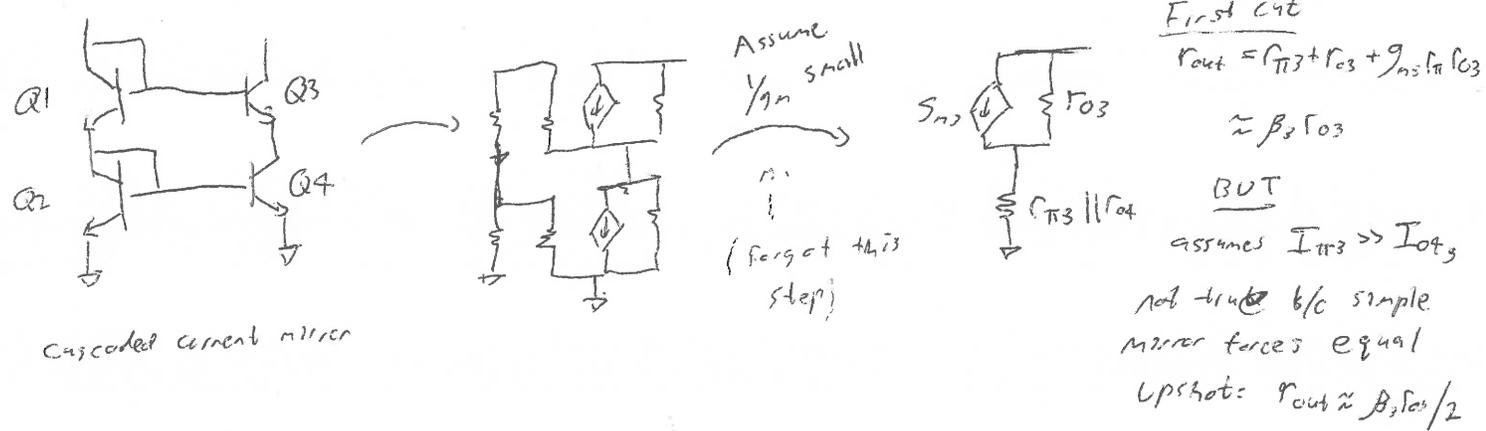


<p>Cascoded Current Mirror</p> <ul style="list-style-type: none"> - $1/g_m$ cleanup - reversed - no derivation - why/where is course 	<p>Direct signaling</p> <ul style="list-style-type: none"> - Need diff amp to make op-amp - How? Need to double differential 	<p>Differential Pair & $1/2$ ckt analysis</p> <ul style="list-style-type: none"> - Draw ckt. w/res. tail - Define A_{dm} & A_{cm} - Rules for making $1/2$ circuits 	<p>Common Design Params</p> <ul style="list-style-type: none"> - CMRR - PSRR - V_{os} Input or output reversed - f_{bias} reminder
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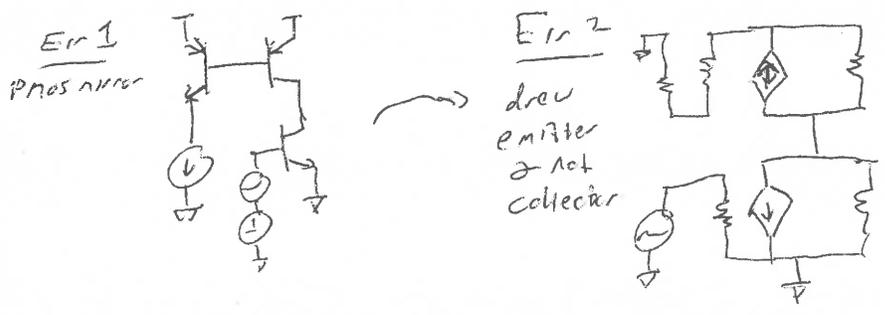
3.5. 1, 2, 4, 5, 63

Start by clearing up details from last time



- Σ for cascoded mirror in notes from last time
- ↳ big take away is that in bipolar devices it is worse than simple mirror
- ↳ other fancy mirrors improve on this
- MOS devices make better mirrors b/c no gate current, worse b/c $V_{th, min} = V_{ov}$

Finally, mid drew active load badly enough that repeating here



- Lots of other current mirror stuff to say + practice
- But we're done!
Building blocks unit!

Differential amplifiers

- we're building an op-amp & they have differential input signals

- $A(v_+ - v_-)$ ← how do we get that?

