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"Satellite Communications: Principles in Albania"

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SATELLITE COMMUNICATIONS:
*PRINCIPLES
*IN ALBANIA

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1. INTRODUCTION

The first voice communications via satellite was achieved in 1958 with a satellite called SCORE. The satellite received a voice message and stored it on tape for retransmission.
In 1960 ECHO 1 was launched - a 30m diameter passive reflector.
TELSTAR (1962) was the first true active communication satellite. TELSTAR 1 was followed soon after by RELAY and TELSTAR 2.
All of these were in a low or medium altitude elliptical orbit (see later).
SYNCOM II became the first near-geostationary (33 deg. inclination) orbital satellite in July 1963, followed by SYNCOM III in 1964 which achieved the first true geostationary orbit.
Satellite Orbits. (SYNCOM I failed before reaching orbit)
These early satellites heralded the subsequent 'explosion' in the use of communications satellites.

Satellites are used for a great many applications, of which communications is just one.
The main communications applications are;

- Fixed Satellite Service (FSS)
- Broadcast Satellite Service (BSS)
- Mobile Satellite Service (MSS)

Just some of the other applications include;

Meteorology, Earth Exploration, Radionavigation, Radioastronomy and Space Operations and even Amateur services.

Satellite Communications services may be divided into four classes of service;

- international (global)
- regional
- domestic (national)
- experimental.

Although varied types of satellite communications systems will be looked at, this course will focus upon digital satellite communications (this being the increasingly preferred method of satellite transmission) and in particular, digital audio systems, as audio is the medium which most greatly interests Trans World Radio.

2. SATELLITE ORBITS
(orbits.drw)

2.1.1 Geostationary Orbit

The Geostationary orbit, with an altitude of 35 786 km, is the most commonly used for communications. It has a 24 hour period and so appears to remain stationary above the earth's surface, thereby providing continuous operation into fixed antennas. The geostationary orbit is not visible at the Polar caps.

2.1.2 Inclined Circular Geosynchronous Orbit

This orbit causes the satellite to remain *approximately* over a fixed point on the earth's surface. The orbit's inclination to the equatorial plane causes it to describe a 'figure of eight' in the sky from the viewpoint of an observer on the ground, thus necessitating the use of a tracking antenna. The greater the inclination, the larger the figure of eight. A geostationary orbit will decay into an inclined geosynchronous orbit if regular adjustments are not made to compensate for the effects of the gravitational pull of the sun and moon. Older satellites, which are running low on station-keeping fuel, may be allowed to slowly decay into an inclined orbit for use by earth stations with tracking capability, before finally being allowed to fall into, and burn up in, the earth's atmosphere or boosted into deep space, at the end of their useful life.

2.1.3 Inclined Elliptical Orbits

Highly eccentric, elliptical orbits inclined at 63.4 degrees to the equatorial plan exhibit significant apsidal dwells around their apogee. Thus the satellites appear to remain quasi-stationary, and are usable for periods of 8-12 hours over the polar cap regions. The Molnya orbit was first used by the Soviet Union in the 1960's for TV transmission to its remote areas. It has an apogee of around 40 000 km and a perigee of around 1000 km. Similar characteristics are exhibited by the second, the tundra orbit, which has an apogee of 46 300 km and a perigee of 25 250 km..

2.1.4 Low Earth Orbits

Low Earth Orbits, or 'LEOs', occurring at 500-1500 km, are used for earth-resources, data relay and navigation satellites as well as low cost store-and-forward communications. Many amateur satellites operate in low earth orbit. Recently proposed global satellite personal communications systems utilise an array of satellites in low earth orbit with complex zone-handover procedures to provide 24-hour, continuous or near-continuous coverage of the earth's surface.

2.1.5 Geostationary Congestion

(conjest.drw)

- because it is so useful for communications, the geostationary orbit is heavily congested - particularly in certain preferred regions e.g. Americas, Europe, Africa/Middle East.
- satellite 'parking slots' have been allocated at 2 deg. intervals for communications satellites and 5 or 8 degrees for direct broadcast (satellite TV) satellites. This has implications for ground station antenna performance.

2.1.6 Satellite Frequency Bands

(freqband.drw)

A number of frequency bands have been assigned for satellite communications. The most common for domestic satellites are the C- and Ku-bands.

2.1.7 Geostationary Earth Coverage

(geo_cov.drw)

A satellite in geostationary orbit must have a beamwidth of 17.4 deg. to provide maximum coverage of the earth, but this still precludes the polar regions, and means a very low elevation angle for regions near to the polar extremes.

2.1.8 Satellite Beams

(beams.drw)

Normally, satellites will have shaped, focused beams which only illuminate a defined area of the earth - usually whole continents.

Three/four types of beam are commonly used;
Global - maximum earth coverage.
Hemispherical - coverage of a complete hemisphere.
Zone - coverage of a continent, culture or major language group.
Spot - coverage of a defined area - nation, state.

3. BASIC PRINCIPLES

3.1 The Satellite Communications Link

(basicsys.drw)

The 'Transmit Earth Station' transmits the signal to the satellite. The satellite relays the signal back down to the 'Receive Earth Station'. A conventional communications satellite acts in what is commonly referred to as 'bent-pipe' mode - the signal from the Transmit Earth Station is received and re-transmitted by the satellite with no change to the signal being sent, except for amplification and frequency transposing.
Some of the major areas to be considered in the link are;
P.A. output power
Tx Antenna Gain
Uplink path loss
Satellite gain/performance
Downlink path loss
Noise contributions
Rx antenna performance
Rx electronics noise figure.

3.2 The Satellite

(basicsat.drw)

A conventional satellite comprises a number of 'Transponders'. Each transponder is tuned to a particular part of the complete operating satellite band. The satellite receive antenna collects the signals sent from the transmit earth station and routes them to the transponders. Each transponder converts frequencies within it's operating band to a new frequency which is a fixed offset from the received frequency, and then amplifies the signals for retransmission to earth via the satellite transmit antenna. A typical transponder bandwidth is 40-80 MHz.

3.3 The Earth Station

(basices.drw)

The signal for transmission over satellite may be analogue TV or audio or raw data, such as from a computer terminal. The Encoder may perform a combination of functions depending upon the system requirement. It is becoming increasingly common for analogue TV or audio signals to be first digitised and compressed in order to provide higher quality and/or to conserve transmission bandwidth. Usually, the encoder will also insert a form of 'Forward Error Correction (FEC)' into the data to be transmitted. FEC is a process whereby extra data is added to the raw data stream

and this extra data is used by the receiving station to correct for any errors introduced over the satellite link (more on this later).
It is also usual for the raw data to be scrambled in order that it more closely approximates a true random pattern. This ensures that the content of the data does not unduly affect the characteristics of the modulated carrier.
Sometimes scrambling will be used, even on analogue signals, in order to provide a degree of encryption.

