Satellite Communications

Part IV-Lecture 2-Satellite Link Design

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Learning Objectives

- System Noise Temperature
- Calculation of System Noise Temperature by Noise Modelling
- Noise Figure and Noise Temperature
- G/T Ratio for Receiving Earth Stations
- Numerical Examples

Introduction

- Performance of a system in determined by C/N ratio at the demodulator input
- Most systems require C/N>10
- In dB: C-N>10dB,Hence C(=P_r)>N+10dB

- We need to know the System Noise Temperature of our receiver to calculate N(=P_n)the noise power

System Noise Temperature

- To determine the performance of a receiving system we need to find the total thermal noise power against which the signal must be demodulated

- System Noise temperature is a useful concept in communication receivers, since it provides a way of determining how much thermal noise is generated by devices in the receiving system

Noise Power of a Source

- At microwave frequencies, a body with a physical temperature T generates electrical noise over a wide bandwidth

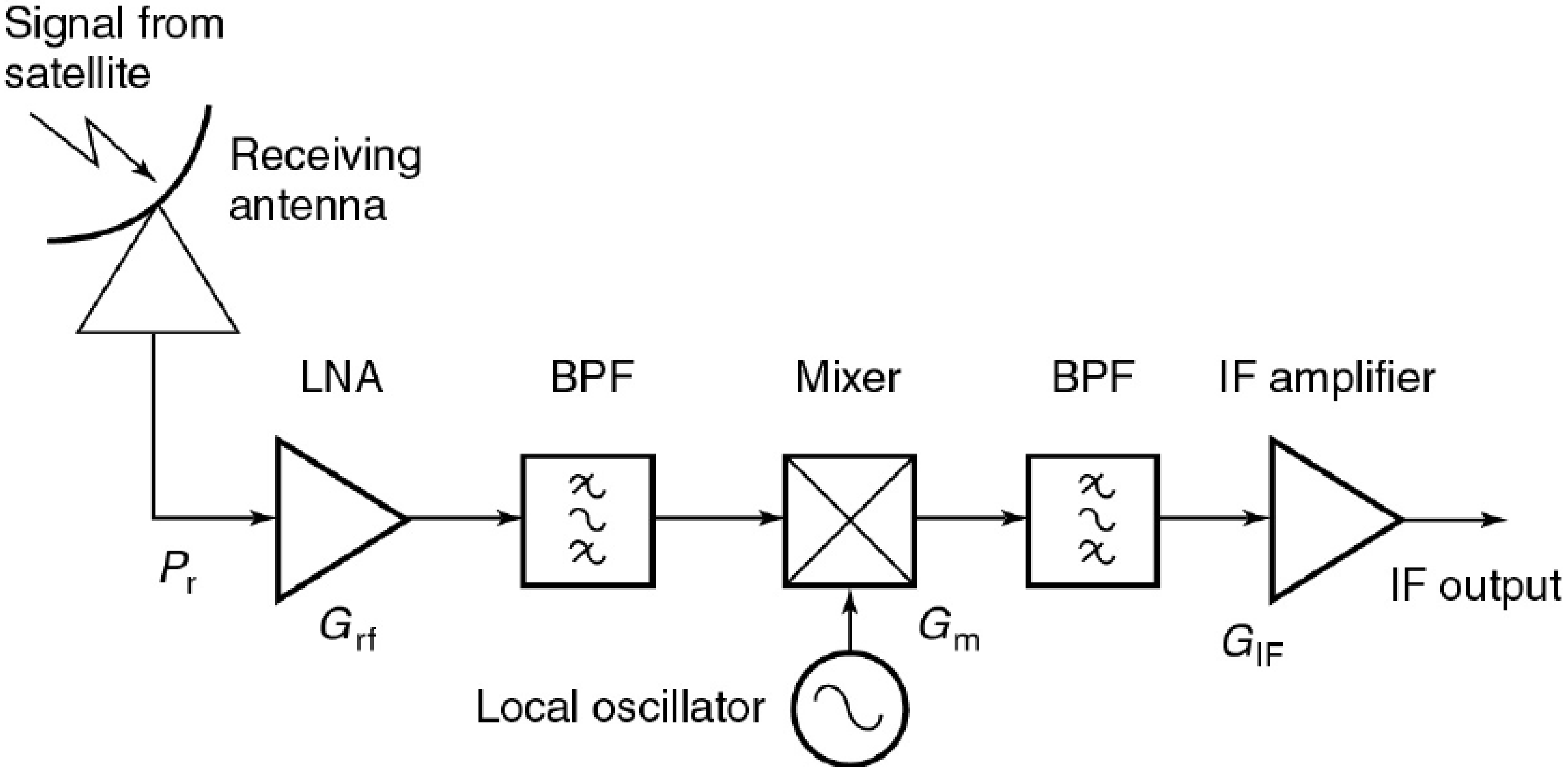
$P_n = KT_nB_n$ (Pn is also denoted as N)

  - where k=Boltzmann’s constant
  - T_n=noise temperature of source in kelvins
  - B_n=noise bandwidth in which the noise is measured,in hertz
- If the over all end-to-end gain of the receiver is G_r and its bandwidth is B_n Hz,the noise power at the demodulator input is

