Satellite Communication

Communication Systems
Lecture 6

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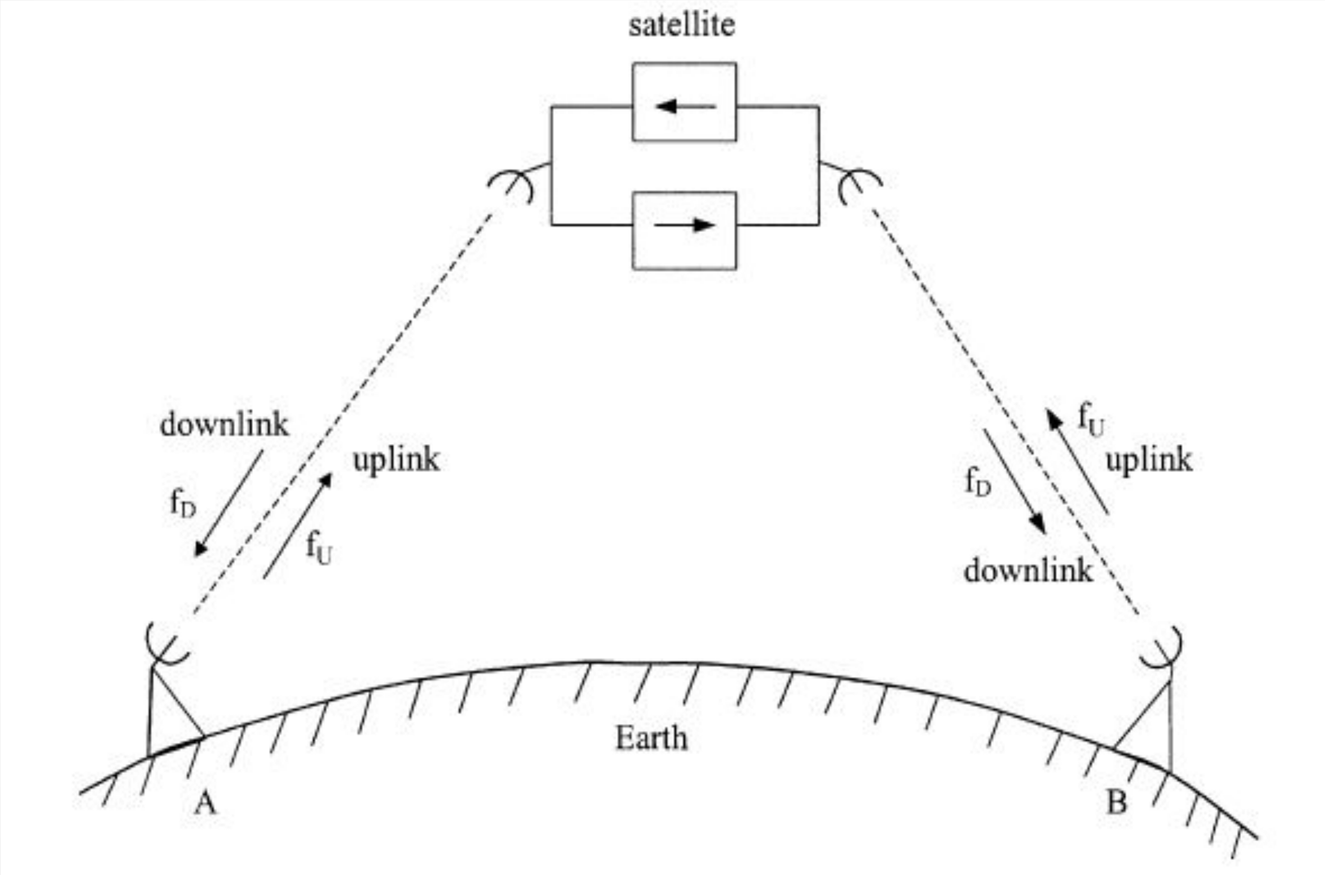
Radio Frequency Satellite Link



