Understanding Ovenized Oscillators

INTRODUCTION

With today's increasingly crowded communications spectrum, the need for high performance frequency references is increasing. High stability test equipment also calls for superior time bases. The ovenized oscillator is an attractive answer to these and other applications requiring a high performance to cost relationship. The ovenized oscillator is more complicated than first glance might suggest, however. This paper explains some of the subtleties of ovenized oscillators, so they may be more fully understood and specified.

CRYSTAL BASICS

The two main categories of crystals used in oscillators at Isotemp are of the AT-cut and SC-cut type. The terms AT-cut and SC-cut refer to the way a piece of quartz is cut to produce individual crystal blanks. In an AT-cut crystal, the quartz is cut at an oblique angle with respect to one crystal axis (singly rotated). The SC-cut crystal is cut at an oblique angle with respect to two crystal axes (doubly rotated). There are many performance differences between an AT-cut crystal and an SC-cut crystal, but for this discussion we will concentrate on the difference in temperature performance. Refer to Figure 1 for the frequency offset over temperature for an AT-cut crystal, and to Figure 2 for an SC-cut crystal. The general shape of the two curves is the same, but note how the SC-cut crystal has a higher inflection point (the point where the second derivative of the curve is equal to zero). Also, SC-cut crystals normally used by Isotemp exhibit a milder change around the turn points (where the first derivative of the curve equals zero). It is important to note that the curves in Figures 1 and 2 represent *only one of a family of curves* for each type of crystal.

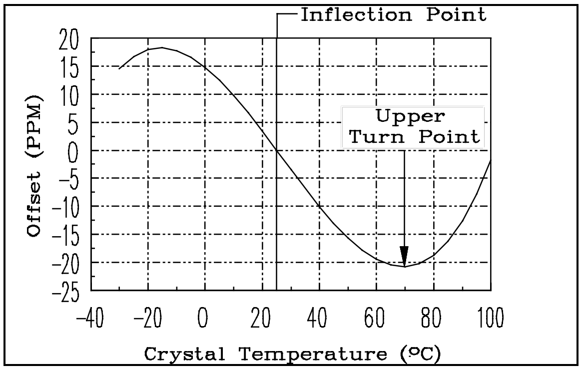

Figure 1: AT-cut crystal curve

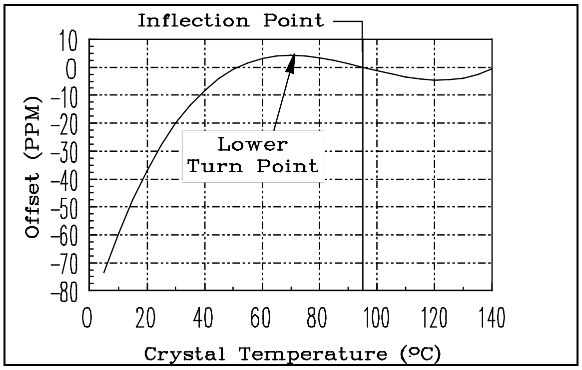

Figure 2: SC-cut crystal curve

Figures 3 and 4 show the family of curves from which Figures 1 and 2 were derived, respectively. Each different curve is achieved by cutting the quartz along slightly different angles with respect to some crystal axis. The amount of angle change is small, and is typically specified to the minute ('), or 1/60th of a degree (°). A crystal can be specified such that its performance is optimized over a certain temperature range, but the frequency stability will be limited. Even over a modest commercial grade temperature range, stabilities of only a few parts-per-million (PPM) are possible. To achieve frequency stabilities better than this, some type of compensation is required. Placing the crystal in a temperature controlled environment is one method of compensation, and will be the topic for the remainder of this paper.

