Optimizing the OX-601/OX-502 Performance

INTRODUCTION

The OX-601 and OX-502 are high performance OCXOs. They are based on a proprietary ASIC design that improves reliability and reduces cost. Realizing the full performance is a matter of following a few simple guidelines provided in this application note. These guidelines include power supply requirements, power supply filtering, optimizing signal integrity, thermal and mechanical management, as well as PCB layout. Optimizing performance is, in some instances, counter to standard methodology. These guidelines should be considered when using any OCXO.

An OCXO block diagram is shown in Figure 1. Fundamentally, an OCXO consists of a voltage regulator, temperature sensor, an oven heater and oven controller, power supply regulation, crystal, crystal oscillator drive circuit, and output buffer. Each section has a specialized function that works in unison to provide a very stable, low wander output frequency. Providing proper operating conditions for all the OCXO design blocks will result in best performance. The intention of this application note is to assist with a fundamental understanding of each and methods to optimize for best performance.

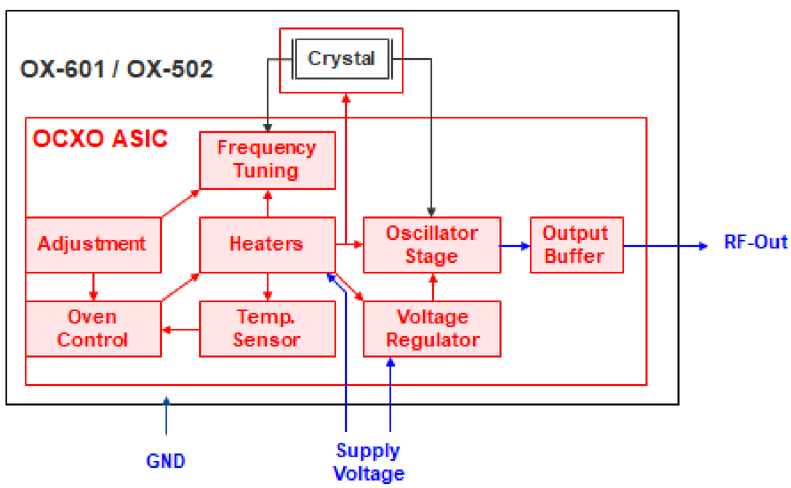

FIGURE 1: *Block Diagram.*

An OCXO's internal temperature is set, and held constant, to a few degrees above the rated maximum operating condition.

POWER SUPPLY AND GROUND

Power-Up Current Requirements

An OCXO will draw more current upon initial power-up and then require less after thermal stabilization. This is a result of the internal heater quickly ramping the internal environment to a high temperature, about 10°C above the maximum operating temperature. During this time, less than 20 seconds at room ambient, the current draw will be 350 mA typical. The power supply, supply filtering, supply, and GND PCB trace widths should accommodate this temporary higher current draw with minimal resistance and voltage drop. Device current draw is 150 mA under typical room ambient conditions and will change depending on the ambient temperature. As examples, the current will be a higher value, 250 mA, when temperatures are at the –40°C low end and 40 mA at the 85°C high end of the operating range.

