SATELLITE LINK DESIGN

The satellite communication system design is a complex process, involved comprimises between many factors, in order to obtain maximum performance. The factors are:

1. The weight of the satellite.
2. The dc power that can be generated onboard.
3. The maximum dimensions of satellite and ground station antennas.
4. The multiple access technique used to share communication capacity between many earth stations.
5. The frequency bands of a satellite.

The weight of the satellite is limited by high cost of launching a spacecraft into geostationary orbit.
The weight of the satellite is driven by two factors.

a) The number and output power of transponders on satellites.
b) Weight of station keeping fuel.

High power transponders require lots of electrical power which can only be generated by solarcells. If increasing the total output power of transponders raises the demand for electrical power and also dimensions of solarcells.

A communication system must be designed to meet certain minimum performance standard like minimum txing power and RF bandwidth. SNR is an important parameter.

While designing a satellite system, we must try to gaurantee a minimum SNR in the receiver's baseband channel.
Increasing total o/p power of transponders raises the demand for

"SNR of a channel depends on

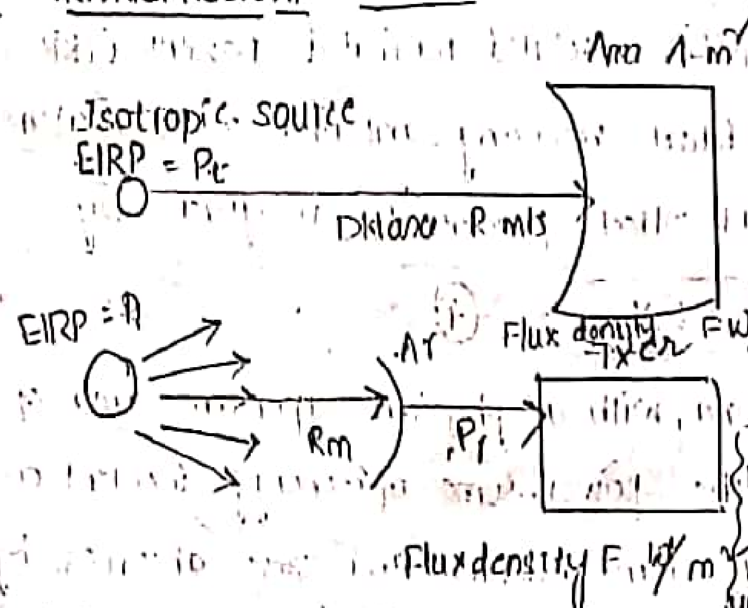
a) C/N of RF signal in receiver.

b) type of modulation used.

c) the IF and channel bandwidth in receiver."

The C/N is calculated at input of receiver and at output terminals of receiving antenna. Designing a satellite system therefore requires knowledge of required performance of uplink & downlink.

BASIC TRANSMISSION THEORY :-



The calc of power received by an earth station from a satellite Txer is fundamental to understanding satellite communication.

Consider a transmitting source in a free space radiating in all directions (uniformly) with total power 'Pt', such a source is called isotropic source. At a distance 'R' mts from hypothetical isotropic source transmitting RF power 'Pt' watts, the flux density crossing the surface of sphere with a radius 'R' is given by

$$\boxed{F = \frac{P_t}{4\pi R^2}} \quad (1)$$

All real antennas are directional. Any real antenna has a gain $g(\theta)$ is defined as the ratio of power per unit solid angle radiated in a direction θ to average power radiated per unit solid angle.

$$\boxed{G(\theta) = \frac{P(\theta)}{(P_0/4\pi)}} \quad \text{—— (2)}$$

For a transmitter ~~of~~ P_t for a driving lossless antenna, with a gain ~~g_t~~ 'G_t', the flux density in a direction of antenna at a distance R is

~~F × A~~ $$\boxed{F = \frac{P_t G_t}{4\pi R^2}} \quad \text{—— (3)}$$

$P_t G_t$: effective isolated radiated power = EIRP

If we have an ideal receiving antenna with aperture area of 'A', we would collect power 'P_r' is given by

$$\boxed{P_r = F \times A} \quad \text{—— (4)}$$

A practical antenna, with a physical aperture area of 'A_r', will not deliver the power. Some of the energy incident on aperture is reflected away from antenna and some absorbed by lossy components. This reduction in efficiency is described by using an effective aperture A_e.

$$\boxed{A_e = \eta_A \times A_r} \quad \text{—— (5)}$$

$$\eta_A : \text{efficiency} ; \begin{cases} 50 \text{ to } 75\% \text{ for paraboloid} \\ 90\% \quad \text{for horn} \end{cases}$$

The power received by a real antenna with physical receiving area 'A_r' and effective aperture 'A_e' is given as

$$\boxed{P_r = \frac{P_t G_t A_e}{4\pi R^2}} \quad \text{—— (6)}$$

The fundamental of an antenna theory is gain and area of antenna is related by

$$\boxed{G_r = \left(\frac{4\pi}{\lambda^2}\right) A_e} \quad \text{—— (7)}$$

$$G_r = \left(\frac{4\pi}{\lambda^2}\right)\left(\frac{P_r \, 4\pi R^2}{P_t G_t}\right)$$

$$P_r = \left(\frac{\lambda}{4\pi}\right)^2 \frac{P_t G_t G_r}{R^2} = \left(\frac{\lambda}{4\pi R}\right)^2 (P_t G_t G_r)$$

$$\boxed{P_r = \underbrace{\left(\frac{\lambda}{4\pi R}\right)^2}_{\text{Path loss}} P_t G_t G_r}$$

Collecting various factors, we can write

$$\boxed{P_r = (EIRP) \times \frac{\text{Received antenna gain}}{\text{Path loss } (L_p)}}$$

$$\boxed{P_r|_{db} = [EIRP + G_r - L_p] \, db} \quad \text{—— (8)}$$

The equation 8 represents in ideal condition. But in practise we need to consider

1) Atmospheric loss - due to signal attenuation by rain, water vapor.

