

Using the S2-LP transceiver with FEM at 500 mW under FCC title 47 part 15 in the 902 – 928 MHz band

Introduction

The S2-LP very low power RF transceiver is intended for RF wireless applications in the sub-1 GHz band, designed to operate in both the license-free ISM and SRD frequency bands at 433, 868 and 920 MHz.

This application note outlines the expected performance when using the S2-LP under FCC title 47 part 15 in the 902–928 MHz band. There are no specific requirements in this band: no specific uses or channel spacing are defined.

For details on the regulatory limits in the 902–928 MHz frequency band, refer to FCC title 47 part 15: "Radio frequency devices" (available at www.scc-ares-races.org/FCCparttitles.html).

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1 An overview of FCC regulations

In the US, the Federal Communications Commission (FCC) regulates the use of frequencies for wireless communication with regulations codified in **Title 47** of the Code of Federal Regulations (CFR). **Part 15** of this code applies to radio frequency devices operating at unlicensed frequencies.

The 902–928 MHz frequency band is one of the Industrial, Scientific, and Medical bands in the US; for operation in this band, low power, non–licensed devices must meet one of the following regulation parts:

- **Part 15.243:** operation is restricted for devices to use radio frequency energy to measure the characteristic of a material. Voice communication or other data transmission is not permitted.
- **Part 15.245:** operation is limited to devices operating as field disturbance sensors, excluding perimeter protection systems.
- **Part 15.247:** Frequency Hopping and Digitally Modulated Intentional Radiators.
- **Part 15.249:** General Non–Licensed Intentional Radiators.

The S2-LP is concerned with Parts 15.247 and 15.249.

1.1 Part 15.247

Devices subject to FCC part 15.247 are limited to frequency hopping and digitally modulated schemes.

To comply with the frequency hopping system operating in the 902–928 MHz band, the device or system must meet the following requirements:

- Frequency hopping systems shall have hopping channel carrier frequencies separated by a minimum of 25 kHz or 20 dB bandwidth of the hopping channel, whichever is greater.
- The system shall hop to channel frequencies that are selected at the system hopping rate from a pseudo randomly ordered list of hopping frequencies. Each frequency must be used equally on the average by each transmitter.
- If the 20 dB bandwidth of the hopping channel is less than 250 kHz, the system shall use at least 50 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 20 second period; if the 20 dB bandwidth of the channel is 250 kHz or greater, the system shall use at least 25 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 10 second period. The maximum allowed 20 dB bandwidth of the hopping channel is 500 kHz.
- For systems employing more than 50 channels, the maximum peak conducted output power output is +30 dBm (1 W). For systems employing less than 50 channels but more than 25 channels, the maximum output power is +24 dBm (0.25 W).
- In any 100 kHz bandwidth outside the frequency band in which the spread spectrum or digitally modulated intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement, provided the transmitter demonstrates compliance with the peak conducted power limits. If the transmitter complies with the conducted power limits based on the use of RMS averaging over a time interval, the attenuation required under this paragraph shall be 30 dB instead of 20 dB.

- Radiated harmonic and spurious emissions which fall within the restricted bands, as defined in FCC Part 15.205 must comply with the radiated emission limits specified in FCC Part 15.209.

To be compliant with the digital modulation scheme, the devices or systems must meet the following requirements:

- The minimum 6 dB bandwidth of the signal shall be at least 500 kHz.
- The maximum permitted peak conducted output power is +30 dBm (1 W). However, the power spectral density conducted from the intentional radiator to the antenna shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission.
- In any 100 kHz bandwidth outside the frequency band of operation, the power shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power based on either an RF conducted or a radiated measurement, provided the transmitter demonstrates compliance with the peak conducted power limits. If the transmitter complies with the conducted power limits based on the use of RMS averaging over a time interval, the attenuation required under this paragraph shall be 30 dB instead of 20 dB.
- Radiated harmonic and spurious emissions which fall within the restricted bands, as defined in FCC Part 15.205 must comply with the radiated emission limits specified in FCC Part 15.209.

1.2 Part 15.249 operation within the bands 902–928 MHz

FCC Part 15.249 in the 902–928 MHz bandwidth does not enforce restrictions on either the modulation scheme or the end application.

Compliance with FCC Part 15.249 requires:

- The maximum permitted field strength is 50 mV/m. Since the field strength limits are specified at a distance of 3 m from the radiating source, this equates to a conducted power of about -1 dBm measured at the antenna port.
- The maximum permitted field strength of harmonic components is 500 μ V/m. This equates, at a 3 m distance, to a conducted power level of about -41 dBm measured at the antenna port.
- Radiated emission other than harmonics shall be attenuated by at least 50 dB below the level of the fundamental or to the general radiated emission limits in Part 15.209 section, whichever involves less attenuation.
- Part 15.31 duty cycle correction applies to pulse modulated transmitters and where an average limit for carrier or spurious field strength is specified.

1.3 Parts 15.205 and 15.209

As already described in the previous paragraphs, radiated harmonics and spurious emissions of devices that comply the part 15.247 which fall within the restricted bands, as defined in FCC Part 15.205, must comply with the radiated emission limits specified in FCC Part 15.209.

For any 100 kHz bandwidth outside the frequency band of operation and outside the restricted bands, the power shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power.

Devices operating under the part 15.249 are restricted to field strength emissions of the fundamental of 50 mV/m and harmonic emissions of 500 μ V/m measured at a distance of 3 m. This means approximately -1 dBm and -41 dBm respectively, when measured conducted into a 50 Ω load. Radiated emission other than harmonics shall be attenuated

by at least 50 dB below the level of the fundamental or to the general radiated emission limits in the 15.209 section, whichever is the lesser attenuation.

Part 15.205 shows the bands where only spurious emissions are permitted. The field strength of emissions appearing within these frequency bands shall not exceed the limits shown in Part 15.209.

