Spring 2019

EECE 588
Lecture 10

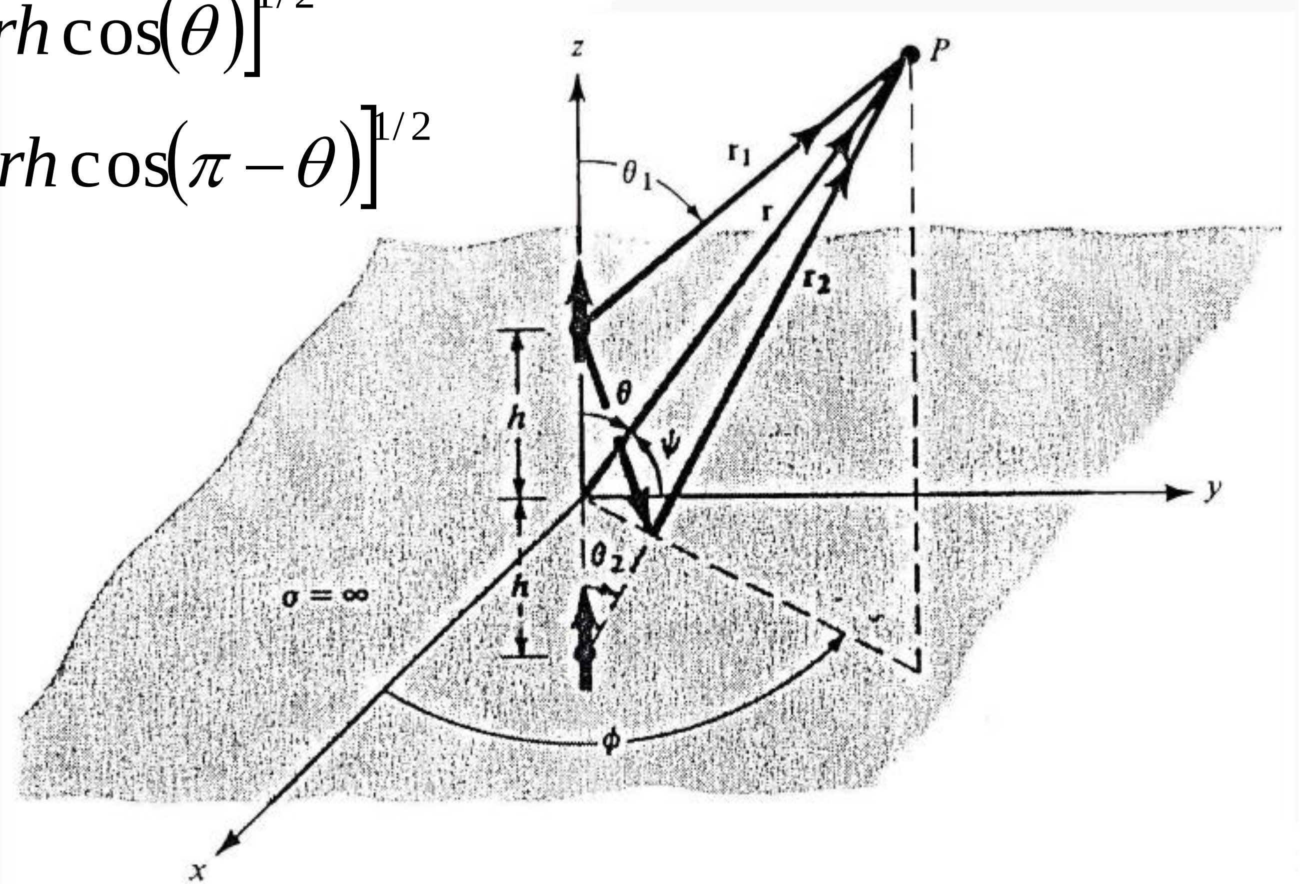
Prof. Wonbin Hong

Analyzing the Vertical Electric Dipole Above PEC

- We use the image theory in conjunction with superposition:

$$r_1 = \left[r^2 + h^2 - 2rh\cos(\theta)\right]^{1/2}$$

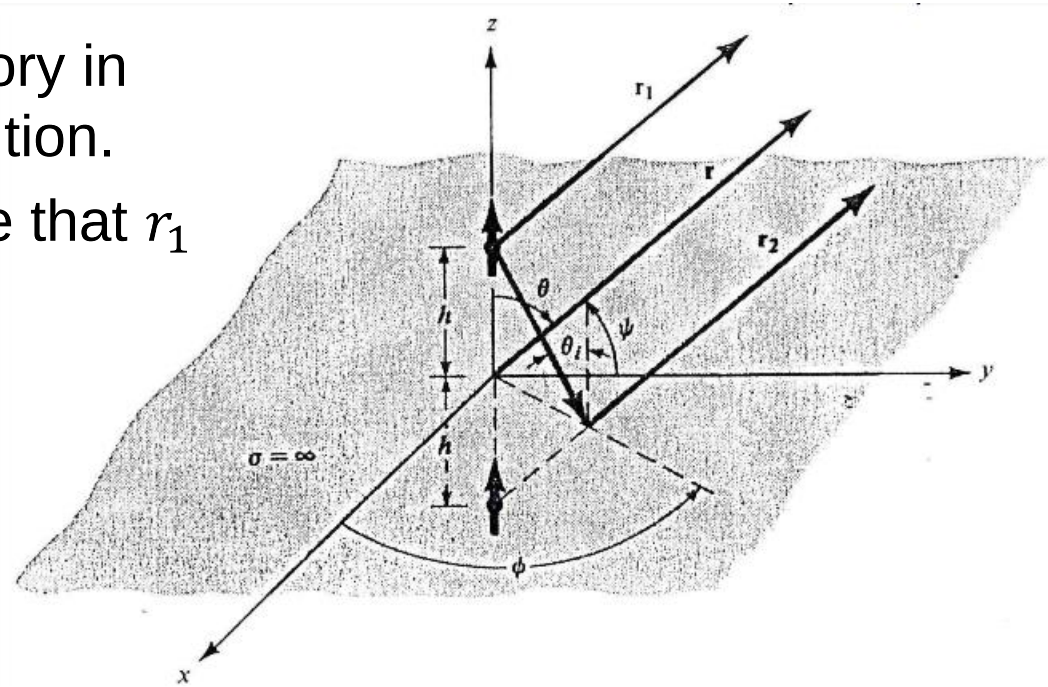
$$r_2 = \left[r^2 + h^2 - 2rh\cos(\pi - \theta)\right]^{1/2}$$



POSTECH

Analyzing the Vertical Electric Dipole Above PEC

- We will use the image theory in conjunction with superposition.
- In far field, we can assume that r_1 and r_2 are in parallel:



$$r_1 \approx r - h\cos(\theta)$$

$$r_2 \approx r + h\cos(\theta)$$

$$E_\theta^d = j\eta \frac{klI_0 e^{-jkr_1}}{4\pi r_1} \sin\theta_1 \qquad E_\theta^r = j\eta \frac{klI_0 e^{-jkr_2}}{4\pi r_2} \sin\theta_2$$

POSTECH

Analyzing the Vertical Electric Dipole Above PEC

- The total field is the sum of the two fields.
- To simplify the expressions, we use the following approximations:

