Application Report
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TI 15.4-Stack Frequency Hopping Mode FCC Compliance

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ABSTRACT

The TI 15.4-Stack (included in the SimpleLink™ Sub-1 GHz CC13x0 software development kit [SDK] [(1)]) provides a Frequency Hopping (FH) MAC protocol to use with SimpleLink CC13xx wireless microcontroller (MCU)-based systems in enabling communication in the Federal Communications Commission (FCC) band (902 to 928 MHz). The FCC allows for a higher transmit power in this band when frequency hopping is used. FCC compliant frequency hopping allows deployments to use a higher transmit power in regions of the world that follow FCC regulations. This document explains how FCC compliance can be achieved with the TI 15.4-Stack specific to test cases related to frequency hopping feature.

Contents

(1) The SimpleLink CC13x0 SDK is part of the SimpleLink MCU platform which consists of Wi-Fi, *Bluetooth*® low energy, Sub-1 GHz and host MCUs, and offers a single development environment that delivers flexible hardware, software, and tool options for wired and wireless applications. All share a common, easy-to-use development environment with a single core SDK and rich tool set. A one-time integration of the SimpleLink platform lets you add any combination of devices from the portfolio into your design. The ultimate goal of the SimpleLink platform is to achieve 100 percent code reuse when your design requirements change. For more information visit www.ti.com/simplelink.

1 Keywords

- FCC Certification
- Frequency Hopping
- TI 15.4-Stack FH Mode

2 Abbreviations

- **FAN** — field area networks
- **FCC** — Federal Communications Commission
- **FH** — frequency hopping
- **MAC** — medium access protocol
- **Wi-SUN®** — Wireless Smart Utility Networks

3 FCC Compliance

The FCC regulates the transmit power to be used for different operating modes and spectrum in the regions of the world following FCC regulations. When a frequency-hopping scheme is used, the FCC allows the use of a higher transmit power (see Table 1) [1][2]. Higher transmit power enables a frequency-hopping solution to achieve up to 34 times more coverage and improved robustness to interference [3]. The compliance to these requirements is verified based on FCC compliance test procedures [5].

Table 1. FCC Regulation Summary

Number of Hopping Channels	Bandwidth	Maximum Allowed Time per Channel	Transmit Power
1 (no hopping)	—	—	–1.25 dBm
25 to 50	20 dB 250 KHz < BW < 50 KHz	No more than 0.4 s during a 10-s period	24 dBm
> 50	20 dB BW < 250 KHz	No more than 0.4 s during a 20-s period	30 dBm

4 Frequency-Hopping Mode Compliance

4.1 FH Mode

The TI 15.4-Stack from Texas Instruments™ provides a FH mode that uses unslotted frequency hopping technique based on Wi-SUN FAN [4]. The solutions allows nodes to hop on their own hopping sequence as shown in Figure 1. A hopping sequence involves the receiver listening on a specific channel for a period of time called dwell interval. The device shall then change its channel based on a channel hopping function every dwell interval that is unique to each device [4]. The nodes shall exchange their channel hopping sequence and other parameters required to track its hopping sequence during an initial join phase through asynchronous frame exchanges explained in [7]. The nodes shall also maintain synchronization with its neighbors based on timing information exchanged through information elements in different MAC frames [7]. A transmitter intending to transmit a frame shall first identify the channel at which its target node is currently listening and shall then transmit the frame on that channel as shown in Figure 2. The channel in which a data transmission shall occur is thus dependent on the listening channel of the receiver. The number of channels on which a node should hop and the period of time it should stay on a specific channel (dwell interval) can be configured to suit a specific application need.