2) Losses due to antenna at the each end of the link.

3) Possible loss of gain due to antenna mispointing

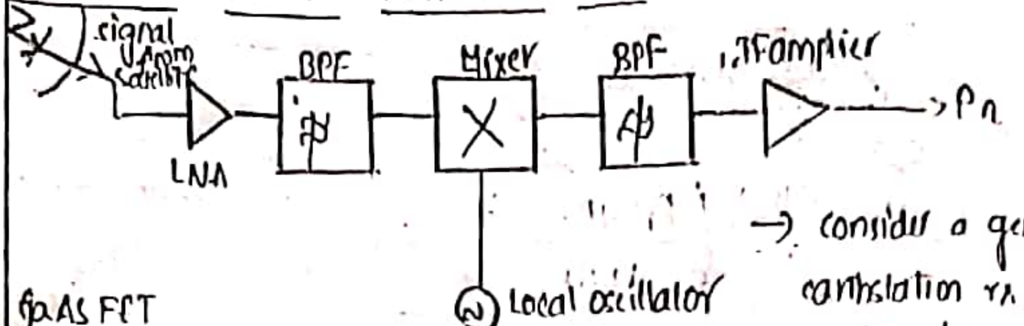
$$P_r = EIRP + G_r - L_p - \underbrace{L_a - L_{ta} - L_{ra}}$$

L_a : atmospheric loss

L_{ta} : loss associated with txing antenna,

L_{ra} : loss associated with Rxing antenna.

SYSTEM NOISE TEMPERATURE :-



→ consider a general translation rx er with antenna, RF amp, freq converter, LO, IF amplifier

→ Now above ckt can be represented by an equi noise generator.

Ga AS FET tmp → 30K – 200K

30 Kelvin for 4 GHz,

100 kelvin for 11 GHz

Equivalent ckt for above design

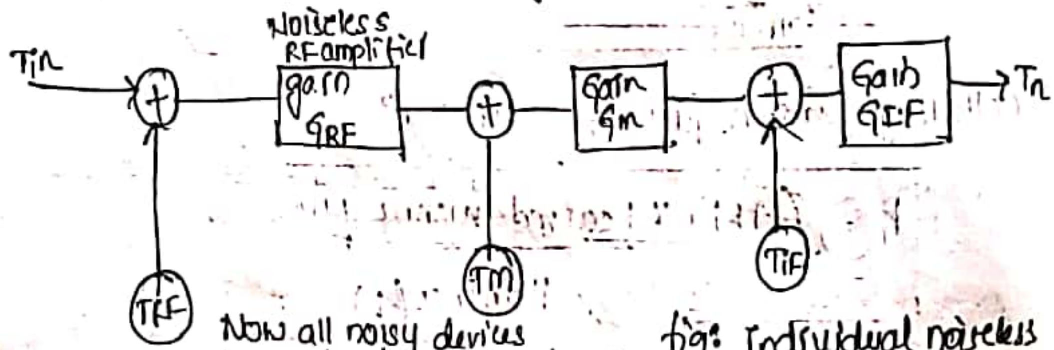


fig: Individual noiseless devices with T_g + noiseless amp & freq converter.

Now all noisy devices are replaced by a simple noise sources with T_n.

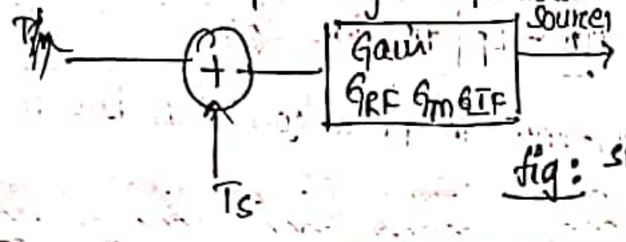


fig: single noise source

from fig1 $P_n = KT_{IF}G_{IF}B + K\,T_m G_{IF}\,G_m B + K\,T_{in}\,G_{IF}G_m G_{RF}\,[T_{RF}+T_{in}]$ — (1)

from fig2 $P_n = KG_{RF}G_m G_{IF}\,T_s B$ — (2)

From equation (1)

$$P_n = K\,G_{RF}\,G_{IF}\,G_m\,B\left[\frac{T_{IF}}{G_m G_{RF}} + \frac{T_m}{G_{RF}} + T_{RF} + T_{in}\right] \text{ — (3)}$$

from eq's (2) & (3)

$$\boxed{T_s = \frac{T_{if}}{G_m G_{RF}} + \frac{T_m}{G_{RF}} + T_{RF} + T_{in}} \text{ — (4)}$$

Noise figure is used frequently used to specify the noise generated within a device.

$$\boxed{\text{Noise figure} = \frac{(S/N)\,i/p}{(S/N)\,o/p}}$$

Because noise temperature is more useful in satellite communication systems. It is best to convert noise figure to noise temperature.

$$\boxed{T_d = T_0\,[NF-1]}$$

T_0: reference tmp = 290K

T_d: noise tmp

NF: Noise figure.

G/T ratio for earth station:-

The link equation can be rewritten in terms of C/N is

$$C/N = \frac{P_t G_t G_r}{K T_s B}\left[\frac{\lambda}{4\pi R}\right]^2$$

$$\boxed{C/N = \left[\frac{P_t G_t}{KB}\right]\left[\frac{\lambda}{4\pi R}\right]^2\left[\frac{G_r}{T_s}\right]}$$

$(C/N) \propto \left(\frac{G_r}{T_s}\right) \longrightarrow$ for determining quality in system.

