## Noise Band Width

Noise The noise bandwidth "BN" is defined as the bandwidth of an ideal (rectangular) filter which passes the same noise power as does the real filter.

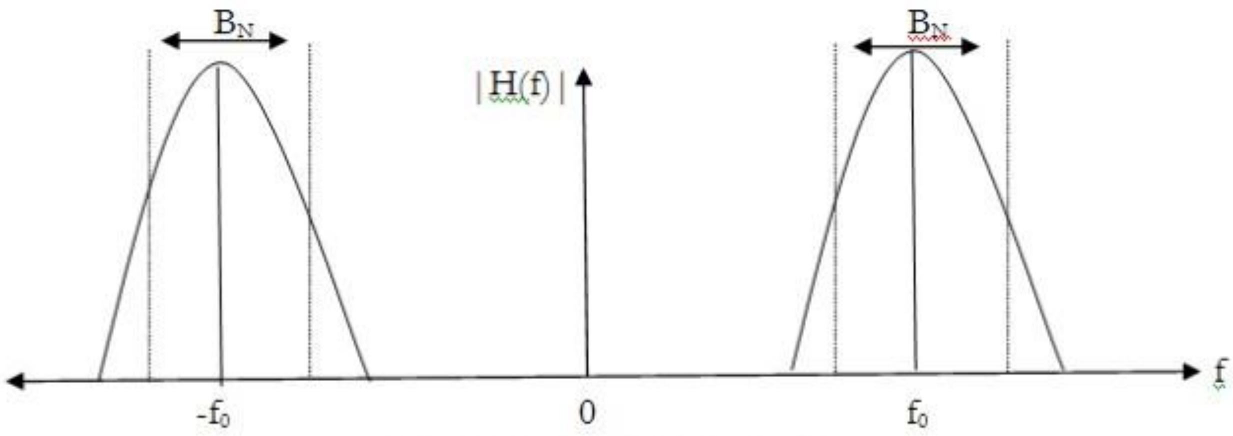


**Figure 4.3.1 Noise Bandwidth of a filter**

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Assume that a white noise is present at the input of a receiver (filter).Let the filter have a transfer function H (f) as shown in fig. This filter is being used to reduce the noise power actually passed on to the receiver. Now consider the dotted plot (ideal filter. The centre frequency of this ideal filter is f0. Let the bandwidth "$B_N$"of the ideal filter be adjusted in such a way that the noise output power of the ideal filter is exactly equal to the noise output power of a real R-C figure 4.3.1lter shown in fig. Then "$B_N$" is called as the noise bandwidth of the real filter.

**Classification Of Noise:**

Noise is random, undesirable electrical energy that enters the communications system via the communicating medium and interferes with the transmitted message. However, some noise is also produced in the receiver or With reference to an electrical system, noise may be defined as any unwanted form of energy which tends to interfere with proper reception and reproduction of wanted signal.

Noise may be put into following two categories.

1. **External noises**, i.e. noise whose sources are external. External noise may be classified into the following three types:

**Atmospheric noises**

**Extraterrestrial noises**

**Man-made noises or industrial noises.**

2. **Internal noise in communication**, i.e. noises which get, generated within the receiver or communication system. Internal noise may be put into the following four categories.

**Thermal noise or white noise or Johnson noise**

**Shot noise.**

**Transit time noise**

**Miscellaneous internal noise.**



External noise cannot be reduced except by changing the location of the receiver or the entire system. Internal noise on the other hand can be easily evaluated mathematically and can be reduced to a great extent by proper design. As already said, because of the fact that internal noise can be reduced to a great extent, study of noise characteristics is a very important part of the communication engineering.

**1. Explanation of External Noise**

**Atmospheric Noise:**

Atmospheric noise or static is caused by lighting discharges in thunderstorms and other natural electrical disturbances occurring in the atmosphere. These electrical impulses are random in nature. Hence the energy is spread over the complete frequency spectrum used for radio communication.

Atmospheric noise accordingly consists of spurious radio signals with components spread over a wide frequency range. These spurious radio waves constituting the noise get propagated over the earth in the same fashion as the desired radio waves of the same frequency. Accordingly at a given receiving point, the receiving antenna picks up not only the signal but also the static from all the thunderstorms, local or remote.

**ü Extraterrestrial noise:**

Solar noise

Cosmic noise

**Solar noise:**

This is the electrical noise emanating from the sun. Under quite conditions, there is a steady radiation of noise from the sun. This results because sun is a large body at a very high temperature (exceeding 6000°c on the surface), and radiates electrical energy in the form of noise over a very wide frequency spectrum including the spectrum used for radio communication. The intensity produced by the sun varies with time. In fact, the sun has a repeating 11-year noise cycle. During the peak of the cycle, the sun produces some amount of noise that causes tremendous radio signal interference, making many frequencies unusable for communications. During other years. The noise is at a minimum level.

**Cosmic noise:**

Distant stars are also suns and have high temperatures. These stars, therefore, radiate noise in the same way as our sun. The noise received from these distant stars is thermal noise (or black body noise) and is distributing almost uniformly over the entire sky. We also receive noise from the center of our own galaxy (The Milky Way) from other distant galaxies and from other virtual point sources such as quasars and pulsars.

**Man-Made Noise (Industrial Noise):**

By man-made noise or industrial- noise is meant the electrical noise produced by such sources as automobiles and aircraft ignition, electrical motors and switch gears, leakage from high voltage lines, fluorescent lights, and numerous other heavy electrical machines. Such noises are produced by the arc discharge taking place during operation of these machines. Such man-made noise is most intensive in industrial and densely populated areas. Man-made noise in such areas far exceeds all other sources of noise in the frequency range extending from about 1 MHz to 600 MHz.

**Explanation of Internal Noise in communication:**

**Thermal Noise:**

Conductors contain a large number of 'free" electrons and "ions" strongly bound by molecular forces. The ions vibrate randomly about their normal (average) positions, however, this vibration being a function of the temperature. Continuous collisions between the electrons and the vibrating ions take place. Thus there is a continuous transfer of energy between the ions and electrons. This is the source of resistance in a conductor. The movement of free electrons constitutes a current which is purely random in nature and over a long time averages zero. There is a random motion of the electrons which give rise to noise voltage called thermal noise.Thus noise generated in any resistance due to random motion of electrons is called thermal noise or white or Johnson noise. The analysis of thermal noise is based on the Kinetic theory. It shows that the temperature of particles is a way of expressing its internal kinetic energy. Thus "Temperature" of a body can be said to be equivalent to the statistical rms value of the velocity of motion of the particles in the body. At -273°C (or zero degree Kelvin) the kinetic energy of the particles of a body becomes zero shown in figure 4.3.2 .Thus we can relate the noise power generated by a resistor to be proportional to its absolute temperature. Noise power is also proportional to the bandwidth over which it is measured. From the above discussion we can write down.

$$P_n \propto TB$$
$$P_n = KTB \text{ ------ } (1)$$

Where Pn = Maximum noise power output of a resistor.

K = Boltzmann's constant = 1.38 x10-23 joules I Kelvin.

T = Absolute temperature.

B = Bandwidth over which noise is measured.

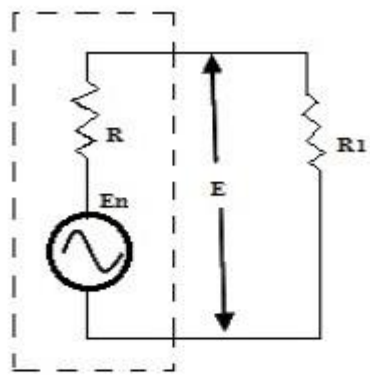


**Figure 4.3.2 Calculation of Noise power from Noise Voltage En**

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$$P_n = \frac{E^2}{R_1} = \frac{E^2}{R} = \frac{(\frac{E_n}{2})^2}{R} = \frac{E_n^2}{4R}$$

$$[\therefore \; from \; Fig \; if \; R = R_2, E_n = \frac{E}{2}]$$

$$E_{n2} = 4RP_n$$

$$E_{n2} = 4R\,KTB$$

$$E_n = \sqrt{4KTRB}$$

**Transit Time Noise:**

Another kind of noise that occurs in transistors is called transit time noise. Transit time is the duration of time that it takes for a current carrier such as a hole or current to move from the input to the output. The devices themselves are very tiny, so the distances involved are minimal. Yet the time it takes for the current carriers to move even a short distance is finite. At low frequencies this time is negligible. But when the frequency of operation is high and the signal being processed is the magnitude as the transit time, then problem can occur. The transit time shows up as a kind of random noise within the device, and this is directly proportional to the frequency of operation.

**Miscellaneous Internal Noises Flicker Noise:**

Flicker noise or modulation noise is the one appearing in transistors operating at low audio frequencies. Flicker noise is proportional to the emitter current and junction temperature. However, this noise is inversely proportional to the frequency. Hence it may be neglected at frequencies above about 500 Hz and it, Therefore, possess no serious problem.



**Transistor Thermal Noise:**

Within the transistor, thermal noise is caused by the em itter, base and collector internal resistances. Out of these three regions, the base region contributes maximum thermal noise.

**Partition Noise:**

Partition noise occurs whenever current has to divide between two or more paths, and results from the random fluctuations in the division. It would be expected, therefore, that a diode would be less noisy than a transistor (all other factors being equal) If the third electrode draws current (i.e.., the base current). It is for this reason that the inputs of microwave receivers are often taken directly to diode mixers.

**Shot Noise:**

The most common type of noise is referred to as shot noise which is produced by the random arrival of 'electrons or holes at the output element, at the plate in a tube, or at the collector or drain in a transistor. Shot noise is also produced by the random movement of electrons or holes across a PN junction. Even through current flow is established by external bias voltages, there will still be some random movement of electrons or holes due to discontinuities in the device. An example of such a discontinuity is the contact between the copper lead and the semiconductor materials. The interface between the two creates a discontinuity that causes random movement of the current carriers.

**Signal to Noise Ratio:**

Noise is usually expressed as a power because the received signal is also expressed in terms of power. By Knowing the signal to noise powers the signal to noise ratio can be computed. Rather than express the signal to noise ratio as simply a number, you will usually see it expressed in terms of decibels.

$$Signal\ TO\ Noise\ Ratio = 10\log\frac{Signal\ power}{Noise\ Power} = 10\log\frac{P_s}{P_n}$$

A receiver has an input signal power of l.2µW. The noise power is 0.80µW. The signal to noise ratio is in figure 4.3.3

Signal to Noise Ratio = 10 Log (1.2/0.8)

= 10 log 1.5

= 10 (0.176)

= 1.76 Db

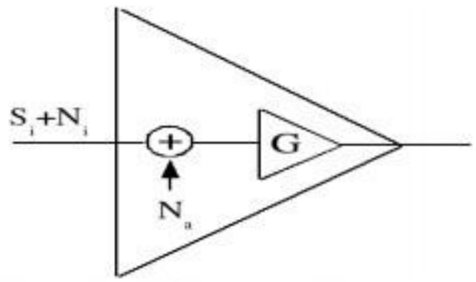


**Figure 4.3.3 Signal to Noise Ratio**

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**Noise Figure:**

Noise Figure is designed as the ratio of the signal-to-noise power at the input to the signal to noise power at the output.The device under consideration can be the entire receiver or a single amplifier stage. The noise figure also called the noise factor can be computed with the expression , F = Signal to Noise power Input/Signal to noise power output .You can express the noise figure as a number, more often you will see it expressed in decibels.

## ANALYSIS OF NOISE IN COMMUNICATION SYSTEMS:

### NOISE FACTOR – NOISE FIGURE:

Consider the network shown figure 4.2.5 in which the signal to noise ratio in the input is represented by $(S/N)_{IN}$ and signal to noise ratio in the input is represented by $(S/N)_{OUT}$.

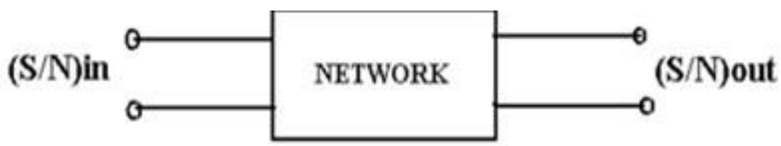



**Figure 4.2.1 Block diagram for S/N Ratio**

*Diagram Source Brain Kart*

In general $\left(\frac{S}{N}\right)_{IN} \geq$ , i.e. the network 'adds' noise (thermal noise tc from the network devices) so that the output (S/N) is generally worst than the input.

