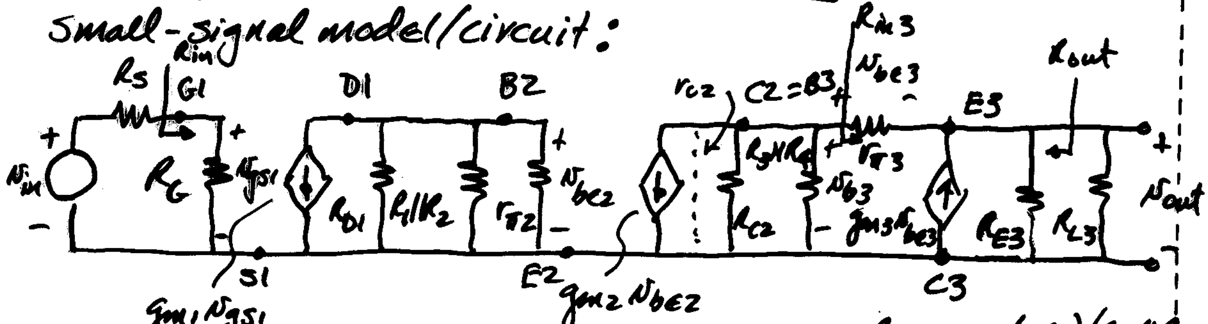
Multistage Amplifier Example - Cont'd

Small-signal model/circuit:



$R_{in3} = r_{\pi 3} + (1+\beta_3)(R_{L3} \| R_{E3})$

$$\frac{v_{out}}{v_{in}} = \left(\frac{v_{out}}{v_{be3}}\right)\left(\frac{v_{be3}}{v_{b3}}\right)\left(\frac{v_{b3}}{v_{be2}}\right)\left(\frac{v_{be2}}{v_{gs1}}\right)\left(\frac{v_{gs1}}{v_{in}}\right)$$

$$= \left[\frac{(1+\beta_3)(R_{E3}\|R_{L3})}{r_{\pi 3}}\right]\left[\frac{r_{\pi 3}}{R_{in3}}\right]\left[-g_{m2}(r_{o2}\|R_{C2}\|R_3\|R_4\|R_{in3})\right]$$

$$\times \left[-g_{m1}(r_{o1}\|R_{D1}\|R_1\|R_2\|r_{\pi 2})\right]\left[\frac{R_G}{R_S+R_G}\right]$$

$$\frac{v_{out}}{v_{in}} = (18.82)\left(\frac{1}{19.82}\right)(-208.6)(-4.786)\left(\frac{1}{1.01}\right) = \underline{\underline{938.6\ \frac{V}{V}}}$$

Find the input signal to keep the amplifier in "small signal" operation:

For s.s. operation - FET $v_{gs} \le 0.2\,(V_{GS} - V_T)$

BJT $v_{be} \le 5\,mV$

Stage 1

$$v_{gs1} \le 0.2\,(V_{GS1} - V_T) = 0.2\,[-5\,mA \times 200\Omega - (-2)]$$
$$= 0.2\,V$$

$\therefore\ v_{in1}(max) = 1.01 \times 0.2V = \underline{\underline{0.2\,V}}$

Stage 2

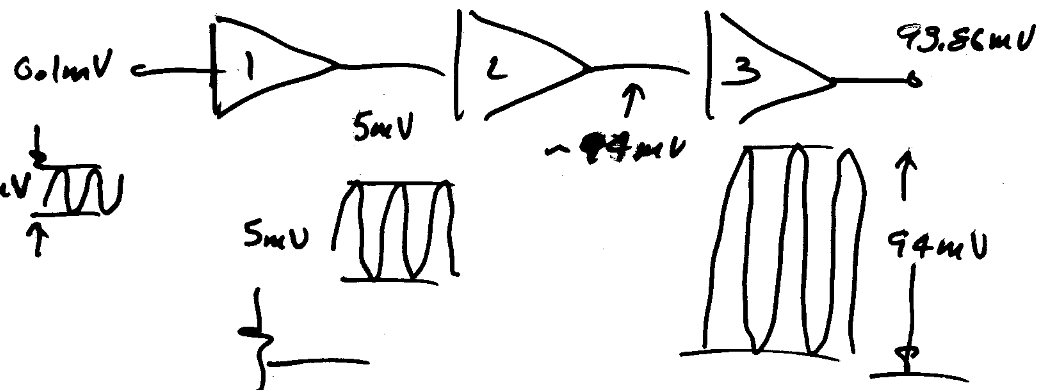
$v_{be2} \le 5\,mV \qquad \left|\frac{v_{be2}}{v_{in}}\right| = 4.786 \rightarrow v_{in2}(max) = \frac{5\,mV}{4.786} = \underline{\underline{1.04\,mV}}$

