Spring 2019

EECE 588
Lecture 1

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Curriculum

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2 Vector analysis, types of antennas, Radiation mechanism, wire antenna current distribution
3 Fundamental Parameters of Antennas
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6 Radiation Integrals & Aux. Potential Functions
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8 Linear Wire Antennas
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11 Arrays: Linear, 2D
12 Arrays: Linear, 2D
13 Antenna Synthesis and continuous Sources

Curriculum

14 Antenna Synthesis and continuous Sources
15 Microstrip Antennas
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17 Helical Antennas Notes,
18 Frequency Independent Antennas, Log-Periodic, Q
19 Aperture Antennas
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21 Reconfigurable Antennas, MEMS Notes
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24 Reflector Antennas
25 Nano Antennas, Plasmonic Antennas
26 Nano Antennas, Plasmonic Antennas
27 Project Presentations
28 Project Presentations – End of Semester

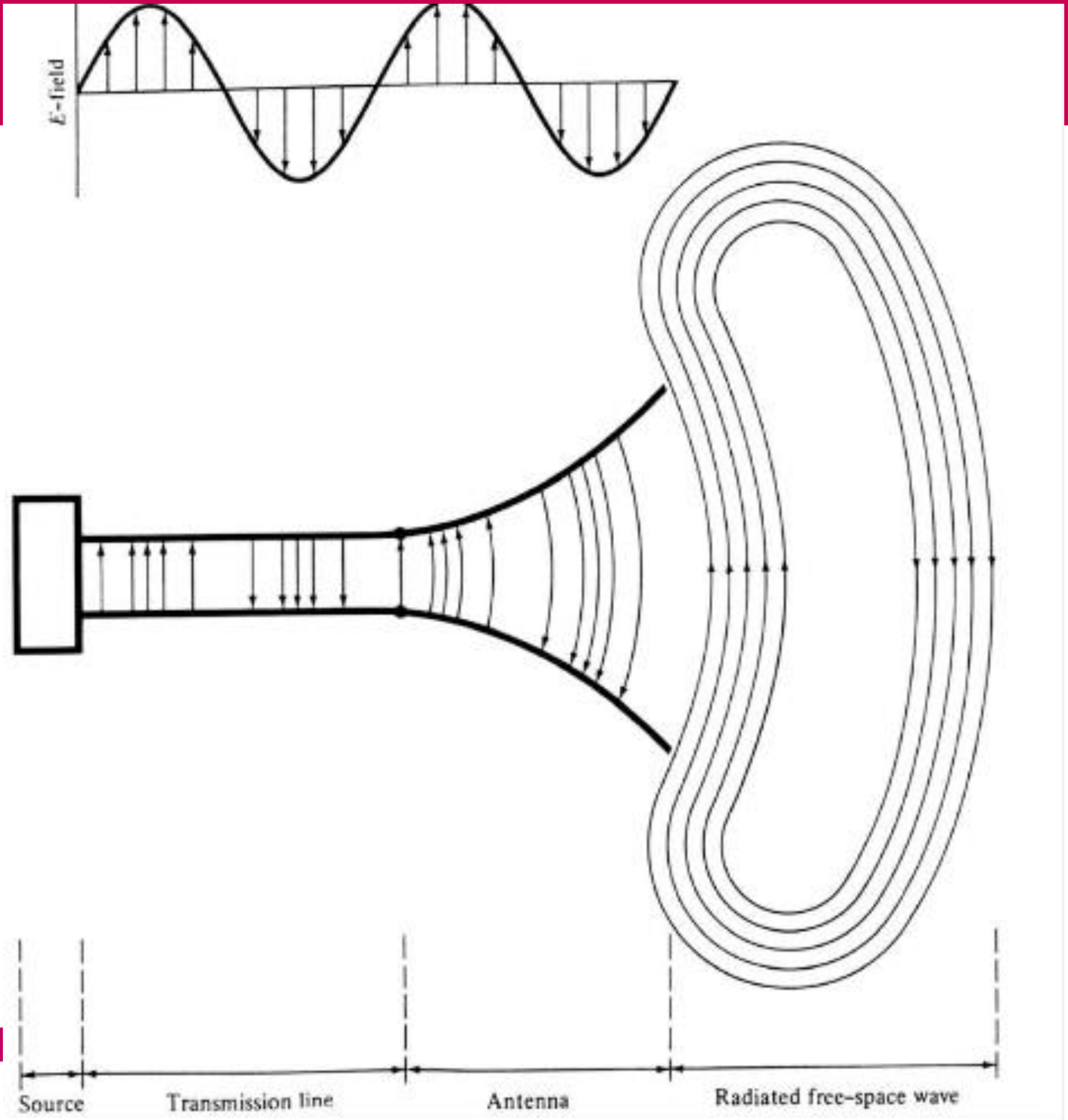
G: Grading: Homework: 20%, Mid-Project: 20%, Term Paper Final-Project: 50%, Attendance: 10%

Reference

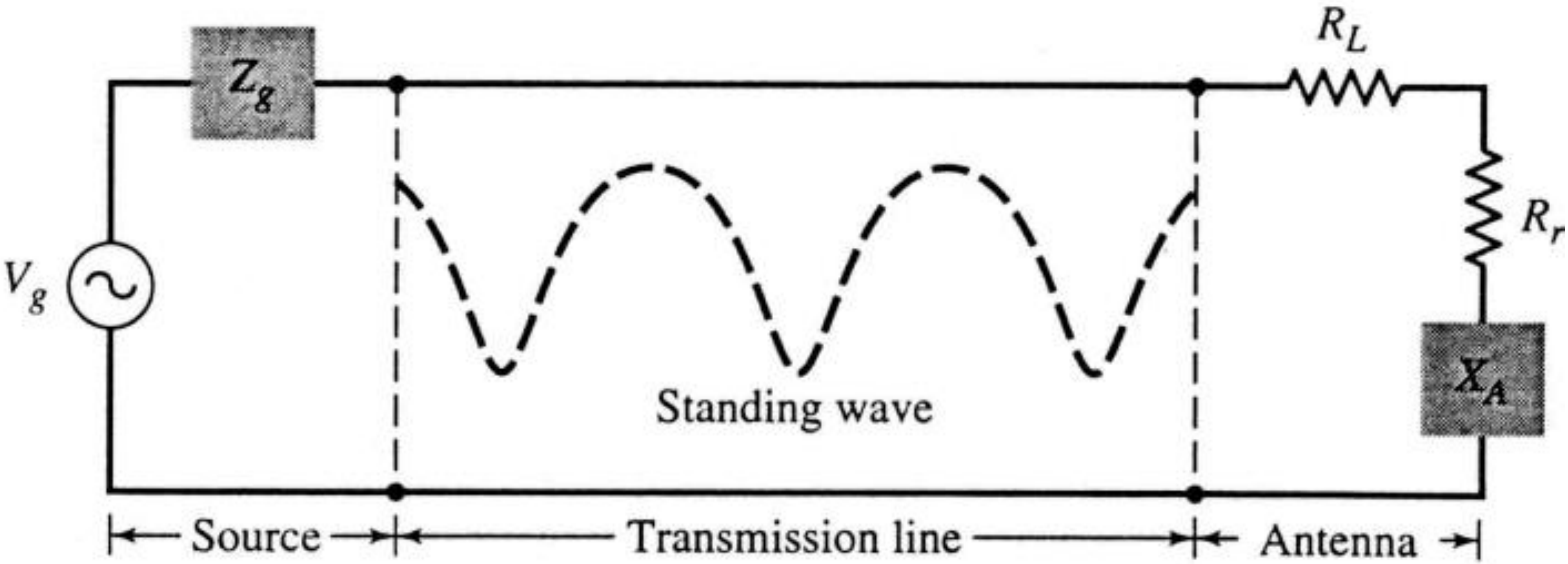
- Advanced Engineering Electromagnetics, Balanis
- Antenna Theory and Design, Stutzman and Thiele
- Antennas for all Applications, Krauss
- Antenna Engineering Handbook, Volakis

Antennas

- What is an antenna?
  - Antennas are devices that transform electric signals propagating in transmission lines into electromagnetic waves propagating in space and vice versa
  - Basically, antennas are transformers
- So, what causes radiation?
  - We will be talking about antennas and their characteristics in great detail
  - But what causes radiation?


