The University of New Mexico

School of Engineering

Electrical and Computer Engineering Department

ECE 535 Satellite Communications

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Module # 6: 5.3, 5.5, 5.7, 5.9, 5.13, 5.14, 5.17, 5.21, 5.24, 5.25, 5.26, 5.27

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5.3 Two electric fields with an amplitude ratio of 3:1 and in time phase, act at right angles to one another in space. On a set of x-y axes draw the path traced by the tip of the resultant. Given that the total power developed across a 50 Ω load is 10 W, find the peak voltage corresponding to the unity amplitude.

P = 10W, Ω = 50, ratio 3:1

Find peak voltage at unity amplitude:

Per Ohm's law and average RMS power in a sinusoidal wave…

$$V_{RMS} = \frac{V}{\sqrt{2}}$$

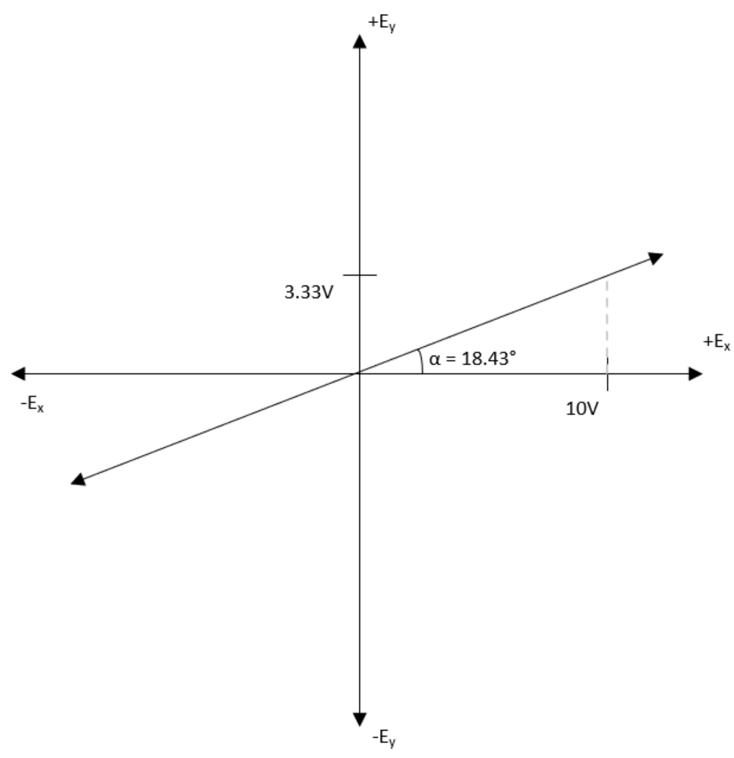
$$P = \frac{\left(\frac{V}{\sqrt{2}}\right)^2}{R} \xrightarrow{yields} P = \frac{(V)^2}{2R} \xrightarrow{yields} V = \sqrt{P * 2R} \xrightarrow{yields} = \sqrt{10W * 2(50ohm)} = 31.62V$$

$$V_{peak}^2 = E_x^2 + (E_y^2 = E_x^2, due\ to\ equal\ time\ phase)$$

$$31.62V^2 = E_x^2 + (3E_x)^2 \xrightarrow{yields} 1000V = E_x^2 + 9E_x^2 \xrightarrow{yields} 1000V = 10E_x^2$$

$$E_x = \sqrt{100} = 10V$$

$$\alpha = tan^{-1}\frac{E_y = \frac{1}{3}E_x}{E_x} \xrightarrow{yields} tan^{-1}\frac{3.33V}{10V} = 18.45°$$



5.5 Two electric field vectors of amplitude ratio 3:1, are 90° out of time phase with one another. On a set of x-y axes draw the path traced by the tip of the resultant vector. If the peak voltages are 3 V and 1 V determine the average power developed in a 10 Ω load.

