## Introduction

The function of the communication system is to make available at the destination a signal originating at a distant point. This signal is called the desired signal. Unfortunately, during the passage of the signal through the channel and front-end of the receiver, this desired signal gets corrupted by a number of undesired signals. This is referred to as Noise. Noise is any unknown or unwanted signal. Noise is the static you hear in the speaker when you tune any AM or FM receiver to any position between stations. It is also the snow or confetti that is visible on a TV screen.

- The received signal is modeled as

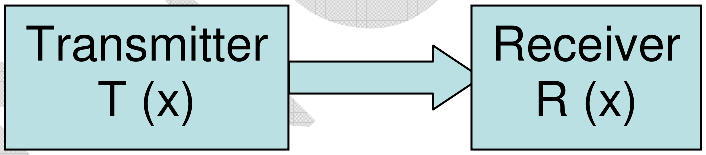
$$r(t) = s(t) + n(t)$$

Where $s(t)$ is the transmitted/desired signal

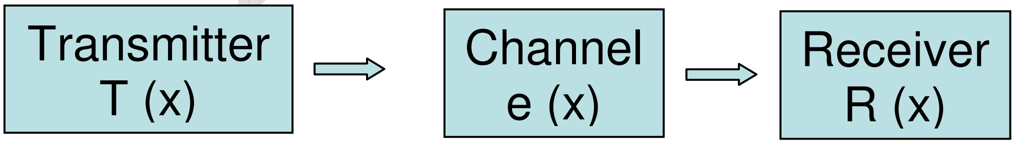
$n(t)$ is the additive noise/unwanted signal

The signal $n(t)$ gets added at the channel. It disturbs the transmission and processing of signal in Communication System. Over which one cannot have a control. In general term it is an unwanted signal that affects a wanted signal. It is a random signal that cannot be represented with a simple equation. But some time can be deterministic components (power supply hum, certain oscillations).Deterministic Components can be eliminated by proper shielding and introduction of notch filters.
If their were no noise perfect communication would be possible with minimum transmitted power. At the receiver only amplification of the signal power to the desired level is required.

**If $R(x)=T(x)$ then $e(x)=0$**



**If $R(x) \neq T(x)$ then $e(x) \neq 0$.The received signal is corrupted.** If channel is noiseless then $e(x)=0$.If channel is noisy then $e(x) \neq 0$



During the course of signal $T(x)$ travel it experience attenuation, time delay, additive noise. These disturbance, attenuation, interference are termed as noise. Practically Noise is always possible.Amplifying the received signal does not help. As Amplifiers amplify both signal as well as noise components equally. Noise cannot be removed by filtering. Because of very large bandwidth. More than the signal bandwidth. In band noise is the noise within the signal bandwidth. Out of band noise is the noise outside the signal bandwidth. In band noise cannot be removed by filters, whereas Out of band noise can be removed by filters. Its effect is degrading system performance for both analog and digital systems. Receiver cannot understand the original signal and hence cannot function as it should be. This reduces the efficiency of communication system. The key contributors for noise interference is Crosstalk, Coupling by scattering of signal in the atmosphere, Cross-polarization: two system that transmit on the same frequency, and interference due to insufficient guard bands or filtering

**Signal Impairment occurs due to**

- **Attenuation**
  - Loss of energy due to resistance of medium.]

- **Distortion**
  - The signal changes its form due to the differing propagating speed of each of the frequencies that make up a signal.

