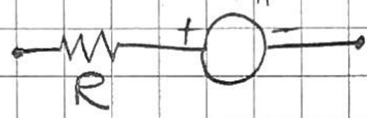
NOISE

Repeat Motivation: Why we are studying Noise?

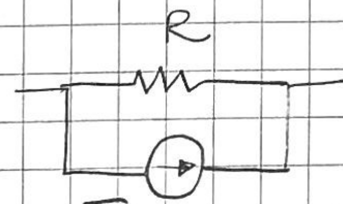
Recap

$\overline{v_n^2} = 4KTR$



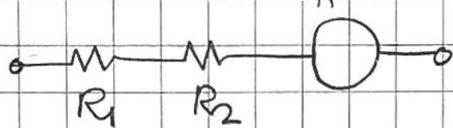
Noiseless

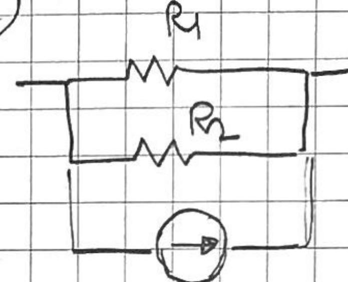
NOISELESS



$\overline{i_n^2} = \frac{4KT}{R}$

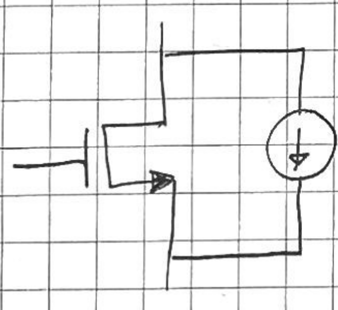
$\overline{v_n^2} = 4KT(R_1+R_2)$





$\overline{i_n^2} = \frac{4KT}{(R_1 \| R_2)}$

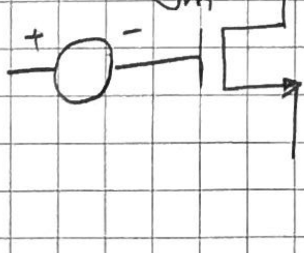
MOSFET Thermal Noise



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

γ: Excess Noise Coeff. $= 2/3$ long ch
$= 2-3$ sh. ch.

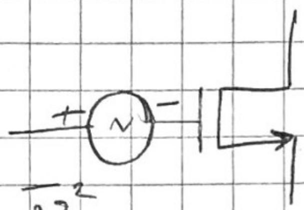
$\overline{v_n^2} = \frac{4KT\gamma}{g_m}$



r_o – Not physical resistor
– does not produce Noise

MOS FLICKER NOISE

MOS in saturation region.



process dependent $10^{-25}\ V^2F$

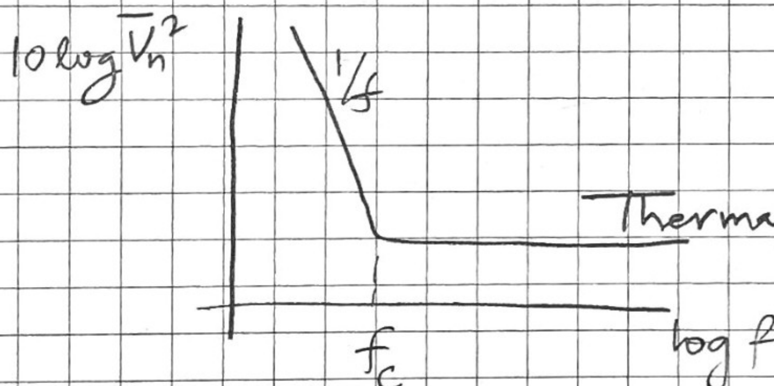
$$\overline{V^2_{n,1/f}} = \frac{K_{1/f}}{C_{ox}\,WL}\cdot\frac{1}{f}$$