E-field
Source
Transmission line
Antenna
Radiated free-space wave

Simple Equivalent Circuit Model

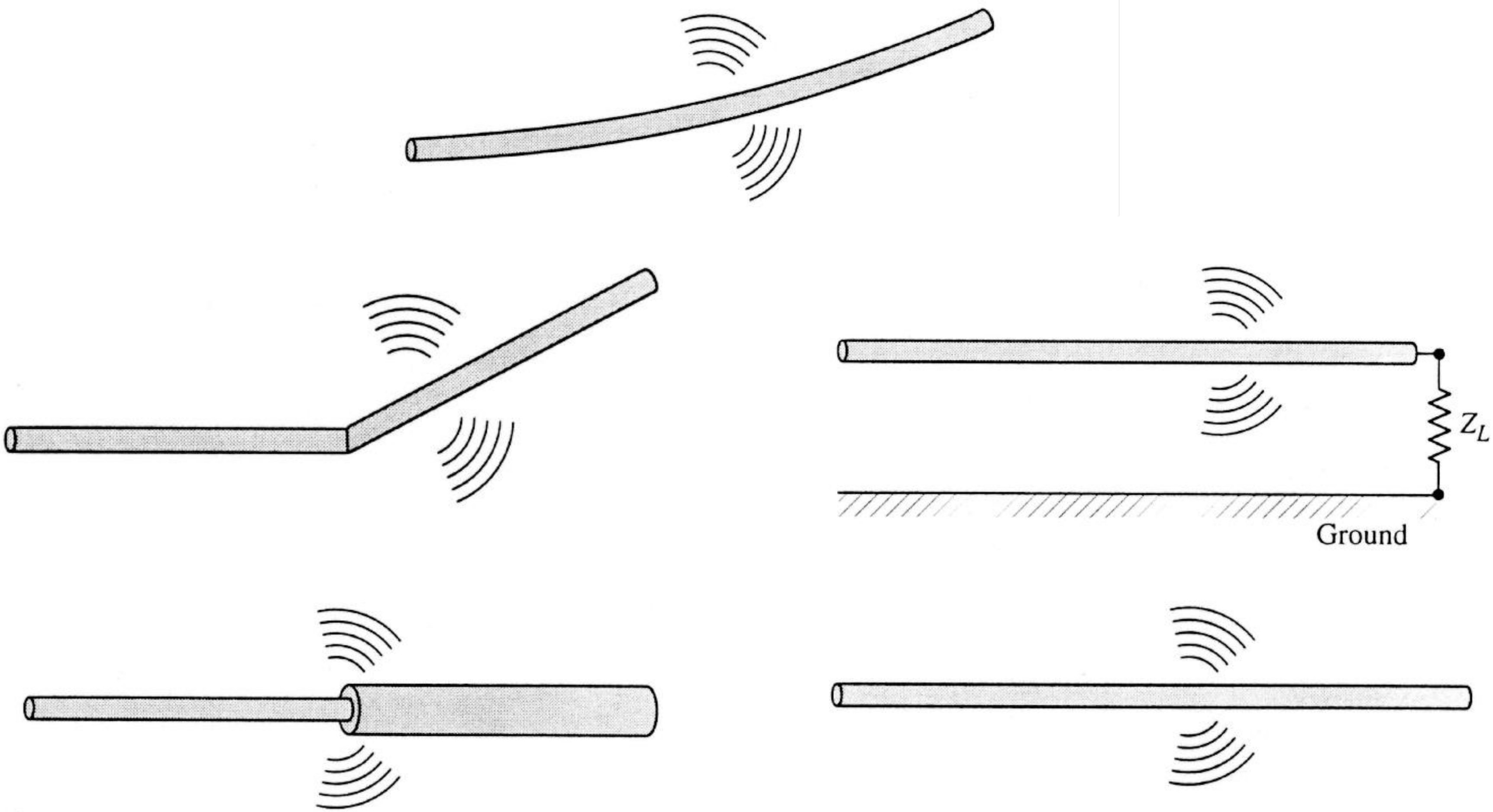


$$Z_A = (R_L + R_r) + jX_A$$

Radiation Mechanism

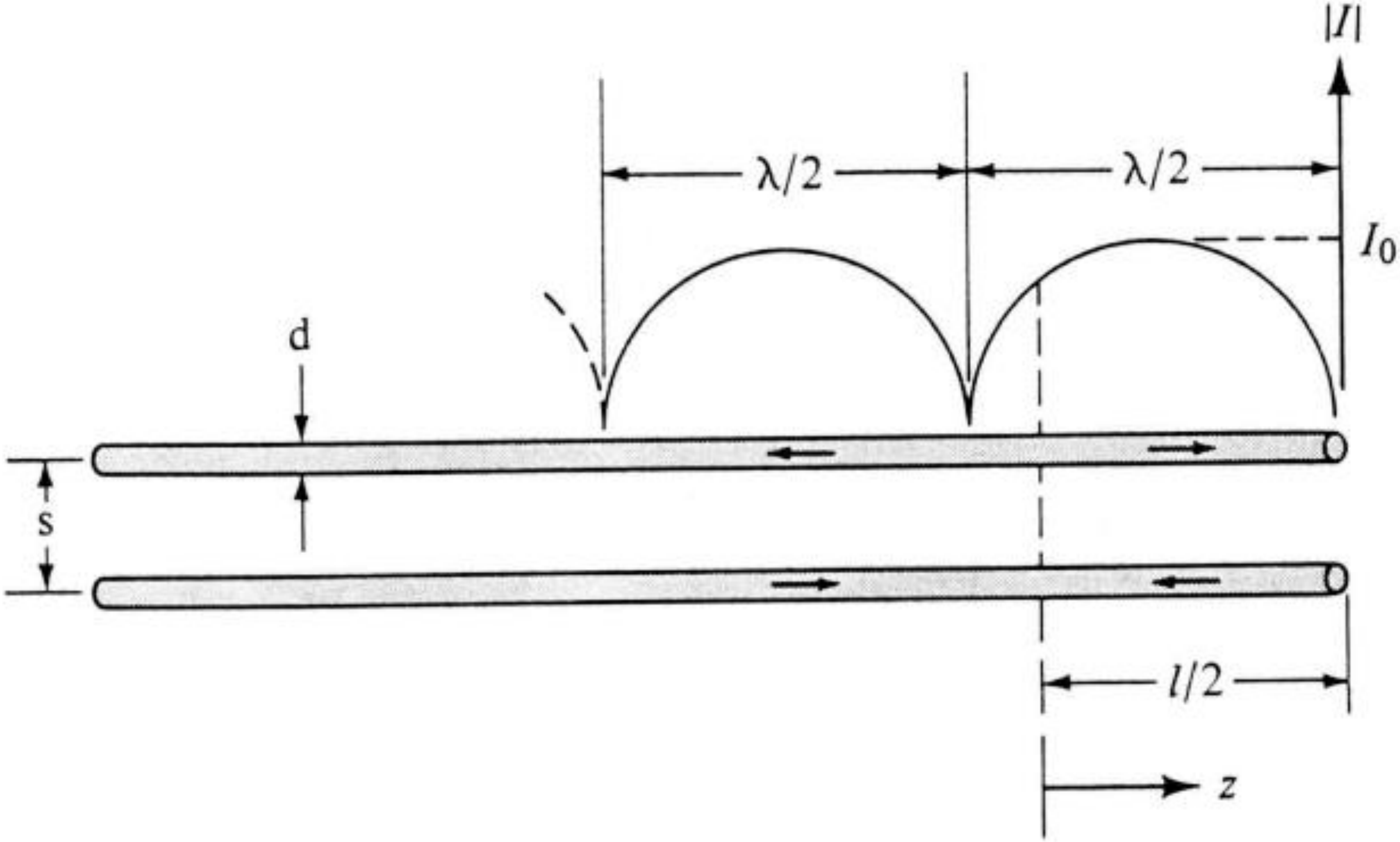
- Radiation is caused by charge acceleration
  - If you take an electron, proton, or other charged particle and some how accelerate it, it then will radiate
- Time harmonic electric currents (sinusoidal variation) by definition has acceleration
  - Remember the definition of acceleration from high school
- If you have a wire that carries a DC current, you can still have accelerated electric charges
  - Let's see some examples next

