Oscillators are essentially waveform generating circuits which fall into two main categories:

1) **Non-Linear Oscillators**:

These are circuits that usually generate square, triangular, pulse (etc.) waveform. These type of circuits are also known as function generator. These circuits usually involve a non-linear element such as an inverter, comparator, etc. in feedback through phase-delay mechanism.

2) **Linear Oscillators**:

These are circuits used to generate very pure sinusoidal waveform for high-performance linear circuits. The circuits usually employ a positive-feedback loop consisting of an amplifier and an RC or LC frequency-selective network. This network feeds back the oscillation frequency with the right amplitude and phase to sustain the oscillation.
**The Barkhausen Criterion:**

The basic structure of a linear (sinusoidal) oscillator can be represented by a simplified block diagram shown below.

![Block Diagram](image)

**Figure: 19.1**

As shown in the figure, the structure consists of an amplifier \( A(s) \). Usually, this amplifier has a very high frequency response compared to the oscillation frequency such that \( A(s) \) can be represented by a constant gain \( A_0 \) (which is the D.C. gain of \( A(s) \)).

The frequency selective network has a transfer function \( B(s) \).

From Figure 22.1, we can write

\[ X_{out} = A(s) \cdot [X_{in} + B(s) \cdot X_{out}] \]
or \[ X_{\text{out}} = \frac{A(s)}{1 - A(s) \cdot B(s)} \times X_{\text{in}} \]

Loosely speaking, we can have an output from this system without any input if:

\[ 1 - A(s) \cdot B(s) = 0 \]

or \[ A(s) \cdot B(s) = 1 \]

This is known as the Barkhausen criterion for oscillation.

An alternative way of stating the condition is:

\[ L(s) = 1 \]

where \( L(s) = A(s) \cdot B(s) \) is known as the loop gain of the system. i.e., if you break the loop, anywhere in the feedback path, and find the transfer function, it turns out to be \( L(s) = A(s) \cdot B(s) \).

**Note:** In order to get a pure sinusoidal waveform, the Barkhausen criterion should be satisfied only for one frequency. Otherwise, you get an oscillation with multiple frequency which compromises the spectral purity of the signal.
If the criterion is satisfied for, say $\omega_0$, then we can write,

$$L(j\omega) = A(j\omega) \cdot B(j\omega) = 1$$

Since the above quantity is a complex number, it implies:

Magnitude, $|A(j\omega) \cdot B(j\omega)| = 1$

AND, the phase $\alpha(j\omega) \cdot \beta(j\omega) = 0$

In other words, if the gain around the loop is exactly one for $\omega_0$ & the phase is shifted by 0° or multiples of 0° for $\omega_0$ then it will sustain an oscillation for the frequency $\omega_0$.

An intuitive feeling for the Barkhausen Criterion can be gained by looking at the feedback structure of Figure 22.1. In order to sustain an oscillation at $\omega_0$ without any input (i.e., $x_{in} = 0$), the feedback output $B(j\omega) \cdot x_{out}$ when amplified by $A(j\omega)$ should give you back $x_{out}$ or,

$$A(j\omega) \cdot B(j\omega) = 1.$$
AN ALTERNATIVE LOOK AT THE OSCILLATION CONDITION

We know from Network theory that 'poles' of a s-domain transfer function determines the time-domain behaviour of the system. Also, the 'zeros' together with 'poles' determine the magnitude of each term in the time-domain response.

Let's look at the time domain response for some common s-domain functions.

Since we're interested only in the behaviour and not in the magnitude, we'll only look at the effect of poles.

a) \( \frac{K_1}{s+a} = \Rightarrow K_1 e^{-at} \Rightarrow \frac{\text{\uparrow}}{t} \)

b) \( \frac{A_1}{(s+\alpha)^2 + \omega^2} = \frac{A_1}{(s+\alpha+j\omega)(s+\alpha-j\omega)} = \Rightarrow K_2 e^{-at} \cdot \sin \omega t \Rightarrow \frac{\text{\uparrow}}{t} \)

c) \( \frac{A_2}{(s-\alpha)^2 + \omega^2} = \frac{A_2}{(s-\alpha+j\omega)(s-\alpha-j\omega)} = \Rightarrow K_3 e^{at} \cdot \sin \omega t \Rightarrow \frac{\text{\uparrow}}{t} \)

d) \( \frac{A_2}{s^2 + \omega^2} = \frac{A_3}{(s+j\omega)(s-j\omega)} = \Rightarrow K_4 \cdot \sin \omega t \Rightarrow \frac{\text{\uparrow}}{t} \)
Graphical View

Figure 19.2

Observation on the Impulse Responses from Fig 22.2

* Left-half 'real' poles just have decaying response.

* Left-half complex-conjugate poles have a decaying sinusoidal response.

* Right-half complex-conjugate poles have a growing sinusoidal response.

* Finally, it can be seen from the inverse Laplace transform that, in order to have a sustained sinusoidal response, the poles need to be exactly on the jw axis.
NON-LINEAR AMPLITUDE CONTROL

As seen from both the views (Barkhausen condition & pole location view), it is a mathematical condition. In practice it is impossible to design an oscillator to maintain Barkhausen criterion for varying temperatures, varying ckt. parameters ($β, R, C, ...$), etc.

Therefore, we need a mechanism, which dynamically adjusts ckt. parameters to ensure the oscillation condition is met.

In practice this is achieved through a non-linear amplitude control which essentially does the following:

* Ensures the oscillation starts by ensuring $A(0) \cdot B(0)$ is slightly greater than one.

* Once the oscillation starts growing, the amplitude control reduces the loop gain to move the poles from the right-half plane to the jω axis.

* If the poles move to the left-half plane, the oscillation starts decaying, the amplitude control detects it and moves the poles back to the jω axis.