$\boxed{\frac{G_r}{T_s} \text{ also called as figure of merit}}$

If you want to calculate carrier to noise ratio (downlink)

$$\boxed{C/N = \frac{\text{Power input}}{\text{Noise power}}}$$

P_r: received power of downlink

$$C/N = \frac{P_r G_r}{K T_s B G_r}$$

$\rightarrow$ A standard 'A' earth station used in intelsat N/W is required to have a G/T ratio of 40.7 dB/K at 4GHz & 5° elevation angle.

$$\boxed{C/N = \frac{P_r}{KT_sB}}$$

Satellite systems using small earthstations :-

Direct Broadcast TV (DBS-TV or DTH)

Europe – Analog - FM tx'on

USA – digital tx'on

Hughes company } — 200 television and audio channels.

Typical mass of domestic satellite — 6800 kg

4Khz → 4° spotbeam → 1.4M ; diameter of satellite antenna.

DIRECT BROADCAST SERVICE :-

C/N calculation is simplified by use of "LINK BUDGET". A link budget is a tabular form method for evaluating received power and noise power in a radio links.

LINK BUDGET FOR KU BAND DBS-TV Rx'er :-

DBS-TV terminal rxed signal power :

Transponder o/p power 160W	22.0dBW
Antenna beam on axis	34.3 db
Rxing antenna gain on axis	33.5db
Pathloss at 12.2Ghz, 38,000m path	-205.7db

Above values belongs to united states DBS TV

Edge of beam loss	– 3.0db
clearsky atmosphere	-0.4db
Rx'ed power C	-119.7dbw

DBS-TV terminal Rxed noise power

Boltzmann's constant : -228.6 dbW/K/hz :

clearsky noise temperature : 21.6 dbK.

Rxer noise bandwidth : 73.0 dbhz.

noise power : -134.0 dbW

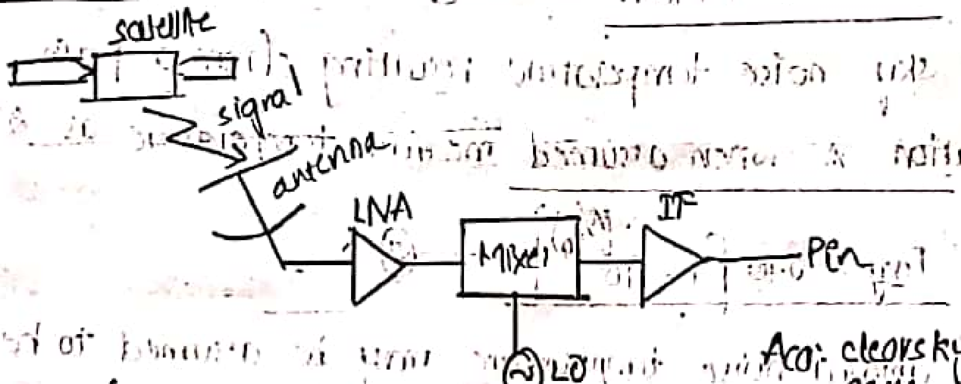
DBS-TV terminal C/N in clearsky

clearsky overall C/N : 14.3 db.

link margin over 8.6 db treshold is 5.7 db

link availability throughout US better than 99.7%.

Calculations:-



Aca: clearsky atmospheric gases

$A = (A_{ca} + A_{rain})\,db$ —— ①

T_{sky} = sky Noise temperature = $270\left[1 - 10^{-\frac{A}{10}}\right]$ —— ②

$T_S = T_{LNA} + T_A$ —— ③

T_A : Antenna noise temperature.

T_{LNA} : low noise amplifier.

$T_A = T_{sky} \times \eta_c$ —— ④

η_c : coupling coefficient.

$$\Delta N_{rain} = \left[\frac{k\,T_{s\,rain}\,B_n}{k\,T_{sca}\,B_n}\right]$$

$(C/N)_{dn\ rain}$?

downlink when rainattenuation is present.

Theory:-

The C/N ratio in home receiver will fall when rain is present in a path between satellite & receiver antenna. Much of reduction in C/N ratio is caused by sky noise temperature. The total attenuation is given as

A_a : attenuation due to clearsky atmospheric gases + attenuation due to rain

$$\boxed{A_a = A_{ca} + A_{rain}} \quad \text{--- (1)}$$

The sky noise temperature resulting from a path attenuation A when assumed medium temperature as 270K, then

$$\boxed{T_{sky} = 270\left[1 - 10^{-(A/10)}\right]} \quad \text{--- (2)}$$

The antenna noise temperature may be assumed to be equal to sky noise temperature. The coupling coefficient η_c of 90-95% is often used when calculating antenna's noise temperature.

$$\boxed{T_A = \eta_c \times T_{sky}} \quad \text{--- (3)}$$

The system noise temperature when a satellite receiver using high gain lownoise amplifier is given as

$$\boxed{T_S = T_{LNA} + T_A} \quad \text{--- (4)}$$

T_A : Antenna's noise temperature.

We will assume there are no feed losses. The increase in noise power ΔN_{rain} caused by increase in sky noise temperature,

$$\boxed{\Delta N_{rain} = 10\log_{10}\left[\frac{K T_{s\,rain} B_n}{K T_{sca} B_n}\right] \text{db}} \quad (5)$$

The total received power is reduced by attenuation caused by rain, so in rain the carrier power value is

$$\boxed{C_{rain} = [C_{ca} - A_{rain}]\ \text{db}} \quad (6)$$

The resulting C/N downlink rain gives

$$\boxed{\left(C/N\right)_{dn\,rain} = \left(C/N\right)_{dn\,ca} - A_{rain} - \Delta N_{rain}} \quad (7)$$