The amount of noise added by the network is embodied in the Noise Factor F, which is defined by

$$\text{Noise factor F} = \frac{\left(S/N\right)_{IN}}{\left(S/N\right)_{OUT}}$$

F equals to 1 for noiseless network and in general F > 1. The noise figure in the noise factor quoted in dB ie. Noise Figure F dB = 10 log10 F  F ≥ 0 dB The noise figure / factor is the measure of how much a network degrades the (S/N)IN, the lower the value of F, the better the network.

The network may be active elements, e.g. amplifiers, active mixers etc, i.e. elements with gain > 1 or passive elements, e.g. passive mixers, feeders cables, attenuators i.e. elements with gain <1.

**Noise Figure – Noise Factor For Active Elements :**

For active elements with power gain G>1, we have

$$F = \frac{(S/N)_{IN}}{(S/N)_{OUT}} = \frac{S_{IN}}{N_{IN}} \frac{N_{OUT}}{S_{OUT}}$$

But $S_{OUT} = G\ S_{IN}$

Therefore $$F = \frac{S_{IN}}{N_{IN}} \frac{N_{OUT}}{G S_{IN}}$$

$$F = \frac{N_{OUT}}{G N_{IN}}$$

If the $N_{OUT}$ was due only to G times $N_{IN}$ the F would be 1 i.e. the active element would be noise free. Since in general F v> 1 , then *NOUT* is increased by noise due to the active element i.e.

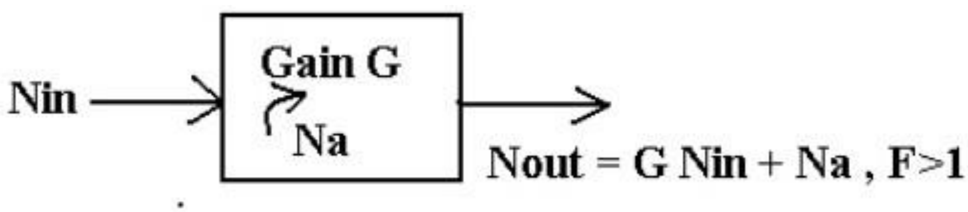



**Figure 4.2.2 Circuit Diagram of Noise Factor**

*Diagram Source Brain Kart*

Na represents 'added' noise measured at the output. This added noise may be referred to the input as extra noise, i.e. as equivalent diagram is

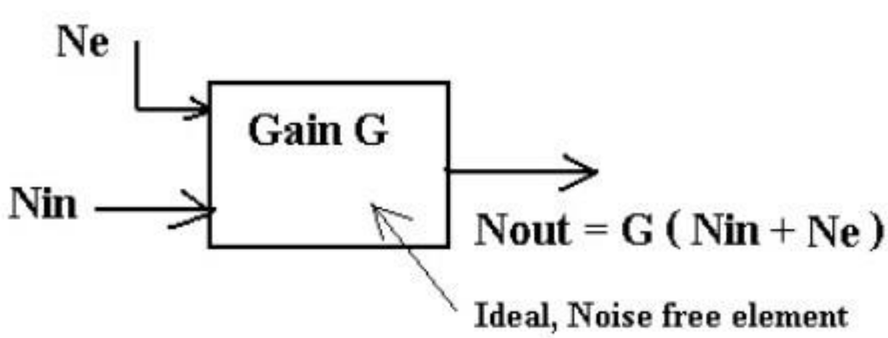



**Figure 4.2.3 Circuit Diagram of Noise Factor with extra Noise**

*Diagram Source Brain Kart*

Ne is extra noise due to active elements referred to the input; the element is thus effectively noiseless.

$$\text{Hence } F = \frac{N_{OUT}}{GN_{IN}} = F = \frac{G(N_{IN}+N_e)}{GN_{IN}}$$

Rearranging gives,

$$N_e = (F-1)N_{IN}$$

## NOISE TEMPERATURE

$N_{IN}$ is the 'external' noise from the source i.e. $N_{IN} = kT_S B_n$

$T_S$ is the equivalent noise temperature of the source (usually 290K).

We may also write $N_e = kT_e B_n$, where $T_e$ is the equivalent noise temperature of the element i.e. with noise factor F and with source temperature $T_S$.

i.e. $kT_e B_n = (F-1)kT_S B_n$

or $T_e = (F-1)T_S$

The noise factor F is usually measured under matched conditions with noise source at ambient temperature $T_S$, i.e. $T_S \sim 290K$ is usually assumed, this is sometimes written as

$$T_e = (F_{290} - 1)290$$

This allows us to calculate the equivalent noise temperature of an element with noise factor F, measured at 290 K.

For example, if we have an amplifier with noise figure FdB = 6 dB (Noise factor F=4) and equivalent Noise temperature *Te* = 865 K.

a) We have introduced the idea of referring the noise to the input of an element, this noise is not actually present at the input, it is done for convenience in the analysis.

b) The noise power and equivalent noise temperature are related, N=kTB, the temperature T is not necessarily the physical temperature, it is equivalent to the temperature of a resistance R (the system impedance) which gives the same noise power N when measured in the same bandwidth Bn.

c) Noise figure (or noise factor F) and equivalent noise temperature Te are related and both indicate how much noise an element is producing.

Since, Te = (F-1) TS

Then for F=1, Te = 0, i.e. ideal noise free active element.

**Noise Figure – Noise Factor For Passive Elements :**

The theoretical argument for passive networks (e.g. feeders, passive mixers, attenuators) that is networks with a gain < 1 is fairly abstract, and in essence shows that the noise at the input, N IN is attenuated by network, but the added noise Na contributes to the noise at the output such that

$N_{OUT} = N_{IN}$ .

Thus, since $F = \frac{S_{IN}}{N_{IN}} \frac{N_{OUT}}{S_{OUT}}$ and $N_{OUT} = N_{IN}$ .

$$F = \frac{S_{IN}}{G S_{IN}} = \frac{1}{G}$$

If we let L denote the insertion loss (ratio) of the network i.e. insertion loss

$$L_{dB} = 10 \log L$$

Then $L = \frac{1}{G}$ and hence for passive network

$$F = L$$

Also, since $T_e = (F\text{-}1) T_S$

Then for passive network

$$T_e = (L\text{-}1) T_S$$

Where $T_e$ is the equivalent noise temperature of a passive device referred to its input.

**Noise Factor – Noise Figure –Temperature:**

F, dB and $T_e$ are related by $F_{dB} = 10 \log_{dB} F$

$T_e = (F-1)290$

Some corresponding values are tabulated below:

| F | $F_{dB}$ (dB) | $T_e$ (degree K) |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 3 | 290 |
| 4 | 6 | 870 |
| 8 | 9 | 2030 |
| 16 | 12 | 4350 |

Typical values of noise temperature, noise figure and gain for various amplifiers and attenuators are given below:

| Device | Frequency | $T_e$ (K) | $F_{dB}$ (dB) | Gain (dB) |
|---|---|---|---|---|
| Maser Amplifier | 9 GHz | 4 | 0.06 | 20 |
| Ga As Fet amp | 9 GHz | 330 | 303 | 6 |
| Ga As Fet amp | 1 GHz | 110 | 1.4 | 12 |
| Silicon Transistor | 400 MHz | 420 | 3.9 | 13 |
| L C Amp | 10 MHz | 1160 | 7.0 | 50 |
| Type N cable | 1 GHz | | 2.0 | 2.0 |

**Additive White Gaussian Noise:**

Noise in Communication Systems is often assumed to be Additive White Gaussian Noise (AWGN).

- **Additive**

Noise is usually additive in that it adds to the information bearing signal. A model of the received signal with additive noise is shown below.

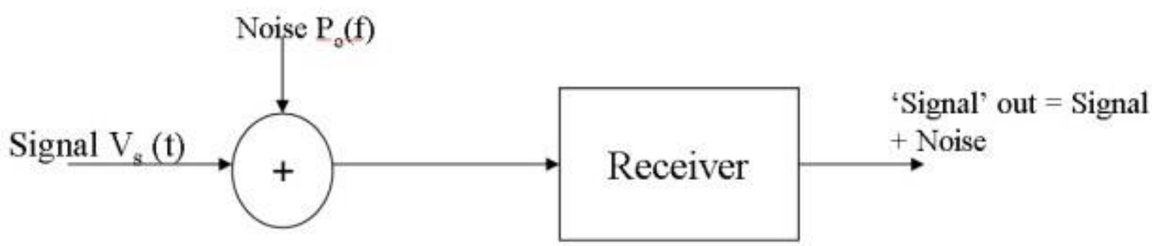



**Figure 4.2.4 Block diagram for White Noise**

*Diagram Source Brain Kart*

The signal (information bearing) is at its weakest (most vulnerable) at the receiver input. Noise at the other points (e.g. Receiver) can also be referred to the input. The noise is uncorrelated with the signal, i.e. independent of the signal and we may state, for average powers

Output Power = Signal Power + Noise Power

= (S+N)

- **White Noise**

As we have stated noise is assumed to have a uniform noise power spectral density, given that the noise is not band limited by some filter bandwidth. We have denoted noise power spectral density by $p_o(f)$. . White noise = $p_o(f)$ is Constant

Also Noise power = Po Bn

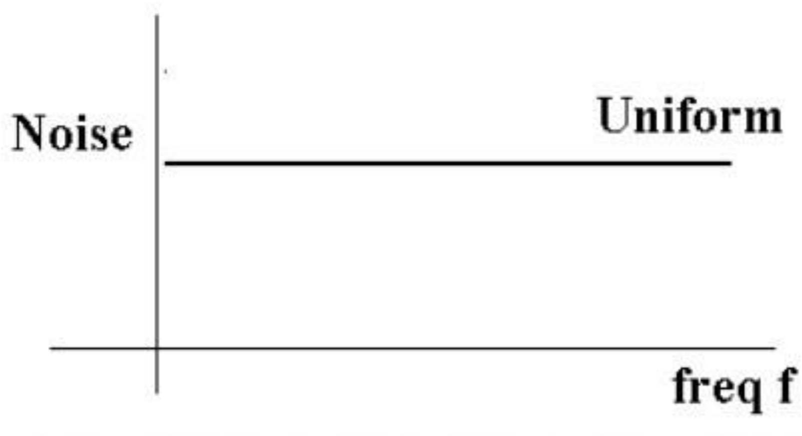



**Figure 4.2.5 Spectral Density of White Noise**

*Diagram Source Brain Kart*

We generally assume that noise voltage amplitudes have a Gaussian or Normal distribution.

## Noise In Cascade Systems

Cascade noise figure calculation is carried out by dealing with gain and noise figure as a ratio rather than decibels, and then converting back to decibels at the end. As the following equation shows, cascaded noise figure is affected most profoundly by the noise figure of components closest to the input of the system as long as some positive gain exists in the cascade.

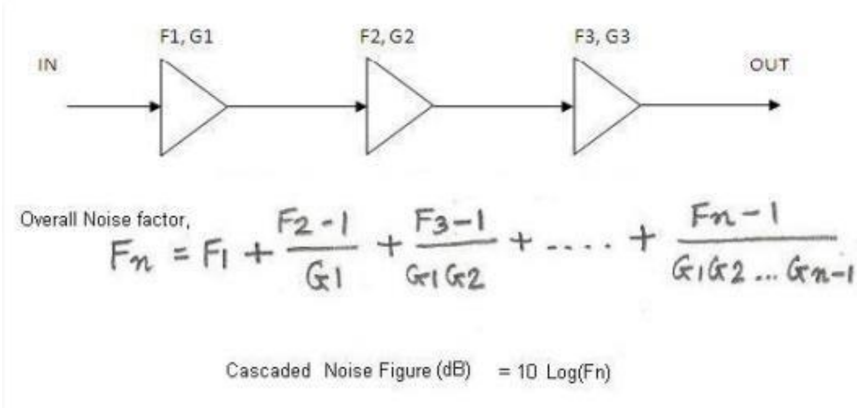





**Figure 4.4.1 Block Diagram of Cascaded Systems**

*Diagram Source Brain kart*

If only loss exists in the cascade, then the cascaded noise figure equals the magnitude of the total loss. The figure 4.4.1 is used to calculate cascaded noise figure as a ratio based on ratio values for gain and noise figure (do not use decibel values).

