Application Note

CC31xx and CC32xx Frequency Tuning

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ABSTRACT

RF systems are dependent on accurate clocks for correct operation. A deviation in clock frequency is reflected as a deviation in radio frequency. This deviation can degrade RF performance, violate regulatory requirements, or lead to a nonfunctioning system.

An accurate clock requires careful selection of the crystal as well as external loading capacitors. This application report describes details of crystal specifications, recommendations for loading capacitor selection, board layout guidelines, frequency measuring technique, and crystal tuning technique.

Table of Contents

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1 Crystal Oscillator Basics

To support the understanding of the trade-offs when selecting a crystal for the CC3xxx devices, this section explains the fundamentals of crystals and oscillator operations.

Section 2 explains the important aspects characteristics of a crystal to select the appropriate crystal. However, to have a more in-depth understanding of the trade-offs when selecting a crystal, it is recommended to comprehend the fundamentals of crystals and oscillator operations (see [1]).

1.1 Crystal Oscillator Model

A crystal-based oscillator is formed by placing a crystal in the feedback loop of an oscillator circuit that provides sufficient gain and phase shift around the loop to start and sustain stable oscillations. A simplified electric model of a crystal is shown in Figure 1-1.

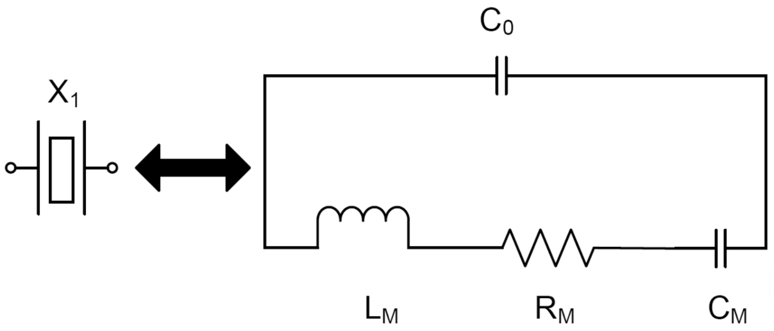

Figure 1-1. Crystal Symbol and the Electrical Model

It has R-L-C series components, called motional resistance (Rm), motional inductance (Lm), and motional capacitance (Cm). The capacitor in parallel, C0, is called the shunt capacitance, and models the package capacitance.

2 Crystal Selection

To select the optimal crystal for the CC31xx and CC32xx devices, it is recommended to take into account:

- Crystal Mode of Operation
- Temperature Tolerance
- Aging (Long-Term Stability)
- Crystal ESR
- Frequency Accuracy

2.1 Crystal Mode of Operation

The recommended oscillation mode of operation for the crystal is the fundamental mode. This simplifies the resonant circuit that is required for the crystal. In addition, fundamental crystals typically have lower equivalent series resistance (ESR) than third overtone crystals.

2.2 Temperature Tolerance

Temperature tolerance, or frequency stability, refers to the allowable deviation from nominal crystal frequency over a specified temperature range. This deviation is measured from the nominal frequency at 25°C.

2.3 Aging (Long-Term Stability)

Aging refers to the cumulative change in frequency of oscillation experienced by a crystal over time. Excessive drive level, various thermal effects, wire fatigue and frictional wear can exacerbate aging effects. Aging rates are stated in ppm per year units.

2.4 Crystal ESR

The Equivalent Series Resistance (ESR) is the resistance the crystal exhibits at the series resonant frequency. Since shunt capacitance (C_O) is typically on the order of 1 pF and usually $C_L >> C_O$, ESR is approximately R_M for many crystals, sometimes ESR is approximated as motional resistance.

2.5 Frequency Accuracy

Frequency accuracy represents the maximum deviation of the reference frequency. The total tolerance of the frequency accuracy of a crystal is dependent on several factors:

- Production tolerance (*Tolinitial*)
- Temperature tolerance (*Toltemp*)
- Aging effects (*Tolage*)
- Frequency pulling of the crystal due to mismatched loading capacitance (*Tolpull*)

When selecting a crystal consider the mentioned parameters. Equation 1 gives the total crystal tolerance.

$$\mathrm{Tol}_{\mathrm{total}} = \mathrm{Tol}_{\mathrm{initial}} + \mathrm{Tol}_{\mathrm{temp}} + \mathrm{Tol}_{\mathrm{age}} + \mathrm{Tol}_{\mathrm{pull}}\ (\mathrm{ppm}) \tag{1}$$

The unit ppm, which is an abbreviation of parts per million, is used to describe the accuracy of a frequency. The ppm is a value that represents the part of a whole number in units of 1/1000000 (100 ppm= .01%). The total tolerance value is in parts per million (ppm) and can be found in the crystal data sheet of the crystal manufacturer.

The CC31XX and CC32XX require crystals for a 32.768-kHz and 40.0-MHz frequency with accuracy of ±150 ppm and ±25 ppm, respectively. Section 2.7.1 has the complete crystal specifications.

Note

Frequency pulling may not appear in the crystal data sheet and can be calculated. For more information, see 1.