3

Design for uplink and downlink:-

1. The primary objective is to gaurantee continuity of link.
2. To provide many channels in a minimum capital cost

LINK BUDGET :-

$$\left(C/N\right)_{uplink} = [EIRP] + [G_r] - [L_A] - [\text{losses}] \qquad \left(C/N_0\right) = \left(C/N_0\right)_{up} + \left(C/N_0\right)_{down} \rightarrow \text{bent pipe}$$

$$\left(C/N_0\right)_{downlink} = [EIRP]_{dn} + [G_i]_{dn} - [L_A] - [K] - [BO_I]$$

BO_I : Input back of

LINK POWER BUDGET:-

$$C/N = EIRP + \left[\frac{G_r}{T_S}\right] - [\text{losses}]$$

TX

Transmission:
- Antenna gain
- TX on losses (Cables & connectors)

Antenna Misalignment loss

RX

Rx'er:-
TX'on losses (cables & connector)

$$\text{losses} = [RFL] + [AA] + [L_a] + L_p + [L_{ta}] + [L_{ra}]$$

$P_r = [EIRP] + [G_r] - [losses]$

$losses = [FSL] + [RFL] + [AML] + [AA] + [PL]$

FSL : free space tx'on loss in db

RFL : Receiver feeder loss in db.

AA : Atmospheric absorption loss in db.

AML : antenna misalignment loss

PL : Depolorisation loss.

System Noise tmp:- Thermal noise due to active & passive components.

Noise tmp of Rxer: Thermal noise due to RF amplifier, mixer and IF amplifier.

20-9-13.

* Sattelite communication link design procedure:

Step1: choose the frequency band for your system.

Step2: Determining the parameters of communication.

Step3: Determine the parameters of rxing & txing earth stations (antenna gain, temperature, efficiency etc).

Step4: Establish an uplink budget to find carrier to noise ratio up.

Step5: output power of a transponder based on transponder gains.

Step6: Establish an downlink budget to find carrier to noise ratio down.

Step7: calculate SNR in a base band channel.

Step8: Evaluate the result and compare with specific requirements.

Step 9: Choose the propagation.

Step 10: Re-design the system with modified parameters.

Design of specified C/N:

1) Hypothetical reference circuit.
2) C/N & C/I addition.
3) Reciprocal method.

Reciprocal method:-

$$\left(\frac{C}{N}\right)_0 = 1 \Big/ \left[\frac{1}{(C/N)_1} + \frac{1}{(C/N)_2} + \frac{1}{(C/N)_3} + \cdots\cdots\right] \quad \text{--- (1)}$$

$$\left(\frac{C}{N}\right)_0 = \frac{C}{[N_1 + N_2 + N_3 + \cdots\cdots]}$$

In decibels

$$\left(\frac{C}{N}\right)_0 = C\,dBW - 10\log(N_1 + N_2 + N_3 + \cdots) \text{ dB}.$$

C: single carrier power 'C'.

Specific thumbrules:-

1) If both (C/N) values are equal, $(C/N)_0$ is 3dB of either value.

20dB

$10\log x = 20$

$x = 10^2$

$x = 100$

2)

$(C/N)_{up} = 20db$

$(C/N)_{dn} = 20db$

$(C/N)_{out} = ?$

$$\left(\frac{C}{N}\right)_0 = \frac{1}{1/(C/N)_{up} + 1/(C/N)_{down}} = \frac{1}{1/100 + 1/100} = 50$$

$$\left(\frac{C}{N}\right)_{out}\Big|_{db} = 10\log(50) = 16.98\,db.$$

$(C/N)_{out} \simeq 17db$.

4) If one $\frac{C}{N}$ value is 10db smaller than other (C/N) value, $(C/N)_o$ is 0.4db smaller than lower smaller of C/N value.

5) If one C/N value is 20db or more greater than other (C/N) value, the overall (C/N) is equal to smaller of 2 (C/N) values within accuracy of decibels calculations.

Eg:- $(C/N)_{up} = 40db = 10^4$ $\quad 10\log x = 40$, $x = 10^4$

$(C/N)_{dn} = 20db = 10^2$ $\quad 10\log_{10} x = 20$

$$(C/N)_o = \frac{1}{1/10^4 + 1/10^2} = 99.0099$$

$$(C/N)_o \Big|_{db} = 10\log(99.0099)$$

$$= 19.95678$$

$$\approx 20db.$$

* Rain attenuation in uplink and downlink:-

$$(C/N)_{o,rain} = \frac{1}{\left[\frac{1}{(C/N)_{\substack{uplink\\rain}}} + \frac{1}{(C/N)_{\substack{downlink\\rain}}}\right]}$$

$$(C/N)_{o,\substack{uplink\\rain}} = \left[(C/N)_{clearair} - A_{rain}\right] db$$

$$(C/N)_{o,\substack{downlink\\rain}} = \left[(C/N)_{dnclearair} - A_{rain}\right] db$$

22-9-13

* VSAT :- [Very Small Aperture terminal]

architecture of VSAT network:-

1) One way implementation.
2) Split two way implementation (split IP).
3) Two way implementation — Star / Mesh.

