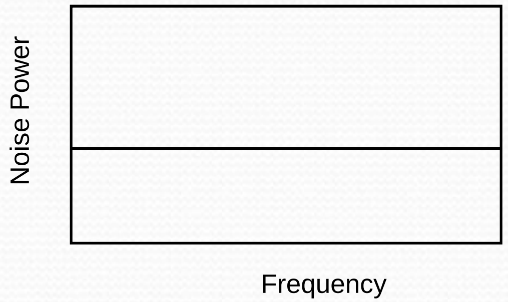
# NOISE

# Noise

***Johnson noise (Gaussian and white)***

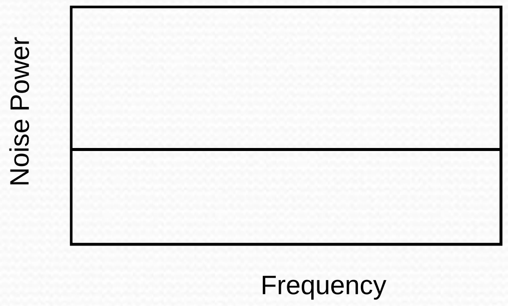
$$\text{Noise Power}=4kTB = \frac{\langle V_n \rangle^2}{R} = \langle i_n{}^2 \rangle R$$

$$i_{rms} = \sqrt{\frac{4kTB}{R}} \qquad V_{rms} = \sqrt{4kTRB}$$




***Shot noise (Gaussian and white)***

$$\text{rms noise current} = \langle i_n{}^2 \rangle^{1/2} = (2qIB)^{1/2}$$



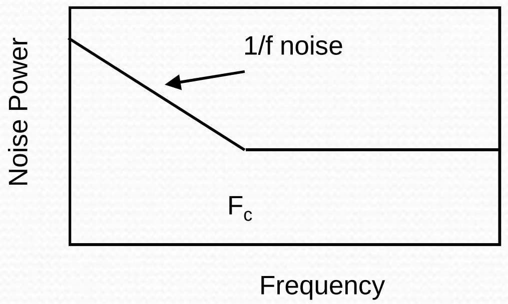

***"1/f" noise***

$$\text{spectral density}=\frac{K}{f} \quad \mathrm{V^2/Hz}$$

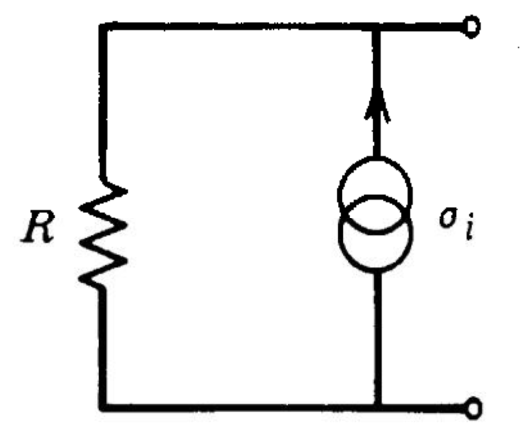
for FETs

$$K=\frac{4kT\Gamma}{g_m} f_c$$

where $f_c$ is the FET corner frequency and $\Gamma$ is the channel noise factor



# Johnson (thermal) Noise




Noise in a resistor can be modeled as due to a noiseless resistor in parallel with a noise current source

The variance of the noise current source is given by:

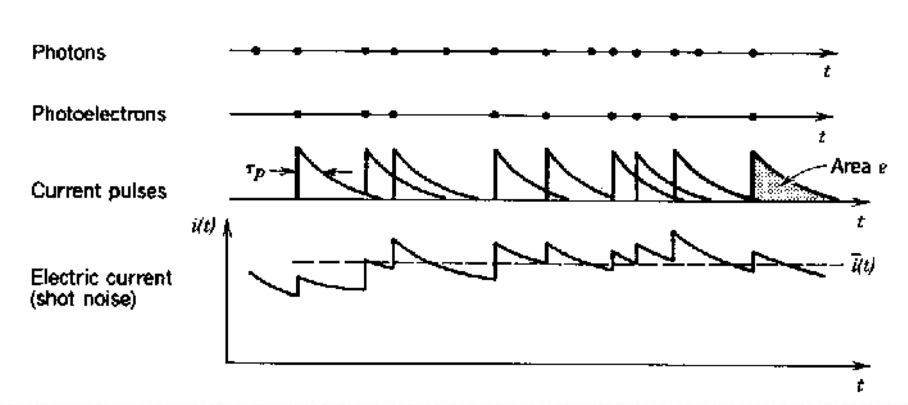
$$\sigma_i^2 = \left\langle i^2 \right\rangle \approx \frac{4k_B TB}{R}$$

