NOISE IN ELECTRICAL CIRCUIT

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Abstract

Noise is any output signal which is not needed. Noise generated by electronic devices varies greatly as it can be produced by several different effects. Such noise include: thermal noise, shot noise, white noise, bipolar junction transistor noise, I/f noise, valve noise, equivalent noise and partition noise. Noise can be evaluated using mathematical concepts which relate either to noise voltage or to noise power, spectral density. In most practical communication systems, the usual criterion for measuring performance is the ratio of signal power to noise power in the system. This is defined as the signal-to-noise ratio at the output of the detector. Noise in electrical circuits can be reduced by shielding the circuit by closing it in a metal box. The box places the contents in a uniform field so that the effects at low frequency radiations are minimized. Since electrical noise is of no use because it tends to hinder the reception of wanted signals, it is therefore necessary to minimize it.

Introduction

Noise generally can be defined as any output signal which is not needed. Since any system has dissipation (with the possible exception of super conductors and super fluids), any system has noise. Electrical noise in particular has been defined by various authors according to their views. Conner (1973) defined electrical noise as an unwanted signal which is always present in a communication systemò. Miller (19790 viewed electrical noise as any undesired voltage or circuits that ultimately end up appearing in the load of the communication receiver, usually a speaker. According to Wikipedia (2011), electrical noise is a random fluctuation in an electrical signal, a characteristic of all electronic circuits.

Whatever way different authors have viewed it, noise can be generally be defined as any unwanted or false signals (voltages or currents) that arise in a communication system. In fact, any addition to the output which is not a function of the input can be termed noise. The presence of electrical noise tends to hinder the reception of the unwanted signal and is usually the limiting factor in its detection. In any communication system therefore, if the described signal receiver received is of the same order of magnitude as the undesired noise signal, it is likely that the result will be unintelligible. This situation is made even worse by the fact that certain receivers themselves introduce noise in addition to the noise already present in the received signal.

Noise composed of randomly occurring voltages which are unrelated in phase or frequency and may sometimes be of a very peaky nature.

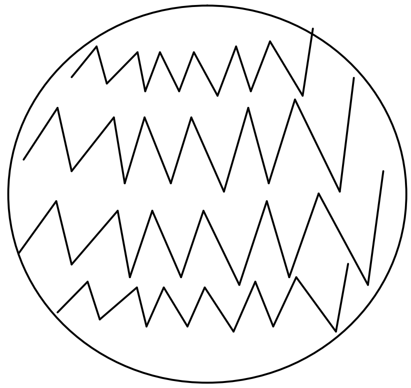


Figure 1: Noise signals

Because of the difficulties and problems posed by noise in a communication system in general and electrical circuits in particular, the study of the nature, types and evaluation of noise in general and electrical noise in particular is therefore very vital and are the major focus of this work.

Analysis of Noise

As there are many sources which produce noise, they may be broadly be classified as ñnatural and artificialò or as ñinternal and external noiseò. Natural Noise includes space noise, atmospheric noise and the circuit noise while artificial noise is the man-made noise. External noise includes man-made noise, atmospheric noise and space noise while internal noise includes all the circuit noise.

However, in electrical circuit, the most important noise is the circuit noise. Other types of noise like the man-made noise, atmospheric noise and space noise will be briefly discussed.

Man-made Noise

This is often produced by spark producing mechanism such as fluorescent lights and commutators in electric motors. It is transmitted from its generating source through the atmosphere in the same way that a few transmitting antenna sends desirable electrical signals to a receiving antenna. It occurs randomly at frequencies up to approximately 500 Hz.

Another common source of man-made noise is contained on the power lines that supply the energy for most electronic system. Man-made noise is the weakest in sparsely populated areas and because of this, the locations of extremely sensitive communication equipments such as satellite tracking stations is done in deserts.

Atmospheric Noise

Atmospheric noise is caused by naturally occurring disturbances. Its frequency content is inversely related to its intensity. It is therefore most troublesome at the lower frequencies. It manifests itself in the static noise that we hear on standard A.M (Amplitude Modulation) radio receivers. However, it is not a very important factor for frequencies exceeding about 20MHz.

Space Noise

Space noise is pretty evenly divided in origin between the sun and all other stars. The sun is the closest star to us. The noise originating from the sun may be in some cases in form of heat and is called solar noise. The noise originating from other stars are termed cosmic noise.

Internal Noise

The noise with which we are concerned in electrical circuits is the circuit noise. It comprises of the thermal noise, the shot noise and the white noise. Others are bipolar junction transistor noise, I/f noise, value noise, equivalent noise and partition noise.

