Unit-IV Satellite Link Design

- The cost to build and launch a GEO satellite is about $25,000 per kg.
  - Satellite cost is recovered by selling comm b/ws for the designed lifetime.
- Max. aperture diameter of the satellite is 3.5m
- The weight of a satellite is driven by two factors:
  ① the no. and o/p power of transponders, and
  ② weight of station-keeping fuel.
- Three other factors influence system design:
  ① The choice of frequency band
  ② Atmospheric propagation effects, and
  ③ Multiple access techniques.
- The major frequency bands are:
  1. 6/4 GHz – C band
  2. 14/11 GHz – Ku band
  3. 30/20 GHz – Ka band
- A satellite using both 6/4 GHz and 14/11 GHz for every 2° spacing.
  - This satellite spacing is provided to avoid interference from uplink earth stations
- Significant rain attenuation above 10GHz.

$\boxed{\text{Rain attenuation (dB)} \propto f^2}$

- So, a satellite uplink at 30 GHz suffers four times as much attenuation as the uplink at 14GHz.

LEO and MEO satellites use multiple beam antennas to increase the gain of the satellite antenna beams and to provide frequency reuse.

Mobile Satellite terminals

- with low gain antennas at mobile unit at a low RF frequency.
- The link between a satellite and the major earth station (called a hub station) usually a different frequency band.

- Maritime Satellites
  - Using GEO satellite
  - with L-band links to mobiles, and
  - with C-band links to fixed hubstat
- All comm. links meet performance objectives:
  ① BER in a digital link or
  ② SNR in an analog link
- TV camera generates a baseband video sig
- and a TV receiver delivers a baseband video signal to the picture tube to for the images.
  - Digital data are generated by computer at baseband, and BER is measured at baseband.
- The baseband channel BER or S/N ratio is determined by CNR at the i/p to the demodulator in Rx
- In most satellite communications, the CNR at the demodulator input > 6dB
  - Digital links: CNR < 10dB must use error correction techniques to improve BER.
- In a noiseless Rx, the CNR is constant at all points in the RF and IF chain, so that CNR at demodulator = CNR at the Rx input.
- In a satellite link there are two signal paths: ① Uplink from earth station to satellite and ② down link from satellite to the earth sta
- over all CNR at station Rx depends on both links.
  - path loss / attenuation in earth's atmospher
  - Rain attenuation
  - CNR falls below threshold
- Ex: 30/20 GHz — lead to link outage.
- Down link parameters
- Uplink "

Lin. Rai.

- ~~Frequencies~~ ...

- Basic Transmission Theory (2)

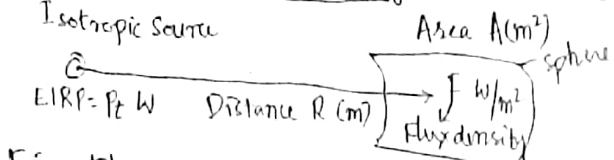


Fig. Flux produced by an isotropic source.

- Isotropic source: radiates uniformly in all directions.
  ↳ Could not create TEM waves.
- At a distance R meters from the hypothetical isotropic source transmitting RF power P_t (W), the flux density crossing the surface of the sphere with radius R given by

$$\boxed{F = \frac{P_t}{4\pi R^2} \; (W/m^2)} \longrightarrow (1)$$

- All real antennas are directional and radiate more power in some direction than in all directions.
- Any real antenna has a gain $G(\theta)$, defined as the ratio of power per unit solid angle radiated in a direction 'θ' to the average power radiated per unit solid angle.

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

where $P(\theta)$ = power radiated / unit Ω
P_0 = Total power radiated
$G(\theta)$ = gain of the antenna at an angle θ.

- The reference for 'θ' is in the direction, in which maximum power is radiated (boresite direction of the antenna).
- The gain of the antenna is the value $G(\theta)$ at angle $\theta = 0°$, and is measure of increase in flux density radiated by the antenna over that from an ideal isotropic antenna radiating the same total power.
- For a transmitter with output P_t (W) driving a lossless antenna with gain G_t, the flux density in the direction of the ... at distance R (m) is

$$\boxed{F = \frac{P_t G_t}{4\pi R^2} \; (W/m^2)} \longrightarrow (3)$$

Here $P_t G_t$ = EIRP = Effective isotropic radiated power

- If we had an ideal receiving antenna with an aperture area of A (m^2).

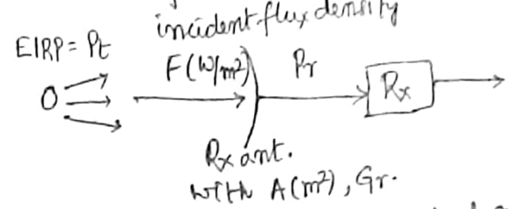


Fig. Power received by an ideal antenna with area A(m^2).

⇒ incident flux density $F = \frac{P_t G_t}{4\pi R^2} (W/m^2)$

R_x power $\boxed{P_r = F \times A = \frac{P_t G_t A}{4\pi R^2} \; (W).} \longrightarrow (4)$

- A practical antenna with a physical aperture area of A_r (m^2) will not deliver the power given by eq (4).
- Some of the energy incident on aperture is reflected away from the antenna and some is absorbed by lossy components.
- This reduction in efficiency is described by an effective aperture A_e, where

$$\boxed{A_e = \eta_A A_r} \longrightarrow (5)$$

where η_A = aperture efficiency of the antenna
- illumination efficiency or aperture taper efficiency of the antenna
- spill over loss
- blockage loss
- phase errors
- diffraction effects
- polarization loss
- Mismatch loss
- For paraboloidial reflector antennas η_A = 50 to 70%
- Lower for small antennas and higher for large Cassegrain antennas.
- Horn antennas: η_A = 90%.

Scanned by CamScanner

- Thus, power received by a real antenna with physical receiving area A_r and effective aperture area A_e (m^2) is

$$\boxed{P_r = \frac{P_t G_t A_e}{4\pi R^2} \ (W)} \longrightarrow (6)$$

- Eq (6) is independent of frequency
- The gain and area of an antenna are related by

$$\boxed{G_r = \frac{4\pi A_e}{\lambda^2}} \longrightarrow (7)$$

- where λ wavelength (m) at frequency of operation.
- By sustuting eq (7) in eq (6), we get

$$P_r = \frac{P_t G_t}{4\pi R^2} \cdot \frac{G_r \lambda^2}{4\pi}$$

$$\boxed{P_r = \frac{P_t G_t G_r}{(4\pi R/\lambda)^2} \ (W)} \longrightarrow (8)$$

- Eq. (8) is known as link equation.
- The term $\left(\frac{4\pi R}{\lambda}\right)^2 = L_p =$ Path loss

$$\therefore \boxed{\text{Power received} = \frac{\text{EIRP} \times \text{Rx ant. gain}}{\text{path loss}} \ (W)} \rightarrow (9)$$

- In decibel terms,

$$\boxed{P_r = EIRP + G_r - L_p \ (dBW)} \rightarrow (10)$$

where $EIRP = 10\log_{10}(P_t G_t)$ dBW

$G_r = 10\log_{10}(4\pi A_e/\lambda^2)$ dB

Path loss $L_p = 10\log_{10}\left(\frac{4\pi R}{\lambda}\right)^2 = 20\log_{10}\left(\frac{4\pi R}{\lambda}\right)$ dB.