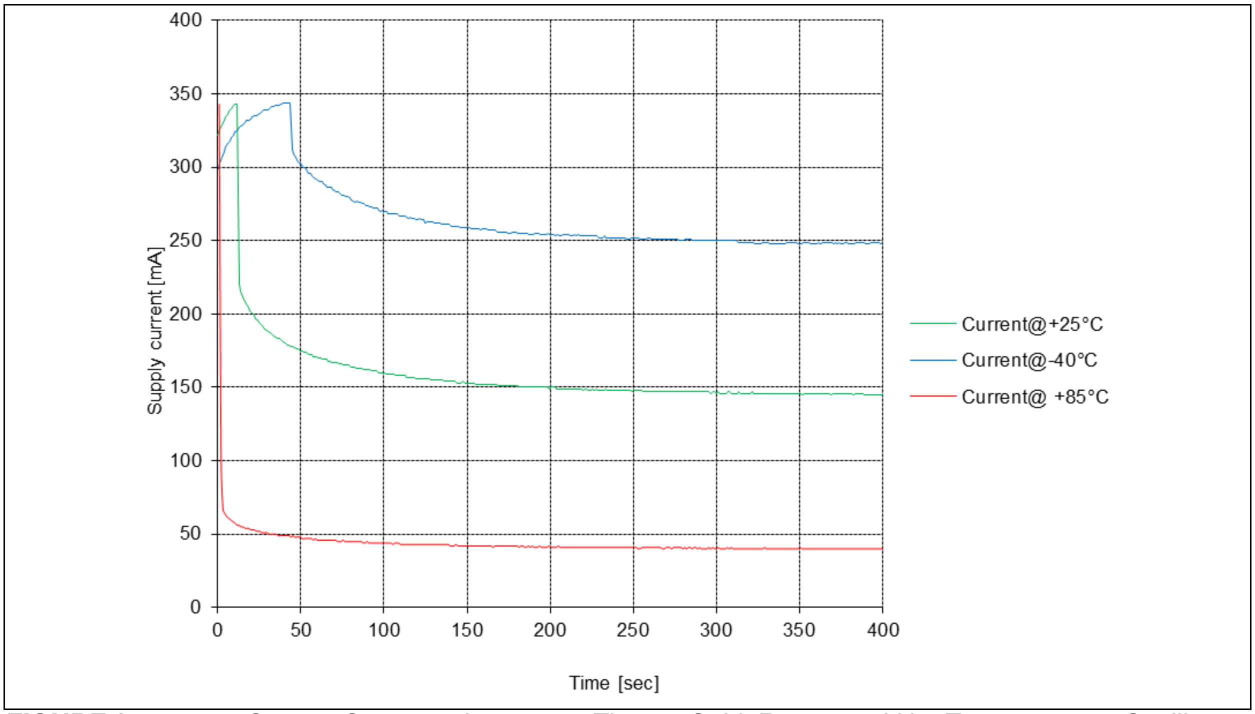

FIGURE 2: *Current Consumption versus Time at Cold, Room, and Hot Temperatures; Oscillator: OX-502, Calm Air, Mounted Horizontally.*

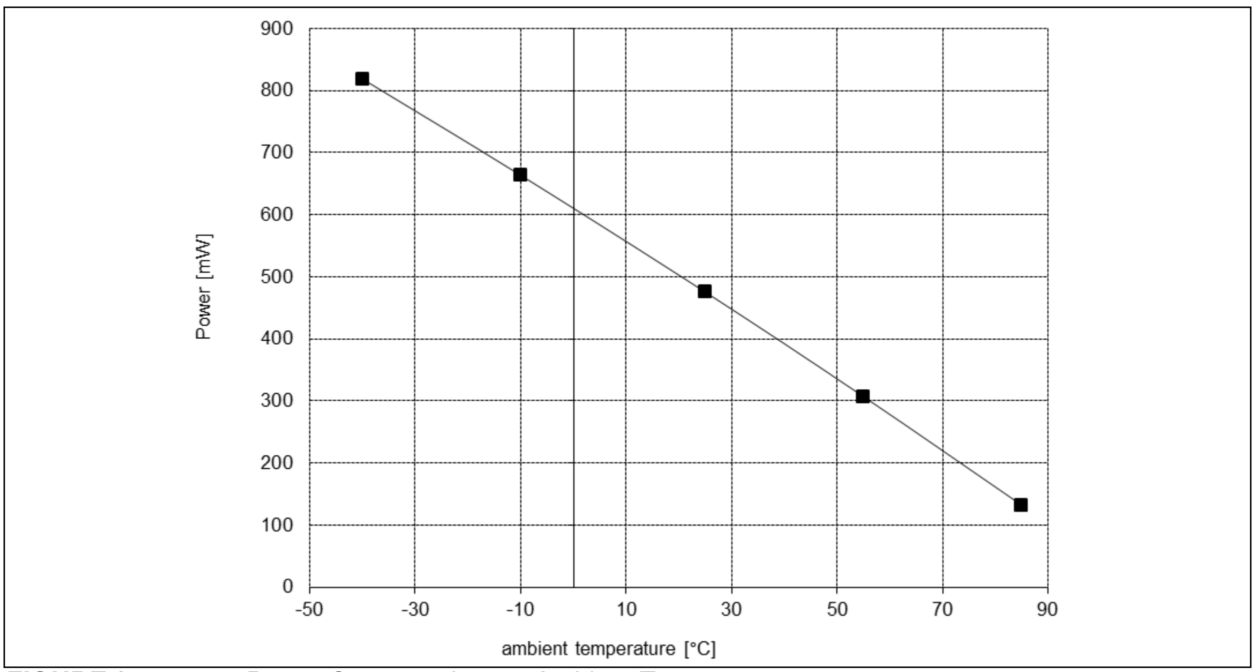

FIGURE 3: *Power Consumption vs. Ambient Temperature.*

Note: While the current draw will stabilize in three minutes under normal conditions, the OX-601 and OX-502 should be allowed an additional 24 hours warm-up for optimal holdover performance and 30 days powered on for aging compliance.

