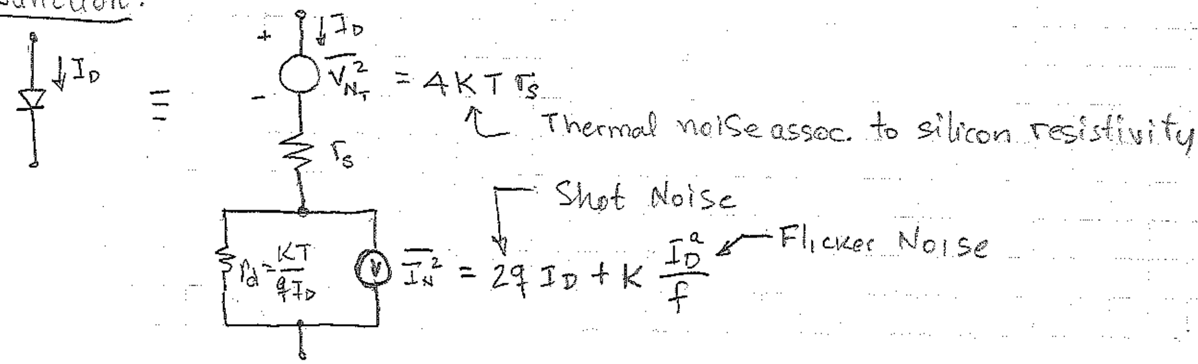
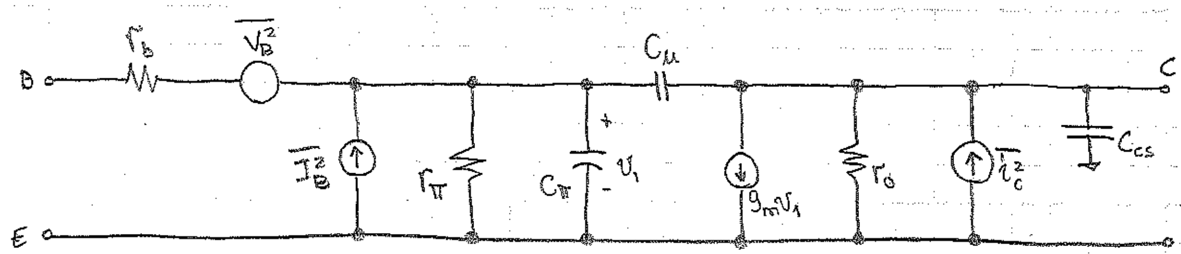
Noise Models for IC components

- **PN Junction:**



- **Bipolar Transistors:**
  - The collector current I_C is made-up of a series of random current pulses. Thus I_C exhibits shot noise
  - I_B also exhibits shot noise due to the random nature of recombination and carrier injection.



$\overline{I_B^2}$ = Combined effect of shot noise, flicker Noise, and burst noise

$$\overline{I_B^2} = \underbrace{2qI_B}_{\text{Shot}} + \underbrace{K_1\frac{I_B^a}{f}}_{\text{Flicker}} + \underbrace{K_2\frac{I_B}{1+(f/f_c)^2}}_{\text{Burst}}$$

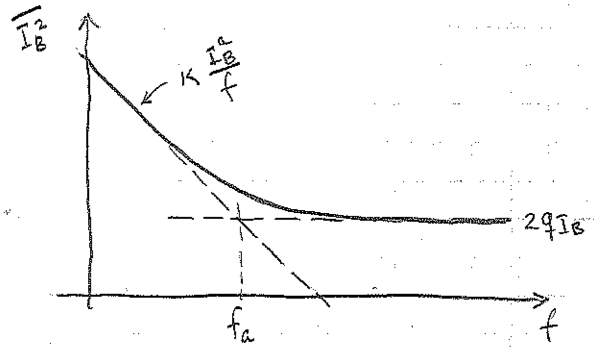
$\overline{V_B^2}$ = Thermal noise in r_b

$$V_B^2 = 4KTr_b$$

$\overline{I_c^2}$ = Shot noise in I_c $\quad \overline{I_c^2} = 2qI_c$

- r_o and r_π are model resistances (not real). Therefore do not generate thermal noise

