

# Control Systems

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**Abstract**—This manual is an introduction to control systems in feedback circuits. Links to sample Python codes are available in the text.

Download python codes using

svn co <https://github.com/gadepall/school/trunk/control/feedback/codes>

## 1 FEEDBACK TRANSCONDUCTANCE AMPLIFIER: SERIES-SERIES

1.0.1. draw the block diagram of a Feedback Transconductance Amplifier(series-series)

**Solution:** fig.1.0.1 gives us the required block diagram

$$T = \frac{I_o}{V_s} = \frac{G}{1 + GH} \quad (1.0.1.1)$$

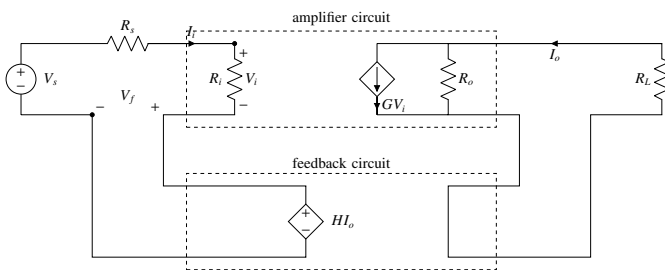


Fig. 1.0.1: Feedback Transconductance Amplifier

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1.0.2. draw the equivalent amplifier circuit block diagram of fig.1.0.1

**Solution:** fig.1.0.2 gives the required block diagram

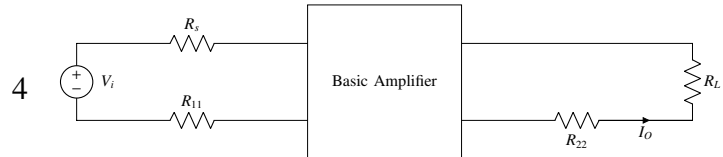


Fig. 1.0.2: Amplifier circuit block diagram

$$G = \frac{I_o}{V_i} \quad (1.0.2.1)$$

$R_{11}$  and  $R_{22}$  are obtained from fig.1.0.2

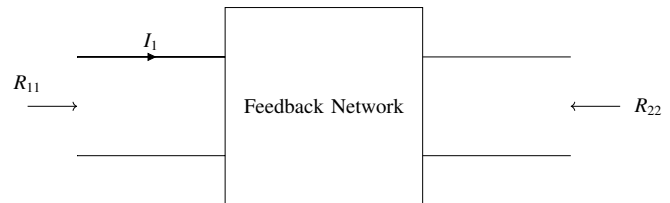


Fig. 1.0.2: feedback network

1.0.3. draw the equivalent feedback circuit block diagram of fig.1.0.1

**Solution:** fig.1.0.3 gives the required block diagram

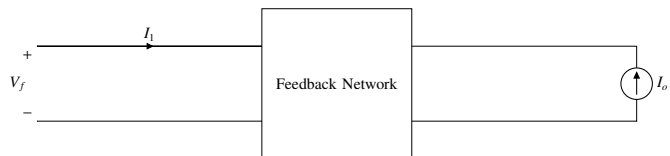


Fig. 1.0.3: Feedback circuit block diagram

$$H = \frac{V_f}{I_o} \Big|_{I_i=0} \quad (1.0.3.1)$$

1.0.4. Part of the circuit of the MC1553 Amplifier is shown in circuit1 in fig.1.0.4 ,Answer below questions using equivalent block diagrams in fig.1.0.1 and values from Table 1.0.4

1.0.5. feedback analysis to find open loop gain G

**Solution:** employing equivalent amplifier block diagram fig.1.0.2 into circuit in fig.1.0.4,  $R_{11}$  and  $R_{22}$  are

