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For Further Research

11.0 Exotic Systems

Objectives

This section will:

- Examine applications of troposcatter systems
- Discuss meteor burst systems
- Consider submarine communications systems
- Examine space shuttle communications
- Review deep space communications

11.1 Troposcatter Communications Systems

http://www.uksmg.org/tropo.htm

Troposcatter systems bounce UHF/SHF radio waves off of the troposphere. The troposphere is the lower 11 km of the atmosphere. Single hop links can cover up to 640 km. To increase this distance, several of them can be operated in tandem.

Most systems transmit with an output power of 1 - 10 kW, and use parabolic antennas ranging from 4.5 m to 18 m in diameter. Some of the advantages of this type of system include:

- Reduced number of links when compared with standard LOS† systems
- Reliable multichannel links over inaccessible terrain or isolated areas
- Links which must bypass national boundaries
- Reasonably secure tactical military applications

11.1.1 Central Graben Project

This system links the UK with nearly 20 oil platforms in the North Sea by means of a tropospheric scatter link. It will provide ISDN service, and is the first system of its kind to be implemented anywhere in the world.

In the past, most communications needs were met by means of a fully duplicated HF radio system. These radio systems will probably continue to be used for international distress communications. With the modernization and automation of the platforms, the data needs have risen from a few kilobits for production monitoring and metering, to the megabit region for complete remote control supervision.

The data requirements identified to date include:

- Platform LAN: 64 Kbps
- Production control and monitoring: 6 x 64 Kbps

† Line Of Sight

- Telephone traffic: 5 x 64 Kbps
- Non-critical control, telex, meteorological data: 3 x 64 Kbps

To meet all contingencies in the immediate future, a nominal 2 Mbps link will be established. As ISDN capabilities grow, and computer systems become more widely used, it is expected that the system will have to expand to 8 Mbps.

Several solutions were considered:

- Fiber Optics: The initial solution called for deploying 12 fiber optic pairs, each with a capacity of 140 Mbps. This approach was abandoned when it ran into unspecified non-technical issues.
- Line-of-Site Radio: This was not capable of reaching all of the platforms
- Satellite: This system was rejected because of cost, dish integrity in the event of an explosion, the danger of the LNA igniting the gas and the fact that the service rig approaches the platform from the south, thus blocking the satellite link.

The net result was that a tropospheric link was deployed.

Some unique requirements for the system include:

- High reliability emergency power and battery backup
- Continued operation in spite of severe damage
- Continuous and safe operation in the presence of hazardous gases

In the past, all electronic systems capable of creating a spark, were shut down if explosive gases were present. This included the communications facilities. With recent events, this is no longer acceptable.

11.1.2 Military Systems

The US military has more than 400 fixed links in daily use. There is even a larger number of mobile tactical troposcatter links in use. The surveillance radar's of the TAC[†] System, which provide connectivity to the Perishing missile fire units, are connected to tactical air bases via troposcatter links. This tandem system links the US to Europe via the UK, Iceland, Greenland, and Canada.

Current tactical FDM/FM radios have 12 - 96 channels, while strategic radios have 60 -300 channels. These systems are not very secure, and are vulnerable to eavesdropping. Furthermore, multipath propagation causes signal fading.

Digital techniques in the region of 1 - 10 Mbps are being employed to improve the security of the transmission, but it is prone to inter symbol interference due to multipath propagation. To minimize this phenomenon, both the transmitters and receivers must measure the amount of multipath interference, and compensate accordingly.[1]

† Tactical Air Control

1 *Digital Troposcatter Communications Systems,* MSN Communications Technology, October 1988

The transmitter inserts an intersymbol guard time equal to the RMS value of the time dispersion, while the receiver attempts to match the frequency selective fading.

11.2 Meteor Burst Communications

http://www.borg.com/~warrend/metburdu.html

http://www.mbcee.com/

http://members.tripod.com/faza1/mbc2.htm

http://www.meteorcomm.com/

MBC or meteor burst communications[2] are very complex systems that require a good knowledge of atmospheric physics to understand.

It is estimated that 10^{10} particles totaling 1000 kg strike the atmosphere every day. Although these particles follow a Poisson or random arrival rate, there are daily and seasonal variations in meteor strikes. When meteors enter the atmosphere, they ionize the gasses and leave a trail of free electrons at an altitude of about 90 - 100 km (E layer) during the day. These trails act as reflectors or reradiators at UHF. The tracks are believed to range in length from a few kilometers to tens of kilometers, and have initial diameters of a few meters.

11.2.1 Underdense Trails

Radio waves are absorbed and reradiated from meteor trails if there is relatively little ionization. Signals received from underdense trails rise to their maximum value within a few hundred microseconds and decay exponentially. The decay times vary from milliseconds to seconds.

11.2.2 Overdense Trails

High-density trails are defined as having an electron density of $2x10^{14}$ electrons per meteor. Under these conditions, radio waves are reflected from the trail. The signals received from this type of trail do not seem to have a distinctive pattern as underdense trails. However, the received signal is stronger and the path lasts longer.

11.2.3 Receiving Area

The illuminated ground spot may extend 20 x 50 km, at a range in excess of 1500 km. It is interesting to note that the optimum sky pointing area is not at the midpoint of the great circle path between the transmitter and receiver. Although there is an illuminated spot at the center, there are larger ones displaced from 50 to 100 km on either side, due to the geometry of the meteor trail with respect to the sender. This means that the sending and receiving antennas normally have a wide beam width of about 30^0.

2 IEEE Communications, September 1990

MBC transmitters operate with output powers of about 100 W to 5 kW. The most common antenna used is a 5 to 8 element yagi for fixed frequency systems and horizontally polarized log periodic antennas for frequency ranges exceeding 5 MHz.

The optimum range for a MBC link is about 400 - 800 km, although it is possible to establish much longer links. If the launch angle is 5^o, the range is about 1200 km, and if the angle decreases to 1^o, the range increases to 200 km. These long links require that the antenna be mounted well above the ground or ground reflections will severely degrade the system.