Area ↑ – flicker ↓

Pmos – better 1/f

└ hole transport in burried channel

1/f corner

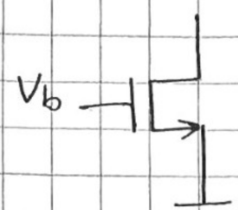


$$f_c = \frac{K_{1/f}}{4kT\gamma}\cdot\boxed{\frac{g_m}{WLC_{ox}}}$$

ω_T

2a

Example: Calculate Thermal & flicker noise for nmos current source. (BW − 1KHz − 10MHz)



Assume $g_m = 1\,mS$

$C_{gs} = 50\,fF$

$K_{1/f} = 10^{-25}\,V^2F$

(integrated) $\overline{i^2_{n,thermal}} = 4KT\gamma g_m (10^7 - 10^3)$

$$= 4 \times 1.38 \times 10^{-23} \times 300 \times \frac{2}{3} \times 1 \times 10^{-3} \times 10^7$$

$$\approx 1.1 \times 10^{-16}\,A^2$$

$$\overline{i_{n\,rms}} = 10.48\,nA_{rms.} \quad \text{(integrated)}$$

FLICKER NOISE

$$\overline{i^2_{n\,1/f}} = \frac{K_{1/f}}{C_{ox} W \cdot L} \cdot \frac{1}{f} \cdot g_m^2$$

$$= \frac{10^{-25}\,V^2F}{50\,fF} \times \frac{(1\,mS)^2}{f} = \frac{2 \times 10^{-18}}{f} \;(A^2/Hz)$$

Total 1/f noise (integrated)

$$= \int_{1K}^{10M} \frac{2 \times 10^{-18}}{f}\,df = 2 \times 10^{-18} \ln\left(\frac{10M}{1K}\right)$$

$$= 18.42 \times 10^{-18}\,A^2$$

$$\overline{i_{n\,1/f\,rms}} = 4.29\,nA_{rms}.$$

$$\overline{i^2_{n_{1/f}}} = K' \ln\left(\frac{f_H}{f_L}\right)$$

(total integrated noise)

$f_L \to 0$ → Extremely slow noise components.

0.01 Hz → 10 s ; 10^{-6} Hz → 1 day

@ Slow rate. - noise indistinguishable from thermal drift & aging.

* Voice Band (20 Hz - 20 KHz)

$1/f$ below 20 Hz - insignificant corruption of signal.

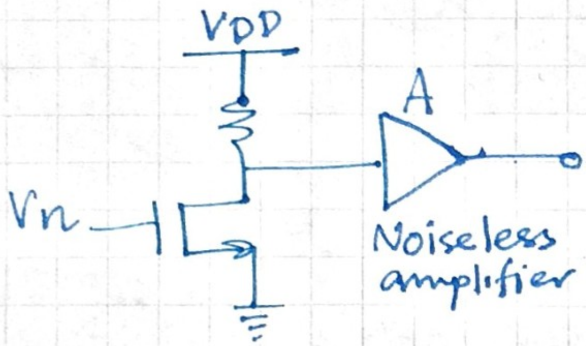
* Total integrated $1/f$ noise $= K' \ln\left(\frac{f_H}{f_L}\right)$

$K' \ln(10000) = 9.21\,K'$

$K' \ln(1 \times 10^6) = 13.8\,K'$

Taking f_L lower doesn't ~~inc~~ increase integrated noise as fast. - due to "ln" function.

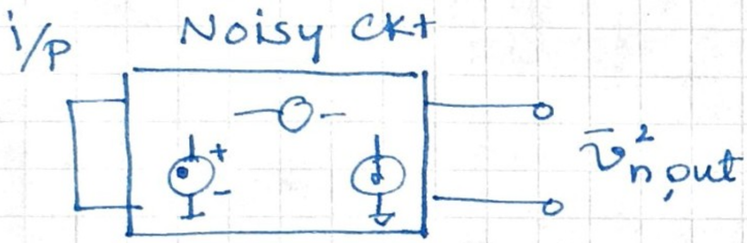
Concept of input referred noise.

