EARTH STATION TECHNOLOGY & LOW EARTH ORBIT & GEO ...

Introduction :-

* The collection of equipment on the surface of the earth for communicating with the satellite is called an earth station.
* Earth stations can be used in the general case to transmit to and receive from the satellite, but in special applications only to receive or only to transmit.
* Receive-only stations are of interest for broadcast tx'ions from a satellite and transmit-only stations for the still much less developed application of data gathering.
* The below figure shows the general block diagram of an earth station capable of tx'ion, Rx'ion and a/a tracking.

Transmitter :-

There may be one or many transmit chains, dependin on the no.of seperate carrier frequencies and satellites with which the station must operate simultaneously.

Receiver :-

There may be one or many receiver/down converter chains, depending on the no.of seperate frequencies and satellites to be received and various operating consideratior

Antenna :-

usually one a/a serves for both tx'ion and Rx'ion, bu not necessarily. with in the antenna subsystem are the a/ proper, typically a reflector and feed; seperate feed syster to permit automatic tracking; and a duplex and multiplex

Unit 5

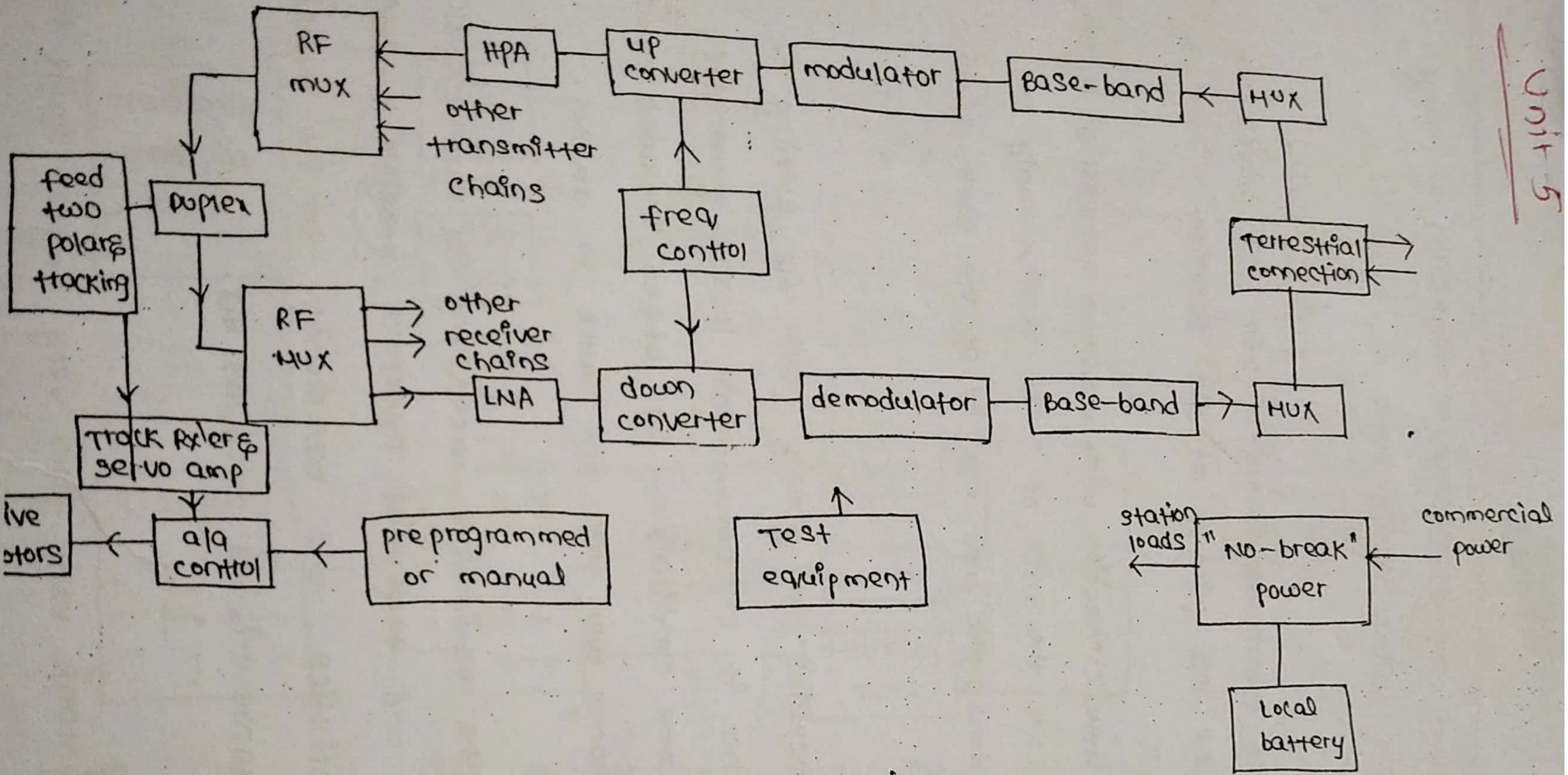

fig: General earth station

angement to permit the simultaneous connection of many ansmit and receive chains to the same a/a.

acking system :-

This comprises whatever control circuit and drives are essary to keep the a/a pointed at the satellite.

estrial interface :-

This is the interconnection with whatever terrestrial systen any is involved. In the case of small receive-only (or) nsmit-only stations, the user may be at the earth station self.

mary power :-

This system includes the primary power for running the th station, whether it be commercial, locally generated, tery supplied or some combination. It often includes provis for 'no break' change over from one source to another.

t equipment :-

This includes the equipment necessary for routine checkir the earth station and terrestrial interface, possible monitorin satellite characteristics, and occasionally for the measur ent of special characteristics such as G/T.

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ransmitters :-

Transmitter sub systems vary from very simple single tx'er of just a few watts for data-gathering purposes to multi channel tx'ers using 10-kw amplifiers.

* when multiple tx'er chains are required, common wide band travelling - wave tube amplifiers can be used (or) each channel can use a seperate high power amp typically a Klystron

* Two - for - one redundancy switching is shown with the TWTAS.

* The common wide band amplifier is the more usual type, and it is suffering from the problem of intermodulation when nonlinear amplifiers handle more than one carrier simultaneously.

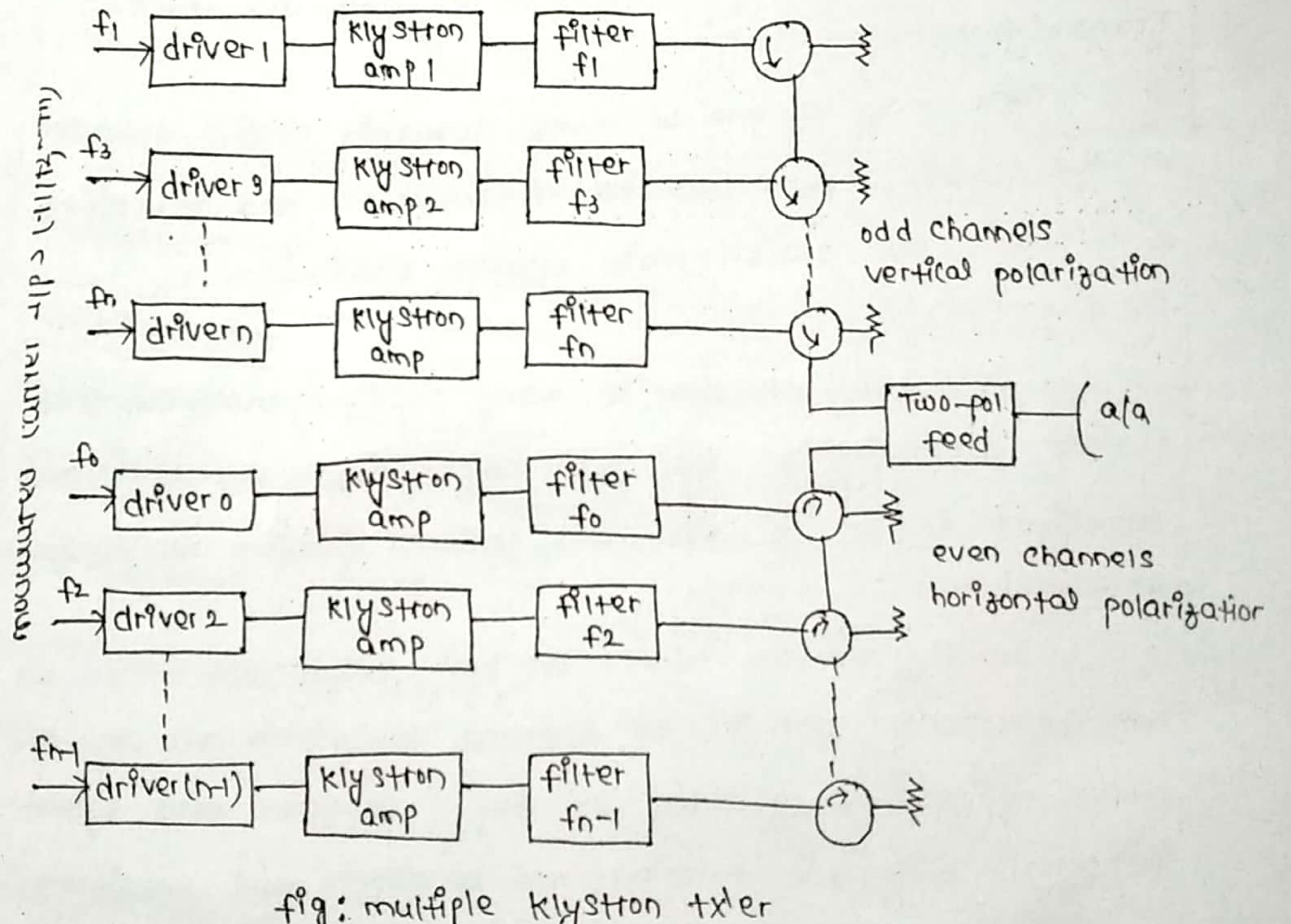

fig: multiple Klystron tx'er

* system using feedback to reduce the nonlinearity effect are coming into use and allow greater power o/p.

performance in high power amplifiers uses predistort this method, a low level non linear amplifier of characteristics similar to the high power amp.

* The alternative of using seperate amplifiers is less flexible in operation.
* usually seperate amplifiers are narrowband and require retuning to change freq's.
* A few typical high power amplifier specifications is shown below.

	TWTA	TWTA	TWTA	SSPA	SSPA
freq band	C	Ku	Ka	C	Ku
power (W)	600	300	100	25	16
efficiency (%)	25	22	18	15	5
B.W (MHz)	500+	500+	2500	500	500
gain (dB)	50	70	50	50	50
Noise fig (dB)	25	28	35	6	12
Third-order intercept (dBm)	10	10	10	20	20
AM-PM	2°/dB	2°/dB	2°/dB	0.5°/dB	0.5°/dB
mean time to fail (MTTF) hrs	15-30,000	15-30,000	15-30000	150 000	150000

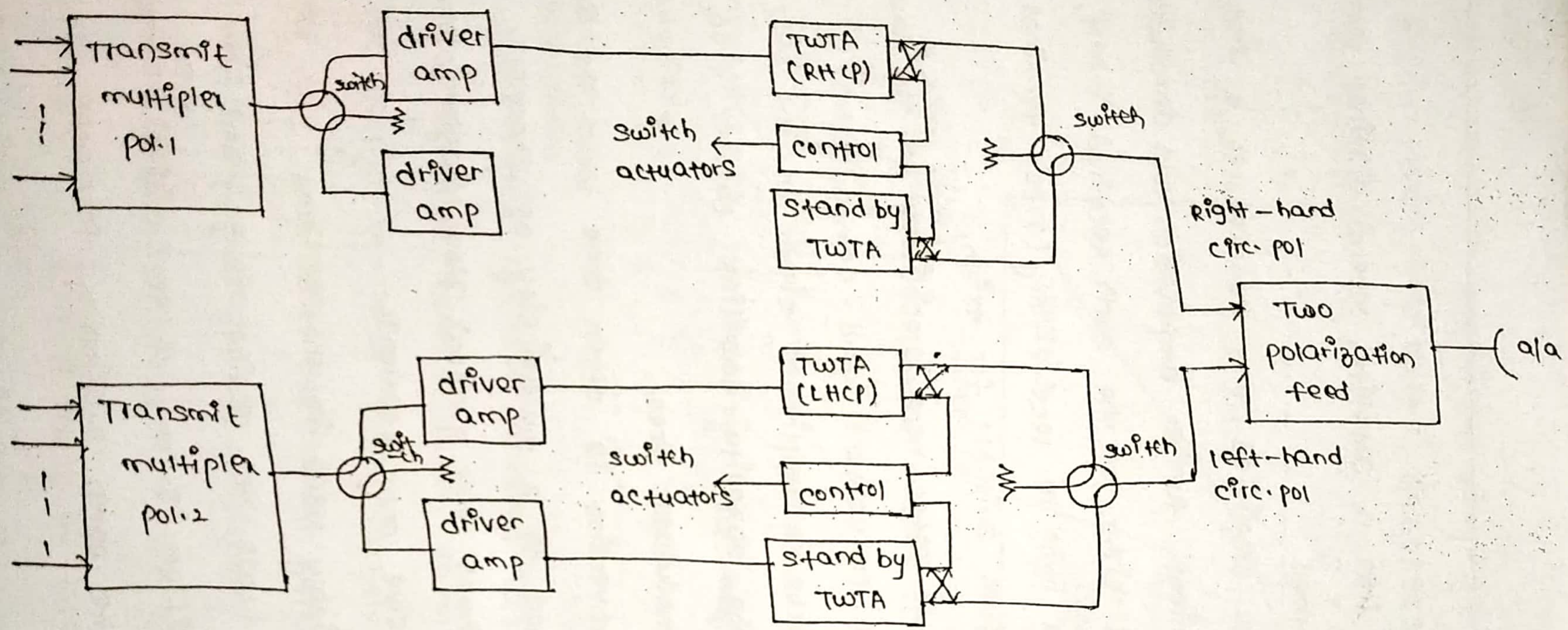

fig: common TWTA transmitted with redundancy (two polarizations)

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Receive:
To receive a signal from a satellite, several distinct operations must be performed.

The sig must first be amplified then reduced to a freq. low enough for convenient further amplification and demodulation.

The s/g may be used either at the earth terminal itself, as in the case of a home TV receive-only (TVRO) terminal, or converted into a form suitable for tx'ion.

In receiver chain, we refer here specifically to the low-noise amplifiers, down converters and demodulators.

