A New Type of Circular Polarizer Using Crossed Dipoles*

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Summary—A method of obtaining a circularly-polarized wave by use of two orthogonal dipoles driven in parallel by a common transmission line is shown. The lengths of the dipoles are so chosen that the real part of their input admittances are equal and the angle of the input admittances differ by 90°. When these two conditions are met the resulting radiated wave in a normal direction will be circularly polarized.

The method is applicable both to a circularly-polarized radiating antenna and to the problem of producing a circularly-polarized wave of the TE_{1} mode in a round waveguide. For the first case, an analysis and a method of design are shown, and for the second case an experimentally developed example is given. The second case employs monopoles rather than dipoles for convenience in energizing from a coaxial line.

Introduction

It has been common practice to produce circular polarization using crossed dipoles.[1] Previous methods have used identical resonant (approximately a half wavelength long) dipoles in each plane, and the proper power and phase relationships in the dipoles were obtained by use of an input phasing and matching network so as to drive the two dipoles from a common generator.

The method presented here uses two unequal length dipoles connected in parallel to a common generator and requires no matching network. The required power and phase relationships are obtained by proper choice of the two dipole lengths. For the first case (dipoles in free space), the lengths are calculable; for the second case (monopoles in waveguide), the lengths must be determined experimentally.

Condition for Circular Polarization

In Fig. 1 are shown two orthogonal cylindrical dipoles fed in parallel and a representative equivalent circuit. The mutual interaction between the two dipoles should be negligible as long as their lengths are much greater than their radii and each dipole is placed in the neutral (or zero) potential plane of the other dipole (as is shown on Fig. 1).

The calculated input admittance of a single dipole as a function of its length is shown in Fig. 2 for lengths in the neighborhood of a half wavelength. These values of admittance are second-order calculated values as given by King[2] for

$$\frac{h_x}{a_x} = \frac{h_y}{a_y} = 75.2.$$

In general, the two dipoles will produce an elliptically-polarized wave. In order to have a circularly-polarized wave, there must be equal power input to each dipole and 90° phase difference between the input currents. This is equivalent to having $G_x = G_y$ and arg $\overline{Y}_x$ = arg $\overline{Y}_y \pm 90°$ (where $\overline{Y}_x = G_x + JB_x \overline{Y}_y = G_y + JB_y$). This condition can be determined from an accurate plot of dipole admittance by a graphical solution as shown in Fig. 2.

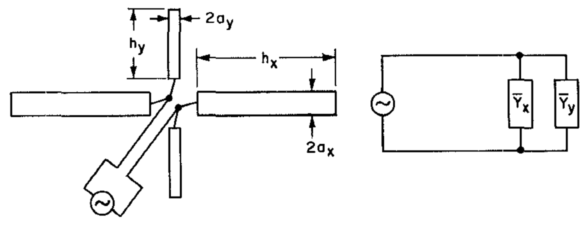

Fig. 1—Arrangement of dipoles and equivalent circuit.

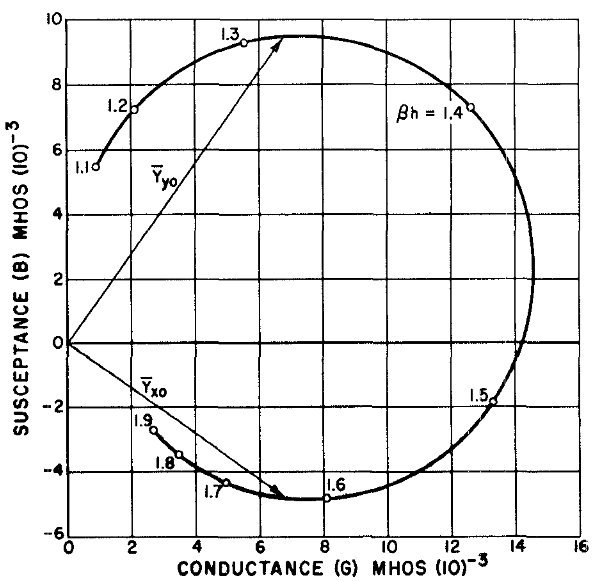

Fig. 2—Dipole input admittance.

* Received by the PGMTT, April 16, 1961.
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[1] G. H. Brown, "The turnstile antenna," *Electronics*, vol. 9, pp. 14–17; April, 1936.
[2] R. W. P. King, "The Theory of Linear Antennas," The Harvard University Press, Cambridge, Mass., p. 172; 1956.

