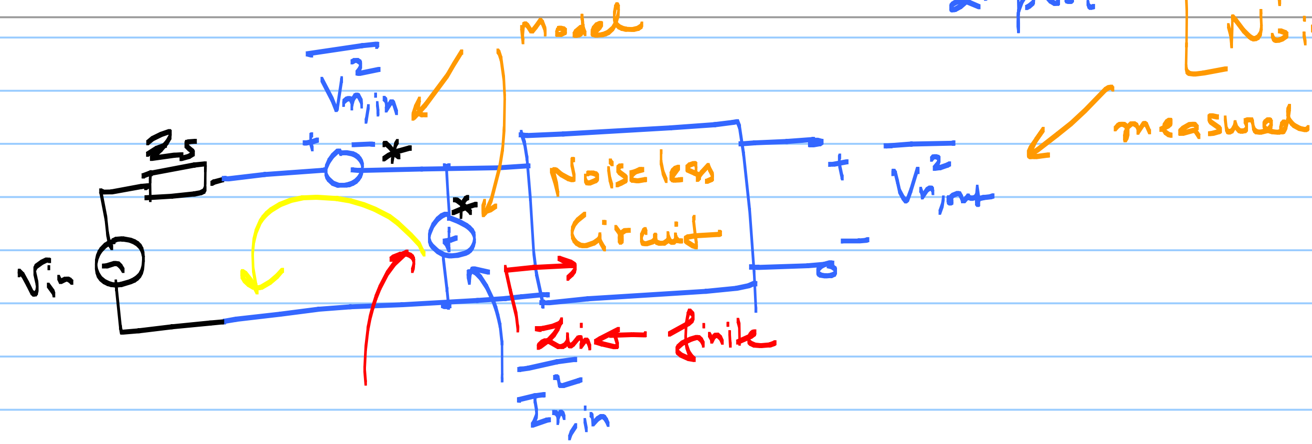
# ECE 614 – Lecture 11

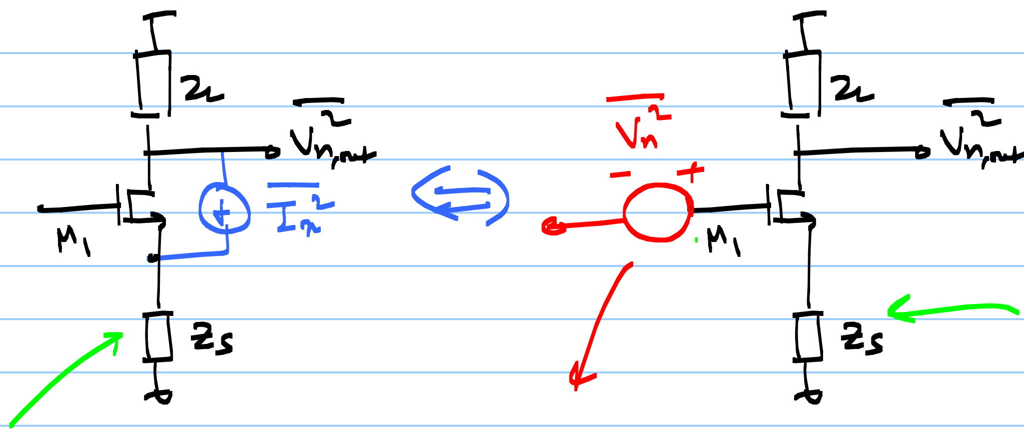
Note Title 10/2/2012

2-port

low-frequency
input-referred
Noise



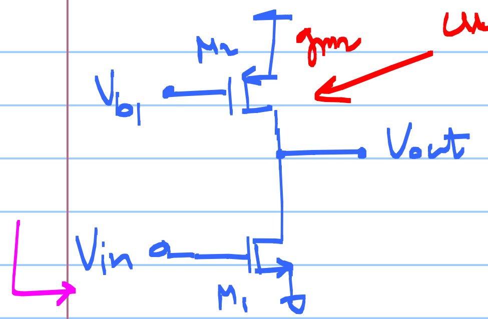
Lemma

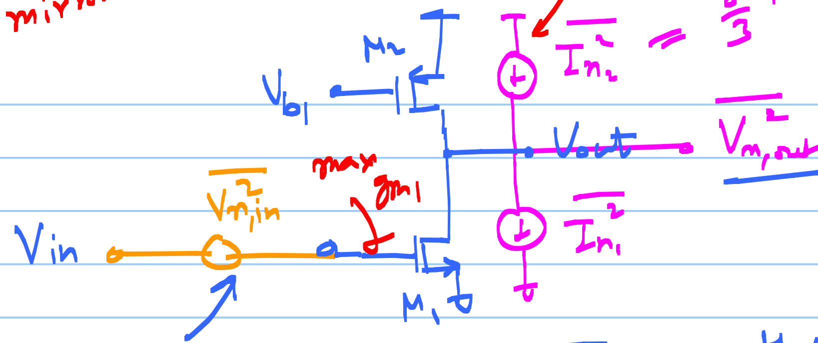



$$\overline{V_n^2} = \frac{\overline{I_n^2}}{g_m^2}$$

* can do this transposition of the noise source irrespective $Z_S$.

Ex. CS Amplifier




minimize $g_{m2}$

$$\overline{I^2_{n_2}} = \frac{8}{3}kT\,\underline{\underline{g_{m2}}}$$

$$\overline{V^2_{n,out}} = \left(\overline{I^2_{n_1}} + \overline{I^2_{n_2}}\right)\cdot(r_{o1}\|r_{o2})^2$$ ← Total output Thermal noise voltage

$$= 4kT\left(\frac{2}{3}g_{m1} + \frac{2}{3}g_{m2}\right)\cdot(r_{o1}\|r_{o2})^2$$