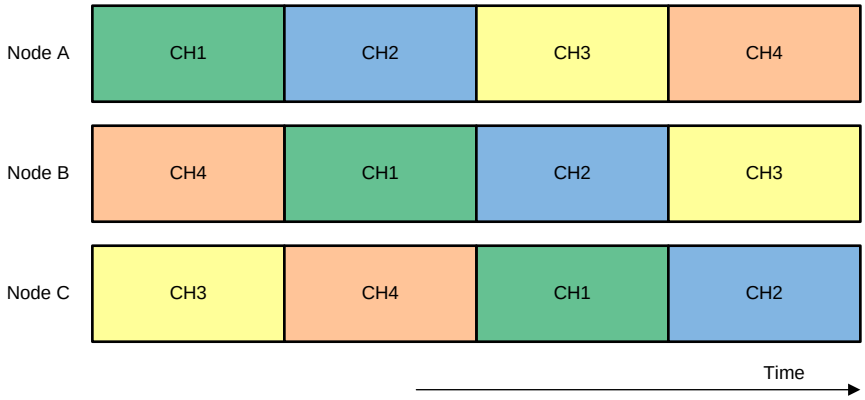

Figure 1. Unicast Hopping Sequence of Device

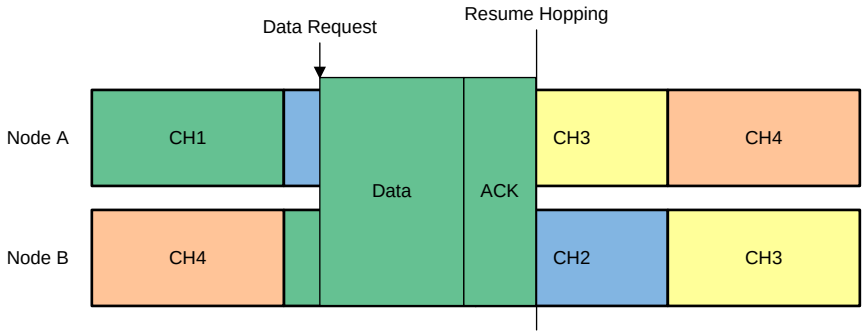

Figure 2. Data Exchange

4.2 Channel-Hopping Application Configuration

A typical application should ensure that its traffic profile and channel-hopping configuration ensures that the solution meets the FCC regulation requirements. The key requirements, detailed in Section 3, are:

- The system will use the hopping-channel carrier frequencies separated by a minimum of 25 KHz or the 20-dB bandwidth of the hopping channel, whichever is greater.
- The system will use at least 50 channels if the 20-dB bandwidth of the hopping channel is less than 250 KHz (TI 15.4-Stack software operates at less than 250-KHz bandwidth). The system shall not occupy more than 400 ms in average on any frequency within a 20-s period.

The hopping sequence of each node ensures that the channel chosen at each slot is random. The sequence can be approximated to occur based on uniform distribution and is independent of previous slots. The number of times a given channel shall appear on the listening hopping sequence can thus be considered to be binomially distributed.

Consider the following configuration (default TI 15.4-Stack software configuration):

- Dwell interview = 250 ms
- Number of channels = 129 (all channels are used)

This configuration implies that over a 20-s period, there will be 80 slots. Each slot can belong to a random channel that is independent of other slots. Considering binomial distribution with a probability of selecting a given channel as 1 / 129, the probability of having more than n slots with the same channel is presented in Table 2.

Table 2. Probability of Channel-Slot Occupancy

Number of Slots[1]	Probability (%)[2]
0	46
1	13
2	2.5
3	0.36
4	0.04

(1) The number of slots is represented by n.
(2) The probability of more than n slots selecting the same channel over a 20-s period, out of 80 slots.

For the default parameters, a given channel will not occupy more than four slots in a 20-s window with a 99.96% probability. Given that a channel should not be occupied for more than 400 ms over a 20-s period, the application profile must ensure that their duty cycle is such that it does not transmit more than 400 ms over four slots (40% duty cycle).

In general, considering any given dwell interval (D_I) and number of hopping channels (N_h):

- Number of slots over a 20-s period (N_S) = 20 s / D_I
- Probability of occurrence of a given channel (p) = 1 / N_h
- The probability that a given channel can occur more than n times is given by Equation 1.

$$P(x > n) = 1 - \sum_{k=0}^{n} \left(\frac{n}{k}\right) p^k (1-p)^{n-k} [6] \quad (1)$$

The number of effective slots (N_{eff}, the maximum expected number of slots on which a same channel can occur) should be determined such that P ($x > N_{eff}$) is at an acceptable low value. The application profile should then be chosen so the effective transmit time is less than 400 ms over N_{eff} × DI period, and that N_h is greater than 50 to meet FCC requirements.

5 FCC Compliance Frequency Hopping Specification

5.1 FCC Certification Mode Application Example

The TI 15.4-Stack provides an example application to perform FCC certification tests. In this example application, the sensor device will generate a packet (approximately 100 bytes) every 50 ms after association with the collector. The collector will not generate any application data traffic but shall continue to hop based on its channel hopping sequence. The transmissions from the sensor device have been used to perform the different tests explained in this section.