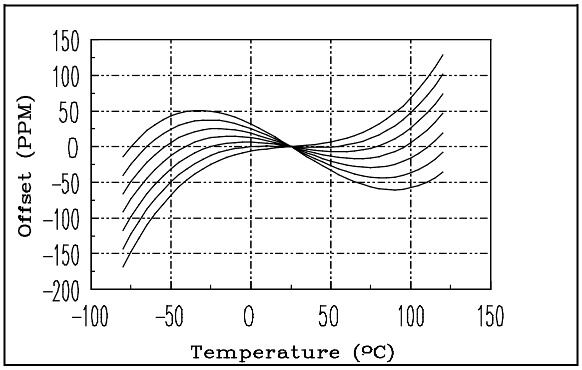

Figure 3: Family of AT-cut crystal curves

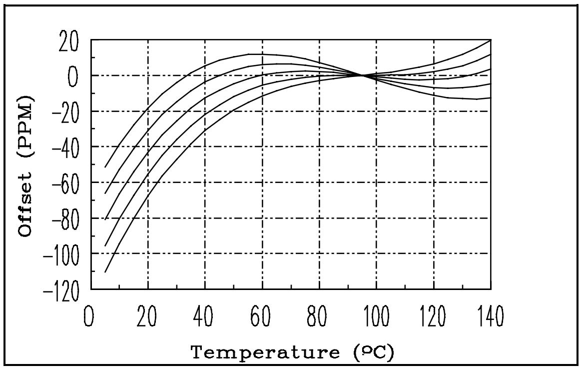

Figure 4: Family of SC-cut crystal curves

OVEN CONTROLLER

The most cost effective way to hold a crystal at a constant temperature in an oscillator assembly is to raise its temperature above any anticipated ambient temperatures. Using this method, only a heat source is required (easy to obtain in a small package) instead of heating and cooling (much more difficult and costly). Figure 5 shows a simplified schematic of an oven controller used in an Ovenized Oscillator (OCXO). The item in the lower left is a thermistor (TM), a passive element that exhibits a resistance curve that is inversely proportional to its temperature. The resistors and TM form a bridge which senses and ultimately controls the temperature of the oven. The output of this circuit drives a heater. The heater and thermistor are thermally connected due to the fact they are both attached to the same object (the heated portion of the oven in this case). With proper attention to placement and mounting technique, temperatures can be maintained to within a few degrees in the oven with almost zero tolerance directly at the TM.

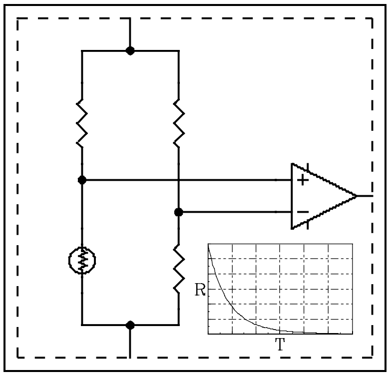

Figure 5: Oven Circuit

This tight level of stability assumes two things:

1) *Ambient temperatures do not fall below design values*.

The gain of the control circuitry is sufficiently high to cause large power drains if the oven temperature is not within a close tolerance to the desired setpoint. This power is limited with additional circuitry to a value that the customer (or Isotemp) specifies. Moreover, power limiting keeps the heater circuit from destroying itself. In the case where ambient temperatures are approaching the desired setpoint of the oven, very little power is required to heat the oven some incremental amount. As the ambient temperature drops, more and more power is required to keep the oven warm. Insulating the oven helps, but as there is no such thing as 100% effective insulation: The power draw will <u>always</u> increase with decreasing ambient temperatures. A point will be reached where the power required to keep the oven at the specified temperature will be higher than the power limit allows. The limit circuitry will activate, and the oven will not have enough power at its disposal to maintain the proper temperature. An oven with an overly small power limit will warm up slowly and have trouble maintaining its temperature over even a modest temperature range.

2) *Ambient temperatures do not approach the set temperature of the oven*.

