Noise in electronic circuits.

Types of Noise

White noise is the type of noise that affects all frequencies equally. It spreads up from zero frequency upwards with a flat amplitude.

Pink noise does not have a flat response. Its power density falls with increasing frequency.

Band limited noise has its frequency band limited either by filters or the circuit through which it passes.

Thermal Noise.

Thermal noise - detected and measured by John B. Johnson in 1926, and later explained by Harry Nyquist

Thermal noise:-

- occurs regardless of the applied voltage
- is always present in electronic circuits and is generated as a result of thermal vibration of the charge carriers, (typically electrons), within an electrical conductor.
- the vibration is dependent upon the temperature - the higher the temperature, the greater the vibration and hence the greater the thermal noise level.
- is random in nature and therefore it is not possible to reduce the effects by cancellation or other similar techniques.
- appears regardless of the quality of component used. The noise level is dependent only upon the temperature and the value of the resistance. (Other forms of noise may also be present, therefore the choice of the resistor type may play a part in determining the overall noise level as the different types of noise will add together.)
- can only be reduced by reducing the temperature of operation, or reducing the value of the resistors in the circuit.
- is only generated by the real part of any impedance, i.e. the resistance. The imaginary part does not generate noise.

Thermal noise extends over a very large (infinite) frequency range. Noise power can be calculated by summing the power over the frequency range considered.

$$P = kT \int_{f_1}^{f_2} df$$

where

- k is the Boltzmann constant,
- T is the absolute temperature (K),
- f_2 is the upper frequency (Hz),
- f_1 is the lower frequency (Hz),

If this noise power is generated within a resistance of R, then consider this as a perfect noise voltage source V in series with a perfect resistor R. For maximum transfer of power, this must be fed into an equal resistance R. The voltage developed across this resistor will be V/2 and the power delivered will be $V^2/4R$

where

- V is the rms noise voltage
- R is the resistance

So, the noise power formula can be written as

$$\frac{V^2}{4R} = kT\int_{f_1}^{f_2} df$$

$$\Rightarrow V^2 = 4kTR(f_2 - f_1)$$

assuming that R does not vary with frequency.

so the rms noise voltage V = $2\sqrt{kTRB}$ where B is the bandwidth in use.

Shot noise.

Shot noise was first investigated by Walter Schottky.

Shot noise:-

- arises because of the discrete nature of the charges carried by charge carriers, electrons or holes.
- is particularly noticeable where current levels are low, i.e. when the statistical nature of the current flow together with the discrete charge levels is more obvious.
- particularly noticeable in semiconductor devices, such as tunnel junctions, Schottky barrier diodes and p-n junctions.
- has a cut-off frequency determined by the time it takes for the electron or other charge carrier to travel through the conductor.
- is dependent upon the current flowing and has no relationship to the temperature at which the system is operating.
- is virtually non-existent for metallic resistors.

Flicker noise.

Flicker noise:-

- occurs in almost all electronic devices and has a variety of different causes, although these are usually related to the flow of direct current.
- has a 1/f characteristic, or a "pink noise" power density spectrum.
- is important in many areas of electronics including within oscillators used as RF sources.
- can show up as a variety of effects, but often occurs as a resistance fluctuation.
- can be expressed in the form S(f) = K/f, where f is frequency.
- manifests itself in oscillators as sidebands that are close to the carrier, the other forms of noise extending out from the carrier with a flatter spectrum, although decaying the greater the offset from the carrier.

Avalanche Noise

Avalanche noise:-

- is a form of noise that occurs in pn junctions that are operated in a region at or close to the point of avalanche breakdown.
- is generating in large amounts by diodes that operate in this region, e.g. 'zener diodes'
- occurs in semiconductors where a very high potential gradient exists. When this occurs electrons rapidly gain momentum and may hit the crystal lattice through which they travel with such energy that they can dislodge other charge carriers creating hole electron pairs. In turn these carriers are accelerated and may similarly hit the lattice and dislodge further carriers. This process can lead to an avalanche of new carriers, and the breakdown of the pn- junction. This results in a very uneven or ragged current flow and a high levels of noise - avalanche noise are generated.
- can be removed using simple capacitor based filter or smoothing networks.

Phase Noise.

There is a variety of terms associated with the basic concept of phase noise.

