



Phase Noise

Introduction

Signal sources such as crystal oscillators produce a small fraction of undesirable energy (phase noise) near the output frequency. As performance of such systems as communications and radar advance, the spectral purity of the crystal oscillators which they employ is increasingly critical.

Phase noise is measured in the frequency domain, and is expressed as a ratio of signal power to noise power measured in a 1 Hz bandwidth at a given offset from the desired signal. A plot of responses at various offsets from the desired signal is usually comprised of three distinct slopes corresponding to three primary noise generating mechanisms in the oscillator, as shown in Figure 1. Noise relatively close to the carrier (Region A) is called Flicker FM noise; its magnitude is determined primarily by the quality of the crystal. Vectron's best close-in noise results have been obtained using 5th overtone AT cut crystals or 3rd overtone SC cut crystals in the the 4-6 MHz range. While not quite as good on average, excellent close-in noise performance may also be achieved using 3rd overtone crystals in the 10 MHz area, especially double rotated types (see page 41 for a discussion of double rotated SC and IT cut crystals). Higher frequency crystals result in higher close-in noise because of their lower Q and wider bandwidths.

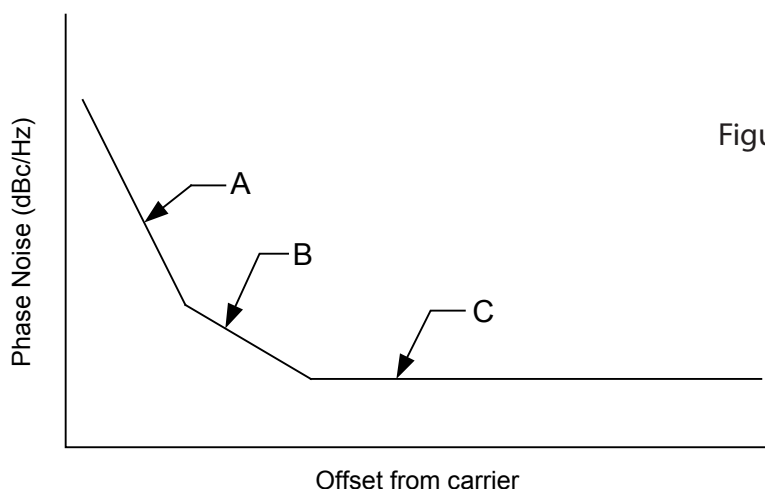


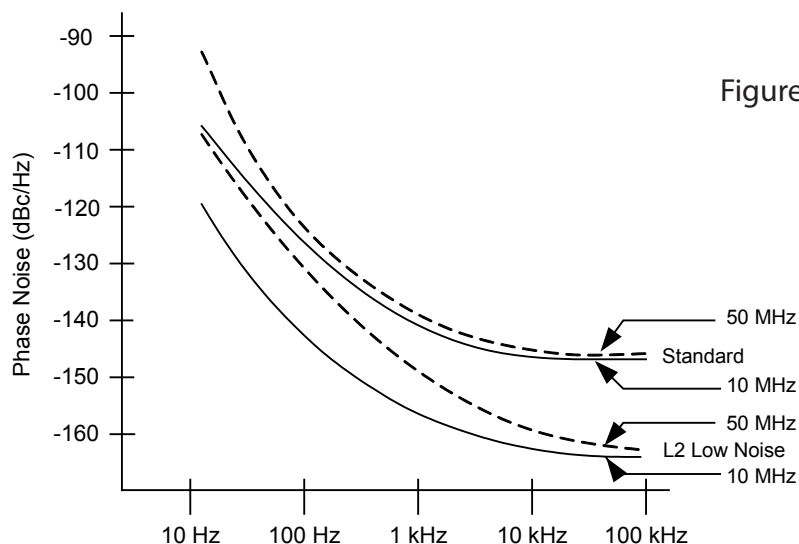
Figure 1.

Noise in Region B of Figure 1, called "1/F" noise, is caused by semiconductor activity. Design techniques employed in Vectron low noise "L2" crystal oscillators limit this to a very low, often insignificant, value.

Region C of Figure 1 is called white noise or broadband noise. Special low noise circuits in Vectron "L2" crystal oscillators offer dramatic improvements (15-20 dB) relative to standard designs.

