

# Guidelines for use of Pluto™ / Pluto+™ Ultra-Stable TCXO

## Application Note

This application note gives advice on how to achieve best TCXO performance in applications where sub  $\pm 100$  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:

- Rakon product models CFPT9xxx and RFPTxxx (Pluto™ based)
- Rakon product models RPT7050x and RPT5032x (Pluto+™ based)
- Individual part numbers from these models with format EnnnnXX (nnnn = 4 digit number, XX = optional suffix)

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 TCXO capable of delivering sub  $\pm 100$  ppb frequency stability. Devices are offered in a range of package styles with 7.0 x 5.0 mm and 5.0 x 3.2 mm surface mount formats generally preferred for volume applications.

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

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

The compensation engines driving this performance are Rakon's proprietary ASICs Pluto™ and its successor Pluto+™. 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 performance better than 1%.

This level of performance enables use of the TCXO in applications where an OCXO may have previously been specified. The TCXO will deliver best 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 of the guiding principles and practical steps that can be taken to ensure best possible performance is realised.

## Temperature Compensation

A free running crystal oscillator demonstrates a significant change in frequency as the temperature of the crystal changes within the operating temperature range of the device. This level of frequency instability with temperature can be improved by around two orders of magnitude using temperature compensation.

Figure 2: Simple Crystal Oscillator (XO)

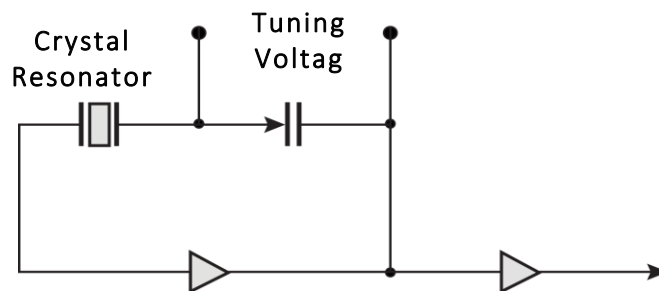


Figure 3: Frequency Stability vs Temperature

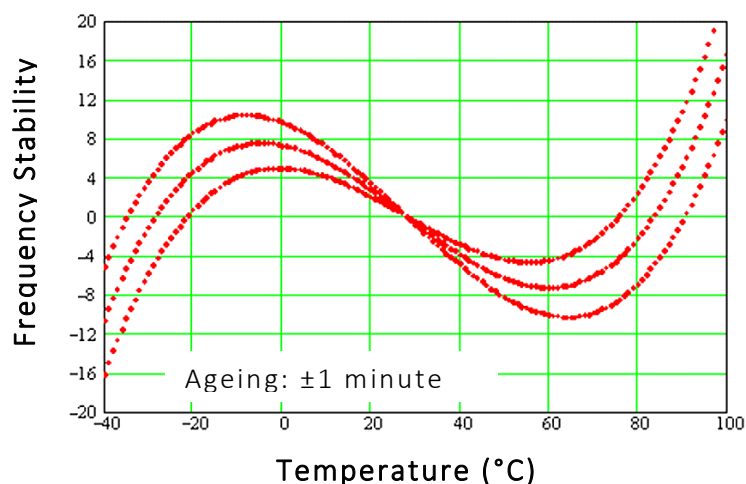
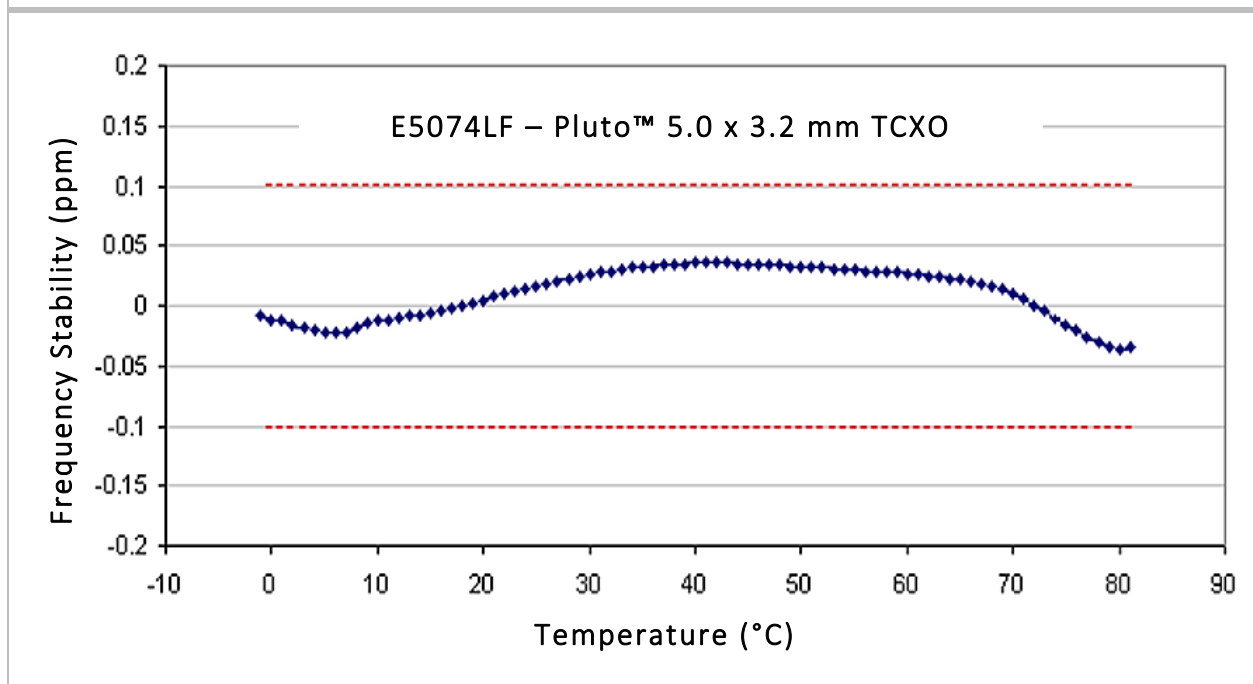


