ECE343 Spring 2025

Objective 9.23:

UPW

Characteristics



SCHEDULE

Lesson	Topics	Reading	Notes
24	BVP (Capacitor, Coax), Electric Potential	5.16	LO 5.3
25	Electric Boundary Conditions	5.18-5.22	LO 5.4
26	BC's/Capacitance	5.23-5.24	
27	Electrostatic Lab	Lab packet	
Chapter 6: Steady Current & Conductivity			
28	Current density, Conductivity, Resistance	Ch. 6	
Chapter 7: Magnetostatics			
29	Magnetic Fields, Gauss' Law for Magnetism	7.1-7.3	LO 7.1-7.2 **GR 2**
30	Ampere's Law	7.4-7.5, 7.9	LO 7.3
31	Ampere's Law Applied	7.6-7.8	LO 7.3
32	Magnetic Boundary Conditions	7.10-7.14	LO 7.4
33	Magnetostatics Lab	Lab packet	
Chapter 8: Time-Varying Fields			
34	Faraday's Law, Displacement Current, Maxwell Eqns	8.3, 8.8, 8.9	LO 8.1
35	Faraday's Law, Displacement Current, Maxwell Eqns	8.3, 8.8, 8.9	LO 8.2-8.3
Chapter 9: Plane Waves in Lossless Media			
36	Maxwell's Equations in lossless, source-free region	9.1-9.2	LO 9.1
37	Maxwell's Equations in lossless, source-free region	9.1-9.2	LO 9.1
38	Uniform Plane Waves & Polarization	9.4-9.6	LO 9.2-9.3
39	Normal Incidence	Vol 2, 5.6-5.7	LO 9.4-9.5
40	Oblique Incidence	Vol 2, 5.6-5.7	LO 9.5
41	Oblique Incidence	Vol 2, 5.6-5.7	LO 9.5
42	Incidence Lab	TBD	LO 9.5

Ch 9 Learning Objectives

9.1 I understand the process of decoupling and finding solutions for Maxwell's equations for dynamic fields.

9.2 I can articulate what a Uniform Plane Wave (UPW) is and describe key properties that relate the electric and magnetic field.

9.3 I can calculate the electric and magnetic fields for a UPW.

9.4 I can articulate the concept of polarization and determine the polarization for various UPWs.

9.5 I can determine the reflection and transmission of UPW at a boundary for Transverse Electric (TE) and Transverse Magnetic (TM) waves, using boundary conditions.

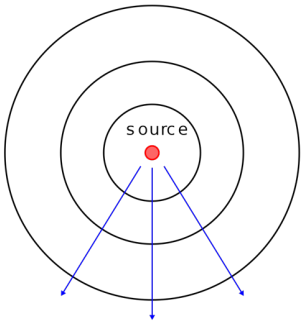
Types of Waves: By Shape of Wave Front

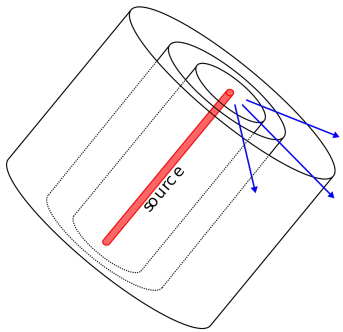
Surfaces of constant phase can be:

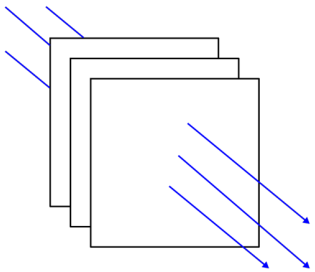
- Spherical
  Appropriate when _____ is _____ relative to _____

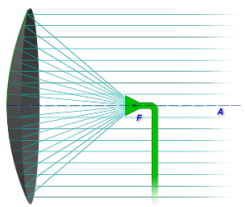
- Cylindrical
  Appropriate when _____ is shaped like a _____.

- Planar
  Appropriate when _____ is observed _____ or when wave is intentionally guided to be _____.









Uniform Plane Waves

Assumptions:

- Simple Media:
  - _____
  - _____
  - _____
  - _____
- Magnitude and phase are constant in a plane perpendicular to direction of propagation (assume z)

Which means:

Now, the wave equation can be written as:

Uniform Plane Waves: Fields

Each component separately must equal zero, allowing us to write 3 equations:

We can make one more simplification, by considering Ampere's Law:

So, the UPW conditions reduce these equations to:

Uniform Plane Waves: Fields

We know how to find solutions for the 2nd order ODEs (right?!)

Now, back to time domain...multiply by _____ and _____.

