SIGNAL GENERATORS

3.1 Introduction

Signal sources have a variety of applications including checking stage gain, frequency response, and alignment in receivers and in a wide range of other electronics equipment. Signal source provide a variety of waveforms for testing electronic circuits, usually low power. The various waveforms are generated by several different kinds of instruments.

Sinusoidal Oscillator is used for an instrument that provides only a sinusoidal output signal. Generator is applied to an instrument that provides several output waveforms, including sine wave, triangular wave, and pulse trains as well as amplitude modulation of the output signal.

3.2 Requirement for Oscillation

Oscillator - An amplifier with positive feedback.
Gain for amplifier with positive feedback.

\[
A_f = \frac{A}{1 + A\beta} \quad (I)
\]

where
- \(A_f\) = gain with feedback
- \(A\) = open-loop gain
- \(\beta\) = feedback factor, \(\frac{V_i}{V_o}\)

![Figure 1: Closed Loop System](image)

If a negative-feedback circuit has a loop gain that satisfies two conditions:
Note that for the circuit to oscillate at one frequency the oscillation criterion should be satisfied at one frequency only; otherwise the resulting waveform will not be a simple sinusoid.

\[|\beta A| \geq 1\] and the system is started oscillating by amplifying noise voltage, which always present. The resulting waveform not exactly SINUSOIDAL. The closer the value \(\beta A = 1\), the more nearly sinusoidal is the waveform. Loop gains are typically chosen to be at least 2 or 3 to ensure oscillation. Oscillators adjust themselves to satisfy the criteria.

### 3.2.1 Audio Oscillator

An audio oscillator is useful for testing equipment that operates in the audio-frequency range. Such instruments always produce a sine-wave signal, variable in both amplitude and frequency, and usually provide a square-wave output as well. The maximum amplitude of the output waveform is typically on the order of 25 V\(_{\text{rms}}\), whereas the range of frequencies covers at least the audio-frequency range from 20Hz to 20 kHz. The most common output impedances for audio oscillators are 75 Ω and 600 Ω.

The two most common audio-oscillator circuits are the Wien bridge oscillator and the phase-shift oscillator, both of which employ \(RC\) feedback networks. The Wien bridge offers some very attractive features, including a straightforward design, a relatively pure sine-wave output, and a very stable frequency.

(a) **Wien bridge Oscillator**

The Wien bridge oscillator is essentially a feedback amplifier in which the Wien bridge serves as the phase-shift network. The Wien bridge is an ac bridge, the balance of which is achieved at one particular frequency. The basic Wien bridge oscillator is shown in Fig. 2.

As can be seen, the Wien bridge oscillator consists of a Wien bridge and an operational amplifier represented by the triangular symbol. Operational amplifiers are integrated circuit
amplifiers and have high-voltage gain, high input impedance, and low output impedance. The condition for balance for an ac bridge is

\[ Z_1 Z_4 = Z_2 Z_3 \] .................................(2)

where

\[ Z_1 = R_1 - \frac{j}{\omega C_1} \]

\[ Z_2 = \frac{R_2 \left( -\frac{j}{\omega C_2} \right)}{R_2 - \frac{j}{\omega C_2}} = -\frac{j R_2}{-j + R_2 \omega C_2} \]

\[ Z_3 = R_3 \]
\[ Z_4 = R_4 \]

Substituting the appropriate expression in equation X yields

\[ \left( R_1 - \frac{j}{\omega C_1} \right) R_4 = \left( -\frac{j R_2}{-j + R_2 \omega C_2} \right) R_3 \] .................................(3)

If the bridge is balanced, both the magnitude and phase angle of the impedances must be equal. These conditions are best satisfied by equating real terms and imaginary terms. Separating and equating the real terms in Eq. 3 yields

\[ \frac{R_3}{R_4} = \frac{R_1}{R_2} + \frac{C_2}{C_1} \] .................................(4)

Separating and equating imaginary terms in Eq 3 yields

\[ \omega C_1 R_2 = \frac{1}{\omega C_2 R_1} \] .................................(5)

where \( \omega = 2\pi f \). Substituting for \( \omega \) in Eq. 5, we can obtain an expression for frequency which is

\[ f = \frac{1}{2\pi \sqrt{C_1 R_1 C_2 R_2}} \] .................................(6)

If \( C_1 = C_2 = C \) and \( R_1 = R_2 = R \), then Eq. 4 simplifies to yield

\[ \frac{R_1}{R_4} = 2 \] .................................(7)

And from Eq.6 we obtain

\[ f = \frac{1}{2\pi RC} \] .................................(8)

where

\( f \) = frequency of oscillation of the circuit in Hertz
\( C \) = capacitance in farads
\( R \) = resistance in ohms
Example 1
Determine the frequency of oscillation of the Wien bridge oscillator if $R = 6 \, k\Omega$ and $C = 0.003 \, \mu F$.

