Guidelines for the use of Pluto®/Pluto+™ Ultra Stable TCXOs

This application note provides guidance on achieving optimal TCXO performance in applications where sub-±100 ppb stability is critical, such as:

- Small cell base stations
- Stratum 3 network clocks
- Cospas-Sarsat emergency beacons

SCOPE

The information in this application note applies to:

Pluto® Series USTCXOs (CFPT#### and RFPT###)

- CFPT9### (7 x 5 mm and 5 x 3.2 mm footprints)
- RFPT### (7 x 5 mm footprint)

Pluto+™ Series USTCXOs (RPT####xx)

- RPT7050xx (7 x 5 mm footprint)
- RPT5032xx (5 x 3.2 mm footprints)

Pluto® and Pluto+2™ COSPAS-SARSAT Beacon TCXOs (RFPT### and RPT####x)
– Individual part numbers from these models with format EnnnnXX (nnnn = 4-digit number, XX = optional suffix

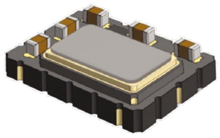
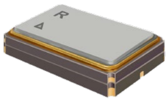
- RFPT100 (7 x 5 mm footprint)
- RPT7050B (7 x 5 mm footprint)

Throughout this application note, the term 'TCXO' is used to denote Temperature-Compensated Crystal Oscillators (TCXO) as well as versions of which the frequency can be tuned with an external control voltage (TCVCXO, aka VCTCXO).

INTRODUCTION

Rakon developed a range of miniature TCXOs capable of delivering sub ±100 ppb frequency stability. Devices are offered in a range of package styles, including 7.0 x 5.0 mm and 5.0 x 3.2 mm surface-mount formats, which are generally preferred for volume applications.

Figure 1: Typical Pluto® and Pluto+™ TCXO Packages

Pluto® Series (Product model code: CFPT... or RFPT...)	7.0 x 5.0 mm 	5.0 x 3.2 mm 
Pluto+™ TCXO (Product model code: RPT...)	7.0 x 5.0 mm 	5.0 x 3.2 mm 

These ASICs deliver true analogue compensation with no digitisation errors, resulting in a smooth frequency characteristic over the full operating temperature range. In addition to excellent compensation performance, the TCXOs feature frequency-tuning linearity better than 1%.

This level of performance enables the use of the TCXO in applications where an OCXO would previously have been specified. TCXO will deliver optimal performance in system environments that are electrically, thermally, and mechanically stable and quiet. There will inevitably be levels of noise and instability in real applications, and this document is intended to allow their impact to be considered and to outline some guiding principles and practical steps to ensure the best possible performance is realised.

TEMPERATURE COMPENSATION

A free-running crystal oscillator exhibits a significant change in frequency as the temperature of the crystal varies within the device's operating temperature range. Approximately two orders of magnitude can improve this level of frequency instability due to temperature through temperature compensation.

Figure 2: Simple Crystal Oscillator (XO)

