UNIT IV EARTH SEGMENT

4.1 Earth Station Technology:

The earth segment of a satellite communications system consists of the transmit and receive earth stations. The simplest of these are the home TV receive-only (TVRO) systems, and the most complex are the terminal stations used for international communications networks. Also included in the earth segment are those stations which are on ships at sea, and commercial and military land and aeronautical mobile stations.

As mentioned in earth stations that are used for logistic support of satellites, such as providing the telemetry, tracking, and command (TT&C) functions, are considered as part of the space segment.

4.1.1 Terrestrial Interface:

Earth station is a vital element in any satellite communication network. The function of an earth station is to receive information from or transmit information to, the satellite network in the most cost-effective and reliable manner while retaining the desired signal quality. The design of earth station configuration depends upon many factors and its location. But it is fundamentally governed by its

Location which are listed below,

- In land
- On a ship at sea
- Onboard aircraft

The factors are

- Type of services
- Frequency bands used
- Function of the transmitter
- Function of the receiver
- Antenna characteristics
4.1.2 Transmitter and Receiver

Any earth station consists of four major subsystems

- Transmitter
- Receiver
- Antenna • Tracking equipment

➢ Two other important subsystems are
- Terrestrial interface equipment
- Power supply

➢ The earth station depends on the following parameters

- Transmitter power
- Choice of frequency
- Gain of antenna
- Antenna efficiency
- Antenna pointing accuracy
- Noise temperature

The functional elements of a basic digital earth station are shown in the below figure.
Digital information in the form of binary digits from terrestrial networks enters earth station and is then processed (filtered, multiplexed, formatted etc.) by the base band equipment.

- The encoder performs error correction coding to reduce the error rate, by introducing extra digits into digital stream generated by the base band equipment. The extra digits carry information.

- In satellite communication, I.F carrier frequency is chosen at 70 MHz for communication using a 36 MHz transponder bandwidth and at 140 MHz for a transponder bandwidth of 54 or 72 MHz.

- On the receive side, the earth station antenna receives the low-level modulated R.F carrier in the downlink frequency spectrum.

- The low noise amplifier (LNA) is used to amplify the weak received signals and improve the signal to Noise ratio (SNR). The error rate requirements can be met more easily.

- R.F is to be reconverted to I.F at 70 or 140 MHz because it is easier design a demodulation to work at these frequencies than 4 or 12 GHz.

- The demodulator estimate which of the possible symbols was transmitted based on observation of the received if carrier.

- The decoder performs a function opposite that of the encoder. Because the sequence of symbols recovered by the demodulator may contain errors, the decoder must use the uniqueness of the redundant digits introduced by the encoder to correct the errors and recover information-bearing digits.

- The information stream is fed to the base-band equipment for processing for delivery to the terrestrial network.

- The tracking equipments track the satellite and align the beam towards it to facilitate communication.
4.1.3. Earth Station Tracking System:

Tracking is essential when the satellite drift, as seen by an earth station antenna is a significant fraction of an earth station’s antenna beam width.

An earth station’s tracking system is required to perform some of the functions such as

i) Satellite acquisition
ii) Automatic tracking
iii) Manual tracking
iv) Program tracking.

4.2 Antenna Systems:
The antenna system consist of

- Feed System
- Antenna Reflector
- Mount
- Antenna tracking System

4.2.1 FEED SYSTEM

The feed along with the reflector is the radiating/receiving element of electromagnetic waves. The reciprocity property of the feed element makes the earth station antenna system suitable for transmission and reception of electromagnetic waves.

The way the waves coming in and going out is called feed configuration Earth Station feed systems most commonly used in satellite communication are:

i) Axi-Symmetric Configuration
ii) Asymmetric Configuration
i) Axi-ASymmetric Configuration

In an axi-symmetric configuration the antenna axes are symmetrical with respect to the reflector, which results in a relatively simple mechanical structure and antenna mount.
Primary Feed:

In primary, feed is located at the focal point of the parabolic reflector. Many dishes use only a single bounce, with incoming waves reflecting off the dish surface to the focus in front of the dish, where the antenna is located. When the dish is used to transmit, the transmitting antenna at the focus beams waves toward the dish, bouncing them off to space. This is the simplest arrangement.