### Cascaded Network:

A receiver systems usually consists of a number of passive or active elements connected in series, each element is defined separately in terms of the gain (greater than 1 or less than 1 as the case may be), noise figure or noise temperature and bandwidth (usually the 3 dB bandwidth). These elements are assumed to be matched. A typical receiver block diagram is shown below, with example

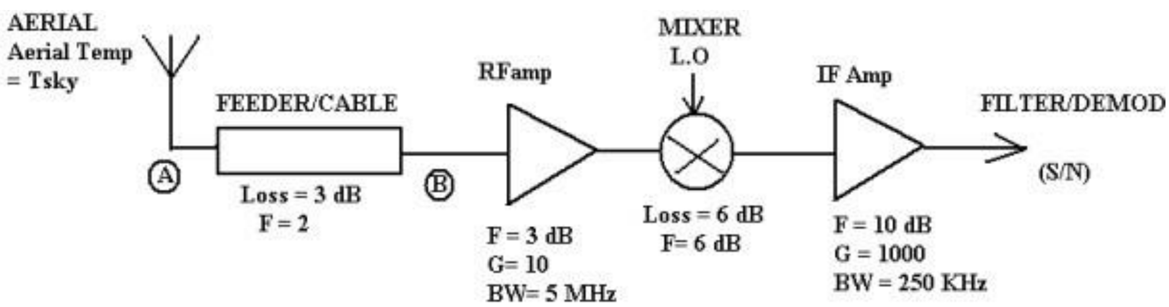



**Figure 4.4.2 Block diagram for Cascade System**,

*Diagram Source Brain Kart*

In order to determine the (S/N) at the input, the overall receiver noise figure or noise temperature must be determined in the figure 4.4.2. In order to do this all the noise must be referred to the same point in the receiver, for example to A, the feeder input or B, the input to the first amplifier. The equations so far discussed refer the noise to the input of that specific element i.e.

Te or N e is the noise referred to the input.

To refer the noise to the output we must multiply the input noise by the gain G. For example, for a lossy feeder, loss L, we had

N e = (L-1) N IN , noise referred to input Or Te = (L-1) TS - referred to the input.

Noise referred to output is gain x noise referred to input, hence

$$N_e \text{ referred to output} = G\ N_e = \frac{1}{L}\,(L\text{-}1)\,N_{IN}$$

$$= (1-\frac{1}{L})\,N_{IN}$$

Similarly, the equivalent noise temperature referred to the output is

$$T_e \text{ referred to output} = (1-\frac{1}{L})\,T_S$$

These points will be clarified later; first the system noise figure will be considered.

**System Noise Figure**:

Assume that a system comprises the elements shown below, each element defined and specified separately shown in the figure 4.4.3 & 4.4.4.

The gains may be greater or less than 1, symbols F denote noise factor (not noise figure, i.e. not in dB). Assume that these are now cascaded and connected to an aerial at the input, with

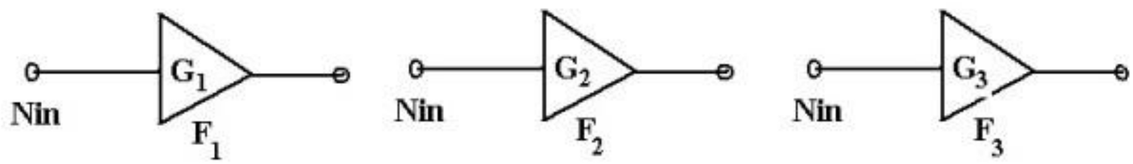



**Figure 4.4.3 Circuit Diagram of cascaded Systems**

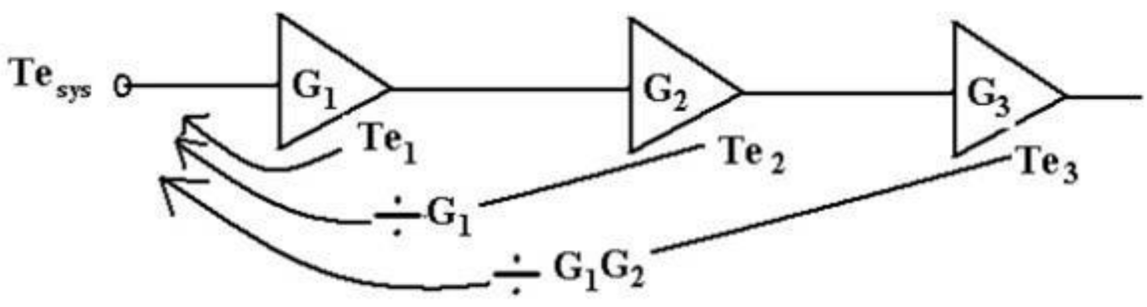



**Figure 4.4.4 Cascaded Systems**

*Diagram Source Brain Kart*

Now, $N_{OUT} = G_3 (N_{IN3} + N_{e3})$

$= G_3 (N_{IN3} + (F_3 - 1) N_{IN})$

Since $N_{IN3} = G_2 (N_{IN2} + N_{e2}) = G_2 (N_{IN2} + (F_2 - 1) N_{IN})$

and similarly $N_{IN2} = G_1 (N_{ae} + (F_1 - 1) N_{IN})$

then

$$N_{OUT} = G_3 [G_2 [G_1 N_{ae} + G_1 (F_1 - 1) N_{IN}] + G_2 (F_2 - 1) N_{IN}] + G_3 (F_3 - 1) N_{IN}$$

The overall system Noise Factor is

$$F_{sys} = \frac{N_{OUT}}{G N_{IN}} = \frac{N_{OUT}}{G_1 G_2 G_3 N_{ae}}$$

$$= 1 + (F_1 - 1) \frac{N_{IN}}{N_{ae}} + \frac{(F_2 - 1)}{G_1} \frac{N_{IN}}{N_{ae}} + \frac{(F_3 - 1)}{G_1 G_2} \frac{N_{IN}}{N_{ae}}$$

If we assume $N_{ae}$ is ≈ $N_{IN}$, i.e. we would measure and specify $F_{sys}$ under similar conditions as $F_1, F_2$ etc (i.e. at 290 K), then for n elements in cascade.



**FRIIS Formula**

$$F_{sys} = F_1 + \frac{(F_2 - 1)}{G_1} + \frac{(F_3 - 1)}{G_1 G_2} + \frac{(F_4 - 1)}{G_1 G_2 G_3} + \dots + \frac{(F_n - 1)}{G_1 G_2 \dots G_{n-1}}$$

The equation is called FRIIS Formula. This equation indicates that the system noise factor depends largely on the noise factor of the first stage if the gain of the first stage is reasonably large. This explains the desire for ―low noise front ends‖ or low noise most head preamplifiers for domestic TV reception. There is a danger however; if the gain of the first stage is too large, large and unwanted signals are applied to the mixer which may produce intermodulation distortion. Some receivers apply signals from the aerial directly to the mixer to avoid this problem. Generally a first stage amplifier is designed to have a good noise factor and some gain to give an acceptable overall noise figure.

**System Noise Temperature:**

Since $T_e = (L-1)T_S$, i.e. $F = 1 + \frac{T_e}{T_s}$

Then $F_{sys} = 1 + \frac{T_{e\,sys}}{T_s}$ $\left\{ \begin{array}{l} where\; T_{e\,sys}\; is\; the\; equivalent\; Noise\; temperature\; of\; the\; system \\ and\; T_s\; is\; the\; noise\; temperature\; of\; the\; source \end{array} \right.$

and

$$\left(1 + \frac{T_{e\,sys}}{T_s}\right) = \left(1 + \frac{T_{e1}}{T_s}\right) + \frac{\left(1 + \frac{T_{e2}}{T_s} - 1\right)}{G_1} + \ldots etc$$

$$i.e.\; from\; F_{sys} = F_1 + \frac{(F_2 - 1)}{G_1} + \ldots\ldots etc$$

*which gives*

$$T_{e\,sys} = T_{e1} + \frac{T_{e2}}{G_1} + \frac{T_{e3}}{G_1 G_2} + \frac{T_{e4}}{G_1 G_2 G_3} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Overall Noise factor,

$$F_n = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots + \frac{F_n - 1}{G_1 G_2 \ldots G_{n-1}}$$

Cascaded Noise Figure (dB) = 10 Log(Fn)

**Application:**

It is important to realize that the previous sections present a technique to enable a receiver performance to be calculated. The essence of the approach is to refer all the noise contributed at various stages in the receiver to the input and thus contrive to make all the stages ideal, noise free.

# UNIT IV

# NOISE CHARACTERISATION

**Noise Source Introduction:**

Noise is often described as the limiting factor in communication systems: indeed if there as no noise there would be virtually no problem in communications. Noise is a general term which is used to describe an unwanted signal which affects a wanted signal. These unwanted signals arise from a variety of sources which may be considered in one of two main categories:-

a) Interference, usually from a human source (man made)

b) Naturally occurring random noise.

Interference arises for example, from other communication systems (cross talk), 50 Hz supplies (hum) and harmonics, switched mode power supplies, thyristor circuits, ignition (car spark plugs) motors … etc. Interference can in principle be reduced or completely eliminated by careful engineering (i.e. good design, suppression, shielding etc). Interference is essentially deterministic (i.e. random, predictable), however observe.

When the interference is removed, there remains naturally occurring noise which is essentially random (non-deterministic),. Naturally occurring noise is inherently present in electronic communication systems from either _external‘ sources or _internal‘ sources.

Naturally occurring external noise sources include atmosphere disturbance (e.g. electric storms, lighting, ionospheric effect etc), so called ‘Sky Noise‘ or Cosmic noise which includes noise from galaxy, solar noise and _hot spot‘ due to oxygen and water vapor resonance in the earth‘s atmosphere. These sources can seriously affect all forms of radio transmission and the design of a radio system (i.e. radio, TV, satellite) must take these into account. The figure 4.1.1 below shows noise temperature (equivalent to noise power, we shall discuss later) as a function of frequency for sky noise.

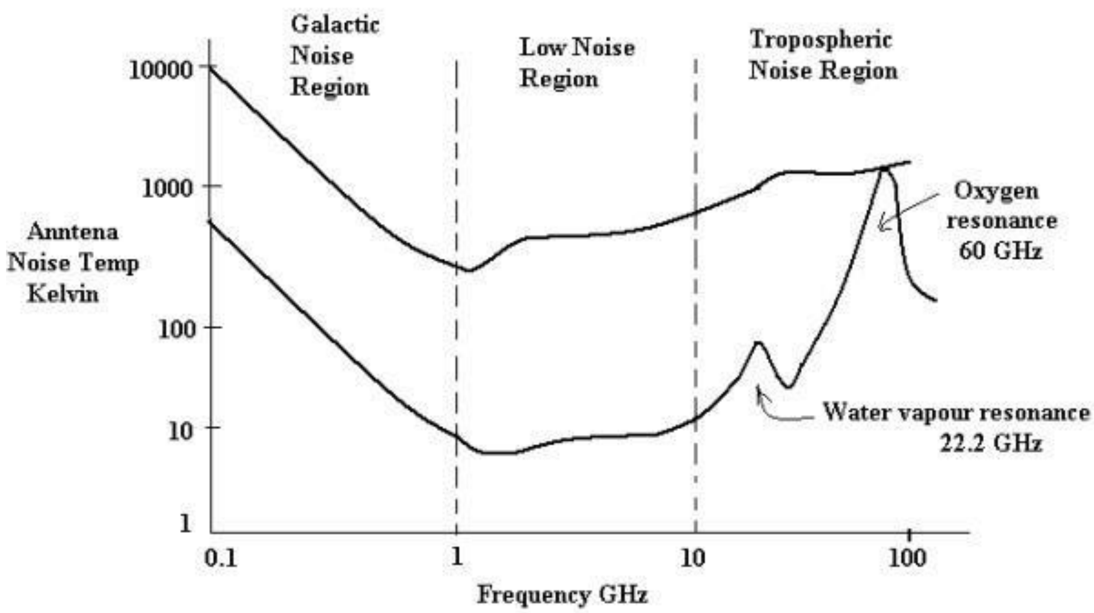





**Fig 4.1.1 Noise temperature as a function of frequency for sky noise**

*Diagram Source Brain Kart*

The upper curve represents an antenna at low elevation (~ $5^o$ above horizon), the lower curve represents an antenna pointing at the zenith (i.e. $90^o$ elevation).

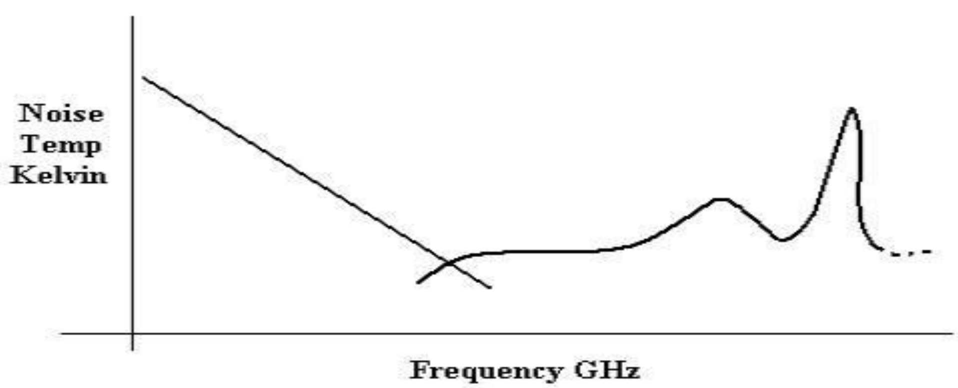



**Figure 4.1.2 Relationship curve for noise temperature as a function of frequency**

*Diagram Source Brain Kart*

Contributions to the above diagram are from galactic noise and atmospheric noise as shown below. Note that sky noise is least over the band – 1 GHz to 10 GHz shown in the figure 4.1.2. This is referred to as a low noise ‘window‘ or region and is the main reason why satellite links operate at frequencies in this band (e.g. 4 GHz, 6GHz, 8GHz). Since signals received from satellites are so small it is important to keep the background noise to a minimum.

