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A Review of Key Oscillator Specifications and What They Mean

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Whether designing or buying an oscillator, the key specifications must be understood in order to make the right choice, or evaluate a design

Understanding the specifications of oscillators is essential when selecting a commercial unit or evaluating the performance of your own design. This tutorial-level article offers a review of oscillator specifications, what they mean, and some of the applications that are most affected by particular specifications. These notes will focus primarily on crystal oscillator specifications, although many of the same measurements and performance factors apply to VCOs, phase-locked loops and direct digital synthesizers.

Stability

The first specification is stability. This is as simple as it sounds—stability is how well an oscillator stays on the desired frequency. The measurement of stability is the deviation in frequency under measurement conditions.

The data is typically presented in parts-per-million (ppm), although percentage is occasionally used. High performance oscillators with stability of less than one ppm will be specified in scientific notation (e.g. 1×10^{-6} is 1 ppm). Measurement conditions include:

Temperature—Oscillators are measured according to their intended use, which means the temperature range may be 0 to 50 ºC for indoor applications, –40 to +70 ºC for outdoor applications, or some other range. The most common crystals are "AT cut" (a specific orientation in the quartz blank), which is easy to manufacture and has a modest, but predictable temperature variation curve. "SC cut" crystals are harder to make, but have much better intrinsic temperature stability, which lessens the need to provide compensation in the oscillator circuitry.

Time—Crystals change slightly with age, so performance specifications include short-term (e.g. one day) and long term (e.g. one year) stability. Oscillators used in reference applications may have 10-year stability specifications as well.

Shock and vibration—Frequency variation due to shock and vibration is a key specification in oscillators that will be used in harsh environments, including military and space applications. The magnitude and type of stress will vary according to the needs of each application—a DSL modem might get dropped on a concrete floor, while some military electronics must survive being fired from big guns.

Applications with the greatest stability requirements include primary references for instrumentation, data communications networks and research. Other applications with a significant need for high stability can be classified as "secondary references" used in applications such as GPS receivers and general purpose instruments.

Phase Noise

You might wonder why phase noise (time/frequency domain noise) is the specification for oscillators rather than noise that includes amplitude. The answer is straightforward. First, the frequency of the oscillator is what's important, and second, amplitude noise can be largely eliminated with limiter circuitry. However, if the oscillator is so poorly designed that it has excessive amplitude noise, some of that energy will be converted to phase noise by the limiter or by other nonlinear components in the circuit.

Phase noise is specified in dB referenced to the carrier amplitude (dBc), versus frequency offset from the carrier (f_c). In a reasonably well-designed oscillator, the noise energy decreases with increasing frequency offset, but the slope of the rolloff in noise has a series of different sections, governed by several different behaviors.

Figure 1 is a simplified sketch that illustrates the various influences on crystal oscillator phase noise. The different mechanism are described in many papers on oscillator measurement, including [1]. Rather than describe each in detail, it is sufficient to note that each is an effect created by the physical properties of the crystal and the active devices in the oscillator circuit. The figure shows how different phenomena contribute to overall phase noise characteristics of an oscillator, each being dominant at different offset frequencies and amplitude levels.

A VCO will have a similar plot, but with significantly higher levels of phase noise, since LC, transmission lines, dielectric resonators etc. have much lower Q than a quartz crystal.

In a phase-locked loop, a similar plot (Figure 2) is used to show phase noise performance. The shape of the plot is quite different, since noise amplitude is greatly reduced outside the loop filter bandwidth. The loop filter determines the phase noise close to f_c, but a well-designed VCO is needed for best performance at large offsets. Practical PLLs may have noise or discrete spurious responses from circuitry between the loop filter and VCO, power supply bounce and ground currents, digital switching, and other circuit-related behaviors. Figure 2 is not dimensioned, since different synthesizer implementations will have different characteristics.