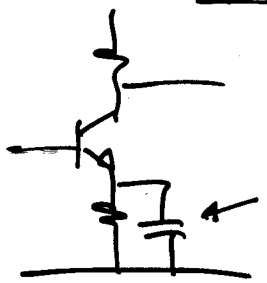
Stage 3

$$v_{be3} \le 5\,mV \rightarrow v_{in}(max) = \frac{5\,mV}{\left(\frac{v_{be3}}{v_{b3}}\right)\left(\frac{v_{b3}}{v_{be2}}\right)\left(\frac{v_{be2}}{v_{gs1}}\right)\left(\frac{v_{gs1}}{v_{in}}\right)}$$

102.5 μV

$$v_{in3}(max) = \frac{5\,mV}{(49.27)} = \text{~~[struck out]~~}\ \mu V \simeq 0.1\,mV$$

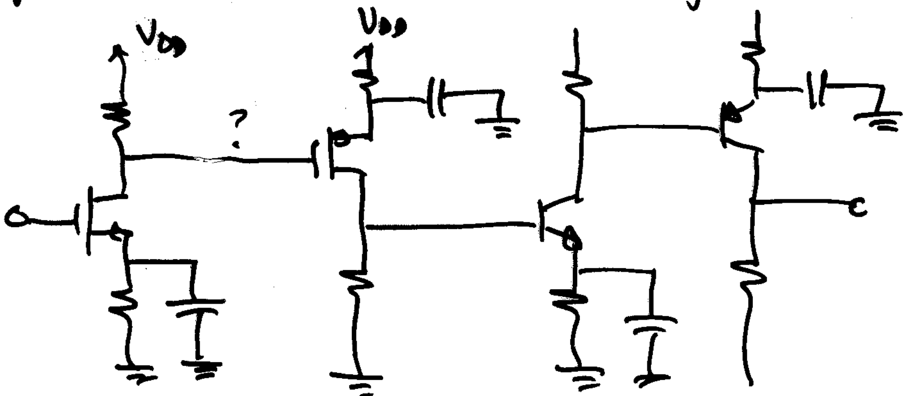


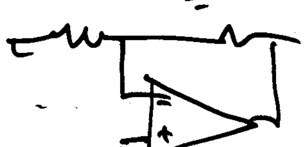


Remove ⇒ Linearizes but reduces the gain

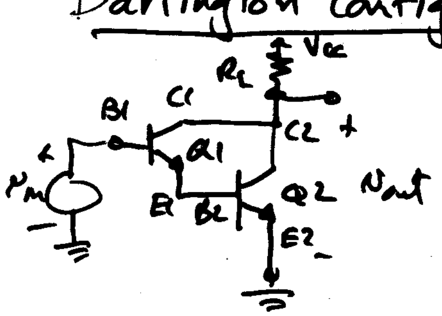
Direct Coupled Amplifiers

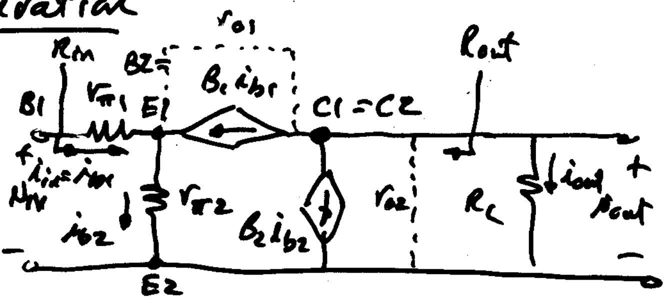
Amplifiers that do not use coupling caps.