Losses in atmosphere: due to attenuation by oxygen, water vapor and rain

Losses in the antenna and reduction in

- All these losses are taken into account by the system margin.
- In more general, eq (10) can be modif as:

$$\boxed{P_r = EIRP + G_r - L_p - L_a - L_{ta} - L_{ra} \ (dBW)}$$

where L_a = attenuation in atmosphere

L_{ta} = Losses associated with Tx anten

L_{ra} = " " " Rx anten

1W ⟶ 0dBW

Ex: $G_r = 4$dB at 4GHz ⟹ $\boxed{G_r(6\text{GHz}) = G_r(4\ldots}$

~~$G_r(6GHz) = 4(6/4)^2$ dB = 36dB~~

G_r (6GHz) $= 20\log(6/4) = 20\log(3) - 20\log(2)$

$= 9.5 - 6 = 3.5$dB

- Thus $G_r(6GHz) = G_r(4GHz) + 3.5$dB

$$\boxed{G_r(6GHz) = 48 + 3.5dB = 51.3dB}$$

Ex: 4.2.1; pp: 104
Ex: 4.2.2; pp: 104

NOTE: The Rx Power P_r calculated by eq (6) and eq (8) is commonly referred to as carrier power C.

- Most satellites uses:
  - FM — for analog Txs.
  - PSK/QPSK/8PSK — for Digital Txs.
- In both of these modulations, the amplitude of the carrier not changed, as data are modulated onto the carrier, so received carrier power C is always equal to the received power P_r.

$$\boxed{C = P_r}$$

~~104, 407,~~ 413, 19, 22, ~~27, 28, 29~~, 30, 31, ~~32~~, 35, 38, 40, 41, 43, 45, ~~46, 48, 50~~, 1 – ~~407, 408~~ 4191

~~04-02-2011, Sat, 2nd period~~

System Noise Temperature

- Noise temperature provides a way of determining how much thermal noise is generated by active and passive devices in the receiving system.
- At MW frequencies, a black body at T_p °K, generates electrical noise over a wide bandwidth.
  - The noise power is given by

$$\boxed{P_n = kT_p B_n \ (W)} \rightarrow (12)$$

where k = Boltzmann's constant
$= 1.39 \times 10^{-23}$ J/K = −228.6 dBW/K/Hz
T_p = Physical temperature of source (°K)
B_n = Noise BW (Hz) = 3dB BW of Rx

- P_n is delivered to load, that is impedance matched to the noise power.
  kT_p = Noise power spectral density (W/Hz)
- The density is constant for all radio frequencies up to 300 GHz.
- ~~Bn~~ ~~Noi~~. Noise temperatures from 30K to 200K without physical cooling, if GaAs FET amplifiers are employed.
- GaAs FET Amplifiers can be built to operate at room temp. with noise temperatures of 30K at 4GHz and 100K at 11GHz.
- Typically, $\boxed{T_p \propto f}$

System Noise temperature (t_s): is the noise temperature of a noise source, located at the i/p of noiseless Rx, which gives the same noise power as the original Rx, measured at the o/p of the Rx and usually includes noise from the antenna.

- If the overall end to end gain of the receiver G_{rx} (ratio; not dB) and its narrowest BW = B_n(Hz), the noise power at the demodulator i/p is:

$$P_{no} = kT_s B_n G_{rx} \ (W) \rightarrow (13)$$

where G_{rx} is the gain of the Rx from RF input to demodulator input.

- The noise power referred to the input of the Rx is P_n where

$$\boxed{P_n = kT_s B_n \ (W)}$$

- Let the antenna deliver a signal power P_r (W) to the receiver RF i/p.
  - The signal power at the demodulator input is $P_r G_{rx}$ $(=C)$ (W) → representing the power contained in the carrier and sidebands after amplification and frequency conversion within the Rx.
  - Hence, the carrier-to-noise ratio at the demodulator is given by

$$\boxed{\frac{C}{N} = \frac{c}{P_{no}} = \frac{P_r G_{rx}}{kT_s B_n G_{rx}} = \frac{P_r}{kT_s B_n}} \rightarrow (14)$$

i.e, the gain of the Rx cancels out.

~~So~~

Calculation of System noise temperature

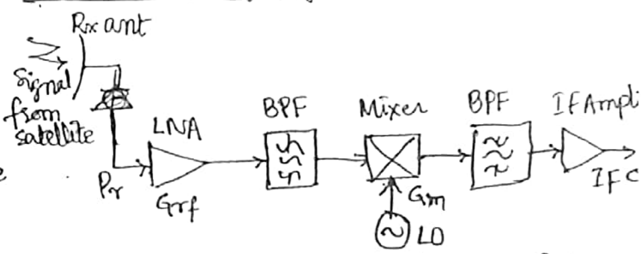


Fig. simplified earth station Rx, BPF.

- Fig. above shows simplified communications receiver with an RF amplifier and single frequency conversion, from its RF input to the IF o/p.
- This Rx is known as superhet (super heterodyne).
- This superhet has 3 main subsystems
  1. a front end (RF amp., mixer and LO)
  2. an IF amplifier (IF amp., and Filters).
  3. a demodulator and baseband section
- The RF amp. must generate as little noise as possible, so it is called Low Noise Amplifier (LNA)

... from a frequency

- The RF signal to a fixed inter- (5)
mediate frequency (IF), where the signal can be amplified and filtered accurately.

— Narrow BPF $\Rightarrow \frac{BW}{f_c} \times 100 < 1\%$

Ex: 10MHz BPF at 11GHz $\Rightarrow \frac{10\times10^6}{11\times10^9} \times 100 = 0.1\%$ of RF

- After down conversion to

10MHz BPF at 1GHz $\Rightarrow \frac{10\times10^6}{1\times10^9} \times 100 = 1\%$ of IF freq.

- This is the advantage of superhet Rx design: Very accurate filters can be used by converting the signal to a convenient $= f_{IF}$ frequency.

