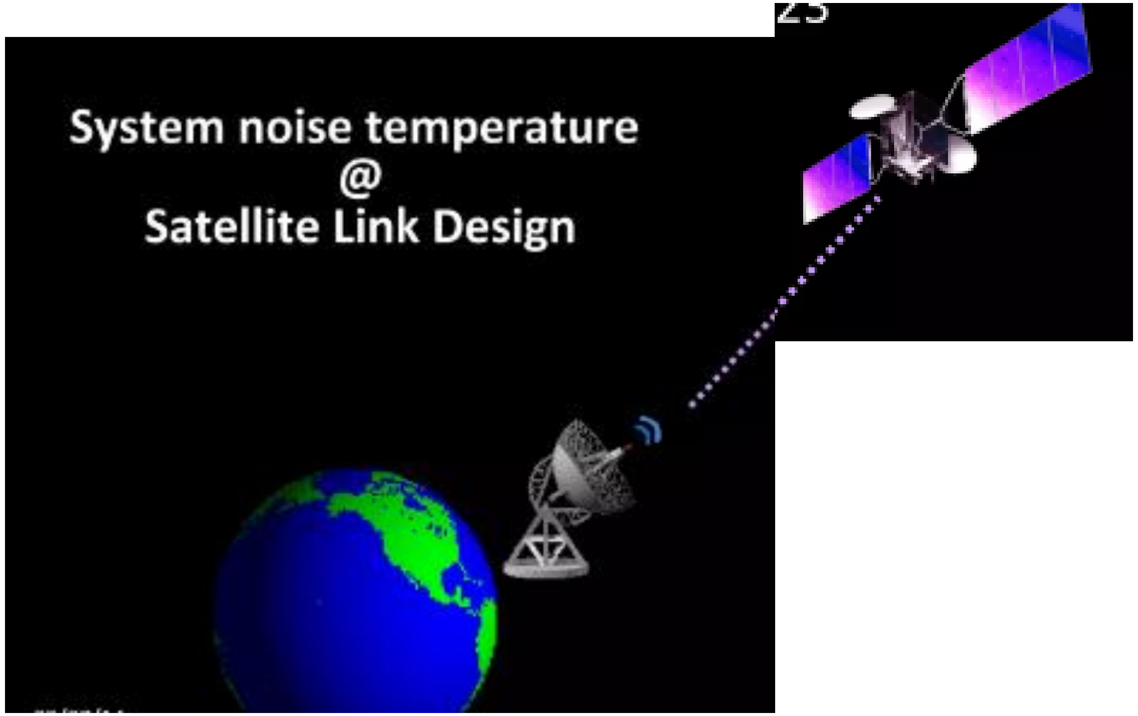
# System Noise Temperature



# Calculation of System Noise Temperature

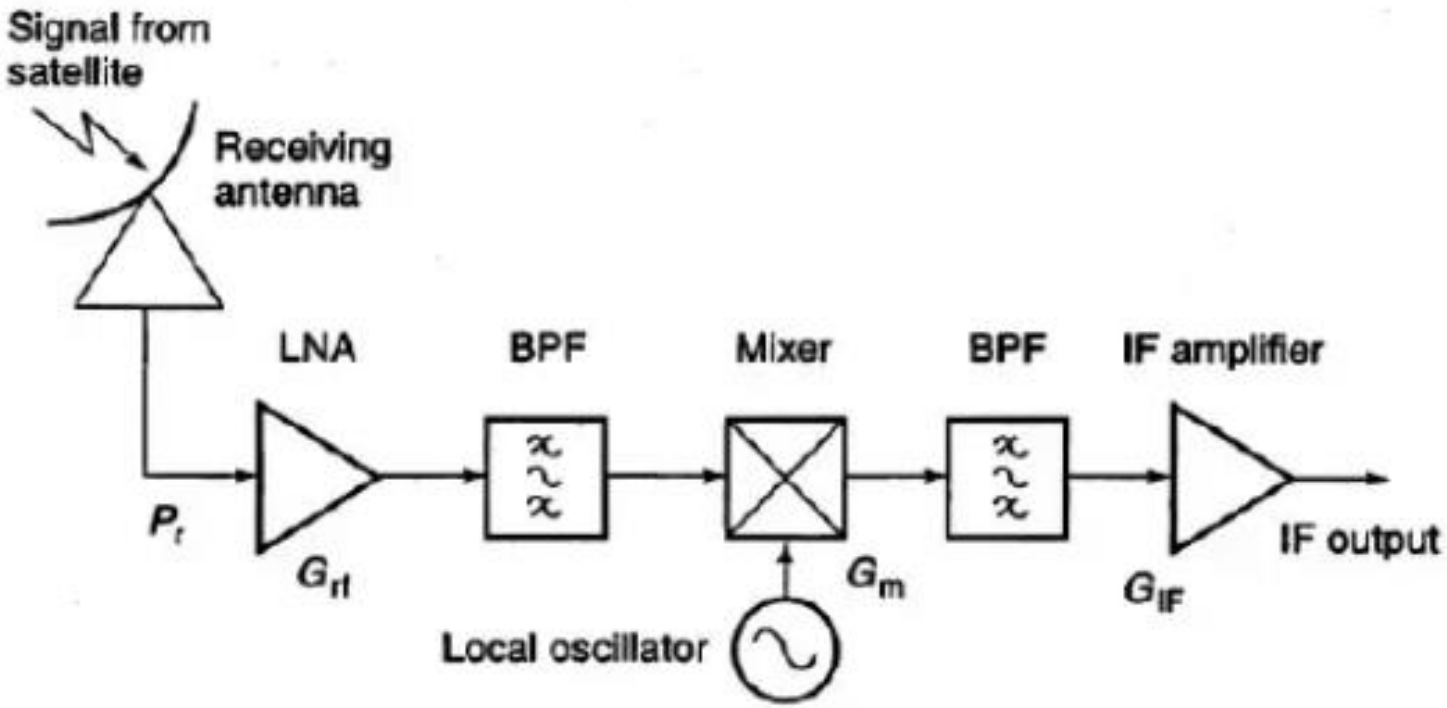
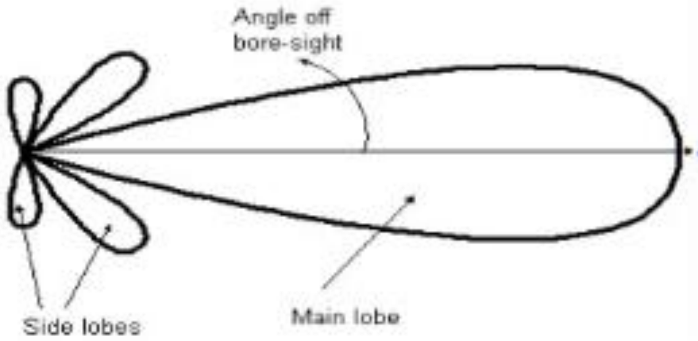
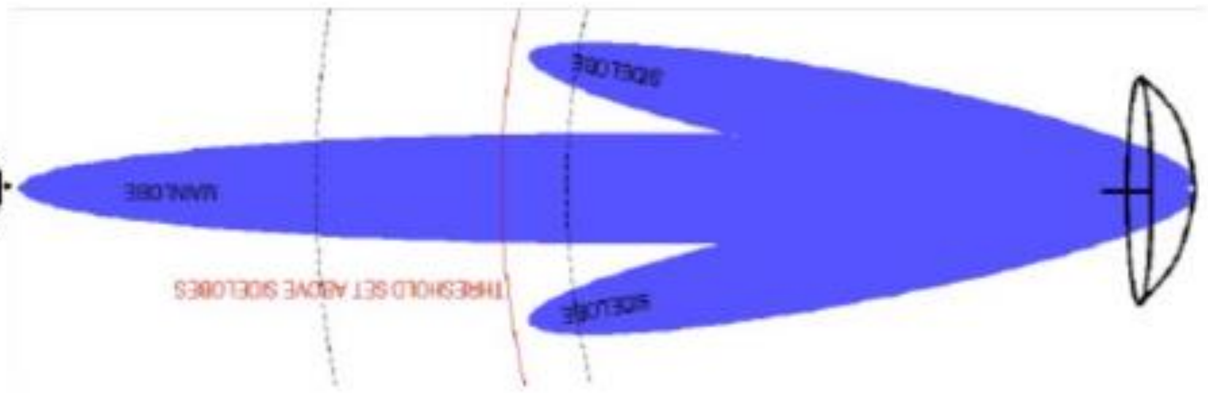



**FIGURE 4.5** Simplified earth station receiver. BPF, bandpass filter.


Angle off
bore-sight
Side lobes
Main lobe


SIDELOBE
MAINLOBE
THRESHOLD SET ABOVE SIDELOBES
SIDELOBE

# $T_S$ = System noise temperature

## Thinks to be noted

- Boltzmann constant = 1.39 x $10^{-23}$ J/K
- Boltzmann constant = - 228.6 dB W/K/Hz

Unit of System noise temperature Is Kelvins

# Noise temperature

Usually achieved without physical cooling .

