chapter 1

+ Radio wave propagation mechanics:

1- ground (surface) waves: follow the earth's surface by diffraction $(f < 3\,MHz)$

2- sky waves: reflected by the ionosphere $(f < 30\,MHz)$

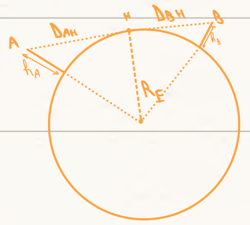
3- space waves: travel in a straight line. $(f > 30\,MHz)$

→ used in line of sight links such as terrestrial microwave and satellite systems

* line of sight distance (distance to radio horizon):

$\because D_{AH} = \sqrt{(R_E + h_A)^2 - R_E^2}$

$\rightarrow D_{total} = \sqrt{2R_Eh_A + h_A^2} + \sqrt{2R_Eh_B + h_B^2}$ +



$\because h_A \wedge h_B \ll R_E$

$\rightarrow D_{total} \simeq \sqrt{2R_Eh_A} + \sqrt{2R_Eh_B}$ $\therefore D_{total} \approx 3.57\left[\underbrace{\sqrt{h_A} + \sqrt{h_B}}_{\text{in km}}\right]$

* satellite: a small object that moves around a large celestial object in a certain orbit.

* artificial satellites: human-built objects that orbit the earth and other celestial objects in order to perform specific tasks.

+ satellite orbits are classified according to:

- height
  - low (200 → 2000 km)
  - medium (10 Mm → 20 Mm)
  - high
- inclination
  - equatorial
  - inclined
- shape
  - circular
  - elliptical
- coverage
  - global
  - zonal
  - spot
- synchronizatio
  - (geosynchronous)

+ major satellite applications:

1- communication, 2- navigation, 3- weather, 4- military

5- earth observing (remote sensing), 6- scientific research

7- recovery, 8- space stations.

+ communication satellite types:

- provide communication links between any two or more points on earth. typically in geosynchronous, molniya, or low earth orbits.

- three GEO satellites cover the whole earth except polar region

- fixed-service satellites: provide point-to-point communication links instead of submarine cables
  - now (optical) submarine cables have higher capacity and reliability, since satellites are subjected to interference.
- satellite phones: connect to other phones on the network through orbiting satellites, therefore they are not limited by terrestrial cell tower coverage
- direct broadcast satellites (DBS): overcomes coverage and bandwidth limitations of terrestrial broadcast through its high angle and operating frequency (12 GHz)

- satellite internet: offer high data rates and low-latency (if in LEO)

\+ advantages of communication satellites:

1- flexibility: provide communication in many ways without needing fixed assets.

2- mobility: ground stations are not confined to a certain coverage area

3- speedy deployment: do not need ground infrastructure.

4- global coverage: depending on the type of satellite and orbit, they can reach all areas of the globe.

\+ disadvantages:

1- limited bandwidth: up to 5 GHz (compared to 1 THz of fiber)

2- cost: expensive to build, place into orbit, and maintain.

3- propagation delay: much larger propagation delay than fibers since distances are longer.

4- lifetime: short lifetime of 7 - 15 years.

5- specialized satellite terminals are required.

- navigation satellites: transmit radio-time signals to determine mobile users' exact location.
  - GPS uses trilateration

- weather (meteorological) satellites: primarily for monitoring weather and climate
  - 1- polar operational environmental satellites (POES):
    - close to earth in sun-synchronous circular orbit
    - proximity to earth enables high resolution images and atmospheric profiles.
  - 2- geostationary operational environmental satellite
- earth observing (remote sensing) satellites: polar-orbiting, low inclination, meant for long-term observation.
  - three geostationary satellites positioned over the equator and separated by 120° longitudinally cover the whole earth.

+ military satellites:
  - reconnaissance (spying) satellites.
  - anti-satellite weapons (killer satellites): used to destroy enemy warhead satellites, and other space assets.
  - warning satellites: detect ICBMs
- scientific research satellites: observe the environment of the earth, sun, etc. (e.g., astronomical satellites)

- Recovery satellites: recover payloads from orbit to earth.
- Space stations: designed for humans to live on, lack propulsion or landing facilities.
  - Require spacecrafts to put the humans into orbit and onto the space station, as well as recover humans back to earth.

Chapter 2:

+ Kepler's laws of planetary motion:

1- orbits of planets are elliptical around the sun

2- the line joining a planet and the sun sweeps equal areas in equal time interval (i.e., angular velocity is greater at perigee)

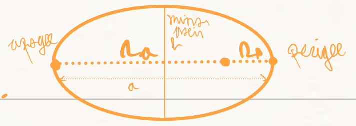
3- the period of a planet's orbit squared is proportional to the orbit's semi-major axis cubed:

$$T^2 = \frac{4\pi^2 \boxed{a}^3}{\boxed{\mu}}$$

→ semi-major axis

→ kepler's constant $(3.986 \times 10^{14}\ m^3/s^2)$

ellipse:



$\frac{r_a + r_p}{2}$ = semi-major axis

+ ellipse can be defined by: • r_a & r_p, • a & b, • a & e

or b

e=0 → circle

where e is the eccentricity and is defined by: $e = \left(1 - \frac{a^2}{b^2}\right)^{1/2}$

- velocity of an object in orbit is greatest at the perigee and smallest at the apogee.

- universal gravitation: $F = \frac{\underbrace{G}_{\text{gravitational constant}} \cdot \underbrace{m_1}_{\text{mass of 1st object}} \cdot m_2}{r^2}$

- for a satellite to remain in orbit, its velocity should give a centrifugal force equal to the gravitational force it is experiencing, for a circular orbit.

$$\frac{G \overset{\text{mass of earth}}{\boxed{M_e}}\, m}{\underset{\text{in meters}}{r^2}} = \frac{mv^2}{r} \rightarrow v = \left(\frac{\overset{\text{constant } \mu}{\boxed{GM_e}}}{r}\right)^{1/2}$$

- for a circular orbit, v is constant, thus the orbital period is: $\frac{2\pi r}{v}$ since one rotation is 2π ω → angular velocity

$$\rightarrow T = \frac{2\pi \cdot r^{3/2}}{\sqrt{\mu}}$$

kepler's third law

→ kepler's constant

example 1: $V = \left(\frac{GM_e}{\underset{\text{in m}}{r}}\right)^{1/2}$ & $r = R_e + h \rightarrow V = 7758.9$ m/s

$$T = \frac{2\pi r}{v} = 5367.5\ s = 1.49\ \text{hours}$$

example 2: geostationary → angular velocity of object = angular velocity of earth

→ orbital period of satellite = rotational period of earth

$$\therefore T^2 = \frac{4\pi^2 \cdot r^3}{\mu} \approx (24 \cdot 60 \cdot 60)^2$$

sidereal day is $\overset{\text{hours mins s}}{\underline{23:56:4.09}}$

inaccurate

$$\rightarrow r = 42.241\ Mm = R_e + h \rightarrow h = 35.863\ km$$

$$\& \quad V = \frac{2\pi r}{T} = 3071.85\ m/s$$

* elliptical orbits:

- since acceleration should be equal at all points in the orbit, therefore the outward acceleration due to the rotation of the satellite must be equal to the inward acceleration due to gravity

$$\rightarrow \frac{\overset{\text{opposite direction}}{\boxed{-}} GM_e m \bar{r}}{r^3} = m \cdot \overset{\text{acceleration}}{\boxed{\frac{d^2r}{dt^2}}}$$

$$\therefore \frac{d^2r}{dt^2} + \frac{\mu \bar{r}}{r^3} = 0$$

- by solving the above equation, r can be found from θ as follows:

$$r = \frac{p}{1 + e\cos(\theta)} = \frac{a(1-e^2)}{1 + e\cos(\theta)}, \quad p = \frac{\overset{\text{orbital angular momentum}}{\boxed{h}}^2}{\mu} = a(1-e^2)$$

$\because (1-e^2) = (1-e)\cdot(1+e)$

→ perigee distance is $\overset{R_p}{a(1-e)}$ and apogee distance is $\overset{R_a}{a(1+e)}$

$$\therefore a = \frac{R_p + R_a}{2} \quad \& \quad e = \frac{R_a - R_p}{R_a + R_p} = \frac{R_a - R_p}{2a}$$

- the orbital period for elliptical orbits is the same as for circular orbit whose radius is the semi-major axis and is independent of e

$$T = \frac{2\pi\, a^{3/2}}{(GM_e)^{1/2}} \rightarrow T^2 = \frac{4\pi^2 a^3}{\mu}$$

- the average angular velocity is found from T as: $\eta = \frac{2\pi}{T} = \left(\frac{\mu}{a^3}\right)^{1/2}$

- the satellite's velocities at the perigee and apogee are found to be:

$$\overset{\text{velocity at perigee}}{V_p} = \underbrace{\overset{\sqrt{\frac{\mu}{r_p}}}{V_{cp}}}_{\text{velocity of circular orbit with radius } r_p} (1+e)^{1/2} \quad \wedge \quad \overset{\text{velocity at apogee}}{V_a} = \underbrace{\overset{\sqrt{\frac{\mu}{r_a}}}{V_{ca}}}_{\text{velocity for circular orbit with radius } r_a} (1-e)^{1/2}$$

- the velocity at any point is: $V = \sqrt{\mu\left(\frac{2}{r} - \frac{1}{a}\right)}$

example 3: semi-major axis $= \frac{r_a + r_p}{2}$ $\wedge$ $r_a = 4000 + 6378$, $r_p = 1000 + 6378$

$\rightarrow a = 8878$ km $\wedge$ $e = \frac{r_a - r_p}{r_a + r_p} = \frac{3000}{17756} = 0.169$

$T = \frac{2\pi\, a^{3/2}}{\mu^{1/2}} = 8325$ s $=$ 2 hours, 18 min, and 45 s

$V_p = \sqrt{\frac{\mu}{r_p}} \cdot (1+e)^{1/2} = 7947$ m/s $\wedge$ $V_a = 5644$ m/s

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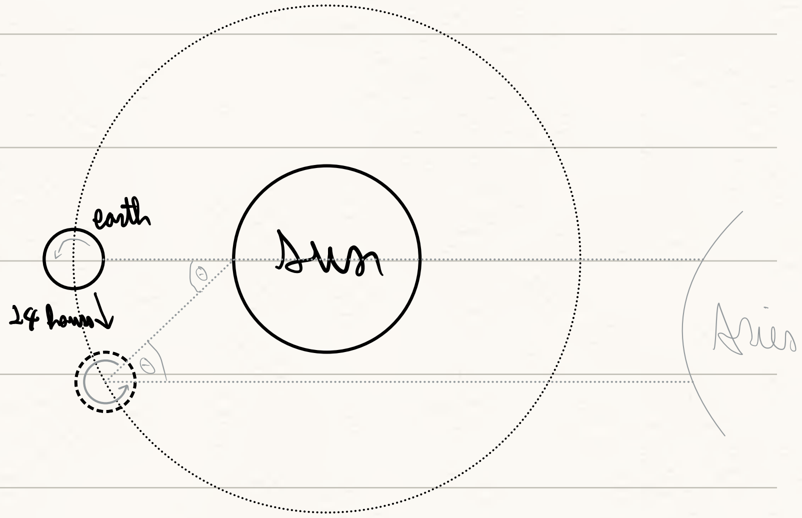
EE558 : homework #1



- since a sidereal day is the time the time between two successive straight lines to be drawn from a certain point on earth to Aries (i.e., Aries is the reference point, not the sun), and since the earth is orbiting around the sun, therefore the same point will form a straight line with Aries before it completes a 360° rotation.
- Additionally, the lines are assumed parallel since Aries is very far away.

∴ earth rotates around the sun in 365.25 days

→ angular velocity of earth orbiting the sun:

$$T = 365.25 \cdot 24 \cdot 60 \cdot 60 = \frac{2\pi r}{v}$$

$$\therefore \frac{v}{r} = 1.141 \times 10^{-5} \text{ degrees/s} \rightarrow 0.9856 \text{ degrees/day}$$

$$\rightarrow \text{sidereal day: } 360 - 0.9856 \rightarrow \frac{T_{sidereal}}{T_{full}} = \frac{359 \cdot \cancel{(r/v)}}{360 \cdot \cancel{(r/v)}}$$

$$\therefore T_{sidereal} = 0.9973 \cdot 24 = 23.9325 = \boxed{23 \text{ hours, } 56 \text{ mins, } 6.7 \text{ s}}$$

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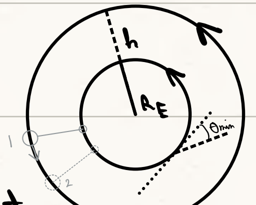
EE538: homework #2

2.2: $\because h = 322\ km$ & circular orbit $\rightarrow V = \sqrt{\frac{\mu}{R_E + h}} = \boxed{7.7\ km/s}$

angular velocity : $\frac{V}{R_E + h} = \boxed{1.15 \times 10^{-3}\ rad/s}$

$\rightarrow$ orbital period $= 5463.6\ s = 1.52$ hours $= \boxed{1\text{ hour }31\text{ mins}}$



2.5: since both satellite and earth are rotating in the same direction the satellite must complete a rotation greater than one orbit to compensate for the earth's rotation. satellite must complete a full orbit plus the earth's rotation.

$\rightarrow$ satellite orbit: $2\pi + \Delta\phi_E$ & $\Delta\phi_E = 4 \cdot \frac{2\pi}{24}$

$\therefore$ satellite rotates $\frac{7}{3}\pi$ every 4 hours

a) $\omega = \frac{\frac{7}{3}\pi}{4 \cdot 3600} = 5.09 \times 10^{-4}\ rad/s$

3 hours 26 min

b) orbital period $= \frac{2\pi}{\omega} = 12344.2\ s = 3.43$ hours

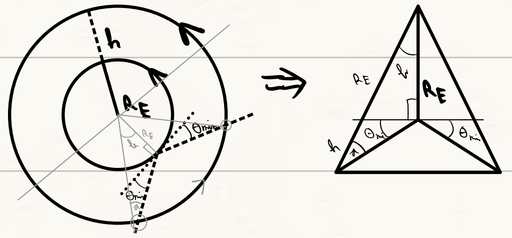
c) $\because T = \frac{2\pi r^{3/2}}{\mu^{1/2}} \rightarrow R_E + h = \left[\frac{T \mu^{1/2}}{2\pi}\right]^{2/3} = 11544.3\ km$

d) $h = 11544.3 - R_E = 5166\ km$

e) $V = \omega \cdot (R_E + h) = 5876\ m/s$

f) $\because \theta_{min} = 10^\circ \rightarrow \theta_{range} = 2 \cdot (90 - 10) = 160^\circ$

using sine law:



$$\frac{R_E}{\sin(a)} = \frac{R_E + h}{\sin(\theta_{min} + 90)}$$

$$\rightarrow a = \sin^{-1}\left[\frac{R_E}{R_E + h} \cdot \sin(100^\circ)\right] = 31.59^\circ$$

$$\rightarrow b = 180 - (90 + 10 + 31.59) = 48.41^\circ$$

∴ satellite is in sight for 48.41 × 2 degrees of its rotation, plus the angle of the earth's rotation.

$$\rightarrow \theta_{los} = 48.41 \times 2\left[1 + \frac{4}{24}\right] = 112.96^\circ = 1.97 \text{ rad}$$

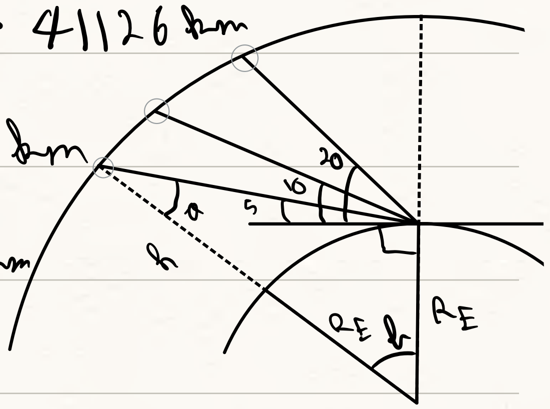
∴ $t_{comm.} = 3873$ s = 64.55 mins

2.7: ∵ FSS satellites are in GEO → min. range = 35786 km

i) C-band: $\frac{R_E}{\sin(a)} = \frac{R_E + h}{\sin(95)} = \frac{?}{\sin(b)}$ → 41126 km

Ku-band: $\frac{R_E + h}{\sin(100)} = \frac{R_E}{\sin(a)} = \frac{?}{\sin(b)}$ → 40586 km

Ka-band: $\frac{R_E + h}{\sin(110)} = \frac{R_E}{\sin(a)} = \frac{?}{\sin(b)}$ → 39554 km



ii) C-band = 274 ms

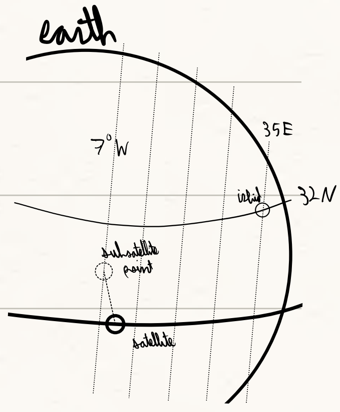
Ku-band = 270 ms

Ka-band = 264 ms

$$\frac{2 \times \text{distance}}{c \ (\text{km/s})}$$

Q4: look angles of an earth station in irbid receiving from Nilesat

- Nilesat is geostationary satellite with subsatellite point at 7° west.



- irbid coordinates ≈ 32° N and 35° E

$\because \cos(\theta_{EL}) = \frac{R_s \sin(\gamma)}{d}$ & $d = R_s \cdot \sqrt{1 + \left(\frac{R_E}{R_s}\right)^2 - 2\left(\frac{R_E}{R_s}\right) \cdot \cos(\gamma)}$

& $\cos(\gamma) = \cos(LA_e) \cdot \cos(Lo_s - Lo_e) = 50.9^\circ$

$\rightarrow \boxed{\theta_{EL} = 31.7^\circ}$

$\because A_z = 180 + \alpha$ & $\alpha = \tan^{-1}\left[\frac{\tan(Lo_s - Lo_e)}{\sin(LA_e)}\right]$

$\rightarrow \boxed{A_z = 239.5^\circ}$

Q5: max doppler shift from satellite in circular orbit at 500 km altitude

$\because V = \sqrt{\frac{\mu}{r}} = 7612.7$ m/s

& $\Delta f = f_T \cdot \left(\frac{V_T}{c}\right)$, $V_T = V\cos(\theta) = V \cdot \frac{R_E}{R_E + h}$

$\therefore \Delta f = f_T \cdot 2.35 \times 10^{-5} = \boxed{\pm 0.0023\%}$

Quiz #2 practice:

1) $\because$ $h = 700 \rightarrow R_s = 700 + 6378 \rightarrow V = 7504.3\ m/s$

$\wedge$ $\omega = \frac{V}{R_s} = 1.06 \times 10^{-3}\ rad/s \rightarrow T = 5926.2\ s$

2) $r_p = R_E + 600\ km$ $r_a = R_E + 2000\ km \rightarrow a = 7628\ km$

$eccentricity = \frac{r_a - r_p}{2a} = 0.098$

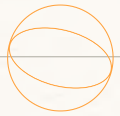
$T = \frac{2\pi a^{3/2}}{\mu^{1/2}} = 6630\ s = 1.84\ hours$

$V_p = V_{cp}(1+e)^{1/2} = 7976.9\ m/s$

$V_a = V_{ca}(1-e)^{1/2} = 6550.9\ m/s$

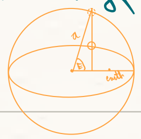
+ locating the satellite in orbit:

- in a circular orbit, the exact position can be easily found since the radius of the orbit and angular velocity are constant. hence the true anomaly is a linear function of time.



- for elliptical orbits, the ellipse is confined by a circle whose radius is the semi-major axis of the ellipse. a hypothetical satellite is assumed to orbit this circle with an angular velocity equal to the average angular velocity of the satellite in the elliptical orbit.
- therefore, the satellite in the elliptical orbit will always form a straight

line with the circular orbit hypothetical satellite and a point at $a\cos(E)$ from the center of the circle.