Some causes of received signal degradation include:

- Sporadic E - interference caused by variations in the E layer that can last from minutes to hours
- Multipath fading and dispersion - multiple signals are radiated or reflected from the multiple trails created as a meteor breaks up
- D layer absorption - this occurs in the daytime, is affected by sunspot activity and is centered at about 40 MHz
- Faraday rotation - the earth's magnetic field and the D layer, cause the electric field in the radio wave to rotate. This daytime phenomenon causes polarization mismatch in the receiver.

During the day, the E layer acts as a reflector in the 2 - 7 MHz region and the F layer as a reflector in the 2 - 30 MHz region. Although MBC links can operate from 20 - 120 MHz, the ideal range is in the area of 40 - 50 MHz, since these frequencies are not reflected by the natural ionization occurring in either the E or F layers.

11.2.4 Data Formats

Since the individual ionization trails, and hence data paths are very short lived, the information is broadcast in a digital-burst format. Over a 24 hour period, an average of about 100 words per minute can be sent.

There are three operating modes used today; broadcasting, probing, and ARQ. Broadcasting networks send data continuously in 100 mSec blocks, long enough so that statistically they get through.

The channel probing technique is full duplex on two different frequencies, and allows the equipment to adjust somewhat to varying conditions. A probing burst of 5 - 20 mSec is repeatedly sent by the transmitter. When the receiver detects a burst, it sends back an acknowledgment. This return signal informs the transmitter that a meteor track has come into existence and that a data burst of 100 - 300 mSec can be successfully transmitted before the track disappears.

The ARQ format simply starts transmitting data, using it as a probe. The data is sent continuously until an ACK is received.

11.2.5 Applications

The first fully functional system JANET, was built in Canada in the 1950's. It operated at about 40 MHz and broadcast 500 watts using double sideband pulse position modulation.

The main application for such a system appears to be military since the main advantages are:

- Inherent anti-jam capabilities
- Can operate after a nuclear event, unlike the D and F layers which are adversely affected
- Continual coverage from 0 - 1200 miles are possible
- Built in time division multiplex since different ion trails create different path lengths

The STC COMET† system was marketed for the military. It has since evolved and is used by NATO for command and control communications.

There are some non-military applications as well.

11.2.6 MBC Systems

	JANET B	COMET	Hannum	Snowtel	AMBCS	Broadcast	Blossom-A
Data	1954	1959	1966	1967	1978	1982	1986
Test/Service	Test	Test	Test	Service	Service	Test	Test
Type	point - point	point - point	point - point	network	network	1 to n	point - point
Plex	Duplex	Simplex	Duplex	Simplex	Simplex	Broadcast	Simplex
Tx [Kw]	0.5	5.8	0.2 - 5	2	0.3 - 5	1 - 5	0.65
Freq [MHz]	40	50	36 - 39	40 - 50	40 - 50	40 - 50	37 - 72
Tx Antenna	2 x Yagi(5)	6 x Yagi(8)	2 x Yagi(5)	Omni	Omni	Omni	Yagi(4)
Rx Antenna	2 x Yagi(5)	Dipole	2 x Yagi(5)	4 x Yagi	6 x Yagi	Yagi(5)	Yagi(4)
Modulation	AM/PM	FSK	FSK	2 PSK	2 PSK	2 PSK	FSK
Rate [bps]	650	2000	2000	2000	2000	5000	2400
Coding		Hamming	Moore	Manchester CRC	Manchester CRC	CRC	Various

- SNOTEL† - gathers meteorological data from 600 remote sites
  http://www.meteorcomm.com/projects/snotel.htm
- AMBCS† - went into service in 1978 in Alaska to collect meteorological data.
- Tsunamis detectors off the Canadian west coast. The tsunamis warning system consists of 53 tidal stations and more than 100 dissemination points around the Pacific Rim. The water level is measured every minute, and a packet of 10 readings is transmitted every 10 minutes. The system operates in a bi-directional mode so that the operator can change testing parameters such as the sampling and transmit intervals.

† COMmunications by METeor Trails

† SNOpack TELemetery

† Alaska Meteor Burst Communications System

11.3 Submarine Communications Systems

http://www.chinfo.navy.mil/navpalib/cno/n87/nssn.html#Command

http://www.naval-technology.com/contractors/sonar/index.html

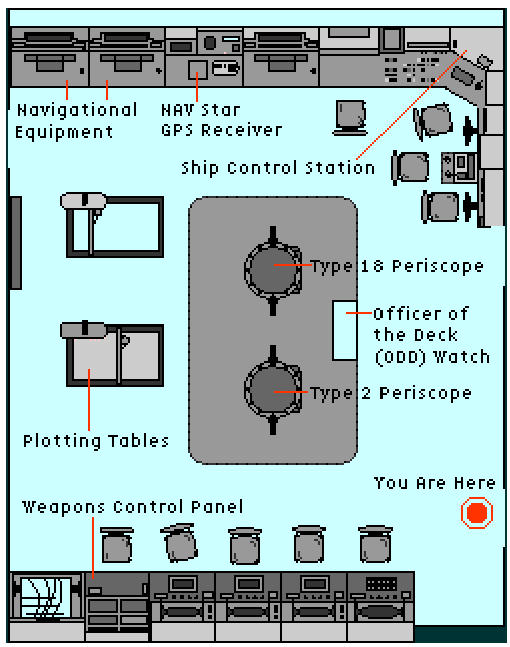
http://www.fas.org/nuke/guide/usa/c3i/elf.htm

http://www.fas.org/man/dod-101/navy/docs/scmp/part07.htm

http://www.fas.org/spp/starwars/congress/1998/s980625-dod-elf.htm

Communicating with a submerged submarine, remains one of the greatest communications challenges of the 20th century. Considering that some of these vessels have enough fire power to devastate a continent, finding effective methods of communicating with them during hostilities has taken on an extraordinary urgency.