UPW Summary

Maxwell's Equations

$$\text{Gauss} \longrightarrow \nabla \cdot \tilde{E} = \frac{\rho_v}{\varepsilon}$$

$$\text{Gauss} \longrightarrow \nabla \cdot \tilde{H} = 0$$

$$\text{Ampere} \longrightarrow \nabla \times \tilde{H} = (\sigma + j\omega\varepsilon)\,\tilde{E}$$

$$\text{Faraday} \longrightarrow \nabla \times \tilde{E} = -j\omega\mu\tilde{H}$$

Helmholtz

$$\nabla^2\tilde{E} - \gamma^2\tilde{E} = 0$$

$$\nabla^2\tilde{H} - \gamma^2\tilde{H} = 0$$

$$\gamma^2 = j\omega\mu\,(\sigma + j\omega\varepsilon)$$

Field Solutions

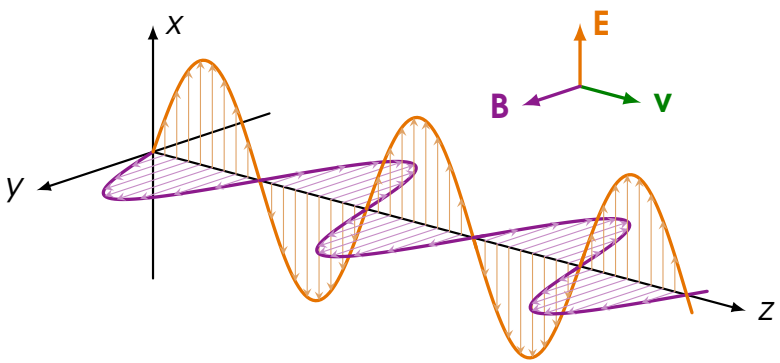
$$E_{x,y}(z,t) = E^{+}_{x0,y0}e^{-\alpha z}\cos(\omega t - \beta z) + E^{-}_{x0,y0}e^{\alpha z}\cos(\omega t + \beta z)$$

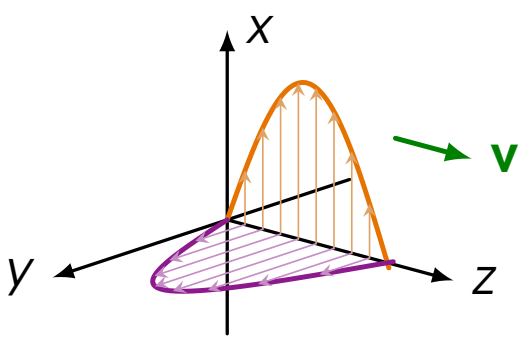
$$H_{x,y}(z,t) = H^{+}_{x0,y0}e^{-\alpha z}\cos(\omega t - \beta z) + H^{-}_{x0,y0}e^{\alpha z}\cos(\omega t + \beta z)$$

Uniform Plane Waves: Interpretation

Observations

- For a UPW, the electric and magnetic field _____ are _____ to propagation.
- The direction of propagation is _____ to the _____ and _____
- The _____ of the _____ and _____ are related





Chapter 3: Lesson 5

$$V(z,t) = \underbrace{V_0^+ e^{-\alpha z}\cos(\omega t - \beta z)}_{\text{Forward Wave}} + \underbrace{V_0^- e^{\alpha z}\cos(\omega t + \beta z)}_{\text{Reverse Wave}}$$

- $V_0^{\pm} \longrightarrow$ Amplitude coefficients
- $e^{\pm\alpha z} \longrightarrow$ Attenuation term
- $\cos(\omega t \pm \beta z) \longrightarrow$ Time and space-varying wave