Naturally occurring internal noise or circuit noise is due to active and passive electronic devices (e.g. resistors, transistors ...etc) found in communication systems. There are various mechanism which produce noise in devices; some of which will be discussed in the following sections.

**Thermal Noise (Johnson Noise):**

This type of noise is generated by all resistances (e.g. a resistor, semiconductor, the resistance of a resonant circuit shown in figure 4.1.3, i.e. the real part of the impedance, cable etc). Free electrons are in contact random motion for any temperature above absolute zero (0 degree K, ~ -273 degree C). As the temperature increases, the random motion increases, hence thermal noise, and since moving electron constitute a current, although there is no net current flow, the motion can be measured as a mean square noise value across the resistance.

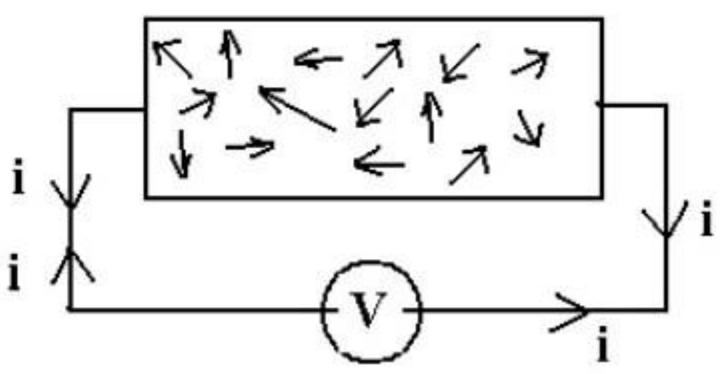



**Figure 4.1.3 Circuit Diagram of Thermal Noise Voltage**

*Diagram Source Brain Kart*

Experimental results (by Johnson) and theoretical studies (by Nyquist) give the mean square noise

$$\text{voltage as } \bar{V}^2 = 4kTBR \ (volt^2)$$

Where k = Boltzmann's constant = 1.38 x 10-23 Joules per K

T = absolute temperature

B = bandwidth noise measured in (Hz)

R = resistance (ohms)

The law relating noise power, N, to the temperature and bandwidth is

N = k TB watts

These equations will be discussed further in later section.

The equations above held for frequencies up to > 1013 Hz (10,000 GHz) and for at least all practical temperatures, i.e. for all practical communication systems they may be assumed to be valid.Thermal noise is often referred to as 'white noise' because it has a uniform 'spectral density'.

Note – noise power spectral density is the noise power measured in a 1 Hz bandwidth i.e. watts per Hz. A uniform spectral density means that if we measured the thermal noise in any 1 Hz bandwidth from ~ 0Hz → 1 MHz → 1GHz …….. 10,000 GHz etc we would measure the same amount of noise. From the equation N=kTB, noise power spectral density is Po is proportional to k T watts per Hz. I.e. Graphically figure 4.1.4 is shown as,

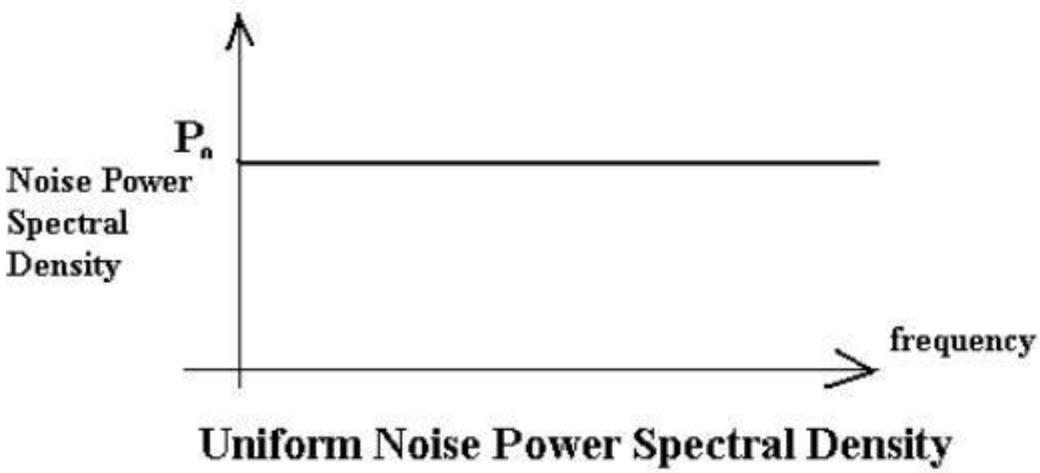



**Figure 4.1.4 Uniform Noise Power Spectral Density**

*Diagram Source Electronics Post*

**Shot Noise:**

Shot noise was originally used to describe noise due to random fluctuations in electron emission from cathodes in vacuum tubes (called shot noise by analogy with lead shot). Shot noise also occurs in semiconductors due to the liberation of charge carriers, which have discrete amount of charge, in to potential barrier region such as occur in pn junctions. The discrete amounts of charge give rise to a current which is effectively a series of current pulses.



For pn junctions the mean square shot noise current is

$$I_n^2 = 2(I_{DC} + 2I_o)q_e B \quad (amps)^2$$

Where

$I_{DC}$ is the direct current as the pn junction (amps)

$I_0$ is the reverse saturation current (amps)

$q_e$ is the electron charge = 1.6 x $10^{-19}$ coulombs

B is the effective noise bandwidth (Hz)

Shot noise is found to have a uniform spectral density as for thermal noise.

**Low Frequency Or Flicker Noise:**

Active devices, integrated circuit, diodes, transistors etc also exhibits a low frequency noise, which is frequency dependent (i.e. non uniform) known as flicker noise or 'one – over – f' noise. The mean square value is found to be proportional to (1/f) where f is the frequency and n= 1. Thus the noise at higher frequencies is less than at lower frequencies. Flicker noise is due to impurities in the material which in turn cause charge carrier fluctuations.

**Excess Resistor Noise:**

Thermal noise in resistors does not vary with frequency, as previously noted, by many resistors also generates as additional frequency dependent noise referred to as excess noise. This noise also exhibits a (1/f) characteristic, similar to flicker noise. Carbon resistor generally generates most excess noise whereas were wound resistors usually generates negligible amount of excess noise. However the inductance of wire wound resistor limits their frequency and metal film resistor are usually the best choices for high frequency communication circuit where low noise and constant resistance are required.



**Burst Noise Or Popcorn Noise:**

Some semiconductors also produce burst or popcorn noise with a spectral density which is proportional to (1/f)2

**General Comments:**

The figure 4.1.5 below illustrates the variation of noise with frequency.

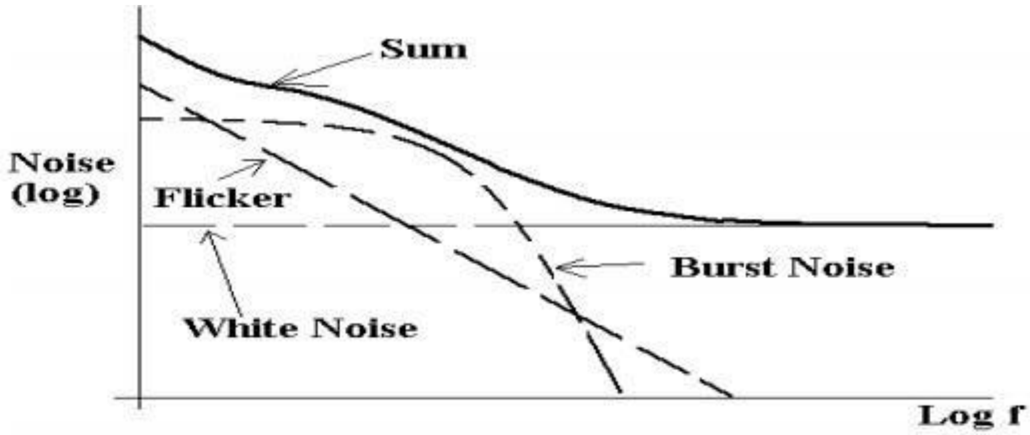



**Figure 4.1.5 Variation of noise with frequency**

*Diagram Source Brain Kart*

For frequencies below a few KHz (low frequency systems), flicker and popcorn noise are the most significant, but these may be ignored at higher frequencies where _white‘ noise predominates.

Thermal noise is always presents in electronic systems. Shot noise is more or less significant depending upon the specific devices used for example as FET with an insulated gate avoids junction shot noise. As noted in the preceding discussion, all transistors generate other types of non-white‘ noise which may or may not be significant depending on the specific device and application. Of all these types of noise source, white noise is generally assumed to be the most significant and system analysis is based on the assumption of thermal noise. This assumption is reasonably valid for radio systems which operates at frequencies where non-white noise is greatly reduced and which have low noise _front ends‘ which, as shall be discussed, contribute most of the internal (circuit) noise in a receiver system. At radio frequencies the sky noise contribution is significant and is also (usually) taken into account.

Obviously, analysis and calculations only gives an indication of system performance. Measurements of the noise or signal-to-noise ratio in a system include all the noise, from whatever source, present at the time of measurement and within the constraints of the measurements or system bandwidth.

Before discussing some of these aspects further an overview of noise evaluation as applicable to communication systems will first be presented.

**Noise Evaluation:**

**Overview:**

It has been stated that noise is an unwanted signal that accompanies a wanted signal, and, as discussed, the most common form is random (non-deterministic) thermal noise. The essence of calculations and measurements is to determine the signal power to Noise power ratio, i.e. the (S/N) ratio or (S/N) expression in dB.

i.e. Let S= signal power (mW)

N = noise power (mW)

$$\left(\frac{S}{N}\right)_{ratio} = \frac{S}{N}$$

$$\left(\frac{S}{N}\right)_{dB} = 10\log_{10}\left(\frac{S}{N}\right)$$

*Also recall that*

$$S_{dBm} = 10\log_{10}\left(\frac{S(mW)}{1mW}\right)$$

$$and\ N_{dBm} = 10\log_{10}\left(\frac{N(mW)}{1mW}\right)$$

$$i.e.\left(\frac{S}{N}\right)_{dB} = 10\log_{10} S - 10\log_{10} N$$

$$\left(\frac{S}{N}\right)_{dB} = S_{dBm} - N_{dBm}$$

Noise, which accompanies the signal is usually considered to be additive (in terms of powers) and its often described as Additive White Gaussian Noise, AWGN, noise. Noise and signals may also Powers are usually measured in dBm (or dBw) in communications systems. The equation (S/N)dB = SdBM - NdBm is often the most useul. The (S/N) at various stages in a communication system gives an indication of system quality and performance in terms of error rate in digital data communication systems and _fidelity' in case of analogue communication systems. (Obviously, the larger the (S/N) , the better the system will be).

AWGN.In order to evaluate noise various mathematical models and techniques have to be used, particularly concepts from statistics and probability theory, the major starting point being that random noise is assumed to have a Gaussian or Normal distribution.

