VCXOs *Voltage Controlled Crystal Oscillators*
VCOs *Voltage Controlled Oscillators. Non-crystal*

A VCXO (voltage controlled crystal oscillator) is a crystal oscillator which includes a varactor diode and associated circuitry allowing the frequency to be changed by application of a voltage across that diode. This can be accomplished in a simple clock or sinewave crystal oscillator, a TCXO (resulting in a TC/VCXO-temperature compensated voltage controlled crystal oscillator), or an oven controlled type (resulting in an OC/VCXO-oven controlled voltage crystal oscillator).

There are several characteristics peculiar to VCXOs. In generating a VCXO specification these apply in addition to the characteristics which define fixed frequency crystal oscillators. Primary among the specifications which are peculiar to VCXOs are the following:

Control Voltage - This is the varying voltage which is applied to the VCXO input terminal causing a change in frequency. It is sometimes referred to as Modulation Voltage, especially if the input is an AC signal.

Deviation - This is the amount of frequency change which results from changes in control voltage. For example. a 5 volt control voltage might result in a deviation of 100 ppm, or a 0 to + 5 volt control voltage might result in total deviation of 150 ppm.

Transfer function (sometimes referred to as Slope Polarity) - This denotes the direction of frequency change vs control voltage. A positive transfer function denotes an increase in frequency for an increasing positive control voltage, as in Figure 1 A. Conversely, if the frequency decreases with a more positive (or less negative) control voltage, as in Figure 1 B, the transfer function is negative.

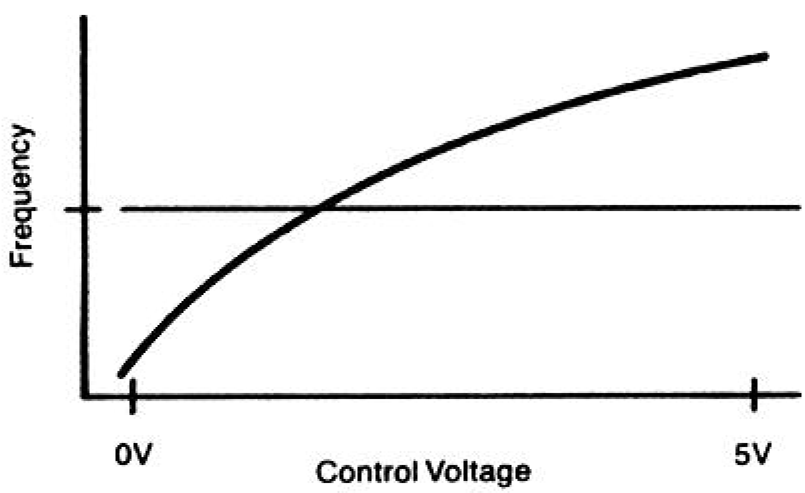

Figure 1A

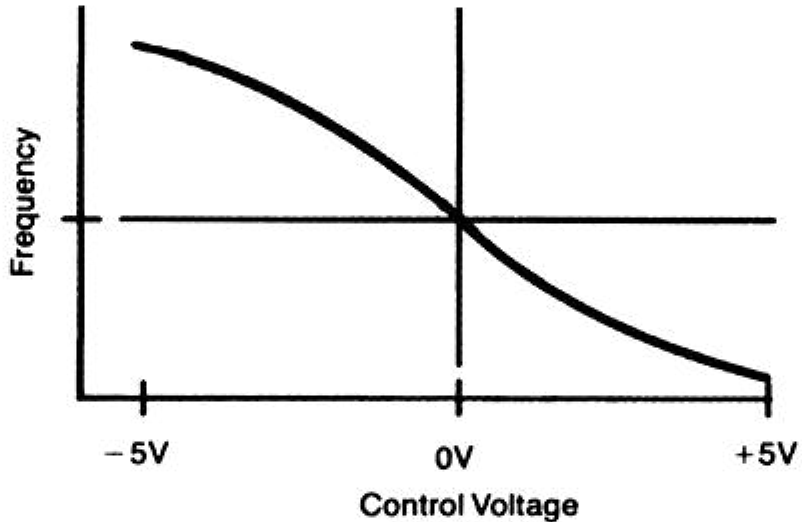

Figure 1B

Linearity - The generally accepted definition of linearity is that specified in MIL-0-55310. It is the ratio between frequency error and total deviation, expressed in percent, where frequency error is the maximum frequency excursion from the best straight line drawn through a plot of output frequency vs control voltage. If the specification for an oscillator requires a linearity of ±5% and the actual deviation is 20 kHz total as shown in Figure 2, the curve of output frequency vs control voltage input could vary ± 1 kHz (20 kHz ±5%) from the Best Straight Line "A". These limits are shown by lines "B" and "C". "D" represents the typical curve of a VCXO exhibiting a linearity within ±5%.

