RC Oscillators

All the oscillators using tuned LC circuits operate well at high frequencies. At low frequencies, as the inductors and capacitors required for the time circuit would be very bulky and RC oscillators are found to be more suitable. Two important RC oscillators are

(i) RC phase-shift oscillator

(ii) Wien-bridge oscillator

(i). RC Phase-Shift Oscillator using BJT with Cascade connection of High-Pass Filter (Phase-lead RC Network)

BJT based RC phase-shift oscillator using phase-lead RC network is shown in Figure 2.

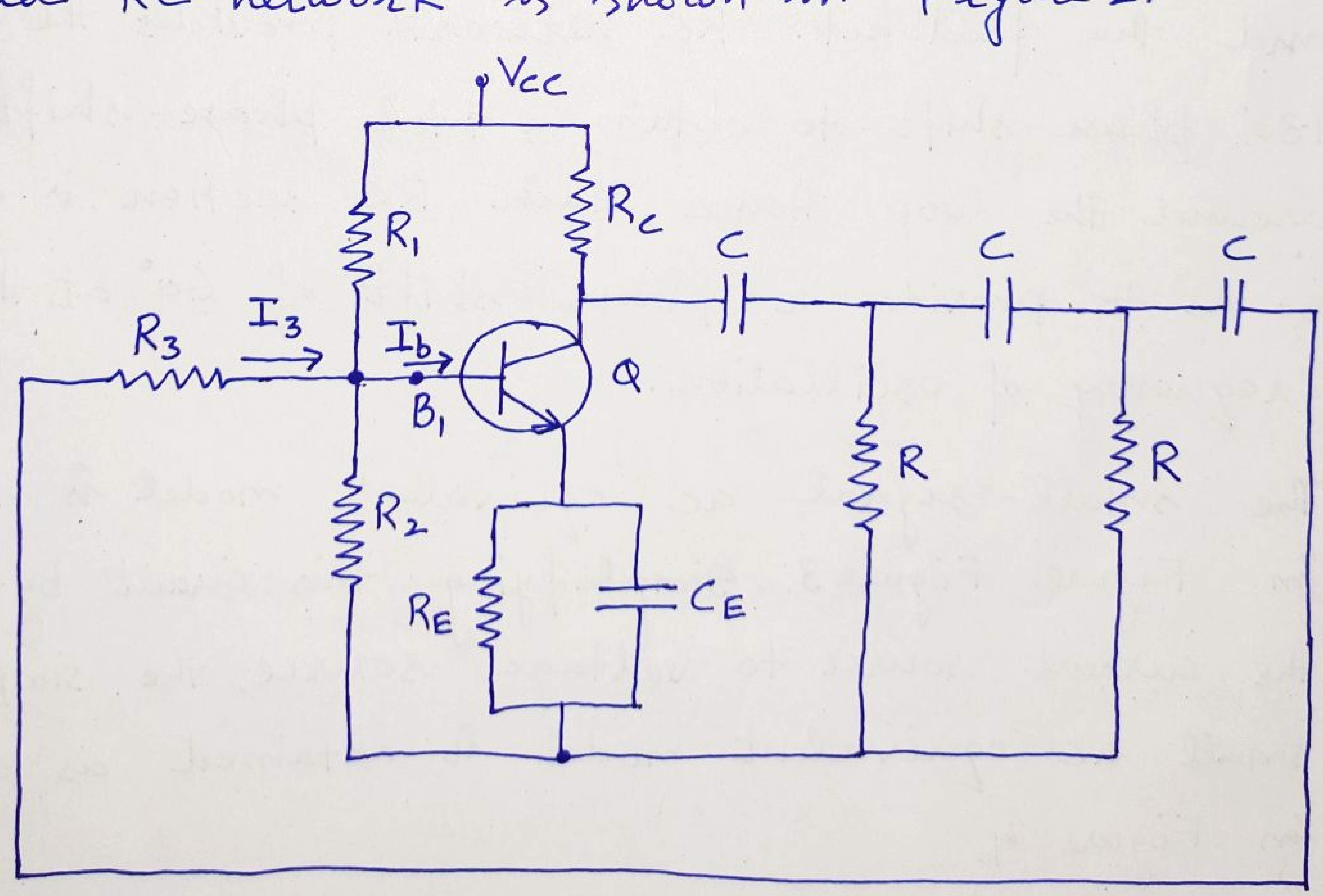

Figure 2. BJT-based RC Phase-Shift Oscillator.