To take a tour of the USS Springfield nuclear submarine, just click on the control room below.



The signal penetration depth is sometimes specified by the e-folding depth, where the signal intensity is reduced by 1/e or 0.37688. Over a large portion of the radio spectrum, this depth increases by the square root of the wavelength. This means that very low frequencies can penetrate the surface, at least for a short distance.

Roddy and Coolen provide a graph of Attenuation of Electromagnetic Waves in Sea Water[3].

11.3.1 ELF

ELF[†] [30 - 300 Hz] radio waves are used to penetrate either the ground or ocean, and today represent the only 'practical' way to communicate with a submerged submarine. The wavelength at these frequency ranges from 1000 - 10000 km and as a result, no traditional fractional wavelength antennas are practical. Transmitting antennas have been constructed, but they cover several square miles. Consequently, this is a one-way system.

ELF antennas are very inefficient and have a usable transmission bandwidth in the neighborhood of 1 Hz. It has been reported that one test at 100 Hz radiated only 69 watts out of a total 3.88 MW applied to the antenna and produced a data rate of 1 bps.

Map of ELF Sites

Radio waves longer than 10 meters are reflected off the ionosphere. The ELF wave is therefor ducted between the ionosphere and the planet surface and travels perhaps all the way around the world. As the wave passes over the ocean, a leakage field penetrates the water. Consequently, the receiving antenna must be near the surface.

The antenna is a 600-meter cable with a pair of embedded electrodes, which detect the electric field gradient. The received signal strength depends somewhat on the alignment of the receiving antenna to the direction of propagation.

An alternate method is to use a SQUID[†] sensor. This super-conducting ring can detect changes in the magnetic field caused by ELF waves. The only other signal in the electromagnetic spectrum that the ocean seems willing to allow pass through, is in the visible blue-green area.

11.3.2 Blue-Green Laser

The amount of light that can penetrate the ocean depends on factors including quantity of micro-marine life, mineral composition, suspended particles and pollution. Because sunlight can penetrate water, marine plant life is possible. Without this ability, life on earth as we know it could not exist.

In Type I or very clear seawater, the e-folding depth is about 55 meters at a wavelength of 475 nm, and drops to 5 meters at a wavelength of 600 nm.

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3 Based on Figure 14.16 in *Electronics Communications*, Roddy & Coolen

† Extremely Low Frequency

† Superconducting QUantum Interface Device

However, in type III or very turbid water, the e-folding depth[4] is about 5 - 10 meters across the entire visible spectrum.

Any light based communication system would require a high power laser. There are only two possible places to put such a laser[5]. It could be placed in orbit, or if it was on the ground, a mirror could be placed in orbit. Either approach would require both numerous satellites for global coverage. A bi-directional link would require that the submarine also have a laser and tracking equipment.

Communicating with a submarine would be relatively simple if the location of the submarine is known but, a direct down beam is detectable and somewhat defeats the purpose of a submerged vessel. Therefor, the satellite would have to either scan the ocean or at least broadcast to multiple locations to keep the position of the submarine a secret.

The sun naturally radiates a great deal of light, a significant portion of it in the blue/green region. Therefor the optical sensors on the submarine must filter off the ambient light. There are few sensors today, which are capable of doing this. However, a QLORD[†] sensor is reported to be able to detect a laser signal at 700 meters in type I water in clear sky conditions, and 570 meters with an overcast sky.

11.3.3 UHF/VHF

Submarines today use more conventional means to communicate when there is little or no threat. A mast antenna can be deployed allowing the submarine to communicate over a standard radio link. However, this defeats the fundamental purpose of a submarine since at least part of it would have to be on the surface.

11.3.4 Spread Spectrum

Spread spectrum techniques can be used to reduce the possibility of detection or jamming. The most common military technique used is frequency hopping.

Frequency hopping is accomplished by multiplying the signal in the time domain, with a pseudo-random code generator. This causes a pseudo-random frequency domain shifting. In order to detect the transmitted signal, the receiver must duplicate the pseudo-random code source.

11.3.5 Acoustic Communication

Although sound waves may travel for thousands of miles underwater, this method is generally limited to relatively short distances, and is employed in ship-to-ship applications.

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4 *Submarine Communications*, M B Callaham, IEEE Communications, November 1981, Figure 6

5 *Submarine Communications*, M B Callaham, IEEE Communications, November 1981, Figure 2

† Quantum-Limited Optical Resonance Detector

_____ Notes _____

Sound travels the furthest in what is called the deep sound channel that occurs at a depth between 1200 to 1800 meters. The velocity of propagation is about 1500 meters per second.

As sound propagates in the ocean, it is prone to multipath interference, as the acoustical energy is refracted from temperature and salinity gradients. There is also interference from echoes generated from both the surface and ocean floor.

11.4 Space Systems

http://www.esoc.esa.de/

http://nssdc.gsfc.nasa.gov/planetary/projects.html

http://www.users.wineasy.se/svengrahn/trackind/Deepspac/Deepspac.htm

http://www.worldspaceflight.com/probes/

11.4.1 NASA Space Shuttle

For more information, please refer to:

http://www.ksc.nasa.gov/shuttle/countdown/

http://spaceflight.nasa.gov/shuttle/index.html

Orbiter Communications

Shuttle can communicate with its own network of ground stations, relay satellites and its own payloads. The shuttle must navigate, track satellites and conduct retrieval operations. The majority of these systems are compatible with the TTDRSS[†].

Operational flight support for the required ground networks of both NASA and the USAF, each with their own unique requirements and characteristics. The USAF uses its own SCF[†] ground stations part of the flight support.

Some of the communications and tracking systems include:

- TACAN: a military aircraft design, used for post-blackout area navigation during entry.
- Microwave Scanning Beam Landing System (MSBLS): a military aircraft design modified, used to provide terminal area navigation.
- Radar altimeter: this provides a readout of altitude above the runway.
- UHF voice transceiver is used for backup voice communications.