Down conversion can be accomplished either in one step, going directly from the satellite downlink carrier freq. to the intermediate demodulator freq.

Two-stage down conversion is often done when the same Rx'ler is to be tuned to a multiplicity of channels.

The below figure shows the general block diagram for a video and audio receive only stations.

Such stations are widely used in the SC and such Rx'lers are used in cable heads to receive TV programs from sat.

The low-noise amplifier is one of the critical element in determining the earth station performance.

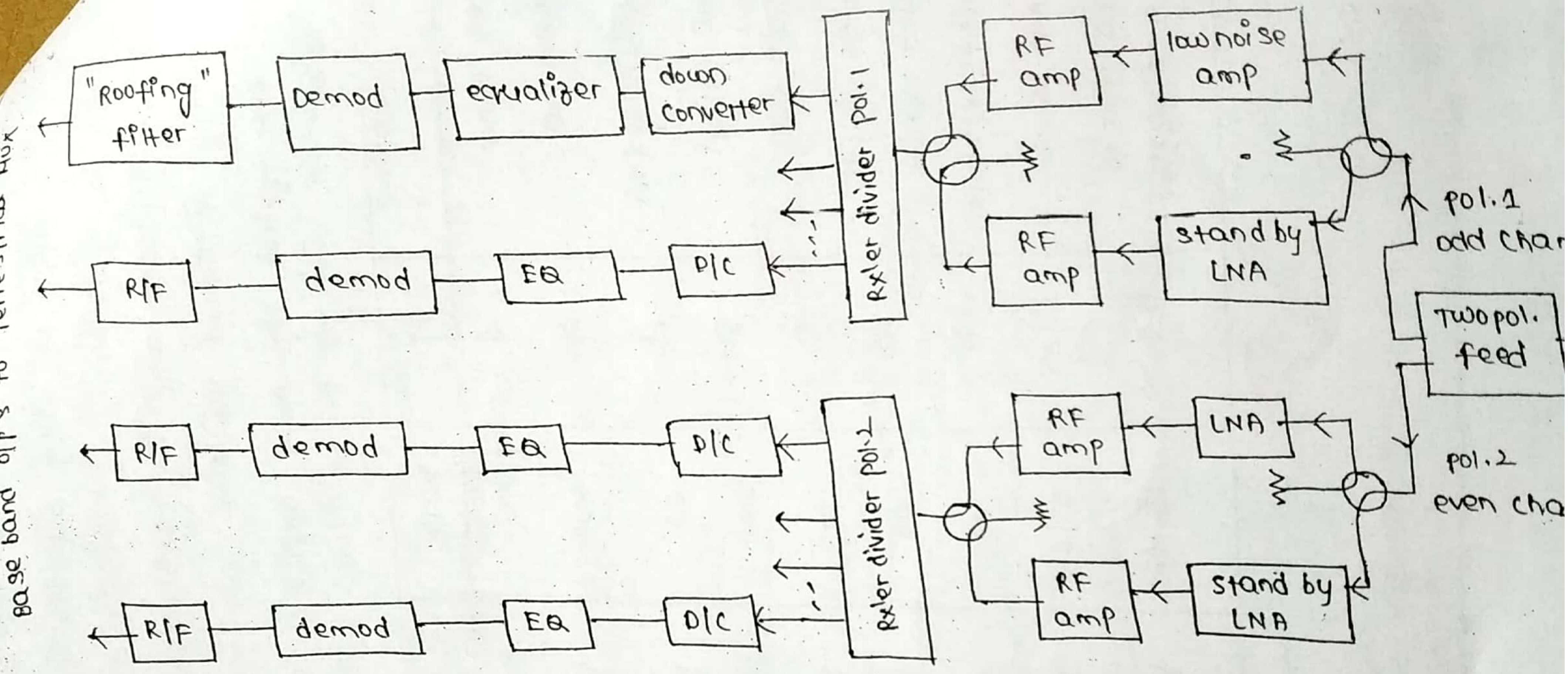

fig: Receive subsystem for multicarrier earth station

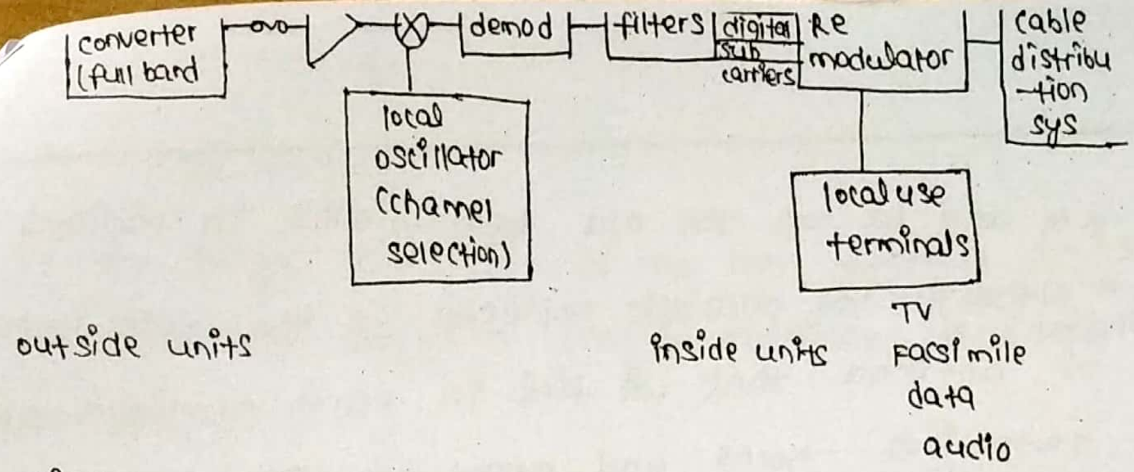

fig: General TVRO station – direct reception or cable distribution

$$T_S = T_a + (L-1)T_0 + LT_R + \frac{L(F-1)}{G_R} T_0$$

* It is not difficult to derive an expression for carrier-to-third-order modulation products. The result is

$$\left(\frac{C}{I}\right)_3 = 2(P_x - P_0)$$

here P_0 – saturated o/p power

P_x – Intercept point

	L-band	C-band	X-band	K_u-band	Ka-band
cooling	uncooled	uncooled/cooled	uncooled/cooled	uncooled/cooled	uncooled/cooled
recv range (GHz)	1.5–2.5	3.0–5.0	7.0–10.0	10–14	11–20
B.W (MHz)	50–100	500	500–1000	1000	1000
noise temp (K)	40–60	35–60	55–75	65–130	200–300
Gain (dB)	45–60	50–60	50–55	50–60	20–25
i/p at 1.0 dB compression (dBm)	13	13	13	13	10
Intercept dB above o/p	10–13	10–13	10–13	10	10
AM-PM (°/dB)	0.03–0.5	0.03–0.50	0.03–0.50	0.03–0.50	0.03–0.50

the LNA.

* Most low-noise amplifiers today (1992) use gallium arseni field-effect transistors, GaASFETS or HEMTS.

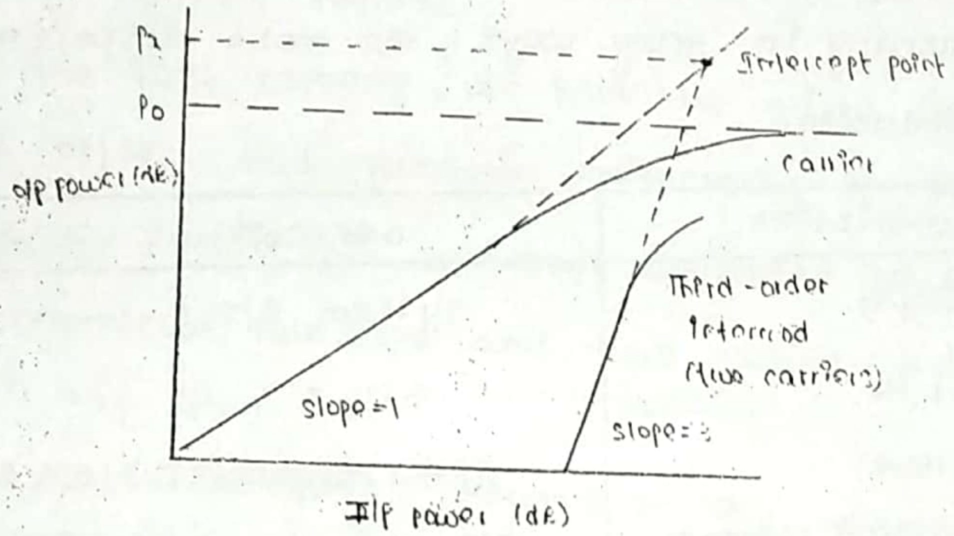

fig: Intercept point as a measure of third-order intermodulati level

* Intercept point and AM-PM conversion are two simple measures of non linearity that help in comparing diffe amplifiers.

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Antennas :-

* The parabolic reflector antenna has become the symbo for a satellite communication earth terminal.

* The carrier-to-noise ratios acheivable on uplink and link, given directly determined fixed tx'er power an geographical coverages are directly determined by the physical size of the earth station a/a.

antennas at K band must be larger than those at band. This is because of the min attenuation

The antenna electrical performance is involved in the system planning in many ways; the most important are the following.

characteristics	affects
overall gain, G	system G/Ts
a/a temp, Ta	G/Ts
side lobe level	Interference (C/I), a/a temp
cross - polarized response	C/I and C/N for entire sys
Beam width	Geographical coverage (satellite ak tracking requirement

for system planning, a generalized antenna pattern is often useful. A good pair of equ's for such use is

on main lobe : $\frac{G}{G_m} = \left[\frac{\sin 1.39(\theta/\theta_0)}{1.39(\theta_0/\theta_0)}\right]^{r}$

far from main lobe : $\frac{G}{G_m} = \frac{1}{1+(\theta/\theta_0)^{2.5}}$

where θ_0 is half the half - power beam width.

Gain is defined as the ratio of radiation intensity in a given direction to that the total radiated power to be radiated isotropically.

$$G \simeq \frac{4\pi}{\theta_1\theta_2} \simeq K\frac{41253}{\theta_1^\circ \theta_2^\circ}$$

where K is a factor to allow for energy not in the main beam.

* θ_1 and θ_2 are the a/a beamwidths in radians or degr

* Although the parabolic reflector is the most important kind of antenna that we find in earth stations and on the satellites. horns and array are also important.

* horns are widely used as primary feeds for reflectors anc occasionally as principal radiators themselves.

* Two other kinds are ocasionally seen in spacecraft. They are lenses (either the dielectric or waveguide type) and phased arrays.

* The array is controlled by varying the phase and amplitud of the individual elements.

Horn antenna :-

* Horn antennas are commonly used as primary. radiators in reflector system.

* we find horn antennas on board the satellite to provide earth coverage beam.

* The angle is about 18° from geostationary orbit and simply acheived with horns.

There are two kinds of horns.

* primary horn as an extension of roctangular waveguid and conical horn as an extension of circular waveguide. The following equations are applicable for those hor that are compared to wavelength.

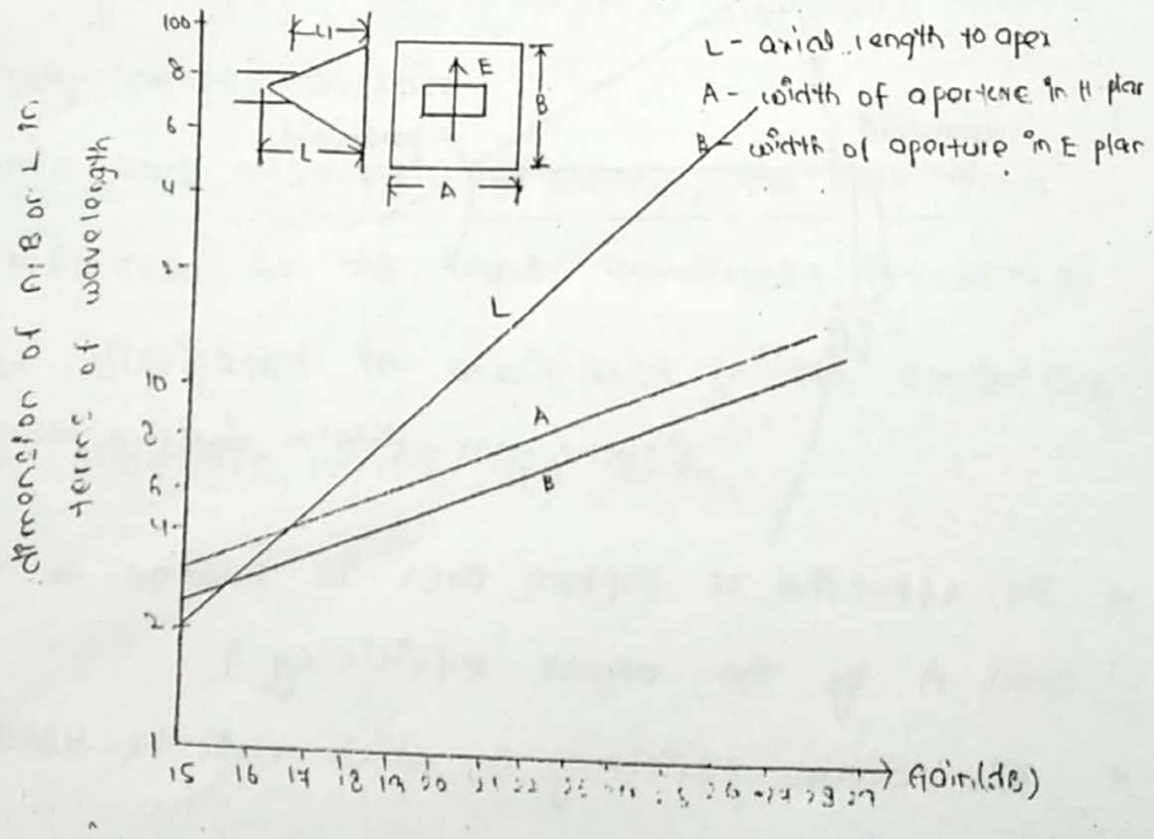
$$\theta_E = 51\frac{\lambda}{B}$$

$$\theta_H = 70\frac{\lambda}{A}$$

here A is the longer dimension of the horn aperture. It is desired to have the shortest length possible, that length L_1 is given by

$$L_1 = L\left(1 - \frac{a}{2A} - \frac{b}{2B}\right)$$

* conical horns, which are natural extension of circular wave guides, are used typically higher-mode propagation
* The TH_{11} and TE_{11} modes circular wave guides are super imposed on each other with suitable control of the relative amplitude and phase.
* The variation of the horn feed very much used in primary feeds for big earth station is a hybrid-mode horn.



