White Paper

Crystal Solutions for Low Power Applications

The Internet of Things [IoT] is the new wireless touchstone connecting live information, control mediums and hubs to wireless devices such as phones, tablets and computers. These applications are widely used in Smart Homes, Smart Cities, Smart Factories, Smart Healthcare, Smart Agriculture and Smart Energy. Communication protocols and transmission frequencies are guided by standards such as IPv6, UDP, QUIC, Aeron and uIP. As a result, next generation MCUs, SoCs or FPGAs created to meet new communication requirements have challenged chipset designers to develop architectures that provide improved fast communication along with low noise performance, but also at low power consumption. Utilizing low power elements helps continuous operation over long periods of time, but also increase challenges like reductions in oscillator gain margin and signal to noise ratios.

Currently there are billions of connected IoT devices. An exponential increase of connected devices is expected over the next decade, as 5G infrastructures will be readily available along with more affordable consumer devices. The seemingly limitless connections promised by 5G will continue to burden infrastructures and push the boundaries of chipset performance, requiring the timing block and associated frequency reference to provide very reliable low power operation.

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Low Power Requirements & Gain Margin G_M

Advanced IoT chipsets utilizing oscillator designs with lower gain margins [G_M] require crystals with low equivalent series resistance [ESR] and low plating capacitance [C_0], to ensure quick start-up over wide temperature ranges and low battery power levels.

The RF function, or timing block, of many chipsets [MCUs, FPGAs, and SOCs] uses an on-chip Pierce oscillator configuration to generate the reference clock frequency. Typically this block is an inverter amplifier that drives the resonant loop completed by the addition of an external crystal resonator [Y_1] and two load capacitors [C_{L1}, C_{L2}], Figure 1. An additional feedback resistor may be included to help stabilize the DC operating point.

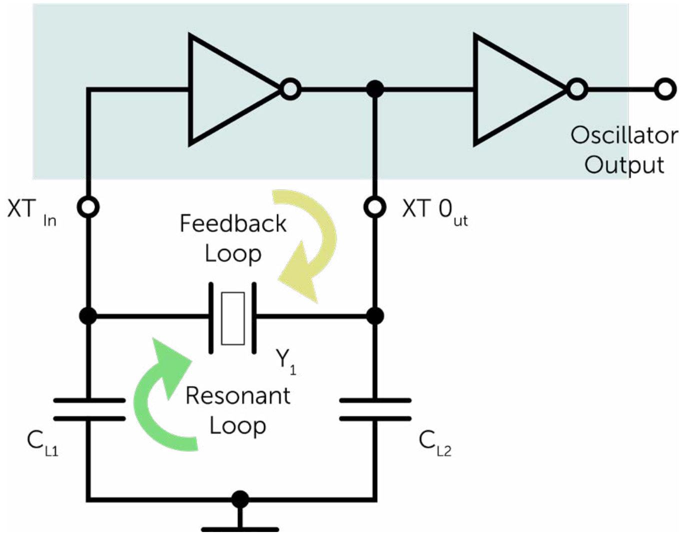


Figure 1: Pierce Oscillator

Using the inverter amplifier's transconductance value, provided by the chipset manufacturer, the gain margin G_M of the reference clock completed by the amplifier feedback loop and crystal resonant loop can be calculated. **See figure 1 as reference.**

To safeguard proper operation of the crystal resonant circuit under all environmental conditions, the gain margin G_M [or safety factor] should be greater than 3.0 minimum with a target goal of greater than 5.0.

$$G_M = g_m/g_{m[minimum]}$$

g_m = inverter amplifier transconductance, in mA/V or μA/V

$g_{m[minimum]}$ = limit of transconductance value that ensures proper oscillation, in mA/V or μA/V

The equivalent circuit values of the crystal also affect the gain margin GM and are accounted for with the following calculation. **See Figure 2 as reference.**

$$g_{m[minimum]} = 4*R_1*[2\pi f]2*[C_0+C_L]2$$

R_1 = motional series resistance of crystal [ESR]

C_0 = shunt capacitance of crystal [electrode and package capacitance]

C_L = plating load capacitance of crystal

Through this formula and assuming a fixed value for gm of the chipset's inverter amplifier, it shows the only way to increase gain margin G_M is to decrease the value of gm[minimum]. The typical value for C_0, of crystals developed for low power operation, is less than 3.0pF, making $g_{m[minimum]}$ dependent on the value of R_1 and the selected load capacitance C_L. CTS IoT Enhanced crystals [4xxW Series] are designed and processed with the lowest series resistance values, while coupled with small load capacitance options, securing a safe gain margin G_M that supports low power consumption and reliable operation over all conditions of a customer application.

