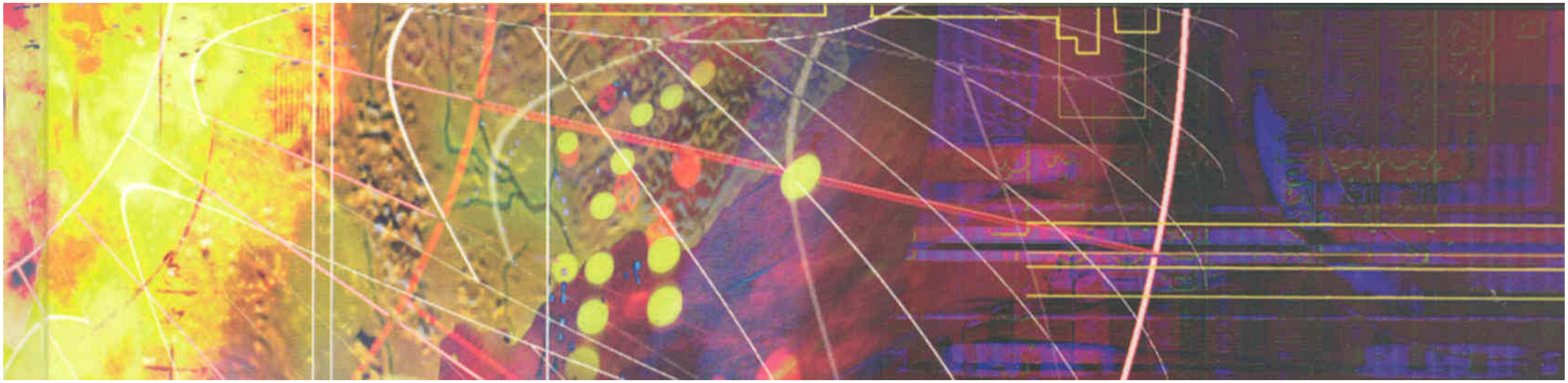


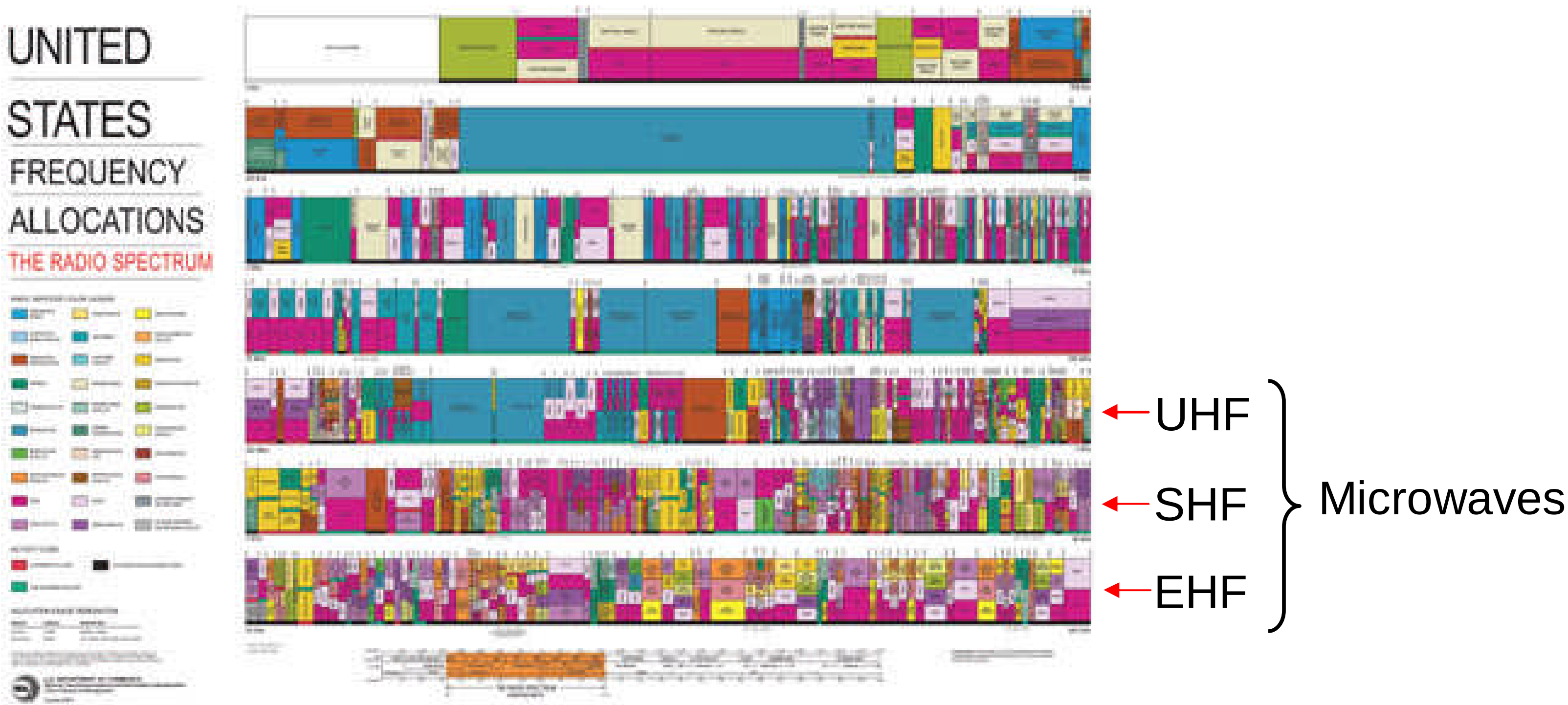
EE303 Lesson 27: Microwave Communications

Microwaves frequencies

- Microwaves consist of ultrahigh (UHF), superhigh (SHF) and extremely high (EHF) frequencies
  - Typically, the practical microwave region is 1 – 30 GHz
- Wavelengths associated with microwave signals are on the order of centimeters
  - For a 1 GHz signal, λ = 30 cm
  - For a 30 GHz signal, λ = 1 cm
- Frequencies above 40 GHz are referred to as millimeter waves

Microwaves frequencies

- Microwaves occupy the upper end of the radio frequency allocation table.



FCC Radio Frequency Allocation Table

Microwaves frequency bands

- Historically (during WWII) microwave frequencies were designated by bands using alphabetic letters.