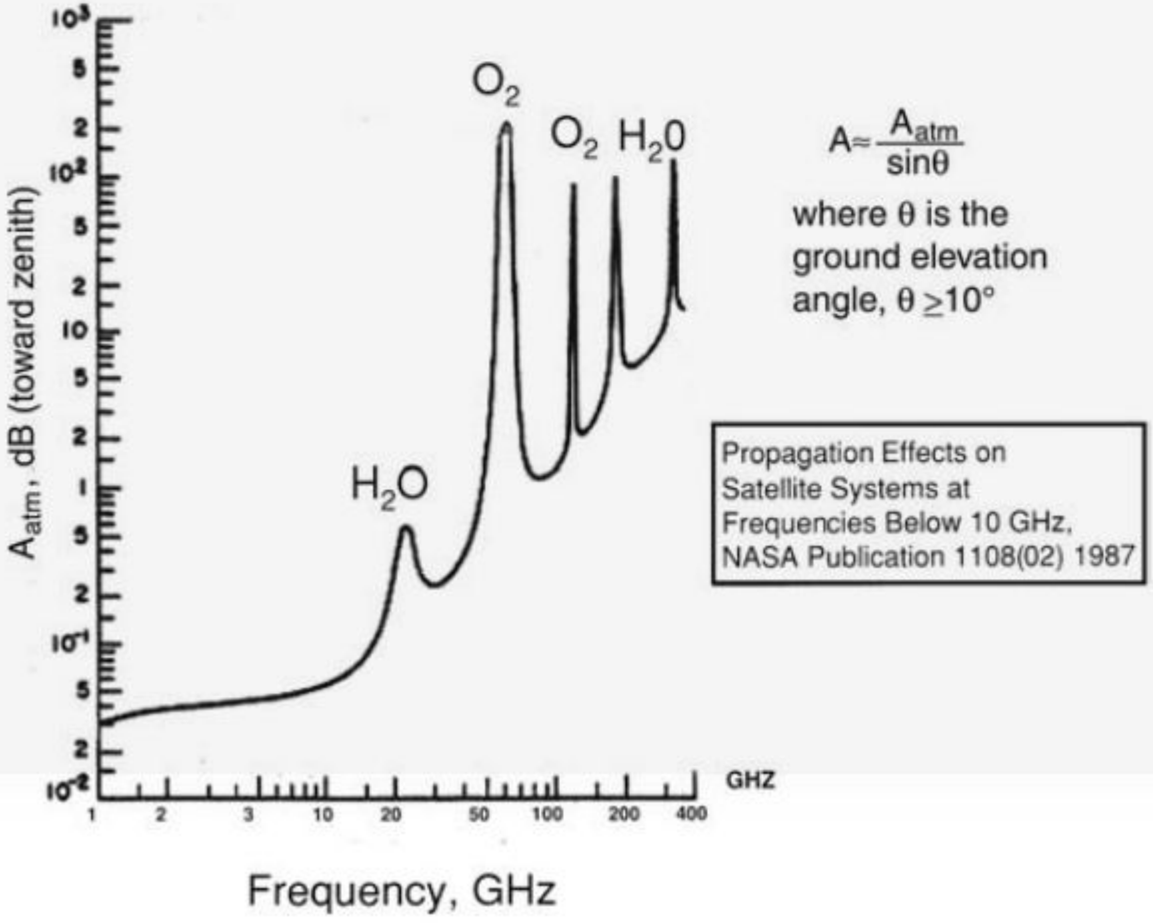
Satellite Communication Link

- The earth station A transmits an uplink signal to the satellite at frequency f_U .
- The satellite receives, amplifies, and converts this signal to a frequency f_D . The signal at f_D is then transmitted to earth station B.
- The system on the satellite that provides signal receiving, amplification, frequency conversion, and transmitting is called a repeater or transponder.

Commercial Satellite Communcation Frequencies

Band	Uplink Frequency (GHz)	Downlink Frequency (GHz)
L	1.5	1.6
C	6	4
X	8.2	7.5
Ku	14	12
Ka	30	20
Q	44	21

Frequency Spectrum Allocation



Atmospheric attenuation effects for space-to-Earth paths as a function of frequency
(clear air conditions)

Comparison of Significant Propagation and Fading Modes and Resulting Losses That Affect Microwave Links over GEO Paths (Values Are Rough Order of Magnitude, in Decibels)

Propagation Mode	*Relative Importance on Satellite Links*	*L-Band (1.6/1.5 GHz)*	*C-Band (6/4 GHz)*	*Ku-Band (14/12 GHz)*	*Ka-Band (30/20 GHz)*
Free space downlink	Dominating factor	187	196	205	210
Atmospheric	Relatively small and nearly constant at high elevation angles	0.1	0.2	0.3	0.5
Rain attenuation	Severe as frequency and elevation angle increases	0.1	0.5	2	6
Refraction	Significant at times at low elevation angles	6	3	2	1
Scattering	Produces local RFI				
Diffraction	Considered for mobile links without line of sight	6 to 12			
Ionospheric scintillation (multipath)	Occasional wide signal variation	3 to 6	1 to 3	<1	
Doppler	Frequency shift for moving vehicles or satellites				

Terminology in Satellite Communication

- **A Channel** : One way link from transmitting earth station through the satellite to the receiving earth station.

A Circuit : A full duplex link between two earth stations

A Half Circuit : A two way link between an earth station and the satellite only

The **capacity of a link is specified by the types and numbers of channels** and the performance requirements of each channel.

Capacity per channel of satellite RF link is directly related to the overall carrier to noise ratio.

Advantages of Satellite Communication

1. Mobile/Wireless Communication, Independent of Location
2. Wide Area Coverage: Country, Continent, or Globe
3. Wide Bandwidth Available Throughout
4. Independence From Terrestrial Infrastructure
5. Rapid Installation of Ground Networks
6. Low Cost Per Added Site

Satellite Services

1. Fixed Satellite Service (FSS):

- This is a satellite service between satellite terminals at specific fixed points using one or more satellites.
- FSS is used for the transmission of video, voice, and IP data over long distances from fixed sites.
- FSS makes use of geostationary satellites with fixed ground Stations.
- FSS may include satellite-to-satellite links, Mobile Satellite Service or the Broadcast Satellite Service.

Satellite Services

2.Broadcast Satellite Service (BSS):

- This is a satellite service that supports the transmission and reception via satellite of signals that are intended for direct reception by the general public. Ex.Direct Broadcast Service(DBS)
- BSS is only a point-to-multipoint service.Therefore, a smaller number of satellites are required to service a market.
- point-to-multipoint service, which means that signals are transmitted from a central location (typically a broadcast center) via satellite to multiple receivers or end-users simultaneously.
- This enables broadcasting content to reach a large audience over a wide geographic area without the need for individual terrestrial infrastructure to reach each user.

