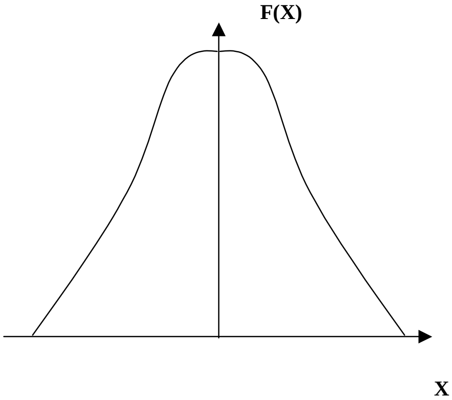
## Noise Tutorial

### Fundamentals

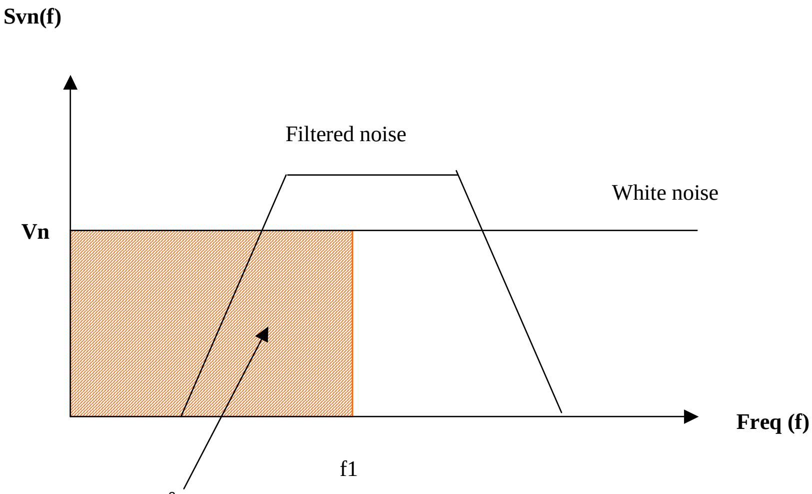
Objects capable of allowing the flow of electrical current will exhibit noise. This occurs as some electrons will have a random motion, causing fluctuating voltage and currents. As noise is random it can only be predicted by statistical means, usually with a Gaussian probability density function as shown below:-




As noise is random then it's mean value will be zero, hence we use **mean square** values, which are measurements of the dissipated noise power. The effective noise power of a source is measured in **root mean square** of **rms** values.

$$ie\ \ Vn_{(rms)} = \sqrt{Vn^2}$$

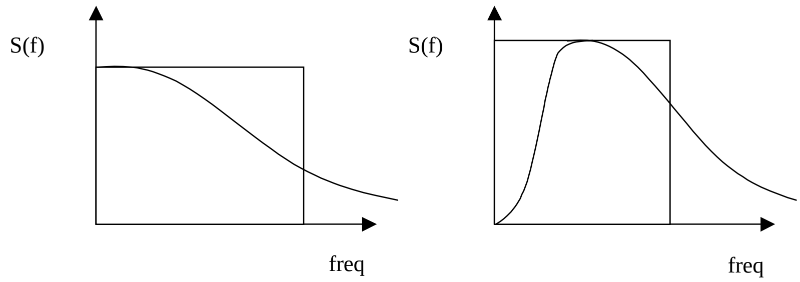
**Noise power spectral density** – describes the noise content in a 1Hz bandwidth. Units are $V^2$/Hz and denotes as $S_{vn}$(f). The graph below shows how $S_{vn}$(f) is defined.




Total square noise $vn^2$ is found by integrating the spectral density function (ie the shaded area)

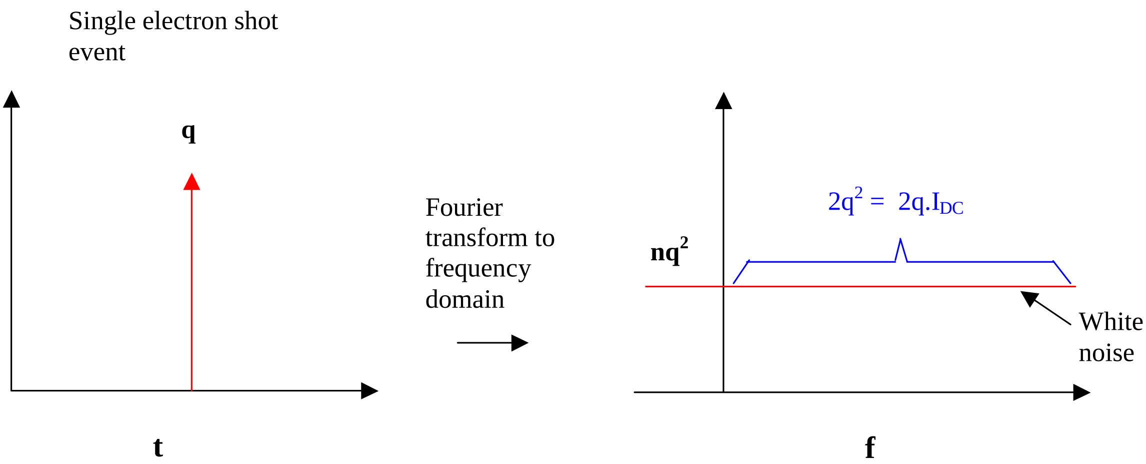
ie $vn^2 = \int S_{VN}(f).df \ = \ vn^2.f1$

**Equivalent Noise Bandwidth (NBW)** - is defined as the frequency span of a noise power curve with an amplitude equal to the actual peak value, and with the same integrated area. In other words the NBW describes the bandwidth of a 'brick wall' system with the same noise power as the actual system (f1 is set such that the area of the 'brick wall' is ~ equal to the whole function). The graph below shows a couple of examples.