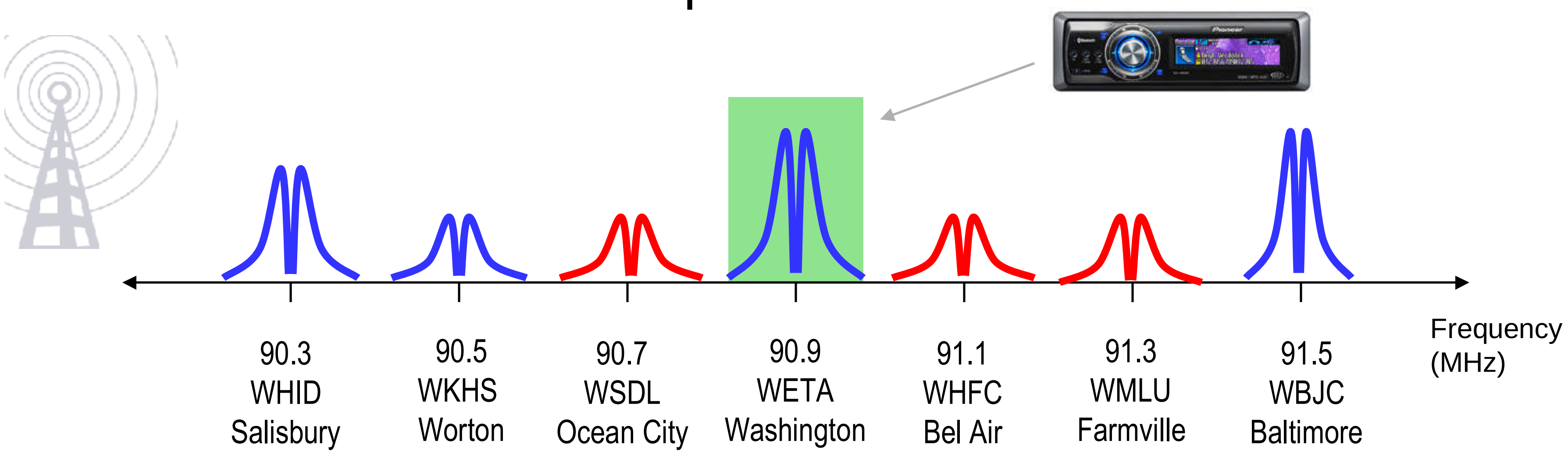
Navy SHF Satellite Program
Navy EHF Satellite Program

Band designation	Frequency range
L band	1 to 2 GHz
S band	2 to 4 GHz
C band	4 to 8 GHz
X band	8 to 12 GHz
K_u band	12 to 18 GHz
K band	18 to 26.5 GHz
K_a band	26.5 to 40 GHz
Q band	30 to 50 GHz
U band	40 to 60 GHz
V band	50 to 75 GHz
E band	60 to 90 GHz
W band	75 to 110 GHz
F band	90 to 140 GHz
D band	110 to 170 GHz
Submillimeter	>300 GHz

Millimeter waves

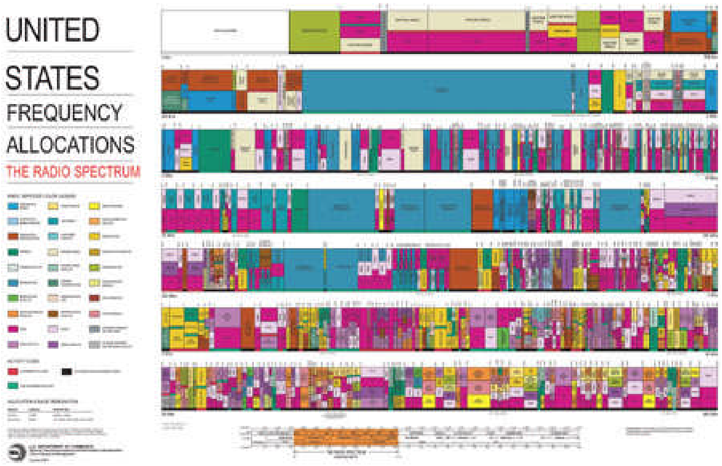
Benefits of microwaves

- Whenever a carrier signal is modulated by an information signal, sidebands are produced.
- The resulting signal occupies a given amount of bandwidth, a channel, in the RF spectrum.
- Channel center frequencies are allocated such that channels do not overlap and cause interference.



Benefits of microwaves

- Frequency spectrum used for radio communication has gotten very crowded (especially below 300 MHz)
- Technology has helped handle crowded spectrum
  - High selective receivers permit closer frequency spacing
  - Narrowband modulation techniques (SSB)
  - Digital modulation techniques (PSK, QAM)
  - Data compression
  - Spread spectrum techniques permit spectrum sharing



Benefits of microwaves

- A huge advantage of microwave frequencies the bandwidth available.
- Consider broadcast AM radio operating at 1000 kHz
  - A 10-kHz bandwidth represents 1% of the spectrum at that frequency.

$$\frac{10\ \text{kHz}}{1000\ \text{kHz}} = 0.01 \text{ or } 1\%$$

- Now consider a microwave carrier at 4 GHz

$$\frac{10\ \text{kHz}}{4,000,000\ \text{kHz}} = 0.0000025 \text{ or } 0.00025\%$$

  - A bandwidth of 1% of 4 GHz could contain 4000 broadcast AM radio stations.

Benefits of microwaves

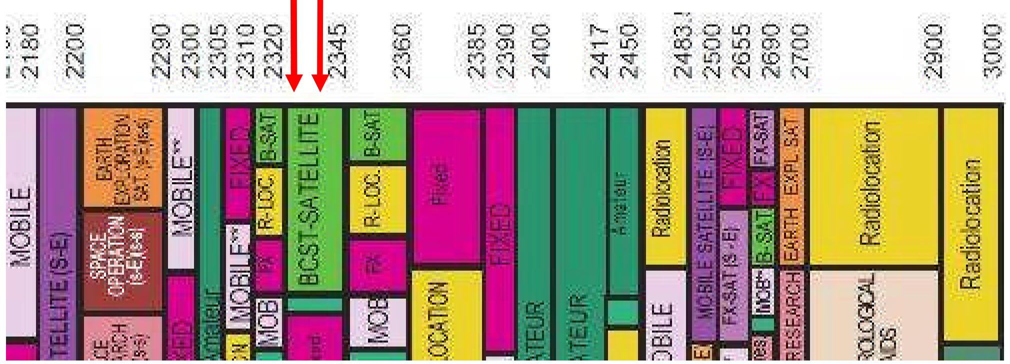
- The huge amount of spectrum available at microwave frequencies permit the transmission of large amounts of information.
  - Transmission of video (recall analog TV bandwidth = 6 MHz)
  - High-speed digital

SIRIUS SATELLITE RADIO

(2320 - 2332.50 MHz)

XM SATELLITE RADIO

(2332.50 - 2345 MHz)