For Phase $\boxed{r_1 \approx r - h\cos(\theta),\ r_2 \approx r + h\cos(\theta)}$

Amplitude $\boxed{r_1 \approx r_2 \approx r}$

$$E_\theta \approx j\eta \frac{klI_0 e^{-jkr}}{4\pi r} \sin\theta [2\cos(kh\cos\theta)] \qquad z \geq 0$$

$$E_\theta = 0 \qquad z < 0$$

POSTECH

Element and Array Factors

- Note that the expression for the total electric field is viewed as

$$E_\theta \approx \underbrace{j\eta \frac{klI_0 e^{-jkr}}{4\pi r} \sin\theta}_{\text{Field of a single electrically small dipole}} \times \underbrace{\left[2\cos(kh\cos\theta)\right]}_{\text{A Factor which is a function of the antenna height and observation angle (the array factor)}}$$

Field of a single electrically small dipole

A Factor which is a function of the antenna height and observation angle (the array factor)

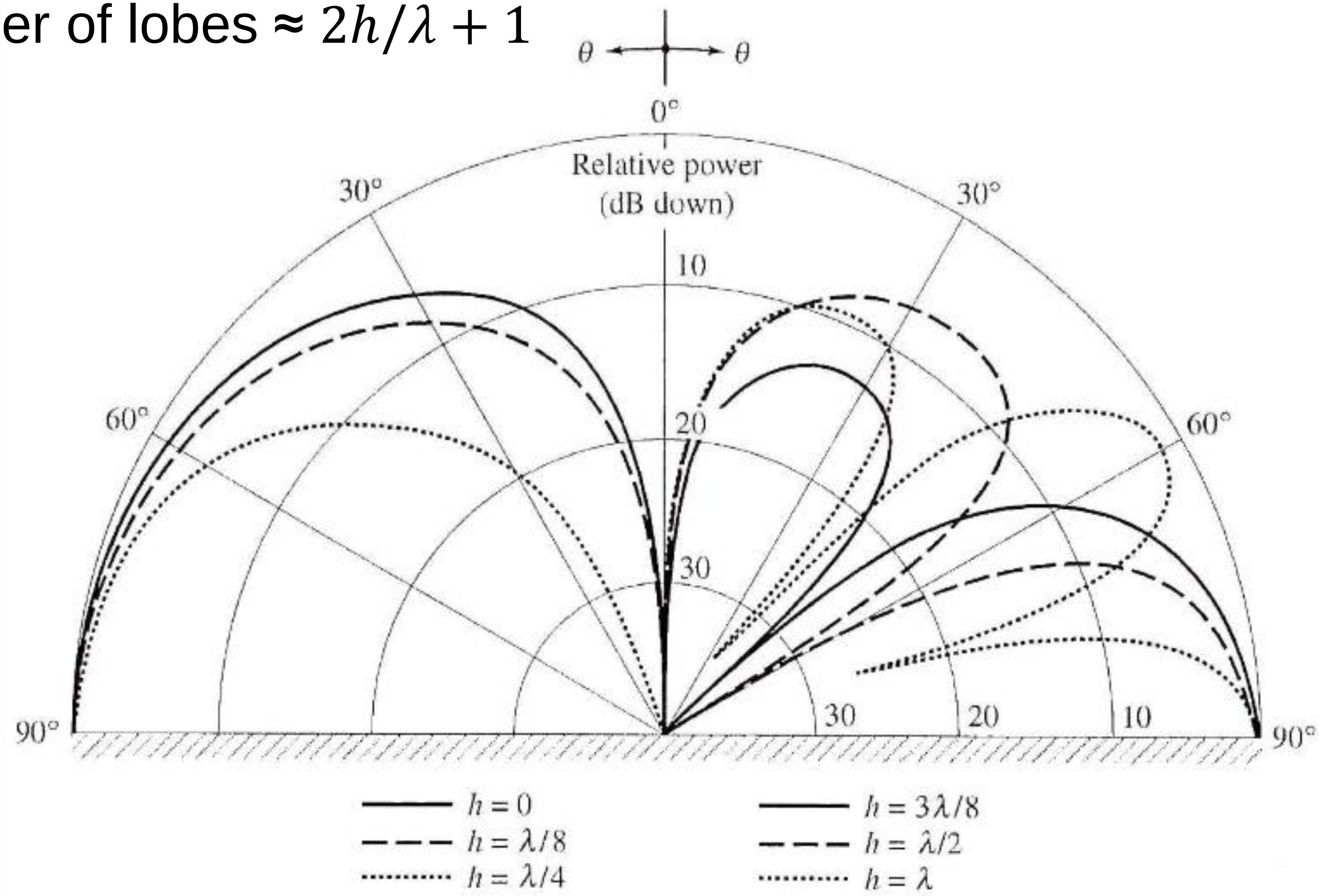
Element and Array Factors

- Note that the array factor has nothing to do with the element itself.
- It is only a function of the relative position of the two antennas and the observation angle.