$$P_{no} = KT_nB_n\,G_r$$

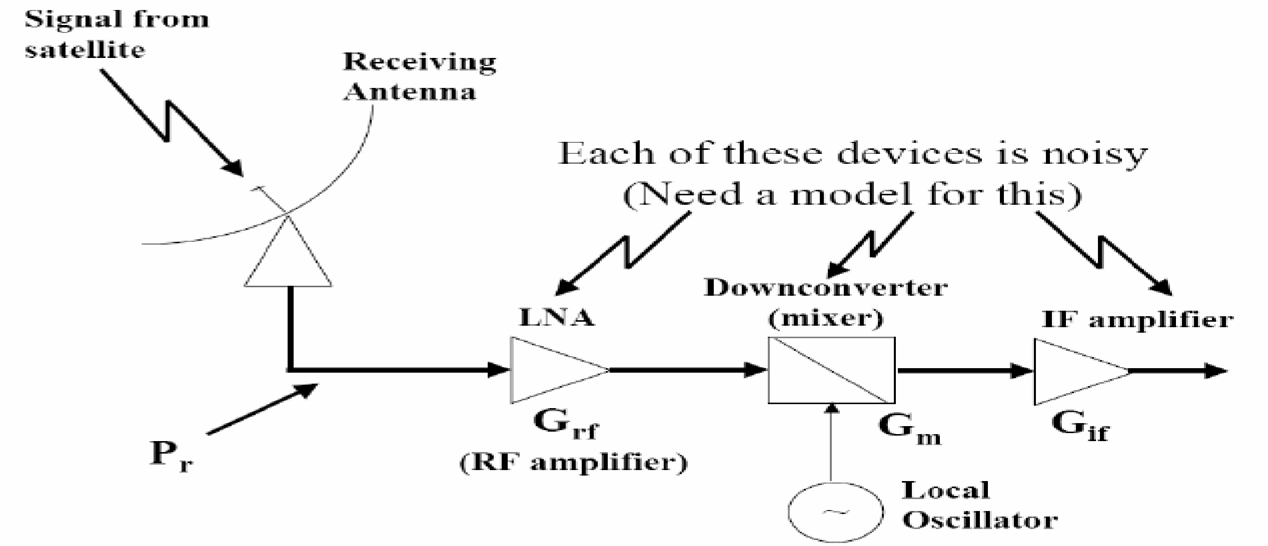
Calculation of System Noise Temperature

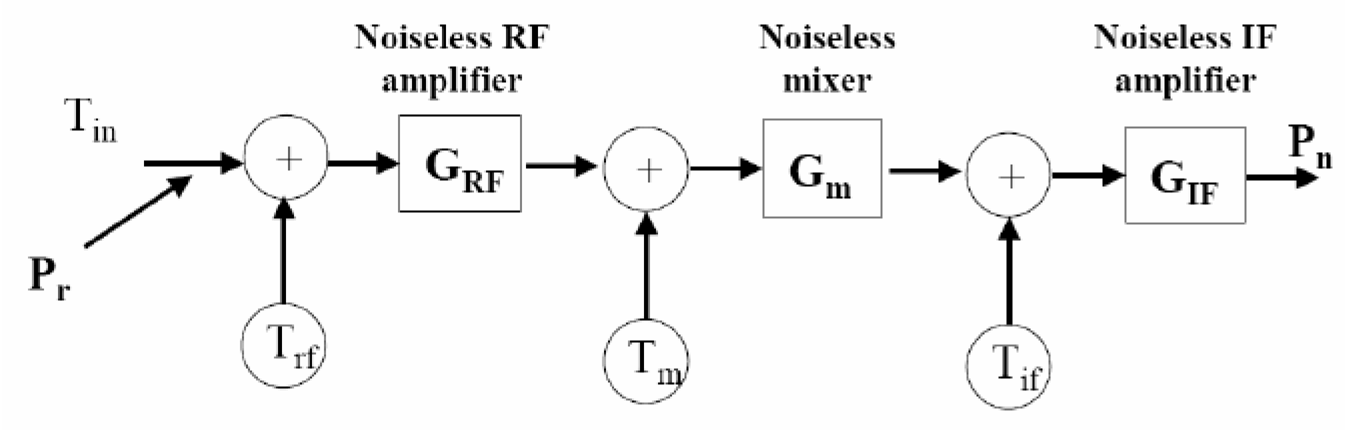
Figure 4.5 (p. 107)
Simplified earth station receiver. BPF, bandpass filter.