{ 30 k – 200 k }

# Noise temperature

**Using Ga As FET ,**

{ 30 k – 4 GHz

100 k – 11 GHz

150 k – 20 GHz }

# NOISE POWER

NOISE POWER = Boltzmann constant x Tθ x BW

Where ,

Tθ = temperature

BW = band width

# Noise figure ( NF )

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

NF

$$NF = \frac{(S/N)\ I/P}{(S/N)\ O/P}$$

# G / T Ratio :

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

$\boxed{G / T}$

$$C/N = \frac{P_T\, G_T\, G_R}{K T_S\, B_N} \times \left[ \frac{\lambda}{4\,\pi R} \right]^2$$

# INFERENCE

$$C/N \;\alpha\; \frac{G}{T_S}$$

**NOTE :**

satellite terminals usually have - ve G / T

ie: the value is below 0 dB / K

# SYSTEM NOISE TEMPERATURE ,C/N AND G/T RATIO

- Thermal noise in its pre amplifier
- PN=KTsB
- SYSTEM NOISE TEMPERATURE IS ALSO CALLED EFFECTIVE INPUT NOISE TEMPERATURE OF THE RECEIVER.
- IT IS DEFINED AS THE NOISE TEMPERATURE OF A NOISE SOURCE LOCATED AT THE INPUT OF A NOISELESS RECEIVER WHICH WILL PRODUCE THE SAME CONTRIBUTION TO THE RECIEVER OUT PUT NOISE AS THE INTERNAL NOISE OF THE ACTUAL SYSTEM ITSELF

# SYSTEM NOISE TEMPERATURE ,C/N AND G/T RATIO

- $T_S$ is located at the input to the receiver.
- RF amplifier
- IF amplifier
- Demodulator
- Over all gain at the receiver G
- Narrowest bandwidth is B
- Noise power at the demodulator input is

$$P_n = KT_S BG$$

# Noise temp contt---

Pr is the signal power at the input of the RF section of the receiver

signal power at the demodulator input will be PrG

$$\frac{C}{N} = \frac{P_r G}{K T_S B G} = \frac{P_r}{K T_s B}$$

$$P_n = G_{If} K T_{If} B + G_{If} G_m K T_m B + G_{If} G_m G_{RF} K B (T_{RF} + T_{in})$$

$$P_n = G_{If} G_M G_{Rf} \left[ \frac{K T_{If} B}{G_{If} G_m} + \frac{K T_m B}{G_{Rf}} + K B (T_{RF} + T_{in}) \right]$$

$$P_n = G_{If} G_M G_{Rf} KB \left[ T_{Rf} + T_{in} + \frac{T_{if}}{G_m G_{Rf}} + \frac{T_m}{G_{RF}} \right]$$

$$P_n = G_{If} G_M G_{Rf} KBT_s$$

*from* above equation

$$\mathrm{KT_s} B = KB \left[ T_{Rf} + T_{in} + \frac{T_{if}}{G_m G_{Rf}} + \frac{T_m}{G_{RF}} \right]$$

$$T_s = \left[ T_{Rf} + T_{in} + \frac{T_{if}}{G_m G_{Rf}} + \frac{T_m}{G_{RF}} \right]$$

# Noise temp cont---

- G/T ratio is 40.7 db $k^{-1}$ at 4 GHz and $5^0$ elevation
- Gr varies with frequency f^2
- Ts depends upon the sky noise temperature

# Noise temp cont---

$$\frac{C}{N} = \frac{P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2}{K T_S B L_A}$$

$$N_0 = \frac{N}{B}$$

$$\left(\frac{C}{N}\right)_{dBHz} = \overbrace{10\log P_T G_T}^{\text{EIRP}} - 20Log\left(\frac{4\pi d}{\lambda}\right) + 10\log\frac{G_R}{T_S} - 10LogL_A$$

$$-10LogK$$

Gr/Ts -- ratio is called figure of merit

# Atmospheric and ionospheric effect on link design

- Absorption
- refraction
- Diffusion(diffraction)
- Rotation of polarization of plane

depend on path length more pronounced at small elevation angles

Absorption and diffusion--- lower layers

---- increase in noise power at receiving antenna

# Satellite Link Design – Part II

# Agenda

- ***System Noise Power (Part II)***
- ***Numerical Examples***

# *System Noise Power*

# System Noise Power - 1

- Performance of system is determined by C/N ratio.
- Direct relation between C/N and BER for digital systems.
- Usually: C > N + 10 dB
- We need to know the noise temperature of our receiver so that we can calculate N, the noise power ($N = P_n$).
- $T_n$ (noise temperature) is in Kelvins (symbol K):

$$T[K] = T[{}^0C] + 273$$

$$T[K] = \left(T[{}^0F] - 32\right)\frac{5}{9} + 273$$

# System Noise Power - 2

- System noise is caused by thermal noise sources
  - External to RX system
    - Transmitted noise on link
    - Scene noise observed by antenna
  - Internal to RX system
- The power available from thermal noise is:

$$N = kT_s B \ \text{(dBW)}$$

where $k$ = Boltzmann's constant = $1.38\text{x}10^{-23}$ J/K(-228.6 dBW/HzK),

$T_s$ is the effective system noise temperature, and

$B$ is the effective system bandwidth

# Noise Spectral Density

- N = K.T.B ➔ N/B = $N_0$ is the noise spectral density (density of noise power per hertz):

$$N_0 = \frac{N}{B} = \frac{kT_sB}{B} = kT_s \text{ (dBW/Hz)}$$

- $N_0$ = noise spectral density is constant up to 300GHz.
- All bodies with Tp >0K radiate microwave energy.

# System Noise Temperature

1) System noise power is proportional to system noise temperature
2) Noise from different sources is uncorrelated (AWGN) Additive White Gaussian Noise (AWGN)

- Therefore, we can
  - Add up noise powers from different contributions
  - Work with noise temperature directly
- So:

$$T_s = T_{transmitted} + T_{antenna} + T_{LNA} + T_{lineloss} + T_{RX}$$

- But, we must:
  - Calculate the effective noise temperature of each contribution
  - Reference these noise temperatures to the same location

# Typical Receiver

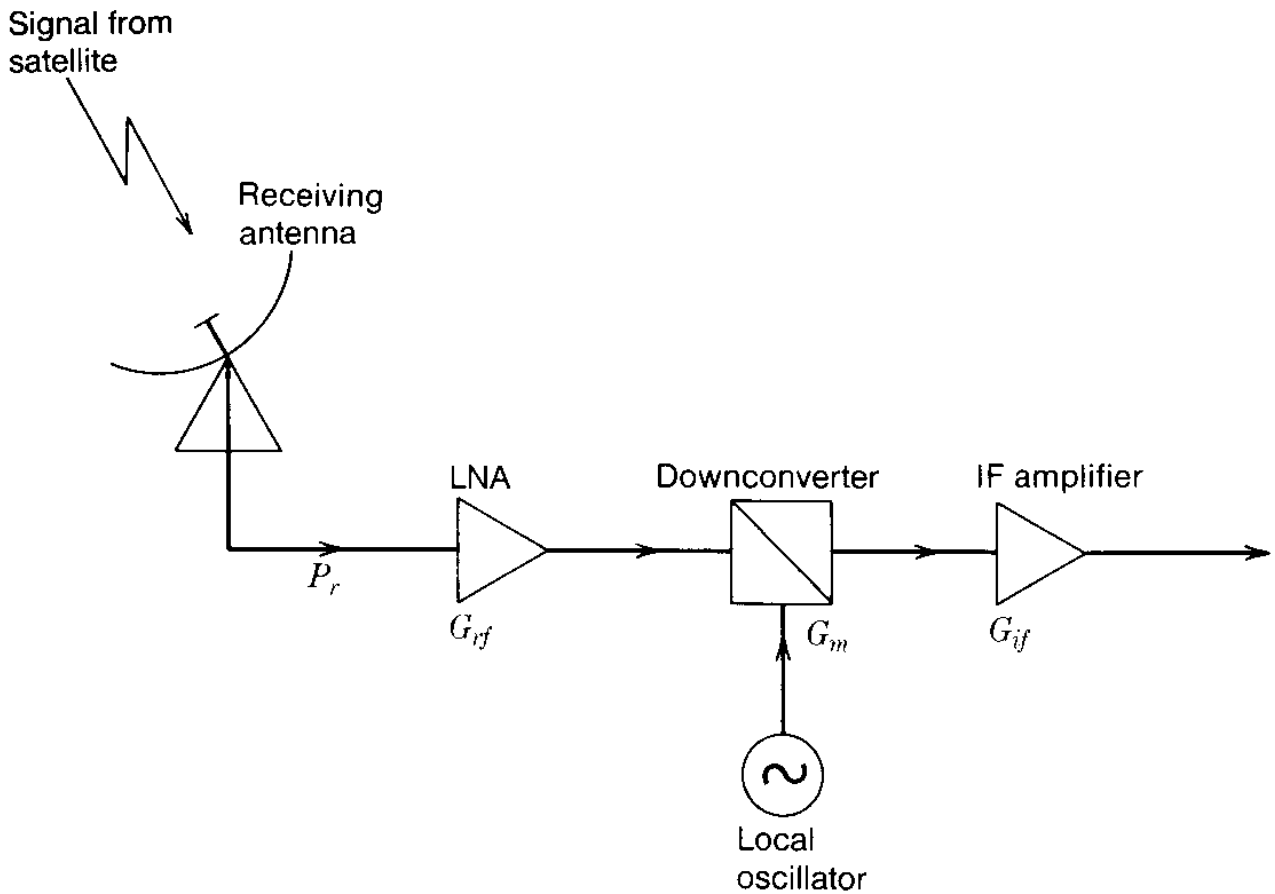



**Figure 4.4** Earth station receiver.

(Source: Pratt & Bostian Chapter 4, p115)

