AN4126
Application note

Using the SPIRIT1 transceiver under FCC title 47 part 15 in the 902 - 928 MHz band

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Introduction

The SPIRIT1 is a very low power RF transceiver, intended for RF wireless applications in the sub-1 GHz band. It is designed to operate in both the license-free ISM and SRD frequency bands at 169, 315, 433, 868 and 915 MHz.

This application note outlines the expected performance when using the SPIRIT1 under FCC title 47 part 15 [2] in the 902 to 928 MHz band. There are no specific requirements in this band, no specific use and no channel spacing are defined. For details on the regulatory limits in the 902 - 928 MHz frequency band, please, refer to the FCC title 47 part 15 regulations [2].

These can be downloaded from www.scc-ares-races.org/FCCpartstitles.html.

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1 An overview of FCC regulations

Low power, non-licensed devices operating in the 902 - 928 MHz band can be found everywhere, in toys, wireless security systems, wireless telemetry or wireless automatic meter reading, and so on.

The FCC is the USA body responsible for implementation rules to limit the potential for interference to licensed operations by low power, non-licensed transmitters. These rules are documented in part 15 of title 47 of the FCC.

For operation in the 902 - 928 MHz band, a low power, non-licensed device must meet one of the following sub-parts of the regulation:

- 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: devices that operate to this part are limited to frequency hopping and digitally modulated schemes.
- Part 15.249: this sub-part does not enforce restrictions on either modulation scheme or the end application.

The SPIRIT1 is designed to meet the 15.247 and 15.249 sub-parts, so this document continues with a description and measurement results of these two parts.

1.1 Part 15.247

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

To be compliant with the frequency hopping system, the device or system must meet the following requirements:

- Frequency hopping systems must 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 must 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 must use at least 50 hopping frequencies and the average time of occupancy on any frequency must 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 must use at least 25 hopping frequencies and the average time of occupancy on any frequency must 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 at least 50 channels, the maximum peak conducted output power output is +30 dBm (1 W). For systems that employ less than 50 channels, but at least 25 channels, the maximum output power is +24 dBm (0.25 W).
- In any 100 kHz bandwidth outside the frequency band of operation, the power must be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power.
- 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 requirement: the minimum 6 dB bandwidth of the signal must 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 must 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 must be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power.
- 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

As opposed to part 15.247, FCC part 15.249 in the 902 - 928 MHz bandwidth does not enforce restrictions on either the modulation scheme or the end application.

To be compliant with part 15.249, the device or system must meet the following requirements:

- The maximum permitted field strength is 50 mV/m. Since the field strength limits are specified at a distance of 3m 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 µV/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 must 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 has the lesser attenuation.

Sub-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 with 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 bandwidths outside the frequency band of operation and outside the restricted bands, the power must be at least 20 dB below that of the 100 kHz bandwidth within the band that contains the highest level of the desired power.

Devices operating under part 15.249 are restricted to field strength emissions of the fundamental of 50 mV/m and harmonic emissions of 500 µV/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 must 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 has 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 must not exceed the limits shown in part 15.209. The following tables show the restricted bands, as defined in part 15.205, and the radiated and conducted emission limits are defined in part 15.209.

Table 1. Restricted bands defined in 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 part 15.209

Frequency [MHz]	Field strength [µV/m]	Measurement distance [m]	Conducted [dBm]
0.009 – 0.490	2400/f [kHz]	300	$12.4-20*\log(f)_{kHz}$
0.490 – 1.705	24000/f [kHz]	30	$12.4-20*\log(f)_{kHz}$
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

Figure 1 shows an image of the SPIRIT1 application board. The application is made up of 2 boards: a daughterboard and a motherboard. The daughterboard contains the SPIRIT1 with the circuits necessary for it to work. For correct functionality, the daughterboard must be plugged on a motherboard (see *Figure 2*) by two header 5x2 connectors (J6 and J7).

The motherboard is provided with an STM32L152VBT6 micro to correctly program the transceiver. The micro is programmed with a firmware developed for the SPIRIT1 application. A graphical user interface (GUI) has been developed to correctly program the SPIRIT1. The daughterboard is provided with a 52 MHz XTAL to provide the correct oscillator.

The SPIRIT1 has an internal SMPS that drastically reduces power consumption, making it the best in class for application on this bandwidth. The SMPS is fed from the battery (1.8 V to 3.6 V) and provides the device with a programmable voltage (1.4 V typical). An SMA connector is present to connect the board at antenna or at instrumentation to verify the correct functionality and verify the ETSI standard request.

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

To reduce application costs, the SPIRIT1 is designed to work without an external antenna switch. This daughterboard is designed to show the SPIRIT1 functionality in this condition. Clearly, an application with antenna switch can be realized, but this is not described in this document.

Figure 1. SPIRIT1 application daughterboard

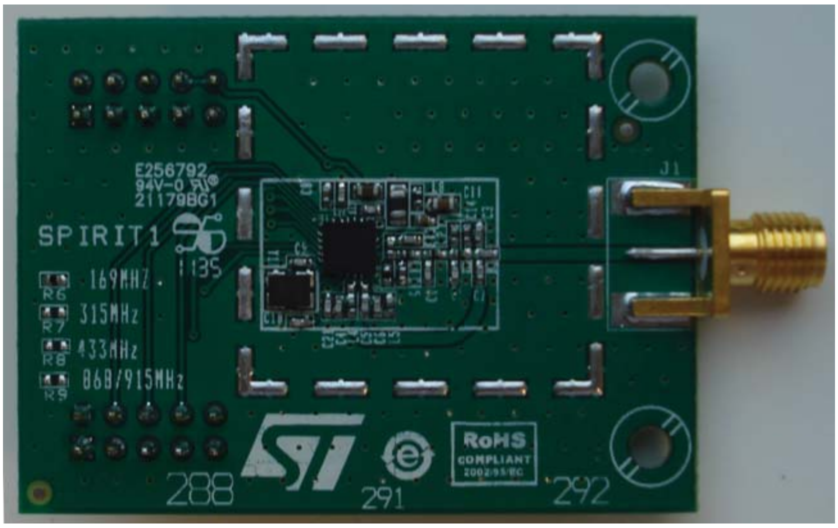

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Figure 2. SPIRIT1 application daughterboard plugged on the motherboard

