EE60032: Analog Signal Processing

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Module-5: Noise

Noise

Any unwanted disturbance that interferes/obscures with a signal of interest is referred as noise.

Examples :
- input offset voltage, input offset current of op-amp → dc noise.
- AC noise → significantly degrades the performance
  - a) External / interference noise
  - b) Internal / inherent noise

External / interference noise :-

- Caused by unwanted interaction between the system and the outside or environment. It could be within different parts ~~within~~ of the system also.
  - i) Electric → through parasitic capacitance. e.g. coupling, VDD/GND bounce.
  - ii) Magnetic → through mutual inductance between ckts.
  - iii) Electromagnetic → through each wire/traces as potential antenna.
  - iv) Electromechanical → through transducers (microphone, piezoelectric) which converts non-electrical noise to electrical noise.

- It can be periodic, intermittent or completely random.
  It can be minimised by filtering, decoupling, guarding, electrostatic or electromagnetic shielding, physical seperation, low-noise power supplies etc.

Internal / Inherent Noise :-

This is generated inside ckt. and this noise is purely random.

Example : Thermal agitation of electrons in resistor.

Random generation and recombination of electron-hole pairs in semiconductor.

Importance of signal-to-noise ratio :-

The noise degrades the quality of a signal.

$$SNR = 10\log_{10} \frac{X_s^2}{X_n^2}$$

X_s = RMS value of signal

X_n = RMS value of noise.

Poorer the value of SNR, more difficult to rescue the signal from noise.

- Noise will be a concern based on performance requirement :-

In 12 bit A/D converter, $\frac{1}{2} LSB = \frac{10V}{2^{13}} = 1.22$ mV where 10 V = fullscale

Lets assume, transducer is producing 10 mV signal.

To use fullscale range of A/D, you have to amplify the signal by 1000 times.

Now $\frac{1}{2}$ LSB corresponds to a signal level of 1.22 μV.

If your amplifier has an input referred noise of 1 μV, then it will be invalidated.

Noise Properties

Noise is a random process, the instantaneous value of noise is unpredictable. We have to deal with noise on a statistical basis.

- **RMS value of noise :-**

RMS value of noise $X_n = \sqrt{\frac{1}{T}\int_0^T x_n^2(t)\,dt}$

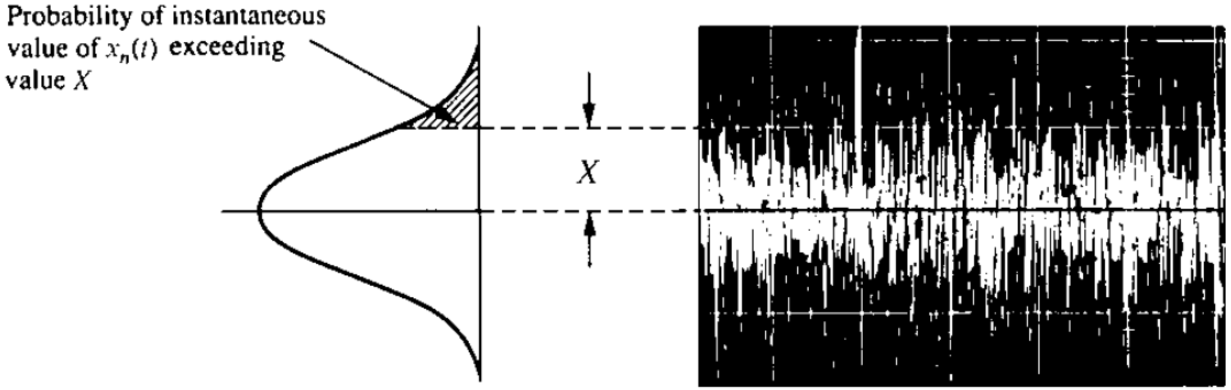
T = suitable averaging time interval.
X_n = RMS value of noise voltage/current.

Physically, X_n^2 represents the average power dissipated by $x_n(t)$ in a $1\,\Omega$ resistor.
If voltage noise source, power $= \frac{X_n^2}{R}$, if current noise source, power $= X_n^2 R$.