The signal, whether digitised or not, is fed to the IF Modulator where it is modulated onto a carrier at an Intermediate Frequency (IF) typically at 70 or 140 MHz. The type of modulation used depends upon the type of input signal, with FM commonly being used for analogue signals and Phase Shift Keying (PSK) being used for digital signals.

The IF is then upconverted by the Frequency Upconverter to the desired frequency for transmission, typically in the 6 (C-band) or 14 GHz (Ku-band) region. The signal is then amplified to the required power by the Power Amplifier unit and fed to the feed unit.

The feed system is a special waveguide construction which fulfils several roles. It routes the transmit and receive signals between the antenna and the transmit/receive electronics, keeping them separate by virtue of their frequency and polarisation difference. The feed system also acts to 'focus' the transmit signals onto the surface of the antenna and, conversely, to 'gather' the receive signals from the surface of the antenna reflector.

The reflector serves to direct the signal energy in the desired direction and thus provides 'gain'.

Conversely, the antenna reflector also gathers the signal energy being transmitted back from the satellite and focuses into the feed system. The feed system directs the signal energy to the input of the Low Noise Amplifier, which is a high gain, low noise amplifier to bring the signal up to a useful amplitude whilst adding as little extra noise as possible. From the LNA the signal is fed to a Frequency downconverter which will convert the signal to an I.F. of, usually, 70 or 140 MHz. Often the function of LNA and Downconverter are combined into a single compact unit called a Low Noise Block (LNB) downconverter. The LNB usually amplifies the complete receive band and downconverts it to a new band in the region 950 up to 2050 MHz (L-Band).

The IF signal at 70/140/L-Band is fed to the demodulator where further frequency conversion may be performed and the signal information is derived from the modulated carrier.

The output from the demodulator may be in the form of directly usable audio, data or TV, but is increasingly taking the form of encoded digital data which must be fed to a suitable decoder in order to extract the final desired audio, data or TV.

The 'dB' Scale

We should take a brief moment to clarify the use of 'dB' in satellite communications (or indeed in any communications environment). The unit of the dB is a convenient method used to do arithmetic where multiplication of very large and very small numbers are concerned, as is the case with satellite communications. A 'dB' is the logarithmic ratio, to the base 10, of two linear numbers. Hence the ratio of 100 to 1 is;
10 log (100/10) = 10 dB.

The primary advantage of the dB scale, is that very large numbers and very small numbers can be represented as more manageable figures under the logarithmic scale. e.g.; 1,000,000,000 = 90 dB, and 0.0000001 = -70 dB. Furthermore, the addition of two logarithms is equivalent to the multiplication of two linear numbers; hence 1,000,000,000 x 0.0000001 is equivalent to 90 dB + -70 dB = 20 dB, which is a much more manageable sum, even when considering the simplistic nature of the example.

The use of the logarithmic scale can be extended beyond simple ratios, and instead used to express absolute quantities by using a base reference for the ratios. e.g. an industry standard for measurement of power is the 'dBW'. A figure in dBW is a measure of how much larger (or smaller) the unit is compared to 1Watt. e.g. 4W = 10 log (4/1W) = 6 dBW. Also used, is the dBm scale, whereby powers are expressed as logarithmic ratios compared to 1 mW.

Usually, as one works with dBs, one forgets about the relationship to linear numbers and the dB merely becomes the 'counting' base for most of the calculations and measurements involved in a system, with the conversion back to linear numbers being made as and when required.

Following this brief clarification, we can now return to a more general consideration of satellite communications.

4. SATELLITE ACCESS TECHNIQUES

(sat_acc.drw)

The resources of a single satellite will usually be shared by a number of independent users. The satellite's available power and bandwidth are shared between a number of different channels and earth stations, each of which may (probably will) have quite different transmit powers and signal characteristics. This section of the course will look at the principle methods used in order to allow multiple users to access the satellite in an orderly and efficient manner.

4.1 Network Architectures

(net_arch.drw)

Types of satellite network;

Point-Point: this is the simplest situation with one user transmitting to another in Simplex mode. A more practical mode might be with a duplex link.

Point-Multipoint: outgoing traffic may be unique to each receive station, or it may be common to all (broadcast). Where the traffic is unique, there must be some method by which the unique signals can be delivered or 'addressed' to the desired receive station.

The reverse scenario is where multiple earth stations are transmitting to a single receive station. Here, there is clearly a requirement to define an access strategy such that the various transmissions do not interfere with each other.

Multipoint-Multipoint: This is the general model and most closely represents the true picture for most communications satellites - many transmit stations transmitting to many receive stations. The complete 'network population' usually consisting of many independent, networks of two or more tx/rx terminals.

4.2 Multiplexing
(multplx.drw)

The technique of multiplexing is whereby a number of user channels may be combined for transmission via a common antenna or communications medium. A signal carrier may be classified as being one of two types;
SCPC - Single Channel Per Carrier e.g. a terrestrial TV channel.
MCPC-Multiple Channel Per Carrier e.g. a high-capacity Telephone trunk line

The TWR-CE transmission consists of three carriers, each carrying two channels of mono audio. Strictly speaking each carrier is MCPC, but is more commonly accepted as being SCPC as the two mono channels are most often used to transmit a single channel of stereo audio.

There are two principle forms of multiplexing;
FDM - Frequency Division Multiplex e.g. Analogue telephony transmission.
TDM - Time Division Multiplex e.g. digital telephony transmission.

A form of **modulation** is normally required to translate the multiplexed signals into a form suitable for transmission over the given communications medium. The details of modulation will be dealt with later in the course.

4.3 Multiple Access Strategies

Several uplink carriers from different earth stations will usually be required to share a satellite's (or, in particular, a transponder's) resources of bandwidth and power.
The access needs to be performed in such a way as to ensure fair and efficient utilisation of the resources, as well as minimising interference between the coexisting carriers.

The management and allocation of accesses may be performed on a fixed-assigned, demand-assigned, or random basis;

Fixed assigned basis: the 'slot' for a carrier/earth-station is preassigned for a long period of time by the network control station.
Demand Assigned Multiple Access (DAMA): the network resources are automatically allocated as 'demanded' by the network users.
Random Access: The network resources are accessed by the users in short, random bursts of packet data. Some collisions are to be expected and so there must be a mechanism for requesting retransmission. This tends to be an inefficient use of network resources and so this method is usually used mainly for 'access request' channels.