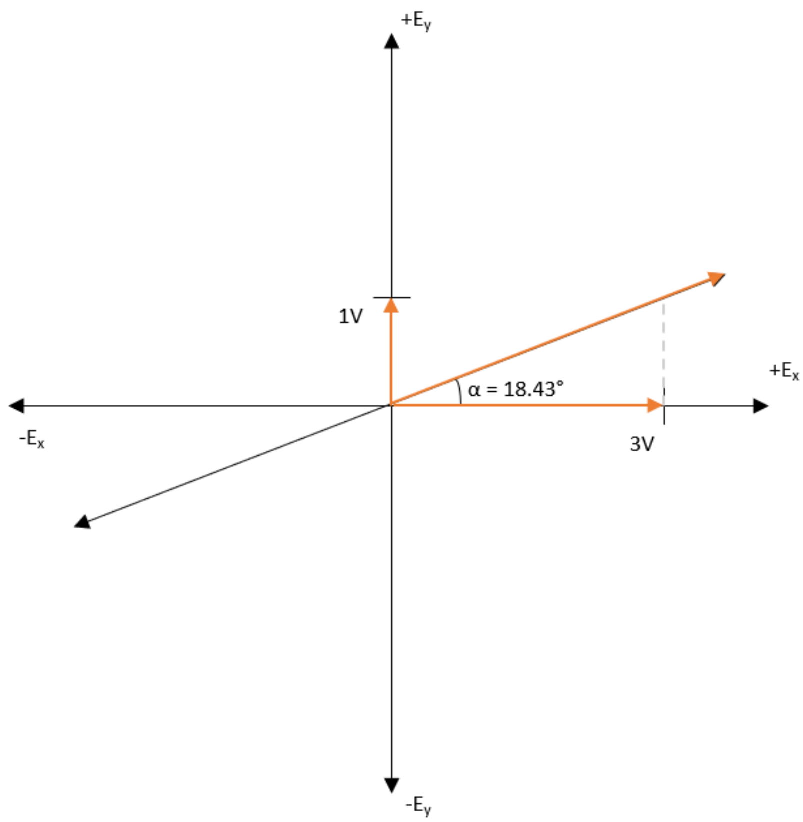
$V_{RMS} = \frac{V}{\sqrt{2}}$; $E_x(t) = 3V cos(wt);\ 1V cos(\omega t + 90°) = 1V sin(\omega t)$

$$V_{rms_x} = \frac{3V}{\sqrt{2}} = 2.12V;\quad V_{rms_y} = \frac{1V}{\sqrt{2}} = 0.707V$$

$$V_{RMS} = \sqrt{V_{rms_x}^2 + V_{rms_y}^2} \xrightarrow{yields} = \sqrt{2.12^2 + 0.707^2} = 2.33V$$

$$P = \frac{V^2}{R} \xrightarrow{yields} P = \frac{(2.33)^2}{10} \xrightarrow{yields} P = 0.54W$$

$V_{peak}^2 = E_x^2 + (E_y^2 = E_x^2, due\ to\ equal\ time\ phase)$



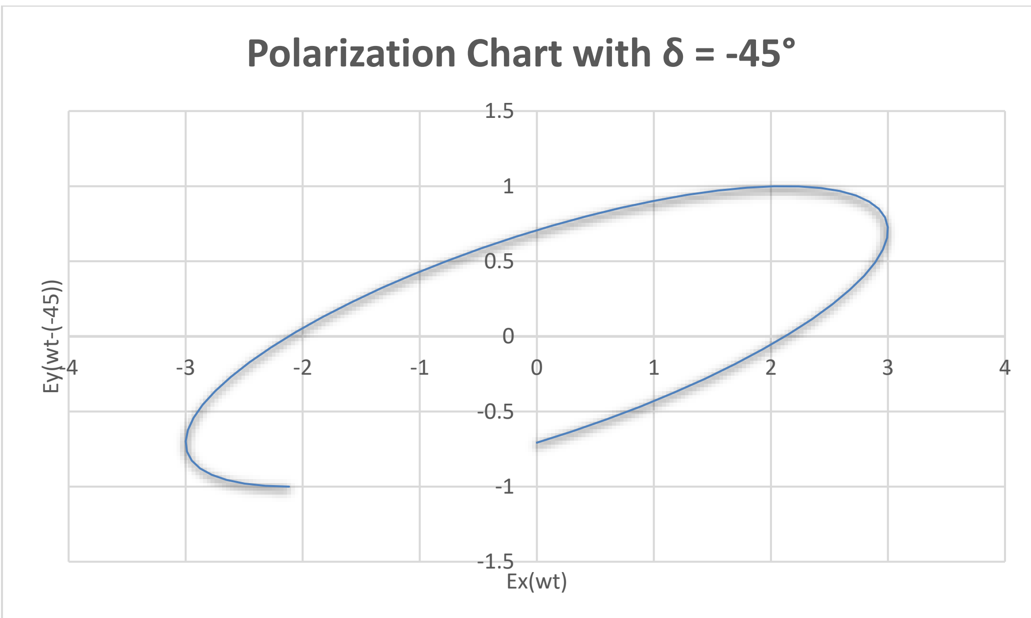
5.7 With δ = -45° and equal amplitude components, determine the sense of polarization of a wave represented by Eq. (5.6).

