Work-Ready Electronics

Synchronizing Curriculum to the Rapidly Changing Workplace

Module: Phase-Locked Loops and Applications

WORKREADY ELECTRONICS

Phase-Locked Loops

Phase-locked loops (PLL) are unique feedback control circuits that offer many useful features and benefits in electronic applications. PLLs are available either in integrated circuit (IC) form for general applications or built into larger system IC chips.

Today, PLLs are found in virtually all types of electronic equipment from PCs to consumer products like TV sets and cell phones.

This module provides an introduction to the PLL and its applications. It begins with an overview of the main components of a PLL and how these components work together. It then describes PLL specifications and a description of the most widely used applications including frequency synthesizers, clock multipliers, clock and data recovery circuits, FM demodulators, and filters.

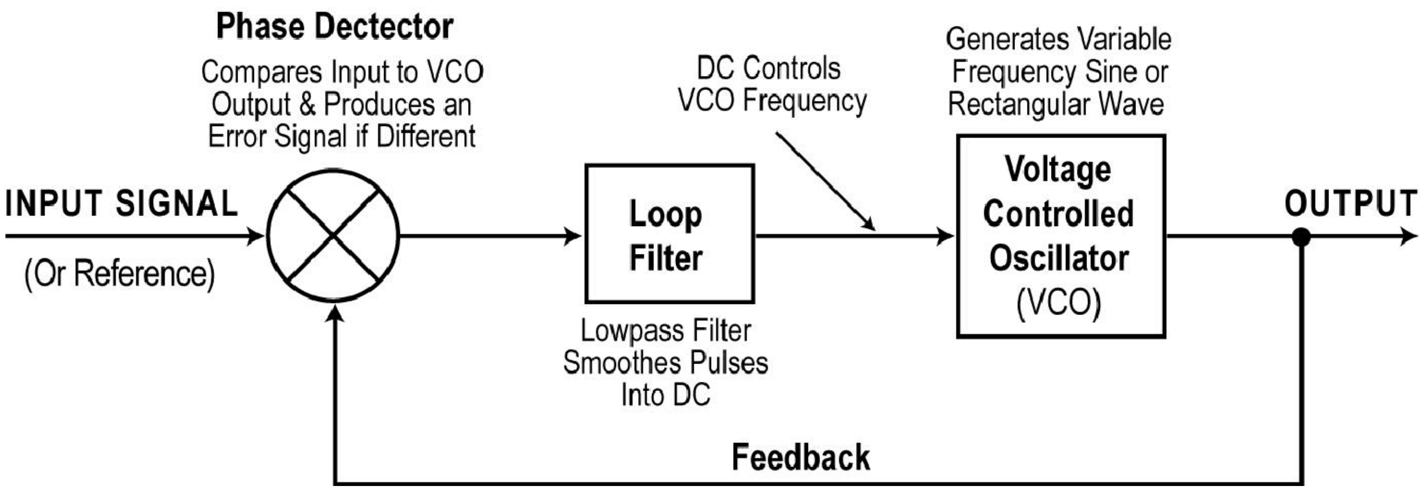
What Technicians Need to Know

As a technician, you should know:

- Main components of a PLL
- Basic operation of a PLL
- Main specifications of a PLL
- How a PLL operates as a filter, a clock and data recovery circuit, an FM demodulator, a clock multiplier, and a frequency synthesizer.

Phase-Locked Loops Theory of Operation

PLL Components



A discussion of this graphic is presented in the pages that follow. You can print this graphic for study purposes before going on.

PLL Components

The three main components of a phase-locked loop (PLL) are the phase detector, loop filter, and the voltage controlled oscillator (VCO).

The phase detector, or error detector as it is sometimes called, is a circuit that compares two input signals and produces an output.

The loop filter is a low pass filter that smoothes the phase detector output into a DC voltage that controls the VCO frequency.

The VCO is an oscillator that generates either a sine wave or a rectangular wave depending upon the application.

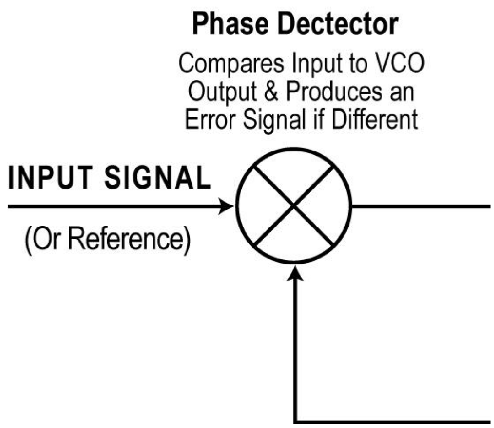
PLL Components: Phase Detector

The phase detector is a circuit that compares two input signals and produces an output that it proportional to the phase (time shift) difference between them.