6. THE RECEIVE STATION

6.1 The Receive-Only Antenna System

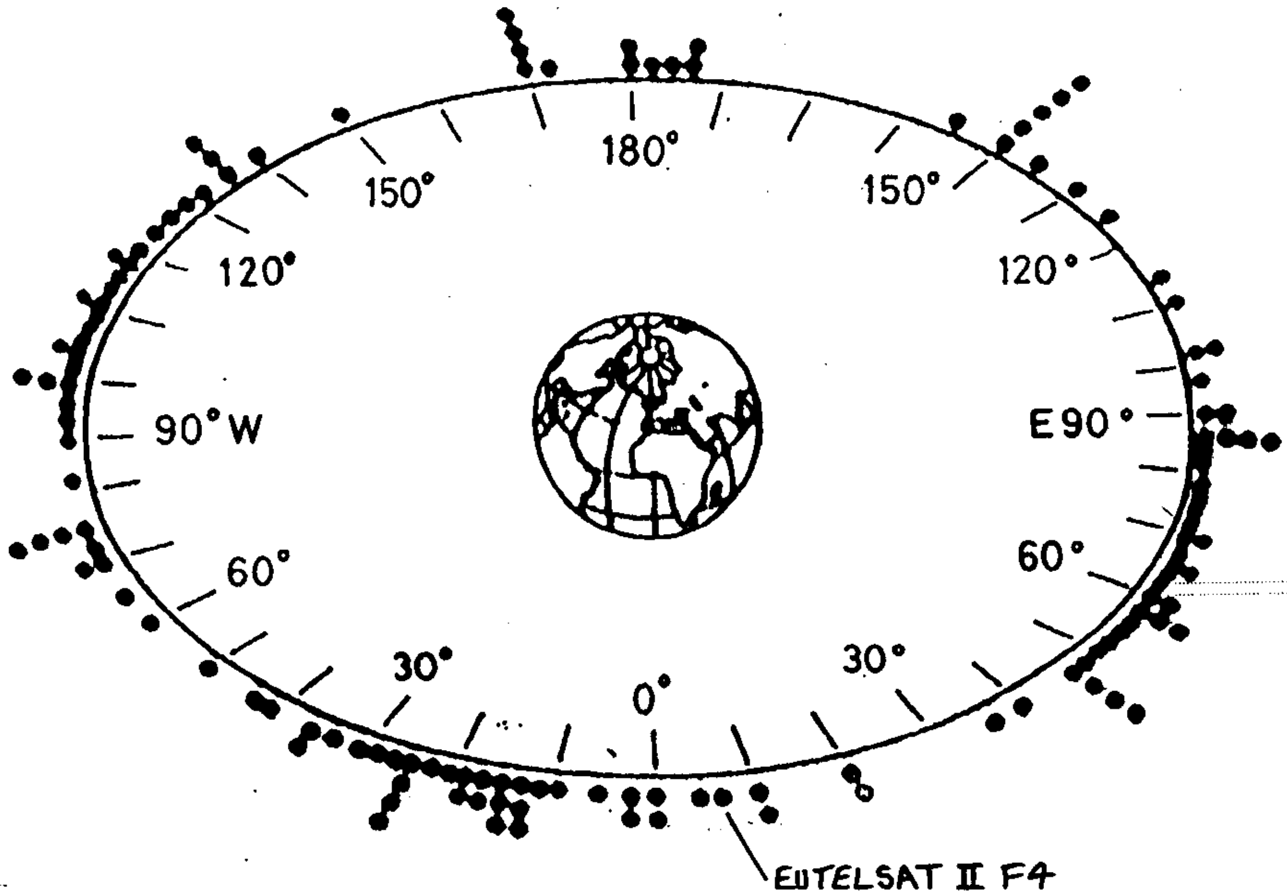
A station configured for receive-only operation typically comprises the following parts; Antenna System, LNB, Cross-site cable run and Receiver.

The antenna system comprises the reflector, Az/El mount, feed/feed-support structure. The reflector may consist of a solid piece of spun metal, or it may be constructed from several smaller sections, in which case it is known as a segmented antenna. Some antennas have been constructed using a reflector made of wire-mesh, but these tend to be cheaper, lower-performance units. The reflector is secured to the mounting structure (or king-post) by the Az/El (pronounced Az-over-El) mount or 'Truss mount'. This is a mechanism which allows the antenna pointing to be changed in both Azimuth (clockwise/anticlockwise), and Elevation (Up/Down) directions. In some cases a 'Polar-mount' may be used. This is similar to the Az/El mount, but is designed in such a way that as the antenna is swung in Azimuth, the Elevation changes automatically so as to track the orbital arc of satellites. For receive-only antennas, a single reflector system is normally used and it may be either prime- or offset-focus. The feed usually has just one output port (single-port feed) and will normally be required to be manually adjusted for correct polarisation (although the more expensive examples of satellite TV reception system may employ mechanical, electrical or electro-mechanical means of switching polarisation). The feed will also normally be capable of operation at only one of C or Ku-Band, and only one of Linear or Circular polarisation. This is usually not a problem as it will already be known what satellite the required signal is on, and hence the signal's frequency and polarisation. More complex feeds, capable of dual-frequency and dual-polarisation operation, are required when it is desired to receive two or more signals of differing characteristics.

As mentioned earlier, no antenna is perfect, and due to these imperfections signals will be picked up from sources other than the desired one. Such unwanted sources will include noise from the ground due to reflector over-illumination and reflector-edge fringe patterns, small amounts of unwanted signals seen from satellites in orbits close to the wanted satellite, and small amounts of signal picked up from the opposite signal polarisation (known as cross-polarisation interference). In addition, the antenna will be 'seeing' a certain amount of noise which is being emitted by the stars and planets etc way out in space. The noise contribution of these entities varies according to the frequency of operation, and the amount of contribution is summarised in the diagram 'Sky Noise'. Note how the noise temperature increases as the antenna elevation is decreased - a result of the antenna beginning to 'see' a greater portion of the earth's surface which is a relatively 'hot' body with a noise temperature of around 290 K.

Because the final performance of a receive system is not only dependant upon the size of the reflector, but also dependant upon the antenna efficiency and how much unwanted energy the antenna gathers, a concept known as G/T is used to characterise the quality of the receive system. This is literally a measure of how much gain (collection of wanted signal) that the system has, over and above the amount of unwanted signals (noise) that it is collecting. The calculation of G/T for a particular system can be somewhat involved and is dealt with later in this course. Since G/T is really a base-line measure of the quality of the receive system, it is also often referred to as the receive station 'Figure of Merit'.