5.2 FCC Compliance Frequency Hopping Parameters

The following FCC compliance specification parameters were measured using TI's SimpleLink, Sub-1 GHz CC1310 wireless MCU LaunchPad™ development kit, Rev1.1 modules in a Lab environment at an ambient temperature. All of the measurements were done in a conductive method. The CC1310 LaunchPad is shown in Figure 3.

Figure 3. CC1310 LaunchPad™

Table 3 provides a summary of the test results.

Table 3. Summary of Test Results

Parameter	FCC Specification	Measurement Result (Typical)
20-dB bandwidth	< 250 KHz	101.4 KHz
Channel spacing	> 25 KHz or > 20 dB BW whichever is greater	200.3 KHz
Number of hopping channels	50 Minimum	129
Channel occupancy time per repetition	< 400-ms average within 20 s	57.9 ms (19.3 × 3) ms
Channel repetition rate		3 in 20 Sec 173.7 ms (60 × 3)

5.2.1 FCC Parameter Plots

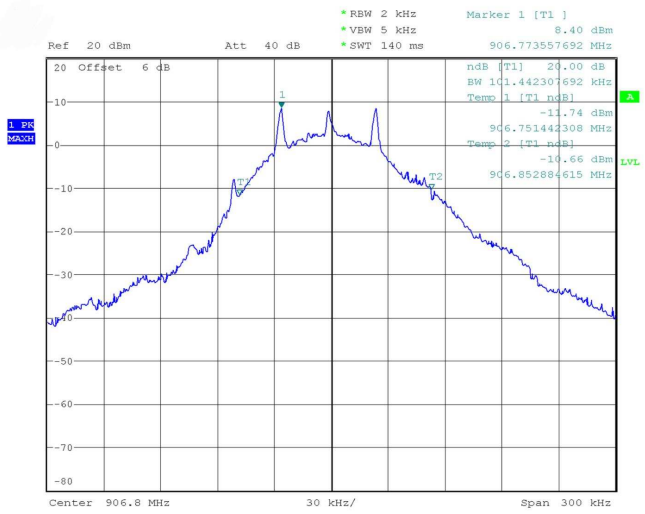

Figure 4. 20-dB Channel Bandwidth Plot

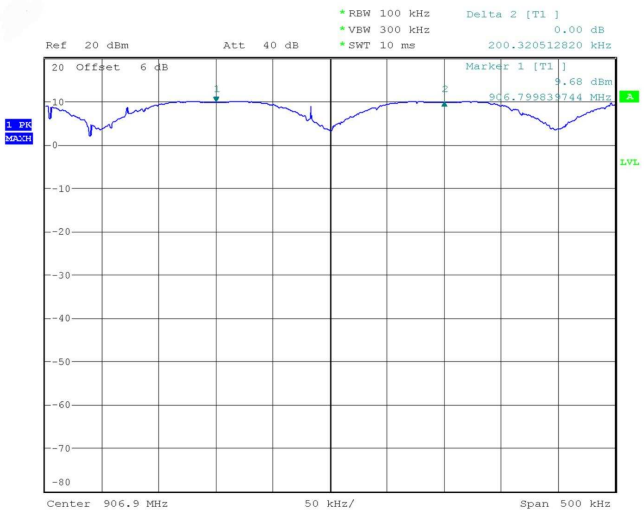