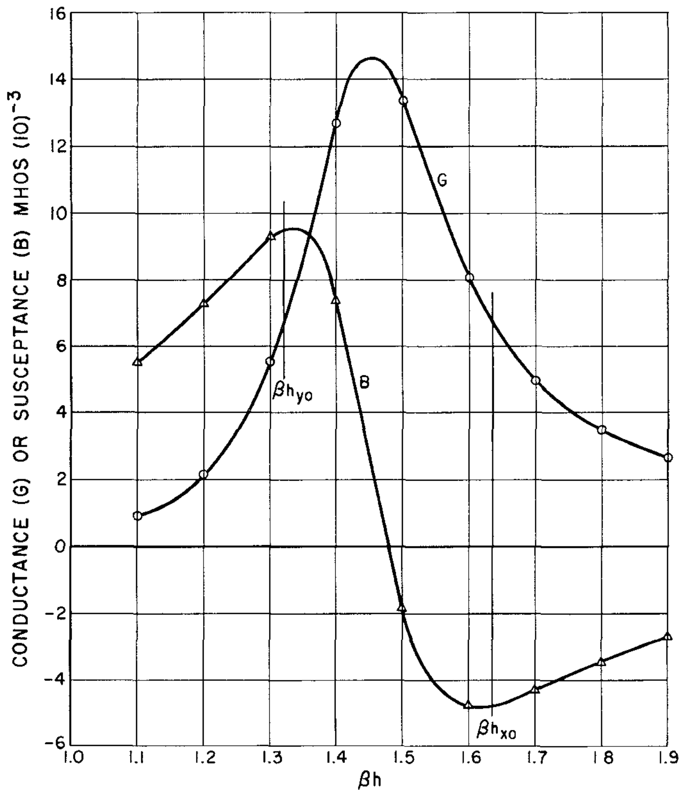

Fig. 3—Real and imaginary parts of dipole admittance.

If the admittance locus were extended to show longer dipole lengths, it would be evident that there are many other combinations of (longer) lengths that would also produce circular polarization.

Variations with Frequency

When the frequency of the driving signal is changed the radiated wave will become elliptically rather than circularly polarized. To determine how the input admittance and ellipticity varies as a function of frequency, it is convenient to replot the real and imaginary parts of the admittance in Fig. 2 as functions of $\beta h = (2\pi/\lambda)h$ as shown in Fig. 3.

From Fig. 3 the two dipole admittances $\overline{Y}_x = G_x + jB_x$ and $\overline{Y}_y = G_y + jB_y$ can be obtained graphically as functions of frequency by simply reading values of $\beta h_x = \beta_0 h_x(f/f_0)$ and $\beta h_y = \beta_0 h_y(f/f_0)$, where f_0 is frequency at which circular polarization occurs. Performing this operation over a frequency range of $f = f_0 \pm 15$ per cent the values of G and B shown in Fig. 4 are obtained.

The total input admittance $\overline{Y}_i = G_i + jB_i = \overline{Y}_x + \overline{Y}_y$ is shown as a function of frequency in Fig. 5.

Polarization Ellipse of Radiated Wave

From the data of Fig. 4 the polarization ellipse of the radiated wave can be calculated. The power in the x or y component waves will be proportional to G_x or G_y, and the amplitude of the component electric fields $\overline{E}_x$ or $\overline{E}_y$ will be proportional to $\sqrt{G_x}$ or $\sqrt{G_y}$. Other nomenclature concerning the polarization ellipse shown in Fig. 6 is defined as follows:

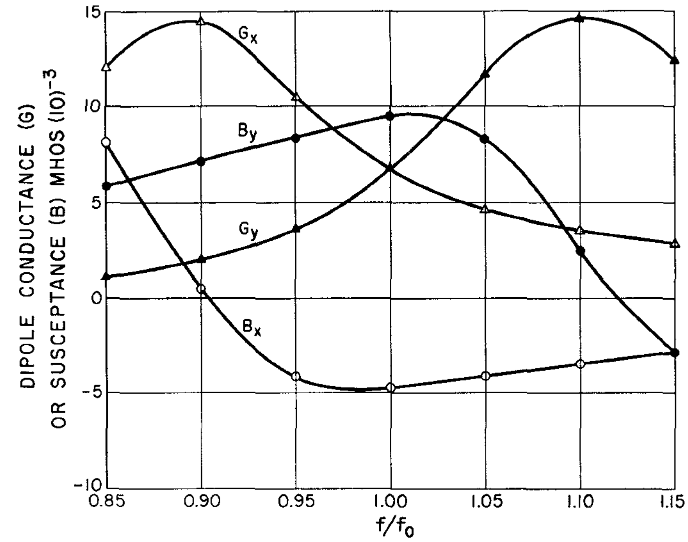

Fig. 4—Input admittance of individual dipoles as a function of frequency.