POSTECH

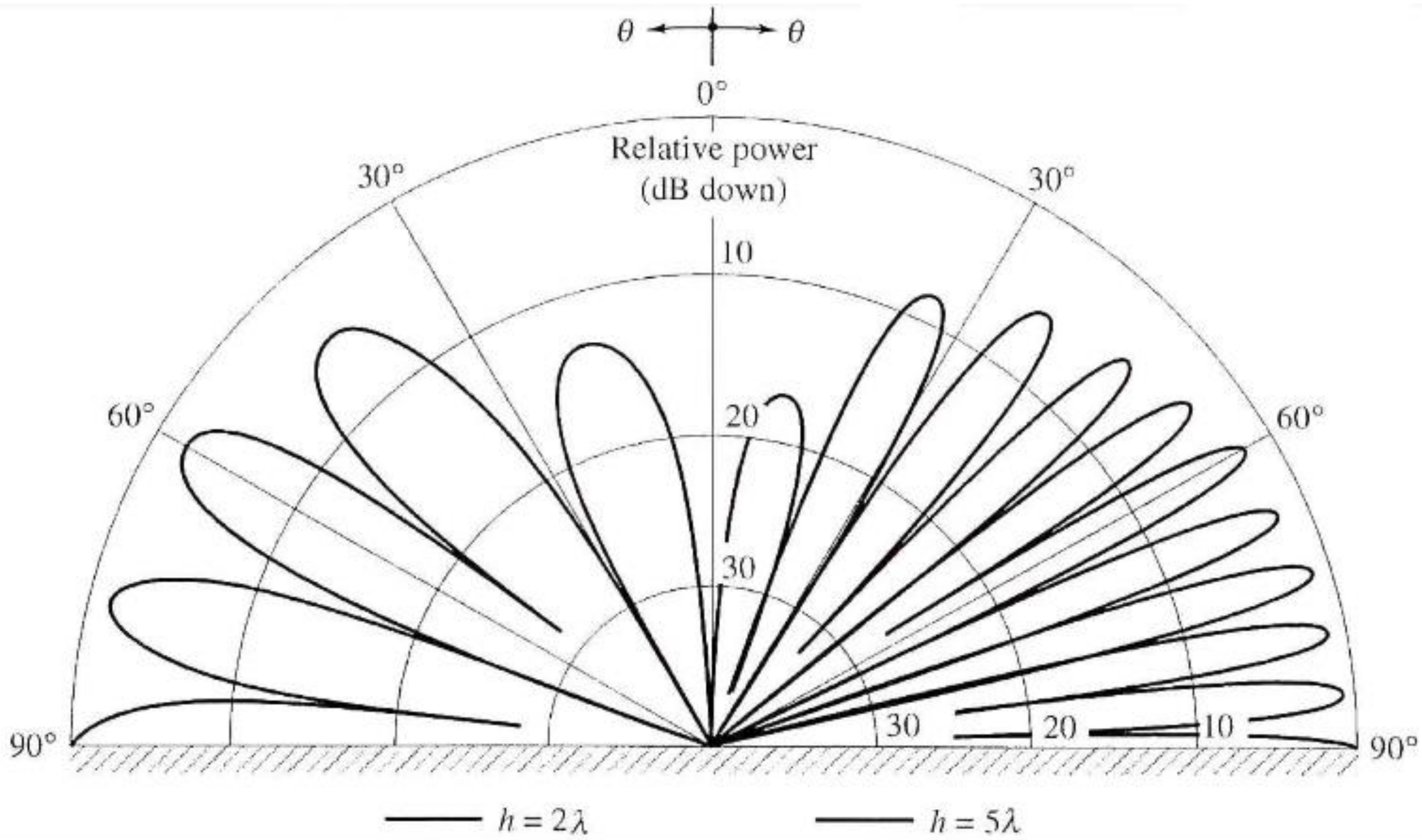
Radiation Patterns

- Number of lobes ≈ $2h/\lambda + 1$



POSTECH

Radiation Patterns



Directivity

$$P_{rad} = \oiint_S \vec{W}_{av} . d\vec{s} = \frac{1}{2\eta} \int_0^{2\pi} \int_0^{\pi/2} |E_\theta|^2 r^2 \sin\theta \, d\theta \, d\varphi = \frac{\pi}{\eta} \int_0^{\pi/2} |E_\theta|^2 r^2 \sin\theta \, d\theta$$

$$P_{rad} = \pi\eta \left| \frac{I_0 l}{\lambda} \right|^2 \left[\frac{1}{3} - \frac{\cos(2kh)}{(2kh)^2} + \frac{\sin(2kh)}{(2kh)^3} \right]$$

As $kh \to \infty$, P_{rad} approaches that of an isolated dipole.

As $kh \to 0$, P_{rad} becomes twice that of an isolated dipole.

$$U = r^2 W_{av} \to U = \frac{\eta}{2} \left| \frac{I_0 l}{\lambda} \right|^2 \sin^2\theta \cos^2(kh\cos\theta)$$

POSTECH

Directivity

$$U_{\max} = U\,\big|_{\theta=\pi/2} \rightarrow U_{\max} = \frac{\eta}{2}\left|\frac{I_0 l}{\lambda}\right|^2$$

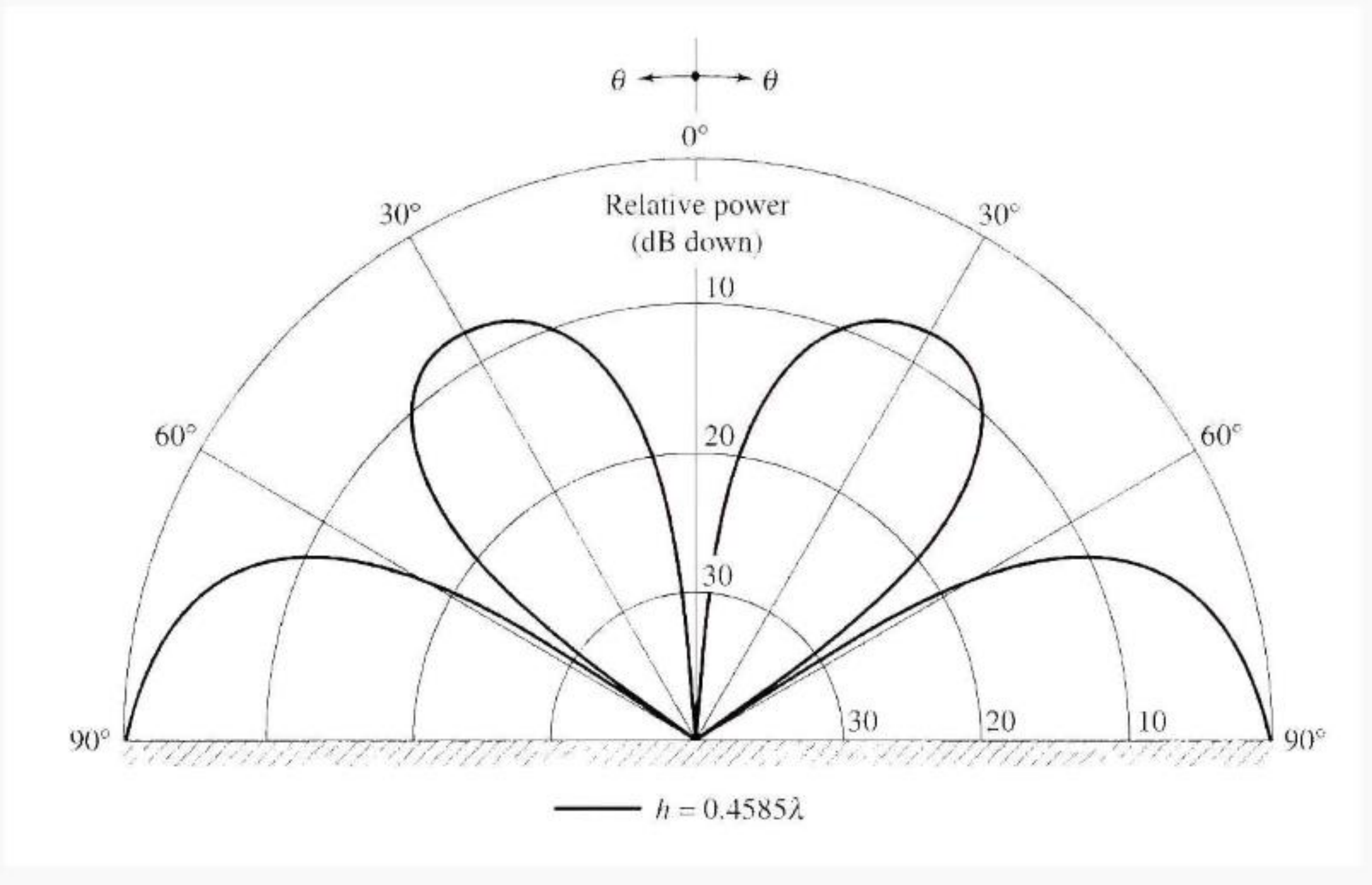
$$D_0 = \frac{4\pi U_{\max}}{P_{rad}} = \frac{2}{\left[\frac{1}{3} - \frac{\cos(2kh)}{(2kh)^2} + \frac{\sin(2kh)}{(2kh)^3}\right]}$$

For $kh = 0$, the value of directivity is 3.

Maximum value of directivity occurs at $kh = 2.88$, ($h = 0.4585\lambda$) and is equal to 6.566.

