

# Fundamentals of Satellite Communications, Part 1



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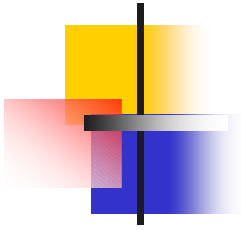
Hauppauge, NY 11788

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# Fundamentals of Satellite Communications Part 1

- Satellite Communications Introduction
- Types of Satellite Services
- Satellite Configurations
- Geostationary Satellites
- Non-Geostationary Satellites
- Satellite Configurations
- Frequency Reuse / Polarization
- Earth Station Antennas
- Major Earth Stations Components
- Satellite Communications Summary
- Part 2 – Communication System Link Analysis
- Part 3 – Specifying Subsystems for Data Communications -



# Satellite Communications Introduction

- ❑ **Are Satellites a Cost Effective Means of Communications? Answer is **NO**.**
  - ❑ Limited Frequency Spectrum
  - ❑ Limited Spatial Capacity (Orbital Slots)
  - ❑ High Equipment Cost
- ❑ **Land lines and Fiber are Much More Cost Effective**
  - ❑ Fiber Reuses Spectrum, Multi-Fiber Cables
  - ❑ A few multi-fiber cables can have as much information as all the satellites in orbit
  - ❑ Land Line Infrastructure is In Place -



# *Satellites Provides Capabilities Not Available with Terrestrial Communication Systems*

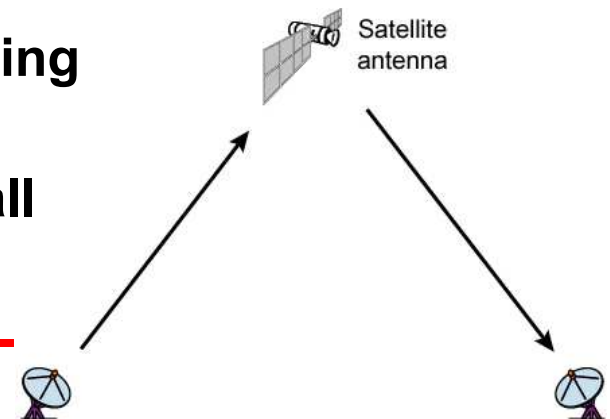
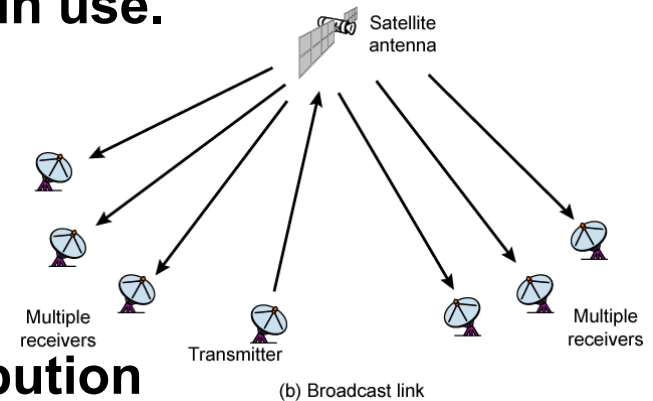
- ❑ **Adaptable to the needs of different customers**
- ❑ **Variable Information Rates**
- ❑ **Mobility**
- ❑ **Cost advantage over building land lines for a limited population**
- ❑ **Versatility in use Paging, Voice, Data, Video**
- ❑ **No geographical obstructions that prohibit landlines**
- ❑ **Quick implementation – e.g. News Gathering**
- ❑ **Alternate routing or redundancy as required**
- ❑ **Cost is independent of distance**
- ❑ **Cost effective for short term requirements e.g. Sporting Events -**

# Types of Satellite Services

## Fixed Service Satellites (FSS)

Communication to non-moving satellites.

- Generally Earth Station is not moving when in use.
  - Low Cost Tracking antennas are making communication on the move a reality
- Types of service
  - Video:
    - Broadcast: Television network distribution
    - Satellite News Gathering (SNG).
  - Voice:
    - Telecommunications traffic / connecting cells.
    - Connecting cellular telephone to small islands
  - Data: Internet, Business to Business -





# **Satellite Industry Issues and Concerns**

- ❑ **Frequency spectrum**
- ❑ **Orbital Slots**
- ❑ **Regulatory inconsistencies**
  - ❑ **Signals reach multiple countries**
- ❑ **Consolidation of manufacturers**
- ❑ **Multiple standards**
- ❑ **Quality control versus production lead time**
- ❑ **Rapid change in telecommunications requirements**
  - ❑ **Digital Television**
- ❑ **Rapid deployment of Fiber optics -**

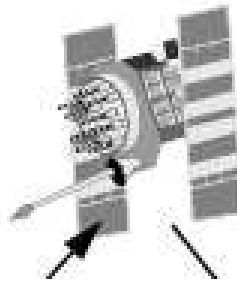
# Satellite Configurations & Stabilization



# Satellite Components

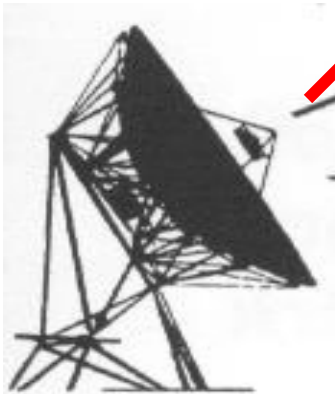
- LNA
- Down Converter
- High Power Amplifier
- Filter

- Propulsion System
- Telemetry
- Attitude Control
- Fuel
- Batteries
- Power & Thermal Control
- Solar Arrays



Up Link  
Path  
Loss

Down Link  
Path  
Loss

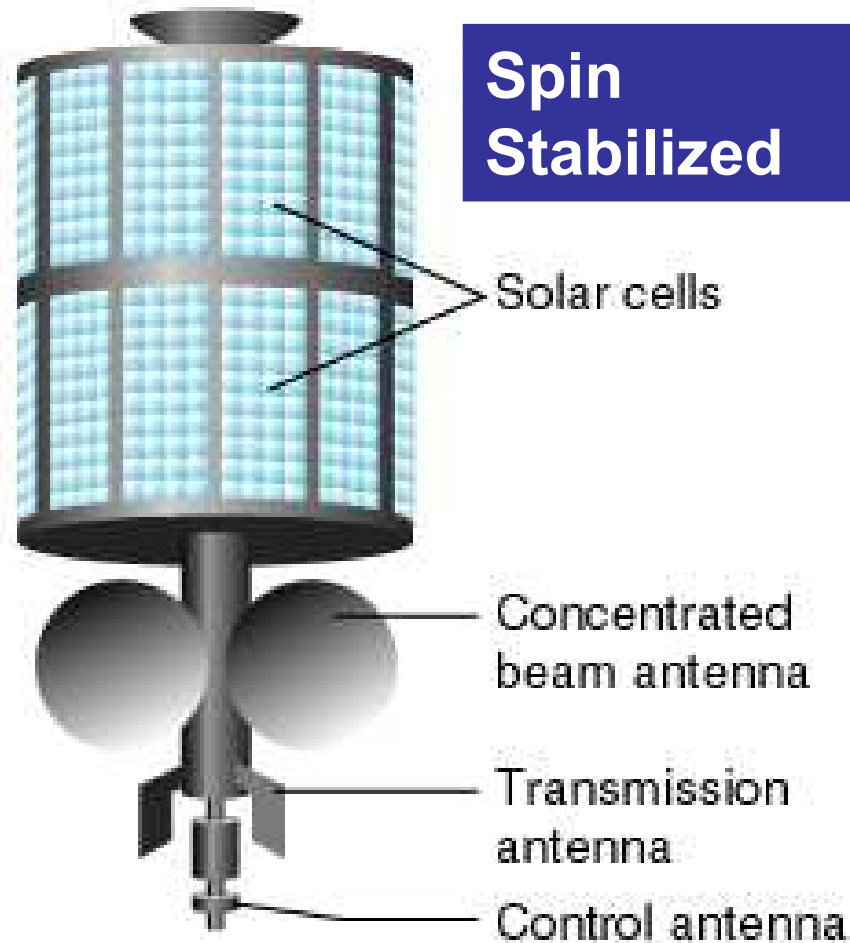


- Up Link Frequency Always Higher than Down Link Frequency -



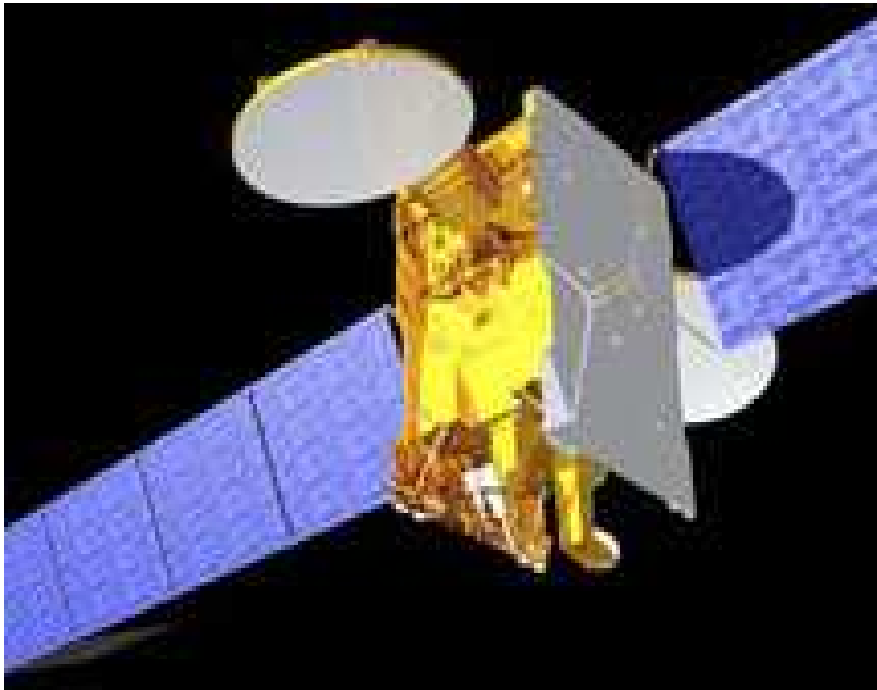


# Spin Stabilized Satellites



- **Satellite Body is Spin Stabilized (60-100 RPM)**
- **Gyroscopic stability**
- **Spins to minimize thermal effects**
- **1/2 the solar cells face the sun at one time**
- **More efficient for smaller satellites**
- **Antenna must de-spin -**

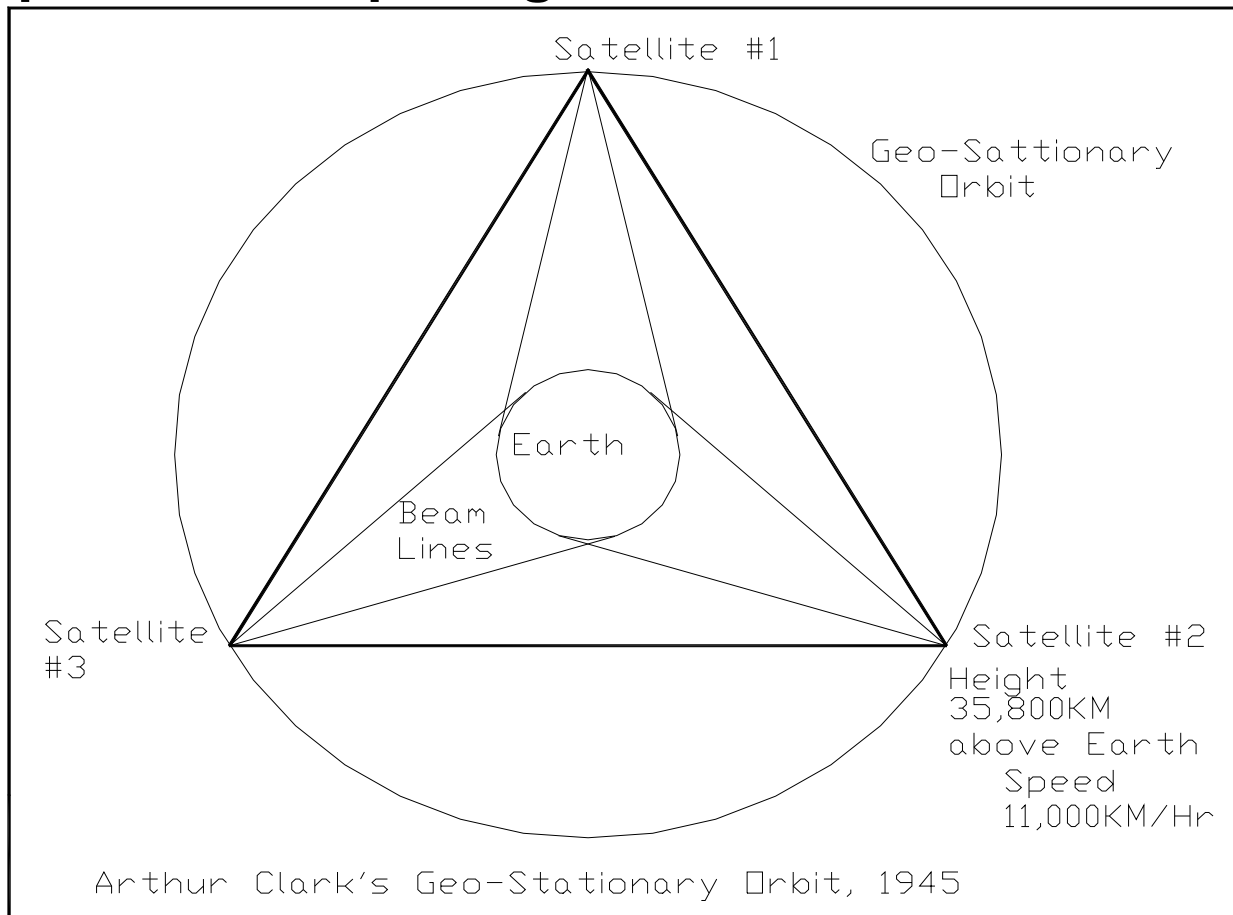
# Body Stabilized Satellites



- ❑ All solar cells face the sun
- ❑ Thermal control more difficult
- ❑ Requires more stabilization control
- ❑ More solar cells than Spin Stabilized Satellites
- ❑ Better design for larger satellites -

# Geo-Stationary Satellites

In a British magazine, "Wireless World", May, 1945, Arthur Clark, a renown science fiction author, wrote a paper predicting that three geo-stationary satellites would provide complete global telecommunications coverage.



