General Sir John Kotelawala Defence University

ET3122 Antennas and Propagation
Antenna Polarization

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Outline

1. Introduction
2. Linear Polarization
3. Elliptical Polarization
4. Conclusion

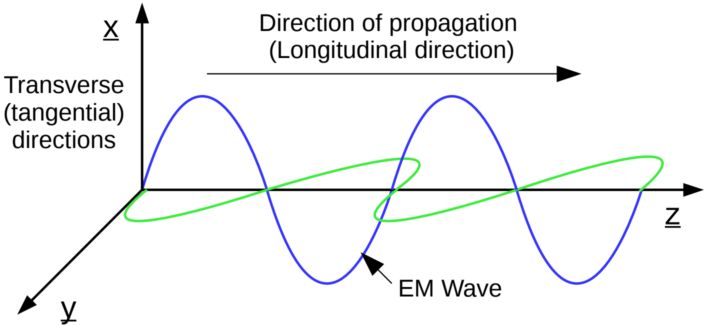
Introduction

Polarization

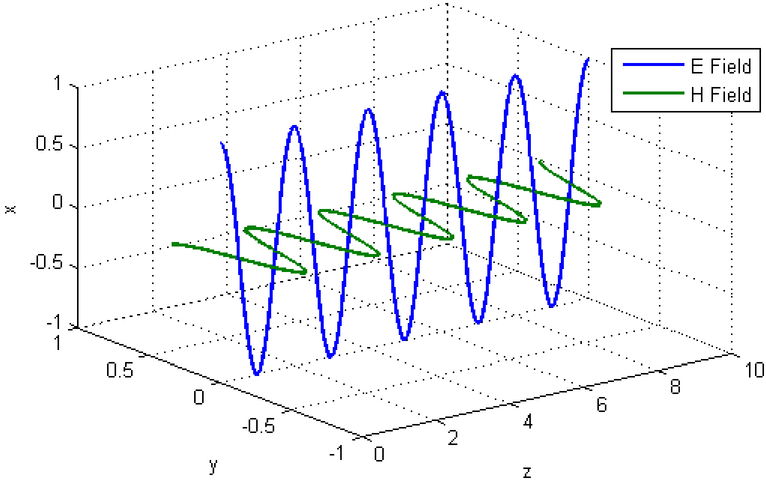
Introduction

- Polarization is the propagation behavior of an EM wave based on its transverse electromagnetic components.
- Depending on the nature of the transverse components different types of propagation can be achieved.
- The polarization of an EM wave is described in terms of its E field.

Wave Directions



Wave Structure



Types of Polarization

Linear Polarization

- Independent E (and H) components.

Elliptical Polarization

- E (and H) components with a phase difference
- This results in a rotating E (and H) field

Linear Polarization

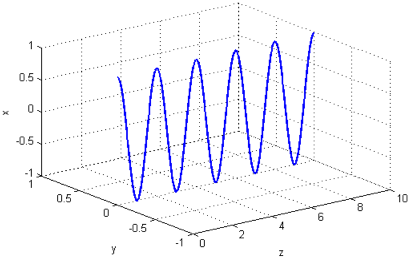
Linear Polarization

- Independent E (and H) components.
- Possible polarizations include E field in
  - The x direction
  - The y direction
  - An arbitrary transverse direction n such that $\underline{n} \cdot \underline{z} = 0$

Linear Polarization (Contd..)

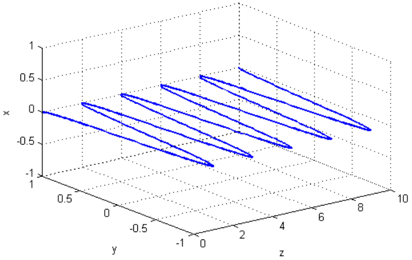
For the x direction,

$$E(z,t) = E_0 e^{j(\omega t - kz)} \underline{x}$$



For the y direction,

$$E(z,t) = E_0 e^{j(\omega t - kz)} \underline{y}$$



Linear Polarization (Contd..)

