Course on

Electronic Circuit Analysis

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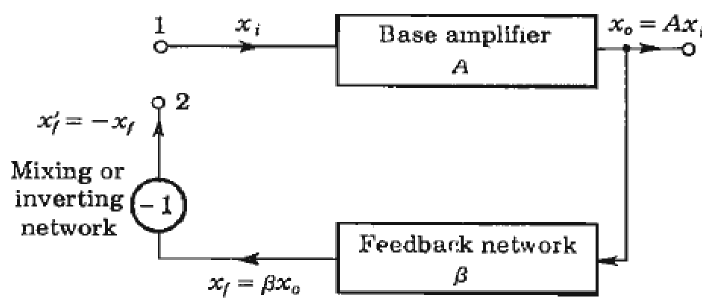
UNIT – IV

1. Barkhausen criterion for sinusoidal oscillators

- An oscillator is an electronic device which generates sinusoidal waves when excited by a DC input supply voltage.
- Barkhausen's criterion applies to linear circuits with a feedback loop. It needs to have positive feedback and the loop gain is unity (i.e. $-\beta A=1$ *or* $|\beta A|=1$).
- It states that if A is the gain of the amplifying element in the circuit and β is the transfer function (feedback factor) of the feedback path, so βA is the loop gain around the feedback loop of the circuit, the circuit will sustain steady-state oscillations only at frequencies for which:

  i. The loop gain is equal to unity, that is, $|\beta A|=1$ and (or $-\beta A=1$)

  ii. The total phase shift of $-\beta A$ around the loop is zero or an integer multiple of 2π. That means the frequency of oscillation at which sinusoidal oscillator operates is the frequency for which the total shift introduced, as the signal proceeds from the input terminals, through the amplifier and feedback network, and back again to the input, is precisely zero (or an integral multiple of 2π).
- Barkhausen's criterion is a *necessary* condition for oscillation but not a *sufficient* condition: some circuits satisfy the criterion but do not oscillate.
- The feedback network introduces 180^0 phase shift, the other 180^0 phase shift is provided by mixer.
- The frequency of oscillation depends mostly on few circuit parameters such as passive elements such as resistance, inductance, and capacitance etc.



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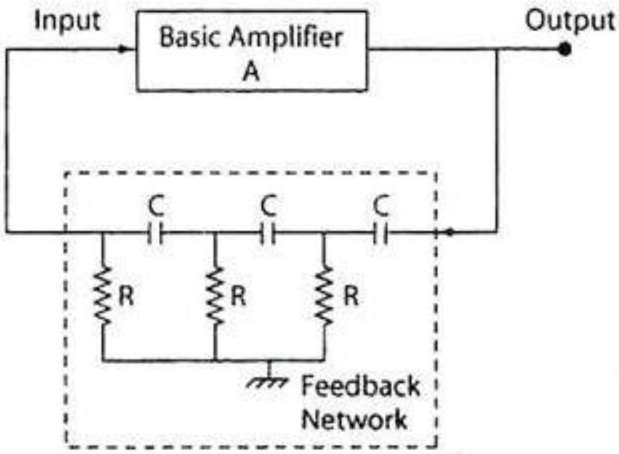
2. RC-phase shift oscillator using FET

- RC phase-shift oscillator is used to generate audio frequency sinusoidal oscillation.
- The figure shows a generalized RC phase-shift oscillator. The basic amplifier introduces180° phase-shift, provided the loading of the phase-shift network can be neglected.
- The additional 180° phase shift is provided by the three cascaded arrangement of capacitorC and resistor R acting as the feedback network. The phase shift amounting to 180° is introduced by this feedback network only at some particular frequency.

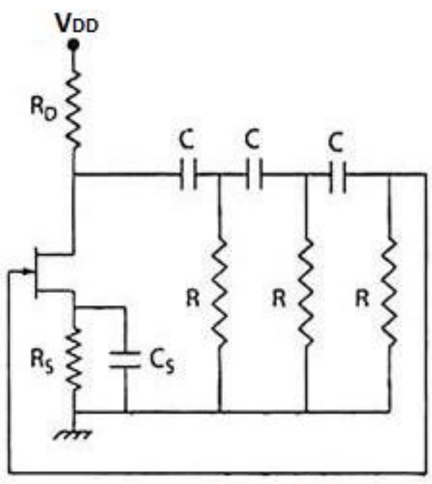


Generalized RC phase-shift oscillator.