Where $k_B$ is Boltzman's constant

T is the Temperature in Kelvins

B is the bandwidth in Hz (not bits/sec)

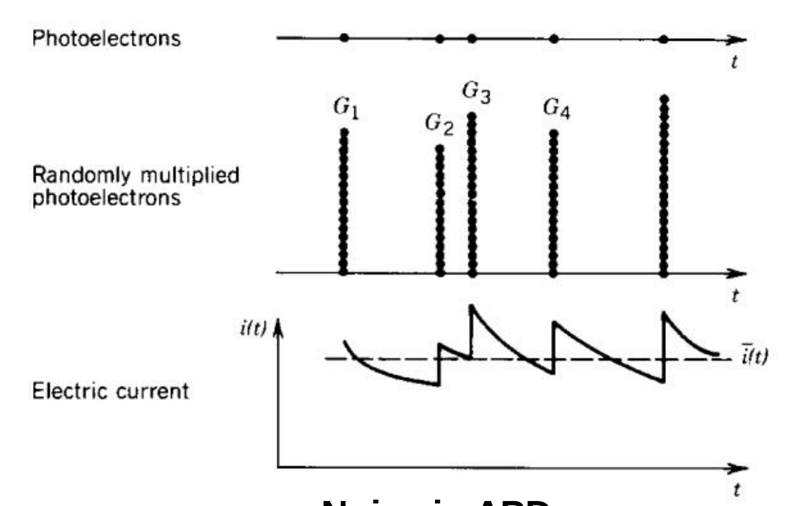
# Photodetection noise




**Noise in photodetector**

The electric current in a photodetector circuit is composed of a superposition of the electrical pulses associated with each photoelectron

The variation of this current is called shot noise




**Noise in APD**

If the photoelectrons are multiplied by a gain mechanism then variations in the gain mechanism give rise to an additional variation in the current pulses. This variation provides an additional source of noise, gain noise

