Miniature Crystal Ovens: Uses, Limitations and Specifications

INTRODUCTION

Practically all electronic and electromechanical devices exhibit performance changes with shifts in ambient temperature, some more than others. There are three ways to respond to these performance changes:

1) Do nothing: the changes are small or can be accepted.

2) Compensate electronically/mechanically for the performance changes.

3) Hold the device at a steady temperature, thus eliminating the problem.

Temperature compensation (choice 2) may not work for all devices, leaving the third choice as the only option: hold the device of interest at a specific temperature. The remainder of this paper will discuss the use of Miniature Crystal Ovens ("Mini-Ovens") for such a purpose.

OVEN BASICS

The most cost effective way to hold a device at a constant temperature 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 1 shows a simplified schematic of an oven controller used in a Mini-Oven. 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 oven in this case). With proper attention to placement and mounting technique, temperatures can be maintained to within a degree or so in the oven, with almost zero tolerance directly at the TM.

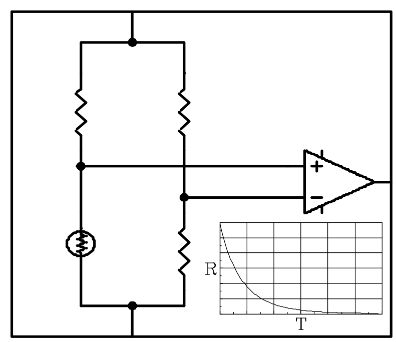

Figure 1: Oven Circuit

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 always 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. If the oven is holding a power dissipating device, it will dissipate a portion of its power as heat, and this heat is independent of the oven controller. Even if the oven controller shuts down the heater completely, heat is still being added by the active device. This addition of heat from the device is referred to as *heat rise*. The heat generated by the device may be 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 2 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.

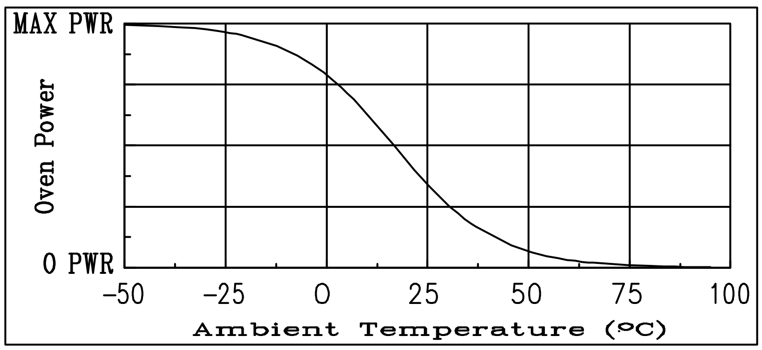

Figure 2: Oven Power vs Ambient Temperature

OVEN INSTALLATION

Currently Isotemp produces Mini-Ovens that fit over HC-43/U and T05 packages. The device to be heated is simply inserted into the oven (more typically, the oven is seated over the device on a PCB). To ensure that the device being heated makes good thermal contact with the heated surfaces of the oven, Isotemp suggests using a thermally conductive compound between the device and the oven. Refer to figure 3 for a cut away view of a typical oven installation using thermal compound. Tests have shown that temperature offsets of 1-2°C can occur without the use of a thermally conductive compound. One suggested thermal compound is manufactured by Wakefield Engineering Inc., part number 120. This is the compound used internally at Isotemp.

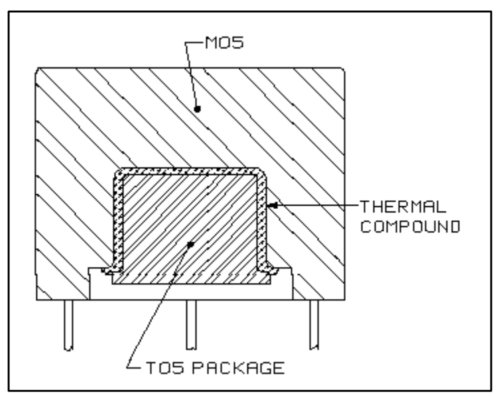

Figure 3: Mini-Oven Cross Section

MINI-OVEN APPLICATIONS: CRYSTAL OSCILLATORS

One good use for a mini-oven is for temperature control of the crystal used in a crystal oscillator. A crystal oscillator is an inherently stable device, but by controlling the temperature of the crystal, *orders of magnitude* of improved stability can be realized. To understand why this is so, we must first understand the nature of a crystal.