Cassegrain:

Many dishes have the waves make more than one bounce. This is generally called as folded systems. The advantage is that the whole dish and feed system is more compact. There are several folded configurations, but all have at least one secondary reflector also called a sub reflector, located out in front of the dish to redirect the waves.

A common dual reflector antenna called Cassegrain has a convex sub reflector positioned in front of the main dish, closer to the dish than the focus. This sub reflector bounces back the waves back toward a feed located on the main dish’s center, sometimes behind a hole at the center of the main dish. Sometimes there are even more sub reflectors behind the dish to direct the waves to the fed for convenience or compactness.
Gregorian

This system has a concave secondary reflector located just beyond the primary focus. This also bounces the waves back toward the dish.

ii) Asymmetric Configuration

Offset or Off-axis feed

The performance of an axi-symmetric configuration is affected by the blockage of the aperture by the feed and the sub reflector assembly. The result is a reduction in the antenna efficiency and an increase in the side lobe levels. The asymmetric configuration can remove this limitation. This is achieved by offsetting the mounting arrangement of the feed so that it does not obstruct the main beam. As a result, the efficiency and side lobe level performance are improved.

4.2.2 ANTENNA REFLECTOR:

Mostly parabolic reflectors are used as the main antenna for the earth stations because of the high gain available from the reflector and the ability of focusing a parallel beam into a point at the focus where the feed, i.e., the receiving/radiating element is located. For large antenna systems more than one reflector surfaces may be used in as in the cassegrain antenna system.

Earth stations are also classified on the basis of services for example:

1. Two way TV, Telephony and data
2. Two way TV
3. TV receive only and two way telephony and data
4. Two way data

From the classifications it is obvious that the technology of earth station will vary considerably on the performance and the service requirements of earth station. For mechanical design of parabolic reflector the following parameters are required to be considered:
The size of the reflector depends on transmit and receive gain requirement and beamwidth of the antenna. Gain is directly proportional to the antenna diameter whereas the beamwidth is inversely proportional to the antenna diameter. For high inclination angle of the satellite, the tracking of the earth station becomes necessary when the beamwidth is too narrow.

The gain of the antenna is given by

\[
Gain = \frac{\eta 4\pi A_{\text{eff}}}{\lambda^2}
\]

Where \( A_{\text{eff}} \) is the aperture
\( \lambda \) is wave length
\( \eta \) is efficiency of antenna system

For a parabolic antenna with circular aperture diameter \( D \), the gain of the antenna is:

\[
Gain = \frac{\eta 4\pi}{\lambda^2} \left( \frac{\pi D^2}{4} \right) = \eta \left( \frac{\pi D}{\lambda} \right)^2
\]
The overall efficiency of the antenna is the net product of various factors such as

1. Cross Polarization
2. Spill over
3. Diffraction
4. Blockage
5. Surface accuracy
6. Phase error
7. Illumination

In the design of feed, the ratio of focal length $F$ to the diameter of the reflector $D$ of the antenna system control the maximum angle subtended by the reflector surface on the focal point. Larger the $F/D$ ratio larger is the aperture illumination efficiency and lower the cross polarization.

4.2.3 ANTENNA MOUNT:

Type of antenna mount is determined mainly by the coverage requirement and tracking requirements of the antenna systems. Different types of mounts used for earth station antenna are:

i) The Azimuth–elevation mount:

This mount consists of a primary vertical axis. Rotation around this axis controls the azimuth angle. The horizontal axis is mounted over the primary axis, providing the elevation angle control.

ii) The X-Y mount.

It consists of a horizontal primary axis (X-axis) and a secondary axis (Y-axis) and at right angles to it. Movement around these axes provides necessary steering.
4.2.4 ANTENNA TRACKING SYSTEM:

Tracking is essential when the satellite drift, as seen by an earth station antenna is a significant fraction of an earth station’s antenna beam width.

An earth station’s tracking system is required to perform some of the functions such as

i) Satellite acquisition
ii) Automatic tracking
iii) Manual tracking
iv) Program tracking.

Recent Tracking Techniques:

There have been some interesting recent developments in auto-track techniques which can potentially provide high accuracies at a low cost.

In one proposed technique the sequential lobing technique has been implemented by using rapid electronic switching of a single beam which effectively approximates simultaneous lobbing.