Table 1: Restricted bands defined in the Part 15.205

MHz	MHz	MHz	GHz
0.090 – 0.110	16.42 – 16.423	399.9 – 410	4.5 – 5.15
0.495 – 0.505	16.69475 – 16.69525	608 – 614	5.35 – 5.46
2.1735 – 2.1905	16.80425 – 16.80475	960 – 1240	7.25 – 7.75
4.125 – 4.128	25.5 – 25.67	1300 – 1427	8.025 – 8.5
4.17725 – 4.17775	37.5 – 38.25	1435 – 1626.5	9.0 – 9.2
4.20725 – 4.20775	73 – 74.6	1645.5 – 1646.5	9.3 – 9.5
6.215 – 6.218	74.8 – 75.2	1660 – 1710	10.6 – 12.7
6.26775 – 6.26825	108 – 121.94	1718.8 – 1722.2	13.25 – 13.4
6.31175 – 6.31225	123 – 138	2200 – 2300	14.47 – 14.5
8.291 – 8.294	149.9 – 150.05	2310 – 2390	15.35 – 16.2
8.362 – 8.366	156.52475 – 156.52525	2483.5 – 2500	17.7 – 21.4
8.37625 – 8.38675	156.7 – 156.9	2690 – 2900	22.01 – 23.12
8.41425 – 8.41475	162.0125 – 167.17	3260 – 3267	23.6 – 24.0
12.29 – 12.293	167.72 – 173.2	3332 – 3339	31.2 – 31.8
12.51975 – 12.52025	240 – 285	3345.8 – 3358	36.43 – 36.5
12.57675 – 12.57725	322 – 335.4	3600 – 4400	Above 38.6
13.36 – 13.41			

Table 2: Radiated and conducted emission limits defined in the Part 15.209

Frequency [MHz]	Field Strength [$\mu\text{V/m}$]	Measurement Distance [m]	Conducted [dBm]
0.009 – 0.490	$2400/f$ [kHz]	300	$12.4 - 20 \cdot \log(f)$ kHz
0.490 – 1.705	$24000/f$ [kHz]	30	$12.4 - 20 \cdot \log(f)$ kHz
1.705 – 30.0	30	30	-46
30 – 88	100	3	-56
88 – 216	150	3	-52
216 – 960	200	3	-49
960	500	3	-41

2 Application circuit

The STEVAL-FKI915V1 application board is designed to evaluate the RF performance of the S2-LP transceiver in 890–915 MHz band. It is compatible with Arduino™ Uno R3 connector layout and allows expansion of the STM32 Nucleo boards.

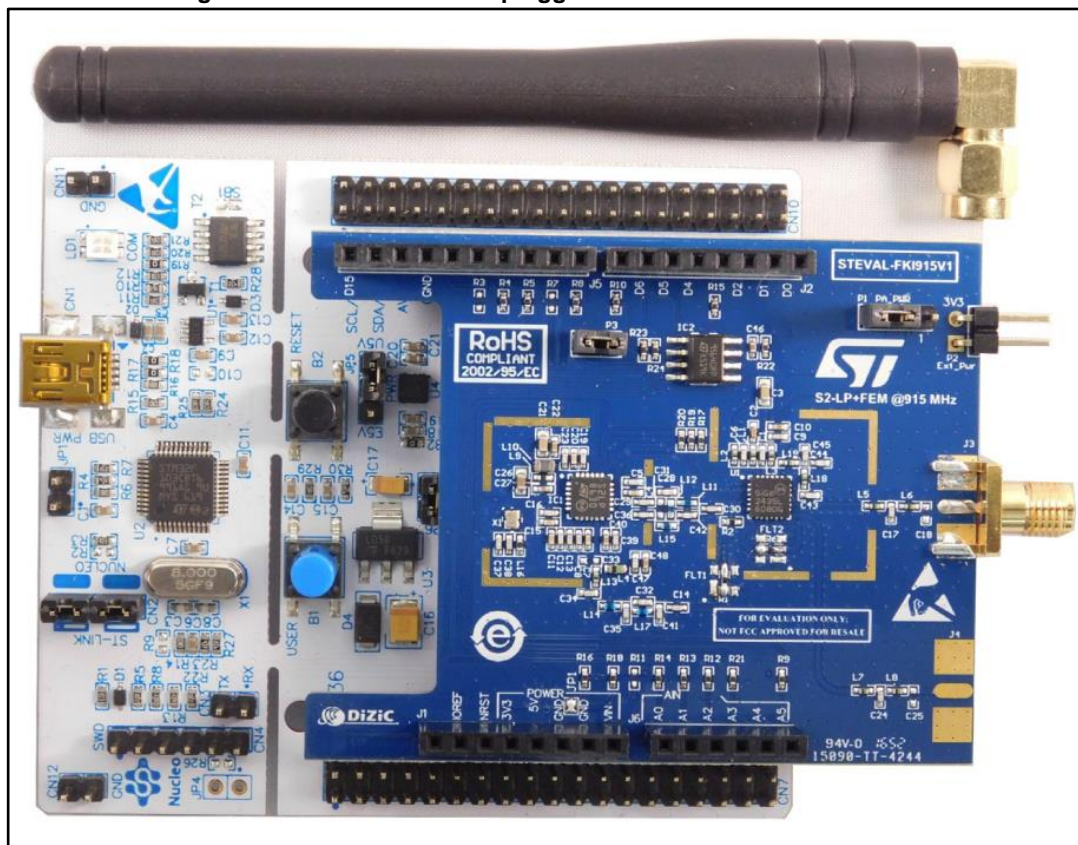
The S2-LP has an internal SMPS to drastically reduce power consumption, rendering the S2-LP the best in class for the application on this bandwidth. The SMPS is supplied by the battery (1.8 V to 3.6 V) and provides a programmable voltage from 1.1 V to 1.8 V (1.5 V typically). An SMA connector connects the board to the antenna or to instrumentation to verify correct operation and compatibility with the requested standards.

A few passive components (inductors and capacitors) are used as matching/filtering for the power amplifier (PA) and balun network for the receiver.

The STEVAL-FKI915V1 includes an 860–930 MHz High Power RF Front End Module (FEM) from SkyWorks®, which allows the application to achieve +27 dBm (500 mW) output power.

