Contents

10.0 Satellite Systems

OBJECTIVES

This section will:

- Examine direct broadcast satellites
- Discuss PCSS
- Examine satellite multiplexing techniques
- Calculate the position of the geostationary orbit
- Examine the link budget equations
- Introduce GPS

http://www.spaceandtech.com/

http://www.comlinks.com/

Satellites can support a number of applications including:

- Communications systems
- Remote sensing
- Global positioning and navigation
- Search and rescue
- Weather and pollution monitoring
- Surveillance

Band	Uplink [GHz]	Downlink [GHz]	Comments
L	.821 - .825	.866 - .870	MSAT
C	5.9 – 6.4	3.7 – 4.2	Fixed ground stations
X	7.9 – 8.6	7.25 – 7.75	Military mobile radio
Ku	14 – 14.5	11.7 – 12.2	Broadcast and fixed point
Ka	27 – 30 30 – 31	17 – 20 20 – 21	
V/Q	50 – 51	40 – 41 41 – 43	Broadcast and fixed point
V	54 – 58 59 – 64	54 – 58 59 – 64	Inter-satellite

Traditionally communications satellites have simply been a high altitude repeater. Today, satellites are required to perform more complex functions. For example, satellites must often be able to communicate directly with each other. This ability allows signals to be routed in space without ground hops. Considerable effort is being made to make satellites act as intelligent switches [sky switch].

The satellite equipment market is quite large, and is expected to grow throughout the balance of the decade.

______ Notes ______

Satellite networks are often categorized by their orbital altitude:

System	Altitude [Km]	Comments
GEOS	35786	Geostationary satellites
MEOS	10000	Medium earth orbit
LEOS	1000	Low earth orbit
HEOS		Highly elliptical orbit

Some Satellite System Facts

System	Sponsor	# Sat	Service	Comments
ACeS		2	2000	GEO Voice, data, paging, e-mail Terrestrial GSM is offered outside of the satellite coverage area
Aries	Constellation	48		290M$ An ATM platform used by the American Petroleum Institute
Celsat	Hughes, Nortel	3	2000	GEO Voice, data, fax, paging
ECCO		12	2000	450M$, LEO South America Voice, data, fax, paging
Ellipso	Ellipsat	14+3	2002	1.5B$ LEO/MEO Voice, data, paging, e-mail CDMA
E-Sat		6	2000	Data Services
FAISAT		26	2000	Data, paging, voice
GEMnet		38	2000	Data
GE Starsys		24	2000	Data messaging
Globalstar	Loral/Qualcom	48	1999	0.8 - 1.2B$ B-LEO Voice, data, fax, paging, GPS CDMA
ICO	NEC, Hughes, Ericsson	10+2	2000	MEO Voice, data, fax, paging TDMA
Iridium	Motorola	66	1998	4.4B$ + B-LEO Voice, data, fax, paging
Inmarsat P	Inmarsat	10 + 2		2.6B$[1] This system was originally designed for maritime shipping, but has since been expanded to other roles.
Koskon		32	2000	B-LEO Voice, data, fax, paging
LEO One Worldwide		48	2000	Data
M-Star	Motorola	72	2000	Broadband services
Odyssey	TRW	12	2002	1.3B$ B-LEO CDMA
Orbcomm	Orbital Sciences - Teleglobe	48	1999	Data service

[1] Microwaves & RF, October 1994, p. 46

Spaceway	Hughes	12	2000	GEO Voice, data, video, broadband
Teledesic	McCaw/Microsoft	840	2002	9B$ LEO Broadband services ATDMA+, CDMA
Thuyara		2	2000	GEO Voice, data, paging, e-mail
VITAsat		2	2000	Data services

10.1 DBS

Most TV satellites operate on the C-band, and broadcast between 5 to 24 watts. C-band receivers require large parabolic antennas, high quality receivers and are used by the general public.

Direct broadcast satellites transmit signals directly to home receivers on the Ku band. The higher frequency reduces the antennas antenna size to approximately one meter in diameter. DBS satellites also broadcast signal levels up to 200 watts, thus further easing the receiver design. A disadvantage of the Ku band is the increased atmospheric losses due to rain.

Ku band satellites carry 32 x 24 MHz channels. Instead of alternating vertical and horizontal polarization on adjacent channels, DBS satellites alternate left and right hand circular polarization.

10.1.1 Video

The most widely used application of DBS satellites is direct to the home video broadcasting in the Ku band (12.2 – 12.7 GHz). This frequency allows consumer dish antennas to be reduced in size to approximately 18 inches. The typical antenna gain is 34 dB and the half-power beam width is about 3.5^o.

Many DVB satellites have 16 transponders operating at 40 Mbps each. In order to provide a very high degree of reliability, approximately 17 Mbps or 40% of this capacity is allocated for forward error correction.

Each transponder can carry several video streams, which are statistically multiplexed on the carrier. This allows more bandwidth to be allocated when needed. If several channels have a high degree of motion, the picture on or more channels may degrade momentarily.

The uncompressed video at the input of the MP2 codec has a bit rate of about 140 Mbps. This is reduced to somewhere between 1.5 – 15 Mbps depending on the nature of the images. Some systems, such as DirecTV standardized on two encoding rates: 3 and 7.5 Mbps. Since the amount of compression is dependant on the amount of inter-frame movement, sports channels are allocated more bandwidth than news telecasts, which largely feature a talking head.

10.1.2 VSAT

These networks are commonly found in private business networks and are generally not accessible to the public. VSAT† networks carry voice, data, and video services via small dish satellite links. They are often used in ALOHA packet networks, and cellular radio facilities.

Most VSAT networks are arranged in a star configuration with all traffic being switched through a master control center which does both inter and intra-beam switching. An inter beam communications link therefor requires two hops. It is certainly possible that in the future, switching will be done in satellite, thus saving one hop.

10.2 PCSS

http://www.looksmart.com/eus1/eus317831/eus317876/eus53839/eus149557/eus149569/eus149572/r?l&

http://www.cellular.co.za/mss.htm

WARC† -92 allocated part of the L-band [1500 to 1700 MHz] for universal personal communications. This includes both terrestrial and satellite components.[2]

PCSS† depends upon the deployment of cheap and reliable LEO† satellites. Although a considerable amount of money has been spent on developing and promoting these systems, here is still considerable debate as to whether these systems are cost effective.[3]

There are a number of proposals for worldwide satellite communications systems. Initially it was thought that these systems might compete with local telcos and cellular radio systems. It is now thought that they will merely supplement the existing cellular system.

There is also a significant market in developing countries where there is little wire line infrastructure.

Some analysts give about a 10% chance of success for PCSS to develop as envisioned.[4]

† Very Small Aperture Terminals

† World Administrative Radio Conference, held in Malaga-Torremolinas, Spain in 1992

2 *Satellite-based Personal Communication Services*, Telecommunications, December 1993

† Personal Communications Satellite Services

† Low Earth Orbit

3 TE&M, Oct 1, 1993

4 TE&M, Feb 15, 1993

Notes

10.2.1 Odyssey

The Odyssey MEO system creates stationary ground cells by dynamically steering the satellite body. The satellite constellation provides full global coverage, with at least one satellite in view above 20 degrees elevation angle on all points of the globe.

CDMA was chosen for the multiple access method.

Usually at least two satellites will be visible from the mobile terminal and the best link is selected at call set-up. Path diversity is not employed and the MT[†] communicates through only one satellite at a time. Continuous service is assured by using a second receiver to link to the next satellite in the constellation.

Earth stations connect the system to the PSTN. Each satellite can support 3000 to 9500 voice circuits depending on the mix of mobile and fixed terminals.