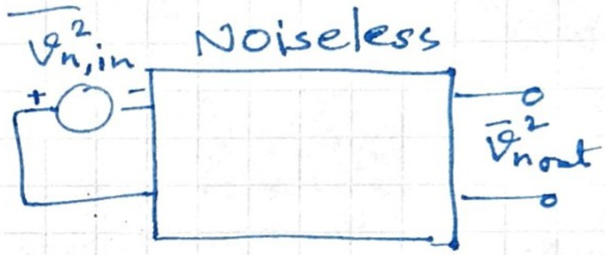


As A ↑ o/p noise ↑.

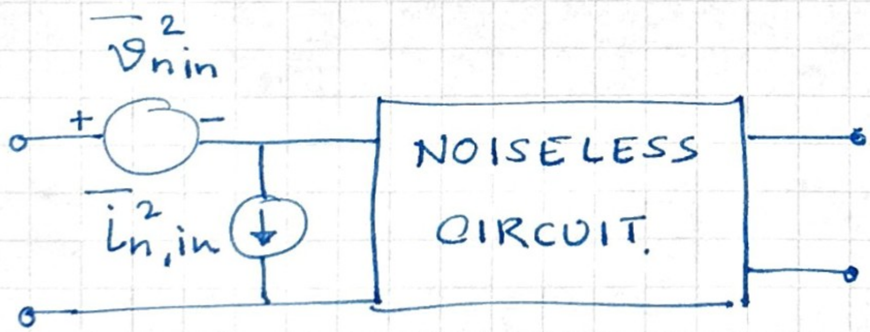
→ A ↑ Signal ↑.

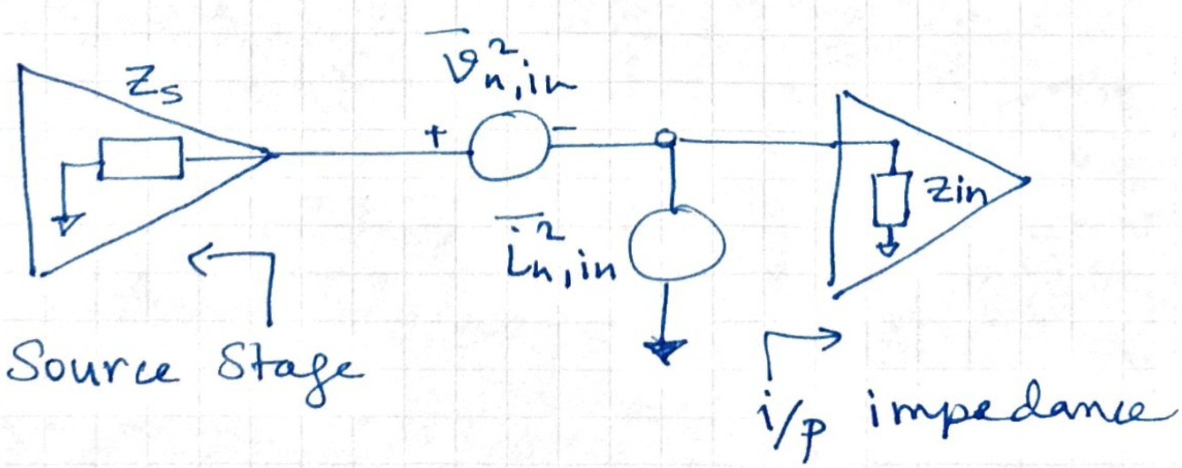
SNR – i/p referred noise.



