EE540 Advance Electromagnetic Theory & Antennas

Prof. Rakhesh Singh Kshetrimayum

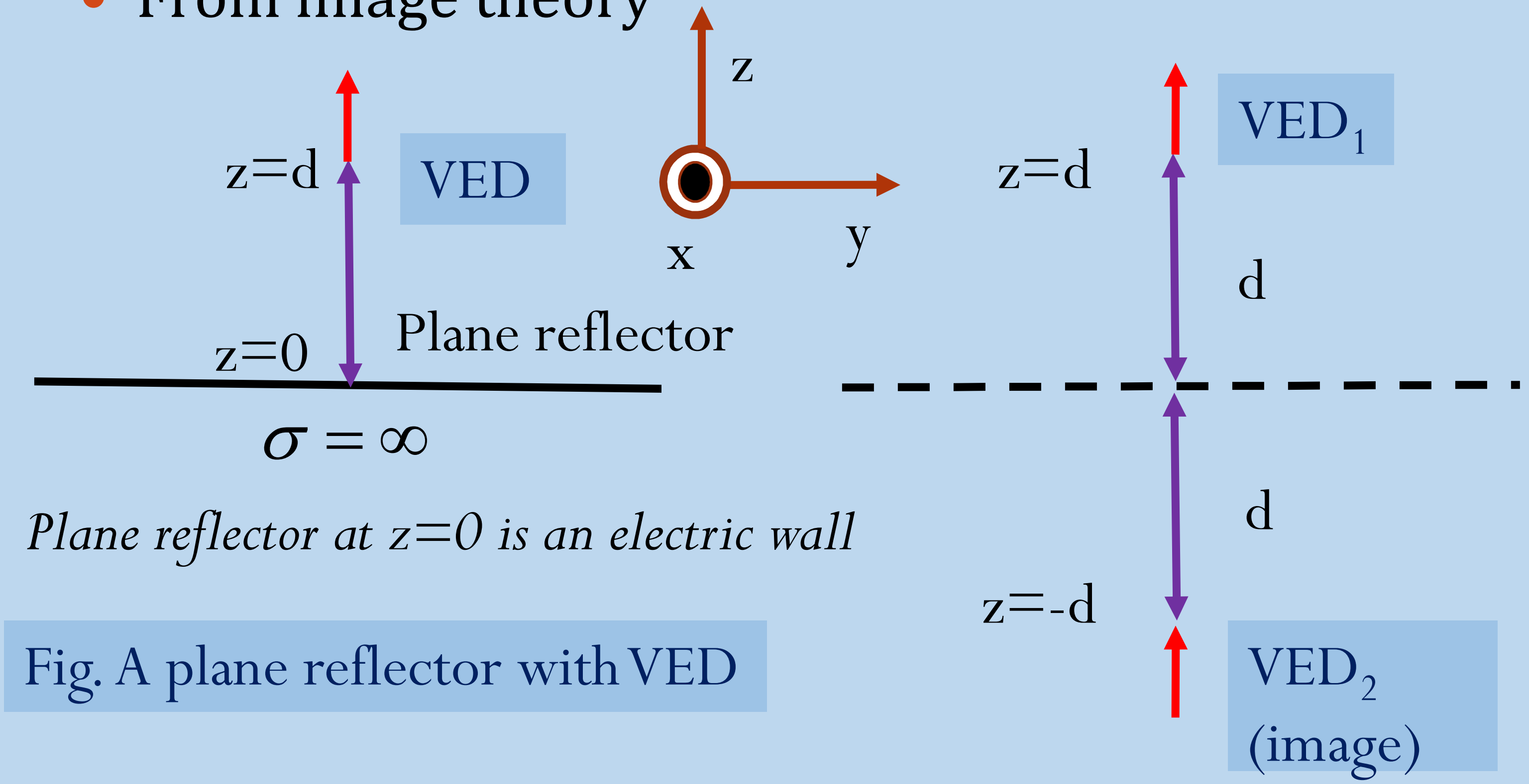
Dept. of EEE, IIT Guwahati, India

Aperture antennas

- *Reflector antennas:*
- What is the motivation for using reflector?
- ***Case study I (VED with a flat-plate reflector):***
  - Consider a z-directed Hertz dipole
  - What was the directivity of Hertz dipole?
  - $D(\theta,\phi) = \frac{3}{2} sin^2\theta$
  - Maximum directivity is 1.5
- Can I increase this directivity of VED without changing the antenna structure?
- It can be achieved with the help of reflectors
- Assume that there is a flat-plate reflector in x-y plane at z=0