$E_x = 3V;\ E_y = 1V;\ -45°\ phase\ angle$

$E_x(t) = 3Vcos(\omega t)$

$E_x(t) = 1Vcos(\omega t - 45°) = 1Vsin(\omega t)$

Plot ωt from 0 to $\frac{\pi}{2}$



LH Elliptical Polarization

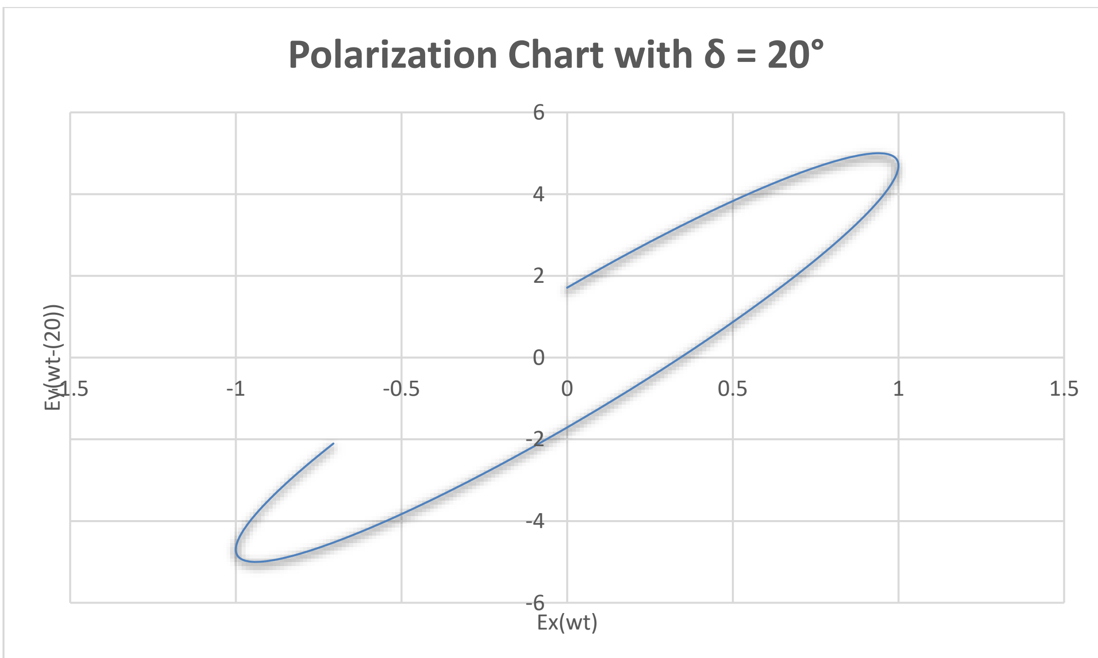
5.9 A plane TEM wave has a horizontal (+*x* directed) component of electric field of amplitude 3 V/m and a vertical (+*y* directed) component of electric field of amplitude 5 V/m. The horizontal component lags the vertical component by a phase angle of 20° . Determine the sense of polarization.

$E_x = 3V;\ E_y = 5V;\ 20°\ phase\ angle$

$E_x(t) = 3Vcos(\omega t)$

$E_x(t) = 1Vcos(\omega t + 20°)$

Plot ωt from 0 to $\frac{\pi}{2}$



LH Elliptical Polarization

5.13 A plane TEM wave has a horizontal (+*x*-directed) component of electric field of amplitude 3 V/m and a vertical (+*y*-directed) component of electric field of amplitude 5 V/m. The components are in time phase with one another. Determine the angle a linearly polarized antenna must be at with reference to the *x* axis to receive maximum signal.