- the distance of the satellite from the center of the earth can thus be found from: $\left.\text{distance from the center of earth}\right\} r = a(1 - e\cos(E))$

- the true anomaly is:

$$r = a \cdot \frac{1 - e^2}{1 + e\cos(\theta)}$$

- the eccentric anomaly is:

$$E - e\sin(E) = \eta(t - \overbrace{t_p}^{\text{time at perigee (reference)}}) = \overbrace{M}^{\text{mean anomaly}}$$

- in rectangular coordinates with the center of the earth at the origin: $x = r\cos(\theta)$ $y = r\sin(\theta)$

+ locating the satellite with respect to the earth:
  - a satellite's orbit does not depend on the earth's rotation around its axis or the sun
  - The geocentric equatorial coordinate system can be used to locate the satellite.
    - in this system, the positive x-axis starts at the center of the earth and goes through the center of the sun pointing towards Aries at the vernal equinox. when the sun is perpendicular to the equator.

+ six orbital elements to locate a satellite:
  - two define the shape: semi-major axis (a) and eccentricity (e)

- three define the orbital plane's orientation:
  - inclination (i) with respect to the equatorial plane

    the point at which the satellite's orbit crosses the equatorial plane while ascending (☊)
  - right ascension of the $\overbrace{\text{ascending node}}$ (Ω), the angular distance from the positive as defined above x-axis measured eastward to the point the satellites orbit crosses the equatorial plane while ascending.
  - angular distance of the perigee measured from the ascending node (ω_p)
- last one defines its position in orbit: true anomaly (θ) measured from the perigee

+ Classification of satellite orbits:
  - altitudes below 600 km are avoided because of air-drag.
  - Van Allen radiation belts should also be avoided (2000 - 10000 km) as the particles in these belts damage, and eventually destroy, the solar cells and electronics in the satellite.

1- Altitude:
  - low earth orbit (LEO): 500 - 2000 km
  - medium earth orbit (MEO): 2000 - 35786 km geostationary
  - high earth orbit (HEO): above altitude of GEO (>35786 km)

2- inclination:
  - equatorial: $i = 0°$

- inclined: $0° < i < 90°$ & $90° < i < 180°$
- polar: $i = 90°$

3- eccentricity:

- circular: $e = 0$
- elliptical: $0 < e < 1$

4 - synchrony:

- nonsynchronous: antennas of ground station must track.
- geosynchronous/geostationary: at 35786 km above sealevel, has orbital period equal to rotational period of earth, antennas of ground stations are fixed.
- sun-synchronous: passes through any point on the earth's surface at the same solar time of the respective point.

5 - direction:

- prograde: $i < 90°$, satellite moves in same direction as earth
- retrograde: $i > 90°$, satellite orbits in the opposite direction of the earth's orbit.

- retrograde is rarely used since the rockets require much more fuel than for prograde orbits. rockets already have an eastward component from the earth's rotation, which makes prograde orbits more fuel-efficient

6- special:

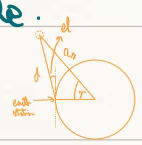
- supersynchronous: close to above GEO, satellite drifts west.
- subsynchronous: close to below GEO, satellite drifts east.
- graveyard: (junk/disposal) a few hundred kilometers above GEO, satellites moved here at the end of their operation.
- hohmann: transfer orbit, moves satellite from one circular orbit to another using two engine impulses.
- molniya: highly elliptical, $i = 63.4^\circ$, $T \approx 12$ hours, mostly covers two designated areas Russia and the USA.
- tundra: highly elliptical, $i = 63.4^\circ$, $T \approx 24$ hours, covers a single area.
- geosynchronous transfer: elliptical orbit with perigee at altitude of LEO and apogee at altitude of GEO

+ look (pointing) angles: (of earth station)

  * subsatellite point: the point on earth through which the line connecting the satellite and the center of the earth passes.

  - azimuth angle: measured along the horizon from the true north to the subsatellite point $0^\circ < Az < 360^\circ$

- elevation angle: vertical angle from the surface of the earth to the line from the antenna to the satellite. $0^\circ < el \leq 90^\circ$
  - the signal must travel through the earth's atmosphere a longer distance for smaller elevation angles, which will cause it to attenuate and distort more. Thus, 5° is generally considered the minimum $\overset{\text{acceptable}}{\uparrow}$ elevation angle.



- elevation angle is found from:

$$\cos(el) = \overbrace{r_s}^{\text{satellite radius}} \cdot \frac{\sin(\gamma)}{d}$$

γ ⟶ angle between lines from center of earth to satellite and to earth station

d ⟶ distance from earth station to satellite

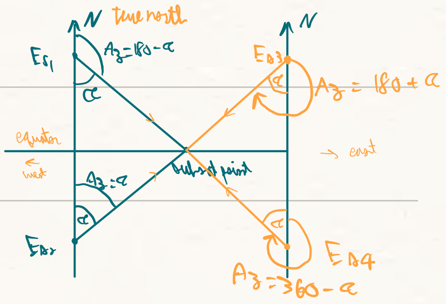
✓ $$\cos(\gamma) = \cos(\overbrace{LA_e}^{\text{earth station lattitude}})\cos(\overbrace{LA_s}^{\text{subsatellite point lattitude}})\cos(\overbrace{LO_s}^{\text{subsatellite point longitude}} - \overbrace{LO_e}^{\text{earth station longitude}}) + \sin(LA_e)\sin(LA_s)$$

- for a GEO satellite, $LA_s = 0 \rightarrow \cos(\gamma) = \cos(LA_e)\cdot\cos(LO_s - LO_e)$

✓ $$d = r_s\left[1 + \left(\frac{\overbrace{r_e}^{\text{earth radius}}}{\underbrace{r_s}_{\text{satellite radius}}}\right)^2 - 2\left(\frac{r_e}{r_s}\right)\cdot\cos(\gamma)\right]^{1/2}$$

- Azimuth angle for geostationary satellites is found from:

$$\tan(\alpha) = \frac{\tan(\overbrace{|LO_s - LO_e|}^{\text{magnitude}})}{\sin(LA_e)}$$



- case 1: earth station in northern hemisphere and the satellite is to its east: $A_z^\circ = 180 - \alpha$
- case 2: earth station in northern hemisphere and the satellite is to its west: $A_z^\circ = 180 + \alpha$
- case 3: earth station in southern hemisphere and the

satellite is to its east: $Az^{\circ} = \alpha$

- Case 4: earth station in southern hemisphere and the satellite is to its west: $Az^{\circ} = 360 + \alpha$

* Orbital perturbations:

- equations were derived assuming the earth is a perfect sphere and the effects of the sun's and moon's gravity can be neglected. these assumptions are not accurate.

+ effect of earth's oblateness:
  - due to rotation
    the radius of the earth is ~ 20 km larger at the equator than at the poles and the earth's density is not uniform (i.e., gravity is not uniform).
  - four equilibrium points exist in the geostationary orbits, two stable and two unstable.
  - east-west drift
    satellites drift from the unstable to the closest stable point

+ effect of the sun's and moon's gravity:
  - the gravity of the sun and moon perturb the satellite's orbit.
  - the net effect changes the plane of the orbit in the direction of the sun-earth plane

and moon-earth plane. (inclination change or north-south drift)

- the moon's gravity causes the satellites figure-8 orbital variations.

+ solar radiation:
  - solar wind (high speed protons and electrons from the sun) causes frictional drag that is stronger for high surface area to mass ratio satellite
  - since the satellite is shielded from solar wind when on the night side of earth, the perturbations caused by solar wind is irregular.

* satellite launching:

+ path types after kick:

1- if speed is $V_c = \sqrt{\frac{\mu}{R_e+h}}$, then the satellite forms a circular orbit.

2- if the speed is less than V_c, then the satellite forms an elliptical orbit with the earth at the focus farthest from the kick point.

3- if the speed is more than V_c, then the satellite forms an elliptical orbit with the earth at the focus nearest to the kick point.

4- if the speed is equal to $\sqrt{2}\, V_c$, a $\underbrace{\text{parabolic}}_{y^2 = ax}$ orbit is formed with the earth at its focus.

- escape velocity is found by equating the potential and kinetic energies: $\underbrace{\frac{1}{2} \cancel{m} V^2}_{\text{kinetic}} = \underbrace{\frac{G M_e \cancel{m}}{r}}_{\text{potential}} \rightarrow V_e = \sqrt{\frac{2 G M_e}{r}} = \sqrt{2} V_c$

5- if the speed is greater than the escape velocity, then the orbit is $\underbrace{\text{hyperbolic}}_{\left(\frac{x}{a}\right)^2 - \left(\frac{y}{b}\right)^2 = 1}$ with the earth at its focus.

+ launching:

1- first stage: heaviest, contains the fuel needed to lift the rocket off the ground and into the sky. the rockets break off once the fuel is depleted.

2- second stage: smaller rockets ignite after the first stage rockets break off. These rockets are meant to place the satellite into initial orbit. breaks off once the fuel is depleted and burns in the atmosphere.

3- Upper stage: connected to the satellite itself, places it in final orbit.

+ parking orbits:

- it is not possible to place satellites in medium-high orbits directly since that would require too much fuel and too high of a velocity that would cause the satellite to burn in the atmosphere.

- instead, satellites are "parked" into initial low earth orbits.
- rockets travel vertically until they have passed the denser layers of the atmosphere, then they are slanted to gain horizontal speed. This is done to avoid drag.

+ launch sites and windows:
  - launching from the equator allows rockets to benefit from the earth's rotational speed, which is max at the equator. Therefore, less propellant is needed a rocket launched from the equator than for the same rocket launched far from the equator.
  - launch site should have a clear pathway for the first stage to land in uninhabited areas and for the rockets to not fly over populated areas.
  - space shuttle also needs a landing strip
  - launch window refers to the span of time during which a rocket can be launched.

- interplanetary launch windows depend on the earth's position in its orbit around the sun, as well as weather and other factors.

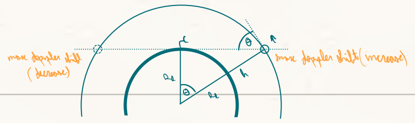
* orbital effects on communication system performance:

+ doppler shift:

- received frequency: $\overset{\text{received}}{f_R} = \overset{\text{transmitted}}{f_T}\left[1 \pm \frac{V_T}{c}\right] = f_T \overset{\text{towards}}{\boxed{+}}\underset{\text{away}}{\boxed{-}} \Delta f$

$$\rightarrow \Delta f = f_T \frac{V_T}{c}$$

- max doppler shift occurs when the satellite appears over the horizon (or disappears) since the satellite's speed component (magnitude) towards or away from the earth station is maximum.



$$V_T = V \cdot \cos(\theta)$$

- when the satellite is at the zenith, its horizontal speed component will be max, but the signal will be transmitted parallel to the satellite's direction of travel and hence there will be no doppler shift.

+ satellite eclipse:

- occurs when the earth's equatorial plane coincides with the earth's orbital plane around the sun. for geostationary satellites

- geostationary satellites are eclipsed once a day for the 23 days before and after the vernal (21 march) and autumnal (23 september) equinoxes (first and last days) for a min of 10 minutes at equinox

and max of 72 minutes.

- satellite power must be supplied from batteries during eclipses.

+ sun transit outage:

max 10 mins

  - occurs for short periods in the six days around both equinoxes.
  - the satellite transits between the sun and earth and the sun enters the beamwidth of the satellite.
  - the sun appears as a very noisy source and completely blanks out the satellite's signals.

+ first exam practice:

4 / 2014 :

Q1: a- the six keplerian orbital elements are:

of orbit

1- semi-major axis (a), 2- eccentricity (e), 3- inclination (i)

4- right ascension of ascending node (Ω), 5- true anomaly (θ)

6- angular distance of the perigee from ascending node.

b) 1- orbit must be circular, 2- must be equatorial,

3- must be prograde and have same angular velocity as earth

4- must have correct altitude for angular velocity.

21/3 23/9

c) for 23 days before and after both vernal and autumnal

equinoxes: Feb 26 - April 14 and sept. 1 - oct. 16

therefore eclipses last for ≃ 57 days for a maximum

duration of 72 minutes.

ELV

d) reusable: space shuttle, disposable: rockets

e) the earth's non-uniform gravity may cause east-west drift

to the closest stable equilibrium point

the gravity of the sun and moon may also cause a north-south

drift.

Q2: a) for the circular parking orbit: $T = 5431\,s$ $T_{GTO} = \frac{2\pi a^{3/2}}{\mu^{1/2}}$

$\rightarrow T_{GTO} = 38230\,s$

the ~~GTO and~~ GSO periods are ~~both~~ only GSO equal to: $T = 86820\,s$

before perigee kick

Velocity for parking orbit: $7725.8\ m/s$

after perigee kick

Velocity at perigee: $7725.8[1+e]^{1/2} = 10155.8\ m/s$

$$\wedge\ a = \frac{r_p + r_a}{2} = \frac{2R_e + 36000\,km + 300\,km}{2}$$

$$\wedge\ e = \frac{r_a - r_e}{2a} = 0.728$$

before apogee kick

Velocity at apogee $= 3066.9 \cdot [1-e]^{1/2} = 1599.5\ m/s$

after apogee kick

Velocity for GSO $= \sqrt{\frac{\mu}{r_{GSO}}} = 3066.9\ m/s$

b) $\cos(\gamma) = 0.6202 \rightarrow range(d) = \overset{GSO}{r_s}\left[1 + \left(\frac{R_e}{r_s}\right)^2 - 2\left(\frac{R_e}{r_0}\right)\cdot\cos(\gamma)\right]^{1/2}$

$\therefore d = 38534\ km$

$\rightarrow \theta_d = 30.89^\circ$

$\wedge\ \alpha = 60.39^\circ \rightarrow A_z = 240.39^\circ$

3/2012:

Q1: $T = 2\,hours = 3600 \times 2 = \frac{2\pi r^{3/2}}{\mu^{1/2}}$

$\rightarrow r^{3/2} = \frac{3600 \times 2}{2\pi} \cdot \mu^{1/2}$ $\rightarrow r_s = 8058.44\ km$

$\rightarrow h = 1680.44\ km$ $\wedge\ V = 25318.1\ km/hr$

Q2: a) LEO, MEO, HEO

b) equatorial, inclined, polar

c) apogee: the farthest point from an ellipse's focus

inclination: the angle between the orbital plane and the equator

ascending node: the point at which the satellite's orbit crosses the

south → north

equatorial plane while the satellite ascends

retrograde orbit: an orbit in which a satellite rotates opposite

inclination $i > 90°$

to the direction of rotation of earth.

d) orbital elements: 1- semi-major axis, 2- eccentricity,

3- inclination, 4- right ascension of ascending

perigee argument

node, 5- angular distance of perigee from N,

6- true anomaly

Q3: $\cos(\gamma) = 0.8342 \rightarrow d = 37003.7$ km

$\rightarrow El = 51.2°$

$Az = 198.4°$

$\wedge \; \alpha = 18.4$, satellite to the south-west of earth station

3/2017:

Q1: a) size: semi-major axis, shape: semi-major and eccentricity,

orientation: inclination, right ascension of N, and perigee argument

position: true anomaly

b) to reduce weight after lift off, which allows higher acceleration from force. also to allow easier rotation by reducing moment.

c) inclination: equatorial; inclined; polar

height: LEO, MEO, HEO

d) the satellite eclipses are longest at vernal and autumnal equinoxes 21/3 and 23/9 respectively for a maximum of 72 mins

eclipses occur daily for 23 days before and after the equinoxes

→ ~57 days

Q2: a) orbital period: parking: $T = 5370$ s

$T_{GTO} = \frac{2\pi a^{3/2}}{\mu^{1/2}}$

$\rightarrow T_{GTO} = 37921$

period of GSO ~~= GTO~~ : 86163.6 s

velocity: parking: 7794.9 m/s

GSO: 3074.7 m/s

for transfer, $a = \frac{2R_e + h_a + h_p}{2} = \frac{r_a + r_p}{2} = 24396$ km

$\rightarrow e = \frac{r_a - r_p}{2a} = 0.728$

$\rightarrow V_p = V_{parking}[1+e]^{1/2} = 10.194$ km/s

& $V_a = V_{GSO}[1-e]^{1/2} = 1603.6$ m/s

b) $\cos(\gamma) = 0.433$ & $d = 34819.5$ km

$\rightarrow El = 17.36°$ & $\alpha = 73.4° \rightarrow Az = 106.1°$

3/2019:

Q1: a) six orbital elements: 1- semi-major axis, 2- eccentricity

3- inclination, 4- right ascension of ascending node,

5- argument of perigee (angular distance between perigee and ascending node, 6- angular position in orbit (true anomaly)

size & shape: semi-major axis and eccentricity

orientation: inclination, right ascension of ascending node, argument perigee

position: true anomaly

b) 1- prograde, 2- altitude, 3- equatorial, 4- circular

c) disposable rockets (ELVs) and reusable space shuttle

d) height: LEO, MEO, HEO

rotation: prograde, retrograde

Q2: $T = \frac{2\pi a^{3/2}}{\mu^{1/2}}$ → parking: 5431 s

$T_{GTO} = \frac{2\pi\left[\overset{a}{\text{semi-major axis}}\right]^{3/2}}{\mu^{1/2}}$

→ $T_{GTO} = 37980.1$ s

T of ~~GTO =~~ GSO: 86163.6 s

$V = \sqrt{\frac{\mu}{r_s}}$ → parking = 7725.83 m/s

GSO = 3074.66 m/s

for GTO V_p and V_a, eccentricity must be found

$\therefore\ a = \frac{r_p + r_a}{2} = \frac{r_{s,\text{parking}} + r_{s,\text{GSO}}}{2} = 24421$ km

& $e = \frac{r_a - r_p}{2a} = \frac{r_{s,GSO} - r_{s,parking}}{2a} = 0.727$

at perigee: $V_p = V_{cp}[1+e]^{1/2}$ & $V_{cp} = V_{parking}$

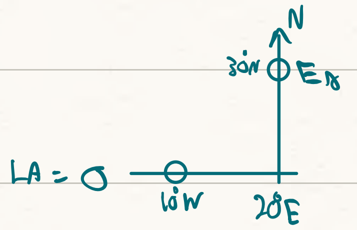
$\rightarrow V_p = 10152.4$ m/s

at apogee: $V_a = V_{ca}[1-e]^{1/2}$ & $V_{ca} = V_{GSO}$

$\rightarrow V_a = 1606.5$ m/s

Q3: N/A

Q4: °s GEO



$\rightarrow \cos(\gamma) = \cos(LA_e)\cos(LO_s - LO_e) = 0.75$

& $d = r_s\left[1 + \left(\frac{r_e}{r_s}\right)^2 - 2\left(\frac{r_e}{r_s}\right)\cos(\gamma)\right]^{0.5} = 37617.8$ km

$\rightarrow El = \cos^{-1}\left[\frac{r_s}{d} \cdot \sin(\gamma)\right) = 42.15^\circ$

& $\tan(\alpha) = \frac{\tan(|LO_s - LO_e|)}{\sin(LA_e)} \rightarrow \alpha = 49.106$

since satellite is to the south west of the earth station,

$Az = 180 + \alpha = 229.12^\circ$

5/2021:

$$\frac{2\pi(24491 km)^{3/2}}{\mu^{1/2}}$$

Q1: $T_{parking} = 5553.5$ s $\quad T_{GTO} = \frac{2\pi \boxed{a}^{3/2}}{\mu^{1/2}}$

$\cancel{T_{GTO}} = T_{GSO} = 86163.6$ s $\quad T_{GTO} = 38096.8$

$V_{parking} = 7668.6$ m/s, $V_{GSO} = 3074.7$ m/s

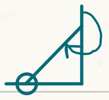
$a = 24471$ km → $e = 0.723$

→ $V_p = V_{parking}[1+e]^{0.5} = 10.07$ km/s

& $V_a = 1.62$ km/s

Q2: a) $\cos(\gamma) = 0.398$ → $d = 40055.2$ km

→ $El = 15.05°$

& $\alpha = 74.3°$  → $Az = 254.3°$

3/2015:

Q1: a) Kepler's laws: 1- orbits are elliptical

2- line connecting satellite and object it orbits sweeps equal areas in same time intervals.

