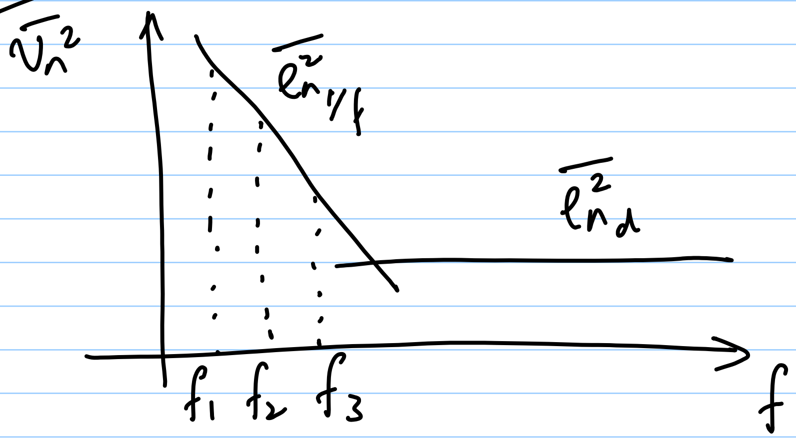
24|1|2012

Note Title

Lec 9

23-01-2012



other forms for $1/f$ noise:

$$\frac{\overline{i^2_{n_{1/f}}}}{\Delta f} = \frac{k}{f} \frac{g_m^2}{WL C_{ox}}$$

not C_{ox}^2 ...

integrated $1/f$ noise:

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

$$\Rightarrow \overline{i^2_{n_{1/f},int}} = \int_{f_1}^{f_2} \overline{i^2_{n_{1/f}}}\, df$$

$$= \frac{k g_m^2}{WL C_{ox}^2} \left[\ln f\right]_{f_1}^{f_2}$$

$$= \frac{k g_m^2}{WL C_{ox}^2} \ln\left(\frac{f_2}{f_1}\right)$$

$\Rightarrow$ total integrated noise is the same in every decade, octave etc.

e.g. $\overline{i^2_{n,tot}}$. (1kHz to 10kHz)

$= \overline{i^2_{n,tot}}$ (10kHz to 100kHz)

$1/f$ noise @ very low freq. (does it go to ∞?):

e.g. Say you are interested in a signal from 100 Hz to 100 MHz

$\Rightarrow$ 6 decades

observe signal for 1 day = 86400 s

$\Rightarrow f_{1\text{-day}} = 1.16 \times 10^{-5}$ Hz

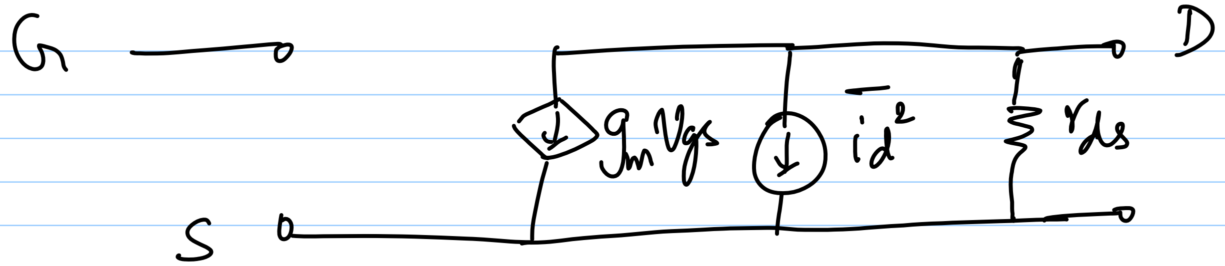
# of decades from $f_{1\text{-day}}$ to 100 Hz

$= 86400 \times 100 \approx 7$

$\therefore$ integration band changes from 6 to 13 decades (if you want to include noise from 1/1 day to 100 MHz

$$\frac{\text{new } \bar{i}_{n,int}}{\text{old } \bar{i}_{n,int}} = \sqrt{\frac{13}{6}} = 1.47$$

