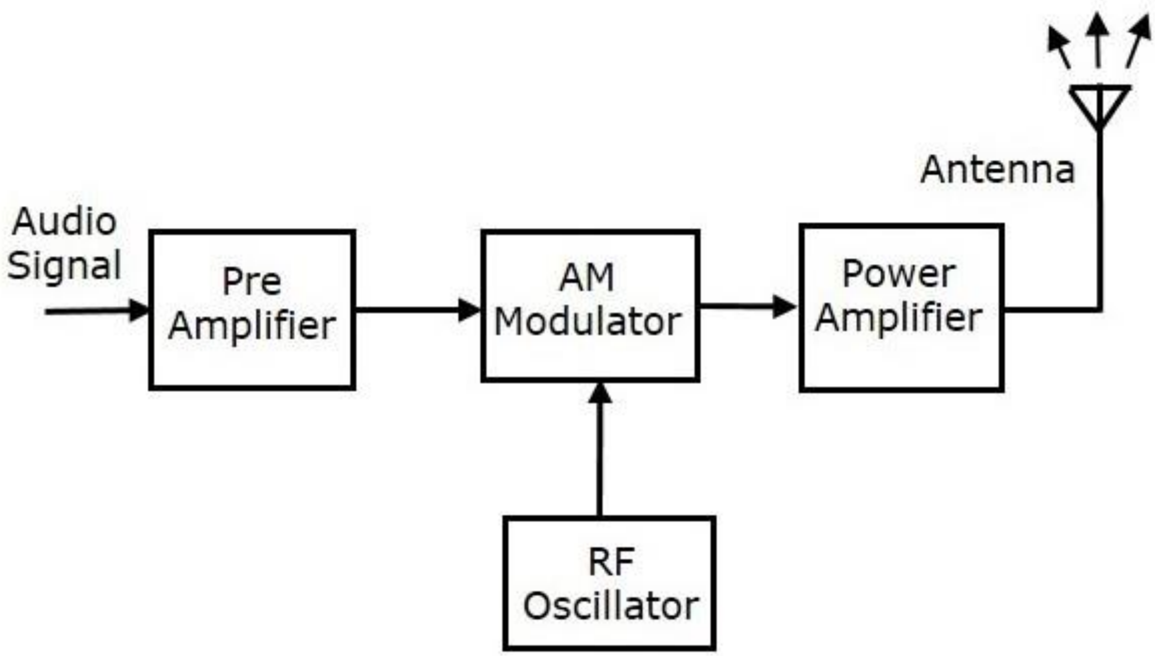
UNIT-3

The antenna present at the end of transmitter section, transmits the modulated wave. In this chapter, let us discuss about AM and FM transmitters.

AM Transmitter

AM transmitter takes the audio signal as an input and delivers amplitude modulated wave to the antenna as an output to be transmitted. The block diagram of AM transmitter is shown in the following figure.

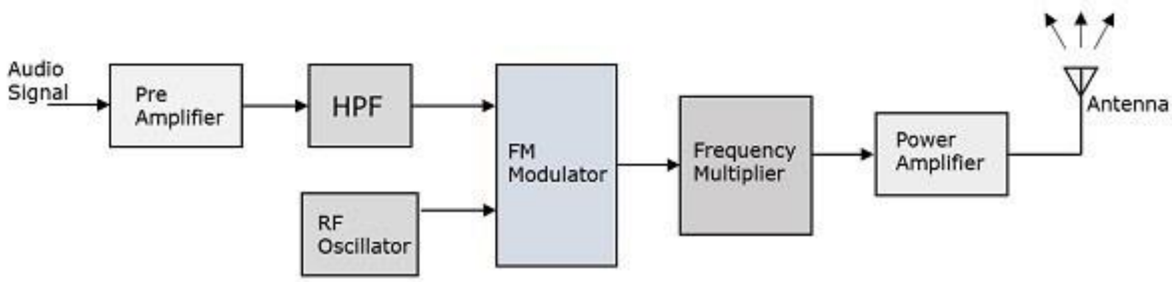


The working of AM transmitter can be explained as follows.

- The audio signal from the output of the microphone is sent to the pre-amplifier, which boosts the level of the modulating signal.
- The RF oscillator generates the carrier signal.
- Both the modulating and the carrier signal is sent to AM modulator.
- Power amplifier is used to increase the power levels of AM wave. This wave is finally passed to the antenna to be transmitted.

FM Transmitter

FM transmitter is the whole unit, which takes the audio signal as an input and delivers FM wave to the antenna as an output to be transmitted. The block diagram of FM transmitter is shown in the following figure.



The working of FM transmitter can be explained as follows.

- The audio signal from the output of the microphone is sent to the pre-amplifier, which boosts the level of the modulating signal.
- This signal is then passed to high pass filter, which acts as a pre-emphasis network to filter out the noise and improve the signal to noise ratio.
- This signal is further passed to the FM modulator circuit.
- The oscillator circuit generates a high frequency carrier, which is sent to the modulator along with the modulating signal.
- Several stages of frequency multiplier are used to increase the operating frequency. Even then, the power of the signal is not enough to transmit. Hence, a RF power amplifier is used at the end to increase the power of the modulated signal. This FM modulated output is finally passed to the antenna to be transmitted.

