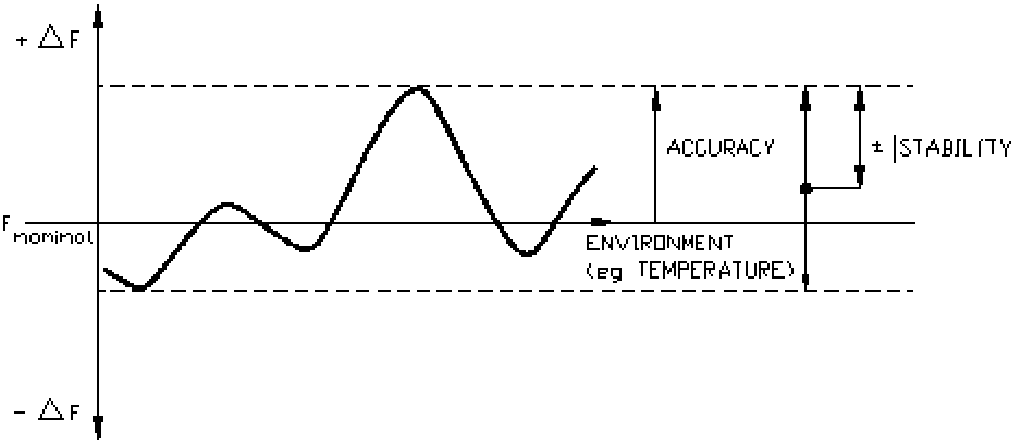
Crystal Oscillator Design Information

Nominal Frequency (Fnom) is the desired frequency of an oscillator.

Frequency Accuracy is a measure of the difference of the oscillator frequency from the nominal frequency.

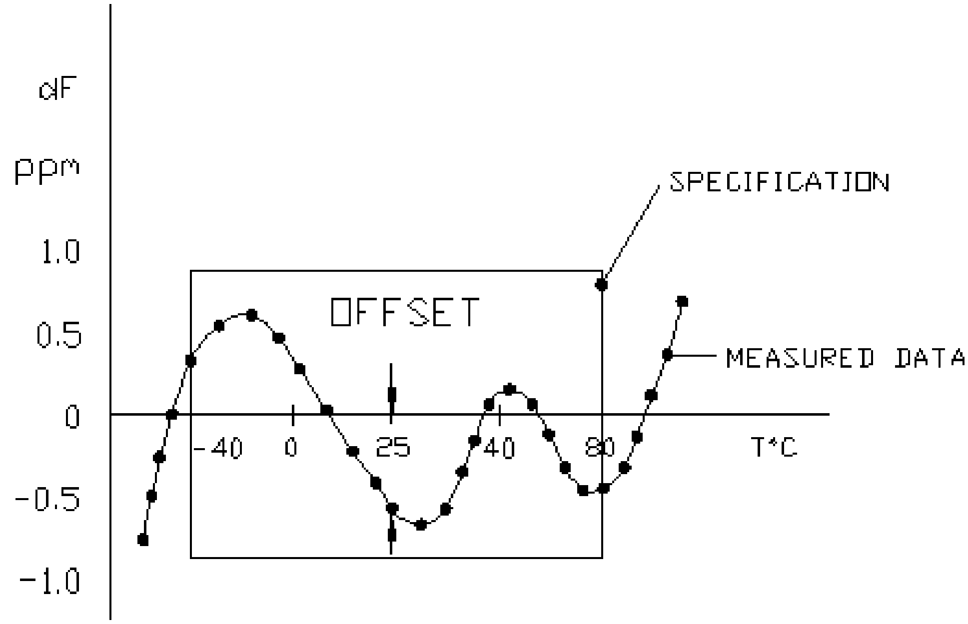
Stability of an oscillator is a measure of the change of frequency on an oscillator as a result of environmental influences. While the stability of a crystal oscillator is very much due to the stability of the crystal, the oscillator is also influenced by the circuitry; both must be optimized for best performance. The stability of an oscillator has many different components such as stability over a specified temperature range, drift (aging) as a function of time, sensitivity to changes in the voltage of a power supply, load sensitivity, thermal hysteresis (in the case of a TCXO), retrace, trim skew an sensitivity to acceleration.

Designing tolerances for stability for a specified environment is a problem because of the multiple factors that come into play. To help the reader allocate the proper tolerances for all conditions that affect the total stability of an oscillator, the following table has been provided which shows a typical percentage the total tolerance used by each condition which, as a result of environmental changes, affect stability. It is intended as a guide only and the specification writer should realize that if any of the environmental conditions are of no importance to the application then the relative numbers will change.