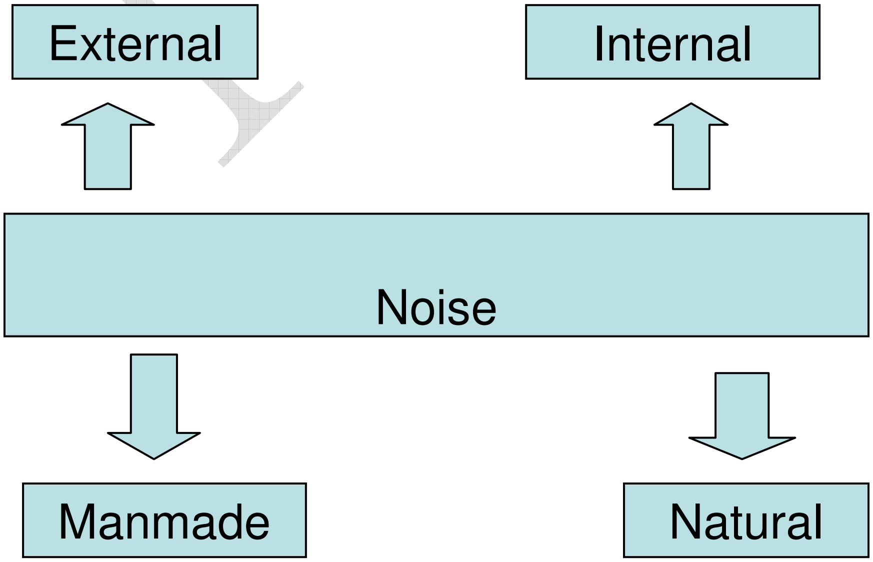
- **Noise**
  - External environment that corrupt a signal.

**Noise Level of a system is proportional to:**

- Temperature and Bandwidth.
- Amount of current flowing in a component.
- Gain of the circuit.
- Resistance of the circuit

**Types of Noise:**

Noise may be classified depending on the location of the source. External and Internal with reference to the receiver.



## Sources

- **Internal to the system.**

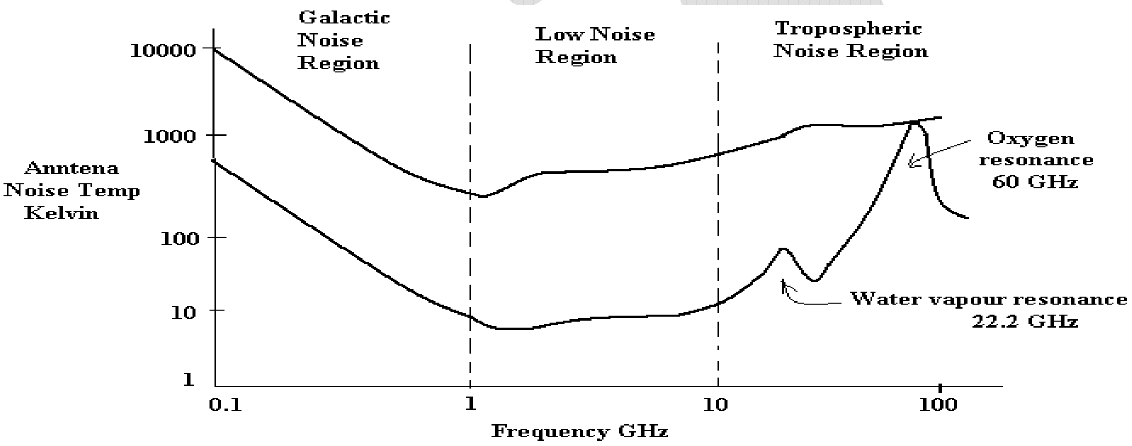
  Due to spontaneous fluctuation in current and voltages in the electrical circuit.

- **External to the system.**

  Due to atmospheric, extraterrestrial and man made noise.

## External Noise

Atmospheric noise (also called static) it dominants at lower frequencies. Atmosphere disturbance like electric storms, lighting, ionospheric effect also contribute to 'Sky Noise.Cosmic noise includes noise from galaxy, solar noise.'Hot spot' due to oxygen and water vapour resonance in the earth's atmosphere.



- Man-Made Noise sources are aircraft ignition, automobile ignition, fluorescent lamps. It ranges between 1MHz-500MHz range. These noises are more intense in urban areas than rural areas. They can travel considerable distance.