2.6 Drive Level

The maximum drive level of a crystal is often specified in the data sheet of the crystal in µW. Exceeding this value can damage or reduce the lifetime the crystal. A higher total capacitance load and ESR require more power to drive the crystal, increasing the power consumption of the oscillator.

2.7 Selecting a crystal

This section presents some important considerations when selecting crystals for the CC31xx and CC32xx. Selecting a crystal for a specific application will depend on the following three factors:

- Size (footprint area and height)
- Performance (accuracy over temperature, lifetime, power consumption, and start-up time)
- Cost

Consider the following when selecting a crystal:

- Crystals must be selected to meet requirements listed in the CC31xx and CC32xx data sheets or specifications.
  - ESR must not be greater than can be driven by CC31xx and CC32xx.
  - Capacitive loading (C_L) and frequency tolerance (ppm) must meet the specifications of the standard used (for example, Wi-Fi®).
- Some other considerations when selecting a crystal include the following:
  - To improve start-up time and reduce power consumption, the crystal must have the following:
    - Low-capacitive loading, at the expense of greater susceptibility to frequency variation caused by the environment (C_L)
    - Low-motional inductance (L_M)
    - Low-motional resistance (R_M)

2.7.1 Crystal Specifications

When selecting a crystal, keep in mind the respective specifications mentioned in the device's data sheets. Table 2-1 and Table 2-2 show the slow and fast clock respective specifications for only 2.4 GHz Wi-Fi.

Table 2-1. CC31xx and CC32xx RTC Crystal Requirements

Characteristics	Test Conditions	Min	Typ	Max	Unit
Nominal frequency			32.768		kHz
Frequency accuracy	Initial + temperature + aging			±150	ppm
Crystal ESR	32.768 kHz			70	kΩ

Note that low-frequency tuning fork crystals have a resonance frequency that changes with temperature with a parabolic coefficient of (–0.04 × 10e^6) / °C2 typically. Figure 2-1 shows an example of this, where it can be seen that a 40-ppm accuracy is maintained only from –10°C to 50°C.

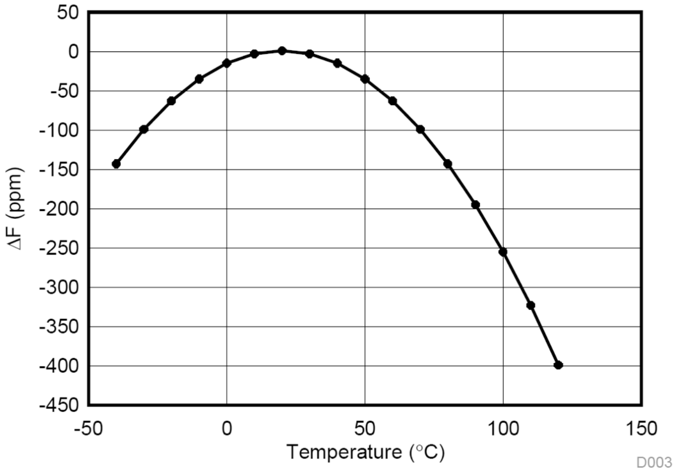

Figure 2-1. Frequency vs Temperature Curve for a 32.768-kHz Tuning Fork Crystal

Table 2-2. CC31xx and CC32xx 2.4GHz only WLAN Fast-Clock Crystal Requirements

Characteristics	Test Conditions	Min	Typ	Max	Unit
Nominal frequency			40		MHz
Production Tolerance (Intial Torance)				±10	ppm
Load Capacitance (CL)			8		pF
Temperature Stability				±10	ppm
Aging	Assuming 5-year life			±5	ppm
Frequency accuracy	Initial + temperature + aging			±25	ppm
Crystal ESR	40 MHz	40	50	60	Ω

Table 2-3 shows the fast clock specifications for 2.4 GHz and 5 GHz Wi-Fi.

Table 2-3. CC31xx and CC32xx for 2.4 GHz and 5GHz WLAN Fast-Clock Crystal Requirements

Characteristics	Test Conditions	Min	Typ	Max	Unit
Nominal frequency			40		MHz
Production Tolerance				±5	ppm
Load Capacitance (CL)			8		pF
Temperature Stability				±15	ppm
Aging	Assuming 5-year life			±3	ppm
Frequency accuracy	Initial + temperature + aging			±20	ppm
Crystal ESR	40 MHz			40	Ω

Note

When using devices CC3135 or CC3235 for frequency bandwidth 5 GHz the crystal specifications will differ to than for 2.4Ghz, since more precision is needed.

2.7.2 Recommended Crystals for the CC31xx and CC32xx

Table 2-4 and Table 2-5 provide the recommended crystals to use for the CC31xx and CC32xx devices.

