Institute of Engineering,
Jiwaji University

Unit - IV BE IV Sem

WAVE POLARIZATION (PART-I)

EL-402 ELECTRONICS

EMT

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WAVE POLARIZATION

Definition → The wave polarization is defined as its electric field vector orientation as a function of time, at a fixed position in space.

Specifically only the electric field direction is sufficient & magnetic field can be found by Maxwell Equations.

TYPES OF POLARIZATION →

1. Linear Polarization →

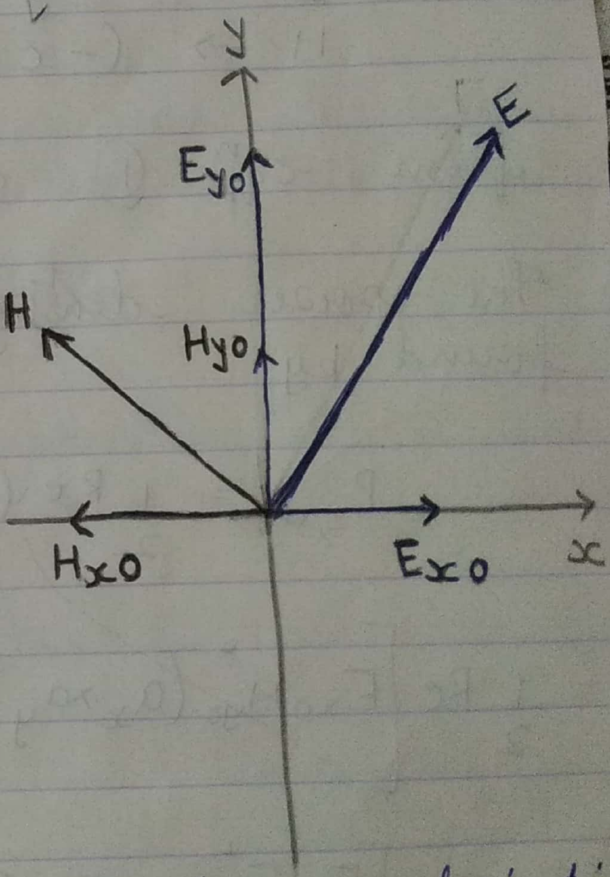

Fig: linear polarization plane wave propagating in the forward z direction.

In the fig. we have taken E to lie along the x axis, but the field could be oriented in any fixed direction in the x-y plane and be linearly polarized.

For positive z-propagation the wave would generally have its electric field phasor expressed as & magnetic field can be found by determining its x and y components directly from those of E_s. Specifically, H_s for the wave.

$$E_s = (E_{xo} a_x + E_{yo} a_y) e^{-\alpha z} e^{-j\beta z} \quad \text{—(1)}$$

$$H_s = (H_{xo} a_x + H_{yo} a_y) e^{-\alpha z} e^{-j\beta z} \quad \text{—(2)}$$

$$= \left[\frac{-E_{yo}}{\eta} a_x + \frac{E_{xo}}{\eta} a_y \right] e^{-\alpha z} e^{-j\beta z}$$

Now, the direction of power flow, given by $E \times H$, is in the positive z direction in this case.

$E \rightarrow$ (+y direction)

$H \rightarrow$ (−x direction)

from eq^n (1) & (2)

The power density in the wave is found by

$$P_{z,av} = \frac{1}{2} Re (E_s \times H_s^*) \quad \Big| \text{ Unit } W/m^2$$

$$= \frac{1}{2} Re \left[E_{xo} H_{yo}^* (a_x \times a_y) + E_{yo} H_{xo}^* (a_y \times a_x) e^{-2\alpha z} \right]$$

$$= \frac{1}{2} Re \left[\frac{E_{xo} E_{xo}^*}{\eta^*} + \frac{E_{yo} E_{yo}^*}{\eta^*} \right] e^{-2\alpha z} a_z$$

$$= \frac{1}{2} Re \left\{ \frac{1}{\eta^*} \right\} \left(|E_{xo}|^2 + |E_{yo}|^2 \right) e^{-2\alpha z} a_z \ W/m^2$$

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Linearly polarized plane wave have two distinct plane waves having x and y polarizations, and whose electric fields are adding in phase to produce the total E. and same for magnetic field.

Note: Any polarization state can be described in terms of mutually perpendicular components of the electric field and their relative phasing.