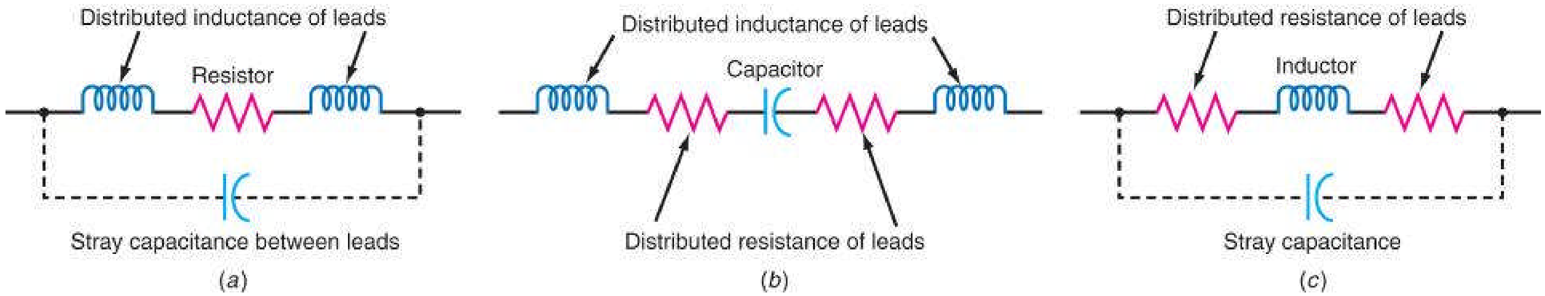


Disadvantages of microwaves

- For frequencies below 30 MHz, standard circuit analysis applies
  - Current-voltage relationships apply (circuit analysis)
- This relationship is not usable at microwave frequencies.
  - Analysis must be done in terms of electric and magnetic fields (wave analysis)
- At microwave frequencies, conventional components become difficult to implement
  - Resistors, capacitors and inductors do not exhibit the same characteristics at microwave frequencies
  - Example, short leads on components will add inductance and capacitance to circuit

Disadvantages of microwaves

- Simple components become complex



Resistor Capacitor Inductor

Disadvantages of microwaves

- Transit time of current carrier (electrons) becomes a problem at microwave frequencies
  - At low frequencies, this is not a problem
  - At microwave frequencies, transit time becomes a high percentage of actual signal period
  - Conventional silicon transistors don’t operate well at microwave frequencies.
- Microwaves travel in straight lines
  - Communications limited to line-of-sight

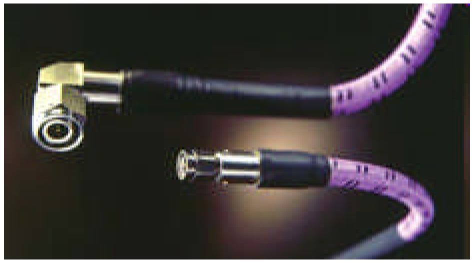
Microwave communication systems

- Microwave transmitters are very similar to their lower frequency counterparts
  - They contain carrier frequency generators, modulators and amplifiers
- Receivers are superheterodyne types
- Transmission lines used for lower frequencies have very high attenuation at microwave frequencies and are unsuitable, except for very short runs
  - Waveguides are used instead

Waveguides

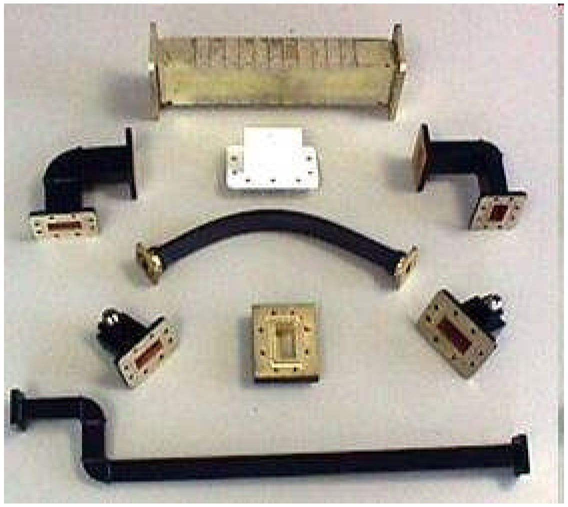
- Long parallel transmission lines radiate electromagnetic energy while transporting it
  - At microwave frequencies, virtually all energy is radiated and very little arrives at the antenna
- Special coaxial cable has been developed for frequencies up to 6 GHz, but the length must be less than 100 ft.
  - Above 6 GHz, a waveguide must be used

special microwave coaxial cable (< 18 GHz)



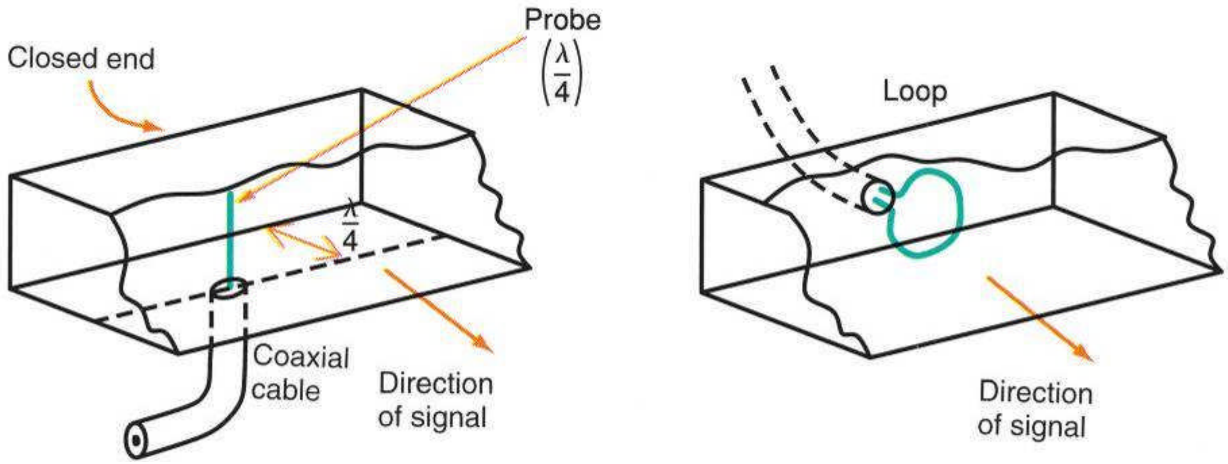
Waveguides

- Waveguides are hollow metal conducting pipes designed to carry and constrain the electro-magnetic waves.
- Shape can be rectangular or circular
- Constructed from copper, aluminum or brass.
  - Inside is often coated with silver to reduce resistance and minimize transmission loss



Signal injection and extraction

- Signals are introduced into the waveguide by an antenna-like probe that creates an electromagnetic wave that propagates through the waveguide
- Waveguide totally contains the signal, so very little escapes by radiation
- The position of the probe determines whether the signal is horizontally or vertically polarized

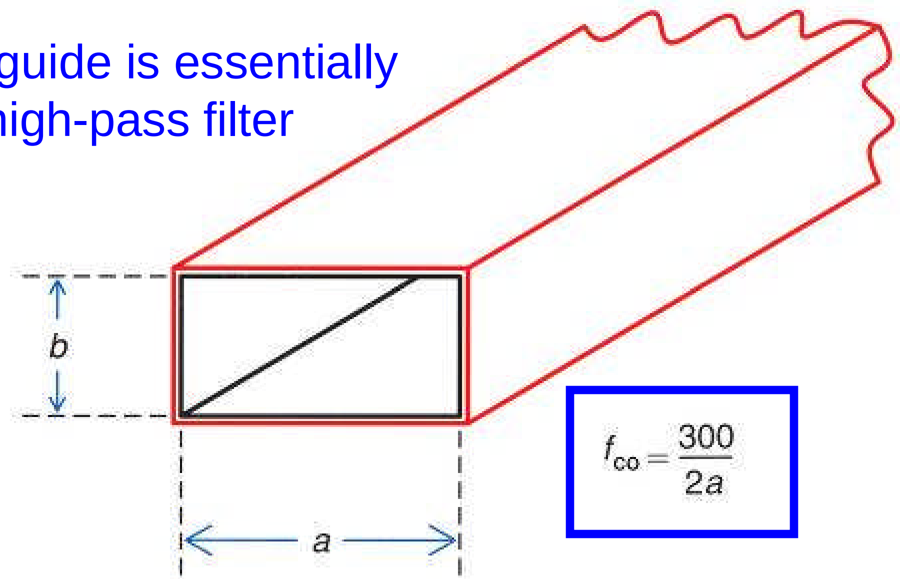


Waveguide size and frequency

- Frequency of operation is determined by the width a of the waveguide
- The width is usually $\lambda/2$, a bit below the lowest operating frequency.
- f_{co} is known as the waveguide cutoff frequency given below where frequency is in MHz and a is in meters

