A Man-Made Noise:

This type of noise is originated from the equipment that are installed near to the communication systems. It is include: ignition systems, commutator sparking, Fluroscent lamps, light dimmers, or the near by communication systems.

B Natural Noise:

It can be subdivided into:

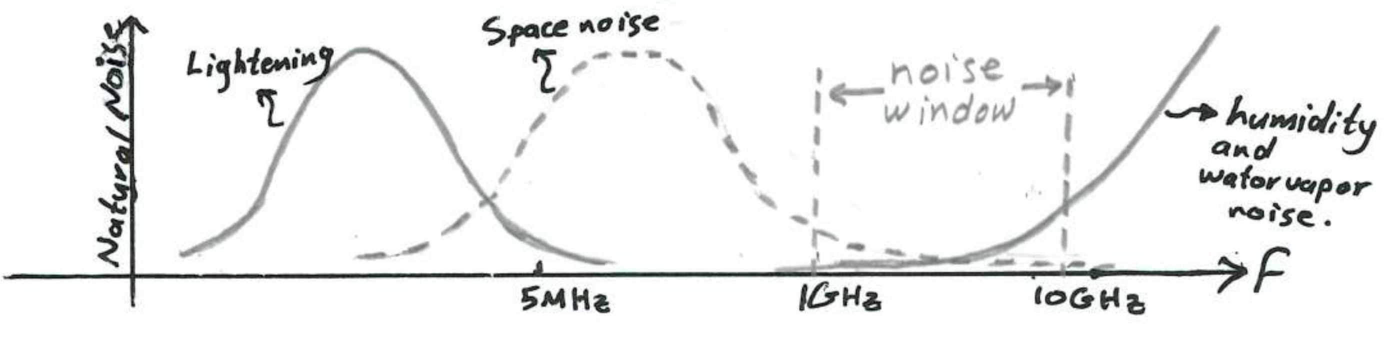
- Atmospheric noise: such as

a) lightening and the thunder storms which travels for long distances and affects the low-Frequency (LF) regions (up to several MHz).

b) Water vapor and humidity which attenuate the traveling signal effectively as the frequency of the signal increased. The effect of this noise is getting sensible at frequency rang larger than 10GHz.

- Space Noise: such as the sun rays, cosmic ray. Sometimes it is called Sky noise. Its effect is extended upto about 1GHz;

<u>Note:</u> It is clear that the frequency range 1GHz-10GHz under goes minimum amount of natural noise, for this reason it is called the "<u>noise window</u>". Therfore, most of the wireless systems chose this rang for their applications. mobile comm., satellite, military comm, WiFi, ...

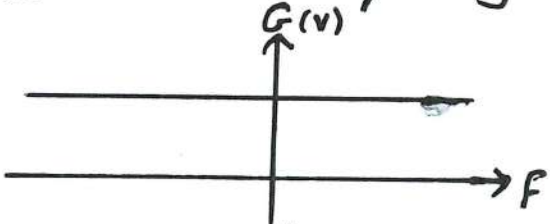


1.2 Internal Noise:

This category of noise is generated within the equipment of the communication system. It can be sub-divided to:

A Thermal Noise:

* It is produced by the random motion of electrons in a conductors due to heat. It belongs to special kind of noise called "White Noise". The power spectral density of the white noise is constant with frequency. It affects all the frequency components equally likely.



white noise.

It just like the "White Color" which has spectrum includes the whole colors. Therefore, the non-white noise is called "Color Noise".

* Thermal noise also have Gaussian random distribution, so it is also called "Gaussian Noise".

* It exist in all kinds of conductors and resistances.

