Novel Super-sensitive Charge Sensors for use in Ion and Antimatter Research

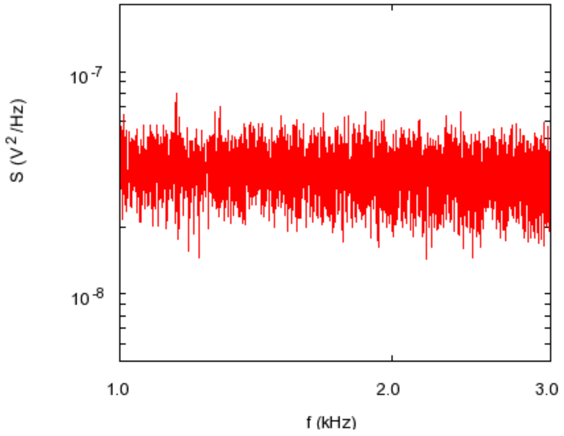
Ilia Blinov

Stahl-Electronics

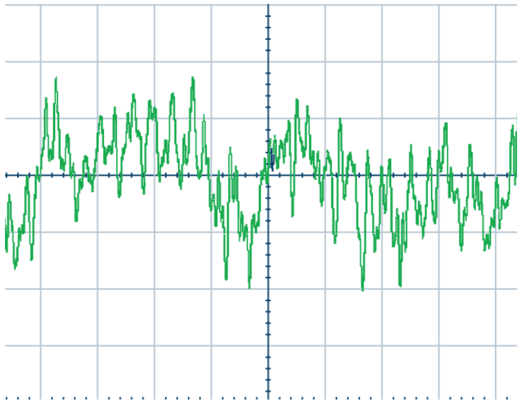
What are the characteristics of a good cryogenic amplifier?

- Ultra Low Input Noise
- Stable Gain at the specific Frequency Range
- High Input Impedance
- Low input capacitance
- Small Size and tiny thermal load of only 300 μWatt

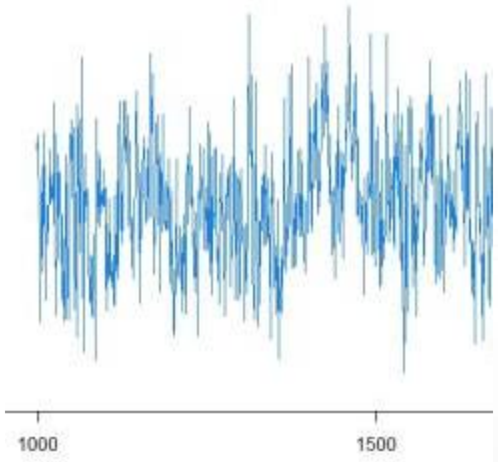
What are the Different Types of Noise?