Table 2-4. 32.768-kHz Crystals Suitable for CC31xc and CC32xx

MnF	MPN	ESR max [kΩ]	CL [pF]	Tol [ppm]	Temp tol [ppm]	Temp Range [deg C]
Abracon Corporation	ABS07-32.768KHZ-9-T	70	9 pf	±20 ppm	±20 ppm	-40°C ~ 85°C
Abracon Corporation	ABS07-32.768KHZ-T	70	12.5 pF	±20 ppm	±30 ppm	-40°C ~ 85°C

Table 2-5. 40-MHz Crystals Suitable for CC31xx and CC32xx

MnF	MPN	ESR max [Ω]	CL [pF]	Tol [ppm]	Temp tol [ppm]	Temp range [deg C]
Epson	Q24FA20H00396	40	8 pF	±30 ppm	±30 ppm	-40°C to 85°C
Abracon Corportation	ABM3-16.000MHZ-D2Y-T	40	18 pF	±20 ppm	±30 ppm	-40°C to 85°C

3 Crystal Tuning

Based on the PCB trace capacitance and the crystal used on the final product, the shunt caps on the crystal may need to be adjusted in order to make sure the net capacitance load is exactly what is required.

The devices require two separate clocks for its operation:

- A slow clock running at 32.768 kHz which is used for the RTC.
- A fast clock running at 40 MHz that is used by the device for the internal processor and the WLAN subsystem.

3.1 The importance of Crystal Tuning

The WLAN standard for 802.11b/g (see [2]) specifies the maximum frequency error to be within ±25 ppm. Beyond this, the device may have difficulty in interoperability with multiple access points. Hence, it is important to restrict the frequency error for the 40 MHz crystal to a small value, and ensure that the average frequency error across multiple boards is centered around 0 ppm.

3.2 Load Capacitance

The load capacitance (C_L) refers to the net capacitance in the oscillator feedback loop. The correct load capacitance is essential to ensure the oscillation frequency of the crystal is within the expected range. The load capacitance is equal to the amount of capacitance seen between the crystal pins, and it includes the shunt capacitors added on the board, the PCB trace parasitic capacitance, the component pad capacitance, device pin capacitance, and so forth.

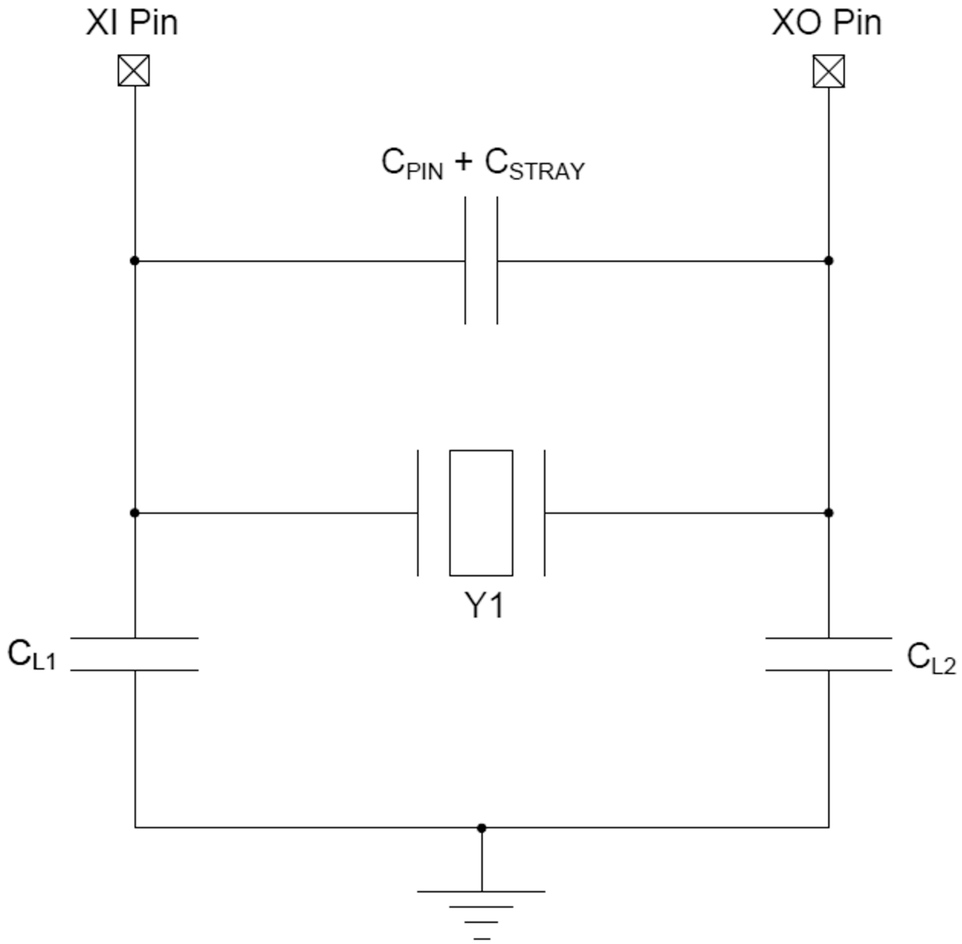

Figure 3-1. Simplified Crystal Equivalent Load Capacitance Circuit

Figure 3-2 illustrates a typical crystal oscillator circuit and sources of load capacitance. The total load capacitance includes discrete load capacitors (C_{L1} and C_{L2}), device pin capacitance (C_{PIN}), and stray board capacitance (C_{STRAY}). It is important to account for all sources of capacitance when calculating value for the discrete capacitor components, C_{L1} and C_{L2}, in Equation 2 for a specific board design.

$$C_L = \frac{(C_{L1} \times C_{L2})}{(C_{L1} + C_{L2})} + C_{PIN} + C_{STRAY} \tag{2}$$

These capacitors, with any parasitic capacitance in the PCB and the crystal terminals, compose the total load capacitance (C_L) that helps set the crystal resonance frequency. The crystal data sheet provides the optimum load capacitance C_L for the crystal. This total C_L typically consists of both the loading capacitors and the parasitic capacitance of the layout and packaging.