Figure 4: Frequency vs Temperature Characteristic after Compensation



Each and every TCXO produced by Rakon is uniquely characterised as part of the manufacturing process. Characterisation is carried out in a carefully controlled test environment that delivers the stable thermal environment needed to ensure that the crystal and temperature sensing components of the oscillator are in stable equilibrium when frequency measurements are made. The compensation voltages required to minimise frequency error with temperature are calculated from these frequency measurements. For this reason 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 characterisation by Rakon and those presented by 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 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 is 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 with all the other active circuitry, care must be taken to keep the power dissipation of the oscillator constant as not to influence the temperature correlation between the sensor and 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.

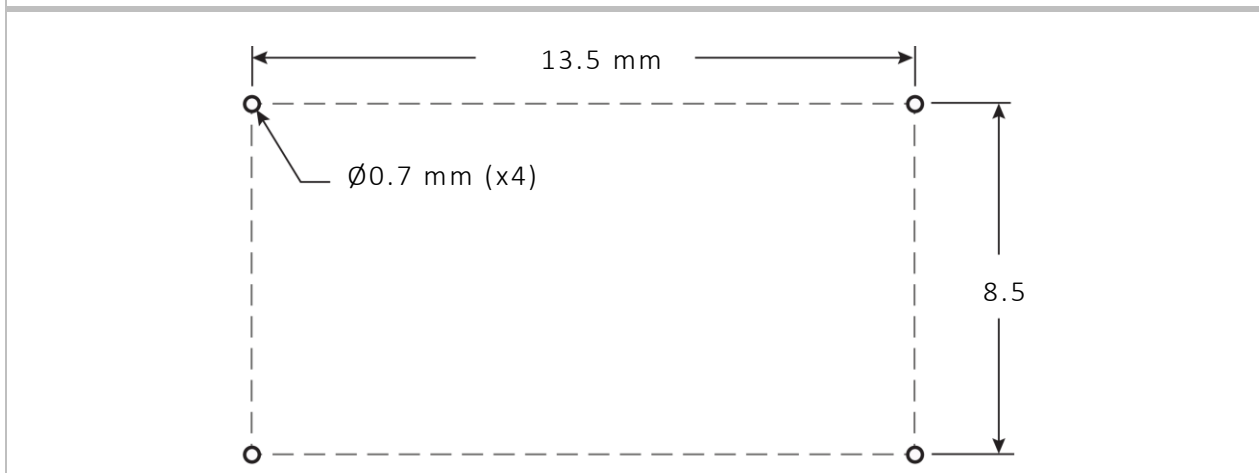
If the design allows, it is preferable to isolate the oscillator from the following effects:

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 infra-red frequency bands
4. Tracking beneath the oscillator (especially dense ground planes) that 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.

