Part 4 NOISE

4.1 INTRODUCTION

Noise in communication systems is caused by unwanted signals. Basically, the sources of these signals are:

(1) External Noise:

- Atmospheric Noise: It is caused by naturally occurring disturbances in the earth's atmosphere such as: lightening discharges, thunderstorms and other natural electric disturbances. At 30MHz and above atmospheric noise is less severe.
- Industrial Noise: this includes sources like ignitions of cars and aircrafts, electric motors, switching equipment, leakage from high voltage lines, etc.
- Extra-terrestrial Noise:
  - Solar Noise: it originates from the sun which radiates a broad spectrum of frequencies, including those which are used for broadcasting.
  - Cosmic Noise: Distant stars also radiate noise in much the same way as the sun. Noise also comes from distant galaxies in much the same way as they come from the Milky Way.

(2) Internal Noise: This type is generated by any of the active or passive devices found in the receiver. It is proportional to the bandwidth over which it is measured.

By careful engineering, the effects of many unwanted signals could be reduced or eliminated, however, other signals could not be removed. One unavoidable cause of electrical noise is the thermal effects of electrons motion in conducting media, wiring, resistors…etc.

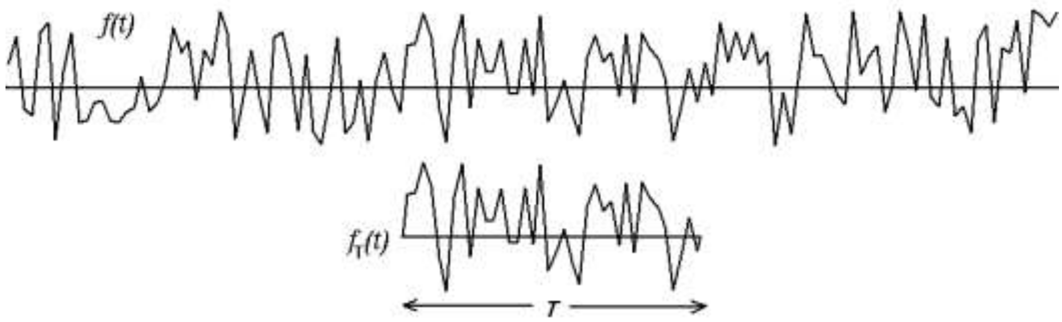
4.2 DEFINITIONS

4.2.1 Power Spectral Density

Because we deal with random signals, we need to review the PSD. The Power Spectral density (PDF) describes the distribution of power versus the frequency for energy signals.

$$G(f) = \lim_{T\to\infty} \frac{|F_T(f)|^2}{T}$$

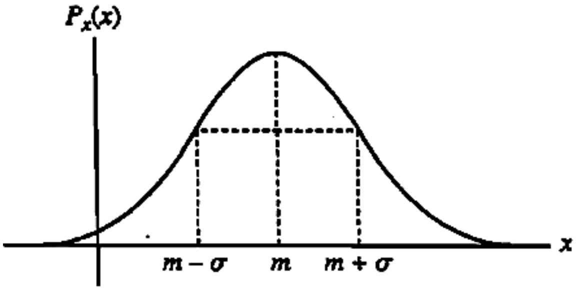
where $F_T(f)$: is the Fourier transform of the *truncated* segment from the random signal.



4.2.2 Gaussian PDF

A Gaussian random variable x is continuous with mean m, variance σ^2, and PDF:

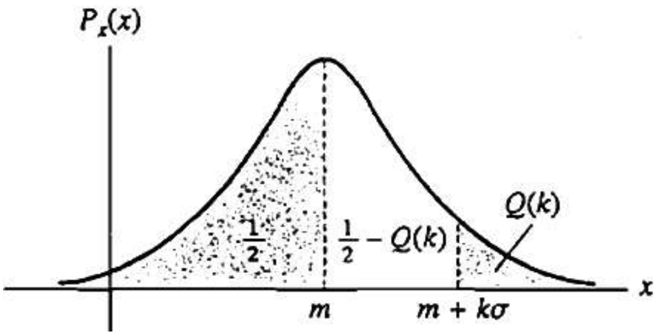
$$p_x(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-m)^2/2\sigma^2} \qquad -\infty < x < \infty$$



