NOISE (short notes)

Almost all the measurements are done using electronic equipments. An electronic signal always shows random uncorrelated fluctuations, called noise.
Some sources of this noise is "non-essential" extrinsic sources that can be minimized by good laboratory practice, other sources are "intrinsic", related to the physics of the system used for the measurements and cannot be minimized.

Intrinsic sources of noise:

Johnson Noise (or thermal noise, or Nyquist noise): in a conductor there is a large number of moving charge carriers (e.g. electrons in a metal). Point by point their density shows statistical fluctuations at finite temperature as a function of time, like the local density of air in a given point of a room. These density fluctuations give rise to voltage fluctuations. The average value of the voltage fluctuation is 0, but the mean square noise voltage is

$$\overline{v^2} = 4kRT\Delta f$$

Where k is the Boltzmann constant ($1.38\ 10^{-23}$ J K^{-1}), R is the resistance of the conductor, and Δf is the bandwidth in hertz over which the noise is measured.
It is a "white noise", i.e. the Fourier transform of this noise has a spectral density that does not depend on the frequency. This noise contains Fourier components of every frequency.
Example: for 1 MΩ resistor if we measure all the frequencies from 0 to 1 MHz the rms Johnson noise is about 100 μV.

Shot Noise: additional current fluctuations occur when a macroscopic current start to flow. This fluctuations occur when the finite number of particle that carry energy (for instance electrons in an electronic circuit, but also photons in an optical or electro-optical device) is small enough to give rise to detectable statistical fluctuations in a measurement. For instance, if a current correspond to a flow of 1000 electron per second, and the motion of the electrons is not correlated, you know that 1000 is the average value of a Poisson distribution, that of the number of electrons that flow through a section of the conductor in a given second. This distribution has a standard deviation that is the square root of the mean value, i.e. about 30. It means that in a given second 981 electron cross the section, in the next second 1034 electron cross the section, in another second 1021 electron flow, and so on. The mean square noise current is

$$\overline{i^2} = 2qI\Delta f$$

where q is the elementary charge, I is the macroscopic average current, and Δf is the bandwidth in hertz over which the noise is measured. For instance if I=1 mA and the signal is measured over 10^4 Hz the rms shot noise is about 2 nA.
It is a white noise, its spectral density does not depend on the frequency.

1/f noise (or pink noise): there is no general accepted theory for the 1/f noise (i. e.no theory that explains it in all the cases where the 1/f noise is present), there are several theories that explain why it occurs in specific systems. It occurs in almost all the electronic devices (referred to as flicker noise).

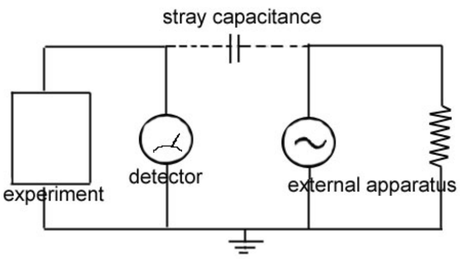
$$\overline{v^2} = A\Delta f / f$$

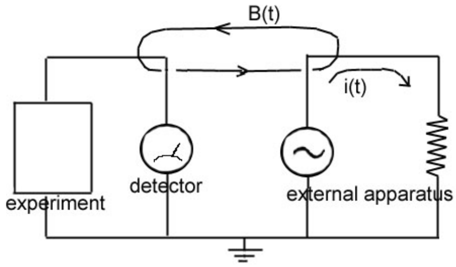
where A is a constant that depends on the physical system. The spectral distribution is inversely proportional to the frequency. Therefore it is important at low frequencies.

Examples of extrinsic sources of noise:

Noise can be produced by a capacitive coupling with a nearby apparatus with a varying voltage via a stray capacitance. A possible cure is capacitive shielding by placing both the experiment and the detector in a grounded metal box (Faraday cage). Another is using low impedance sources if voltages are measured.

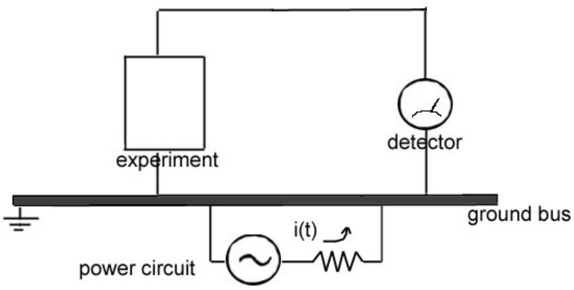
An inductive coupling can give rise to noise via a magnetic field. A changing current in a nearby circuit gives rise to a changing magnetic field which induces an electromotive force (efm) in the circuit connecting the experiment to the detector.





A possible cure is the reduction of the area of the pick-up loop by using twisted pairs or coaxial cables.

Resistive coupling (or “ground loops”)
Currents through common connections can give rise to noise voltages. In the figure below the detector is measuring the voltage across the experiment, plus the voltage due to the noise current passing through the finite resistance of the ground bus. This problem arises because two different grounding points are used, one for the experiment and one for the detector, which are not exactly at the same potential.



Cures for resistive coupling include:
Grounding everything to the same physical point
Using ground bus with lower resistance
Remove sources of large currents from ground wires used for small signals

Microphonic effects: Vibrations may cause changes in the capacitance between electrodes in the experimental setup. This causes noise currents that affect the detector.

Thermocouple effects: the potentials created by dissimilar metal junctions held at different temperatures can be sources of noise if the temperatures are not constant. These potentials may be of the order of microvolts or millivolts.