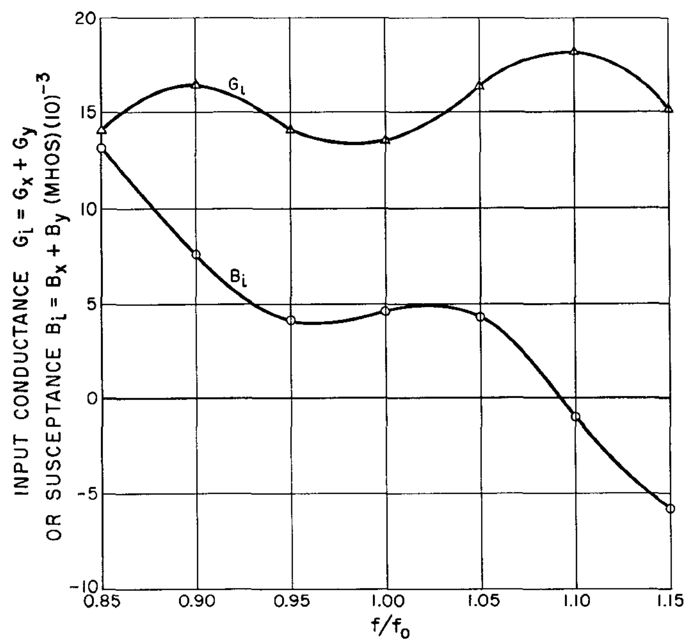

Fig. 5—Input admittance of dipoles connected in parallel.

E_x = electric field component in x (dipole) direction
E_y = electric field component in y (dipole) direction
E_x' = electric field component in x' direction
E_y' = electric field component in y' direction
τ = polar angle between xy and $x'y'$ frames
τ_0 = polar angle between dipoles and principal axis of polarization ellipse
$A_x = \sqrt{G_x}$ = amplitude of electric field component in x (dipole) direction
$A_y = \sqrt{G_y}$ = amplitude of electric field component in y (dipole) direction
$R = A_y/A_x$

δ_x = phase of electric field component in x (dipole) direction

δ_y = phase of electric field component in y (dipole) direction.

The field in the x' direction will be

$$E_x' = E_x \cos \tau + E_y \sin \tau, \qquad (1)$$

where

$$E_x = A_x \cos (\omega t + \delta_x) \quad \text{and} \quad E_y = A_y \cos (\omega t + \delta_y). \qquad (2)$$

This can be written

$$E_x' = A_x' \cos (\omega t + \delta_x'), \qquad (3)$$

where

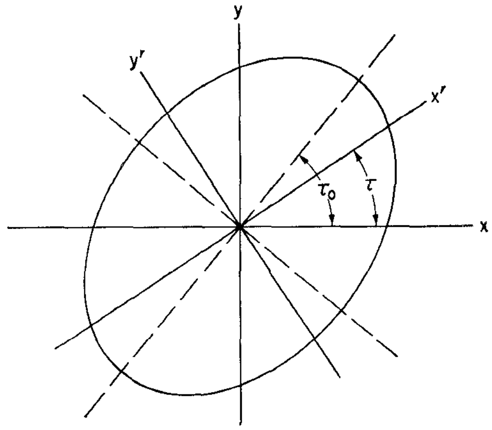

Fig. 6—Polarization ellipse.

$$A_x' = \sqrt{(A_x \cos \delta_x \cos \tau + A_y \cos \delta_y \sin \tau)^2 + (A_x \sin \delta_x \cos \tau + A_y \sin \delta_y \sin \tau)^2}, \qquad (4)$$

and

$$\delta_x' = \tan^{-1} \frac{A_x \sin \delta_x \cos \tau + A_y \sin \delta_y \sin \tau}{A_x \cos \delta_x \cos \tau + A_y \cos \delta_y \sin \tau}. \qquad (5)$$

The angle τ_0 between the x dipole and the principal axis of the polarization ellipse is obtained by differentiating A_x' with respect to x, setting the result equal to zero, and solving for $\tau = \tau_0$. Carrying out these operations and simplifying the result yields

$$\tau_0 = 1/2 \tan^{-1} \frac{2R \cos \delta}{1 - R^2}, \qquad (6)$$

where

$$R = A_y/A_x \quad \text{and} \quad \delta = \delta_y - \delta_x. \qquad (7)$$

This is the same formula which Born[3] obtained by a different method.