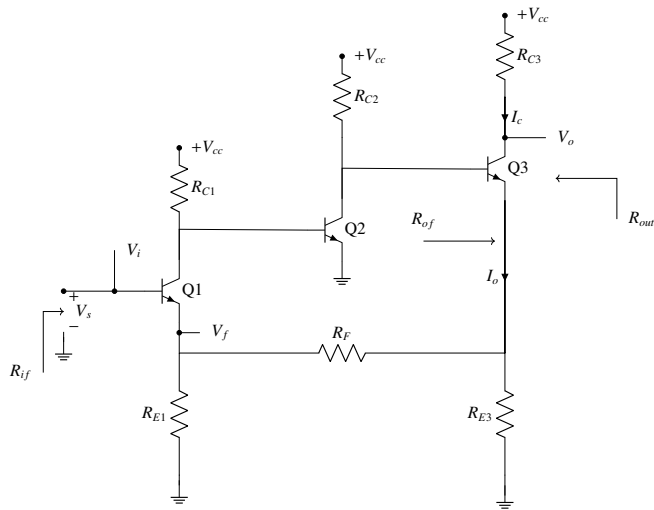


Fig. 1.0.4: circuit1

Parameter	Value
$R_{C1}$	$9k\Omega$
$R_{E1}$	$100\Omega$
$R_{C2}$	$5k\Omega$
$R_F$	$640\Omega$
$R_{E2}$	$100\Omega$
$R_{C3}$	$600\Omega$
$h_{fe}$	<b>100</b>
$r_o$	$\infty\Omega$
$I_{C1}$	<b>0.6mA</b>
$I_{C2}$	<b>1mA</b>
$I_{C3}$	<b>4mA</b>
$r_{e1}$	$41.7\Omega$
$r_{\pi2}$	$2.5k\Omega$
$\alpha_1$	<b>0.99</b>
$g_{m2}$	<b>40mA/V</b>
$r_{e3}$	$6.25\Omega$
$r_{o3}$	$25k\Omega$
$r_{\pi3}$	$625\Omega$

TABLE 1.0.4: parameters

found from feedback circuit in fig.1.0.4 using rule from fig.1.0.2 we finally obtain