Phase noise:-	defined as the phase variations arising from the random frequency variations of the signal resulting from general noise in the circuit. The fluctuations manifest themselves as sidebands which appear as a noise spectrum spreading out either side of the signal. Phase noise describes the performance in the frequency domain and is measured in dBc/Hz at a given offset from the carrier. This is the noise power in a 1 Hz bandwidth at the offset from the carrier.
Phase jitter:-	is the term used for looking at the phase fluctuations themselves, i.e. the deviations in the position of the phase against what would be expected from a pure signal at any given time. Accordingly phase jitter is measured in radians. This indicates the angular jitter from the steady carrier. Phase jitter describes the performance in the time domain.
Spectrum:-	the plot that would be obtained from a spectrum analyser. The spectrum of the signal would show the centre wanted signal with the noise sidebands extending either side of the main carrier.
Spectral density:-	is the RMS phase distributions as a continuous function, expressed in units of RMS phase for a given unit bandwidth.
SSB phase noise:-	is the noise that spreads out from the carrier as a sideband. The single sideband phase noise is specified in dBc/Hz at a given frequency offset from the carrier.

Burst Noise.

Burst Noise:-

- also known as RTS noise or Popcorn noise.
- a low frequency noise (1/f).
- looks, on an oscilloscope, like a square wave with the constant magnitude, but with random pulse widths. In some cases, the burst noise may have not two but several different levels.
- is a function of temperature, induced mechanical stress, and also radiation can be a problem for nanotransistors and devices fabricated with other than silicon materials

Noise in BJT.

A mixture of:-

- thermal noise (proportional to internal base resistance, r_b),
- flicker noise (proportional to base bias current and 1/f)
- shot noise (proportional to base current and also collector current).

npn transistors have usually higher levels of 1/f noise than pnp transistors.
Flicker noise can be dominant up to several kHz, thermal and shot become dominant at higher frequencies.

One way to reduce the thermal noise level of the internal base resistance, is the connection of several (N) BJTs in parallel and to assure that the total current of all transistors is the same as for one transistor. In this way, the level of shot noise stays on the same level and the thermal noise is reduced by a factor of 1/N.
Medium power transistors have lower r_b than low power high gain transistors.

Noise of JFETs

A mixture of:-

- thermal noise (proportional to resistance of drain source channel),
- flicker noise (proportional to drain current and 1/f)
- shot noise (proportional to gate current and also collector current).

At the normal operating conditions, the gate-source junction is reverse biased and the shot noise of gate current, can be neglected.
Flicker noise can be dominant up to several kHz, thermal and shot become dominant at higher frequencies.

Noise in Resistors.

A mixture of:-

- thermal noise (proportional to the actual value of resistance),
- flicker noise (proportional to current and 1/f),
- type of material (affects the amount of flicker noise)

Resistor noise (lowest to highest):-

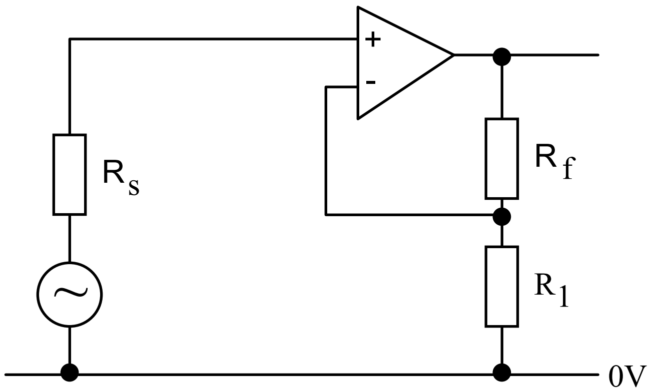
- wire wound (inductive),
- metal film (often non-inductive),
- thin film,
- deposited carbon,
- thick film,
- carbon composition

Noise in op-amps

A mixture of:-

- thermal, flicker and shot noise from all of the transistors (see earlier) in the op-amp
- resistors used to control the gain.

For a non-inverting amplifier, the lowest noise is when the value of R_1 in parallel with R_f is much less than R_s.



When choosing low noise op-amps, the two parameters to consider are:-

- the noise voltage - expressed in nV/√Hz - aim for < 4nV/√Hz
- the noise current - expressed in pA/√Hz - aim for <1pA/√Hz

For small values of R_s, the noise voltage is important.
For large values of Rs, the noise current is important.

So BJTs are of more use when R_s is small and FET when R_s is large.

Component data

2N3906 PNP

Lowest noise with Ic = 100µA, V_{ce} = 5V and when R_s = 2kΩ.
Noise figure above 300Hz is ≈1.5dB

2N3904 NPN

Lowest noise with Ic = 100µA, V_{ce} = 5V and when R_s = 500Ω.
Noise figure above 300Hz is ≈4dB

Useful information

National Semiconductors AN104 and AN222