$\Rightarrow$ only 47% more flicker noise

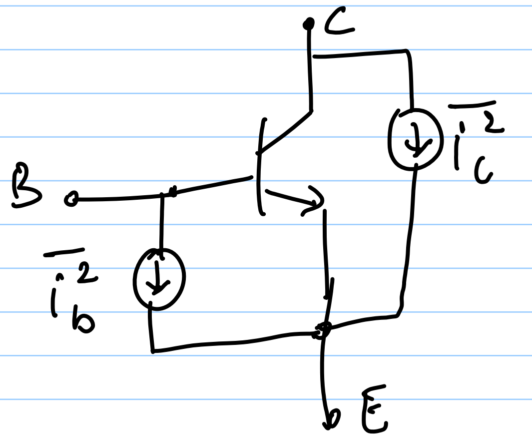


$$\frac{\overline{i_d^2}}{\Delta f} = 4KT\gamma g_m + \frac{K_f}{f}\cdot\frac{g_m^2}{WL\,C_{ox}^2}$$

* How about noise of r_{ds}?

→ r_{ds} is noiseless – only a virtual resistor that models $\partial I_D / \partial V_{DS}$ due to CLM

Bipolar Transistor noise:



2 shot noise sources (uncorrelated)

$$\overline{i_c^2} = 2qI_C\Delta f = 2KT g_m \Delta f$$

$$\overline{i_b^2} = 2qI_B\Delta f = 2KT\cdot\frac{g_m}{\beta}\Delta f$$

$$= \frac{2KT}{r_\pi}\Delta f$$

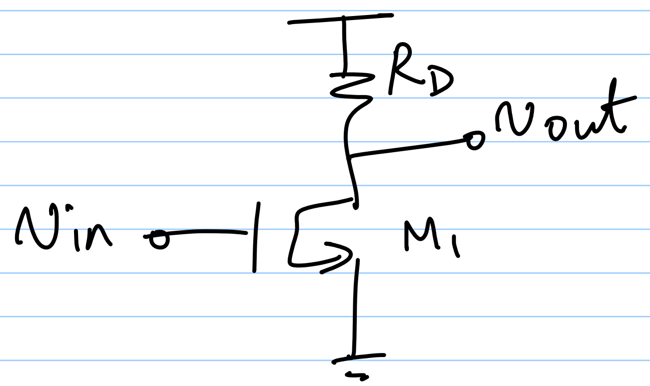
BJT flicker noise

$$\overline{i_b^2} \simeq \frac{K_1}{f} I_B^a \Delta f$$

usually small enough to be negligible

1/f noise of BJT is much smaller than that of MOSFETs

E.g. CS stage



$$\frac{\overline{V_{n,out}^2}}{\Delta f} = \left\{ 4kT\gamma g_m + \frac{K}{f}\frac{g_m^2}{WLC_{ox}^2} + \frac{4kT}{R_D} \right\} R_D^2$$

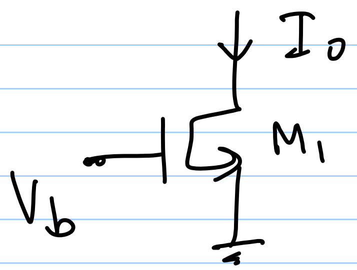
$$a_v = -g_m R_D$$

$$\therefore \frac{\overline{v_{n,in}^2}}{\Delta f} = \frac{1}{|a_v|^2} \cdot \overline{v_{n,out}^2}$$

$$= \frac{4KT\gamma}{g_m} + \frac{K}{f} \cdot \frac{1}{WLC_{ox}^2} + \frac{4KT}{g_m^2 R_D}$$

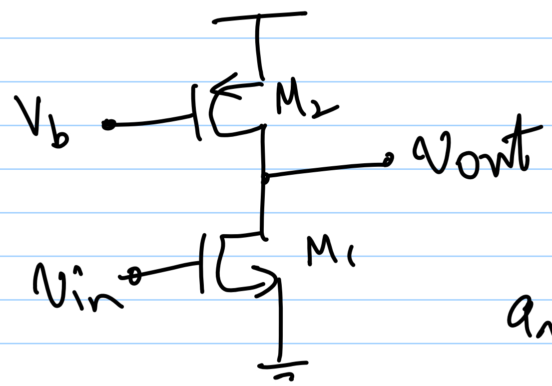
$\Rightarrow$ maximise g_m to minimise $\overline{v_{n,in}^2}/\Delta f$

larger $g_m \Rightarrow$ lower input-referred voltage noise



* when operated as a current source – minimise g_m!

e.g.



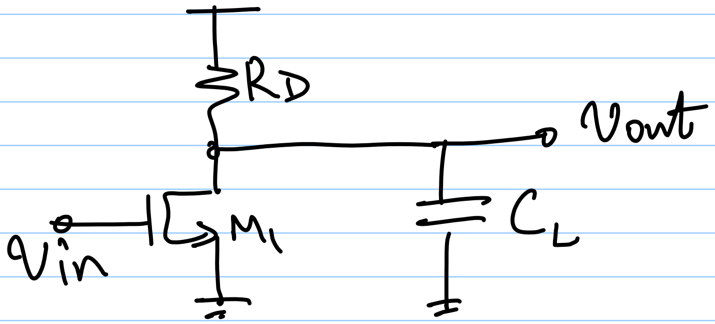
$$\frac{\overline{v_{n,out}^2}}{\Delta f} = 4KT(\gamma_1 g_{m_1} + \gamma_2 g_{m_2}) \cdot (r_{ds_1} \| r_{ds_2})^2$$

$$a_v = -g_{m_1} \cdot (r_{ds_1} \| r_{ds_2})$$

$$\Rightarrow \frac{\overline{v_{n,in}^2}}{\Delta f} = 4KT\left[\frac{\gamma_1}{g_{m_1}} + \frac{\gamma_2 g_{m_2}}{g_{m_1}^2}\right]$$

$\Rightarrow$ maximise g_{m_1} & minimise g_{m_2}

load cap:



$$\frac{\overline{v_{n,out}^2}}{\Delta f} = \left[4kT\gamma g_m + \frac{K}{f}\cdot\frac{g_m^2}{WLC_{ox}^2} + \frac{4kT}{R_D}\right] \cdot \left|R_D \,||\, \frac{1}{j\omega C_L}\right|^2$$

$$= \left[4kT\gamma g_m + \frac{K}{f}\,\frac{g_m^2}{WLC_{ox}^2} + \frac{4kT}{R_D}\right] R_D^2 \cdot \frac{1}{1+(\omega R_D C_L)^2}$$

$\Rightarrow$ o/p PSD shaped by squared magnitude of 1-pole response

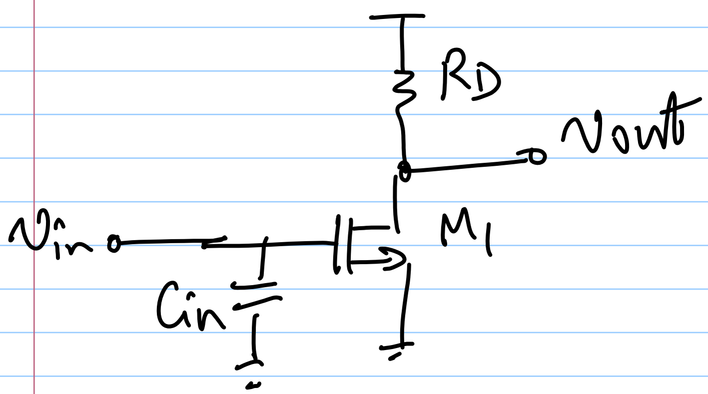
$$a_v(j\omega) = -g_m \cdot \left(R_D \,||\, \frac{1}{j\omega C_L}\right)$$

$$|a_v(j\omega)|^2 = g_m^2 R_D^2 / \left[1+(\omega R_D C_L)^2\right]$$

$$\frac{\overline{v_{n,in}^2}}{\Delta f} = \frac{4kT\gamma}{g_m} + \frac{K}{f}\cdot\frac{1}{WLC_{ox}^2} + \frac{4kT}{g_m^2 R_D}$$

⇒ input-referred noise is same as before because $\overline{v_{n,out}}$ and gain have same freq. roll-off (all noise is being added before RC-pole)