* we divide the reflector antennas broadly into two categ[ories]
those using a single reflector and horn feed and th[ose]
using multiple reflectors.

* In the first category, we have the prime focus feed [and]
the offset - fed parabolic reflectors; in the second [we]
have a family of antennas developed by analogy to
astronomical telescope and thus called Newtonian, ca[sse]
-grain and Gregorian.

* The later categories depend on the whether the subr[eflector]
is plane, hyperbolic or ellipsoidal.

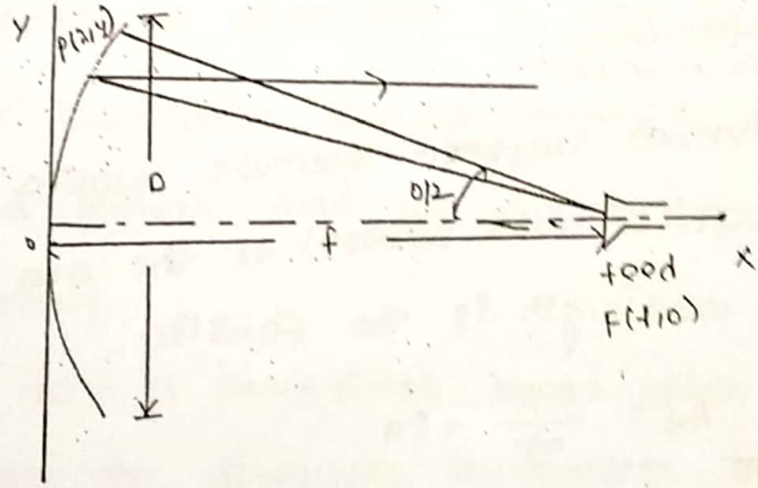


fig: Basic geometry; prime-focus-feed parabolic ref[lector]

* An important effect of the secondary reflector on a
cassegrainian or Gregorian a/a is to increase the
apparent focal length of the a/a. This increase
called magnification.

The equivalent focal length of the cassegrainian reflector ystem is given by

$$f_e = mf = \frac{e+1}{e-1} f$$

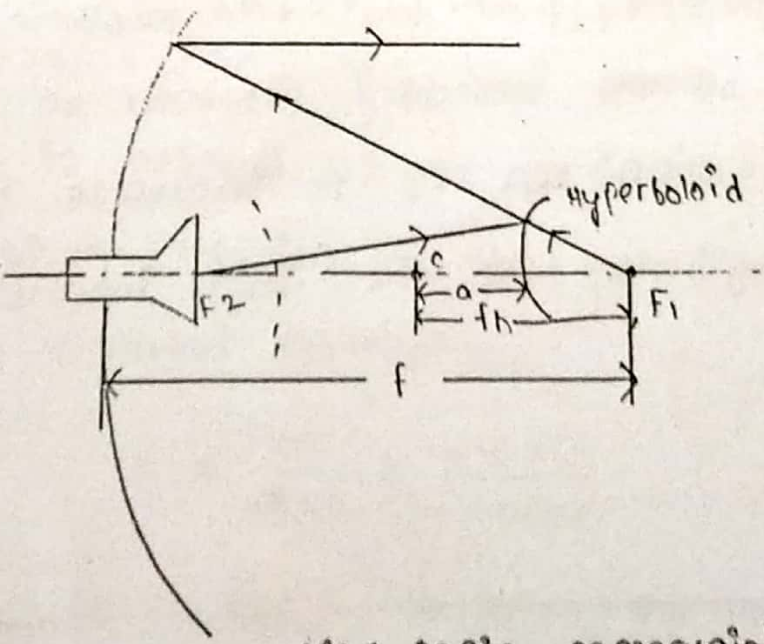
-If several horn feeds with emerging beams at diff gles are to be use a main reflector that is circular in ne cross section and parabolic in the other.

This kind of toroidal antenna was first used in large arly -warning radars to permit rapid beam scanning

tenna performance :-

The universal antenna formula relating the effective ea (or capture cross section) of the a/a A_{eff} and its ain and wavelength is the familiar

$$A_e = \frac{G\lambda^2}{4\pi} = \eta A$$



$$e = \frac{f_h}{a} > 1$$

$$f' = \frac{e+1}{e-1} f$$

fig: Basic cassegrainian antenna

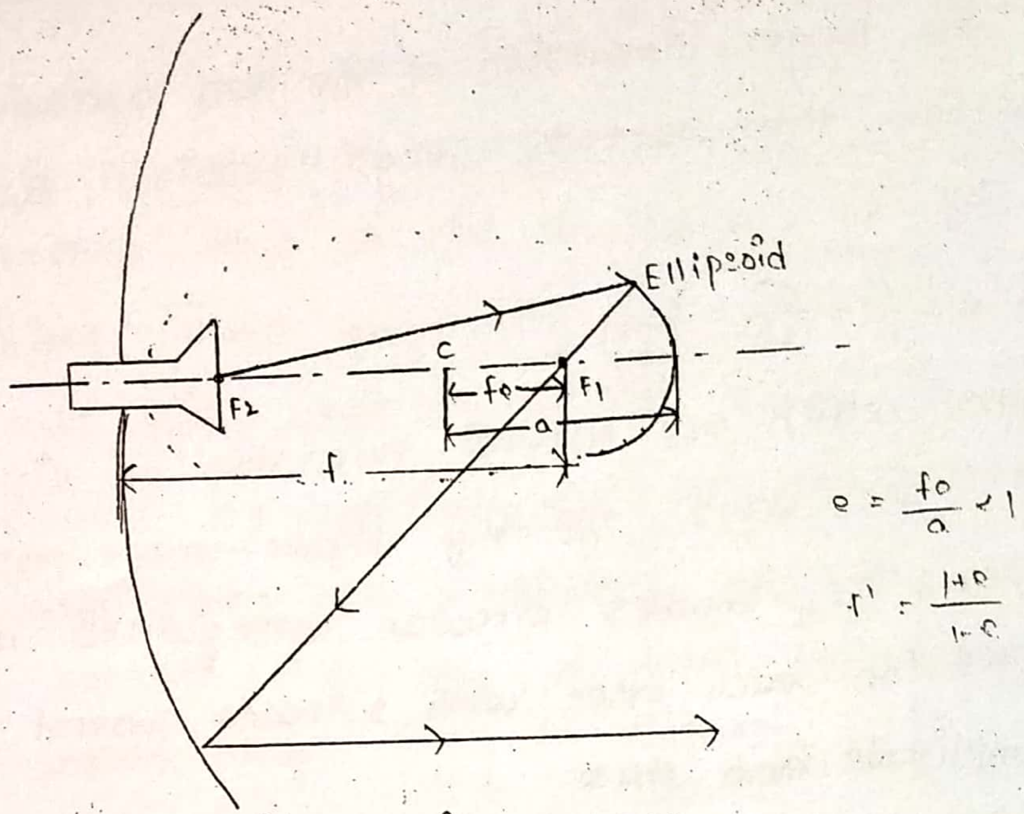


fig: Basic Gregorian antenna

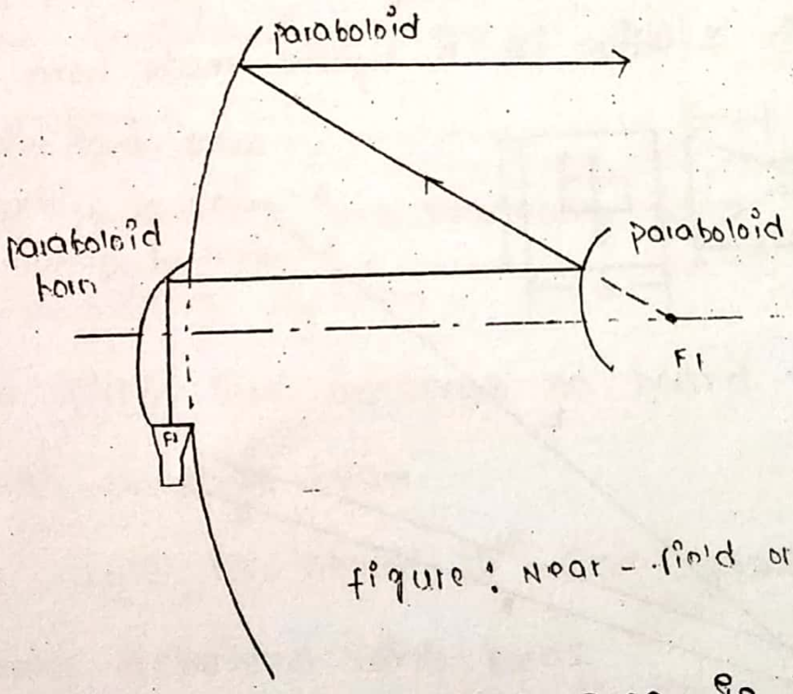


figure: Near - field or modified cassegrainian ant

* The effective or capture area is related to the physical area A by the overall efficiency η.
* This overall efficiency η, which must be used in calculating received carrier level.

$$\eta = \eta_a \eta_b \eta_s \eta_p \eta_e \eta_L$$

, phase errors and so on; it increases as the side lobe level increases.

η_b = blockage efficiency, resulting from blockage of main reflector by the subreflector or feeds

η_s = spilover efficiency, the loss of energy because the subreflectors and main reflectors do not intercept all the energy directed toward them.

η_p = cross - polarization efficiency, the loss of energy due to energy coupled into the polarization orthogonal to that desired.

η_e = surface efficiency, the loss in gain resulting from surface irregularities, the statistical departure from a theoritically correct surface

η_L = ohmic and mismatch efficiency, the loss from energy reflected at the input terminals (VSWR>1.0) and that dissipated in ohmic loss in the conducting surfaces, dielectric lenses and so on,

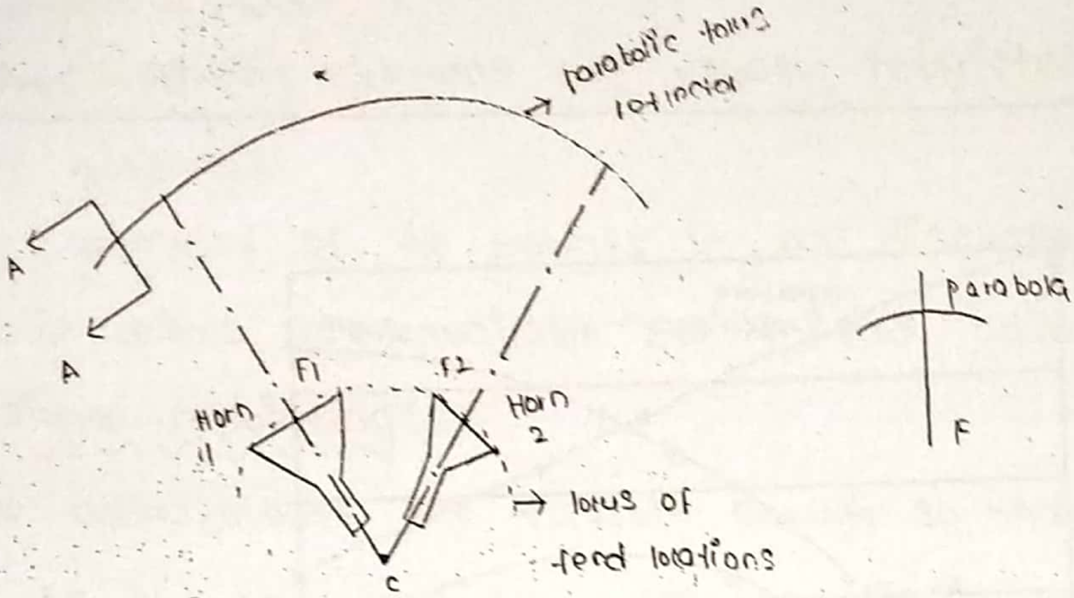


fig: multifeed toroidal antenna

* The aperture efficiency η_a is equal to unity for an aperture that is illuminated uniformly in amplitude phase, in which the directivity is max for given a
* The reflector illumination has two components : one due the horn feed pattern and one due to the inherent reflector geometry.
* The second term is sometimes called space attenua. and is simply the difference in inverse square - la loss b/w the edge and centre of the aperture.
* from the geometry of the parabola, it can be show that this loss is given by

$$\text{space attenuation} = \left(\frac{R}{f}\right)^2 = \sec^2 \theta/4$$

where θ is the full angle subtended by the reflector

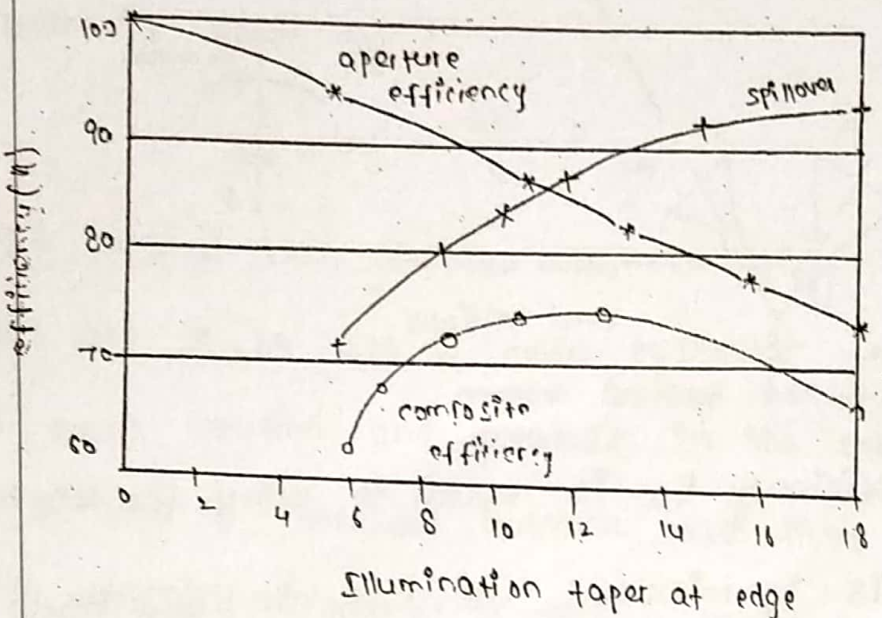


fig: Typical spillover and aperture efficiencies as a function of illumination taper

A good approximation to a cosine horn pattern is simply $\cdot(\theta/\beta_{10})^2$. where β_{10} is the horn beamwidth at the tenth power point.