## Noises due to Electrical Circuits

**Thermal noise**: Random free electron movement in a conductor (resistor) due to thermal agitation. **Shot noise**: Due to random variation in current superimposed upon the DC value. It is due to variation in arrival time of charge carriers in active devices. **Flicker noise:** Observed at very low frequencies, and is thought to be due to fluctuation in the conductivity of semiconductor devices.Circuit elements like diodes, transistors, R, L and C components gives rise to internal noise. The fundamental limits on communication of acceptable quality are decided by this noise. Johnson and Nyquist first studied thermal noise in metallic resistors. It is also known as Johnson noise or resistance noise. In conductor due to thermal agitation random motion of the *free electrons* is caused. This will give rise to a voltage $V(t)$ even if no electrical field is applied $V(t)$ is a Gaussian process with zero mean

**Thermal Noise**

Generated by all resistances.(e.g. a resistor semiconductor the resistance of a resonant circuit i.e. the real part of the impedance cable etc).Kinetic energy is formed in the conductor due the movement of the electrons. This is related to the temperature of the conductor. With increase in temperature, the movements of free electrons will increases. This causes current flows through the conductor. Creates random voltage across conductor. Noise voltage fluctuates about the mean valve of zero. Thermal noise is often referred to as white noise. Because it has a uniform spectral density across the EM frequency spectrum. Analogous to the colour white which consists of the entire colour spectrum.The power spectral density of thermal noise across a conductor having resistance of Rohm is

$$P(f) = \frac{2Rh|f|}{(e^{\frac{h|f|}{kT}} - 1)} volts^2 / Herts$$

Where h=planck's constant=6.6*10-34j/s

**k = Boltzmann's constant**

Maximum P(f) occurs at f=0 using L'Hospital's rule

$$P(f)_{|f=0} = 2kRTvolts^2 / Herts$$

With variation in P(f) is very small Hence it is constant and independent of frequency. Let the Thermal Noise Voltage appearing across the two terminals of a resistor be VTN , let Δf be the bandwidth or frequency of the applied voltage .Then the Mean Square value of VTN is given by:

$$E[V_{TN}^2] = 4kTR\ \Delta f \text{ volts}^2$$

**Where**

k = Boltzmann's constant =1.38 x 10-23 Joules per $o^K$

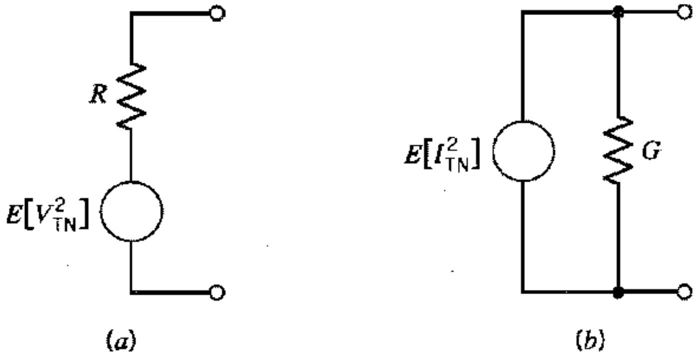
T = absolute temperature in $o^K$

R = resistance in ohms

**Noise Power**

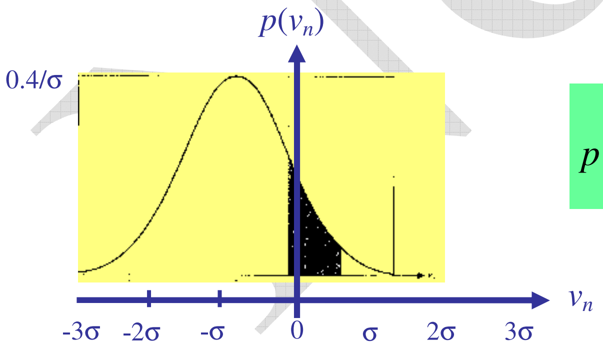
Noise power generated is proportional to the **temperature** and the **BW**. In dB it is defined as **PdBm10log(KTB/0.001).**Noise power can be modeled using voltage equivalent circuit (Thevenin equivalent circuit) or current equivalent circuit (Norton equivalent circuit)