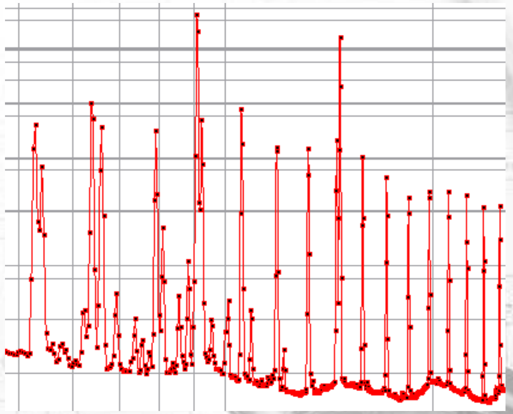
Johnson noise



Flicker noise



Shot noise



External noise

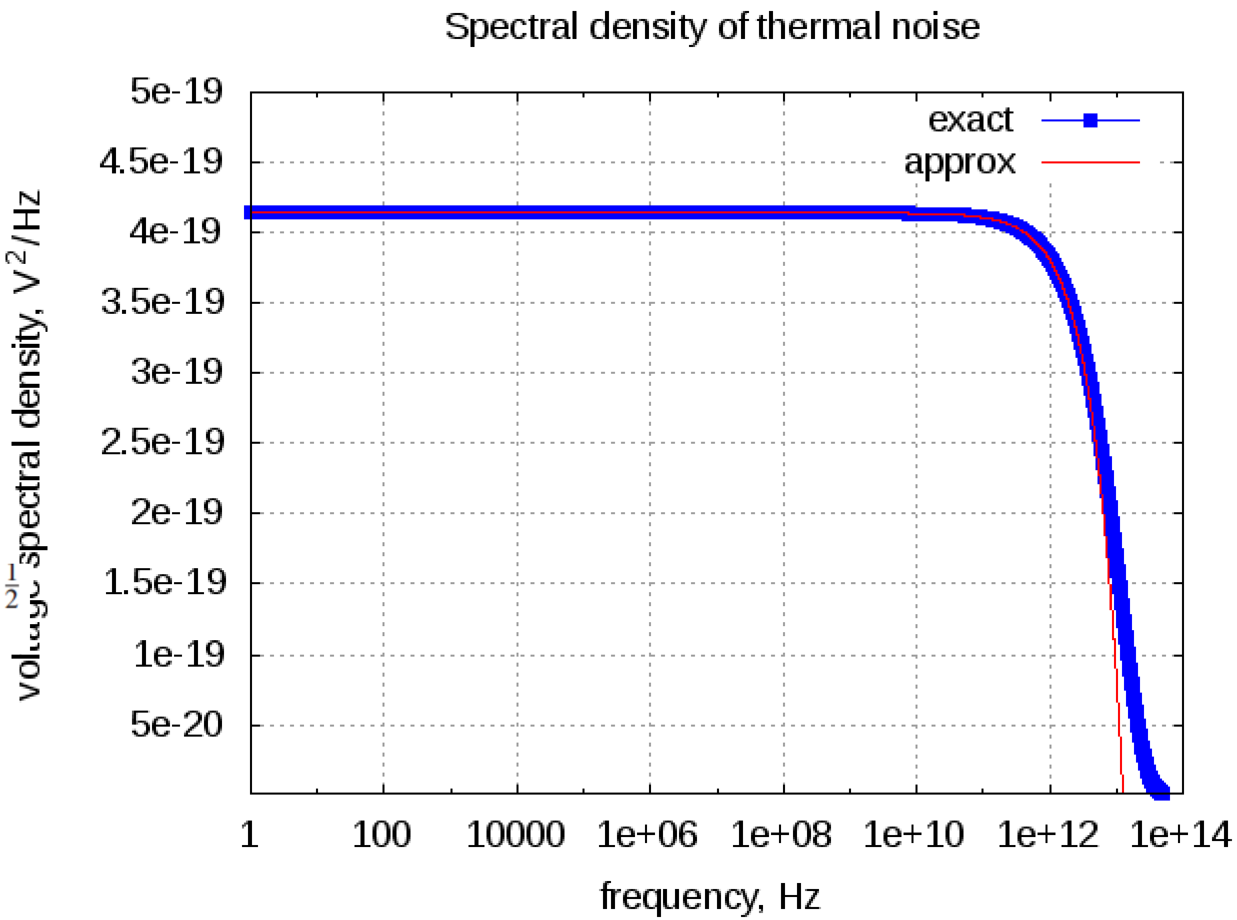
Johnson noise

$$v_{\text{noise}}(\text{rms}) = v_{\text{n}} = (4kTRB)^{\frac{1}{2}} \quad \text{V(rms)}$$

