Voltage Amplifier Example - Continued

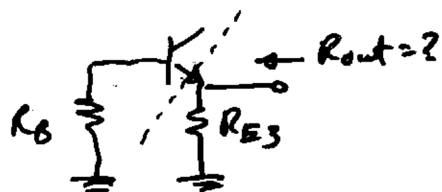
Small-signal model -

$R_S = 10K$ $\quad g_{m1}v_{gs1}$ $\quad r_{01} = 122K$ $\quad g_{m2}v_{be2}$ $\quad r_{02} = 54.2K$ $\quad g_{m3} = 79.6mS$ $\quad R_{E3} = 3.3K$

$R_G = 1M$ $\quad g_{m1} = 10mS$ $\quad R_{D1} = 620\Omega$ $\quad g_{m2} = 62.8mS$ $\quad R_{C2} = 4.7K$ $\quad r_{\pi 3} = 1K$ $\quad R_L = 250\Omega$

$R_{B2} = 17.16K$ $\quad r_{\pi 2} = 2.39K\Omega$ $\quad R_{B3} = 51.75K$ $\quad r_{03} = 34.4K$

Find R_{in}, R_{out} and $\frac{v_{out}}{v_{in}}$:



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

$$R_{out} = R_{E3} \| r_{o3} \| \left[\frac{r_{\pi 3} + R_{B3} \| R_{C2} \| r_{o2}}{1 + \beta_3} \right]$$

$$R_{out} = R_{E3} \| \frac{r_{\pi 3} + R_B}{1+\beta}$$

$$= 3.3k \| 34.4k \| \left[\frac{1k + 51.75k \| 4.7k \| 54.2k}{81} \right] = \underline{60.4\Omega}$$

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

$$\frac{v_{out}}{v_{be3}} = \left(g_{m3} + \frac{1}{r_\pi}\right)\left[r_{o3} \| R_{E3} \| R_L\right] = (1+\beta_3)\frac{r_{o3} \| R_{E3} \| R_L}{r_{\pi 3}}$$

$$\cong 81\left(\frac{R_{E3} \| R_L}{r_{\pi 3}}\right) = 81\left(\frac{232}{1000}\right) = 18.82$$

$$\frac{v_{be3}}{v_3} = \frac{r_{\pi 3}}{R_{in3}} = \frac{r_{\pi 3}}{r_{\pi 3} + (1+\beta_3)\left[r_{o3} \| R_{E3} \| R_L\right]} = \frac{1K}{19.82K} = \frac{1}{19.82}$$

$$\frac{v_3}{v_{be2}} = -g_{m2}\left[r_{o2} \| R_{C2} \| R_{B3} \| R_{in3}\right] = -62.8\,(3.322) = -208.6$$

$$\frac{v_{be2}}{v_{gs1}} = -g_{m1}\left[r_{o1} \| R_{D1} \| R_{B2} \| r_{\pi 2}\right] = (-10)(0.478) = -4.786$$

$$\frac{v_{gs1}}{v_{in}} = \frac{R_G}{R_S + R_G} = \left(\frac{1}{1.01}\right)$$

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

Voltage Amplifier Example – Cont'd

Current gain:

$$\frac{i_{out}}{i_{in}} = \frac{\frac{v_{out}}{R_{L3}}}{\frac{v_{in}}{R_S+R_{in}}} = \left(\frac{v_{out}}{v_{in}}\right)\left(\frac{R_S+R_{in}}{R_{L3}}\right) = \underline{\underline{3.79\times10^{6}\ A/A}}$$

Power gain:

$$\frac{P_{out}}{P_{in}} = \left(\frac{v_{out}}{v_{in}}\right)\left(\frac{i_{out}}{i_{in}}\right) = 3.56\times10^{9}\ W/W$$

Input signal range:

How large can v_{in} be and still be small signal?

