Solutions to Selected Problems (Problem Set 3)

Chapter 7: 7.37, 7.38. 7.39. 7.40. 7.42. 7.46. 7.57. 7.67. 7.68

7.37

Refer to Fig. P7.37

$$\frac{v_o}{v_i} = \frac{\alpha \times 20\,k\Omega}{(2r_e + 2\times 200)\,\Omega}$$

Where $r_e = \dfrac{V_T}{0.5/2} = \dfrac{0.05\,V}{0.5\,mA} = 100\,\Omega$

$$\frac{v_o}{v_i} \simeq \frac{20\,000}{600} = \underline{33.3\,V/V}$$

$$R_i = (\beta+1)(2r_e + 2\times 200) = 101\times 2\times 300 \simeq \underline{60\,k\Omega}$$

7.38

Refer to Fig P.7.38

Each transistor is operating at $I_E = 1\,mA$, thus

$r_e = 25\,\Omega$ and $r_\pi = 101\times 25 = 2525\,\Omega$

$$\frac{v_o}{v_i} = \frac{\alpha \times 7.5\,k\Omega}{(2r_e + 200)\,\Omega} \simeq \frac{7500}{250} = \underline{30\,V/V}$$

$$R_i = (\beta+1)(r_e + 200 + r_e) \simeq \underline{25\,k\Omega}$$

7.39

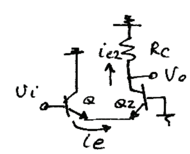
Refer to Fig P.7.39

(a) As a differential amplifier, the gain is given by

$$\frac{v_o}{v_i} = \frac{\alpha R_C}{2r_e} \quad (1)$$

(b) Transistor Q_1 can be considered as a common-collector stage. It is biased at $I/2$ and has a resistance r_{e2} in its emitter, thus.

$$i_e = \frac{v_i}{r_{e1} + r_{e2}} = \frac{v_i}{2r_e} \quad (2)$$



Now, Q_2 is connected in the common-base configuration. It has an input signal current i_e. Thus its collector signal current (in the direction indicated) will be $i_{e2} = \alpha i_e$ (3)

The output voltage will be

$v_o = i_{e2} \cdot R_C$ (4)

Combining equations (2) (3) and (4) provides:

CONT.

$\frac{v_o}{v_i} = \frac{\alpha R_C}{2 r_e}$, which is identical to the result found above in part (a)

7.40

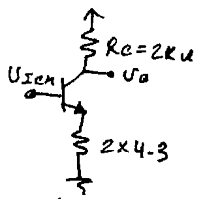
(a) $V_E = -0.7V$

Thus, $I = \frac{-0.7-(-5)}{4.3} = 1mA$ $\quad r_e = 50\Omega$

$A_d = \frac{v_o}{v_d} = \frac{\alpha \times 2}{2 r_e} \simeq \frac{2000}{2 \times 50} = 20$ V/V

(b) $A_{cm} \simeq \frac{\alpha R_C}{8.6 + r_e}$

$\simeq \frac{2}{8.65} = 0.23$ V/V



CM half circuit

(c) CMRR

$= 20 \log \left| \frac{A_d}{A_{cm}} \right| = 20 \log \frac{20}{0.23}$

$= 38.8$ dB

(d) $v_d = 2 \times 0.005 \sin(2\pi \times 1000t)$

$v_{Icm} = 0.1 \sin(2\pi \times 60t)$

Thus, $v_o = A_d \cdot v_d + A_{cm} \cdot v_{Icm}$

$= 20 \times 0.01 \sin 2\pi \times 1000t$

$+ 0.23 \times 0.1 \sin(2\pi \times 60t)$

$= 0.2 \sin 2\pi \times 1000t + 0.023 \sin 2\pi 60t$

7.42

Assume $\alpha = 1$ in small-signal calculations

(a) $A_d \Big|_{\text{single-ended output}} = \frac{\alpha (R_C \| r_o)}{2 r_e}$

where $r_e = \frac{0.025V}{0.25mA} = 100\Omega$

$r_o = \frac{200V}{0.25mA} = 800k\Omega$

$A_d \Big|_{\text{single ended}} \simeq \frac{20}{2 \times 0.1} = 100$ V/V

(b) $A_d \Big|_{\text{diff output}} = 2 \times A_d \Big|_{\text{single ended}}$

$= 200$ V/V

(c) $R_{id} = 2 r_\pi = 2 \times 201 \times 100$

$= 40.2 k\Omega$

CONT.

(d) $A_{cm} \Big|_{\text{single-ended output}} = \frac{R_C}{2R}$

$= \frac{20}{2000} = 0.01$ V/V

(e) $A_{cm} \Big|_{\text{diff out}} = 0$

7.46

Taken single-endedly

$A_{cm_s} = \frac{\alpha R_c}{2R_o}$

Let collector resistors be R_c & $R_c + \Delta R_c$, then

$A_{cm} = \frac{\alpha}{2R_o}(R_c + \Delta R_c - R_c)$

$= \alpha \frac{\Delta R_c}{2R_o}$

Which can be written as

$A_{cm_d} = \frac{\alpha R_c}{2R_o} \cdot \frac{\Delta R_c}{R_c} = A_{cm_s} \frac{\Delta R_c}{R_c}$

$CMRR = \frac{A_d}{A_{cmd}} = \frac{2 \cdot A_s}{A_{cm_s} \frac{\Delta R_c}{R_c}}$

$= \frac{A_s}{A_{cms}} \cdot \frac{2}{\frac{\Delta R_c}{R_c}}$

Thus, $20 \log \frac{2}{\frac{\Delta R_c}{R_c}} = 40\,dB$

$\rightarrow \Delta R_c / R_c = \underline{\underline{2\%}}$

7.57

Refer to Fig. P7.57.

