ECE 515 - Lecture 20

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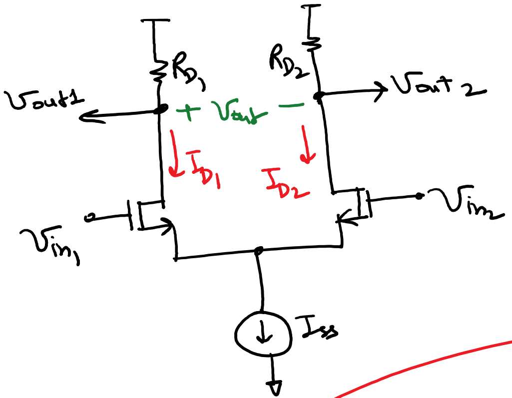
Large Signal Behavior :



$$v_{out_1} = V_{DD} - I_{D_1} R_{D_1}$$

$$v_{out_2} = V_{DD} - I_{D_2} R_{D_2}$$

$R_D = R_{D_1} = R_{D_2}$

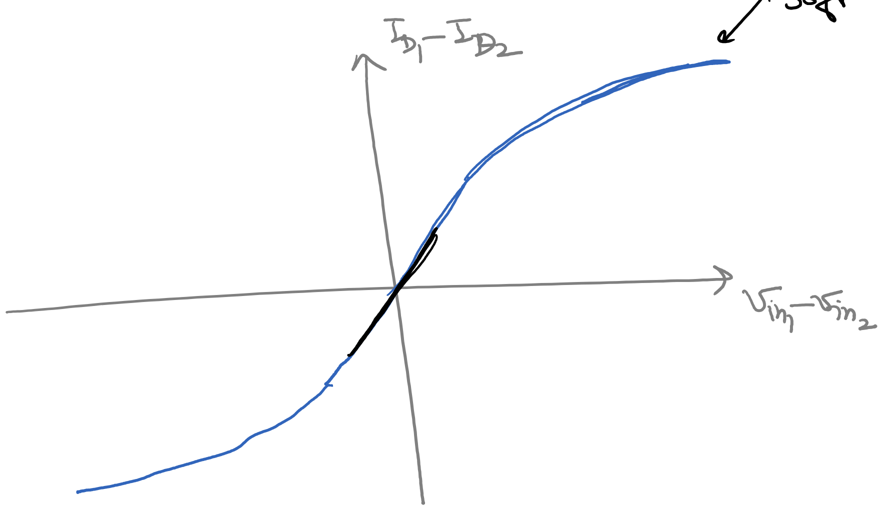
$$\Rightarrow v_{out} = v_{out_1} - v_{out_2} = -(I_{D_1} - I_{D_2}) R_D$$

$$I_{D_1} - I_{D_2} = \underbrace{\frac{\beta}{2}(\overbrace{v_{in_1} - v_{in_2}}^{v_{d,in}})}_{\text{linear}} \underbrace{\sqrt{\frac{4I_{ss}}{\beta} - (v_{in_1} - v_{in_2})^2}}$$

decreases as $(v_{in_1} - v_{in_2}) \uparrow$

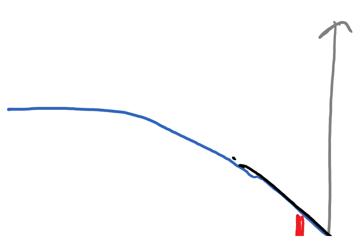
$$\simeq \frac{\beta}{2}(v_{in_1} - v_{in_2}) \quad \text{for} \quad |v_{in_1} - v_{in_2}| < \sqrt{\frac{4I_{ss}}{\beta}}$$

