Oscillator

Neil Dhami*

1. Three identical inverting amplifier stages each characterized by a low frequency gain K and a single pole response with

$$f_{3dB} = 100kHz \tag{1.1}$$

are connected in a feedback loop with H = 1. What is the minimum value of K at which the circuit oscillates? What would the frequency of oscillation be?

2. Find $G(s)$.

Solution: $\because$ the amplifier is inverting, the gain at the ith stage is

$$G_i(s) = \frac{-K}{1 + \frac{s}{2\pi f_{\text{3dB}}}} \tag{2.1}$$

$$= \frac{-K}{1 + \frac{s}{2\pi 10^5}} \tag{2.2}$$

upon substituting for the pole from Table 2. The open loop gain

Parameter	Value
f_{3dB}	100kHz
H	1

TABLE 2: INPUT TABLE

$$G(s) = \prod_{i=1}^{3} G_i(s) \tag{2.3}$$

$$= -\left[\frac{K}{1 + \frac{s}{2\pi 10^5}}\right]^3 \tag{2.4}$$

3. Draw the block diagram for the feedback system .

Solution: See Fig. 3

4. Find the loop gain of the system.

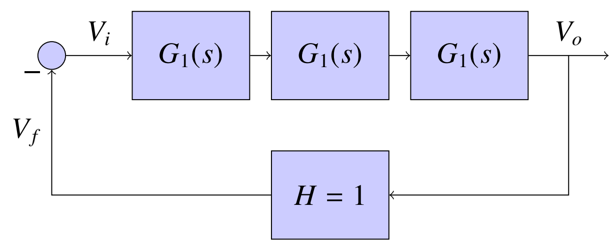

Fig. 3: CONTROL SYSTEM BLOCK

Solution: The loop gain is given by

$$L(s) = G(s)H \tag{4.1}$$

$$= -\left[\frac{K}{1 + \frac{s}{2\pi 10^5}}\right]^3 \tag{4.2}$$

$$\tag{4.3}$$

5. Find the frequency of oscillation.

Solution: According to BarkHausen's criteria..,

- The magnitude of loop gain of the system at the oscillating frequency should be greater than or equal to 1.
- The phase angle of loop gain at the oscillating frequency must be equal to -180 degrees.

Let the frequency of oscillation is fs.,

$$\angle LG(j\omega) = -180^\circ \tag{5.1}$$

$$180^\circ - 3tan^{-1}\left[\frac{\omega_s}{2\pi 10^5}\right] = -180^\circ \tag{5.2}$$

$$-3tan^{-1}\left[\frac{\omega_s}{2\pi 10^5}\right] = -360^\circ \tag{5.3}$$

$$\frac{\omega_s}{2\pi 10^5} = \tan(120^\circ) \tag{5.4}$$

$$\implies \omega_s = 1.088 \times 10^6 \text{ rad/sec} \tag{5.5}$$

Thus,the frequency of oscillation is 1.088M rad/sec.

6. Find the minimum value of K.

Solution: We know the magnitude of loop gain is greater than or equal to 1.The range of K can

*The author is with the Department of Electrical Engineering, Indian Institute of Technology, Hyderabad 502285 India.

be found as follows,

$$|LG(j\omega_s)| \geq 1 \tag{6.1}$$

$$\frac{K^3}{\left|1+\frac{j\omega_s}{2\pi 10^5}\right|^3} \geq 1 \tag{6.2}$$

$$K^3 \geq \left|1+\frac{j1.088\times 10^6}{2\pi 10^5}\right|^3 \tag{6.3}$$

$$K^3 \geq |1+j1.73|^3 \tag{6.4}$$

$$K^3 \geq 8 \tag{6.5}$$

$$K \geq 2 \tag{6.6}$$

Therefore, The minimum value of K is 2.

7. Design the three stage oscillator for the above given question.
Solution: Consider the circuit shown in the figure.7.
Considering the first stage.,

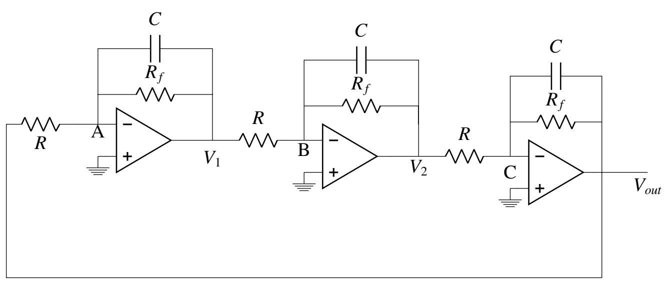

Fig. 7: 1

$$\frac{V_1}{V_{out}} = -\frac{R_f \| \frac{1}{sC}}{R} \tag{7.1}$$

$$\frac{V_1}{V_{out}} = -\frac{\frac{R_f}{R}}{1+sCR_f} \tag{7.2}$$

Similarly for second stage.,

$$\frac{V_2}{V_1} = -\frac{\frac{R_f}{R}}{1+sCR_f} \tag{7.3}$$

Similarly For third stage.,

$$\frac{V_{out}}{V_2} = -\frac{\frac{R_f}{R}}{1+sCR_f} \tag{7.4}$$

Loop gain of the oscillator is computed as follows.,

$$LG(s) = \frac{V_1}{V_{out}} \times \frac{V_2}{V_1} \times \frac{V_{out}}{V_2} \tag{7.5}$$