MOSFETs $\quad v_{gs} \le 0.2\,(V_{GS}-V_T)$

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

Stage 1 –

$5mA \times 0.2K = 1V$

$$v_{gs1} \le 0.2\,(V_{GS1}-V_{TN}) = 0.2\,(-1V+2) = 0.2\ V$$

max $v_{in} \simeq 200mV$

Stage 2 –

$$v_{be2} \le 5mV \rightarrow v_{in}(max) = \frac{5mV}{Gain^{*}}$$

* Gain from output of stage to amplifier input

$$v_{in}(max) = \frac{5mV}{4.726} = 1.06mV$$

Stage 3 –

$$v_{be3} < 5mV \rightarrow v_{in}(max)$$

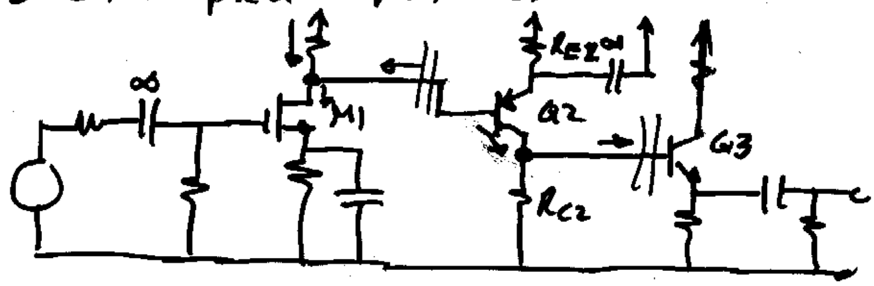
$$v_{in}(max) = \frac{5mV}{\left(\frac{v_{be3}}{v_3}\right)\left(\frac{v_3}{v_{be2}}\right)\left(\frac{v_{be2}}{v_{gs1}}\right)\left(\frac{v_{gs1}}{v_{in}}\right)} = 0.1mV$$

To keep the voltage in small-signal conditions

$v_{in}(max) = 100\mu A \rightarrow v_{out} = \underline{\underline{98.4mV}}$

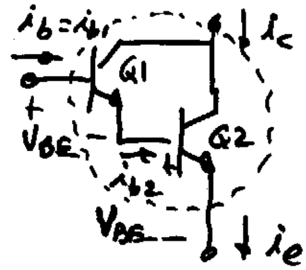
Comments on Sec. 15.2

1.) Direct coupled amplifiers.



$I_{D1} >> I_{B2}$ $\quad$ $I_{C2} >> I_{B3}$

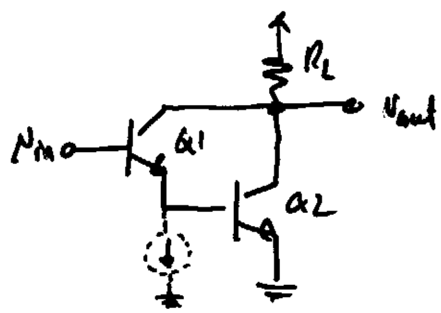
2.) Darlington Configuration



$$i_c = i_{c1} + i_{c2} = \beta_1 i_{b1} + \beta_2 i_{b2}$$

$$= \beta_1 i_b + \beta_2 (1+\beta_1) i_b \approx \beta_2 (1+\beta_1) i_b$$

$$i_c = \beta_{eff}\, i_b \rightarrow \beta_{eff} = \beta_2 (1+\beta_1)$$



$$R_{in} = r_{\pi 1} + (1+\beta_1) r_{\pi 2} = \frac{v_{in}}{i_b}$$

$$v_{out} = -\beta_{eff} R_L i_b$$

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

$$r_{\pi 1} = \frac{\beta_1 V_t}{I_{c1}} \quad \text{and} \quad r_{\pi 2} = \frac{\beta_2 V_t}{I_{c2}} = \frac{\beta_2 V_t}{\beta_1 I_{c1}} \approx \frac{1}{g_m}$$

Sec. 15.3

Diff. amps.

Quiz 06