Sir Arthur Clark wrote '2001, A Space Odyssey' Died this year 2008 -

## Geo-Stationary Satellites (Continued)

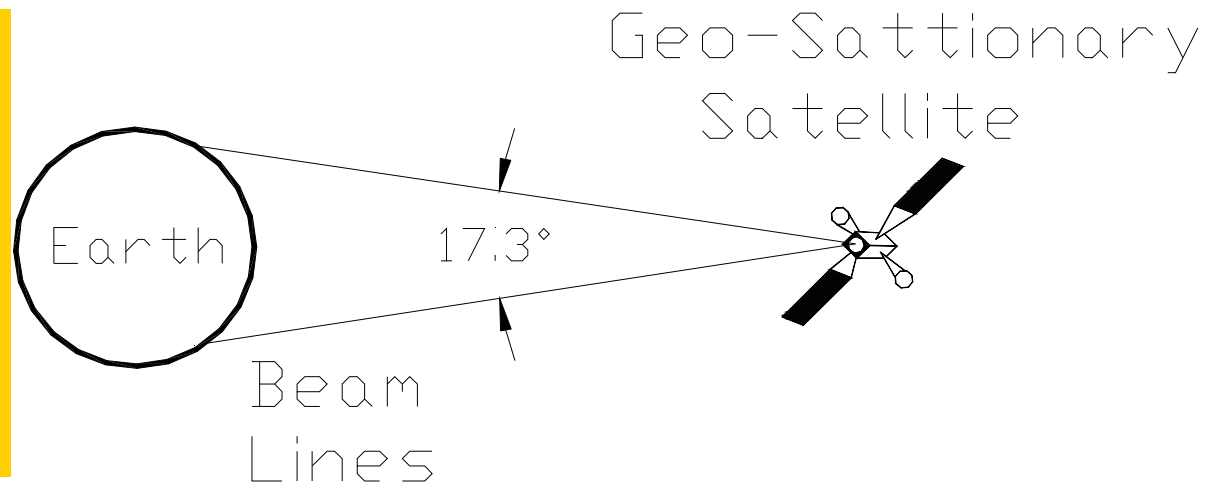
### **Clark Orbit, which is Equatorial Circular**

- ❑ **35,800km (22,300 Miles ) above the Earth traveling at a speed of 11,000km/hour**
  - ❑ **One Orbit takes 24 hours**
  - ❑ **Synchronous with the spinning of the Earth**
- ❑ **Satellites headed for geosynchronous orbit first go to a Geostationary Transfer Orbit (GTO)**
  - ❑ **Elliptical orbit with apogee about 23,000 miles.**
  - ❑ **Firing the rocket engines at apogee then makes the orbit circular.**
- ❑ **A Single Satellite is visible from  $\approx 1/3$  of the earth's surface, excluding extreme Polar Regions.**
- ❑ **Cannot see latitudes greater than  $\pm 77^\circ$**
- ❑ **Orbital locations are regulated by the International telecommunications Union (ITU) -**

## Geo-Stationary Satellites Beams

- Generally satellites must be spaced at least  $1.5^\circ$  to  $2^\circ$  apart ( $2^\circ \approx 911$  miles or 1,466 Km).
  - Earth Station antenna will illuminate multiple satellites if they are spaced closer
- Orbital slots are measured in degrees going East from Greenwich meridian =  $0^\circ$

• Satellite antenna beam width is  $17.3^\circ$  for full earth coverage -





# Advantages/Disadvantages of Geo-Synchronous Orbits

- **Advantages:**
  - **No ground station tracking required**
  - **No inter-satellite handoff, permanently in view**
  - **Three satellites give full earth coverage**
  - **Almost no Doppler shift, yields reduced complexity receivers**
- **Disadvantages:**
  - **35786 km orbits imply long transmission latencies**
  - **Weak received signal**
  - **Poor coverage at high latitudes (>77 degrees) -**

# Satellite Link Delays

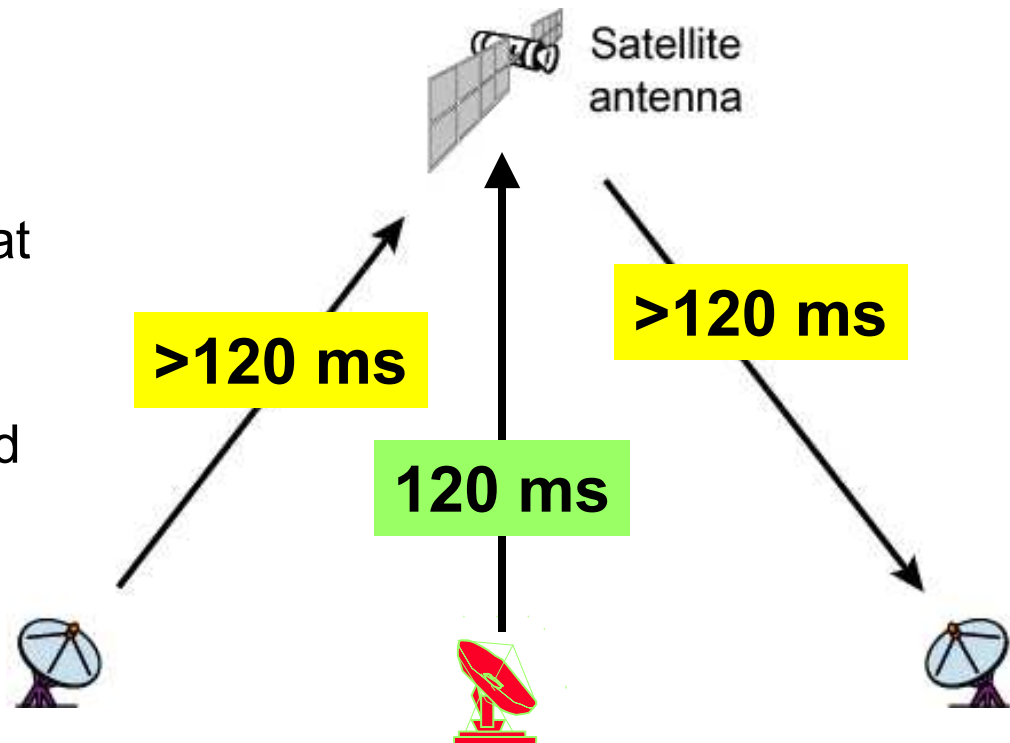
- ❑ Satellite to the surface of the Earth is 22,300 miles
- ❑ Two way transmission is 44,600 miles
- ❑  $C$  = speed of light = 186,282 miles per second

- ❑ 239 milliseconds Minimum delay

- ❑ Transmit and receive stations on the equator at the same longitude as the satellite.

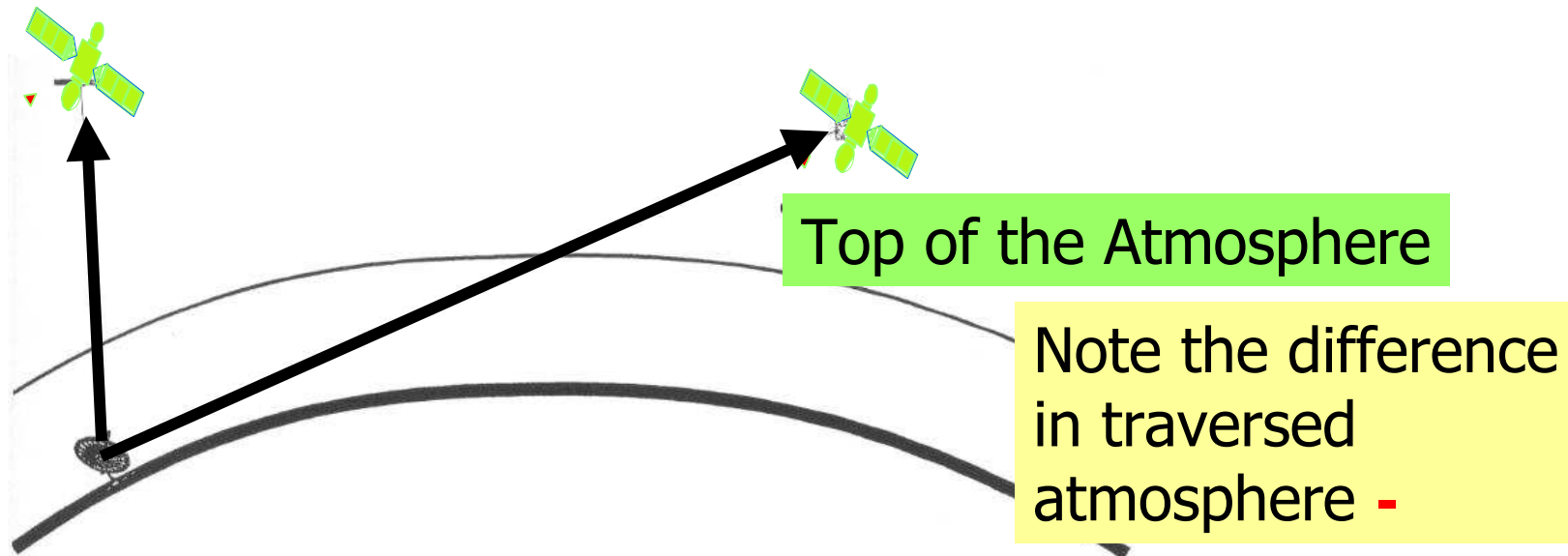
- ❑ Typical signals may required two hops through the satellite, i.e. around 500mSec

- ❑ 500mS echo is barely distinguishable -



# Elevation & Slant-Range

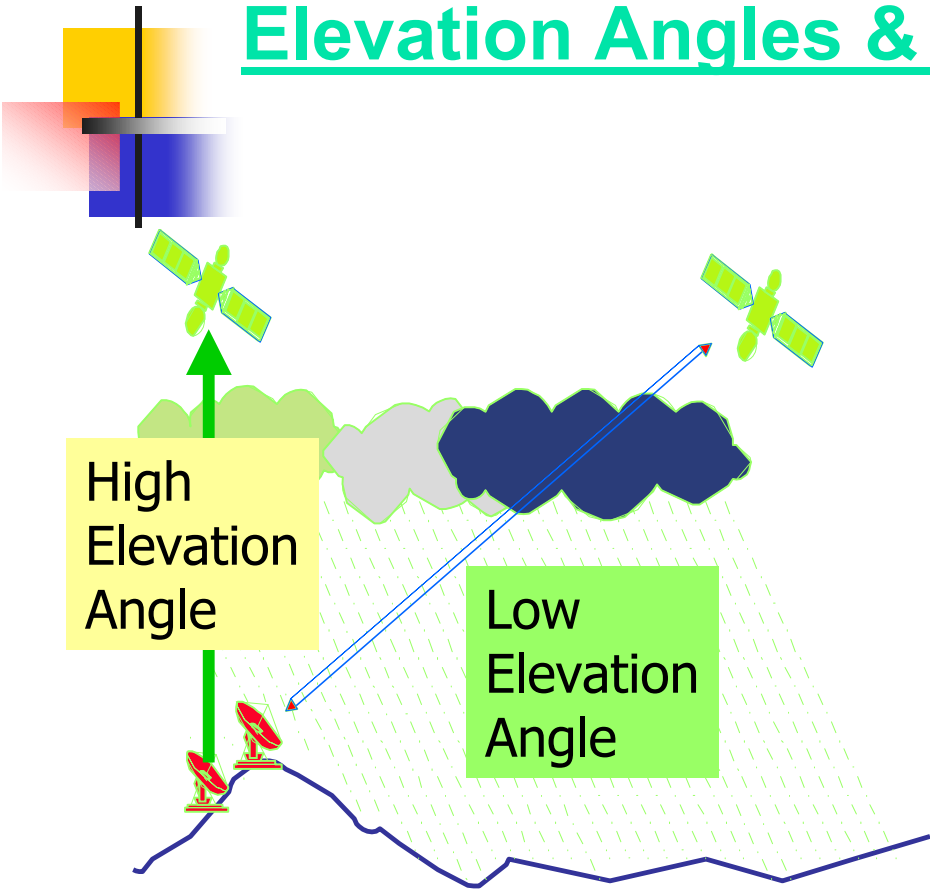
- Not All Satellites are located above the Earth Station
- At Higher Elevation Angles
  - Signals Traverse Less Atmosphere
  - Overall Slant-Range is Reduced.
- Signal Strength is Inversely Proportional to the Square of the Distance
- Atmospheric Effects are Significant at Low elevation





# Elevation Angles & Atmospheric Effects

- Atmospheric Effects are critical to signal path Loss
- 22,300 miles Earth to Satellite
  - 1<sup>st</sup> 5 miles is most critical
  - > 5 miles at low angles of elevation
- Atmospheric Problems
  - Potential interference from terrestrial sources.
  - Increased atmospheric absorption
  - Partially depolarizes signal -