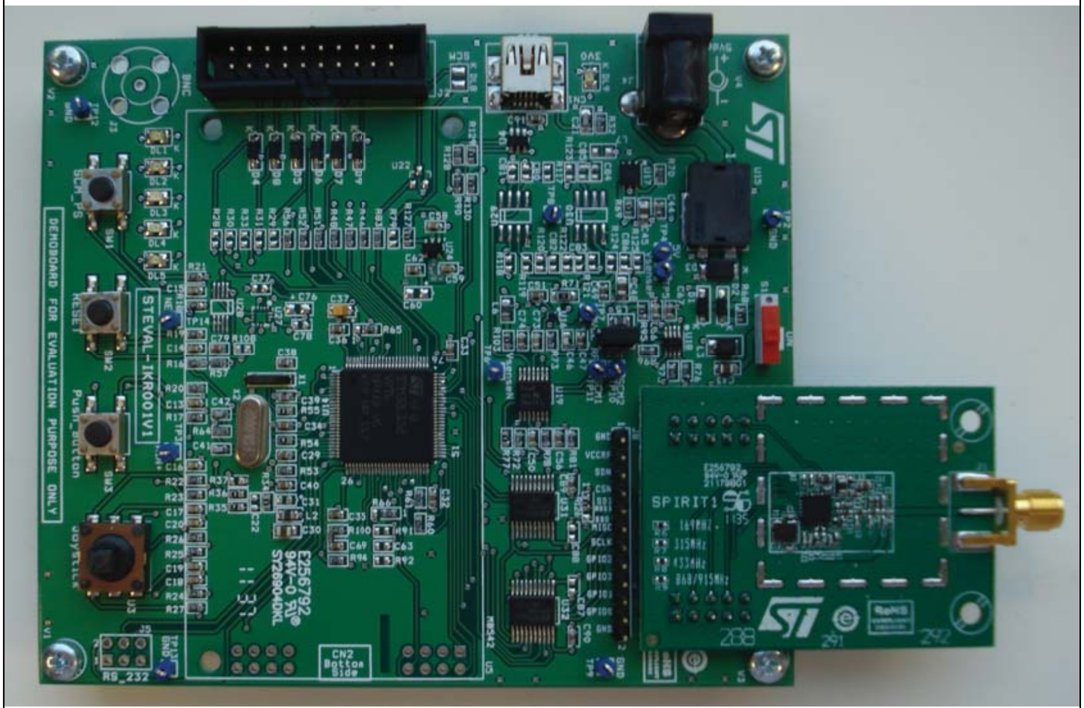

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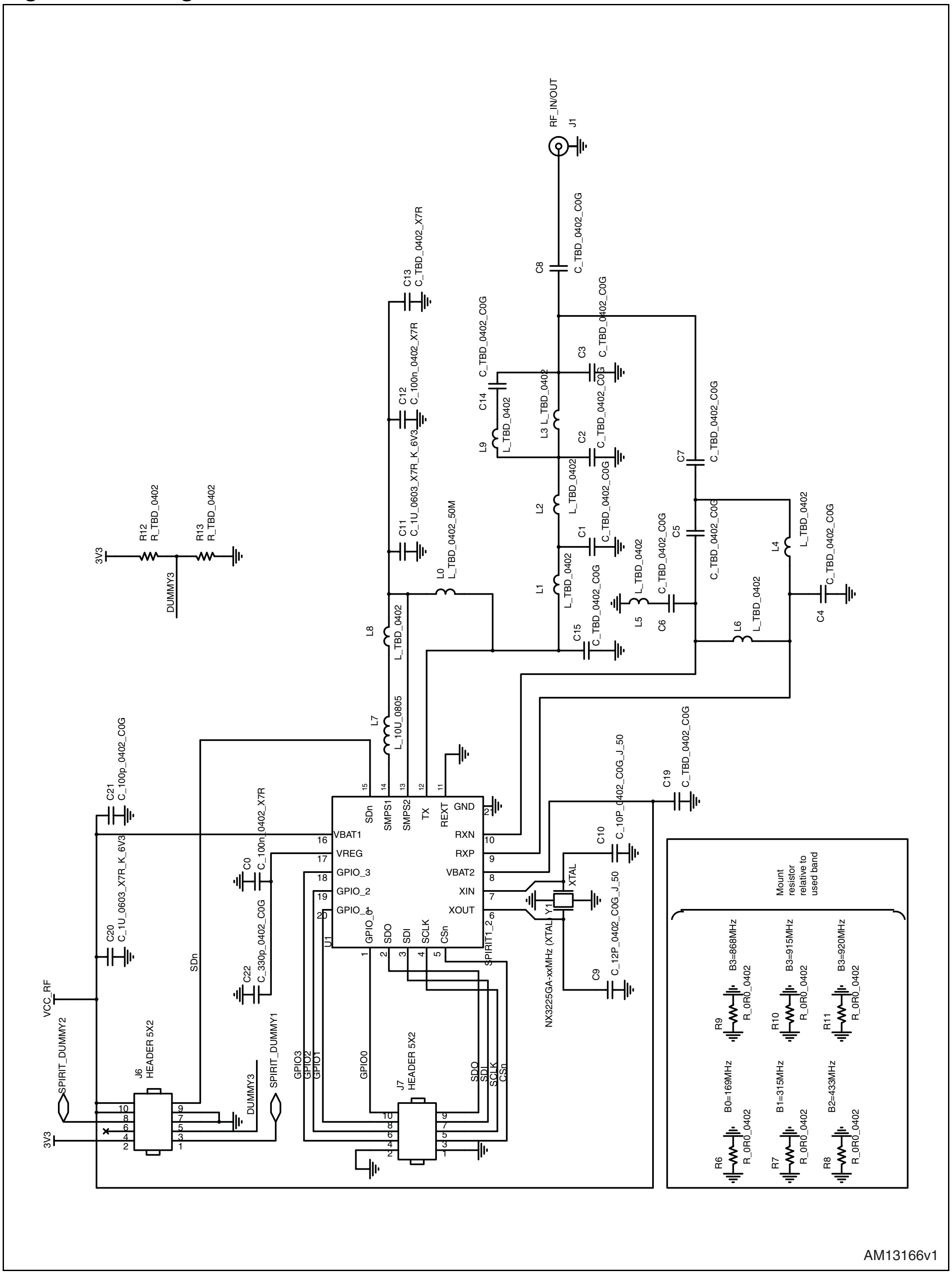
Figure 3. Daughterboard schematic



3 Transmitter parameter

All the measurements here reported are measured with the following parameters: Tc = 25 °C, Vdd = 3.0 V, f = 915 MHz (middle frequency of the useful bandwidth), unless otherwise specified.

Unless specified, the spectrum analyzer detector should be set to peak; the video bandwidth (VBW) should be equal or greater than the resolution bandwidth (RBW) of the instrument, and the display set to peak hold.

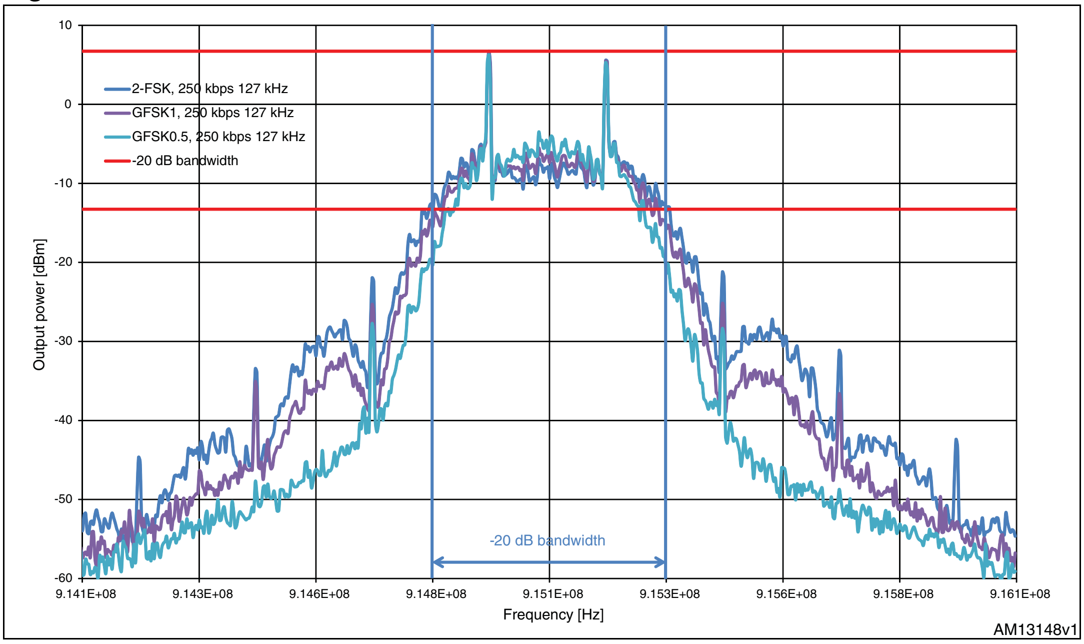
3.1 Part 15.247 measurement for frequency hopping systems