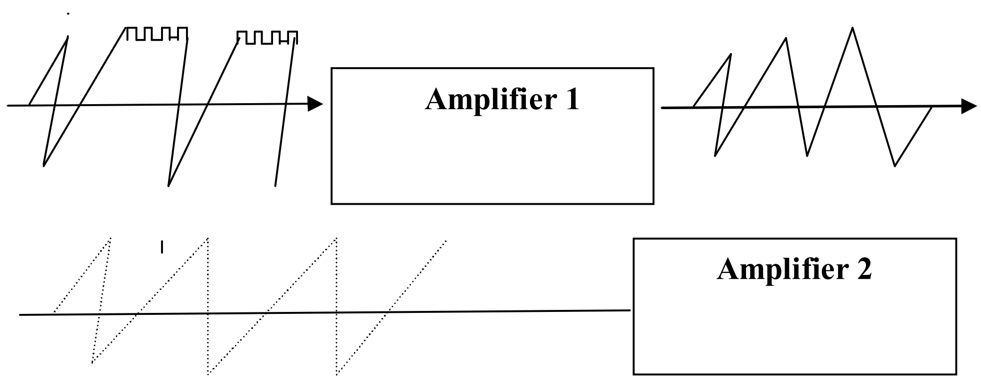


Fig 2: Noise effect on receiver first and second amplifiers.

Thermal noise is due to thermal interaction between the free electrons and vibrating ions in a conductor. Resistors are the major contributors of this noise as they constantly produce voltage. This form of noise was first thoroughly studied by J.B Johnson in 1928 and is often termed Johnson noise. Since it is dependent on temperature, it is also referred to as thermal noise. This noise can also be called white noise because of its frequency content which spread throughout the usable spectrum. Thus, these terms Johnson, thermal and white noise may be used interchangeably. Johnsons was able to show that power of this generated noise is given by

Pnoise = KTF ---(1)

Where K = Boltzmannôs constant

$= 1.38 \times 10^{-23}$ Joule/K ; T = resistor

Temperature (k) ; F = Bandwidth of frequencies that the subsequent amplifier is able to amplify.

Also, the root mean square (R.M.S) voltage due to thermal noise V_n generated in a resistance R (ohnis) over bandwidth F(hertz) is given by

$$V_n = \sqrt{4K_BTR\Delta F} \quad \text{--------------------------------------(1)}$$

Where K_B is Boltzmannôs constant (Joules per Kelvin) and T is the resistors absolute temperature (Kelvin), (Wikipedia, 2011).

As the amount of thermal noise generated depends upon the temperature of the circuit, very sensitive circuits such as pre amplifiers in radio telescopes are sometimes cooled in liquid nitrogen to reduce the noise level.

Shot Noise

Shot noise in electronic devices consists of unavoidable random statistical fluctuations of the electrical current in an electrical conductor, (Wikipedia, 2011). When content flows in a vacuum diode, electrons are emitted from the cathode which travels to the anode. Each electron carries a discrete amount of charge to the anode and produces a small current pulse. The rate of which charge carriers arrive at the collector of a transistor varies very rapidly and as such charge carrier arrives, it gives up its charge and generates a ñspikeò in the collector current waveform. The summation of all the current pulses produces the average anode current in the diode.

However, the emission of electrons is a random process depending on the surface condition of the cathode, shape of the electrodes and the potential between. This gives rise to random fluctuations in the number of emitted electrons and so the diode current contains a time varying component. Thus, shot noise is due to the random nature of current.

Shot noise is generally specified in terms of its mean square variation about the average value. This is written as:-

$$\overline{L}n^2 \text{ where } \overline{L}n^2 = (i\overline{i}_D)^2 = \acute{\omega}2qi_Ddf \quad \text{--(2)}$$

Where q is the electron charged (1.62×10^{-19}c) and df is differential frequency, (Wikipedia, 20111).

Shot noise has uniform power density meaning that when plotted versus frequency, it has a constant value. The term qi_D is a current power density having units A^2/Hz.

