reference for phase)

The component of the field in the z direction is everywhere zero ($E_z=0$). The instantaneous values of the fields may also be expressed as the imaginary (Im) of a complex function. Thus,

$$E_x = I_m\dot{E}_x = E_1 I_m e^{j(wt-\beta z)}$$

$$= E_1\sin(wt-\beta z) \tag{3.a}$$

and $$E_y = E_2\sin(wt-\beta z+\delta) \tag{3.b}$$

where $$\dot{E}_x = E_1 e^{j(wt-\beta z)} \tag{4.a}$$

$$\dot{E}_y = E_2 e^{j(wt-\beta z+\delta)} \tag{4.b}$$

The instantaneous value of the total field E resulting from two linearly polarized wave is

$$E = iE_1\sin(wt-\beta z) + jE_2\sin(wt-\beta z+\delta) \tag{5}$$

At z=0, (5) reduces to

$$E = iE_1\sin wt + jE_2\sin(wt+\delta) \tag{6}$$

Evaluating (6) as a function of time t and plotting the values of the total field E, the time variation of E in the X-Y plane is obtained. In general the tip of the vector E describes a locus that is an ellipse. If $E_1 = E_2$ and $\delta = 90^{\circ}$, the ellipse becomes a circle.

The fact that, in general, the locus is an ellipse may be shown in another way by proving that (1) and (2) with z=0 are the parametric equations of an ellipse. Thus, we have

$$E_x = E_1\ \sin wt \tag{7}$$

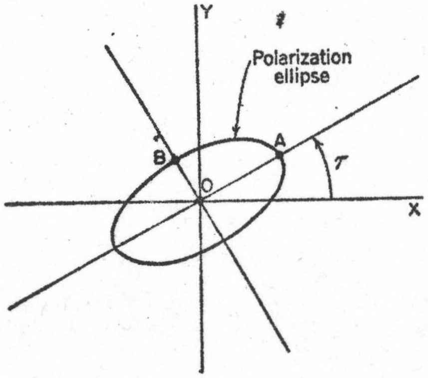

Fig. 1-3 Polarization ellipse.

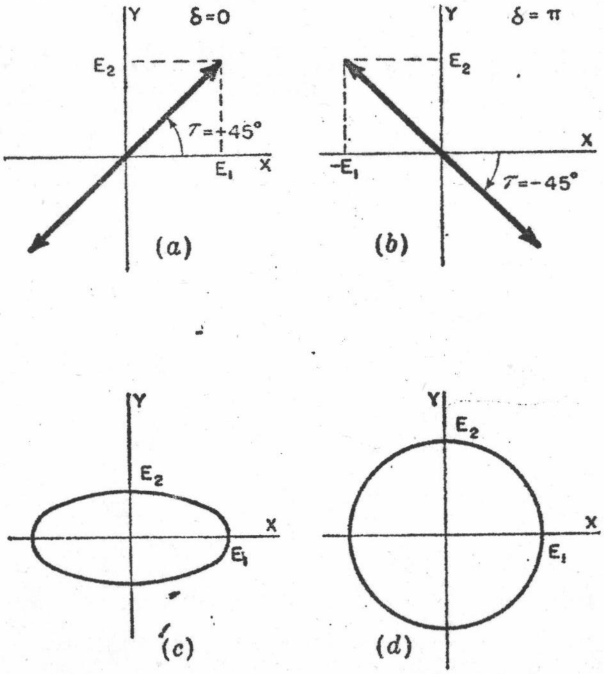

Fig. 1-4 Examples of linearly, elliptically and circularly polarized wave.