# Circuit Noise

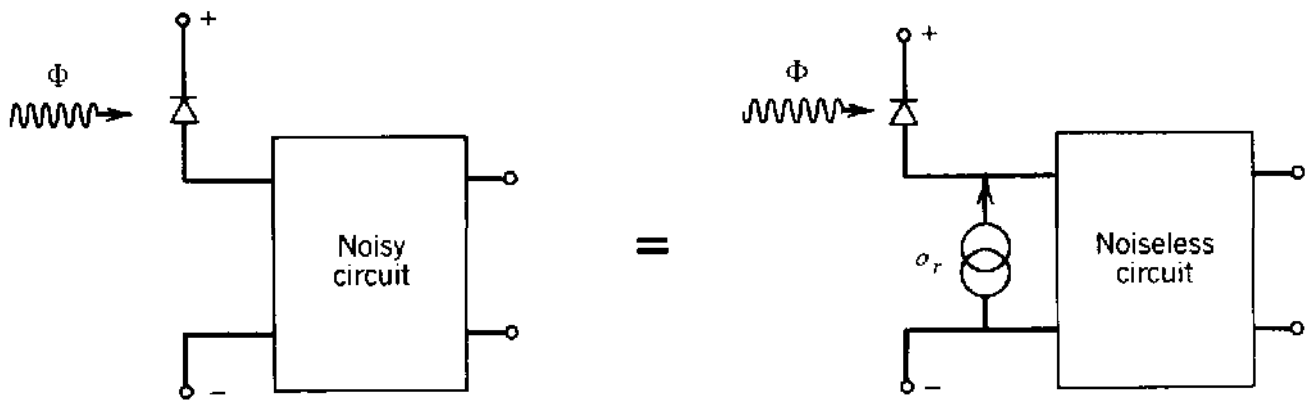
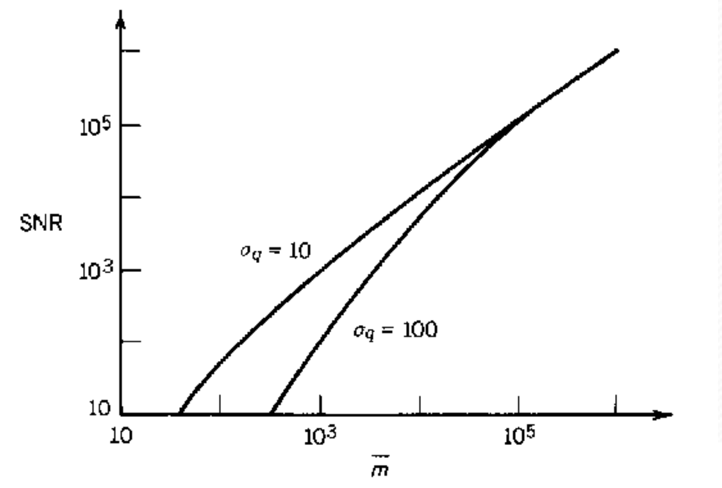
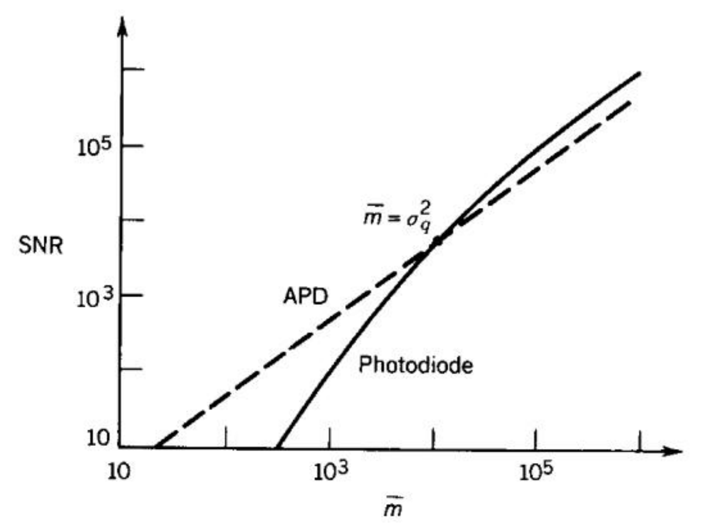



**Figure 17.5-6** Noise in the receiver circuit can be replaced with a single random current source with rms value $\sigma_r$.