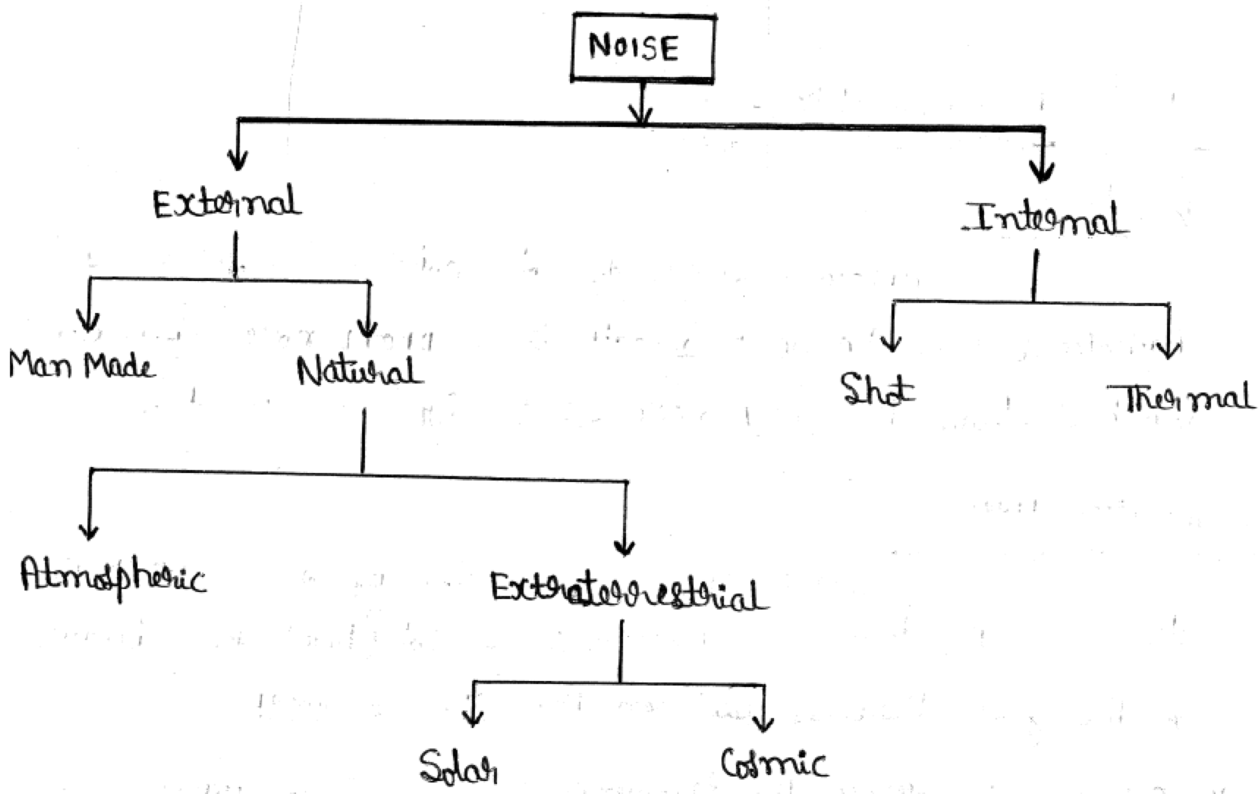
NOISE

NOISE :-

Noise is an unwanted Signal. Noise is random in nature & interferes with the desired Signal.

* Noise disturb the proper reception & reproduction of transmitted Signals.

Classification of Noise :-



II) Internal Noise :-

Internal noise is generated internally in the circuit. Electronic components such as resistors, diodes and transistors etc produce this noise.

1) Shot Noise :-

* Shot Noise arises in electronic devices because of the discrete (pulse) nature of current flow in the device.
* Shot noise appears in the active devices due to random behaviour of charge carriers (electrons & holes).
* In vaccum tubes shot noise is generated due to random emission of electrons from the cathode.
* In semiconductor devices due to random diffusion of electrons & the random recombination of electrons with holes.
* In a photo diode, it is the random emission of photons.
* The nature of current variation w.r.to time in a vaccum diode is as shown in fig below.

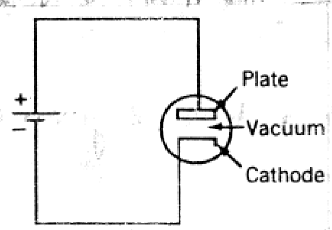


Fig ①: vaccum diode

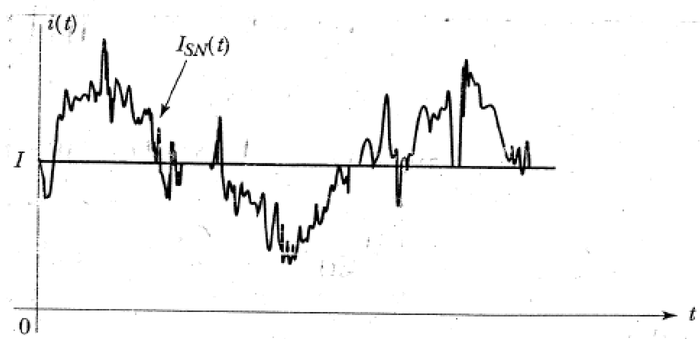


Figure 2 ■ Shot noise current.

* Fig ② Shows the current fluctuation over the mean value 'I'.

* The fluctuating current is called Shot Noise & denoted as 'I_{SN}'. The fluctuating current $I_{SN}(t)$ is not observed by normal measuring instrument i.e. it look like constant current 'I'

* The fluctuating nature of $I_{SN}(t)$ can be seen only in fast acting oscilloscopes.