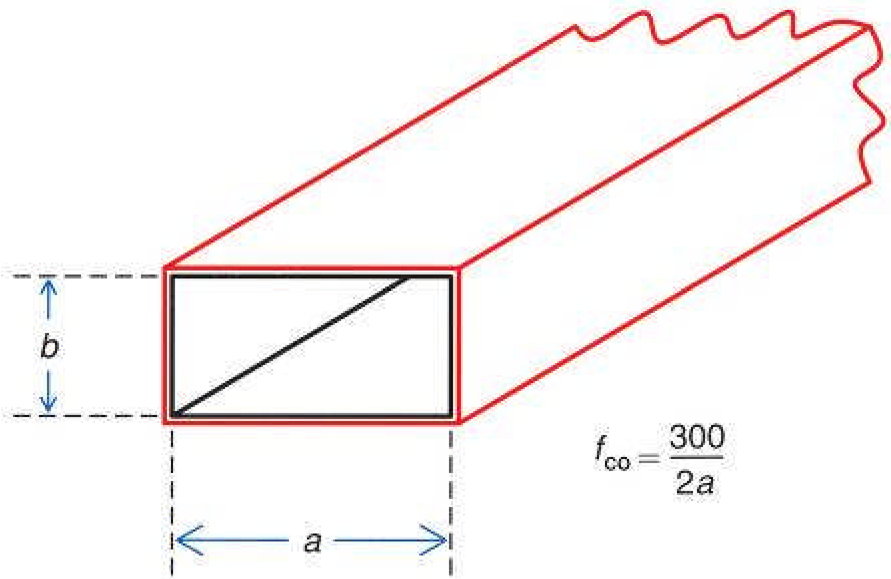
A waveguide is essentially
a high-pass filter

Height *b* is normally
half the width *a*



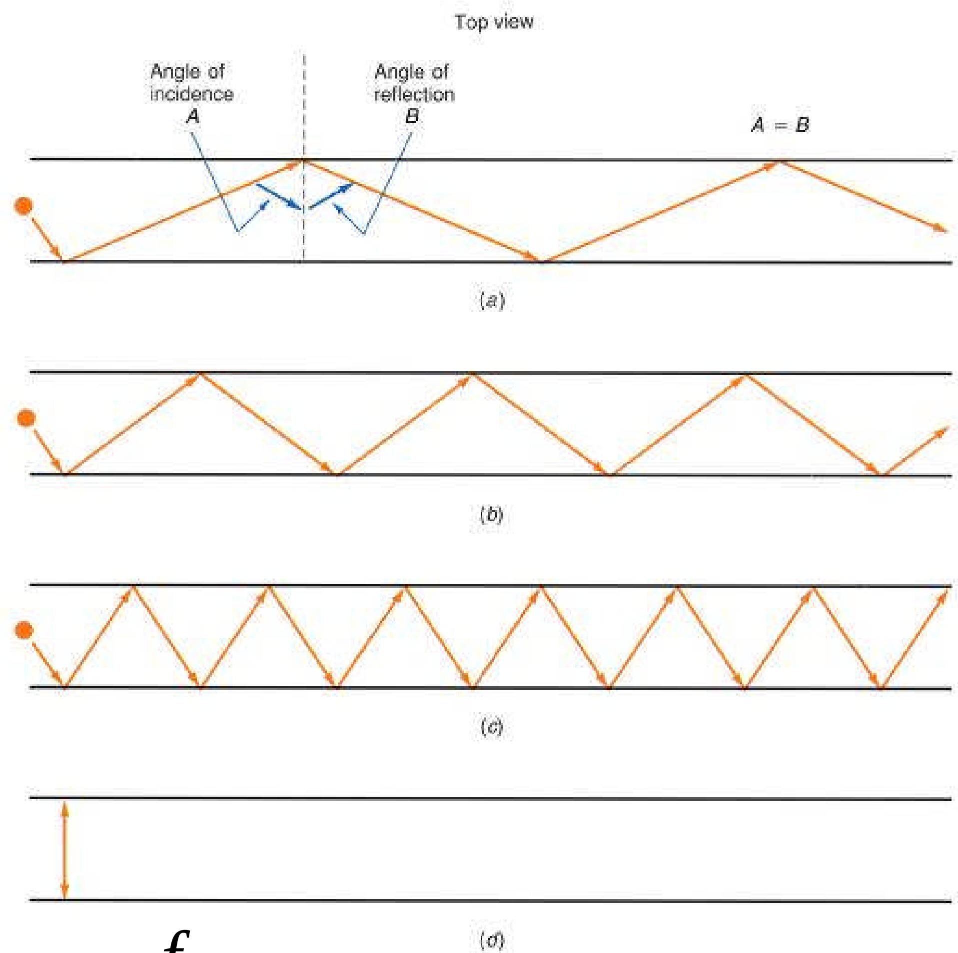
Example Problem 1

Calculate the waveguide cutoff frequency (in GHz) for a waveguide with a width $a = 0.7$ inches (note: 1 inch = 2.54 cm).



Signal propagation

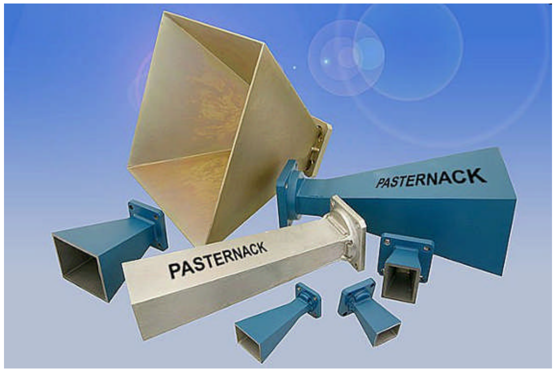
- The angles of incidence and reflection depend on frequency
- The lower the frequency, the smaller the angles and the shorter the path
- Until the f_{co} is reached and the signal simply bounces back and forth, no energy is propagated



f_{co}

Microwave antennas

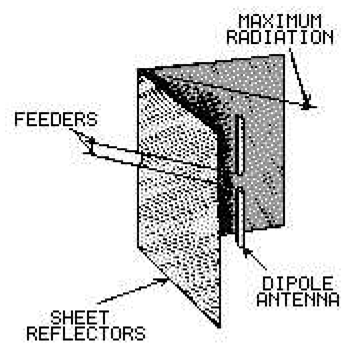
- All antennas discussed previously (half-wave dipole, quarter-wave dipole, etc) can be used at microwave frequencies
- These antennas will be extremely small.
  - At 5 GHz, half-wave dipole is less than 1 inch long
- These antennas also radiate inefficiently
- Because of the line-of-site restrictions, high-gain/highly directive antennas are normally used