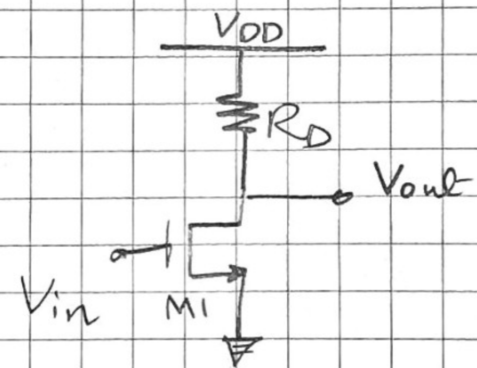


* To account for ~~source~~ input impedance of the circuit & source impedance.

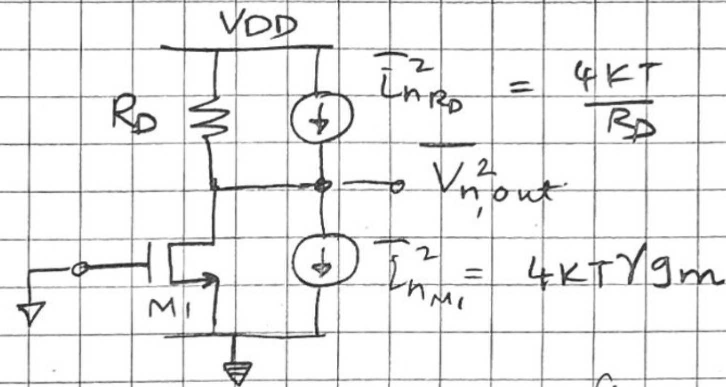




Noise Analysis Examples

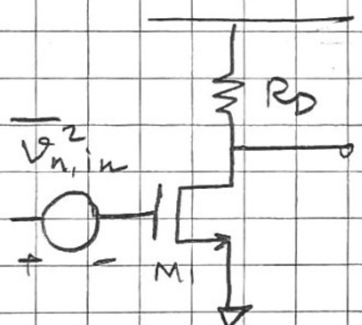


$\Rightarrow$



(ignoring flicker)

$$\overline{v^2_{nout}} = \left(\frac{4KT}{R_D} + 4KT\gamma g_m\right) R_D^2 \qquad (R_D \ll r_o)$$



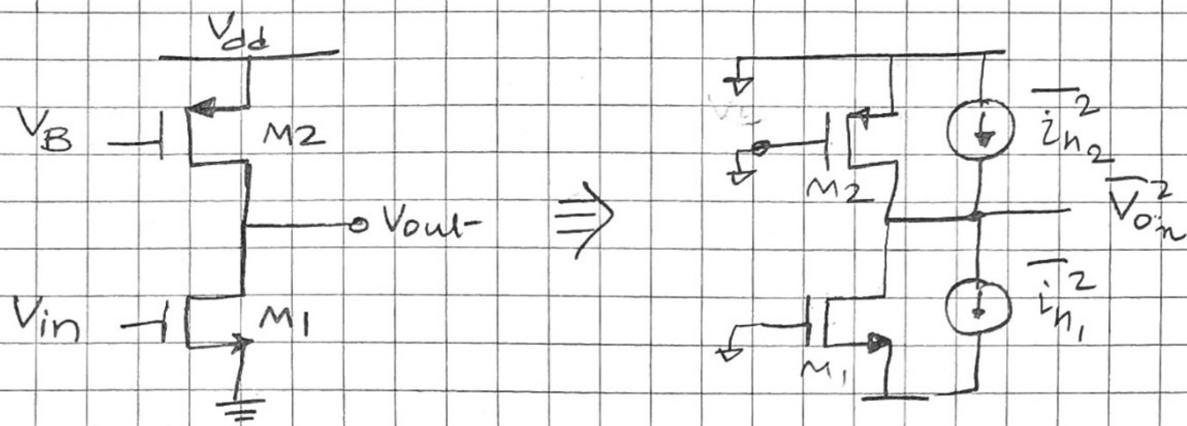
$$\overline{V^2_{n,in}} = \frac{\overline{v^2_{n,out}}}{A_V^2} = \frac{\overline{v^2_{n,out}}}{(g_m R_D)^2}$$

$$= \left(\frac{4KT}{R_D} + 4KT\gamma g_m\right) \frac{R_D^2}{(g_m \cdot R_D)^2}$$

$$= \frac{4KT}{g_m}\left(\frac{1}{g_m R_D} + \gamma\right)$$

(ONLY THERMAL NOISE CONSIDERED)

