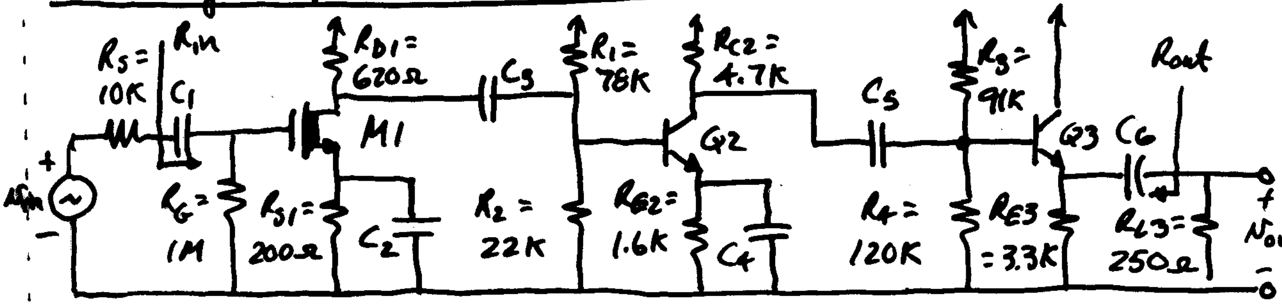
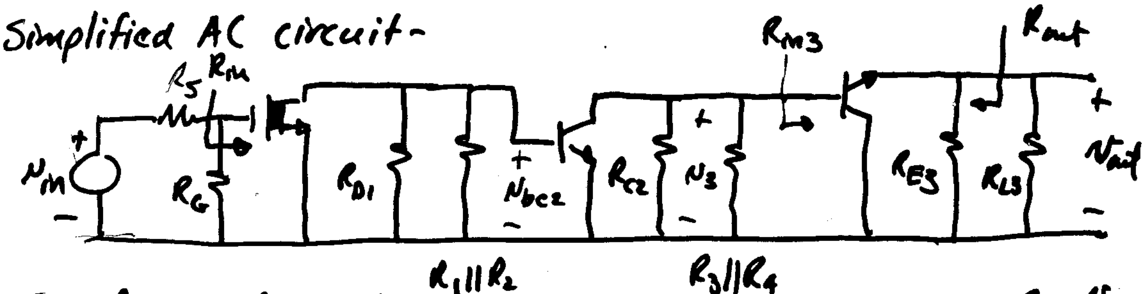
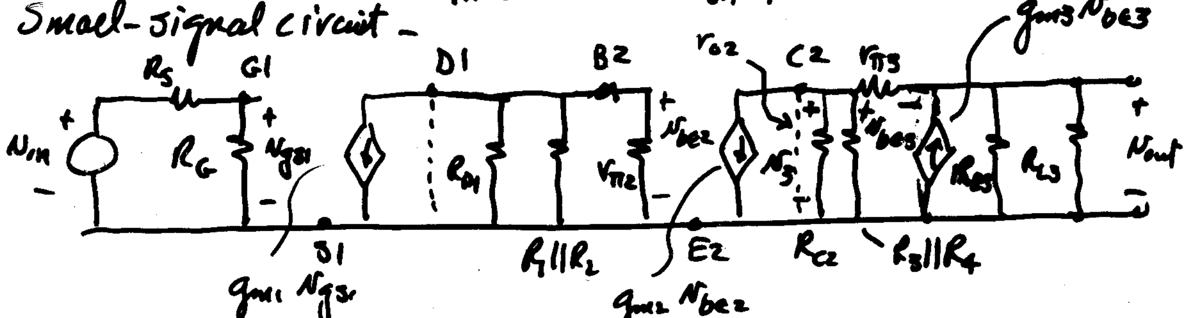
Multistage Amplifier Example – Cont'd



Simplified AC circuit –



Small-signal circuit –



$$R_{in} = R_G = 1M\Omega$$

$$R_{out} = R_{E3} \| \left[\frac{r_{\pi 3} + R_{C2} \| R_3 \| R_4}{1+\beta_3} \right]$$