In the case of a completely empty oven, when ambient temperatures equal that of the oven's setpoint, the oven will need zero power to maintain its temperature (all of the required energy is being supplied by the surrounding environment). If ambient temperatures exceed the oven setpoint temperature, the oven temperature will rise as well. The controller will be asking the heater to **remove** power from the oven! Without specialized thermo-electric devices, this cannot be done. Note that the previous example is for a *completely empty* oven. In the case of an ovenized oscillator, the crystal and oscillator circuit are enclosed in the oven. This circuit dissipates a portion of its power as heat, and this heat is independent of the oven controller. Even if the oven controller shuts down the main heater completely, heat is still being added by the oscillator circuitry. This addition of heat from the oscillator circuitry is referred to as *heat rise*. The heat generated by the oscillator is small compared to the potential of the heater, but can still make the heater shut down even before ambient temperatures reach the oven setpoint. For this reason, the oven setpoint should be a few degrees higher than the highest expected ambient temperature.

Figure 6 graphically demonstrates the principles of the above two sections with a power graph of a hypothetical oven. Below about -40°C, the power is clipped to some maximum value due to power limiting, and the oven temperature will fall out of regulation. Above about 90°C, the power drops to zero as ambient temperatures exceed the setpoint of the oven.

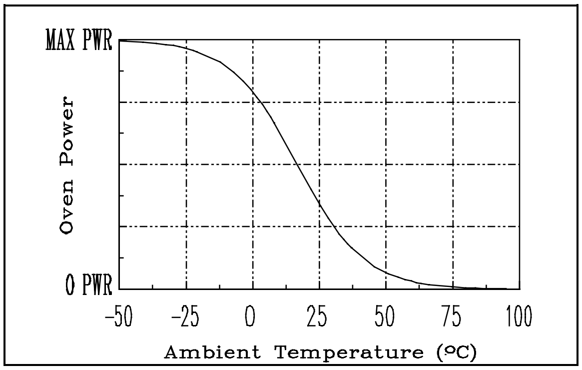

Figure 6: Oven Power vs Ambient Temperature

CRYSTAL TEMPERATURE SENSITIVITY

Refer to Figure 1: If ambient temperatures swing from -30°C to 70°C, an optimally chosen crystal (Refer to Figure 3) will change about ±5 PPM. Now refer to Figure 7: The slope around 70°C is near zero. If the crystal temperature could be maintained around this point, the frequency change would be greatly reduced. Combining this knowledge with the previous section on oven controllers leads to the next section on ovenized crystals.

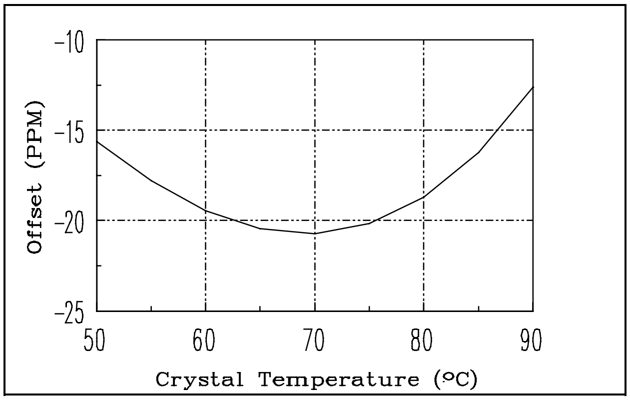

Figure 7: AT-cut crystal @ Upper Turn

OVENIZED CRYSTALS

By installing the crystal in an oven, and setting the oven to maintain a temperature corresponding to the upper turn point of the crystal (the point at which the slope of the curve equals zero) very tight ambient frequency stabilities can be achieved. Ambient frequency stabilities can go from the parts-per-million range to the parts-per-billion range, *three orders of magnitude improvement*. This improvement is realizable in normal production with no special treatment outside of normal processes. However, due to manufacturing tolerances when cutting the crystal blanks, the turn temperatures are different for each crystal. To optimize the temperature performance of the oscillator, the oven for each different crystal must have a custom temperature setpoint.