$f_{LO} + f_{RF}$ and $(f_{LO} - f_{RF})$

- AM Superhet

$\boxed{f_{IF} = f_{LO} - f_{RF}}$

Here, $f_{LO} > f_{RF}$ → Super (Up side injection)

$f_{si} = |f_{LO} \pm f_{IF}|$

$= f_{LO} + f_{IF}$

$= (f_{RF} + f_{IF}) + f_{IF}$

$\boxed{f_{si} = f_{RF} + 2f_{IF}}$

FM/RF Superhet

$\boxed{f_{IF} = f_{RF} - f_{LO}}$

Here $f_{LO} < f_{RF}$ (Low side injection)

$f_{si} = |f_{RF} \pm f_{IF}|$

$= f_{RF} + f_{IF}$

$= (f_{IF} + f_{LO}) + f_{IF}$

$\boxed{f_{si} = 2f_{IF} + f_{LO}}$

- This image freq. is blocked by RF amplifier's BPF.

- In many VSATs, the LNA, LO and First IF Amp. and filters all are included in a single package called a Low Noise block Converter (LNB) located immediately behind the antenna feed.

Double superhet

- Many earth station receivers use the double superhet configuration as shown in Fig. below, which has two stages of frequency conversion.

- The front end of the receiver is mounted behind the antenna feed and converts the incoming RF signals to the first IF in the range 900 to 1400MHz (BW=500MHz).

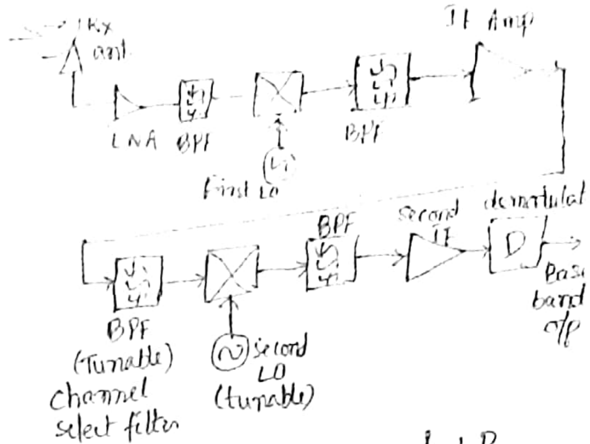


Fig. Double Conversion Superhet Rx

- High gain RF amp. + Mixer + IF ampli. = LNB (Low noise block converter).

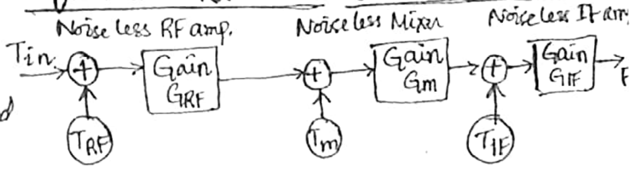
- The 900-1400MHz signal is sent over a coaxial cable to a set top Box (STB) Rx that contains another down converter and a tunable local oscillator.

- The LO is tuned to convert the incoming signal from a selected transponder to a second IF frequency.

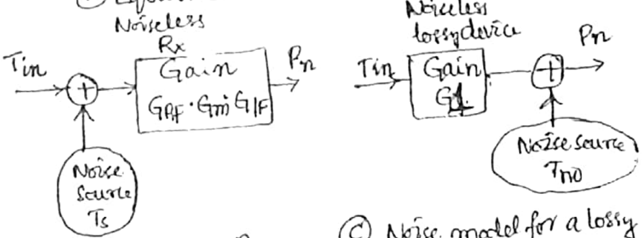
- The second IF amplifier has a BW matched to the spectrum of the transponder signal.

- Direct broadcast satellite TV receivers at Ku band use this approach, with a second IF filter BW = 20MHz

Equivalent Rx circuit for noise analysis



(a) Equivalent Noise sources



(b) Equivalent Rx

(c) Noise model for a lossy device.

- The noisy devices in the Rx are replaced by equivalent noiseless blocks with same gain and noise generators at the inputs to each

- Then the entire Rx is reduced to a single equivalent noiseless block with the same end-to-end gain as the actual receiver and a single noise source at its input with temperature T_n.
- The total noise power at the o/p of the IF amplifier of the Rx in Fig(a) is given by

$$P_n = G_{IF}\, kT_{IF} B_n + G_{IF} G_m kT_m B_n + G_{IF} G_m G_{RF}\, kB_n (T_{RF} + T_{in}) \rightarrow (15)$$

where G_{RF}, G_m and G_{IF} are the gains of the RF amplifier, mixer and IF amplifier, and T_{RF}, T_m and T_{IF} are their equivalent noise temperatures.

T_{in} is noise temperature of the antenna measured at its output port.

- Eq (15) can be rewritten as

$$P_n = G_{IF} \cdot G_m G_{RF} \left[\frac{(kT_{IF} B_n)}{G_{RF} \cdot G_m} + \frac{(kT_m B_n)}{G_{RF}} + (T_{RF} + T_{in}) \right]$$

$$\boxed{P_n = G_{IF} \cdot G_m \cdot G_{RF}\, kB_n \left[T_{RF} + T_{in} + \frac{T_m}{G_{RF}} + \frac{T_{IF}}{G_{RF} G_m} \right]} \rightarrow (16)$$

- The single source of noise shown in Fig(b) with noise temperature T_s generates the same noise power P_n at its output, if

$$\boxed{P_n = G_{IF} G_m G_{RF}\, kT_s B_n} \rightarrow (17)$$

- The noise power at the o/p of the noise model in Fig. (b) will be the same as the noise power at the o/p of the noise model in Fig. (a), if

$$kT_s B_n = kB_n \left[(T_{in} + T_{RF} + \frac{T_m}{G_{IF}} + \frac{T_{IF}}{G_m G_{RF}}) \right]$$

- Hence the equivalent noise source in Fig (b) has a system noise temperature T_s
- where

$$\boxed{T_s = \left[T_{in} + T_{RF} + \frac{T_m}{G_{RF}} + \frac{T_{IF}}{G_m G_{RF}} \right]} \rightarrow (18)$$

- Succeeding stages of the receiver contributes [illegible] noise

(6) • Frequently, when RF AMP in the Rx front end has a high gain, the noise contributed by the IF amplifier and later stages can be ignored and the system noise temperature is simply the sum of the antenna noise temperature and the LNA noise temperature, so

$$\boxed{T_s = T_{antenna} + T_{LNA}}$$

NOTE: In Eq (18) gains are linear ratios, not in dB

Fig. (c): In some circumstances, we need to use a different model to deal with noise that reaches the Rx after passing through a lossy medium.

Ex: Waveguide and rain losses

- when rain drops cause attenuation, they radiate additional noise whose level depends on the amount of attenuation.

- we can model the noise emission as a noise source placed at the "output" of the atmosphere, which is antenna aperture
- The noise model for an equivalent output noise source is shown in Fig (c) and produces a noise temperature T_{no} given by

$$\boxed{T_{no} = T_p (1 - G_1)} \rightarrow (19)$$

where G_1 is the linear gain (less than unity, not in dB) of the attenuating device or medium, and

T_p = Physical temperature in °K of the device or medium.