The most popular and least expensive crystal used in oscillators is the AT-cut type. The term AT-cut refers to the way a piece of quartz is cut to produce the individual crystal blanks. In an AT-cut crystal, the quartz is cut at an oblique angle with respect to one crystal axis (singly rotated). Refer to Figure 4 for the frequency offset over temperature for an AT-cut crystal. It is important to note that the curve in Figure 4 represents *only one of a family of curves*. Figure 5 shows the family of curves from which Figure 4 was derived. 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. Refer again to Figure 5: If ambient temperatures swing from -30°C to 70°C, an optimally chosen crystal will change about ±5 PPM. Now refer to Figure 6: 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. By using a Mini-Oven to maintain the crystal temperature at the upper turn point of the crystal (the point at which the slope of the curve equals zero) tighter ambient frequency stabilities can be achieved. Low cost Mini-Ovens can maintain better than ±5°C over ambient ranges of -30°C to 60°C or greater. Ambient frequency stabilities can go from many parts-per-million to less than ½ part-per-million. Stabilities much tighter than this are not easy to achieve by heating the crystal alone, since the other circuit elements also control the frequency, to a lesser degree. In these cases, a custom TCXO or OCXO may be needed. Isotemp manufactures a full line of these products in addition to the Mini-Oven.

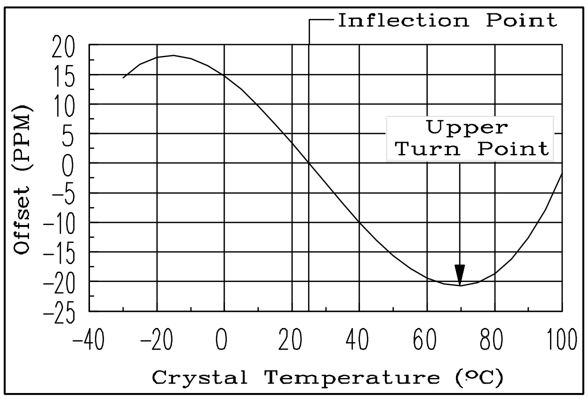

Figure 4: AT-cut crystal curve

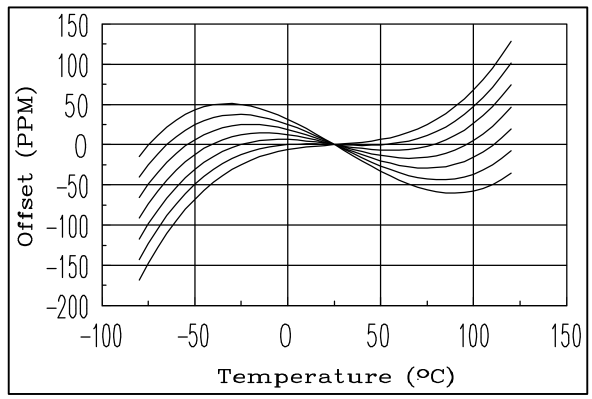

Figure 5: Family of AT-cut crystal curves

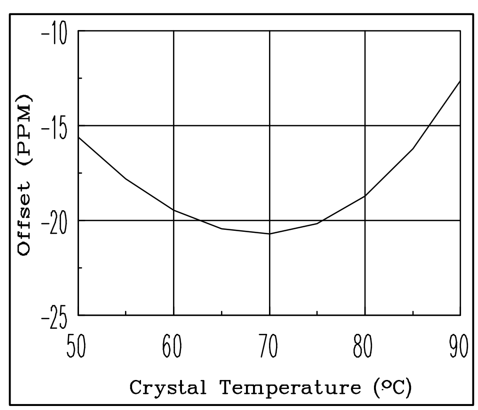

Figure 6: AT-cut crystal @ Upper Turn

MINI-OVEN APPLICATIONS: OTHER

The applications for Mini-Ovens are limited only by the package style of the device you wish to heat. Items other than crystals which are packaged in T05 packages include but are not limited to: Accelerometers, Transistors, Voltage References and Operational Amplifiers. Depending on the exact parameters of the device, heating can provide substantial performance gains in terms of temperature related drifts.

DEFINITIONS

Set Temperature — The steady state operation temperature of the oven at +25°C ambient.

Initial Tolerance — The absolute accuracy of the oven temperature.

Ambient Stability — The change in oven temperature vs. the range of ambient temperatures the oven will be exposed to during operation.

Voltage Stability — The change in oven temperature vs. variations in supply voltage.

Warmup — The period of time after initial application of power during which the Mini-Oven is heating to the desired setpoint.

Turn-on Power — The amount of power consumed by the Mini-Oven during initial turn-on and warmup.

Steady State Power — The amount of power consumed by the Mini-Oven (at a certain ambient temperature) once it has warmed up and reached internal thermal equilibrium.

Slope — The relation of steady state power consumption to changes in ambient temperatures.

ADDITIONAL INFORMATION

Visit our web site to review what is available in our standard Mini-Oven line. Please note that special units can be engineered to change such items as turn on power, warmup time and ambient temperature specifications. For further information on the specification and application of Miniature Ovens, or any other questions regarding our product line, please contact the sales or engineering staff at Isotemp Research, Inc.

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