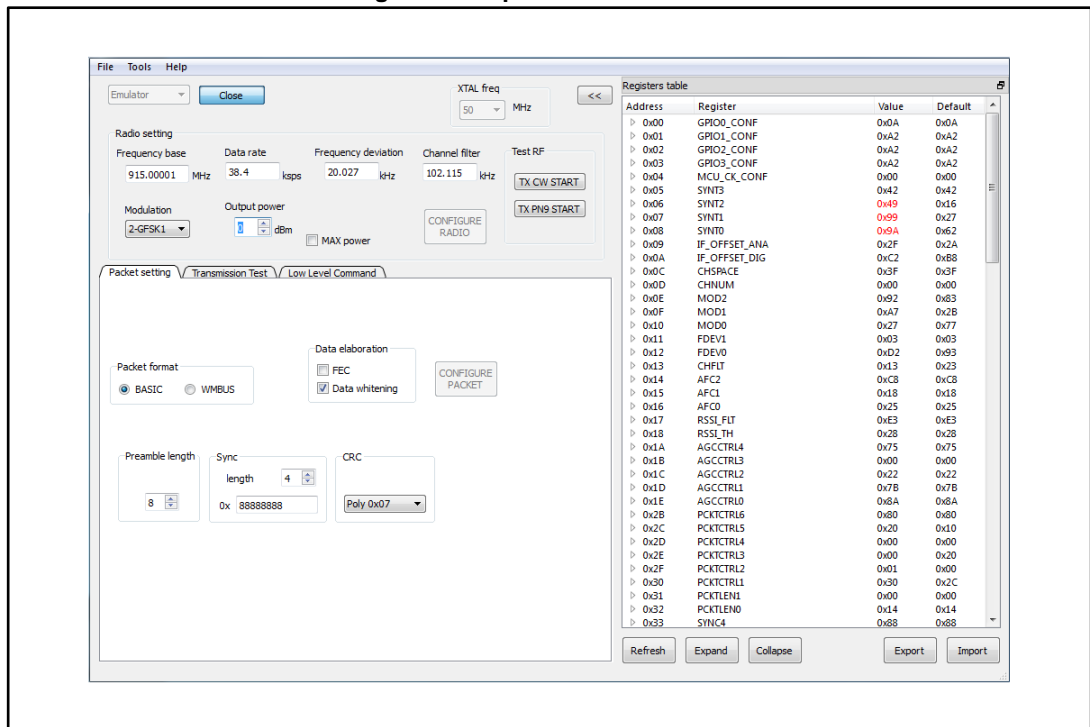
To reduce the application cost, the S2-LP is designed to work without external antenna switch.

Figure 1: STEVAL-FKI915V1 plugged on NUCLEO-L152RE board



A dedicated graphical user interface (GUI) has been developed to correctly configure the S2-LP.

Figure 2: Graphical user interface



3 Device measurements

All measurements herein are taken with the following parameters, unless otherwise specified:

- $T_c = 25\text{ }^{\circ}\text{C}$
- $V_{dd} = 3.3\text{ V}$
- $f = 915\text{ MHz}$ (center frequency)

3.1 Part 15.247 measurements for frequency hopping systems

3.1.1 20 dB channel bandwidth

The 20 dB channel bandwidth is defined as the difference between the upper and lower frequencies that are -20 dB relative to the peak. The measurement is performed in conducted mode connecting the STEVAL-FKI915V1 application board to a spectrum analyzer, with the following settings:

- Span = approximately 2 to 3 times the 20 dB bandwidth, centered on a hopping channel
- $RBW \geq 1\%$ of the 20 dB bandwidth
- $VBW \geq RBW$
- Sweep = auto
- Detector function = peak
- Trace = max hold

FCC imposes certain limits for frequency hopping systems operating in the 902–928 MHz bandwidth:

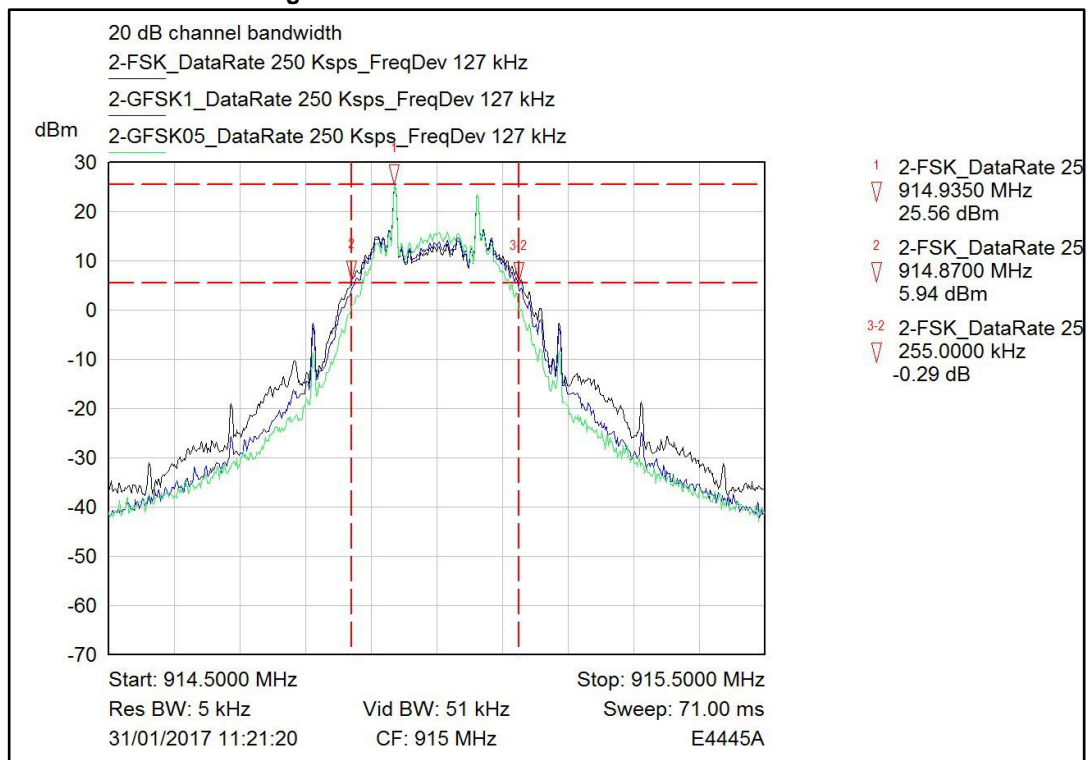
- for systems with at least 50 hopping frequency channels, the 20 dB bandwidth has to be less than 250 kHz;
- for systems with at least 25 hopping frequency channels, the 20 dB bandwidth has to be less than 500 kHz.

Figure 3: "20 dB channel bandwidth measurement" shows the 20 dB bandwidth with 250 kbps data rate and 127 kHz frequency deviation at different modulation schemes:

- Data rate = 250 kbps
- Frequency deviation = 127 kHz
- Modulations = 2-FSK, GFSK with BT = 1 and GFSK with BT = 0.5

The measured 20 dB bandwidth in the three cases is 255 kHz; as this is lower than 500 kHz, it is possible to implement a frequency hopping system with 25 hopping channels and with a data rate of 250 kbps or lower.

Figure 3: 20 dB channel bandwidth measurement



3.1.2 Carrier frequency separation

Frequency hopping systems shall have hopping channel carrier frequencies separated by minimum of 25 kHz or the 20 dB bandwidth of the hopping channel, whichever is greater.