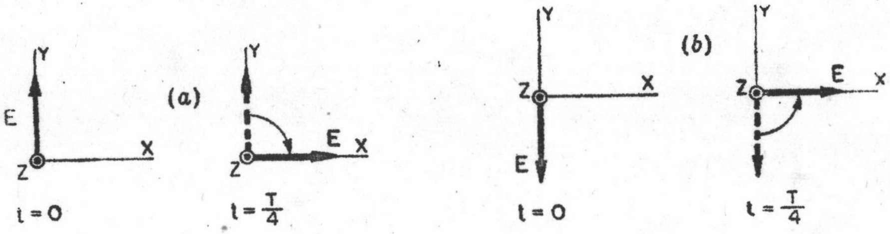

Fig. 1-5 Examples of clockwise rotation of E (a) and counterclockwise rotation (b).

$$E_y = E_2\sin(wt+\delta) \qquad (8)$$

where wt is the independent variable. The procedure used in the proof will be to eliminate wt and rearrange the resulting expression into the form of the equation for an ellipse. First we expand (8). That is,

$$E_y = E_2(\sin wt.\cos\delta + \cos wt.\sin\delta) \qquad (9)$$

From (7)

$$\sin wt = \frac{E_x}{E_1} \qquad (10)$$

We also can write

$$\cos wt = \sqrt{1-\sin^2 wt}$$

$$= \sqrt{1-(E_x/E_1)^2} \qquad (11)$$

Substituting (10) and (11) into (9) and rearranging and squaring yield

$$\frac{E_x^2}{E_1^2} - \frac{2E_xE_y\cos\delta}{E_1E_2} + \frac{E_y^2}{E_2^2} = \sin^2\delta \qquad (12)$$

Dividing by $\sin^2\delta$, (12) can be reduced to

$$aE_x^2 - bE_xE_y + cE_y^2 = 1 \qquad (13)$$

where $a = 1/E_1^2\sin^2\delta$

$b = 2\cos\delta/E_1E_2\sin^2\delta$

$c = 1/E_2^2\sin^2\delta$

Equation (13) may be recognized as the equation for an ellipse in its most general form, the axes of the polarization ellipse not, in general, co-inciding with the X and Y axes (Fig. 1-3). This is the general case of elliptical polarization. The segment OA is the semimajor axis, and the line segment OB is the semiminor axis of the ellipse. The ratio OA to OB is called the axial ratio(AR) of the polarization ellipse or simply the axial ratio. Thus,

$$\text{Axial ratio} = \frac{OA}{OB}$$

Returning now to (12), three special cases will be considered.

Case 1 The E_y is either exactly in phase or 180° out of phase with E_x. Then $\delta = k\pi$, where $k=0,1,2,\ldots$ and equation(12) then reduces to

$$E_y = \frac{\pm E_2 E_x}{E_1} \tag{14}$$

Thus, when the two linearly polarized component waves are exactly in phase or 180° out of phase, the resultant in linearly polarized with E, in general, not in x or y direction.

Case 2 Next consider the situation where E_x and E_y are in time phase quadrature. That is,

$$\delta = \frac{1+2k}{2}\pi \tag{15}$$

where $k=0,1,2,\ldots\ldots$

Then the cross product term in (12) disappears and (12) reduces to

$$\frac{E_x^2}{E_1^2} + \frac{E_y^2}{E_2^2} = 1 \tag{16}$$

That is an ellipse with its axes coincident with the coordinate axes. This is a special case of elliptical polarization.

Case 3 Finally consider Case 2 for the special condition of $E_1=E_2$. Then (16) becomes

$$E_x^2 + E_y^2 = E_1^2 \tag{17}$$

This is the equationoof circle. Hence, when the two linearly polarized waves are in time phase quadrature and also are equal in amplitude, the resultant wave is circularly polarized. According to (17) the locus of the tip of the vector E is a circle. That is, at a fixed position on the Z-axis theresultant electric field vector E is constant in magnitude and rotates uniformly with time in the X-Y plane completing one revolution each cycle. To determine the revolution direction, let us rewrite (7) and (8) for the special case we are considering, namely,

$$\delta = \frac{1+2k}{2}\pi \qquad \text{and } E_1 = E_2$$

where k = 0,1,2,......