4.3 Receive-Only Home TV Systems:

Planned broadcasting directly to home TV receivers takes place in the Ku (12-GHz) band. This service is known as direct broadcast satellite (DBS) service.

There is some variation in the frequency bands assigned to different geographic regions. In the Americas, for example, the down-link band is 12.2 to 12.7 GHz.

The comparatively large satellite receiving dishes [ranging in diameter from about 1.83 m (6 ft) to about 3-m (10 ft) in some locations], which may be seen in some “backyards” are used to receive downlink TV signals at C band (4 GHz).
Originally such downlink signals were never intended for home reception but for network relay to commercial TV outlets (VHF and UHF TV broadcast stations and cable TV “head-end” studios).

4.3.1 **The Indoor unit:**

Equipment is now marketed for home reception of C-band signals, and some manufacturers provide dual C-band/Ku-band equipment. A single mesh type reflector may be used which focuses the signals into a dual feed horn, which has two separate outputs, one for the C-band signals and one for the Ku-band signals.

Much of television programming originates as *first generation signals*, also known as *master broadcast quality signals*.

These are transmitted via satellite in the C band to the network head-end stations, where they are retransmitted as compressed digital signals to cable and direct broadcast satellite providers.

- Another of the advantages, claimed for home C-band systems, is the larger number of satellites available for reception compared to what is available for direct broadcast satellite terms.

- Although many of the C-band transmissions are scrambled, there are free channels that can be received, and what are termed “wild feeds.”

- These are also free, but unannounced programs, of which details can be found in advance from various publications and Internet sources.

- C-band users can also subscribe to pay TV channels, and another advantage claimed is that subscription services are cheaper than DBS or cable because of the multiple-source programming available.

- The most widely advertised receiving system for C-band system appears to be 4DTV manufactured by Motorola.
This enables reception of:

- Free, analog signals and “wild feeds”
- VideoCipher II plus subscription services
- Free DigiCipher 2 services
- Subscription DigiCipher 2 services

Figure 4.3 TVRO System block diagrams
4.3.2 The outdoor unit:

This consists of a receiving antenna feeding directly into a low-noise amplifier/converter combination. A parabolic reflector is generally used, with the receiving horn mounted at the focus. A common design is to have the focus directly in front of the reflector, but for better interference rejection, an offset feed may be used as shown.

Comparing the gain of a 3-m dish at 4 GHz with a 1-m dish at 12 GHz, the ratio $D/l$ equals 40 in each case, so the gains will be about equal. Although the free-space losses are much higher at 12 GHz compared with 4 GHz.

The downlink frequency band of 12.2 to 12.7 GHz spans a range of 500 MHz, which accommodates 32 TV/FM channels, each of which is 24-MHz wide. Obviously, some overlap occurs between channels, but these are alternately polarized left-hand circular (LHC) and right-hand circular (RHC) or vertical/horizontal, to reduce interference to acceptable levels. This is referred to as polarization interleaving. A polarizer that may be switched to the desired polarization from the indoor control unit is required at the receiving horn.

The receiving horn feeds into a low-noise converter (LNC) or possibly a combination unit consisting of a low-noise amplifier (LNA) followed by a converter.

The combination is referred to as an LNB, for low-noise block. The LNB provides gain for the broadband 12-GHz signal and then converts the signal to a lower frequency range so that a low-cost coaxial cable can be used as feeder to the indoor unit.

The signal fed to the indoor unit is normally a wideband signal covering the range 950 to 1450 MHz. This is amplified and passed to a tracking filter which selects the desired channel, as shown in Fig.

As previously mentioned, polarization interleaving is used, and only half the 32 channels will be present at the input of the indoor unit for any one setting of the antenna polarizer. This eases the job of the tracking filter, since alternate channels are well separated in frequency.

The selected channel is again down converted, this time from the 950- to 1450-MHz range to a fixed intermediate frequency, usually 70 MHz although other values in the very high frequency (VHF) range are also used.
The 70-MHz amplifier amplifies the signal up to the levels required for demodulation. A major difference between DBS TV and conventional TV is that with DBS, frequency modulation is used, whereas with conventional TV, amplitude modulation in the form of *vestigial single side-band* (VSSB) is used.

The 70-MHz, FM *intermediate frequency* (IF) carrier therefore must be demodulated, and the baseband information used to generate a VSSB signal which is fed into one of the VHF/UHF channels of a standard TV set.