High Elevation Angle

Low Elevation Angle

Minimum Elevation Angles

C-Band Elevations  $\geq 5^\circ$

Ku-Band Elevations  $\geq 10^\circ$

# Geo-Stationary Satellite Movement



## North-South perturbations

- Due to gravitational pulls of the Sun and Moon (Similar to Tidal Effects)

- North-South perturbations are the largest

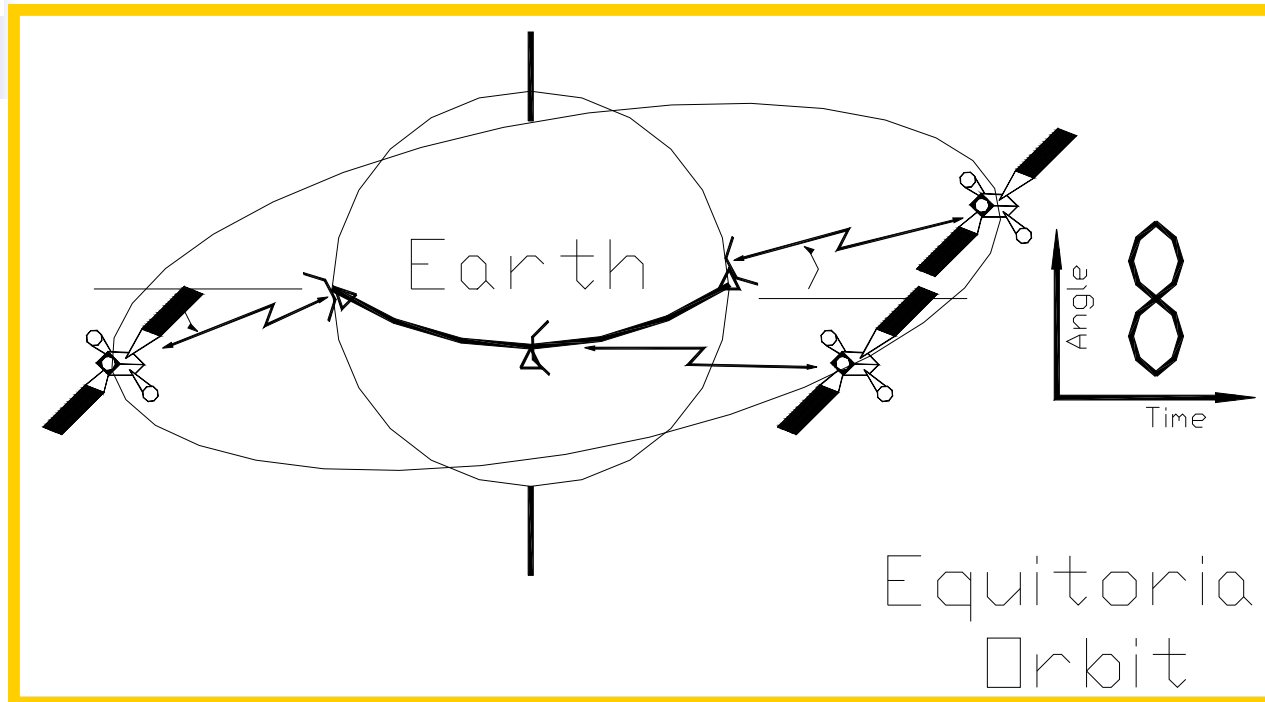
- Most demanding on satellite fuel reserves

## East-West perturbations

- Due to lumpiness of the Earth

- Incorrect satellite velocity & altitude -

# North-South Satellite Movement



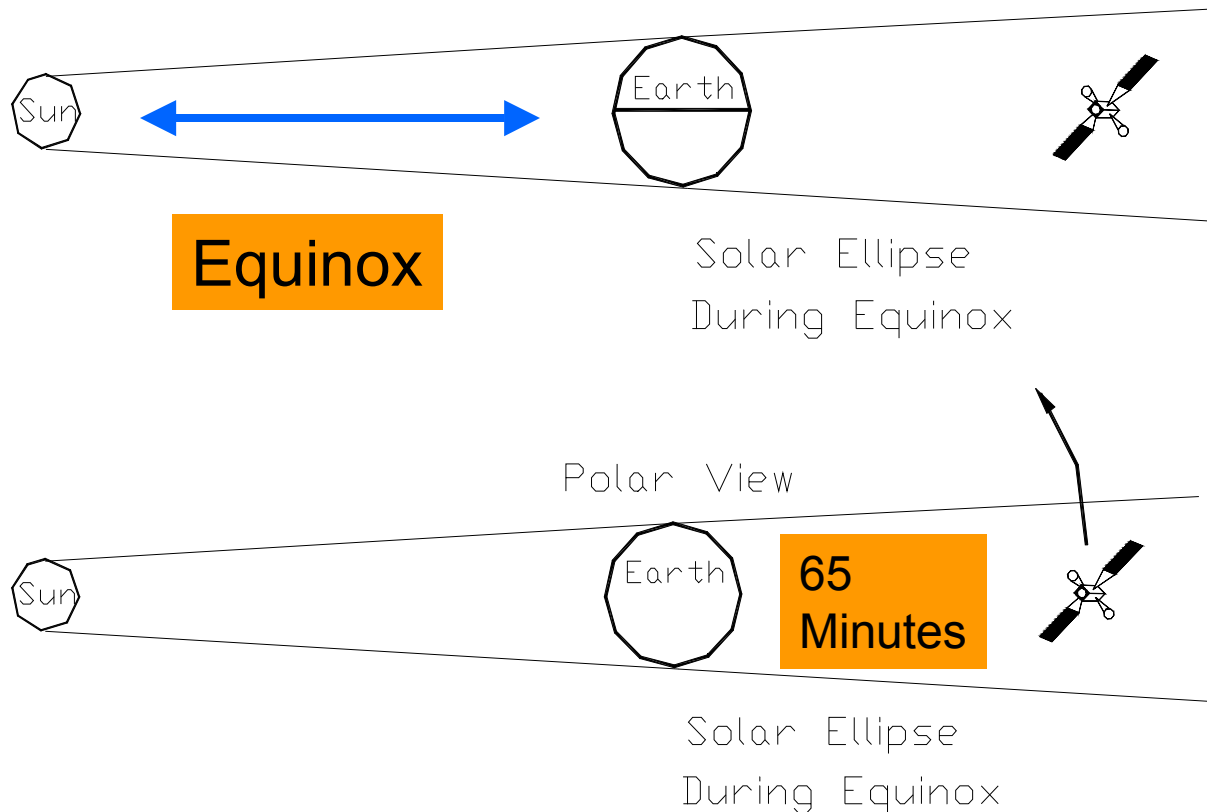
- An Object **not exactly over the equator**, transcribes a figure eight pattern to an observer on Earth
- Satellite lateral errors can be as much as  $\pm 3^\circ$  at end of life
- Looks like an up and down motion two times every 24 hours
- Large Earth Station Antennas must track the motion -

# Satellite Orbit Stabilization & Life

- Positioning is regularly corrected to within  $\pm 0.1^\circ$
- Without correction the movement in the North-South direction will be about  $0.85^\circ$  per year
  - $\pm 15^\circ$  over the satellites typical 12 year lifetime
- Life of satellite is determined by how much fuel is stored to correct its position
  - Last remaining fuel is used to move the satellite out of orbit
- Satellite fuel capacity is typically designed for 13 years, because the satellite technology becomes obsolete.
- Satellite life can be extended by making less frequent position corrections
- Allowing  $\pm 3^\circ$  latitude shift can extend the satellite life as much as 3 years. -

## Solar Outages Due to a Solar Eclipse

- Satellites experience a solar eclipse two times a year
- Vernal & Autumnal equinoxes for about 6 weeks each year.
- Satellites are in the earth's shadow for a few minutes to as much as 65 minutes on the day of the equinox.

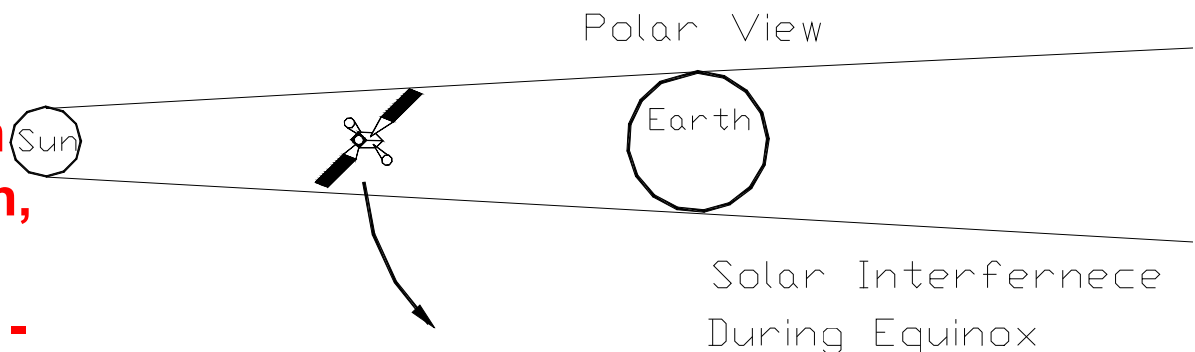


### During Eclipse

- No Solar power - Need battery power
- No Solar warming - Requires heaters. -

# Satellite Eclipse of the sun

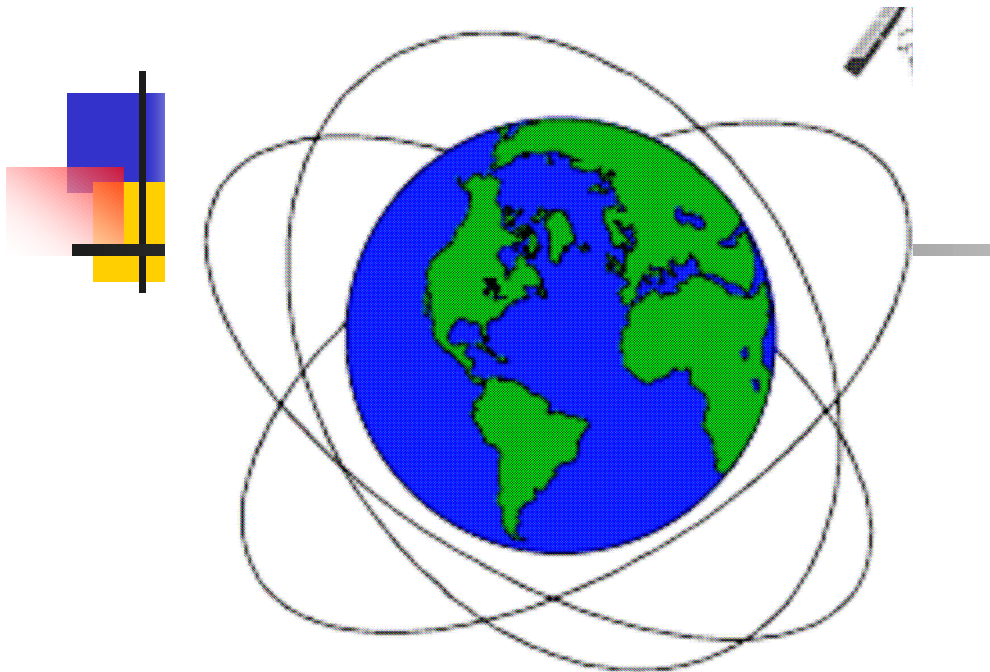
- For about five days during the eclipse season (65 days) the sun passes behind the satellite with respect to the earth station.
- The background noise builds up as this event unfolds
  - Plateaus for about 10 minutes.
- The satellite may be unusable (due to lower C/N) for this period
  - Traffic may have to be switched to another satellite.
- Outage occurs around noon
  - Larger diameter receive antennas (small beam width) exhibit this a shorter time and fewer days
- Tracking: mode is usually turned off to prevent the Earth Station from tracking the Sun, which at this time is a higher source of energy.**



# Non-Geostationary Satellites

Medium Earth Orbits (MEO)

Low Earth Orbits (LEO)