3- square of orbital period is proportional to cube of semi-major axis $T^2 \propto a^3$

orbital elements: 1- semi major axis, 2- eccentricity

3- inclination, 4- right ascension of N

5- perigee argument, 6- true anomaly

b) - geostationary satellite solar eclipses occur 23 days before and after vernal and autumnal equinoxes. during this period, the orbit of the satellite appears to be completely parallel and in-line with the orbit of the earth around the sun. hence the earth crosses the satellite from the sun once a day.

- sun-transit outages also occur around the equinoxes this phenomenon describes when GSO satellites cross the direct line of sunlight, thereby blanking their signals and sending the SNR to zero.
- launching vehicles are multistage rockets used to place satellites in orbit. the first stage rocket booster is generally disposable; however, the rest of the vehicle can be a reusable space shuttle or disposable rocket
- GSO satellites will experience an east-west drift due to the earth's uneven gravity. they may also experience north-south drift due to the sun and moon
- The GSO is a special type of circular, equatorial, prograde orbit with a certain height and speed

that allow it to rotate at the same speed of the earth, thereby keeping a fixed subsatellite point

Q2: a) parking : $T = \frac{2\pi[r_e + 250\,km]^{3/2}}{\mu^{1/2}} = 5370.1\,s$

$\rightarrow V = \sqrt{\frac{\mu}{r_e + 250\,km}} = 7754.9\,m/s$

GSO : $T = \frac{2\pi[r_e + 35786\,km]^{3/2}}{\mu^{1/2}} = 86163.6\,s$

$\rightarrow V = \sqrt{\frac{\mu}{r_e + 35786\,km}} = 3074.7\,m/s$

for GTO : $a = \frac{r_a + r_p}{2} = \frac{r_{GSO} + r_{parking}}{2} = 24396\,km$

$\rightarrow e = \frac{r_a - r_p}{2a} = 0.7283$

$T = \frac{2\pi a^{3/2}}{\mu^{1/2}} = 37921.8\,s$

$\because V_{cp} = V_{parking}$ & $V_{ca} = V_{GSO}$

$\rightarrow V_p = V_{parking} \cdot [1+e]^{1/2} = 10.2\,km/s$

& $V_a = V_{GSO} \cdot [1-e]^{1/2} = 1602.7\,m/s$

b) $\cos(\gamma) = 0.8352$ & $d = 37003.7\,km$

$\rightarrow El = 51.2^\circ$

& $\alpha = 18.4^\circ \rightarrow Az = 198.4^\circ$

4/2022:

Q1: a) surface waves $f < 3 MHz$

sky waves $3 MHz \leq f < 30 MHz$

space waves $f > 30 MHz$

b) orbital elements: 1- semi-major axis, 2- inclination,

3- eccentricity, 4- right ascension of N

5- perigee argument, 6- true anomaly

c) height: LEO, MEO, HEO

inclination: equatorial, inclined, polar

d) for 23 day before and after 21/3 and 23/9

Q2: a) parking: $T = 5431 s$, $V = 7725.8 m/s$

GSO: $T = 86163.6 s$, $V = 3074.9 m/s$

for GTO: $a = 24421 km$, $e = 0.7264$

$\rightarrow V_p = 10151.6 m/s$

و $V_a = 1607.8 m/s$

b) $\cos(\gamma) = 0.5868$ و $d = 38766.9 km$

$\rightarrow El = 28.3^\circ$

و $\alpha = 52.5^\circ \rightarrow Az = 180 + \alpha = 232.5^\circ$

Chapter 3: Satellite subsystems

+ satellite communication systems are divided into:

- space segment: satellite and control earth station needed to keep the satellite operational.
- ground segment: earth stations and terminals that communicate with the satellite for different applications.

+ Satellite subsystems:

orientation in space and pointing direction

to keep antennas and solar panels pointing in the right direction

1- power subsystem, 2- attitude and orbit control subsystem (AOCS),

measurement from afar

3- Telemetry, tracking, command, and monitoring (TTC&M) subsystem,

to shield the satellite from extreme heat and cold, and improve dissipation

communicates with earth

equipment

4- thermal control subsystem, 5- communication subsystem, 6- payload,

for orbit correction, etc. determines the lifetime of the satellite

7- propulsion subsystem

and spacecraft control processor

+ AOCS:

- perturbations can alter the attitude and position of the satellite.
- The AOCS serves to correct any changes due to perturbations by keeping the satellite's body pointing in the same direction in space and maintaining its
  orbital plane and orientation
  position in orbit.
- attitude control is necessary to keep the antennas pointing to the earth station and collect the largest amount of solar power.
- attitude control is usually done autonomously on the satellite but can be done from earth.

+ Attitude determination sensors:

1- horizon sensors: infrared sensors used to detect the rim of the earth against the background of space. four sensors are used to locate the center of the earth and establish it as a reference point.

one sensor for each quadrant

2- sun sensors: two perpendicular light sensors used to measure the two angles between the sun and the sensor axes to find the sun vector.

3- magnetometers: used to measure the local magnetic field of the earth.

4- gyroscopes: used to measure the rate of rotation of the satellite

5- star sensors: cameras that see different star patterns and determine which way the sensors are oriented by processing the images and comparing with stored images.

+ Attitude control mechanisms:

- spin stabilization: satellite is made to be balanced about one particular axis then it is set to spin about that axis in order to resist perturbations by exploiting the gyroscopic effect, where the satellite's body acts as the gyroscope and the solar panels are wrapped around the satellite's cylinderical body. This spin is initialised at launch and directional antennas must be despun (by spinning in opposite direction at same rate)

- Three-axis stabilization: three momentum wheels along the pitch, yaw and roll axes, which all pass through the satellite's center of gravity, are placed inside the satellite's body and spun to stabilise it about the three axes.
- magnetorques: since the earth's magnetic field exerts a force on current carrying coils, the magnitude of the force can be controlled by controlling the current in the coils. This only works for satellites near the earth.
- gravity gradient stabilization: depends on the satellite's interaction with the gravitational field of earth

+ Orbit control:

- orbit control (station keeping) is the maintenance of a satellite's orbit and position.

- Station keeping is done by controlled ejection of hydrazine for propulsion
- Station keeping is required to correct satellites' figure-8 drift and keep satellites within ±0.15° of their correct position.

north-south and east-west

- to counter the east-west drift towards the stable gravitational points, a thrust opposite to the shift must be imparted every 2-3 weeks.

4-6 GHz → ±0.15° , 12-14 GHz → ±0.05°

- geostationary satellites experience a 0.85°/year inclination change, which must be corrected by pulsing the propulsion jets precisely when the inclination is at zero to stop further change.

similar allowed range as for same frequency bands in east-west shifts

- north-south station keeping maneuvers require more fuel than east-west
- satellite altitude varies due to the figure-8 movement by about 0.1% of the nominal altitude.

±36 km

- a C-band satellite will be anywhere in a box bounded by the altitude variation and the east-west and north-south drifts. The earth station antenna's beamwidth must be chosen to cover this box.
- orbital corrections are commanded by the earth TT&C station.

+ propulsion subsystem classification:
  - launch propulsion: place the satellite into an orbit.

    such as apogee kick motors (AKM)

  - orbit control: maintain the satellite in its precise position in orbit

- attitude control: keep the satellite oriented in the right direction.

+ propulsion subsystem types:

1- chemical:

  - cold gas: compressed gas (nitrogen) or vaporizing liquid (propane)

    once ignited, cannot be stopped (single firing) used exclusively for launching and orbit change

  - hot gas: solid propellant, mono-propellant (hydrazine), or bi-propellant (MMH/N_2O)

2- electrical:

  - electrothermal: resistojet or arcjet

  - electromagnetic: MPD-thruster

  - electrostatic: field emission

+ TTC&M subsystem functions:

  - control the orbit and attitude of the satellite,
  - monitor the status of all sensors,
  - point the antennas in the correct direction,
  - switch on or off the transponders of the communication subsystem.

- during transfer and drift orbital phases, omnidirectional antennas are used at the ground station, since the pointing angles will not be known.

doppler shift can also be measured at ground station to find rate of change of the orbit's range

- satellites can be tracked by using velocity and acceleration sensors on the satellite to measure the change in orbit from the last known position.

- command subsystem demodulates and decodes often encrypted command signals from the earth station and sends them to the targeted equipment to be executed.
- command subsystem is used to fire the AKM, spin the satellite, etc.
- all communication satellites obtain their required electrical power from the sun via solar panels/cells.
- flat panels on three-axis stabilized satellites are rotated using electric motors and tracking systems in order to maintain normal incidence of the sun light on the panels.
- since the body of spin-stabilized satellites is covered in solar cells, then the total cell area required is three times that of a three-axis stabilized satellite's panels since nearly one-third of the spin satellite's body will receive direct sunlight at any given time, whereas the whole cells' area receive direct sunlight at all times in three-axis stabilized satellites.
- solar sails (flat panels) must only be unfolded when the satellite is in its final orbit. Their main disadvantage compared to spin-stabilized is that they heat up, which reduces efficiency
- micrometeors impact reduce the efficiency of solar sails, hence an extra 15% of the panels' required area is added.

+ example: ∴ light intensity in outer space $I = 1.39\,kW/m^2 \wedge \eta = 25\%$, +15% margin

$$\rightarrow A = \frac{P}{I \times \eta} \text{ (+ margin) } = 3.31\,m^2 \text{ for } 1kW$$

lithium-ion (Li-ion) batteries used

- because of satellite eclipses, batteries with high power-to-weight ratios should be used to maintain service while keeping the satellite light.

\+ example 1 :

∴ $I = 1.25\ kW/m^2$ & $\eta = 15\%$, required $= 2\ kW$

→ $A = 10.667\ m^2$, actual area required (Ae) : $\dfrac{\overbrace{\pi DL}^{\text{area of cylinder}}}{\underbrace{DL}_{\text{rectangular projection of cylinder}}} = \pi A = 33.5\ m$

→ for normal incidence : cells : $\dfrac{Ae}{4 \times 10^{-4}} = 83790$ cells

→ for oblique incidence : received power $= I \cdot \cos(10^\circ) \rightarrow 85068$ cells

\+ example 2:

∴ 3.6 kW required for 72 minutes

& 1 cell : $1.3 \times 90 \times \underbrace{80\%}_{\text{lowest amount it can discharge to}} \times 95\% = 88.92\ Wh$

$\therefore \dfrac{3.6k \cdot \frac{72}{60}}{88.92} = 48.58 \rightarrow 49$ cells required

$\text{mass} = \dfrac{\text{power required}}{0.8 \times 0.95 \times \text{specific energy}} = 94.74\ kg$

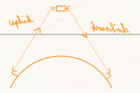
mass of 49 cells : $\dfrac{1.3 \times 90}{60} \times 49 = 95.55\ kg$

- thermal blankets, shields, and radiation mirrors are used to provide insulation and remove heat from the communications payload.

- spin-stabilised satellites have the advantage of (over three-axis stabilized satellites) averaging the temperature extremes.

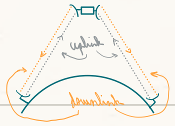
+ communication subsystems:

- satellites are essentially repeaters / transponders.
- a satellite communication system consists of an earth segment with a transmitting station and a receiving station, and a space segment with many transponders on the satellite.



DBS

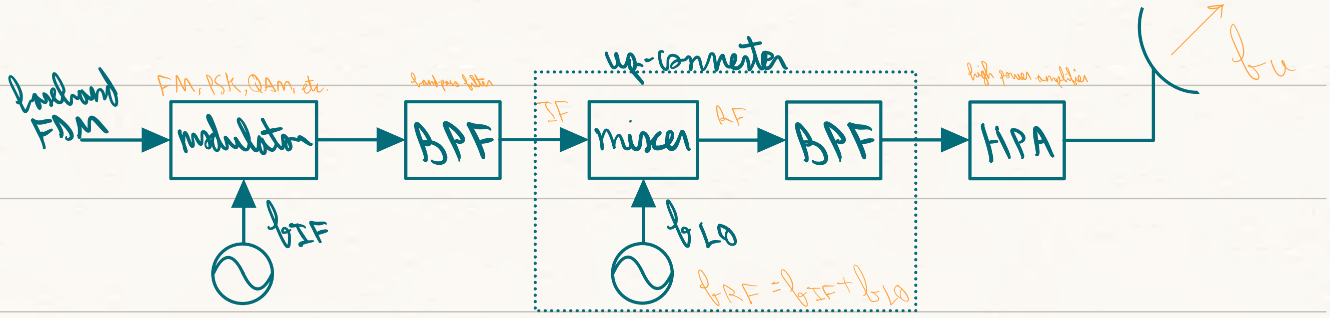
- typically satellite communications requires two links (one uplink and one downlink) with different frequency ranges to prevent interference.
- many satellites, however, have four links (two uplinks and two downlinks) such as mobile, internet, and fixed service satellites.



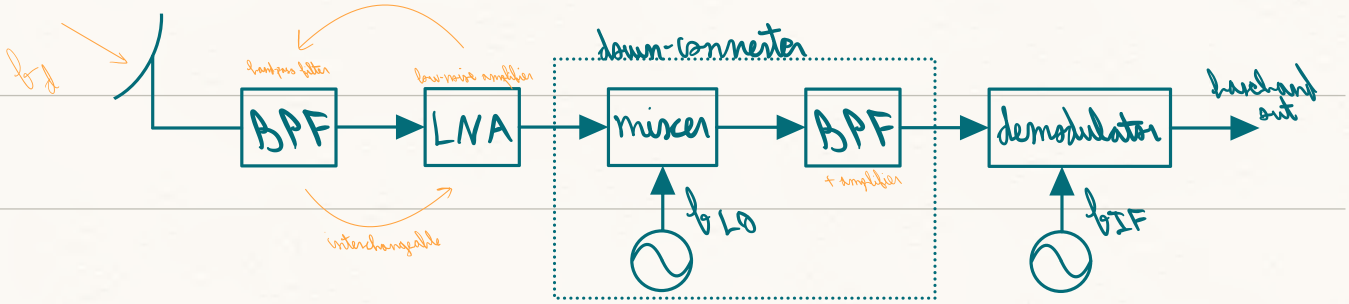
1 GHz → 300 GHz

- almost all satellites operate in the microwave band with frequencies from 1 GHz to 30 GHz, with each link given a bandwidth of 500 MHz.

+ earth station transmitter:



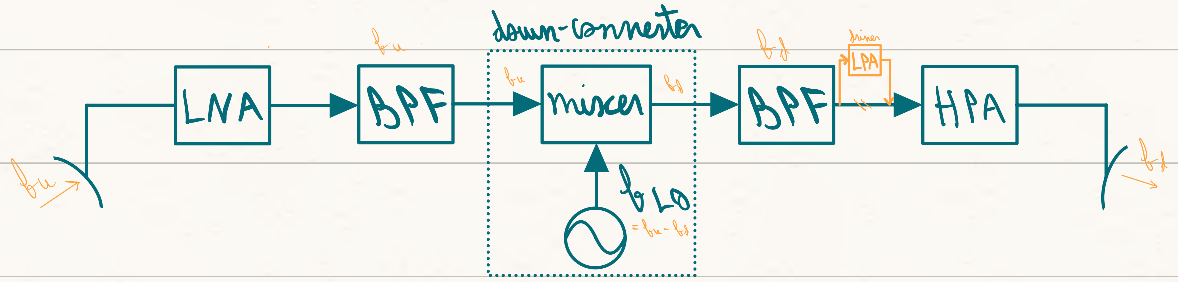
+ earth station receiver:



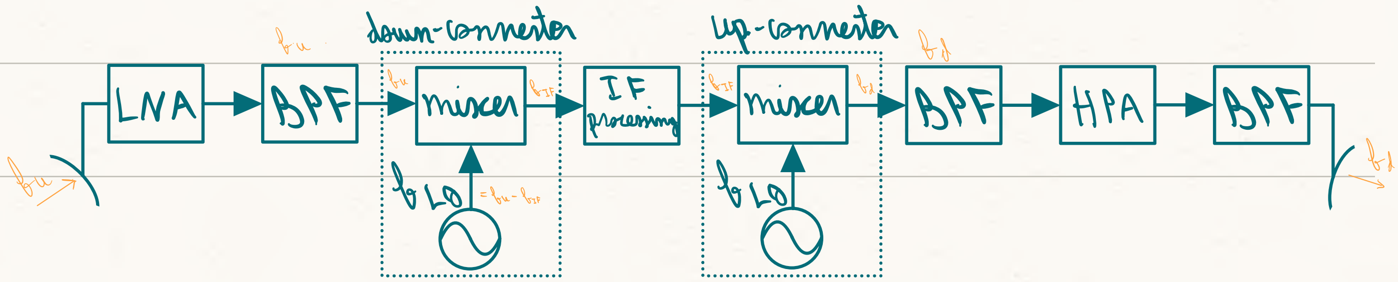
- the most basic task of transponders is to filter and amplify the received signals and translate their frequency to the appropriate downlink frequency. There are three essential transponder configurations.

+ single conversion transponder:

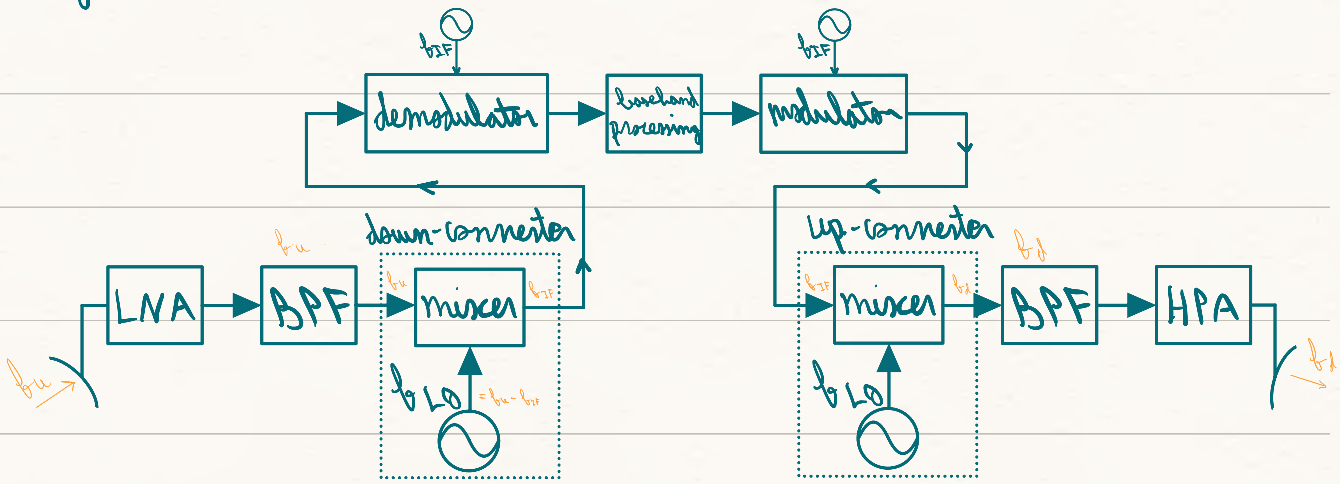
fu to fd in one step
(RF → RF)



+ double conversion transponder:



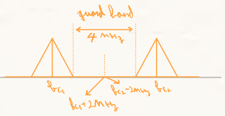
+ Regenerative (bent-pipe) transponder:



- since the total bandwidth assigned to each satellite is 500 MHz many transponders are used, where each is made to operate in a

36 + 4 guard band

different sub-band with bandwidth of 40 MHz.