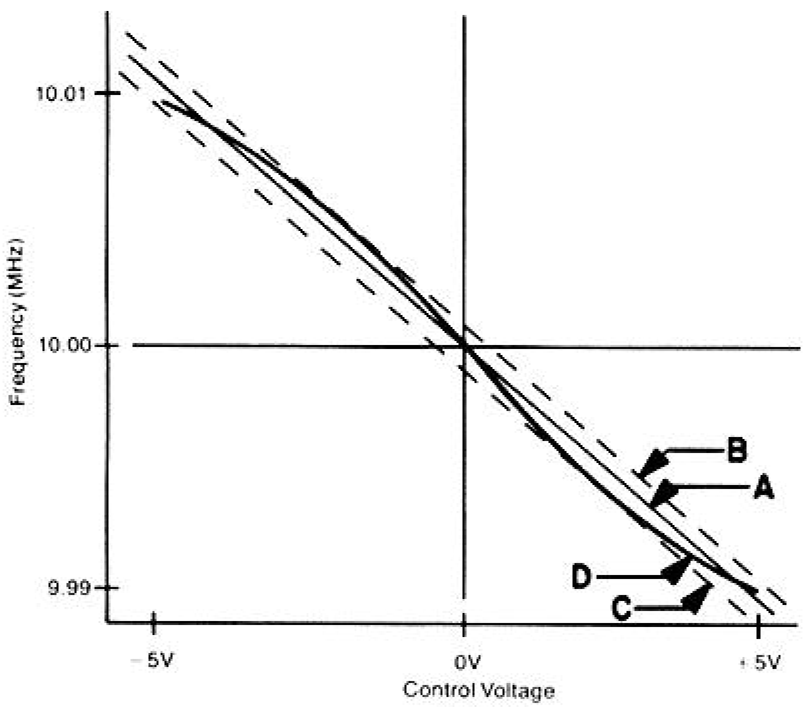

Figure 2

In Figure 3, the maximum deviation from Best Straight Line "A" is - 14 ppm and the total deviation is 100 ppm, so the linearity is ±14ppm/100 ppm = ±14%.

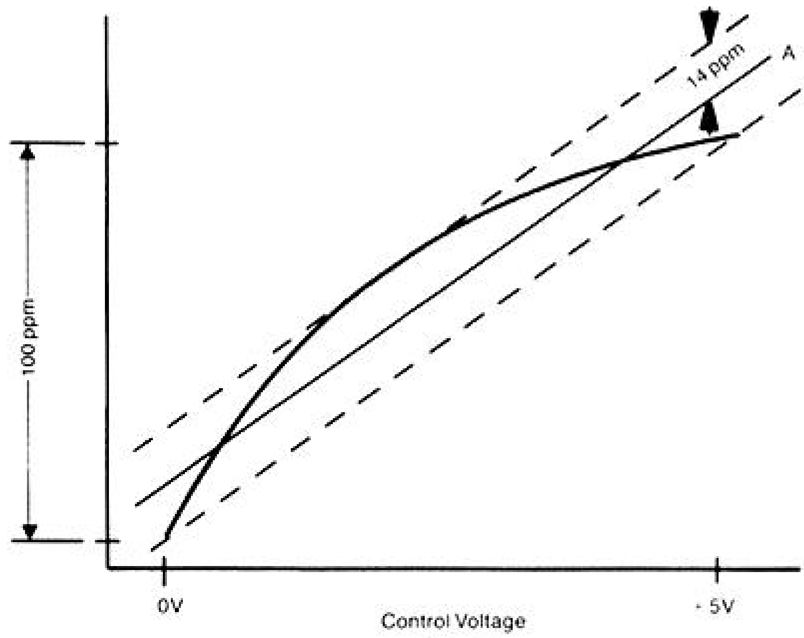

Figure 3

The VCXO which produces the characteristic indicated in Figure 2 uses a hyper-abrupt junction varactor diode, biased to accommodate a bipolar (±) control voltage. The VCXO which produces the characteristic in Figure 3 uses an abrupt junction varactor diode with an applied unipolar control voltage (positive in this case).