The axial ratio of the polarization ellipse is defined as

$$R_0' = \frac{A_y'}{A_x'} \Big/_{\tau=\tau_0}, \qquad (8)$$

where A_x' is given by (4), and A_y' is obtained in similar manner from

$$E_y' = - E_x \sin \tau + E_y \cos \tau = A_y' \cos (\omega t + \delta_y') \qquad (9)$$

$$A_y' = \sqrt{(- A_x \cos \delta_x \sin \tau + A_y \cos \delta_y \cos \tau)^2 + (- A_x \sin \delta_x \sin \tau + A_y \sin \delta_y \cos \tau)^2}. \qquad (10)$$

After some simplification, one obtains

$$R_0'^2 = -1 + \frac{1 + R^2}{\cos^2 \tau_0 + R^2 \sin^2 \tau_0 + 2R \cos \tau_0 \sin \tau_0 \cos \delta}. \qquad (11)$$

[3] Max Born, "Optik," Verlag Julius Springer, Berlin, Germany, p. 23; 1933.

The axial ratio is obtained from this equation when

$$1/2 \tan^{-1} \frac{2R \cos \delta}{1 - R^2}$$

is substituted for τ_0. This calculation was performed using the data of Fig. 4 and gave the axial ratio (in db) and orientation of the polarization ellipse shown in Fig. 7 over the 30 per cent band.

If the signs of $\cos \delta$ and $1 - R^2$ in (6) are considered, then the angle τ_0 would have to be in the second quadrant for values of $f > f_0$; however, due to the symmetry of the polarization ellipse, plotting τ_0 in the fourth quadrant as shown will cause no error in describing the ellipse.

The shape of the curve for τ_0 shown in Fig. 7 in the region of $f = f_0$ would probably not be duplicated in measurements on an actual antenna. It is unlikely that there would be any cusp at this point. The cusp probably appears in the calculated values because small deviations in the input values of R and δ in the neighborhood of $f = f_0$ result in relatively large changes in the calculated values of τ_0 due to the indeterminate form of (6).

$$\lim_{\substack{R \to 1 \\ \delta \to 90^\circ}} \left[\frac{\cos \delta}{1 - R^2} \right] \to \frac{0}{0} \to 0. \qquad (12)$$

The order of the zero of $\cos \delta$ is greater than that of $1 - R^2$ when R and δ are considered as functions of frequency.

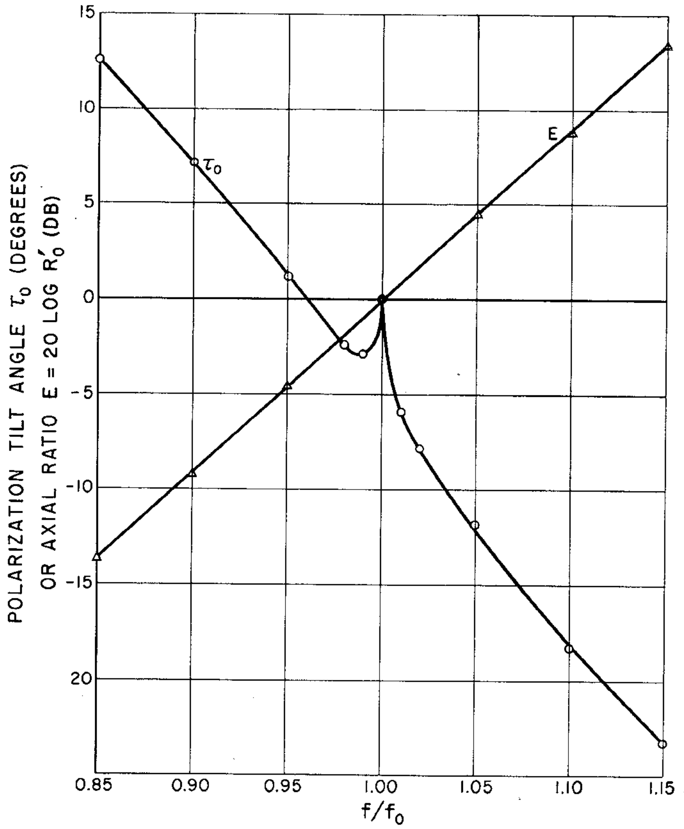

Fig. 7—Axial ratio and tilt angle of polarization ellipse.