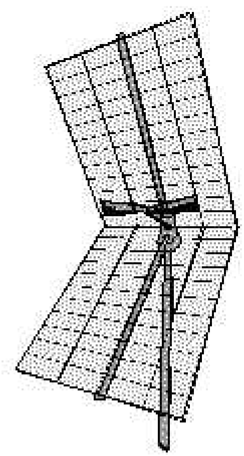
Low frequency antennas

- At frequencies less than 2 GHz, standard antennas are used (dipole, bow tie, Yagi, etc.)
- One commonly used variation is called a corner reflector
  - Wide bandwidth
  - Better reflection than a rod reflector (Yagi)
  - Overall gain is 10-15 dB

(9) CORNER REFLECTOR



A

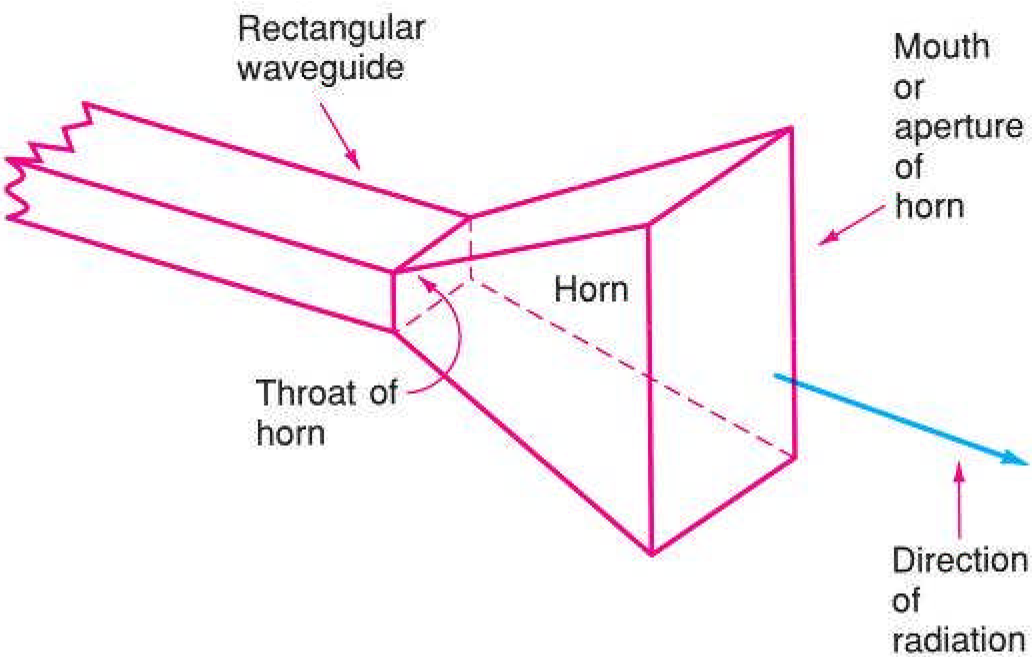


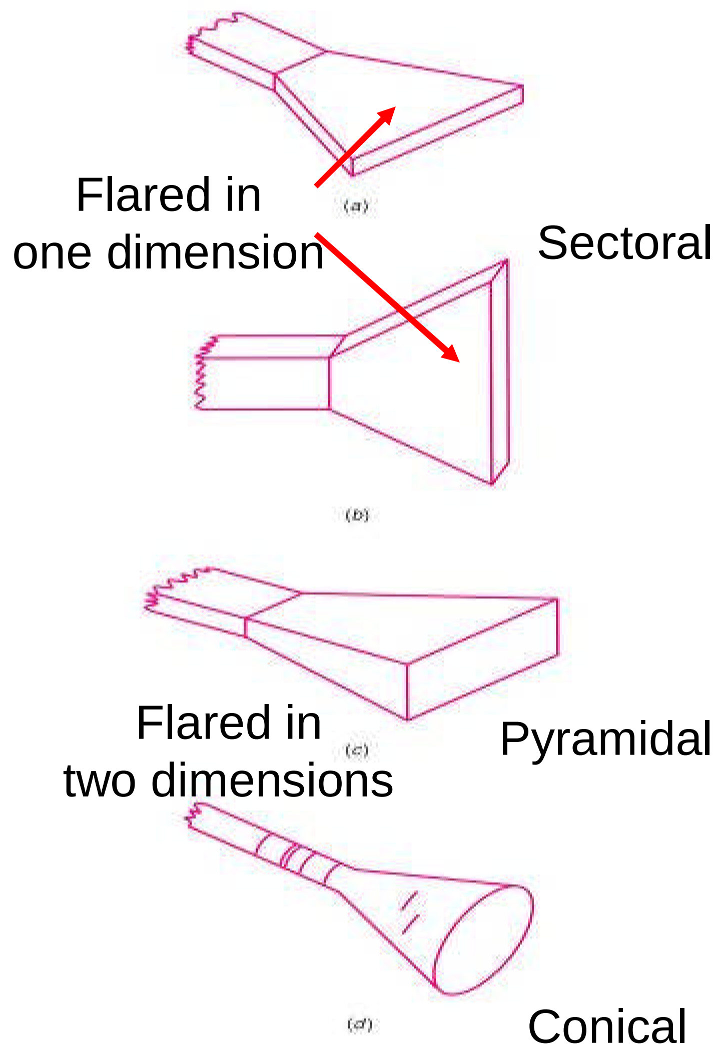
B

Horn antennas

- Above 6 GHz, signals travel from the transmitter to the antenna via waveguides
- If simply left open at the end, waveguides are inefficient radiators
- This can be offset by flaring the end of the waveguide to create a horn
  - Horn antennas have excellent gain and directivity
  - The longer the horn, the greater the gain and directivity