We may relate the concept of white noise with a Gaussian distribution as follows:



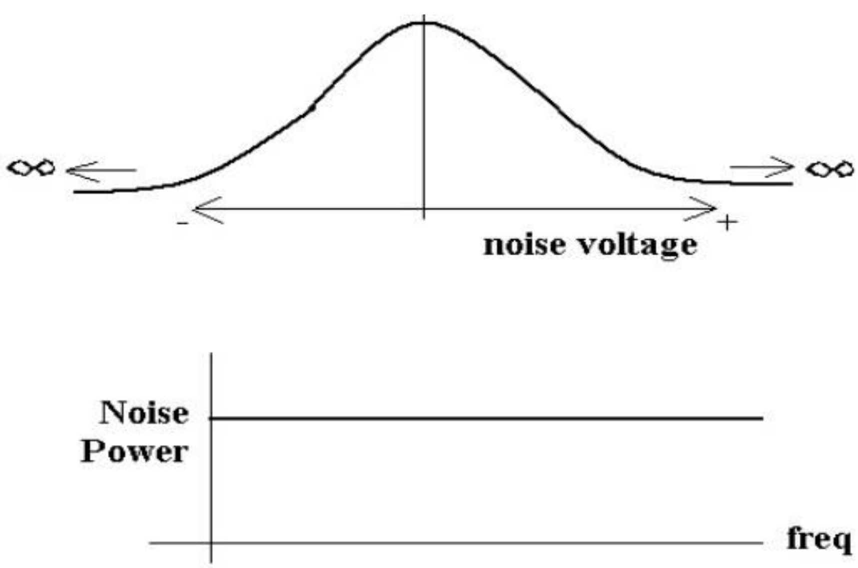



**Figure 4.1.6 Probability of Noise Vs Voltage and Frequency Vs Noise Power**

*Diagram Source Brain Kart*

Gaussian distribution – ‗graph‘ shows Probability of noise voltage vs voltage – i.e. most probable noise voltage is 0 volts (zero mean) shown in figure 4.1.6. There is a small probability of very large +ve or –ve noise voltages. White noise – uniform noise power from 'DC' to very high frequencies. Although not strictly consistence, we may relate these two characteristics of thermal noise as follows:

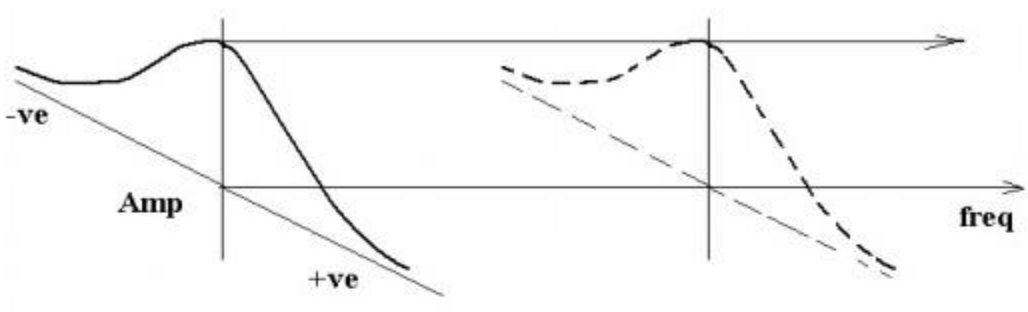



**Figure 4.1.7 Characteristics of Thermal Noise**

*Diagram Source Brain Kart*



The probability of amplitude of noise at any frequency or in any band of frequencies (e.g. 1 Hz, 10Hz… 100 KHz .etc) is a Gaussian distribution. Noise may be quantified in terms of noise power spectral density, p0 watts per Hz, from which Noise power shown in the figure 4.1.7 may be expressed as

N= p0 Bn watts

Where Bn is the equivalent noise bandwidth, the equation assumes p0 is constant across the band (i.e. White Noise).

Note - Bn is not the 3dB bandwidth, it is the bandwidth which when multiplied by p0

Gives the actual output noise power N. This is illustrated further below the figure 4.1.8.

Ideal low pass filter

Bandwidth B Hz = Bn

N= p0 Bn watts

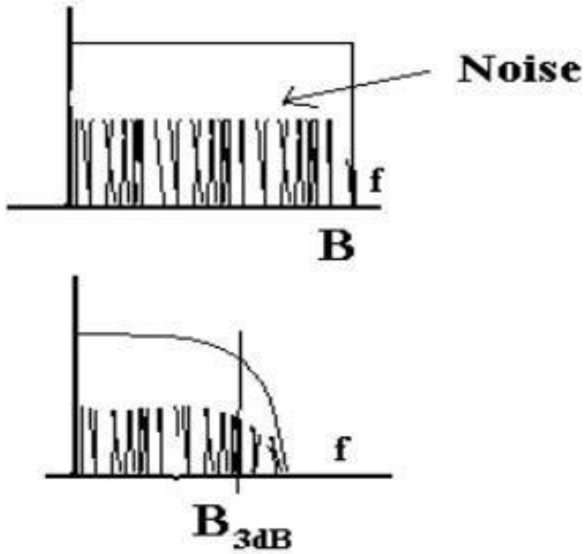



**Figure 4.1.8 Basic ideal Low Pass Filter**

*Diagram Source Brain Kart*



Practical LPF

3 dB bandwidth shown, but noise does not suddenly cease at B3dB

Therefore, Bn > B3dB, Bn depends on actual filter.

N= p0 Bn

In general the equivalent noise bandwidth is > B3dB.

Alternatively, noise may be quantified in terms of 'mean square noise' i.e. bar (V2) , which is effectively a power. From this a _Root mean square (RMS)' value for the noise voltage may be determined.

$$\text{i.e. RMS} = \sqrt{\overline{V^2}}$$

In order to ease analysis, models based on the above quantities are used. For example, if we imagine noise in a very narrow bandwidth, δf, as δf->df, the noise approaches a sine wave (with frequency 'centred' in df).Since an RMS noise voltage can be determined, a _peak' value of the noise may be invented since for a sine wave

$$\text{RMS} = \frac{Peak}{\sqrt{2}}$$

Note – the peak value is entirely fictious since in theory the noise with a Gaussian distribution could have a peak value of + ∞ or - ∞ volts.

Hence we may relate

$$\text{Mean square} \rightarrow \text{RMS} \rightarrow \sqrt{2}\,(\text{RMS}) \rightarrow \text{Peak noise voltage (invented for convenience)}$$

Problems arising from noise are manifested at the receiving end of a system and hence most of the analysis relates to the receiver / demodulator with transmission path loss and external noise sources (e.g. sky noise) if appropriate, taken into account.

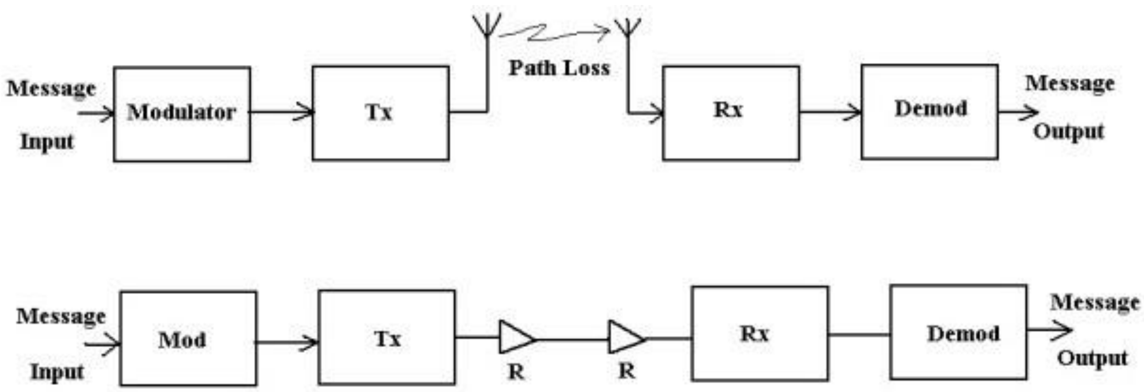



**Figure 4.1.9 Block Diagram of Communication Systems**

*Diagram Source Electronic Tutorials*

R = repeater (Analogue) or Regenerators (digital)

Figure 4.1.9 shows the block Diagram of Communication Systems.These systems may facilitate analogue or digital data transfer

**Thermal Noise (Johnson noise)**

The thermal noise in a resistance R has a mean square value given by

$$\overline{V^2} = 4kTBR\ (volt^2)$$

Where k = Boltzmann's constant = 1.38 x 10-23 Joules per K

T = absolute temperature

B = bandwidth noise measured in (Hz)

R = resistance (ohms)

This is found to hold for large bandwidth (>1013 Hz) and large range in temperature. This thermal noise may be represented by an equivalent circuit as shown below the figure 4.1.10.

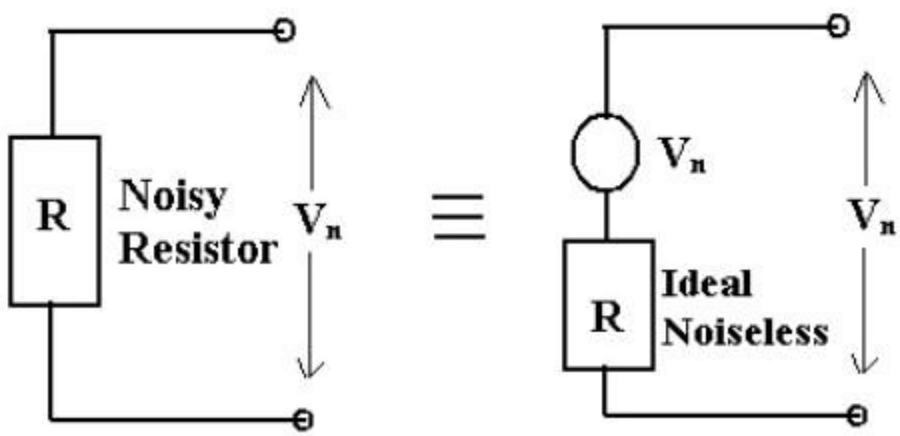



**Figure 4.1.10 Equivalent Circuit of Thermal Noise**

*Diagram Source Brain Kart*

i.e. equivalent to the ideal noise free resistor (with same resistance R) in series with a voltage source with voltage Vn. Since

$$\overline{V^2} = 4kTBR\ (volt^2) \quad \text{(mean square value , power)}$$

$$\text{then} \quad V_{RMS} = \sqrt{\overline{V^2}} = 2\sqrt{kTBR} = V_n \quad \text{in above}$$

i.e. Vn is the RMS noise voltage. The above equation indicates that the noise power is proportional to bandwidth. For a given resistance R, at a fixed temperature T (Kelvin)

We have $\overline{V^2} = (4kTR)\,B$, where $(4kTR)$ is a constant – units watts per Hz.

For a given system, with (4 k TR) constant, then if we double the bandwidth from B Hz to 2B Hz, the noise power will double (i.e increased by 3 dB). If the bandwidth were increased by a factor of 10, the noise power is increased by a factor of 10.For this reason it is important that the system bandwidth is only just _wide' enough to allow the signal to pass to limit the noise bandwidth to a minimum.

Signal Spectrum Signal Power = S and the System Band width is W = B Hz

**Noise Voltage Spectral Density**

Since date sheets specify the noise voltage spectral density with unit's volts per $\sqrt{Hz}$ (volts per root Hz).

This is from $V_n = (2\sqrt{kTR})\sqrt{B}$ i.e. Vn is proportional to $\sqrt{B}$. The quantity in bracket, i.e. $(2\sqrt{kTR})$ has units of volts per $\sqrt{Hz}$. If the bandwidth B is doubled the noise voltage will increased by $\sqrt{2}$. If bandwidth is increased by 10, the noise voltage will increased by $\sqrt{10}$.

**Resistance in Series**

Assume that R1 at temperature T1 and R2 at temperature T2 are connected in series shown in Figure 4.1.11 , then

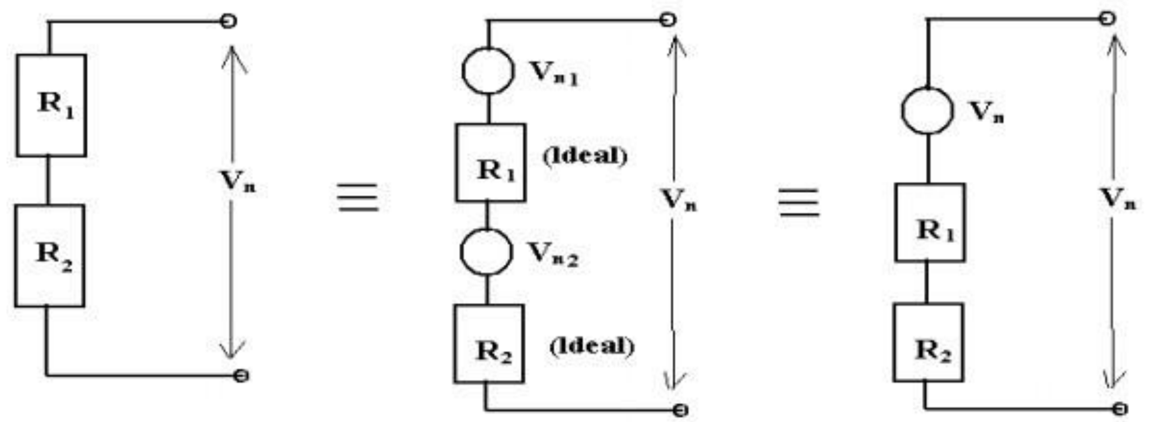



**Figure 4.1.11 Circuit diagram for Resistors connected in series**

*Diagram Source Brain Kart*

Assume that $R_1$ at temperature $T_1$ and $R_2$ at temperature $T_2$, then

$$\overline{V_n^2} = \overline{V_{n1}}^2 + \overline{V_{n2}}^2 \quad \text{(we add noise power not noise voltage)}$$

