18-1-12

Lec 8

Noise in MOSFETs

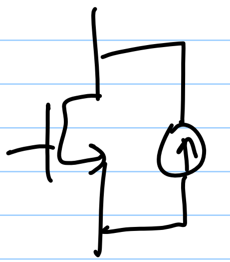
1) Thermal noise

a) Triode region:

$$I_D = k'\left(\frac{W}{L}\right)\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$$g_d = \frac{\partial I_D}{\partial V_{DS}} = k'\left(\frac{W}{L}\right)\left[V_{GS}-V_T-V_{DS}\right]$$

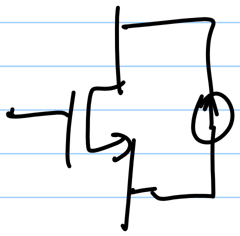
$$g_{d0} = k'\left(\frac{W}{L}\right)(V_{GS}-V_T)$$



$4kT\, g_{d0}\, \Delta f$

$$\overline{i_{nd}^2} = 4kT\,\gamma\, g_{d0}\,\Delta f \qquad [\gamma = 1 \text{ in triode}]$$

b) long-channel device in sat.



$$\overline{i_{nd}^2} = 4kT\,\gamma\, g_{d0}\,\Delta f$$

$\gamma = \frac{2}{3}$ in sat. region for L.C. device

$$I_D = \frac{k'}{2}\left(\frac{W}{L}\right)(V_{GS}-V_T)^2$$

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = k'\left(\frac{W}{L}\right)(V_{GS}-V_T) = g_{d0}$$

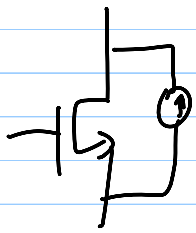
$$\boxed{\overline{i_{nd}^2} = 4kT\cdot\frac{2}{3}g_m\,\Delta f}$$ common form

c) S.C. devices

$$\overline{i_{nd}^2} = 4kT\,\gamma\, g_{d0}\,\Delta f$$

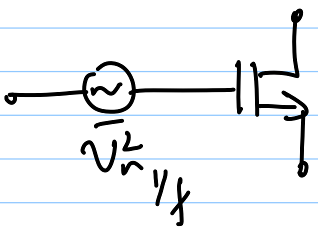
$$\gamma > 2/3\ ;\quad g_{d0} > g_m \quad \left(g_{d0} = \frac{g_m}{\alpha}\right)$$

2) Flicker noise (1/f noise)



$$\overline{i^2_{n,1/f}} = \frac{K}{f}\cdot\frac{g_m^2}{WL\,C_{ox}^2}\cdot\Delta f$$

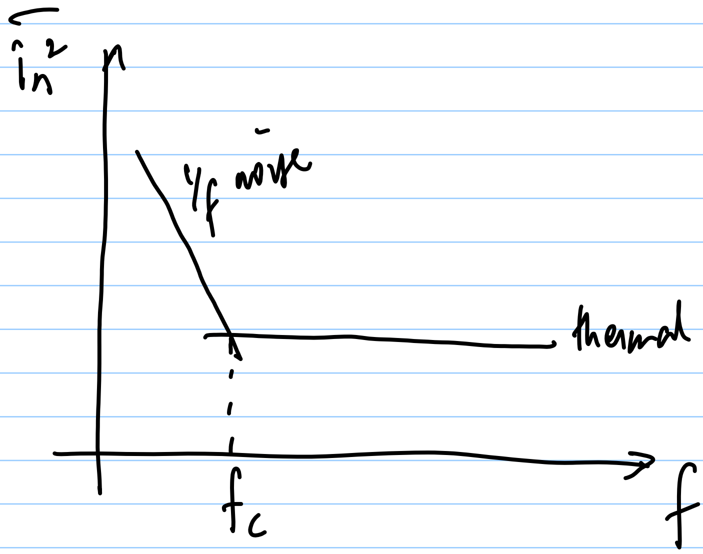
$$= \frac{K'}{f}\cdot\omega_T^2\cdot W\cdot L\cdot\Delta f$$



$$\overline{v^2_{n,1/f}} = \frac{K}{f}\cdot\frac{1}{WL\,C_{ox}^2}\,\Delta f$$

$K_n \sim 50\cdot K_p$; $K_p \sim 10^{-28}$ C^2/m^2 [PMOS may have lower 1/f noise]

* Use larger area for low flicker noise
* flicker noise important @ low freq.