The inputs to the phase detector are the external signal used in the application and the VCO output.

Depending upon the application, the phase detector may be either a linear circuit like a differential amplifier, a digital circuit like an exclusive OR gate or flip flop, or some special design.

Usually the phase detector output includes pulses whose width is proportional to the phase/frequency difference of the two inputs.

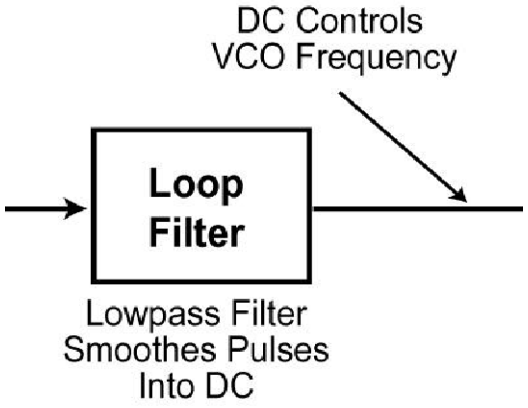


PLL Components: Loop Filter

The loop filter is a low pass filter that smoothes the phase detector output into a DC voltage that is used to control the VCO frequency.

The loop filter is usually an RC filter whose configuration and time constant is carefully adjusted to ensure the desired operation.

In terms of performance, the loop filter is the key operational circuit.



PLL Components: VCO

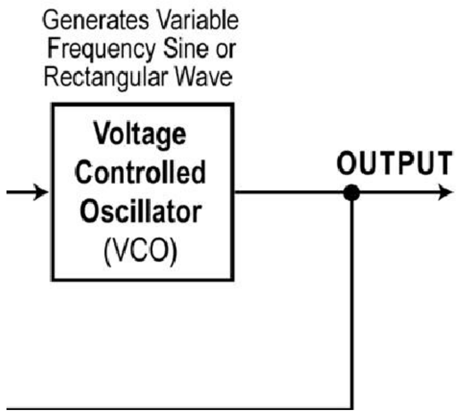
In most applications, the output is usually derived from a voltage controlled oscillator (VCO).

The VCO is an oscillator that generates either a sine wave or a rectangular wave depending upon the application.

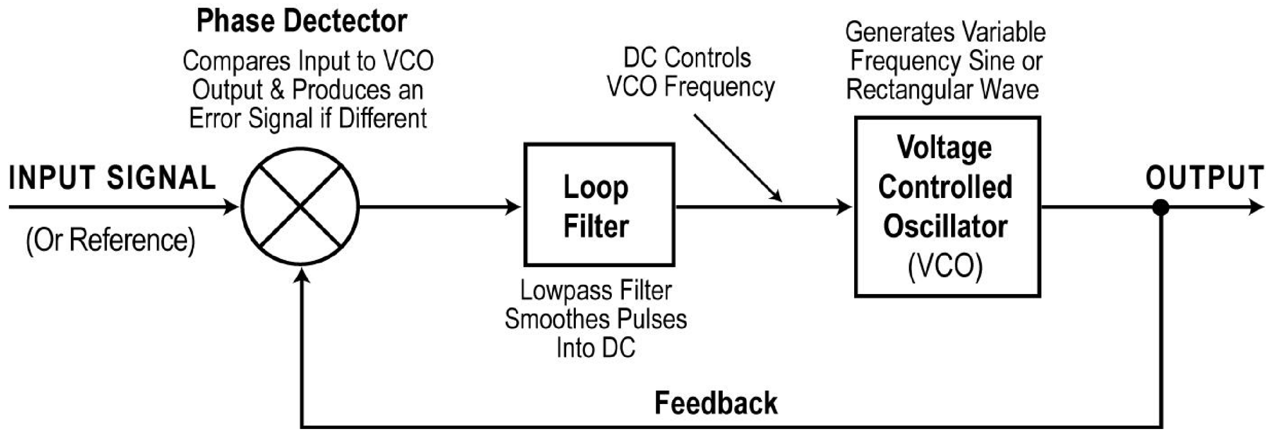
The center frequency of the VCO is set by the design. This is called the free-running frequency.