Darlington Configuration





Find $\frac{v_{out}}{v_{in}}$, R_{in} & R_{out} & $\frac{i_{out}}{i_{in}}$

$R_{in} = r_{\pi 1} + (1+\beta_1) r_{\pi 2}$ $\quad R_{out} = \infty \quad (r_{o2} = \infty)$

$\frac{v_{out}}{v_{in}} = ?$ $\quad \beta_1 i_{b1} + \beta_2 i_{b2} + \frac{v_{out}}{R_L} = 0$ $\quad \beta_1 i_{b1} + \beta_2(\beta_1+1) i_{b1} = -\frac{v_{out}}{R_L}$

Note that $i_{b1}(1+\beta_1) = i_{b2}$

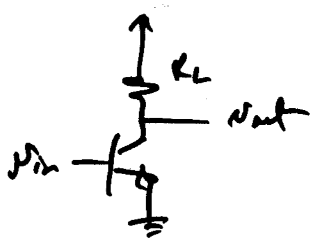
$$\frac{v_{out}}{i_{b1}} = -[\beta_1 + (1+\beta_1)\beta_2] R_L$$

$$\frac{v_{out}}{v_{in}} = \left(\frac{v_{out}}{i_{b1}}\right)\left(\frac{i_{b1}}{v_{in}}\right) = \frac{-[\beta_1 + (1+\beta_1)\beta_2] R_L}{r_{\pi 1} + (1+\beta_1) r_{\pi 2}} \approx -\frac{(1+\beta_1)\beta_2 R_L}{2 r_{\pi 1}}$$

$$\frac{i_{out}}{i_{in}} = \left(\frac{v_{out}}{R_L}\right)\left(\frac{R_{in}}{v_{in}}\right) = \frac{v_{out}}{v_{in}}\left(\frac{R_{in}}{R_L}\right) = -\frac{(1+\beta_1)\beta_2 \cancel{R_L}}{\cancel{R_{in}}} \times \frac{\cancel{R_{in}}}{\cancel{R_L}}$$

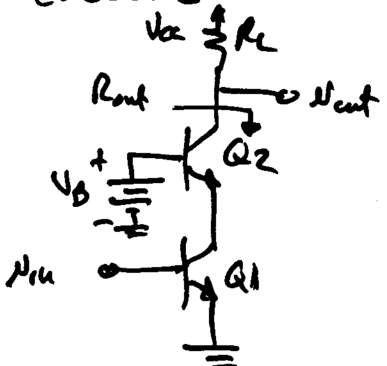
Compare with CE:

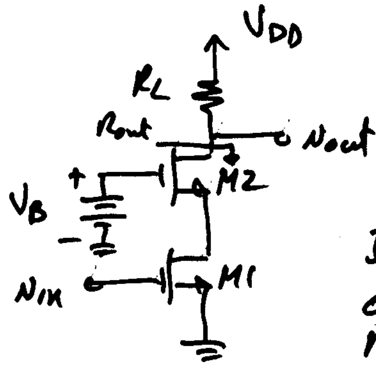
?



$$\frac{v_{out}}{v_{in}} = \left(\frac{v_{out}}{i_b}\right)\left(\frac{i_b}{v_{in}}\right) = -\frac{\beta R_L}{r_\pi}$$

Cascode Circuit -





Increases the output resistance of a transistor above r_o.

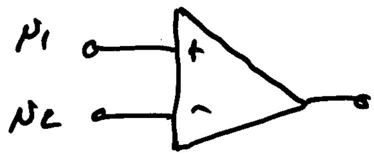
$\frac{v_{out}}{v_{in}} = -g_{m1} R_L = -\frac{\beta_1 R_L}{r_\pi}$ $\qquad -g_{m1} R_L$

$R_{in} = r_{\pi 1}$ $\qquad \infty$

$R_{out} = r_{o1}\beta$ $\qquad r_{o1} g_{m1} r_{o2}$

Differential Amplifiers

Differential amplifiers are amplifiers that sense and amplify the difference between two voltages and reject the average of the voltages.



$$v_{out} = A_{vd}(v_1 - v_2) \pm A_{cm}\left(\frac{v_1 + v_2}{2}\right)$$

$$= A_{vd}\, v_{id} \pm A_{cm}\, v_{cm}$$

$\therefore$ $v_{id} \equiv v_1 - v_2$ and $v_{cm} \equiv \frac{v_1 + v_2}{2}$

A "good" differential amplifier has $|A_{vd}| >> |A_{cm}|$.