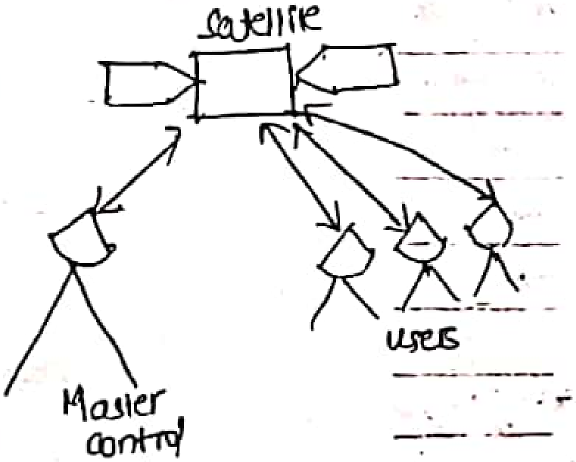
One-way implementation

TCP/IP → N/w layer

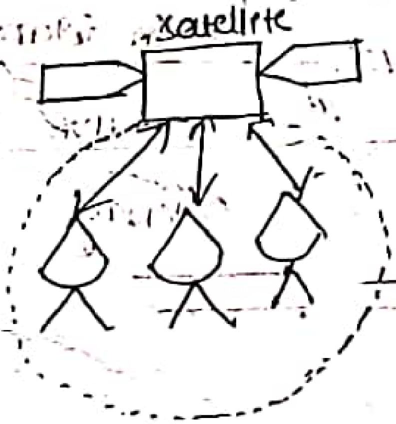
layers

1. Physical layer
2. Datalink layer
3. N/w ing layer
4. Transport layer
6. Presentation layer
5. Session layer
7. Application layer

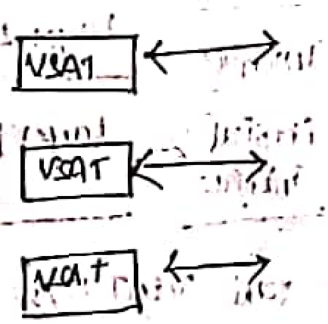
→ Star architecture



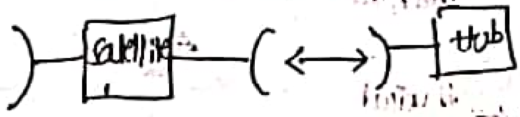
In Mesh, without design of hub station, any user can connect with another user.



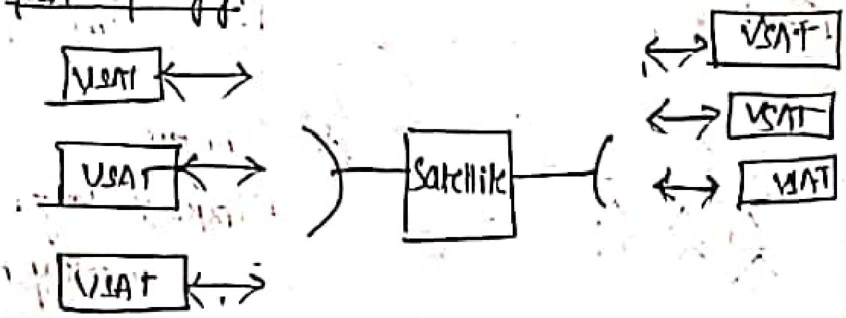
Satellite topology view:



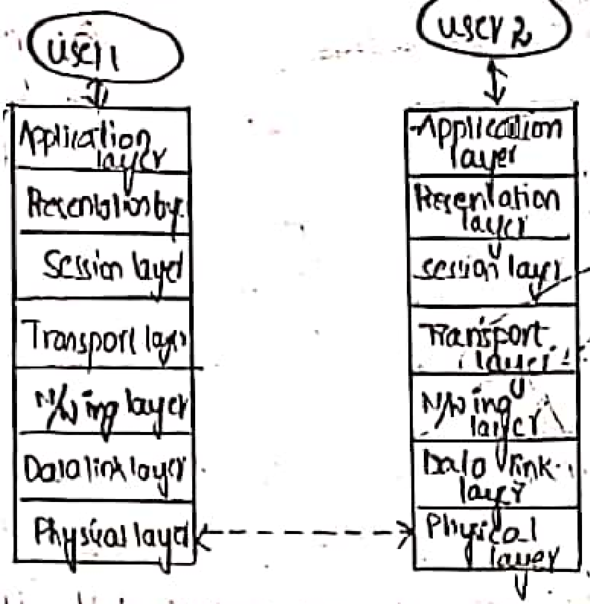
Star topology



Mesh topology:



Access Control Protocols:-



① Acknowledgement (ACK)

② Not Acknowledgement (NAK)

→ Automatic Repeat request (ARQ)

↓

used in internet protocols.