OTHER CONSIDERATIONS

An Ovenized Oscillator (refer to Figure 8) does exhibit superior ambient performance, but there are other performance considerations to be taken into account. Previously mentioned is the power draw of the oven circuit. Depending on a variety of factors including desired ambient frequency stability and form factor, power requirements can range from less than 1W to more than 10W. Maximum current draw is experienced during initial turn on, and operation at low ambient temperatures. At room temperature, once the oven has warmed up, the power draw drops to some lower steady-state value. While the power floor is continually being lowered through advances in technology, ovenized oscillators will draw more power than other non-heated compensation means.

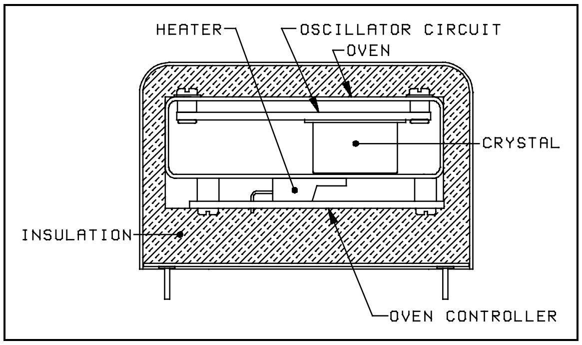

Figure 8: Cross Section of OCXO

Another performance issue is the warmup time required for the oven that is heating the crystal. Because of the mass of the oven and the finite amount of power used to heat it, there will be some delay after initial application of power before the crystal has heated up and the frequency has stabilized. The exact times, frequency offsets, power consumption and general curve shapes vary from one design to the next, but the principles are the same. Some of the factors that control the warmup characteristics are:

- Mass & Surface Area of the heated parts
- Surrounding temperature
- Power limit for the oven
- Amount of insulation around the oven

Refer to Figures 9 and 10 to see the warm-up characteristic of an actual ovenized oscillator.

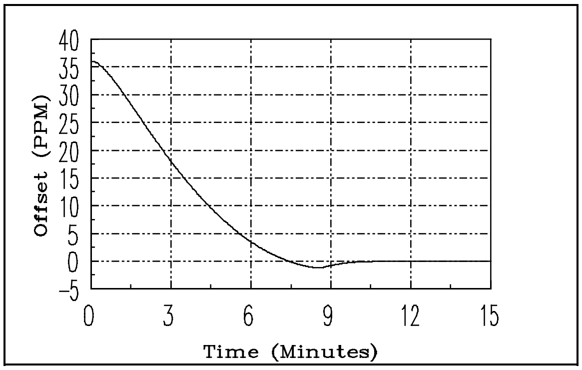

Figure 9: OCXO Warmup with AT-cut crystal

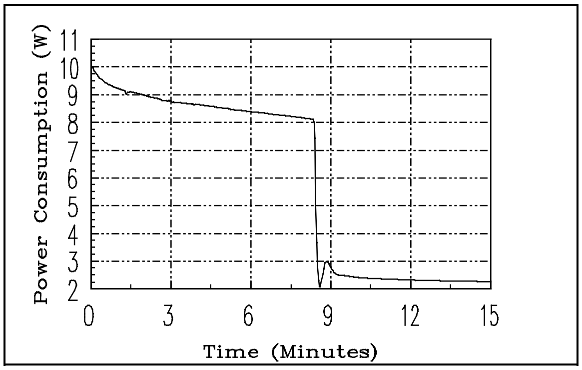

Figure 10: OCXO Warmup (Power)

If a particular warmup characteristic is of concern, the oscillator can be designed in such a way as to help correct or eliminate the offending characteristic. Some examples might be:

- ■ Place more insulation around the oven, reducing steady-state power draw
- ■ Allow a higher power limit for faster warmup/lower temperatures

There are tradeoffs, however: Making the oven smaller for quicker warmup will reduce ambient frequency stability, as the smaller mass is more affected by ambient temperature fluctuations. Making the oven larger for better ambient frequency stability will raise the amount of power required to maintain oven temperature. Lower the power limit, and the lowest permissible ambient temperature will rise. Knowing how one parameter affects another is invaluable when specifying the performance characteristics of an oscillator.