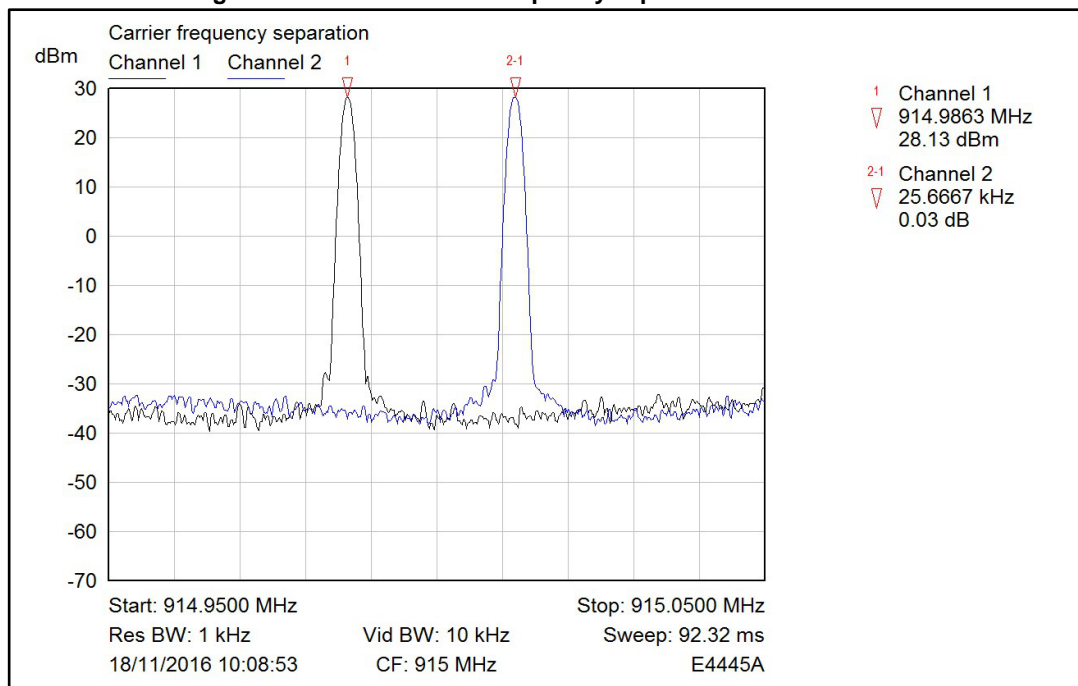
The measurement is performed in conducted mode, connecting the S2-LP application board to a spectrum analyzer, with the following settings:

- Span = wide enough to capture the peaks of two adjacent channels
- RBW \geq 1% of the span
- VBW \geq RBW
- Sweep = auto
- Detector function = peak
- Trace = max hold

As the FCC refers to the carrier frequency separation, this parameter can be measured on an unmodulated or modulated signal.

This test was performed with an unmodulated carrier. The measured channel separation is the minimum possible 25 kHz and the hop is shown in the figure below.

Figure 4: Minimum carrier frequency separation measurement



3.1.3 Number of hopping channels

For frequency hopping systems operating in the 902–928 MHz band:

- if the 20 dB bandwidth of the hopping channel is less than 250 kHz, the system shall use at least 50 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 20 second period
- if the 20 dB bandwidth of the hopping channel is 250 kHz or greater, the system shall use at least 25 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 10 second period.

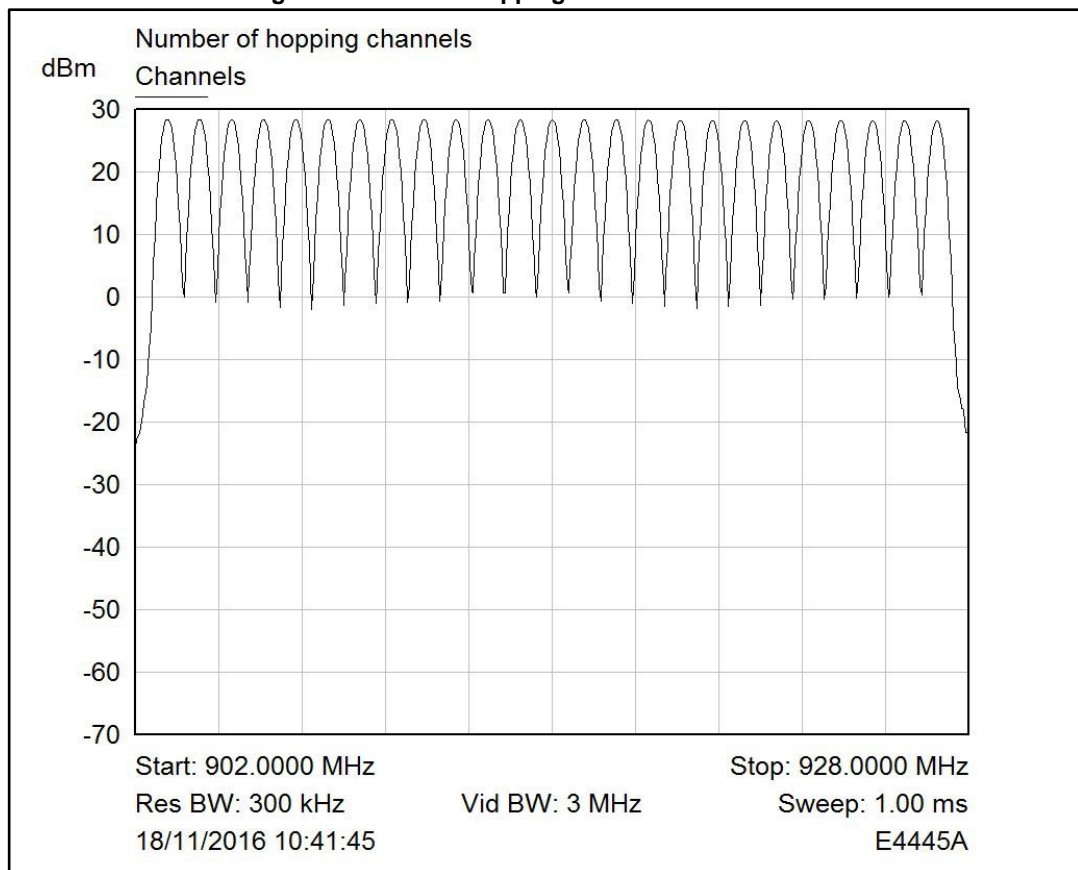
The maximum allowed 20 dB bandwidth of the hopping channel is 500 kHz.

The spectrum analyzer settings are:

- Span = the frequency band of operation 902–928 MHz
- RBW \geq 1% of the span
- VBW \geq RBW
- Sweep = auto
- Detector function = peak
- Trace = max hold

The full bandwidth coverage is measured with 26 jumps from 902 MHz to 928 MHz with a step of 1 MHz. The test demonstrates that it is possible to implement a frequency hopping system with more than 25 hopping channels.

Figure 5: Full band hopping channels measurement



3.1.4 Peak output power

The maximum peak conducted output power of the intentional radiator shall not exceed 1 watt for systems employing at least 50 hopping channels and 0.25 watts for systems employing less than 50 hopping channels, but at least 25 hopping channels.