- For an antenna of A dB, the value of G_1 is given by

$$\boxed{G_1 = 10^{A/10}} \rightarrow (20)$$

Ex: 4.3.1; pp: 110
Ex: 4.3.2; pp: 110

NOTE: when system noise temperature is low each 0.1 dB of attenuation ahead of RF AMP [illegible] 6.6K to the system [illegible]

NOTE 2: This is the reason for placing (7) the front end of the receiver at the output of the antenna feed.

NOTE 3: Waveguide losses ahead of the LNA can have a disastrous effect on the system noise temperature of low noise Rx systems.

Noise Figure and Noise temperature

NF is used to specify the noise generated within a device.

• NF is defined as

$$\boxed{NF = \frac{(S/N)_{in}}{(S/N)_{out}}} \rightarrow (21)$$

~~Because~~ The relation between noise figure and noise temperature T_d is

$$\boxed{T_d = T_0(NF-1)} \rightarrow (22)$$

where NF = linear ratio, not in dB here in eq (22)

T_0 = Reference temp = 290 K

NF also given in dB.

Ex: 4.3.3 ; pp: 112

G/T Ratio for Earth stations

The link equation [eq (8)] in terms of C/N at the earth station [using eq (4)]

$$\frac{C}{N} = \left[\frac{P_t G_t G_r}{KT_s B_n}\right]\cdot\left[\frac{\lambda}{4\pi R}\right]^2 = \left[\frac{P_t G_t}{kB_n}\right]\cdot\left[\frac{\lambda}{4\pi R}\right]^2\left[\frac{G_r}{T_s}\right] \rightarrow (23)$$

• Thus, $\boxed{\frac{C}{N} \propto \frac{G_r}{T_s}}$, and the terms in the brackets are all constants for a given satellite system.

The ratio $\frac{G_r}{T_s}$ quoted as simply $\frac{G}{T}$ (in dB)

• with units dB/K

— Can be used to specify the quality of a receiving earth station or a satellite receiving system, since increasing $\frac{G_r}{T_s}$ increases C/N ratio.

NOTE: Satellite terminals having negative G/T (which is below ... dB/K) This simply

[Ex: 4.3.4 ; pp: 112]

Satellite System Link Models

(Advanced Electronic Comm systems - 6/e, - Wayne Tomasi)

• Essentially, a satellite system consists of three basic sections:

1. An uplink,
2. A satellite transponder and
3. A down link

1. Uplink Model

• The primary component within the uplink section of a satellite system is the earth station transmitter.

• A typical earth station transmitter consists of an IF modulator, an IF to RF MW-converter, a HPA and BPFs.

• Fig. below shows the block diagram of a satellite earth station transmitter.

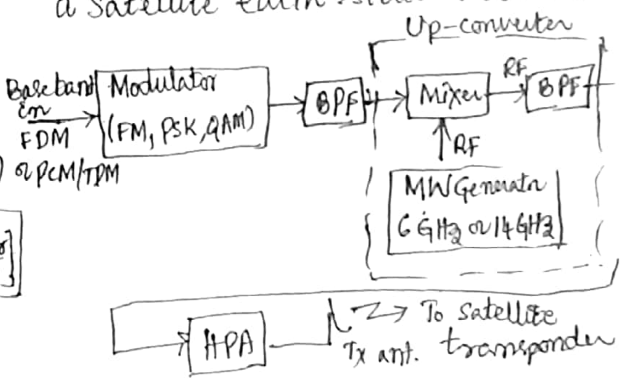


Fig. Satellite uplink Model

• The IF modulator converts the input baseband signals to either an FM, a PSK, or a QAM-modulated IF.

• The upconverter (mixer + BPF) converts the IF to an appropriate RF carrier frequency.

• The HPA provides adequate gain and

- Commonly used HPAs are klystrons and travelling wave tubes (TWTA).

(2) Transponder

- A typical satellite transponder consists of an i/p BPF, an i/p LNA, a frequency translator, a low-level power amplifier and an o/p BPF.
- Fig. below shows a simplified block diagram of a satellite transponder
- This transponder is an RF to RF repeater.

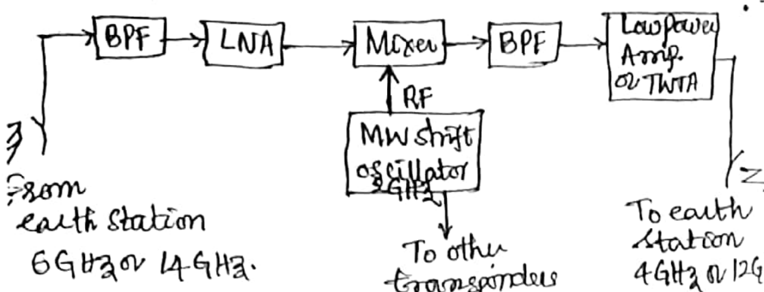


Fig. Satellite transponder.

- The input to BPFs limits the total noise applied to the i/p of the LNA (tunnel diode).
- The o/p of LNA is fed to a frequency translator (a shift oscillator + BPF), which converts the high band uplink frequency to the low-band down link frequency.
- The low-level power amplifier, which commonly a SSPA (solid state power Amp) or TWTA, amplifies RF signal for transmission through the down link to earth station receivers.
- Each RF satellite channel requires a seperate transponder.

3) Down Link Model

- An earth station receiver includes an i/p BPF, an LNA, and an RF to IF down converter.
- Fig. below shows a block diagram of a

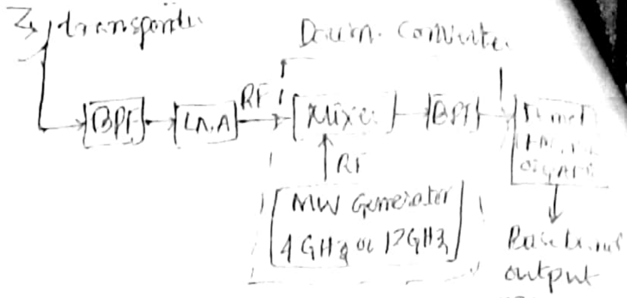


Fig. Satellite down link model

- The BPF limits the input noise power to the LNA.
- The LNA is a highly sensitive, low-noi device, such as a tunnel diode amplifier or parametric amplifier.
- The RF to IF down converter is a mixer/BPF combination that convert the received RF signal to the IF frequency.