The net edge taper is

$$T = 10\log \sec^4 \frac{\theta}{4} + 10\left(\frac{\theta}{\beta_{10}}\right)^2$$

aperture blockage is a significant problem especially in cassegrainian and Gregorian antennas.

The related efficiency η_b is given by $[1 - 2a(A_B/A)^2]$, where A_B is the blocked area and A is the total aperture area.

cross - polarization efficiency η_p is another important problem in satellite antennas.

* There is always a fundamental loss in efficiency because of random surface irregularities.

* Ruze (1952) in a classic paper developed the following equation for the effect of surface variation:

$$\eta_e = \frac{G}{G_0} = e^{-k(4\pi\delta/\lambda)^2}$$

$$K = \frac{1}{1+(D/4f)^2} \simeq 1$$

* These equations hold for gaussian distibution of phas errors due to surface imperfections.

here δ is the mass surface deviation

G_0 is the gain of a perfect surface reflector general, nongeostationary orbits require more tracking than geostationary.

* For instance, messaging systems for ground mobile service from low earth orbit often use hemispherical coverage a/a's, aeronautical and many marine terminals and require no tracking.

* on the other hand, there are successful mbl services to vehicles using ku band with the narrow beams and trackin because of vehicular motion.

* we identify a hierarchy of pointing and tracking categories as follows.

1. No tracking is necessary and only initial fixed-pointing adjustment is required.
2. Repointing of the a/a is needed to switch from one satellite to another and possibly to correct for satellite motion. This repointing can be needed rarely (or) frequently
3. Tracking is required, but it is satisfactory to drive the a/a in two axes and to preprogram this drive in accordance with the calculated satellite motion.
4. Automatic tracking is necessary but can be achieved by a simple step tracking system.
5. Fully automatic continuous tracking is necessary.

* fixed - pointing systems are usually restricted to beam antennas.

* The geometry of the mounts is as discussed - in

) screw drives are available for initial adjustmer

occasional repointing: -

* The adjustments are flexible enough so that they can be changed manually with out difficulty.

* simple motor drives may be added to do it remo.

preprogrammed: -

* once motor drives are available for one - or two axis control, both automatic and preprogrammed can be

* If the a/a beamwidth is wide relative to the predi error, it can be preprogrammed to track open loop.

* often the principal apparent GEO satellite motion is due to imperfect inclination control.

* This motion, for small inclinations and otherwise pe orbits, is a figure eight with a period of one s real day.

* It's vertical height is twice the orbital inclinatio and it's width is only a small fraction of th value.

* If the orbit has zero inclination but has a sm

centricity e, the amplitude of the maximum longitudinx *

parture is 2e radians.

ep tracking :-

Step tracking uses a primitive servomechanism in ich the a/a is moved a discrete amount and if e signal level increases, it is moved again in is direction.

s soon as the signal level does not increase, it turns to the previous position.

This method obviously depends on the size of the step.

lly automatic :-

fully automatic tracking can be provided using method iginally developed for the pointing of radar a/a's.

The most common is the monopulse or simultaneous lobing system, in which four beams are generated n an auxilary feed and combinations of the signals om these four beams provide left-right and up-down ror signals.

These error signals are detected, amplified and used to generate control signals for driving the a/a.

It is possible to derive the error signals either wit multiple horn ~~feed~~ systems or by the use of higher

* The multiple - horn feeds use four horns grouped toge[ther] (or) sometimes four horns grouped around a single larger horn.
* where as the higher - mode error - determining signals use circular wave guide modes such as TM01 or TE01, which have no field component on the axis.

TERRESTRIAL INTERFACE :-

* The terrestrial interface comprises a wide variety of equipment.
* At one extreme, when the terminal is a mobile or receive - only station, there may be no terrestrial interface equipment.
* The operating devices such as TV Rx'ers, telephones, data sets and so on are used at earth station.
* at other extreme, we find the interface equipment necessary in a large commercial satellite system fo[r] fixed service.
* In such cases, hundreds of telephone channels, together with data and video are brought to the station by microwave and cable systems using eith[er] frequency (or) time division multiplex methods.
* The signals must be changed from those formats into suitable formats for satellite tx'ion.

...ending on their source and put together with the corresponding outgoing circuit to make up a terristrial circuit.

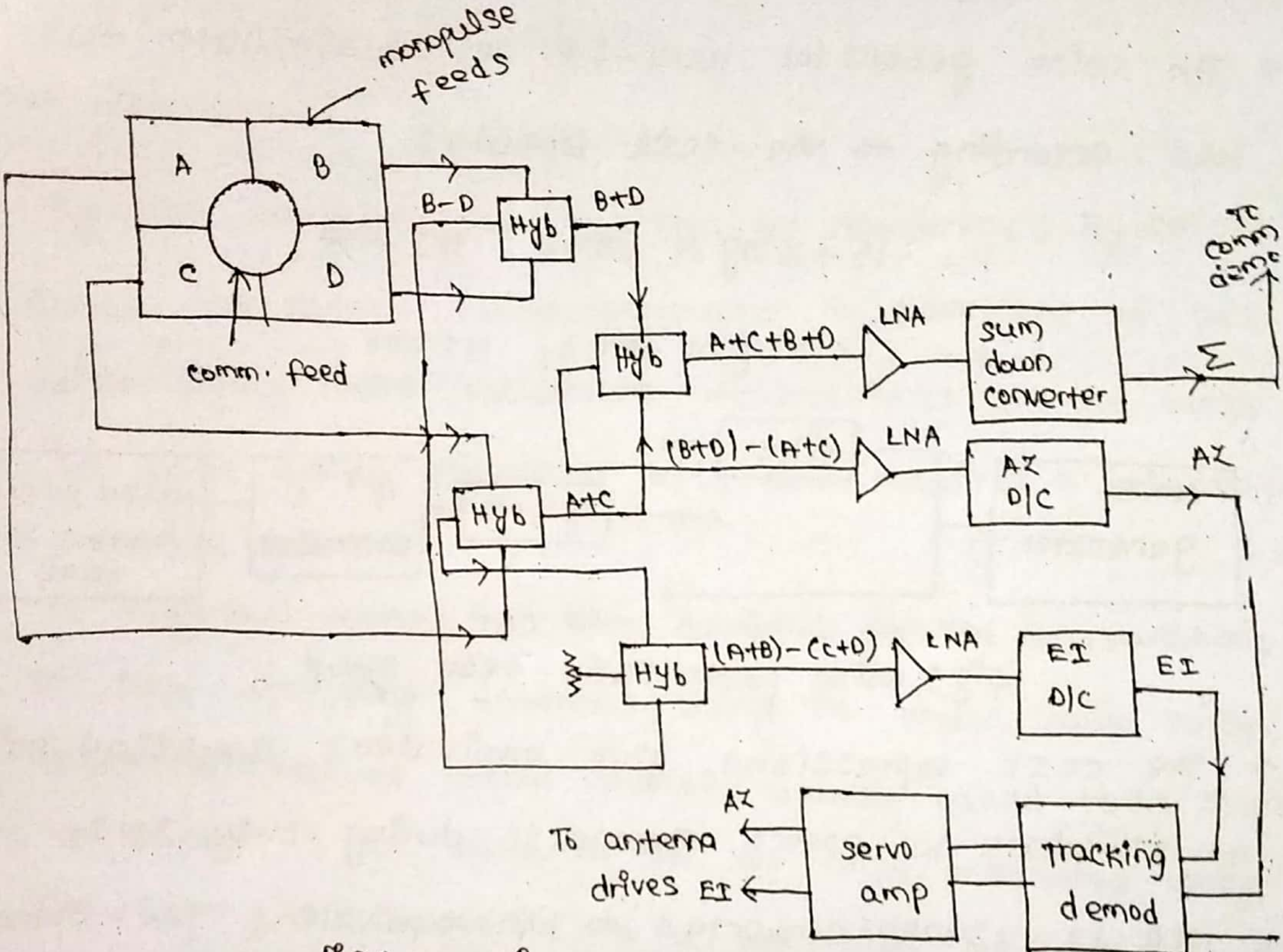


fig: Tracking system

* If the satellite tx'ion is single channel per carrier, it is necessary to bring each terrestrial carrier down to base band before remodulation.

The interfaces b/w terrestrial time division and satellite freq-division systems and vice-versa are complicated.

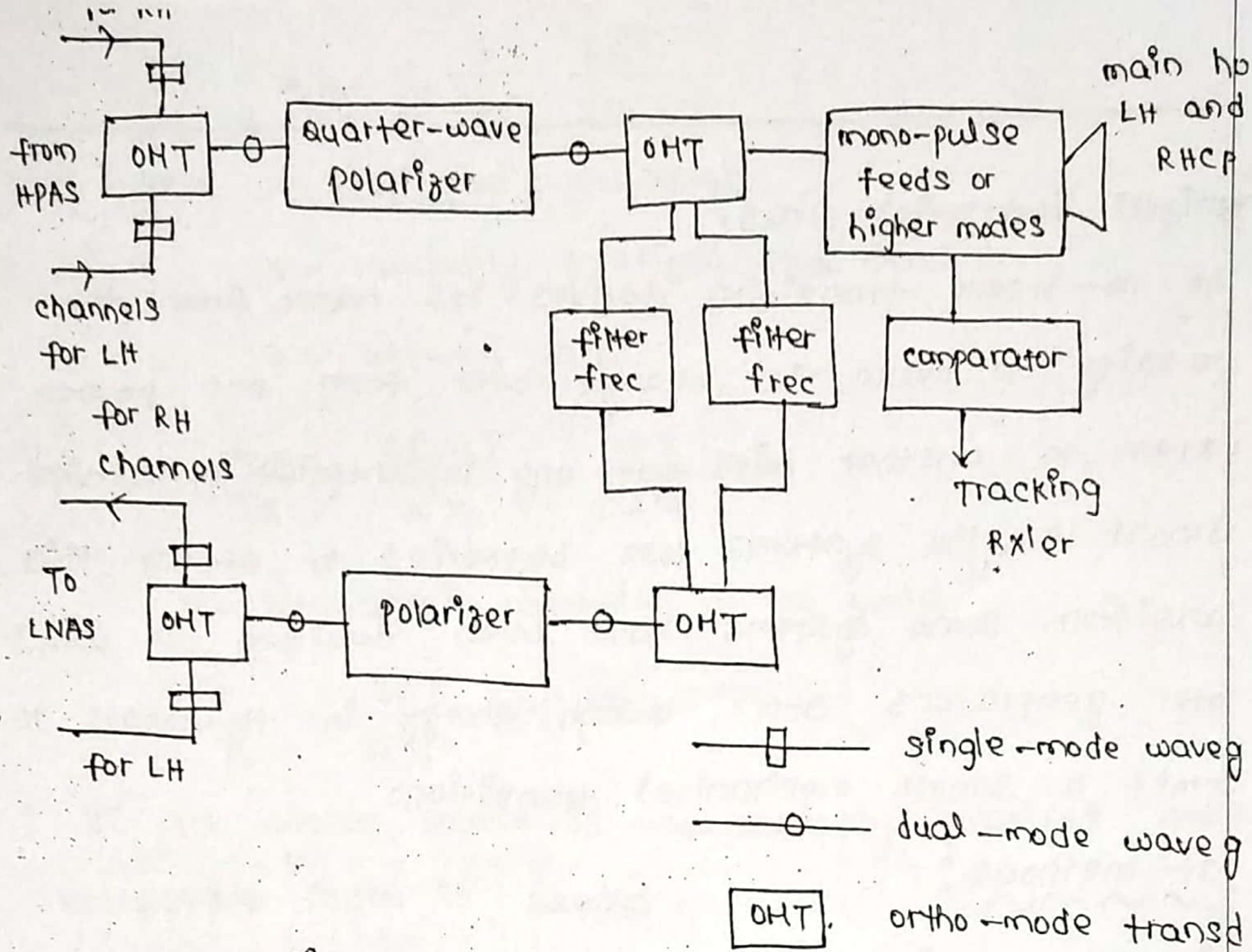


fig: Two - polarization horn - feed systems

primary power :—

* primary power systems vary from plain battery or sol - cell operated remote tx'ers for data gathering. huge, combined commercial power and diesel genera systems for large stations.

* Host transmit and Receive earth stations require s kind of "no-break" power systems, that is emerger power to continue the comm's during commercial po outages.

* such power outages are frequent, even in highly

anized industrial areas.

The no-break transition derives its name from the cessity to make the change over from one power ystem to another with out any interruption in service. Almost all the systems use batteries to effect this ransition. Some systems have been devised in which otor generators store enough energy in flywheels to ermit a smooth mechanical transition.

est methods :-

oise power ratio (NPR) :-

earth stations are typically provided with complex est equipment, ranging from that necessary for outine measurements of voltage, power, temp and so on.

The Noise power ratio (NPR) is the traditional measure of intermodulation noise for FDM systems in he comm's field.

The principle of NPR measurement involves loading he entire base band spectrum, save for the noise ne voice-freq channel slot, with noise.

NPR is measured by a set up as shown in below fig.

The noise generator band is limited by filters to the base band.

* The noise generator band is limited by

* The noise generator level is set to simulate full load according to the CCIR formulas.

$$P = -15 + 10\log N \text{ dBm0}, \quad N \geq 240$$

$$P = -1 + 4\log N \text{ dBm0}, \quad N < 240$$

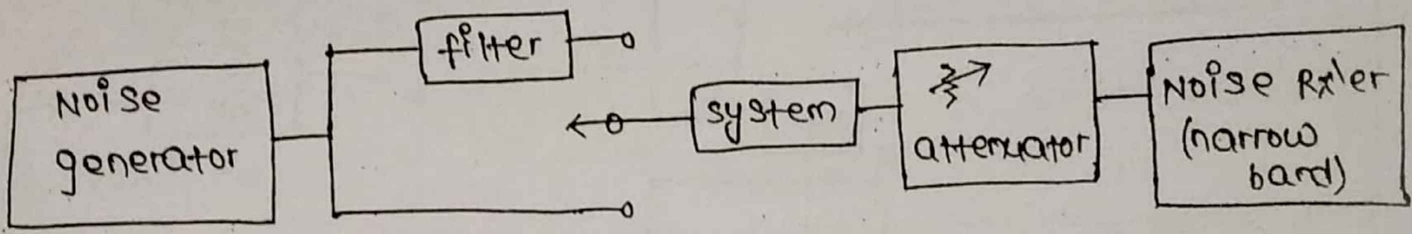


fig: Noise power ratio test setup

* The CCIR expressions give equivalent Gaussian noise to simulate N speech channels during busy hors.