GEOSTATIONARY CONJESTION



conjest.drw

COMMUNICATION FREQUENCY BANDS

OFF-AIR BROADCAST BANDS

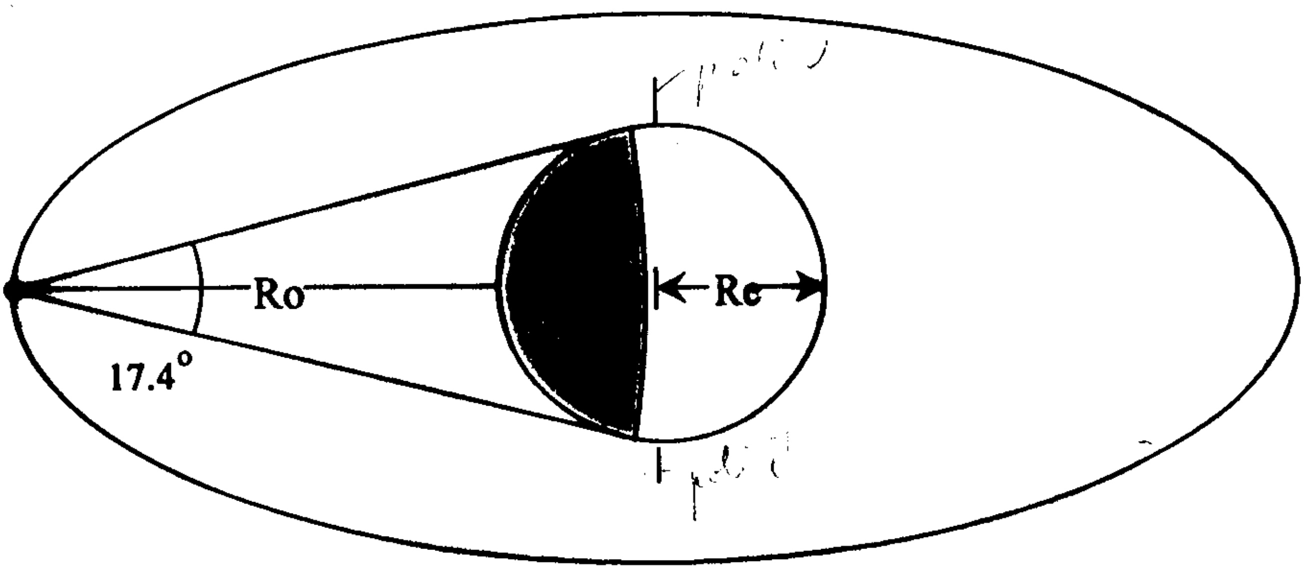
Broadcast Service	Bandwidth (MHz)
AM Radio	0.5 - 1.6
Shortwave Radio	1.6 - 30
CB Radio	27
VHF Channels 2-6	54 - 82
FM Radio	88 - 106
VHF Channels 7-13	174 - 210
UHF TV	470 - 884

SATELLITE BROADCAST BANDS

Band Name	Bandwidth (GHz) = 1000MHz	
L-band	1.53 - 2.70	MOBILE
S-band	1.50 - 2.70	MOBILE
C-band	3.40 - 4.20	COMMERCIAL
	4.40 - 4.70	COMMERCIAL
	5.725 - 6.425	COMMERCIAL
X-band	7.25 - 7.75	MILITARY
	7.90 - 8.40	MILITARY
Ku-band	10.95 - 14.50	COMMERCIAL/MILITARY
Ka-band	17.7 - 21.2	COMMERCIAL/MILITARY
K-band	27.5 - 31.0	COMMERCIAL/MILITARY