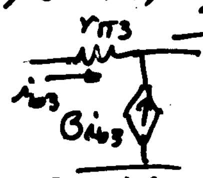
$$= 3.3K \| \left[\frac{1K + 4.7 \| 51.75K \| 54.2K}{81} \right]$$

(r_{o2})

$$= 60.4\,\Omega$$

$$\frac{v_{out}}{v_{in}} = \left(\frac{v_{out}}{v_{be3}}\right)\left(\frac{v_{be3}}{v_3}\right)\left(\frac{v_3}{v_{be2}}\right)\left(\frac{v_{be2}}{v_{gs1}}\right)\left(\frac{v_{s1}}{v_{in}}\right)$$

$$i_{b3}(1+\beta_3) = \frac{v_{be3}}{r_{\pi 3}}(1+\beta_3)$$



$$\frac{v_{out}}{v_{be3}} = \frac{(1+\beta_3)(R_{E3} \| R_{L3})}{r_{\pi 3}}$$

$$= \left(\frac{1}{r_{\pi 3}} + g_{m3}\right)(R_{E3} \| R_{L3}) = 18.82\ \text{V/V}$$

$$\frac{v_{be3}}{v_3} = ?$$

$$R_{in3} = r_{\pi 3} + (1+\beta_3)\left[R_{E3} \| R_{L3}\right] = 19.82\ K\Omega$$

$$\rightarrow \frac{r_{\pi 3}}{R_{in3}} = \frac{1}{19.82}$$

Cont'd –

$$\frac{v_3}{v_{be2}} = -g_{m2}\left[r_{o2} \| R_{C2} \| R_3 \| R_4 \| R_{in3}\right] = -62.8\,(3.322) = -208.6 \text{ V/V}$$

$$\frac{v_{be2}}{v_{gs1}} = -g_{m1}\left[r_{o1} \| R_{D1} \| R_1 \| R_2 \| r_{\pi 2}\right] = -10\text{mS}\,(0.4786\,\Omega) = -4.786 \text{ V/V}$$

$$\frac{v_{gs1}}{v_{in}} = \frac{R_G}{R_S + R_G} = \frac{1}{1.01}$$

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

Input signal –

Find the max. input to keep the amplifier in "small signal"

~~Stage~~:

	FET		BJT
For "s.s.",	$v_{gs1} \le 0.2\,(V_{GS} - V_T)$	or	$v_{be} \le 5\text{mV}$

Stage 1:

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

$$= 0.2\left[-1 + 2\right] = 0.2\text{ V}$$

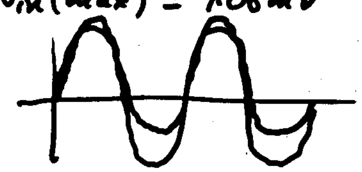
$v_{in} = 1.01\,(0.2) = 0.202\text{ V}$ ← max input to keep M1 "small signal"

Stage 2:

$v_{be2} \le 5\text{mV}$ $\qquad \frac{v_{be2}}{v_{in}} = 4.786 \rightarrow v_{in}(max) = \frac{5\text{mV}}{4.786}$

$v_{in}(max) = 1.06\text{mV}$

Stage 3:



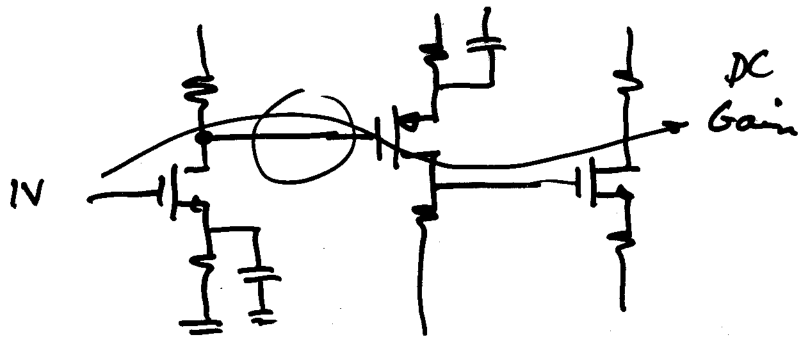
$v_{be3} \le 5\text{mV}$

$$v_{in}(max) = \frac{5\text{mV}}{\left(\frac{v_{be3}}{v_3}\right)\left(\frac{v_3}{v_{be2}}\right)\left(\frac{v_{be2}}{v_{gs1}}\right)\left(\frac{v_{gs1}}{v_{in}}\right)} \approx 0.1\text{ mV}$$

