Oscillator

Venkata Tejaswini Anangani*

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.

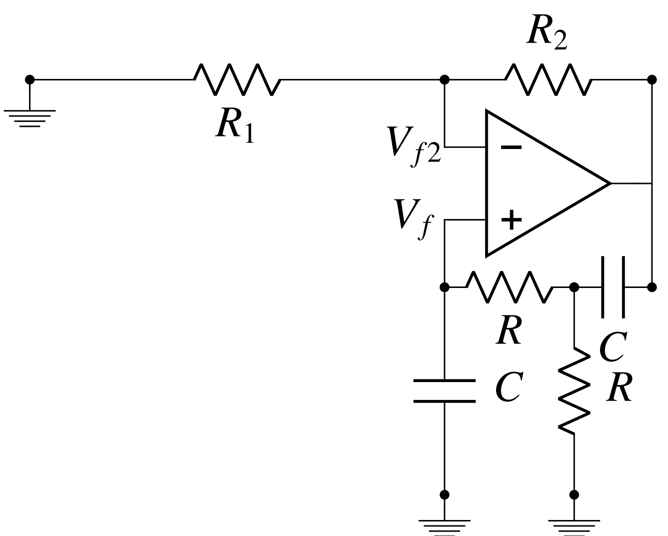

Fig. 1.1

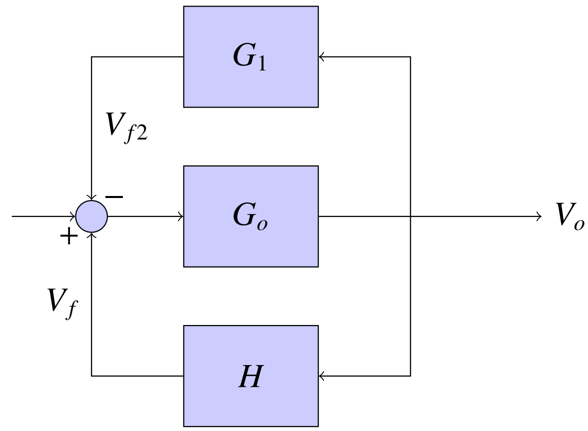

Fig. 1.2: Block diagram

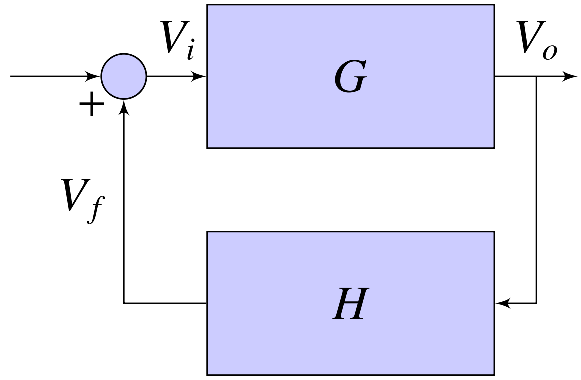

Fig. 1.3: Simplified equivalent block diagram

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),

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

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

   after simplification.
4. Find R_{11} and R_{22} from Fig. 2.6.

*The author is with the Department of Electrical Engineering, Indian Institute of Technology, Hyderabad 502285 India. All content in this manual is released under GNU GPL. Free and open source.