$$\overline{V^2_{n,in}} = \frac{\overline{V^2_{n,out}}}{A_v^2} = \frac{4kT\left(\frac{2}{3}g_{m1} + \frac{2}{3}g_{m2}\right)\cdot\cancel{(r_{o1}\|r_{o2})^2}}{g_{m1}^2\cdot\cancel{(r_{o1}\|r_{o2})^2}}$$

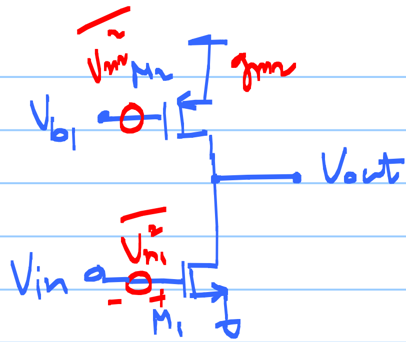
$$\boxed{\overline{V^2_{n,in}} = 4kT\left(\underline{\frac{2}{3g_{m1}}} + \frac{2}{3}\frac{g_{m2}}{g_{m1}^2}\right)}$$

$\frac{V^2}{Hz}$

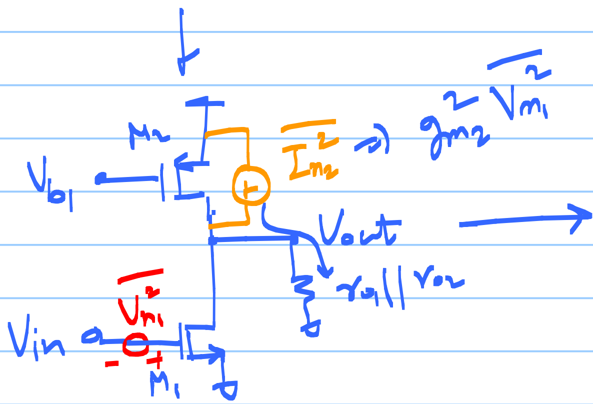
To minimize $\overline{V^2_{n,in}}$ $\Rightarrow$ $g_{m1} \uparrow$

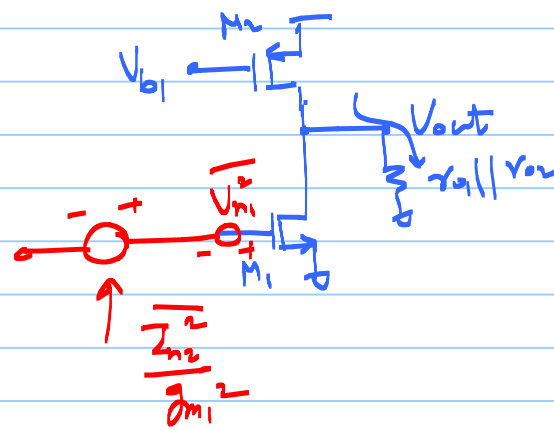
$\Rightarrow$ $g_{m2} \downarrow$

$$\overline{V^2_{n,1/f}} = \frac{K_N}{C_{ox}(WL)_1} \cdot \frac{1}{f}$$




* Input referred 1/f noise?