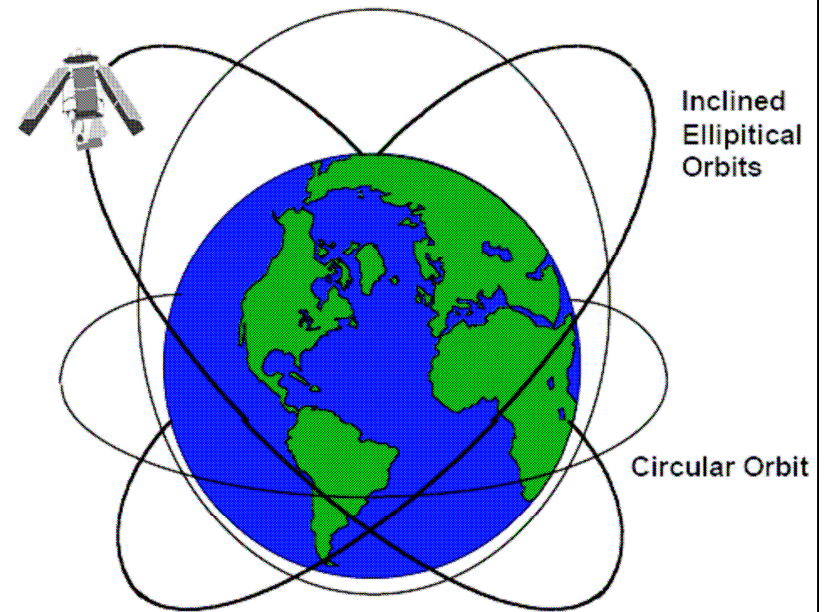
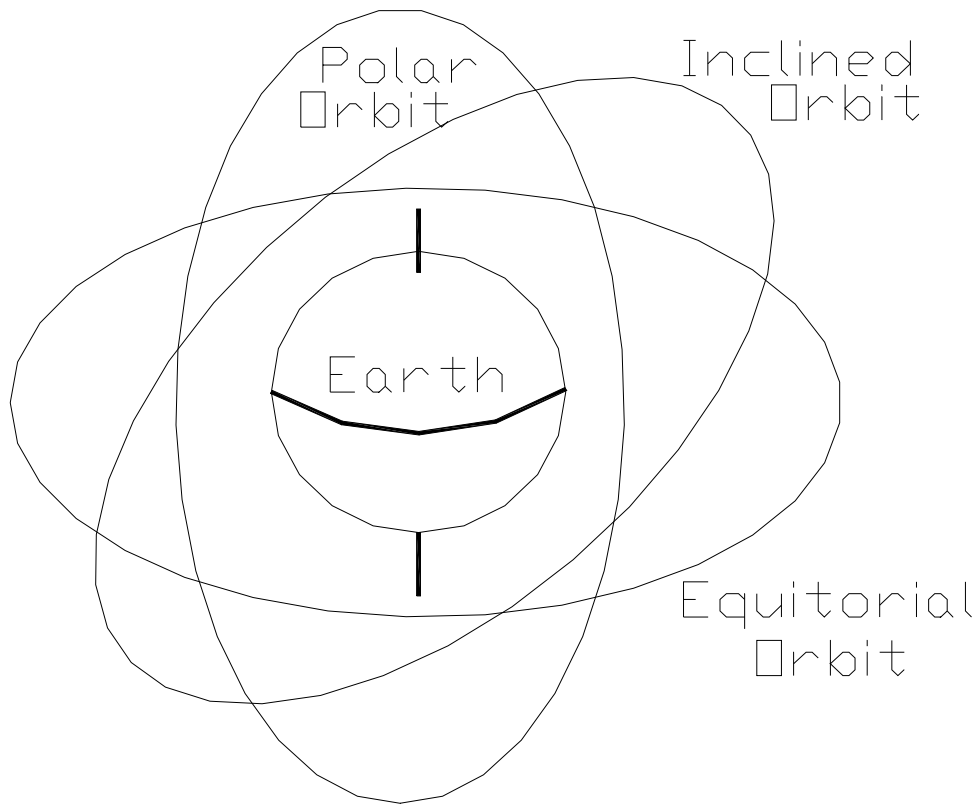
**Medium Earth Orbits**  
Height: 6000-12000 miles  
Rotation Period: 5-12 hrs.



**Low Earth Orbits**  
Height: 100-300 miles  
Rotation Period: approx. 90 min.

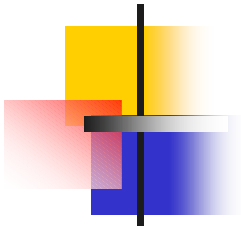


# Types of Orbits

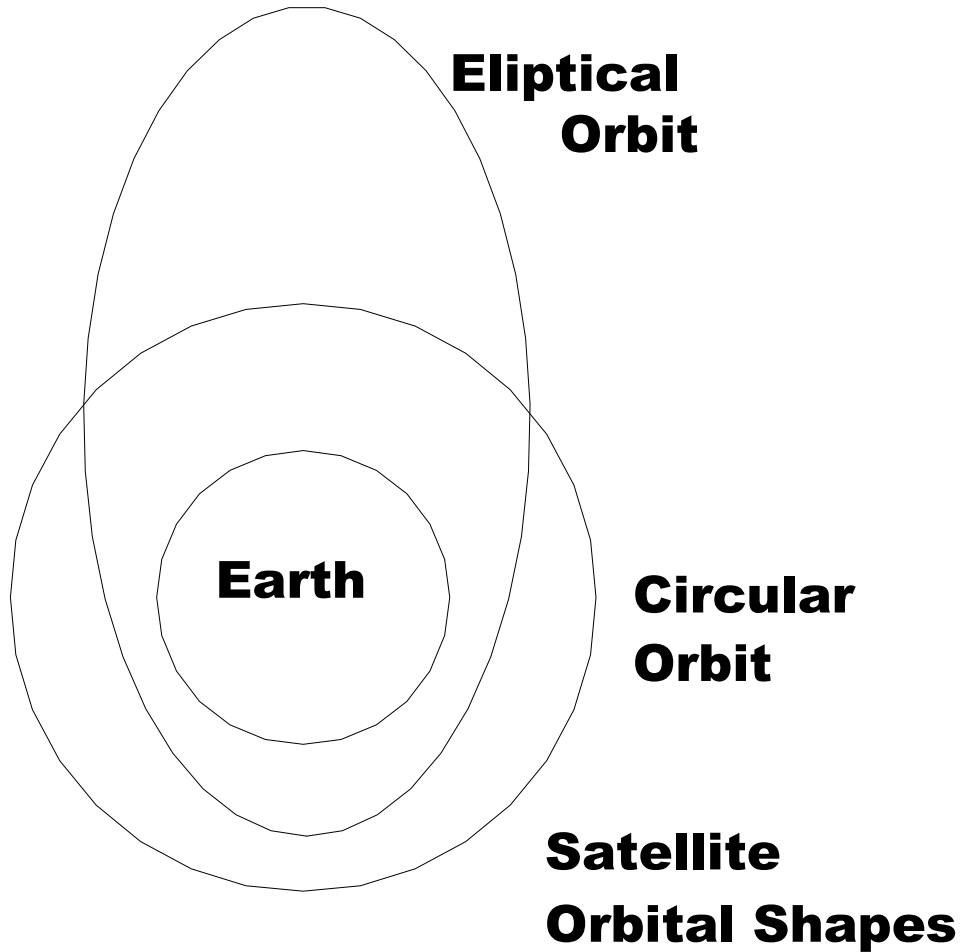


- ❑ Polar
- ❑ Equatorial
- ❑ Inclined -





# Orbit Shapes

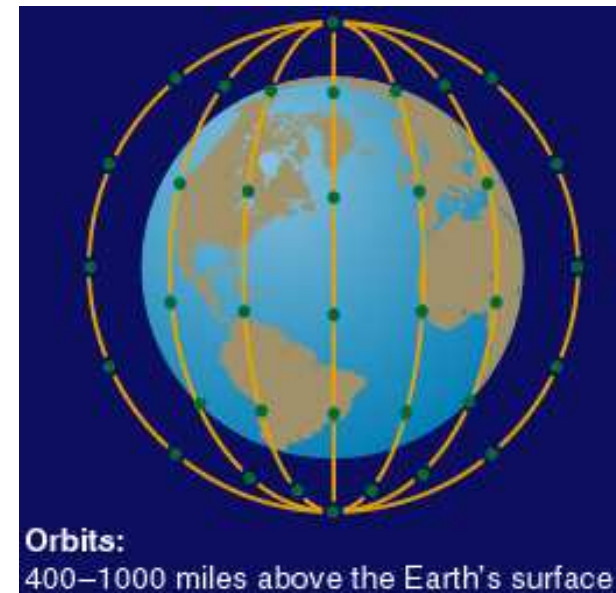


□ **Circular**

□ **Elliptical -**

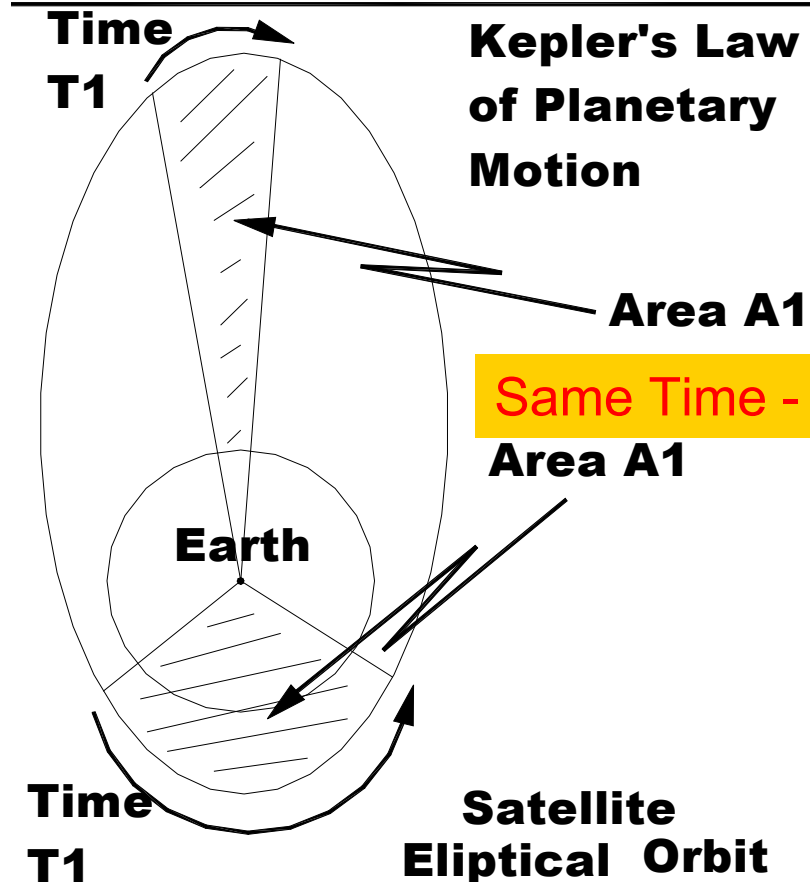
## Polar Circular Orbital Characteristics

- ❑ Full global coverage with a single satellite
- ❑ Continuous communications requires many satellites
  - ❑ Iridium uses 66 satellites
- ❑ Transfer of information between satellites
  - ❑ Information is handed off from satellite to satellite like a cellular system
  - ❑ Satellite moves and customer stays relatively still
- ❑ Constellation of satellites separated in time and angle
  - ❑ Every customer is always in the foot print
- ❑ Higher orbits require fewer satellites
  - ❑ More terrestrial up-link



(User) RF power -

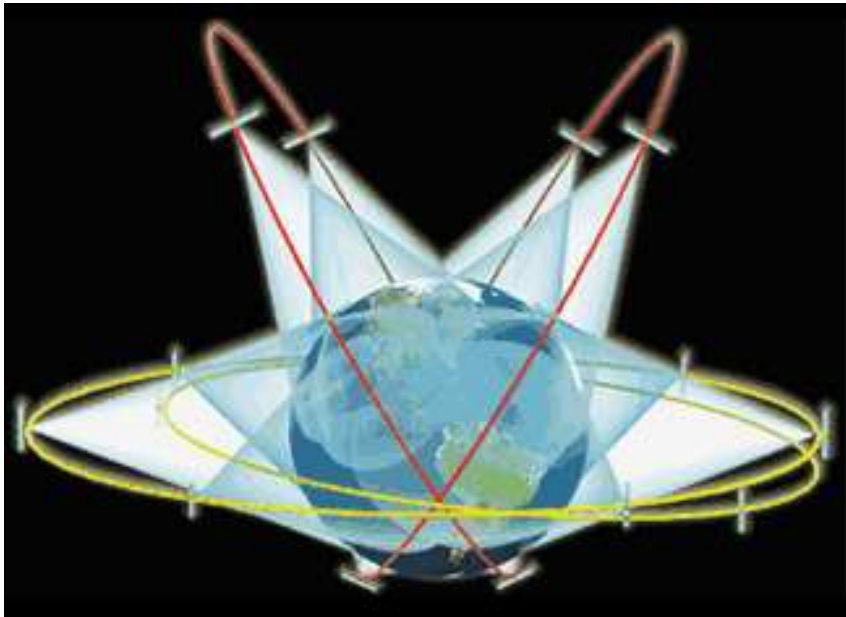
# Kepler's laws of Planetary Motion



- In the early 17th century, Kepler discovered the three laws of planetary motion:
- The orbits of the planets have the same physics as earth satellites.
  - 1.The law of orbits: Planets move in elliptical orbits with the Sun at one of the foci.
  - 2.The law of areas: the line from the Sun to a planet sweeps out equal areas in equal times.
  - 3.The law of periods: The square of the period is proportional to the cube of the ellipse's major axis.