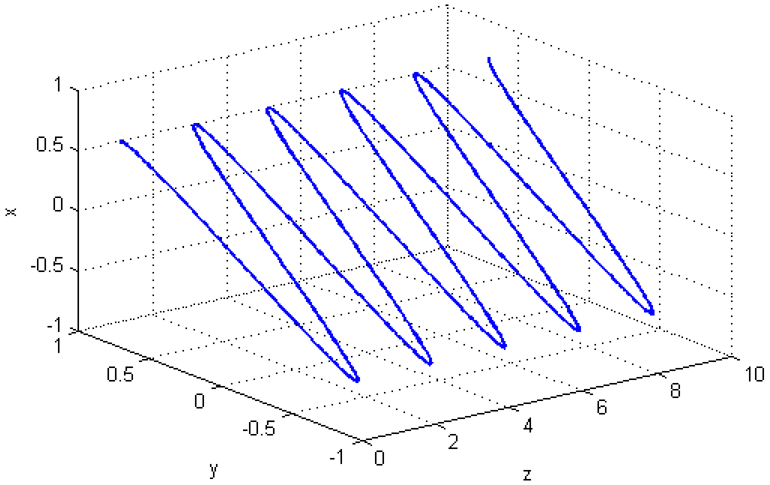
For an arbitrary transverse direction n,

$$E(z,t) = E_0 e^{j(\omega t - kz)} \underline{n}$$

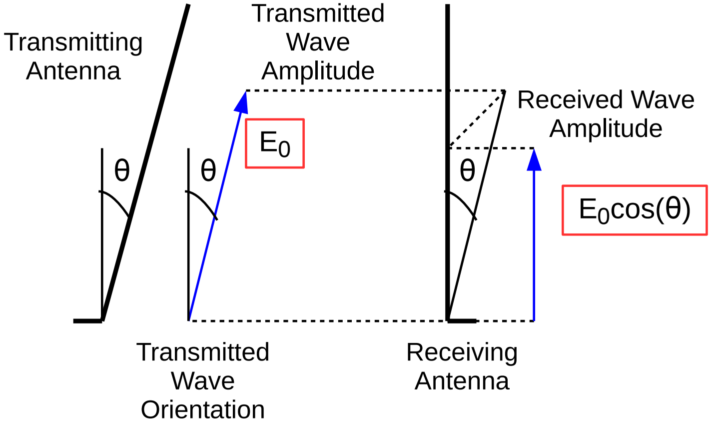
Where $\underline{n}$ has a counterclockwise angle θ with $\underline{x}$,

$$\begin{aligned} \underline{n} &= cos(\theta)\underline{x} + sin(\theta)\underline{y} \\ \underline{n} \cdot \underline{z} &= 0 \\ E(z,t) &= E_0 e^{j(\omega t - kz)} \left[cos(\theta)\underline{x} + sin(\theta)\underline{y} \right] \end{aligned}$$

Linear Polarization (Contd..)



Antenna Orientation

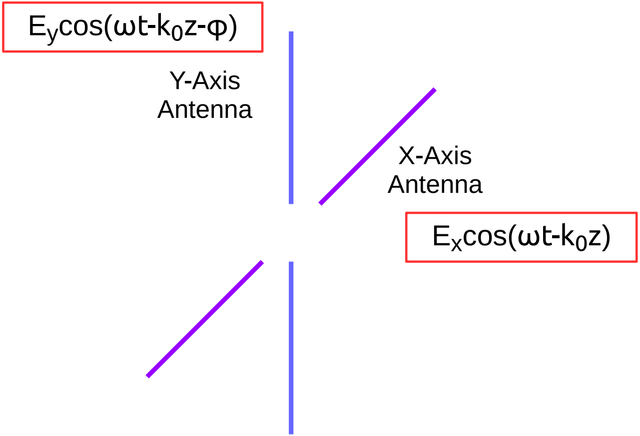


Antenna Orientation (Contd..)