White Noise

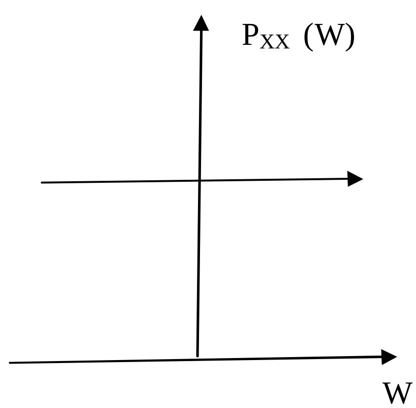
This consists of the component of noise which are independent of frequency (they exist at all frequencies up to about 10^{13}Hz). It is due to a number of components including thermal noise, shot noise, partition noise etc. it has equal power in each limit of frequency increment for all frequencies. White noise therefore has a constant power spectral density from minus infinity to plus infinity. Considering the case where the signal is white i.e the power spectral density has a constant amplitude A, then P_{xx} (W) = A, where W = angular frequency. Applying the Wiener ï Khintchine relationship, we find that the auto-correlation function is given by:-

$$P_{xx}(T) = \frac{1}{2\pi} \int_{-\infty}^{\infty} A e^{-iwt} \, dw = AJ(T) \text{ ---(3)}$$

Where T = Period

$$r(T) = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{-iwt} \, dw \text{ ---(4)}$$

That is, the function is only correlated at the origin and completely uncorrelated elsewhere. A sketch of the power spectral density and the auto- correlation function for white noise is given below.



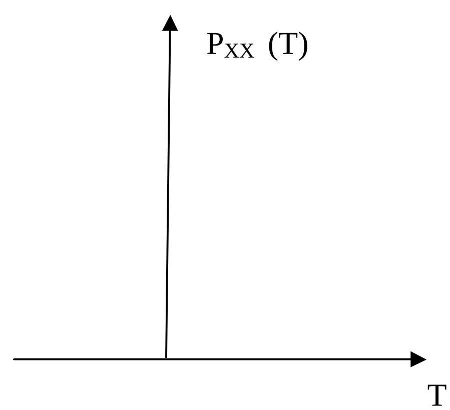


Figure 3: Power Spectral and Auto Correlation for White Noise.

Bipolar Junction Transistor Noise

This is also an example of noise produced by electronic components.

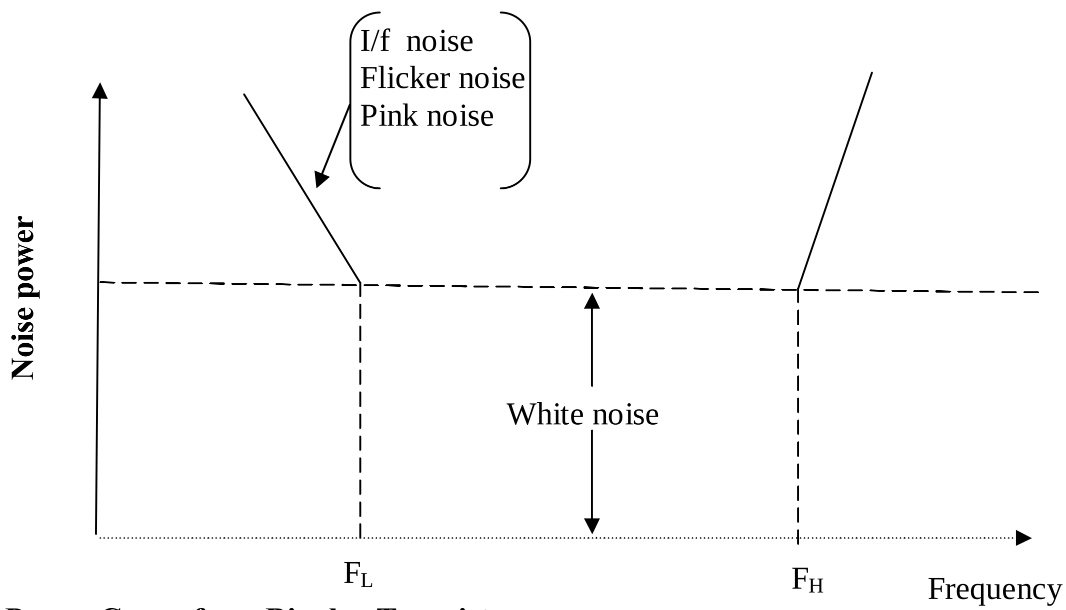


Figure 4: Power Curve for a Bipolar Transistor

F_L = lower frequency break point
F_H = higher frequency break point

At high frequencies above F_H (higher frequency) break point, the signal power gain of the transistor reduces, this causes a relative increase in noise power. At frequencies below, F_L(lower frequency) break point, the noise power increases with reducing frequency and for those reason, it is described as I/f noise (F = frequency). This can be obtained from flicker in rectifiers. Since the noise is spread over a narrow band width, it is known as coloured noise
and is frequently referred to as ñpinkò noise. Therefore, this type of noise can be called I/f noise, flicker noise or pink noise.