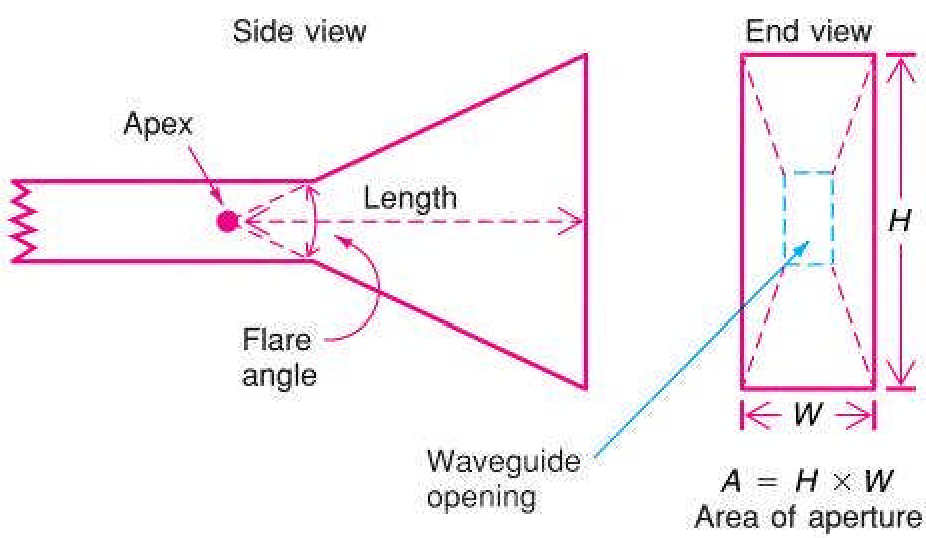
Types of horn antennas





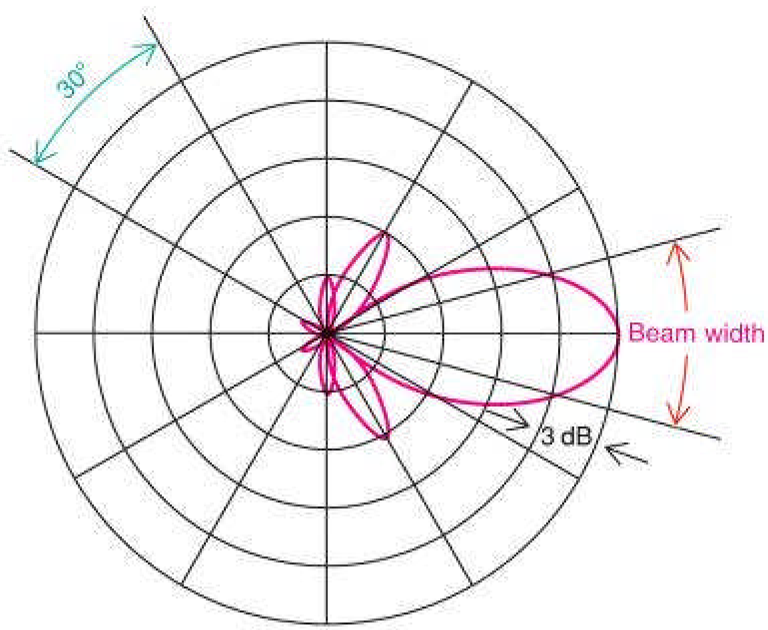
Horn antennas

- Gain and directivity are a function of the horn's dimensions
- Most important are length, aperture area and flare angle
- The length is usually 2λ to 15λ, at the operating frequency
- The greater the aperture area, the higher the gain and directivity
- Flare angles range from 20° to 60°

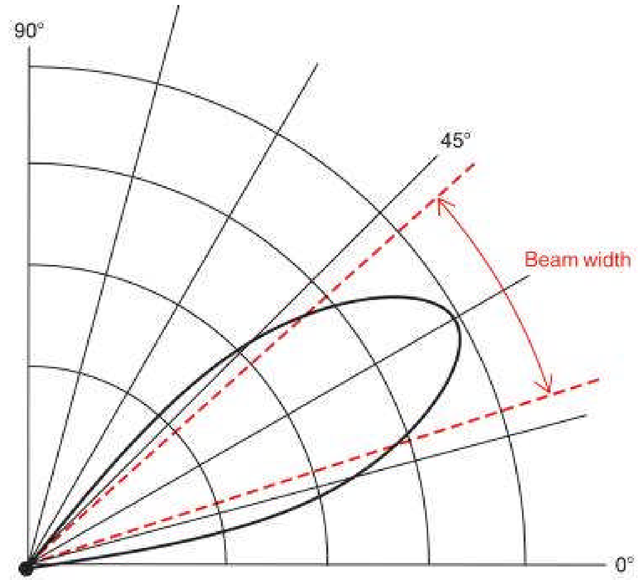


Beam width

- Directivity of an antenna is measured in terms of beam width, the angle between 3-dB down points.
- Typical beam widths for horn antennas are 10º to 60º.



Horizontal (azimuth) beam width



Vertical beam width

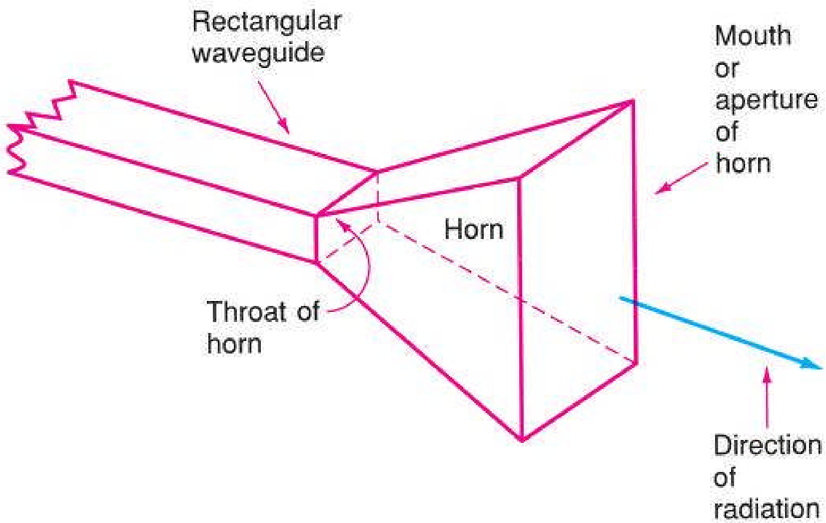
Beam width for pyramidal horn

- The horizontal beam width for a pyramidal horn is

$$B = \frac{80}{w/\lambda}$$

  where w = horn width, λ = wavelength

- The horizontal and vertical beams are approximately the same.