- Antenna orientation results in only a component of the amplitude being received
  - When orthogonal ($\theta = \pi/2$) no signal will be received
- An issue for mobile communication
- What is the solution?

Elliptical Polarization

Orthogonal Antennas

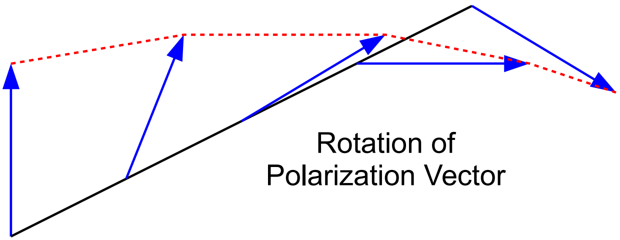


Elliptical Polarization

- If the two orthogonal components of the E field in the transverse directions have a phase difference, then the direction of the *resultant* E field of the wave will change with time.
  - It will rotate
  - Depending on the conditions its magnitude will also change
- If the vertical and horizontal components had equal amplitude and a phase difference of 90^o, the resultant polarization would be circular.

Elliptical Polarization (Contd..)

- The polarization vector E rotates as the wave propagates.



Analysis

Consider a wave with E fields in both transverse directions with a phase difference ϕ,

$$\begin{aligned}
E(z,t) &= E_x exp\left[j(\omega t - k_0 z)\right] \underline{x} + E_y exp\left[j(\omega t - k_0 z - \phi)\right] \underline{y} \\
Re[E(z,t)] &= E_x cos\left(\omega t - k_0 z\right) \underline{x} + E_y cos\left(\omega t - k_0 z - \phi\right) \underline{y} \\
Re[E(z,t)] &= E_x cos\left(\omega t - k_0 z\right) \underline{x} + E_y [cos\left(\omega t - k_0 z\right) cos\left(\phi\right) \\
&\quad + sin\left(\omega t - k_0 z\right) sin\left(\phi\right)] \underline{y}
\end{aligned}$$

Analysis (Contd..)

The locus of the resultant wave,

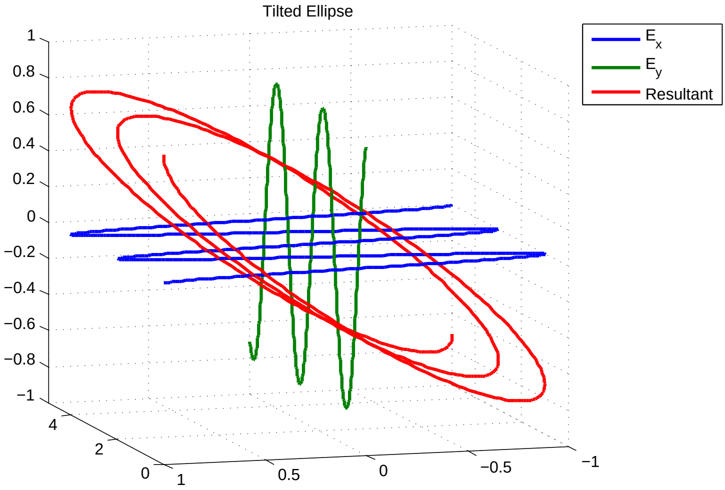
$$
\begin{aligned}
E_x(z,t) &= E_x cos\,(\omega t - k_0 z) \\
E_y(z,t) &= E_y[cos\,(\omega t - k_0 z)\, cos\,(\phi) + sin\,(\omega t - k_0 z)\, sin\,(\phi)]
\end{aligned}
$$

By eliminating $(\omega t - k_0 z)$,

$$
\frac{E_y(z,t)}{E_y} = \frac{E_x(z,t)}{E_x} cos(\phi) + \sqrt{1 - \left(\frac{E_x(z,t)}{E_x}\right)^2} sin(\phi)
$$

This is the locus of a *tilted ellipse*.