Satellite Services

3. Mobile Satellite Service (MSS):

- This is a satellite service intended to provide wireless communication to any point on the globe. With the broad penetration of the cellular telephone, users have started to take for granted the ability to use the telephone anywhere in the world, including rural areas in developed countries.
- MSS typically uses satellite systems in MEOs or LEOs

Satellite Services

4. Maritime Mobile Satellite Service (MMSS):

This is a satellite service between mobile satellite earth stations and one or more satellites.

5. Global Positioning (Service/) System (GPS)

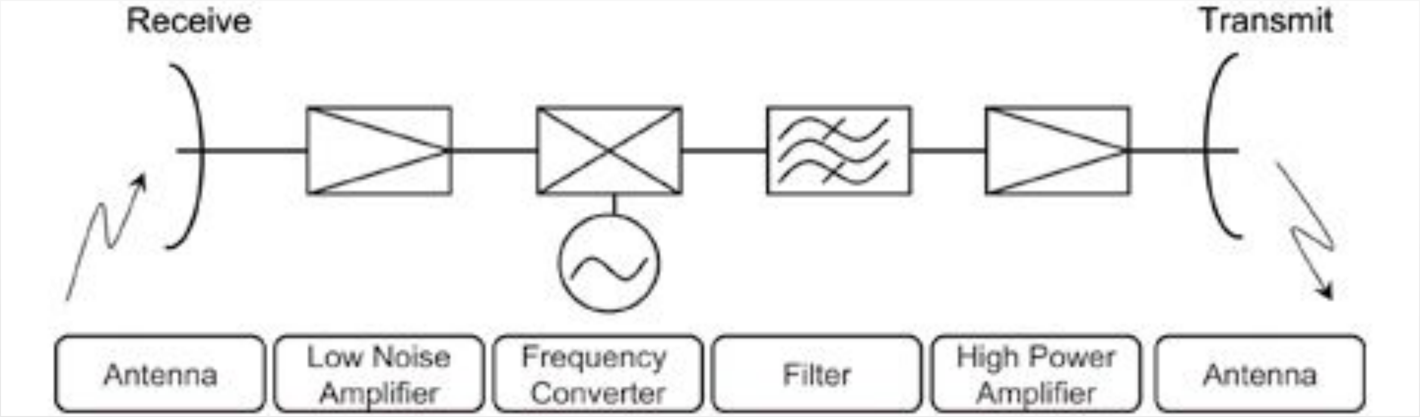
- This service uses an array of satellites to provide global positioning information to properly equipped terminals.

The Satellite Transponder

Similar to distant microwave repeater.

Functionalities: Receives uplink transmissions, filtering, amplification,processing and frequency transalation to the downlink band for retransmission.

The uplink and the down link is separated in frequency to prevent oscillation within the satellite amplifier. ……………………………………………………
Lower frequency band is used on the down link.



Earth Station

<u>Transmit and Receive Stations</u>

Early stations consists of large antennas mostly excess than 30m and transmit power greater than 5kW.

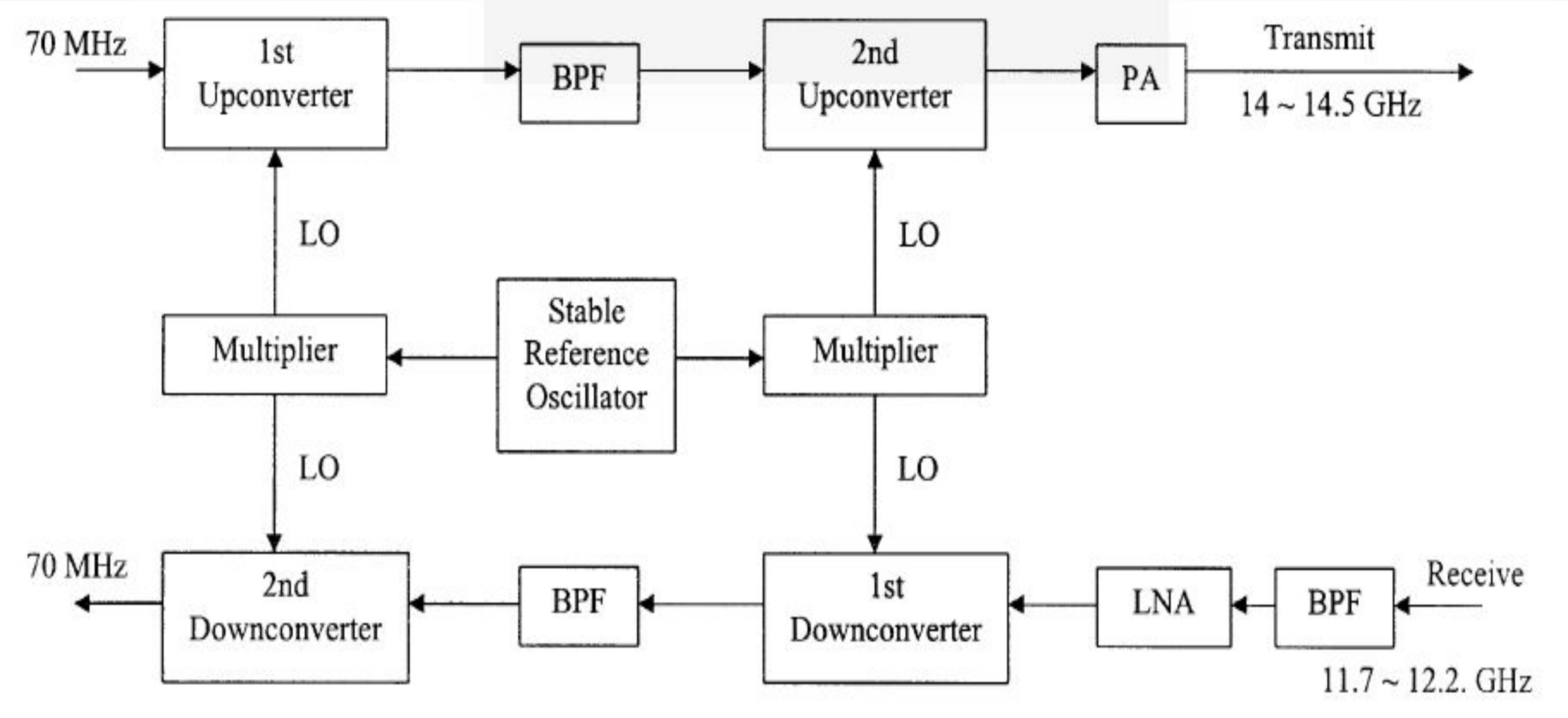
Stations for domestic services use antenna from 5m