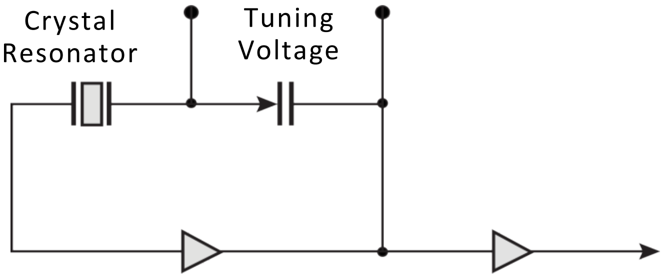


Figure 3: Frequency Stability vs Temperature

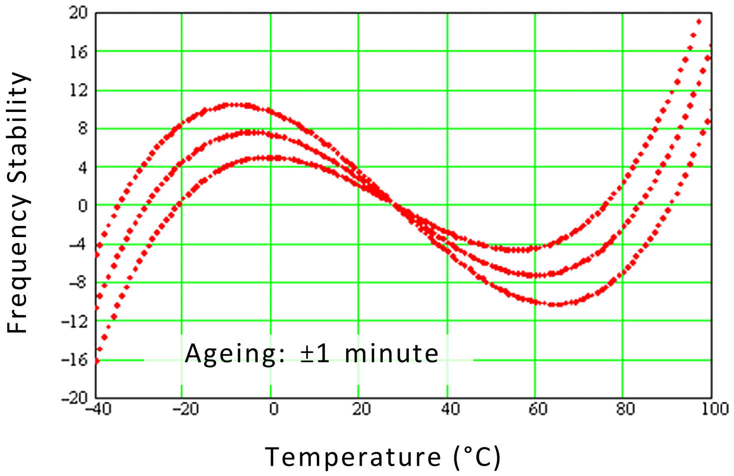
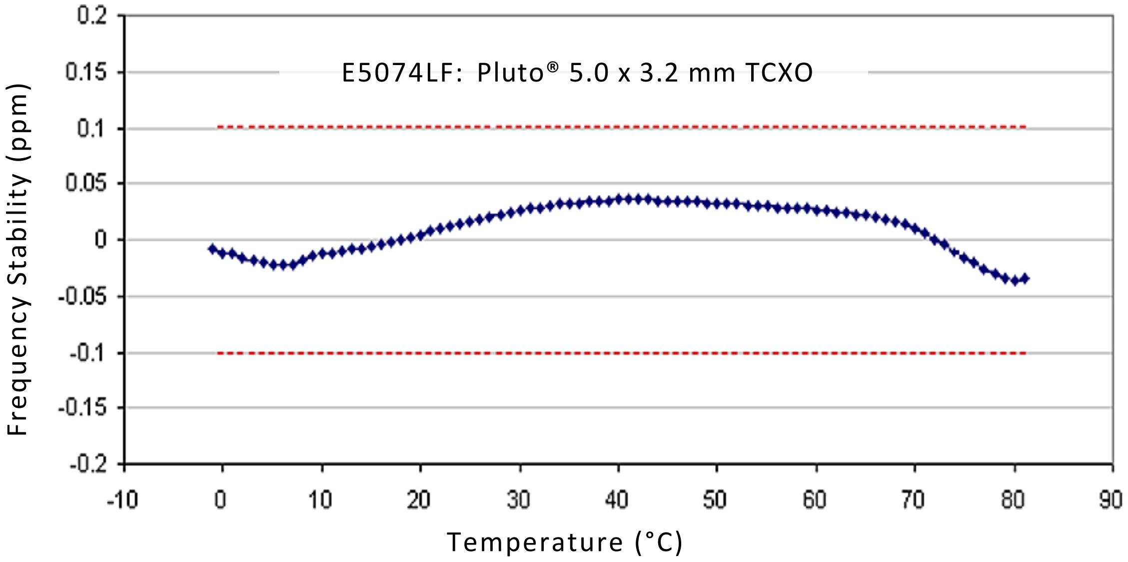


Figure 4: Frequency vs Temperature Characteristic after Compensation



Every TCXO produced by Rakon is uniquely characterised during manufacturing. Characterisation is carried out in a carefully controlled test environment that provides a stable thermal environment, ensuring that the crystal and temperature-sensing components of the oscillator are in stable equilibrium during frequency measurements. The compensation voltages required to minimise frequency error with temperature are calculated from these frequency measurements. For this reason, the best TCXO performance will be delivered when the oscillator’s operating environment has the same stable thermal characteristics as the manufacturing test environment used for device characterisation.

Naturally, there are significant differences between the physical, electrical and thermal environments used for Rakon's characterisation and those encountered in end-user applications. In an ideal oscillator temperature control system, the active area of the quartz crystal and the temperature sensing element would experience identical temperatures and identical temperature changes. Under these conditions, there would be no error component in the compensation due to the temperature differential between the quartz crystal and the temperature sensor. To achieve this, however, the two components would need to occupy the exact same physical space within the device, and this is not possible. In practice, the oscillator is designed to minimise any temperature differential between the crystal and the temperature sensor, and great care is taken to ensure that both physical separation and thermal impedance between them are minimised.

The principles of thermal management must be extended to the system environment where, once again, best performance will be achieved when temperature gradients between the crystal and the temperature sensor are minimised. Furthermore, as the temperature sensor is located on the TCXO ASIC alongside all the other active circuitry, care must be taken to maintain a constant power dissipation of the oscillator, so as not to influence the temperature correlation between the sensor and the crystal.