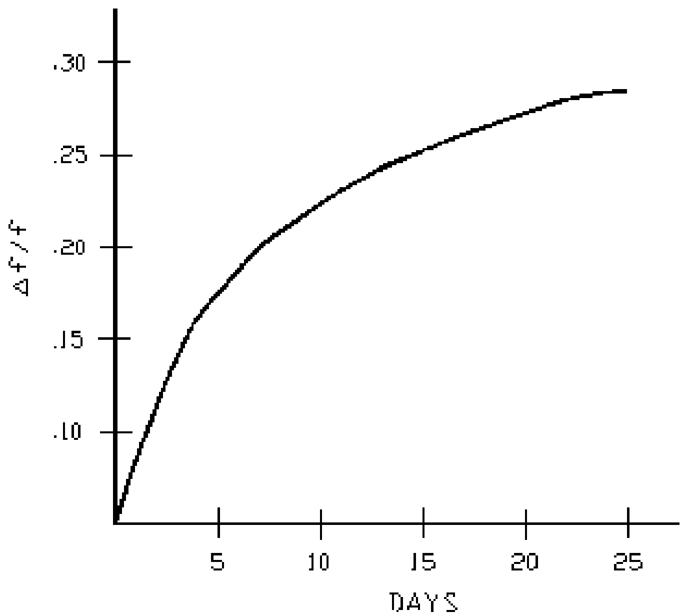
Stability Tolerances Distribution		
	OCXO (%)	**TCXO (%)**
Temperature	4.50	45.85
Aging / Year	90.50	35.00
Supply sensitivity	0.50	0.05
Load sensitivity	1.00	1.00
Hysteresis	-	12.00
Retrace	2.00	-
Acceleration Sensitivity / G	1.50	0.10
Trim Skew	-	6.00
Total Stability Tolerance	100.00	100.00

Room Temperature Offset: The oscillator frequency is often deliberately offset at room temperature to minimize the largest deviation from nominal frequency over the whole temperature range. This results in the maximum positive and negative frequency deviations being equally spaced about the nominal frequency.



Temperature Stability is a measure of the frequency change due to ambient temperature changes. Frequency stability is typically measured by placing the oscillator is a temperature chamber at the lowest temperature all allowing it to stabilize. After the frequency is measured, the temperature is increased and the sequence is repeated until the whole temperature range has been covered. The stability is calculated by finding the difference between the maximum and minimum frequencies and dividing it by 2, to give the + and - figure. The accuracy is found by finding the frequency furthest from Fnom.

Aging is the slow change of oscillator frequency with respect with time. The primary causes, mass transfer and stress relaxation mechanisms in the crystal unit, can be reduced by maximizing the ratio of quartz resonator mass to contamination mass by minimizing the resonator frequency, and by careful design and processing of the resonators. In a well behaved oscillator or resonator the aging rate will tend to decrease with time.