- for a sub-bandwidth of 40 MHz, the can be a maximum of 12 sub-bands, with 20 MHz left unutilized.
- the bandwidth efficiency can be doubled by using orthogonal

  right and left hand circular polarization

  polarization (vertical + horizontal or RHCP + LHCP). Therefore, there

  instead of 40 MHz without polarization

  will be a total of 24 sub-bands with a separation of 20 MHz

  orthogonally polarized

  between the center frequencies of two adjacent subbands.
- The receiver and down converter of a satellite must have a wideband to cover the entire 500 MHz bandwidth.
- input demultiplexers are used to separate the broadband input signal into the subchannels used by transponders, which are usually

  e.g., vertical e.g., horizontal to increase frequency separation and reduce adjacent channel interference

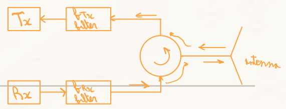
  arranged into even and odd-numbered groups.
- all transponders need high-power amplifiers, which are generally either traveling wave tube amplifiers (TWTA) or solid state power amplifiers (SSPA) both preceded by attenuators to control the output power level.

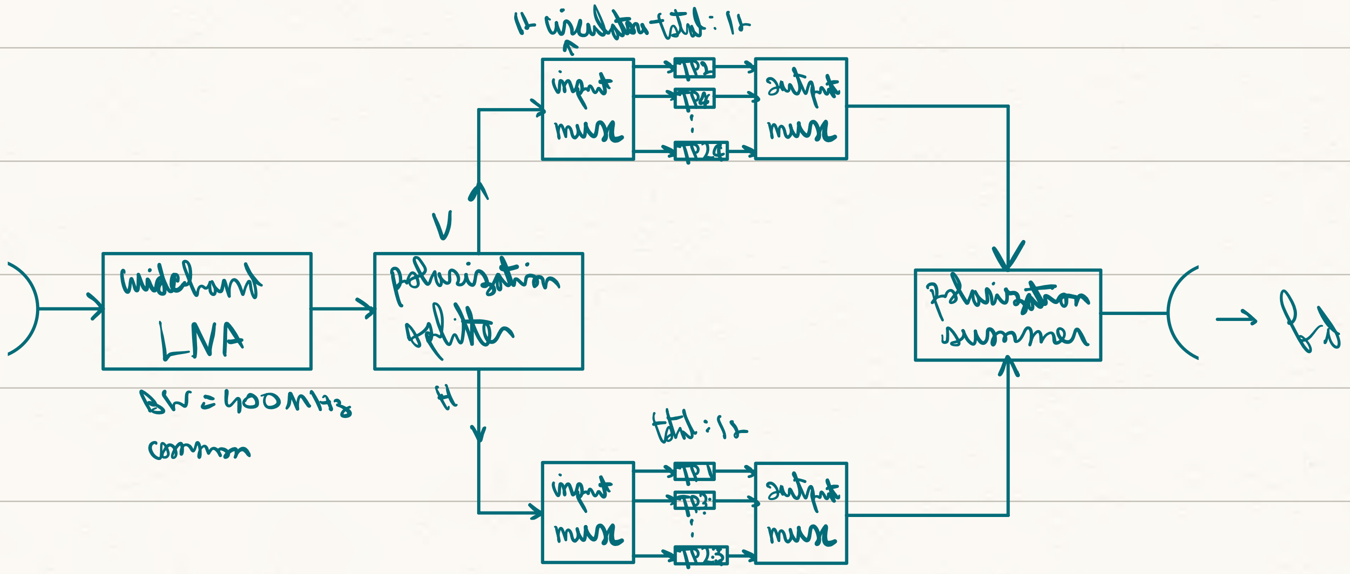
TWT	SSP
· up to 2 kW output, higher than SSPA · higher efficiency at 60% · bulkier than SSPA · very wide bandwidth	· lower max output power, up to 20 W output · lower efficiency at 25% · smaller size and volume · lower bandwidth

* Transponder backoff: the maximum power accepted without causing intermodulation distortion.

- full duplex communication systems use the same antenna for transmission and reception. This can be done by using circulators and different frequencies for uplink and downlink

primary reason for using different frequencies





+ satellite antennas and coverage beams:

- the coverage or footprint of a satellite is the geographical area where an earth station or user can communicate with that satellite.

+ types of coverage beams:

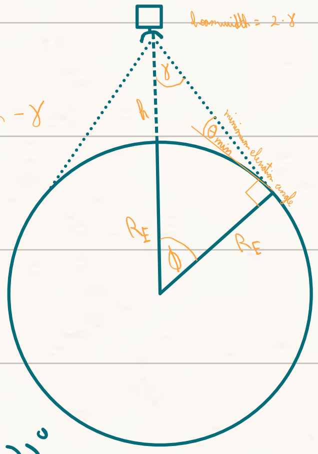
1- earth (global) coverage beam, covers up to 42% of the earth's surface with a beamwidth of 17°

2- hemispherical coverage beam, covers up to 20% of the earth's surface

3- zonal coverage beam, up to 10% of earth's surface covers small geographical areas less than 5% of the earth's surface

4- Spot coverage beam.

+ coverage area calculations:



- covered area radius: $R_E \cdot \phi$, $\phi = 180 - 90 - \theta_{min} - \gamma$

in radians

- from sine law: $\dfrac{R_E + h}{\sin(90^\circ + \theta_{min}^\circ)} = \dfrac{R_E}{\sin(\gamma)}$

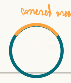
example: $\theta_{min} = 5^\circ$, GEO → $R_E + h = 42164$ km

→ $\gamma = \sin^{-1}\left(\frac{R_E}{R_E+h} \cdot \sin(95^\circ)\right) = 8.67^\circ \rightarrow \phi = 76.33^\circ$

→ radius of covered area: $76.33 \cdot \frac{\pi}{180} \cdot R_E = 8496.83$ km

calculated from circumference of earth

→ percentage coverage: $\dfrac{2\cdot(8496.83)}{2\pi \cdot R_E} = 42.4\%$



- the required coverage area dictates the beamwidth and, in-turn, the diameter of the dish antenna.

+ Antenna parameters:

- radiation pattern: plot of the power radiated from the antenna per unit solid angle (steradian). Characteristics are determined by the antenna's shape and current distribution.

D

- directivity: ratio of radiation intensity in the direction (θ, ϕ) to the mean radiation intensity.

or to an isotropic antenna radiating the same total power

G

- power gain: the product of the maximum directivity and the efficiency.

ratio of power radiated to power fed into the antenna

HPBW

- beamwidth: angle between the two half-power points on the main lobe.

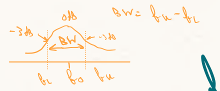
for surface waves: horizontal polarization implies electric field is parallel to the ground, whereas vertical polarization implies electric field is perpendicular to the ground

- polarization: the direction of the electric field (linear polarization) (or its direction of rotation) (circular/elliptical polarization (RHCP, LHCP)) compared to some reference. polarization should be known to align the receiving antenna with the wave for max power.

for space waves (i.e., with satellites) the surface cannot be used as a reference for linear polarization, instead waves with E-fields along the east-west are considered horizontally polarized, whereas waves with E-fields in the north-south direction are vertically polarized

received power: power at antenna x $\cos$ (misalignment angle) → 0 power received when antenna is perpendicular to the wave

- bandwidth: measure of how much the frequency can vary around the center while still obtaining an acceptable power gain in the desired direction. measured as the frequency range between the two side frequencies at which the power is half the central.



$BW = f_u - f_L$

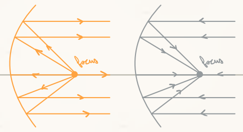
- input resistance: found from the effective antenna current and power supplied.

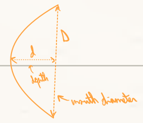
$$Z_i = \frac{P_{in}}{I^2_{effective}}$$

→ measured at feed point

+ main types of antennas used:

- wire antennas (active): used for their omnidirectional pattern to provide communication for the TTC&M subsystem.
- horn antennas (active): used as feeders for reflectors and for global coverage their max gain is 23 dB, and min beamwidth 10°.
- reflector (dish) antennas (passive): metallic reflectors that are illuminated by a feeder antenna. parabolic reflectors are generally used due to their focusing property





the distance from the deepest point on the dish to the focus point

the focal length is: $f = \frac{D^2}{16d}$

for $\frac{f}{D} < 0.25$, the focus point is in between the reflector and aperture plane, if $\frac{f}{D} > 0.25$ the focus is outside the aperture plane giving uniform illumination but more spillover

+ feed mechanisms for dish antennas:

- center-fed: the feeder is at the focus point of the reflector and pointed towards the center of the reflector. hence, the feeder and its supports partially block the main lobe and reduce the efficiency by 10%.
- offset-fed: primary antenna is offset to illuminate only the upper part of the reflector and avoid blocking. the main lobe
- double reflector-fed: a sub reflector is fed from the primary feeder through a hole in the center of the main reflector. the sub reflector then reflects the waves to the main reflector. This method reduces blockage

+ gain and beamwidth of aperture antennas:

such as horn and reflector antennas

- the gain of aperture antennas is: $G = \overset{\text{efficiency}}{\eta} \cdot \underset{\text{max directivity}}{\boxed{\frac{4\pi A}{\lambda^2}}}$
  area of the aperture
  $\frac{\pi D^2}{4}$ for parabolid reflector
  $a \times b$ for horn
- for a dish antenna: $G = \eta \cdot \left(\frac{\pi D}{\lambda}\right)^2$
  or other aperture antennas with circular areas (e.g., circular horn antenna)
- the half-power beamwidth for dish antenna is: $\Theta_{3\,dB} = \frac{75\lambda}{D}$ (in degrees)

+ Equipment reliability and space qualification:

+ equipment reliability is increased by:

selection, screening, and testing of each component under space conditions

thermal, vacuum, electrical, and vibration tests of the whole satellite

- space qualification: quality control and shake and bake tests.

receiver and power amplifier mainly

- redundancy: one or more spare devices are added, for the critical parts of the system, in parallel with the active parts so that they may be switched to if the active part breaks down.

+ reliability:

R(t) at a specific time (t)

- reliability is the ratio of the number of surviving components to the number of components at the start of the test.
- for most electronic components, the probability of failure is highest at the beginning of their operation and near the end of their lifetime.

  burn-in period aging

- mean time between failure (MTBF) is the average failure time of a large number of components.

  m equal to the useful time

- the reliability is given by: $R = e^{\overset{\text{average failure rate}}{-\lambda}\overset{\text{time}}{t}}$ s.t., $\lambda = \frac{1}{m} \rightarrow \text{MTBF}$

MOHAMMAD SANAD ALTAHER 130806

EE558: homework #2

3.1: 100 samples, each sample 8-bits, + 200 bits per frame

a) for a set of samples, the total frame size is $8 \times 100 + 200 = 1$ k-bits

transmission time: 1 second + propagation delay.

b) for GEO, propagation delay: $\frac{40000 \times 10^3}{3 \times 10^8} = 0.133$ seconds

$\rightarrow$ total time = $\boxed{1.133 \text{ seconds}}$

3.3: power required: 4 kW

a) ∵ light intensity = $1.39 \text{ kW/m}^2 \rightarrow \eta \cdot I \cdot A = 4\text{kW}$

$\rightarrow A = \frac{4k}{1.39k \cdot 0.15} = 2 \times l \rightarrow l = 9.6$ m

∴ length of each sail: $\boxed{4.8 \text{ m}}$

b) $\eta \cdot I \cdot D \cdot h = 4\text{kW} \rightarrow h = \frac{4k}{1.39k \cdot 0.18 \cdot 3.5} = \boxed{4.6 \text{ m}}$

3.4: total power: 5.5 kW

a) ∵ power = 5.5 kW ∧ Voltage = 48V $\rightarrow$ $\boxed{\text{current} = 114.6 \text{ A}}$

b) ∵ current = 114.6 A $\rightarrow$ capacity: $114.6 \times \frac{70 \text{ min}}{60}$

battery $\cdot \overset{0.9}{\cancel{0.3}}$ = capacity $\rightarrow$ battery = $\boxed{445.7 \text{ Ah}}$

c) weight = $\boxed{557.1 \text{ kg}}$

b) if half transponders are shut down → total power = 3.5 kW

$$\text{capacity} = \frac{70}{60}\cdot\frac{\overset{3.0}{\cancel{3.5}}\,k}{48} \rightarrow \text{battery} = 283.6\ \text{Ah}$$

$\rightarrow 354.5\ \text{kg} \approx \boxed{200\ \text{kg less}}$

3.5: ∴ beamwidth = 1.8°

a) ∴ $\theta_{3dB} = \dfrac{75\cdot\lambda}{D}$, Tx at $\overset{ku}{11.5}$ GHz and $\overset{ka}{20}$ GHz

$\rightarrow D = 1.09\ \text{m} \wedge G = 40.14\ \text{dB}$

for Tx of ku band

$\rightarrow D = 0.625\ \text{m} \wedge G = 40.12\ \text{dB}$

for Tx of ka band

b) for Rx of ku band: $D = 0.893$, $G = 40.12\ \text{dB}$

for Rx of ka band: $D = 0.417$, $G = 40.13\ \text{dB}$

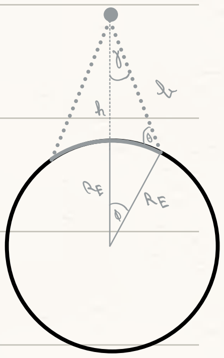
Q5: GEO satellite antenna covers area with diameter of 2000 km:

$\rightarrow \phi = \dfrac{2000}{2\cdot R_E} = 0.1568\ \text{rad}$

using cosine law: $d^2 = R_E^2 + (R_E+h)^2 - 2R_E\cdot(R_E+h)\cdot\cos(\phi)$

$\rightarrow d = 35860.1\ \text{km}$

using sine law: $\dfrac{d}{\sin\phi} = \dfrac{R_E}{\sin\gamma} \rightarrow \gamma = 1.59°$



∴ beamwidth: $2\gamma = \boxed{3.18°}$

quiz 3 practice :

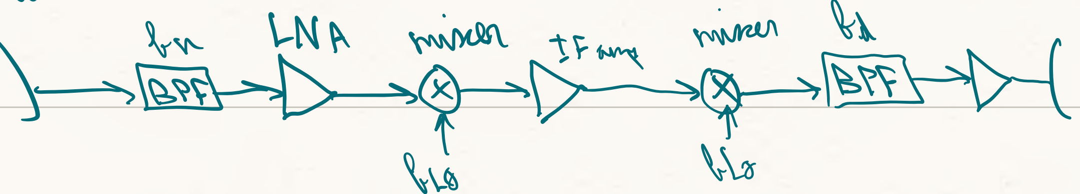
first 2019 :

Q3 :

a) 1- power subsystem, 2- attitude and orbit control, 3- thermal cont, 4- communication, 5- payload, 6- propulsion, 7- TTC&M

b) sensors to determine attitude : earth horizon sensor, sun sensors magnetometers, gyroscopes, star sensors

c) double conversion :



d)

Chapter 4:

- satellite design is complex and requires trial and error in order to find the suitable compromise for a given performance measure.

+ The following must be specified to design a satellite system:

fixed satellite service (international telephony, internet, etc.)

1- type of service. direct broadcast, mobile satellite, internet satellite

2- Required orbit and range, elevation angle, position.

3- information carrying capacity, number of transponders.

4- frequency bands and frequency plan. cost of satellites >> cost of earth stations

earth stations + satellites

- The primary objective is minimizing the overall cost, which mainly

depends on number and power of transponders (which dictate the solar sails and battery sizes)

depends on the cost of the satellite.

+ The design process starts by specifying:

- source encoding
- channel encoding
- modulation scheme
- multiple access technique
- performance measure ($\frac{S}{N}$ or BER)

analog: $\frac{S}{N}$ digital: BER

+ cost can be reduced by reducing $(\frac{C}{N})_{min}$ required for a certain $\frac{S}{N}$ or BER by using:

otherwise P_t becomes very large to overcome the path loss ($\approx$ 200 dB)

- power efficient modulation schemes. e.g., BPSK and QPSK

BPSK requires half the power of ASK

channel encoder

- forward error correction techniques. gives coding gain by using efficient channel encoding techniques

adds redundancy for better error correction for same $\frac{C}{N}$

source encoder

- compression techniques that improve bandwidth efficiency.

removes redundancy

- high carrier frequency to increase antenna gain. $G \propto \frac{1}{\lambda^2}$

- power density at distance R : $S = \frac{\overset{\text{power transmitted}}{P_t}\ \overset{\text{gain of transmitting antenna}}{G_t}}{(4\pi R)^2}$ (W/m^2)

output of power amplifier at transmitter ← P_t

Transmission distance ← R

- the received power is : $S \times \overset{\text{area of receiving antenna}}{A_r}$. since $\overset{\text{gain of receiving antenna}}{G_r} = \frac{4\pi A_r}{\lambda^2} \rightarrow A_r = \frac{G_r \lambda^2}{4\pi}$

EIRP: effective isotropic radiated power

EIRP used by regulation agencies instead of P_t because it accounts for both P_t and directive gain

assuming lossless antennas and free space

- Therefore the friis equation is : $P_r = \frac{\overbrace{P_t G_t}^{} G_r}{(\frac{4\pi R}{\lambda})^2}$ (W)

→ path loss (L_p)

in dB → $P_r = \overbrace{P_t + G_t}^{\text{EIRP (dBW)}} + G_r - L_p$ (dBW) $L_p = 20 \log \left(\frac{4\pi R}{\lambda}\right)$ dB

+ other losses that must be included:

pointing and polarization

- antenna misalignment losses (L_{ant})

depends on feeder (WG, coax, etc.

- feeder losses (L_f)

absorption   clear, rain must also be accounted for

- atmosphere losses (L_a)

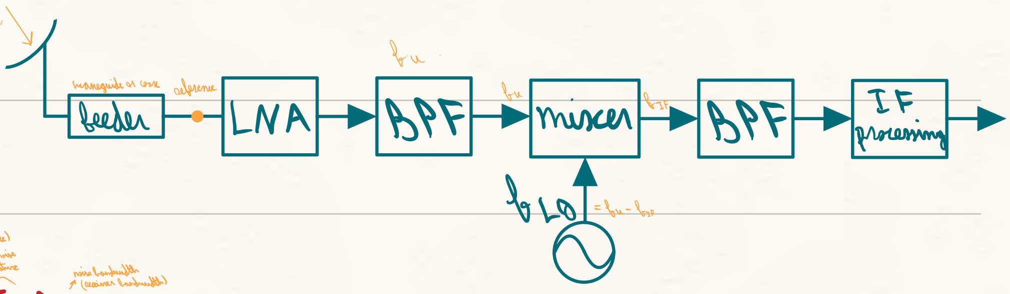
- other miscellaneous losses (L_m)

$P_r = P_t + \text{gains} - \text{losses}$

hence, the equation becomes : $P_r = \overbrace{EIRP + G_r - L_p}^{\text{ideal}} - L_{ant} - L_f - L_a - L_m$

- the signal to noise ratio at the output of a communication receiver is found from the carrier to noise ratio measured at a reference.

input to low noise amplifier



- noise power : $\underbrace{P_n}_{\text{noise power}} = \overset{\text{boltzmann constant}}{k}\ \underbrace{T_s}_{\text{(at reference) system noise temperature}}\ \overset{\text{noise bandwidth (receiver bandwidth)}}{B_n}$ (W)

- for a typical superhetrodyne receiver : $T_s = \overbrace{T_{in}}^{\text{noise temperature of the antenna, feeder, atmosphere at the input of the LNA}} + \overbrace{T_{RF}}^{\text{noise temperature of RF amplifier at its input}} + \frac{\overbrace{T_m}^{\text{noise temperature of mixer}}}{\underset{\text{RF amplifier gain}}{G_{RF}}} + \frac{\overbrace{T_{IF}}^{\text{noise temperature of IF amplifier}}}{G_{RF}\underset{\text{mixer gain}}{G_m}}$

- the noise temperatures of the blocks after the reference point are found from their noise factors at that reference point : $\underbrace{T_e}_{}^{\text{equivalent noise temperature}} = (F-1)\overbrace{T_0}^{\text{room temperature (290 or 300 K)}}$

- the overall system noise temperature is : $T_s = (F_T - 1)T_0$,

where : $F_T = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \dots$

- the noise temperature of the feeders, atmosphere, and antennas is found from:

$$T_e = (1 - G)T_0 = \left(1 - \frac{1}{L}\right)T_0 , \quad \because \; G = \frac{1}{L}$$

- carrier to noise ratio is : $\frac{C}{N} = \frac{\overset{\text{noise in received carrier of modulated signal}}{P_r}}{P_n} = \frac{P_r}{kT_0B_n} = EIRP + G_r - L_p - L_{ant} - L_a - L_f - L_m \; (dB)$

$$\rightarrow \frac{C}{N}(dB) = EIRP + G_r - \text{losses} - 10\log(kTB_n)$$

$$\rightarrow \frac{C}{N}(dB) = EIRP - \text{losses} - 10\log(kB_n) + \overset{\text{gain to noise ratio at receiving antenna } \left(\frac{dB}{K}\right)}{\frac{G_r}{T}} \rightarrow \text{measure of earth station quality}$$

- rain is often the most significant cause of signal fading, and affects higher frequencies more.