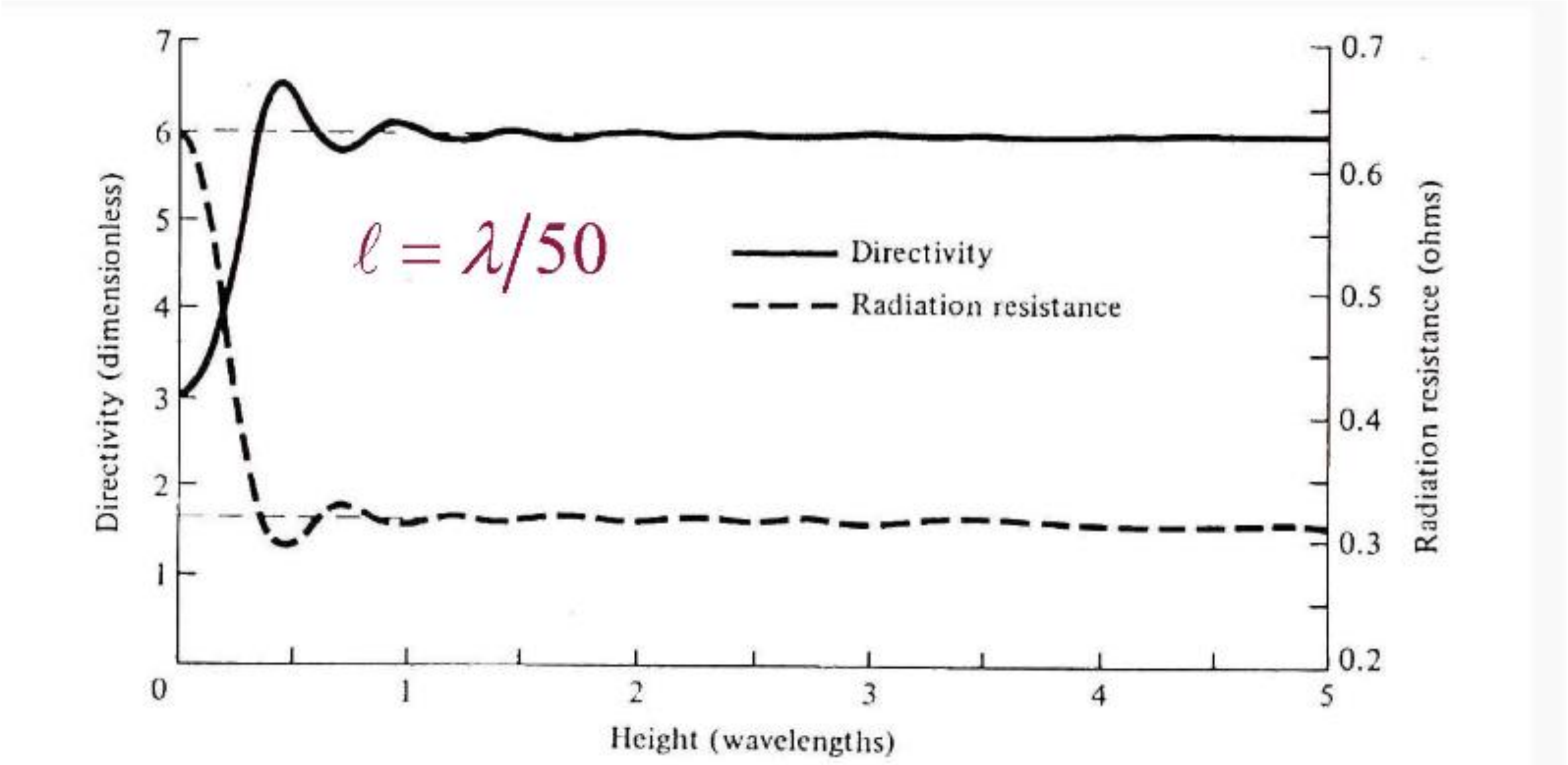
POSTECH

Radiation Patterns at h=0.4585



Directivity and Radiation Resistance

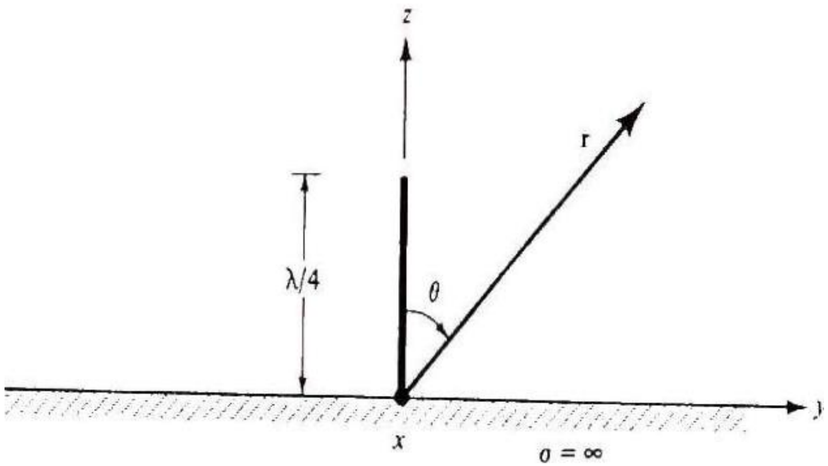
$$R_r = \frac{2P_{rad}}{|I_0|^2} \rightarrow R_r = 2\pi\eta\left(\frac{l}{\lambda}\right)^2\left[\frac{1}{3} - \frac{\cos(2kh)}{(2kh)^2} + \frac{\sin(2kh)}{(2kh)^3}\right]$$



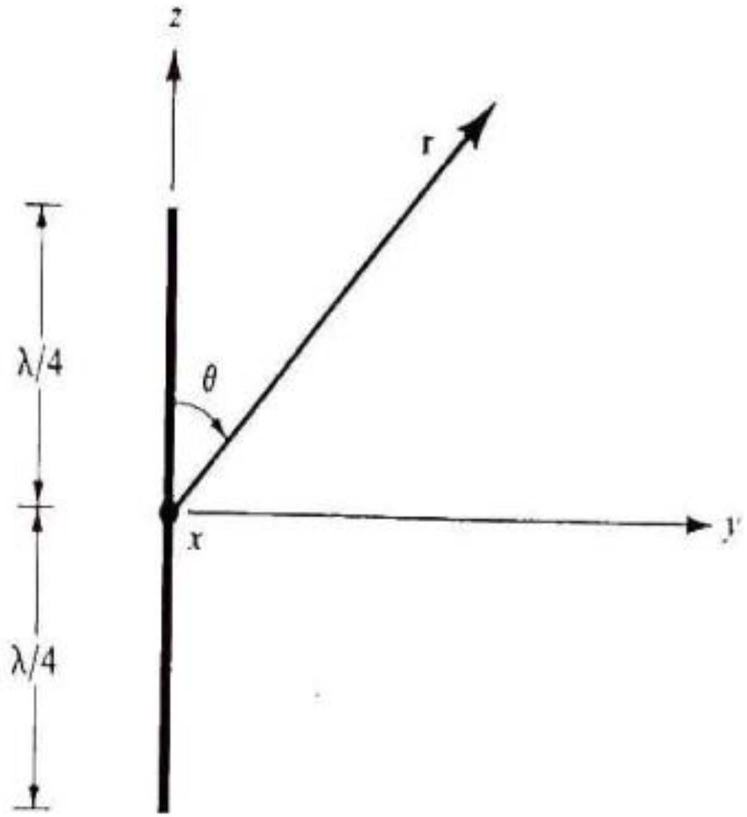
Radiation Resistance

- For $kh \to \infty$ R_r is the same as radiation resistance of isolated element.
- For $kh = 0$, R_r is twice the radiation resistance of isolated element.
- When $kh = 0$, the value of R_r is only one half of the value of an isolated element with $l' = 2l$.

