General Sir John Kotelawala Defence University

ET3122 Antennas and Propagation
Aperture Antennas

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Outline

Introduction

Antenna Categories

- Wired antennas
  - Radiate energy from a feed current
  - Generally used for low frequencies
  - Relatively low gain
- Aperture antennas
  - Modify an existing EM field
  - Aperture dimensions are practical for high frequencies
  - Medium to very high gain
- Antenna arrays
  - Multi element antennas

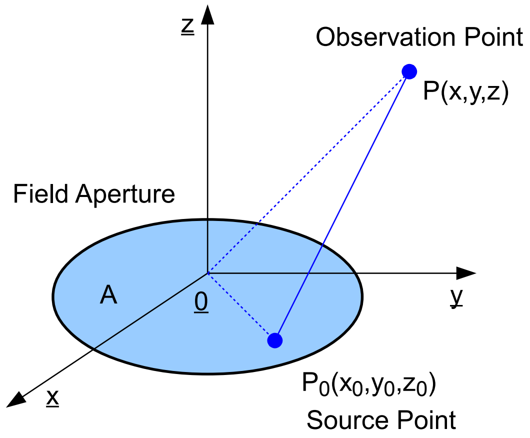
Antenna Aperture

The antenna aperture can be given in terms of its gain and the signal wavelength

$$A_E = \frac{\lambda^2 G}{4\pi}$$

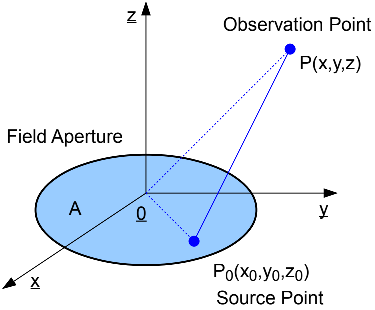
- The *physical aperture* of an antenna is tangible
- However, the *effective aperture* that takes into account losses due to boundary conditions is less than the physical aperture

Stutzmann's Method



Stutzmann's Method (Contd..)

The use of Huygen's principle (individual point sources) to find a radiation pattern.

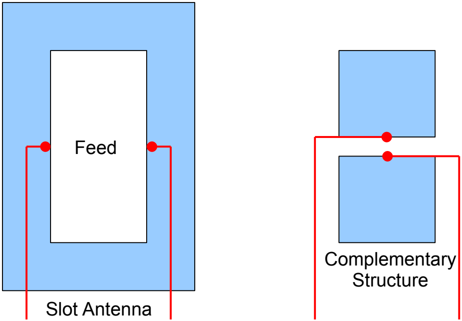


$$E(r) = \frac{jk}{2\pi}\int_S E_A(r_0)\frac{e^{-jk|r-r_0|}}{|r-r_0|}ds$$

Complementary Wire Antennas

Babinet's Principle

- The radiation pattern of an aperture is similar to the *complementary* wired structure



Complementary Wire Antennas (Contd..)

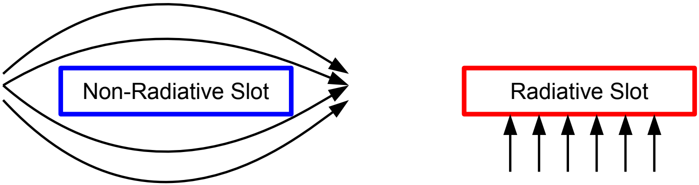
Booker's Law

- The feed impedance of an aperture (z_A) is related to that of the *complementary* wired structure (z_C) by

$$z_A z_C = \frac{\eta^2}{4}$$

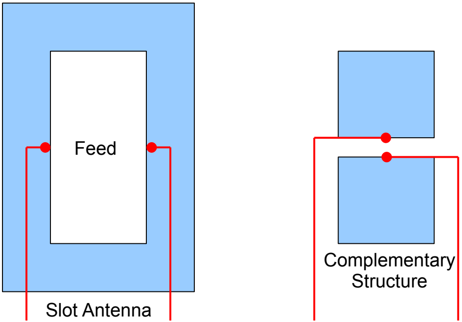
Slot Antennas

Radiating Slots



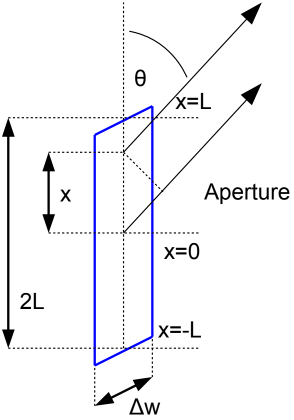
- A slot is a removal of metal from a waveguide or cavity wall
- If a slot is placed such that the current can easily bypass it, it is *non-radiative*
  - Has to be thin so that the parallel current can flow around it
  - If not, (i.e., current is normal) the slot is *radiative*
  - Even in a non-radiative slot a small amount of radiation can leak out
- Used for mode filters in waveguides

Slot Feeds



- A feed is used when the metal structure is not a waveguide (or cavity)
  - Commonly employed in aircraft, cellular phones etc.