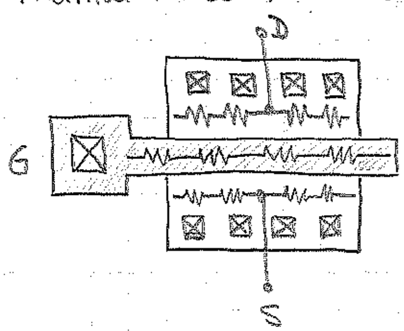
- All noise sources in BJT analysis are considered independent.
- The interception between flicker and shot noise PSDs happens at f_a (corner frequency)



- Circuit model valid for NPN & PNP BJTs
- f_a can be 100 Hz → 10 MHz

N-12

- MOS Transistors
  - Major sources of noise in MOSFETs are thermal and flicker noise.
  - In a lesser degree, the gate leakage current produces shot noise
  - Thermal Noise is associated to the resistivity of the terminals (Gate, Source, Drain)



MOS TERMINAL RESISTANCE

- Channel resistance is the major source of thermal noise with PSD

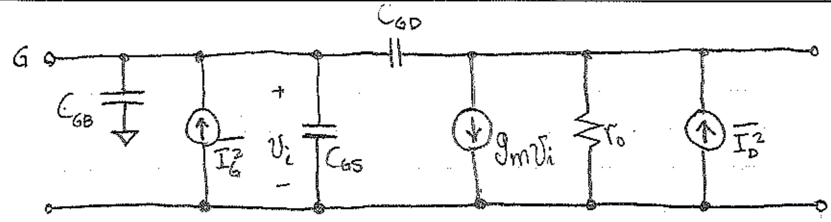
$$\overline{I_N^2} = 4KT\gamma g_m ,$$

where $\gamma = 2/3$ for long channel devices and higher for small channel MOSFETS

- Resistances R_G, R_S and R_D are typically negligible. Gate resistance is large in wide transistors.

- Flicker Noise is associated to the gate-oxide interface.

$$\overline{I_{nf}^2} = \frac{K}{C_{ox}WL}\frac{1}{f}g_m^2$$



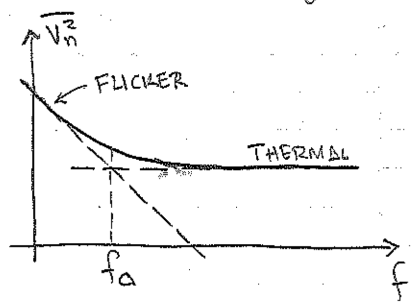
$\overline{I_G^2} = 2q I_G$ } SHOT NOISE

$$\overline{I_D^2} = \underbrace{4KT\left(\tfrac{2}{3} g_m\right)}_{\text{THERMAL NOISE}} + \underbrace{\frac{K}{C_{ox}WL}\frac{1}{f} g_m^2}_{\text{FLICKER NOISE}}$$

- All NOISE sources in FETs can be considered independent

- **Passive Components**: Resistors, Inductors, and capacitors.
  - When the element series resistance is considered, introduce thermal noise

The comparative flicker and thermal noise effects in MOSFETs can be viewed by superimposing their PSDs



- Allows to visualize in which portion of the spectrum each is dominant
- At f_a (corner frequency)

$$\overline{I_{n_f}^2} = \overline{I_{n_t}^2}$$

So $4KT\left(\frac{2}{3} g_m\right) = \frac{K_x}{C_{ox}WL} \cdot \frac{1}{f_c} \cdot g_m^2$

So $f_c = \frac{K}{C_{ox}WL} g_m \frac{3}{8K_xT}$

Example:

For an NMOS current source, calculate the total thermal & 1/f noise in I_D in a band from 1KHz to 1MHz

$$\overline{I_{N_{Th}}^2} = 4KT\left(\tfrac{2}{3} g_m\right)\Delta f \cong 4KT\left(\tfrac{2}{3} g_m\right) \times 10^6 \ A^2$$

$$\overline{I_{n_{1/f}}^2} = \frac{K}{C_{ox}WL} \cdot \frac{1}{f} g_m^2 \quad \leftarrow \text{single frequency}$$

$$\overline{I_{n_{1/f\,total}}^2} = \int_{f_1}^{f_2} \overline{I_{n_{1/f}}^2}\, df$$

$$= \frac{K g_m^2}{C_{ox}WL} \int_{1K}^{1M} \frac{df}{f} = \frac{K g_m^2}{C_{ox}WL} \ln\left[\frac{10^6}{10^3}\right] = \frac{6.91\, K g_m^2}{C_{ox}WL}$$