Then, when k is even

$$E_x = +E_1 \sin wt \tag{18}$$

$$E_y = +E_1 \cos wt \tag{19}$$

and when k is odd E_x is the same but

$$E_y = -E_1 \cos wt \tag{20}$$

Consider first the case where k is even ($\delta = \frac{\pi}{2}, \frac{5\pi}{2}$ ... etc). When t=o, E_x=o, and E_y=+E_1 so that E is in the positive Y direction. One quarter of a cycle later E_x=+E_1 and E_y=o so that E is in the positive x direction. Hence, at a fixed position on the Z axis the resultant electric field vector E rotates in a clockwise direction as illustrated in Fig. 1-5a. Next consider the case for k odd($\delta = \frac{3}{2}\pi$, $\frac{7}{2}\pi$ etc.) when t=o, E_x=o and E_y=-E_1 so that E is in the negative Y direction. One quater cycle later E_x=+E_1 and E_y=o so that E is in the positive X direction. Hence at a fixed position on the Z axis the resultant electric field vector E rotates in counterclockwise direction as illustrated in Fig. 1-5b. The wave is traveling in the positive Z direction(out of page) in both this case and the one illustrated by Fig. 1-5a. To avoid any uncertainty as to the wave direction, we can call the first case "clockwise circular polarization wave approaching" and the second case "counterclockwise circular polarization wave approaching".

1.3 Circular Polarization.

1.3.1 **Combinations of electric and magnetic antennas** Circular polarization can be achieved by a combination of electric and magnetic antennas provided that the field produced by these antennas are equal in magnetude and in time phase quadrature. A simple case of this combination is a horizontal loop and a vertical dipole. The time phase quadrature relationship is a fundamental relationship between the field of the loop and dipole when their currents are in phase. If the loop and dipole are oriented as in Fig. 1-6, the field in the plane of the loop are given by

$$E_l = jCJ_1(ka)e^{j(wt-kr)} \qquad (21)$$

$$E_d = C_1e^{j(wt-kr)} \qquad (22)$$

where C and C_1 = constants

$k = 2\pi/\lambda$

λ = free-space wavelength

a = radius of loop

r = distance from center of loop

J_1 = Bessel function of the first order

provided that the currents in the loop and dipole are in phase. Thus, if

$$CJ_1(ka) = C_1 \tag{23}$$

the resulting field of the combination will be circularly polarized. Equation(23) will be true if the loop diameter is less than about 0.6 wavelength and the dipole length is less than a half wavelength. In this particlar combination it should be noted that the resulting radiation pattern is circularly polarized at all points since the individual pattern of the and dipole are essentially the same. However, in practice this is difficult to obtain, except over narrow bandwidths, because of the different impedance characteristics of the loop and dipole.

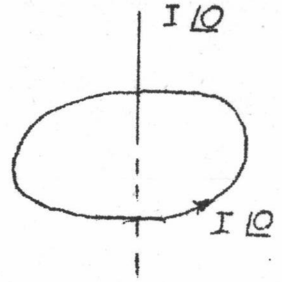

Fig. 1-6 Horizontal loop and vertical dipole

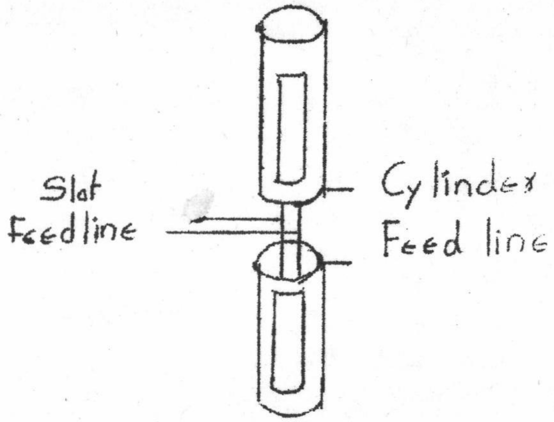

Fig. 1-7 Slotted-cylinder circularly polarized antenna.

A second combination is that shown in Fig. 1-7, consisting of two vertical one-half wavelength-long cylinders in which vertical slots are cut. Feeding the two vertical cylinders will give a vertically polarized omnidirectional pattern in the plane normal to the axis of the cylinders, while feeding the two slots will give a horizontally polarized pattern in thesame plane. If the power to both feeding arrangements is adjusted to be equal and the phase adjusted by controlling thellength of the feed line such that the two are in time-phase quadrature, the resulting pattern will be circularly polarized.