Meeting Performance upon Power-Up

All OX-601 and OX-502 devices undergo aging rate verification at the factory. This includes powering the OCXO and measuring the frequency over time and from this the aging rate is calculated. Devices are shipped once the aging rate has been verified and final electrical testing has been performed.

Once the OX-601 and OX-502 are powered up, the output will be active within 200 milliseconds, the frequency will be within ±50 ppb of frequency reading within three minutes compared to the frequency after one hour of operation, and the aging performance is guaranteed after 30 days.

Note: Additionally, reflow stress during the manufacturing process can induce a short-term change in initial accuracy, a one-day wait time is recommended before OCXO related frequency adjustments are made. Unpowered storage time also has an influence on the time needed for an OCXO to reach the drift rates. This should be accounted for before any conformance testing or guaranteed field performance.

Power Supply Filtering

The OX-601 and OX-502 have excellent close-in phase noise performance that is equivalent to low-wander phase/frequency performance in the time domain. Realizing this performance is aided by thorough power supply filtering. While it's difficult to provide a one-size-fits-all solution, it's recommended to use a large value bypass capacitor—such as 10 μF to 100 μF—a series ferrite bead, then three capacitors—such as 22 μF, 100 nF, and 10 nF.

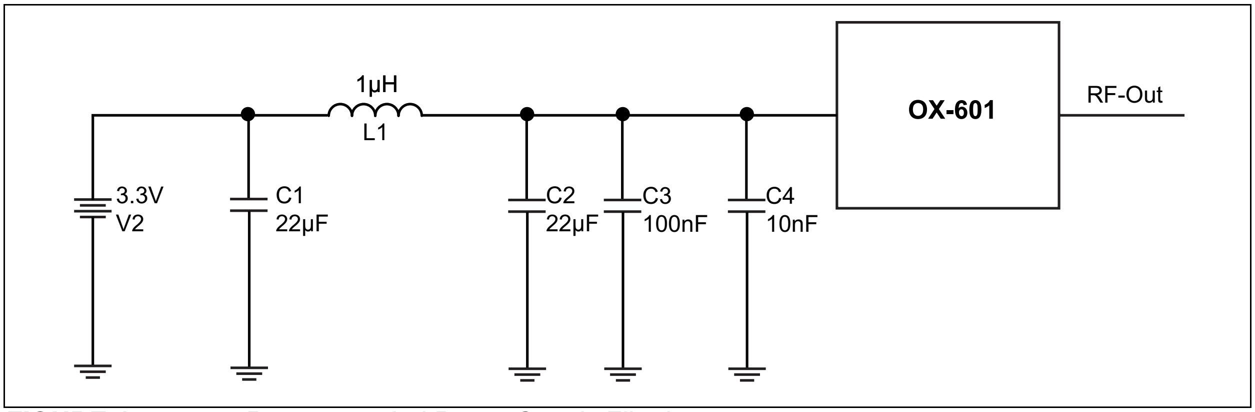

FIGURE 4: *Recommended Power Supply Filtering.*

Each capacitor should have its own ground via. Ground vias should not be shared. The goal is to minimize inductive ground paths by using as short a path as possible to the ground plane. In some instances, two capacitors of the same value are used in parallel to minimize inductance and reduce impedance, similar to when smaller value capacitance is used to shunt higher frequencies. Capacitors should be located as close to the device supply voltage pin as possible, with priority given to the smaller value capacitors. Using a wide range of capacitors values provides filtering at various and a wider range of noise frequencies. Figure 5 shows capacitor impedance performance versus frequency. The values can be selected to optimize filtering at known noise frequency issues. Using a tantalum capacitor with a relatively high ESR will provide a broadband low impedance path for lower frequencies and lower value ceramic capacitors will provide a broadband low impedance source to filter higher frequency power supply noise.