The following presents the relative advantages of crystals with different C_L values. The disadvantages of lower C_L are as follows:

- Crystals with C_L < 8-pF are more difficult to source with short lead times
- Frequency becomes more sensitive to changes in board capacitance as C_L decreases.
- Lowering C_L results in degraded RF phase noise.

Advantages of lower C_L are as follows:

- Lower C_L causes a much faster start-up time. (Start-up time goes as)
- Lower C_L causes a faster amplitude control loop response time.
- Lower C_L makes it easier to use small size crystals (2.0 × 1.6 and so on) and maintain a start-up time at or less than 400 µs. Start-up time worsens with smaller crystals due to an increase in LM.

3.3 Crystal Tuning With C_L

To achieve the specified frequency from a crystal, the net capacitance load should exactly match the specified load capacitance, C_L, of the crystal. If the crystal specifies C_L = 8 pF, then each capacitor on the crystal pin would be 16 pF (equal to 2 x 8 pF) as the capacitors would be in series. Out of this 16 pF, account for 2 to 3 pF for the board parasitic. Then, the CC31xx/CC32xx device input has 5 to 6 pF per pin. This calls for a total added capacitor of 7-9 pF on each pin. Fine tune the C_L based on the transmitted (TX) output frequency.

For example when using the recommended crystal "Q24FA20H00396", with specified C_L of 8 pF, it would resonate at 40 Mhz accurately only when the net capacitance between the "XI Pin" and "XO Pin" pins is accurately 8 pF.

Keep in mind that the capacitance moves away from 8 pF in temperature changes, thus the frequency error will also change. A typical plot indicating the ppm error with variation in C_L is shown in Figure 3-2.

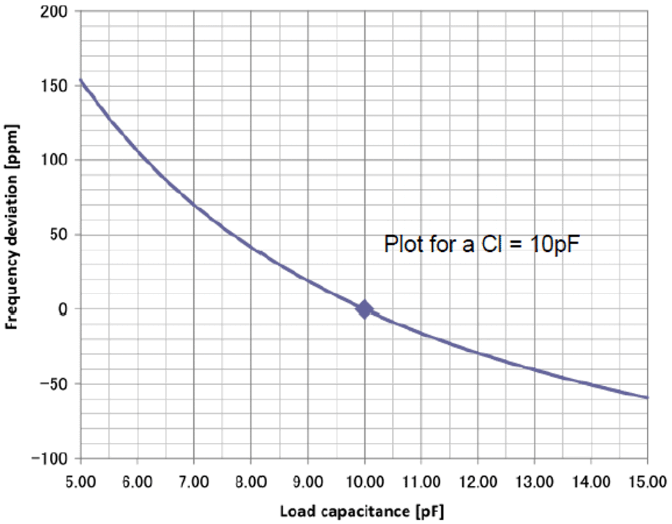

Figure 3-2. Frequency Error vs. Load Capacitance

Note

Never tune the crystal by monitoring the crystal itself. Loading the crystal with an oscilloscope probe will reduce the frequency of oscillation.

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4 Measuring the ppm Error for the Fast Clock (High Frequency)