10.2.2 ICO

The ICO system is a TDMA MEO system, with 10 satellites and 2 spares in 2 inclined circular orbits. The orbit is designed for satellite diversity, in that two or more satellites are in view of the MT at most times. The satellites relay calls between the MT and one of 12 earth stations. The ESs are linked to the PSTN.

ICO plans to use as much the GSM technology as possible. MTs are planned both as single mode and as dual mode, where the MT will work with both the ICO standard and the regional terrestrial cellular standard.

The MEO altitude of 10355 Km provides for slow-moving satellites as seen from the earth, leading to fewer and simpler handover arrangements than a LEO system.

TDMA was chosen because it permits power efficient modulation schemes, and maximizes traffic.

10.2.3 Globalstar

http://www.globalstar.com/

Coverage Map

The Globalstar system has 48 LEOs in eight planes. It will employ path diversity and up to three satellites may at any one time be used to complete the call.

It uses CDMA for the mobile link and it will require the full 16.5 MHz portion of the feeder link for re-use between beams.

The data rates are 1.2, 2.4, 4.8 and 9.6 Kbps, and the vocoder rate is allowed to drop to 1.2 Kbps when no voice activity is detected. This reduces interference and increases capacity, while maintaining synchronization and conveying

† Mobile Terminal

background comfort noise. The antennas are shaped for elliptical beams aligned with the satellite direction to increase the time a user stays within each beam.

10.2.4 Iridium

The Iridium† system was being developed by Motorola. It was intended to connect the cellular telephone system to a constellation of 66 LEO satellites[5]. It has since filed for bankruptcy.

Some of the system characteristics were:

- There will be 6 polar orbital planes, each with 11 satellites
- Cell diameter: 372 nautical miles
- L-band subscriber link
- Ka-band intersatellite, gateway, and feeder links
- Maximum number of simultaneous customers per cell: 110 [assuming 10.5 MHz total spectrum]

The service offering includes:

- Voice communications: full duplex 4800 bps path utilizing hand held, portable, and vehicle-mounted terminal.
- Radio determination services: used for automated position finding
- Facsimile services: stand-alone and Iridium telephone accessory models
- Data transmission: 2400 bps
- Worldwide paging: an alphanumeric unit

This system operates much in the same manner as terrestrial cellular radio, with one notable exception. In the Iridium network, it is the satellite rather than a central MTX†, which provide the hand-off to the next satellite.

The Iridium system uses ISL†, the GSM architecture and a controlled access process. Of the Iridium system's 3168 beams only approximately 2150 will be active at any one time, as some beams will be switched off around the earth poles where beam overlap occurs.

† An element with 77 orbiting electrons

5 TE&M, February 15, 1993

† Mobile Telephone eXhange

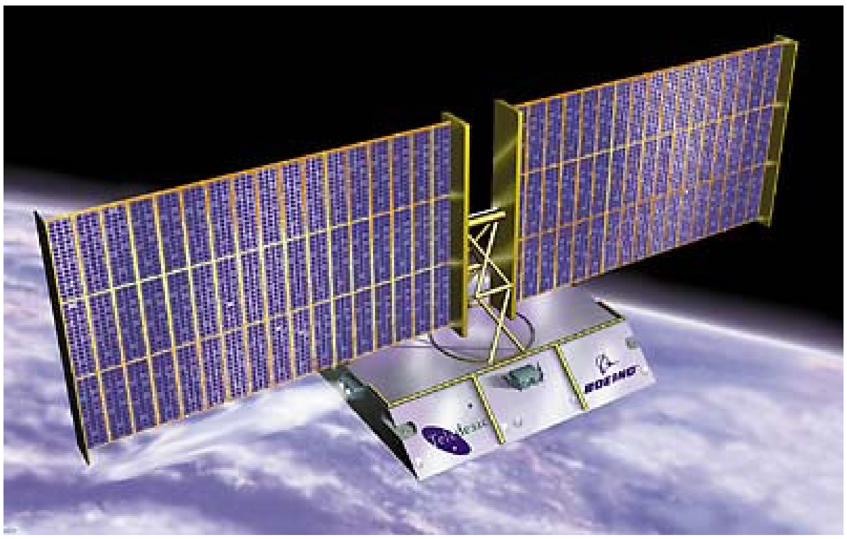
† Inter-Satellite Links

Iridium proposes time division duplex. Both uplink and downlink use a combination of TDMA and FDMA.

10.2.5 Teledesic

This proposed network is to consist of 840 LEO active satellites. Data transmission is to use a fixed length, fast packet approach.

The network carries 16 Kbps channels which can be aggregated to form a 2 Mbps link. Gateways to domestic communications carries are made with DS-3 and OC-1 links.



Each satellite cell is 53.3 square km. One of the unique features of this system is that the earth cells are fixed. Each satellite has high gain phased array, tracking antennas aimed for their assigned cell. If the beam angle becomes severe, all of the traffic on the satellite is handed off to the next satellite assigned to that cell. This approach requires fewer handoffs than moving cell systems. Each satellite is to be able to communicate with up to 8 other satellites, thus providing alternate routing in case of congestion or failure.

A Ka-band mobile link was chosen to support high bit rates. To reduce propagation delays the earth terminal elevation mask angle is 40^{o}. This also reduces fading due to rain. The elevation angle and low earth orbit together dictates the number of satellites needed to provide continuous global coverage. The system is designed for dual satellite visibility from a MT to enable load sharing between the satellites.

Each satellite has intersatellite connectionless links with its eight neighboring satellites, and each satellite acts as a switch in the mesh network so constructed. All communication within the network is treated as streams of short, fixed length (512 bits) packets similar to ATM. Each intersatellite link has a bit rate of 155.52 Mbps.

Each satellite has the capacity to support a total of 100000 x 16 Kbps channels.

Teledesic uses steerable antennas and regional resource mapping to reduce the number of handoffs required. The earth's surface is mapped into a fixed grid of approximately 20,000 supercells, each of which is a 160-km square divided into 9 cells.

A satellite footprint encompasses a maximum of 64 supercells, or 576 cells, corresponding to one supercell per beam. The channel resources (frequencies and time slots) are associated with each cell, and managed by the serving satellite.

A mobile terminal will retain the same channel resources during a call, irrespective of which and how many satellites are serving the MT during the call's lifetime. Channel reassignments are thus reduced. A database onboard each satellite defines the service types within each earth-fixed cell Service areas may also be contoured to national borders or regional boundaries using this earth-fixed cell technique.

Teledesic uses a combination of space, time, and frequency division multiple access. Each supercell has one dedicated receive and transmit beam. Each beam is scanned cyclically over the 9 cells in the beam's supercell, covering one cell at a time. The scan cycle is 23.11 mSec long. Each scanning beam supports 1440 x 16-Kbps channels. Therefore TDMA is used between cells in a supercell, and SDMA[†] is used between cells scanned simultaneously in adjacent supercells.

Within each cell's time slot, terminals use FDMA uplink and ATDMA[†] downlink. Transmissions from the satellites are synchronized such that each supercell receives transmissions at the same time, and there is a guard band of 0.292 ms per cell to ensure that there is no overlap between signals from time-consecutive cells.

Each terminal is allocated one or more frequency slots on the uplink for the call's duration. On the downlink, the 512-bit packet header is used to discriminate users rather than a fixed assignment. Each packet is delimited by a unique bit pattern. A standard 16 Kbps terminal requires one packet per scan, and the satellite transmits only as long as it takes to transmit the packets queued for a cell. Due to the space separation of the Teledesic system, all supercells use all available frequencies simultaneously. However, only 1 out of the 9 cells in a supercell is using all available frequencies at a time, and this corresponds to a re-use pattern of 9. The corresponding global re-use factor becomes 2222 (the 20000 supercells divided by the re-use pattern).

10.2.6 ORBCOMM

The ORBCOMM 48-satellite constellation supports data and messaging services.