The spectrum analyzer settings are:

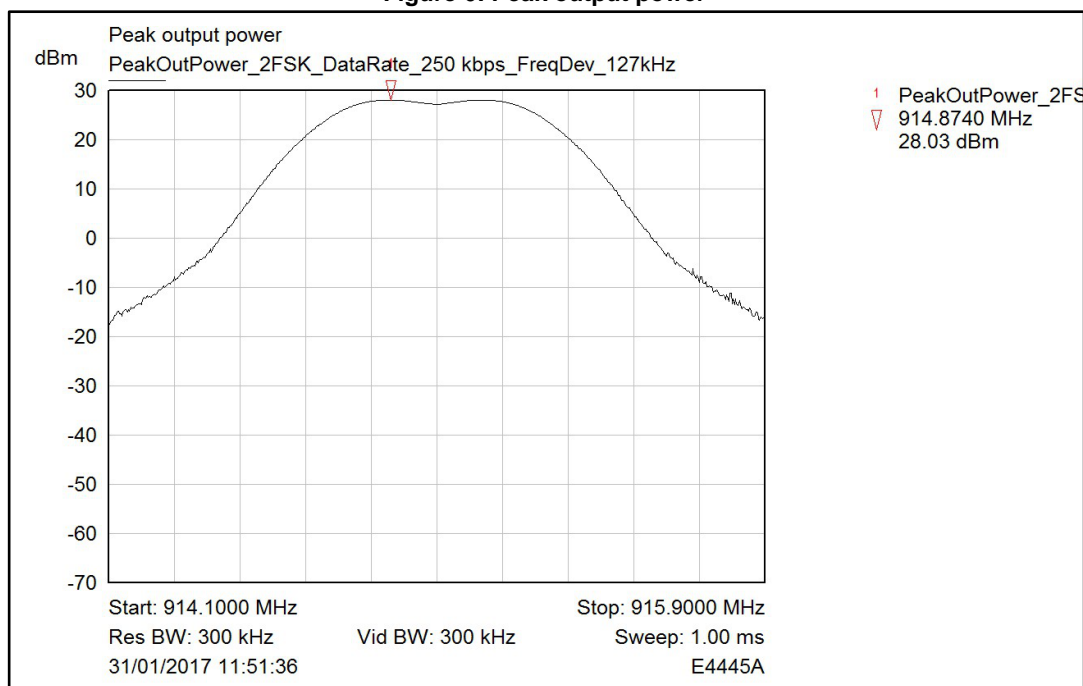
- Span = approximately 5 times the 20 dB bandwidth
- RBW \geq the 20 dB bandwidth of the emission being measured
- VBW \geq RBW
- Sweep = auto
- Detector function = peak
- Trace = max hold

S2-LP settings:

- Modulation = 2-FSK
- Data rate = 250 kbps
- Frequency deviation = 127 kHz
- Output power = max output power

The measured output power 28 dBm is lower than the 30 dBm maximum permitted output power.

Figure 6: Peak output power



3.1.5 Band edge conducted emissions

According to Part 15.247, in any 100 kHz bandwidth outside the frequency bands in which the spread spectrum intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power.

Additionally, radiated emissions which fall in the restricted bands defined in Part 15.205 must also comply with the radiated emission limits specified in Part 15.209.

To perform these measurements, select the channels closest to the frequency band edges at 902 MHz and 928 MHz.

The spectrum analyzer settings are^a:

- Span = wide enough to capture the peak level of the emission operating on the channel closest to the band-edge, as well as any modulation products which fall outside of the authorized band of operation
- RBW \geq 100 kHz
- VBW \geq RBW
- Sweep = auto
- Detector function = peak
- Trace = max hold

S2-LP settings:

- Modulation = 2-FSK
- Data rate = 250 kbps
- Frequency deviation = 127 kHz
- Output power = max output power
- Output frequency = 902.5 MHz and 927.5 MHz

^a as per "Filing and Measurement Guidelines for Frequency Hopping Spread Spectrum Systems" FCC, Public Notice DA 00-705, 03/30/2000

The band edge compliance of the RF conducted emission is shown in [Figure 7: "902 MHz band edge conducted emission measurement"](#) and [Figure 8: "928 MHz band edge conducted emission measurement"](#).

The conducted emissions in the band edges are lower than 20 dB integrated in 100 kHz bandwidth, making S2-LP usable for FCC Part 15.247 in a frequency hopping system.