The output frequency is varied by an external DC input. The output frequency is typically linearly proportional to the DC input voltage.

The method of frequency change is usually by a varactor (voltage variable capacitor) in the VCO. The capacitance of the varactor is varied by the DC from the loop filter.

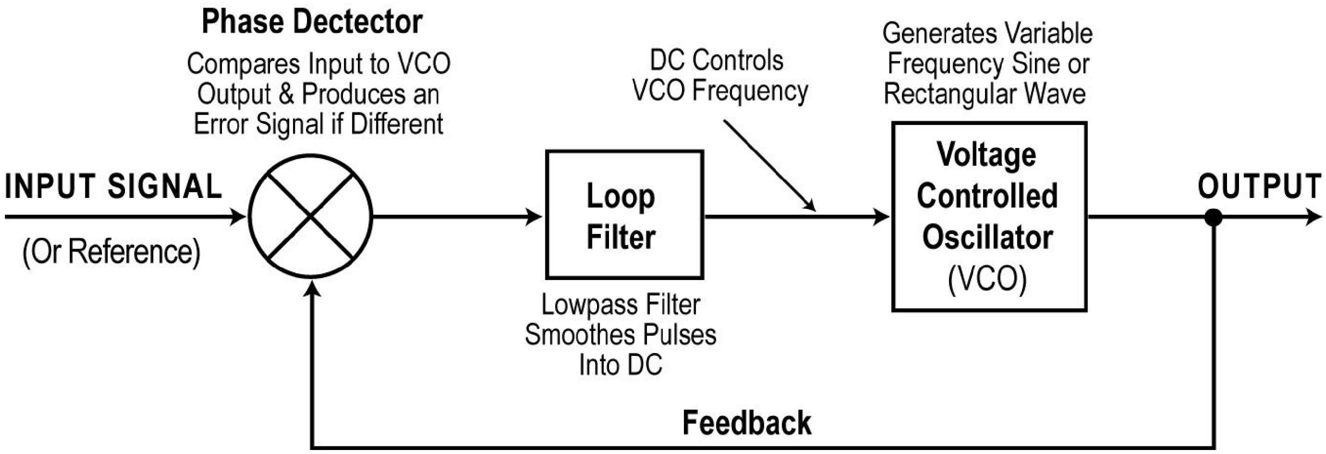


PLL Operation: Phase Detector



When an external sine wave signal is applied to the phase detector input, the phase detector compares it to the feedback signal. The input frequency should be approximately equal to the center frequency of the VCO. The phase detector produces an error signal that is proportional to any frequency or phase difference. The phase detector interprets a frequency difference as a phase difference and produces an error signal.

PLL Operation: Loop Filter and VCO

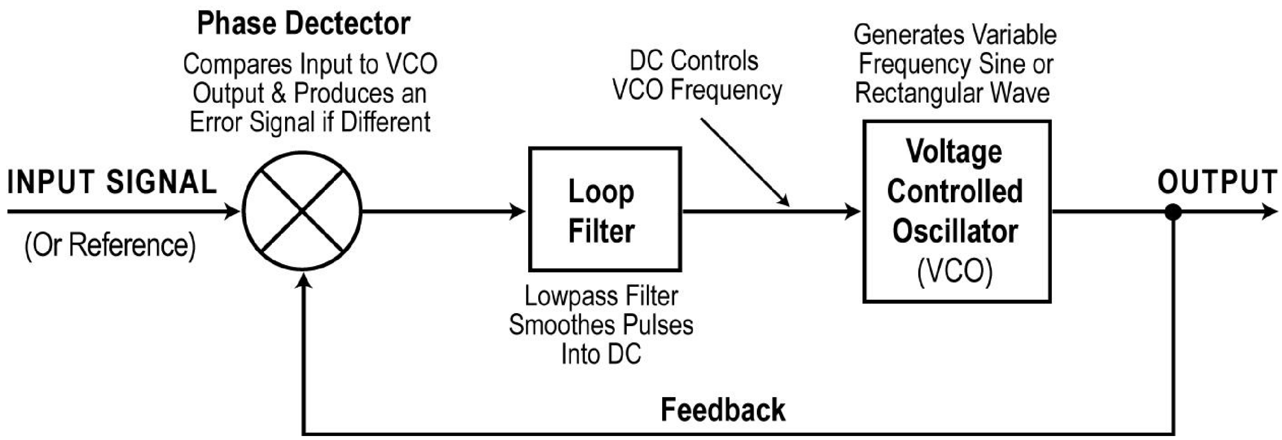


The phase detector output is filtered into DC by the loop filter. The resulting DC adjusts the VCO frequency until it is equal to the frequency of the input signal.