$$R_s, R_L = 0 \quad (1.0.5.1)$$

$$R_{11} = R_{E1} \parallel (R_F + R_{E2}) \quad (1.0.5.2)$$

$$R_{22} = R_{E2} \parallel (R_F + R_{E1}) \quad (1.0.5.3)$$

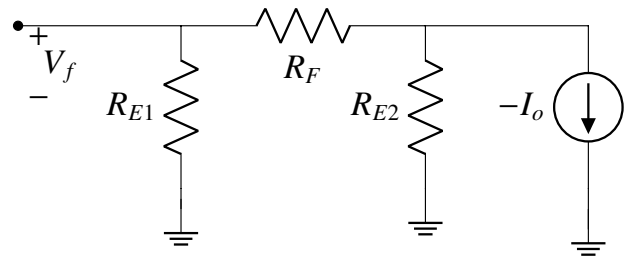


Fig. 1.0.4: H circuit

finally Amplifier circuit is obtained shown in fig.1.0.5

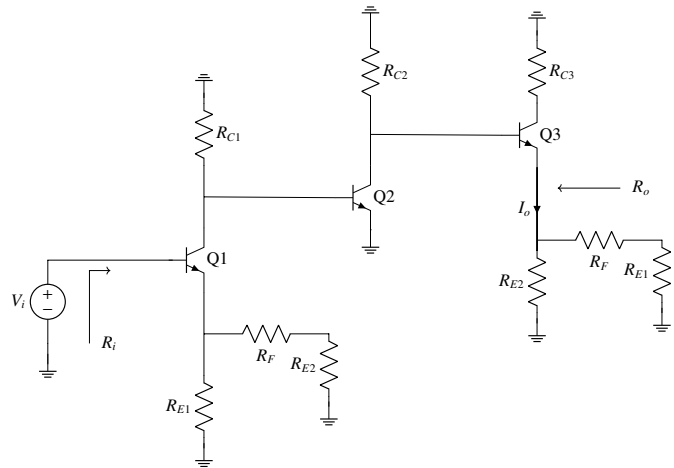


Fig. 1.0.5: G circuit

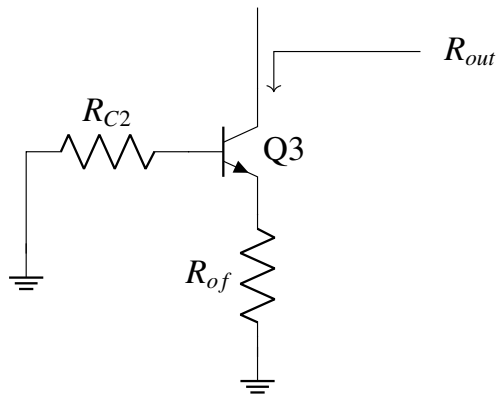


Fig. 1.0.5: circuit4

to find  $G = \frac{I_o}{V_i}$  we determine the gain of first stage, this is written by inspection as-

$$\frac{V_{c1}}{V_i} = \frac{-\alpha(R_{C1} \parallel r_{\pi2})}{r_{e1} + (R_{E1} \parallel (R_F + R_{E2}))} \quad (1.0.5.4)$$

using values from 1.0.4

$$\frac{V_{c1}}{V_i} = -14.92V/V \quad (1.0.5.5)$$

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

$$\frac{V_{c2}}{V_{c1}} = -g_{m2}R_{c2}[(h_{fe} + 1)(r_{e3} + (R_{E2} \parallel (R_F + R_{E1})))] \quad (1.0.5.6)$$

substituting results in

$$\frac{V_{c2}}{V_{c1}} = -131.2V/V \quad (1.0.5.7)$$

Finally, for the third stage we can write by inspection

$$\frac{I_0}{V_{c2}} = \frac{I_{e3}}{V_{b3}} = \frac{1}{r_{e3} + (R_{E2} \parallel (R_F + R_{E1}))} \quad (1.0.5.8)$$

substituting values from 1.0.4 gives

$$\frac{I_0}{V_{c2}} = 10.6mA/V \quad (1.0.5.9)$$

combining the gains of the three stages results in

$$G = \frac{I_0}{V_i} = -14.92 \times -131.2 \times 10.6 \times 10^{-3} = 20.7A/V \quad (1.0.5.10)$$

#### 1.0.6. Find Feedback Factor H

**Solution:** employing the equivalent feedback circuit block diagram we get H circuit in fig.1.0.4

$$H = \frac{V_f}{I_0} = \frac{R_{E2}}{R_{E2} + R_F + R_{E1}} \times R_{E1} \quad (1.0.6.1)$$

$$H = \frac{100}{100 + 640 + 100} \times 100 = 11.9\Omega \quad (1.0.6.2)$$

#### 1.0.7. Find closed loop gain T and Voltage Gain $V_0/V_s$

**Solution:**

$$T = \frac{I_0}{V_s} = \frac{G}{1 + GH} = \frac{20.7}{1 + 20.7 \times 11.9} = 83.7mA/V \quad (1.0.7.1)$$

the voltage gain is found from

$$\frac{V_0}{V_s} = \frac{-I_c R_{c3}}{V_s} \approx \frac{-I_0 R_{c3}}{V_s} = -T R_{c3} \quad (1.0.7.2)$$

$$= -83.7 \times 10^{-3} \times 600 = -50.2V/V \quad (1.0.7.3)$$

#### 1.0.8. Now assume Loop gain is large and find approximate expression for closed loop gain $T = \frac{I_0}{V_s}$

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

$$T = \frac{I_0}{V_s} \approx \frac{1}{H} \quad (1.0.8.1)$$

as

$$H = \frac{V_f}{I_0} = \frac{R_{E2}}{R_{E2} + R_F + R_{E1}} \times R_{E1} \quad (1.0.8.2)$$

$$= \frac{100}{100 + 640 + 100} \times 100 = 11.9\Omega \quad (1.0.8.3)$$

thus,

$$T = \frac{1}{11.9} = 84mA/V \quad (1.0.8.4)$$

$$\frac{I_c}{V_s} \approx \frac{I_0}{V_s} = 84mA/V \quad (1.0.8.5)$$

which we note is very close to the approximate value found in (1.0.7.1)