# Noise Model

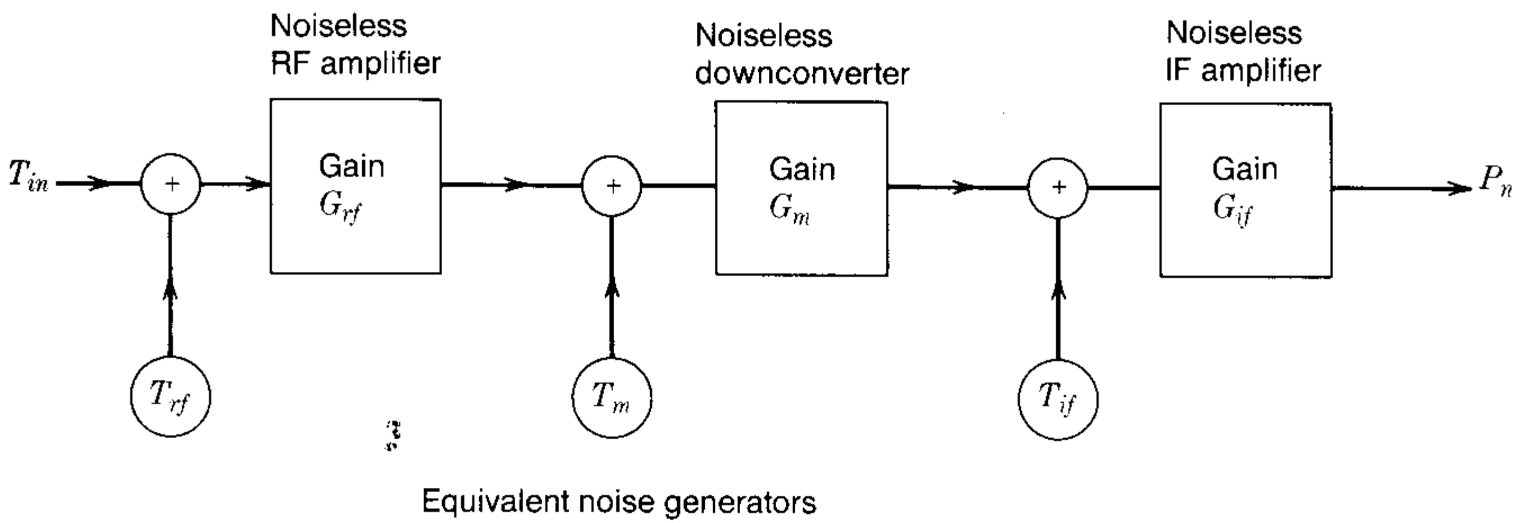



**Figure 4.5*a*** Equivalent circuit of receiver. The noisy amplifiers and downconverter have been replaced by noiseless units, with equivalent noise generators at their inputs.

(Source: Pratt & Bostian Chapter 4, p115)

Noise is added and then multiplied by the gain of the device (which is now assumed to be noiseless since the noise was already added prior to the device)

# Equivalent Noise Model of Receiver

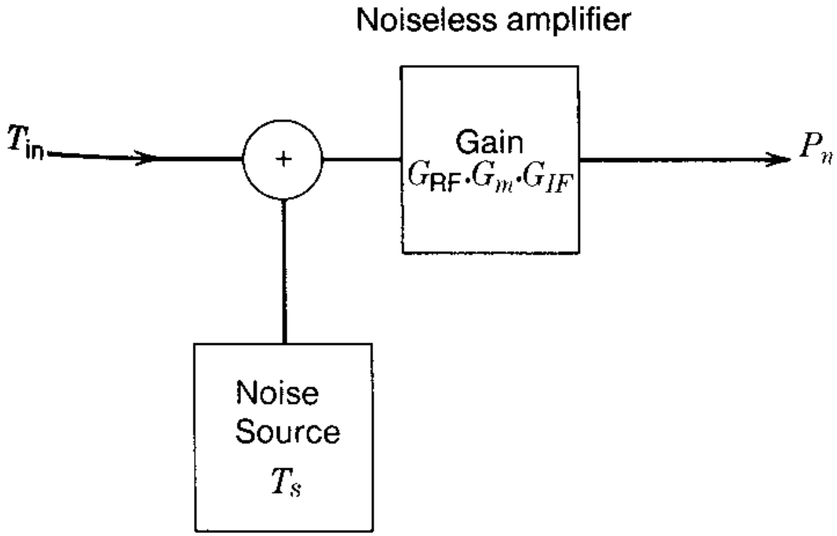



**Figure 4.5*b*** Equivalent circuit of receiver. All noisy units have been replaced by one noiseless amplifier, with a single noise source $T_s$ as its input.

(Source: Pratt & Bostian Chapter 4, p115)

Equivalent model: Equivalent noise Ts is added and then multiplied by the equivalent gain of the device, $G_{RF}G_mG_{IF}$ (noiseless).

# Calculating System Noise Temperature - 1

- Receiver noise comes from several sources.
- We need a method which reduces several sources to a single equivalent noise source at the receiver input.
- Using model in Fig. 4.5.a gives:

$$
\begin{aligned}
P_n &= G_{IF} k T_{IF} B && \text{(IF)} \\
&\quad + G_{IF} G_m k T_m B && \text{(Mixer)} \\
&\quad + G_{IF} G_m G_{RF} k B \left( T_{RF} + T_{in} \right) && \text{(Front - End)}
\end{aligned}
$$

*(Eqn. 4.15)*

# Calculating System Noise Temperature - 2

- Divide equation 4.15 by $G_{IF}G_mG_{RF}kB$:

$$P_n = G_{IF}G_mG_{RF}kB\left[T_{RF} + T_{in} + \frac{T_m}{G_{RF}} + \frac{T_{IF}}{G_mG_{RF}}\right]$$

*(Eqn. 4.16)*

- If we replace the model in Fig. 4.5.a by that in Fig. 4.5b

$$P_n = G_{IF}G_mG_{RF}kT_sB \qquad \textit{(Eqn. 4.17)}$$

# Calculating System Noise Temperature - 3

- Equate Pn in Eqns 4.16 and 4.17:

$$T_S = \left[ T_{RF} + T_{in} + \frac{T_m}{G_{RF}} + \frac{T_{IF}}{G_m G_{RF}} \right] \qquad \textit{(Eqn. 4.18)}$$

- Since C is invariably small, N must be minimized.
- How can we make N as small as possible?

# Reducing Noise Power

- Make B as small as possible – just enough bandwidth to accept all of the signal power (C ).
- Make $T_S$ as small as possible
  - Lowest $T_{RF}$
  - Lowest $T_{in}$ (How?)
  - High $G_{RF}$
- If we have a good low noise amplifier (LNA), i.e., low $T_{RF}$, high $G_{RF}$, then rest of receiver does not matter that much.

$$T_S = \left[ T_{RF} + T_{in} + \frac{T_m}{G_{RF}} + \frac{T_{IF}}{G_m G_{RF}} \right] \cong T_{RF} + T_{in}$$

# Reducing Noise Power

## Low Noise Amplifier

- Parametric amplifier (older technology, complex and expensive):

  Cooled (thermo-electrically or liquid nitrogen or helium):

  - 4 GHz : 30 K
  - 11 GHz: 90 K

  Uncooled:

  - 4 GHz : 40 K
  - 11 GHz: 100 K

- Ga AS FET (Galium Arsenide Field-Effect Transistor): Cooled (thermo-electrically):

  - 4 GHz : 50 K
  - 11 GHz: 125 K

  Uncooled:

  - 4 GHz : 50 K
  - 11 GHz: 125 K

# Reducing Noise Power

## *Discussion on $T_{in}$*

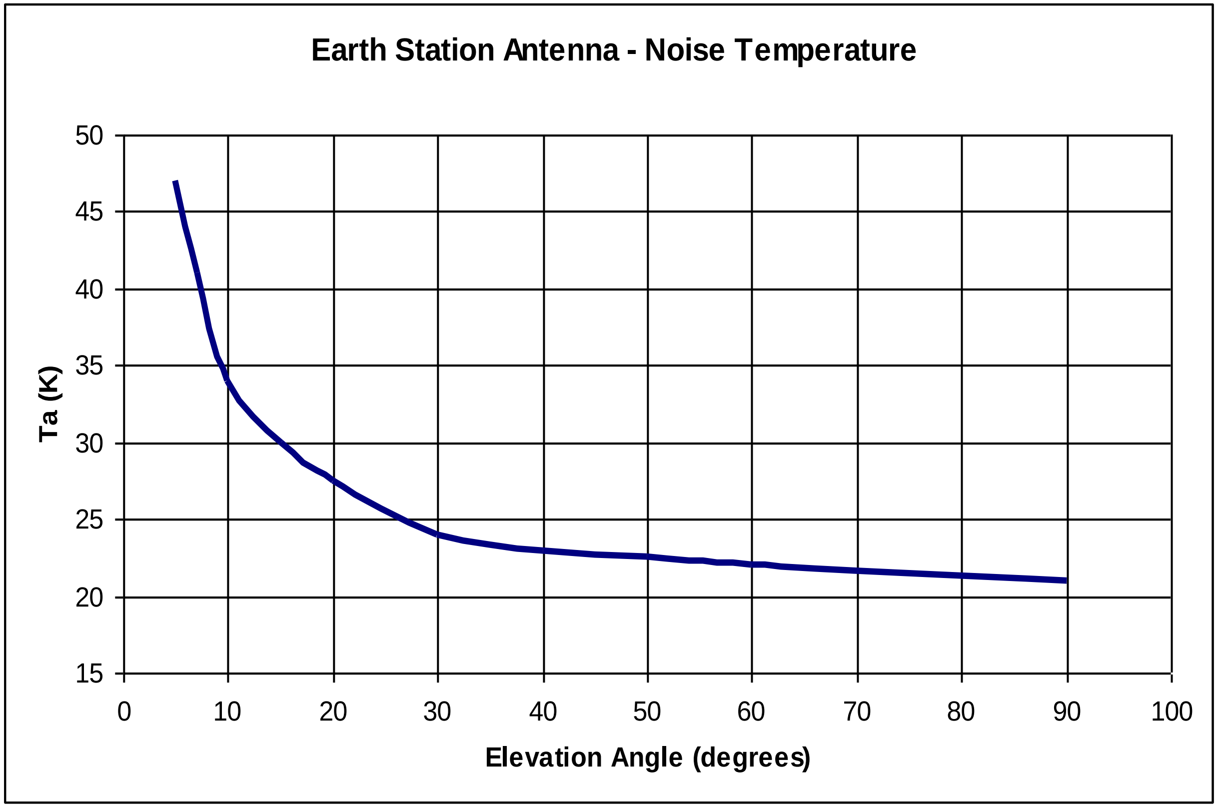
- Earth Stations: Antennas looking at space which appears cold and produces little thermal noise power (about 50K).
- Satellites: antennas beaming towards earth (about 300 K):
  - Making the LNA noise temperature much less gives diminishing returns.
  - Improvements aim reduction of size and weight.