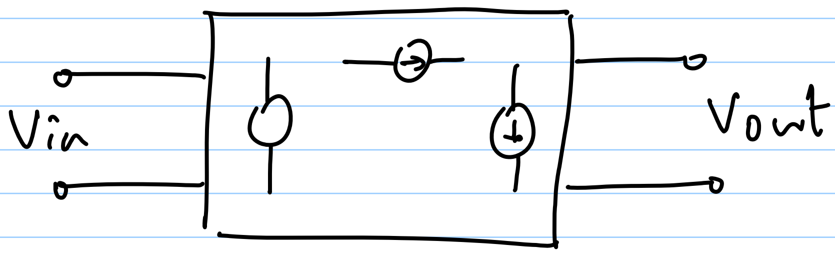


$$f_c = \frac{K_{1/f}}{4KT\gamma} \cdot f_T$$

II shot noise in Diodes

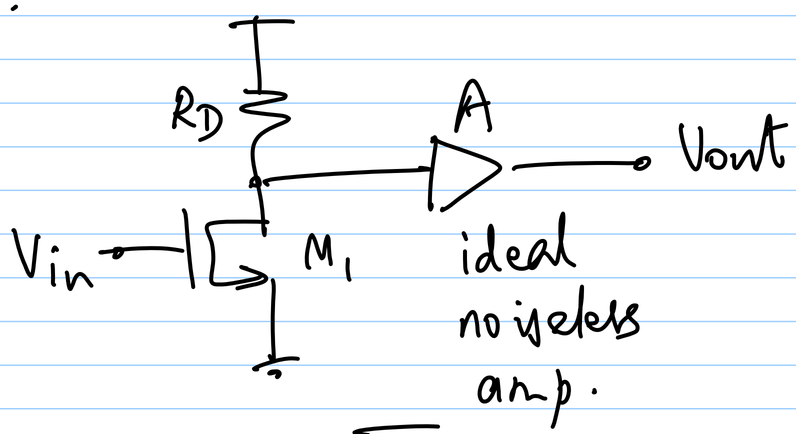
$$\overline{i_n^2} = 2q I_{DC} \Delta f \quad (\text{use in BJTs})$$

Noise representation in ckts



* Set $V_{in} = 0$ & measure $\overline{V_{n,out}^2}$
→ depends on gain of system

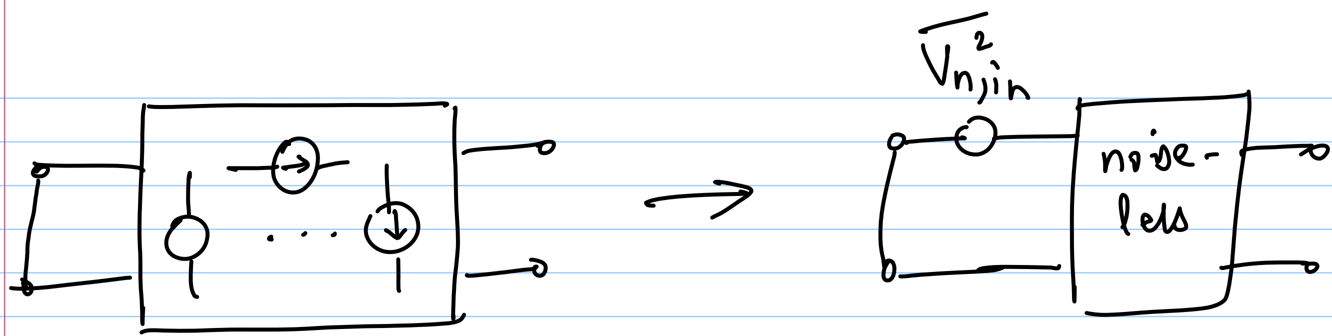
e.g.