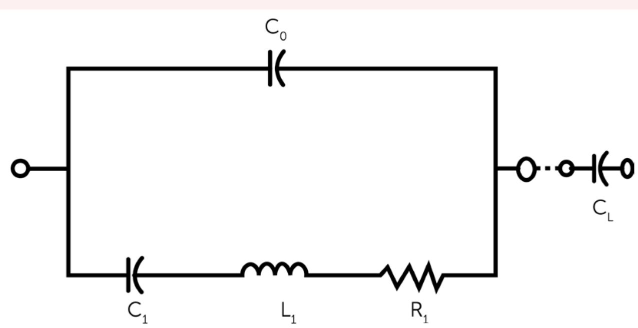


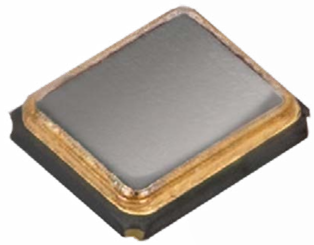
Figure 2: Crystal Equivalent Circuit

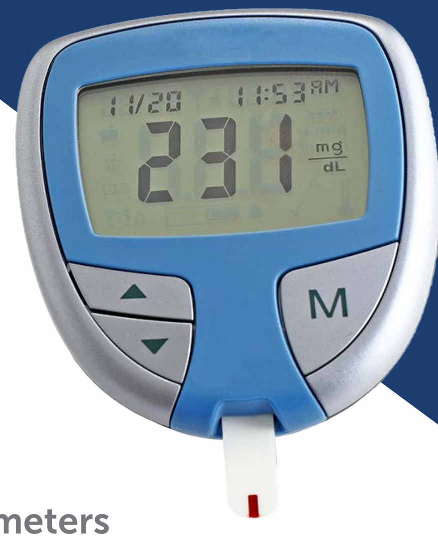
CTS IoT Frequency Reference Portfolio

MCUs, FPGAs or SOCs containing the RF function previously described are typically used to transmit and receive a wide variety of information through wireless protocols. These chipsets require a reference crystal in the MHz range to complete the oscillator circuit that provides the main system data clock signal. In addition, the chipset may also contain a real time clock reference [kHz crystal] for timekeeping functions. To support next generation chipsets for IoT, CTS has developed crystal families that have required performance attributes previously outlined.

IoT Enhanced Crystals [4xxW Series]

New CTS models [412W, 416W, 402W, 425W, 403W] provide enhanced design parameters targeted for low power wireless protocols used in IoT enterprises for consumer and industrial [IIoT]. These include operating temperature range to -40°C to +125°C, tight tolerance and stability options, low plating capacitance, small load capacitance values and a variety of industry standard package sizes.





Key 4xxW Crystal Parameters

- Low Plating Capacitance [C_0], <3.0pF
- Low ESR Ranges [R_1]
- Small Load Capacitance Options [C_L]
- Temperature Range to -40°C to +125°C
- Stability Options – ±10ppm to ±150ppm
- Fundamental Crystal Designs
- Small Ceramic Surface Mount Package
- Tape and Reel Packaging

Model/ Data Sheet	Package Size [mm]	Frequency [MHz]	Tolerance @ +25°C	Temperature Stability	Temperature Range	ESR Maximum [Ohm]	C_0 Parameters [pF]
412W	1.2 x 1.0	32 – 80 Fundamental	±7ppm - 30ppm	±10ppm - 100ppm	-40°C to +85°C -40°C to +105°C -40°C to +125°C	100 – 60	1.0 Typ. <3.0 Max.
416W	1.6 x 1.2	24 – 52 Fundamental	±10ppm - 30ppm	±10ppm - 100ppm	-40°C to +85°C -40°C to +105°C -40°C to +125°C	150 – 80	1.0 Typ. <3.0 Max.
402W	2.0 x 1.6	16 – 52 Fundamental	±10ppm - 30ppm	±10ppm - 100ppm	-40°C to +85°C -40°C to +105°C -40°C to +125°C	150 – 50	1.0 Typ. <3.0 Max.
425W	2.5 x 2.0	16 – 52 Fundamental	±10ppm - 30ppm	±10ppm - 100ppm	-40°C to +85°C -40°C to +105°C -40°C to +125°C	100 – 40	1.0 Typ. <3.0 Max.
403W	3.2 x 2.5	10 – 54 Fundamental	±10ppm - 30ppm	±10ppm -100ppm	-40°C to +85°C -40°C to +105°C -40°C to +125°C	150 – 35	1.0 Typ. <3.0 Max.