Here, the output of the feedback network is loaded appreciably by the relatively low resistance of the transistor. Thus, the resistance R of the feedback network is in parallel with the low input resistance h_{ie} of the transistor, which reduces the effective value of R in the last section of the feedback network.

The feedback signal is coupled through the feedback resistor R_3 in series with the amplifier stage input resistor. In order to make the three sections identical, R_3 is chosen as $R_3 = R - R_i$ where R_i is the input impedance of the circuit.

The BJT amplifier provides a phase-shift of 180° and the feedback RC network provides the remaining 180° phase-shift to obtain a total phase-shift of 360° around the loop. Hence, each RC section is designed so as to provide a phase-shift of 60° at the desired frequency of oscillation.

The small-signal ac equivalent model is shown in Figure Figure 3. Simplifying this circuit by replacing the current source to voltage source, the simplified small ac equivalent model is obtained as shown in Figure 4.

Applying KVL, we get

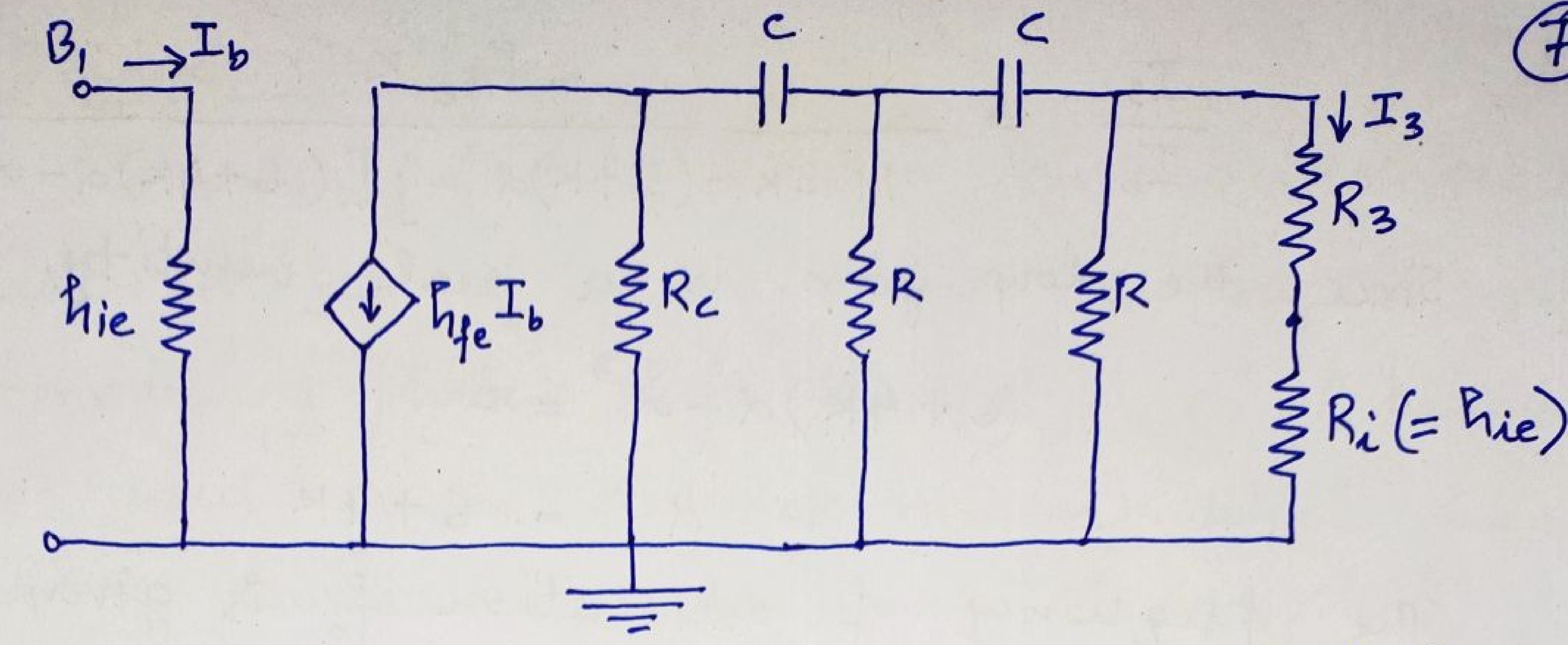

Figure 3. Small-signal ac equivalent model

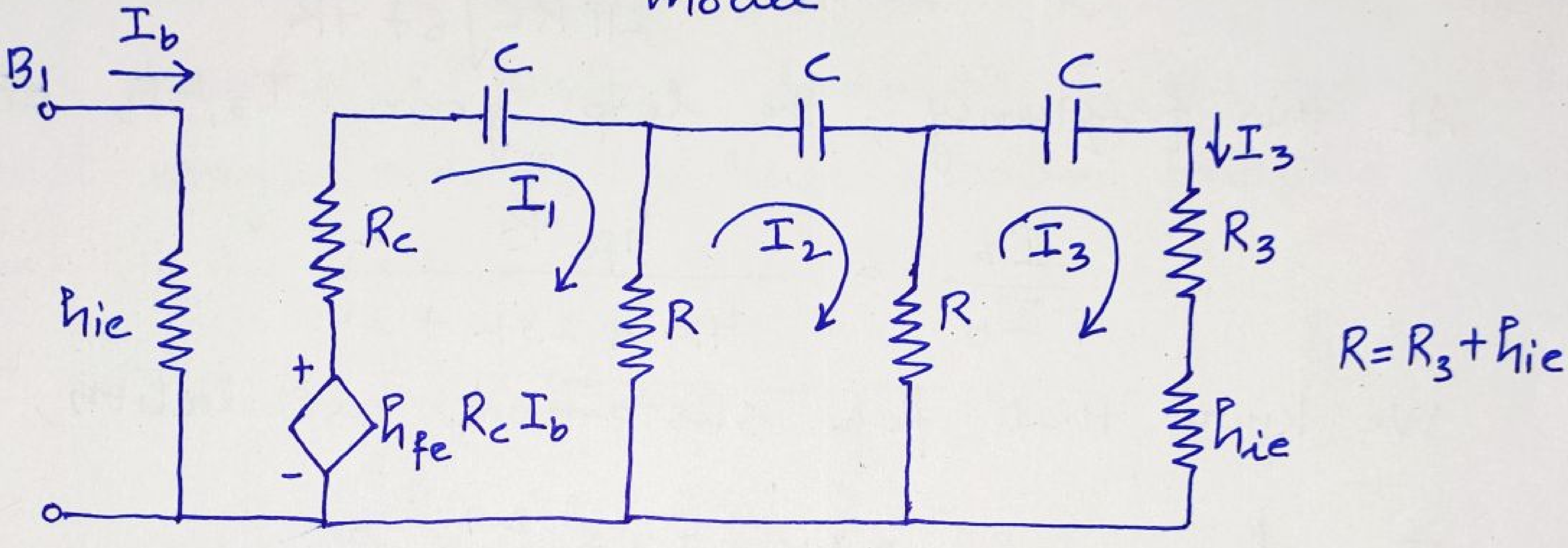

Figure 4. Simplified small-signal ac equivalent model.

$$I_1 \left(R_c + R + \frac{1}{j\omega C} \right) - I_2 R = - h_{fe} R_c I_b$$

$$- I_1 R + I_2 \left(2R + \frac{1}{j\omega C} \right) - I_3 R = 0$$

$$- I_2 R + I_3 \left(2R + \frac{1}{j\omega C} \right) = 0$$

Let $\alpha = \frac{1}{\omega RC}$ and $K = \frac{R_c}{R}$

Upon solving the above equations, we get

$$I_2 = I_3 (2 - j\alpha)$$

and $$I_1 = I_3 (3 - \alpha^2 - j4\alpha)$$

Substituting the above I_1 and I_2 equations in the first KVL equation, we get loop gain I_3 / I_b as

$$\frac{I_3}{I_b} = \frac{-h_{fe} K}{1+3K-(5+K)\alpha^2 - j[(6+4K)\alpha - \alpha^3]}$$

Since the loop gain is a real quantity, we have

$$(6+4K)\alpha - \alpha^3 = 0$$

$$\alpha^2 = 6+4K$$

The frequency of oscillation f_o is given by

$$f_o = \frac{1}{2\pi RC\sqrt{6+4K}}$$

At this frequency, the loop gain I_3/I_b becomes,

$$\frac{I_3}{I_b} = \frac{h_{fe} K}{4K^2+23K+29}$$

We know that for sustained oscillation, $I_3/I_b > 1$.

