Technical note

Sigfox oscillator device recommendation design

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GLOSSARY

PA: Power Amplifier

AT CUT:

The commercial designation for a specifically oriented resonator plate, having desirable and repeatable operating characteristics. The "AT cut" is the most popular thickness-shear crystal unit manufactured today.

PCB: Printed Circuit Board

pF: pico Farad

ppb: 1Part Per billon

ppm: 1 Part Per million

RC: Radio Configurations (sigfox zones depending on frequencies)

RF: Radio Frequency

RX: Reception

SPI: Serial Peripheral Interface

TCXO: Temperature Compensated X (Crystal) Oscillator

TX: Transmission

1. GENERAL INFORMATION

1.1 Sigfox technology

The SIGFOX technology is based on a software defined network providing a cognitive behavior. This means the network does not impose any form of synchronization or heavy requirement to the terminals, but "discovers" their appearance in the monitored spectrum and "adapts" as much as possible to their imperfections, at least up to a certain level that are the published "limits".

As this note is focusing on master crystal oscillator, it can therefor be assumed the following statements:

- Absolute frequency accuracy is not of a high importance, as long as the signal is within the monitored spectrum
- SIGFOX allows up to +/-20 ppm frequency inaccuracy
- Aging must be considered more from a device failure perspective than from a pure detuning stand-point – Crystal aging quickly are overdriven and thus highly susceptible of breakage over time, which is particularly important regarding quality for "long term service devices"
- Dynamic drift (frequency drift during operation, TX frames, RX vacation… Etc) is partly compensated by the network signal processing, so that drift figures below the ppb of typical medium to high grade TCXO's are not needed. However, SIGFOX relies on devices exhibiting dynamic drifts below few tens of ppb's. This can be considered as reasonable, not only for basic TCXO's, but also for simple non-compensated crystal oscillators. This is important as crystal oscillators exhibiting higher drifting rates betrays dangerous design flaws with undirect serious consequences for product quality and durability:
    - Overdrive of the crystal, once again leading to medium or long term fatal failure

- Over-exposure to quick temperature change, also leading to potential fatal failure, particularly for low duty cycle devices… which is often the case of IoT devices.
- Over-exposure to electromagnetic aggression, leading to quality degradation (remodulation effects, brutal phase changes…)

1.2 Purpose of document

This document describes the best solutions for the oscillator design of a Sigfox device's radio part.

The following questions can help facilitate selection of the optimal crystal for the application:

• What frequency is needed?

• What is the maximum drift the system can tolerate over its expected lifetime of operation?

• What is the typical temperature range of operation?

• How much stability over temperature is required?

• What is the load capacitance of the board?

• What is the layout ?

2. CRYSTAL PARAMETTERS

2.1 Final product considerations

According to the specifications of the final product, these crystal or TCXO parameters will be define by:

- Temperature stability @temperature range
- Aging (depends on the life of the product)
- Frequency tolerance @ambient temperature

Sigfox requires +/- 20 ppm for operational bands (with frequency calibrated at 25°C : offset = zero)
For example for RC1 "Sigfox Verified™ Modem Specification for RC1-UDL-ENC" document at https://resources.sigfox.com/document/test-procedure-rc1 : see the others RC on same site.

These 20 ppm are managed by the Sigfox system (network + Firmware library) .
This requirement respects the ETS 300-220.
• Static Frequency Tolerance: precision is not so important if this parameter is calibrated in factory setting in order to cancel this static imprecision.
• Temperature Frequency tolerance added to Aging frequency tolerance must be less or equal to +/- 20 ppm during all the product life.
All other system can be used if the global imprecision is +/- 20 ppm for operational bands all over the product life.

2.2 Parameters adapted to the transceiver

Some parameters of the crystal used by the transceiver to be defined:

- **Frequency**
- **Drive level.**

An important factor that can affect drift is how hard the crystal is being driven. Overdriving can arise when a crystal is driven higher than originally anticipated. The harder a crystal is driven over its rated maximum drive power (typically measured in µW), the faster it will age.
The effects of overdriving can be significant, causing the crystal to age in a month what it would have aged in a year at its rated drive power.
Too much overdrive may heat the crystal which causes a drift frequency.

For example: 800mVpp for oscillation amplitude and 240µA for Current override.

Crystal Drive level 10µW Typ., 200µW Max.

- **Crystal equivalent series resistance: 50 ohms for example.**

The lower the equivalent series resistance, the faster the quartz will start up.

- **Parallel resonant crystal mode.**

AT cut for example, it provides excellent temperature performance for a wide range of frequencies. It is, however, sensitive to mechanical stresses.