(4) Cross links

- Occasionally, there is an application where it is necessary to communicate between satellites.
- This is done using satellite crosslinks or Intersatellite links (ISLs) as shown in Fig. below:

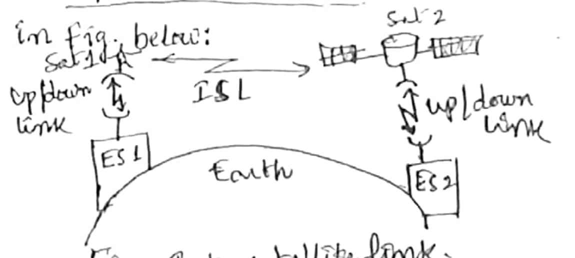


Fig. Intersatellite link.

- A disadvantage of using ISL is that both the transmitter and the receiver are space bound.
- Consequently, both transmitter's output power and the receiver's input sensitivity are limited.

Satellite System Parameters

1. Back-off Loss

- HPA used in the earth station transmitters and TWTA used in satellite transponders are non-linear devices; their gain (o/p power vs i/p power) is dependent on input signal level.
- A typical input/output power characteristic curve is shown Fig. below:

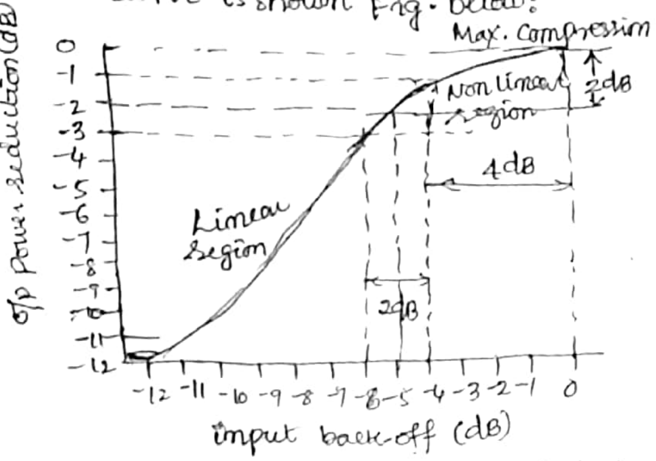


Fig. HPA input/output characteristics

- It can be seen that as the input power is reduced by 4dB, the output power is reduced by 1dB.
- There is an obvious power compression.
- To reduce the amount of intermodulation distortion caused by the non linear amplification of the HPA, the input power must be reduced (backed off) by several dB.
- This allows the HPA to operate in a more linear region.
- The amount of the o/p level is backed off from rated levels is equivalent to a loss and appropriately called back off loss (L_{bo}).

2. Transmitted power and Bit energy

- In satellite systems P_t is the transmitted power in dBW (dB in respect to 1W) rather ...

(4)

- Most modern satellite systems use either PSK or QAM rather than conventional FM.
- With PSK and QAM, the i/p baseband is generally a PCM-encoded, time-division multiplexed signal that is digital in nature.
- Also, with PSK and QAM, several bits may be encoded in a single transmit signalling element.
- Consequently, a parameter more meaningful than carrier power is energy per bit (E_b).
- Mathematically E_b is

$$\boxed{E_b = P_t T_b}$$

where E_b = energy of a single bit (J/bit)
P_t = total tred power (W or J/s)
T_b = Time of a single bit (seconds)

- Because $T_b = \frac{1}{f_b}$, where f_b is the bit rate in bps.

$$\therefore \boxed{E_b = \frac{P_t}{f_b} = \frac{J/s}{b/s} = \frac{\text{Joules}}{\text{bit}}}$$

[Ex: 14.2 ; PP: 587, Wayne Tomasi]

3. Effective Isotropic Radiated Power

- EIRP is defined as an equivalent transmit power and is expressed mathematically as

$$\boxed{EIRP_{(W)} = P_{in} A_t}$$

where P_{in} = Antenna i/p power (W)
A_t = transmit antenna gain (ra...

(or) $\boxed{EIRP_{(dBW)} = P_{in}\,(dBW) + A_t\,(dB)}$

- With respect to transmitter output,

$P_{in} = P_t - L_{bo} - L_{bf}$

$\therefore \boxed{EIRP = P_t - L_{bo} - L_{bf} + A_t}$

Ex: 14-3; pp: 588; Wayne Tomasi)

4. Equivalent Noise ~~Pow~~ Temperature

In terrestial MW systems, the noise introduced in a receiver or a component within a Rx is commonly specified by Noise Figure (NF).

The total noise power is given by

$$\boxed{N = KTB \Rightarrow T = \frac{N}{KB}}$$

where N = Total noise power (W)
k = Boltzmann's constant (J/K)
B = BW (Hz)
T = Temp. of the environment (K)

The noise factor (unitless) is defined as $\boxed{F = 1 + \frac{T_e}{T}} \Rightarrow \boxed{T_e = T(F-1)}$

where T_e = equivalent noise temp (K)
T = Temp of the environment (K)

- Typically T_e = 1000K (Rx in transponder)
  T_e = 20K to 1000K (Earth station Rxs).
- In log (1K referenced to dBK):

$$\boxed{T_e\,(dBK) = 10 \log T_e}$$

Ex: T_e = 100K → T_e (dBK) = 10log100 = 20dBK

Table: Noise Unit comparison

~~NF~~ Noise factor (F) (unitless)	Noise Figure (NF) (dB)	Te	Te (dBK)
1.2	0.79	60	17.78
1.3	1.14	90	19.54
1.4~~2~~	1.46	120	20.79
2.5	4	450	26.53
10	10	2700	34.31

Ex: 14-4; pp: 589, Wayne Tomasi

5. Noise density

- Noise density (N_0) is the noise power normalized to a 1-Hz BW. (OR) ... in a 1 Hz BW.

- The noise density is given by

$$\boxed{N_0 = \frac{N}{B} = \frac{KT_eB}{B} = KT_e}$$

Where N_0 = noise density (W/Hz)

$$1\,W/Hz = \frac{1\,J/sec}{1\,cycle/sec} = \frac{1\,Joule}{cycle}$$

N = total noise power (W)
B = BW (Hz)
K = Boltzmann's constant (J/K)
T_e = Equivalent noise temp. (K)

- Expressed in log:

$$\boxed{\begin{aligned} N_0\,(dBW/Hz) &= 10 \log N - 10 \log B \\ &= 10 \log K + 10 \log T_e \end{aligned}}$$

Ex: 14.5; pp: 590; Wayne Thomasi

6. Carrier-to Noise Density Ratio

- C/N_0 is the average wideband carrier power-to-noise density ratio.
- The wideband carrier power is the combined power of the carrier and its associated sidebands.
- The noise density is the thermal noise present in a normalized 1Hz BW.
- The carrier-to noise density ratio may also be written as a function of noise temperature.
- Mathematically,

$$\boxed{\frac{C}{N_0} = \frac{C}{KT_e} \text{ or } \frac{C}{N_0}(dB) = C\,(dBW) - N_0\,(dBW)}$$