Noise Model

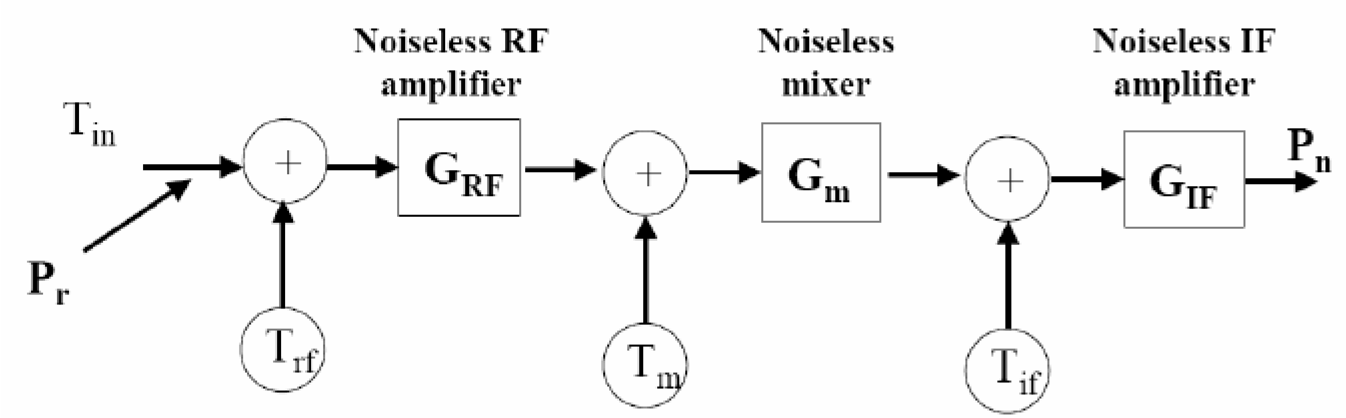
Calculation of System Noise Temperature





Noise Model

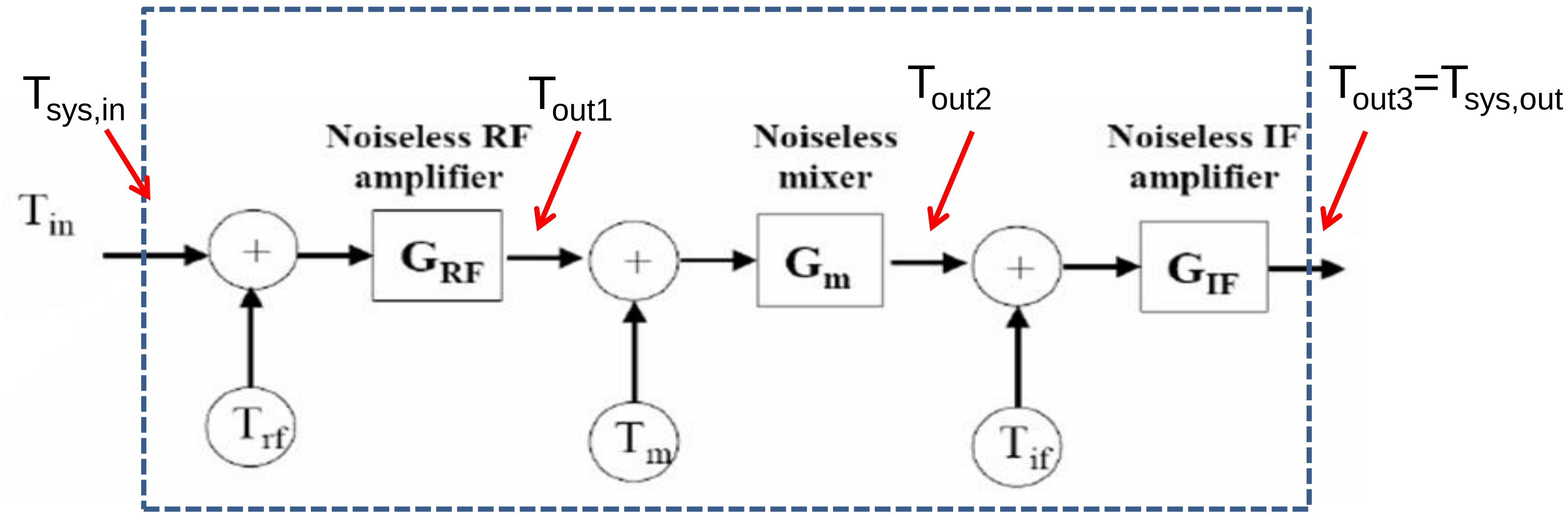
Calculation of System Noise Temperature



- Components are replaced by equivalent noiseless blocks with same gain and noise generators at the input to each block such that the block produces the same noise at its output as the device it replaces
- Noise at component input must be multiplied by corresponding gain to reference at component output
- System Noise Temperature,T_s, is the noise temperature of a noise source, located at the input of a noiseless receiver, which gives the same noise power as the original receiver measured at the output of the receiver and usually includes noise from the antenna

Noise Model for a Cascaded System

Calculation of System Noise Temperature



$T_{out1}=(T_{in}+T_{RF})G_{RF}$ $T_{out2}=(T_{out1}+T_m)G_m$ $T_{out3}=(T_{out2}+T_{IF})G_{IF}$

Therefore,Noise temperature at the output of IF amplifier

$$T_{out3}=\{[(T_{in}+T_{RF})G_{RF}+T_m)]G_m+T_{IF}\}G_{IF}=T_{in}G_{RF}G_mG_{IF}+T_{RF}G_{RF}G_mG_{IF}+T_mG_mG_{IF}+T_{IF}G_{IF}$$

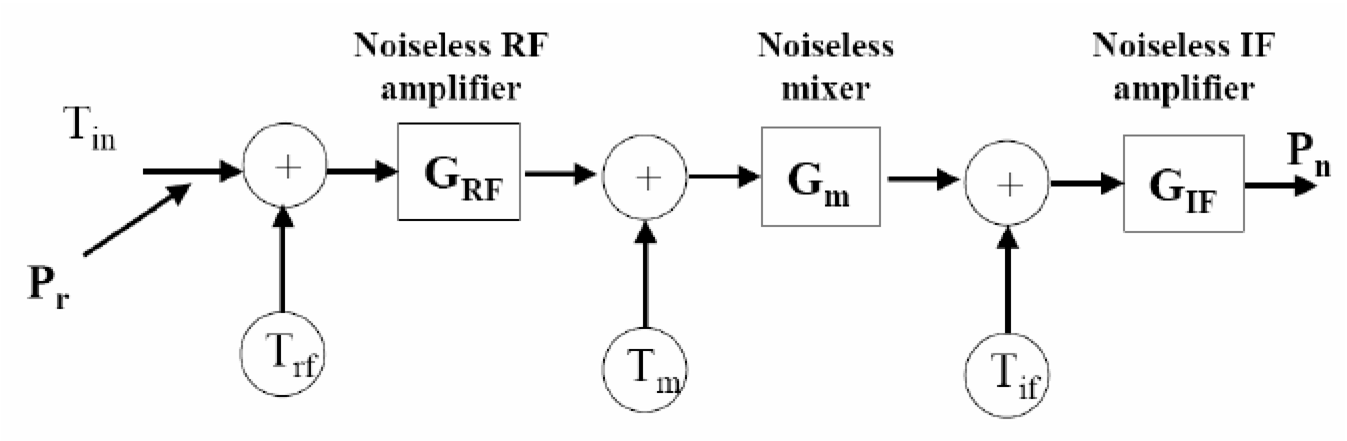
This temperature can be referred to the input of RF Amplifier(LNA),by dividing above eqn by $G_{RF}G_mG_{IF}$ to get $T_{sys,in}$