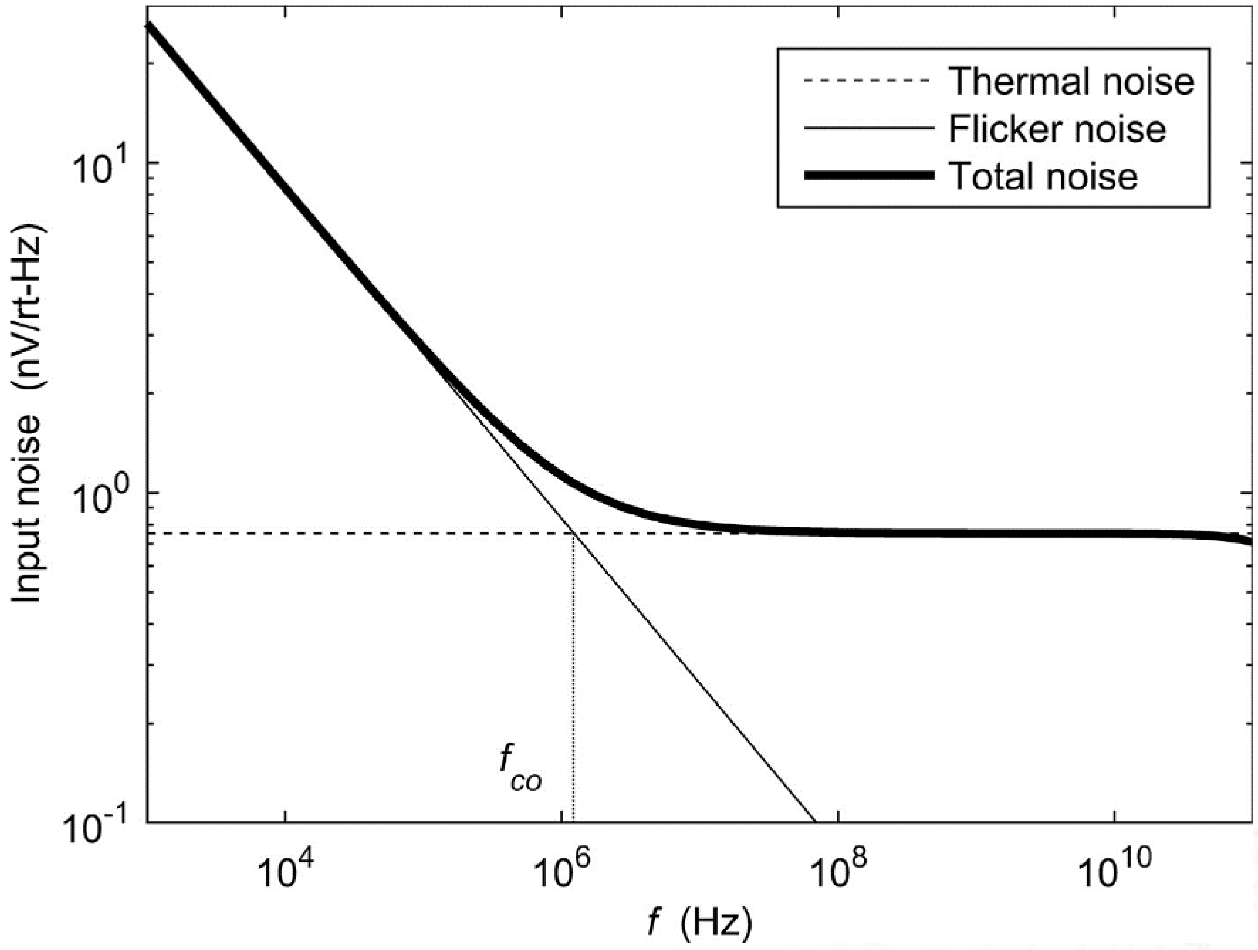
Open-circuit RMS~1,3uV

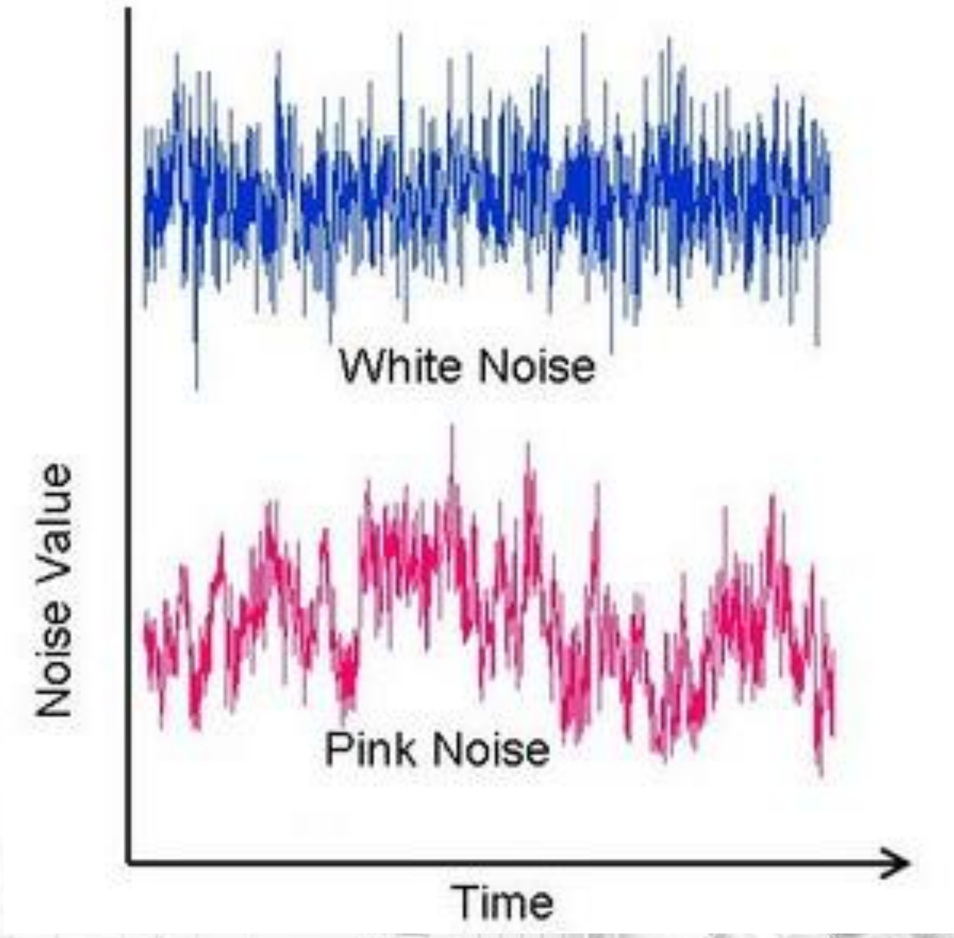
$$i_{\text{noise}}(\text{rms}) = v_{\text{noise}}(\text{rms})/R = v_{\text{nR}}/R = (4kTB/R)^{\frac{1}{2}}$$

$$e_{\text{n}} = \sqrt{4kTR} \quad \text{V/Hz}^{\frac{1}{2}}$$



Flicker noise (1/f noise)