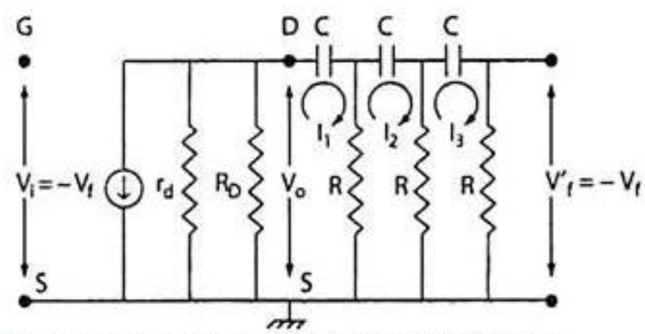
Types of Phase-Shift Oscillator:

I. Phase-Shift Oscillator using FET:

- The below figure (a) shows the FET based phase shift oscillator. The basic FET amplifier is self-biased with a source resistor R_S bypassed by capacitor R_S and a drain bias resistor R_D. Figure (b) shows the equivalent circuit of the FET oscillator of figure (a).



(a) Phase-shift oscillator using JFET.



(b): Equivalent circuit of JFET phase-shift oscillator

- We know the gain of the FET amplifier is given by:

$$A_V = -g_m R'_D,$$

where $R'_D = r_d \parallel R_D$.

- Here we assumed the input impedance of FET is infinite. This assumption is valid in the low frequency range of operation of phase-shift oscillator, as in this frequency the effect of capacitive impedance can be neglected.
- From FIG (b) it is clear that the feedback network will not load the amplifier when output impedance R'_D is much smaller in comparison with R. Now to find the frequency of oscillation let us find the feedback factor β.
- Applying Kirchhoff's voltage law in FIG (b) we get:

$$I_1 \frac{1}{j\omega C} + I_1 R - I_2 R = V_o$$

$$- \quad I_1 R + I_2 \frac{1}{j\omega C} + I_2 2R - I_3 R = 0$$

$$- \quad I_2 R + I_3 \frac{1}{j\omega C} + I_3 2R = 0.$$

- Solving above equation we get:

$$I_2 = I_3 \left(2 + \frac{1}{j\omega CR}\right).$$

And

$$I_1 = I_2 \left(2 + \frac{1}{j\omega CR}\right) - I_3 = I_3 \left(3 + \frac{4}{j\omega CR} - \frac{1}{\omega^2 C^2 R^2}\right).$$

And

$$I_3 R = \frac{V_o}{1 - 5\alpha^2 - j(6\alpha - \alpha^3)},$$

where

$$\alpha = \frac{1}{\omega RC}.$$

- Now $I_3 R = V'_j = -V_f$ is the feedback voltage.Therefore, the feedback factor β is given by:

$$-\beta = \frac{V'_f}{V_o} = \frac{1}{1 - 5\alpha^2 - j(6\alpha - \alpha^3)}.$$

- For 180° phase shift, the coefficient of **j** must be zero.Therefore,

$$\alpha^2 = 6, \quad \text{or,} \quad \omega = \frac{1}{CR\sqrt{6}}.$$

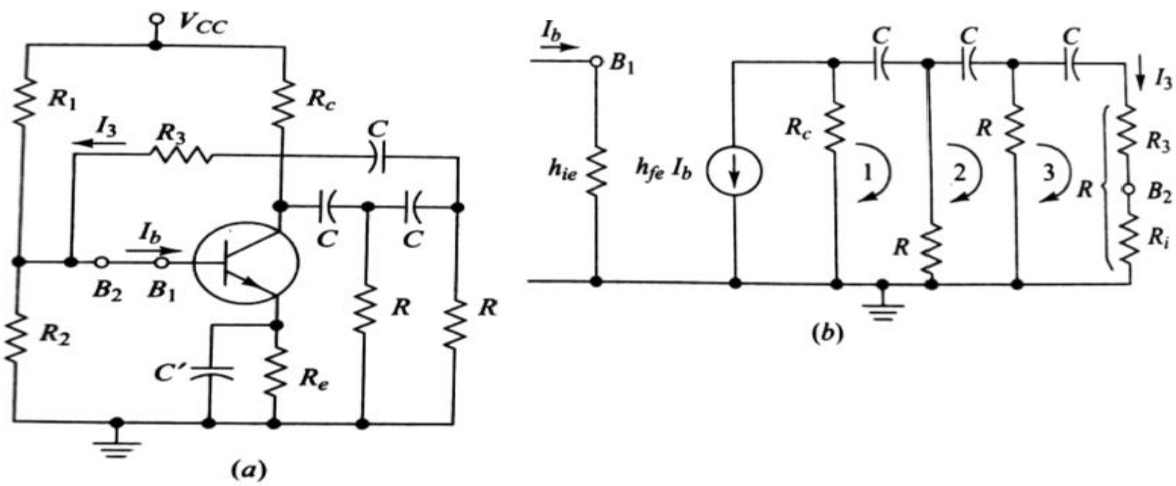
or the frequency of oscillation is given by