Aperture antennas

- From image theory



Plane reflector at z=0 is an electric wall

Fig. A plane reflector with VED

Aperture antennas

- Application of antenna array theory
- What is the array factor for two VED element array?
- Assume equal phase excitation and $\alpha = 0$
- note that the distance between the two VEDs is 2d now
- VED$_1$ is at (0,0,d) and VED$_2$ is at (0,0,-d)
- $AF = e^{j\vec{\beta}\cdot\vec{r}_1'} + e^{j\vec{\beta}\cdot\vec{r}_2'} = e^{j\beta_z d} + e^{-j\beta_z d} = e^{j\beta cos\theta d} + e^{-j\beta cos\theta d} = 2cos(\beta dcos\theta)$
- What is the far field electric field of the two element VED antenna array?
- Use pattern multiplication principle (far field of VED is derived in lecture 21)
- $E_\theta \cong \boxed{\frac{j\eta\beta I_0 dle^{-j\beta r}}{4\pi r} sin\theta}\boxed{[2cos(\beta dcos\theta)]}, z \geq 0$

Aperture antennas

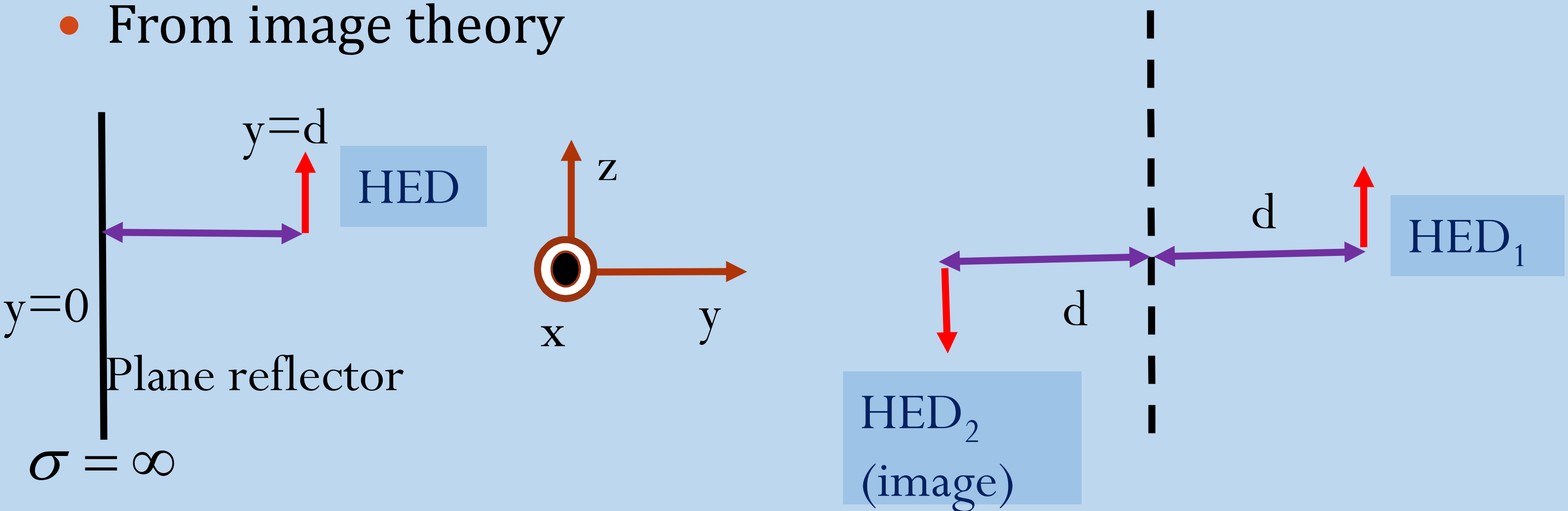
- What is the gain after putting the reflector?
- From electric field one can always find the radiation intensity and total radiated power, hence
- $D_0(\theta,\phi) = \frac{4\pi U_{max}}{P_{rad}} = \frac{2}{\left[\frac{1}{3} - \frac{cos(2\beta d)}{(2\beta d)^2} + \frac{sinc(2\beta d)}{(2\beta d)^2}\right]}$
- The maximum directivity is observed as 6.566 for $\mathrm{d} = 0.4585\lambda$
- which is *four times 1.5 which is the maximum directivity of single VED*
- ***Case study II (HED with a flat-plate reflector):***
  - Consider a z-directed Hertz dipole
  - $D(\theta,\phi) = \frac{3}{2} sin^2\theta$
  - Maximum directivity is 1.5

