Design Notes Expt 5

Setting the differential input resistance

$$R_{id} = 2r_{be} = \frac{2\beta_o}{g_m} = \frac{2\beta_o}{40I_C}$$

← PN2907, value is 254

require R_{id} > 100k

set 1M

So bias current, I_O in differential amplifier is

$$I_O = 2I_C = 2\frac{2\beta_o}{40R_{id}}$$

$$I_O = \frac{\beta_o}{10R_{id}} = \frac{254}{10 \times 1M} \simeq 25\mu A$$

Now to design the Widlar current mirror to bias the diff amp stage.

$$R_E I_O = V_T \ell n\left(\frac{I_{ref}}{I_O}\right) \text{ or } I_{ref} = I_O \exp\left(\frac{I_O R_E}{V_T}\right)$$

Don't know R_E or I_{ref}

? Try $I_O R_E = V_T$

绝对不这么try

Then $I_{ref} = I_O \exp(1)$

那就选这个

OR Set $I_{ref} = 10 \times I_O$ then

V_T is thermal vol and is appx 25mV at room temp

$$R_E = \frac{V_T}{I_O}\ell n(10) = \frac{25m}{25\mu}\ln(10) \simeq 2.3k\Omega$$

Resistor in other branch of CM is

$$R = \frac{V_{CC} + V_{EE} - 0.6}{I_{ref}} = \frac{9+9-0.6}{10 \times I_o} = \frac{9+9-0.6}{10 \times 25\mu} = 696k\Omega$$

元件props里有写

Gains

Gain of differential amplifier

forward Early Vol of PN2222

74.03

$$A_{Vd} = \frac{1}{V_T}\frac{V_{An}V_{Ap}}{V_{An}+V_{Ap}}$$

→ PN2907

115.7

$$= \frac{1}{25m}\,\frac{74.03 \times 115.7}{74.03 + 115.7} \simeq 1.8k$$

Gain of CE stage (assume CC gain is unity)

$$A_{VT} \approx A_{Vd} \times A_{VCE}$$

$$\text{So } A_{VCE} > \frac{5 \times 10^5}{A_{Vd}}$$

$$A_{VCE} = \frac{1}{V_T}\frac{V_{An}V_{Ap}}{V_{An}+V_{Ap}}$$

$A_{VT} = 1.8k \times 1.8k = 3.2M$

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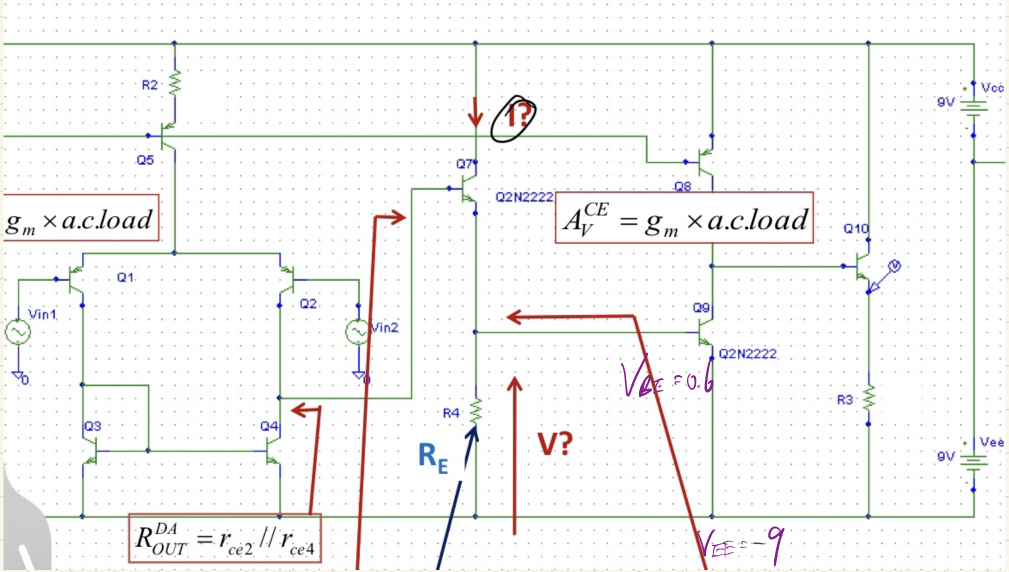