(a) $R_{c1} = 5 \times 1.05 = 5.25\,K\Omega$

$R_{c2} = 5 \times 0.95 = 4.75\,K\Omega$

Perfect offset nulling will be achieved when x is such that

$R_{c1} + (x \times 1K\Omega) = R_{c2} + (1-x) \times 1K\Omega$

$\Rightarrow 5.25 + x = 4.75 + 1 - x$

$\Rightarrow x = \underline{\underline{0.25}}$

(b) $I_{c1} = 1.05\,mA$

$I_{c2} = 0.95\,mA$

Offset nulling is achieved when x is such that

$1.05(x + 5) = 0.95((1-x)+5)$

$x = \underline{\underline{0.225}}$

7.67

$R_{id} = (\beta+1)\,2r_e$; $r_e = \frac{25mV}{50\mu A} = 500\Omega$

$\rightarrow R_{id} = 101 \times 1000 = \underline{\underline{101K\Omega}}$

$R_o = r_{o4} // r_{o2} = \frac{r_o}{2}$; $r_o = \frac{V_A}{I_c}$

$\rightarrow r_o = \frac{160V}{50\mu A} = 3.2M\Omega$

Thus, $R_o = \underline{\underline{1.6M\Omega}}$

$G_m = g_{m1} = g_{m2} = \frac{50\mu A}{25mV} = \underline{\underline{2mA/V}}$

$A_d = G_m R_o = 2 \times 1600 = \underline{3200\ V/V}$

With a subsequent stage having a 100KΩ input resistance,

$A_d = G_m (R_o \parallel 100K\Omega)$

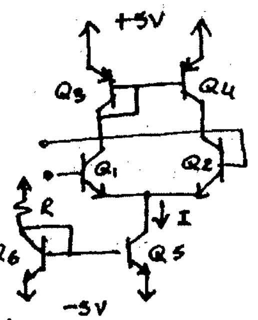
$= \underline{188.2\ V/V}$

even through its base-collector junction is forward biased by 0.4V)

$R_{icm} \simeq (\beta+1)\,[r_{o5} \parallel r_{o1} \parallel r_{o2}]$

$= 151 \times (400 \parallel 800 \parallel 800) = \underline{30M\Omega}$

7.68



$G_m = \frac{I/2}{V_T} = 5\frac{mA}{V}$

$I = \underline{250\mu A}$

$R = \frac{5-(-5)-V_{BE}}{I}$

$= \frac{9.3}{0.25} = \underline{37.2K\Omega}$

$R_{id} = (\beta+1)\,2r_e$ where,

$r_e = \frac{V_T}{I/2} = \frac{25mV}{0.125mA} = 200\Omega$

$\Longrightarrow R_{id} = 151 \times 2 \times 0.2 = \underline{60.4K\Omega}$

$r_o = \frac{V_A}{I_C} = \frac{100}{0.125} = 800K\Omega$

$R_o = \frac{r_o}{2} = \underline{400K\Omega}$

$A_d = g_m R_o = 5 \times 400 = \underline{2000}\ V/V$

$I_B = \frac{I/2}{\beta+1} = \frac{125}{151} = \underline{0.83\mu A}$

$v_{ICM}|_{max} \simeq V_{C1} + 0.4V$

$= 5 - 0.7 + 0.4 = \underline{4.7V}$

$v_{ICM}|_{min} = V_{B5} - 0.4 + 0.7$

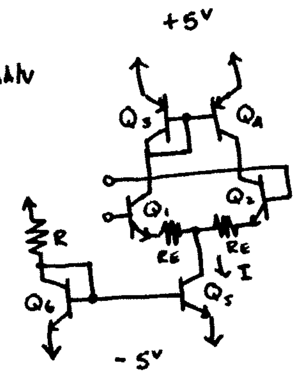
$= -4.3 - 0.4 + 0.7$

$= -4V$

Thus, the input common-mode range is −4V to +4.7V (where we have assumed that a transistor remains active

CONT.

For $R_E = 100\Omega$



$G_m = \frac{\alpha}{V_T/(I/2) + R_E} = 5\,mA/V$

$I = \underline{500\mu A}$

$R = \frac{5-(-5)-V_{BE}}{I}$

$= \frac{9.3}{0.5} = \underline{18.6\ k\Omega}$

$R_{id} = (\beta+1)(2r_e + 2R_E)$ where

$r_e = \frac{V_T}{I/2} = \frac{25mV}{0.25mA} = 100\Omega$

$\Longrightarrow R_{id} = 151 \times (2\times100 + 2\times100) = \underline{60.4k\Omega}$

$r_o = \frac{V_A}{I_C} = \frac{100}{0.25} = 400k\Omega$

$R_o = \frac{r_o}{2} = \underline{200k\Omega}$

$A_d = G_m R_o = 5 \times 200 = \underline{1000}\ V/V$

$I_B = \frac{I/2}{\beta+1} = \frac{250}{151} = \underline{1.66\mu A}$

$v_{ICM}|_{max} = V_{C1} + 0.4V$

$= 5 - 0.7 + 0.4 = \underline{4.7V}$

$v_{ICM}|_{min} = V_{B5} - 0.4 + (I/2)R_E + 0.7$

$= -4.3 - 0.4 + 0.05 + 0.7$

$= \underline{-3.95V}$