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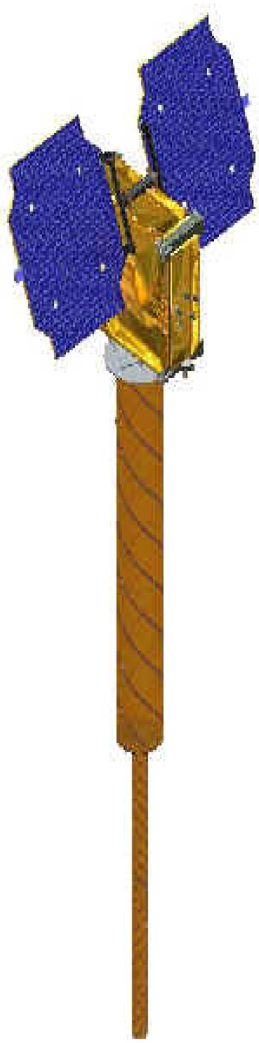
† Space Division Multiple Access

† Asynchronous TDMA

10.2.7 LEO One Worldwide



Click here for a view from space.

48 operational satellites
Frequency Bands

Subscriber downlink 137 -138 MHz

Subscriber uplink 148 - 150.05 MHz

Other 400.15 - 401 MHz

Subscriber channels use FDM while all other links use TDM. OQPSK modulation and FEC are used to provide robustness.

Data rates:

Subscriber

Subscriber uplink 2.4 – 9.6 Kbps, downlink 24 K bps

Gateway uplink 50,000 bps, downlink 50,000 bps

10.3 Multiple Access Formats

There are three methods to multiplex multiple users onto a satellite link:

- FDMA - frequency division multiple access
- TDMA - time division multiple access
- CDMA - code division multiple access

10.3.1 FDMA

FDMA is the simplest arrangement for allowing multiple access since each ground stations is assigned specific up and downlink frequencies. The most common technique uses FM carriers and analog inputs.

Although FM consumes more bandwidth than AM, it has a better S/N ratio and constant amplitude. The constant power aspect is important when using microwave amplifiers. As the number of active channels increase, the amplitude of each channel must be reduced in order to keep the power constant. This has the effect of reducing the carrier deviation on each FM link. Consequently, loading factors are related to the number of active channels and used to set the carrier deviation.

To increase satellite utilization multiple narrow spot beams are employed. This allows frequency reuse in different parts of the service area,

10.3.2 SPADE

Spade[†] was a combined digital FDM format used on satellite links.

The total allocated bandwidth of 36 MHz was divided into 800 – 45 KHz slots with 400 RF carrier pairs. Full duplex paths were established by assigning frequency pairs separated by 18.045 MHz. Of the 800 carriers, 6 were reserved for control channels.

Of the 397 full duplex channels available, only 320 could be used simultaneously. Voice signals were digitized into 7 bit PCM at a sampling rate of 8 KHz and then encoded on a 64 Kbps QPSK analog carrier.

Each channel had a 45 KHz bandwidth, 38 KHz for the voice signal and 7 KHz for a guard band. To minimize the power demand on the satellite the analog carrier was voice actuated.

The common signaling channel [CSC] carried a repetitive 50 slot TDM frame. The first slot was reserved, for synchronization and the remaining 49 slots assigned for ground station use.

To establish a connection, a station uses its CSC to broadcast a destination address and a suggested free voice channel. The receiving station uses its CSC time slot to respond.

[†] Single channel per carrier, Pulse code modulation, multiple Access, Demand assignment Equipment

Notes

10.3.3 TDMA

Each ground station is assigned its own time slot. Certain signals such as voice and video, must be carried with no timing variation. This restriction however, does not generally apply to data transmissions. As demand increases, more time slots can be added, thus gradually slowing down the overall response time. This creates a soft limit to the maximum number of customers that can be handled. If the customer is made aware of the delay, they can make the decision to either wait in the queue or to try again at some other time.

In order to maintain synchronization, a master clock, and ranging compensation is necessary. Synchronization methods can be categorized as either closed loop or open loop.

Open-loop synchronization requires that the ground stations use predicted orbital parameters to calculate the transmission delay unique to each user and then align their data transmissions accordingly.

Closed-loop synchronization requires that each ground station calculate the satellite range by making a round trip transmission delay measurement by sending a BCW[†]. This is then aligned with the frame burst sent by the reference station.

The frame period is usually a multiple of 125 µs, and in the INTELSAT system is 750 µs. In order to transmit at digital carrier rates, the data is time compressed and sent in high speed bursts of up to 60 Mbps.

10.3.4 CDMA

This method is sometimes referred to as SSMA[†]. Individual radio carriers can be spread out over the entire satellite bandwidth. This would normally prevent any other station from using the facility, but there are ways of minimizing this conflict:

- DS–CSMA: direct sequence CSMA - the station address is superimposed on the carrier along with customer data.
- FH–CSMA: frequency-hopping CSMA - the station address is used to continually change the carrier frequency.

These systems are very popular with the military since the wide bandwidth used makes the signals hard to jam. A principle advantage for commercial applications is the soft limiting. As more customers are added to the system, the signal to noise ratio begins to drop, thus customers can decide whether to accept the degradation or try later.

10.3.4.1 Frequency Re-Use

Two basic methods are used to increase satellite frequency utilization:

- Beam polarization

† Burst Code Word

† Spread Spectrum Multiple Access

- Multiple beams

Two beams of the same frequency can be distinguished from each other if their electric fields are orthogonal. This method is often used on terrestrial digital microwave links where the fields can be horizontally and vertically polarized. Both spacecraft and earth stations require about 30 dB of isolation between the two polarizations.

An alternative arrangement is to use circularly polarized fields. These can be oriented to the right or left. These methods are effective below 10 GHz, but in the 10 – 30 GHz region, non-spherical water droplets tend to affect the polarization, and this method is not appropriate.

To minimize coupling between transponders using two polarizations, the frequency slots are interleaved so that the center of one transponder is located in the guard band of the other.

Another way to increase frequency utilization is by means of spot beams. These can be created in three ways:

- Multiple antennas
- Common reflector and multiple feed
- Phase shift array

Anyone of these techniques allows frequencies to be reused in other beams. Consideration must be give to the amount of spillover from one spot to another. To increase the isolation between similar carriers on different beams, polarization may be used.

Multiple beams not only make better use of the spectrum, but it also allows satellites to perform switching function from one beam to another.

10.4 Geostationary Orbit

A satellite which orbits around the earth at the same rate that the earth turns is known as a synchronous orbit. Synchronous orbits can be of any inclination. If they are polar orbiting, the satellite will appear to be over the same spot at the same time every day.

Remote sensing satellites can be place in orbits that are synchronous with the earth's rotation over a longer period than a day, and thus will be able to view the entire ground surface over a number of orbits.

If a geosynchronous orbit is placed over the equator, something very interesting happens. The satellite will appear to stop moving in the sky. This is referred to as a geostationary orbit.