# Elliptical Satellite Orbits

Inclined Elliptical Orbits allow **asymmetrical** time coverage over different sectors of the Earth



- ❑ Geostationary satellites do not provide coverage for the Polar regions
- ❑ Elliptical orbits cover the same area per unit time in all parts of the ellipse, **Satellite travel slower further away**
- ❑ To serve Polar Regions establish an **Inclined Orbit with the apogee over the Polar regions**
- ❑ **Most of the satellites orbital time is over the Polar region -**



# Low Earth Orbit Advantages/Disadvantages

- **Advantages:**
  - **Reduced launch costs to place in low Earth orbit**
    - e.g., airplane/booster launched
  - **Reduced pass loss**
  - **Lower Power, Lower cost satellite (\$0.5-2M)**
  - **Much shorter transmission delays**
- **Disadvantages:**
  - **Short visibility from any point on earth, as little as 15 minutes**
    - **Potentially large constellations**
  - **Radiation effects reduce solar cells and electronics lifetimes**
    - **Van Allen radiation belts limit orbit placement**
      - **Belt 1: 1500-5000 km**
      - **Belt 2: 13000-20000 km -**



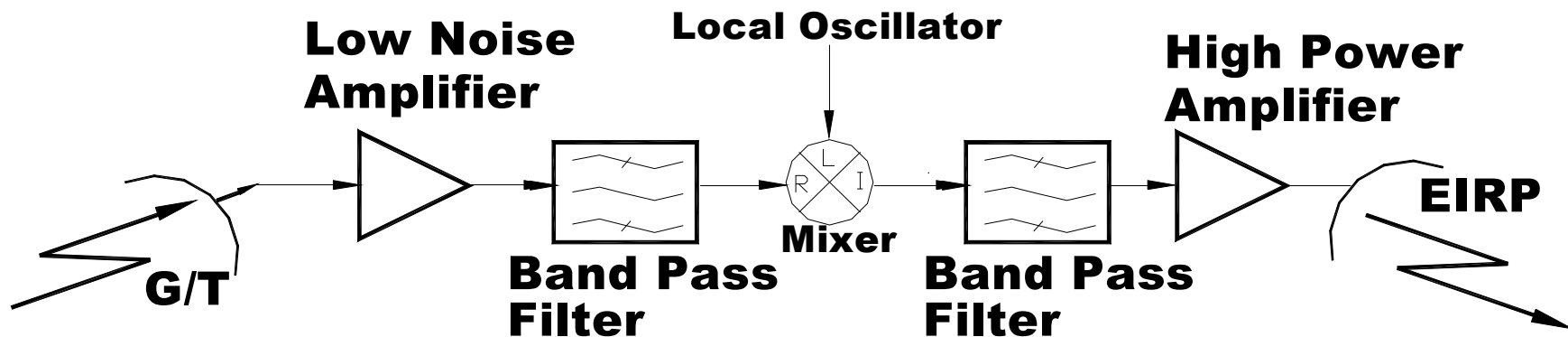
## LEO Example: IRIDIUM

- Voice (4.8 kbps), Data (2.4 kbps), Fax, Location Services
- 66 satellites in 6 polar orbits (780 km)
  - Iridium has an atomic number 77
    - Original design called for 77 satellites
- 48 spot beams per satellite forming “cells”
- 230 simultaneous duplex conversations
- Satellite-to-satellite links as well as to ground
- Ka band @20 GHz to gateways & crosslinks,
- L band at 1.5GHz to handheld units
- FDMA uplink, TDMA downlink
- Supports satellite handoff during calls -

# Satellite Configurations: Bent Pipe

Keep the satellite simple

- RF to RF – Frequency Translator
- C-Band Earth Station Transmits typically at 5.925 GHz to 6.425GHz
- Earth Station Receives signals at 3.7GHz to 4.2 GHz
- Satellite has a fixed Local Oscillator at 2.225 GHz
- Satellite transmits at a lower frequency (Less loss) -



## Satellite Transponder



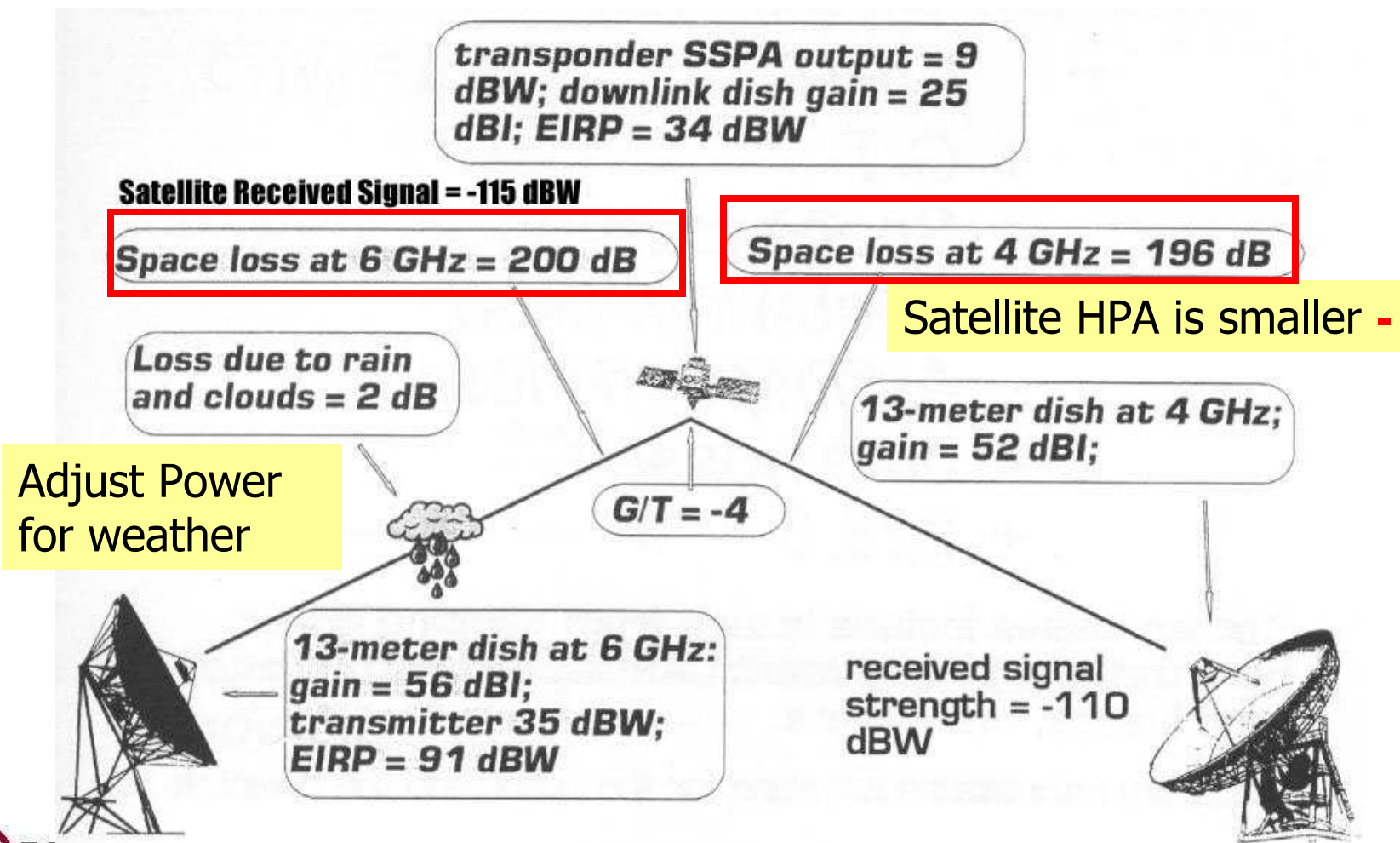
## On-Board Processing vs. Bent Pipe

- **More control over signal routing**
  - **Higher Cost, more complicated, Higher failures**
  - **Typical Configurations**
    - **RF to IF → Microwave switch matrix → IF to RF**
      - **Allows Changing Signal Path Transponders**
    - **RF to IF → Demodulator → Baseband → Modulator → IF to RF**
      - **Reprocessing eliminated accumulative noise**
  - **Intersatellite Links, Handing off Signals**
    - **some LEO's**
    - **Military satellites**
    - **NASA TDRSS system -**



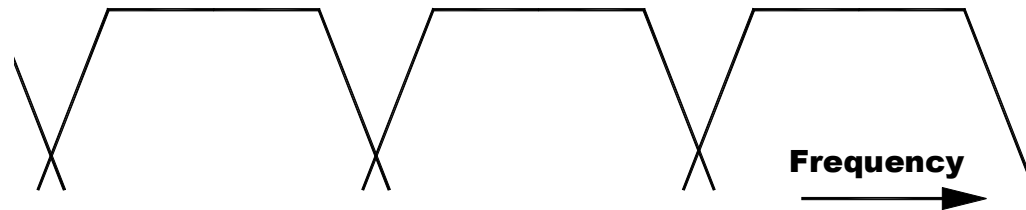
# Typical C-Band Link

- This Example Ignores Line, Atmospheric, and Other Losses.
- Does Not Include C/N Requirement Data.



# Satellite Transponders

Satellite Bandwidth (Typically 500 MHz to 750MHz) is broken up into segments called transponders

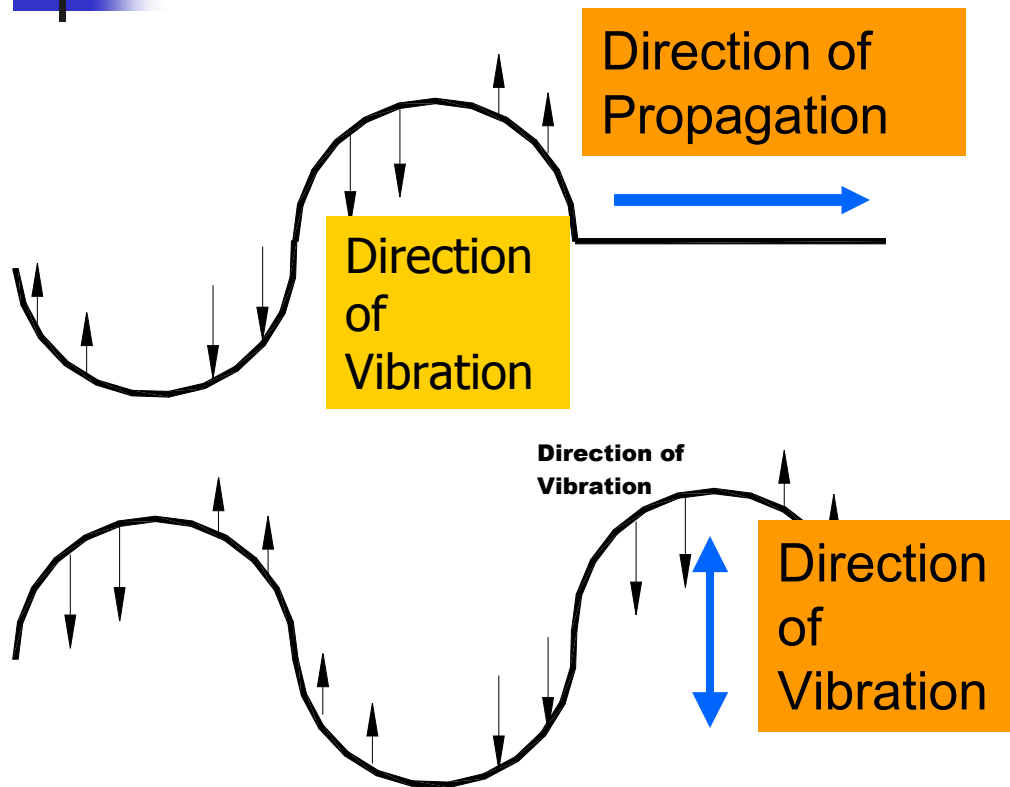


- Transponders are characterized by:
  - Center Frequency
  - Bandwidth
  - Down Link power (Satellite EIRP)
    - Different bandwidths have different power
    - **All signals to a satellite must have the same power spectral density**
  - Polarization -

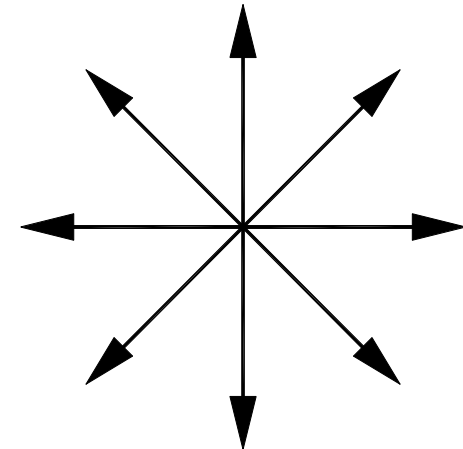


# Frequency Reuse by Polarization

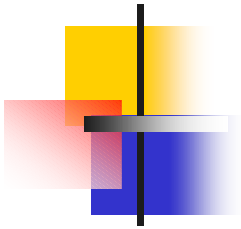
## Electromagnetic Wave Behavior



Non-Polarized  
Electromagnetic  
Wave Viewed  
Head-On

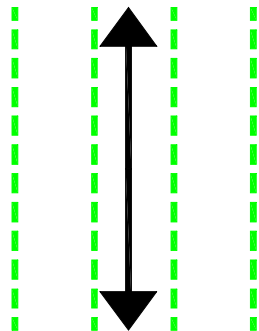


**Polarization Refers to the orientation of the electric field vector as a function of time. -**

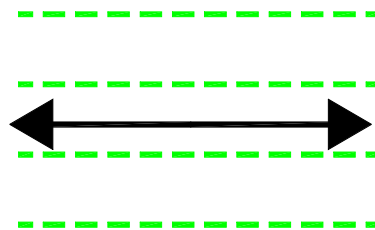


# Linear Polarization

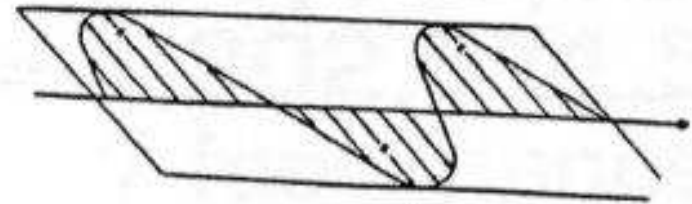
**Vertically Polarized Wave**



**Horizontally Polarized Wave**



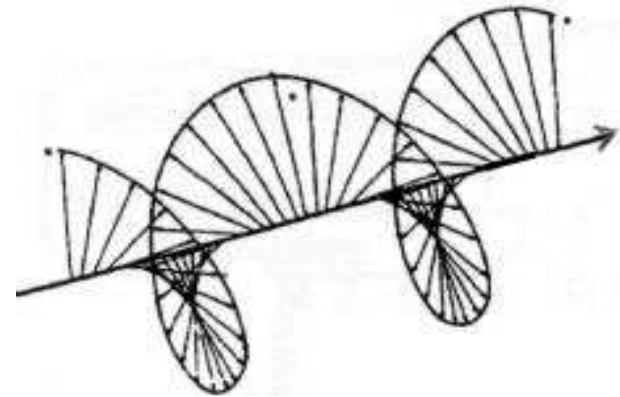
**Electromagnetic Wave Transmits in a single plane**