Solution

$$f = \frac{1}{2\pi RC} = \frac{1}{(2\pi)(6\,k\Omega)(0.003\,\mu F)} = 8.885 \, kHz$$

The design of Wien bridge oscillator can be approached by selecting an operating frequency and level of current that will be acceptable through each arm of the bridge. The bridge currents are typically larger by at least a factor of 100 than the maximum input current to the amplifier, and the peak value of the sinusoidal output voltage is typically on the order of 90% of Vcc.

![Figure 2: Wien bridge oscillator](image)

(b) Phase-shift Oscillator

The phase-shift networks for the phase-shift oscillator is an RC network made up of equal-value capacitor and resistor connected in cascade as shown in Fig 3. Each of the three RC stages shown provides a 60° phase shift, with the total phase shift equal to the required 180°.

The phase-shift oscillator is analyzed by ignoring any minimal loading of the phase-shift network by the amplifier. By applying classical network analysis techniques, we can develop an expression for the feedback factor in terms of the phase-shift networks components.

The phase-shift oscillator is useful for the noncritical applications, particularly at medium and low frequency, even down to 1 Hz, because of its simplicity. However, its frequency stability is not as good as that of the Wien bridge oscillator, distortion is greater and changing frequency is inconvenient because the value of each capacitor must be adjusted. The choice of an oscillator circuit to operate in the audio-frequency range is determined by the particular application.
### 3.2.2 Radio-Frequency Oscillator

Radio-frequency (RF) oscillators must satisfy the same basic criteria for oscillation as was discussed in Section 3.2 for audio oscillators. That is, the Barkhausen criteria must be satisfied. The phase-shift network for RF oscillators is an inductance–capacitance (LC) network. This LC combination, which is generally referred to as a tank circuit, acts as a filter to pass the desired oscillating frequency and block all other frequencies. The tank circuit is designed to be resonant at the desired frequency of oscillation. An LC circuit is said to be resonant when the inductive and capacitive reactance are equal, that is, when

\[ X_L = X_C \]  

or when

\[ 2\pi f L = \frac{1}{2\pi f C} \]

Solving Eq. 10 for the frequency \( f \), we obtain an expression for the frequency of oscillation of an RF oscillators, which is

\[ \text{Frequency of oscillation}, f = \frac{1}{2\pi \sqrt{LC}} \]

where

- \( f \) = frequency of oscillation
- \( L \) = total inductance of the phase-shift network
- \( C \) = total capacitance of the phase-shift network

There are a number of standard RF oscillator circuits in use; the most popular are the Colpitts oscillator and the Hartley oscillator shown in Fig. 3.

As can be seen, the phase-shift network contains a tapped inductor consisting of sections \( L_1 \) and \( L_2 \) and an adjustable capacitor to vary the frequency of oscillation. The feedback factor \( \beta \), is given as

\[ \text{Feedback factor}, \beta = -\frac{L_1}{L_2} \]

The negative sign means there must be a 180° phase shift across the amplifier. This is accomplished by connecting the amplifier in the inverting configuration as shown in Fig. 3. As we stated earlier, the circuit must satisfy the Barkhausen criterion which states that \( A\beta \geq 1 \) to sustain oscillation. This may be written as

\[ A \geq \frac{1}{\beta} = -\frac{L_2}{L_1} \]

Equation 13 states that the gain of the amplifier must be greater than or equal to the ratio of \( L_1 \) to \( L_2 \) to sustain oscillation. Using the equation for the gain of an inverting amplifier yields

\[ A = -\frac{R_f}{R_i} \]

We can determine the value of either \( R_f \) or \( R_i \) given the value of the other.
Example 2
Determine the frequency of oscillation and the minimum value of $R_f$ to sustain oscillation for the Hartley oscillator shown in Fig. 4.
**Solution**

The frequency of oscillation is determined from Eq. 11 as

\[
  f = \frac{1}{2\pi[(L_1 + L_2)C]^{1/2}}
\]

\[
  = \frac{1}{2\pi[(280 \mu H)(0.001 \mu F)]^{1/2}}
\]

\[
  = \frac{1}{(2\pi)(5.29 \times 10^{-7})} = 300 \text{Hz}
\]

The minimum gain of the amplifier is computed using Eq. 13 as

\[
  A_{\text{min}} = \frac{L_2}{L_1} = \frac{270 \mu H}{10 \mu H} = -27
\]

Using Eq. 14, we can compute the value of the feedback resistor \( R_f \) as

\[
  R_f = A R_L
\]

\[
  = (27)(15 \text{ k}\Omega) = 405 \text{ k}\Omega
\]