Quarter-Wave Monopole



- The field of the monopole is the same as the field of a dipole due to the image theory.



Directivity and Input Impedance

- However, the fields of the monopole antenna only exist for $z > 0$.
- Therefore, P_{rad} of the monopole is half of P_{rad} of the dipole.
- This means that $Z_{in}\,(monopole) \;=\; ½\, Z_{in}\,(Dipole)$.
  - $Z_{in} = 36.5 + j21.25\ \Omega$.
- Directivity of the monopole is twice that of dipole.
- Note:

$$D = 4\pi U_{max}/P_{rad}$$

POSTECH

VLF/LF Monopole Antennas

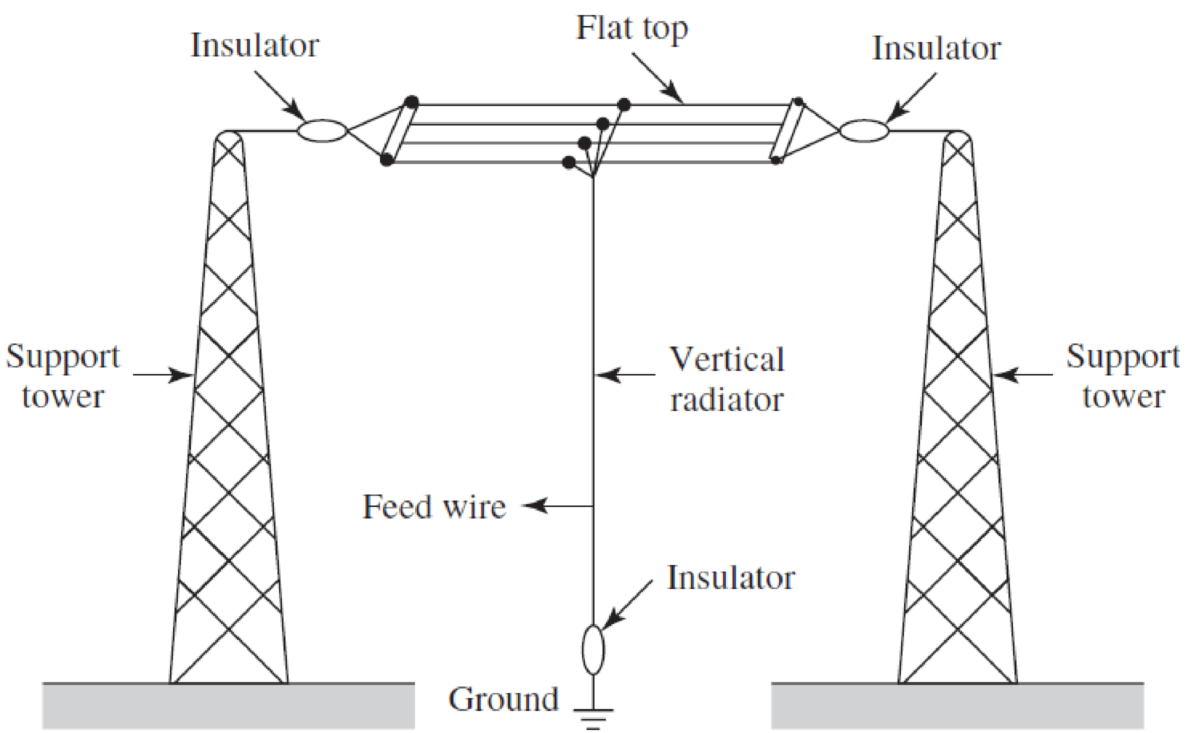


Figure 2.5 A top-loaded short-monopole antenna typical of VLF/LF communication systems.

POSTECH

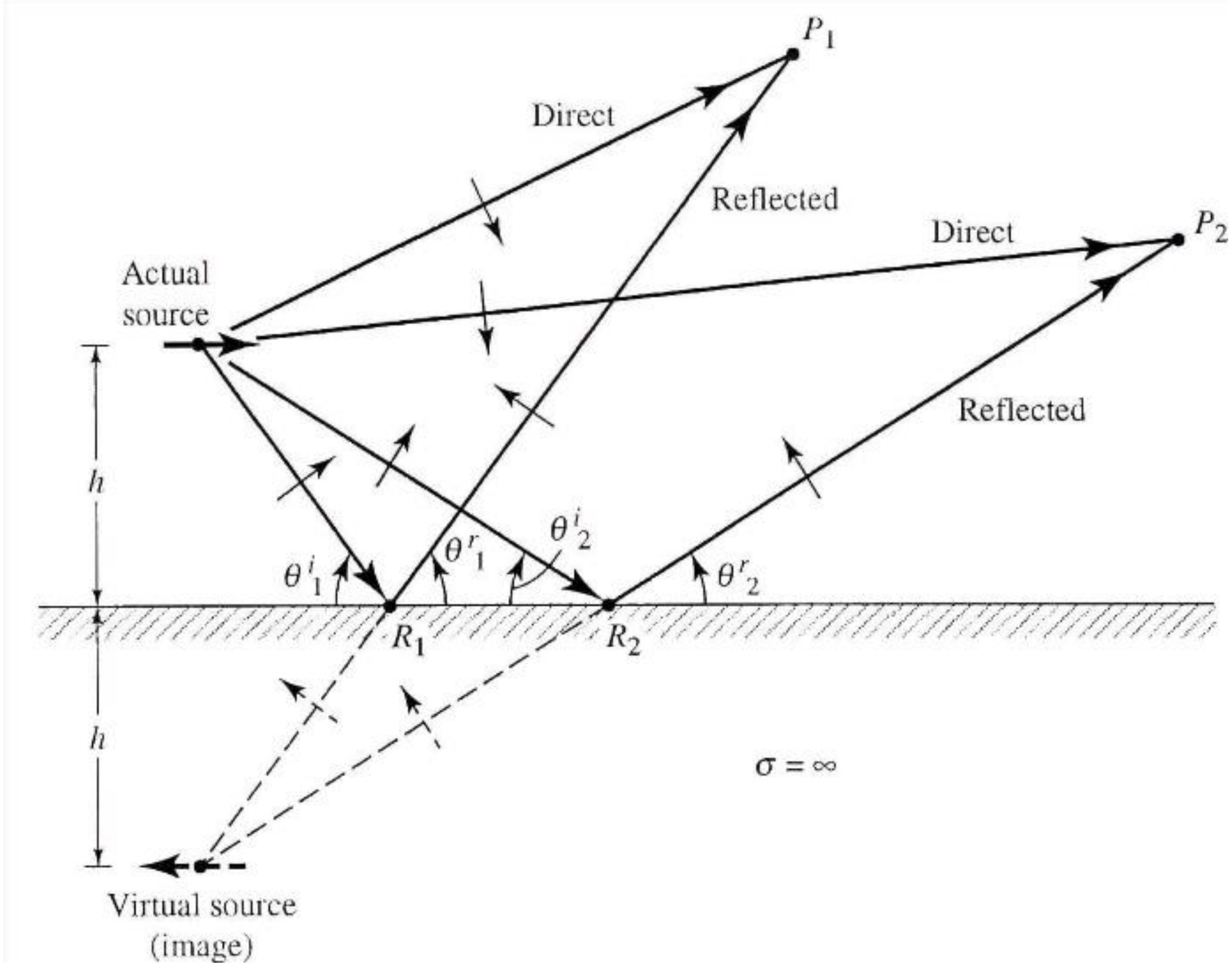
Monopole Antennas (Mast Radiators)

- Image from Wikipedia:
  - http://en.wikipedia.org/wiki/Mast_radiator
  - A typical mast radiator in Chapel Hill, North Carolina. The high RF voltage on the mast can deliver a dangerous electrical shock to anyone touching it. So, the base is surrounded by a fence to prevent access.