∴ The total current flowing in the vaccum diode

$$\boxed{i(t) = I + I_{SN}(t)}$$

* For a vaccum diode, the mean square value of randomly - fluctuating component of current is given by :

$$\boxed{I_{SN}^2 = 2qIB_N \text{ amps}^2}$$

Where,

$q \rightarrow$ electron charge equal to 1.6×10^{-19} coulombs.

$I \rightarrow$ The mean value of the current in amperes &

$B_N \rightarrow$ Noise bandwidth in Hz.

* Shot Noise has a uniform spectral density (like Thermal Noise)

* The mean square shot noise current for a diode is given as:

$$\boxed{I_{SN}^2 = 2q(I + 2I_S)B_N}$$

Where, $I \rightarrow$ dc current across the junction

$I_S \rightarrow$ Reverse Saturation current

$q \rightarrow$ electron charge $= 1.6 \times 10^{-19}$ C

$B_N \rightarrow$ Noise Bandwidth.

---

1) A noise generator using diode is required to produce 15 µV noise voltage in a receiver which has an I/p impedance of 75 Ω (purely resistive). The receiver has a noise power bandwidth of 200 KHz. Calculate the current through the diode.

Sol :- Given : $V_{SN} = 15\,\mu V$, $R = 75\,\Omega$, $B_N = 200\,KHz$, $I = ?$

W.K.T. $$I_{SN}^2 = 2q(I + 2I_S)B_N$$

$I \gg I_S$, neglecting I_S.

$$I_{SN}^2 = 2q(I)B_N \rightarrow ①$$

W.K.T. $$I_{SN} = \frac{V_{SN}}{R} = \frac{15\,\mu V}{75\,\Omega} = 0.2\,\mu A$$

* From eq ①,

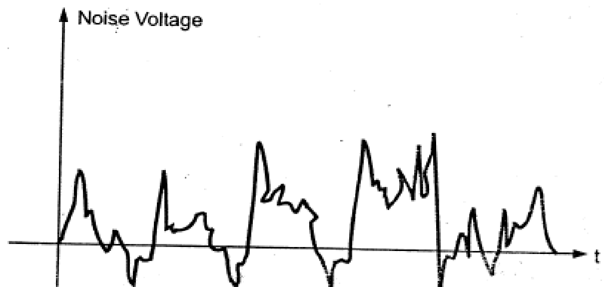
$$I = \frac{I_{SN}^2}{2q B_N} = \frac{(0.2\,\mu A)^2}{2 \times 1.6 \times 10^{-9} \times 200\,KHz}$$

$$\therefore \boxed{I = 625\,mA}$$

2) Thermal Noise or Johnson's Noise :-

* The random movement of electrons inside the conductor - resulting in a randomly varying voltage across the conductor as shown in fig.

Figure
Thermal noise



* This randomly varying noise voltage produced across the conduct is called as thermal Noise. It is also known as Johnson Noise.

* The power spectral density of thermal noise produced by a resistor is given by:

$$\boxed{S_{TN}(f) = \frac{2h|f|}{\exp(h|f|/KT) - 1}} \longrightarrow (1)$$

Where, $T \rightarrow$ absolute temperature in degrees Kelvin.

$K \rightarrow$ Boltzmann's Constant i.e. 1.38×10^{-23} Joules/°K

$h \rightarrow$ Planck's Constant i.e. 6.63×10^{-34} Joules/Sec.

* The power spectral density for low frequency is defined by $f \ll \frac{K}{}$

we may use the approximation $\boxed{\exp\left(\frac{h|f|}{KT}\right) = 1 + \frac{h|f|}{KT}} \longrightarrow (2)$

Substituting eq ② in eq ①, we get

$$S_{TN}(f) = \frac{2h|f|}{\cancel{1} + \frac{h|f|}{KT} - \cancel{1}} = \frac{2h|f|}{\frac{h|f|}{KT}} = \frac{2\cancel{h|f|}\,KT}{\cancel{h|f|}}$$

$$\boxed{S_{TN}(f) = 2KT} \longrightarrow ③$$

* The mean square value of the thermal noise voltage measured across the terminals of the resistor equals

$$\boxed{V_{TN}^2 = 2RB_N S_{TN}(f)} \longrightarrow ④$$

Substituting eq ③ in eq ④, we get

$$V_{TN}^2 = 2RB_N(2KT)$$

$$\boxed{V_{TN}^2 = 4KTB_N R \ \text{volts}^2}$$

Where,

$V_{TN} \rightarrow$ root-mean square noise voltage

$K \rightarrow$ Boltzmann's constant

$T \rightarrow$ Temperature of the conductor in Kelvins

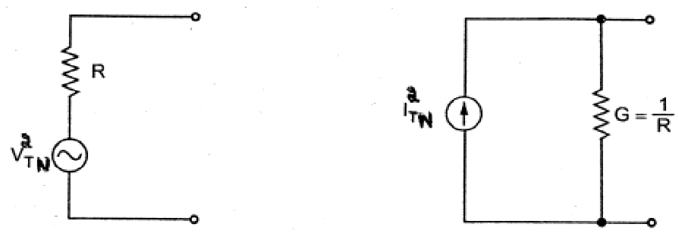
$B_N \rightarrow$ Noise bandwidth in Hz.

$R \rightarrow$ Resistance of the conductor in ohms.

Equivalent Noise Sources for the thermal Noise :-

► Figure

Equivalent noise sources for thermal noise



(a) Thevenin equivalent circuit (b) Norton equivalent circuit

* Fig ⓐ shows a model of a Noisy resistor.
  The Thevenin equivalent ckt consisting of a Noise voltage generator with a mean-square values of V^2_{TN} in series with a noiseless resistor.