* NPR is usually converted to an equivalent per-channel signal-to-noise-ratio.

$$BWR = 10\log \frac{\text{base band total B.W}}{\text{signal channel B.W}}$$

$$NLR = 10\log \frac{\text{base band noise test power}}{\text{test-one power per channel}}$$

$$= \text{dBm0 of loading calculation}$$

* The equivalent base band signal-to-noise ratio due to intermodulation is then

$$S/N = NPR + BWR - NLR$$

$B = 4028 - 60$

then $BWR = \frac{4028 - 60}{3} = 31.2\,dB$

$NLR = 10\log 960 - 15 - 14.8\ dBm0$

$(S/N)_{equiv} = 71.4\ dB$

The measurement of G/T:-

* System temperature Ts can be determined by conventional laboratory noise generator measurement of Rx'er noise figure and radiometric measurements of a/a temp.
* The basic system parameter G/Ts also requires a knowledge of antenna gain.
* An ingenious method has been developed for the measurement of G/Ts for large antennas using the known radio noise characteristics of stellar sources usually called radio stars.
* Y factor is the ratio of the o/p noise measured when the Rx'er is connected to a hot noise source (Th), to the o/p noise measured when connected to a cold source(Tc)
* excess noise Tc is related to the Y factor by

$$T_\omega = \frac{T_h - Y T_c}{Y-1}$$

* If the cold source is the normal sky and the hot source the radio star, the operating system temperature Ts is

$$T_s = \frac{T_h - T_c}{Y-1} = \frac{\Delta T_a}{Y-1}$$

$$\Delta T_a = \frac{S}{2aK} \frac{G\lambda^2}{4\pi}$$

Here K - Boltzman's constant

S - randomly polarized flux density

G - antenna gain

$$\frac{G}{T_S} = \frac{G(Y-1)}{\Delta T_a} = \frac{8\pi K}{S\lambda^2 a}(Y-1)$$

a - atmospheric absorption at the zenith

$$\frac{G}{T_S} = \frac{8\pi K}{S\lambda^2 a A}(Y-1)\sin\theta$$

* If the stellar source is not randomly polarized, anoth correction factor is needed.
* cassiopeia A is the most commonly used source.

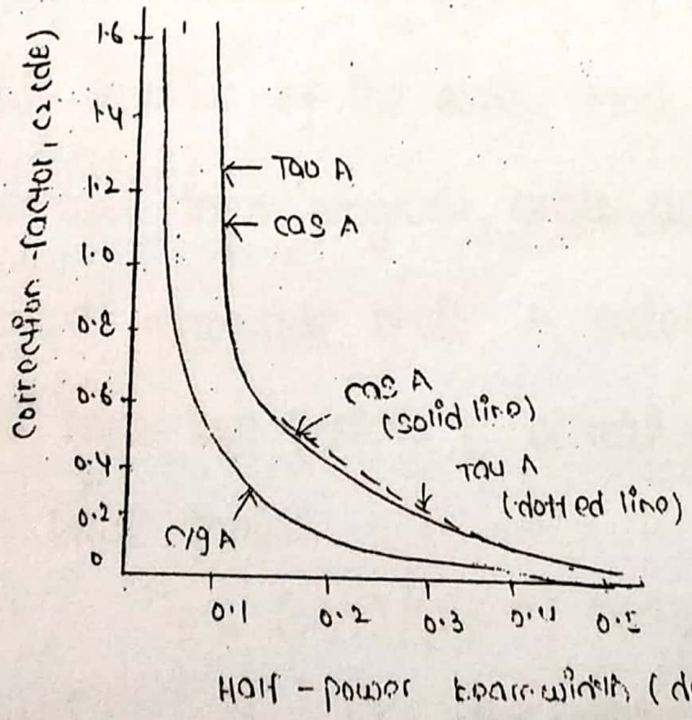


fig: correction factor for G/T measurement using extended sources

ome further correction may be necessary if the beamwidth
: the a/a under test is narrow compared to the stellar radi
source.

) extended source of varying brightness can be considered
3 equivalent to a Rayleigh - Jeans black - body radiator.

The primary reason for the use of LEO was the generally small "throwmass" of the launchers.

→ Throw mass includes both payload and spacecraft bus syste also includes additional rocket motors and fuel.

→ LEO range is 500 km to 1500 km.

→ LEO and MEO are generally refered as Non-geo-stationary ort -s mostly used for internet

→ NGSO satellites brought us the first communication satellite (SCORE), the first pictures of our cloud cover of weather forecasting (TIROS), the first Navigation aids in space (TRANSIT) the first live television pictures across oceans (TELSTAR) etc.

GEO stationary:

→ The reason for using GEO is "more bits can be sent per dollor of capital investment".

→ There are some specialized applications:

* Surveillance of earth's surface for military and gathering the earth resources.

* Providing global navigation such as GPS.

GPS uses 24 satellites in orbits with an altitude of 20,000 km and an inclination of 55°.

* For cellular telephone system.

satellite television broadcasting.

→ The major drawback of LEO satellite system is "buildi launching and maintaining of communication satellites i expensive.

Orbit considerations:

The satellite motion is determined by orbital mechanics with balanced centripetal and centrifugal for The motion of the satellite in orbit depends on the spe design goals, sun light, gravitational pull of sun and m and also the thermal radiation levels in space.

Equatorial orbits:

Equatorial orbits lie exactly in the plane of the geographical equator of the earth. Most satellites are laun toward the east into prograde orbit and westerly directe orbit is called retrograde orbit. A satellite in eastwardly directed will have two periods : a real orbital period and apparent or bital period.

$$P = (24T)/(24-T) \text{ hours}$$

where T = real orbital period

P = apparent orbital period.

Table for orbital periods and observing time:

orbital height (km)	orbital period		observing time (hours)
	True (hours)	Apparent (h)	
500	1.408	1.496	0.183
1000	1.577	1.638	0.283
5000	1.752	1.890	0.587
10,000	5.794	7.645	2.894
35,786	23.934	∞	∞

Inclined orbits:

→ The greater the inclination of the orbit is, larger the surface area of earth that the satellite will pass over.

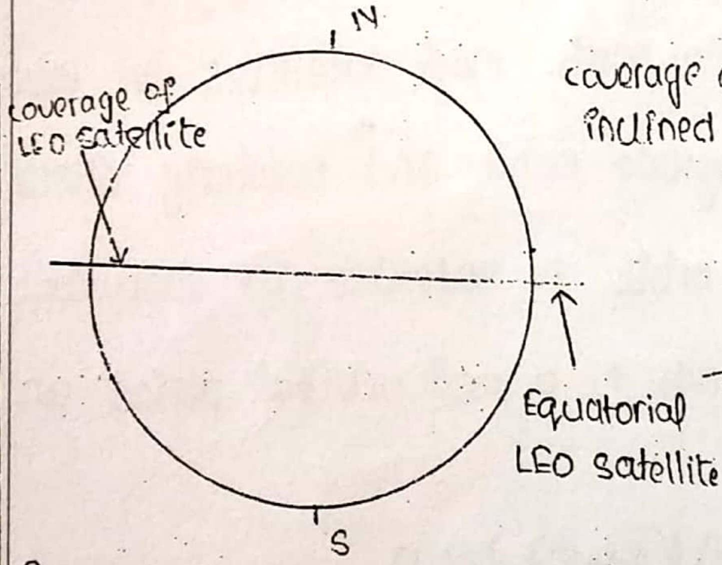


fig (a): coverage of an equatorial orbit LEO satellite

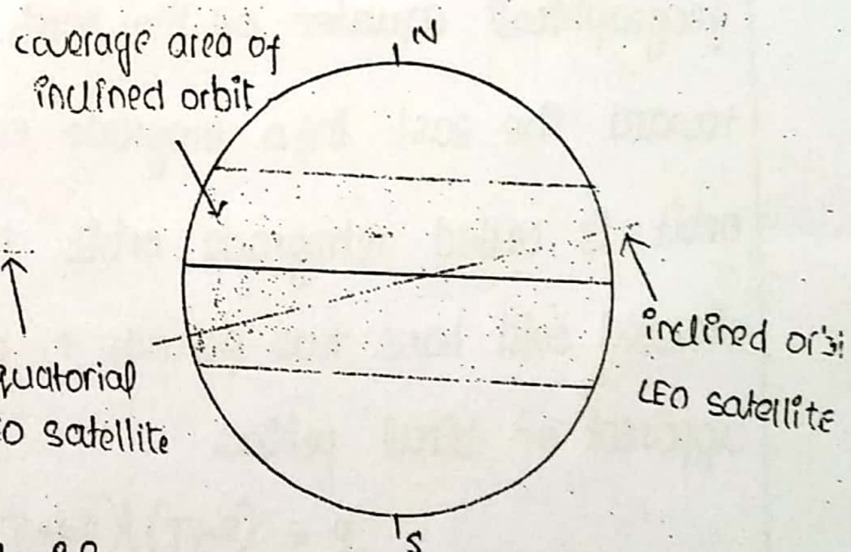


fig (b): coverage of an inclined orbit LEO satellite.

Disadvantage: MCS (master control station) when covering large geographical area

→ Multiple ~~stations~~ satellites are required to avoid the errors when

→ It uses the store-and-forward mechanism.

→ It requires continuous real time connection b/w LEO satellite and MCS as

• To locate control stations around the world so that LEO satellite is never out of sight and establishing terristrial or geo satellite connections b/w many control stations and MC

• Establishing inter satellite links (ISL's) to relay the LEO data traffic back to the MCS.

<u>Elliptical orbits</u>:

Elliptical orbit will have a non zero eccentricity. The orbit eccentricity 'e' is determined by the lengths of semi major axis 'a' and the semi minor axis 'b'

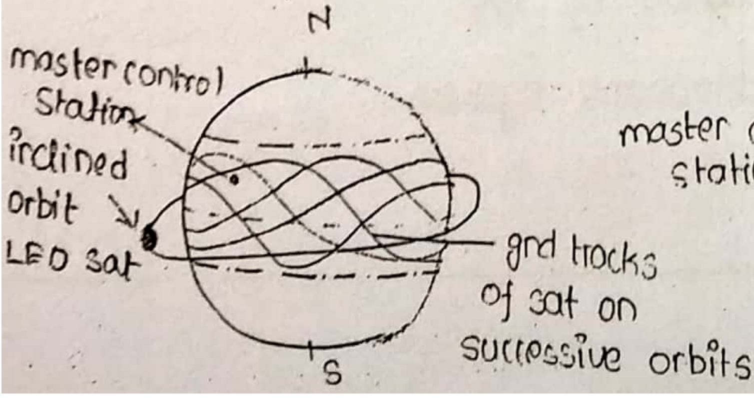
$$e^2 = 1 - (b^2/a^2)$$

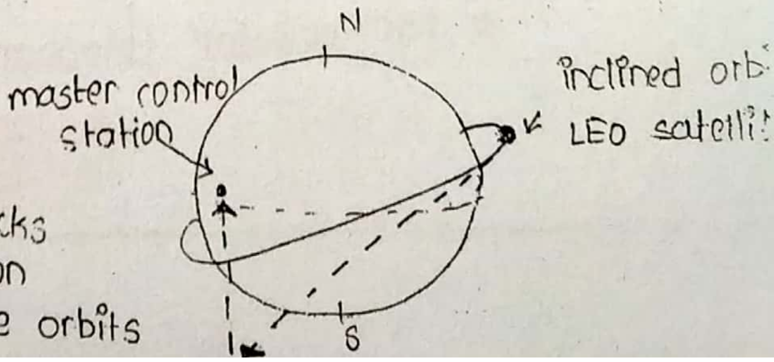
$$e = (Ra - Rp) / (Ra + Rp)$$

where Ra = distance b/w earth center and apogee poi of orbit.

Rp = distance b/w earth center and perigee po.

if $a = b$ & $Ra = Rp \Rightarrow \boxed{e=0} \Rightarrow$ circle.





Rav = avg radius of an orbit

ΔR = variation in the radius of the orbit.

- if $e = 10^{-4} \Rightarrow \Delta R = \pm 4.2\,km$, 800 km above the earth ($R_{av} = 42{,}164.17\,km$) for GEO

if $e = 10^{-4} \Rightarrow \Delta R = \pm 0.7178\,km$ for LEO.

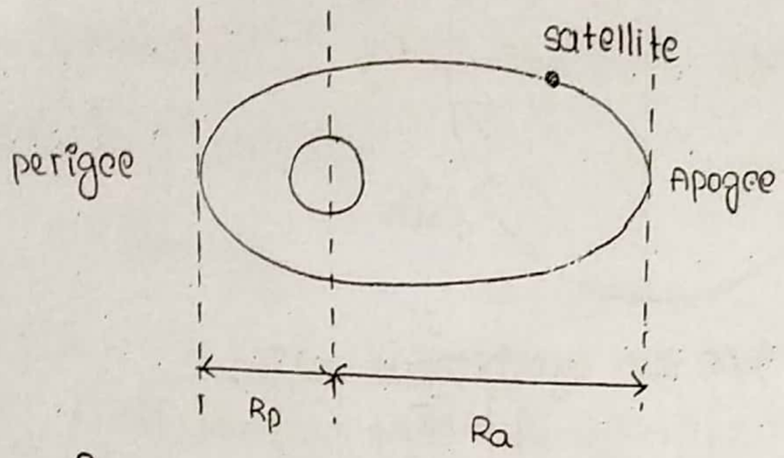


fig: schematic of an elliptical orbit.

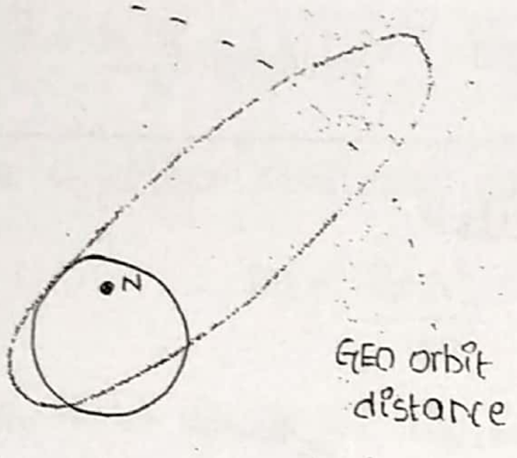
→ if eccentricity ≈ 0.74 is a special case of highly elliptical orbit (HEO) known as Molniya orbit.