Direct digital synthesizers (DDS) or numerically controlled oscillators (NCO) have unique phase noise characteristics, as well as spurs that are a result of the digital circuitry and digital-to-analog conversion. Rather than try to describe them in this short article, the reader is advised to read further on this subject.

Phase noise is the single most important specification in some communication systems. A receivers that must operate in the presence of nearby strong signals is one such application. A transmitter modulated with a highly complex waveform is another. In each case, excessive phase noise can mask desired signal content.

Additional VCO Specifications

A voltage-controlled oscillator will have its own phase noise plot, but also requires tuning range information. The power supply must provide the maximum tuning voltage, while the frequency vs. tuning voltage curve will influence the design of a synthesizer's loop filter. Stability vs. temperature data will tell an engineer how much of the tuning range is available to be used in his or her application.

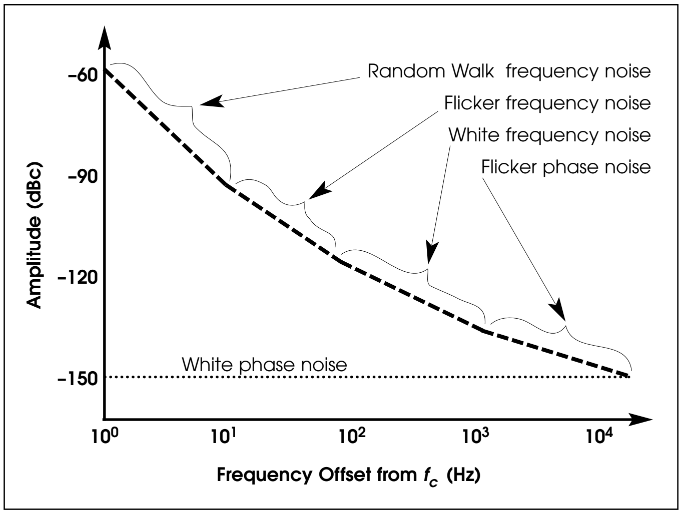

Figure 1 · The effects of different physical phenomena on crystal oscillator phase noise.

Jitter in Digital Oscillators

Jitter is related to phase noise, but is described in the time domain rather than the frequency domain because it relates to digital signals. Jitter, usually specified in picoseconds, is the maximum time variation from the ideal succession of rise and fall transitions in a square wave. This is an important specification for high-speed digital computing and communications systems which must maintain precise timing. Gigabit/second optical systems are a key application requiring low jitter specs.

Reference

1. D. B. Sullivan, D. W. Allan, D. A. Howe and F. L. Walls, editors, *Characterization of Clocks and Oscillators*, NIST Technical Note 1337, National Institute of Science and Technology, Time and Frequency Division, 1990.

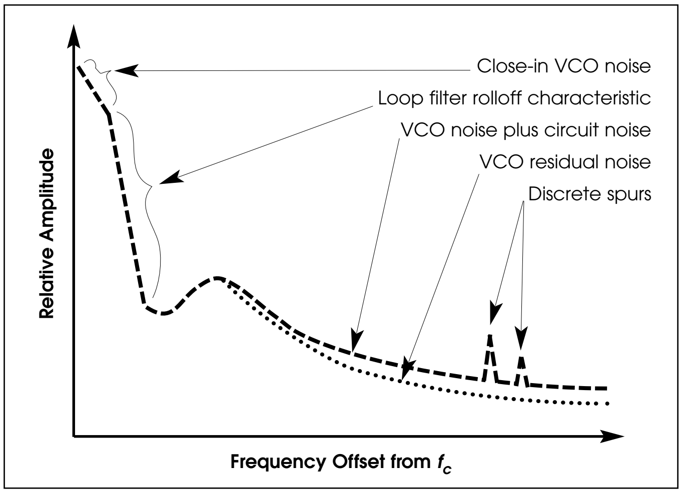

Figure 2 · The phase noise characteristics of a typical phase-locked loop.