The gravitational acceleration of an object as a function of altitude is:

$$a_c = \left(\frac{r_e}{r_s}\right)^2 g$$

where r_e = equatorial radius of the earth

= 6378.388 Km

r_s = radius of satellite position

g = earth's gravitational acceleration constant

= 9.80665 m/Sec^2

The centrifugal acceleration on a satellite is given by:

$$a_c = r_s \omega^2 = r_s \left(\frac{2\pi}{T_s}\right)^2$$

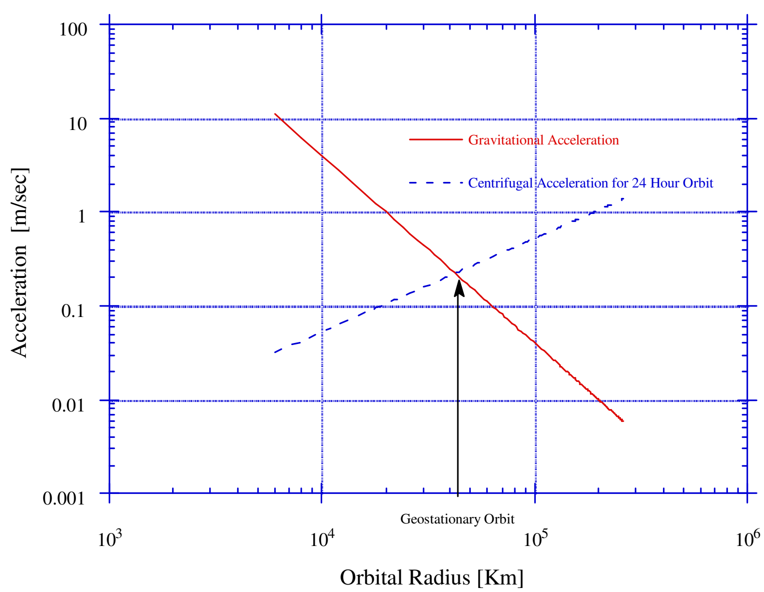
where ω = angular velocity in radians/sec

T_s = time for 1 orbit

= 86400 seconds (24 hrs) for geostationary orbit

For a stable orbit, the two forces associated with these accelerations must be equal:

$$\left(\frac{r_e}{r_s}\right)^2 g = r_s \left(\frac{2\pi}{T_s}\right)^2$$



Solving for r_S we obtain:

$$r_e^2 g = r_s^3 \left(\frac{2\pi}{T_s}\right)^2 \quad \Rightarrow \quad r_s^3 = \left(\frac{r_e T_s}{2\pi}\right)^2 g$$

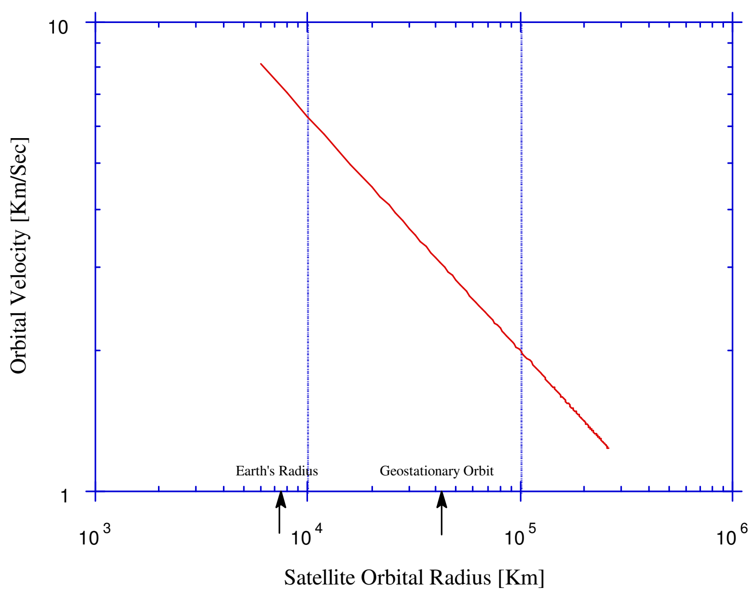
$$r_s = \sqrt[3]{\left(\frac{r_e T_s}{2\pi}\right)^2 g} = \sqrt[3]{\left(\frac{6378\ Km \times 86400\ \sec}{2\pi}\right)^2 9.8\ m/\sec^2}$$
$$= 42,254.22\ Km$$

Therefor the height above the earth is 42,254 Km - 6378 Km = 35,876 Km or 22,292 miles.

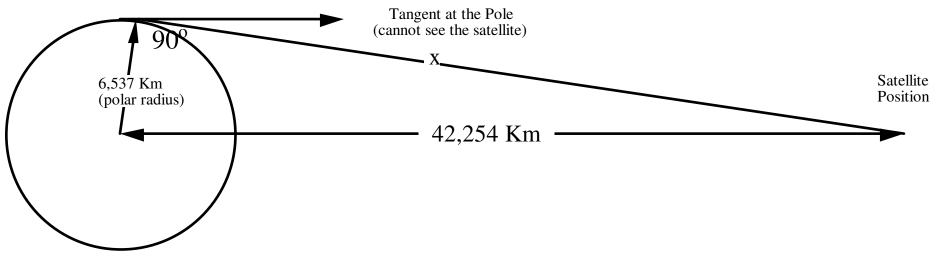
The velocity of a satellite in a circular orbit is given by:

$$v = r_e \sqrt{\frac{g}{r_s}}$$

This works out to 3.073 Km/Sec for a satellite in a geostationary orbit.



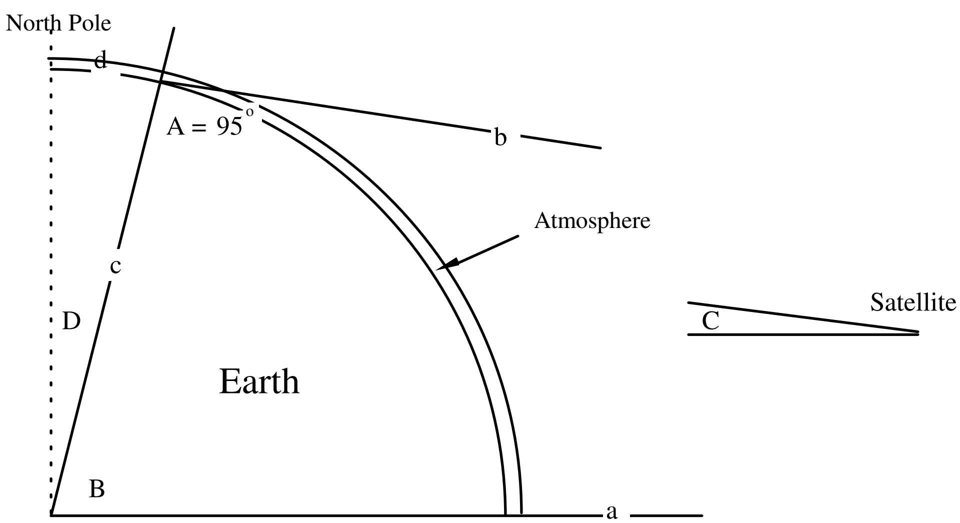
PATH LENGTH



The transmission path length can be found by applying Pythagorean Theorem:

$$x^2 + (6,357)^2 = (42,254)^2$$
$$x = 41,773\ Km$$

In actual practice, the angle of elevation must be at least 5 degrees above the horizon. Therefor the actual geometry is closer to:



By applying the law of sines, a better approximation of the maximum path length can be determined, as well as the minimum distance from the pole required to see the satellite.

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C} \quad \Rightarrow \quad \sin C = \frac{c}{a} \sin A$$

$$\sin C = \frac{6,357}{42,254} \sin 95^o = .14987$$

$$C = \sin^{-1} .14987 = 8.62^o$$

$$B = 180^o - 95^o - 8.62^o = 76.38^o$$

$$D = 90^o - 76.38^o = 13.62^o$$

Using the polar radius to calculate the total arc length of the earth, with the polar curvature, we obtain an effective polar circumference of:

$$2\pi \times 6{,}357\ Km = 39{,}942\ Km$$

Which means that the minimum distance *d* from the pole, at which the satellite can be seen is:

$$39{,}942\ Km \times \frac{13.62^o}{360^o} = 1511\ Km$$

It is evident from the sketch, that the further north one goes, the greater the signal path length through the atmosphere.