Value Noise

The source of this noise includes those for bipolar transistors. Another source is the microphony which results from vibration of the electrodes when the value is subjected to mechanical shock

Equivalent Noise

Further noise can be produced in the circuit with the effect of shot noise such as thermal noise and this can be reduced to equivalent thermal noise by associating it with an equivalent resistance Req for a triode, the hypothetical resistor is inserted in series with the grid and is given y Req = 2.5 / g_m where g_m is the mutual conductance of the triode. The equivalent r.m is thermal noise voltage V_t can be given by:-

$$V_t \sqrt{4KT\Delta f\ (R_g + R_{eq})} \quad \text{-------------------------------------} \quad (5)$$

Where f = The effective bandwidth of the system.

Partition Noise

The division of current to one or other electrodes in multi grid values like tetrodes and pentodes is subject to random fluctuations. Thos gives rise to noise effect basically similar to shot noise called partition noise. The effect of this noise can be calculated by increasing the value of the equivalent noise resistance, R_{eq} obtained in a triode. For instance, the value of R_{eq} for a pentode is given by :

$$R_{eq} = \frac{I_a}{I_a + I_s}\left(\frac{2.5}{g_m} = \frac{20\ 1_s}{g_m^2}\right) \text{---} (6)$$

Where I_a = anode current, I_s + screen current
g_m = mutual conductance of the value.

Some values of Req are between 1000vz to 10 Kvz. Because of partition noise, multi grid values are noisier than triodes.

Evaluation of noise

In evaluating noise, we can use mathematical concepts which relate either to noise voltage or to noise power spectral density. Since noise fluctuations are both positive and negative, the mean- square noise voltage (or current) is first determined which then leads to the expression of A.C noise power.

$P = \sqrt{\overline{Vn}^2}/ R$ where $\overline{Vn^2}$ is the R.M.S noise voltage and R is the circuit resistance involved. The average noise power or the mean-square noise power voltage can be evaluated using integration. This can be seen in the case of white noise which id=s often used as a standard or reference.

In most practical communication systems, the usual performance is the ratio of signal power to noise power in the system. This is defined as the signal-to-noise ratio or S/N ratio at the output of the detector.

Signal- to-Noise Power Ratio.

The ratio is given by

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

But $P = \dfrac{V^2}{R}$

Hence, $$\frac{S}{N} = \frac{V_s^2 / R}{V_n^2/R} = \frac{V_s^2}{V_n^2} \text{---} (7)$$

Where V_s and V_n are the respective values of signal voltage and noise voltage. Equation (7) is usually e[illegible] in decibels as

$$\frac{S}{N} = 10\ l[\text{illegible}]\left(\frac{V_s}{V_n}\right)^2 = 20 \log\left(\frac{V_s}{V_n}\right) \text{ db} \text{---------------------------------------} (8)$$

Where log is logarithm to base 10 and $\frac{Vs}{Vn}$ implies $\frac{S}{N}$ voltage ratio

Noise Figure

Noise figure for a circuit is given by :

Noise figure, F = $\dfrac{\text{signal-to-noise power Ratio at the input}}{\text{Signal-to-power ratio at the output}}$

$$= \frac{V_{si} / V_{ni}{}^{2}}{V_{so} / V_{no}{}^{2}}$$

This is expressed in decibels as follows

$$Fdb = 20 \log \left(\frac{V_{si} / V_{ni}}{V_{so} / V_{no}} \right) db$$

Reduction of Noise

According to Wikipedia (2011), noise in electrical circuit can be reduced for the following reasons:-

i. To improve sensitivity of the circuit to detect desired signals in a receiver.
ii. To reduce harmonic content and phase noise in a transmitter.
iii. To improve output signal to noise ratio.

In order to reduce voltage induced in circuits from unwanted external signals, we shield the circuit by enclosing it in a metal box. The box places the content in a uniform field so that the effects at low frequency radiations are minimized. If the box is made of iron, it provides a degree of magnetic shielding; if it is of aluminum or copper, it provides high frequency shielding.

However, valve noise can be reduced by mounting the valve in a resilient holder and by acoustically shielding the valve.

Conclusions

Noise is inevitable in electric circuits. It can block, distort or change the meaning of a message in electronic communication, (Wikipedia, 2011). Since electrical noise is of no use because it tends to hinder the reception of the wanted signal and hence limiting factor in its reception, it is therefore very important to minimize it.

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