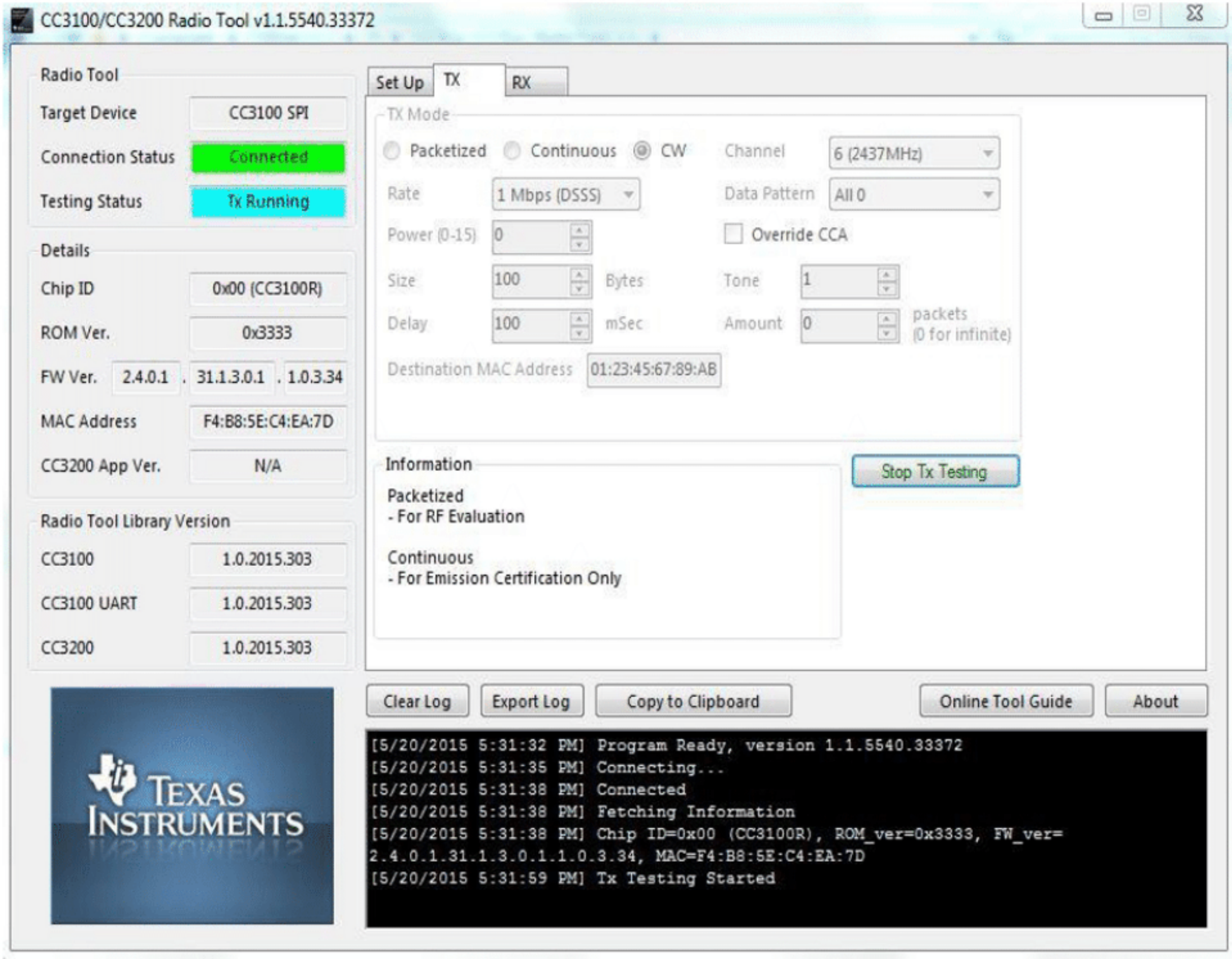
The crystal frequency must never be measured directly because the measurement resolution is typically not sufficient to calculate the frequency deviation to within a few ppm for measuring the CC31xx and CC32xx 40 MHz Fast Clock. A spectrum analyzer or frequency counter, with either using a stable reference, must be used to measure frequency. The correct procedure would be to use Radio Tool to transmit a signal and then evaluate the frequency using the spectrum analyzer.

The mentioned SimpleLink™ Wi-Fi Radio Tool is a Microsoft Windows-based software application with graphical user interface for RF Evaluation and testing the CC31xx and CC32xx designs during development and certification. The tool enables low-level radio testing capability by manually setting the radio into transmit mode or receive mode. It also provides device information for hardware and software version checking.

4.1 Setting Up for the CC3x00 Devices

In order for Radio Tool to operate this tool correctly, the devices need to be flashed with the correct firmware. For instructions on how to flash firmware onto the device, see the SimpleLink Wi-Fi CC3100, CC3200 UniFlash User's Guide 13.

For CC3100 and CC3200 devices, make sure to download and install the SimpleLink Wi-Fi radio testing tool for CC3100 and CC3200. For instructions on the installation process, see the CC3x20, CC3x35 SimpleLink Wi-Fi and Internet-on-a chip™ Solution Radio Tool [15].



Target Device: CC3100 SPI
Connection Status: Connected
Testing Status: Tx Running

Chip ID: 0x00 (CC3100R)
ROM Ver.: 0x3333
FW Ver.: 2.4.0.1 . 31.1.3.0.1 . 1.0.3.34
MAC Address: F4:B8:5E:C4:EA:7D
CC3200 App Ver.: N/A

CC3100: 1.0.2015.303
CC3100 UART: 1.0.2015.303
CC3200: 1.0.2015.303

○ Packetized ○ Continuous ● CW
Channel: 6 (2437MHz)
Rate: 1 Mbps (DSSS)
Data Pattern: All 0
Power (0-15): 0
☐ Override CCA
Size: 100 Bytes
Tone: 1
Delay: 100 mSec
Amount: 0 packets (0 for infinite)
Destination MAC Address: 01:23:45:67:89:AB