It is recommended to use the fundamental mode rather than the overtone mode.

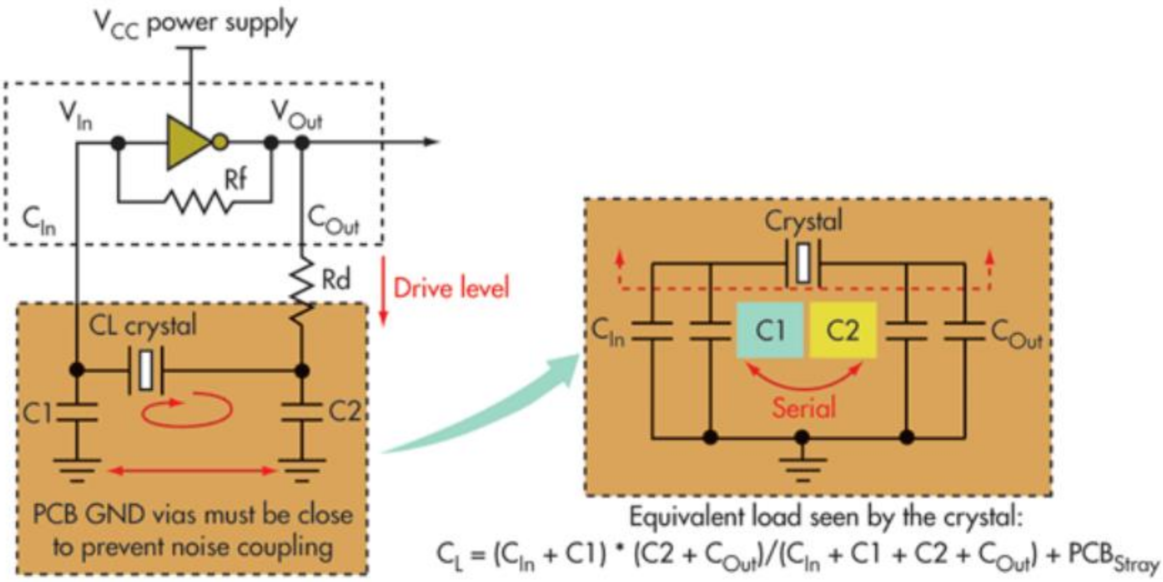
- **Load capacitance (CL)**

When specifying a crystal, it needs to be matched to the load that will be present.

While this load comprises capacitive, resistive, and inductive components, the capacitive load affects frequency and, therefore, drift the most.

The lower the capacitors, the faster the quartz will start up.

External capacitor around crystal can be calculated as follows:



PCB stray is the parasitic component of the layout that can be of some pF.

3. COMPONENT PLACEMENT

The crystal and 2 capacitors should be **positioned as close as possible to the transceiver** to minimize unwanted parasitic elements (capacitor, resistor, inductor).

Additionally, **all digital signals**, such as the SPI clock, **should be shielded from the crystal ground area** to suppress crosstalk by using a ground signal trace (digital ground) between the digital trace and the ground free space around the crystal.
This will suppress crosstalk which can produce receiver errors. All signals should have a **parallel ground trace in very close proximity**, or alternatively **be "covered" by a ground plane** on the back-side of the PCB.

4. TEMPERATURE CONSIDERATIONS

Place the crystal away from elements that vary in temperature (PA, supply voltage regulator…).
In case of designing an external power amplifier it is strongly recommended to separate the amplification from the reference frequency crystal.
It is possible to reduce the thermal effect especially in presence of air flow by adding thermal gap pad to insulate the crystal stage from the external air flow, but **beware the pad has a parasitic capacitance and can generate spurious on the output carrier.**

5. RADIATIVE CONSIDERATIONS

Isolate the crystal from any element radiating radio or magnetic waves: inductors, antenna, amplifiers ....
You can use separate shields between the parts that can radiate powerfully and the oscillator part.