$$I_C \simeq I_E = \frac{V_{BE}}{R_E}$$

$$= \frac{0.6}{R_E} \qquad (1)$$

Require $R_i(CC) = 10R_o$

Sub

$$\frac{\beta_o}{40I_c} + (1+\beta_o)R_E \| R_L = 10\frac{V_{An}V_{Ap}}{(V_{An}+V_{Ap})I_c}$$

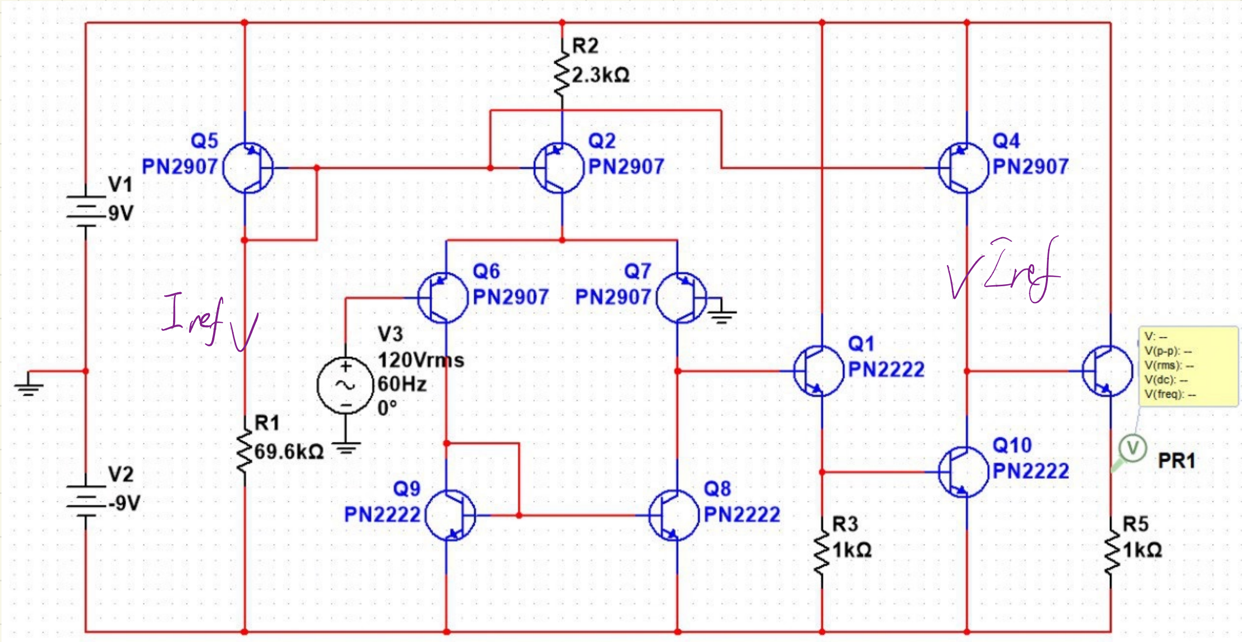
$$\frac{\beta_o}{40} + I_c(1+\beta_o)R_E \| R_L = 10\frac{V_{An}V_{Ap}}{V_{An}+V_{Ap}}$$

$$\frac{\beta_o}{40} + I_c(1+\beta_o)\frac{R_E\, r_{be}(CE)}{R_E + r_{be}(CE)} = 10\frac{V_{An}V_{Ap}}{V_{An}+V_{Ap}} \quad \text{———} \quad ②$$