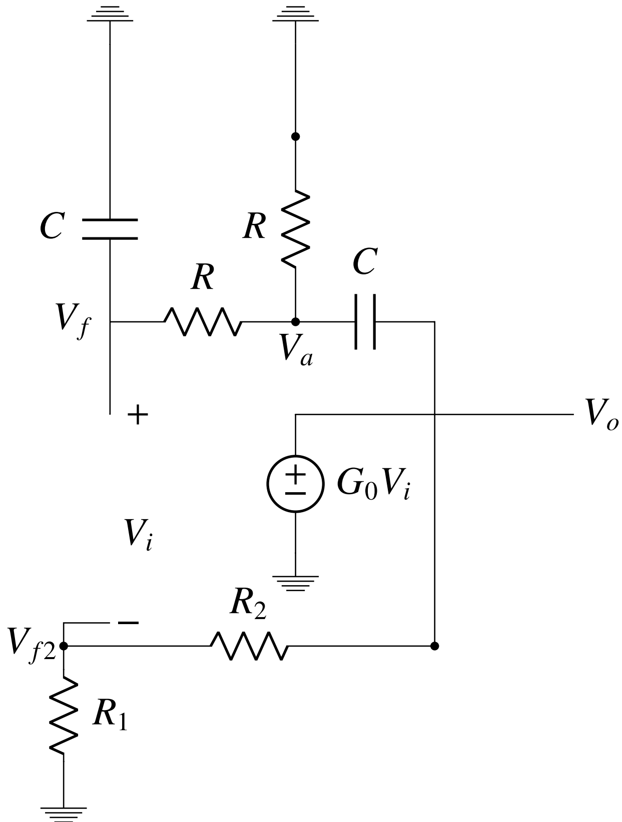

Fig. 1.4

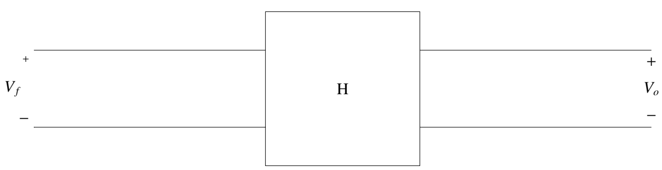

Fig. 2.5: Feedback block diagram

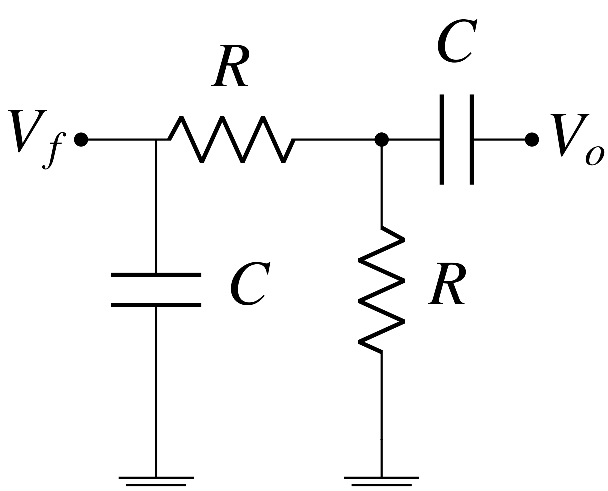

Fig. 2.6: Feedback circuit

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.

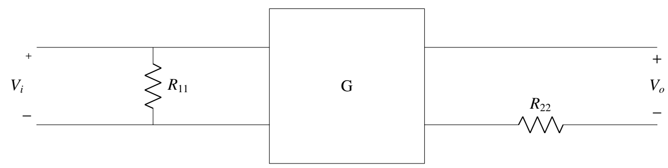

Fig. 5.1: Open loop block diagram

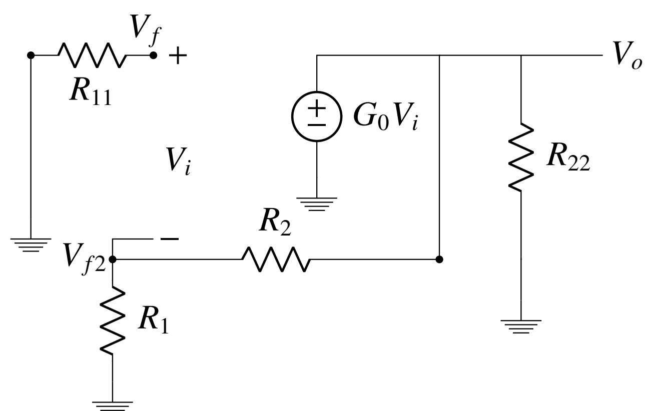

Fig. 5.2: Open loop circuit diagram

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

$$G = \frac{G_0}{1 + G_0 G_1} \tag{6.4}$$

$$= \frac{1}{\frac{1}{G_0} + G_1} \tag{6.5}$$

$$\implies G \approx \frac{1}{G_1}, \quad G_0 \to \infty \tag{6.6}$$

$$\text{or, } G = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1} \tag{6.7}$$