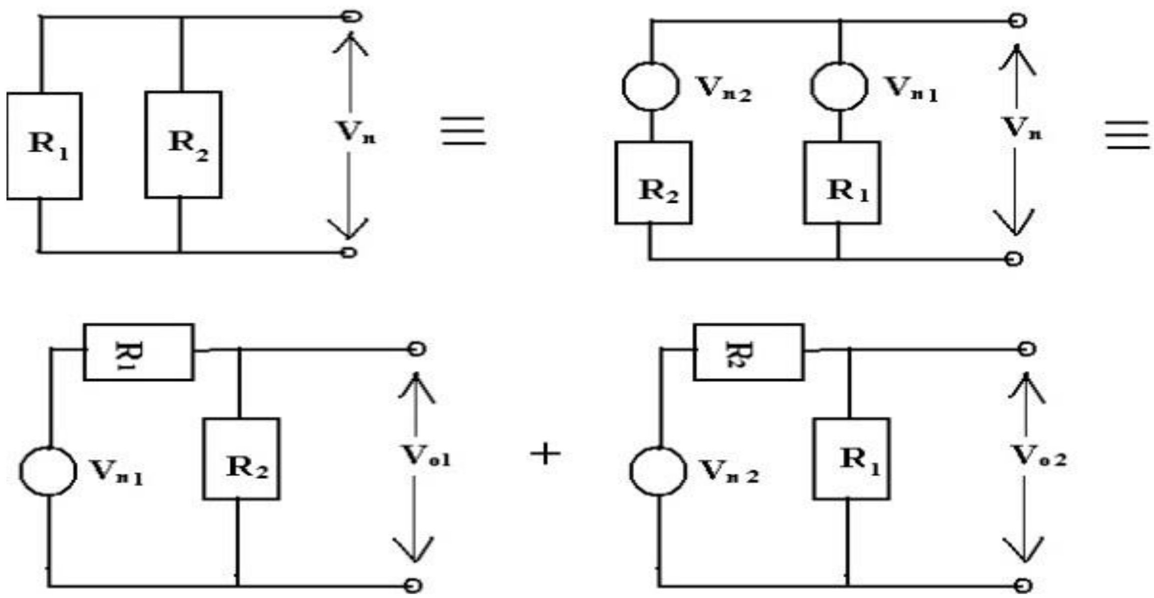
$$\overline{V_{n1}^2} = 4kT_1BR_1 \qquad \overline{V_{n2}^2} = 4kT_2BR_2$$

$$\therefore \overline{V_n^2} = 4kB(T_1R_1 + T_2R_2) \quad \text{Mean square noise}$$

If $T_1 = T_2 = T$ then $\overline{V_n^2} = 4kTB(R_1 + R_2)$

i.e. The resistor in series at same temperature behave as a single resistor (R1 + R2)

ü Resistance in Parallel shown in Figure 4.1.12.


$R_1$
$R_2$
$V_n$
≡
$V_{n2}$
$V_{n1}$
$R_2$
$R_1$
$V_n$
≡
$R_1$
$V_{n1}$
$R_2$
$V_{o1}$
+
$R_2$
$V_{n2}$
$R_1$
$V_{o2}$

$$V_{o1} = V_{n1}\frac{R_2}{R_1+R_2} \qquad V_{o2} = V_{n2}\frac{R_1}{R_1+R_2}$$

$$\overline{V_n}^2 = \overline{V}_{o1}^{\,2} + \overline{V}_{o2}^{\,2}$$

Assuming $R_1$ at temperature $T_1$ and $R_2$ at temperature $T_2$

$$\overline{V_{n1}}^2 = 4kT_1BR_1 \quad \text{and} \quad \overline{V_{n2}}^2 = 4kT_2BR_2$$

Hence,

$$\overline{V_{o1}^2} = 4kT_1BR_1\left(\frac{R_2}{R_1+R_2}\right)^2$$

and

$$\overline{V_{o2}^2} = 4kT_2BR_2\left(\frac{R_1}{R_1+R_2}\right)^2$$

$$\left\{\begin{aligned} &e.g.\ \ V_{o1} = \mathrm{V}_{n1}\frac{\mathrm{R}_1}{\mathrm{R}_1+R_2}, \quad \overline{V_{o1}^2} = (\mathrm{V}_{n1})^2\left(\frac{\mathrm{R}_2}{\mathrm{R}_1+R_2}\right)^2 \\ &\mathrm{V}_{n1} = RMS,\ \therefore (\mathrm{V}_{n1})^2 = Meansqaure = \overline{V_{n1}^2} \\ &\overline{V_{o1}^2} = \overline{\mathrm{V}_{n1}^2}\left(\frac{\mathrm{R}_2}{\mathrm{R}_1+R_2}\right)^2 \end{aligned}\right\}$$

$$\text{Thus } \overline{V_n}^2 = \overline{V}_{o1}^{\,2} + \overline{V}_{o2}^{\,2} = \frac{4kB}{(R_1+R_2)^2}\left[R_2^2T_1R_1 + R_1^2T_2R_2\right]\times\left(\frac{R_1R_2}{R_1R_2}\right)$$

$$\overline{V_n^2} = \frac{4kBR_1R_2(T_1R_1+T_2R_2)}{(R_1+R_2)^2}$$

or

$$\overline{V_n^2} = 4kTB\left(\frac{R_1R_2}{R_1+R_2}\right)$$

i.e. the two noisy resistors in parallel behave as a resistance $\left(\frac{R_1R_2}{R_1+R_2}\right)$ which is the equivalent resistance of the parallel combination.

**Noise Equivalent Voltage**

An equivalent circuit, when the line is connected to the receiver is shown below the figure 4.1.13 in fi. (Note we omit the noise due to Rin – this is considered in the analysis of the receiver section).



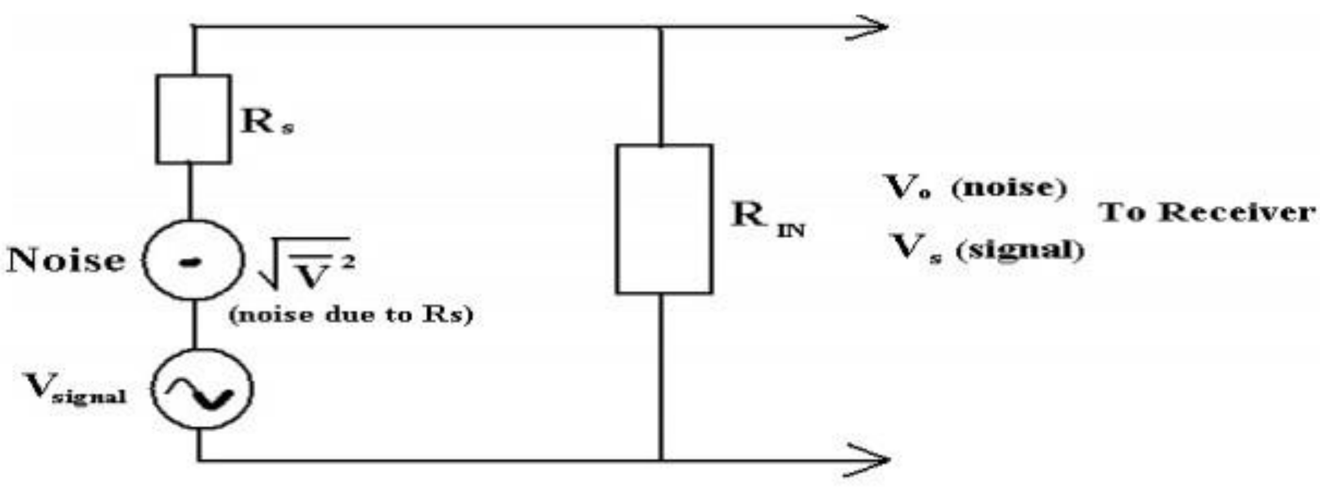



**Figure 4.1.13 Equivalent Circuit of Noise Voltage**

*Diagram Source Brain Kart*

The RMS voltage output, $V_o$ (noise) is

$$V_o(noise) = \sqrt{\overline{v^2}}\left(\frac{R_{IN}}{R_{IN} + R_S}\right)$$

Similarly, the signal voltage output due to $V_{signal}$ at input is

$$Vs(_{signal}) = (V_{signal})\left(\frac{R_{IN}}{R_{IN} + R_s}\right)$$

For maximum power transfer, the input $R_{IN}$ is matched to the source $R_S$, i.e. $R_{IN} = R_S = R$ (say)

Then $$V_o(noise) = \sqrt{\overline{v^2}}\left(\frac{R}{2R}\right) = \frac{\sqrt{\overline{v^2}}}{2} \ (RMS\ Value)$$

And signal, $V_{S(signal)} = \dfrac{V_{signal}}{2}$

Continuing the analysis for noise only, the mean square noise is $(RMS)^2$.

$$(V_o(noise))^2 = \left(\frac{\sqrt{\overline{v^2}}}{2}\right)^2 = \frac{\overline{v^2}}{4}$$

But $\overline{v^2}$ is noise due to Rs =R, i.e. $\overline{V^2} = 4kTBR\ (volt^2)$.

Hence $$(V_o(noise))^2 = \frac{4kTBR}{4} = kTBR$$

Since average power = $\dfrac{(V_{rms})^2}{2}$

Then $$N = \frac{\overline{V^2}}{R} = kTB_n$$

i.e. Noise Power $= kTB_n$ watts

For a matched system, N represents the average noise power transferred from the source to the load. This may be written as

$$p_0 = \frac{N}{B_n} = kT \text{ watts per Hz}$$

where p0 is the noise power spectral density (watts per Hz)

Bn is the noise equivalent bandwidth (Hz) k is the Boltzmann‘s constant

T is the absolute temperature K.

Note: that p0 is independent of frequency, i.e. white noise.

These equations indicate the need to keep the system bandwidth to a minimum, i.e. to that required to pass only the band of wanted signals, in order to minimize noise power, N.

For example, a resistance at a temperature of 290 K (17 deg C), p0 = kT is 4 x 10-21 watts per Hz. For a noise bandwidth Bn = 1 KHz, N is 4 x 10-18 watts (-174 dBW).If the system bandwidth is increased to 2 KHz, N will decrease by a factor of 2 (i.e. 8 x 10-18 watts or -171 dBW) which will degrade the (S/N) by 3 dB.Care must also be exercised when noise or (S/N ) measurements are made, for example with a power meter or spectrum analyser, to be clear which bandwidth the noise is measured in, i.e. system or test equipment. For example, assume a system bandwidth is 1 MHz and the measurement instrument bandwidth is 250 KHz.

In the above example, the noise measured is band limited by the test equipment rather than the system, making the system appears less noisy than it actually is. Clearly if the relative bandwidths are known (they should be) the measured noise power may be corrected to give the actual noise power in the system bandwidth. If the system bandwidth was 250 KHz and the test equipment was 1 MHz then the measured result now would be – 150 dBW (i.e. the same as the actual noise) because the noise power monitored by the test equipment has already been band limited to 250 KHz.

**(ii) Signal to Noise Ratio**

The signal to noise ratio is given by

$$\frac{S}{N} = \frac{Signal\ Power}{Noise\ Power}$$

The signal to noise in dB is expressed by

$$\left(\frac{S}{N}\right)_{dB} = 10\log_{10}\left(\frac{S}{N}\right)$$

or $$\left(\frac{S}{N}\right)_{dB} = 10\log_{10} S - 10\log_{10} N$$

since $10\log_{10} S =$ S dBm if S in mW

and $10\log_{10} N =$ N dBm

then $$\left(\frac{S}{N}\right)_{dB} = S_{dBm} - N_{dBm}$$ for S and N measured in mW

**Narrow Band Noise**

**Definition:**

A random process X(t) is bandpass or narrowband random process if its power spectral density SX(f) is nonzero only in a small neighborhood of some high frequency fc Deterministic signals: defined by its Fourier transform Random processes: defined by its power spectral density.

1. Since X(t) is band pass, it has zero mean: E[(X(t)] = 0.
2. fc needs not be the center of the signal bandwidth, or in the signal bandwidth at all.

**Narrowband Noise Representation:**

In most communication systems, we are often dealing with band-pass filtering of signals. Wideband noise will be shaped into bandlimited noise. If the bandwidth of the bandlimited noise is relatively small compared to the carrier frequency, we refer to this as narrowband noise. We can derive the power spectral density Gn(f) and the auto-correlation function Rnn(τ) of the narrowband noise and use them to analyse the performance of linear systems.