Examples of How to Create Accelerated Charges in DC Current Carrying Wires

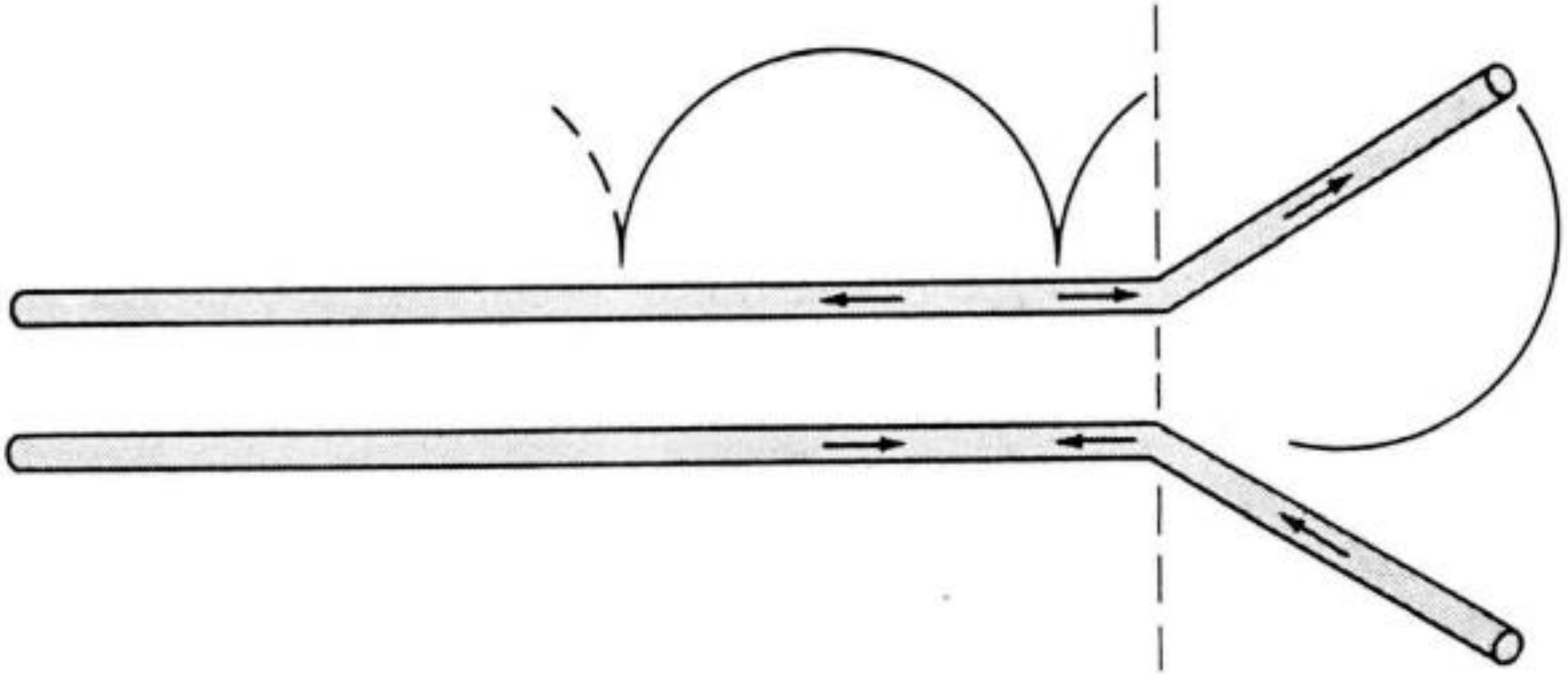


(e) Truncated

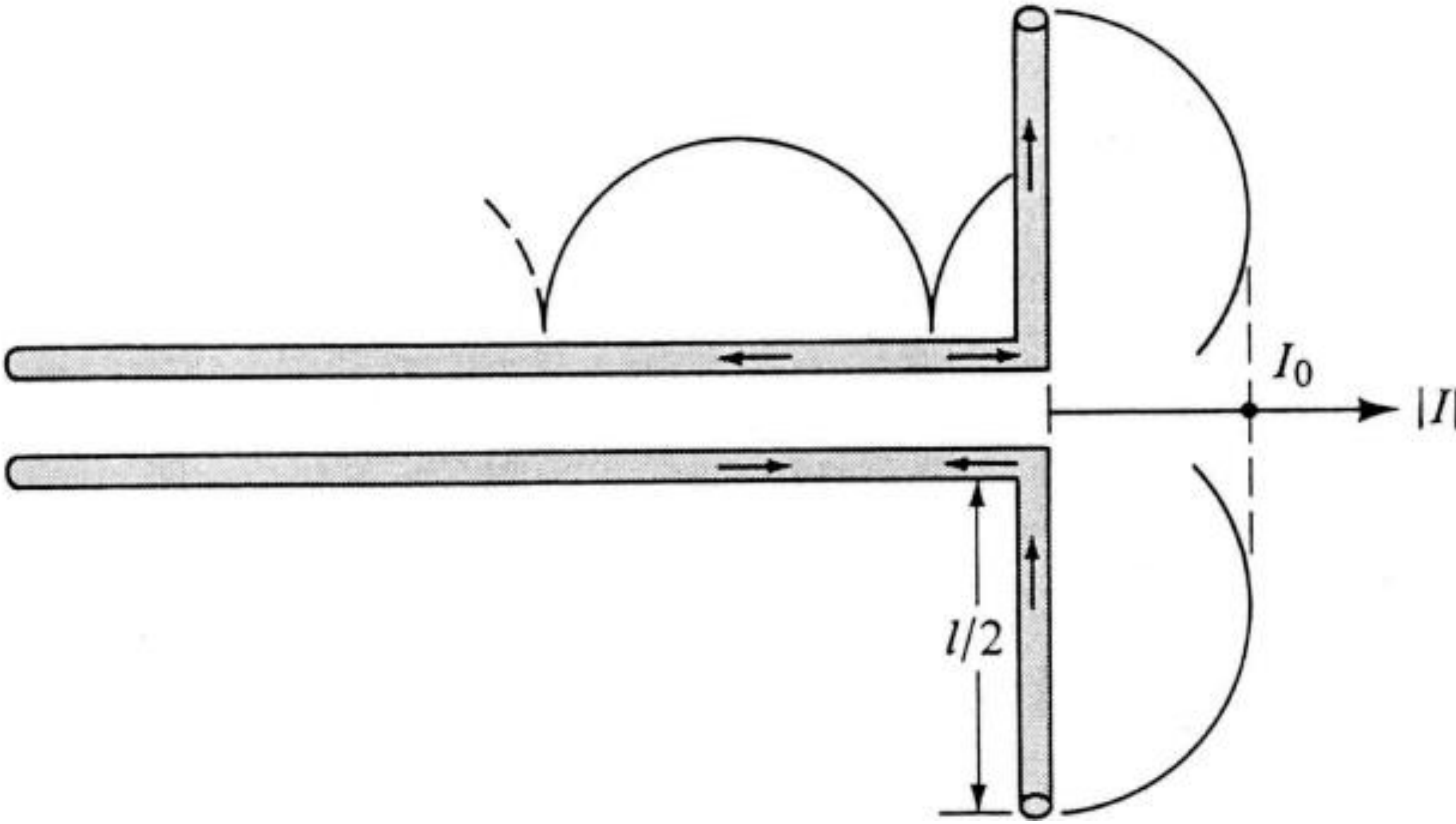
Let Us Consider an Open Circuited Transmission Line



Now, Let's Bend this Transmission Line



