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**Abstract**—This manual is an introduction to control systems based on GATE problems. Links to sample Python codes are available in the text.

Download python codes using

## 1 STABILITY

## 2 ROUTH HURWITZ CRITERION

## 3 COMPENSATORS

## 4 NYQUIST PLOT

## 5 FEEDBACK SYSTEMS

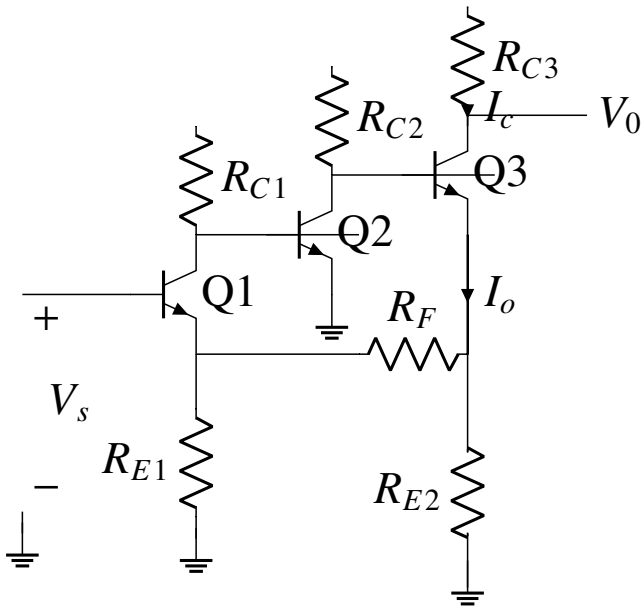


Fig. 5.0.0: circuit1

5.0.1. Part of the circuit of the MC1553 Amplifier is shown in circuit1 in fig.5.0.0. Assume the loop gain is large, find an approximate expression and value for the closed loop gain  $A_f = \frac{I_o}{V_s}$  and hence for  $\frac{I_c}{V_s}$ , take  $R_{E1} = 100\Omega$ ,  $R_{C1} = 9K\Omega$ ,  $R_{C2} = 5K\Omega$ ,  $R_F =$

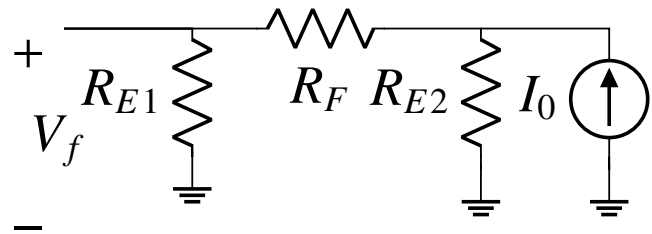


Fig. 5.0.1: circuit2

$640\Omega$ ,  $R_{E2} = 100\Omega$ ,  $R_{C3} = 600\Omega$ ,  $h_{fe} = 100$ ,  $r_0 = \infty$ ,  $I_{C1} = 0.6mA$ ,  $I_{C2} = 1mA$ ,  $I_{C3} = 4mA$

**Solution:** When  $GH \gg 1$ ,

$$A_f = \frac{I_o}{V_s} \approx \frac{1}{H} \quad (5.0.1.1)$$

feedback factor H can be found from feedback network. The feedback network consists of resistors  $R_{E1}$ ,  $R_F$ ,  $R_{E2}$  using circuit2 in fig.5.0.1 we get

$$H = \frac{V_f}{I_o} = \frac{R_{E2}}{R_{E2} + R_F + R_{E1}} \times R_{E1} \quad (5.0.1.2)$$

$$= \frac{100}{100 + 640 + 100} \times 100 = 11.9\Omega \quad (5.0.1.3)$$

thus,

$$A_f \approx \frac{1}{H} \quad (5.0.1.4)$$

$$= \frac{1}{R_{E2}} \left( 1 + \frac{R_{E2} + R_F}{R_{E1}} \right) \quad (5.0.1.5)$$

$$= \frac{1}{11.9} = 84mA/V \quad (5.0.1.6)$$

$$\frac{I_c}{V_s} \approx \frac{I_o}{V_s} = 84mA/V \quad (5.0.1.7)$$

5.0.2. Find  $\frac{V_0}{V_s}$

**Solution:**

$$\frac{V_0}{V_s} = \frac{-I_c R_{C3}}{V_s} = -84 \times 0.6 = -50.4V/V \quad (5.0.2.1)$$