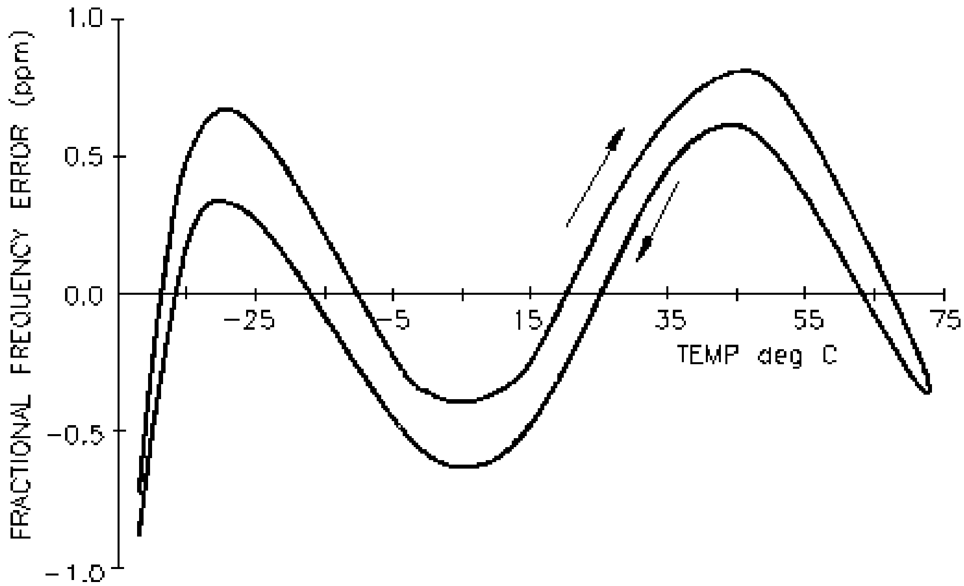


All aging measurements are taken automatically at PTI and are made in a dedicated temperature controlled room. Over a thousand oscillators can be monitored with a computer controlled measurement system which reads each oscillator several times a day. Ovenized oscillators are measured at room temperature; TCXOs are measured in temperature chambers set to the required aging temperature. All measurements are referenced to the in-house rubidium standard which is backed up by two Hewlett-Packard reference oscillators and all standards are referenced to NIST via a LORAN system.

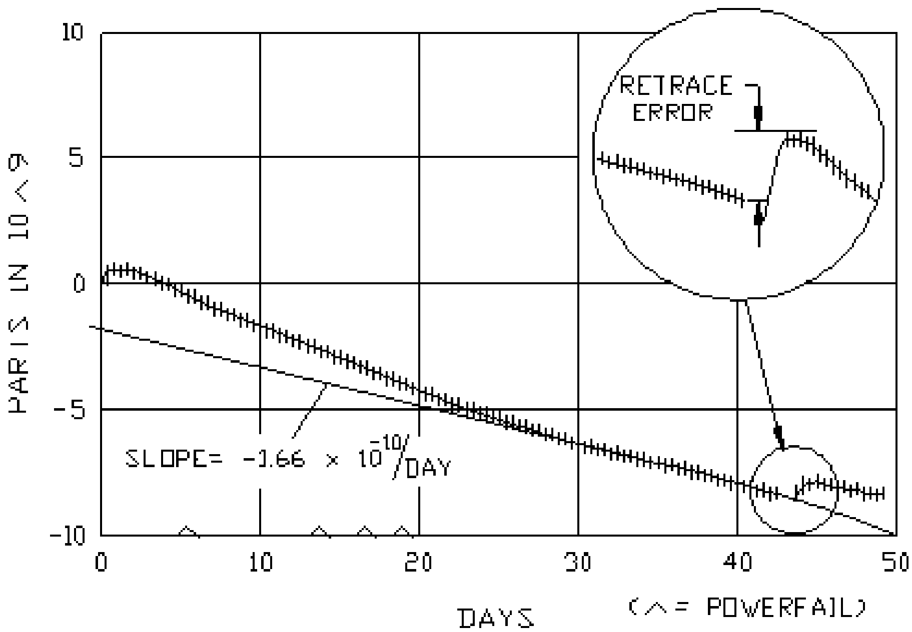
Oscillator frequency will change slightly as the supply voltage changes. The typical fractional frequency ranges from ± 1 to ±10 ppb for a ±10% change in supply voltage. Voltage sensitivity tends to be largest in TCXOs having a low supply voltage.

Load Sensitivity: Oscillator frequency will also change as the load applied to the output port varies. The typical fractional frequency changes from ±0.1ppb to ±10ppb for a load change of ±10% for sinewave outputs, or a ± gate for logic outputs. Since the load can be made nearly constant in most applications, load sensitivity is usually not significant.