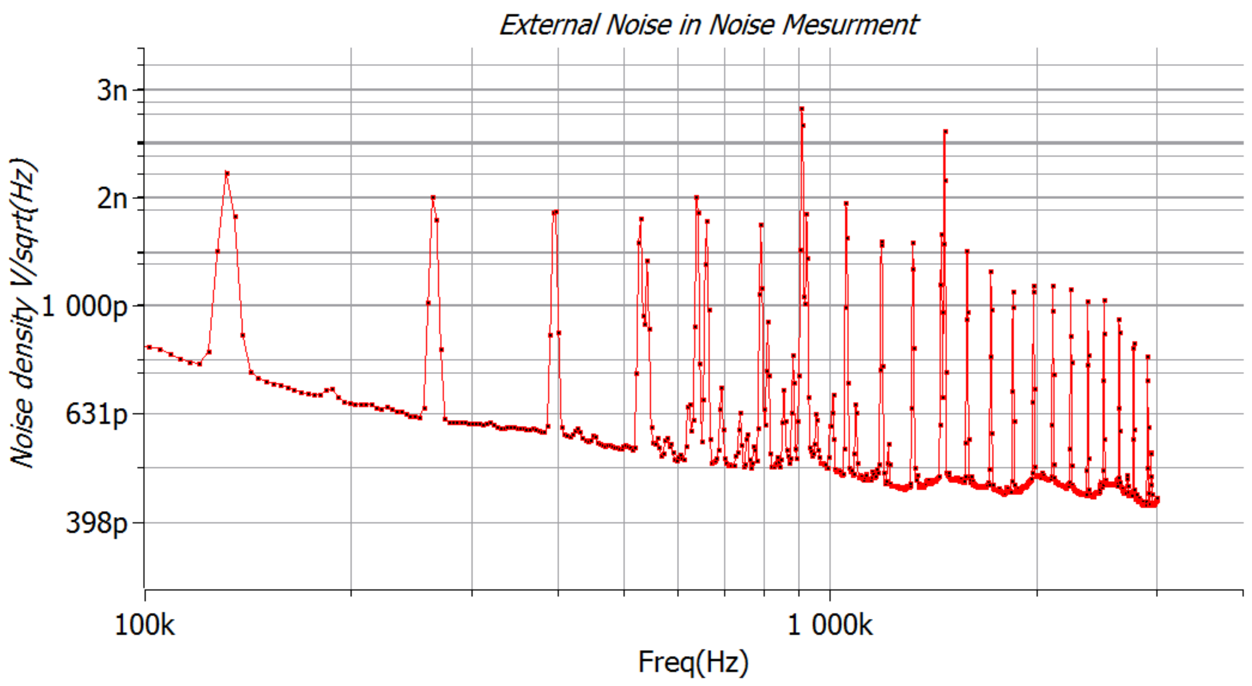
Shot noise

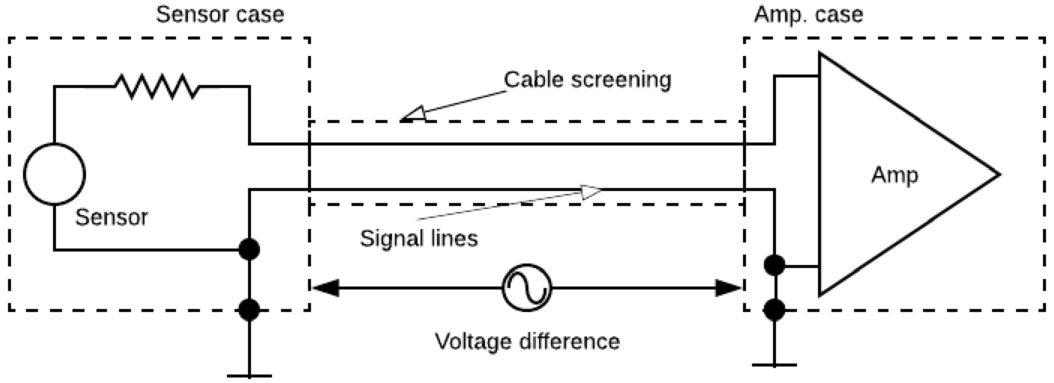
- Shot noise is a type of electronic noise that occurs when the finite number of particles that carry energy
- Shot noise was originally used to describe noise due to random fluctuations in electron emission from cathodes in vacuum tubes (called shot noise by analogy with lead shot).
- Shot noise also occurs in semiconductors due to the release of charge carriers.
- Shot noise is found to have a uniform spectral density as for thermal noise (White noise)

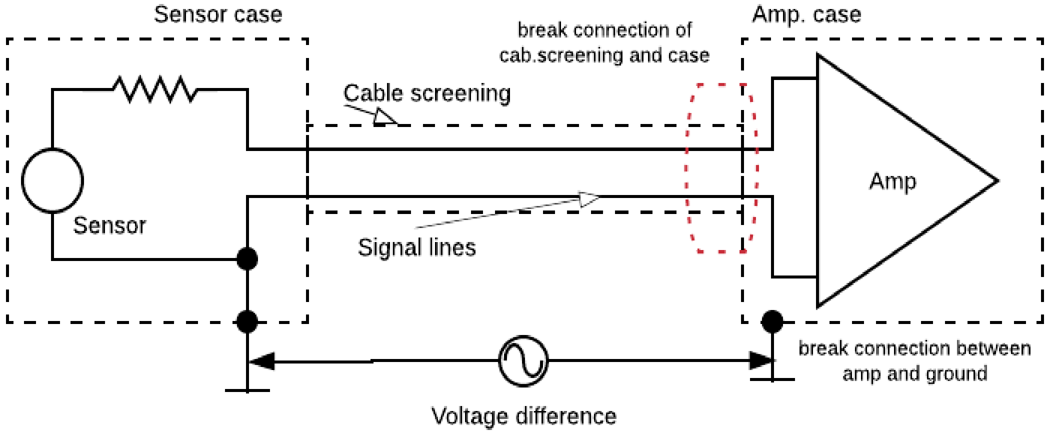
$$i_{n_s} = \sqrt{2Iq\Delta f}$$

where I is the DC current, q is the electron charge, and Δf is the bandwidth in Hz

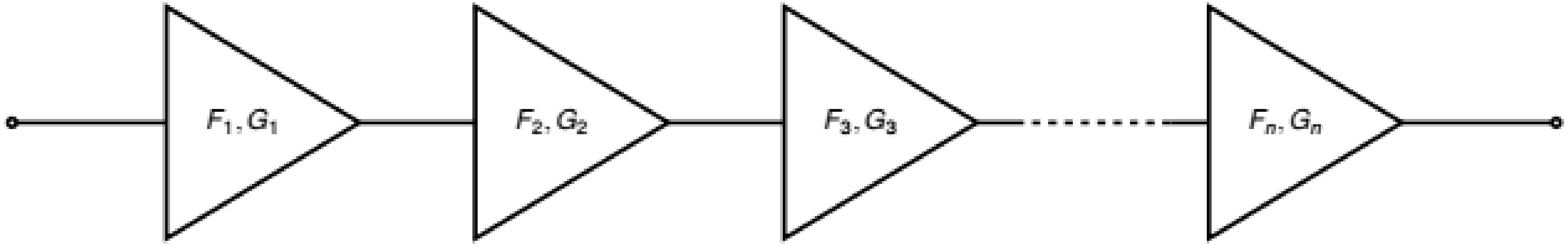
External noise







Multi-stage low noise amplifier design



$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots \frac{F_n - 1}{G_1 G_2 G_3 \ldots G_{n-1}}$$