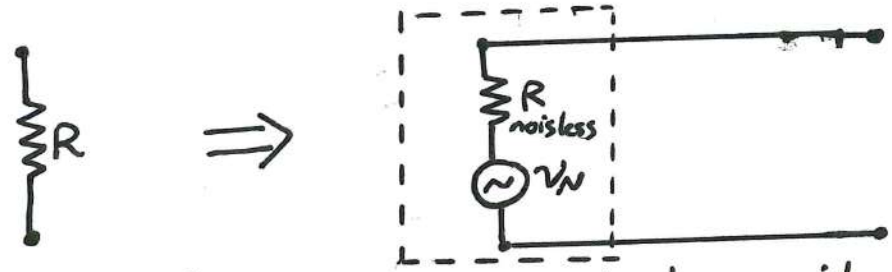
- Noise Nyquist Theorem: states that the mean-square noise voltage ($\overline{v_N^2}$) appearing across the terminals of a resistance (R) ohms at a temprature (T) kelvin in frequency band (B) Hz is given by:

$$\overline{v_N^2} = 4kTRB$$

and the (r.m.s) noise voltag ($V_{rms} = v_N$) is given by:

$$v_N = \sqrt{\overline{v_N^2}} = \sqrt{4kTRB}$$

where k is Boltzmann's constant $= 1.38 \times 10^{-23}$ (J/K)

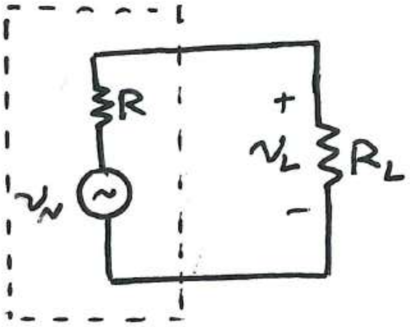


Noisy resistance   Equivalent circuit

- Maximum Available Power:

For matched load ($R_L = R$)

P_a = max. available power delivered to the load $= \frac{1}{2} P_{source}$



$$P_a = \frac{v_L^2}{R_L} \quad , \quad v_L = \frac{R_L}{R+R_L} v_N = \frac{1}{2} v_N$$

$$\therefore P_a = \frac{(\frac{1}{2} v_N)^2}{R} \cong \frac{\overline{v_N^2}}{4R}$$

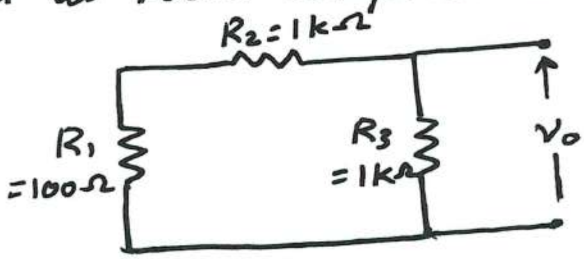
$$\therefore P_a = \frac{4kTBR}{4R} \Rightarrow \boxed{P_a = KTB}$$

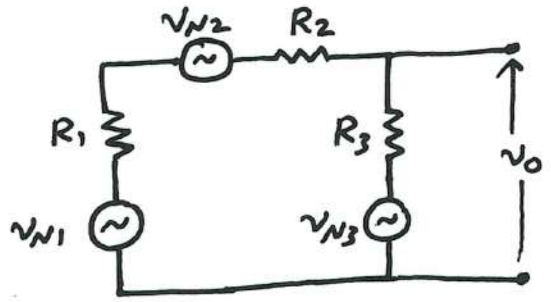
This means that the noise power generated by a resistor is directly proportional to its <u>absolute temprature</u> and to the <u>bandwidth</u> over which the noise to be measured.

* The total rms voltage of a circuit comprising number of noisy sources can be calculated as follows:

$$\boxed{v_o = \sqrt{\overline{v_{N1}^2} + \overline{v_{N2}^2} + \overline{v_{N3}^2} + \cdots + \overline{v_{Nn}^2}}}$$

Example: For the network shown below, find the total r.m.s noise voltage appearing at the output (v_o) in a 100KHz BW and at room temprature (17°C).





Sol.