- rain results in signal attenuation and increases the overall noise temperature

- rain's effect on uplink is greater than downlink due to the higher frequency such that: $L_{u,rain} = L_{d,rain} \cdot \left(\frac{f_u}{f_d}\right)^{\alpha}$ (2 to 4)

- however, increase in noise due to rain can be ignored in uplink since the radiation emanating from the earths surface contributes most to the received noise. $\left(\frac{C}{N}\right)_{rain} = \left(\frac{C}{N}\right)_{clear} - L_{rain} - \underbrace{\overbrace{\Delta N_{rain}}^{\text{ignored for uplink}}}_{\text{change of system noise power due to rain}}$

- in downlink, rain degrades the received $\frac{C}{N}$ by attenuation and increasing the sky-atmosphere noise temperature, such that:

$$\left(\frac{C}{N}\right)_{rain} = \left(\frac{C}{N}\right)_{clear} - \overbrace{L_{rain}}^{\text{loss due to rain}} - \overbrace{\Delta N_{rain}}^{\text{included}}$$

$$\wedge \qquad \Delta N_{rain} = 10 \log \left(\frac{\overset{\text{system temperature with rain}}{T_{s,rain}}}{\underset{\text{system temperature without rain}}{T_{s,clear}}} \right)$$

- due to rain drops being elliptical in shape, a polarized wave passing through will have its vertical and horizontal fields affected differently by the drops hence the signal will be depolarized.

- to avoid operating the amplifiers in their saturation regions and minimize intermodulation, the operating point of the transmitted power is backed off from the saturation point, giving rise to the backoff loss:

$$EIRP = \overset{\text{saturation power}}{P_{ts}} + G_t - \overset{\text{backoff loss}}{L_{bo}}$$

- for small earth stations (e.g., DBS), the receiving antenna gain is small and must be compensated for by increasing the transmission power.

- the design of uplink is generally easier than downlink, since there aren't limitations on transmitted power. Additionally, uplink power control can be used to compensate for temporary reductions of $\frac{C}{N}$ received by the satellite.

other than for mobile satellite systems, for example

- power transmitted by the earth station is still limited by the satellite transponders' saturation power.

- since the noise received by the satellite is amplified, it must be added to the downlink noise:

$$\underbrace{P_n}_{\text{received by earth station}} = \underbrace{\gamma}_{\text{total gain of satellite}} \cdot \underbrace{P_{nu}}_{\text{uplink noise}} + \underbrace{P_{nd}}_{\text{downlink noise}}$$

- the overall noise to carrier ratio is: $\left(\frac{N}{C}\right)_o = \frac{\gamma P_{nu} + P_{nd}}{P_{nd}} = \frac{\gamma P_{nu}}{\gamma P_{nu}} + \frac{P_{nd}}{P_{nd}}$ $= \left(\frac{N}{C}\right)_u + \left(\frac{N}{C}\right)_d + \left(\frac{I}{C}\right)$ $+ \frac{I}{C}$

$$\rightarrow \left(\frac{C}{N}\right)_o = \frac{(C/N)_u \cdot (C/N)_d}{(C/N)_u + (C/N)_d}$$

$$\frac{1}{(C/N)_o} = \frac{1}{(C/N)_u} + \frac{1}{(C/N)_d} + \frac{1}{(C/I)}$$

- when including the effect of rain, it should only be factored in one of the links, since rain is unlikely to be in both up and downlink paths at the same time. calculations are done once for rain in the uplink path and once in the downlink. the calculation giving a lower $\frac{C}{N}$ is used.

example 1:

$$\delta = \frac{P_t G_t}{4\pi R^2} = 24.9\ \text{fW/m}^2 \rightarrow P_r = 244\ \text{fW} = -126\ \text{dBW}$$

example 2:

$$\text{EIRP} = 27\ \text{dBW}, \quad \therefore\ G = \frac{4\pi A}{\lambda^2} \rightarrow G_r = 52.3\ \text{dB}$$

$$\wedge\ L_p = \left(\frac{4\pi R}{\lambda}\right)^2 = 205.3\ \text{dB} \rightarrow P_r = 27 + 52.3 - 205.3 = -126\ \text{dB}$$

example 3:

$$\text{case 1: } T_s = 25 + 50 + \frac{500}{10^{2.3}} + \frac{1000}{10^{2.3}} = 82.5\ \text{K}$$

10 dB loss at mixer

$$\text{case 2: } T_s = 25 + 50 + \frac{500}{10^{2.3}} + \frac{1000}{10^{2.3} \cdot 10^{-1}} = 127.6\ \text{K}$$

example 4: to refer the temperatures to the input of the LNA, they must be multiplied by the feeder loss: $T_{in} = 25\text{K} \times 10^{-0.2}$, $T_{WG} = \left(1 - \frac{1}{10^{0.2}}\right) \times \overset{300\text{K}}{T_o}$

$\therefore T_s = T_{in} + T_{WG} + T_{RF} + \frac{T_m}{G_{RF}} + \frac{T_{IF}}{G_{RF} G_m} = 176.6\ K$

example 5:

$C = 10\log_{10}(20) + 20 - 2 + 49.7 - 196.5 - 3 - 0.2 - 0.5 = -119.5\ dBW$

$N = 10\log_{10}(k \cdot T_s \cdot 27M) = -135.5\ dBW$

$\rightarrow \frac{C}{N} = C(dB) - N(dB) = -119.5 - (-135.5) = 16\ dB$ $> \left(\frac{C}{N}\right)_{min}$ 6.5 dB margin

- for a 1 dB rain loss:

$\because T_{s,clear} = 75\ K$, $T_{a,clear} = \left(1 - \frac{1}{10^{0.02}}\right) T_0 = 13\ K$

& $T_{a,clear+rain} = \left(1 - \frac{1}{10^{0.12}}\right) \cdot T_0 = 70\ K$

$\therefore T_{s,rain} = T_s - T_{a,clear} + T_{a,clear+rain} = 132\ K$

$\rightarrow \Delta N_{rain} = 10\log_{10}\left(\frac{T_{s,rain}}{T_{s,clear}}\right) = 2.46\ dB$

$\therefore \left(\frac{C}{N}\right)_{rain} = \left(\frac{C}{N}\right)_{clear} - 1 - 2.46 = 12.54\ dB$ $> \left(\frac{C}{N}\right)_{min}$ 3 dB margin

example 6:

$C = 10\log_{10}(160) + 34.3 + 33.5 - 205.7 - 3 - 0.4 - 0.4 = -119.7\ dBW$

$N = 10\log_{10}(k \cdot T_s \cdot 20M) = -133.9\ dBW$

$\because \left(\frac{C}{N}\right)_{min} = 8.6\ dB \rightarrow 5.7\ dB$ margin

$\rightarrow \frac{C}{N} = 14.2\ dB$

including rain loss of 3 dB:

$T_{a,clear} = \left(1 - \frac{1}{10^{0.04}}\right) T_0$, $T_{a,clear+rain} = \left(1 - \frac{1}{10^{0.34}}\right) \cdot T_0$

$\rightarrow T_{s,rain} = 145 + 157.4 - 25.5 = 279\ K$

$$\therefore \left(\frac{C}{N}\right)_{min} = \left(\frac{C}{N}\right)_{clear} - \overset{\text{rain loss}}{3} - \overbrace{10\log_{10}\left(\frac{277}{144}\right)}^{\Delta N \text{ (dB)}} = 8.39 \text{ dB}$$

$< \left(\frac{C}{N}\right)_{min}$!

example 7 : received power + gain = transmitted power

saturation - backoff

$\therefore P_{rxp} + G = P_{txp}$

a) $P_{rxp} = \overbrace{P_{to} - L_{bo}}^{0 \text{ dBW } = 1 \text{ Watt}} - G_{xp} \rightarrow P_{rxp} = -127 \text{ dBW}$

$\rightarrow -127 \text{ dBW} = P_t + G_t + G_r - L_p - L_f - L_a - 2$

$\therefore P_t = 8.2 \text{ dBW} = 6.61 \text{ W}$

b) $P_{t,rain} = P_{t,clear} + L_{rain} = 15.2 \text{ dBW}$ ΔN_{rain} neglected

example 8: $\frac{1}{(C/N)_o} = \frac{1}{(C/N)_u} + \frac{1}{(C/N)_d} + \frac{1}{(C/I)} = 10^{-2} + 10^{-2} + 10^{-2.4}$

$\rightarrow \left(\frac{C}{N}\right)_o = 41.7 = 16.2 \text{ dB}$

+ system design examples:

example 9 :

- must find P_t for uplink and G_r at ES.

1- clear air:

uplink: $P_r = P_t + G_t + G_r - L_p - L_{ant} - L_a - \overset{0}{L_{rain}} - L_m$

for $C/N = 30$ dB $\wedge$ $T_r = 500$ K $\rightarrow C = 30 + 10\log_{10}(k T_r \underset{}{\overset{\text{signal BW } 43.2\text{M}}{B_n}})$

$\therefore C = P_r = -95.26 \text{ dBW}$

$\rightarrow -95.26 = P_t + 55.7 + 31 - 207.2 - 2 - 0.7 - 0.3$

$\therefore P_t = 28.24 \text{ dBW}$

downlink:

$$P_r = \overset{\checkmark}{P_{tx}} - \overset{\checkmark}{L_{fx}} + \overset{\checkmark}{G_t} + G_r - \overset{\checkmark}{L_p} - \overset{\checkmark}{L_{ant}} - \overset{\checkmark}{L_a} - \overset{0}{L_{rain}} - \overset{\checkmark}{L_m}$$

$\because \left(\frac{C}{N}\right)_0 = 19$ dB & $\left(\frac{N}{C}\right)_0 = \left(\frac{N}{C}\right)_u + \left(\frac{N}{C}\right)_d$

$\rightarrow \frac{1}{10^{1.9}} = \frac{1}{10^{3}} + \left(\frac{N}{C}\right)_d \rightarrow \left(\frac{C}{N}\right)_d = 52.96$

$\therefore \left(\frac{C}{N}\right)_d = 17.22$ dB $\therefore C = -113.6$ dBW

$\therefore G_r = 46.5$ dB $= 44668.36$

$\because G_r = \eta \left(\frac{\pi D}{\lambda}\right)^2$ for dish assume $\eta \approx 65\%$

$\rightarrow (\pi D)^2 = \frac{G_r}{0.65} \cdot \left(\frac{c}{f_d}\right)^2 \rightarrow D = 2.19$ m

2- effect of rain (only one link can be affected)

uplink:

$T_{clear} = \left(1 - \frac{1}{10^{0.07}}\right) \cdot 290 = 43.17$ K

$T_{clear + rain} = \left(1 - \frac{1}{10^{0.67}}\right) \cdot 290 = 227.94$ K

$\rightarrow T_{s, rain} = 500 - 43.17 + 227.94 = 684.93$

$\rightarrow \Delta N_{rain} = 10 \log_{10}\left(\frac{684.93}{500}\right) = 1.365$ dB

& $\left(\frac{C}{N}\right)_{u, rain} = \left(\frac{C}{N}\right)_{u, clear} - L_{rain} - \Delta N_{rain}$

$= 22.635$ (24 if ΔN_{rain} ignored)

ignore ΔN_{rain} in uplink

$\rightarrow \left(\frac{C}{N}\right)_{u, rain} = 24$ dB

$\left(\frac{C}{N}\right)_d$ is affected by the rain even though there is no rain in the link. This is because the power received at the input of the transponder is attenuated, hence the power output of the transponder will be attenuated by the same amount. no change in noise temperature

$$\therefore \left(\frac{C}{N}\right)_{u,\,rain} = \left(\frac{C}{N}\right)_{u,\,clear} - L_{rain,u}$$

$$\rightarrow \left(\frac{C}{N}\right)_{u,\,rain} = 11.22 \text{ dB}$$

>9.5 dB 1.5 marg

$$\therefore \left(\frac{N}{C}\right)_{o,\,rain} = 10^{-2.4} + 10^{-1.122} \rightarrow \left(\frac{C}{N}\right)_{o,\,rain} = 10.94 \text{ dB}$$

downlink:

$$T_{clear} = (1 - 10^{-0.05})\cdot 290 = 31.54 \text{ K}$$

$$T_{rain+clear} = (1 - 10^{-0.55})\cdot 290 = 208.27 \text{ K}$$

$$\therefore T_{s,\,rain} = 140 - 31.54 + 208.27 = 316.73 \text{ K}$$

$$\rightarrow \Delta N_{rain} = 10\log_{10}\left(\frac{316.73}{140}\right) = 3.546 \text{ dB}$$

$$\rightarrow \left(\frac{C}{N}\right)_{d,\,rain} = 17.22 - 3.546 - 5 = 8.694 \text{ dB}$$

<9.5 dB

$$\therefore \left(\frac{N}{C}\right)_{o} = 10^{-3} + 10^{-0.869} \rightarrow \left(\frac{C}{N}\right)_{o} = 8.638 \text{ dB}$$

mobile communication system

+ personal communication system using LEO satellites:

* outbound link: the link from the gateway station to the mobile terminal.

* inbound link: the link from the mobile terminal to the gateway station

time division multiplexing high bit rate

- the outbound link uses TDM, where many users share a single transponder

DAMA, demand assignment MA

single channel per carrier frequency division multiple access

- the inbound link uses SCPC FDMA with very low bit rate.

- using TDM has the advantage of less backoff loss. The backoff loss for FDMA is much greater since many carriers pass through one transponder and saturate it.

- for global coverage, the beamwidth is very large. since beamwidth

$\theta \propto \frac{1}{D}$, $D \propto G$

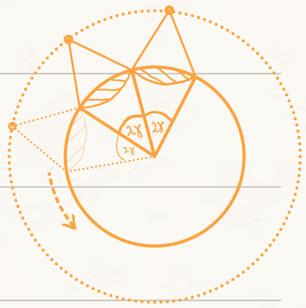
is inversely proportional to gain, the transmitted power must be very large.

- for frequency reuse, most LEO satellites use multiple beam antennas which also increases the gain of each antenna.

+ for global coverage with LEO satellite constellation:

- the total satellites in one orbit is : round up

$$\frac{360^\circ}{2\gamma^\circ}$$



- the total orbits are : $\frac{360}{2\gamma} \cdot \frac{1}{2}$ round up

example 10 : $L_{p,\,mobile,\,u} = 163.64$ dB

inbound link : bandwidth = bit rate

uplink

$P_R = C_u = 10\log_{10}(0.5) + 0 + 23 - 163.64 - 3 - 0.5$

$\rightarrow C_u = -147.15$ dBW $\rightarrow \left(\frac{C}{N}\right)_u = 17.65$ dB forwardlink $L_p = 180.5$ dB

divide by number of mobile users

$P_r = C_d = 10 - 3 + 3 + 53.5 - L_p - 3 - 1 - 10\log_{10}(\#\text{ of terminals})$

$\rightarrow C_d = -138$ dBW, $\left(\frac{C}{N}\right)_d = 32.33$ dB

$\therefore \left(\frac{N}{C}\right)_0 = 10^{-1.765} + 10^{-3.233} \rightarrow \left(\frac{C}{N}\right)_0 = 17.5$ dB

Outbound:

uplink $L_p = 182.2$

$C_u = 10 + 55 + 3 - L_p - 1 - 3 = -118.2$ dBW

$\rightarrow \left(\frac{C}{N}\right)_u = 28.64$ dB

downlink $L_p = 163.1$ dB

$C_d = 10 - 1 + 23 + 0 - L_p - 0.5 - 3 = -134.6$ dBW

$\rightarrow \left(\frac{C}{N}\right)_d = 14.46$ dB

$\therefore \left(\frac{N}{C}\right)_0 = 10^{-2.864} + 10^{-1.446} \rightarrow \left(\frac{C}{N}\right)_0 = 14.29$ dB

+ Total bandwidth:

- for half-rate convolutional code:

$$B_{total} = \left[\overbrace{R_b}^{\text{initial bit rate}} \overbrace{\times 2}^{\text{double bit rate required for code}} \times (1 + \overbrace{\alpha}^{\text{filter rolloff factor}}) + \overbrace{GB}^{\text{guard band}}\right] \times \text{users}$$

$\rightarrow \frac{C}{N}$ will decrease by 3 dB since doubling bit rate doubles noise B_n

- noise bandwidth for a raised cosine filter, similar to a nyquist filter, is independent of the roll-off factor (α).

$(\overset{\text{total bits}}{n}, \overset{\text{data bits}}{k})$ FEC

$\rightarrow \left(\frac{C}{N}\right)_{new} = \left(\frac{C}{N}\right)_{old} + \text{coding gain} - 10\log_{10}\left(\frac{n}{k}\right)$

- overall: $\left(\frac{N}{C}\right)_{0,new} = \left(\frac{N}{C}\right)_{u,new} + \left(\frac{N}{C}\right)_{d,new}$

MOHAMMAD SANAD ALTAHER 130806

EE558: Homework #4

4.1: $G_t = 54$ dB, $G_r = 26$ dB, $P_t = 100$ W, $R = 37500$ km

a) $L_p = \left(\frac{4\pi R}{\lambda}\right)^2 = 199.6$ dB

b) $P_t + G_t + G_r - L_p = P_r$

$20 + 54 + 26 - 199.6 = -99.6$ dBW

c) $N = 10\log_{10}(k T_s B_n) = -126$ dBW

d) $C - N = 26.4$ dB

e) $C_{out} = C_{in} + 110 = 10.4$ dBW $= 10.96$ W

$4\pi A_e$

4.2: a) $G = \frac{33000}{6 \times 3} = 32.6$ dB, at edge: $G = 29.6$ dB

b) $P_t + G_t + G_r - L_p = P_r$, $L_p = 196$ (assuming 3.875 GHz)

$10 + 29.6 + 53 - 196 = -103.4$ dBW

c) $N = 10\log_{10}(k T_s \cdot 36M) = -133$ dBW

d) $C - N = 29.6$ dB $= \left(\frac{C}{N}\right)_{dB}$

4.3: a) $\because P_{t,\text{total}} = 20\,W \rightarrow P_{t,\text{channel}} = \frac{20}{500} = 40\,mW/\text{channel}$

b) $P_{t,\text{channel}} + G_t + G_r - L_p = C$

$$\left.\begin{array}{l} -14 + 30 + 40 - 206 = -150\ dBW \\ \wedge\ N = 10\log_{10}(k \cdot 150 \cdot 500k) = -159.9\ dBW \end{array}\right\} \frac{C}{N} = 9.9\ dB$$

c) margin $= \left(\frac{C}{N}\right)_{\text{received}} - \left(\frac{C}{N}\right)_{\text{min}} = 9.9 - 6 = 3.9\ dB$

4.7: a) $P_t + G_t + G_r - L_p - 3\,dB = P_r$

$10\log_{10}(0.5) + 18 + 1 - 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) - 3\,dB = -153.4\ dBW$

b) $N = 10\log_{10}(k \cdot 260 \cdot 20k) = -161.4\ dBW$

c) $\left(\frac{C}{N}\right)_{dB} = 8\ dB$

quiz practice :

1) $P_t + G_t + G_R - L_p = C$

$20 + 54 + 25 - 20\log(\frac{4\pi R}{\lambda}) = -100.4$ dBW

& $N = 10\log_{10}(k \cdot 500 \cdot 36M) = -126.1$ dBW

$\rightarrow (\frac{C}{N})_{dB} = 25.7$ dB

$C_{transponder, out} = C_{in} + 110 = 9.6$ dBW

2) a) EIRP = $10\log_{10}(500) + 20 = 47$ dBW

$\therefore L_p = 206 \rightarrow \frac{4\pi R}{\lambda} = 10^{\frac{206}{20}} \rightarrow R = 39694.5$ km

$\therefore G_t = \frac{4\pi A}{\lambda^2} \cdot \eta \rightarrow A = 7.65 \times 10^{-3}\ m^2 \rightarrow r = 4.9$ cm

$\therefore$ diameter = 9.8 cm

b) $EIRP + G_R - L_p = P_R$

$47 + 30 - 206 = -129$ dBW

& $N = 10\log_{10}(kT_s\, 10M) = -138.6$ dBW

$\Big\} (\frac{C}{N})_{dB} = 9.6$ dB

second exam practice

29/4/2022

a) two functions of attitude and orbit control are to maintain the satellite's orbit, and to keep antennas and solar panels pointing in the right direction.