These facilities required the development of new hardware, as few of the shelf components existed.

† Tracking and Data Relay Satellite System

† Satellite Control Facility

_____ Notes _____

11.4.1.1 Overview of Shuttle Communications Systems

The Space Shuttle Orbiter Communications and Tracking System is an unusual combination of equipment which must be compatible with many different systems and standards:

- NASA TDRSS
- USAF SCF
- Other satellites
- Crew members performing extravehicular activities
- FAA Air Traffic Control voice communications.
- FAA and military air navigational aids.
- Interface with the multiple on-board computers of the data processing system, Orbiter displays and controls, and other on-board systems.

11.4.1.2 UHF Transceivers

The UHF transceivers to provide voice contact during landing operations and during extra vehicular activity.

Early flights used a modified Magnavox AN/ARC-150 transceiver during landing operations. It is widely used by the USAF and can be tuned to any of 7000 channels. It broadcast between 225 and 399.975 MHz and continuously monitored the international emergency channel at 243 MHz. It provided 185mW of audio reception at 50% modulation and transmitted 10W at 90% AM.

Later flights replaced this system with RCA's EVA-ATC, which was primarily designed for EVA† support for one or two astronauts.

EVA mode provided a RF link at either 296.8 or 259.7 MHz. The shuttle transmitters deliver 10 watts and those on the space suits deliver 500 mW. It provides a voice link and monitors electrocardiograph activity.

Two antennas, one inside an airlock and one on bottom of the orbiter are provided. The transmitters are connected to the audio distribution system, and allow direct voice contact with the ground or orbiter.

This shuttle audio distribution system is quite complex and provides intercom and radio access functions for the various crew stations and mission control.

11.4.1.3 Air Navigation Aids (NAVAID's)

For aerodynamic flights, two radar altimeters used only in the last few minutes of flight, three TACAN's, and three microwave scan-beam landing systems (MSBLS) are used.

The TACAN (Tactical Air Navigation) enjoys wide military and civilian aircraft use. Ground signal acquisition, in normal Orbiter entry trajectory, is about 300 nautical miles (550 km) downrange to the landing site at an altitude of 150,000 ft.(45.7 km)

† Extra Vehicular Activity

MSBLS takes over final navigational sensor duties from the TACAN and provide range and bearing from 10,000 ft. to touch down.

The radar altimeter operates at 4300 MHz C-band, and is used for precision altitude determination on final approach for the last 100 ft. (30m) of descent if automatic landing mode is engaged

11.4.1.4 S - Band System

This system consists of network and payload subsystems. The network subsystem provides tracking and two-way communications to ground via PM links

Interfacing multiplexers/demultiplexers (MDM's) provide telemetry for configuration data and performance parameters instructions from the DPS computers. Network signal processors (NSP) route received data and to be transmitted data through communications security boxes for decryption or encryption.

The signal is spread with pseudo random noise (PRN) code rate of 11.232 Mchips/s to reduce TDRSS interference with ground-based communications. Return link frequencies in the 1.7 GHz to 2.3 GHz range minimize interference with payload communications.

FM signal processors and transmitters provide television, digital data from main engines during launch or wideband (to 4 MHz) payload data. Narrower-band digital engine data placed on subcarriers at 576, 768, and 1024 KHz

The payload subsystem checks operation of released payload prior to moving from its immediate vicinity and saving a satellite before taking it aboard.

There are 851 full duplex channels:

- 20 channels in SGLS mode
- 808 channels in STDN mode
- 23 channels in DSN (deep space network) mode

11.4.1.5 Ku Band Radar/Communications System

Operates as a radar during space rendezvous, measuring angles, range and their rates. It also doubles as a two-way communications subsystem, transmitting through TDRSS at data rate up to 50 Mbps and receiving at rate up to 216 Mbps

A 0.9-meter parabolic tracking antenna, mounted on the starboard side of the payload bay is deployed when the payload doors are open. Target acquisition is acquired by a spiral search.

As a rendezvous aid, Ku-band system is a frequency-hopping Doppler radar with 66 mSec pulses for long ranges [22 km] and 22 nSec pulses for short range (30m). As range decreases, so does the output power, thus preventing damage to nearby targets.

Notes

11.4.1.6 Television

Video provides monitoring from ground of on-board activities and allows the payload bay to be observed. Signals originating from orbiter can be transmitted to the ground by direct FM S-band link or Ku-band link.

Orbiter cameras use a rotating color wheel to generate a field sequential color video signal. Payload cameras are back and white.

11.4.1.7 Antennas

All antennas except UHF airlock and deployable Ku-band antennas are flush mounted near front outer-surface of the orbiter. All flush antennas are overlaid with a thermal protective material otherwise they would not survive the heat of entry. The material is 2.5 inches thick on the shuttle bottom. It has electrical characteristics similar to polyurethane foam, thus special attention required where radiation patterns are critical. The wavelengths used in the MSBLS are in the order of material thickness.

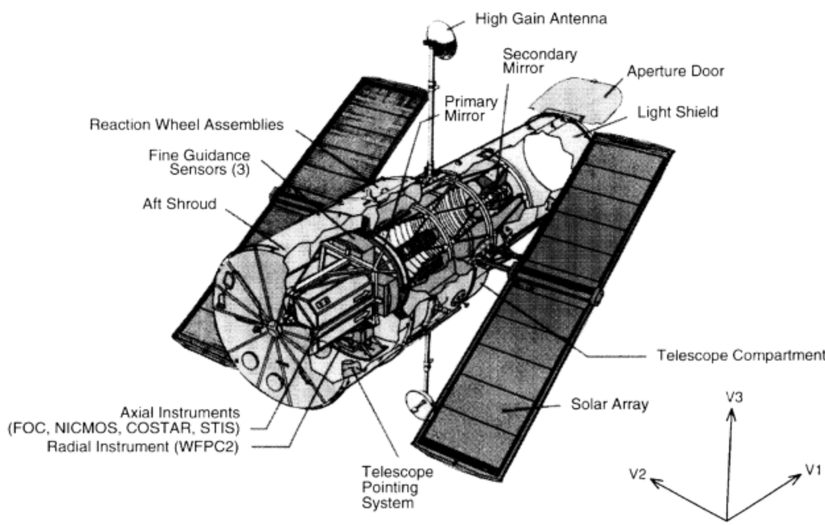
11.4.2 Hubble Space Telescope

http://www.stsci.edu/

http://oposite.stsci.edu/pubinfo/

http://heritage.stsci.edu/

http://www.ncc.com/misc/hubble_sites.html



The HST is controlled from STOCC†, located at GSFC. Communication with the spacecraft is via TDRSS†, which consists of a set of satellites in geosynchronous orbit.