Example 2. CS AMP.



$$\overline{v_{o_n}^2} = \left(4KT\gamma_n g_{m_1} + 4K\gamma_p g_{m_2}\right) r_{out}^2$$

$$\text{Gain} = A_v = g_{m_1} r_{out}$$

$$\overline{v_{o,in}^2} = \left(4KT\gamma_n g_{m_1} + 4KT\gamma_p g_{m_2}\right) \frac{r_{out}^2}{g_{m_1}^2 r_{out}^2}$$

$$= \frac{4KT\gamma_n}{g_{m_1}} + \frac{4KT\gamma_p}{g_{m_2}}\left(\frac{g_{m_2}}{g_{m_1}}\right)^2$$

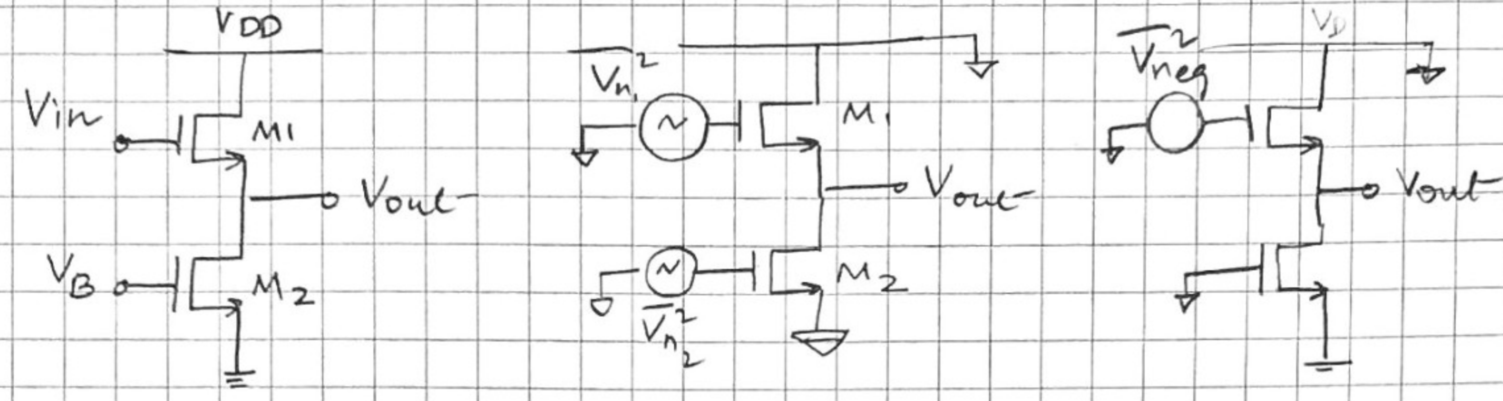
i/p refered due to M1 only.

→ keeping g_{m_1} high. Reduces contributions of current source.

$$= \overline{v_{n_1}^2} + \overline{v_{n_2}^2}\left(\frac{g_{m_2}}{g_{m_1}}\right)^2$$

Gate Refered Noise of Each transistor.