* Similarly Fig ⓑ shows Norton equivalent ckt consisting of a Noise current generator in parallel with a Noiseless conductance.

  The mean-square value of the Noise current generator is :

$$I^2_{TN} = \frac{V^2_{TN}}{R^2} = \frac{4KTB_N \cancel{R}}{R^{\cancel{2}}} = 4KTB_N \frac{1}{R}$$

$$\boxed{I^2_{TN} = 4KTB_N G} \quad \text{amps}^2$$

Where, $G = \frac{1}{R}$ is the conductance.

Available Noise power :-

* The Root-mean square value of the voltage V_{RMS} across the matched load R_L is

$$\boxed{V_{RMS} = \frac{\sqrt{V^2_{TN}}}{2}}$$

* The maximum average Noise power delivered to the load is :

$$P_n = \frac{V_{RMS}^2}{R} = \frac{V_{TN}^2}{4R} = \frac{\cancel{4}KTB_N\cancel{R}}{\cancel{4R}}$$

$$\boxed{P_n = KTB_N}$$

Thus, the available Noise power 'P_a' is equal to 'KTB_N' & is independent of 'R'.

FORMULAE :

1) RMS Noise voltage : $V_{TN}^2 = 4KTB_NR$

$$\boxed{V_{TN} = \sqrt{4KTB_NR}}$$

2) Thermal Noise power

$$\boxed{P_n = KTB_N}$$

---

1) Calculate the rms noise voltage and thermal noise power appearing across a 20 KΩ resistor at 25°C temperature with an effective noise bandwidth of 10 KHz.

Sol :- Given : $R = 20K\Omega$, $T = 273 + 25 = 298K$, $B_N = 10\,KHz$, $K = 1.38\times10^{-23}$

* $V_{TN} = \sqrt{4KTB_NR} = \sqrt{4\times1.38\times10^{-23}\times298\times10\times10^3\times20\times10^3}$

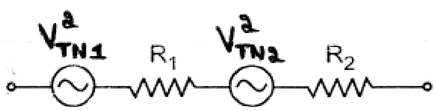
$$\boxed{V_{TN} = 1.81\,\mu V}$$

* $P_n = KTB_N = 1.38\times10^{-23}\times298\times10\times10^3$

$$\boxed{P_n = 4.11\times10^{-17}}$$

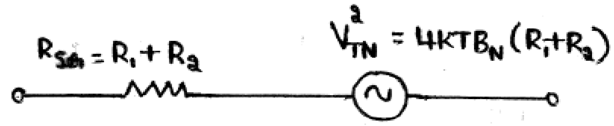
Thermal Noise Calculation :-

1) In Series resistors :-



(a) Series resistors

=



(b) Equivalent Ckt

* Fig (a) Shows two resistors R_1 & R_2 connected in Series.

∴ The total Series resistance is given as

$$R_{Ser} = R_1 + R_2$$

W.K.T
$$V^2_{TN} = 4KTB_N R_{Ser}$$
$$= 4KTB_N [R_1 + R_2]$$
$$V^2_{TN} = 4KTB_N R_1 + 4KTB_N R_2$$
$$V^2_{TN} = V^2_{TN1} + V^2_{TN2}$$

$$\boxed{V_{TN} = \sqrt{V^2_{TN1} + V^2_{TN2}}}$$

---

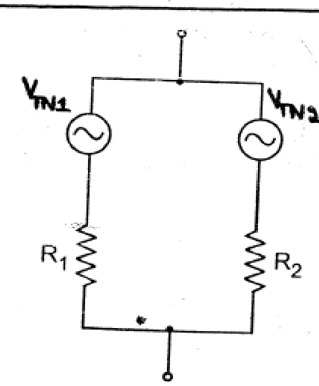
2) In parallel resistor :-

* When two resistors R_1 & R_2 are Connected in parallel, then total Noise voltage V_{TN} is obtained.

$$V^2_{TN} = 4KTB_N R_P$$

Where R_P = Equivalent resistance of parallel resistors R_1 & R_2 i.e.

$$R_P = R_1 \| R_2$$



Parallel resistors

* The transit time occupies a small portion of the I/p period at lower frequencies. As the frequency is increased, the transit time occupies a considerable portion of the I/p period.

  In such a situation, the charge carriers may start diffuse back to the source i.e. emitter in the case of a transistor without reaching the collector.

* The diffusion of the carrier back to the source give rise to an I/p admittance in which the conductance increases with frequency.

* The noise current generator associated with this conductance increases with frequency.

* At very high frequencies it becomes a predominant noise component.

Flicker Noise or Low frequency Noise :-

* The flicker noise will appear at low frequency's. It is sometimes called as "$1/f$" noise.

* In the semiconductor devices, the flicker noise is generated - to the fluctuations in the carrier density.

Partition Noise :-

* partition Noise is generated when the current gets divided between two or more paths.

* It is generated due to the random fluctuations in the carrier divisions.

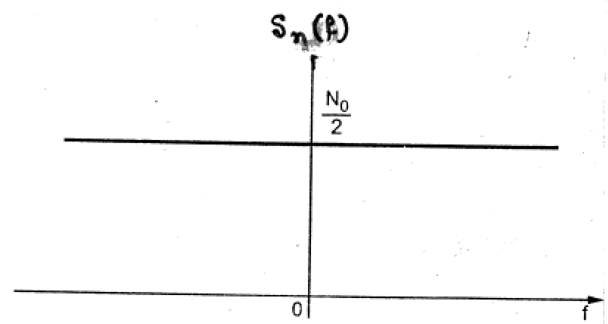
∴ The partition noise in a transistor will be higher than that in a diode.

