Oscillator

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Contents

For the circuit shown in Fig. 1.1, find the loop gain $L(s) = G(s)H(s)$, $L(\jmath\omega)$, the frequency for zero loop phase, and R_2/R_1 for oscillation.

1. Draw the equivalent control system representation for the circuit in Fig. 1.1 as well as the small signal model.
   Solution: See Figs. 1.2, 1.3 and 1.4. Oscillators do not include input signal.

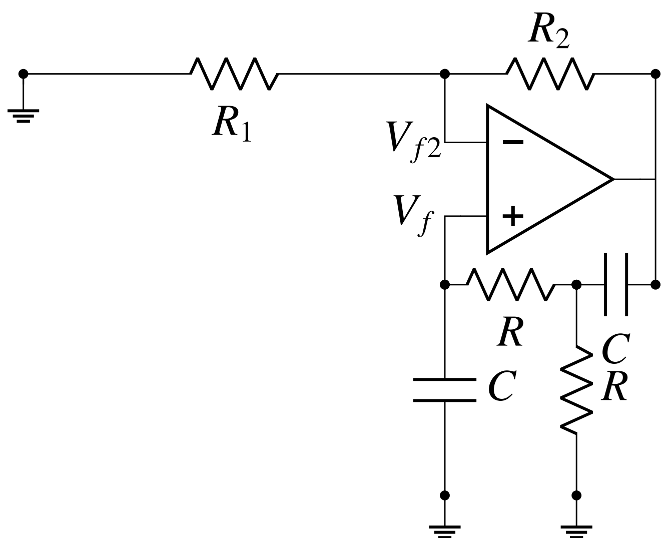

Fig. 1.1

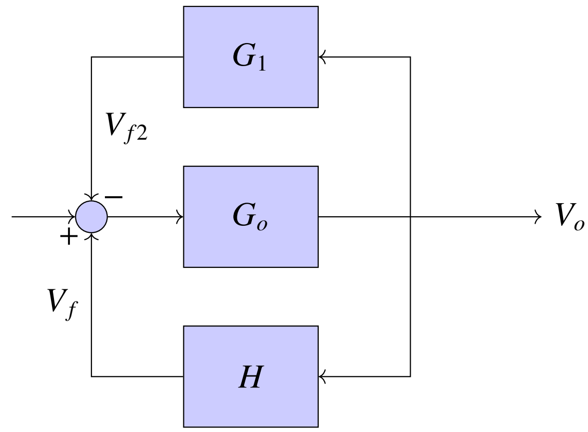

Fig. 1.2: Block diagram

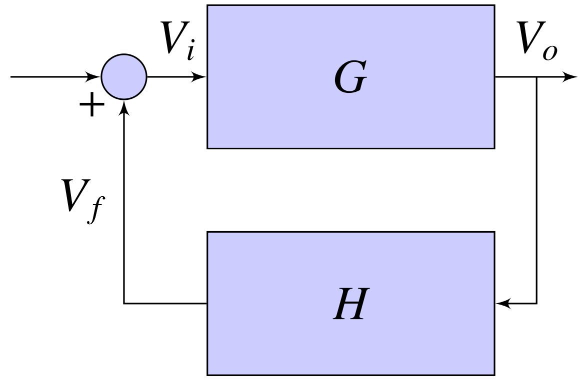

Fig. 1.3: Simplified equivalent block diagram

2. Draw the block diagram and circuit diagram for H.
   Solution: See Figs. 2.5 and 2.6.
3. Find H.
   Solution: In Fig. 2.6, let I_o be the current flowing from V_o. Then

$$I_o = \frac{V_o}{\frac{1}{sC} + R \parallel \left(R + \frac{1}{sC}\right)} \tag{3.1}$$

Using current division,

$$V_f = I_o \frac{R}{R + \left(R + \frac{1}{sC}\right)} \times \frac{1}{sC} \tag{3.2}$$