† Space Telescope Operations Control Center

______ Notes ______

Commands to HST originate at the STOCC and are sent to the TDRSS ground station at White Sands. From there, the commands are sent via the appropriate TDRSS to HST. Scientific data are sent from HST to the STOCC via the reverse path and then from the STOCC to the STScI via dedicated high-speed links.

The TDRSS network supports many other spacecraft. Therefore, observation command sequences are periodically up-linked and stored. HST then executes the observations automatically. The observations are stored and sent back to the ground several hours later.

Occasionally real-time observations must be scheduled, but this happens, fewer than 50 times per year.

The Hubble telescope is in a low enough orbit that it can be repaired by the space shuttle.

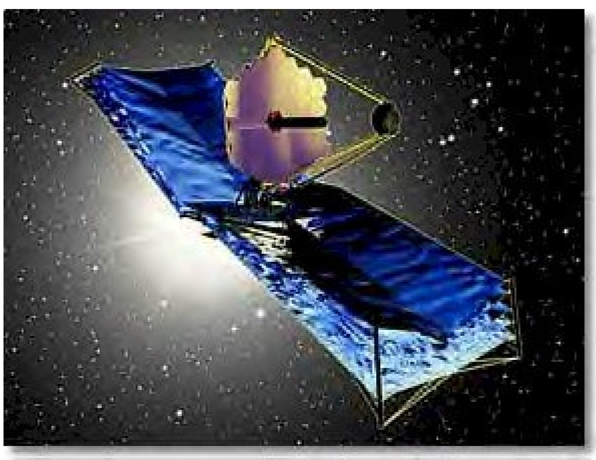
NGST

http://www.trw.com/ngst/

http://www.ngst.stsci.edu/

http://www.spacetelescopes.com/

Next Generation Space Telescope.



11.4.3 International Space Station

http://www.boeing.com/defense-space/space/spacestation/

http://www.spacestation.com/

To view the proposed space station, simply click on one of the links: ISS Photo 1, ISS Photo 2, ISS Photo 3

† Tracking and Data Relay Satellite System

_____ Notes _____

The location of the space station can be found at the following web site:

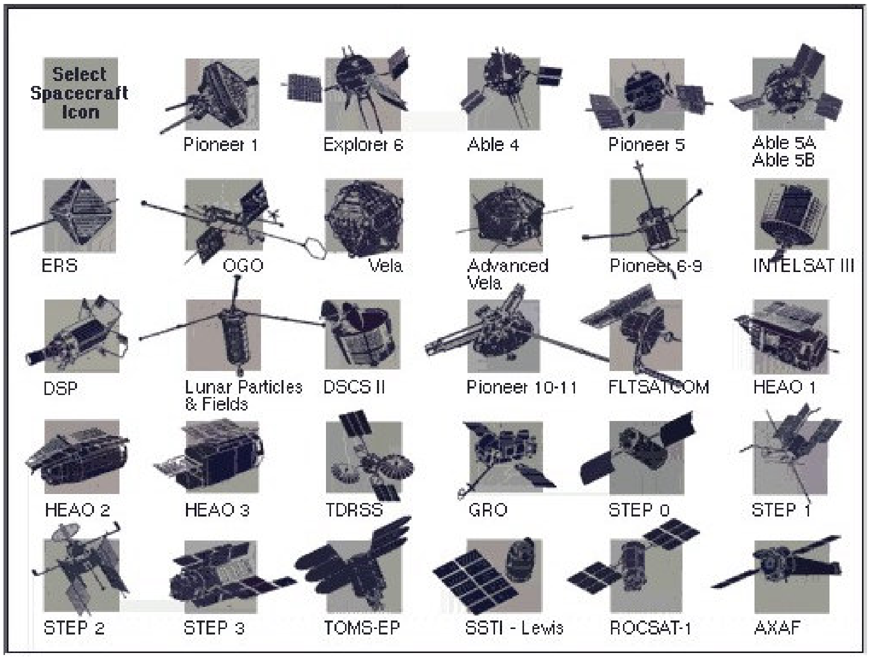
http://liftoff.msfc.nasa.gov/temp/StationLoc.html

The location of the MIR space station can be found at:

http://liftoff.msfc.nasa.gov/temp/mir_loc.html

Spacecraft Guide

http://www.trw.com/seg/space_guide/



11.4.4 Deep Space Network

http://deepspace.jpl.nasa.gov/dsn/comms/intro.html

http://www.powerup.com.au/~woomera/tracking.htm

http://www.goonhilly.bt.com/

Deep space communications links must support at least the following functions:

- High-speed telemetry for imaging
- Low speed telemetry for field experiments and engineering monitoring
- Routine command
- Emergency command during unplanned events
- Emergency telemetry and weak signal search
- Radio navigation
- Complex radio science instrumentation

The antennas, transmitters and modulators are shared by all functions on a single link. The signals are split for processing by individual subsystems

A number of spacecraft used the UHF band at about 100 MHz for communications:

- Explorer: earth orbiters
- Pioneer: lunar probe
- Ranger: lunar spacecraft
- Mariner: Venus & Mars orbiter and lander
- Pioneer: Jupiter & Saturn
- Voyager: Jupiter, Saturn, Uranus, & Neptune flybys
- Magellan: Venus radar mapper
- Galileo: Jupiter atmospheric probe

As communications demands have increased, the operating frequencies moved up to the S-band [2.3 GHz] and then to the X-band [8.4 GHz].