- **Crest factor :-**

In many applications, such as A/D converter/comparator, the resolution or accuracy etc. are affected by instanteous value rather than RMS value of noise. Peak noise is more a concern.
Most noise has a Gaussian distribution, instanteous values can be predicted in terms of probability.

Crest factor $= \dfrac{\text{Peak value of the noise}}{\text{RMS value of the noise}}$.



Voltage noise (right), and Gaussian distribution of amplitude.

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Noise Spectrum :-

X_n^2 represents average power dissipated by $x_n(t)$ in a 1-Ω resistor.

For an AC signal, power is concentrated at one frequency.

However, for noise, power is spreaded over all frequencis due to random nature.

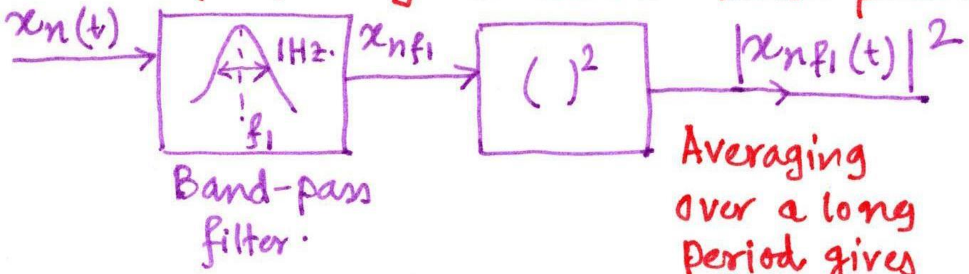
For noise, we must specify average noise power over a frequency band.

The rate of change of noise power with frequency is called noise power spectral density.

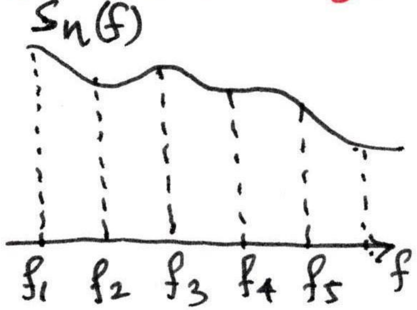
$$S_n^2(f) = \frac{dX_n^2}{df}$$

Unit of $S_n^2(f)$ → V^2/Hz, A^2/Hz

Unit of $S_n(f)$ → $V/\sqrt{Hz}$, $A/\sqrt{Hz}$.



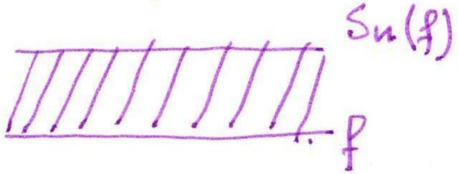
Averaging over a long period gives $S_n^2(f)$



Power spectral density of a random process may be random.
However, most of noise sources of exhibit a predictable spectrum.

Example :

White spectrum



Total power carried out by white noise is "infinite", which is impractical.
In practice, any noise spectrum that is flat in the band of interest is called white.

Noise summation :-

Two noise sources : $x_{n1}(t)$ and $x_{n2}(t)$ and their corresponding rms values are known as X_{n1} and X_{n2} respectively.

$$x_{no}(t) = x_{n1}(t) + x_{n2}(t)$$

Then,
$$X_{no}^2 = \frac{1}{T}\int_0^T x_{no}^2(t)\,dt = \frac{1}{T}\int_0^T \left[x_{n1}(t) + x_{n2}(t)\right]^2 dt.$$

$$= \frac{1}{T}\int_0^T x_{n1}^2(t)\,dt + \frac{1}{T}\int_0^T x_{n2}^2(t)\,dt + \frac{1}{T}\int_0^T 2\,x_{n1}(t)\,x_{n2}(t)\,dt.$$

$$= X_{n1}^2 + X_{n2}^2 + \frac{2}{T}\int_0^T x_{n1}(t)\,x_{n2}(t)\,dt.$$

If correlation coefficient $C = \dfrac{\frac{1}{T}\int_0^T x_{n1}(t)\,x_{n2}(t)\,dt}{X_{n1} X_{n2}}$ where $-1 \le C \le 1$

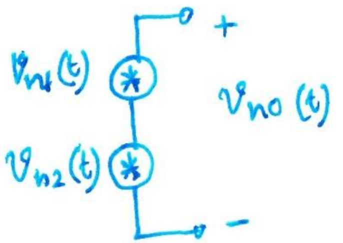
If $C = \pm 1$, then two signals are fully correlated.

