NOISE

* Any unwanted signal is considered as noise.
* Noise tends to interfere with received or produced signals.
* EXAMPLES :-
  * In receivers, several electrical distrurbances produces noise and thus modifying the required signal in an unwanted form.
  * Radio Receivers : The loudspeaker produce a hiss type sound due to noise.
  * T.V. ; The noise can be seen as snow in the displaying screen.
  * In pulse communication : The noise may alter the pulse from +ve to -ve.

Thus The Noise may Limit the performance of a communication system.

* Generally speaking: There are External & Internal noises.

* External Noise: Atmospheric noise,
Extraterrestrial noise,
Industrial noise

External noise is that noise generated outside the communication system.

* Internal Noise: shot noise,
Partition noise,
Low frequency or Flicker noise.
High frequency or transit-time noise.
Thermal noise.

Internal noise is that noise which is generated inside a communication system

Atmospheric Noise :

* Atmospheric noise also called static noise.
* static noise produced by discharges in thunderstorms and other natural electrical disturbances of the atmosphere.
* It is electrical impulses & random in nature.
* Atmospheric noise distributed over the complete frequency spectrum used for radio communication.
* $\boxed{\text{atmospheric noise strength} \propto \dfrac{1}{\text{frequency}}}$
* Large atmospheric noise is produced in Low & Medium frequency bands.
* Very Small noise is produced in VHF & UHF bands.
* Atmospheric noise becomes Less severe when $F > 30$ MHz.

Extraterrestrial Noise : خارج الأرض

* Extraterrestrial noise also called space noise.

* Extraterrestrial noise
  - Solar Noise
  - Cosmic Noise

* Solar noise :- eminating from sum.

* Cosmic noise :- eminating from distant stars and galaxies.

* cosmic noise also called space noise.

* cosmic noise is significant at $F = 1.43\ GHz$.

* However, cosmic noise exists in the range 15 MHz - 100 GHz.

Industrial Noise : (Manmade Noise)

* Industrial or manmade noise is due to :-
  * Automobile & aircraft ignition,
  * electrical motors,
  * switch gears and leakage from high voltage transmission Lines
  * other heavy electrical equipments.

* Manmade noise extending in the range 1 MHz - 600 MHz.

Shot Noise :-

* Arises in active devices due to random behaviour of charge carriers.

  - Electron tubes,
  - Semiconductor devices
  - Solid state devices

* Shot Noise current is given by

$$\boxed{i(t) = I_o + i_n(t)}$$

where I_o is the mean (constant)

and $i_n(t)$ is the shot (fluctuating) noise.

* $i_n(t)$ is random (indeterministic), therefore it can be specified by its power density spectrum.

* power density spectrum of $i_n(t)$ is

$$i_n(t) \xleftrightarrow{F.T.} S_i(\omega) = q I_o$$

where q is electronic charge,

and I_o is the mean value.

* The transit time of an electron in a diode is

$$\boxed{\tau = 3.36 * \frac{d}{\sqrt{V}}} \quad \mu\text{second}$$

d = distance between cathode and anode

V = Voltage accross diode.

Partition Noise:

* generated in a circuit when a current has to divide between two or more paths.

* Hence, diode less noise than a BJT transistor.

* Metal-oxide Semiconductor Field Effect Transistor MOSFET transistor less noise than BJT transistor because the gate draws zero current.

* Therefore, MOSFET used in Low noise microwave amplification.

Flicker Noise :

* also called Low-Frequency Noise
* also known as 1/f noise
* power spectral density inversally proportional to the frequency.

$$F \propto \frac{1}{S(\omega)}$$

- As Frequency decreases → noise increases.
- As frequency increases → noise decreases.

* Flicker noise generated from fluctuation in the carrier density.

Transit-Time noise :

* Also called High-frequency noise.
* Generated when charge-carriers crossing a junction.
* Some charge-carriers diffuse back to the source.
* When diffusing back, input admittance increases.
* power spectral density $\propto F$.

Thermal Noise :

* Also called as :

  (i) White noise,

  (ii) Johnson noise,

  (iii) KTB noise

* Generated randomly in a resistor or resistive components of complex impedances due to rapid and random motion of the molecules, atoms and electrons.

* Maximum noise power of a resistor is :-

$$P_n \propto T \cdot B$$

or

$$\boxed{P_n = K \cdot T \cdot B}$$

where K = Boltzmann's constant = 1.38×10^{-23} J/deg. K

T = Absolute temprature. = (ambient temprature + 273) °K

B = Bandwidth of operation in Hz.