Figure 7: 902 MHz band edge conducted emission measurement

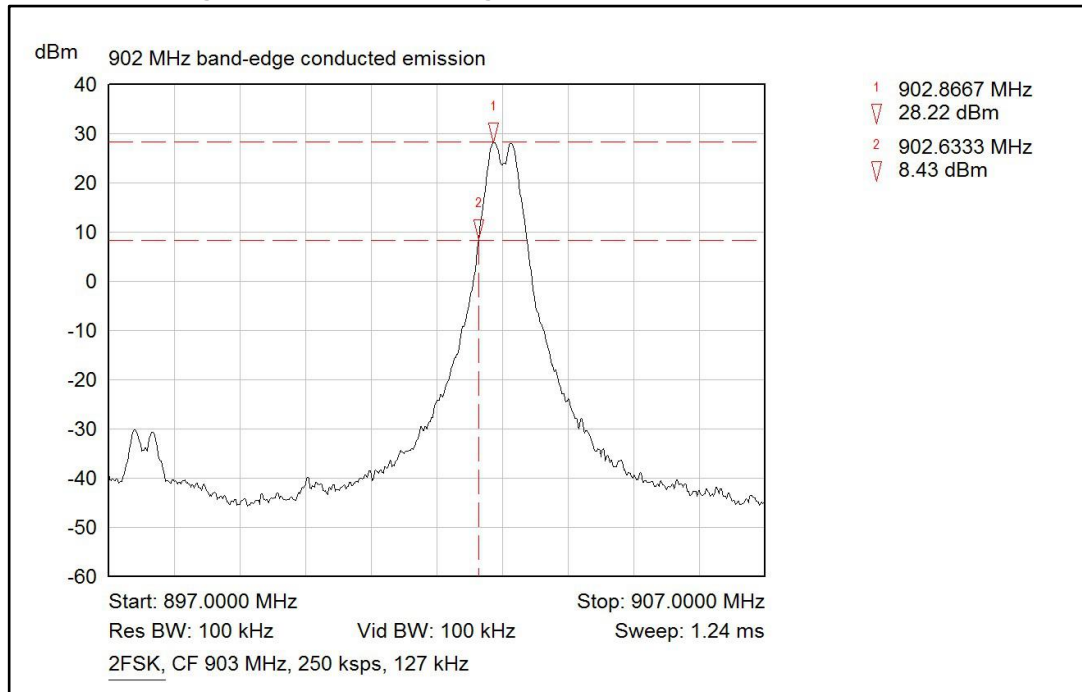
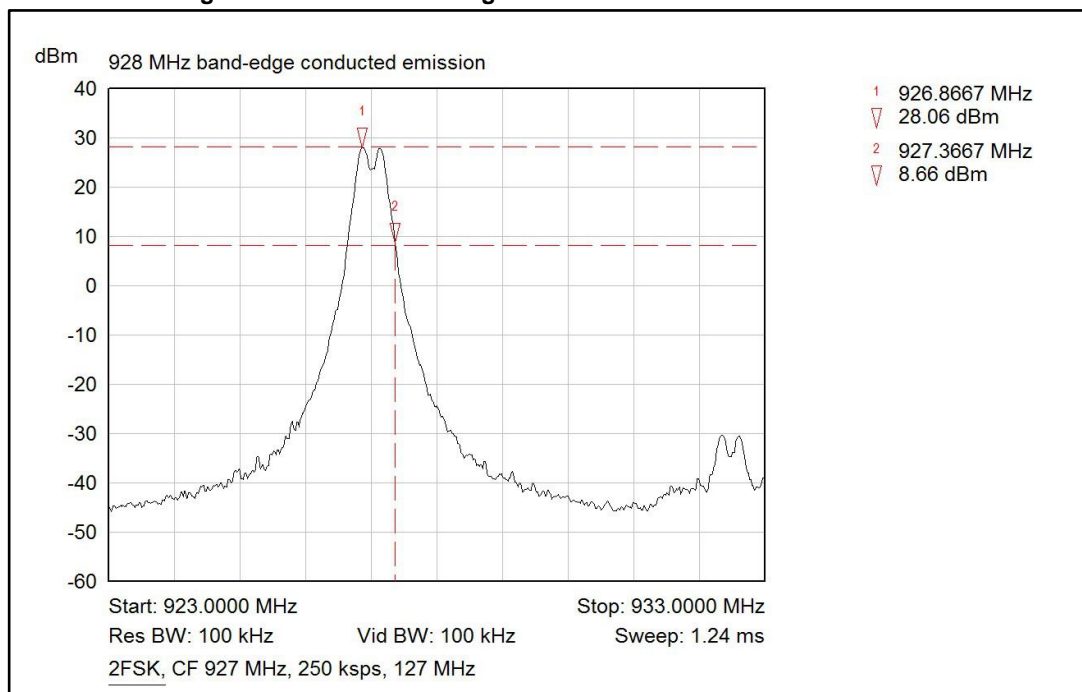


Figure 8: 928 MHz band edge conducted emission measurement



3.1.6 Spurious RF conducted emission

According to FCC Part 15.247, all the other emissions outside these bands shall not exceed the general radiated emission limits specified in Part 15.209. According to Part 15.33, for an intentional radiator operates below 10 GHz, the frequency range of measurements must be up to the tenth harmonic of the highest fundamental or 40 GHz, whichever is lower. As the highest S2-LP fundamental frequency is 928 MHz, the tenth harmonic is 9.28 GHz, representing the frequency range of measurement.

The spectrum analyzer settings are^a:

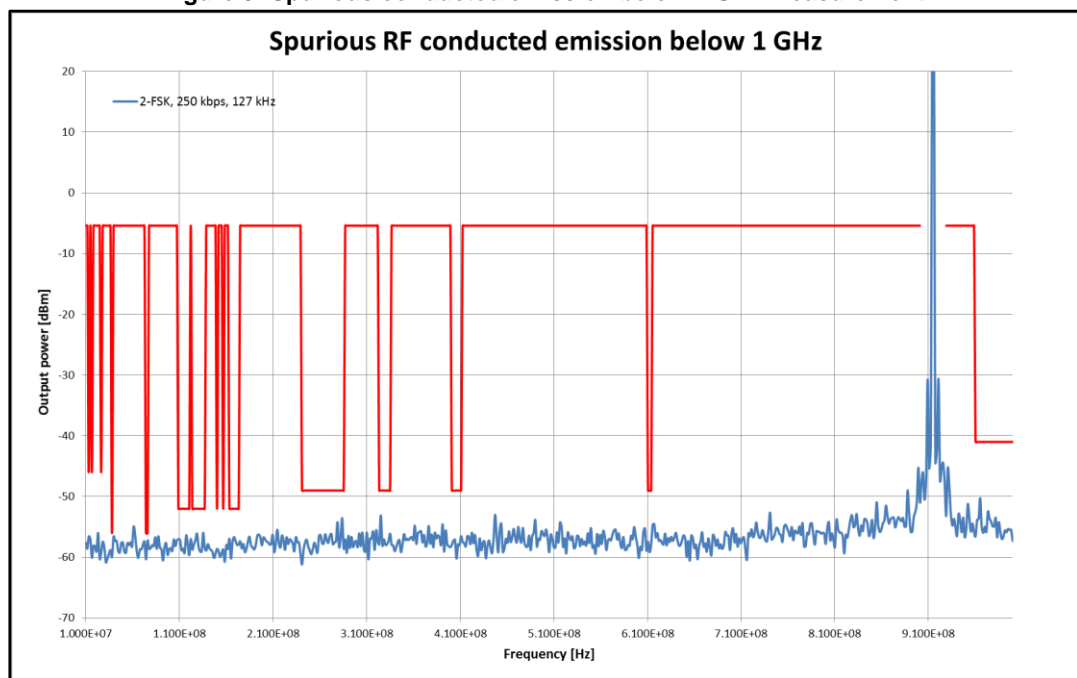
- Span = wide enough to capture the peak level of the in-band emission and all spurious emissions (e.g., harmonics) from the lowest frequency generated in the EUT up through the 10th harmonic.
- RBW \geq 100 kHz
- VBW \geq RBW
- Sweep = auto
- Detector function = peak
- Trace = max hold

S2-LP settings:

- Modulation = 2-FSK
- Data rate = 250 kbps
- Frequency deviation = 127 kHz
- Output power = max output power