7. Energy of bit to Noise Density Ratio

$$\frac{E_b}{N_0} = \frac{C/f_b}{N/B} = \frac{CB}{N f_b}$$

(or) $$\frac{E_b}{N_0} = \frac{C}{N} \times \frac{B}{f_b}$$

(or) $$\frac{E_b}{N_0}(dB) = \frac{C}{N}(dB) + \frac{B}{f_b}(dB)$$

Ex: 14.6; pp: 591 and Ex: 14.7; pp: 594 Wayne Tomasi

8. Gain to Equivalent Noise temperature Ratio (G/T_e).

- G/T_e → figure of merit used to represent the quality of a satellite or earth station Rx.

$$\boxed{\frac{G}{T_e} = G - 10\log T_s}$$

where G = Rx ant. gain (dB)

T_s = operating or System Temp (K)

and $T_s = T_a + T_r$

where T_a = Antenna Temp (K)

T_r = Rx effective i/p noise temp (K)

Satellite System Link Equations

- The error performance of a digital System is quite predictable.
- Fig. below shows a simplified block diagram of a digital satellite system and identifies the various gains and losses that may affect the system performance.

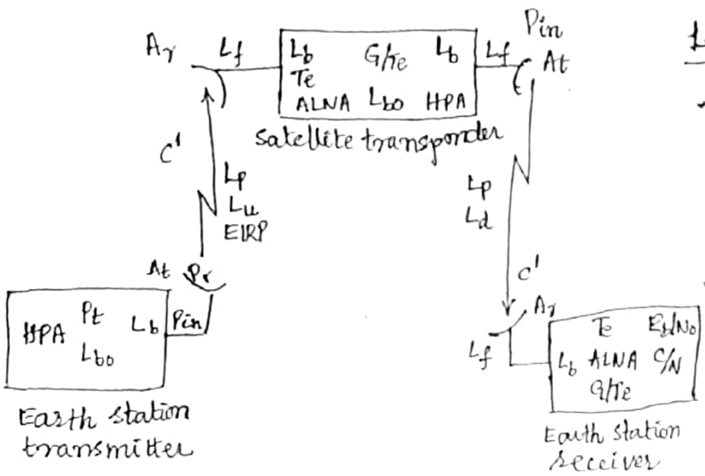


Fig. overall satellite system showing the gains and losses incurred in both the uplink and down link sections.

where: HPA : high-power amplifier

P_t : HPA o/p power

L_{bo} : Back off loss

L_f = feeder loss

P_r = Total radiated power $= P_t - L_{bo} - L_b - L_f$

EIRP = $P_{rad} \cdot A_t$;

L_u : additional uplink loss

G/T_e : Gain to equivalent noise temp ratio

L_d : Additional down link loss due to atmosphere

LNA : low noise amplifier

C/T_e : carrier to equivalent noise ratio

C/N_0 : carrier to noise density ratio

E_b/N_0 : Energy of bit to noise density ratio;

C/N : carrier to noise ratio

- When evaluating the performance of a digital satellite system, the uplink and down link parameters are first considered separately, then the overall performance is determined by combining them in appropriate manner.
- In digital satellite radio, the original demodulated baseband signals are digital in nature.
- The RF section of the radio is analog: that is FSK, PSK, QAM or some other higher level modulation riding on a analog MW carrier.

Link Equations

- The following link equations are used separately analyze the uplink and down link sections of a single RF carrier satellite system.
- These equations consider only the ideal gains and losses and effects of thermal noise associated with the earth station transmitter, earth station receiver and the satellite transponder.

Uplink Equation

$$\frac{C}{N_0} = \frac{A_t P_{in} (L_p L_u) A_r}{K T_e} = \frac{A_t P_{in} (L_p L_u)}{K} \times \frac{G}{T_e} \quad (1)$$

where L_d and L_u are the additional uplink and downlink atmospheric losses, respectively.

- The uplink and downlink signals must pass through Earth's atmosphere, where

- Depending on the elevation angle, the distance of the RF signal travels through the atmosphere varies from one earth station to another. (12)
- Because L_p, L_u and L_p represent losses, they are decimal values less than 1.
- G/T_e is the receive antenna gain plus gain of the LNA divided by the equivalent input noise temperature.
- By expressing in Decibels:

$$\frac{C}{N_0} = \underbrace{10\log A_t P_{in}}_{\text{EIRP earth station}} - \underbrace{20\log\left(\frac{4\pi D}{\lambda}\right)}_{\text{free space path loss } L_p} + \underbrace{10\log\left(\frac{G}{T_e}\right)}_{\text{satellite } G/T_e}$$

$$- \underbrace{10\log L_u}_{\text{Additional atmospheric Losses}} - \underbrace{10\log K}_{\text{Boltzmann's constant}}$$

→ (2)

$$\boxed{\frac{C}{N_0} = EIRP\,(dBW) - L_p\,(dB) + \frac{G}{T_e}\,(dB/K) - L_u\,(dB) - K\,(dBW/K)}$$

Down Link equation

→ (3)

$$\frac{C}{N_0} = \frac{A_t P_{in}(L_p L_d) A_r}{K T_e} = \frac{A_t P_{in}(L_p L_d)}{K} \times \frac{G}{T_e}$$

Expressed as a log,

$$\frac{C}{N_0} = \underbrace{10\log A_t P_{in}}_{\text{EIRP satellite}} - \underbrace{20\log\left(\frac{4\pi D}{\lambda}\right)}_{\text{free space path loss } L_p} + \underbrace{10\log\left(\frac{G}{T_e}\right)}_{\text{Earth station } G/T_e}$$

$$- \underbrace{10\log L_d}_{\text{Additional atmospheric losses}} - \underbrace{10\log K}_{\text{Boltzmann's constant}}$$

→ (4)

$$\boxed{\frac{C}{N_0} = EIRP\,(dBW) - L_p\,(dB) + \frac{G}{T_e}\,(dB/K) - L_d\,(dB) - K\,(dBW/K)}$$

Link Budget

$\boxed{\text{pp: 596 to 603; Wayne Tomasi; Xerox}}$

SEC 4-7

How the system noise temperature and $(C/N)_{dn}$ are determined & when rain attenuation is present?

- The total path attenuation A (dB) is the sum of the clear sky path attenuation due to atmospheric gaseous absorption (A_{ca}) and attenuation due to rain (A_{rain})

$$\therefore \boxed{A\ (dB) = A_{ca} + A_{rain}}\ dB \rightarrow (1)$$

- The sky noise temperature resulting from path attenuation A_{total} (dB) is given by

$$\boxed{T_{sky} = 270 \times (1 - 10^{-\frac{A}{10}})}\ K \rightarrow (2)$$

Note: Here rain temperature is assumed as 270 K.