# Antenna Noise Temperature

- Contributes for $T_{in}$
- Natural Sources (sky noise):
  - Cosmic noise (star and inter-stellar matter), decreases with frequency, (negligible above 1GHz). Certain parts of the sky have punctual "hot sources" (hot sky).
  - Sun ($T \cong 12000\ f^{-0.75}$ K): point earth-station antennas away from it.
  - Moon (black body radiator): 200 to 300K if pointed directly to it.
  - Earth (satellite)
  - Propagation medium (e.g. rain, oxygen, water vapor): noise reduced as elevation angle increases.
- Man-made sources:
  - Vehicles, industrial machinery
  - Other terrestrial and satellite systems operating at the same frequency of interest.

# Antenna Noise Temperature

- Useful approximation for Earth Station antenna temperature on clear sky (no rain)



# Noise from Active Devices

- Active devices produce noise from:
  - Dissipative losses in the active device
  - Dissipative losses in the supporting circuits
  - Electrical noise caused by the active device
- The effective temperature of active devices is specified by the manufacturer
  - Can be measured by a couple of methods
  - Can be (somewhat laboriously) calculated
  - Assumes specific impedance matches
- The effective temperature is (almost) always specified at the <u>input</u> of the device
- The noise is often given as a noise figure (see later)

# Noise from Lossy Elements -1

- All lossy elements reduce the amount of power transmitted through them
  - Carrier or signal power
  - Noise power
- The noise temperature contribution of a loss is:

$$T_N = T_0(1 - G)\,[K]$$

G = 1/Loss

where G is the "gain" (smaller than unit) of the lossy element, also called transmissivity ($P_{out}/P_{in}$) and $T_0$ is the physical temperature of the loss.

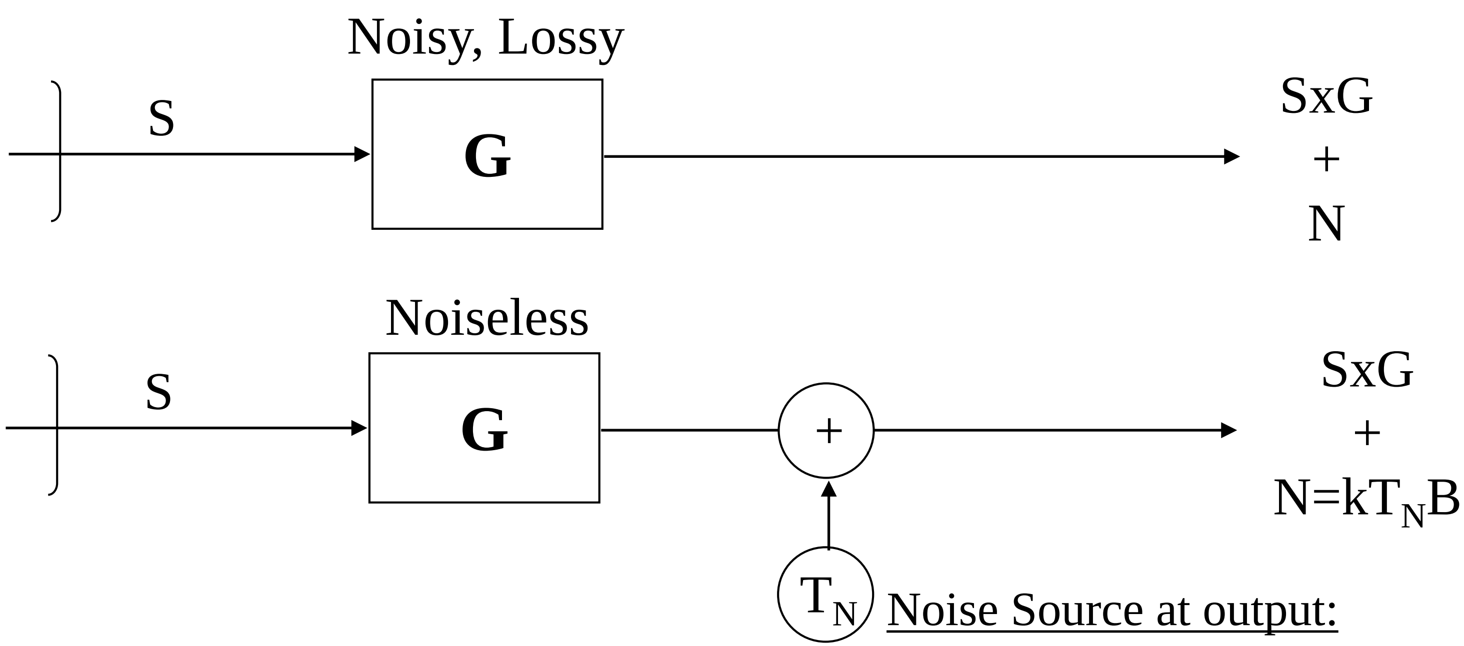
- Note the temperature is at the <u>output</u> of the loss.

# Noise from Lossy Elements –2

Assume lossy element has gain = $G_L = 1/L$

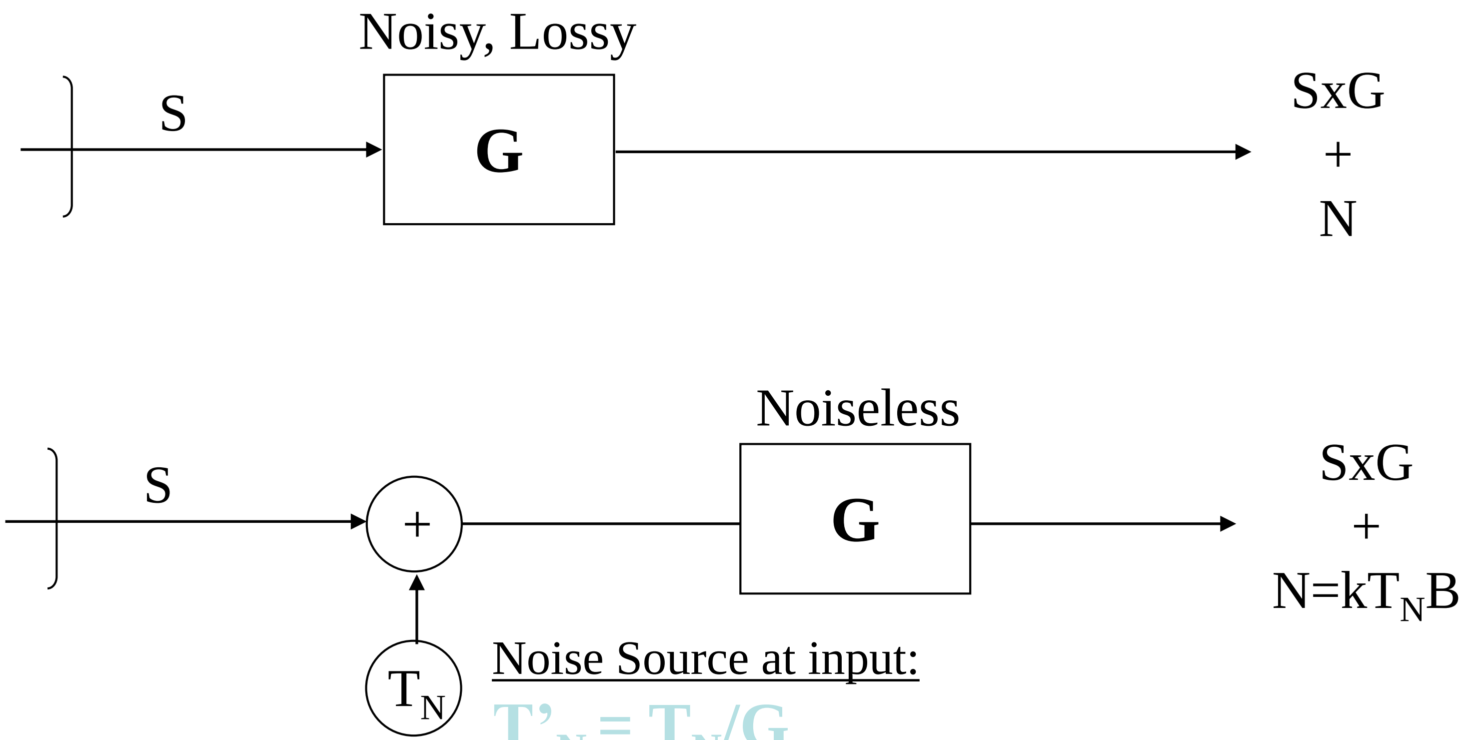
Notes: $G_L < 0$ dB (because $0 < G_L < 1$)