The normal radiation(broadside) mode of a helix can also be considered as a combination of electric and magnetic antennas(dipole and loops) producing circular polarization.

A pair of crossed slots in the broad wall of a rectangular wave guide in which the field configurations in the waveguide are such that that one slot is in time-phase quadrature with the other can also be considered as a combination of electric and magnetic antennas producing circular polarization. This combination will be discussed in more detail in the following section.

1.3.2 <u>Combinations of similar antennas</u> Two or more antennas when properly oriented in either time phase or space phase or a combination of both may be used to give a circularly polarized radiation

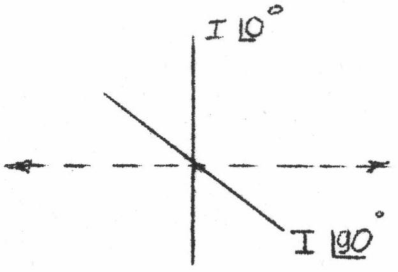

Fig. 1-8 Crossed dipoles current in phase quadrature.

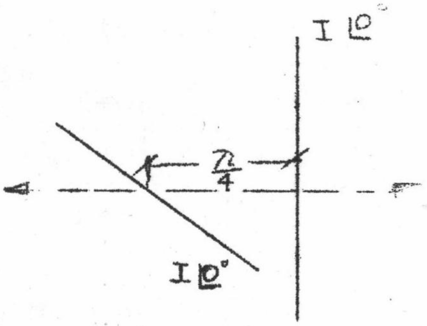

Fig. 1-9 Crossed dipoles current in phase $\lambda/4$ separation.

field. A simple case is a pair of crossed half-wavelength dipoles. In Fig 1-8 circular polarization is obtained by having the equal currents in the dipoles in phase quadrature. Radiation in one direction is right circularly polarized and left circularly polarized in the opposite direction. If the pair of crossed dipoles are fed

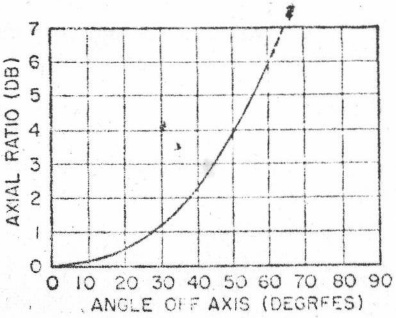

Fig. 1-10 Deviation of circularity as a function of off-axis angle for a pair of crossed dipoles

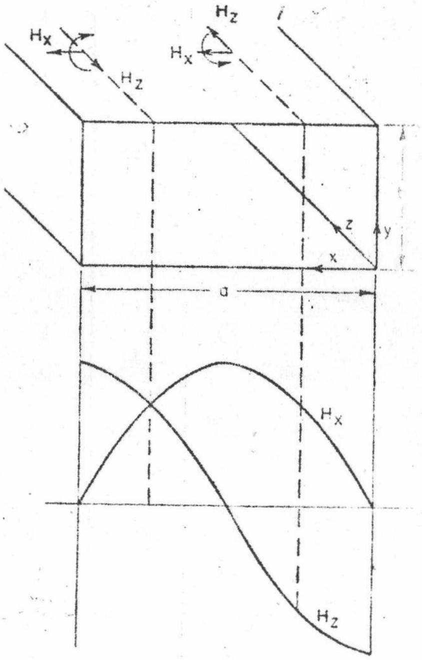

Fig. 1-11 Field configuration, TE_{10} mode.