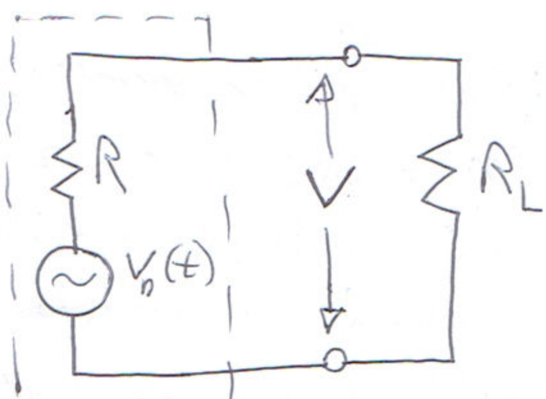
Noisy Resistor :-

* Thermal or Johnson or white noise generated in a noisy resistor is random and has zero average (dc) value.

* If a very sensitive AC-Voltmeter connected accross a resistor in temperature of 27°C (room temperature = 27°C + 273 = 300°K), then

* Some rms voltage can be captured, this is the noise voltage.

* Voltage model of a noisy resistor ⟶



* According to maximum power transfer theorem:-

$$R_L = R$$

$$P_n = \frac{V^2}{R}$$

* using voltage divider rule : $V = \frac{V_n}{2}$

$$\therefore \boxed{P_n = \frac{V_n^2}{4R}}$$

* Since $P_n = KTB$

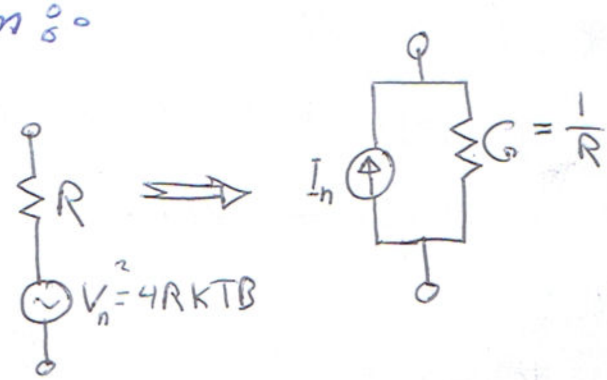
$$\therefore \boxed{V_n = \sqrt{4RKTB}}$$

فولتية النويز = جذر أربع طتب

* *Using Norton's theorem:*

and let $G = \frac{1}{R}$

$$\therefore \boxed{I_n = \sqrt{4GKTB}}$$



EX. 1: An amplifier operating over the frequency range 18–20 MHz has a 10 KΩ input resistor. Calculate the rms noise voltage at the input to this amplifier if the ambient temperature is 27°C.

solution: Boltzmann's constant $K = 1.38 \times 10^{-23}$ J/degK

$R = 10\,K\Omega$.

$T = 27 + 273 = 300°K$

Bandwidth $B = 20 - 18 = 2$ MHz

$$V_n = \sqrt{4KRTB} = \sqrt{4 \times 10000 \times 1.38 \times 10^{-23} \times 300 \times 2 \times 10^{6}}$$

$$= \sqrt{8 \times 10^{10} \times 300 \times 1.38 \times 10^{-23}}$$

$$\cong 18.199\ \mu \text{ Volts.}$$

Ex. 2 Calculate the rms noise voltage at the input of a video amplifier using a device having 300 Ω equivalent noise resistance and 400 Ω input resistance. It is given that the bandwidth of the amplifier is 7 MHz and the ambient temperature is 27°C. Note that the two resistors are connected in series.

Solution $T = 27°C + 273 = 300°K.$

$$R_{series} = R_S = R_1 + R_2 = 700\,\Omega$$

$$B = 7 \times 10^6\ Hz.$$

$$V_{nt} = \sqrt{4R_S KTB} = \sqrt{4 \times 700 \times 1.38 \times 10^{-23} \times 300 \times 7 \times 10^6}$$

$$V_{nt} \cong 9\,\mu V.$$

Ex. 3 Two resistors of 20 KΩ and 50 KΩ are connected in parallel when the room temperature was 15°C or 290 K. For a given bandwidth of 100 KHz, determine the thermal noise voltage generated by: (a) each resistor (b) the two resistors in parallel.