Therefore $\quad h_{fe} > 4K + 23 + \frac{29}{K}$

Thus, $\quad \frac{dh_{fe}}{dK} = 4 - \frac{29}{K^2} = 0$

$$K = \left(\frac{29}{4}\right)^{1/2} = 2.7$$

Therefore, $\quad (h_{fe})_{min} = 4(2.7) + 23 + \frac{29}{2.7} = 44.5$

Hence, the value of h_{fe} for a transistor must be at least 45 for the circuit to oscillate.

Wien-Bridge Oscillator

Figure 1 shows the circuit of a Wien-bridge oscillator. The circuit consists of a two-stage RC coupled amplifier which provides a phase-shift of 360° or 0°. A balanced bridge is used as the feedback network which has no need to provide any additional phase-shift. The feedback network consists of a lead-lag network (R_1-C_1 and R_2-C_2) and a voltage divider (R_3-R_4). The lead-lag network provides a positive feedback to the input of the first stage and the voltage divider provides a negative feedback to the emitter of Q_1.

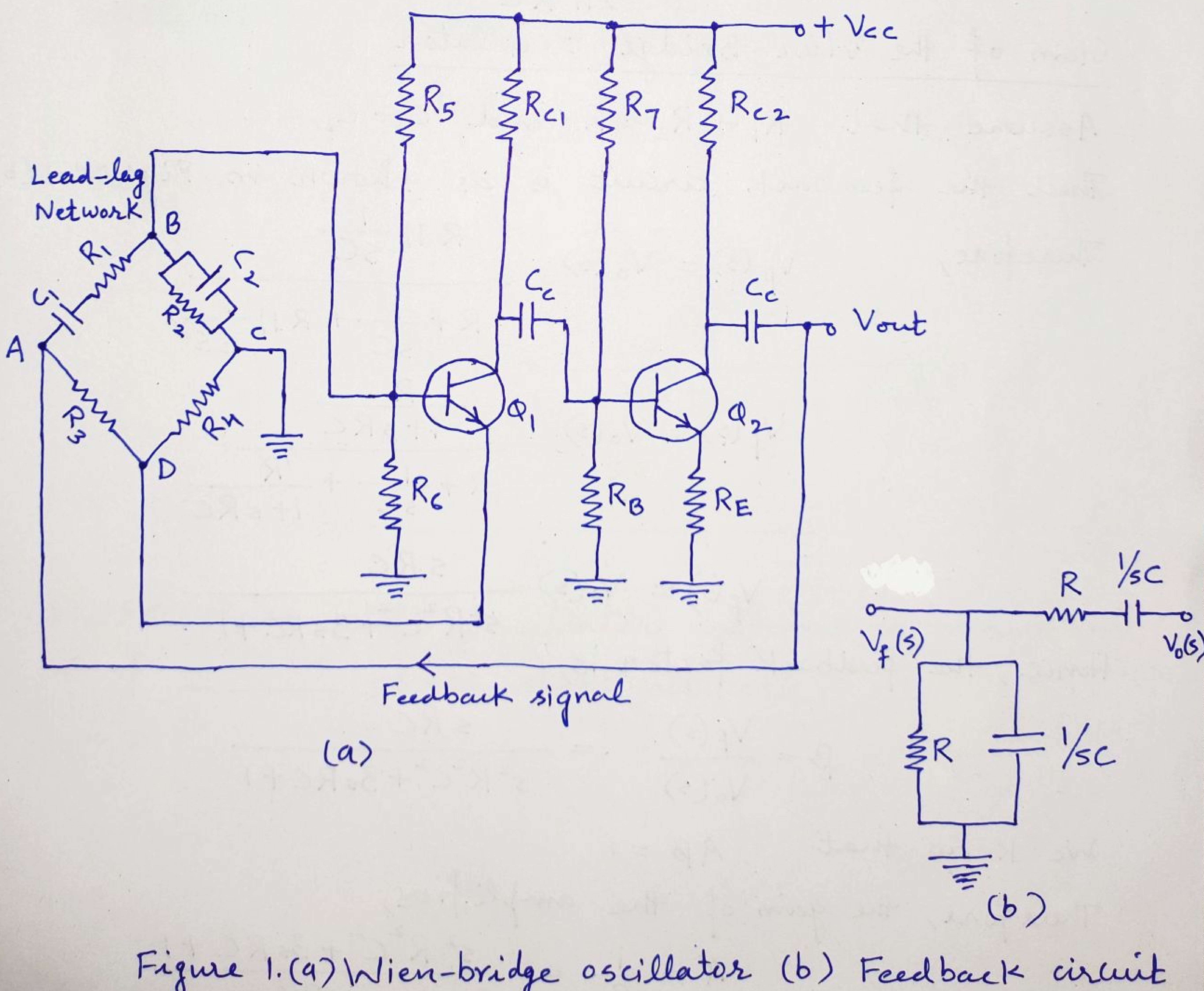

Figure 1. (a) Wien-bridge oscillator (b) Feedback circuit

If the bridge is balanced,

$$\frac{R_3}{R_4} = \frac{R_1 - jX_{C1}}{\left[\frac{R_2(-jX_{C2})}{R_2 - jX_{C2}}\right]}$$

where X_{C1} and X_{C2} are the reactances of the capacitors. Simplifying the above equation and equating the real and imaginary parts on both sides, we get the frequency of oscillation as,

$$f_o = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

$$f_o = \frac{1}{2\pi RC}, \text{ if } R_1 = R_2 = R, C_1 = C_2 = C$$

Gain of the Wien-Bridge Oscillator

Assume that $R_1 = R_2 = R$ and $C_1 = C_2 = C$

Then the feedback circuit is as shown in Figure 1(b).

Therefore,

$$V_f(s) = V_o(s) \frac{R \,||\, \frac{1}{sC}}{R + \frac{1}{sC} + R \,||\, \frac{1}{cS}}$$