Aperture antennas

- We will try to increase the directivity with the help of reflectors
- What if the orientation of the flat-plate is changed?
- Consider a slight change in the orientation of the flat-plate reflector
- Instead of keeping it at z=0,
  - let us keep it at y=0 in x-z plane

Aperture antennas

- From image theory



Plane reflector at y=0 is an electric wall

Fig. A plane reflector with VED

Aperture antennas

- What is the array factor for two HED element array?
- Assume equal phase excitation and $\alpha = 0$
- note that the distance between the two HEDs is 2d now
- HED$_1$ is at (0,d,0) and HED$_2$ is at (0,-d,0)
- $AF = e^{j\vec{\beta}\cdot\vec{r}_1'} + e^{j\vec{\beta}\cdot\vec{r}_2'} = e^{j\beta_y d} - e^{-j\beta_y d} = e^{j\beta sin\theta sin\phi d} - e^{-j\beta sin\theta sin\phi d} = 2jsin(\beta d sin\theta sin\phi)$
- What is the far field electric field of the two element VED antenna array?
- Use pattern multiplication principle (far field of HED is derived in lecture 21)
- $E_\theta \cong \boxed{-\eta \frac{j\beta I_0 dl e^{-j\beta r}}{4\pi r}\left\{cos\theta sin\varphi\hat{\theta} + cos\varphi\hat{\varphi}\right\}}\boxed{\left[2jsin(\beta d sin\theta sin\phi)\right],} y \geq 0$

Aperture antennas

- What is the gain after putting the reflector at y=0?
- From electric field one can always find the radiation intensity and total radiated power, hence
- $$D_0(\theta,\phi)=\frac{4\pi U_{max}}{P_{rad}}=\begin{cases}\dfrac{4sin^2(\beta d)}{\frac{2}{3}-sinc(2\beta h)-\frac{cos(2\beta h)}{(2\beta h)^2}+\frac{sinc(2\beta h)}{(2\beta h)^2}}, & d\le\frac{\lambda}{4}\\ \dfrac{4}{\frac{2}{3}-sinc(2\beta h)-\frac{cos(2\beta h)}{(2\beta h)^2}+\frac{sinc(2\beta h)}{(2\beta h)^2}} & d>\frac{\lambda}{4}\end{cases}$$
- The maximum directivity is observed as 7.5 for small values of d
- The maximum directivity is observed as 6 for $\mathrm{d}\cong\left(0.725+\frac{n}{2}\right)\lambda$ for n=0,1,2,3,…
- which is *four times 1.5 or more which is the maximum directivity of single HED*

Aperture antennas

- ***Case study III (Corner reflectors):***
- Made of two flat-plate reflectors
- Joined to form a corner (angle between two reflectors could be $\alpha = \frac{\pi}{n}$ where n=1,2,3,…)
- Number of images: $\frac{2\pi}{\alpha} - 1$