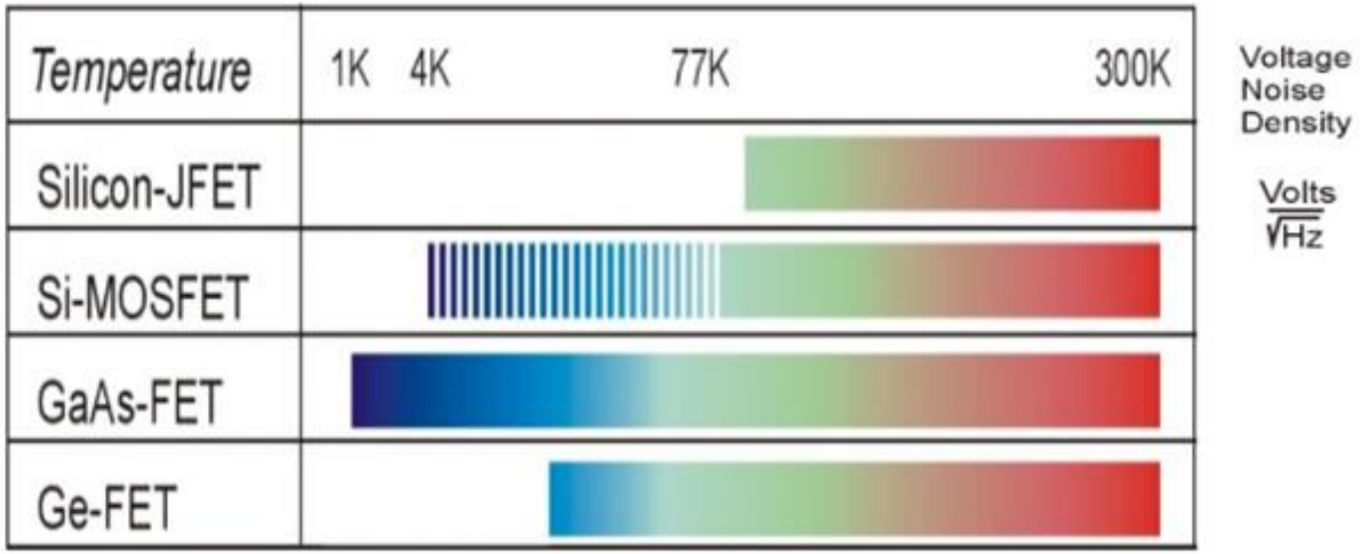
Where :

F = noise factor of the cascade

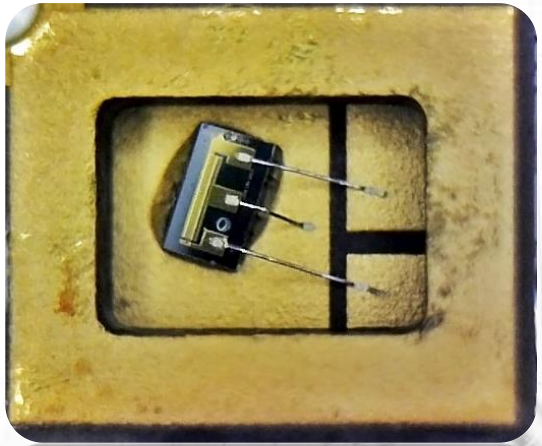
F_n = noise factor of the n^{th} stage

G_n = gain of the n^{th} stage

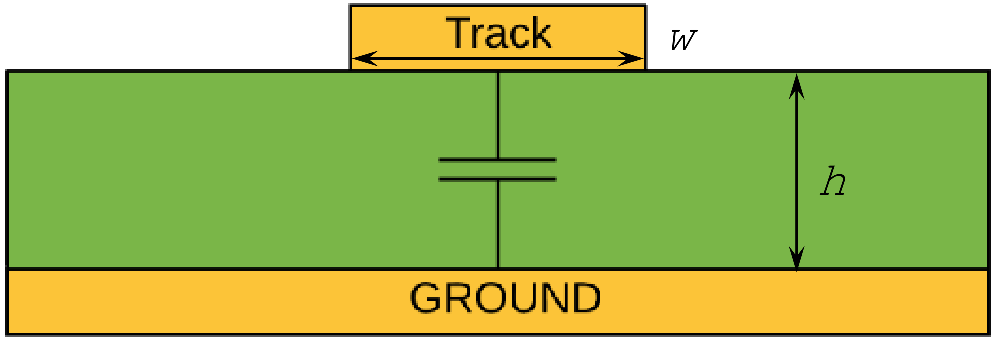
Why FET?