10.5 Molniya Orbit

The former USSR is not able to make great use of geostationary satellites, because of the northern latitude of the country. Consequently, communications satellites have required a slightly different approach. The term molniya means "flash of lightning".

orbital inclination	63.4°
orbital period	719.19 minutes
perigee	1000 Km
apogee	39,375 Km

The size of the ellipse was chosen to make the orbital period equal to half a sidereal day, and therefore in synchronism with the earth. Because the earth is an oblate spheroid, most elliptical orbits of this type would slowly precess around the earth. However, this apsidal rotation does occur if the orbit is inclined 63.4°.

The satellite remains visible in the sky for about 11 of the 12 hours of its orbit. Three satellites are usually placed in the same orbit in order to provide continuous coverage. The earth stations are more complex than those for geostationary satellites, since they must track the satellite. There are 8 orbital planes separated by 45°.

Fixed ground stations use 12 m antennas and transportable stations use with 7 m antennas. Molniya-1 satellites are used for government and military communications whereas Molniya-3 satellites are used for TV programs.

The second stratum of the Russian space-based communications consists of 16 Molniya-class spacecraft in highly elliptical, inclined (63 degrees) semi-synchronous orbits. With initial perigees between 450 and 600 km and apogees near 40,000 km.

The first Molniya satellite was launched in 1964 and to date more than 150 have been deployed. They weigh approximately 1.6 metric tons at launch and stand 4.4 m tall with a base diameter of 1.4 m. Power is provided by six windmill-type solar panels producing up to 1 kW. A liquid propellant attitude control and orbital correction system maintains spacecraft stability. Sun and Earth sensors are used to determine spacecraft attitude and antenna pointing.

The 16 operational Molniya satellites are divided into two types and four groups.

Eight Molniya 1 satellites are divided into two constellations of four vehicles each. Both constellations consist of four orbital planes spaced 90 degrees apart, but the ascending node of one constellation is shifted 90 degrees from the other, i.e., the Eastern Hemisphere ascending nodes are approximately 65 degrees and 155 degrees E, respectively. Although the system supports the Russian Orbita Television network, a principal function is to service government and military communications traffic via a single 40 W. 1.0/0.8 GHz transponder.

The first Molniya 3 spacecraft appeared in 1974, primarily to support civil communications. It has a slightly enhanced electrical power system and a communications payload of three 6/4 GHz transponders with power outputs of 40 W or 80 W. Until 1983 the Molniya 3 constellation consisted of only four satellites which were essentially co-located with four Molniya 1 satellites.

When the Molniya 3 system was expanded to eight vehicles in 1983-1985, the new additions inaugurated the 155 degrees E ascending node geometry. After the restructuring of the Molniya 1 constellations in 1991, the Molniya 1 and Molniya 3 systems are essentially the same from a deployment perspective and to some extent provide an inherent backup capability.

On the average, Molniya 3 spacecraft are replaced slightly less frequently than their Molniya 1 cousins, representing an apparent longer operational life by 5-6 months. Two Molniya 3 spacecraft were launched in 1993, Molniya 3-44 and Molniya 3-45, to replace Molniya's 3-41 and 3-37, respectively. Like the Molniya 1 constellation, the Molniya 3 network received only one new number in 1994: Molniya 3-46 to replace Molniya 3-40. Thus, at the end of 1994 the Molniya 3 constellation consisted of these three new spacecraft as well as five older spacecraft (Molniya's 3-36, 3-38, 3-39, 3-42, and 3-43). The oldest spacecraft was five years old.

In 1990 the Applied Mechanics NPO announced that it was developing a successor to the Molniya series of spacecraft. The latest design for the Mayak spacecraft closely resembles the Arcos GEO spacecraft, with which it will form the Marathon communications system. The total on-orbit mass will be 2,500-3,000 kg which includes a payload mass of 580 kg. Mayak will support both L-band and C-band communications and will be compatible with INMARSAT standards. Four spacecraft will comprise the Mayak system and the design lifetime for each vehicle will be twice that of Molniya: 5-7 years. The first launch of a Mayak spacecraft by the new Rus launch vehicle will not come until 1997 or later, five years after the original schedule

SUN SYNCHRONOUS ORBIT

If the node precession rate is one revolution per year then the satellite precesses around the Earth at the same rate as the Earth rotates around the sun. The solar illumination of the part of the Earth seen by the satellite is then constant. Many satellites which make use of solar radiation for imaging use such orbits which are called sun-synchronous.

The sun-synchronous orbit provides a constant node-to-sun angle, and the satellite passage over a certain area occurs at the same time of the day.

9.6 Link Equations

Recall that isotropic antenna radiation density is given by:

$$P_i = \frac{P_t}{4\pi r^2} \qquad \frac{watts}{meter}$$

Antenna gain [receiving or transmitting] can be defined as:

$$G = \frac{\text{maximum radiation intensity}}{\text{isotropic radiation intensity}}$$

The power received at some distance is therefor:

$$P_d = \frac{P_t G_t}{4\pi r^2} \qquad \frac{watts}{meter^2}$$

The receiving antenna will intercept energy in direct proportion to its aperture, which is given by:

$$A_r = \frac{\eta \lambda^2 G_r}{4\pi} \qquad meters^2$$

where $\eta =$ antenna efficency

The received power is then:

$$P_r = \frac{\eta P_t G_t G_r \lambda^2}{(4\pi r)^2} \quad watts$$

$$P_{r\,dB} = 10 \log P_t G_t - 20 \log \frac{4\pi r}{\lambda} + 10 \log \eta G_r$$

The middle term is the path loss due to signal spreading, and is often written as:

$$L = 32.5 + 20 \log d + 20 \log f$$

where d is in Km and f is in MHz

Additional losses occur because of absorption and scattering. Since these are proportional to the atmospheric path length, they are inversely proportional to the angle of elevation. Atmospheric noise also tends to increase with frequency. Two particularly lossy frequencies are 22 GHz, which is the resonant frequency of water molecules, and 60 GHz, which is the resonant frequency of oxygen molecules.

It should be self evident that a satellite looking at the earth will see a far larger source of noise, than the ground station looking up at the satellite. The ground station will detect galactic noise, which decreases with frequency.

To increase the usefulness of the link equation, additional terms are usually defined:

Noise density: the amount of thermal noise present in a normalized 1 Hz bandwidth

$$N_o = kT_e$$

where k = Boltzmann's constant

= -198.6 dBm/^oK

T_e = equipment noise temperature in ^oK

carrier to noise density ratio:

$$\frac{C}{N} = \frac{C}{kTB} \qquad \text{dB}$$

$$\frac{C}{N_o} = \frac{C}{kT_e} \qquad \text{dB Hz}$$

$$\frac{C}{T} = \frac{C}{N_o} + 10\log k \qquad \text{dBW/}^o\text{K}$$

where C = average carrier wideband power

gain to equivalent noise temperature ratio: a figure of merit used to specify the efficiency of a satellite and earth station

$$M = \frac{G}{T_e} \quad \frac{dB}{^oK}$$

ratio of energy per bit to noise density: allows for the comparison of different systems irrespective of such factors as: transmission rate, modulation type, and encoding system.

$$\frac{E_b}{N_o} = \frac{CT_b}{kT_e} = \frac{CT_b}{N_o}$$

where $T_b = \frac{1}{\text{bit rate}}$

The uplink carrier to noise ratio is therefor given by:

$$\frac{C_u}{N_{ou}} = \frac{P_{ru}}{kT_e} = \frac{\eta P_t G_t G_r \lambda^2}{(4\pi r)^2 kT_e} \qquad or \qquad \underbrace{\left(\frac{\eta P_t G_t}{4\pi r^2}\right)}_{\text{flux density}} \frac{\lambda G_r}{4\pi kT_e}$$

or in terms of dBs:

$$\left(\frac{C_u}{N_{ou}}\right)_{dB} = 10\log P_t G_t - 20\log\frac{4\pi r_u}{\lambda_u} + 20\log\frac{G_{ru}}{T_e} - 10\log k + 10\log\eta$$