Monopole Antennas (Mast Radiators)

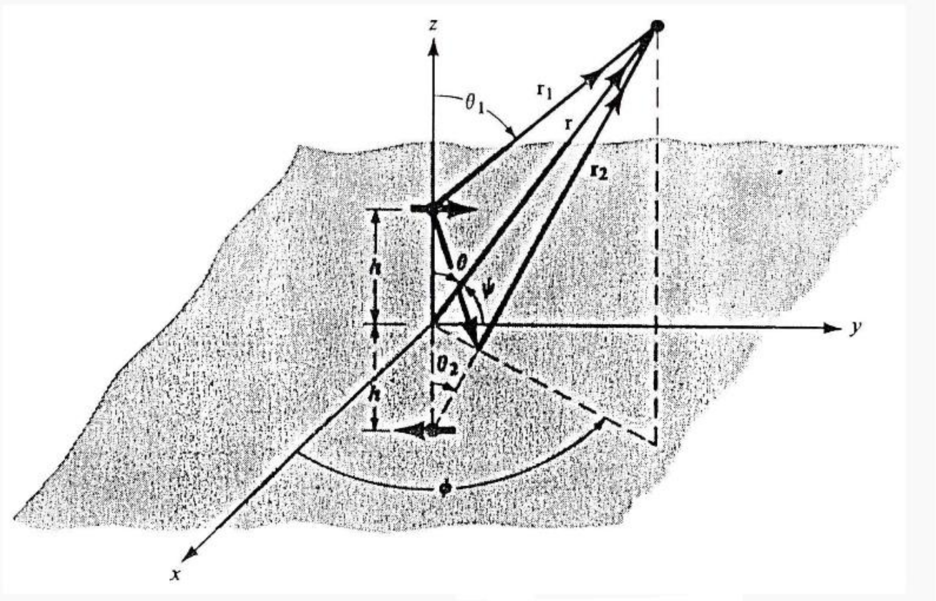
- Image from Wikipedia:
  - http://en.wikipedia.org/wiki/Mast_radiator
- Base feed: Radio frequency power is fed to the mast by a wire attached to it, which comes from an antenna tuning unit inside the "helix building" at right. The brown ceramic insulator at the base keeps the mast isolated from the ground.
- On the left there is an earthing switch and a spark gap for lightning protection.

Horizontal Electric Dipole



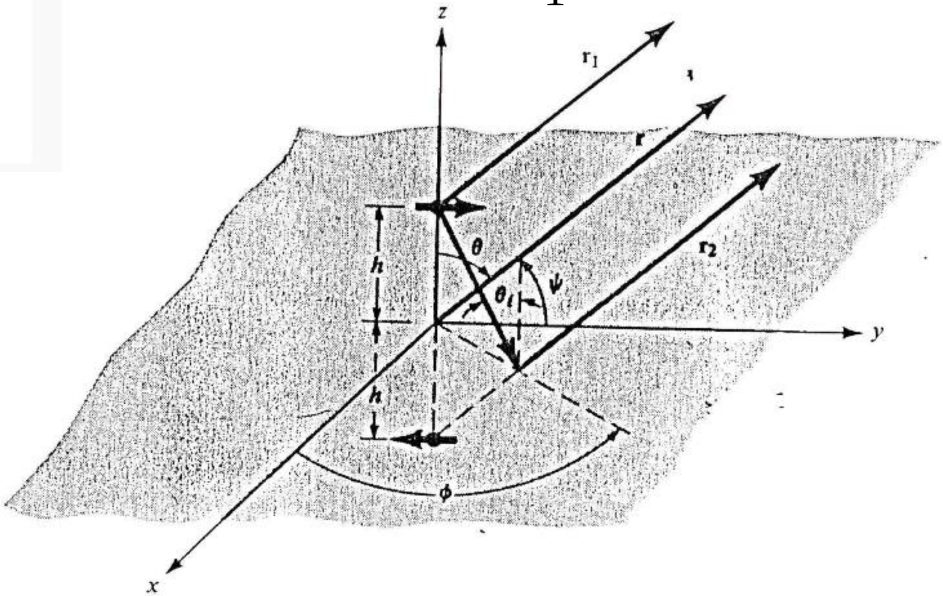
POSTECH

Horizontal Electric Dipole



$$E_{\psi}^{d} = j\eta \frac{klI_0 e^{-jkr_1}}{4\pi r_1} \sin\psi$$

$$E_{\psi}^{r} = -j\eta \frac{klI_0 e^{-jkr_1}}{4\pi r_1} \sin\psi$$



$$E_{\psi}^{r} = -j\eta \frac{klI_0 e^{-jkr_1}}{4\pi r_1} \sin\psi$$

Horizontal Electric Dipole

Note that angle ψ, is measured from the y axis to the observation point.

$$\cos\psi = \hat{y}.\hat{r} = \hat{y}.\left(\hat{x}\sin\theta\cos\varphi + \hat{y}\sin\theta\sin\varphi + \hat{z}\cos\theta\right) = \sin\theta\sin\varphi$$

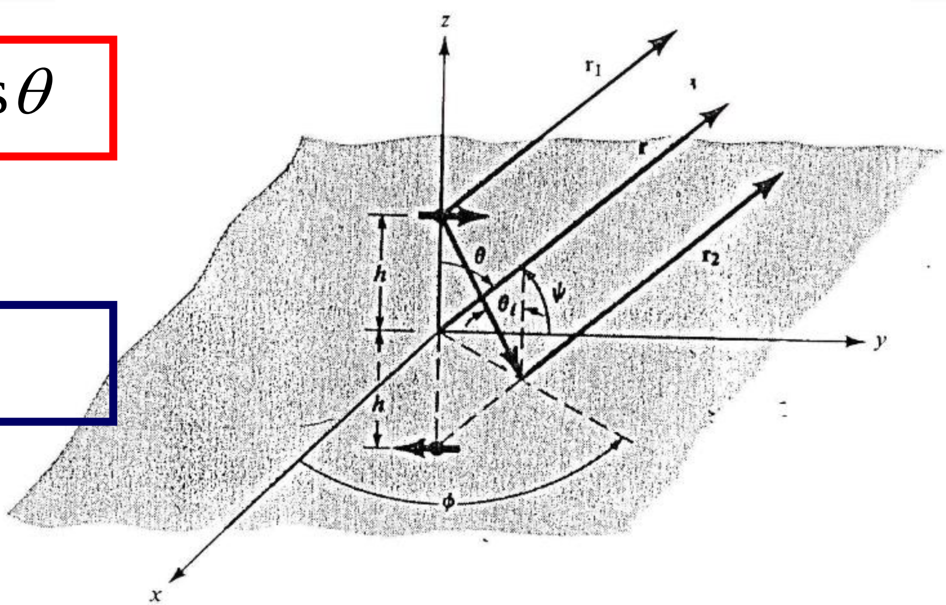
$$\sin\psi = \sqrt{1-\cos^2\psi} = \sqrt{1-\sin^2\theta\sin^2\varphi}$$