6. MICROPHONICS EFFECTS

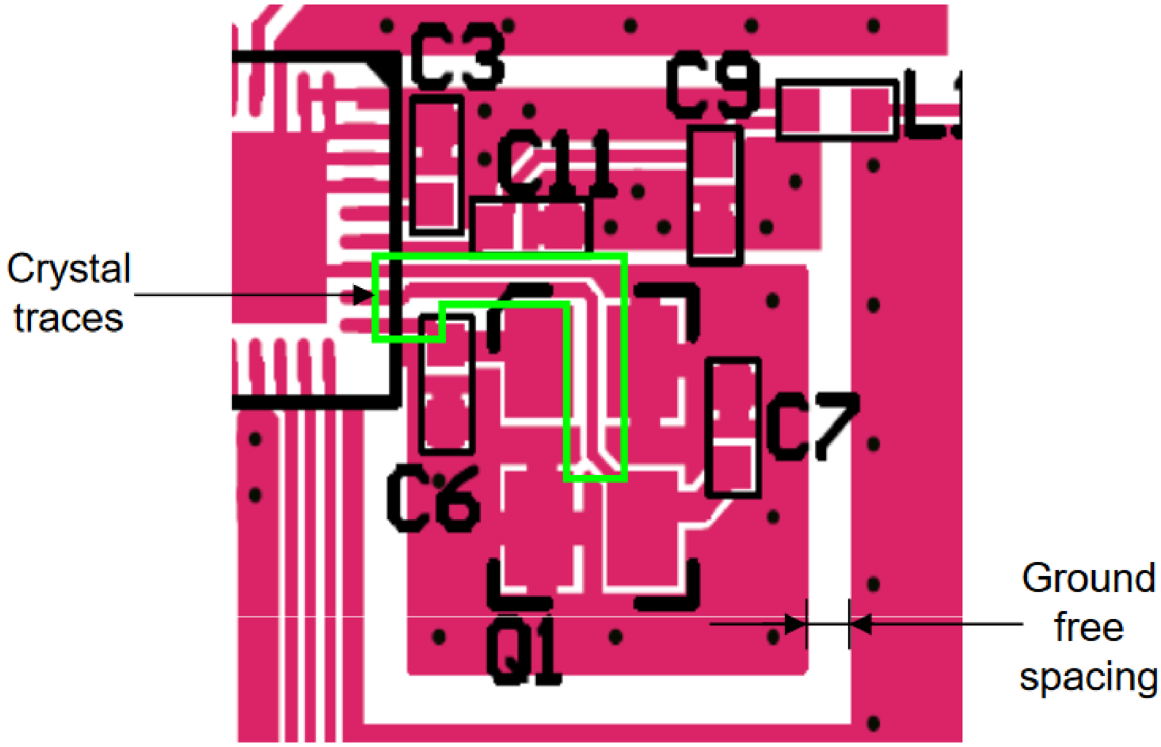
In case of objects that are exposed to vibration constraints such as motor sensors, mobile equipment, the crystal can be modulated by the frequency of the vibration or the movement. This will affect the synthesis by adding additional spurious around the main carrier and can also degrade the modulation if the frequency is very low.

It is important to take care of these phenomena during the design phase.

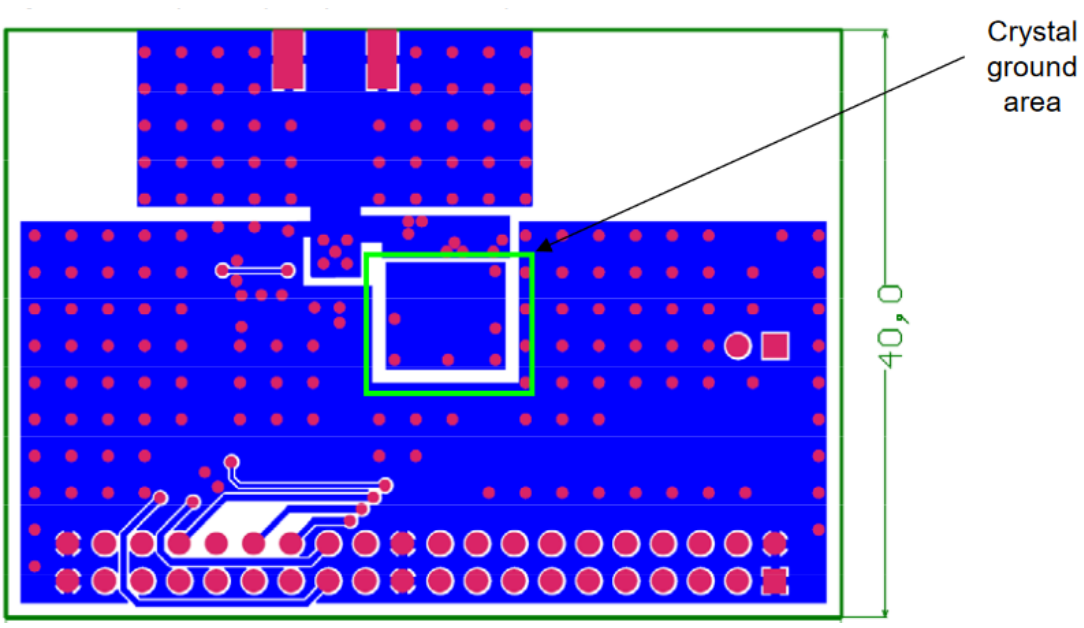
It is possible to reduce this effect by adding vibration damper to the PCB or the electronic section.