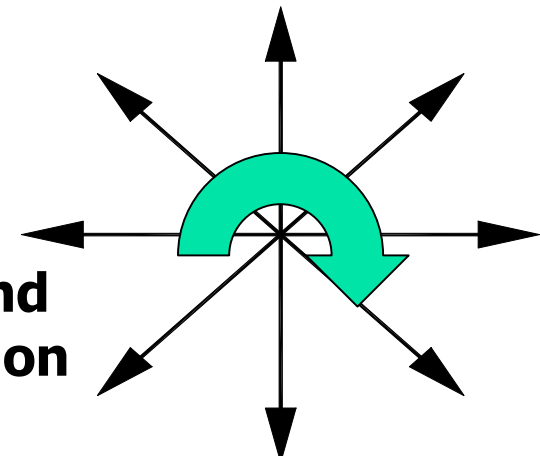
**❑ Linear Polarization requires precision alignment of the transmitter and receiver, i.e. Satellite & Earth Station -**

# Circular Polarization

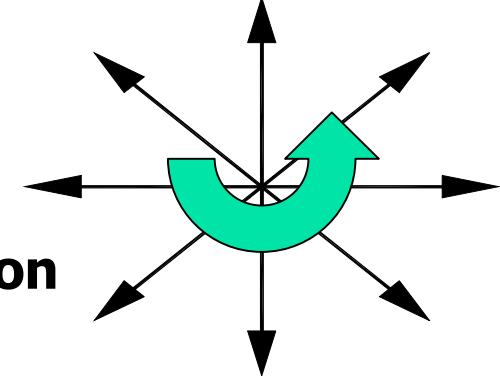
- Electromagnetic Plane rotates clockwise with time
  - Right Hand Polarization
- Electromagnetic Plane rotates counterclockwise with time
  - Left Hand Polarization
- A Right Hand Polarized Satellite signal is Left Hand Polarized at the Earth Station
  - Mirror Image -



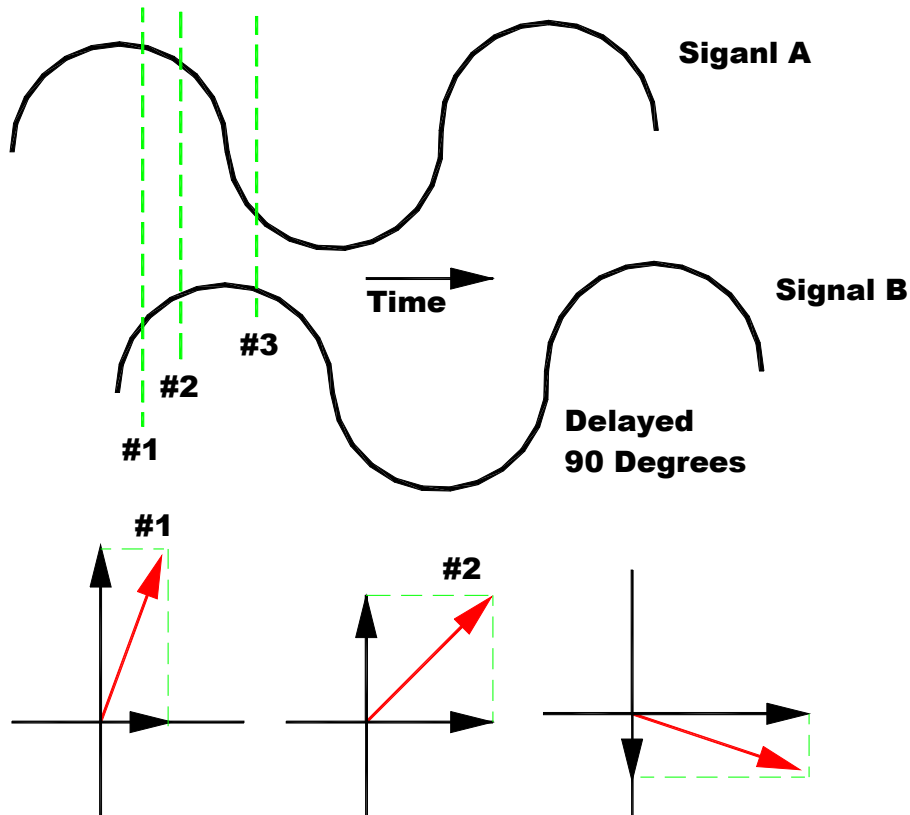
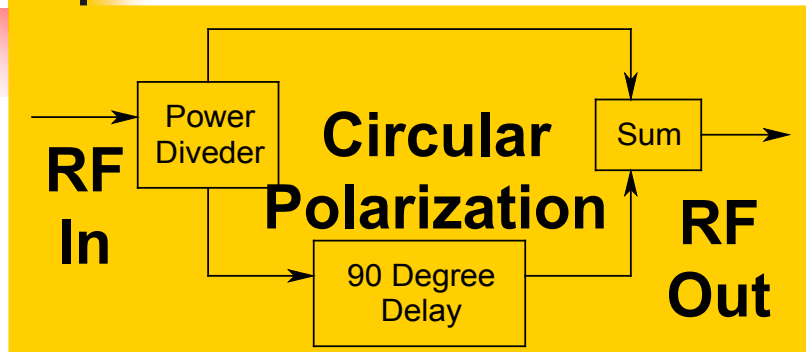
**Right Hand Polarization**



**Left Hand Polarization**



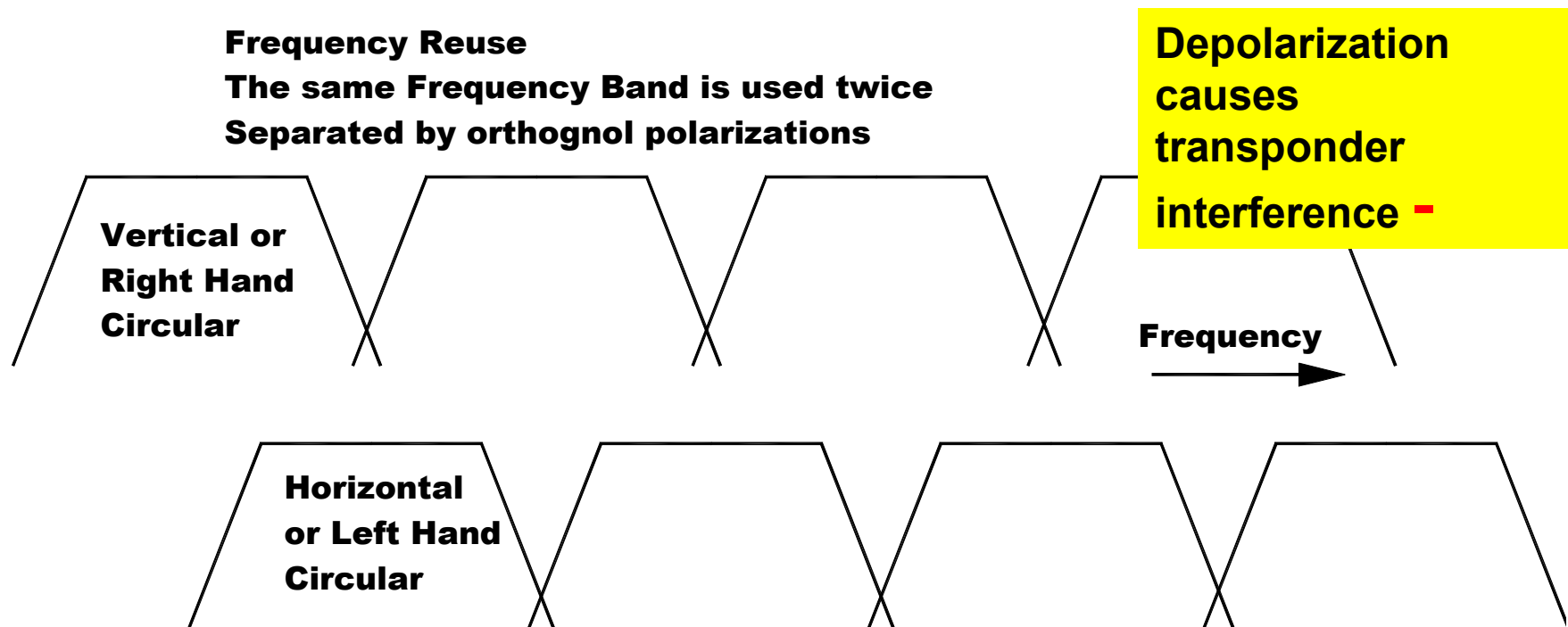
# Creating Circular Polarization



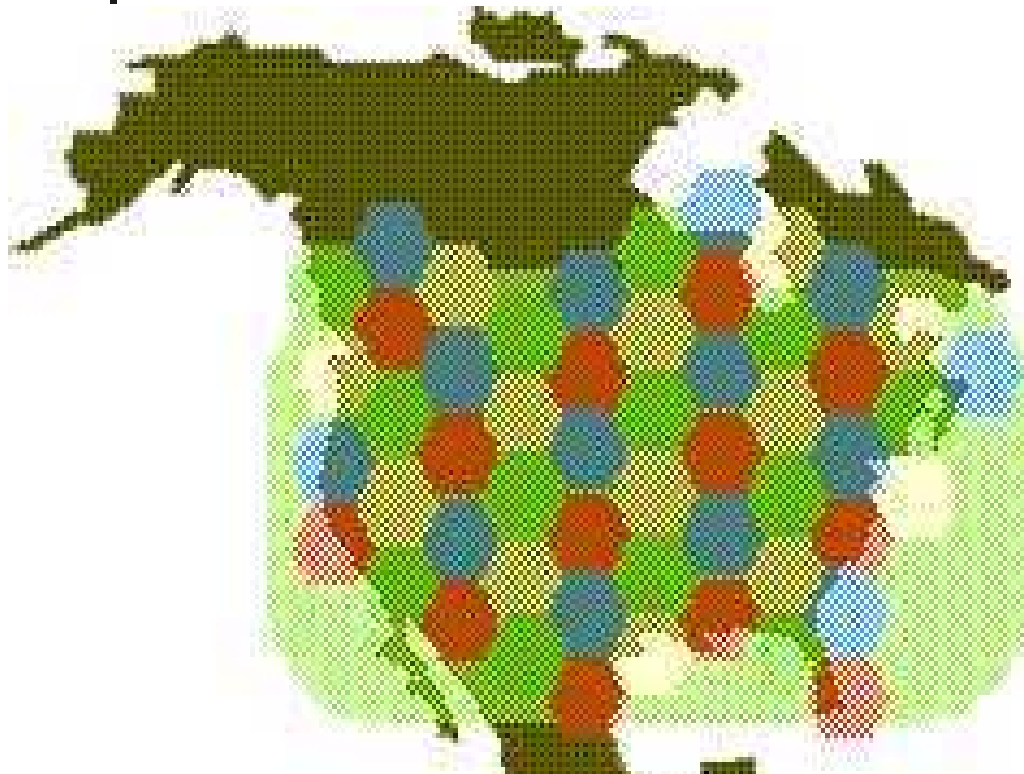
- **Circular polarization is achieved**
  - **Splitting the linearly polarized signal into two orthogonal vectors**
  - **Delaying one with respect to the other by a quarter wave length ( $90^\circ$ )**
  - **Summing the vectors -**

# Polarization and Frequency Reuse

- ❑ Frequency Reuse is receiving and transmitting signals at the same frequency, but with orthogonal polarization.
- ❑ Linear polarization needs absolute alignment
- ❑ Circular requires no alignment but more effected by rain
- ❑ Transponder Frequencies are offset to minimize interference



# Spatial Reuse – Spot Beams



- Each color is a different frequency range
- Similar colors don't touch -

- Ka Band uses multiple narrow beams
- Focused beams cover a much smaller area
- Hundreds of miles across, rather than thousands of miles with Lower Frequency FSS
- Form coverage cells
- Adjacent cells use different frequency ranges
- Frequency range reused many times over a wide geographical area



# Advantage of Spot Beams

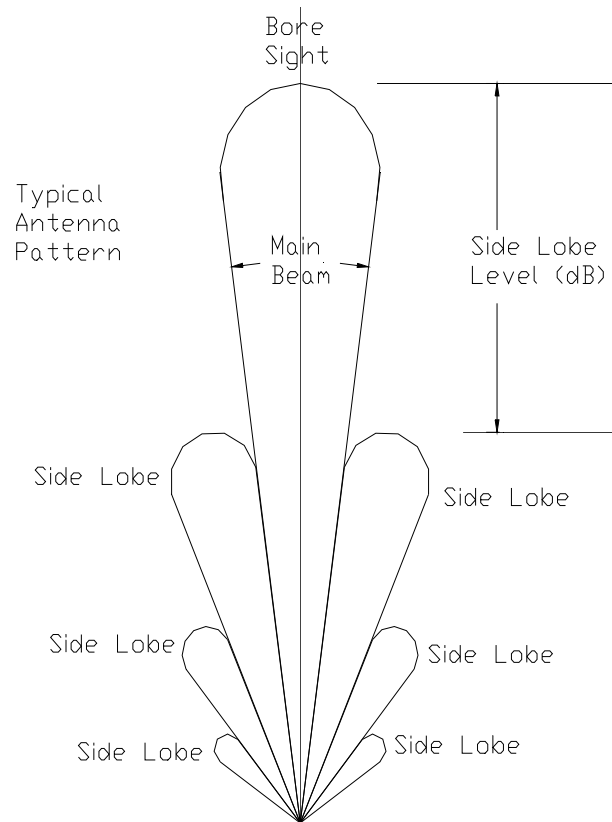
- Large increase in overall capacity
- Spot beams provide 30 to 60 times the system capacity of the FSS
- Capacity of 30 Gbits/Sec makes satellite broadband services a long-term, economically viable business
- Flexible Spatial Redundancy with Phase Array Spot Beams