Solution: (a) $V_{n1} = \sqrt{4 \times 20 \times 10^3 \times 1.38 \times 10^{-23} \times 290 \times 100 \times 10^3} \cong 5.66\,\mu V.$

$V_{n2} = \sqrt{4 \times 50 \times 10^3 \times 1.38 \times 10^{-23} \times 290 \times 100 \times 10^3} \simeq 8.95\,\mu V.$

(b) in parallel $R_{parallel} = R_P \simeq 14.2857\ K\Omega.$

$$V_{np} = \sqrt{4 \times 14.2857 \times 10^3 \times 1.38 \times 10^{-23} \times 290 \times 100 \times 10^3}$$

$$V_{np} \simeq 4.78\,\mu V.$$

EX. What will be the thermal noise power density of a resistor in room temperature T = 290 K under maximum power transfer conditions?

Solution $T = 290\ K$

$P_n = 4RKTB$] under maximum power transfer should divide by 4R.

$\frac{P_n}{4RB} = KT = 4.002 \times 10^{-21} \ \frac{W}{Hz}$.

* For communication system analysis, power ratio in decibels (dB) is usually uses.

* $$1\text{ watt} = 10\log_{10}\left(\frac{P_{watts}}{1\text{ Watt}}\right)$$

$$= 10\log_{10}\left(\frac{1}{1}\right) = 10\log_{10}(1)$$

$$= 0\text{ dBW}$$

* $$1\text{ mwatt} = 10\log_{10}\left(\frac{P_{mwatt}}{1\text{ mW}}\right)$$

$$= 10\log_{10}\left(\frac{1\text{ mW}}{1\text{ mW}}\right)$$

$$= 10\log_{10}(1)$$

$$= 0\text{ dBm}$$

* EX. $13\text{ W} = 10\log_{10}\left(\frac{13\text{ W}}{1\text{ W}}\right) = \log_{10}(13) \cong 11.14\text{ dBW}$

$50\text{ mW} = 10\log_{10}\left(\frac{50\text{ mW}}{1\text{ mW}}\right) = \log_{10}(50) \cong 17\text{ dBm}$

$13\text{ W} = 10\log_{10}\left(\frac{13000\text{ mW}}{1\text{ mW}}\right) = \log_{10}(13000) \cong 41.14\text{ dBm}$

Signal-to-Noise Ratio :- (SNR)

* The ratio of signal power to the noise power at the same band of frequency is called signal-to-Noise Ratio (SNR) or (S/N).

$$\boxed{\frac{S}{N} = \frac{\text{Signal power}}{\text{Noise power}} = \frac{\text{Power spectrum density of signal}}{\text{Power spectrum density of noise}}}$$

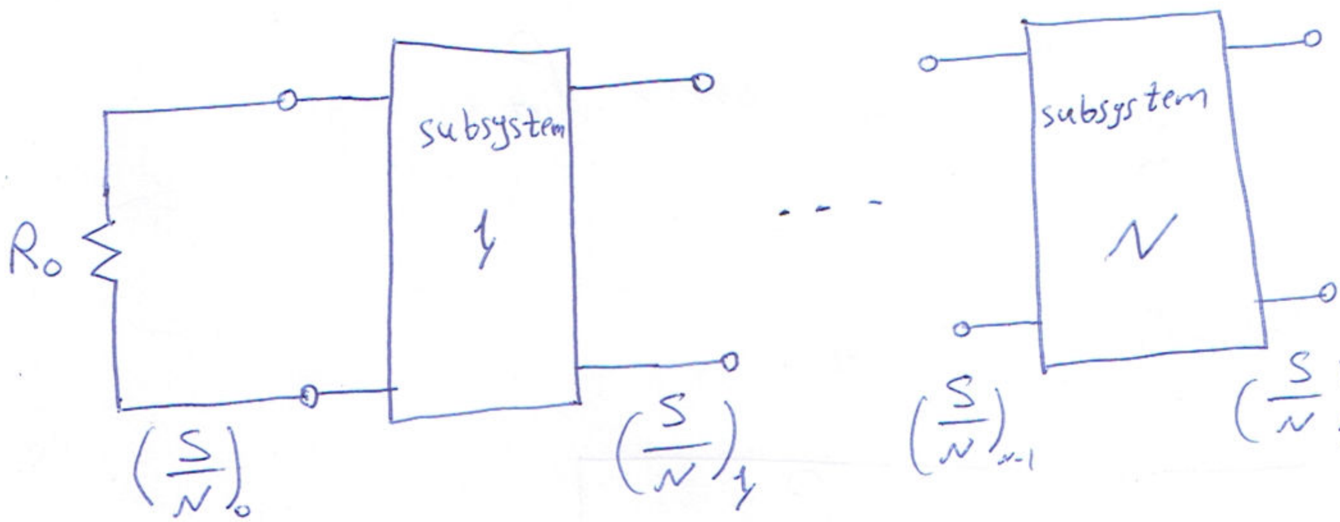
Noise Factor :-

* Also called noise Figure
* Noise figure is defined as:-

$$\boxed{NF = \frac{\text{Input SNR}}{\text{output SNR}} = \frac{SNR_i}{SNR_o}}$$

* Systems are usually represented as subsystems connected in cascade form.