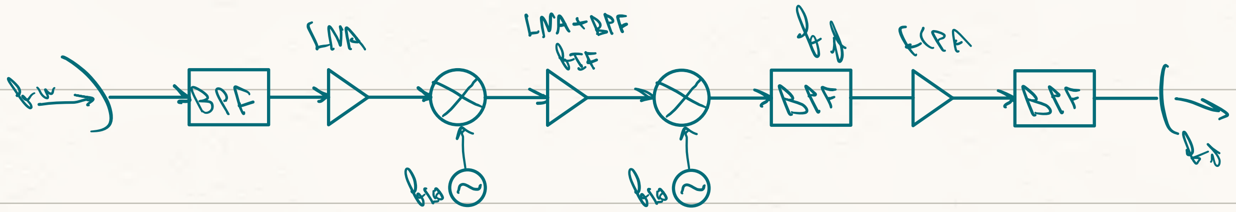
b) five types of sensors: 1- earth horizon, 2- sun, 3- star

4- magnetometer, 5- gyroscopes

c) 1- global (earth) coverage, 2- hemispherical, 3- zonal, regional

4- spot coverage

d)



Q4: a) $P = 5kW = 1240 \times \eta \times A_e \rightarrow A_e = 16\,m^2$

$\rightarrow \frac{16}{4 \times 10^{-4}} \rightarrow 40000$ cells

energy needed $= 5kW \times \frac{72}{60} = 6kWh$

battery cell: $1.3 \times 100 = 130\,Wh$

effective charge: $130\,Wh \times 0.95 \times 0.8$

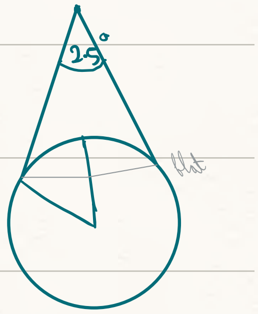
$\rightarrow$ number of cells $= 60.73 = 61$ cells

$\rightarrow$ weight $= 61 \times 130\,Wh \times 0.95 \times 0.8 / 60$

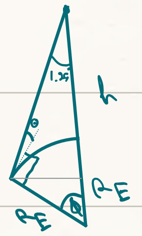
$= 100.45\,kg$

b) $G = \eta \left(\frac{\pi D}{\lambda}\right)^2 = 37.27\,dB$

$\theta_{3dB} = \frac{75\lambda}{D} = 2.5^0$



for spherical earth



$$\frac{RE+h}{\sin(40+\theta)} = \frac{RE}{\sin(1.25)}$$

$\rightarrow \sin(40+\theta) = 0.144 = \sin(180-(90+\theta))$

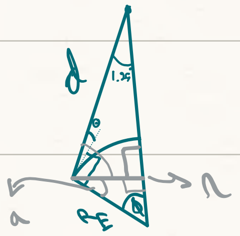
$\rightarrow \sin(90-\theta) = 0.144 \rightarrow \theta = 81.71^\circ$

$\rightarrow \phi = 180 - (90 + 81.71 + 1.25) = 7.04^\circ$

$\rightarrow l = 7.04 \times \frac{\pi}{180} \times R_E = 783.7$ km

$\rightarrow$ diameter assuming spherical earth $= 1567.4$ km

for flat earth:



$\therefore a = 180 - 90 - \phi = 82.96^\circ$

$$\therefore \frac{r}{\sin(\phi)} = \frac{R_E}{\sin(90)}$$

$\therefore r = 781.7$ km

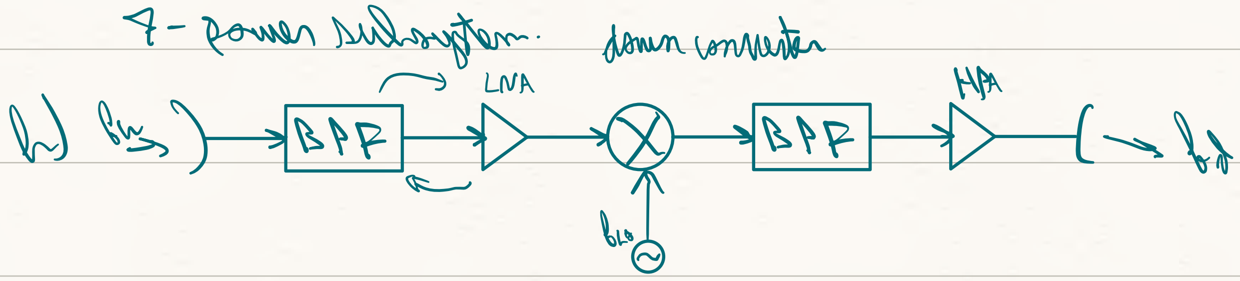
$\rightarrow$ diameter $= 1563.4$

1/4/2014:

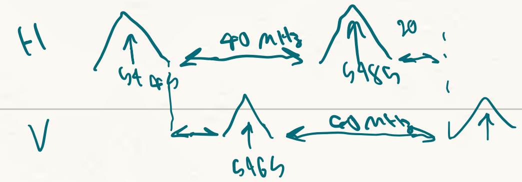
Q3: a) 1- communication subsystem, 2- payload, 3- attitude and orbit control subsystem, 4- telemetry, tracking, monitoring and command subsystem, 5- propulsion, 6- therm

7- power subsystem.

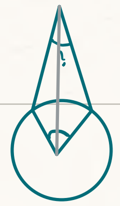
b)



c)



Q4: a) if diameter = 1000 km → ϕ = 0.159 rad



$\rightarrow \frac{1}{2}\phi = 4.5°$

cosine law: $C^2 = \overset{R_s}{A^2} + \overset{R_E}{B^2} - 2\overset{R_s\,R_E}{AB}\cos(\overset{\frac{1}{2}\phi}{C})$

C is range → $d = 35809$ km

$\rightarrow \frac{d}{\sin(4.5)} = \frac{R_E}{\sin(\gamma)} \rightarrow \gamma = 0.8° \rightarrow BW = 1.6°$

$\rightarrow 1.6 = \frac{75\lambda}{D} \rightarrow D \simeq 1.17$ m

$G_r = 41.13$ dB

11/4/2019

Q2: a) $C = 10 - 1 + 23 + 3 - 163.1 - 3 - 0.5 - 4 - 1$

$L_p = 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) = 163.1$ dB

$\rightarrow C = -136.6$ dBW

$N = 10\log_{10}(kT_sB)$, $T_{s,\,clear} = 32.6$ K

$T_{s(rain+clear)} = 193.56$ K $\rightarrow T_{s\,rain} = 660.96$ K

$\rightarrow N = -140.34$ dBW

$\rightarrow C/N = 3.74$ dB

Chapter 5 :

+ modulation is necessary for:
  - utilizing large bandwidth of the channel by multiplexing.
  - difficult to use antennas at low frequency baseband.
  - baseband signals cannot be transmitted directly through bandpass channels. like air
  - type of modulation can reduce power or bandwidth required.

* analog modulation: carrier is continuously varied with message

* digital modulation: carrier is varied discretely in time and amplitude.

- power-efficient modulation: transmitted power decreased by increasing bandwidth.
  suitable for power-limited systems.
  → examples: FM , MFSK

- bandwidth-efficient modulation: bandwidth decreased by increasing power,
  suitable for bandwidth limited systems.
  → examples: MASK, MPSK, QAM

- figure of merit: ratio of SNR at output of the receiver to the channel

$$SNR : \frac{(SNR)_o}{(SNR)_c}$$

- improvement factor: ratio of output SNR to input SNR of a specific receiver:

$$\frac{(SNR)_o}{(SNR)_I}$$

no improvement factor for analog amplitude modulation

- if the figure of merit or improvement factor is greater than unity, then the output SNR is traded off with bandwidth.
- the figure of merit of DSB-SC, SSB, and VSB signals are all 1. they also have the same SNRs.
- the figure of merit of DSB-LC is less than 1 and it wastes power in the carrier; however, signals can be recovered easily with envelope detectors, whereas coherent demodulators are required for DSB-SC, SSB, and VSB.

  synchronization

- in frequency modulation, the frequency varies with the message signal, whereas in phase modulation the frequency's derivative varies with the message signal.
- FM has the advantage of easy modulation and demodulation, in addition to power-efficiency.
- FM bandwidth is calculated from Carson's rule as:

$$BW = 2(\Delta f + \overbrace{W}^{\text{baseband signal bandwidth}}) = 2W(\overbrace{D}^{\substack{\text{deviation ratio} \approx \text{modulation index} \\ D = \frac{\Delta f}{W}}} + 1)$$

- The output signal to noise ratio is:

$$\left(\frac{S}{N}\right)_o = \frac{C}{N} + \overbrace{10\log_{10}[2(D+1)] + 20\log_{10}(D) + 10\log_{10}\left(\frac{3}{2}\right)}^{\text{FM improvement factor}}$$

for a fixed $\frac{S}{N}$, the deviation ratio can be increased to decrease $\frac{C}{N}$

- including pre-emphasis, de-emphasis, and noise weighting:

$$\left(\frac{S}{N}\right)_o = \frac{C}{N} + 10\log_{10}[2(D+1)] + 20\log_{10}(D) + 10\log_{10}\left(\frac{3}{2}\right) + \overbrace{P}^{\substack{\text{improvement from} \\ \text{pre-emphasis and de-emphasis}}} + \underbrace{Q}_{\substack{\text{improvement from} \\ \text{noise weighting}}}$$

+ advantages of digital signals:

- immune to noise, can 'clean' the signal before accumulating.
- easy design of digital electronic circuits and systems.
- easy storage and retrieve.
- easy to encrypt and add security.
- easy to compress.
- easy to multiplex and demultiplex.

+ steps to convert from analog to digital:

nyquist rate

1- sampling: at a rate higher than twice the highest frequency.

2- quantizing: quantization error can be decreased by increasing the number of levels, but this would increase the number of bits required.

3- encoding: various line codes may be used, each with its respective advantages and disadvantages.

- M-ary PAM has the advantage of reducing bandwidth, where:

$$\overbrace{R_s}^{\text{symbol rate}} = \frac{\overbrace{R_b}^{\text{bit rate}}}{\log_2 (\underbrace{M}_{\text{number of possible symbols}})} \quad , \quad B_T = \frac{R}{2} \rightarrow B_{T,\, M\text{-ary}} = \frac{R_b}{2 \log_2 (M)}$$

+ bit error probability (rate) depends on: in addition to the power density of noise

- line code, - energy in pulses, - euclidean distance between two adjacent signals.

$P_e = \frac{1}{2}\,\text{erfc}\sqrt{\frac{E_b}{N_0}}$ $\quad$ $P_e = \frac{1}{2}\,\text{erfc}\sqrt{\frac{E_b}{2N}}$

- PSK is better than ASK, since it requires half the bit energy for the same performance.

- given that there are $\log_2(M)$ bits in a symbol, the symbol energy is:

$$E_s = E_b \cdot \log_2(M)$$

- the symbol to noise ratio can be obtained from the carrier to noise ratio as:

$$\frac{E_s}{N_0} = \frac{\overset{\text{symbol period}}{C\,T_s}}{N/B_n}$$

carrier power ← C $\quad$ → energy = power × time

noise power ← N $\quad$ → noise bandwidth $\quad$ energy = $\frac{\text{power}}{\text{Hz}}$

$$\therefore\ T_s = \frac{1}{R_s}\ ,\ T_s B_n = \frac{B_n}{R_s} = 1 \rightarrow \frac{E_s}{N_0} = \frac{C}{N}$$

- for analog signals using digital transmission:

$$\underbrace{\left(\frac{S}{N}\right)_{PCM}}_{\text{pulse code modulation}} = \frac{2^{2\boxed{n}}}{1 + 4\underbrace{P_b}_{\text{bit error rate}} \cdot 2^{2n}} \approx \frac{1}{4P_b}$$

number of bits to represent level

→ quantization noise

→ {this implies that quantization errors may be ignored

- the required symbol/bit energy to noise ratio is found from the BER specified.

$\frac{E_s}{N_0}$ $\quad$ $\frac{E_b}{N_0}$

+ chapter 5 examples:

Ex1:

$$\frac{S}{N} = \frac{C}{N} + 10\log[2(D+1)] + 20\log(D) + P + Q + 10\log_{10}\left(\frac{3}{2}\right)$$

$\therefore$ Carson's rule

$$B = 2W(D+1) \rightarrow 30 = 2 \cdot 4.2\,(D+1)$$

$$\rightarrow D = 2.57$$

$$\therefore \frac{S}{N} = 15 + 1.8 + 9 + 8 + 10\log[2(D+1)] + 20\log(D)$$

$$\rightarrow \frac{S}{N} = 50.53\ \text{dB}$$

Ex2:

for BPSK: $B = (1+\alpha)R_b \rightarrow R_b = 25.7$ Mb/s

for QPSK: $B = (1+\alpha)R_s$, $R_s = \frac{R_b}{2} \rightarrow R_b = 51.4$ Mb/s

Ex3:

for BPSK: assume noise bandwidth = signal bandwidth = 1MHz

symbol rate = noise bandwidth $\rightarrow R_s = R_b = 1$ Mb/s

$\rightarrow B = (1+0.3)\cdot 1M = 1.3$ MHz

$\because \mathrm{erfc}(x) \approx \frac{e^{-x^2}}{2\pi} \rightarrow P_e \approx 9.8\times10^{-13}$

for QPSK: signal bandwidth = 1MHz

$R_s = \frac{R_b}{2} \rightarrow R_b = 2$ Mbps

$\rightarrow B = (1+\alpha)R_s = 1.3$ MHz

$\because \frac{E_s}{N_0} = \frac{C}{N}$ & $E_s = 2E_b \rightarrow \frac{2E_b}{N_0} = \frac{C}{N}$

$\therefore P_e = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{1}{2}\frac{C}{N}}\right) = 2.79\times10^{-7}$

Ex4:

$\because \left(\frac{S}{N}\right)_{PCM} = \frac{2^{2n}}{1+4P_b\times2^{2n}} = \frac{2^{16}}{1+2^{18}\cdot P_b}$

a) $\left(\frac{S}{N}\right)_{PCM} = 48.15$ dB, b) $\left(\frac{S}{N}\right)_{PCM} = 48.05$ dB,

c) $\left(\frac{S}{N}\right)_{PCM} = 47.14$ dB, d) $\left(\frac{S}{N}\right)_{PCM} = 42.58$ dB,

e) $\left(\frac{S}{N}\right)_{PCM} = 33.82$ dB

Exe 5:

for BPSK: $P_e = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right)$

$\rightarrow 10^{-9} = \frac{1}{2} \cdot \frac{e^{-x^2}}{2\pi} \rightarrow e^{-x^2} = 1.2566 \times 10^{-8}$

$\rightarrow x = 4.265 = \sqrt{\frac{E_b}{N_0}}$

$\therefore \frac{E_b}{N_0} = 18.19 \quad (12.6\,\mathrm{dB}) \quad \approx \frac{C}{N}$

$\because \left(\frac{S}{N}\right)_{PCM} \approx \frac{1}{4P_b} = 83.98\,\mathrm{dB}$

for QPSK: $P_e = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right) \rightarrow \frac{E_b}{N_0} = 18.19$

$\because \frac{C}{N} = \frac{E_b}{N_0} \rightarrow \frac{C}{N} = 2\,\frac{E_b}{N_0} = 36.4 \;(15.6\,\mathrm{dB})$

$\left(\frac{S}{N}\right)_{PCM} = 83.98\,\mathrm{dB}$

Chapter 6 :

fixed number of signals and bandwidth (or bit rate)

* multiplexing : group of signals made to share a common channel while utilizing its whole resources.

similar to multiplexing

* multiple access : group of signals share a channel, but the number of signals usually exceeds the channel's capacity and the users are highly dispersed with varying traffic.

\+ multiple access vs. multiplexing :

- in multiplexing, users are centered at common point, whereas users are geographically dispersed in multiple access.
- in multiplexing, the number of users is equal to the maximum whereas multiple access has more users than max.

\+ types of multiple access :

- preassigned : resources fixed for certain users.
  or partially fixed
- demand-assigned : Resources available to all users and assigned according to demand.

- FDMA and TDMA can be demand-assigned or preassigned, but CDMA is random access.

+ most important criteria for selecting the multiple access technique:

1- throughput or capacity of the system.

2- power transmitted for given bit rate.

3- synchronization requirements between transmission of different users to avoid interference.

4- complexity and cost of the system.

5- ease of reprogramming for new protocols.

* frequency division multiplexing: total available bandwidth is divided into non-overlapping frequency subbands.

- due to its simplicity and effectiveness, FDM is the most commonly used type of multiplexing.

+ Types of FDMA:

1- single access: single modulated carrier occupies the whole bandwidth of the transponder.

2- preassigned.

3- demand-assigned: a frequency slot is assigned to a user from the pool of available frequencies using $\overbrace{\text{polling}}^{\text{introduces polling delay}}$, users request calls and a master station assigns

centrally controlled random access, or distributed

each earth station assigns itself a frequency based on information of available channels

control random access.

SCPC PCM multiple-access demand-assignment equipment

4- Spade system: uses a pilot frequency for frequency control and a common signaling channel for demand assignment.