In practice, we often deal with mixing (multiplication), which is a non-linear operation, and the system analysis becomes difficult. In such a case, it is useful to express the narrowband noise as $n(t) = x(t) \cos 2\pi f_c t - y(t) \sin 2\pi f_c t$.

where fc is the carrier frequency within the band occupied by the noise. x(t) and y(t) are known as the quadrature components of the noise n(t). The Hibert transform of n(t) is $\hat{n}(t) = H[n(t)] = x(t) \sin 2\pi f_c t + y(t) \cos 2\pi f_c t$.

· Generation of quadrature components of n(t).

x(t) and y(t) have the following properties:

1. E[x(t) y(t)] = 0. x(t) and y(t) are uncorrelated with each other.
2. x(t) and y(t) have the same means and variances as n(t).
3. If n(t) is Gaussian, then x(t) and y(t) are also Gaussian.

4. x(t) and y(t) have identical power spectral densities, related to the power spectral density of n(t) by Gx(f) = Gy(f) = Gn(f- fc) + Gn(f+ fc) (28.5)

for fc - 0.5B < | f | < fc + 0.5B and B is the bandwidth of n(t).

**Inphase and Quadrature Components:**

In-Phase & Quadrature Sinusoidal Components

$$\sin(A+B) = \sin(A)\cos(B) + \cos(A)\sin(B)$$

From the trig identity, we have

$$\begin{aligned} x(t) &\triangleq A\sin(\omega t + \phi) = A\sin(\phi + \omega t) \\ &= [A\sin(\phi)]\cos(\omega t) + [A\cos(\phi)]\sin(\omega t) \\ &\triangleq A_1\cos(\omega t) + A_2\sin(\omega t). \end{aligned}$$

From this we may conclude that every sinusoid can be expressed as the sum of a sine function phase zero) and a cosine function (phase 2). If the sine part is called the ``in-phase'' component, the cosine part can be called the ``phase-quadrature'' component. In general, ``phase quadrature'' means ``90 degrees out of phase,'' i.e., a relative phase shift of ± 2. It is also the case that every sum of an in-phase and quadrature component can be expressed as a single sinusoid at some amplitude and phase. The proof is obtained by working the previous derivation backwards. Figure

4.5.1 illustrates in-phase and quadrature components overlaid. Note that they only differ by a relative 0 degree phase shift.



**PHASOR REPRESENTATION OF SIGNAL AND NOISE:**

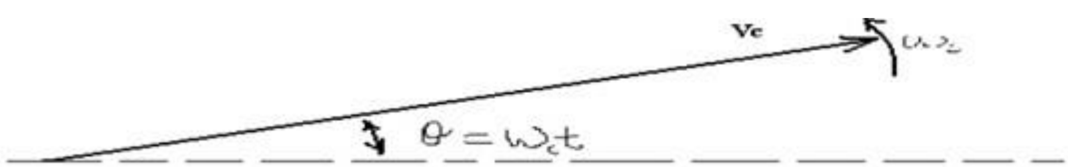



**Figure 4.5.1 Phasor Diagram - 1**

*Diagram Source Brain Kart*

The phasor represents a signal with peak value Vc, rotating with angular frequencies ωc rads per sec and with an angle ω*ct* some reference axis at time t=0.

If we now consider a carrier with a noise voltage with ―peak‖ value superimposed we may represents this as:

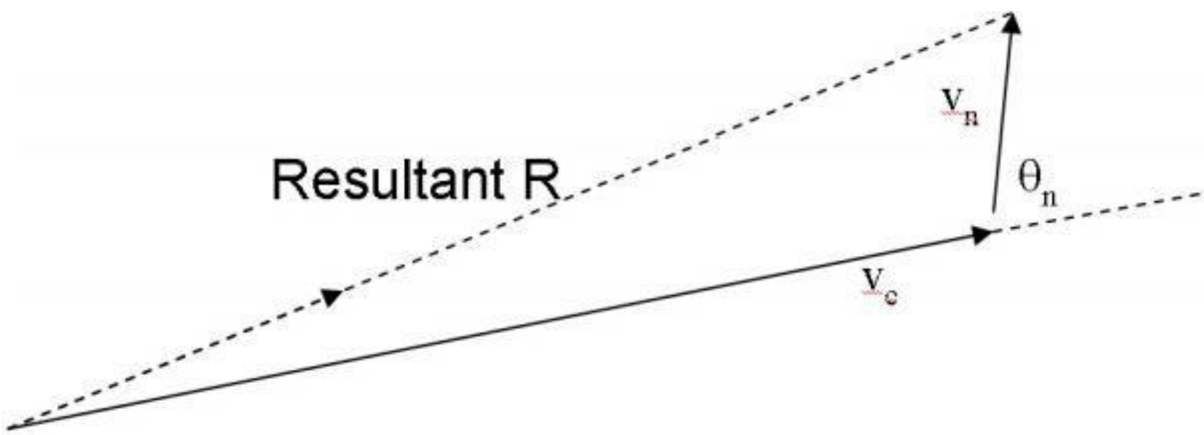





**Figure 4.5.2 Phasor Diagram-2**

*Diagram Source Brain Kart*

In this case Vn is the peak value of the noise and is the phase of the noise relative to the carrier. Both Vn and θ n are random variables, the above phasor diagram represents a snapshot at some instant in time in figure 4.5.2 and 4.5.3. The resultant or received signal R, is the sum of carrier plus noise. If we consider several snapshots

overlaid as shown below we can see the effects of noise accompanying the signal and how this affects the received signal R.

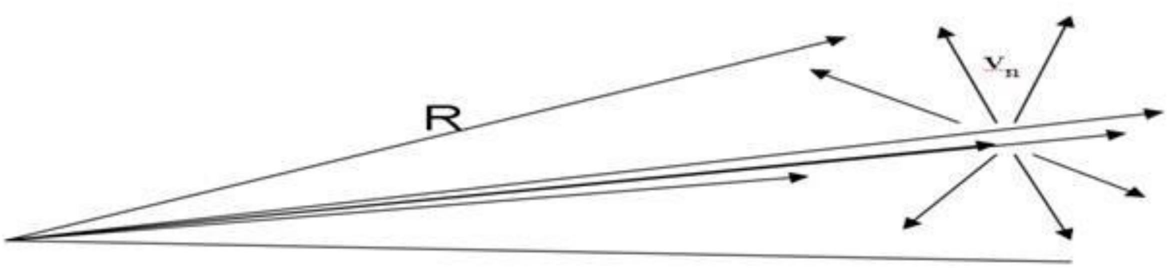



Fig 4.5.3 Phasor Diagram-3 , Diagram Source Brain Kart

Thus the received signal has amplitude and frequency changes (which in practice occur randomly) due to noise.We may draw, for a single instant, the phasor with noise resolved into 2 components, which are in the figure 4.5.4:

a) x(t) in phase with the carriers

x(t) Vn Cos θ n

b) y(t) in quadrature with the carrier

y(t) = Vn Sin θ n

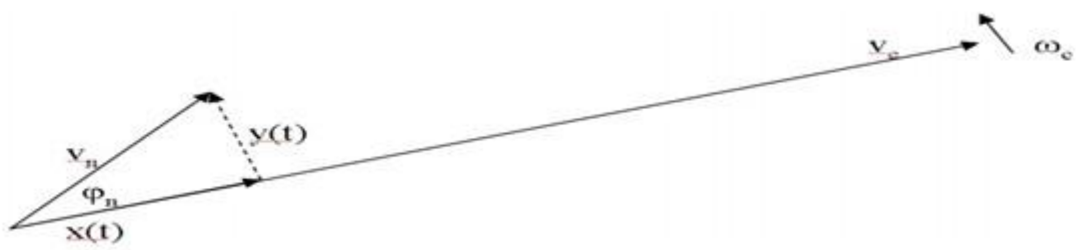





Fig 4.5.4 Phasor Diagram-4 , Diagram Source Brain Kart

The reason why this is done is that x(t) represents amplitude changes in Vc (amplitude changes affect the performance of AM systems) and y(t) represents phase (i.e. frequency) changes (phase / frequency changes affect the performance of FM/PM systems)

We note that the resultant from x(t) and y(t) i.e.

We can regard x(t) as a phasor which is in phase with Vc Cos c t , i.e a phasor rotating at ωc . i.e. x(t)Cosω*c* t

and by similar reasoning, y(t) in quadrature i.e. y(t)Sinω*c* t

Hence we may write

Vn ( *t)* + x(t) Cosω*c* t + y(t) Sinω*c* t

This equation is algebraic representation of noise and since

$$V_n = \sqrt{y(t)^2 + x(t)^2}$$
$$= \sqrt{V_n^2\, Cos^2\phi_n + V_n^2\, Sin^2\phi_n}$$
$$= V_n \qquad (Since\ Cos^2\theta + Sin^2\theta = 1)$$

We can regard x(t) as a phasor which is in phase with $V_c\, Cos\,\omega_c t$, i.e a phasor rotating at $\omega_c$.

i.e. x(t)Cos $\omega_c$ t

and by similar reasoning, y(t) in quadrature

i.e. y(t)Sin$\omega_c$ t

Hence we may write

$$V_n(t) = x(t)\,Cos\omega_c t + y(t)\,Sin\omega_c t$$

Or – alternative approach

$$V_n(t) = V_n\, Cos(\omega_c t - \phi_n)$$
$$V_n(t) = V_n\, Cos\phi_n\, Cos\omega_c t + V_n\, Sin\phi_n\, Sin\omega_c t$$
$$V_n(t) = x(t)\,Cos\omega_c t + y(t)\,Sin\omega_c t$$

This equation is algebraic representation of noise and since

$$x(t)=V_n\,Cos\,\phi_n = \sqrt{2\,p_oB_n}\,Cos\,\phi_n$$

the peak value of x(t) is $\sqrt{2\,p_oB_n}$ (i.e. when $Cos\,\phi_n = 1$)

Similarly the peak value of y(t) is also $\sqrt{2\,p_oB_n}$ (i.e. when $Sin\phi_n = 0$)

The mean square value in general is $\left(\frac{V_{peak}}{\sqrt{2}}\right)^2 = (V_{rms})^2$

and thus the mean square of x(t), i.e $\overline{x(t)^2} = \left(\frac{\sqrt{2p_oB_n}}{\sqrt{2}}\right)^2 = p_oB_n$

also the mean square value of y(t), i.e $\overline{y(t)^2} = \left(\frac{\sqrt{2p_oB_n}}{\sqrt{2}}\right)^2 = p_oB_n$

The total noise in the bandwidth, Bn is

$$N = \left(\frac{V_v}{\sqrt{2}}\right)^2 = p_oB_n = \frac{\overline{x(t)^2}}{2} + \frac{\overline{y(t)^2}}{2}$$

i.e. NOT $\overline{x(t)^2} + \overline{y(t)^2}$ as might be expected.

The reason for this is due to the Cos $\phi n$ and Sin $\phi n$ relationship in the representation e.g. when say —x(t)‖ contributes po Bn , the —y(t)‖ contribution is zero, i.e. sum is always equal to po Bn .

The algebraic representation of noise discussed above is quite adequate for the analysis of many systems, particularly the performance of ASK, FSK and PSK modulated systems.

When considering AM and FM systems, assuming a large (S/N) ratio, i.e Vc>> Vn, the following may be used.

Considering the general phasor representation shown in the figure 4.5.5 below:-

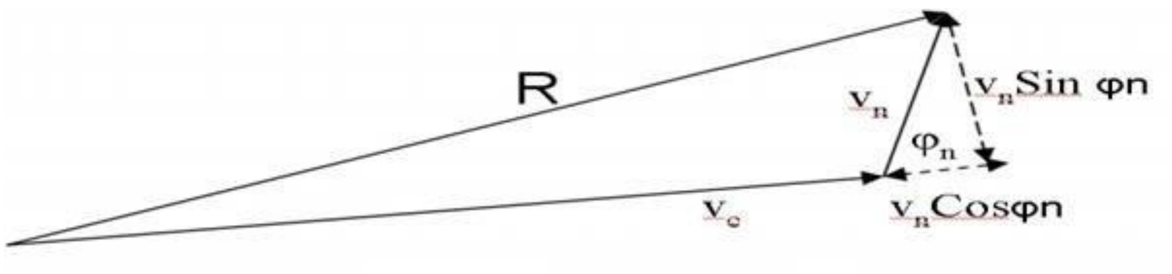



**Figure 4.5.5 Phasor Diagram-5** ,

*Diagram Source Brain Kart*

Since AM is sensitive to amplitude changes, changes in the Resultant length are predominantly due to x(t) in the figure 4.5.6.



