Technical Introduction Crystal Oscillators

Crystals and Crystal Oscillators are the most important components for frequency control applications like telecommunication and data transmission. The reasons are high frequency stability, high quality factor of the resonance, low temperature drift and reasonable prices. The wide range of crystal oscillators requires exact specification to ensure optimal performance.

Standard Crystal Oscillators or XOs provide a stability of ±100ppm with +5V (+3.3V) supply voltage in DIP-14, 14mm x 9mm or 7 x 5 mm SMD-packages. Applications are clocks for microprocessors and the consumer electronic market. Due to price-sensitive applications the requirements of the oscillators are mainly defined by case-style, frequency, stability, output signal and temperature range.

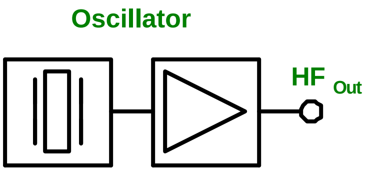

Figure 1 Block diagram crystal oscillator

Professional applications in Telecommunication, Measurement Equipments, Satellite Navigation have much higher requirements such as tight stability, low impedance output (HCMOS or ECL/PECL for higher frequencies), low phase jitter and much longer lifetime of 15 years and more. To achieve a sufficient long term stability the complete oscillators need preaging and a stable process of the crystal production. While low-cost oscillators just give an overall stability all stability parameters are clearly defined for most of the professional oscillators.

While simple XOs (X-tal Oscillator, Crystal Oscillator) only offer a fixed output frequency, other types of oscillators provide a pulling option, which is mainly used for PLL-applications. These VCXOs (Voltage Controlled X-tal Oscillators) use an internal varactor diode in parallel to the internal crystal, which enables an electrical frequency change of approximately ±20ppm to ±200ppm. This nominal pulling range is used to compensate the frequency deviation of the oscillator itself and provides enough capture range to lock to a certain frequency. The nominal pulling range deducting all stability parameters like temperature stability, aging and calibration is called Absolute Pulling Range APR and is often used for specifying VCXOs.

Another important issue is implementing the VCXO modulation characteristics into the PLL-loop. The two most important parameters are modulation bandwidth and nonlinear modulation response. Due to the limited modulation bandwidth, spurious resonances and transfer characteristic, the PLL-loop bandwidth has to be adapted according to the individual oscillator modulation response. It has to be lower than the modulation bandwidth of the frequency control circuit, and much lower than the first spurious resonance to suppress any ringing or locking to the spurious resonance.

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Especially PLLs used for SONET / SDH networks have to be calculated very precisely, since spurious resonances may cause Bit Errors due to jitter transfer. Often, this effect may only be found in combined network systems.

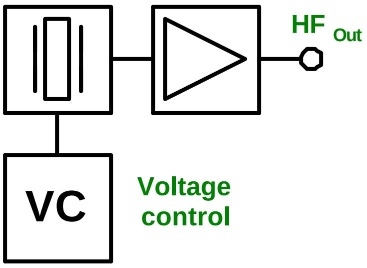

Figure 2 Block diagram Voltage Controlled Crystal Oscillators

Wide area telecommunication systems like SONET SDH also require a high stability system clock to prevent time slips or data loss. The required stability may be much higher than standard crystal oscillators would offer. The physical limits for conventional crystal oscillators are in the range of ±10ppm including temperature stability, aging and initial calibration. Temperature characteristics may be determined by a 3rd order function, which is symmetric to +25°C