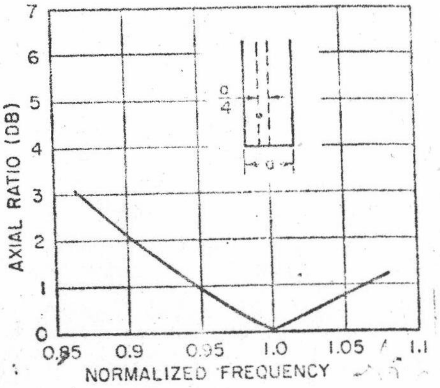

Fig. 1-12 Theoretical axial ratio for x=a/4

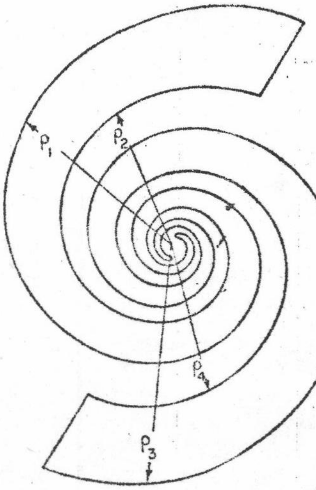

Fig. 1-13 Equiangular spiral.

in phase and separated in space by a quater wavelength as shown in Fig. 1-9, circular polarization is again produced: In both of these combinations the resulting field is circularly polarized only on axis. The deviation in circularity as a function of the off-axis angle is plotted in Fig. 1-10. Another case of a simple combination of similar antennas to produce circular polarization is a pair of narrow slots at right angles and located at the proper point in the broad wall of a rectangular wave-guide. This may be explained by noting that the equations for transverse and longitudinal magnetic fields of the dominant(TE_{10})mode in rectangular waveguide(Fig. 1-11)are

$$H_x = H_o\sqrt{1-(\frac{\lambda}{2a})^2}\ \sin\frac{\pi x}{a} \tag{24}$$

$$H_z = -jH_o\frac{\lambda}{2a}\ \cos\frac{\pi x}{a} \tag{25}$$

From these two equations it may be seen that the fields are in phae quadrature and there are two values of x at which $H_x = H_z$. These v values of x are given by

$$x = \frac{a}{\pi}\text{ctn}^{-1}\left[\pm\sqrt{(\frac{2a}{})^2-1}\right] \tag{26}$$

Two crossed slots at either of these points will then radiate circularly polarized energy. The orientation of the slots is arbitrary, and they may be made resonant and thus radiate a large amount of power. The theorectical axial ratio for x=a/4 is shown in Fig. 1-12, which give circular polarization at a frequency for which $\pi=2a/\sqrt{2}$.

The equiangular spiral, which is one of a class of frequency-independent antennas, where the antenna is completely defined by angles, is another case of a combination of similar antennas which produce circular polarization. If a conductor with edges defined by the two curves

$$\rho_1 = ke^{a\theta} \qquad (27)$$

and

$$\rho_2 = ke^{a(\theta-\delta)} \qquad (28)$$

is cimbined with a second conductor defined by the two curves

$$\rho_3 = ke^{a(\theta-\pi)} \qquad (29)$$

and

$$\rho_4 = ke^{a(\theta-\pi-\delta)} \qquad (30)$$

(which simply is the first conductor with a 180° rotation), the result is the balanced antenna of infinite length. In practice, the antenna will be finite in size and therefore limited in operation as a function of frequency. Fig. 1-13 shows a practical antenna.

If the arm lengthis longer than approximately one wavelength, the field on the axis perpendicular to the plane of the antenna will be circularly polarized. Pattern bandwidths of better than 20:1 have been measured with this type of antenna with correspondingly good impedance bandwidths,

An omnidirectional circularly polarized antenna can be obtained by four in phase half wavelength dipoles arrayed in a circle of about one-third wavelength in diameter and inclined to the horizontal as shown in Fig. 1-14. The axial ratio in the horizontal plane for this configuration is less than 1db.

The same general type of pattern can also be obtained by using an array of inclined slots on a cylinder feeding a biconical horn(Fig. 1-15). In this case the slant length of the biconical horn is adjusted to give a time phase quadrature relationship between the two modes of propagation for horizontal and vertical polarization. There is no simple theorectical relationship that enables one to specify

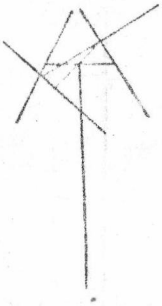

Fig. 1-14 Four-dipoles ommidirectional circularly polarized antenna.