Now, the Bend is Complete



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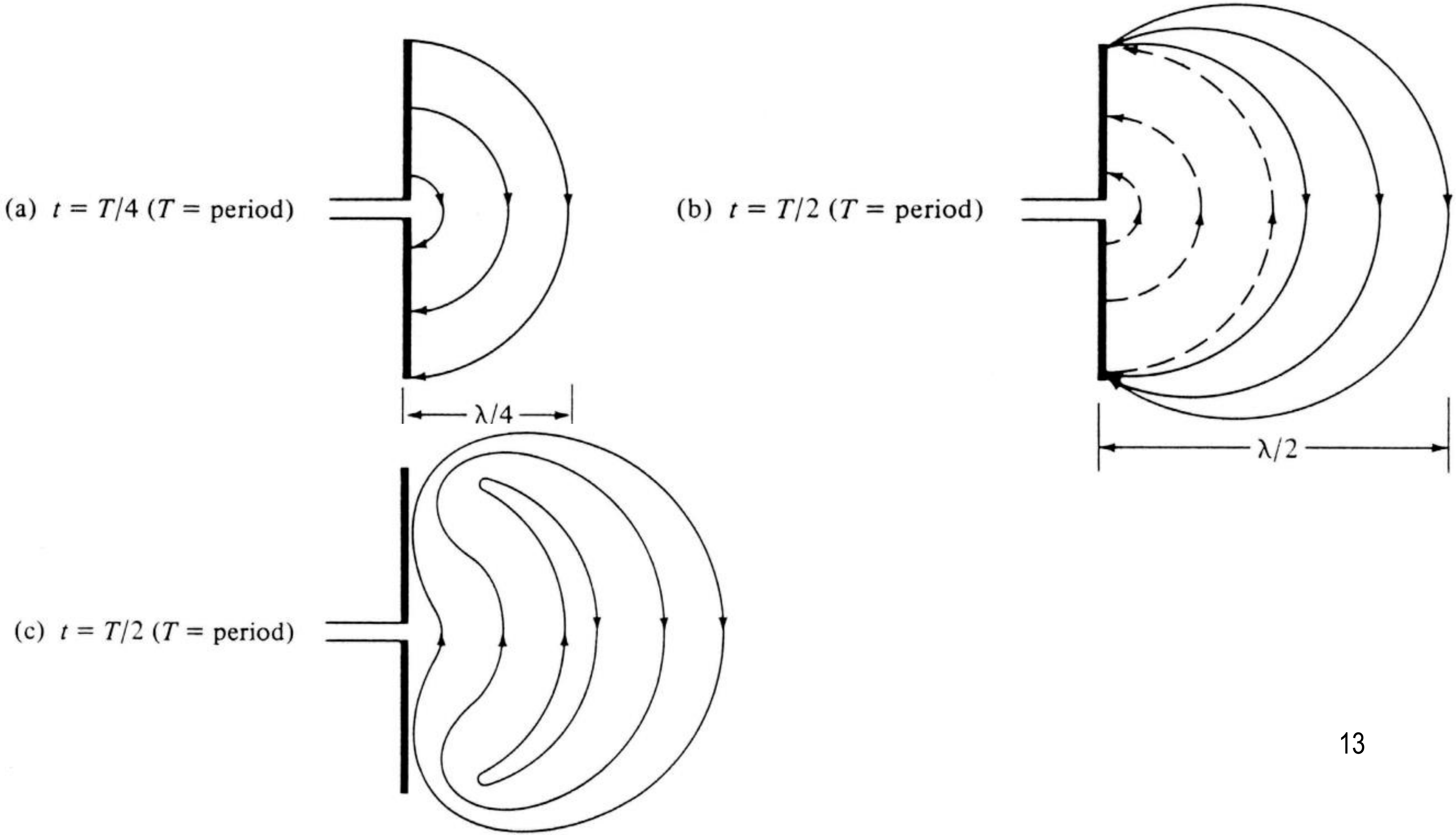
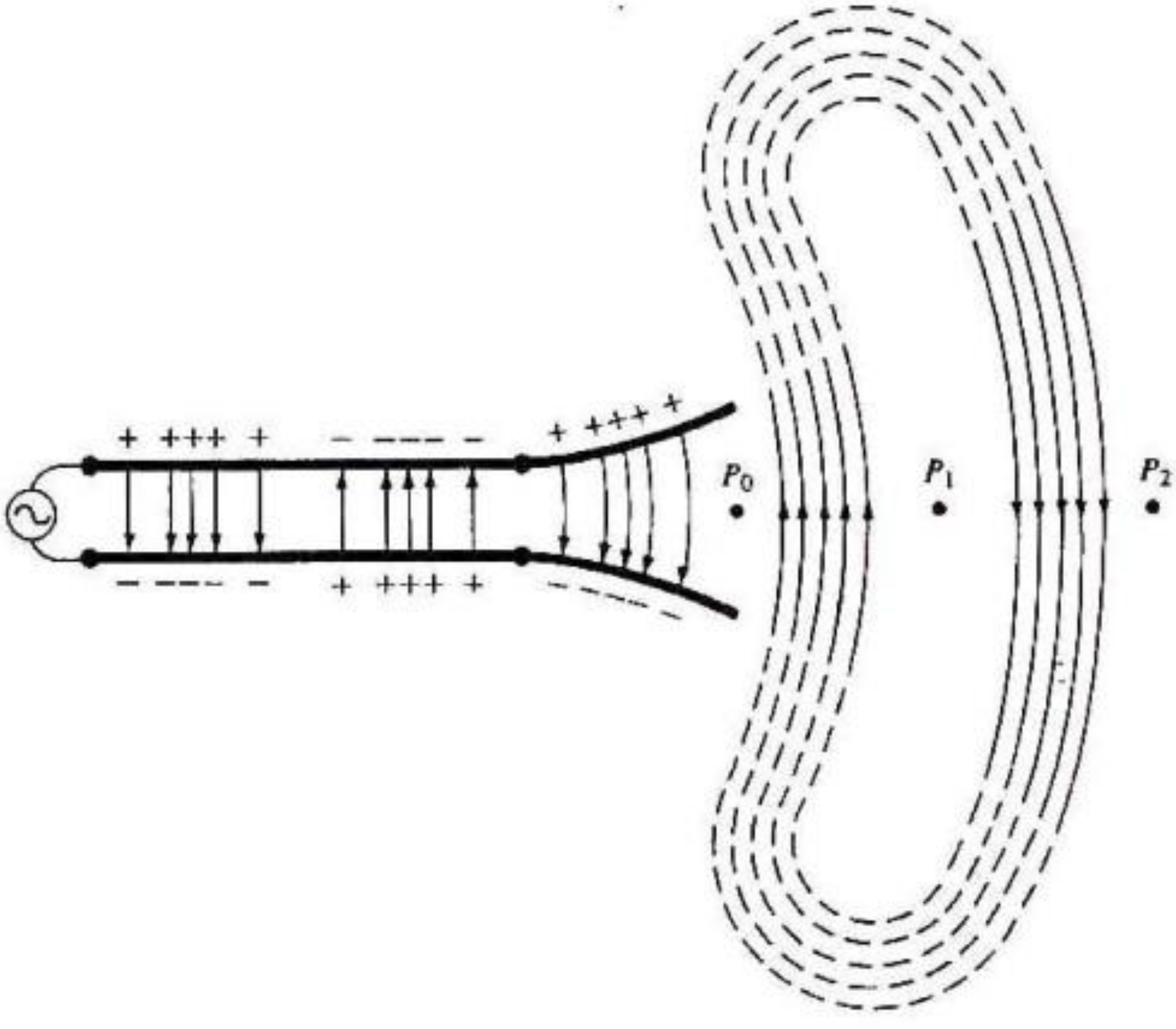
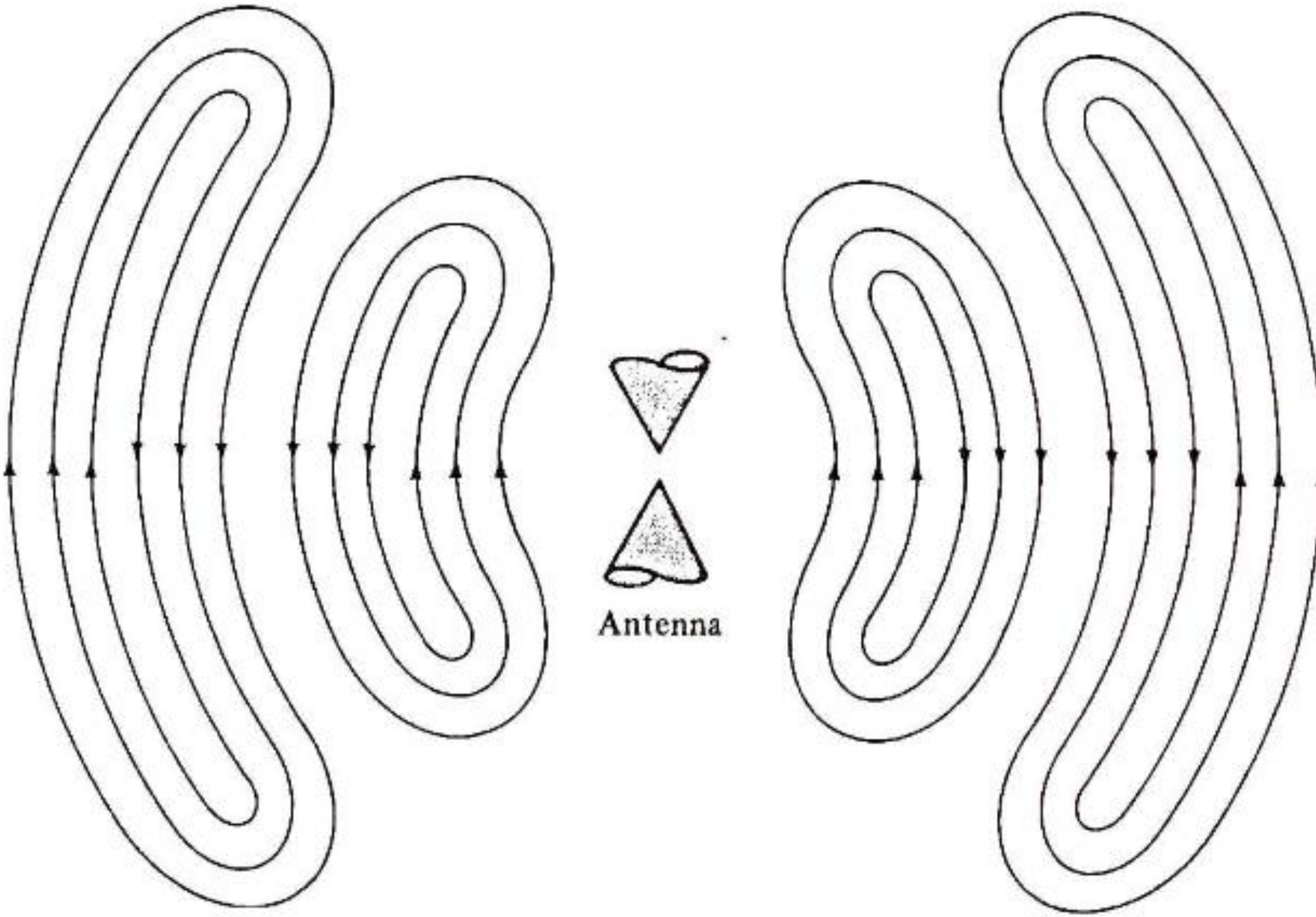
Fields of a Time Harmonically Excited Dipole Antenna