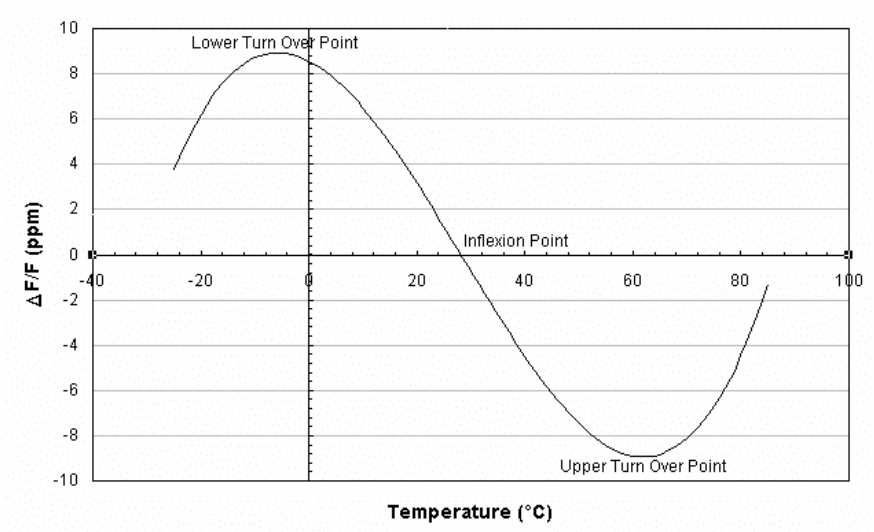

Figure 3 Typical temperature characteristics of AT-cut crystals

This cubic function can be compensated by using a 3rd order network, where up to ±0.5ppm over –20 ... +70°C can be achieved for conventional compensation. These TCXOs (Temperature Compensated X-tal Oscillators) are mostly used as reference clocks in switching, data transmission or frequency counters. The improved temperature stability requires also improved aging characteristics of the crystal to achieve a corresponding overall performance.

Aging rate may only be in the range of a few ppm over lifetime of 10 ... 15 years. Electrical or mechanical trimming options allow recalibration after some time.

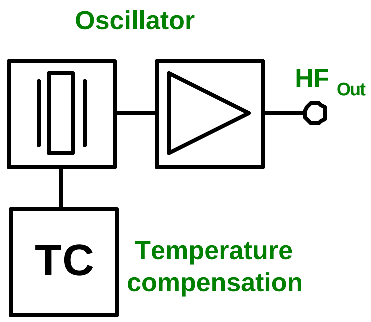

Figure 2 Block diagram Temperature Controlled Crystal Oscillators

Following the global trend of miniaturization also TCXOs have to become smaller while meeting all specification points of larger conventional TCXOs. One way is the application of ASICs (Application Specific Integrated Circuits). KVG is offering ASIC technology for highest stabilities to provide best performance and small package size.

Especially 3G/GSM/CDMA basestations, microwave links or SDH/SONET networks have much higher stability requirements in the range of some ppb (10^{-9}). These stabilities can be achieved with ovenized crystal oscillators OCXO (Oven Controlled X-tal Oscillator). Their temperature is held constant above the nominal operating temperature e.g. +85°C. Due to an internal heating element their power consumption is much higher compared to TCXOs or VCXOs. Therefore they are not suitable for every application, especially not for battery operation.

SC-cut crystals can improve the temperature stability. OCXOs with SC-cut crystals reach easily temperature stabilities up to 10^{-9} and special designs like double-ovens extend this range up to 10^{-10} or 10^{-11}. This makes them even suitable for applications with extremely high stability needs.

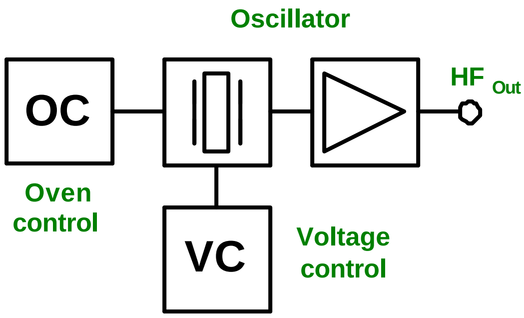

Figure 4 Block diagram Temperature Controlled Crystal Oscillators

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Specifying OCXOs also includes aging and retraceability. To minimize the initial aging effect all OCXO will go through a certain "burn-in" process, the so-called preaging. For some days or even weeks these oscillators are being operated on a fully computerized aging facility and the frequency drift is monitored every day. The results will enable the manufacturer to determine the long term aging of all individual OCXOs in production, eliminate parts with insufficient aging and improve the manufacturing process.