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

Book’s approach to calculate T_s

Noise Model

Calculation of System Noise Temperature



- Use noise model to write P_n

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

Noise Model

Calculation of System Noise Temperature

- Use noise model to write P_n

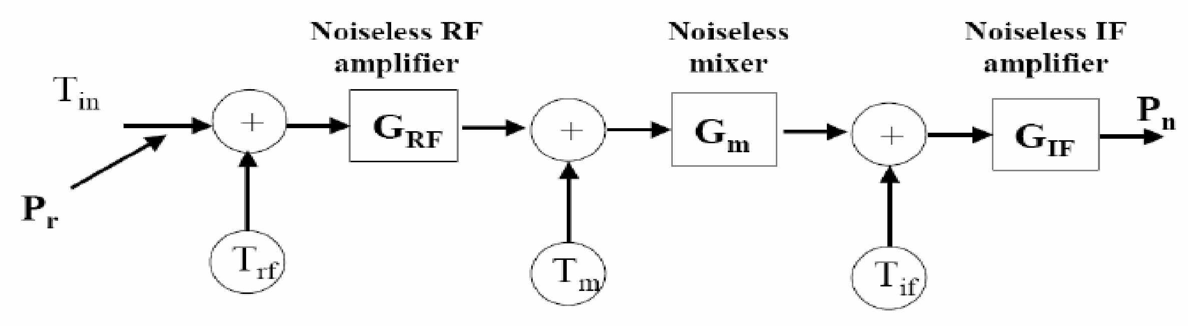
$$
\begin{aligned}
P_n &= G_{IF} k T_{IF} B && \text{(IF)} \\
&+ G_{IF} G_m k T_m B && \text{(Local Oscilator)} \\
&+ G_{IF} G_m G_{RF} k B \left(T_{RF} + T_{in} \right) && \text{(Front-End: RF + Input)}
\end{aligned}
$$

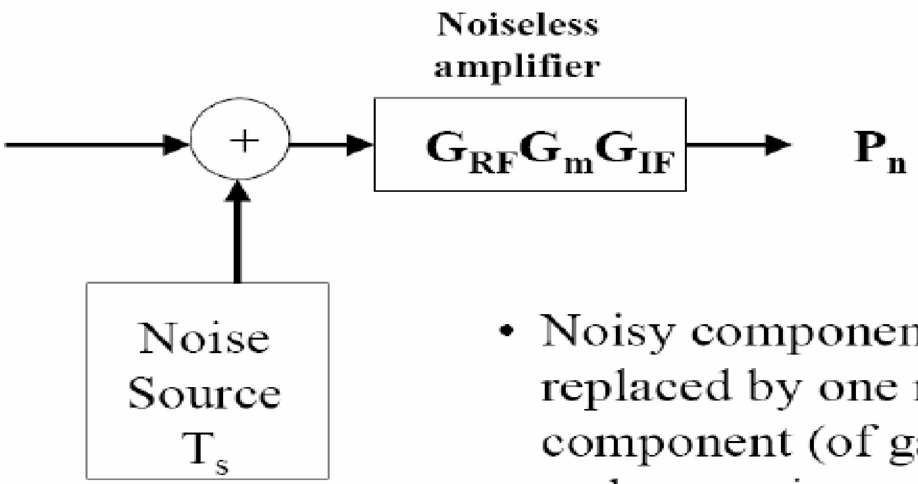
Equation can be written as

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

Equivalent Noise Model of Receiver

Calculation of System Noise Temperature

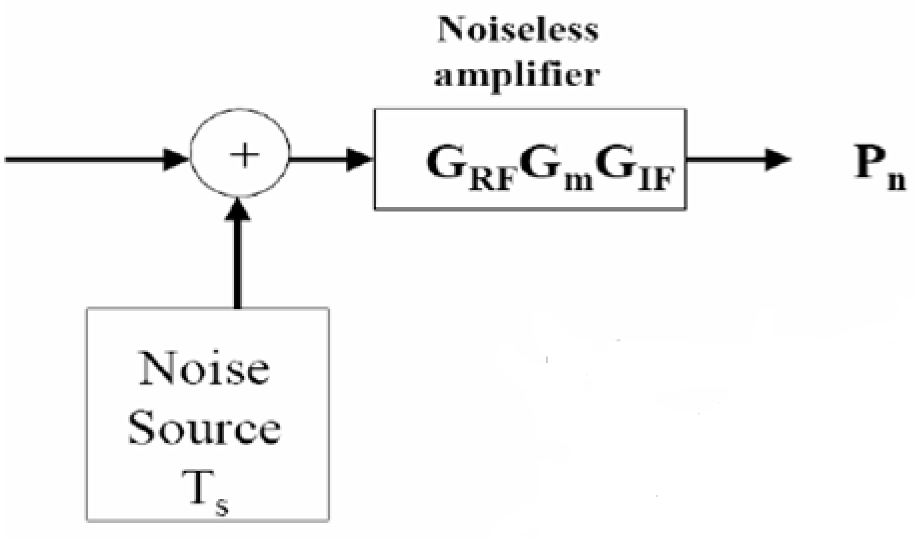




- Noisy components have been replaced by one noiseless component (of gain = $G_{RF}G_mG_{IF}$)
- and one noise source (T_s) at the input, where T_s is the system noise temperature.