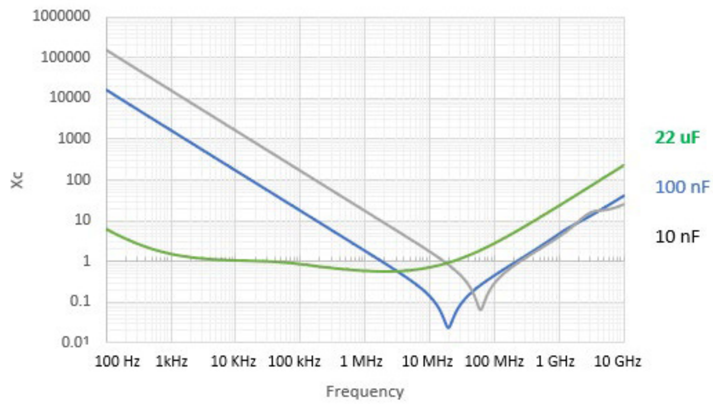

FIGURE 5: *Theoretical Impedance vs. Frequency.*

Once it has been verified that power supply filtering is adequate, and if cost reduction is a premium, then capacitors can be de-populated one at a time and the ferrite bead can be replaced with a 0Ω resistor capable of carrying 1A of current. The OX-601 and OX-502 should be evaluated with the complete bypass circuit and then again with by eliminating capacitors on a one-by-one basis. The recommendation is to use the complete bypass circuit shown in Figure 4 or Figure 6. Even more capacitors may be needed depending on the number of different frequency clocks, clocks that are close to the OCXO frequency, RF signals, and power supply noise.

If the supply voltage also contains DC variations in addition to noise, then a low dropout/low noise power supply regulator, such as the MIC94325, should be used.

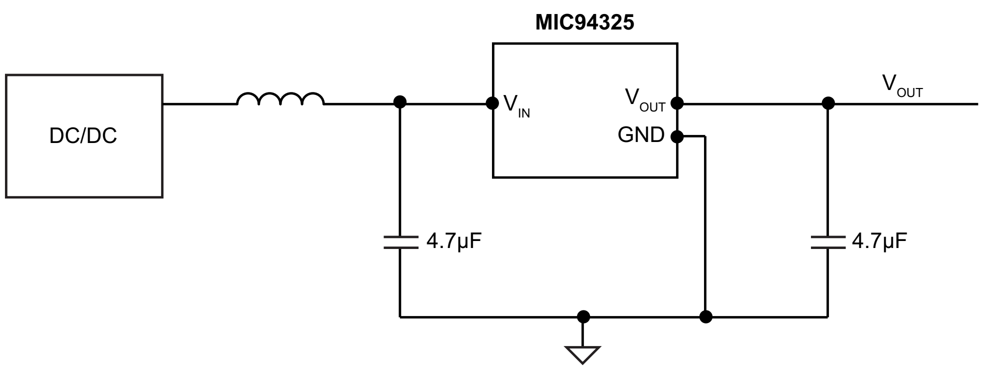

FIGURE 6: *MIC94325 LDO Used for Power Supply Filtering.*

Optimizing Signal Integrity

The CMOS output of the OX-601 and OX-502 is intended to drive a high impedance receiver input and is rated for a 15 pF nominal load. Being a CMOS clock signal, it's ideal to use shorter trance lengths. The OX-601/OX-502 should be located as close to the receiver as possible. For moderately longer trace lengths, it is common practice to set both the output impedance and PCB trace to a matching 50Ω value. The PCB is designed to a 50Ω impedance by standard practices of PCB trace width versus thickness to the GND plane. The OX-601/OX-502 have a nominal R_{ON} value of 27Ω and R_{OFF} value of 24Ω. A 24Ω series resistor should be located as close as possible to the OX-601/OX-502 output. This will set the total output impedance to about 50Ω, matching the 50Ω PCB trace value.

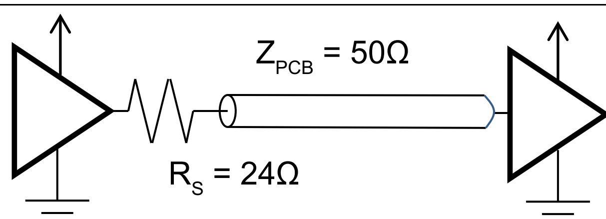

FIGURE 7: *Improving Signal Integrity, A 24Ω Resistor is Placed as Close as Possible to RF Output.*

The OX-601/OX-502 were not designed to drive a low impedance input–such as 50Ω, LVDS, LVPECL, or HCSL. A low noise buffer with a CMOS-compatible input and differential outputs should be used. The ZL40234 is a low additive jitter choice; it has dual inputs, four differential outputs, plus one CMOS output.

If the receiver's load impedance will vary under use, then a buffer should be used for best stability performance. It's recommended to verify the receiver's load impedance variations with the manufacturer.

A buffer should also be used when driving multiple CMOS loads, as well as when there is no avoiding a long PCB trace. The PL-133 buffer series are low power/low additive jitter CMOS in/CMOS output jitter buffers recommended for use in this application. Alternatively, a buffer with a differential output could be used when driving clock signals over a long distance in a less than ideal situation, such as close proximity with other clock or noise sources. In this case, the differential signal may need to converted back to a CMOS level depending on the receiver input.