Small station to use in industrial and other specialized data systems, VSAT (Very Small Aperture Terminals) s are used with aperture size of 1m to 2 m

<u>Receive Only Station</u>

TVRO stations stations for the direct reception of video from satellites direct reception of audio, navigational information.

Block Diagram of the Earth Station



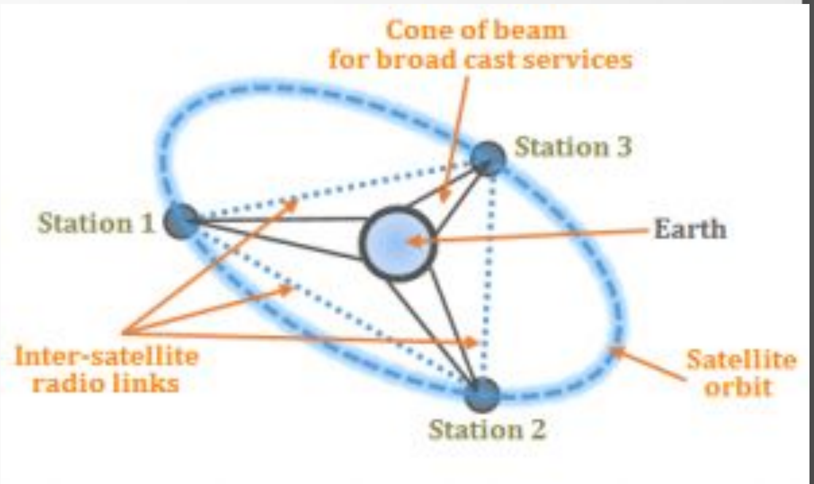
Satellite Orbit Configurations

GEO (Geostationary Earth Orbit)

A satellite in a geostationary Earth orbit (GEO) revolves around the Earth in the plane of
the equator once in 24 hours, maintaining precise synchronization with the Earth's
Rotation.

There are two other classes of 24-hour orbits:

- The geosynchronous orbit
- Highly elliptical synchronous orbit.



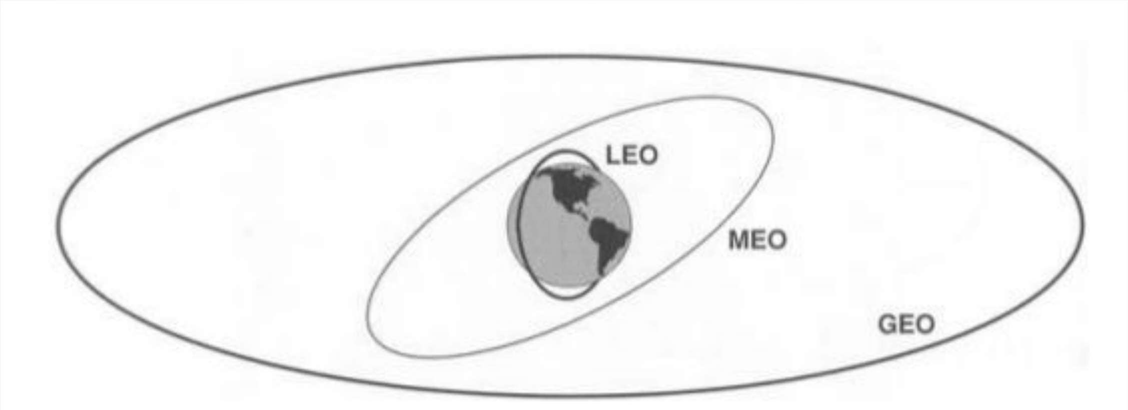
Orbits that are below a mean altitude of about 36,000 km have periods of revolution shorter than 24 hours and hence are termed non-GEO

The Advantage of using a Non-GEO Satellite Network

Range to the user is shorter;
-Less radiated power is required and the propagation delay is reduced.