Equivalent Noise Model of Receiver

Calculation of System Noise Temperature



- Note that equivalent noise model gives

$$P_n = G_{IF} G_m G_{RF} k T_s B$$

Calculating System Noise Temperature

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

Equation 1

$$P_n = G_{IF} G_m G_{RF} k T_s B$$

Equation 2

- Equate to obtain

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

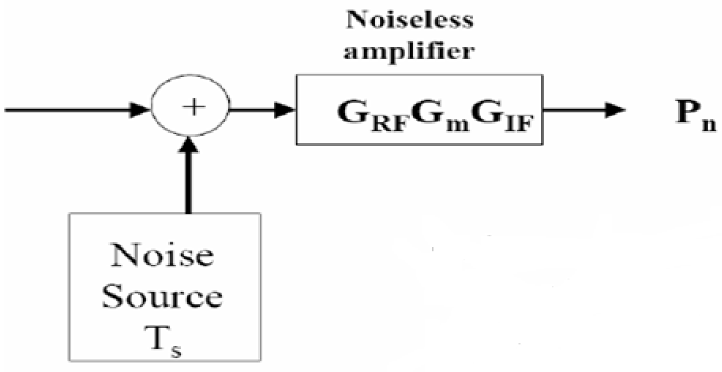
Calculating System Noise Temperature

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

- Succeeding stages of the receiver contribute less and less noise to the total system
- When RF amplifier in receiver frontend has high gain, noise contributed by IF amplifier and later stages can be ignored
- In such a case

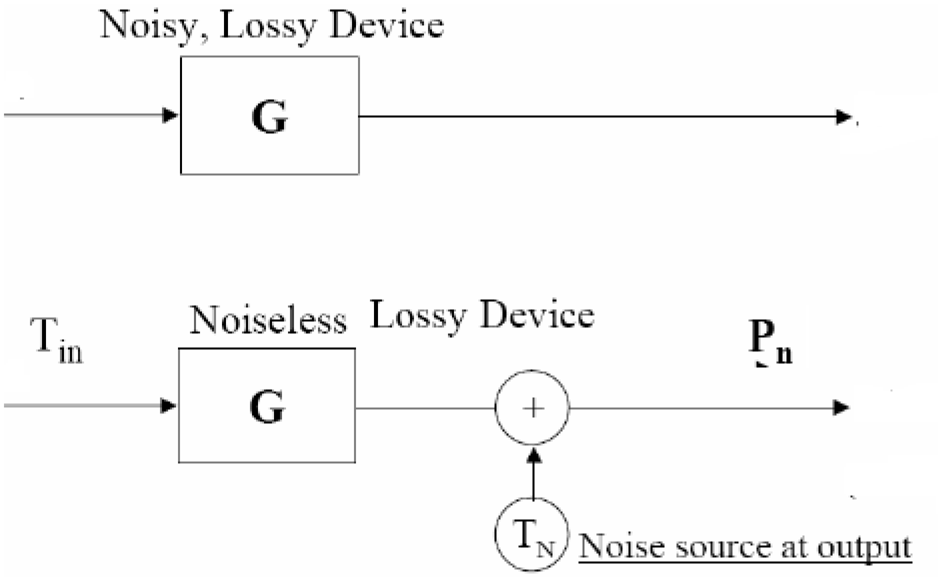
  $T_s = T_{\text{antenna}} + T_{\text{LNA}}$
- Values of gains in above equation are all linear and not decibels

Noise Model For a Lossy Device



- Till now in this model, all noise sources in receiver were replaced by single noise source at the receiver input
- This assumes that all noise comes in from the antenna or is internally generated at the receiver

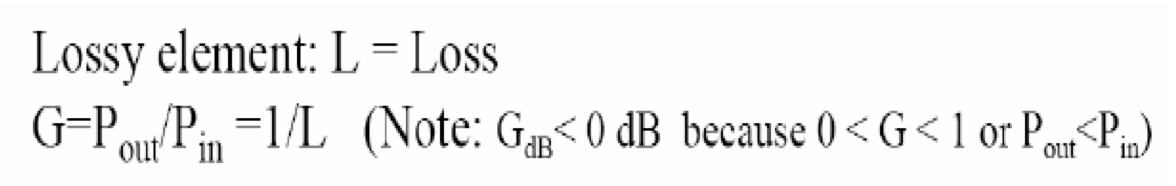
- In some circumstances, we need to use a different model to deal with the noise that reaches the receiver after passing through lossy medium e.g waveguide transmission line and rain losses
- Noise emission is modeled as noise source placed at "output" of atmosphere