Basic Tilted Ellipse

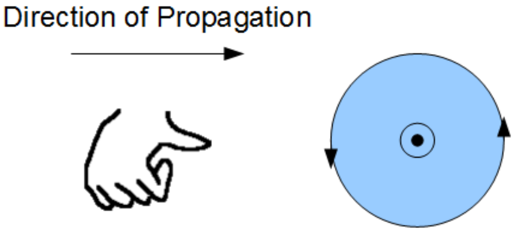


Phase Behavior

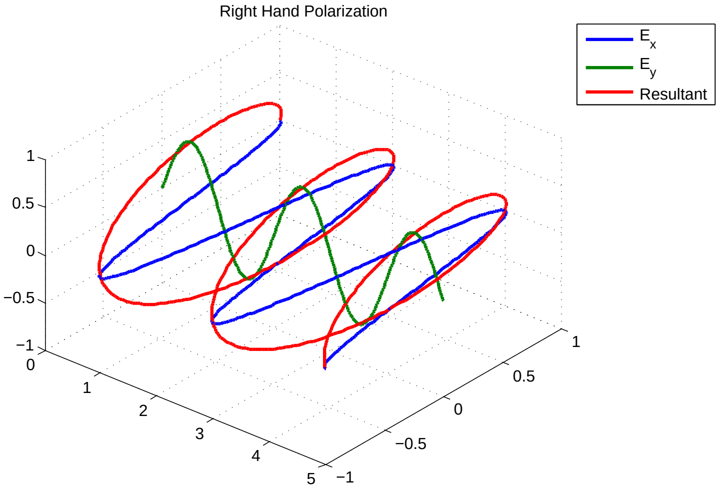
- If $\phi = m\pi$ - linear polarization
- $\phi \in (0, n\pi)$ ($\underline{y}$ leads $\underline{x}$) - clockwise rotation or left handed polarization
- $\phi \in (0, -n\pi)$ ($\underline{y}$ lags $\underline{x}$) - counterclockwise rotation or right handed polarization
- When the polarization is *elliptical* the major and minor axes align with the transverse axes when $\phi = \pm\pi/2$
  - For all other values the resulting elliptical locus is *tilted*
  - Even when *circular* polarized, the circular locus is only observable when $\phi = \pm\pi/2$

Right Hand Polarization

- $\phi < 0$ ($\underline{y}$ lags $\underline{x}$)
- Similar to Maxwell's corkscrew law (counter-clockwise rotation)

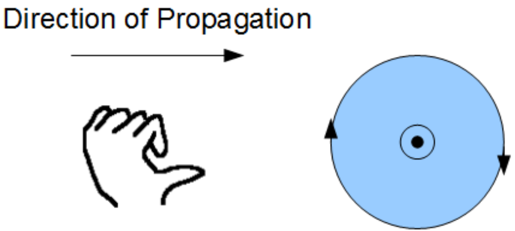


Right Hand Polarization (Contd..)

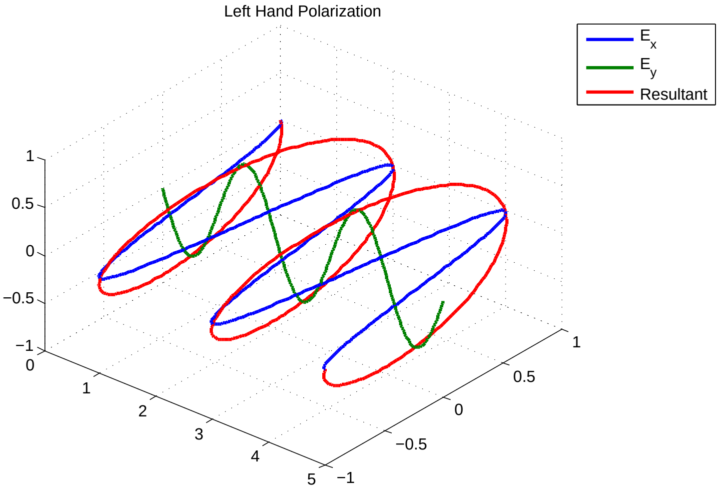


Left Hand Polarization

- $\phi > 0$ ($\underline{y}$ leads $\underline{x}$)
- Anti-Maxwell's corkscrew law (clockwise rotation)



Left Hand Polarization (Contd..)