If $C = 0$, then they are un-correlated.

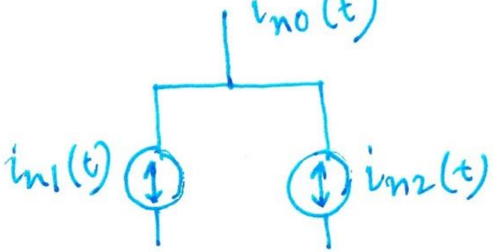
Then $X_{no}^2 = X_{n1}^2 + X_{n2}^2 + 2C X_{n1} X_{n2}$

Usually noise signals are uncorrelated,

Then, $X_{no}^2 = X_{n1}^2 + X_{n2}^2$



$V_{no}^2 = V_{n1}^2 + V_{n2}^2$

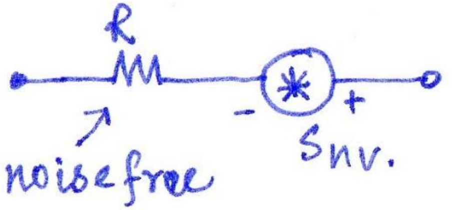


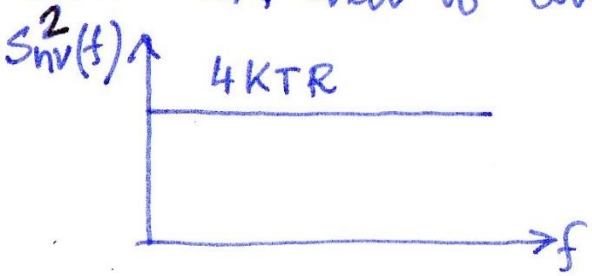
$I_{no}^2 = I_{n1}^2 + I_{n2}^2$

Types of noise :- Different circuit components introduces noise.

1) Thermal noise :- (Also known as Johnson noise)

The random motions of electron introduces fluctuations in voltage measured across the conductor, even if average current is zero. This is thermal noise





$$S_{nv}^2(f) = 4KTR. \quad , \quad f \geq 0.$$

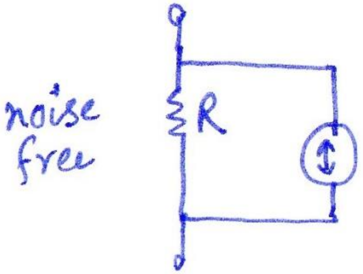
K = Boltzmann Constant = $1 \cdot 38 \times 10^{-23}$ J/K.

T = Absolute temp.

R = Resistance value.

$S_{nv}^2(f) \rightarrow$ power spectral density.

$S_{nv}(f) \Rightarrow$ voltage spectral density. $= \sqrt{4KTR}$.



$S_{ni}(f) \rightarrow$ current spectral density $= \dfrac{\sqrt{4KTR}}{R} = \sqrt{\dfrac{4KT}{R}}$.

$S_{ni}^2(f)$ = Current power spectral density $= \dfrac{4KT}{R}$.

2) Shot noise :-

This type of noise arises whenever charges crosses a potential barrier, such as in diodes or transistors. Barrier crossing is purely ~~ran~~ random and produces random current noise.

Shot noise has a uniform power density. $S_{ni}^2(f) = 2qI$.

q = charge of electron $= 1.602 \times 10^{-19}$ C.

I = dc current through the barrier.

3) Flicker noise :- (1/f noise or contact noise)

It is present in all active device and in some passive device.

In active device : it is due to traps. When current flows, these traps capture and release carriers randomly, causing random fluctuations of current.

E.g. in BJT – contamination and crystal defects at BE jn.

$$S_{ni}^2(f) = K \cdot \frac{I^a}{f}$$

K = device constant.

I = device current.

a = another device constant [range $\frac{1}{2}$ to 2].

Summary of the course

1. Module-1: Signal processing using operational amplifier
2. Module-2: Analog and switched capacitor Filters
3. Module-3: Data converters
4. Module-4: Phase locked loop and Oscillator
5. Module-5: Noise