There are other advantages to using an OCXO which simply cannot be achieved when using other compensation methods. Refer again to Figure 8, and note that the oscillator circuit is enclosed in the oven along with the crystal. Keeping the crystal at a constant temperature does help frequency stability, but to achieve even tighter stabilities, the entire oscillator circuit must be kept at a constant temperature. All of the components in the oscillator circuit have their own temperature characteristics, which, if not held at a constant temperature, degrade the temperature performance of the oscillator. Other items such as R.F. output level, electrical trim (frequency modulation) characteristics, and even the long term aging rate of the oscillator can be stabilized by placing the oscillator circuitry in an oven.

CONCLUSIONS

While this paper does not provide an exhaustive analysis of ovenized oscillators, the critical basics have been covered:

- · The need for temperature control of the crystal and its associated circuitry
- · Design considerations of the oven & oscillator (power, insulation, size, etc)
- · The benefits from temperature control of the crystal and oscillator circuitry

Other than the power consumption of the ovenized oscillator (usually not a factor in high precision, fixed installations), there are no real obstacles to integrating a high stability OCXO into a communications or test system design. Most any power, stability, and form factor requirements can be designed to meet your specific needs. In short, the ovenized oscillator provides the highest performance to cost ratio over other oscillator technologies currently available.

DEFINITIONS

Warmup	The period of time after an oscillator is first powered up, during which the oven is warming up and the frequency is settling to nominal.
Retrace	The difference in frequency taken at two times, T_1 and T_2, between which there is an off period. T_1 refers to the time immediately before removal of power. T_2 refers to the time at the end of a specified warmup period after the oscillator has been off power.
Ambient	The range of temperatures the oscillator will be exposed to during operation.
Steady State Power	The amount of power consumed by the oscillator (at a certain ambient temperature) once the oven has warmed up and the oscillator has reached internal thermal equilibrium.
Turn-on Power	The amount of power consumed by the oscillator during initial turn on. *(This item is actually specified as current (A) by Isotemp. This is because current limiting circuitry is used, rather than power limiting circuitry. The current limit is specified such that the power consumption is under the desired value over the specified range of input voltages for the oscillator.)*

EXAMPLE SPECIFICATION

A portion of an Isotemp OCXO specification sheet is shown below which uses the above terms. The numbers presented are for use only as a rough guideline of possible performance. Exact specifications will vary from one design to the next.

FREQUENCY STABILITY	
Ambient	< ±5x10^{-9} from -30°C to +70°C (referenced to +25°C)
Warmup	< ±1x10^{-8} in 60 minutes at -30°C (referenced to frequency @ 24 Hrs)
Retrace	< ±5x10^{-9} (minimum of 168 hours on time *{read frequency}*, maximum of 24 hours off time, and 24 hours warmup *{read frequency}*)
INPUT POWER	
Voltage	+12 VDC ±10%
Current	< 450 mA @ turn on
Steady state	
@ -30°C	< 3 W
@ 25°C	< 1.5

REFERENCES

Bottom, Virgil E. Introduction to Quartz Crystal Unit Design
New York, NY: Van Nostrand Reinhold, 1982.

MIL-O-55310B Military specification for crystal oscillators.
U.S. government

For further information on the specification and application of Ovenized Crystal Oscillators, please contact the sales or engineering staff at Isotemp Research, Inc. For reprints of this article, ask for document number 146-005.

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Isotemp Research Inc. is an American company building performance ovens and oscillators since 1968