freqband.drw

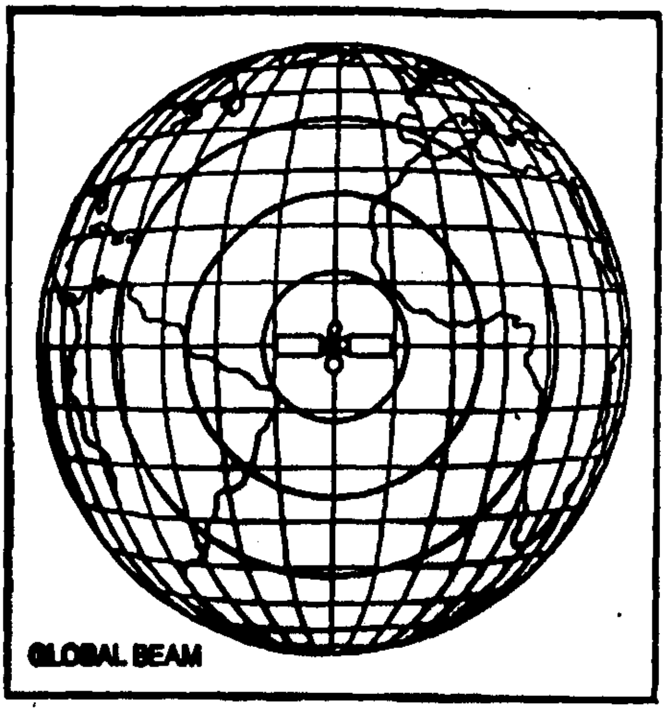
GEOSTATIONARY EARTH COVERAGE

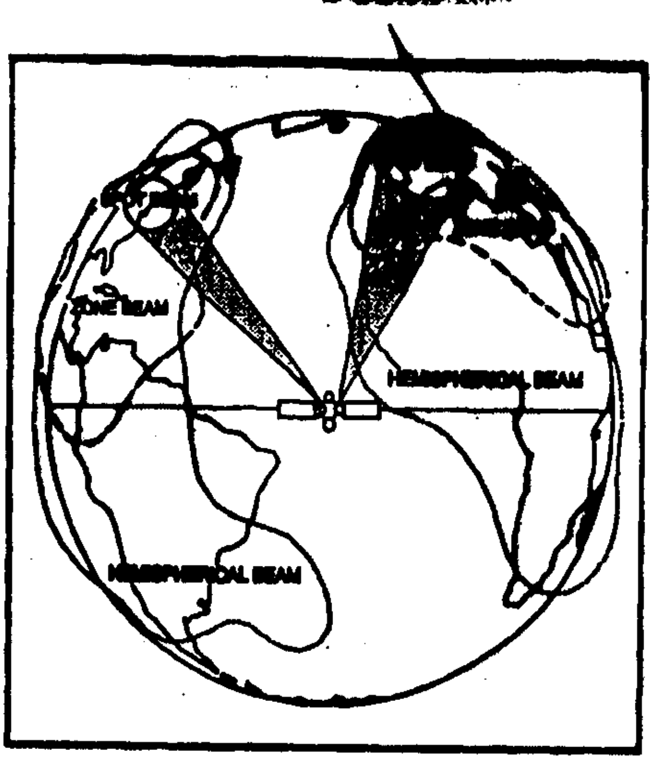


Re = earth's radius = 6`378 km
Ro = satellite altitude = 35`786 km

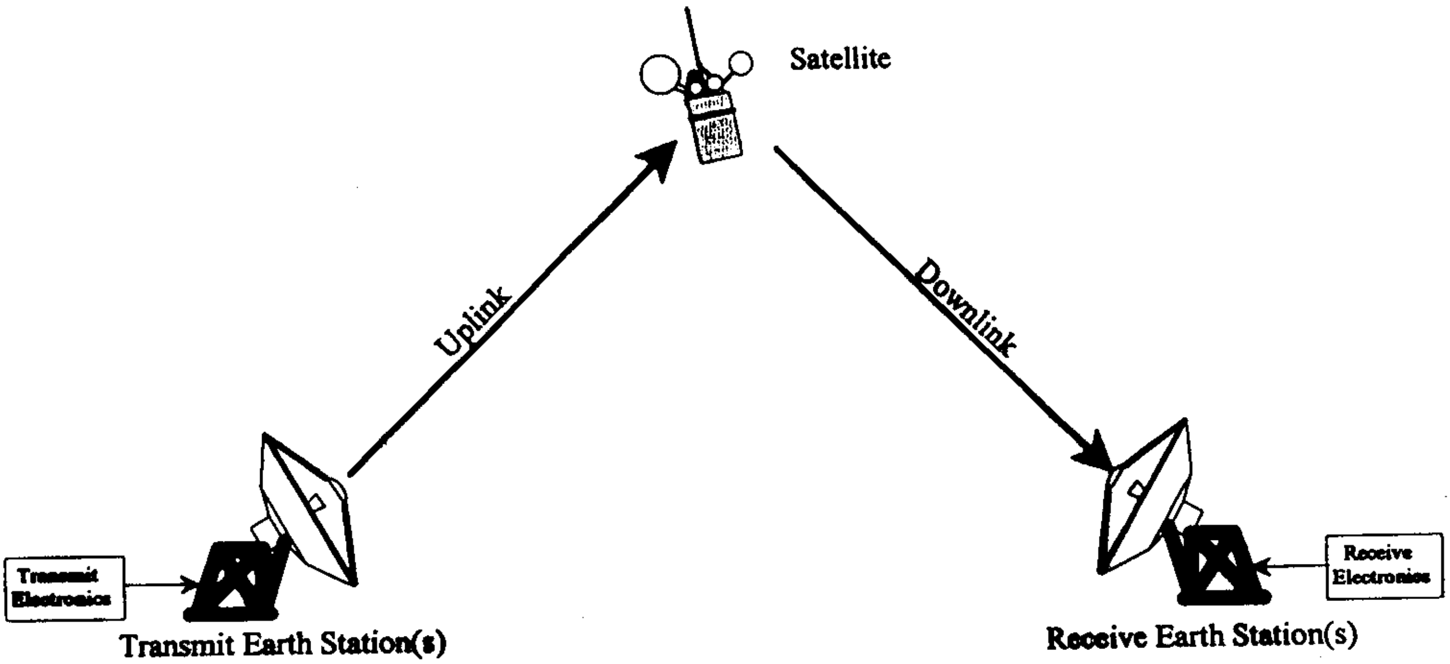
geo_cov.drw

SATELLITE BEAMS

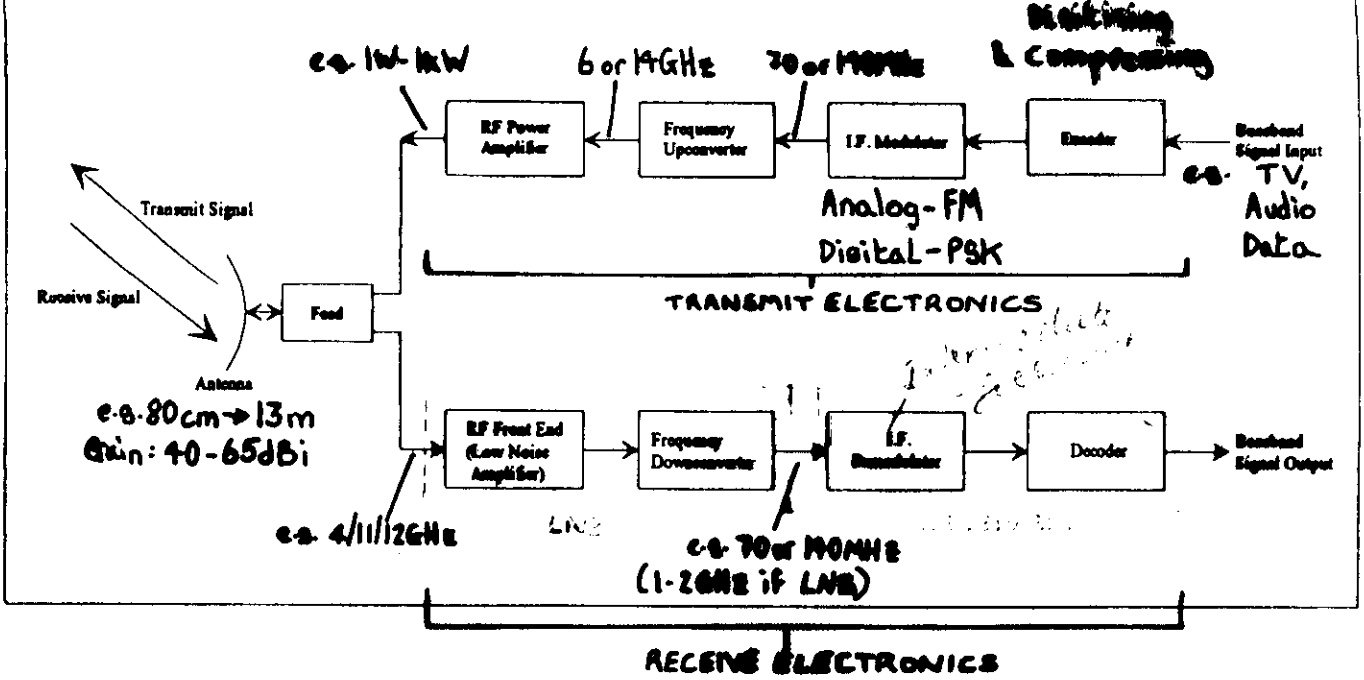