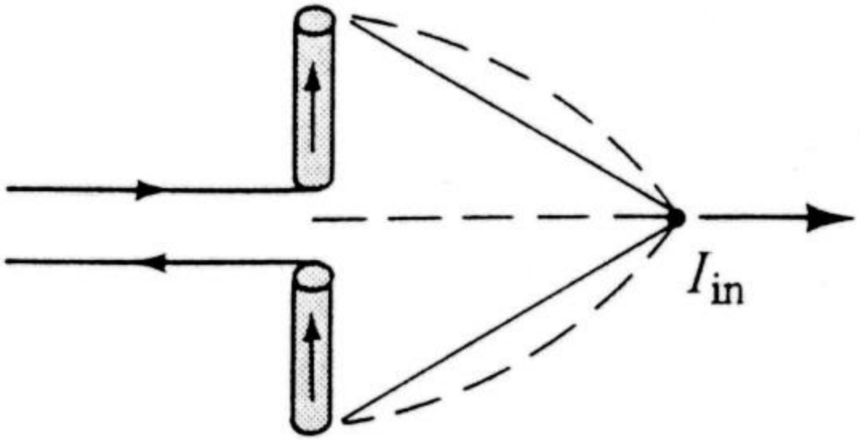




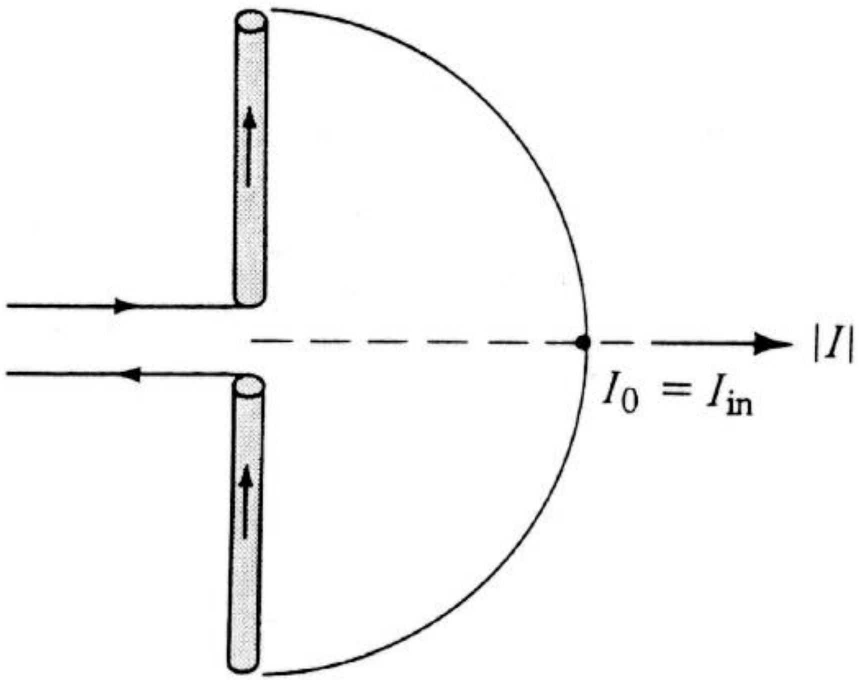
P_0
P_1
P_2


Antenna

Current Distribution of Linear Antennas



$$\ell << \lambda$$



$$\ell = \lambda / 2$$

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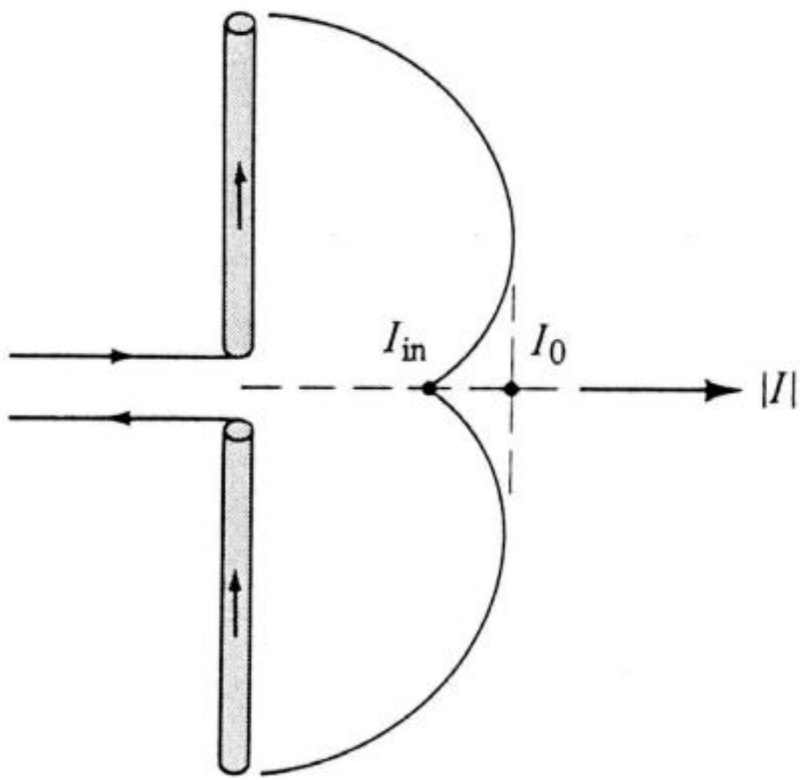
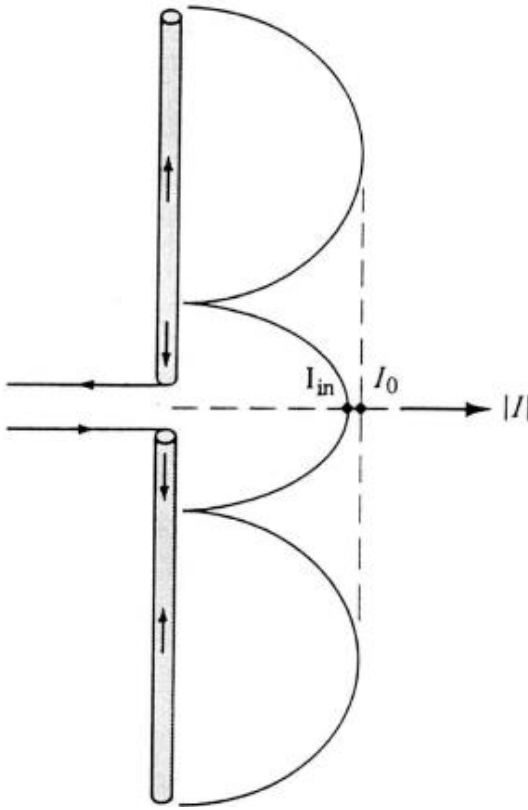
Current Distribution of Linear Antennas



$$\lambda / 2 < \ell < \lambda$$



$$\lambda < \ell < 3\lambda / 2$$

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Fundamental Parameters of Antennas

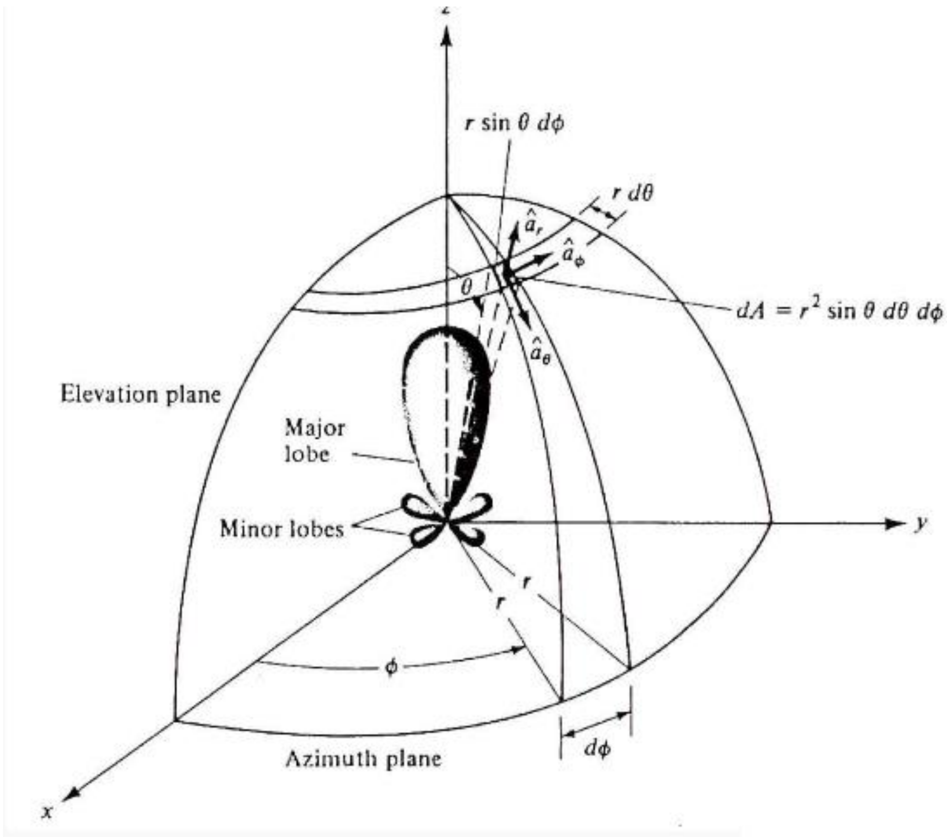
- There are several fundamental parameters (system level parameters) that can be used for assessing the performance of any antenna.
- These parameters are:
  - Radiation Pattern
  - Radiation Power Density
  - Radiation Intensity
  - Beam Width
  - Directivity
  - Gain
  - Beam Efficiency
  - Bandwidth
  - Antenna Efficiency
  - Polarization
  - Radiation Efficiency
  - Input Impedance
  - Antenna Vector Effective Length
  - Equivalent Areas
  - Maximum Directivity and Maximum Effective Area

Fundamental Parameters of Antennas

- Radiation Pattern
  - Radiation pattern is defined as **"a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates"**
  - Radiation pattern is defined in the far field
  - It is represented as a function of the directional coordinates
- Radiation properties
  - Power flux density, radiation intensity, field strength, directivity, phase, or polarization
  - The radiation property of most concern is the two- or three-dimensional spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius.

Radiation Pattern

- We generally use the spherical coordinate system
- For r=constant, measure the amplitude of **E** or **H** and plot it
  - This will give you the field pattern
- Similarly, for r=constant, measure the power density for every point on a sphere
  - This will give you the power pattern



Radiation Patterns

- We will almost always normalize the radiation pattern values to the maximum value
  - i.e., on a constant r sphere, you will measure various |**E**| and |**H**| values. Normalize everything to max(|E|), etc.
  - Why do we do this? Because we don't care about absolute values. They do depend on the distance from source and we have better ways of quantifying these parameters
  - We want to see how the spatial distribution changes
- We also, almost always, use dB. Never use linear scales
- Do you know what dB is?
- Why is dB preferred?

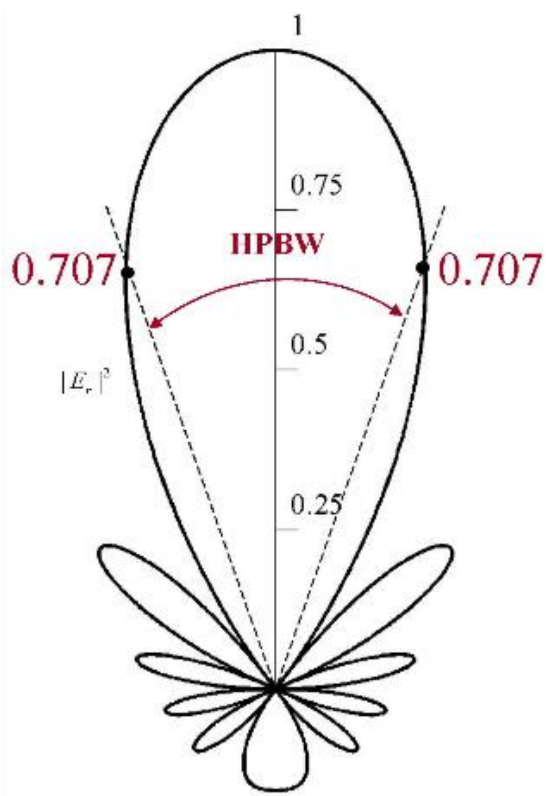
dB: A short Review

- **Lets assume we have V (voltage) and P (power)**
  - $dBV = 20 * \log_{10}(V/(1 \text{ volts}))$
  - $dBW = 10 * \log_{10}(P/(1 \text{ Watt}))$
- **Similarly, we can have:**
  - $dBmV = 20 * \log_{10}(V/(1 \text{ mv}))$, $dBuV = 20 * \log_{10}(V/(1 \text{ uv}))$
  - $dBm = 10 * \log_{10}(P/(1 \text{ m-Watts}))$, $dBu = 10 * \log_{10}(P/(1 \text{ u-Watts}))$
- **For example:**
  - 10 Volts = 20 dBV = 80 dBmV = 140 dBuV
  - 10 Watts = 10 dBW = 40 dBm = 70 dBu

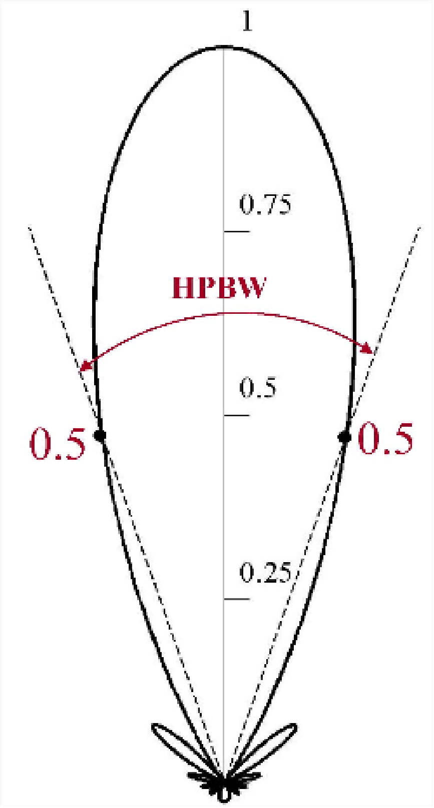
Different Types of Radiation Patterns!