$\overline{v_{N1}^2} = 4KTBR_1$, $\overline{v_{N2}^2} = 4KTBR_2$, $\overline{v_{N3}^2} = 4KTBR_3$

where $T = 17 + 273 = 290\ K^\circ$

$B = 100\ kHz = 10^5\ Hz$, $K = 1.38 \times 10^{-23}\ J/K^\circ$

$\overline{v_{N1}^2} = 1.6 \times 10^{-13}\ W \Rightarrow v_{N1} = 4 \times 10^{-7}$ volt.

$\overline{v_{N2}^2} = 1.6 \times 10^{-12}\ W \Rightarrow v_{N2} = 1.265 \times 10^{-6}$ volt.

$\overline{v_{N3}^2} = 1.6 \times 10^{-12}\ W \Rightarrow v_{N3} = 1.265 \times 10^{-6}$ volt.

but $\overline{v_o^2} = \overline{v_{o1}^2} + \overline{v_{o2}} + \overline{v_{o3}}$ {Superposition}

$$v_{o1} = I_1 R_3 = \frac{v_{N1}}{R_1 + R_2 + R_3} \cdot R_3 = 1.9 \times 10^{-7} \text{ volt.}$$

$$v_{o2} = I_2 R_3 = \frac{v_{N2}}{R_1 + R_2 + R_3} \cdot R_3 = 6.024 \times 10^{-7} \text{ volt.}$$

$$v_{o3} = I_3 (R_1 + R_2) = \frac{v_{N3}}{R_1 + R_2 + R_3} (R_1 + R_2) = 6.626 \times 10^{-7} \text{ volt.}$$

$$v_o = \sqrt{\overline{v_{o1}^2} + \overline{v_{o2}^2} + \overline{v_{o3}^2}} \Rightarrow \boxed{v_o = 9.154 \times 10^{-7} \text{ volt}}$$

B Shot Noise:

It is due to random variation in current flow in semi-conductor devices (Transistors, diodes, tubes, ---). It seems like the pellets of the shotgun. Its major effect appears at the junction points between the semi-conductor and the conductor.

C Partition Noise:

It occurs only in devices where a single current separates into two or more paths. An example of such devices is a BJT transistor where the emitter current is the sum of the collector and base currents.

D Flicker Noise :

It also occurs in semi-conductor devices, but its effect is negligible in communication systems because it caused by the variations in carrier density which is proportional to $(\frac{1}{f})$. Its effect at 1kHz is negligible.

E Transit-Time Noise :

Many junction devices produce more noise at frequencies approaching their resonant frequencies. It is a high-freq. noise occurs when the time taken by charge carriers to cross a junction ~~is comparable to cross a junction~~ is comparable to the period of the signal.

2. Signal-to-Noise Ratio (S/N):

It is the ration of signal power (P_s) to noise power (P_N), and usually expressed in (dB) as:

$$(S/N) = SNR = \frac{P_s}{P_N}$$

$$(S/N)_{dB} = 10 \log\left(\frac{P_s}{P_N}\right) \quad dB$$

Some important units:

- dBm (dB per 1mW): $dBm = 10 \log\left(\frac{P(watt)}{1\,mW}\right)$
- dBW (dB per 1W): $dBW = 10 \log\left(\frac{P(watt)}{1\,Watt}\right)$
- dBrn (dB per reference noise $1pW = 10^{-12}$ watt):

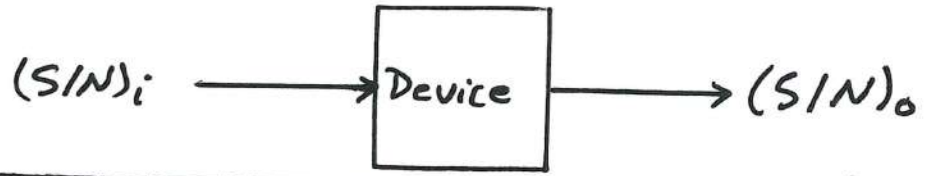
$$dBrn = 10 \log\left(\frac{P(watt)}{1\,pW}\right).$$