THE SATELLITE COMMUNICATIONS LINK



THE SATELLITE EARTH STATION



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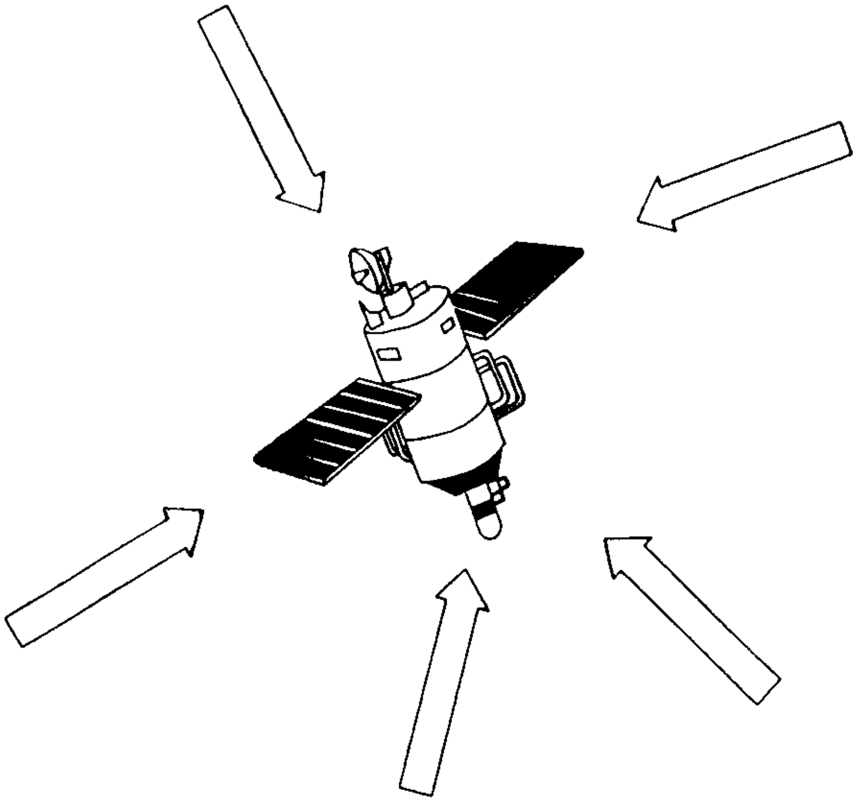
SATELLITE ACCESS TECHNIQUES

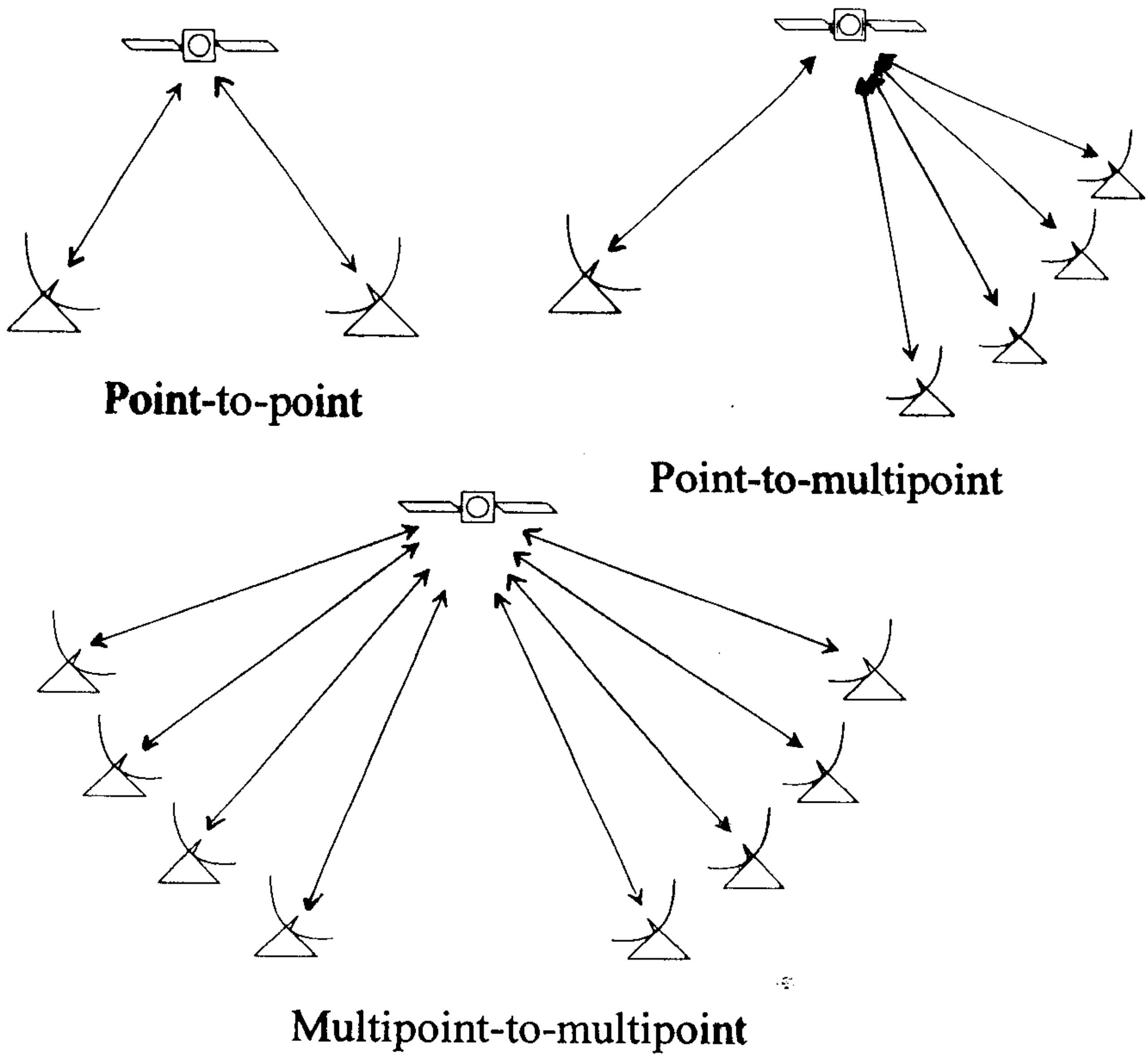


A SATELLITE'S RESOURCES WILL USUALLY BE SHARED BY A NUMBER OF INDEPENDANT USERS.