$$f = \frac{1}{2\pi CR\sqrt{6}}.$$

- And at the frequency of oscillation the value of feedback factor β **= + 1/29** So the minimum value of the gain of the amplifier **|Av| is 29** for sustained oscillation at frequency **1/ (2πRC√6).**

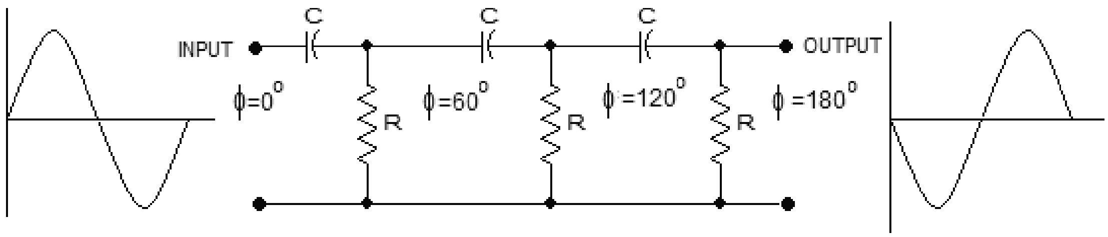
II. Phase-Shift Oscillator using BJT:

- FIG (a) shows the circuit of a phase-shift oscillator using a BJT. In this oscillator a CE amplifier with self-biasing arrangement using resistor R_e and bypass capacitor C' is used as basic amplifier.
- FIG (b) shows the small signal AC equivalent circuit of FIG (a), using approximate hybrid parameter model for the transistor in the low frequency region.
- Voltage-shunt feedback is used for transistor phase-sift oscillator whereas voltage-series feedback is used for FET phase-sift oscillator.
- In transistor phase-sift oscillator, the output R of the feedback network would be shunted by a relatively low input resistance of the transistor.



- The resistor R_3 in the last stage of RC feedback network is chosen equal to R_3=R-R_i where $R_i \simeq h_{ie}$ is the input resistance of the transistor.
- RC phase shift oscillator or simply RC oscillator is a type of oscillator where a simple RC network (resistor-capacitor) network is used for giving the required phase shift to the feedback signal.
- The main feature of an RC phase shift oscillator is the excellent frequency stability. The RC oscillator can output a pure sine wave on a wide range of loads.
- RC phase shift network is a simple resistor capacitor network that can be used to give a desired phase shift to a signal.
- Phase shift of a practical RC network depends on the value of the capacitor, resistor and the operating frequency.

- Just by making an RC network with phase shift equal to 60° and cascading three of them together the desired phase shift of 180° can be attained. This 180° phase shift by the RC network plus the 180° phase shift made by the transistor gives a total phase shift of 360° between the input and output which is the necessary condition for maintaining sustained oscillations. The circuit diagram of a three stage RC network producing a phase shift of 180° is shown in the figure below.



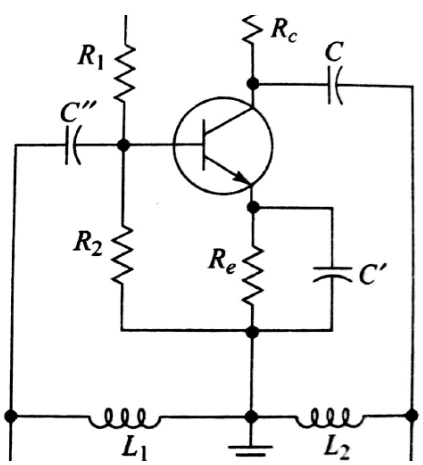
Three stage RC phase shift network

- The frequency of the transistor RC phase shift oscillator can be expressed by the equation:

$$F = \frac{1}{2\pi RC\sqrt{2N}}$$

- Where F is the frequency, R is the resistance, C is the capacitance and N is the number of RC phase shift stages. The RC phase shift oscillator can be made variable by making the resistors or capacitors variable.