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 SPIRIT1 application board to a spectrum analyzer. The RBW (resolution bandwidth) of the spectrum must be set to about 1% of the measured 20 dB bandwidth, the VBW (video bandwidth) must be equal to or greater than the RBW. The span must be set two or three times higher than the 20 dB measured bandwidth.

Some limits are established from the FCC for frequency hopping systems operating in the 902 - 928 MHz bandwidth: for systems with at least 50 hopping frequency channels the 20 dB bandwidth must be less than 250 kHz, for systems with at least 25 hopping frequency channels the 20 dB bandwidth must be less than 500 kHz. The SPIRIT1 supports the two cases with different data rates and deviations. For example, the cases with 250 kbps data rate, 127 kHz frequency deviation and 2-FSK, GFSK with BT = 1 and GFSK with BT = 0.5 as modulation are shown in *Figure 4*. The three different cases have a 20 dB bandwidth lower than 500 kHz, so it is possible to work in a frequency hopping system with a data rate of 250 kbps or lower.

Figure 4. 20 dB channel bandwidth measurement



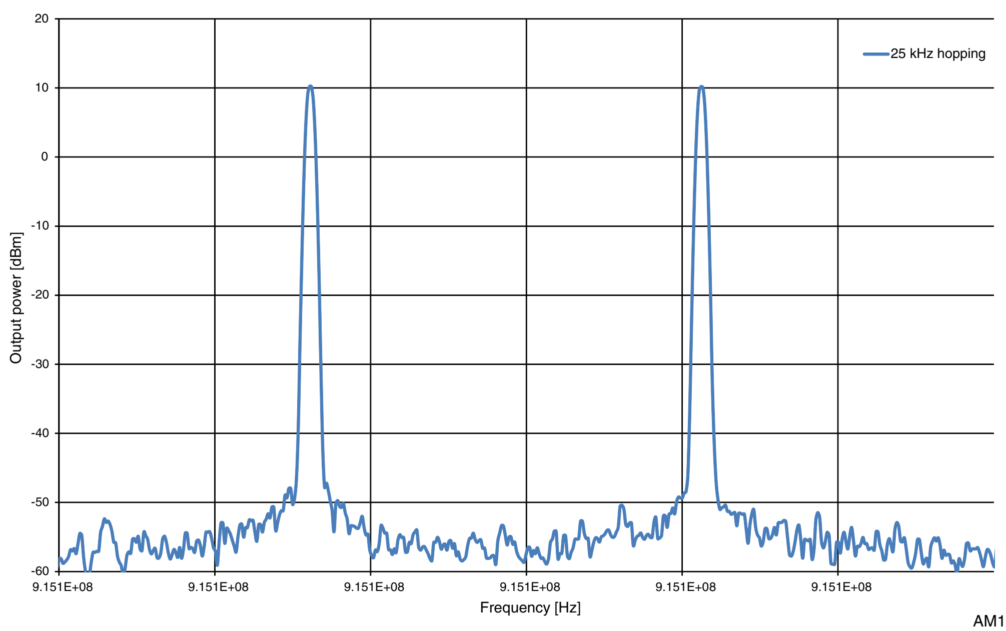
3.1.2 Carrier frequency separation

Frequency hopping systems must have hopping channel carrier frequencies separated by a 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 SPIRIT1 application board to a spectrum analyzer. The RBW (resolution bandwidth) of the spectrum is set to 100 kHz, the VBW (video bandwidth) is set equal to the RBW. The center frequency of the spectrum analyzer is set to the middle of the hopping channel, the span is adjusted wide sufficient to see the hopping channels. Since the FCC refers to the carrier frequency separation, this parameter can be measured on either an unmodulated or modulated signal.

The measurement on the SPIRIT1 is done with an unmodulated carrier. The measured channel separation is the minimum possible, 25 kHz, and the hop is shown in *Figure 5*. If numerous data rates and deviation settings are applied for different modes of operation, a separate measurement must be made for each mode.

Figure 5. Minimum carrier frequency separation measurement



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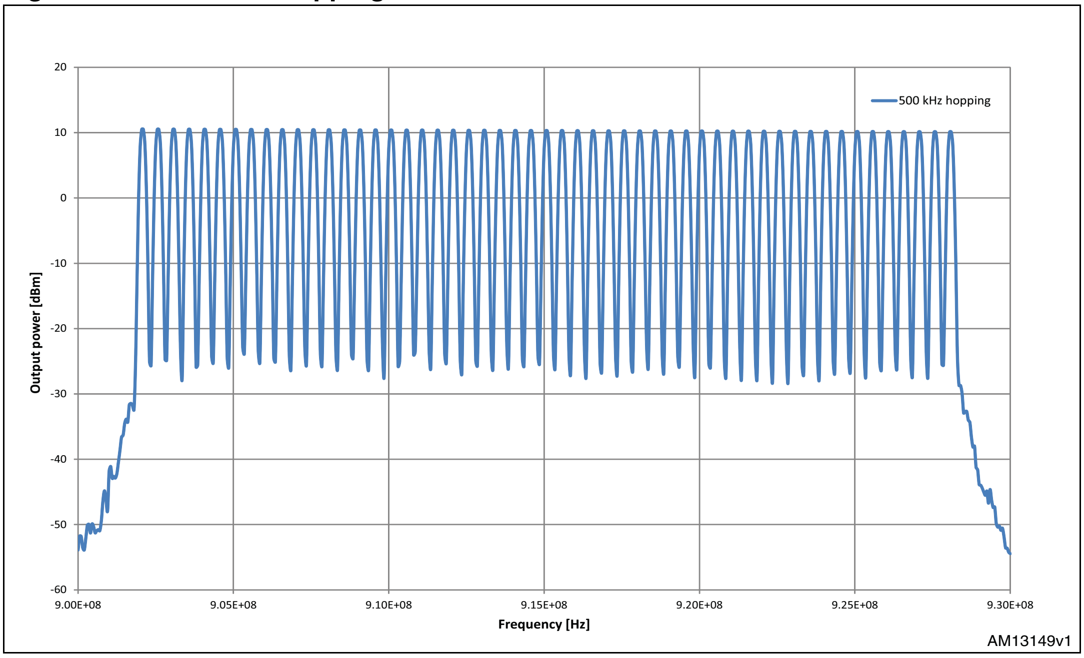
3.1.3 Number of hopping channels

Frequency hopping systems operating in the 902 - 928 MHz band use at least 25 or 50 hopping frequencies. To perform this measurement, set the spectrum with the start frequency to 902 MHz and stop frequency to 928 MHz. The RBW (resolution bandwidth) of the spectrum is set to 100 kHz, the VBW (video bandwidth) is set equal to the RBW.