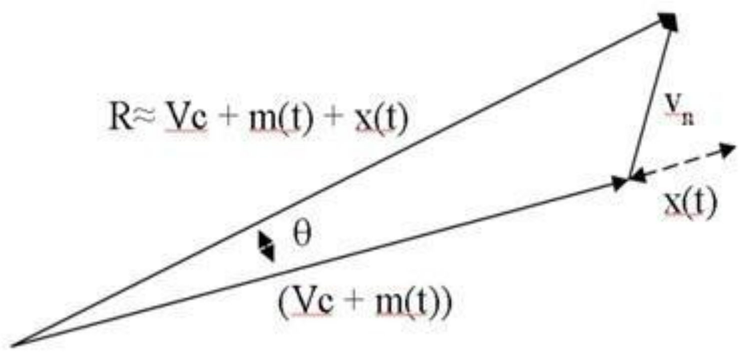



**Figure 4.5.6 Phasor Diagram-6**

*Diagram Source Brain Kart*

For FM systems the signal is of the form *Vc Cosωct* Noise will produce both amplitude changes (i.e. in Vc) and frequency variations – the amplitude variations are removed by a limiter in the FM receiver. Hence,

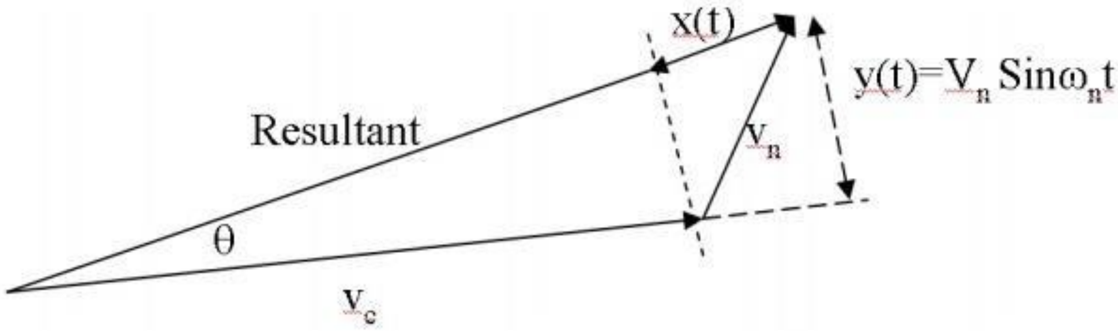



**Figure 4.5.7 Phasor Diagram -7**

*Diagram Source Brain Kart*

The angle theta represents frequency / phase variations in the received signal due to noise. From the diagram.

$$\theta = \tan^{-1}\left(\frac{V_n Sin\omega_n t}{V_c + V_n Cos\omega_n t}\right)$$

$$= \tan^{-1}\left(\frac{\frac{V_n}{V_c} Sin\omega_n t}{1 + \frac{V_n}{V_c} Cos\omega_n t}\right)$$

Since $V_c >> V_n$ (assumed) then $\frac{V_n}{V_c} Cos\omega_n t << 1$

So $\theta = \tan^{-1}\left(\frac{V_n}{V_c} Sin\omega_n t\right)$ {which is also obvious from diagram}

Since $\tan\theta = \theta$ for small $\theta$ and $\theta$ is small since $V_c >> V_n$

Then $\theta \approx \frac{V_n}{V_c} Sin\omega_n t$

The above discussion for AM and FM serve to show bow the ‘model‘ may be used to describe the effects of noise. Applications of this model to ASK, FSK and PSK demodulation, and AM and FM demodulation are discussed elsewhere.

**Fm Capture Effect:**

A phenomenon, associated with FM reception, in which only the stronger of two signals at or near the same frequency will be demodulated The complete suppression of the weaker signal occurs at the receiver limiter, where it is treated as noise and rejected. When both signals are nearly equal in strength, or are fading independently, the receiver may switch from one to the other.

In the frequency modulation, the signal can be affected by another frequency modulated signal whose frequency content is close to the carrier frequency of the desired FM wave. The receiver may lock such an interference signal and suppress the desired FM wave when interference signal is stronger than the desired signal. When the strength of the desired signal and interference signal are nearly equal, the receiver fluctuates back and forth between them, i.e., receiver locks interference signal for some times and desired signal for some time and this goes on randomly· This phenomenon is known as the capture effect.



**Pre-Emphasis & De-Emphasis:**

Pre-emphasis refers to boosting the relative amplitudes of the modulating voltage for

**1. Pre-Emphasis Circuit:**

At the transmitter, the modulating signal is passed through a simple network which amplifies the high frequency, components more than the low-frequency components. The simplest form of such a circuit is a simple high pass filter of the type shown in fig (a). Specification dictate a time constant of 75 microseconds (µs) where t = RC. Any combination of resistor and capacitor (or resistor and inductor) giving this time constant will be satisfactory. Such a circuit has a cutoff frequency fco of 2122 Hz. This means that frequencies higher than 2122 Hz will he linearly enhanced. The output amplitude increases with frequency at a rate of 6 dB per octave. The pre-emphasis curve is shown in Figure 4.6.1 & 4.6.2. This pre-emphasis circuit increases the energy content of the higher-frequency signals so that they will tend to become stronger than the high frequency noise components. This improves the signal to noise ratio and increases intelligibility and fidelity.

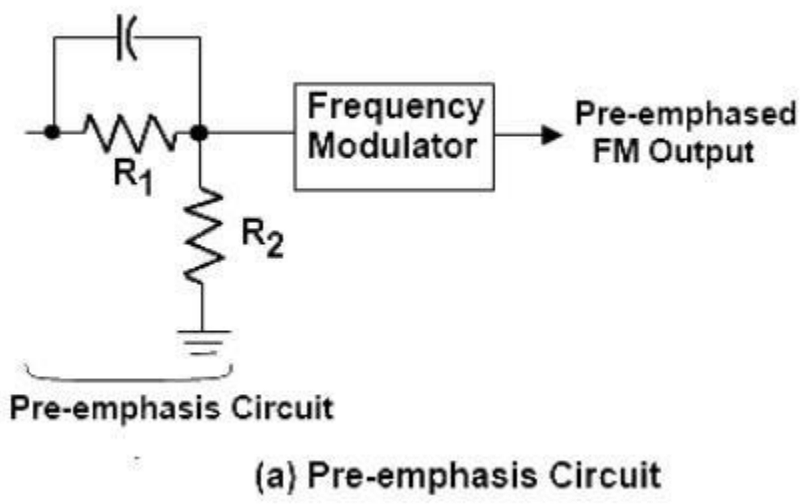



**Figure 4.6.1 Pre Emphasis Circuit**

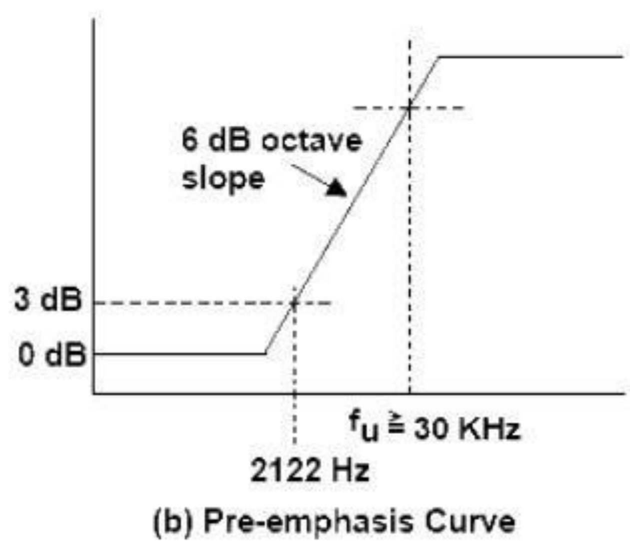



**Figure 4.6.2 Pre Emphasis Curve**

*Diagram Source Brain Kart*

**De-Emphasis Circuit**:

Its higher audio frequencies from 2 to approximately 15 KHz. De-emphasis means attenuating those frequencies by the amount by which they are boosted. However pre-emphasis is done at the transmitter and the de-emphasis is done in the receiver. The purpose is to improve the signal-to-noise ratio for FM reception. A time constant of 75μs is specified in the RC or L/Z network for pre-emphasis and de-emphasis shown in the figure 4.6.3 & 4.6.4

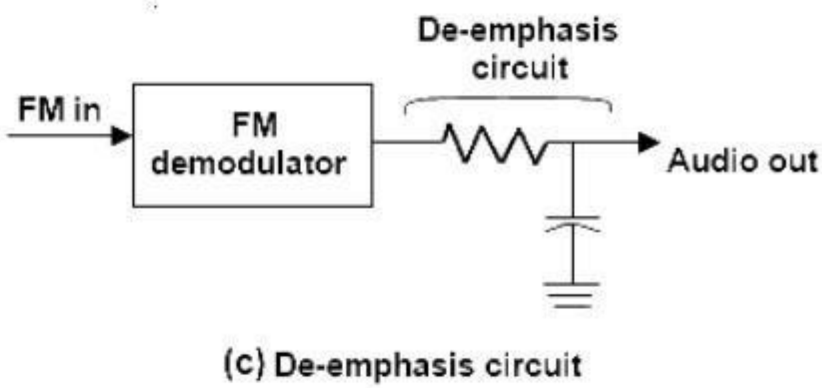



**Figure 4.6.3 De Emphasis Circuit**

*Diagram Source Brain Kart*

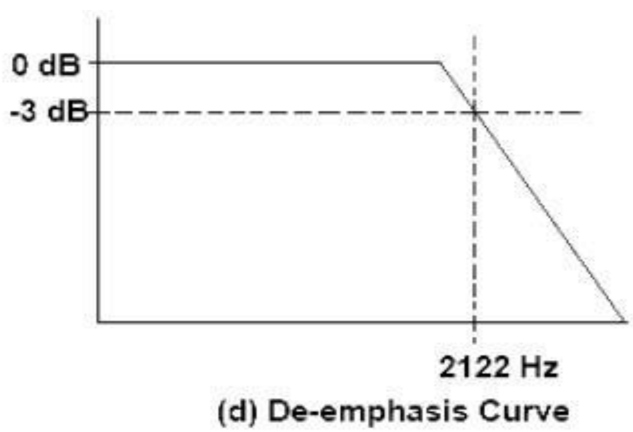



**Figure 4.6.4 De Emphasis Curve**

*Diagram Source Brain Kart*

**Fm Threshold Effect:**

In an FM receiver, the effect produced when the desired-signal gain begins to limit the desired signal, and thus noise limiting (suppression). Note: FM threshold effect occurs at (and above) the point at which the FM signal-to-noise improvement is measured. The output signal to noise ratio of FM receiver is valid only if the carrier to noise ratio is measured at the discriminator input is high compared to unity. It is observed that as the input noise is increased so that the carrier to noise ratio decreased, the FM receiver breaks. At first individual clicks are heard in the receiver output and as the carrier to noise ratio decreases still further, the clicks rapidly merge in to a crackling or sputtering sound. Near the break point eqn8.50 begins to fail predicting values of output SNR larger than the actual ones. This phenomenon is known as the threshold effect. The threshold effect is defined as the minimum carrier to noise ratio that gives the output SNR not less than the value predicted by the usual signal to noise formula assuming a small noise power. For a qualitative discussion of the FM threshold effect, Consider, when there is no signal present, so that the carrier is unmodulated. Then the composite signal at the frequency discriminator input is



$$x(t) = [A_c + n_I(t)] \cos 2\pi f_c t - n_Q(t) \sin 2\pi f_c t$$

Where nI(t) and nQ(t) are inphase and quadrature component of the narrow band noise n(t) with respect to carrier wave Accos2 fct. The phasor diagram of fig8.17 below shows the phase relations b/n the various components of x(t) in eqn (1).This effect is shown in fig below, this calculation is based on the following two assumptions:

1. The output signal is taken as the receiver output measured in the absence of noise. The average output signal poweris calculated for a sinusoidal modulation that

produces a frequency deviation Iequal to 1/2 of the IF filter bandwidth B, The carrier is thus enabled to swing back and forth across the entire IF band.

2. The average output noise power is calculated when there is no signal present, i.e.,the carrier is unmodulated, with no restriction placed on the value of the carrier to noise ratio.

- Single-tone modulation, ie: m(t) = Am cos(2Δ fmt)
- The message bandwidth W = fm;
- For the AM system, μ = 1;
- For the FM system, β = 5 (which is what is used in commercial FM transmission, with Δf = 75 kHz, and W = 15 kHz).

**Noise Characterization - Application & Its Uses:**

- Tape Noise reduction.
- PINK Noise or 1/f noise.
- Noise masking and baby sleep