Good VCXO design dictates that the voltage to frequency curve be smooth (no discontinuities) and monotonic. All Vectron VCXOs exhibit these characteristics.

Modulation rate (sometimes referred to as Deviation Rate or Frequency Response) - This is the rate at which the control voltage can change resulting in a corresponding frequency change. It is measured by applying a sinewave signal with a peak value equal to the specified control voltage, demodulating the VCXO's output signal, and comparing the output level of the demodulated signal at different modulation rates. The modulation rate is defined by Vectron as the maximum modulation frequency which produces a demodulated signal within 3 dB of that which is present with a 100 Hz modulating signal. While non-crystal controlled VCOs can be modulated at very high rates (greater than 1 MHz for output frequencies greater than 10 MHz), the modulation rate of VCXOs is restricted by the physical characteristics of the crystal. While the VCXO's modulation input network can be broadened to produce a 3 dB response above 100 kHz, the demodulated signal may exhibit amplitude variations of 5-15 dB at modulation frequencies greater than 20 kHz due to the crystal.

Slope/Slope Linearity/Incremental Sensitivity - This can be a confusing area as these terms are often mis-applied. Slope should be really called average slope if it is intended to define the total deviation divided by the total control voltage swing. For the VCXO depicted in Figure 2, the average slope is -20 kHz * 10 volts = -2 kHz/volt. Incremental sensitivity, often misnomerred Slope Linearity means the incremental change in the frequency vs control voltage. Thus, while the average slope in this example is -2 kHz per volt, the slope for any segment of the curve may be considerably different from -2 kHz/volt. In fact, for VCXOs with Best Straight

Line linearity of ±1% to ±5%, the Incremental Sensitivity is approximately (very approximately) 10 times as great as the Best Straight Line linearity. Thus a VGXO with ±5% Best Straight Line linearity can exhibit a slope change of ±50% on a per volt basis. Therefore, a specification which reads "Slope: 2 kHz/volt ± 10%" requires clarification as it could mean either Average Slope or Incremental Sensitivity. If it were intended to define average slope, it simply specifies a total deviation of 18 kHz to 22 kHz and would more properly have stated, "Total Deviation: 20 kHz - 10%." However, if it were intended that the frequency change for each incremental volt must fall between 1.8 kHz and 2.2 kHz, a highly linear VCXO is being specified as a ±10% Incremental Sensitivity relates approximately to a ±1% Best Straight Line linearity. That element of the specification should read, "Incremental Sensitivity: 2 kHz ± 10% per volt."

Other Design Considerations

Stability - A quartz crystal is a high Q device which is the crystal oscillator's stability determining element. It inherently resists being "pulled" (deviated) from its designed frequency. In order to produce a VCXO with significant deviation, the oscillator circuit must be "de-Q'd". This results in degrading the inherent stability of the crystal in terms of its frequency vs temperature characteristic, its aging characteristic, and its short-term stability (and associated phase noise) characteristic. Therefore, it is in the user's best interest not to specify a wider deviation than that absolutely required.

Phase Locking - When a VCXO is used in phase lock loop application, the deviation should always be at least as great as the combined instability of the VCXO itself and the reference or signal onto which it is being locked. Vectron produces a line of VCXOs especially intended for use in phase lock loop applications (described on the pages which follow). However, if the open loop stability requirements of a system are more stringent than available in this product line, a TC/VCXO may be required. For the highest stability open loop requirements, the appropriate oscillators may be those described in the TCXO or OCXO sections of this catalog, incorporating a narrow deviation VCXO option, rather than those described in the VCXO section.

Basic Oscillator Frequencies - Fundamental mode crystals (generally 10-25 MHz) permit the widest deviation, while 3rd overtone crystals (generally 20-70 MHz) allow deviation approximately 1/9th of that which applies to fundamentals. Therefore, all wide deviation VCXOs (greater than ±100 to ±200 ppm deviation) use fundamental crystals; narrower deviation VCXOs can use fundamental mode or 3rd overtone crystals, the selection of which often depends upon such specifications as linearity and stability. It is rare that higher overtone, and therefore higher frequency crystals find application in VCXOs. Thus, VCXOs with output frequencies higher or lower than available from the appropriate crystal frequencies include frequency multipliers or dividers.

General Note - While it is true of any type of crystal oscillator, it is especially important with VCXOs that the user not over-specify the product. The particular problem with VCXOs is that increased deviation results in degraded stability which can result in the need for still wider deviation, further degrading stability, resulting in a spiraling increase in the required deviation.