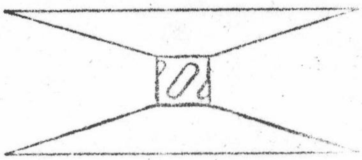

Fig. 1-15 Circularly polarized biconical.

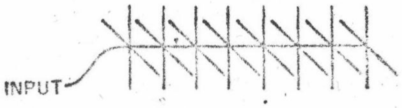

Fig. 1-16 Circularly polarized Yagi.

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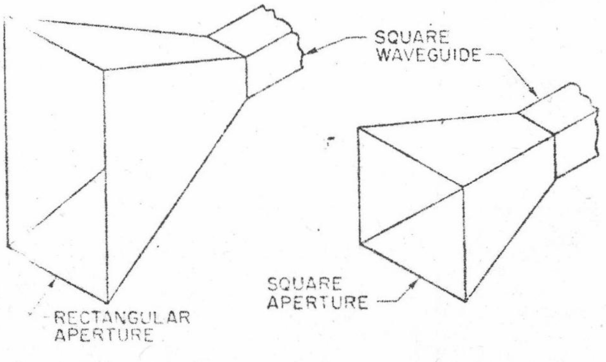


ASYMMETRICAL HORN

SYMMETRICAL HORN

Fig. 1-17 Examples of symmetrical and asymmetrical dual-mode horns.

the slant length to give circular polarization, and it is best done on an experimental basis.

The combination of crossed half wavelength dipoles can be used to feed a crossed Yagi structure to give a directional circularly polarized beam as suggested in Fig. 1-16.

Directional beam can, in general, be produced by using any of the basic combinations in arrays.

1.3.3 Dual mode horn radiators A conventional waveguide horn may be used for the radiation and beaming of circularly polarized waves, provided that it is fed with waveguide capable of propagating vertically and horizontally polarized wave simultaneously. The horn may be either symmetrical or asymmetrical, that is, square(round) or rectangular(elliptical). Fig. 1-17 illustrates the two types.

Symmetrical case. A circularly polarized field will be obtained on the peak of the radiation pattern when the horn is fed through the square waveguide with equal amplitude vertically and horizontally polarized modes arranged to be in quadrature. The radiated field will not, in general, be circularlypolarized at other points on the radiation pattern because the vertically and horizontally polarized radiation patterns will be different beamwidths in almost any particular plane of interest. Such is the case because the horizontal dimension(for example) of the aperture is an E-plane dimension for the horizontally polarized field and an H-plane dimension for the vertically polarized field. Fig. 1-18 illustrates a typical variation in ellipticity as a function of position on the radiation pattern.

Asymmetrical case. The previous discussion is also applicable to asymmetrical horn, except that circularly polarized fields on the peak of the radiation pattern will not be obtained unless allowance is made for the difference in phase velocity of the vertically and horizontally polarized waves within the asymmetrical horn flare. This differential phase shift may attain quite large values in some horns. For example, a measured differential phase shift of about 220° has been observed at 2,800 Mc in a horn having a flare length of about 14 in., a width of 2.84 in., and a hight of 7.8 in.

The magnetude of differential phase shift can be computed to an accuracy of perhaps 10 per cent by evaluating the integral

$$\text{Differential phase shift} = \int_0^L [\beta(l)_{V\,pol} - \beta(l)_{H\,pol}]\, dl.$$

in which L is the flared length of the horn, and is based simply on the appropriate width of the flare andthe operating wavelength. Fig. 1-19 shows the information in detail. Note that the differential phase shift may vary fairly rapidly with frequency. In the example mentioned above, the differential phase shift increased about 15° for every 100 Mc decrease in frequency between 2,900 and 2,700Mc

1.3.4 Transmission type polarizers. Transmission polarizers are designed to take existing linearly polarized energy and transform it in to circularly polarized energy. The advantage of such polarizers is that their design is relatively independent of the characteristics of the source of the wave on which they operate. The disadvantage is that this type of polarizer tends to be quite large physically and difficult to modify or adjust.