When frequency multiplication is employed to achieve the required output frequency from a lower frequency crystal, the phase noise of the output signal increases by $20 \log$ (multiplication factor). This results in noise degradation of approximately 6 dB across the board for frequency doubling, 10 dB for frequency tripling and 20 dB for decade multiplication.

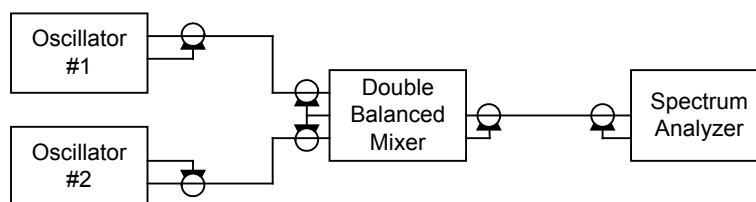
As shown in Figure 2, the noise floor is almost independent of the crystal frequency for oscillators which do not employ frequency multiplication. Thus for low noise floor applications, the highest frequency crystal which satisfies longterm stability requirements should generally be used. However, when a higher frequency application specifically requires minimum close-in phase noise, lower frequency crystals may often be multiplied to advantage. This is so because close-in phase noise is disproportionately better than the noise performance obtained using higher frequency crystals.



Note that the introduction of a varactor diode and moderate Q crystal, used typically in TCXO and VCXO products, result in poorer close-in noise performance when compared with fixed frequency non-compensated crystal oscillators.

Phase Noise Testing

The phase noise test characterizes the output spectral purity of an oscillator by determining the ratio of desired energy being delivered by the oscillator at the specified output frequency to the amount of undesired energy being delivered at neighboring frequencies. This ratio is usually expressed as a series of power measurements performed at various offset frequencies from the carrier. The power measurements are normalized to a 1 Hz bandwidth basis and expressed with respect to the carrier power level. This is the standard measure of phase fluctuations described in NIST Technical Note 1337 and is called $\ell(f)$.



General Block Diagram

Figure 3 shows a block diagram of the method suggested by NIST, and used by Vectron, to measure $\ell(f)$. Signals from two oscillators at the same nominal frequency are applied to the mixer inputs. Unless the oscillators have exceptional stability, one oscillator must have electronic tuning for phase locking. A very narrow band phase-locked loop (PLL) is used to maintain a 90 degree phase difference between these two sources. The mixer operation is such that when the input signals are 90 degrees out of phase (in quadrature), the output of the mixer is a small fluctuating voltage proportional to the phase difference between the two oscillators. By examining the spectrum of this error signal on the spectrum analyzer, the phase noise performance of this pair of oscillators may be measured. If the noise of one oscillator dominates, its phase noise is measured directly. A useful and practical approximation when the two test oscillators are electrically similar is that each oscillator contributes one-half the measured noise power. When three or more oscillators are available for test, the phase noise of each oscillator may be accurately calculated by solving simultaneous equations expressing data measured from the permutations of oscillator pairs.

Figure 4 shows a practical system of measurement of $\ell(f)$. The steps taken to measure phase noise with this system are:

1. Calibration of the spectrum analyzer screen.
2. Phase lock the oscillators and establish quadrature.
3. Record spectrum analyzer readings and normalize readings to dBc/Hz SSB per oscillator.

These steps are detailed below.