MULTIPLE ACCESS TECHNIQUES HAVE BEEN DEVELOPED TO ENABLE USERS TO HAVE ACCESS TO THE SATELLITE IN AN ORDERLY AND EFFICIENT MANNER

sat_acc.drw

NETWORK ARCHITECTURES



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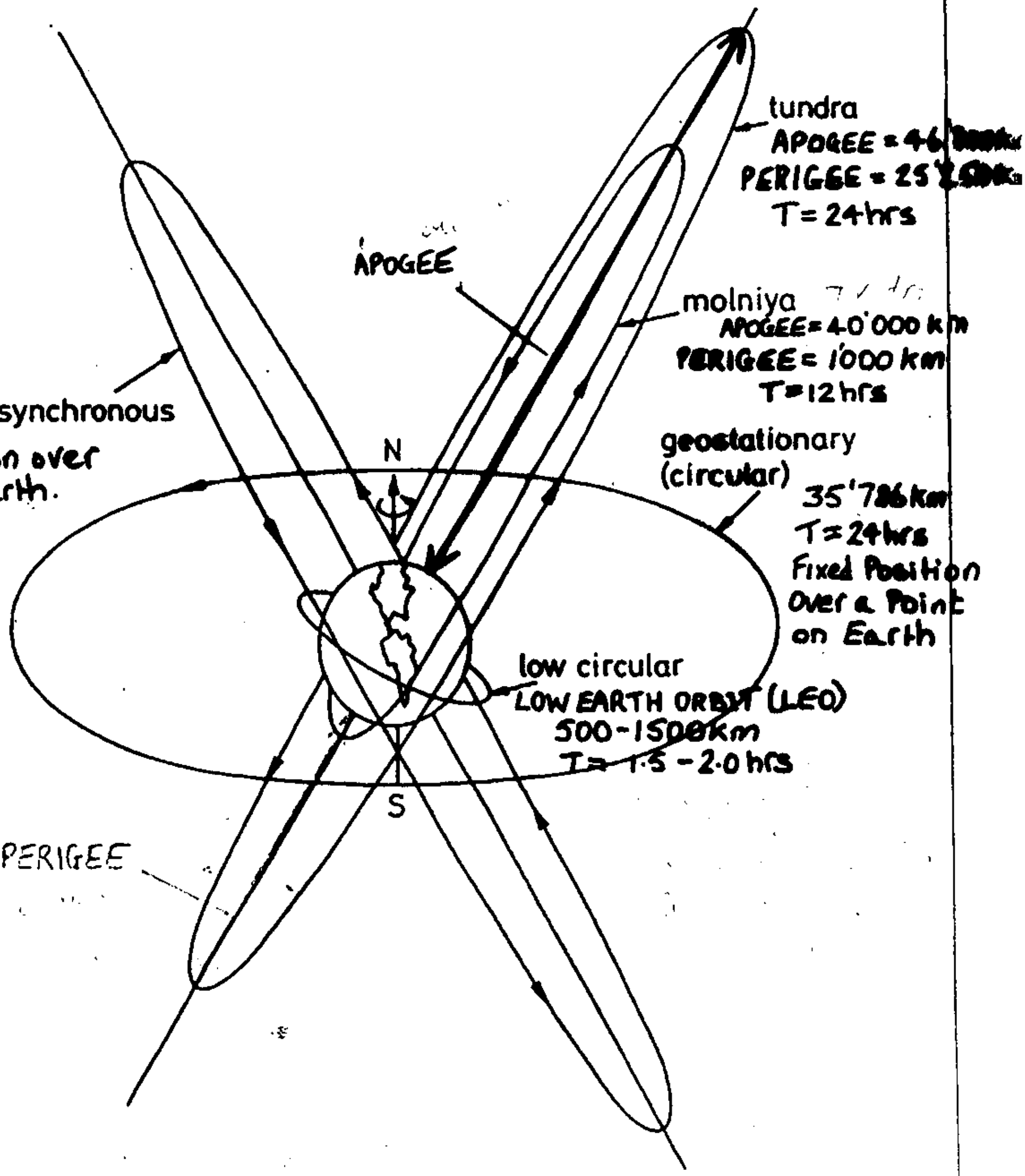
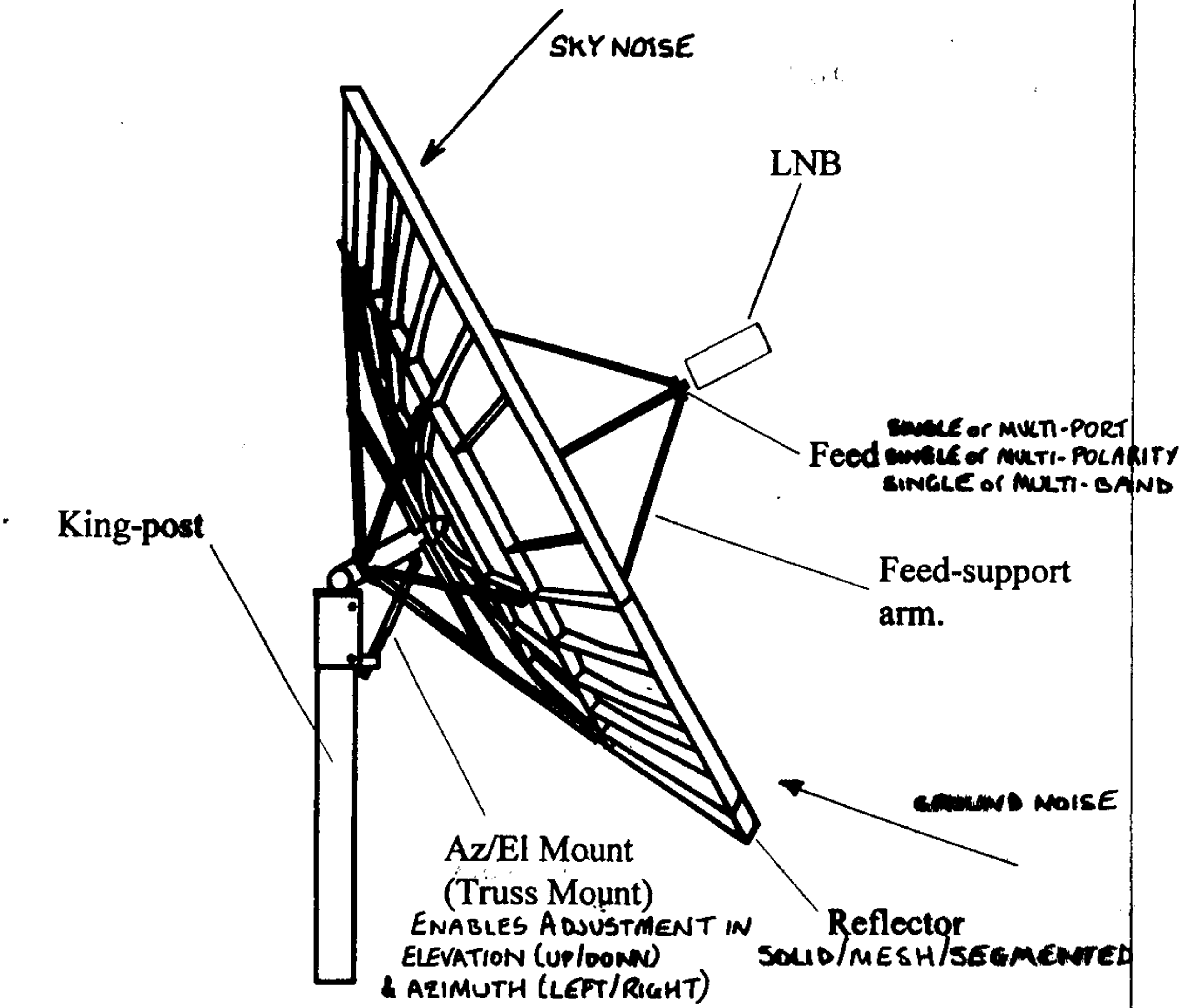
SATELLITE ORBITS