$$\overline{V_{n,in}^2} = \underbrace{4kT\cdot\frac{2}{3}\left(\frac{1}{g_{m1}} + \frac{g_{m2}}{g_{m1}^2}\right)}_{\text{Thermal Noise}} + \underbrace{\frac{K_N}{C_{ox}(WL)_1}\cdot\frac{1}{f} + \frac{K_P}{C_{ox}(WL)_2}\cdot\frac{1}{f}\cdot\frac{g_{m2}^2}{g_{m1}^2}}_{1/f \text{ noise}}$$

$$g_m = \begin{cases} \beta V_{ov}, & I_D = \text{cnst} \\ \dfrac{2I_D}{V_{ov}}, & \beta = \text{cnst} \\ \sqrt{2\beta I_D}, & V_{ov} = \text{cnst} \end{cases}$$

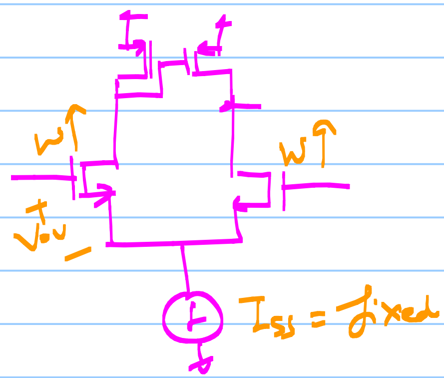
$g_{m1}\uparrow$, $g_{m2}\downarrow$

$\Rightarrow$ Reduce $1/f$ noise $\Rightarrow$ $(WL)\uparrow$ with $\left(\frac{W}{L}\right)$ same

increase device Area

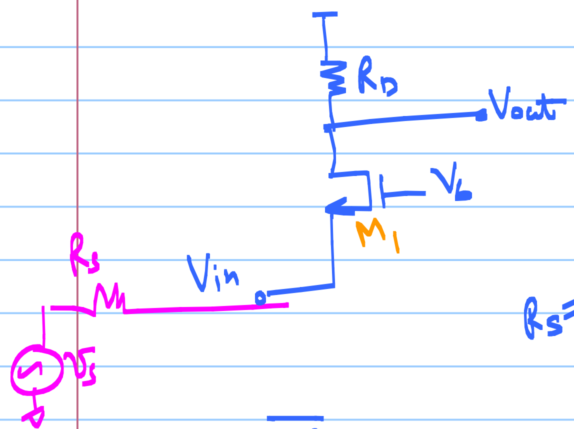
BW $\downarrow$

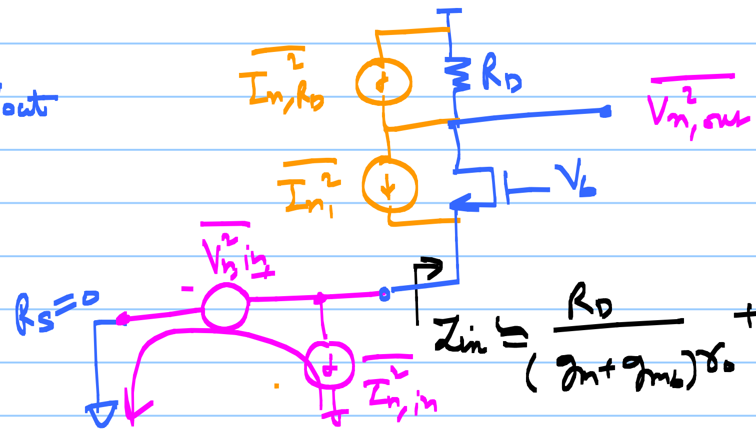
$g_m\uparrow$




* Use PMOS input if process has lower $1/f$ noise for same W & L.