Since the antenna efficiency $\eta < 1$, this represents a loss. Additional losses occur because of cables, connectors and so on. If these are all lumped together, we obtain:

$$\left(\frac{C_u}{N_{ou}}\right)_{dB} = \underbrace{10\log P_t G_t}_{\text{earth station EIRP}} - \underbrace{20\log\frac{4\pi r_u}{\lambda_u}}_{\text{free space uplink loss}} + \underbrace{20\log\frac{G_{ru}}{T_e}}_{\text{satellite figure of merit}} + \underbrace{10\log L_u}_{\text{additional uplink losses}} - \underbrace{10\log k}_{\text{a physical constant}}$$

For the downlink, the equation is much the same:

$$\left(\frac{C_d}{N_{od}}\right)_{\text{dB}} = \underbrace{10\log P_t G_t}_{\text{satellite EIRP}} - \underbrace{20\log\frac{4\pi r_d}{\lambda_d}}_{\text{free space downlink loss}} + \underbrace{20\log\frac{G_{rd}}{T_e}}_{\text{ground station figure of merit}} + \underbrace{10\log L_d}_{\text{additional downlink losses}} - \underbrace{10\log k}_{\text{a physical constant}}$$

The noise in the uplink path will contribute to the noise in the downlink path.

There are additional noise sources which are a function of the technology used to construct the communications system. Intermodulation noise for example, is caused by non-linear amplification. It is very difficult to model this noise source, and as a result, it is simply measured. For satellites utilizing TWTs [traveling wave tubes], intermodulation noise levels are typically 2000 to 2500 pW0p.

TYPICAL C-BAND SATELLITE CHARACTERISTICS[6]

		Type of Coverage	
Parameter	**Global**	**Regional**	**National**
Tx Antenna Gain [dBi]	17 - 19	21 - 25	28 - 32
Rx Antenna Gain [dBi]	17 - 19	21 - 24	30 - 34
EIRP [dB]	22 - 24	26 - 31	30 - 34
Rx Noise Temp [^{o}K]	8000 - 2000	800 - 2000	800 - 2000
G/T [dB/^{o}K]	-17 to -14	-12 to -5	-3 to +5

6 Electronic Communications Handbook, A. F. Inglis, ed.

TYPICAL C-BAND EARTH STATION CHARACTERISTICS

	Type of Coverage		
Parameter	**Global**	**Regional**	**National**
Antenna Size [m]	4.5 - 32	4.5 - 25	3 - 30
Tx Antenna Gain [dBi]	47 - 64	47 - 62	43 - 63
Rx Antenna Gain [dBi]	43 - 61	43 - 59	40 - 60
EIRP [dBW]	46 - 95	46 - 74	45 - 84
Rx Noise Temp [^oK]	50 - 150	50 - 150	50 - 200
G/T [dB/^oK]	23 to 41	23 to 38	17 to 41
Tx Power [kW]	1 - 12	0.3 - 3	0.005 - 1

10.6.1 Ku Band

The high power and high frequency characteristics of Ku band satellite systems, allows for the deployment of very small antennas. Some of the typical characteristics of these systems are:

- Spacecraft EIRP 35 - 50 dBW
- Spacecraft G/T - 3 to +9 dB/^oK
- Earth Station G/T 14 to 45 dB/^oK
- Transponder Bandwidth 36 - 72 MHz

CANADIAN COMMUNICATIONS SATELLITES

The Anik series of satellites are owned and operated by Telesat Canada.

COMPARISON OF ANIK SERIES SPACECRAFT[7]

	Anik A	**Anik B**	**Anik C**	**Anik D**
Contractor	Hughes	RCA	Hughes	Spar
Number	4	1	2	1
Design Life [yrs]	7	7	10	10
Mass [kg]	272	440	567	653
Solar Power [W]	260	650	800	830
Stabilization	spin	3 axis	spin	spin
# Channels	12	12 & 6	18	24
Channel Bandwidth [MHz]	36	36 & 72	54	36
Up/Down Freq Band [GHz]	6/4	6/4 &14/12	14/12	6/4
Transmission Band	C	C & Ku	Ku	C
Satellite EIRP [dBW]	33	36 & 47	47	36
Receive G/T [dB/K]	-7	-6 and -1	+2	-3

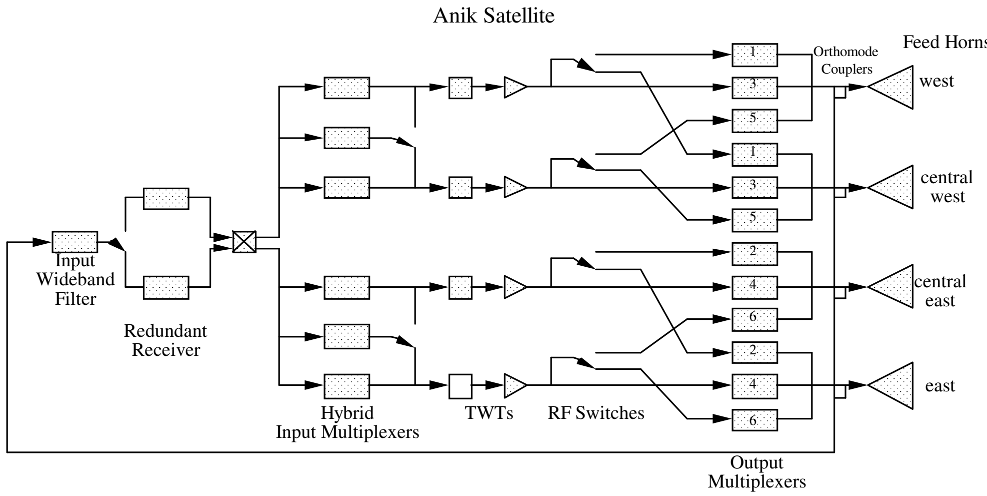
10.6.2 Anik-B

The Canadian Anik-B satellite is in geostationary orbit. It has 6 channels, each of which is 72 MHz wide. There is an 8 MHz guard band between each channel.

7 *A Technical Description*, Telesat Canada, 1983

The uplink frequency band is approximately 14 - 14.5 GHz and are vertically polarized [north - south orientation]. The down link band is 11.7 to 12.2 GHz and the carriers are horizontally polarized [east - west orientation].

The satellite utilizes four antennas, each of which is used for both reception and transmission. The combined reception pattern covers almost the entire country, but the transmission pattern consists of four spot beams.



The uplink signal from all antennas are coupled from the horn antennas to the receiver section by orthomode couplers. These respond only to the vertically polarized signal. The received signal is then amplified and down converted to the downlink frequency band.

On retransmission, the odd channels can be switched by the master ground station to either the west or central west antennas. Likewise, the even channels can be switched between the east and central east antennas.

All telephone traffic on the Anik satellite is passed through transponder four and routed to the Ottawa ground station. Consequently, all telephone calls take two hops through the satellite to reach their destination.

10.7 Satellite Launch Vehicles

The majority of communications satellites are put into orbit by means of large rockets or the American Space Shuttle. At the moment there is no alternative for the high orbiting satellites. However, recently a Brazilian communications satellite was placed in orbit by means of a Pegasus rocket fired from a B52 bomber flying at an altitude of 8 miles. The relatively small payload of 330 lb. was placed in a low earth orbit of 320 miles. The cost of 14.5M$US is about one third to one quarter of the cost of a conventional launch.