Service is restored by moving beams to effected areas -



# Earth Station Antennas

## Antenna Mounts

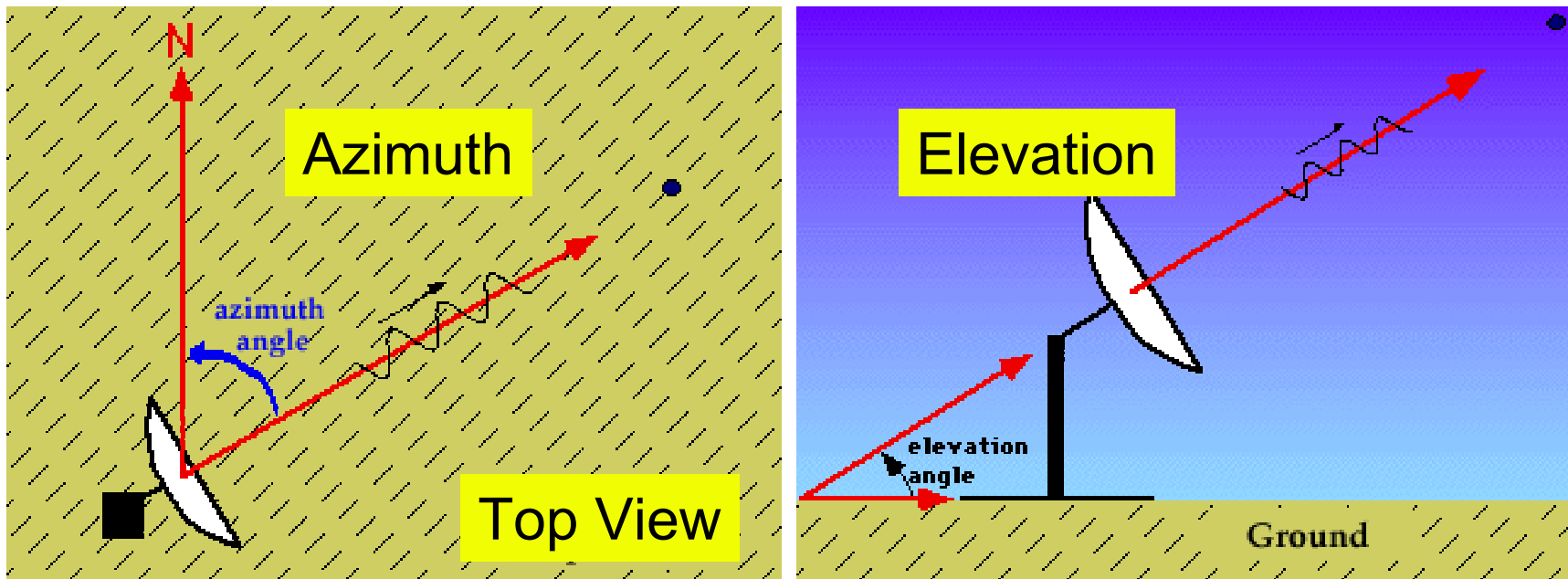


- **Fixed:**
  - **views one satellite**
  - **Inexpensive**
- **Elevation-Azimuth:**
  - **Vertical and horizontal movement**
  - **Narrow Beam Width**
  - **High Gain**

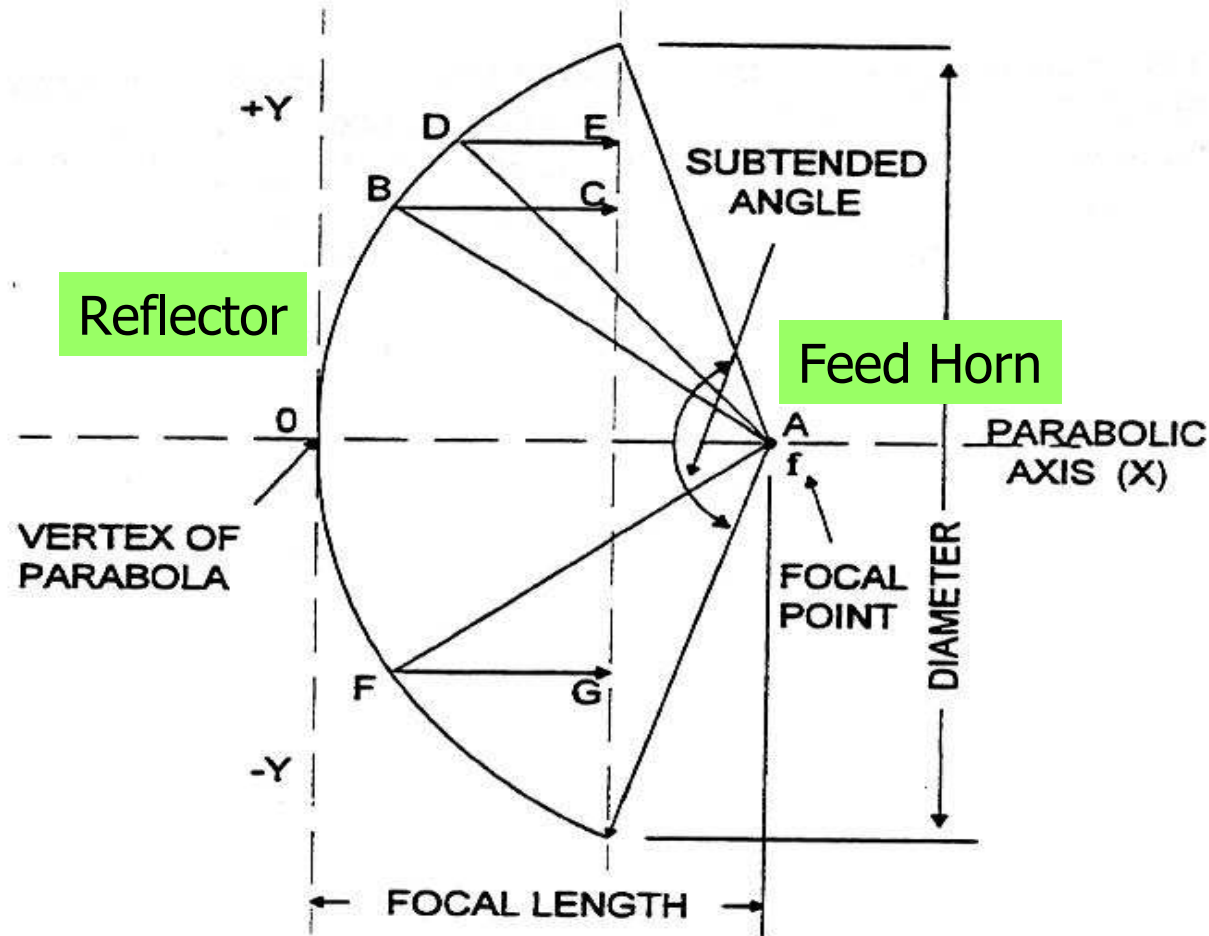


# Azimuth & Elevation Angles

- Azimuth is the axis of angular rotation
- Elevation is the Angle with respect to the horizon -



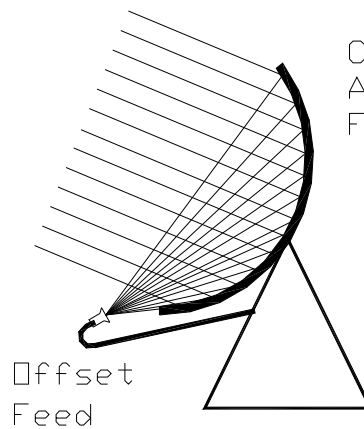
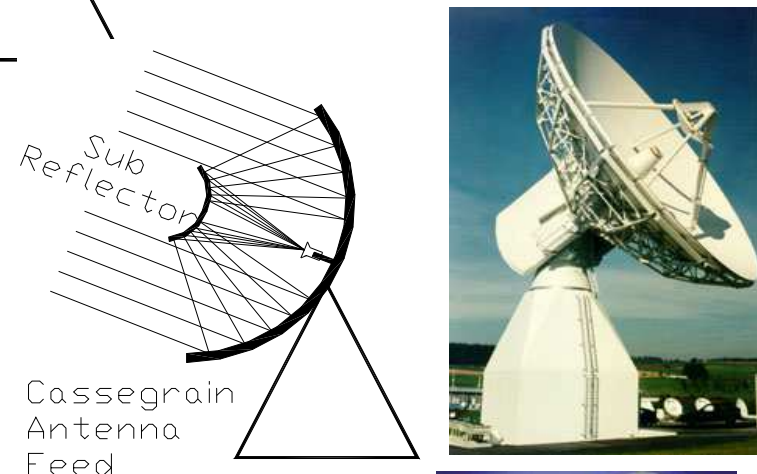
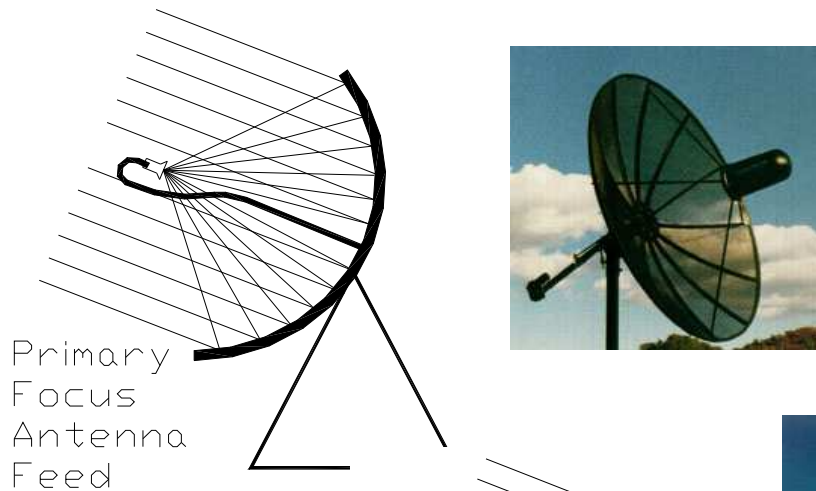
# Parabolic Reflector Geometry



- Signals are fed from a point source
- Feed Horn is the antenna
- Dish is a Reflector
- Geometry is such that all signals are reflected in parallel ■

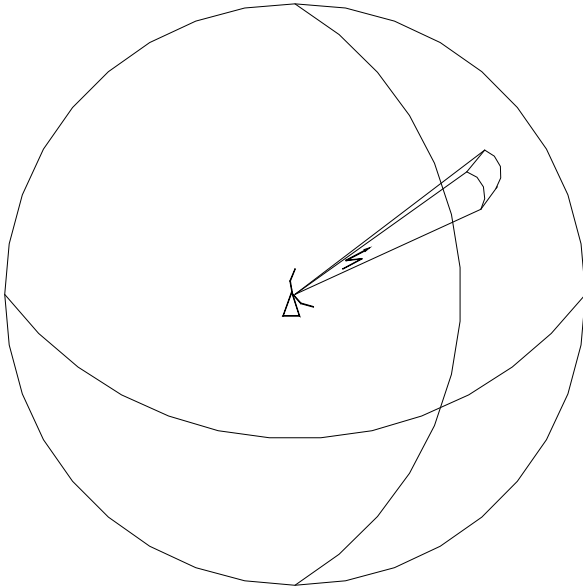
# Parabolic Antenna Types

- Prime Focus Feed
  - Simplest Antenna Design
- Cassegrain Feed
  - Allows for Shorter Feedlines
- Offset Feed
  - Minimizes Feed Blockage



# Antenna Beam-Width

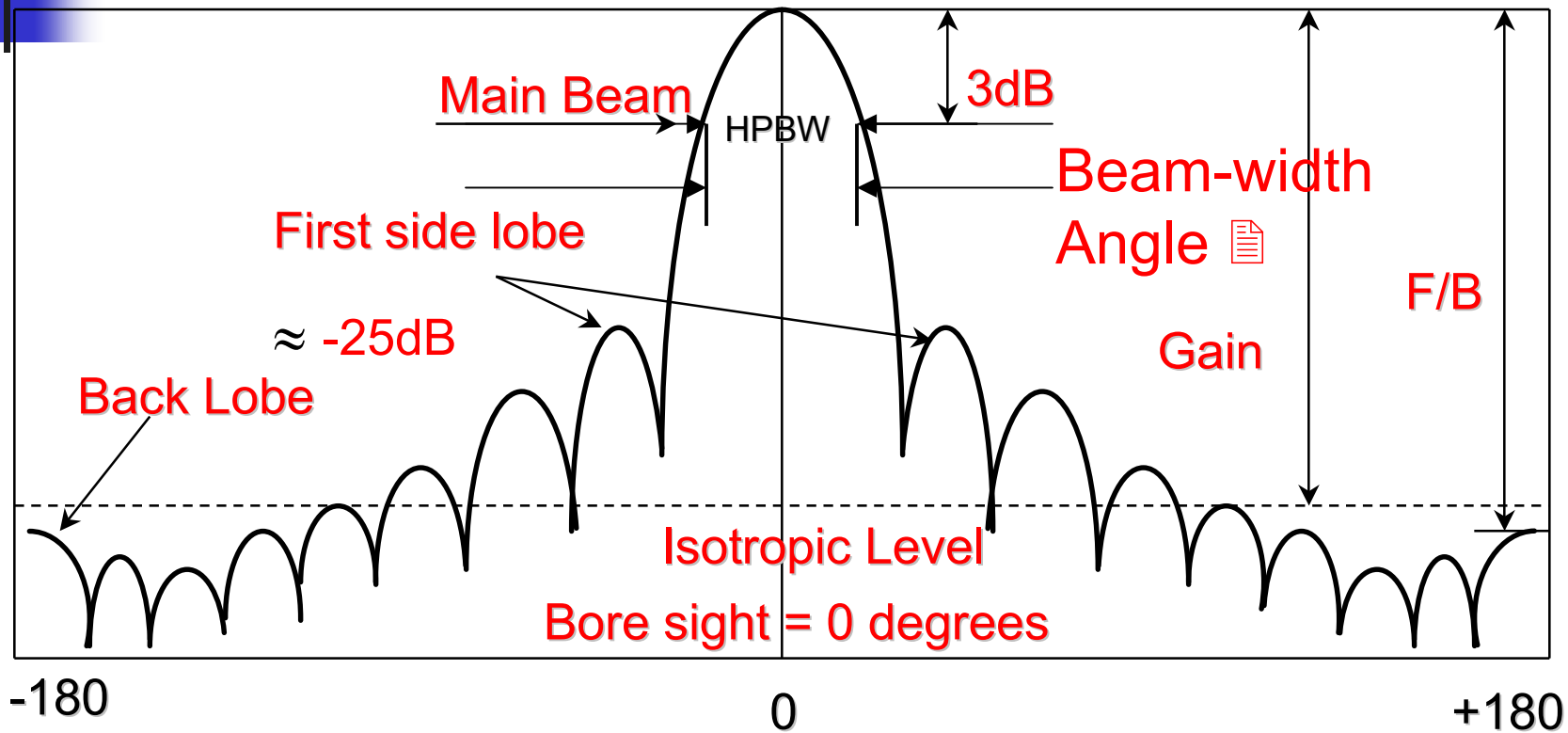
## Antenna Beam Width




□ Example: 3  
Meter Antenna @ 4  
GHz has a 1.75°  
Beam width (-3 dB) -

- Beam width is the angle where the antenna power is within 3 dB of the peak
  - Beam Mid-Point: Boresight
- Beam width is a solid angle
- Beam width  $\approx 21 / (F * D)$  in degrees (Parabolic dish)
  - F = Frequency in GHz
  - D = diameter of the dish in Meters
- For a parabolic dish D is the same in all directions