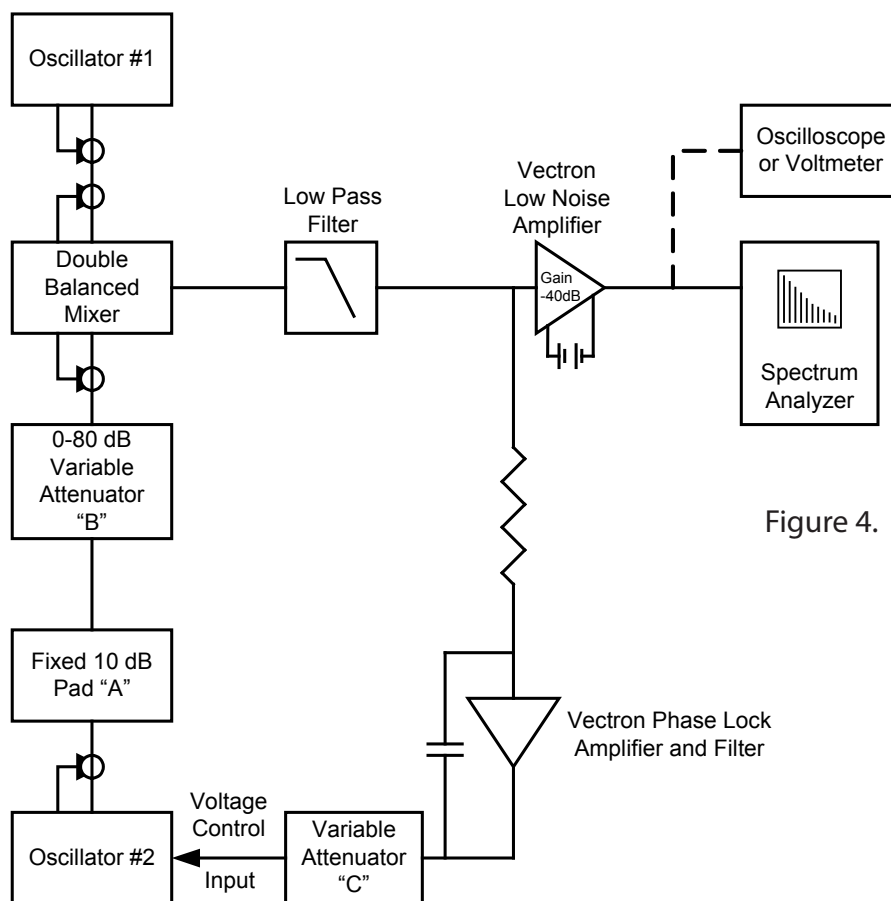


Figure 4.

Measurement System

Step I - Calibration

To avoid saturating the mixer, the signal level of one oscillator is permanently attenuated by 10 dB pad (Attenuator "A"). During the calibration, the level of this oscillator is additionally attenuated by 80 dB (Attenuator "B") to improve the dynamic range of the spectrum analyzer. The oscillators are mechanically offset in frequency and the amplitude of the resulting low frequency beat signal represents a level of -80 dB; it is the reference for all subsequent measurements. When using a swept spectrum analyzer, this level is adjusted to the top line of the spectrum analyzer's screen. When using a digital (FFT) spectrum analyzer, the instrument is calibrated to read RMS VOLTS/ $\sqrt{\text{Hz}}$ relative to this level. When full level is restored to the mixer, and the oscillators are phase locked, the phase noise will be measured with respect to this -80 dB level.

Step II - Phase Lock

The oscillators are phase locked to quadrature by mechanically adjusting them to the same frequency. The desired 90 degree phase difference between the two oscillators is indicated when the mixer output is 0 Vdc. An oscilloscope or zero-center voltmeter connected temporarily at the input to the spectrum analyzer is a convenient way to monitor progress toward quadrature. The operating bandwidth of the PLL must be much lower than the lowest offset frequency of interest because the PLL partially suppresses phase noise in its bandwidth. A widely used empirical method of establishing an appropriate loop bandwidth is to progressively attenuate the voltage control feedback via Attenuator "C". By comparing successive noise measurements at the lowest offset frequency of interest while advancing Attenuator "C", an operating point may be found where the measured phase noise is unaffected by changes in the attenuator setting. At this point the loop bandwidth is not a factor of the measured phase noise.

Step III - Readings

Readings are taken with respect to the -80dB calibration level previously established in Step 1. Smoothing or averaging is used if the spectrum analyzer is so equipped to avoid measurement variations. Swept spectrum analyzer readings generally require each of the following corrections while digital analyzer readings displayed in RMS/ $\sqrt{\text{Hz}}$ do not require the first two corrections. The analyzer's manual should be consulted regarding corrections for analyzer noise response.

	Correction
Normalize to 1 Hz bandwidth "BW" is the measurement bandwidth. Calculation assumes the noise is flat within the measurement bandwidth	$10 \log_{10}(1/\text{BW})$
Video response of swept analyzer to noise signals.	+3dB
Double sideband to single sideband display.	-6dB
Contribution of two oscillators assuming they are of equal noise quality	-3dB

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