•There are several different launch vehicles:

Boeing Delta-5

http://www.boeing.com/defense-space/space/delta/deltahome.htm

[Lockheed Martin Atlas rocket]

[http://www.lmco.com/]

[Sea Launch]

[http://www.sea-launch.com/]

[Pegasus air-launched vehicle]

[http://www.orbital.com/]

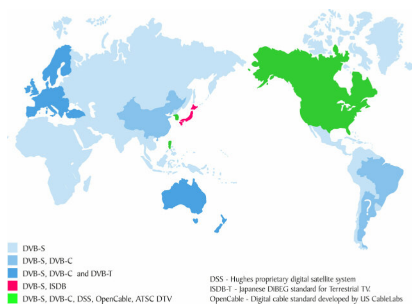
[Russian Khrunichev Proton rocket]

[European Ariane rocket]

[http://www.arianespace.com/]

China's Great Wall Long March 2C

10.8 DVB



DVB-S

DVB-S is the DVB standard for digital satellite broadcasting. It is designed to cope with the full range of satellite transponder bandwidths.

DVB-S is a single-carrier system. The video, audio, and other data is inserted into fixed-length MPEG Transport Stream packets.

There are a number of processing stages:

- The data are formed into a regular structure by inverting synchronization bytes, every eighth packet header.
- The contents are randomised.
- A Reed-Solomon Forward Error-Correction (FEC) overhead is then added to the packet data. This is a very efficient system which adds only around 8% overhead to the signal. It is called the Outer Code. There is a common Outer Code for all the DVB delivery systems.
- Next, Convolutional Interleaving is applied to the packet contents.
- Following this, a further error-correction system is added, using a punctured Convolutional Code. This second error-correction system, the Inner Code, can be adjusted, in the amount of overhead, to suit the needs of the service provider.
- Finally, the signal is used to modulate the satellite broadcast carrier using quadrature phase-shift keying (QPSK).

In essence, between the multiplexing and the physical transmission, the system is tailored to the specific channel properties. The system is arranged to adapt to the error characteristics of the channel. Burst errors are randomized, and two layers of forward error correction are added. The second level, or Inner Code, can be adjusted to suit the circumstances (power, dish size, bit rate available).

There are thus two variables for the service provider: the total size of the 'onion' and the thickness of the second error-correction outer 'skin'. In each case, in the home, the receiver will discover the right combination to use by very rapid trial and error on the received signal. An appropriate combination of payload size and Inner Code can be chosen to suit the service operator's environment.

One example of a parameter set would be for a 36 MHz (-1 dB) transponder to use a 3/4 Convolutional Code, in which case a useful bit rate of about 39 Mbps will be available as the payload.

The 39 Mbps (or other bit rates allowed by parameter sets for a given satellite transponder) can be used to carry any combination of MPEG-2 video and audio. Thus, service providers are free to deliver anything from multiple-channel SDTV, 16:9 Widescreen EDTV or single-channel HDTV, to Multimedia Data Broadcast Network services and Internet over the air.

DVB-C

DVB-C digital cable services are on the air or planned in the USA, Scandinavia, France, Germany, Brazil, Italy, Spain, Argentina, Australia, and the UK.

The DVB-C cable system is based on DVB-S, but the modulation scheme is used is Quadrature Amplitude Modulation (QAM) instead of QPSK

For cable networks, no inner-code forward error-correction (FEC) is needed. The system is centred on 64-QAM, but lower-level systems, such as 16-QAM and 32-QAM, and higher level systems such as 128-QAM and 256-QAM can also be used. In each case, the data capacity of the system is traded against robustness of the data.

In terms of capacity, an 8 MHz channel can accommodate a payload capacity of 38.5 Mbit/s if 64-QAM is used, without spill-over into adjacent channels.

Higher-level systems, such as 128-QAM and 256-QAM are also possible, but their use depends on the capacity of the cable network to cope with the reduced decoding margin.

DVB-T

DVB-T will be the Digital Terrestrial Television Broadcasting (DTTB) standard in at least 17 countries, including the 15 members of the European Union, Australia and New Zealand.

A transmission scheme based on Coded Orthogonal Frequency Division Multiplexing (COFDM), allows for the use of either 1705 carriers (usually known as '2k'), or 6817 carriers ('8k').

Concatenated error correcting is used. The '2k' mode is suitable for single transmitter operation and for relatively small single frequency networks with limited transmitter power. The '8k' mode can be used both for single transmitter operation and for large area single frequency networks. The guard interval is selectable. The '8k' system is compatible with the '2k' system.

Reed-Solomon outer coding and outer convolutional interleaving are used, in common with the other DVB standards.

The inner coding (punctured Convolutional Code) is the same as that used for DVB-S.

The data carriers in the COFDM frame can use QPSK and different levels of QAM modulation and code rates, in order to trade bit rate against ruggedness

Two-level hierarchical channel coding and modulation can be used, but hierarchical source coding is not used, since its benefits do not justify the extra receiver complexity involved.

The modulation system combines OFDM (Orthogonal Frequency Division Multiplexing) with QPSK/QAM. OFDM uses a large number of carriers which spread the information content of the signal. Used very successfully in DAB (Digital Audio Broadcasting), OFDM's major advantage is that it thrives in a very strong multipath environment.

All this does not come without a price. The multipath immunity is obtained through the use of a 'guard interval', which is a proportion of the digital signal given away for echo resistance. This guard interval reduces the transmission capacity of OFDM systems. However, the greater the number of OFDM carriers provided, for a given maximum echo time delay, the less transmission capacity is lost. But a trade-off is involved. Increasing the number of carriers is not all benefit. It has a negative impact on receiver complexity and on phase-noise sensitivity.

DVB-T development work was based on a set of user requirements produced by the Commercial Module of the DVB Project. DVB members contributed to the technical development of DVB-T through the DTTV-SA (Digital Terrestrial Television – Systems Aspects) working group of the Technical Module. The European Projects SPECTRE, STERNE, HD-DIVINE, HDTVT, dTTb, and several other organisations, developed system hardware and produced results which were fed back to DTTV-SA.

Because of the multipath immunity of OFDM, it is potentially possible to operate an overlapping network of transmitting stations with a single frequency. In the areas of overlap, the weaker of the two received signals is like an echo signal. However, if the two transmitters are far apart, the time delay between the two signals will be large and the system will therefore need a large guard interval.

There are three potentially different operating environments for digital terrestrial television in Europe: broadcasting in a currently unused channel such as an adjacent channel or a clear channel, broadcasting in a small-area Single-Frequency Network (SFN), and broadcasting in a large area SFN. One of the main problems for the DVB-T developers to solve was how to optimise the system to cope with the variety of operating environments. This they have successfully done, with the result that DVB-T is the ascendant global solution to digital terrestrial broadcasting.

DSS is the proprietary digital satellite standard developed by Hughes, which is used by DirecTV in the United States. In Japan, DirecTV uses DVB-S.

ISDB-T is the Japanese Digital Broadcasting Experts Group (DiBEG's) variant of the DVB-T system. It differs in one key respect only, the use of an intermediate (software driven) data segmentation system, whereby services such as radio, SDTV, HDTV and Mobile TV can be flexibly allocated pieces of the overall service bandwidth. The ISDB-T system is anticipated to launch in Japan no earlier than 2003.

CableLabs, also known as "OpenCable" is a return channel enabled variant of the 256-QAM digital cable system developed in the US by the CableLabs" project.

ATSC, also known as "DTV" is the US-developed (by the so-called Grand Alliance) Digital Terrestrial Broadcasting System.

