Fundamentals of operational Amplifiers
& Linear Integrated Circuits
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The Phase-Locked Loop :

Objective :-

Upon completing this chapter, you will be able to

- * Draw the block diagram of the basic phase locked loop.
- * Explain the general principles of the phase locked loop.
- * Briefly explain the function of the phase detector, loop filter and VCO.
- * Explain the difference between free running, capture, and phase locked states in terms of their frequency ranges.
- * Explain different applications

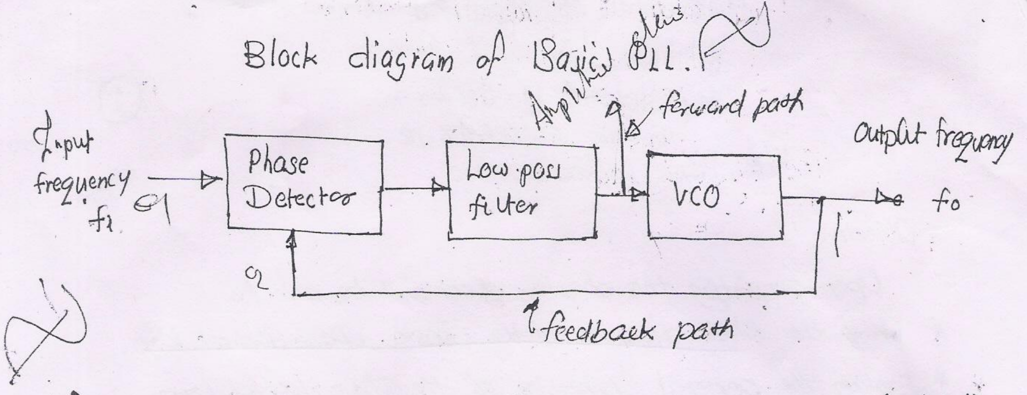
Introduction

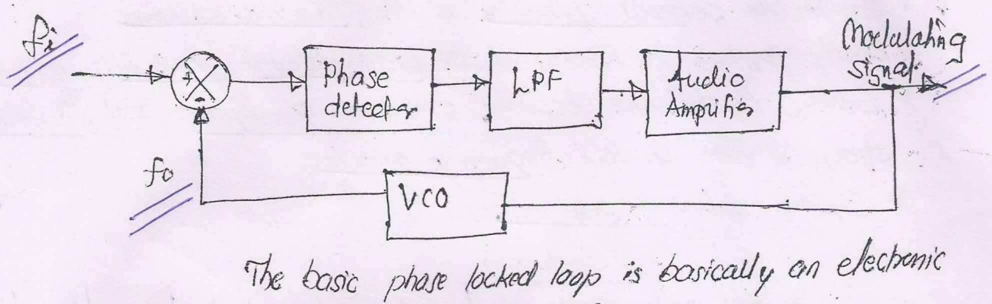
In the early 1930, the superheterodyne receiver was king, but a simpler method was sought to reduce the number of tuned stages. The new receiver that resulted was called a synchrodyne and it first consisted of a local oscillator, mixer and an audio amplifier. However frequency drift of local oscillator hampered reception. To combat this drift, the frequency of local oscillator was then compared with the receivers input by a phase detector so that a correction voltage would be generated. This electronic feedback circuit began the evolution of the Phase Locked Loop (PLL).

Rise of PLL

PLL is a very sophisticated electronic network that is often used in diverse application as: (Motor speed control) (Touch Tone (DTMF) decoder) modulation, demodulation, filtering, frequency scaling & frequency control of electronic Communication equipment)

Block diagram of Basic PLL.





The basic phase locked loop is basically an electronic feedback loop system consisting of the following component

1. Phase detector
2. Low pass filter
3. Voltage controlled oscillator (VCO)

The characteristics of ~~each~~ these individual building blocks together determine the overall response characteristics of the loop.

The Phase Detector :

The phase detector is also called a mixer or phase comparator generates an average DC output voltage that is proportional to the phase difference ($\Delta\theta$) between the input signal ~~and~~ of the phase locked loop and that of ~~the~~ output of the VCO. This output voltage V_0 is referred to as the error voltage and is given by

$$\boxed{V_0 = K_\theta \Delta\theta} \text{ ——— } ①$$

where K_θ is the phase detector conversion gain in Volts/radian

The Voltage-Controlled Oscillator

The voltage controlled oscillator (VCO) is a voltage-to-frequency converter that changes a DC control voltage input into a pulsed waveform whose output frequency is proportional to the magnitude of the input control voltage. Its conversion gain (K_{VCO}) relates output frequency to input voltage in the form of the equation for a straight line

$$\boxed{f_0 = f_{min} + K_{VCO} V_{in}} \qquad ②$$

where f_{min} - output frequency when $V_{in} = 0$

K_{VCO} - VCO conversion gain, Hz/V.