$T_0$= physical temperature




$T_N = T_0(1-G)$ [K]

# Noise from Lossy Elements –2




<u>Noise Source at input:</u>

$T'_N = T_N/G$

$\quad = T_0(1/G-1)$ [K]

# Noise Figure

- Noise Figure:
  - Relates the noise temperature to a reference
  - Easily used in dB scale
- Definition:

$$F_N = \frac{[S/N]_{in}}{[S/N]_{out}} = \frac{N_{out}}{kT_0 B_N G}$$

- Convert to Noise Temperature:

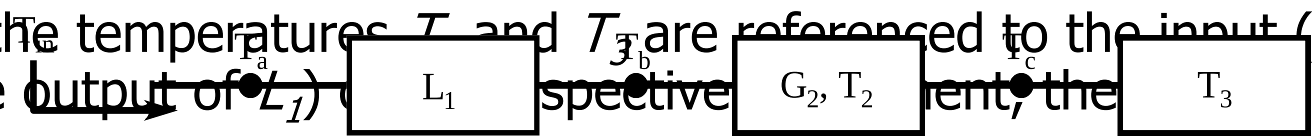
$$T_e = T_0(F_n - 1)$$

$T_0$ = standard noise temperature = 290 K

G = gain of network

# Translating Noise

- We need to have all of the noise referenced to a common point
- The output flange of a lossless antenna is the standard reference
- Noise temperature can be moved through components just like power is since the two are linearly related
  - This is only valid if the system is linear
  - Note that the RX bandwidth must still be wide enough for the signal!
- If the temperatures $T$ [illegible] and $T_3$ are referenced to the input ($T_1$ at the output of $L_1$) [illegible] spective [illegible] ent, the




$$G_1 = \frac{1}{L_1} \qquad T_1 = (1 - G_1) T_{phys} \qquad T_{sysa} = T_{in} + \frac{T_1}{G_1} + \frac{1}{G_1}\left(T_2 + \frac{T_3}{G_2}\right)$$

$$T_{sysb} = T_{sysa} G_1 = T_{in} G_1 + T_1 + T_2 + \frac{T_3}{G_2} \qquad T_{sysc} = G_2 T_{sysb} = G_1 G_2 T_{sysa} = G_2 (G_1 T_{in} + T_1 + T_2) + T_3$$

# Multi-bounce link budgets

- If the C/N ratios for each of the linear bent pipe transponder links are available:

$$\left(\frac{C}{N}\right)_{total} = \left[\left(\frac{C}{N}\right)_1^{-1} + \left(\frac{C}{N}\right)_2^{-1} + \ldots + \left(\frac{C}{N}\right)_n^{-1}\right]^{-1}$$

so long as the noise is uncorrelated between the links

- For baseband processing links:

$$BER_{total} = BER_1 + BER_2 + \ldots + BER_n$$

# So many trade-offs !!!

$$G = \left(\frac{\pi D}{\lambda}\right)^2 \times \eta$$

$$P_r = \frac{P_t G_t G_r}{L_p L_a L_{ta} L_{ra} L_{pol} L_{other} L_r}$$

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

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

$$L_a \propto F$$

$$T_S = \left[ T_{RF} + T_{in} + \frac{T_m}{G_{RF}} + \frac{T_{IF}}{G_m G_{RF}} \right]$$

# *Numerical Examples*

# Noise Temperature

## *Example – 4.2.1*

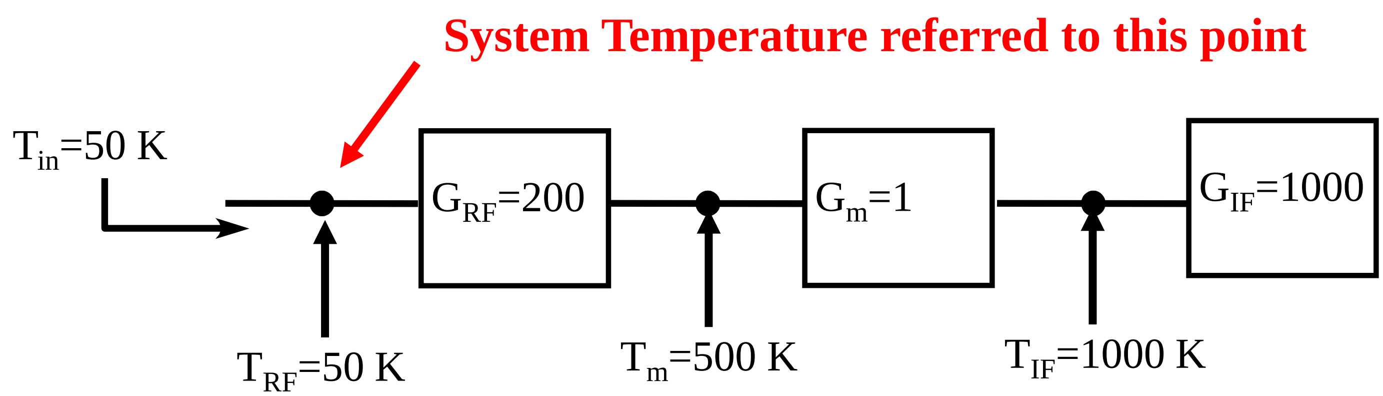
- 4GHz Receiver

  $T_{in} = T_a = 50$ K

  $T_{RF} = 50$ K $\qquad G_{RF} = 23$ dB $(=200)$

  $T_m = 500$ K $\qquad G_m = 0$ dB $(=1)$

  $T_{IF} = 1000$ K $\qquad G_{IF} = 50$ dB $(=1000)$



# Noise Temperature

## *Example – 4.2.1*

- Solution:

$$T_S = \left[ T_{RF} + T_{in} + \frac{T_m}{G_{RF}} + \frac{T_{IF}}{G_m G_{RF}} \right]$$

$$= \left[ 50 + 50 + \frac{500}{200} + \frac{1000}{200 \text{ x } 1} \right]$$

$$= [50 + 50 + 2.5 + 5] = 107.5K$$

# Noise Temperature

## *Example – 4.2.1*

- If mixer had 10 dB loss

  $G_m$ = -10 dB (=0.1)

$$T_S = \left[ 50 + 50 + \frac{500}{200} + \frac{1000}{20} \right] = 152.5K$$

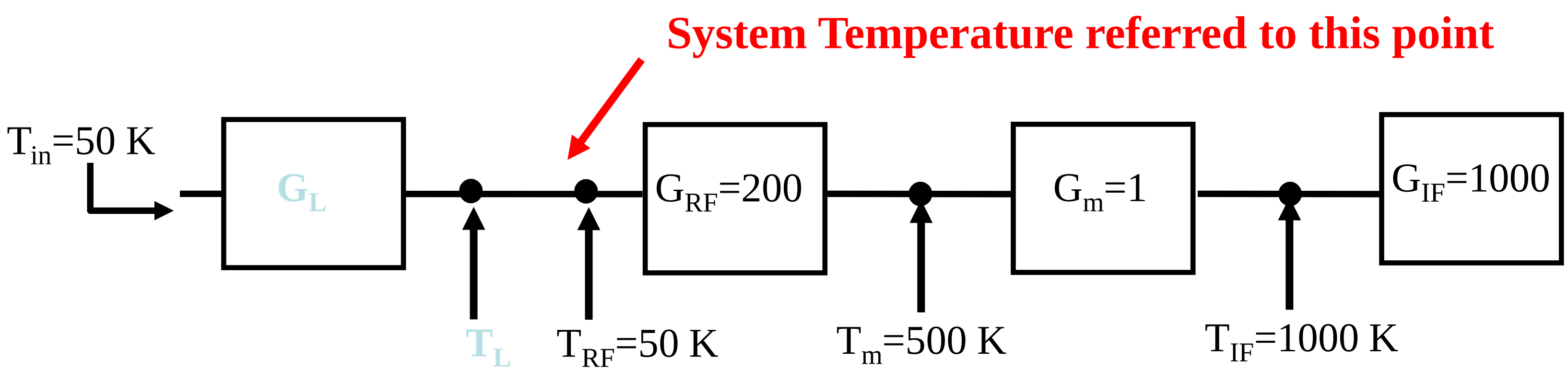
Comment: $G_{RF}G_m$ is too small here, so the IF amplifier contribution is large.