$$r_1 \approx r - h\cos\theta \qquad r_2 \approx r + h\cos\theta$$

Phase Variations

$$r_1 \approx r_2 \approx r$$

Amplitude Variations



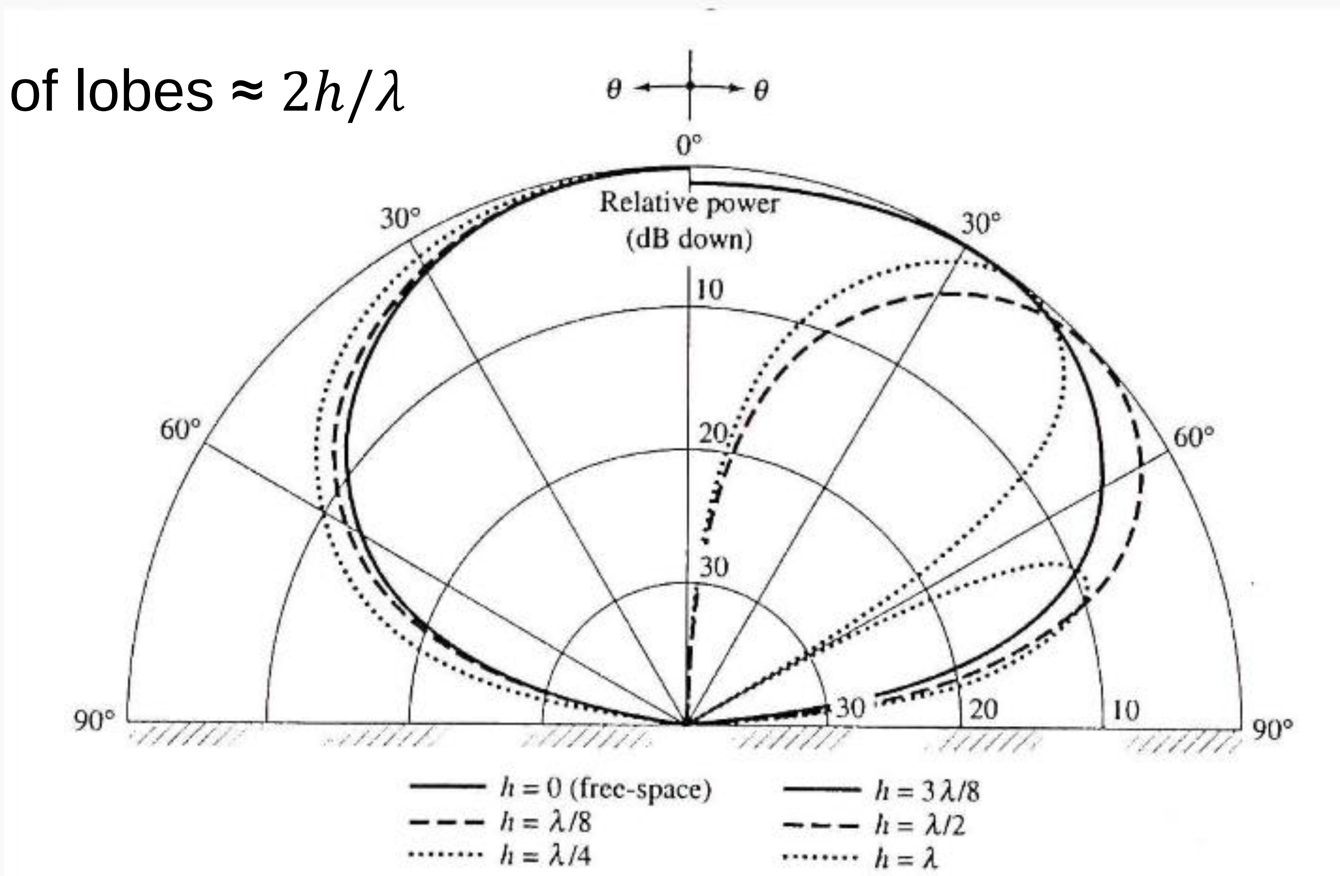
Horizontal Electric Dipole

$$E_\psi = \underbrace{j\eta \frac{klI_0 e^{-jkr}}{4\pi r}\sqrt{1-\sin^2\theta\sin^2\varphi}}_{\text{Element Factor}} \times \underbrace{\left[2j\sin(kh\cos\theta)\right]}_{\text{Array Factor}}$$

Horizontal Electric Dipole

- Number of lobes ≈ $2h/\lambda$

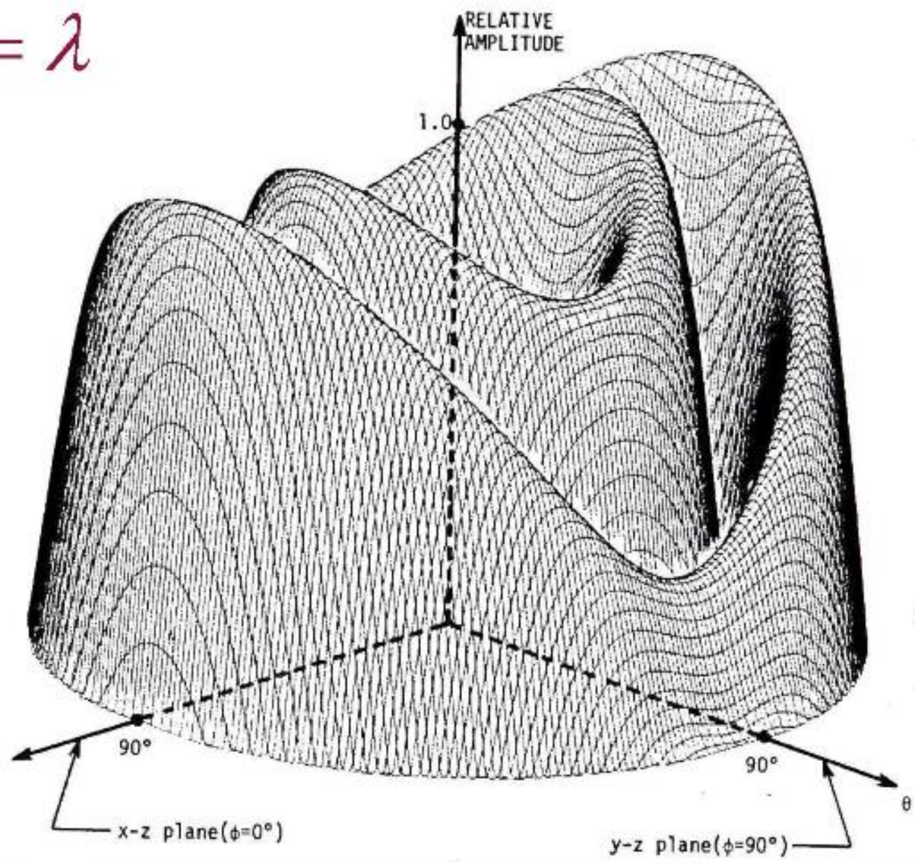
Elevation Plane ($\phi = 90°$) Amplitude Patterns