#### 1.0.9. Find $R_{in}$ and $R_{out}$ for circuit in fig.1.0.4

**Solution:**

$$R_{in} = R_{if} = R_i(1 + GH) \quad (1.0.9.1)$$

where  $R_i$  is the input resistance of the G circuit. The value of  $R_i$  can be found from the circuit in fig.1.0.5 as follows:

$$R_i = (h_{fe} + 1)(r_{e1} + (R_{E1} \parallel (R_F + R_{E2}))) = 13.65K\Omega \quad (1.0.9.2)$$

$$R_{if} = 13.65(1 + 20.7 \times 11.9) = 3.38M\Omega \quad (1.0.9.3)$$

$$R_{of} = R_o(1 + GH) \quad (1.0.9.4)$$

where  $R_o$  can be determined to be

$$R_o = (R_{E2} \parallel (R_F + R_{E1})) + r_{e3} + \frac{R_{C2}}{h_{fe} + 1} \quad (1.0.9.5)$$

from values in Table 1.0.4, yields  $R_o = 143.9\Omega$ . The output resistance  $R_{of}$  of the feedback amplifier can now be found as

$$R_{of} = R_o(1 + GH) = 143.9(1 + 20.7 \times 11.9) = 35.6K\Omega \quad (1.0.9.6)$$

$R_{out}$  is found by using circuit4 in fig.1.0.5

$$R_{out} = r_{o3} + [R_{of} \parallel (r_{\pi3} + R_{C2})](1 + g_{m3}r_{o3} \frac{r_{\pi3}}{r_{\pi3} + R_{C2}}) \quad (1.0.9.7)$$

$$= 25 + [35.6 \parallel (5.625)][1 + 160 \times 25 \frac{0.625}{5.625}] = 2.19M\Omega \quad (1.0.9.8)$$

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

#### 1.0.10. put the obtained parameters in a table

**Solution:** 1.0.10 table gives us the calculated values

#### 1.0.11. Represent this amplifier in a control system Block Diagram

**Solution:** figure in fig.1.0.11 represents our control system

#### 1.0.12. write a code for doing calculations and verify the values obtained in 1.0.10

**Solution:** following code does all the calculations of above equations to give parameters in 1.0.10

```
codes/ee18btech11007/circuit_calc.py
```

Parameter	Value
<b>G</b>	<b>20.7A/V</b>
<b>H</b>	<b>11.9Ω</b>
<b>T</b>	<b>83.7mA/V</b>
$V_o/V_s$	<b>-50.2V/V</b>
$R_{in}$	$3.38M\Omega$
$R_{out}$	$2.19M\Omega$
$R_{of}$	$35.6k\Omega$

TABLE 1.0.10: calculated parameters

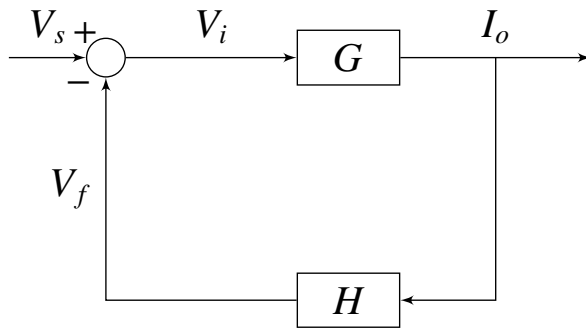


Fig. 1.0.11: block diagram

2 FEEDBACK VOLTAGE AMPLIFIER: SERIES-SHUNT

3 FEEDBACK CURRENT AMPLIFIER: SHUNT-SERIES

3.1 *Ideal Case*

3.2 *Practical Case*