5.0.3. use feedback analysis to find G, H,  $A_f$ ,  $\frac{V_0}{V_s}$ ,  $R_{in}$  and  $R_{out}$ . for calculating  $R_{out}$  assume  $r_0$  of  $Q_3$  is  $25k\Omega$

**Solution:** employing loading rules in fig.5.0.0, we obtain circuit3 given in fig.5.0.3

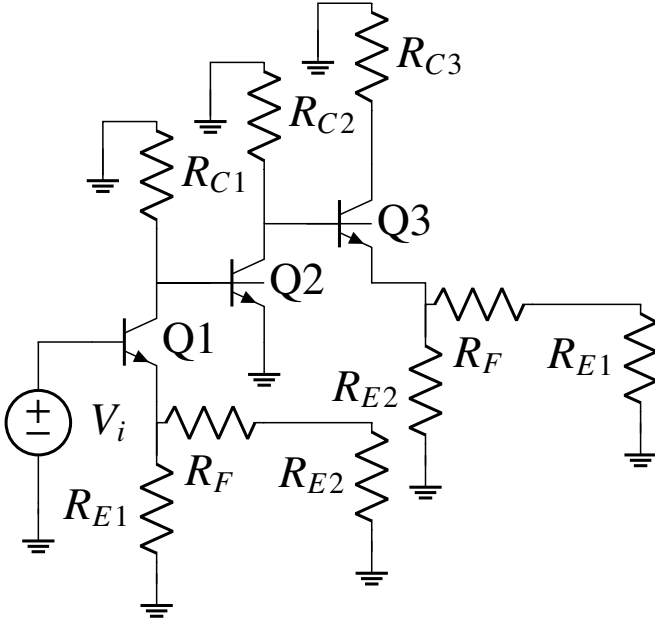


Fig. 5.0.3: circuit3

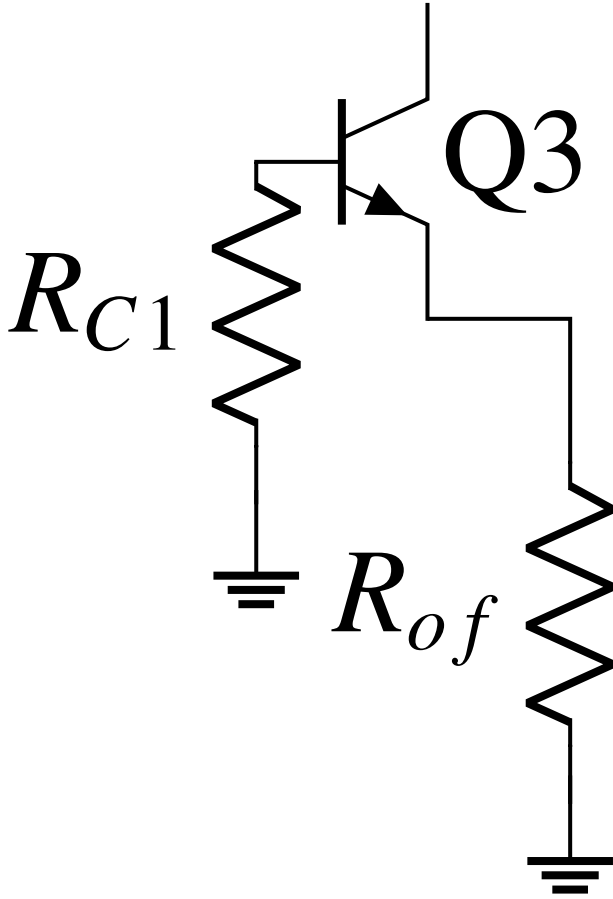


Fig. 5.0.3: circuit4

stage, this is written by inspection as-

$$\frac{V_{c1}}{V_i} = \frac{-\alpha(R_{c1} \parallel r_{\pi 2})}{r_{e1} + (R_{E1} \parallel (R_F + R_{E2}))} \quad (5.0.3.1)$$