A transmission-type polarizer is a strucrure that exhibits a differential phase shift to two mutually perpendicular electric vector

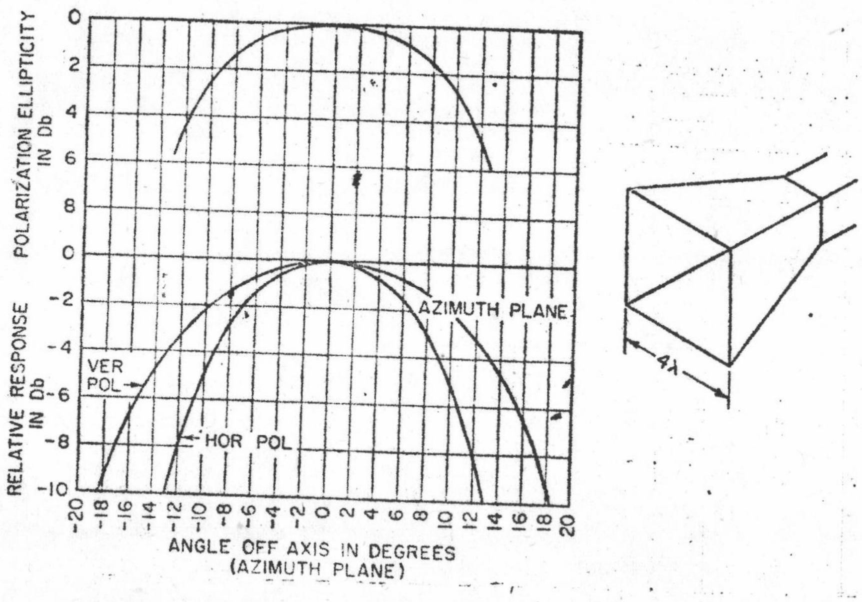
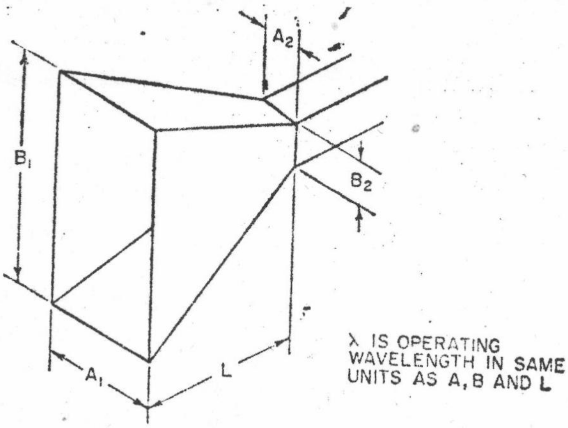


Fig. 1-18 Typical variation in polarization ellipticity.



λ IS OPERATING WAVELENGTH IN SAME UNITS AS A, B AND L

$$\Delta = \frac{2\pi}{\lambda}\int_0^L\left\{\sqrt{1-\frac{\frac{1}{2}\lambda}{A_2+\frac{A_1-A_2}{L}\ell}}-\sqrt{1-\frac{\frac{1}{2}\lambda}{B_2+\frac{B_1-B_2}{L}\ell}}\right\}d\ell\cdot$$

Δ IS DIFFERENTIAL PHASE SHIFT IN RADIANS

Fig. 1-19 Method of determining Differential phase shift in a horn.