From (3.1) and (3.2),

$$\frac{V_f}{V_o} = \frac{R}{R + \left(R + \frac{1}{sC}\right)} \times \frac{1}{sC} \times \frac{1}{\frac{1}{sC} + R \parallel \left(R + \frac{1}{sC}\right)} \tag{3.3}$$

$$\implies H = \frac{1}{\left(3 + sRC + \frac{1}{sRC}\right)} \tag{3.4}$$

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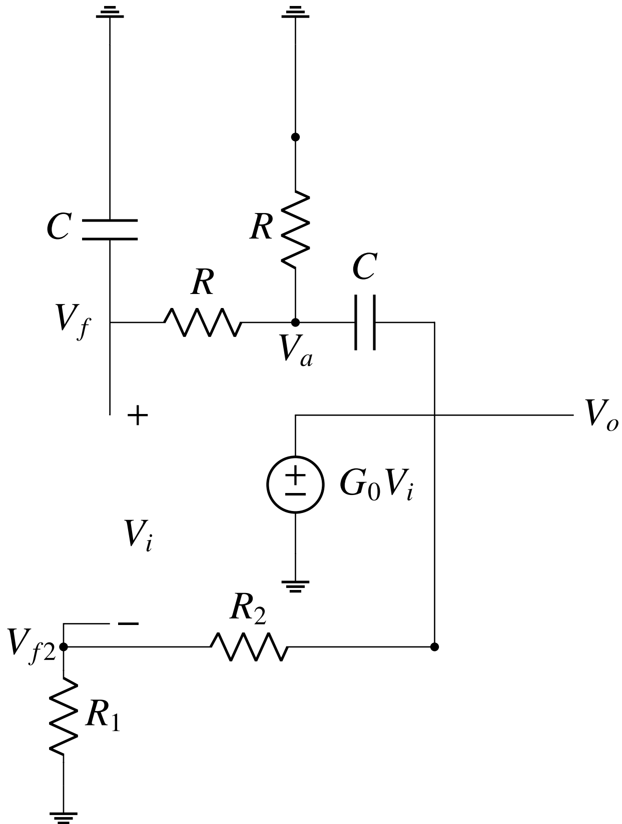

Fig. 1.4

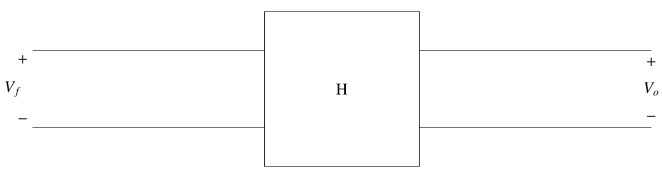

Fig. 2.5: Feedback block diagram

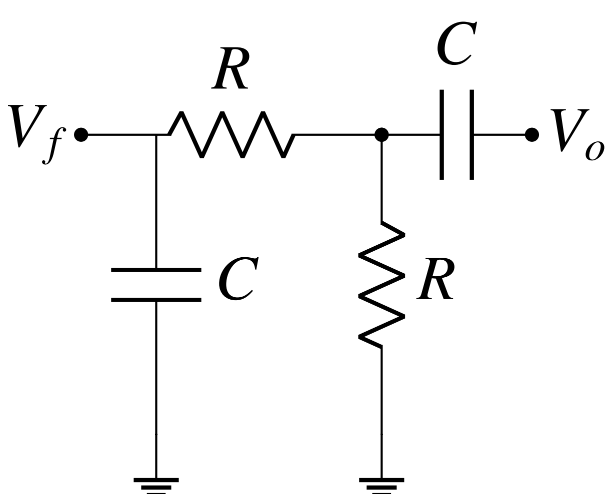

Fig. 2.6: Feedback circuit

after simplification.

4. Find R_{11} and R_{22} from Fig. 2.6.
Solution: Shorting V_o to ground,

$$R_{11} = \frac{1}{sC} \parallel \left(R + R \parallel \frac{1}{sC}\right) \tag{4.1}$$