RECOMMENDED BOARD LAYOUT

Reduce EMI

The PCB layout underneath the OX601/OX-502 should be void of ground plains, high speed clock signals, and power supply islands. Not including a GND plane underneath the OCXO goes against conventional guidelines. The reasons for this are detailed in the thermal guidelines and power supply ramp sections. In summary, any efforts to reduce or add localized heating are counterproductive.

The OX-601/OX-502 output PCB trace should utilize standard high-speed clock/RF design practices and a continuous GND plane would be the next layer below, and above if applicable. A 90° degree corner should be rounded or consist of two 45° bends. The OX-601/OX-502 RF output trace should not closely parallel another clock or RF signal. The data sheet includes a recommended pad layout which should be followed.

Medical imaging applications can include high strength magnetic fields, the OX-601/OX-502 should not be used within this environment. Please contact https://www.microchip.com/en-us/support/design-help/client-support-services for help with product selection.

THERMAL CONSIDERATIONS

Do Not Heat Sink

The OX-601/OX-502, being an OCXO, is designed with the internal temperature purposely set to a few degrees above the highest rated ambient operating temperature. Heat sinks should not be employed in effort to reduce the heat. Thermal islands can be incorporated in the PCB design if there are multiple ground/heat sink layers. An OCXO should be positioned away from air flow and vibrations due to fans as noted next.

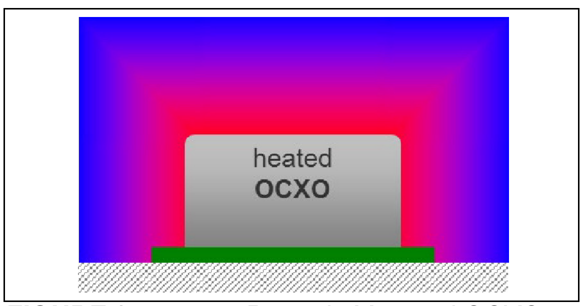

FIGURE 8: Properly Mounted OCXO (No Heat Sink).

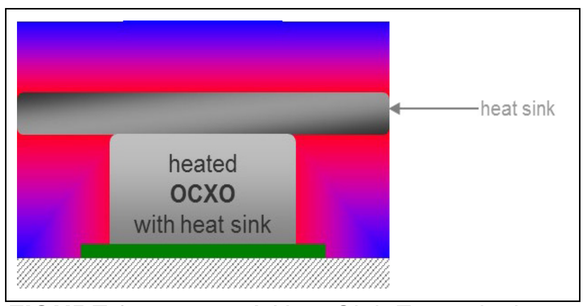

FIGURE 9: A Heat Sink Expands the Effective Surface of the OCXO and Transfers Additional Heat to the Ambient. Thus, the Internal Heaters have to Provide More Power, which Increases Current Consumption.

Avoid Parasitic Heat

Due to the thermal concept of an OCXO, it is necessary to keep parasitic heat sources and sinks away from the OCXO. This includes power supply sources, high power consumption ICs, heat sinks, and fans. A parasitic heat source may increase the OCXO's internal temperature due to conduction of heat through the board. The OCXO will no longer maintain its frequency stability if the inner temperature of the OCXO exceeds the internally set operating temperature.