When the VCO output frequency is equal to the input frequency, no further error is developed by the phase detector.

At this time, the PLL is said to be in the “locked” state.

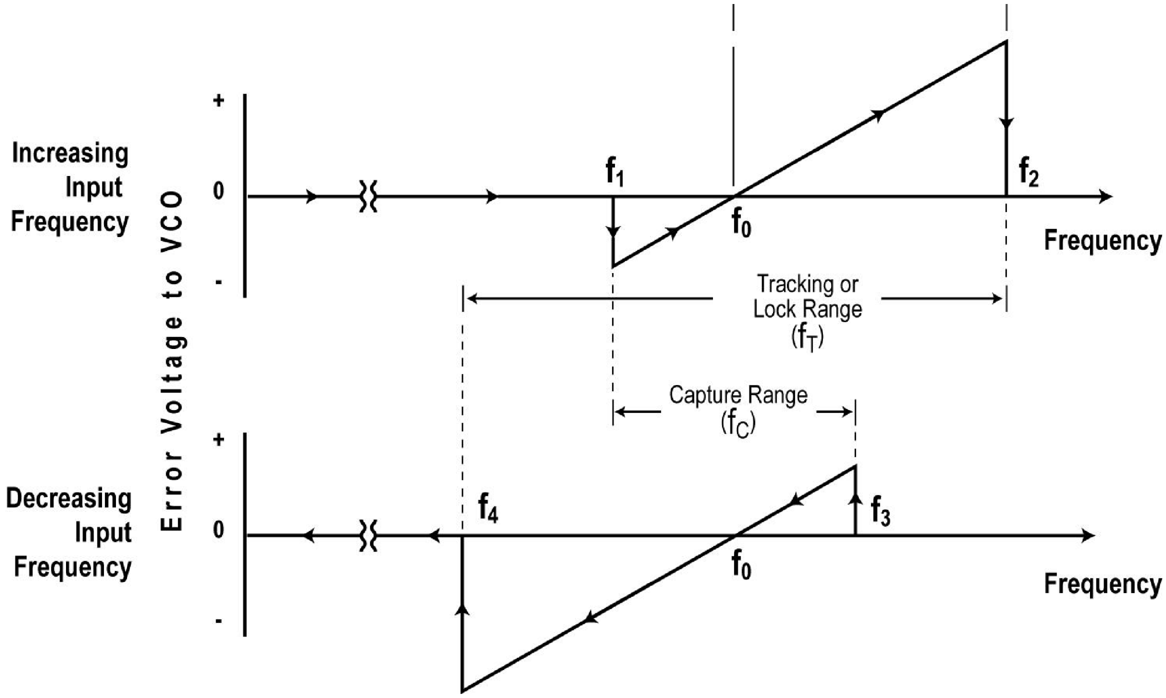
PLL Operation



If the input frequency should change, a frequency difference will exist between the input and output. The phase detector produces an error signal which is smoothed into DC. This, in turn, adjusts the VCO frequency so that it again equals the new input frequency.

The VCO output tracks the input frequency. Any frequency changes at the input are immediately detected and the VCO frequency is adjusted to reduce the error to zero.