$\therefore |v_{in}| < 0.1\text{mV} \Longrightarrow$ max $V_{out} = 938.6\,(0.1\text{mV})$

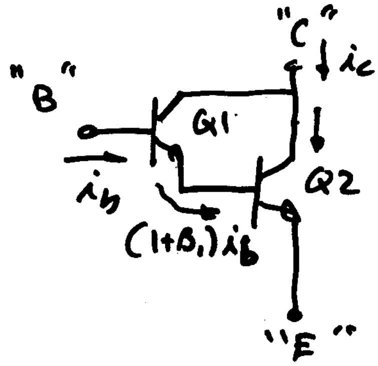
Direct Coupled Amplifiers

Amplifiers that don't use coupling capacitors.



Darlington Circuit

A BJT circuit to increase the CE current gain



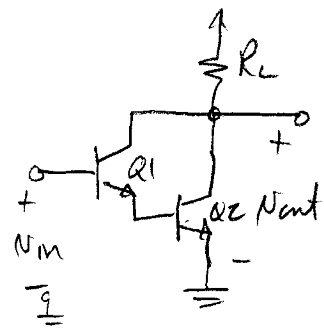
$$i_c = i_{c1} + i_{c2} = \beta_1 i_b + (1+\beta_1) i_b \beta_2$$

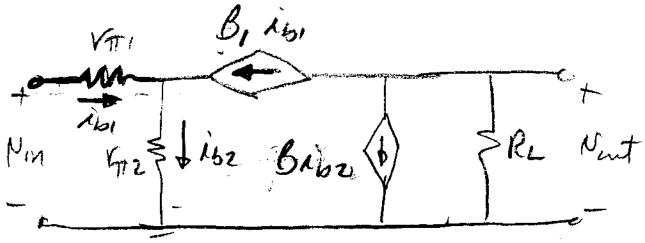
$$i_c \approx (1+\beta_1)\beta_2 \, i_b$$

Diff. Amps

This page includes material that is important but skipped in lecture 2/25/04

Darlington Amplifier





$$v_{out} = -\beta_1 i_{b1} R_L - \beta_2 i_{b2} R_L$$

$$v_{in} = i_{b1} r_{\pi 1} + (1+\beta_1) i_{b1} r_{\pi 2} \rightarrow i_{b1} = \frac{v_{in}}{r_{\pi 1} + (1+\beta_1) r_{\pi 2}}$$

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

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

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

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

$$r_{\pi 1} = \frac{\beta_1 V_t}{I_{C1}} \quad \& \quad r_{\pi 2} = \frac{\beta_2 V_t}{I_{C2}}$$

$$r_{\pi 2} = \frac{\beta_2 V_t}{(1+\beta_1) I_{C1}} = \frac{r_{\pi 1}}{1+\beta_1}$$

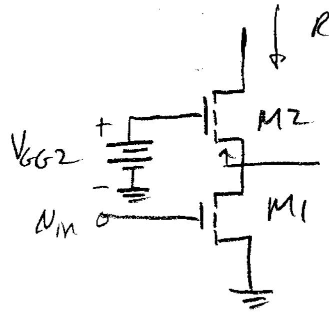
$R_L = 10K$
$\beta = 100$
$r_\pi = 1K$

$$\therefore \frac{v_{out}}{v_{in}} \simeq \frac{-\beta_2 \beta_1 R_L}{2 r_\pi} = \frac{10^4 \cdot 10^4}{2(1K)} = 5 \times 10^4$$

$$R_{in} = r_{\pi 1} + (1+\beta_1) r_{\pi 2} = 102K \qquad R_{out} = R_L$$

Cascode Amplifier

Increases "r_o"



$R_{out} \simeq g_{m2} r_{o2} r_{o1}$

$R_{i2} \simeq \frac{1}{g_{m2}}$ (depends on where drain is connected)