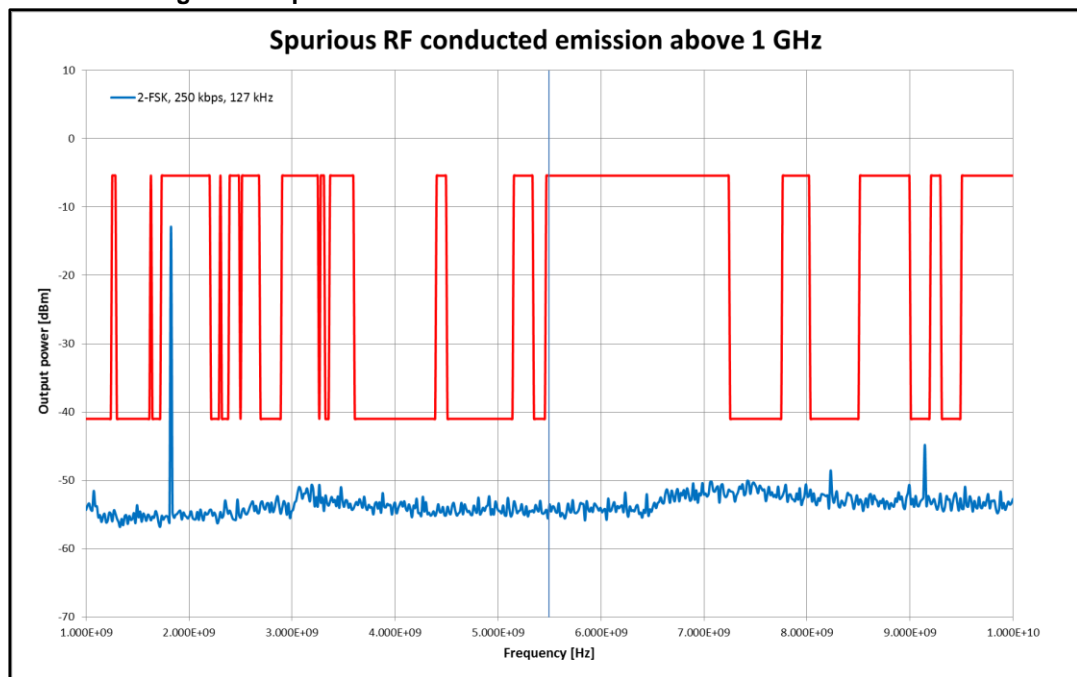
Figure 9: "Spurious conducted emission below 1 GHz measurement" and Figure 10: "Spurious conducted emission above 1 GHz measurement" demonstrate the full compliance of the S2-LP with conducted spurious emission requirements.

Figure 9: Spurious conducted emission below 1 GHz measurement



^a as per "Filing and Measurement Guidelines for Frequency Hopping Spread Spectrum Systems" FCC, Public Notice DA 00-705, 03/30/2000

Figure 10: Spurious conducted emission above 1 GHz measurement



3.2 Part 15.249 measurements

3.2.1 Peak output power

There are no particular requirements regarding the maximum permitted peak output power. The maximum output power must be about -1 dBm and no restrictions are defined for the modulation scheme or the end application.

The spectrum analyzer settings are:

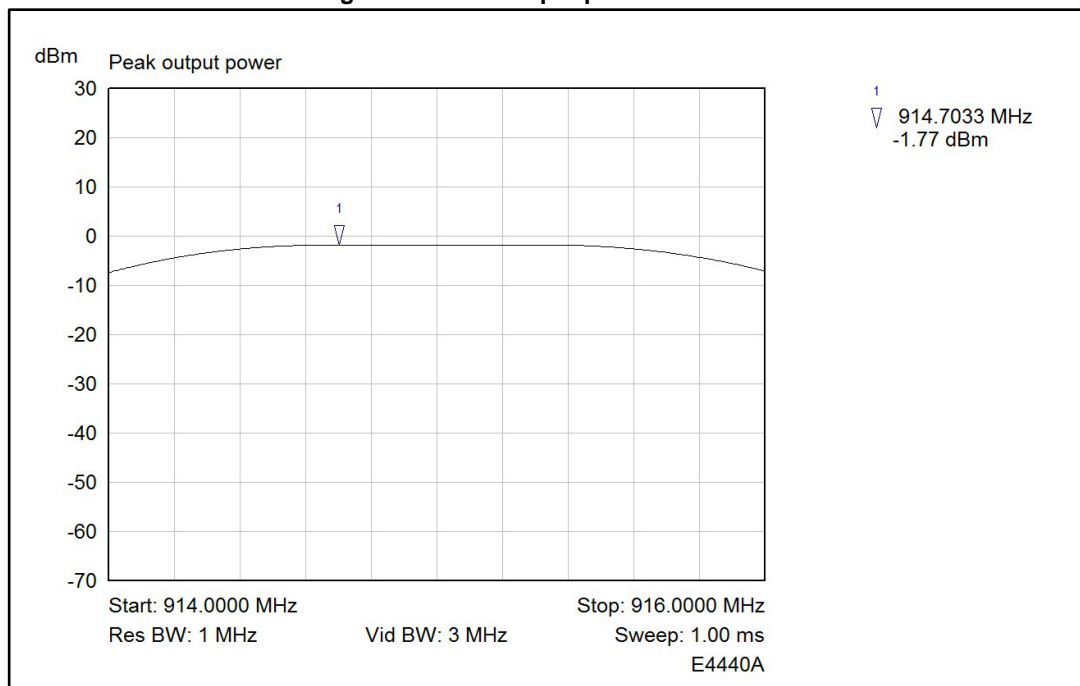
- Span ≥ 2 MHz
- RBW ≥ 1 MHz
- VBW $\geq 3 \times$ RBW
- Sweep = auto
- Detector function = peak
- Trace = max hold

S2-LP settings:

- Modulation = 2-FSK
- Data rate = 250 kbps
- Frequency deviation = 250 kHz
- Output power = -1 dBm
- Output frequency = 915 MHz

The measured S2-LP output power is -1 dBm, which complies with the maximum output power permitted in the FCC Part 15.249 requirements.

Figure 11: Peak output power at -1 dBm



3.2.2 Conducted harmonics and other than harmonic emissions

FCC Part 15.249 establishes different limits for harmonic and non-harmonic unwanted emissions:

- **Harmonic unwanted emission:** maximum permitted field strength of harmonic components for the device working in the 902–928 MHz band is 500 $\mu\text{V/m}$ at 3 m distance, equating to a conducted power level of about -41 dBm.
- **Non-harmonic unwanted emission:** emissions radiated outside the specified frequency band, except for harmonics, shall be attenuated by at least 50 dB below the level of the fundamental or to the general radiated emission limits in Part 15.209, whichever involves less attenuation.

According to Part 15.33, for an intentional radiator operates below 10 GHz, the frequency range of measurements must be up to the tenth harmonic of the highest fundamental or 40 GHz, whichever is lower. As the S2-LP highest fundamental frequency is 928 MHz, the tenth harmonic is 9.28 GHz for the frequency limit of measurement.