- The antenna noise temperature may be assumed to be equal to the sky noise temperature.
  - But in practice not all of the incident noise energy from the sky is output by the antenna, and a coupling coefficient, η_c of 90 to 95% is often used when calculating antenna noise temperature in rain.
- Thus antenna noise temperature may be calculated as

$$\boxed{T_A = \eta_c \times T_{sky}}\ K \rightarrow (3)$$

- Almost all satellite receivers use a high gain LNA as the first element in the Rx frontend. This makes the contribution of all later parts of the receiver to the system noise temperature negligible. Then system noise temperature

- The increase in noise power ΔN_{rain} (dB), caused by the increase in sky noise temperature is given by

$$\Delta N_{rain} = 10 \log_{10}\left[\frac{K T_{s,rain} B_n}{K T_{sca} B_n}\right]$$

$$\therefore \boxed{\Delta N_{rain} = 10 \log_{10}\left[\frac{T_{srain}}{T_{sca}}\right]}\ dB \rightarrow (4)$$

where T_{sca} is the system noise temperature in clear sky conditions.

- The received power is reduced by the attenuation caused by the rain in the slant path, so in rain the value of carrier power is C_{rain} where

$$\boxed{C_{rain} = C_{ca} - A_{rain}}\ dB \rightarrow (6)$$

- The resulting $(C/N)_{dn\ rain}$ value when rain intersects the downlink is given by

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

where $(C/N)_{dn\ ca}$ is the downlink C/N ratio in clear sky conditions.

Ex: 4.5.1; pp: 123

Ex: 4.7.1; pp: 129

→ When more than one C/N ratio is present in the link, we can add the individual $\frac{C}{N}$ ratios reciprocally to obtain an over all $(C/N)_o$ ratio.

$$\text{i.e } \boxed{(C/N)_o = \frac{1}{\left[\frac{1}{(C/N_1)}\right] + \left[\frac{1}{(C/N_2)}\right] + \left[\frac{1}{(C/N_3)}\right] + \cdots}} \rightarrow (8)$$

↳ Reciprocal (C/N) formula

C/N values are linear ratios (not.

$$\left(\frac{C}{N}\right)_o = \frac{1}{\left[\frac{N_1}{c} + \frac{N_2}{c} + \frac{N_3}{c} + \cdots\right]}$$

$$\left(\frac{C}{N}\right)_o = \left[\frac{C}{(N_1 + N_2 + N_3 + \cdots)}\right] \rightarrow (9)$$

Satellite link Design: Tri T. Ha: pp: 178

From the design of a satellite link, it is seen that the establishment of carrier-to-noise plus interference ratio to meet specified performance criteria is a complex task.

- The performance criteria may vary with system and applications
- The system engineer must determine the earth station EIRP G/T (i.e the antenna gain and noise temperature, output power of HPA, and noise temperature of LNA) within specified cost constraints to achieve desired performance.
- If the type of modulation of carrier and type of multiple access are selected, the remaining factors that influence the link design are as follows.

1. Adjacent satellite interference that can be minimized only by using a low sidelobe antenna.
2. Terrestrial interference that can be minimized by site selection and earthstation shielding or by using a higher frequency band, say 14/12 GHz.
3. Cross-polarization interference caused by satellite and earthstation dual-polarization antennas that can be minimized by good antenna design.
4. Adjacent channel interference that can be minimized by operating the HPA with appropriate output back-off and with appropriate filtering by the satellite output multiplexer and the demodulator filter.
5. Intermodulation interference that can be minimized by appropriate transponder TWTA output back-off or by using a single carrier per transponder such as TDMA.
6. Intersymbol interference that can be minimized by minimized by appropriate selection of modulator and demodulator filters.
7. Rain-induced attenuation that can be minimized by operating the satellite TWTA at or close to
8. Rain-induced cross polarization interference that can be minimized by using orthogonal linear polarizations instead of orthogonal circular polarizations.
9. Antenna pointing loss that can be minimize by using an appropriate tracking system.

Link without Frequency Reuse

- This is a systematic approach to the design of a digital satellite link without frequency reuse to meet the performance criterion that the avg. probability of bit error exceed P_b for P% of the year at most.
- Consider a 14/12 GHz satellite link between station A—satellite (A uplink) and satellite—station B (B downlink). Such a link is called a simplex link.
- Two simplex links between A-satellite-B and B-satellite-A form a duplex link
- The total outage time for an A-satellite-B simplex link is approximately equal to sum of A-uplink outage and B-downlink outage
- The total outage time for A-satellite-B duplex link is approximately equal to sum of the A-uplink and downlink outages and B-uplink and downlink outages.
- The satellite link parameters are as follows.

Carrier modulation parameters.

Type of modulation: QPSK

Bit rate: 60 Mbps.

Bit duration-bandwidth product: 0.6

Noise bandwidth: 36 MHz

Satellite parameters:

Power flux density at satellite for transponder saturation: −81.5 dBW/m²

Antenna gain-to-noise temperature ratio: 3.1 dB/

Satellite saturation EIRP: 44.[illegible]

Clear-sky TWTA input back-off : 3dB

Clear-sky TWTA output back-off : 0.3dB

Uplink slant range : 38,371,506 km

Downlink slant range : 37,000 km

Antenna tracking and atmospheric losses: 1.5dB (uplink) and 1.2 dB (downlink)

Interference parameter.

Carrier-to-adjacent satellite interference ratio: 32dB (uplink) and 32dB (downlink)

Carrier-to-adjacent channel interference ratio: 29dB (uplink) and 29dB (downlink)

Margin for intersymbol interference : 3 dB

Link requirement : $P_b \geq 10^{-4}$ for $P\% = 0.15\%$ of the year at most.

1. **Allocation of outages**

- The first task should be the allocation of outages to the uplink and the downlink
- Since most satellites are downlink limited, one should allocate more outage on downlink than on the uplink.
- A 2:1 ratio would be a good start

2. **Sky noise temperature:**

- The down link rain attenuation increases the sky noise temperature by an amount equal to $\Delta T = 273\left[1 - \frac{1}{\log^{-1}[L_{r,d}(dB)/10]}\right]$

$$= 176K$$

- This adds to the system noise temperature of earth station B.