All OCXOs reach their final stability after some days of operation. To achieve maximum stability, the OCXO should not be turned off since it will take some time until the OCXO reaches the final frequency. Furthermore the final frequency is different from the frequency before turn-off of the oscillator. This retrace problem is well known by all manufacturers and might cause problems after a long power-off time e.g. measurement equipment, which is turned off for weeks.

Depending on the oscillator design, crystal performance and optional frequency multiplication method, there is always some kind of noise added to the output signal, which degrades the quality of the output signal. Phase noise should be as low as possible to achieve maximum S/N-ratio and low BER. Phase noise < 1kHz mostly depends on the quality factor of the crystal, while for frequencies > 1Khz the oscillator circuit is mostly affecting the phase noise on the output. Since the spectral density of the phase noise near the nominal frequency is much higher, the impact on the jitter performance is mostly given by spectral content of the lower frequencies in the spectrum.

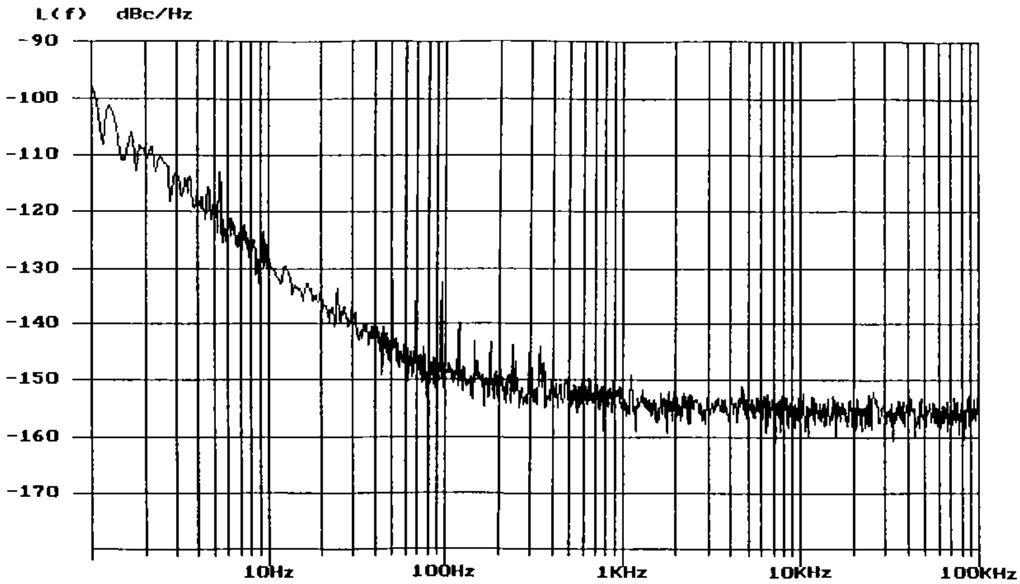

Figure 5 Typical phase noise plot of a low noise crystal oscillator

Most telecommunication applications use multiplier stages to generate frequencies much higher than the oscillator frequency. Due to this multiplication the degradation of the phase noise is calculated by the following formula:

$d=20 \log n$ (d = phase-noise degradation in dB; n is the multiplication factor)

Oscillators

There are many various application fields for crystals and crystal oscillators and therefore there is a never ending list of individual parameters which might be important for a specific application. Some of them, like automotive, avionics, space programs or research have extended their environmental requirements to withstand extreme temperatures, shock and vibration. Others require enhanced purity of the output spectrum. KVG Quartz Crystal Technology will help you to find the right oscillator for your application with respect to your specific needs.

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