# Common-Gate:

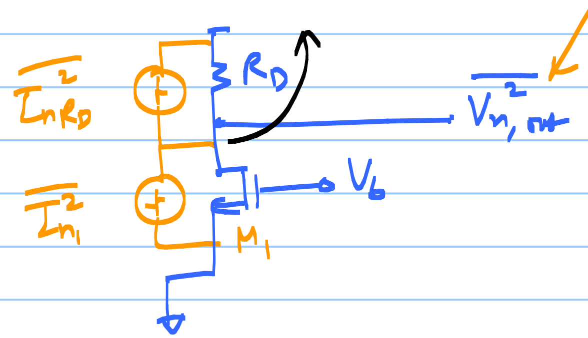


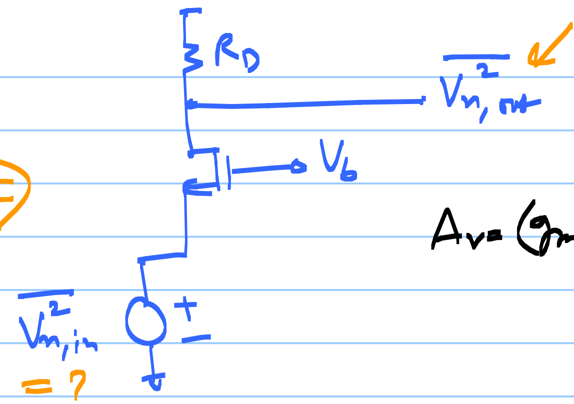

$$Z_{in} \simeq \frac{R_D}{(g_m + g_{mb}) r_o} + \frac{1}{g_m} \simeq \frac{1}{g_m}$$

Find $\overline{V^2_{n,in}}$: $\Rightarrow$ Short the input

① Find $\overline{V_{n,in}^2}$ : ⇒ Short the input




⇒

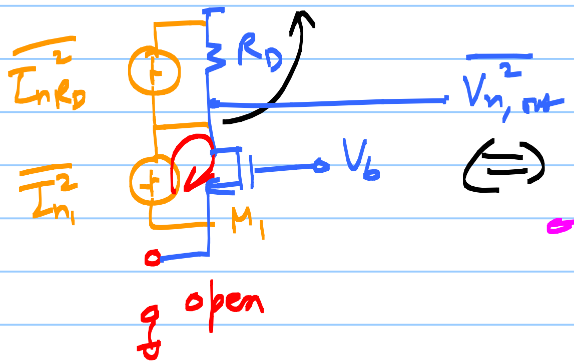



$$A_v = (g_m + g_{mb}) R_D$$

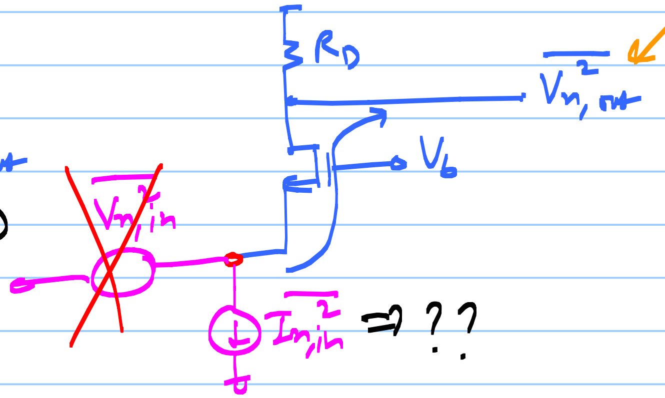
$$\overline{V_{n,out}^2} = \left(\frac{8}{3} kT g_m + \frac{4kT}{R_D}\right) R_D^2 \Leftrightarrow \overline{V_{n,out}^2} = \overline{V_{n,in}^2} \cdot (g_m + g_{mb})^2 R_D^2$$

$$\boxed{\overline{V_{n,in}^2} = \frac{4kT\left(\frac{2}{3} g_m + 1/R_D\right)}{(g_m + g_{mb})^2}}$$

② find $\overline{I^2_{n,in}}$ : open the input ($R_S \to \infty$)