# Signal to Noise Ratio



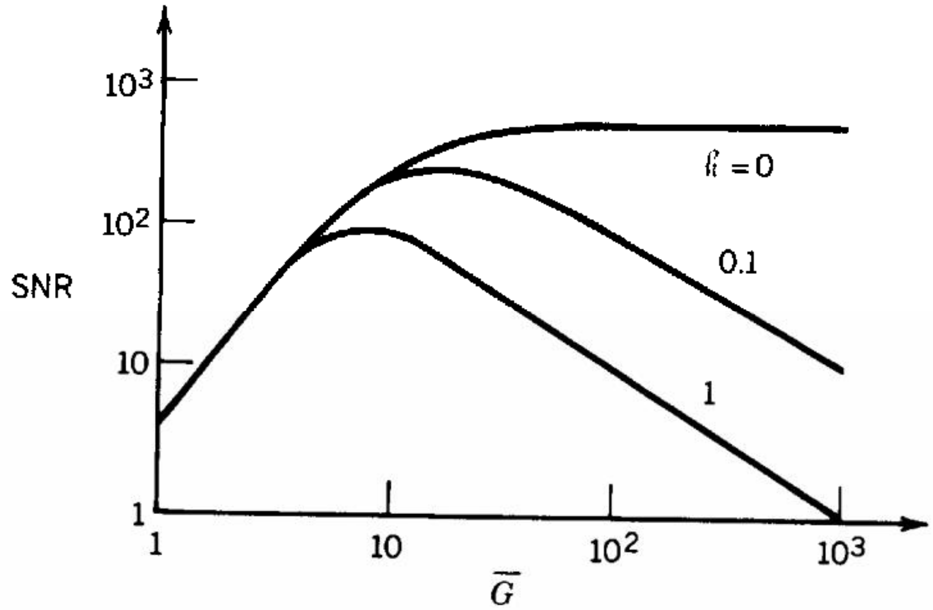

Signal to noise Ratio (SNR) as a function of the average number of photo electrons per receiver resolution time for a photo diode receiver at two different values of the circuit noise




Signal to noise Ratio (SNR) as a function of the average number of photoelectrons per receiver resolution time for a photo diode receiver and an APD receiver with mean gain G=100 and an excess noise factor F=2

At low photon fluxes the APD receiver has a better SNR. At high fluxes the photodiode receiver has lower noise

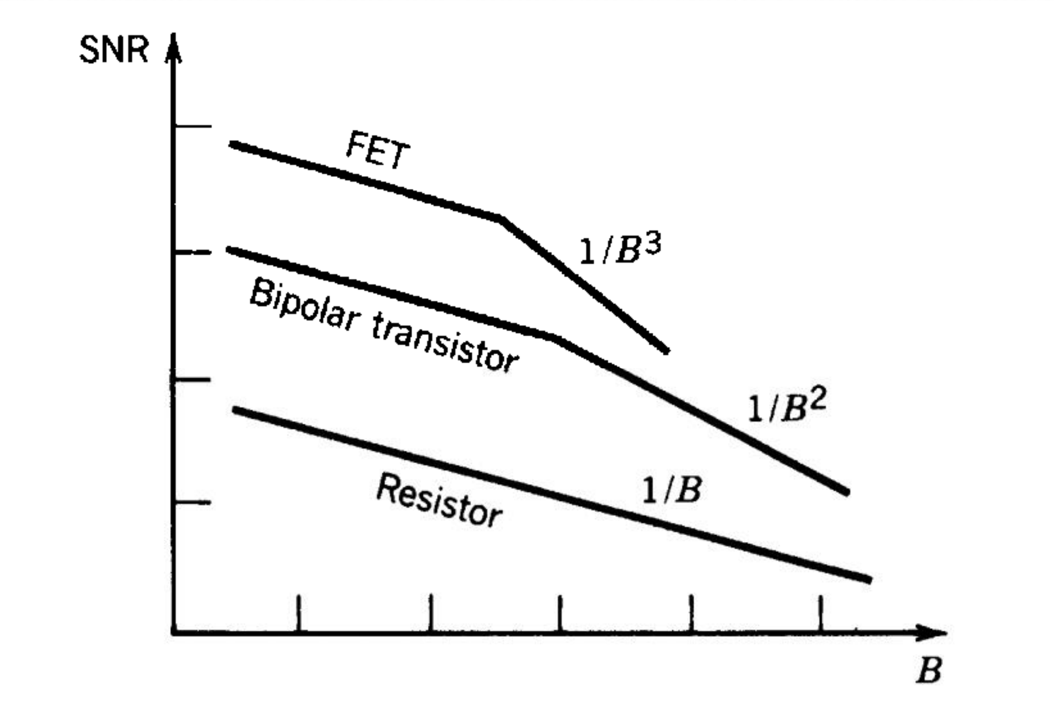
# Dependence of SNR on APD Gain




Curves are parameterized by k, the ionization ratio between holes and electrons

Plotted for an average detected photon flux of 1000 and constant circuit noise

# Receiver SNR vs Bandwidth




Double logarithmic plot showing the receiver bandwidth dependence of the SNR for a number of different amplifier types