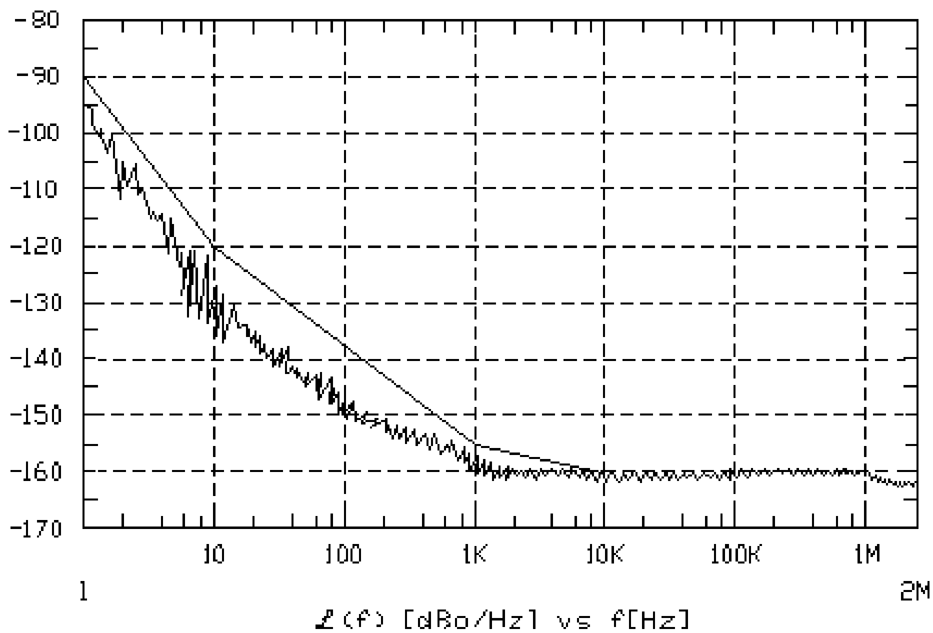
Thermal hysteresis: If the frequency of a TCXO is measured at one temperature and if this temperature is changed and then returned to the original temperature and the frequency is measured again, the two frequencies will not be exactly alike. The difference between the two frequencies is called "thermally induced hysteresis". The phenomena has two components, static and dynamic. The static component is present if the unit is allows to stabilize at temperature for a long time, whereas the dynamic effect is a function of the rate of change of temperature and is a transient effect. If the frequency is monitored as the temperature is varied over a range of temperature, a classic hysteresis loop is obtained. The effect on a typical TCXO frequency/temperature characteristic is shown. Typical values are less than 0.2ppm.

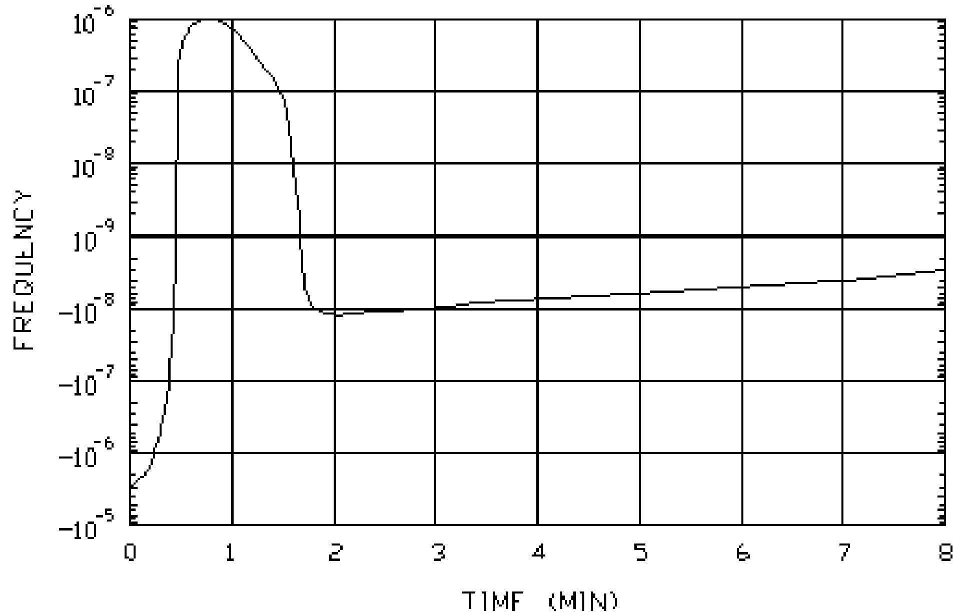


Retrace: When an OCXO is turned off for an extended period of operation and then turned on again, the frequency will not immediately return (retrace) to the previous value and aging rate. Good retrace is obtained by proper oscillator and resonator design and careful resonator processing.