* Assuming output impedance of a certain system is equal to the input impedance of the next system. (usually $50\,\Omega$).



* Now, for the l^{th} subsystem, noise figure F_l is

$$\left(\frac{S}{N}\right)_l = \frac{1}{F_l}\left(\frac{S}{N}\right)_{l-1}$$

* Assuming that the l^{th} subsystem has gain G_a, then

$P_{nl} = G_a P_{nl-1}$ Assuming the system is linear

$\therefore \quad \left(\frac{S}{N}\right)_l = \frac{1}{F_l}\left(\frac{S}{N}\right)_{l-1}$

and

$$F_l = \frac{P_{n,l}}{G_a P_{n,l-1}} = \frac{P_{nl}}{G_a KTB}$$

* considering the internal power $P_{int,l}$

$$P_{n,l} = G_a P_{n,l-1} + P_{int,l}$$

$$\therefore \quad \boxed{F_l = 1 + \frac{P_{int,l}}{G_a KTB}}$$

Noise Temperature :

* Equivalent Noise Temperature of a system is :-

$$\boxed{T_n = \frac{P_{n,max}}{KB}}$$

* $P_{n,max}$ is the maximum noise power of the source into bandwidth B.

Effective Noise Temperature :

* effective noise temperature of subsystem ℓ is

$$\boxed{T_e = \frac{P_{int,\ell}}{G_a K B}}$$

$$\therefore \quad F_\ell = 1 + \frac{P_{int,\ell}}{G_a K T_o B} = 1 + \frac{T_e}{T_o}$$

where $T_o = 290\ K. = T + 273^\circ$

* We can express $P_{n,\ell}$ as

$$\boxed{P_{n,\ell} = G_a K B (T_e + T)}$$

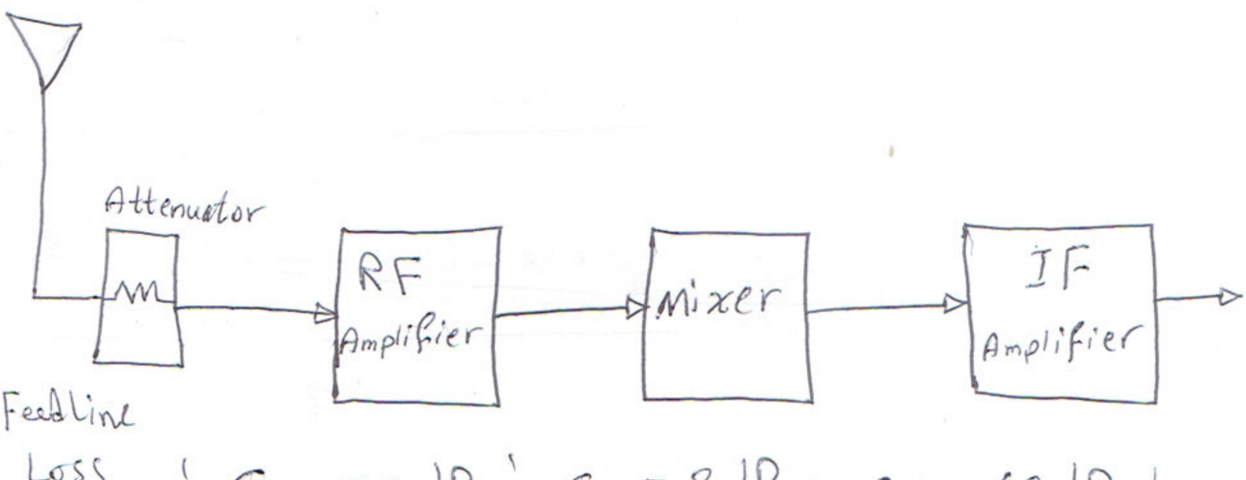
* In general for an arbitrary number of stages of subsystems (Frii's Formula)

$$\boxed{F = F_1 + \frac{F_2 - 1}{G_{a1}} + \frac{F_3 - 1}{G_{a1} G_{a2}} + \frac{F_4 - 1}{G_{a1} G_{a2} G_{a3}} \cdots}$$

$$\boxed{T_e = T_{e1} + \frac{T_{e2}}{G_{a1}} + \frac{T_{e3}}{G_{a1} G_{a2}} + \frac{T_{e4}}{G_{a1} G_{a2} G_{a3}} \cdots}$$

* An attenuator of x dB means an attenuator has a noise Figure of $-x$ dB.