3. Hartley oscillator:



- The Hartley oscillator is an electronic oscillator circuit in which the oscillation frequency is determined by a tuned circuit consisting of capacitors and inductors, that is, an LC oscillator.
- The distinguishing feature of the Hartley oscillator is that the tuned circuit consists of a single capacitor in parallel with two inductors in series (or a single tapped

inductor), and the feedback signal needed for oscillation is taken from the center connection of the two inductors.

- The Hartley oscillator is Suitable for oscillations in RF (Radio-frequency) range, up to 30MHz.
- The frequency of oscillation is approximately the resonant frequency of the tank circuit. If the capacitance of the tank capacitor is C and the total inductance of the tapped coil is L then

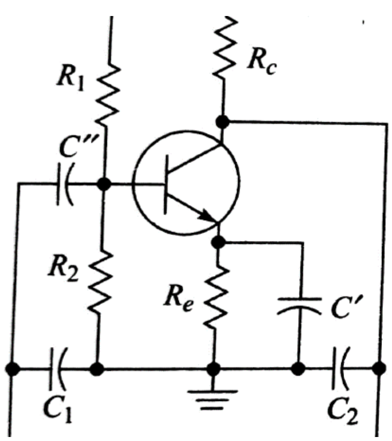
$$f = \frac{1}{2\pi\sqrt{LC}}$$

- If two uncoupled coils of inductance L_1 and L_2 are used then

$$L = L_1 + L_2$$

- Advantages of the Hartley oscillator:
  i. The frequency may be adjusted using a single variable capacitor, one side of which can be earthed.
  ii. The output amplitude remains constant over the frequency range
- Disadvantages:
  i. Harmonic-rich output if taken from the amplifier and not directly from the LC circuit (unless amplitude-stabilisation circuitry is employed).

4. Colpitts oscillator:



- A Colpitts oscillator, is one of a number of designs for LC oscillators, electronic oscillators that use a combination of inductors (L) and capacitors (C) to produce an oscillation at a certain frequency.
- The distinguishing feature of the Colpitts oscillator is that the feedback for the active device is taken from a voltage divider made of two capacitors in series across the inductor.

- A Colpitts oscillator is the electrical dual of a Hartley oscillator, where the feedback signal is taken from an “inductive” voltage divider consisting of two coils in series (or a tapped coil).
- L and the series combination of C_1 and C_2 form the parallel resonant tank circuit, which determines the frequency of the oscillator.
- The frequency of oscillation is approximately the resonant frequency of the LC circuit, which is the series combination of the two capacitors in parallel with the inductor:

$$F = \frac{1}{2\pi\sqrt{LC_{eff}}}$$

Where

$$\frac{C_1C_2}{C_1 + C_2}$$

- Colpitts oscillator is generally used in RF applications and the typical operating range is 20KHz to 300MHz.
- Main advantage of Colpitts oscillator over Hartley oscillator is the improved performance in the high frequency region. This is because the capacitors provide a low reactance path for the high frequency signals and thus the output signals in the high frequency domain will be more sinusoidal.
- Due to the excellent performance in the high frequency region, the Colpitts oscillator can be even used in microwave applications.

5. Wien bridgeoscillator

An oscillator circuit in which a balanced bridge is used as the feedback network is the Wien bridge[10] oscillator shown in Fig. 14-34. The active element is an operational amplifier (Chap. 15) which has a very large positive voltage gain

($V_o = A_V V_i$), negligible output resistance, and very high (infinite) input resistance. We assume further that A_V is constant over the range of frequencies of operation of this circuit.

To find the loop gain $-\beta A$, we break the loop at the point marked P and apply an external voltage V'_o across terminals 3 and 4.