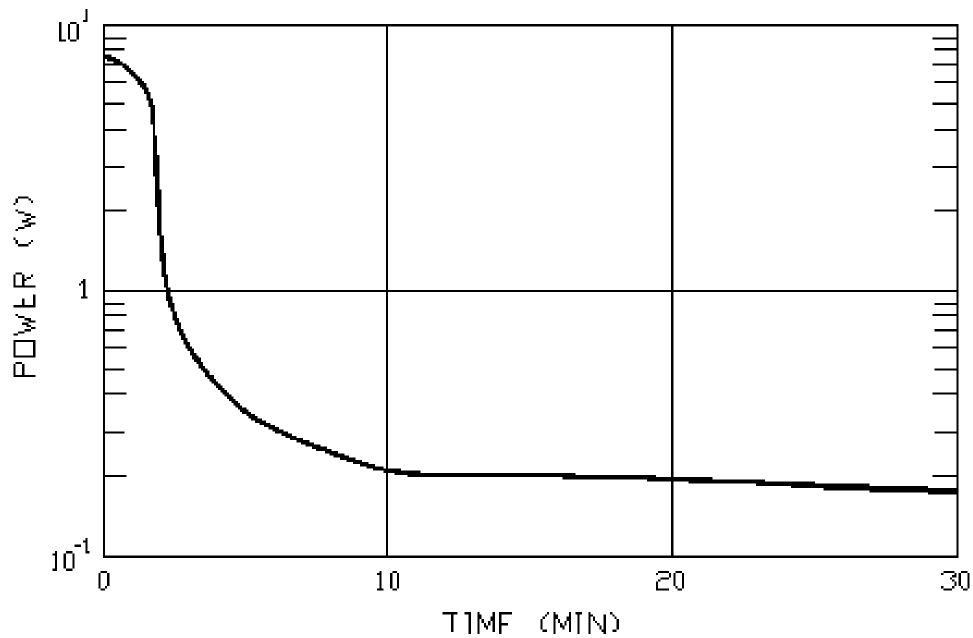


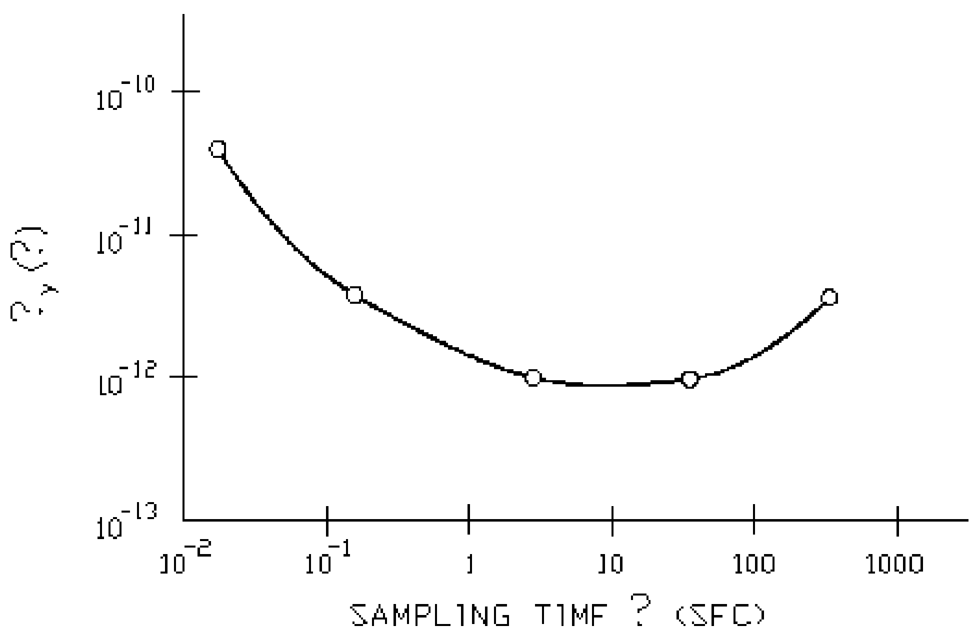
Phase Noise is a frequency domain measurement of stability and is usually expressed as the SSB spectral density in dBc/Hz. It is important in numerous applications. Low levels of phase noise are achieve through careful circuit design and the use of carefully processed high-Q resonators. At PTI, several phase noise measurement systems are in use, including a Hewlett Packard 3048 system. Typically, to measure the phase noise of a crystal oscillator an identical tunable oscillator is used as a reference and phase locked to the oscillator being tested. This allows the removal of the carrier signal while leaving the sidebands to be measured at baseband with a low frequency FFT analyzer. If the two oscillators have identical noise, the noise of each oscillator is 3dB better than that measured for both.





Stabilization Time (warm-up) for an OCXO is defined as the time taken to reach a certain level of stability after a long period of inoperation. Oven power decreases with time during warm-up, reaching a steady state when the oven has reached its operating temperature.