EX. 1 For a receiver system, the antenna was connected to an RF-amplifier with feedline loss of 1.5 dB. The RF-amplifier has gain = 20 dB and noise factor of 7 dB. The RF-amplifier has been connected to a mixer of gain = 8 dB and noise figure = 10 dB; the IF-amplifier was connected to the output of the mixer, where the IF-amplifier has gain = 60 dB and noise figure = 6 dB. Calculate the system noise figure and the system's effective temperature at 290K.



$L = 1.5$ dB	$G_2 = 20$ dB	$G_3 = 8$ dB	$G_4 = 60$ dB
$F_1 = 1.5$ dB	$F_2 = 7$ dB	$F_3 = 10$ dB	$F_4 = 6$ dB

Solution

$G_1 = 1.5\ dB,\ G_2 = 20\ dB,\ G_3 = 8\ dB,\ G_4 = 60\ dB.$

$F_1 = 1.5\ dB,\ F_2 = 7\ dB,\ F_3 = 10\ dB,\ F_4 = 6\ dB.$

$$G_{dB} = 10 \log_{10} G \Rightarrow \log_{10} G = \frac{G_{dB}}{10} \Rightarrow \boxed{G = 10^{\frac{G_{dB}}{10}}}$$

* we have $G_1 = L = \text{losses} = 1.5\ dB$, hence it is $\boxed{-1.5\ dB}$

$\therefore G_1 = 10^{-\frac{1.5}{10}} = 0.70795.$

$G_2 = 10^{\frac{20}{10}} = 100.$

$G_3 = 10^{\frac{8}{10}} = 6.3.$

$G_4 = 10^{\frac{60}{10}} = 10^6 = 1000000.$

$F_1 = 10^{\frac{1.5}{10}} = 1.41$

$F_2 = 10^{\frac{7}{10}} = 5.01$

$F_3 = 10^{\frac{10}{10}} = 10$

$F_4 = 10^{\frac{6}{10}} = 3.98$

The system noise figure is

$$F = 1.41 + \frac{5.01-1}{0.707} + \frac{10-1}{0.707*100} + \frac{3.98-1}{0.707*100*6.3} = 7.19 \text{ or } 8.57\ dB$$

The effective noise temperature is

$$F = \frac{T_e}{T_0} + 1 \Rightarrow F - 1 = \frac{T_e}{T_0} \Rightarrow \boxed{T_e = T_0(F-1)}$$

$$\therefore T_e = 290(7.19-1) = 1796.3\ K.$$

Comments and enhancements on EX.1, pages [197-198].

* To reduce the noise figure (to improve system performance), interchange the cable and RF pre-amplifier.

* In practice this may mean locating an RF preamplifier on back of the receive antenna, as in a satellite TV receiver

$$F = 5.01 - \frac{1.41-1}{100} + \frac{10-1}{100 * 0.707} + \frac{3.98-1}{100 * 0.707 * 6.3} = 5.15 \text{ or } 7.12\,dB$$

$T_e = 1202.9\ K$

* Going back to the original example, let the antenna, suppose the antenna has an effective noise temperature of $T_s = 400\ K$ and the system bandwidth $B = 100\ kHz$. What is the maximum available output noise power in dBm?

$$P_n = G_a k B (T_s + T_e) \Rightarrow G_a = \overset{L}{-1.5} + \overset{G_2}{20} + \overset{G_3}{8} + \overset{G_4}{60} = 86.5\,dB$$

$kT_o = -174\ dBm/Hz$, $T_o = 290\ K$

$$P_n = 86.5 - 174 + 10\log_{10}\left(\frac{400 + 1796.3}{290}\right) + 10\log_{10} 10^5$$

$$= -28.71 \text{ dBm}.$$

* what will be the received signal power at the antenna terminals for a system output SNR of 20dB ?

$$10\log_{10}\left(\frac{G_a P_r}{P_n}\right) = 20$$

$$\therefore \quad P_{r\,dB} = 20 + P_{n\,dB} - G_{a\,dB}$$

$$= 20 + (-28.71) - 86.5$$

$$= -95.21 \text{ dBm}$$