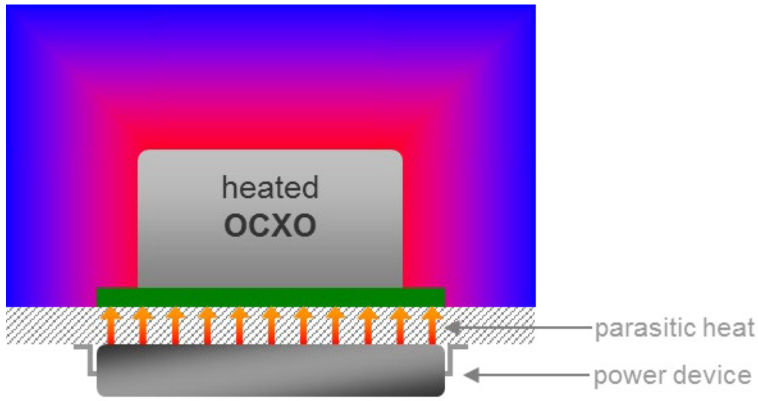

FIGURE 10: *Avoid All Sources of Heat Coupling.*

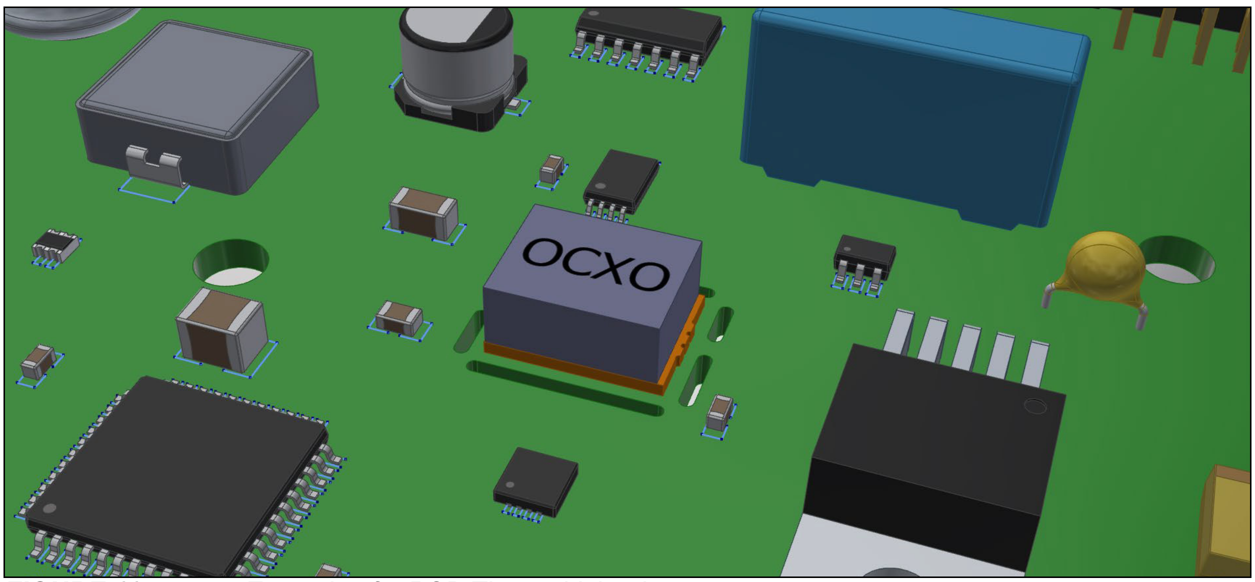

FIGURE 11: *Example of a PCB Thermal Island.*

Reduce Air Flow

Air flow increases thermal conduction, which can increase or degrade short-term stability. Air flow should be minimized. Placing the OX-601 or OX-502 where air flow is minimal, or protecting it by placing it near taller components, or using a cover to shield the device, will help optimize short-term stability/Allan variance and MTIE/TDEV performance. Just to note, a change in air flow will degrade performance more than a constant flow. It's best is to keep the operating environment as constant as possible.

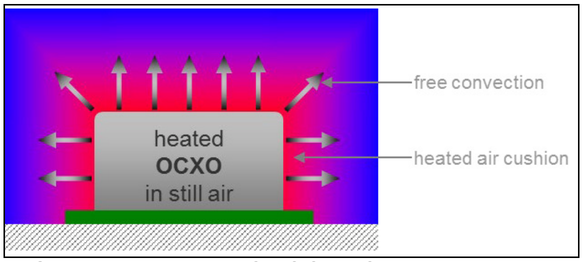

FIGURE 12: OXCO in Calm Air.

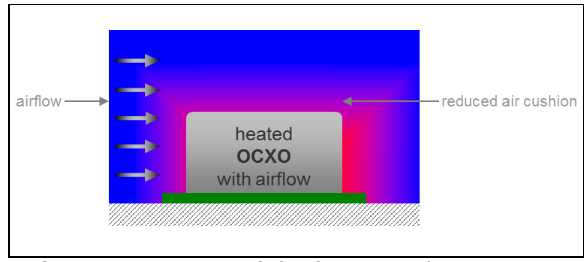

FIGURE 13: OCXO with Airflow.

If airflow and convection can't be avoided, then it is very helpful to shield the OX-601/OX-502 against airflow. A simple air shield (e.g. made of plastic) significantly improves the short-term stability in turbulent environments. Mount the shield with a gap of few millimeters to the OCXO enclosure. Air may move inside the shielding due to free convection. This can be avoided by the use of a foam cover to suppress free convection. In general, it is advantageous to have additional thermal insulation around the OCXO.

