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.

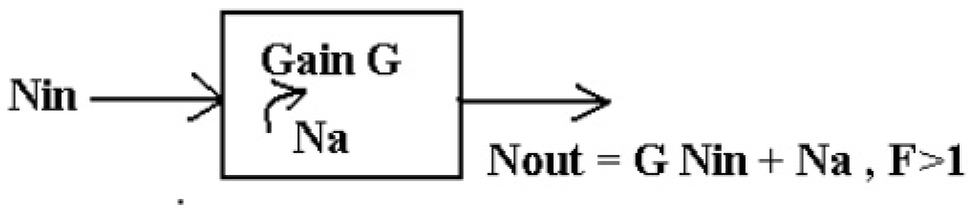

Figure 4.2.2 Circuit Diagram of Noise Factor

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

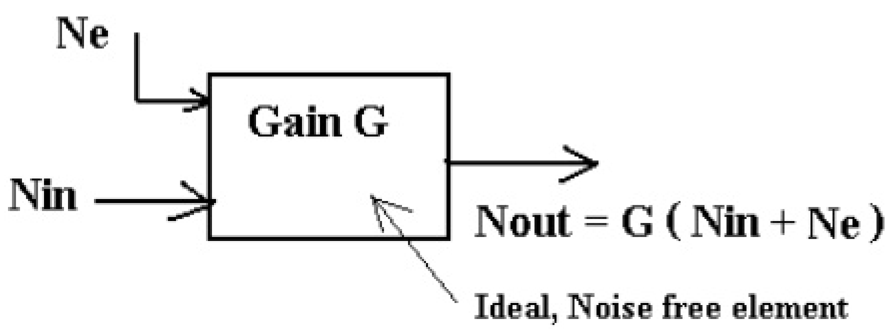

Figure 4.2.3 Circuit Diagram of Noise Factor with extra Noise

Diagram Source Brain Kart

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

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

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 $F_{dB} = 10 \log_{dB} F$

$T_e = (F\text{-}1)290$

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.

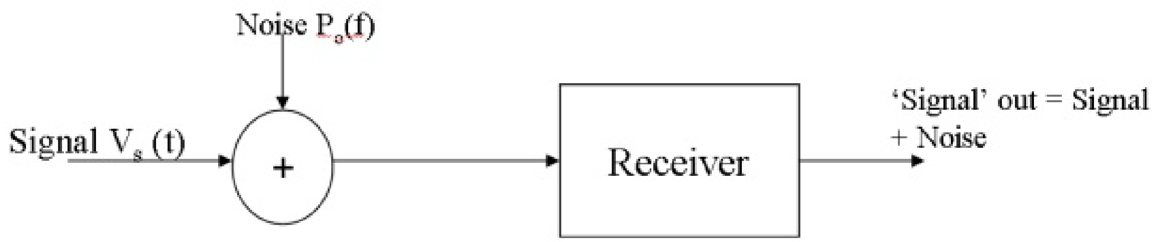

Figure 4.2.4 Block diagram for White Noise

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 $po(f)$. . White noise = $po(f)$ is Constant

Also Noise power = Po Bn

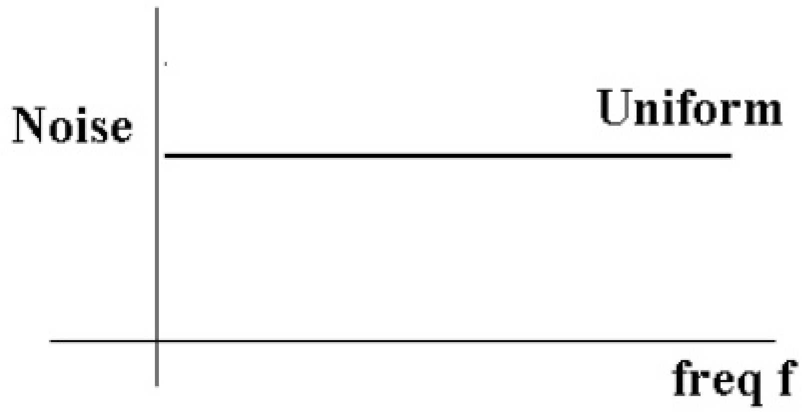

Figure 4.2.5 Spectral Density of White Noise

Diagram Source Brain Kart

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