Packetized
- For RF Evaluation

Continuous
- For Emission Certification Only

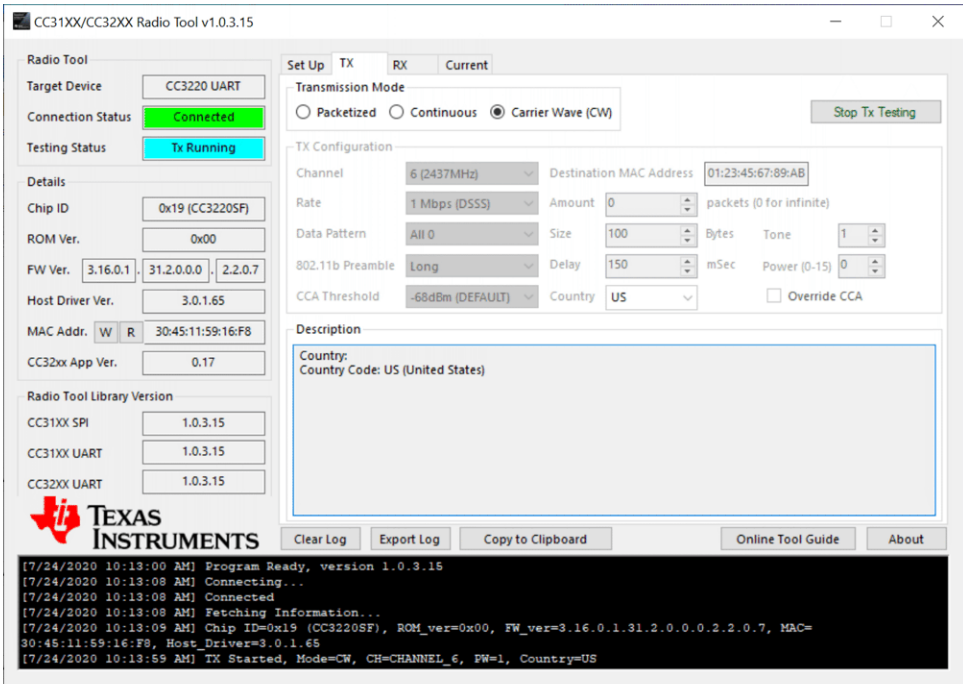
```
[5/20/2015 5:31:32 PM] Program Ready, version 1.1.5540.33372
[5/20/2015 5:31:35 PM] Connecting...
[5/20/2015 5:31:38 PM] Connected
[5/20/2015 5:31:38 PM] Fetching Information
[5/20/2015 5:31:38 PM] Chip ID=0x00 (CC3100R), ROM_ver=0x3333, FW_ver=
2.4.0.1.31.1.3.0.1.1.0.3.34, MAC=F4:B8:5E:C4:EA:7D
[5/20/2015 5:31:59 PM] Tx Testing Started
```

Figure 4-1. Setting Up for the CC3x00 Devices

4.2 Setting Up for the CC3x20 and CC3x35 Devices

In order for Radio Tool to operate correctly, the devices need to be flashed with the correct firmware. For instructions on how to flash firmware onto the device, see the *SimpleLink Wi-Fi CC31xx, CC32xx UniFlash User's Guide* [14].

For the CC3x20 and CC3x35 devices, make sure to download and install SimpleLink Wi-Fi radio testing tool for CC31xx and CC32xx. For instructions on the installation process, see the *CC3x20, CC3x35 SimpleLink Wi-Fi and Internet-on-a chip Solution Radio Tool* [15].



Target Device: CC3220 UART
Connection Status: Connected
Testing Status: Tx Running
Chip ID: 0x19 (CC3220SF)
ROM Ver.: 0x00
FW Ver.: 3.16.0.1 . 31.2.0.0.0 . 2.2.0.7
Host Driver Ver.: 3.0.1.65
MAC Addr. W R: 30:45:11:59:16:F8
CC32xx App Ver.: 0.17
CC31XX SPI: 1.0.3.15
CC31XX UART: 1.0.3.15
CC32XX UART: 1.0.3.15

Transmission Mode: ○ Packetized ○ Continuous ● Carrier Wave (CW)
Channel: 6 (2437MHz)
Rate: 1 Mbps (DSSS)
Data Pattern: All 0
802.11b Preamble: Long
CCA Threshold: -68dBm (DEFAULT)
Destination MAC Address: 01:23:45:67:89:AB
Amount: 0 packets (0 for infinite)
Size: 100 Bytes
Delay: 150 mSec
Country: US
Tone: 1
Power (0-15): 0
☐ Override CCA

Country:
Country Code: US (United States)

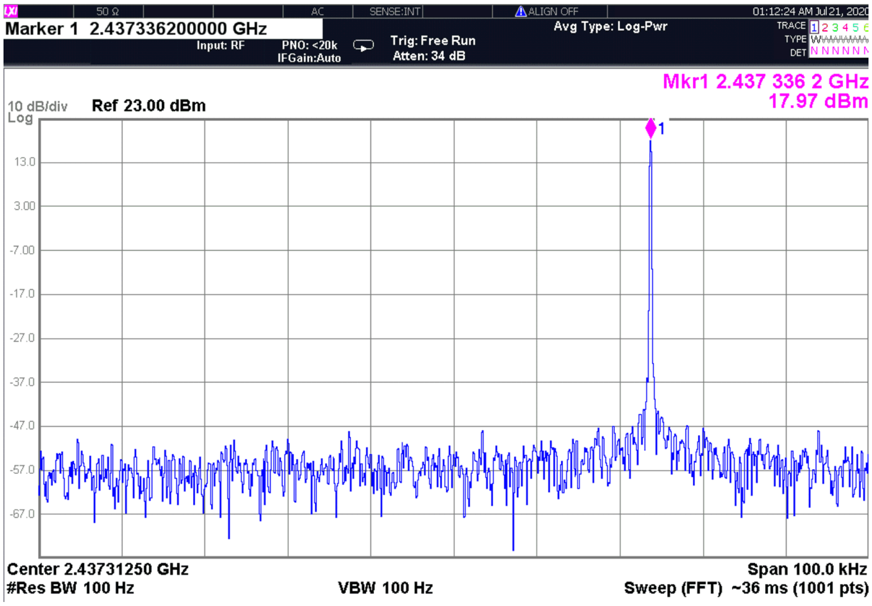
```
[7/24/2020 10:13:00 AM] Program Ready, version 1.0.3.15
[7/24/2020 10:13:08 AM] Connecting...
[7/24/2020 10:13:08 AM] Connected
[7/24/2020 10:13:08 AM] Fetching Information...
[7/24/2020 10:13:09 AM] Chip ID=0x19 (CC3220SF), ROM_ver=0x00, FW_ver=3.16.0.1.31.2.0.0.0.2.2.0.7, MAC=
30:45:11:59:16:F8, Host_Driver=3.0.1.65
[7/24/2020 10:13:59 AM] TX Started, Mode=CW, CH=CHANNEL_6, PW=1, Country=US
```