White Noise :-

White Noise is the noise whose power Spectral density is uniform over the entire frequency range as shown in fig.

▶ **Figure**

(a) Power spectral density of white noise



* The Spectral density of white Noise is given by

$$\boxed{S_n(f) = \frac{N_0}{2}}$$

Where, $N_0 = KT_e$

$K \rightarrow$ Boltzmann's Constant

$T_e \rightarrow$ Equivalent noise temperature of the System.

Noise Equivalent Bandwidth:-

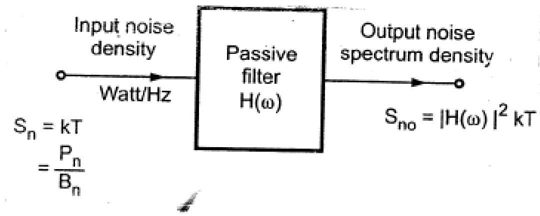
(Q) What is noise equivalent bandwidth? Derive an expression for noise equivalent bandwidth.

Jan - 2005, 8M

* Consider a passive filter having voltage-ratio transfer function $H(\omega)$. Let the I/p noise spectrum density be

$$S_n = KT = \frac{P_n}{B_n}$$

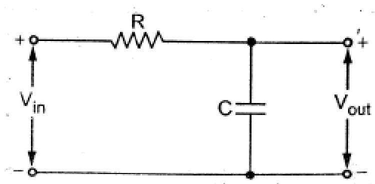
Where, P_n is noise power.



* The o/p Noise Spectrum density S_{no}, for an I/p density of $S_n = KT$ is

$$\boxed{S_{no} = |H(\omega)|^2 \cdot KT} \longrightarrow (1)$$

* Consider the passive R-C LPF shown below.



* The transfer function is given by:

$$H(s) = \frac{V_{out}}{V_{in}} = \frac{1/sC}{R+\frac{1}{sC}} = \frac{1/\cancel{sC}}{\frac{RsC+1}{\cancel{sC}}}$$

$$H(s) = \frac{1}{1+sCR}$$

$$|H(\omega)| = \frac{1}{\sqrt{1+(\omega CR)^2}}$$

$$\boxed{|H(\omega)|^2 = \frac{1}{1+(\omega CR)^2}} \longrightarrow (2)$$

Substituting eq (2) in eq (1), we get

$$S_{no} = \frac{1}{1+(\omega CR)^2} \cdot KT$$

$$\boxed{S_{no} = \frac{KT}{1+(\omega CR)^2}} \longrightarrow (3)$$

* The o/p Spectrum density, S_{no} decreases as the frequency increases. The total noise power is obtained by integrating S_{no} over the frequency range from 0 to ∞.

i.e. $$P_{no} = \int_0^\infty S_{no}\, df \longrightarrow (4)$$

Substituting eq (3) in eq (4), we get

$$P_{no} = \int_0^\infty \frac{KT}{1+(\omega CR)^2} \cdot df$$

WKT
$\boxed{\omega = 2\pi f}$

$$P_{no} = \int_0^{\pm} \frac{KT}{1+(2\pi f RC)} df$$

Let $2\pi f RC = x \rightarrow (a)$

differentiating eq (a) w.r.to 'f'

$$\frac{df}{dx} 2\pi RC = (1)$$

$$df = \frac{dx}{2\pi RC}$$

The limits remain unchanged

$$P_{no} = \int_0^\infty \frac{KT}{1+x^2} \cdot \frac{dx}{2\pi RC}$$

$$P_{no} = \frac{KT}{2\pi RC} \int_0^\infty \frac{dx}{1+x^2}$$

$$= \frac{KT}{2\pi RC} \int_0^\infty \frac{1}{1+x^2} dx$$

$$= \frac{KT}{2\pi RC} \left[\tan^{-1} x\right]_0^\infty$$

$$= \frac{KT}{2\pi RC} \left[\tan^{-1}(\infty) - \tan^{-1}(0)\right]$$

$$P_{no} = \frac{KT}{2\cancel{\pi} RC} \left[\frac{\cancel{\pi}}{2} - 0\right] = \frac{KT}{2RC} \cdot \frac{1}{2}$$

$\therefore$ The total noise power at the o/p is

$$\boxed{P_{no} = \frac{KT}{4RC}} \longrightarrow (5)$$

Comparing eq (5) with $P_n = KTB_N$, we get

Effective Noise BW as $\boxed{B_N = \frac{1}{4RC}} \longrightarrow (6)$

* The rms noise voltage, V_N will be given by

$$V_N^2 = 4KTB_N \cdot R \longrightarrow (7)$$

Substituting eq ⑥ in eq ⑦, we get

$$V_N^2 = \cancel{4}KT\left(\frac{1}{\cancel{4}\cancel{R}C}\right)\cdot\cancel{R}$$

$$\boxed{V_N^2 = \frac{KT}{C}}$$

* Although the Capacitance 'C' does not contribute to the noise, it acts as a limiting factor to the rms noise voltage.

---

1) A Signal Circuit is equivalent to a parallel Combination of $R = 1K\Omega$ & $C = 0.47\,\mu F$. Calculate the effective noise bandwidth.

