

# Sessions 3 and 4

Network Planning and Link Budget Analysis

# 1- Satellite Network Topology

## Topologies

Satellites networks have various topologies. We can enumerate the following :

- Star Networks
- Mesh Networks
- SCPC
- DVB
- Cellular backhaul

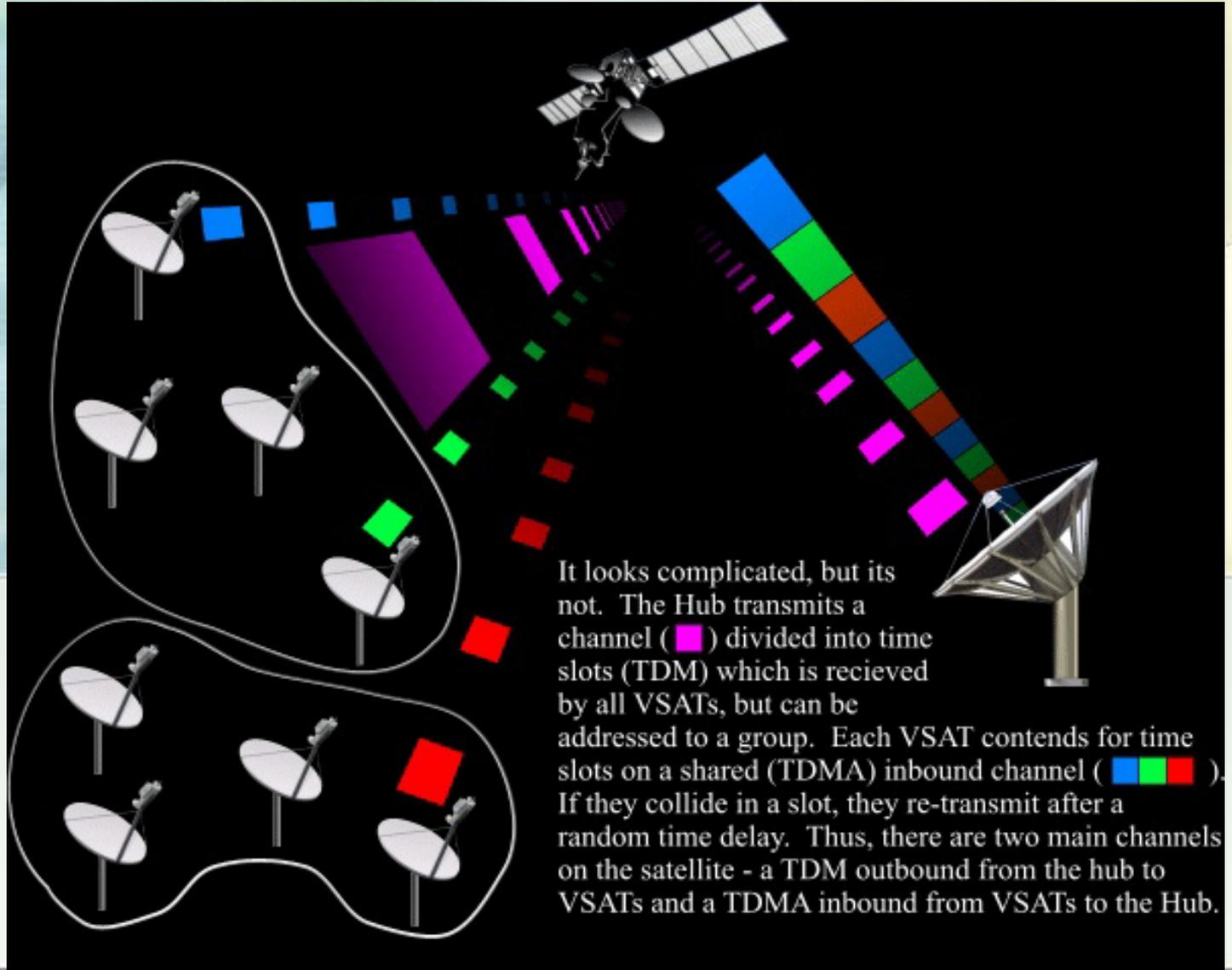
# 1- Satellite Network Topology

## Star Network

The next Slide shows how a star data, TDM/TDMA VSAT network works using a hub station, usually six metres or more in size and small VSAT antennas (between 75 centimetres and 2.4 metres). All the channels are shared and the remote terminals are online, offering fast response times. Historically, TDM/TDMA systems competed with terrestrial X.25 or frame relay connections, but as VSAT transmit data rates have risen to 2 Mbps or more and receive rates begin approaching 100 Mbps DSL and MPLS services have become the main competitors in most markets.