CREATING A QUIET THERMAL ENVIRONMENT – THERMAL SYSTEM DESIGN

The actions of convection, conduction and radiation can all give rise to thermal gradients, and the impact of these mechanisms should be carefully considered in the system design. The ideal environment for the oscillator is one where the temperature is stable and uniform on all sides of the device. In practice of course, the base of the oscillator is soldered to a printed circuit board, whilst its top surface is likely to be in still or forced air and the rate of heat transfer from these two surfaces will be different. Additionally, the system design and layout may require that the oscillator is close to a power component on one face, whilst the opposite face is exposed to forced air from a cooling fan. Again, the objective is to avoid these differences and to minimise their impact where they cannot be avoided.

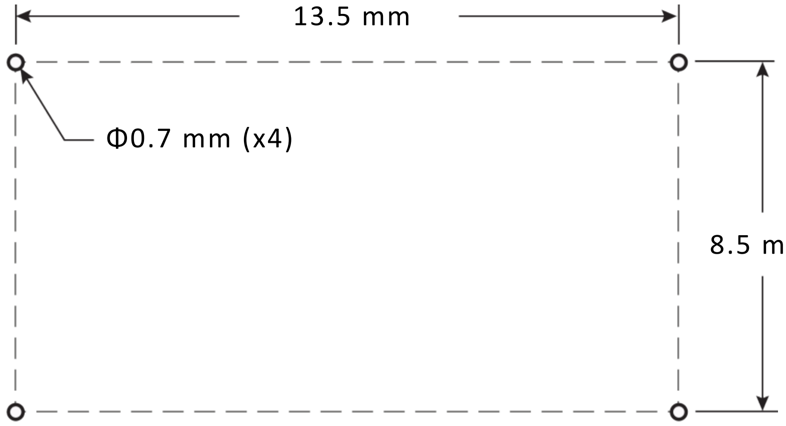
If the design allows, it is preferable to isolate the oscillator from the following effects:

1. Local hot spots in the equipment caused by high-power dissipation components
2. Forced air flow from cooling fans
3. Radiated energy in the visible light and infrared frequency bands
4. Tracking beneath the oscillator (especially dense ground planes) can increase heat transfer by conduction

These effects can be attenuated by incorporating a cover in the oscillator design. This will shield the device from the direct effects of convection and radiation and will reduce the impact of (1), (2) and (3) above. The enclosed volume of (still) air will also provide a thermal baffle, reducing the impact of thermal transients.

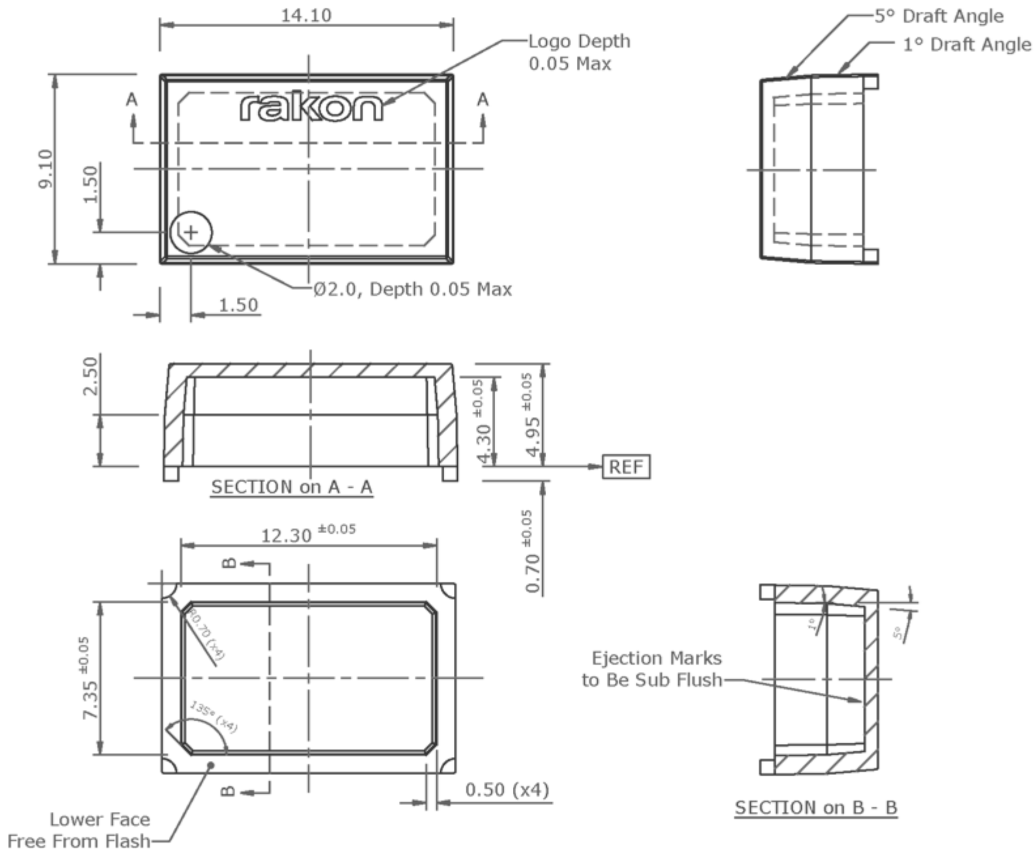
Rakon offers a plastic cover (P/N PCV00015AA1) for this purpose. To fit the cover drill 4 holes (0.7 mm diameter, x = 13.5 mm, y = 8.5 mm) equidistant from the TCXO location as per the following sketch:

Figure 5: Plastic Cover Locating Hole Sketch



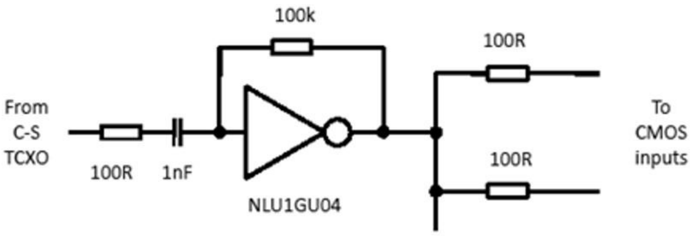
The cover needs to be secured with adhesive. Any adhesive suitable for bonding components to printed circuit boards can be used. Examples are Loctite 3220 and Epotek TJ1104-LH (formerly known as Epotek 102-104). These examples are provided for informational purposes only – users remain responsible for assessing their suitability for their specific application. For proper use of the adhesive, please consult the manufacturer's Technical Data Sheet and Material Safety Data Sheet.

Figure 6: Cover Outline Drawing (PCV00015AA1)



Heat transfer by conduction can be minimised by keeping the area under the oscillator free of high-conductivity metallic tracking and by introducing slots in the printed circuit boards to create a discontinuity in the thermal conduction path.

Figure 7: Clipped Sinewave to CMOS Buffer



For optimum stability, it is recommended to load the output with the nominal load specified in the detailed specification, as this will result in the same power dissipation in the output stage as when it was compensated in production. Depending on the load driven by the input stage, it may be necessary to add a capacitor. For example, if the combined load of the input and tracks is 5 pF and the nominal load is 10 pF, then a capacitor of ~5 pF should be added from the output to GND.

For devices with voltage control, sensitivity to instabilities on the Control Voltage (Vc) line depends on the device's tuning range. For illustration purposes, a 1 mV error on the Vc line of a device with a typical gain transfer (Kv) of +10 ppm/V would result in a 10 ppb error in the device's output frequency. This represents a significant portion of the available frequency stability budget and underscores the need for the Vc signal to be accurate, stable, and noise-free.

REFLOW SOLDER ASSEMBLY

These TCXOs are suitable for reflow soldering with a lead-free process, provided the temperature profile is compatible with the profile included in the oscillator’s detailed specification. Exposure to reflow temperatures will cause dimensional changes in the bonding adhesive used to mount the crystal blank. It is essential to allow sufficient time for the bonding adhesive to relax to its normal cured condition before performing any frequency calibration of the system. Rakon recommend that the system be left quiescent for 24 hours after reflowing before any system calibration is carried out.