Sol :- Effective bandwidth

$$B_N = \frac{1}{4RC} = \frac{1}{4\times 1\times 10^{3}\times 0.47\times 10^{-6}} = \underline{531.915\ Hz}$$

Signal to Noise Ratio :- (SNR)

* Signal to Noise ratio is defined as the ratio of Signal power to Noise power.

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

$$= \frac{V_s^2/\cancel{R}}{V_N^2/\cancel{R}}$$

$$\boxed{\frac{S}{N} = \left(\frac{V_s}{V_N}\right)^2}$$

* The Signal to Noise ratio interms of decibels :

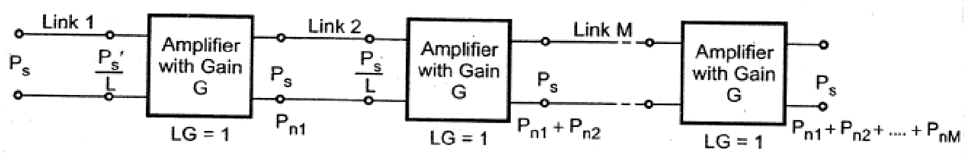
$$\left(\frac{S}{N}\right)_{dB} = 10\log\left(\frac{V_s}{V_N}\right)^2$$

$$\boxed{\left(\frac{S}{N}\right)_{dB} = 20 \log \left(\frac{V_S}{V_N}\right)}$$

* Signal to Noise ratio of a Tandem Connection :-

▶ **Figure**

Tandem connection



* In telephone Systems, telephone cables are used as media to transmit Signals. The Signals gets attenuated as it travels through telephone cables due to power loss in the telephone cables. To make up this power loss the Signal is amplified such that, if the power loss of a line Section is 'L', then the amplified power gain 'G' is chosen so that $LG = 1$.

* A long telephone line is divided into equal Sections called links.

* As Signals travel through these links, each amplifier adds its own noise to the System.
  Therefore at the receiving end we get the accumulated Noise power as shown in Fig above.

* The total Noise power at the o/p of the M^{th} link is

$$P_n = P_{n1} + P_{n2} + P_{n3} + \dots + P_{nM}$$

Where,

P_{n1} = Noise power added at the end of 1st link

P_{n2} = Noise power added at the end of 2nd link.

P_{n3} = Noise power added at the end of 3rd link.

⋮

P_{nM} = Noise power added at the end of Mth link.

* If links are identical such that each link adds Noise power 'P_n' then the total Noise power is given as:

$$\boxed{P_{n\,total} = M \times P_n}$$

∴ The o/p Signal to Noise ratio is:

$$\left(\frac{S}{N}\right)_{M\,dB} = 10 \log\left(\frac{P_s}{P_{n\text{-}total}}\right)$$

$$= 10 \log\left(\frac{P_s}{MP_n}\right)$$

$$= 10 \log\left(\frac{P_s}{P_n}\right) - 10 \log(M)$$

$$\boxed{\left(\frac{S}{N}\right)_{M\,dB} = \left(\frac{S}{N}\right)_{1\,dB} - (M)_{dB}}$$

Where,

$(M)_{dB}$ → Signal to Noise ratio at the end of M-links

$\left(\frac{S}{N}\right)_{1\,dB}$ → Signal to Noise ratio at the end of 1st link.

1) Calculate the o/p Signal to Noise ratio in decibels for Four identical links. Assume that Signal to Noise of each link is 80 dB.

Sol :- Given : $\left(\frac{S}{N}\right)_{dB} = 80\,dB$, $M = 4$.

$$(M)_{dB} = 10\log(M)$$
$$(M)_{dB} = 10\log(4) = 6.02\,dB$$

$$\left(\frac{S}{N}\right)_{M\,dB} = \left(\frac{S}{N}\right)_{1\,dB} - (M)_{dB}$$

$$= 80\,dB - 6.02\,dB$$

$$\boxed{\left(\frac{S}{N}\right)_{M\,dB} = 73.98\,dB}$$

Noise Factor :-

* The Noise factor 'F' of an amplifier or any Network is defined interms of Signal to Noise ratio is defined as:

$$\text{Noise factor, } F = \frac{\text{available S/N power ratio at the I/p}}{\text{available S/N power ratio at the o/p}} = \frac{(SNR)_i}{(SNR)_o}$$

$$F = \frac{P_{Si}/P_{ni}}{P_{So}/P_{no}}$$

$$\boxed{F = \frac{P_{Si}}{P_{ni}} \times \frac{P_{no}}{P_{So}}} \longrightarrow (1)$$

{* In general any amplifier will add Noise to the I/p Signal, therefore the SNR at the o/p of the amplifier is less than the SNR at the I/p. Hence the Noise factor is a measure of degradation of the Signal to Noise ratio or the amount of noise added by the S/M}

* The available power gain 'G' is given by

$$G = \frac{\text{Signal power at the o/p}}{\text{Signal power at the I/p}}$$

$$\boxed{G = \frac{P_{so}}{P_{si}}} \longrightarrow (2)$$

From eq (1), we can re-arrange

$$F = \left(\frac{P_{si}}{P_{so}}\right) \times \frac{P_{no}}{P_{ni}} \longrightarrow (3)$$

Substituting eq (2) in eq (3), we get

$$F = \frac{1}{G} \cdot \frac{P_{no}}{P_{ni}}$$

$$F = \frac{P_{no}}{G P_{ni}}$$

$$P_{no} = F G \underline{P_{ni}}$$

W.K.T the Noise power at I/p, $P_{ni} = KTB_N$

$$\boxed{P_{no} = FGKTB_N}$$

Thus With increase in the Noise factor 'F', the noise power at the o/p will increase.