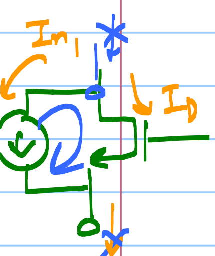

$\Longleftrightarrow$




$\lambda_1 \Rightarrow 0$

$r_{o1} \Rightarrow \infty$

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




$I_D + I_{n1} = 0$

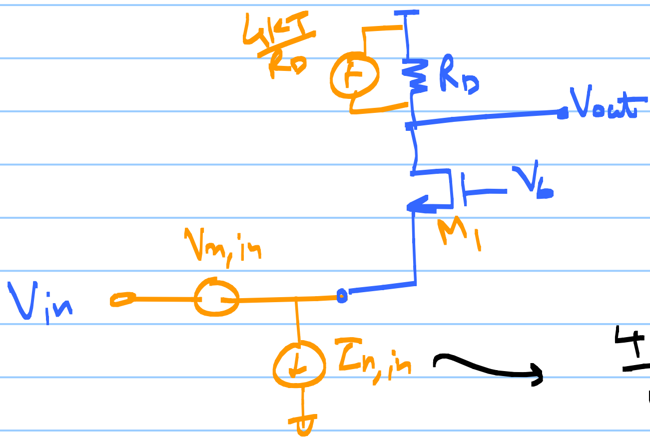
$I_{n1}$ doesn't flow through $R_D$

$\Rightarrow$ has no effect on the output

$$\overline{V^2_{n,out}} = 4kT R_D$$

=

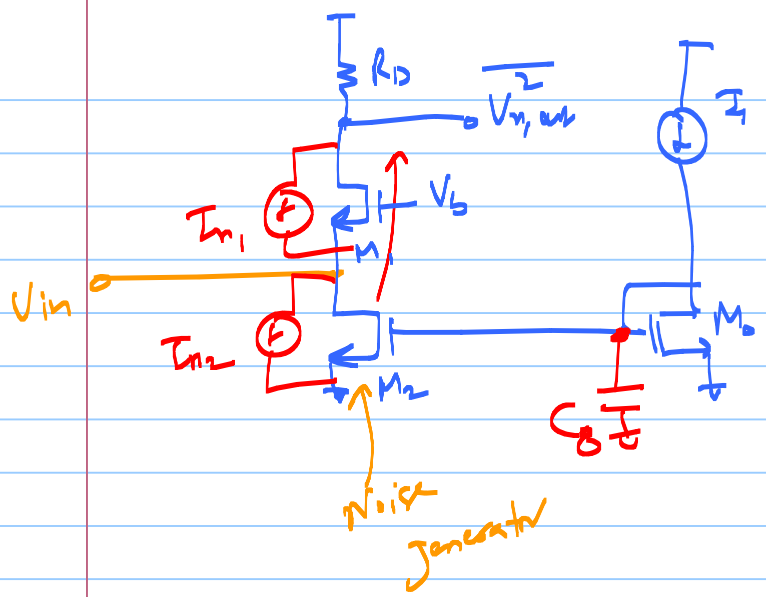
$$\boxed{\overline{I^2_{n,in}} = \frac{4kT}{R_D}}$$




$$\frac{4kT}{R_D}$$

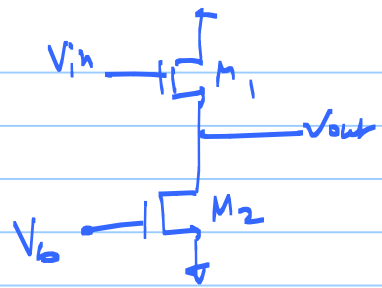
$R_D$'s noise current is referred to the input

$\Rightarrow$ not used for low-noise Amplification



$R_D$
$\overline{V^2_{n,out}}$
$V_b$
$I_1$
$I_{n,1}$
$M_1$
$V_{in}$
$I_{n_2}$
$M_2$
$M_o$
$C_B$
Noise generator

SF:




$$\overline{V_{n,in}^2} = \overline{V_{n_1}^2} + \frac{\overline{V_{n,out}^2}\Big|_{M_2}}{A_v^2}$$

$A_v < 1$

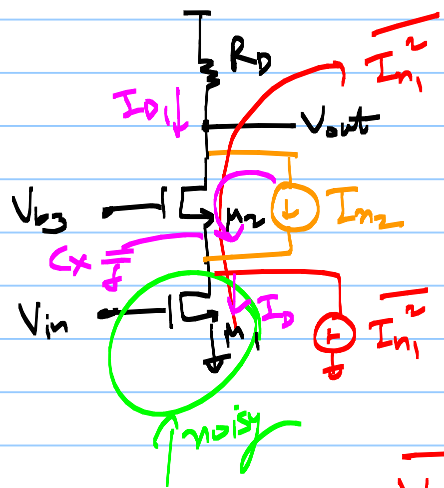
$$= 4kT \cdot \frac{2}{3}\left(\frac{1}{g_{m_1}} + \frac{g_{m_2}}{g_{m_1}^2}\right)$$