* as $A \uparrow$, $\overline{V^2_{n,out}} \uparrow$, but signal power also $\uparrow$

$\Rightarrow$ define noise performance as "input-referred noise"

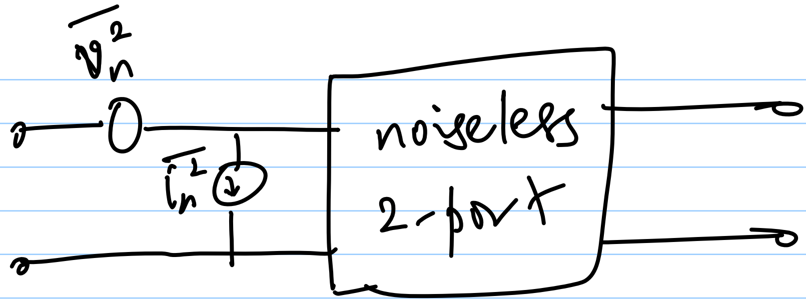
$\Rightarrow$ fictitious quantity (cannot be measured)



$$\overline{V^2_{n,out}} = A_V^2 \cdot \overline{V^2_{n,in}}$$

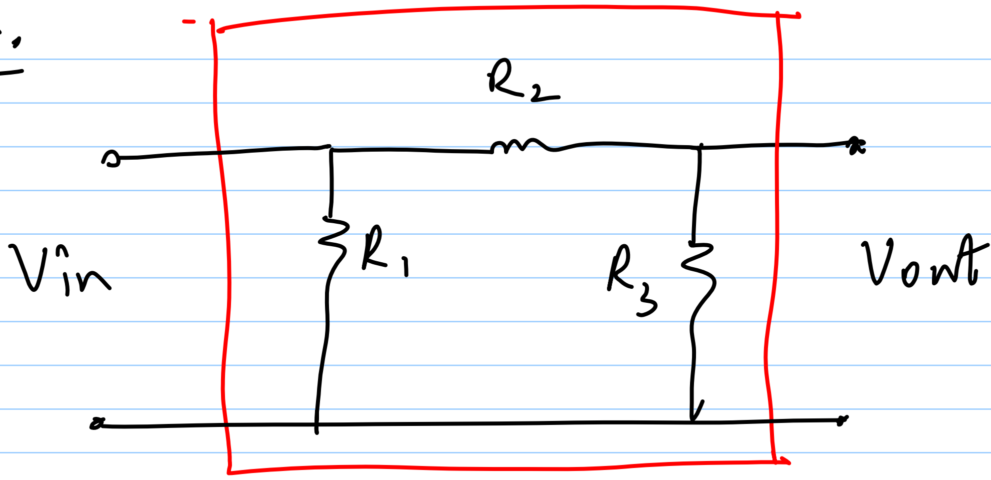
as source imp. $\to \infty$ $\Rightarrow$ no noise current drawn from $\overline{V_{n,in}}$