11.4.4.1 Voyager[6]

Two Voyager spacecraft explored the outer planets of the solar system. The first was launched in 1977, and although the design of the probe was fixed, the ground support facilities continued to develop while the mission was in progress.

The Voyager transmitter output power was only 20 watts, but since the 3.66 meter antenna had a gain of 48.2 dB, the EIRP was 1.32 MW. The antenna was fed both the X-band [8.5 GHz] and S-band [2 GHz] transmitters. Altogether, approximately 80,000 images were transmitted back to Earth. The Uranus images were transmitted over a distance of 2.75 billion miles.

6 IEEE Communications, September 1990

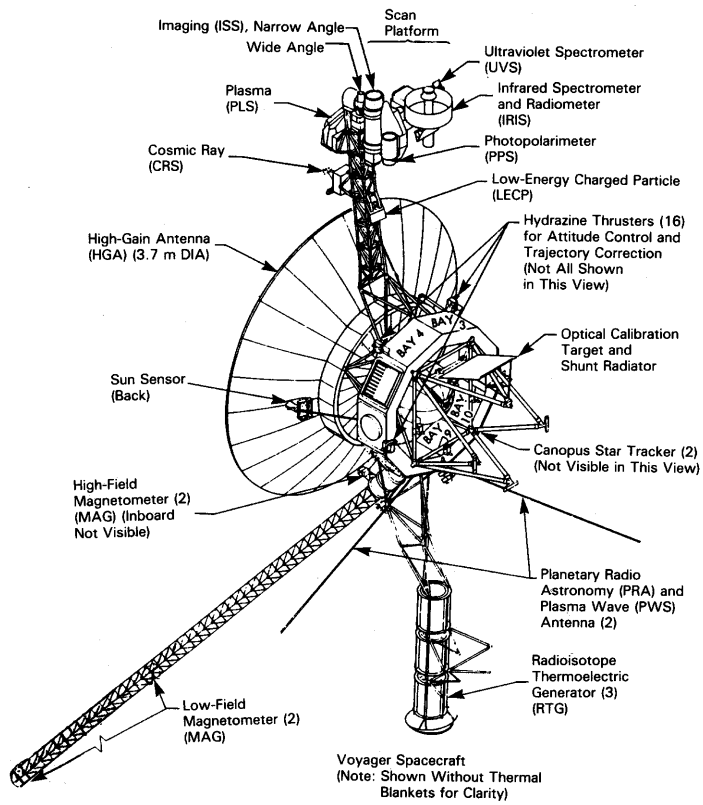


Fig. 2. Voyager spacecraft. The subsystems are shown by callout. The 3.66 m diameter antenna is a highly visible feature.

Voyager to Uranus Spacecraft Parameters

Transmitted Power	18.2 W [42.6 dBm]
Antenna Gain	48.0 dB
Space Loss	-301.0 dB

64 Meter Ground Station Parameters

Transmitted Power	18.2 W [42.6 dBm]
Antenna Gain	72.0 dB
Receiver Noise Spectral Density	-187.4 dBm/Hz
90% Weather Losses	-4.6 dB
Received S/N	44.4 dB Hz
Array Contribution	3.6 dB
Array S/N	48.0 dB
S/N per bit	3.2 dB
Minimum S/N per bit required	2.6 dB
Margin	0.6 dB
Coding Efficiency	40%

The signaling rate when the Voyager spacecraft was at Saturn was 44.8 Kbps. However, since the received power drops as distance increases, this rate was dropped to 29.9 Kbps for the Uranus flyby in order to maintain the S/N per bit. A total of 28 different telemetry rates were used over the life of the mission.

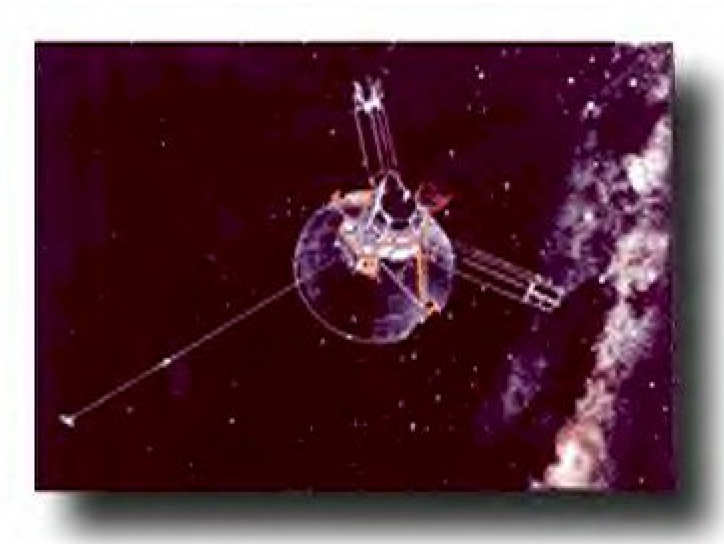
Achieving these rates required the cooperation of several agencies to combine signals from several ground stations.

The ground station tracking network included:

- The 27, 34 meter array at Socorro, New Mexico
- 64 meter antenna in Australia
- 70 meter antenna in California
- Antennas in Japan and Spain

Although one spacecraft receiver completely failed on the Voyager II mission, and another partially failed, it was still possible to maintain the uplink by clever programming and the 400 kW output power of the 70 m Goldstone antenna [EIRP: 200 GW].

Pioneer 10



Pioneer 10 lifted off March 2, 1972, to begin a 21-month journey to Jupiter.

In December 1973, Pioneer 10 passed within 82,000 miles above the cloud tops of Jupiter. It took more than 500 images of the planet and its four largest moons.