NOISE Figure :-

* When noise factor is expressed in decibels, it is called Noise figure.

$$\text{Noise Figure} = 10 \log_{10}(F)$$

$$= 10 \log_{10}\left[\frac{S/N \text{ at the I/p } ``(S/N)_i"}{S/N \text{ at the o/p } ``(S/N)_o"}\right]$$

$$= 10 \log_{10}\left[\frac{(S/N)_i}{(S/N)_o}\right]$$

$$\boxed{\text{Noise Figure }(F)_{dB} = 10 \log_{10}(S/N)_i - 10 \log_{10}(S/N)_o}$$

* The Ideal value of Noise figure is 0 dB.

---

1) The Signal power & Noise power measured at the I/p of an amplifier are 150 μW & 1.5 μW respectively. If the Signal power at the o/p 1.5W & Noise power is 40 mW, calculate the amplifier noise factor & Noise figure.

Sol :- Given : $P_{Si} = 150\,\mu W$, $P_{ni} = 1.5\,\mu W$, $P_{So} = 1.5\,W$, $P_{no} = 40\,mW$.

* Noise Factor 'F' $= \dfrac{P_{Si}}{P_{ni}} \times \dfrac{P_{no}}{P_{So}}$

$$= \frac{150 \times 10^{-6}}{1.5 \times 10^{-6}} \times \frac{40 \times 10^{-3}}{1.5}$$

$$\boxed{F = 2.666}$$

* Noise Figure $(F)_{dB} = 10 \log_{10}(F) = 10 \log_{10}(2.666)$

$$\boxed{(F)_{dB} = 4.26\text{ dB}}$$

3) The Signal to Noise ratio at the I/p of an amplifier is 40 dB. If the Noise Figure of an amplifier is 20 dB, Calculate the Signal to Noise ratio in dB at the amplifier o/p.

Sol :- Given : $(S/N)_i = 40\,dB$, $(S/N)_o = ?$, $(S/N)_o = 20\,dB$

W.K.T Noise Figure $(F)_{dB} = (S/N)_{i\,dB} - (S/N)_{o\,dB}$

$$(S/N)_{o\,dB} = (S/N)_{i\,dB} - (F)_{dB}$$

$$= 40\,dB - 20\,dB$$

$$\boxed{(S/N)_{o\,dB} = 20\,dB}$$

Amplifier I/p Noise interms of 'F' (P_{na}) :-

The total noise at the I/p of the amplifier is given by:

$$\boxed{\text{Total } P_{ni} = \frac{P_{no}}{G}} \longrightarrow (1)$$

W.K.T $P_{no} = FGKTB_N$.

Substituting 'P_{no}' value in eq (1), we get

$$\text{Total } P_{ni} = \frac{F\cancel{G}KTB_N}{\cancel{G}}$$

$$\therefore \boxed{\text{Total } P_{ni} = FKTB_N}$$

* out of this total I/p noise power, the I/p Source Contribution is only KTB_N & the remaining is contributed by the amplifier :

$$P_{ni(total)} = P_{ni} + P_{na}$$

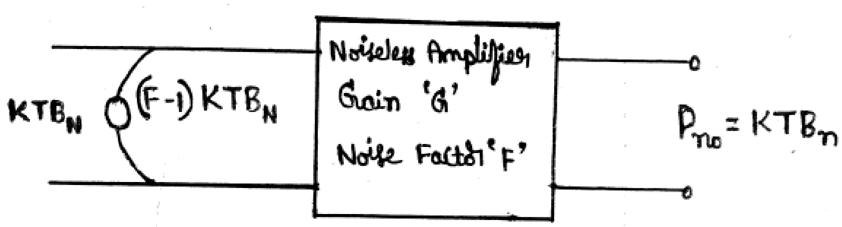
$$P_{na} = P_{ni(total)} - P_{ni}$$

$$P_{na} = FKTB_N - KTB_N$$

$$P_{na} = KTB_N(F-1)$$

$$\boxed{P_{na} = (F-1)\,KTB_N}$$

This can be Shown in below Figure :



∴ The Fraction of total available noise Contributed by the amplifier

$$\frac{(F-1)\cancel{KTB_N}}{(F)\cancel{KTB_N}} = \frac{(F-1)}{F}$$

Equivalent Noise Temperature at Amplifier I/P :-

Jan-06, 4M
July-09, 4M

* W.K.T, the noise power due to amplifier, having a noise factor 'F' is

$$\boxed{P_{na} = (F-1)\,KTB_N} \longrightarrow ①$$

* If 'T_e' represents the equivalent noise temperature representing noise power, then

$$\boxed{P_{na} = KT_eB_N} \longrightarrow ②$$

Equating eq ① & ②, we get

$$\cancel{K}T_e\cancel{B_N} = (F-1)\cancel{K}T\cancel{B_N}$$

$$\boxed{T_e = (F-1)\,T} \longrightarrow ③$$

$$(F-1) = \frac{T_e}{T}$$

$$\boxed{F = \frac{T_e}{T} + 1}$$

Noise Temperature of Cascaded N/W :-

1) Derive an expression for overall Equivalent Noise temperature of the cascade connection of any number of noises for two port N/w

July-09, 5M

* It is possible to develop an expression for the overall Noise temperature using Friis formula i.e.