In the SPIRIT1, the full bandwidth coverage is measured with 53 jumps from 902 MHz to 928 MHz with a step of 500 kHz. So it is possible to show that more than 50 hopping channels are covered by SPIRIT1, making it useful in applications that want to work on FCC part 15.247 frequency hopping systems.

Figure 6. Full band hopping channels measurement

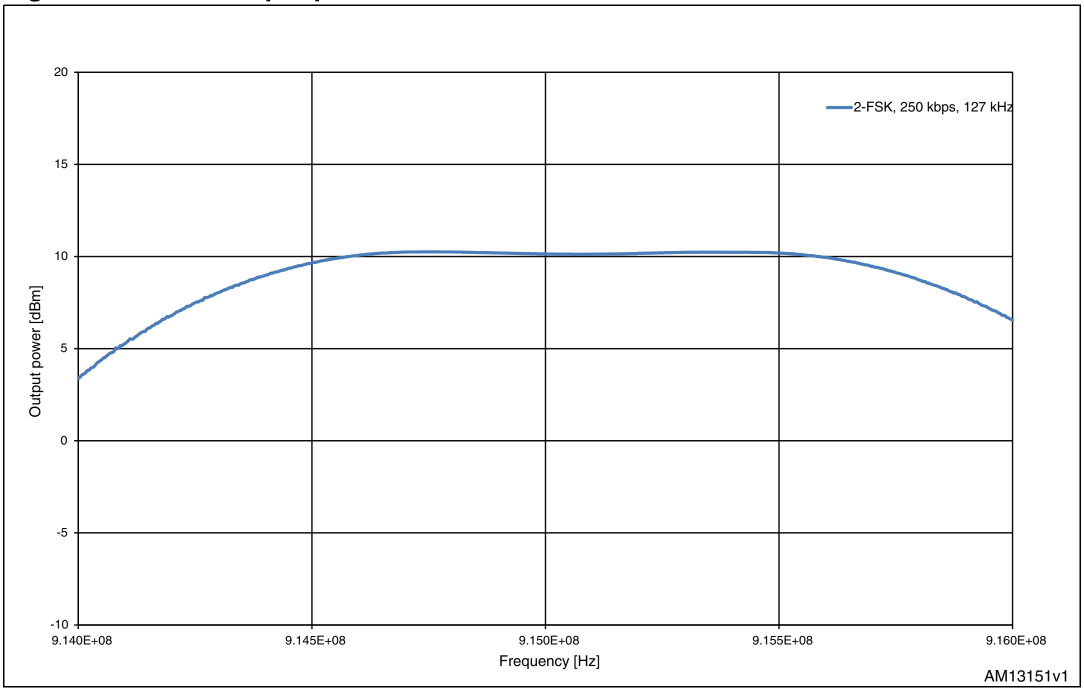


3.1.4 Frequency hopping systems peak output power

To measure the peak output power, center the spectrum analyzer on a hopping channel and put the SPIRIT1 into modulated mode. Set the span about 5 times the 20 dB bandwidth measured, the RBW greater than the 20 dB bandwidth and the VBW equal or greater than the RBW. The maximum permitted output power is 30 dBm (1 W) for the 50 hopping channels and 24 dBm (0.25 W) for the 25 hopping channels.

To perform this measurement on the SPIRIT1, the cases with 2-FSK modulation, 250 kbps data rate and 127 kHz frequency deviation are chosen. The span is set to 2 MHz (4 times the 20 dB measured bandwidth), the RBW is set to 1 MHz (greater than the 20 dB bandwidth), and the VBW equal to the RBW. The measured SPIRIT1 output power is 10 dBm. This output power is lower than the maximum permitted output power. An external PA must be used to reach the maximum output power.

Figure 7. Peak output power measurement



3.1.5 Frequency hopping systems 100 kHz bandwidth of band edges conducted emission

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 must be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power. In addition, radiated emissions which fall in the restricted bands, as 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. Set the span to be wide enough to observe the peak level of the emission on the channel closest to the band edge as well as any modulation products that fall outside the authorized band of operation. The RBW (resolution bandwidth) is set to 100 kHz, and the VBW is set to 100 kHz or greater. The measurements are performed at 902 and 928 MHz with a data rate of 250 kbps, a frequency deviation of 127 kHz and a 2-FSK modulation. In *Figure 8* and *9* the measured spectrums are shown. The conducted emissions in the band edges are lower than 20 dB integrated in 100 kHz bandwidth, making the SPIRIT1 usable for FCC part 15.247.

Figure 8. 902 MHz band edge conducted emission measurement

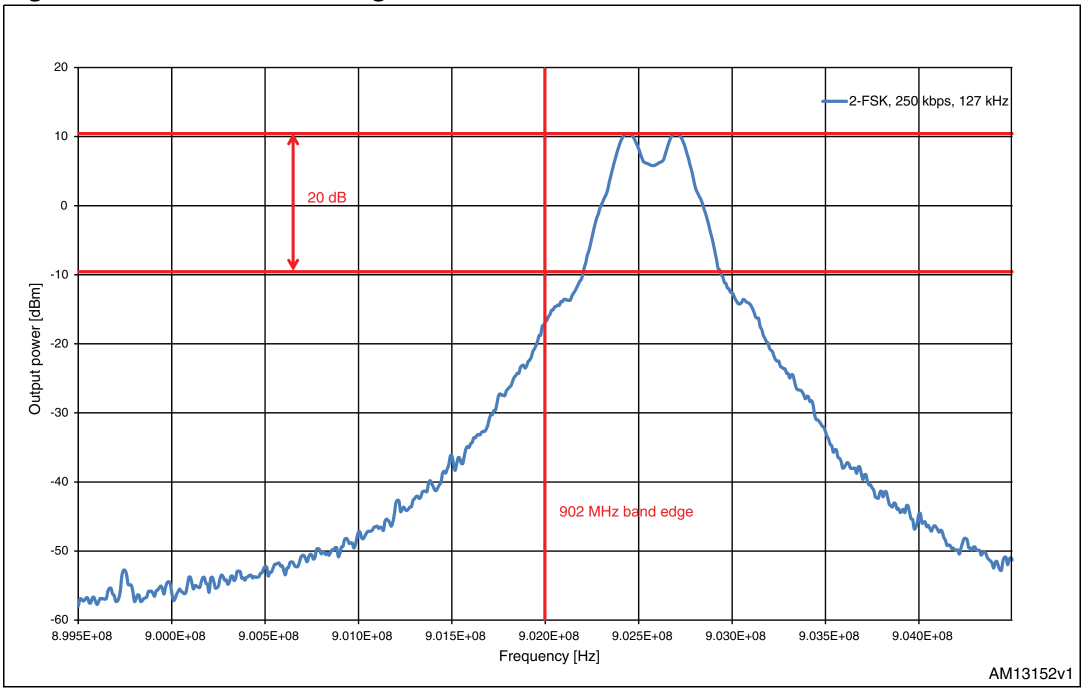
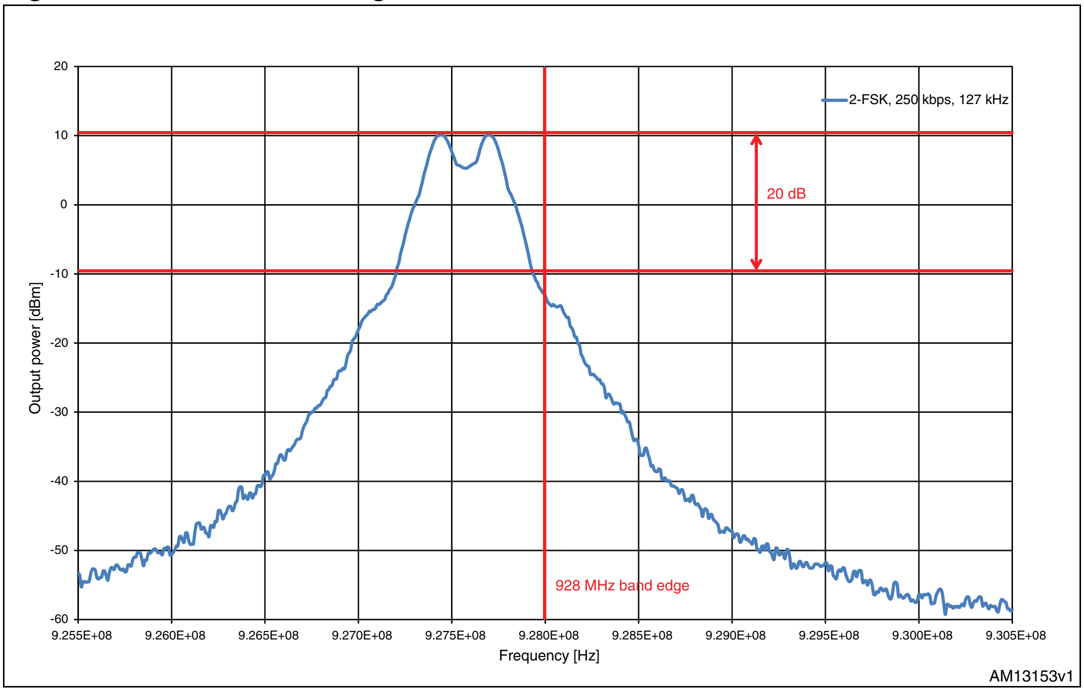