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

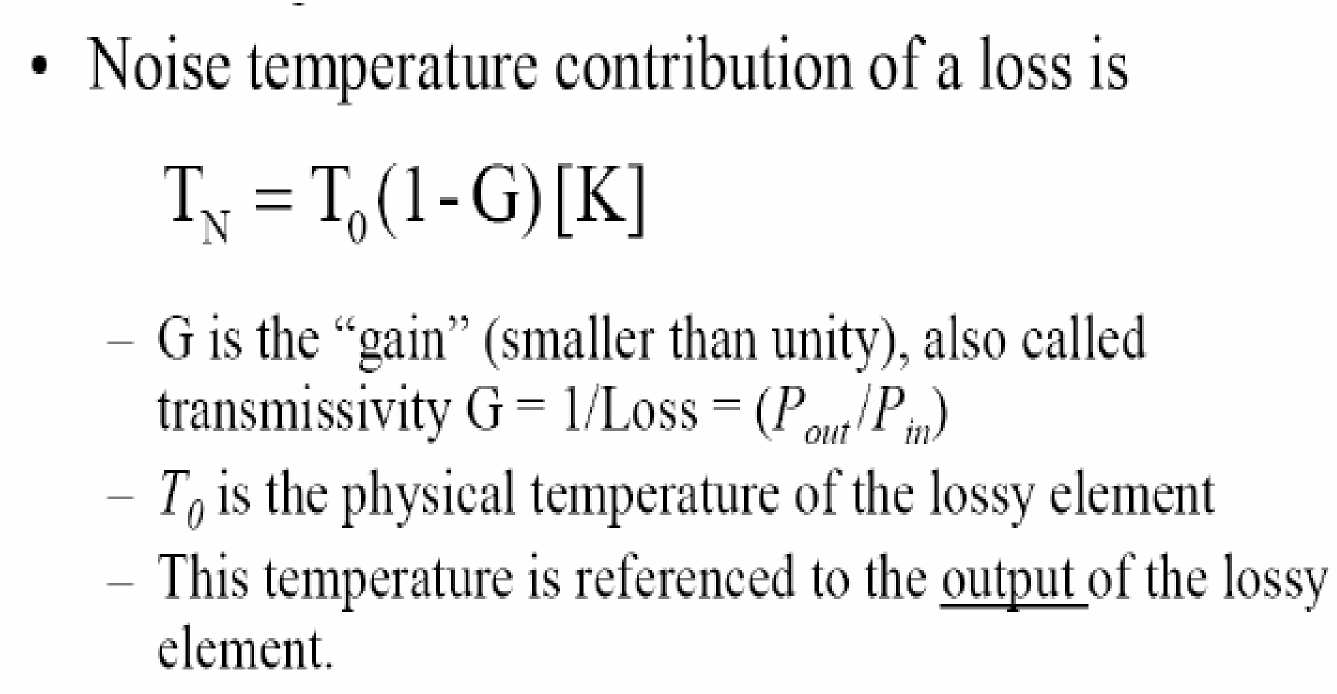
Noise Model For a Lossy Device

It is important to remember that the 'gain' of the individual subsystems can be greater or less than 1.0



Lossy element: L = Loss

$G = P_{out}/P_{in} = 1/L$ (Note: $G_{dB} < 0$ dB because $0 < G < 1$ or $P_{out} < P_{in}$)



- Noise temperature contribution of a loss is

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

  - G is the "gain" (smaller than unity), also called transmissivity $G = 1/\text{Loss} = (P_{out}/P_{in})$
  - T_0 is the physical temperature of the lossy element
  - This temperature is referenced to the output of the lossy element.

Noise Figure and Noise Temperature

- Noise figure (NF) is a measure of degradation of the signal to noise ratio (SNR), caused by components in the RF signal chain
- Noise Figure is defined as the ratio of signal to noise ratio at the input to that at the output
- NF= $\dfrac{[S/N]_{in}}{[S/N]_{out}}$
- Noise Figure can be converted to noise temperature T_d
- $T_d = T_o(NF-1)$,
  - where NF is a linear ratio, not in decibels and where T_o is reference temperature used to calculate standard noise figure. Usually 290 K

G/T Ratio for Earth Station: A Figure of Merit

- Transmitters are characterized by EIRP
- Receivers are characterized by G_r/T_s or G/T
- G/T describes the sensitivity of a receive system
- Also called the system figure of merit as it specifies the quality of a receiving earth station or a satellite receiving system

Link Budget Equation and G/T

- Now we have defined C and N, write C/N as

$$\frac{C}{N} = \frac{P_r}{kT_sB} = \frac{P_tG_tG_r}{kT_sB}\left[\frac{\lambda}{4\pi R}\right]^2$$

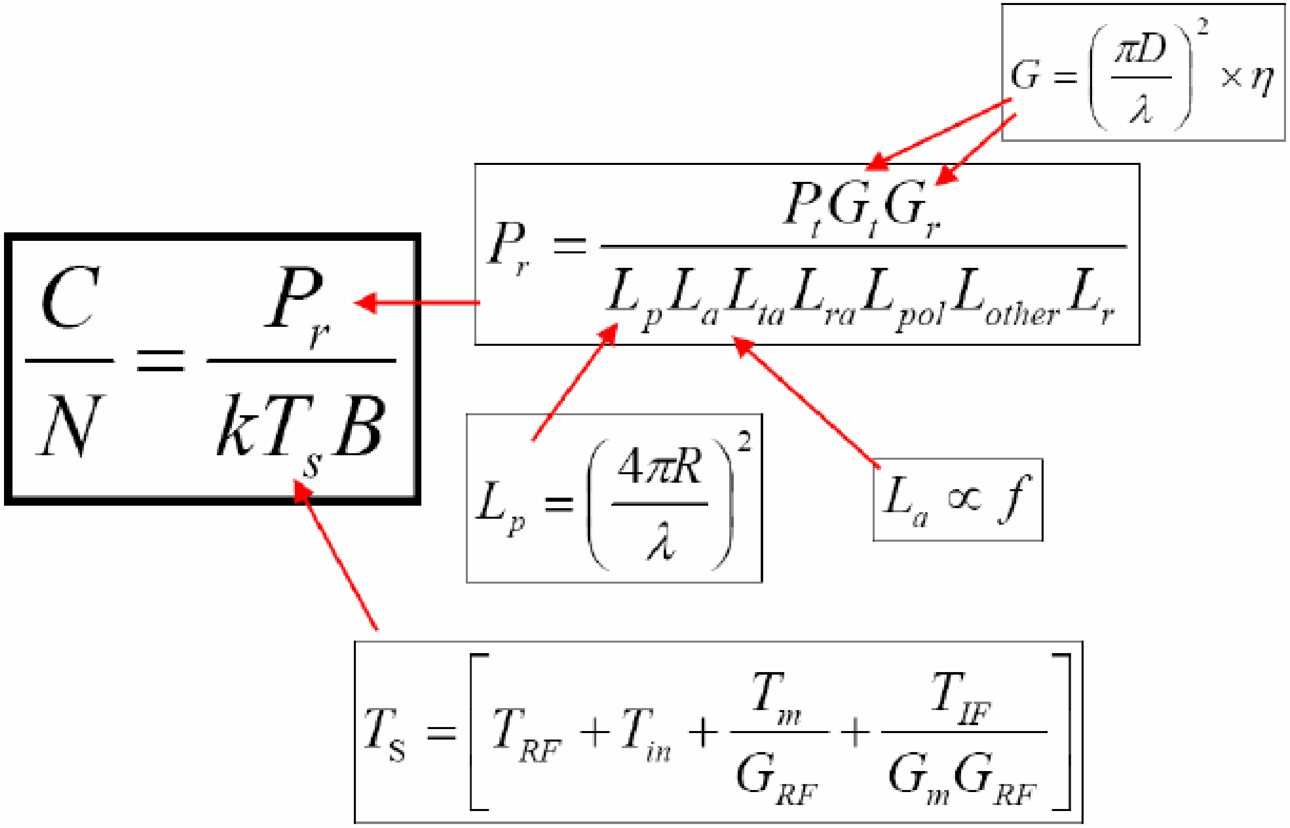
$$= \frac{P_tG_t}{kB}\left[\frac{\lambda}{4\pi R}\right]^2 \frac{G_r}{T_s}$$