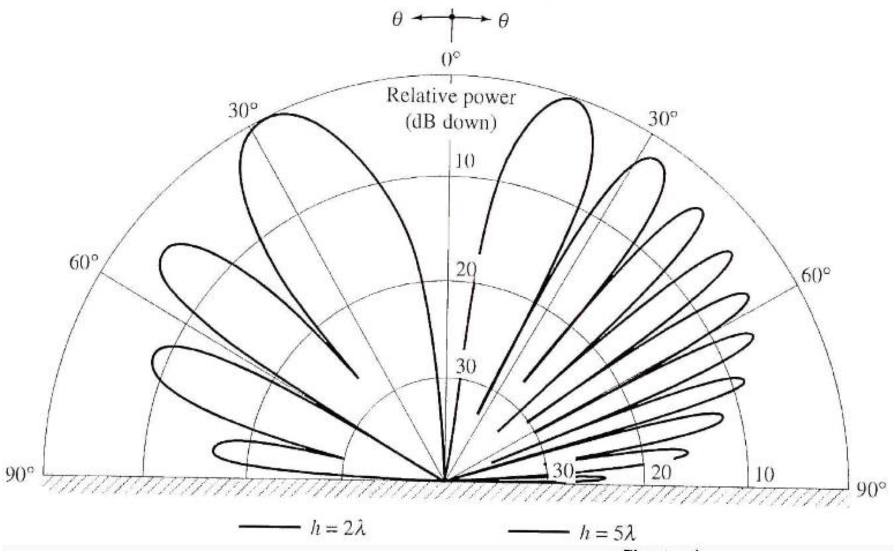


POSTECH

Horizontal Electric Dipole

$h = \lambda$

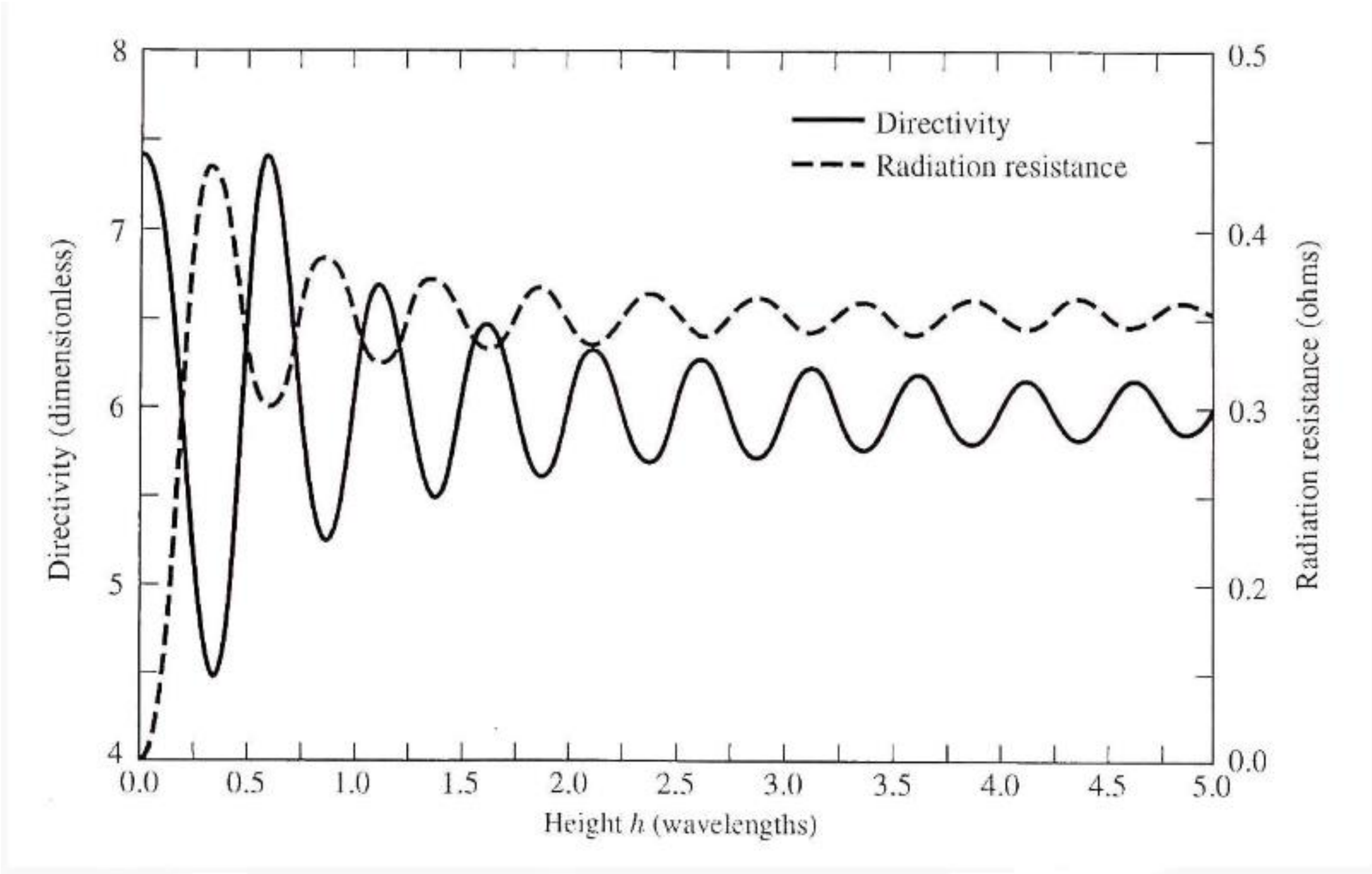




Radiation Resistance and Directivity

- By now, you know how to calculate the radiation resistance and directivity of the antenna.
- In the interest of time, I am not going to go over the details of this calculation:
  - You can see the details in your text.
- However, you are expected to know these details.

Radiation Resistance and Directivity



Ground Effects

- Section 4.8 of your book does not include any new concepts.
- Therefore, in the interest of time, it is assigned to you as a reading assignment.
- **Make sure to read this.**
- **Even though this will not be covered in class, it will be covered in HWs and the exams.**

Specialized Dipole Antennas

- Matching networks of reactive elements are generally required to match the feed-point impedance ($R_a + jX_a$) of center-fed dipoles to transmission lines.
- Typically these lines have characteristic impedance on the order of 300–600, and a thin half-wave dipole has impedance $Z = 73 + j42$. To alleviate the need for matching networks, the dipoles are at times shunt-fed at symmetric locations off the center point as shown in Figure 2.11. This procedure using either the delta match (Figure 2.11a) or the T-match (Figure 2.11b) is often used for half-wave dipoles ($2h = \lambda/2$) with A and B dimensions that are typically on the order of 0.10λ to 0.15λ.

POSTECH