The VCO output frequency (f_0) is fed to one ~~of~~ input of the phase detector, where it compared with the frequency of the input signal (f_i) at the other input of the phase detector.

The Loop Filter

The inclusion of an (active or passive ~~filter~~ low pass filter network in the PLL has two major functions.)

1. It removes any noise and high frequency components from the output voltage of the phase detector resulting ~~an~~ in an average (DC) control voltage and drives the VCO).
2. It is the primary building block that determines the dynamic performance of the loop covering the following factors
    - * Capture & Lock range
    - * Bandwidth
    - * Transient response

A complete phase locked loop system exhibits the characteristics of a second order system.

(Free-Running . Capture and Phase Locked)

In operation, the phase-locked loop is in any one of the following three states:

- * Free-running
- * Capture
- * Phase. lock

→ (If we assume that initially the phase-locked loop has no input signal. the VCO then runs at its free-running frequency which is set by either and external RC or LC network. Here the loop is said to be unlocked. When an input signal is applied to the phase detector and the VCO frequency starts to change in a direction that reduces the frequency difference between the VCO and the input, the loop is said to have acquired capture and is now in the capture state. The input and output frequencies are not equal, but in time they will be.)

→ (In order for a phase-locked loop that is initially unlocked to respond to an input signal and then be in the capture state. the frequency of the input signal must be within a narrow frequency range called the capture range, which is set by the response-parameters of the loop circuit). (If the input frequency is outside this capture range, the loop will never acquire capture and the output frequency of the VCO will equal its free running frequency). (On the other hand if the input frequency is within the loop's capture range. then the VCO frequency starts to change in a direction that reduce the frequency difference between the VCO and the input.)

Capture Range:

The capture range is often specified as a percentage of the VCO's free running frequency so that the free-running frequency is within the range.

For example ±2% of free running frequency 1250 Hz.

$\therefore$ capture range is $\pm 2 \times \frac{1250}{100} = \pm 25\,Hz$ about the free running frequency.

Hence if the input frequency is between 1225 Hz to 1275 Hz then the loop will acquire capture and the VCO frequency will then shift to equal that of input frequency. Otherwise, the output frequency of the VCO will remain at 1250 Hz for those input frequencies less than 1225 Hz and above 1275 Hz.

When the loop acquires capture, the input and output frequencies are not equal. However, the process is repeated many times going around the loop. The input and VCO frequencies are compared by the phase detector. Its DC output voltage is proportional to this frequency difference. After filtering this frequency difference drives the VCO whose output frequency tries to get closer to the input frequency. Eventually the loop will reach the situation where the VCO's frequency and loop input frequency are exactly equal except for possible phase shift. When the input and output signals have exactly same frequency except for a given phase shift, the loop is then said to be locked or phase-locked. The phase shift, if any, occurs because the VCO is asynchronous with input signal. If there is no input signal, the VCO runs along at its own pace (i.e. its free running frequency). When the loop receives the input signal it is then asynchronous with the VCO signal.

Because of the loop's transient behaviour, it takes a finite amount of time for the loop, once it acquire to become locked; this is referred to as settling time. In a well designed phase-locked loop system this may be of the order of several milliseconds, hence the transition from being an unlocked loop to acquire capture and becoming locked may appear as a virtually instantaneous process.

Once locked, the input frequency can change within certain limits and the VCO's output frequency will follow this change. When the input frequency and the shifting process starts all over again until the VCO output and input frequencies are exactly the same (except for a possible phase shift). Once locked, the input frequency range over which the VCO can track is called the lock range or hold in range. As capture range it is also specified as % of the VCO's free running frequency and is always wider than the capture range. Once the loop has acquired capture and phase lock, if the input frequency then shifts to a frequency outside the lock range, then the loop immediately loses phase lock and output frequency equals the VCO's free running frequency. For the loop to again be phase locked, the new input signal then has to be within the loop's capture range to start the cycle all over again.

Characteristics of PLL.