Figure 5. Channel Spacing Plot

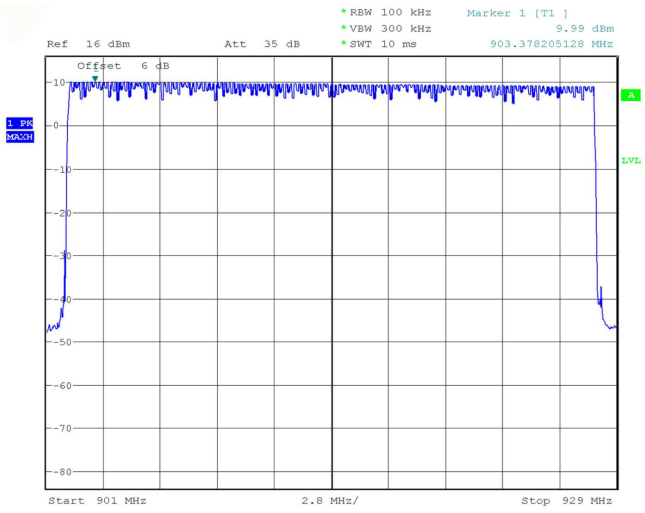

Figure 6. Number of Channels Plot

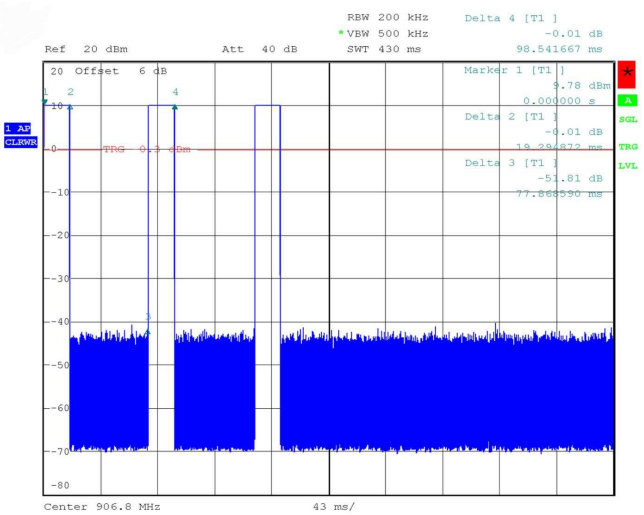

Figure 7. Channel Occupancy Time per Repetition

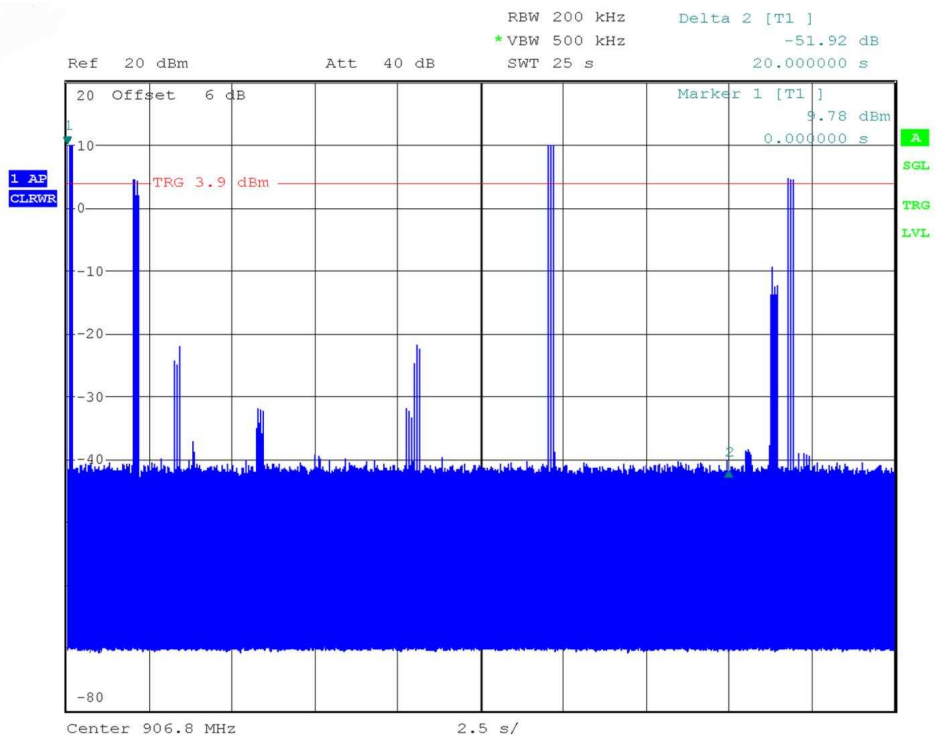

Figure 8. Channel Repetition Rate Plot

6 References

1. FCC Title 47, Telecommunication Part 248, *Code of Federal Regulations*
2. FCC Title 47, Telecommunication Part 247, CFR 15.247, *Code of Federal Regulations*
3. *Frequency hopping for long-range IoT networks* (SWRY025)
4. Wi-SUN FAN Specification v1.0, *Information About Field Area Networks*
5. C63.10-2013, *American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices*
6. *Binomial Distribution*
7. *CC13x0 SimpleLink™ TI 15.4-Stack Software Developer's Guide*
8. *SimpleLink Sub-1 GHz CC13x0 Software Development Kit*

Changes from December 2, 2016 to March 31, 2017 **Page**

- Changed the *References* section 6

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