# 1- Satellite Network Topology

## Star Network



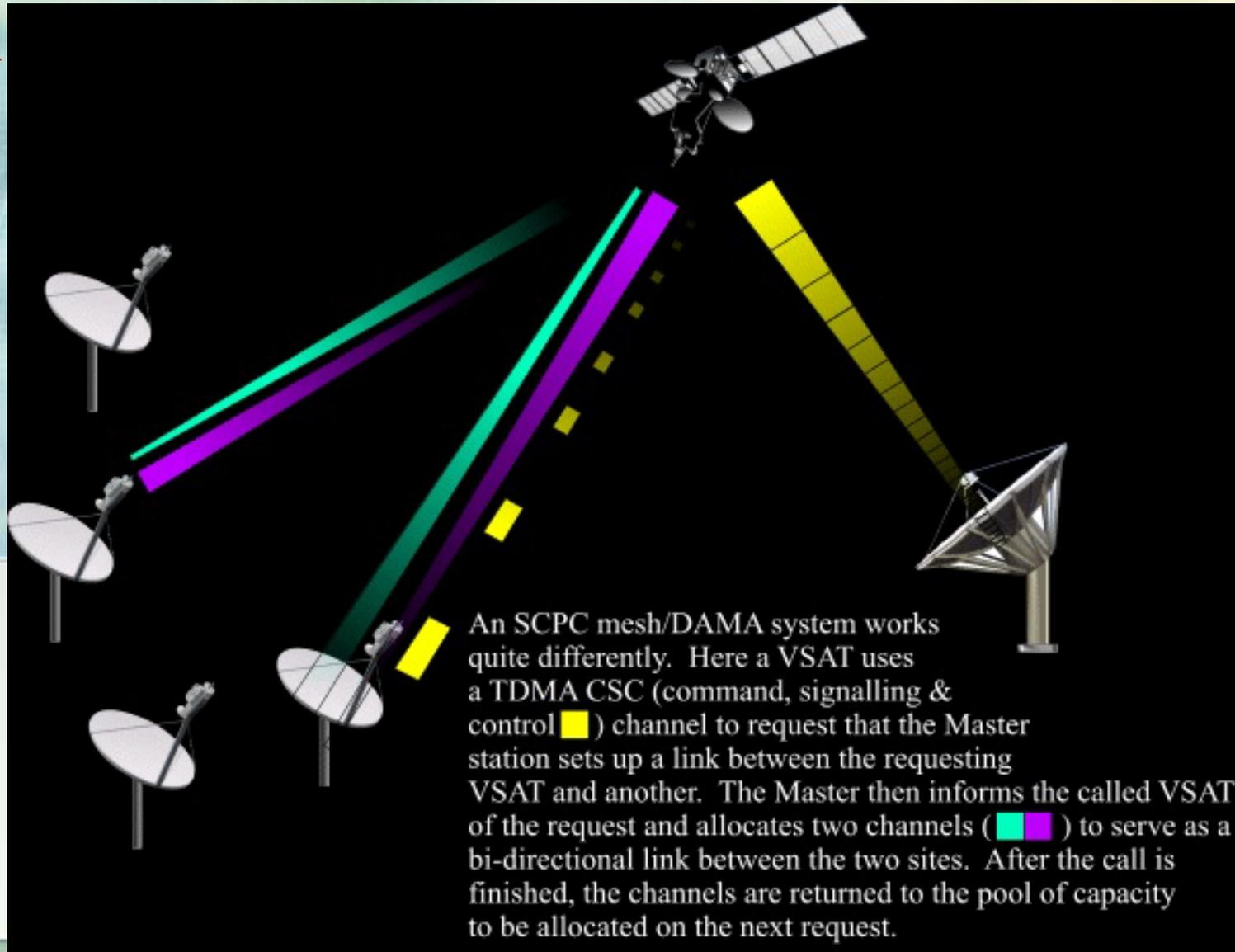
# 1- Satellite Network Topology

## Mesh Network

However, mesh networks which use capacity on a demand assigned multiple access (DAMA) basis take a different approach. The master control station merely acts as a controller and facilitator rather than a hub through which traffic passes as in a star network. However, these connections take a little time to set-up and thus, mesh/DAMA systems are often equated to a terrestrial dial-up connection.

# 1- Satellite Network Topology

## Mesh Network



# 1- Satellite Network Topology

## Mesh Network

There are also mesh systems which use a TDMA access scheme where all of the terminals in a network receive and transmit to the same channel, selecting different time slots because each terminal is aware of what the others have reserved. In the past this type of system has been costly and therefore, reserved for large scale trunking applications, but, more recently, costs have come down considerably and now they can be cost competitive with SCPC/DAMA systems for thin route applications as well.

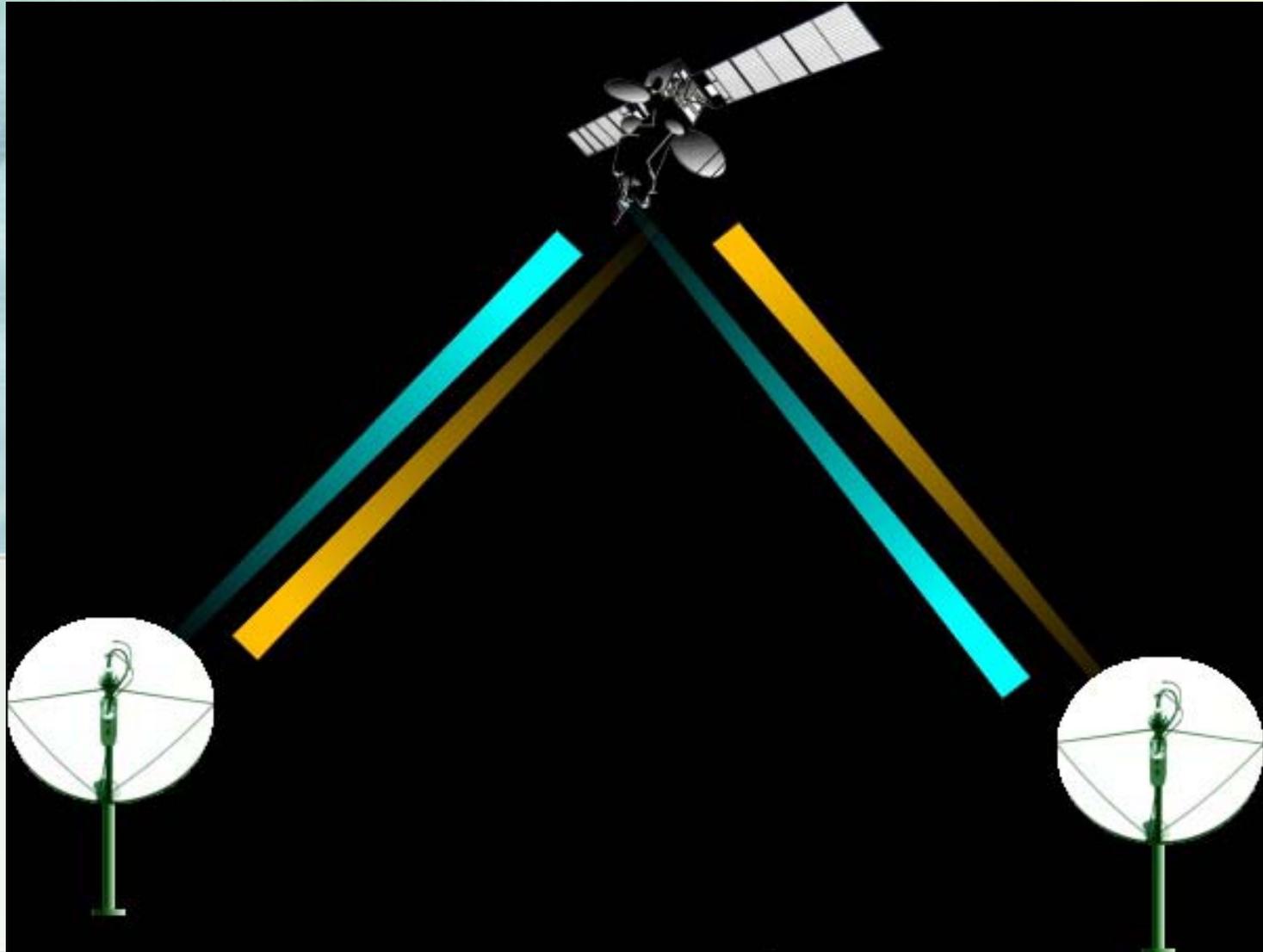
# 1- Satellite Network Topology

## SCPC Network

Point-to-point SCPC (single channel per carrier) links are the satellite equivalent of a terrestrial leased line connection. They are usually set-up on a permanent, 24 hour basis and are thus more costly in satellite capacity and less efficient if not used all the time. However, they do support dedicated high bandwidth links without any sharing or contention. Typically we only classify terminals running rates from 9.6 kbps to 2 Mbps as VSATs and can easily be used to carry data, voice and even video traffic.