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,

$$\text{Im}\{L(\jmath\omega)\} = 0 \tag{9.1}$$

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

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	$1mF$
R_2	$2k\Omega$
R_1	$1k\Omega$

TABLE 10

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

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

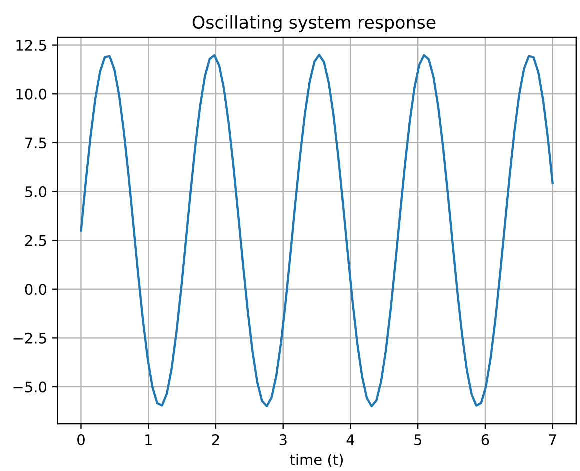

Fig. 10

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

$$V_{p-p} = 11.929 - (-5.957) = 17.886 \tag{10.1}$$

$$V_{max} = \frac{V_{p-p}}{2} = 8.943 \tag{10.2}$$

Frequency: From equation (9.5)

$$\omega = \frac{1}{RC} = 4 rad/sec \tag{10.3}$$

$$f = \frac{\omega}{2\pi} = 0.636Hz \quad (10.4)$$

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
```

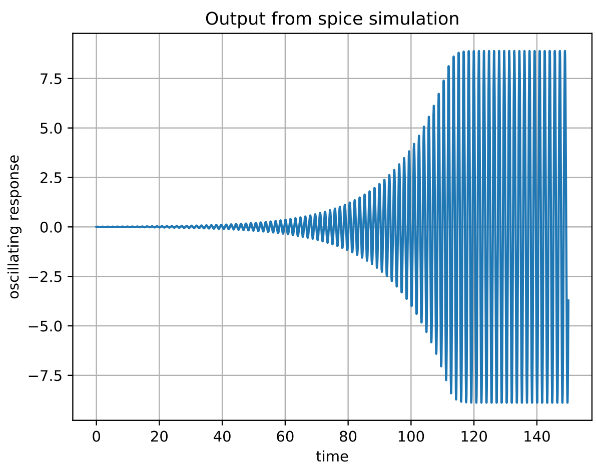

Fig. 11.1

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

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

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

$$V_{p-p} = 8.89 - (-8.89) = 17.78 \quad (11.1)$$

$$V_{max} = \frac{V_{p-p}}{2} = 8.89 \quad (11.2)$$

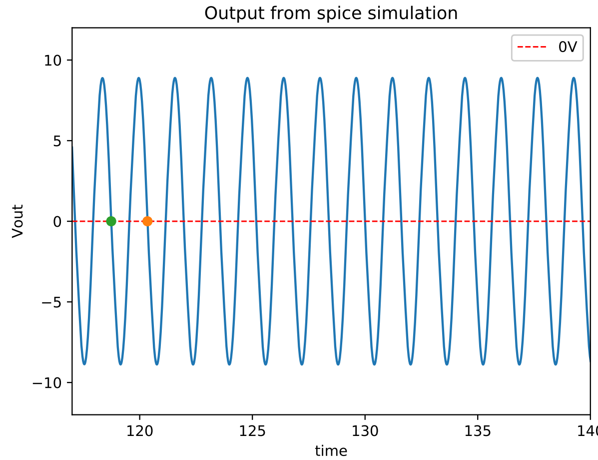

Fig. 11.2

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

$$T = 120.344 - (-118.734) = 1.61sec \quad (11.3)$$

$$f = \frac{1}{T} = 0.621Hz \quad (11.4)$$

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