There is considerable complexity and delay in the processing of telephone calls and data communications due to satellite motion and handoffs

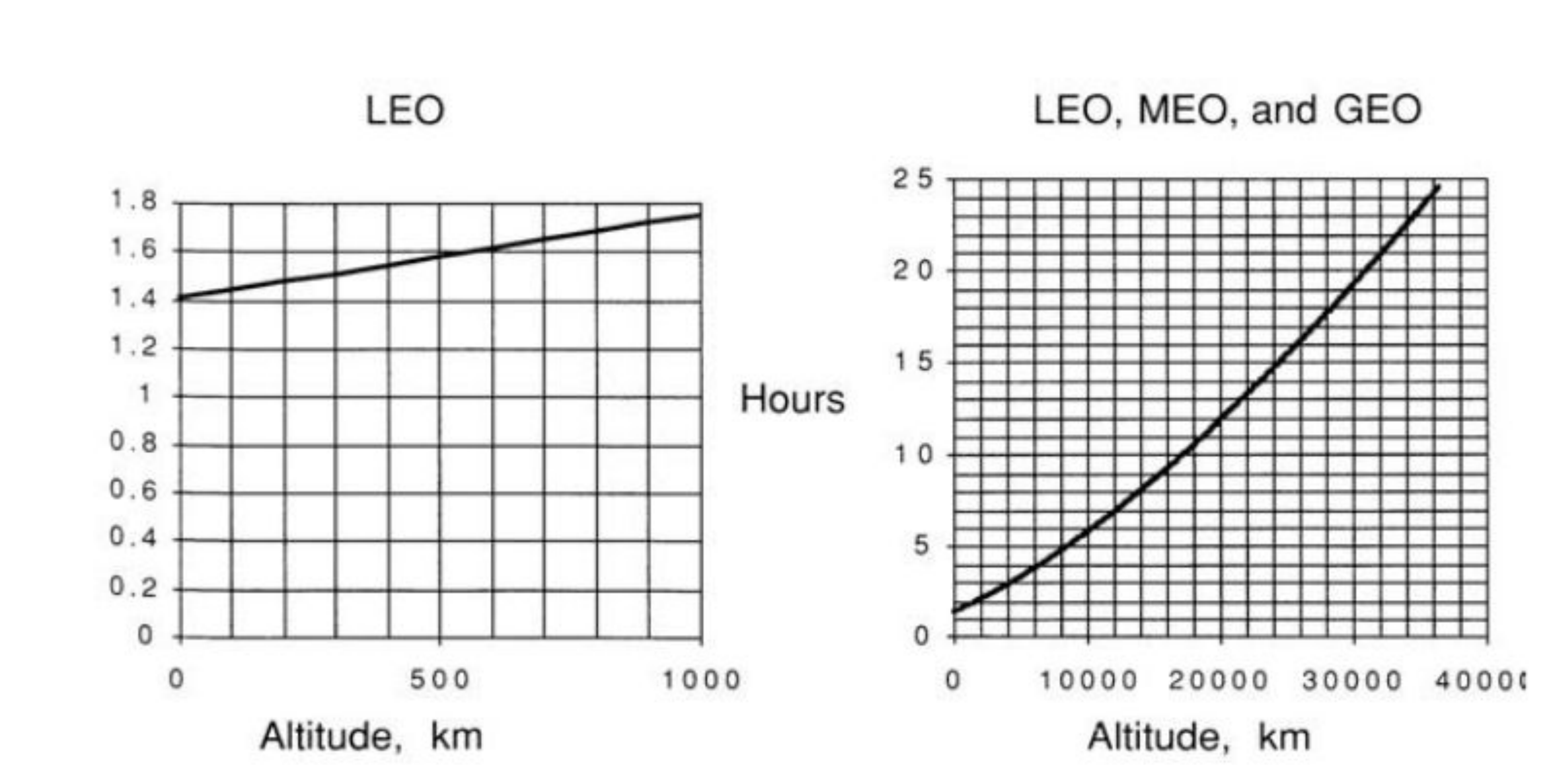
Most Popular Orbits



LEO systems employ satellites at altitudes ranging from 500 to 1,000 km and the orbit period is between 1.6 and 1.8 hours.