The instrument setting is^a:

- Span = 1 GHz for frequencies < 1 GHz, 8 GHz for frequencies \geq 1 GHz
- RBW = 100 kHz for frequencies < 1 GHz, 1 MHz for frequencies \geq 1 GHz
- VBW \geq 3 x RBW
- Sweep time = auto
- Detector function = peak
- Trace = max hold

S2-LP settings:

- Modulation = 2-FSK
- Data rate = 250 kbps

^a according to FCC title 47 part 15: "Radio frequency devices"

- Frequency deviation = 250 kHz
- Output power = -1 dBm
- Output frequency = 915 MHz

Figure 12: "Spurious conducted emission below 1 GHz" and Figure 13: "Conducted harmonics and not harmonics emission above 1 GHz" show the harmonics and other than harmonic conducted emissions. The FCC emission mask in accordance with Part 15.249 and 15.209 requirements is also given.

Figure 12: Spurious conducted emission below 1 GHz

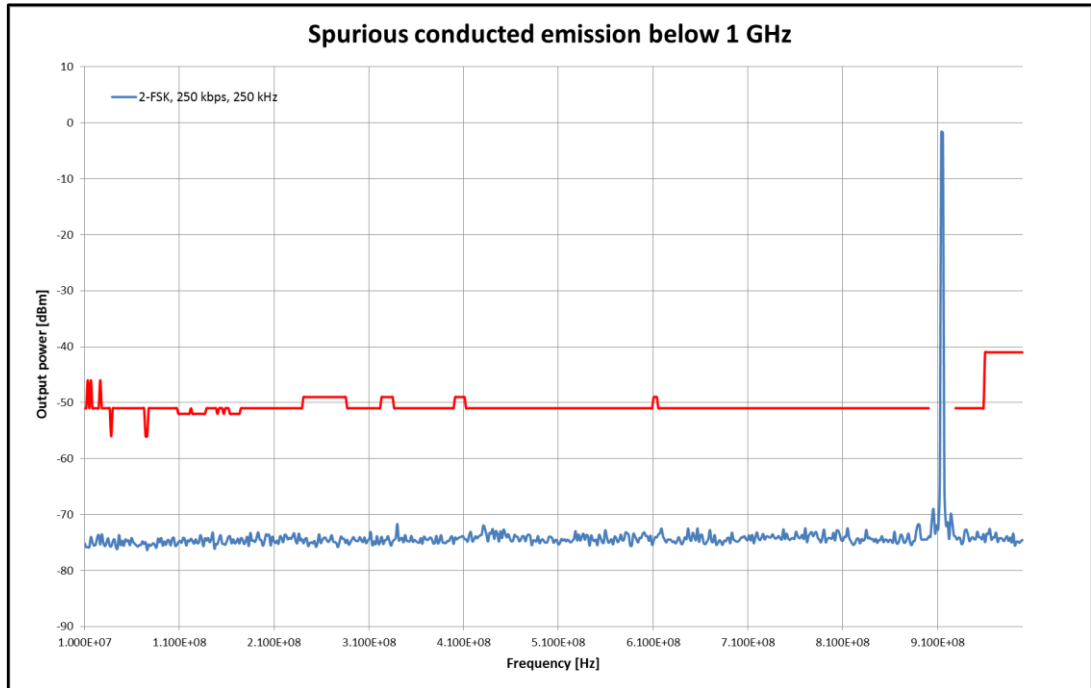
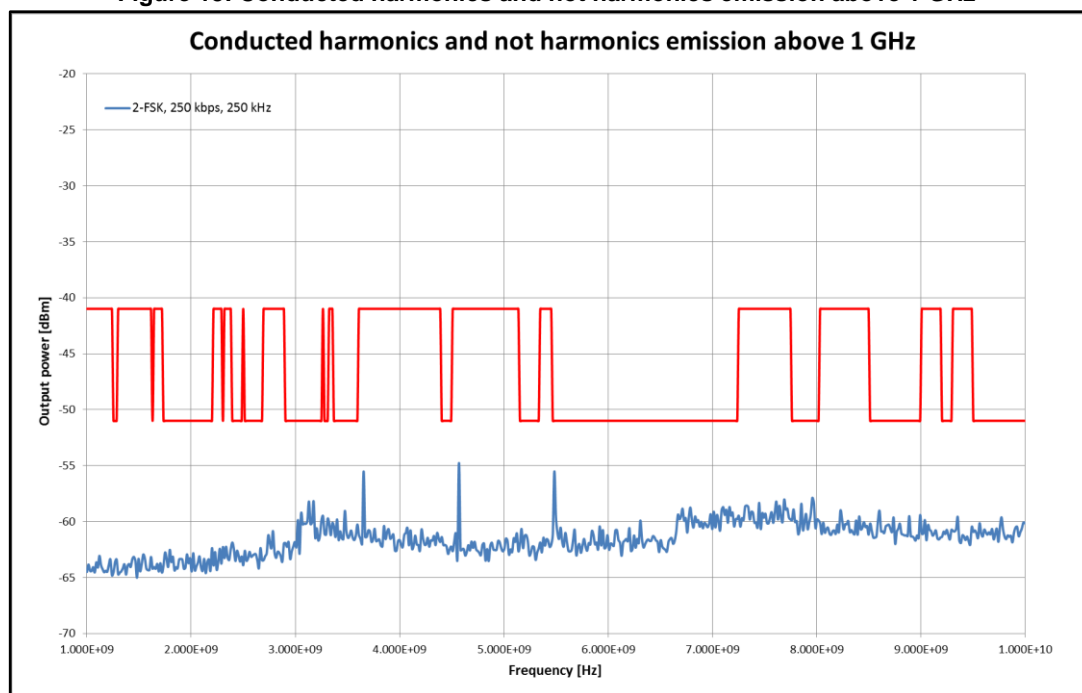


Figure 13: Conducted harmonics and not harmonics emission above 1 GHz

4 Receiver parameter

No specific requirements are defined for the FCC compliance of the receiver in US FCC Title 47 Part 15 in the 902 to 928 MHz band, hence no measurements were performed for the receiver.

5 References

1. S2-LP Datasheet
2. FCC title 47 part 15: "Radio frequency devices"
3. "Guidance for performing compliance measurements on digital transmission systems (DTS) operating under §15.247", FCC, 558074 D01 DTS Meas Guidance v03r05, 04/08/2016
4. "Filing and Measurement Guidelines for Frequency Hopping Spread Spectrum Systems" FCC, Public Notice DA 00-705, 03/30/2000
5. "Measurement of radiated emissions at the band edge of the band for a part 15 RF device", FCC, publication number 913591, publication date 03/26/2007

6 Revision history

Table 3: Document revision history

Date	Version	Changes
15-Jun-2017	1	Initial release.

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