Since  $Q_1$  is biased at 0.6mA,  $r_{e1} = 41.7\Omega$ . Transistor  $Q_2$  is biased at 1mA: thus  $r_{\pi 2} = \frac{h_{fe}}{g_{m2}} = \frac{100}{40} = 2.5K\Omega$ . Substituting these values together with  $\alpha_1 = 0.99$ ,  $R_{C1} = 9K\Omega$ ,  $R_{E1} = 100\Omega$ ,  $R_F = 640\Omega$ , and  $R_{E2} = 100\Omega$ , results in

$$\frac{V_{c1}}{V_i} = -14.92V/V \quad (5.0.3.2)$$

Next, we determine the gain of the second stage, which can be written by inspection (noting that  $V_{b2} = V_{c1}$ ) as

$$\frac{V_{c2}}{V_{c1}} = -g_{m2}R_{c2} \parallel (h_{fe} + 1)[r_{e3} + (R_{E2} \parallel (R_F + R_{E1}))] \quad (5.0.3.3)$$

substituting the values, results in

$$\frac{V_{c2}}{V_{c1}} = -131.2V/V \quad (5.0.3.4)$$

Finally, for the third stage we can write by inspection

$$\frac{I_0}{V_{c2}} = \frac{I_{e3}}{V_{b3}} = \frac{1}{r_{e3} + (R_{E2} \parallel (R_F + R_{E1}))} \quad (5.0.3.5)$$

$$\frac{1}{6.25 + (100 \parallel 740)} = 10.6mA/V \quad (5.0.3.6)$$

combining the gains of the three stages results in

$$G = \frac{I_0}{V_i} = -14.92 \times -131.2 \times 10.6 \times 10^{-3} = 20.7A/V \quad (5.0.3.7)$$

the closed loop gain  $A_f$  is found from

$$A_f = \frac{I_0}{V_s} = \frac{G}{1 + GH} = \frac{20.7}{1 + 20.7 \times 11.9} = 83.7mA/V \quad (5.0.3.8)$$

which we note is very close to the approximate value found in (5.0.1.7), above the voltage gain is found from

$$\frac{V_0}{V_s} = \frac{-I_c R_{c3}}{V_s} \approx \frac{-I_0 R_{c3}}{V_s} = -A_f R_{c3} \quad (5.0.3.9)$$

$$= -83.7 \times 10^{-3} \times 600 = -50.2V/V \quad (5.0.3.10)$$

to find  $G = \frac{I_0}{V_i}$  we determine the gain of first

which is also very close to the approximate value found in (5.0.1.7) above given by

$$R_{in} = R_i f = R_i(1 + GH) \quad (5.0.3.11)$$

where  $R_i$  is the input resistance of the A circuit. The value of  $R_i$  can be found from the circuit in fig.5.0.3 as follows:

$$R_i = (h_{fe} + 1)(r_{e1} + (R_{E1} || (R_F + R_{E2}))) = 13.65 K\Omega \quad (5.0.3.12)$$

$$R_{if} = 13.65(1 + 20.7 \times 11.9) = 3.38 M\Omega \quad (5.0.3.13)$$

$$R_{of} = R_o(1 + AH) \quad (5.0.3.14)$$

where  $R_o$  can be determined to be

$$R_o = (R_{E2} || (R_F + R_{E1})) + r_{e3} + \frac{R_{C2}}{h_{fe} + 1} \quad (5.0.3.15)$$

which, for the values given, yields  $R_o = 143.9\Omega$ . The output resistance  $R_{of}$  of the feedback amplifier can now be found as

$$R_{of} = R_o(1 + GH) = 143.9(1 + 20.7 \times 11.9) = 35.6 K\Omega \quad (5.0.3.16)$$

$$R_{out} = r_{o3} + [R_{of} || (r_{\pi3} + R_{C2})](1 + g_{m3} r_{o3} \frac{r_{\pi3}}{r_{\pi3} + R_{C2}}) \quad (5.0.3.17)$$

$$= 25 + [35.6 || (5.625)][1 + 160 \times 25 \frac{0.625}{5.625}] = 2.19 M\Omega \quad (5.0.3.18)$$

thus  $R_{out}$  is increased (from  $r_{o3}$ ) but not by  $(1+GH)$