# 1- Satellite Network Topology

## SCPC Network



## 2- Accessing schemes

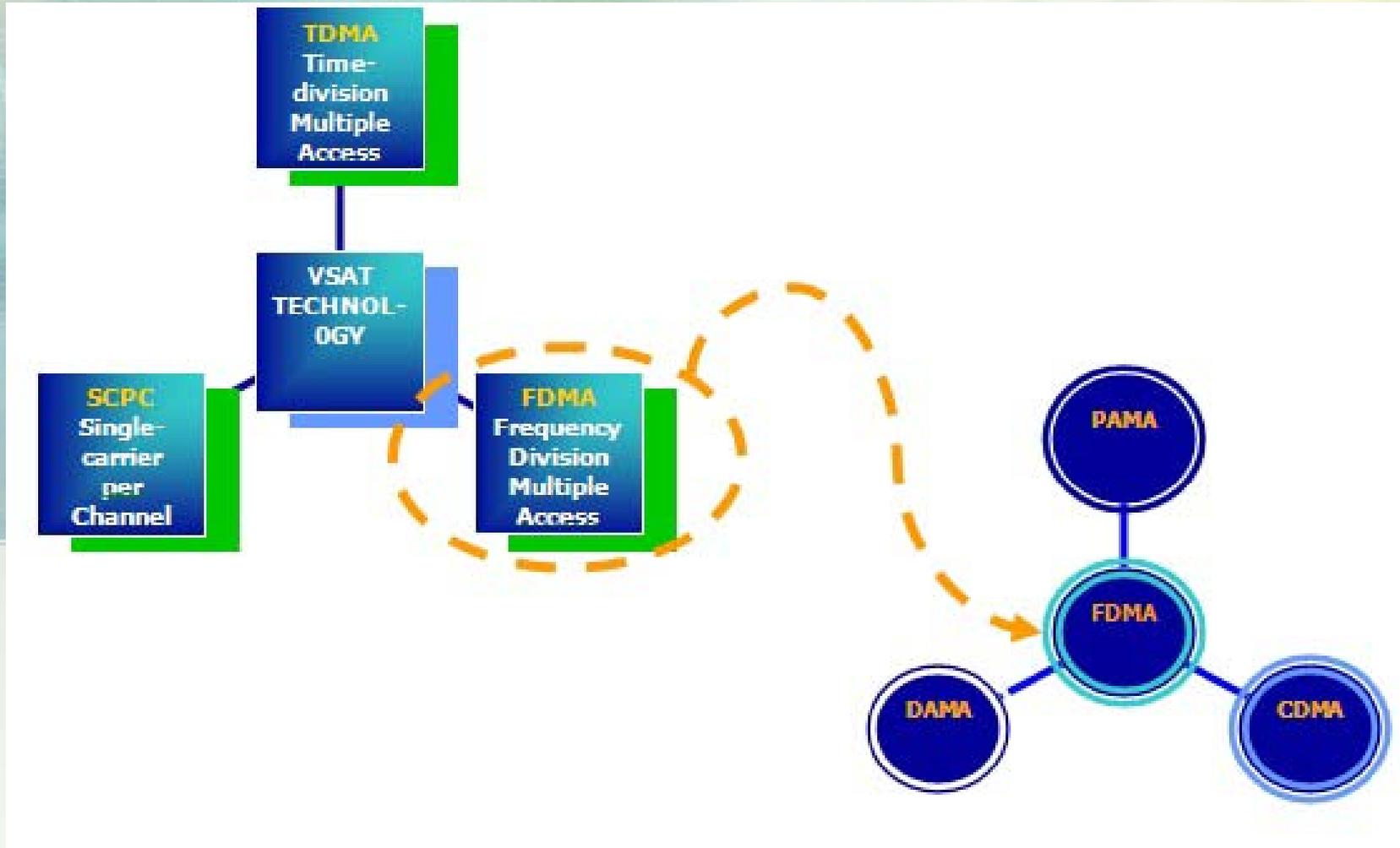
The primary objective of the VSAT networks is to maximize the use of common satellite and other resources amongst all VSAT sites.

The methods by which these networks optimize the use of satellite capacity, and spectrum utilization in a flexible and cost-effective manner are referred to as satellite access schemes.

Each of the above topologies is associated with an appropriate satellite access scheme. Good network efficiency depends very much on the multiple accessing schemes.

There are many different access techniques tailored to match customer applications.

## 2- Accessing schemes



## 3- C Band vs. Ku Band

### C Band

The C band is a name given to certain portions of the electromagnetic spectrum, as well as a range of wavelengths of microwaves that are used for long-distance radio telecommunications. The IEEE C-band - and its slight variations - contains frequency ranges that are used for many satellite communications transmissions; by some Wi-Fi devices; by some cordless telephones; and by some weather radar systems. For satellite communications, the microwave frequencies of the C-band perform better in comparison with K<sub>u</sub> band (11.2 GHz to 14.5 GHz) microwave frequencies, under adverse weather conditions, which are used by another large set of communication satellites. The adverse weather conditions all have to do with moisture in the air, such as during rainfalls, thunderstorms, sleet storms, and snowstorms.

- Downlink: 3.7 - 4.2 GHz
- Uplink: 5.9 - 6.4 GHz

## 3- C Band vs. Ku Band

### Ku Band

The  $K_u$  band is a portion of the electromagnetic spectrum in the microwave range of frequencies. This symbol refers to "K-under" (in the original German, "Kurz-unten", with the same meaning)—in other words, the band directly below the K-band. In radar applications, it ranges from 12 to 18 GHz according to the formal definition of radar frequency band nomenclature in IEEE Standard 521-2002.

- Downlink: 11.7 – 12.2 GHz
- Uplink: 14.0 – 14.5 GHz

# 3- C Band vs. Ku Band

## Comparison between C Band and Ku Band

	Advantages	Disadvantages
C Band	<ul style="list-style-type: none"><li>✓ Less disturbance from heavy rain fade</li><li>✓ Cheaper Bandwidth</li></ul>	<ul style="list-style-type: none"><li>❖ Needs a larger satellite dish (diameters of minimum 2-3m)</li><li>❖ Powerful (=expensive) RF unit</li><li>❖ More expensive hardware</li><li>❖ Possible Interference from microwave links</li></ul>
Ku Band	<ul style="list-style-type: none"><li>✓ No interference from microwave links and other technologies</li><li>✓ Operates with a smaller satellite dish (diameters from 0.9m) -&gt; cheaper and more easy installation</li><li>✓ Needs less power -&gt; cheaper RF unit</li></ul>	<ul style="list-style-type: none"><li>❖ More expensive capacity</li><li>❖ Sensitive to heavy rain fade (significant attenuation of the signal) / possibly can be managed by appropriate dish size or transmitter power.</li></ul>

### 3- C Band vs Ku Band

#### Other frequency bands

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 <sub>u</sub> band	12 to 18 GHz
K band	18 to 26.5 GHz
K <sub>a</sub> 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

## 4- VSATs and Data Communications

- VSAT networks are composed of low-cost Earth stations for use in a wide variety of telecommunications applications.
- Unlike the point-to-multipoint systems VSATs are two-way communications installations designed to achieve interactivity over the satellite
- Interconnection with various terrestrial networks is also a feature.
- Internet has taken over the role of the common structure for integrating data communications for the majority of applications in information technology (IT).
- This has rationalized the field to the point that a single protocol and interface standard provide almost all of what an organization needs.

## 4- VSATs and Data Communications

- Today, terrestrial copper, fiber lines, data routing and switching in conjunction with VSATs provide a fast and effective mix to advance the competitive strategy of many medium to large businesses.
- VSAT networks also address the needs of small businesses and individuals.
- The three classic architectures for IT networks are host-based processing (utilizing centralized large-scale computers like mainframes), peer-to-peer networks (usually employing minicomputers or large servers that are deployed at different locations to serve local requirements), and client/server networks (which tie together personal computers, servers, and peripherals using LANs and WANs).

## 5- Digital Communications techniques

### Protocols supported by VSAT Networks

- A summary of the protocols in general use and their support over typical VSAT networks is provided in Table 8.2.
- When first introduced in the 1980s, VSATs played heavily on the traditional IBM proprietary protocol, Systems Network Architecture (SNA), which followed the same centralized approach as the VSAT star network.
- While still in existence in some legacy environments, it has been replaced with the more open Internet Protocol suite (TCP/IP).
- Transporting TCP/IP over VSAT has its shortcomings, which are being addressed by standards bodies and major vendors like Cisco.
- Employing TCP/IP in a private network is very straightforward and is well within the means of any organization or individual.

## 5- Digital Communications techniques

# Protocols supported by VSAT Networks

**Table 8.2** Network Protocols and Applications in Common Use for IT Networks and Their Availability over VSATs

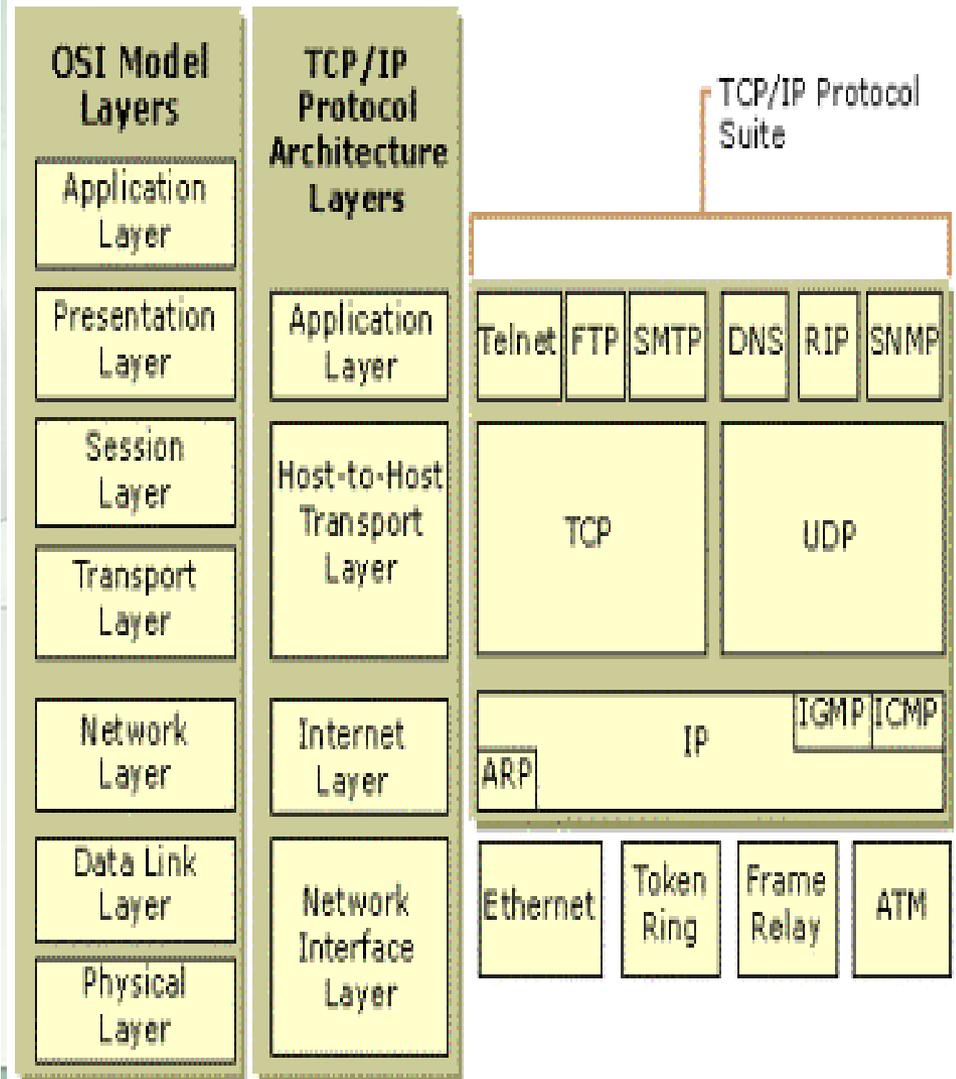
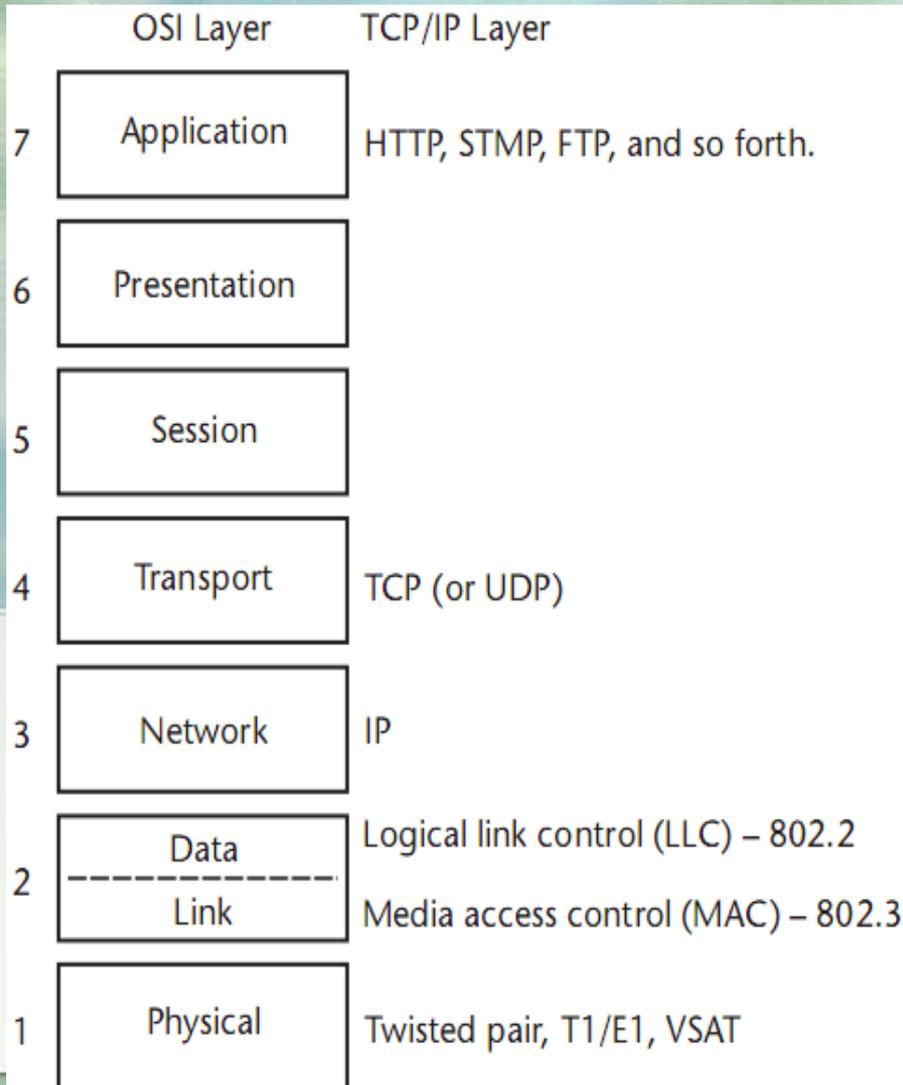
<i>Protocol</i>	<i>Applications</i>	<i>Availability on VSATs</i>
Internet (TCP/IP)	Web, e-mail, file transfer, VoIP, streaming video, videoconferencing	Supported since 1995, now becoming the standard for access and data handing
Frame Relay (ISDN)	Wide area network, private voice networks	Limited (may be substituted by TCP/IP)
Ethernet (MAC layer)	Virtual LANs	Supported since 1992
Novell NetWare (IPX/SPX)	Wide area network	Supported in early VSAT implementations; being replaced by TCP/IP which is provided by NetWare 6

## 5- Digital Communications techniques

### Protocols supported by VSAT Networks

- However, the complexity comes when an organization wishes to interconnect with the global Internet and with other organizations.
- This is due to the somewhat complex nature of routing protocols like the Border Gateway Protocol (BGP) and a new scheme called Multi Protocol Label Switching (MPLS).
- Frame Relay has been popular in WANs for more than a decade, thanks to its ease of interface at the router and availability in (and between) major countries.
- It is capable of near-real-time transfer and can support voice services. With access speeds generally available at 2 Mbps or less.
- Satellite provision of Frame Relay has been limited to point-to-point circuits as the protocol is not directly supported in VSATs currently on the market.
- The best approach would be to use TCP/IP in lieu of Frame Relay when VSAT links are interfaced at the router.

# OSI and TCP/IP (DARPA) Model



## 5- Digital Communications techniques

### IP Networks

#### TCP/IP Protocol

The immense influence of the Internet caused its communications protocol to become the world standard. Almost all networks, except for the circuit-switched networks of the telephone companies, have migrated to TCP/IP.

TCP/IP is a robust and proven technology that was first tested in the early 1980s on ARPAnet, the U.S. military's Advanced Research Projects Agency network, the world's first packet-switched network. TCP/IP was designed as an open protocol that would enable all types of computers to transmit data to each other via a common communications language.

## 5- Digital Communications techniques

### IP Networks

#### Multiple Layers

TCP/IP is a layered protocol, which means that after an application initiates the communications, the message (data) to be transmitted is passed through a number of software stages, or layers, until it actually moves out onto the wire, or if wireless, into the air. The data are packaged with a different header at each layer. At the receiving end, the corresponding software at each protocol layer unpackages the data, moving it "back up the stack" to the receiving application.

#### TCP and IP

TCP/IP is composed of two parts: TCP (Transmission Control Protocol) and IP (Internet Protocol). TCP is a connection-oriented protocol that passes its data to IP, which is connectionless. TCP sets up a connection at both ends and guarantees reliable delivery of the full message sent. TCP tests for errors and requests retransmission if necessary, because IP does not.

## IP Networks

### UDP

An alternative protocol to TCP within the TCP/IP suite is UDP (User Datagram Protocol), which does not guarantee delivery. Like IP, UDP is also connectionless, but very useful for transmitting audio and video that is immediately heard or viewed at the other end. If packets are lost in a UDP transmission (they can be dropped at any router junction due to congestion), there is neither time nor a need to retransmit them. A momentary blip in a voice or video transmission is not critical.

## 5- Digital Communications techniques

### Compression

#### Analog Video Compression

In communications, data compression is helpful because it enables devices to store or transmit the same amount of data in fewer bits, thus making the transmission of the data faster.

A hardware circuit converts analog video (NTSC, PAL, SECAM) into digital code and vice versa. The term may refer to only the A/D and D/A conversion, or it may include the compression technique for further reducing the signal

# 5- Digital Communications techniques

## Compression

### Digital Video Compression

Hardware and/or software that compresses and decompresses a digital video signal. MPEG, Windows Media Video (WMV), H.264, VC-1 and QuickTime are examples of codecs that compress and decompress digital video.

## 5- Digital Communications techniques

### VoIP

#### Definition

Referring to voice communications over the public Internet or any packet network employing the TCP/IP protocol suite. Specifically, VoIP operates in datagram mode, employing the Internet Protocol (IP) for addressing and routing, the User Datagram Protocol (UDP) for host-to-host data transfer between application programs, and the Real Time Transport Protocol (RTP) for end-to-end delivery services.

VoIP also typically employs sophisticated predictive compression algorithms, such as low delay code excited linear prediction (LD-CELP), to mitigate issues of latency and jitter over a packet-switched network.

## 6- Modulation

In telecommunications, **modulation** is the process of conveying a message signal, for example a digital bit stream or an analog audio signal, inside another signal that can be physically transmitted. Modulation of a sine waveform is used to transform a baseband message signal to a passband signal, for example a radio-frequency signal (RF signal). In radio communications, cable TV systems or the public switched telephone network for instance, electrical signals can only be transferred over a limited passband frequency spectrum, with specific (non-zero) lower and upper cutoff frequencies.

## 6- Modulation

The three basic types of modulation are :

- Amplitude Shift Keying (ASK)
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)

All of these techniques varies a parameter of a sinusoid to represent the information which we wish to send. A sinusoid has 3 different parameters that can be varied. These are amplitude, phase and frequency

## 6- Modulation

### Amplitude Modulation (AM)

Varying the voltage of a carrier or a direct current in order to transmit analog or digital data. Amplitude modulation (AM) is the oldest method of transmitting human voice electronically. In an analog telephone conversation, the voice waves on both sides are modulating the voltage of the direct current loop connected to them by the telephone company.

AM is also used for digital data. In quadrature amplitude modulation (QAM), both amplitude and phase modulation are used to create different binary states for transmission

## 6- Modulation

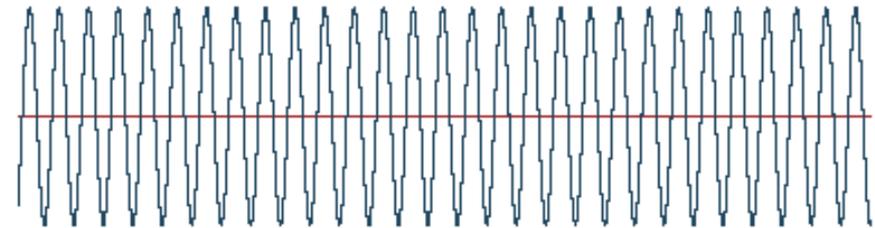
### Amplitude Modulation (AM)

#### Vary the Amplitude

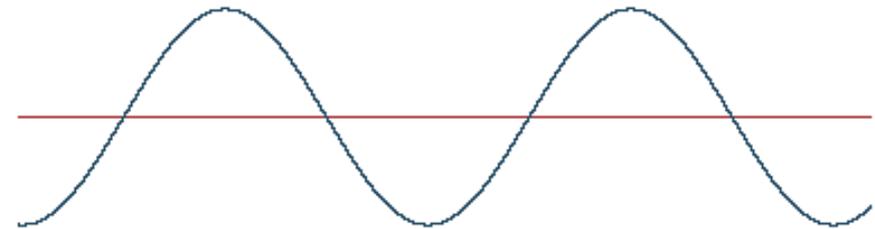
In AM modulation, the voltage (amplitude) of the carrier is varied by the incoming signal. In this example, the modulating wave implies an analog signal.

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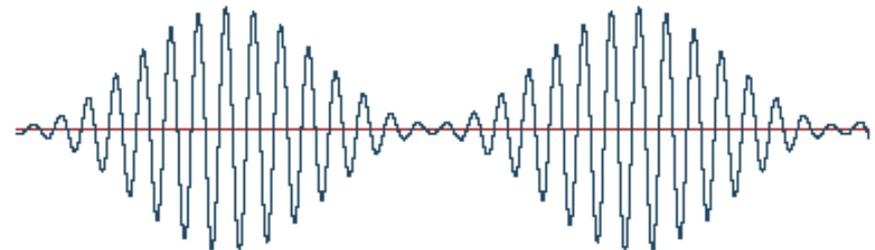
Carrier



Modulating Wave



Modulated Result

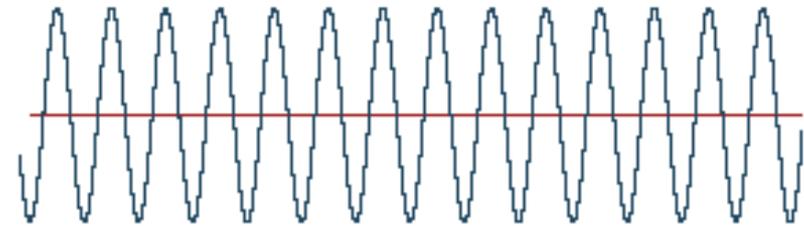


## 6- Modulation

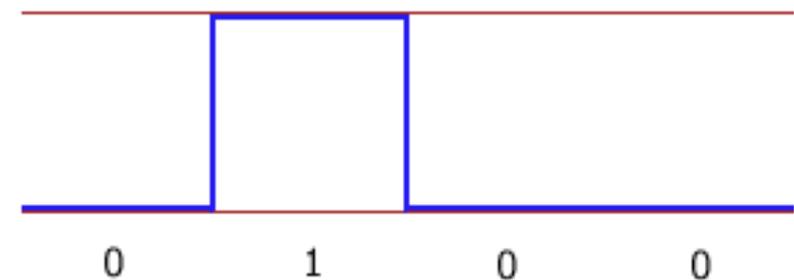
### Digital Amplitude Shift Keying (ASK)

For digital signals, amplitude shift keying (ASK) uses two voltage levels for 0 and 1 as in this example.

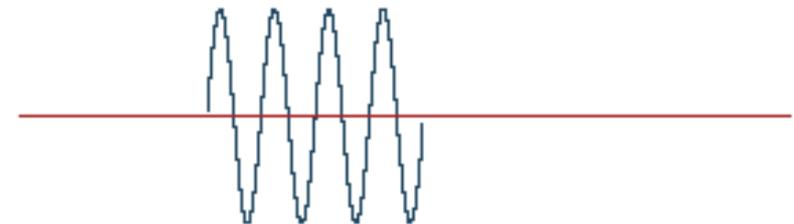
Carrier



Modulating Wave (digital)



Modulated Result

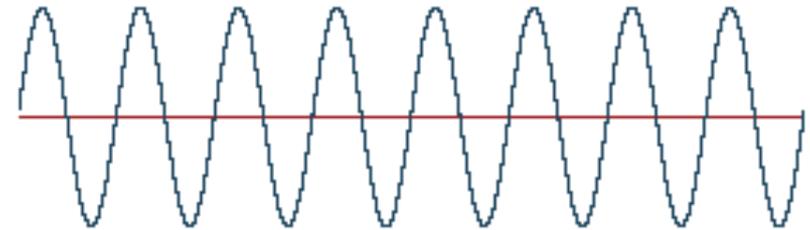


## 6- Modulation

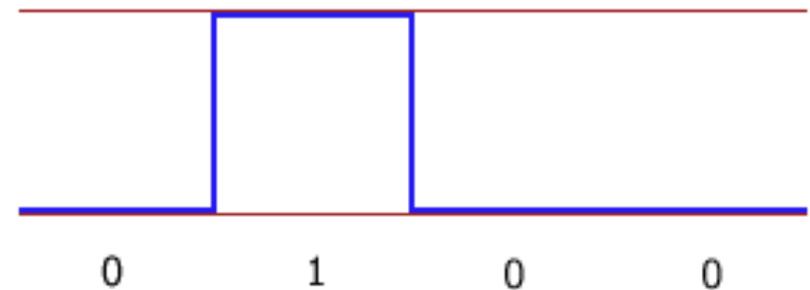
### Phase Shift Keying (PSK)

For digital signals, phase shift keying (PSK) uses two phases for 0 and 1 as in this example.

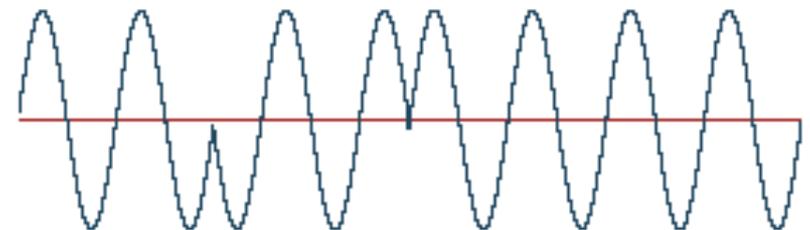
Carrier



Modulating Wave (digital)



Modulated Result



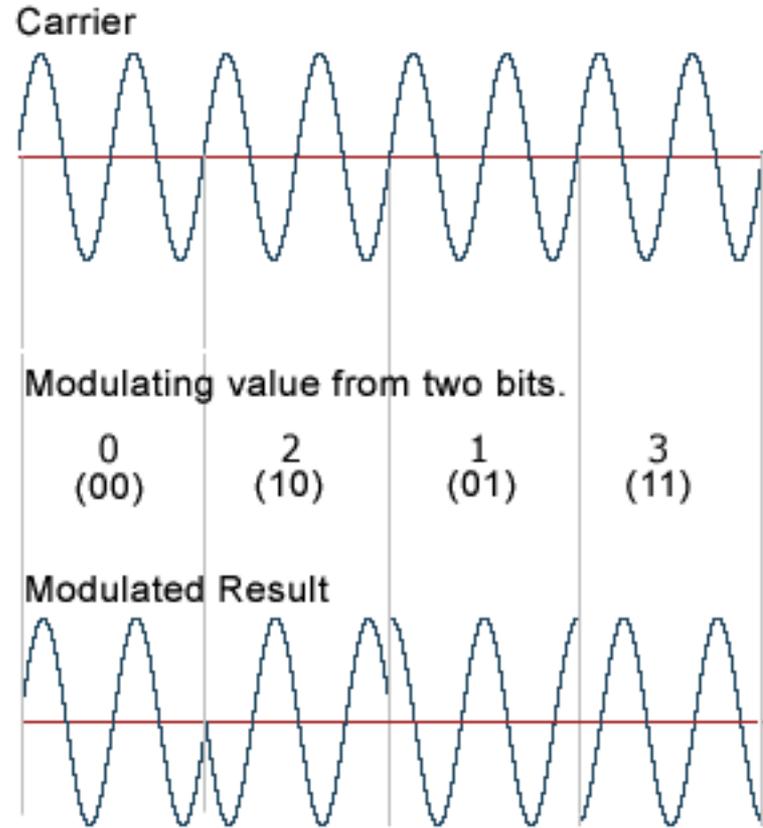
# 6- Modulation

## Quadrature Phase Shift Keying (QPSK)

QPSK uses four phase angles to represent each two bits of input; however, the amplitude remains constant.

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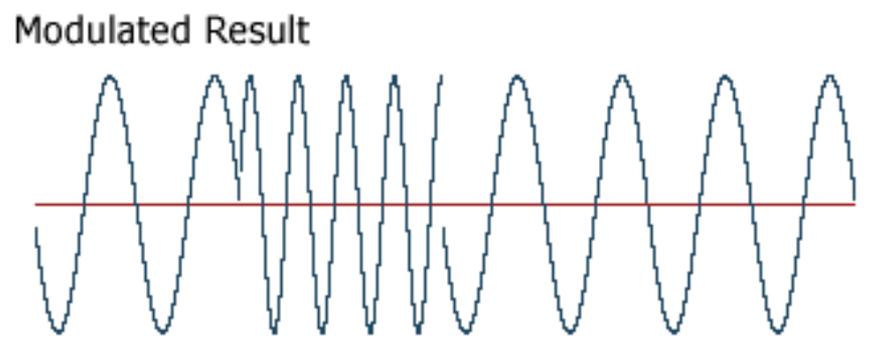
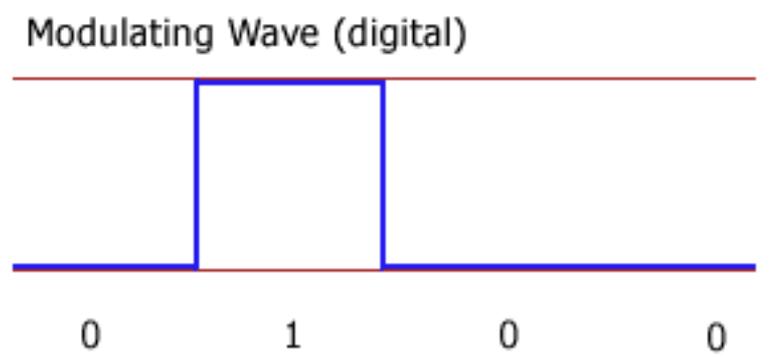
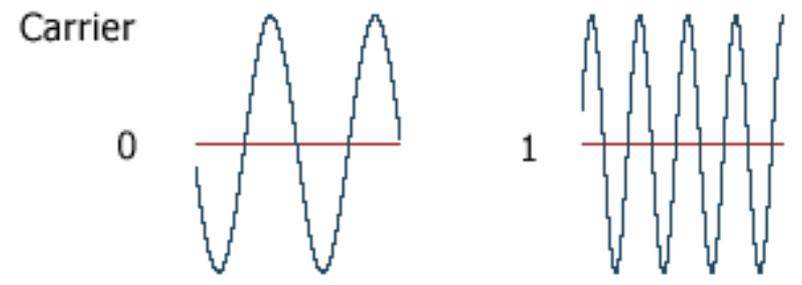
### QPSK



# 6- Modulation

## Frequency Shift Keying (FSK)

FSK is a simple technique that uses two frequencies to represent 0 and 1.



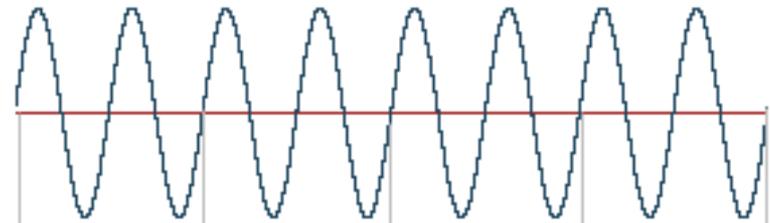
## 6- Modulation

### Digital 8QAM

In this 8QAM example, three bits of input generate eight different modulation states (0-7) using four phase angles on 90 degree boundaries and two amplitudes: one at 50% modulation; the other at 100% (4 phases X 2 amplitudes = 8 modulation states). QAM examples with more modulation states become extremely difficult to visualize.

### DIGITAL QAM (8QAM)

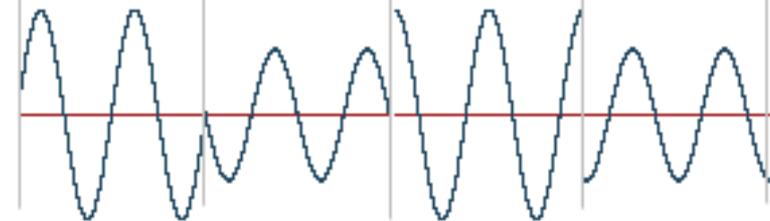
Carrier



Modulating value from three bits.

0 (000)	6 (110)	1 (001)	7 (111)
------------	------------	------------	------------

Modulated Result



Note: Only four (0, 6, 1 and 7) out of the eight possible modulation states (0-7) are shown in this illustration.

## 6- Modulation

### Popular Modulation schemes used in satellite

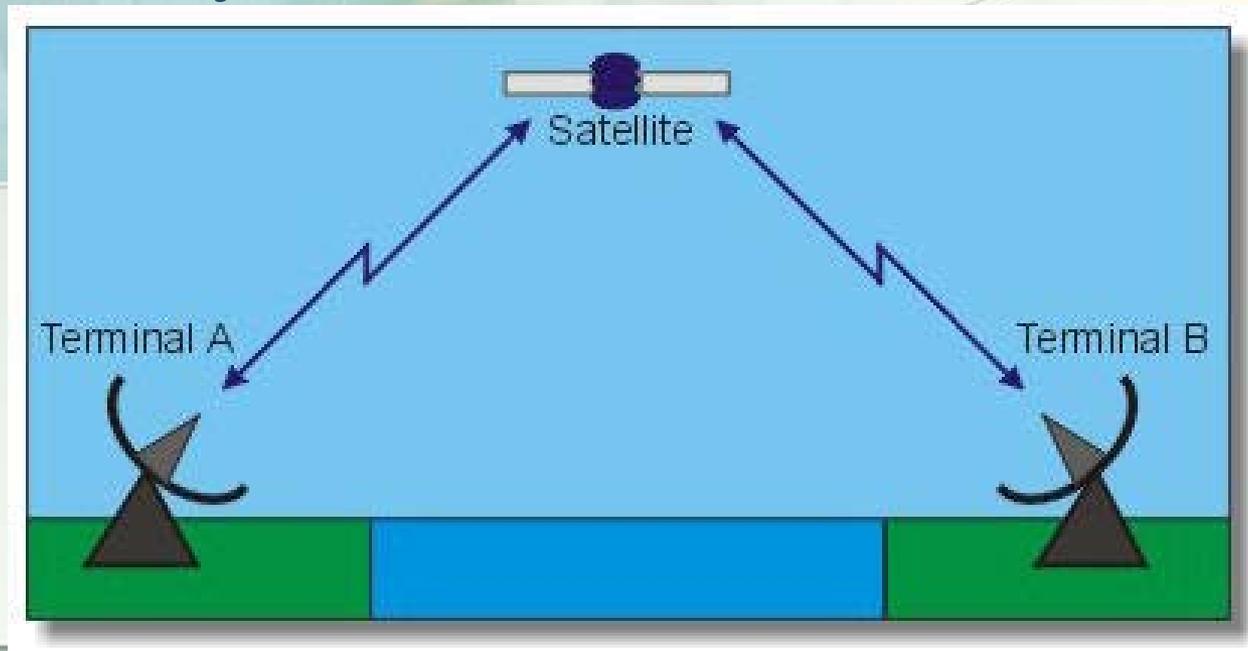
Popular modulation types being used for satellite communications:

- Binary phase shift keying (BPSK);
- Quadrature phase shift keying (QPSK);
- 8PSK;
- Quadrature amplitude modulation (QAM), especially 16QAM.

## 7- Link Budget Analysis and Design

### Satellite link budget objective

The first step in designing a satellite network is performance of a satellite link budget analysis. The link budget will determine what size of antenna to use, SSPA or TWTA PA power requirements, link availability and bit error rate, and in general, the overall customer satisfaction with your work.



## Understand Link budget

A satellite link budget is a listing of all the gains and losses that will affect the signal as it travels from the spacecraft to the ground station. There will be a similar list of gains and losses for the link from the ground station to the satellite. Link budgets are used by the system engineers to determine the specifications necessary to obtain the desired level of system performance. After the system has been built, the link budget is invaluable to the maintenance personnel for isolating the cause of degraded system performance.

## Understand Link budget

None of the components of a link is fixed, but instead will have some variation. The link budget must account for this. Typically the variables will be listed with a maximum and minimum value or with a nominal value plus a tolerance. The design engineer will allocate signal power to each variable so that the variations don't result in unacceptable signal fade. It is usually too expensive to build a system that will work with the worst case scenario for all variables, so it is the engineer's job to find an acceptable balance between cost and link availability. The maintenance engineer must also be aware of the variations so that he can properly differentiate between expected link degradation and a link failure.

## Understand Link budget

The satellite link is composed of many variables and it's important to understand when specific variables need to be included and when they can be ignored. In this tutorial we will discuss the most common variables and provide guidelines to help determine when they can be ignored.

The first variable in our link budget will be the spacecraft **EIRP**. This is the power output from the spacecraft. All other variables will be gains or losses that will be added or subtracted from the EIRP. Variations in the EIRP are normally pretty small and can be ignored by the maintenance engineer once the nominal EIRP is known. There may be small variations due to temperature and a larger change can be expected if the spacecraft configuration is changed, such as switching to a backup HPA.

## Understand Link budget

**Path loss ( $L_{\text{path}}$ )** is the amount of signal attenuation due to the distance between the satellite and the ground station. This is the largest loss in the link. For example, the path loss for an S band signal from a geosynchronous satellite will be about 192 dB. Path loss varies with distance and frequency. The greater the distance, the greater the path loss. Higher frequencies suffer more loss than lower frequencies. Thus the path loss will be greater for a Ku band signal than for an S band signal at the same distance. For a geosynchronous satellite, the distance between the satellite and the ground station varies slightly over a 24 hour period. This variation may be important to the design engineer, but the maintenance engineer can usually work with a fixed average value for the path loss. For a low earth orbit (LEO) satellite the distance between the satellite and ground station is constantly changing. The maximum and minimum path loss will be important to both the design engineer and the maintenance engineer.

## Understand Link budget

The next loss we'll consider is the **polarization loss** ( $L_{pol}$ ). The transmitting and receiving antennas are usually polarized to permit frequency reuse. Satellite links usually employ circular polarization, although linear polarization is occasionally used. In the case of circular polarization, the design engineer will use the axial ratio of the transmit and receive antennas to determine the maximum and minimum polarization loss. The maximum loss is usually small enough (0.3 dB typically) to be ignored by the maintenance engineer. There are, however, a couple of special cases that the maintenance engineer will need to keep in mind. If the ground antenna is capable of being configured for either LHCP or RHCP, a misconfiguration of the polarization will result in a significant loss, on the order of 20 dB or more. Also, polarization is affected by atmospheric conditions. If there is rain in the area, polarization loss may increase. More information on this is provided in the discussion of rain fade.

## Understand Link budget

**Pointing loss** ( $L_{\text{point}}$ ) is the amount of signal loss due to inaccurate pointing of the antennas. To determine the expected amount of pointing loss, the design engineer will consider such things as antenna position encoder accuracy, resolution of position commands, and autotrack accuracy. The pointing accuracy of both the spacecraft antenna and the ground station antenna must be considered, although they may both be combined into one entry in the link budget. Pointing loss will usually be small, on the order of a few tenths of a dB. This is small enough for the maintenance engineer to ignore under normal circumstances. However, pointing loss is one of the most common causes of link failure. This is usually due to inaccurate commanded position of the antenna, but can also be caused by a faulty position encoder.

### Understand Link budget

**Atmospheric loss ( $L_{\text{atmos}}$ )** is the amount of signal that is absorbed by the atmosphere as the signal travels from the satellite to the ground station. It varies with signal frequency and the signal path length through the atmosphere, which is related to the elevation angle between the ground station and the spacecraft. Theoretically, the amount of signal absorbed by rain could also be considered an atmospheric loss, but because rain fade can be quite large and unpredictable, it is given its own variable in the link budget. In general, atmospheric loss can be assumed to be less than 1 dB as long as the look angle elevation from the ground station is greater than 20 degrees.

## Understand Link budget

**Rain fade** is a unique entry in the link budget because it is derived from the system specification instead of being dependent on the natural elements of the link. The actual rain fade on a link can be quite large and unpredictable. It probably isn't practical to attempt to design a link that will perform to specifications under worst case rain conditions. Instead, the system specification might specify the amount of rain fade that the system must be able to tolerate and still meet the performance specifications. Specified rain fade is typically in the range of 6 dB. Therefore the link budget will list a maximum rain fade of 6 dB and a minimum of 0 dB. If the link is designed to this budget, it will have an additional 6 dB of link margin to compensate for a rain fade

## Understand Link budget

The variables we've discussed so far (EIRP, path loss, polarization loss, pointing loss, atmospheric loss, rain fade) are sufficient to define the signal power level at the ground station. The power would be shown by:

$$\text{Power Level} = \text{EIRP} - L_{\text{path}} - L_{\text{pol}} - L_{\text{point}} - L_{\text{atmos}} - \text{rain fade}$$

## Understand Link budget

The last two items we're going to include in our link budget are the **ground station antenna and LNA**. These two items aren't really variables, but are constants that the design engineer will select. Based on the power level indicated by the link budget and the carrier to noise requirement indicated by the system specs, the engineer will select an antenna/LNA pair that will amplify the signal sufficiently for further processing without adding more noise than the system spec allows. The antenna gain and the LNA noise will be combined into a single parameter called the "gain over noise temperature", or **G/T**. This will be the final entry in our link budget.

### Understand Link budget

The carrier to noise ratio  $C/N_0$  for the link can now be calculated as:

$$C/N_0 = \text{EIRP} - L_{\text{path}} - L_{\text{pol}} - L_{\text{point}} - L_{\text{atmos}} - \text{rain fade} + G/T - \text{Boltzmann's Constant}$$

This completes the link budget for the space to ground link. A link budget for the ground to space link would be composed of the same variables. The variables would need to be updated for the uplink frequencies, the G/T would be the spacecraft G/T, and the ground station design engineer would then select the ground station EIRP required to meet system specs.

## Understand Link budget

Boltzmann's Constant (k) Amount of noise power contributed by 1 degree of temperature, kelvin.

$$k = 1.38 * 10^{(-23)} \text{ Watt-second/K}$$

or

$$-228.6 \text{ dBw/Hz}$$

# End of Sessions 3 and 4

Network Planning and Link Budget Analysis