4.4 Master Antenna TV System:

A *master antenna TV* (MATV) system is used to provide reception of DBS TV/FM channels to a small group of users, for example, to the tenants in an apartment building. It consists of a single outdoor unit (antenna and LNA/C) feeding a number of indoor units, as shown in Fig.

It is basically similar to the home system already described, but with each user having access to all the channels independently of the other users. The advantage is that only one outdoor unit is required, but as shown, separate LNA/Cs and feeder cables are required for each sense of polarization.

Compared with the single-user system, a larger antenna is also required (2- to 3-m diameter) in order to maintain a good signal-to-noise ratio at all the indoor units.

Where more than a few subscribers are involved, the distribution system used is similar to the *community antenna* (CATV) system described in the following section.
4.5 Community Antenna TV System:

The CATV system employs a single outdoor unit, with separate feeds available for each sense of polarization, like the MATV system, so that all channels are made available simultaneously at the indoor receiver.

Instead of having a separate receiver for each user, all the carriers are demodulated in a common receiver-filter system, as shown in Fig. The channels are then combined into a standard multiplexed signal for transmission over cable to the subscribers.

In remote areas where a cable distribution system may not be installed, the signal can be rebroadcast from a low-power VHF TV transmitter.
Figure shows a remote TV station which employs an 8-m (26.2-ft) antenna for reception of the satellite TV signal in the C band.

Figure 4.5 One possible arrangement for the indoor unit of a community antenna TV (CATV) system.

With the CATV system, local programming material also may be distributed to subscribers, an option which is not permitted in the MATV system.

4.6 Test Equipment Measurements on G/T, C/No, EIRP:

Measurement of G/T of small antennas is easily and simply measured using the spectrum analyser method. For antennas with a diameter of less than 4.5 meters it is not normally necessary to point off from the satellite.

A step in frequency would be required into one of the satellite transponder guard bands.

However antennas with a G/T sufficiently large to enable the station to see the transponder noise floor either a step in frequency into one of the satellite transponder guard bands and/or in azimuth movement would be required.

The test signal can be provided from an SES WORLD SKIES beacon.
Procedure:

(a) Set up the test equipment as shown below. Allow half an hour to warm up, and then calibrate in accordance with the manufacturer’s procedures.

![Diagram of test equipment setup]

(b) Adjust the centre frequency of your spectrum analyzer to receive the SES WORLD SKIES beacon (data to be provided on the satellite used for testing).

(c) Carefully peak the antenna pointing and adjust the polarizer by nulling the cross polarized signal. You cannot adjust polarization when using the circularly polarized SES WORLD SKIES beacon.

(d) Configure the spectrum analyser as follows:

- Centre Frequency: Adjust for beacon or test signal frequency (to be advised).
- Use marker to peak and marker to centre functions.
  - Frequency Span: 100 KHz
  - Resolution Bandwidth: 1 KHz
Video Bandwidth: 10 Hz (or sufficiently small to limit noise variance)
Scale: 5 dB/div
Sweep Time: Automatic
Attenuator Adjust to ensure linear operation. Adjust to provide the "Noise floor delta" described in steps 7 and 8.

(e) To insure the best measurement accuracy during the following steps, adjust the spectrum analyser amplitude (reference level) so that the measured signal, carrier or noise, is approximately one division below the top line of the spectrum analyser display.

(f) Record the frequency and frequency offset of the test signal from the nominal frequency:

For example, assume the nominal test frequency is 11750 MHz but the spectrum analyser shows the peak at 11749 MHz. The frequency offset in this case is -1 MHz.

(g) Change the spectrum analyser centre frequency as specified by SES WORLD SKIES so that the measurement is performed in a transponder guard band so that only system noise power of the earth station and no satellite signals are received. Set the spectrum analyser frequency as follows: Centre Frequency = Noise slot frequency provided by the PMOC

(h) Disconnect the input cable to the spectrum analyser and confirm that the noise floor drops by at least 15 dB but no more than 25dB. This confirms that the spectrum analyser’s noise contribution has an insignificant effect on the measurement. An input attenuation value allowing a "Noise floor Delta" in excess of 25 dB may cause overloading of the spectrum analyser input. (i) Reconnect the input cable to the spectrum analyser.