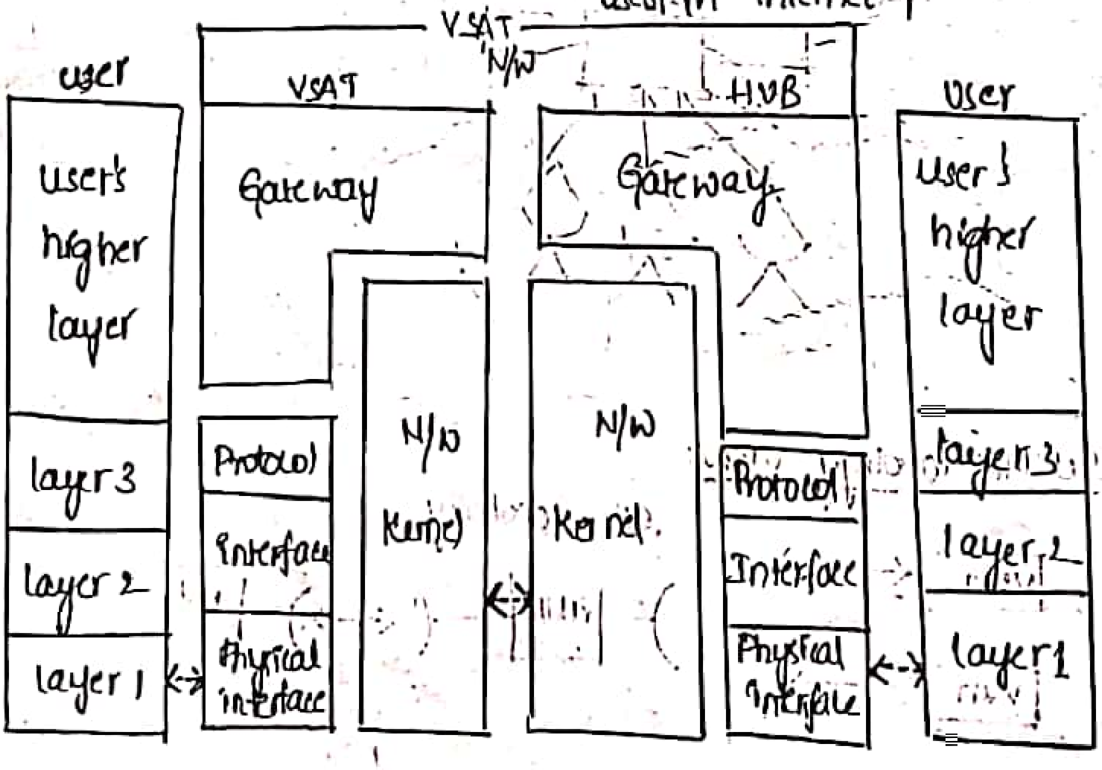


fig: Protocol architecture of star VSAT N/W "spoofing" – separating the satellite link and terrestrial link.

1. modulo-8
2. modulo-128

} operations made by users while forming a link.

modulo-8 :- user can transmit 7 packets at a time.

modulo-128 :- user can transmit 127 packets at a time. Most VSATs uses this modulo-128 operation.

VSAT EARTH STATION ENGINEERING :-

1. outdoor unit (ODU) :-
2. Inter-facility link (IFL) :-
3. Indoor Unit (IDU) :-

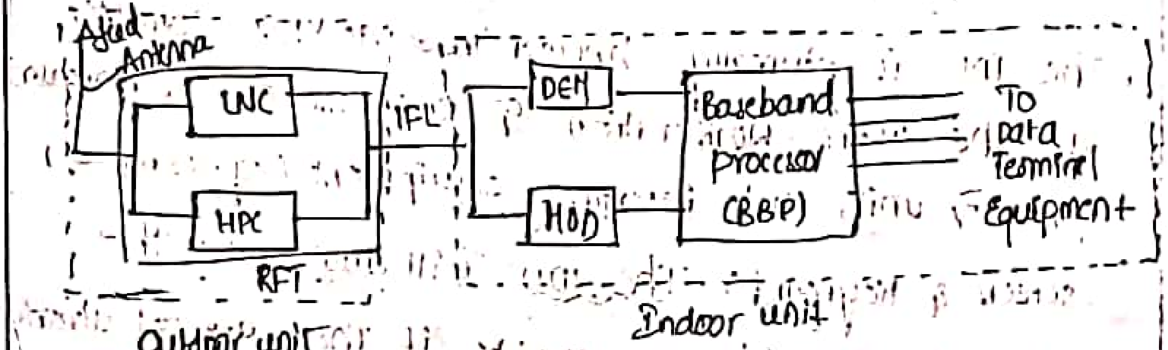
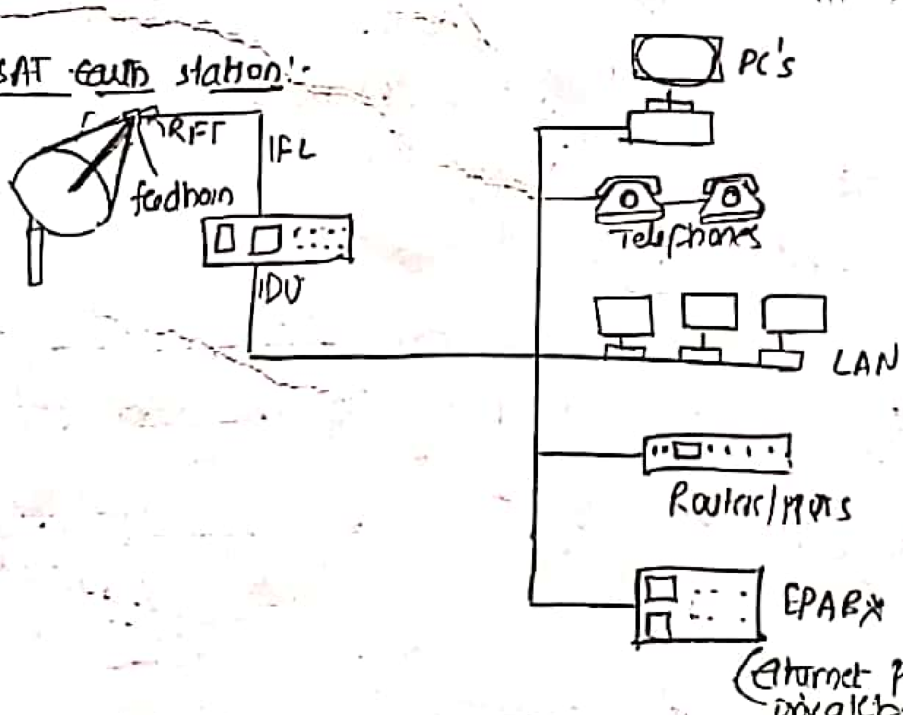


fig: VSAT earth station block dgm.

VSAT earth station :-



Horn → more coverage antenna

DTH → antenna → cassegrain-feed system.

phased array antenna → Telephone conversation

* VSAT Earth Station:-

- The VSAT outdoor unit is located where it will have a clear line of sight to the satellite & is free from casual blockage by people and/or equipment moving infront of it. It includes the Radio freq. transreceiver (RFT).

- The Interfacility link (IFL) carries the electronic signal b/w the ODU and the indoor unit as well as power cables for the ODU & control signals from the IDU.

- The IDU is normally housed in a desktop computer at the user's workstation & consists of the baseband processor units and interface equipment (eg. computer screen & keyboard). The IDU will also house the modem & mux/demux units if these are not already housed in the ODU.