Figure 9. 928 MHz band edge conducted emission measurement



3.1.6 Spurious RF conducted emission

According to FCC part 15.247, all the other emissions outside these bands must not exceed the general radiated emission limits specified in part 15.209. According to part 15.33, for an intentional radiator operating below 10 GHz, the frequency range of measurements must be until the tenth harmonic of the highest fundamental or to 40 GHz, whichever is lower. The SPIRIT1's highest fundamental frequency is 928 MHz, so the tenth harmonic is 9.28 GHz which is the frequency range of measurement.

In *Figure 10* and *11* the spurious conducted emissions and the FCC emission mask are shown. The carrier is modulated with a 2-FSK modulation with a data rate of 250 kbps and a frequency deviation of 127 kHz. The SPIRIT1 fully complies with the conducted spurious emission requirements.

Figure 10. Spurious conducted emission below 1 GHz measurement

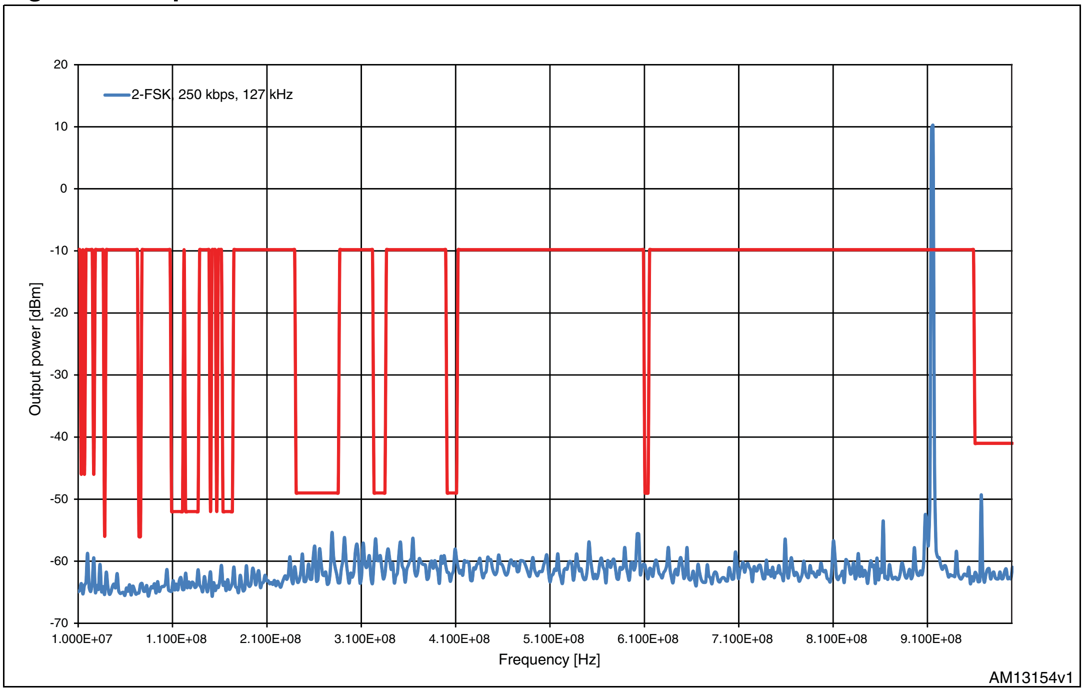
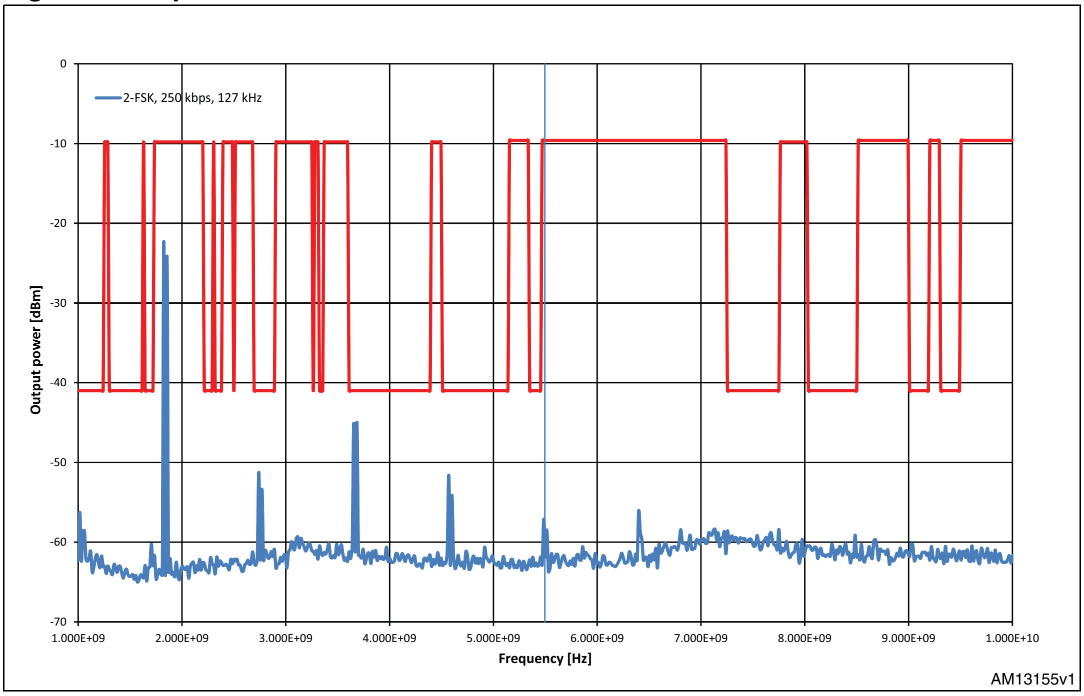