$\Rightarrow \quad g_{m_1} \uparrow, \; g_{m_2} \downarrow$

$A_v < 1 \Rightarrow$

## Cascode

$\lambda_2 = 0 \Rightarrow r_{o_2} \to \infty$



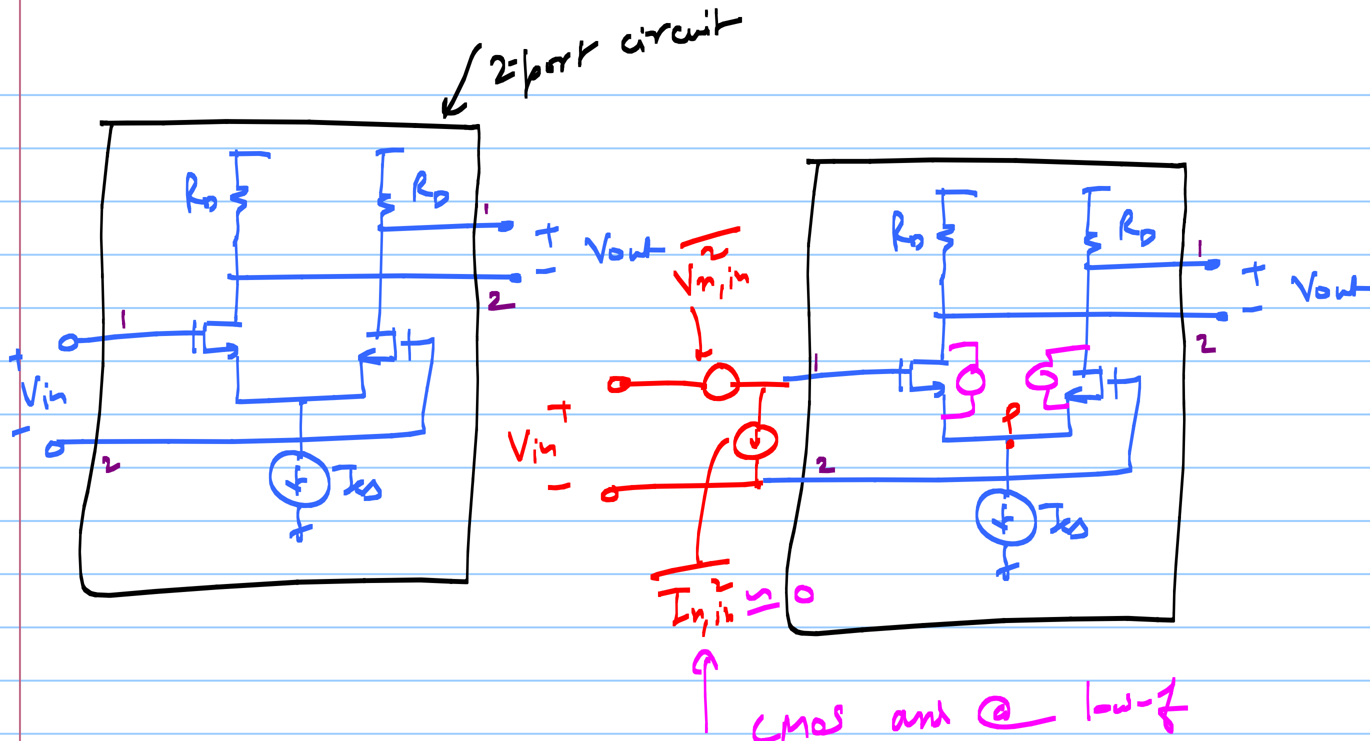

$I_{D_2} + I_{n_2} = 0$

@ low-frequencies with $r_{o_2} \to \infty$

$I_{n_2}$ doesn't affect $\overline{V_{n,out}^2}$

$$\overline{V_{n,out}^2} \simeq \overline{I_{n_1}^2} \cdot (g_m r_o^2 \| R_D)^2$$

# Diff Amp


2-port circuit
$R_D$
$R_D$
$V_{out}$
$V_{in}$
$I_{SS}$
$\overline{V_{n,in}^2}$
$\overline{I_{n,in}^2} \simeq 0$
CMOS and @ low-f