Radiation Pattern



Path difference between two waves is given by,

$$\Delta = x cos(\theta)$$

Therefore,

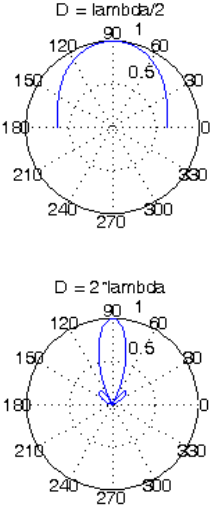
$$|r - r_0| \approx r - x cos(\theta)$$

Radiation Pattern (Contd..)

From Stutzmann's principle

$$
\begin{aligned}
E(r) &= \frac{jk}{2\pi}\int_{-L}^{L} E_A \frac{e^{-jk(r-xcos(\theta))}}{r}(\Delta w)dx \\
&= \frac{jk\Delta w E_A e^{-jkr}}{2\pi r}\int_{-L}^{L} e^{jkxcos(\theta)}dx \\
&= \frac{jk\Delta w E_A e^{-jkr}}{2\pi r}\left[\frac{e^{jkxcos(\theta)}}{jkcos(\theta)}\right]_{-L}^{L} \\
&= j\frac{\Delta w E_A e^{-jkr}}{\pi r}\left[\frac{sin\left(kLcos(\theta)\right)}{cos(\theta)}\right]
\end{aligned}
$$

Radiation Pattern (Contd..)

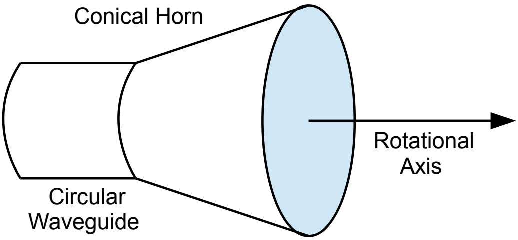


Lens and Reflector Antennas

Lens and Reflector Antennas

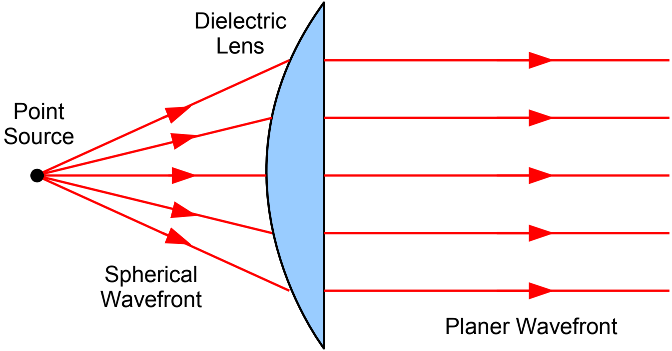
- Use dielectric refraction or metallic reflection to modify radiation patterns
  - Radiation patterns can be derived using geomtric optics
- Lens antennas can also double as protective covers
  - The difficulty in supporting the weight of a lens antenna restricts its applicable size
- Reflector antennas can achieve the *highest gain*
  - Can be supported effectively to allow a large physical size
  - Wire mesh can be used instead of solid metal to reduce weight and wind induced stresses at the expense of a reduced effective aperture for higher wavelengths

Body of Revolution (BOR) Antennas



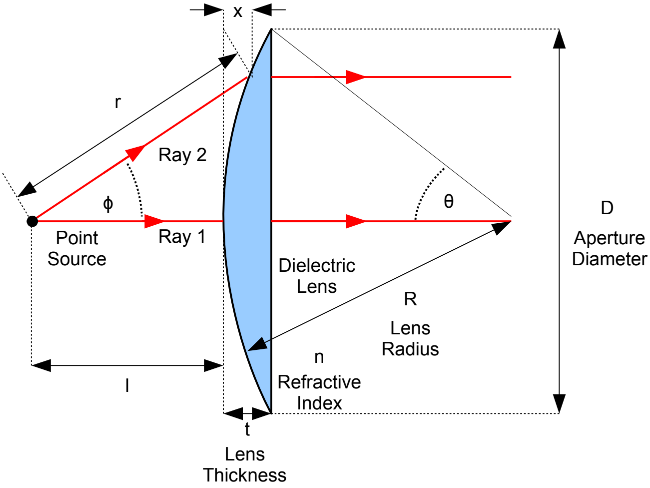
- An antenna that has a mechanical structure that is rotationally invarient (i.e., symmetric around an axis of rotation)
  - For example, the conical horn antenna
  - Used as point source feeders for lens and reflector antennas
  - It is obviously directive in the azimuth plane

Lens Antennas



- No interference between the source and transmitted waves

Lens Antenna Design



Lens Antenna Design (Contd..)