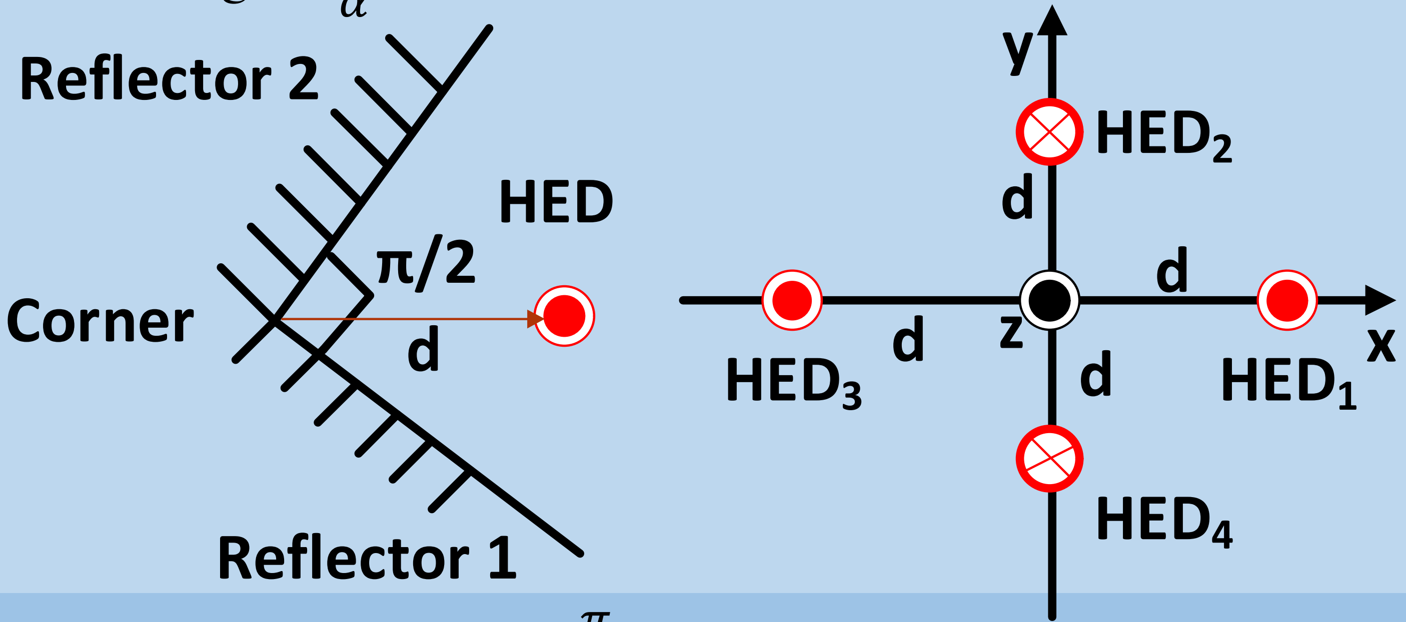


Fig. A corner reflector with $\alpha = \frac{\pi}{2}$ for HED (most popular corner reflector)

Aperture antennas

- Application of antenna array theory
- What is the array factor for four HED element array?
- Assume equal phase excitation and $\alpha = 0$
- note that the distance between the two HEDs is 2d now
- HED$_1$ is at (d,0,0), HED$_2$ is at (0,d,0), HED$_3$ is at (-d,0,0) and HED$_4$ is at (0,-d,0)
- $AF = e^{j\vec{\beta}\cdot\vec{r}_1'} + e^{j\vec{\beta}\cdot\vec{r}_2'} + e^{j\vec{\beta}\cdot\vec{r}_3'} + e^{j\vec{\beta}\cdot\vec{r}_4'} = e^{j\beta_x d} - e^{j\beta_y d} + e^{-j\beta_x d} - e^{-j\beta_y d} = 2cos(\beta_x d) - 2cos\left(\beta_y d\right) = 2cos(\beta sin\theta cos\phi d) - 2cos(\beta sin\theta sin\phi d)$