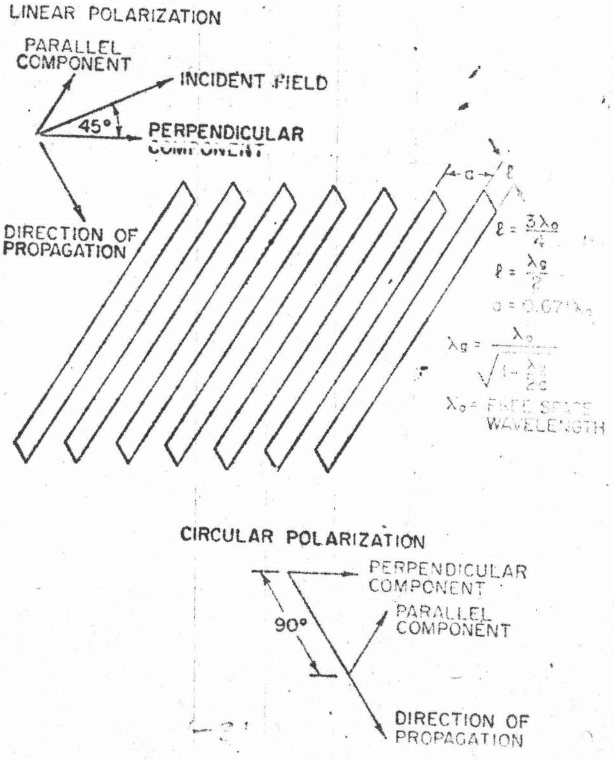


Fig. 1-21 Parallel-plate polarizer.

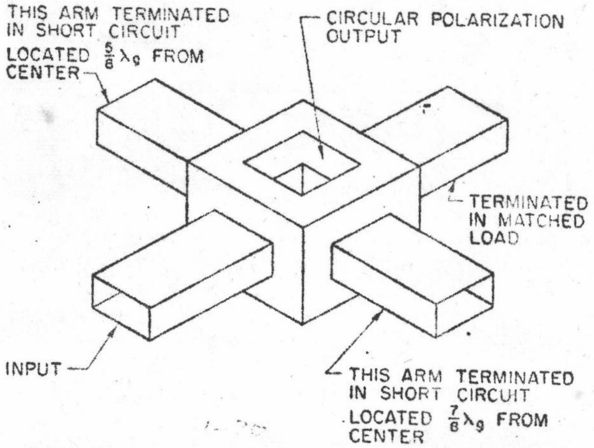


Fig. 1-20 Turnstile junction.

This differential phase shift is then adjusted to be 90°, and assuming the two perpendicular vectors are equal in magnetude, circular polarization results.

The simplest type of polarizer is a parallel metal plate structure Fig. 1-21. In this structure, the incident linearly polarized energy is incident at an angle of 45° to the plane of the metal plates, so that there are two equal field componemts, one parallel to the plates and one perpendicular to the plates. The component perpendicular to the plates will pass through the structure undisturbed, while the c component parallel to the plates will see a parallel-plate waveguide structure, and hence a phase shift relativeto free-space propagation. If the spacing and the length of the plates are adjusted so that the field parallel to the plates is advanced $\lambda/4$(90°)in phase with respect to the field perpendicular to the plates, the two field at the exit of the plates are now in space-and-time quadrature, and hence result in a circularly polarized wave. This structure is commonly referred to as a "quarter-wave plate."

The parallel plate structure is an anisotropic dielectric, with a dielectric constant less than unity. Any anisotropic dielectric,regardless of dielectric constant, will act as a transmission-type polarizer, provided that the amplitude and phase requirements are met.

1.3.5 <u>Reflection type polarizers</u>. Reflection type polarizers are essentially transmission-type polarizers cut in half and placed on a conducting sheet.

The simplest type of reflection-type polarizer is a series of metal vanes on a conducting sheet. These vanes are one-eighth-wavelength

[illegible] the energy is polarized at 45° to the vanes, so that high. The incident energy is polarized at 45° to the vanes, so that the component parallel to the vanes is reflected by edges of the vanes and the component perpendicular to the vanes is reflected by the conducting sheet, this delaying it 90° with respect to the parallel component and producing circular polarization.

Another method of obtaining circular polarization utilizes the difference in phase between the perpendicular and parallel components, when total reflected from the surface of a lossless dielectric. This occurs if the dielectric constant e is greater than 5.8. The angle θ_o at which this occurs is given by $\sin^2\theta_o=2/(e+1)$.

1.3 Scope of Study.

1.3.1 To make a theoretical research by means of approaching things e.g. image antenna etc.

1.3.2 To analyse to find out the function of polarization in terms of variations concerned.

1.3.3 To make an experiment in testing the theoretical result.

1.3.4 To compare of experimented and theoretical to see and discuss the differences.