Elliptical and Circular Polarization

When $\phi = \pm\frac{\pi}{2}$,

$$\begin{aligned} E_x(z,t) &= E_x cos\left(\omega t - k_0 z\right) \\ E_y(z,t) &= E_y sin\left(\omega t - k_0 z\right) \end{aligned}$$

Thus the locus of the resultant wave becomes,

$$\left[\frac{E_x(z,t)}{E_x}\right]^2 + \left[\frac{E_y(z,t)}{E_y}\right]^2 = 1$$

Elliptical and Circular Polarization (Contd..)

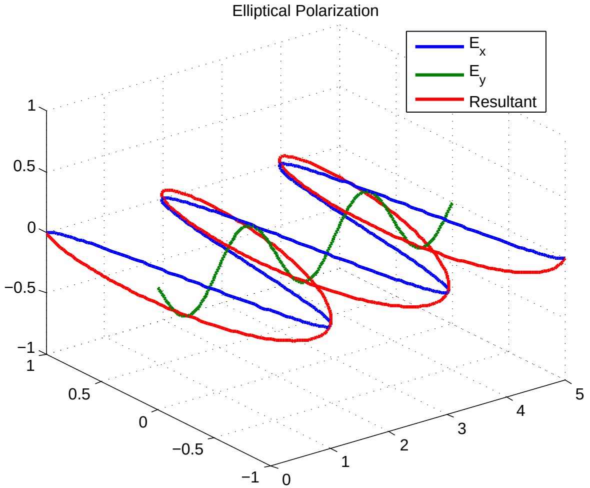
When $E_x \neq E_y$,

- Results in an ellipse with major and minor axes along $\underline{x}$ and $\underline{y}$.
- Commonly referred to as *elliptical polarization* in the communication industry

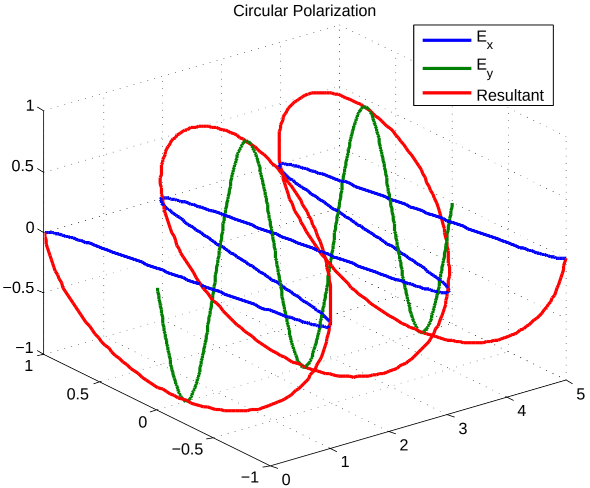
When $E_x = E_y$,

- Circular polarization

Elliptical Polarization



Circular Polarization



Antennas and Polarization

- Television transmissions are *horizontally polarized* (the antenna dipole is *horizontal*)
- Fixed wireless transmissions are *vertically polarized* (the antenna dipole or monopole is *vertical*)
- Mobile communications require circular polarization so that no specific antenna orientation is needed

Conclusion

Summary

- Linear polarization occurs when the transverse E and H components are orthogonal
  - The must be no phase difference
- If there is a phase difference between the transverse E components, the result will be elliptical polarization
  - If the phase difference is an integer multiple of $\pi/2$, the major and minor axes of the ellipse will be along the E fields
  - Right hand polarization (rotation according to Maxwell's corkscrew law) occurs for a lagging phase difference
  - Left hand polarization occurs for a leading phase difference
- If the amplitudes of the orthogonal transverse components are equal and have a phase difference of $n\pi/2$, the result is circular polarization