- Need to make some kind of "differential amplifier", but need to decouple differential

• Any two signals v_1 & v_2 can be decomposed into differential mode & common mode

$$v_{dm} = v_1 - v_2 \quad \& \quad v_{cm} = \frac{v_1 + v_2}{2} \quad \begin{matrix} \text{instantaneous} \\ \text{average value} \end{matrix}$$

(usually small signal) } can express $v_1 = v_{cm} + \frac{v_{dm}}{2}$ ($v_2 = v_{cm} - \frac{v_{dm}}{2}$)

Example

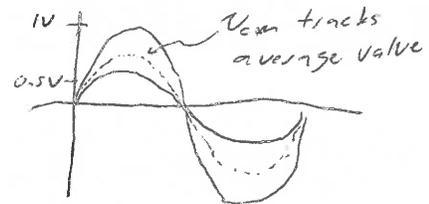
$$v_1 = 1V \cdot \sin(\omega t)$$

$$v_2 = 0.5V \cdot \sin(\omega t)$$

$v_{cm} \neq 0V$ → average of each individually is 0V over time

$$= 0.75V \sin(\omega t)$$

$$v_{dm} = 0.5V \sin(\omega t)$$

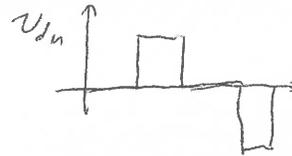
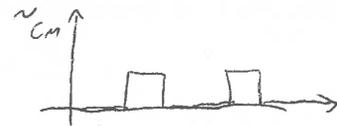
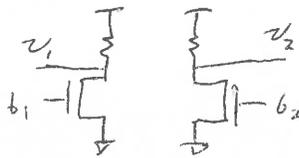


You try pseudo-diff signaling ~ a common digital technique



- You draw v_{cm} & v_{dm}

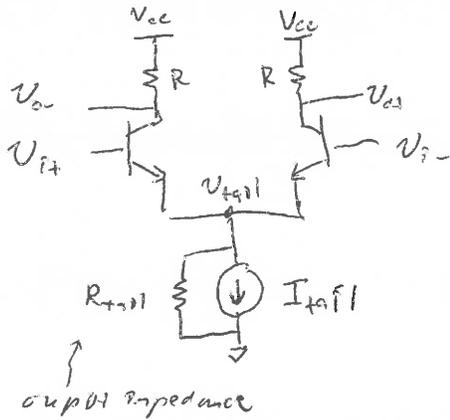
- from this common link



- want to build a circuit that is sensitive to d_m & not c_m .

- Most noise in the world is c_m eg: power supply, pickup, inductive parasitics

The classic diff amp ~ an emitter coupled pair



- can build w/ R_{tail} in place of I_{tail} , or Norton
- current steering $V_{i+} > V_{i-}$ means more of I_{tail} goes left
- can swap gain by -1 by switching V_{o+} & V_{o-}

- Biasing ~ don't saturate (R small) & don't cut off (V_{i+} & V_{i-} high enough)
- large signal KVL

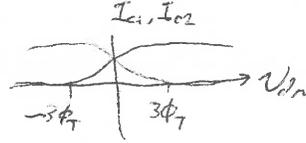
↙ invert the $I_s e^{v_{be}/\phi_T}$ expression

$$V_{i+} - V_{be1} + V_{be2} - V_{i-} = 0 \quad \& \quad V_{be} = \phi_T \ln \frac{I_{Ck}}{I_{Sk}}, \text{ same } I_S \Rightarrow \text{same } I_C$$

$$V_{i+} - V_{i-} + \phi_T \left(\ln \frac{I_{C2}}{I_{S2}} - \ln \frac{I_{C1}}{I_{S1}} \right) = 0$$