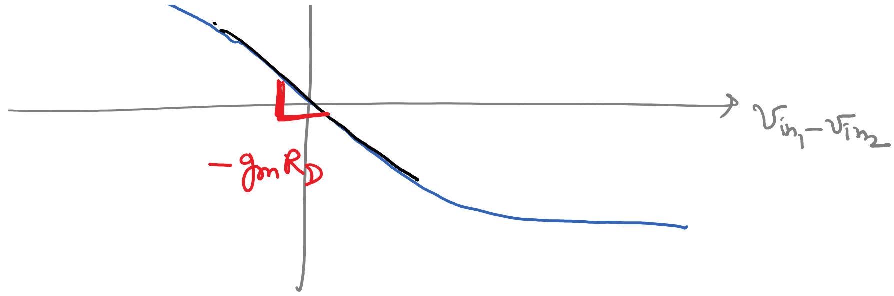
Soft Saturation



$$v_{out_1} - v_{out_2} = -(I_{D_1} - I_{D_2}) R_D$$

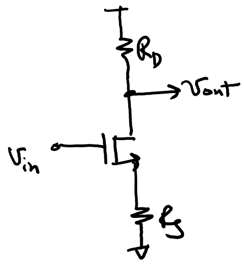
$v_{out_1} =$

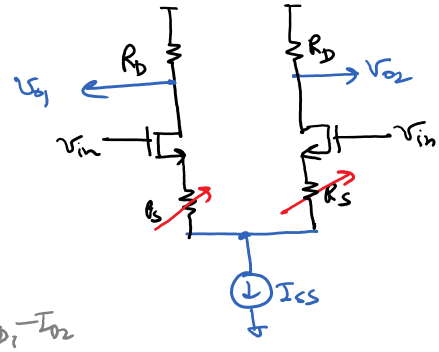




$v_{in_1} - v_{in_2}$
$-g_m R_D$

Source Degeneration

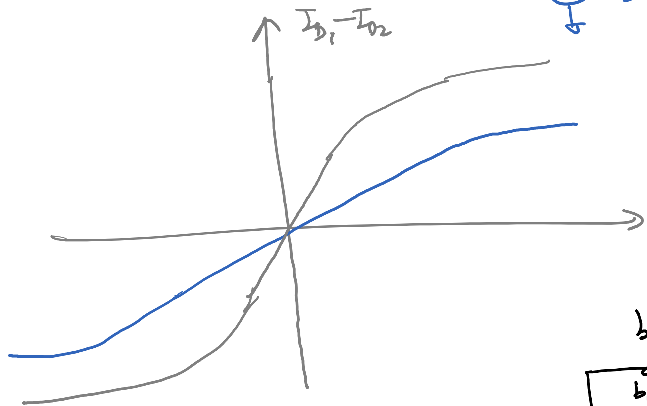




Linear gain stage

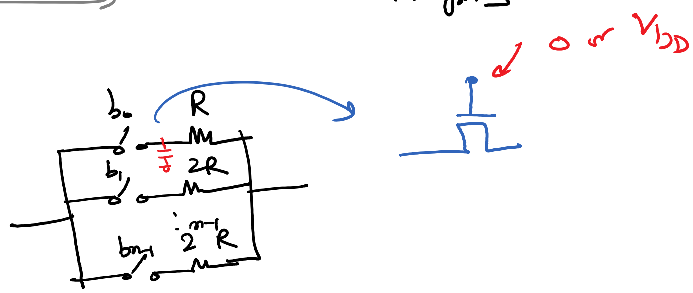
Programmable gain stage

↳ $R_S \rightarrow$ Triode Transistor



more linear

$$|A_v| = \frac{g_m R_D}{1 + g_m R_S}$$



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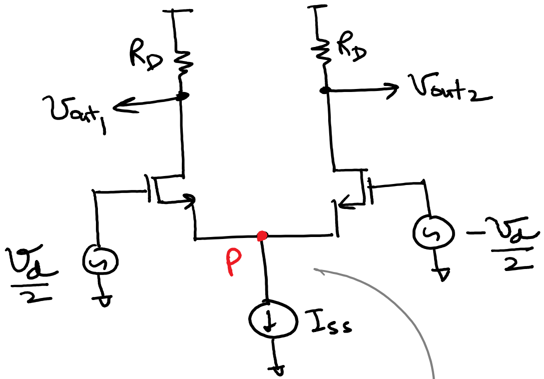
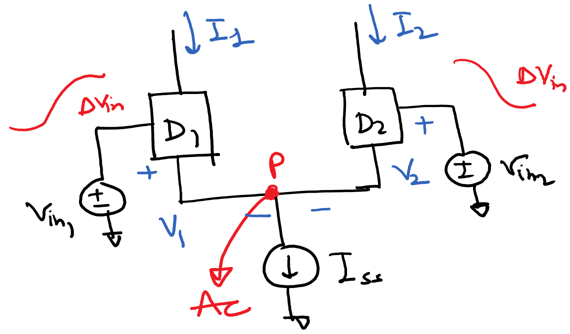
Lemma: Consider the symmetric circuit shown below





If v_{in_1} changes from V_0 to $V_0 + \Delta V_{in}$

& V_{in_2} changes from V_0 to $V_0 - \Delta V_{in}$

Then, if the circuit remains linear

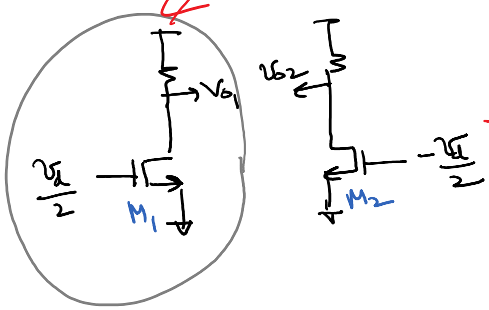
V_p doesn't change.

↳ P is effectively an AC ground.

See Proof in the Book.

* Due to symmetry in circuit with differential inputs

Differential Half Circuit



only valid for purely differential inputs

$v_d = v_{in_1} - v_{in_2}$

$$\frac{v_{out_1}}{v_{in_1}} = -g_m R_D \qquad \frac{v_{out_2}}{v_{in_2}} = -g_m R_D$$

precise gain

$$-g_{m_{1,2}}(R_D || r_{o_{1,2}})$$

$$\frac{v_{out_1} - v_{out_2}}{v_{in_1} - v_{in_2}} = -g_m R_D$$

$$\frac{v_{out_1}}{v_{in_1} - v_{in_2}} = -\frac{1}{2} g_m R_D$$

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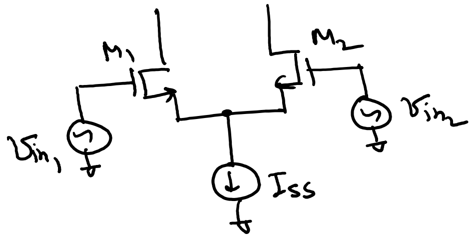
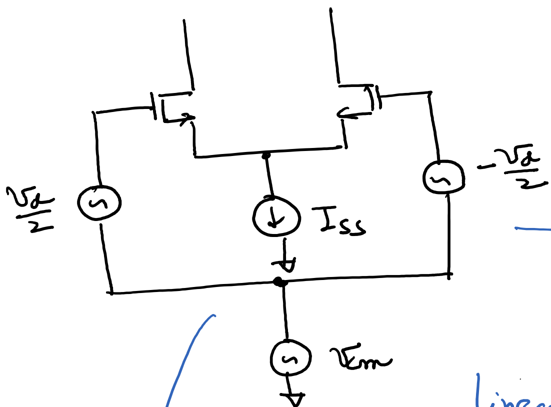
* What if the inputs are not fully-differential?

may not be DC voltage

$$v_{in_1} = \overbrace{\left(\frac{v_{in_1}-v_{in_2}}{2}\right)}^{v_d/2} + \overbrace{\left(\frac{v_{in_1}+v_{in_2}}{2}\right)}^{v_{cm}}$$

$$v_{in_2} = \underbrace{\left(\frac{v_{in_2}-v_{in_1}}{2}\right)}_{-v_d/2} + \underbrace{\left(\frac{v_{in_1}+v_{in_2}}{2}\right)}_{v_{cm}}$$

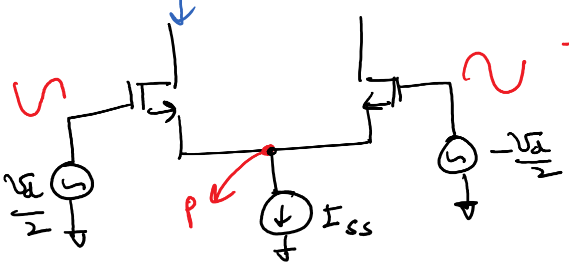


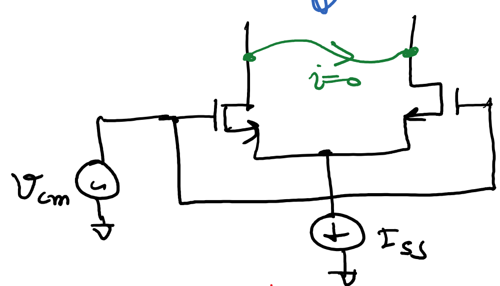


Linear Superposition

Differential Circuit

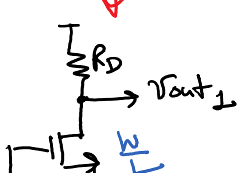
Common Mode Circuit

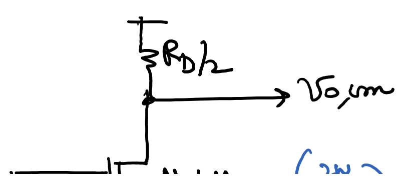


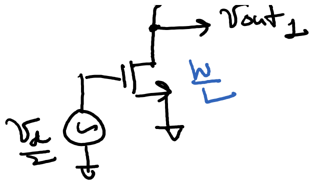


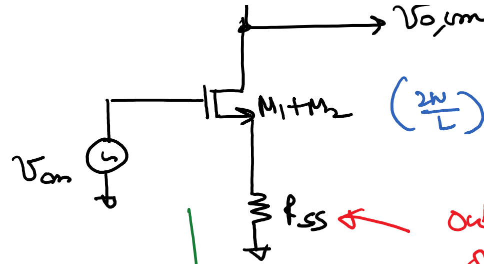
Differential Half Circuit

CM Equivalent Circuit









output resistance of the tail current source.

Differential gain

poles, zeros, f_{un}

CM gain

Combine the results together

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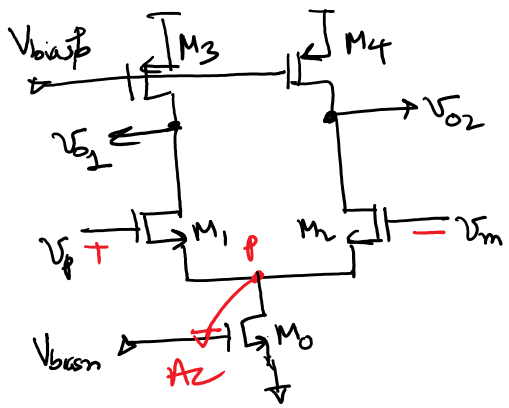
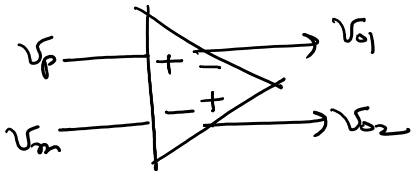
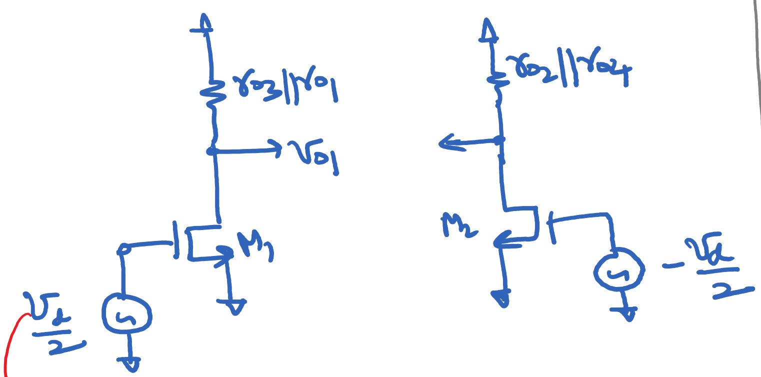
"Not showing CMFB loop"