- If we made $G_{RF}$ = 50 dB (=$10^5$)

$$T_S = \left[ 50 + 50 + \frac{500}{100{,}000} + \frac{1000}{10{,}000} \right] = 100.1K$$

# Noise Temperature – Lossy Elements
## *Example – 4.2.2*

- In original problem, insert lossy waveguide with 2 dB attenuation between antenna and LNA



# Noise Temperature – Lossy Elements

## *Example – 4.2.2*

- Loss of 2 dB, obtain $G_L$ and $T_L$:

$$G_L = -2dB = \frac{1}{1.58} = 0.63$$

$$\begin{aligned} T_L &= 290(1-G_L) \\ &= 290(1-0.63) \\ &= 107.3K \end{aligned}$$

•Input noise power is attenuated by 2 dB:

New $T_{in}$:

$$\begin{aligned} T_{in} &= T_a \mathrm{G_L} + \mathrm{T_L} \\ &= 50 \text{ x } 0.63 + 107.3\,\mathrm{K} \\ &= 138.8\,\mathrm{K} \end{aligned}$$

# Noise Temperature – Lossy Elements

## *Example – 4.2.2*

$$T_S = \left[ T_{in} + T_{RF} + \frac{T_m}{G_{RF}} + \frac{T_{IF}}{G_m G_{RF}} \right]$$

$$= \left[ 138.8 + 50 + \frac{500}{200} + \frac{1000}{200 \text{ x } 1} \right]$$

$$= [138.8 + 50 + 2.5 + 5] = 196.3K$$

- Increased from 107.5 to 196.3 K at the same reference point:

$$\frac{N_2}{N_1} = \frac{KT_{s2}B}{KT_{s1}B} = \frac{T_{s2}}{T_{s1}} = 1.82 = 2.6dB$$

# Noise Temperature – Lossy Elements

## *Example – 4.2.2*

- Inserting 2 dB loss in the front end of the received carrier power (C ) by 2 dB and increased noise temperature by 88.8 K, from 107.5 K to 196.3 K (comparing at the same reference point).
- N has increased by 2.6 dB.
- C has decreased by 2 dB.
- Result: C/N has been reduced by 4.6 dB!

Moral:

**Losses before LNA must be kept very small.**

# Antenna Example - 1

3.7.1 Earth subtends an angle of 17 degrees when viewed from geostationary orbit.

a. What should be the dimensions of a reflector antenna to provide global coverage at 4 GHz?

b. What will be the antenna gain if efficiency =0.55?

a. $\theta_{3dB}$ = 17 degrees

$$\theta_{3dB} \cong \frac{75\lambda}{D}$$

$$D \cong \frac{75\lambda}{\theta_{3dB}} = \frac{75\text{x}0.075}{17} = 0.33m$$

b. $\eta$=0.55

$$Gain \cong \eta\left(\frac{75\pi}{\theta_{3dB}}\right)^2 = 0.55\frac{(75\pi)^2}{17^2{}_E} = 105.65 = 20.23dB$$

# Antenna Example - 2

3.7.1 Continental US subtends a "rectangle" of 6 x 3 degrees.

Find gain and dimensions of a reflector antenna to provide global coverage at 11 GHz? a. Using 2 antennas (3 x3 degrees)

b. Using only 1 antenna (3 x 6 degrees)

a. $\theta_{3dB}$ = 3 degrees

$$D \cong \frac{75\lambda}{\theta_{3dB}} = \frac{75\text{x}0.0273}{3} = 0.68m$$

$$Gain \cong \eta\left(\frac{75\pi}{\theta_{3dB}}\right)^2 = 0.55\left(\frac{75\pi}{3}\right)^2 = 3392.7 = 35.2dB$$

b. $\theta_{3dBA}$ = 6 degrees $D_E = 0.68\text{m}$

$\theta_{3dBE}$ = 3 degrees

$$D_A \cong \frac{75\lambda}{\theta_{3dB}} = \frac{75\text{x}0.0273}{6} = 0.34m$$

$$Gain \cong \eta\frac{(75\pi)^2}{\theta_{3dB\,A}\theta_{3dB\,E}} = 0.55\frac{(75\pi)^2}{6\text{x}3} = 1696.3 = 32.3dB$$

# Power Budget Example - 1

4.1.1 Satellite at 40,000 km (range)

Transmits 2W

Antenna gain Gt = 17 dB (global beam)

Calculate: a. Flux density on earth's surface

b. Power received by antenna with effective aperture of 10m$^2$

c. Gain of receiving antenna.

d. Received C/N assuming Ts =152 K, and Bw =500 MHz

a. Using Eqn. 4.3: (Gt = 17 dB = 50)

$$F = \frac{EIRP}{4\pi R^2} = \frac{P_t G_t}{4\pi R^2} = \frac{2 \text{ x } 50}{4\pi \text{ x}(4\text{x}10^7)^2}$$

$$= 4.97 \text{ x } 10^{-15}\, \text{W/m}^2 = -143\,\text{dBW/m}^2$$

(Solving in dB…)

$$EIRP = (Pt + Gt) = 3 + 17 = 20\,\text{dBW}$$

$$\text{R}^2 \quad = 2 \text{ x } \log_{10}(4\text{x}10^7) \quad \text{dB[meter]}^2$$

$$4\pi = 11 dB$$

$$F = 20 - 11 - 152 = -143 \text{ dBW/m2}$$

# Power Budget Example - 1

b. Received Power

$$P_r = F \text{ x } A = (4.97 \text{x} 10^{-15}) \text{ x } 10$$

$$P_r = 4.97 \text{ x } 10^{-14} W = -133 dBW$$

(Solving in dB…)

$$P_r = F + A = (-143) + 10$$

$$P_r = -133 \text{ dBW}$$

c. Gain given Ae = 10 $m^2$ and Frequency = 11GHz ( eqn. 4.7)

$$G_r = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi \text{ x } 10}{0.0273} = 52.3 dB$$

# Power Budget Example - 1

b. System Noise Temperature

$$\mathrm{N} = \mathrm{P_n} = KTB = 1.38 \,\mathrm{x}\, 10^{-23} \,\mathrm{x}\, 152 \,\mathrm{x}\, 500 \,\mathrm{x}\, 10^{6}$$

$$or = K_{dB} + T_{dB} + B_{dB} = -228.6 + 21.82 + 86.99$$

$$= -119.79 \;\; dBW$$

$$\mathrm{C} = \mathrm{P_r} = 4.97 \,\mathrm{x}\, 10^{-14} W = -133 dBW$$

$$C / N = C - N = -133 - (-119.79)$$

$$C / N = -13.2 dB$$

# Power Budget Example - 2

## Generic DBS-TV:

**Received Power**

| | |
|---|---|
| Transponder output power , 160 W | 22.0 dBW |
| Antenna beam on-axis gain | 34.3 dB |
| Path loss at 12 GHz, 38,500 km path | -205.7 dB |
| Receiving antenna gain, on axis | 33.5 dB |
| Edge of beam | -3.0 dB |
| Miscellaneous losses | -0.8 dB |
| Received power, C | -119.7 dBW |

# Power Budget Example - 2

**Noise power**

| | |
|---|---|
| Boltzmann's constant, k | -228.6 dBW/K/Hz |
| System noise temperature, clear air, 143 K | 21.6 dBK |
| Receiver noise bandwidth, 20MHz | 73.0 dBHz |
| Noise power, N | -134.0 dBW |
| **C/N in clear air** | 14.3 dB |
| Link margin over 8.6 dB threshold | 5.7 dB |
| Link availability throughout US | Better than 99.7 % |

# System noise temperature and G/T ratio

# Noise temperature

- It provides a way for determining how much thermal noise is generated by active and passive devices in the receiving system.

$$\mathit{Noise}\ \text{temperature} = \frac{\text{Noise produced by an amplifier}}{\text{Thermal noise from a matched load}}$$

- At same physical temperature at the input of the amplifier

- All objects with physical temperature , ***Tp*** greater than 0$^{o}$ K generate electrical noise at the receiver in microwave frequencies.

# Noise power

$$P_n = k\,T_p\,B_n \quad - (1.1)$$

- K = Boltzman's constant
  ($1.38X10^{-23}$ J/K = -228.6dBW/K/Hz)
- Tp = Physical temperature of source in kelvin degree
- $B_n$ = Noise bandwidth in which the noise power is measured in hertz
- $P_n$ = avaliable noise power
- $k\,T_p$ = noise power spectral denisty in watts per hertz
  It is constant upto 300GHz

# Method for designing receiving system #1

- Set the BW in the receiver large to allow the signals keeiping the noise power as low as possible
- Equ (1.1) can be the equivalent noise band width unfortunately this cant be determined in the receiver
- So, 3-dB is chosen in the receiver

# Method for designing receiving system #2

- Keep the noise temperature low
- Immerse the front end amplifier in liquid helium to hold the temperature at 4 degree Kelvin
- Expensive and difficult to maintain
- Use GaAsFET amplifiers with noise temperature of 70K at 4 GHz and 180 K at 11 GHz without cooling

# Performance of the receiving system

- Find the thermal noise against which the signal must be demodulated
- To do this system noise temperature must be found out , $T_s$
- $T_s$ - noise temperature of a source ,

  located at the input of a noise less receiver,

  which gives the same noise power as the original receiver, measure at the output of the receiver

# Noise power

- Noise power at the input of demodulator is,

$$\mathbf{P_{no} = k\ T_s\ B_n\ G_{rx} \quad watts\ -\ (1.2)}$$

Where

$G_{rx}$ = gain of the receiver from RF input to the demodulator input

# Problem 1

- An antenna has noise temperature of 35 K and is matched into a receiver which has a noise temperature of 100 K calculate:

  a) noise power density and

  b) the noise power for a bandwidth of 36 MHz.