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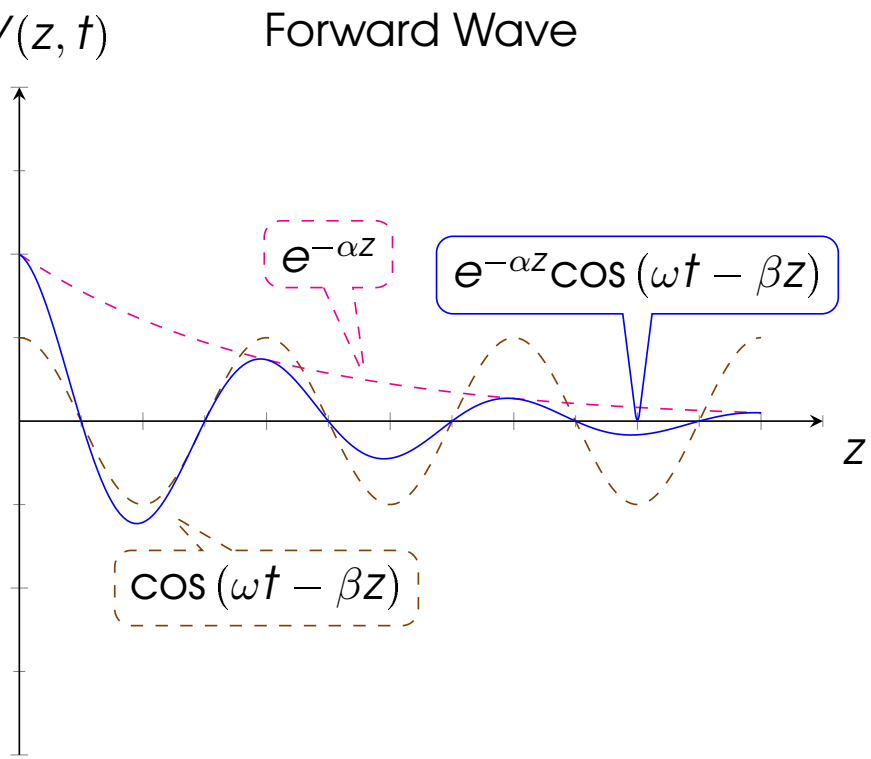
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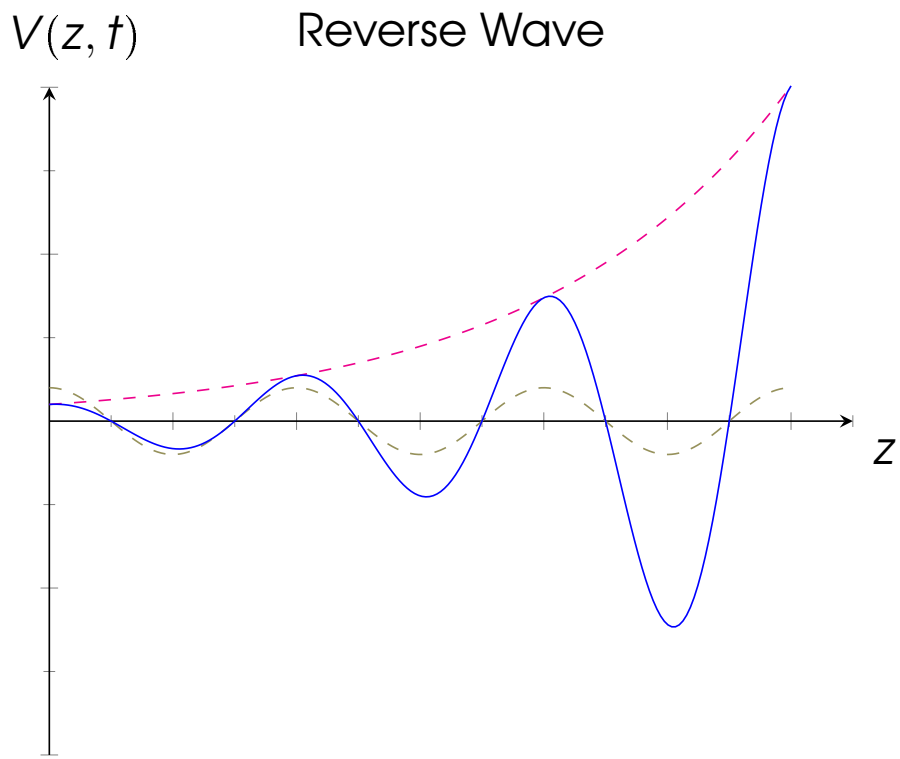
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Uniform Plane Waves: Characteristics

Assume an $\hat{\mathbf{x}}$ Electric field...

Intrinsic impedance is like characteristic impedance...

$\tilde{E}$, $\tilde{H}$, and propagation ($\hat{a}_p$) are **generally** related:

Uniform Plane Waves: General

Summary

$$\vec{E}(z,t) = \hat{\mathbf{x}}E_x(z,t) + \hat{\mathbf{y}}E_y(z,t)$$

$$E_{x,y}(z,t) = E^{\pm}_{x0,y0}e^{\mp\alpha z}\cos(\omega t \mp \beta z)$$

$$\tilde{H}(z,t) = \hat{\mathbf{x}}H_x(z,t) + \hat{\mathbf{y}}H_y(z,t)$$

$$H_{x,y}(z,t) = H^{\pm}_{x0,y0}e^{\mp\alpha z}\cos(\omega t \mp \beta z)$$

$$\tilde{E} = -\eta\hat{a}_p \times \tilde{H} \qquad \tilde{H} = \frac{1}{\eta}\hat{a}_p \times \tilde{E} \qquad \eta = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}}$$

Uniform Plane Waves: Dielectrics

For dielectrics ($\sigma = 0, \varepsilon = \varepsilon_r \varepsilon_0, \mu = \mu_0$):

Free Space

Silicon, $\varepsilon_r = 11.6$

Uniform Plane Waves: Conductors

For conductors:

What does this mean?!?!

Uniform Plane Waves: Conductors

$\tilde{E} \overset{?}{\leftrightarrow} \tilde{H}$

Dispersion

Skin Depth $\sim e^{-\alpha z}$

Define δ as skin depth, where $\tilde{E}(z = \delta) = E_0 e^{-1}$: