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Day 2, Session 2:

Satellite Network Topologies

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Topics in this Module

1. Satellite Network Topologies
2. Access Schemes (FDMA, TDMA, DAMA, PAMA etc)
3. C-Band vs Ku-Band
4. VSATs and Data Communications
5. Digital Communication Techniques
   - ✓ Protocols e.g., TCI/IP, Frame Relay
   - ✓ Compression
   - ✓ VoIP
6. Modulation (AM, PSK , FSK , CDMA)
7. Understanding Link Budget Analysis

Satellite Network Topology 1/9

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

- Star Networks
- Mesh Networks
- SCPC

Satellite Network Topology 2/9

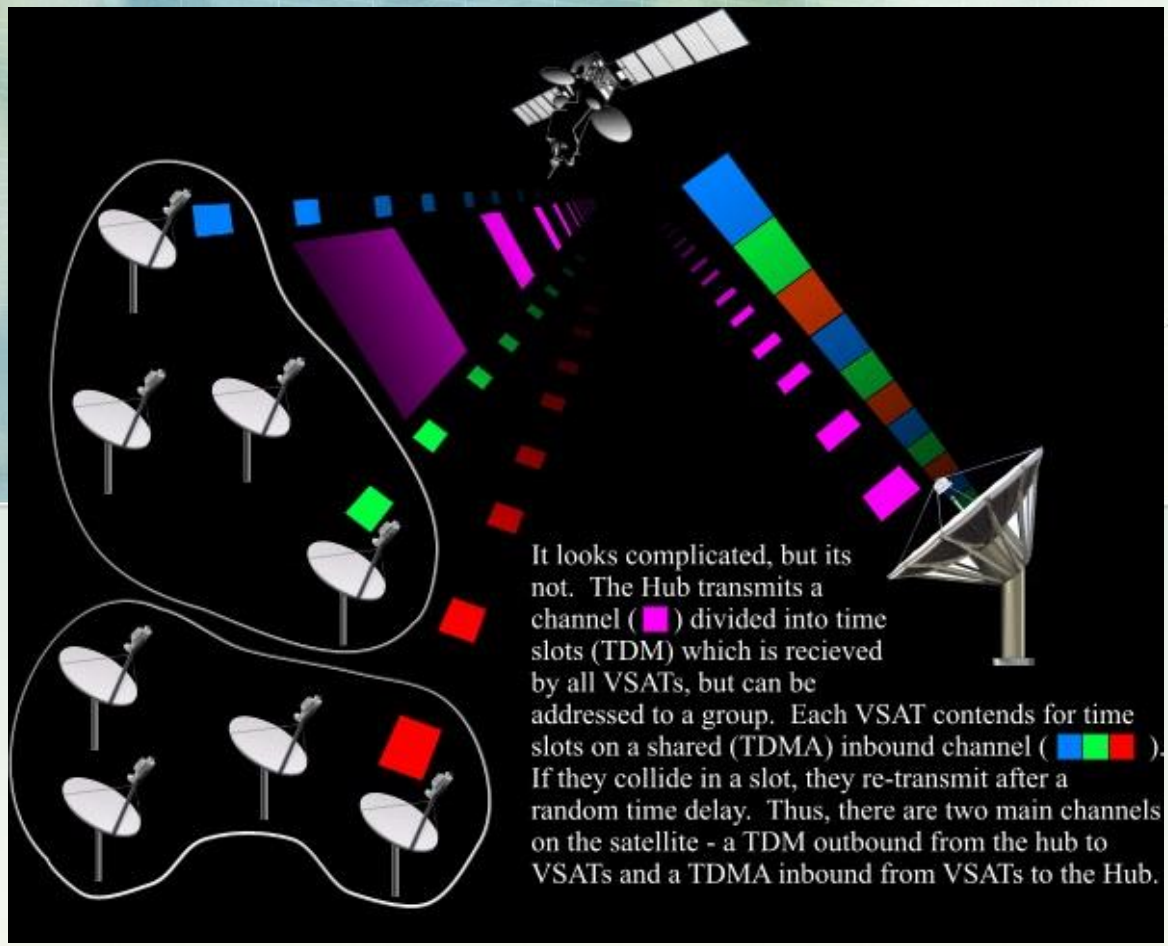
Star Network

Common used for data networks

- It involves a Hub Station and Remotes. All the channels are shared and the remote terminals are online, offering fast response times.
- All the traffic goes through the Hub station
- Use capacity on a TDM/TDMA basis

Satellite Network Topology 3/9

Star Network



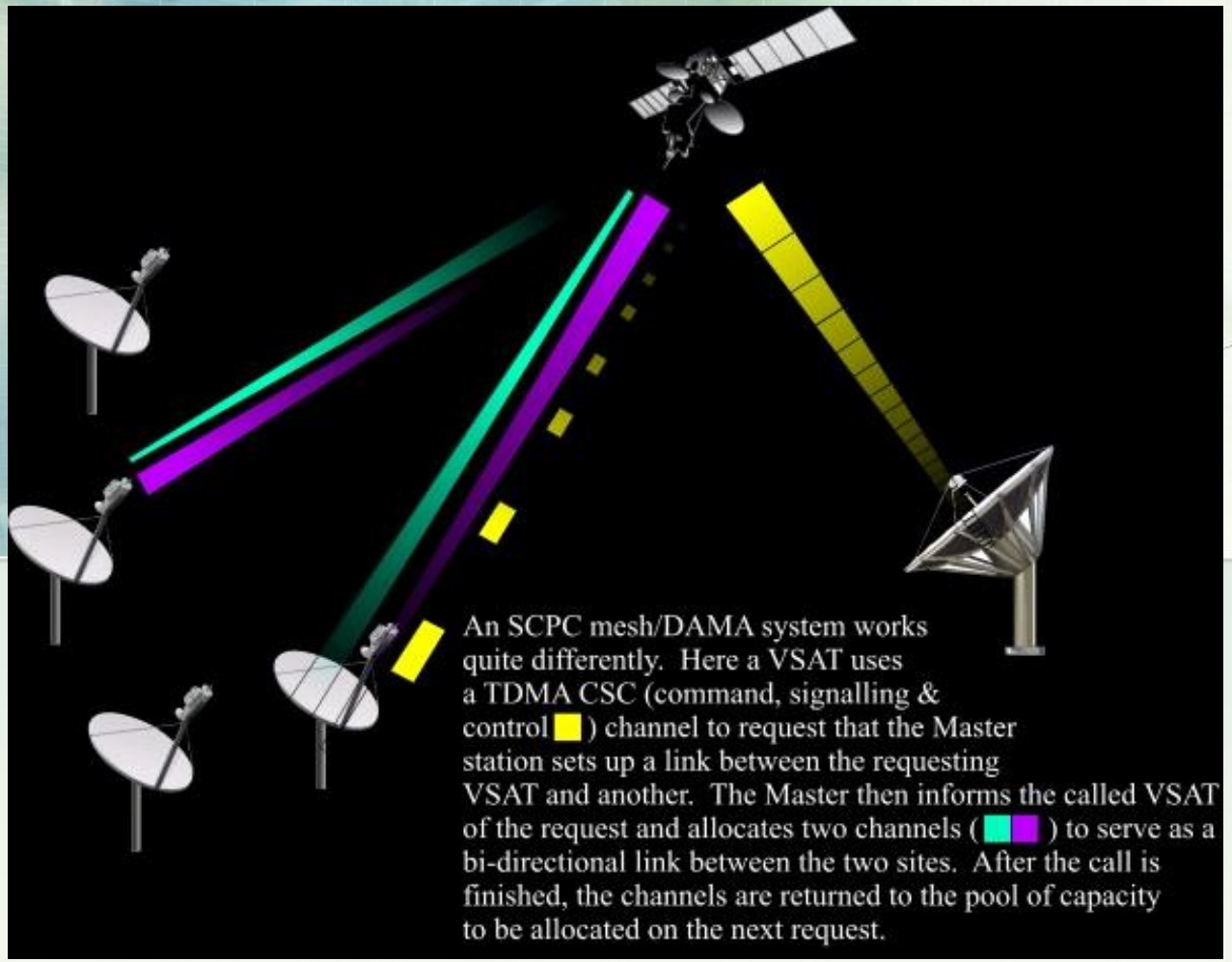
Satellite Network Topology 4/9

Mesh Network

- Involve a Master Control Station and traffic VSATs
- The master control station merely acts as a controller and facilitator .
- Typically use capacity on a TDM/TDMA basis

Satellite Network Topology 5/9

Mesh Network



Satellite Network Topology 6/9

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.

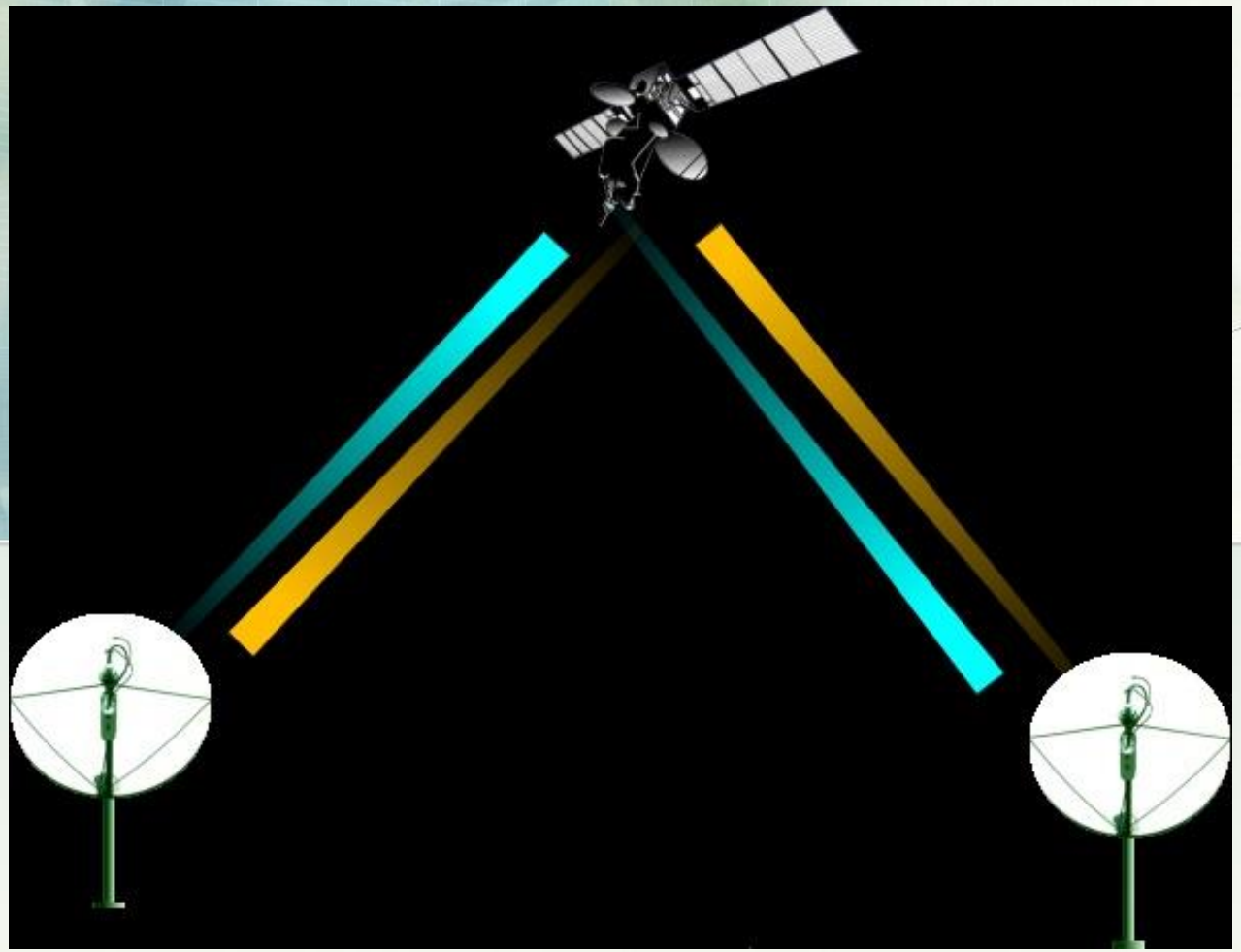
Satellite Network Topology 7/9

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. .

Satellite Network Topology 8/9

SCPC Network



Satellite Network Topology 9/9

Other Network Topologies

All other systems are usually a variation on one of the themes described above, either in a star, mesh or hybrid (star and mesh) configuration. Most of the TDM/TDMA manufacturers also offer a mesh product which can be deployed in a hybrid-ised configuration, sharing common components such as antennas and RF units, at a remote site.

Access schemes 1/13

- The methods by which VSAT 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 topology is associated with an appropriate satellite access scheme. Good network efficiency depends very much on the multiple access schemes.

- Examples of Access Schemes discussed in this Module are: SCPC, TDMA, FDMA, DAMA, CDMA

Access schemes 2/13

Single Channel Per Carrier (SCPC)

SCPC may be looked as both a topology and an access..

Access schemes$_{3/13}$

SCPC

SCPC satellite backbone connectivity provides constant dedicated communications to deliver one way, full duplex or asymetrical service in point to point, point to multi-point, star, mesh, or hybrid network configurations.

In these designs, an SCPC network can deliver high bandwidth to easily support the most demanding service applications, such as, video-conferencing, voice communications, and data transmission. Dedicated bandwidth connectivity is offered on SCPC, iSCPC, DVB and DVP-S2 platforms.

Access schemes 4/13

SCPC

Important Satellite SCPC features

- Supports true multimedia capabilities - voice,video,data
- Replacement of terrestrial circuits
- Backup circuits for redundancy or diversity
- Remote access where high-speed terrestrial connectivity isn't available

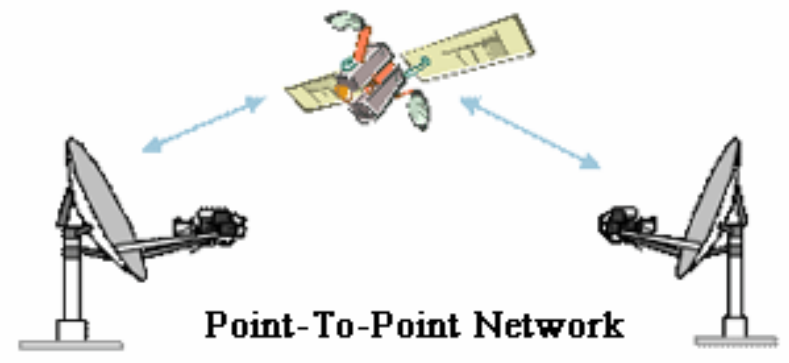
Potential SCPC applications

- High-speed access to IP networks
- Replacement of terrestrial circuits
- Credit authorizations and inventory management
- Corporate operations and account management
- WAN connectivity

Access schemes 5/13

SCPC

Point-To-Point Dedicated



Depending upon the satellite and provider, some links can deliver high speeds of up to 155Mbps which is comparable to a terrestrial leased line connection.

Access schemes 6/13

SCPC

These networks easily support voice, video, and data transmissions utilizing a standard data/voice multiplexer, an SCPC satellite modem, and a VSAT terminal at each site. This is a very simple approach for point-to-point networks as communications are only between the two sites. Similarly, Point-To-MultiPoint satellite connectivity is a network configuration composed of multiple Point-To-Point SCPC connections.

There is no connectivity to the teleport which requires the satellite signal to make a double hop. More important, the quality of real time applications is not affected.

There are no costs associated with the usage of a teleport or backhaul which makes this a less expensive solution

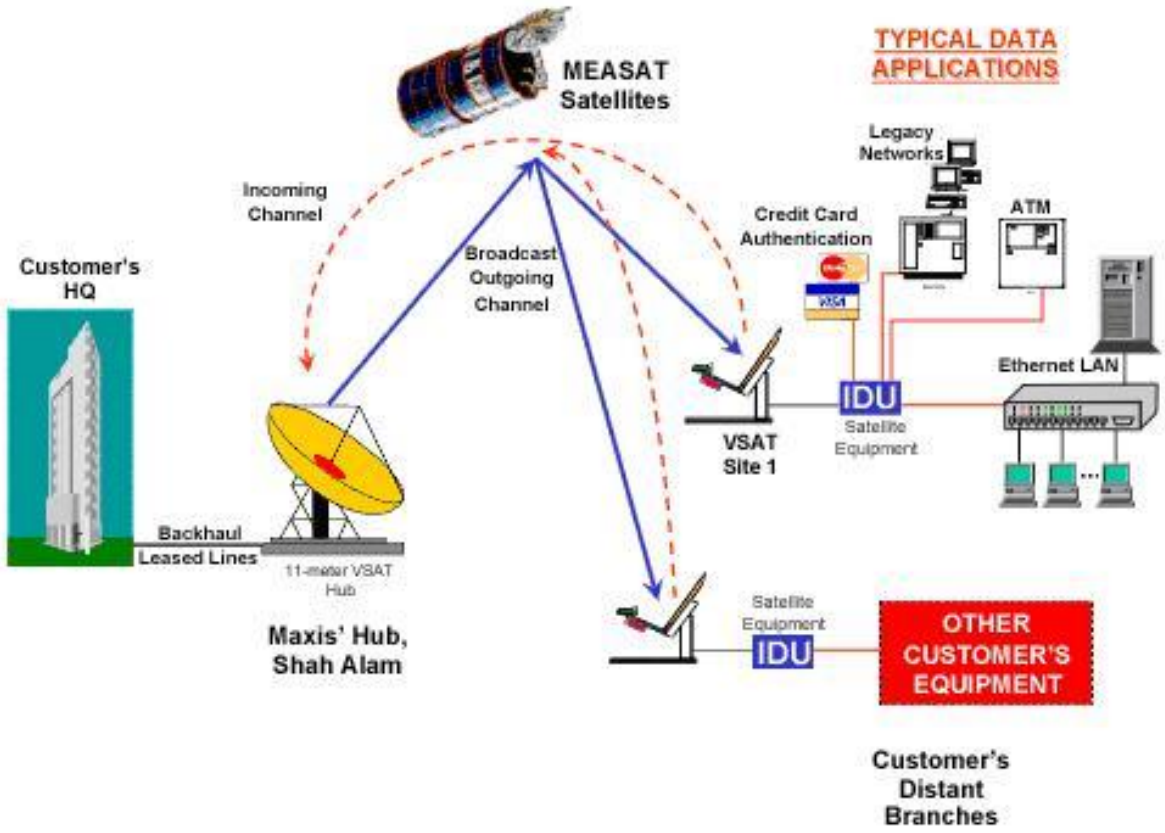
Access schemes 7/13

TDMA

- Numerous remote sites communicate with one central hub
- Remote sites in a TDMA network compete with one another for access to the central hub, restricting the maximum available bandwidth.
- All VSATs share satellite resource on a time-slot basis.
- Remote VSATs use TDMA channels or in routes for communicating with the hub. There could be several inroutes associated with one outroute. Several VSATs share one inroute hence sharing the bandwidth. Typical inroutes operate at 64 or 128 Kbit/s.

Access schemes 8/13

TDMA



Typical SkyNet (TDM/TDMA) configuration supporting various interactive data applications

Access schemes 9/13

FDMA

Here, all VSATs share the satellite resource on the frequency domain only. Typically implemented in a mesh or single satellite hop topology.

FDMA has the following variants:

- PAMA (Pre-Assigned Multiple Access)
- DAMA (Demand Assigned Multiple Access)
- CDMA (Code Division Multiple Access)

Access schemes 10/13

PAMA

VSATs are pre-allocated designated frequencies.

PAMA solutions use the satellite resources constantly. Consequently, there is no "call-up" delay what makes them most suited for interactive data applications or high traffic volumes. As such, PAMA connects high data traffic sites within an organization.

Access schemes 11/13

DAMA

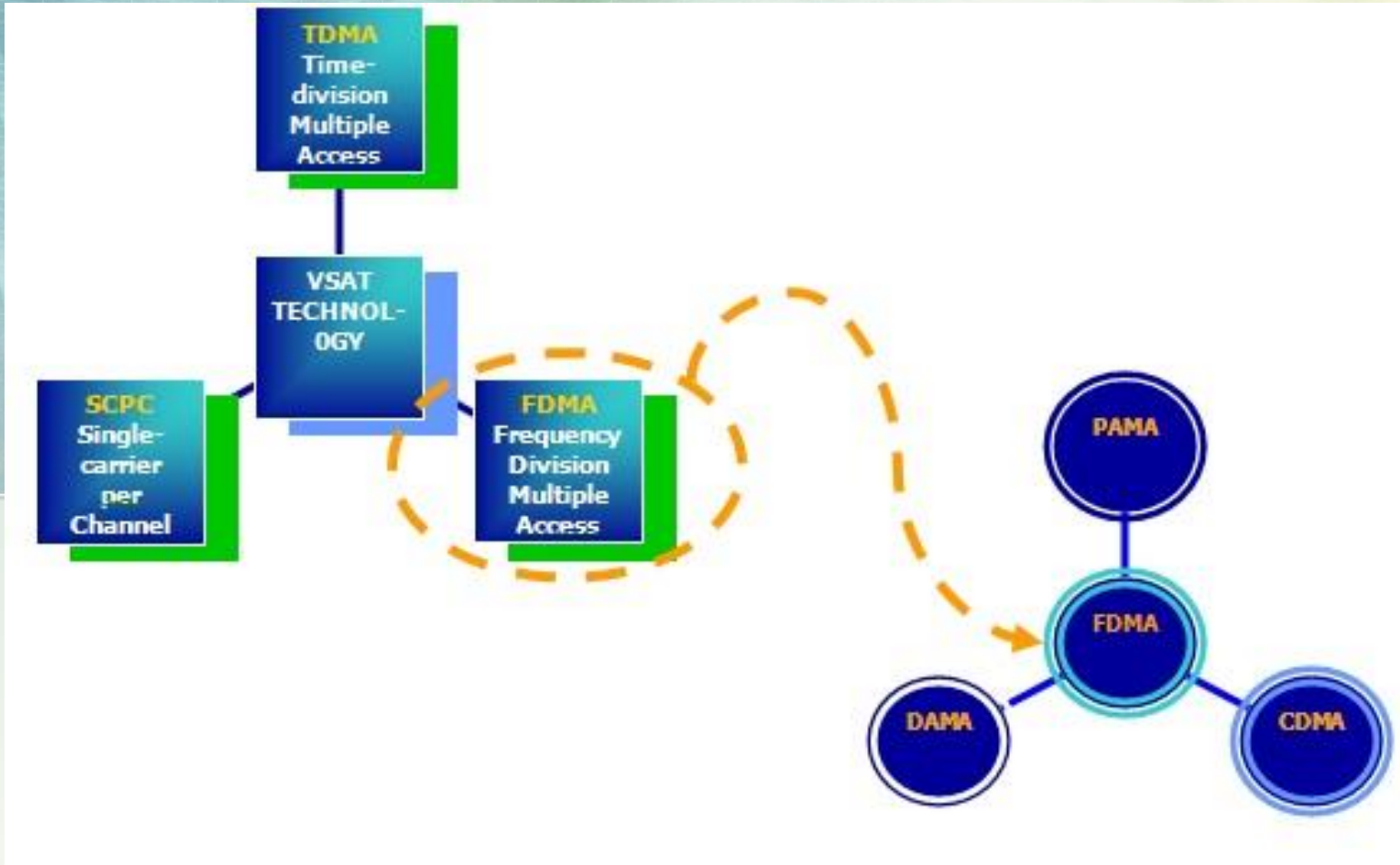
The network uses a pool of satellite channels, which are available for use by any station in that network. On demand, a pair of available channels is assigned so that a call can be established..

Access schemes 12/13

CDMA

Under this access scheme, a central network monitoring system allocates a unique code to each of the VSATs enabling multiple VSATs to transmit simultaneously and share a common frequency band. To permit this to be achieved without undue interference between the users CDMA employs spread-spectrum technology.

Access schemes 13/13



Questions so far?

C Band vs. Ku Band 1/4

C Band: For satellite communications, the microwave frequencies of the C-band perform better in comparison with K_u 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

C Band vs. Ku Band 2/4

C Band

`C-Band Variations Around The World		
Band	Transmit Frequency (GHz)	Receive Frequency (GHz)
Extended C-Band	5.850-6.425	3.625-4.200
Super Extended C-Band	5.850-6.725	3.400-4.200
INSAT C-Band	6.725-7.025	4.500-4.800
Russian C-Band	5.975-6.475	3.650-4.150
LMI C-Band	5.7250-6.025	3.700-4.000

C Band vs. Ku Band 3/4

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

C Band vs. Ku Band 4/4

	Advantages	Disadvantages
C Band	✓ Less disturbance from heavy rain fade ✓ Cheaper Bandwidth	❖ Needs a larger satellite dish (diameters of minimum 2-3m) ❖ Powerful (=expensive) RF unit ❖ More expensive hardware ❖ Possible Interference from microwave links
Ku Band	✓ No interference from microwave links and other technologies ✓ Operates with a smaller satellite dish (diameters from 0.9m) -> cheaper and more easy installation ✓ Needs less power -> cheaper RF unit	❖ More expensive capacity ❖ Sensitive to heavy rain fade (significant attenuation of the signal) / possibly can be managed by appropriate dish size or transmitter power.

Protocols supported by VSAT Networks 1/3

- A summary of the protocols in general use and their support over typical VSAT networks is provided in Table 8.2.
- While still in existence in some legacy environments, it has been replaced with the more open Internet Protocol suite (TCP/IP).

Protocols supported by VSAT Networks 2/3

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

Protocol	*Applications*	*Availability on VSATs*
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

Protocols supported by VSAT Networks 3/3

- **Frame Relay**
- 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.

Digital Communications techniques 1/??

Protocol Layering

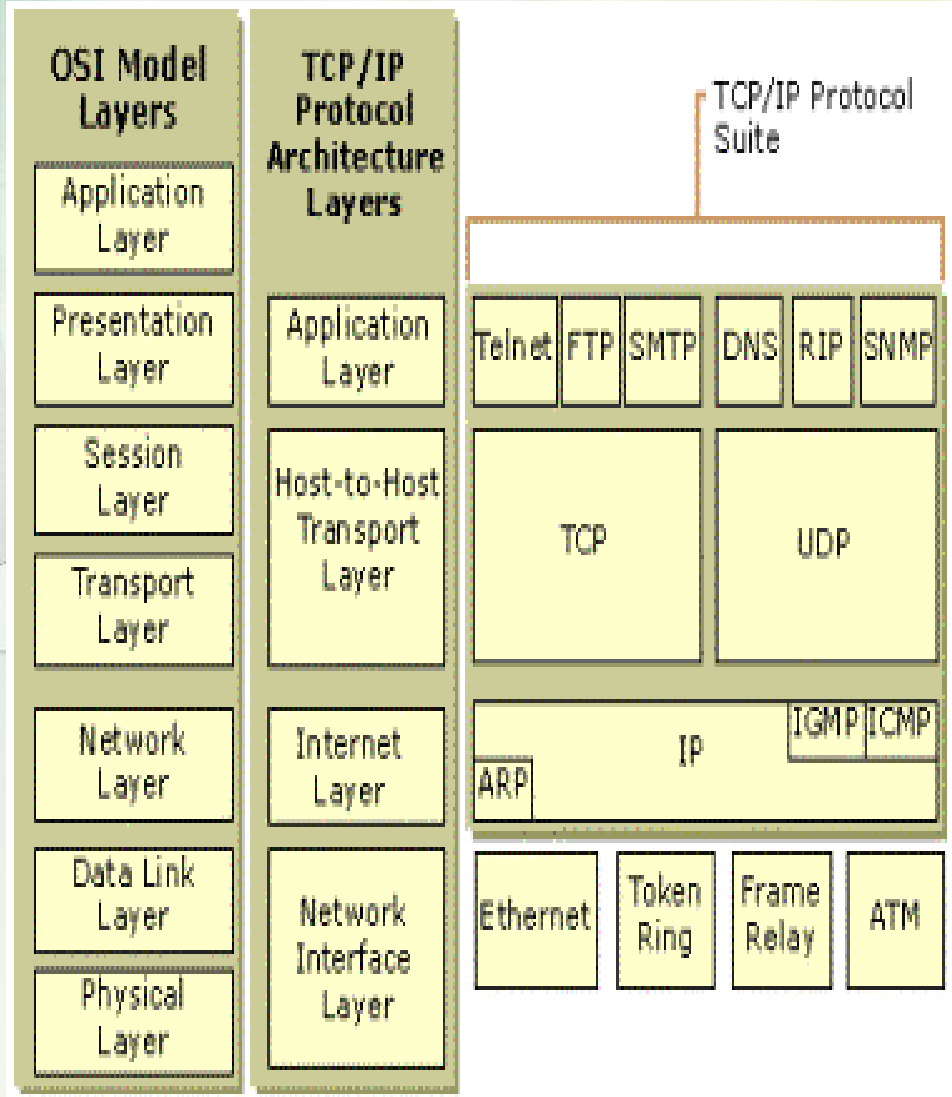
- Modern data communications theory and practice is literally built upon the concept of **protocol layering**, where the most basic transmission requirement is at the bottom and more complex and sophisticated features are added one on top of each other.
- While this concept is abstract, it is important to understanding how the data in a network is assembled, processed, and reliably transferred between sender and receiver.

Digital Communications techniques 1/??

- The layering concept is embodied in the Open Systems Interconnection (OSI) model shown in the figure on next page and contained in relevant standards of the International Organization for Standardization (ISO) and the ITU-Telecommunication Sector (ITU-T).

OSI and TCP/IP (DARPA) Model

	OSI Layer	TCP/IP Layer
7	Application	HTTP, STMP, FTP, and so forth.
6	Presentation	
5	Session	
4	Transport	TCP (or UDP)
3	Network	IP
2	Data	Logical link control (LLC) – 802.2
	Link	Media access control (MAC) – 802.3
1	Physical	Twisted pair, T1/E1, VSAT



IP Networks 1/3

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.

IP Networks 2/3

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..

TCP and IP

TCP/IP is composed of two parts: TCP (Transmission Control Protocol) and IP (Internet Protocol)..

UDP

An alternative protocol to TCP within the TCP/IP suite is UDP (User Datagram Protocol), which does not guarantee delivery.

Compression 1/2

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 and less costly .

Compression 2/2

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

Voice over Internet Protocol 1/4

What is VoIP?

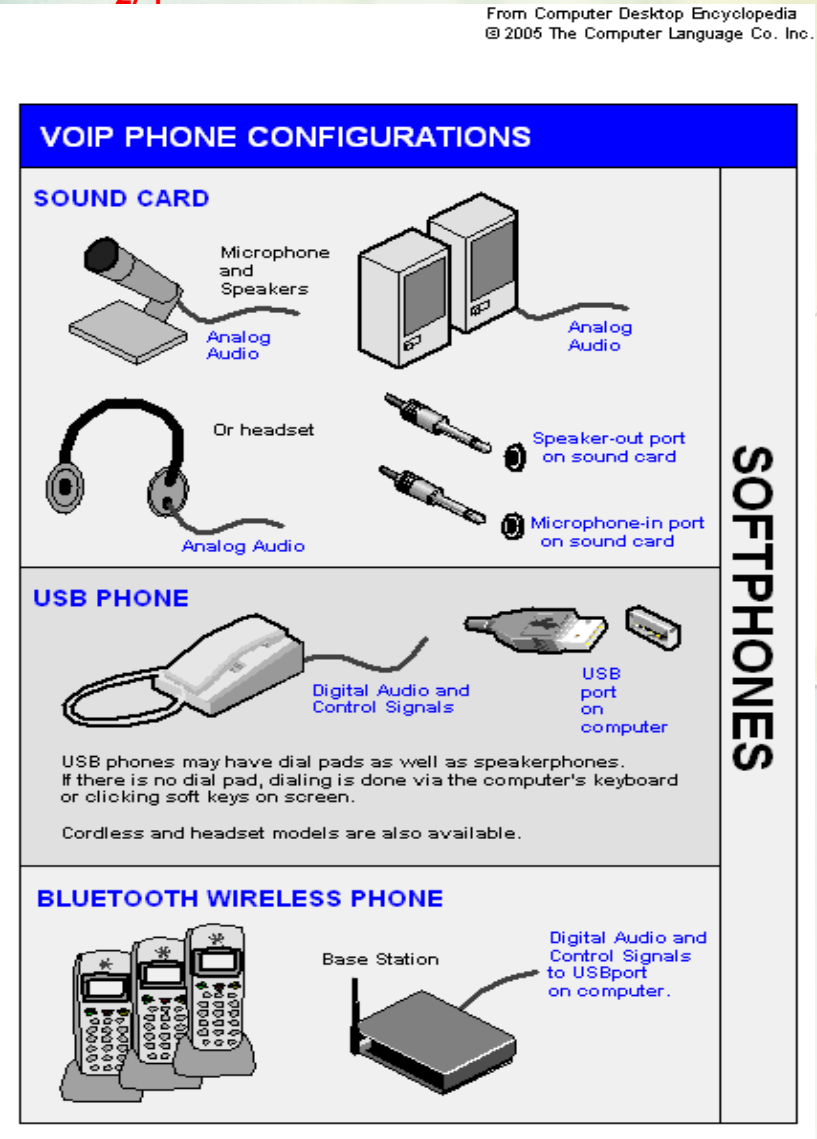
Referring to voice communications over the public Internet or any packet network employing the TCP/IP protocol suite.

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.

Voice over Internet Protocol 2/4

Softphone based

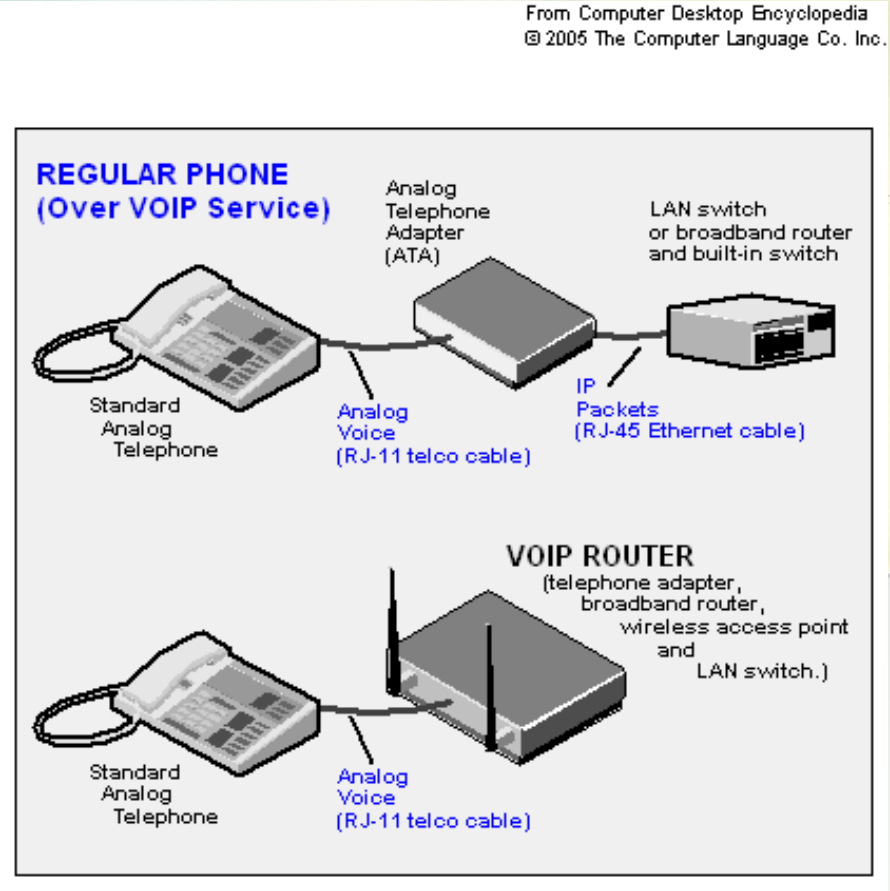
VoIP providers may be entirely softphone based, which requires a computer, phone software and microphone and speakers (or headset) to make and receive calls.



Voice over Internet Protocol 3/4

Handset based

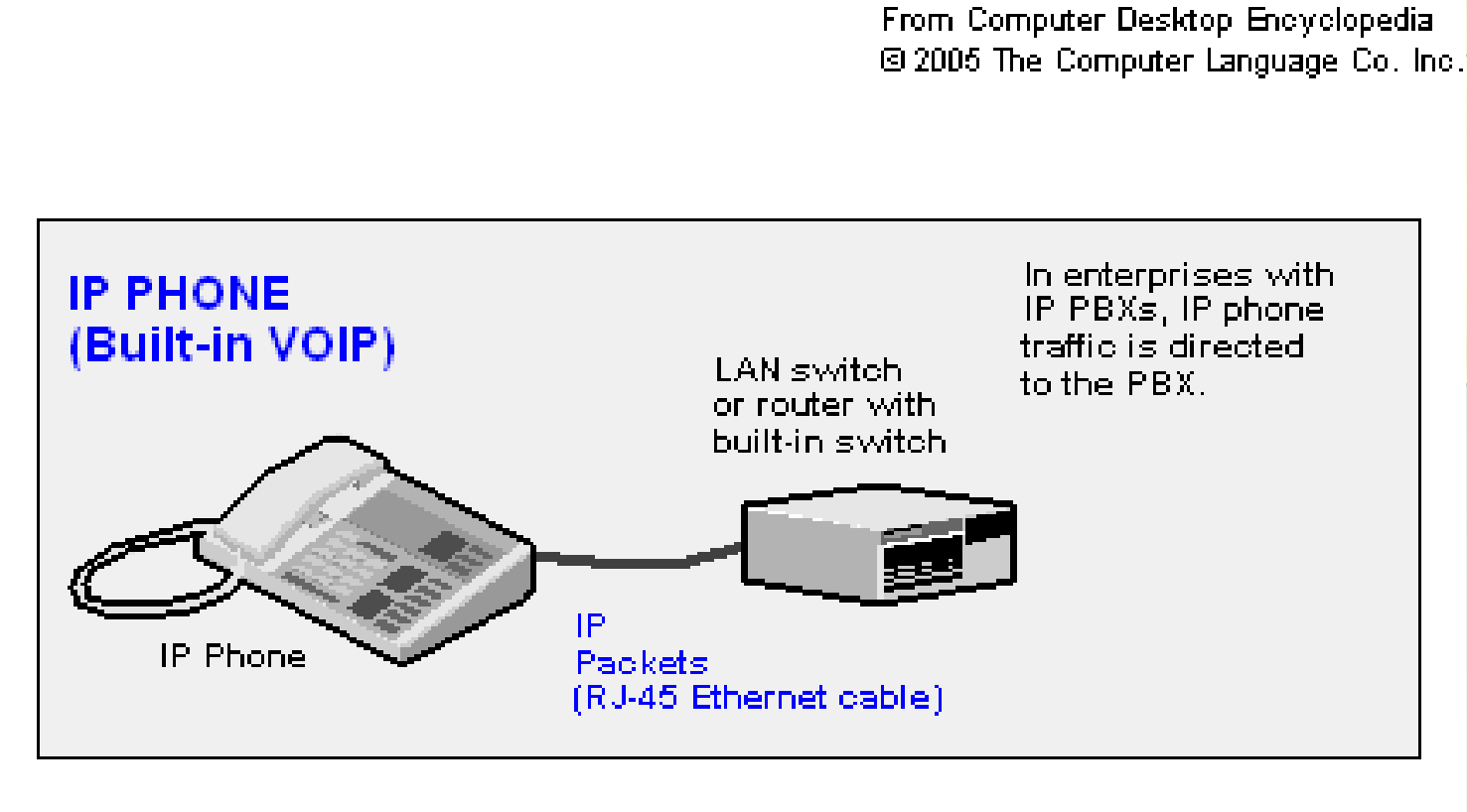
Regular phones can be used with many VoIP services by plugging them into an analog telephone adapter (ATA) provided by the VoIP provider or purchased from a third party. The ATA converts the phone to IP packets. IP phones can also be used that have built-in IP packet support.



Voice over Internet Protocol 4/4

IP Phone : Built-in VoIP

IP Phones can be directly connected to the IP network.



Modulation 1/10

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 2/10

The three basic types of modulation are :

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

All of these techniques vary 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.

Modulation 3/10

Amplitude Modulation (AM)

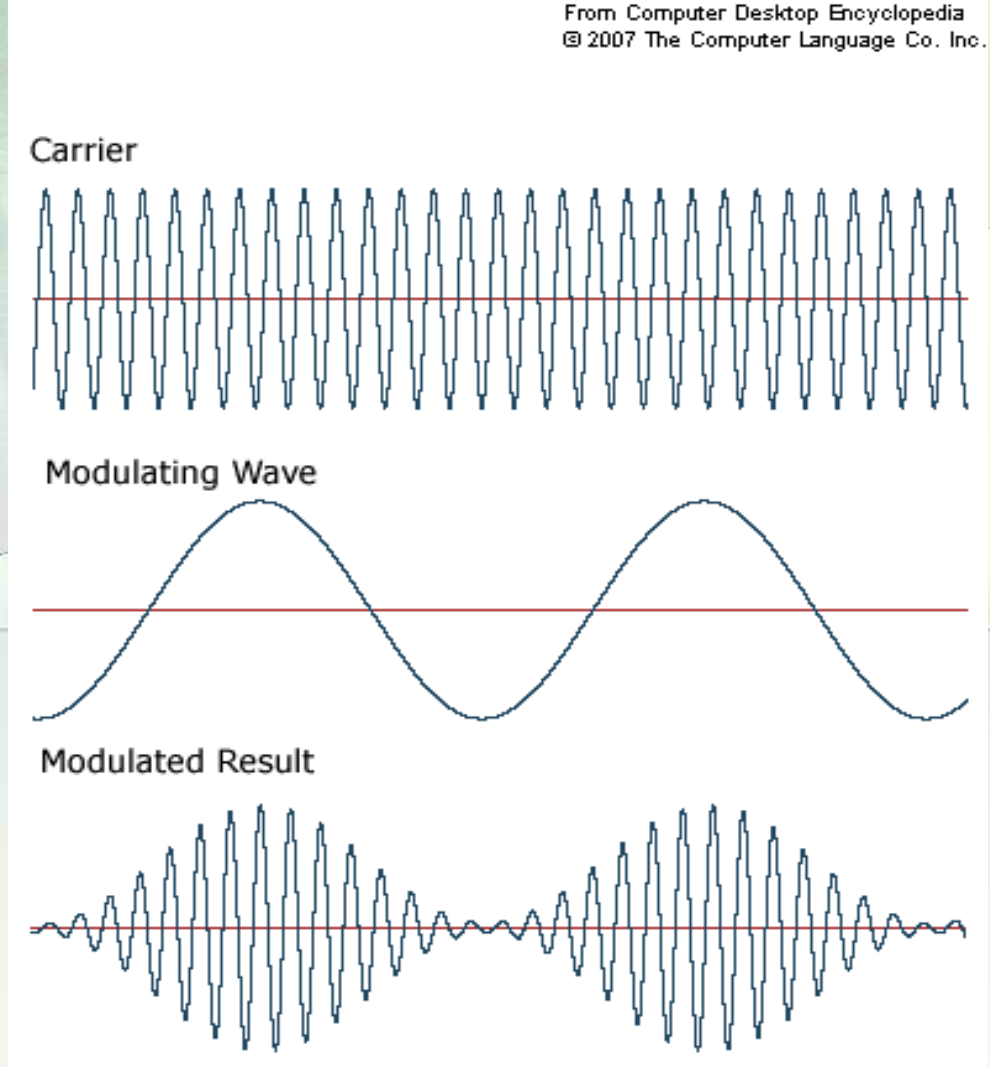
Varying the voltage of a carrier or a direct current in order to transmit analog or digital data. Amplitude modulation (AM) is the oldest method of transmitting human voice electronically.

Modulation 4/10

Amplitude Modulation (AM)

Vary the Amplitude

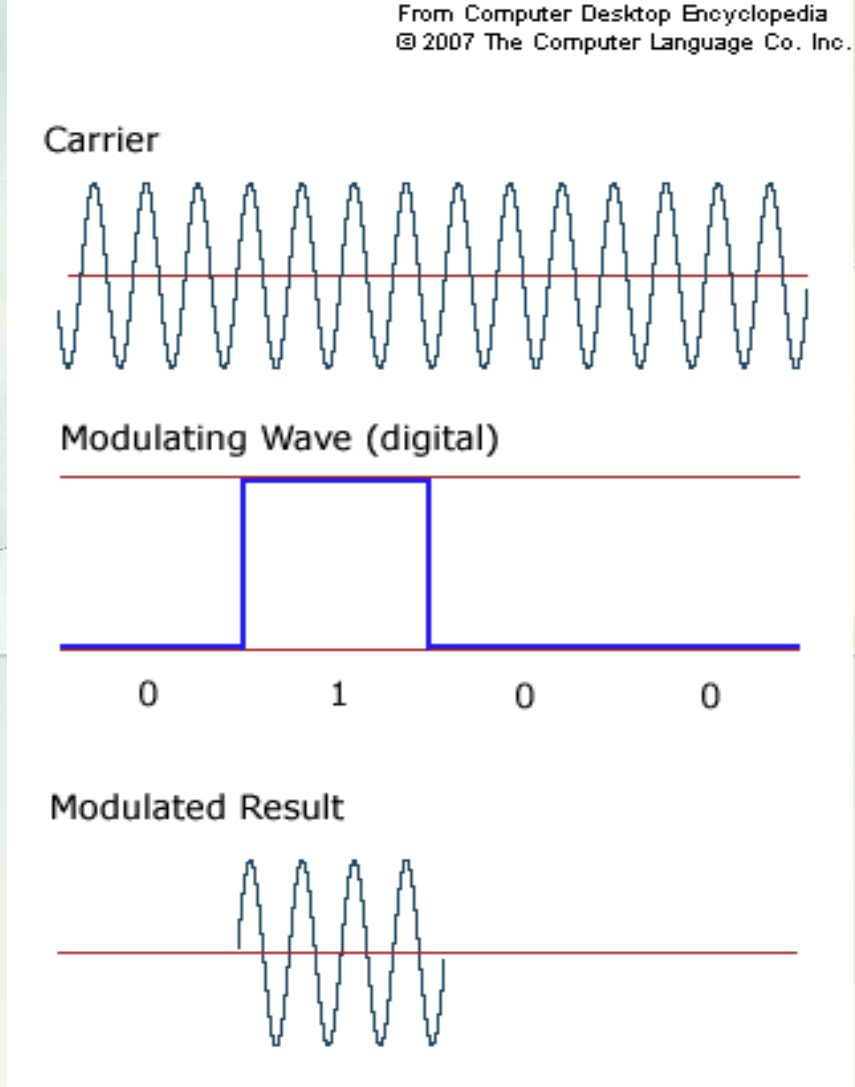
In AM modulation, the voltage (amplitude) of the carrier is varied by the incoming signal. In this example, the modulating wave implies an analog signal.



Modulation 5/10

Digital Amplitude Shift Keying (ASK)

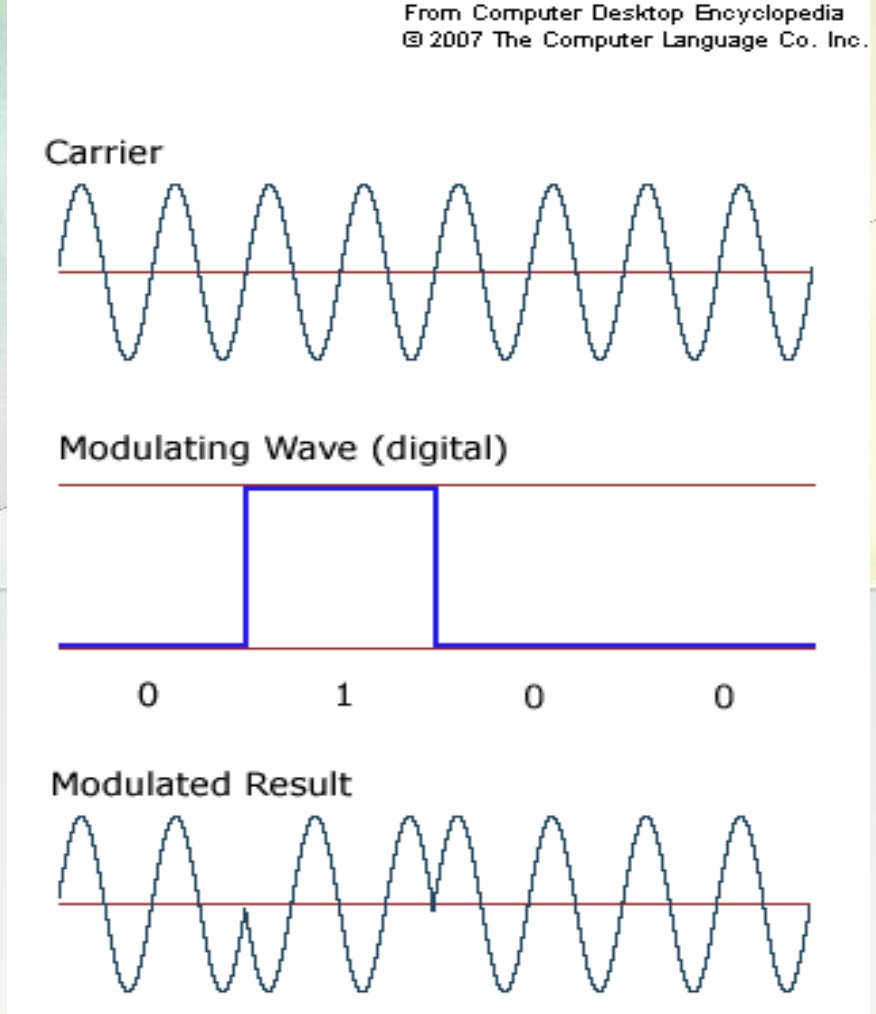
For digital signals, amplitude shift keying (ASK) uses two voltage levels for 0 and 1 as in this example.



Modulation 6/10

Phase Shift Keying (PSK)

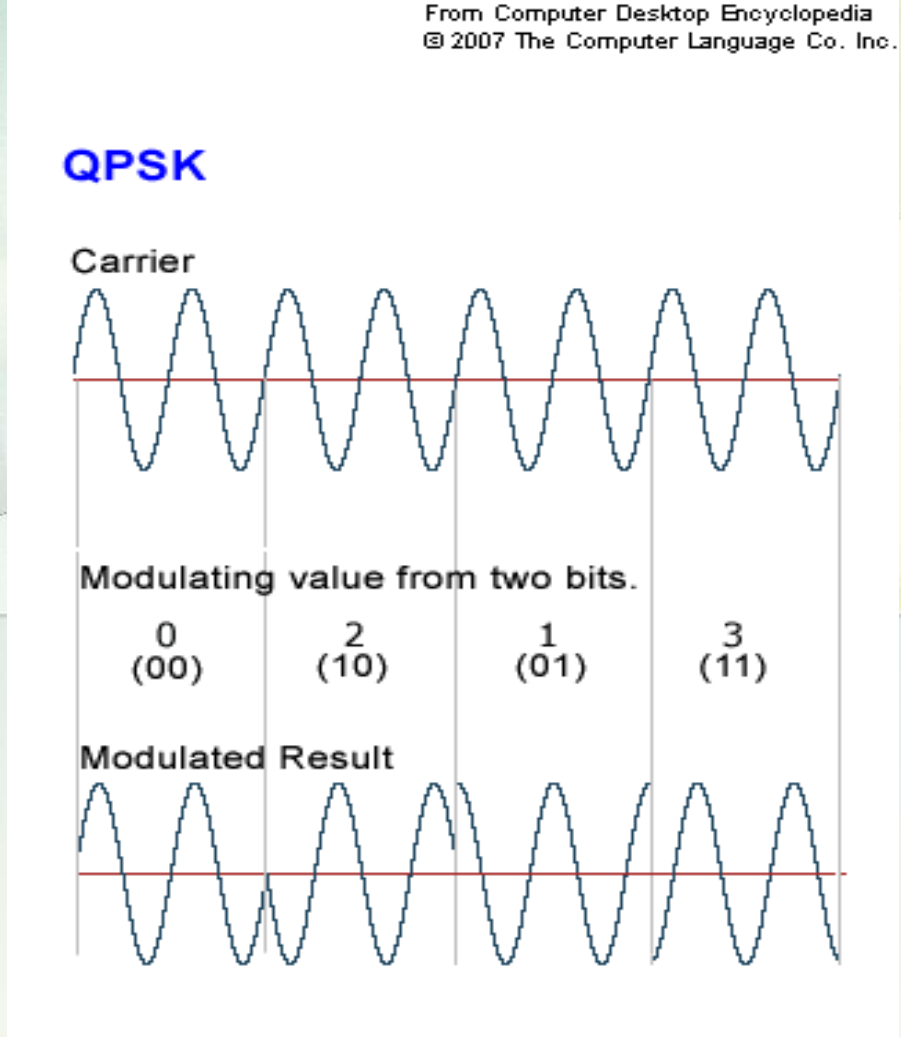
For digital signals, phase shift keying (PSK) uses two phases for 0 and 1 as in this example.



Modulation 7/10

Quadrature Phase Shift Keying (QPSK)

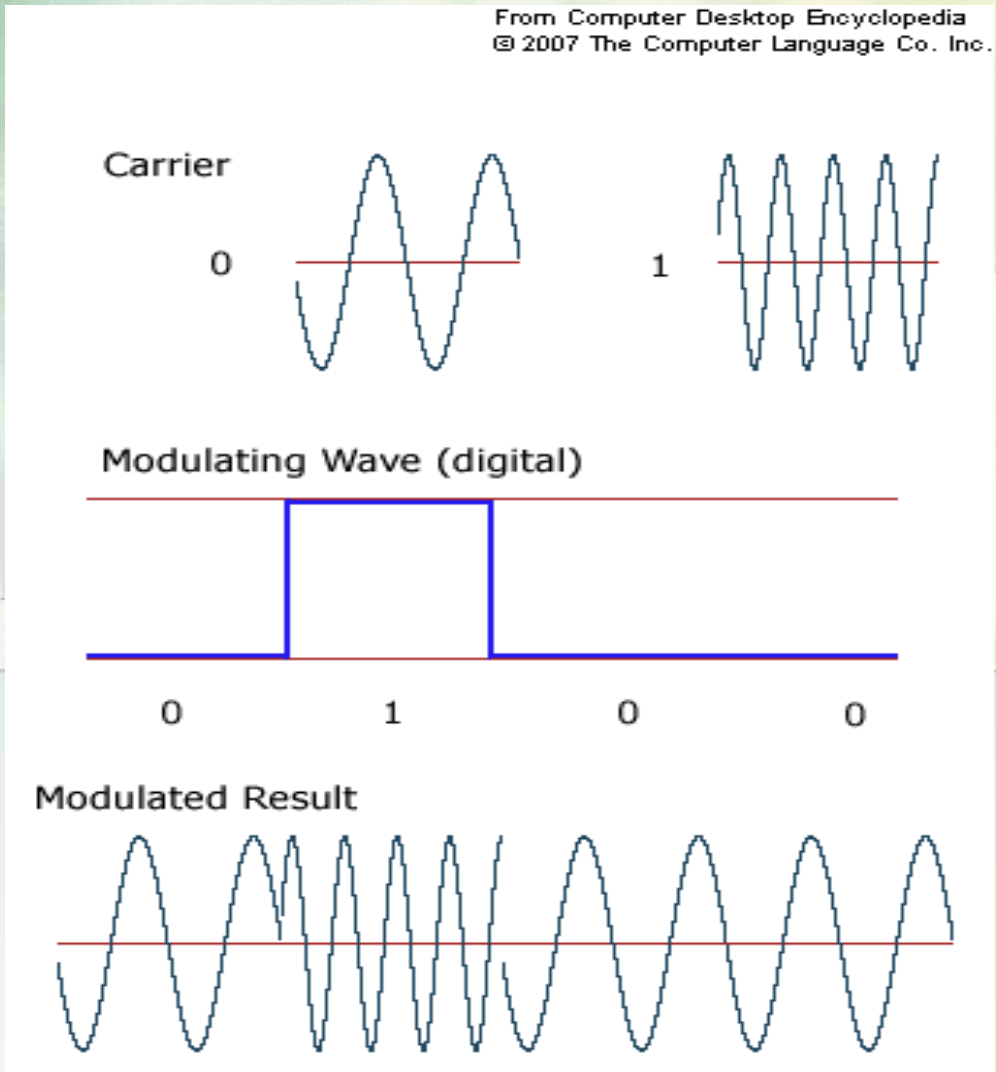
QPSK uses four phase angles to represent each two bits of input; however, the amplitude remains constant.



Modulation 8/10

Frequency Shift Keying (FSK)

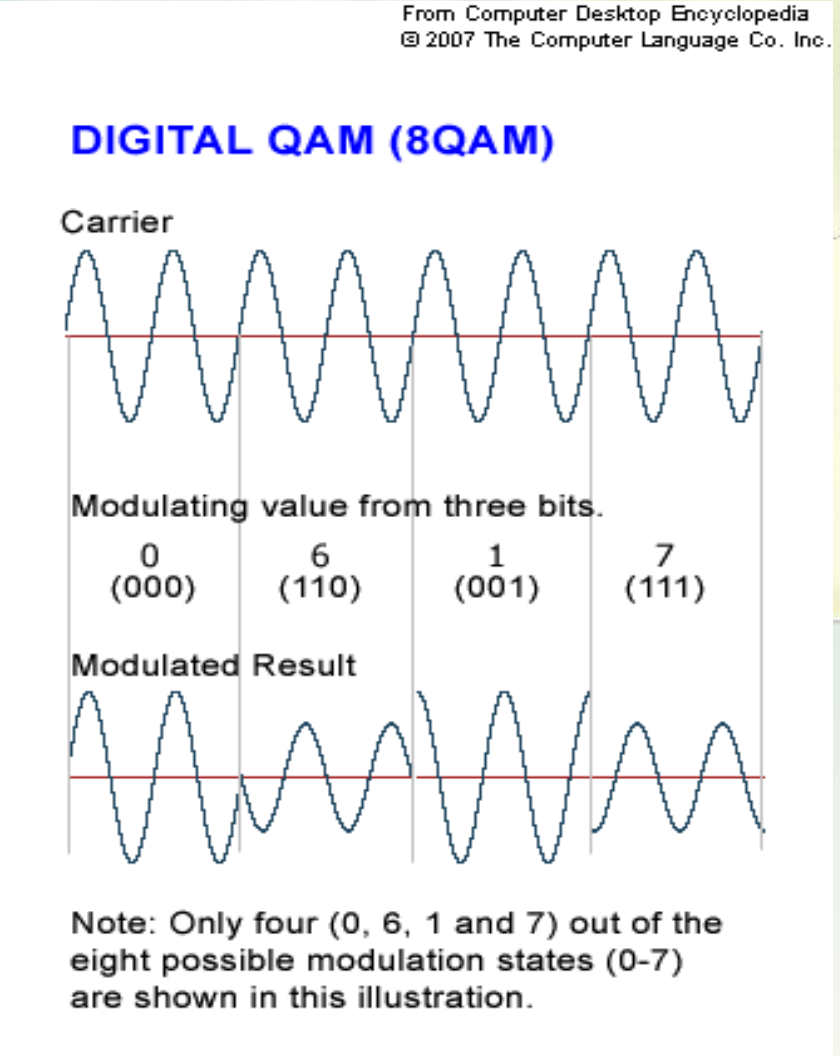
FSK is a simple technique that uses two frequencies to represent 0 and 1.



Modulation 9/10

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.



Modulation 10/10

Popular Modulation schemes used in satellite

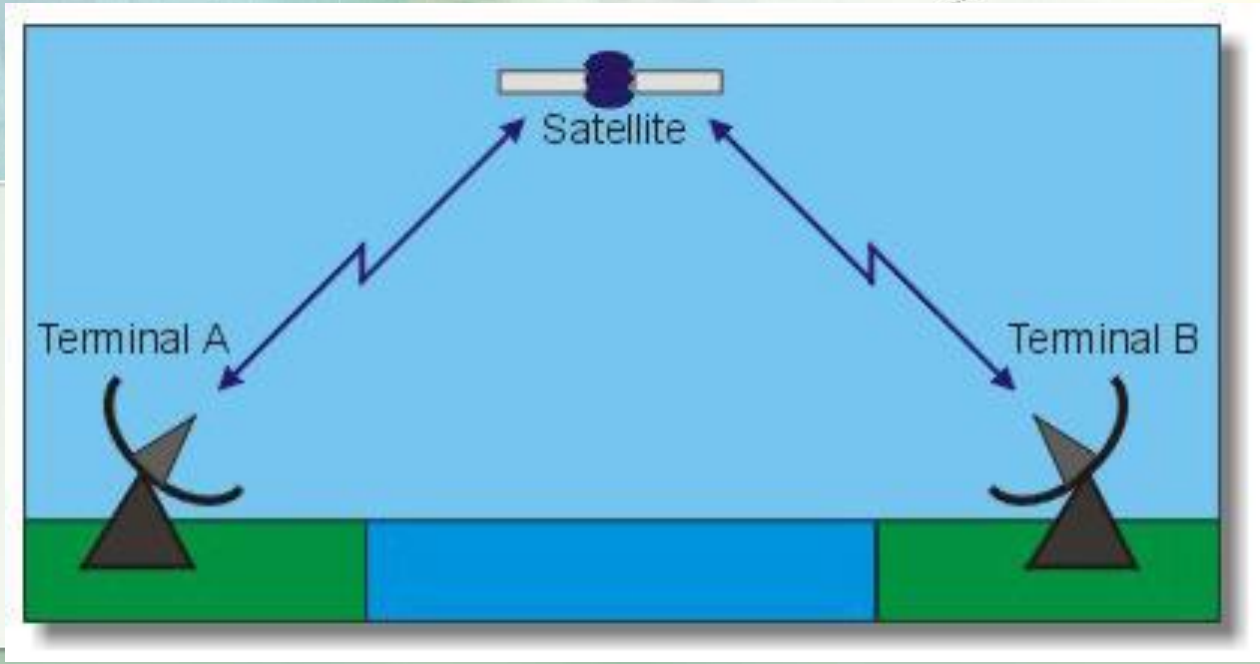
Popular modulation types being used for satellite communications:

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

Questions so far?

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.



Understanding Link Budget Analysis and Design 2/14

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. After the system has been built, the link budget is invaluable to the maintenance personnel for isolating the cause of degraded system performance.

Understanding Link Budget Analysis and Design 3/14

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.

Understanding Link Budget Analysis and Design 4/14

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.

Understanding Link Budget Analysis and Design 5/14

Path loss (L_{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 geosyncronous 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 geosyncronous 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.

Understanding Link Budget Analysis and Design 6/14

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.

Understanding Link Budget Analysis and Design 7/14

Pointing loss (L_{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.

Understanding Link Budget Analysis and Design 8/14

Atmospheric loss (L_{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.

Understanding Link Budget Analysis and Design 9/14

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

Understanding Link Budget Analysis and Design 10/14

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:

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

Understanding Link Budget Analysis and Design 11/14

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.

Understanding Link Budget Analysis and Design 12/14

The carrier to noise ratio C/N0 for the link can now be calculated as:

$$C/N0 = EIRP - L_{path} - L_{pol} - L_{point} - L_{atmos} - \text{rain fade} + G/T - \text{Boltzmann's Constant}$$

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.

Understanding Link Budget Analysis and Design 13/14

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

k = 1.38 * 10^(-23) Watt-second/K

or

-228.6 dBw/Hz

Understanding Link Budget Analysis and Design 14/14

Satellite Link Design – Example of Satellite Link Budget

Table 1 C-band GEO Satellite link budget in clear air. [1]

C-band satellite parameters		
	Transponder saturated output power	20 W
	Antenna gain, on axis	20 dB
	Transponder bandwidth	36 MHz
	Downlink frequency band	3.7–4.2 GHz
Signal	FM-TV analog signal	
	FM-TV signal bandwidth	30 MHz
	Minimum permitted overall C/N in receiver	9.5 dB
Receiving C-band earth station		
	Downlink frequency	4.00 GHz
	Antenna gain, on axis, 4 GHz	49.7 dB
	Receiver IF bandwidth	27 MHz
	Receiving system noise temperature	75 K
Downlink power budget		
	P_s = Satellite transponder output power, 20 W	13.0 dBW
	B_o = Transponder output backoff	−2.0 dB
	G_t = Satellite antenna gain, on axis	20.0 dB
	G_r = Earth station antenna gain	49.7 dB
	L_p = Free space path loss at 4 GHz	−196.5 dB
	L_{ant} = Edge of beam loss for satellite antenna	−3.0 dB
	L_a = Clear air atmospheric loss	−0.2 dB
	L_m = Other losses	−0.5 dB
	P_r = Received power at earth station	−119.5 dBW
Downlink noise power budget in clear air		
	k = Boltzmann's constant	−228.6 dBW/K/Hz
	T_s = System noise temperature, 75 K	18.8 dBK
	B_n = Noise bandwidth, 27 MHz	74.3 dBHz
	N = Receiver noise power	−135.5 dBW
C/N ratio in receiver in clear air		
	C/N = $P_r - N$ = −119.5 dBW − (−135.5 dBW) = 16.0 dB	

Table 2 C-band GEO Satellite link budget in rain. [1]

	P_{rca} = Received power at earth station in clear air	−119.5 dBW
	A = Rain attenuation	−1.0 dB
	P_{rain} = Received power at earth station in rain	−120.5 dBW
	N_{ca} = Receiver noise power in clear air	−135.5 dBW
	ΔN_{rain} = Increase in noise temperature due to rain	2.3 dB
	N_{rain} = Receiver noise power in rain	−133.2 dBW
C/N ratio in receiver in rain		
	C/N = $P_{rain} - N_{rain}$ = −120.5 dBW − (−133.2 dBW) = 12.7 dB	

End

Thank You!

Final Questions?