3. **Uplink C/N ratio with uplink rain only**

, This can be evaluated from

$$EIRP_{sat}(dBW) = \Omega_{sat}(dBW) + 10\log(4\pi d_u^2) + L(dB)$$

Thus $\left(\frac{C}{N}\right)_{u,r} = 19.5\,dB$

4. **Uplink $\left(\frac{C}{N}\right)$ plus interference ratio with uplink only**

- We assume that in the worst case, the rain does not occur at the interfering sources
- Therefore the uplink C/N ratio with rain attenuation of $L_{r,u} = 7.8dB$ at station A is

$$\left(\frac{C}{I}\right)_{u,r} = \left(\frac{C}{I}\right)_u - L_{r,u}$$

$$= 27.24 - 7.8 = 19.44\,dB$$

- Hence uplink C/N plus interference ratio with rain attenuation of $L_{r,u} = 7.8\,dB$ at station A is given by

$$\left(\frac{C}{N}\right)_{u,r} = \left[\left(\frac{C}{N}\right)_{u,r}^{-1} + \left(\frac{C}{I}\right)_{u,r}^{-1}\right]^{-1} = 16.46\,dB$$

5. **Downlink $\frac{C}{N}$ plus interference ratio with uplink rain only**

- The 10^{-4} threshold requires a link C/N plus interference ratio equal to 10.6dB
- A margin of 3dB is required for intersymbol interference; thus the total link C/N must be

$$\left(\frac{C}{N}\right) = 13.6\,dB$$

- This yields a downlink $\frac{C}{N}$ plus interference ratio.

$$\left(\frac{C}{N}\right)_d = \left[\left(\frac{C}{N}\right)^{-1} - \left(\frac{C}{N}\right)_{u,r}^{-1}\right]^{-1} = 16.77\,dB$$

- With an uplink attenuation of 7.8dB, the total TWTA input back-off is 10.8dB, which corresponds to output back off of 3.7dB.
- Thus an additional output back-off due to an uplink attenuation of 7.8dB is 3.4dB.
- Hence the downlink C/N ratio is

- Therefore the required downlink C/N ratio with uplink rain only is

$$\left(\frac{C}{N}\right)_d = \left[\left(\frac{C}{N}\right)_d^{-1} - \left(\frac{C}{I}\right)_d^{-1}\right] = 17.72\,dB$$

6- G/T with uplink rain only

- From the system gain-to-noise temperature $\frac{G}{T}$ is given by

$$\frac{G}{T} = 28.77\ dB/k$$

7. EIRP

- The uplink EIRP of earthstation A is

$$EIRP = EIRP_{sat} - BO_{I} = 82.5 - 3 = 79.5\,dBW$$

8. Uplink $\frac{C}{N}$ plus interference ratio with downlink rain only

$$\left(\frac{C}{N}\right)_u = \left(\frac{C}{N}\right)_{u,r} + 7.8$$

$$= 16.46 + 7.8 = 24.26\,dB$$

9. Downlink $\frac{C}{N}$ plus interference ratio with downlink rain only

- Since the required total link $C/N = 13.6\,dB$, the corresponding $(C/N)_{d,r}$ with $L_{r,d} = 4.5\,dB$ is

$$\left(\frac{C}{N}\right)_{d,r} = \left[\left(\frac{C}{N}\right)^{-1} - \left(\frac{C}{N}\right)_u^{-1}\right]^{-1} = 14\,dB$$

- When the rain occurs on the downlink only, the C/I ratio remains at clear sky value.

Thus $\left(\frac{C}{I}\right)_{d,r} = \left(\frac{C}{I}\right)_d = 27.24\,dB$

- Therefore, the downlink C/N ratio with a downlink rain attenuation of 4.5dB is

$$\left(\frac{C}{N}\right)_{d,r} = \left[\left(\frac{C}{N}\right)_{d,r}^{-1} - \left(\frac{C}{I}\right)_{d,r}^{-1}\right]^{-1}$$

10. $(G/T)_r$ with downlink rain only

- From the system gain-to-noise temperature $(G/T)_r$ with downlink rain only is $\frac{G}{(T+\Delta T)}$

$$\left(\frac{G}{T}\right)_r = 26.35\ dB/k$$

- By comparing $(G/T)_r$ to G/T with uplink rain only in (6) and using $\Delta T = 176K$ in (2), we have

$$10\log\frac{T+\Delta T}{T} = 2.42\,dB$$

- This yields the system's clear-sky noise temperature:

$$T = 236k.$$

11. Receive antenna gain

- Since $\frac{G}{T} = 28.77\,dB/k$ and $T = 236\,K$, the receive antenna gain is

$$G_r = 52.5\,dB$$

12. Transmit antenna gain

- Assume that the same apperture efficiency for both transmit and receive modes; then transmit antenna gain is.

$$G_t = G_r\left(\frac{f_u}{f_d}\right)^2 = 53.8\,dB$$

13. Antenna diameter

- Assume an aperture efficiency of 0.56, then antenna diameter is 4.5m

14. HPA o/p power

- The EIRP for the uplink is 79.5dBW as in (7)
- With a transmit antenna gain of 53.8 dB, the require power to antenna is 25.7 dBW or 371.5W.

- The rain depolarization effect at station B which is 20dB.
- The total $(C/I)_{d,r}$ is 19 dB.

$$\therefore \left(\frac{C}{N}\right)_{d,r} = \left[\left(\frac{C}{N}\right)^{-1}_{d,r} - \left(\frac{C}{I}\right)^{-1}_{d,r}\right]^{-1} = 15.8\text{dB}$$

10- $(G/T)_r$ with downlink rain only

- We have.

$$\left(\frac{C}{N}\right)_{d,r} = EIRP_{S,sat}(dBW) - 20\log\left(\frac{4\pi f_d d_d}{c}\right)$$

$$+ \frac{G}{T+273\{1-1/\log^{-1}[L_{r,d}(dB)/10]\}} (dB/k)$$

$$-10\log k - 10\log B - BO_o^*(dB) - L'(dB) - L_{r,d}(dB)$$

- The system gain-to-noise temperature ratio with $L_{r,d} = 4.5$dB is

$$\left(\frac{G}{T}\right)_r = 27.95\ dB/k.$$

- By comparing $(G/T)_r$ to $\frac{G}{T}$ with uplink rain only in 6 and using $\Delta T = 176k$ in 2, we have.

$$10\log\frac{T+\Delta T}{T} = 2.8\,dB$$

- This yields the systems clear-sky noise temperature:

$$T = 194.4\,k.$$

11. Receive antenna gain

- Since $\frac{G}{T} = 30.75\ dB/k$ and $T = 194.4\ k$, the receive antenna gain is $G_r = 53.64dB$.

12. Transmit antenna gain

- Assuming identical aperture efficiency for both the transmit and receive modes, we have.

$$G_t = 54.98\,dB$$

13. Antenna diameter

- Assume an aperture efficiency of 0.56, then antenna diameter is 5.1m

14. HPA output power

- The HPA o/p power is 303.4W, assuming a waveguide loss of 0.3dB.

15. Remarks:

- We have not included the effect of uplink cross polarization interference by rain at station A.
- In practice, one should avoid this situation by not allowing simultaneous traffic in two co-polarized transponder.