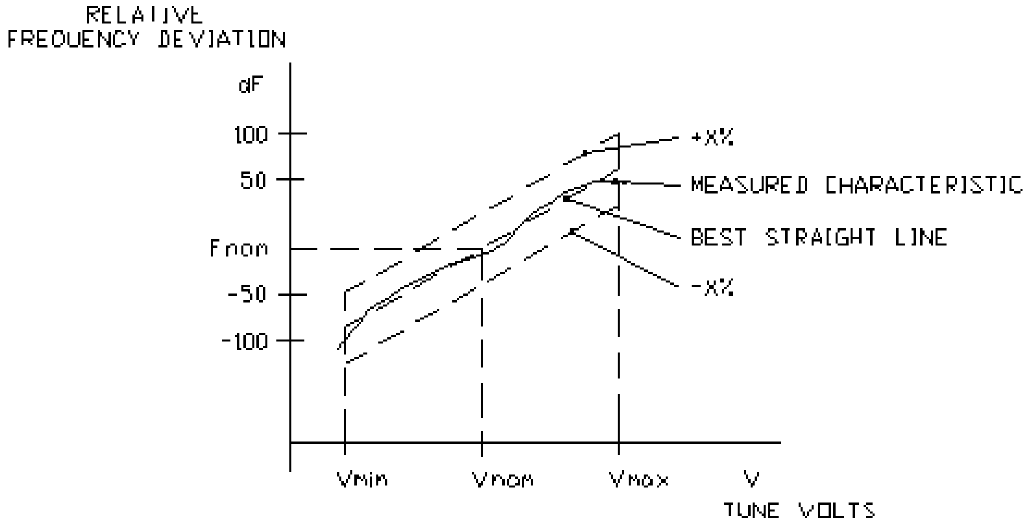




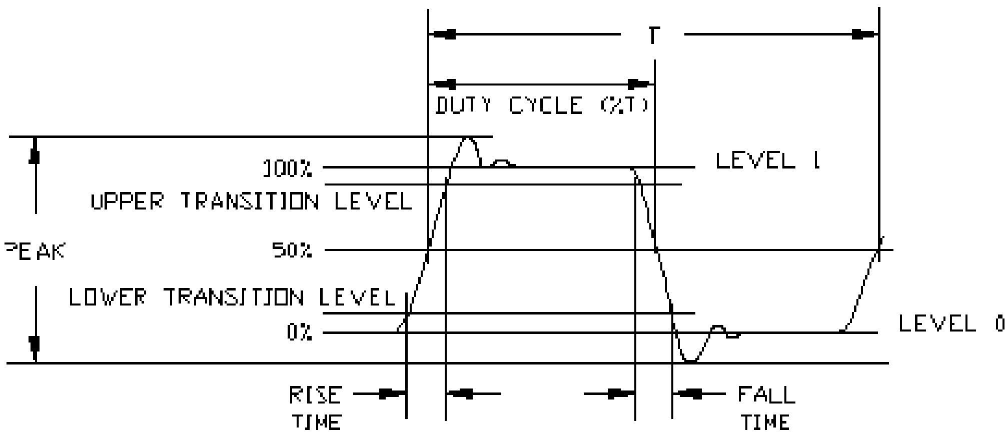
Short Term Stability: The usual time-domain measure of oscillator stability, Allen-variance, measures rms change in successive frequency measurement for short gate times (milliseconds to seconds) and is important in timing applications. It typically improves as the gate time increases until it becomes a measurement of the long term drift or aging of the oscillator.

Tuning Sensitivity is the slope of the frequency vs. tuning voltage characteristic. It is expressed in ppm/volt.

Linearity can be expressed in several ways. In the method of MIL-0-55310 a best-fit straight line is drawn and the ratio of the deviation of the worst point on that line to the maximum deviation is used at the specification. Other measures are based on the resulting modulation distortion or slope variation.



Output Type and Levels:
Outputs can be specified as either sinewave or logic (TTL, CMOS, ECL, etc.) Associated parameters include levels, load impedance and stability, source impedance, harmonic and spur levels and the frequency sensitivity to load changes. In the case of logic signals the number of gates, duty cycle, and rise and fall time are specified. Logic levels are typically defined by the integrated circuit manufacturer.



RECTANGULAR OUTPUT WAVEFORM

Adjustability: To compensate for long term aging, a frequency adjustment capability is often required. Generally, the frequency adjustment range and resolution are specified. The adjustment may be controlled by a trim screw within the oscillator or by external resistance (fixed or variable). An external resistance is usually preferable, as it allows the oscillator case to be hermetic, allows smaller volume and can be more conveniently located for access during calibration. For high shock and/or vibration a replaced fixed resistor is preferable to a potentiometer or switch because it is inherently more rugged.

A factor that must be considered with frequency adjustment is trim skew. When a TCXO oscillator is first delivered, it will meet the required stability. After the unit has aged and is readjusted to frequency, the adjustment can impact the stability over temperature. This effect is known as trim skew. Its effect can be reduced with careful circuit design.