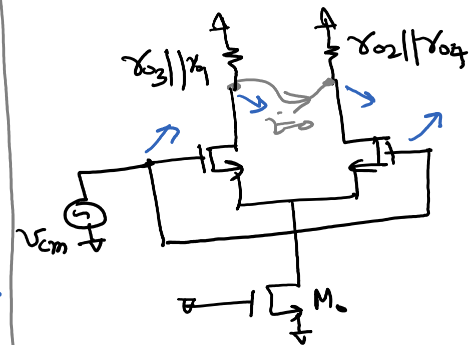


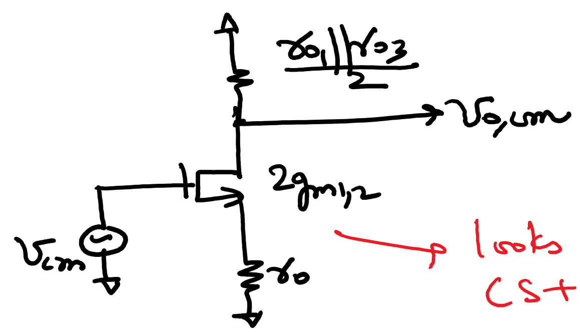
Differential half circuits



$v_d = v_p - v_m$

CM Equivalent circuit





looks like CS + SD

Differential gain

$$\frac{v_{o1} - v_{o2}}{v_p - v_m} = -g_{m1,2}(r_{o1,2} || r_{o3,4})$$

$$A_{DM} = \frac{v_{o2} - v_{o1}}{v_p - v_m} = + g_{m1,2}(r_{o1,2} || r_{o3,4})$$

$$A_{CM} = -\frac{2g_{m1,2}\left(\frac{r_{o1}||r_{o3}}{2}\right)}{1 + 2g_{m1,2} R_{SS}}$$

$R_{SS} \to r_o$

$$\boxed{CMRR = \left|\frac{A_{v,DM}}{A_{v,cm}}\right|}$$ in dB

$= g_{m1,2}(r_{o1,2} || \cancel{r_{o3,4}}) \times (1 + 2g_{m1,2} R_{ss})$

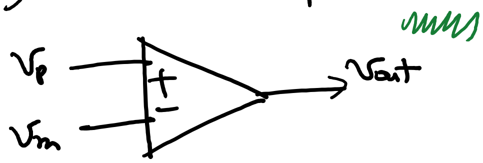
$$\mathrm{CMRR} = \frac{g_{m1,2} \cancel{(r_{o1,2} \| r_{o3,4})} \times}{\cancel{2} g_{m1,2} \frac{\cancel{(r_{o1,2} \| r_{o3,4})}}{\cancel{2}}} \cdot (1 + 2 g_{m1,2} R_{SS})$$

$$\mathrm{CMRR} = 1 + 2 g_{m1,2} R_{SS} \simeq 2 g_{m1,2} R_{SS}$$

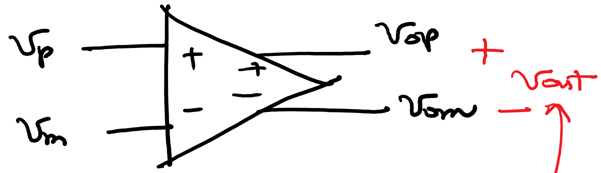
for very high CMRR $\Rightarrow$ we need $R_{SS} \to \infty$

$\Rightarrow$ Better use Cascode current source.