Since $V_o = A_V V_i$, the loop gain is given by

$$\text{Loop gain} = \frac{V_o}{V'_o} = \frac{V_i}{V'_o} A_V = -\beta A \qquad (14\text{-}70)$$

Two auxiliary voltages V_1 and V_2 are indicated in Fig. 14-34 such that $V_i = V_2 - V_1$. From Eq. (14-70) $A = A_V$ and

$$-\beta = \frac{V_i}{V_o'} = \frac{V_2 - V_1}{V_o'} = \frac{Z_2}{Z_1 + Z_2} - \frac{R_2}{R_1 + R_2} \tag{14-71}$$

It is not difficult to show that Z_1 and Z_2 have the same phase angle at the frequency

$$f_o = \frac{1}{2\pi RC} \tag{14-72}$$

and that at this frequency $Z_1 = (1 - j)R$ and $Z_2 = (1 - j)R/2$. Hence $V_2 = \frac{1}{3}V_o'$, at $\omega = \omega_o$. If a null is desired, then R_1 and R_2 must be chosen so that $V_i = 0$. From Eq. (14-71) $R_2/(R_1 + R_2) = \frac{1}{3}$, or $R_1 = 2R_2$.

In the present case, where the bridge is used as the feedback network for an oscillator, the loop gain of Eq. (14-70) must equal unity and must have zero phase. Thus, since A_V is a positive number, the phase of $-\beta$ from Eq. (14-71) must be zero, but the magnitude must not be zero. This is accomplished by taking the ratio $R_2/(R_1 + R_2)$ smaller than $\frac{1}{3}$.

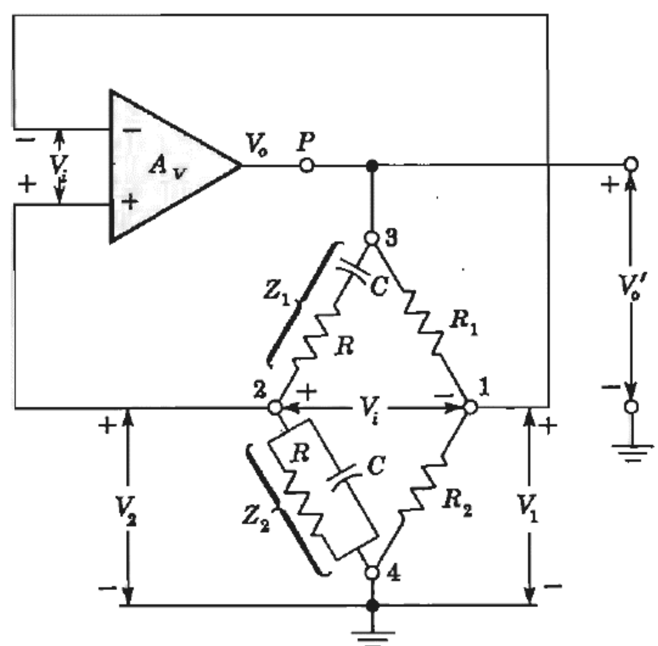


Fig. 14-34 Wien bridge oscillator using an operational amplifier as the active element.

If we let

$$\frac{V_1}{V_o'} = \frac{R_2}{R_1 + R_2} = \frac{1}{3} - \frac{1}{\delta}$$

where δ is a number greater than 3, then

$$-\beta = \frac{V_2 - V_1}{V_o'} = \frac{V_2}{V_o'} - \frac{1}{3} + \frac{1}{\delta} \tag{14-73}$$

At $\omega = \omega_o$, $V_2/V_o' = \frac{1}{3}$ and $\beta = -1/\delta$. The condition $-\beta A = 1$ is now satisfied by making

$$\delta = A_V \tag{14-74}$$

Note that the frequency of oscillation is precisely the null frequency of the balanced bridge, given by Eq. (14-72). At any other frequency V_2 is not in phase with V_o', and therefore $V_i = V_2 - V_1$ is not in phase with V_o', so that the condition $-\beta A = 1$ is satisfied only at the one frequency f_o.

Continuous variation of frequency is accomplished by varying simultaneously the two capacitors (ganged variable air capacitors). Changes in frequency range are accomplished by switching in different values for the two identical resistors R.

6. The Crystal oscillator

- A crystal oscillator is an electronic oscillator circuit that uses the mechanical resonance of a vibrating crystal of piezoelectric material to create an electrical signal with a precise frequency.
- A variety of crystal-oscillator circuits are possible. A 1-MHz crystal oscillator consisting of a crystal, a tuned *LC* combination and capacitance C_{dg} between drain and gate is shown in below figure.
- The crystal reactance as well as that of the *LC* network must be inductive.
- For the loop gain to be greater than unity. Hence the circuit will oscillate at a frequency which lies between w_s and w_p but close to the parallel-resonance value.
- Since w_s=w_p, the oscillator frequency is essentially determined by the crystal and not by the rest of the circuit.