# Solution

a) $N_O = k\,T_N = 11.38 \times 10^{-23} \times (35 + 100) = 1.86 \times 10^{-21}$ J

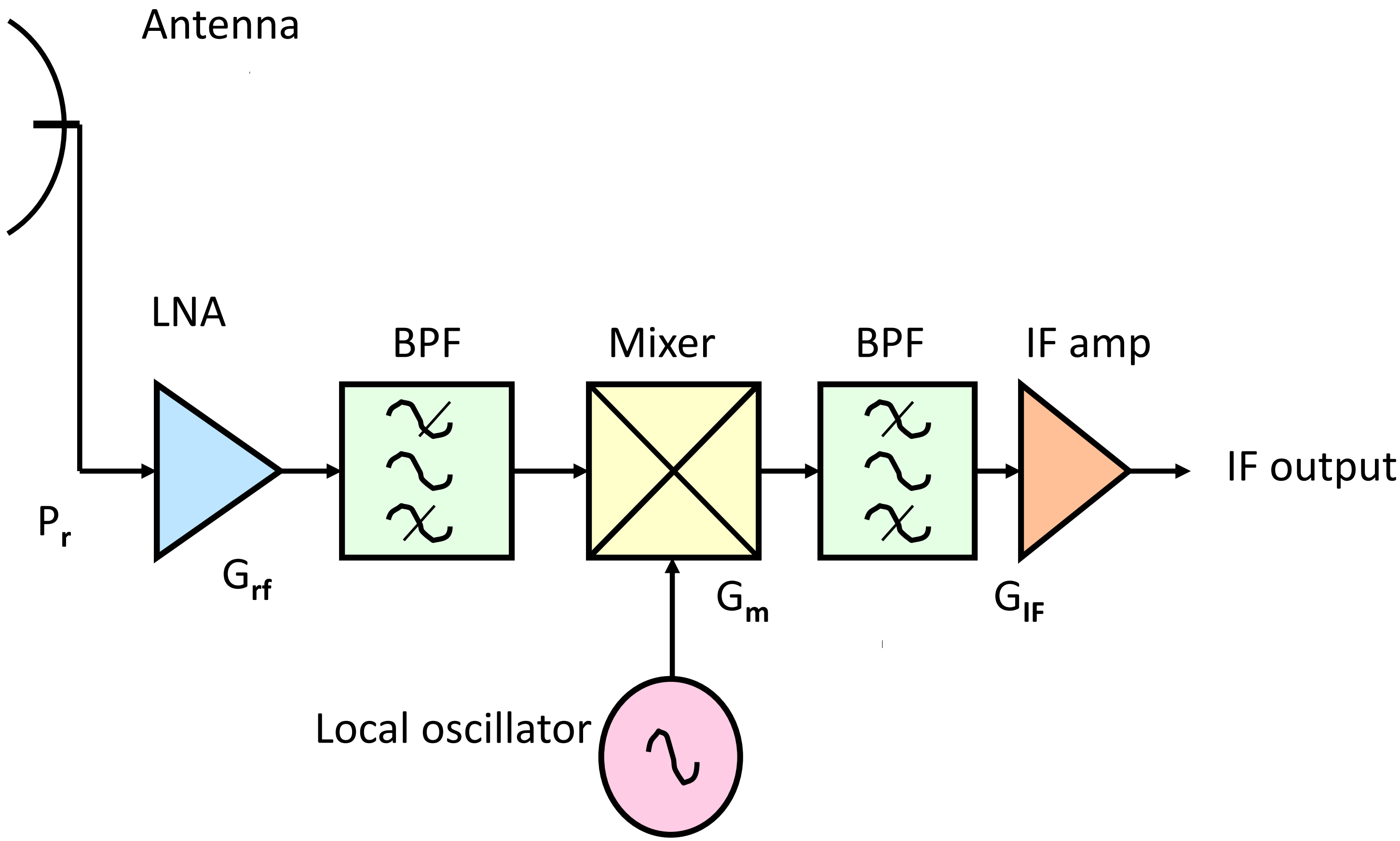
b) $P_N = N_O\,B_N = 1.86 \times 10^{-21} \times 36 \times 10^{6} = 0.067$ pW

# Carrier-to-noise ratio

- Let the antenna deliver a power $P_r$ to the receiver RF input
- The signal power at the demodulator input is $P_r \, G_{rx}$ watts
- Carrier –to-noise ratio at the demodulator is,

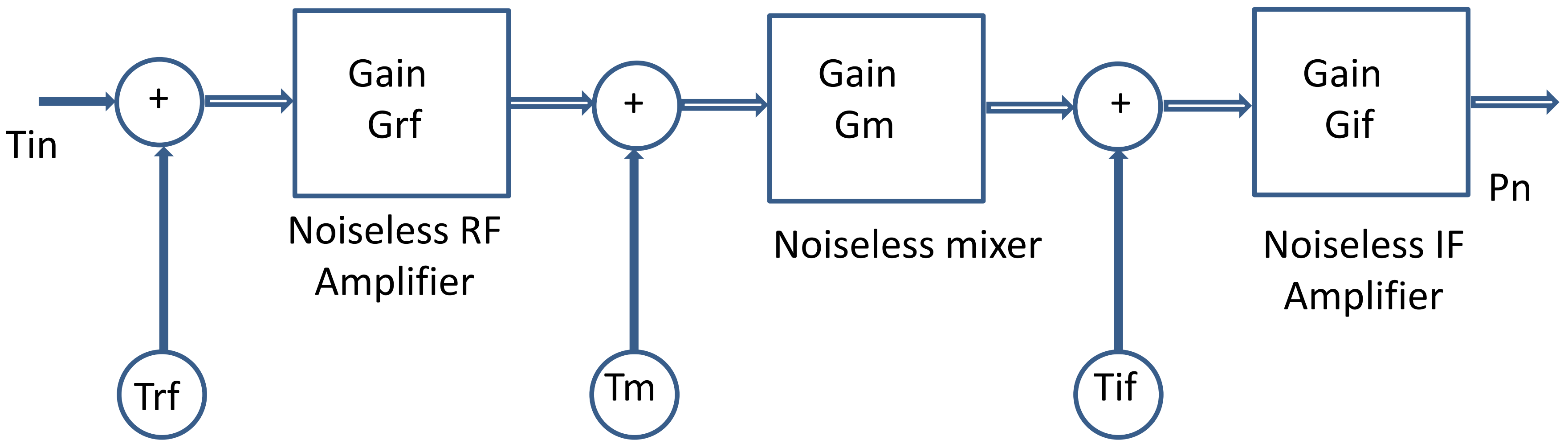
$$\frac{C}{N} = \frac{P_r G_{rx}}{kT_s B_n G_{rx}} = \frac{P_r}{kT_s B_n}$$

# Calculation of system noise temperature



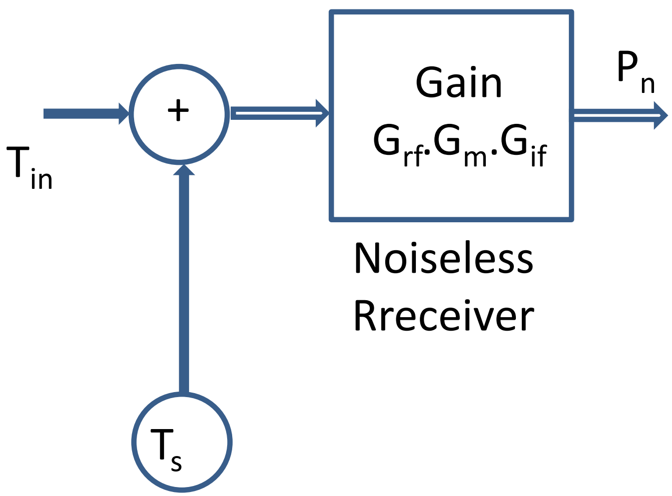

**Single Super heterodyne receiver**

# Noise model of receiver

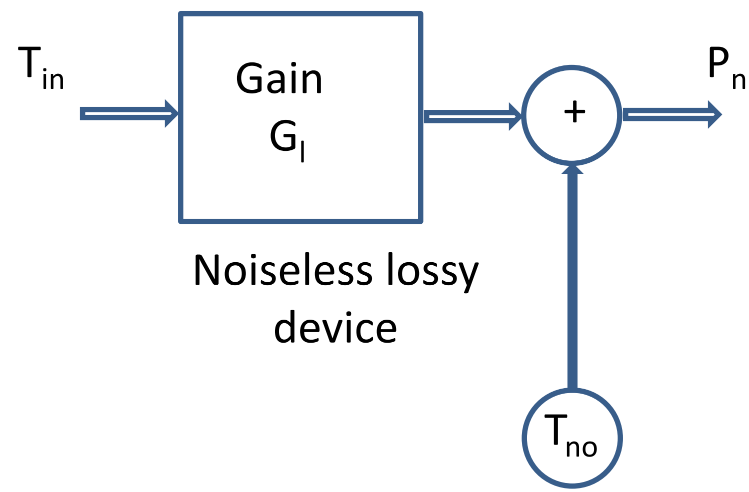



a) The Noisy amplifier and down converters are replaced by noise less units with equivalent noise generators at their inputs

# Noise model of receiver




b) All noisy unit replaced with one noiseless amplifier with a single noise source Ts




c) The lossy device is replaced with lossless device , with a signal noise source Tno

# Noise power

Total noise power :

$P_n = G_{IF}\ k\ T_{IF}\ B_n + G_{IF}G_m k T_m B_n + G_{IF}G_m G_{RF} k B_n (T_{RF}+T_{in})$

$P_n = G_{IF}G_m G_{RF}\ [(k\ T_{IF}\ B_n)/G_{RF}G_m + (kT_m B_n)/G_{RF} + (T_{RF}+T_{in})]$