It passed the orbit of Saturn in February 1976; Uranus in July 1979. On June 13, 1983, Pioneer 10 passed beyond the orbit of Neptune. At that time, Neptune's elliptical orbit took it beyond Pluto, making it the outermost planet and, therefore, the accepted outer edge of the solar system.

The 570-lb Pioneer spacecraft measured magnetic fields, solar wind, high-energy cosmic rays, cosmic and asteroidal dust, and Jupiter's ultraviolet and infrared radiation. The spacecraft is powered by four radioisotope thermoelectric generators that supply 40 Watts each. A nine-foot-diameter dish antenna is mounted on the spacecraft's spin-stabilized body. It transmits 8-Watt radio signals to NASA's DSN.

_____ Notes _____

Pioneer 10 was retired by NASA on March 31, 1997.

Tracking and Data Relay Satellite System (TDRSS)

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Mission	Tracking and Data Relay Satellite System. Track NASA spacecraft and relay their data and commands more efficiently than ground-based tracking networks
Number Built	7
Launch Vehicle and Dates	Shuttle/IUS; 1: 4/4/83; B: 1/28/86; 3: 9/29/88; 4: 3/13/89; 5: 8/2/91; 6: 1/13/93; 7: 7/13/95
Orbit(nmi)	19,323 geosync
Design Life(years)	10
Size/Weight/Power	9' diam, 5' high, 57' span, two 16' antennas; 5,000 lb; 1,850 W
Features	7 antennas. Continuous communications throughout entire orbit. Highly automated space-ground operations. 3-axis stabilized
Customers	NASA Goddard Space Flight Center
Comments	The largest, most sophisticated communications satellite. First space-based global tracking system

11.5 GPS

http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html

http://www.mercat.com/QUEST/gpstutor.htm

http://www.trimble.com/gps/

http://www.cns-atm.com/cns-atm/gpsback-up.html

http://www.earthsurface.com/

The Global Positioning System is not a communications system in the ordinary sense, but it does have some similarities. The system consists of orbiting radio stations broadcasting on the L1 and L2 bands.

The system was developed by the US military to accurately locate targets and their own forces.

There are 28 satellites in the system. Of these, 21 are active, 3 spares in orbit, and 4 ground based spares. It is expected that 4 to 10 satellites will be in the sky anywhere in the world at one time.

These satellites are in circular orbits at an altitude of 20,200 Km, and travel at about 4 Km per second. GPS broadcasts two pseudo-random binary codes known as the C/A [clear access] code and P [precise] code.

The C/A code has a one-millisecond long sequence and is broadcast on the L1 band. It is intended for commercial applications and was to be accurate to 100 meters. In practice however, the C/A code allowed positioning to within 20 meters. Since this is perceived as a military threat, an artificial clock error has been introduced to reduce the accuracy to 300 meters.

The P code, has a 267-day sequence, and is broadcast on both bands. The P code is broken down into weeklong segments, and each satellite is given a portion of it to broadcast. This allows for position accuracy to within 10 meters.

Surveyors have developed sophisticated techniques to get around these restrictions and can determine an accuracy of less than a meter. This requires using two receivers used to make differential carrier wave measurements, and a great deal of time to take the satellite readings.

Each satellite has an atomic clock. The receivers use a much cheaper and less accurate quartz clock. The receiver checks the time on its internal clock with that of the incoming satellite signal. The time delay between the two signals can be measured, and a distance to the satellite can be calculated. To determine position, the time delay to a minimum of 3 satellites must be determined. In practice, a fourth satellite is needed, to help compensate for slight errors, which can occur in the system.

Two frequency bands are used to help compensate for the effects of the ionosphere. The propagation velocity through the ionosphere is not always a constant.

GLONASS

http://www.rssi.ru/SFCSIC/SFCSIC_main.html

http://www.nz.dlr.de/gps/glonass.html

http://www.magellangps.com/geninfo/glonass.htm

http://samadhi.jpl.nasa.gov/msl/QuickLooks/glonassQL.html

Each GLONASS satellite transmits a standard precision (SP) and high precision (HP) signal. SP signal is broadcast in the L1-band with a frequency of 1602 + n0.5625 MHz, where "n" is channel number (n=0,1,2...) and unique to each satellite in view.

The receiver requires signals from at least 4 satellites to calculate the three position coordinates, velocity vectors, and time.

The Russian Global Navigation Satellite System (GLONASS) is based on a constellation of active satellites which continuously transmit coded signals in two frequency bands, which can be received by users anywhere on the Earth' s surface to identify their position and velocity in real time based on ranging measurements.

The system is a counterpart to the United States Global Positioning System (GPS) and both systems share the same principles in the data transmission and positioning methods.

In 1982 the first GLONASS satellites were set into orbit, and the experimental work with GLONASS began. Over this time span, the system was tested, and different aspects were improved, including the satellites themselves. Although the initial plans pointed to 1991 for a complete operational system, the deployment of the full constellation of satellites has been completed in late 1995, early 1996.

The space segment of GLONASS, is formed by 24 satellites located on three orbital planes. Each satellite is identified by its slot number, which defines the orbital plane (1-8, 9-16,17-24) and the location within the plane. The three orbital planes are separated 120 degrees, and the satellites within the same orbit plane by 45 degrees. During 1996 two satellites have been decommissioned, and the current stand has 22 active satellites.

The GLONASS orbits are roughly circular orbits with an inclination of about 64.8 degrees, a semiaxis of 25440 Km and a period of 11h 15m 44s.

The ground control segment of GLONASS is entirely located in former Soviet Union territory. The Ground Control Center and Time Standards in Moscow and the telemetry and tracking stations in St. Petersburg, Ternopol, Eniseisk, Komsomolsk-na-Amure.

The coordinate system of the GLONASS satellite orbits is defined according to the PZ-90 system, formerly the Soviet Geodetic System 1985/1990. The time scale is defined as Russian UTC. As a difference from GPS, the GLONASS time system includes also leap seconds.