(j) Activate the display line on the spectrum analyser.

(k) Carefully adjust the display line to the noise level shown on the spectrum analyser. Record the display line level.

(l) Adjust the spectrum analyser centre frequency to the test carrier frequency recorded in step (e).
(m) Carefully adjust the display line to the peak level of the test carrier on the spectrum analyser. Record the display line level.

(n) Determine the difference in reference levels between steps (l) and (j) which is the \((C+N)/N\).

(o) Change the \((C+N)/N\) to \(C/N\) by the following conversion:

\[
\left( \frac{C}{N} \right) = 10 \log_{10} \left( \frac{C+N}{N} \right) \text{ dB}
\]

This step is not necessary if the \((C+N)/N\) ratio is more than 20 dB because the resulting correction is less than 0.1 dB.

(p) Calculate the carrier to noise power density ratio \((C/No)\) using:

\[
\left( \frac{C}{N} \right) = \left( \frac{C}{No} \right) - 2.5 + 10 \log_{10}(RBW \times SA_{corr}) \text{ dB}
\]

The 2.5 dB figure corrects the noise power value measured by the log converters in the spectrum analyser to a true RMS power level, and the \(SA_{corr}\) factor takes into account the actual resolution filter bandwidth.

(q) Calculate the \(G/T\) using the following:

\[
\left( \frac{G}{T} \right) = \left( \frac{C}{No} \right) - (EIRP_{Sc}-A_{corr}) + (FSL+L_a) - 228.6 \text{ dB/K}
\]

where,

- \(EIRP_{Sc}\) – Downlink EIRP measured by the PMOC (dBW)
- \(A_{corr}\) – Aspect correction supplied by the PMOC (dB)
- \(FSL\) – Free Space Loss to the AUT supplied by the PMOC (dB)
- \(L_a\) – Atmospheric attenuation supplied by the PMOC (dB)

(r) Repeat the measurement several times to check consistency of the result.
4.7 Antenna Gain:

*Antenna gain* is usually defined as the ratio of the power produced by the *antenna* from a far-field source on the *antenna*'s beam axis to the power produced by a hypothetical lossless isotropic *antenna*, which is equally sensitive to signals from all directions.

*Figure 4.6* One possible arrangement for Measurement of Antenna Gain

Two direct methods of measuring the Rx gain can be used; integration of the Rx sidelobe pattern or by determination of the 3dB and 10dB beamwidths.

The use of pattern integration will produce the more accurate results but would require the AUT to have a tracking system. In both cases the test configurations for measuring Rx gain are identical, and are illustrated in Figure.

In order to measure the Rx gain using pattern integration the AUT measures the elevation and azimuth narrowband (±5° corrected) sidelobe patterns.

The AUT then calculates the directive gain of the antenna through integration of the sidelobe patterns. The Rx gain is then determined by reducing the directive gain by the antenna inefficiencies.
In order to measure the Rx gain using the beamwidth method, the AUT measures the corrected azimuth and elevation 3dB/10dB beamwidths. From these results the Rx gain of the antenna can be directly calculated using the formula below.

\[
G = 10 \log_{10} \left[ \frac{1}{2} \left( \frac{31000}{(\text{Az}_3 \times \text{El}_3)} + \frac{91000}{(\text{Az}_{10} \times \text{El}_{10})} \right) \right] - F_{\text{Loss}} - R_{\text{Loss}}
\]

where:

- \(G\) is the effective antenna gain (dBi)
- \(\text{Az}_3\) is the corrected azimuth 3dB beamwidth (°)
- \(\text{El}_3\) is the elevation 3dB beamwidth (°)
- \(\text{Az}_{10}\) is the corrected azimuth 10dB beamwidth (°)
- \(\text{El}_{10}\) is the elevation 10dB beamwidth (°)
- \(F_{\text{Loss}}\) is the insertion loss of the feed (dB)
- \(R_{\text{Loss}}\) is the reduction in antenna gain due to reflector inaccuracies, and is given by:

\[
R_{\text{Loss}} = 4.922998677(S_{\text{dev}} f)^2 \text{ dB}
\]

where: \(S_{\text{dev}}\) is the standard deviation of the actual reflector surface (inches) \(f\) is the frequency (GHz)