Although both the ATSC "DTV" and the DVB-T systems use MPEG-2, they are different in the following respects:

- RF Modulation: ATSC uses the single carrier 8-VSB modulation technology where DVB-T uses the multiple-carrier COFDM system. MobileTV using the 8-VSB system is impossible, and set-top antenna reception highly problematic. DVB-T is not only capable of both applications, but does HDTV just as well as the US standard does.
- Audio: The surround-sound audio system used by ATSC is the proprietary Dolby AC3 system, which offers no performance advantages over the DVB MPEG Layer II Audio system, which has the advantage of being an open standard.
- Service Information: The ATSC system also makes use of a unique Service Information system, making interoperability between ATSC and DVB-T as unfeasible as interoperability between ATSC and US cable and satellite standards.

There is no interoperability between the CableLabs and ATSC and DSS standards, i.e. MPEG-2 streams must be decoded and recoded for jumps from one of these systems into another. This is another key advantage of the Interoperability which is featured as standard on all DVB systems for any delivery medium.

MPEG2/DVB satellite channel list - USA

Few people know that there are probably more DTH DVB-S viewers in the United States than there are in Europe. Here is a list of services as at 5th February 1998.

Intelsat K 21.5w - Brightstar, Reuters

Hispasat 30w - TVE America, Euronews, Hispavision, 24 Horas, TVE

Orion-1 37.5w - ONN, ART America, RAI International, TV Polonia

TDRS-4 41w - MTA International

PAS-3 C-band 43w - Bloomberg, TV5

TDRS-5 47w - CPT Serbia (PAL)

PAS-5 C-band 58w - APTV, CBS Spanish, CBS Portugal, Locomotion (PAL), Locomotion, CCTV 3, 4 and 9, The Weather Channel S. America

Galaxy 6 - Religious TV (NTSC/PAL)

GE-2 C-band - Worldnet

GE-3 C-band - APTV

Galaxy 7 C-band - Golf channel feeds, fX west, fX east, fX movies

Telstar 5 Ku-band - ATN, Religious / Health South, Bloomberg, Re/Max, Health South, Japan 1241, Arab, Nile TV, Chinese TV

Galaxy 4 Ku-band - TFC, ABS (SNN), Taiwan (China)

GE-1 Ku-band - Empire Sports, WRAL

Anik E2 C-band - Meteomedia, Tele-Quebec, Newsworld International, CBC, The Weather Network

Anik E1 C-band - TVNC

Galaxy 9 - VH-1 feed

Satcom C3 - E! TV, Family Channel, FIT TV

Successful 4:2:2 trial brings NDS Americas Bell Canada and Nagano Olympics business.

Los Angeles, February 1998 - NDS Americas, the conditional access and digital technology arm of News Corp., completed the first successful encoding and transmission of 4:2:2 digital signals via a satellite and a DS3 telecom link.

Because DS3 has never been tested for use with multiple MPEG-2 4:2:2 format digital video feeds in conjunction with satellite, the trial marks an industry milestone and establishes existing DS3 infrastructures as a viable transmission alternative for digital video feeds down-linked via satellite, the company said.

The technology will allow for a clearer picture of fast action sequences such as those delivered in sports, programming that has traditionally challenged digital broadcasters with ghosting in the video. The encoding systems offers broadcasters the ability to compress, decompress and re-compress an original digital source feed without experiencing picture degradation.

As a result of the trial, Bell Canada purchased NDS 4:2:2 encoders to expand digital programming throughout Canada and to broadcast the 1998 Winter Olympics from Nagano, Japan.

http://www.ndsworld.com

Assignment Questions

Quick Quiz

1. VSAT networks use satellites placed in [geostationary, polar] orbits.
2. MEOS systems use highly elliptical orbits. [True, False]
3. Although SPADE is an FDMA system, it uses TDM CSC signaling. [True, False]
4. LEOS satellites travel [faster, slower] than MEOS satellites.
5. The ratio G/T is unitless. [True, False]
6. When the global positioning system is completed, approximately ___________ satellites will be visible at any given time.

Analytical Problems

1. A satellite system has the following characteristics:

   Uplink frequency = 2.5 GHz
   Downlink frequency = 2.4 GHz
   Satellite transmitter power = 15 watts
   Ground station transmitter power = 150 watts
   Satellite antenna gain = 9 dB
   Ground station antenna gain = 25 dB
   Distance = 36,000 km

   Determine:

   a. Path loss
   b. The satellite received signal power level
   c. The ground station received signal power level

Composition Questions

1. What is the furthest north that a geo-stationary satellite ground station can be placed?
2. Define EIRP.
3.
4. List three applications for PCSS systems.
5. What are the two basic methods of code division multiple access?

For Further Research

Gagliardi, Robert M; *Satellite Communications*, Lifetime Learning Publications, Belmont, California, 1984

Prichard & Sauulli; *Satellite Communications Systems Engineering*

MSAT Phase B Final Report; Dept. of Communications Gov't of Canada, Cat. No. Co22-77/1987E

Special Series on VSAT; IEEE Communications Magazine, July, September 1988

Series on Satellite Communications; MSN & CT November 1986

"Satellite Communications", Electronics & Wireless World December 1985

"Communications Satellites move to Higher Frequencies", High Technology November 1984

Special Series on Satellite Communications, IEEE Communications Magazine May 1984

"Air and Sea Rescue via Satellite Systems", IEEE Spectrum March 1984

web-sites:

Satellite Industry Association

http://www.sia.org/index.htm

http://www.spacecom.com/

http://coolstf.com/mpeg/

http://www.ee.surrey.ac.uk/Personal/L.Wood/constellations/overview.html

http://www.skyreport.com/index.htm

http://www.comsat.com/

http://itre.uncecs.edu/misc/sj/sj.html

http://www.funet.fi/index/esi/skyguide.html

http://www.funet.fi/index/esi/satnews.html

http://www.funet.fi/index/esi/TELE-Satellite.html

http://www.tele-satellit.com/tse/

http://www.satellitetelephone.com/

http://www.satnews.com/

http://www.fas.org/spp/index.html

http://members.aol.com/wsnspace/

http://www.nasa.gov/hqpao/space_agencies.html

http://www.yahoo.com/Government/Research_Labs/NASA/

http://www.teletechnics.com/reference/telecom/leo/index.htm

http://www.telesat.ca/

http://www.eutelsat.com/

http://www.ge.com/capital/americom/

Magazines

http://www.inmarsat.org/magazine/index2.html

http://www.telecomclick.com/magazine.asp?magazineid=5

http://www.satnews.com/

GPS

http://www-geology.ucdavis.edu/~GEL214/Lecture_Notes/LN_Mar07.html

http://tycho.usno.navy.mil/gps.html

ICO:

www.i-co.co.uk/

http://www.nec.com.au/ico1.htm

Globalstar:

http://www.globalstar.com/

www.wp.com/mcintosh_page_o_stuff/globals.html

Iridium:

www.iridium.com

Teledesic:

www.teledesic.com

Canadian Satellites

http://www.cancom.net/

http://www.telesat.ca/

US Satellites

http://www.ussbtv.com

European Satellites

http://www.funet.fi/index/esi/

DVB

http://dvb.org

DBS

http://www.primestar.com/

http://www.lookup.com/Homepages/95191/cvn.html

http://www.dbs-online.com/

http://www.directv.com/

http://www.echostar.com

http://www.expressvu.com

http://www.dbsdish.com/

http://www.sbca.com/

Astasat

http://www.astrasat.co.za/index.htm

Hughes

http://www.hcisat.com/

Space Innovations Ltd.

http://www.sil.com/

http://www.sat-net.com/uk-satellite/

http://www.orbitsat.com/

http://dbcp.nos.noaa.gov/dbcp/1smms.html

______ Notes ______

http://www.vii.org/afdbs.htm

View from Satellite

http://www.vii.org/afdbs.htm

http://www.ifs.univie.ac.at/~jstb/home.html

http://www.satellite-dvb-mpeg-satellite-broadcast-audio.com/