- Field Pattern (Linear Scale): Plot of the $|\mathbf{E}|$ or $|\mathbf{H}|$ as a function of the angular space.
- Power Pattern (Linear Scale): Plot of the $|\mathbf{E}|^2$ or $|\mathbf{H}|^2$ as a function of the angular space.
- Power Pattern (dB): $|\mathbf{E}|$ or $|\mathbf{H}|$ in dB
  - Note that $20*\log(|\mathbf{E}|)=10*\mathrm{Log}(|\mathbf{E}|^2)$
  - Also note that power density in the far field is $|\mathbf{E}|^2/Z_0$.
  - Therefore, the field pattern in dB and the power pattern in dB, provided that they are normalized, are exactly identical
- A radiation pattern is a three-dimensional graph and we generally plot a 2D cut of this pattern.

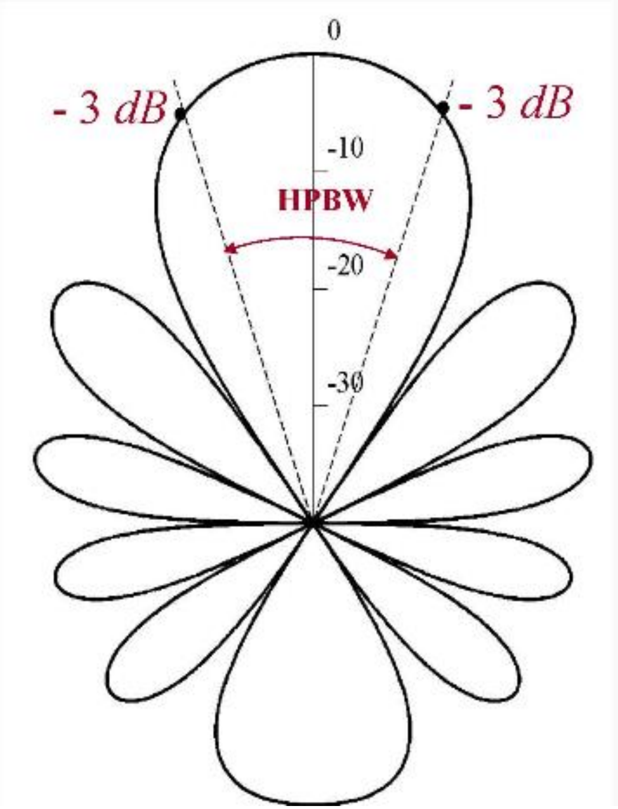
Radiation Patterns of a 10 Element Linear Array with d=0.25λ



Field Pattern (Linear Scale)

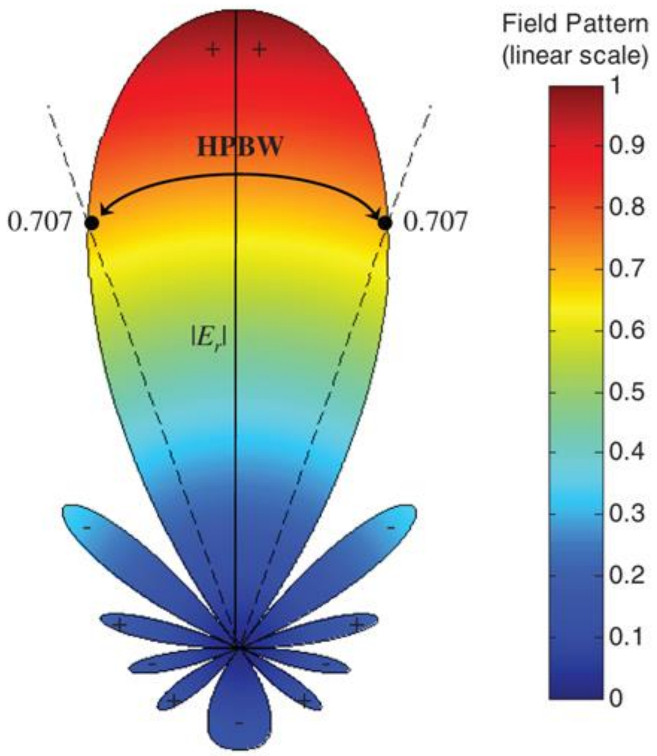


Power Pattern (Linear Scale)

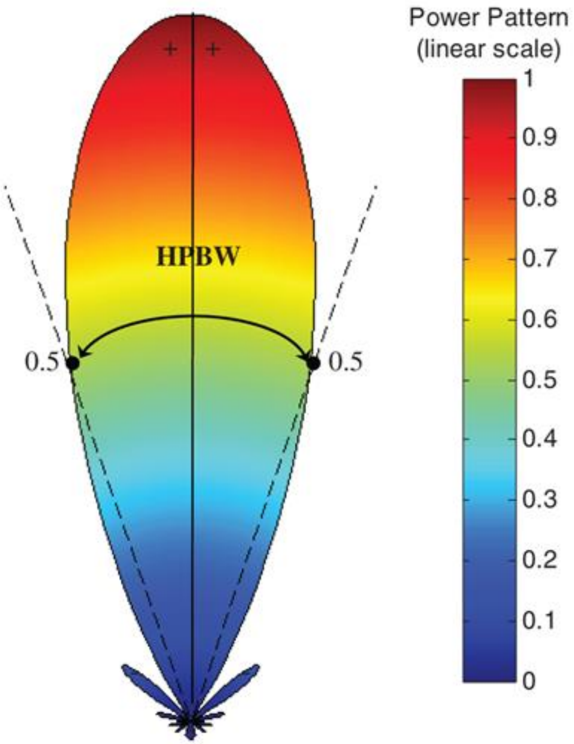


Power Pattern (dB Scale)

Radiation Patterns of a 10 Element Linear Array with d=0.25λ

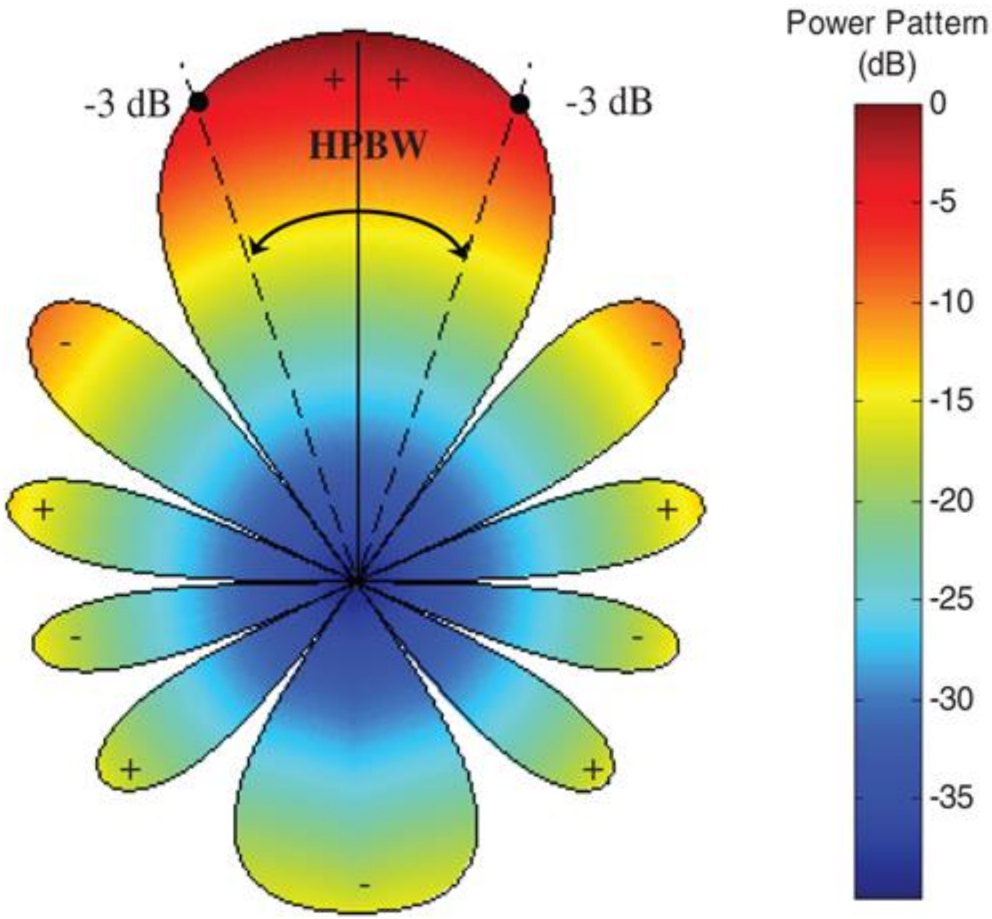


Field Pattern
(Linear Scale)



Power Pattern
(Linear Scale)