Sub ① into ②

$$\frac{\beta_o}{40} + \frac{0.6}{R_E}(1+\beta_o)\frac{R_E\, r_{be}(CE)}{R_E + r_{be}(CE)} = 10\frac{V_{An}V_{Ap}}{V_{An}+V_{Ap}}$$

$$\frac{\beta_o}{40} + 0.6(1+\beta_o)\frac{r_{be}(CE)}{R_E + r_{be}(CE)} = 10\frac{V_{An}V_{Ap}}{V_{An}+V_{Ap}} \quad \text{———} \quad ③$$



$$r_{be}(CE) = \frac{\beta_0}{40 I_c} = \frac{\beta_0}{40 I_{ref}} \qquad (4)$$

Sub ④ into ③

$$\frac{\beta_0}{40} + 0.6\,C(1+\beta_0)\frac{\frac{\beta_0}{40I_{ref}}}{R_E + \frac{\beta_0}{40I_{ref}}} = 10\,\frac{V_{An}V_{Ap}}{V_{An}+V_{Ap}}$$

$$\frac{10\frac{V_{An}V_{Ap}}{V_{An}+V_{Ap}} - \frac{\beta_0}{40}}{0.6\,C(1+\beta_0)} = \frac{\frac{\beta_0}{40I_{ref}}}{R_E + \frac{\beta_0}{40I_{ref}}}$$

$$R_E = \frac{\beta_0}{40I_{ref}}\frac{0.6\,C(1+\beta_0)}{10\frac{V_{An}V_{Ap}}{V_{An}+V_{Ap}} - \frac{\beta_0}{40}} - \frac{\beta_0}{40I_{ref}}$$

$$= \frac{182}{40\times 250\mu}\frac{0.6\,C(1+182)}{10\times\frac{79.03\times 115.7}{79.03+115.7} - \frac{182}{40}} - \frac{182}{40\times 250\mu}$$

$$\frac{\beta_o}{g_m} = \frac{\beta_o}{40 I_C} \text{ ?}$$

goto page ①

Calculation for input resistance of CC coupling stage

$$R_i(CC) = r_{be}(CC) + (1+\beta_o)R_E // R_L$$

PN2222
182

$$R_E // R_L = \frac{R_E r_{be}(CE)}{R_E + r_{be}(CE)}$$

Set R_i (CC) to be much bigger than the output resistance of the Diff/ amp stage (which acts as the source resistance of the CC stage):

$$R_o^{DA} = \frac{\frac{V_{An}}{I_C} \times \frac{V_{Ap}}{I_C}}{\frac{V_{An}}{I_C} + \frac{V_{Ap}}{I_C}} = \frac{V_{An} V_{Ap}}{(V_{An} + V_{Ap}) I_C}$$

(need to try a bias current for the common emitter, CE stage)

Then get a quadratic equation for the CC bias current. Use this to calculate the gain of the CC stage

$$A_V = \frac{g_m R_E // R_L}{1 + g_m R_E // R_L} = \frac{g_m R_E // r_{be}(CE)}{1 + g_m R_E // r_{be}(CE)}$$

Output resistance of op-amp (set by another CC stage)

require $R_o < 1k$, set 100

$$R_o = \frac{r_{be} + R_S}{1+\beta_o} // R_E, \quad R_o = \left(\frac{r_{be}}{\beta_o} + \frac{R_S}{\beta_o}\right) // R_E \quad \text{This } r_{be} \text{ is that of CC} \quad (\beta_o = g_m r_{be})$$

?

$$R_o = \left(\frac{r_{be}}{\beta_o} + \frac{R_S}{\beta_o}\right) // \frac{V_{EE}}{I_C}$$

The source resistance, R_S is the output resistance of the previous stage (CE) – see equation for the differential amplifier.

Set R_o to meet the specification; rearranging gives a quadratic equation for this CC bias current.