$= G_{IF}G_m G_{RF}\ k\ B_n\ [T_{RF}+T_{in} + T_m/G_{RF} + T_{IF}/(G_{RF}G_m)]$

Here $T_s$ generates the same noise power $P_n$ at its output if

$P_n = G_{IF}G_m G_{RF}\ k\ T_s\ B_n$

Noise power in the noise model (b) will be equal to (a) if

$k\ T_s\ B_n = k\ B_n\ [T_{RF}+T_{in} + T_m/G_{RF} + T_{IF}/(G_{RF}G_m)]$

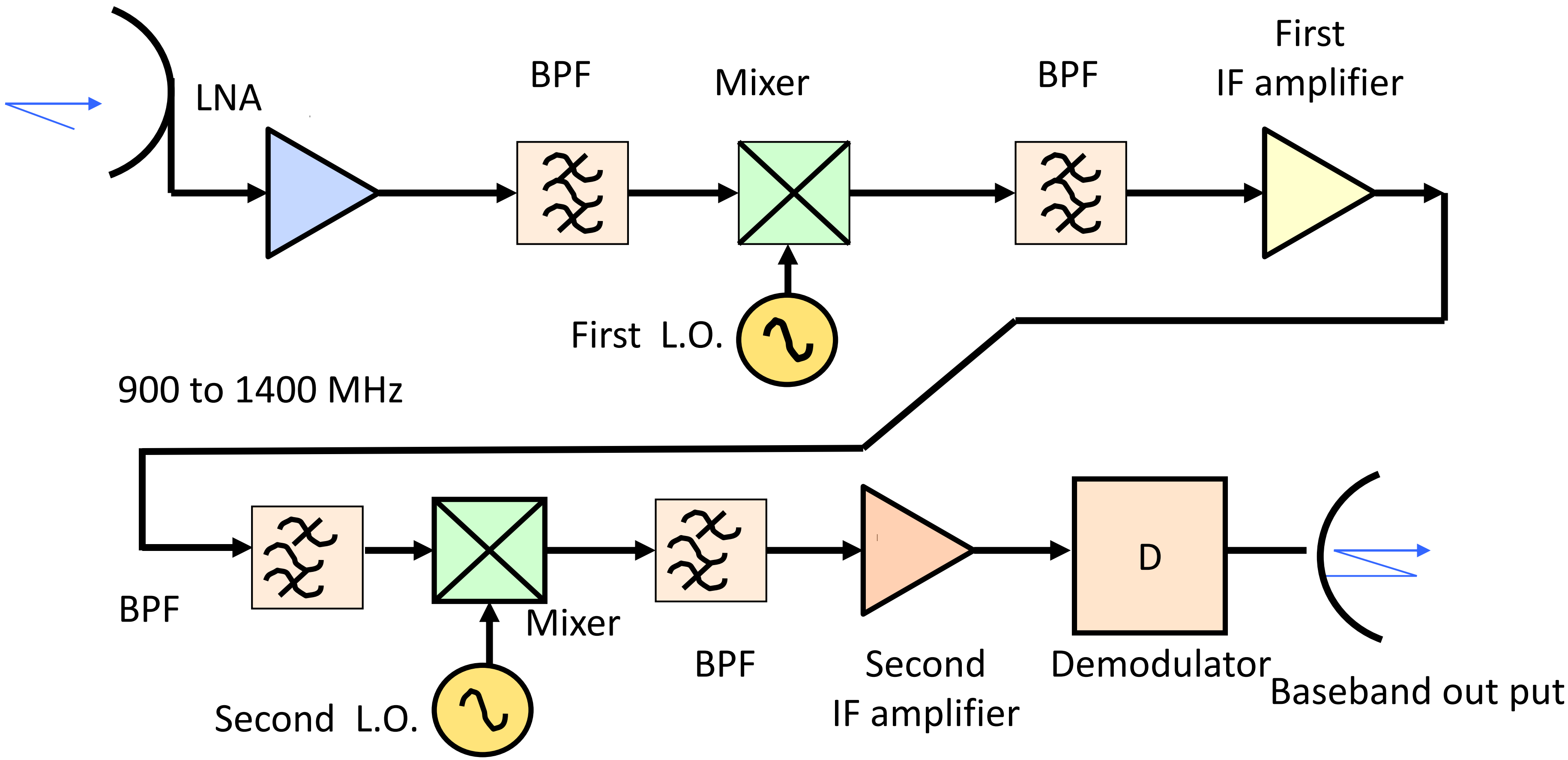
Hence,

$T_s = [T_{RF}+T_{in} + T_m/G_{RF} + T_{IF}/(G_{RF}G_m)]$

**Conclusion:**

**The receiver gives less noise as the gain from each stage is added hence the noise contributed by the IF amplifier and later sages can be ignored**

# Calculation of system noise temperature




**Double Super heterodyne receiver**

# G/T ratio for earth station

The link equation can be rewritten as :

$$\frac{C}{N} = \frac{P_t G_t G_r}{k T_s B}\left(\frac{\lambda}{4\pi R}\right)^2$$

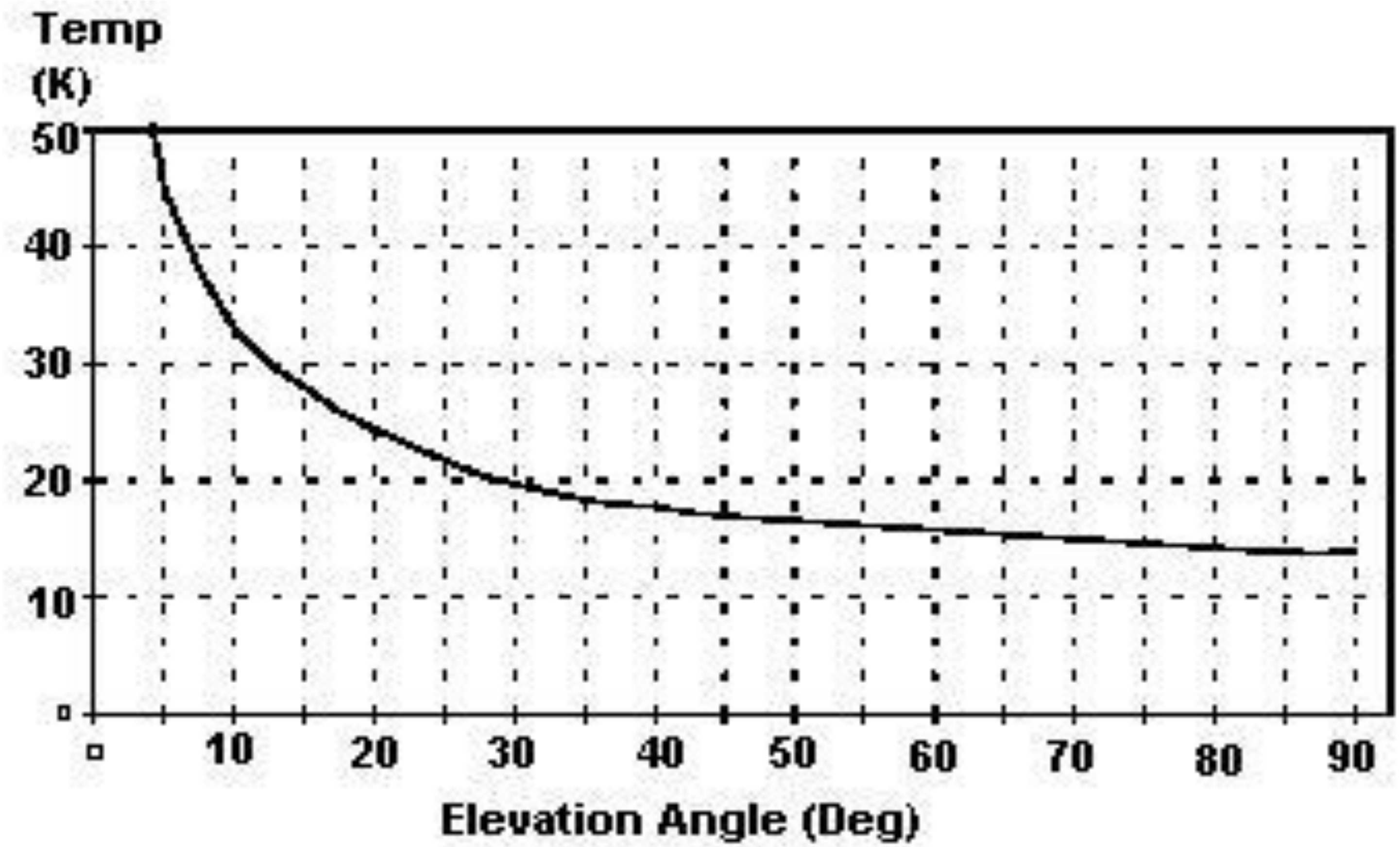
$$\frac{C}{N} = \frac{P_t G_t}{k B}\left(\frac{\lambda}{4\pi R}\right)^2 \frac{G_r}{T_s}$$

**Constants**

**Figure of merit**
Gives the quality of an earth station

# Antenna Noise Temperature

**Noise Temperature of an Antenna as a Function of Elevation Angle:**



# Problem 2

Suppose we have a 4 GHz receiver with the following gains and noise temperature

- ✓ Tin = 50 K
- ✓ Trf = 50 K
- ✓ Tin = 500 K
- ✓ Tif = 1000 K
- ✓ Grf = 23 dB
- ✓ Gm = 0 dB
- ✓ Gif = 30 db

- Calculate the system noise temperature.

# Solution

$T_s = 152.5$ K

# Problem 3

- An earth station antenna has a diameter of 30 m , has an overall efficiency of 68% , and is used to receive a signal at 4150 MHz. At this frequency , the system noise temperature is 79 K when the antenna points at the satellite at an elevation angle of 28 degree. What is the earth station G/T under these conditions? If heavy rain causes the sky temperature to increase so that the system noise temperature rises to 88 K , what is the new G/T value

# Solution

$$G/T = 41.6\ dBK^{-1}$$

If heavy rain

$$G/T = 41.2\ dBK^{-1}$$