The main constituents of noise in a system, is due to Shot, Thermal, Burst, Avalanche and Flicker noise.

**Shot noise** – This noise is generated by current flowing across a P-N junction and is a function of the bias current and the electron charge. The impulse of charge q depected as a single shot event in the time domain can be Fourier transformed into the frequency domain as a wideband noise ie




$$in^2 = 2nq^2 \Delta f = 2qI_{DC} \Delta f \qquad I_{DC} = \text{bias current; } q = \text{electron charge}$$

**Thermal noise –** In any object with electrical resistance the thermal fluctuations of the electrons in the object will generate noise ie

$$vn^2 = 4kTR \ \ V^2/Hz \ \ \text{Where } k = \text{Boltzmann's constant } (1.38x10^{-23} \ J/K)$$

The spectral density of thermal noise is flat with frequency and is known as white noise.
**Burst noise** – occurs in semiconductor devices, especially monolithic amplifiers and manifests as a noise crackle.

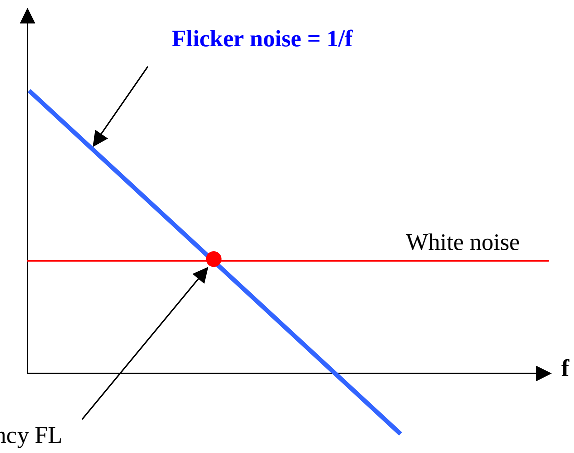
**Avalanche noise** – occurs in Zener diodes are reversed biased P-N junctions at breakdown. This noise is considerably larger than shot noise, so if zeners have to be used as part of a bias circuit then they need to be RF decoupled.

**Flicker noise** – This noise occurs in almost all electronic devices at low frequencies and takes the form of:-

$$if^2 = k\Delta f\left(\frac{Ia}{fb}\right)$$

Where a is between 0.5 & 2, with b ~ 1
k is variable depending on the device process

$$k = \frac{2q.I_b.FL}{f}$$

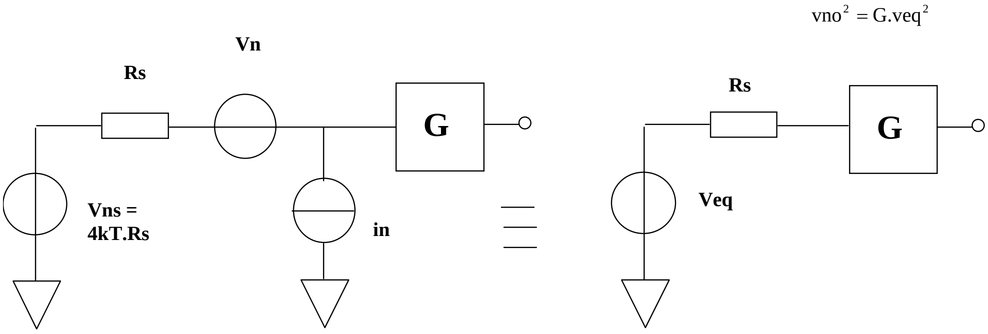



Flicker noise is usually defined by the corner frequency FL.

**Equivalent Noise Model**

When analysing a circuit we transform the many possible sources of noise (generating noise currents and voltages) to an equivalent noise source at the input of the circuit ie

Total equivalent output noise =
$vno^2 = G.veq^2$




Total equivalent input noise voltage =

$$veq^2 = vns^2 + vn^2 + in^2Rs^2 \quad \text{where } vns^2 = 4kTRs$$

**Noise Figure/Noise Factor**

The noise factor (F) of a device specifies how much additional noise the device will contribute to the noise already from the source.

The total equivalent input noise voltage =

$$veq^2 = vns^2 + vn^2 + in^2Rs^2 \quad \text{where } vns^2 = 4kTRs$$

$$\text{Noise Factor} = \frac{vns^2 + vn^2 + in^2Rs^2}{vns^2} = 1 + \frac{vn^2 + in^2Rs^2}{vns^2}$$

$$vns^2 = 4kT.Rs \qquad F = 1 + \frac{vn^2 + in^2Rs^2}{4kT.Rs}$$

**Noise factor (F)** is defined as the ratio of:

$$F = \frac{\text{Total equivalent input noise power}}{\text{Input noise power due to the source only}} \approx \frac{veq^2}{vns^2} = \frac{1 + vn^2 + in^2Rs^2}{vns^2}$$

$$\text{Ideally } F = 1$$

**Noise figure (NF)** is the Noise factor converted to dB ie

$$\text{Noise Figure (NF)} = 10\log_{10}(F)\text{dB}$$

Signal to Noise Ratio

$$SNR_{IN} = \frac{\text{Received signal power}}{\text{Received noise power}} = \frac{vsig^2}{vns^2} \qquad \text{Where } vns^2 = \text{receive noise from source}$$

$$\text{Similarly } SNR_{OUT} = \frac{\text{Output signal power}}{\text{Output noise power}} = \frac{Gvsig^2}{Gveq^2} = \frac{vsig^2}{veq^2}$$

$$\text{Thus, } \frac{SNR_{IN}}{SNR_{OUT}} = \frac{veq^2}{vns^2} = F$$