$$\frac{I_{C1}}{I_{C2}} = e^{v_{dn}/\phi_T}$$

cool! I_{C1}, I_{C2} dependent current steering



$$I_{C1} + I_{C2} = I_{tail}$$

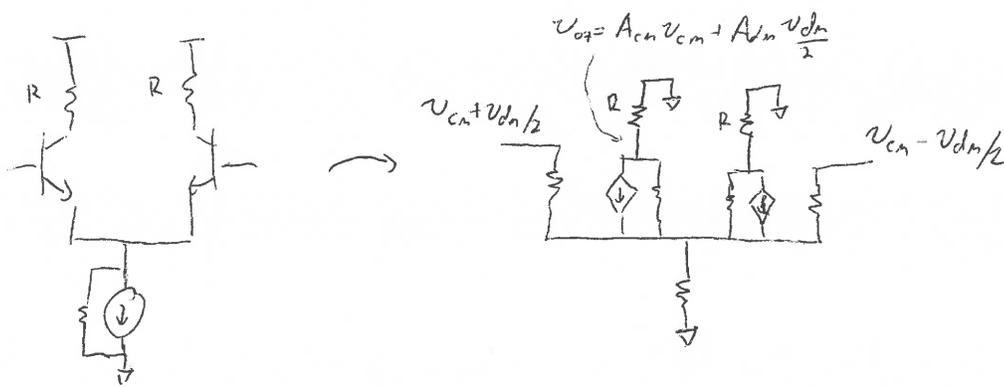
$$\frac{\beta+1}{\beta} (I_{C1} + I_{C2}) = I_{tail} \implies I_{C1} = \frac{\frac{\beta+1}{\beta} I_{tail}}{1 + \exp(-v_{dn}/\phi_T)} \quad \& \quad I_{C2} = \frac{\frac{\beta+1}{\beta} I_{tail}}{1 + \exp(v_{dn}/\phi_T)}$$

- Not linear over large range, can add degeneration to help, next time
- Small signal behavior comes from many places, need to find A_{cm} & A_{dm} , see one easy way to attack is with $\frac{1}{2}$ circuit analysis

↳ circuit like a seesaw ground cm ~ 1 voltage up & other down

↳ means diff current sometimes conveniently zero & can use symmetry

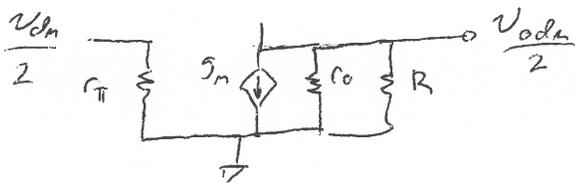
$$A_{cm}, A_{dm}, A_{cm \rightarrow dm}, A_{dm \rightarrow cm}, \text{ Note } CMRR \equiv \frac{A_{dm}}{A_{cm}}$$



- Superposition breaks into $cm \approx dm$ circuits
- Symmetry lets us draw $1/2$ circuits

dm $1/2$ circuit

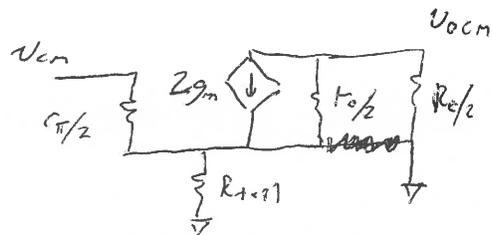
- v_{tail} is dm ground, no seesawing \therefore small sig. gnd.
- dm doesn't result in any i_{tail} into R



$$A_{dm} = g_m (r_o || R)$$

cm $1/2$ circuit

- everything is in parallel



$$A_{cm} \approx \frac{R_c}{2R_{tail}} \quad \text{1/2 looks like CE w/ degen}$$

- Get CMRR $\therefore A_s \approx 2g_m R_{tail}$... want big R_{tail}
- Can specify differential input resistance & cm input resistance

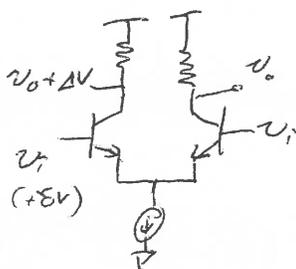
$$R_{in} \equiv \frac{v_{dm}}{i_b} \quad \text{we have } \frac{v_{dm}}{2} = i_b r_{\pi}$$

$$R_{in} = \frac{v_{cm}}{i_b} = r_{\pi} + (\beta + 1)R_{tail} \quad \text{1/2 degen. CE}$$

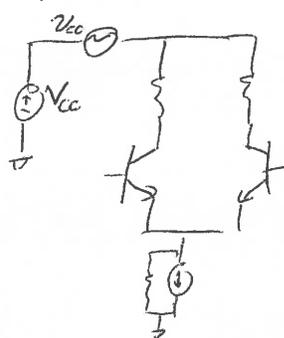
$$\hookrightarrow R_{dm} = 2r_{\pi}$$

2 other design specs

- V_{os} - offset voltage
- $I_{s1} \neq I_{s2} \rightsquigarrow$ different current in each leg
- ΔV is output referred offset voltage
- Input-referred: divide by gain - amt of δV needed so there's no ΔV



PSRR



$$A_{cc} \equiv \frac{v_{cm}}{v_{cc}}$$

- use cm $1/2$ ckt

$$- PSRR = A_{dm} / A_{cc}$$