Aperture antennas

- What is the far field electric field of the four element HED antenna array?
- Use pattern multiplication principle (far field of HED is derived in lecture 21)
- $E_\theta \cong \boxed{-\eta \frac{j\beta \ _0 dl \ ^{-j\beta r}}{4\pi r}\{cos\theta sin\varphi\hat{\theta} + cos\varphi\hat{\varphi}\}}\boxed{[2cos(\beta sin\theta cos\phi d) - 2cos(\beta sin\theta sin\phi d)]}$
- Invented by J. D. Kraus in 1938
- It has moderate gain from 10-15 dBi, for $\alpha = \frac{\pi}{2}$, in order to have single lobe, $d < 0.75\lambda$
- How to improve the shape of the reflector to have higher gain?

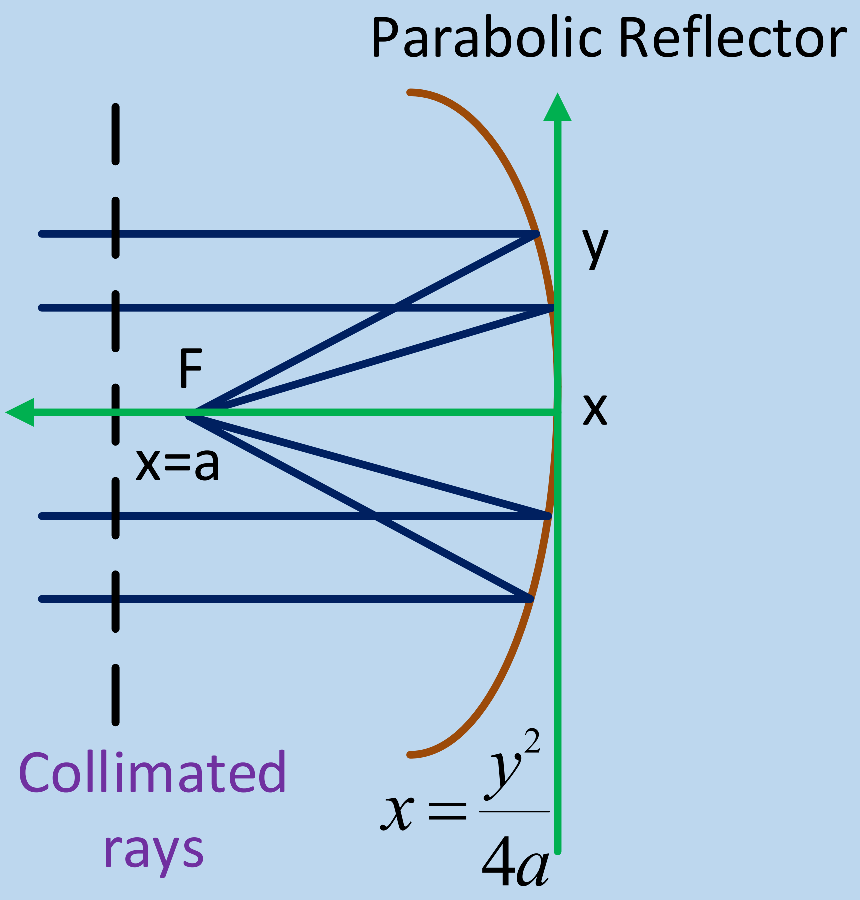
Geometrical optics:

- if a beam of parallel rays is incident upon a parabolic reflector,
  - the radiation will converge (focus) at a spot

Aperture antennas

  - which is known as **the** ***focal point***.
  - It is denoted by F
- Similarly,
- if ***a point source*** is placed at the focal point F,
- the rays reflected by a parabolic reflector will emerge as a parallel beam
- In other words,
  - Rays that emerge in a parallel formation are usually said to be *collimated*
- Beam collimation is a characteristic of highly directional antennas

Aperture antennas



$$x = \frac{y^2}{4a}$$

Fig. Beam collimation in Parabolic reflector antennas