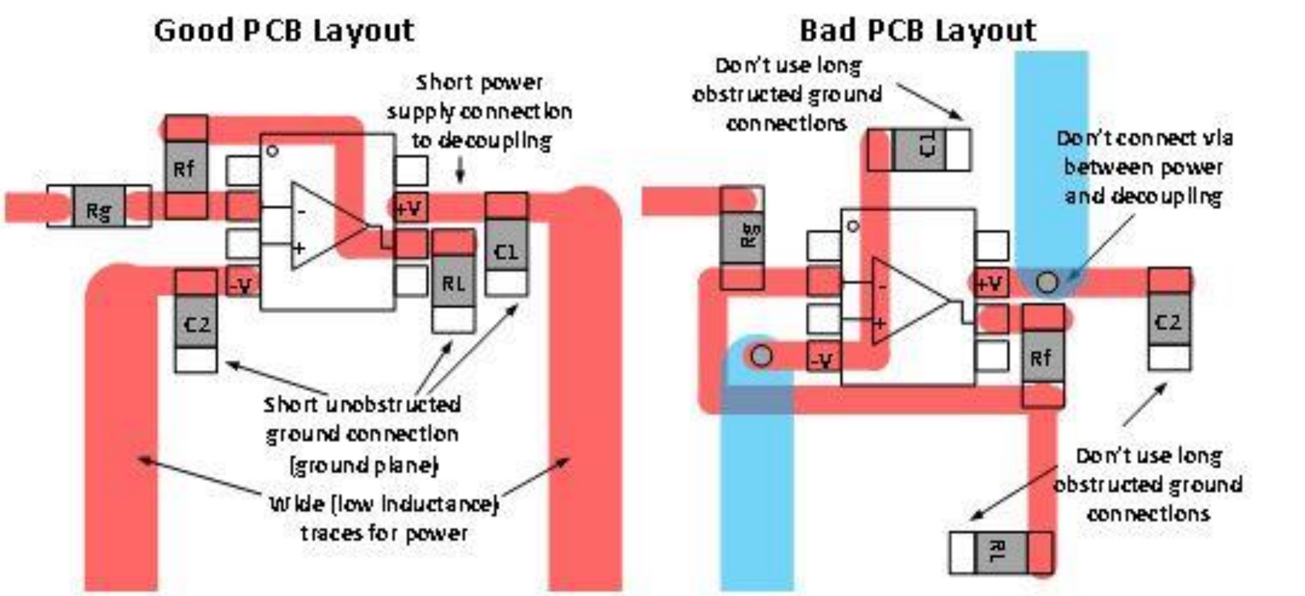


Usable temperature range of several semiconductor materials. Readily available and well-developed Silicon based components fail to work at low temperatures.



Input capacitance





$$C = \frac{\epsilon_r l}{60 v_0 \ln\left[\frac{8h}{w} + \frac{w}{4h}\right]} \quad \text{for } \frac{w}{h} < 1$$

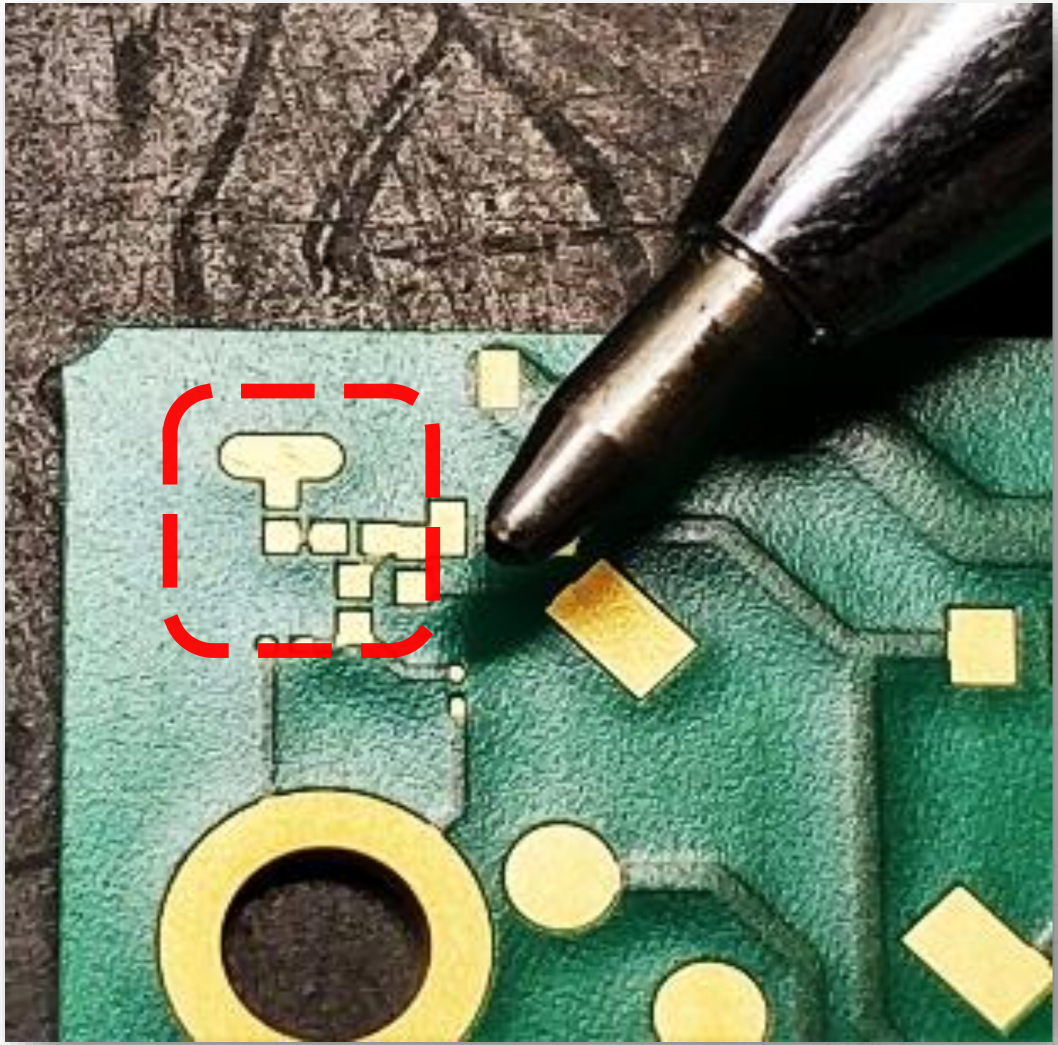
$$C = \frac{\epsilon_r l\left[\frac{w}{h} + 1.393 + 0.667 \ln\left(\frac{w}{h} + 1.444\right)\right]}{120 \pi v_0} \quad \text{for } \frac{w}{h} \geq 1$$