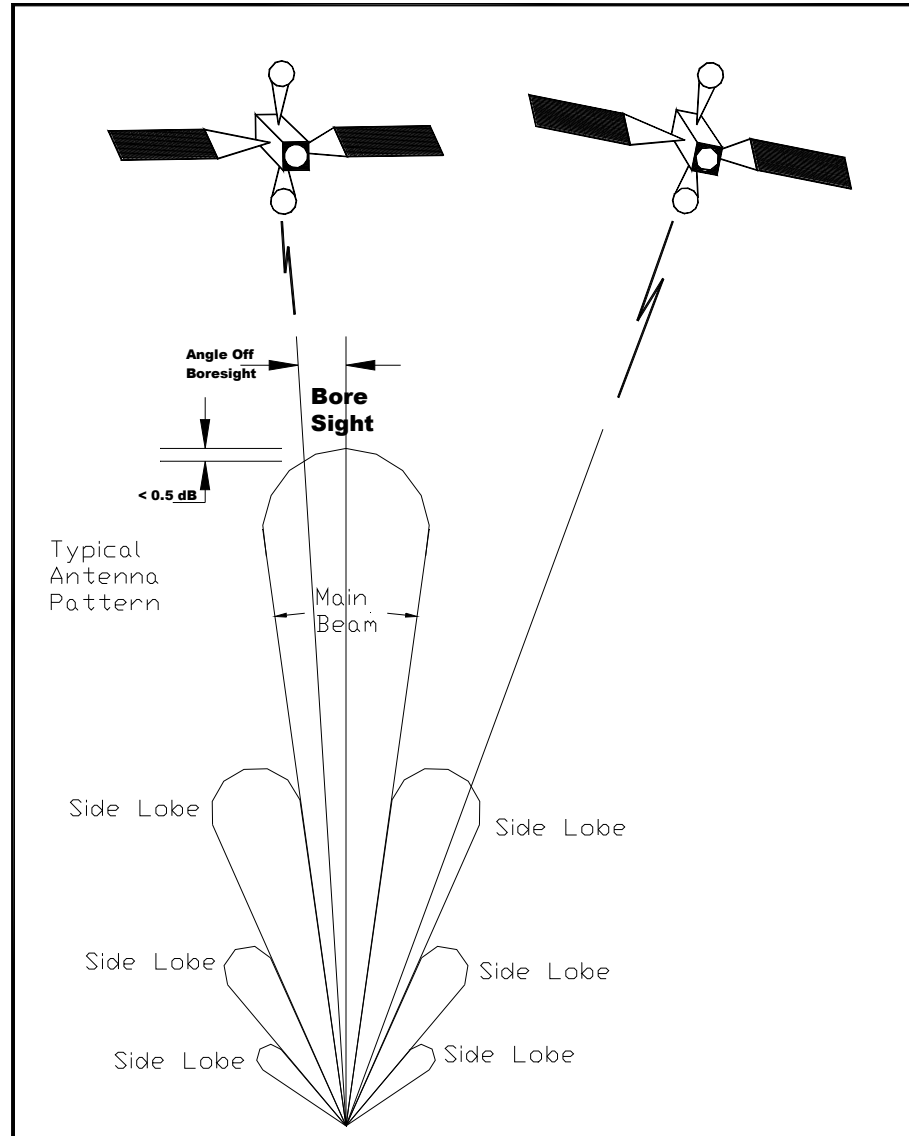
# Antenna Radiation Pattern



- All angles are referenced to Bore-sight
-  is the 1/2 Power (3dB) Beam Width
- **Side Lobes:** The antenna patterns are repeated at lower gains on either side of the main beam -

# Side Lobe Radiation Problem

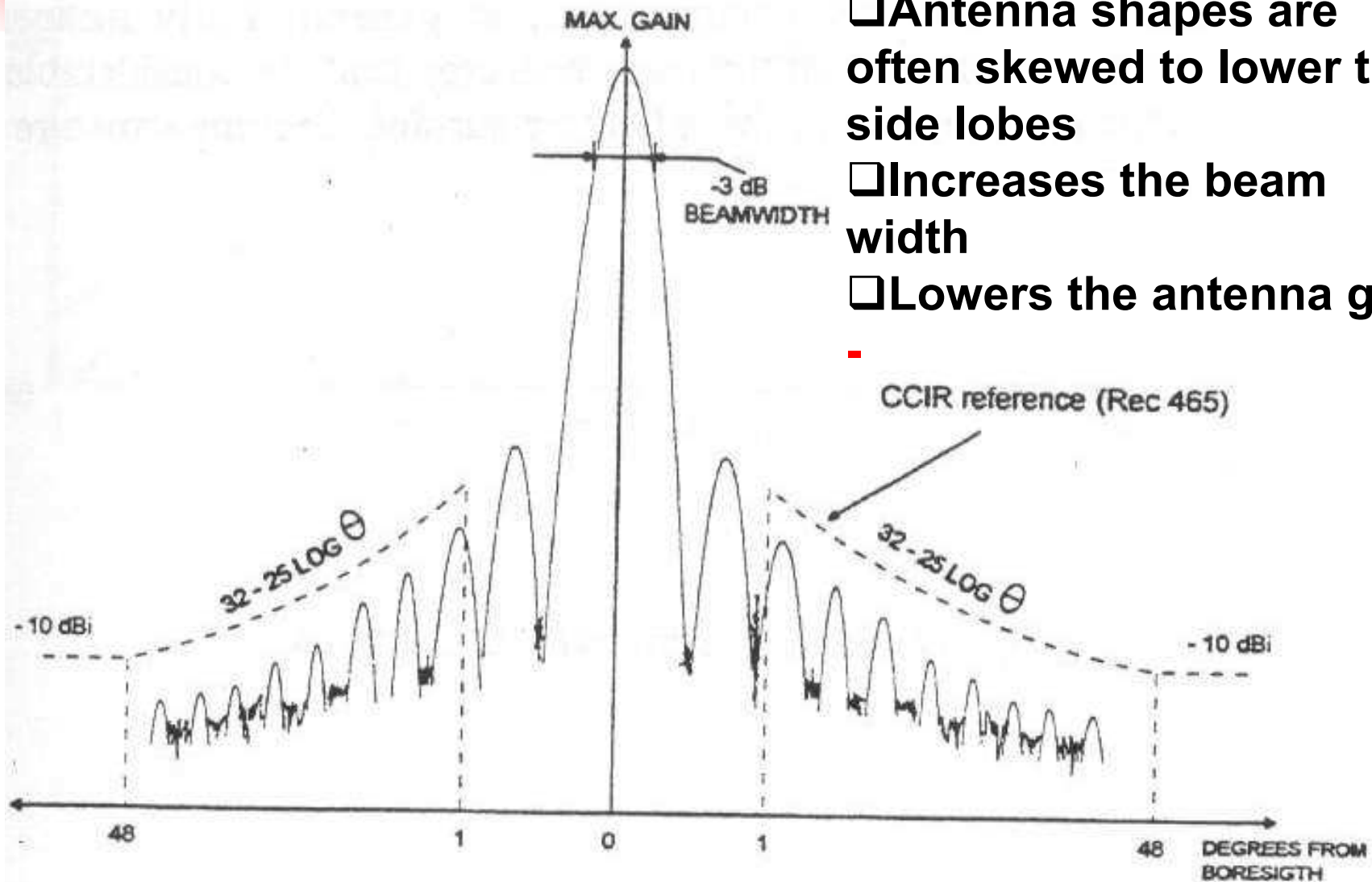
- ❑ Side Lobe Energy Limits: Limit interference to nearby satellites
- ❑ IESS Spec: Side Lobe Max:  $\leq 29 - 25^* \text{Log}_{10} (A)$  in dB  
A = the angle off boresight. -



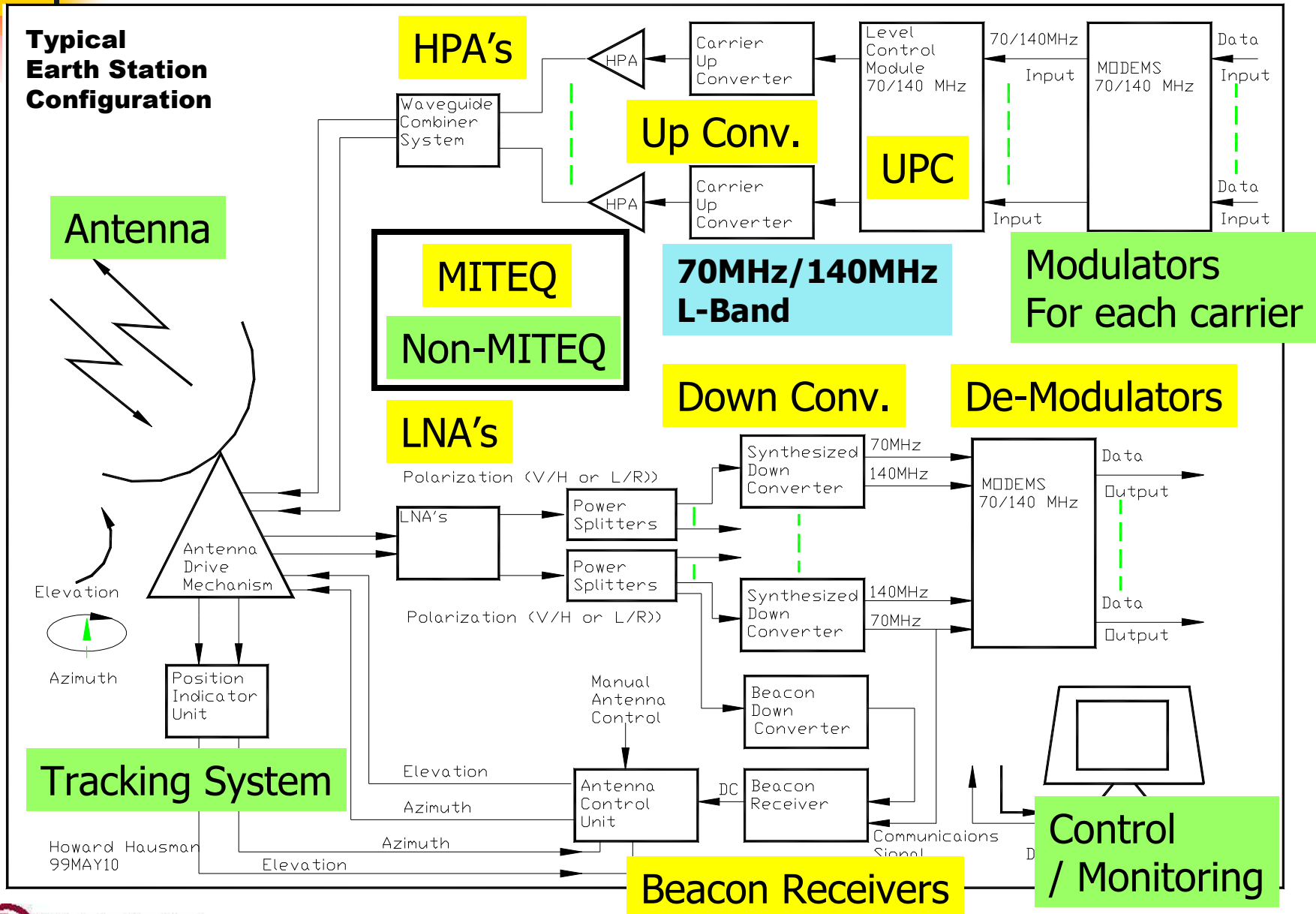


# Antenna Side Lobes Limits

- ❑ Antenna shapes are often skewed to lower the side lobes
- ❑ Increases the beam width
- ❑ Lowers the antenna gain



# Major Earth Stations Components





# Satellite Communications Summary

- Broadcasting
  - One Transmitter to millions of receivers
- Voice, Data, Internet, etc. access everywhere
  - On the move
  - In the Air
  - Isolated locations
- Communications with minimal infrastructure
- Satellite Communications is versatile enough to let your imagination runaway with ideas