OSCILLATOR WARM-UP TIME

A TCXO will provide an output signal instantly (less than 15 ms), and the frequency will be close to the nominal frequency within seconds. However, due to its internal power dissipation, the temperature will increase about 1°C in the first minute (for a TCXO measured in isolation). Other circuitry on the board will likely generate considerably more heat, and board temperatures 10–25°C above ambient are not uncommon. The oscillator and board on which it is placed should be allowed to reach thermal equilibrium before any calibration or measurement takes place.

AGEING

The frequency of a TCXO changes very slowly with time; this is known as ageing. Ageing decreases logarithmically. The most significant change occurs shortly after manufacturing and amounts to typically < ±20 ppb per day. This will reduce to less than a few ppb per day after a couple of weeks. For parts with voltage control, the tuning range will be dimensioned so that the frequency can always be tuned back to nominal over the useful life of the product. Parts with tight ageing requirements undergo special processing in the factory.

PHASE NOISE / EVM CONSIDERATIONS

Getting the best phase noise out of the TCXO is a critical requirement for many applications. For example, in base station transceivers, phase noise will directly affect the Error Vector Magnitude (EVM). In order to meet the required Phase Noise / EVM performance, it is important to consider the following:

- Select the output type that is best suited to drive the next stage. Please check with the chipset manufacturer to determine which input signal (levels, waveform) yields the best phase noise / EVM performance.
- Rakon recommends Pluto+ for the best phase noise performance.
- Use a low-noise power supply regulator with < 20 µV supply ripple.
- Do not buffer the output signal if not required, as buffers can degrade the phase noise. If buffering is unavoidable, use a low noise buffer and decouple its power line with a 100 Ω + 1 µF low-pass filter.
- The control voltage (if part of the specification) needs to be noise free as any noise on the control voltage will modulate the carrier. To troubleshoot this, it is recommended to repeat the phase noise or EVM measurement with the control voltage disconnected from its normal driving circuit but connected to a clean external voltage instead.

ADDITIONAL GUIDELINES FOR COSPAS-SARSAT BEACON TCXO

Use only TCXOs that are explicitly designed for use in Cospas-Sarsat beacons. Make note of the TCXO's serial number (i.e., the marking) used for Type Approval, as the manufacturer will need to provide Medium-Term Stability (MTS) data for comparison with the finished beacon's MTS. Make sure the TCXO class matches the beacon class (NB: If the application requires it, Rakon can offer a TCXO with an extended operating temperature range beyond that needed by Cospas-Sarsat Class 1 & 2 profiles). Ensure the oscillator's nominal frequency is suitable for the channel currently open for qualifying new beacons.

Do not exceed the supply voltage range specified in the document. It is recommended to assess how the finished product's supply voltage changes over time.

Thermal-shock test performance depends on the beacon's thermal characteristics, i.e., how quickly the external temperature shock is transmitted to the oscillator. For first-generation beacons (FGB), it is best to initiate the temperature change as soon as possible (let the temperature settle during the 15-minute warm-up period). It may be possible to achieve this by bringing the oscillator in thermal contact with the beacon's outer case. This provides a low-thermal-impedance path between the TCXO and the environment and adds thermal mass, which dampens small temperature variations. However, for second-generation beacons (SGB), this may not be the optimum thermal position, as the beacon is active for seconds. The standard SGB oscillator specification has been established to meet the EVM requirements, provided the oscillator's temperature change within the beacon is less than 10 °C C/minute under thermal shock conditions. Therefore, it may be necessary to thermally insulate the oscillator from the outside of the beacon for SGB, unlike in the first generation. If the maximum temperature change of the oscillator in the beacon exceeds 10° C/min, please consult Rakon for options.

- RFPT100 – Rakon’s Pluto® TCXO supports FGB. Providing Medium Term Stability (MTS) data.
- RPT7050B – Rakon’s Pluto+2™ TCXO supports SGB. Providing Long Term Stability (LTS) data.

If specific circuitry is intermittently activated, it could generate enough heat to disrupt the thermal balance, causing the MTS to fail. Keep such circuitry away from the oscillator area.

We recommend that the beacon manufacturer test the beacon's compliance before submitting it for Type Approval (specifically the 'Thermal Shock Test' and 'Frequency Stability Test with Temperature Gradient').