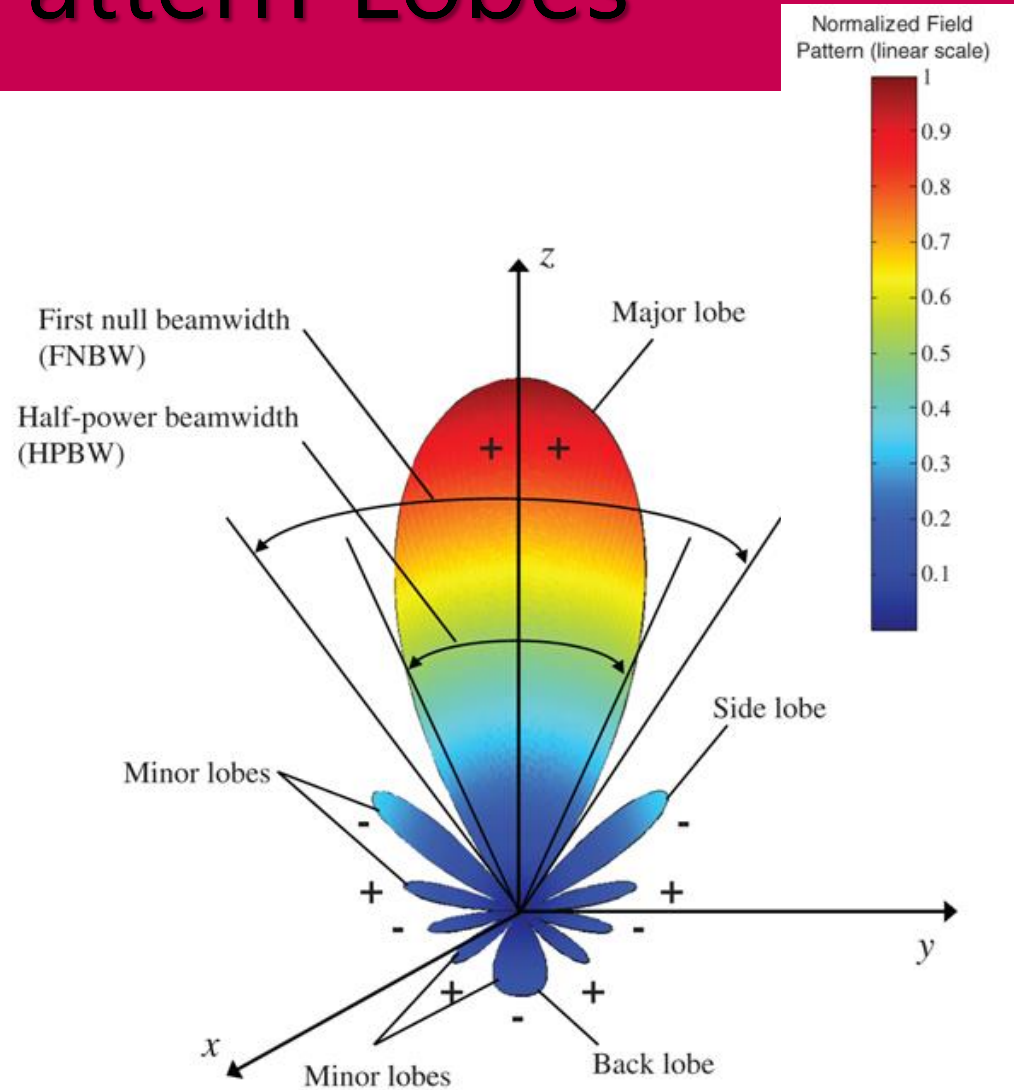
Radiation Patterns of a 10 Element Linear Array with d=0.25λ



Power Pattern (dB Scale)

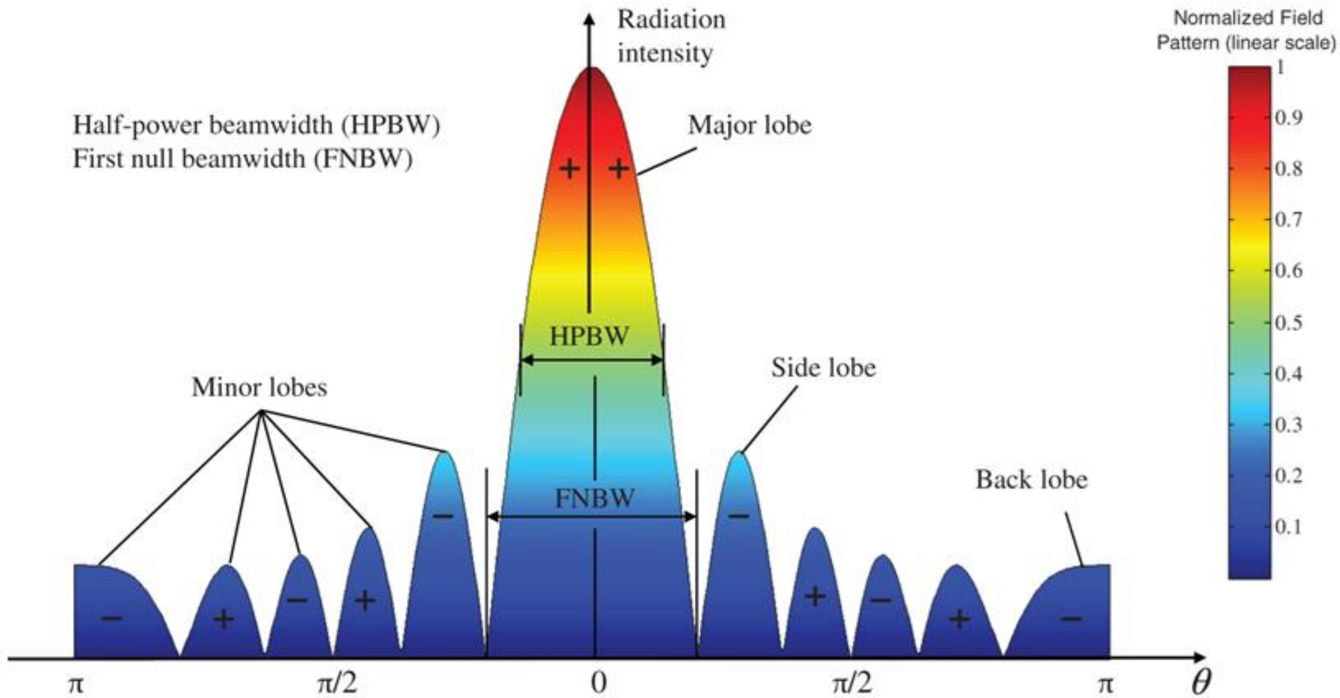
Radiation Pattern Lobes

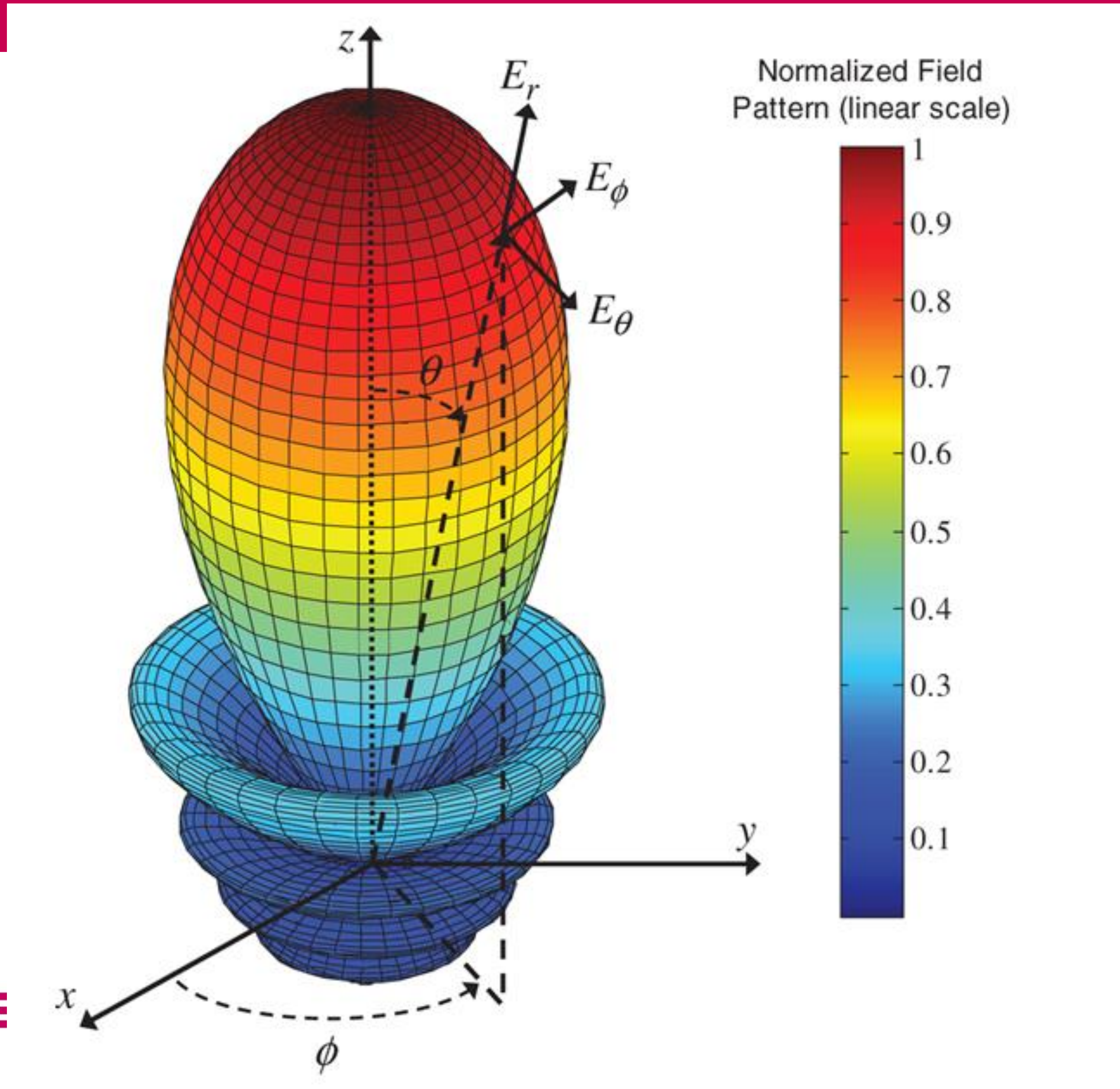
- Various parts of a radiation pattern are referred to as lobes.
  - Major or main lobe, minor lobe, side lobe, and back lobes.
- A radiation lobe is a “portion of the radiation pattern bounded by regions of relatively weak radiation intensity”.
- Major lobe or main beam Radiation lobe containing the direction of maximum radiation.