All satellites transmit simultaneously in two frequency bands to allow the user to correct for ionospheric delays on the transmitted signals. However, each satellite is allocated a particular frequency within the band, determined by the frequency channel number of the satellite. These different frequencies allow the user' s receivers to identify the satellite. In the current set up, two satellites in the same orbit, occupying antipodal locations, transmit in exactly the same frequency, with a few exceptions.

The actual frequency of transmission can be derived from the channel number k by applying the following expressions:

Frequency band L1: $f1(k) = 1602 \text{ MHz} + k * 9/16 \text{ MHz}$

Frequency band L2: $f2(k) = 1246 \text{ MHz} + k * 7/16 \text{ MHz}$

Superimposed to the carrier frequency, the GLONASS satellites modulate their navigation message. Two modulations can be used for ranging purposes, the

Coarse Acquisition code, with a chip length of 586.7 meters and the Precision code, of 58.67 meters. The satellites also transmit information about their ephemerides, almanac of the entire constellation and correction parameters to the time scale.

The ephemerides values are predicted from the Ground Control Center for a 24-h period, and the satellite transmits a new set of ephemerides every 30 minutes. The almanac is updated approximately once per day.

WAAS (Wide Area Augmentation System)

http://www.isicns.com/GPSWSLS.HTM

The U.S. Federal Aviation Administration (FAA) is implementing the WAAS. The WAAS augments the GPS to meet the basic navigation requirements for a navigation system. WAAS will provide the following capabilities:

An *integrity* capability to notify the users when GPS should not be used for navigation.

An *accuracy* enhancement capability that will improve the accuracy of GPS to meet the requirements for precision approaches.

An improvement in *availability* by providing ranging sources from geostationary satellite that can be used for user position determination.

WAAS is expected to have Initial Operational Capability (IOC) in 1999. The FAA is expected to approve Full Operational Capability (FOC) for the WAAS to be used as the primary navigation system in all phases of flight by the year 2001.

LAAS (Local Area Augmentation System)

The second augmentation to the GPS signal is the Local Area Augmentation System (LAAS). The LAAS is intended to complement the WAAS and function together to supply users of the U.S. NAS with seamless satellite based navigation for all phases of flight. In practical terms, this means that at locations where the WAAS is unable to meet existing navigation and landing requirements (such as availability), the LAAS will be used to fulfill those requirements. In addition, the LAAS will meet the more stringent Category II/III requirements that exist at selected locations throughout the U.S. Beyond Category III,

the LAAS will provide the user with a navigation signal that can be used as an all weather surface navigation capability enabling the potential use of LAAS as a component of a surface navigation system and an input to surface surveillance/traffic management systems.

Similar to the WAAS concept which incorporates the use of communication satellites to broadcast a correction message, the LAAS will broadcast its correction message via very high frequency (VHF) radio datalink from a ground-based transmitter.

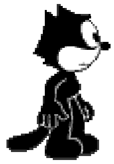
LAAS will yield the extremely high accuracy, availability, and integrity necessary for Category II/III precision approaches. It is fully expected that the end-state configuration will pinpoint the aircraft' s position to within one meter or less and at a significant improvement in service flexibility, and user operating costs.

Galileo

11.6 Data Buoys

http://dbcp.nos.noaa.gov/dbcp/index.html

Assignment Questions



Quick Quiz

1. Troposcatter systems are not immune to multipath propagation. [True, False]
2. Overdense meteor trails cause reradiation by [absorption, reflection].
3. The depth at which an electromagnets wave is reduced in intensity by 0.377 is known as the [e-folding, Bragg, Cummings] depth.
4. The velocity of sound in water is approximately [1000, 1500, 2000] meters per second.
5. The space shuttle has (227, 493, 851) full duplex S-band channels.
6. The transmission output of a deep space probe is approximately [20, 200, 2000] watts.

Analytical Questions

1. Stating any and all assumptions, calculate the approximate signal power received at a typical 64 meter ground station, from the Voyager space probe when it passed Uranus.

Composition Questions

1. What range of plane electromagnetic waves can propagate in seawater?
2. What is spread spectrum communications?
3. What is the average data throughput that can be expected from a MBC link?
4. What are the two categories of meteor trails?
5. How long does as underdense meteor trail last?
6. What type of modulation is typically used on MBC links?
7. What are some of the advantages, limitations and uses of meteor burst systems?
8. What are 4 methods of communicating with a submarine?
9. What basic difficulties associated with troposcatter communications?

Notes

For Further Research

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Oetting John D, "Meteor Burst Communications", IEEE Transactions on Communications, September 1980

Freeman Roger L, Telecommunications Transmission Handbook [3rd ed], John Wiley & Sons, 1991

Johnson Joseph H, "Solid–State Amplifier Delivers Reliable Meteor–Burst Communication", MSN&CT, September 1987

Mustard Robert, "The Amethyst Nuclear Submarine - An Overview", IEEE Canadian Review, December 1988

Wiener & Karp, "Strategic Submarine Communications", IEEE Transactions on Communications, September 1980

http://tmod.jpl.nasa.gov/

http://www.tothestars.com/

http://sci.esa.int/

Deep Space Network

http://deepspace.jpl.nasa.gov/dsn/index.html

http://tid.cdscc.nasa.gov/

Meteor Burst Communications

http://www.meteorcomm.com/

http://www.borg.com/~warrend/metburdu.html

Troposcatter Systems

http://www.islandnet.com/~rlecuyer/pinetree/misc/other/misc3a.html

http://www.creativexposure.com/nars/abtnars.htm

http://www.quercus.demon.co.uk/tropo.html

http://www2.magmacom.com/~lwilson/dewline.htm

Satellites

http://www.asahi-net.or.jp/~VQ3H-NKMR/satellite/trk-e.html

http://spaceflight.nasa.gov/index-m.html

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