Figure 4-2. Setting Up for the CC3x20 and CC3x35 Devices

4.3 Measuring ppm Frequency Error

After flashing the device and running “RadioToolGUI.exe”, connect the device using Radio Tool. In the “TX” tab choose “CW” mode and select the “Tone” as 1, once you click “Start TX testing” the device will transmit a RF unmodulated sin wave. This RF signal will transmit at a Channel frequency + 312.5 KHz. For example, when on CH6, the sine wave would be at 2437.3125 Mhz.

Measure the actual frequency with the spectrum analyzer and the delta from the expected frequency gives the frequency error. For accurate measurement, set a low span in the spectrum analyzer, like 100 KHz and RBW of 100Hz. Ensure that there is minimum drift over a period of time.



Marker 1 2.437336200000 GHz
Input: RF
PNO: <20k
IFGain:Auto
Trig: Free Run
Atten: 34 dB
Avg Type: Log-Pwr
Mkr1 2.437 336 2 GHz
17.97 dBm
10 dB/div
Log
Ref 23.00 dBm
Center 2.43731250 GHz
#Res BW 100 Hz
VBW 100 Hz
Span 100.0 kHz
Sweep (FFT) ~36 ms (1001 pts)

Figure 4-3. Usign the Spectrum Analyzer to Measure the Frequency Error

Figure 4-3 shows using the spectrum analyzer to measure the frequency, 2437.3362 MHz at marker 1 when the expected frequency was 2437.3125MHz.

Thus the frequency error is 2437.3125 Mhz - 2437.3362 Mhz = -.0237 Mhz = -23.7 Khz

To convert this frequency error to ppm unit, the following equation is used:

$$\left[\frac{\text{Freq error}}{\text{expected frequency}}\right]\times 10^{6} \tag{3}$$

The example ppm would be: [0.0237 Mhz/ 2437.3125 Mhz]*10^6 = -9.724 ppm.

With that knowledge adjust the onboard shunt capacitance to bring the frequency error to as low value as possible (at 25°C). A positive ppm error (larger frequency) indicates you need to increase the capacitance and negative ppm error indicates you need to decrease the cap. Note that the two shunt caps effectively come is series. For fine adjustments, the two capacitors can have different values.

5 PCB Layout Guidelines

The layout of the crystal can reduce the parasitic capacitance and, more importantly, reduce noise from coupling on the input of the oscillators. Noise on the input of the oscillator can lead to severe side effects such as clock glitches, flash corruption, or system crashes because the CC31xx and CC32xx devices rely on the crystal oscillators for the systems fast and slow clock.

The following are a few general recommendations for the layout of the crystals:

- Place the crystal as close as possible to the device to minimize the length of the PCB traces. (This placement reduces crosstalk and minimizes EMI.)
- TI recommends a solid ground plane under the crystal.
- Ensure no high-speed digital signals are close to the crystal to minimize cross-coupling of noise into the oscillator.

Figure 5-1 shows the top layer of the layout of the CC32xx reference design. The bottom layer is a solid ground plane. For more details, see the *CC3235S/CC3235SF SimpleLink™ Wi-Fi® LaunchPad™ Design Files*, see [12]. The same crystal layout can be used with CC31xx device.