Shorting V_f to ground,

$$R_{22} = \frac{1}{sC} + \frac{R}{2} \tag{4.2}$$

5. Draw the block diagram and circuit diagram for G.
Solution: See Figs. 5.1 and 5.2.

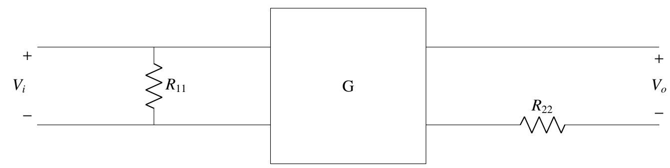

Fig. 5.1: Open loop block diagram

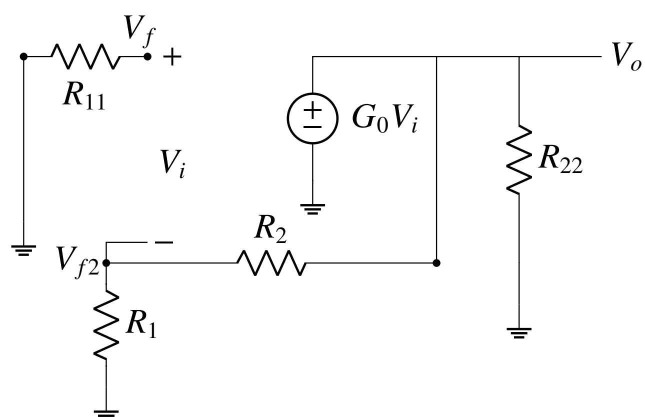

Fig. 5.2: Open loop circuit diagram

6. Find G.
Solution: From Fig. 5.2,

$$V_{f_2} = \left(\frac{R_1}{R_1 + R_2}\right) V_o \tag{6.1}$$

From Fig. 1.2,

$$G_1 = \frac{V_{f_2}}{V_o} \tag{6.2}$$

$$= \frac{R_1}{R_1 + R_2} \tag{6.3}$$

From Fig. 1.2 ,G_1 is the negative feedback factor and G_0 is the gain of the opamp.Therefore,equivalent G is given by

$$G = \frac{G_0}{1+G_0G_1} \tag{6.4}$$
$$= \frac{1}{\frac{1}{G_0}+G_1} \tag{6.5}$$
$$\implies G \approx \frac{1}{G_1}, \quad G_0 \to \infty \tag{6.6}$$
$$\text{or, } G = \frac{R_1+R_2}{R_1} = 1+\frac{R_2}{R_1} \tag{6.7}$$

using (6.3).

7. Find the loop gain $L(s)$.
Solution: From (6.7) and (3.4),

$$L(s) = G(s)H(s) \tag{7.1}$$
$$\implies L(s) = \left(\frac{1+\frac{R_2}{R_1}}{3+sRC+\frac{1}{sRC}}\right) \tag{7.2}$$

8. Find the closed loop gain $T(s)$.
Solution: From Fig. 1.3,

$$T(s) = \frac{G}{1-GH(s)} = \frac{G}{1-L(s)} \tag{8.1}$$
$$= \frac{\left(1+\frac{R_2}{R_1}\right)}{1-\left(\frac{1+\frac{R_2}{R_1}}{3+sRC+\frac{1}{sRC}}\right)} \tag{8.2}$$

9. Find the conditions for oscillation.
Solution: For oscillations to start,
- $T(s)$ should have imaginary poles.
- $L(0) \geq 1$

For $T(s)$ to have imaginary poles,

$$\text{Im}\left\{L(\jmath\omega)\right\} = 0 \tag{9.1}$$
$$\implies L(\jmath\omega) = \left(\frac{1+\frac{R_2}{R_1}}{3+j\left(\omega RC-\frac{1}{\omega RC}\right)}\right) \tag{9.2}$$

From (7.2),

$$L(\jmath\omega) = \left(\frac{1+\frac{R_2}{R_1}}{3+j\left(\omega RC-\frac{1}{\omega RC}\right)}\right) \tag{9.3}$$
$$\implies j\left(\omega RC-\frac{1}{\omega RC}\right) = 0 \tag{9.4}$$
$$\text{or, } \omega = \frac{1}{RC} \tag{9.5}$$

Also, from equation (7.2)

$$L(0) \geq 1 \implies \left(\frac{1+\frac{R_2}{R_1}}{3+j(0)}\right) \geq 1 \tag{9.6}$$
$$\text{or, } \frac{R_2}{R_1} \geq 2 \tag{9.7}$$

10. Find the amplitude and frequency for some arbitrary R,C values given in Table 10.

Parameter	Value
R	250Ω
C	$0.2\mu F$
R_2	$2k\Omega$
R_1	$1k\Omega$

TABLE 10

Solution: Substituting the above values in equation (8.2) results in

$$T(s) = \frac{3\left(25\times10^{-10}s^2+15\times10^{-5}s+1\right)}{25\times10^{-10}s^2+1} \tag{10.1}$$

The following code gives the step response shown in equation(10.2).

```
codes/ee18btech11047/
    ee18btech11047_response.py
```

$$y(t) = 3\left(3\sin 20000t+1\right)u(t) \tag{10.2}$$

The following code plots the step response of the system. This, in fact is the output of Fig. 1.1.

```
codes/ee18btech11047/ee18btech11047.py
```