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

Subtract 1 from both Sides of eq ①, we get

$$F - 1 = F_1 - 1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \dots$$

* If 'T_e' is overall equivalent Noise temperature of the Cascade, While T_{e1}, T_{e2}, ... are corresponding values for each amplifier in Cascade, then from eq ③ " $\frac{T_e}{T} = (F-1)$ ", we have

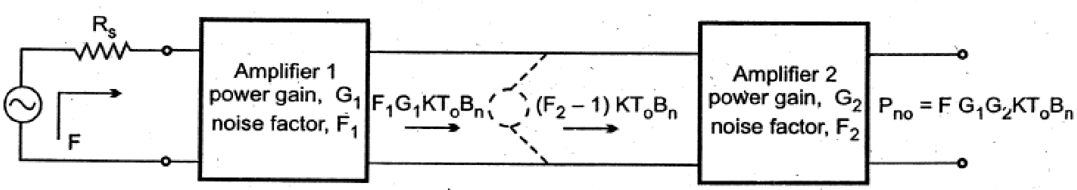
$$\frac{T_e}{T} = \frac{T_{e1}}{T} + \frac{T_{e2}/T}{G_1} + \frac{T_{e3}/T}{G_1 G_2} + \dots$$

$$\boxed{T_e = T_{e1} + \frac{T_{e2}}{G_1} + \frac{T_{e3}}{G_1 G_2} + \dots}$$

Noise Factor of amplifier in Cascade :-

▶ **Figure**

Noise factor of two amplifiers in cascade



* Consider two amplifier connected in Cascade as Shown above. The - available Noise power at the o/p of 1^{st} amplifier is

$$\boxed{P_{no1} = F_1 G_1 K T_o B_N} \longrightarrow ①$$

* This is available to the 2^{nd} amplifier & 2^{nd} amplifier has noise $(F_2 - 1) KTB_N$ of its own at its I/p of the 2^{nd} amplifier is

$$\boxed{P_{ni2} = F_1 G_1 KTB_N + (F_2 - 1) KTB_N} \longrightarrow ②$$

* Consider 2nd amplifier as a Noiseless amplifier with amplifier gain 'G_2'

We have

$$\boxed{P_{no2} = G_2 P_{ni2}} \longrightarrow (3)$$

Substituting eq (2) in eq (3), we get

$$P_{no2} = G_2 \left[F_1 G_1 KTB_N + (F_2 - 1) KTB_N \right] \longrightarrow (4)$$

* WKT, the overall voltage gain of the two amplifiers in cascade is

$$G = G_1 G_2 \quad \&$$

* From figure, the overall Noise power is

$$\boxed{P_{no} = F G_1 G_2 KTB_N} \longrightarrow (5)$$

* Equating eq (4) & (5), we get

$$P_{no} = P_{no2}$$

$$F G_1 G_2 KTB_N = G_2 \left[F_1 G_1 KTB_N + (F_2 - 1) KTB_N \right]$$

$$F = \frac{F_1 G_1 G_2 KTB_N + (F_2 - 1) G_2 KTB_N}{G_1 G_2 KTB_N}$$

$$F = \frac{F_1 \cancel{G_1 G_2 KTB_N}}{\cancel{G_1 G_2 KTB_N}} + \frac{(F_2 - 1) \cancel{G_2 KTB_N}}{G_1 \cancel{G_2 KTB_N}}$$

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

By having G_1 large, the noise contribution of the 2nd stage can be made negligible.

* For Multistage amplifier

$$\boxed{F = F_1 + \frac{(F_2-1)}{G_1} + \frac{(F_3-1)}{G_1 G_2} + \cdots} \longrightarrow (7)$$

Equation (7) is Known as "Friis" Formula.

NOTE :-

For 4- Stage amplifier

$$\boxed{F = F_1 + \frac{(F_2-1)}{G_1} + \frac{(F_3-1)}{G_1 G_2} + \frac{(F_4-1)}{G_1 G_2 G_3}}$$

Important Formulae

Sr. No.			Expression
1.	Speed of light	:	$C = \lambda \times f$
2.	Thermal noise power	:	$P_n = kTB$
3.	Shot noise	:	$I_n^2 = 2(I + 2I_o)\,qB$
4.	Signal to noise ratio	:	$\frac{S}{N} = \left[\frac{V_s}{V_n}\right]^2$
5.	Noise factor	:	$F = \frac{S/N \text{ ratio at the input}}{S/N \text{ ratio at the output}}$
6.	Noise figure	:	$F_{dB} = 10 \log_{10}$ (Noise factor)
7.	Noise temperature	:	$T_e = (F - 1)\,T_o$
8.	Thermal noise voltage	:	$V_n = \sqrt{4\,k\,TBR}$
9.	Noise voltage for resistors in series	:	$V_n = \left[V_{n1}^2 + V_{n2}^2\right]^{1/2}$ and $R = R_1 + R_2$
10.	Total noise voltage for resistors in series	:	$V_n = 4\,k\,TB\,R_P$ where $R_P = R_1 \parallel R_2$
11.	Noise power contributed by an amplifier	:	$P_{na} = (F - 1)\,k\,T_o\,B$
12.	Friiss formula	:	$F = F_1 + \frac{(F_2 - 1)}{G_1} + \frac{(F_3 - 1)}{G_1 G_2} + \ldots$
13.	Friiss formula for noise temperature	:	$T_{eq.} = T_{eq.1} + \frac{T_{eq2}}{G_1} + \frac{T_{eq3}}{G_1 G_2} \ldots$