Lock and Capture Ranges



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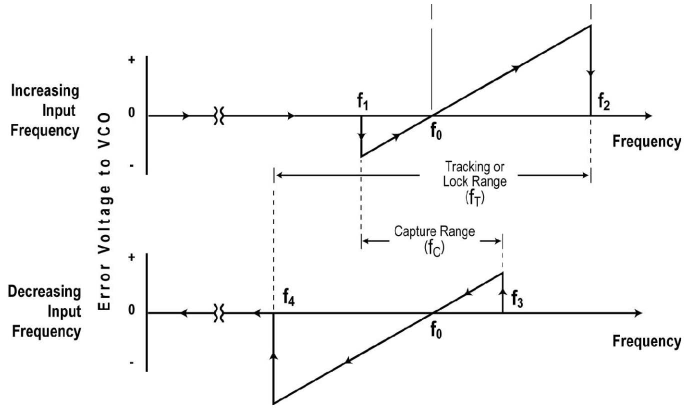
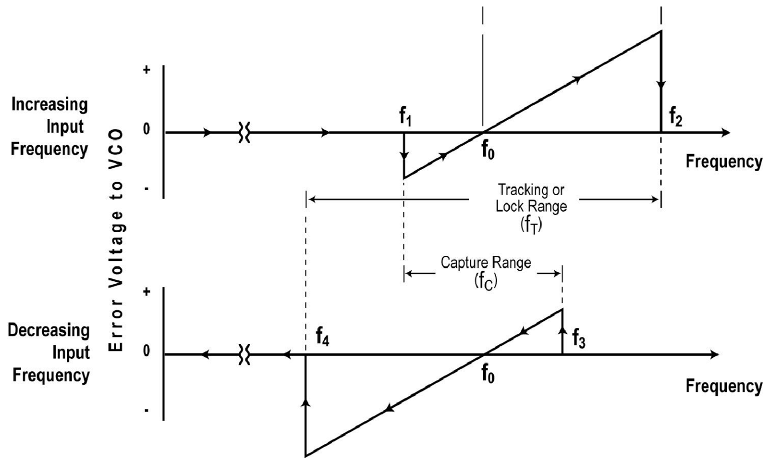
Tracking Range



The variable frequency of the VCO has a limited range. This frequency can be varied above and below the center operating frequency by a small percentage. If the DC input exceeds this range, no further frequency changes occur and the output frequency stays at either the upper or lower limit. This is called the tracking range. It is also known as the lock range.

The VCO output frequency tracks or follows the input frequency only over the tracking range.

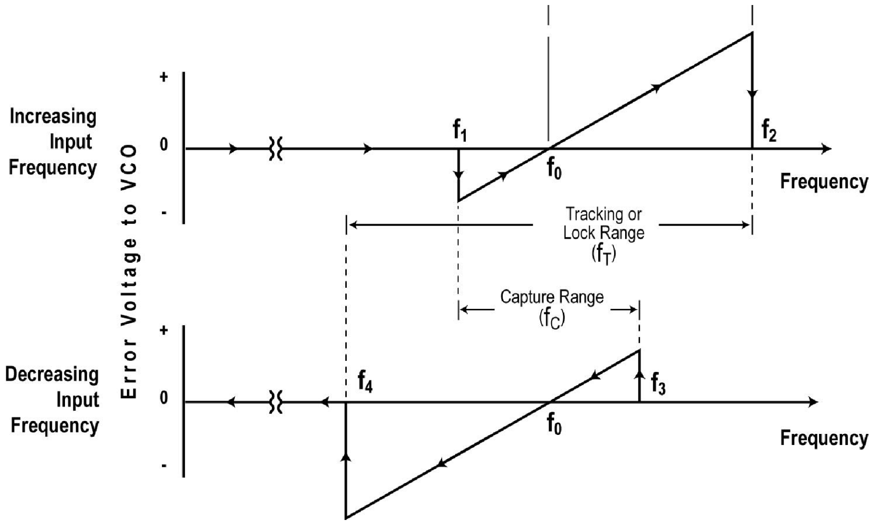
Capture Range



To bring the PLL into its stable locked condition, the initial input frequency must be within another more limited range called the capture range.

If the input frequency is outside of the capture range, the PLL will not go into its locked state. The VCO output reverts to its standard preset free-running center frequency.

Lock and Capture Ranges

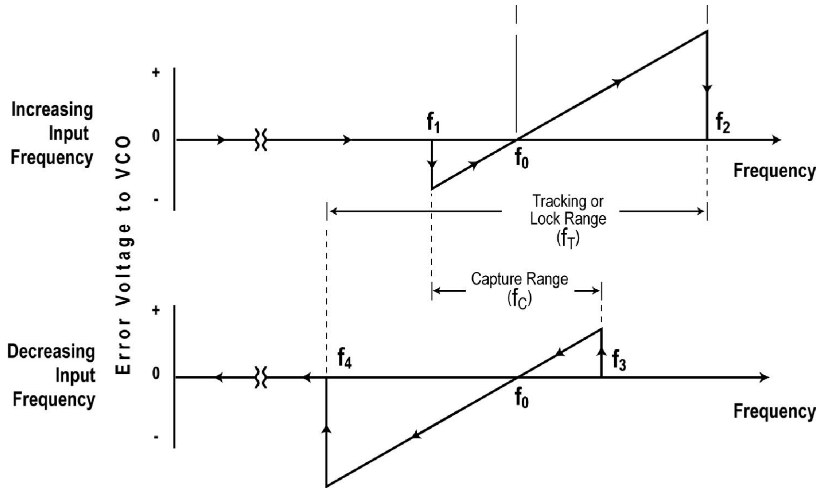


The plots show the DC error voltage driving the VCO as a function of the input frequency. The frequency f_o is the center free-running frequency of the VCO.