- dBmV (dB per 1mV): $dBmV = 20 \log\left(\frac{V_{rms}}{1\,mV}\right)$
- The Neper (N): $N = \frac{1}{2} \ln\left(\frac{P_o}{P_i}\right)$

$$N = 0.1151\ dB$$
$$dB = 8.686\ N$$

3. Noise Figure (F):

It is a figure of merit relating $(S/N)_i$ input signal-to-noise ratio to the $(S/N)_o$ output signal-to-noise ratio of a certain device.



$$F = \frac{(S/N)_i}{(S/N)_o} \qquad F(dB) = 10 \log(F)$$

$$F(dB) = 10 \log\left(\frac{(S/N)_i}{(S/N)_o}\right)$$
$$F(dB) = (S/N)_i(dB) - (S/N)_o(dB)$$

* The <u>minimum</u> value of F is:

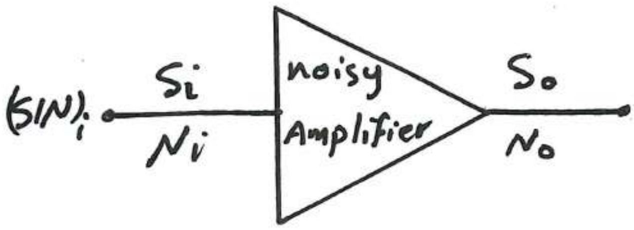
$$F = 1 \quad \text{or} \quad F(dB) = 0\ dB$$

This means the device add zero amount of noise to the signal $[(S/N)_i = (S/N)_o]$.

* As F increases, the quality of the device decreases.

4. Effective Noise Temperature (T_e):

It is the absolute temprature required of a <u>thermal resistance</u> placed at the input of a noiseless system in order to produce the same available noise power at the output as is produced by the internal noise source of the system.



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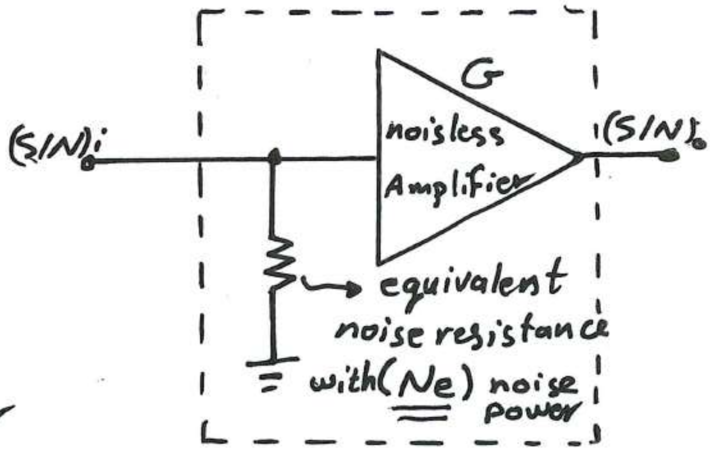


$$G = \frac{S_o}{S_i}$$

where S is the signal power
N is the noise power
G is the power gain of the amplifier.

$$F = \frac{(S/N)_i}{(S/N)_o} = \frac{S_i \cdot N_o}{S_o \cdot N_i} \quad , \text{ but } \frac{S_o}{S_i} = G$$

$$\therefore \boxed{F = \frac{N_o}{G\,N_i}}$$

It is clear from the equivalent circuit of the amplifier:

$$N_o = G N_i + G N_e$$

$$N_o = G(N_i + N_e)$$

where N_e is the effective noise power of the amplifier

$$\therefore F = \frac{G(N_i + N_e)}{G N_i} \Rightarrow F = 1 + \frac{N_e}{N_i}$$

$$\therefore \boxed{N_e = (F-1) N_i}$$

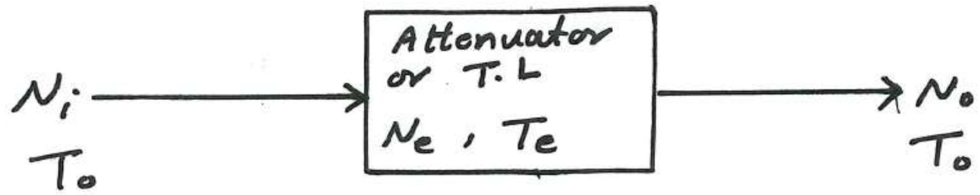
The input noise (N_i) is thermal noise at room temperature (T_o), while the device noise (N_e) is thermal noise with effective noise temprature (T_e).