$$V_f(s) = V_o(s) \frac{\frac{R}{1+sRC}}{R + \frac{1}{sC} + \frac{R}{1+sRC}}$$

$$V_f(s) = V_o(s) \frac{sRC}{s^2R^2C^2 + 3sRC + 1}$$

Hence, the feedback factor is,

$$\beta = \frac{V_f(s)}{V_o(s)} = \frac{sRC}{s^2R^2C^2 + 3sRC + 1}$$

We know that $A\beta = 1$

Therefore, the gain of the amplifier,

$$A = \frac{1}{\beta} = \frac{s^2R^2C^2 + 3sRC + 1}{sRC}$$

Substituting $s = j\omega_o$, where the frequency of oscillation

$$f_o = \frac{1}{2\pi RC} \quad \text{i.e } \omega_o = \frac{1}{RC}$$

in the equation of gain of the amplifier and simplifying, we get $A = 3$. Hence, the gain of the Wien-bridge oscillator using a BJT amplifier is at least equal to 3 for oscillations to occur.

Q1. In a Wien-bridge oscillator, if the value of R is 100 KΩ, and frequency of oscillation is 10 KHz, find the value of the capacitor C.

Solution: The operating frequency of a Wien-bridge oscillator is given by,

$$f_o = \frac{1}{2\pi RC}$$

Therefore,

$$C = \frac{1}{2\pi R f_o}$$

$$C = \frac{1}{2\pi \times 100 \times 10^3 \times 10 \times 10^3}$$

$$C = 159\ \text{pF}.$$

MCQ

Q1. RC phase shift oscillator contain a minimum of ________ phase shift network

(a) 1 (b) 2 (c) 3 (d) 0

Q2. One phase shift network of an RC phase shift oscillator contains ________ capacitor.

(a) 1 (b) 2 (c) 3 (d) 0

Q3. One phase shift network of an RC phase shift oscillator contains ________ inductor.

(a) 1 (b) 2 (c) 3 (d) 0

Q4. One phase shift network of an RC phase shift oscillator contain ________ resistor.

(a) 1 (b) 2 (c) 3 (d) 0

Q5. Phase shift provided by one phase shift network in RC phase shift oscillator in 3 stage is ________

(a) 180° (b) 60° (c) 120° (d) 90°