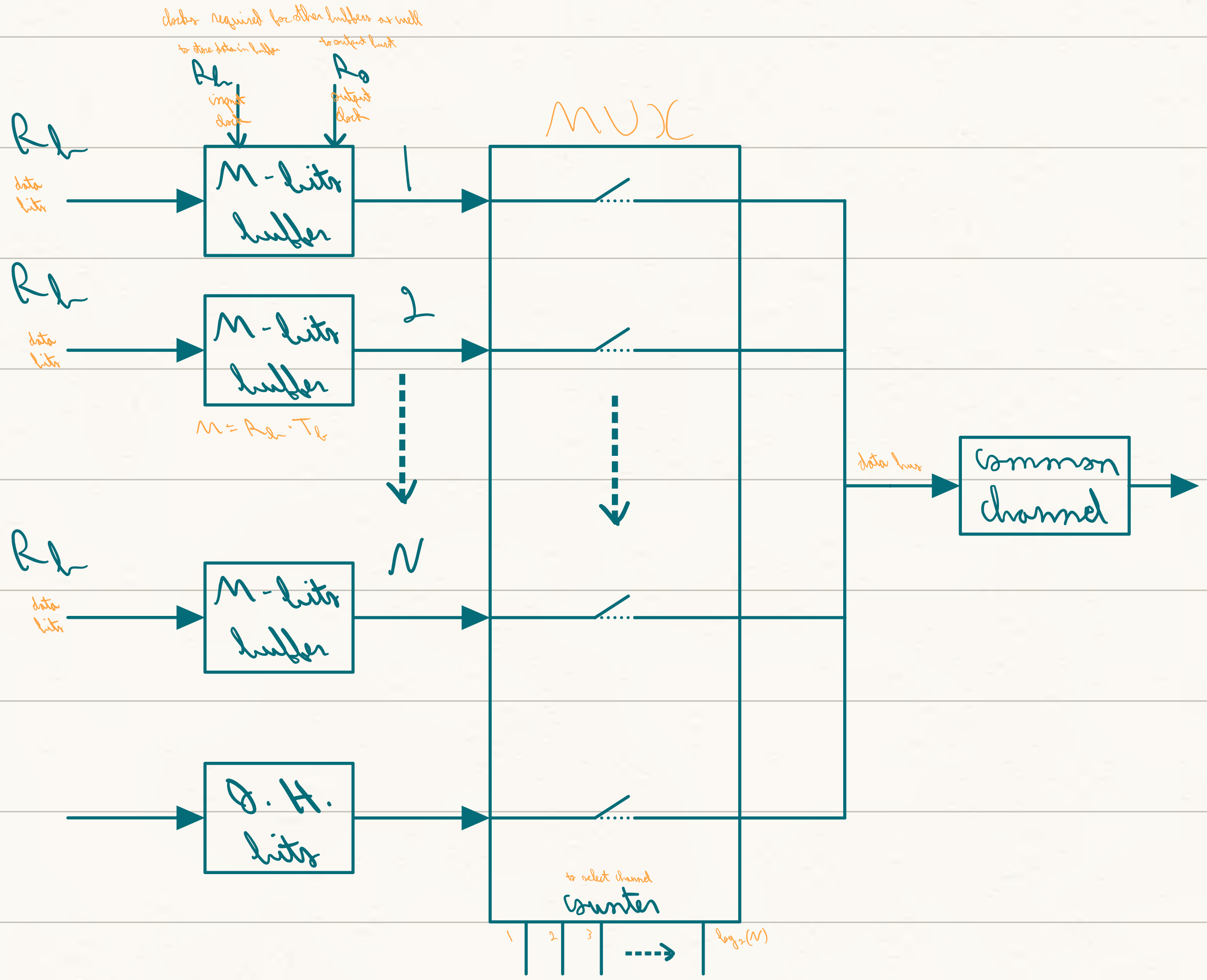
* time division multiplexing: each user uses the whole channel in a cyclic manner during a given time slot.

- output bit rate is given as:

$R_b \cdot T_f$ = number of bits for one user in the frame

$N \cdot (R_b \cdot T_f)$ = total data bits in a frame for N users

$$R_o = \Big[\overbrace{O.H.}^{\text{overhead bits}} + \underbrace{N}_{\text{number of input signals}} \cdot (\overbrace{R_b}^{\text{input bit rate}} \cdot \underbrace{T_f}_{\text{frame period}})\Big] \cdot \overbrace{R_f}^{\text{frame rate } (\frac{1}{T_f} : s^{-1})} \quad \text{bits/s}$$



- the frame rate is often chosen as an integer multiple of the sampling period of voice signals. $T_f = k \cdot \frac{1}{8000}$ → sampling rate of voice signals

- The main disadvantage of FDM is the high backoffs loss due to multicarriers.

- The main disadvantage of TDM is requiring many input buffers.

- FDM and FDMA are very similar; however, TDM and TDMA are different since no collisions occur in TDM, given that all users are in the same location, whereas TDMA is prone to collisions.
  due to different geographical locations of users, hence the different ranges may cause identical arrival times despite different transmission times, also GEO satellites not perfectly stationary

- The number of time slots in TDMA are equal to the number of earth stations served concurrently plus one slot for the reference bursts.
  station must transmit its data within its allotted slot at a bit rate to occupy the entire bandwidth (burst bit rate = $\frac{M}{T_B}$, T_B: burst time)

- since only one carrier uses the transponder at a time, there is no intermodulation distortion, which allows operating the TWT at maximum power.
  due to non-linear amplification of multiple carriers
  no backoff loss

- guard times are inserted between bursts to avoid bursts overlapping.

- throughput efficiency is: in FDM/FDMA $\frac{\text{used BW for data}}{\text{total BW (used + O.H.)}}$

- frame efficiency is: TDM/TDMA $\frac{\text{data bits}}{\text{total bits (data + O.H.)}} \rightarrow \eta = 1 - \frac{\text{O.H. bits}}{\text{total bits}}$

- The time available for data transmission for each station:

$$\overbrace{T_d}^{\text{data time for each station}} = \Big[\overbrace{T_F}^{\text{total frame time}} - \overbrace{T_R}^{\text{reference burst time}} - \overbrace{N}^{\text{number of stations}} \cdot (\overbrace{T_G}^{\text{guard time}} + \overbrace{T_{O.H.}}^{\text{time for preamble, postamble, etc for each station}})\Big] / N$$

- The burst rate is given as: $\overbrace{\log_2(M)}^{\text{number of bits per symbol}} \cdot \frac{B \rightarrow \text{transponder bandwidth}}{1+\underbrace{\alpha}_{\text{shaping filter rolloff factor}}} = R_{burst} = R_0$

- The buffers' input bit rate is : $R_{burst} \cdot \frac{T_a}{T_b} = R_b$

- TDMA cannot be used with satellites other than GEO, since earth stations' ranges will change too quickly causing collisions.

- since bursts and subbursts in TDMA are controlled by software, the networks are more flexible in reassigning channels and changes can be made quickly, when compared to FDMA systems.
  carrier frequency assignment is controlled by hardware

+ FDMA examples:

Ex 1: total power transmitted : 250 W

$\therefore$ 3 dB backoff loss $\rightarrow P_{t,\text{transponder}} = 20$ W

assuming even distribution :

$$P_{ESA} = 250 \cdot \frac{15}{\text{total BW}} = 250 \cdot \frac{15}{30} = 125 \text{ W}$$

$$P_{ESB} = 250 \cdot \frac{10}{30} = 83.33 \text{ W}$$

$$P_{ESC} = 250 \cdot \frac{5}{30} = 41.67 \text{ W}$$

output of transponder :

$P_{t,ESA} = 20 \cdot \frac{15}{30} = 10$ W,

$P_{t,ESB} = 6.67$ W, $P_{t,ESC} = 3.33$ W

Ex2:

for bandwidth: users: $\frac{1 \text{ MHz}}{12+4 \text{ kHz}} = 62.5 = 62$ users

for power: $P_{out} = -144 + 134 = -10 \text{ dBW} = 0.1 \text{ W}$

power limited

∴ number of users for 5 W output : <u>50 users</u>

the number can be increased to 62 if the input power is:

∵ $P_{out} = 5 \text{ W} \rightarrow P_{out, user} = \frac{5}{62} = 0.0806 \text{ W}$

$\rightarrow P_{in, user} = 10 \log_{10}(0.0806) - 134 \approx -145 \text{ dBW}$

which would reduce $\frac{C}{N}$ to ≈ 15 dB (from 16 dB)

+TDMA examples:

Ex1:

∵ $T_d = [T_f - T_R - N(T_G + T_{g.H.})]/N$

$\rightarrow T_d = [2m - 5 \cdot (5u + 20u)]/5 = 375 \text{ us}$

$\rightarrow R_{burst} = R_s = \log_2(4) \cdot \frac{B}{(1+\alpha)} = 2 \cdot 30 = 60 \text{ Mb/s}$

$\rightarrow R_d = 11.25 \text{ Mb/s}$, bit rate of each ES

∴ $\frac{11.25 M}{64 k} = 175$ channels

$\eta = \frac{N \cdot T_d}{T_f} = 43.75 \%$

Ex 2:

∵ total input bit rate = 30 Mb/s = 30 kb/ms

& $T_s = [T_f - T_R - N(T_G + T_{pre})]/N$

$\rightarrow N \cdot T_s = 1\,ms - 3(2\mu + 10\mu) = 964\,\mu s$

∴ burst times:

$ESA = 964\mu \cdot \frac{15}{30} = 482\,\mu s$

$ESB = 321.33\,\mu s$, $ESC = 160.667\,\mu s$

∴ burst rate $= \frac{30\text{ kbits}}{964\,\mu} = 31.12\text{ Mb/s}$

$\rightarrow$ symbol rate $= 15.56\text{ MS/s}$

∵ $L_{bo} = 1\,dB \rightarrow P_{t,\text{transponder}} = 10\log_{10}(40) - 1$

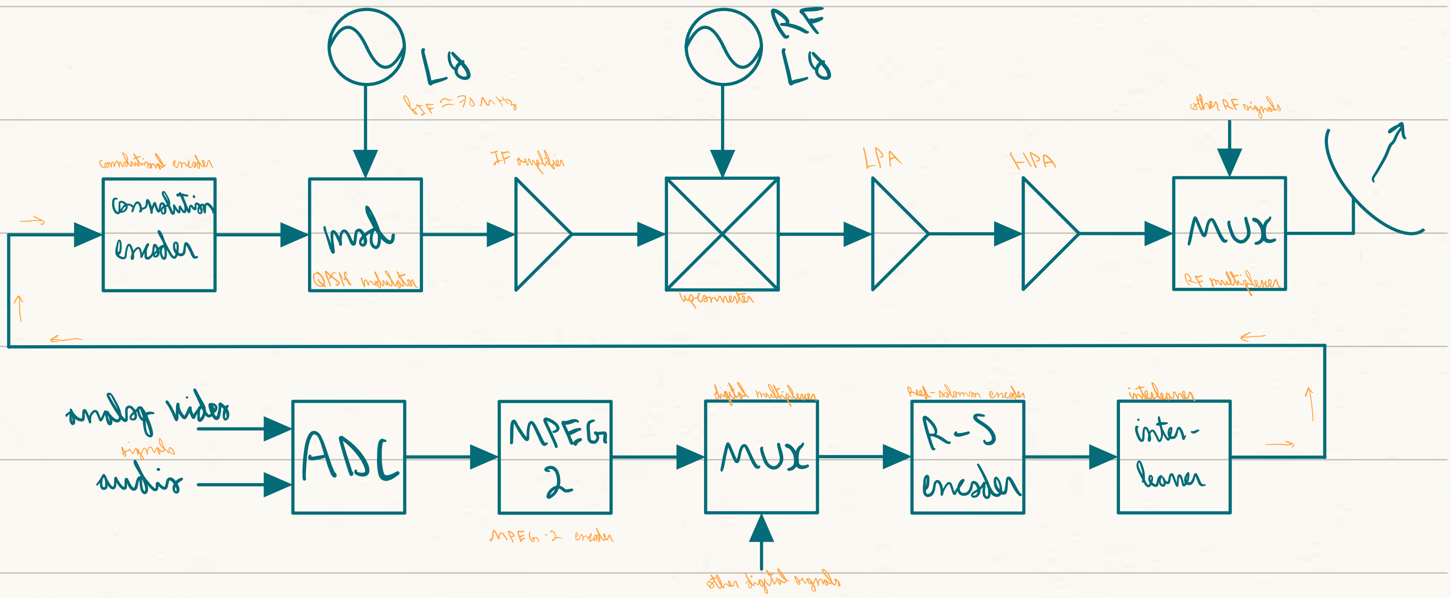
$\rightarrow P_{t,\text{transponder}} = 10^{1.5} = 31.62\,W$

∴ total power of ESs $= \frac{31.62}{20} \cdot 250 = 395.25\,W$

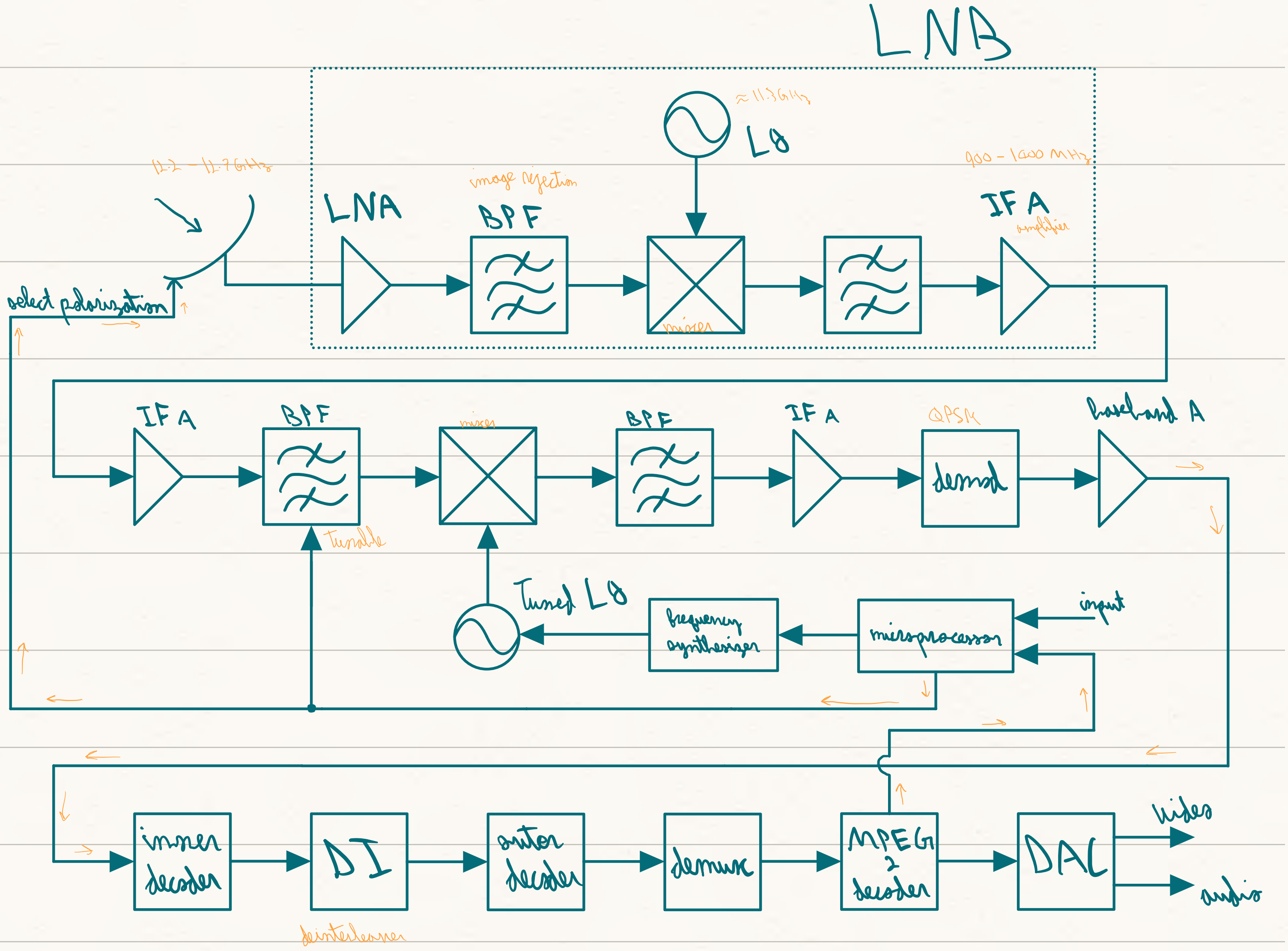
- to utilise the whole bandwidth available, each station transmits the same symbol rate and hence the same power

Chapter 11:

+ DBS TV Uplink transmitter



+ DBS TV receiver:



+ DBS TV link budget example:

$P_R = P_t + G_t + G_R - L_{ant} - L_a - L_p$, $L_p = 20 \log_{10}\left(\frac{4\pi R}{\lambda}\right) = 205.88$

$\rightarrow P_R = -117.68$ dBW

$\rightarrow \frac{C}{N} = P_R - 10\log_{10}(kTB_n)$ $\wedge$ $B = 20$ MHz

$\rightarrow \frac{C}{N} = 16.36$ dB

to find $\frac{C}{N}$ min: $P_{e,QPSK} = \frac{1}{2}\,\text{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right)$

$\wedge$ $\frac{E_b}{N_0} = \frac{C}{N} \cdot \frac{1}{2} \rightarrow 10^{-6} = \frac{1}{2} \cdot \frac{e^{-x^2}}{2\pi}$

$\therefore x^2 = \frac{C}{2N} = 11.28 \rightarrow \left(\frac{C}{N}\right)_{min} = 22.57$

$\rightarrow \left(\frac{C}{N}\right)_{min} = 13.53$ dB (uncoded)

$\left(\frac{C}{N}\right)_{min,\,coded} = \left(\frac{C}{N}\right)_{min,\,uncoded}$ − coding gain $= 7.53$ dB

$\therefore$ system margin $= 8.83$ dB

final exam practice:

final 6/2020:

Q1: QPSK, $\alpha = 0.25$, $R = 38500$ km, $f_d = 12$ GHz

a) $EIRP = P_{to} - L_{ta} + G_t = 10\log_{10}(200) - 1 + 40$

$\therefore EIRP = 62$ dBW

& $L_p = 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) = 205.73$ dB

$P_r = EIRP + G_t - L_p - L_{ant} - L_r - L_m$

$\rightarrow P_r = -114.73$ dBW

$\because G_r = 34$ dB $= 10^{3.4} = \eta\left(\frac{\pi D}{\lambda}\right)^2$ assuming dish

$\therefore D = \left(\frac{10^{3.4}}{\eta}\right)^{1/2} \cdot \frac{\lambda}{\pi} = 0.495$ m

$\therefore P_r/A = S = \frac{10^{-11.473}}{\left(\frac{0.495}{2}\right)^2 \pi} = 17.49$ pW/m^2

b) $\because P_r = C = -114.73$ dBW

$\rightarrow \frac{C}{N} = P_r - 10\log_{10}(kT_sB_n) = 18.31$ dB

c) $\because T_{clear} = \left(1 - \frac{1}{10^{0.05}}\right) \cdot 290 = 31.54$ K

& $T_{clear+rain} = \left(1 - \frac{1}{10^{0.15}}\right) \cdot 290 = 84.69$ K

$\rightarrow T_{s,rain} = 150 - 31.54 + 84.69 = 203.15$ K

$\rightarrow \left(\frac{C}{N}\right)_{rain} = \left(\frac{C}{N}\right)_{clear} - L_{rain} - \Delta N_{rain}$

$= 15.99 \approx 16$ dB

Q3:

a) $\left(\frac{S}{N}\right)_o = \frac{C}{N} + 10\log[2(D+1)] + 20\log(D) + 10\log\left(\frac{3}{2}\right)$

$+ P + Q$

$\because \; B_{RF} = 2(\Delta f_{pk} + f_{max}) = 2 f_{max}(D+1)$

$\rightarrow 36M = 2 \cdot 4.5M \cdot (D+1) \rightarrow D = 3$

$\therefore \left(\frac{S}{N}\right)_o = 12 + 10\log_{10}(8) + 20\log_{10}(3) + 10\log_{10}\left(\frac{3}{2}\right)$

$+ P + Q$

$\rightarrow \left(\frac{S}{N}\right)_o = 32.33 + 8 + 10 \approx 50$ dB

b) noise bandwidth = 36 MHz for all

$R_s = \frac{B}{1+\alpha} = 24$ MS/s

for BPSK, $R_b = R_s \wedge BER = \frac{1}{2}\operatorname{erfc}\left(\sqrt{\frac{C}{N}}\right)$

for QPSK, $R_b = 48$ Mb/s $\wedge BER = \frac{1}{2}\operatorname{erfc}\left(\sqrt{\frac{C}{2N}}\right)$

for 8-ary PSK, $R_b = \log_2(8) \cdot 24 = 72$ Mb/s

$\wedge BER = \frac{1}{2}\operatorname{erfc}\left(\sqrt{\frac{C}{3N}}\right)$

c) FDMA:

$B = \frac{30M}{50} - 100k = 500$ kHz per user

$\rightarrow R_b = 50 \times 500\text{kHz} \cdot \frac{1}{1.25} = 20$ Mb/s

TDMA:

$T_f = [2m - 20\mu - 50[5\mu + 4\mu]] / 50$

$\rightarrow T_f = 30.6\ \mu s$

$\rightarrow R_s = 24\ Mb/s$

$\rightarrow R_b \cdot N = 24M \cdot \frac{30.6\mu}{2m} \cdot N = 18.36$ Mb/s

5/2019:

Q1:

a) The iridium mobile phone system requires 6 LEO polar circular orbits for a total of 66 satellites

b) digital technology allows using digital modulation which enables forward error correction, compression is immune to noise, and reduces transmitted power

c) FDM/WDM, TDM, CDM

FDMA, TDMA, CDMA

the main differences between multiplexing and multiple access are:

fixed traffic equal to capacity

- in multiplexing, users fill entire capacity of system, whereas users exceed max possible in MA

in multiple access, number of users is not fixed, usually exceeds capacity and is not fixed

- second difference is users are dispersed in multiple access

d) ASK, FSK, PSK (BPSK, QPSK, etc.)