Elliptical Polarization →

We consider the effect of a phase difference, ϕ, between E_{x0} and E_{y0}, where $\phi < \pi/2$. Total field phasor form.

$$E_s = (E_{x0}a_x + E_{y0}e^{j\phi}a_y)e^{-j\beta z} \quad -①$$

propagation in a loss-less medium

$$E_{(z,t)} = E_{x0}\cos(\omega t - \beta z)a_x + E_{y0}\cos(\omega t - \beta z + \phi)a_y \quad -②$$

Considering real part

We have assumed that E_{x0} and E_{y0} are real, $t = 0$. $\cos(-x) = \cos(x)$

$$E_{(z,0)} = E_{x0}\cos(\beta z)a_x + E_{y0}\cos(\beta z - \phi)a_y \quad -③$$

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In equation (3) A observer can move along the z axis, measuring the component magnitudes and thus the orientation of the

Spatial Dimension →

Let's consider a crest of E_x indicated as point a in the figure. If ϕ were zero, E_y would have a crest at the same location. Since ϕ is not zero (+), the crest of E_y that would otherwise occur at point a is now displaced to point b further down z. The two points are separated by distance ϕ/β. E_y thus lags behind E_x when considering the spatial dimension.

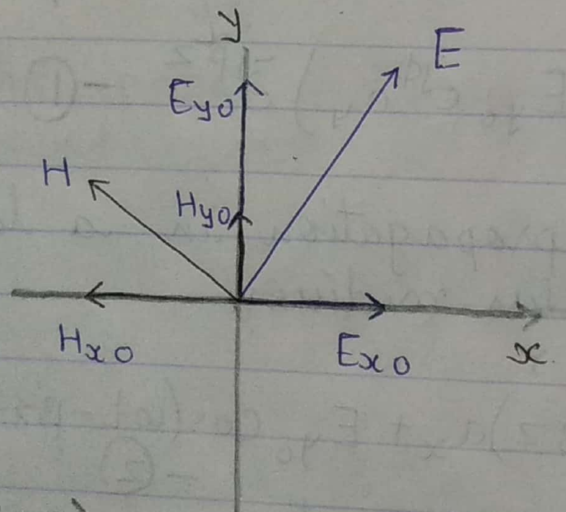

Fig:- Electric field & Magnetic field for polarized plane wave.

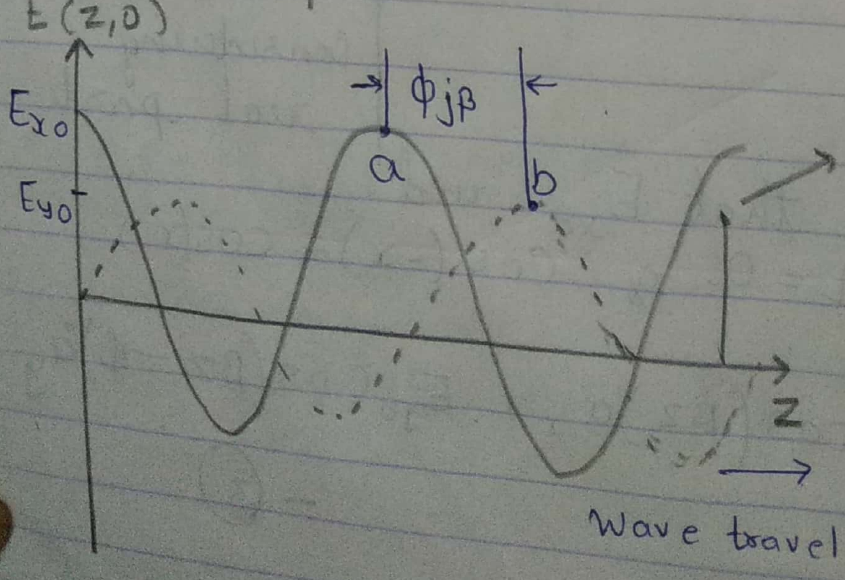

Fig:- Electric field components magnitude Eq^n (3)

Time Dimension → Now, suppose the observer stops at some location on the z direction, eq^n (2). But point b reaches the observer first, followed by point a. So we see that E_y leads E_x when considering the time dimension.

If we take the length of the field vector as a measure of its magnitude, we would find that a fixed position, the tip of the vector would trace out the shape of an ellipse over time $t = 2\pi/\omega$. The wave is thus said to be elliptically polarized.