Input Cap



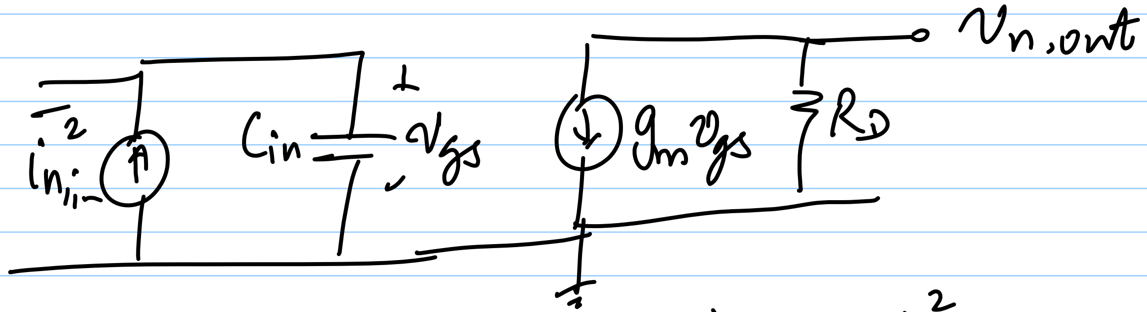
$\overline{v_{n,in}^2} = ?$

$\overline{i_{n,in}^2} = ?$

neglect 1/f noise

$\dfrac{\overline{v_{n,in}^2}}{\Delta f}$ = same as before (Cin falls in shunt across GS)

But now, an $\overline{i_{n,in}^2}$ exists: o.c. input



$$v_{gs}^2 = \overline{i_{n,in}^2} \cdot \left|\frac{1}{j\omega C_{in}}\right|^2$$

$$\overline{v_{n,out}^2} = g_m^2 \cdot \overline{i_{n,in}^2} \cdot \frac{1}{(\omega C_{in})^2} \cdot R_D^2$$

actual $\overline{v_{n,out}^2} = \left(4kT\gamma g_m + \frac{4kT}{R_D}\right) R_D^2 \cdot \Delta f$

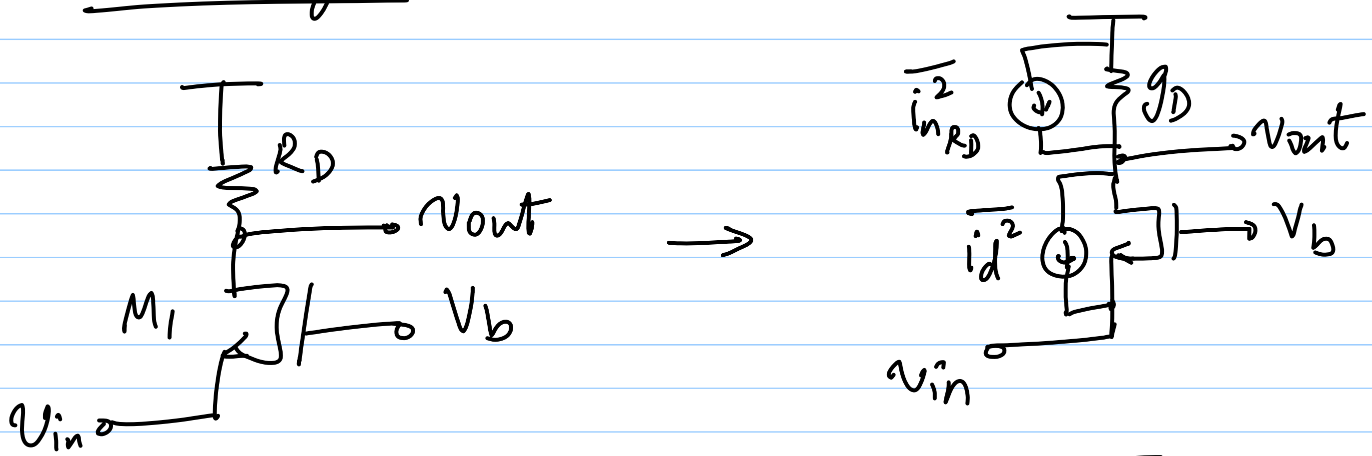
Equate the two:

$$\frac{\overline{i_{n,in}^2}}{\Delta f} = \left(\frac{4kT\gamma}{g_m} + \frac{4kT}{g_m^2 R_D}\right)(\omega C_{in})^2$$