Low ESR Tuning Fork Crystals @ 32.768kHz

Many of today's electronic devices require some form of timekeeping that include current time, calendar events or processing scheduled tasks. Keeping track of time and organizing multiple tasks such as taking measurements, monitoring communications and wake-up on demand surveillance; real time clock references [RTC] at 32.768kHz provide a cost effective solution that support such critical functions.

Portable or handheld electronics use low power FPGAs and microcontrollers [MCUs] to preserve battery life for long hours of operation. Operating at voltage levels below +1.5V require crystals with low ESR to ensure crystal start-up and minimize current consumption during wake-up on demand operations. CTS Low ESR Series Tuning Fork Crystals, offer resistances as low as 50k ohms maximum, a classic parabolic temperature curve with -0.035ppm/°C^2 temperature coefficient, +25°C turnover point, standard load capacitance options and are available in three industry standard ceramic package size options; 3.2mmx1.5mm [TFE32], 2.0mmx1.2mm [TFE20] and 1.6mmx1.0mm [TFE16].

Key TFE Crystal Parameters

- Low Plating Capacitance [C_0], 1.0pF Typical
- Low ESR Values [R_1] <50k Ohms
- Small Load Capacitance Options [C_L]
- Temperature Range to -40°C to +85°C
- Small Ceramic Surface Mount Package
- Tape and Reel Packaging

Model/ Data Sheet	Package Size [mm]	Frequency [MHz]	Tolerance @ +25°C	Temperature Stability	Temperature Range	ESR Maximum [Ohm]	C_0 Parameters [pF]
TFE16	1.6 x 1.0	32.768kHz Tuning Fork	±20ppm	-0.034ppm/°C^2 Temp Coefficient	-40°C to +85°C	60k	1.5 Typ.
TFE20	2.0 x 1.2	32.768kHz Tuning Fork	±20ppm	-0.034ppm/°C^2 Temp Coefficient	-40°C to +85°C	50k	1.8 Typ.
TFE32	3.2 x 1.5	32.768kHz Tuning Fork	±20ppm	-0.034ppm/°C^2 Temp Coefficient	-40°C to +85°C	50k	1.0 Typ.

CTS | Connect | CTS Crystals

RTC TCXO @ 32.768kHz

For applications the need a more precise 32.768kHz reference, common for GPS functions, the CTS RTC solution is Model TT32 TCXO. TT32 operates with a maximum current draw of 1.5µA @ +3.3V and delivers a very tight frequency stability at ±5.0ppm over -40°C to +85°C; for accurate time keeping over variations in temperature; when compared to simple crystal devices that utilize tuning fork resonators. TT32's low power consumption is important for preserving battery life of portable or handheld electronics employing low power FPGAs and microcontrollers [MCUs]. It will also help minimize current consumption during wake-up on demand operations.

Key TT32 TCXO Parameters

- Low Current Consumption, <2µA
- Tight Frequency Stability, ±5.0ppm
- Temperature Range to -40°C to +85°C
- Small Ceramic Surface Mount Package
- Tape and Reel Packaging

Model/ Data Sheet	Package Size [mm]	Frequency [MHz]	Input Voltage [V]	Temperature Stability	Temperature Range	ESR Maximum [µA]	Output Load [PF]
TT32	3.2 x 2.5	32.768kHz HCMOS	+1.8V - +3.3V	±5.0ppm	-40°C to +85°C	2.0	15

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Low Power Wireless Application Examples

Smart Home

Security System

Application: Video Surveillance

Device: TI CC3220 SimpleLink Wi-Fi. **See Figure 3**

Frequency Reference: **Crystal 1** – CTS PART NUMBER TFE322P32K7680R

[32.768kHz, ±20ppm Tolerance, ±150ppm Stability, -40°C to +85°C, 50k Ohms Maximum ESR]

CTS Advantage: Small Size, Low ESR

Frequency Reference: **Crystal 2** – CTS PART NUMBER 425WF40011IKR

[40MHz, ±10/10±ppm Tolerance/Stability, -40°C to +85°C, 8pF C_L, 25 Ohms typical 40 Ohms maximum ESR]