Figure 11. Spurious conducted emission above 1 GHz measurement



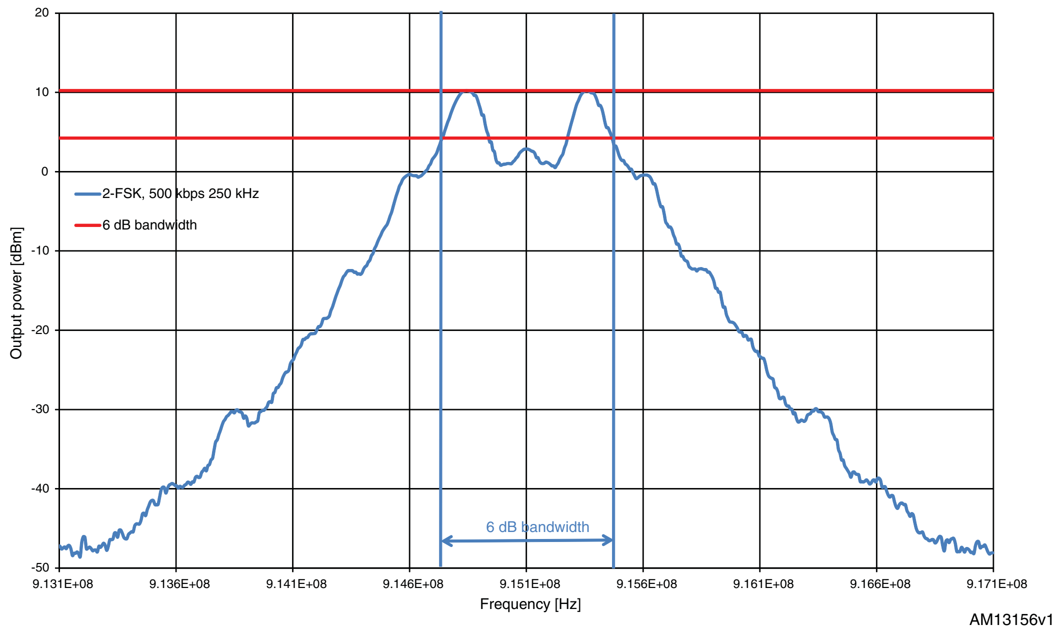
3.2 Part 15.247 measurement for digital modulation schemes

3.2.1 Signal bandwidth

The 6 dB channel bandwidth is defined as the difference between the upper and lower frequencies that are -6 dB relative to the peak. The measurement is performed in conducted mode connecting the SPIRIT1 application board to a spectrum analyzer. The RBW (resolution bandwidth) of the spectrum must be set to about 1% of the measured 6 dB bandwidth, the VBW (video bandwidth) must be equal or greater than the RBW. The span must be set wide enough to capture the entire modulation envelope.

In *Figure 12* the case with 2-FSK modulation, 500 kbps data rate and 250 kHz frequency deviation is shown. The 6 dB bandwidth is more than 500 kHz, so the SPIRIT1 is usable for the digital modulation schemes as defined in FCC part 15.247.

Figure 12. 6 dB bandwidth measurement

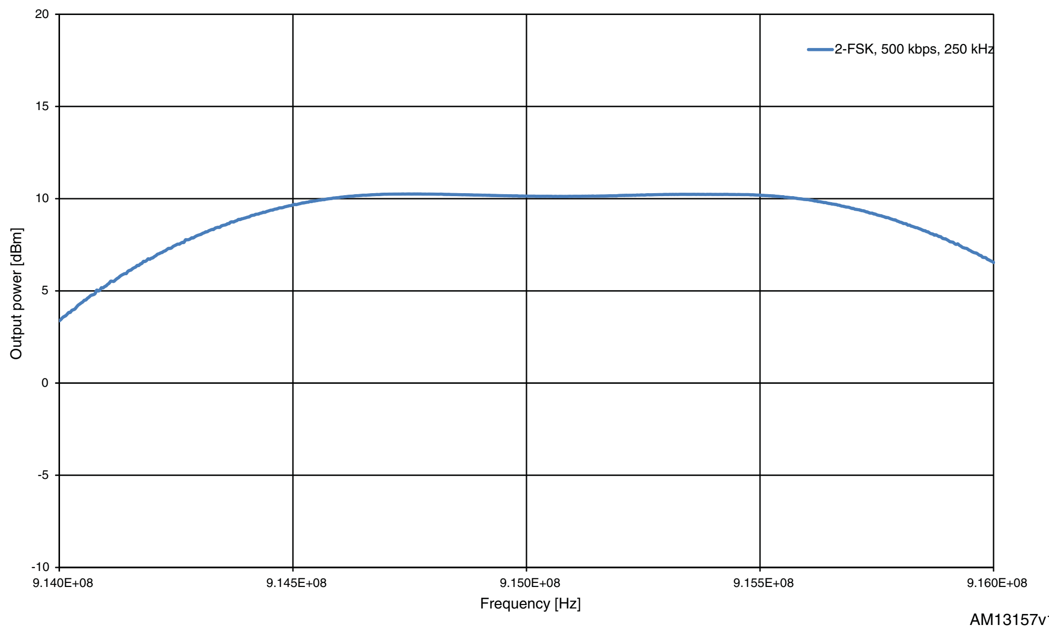


3.2.2 Digital modulation schemes peak output power

To measure the peak output power, center the spectrum analyzer on the required channel and put the SPIRIT1 into modulated mode. Set the span about 5 times the 6 dB bandwidth measurement, the RBW greater than the 6 dB bandwidth and the VBW equal to or greater than the RBW. The maximum permitted peak conducted output power is 30 dBm (1 W). The SPIRIT1 output power is lower than the maximum permitted output power. An external PA can be used to reach the maximum output power.

To perform this measurement on the SPIRIT1, the cases with 2-FSK modulation, 500 kbps data rate and 250 kHz frequency deviation are chosen. The span is set to 2 MHz (3 times the 6 dB measured bandwidth), the RBW is set to 1 MHz (greater than the 6 dB bandwidth), and the VBW equal to the RBW. The measured SPIRIT1 output power is 10 dBm. This output power is lower than the maximum permitted output power. An external PA must be used to reach the maximum output power.