Molniya orbit:

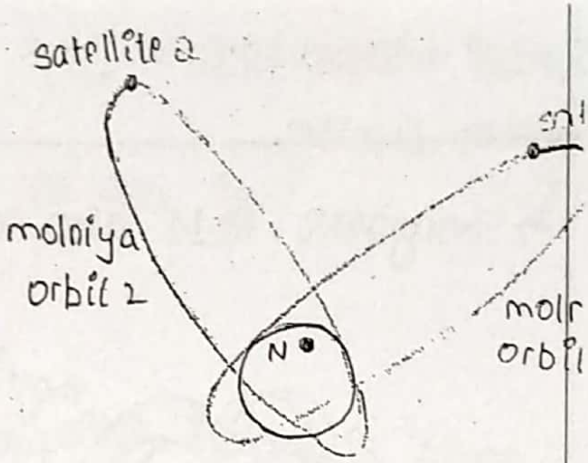
The eccentricity is equal to 0.74, it is molniya orbit. The first Molniya satellite was launched in April 1965. The word Molniya means "flash of lightning" in Russian. The apogee is at 39,152 km and perigee is at 500km for Molniya

→ The orbital period is 12 hours 38 minutes

→ orbital inclination is 62.9°



fig(a): schematic of a molniya orbit.



fig(b): schematic of an operational molniya sy.

→ used for specific services
→ long delay occurs
→ The first requirement to track the spacecraft

Radiation effects:

The effect of radiation on electronics in space is gene seperated out into 2 aspects

i. total dose : the culmulative effect of the radiation over the lifetime of electronics and it will mainly due to trapped electrons and protons in the van allen belts.

ii. single event upsets : These are more critical if the bit flip is permanent i.e latch up occurs.

→ The geomagnetic latitude ϕ can be computed as

$$\phi = \arcsin[\sin\alpha \sin 78.5^\circ + \cos\alpha \cos 78.5^\circ \cos(69^\circ + \beta)]$$

where α = geographic latitude

β = geographic longitude.

→ Magnetic field also 'effects.

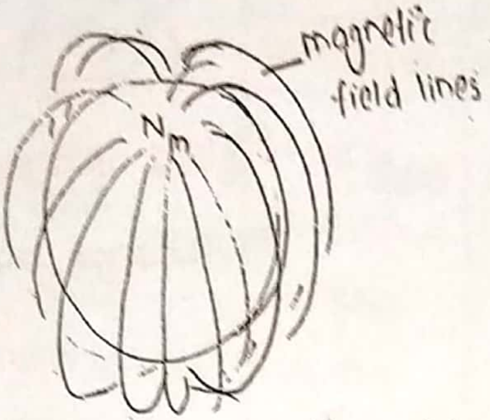


fig (a): Representation of magnetic field lines.

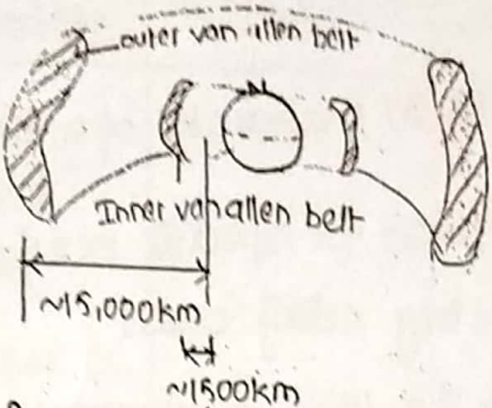


fig (b): pictorial representation of two van allen radiation belt

→ table for typical total Doses for various orbits

orbital type (degrees)	orbital height (km)		
	800	1100	8000
polar orbit (90°)	30krad(si)	100krad(si)	>500krad(si)
Equatorial orbit (0°)			>2000krad(si)

→ choosing an orbit that has reduced level of radiation can reduce ~~redu~~ the potential for radiation damage

→ Radiation hardend devices must be used

→ developing electronic devices withstand total radiation doses of 1Mrad (si) is possible with rad-hard technologies.

These are the methods to overcome radiation effects.

Sun synchronous orbit:

It is a special form of low earth orbit where the plan to the sun.

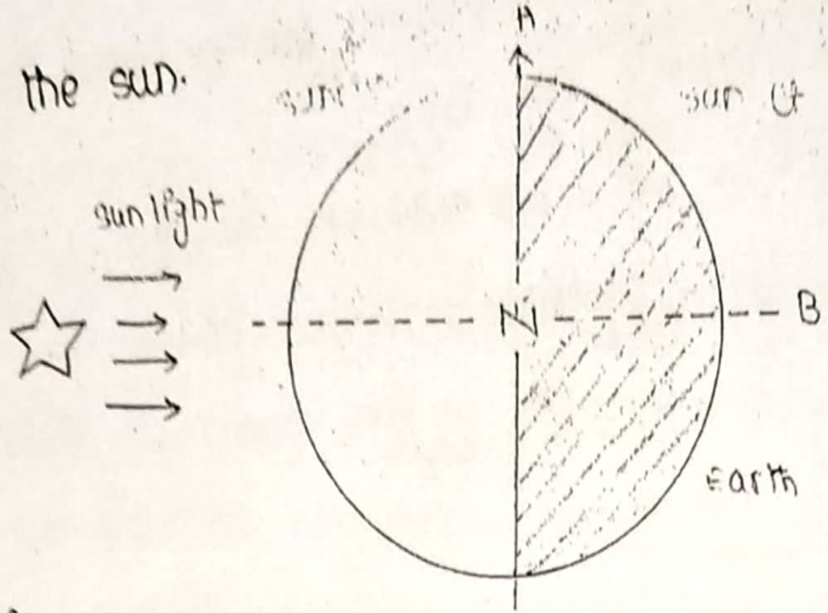


fig: Examples of two sun synchronous orbits.

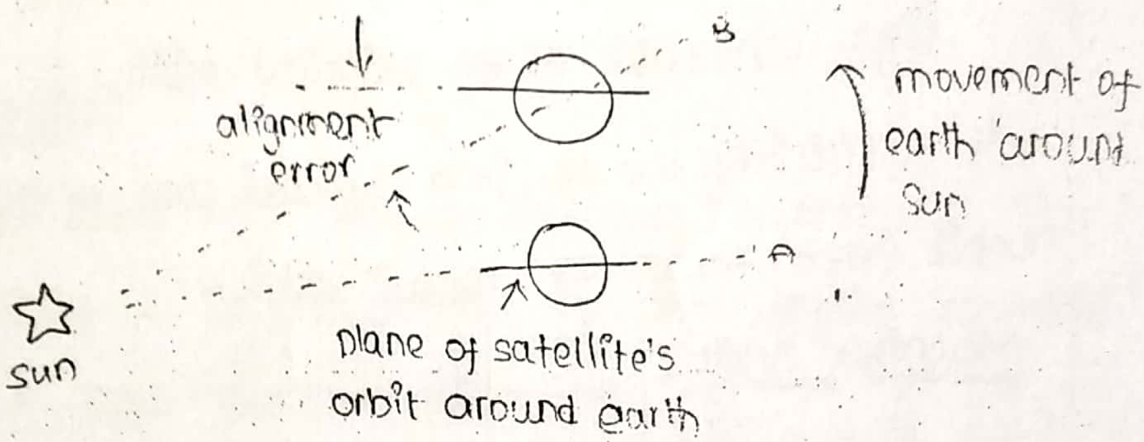


fig: Illustration of alignment changes of the orbital plane due to the movement of earth around the sun.

→ Elliptical orbits with different retrograde inclinations will al[so] yield sun synchronous orbits.

→ The change in the orbital plane is called precession

→ The adv of sun synchronous orbit is it will repeat track every half day.

In some cases the designer of a satellite system has few degrees of freedom in designing a payload to provide optimum coverage This leads to selection of orbi payload technologies etc. A GEO orbit can be selected or a constellation NGSO satellites can be designed to provide necessary coverage

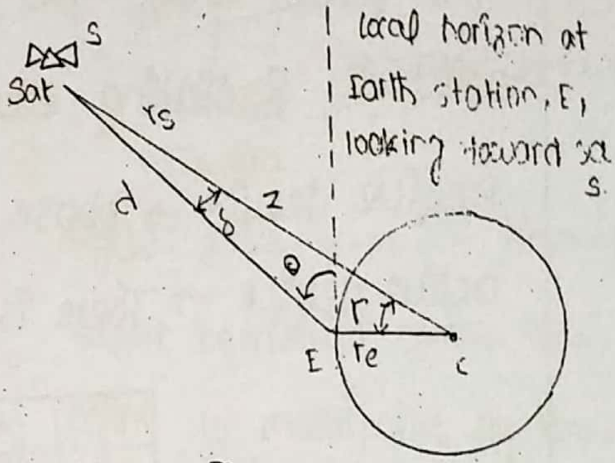


fig: geometry for calculating coverage are

from fig

$$\frac{r_s}{\sin(90+\theta)} = \frac{d}{\sin r}$$

$$\cos\theta = \frac{r_s \sin\phi}{d}$$

where θ is the elevation angle

r_s is the distance from earth center to spacecraft.

→ coverage & frequency considerations

Frequency band:

Low earth orbit satellite systems providing data & voice service to mobile users tend to use the lowest availab RF frequency.

→ EIRP = (RF freq, downlink)^2

→ Power that must be tx'd by mbl tx'r also proportional to the RF frequency, L band is used for mbl satellite service

→ consider a sat LEO sat with 'A m^2' earth coverage

$f = \frac{P_t G_t}{A}$ watts/m^2 here $P_t G_t$ = EIRP (effective isotropic radiated power)

→ The effective receiving area of a/a is.

$$A_e = \frac{G_r \lambda^2}{4\pi}$$

→ The Rx'd power at the mbl earth station is given b

$$P_r = f \times A$$

$$\boxed{P_r = \frac{P_t G_t G_r \lambda^2}{4\pi A} \text{ watts}}$$ (for omnidirectional a

→ Relay LEO sat system uses VHF and UHF frequencies.

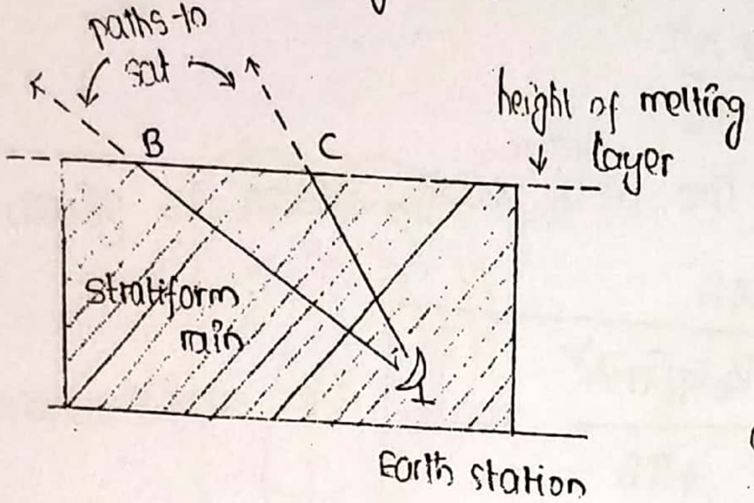
→ L band uses for mobile satellite services, VHF also ca achieve the same applications.

→ High noise power due to environment is the dis advan. of VHF & UHF frequency bands.

→ ka band is worst choice due to it's down link opera at 20 GHz requires 22.5 dB more tx'd EIRP, a/a cost also expensive for ka band.

Elevation angle considerations:

Most commercial satellite systems require ea stations operate above certain minimum elevation angle Most sat systems now, whether for the mbl sat service the elevation angle of the user to no less than 10dB.



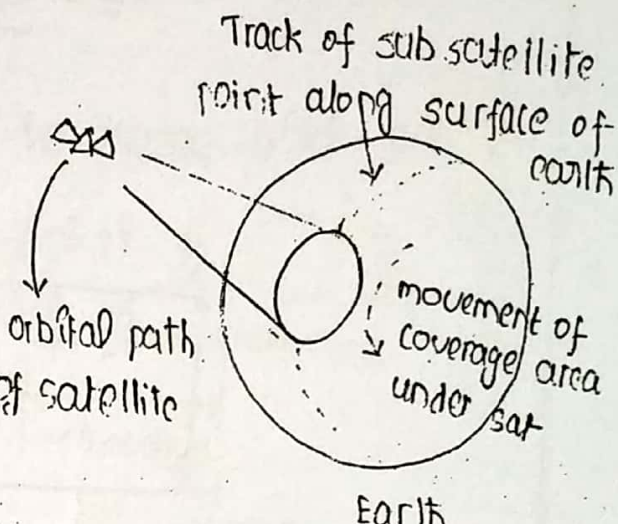


fig: Illustration in the decrease in the path through rain as the elevation angle to sat increases.

fig: Illustration of coverage are under a satellite.

→ Three cell reuse pattern is developed to analyze the coverg area of satellite on the surface of the earth.

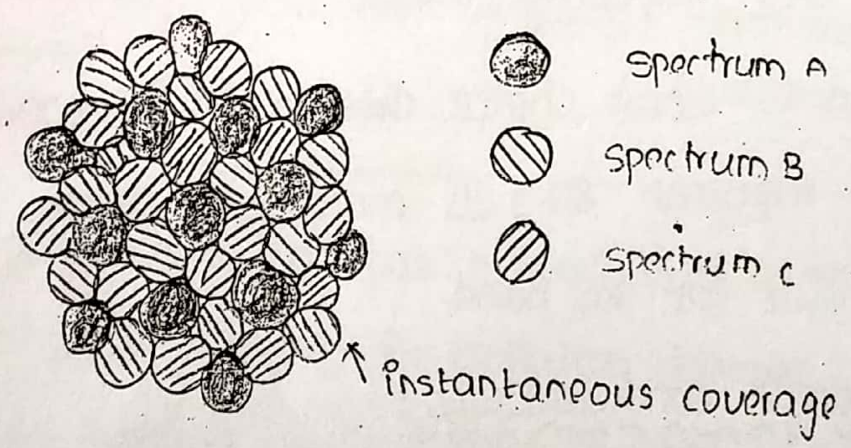


fig: Illustration of a three cell reuse pattern.

→ Each cell have a ~~sp~~ seperate beam from the satellite a/a, a portion of spectrum allocated to it.

Number of beams per coverage:

→ MSS (mbl sat service) have very small spectrum allocation

→ Traditional satellite a/a's have evolved from simple, front fed reflector a/a with one feed horn, to offset-fed designs with more than a hundred feeds.

→ A phased array a/a has non mechanically steered array of radiators. Radiating element can be active or passive devices

Passive device → phase control is achieved in the feed matrix

active device → There is a phase shifter per element per beam.