6-12

UNIT-III : GLOBAL POSITIONING SYSTEM

Navigation satellite timing & Ranging.
NAVSTAR → first GPS satellite – 1978 – U.S

Later it is converted into GPS satellite.

24 GPS satellites are launched by US.

4 satellite } → constellation
together }

Placed at 12,000 kms away from the surface of earth.

L2 : precise code (public use) } ← L band
L1 : military code

GPS is a space-based satellite navigation system

Galileo – European

Glonass – Russia

Navstar – USA

GPS satellite Vehicle

- 4 atomic clcks
- 3 Ni-Cd battery
- Two solar panels
  → battery charging
  → power generation
- S band → satellite control

GPS signals:-

- signals driven by an atomic clock.
  → fundamental freq at 10.23 MHz.
- 2 carrier signals (sine waves)

→ L1 : $f = 1575.43$ MHz ($\lambda = 19$ cm)
→ L2 : $f = 1227.60$ MHz ($\lambda = 24$ cm)

→ephemeris → stores information in a tabular form.
⇒ almanacs → status of satellites orbit

* GPS are made up of 3 segment
1. space segment :- 6 orbital planes are placed with an inclination of 55°.
2. user segment.
3. control segment.

4- 1 sidereal period = 2 [time of GPS to rotate].

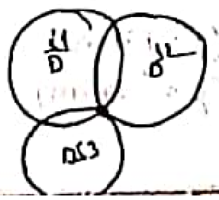
* CS consists of 3 entities
1. Master control system.
2. Monitor station.
3. Gnd antennas.

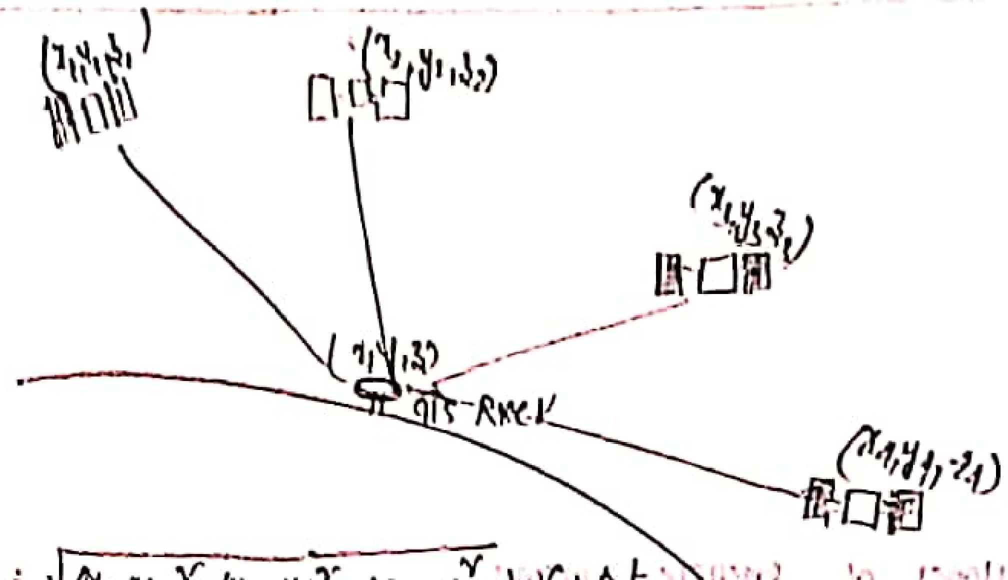
- Rxer performs following tasks:
1. selecting one or more satellites.
2. Acquiring GPS signals.
3. Measuring & tracking.
4. Recovering navigation data.

GPS provides

- SPS → standard positioning service → C/A code → used for general purpose. → civilian purpose
- PPS → precise positioning service.

- C/A → coarse/acquisition or clear/access. ← SPS
- PPS → both P code and C/A code.
- Trilateration method → method used to locate the user on the surface of the earth.





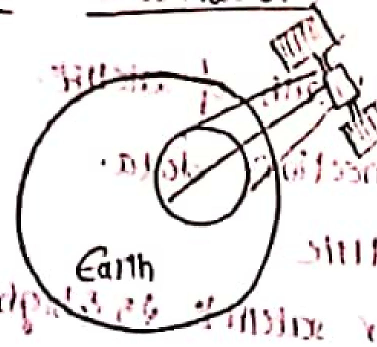
$$\rho_1 = \sqrt{(x_1-x)^2+(y_1-y)^2+(z_1-z)^2} + c\cdot\Delta t$$

$$\rho_2 = \sqrt{(x_2-x)^2+(y_2-y)^2+(z_2-z)^2} + c\cdot\Delta t \qquad \underline{c = \text{speed}}$$

$$\rho_3 = \sqrt{(x_3-x)^2+(y_3-y)^2+(z_3-z)^2} + c\cdot\Delta t$$

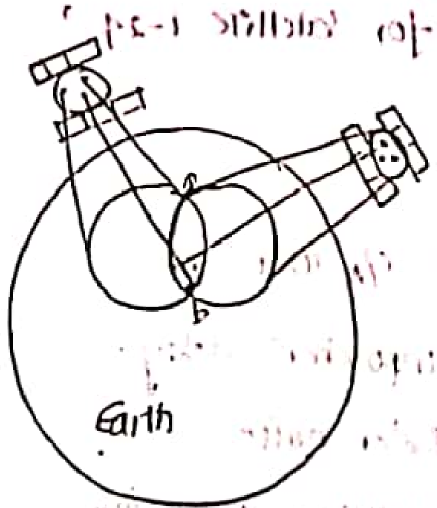
$$\rho_4 = \sqrt{(x_4-x)^2+(y_4-y)^2+(z_4-z)^2} + c\cdot\Delta t$$