Figure 13. Peak output power measurement



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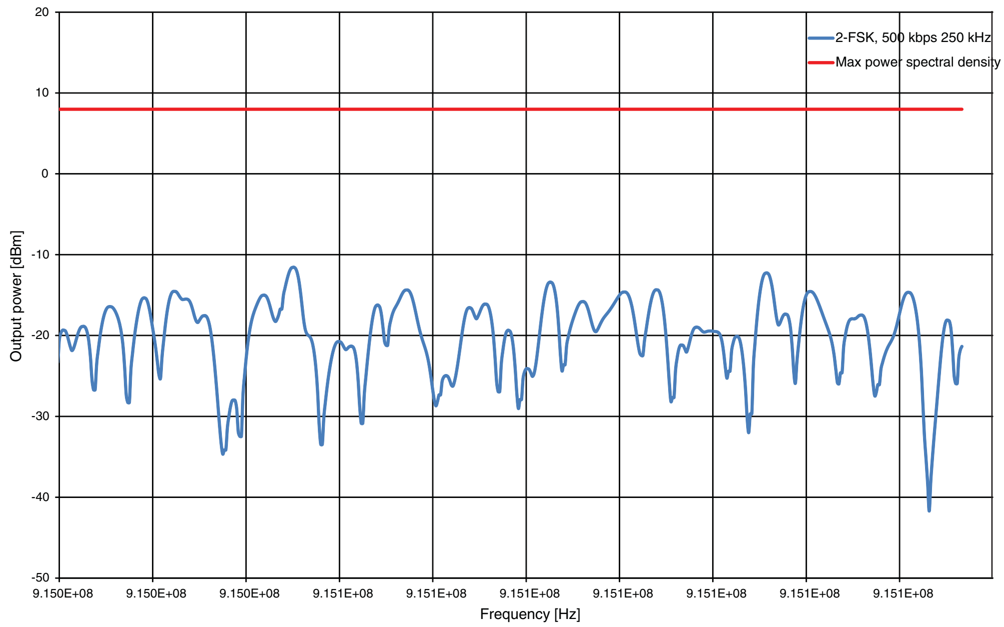
3.2.3 Power spectral density

The power spectral density conducted from the intentional radiator to the antenna must not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission. The method to measure the power spectral density is similar to that used for the conducted output power. The spectrum analyzer must be centered on the emission peak within the signal passband. Set the RBW (resolution bandwidth) to 3 kHz and the VBW (video bandwidth) greater than the RBW. Set the span to obtain a measured spectral line spacing greater than 3 kHz: in this case no correction factor is required. If it is not possible to set a measured spectral line spacing greater than 3 kHz, measure directly the noise power density normalized to 1 Hz, then add 35 dB for correction to 3 kHz. The peak measured signal level should not exceed +8 dBm.

To perform this measurement, the SPIRIT1 is programmed with a 2-FSK modulation with 500 kbps data rate and 250 kHz frequency deviation. The measurement result is shown in *Figure 14*. The SPIRIT1 meets the power spectral density requirement with large margin.

Figure 14. Power spectral density measurement



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3.2.4 Digital modulation schemes 100 kHz bandwidth of band edges conducted emission

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 must be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power. In addition, radiated emissions which fall in the restricted bands, as 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. Set the span to be wide enough to observe the peak level of the emission on the channel closest to the band edge as well as any modulation products that fall outside the authorized band of operation. The RBW (resolution bandwidth) is set to 100 kHz, the RBW is set to 100 kHz or greater. The measurements are performed at 902 and 928 MHz with a data rate of 500 kbps, a frequency deviation of 250 kHz and a 2-FSK modulation. In *Figure 15* and *16* the measured spectrums are shown. The conducted emissions in the band edges are lower than 20 dB integrated in 100 kHz bandwidth, making the SPIRIT1 usable for the FCC part 15.247 digital modulation scheme.

Figure 15. 902 MHz band edge conducted emission measurement

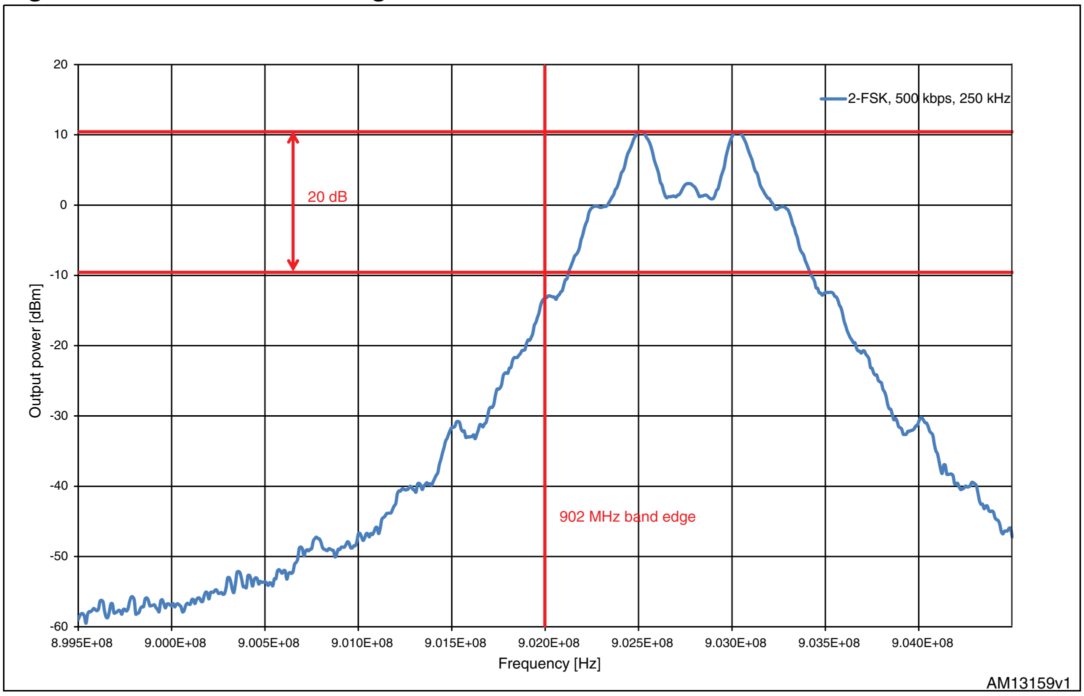
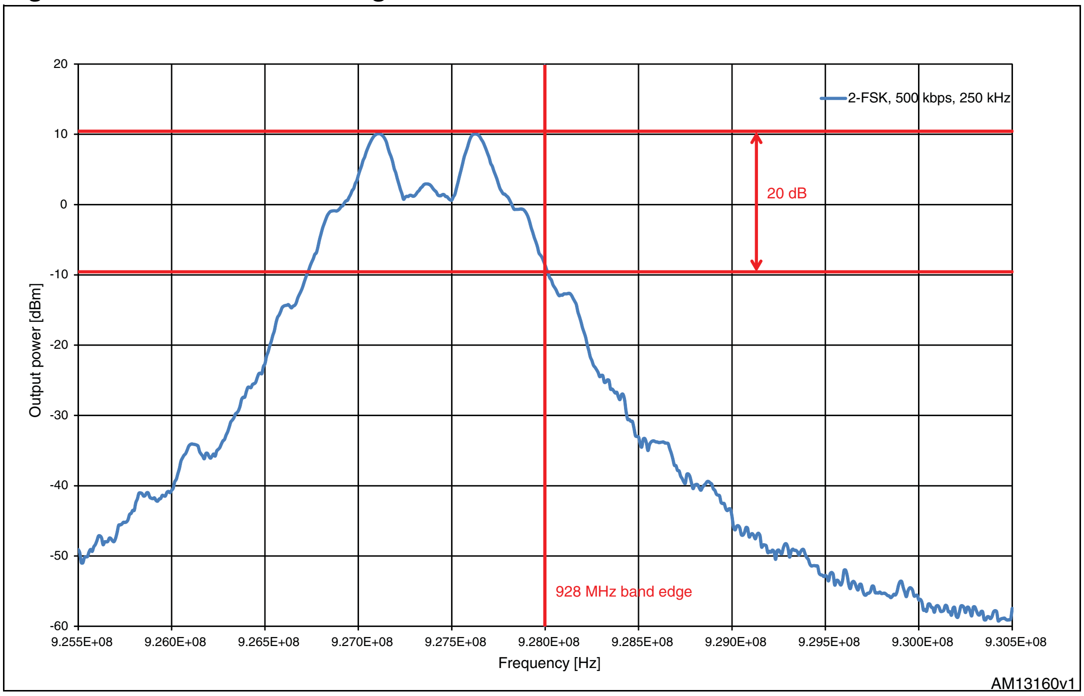