### Resistors in Series/Parallel



$$E[I^2_{TN}] = \frac{1}{R^2} E[V^2_{TN}] = 4kTG\,\Delta f \text{ amps}^2$$

When two resistors are in series it is their noise power or their noise PSD's in volts$^2$ /Hz which can be added and not there noise voltages. When two resistors are in parallel it is their noise power or their noise PSD's in amp$^2$ /Hz which can be added and not there individual noise currents.The random motions of electrons inside the resistors are statistically independent.Central Limiting Theorem indicates that thermal Noise is a Gaussian Distribution with Zero mean. Noise Power in watts is directly proportional to Bandwidth in Hz, and the temperature in degrees Kelvin.The variance is a function of *R* and *T*, where *R* is the value of the resistance and *T* is the temperature of *R*.



$$p(v_n) = \frac{1}{\sigma\sqrt{2\pi}} e^{\left(-\frac{v^2_n}{2\sigma^2}\right)}$$

Where $\sigma^2$ is the variance of noise voltage $v_n$

PDF of zero mean and standard deviation σ

For zero mean, normalized noise power or mean square voltage:

$$P_n = \overline{v_n^2} = \sigma^2$$

**Problem 1**

Find V rms value of noise thermal noise volatage across a resistor of 1MΩ at a temperature of 270C , if the measurement is made with an instrument having a bandwidth of 104Hz.

$$erms=\sqrt{4kTR(\Delta f)}$$

$$=12.868\mu v$$

**Shot Noise:**

- Arises due to discrete nature of current flow in Diodes and Transistors.
- Photons in an optical device or electrons in an electronic circuit.
- If we assume the electrons in these components are emitted at random interval, τk where -∞ < k < ∞.
- If this random emission are observed for a long period.
- The total current flow through the component can be expressed as

$$X(t) = \sum_{k=-\infty}^{\infty} h(t - \tau_k)$$

- Where X (t) is stationary and is called Shot Noise.

**Flicker Noise:**

- The noise exists in natural phenomena such as nuclear radiation, electron flow through a conductor, or even in the environment.
- It is a low frequency noise.
- It is frequency dependent
- Non Uniform in nature.
- Because of its low frequency variation it is also referred to as **1/f noise (one over f noise).**
- The noise power is **proportional to the bias current**
- Since the noise is device specific, an exact **mathematical model** does not exist.
- Though the noise is random it is not white noise because its frequency spectrum is flat.
- Most of the power is concentrated at the lower end of the frequency spectrum.

**White Noise:**

- **White** – White light contain equal amount of all frequencies in visible spectrum.
- It also gives you perfect randomness, which can not be attained in real systems.
- Generally noise Analysis is based on idealized form of noise called **WHITE NOISE**.
- The Power Spectral Density is of white noise is independent of operating frequency.
- The time-average autocorrelation function of the noise voltage is:

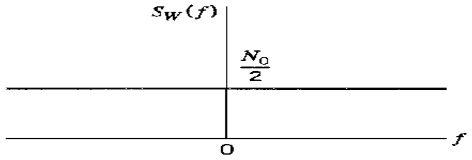
$$R_v(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_0^T v_n(t) v_n(t+\tau)\, dt$$