Example 3 SOURCE FOLLOWER



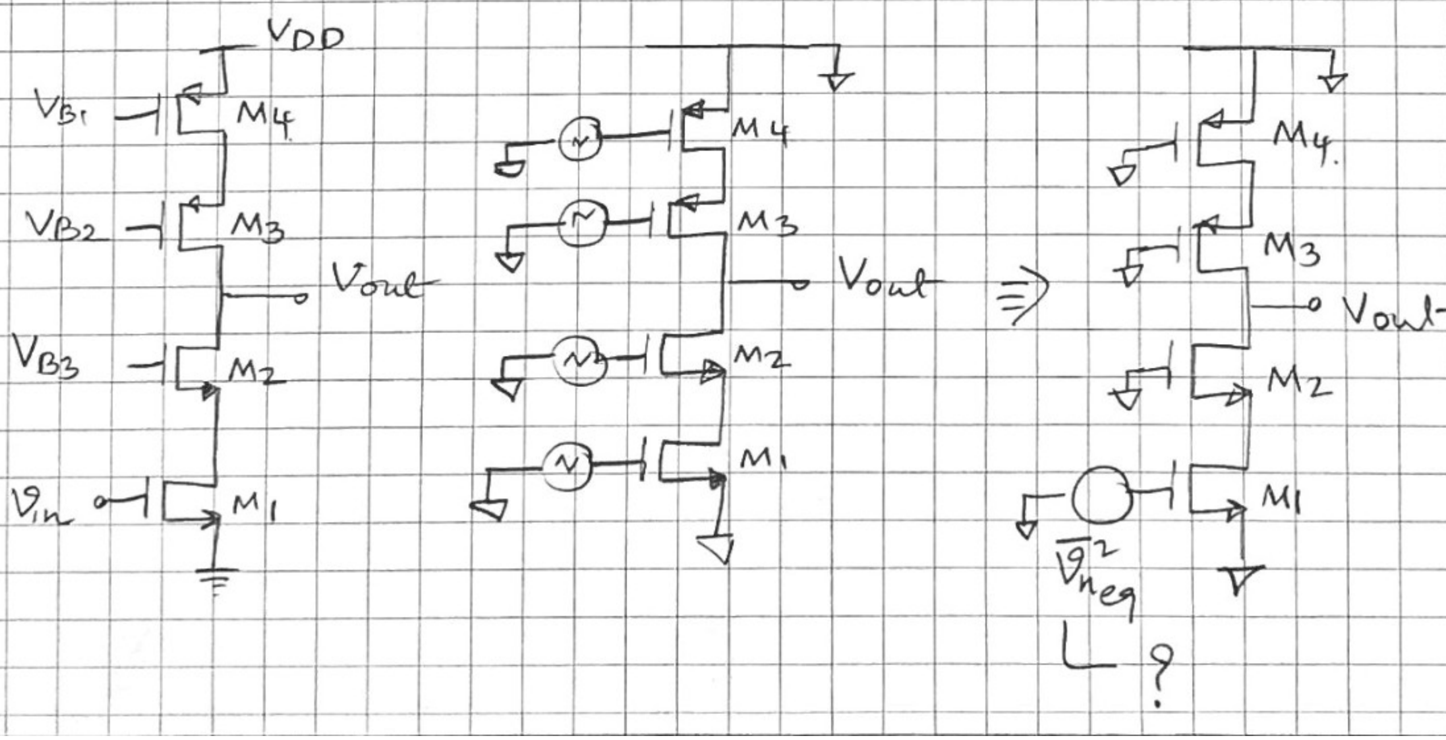
Using superposition

$$\overline{V^2_{out}} = \overline{V^2_{n_1}} + \overline{V^2_{n_2}}\left(\frac{g_{m_2}}{g_{m_1}}\right)^2 = \overline{V^2_{neq}}$$

(Since $A_v = 1$ unity gain)

$$\overline{V^2_{neq}} = \left(\overline{V^2_{n_1}} + \overline{V^2_{n_2}}\left(\frac{g_{m_2}}{g_{m_1}}\right)^2\right)$$

Example 4. CASCODE CS AMP.