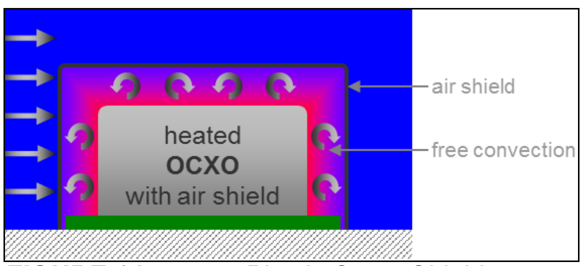

FIGURE 14: Plastic Cover Shield.

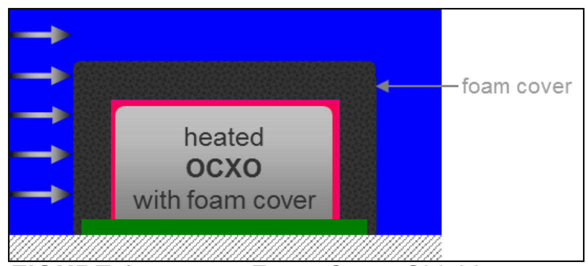

FIGURE 15: Foam Cover Shield.

Figure 16 and Figure 17 show frequency stability performance under cycled airflow without and with cover, respectively, for the OX-502. Figure 18 and Figure 19 show frequency stability performance under cycled air flow without and with cover, respectively, for the OX-601. Airflow (1 m/s) is switched on and off periodically during the measurement period of several minutes. A plastic cover will provide performance protection from degradation due to airflow, or worse, cycled air flow. These performance plots also show the advantage of using the OX-502 under harsher environmental conditions. The OX-502 should be selected over the OX-601 when air flow and changes in airflow cannot be avoided.

Oscillator: OX-502

Airflow 1 m/s; Oscillator is mounted horizontally.

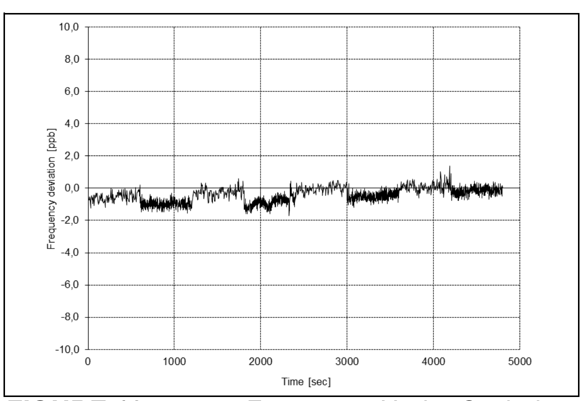

FIGURE 16: Frequency Under Cycled Airflow without Cover.

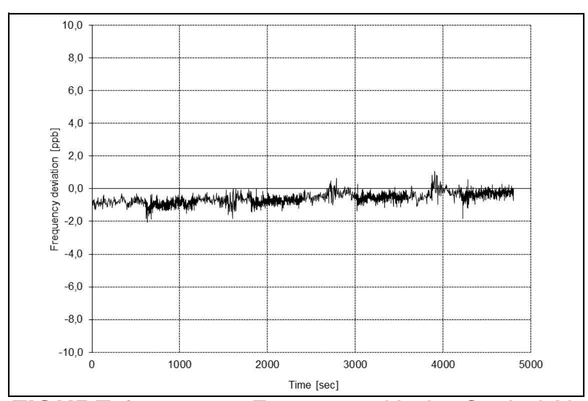

FIGURE 17: Frequency Under Cycled Air Flow with Cover.

Oscillator: OX-601

Airflow 1 m/s; Oscillator is mounted horizontally.