PSK is most used, although others may be used.

e) source coding means compressing the signal to reduce bit rate

channel coding means adding redundant bits for error correction and detection

Q2:

a) assuming FM

$$\frac{S}{N} = \frac{C}{N} + 10\log[2(D+1)] + 20\log(D) + P + Q$$
$$+ 10\log\left(\frac{3}{2}\right)$$

$\because$ $B = 2W(D+1) \rightarrow D = \frac{B}{2W} - 1 = 3.286$

$\rightarrow 55 = \frac{C}{N} + 10\log(2(4.286)) + 20\log(3.286)$
$+ 18 + 11 + 4$

$\therefore \frac{C}{N} = 13.536$ dB

$\frac{C}{N} = \frac{S}{N}$ in DSB-SC $= 55$ dB

b) for BPSK:

$R_b = R_s = 4$ Mbits/s

$\rightarrow B_{RF} = 4M \cdot (1+\varepsilon) = 5$ MHz

$$BER = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right) \wedge \frac{E_b}{N_0} = \frac{C}{N}$$

$$\rightarrow BER \simeq \frac{1}{2} \cdot e^{-10} \cdot \frac{1}{2\pi} = 3.6 \times 10^{-6}$$

for QPSK

$$R_s = \frac{R_b}{2} = 4\ \text{Mbit/s} \rightarrow R_b = 8\ \text{Mbit/s}$$

$$\rightarrow B_{RF} = R_s(1+\alpha) = 5\ \text{MHz}$$

in QPSK $\frac{E_s}{N_0} = \frac{C}{N} = \frac{2E_b}{N_0}$

$$\rightarrow \frac{E_b}{N_0} = \frac{C}{2N} \quad \therefore BER = 5.36 \times 10^{-4}$$

Q3:

a) for FDMA:

data BW for each ES: $\frac{36M - 40 \cdot 100k}{40} = 800\ \text{kHz}$

$\therefore$ BPSK $\rightarrow BW = R_b \cdot (1+\alpha) \rightarrow R_b = 640\ \text{kbit/s}$

$\therefore$ $P_{t,\text{transponder}} = 25\ W$

$\rightarrow P_{\text{total},ES} = 250\ W \rightarrow 6.25\ W/ES$

for TDMA:

$$T_s = [t_F - T_R - N(T_G + T_{pre})]/N$$

$$\rightarrow T_s = 41.5\ \mu s$$

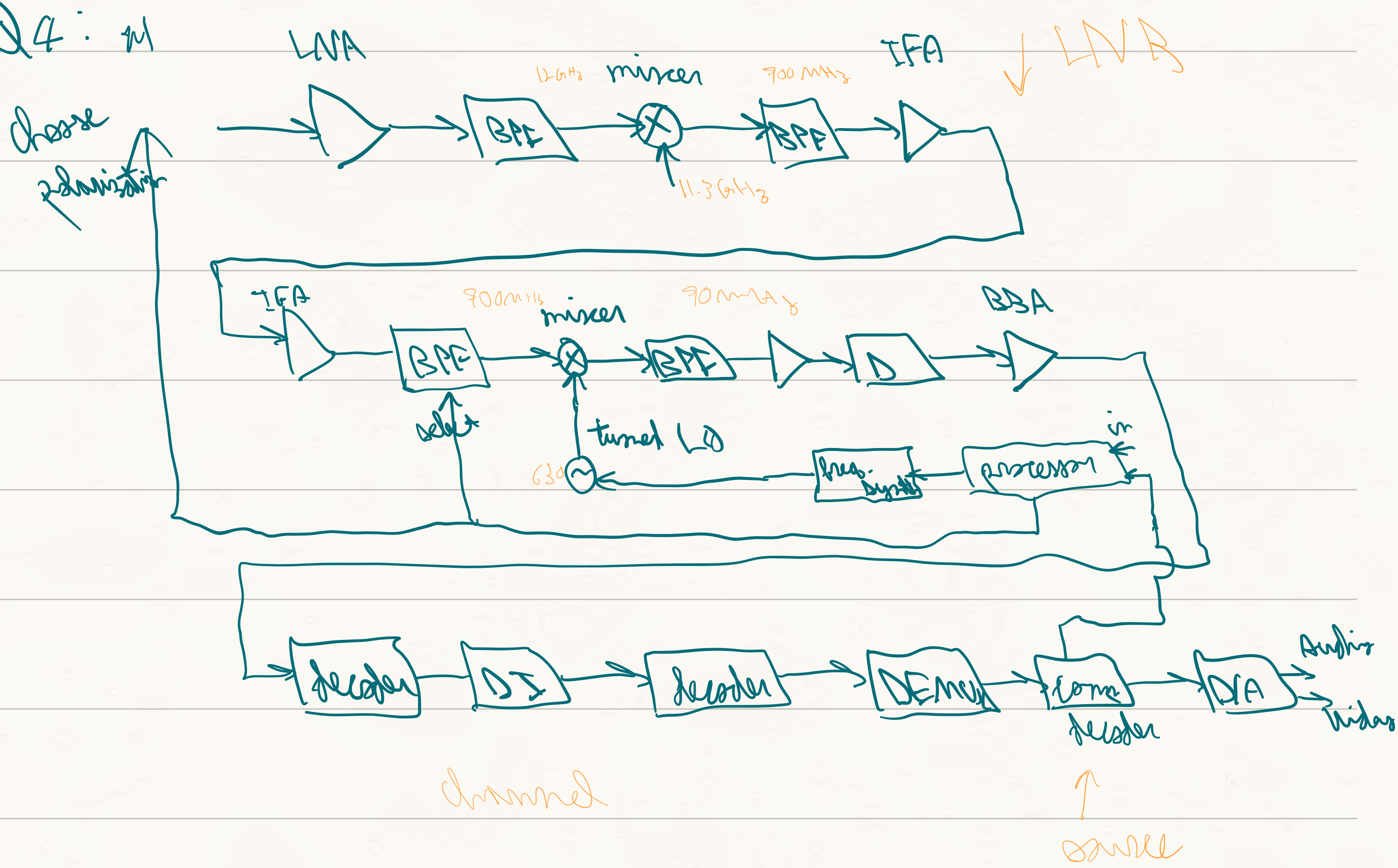
$$R_{burst} = \frac{\overset{\text{all transponder bandwidth}}{36M}}{(1+\alpha)} = 28.8\ \text{Mb/s}$$

$$\therefore R_b = 28.8 \cdot \frac{41.5m}{2m} = 597.6\ \text{kbit/s}$$

$P_t = 40W \rightarrow 400W$ transmitted

$\rightarrow 10W/ES$

Q4: a)



b) $BW = 30M = R_s(1+\alpha) \rightarrow R_s = 20\ Mb/s$

$R_b = 40\ Mb/s$

$G_t = \eta\left(\frac{\pi D}{\lambda}\right)^2 = 40.434\ dB$

$G_r = 27.7$

$P_r = 10\log_{10}(200) - 1 + 40.435 + 27.7 - L_p -$

$3 - 0.5 - 1.5$

$L_p = 206.1\ dB$

$\rightarrow P_r \approx -121\ dBW$

$\rightarrow \frac{C}{N} = -121 - 10\log_{10}(kTB_n)$

& $B_n = R_s = 20\,MHz$

$\rightarrow \frac{C}{N} = 14.6$ dB

$\frac{E_b}{N_0} = \frac{C}{N} \cdot \frac{1}{2}$ $\because$ QPSK $= 11.6$ dB

$BER \simeq \frac{1}{2}\,\frac{e^{-10^{1.16}}}{2\pi} = 4.2 \times 10^{-8}$

$\frac{S}{N} \simeq \frac{1}{4 \times 4.2 \times 10^{-8}} = 67.75$ dB

6/2021

Q1:

a) $EIRP = 59.76$ dBW

path distance: $10^{\frac{206}{20}} = \frac{4\pi R}{\lambda} \rightarrow R = 39694.5$ km

$P_r = EIRP + G_r - 206 - 3 - 0.5 - 2 = -117.74$ dBW

$\because G_r = 34 \rightarrow D \simeq 0.5$ m assuming $\eta = 0.65$

$\therefore S = \frac{10^{-11.774}}{0.25^2 \cdot \pi} = 8.57\,pW/m^2$

or $S = \frac{EIRP}{4\pi R^2} \cdot 10^{-L_{total}} \cdot \eta$

b) $\because B_n = 24\,MHz \rightarrow R_s = 24\,MS/s$

$\rightarrow B = R_s(1+\alpha) = 30\,MHz$

$\therefore$ QPSK $\rightarrow R_b = 2R_s = 48$ Mb/s

c) $\therefore P_R = -117.74$ dBW

$\rightarrow \frac{C}{N} = -117.74 - 10\log(kT_sB_N) = 14.05$ dB

d) $\therefore T_{sr\ clear} = (1 - 10^{-0.05}) \cdot 290 = 31.54$ K

& $T_{r,\ clear+rain} = (1 - 10^{-0.24})\ 290 = 126.92$ K

$\rightarrow T_{S,\ rain} = 200 - 31.54 + 126.92 = 295.38$

$\therefore \left(\frac{C}{N}\right)_{rain} = \left(\frac{C}{N}\right)_{clear} - 2 - 10\log_{10}\left(\frac{295.38}{200}\right) = 10.36$ dB

Q2:

$D = 2$

a) $\frac{S}{N} = \frac{C}{N} + 10\log(2(D+1)) + 20\log(D) + P + Q$

$\frac{S}{N} = 10 + 7.78 + 6 + 0 + 8$

$\rightarrow \frac{S}{N} = 41.78$ dB

b) $\therefore BW = 30$ MHz $= R_s\ (1+\alpha) \rightarrow R_s = 24$ Ms/s

for FDMA:

$BW/ES = \frac{30M - 40 \times 100k}{40} = 650$ kHz

$\rightarrow R_b = R_s = \frac{650k}{1.25} = 520$ kb/s

for TDMA

$T_d = [T_f - T_R - 40(T_G + T_{pre})]/40$

$\rightarrow T_d/ES = 40.5\ \mu s$ per ES

$\rightarrow R_{ch} = R_{burst} \cdot \frac{T_d}{T_b}$

& $R_{burst} = \frac{30\,\text{MHz}}{1.25} = 24$ Mb/s

$\therefore R_{ch} = 486$ kb/s

Q3:

a) $\left(\frac{C}{N}\right)_{min} \cdot 10^{0.6} \rightarrow 10^{-6}$ BER

$10^{-6} = \frac{1}{2} e^{-x} \cdot \frac{1}{2\pi} \rightarrow x = \left(\frac{C}{N}\right)_{min} \cdot 10^{0.6}$

$\rightarrow \left(\frac{C}{N}\right)_{min} = 2.834 = 4.5$ dB

b) $P_R = -118$ dBW

$\rightarrow \frac{C}{N} = P_R - 10\log_{10}(kT_sB_N) = 15.84$

$\therefore$ margin $= 11.34$ dB

c) $\because G_R = 33$ dB & $G_R = \left(\frac{\pi D}{\lambda}\right)^2 \cdot \eta$

$\rightarrow D = 0.441$ m

Chapter 4 examples:

1) $S = \frac{P_t G_t}{4\pi R^2} = 2.5 \times 10^{-14}$ W/m² $\rightarrow P_r = 2.5 \times 10^{-13}$ W

5) $C = P_R = 31 + 44.9 - 196.5 - 3 - 0.2 - 0.5 = -119.5$ dBW

$\rightarrow \frac{C}{N} = -119.5 - 10\log_{10}(kT_sB_N) = 16.03$ dB

for 1 dB rain loss

$T_{s,\,rain} = (1 - 10^{-0.02})\,290 = 13.05$ K

$T_{r, clear+rain} = (1 - 10^{-0.12})\, 290 = 70\ K$

$\rightarrow T_{s, rain} = 132\ K$

$\rightarrow \left(\frac{C}{N}\right)_{rain} = 16 - 1 \quad - 10\log_{10}\left(\frac{132}{70}\right) = 12.49\ dB$

6) $\frac{C}{N} = 14.32\ dB$

for rain loss of 3dB, $T_{s, rain} = 276.93\ K$

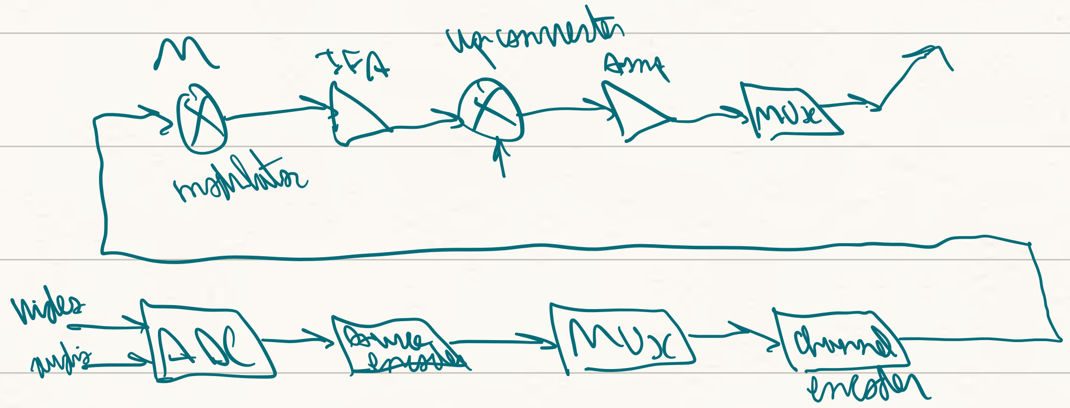
$\rightarrow \left(\frac{C}{N}\right)_{rain} = 8.51\ dB$

7) $P_r = 1 \cdot 10^{-} \quad = 0.199\ pW$

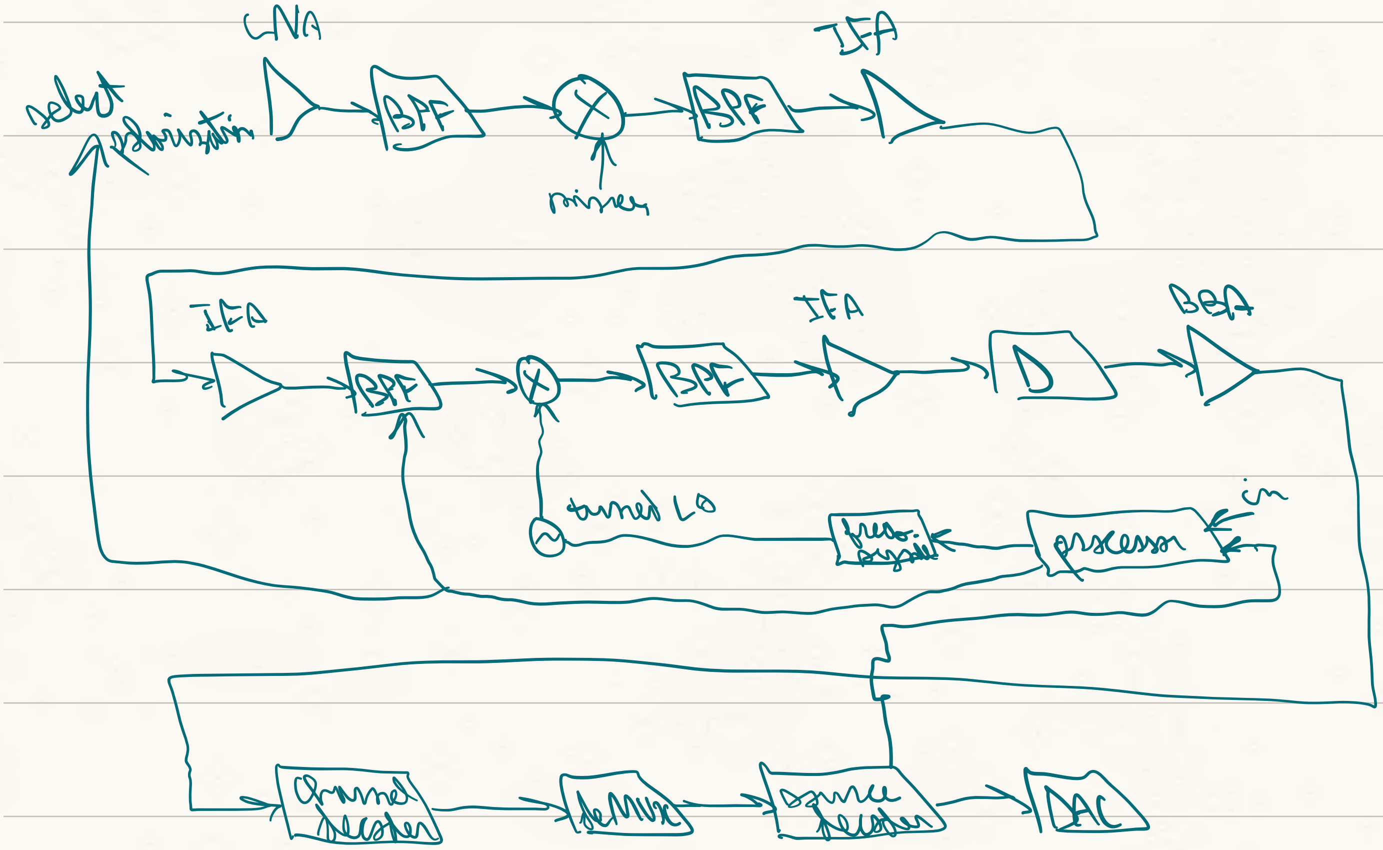
$\therefore P_r = P_t + G_t + G_r - L_p - 1.5 - 0.5 - 2$

$\rightarrow P_t = 8.19\ dBW$

DBS - uplink:



DBS downlink:



6/2022:

Q1:

a) uplink: $L_p = 163.64$

$P_r = P_t + 23 - L_p - 3 - 0.5$

$\to \left(\frac{C}{N}\right)_u = -147.15 - 10\log(kT_0B_n) = 19.87$ dB

downlink: $L_p = 180.5$

$P_r = 10 - 3 + 3 + 53.5 - L_p - 3 - 1 = -121$ dBW

$\to \left(\frac{C}{N}\right)_d = 49.33$ dB

$\therefore \left(\frac{C}{N}\right)_o = 19.863$ dB

Q2: a) power efficient : FM and MFSK

bandwidth efficient : MASK, QAM, MPSK

Chapter 4

example 9 :

$\because \left(\frac{C}{N}\right)_u = 30$ dB $\rightarrow C_u = -95.26$ dBW

$\because P_r = P_t + G_t + G_r - L_p - L_{ant} - L_r - L_m$

$\rightarrow P_t = 28.24$ dBW $= 666$ W

for $\left(\frac{C}{N}\right)_o = 17$ dB $\rightarrow \left(\frac{C}{N}\right)_d = 17.22$ dB

$\rightarrow P_r = -113.57$ dBW

$\rightarrow G_r = 46.5$ dB

including rain :

- uplink : omit ΔN, deduct attenuation from both $\left(\frac{C}{N}\right)_u$ and $\left(\frac{C}{N}\right)_d$
- downlink : std.

example 10 :

inbound :

uplink : $\frac{C}{N} = 17.65$ dB

downlink: $L_p = 180.5$ → $\frac{C}{N} = 32.34$ dB

∴ $\left(\frac{C}{N}\right)_0 = 17.6$ dB

- need to divide by number of terminals for power received from 1 device