(a) At 0.01 percent:

$$\alpha = tan^{-1}\frac{E_y}{E_x}$$

$$\alpha = tan^{-1}\frac{5V/m}{3V/m}$$

$$\alpha = 59.04°$$

5.14 For Prob. 5.13, what would be the reduction in decibels of the received signal if the antenna is placed along the x axis?

(a) At 0.01 percent:

$$E = \sqrt{E_x^2 + E_y^2}$$

$$E = \sqrt{3^2 + 5^2} = 5.83V/m$$

Reduction of decibels $= \; dB = 20\log\left(\frac{F_1}{F_2}\right)$

Reduction of decibels = $20\log\left(\frac{E_{received}}{E_{max}}\right) = 20\log\left(\frac{3}{5.83}\right) = -6.76dB$

5.17 A geostationary satellite stationed at 90°W transmits a vertically polarized wave. Determine the polarization of the resulting signal received at an earth station situated at 70°W, 45°N.

$\Phi_{SS} = -90°;\ \lambda_E = 45°;\ \Phi_E = -70°; vertically\ polarized\ \&\ geostationary$

$a_{GSO} = 42{,}164km; R = 6{,}371km$

$B = \Phi_E - \Phi_{SS} = (-70°) - (-90°) = 20°$

$R_x = Rcos\lambda cosB \xrightarrow{yields} (6{,}371km)(\cos(45°))(\cos(20°)) = 4{,}233.29km$

$R_y = Rcos\lambda sinB \xrightarrow{yields} (6{,}371km)(\cos(45°))(\sin(20°)) = 1{,}540.79km$

$R_x = Rsin\lambda \xrightarrow{yields} (6{,}371km)(\sin(45°)) = 4{,}504.30km$

r = -R = -$\begin{bmatrix} 4{,}233.29km \\ 1540.79km \\ 4{,}504.30km \end{bmatrix}$ k = $\begin{bmatrix} R_x - a_{GSO} \\ R_y \\ R_z \end{bmatrix} = \begin{bmatrix} -37{,}929km \\ 1{,}540.79km \\ 4{,}504.30km \end{bmatrix}$ e = $\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$

f = k × r

f = $\begin{bmatrix} a_x & a_y & a_z \\ -37{,}930.71km & 1{,}540.79km & 4{,}504.98km \\ -4233.29km & -1540.79km & -4504.98km \end{bmatrix} = a_x 0 - a_y 1.899x10^8 + a_z 6.497x10^7$

g = k × e

g = $\begin{bmatrix} a_x & a_y & a_z \\ -37{,}930.71km & 1{,}540.79km & 4{,}504.98km \\ 0 & 0 & 1 \end{bmatrix} = a_x 1540.79 + a_y 3.79x10^4 + a_z 0$

h = g × k

h = $\begin{bmatrix} a_x & a_y & a_z \\ 1540.79km & 3.79x10^4 km & 0km \\ -37{,}930.71km & 1{,}540.79km & 4{,}504.98km \end{bmatrix} = a_x 1.709x10^8 + a_y 6.94x10^6 + a_z 1.43610^9$

$|h| = \sqrt{1.709x10^8 + 6.94x10^6 + 1.436x10^9} = 1.447x10^9$

$p = \frac{h}{|h|} = a_x 0.118 + a_y 0.005 + a_z 0.993$

p * f = $6.36x10^7$

|f| = $0 + 1.899x10^8 + 6.497x10^7 = 2.01x10^8 km^2$

$\xi = sin^{-1}\frac{p*f}{|f|} \xrightarrow{yields} sin^{-1}\frac{6.36}{2.01} = 0.322\ rad\ or\ 18.46°$

5.21 A linearly polarized wave traveling through the ionosphere suffers a Faraday rotation of 9°. Calculate (a) the polarization loss and (b) the cross polarization discrimination.