- Therefore,

$$\frac{C}{N} \propto \frac{G_r}{T_s}$$

- Usually given in dB/K or dBK^{-1}

Link Budget Summary



$$\frac{C}{N} = \frac{P_r}{kT_s B}$$

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

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

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

$$L_a \propto f$$

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

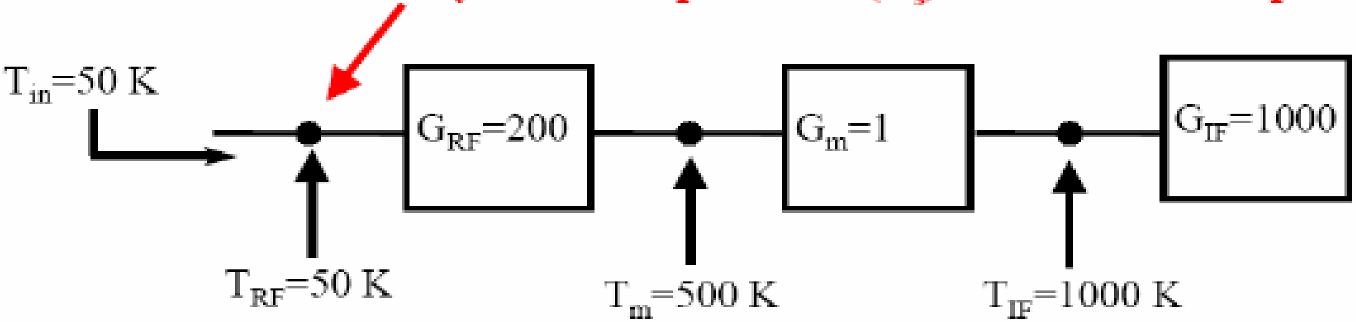
Numerical Example 1-Noise Temperature

- Given: 4 GHz Receiver

$T_{in} = T_a = 50\text{ K}$

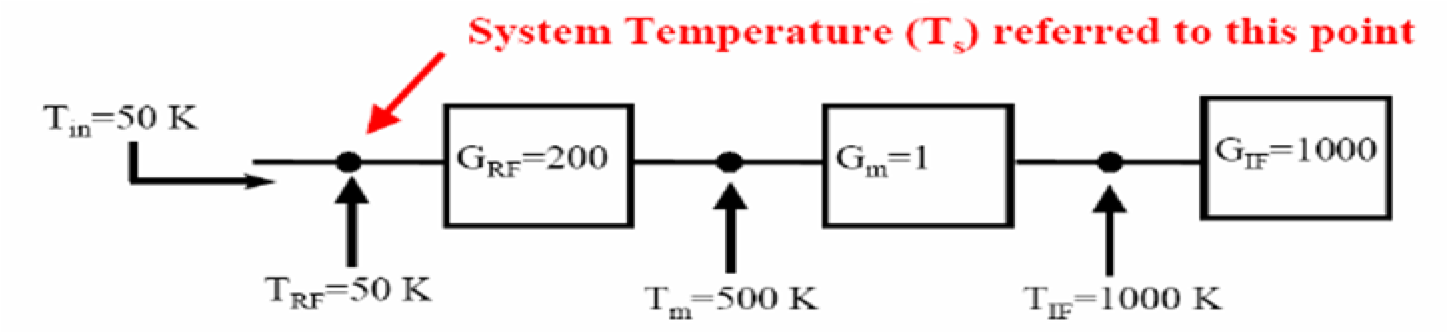
$T_{RF} = 50\text{ K}$	$G_{RF} = 23\text{ dB} \quad (=200)$
$T_m = 500\text{ K}$	$G_m = 0\text{ dB} \quad (=1)$
$T_{IF} = 1000\text{ K}$	$G_{IF} = 30\text{ dB} \quad (=1000)$

- Find: System temperature T_s at antenna output



System Temperature (T_s) referred to this point

Numerical Example 1-Noise Temperature



System Temperature (T_s) referred to this point

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

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

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

Numerical Example 1-Noise Temperature

(b) If mixer has 10 dB loss

$$G_m = -10\text{dB} = 0.1$$

$$T_S = \left[50 + 50 + \frac{500}{200} + \frac{1000}{0.1 \times 200}\right] = 152.5K$$

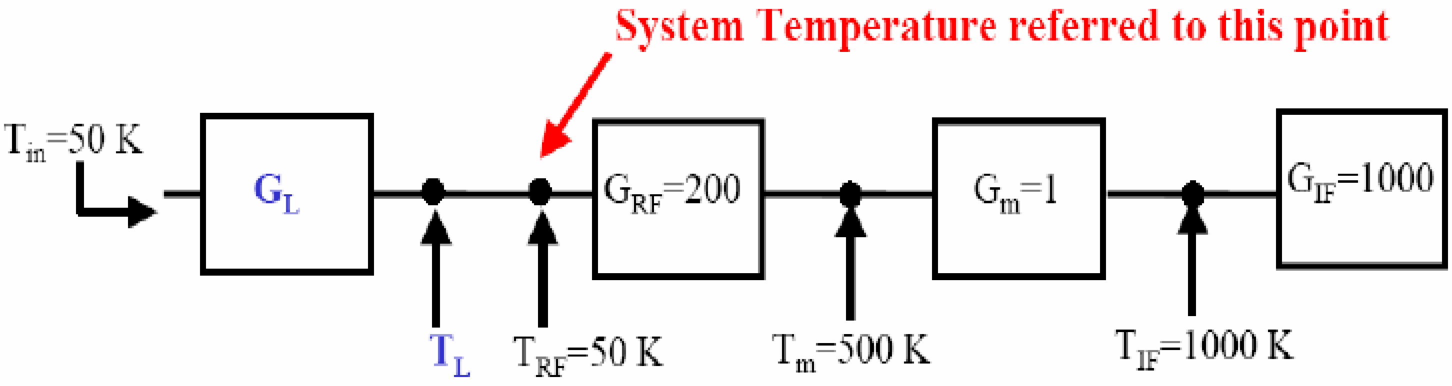
– Comment: $G_{RF}G_m$ is too small, so IF amplifier contribution is large