$\Rightarrow$ seems as if ckt is not noisy

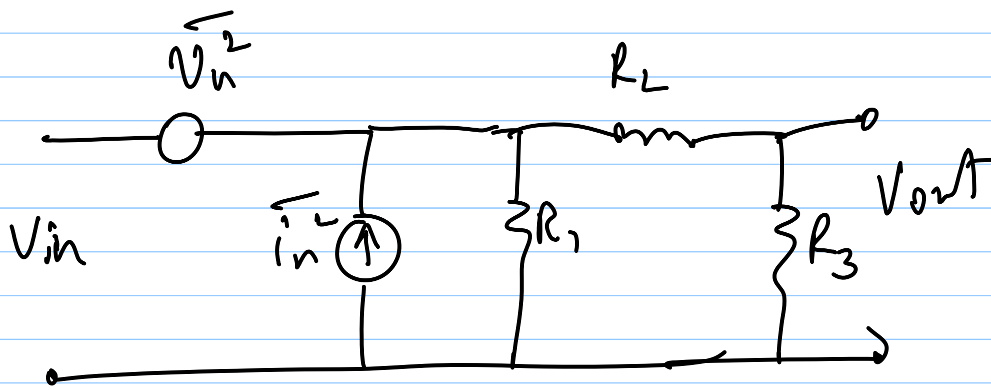


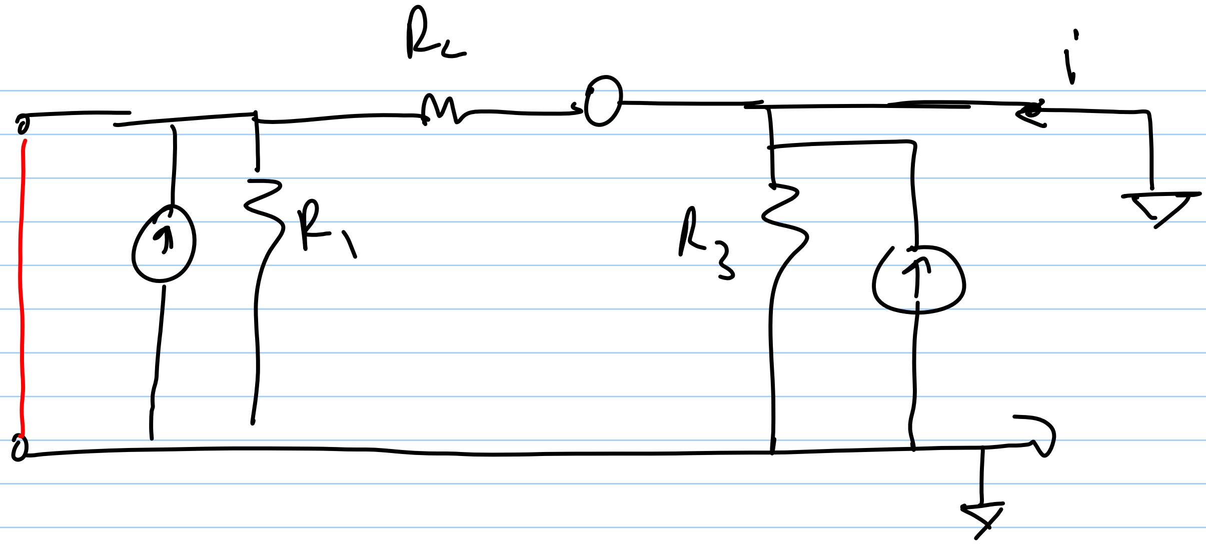
* In general, $\overline{v_n}$ & $\overline{i_n}$ may be <u>correlated</u> (same noise sources in the ckt)

e.g.



eq. to

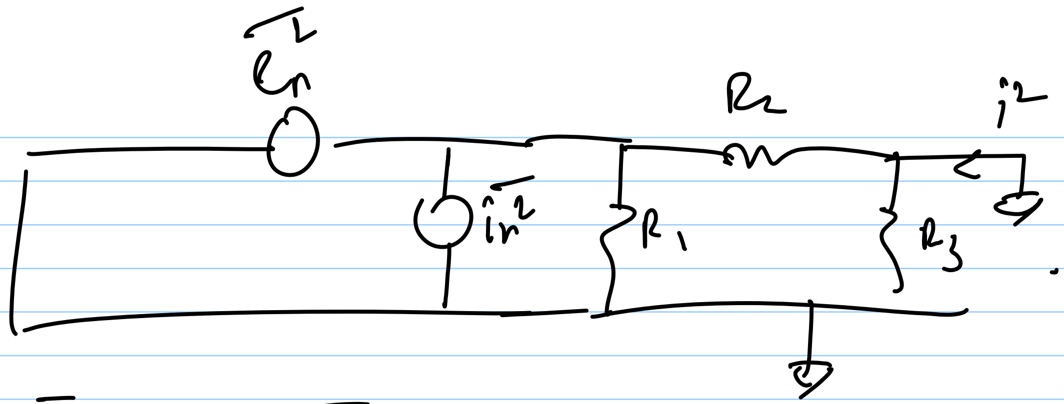




1) short i/p :

$$\overline{i^2} = \frac{4kT}{R_3}\Delta f + \frac{4kT R_2 \Delta f}{R_2^2}$$

$$= 4kT\Delta f \left(\frac{1}{R_2} + \frac{1}{R_3} \right)$$



$$\overline{i^2} = \frac{\overline{e_n^2}}{R_2^2}$$

equate :

$$\overline{e_n^2} = 4kT\Delta f \, R_2^2 \left(\frac{1}{R_2} + \frac{1}{R_3} \right)$$

2) o-c input:

$$\overline{i^2} = \frac{4kT\Delta f}{R_1}\left(\frac{R_1}{R_1+R_2}\right)^2$$

$$+ \frac{4kT\Delta f}{R_3} + \frac{4kTR_2\Delta f}{(R_1+R_2)^2}$$

2-port

$$\overline{i^2} = \overline{i_n^2}\left(\frac{R_1}{R_1+R_2}\right)^2$$

$\Rightarrow$ equate;

$$\overline{i_n^2} = \overline{i^2}\cdot\left(\frac{R_1+R_2}{R_1}\right)^2$$

$$= 4kT\Delta f\left\{\frac{1}{R_1} + \frac{(R_1+R_2)^2}{R_2^2 R_3} + \frac{R_2}{R_1^2}\right\}$$