Assumption

- The v n(t+τ) and vn(t) values are random and independent.
- The condition holds no matter how small τ is, provided it is not zero.
- The autocorrelation of white noise is:

$$R_w(t) = \begin{cases} P_n & \tau = 0 \\ 0 & \tau \neq 0 \end{cases}$$

- Rw(t) is a zero width of height Pn with an area under the pulse = ηo/2



- Hence this type of noise is called Additive White Gaussian (AWGN) with power spectral density of

$$S_W = \frac{N_0}{2}$$

- Where $N_0 = k * T_e$
    - **k = Boltzmann's constant**
- Te = Equivalent Noise temperature of receiver.
- Its not physical temperature.
- A theoretical construct i.e equivalent temperature that produces that amount of noise power internal to the device
- Noise equivalent temperature (T e) is expressed as T e= T(F-1)

Where,

T= environmental temperature (290 K)

F= Noise factor

**Noise Equivalent BW**

A system with transfer function H(ω) and input signal power density spectrum Si(ω) has a mean square valve of the output signal

$$\overline{v_0^2} = \frac{K}{2\pi} \int_{\infty}^{-\infty} S_{i(\omega)} |H(\omega)|^2 \, d\omega$$

- BW is low, noise have constant spectral density

$$\overline{v_0^2} = \frac{K}{2\pi} \int_{\infty}^{-\infty} |H(\omega)|^2 \, d\omega$$

i.e $S_{i(\omega)}$ is a constant say k

$$\overline{v_0^2} = \frac{K}{\pi} \int_{0}^{-\infty} |H(\omega)|^2 \, d\omega$$

- Equivalent Noise Bandwidth

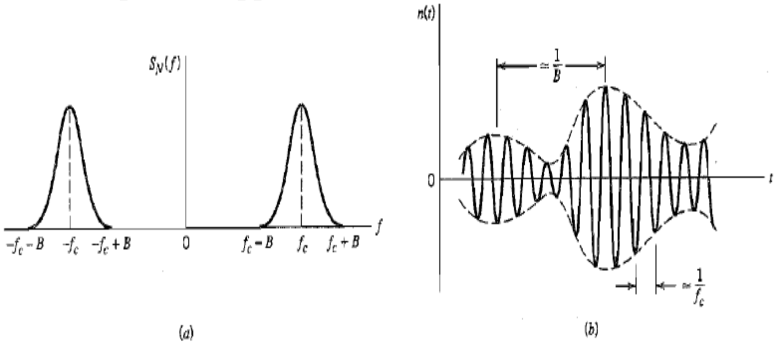
$$w_0 = \frac{1}{|H(\omega)|^2}\int_0^\infty |H(\omega)|^2 d\omega$$

Hence

$$\overline{v_0^2} = \frac{K}{\pi}|H(\omega_0)|^2 W_0$$

RMS of noise signal ≡ideal BP system with constant gain

Narrow Bandwidth can be defined in terms of In phase and quadrature components Or Envelop and phase components. NB Noise concentrates about **±fc.**A sample function n(t) of such process appears somewhat similar to a sinusoidal wave of frequency **fc**



(a) Power spectral density of narrowband noise. (b) Sample function of narrow- band noise.

**Properties of NBN**

1. $n_1(t)$ and $n_Q(t)$ of n(t) has Zero mean.
2. If n(t) is Gaussian then $n_I(t)$ and $n_Q(t)$ are jointly Gaussian.
3. If n(t) is stationary then $n_1(t)$ and $n_Q(t)$ are jointly stationary.
4. Both $n_1(t)$ and $n_Q(t)$ have the same psd related to the psd of n(t ).
5. $n_1(t)$ and $n_Q(t)$ have the same variance as that of n(t).
6. The cross spectral density of $n_1(t)$ and $n_Q(t)$ of n(t) is purely imaginary.
7. If n(t) is Gaussian and the psd of n(t) is symmetric about fc then $n_1(t)$ and $n_Q(t)$ are statistically independent.

**Problem 2**
One operational amplifier with a frequency range of (18-20) MHz has input resistance 10 k. Calculate noise voltage at the input if the amplifier operate at ambient temperature of 270C.