$\theta = 9°$

(a) Polarization Loss

$PL = 20\log(cos\theta_F) = 20\log\left(\cos(9°\right) = -0.11 dB\ loss$

(b) Cross Polarization Discrimination

$XPD = 20log\frac{E_{11}}{E_{12}}\ or 20\log(cot(9°)) = 16dB$

5.24 A transmission path between an earth station and a satellite has an angle of elevation of 32° with reference to the earth. The transmission is circularly polarized at a frequency of 12 GHz. Given that rain attenuation on the path is 1 dB, calculate the cross-polarization discrimination.

$EL = 32°;\ f = 12GHz; A = 1dB; Circular\ Polarized: \tau = 45°$

$XPD = U - VlogA$

$U = 30\log(f) - 10\log(0.5 - 0.4697cos4\tau) - 40cos\theta$

$Identity: cos4(\tau) = 8cos^2(\tau) - 8cos^2(\tau + 1)$

$U = 30\log(f) - 10\log(0.5 - 0.4697(8cos^2(\tau) - 8cos^2(\tau + 1))) - 40cos\theta$

$U = 30\log(12GHz) - 10\log\big(0.5 - 0.4697(8cos^2(45) - 8cos^2(45 + 1)\big) - 40\log(\cos(32))$

$U = 31.08 + 0.13 + 2.86$

$U = 34.07$

$$V = \begin{cases} 20\ for\ 8\ \leq f\ \leq 15\ GHz \\ 23\ for\ 15\ \leq f\ \leq 35\ GHz \end{cases}$$

$XPD = 34.07 - (20\log(1)) = 34.07dB$

5.25 Repeat Prob. 5.24 for a linearly polarized signal where the electric field vector is parallel to the earth at the earth station.

$EL = 32°;\ f = 12GHz; A = 1dB; Parallel\ to\ Earth\ Station\ \tau = 0°$

$XPD = U - VlogA$

$U = 30\log(f) - 10\log(0.5 - 0.4697cos4\tau) - 40cos\theta$

$U = 30\log(12GHz) - 10\log\big(0.5 - 0.4697(8cos^2(0) - 8cos^2(0+1)\big) - 40\log\ (\cos(32))$

$U = 32.38 + 15.19 + 2.86$

$U = 50.42$

$$V = \begin{cases} 20\ for\ 8\ \leq f\ \leq 15\ GHz \\ 23\ for\ 15\ \leq f\ \leq 35\ GHz \end{cases}$$

$XPD = 50.42 - (20\log(1)) = 50.4dB$

5.26 Repeat Prob. 5.24 for a linearly polarized signal where the electric field vector lies in the plane containing the direction of propagation and the local vertical at the earth station.

$EL = 32°;\ f = 12GHz; A = 1dB; Parallel\ to\ Earth\ Station: \tau = 90 - \theta°$

$XPD = U - VlogA$

$U = 30\log(f) - 10\log(0.5 - 0.4697cos4\tau) - 40cos\theta$

$U = 30\log(12GHz) - 10\log(0.5 - 0.4697cos4(90 - 32°)) - 40\log(\cos(32))$

$U = 32.38 + 1.02 + 2.86$

$U = 36.26$

$$V = \begin{cases} 20\ for\ 8 \le f \le 15\ GHz \\ 23\ for\ 15 \le f \le 35\ GHz \end{cases}$$

$XPD = 36.26 - (20\log(1)) = 36.26dB$

5.27 Repeat Prob. 5.24 for a signal frequency of 18 GHz and an attenuation of 1.5 dB.

$EL = 32°;\ f = 18GHz; A = 1.5dB; Parallel\ to\ Earth\ Station: \tau = 45°$

$XPD = U - VlogA$

$U = 30\log(f) - 10\log(0.5 - 0.4697cos4\tau) - 40cos\theta$

$U = 30\log(18GHz) - 10\log(0.5 - 0.4697cos4(45°)) - 40\log(\cos(32))$

$U = 3.77 + 0.13 + 2.86$

$U = 6.76$

$$V = \begin{cases} 20\ for\ 8\ \le f\ \le 15\ GHz \\ 23\ for\ 15\ \le f\ \le 35\ GHz \end{cases}$$

$XPD = 6.76 - (20\log(1.5)) = 3.24dB$