$$\therefore k T_e B = (F-1)\, k T_o B$$

$$\therefore \boxed{T_e = (F-1) T_o}$$

or $\boxed{F = 1 + \frac{T_e}{T_o}}$ where $T_o = 17^\circ C + 273 = 290^\circ K$

Special Case: Attenuators and Transmission Lines



$$G = \frac{1}{L}$$

or $\boxed{L = \frac{1}{G}}$ where L is the losses.

$$F = \frac{N_o}{G\,N_i}$$

$$N_o = G\,N_i\,F$$

$$K T_o B = G(K T_o B)\left(1 + \frac{T_e}{T_o}\right)$$
, since the attenuators and T.L.s have the same BW at the input and output,

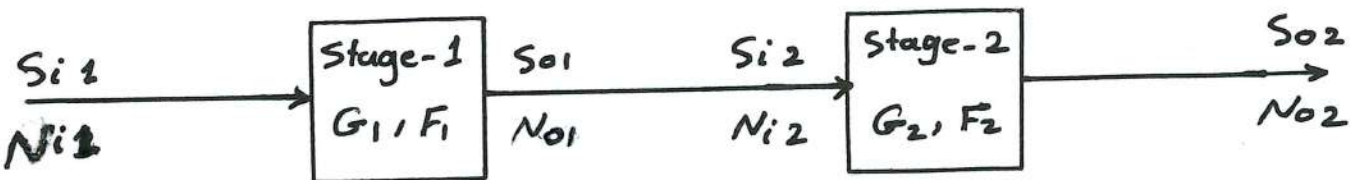
$$1 = G\left(1 + \frac{T_e}{T_o}\right)$$

$$\therefore \frac{1}{G} = \left(1 + \frac{T_e}{T_o}\right) \Rightarrow L = 1 + \frac{T_e}{T_o}$$

but $1 + \frac{T_e}{T_o} = F$

$$\therefore \boxed{F = L = \frac{1}{G}}$$
For attenuators and T.L only.

5. System Noise Calculations:



$N_{e1} = (F_1 - 1) N_{i1}$ $\qquad$ $N_{e2} = (F_2 - 1) N_{i2}$

where

$$N_{i1} = K T_o B$$

$$\therefore N_{o1} = G_1\,N_{i1}\,F_1 \Rightarrow N_{o1} = G_1\,F_1\,K T_o B$$

Now, let's derive an expression for the entire noise figure (F_t) in term of F_1 and F_2

$$Ne_2 = (F_2 - 1) \cdot Ni_2 = (F_2 - 1) K T_o B$$

$$\therefore No_2 = (No_1 \cdot G_2) + (Ne_2 \cdot G_2)$$

$$No_2 = (G_1 F_1 \cdot K T_o B \cdot G_2) + (F_2 - 1) \cdot K T_o B \cdot G_2$$

$$No_2 = K T_o B G_2 [G_1 F_1 + (F_2 - 1)]$$

but $F_t = \dfrac{No_2}{G_t \cdot Ni_1} = \dfrac{K T_o B G_2 [G_1 F_1 + (F_2 - 1)]}{G_1 G_2 \; K T_o B}$

$$F_t = \frac{G_1 F_1 + (F_2 - 1)}{G_1} \Rightarrow \boxed{F_t = F_1 + \frac{F_2 - 1}{G_1}}$$

The above equation can be generalized for any number of stages as:

For N number of stages
$$\boxed{F_t = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} + \cdots + \frac{F_N - 1}{G_1 G_2 G_3 \cdots G_{N-1}}}$$

but $F = 1 + \dfrac{T_e}{T_o}$

$$\therefore 1 + \frac{T_{et}}{T_o} = \left(1 + \frac{T_{e1}}{T_o}\right) + \frac{1 + \frac{T_{e2}}{T_o} - 1}{G_1} + \frac{1 + \frac{T_{e2}}{T_o} - 1}{G_1 G_2} + \cdots$$

$$\therefore \boxed{T_{et} = T_{e1} + \frac{T_{e2}}{G_1} + \frac{T_{e3}}{G_1 G_2} + \cdots + \frac{T_{eN}}{G_1 G_2 \cdots G_{N-1}}}$$

<u>Notes:</u>

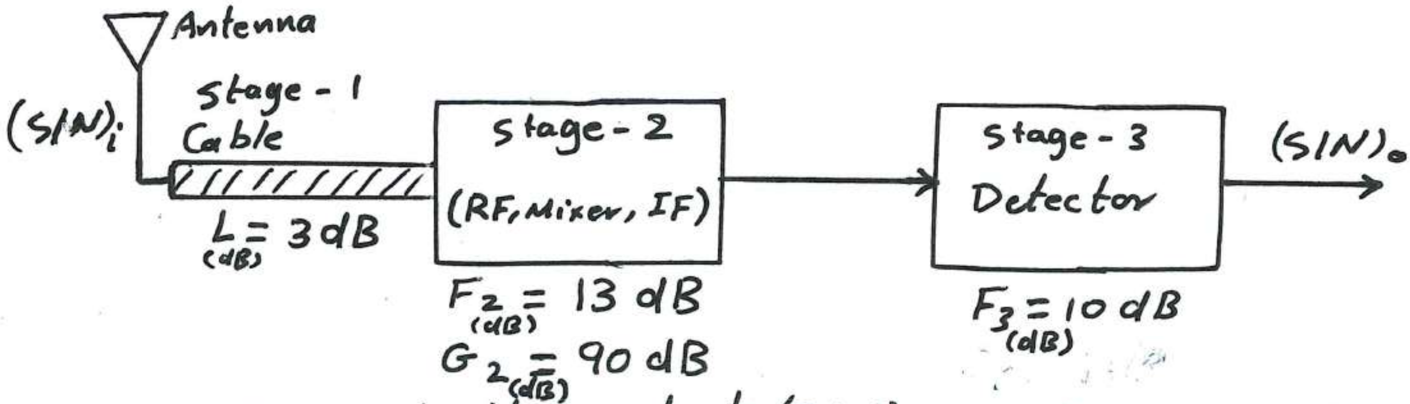
$$F_t = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \cdots$$

a) The 1st device dominates the system noise figure if it has high gain, so the system designers always put Low-Noise Amplifiers (or Low-Noise Blocks LNB) at the first stage to keep the overall noise figure (F_t) as small as possible.

b) If we have the choice of interchanging between the amplifiers, we should put the amplifier with the <u>lowest noise figure</u> to be the <u>1st stage</u>.

c) The gain of the last stage does not affect the system noise figure at all.

<u>Example:</u> The TV Receiver:



Find F_t and the output $(S/N)_o$ if $(S/N)_{i\,(dB)} = 52\,dB$.

<u>Sol.</u>

Cable is a T.L so $F_{1(dB)} = L_{dB} = 3\,dB$ and $G_1 = \frac{1}{L_{(ratio)}}$

Now Let's convert the noise figure values and the gain values to ratio.

$L = 10^{3/10} \cong 2$

$\therefore F_1 = 2 \quad , \quad G_1 = \frac{1}{2}$

$F_2 = 10^{13/10} \cong 20 \quad , \quad G_2 = 10^{90/10} = 10^9$

$F_3 = 10^{10/10} = 10$

$$\therefore F_t = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2}$$

$$F_t = 2 + \frac{20 - 1}{(\frac{1}{2})} + \underbrace{\frac{10 - 1}{\frac{1}{2} \times 10^9}}_{\approx 0}$$