**Problem 3**
A receiver has a noise power bandwidth of 10 kHz. A resistor that matches the receiver input impedance is connected across its antenna terminals. Determine the Noise Power if the resistor has temperature of 27 oC.

**Parameters**

Noise effect can be determined by measuring

- Signal to Noise Ratio(SNR)
- Noise Factor (F)
- Noise Temperature (Te)
- Probability of error or bit error rate BER for digital system
- To determine the quality of received signal at the receiver or an antenna SNRi is used.
- SNR o is always less than SNRi due to the facts that the existence of noise in the receiver itself.
- The receiver usually constitute a process of filtering, demodulation and amplification.

**Noise Calculation**

- SNR is a ratio of signal power S to noise power N.

$$SNR\,(\mathrm{dB}) = 10\log_{10}\left(\frac{\mathrm{P_S}}{P_N}\right)$$

where: $P_S$ is the signal power in watts
$P_N$ is the noise power in watts

- Noise Figure(F)

$$F = \frac{N_{out}}{GN_{in}}$$

- Where
  - $N_{out}$=Noise output of actual receiver
  - $GN_{in}$=Noise output of ideal receiver
  - $G$= Antenna Gain
- Spot Noise Figure- as it varies with frequency.
- Integrated Noise Figure-over the entire bandwidth of interest.
- Noise factor (NF)

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

Noise Factor- Noise Figure

- lower the value of F the better the network.
- F =1 for noiseless;In general F<1.
- Noise figure (NF) is the Noise factor converted to dB

Noise Figure (NF) = 10 log10 (F)

NF = SNR in – SNR out

**Problem 4**

For an amplifier with an output signal power of 10 W and an output noise power of 0.01 w determine the signal to noise power ratio

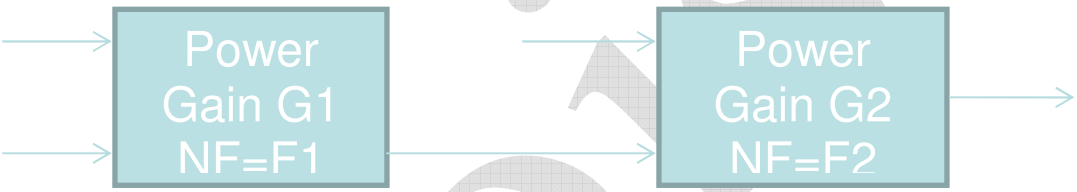
**Problem 5**

For an amplifier with an output signal voltage of 4V an output noise voltage of 0.005 V and an input and output resistance of 50 ohm determine the signal to noise power ratio

**Problem 6**

The signal to noise ratio at the input to a communication receiver is 40 dB. If the receiver has a noise figure of 12 dB calculate the output signal to noise ratio.

**Cascaded Network**



- The overall system Noise Figure is
  F= Actual output noise power/ Output noise power assuming amplifier noise free

**System Noise Figure**

$F=F1+F2-1/G1$

➢ The equation is called FRIIS Formula.

$F=F1+F2-1/G1+F3-1/G1G2+F4-1/G1G2G3+\dots$

**System Equivalent Noise Temperature**

- If the available power gain G1 of the first amplifier is quite large then overall noise figure F of the cascade connection will be approximately equal to the noise figure of the first system.
- Equivalent Noise Temperature:
  $1+Te/T0=1+Te1/T0+Te2/G1T0+Te3/G1G2T0+\dots$

**Problem 7**

For three cascaded amplifier stages each with noise factor of 2 dB and power gains of 10 d determine the total noise figure.

**Problem 8**

Cascade three amplifiers ABC was connected in series. Noise figure and power gain of the amplifiers are given below
Amplifier A GA=20 dB; FA=3 dB
Amplifier B GB=10 dB; FB= 5 dB
Amplifier C GC=5 dB; FC=10dB
An input signal of 50 dB higher than noise level was fed at the input of the network. Calculate (a)Total noise factor (b) SNR at the output