(c) If, in addition, $G_{RF} = 50$ dB ($=10^5$)

$$T_S = \left[50 + 50 + \frac{500}{100{,}000} + \frac{1000}{0.1 \times 100{,}000}\right] = 100.1K$$

Numerical Example 2-Lossy Elements

- Now insert a lossy waveguide with L = 2 dB between antenna and LNA
- Find system temperature at LNA input



Numerical Example 2-Lossy Elements

- 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}:

$$\begin{aligned} T_{\mathrm{in}} &= T_{\mathrm{a}}\mathrm{G}_{\mathrm{L}} + \mathrm{T}_{\mathrm{L}} \\ &= 50 \text{ x } 0.63 + 107.3\ \mathrm{K} \\ &= 138.8\ \mathrm{K} \end{aligned}$$

Numerical Example 2-Lossy Elements

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

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

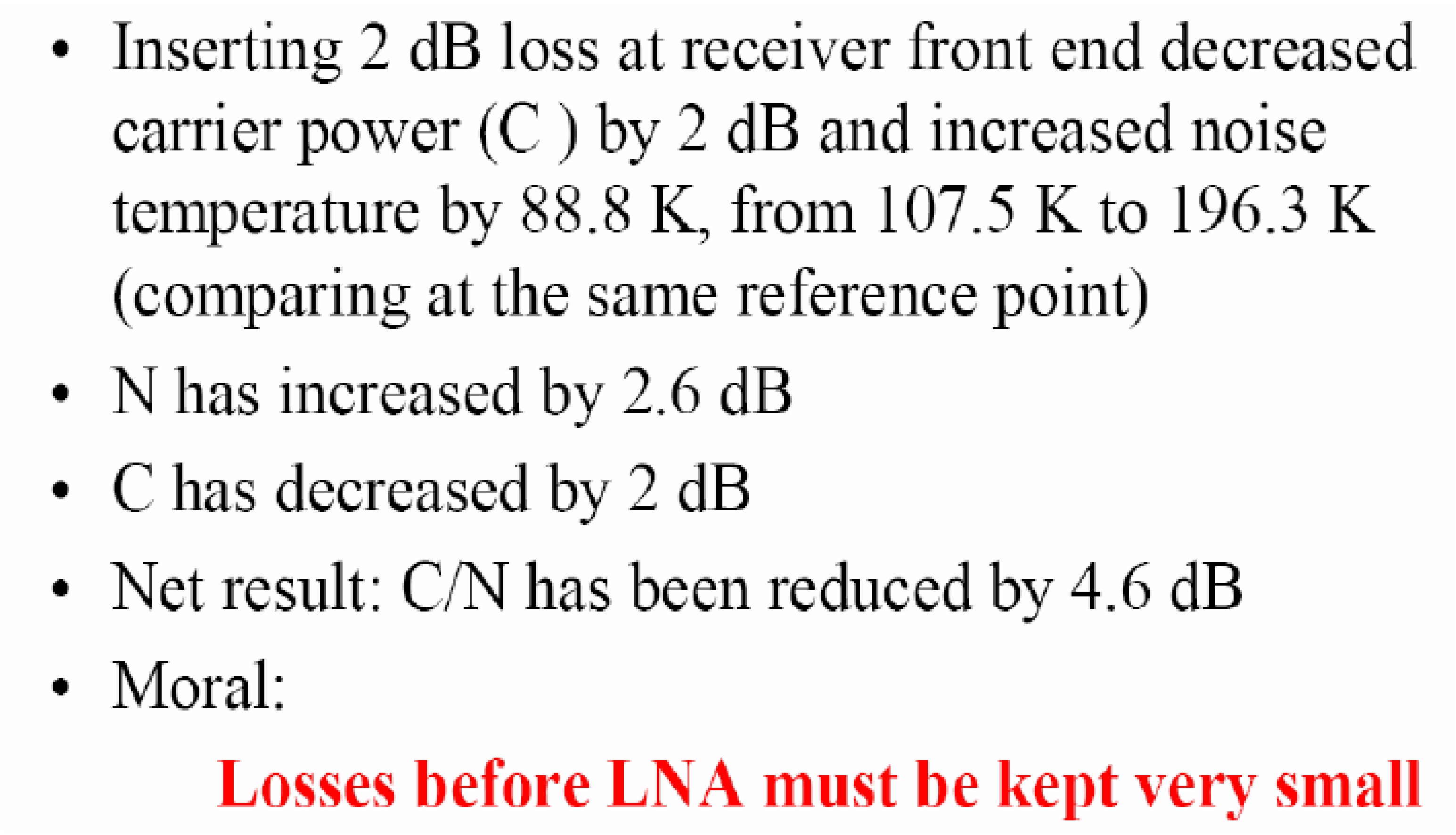
$$= [138.8 + 50 + 2.5 + 5] = 196.3K$$

From Previous Example of Noise Temperature

- So noise temperature (power) increased from 107.5 to 196.3 K *at the same reference point*

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

Numerical Example 2-Lossy Elements



- Inserting 2 dB loss at receiver front end decreased 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
- Net result: C/N has been reduced by 4.6 dB
- Moral:

Losses before LNA must be kept very small