The curve of this function has even symmetry about the peak, i.e. at $x = m$. For some integer k, we find the probability of the event $x > m + k\sigma$ using:

$$Q(k) \cong \frac{1}{\sqrt{2\pi}} \int_k^\infty e^{-\lambda^2/2} d\lambda \qquad \text{at } \lambda = (x-m)/\sigma$$

$Q(k)$ represents the area under the Gaussian tail, as illustrated by Figure below:



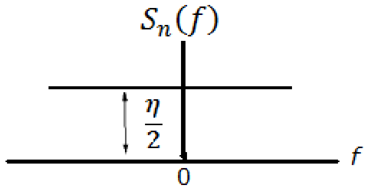
Since this integral cannot be evaluated in closed form, numerical methods are used to generate extensive tables of the normalized integral.

4.3 WHITE NOISE AND FILTERED NOISE

Most noise sources in the electrical systems are Gaussian. They also have a flat spectral density over a wide frequency range. This means the noise is almost the same at all frequencies in equal proportion. Therefore, it is called "white noise" by analogy to white light. White noise is a convenient model (and often an accurate one) in communications. The assumption of a Gaussian process allows us to invoke all the noise properties, however, some applications (beyond our scope) may need a more advanced model for the noise.

We'll write the spectral density of the white noise in general as:

$$S_n(f) = \frac{\eta}{2} \quad \text{for all } f \text{ (two-sided PSD)}$$



Where: η (in Watt per Hertz) is the power spectral density of the white noise. The PSD $S_n(f)$ is η when it is measured for the positive frequency only, and hence it is referred as one-sided PSD. For the two-sided PSD, $S_n(f) = \frac{\eta}{2}$ when it is used for all the frequencies. The value of η depends upon two factors: the type of noise, and the type of spectral density. If the source is a thermal resistor; then the mean square voltage and mean square current densities are

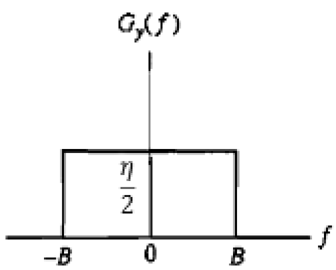
$$\eta_v = 4kTR \quad \text{Volts} \quad , \quad \eta_i = 4kT/R \quad \text{Ampers}$$

We can find noise power P_n as:

$$P_n = \int_{-\infty}^{\infty} \frac{\eta}{2} df \to \infty$$

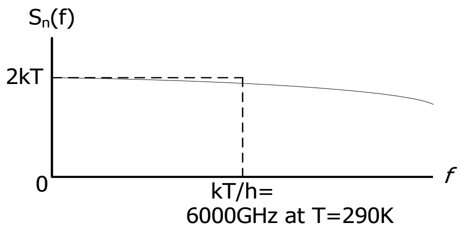
Normally, the communication systems are band limited to B Hz

$$P_n = N = \int_{-B}^{B} \frac{\eta}{2} df = \eta B \text{ Watt}$$



4.4 THERMAL NOISE

Among the mentioned noise sources, we can focus on the thermal noise as it is one of the most commonly considered sources. Thermal noise is an important noise source of white noise. Thermal Noise is produced because of the thermally excited random motion of free electrons in a conducting medium, such as resistor. The path of each electron in motion is randomly oriented due to collisions. The net effect of the motion of the electrons is an electric current in the resistor which is random with a mean of zero. From thermodynamic and quantum mechanical considerations, the PSD of thermal noise is:



$$S_n(f) = \frac{2h|f|}{e^{\frac{h|f|}{kT}} - 1} \approx 2kT \text{ Watt/Hz} \quad \text{for} \quad |f| \ll \frac{kT}{h}$$

T = temperature of conducting medium in Kelvin

k = Boltzmann's constant = $1{,}38 \times 10^{-23}$ Joule/Kelvin

h = Planck's constant = $6{,}625 \times 10^{-34}$ Joule·sec

$$P_n = \int_{-B}^{B} S_n(f)df = 4kTB \text{ Watt}$$

So, the mean-square voltage and current generated by a resistor R within the band width B is:

$$\overline{v_n^2(t)} = RP_n = 4kTRB \quad \text{Volt}^2$$

$$\overline{\iota_n^2(t)} = \frac{P_n}{R} = \frac{4kTB}{R} \quad \text{Ampere}^2$$

For band-limited thermal noise, the models for voltage and current equivalent circuits are shown below, assuming R is noise-free and bandwidth B.