7. LAYOUT

The crystal ground must be analog ground of the transceiver, NOT RF ground. If RF ground is used this will inject transient into the RF ground and affect the RF performance.



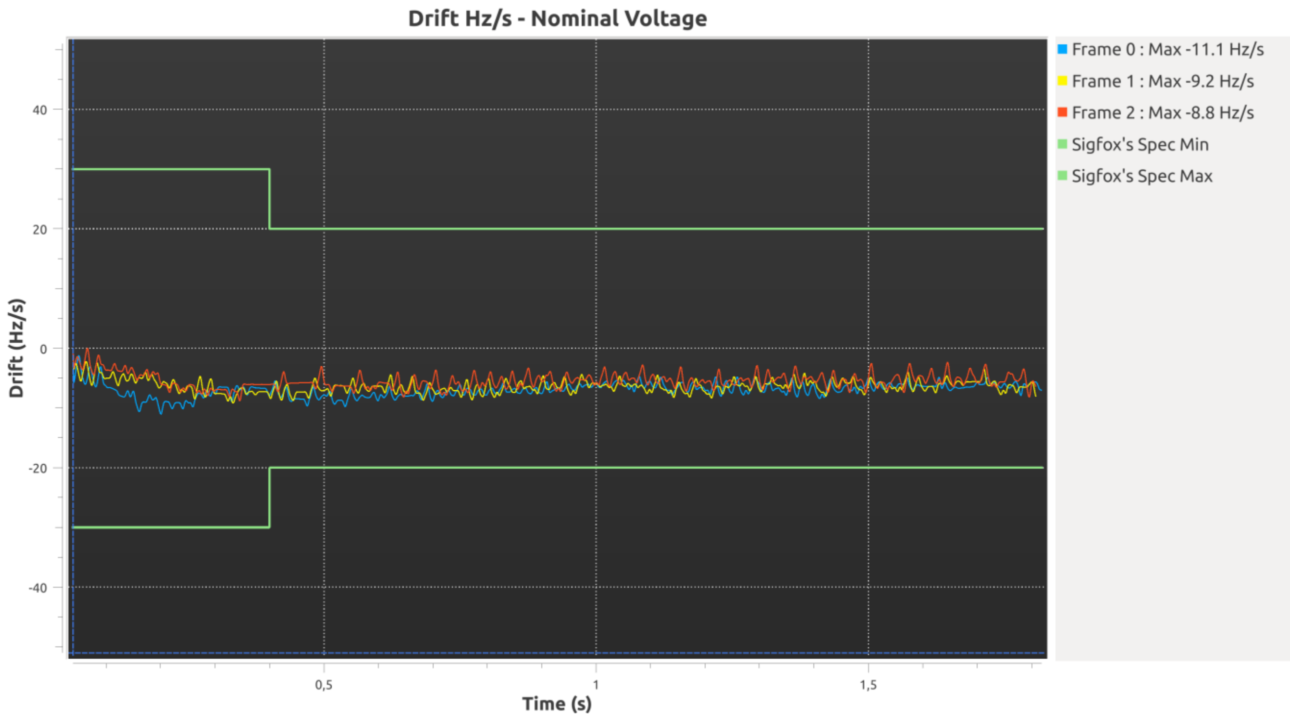
Top view



Bottom view (back-side)

8. DRIFT

The sigfox certification request a drift minimum, according to the zones, to the passage in the emission which can be in transient of 30hz/s during 320ms for RC1, RC3, RC5 and in established mode of 20hz/s during 1.76s for RC2 and RC4.



Vibration caused by acceleration and movement, for example, affects drift in part per billion range (ppb). Given the magnitude of other sources of drift, vibration is not a concern for most applications.

Typically, the most significant environmental factor affecting drift for developers to consider is the crystal temperature variation.

To create a better thermal inertia, the crystal ground pins must be well connected to the PCB ground if possible without PCB thermal pads.

If thermal pad is necessary, as seen in § 4, beware it has a parasitic capacitance and can generate spurious on the output carrier.

Quartz oscillator tests and measurements shall be carried out in an atmosphere protected from any airflow that could disturb and affect drift.

9. OSCILLATOR START-UP

Most transceivers have a sleep mode. It is better to use this mode rather than switch off the power supply of the circuit because waking will be faster and cause less drift.

To be compliant with this specification, it may be necessary to wait until the oscillator is stable before transmission.

10. CONCLUSION

These different design tips should enable a more robust product that is compatible with sigfox's requirements.

MEMS technology can also present a good alternative for devices.