w – width of track, h – height of PCB, l – length of track

v_0 *- speed of light* ϵ_r *- Relative Permittivity*

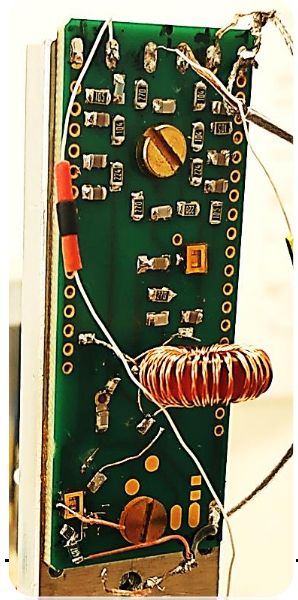
Input capacitance

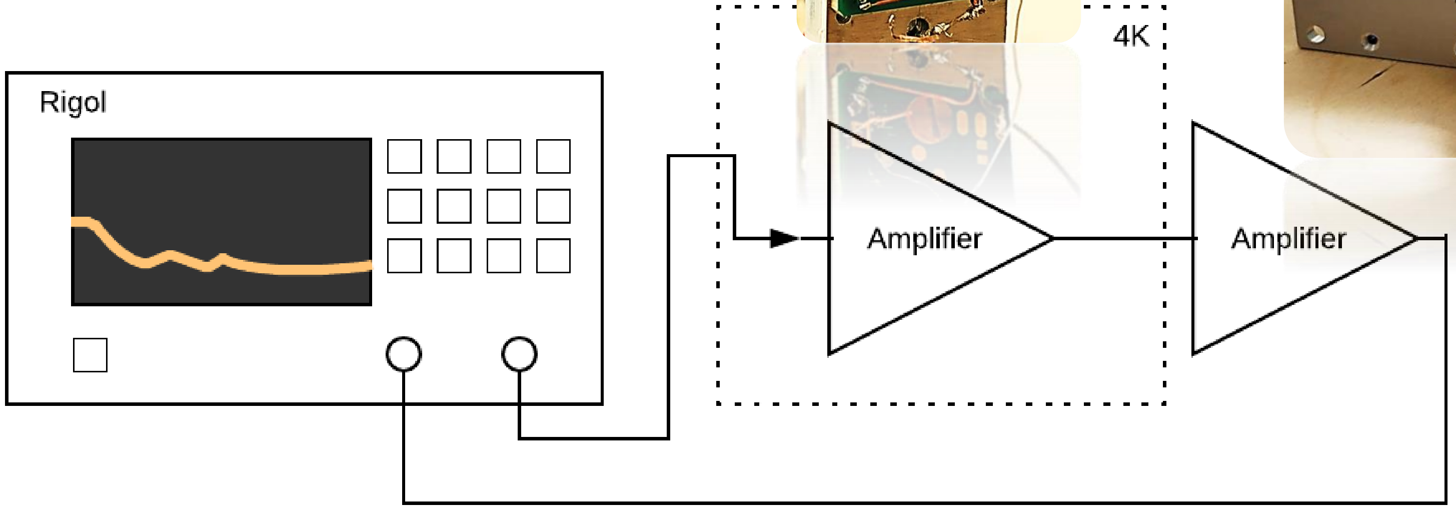
~1,0 pF



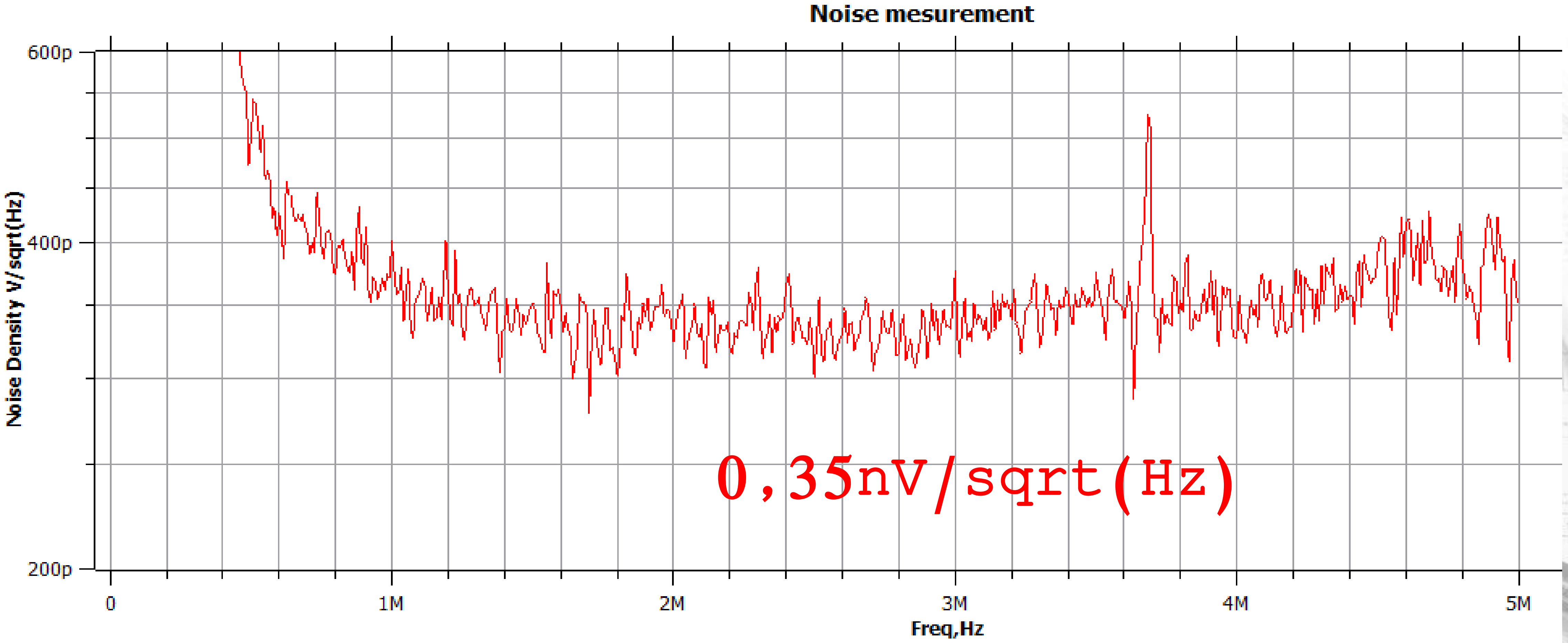
Noise measurements