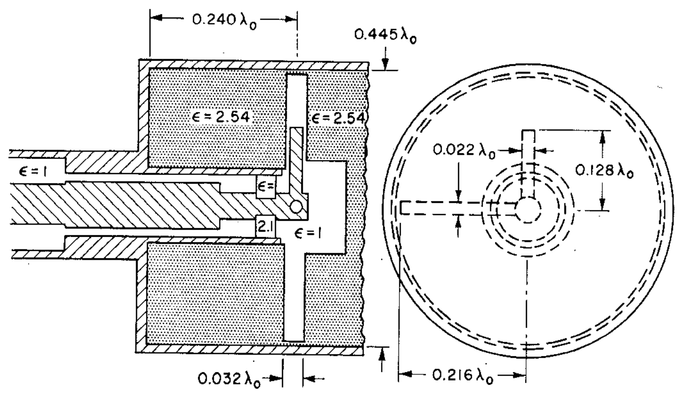

Fig. 8—Circular polarizer in dielectric-filled round waveguide with input matching transformer.

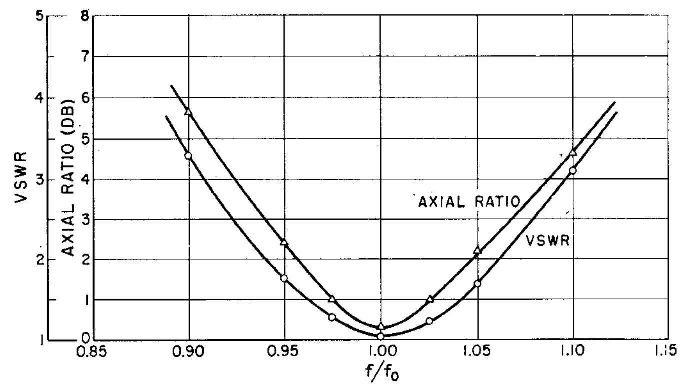

Fig. 9—VSWR and axial ratio of polarizer in dielectric-filled round waveguide with input matching transformer.

Application to Waveguide

The same technique can also be used to produce circular polarization in round waveguide, however, the characteristics are not as readily calculable. Consider a pair of crossed monopoles mounted at 90° to each other and connected together at one end. The two could then be fed in parallel from the center conductor of a coaxial line. If the assembly is next placed inside a round waveguide it is possible to obtain circular polarization in the waveguide by experimental adjustment of the monopole parameters.

An experimentally-adjusted circular polarizer of this type using a dielectric-filled waveguide is shown in Fig. 8. This polarizer was designed to operate over a 10 per cent frequency band from 3000 to 3300 Mc. The monopole elements are arranged to rotate in a circular slot in the dielectric ($\epsilon = 2.54$), and the waveguide diameter (1.666 inch) was chosen so as to propagate only the TE_{11} mode over the desired band.

For the polarizer and coaxial matching transformer shown in Fig. 8, the measured input VSWR and axial ratio of the wave propagated in the waveguide are shown in Fig. 9 for a ± 10 per cent frequency band centered at $f_0 = 3.15$ Gc.

It may be noted that there is approximate agreement in the rate of change of ellipticity between the simple dipoles and the more complex waveguide polarizer of Fig. 8. For a bandwidth of $f_0 \pm 10$ per cent, the dipole ellipticity is about 9 db (Fig. 7), while it is about 5 or 6 db for the waveguide polarizer (Fig. 9).

Conclusions

It is possible to obtain circular polarization by proper choice of the dimensions of the radiating elements themselves, rather than by use of power splitting and phasing networks. The principle is applicable to any type of elements which have input admittance characteristics similar to the dipole of Fig. 2, and it may be accomplished either in free space or inside waveguide.

The free-space type of polarizer would be useful as a circularly-polarized antenna. The fact that no input-phasing network is necessary is a definite advantage. The waveguide type could be used as a waveguide feed for a horn antenna or as a phase shifter by mechanically rotating the monopoles about the axis of the coaxial line. The small moment of inertia would allow rapid rotation with better angular stability and smaller driving torque than previous methods (rotating helix or rotating dielectric plate).