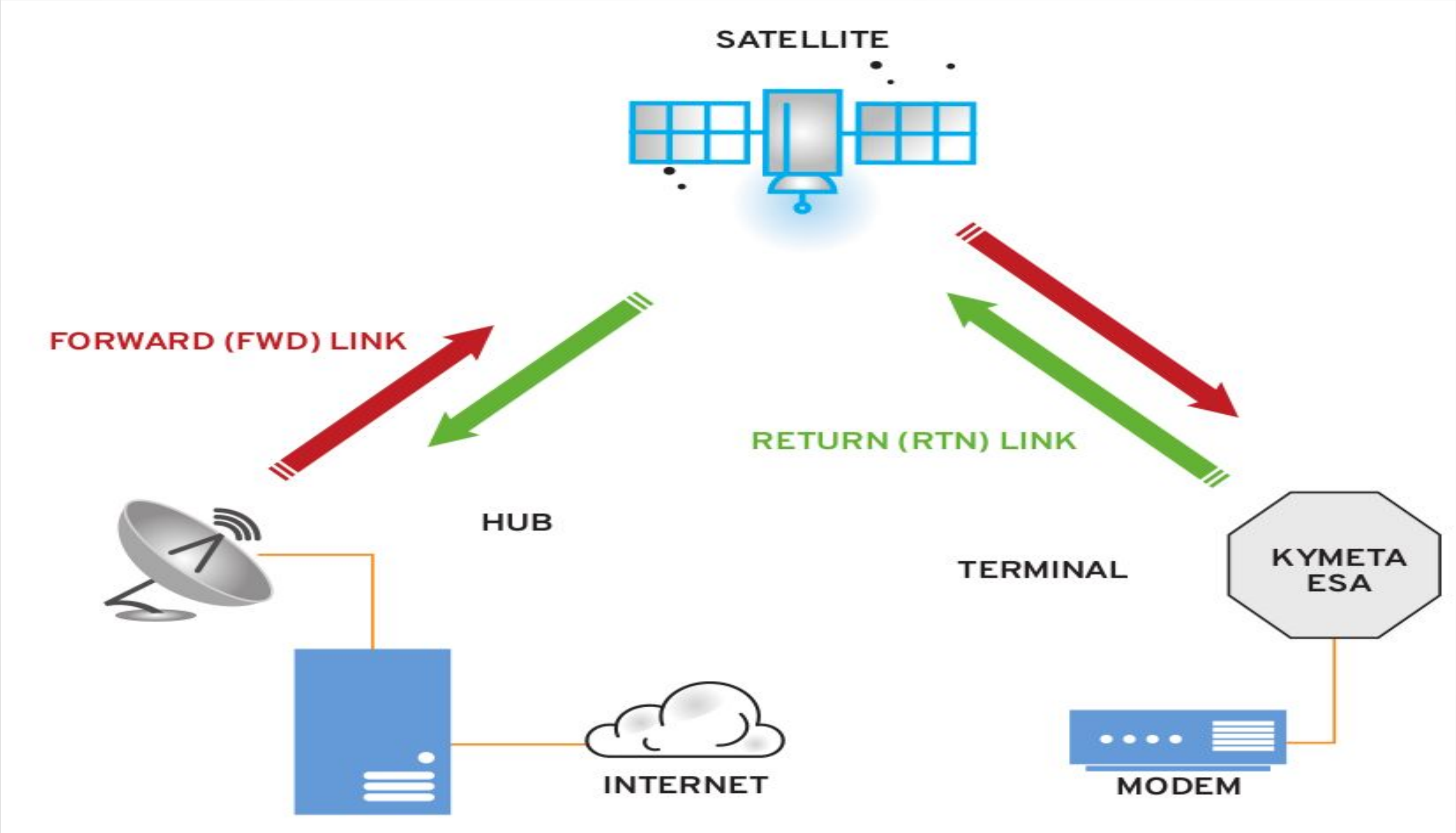
The altitude of a medium Earth orbit (MEO) is around 10,000 km (a period of about 6 hours).

Orbit Period (in hours) Versus Altitude



Introduction to Electronically Steerable Antenna (ESA) terminal

- Flat panel antennas that electronically steer (scan) their beams to track satellites.
- Due to the accuracy and speed of electronic beam steering of ESAs, it can easily stay connected to a satellite while the vehicle is moving. They can be sealed against weather and contamination than dish antenna assemblies.
- The main **disadvantages of ESAs compared to dish antennas are lower gain, and the variation in gain as the location and orientation are changed**.
- With the non-geostationary LEO (Low Earth Orbit) and MEO (Medium Earth Orbit) satellite constellations become available, this problem will diminish, since the satellites are moving, so that there will always be a satellite overhead.


SATELLITE
FORWARD (FWD) LINK
RETURN (RTN) LINK
HUB
TERMINAL
KYMETA ESA
INTERNET
MODEM

Link Budget Calculation for Satellite communication

Accounts for all the gains and losses of the link under a specific set of conditions.

The most common figures of merit are:

- SNR (signal-to-noise ratio)
- Spectral efficiency (bits per second/Hz)
- Throughput (bits per second)

Three Types of Link Budgets

1. FWD LINK: HUB TO TERMINAL
Hub can be assumed to have sufficient uplink power to drive the FWD carrier up to the limits of the satellite transponder, ensuring constant output power.

2. SIMPLE RTN LINK: TERMINAL TO SATELLITE
RTN link budget considers only the uplink from the user terminal to the satellite, and so does not require knowledge of certain satellite and hub parameters, which can be difficult to obtain.

3. COMPLEX RTN LINK: TERMINAL TO SATELLITE AND SATELLITE TO HUB

Three Types of Link Budgets

3. COMPLEX RTN LINK: TERMINAL TO SATELLITE AND SATELLITE TO HUB

The power from the user terminal received by the satellite varies with antenna orientation, and because this power is not enough to drive the satellite output power to the maximum level, additional noise is introduced into the link from satellite to hub.

Therefore, an accurate calculation of the SNR for the entire RTN link must consider:

1. The SNR of the terminal-to-satellite link
2. The SNR of the satellite-to-hub link

Link Components & Their Parameters

1. TERMINAL

1.1 Antenna Scan Angle & Cosine Roll-Off

- To determine the gain of an ESA terminal, the scan angle must be known.
- The scan angle is one of two angles that define the direction of the satellite beam relative to the antenna in a spherical coordinate system