orbits.drw

PRODELIN 3.4m RECEIVE-ONLY
ANTENNA SYSTEM



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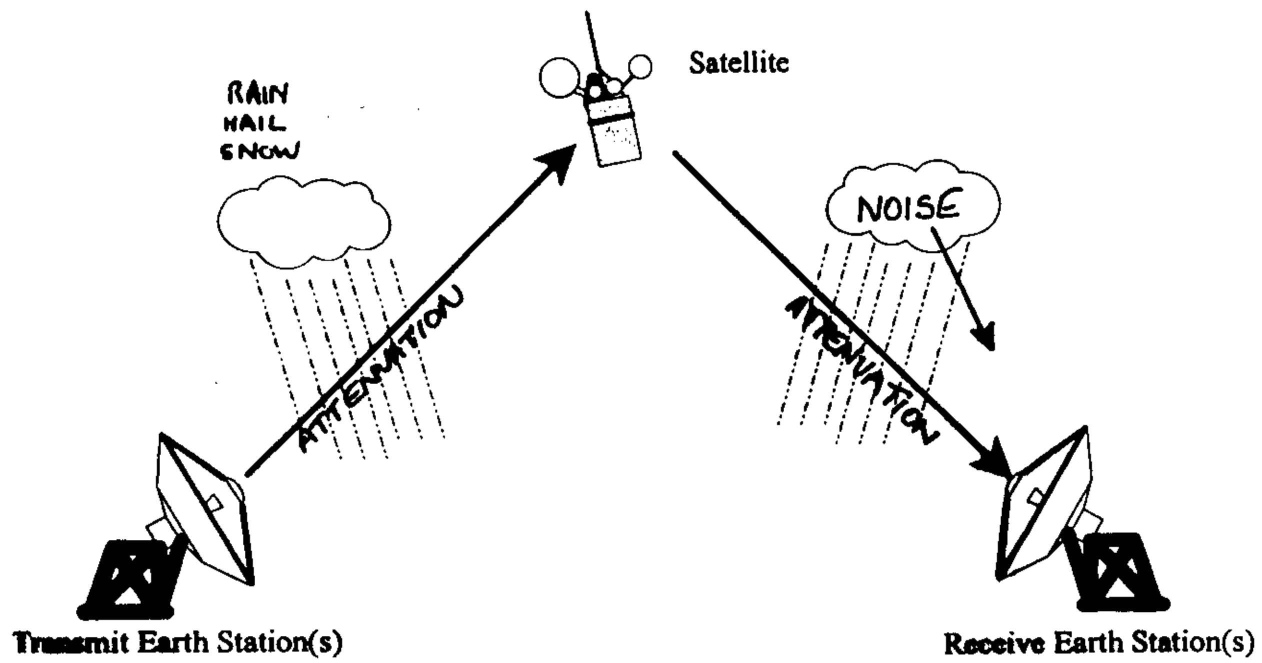
ATMOSPHERIC IMPAIRMENTS



atmos.drw

SATELLITE ANTENNA SYSTEMS

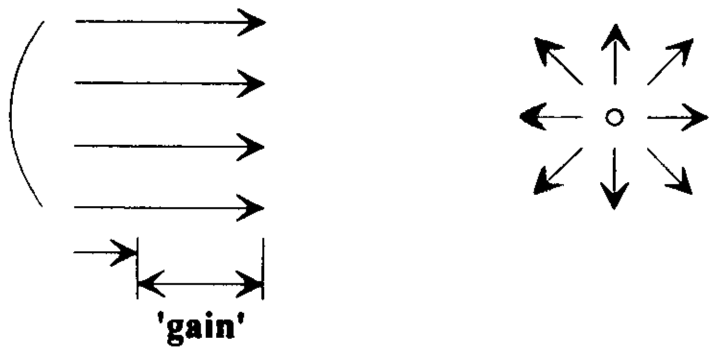
Important points about satellite antennas are;

i) **Antennas obey the principle of reciprocity. That is; the behaviour of an antenna for a given signal is the same whether it is being used to transmit or to receive.**

ii) **The gain of a parabolic antenna is directly related to it's area, or '*aperture*', and to the frequency of the transmitted/received signal.**

iii) **Antennas are passive devices and therefore do not have 'gain' in the true sense of the word. The 'gain' of an antenna is actually a measure of it's *directivity*. That is, a measure of how much signal energy can be directed in the desired direction, as compared to a theoretical point source which radiates uniformly in all directions.**

e.g.;



iv) **A parabolic antenna is more correctly described as an *antenna system*, comprising a reflector, feedhorn, and the LNB which houses a small monopole used to translate the wave energy collected by the reflector/feed into electrical energy.**

v) **The feed performs the dual purpose of focusing the signal energy onto the reflector surface, as well as seperating the transmit and receive signals.**

vi) **The antenna can never be perfect and so will collect signals from sources and directions other than the desired one. This is seen as noise and interference to the wanted signal.**