Single-ended Diff Amp

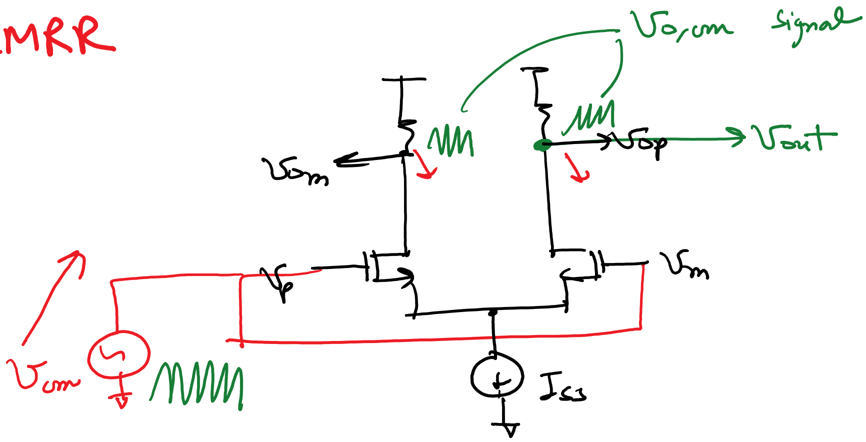


FD Amp



CM component cancels out!

CMRR



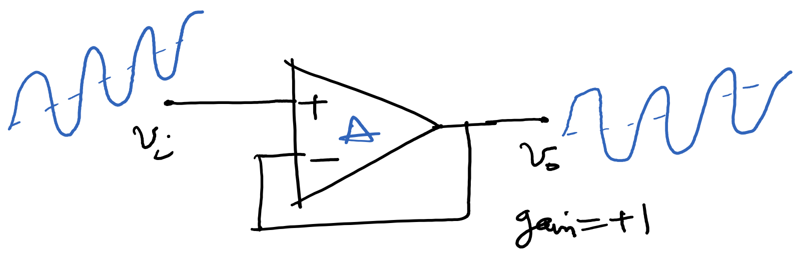
CM gain = 0

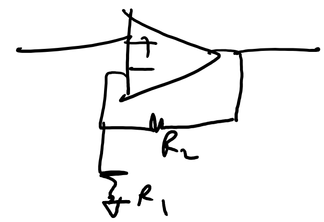
→ CMRR → ∞

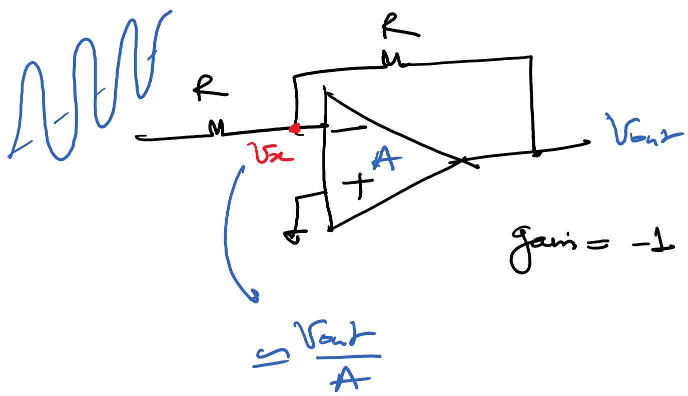
unless there are circuit mismatches

* CMRR is mostly used to characterize single-ended amplifiers

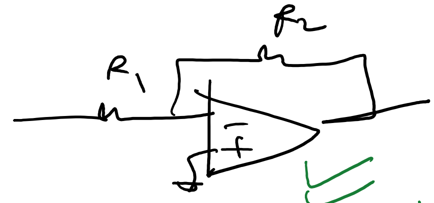
CMRR ≥ 70dB







more tolerant to CM disturbances.



more tolerant to input CM disturbances.