Amplitude: From Fig. 10 V(peak-peak) is

$$V_{p-p} = 11.99-(-5.99) = 17.98 \tag{10.3}$$

$$V_{max} = \frac{V_{p-p}}{2} = 8.99 \tag{10.4}$$

Frequency: Theoretical frequency is obtained using equation (9.5)

$$\omega = \frac{1}{RC} = \frac{1}{250\times(0.2\times10^{-6})} \tag{10.5}$$

$$\implies \omega = 2\times10^4 rad/sec \tag{10.6}$$

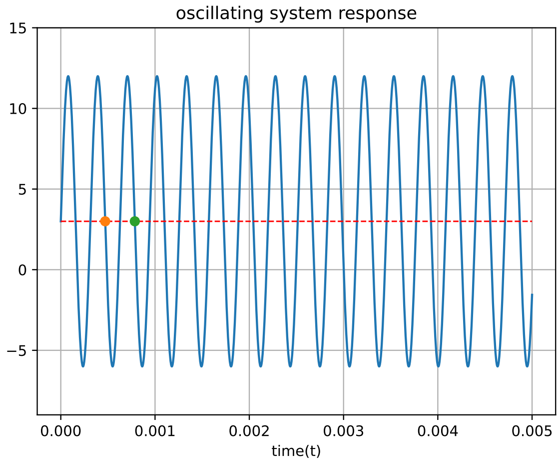

Fig. 10

$$f = \frac{\omega}{2\pi} = 3.183kHz \tag{10.7}$$

From Fig. 10 time period is calculated by any two end points of one cycle.

$$T = 0.000785391 - 0.000471071 \tag{10.8}$$

$$T = 0.00031432sec \tag{10.9}$$

$$f = \frac{1}{T} = 3.181kHz \tag{10.10}$$

11. Verify the amplitude and frequency using spice simulation.
Solution: The following readme file provides necessary instructions to simulate the circuit in spice.

```
codes/ee18btech11047/spice/README
```

The following netlist simulates the given circuit.

```
codes/ee18btech11047/spice/ee18btech11047.
    net
```

The following code plots the output from the oscillator spice simulation which is shown in Fig. 11.1.

```
codes/ee18btech11047/spice/
    ee18btech11047_spice.py
```

The following code plots a part of the spice output from which we can observe a clear sinusoidal output shown in Fig. 11.2.

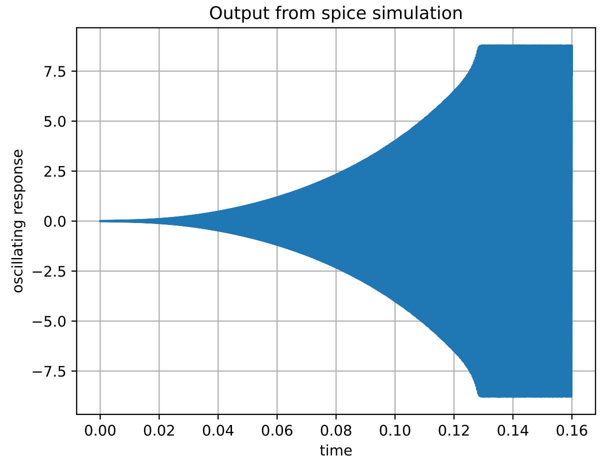

Fig. 11.1

```
codes/ee18btech11047/spice/
    ee18btech11047_spice2.py
```

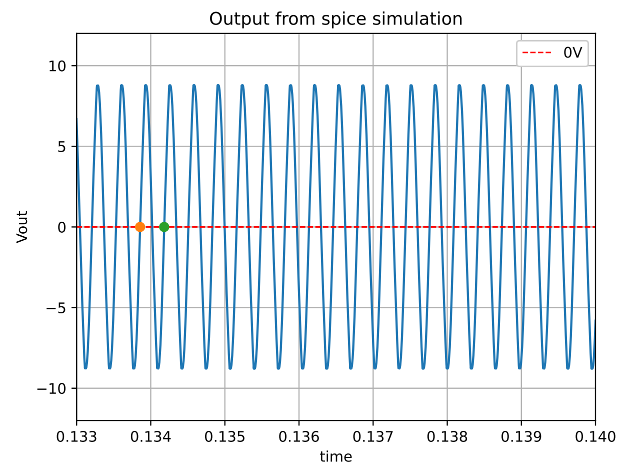

Fig. 11.2

Amplitude: From Fig. 11.2 V(peak-peak) is

$$V_{p-p} = 8.79 - (-8.79) = 17.58 \tag{11.1}$$

$$V_{max} = \frac{V_{p-p}}{2} = 8.79 \tag{11.2}$$

Frequency: From Fig. 11.2 time period is calculated by any two end points of one cycle,

$$T = 0.134181 - 0.133856 = 0.000325sec \tag{11.3}$$

$$f = \frac{1}{T} = 3.076kHz \tag{11.4}$$

Hence,the ampitude and frequency are verified through the spice simulation.