Elliptical polarization is a state of a wave since state of a wave, since it encompasses any magnitude and phase difference between E_x and E_y.

Circular Polarization → When $E_{x0} = E_{y0} = E_0$ and when $\phi = \pm\pi/2$.

Eq^n (2) becomes

$$E(z,t) = E_0\left[\cos(\omega t - \beta z)a_x + \cos(\omega t - \beta z \pm \pi/2)a_y\right]$$

$$= E_0\left[\cos(\omega t - \beta z)a_x \mp \sin(\omega t - \beta z)a_y\right] \quad -(4)$$

If we consider a fixed position along z $(z=0)$ and allow time to vary, with $\phi = \pm\pi/2$, becomes,

$$E(0,t) = E_0\left[\cos(\omega t)a_x - \sin(\omega t)a_y\right] \quad -(5)$$

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If we choose $\phi = -\pi/2$ in (4), we obtain

$$E(0,t) = E_0\left[\cos(\omega t)a_x + \sin(\omega t)a_y\right] \quad -(6)$$

Polarization

Left Circular → The wave exhibits left circular polarization if when orienting the left hand with the thumb in the direction of propagation, the fingers curl in the rotation direction of the field with time.

Right Circular Polarization → If with the right hand thumb in the propagation direction, the fingers curl in the field rotation direction.

Linear polarization is a special case of elliptical polarization, in which the phase difference is zero.

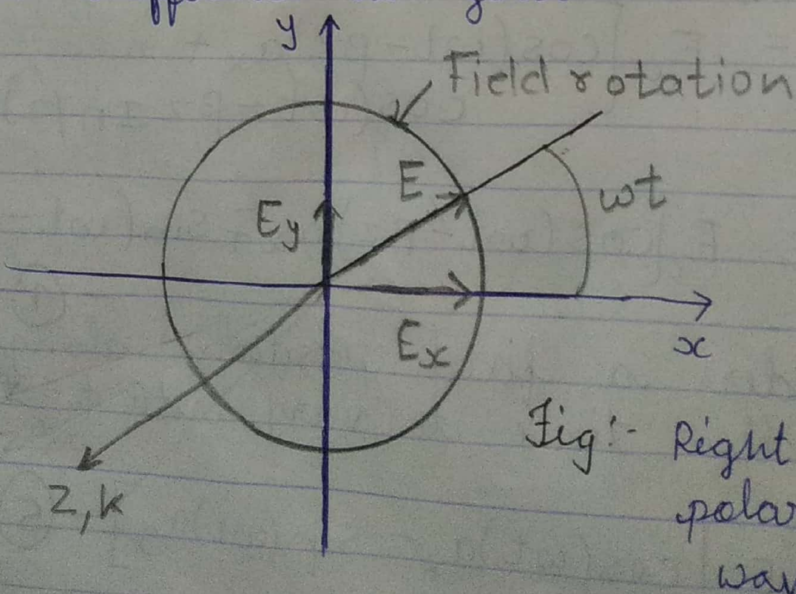

Fig:- Right Circularly polarized wave

Using (4), the instantaneous angle of the field from the x direction can be found for any position along z through

$$\theta(z,t) = \tan^{-1}\left(\frac{E_y}{E_x}\right) = \tan^{-1}\left(\frac{\mp \sin(\omega t - \beta z)}{\cos(\omega t - \beta z)}\right)$$

$$= \mp(\omega t - \beta z) \quad - (7)$$

Applications →

i) Dipole antennas → circular polarization
ii) Linear polarization with superposition as a circular polarization, & viceversa.

It is useful to express circularly polarized waves in phasor form. Eq^n (4).

$$E(z,t) = Re\left\{E_0 e^{j\omega t} e^{-j\beta z}\left[a_x + e^{\pm j\pi/2} a_y\right]\right\}$$

Using the fact the $e^{\pm j\pi/2} = \pm j$ Now in phasor form.

$$E_s = E_0(a_x \pm j a_y)e^{-j\beta z} \quad - (8)$$

Left circular polarization → (+ve)
Right circular polarization → (-ve)

$$E_s = E_0(a_x \pm j a_y)e^{+j\beta z} \quad - (9)$$

Left circular polarization → (-ve) | wave propagates in negative z direction
Right circular polarization → (+ve)

Ex-11.7

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