$$= \frac{4kT}{g_m^2}(\omega C_{in})^2 \left[\gamma g_m + \frac{1}{R_D}\right]$$

@ low freq., $\overline{i_{n,in}^2}$ is insignificant

CG stage

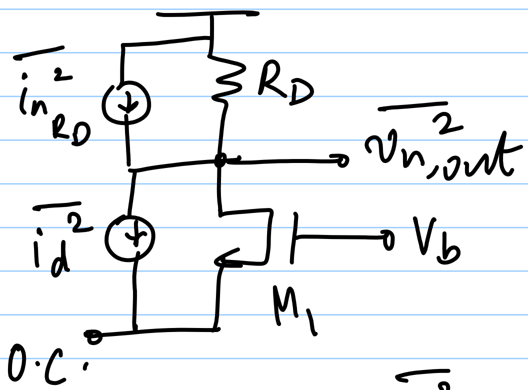


* input impedance is low ⇒ $\overline{i_n^2}$ is significant even @ low freq.

$$\left(4kT\gamma g_m + 4kT g_D\right) R_D^2 \Delta f = \overline{V_{n,in}^2}\,(g_m + g_{mbs})^2 R_D^2$$

$$\frac{\overline{v_{n,in}^2}}{\Delta f} = \frac{4kT(\gamma g_m + g_D)}{(g_m + g_{mbs})^2}$$

O.C. input:



* $\overline{i_d^2}$ flows completely through M_1

$\Rightarrow$ produces no noise @ output

$$\frac{\overline{v_{n,out}^2}}{\Delta f} = 4kTg_D \cdot R_D^2 = 4kTR_D$$

with input-referred source:

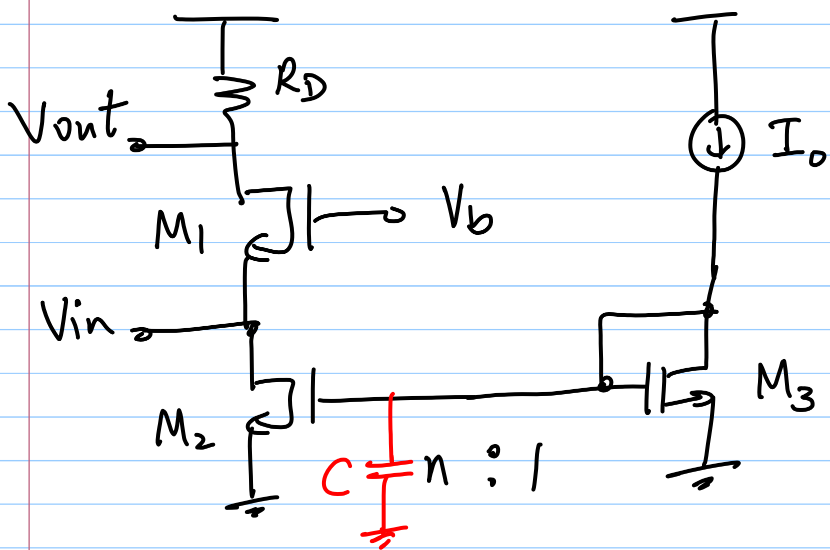
$$\overline{v_{n,out}^2} = \overline{i_{n,in}^2} \cdot R_D^2$$

$$\Rightarrow \frac{\overline{i_{n,in}^2}}{\Delta f} = \frac{4kT}{R_D}$$

* C.G. stage directly refers load noise current to the input

$\Rightarrow$ C.G. has no current gain.

C.G. w/ bias



* noise of M_0
  — gets multiplied into signal path
  ⇒ add cap C to shunt this noise to gnd

* Noise of M_2:
  S.C. input ⇒ $\overline{i_{d_2}^2}$ flows into S.C.

⇒ $\overline{v_{n,in}^2}$ is same as before

O.C. input:

all of $\overline{i_{d_2}^2}$ flows into R_D to produce

$$\overline{v_{n,out_{M_2}}^2} = \overline{i_{d_2}^2} \cdot R_D^2$$

⇒ $\overline{i_{d_2}^2}$ directly adds to $\overline{i_{n,in}^2}$

* minimise g_{m_2}
  ⇒ for given bias current, V_{DSAT_2} increases
  ⇒ V_{b_2} ↑ ⇒ output voltage swing ↓