1. Measure the transfer voltage gain
2. Measure the total output noise.
3. Calculate the equivalent input noise by dividing the output noise by the transfer voltage gain.

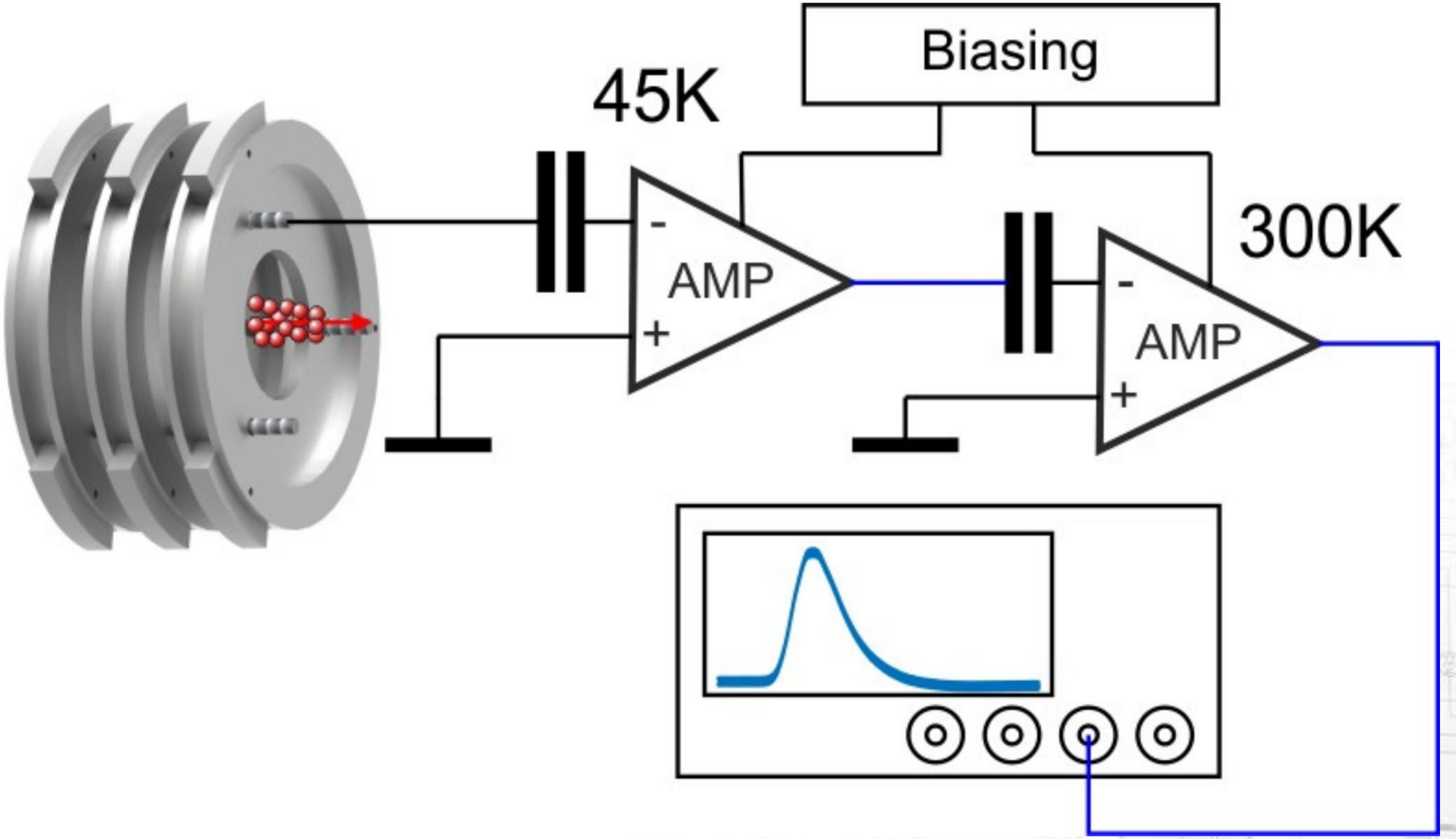




Noise measurements



Application for charge counting



Thank you!