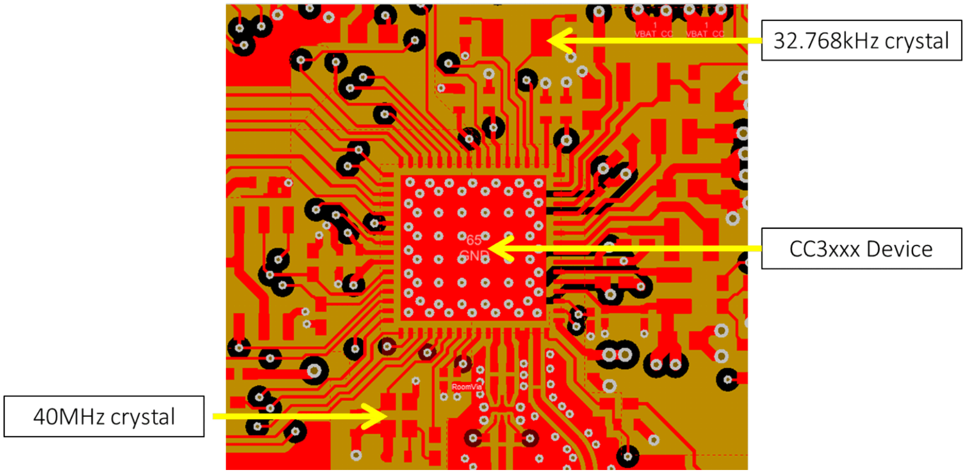


Figure 5-1. Layout of the CC32xx EVM

5.1 The 32.768-kHz Crystal (Slow Clock)

This crystal is used as the RTC, which supplies the free-running slow clock. The crystal requirements for the 32.768-kHz crystal oscillator can be seen in Table 2-1.

Below are the PCB gudelines for the slow clock:

- The 32.768-kHz crystal oscillator is used as the RTC, consequently it should be placed close to the VQFN package.
- Ensure that the load capacitance is tuned according to the board parasitic capacitance, thus ensuring the frequency tolerance is within ±150 ppm at room temperature, as described in Section 4.
- The ground plane on layer two is solid below the trace lanes, and there should be ground around these traces on the top layer, as shown in Figure 5-1.

5.2 The 40-MHz Crystal (Fast Clock)

The 40-MHz Crystal is used to produce the fast clock, which supports the frequency for the WLAN. The crystal requirements for the 32.768-kHz crystal oscillator can be seen in Table 3-1. Below are the PCB gudelines for the slow clock.

The crystal requirements for can be seen in Table 2-2 and Table 2-3.

- The 40 MHz crystal l should be placed close to the QFN package.
- Ensure the load capacitance is tuned based on the board parasitic, thus ensuring the frequency tolerance is within ±10 ppm at room temperature, as described in Section 3.
- The total frequency accuracy for the crystal across parts, temperature, and with aging, should be ±25 ppm to meet the IEEE WLAN standard for 802.11b/g.
- Ensure no high-frequency lines are routed closer to the crystal routing, to avoid any phase noise degradation.

6 References

1. Texas Instruments: *Crystal Oscillator and Crystal Selection for the CC26xx and CC13xx Family of Wireless MCUs*
2. IEEE Standard for Information technology—Telecommunications and information exchange between systems Local and metropolitan area networks—Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," in IEEE Std 802.11-2016 (Revision of IEEE Std 802.11-2012) , vol., no., pp. 2242, 14 Dec. 2016, doi: 10.1109/IEEESTD.2016.7786995.
3. Texas Instruments: *CC3100 and CC3200 SimpleLink™ Wi-Fi® and Internet of Things Solution Layout Guidelines User's Guide*
4. Texas Instruments: *CC3120 and CC3220 SimpleLink™ Wi-Fi® and IoT Solution Layout Guidelines*
5. Texas Instruments: *CC3x35 SimpleLink™ Wi-Fi® and IoT Solution Layout Guidelines*
6. Texas Instruments: *CC3100 SimpleLink™ Wi-Fi® Network Processor, Internet-of-Things Solution for MCU Applications Data Sheet*
7. Texas Instruments: *CC3200 SimpleLink™ Wi-Fi® and Internet-of-Things Solution, a Single-Chip Wireless MCU Data Sheet*
8. Texas Instruments: *CC3120 SimpleLink™ Wi-Fi® Wireless Network Processor, Internet-of-Things Solution for MCU Applications Data Sheet*
9. Texas Instruments: *CC3220R, CC3220S, and CC3220SF SimpleLink™ Wi-Fi® Single-Chip Wireless MCU Solutions Data Sheet*
10. Texas Instruments: *CC3100 SimpleLink™ Wi-Fi® Network Processor, Internet-of-Things Solution for MCU Applications Data Sheet*
11. *CC3235S and CC3235SF SimpleLink™ Wi-Fi®, Dual-Band, Single-Chip Solution Data Sheet*
12. Hardware design reviews for SimpleLink™ Wi-Fi devices. Retrieved from:
13. Texas Instruments: *CC3100 SimpleLink Wi-Fi Wireless Networking Solution Booster Pack Design Files*
14. Texas Instruments: *SimpleLink™ Wi-Fi® CC3100, CC3200 UniFlash User's Guide*
15. Texas Instruments: *CC3x20, CC3x35 SimpleLink™ Wi-Fi® and Internet-on-a chip™ Solution Radio Tool User's Guide*

For more device-specific PCB guidelines, see one of the following documents (depending on device):

1. For CC3x00, see the *CC3100 and CC3200 SimpleLink™ Wi-Fi® and Internet of Things Solution Layout Guidelines User's Guide*.
2. For CC3x20, see the *CC3120 and CC3220 SimpleLink™ Wi-Fi® and IoT Solution Layout Guidelines*.
3. For CC3x35, see the *CC3135 and CC3235 SimpleLink™ Wi-Fi® and IoT Solution Layout Guidelines User's Guide*.

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