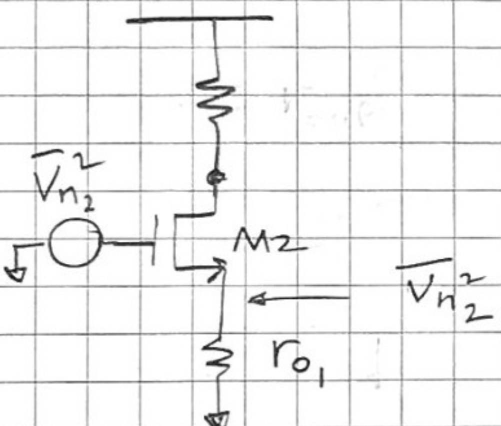


Consider M_1 & M_4 only.

$$\overline{V_{neq}^2} = \overline{v_{n_1}^2} + \overline{v_{n_4}^2}\left(\frac{g_{m4}}{g_{m_1}}\right)^2$$

(Based on previous example)

Imp point: Cascode $\Leftrightarrow$ Noise ?



$$\overline{v_{n_{out}}^2} = \frac{\overline{v_{n_2}^2}}{r_{o_1}^2} \times r_{out}^2$$

i/p referred to gate of M_1

$$\overline{V_{neq}^2} = \frac{\overline{V_{n_2}^2}}{r_{o_1}^2} \times \frac{r_{out}^2}{g_{m_1}^2 r_{out}^2}$$

$$= \frac{\overline{V_{n_2}^2}}{(g_{m_1} r_{o_1})^2}$$

Insight: Cascode Noise contributions divided by $(g_m r_o)$
Large #

Same applicable to M3.

By superposition

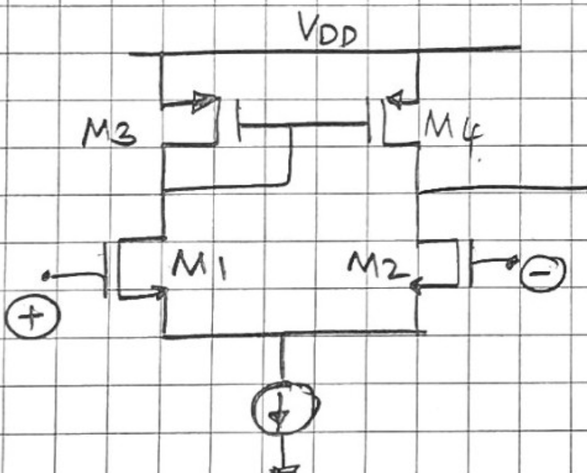
$$\overline{V_{n_{eq}}^2} = \overline{v_{n_1}^2} + \overline{v_{n_4}^2}\left(\frac{g_{m_4}}{g_{m_1}}\right)^2$$

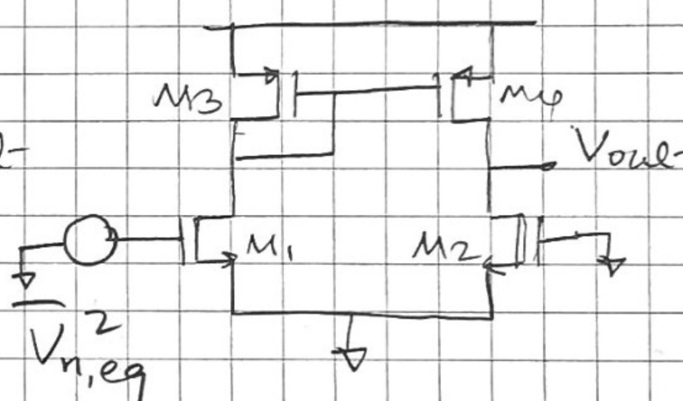
$$+ \frac{\overline{v_{n_2}^2}}{(g_{m_1} r_{o_1})^2} + \frac{\overline{v_{n_3}^2}}{(g_{m_1} r_{o_4})^2}$$

Cascode contribution

Cascode generally does not degrade noise performance.

Example: 5
CMOS DIFF AMP





$$\overline{V_{n_1,eq}^2} = 2\left[\overline{v_1^2} + \overline{v_3^2}\left(\frac{g_{m_3}}{g_{m_1}}\right)^2\right]$$

(PROVE URSELF)