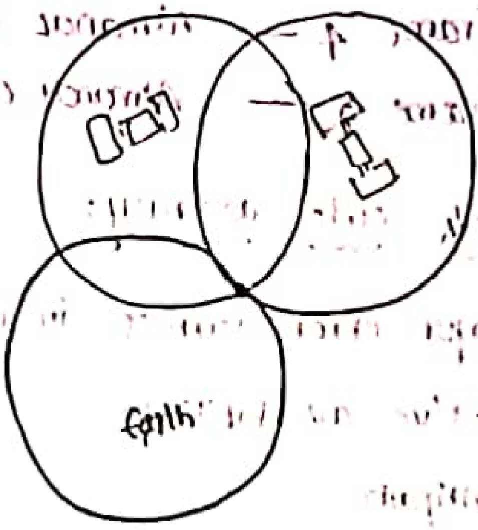
<u>GPS</u> <u>Trilateration</u> :-



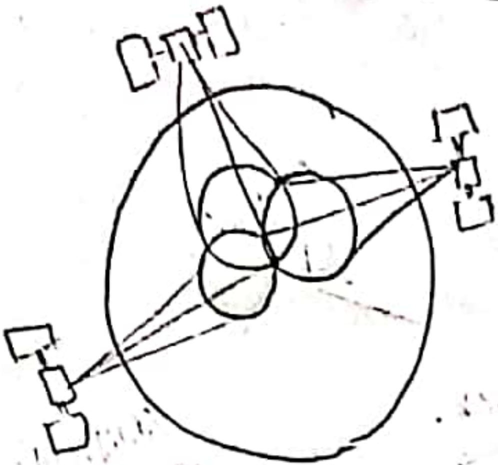
<u>eq</u>:-

$\boxed{\text{distance} = \text{speed} \times \text{time}}$





Distance of GPS satellites from surface of earth is <u>20,200 kms</u>
<u>11,000 miles</u>
Placed in MEO orbit.



Milestones of satellite system:-

Introduction:-

From invention to upto now. } 1st unit → history of satellite.

GPS navigation message:-

1500 bits → 12.5 minutes.

frame details:-

Header — Telemetry message health of satellite.

subframe 1 — satellite clock correction data.

subframe 2&3 — ephemeris for satellite

subframe 4 — Almanac data for satellite 25 & higher

subframe 5 — Almanac data for satellite 1-24.

GPS C/A code accuracy:-

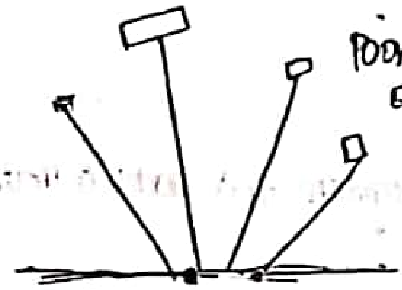
Major error sources in a GPS C/A code are:-

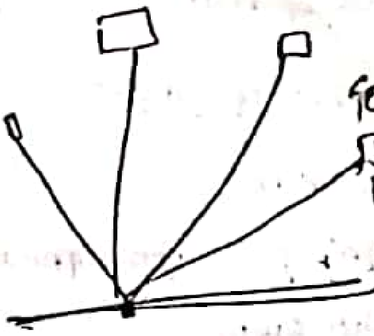
a) selective availability.
b) Multipath.
c) satellite clock.
d) ephemeris error.
e) Ionospheric delay.
f) Tropospheric delay.
g) Rx'er noise.
h) Satellite geometry.

The selective availability was designed by US Department of Defence which deliberately degrades the signal, and provides less accuracy in determining the position of a user on earth. It is switched off in May 1, 2000.

Ionosphere:- X-rays & UV rays present in ionosphere.

Dilution of precision:- [Satellite Geometry]





Four dilution of precision:-

GDOP :- (Geometric) A combination of navigational position & time error.

PDOP :- (Positional) The spatial geometrical quality of the positional solution.

HDOP :- Horizontal :- Measure of the quality of the horizontal position.

VDOP = Vertical :- Measure of the quality of the vertical position.

TDOP:- Time :- Mean error of the time estimation.

As DOP ↑ , accuracy ↓

DOP —

DOP	Rating
1	Ideal
2-3	Excellent
4-6	Good
7-8	Moderate.
9-20	Fair.
20-50	Poor

Applications of GPS:-

Industry

1) Agriculture.
2) Mapping & Geographical Information system (GIS) Data collection
3) Public safety.
4) Surveying.
5) Telecommunications.

Military

- Intelligence & Target location.
- Navigation.
- Weapon aiming & Guidance.

Transportation

- Aviation.
- Fleet tracking.
- Marine.

Science:-

- Archeology.
- Atmospheric Science.
- Environmental.
- Geology & Geophysics.
- Oceanography.
- Wildlife.

SPADE:-

single ~~channel~~ carrier per ~~carrier~~ channel PCM multiple access demand alignment technique. It is an example of DAMA.

- With SPADE, 800 PCM encoded voice band channels separately QPSK modulate an IF carrier signal [Hence named as single channel per carrier].

→ Each 4khz voice band channel is sampled at 8khz rate and are converted into 8bit PCM code.

⇒ so 64kbps PCM code for each voiceband channel.

→ For QPSK, min req b-w = 1/2 bitrate = 30 Khz.

→ Each channel is allocated 45khz with 15 khz as GB.

→ 36MHz is divided producing ~~the~~ 400 channel bands (each 45khz)

→ 400 channels 4r Txion & 400 for Rxion.

→ Channels 1,2 & 400 are let unused. so used band channels are 397.

→ Centre of transponder band is marked by pilot freq. [fcMHz]

→ Each RF channel capacity is 397.

→ Each RF channel has CSC
CSC code is used to establish or disconnect voice band link when 2 earth station: when demand alignment channel allocation is used.