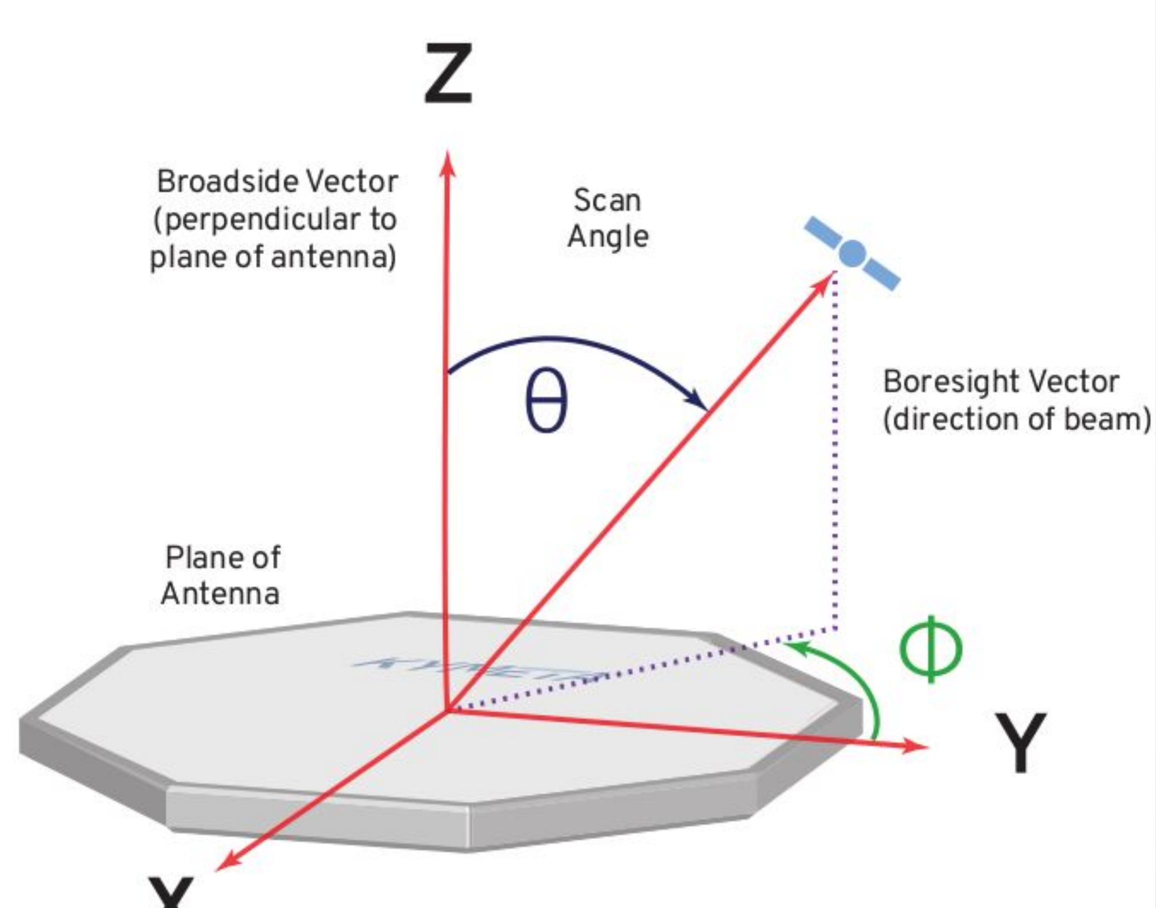


FIGURE 5. ESA BEAM POINTING COORDINATES

Link Components & Their Parameters

1. TERMINAL

1.1 Antenna Scan Angle & Cosine Roll-Off

- **Theta (θ) is the scan angle.** This is the angle between the boresight vector and the broadside vector (the axis that is perpendicular to the plane of the antenna). If the plane of the antenna panel is horizontal, the broadside vector is vertical.
-
- **Phi (φ) is the angle coordinate that determines the direction of the boresight vector**. It is measured in the plane of the antenna from a reference direction, which can be different for various antennas. For the Kymeta u7 antenna, the reference is a line connecting the center with the midpoint of the right side (the y-axis in Figure 5), and phi is measured.

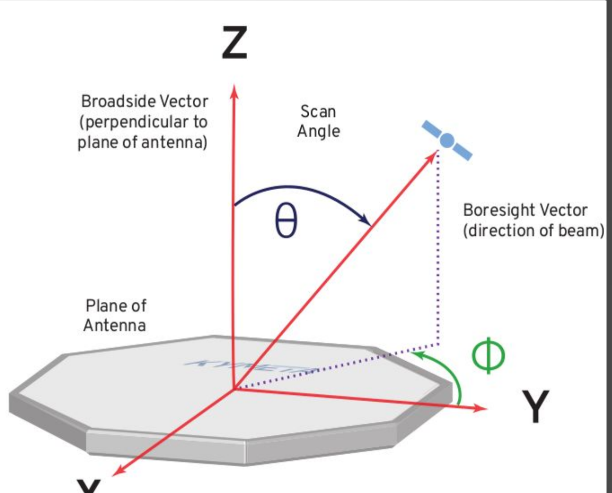
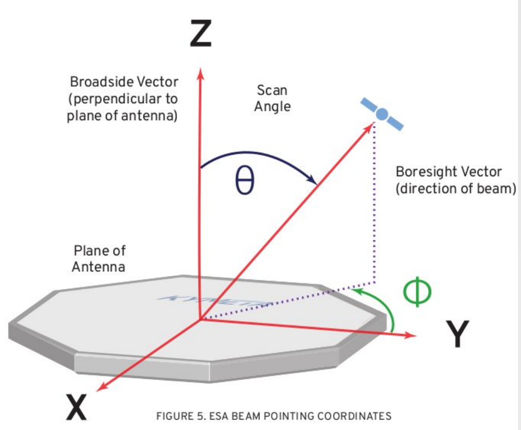


FIGURE 5. ESA BEAM POINTING COORDINATES

Link Components & Their Parameters

1. TERMINAL

1.2 Antenna Scan Angle & Cosine Roll-Off impact to the Gain



For calculations of SNR, theta should be considered.
In fixed applications, the broadside vector is normally pointed at the satellite, so the angle between the broadside and boresight vectors (theta) is zero.