$$LG(s) = \left[-\frac{\frac{R_f}{R}}{1+sCR_f}\right]^3 \tag{7.6}$$

Comparing with the equation.4.3

$$\frac{R_f}{R} = K \tag{7.7}$$

$$CR_f = \frac{1}{2\pi 10^5} \tag{7.8}$$

For the circuit to oscillate,

$$K \geq 2 \tag{7.9}$$

$$R_f \geq 2R \tag{7.10}$$

Choose

$$R = 1000\Omega \tag{7.11}$$

$$\implies R_f = 2000\Omega \tag{7.12}$$

$$\implies C = 7.9577 \times 10^{-10} F \tag{7.13}$$

Parameter	Value
R	1000Ω
R_f	2000Ω
C	7.9577×10^{-10}

TABLE 7

8. Verify the above result using the ngspice simulation.
Solution: Follow the instructions of the following README file.

```
spice/ee18btech11031/README
```

Connect the circuit shown in fig.7:1 in ngspice. The following netlist file is connected accordingly

```
spice/ee18btech11031/gvv_ngspice.net
```

This netlist file results in a sinusoidal wave with particular frequency. The following code generates the graph shown in fig.8

```
spice/ee18btech11031/
    ee18btech11031_ngspice.py
```

9. Find the frequency of sinusoid obtained from the simulation.

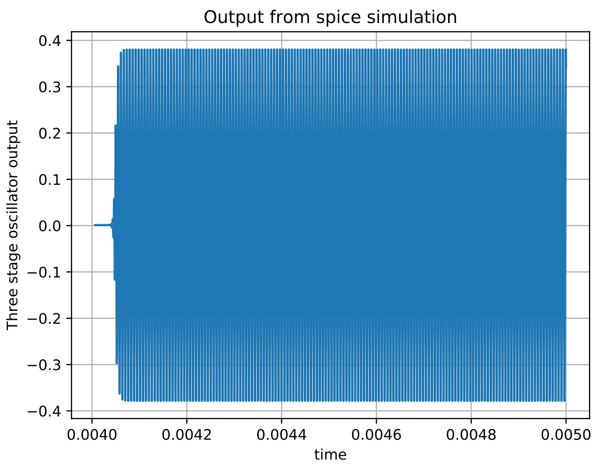

Fig. 8: Output of three stage oscillator

Solution: The following Netlist file is to generate the output from 4.22msec to 4.26msec

spice/ee18btech11031/gvv_ngspice2.net

The following code generates the variation of output voltage with respect to time.

spice/ee18btech11031/ ee18btech11031_ngspice_2.py

The data obtained from the above netlist file is plotted in the figure.9. The frequency obtained

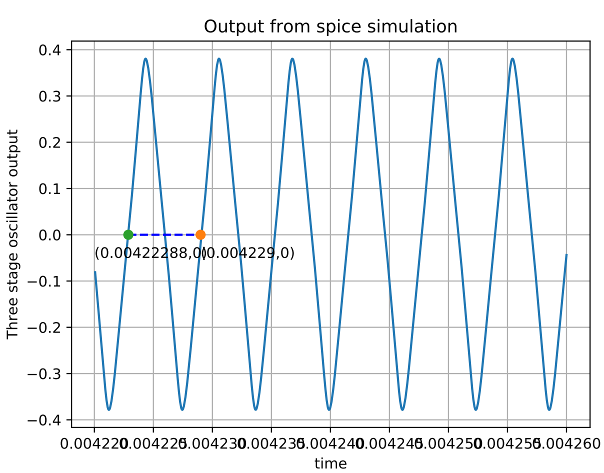

Fig. 9: Output of three stage oscillator

in simulation is as follows.,

$$T_s(spice) = 4.229 \times 10^{-3} - 4.2228 \times 10^{-3} \tag{9.1}$$

$$T_s(spice) = 6.2 \times 10^{-6} \tag{9.2}$$

$$\implies F_s(spice) = 0.1612\text{MHz} \tag{9.3}$$

$$\implies \omega_s(spice) = 1.012 \text{ Mrad/sec} \tag{9.4}$$

But the obtained value in equation.5.5 is 1.088MHz. Thus, the frequency obtained in the spice simulation is approximately equal to the calculated frequency.