Design parameters

1. Distance of source from lens
2. Lens thickness
3. Lens radius
4. Refractive index of lens
5. Aperture diameter

Lens Antenna Design (Contd..)

For there to be no phase difference, the propagation times for both waves should be equal.

- Ray 1 travels a distance l in air and x in the lens
- Ray 2 travels a distance r in air

Therefore,

$$\frac{r}{c} = \frac{l}{c} + \frac{nx}{c} \rightarrow r = l + nx$$

Lens Antenna Design (Contd..)

From the Lensmaker's equation,

$$\frac{1}{l} = (n-1)\left[\frac{1}{R_N} - \frac{1}{R_F} + \frac{(n-1)t}{nR_NR_F}\right]$$

where R_N (near source side radius) is infinite and $R_F = R$ (far from source side radius). This results in,

$$R = (n-1)l \tag{1}$$

For a given aperture diameter D ($R > D/2$), the lens thickness is given by,

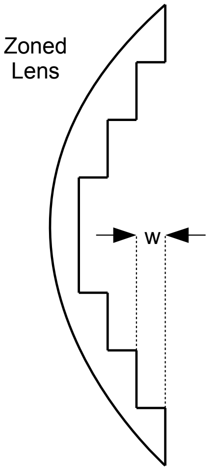
$$t = R - \sqrt{R^2 - \frac{D^2}{4}} \tag{2}$$

Lens Antenna Design (Contd..)

Design methodologies (according to requirement)

1. Start from focal length l
   - Obtain R for given n from (1)
   - Obtain t for required D from (2)
2. Start from D and t
   - Numerically obtain R for given t and D from (2)
   - Obtain l from (1) for given n
3. Other possibilities also exist
   - May be necessary to find required D or n first etc.

Lens Zoning (Stepping)

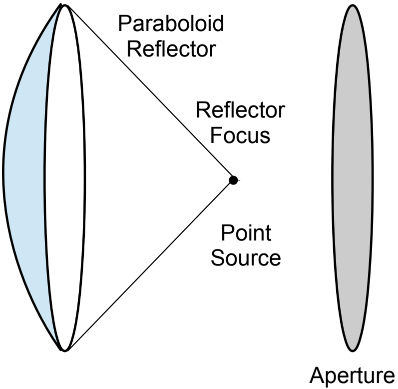


- Zoning helps reduce the material usage and weight of a lens antenna
- The width of a step w is given by,

$$w = \frac{\lambda}{n-1}$$

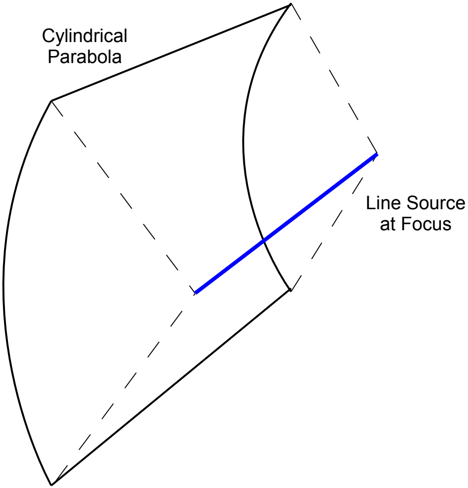
- Zoning reduces the bandwidth of the antenna
  - Can also increase distortion

Paraboloid Reflector

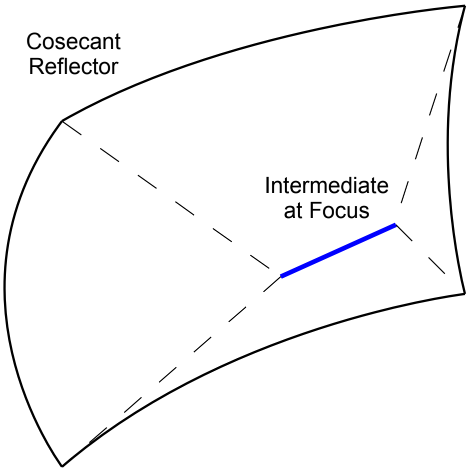


- Has to be used with a BOR feed antenna

Cylindrical Parabolic Reflector



Cosecant Reflector



Conclusion

Summary

- An antenna is an interface between the electric signal and radiated EM wave
    - All practical antennas are anisotropic radiators
    - Most efficient within the bandwidth
    - Has to be matched to the transmission line
- A *good* antenna must have a useful radiation pattern and matching feed impedance
- At microwave frequencies
    - Short wavelengths result in small antenna dimensions
    - Large effective apertures therefore high gain