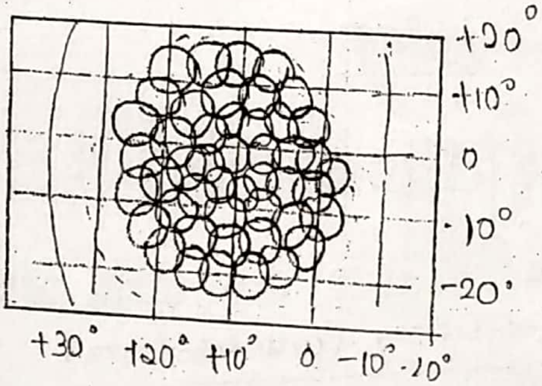
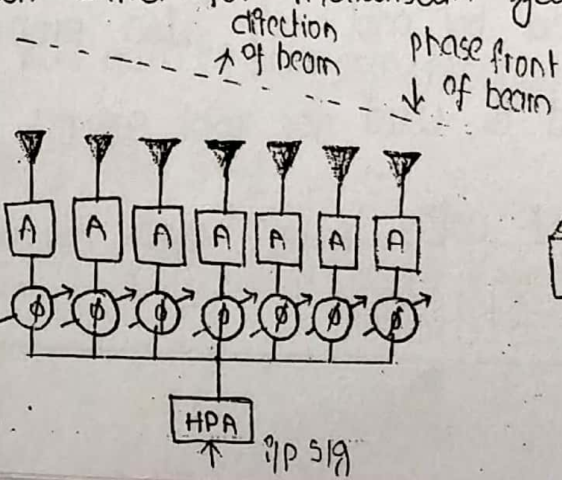
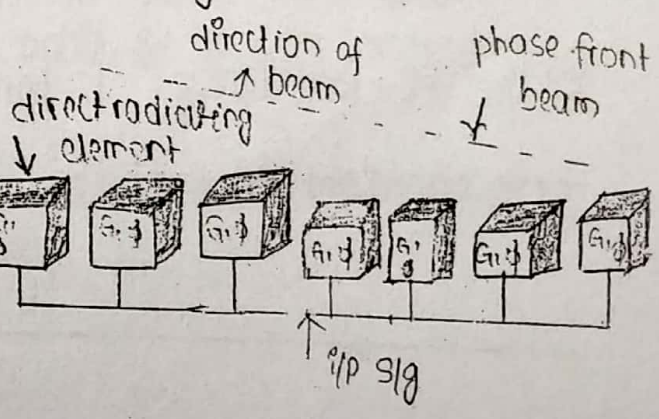


fig : User spot beams developed by an Iridium satellite.

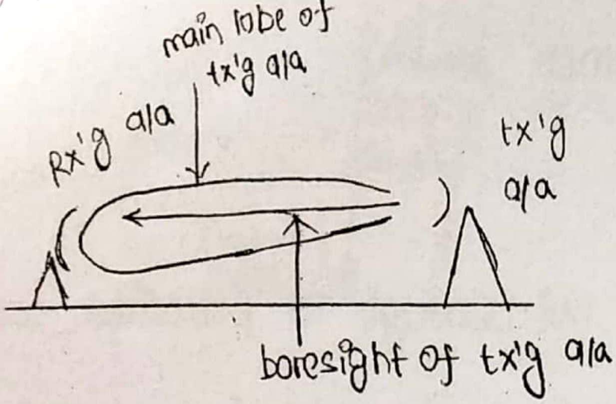
Off - Axis scanning :

The design of a point to point wireless communication system requires a/a's at either end or be directed toward each other for maximum gain advantage.

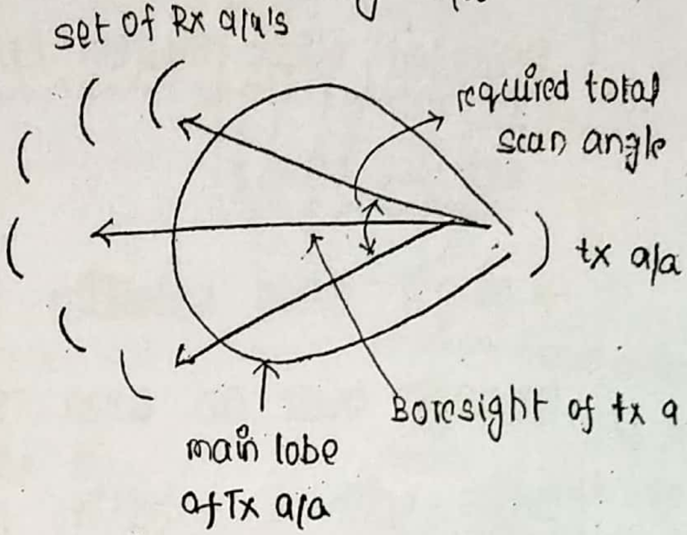




a/a's are located at different positions, it leads to the Rx a/a's will not be on the bore sight of the tx'g a/a



fig(a): point-to-point line-of-sight terristrial links



fig(b): point-to-point line-of sight terristrial comm. lins.

* satellite is a prime example of point to multipoint system. There are 2 basic parameters that are used in initial design
  i. Orbital height : LEO, MEO, GEO
  ii. Instantaneous coverage requirements for single satellite.

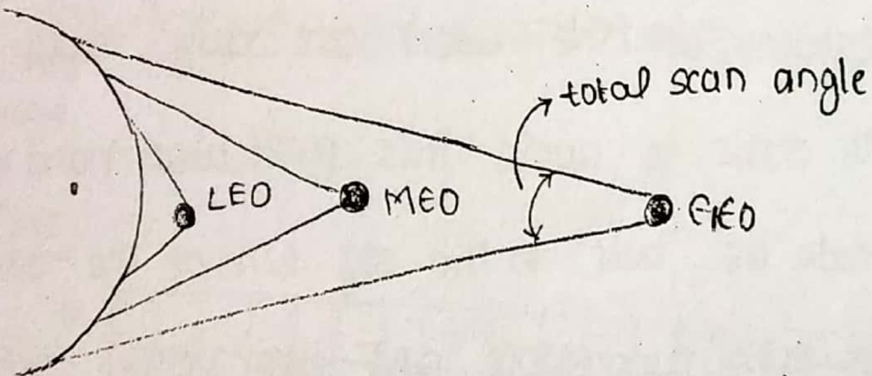


fig: schematic of the total scan angles for LEO, MEO and GEO

* A fixed a/a with parabolic reflector is able to scan its main beam away from electrical boresight axis
* When the plane wave is distorted from the focused parabolic

orbit & orbital height	LEO 750km	LEO 1800km	MEO 10,000km	MEO 14,000km	GEO 35,786k
scan angle	±57.2°	±47.1°	±21.5°	±17.1°	±8
latitude / longitude range	±12.8°	±22.9°	±48.5°	±52.9°	±6

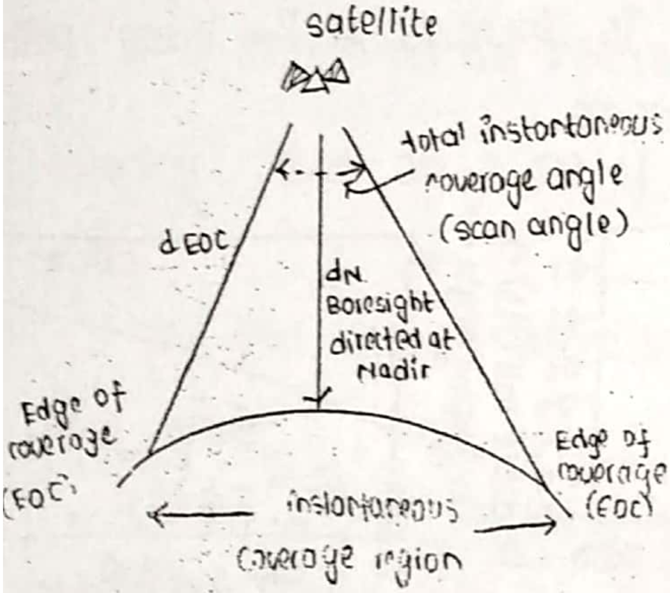


fig: Illustration of path loss & scan angle loss for phased array

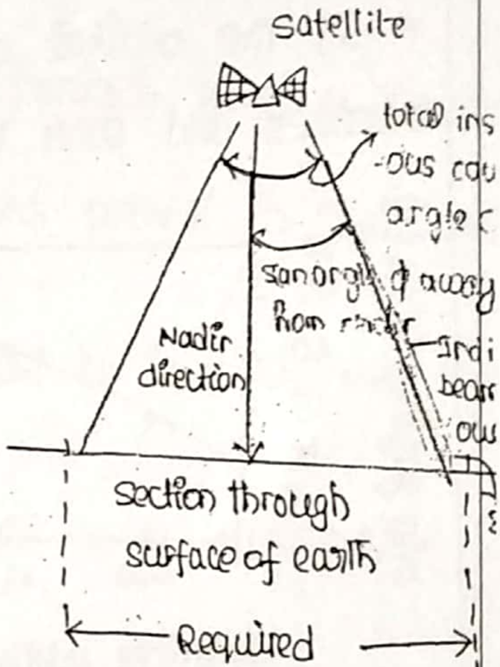


fig: Illustration of scan of individual beam.

* scan loss for a phased array follows the relationship

$$-\text{Scan loss} = (\text{cosine}\,\phi)^{k}$$

where ϕ, K are emphirical values of 57.2 & 1.3

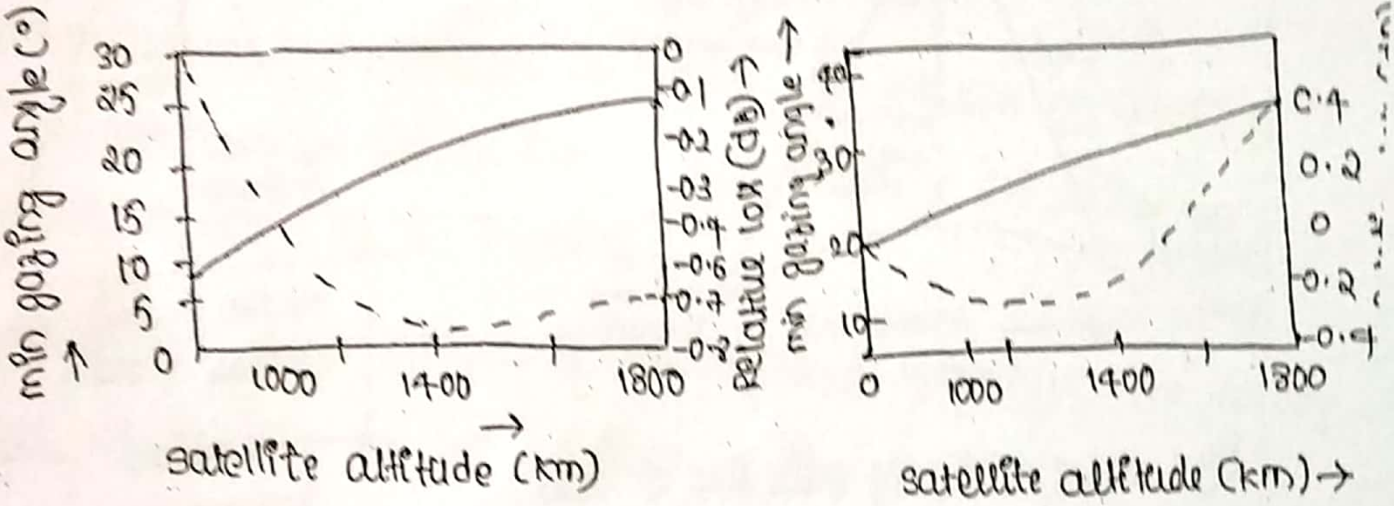
$$-\text{Scan loss} = (\text{cosine } 57.2)^{1.3}$$

$$= 0.4507 \Rightarrow -3.5\,dB$$

Determination of optimum orbital altitude :

* Minimizing the total additional loss in the tx'n path to edge of coverage is a design goal.

* If the orbital altitude is increased - free space path loss increases and scan loss decreases.



* The locations at the edge of coverage within the instantanea coverage region presents the problems in design

Radiation safety and satellite telephones:

In united states the federal communication commission (FCC) mandates strict limits on radiated power levels throughout the spectrum. FCC provides many guidelines on the specific absorption rate (SAR) for wireless phones & devices through IEEE committees. Less handset powers causes ionization damage to tissue.

Projected NGSO system customer

service base:

→ single NGSO satellite is not enough to provide con 24-h courage over an area. This leads to adopting two molniyc orbits with 2 satellites provide continuous 24-h service.

→ Most of NGSO systems are aimed at mobile users, the problem for mbl users is at to generate sufficient tx't power in a handheld terminal.

Delay and throughput considerations:

Delay in communications link is not normally a prol unless the interaction b/w the users are very rapid. call interruption will occur to avoid this particular hand off is needed with code as "over" to the sig end of the users i/p. development of echo suppressors and even better, echo canceller solved the problem. customer acceptance on a service has beu found to be driven by three factors : i. access ability ii. availability iii. performance

Delay occured when the sig is mismatched, if tl mismatch is large then strong echo sig will return.