If input frequency is very low, the PLL will not be locked and the output will be f_o.

As the input frequency is increased at some frequency, f_1, the PLL will come into a locked state. The error voltage is negative. The frequency f_1 is the lower limit of the capture range.

Lock and Capture Ranges

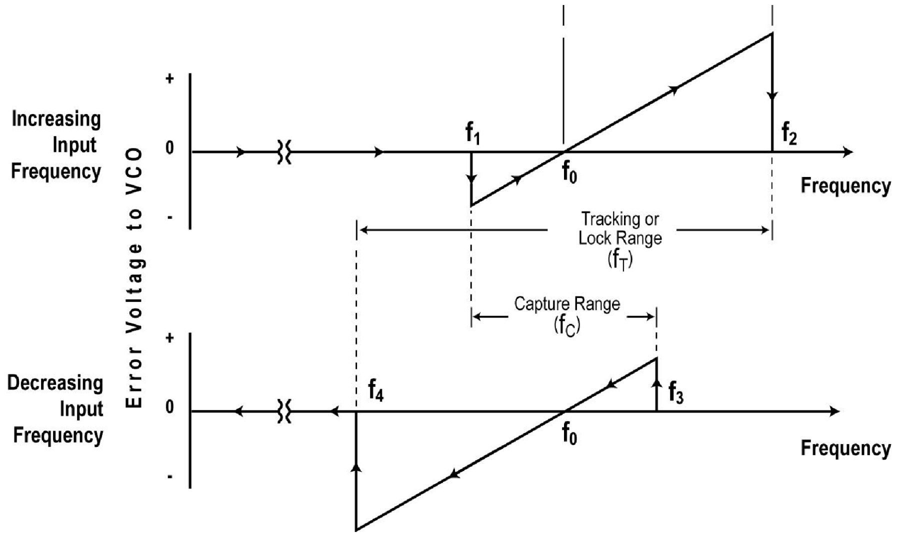


As the input frequency continues to increase, the error voltage increases becoming zero at the free-running frequency and then going positive.

At some higher frequency f_2, the VCO range is exceeded and the circuit goes out of lock. The frequency f_2 is the upper limit of the tracking or lock range.

If the input frequency is much higher than the tracking range and the frequency is decreased, at some point, f_3, the PLL will come into the locked state. The frequency f_3 is the upper end of the capture range.

Lock and Capture Ranges



As the input frequency is decreased, the PLL remains locked as the error voltage decreases linearly from a positive level to zero at f_o and then going negative.

At some frequency f_4, the PLL goes out of lock and the output goes to f_o. The frequency f_4 is the lower end of the tracking range.

In summary, the tracking range is $f_T = f_2 – f_4$. The capture range is $f_C = f_3 – f_1$. The capture range is less than the lock range.

Phase and Frequency Relationships

When the PLL is in its stable locked state, the input and output frequencies will be identical.

However, there will be a phase difference between the input and VCO frequencies.   This phase difference may be 0, 90, or 180° depending upon the type and design of the phase detector circuit.

This phase difference may or may not be an important operational issue depending upon the application.

The inputs to the phase detector must be at the same or approximate frequency or lock will not be achieved.

PLL Specifications

The four most important PLL specifications are the operational frequency range, the tracking range, the capture range, and the latency or transient response time.

The latency and transient response are a measure of how fast the VCO output responds to input frequency changes.

The VCO frequency cannot change instantaneously with an input change. The response time is determined by the loop filter characteristics. The faster the response time, the better.

Low phase detector frequencies require loop filters with a higher time constant thereby slowing the response to change. Higher frequency phase detector inputs require shorter time constants in the loop filter and produce faster response time. The loop filter also sets the bandwidth of the circuit when used as a filter. The loop filter is usually outside the IC chip so its characteristics can be tailored to the application.

Test your knowledge

Phase-Locked Loops and Applications
Knowledge Probe 1
Phase-Locked Loops Theory of Operations

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Then choose **Knowledge Probe 1**.