Radiation Patterns and Lobes

- In some antennas, we can have more than one major lobe.
- A minor lobe is any lobe other than the major lobe.




z
E_r
E_ϕ
E_θ
θ
y
x
ϕ
Normalized Field
Pattern (linear scale)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

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Side and Back Lobes

- A side lobe is "a radiation lobe in any direction other than the intended lobe"
  - Usually a side lobe is adjacent to the main beam and occupies the same hemisphere in the direction of the main beam.
- A back lobe is "a radiation lobe whose axis makes an angle of approximately 180° with respect to the main beam of the antenna"
  - Usually it refers to a minor lobe that occupies the hemisphere in a direction opposite to that of the major lobe.
- Minor lobes usually represent radiation in undesired directions and they should be minimized.
- Side lobes are usually the largest of minor lobes.

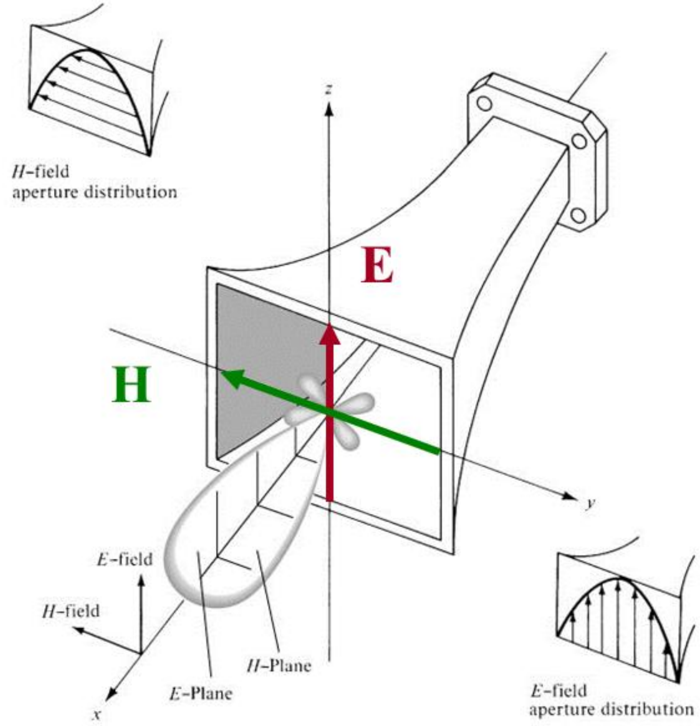
Side and Back Lobes

- The level of minor lobes is usually expressed as a ratio of the power density in the lobe in question to that of the major lobe.
- Side lobe level
- Larger SLLs are generally not desired. Although, it depends on the application.
- In radar applications, we need very small SLLs (smaller than -30 dB).
- This minimizes the chances of false alarm and reduced the jamming susceptibility of your radar by enemy's ECM system

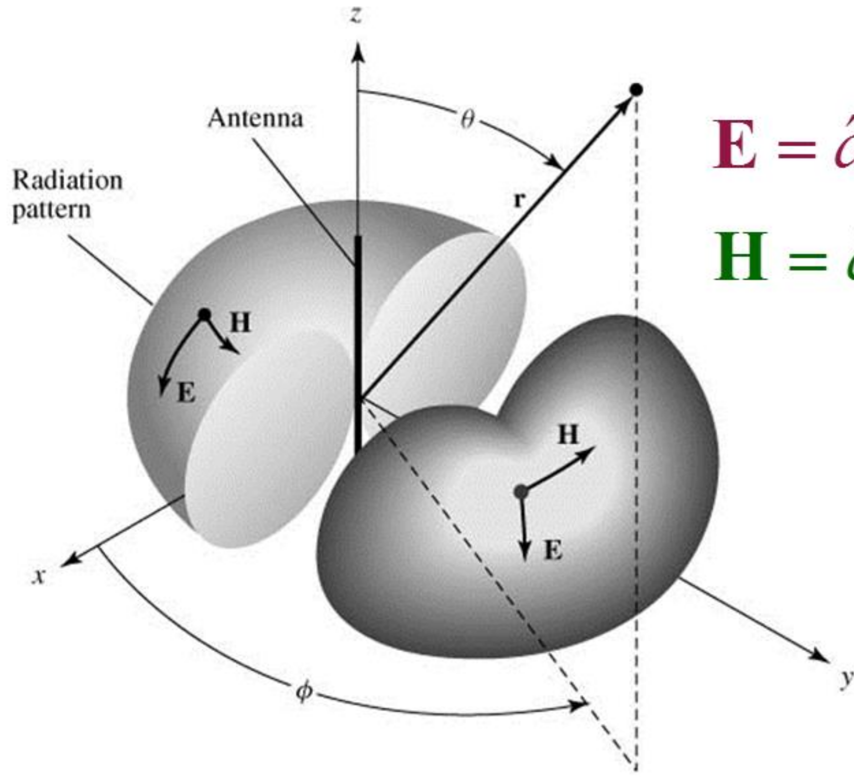
Isotropic, Directional, and Omnidirectional Patterns

- An isotropic radiator is defined as "**a hypothetical lossless antenna having equal radiation in all directions**"
- Isotropic Radiators DO NOT exist!!!!
- **It is often taken as a reference for expressing the directive properties of actual antennas**
- A directional antenna is one "**having the property of radiating or receiving electromagnetic-waves more effectively in some directions than others**".
- This term is usually used for an antenna whose maximum directivity is significantly greater than that of a $\lambda/2$ dipole
- Omni-directional antenna: is an antenna having essentially a non-directional radiation pattern in one plane and a directional pattern in any orthogonal plane.

Directional, and Omnidirectional Patterns



Directional Antenna



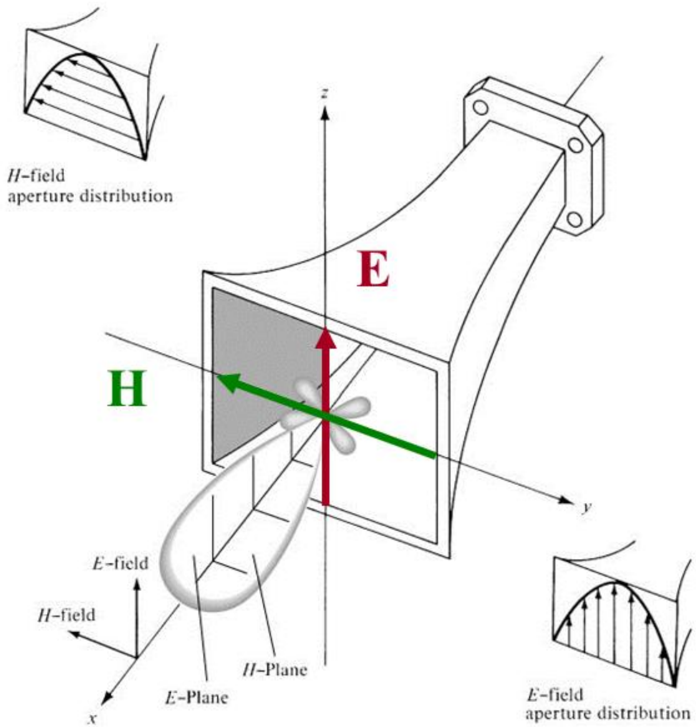
$$\mathbf{E} = \hat{a}_\theta E_\theta$$

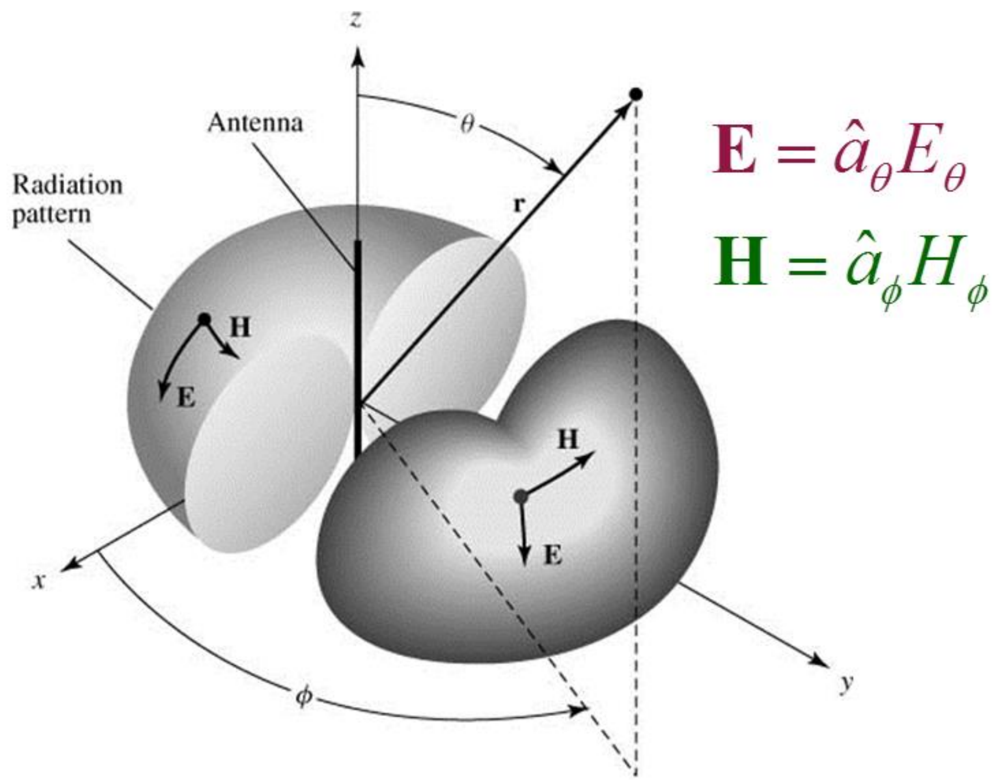
$$\mathbf{H} = \hat{a}_\phi H_\phi$$

Omni-Directional Antenna

Directional in one plane (Elevation Plane) and non-directional in another (Azimuth)

Directional and Omnidirectional Radiation Patterns





X-Z Plane: E-Plane

Y-Z Plane: H-Plane

X-Z Plane: E-Plane

Y-Z Plane: H-Plane