The vocoders sample the incoming analog sig

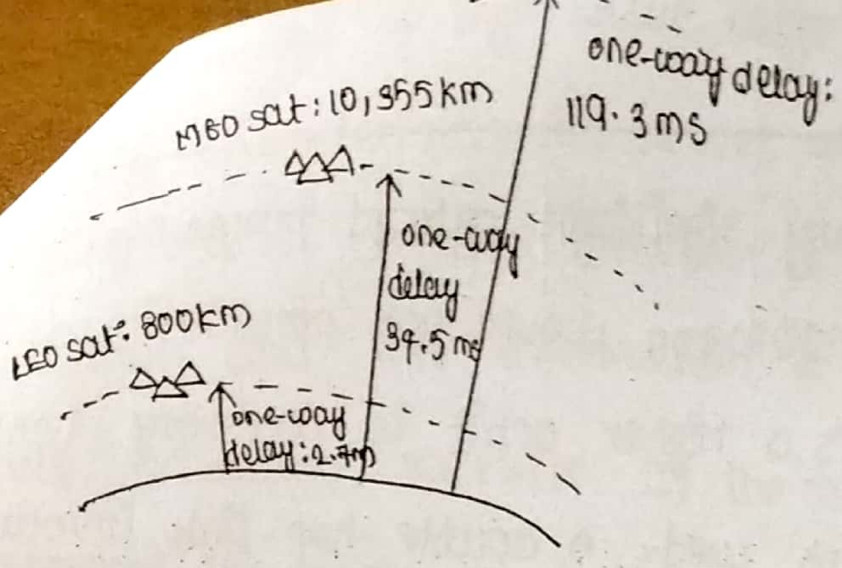
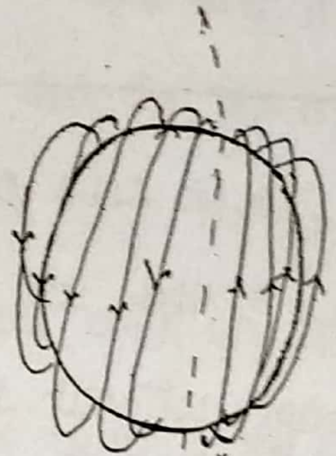


fig: One-way propogation delay for the three orbits: LEO, GEO, MEO



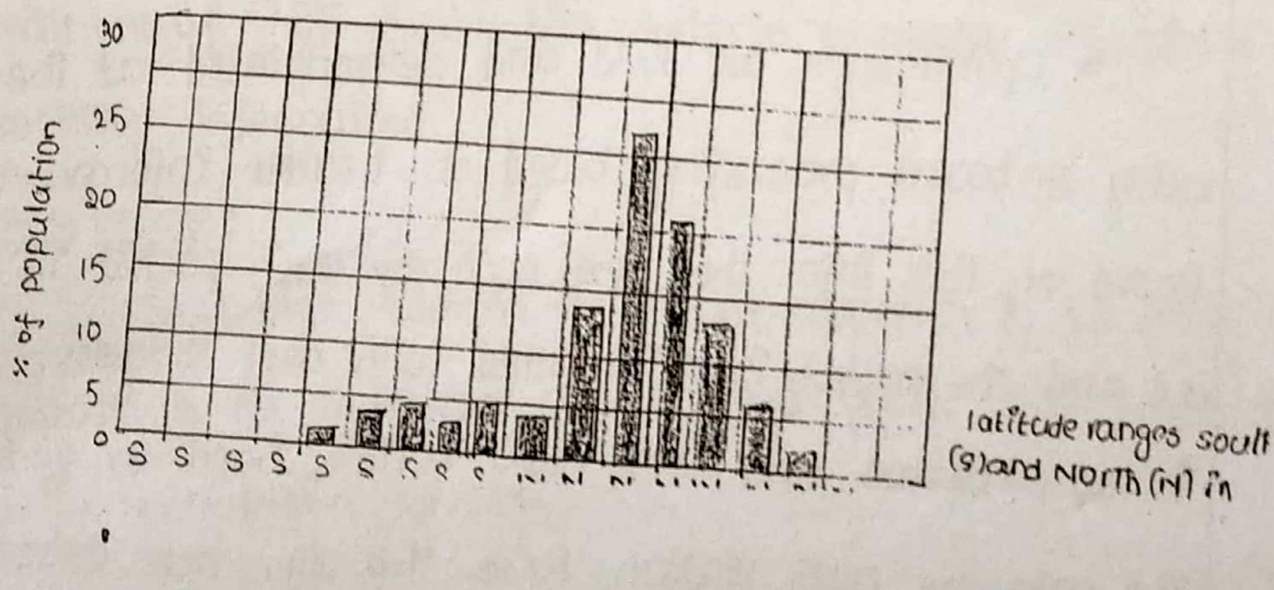
"seam" across which microwave ISLs a unable to track LEO sat in adjacent plane

fig: Schematic of ISL seam in the Iridium constellation.

⇒ Operational NGSO constellation Designs:

Seven satellite constellation designs are reviewed briefly in following. Four MSS offering with multiple beams, one with single beam coverage providing both two-way and one-way store-and-forward services and two internet-multimedia satellite systems.

Ellipso:



population distribution and the potential market for MSS

From the above graph more than 85% of the wo population lives North of the equator and equatorial constellation of MEO sat could serve the bulk of the wo population.

"Ellipso is an intermental approach th to their so offering." There are 3 set of satellites present in their re orbits.

i. The first set of satellites would be in a circular equ -rial orbit.

ii. The 2nd set of satellites would be in elliptical equatorial orbit

iii. The 3rd set of satellites would be in sun synch -us 3-hour orbit inclined at 116.6°

→ The equatorial orbit groups of the Ellipso system are ca "concordia" and the sun synchronous group is called "Borealis"

→ No ISL (inter satellite link) are used.

Global star:

Global star elected to develop a constellation that a aimed at the populous regions of the earth.

The globalstar orbitals are inclined at 52° to the equator

To minimize the power requirements of the user handset the constellation altitude is lowered to below the first van allen radiation belt. This results 48 satellites needed. No ISL's are used

The s/g is transponded down and the gateway earth stations process the s/g.

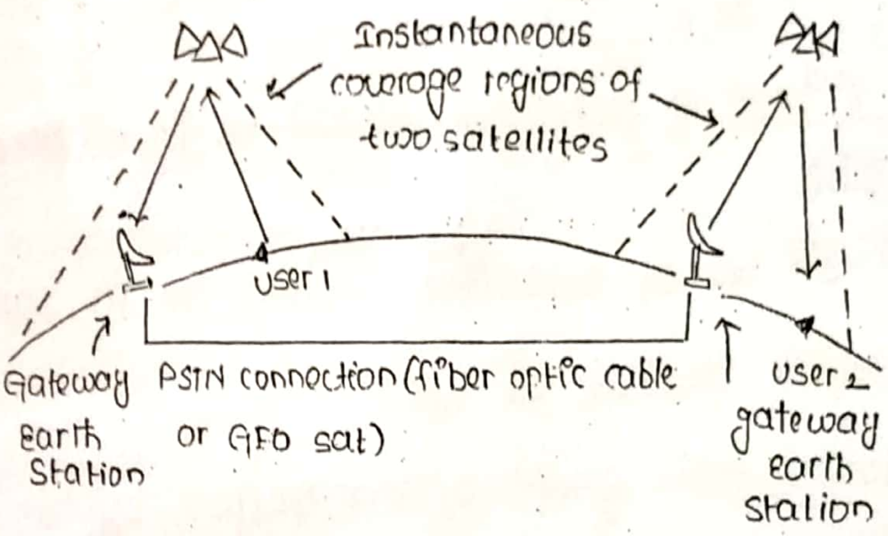


fig: schematic of end-to-end connection for satellites that have no onboard processing or ISL's.

New ICO:

* ICO global is the company that was spun off from the International maritime satellite organization (Inmarsat)

* New ICO is the company that emerged from bankruptcy protection in 2000.

* New ICO is primarily aimed at the LMS (land mbl

* No ISL's or any significant onboard processing is nee

* Here LEO constellation would not provide maritime coverage without ISL's, a higher orbit is necessary hence th use of double-hop link used. A double hop link involves two uplinks and two downlinks.

* New ICO threfore adopted a MEO constellation

Iridium:

The genesis of Iridium was formed around the need to communicate from anywhere to any where on the surface of the earth even there is no telecommunication infrastructure existed.

* The system must stand alone. The satellites in th constellation act as switching nodes.

* Uplink sig's are Rx'd and demodulated at the satelli using onboard processing based on header information. Based on this info. the next node for each packet is determ-ed and the packet is reformatted with next address. The sig is up converted and it is tx'd with L band to gnd at 20 The gateway earth station Rx've the sig, here onboard processing is needed for msg routing and formatting

Tracking of high value cargo on trucks and measuring water characteristics in revers and sea are the major applications. A GPS receiver on the cargo determines it's location and this information is sent with an ID numbe via orbcomm satellite. If the truck carrying the cargo is hijacked it's route can be followed and the truck intercepted.

Orbcomm developed their system around this requirem-ent and have orbited with both two-way data communicatio and store-and-forward capabilities.

These satellites are simple and lightweight (40kg) simple in deign and execution. Single beam is used for coverag

A terminal with in the coverage area send short msg to gate way station in real time. The msg length is limited to a few hundred bytes. Orbcomm satellites carry short msgs, the system is therefore most attractive to users who want to sen small no. of high value bits, helps in emergency situations or tracking information.

<u>Sky Bridge</u>:

Sky bridge evolved a similar approach to coverage as Globalstar by selecting an inclined orbit that covers the major population densities do not have inter satellite links (ISLs), so all traffic is transponded down to the gateway earth stations for proc and onward routing.

Skybridge satellites are intended to carry wide traffic and uses the freq's above 10GHz. It uses ku bo frequencies for GEO : 12.75 – 14.5 GHz for uplink and 10.7–1 for downlink.

Large no.of satellites (80 vs 40) are required. No are used. Skybridge uses the concept of fixed cell.

Table for system parameters of two NGSO constellations at at internet multimedia communications.

system parameter	skybridge	Teledesic.
No. of planes	20	12
satellite per plane	4	24
Total complement	80	288
orbital inclination	53°	~90°
orbit type	circular	circular
orbital height (km)	1469	~1400
spot beams per sat	18	–
satellite life time.	~7 years	~7 years

Tele desic :

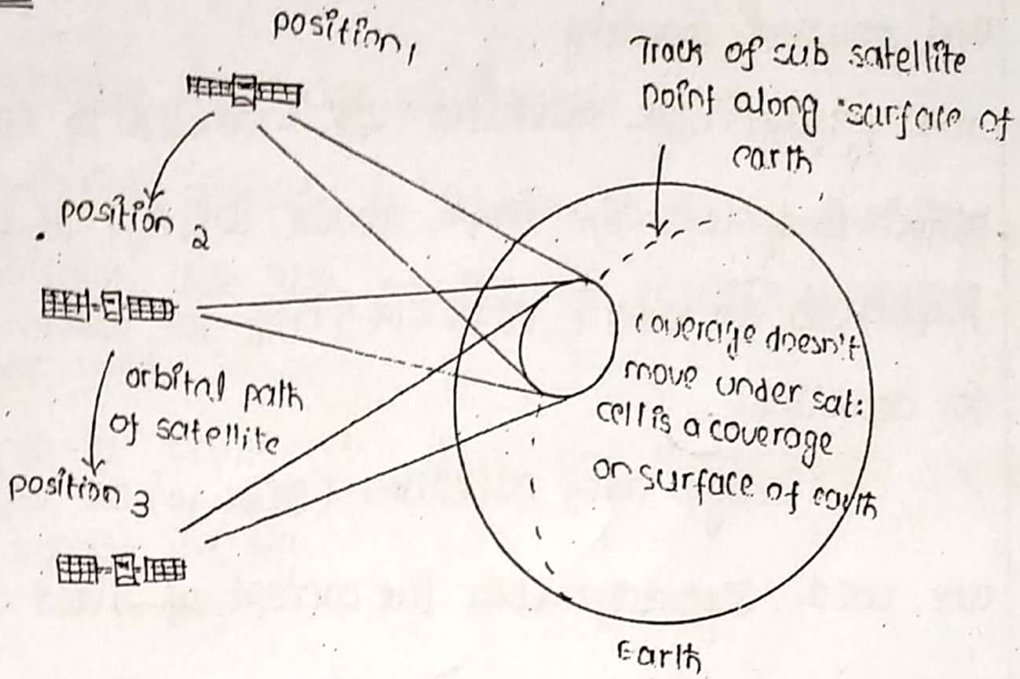


fig: concept of stationary cell.

Teledesic started from the same precept as Iridium but is designed for Internet like data traffic rather than voice communication. Any user can access any other user or ISP (internet service provider).

The concept of Teledesic is to provide a complete worldwide data communications system above the surface of the earth using satellites instead of earth surface fiber optic cables on earth.

Teledesic also limited the elevation to angle to 40° and it choose the Ka band for tx'n.

The initial Teledesic constellation had a compleme

The orbital altitude later moved up from 700km to about 1400 km which reduced the planes to 12.

Reduction of no. of satellites to 288 lowered the cost significantly and further the satellites are decreased in numb

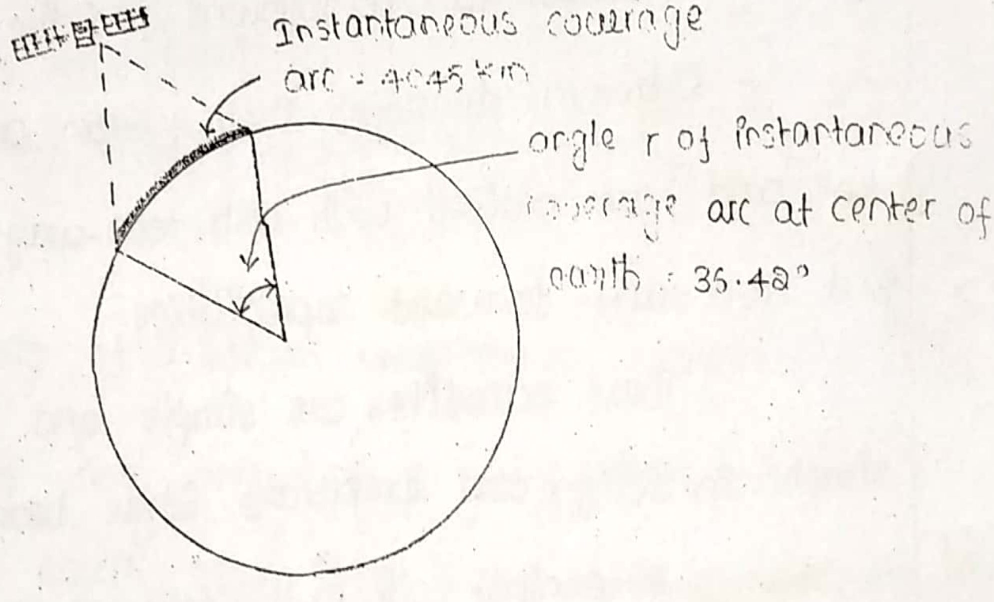


fig: coverage of one satellite orbiting at 750km altitu

comparision of NGSO system constallation parameters.

system parameter	Ellipso	Globalstar	New ICO	Iridium	orbcomm
No.of planes	1→3→5	8	2	6	4→5
satellites per plane	1x7 then 1x7 and 2x3 then 1x7, 2x3, 2x5	8	5	11	4x8 then 4x8 and 1x4
Total complement	23	48	10	66	36
orbital inclination	3 at 0°, 2 at 116.6°	52°	45°	86.5°	4 at 45°, 1 at 72°
orbital type	1 circular (0°) 2 elliptical (0°) 2 sun synchronous	circular	circular	circular	circular (45° and 72°
orbital height (km)	1 circular → 8050 2 elliptical → 649-8050 2 sun syn → 633-7605	1414	10,255	780	775
spot beams per sat	161	16	163	48	1