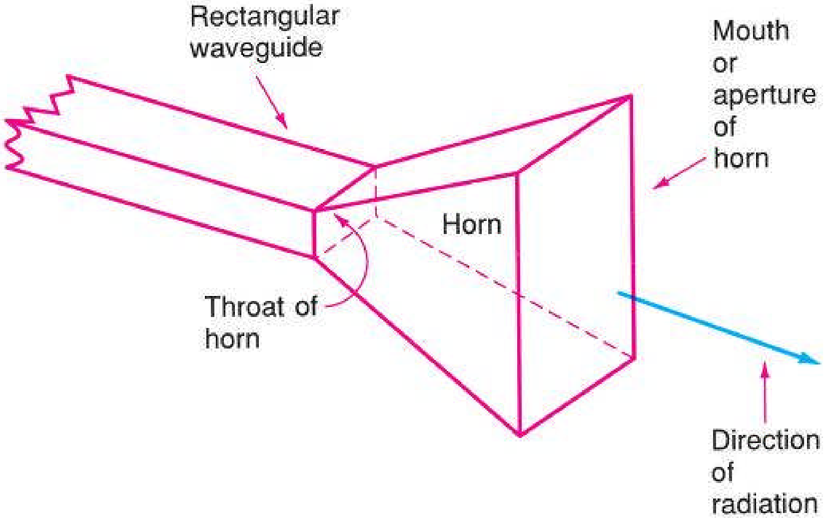
Gain for pyramidal horn

- The power gain of a pyramidal horn is approximately

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

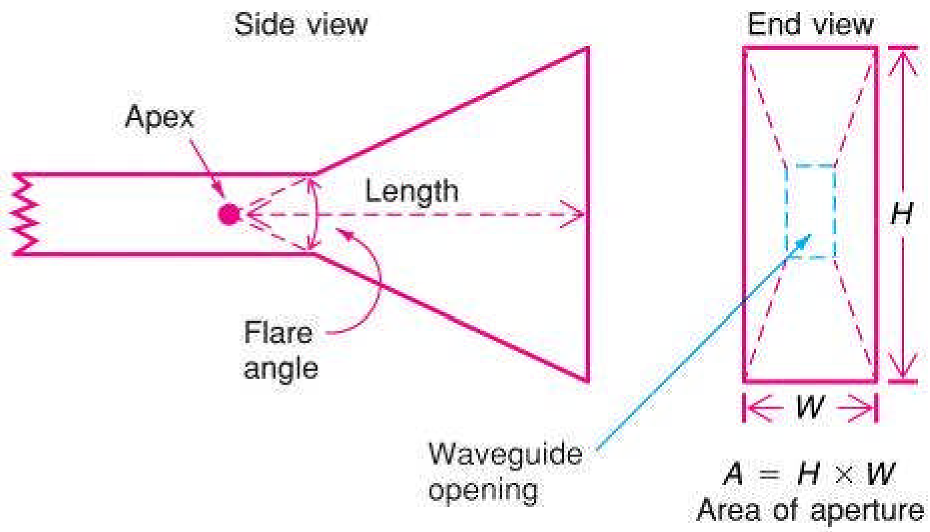
where A = aperture (m^2), K = constant ~ 0.5-0.6
λ = wavelength

- This power gain is relative to a half-wave dipole.



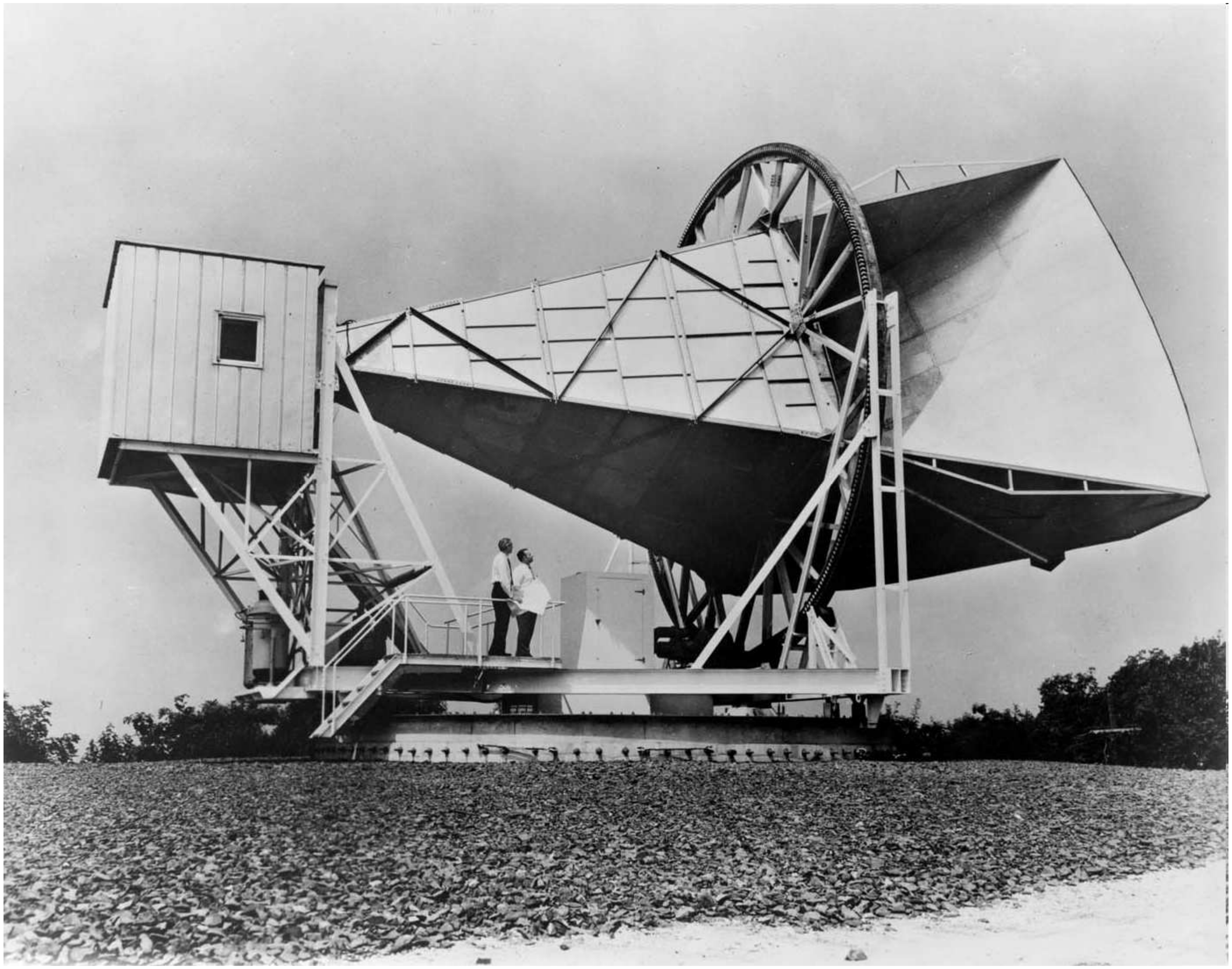
Example Problem 2

Consider the pyramidal horn antenna below for which height = 10 cm and width = 12 cm. What is the beam width of this antenna? Calculate power gain at an operating frequency of 10 GHz and express in dBi. (Assume K = 0.5).