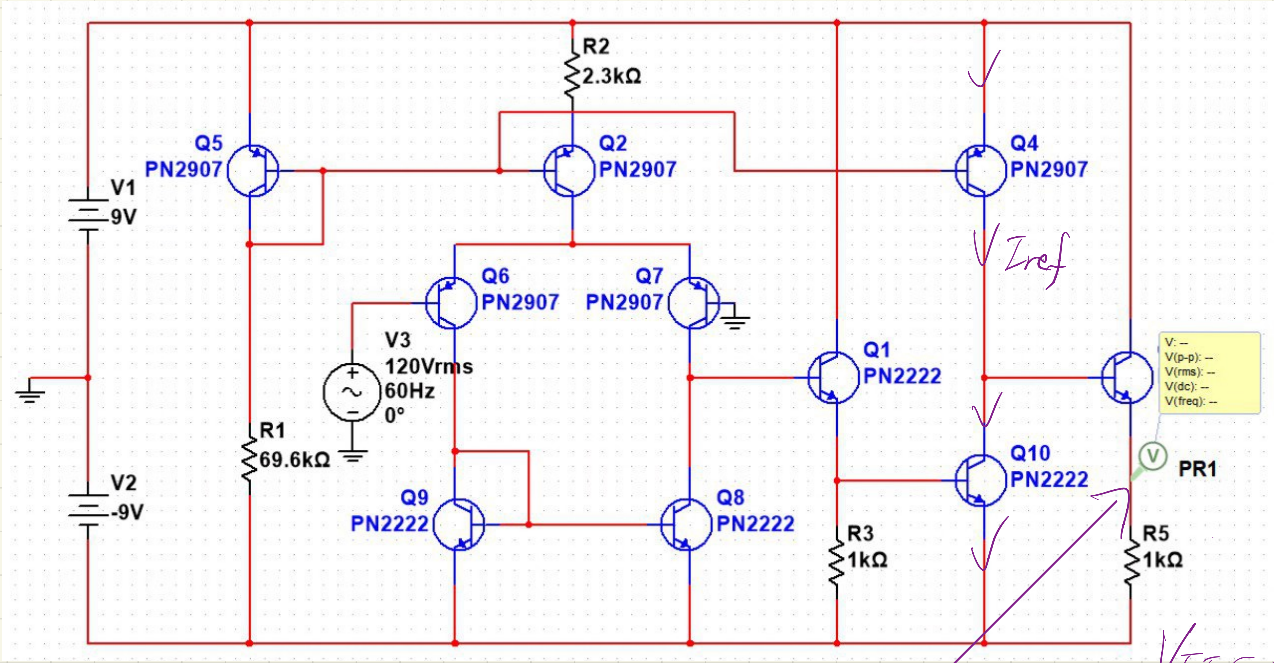
$$R_o = \left(\frac{\frac{\beta_o}{40 I_C}}{\beta_o} + \frac{R_S}{\beta_o}\right) // R_E$$

$$= \left(\frac{1}{40 I_C} + \frac{R_S}{\beta_o}\right) // R_E$$

$$= \left(\frac{1}{40 \frac{9}{R_E}} + \frac{R_S}{\beta_o}\right) // R_E$$

$$\frac{1}{R_o} = \frac{1}{\frac{R_E}{360} + \frac{R_S}{\beta_o}} + \frac{1}{R_E}$$

$$R_E \simeq 111\,\Omega$$



$V_{EE} = -9V$

As per specs, DC output vol = 0 V

$$I_C \simeq I_E = \frac{0-(-9)}{R_E}$$

$$= \frac{9}{R_E}$$

$$R_S = r_{CE}^{2907} \,//\, r_{CE}^{2222}$$

$$= \frac{V_A^{2907}}{I_{ref}} \,//\, \frac{V_A^{2222}}{I_{ref}}$$

$$= \frac{115.7}{250\mu} \,//\, \frac{74.03}{250\mu}$$

$$\simeq 180k$$