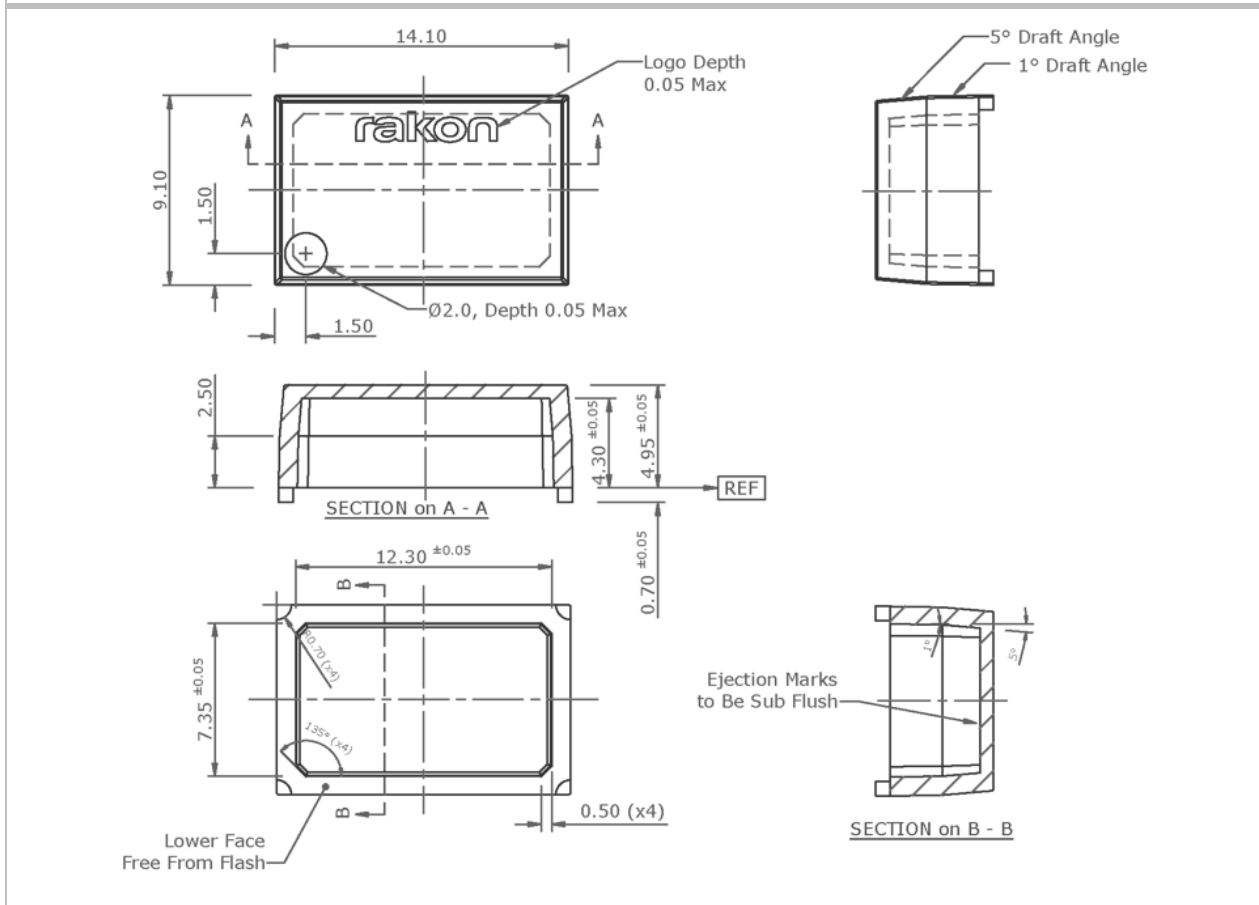
Rakon offers a plastic cover (P/N PCV00015AA1) for this purpose. To fit the cover drill 4 holes (0.7 mm diameter, x = 13.5 mm, y = 8.5 mm) equidistant from the TCXO location as per following sketch:

Figure 5: Plastic Cover Locating Hole Sketch



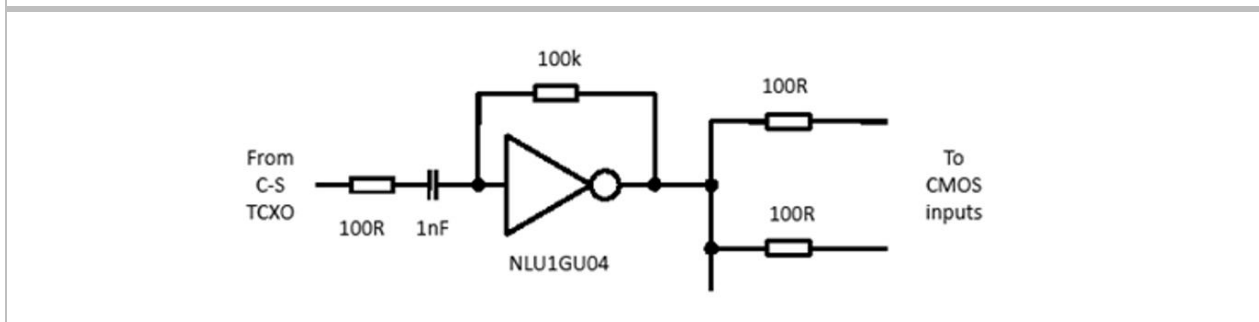
The cover needs to be secured with adhesive. Any adhesive suitable for bonding components to printed circuit boards can be used. Examples are Loctite 3220 and Epotek TJ1104-LH (formerly known as Epotek 102-104). These examples are provided for information only – users remain responsible for assessing suitability for their 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 both by keeping the area under the oscillator free from 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 as stated in the detail specification as using this load will result in the same power dissipation of the output stage as when it was compensated in production. Depending on the load represented by the input stage that is driven, it may be necessary to add an additional capacitor. For example, if the combined load of input and tracks is 5 pF and the nominal load is stated as 10 pF then a capacitor of ~5 pF should be added from output to GND.

For devices with voltage control, sensitivity to instabilities on the Control Voltage (Vc) line will depend on the tuning range specified for the device. 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 on the output frequency of the device. This represents a significant proportion of the available frequency stability budget and underlines the need for the Vc signal to be accurate, stable and noise-free.

## Reflow Solder Assembly

These TCXO are suitable for reflow soldering with a lead-free process provided the temperature profile is compatible with the profile included in the oscillator's detail specification. Exposure to the reflow temperatures will give rise to dimensional changes in the bonding adhesive used to mount the crystal blank. It is important 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 is left quiescent for 24 hours after reflow 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 with 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). It is likely that other circuitry on the board will generate considerably more heat and board temperature increases of 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 aging. The ageing decreases logarithmically. The largest change occurs shortly after manufacture 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 in such a way that the frequency can always be tuned back to nominal over the useful life of the product. Parts with tight aging 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 suitable to drive the next stage. Please check what input signal (levels, wave shape) will give the best phase noise / EVM performance with the chip set manufacturer.
- Rakon recommends Pluto+ for best phase noise performance.
- Use a low-noise power supply regulator with  $< 20 \mu\text{V}$  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 powerline with a  $100 \Omega + 1 \mu\text{F}$  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 a note of the serial number of the TCXO (i.e. the marking) used for Type Approval as the manufacturer will have to provide Medium Term Stability (MTS) data for comparison with the MTS of the finished beacon. Make sure the class of the TCXO matches the class of the beacon (NB If the application requires it, Rakon is able to offer a TCXO with an extended operating temperature range beyond that which is required by Cospas-Sarsat Class 1 & 2 profiles). Make sure the nominal frequency of the oscillator is suitable for the channel currently open for qualification of new beacons.

Do not exceed the supply voltage range as stated in the specification. It is recommended to assess how the supply voltage of the finished product changes over time.

Thermal shock test performance is dependent on the thermal characteristics of the beacon itself, i.e. how fast the external temperature shock is passed on to the oscillator. For first generation beacons it is best to make the temperature change happen as quickly as possible (let the temperature settle within 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 TCXO and environment and adds thermal mass which dampens small temperature variations. However for second generation beacons this may not be the optimum thermal position, as the beacon is active in seconds. The standard second generation beacon oscillator specification has been established to meet the EVM requirements, so long as the temperature movement of the oscillator inside the beacon is less than  $10^\circ \text{C}/\text{minute}$ , under thermal shock conditions. Therefore it may be necessary to thermally insulate the oscillator from the outside of the beacon for second generation beacons compared to first generation. If the maximum rate of temperature change of the oscillator in the beacon is greater than  $10^\circ \text{C}/\text{min}$  then please consult Rakon for options.

Structural differences in the relative positioning and different attachment method of the ASIC in the  $5 \times 3.2$  vs the  $7 \times 5$  package lead to the  $5 \times 3.2$  having a significantly greater sensitivity to heat sources either due to conduction, convection or radiant energy. To minimise thermal gradient effects the oscillator should be positioned so that conduction of heat from heat sources on the same PCB to the oscillator is low, and shielded from both convection of air flow around the device, and incident radiant energy upon it. Techniques such as, the splitting of earth and power planes to reduce conduction, and the use of a RF shield to eliminate both convection and radiant energy can be very effective in this regard.

If certain circuitry is switched on intermittently this could generate enough heat to disturb the thermal balance causing the MTS to fail. Keep such circuitry away from the oscillator area.

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