Bandwidth

- Horns operate over a wide frequency range
- The bandwidth of a typical horn is approximately 10% of the operating frequency
  - At 10 GHz, the bandwidth is approximately 1 GHz
- This very large bandwidth and can accommodate almost any complex modulating signal



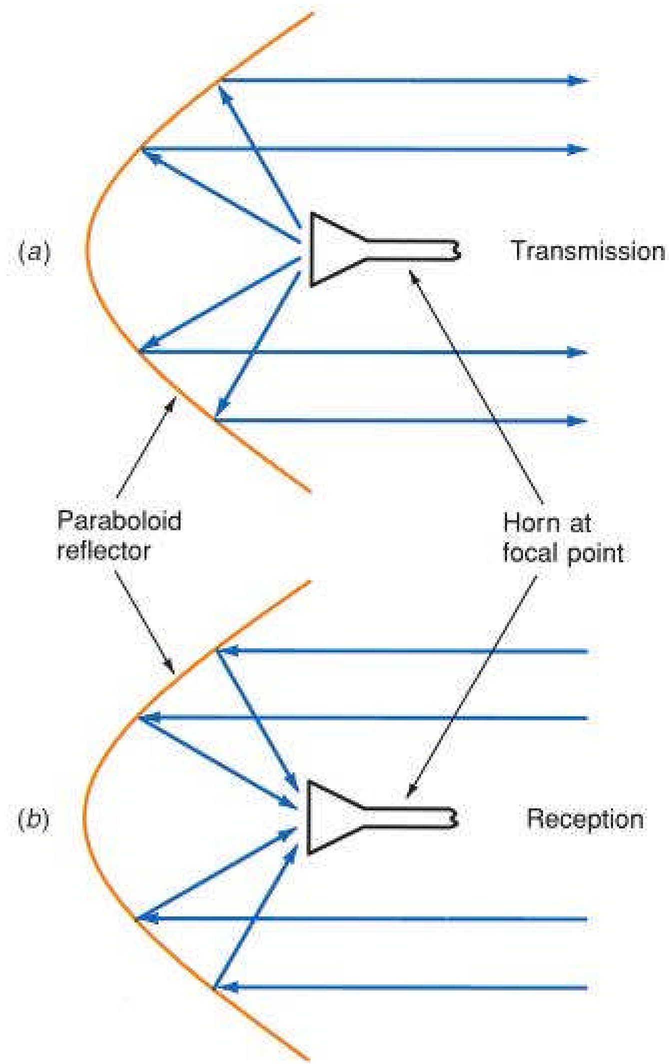
The Horn reflector antenna at Bell Telephone Laboratories in Holmdel, New Jersey was built in 1959 for pioneering work in communication satellites for the NASA ECHO I. The antenna was 50 feet in length and the entire structure weighed about 18 tons

Parabolic antennas

- Using a horn in conjunction with a parabolic reflector provides higher gain and directivity
- Energy radiated by the horn is focused by the reflector into a narrow beam
- Beam widths of only a few degrees are typical with a parabolic reflector

Parabolic antennas

- Can be used for transmit and receive
- Any common antenna type (dipole, etc) can be used with a parabolic reflector
- Most parabolic reflectors are designed so that the diameter is no less than λ at the lowest operating frequency



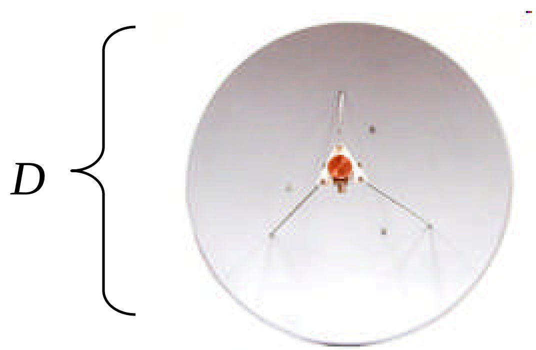
Gain for parabolic antennas

- The power gain of a parabolic antenna is approximately

$$G = 6\left(\frac{D}{\lambda}\right)^2$$

  where D = diameter of dish (m)

- This power gain is relative to a half-wave dipole.



Beam width for parabolic antennas

- The beam width for a parabolic antenna is

$$B = \frac{70}{D/\lambda}$$

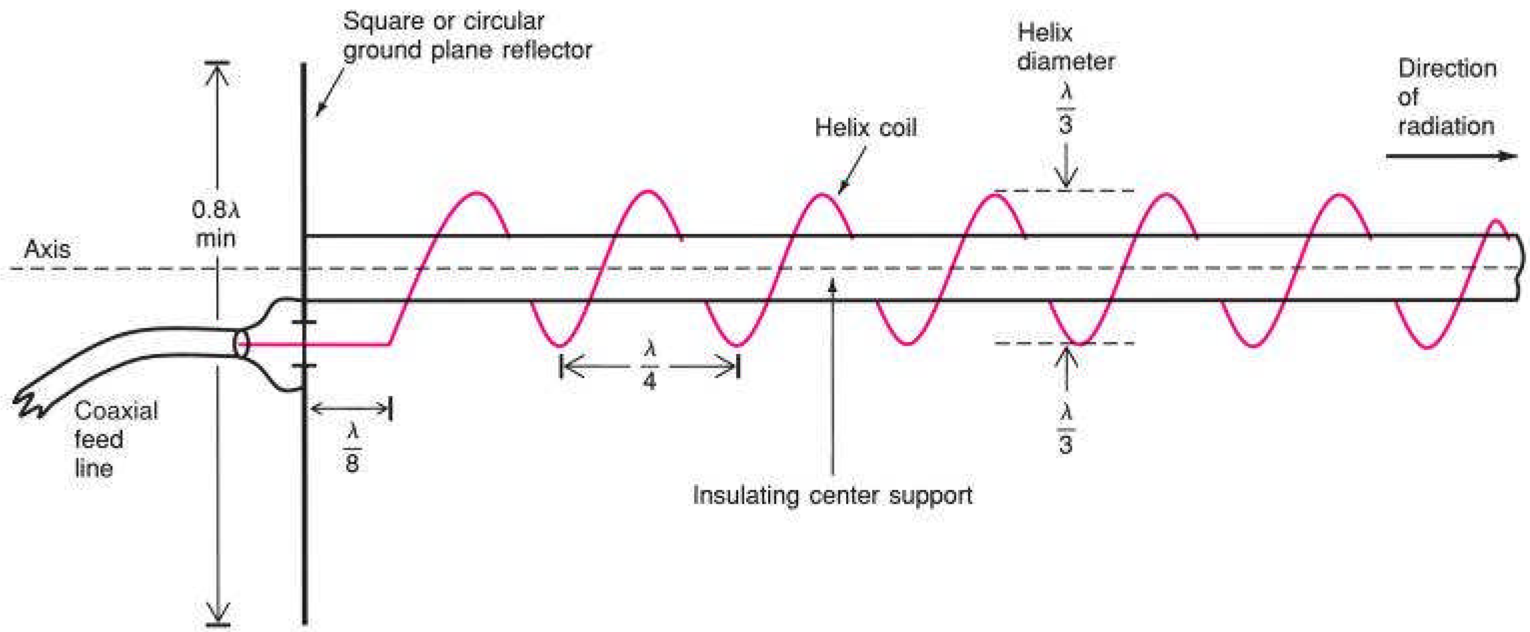
where D = diameter of dish (m)

Example Problem 3

Consider a 5-m parabolic dish antenna operating at 10 GHz. What is the beam width of this antenna? Calculate power gain and express in dBi.

Helical antennas

- Favored because of their simplicity and low cost
- Typically use from 6 to 8 turns
- Gain is from 12 – 20 dB, with beam widths from 12° - 45°
- Widely used in VHF and UHF ranges



Helical antennas

- Electromagnetic field is circularly polarized, either right-hand (clockwise) or left-hand (counterclockwise)
- Because signal is rotating, it can be received by either a vertically or horizontally polarized antenna
- But, a right-hand circularly polarized antenna can not pick up a left-hand polarized signal, and vice versa