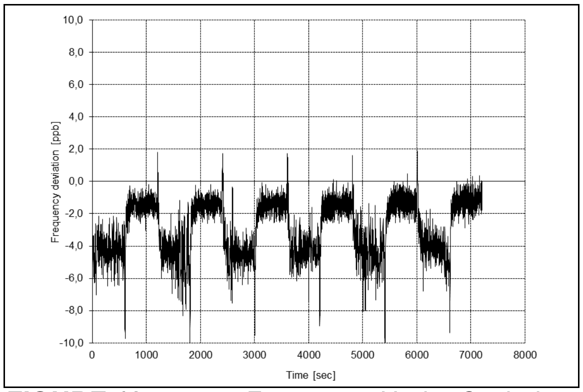

FIGURE 18: *Frequency Under Cycled Airflow without Cover.*

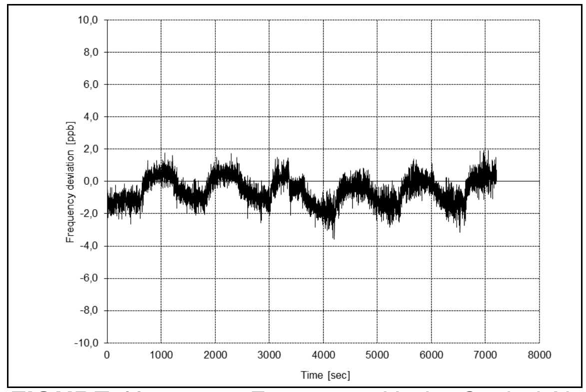

FIGURE 19: *Frequency Under Cycled Air Flow with Cover.*

Changes in Operating Temperature

While it's desirable for the thermal environment to be held constant, there are some conditions (such as outdoor use or indoor heating/cooling failure) where temperature will undergo change. The internal thermal PLL is designed to keep the internal temperature at a constant temperature despite external changes. However, it's expected that the environmental temperature will change no faster than 1°C/minute. If abrupt temperature change cannot be avoided, then an undesirable phase and frequency jump may result. As previously described, an external shield and insulation should be used.

Minimize Shock and Vibration

Crystals are piezoelectrical devices, which means that exposure to mechanical vibration results in an electrical response. Under normal use, the crystal drive circuit plus a high Q crystal results in a very pure tone (there will be odd harmonics in the case of digital outputs). Mechanical vibration results in unwanted spurious tones that can degrade both jitter and wander performance; this undesirable response depends on both the vibration frequency and amplitude.

A shock contains a broadband frequency range. However, it is typically a non-reoccurring event, meaning the OCXO will recover. The exception is when shock or vibration events exceed the maximum rating. In this case, permanent damage may occur and needs to be avoided.

In some cases, there may be no avoiding shock and vibration. In these cases, it's best to minimize effects by locating the OCXO in the most environmental friendly location. For example, mounting the OCXO as far away from fan vibration, closer to the mechanical mounting locations, as opposed to mounting it to the center of the board. Software simulation that incorporates vibration analysis may be required in the design. It's critical to understand the vibration's frequency (or frequencies) and amplitude to select the correct solutions. Contact applications support, https://www.microchip.com/en-us/support/design-help/client-support-services, for OCXO selection designed for performance under vibration.

Assembly

The OX-601 and OX-502 are SMD devices designed for pick-and-place reflow soldering with a 250°C maximum PCB solder joint temperature over a 10 to 40 second period. Devices are not hermetically sealed and should not undergo a wash process; otherwise, key parameters such as aging, accuracy, and stability can be affected.

PCB Layout

There are several guidelines provided in this application note. In summary:

- Do not make an effort to cool or heat the OX-601 and OX-502.
- Eliminate or minimize air flow, use a cover, and consider using additional insulation if it’s not possible to eliminate air flow or changes in air flow.
- Incorporate a PCB thermal island.
- Incorporate power supply filtering.
- Each bypass capacitor should have a dedicated ground connection. Do not share a via and make the connection as short and low inductive as possible.
- Allow the defined time as listed in the data sheet after power-on for spec compliance.
- Keep PCB layers underneath the OCXO void of signals, GND planes, and power supply islands.
- Use the recommended pad layout in the data sheet.
- Use a 24Ω series resistor in the output path, located as close as possible to the OXCO output.
- Use 50Ω PCB impedance.
- Use rounded PCB bends or, better yet, two 45° bends.
- Keep RF Output PCB trace lengths to a minimum. If long runs are required, consider using a low noise buffer or a differential buffer if the RF output is subjected to noise.
- Locate the OX-601/OX-502 close to the receiver, but distant from air flow. If these are at odds, keep the OCXO isolated from environmental turmoil.
- Use a buffer if driving multiple sources or if the receiver load changes under operation.
- The output trace should not run close or in parallel to other clock sources and RF signals.
- A GND fence post maybe required if the above cannot be avoided.
- Do not excessively load the output; use logic translating buffers when driving differential inputs or 50Ω inputs.
- The “Do Not Connect pins” are used for programming. Do not make connections.
- Eliminate shock and vibration under operation. Eliminate excess shock under non-operational conditions. Devices should not be dropped.
- The OX-601 and OX-502 are non-washable.

Summary

An OCXO’s internal temperature is purposely set and held constant to a high operating temperature. This results in optimized temperature stability, holdover phase and frequency/MTIE TDEV performance, and is one of the most accurate free running clock timing sources available. Following the guidelines outlined, with data sheet parameters in mind, will result in the rated performance.

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