In mobility scenarios, the antenna is typically mounted horizontally, hence broadside vector is vertical, as the boresight vector must always point at the satellite, theta is positive. Since less antenna area (aperture) is available to the beam in the case of a positive scan angle, the effective gain of the antenna is reduced. **The reduction in gain with increasing theta is called the cosine (or scan) roll-off.**

Link Components & Their Parameters

2. GAIN

$$G(dBi) = Peak\ Gain\ (dBi) - cosine\ roll\text{-}off \times 10 \times log\ (cos\ \theta)$$

- Peak Gain (dBi) = Peak gain of the antenna when the broadside and boresight vectors are aligned ($\theta = 0$)

- Cosine roll-off = An antenna coefficient for the reduction in gain caused by scan angle (θ).
- (Also called scan roll-off)

Link Components & Their Parameters

3. TERMINAL NOISE TEMPERATURE

- There are three main contributors to the noise temperature of the terminal:
- 1. Noise temperature of the antenna aperture
- 2. Loss of passive components (such as a diplexer)
- 3. Noise of active units (such as the LNB/Low noise block downconverter)
-
- The additional gain from the LNB allows to disregard the thermal noise following the LNB (including the modem), since it will not significantly impact the total noise temperature.
-
- The noise temperature of a passive component is calculated using this equation:

$$T_p = T_e \times (A - 1)$$

T_p = noise temperature of the passive component
T_e = ambient temperature of the component (a good assumption is 290 K)
A = linear attenuation of the component

Link Components & Their Parameters

3. TERMINAL NOISE TEMPERATURE

- The passive component in the RF chain between the antenna and the LNB is the diplexer(to combine or separate). A diplexer with 0.15 dB of loss (a typical value) introduces noise into the system as follows:

$$T_p = 290\times\left(10^{\frac{0.15}{10}} - 1\right) = 11\ \mathrm{K}$$

Assume the noise figure specification for the LNB is is 1.0dB. The ambient temperature, Te = 290 K
Using the same equation as for the passive noise temperature:

$$T_p = 290\times\left(10^{\frac{NF}{10}} - 1\right) = 290\times\left(10^{\frac{1}{10}} - 1\right) = 75\ \mathrm{K}$$

overall terminal noise temperature with the above example values and assuming noise temperature of antenna aperture is 170K:

$$\mathrm{T} = 170 + 11 + 75 = 256\ \mathrm{K} = 24.1\ \mathrm{dBK}$$

Link Components & Their Parameters

3. ATMOSPHERIC LOSS

- For Ku band, it is generally agreed that atmospheric absorption is between 0.01 and 0.02 dB/km.

Assume the noise figure specification for the LNB is is 1.0dB. The ambient temperature, Te = 290 K
Using the same equation as for the passive noise temperature:

$$T_p = 290\times\left(10^{\frac{NF}{10}} - 1\right) = 290\times\left(10^{\frac{1}{10}} - 1\right) = 75\ \mathrm{K}$$

overall terminal noise temperature with the above example values and assuming noise temperature of antenna aperture is 170K:

$$\mathrm{T} = 170 + 11 + 75 = 256\ \mathrm{K} = 24.1\ \mathrm{dBK}$$

CALCULATING SNR

1. FWD EQUATION

- ***SNR = Satellite Transponder EIRP (dBW) – transponder BW (dBHz) – FSPL (dB) –***
  - ***atmospheric loss (dB) + G/T of Terminal (dB/K) – k (dB/K/Kz)***

2. Simple RTN EQUATION

- ***SNR_{up} = BUC operating Power (dBW) + G (dBi) - channel BW (dBHz) – FSPL (dB) –***
  - ***atmospheric loss (dB) + G/T of Satellite (dB/K) – k (dB/K/Kz)***

3. COMPLEX RTN EQUATION

- ***SNR_{down} = Saturated satellite EIRP (dBW) – terminal SFD- PFD + 2.7) -10 log (transponder BW) – FSPL (dB) – atmospheric loss (dB) + G/T of hub (dB/K) – k (dB/K/Kz)***

Link Budget Calculation

Example 2:

A fixed Kymeta u7 Ku-band terminal in broadside orientation ($\theta = 0$) located in Seattle, using the Galaxy 18 (G-18) geosynchronous satellite.

d= 38200km

Satellite EIRP = 46.6 dB

Transponder BW = 36 MHz

Atmospheric loss = 0.35 dB

Peak receive gain = 33.0 dB

Example 3:

A Kymeta u7 Ku-band terminal in mobility mode in Seattle using G-18 with a scan angle of 55 degrees.

Satellite EIRP = 46.6 dBW

Transponder BW = 36 MHz

Theta = 55 degrees

Cosine roll-off = 1.2

Peak receive gain = 33.0 dB

Atmospheric loss = 0.35 dB

Link Budget Calculation

Example 1:

At 10 GHz, a ground station transmits 128 W to a satellite at a distance of 2000 km. The ground antenna gain is 36 dB with a pointing error loss of 0.5 dB. The satellite antenna gain is 38 dB with a pointing error loss of 0.5 dB. The atmospheric loss in space is assumed to be 2 dB and the polarization loss is 1 dB.

Calculate the received input power level and output SNR. The satellite receiver has a noise figure of 6 dB at room temperature. A bandwidth of 5 MHz is required for a channel, and a margin (loss) of 5 dB is used in the calculation.