CTS Advantage: Small Size, Low ESR, Low C_0, Customization Available

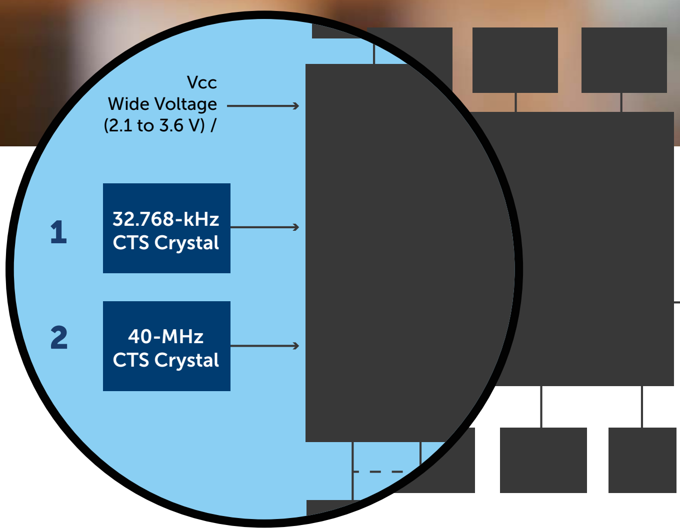

Figure 3: TI CC3220x Block Diagram

See the CTS quick page

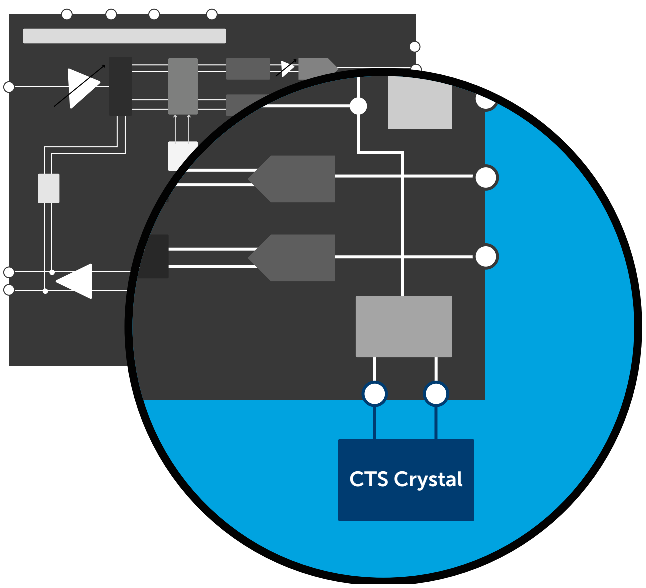

Figure 4: Semtech S1257 Block Diagram

See the CTS quick page

Smart Agriculture

RFID Cow Ear Tag

Application: LoRa Gateway

[wireless wide area network, bi-directional communication between a device and a gateway]

Device: Semtech SX1257 RF Front-End Transceiver. **See Figure 4**

Frequency Reference: Crystal – CTS PART NUMBER 402WF3201XIAR

[32MHz, ±10/±15ppm Tolerance/Stability, -40°C to +85°C, 10pF C_L, 30 Ohms typical 60 Ohms maximum ESR]

CTS Advantage: Small Size, Low ESR, Low C_0, Customization Available

Common Wireless Frequencies

Frequency	Wireless Protocol	CTS Solutions
32.768kHz	Real Time Clock Reference [RTC]	TFE16 TFE20 TFE32
12.00MHz	CAN Bus, USB	403W
13.56MHz	RFID	
16.00MHz	Wi-Fi, ZigBee, Bluetooth, Bluetooth Low Energy	403W 425W 402W
19.20MHz	DECT, GPS, Bluetooth Low Energy	
20.00MHz	Wi-Fi, Bluetooth, USB	
24.00MHz	Wi-Fi, Bluetooth, Bluetooth Low Energy	403W 425W 402W 416W
25.00MHz	Industrial, Scientific, Medical Radio Band	
26.00MHz	WLan, Wi-Fi, Bluetooth, Bluetooth Low Energy, GSM, Near-Field Communication	
27.12MHz	RFID	
30.00MHz	Industrial, Scientific, Medical Radio Band	
32.00MHz	ZigBee, Bluetooth, Bluetooth Low Energy, 6LowPan, RF4CE, LoRa	403W 425W 402W 416W 412W
37.40MHz	Wi-Fi, Bluetooth	
38.40MHz	DECT, Wi-Fi, Bluetooth	
40.00MHz	Wi-Fi, Bluetooth, Bluetooth Low Energy, Near-field Communication, SimpleLink	
48.00MHz	Wi-Fi, Bluetooth, USB	
52.00MHz	WLan, Wi-Fi, GSM	

Conclusion

The Internet of Things is an infinite space that will continue to grow, connecting and communicating a myriad of devices and is only limited by human imagination and innovation. As low power operational boundaries are pushed, design risks will more than ever need to be reviewed and accounted for during development of the chipset RF function and associated frequency reference, in order to provide robust user devices with long-lasting reliable operation.

More Information:

https://www.ctscorp.com/connect_product_line/clock-oscillators/
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