Figure 16. 928 MHz band edge conducted emission measurement



3.2.5 Spurious RF conducted emission

According to FCC part 15.247, all the other emissions outside these bands must not exceed the general radiated emission limits specified in part 15.209. According to part 15.33, for an intentional radiator operating below 10 GHz, the frequency range of measurements must be until the tenth harmonic of the highest fundamental or to 40 GHz, whichever is lower. The SPIRIT1's highest fundamental frequency is 928 MHz, so the tenth harmonic is 9.28 GHz which is the frequency range of measurement. In *Figure 17* and *18* the spurious conducted emissions and the FCC emission mask are shown. The carrier is modulated with a 2-FSK modulation with a data rate of 500 kbps and a frequency deviation of 250 kHz. The SPIRIT1 fully complies with the conducted spurious emission requirements.

Figure 17. Spurious conducted emission below 1 GHz measurement

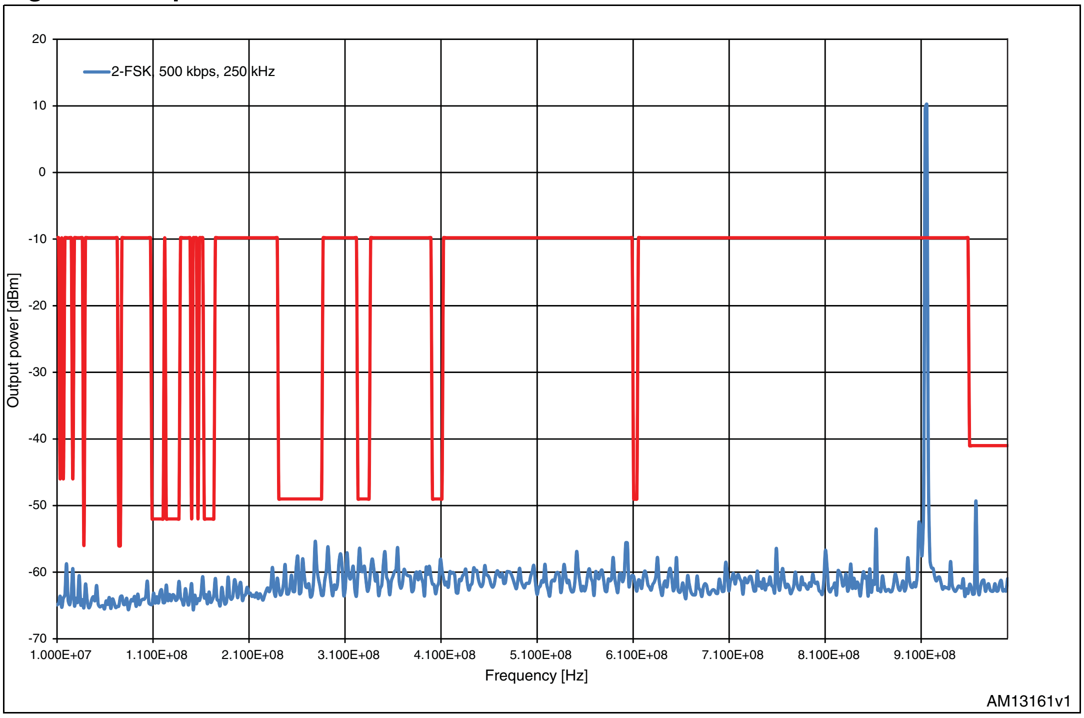
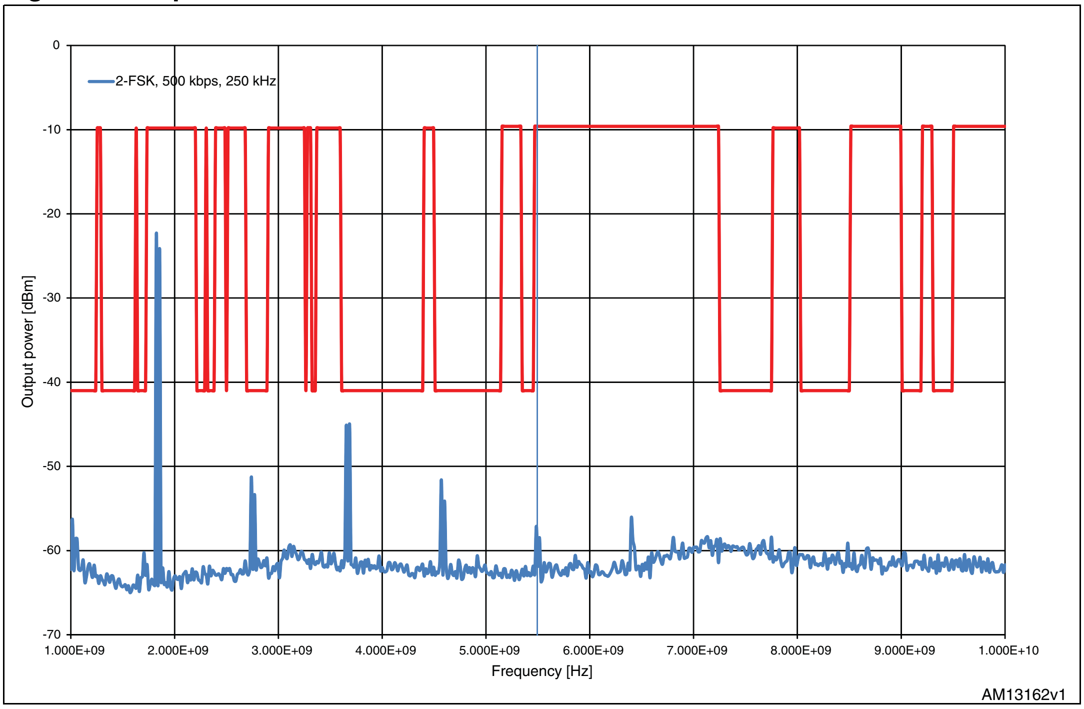


Figure 18. Spurious conducted emission above 1 GHz measurement



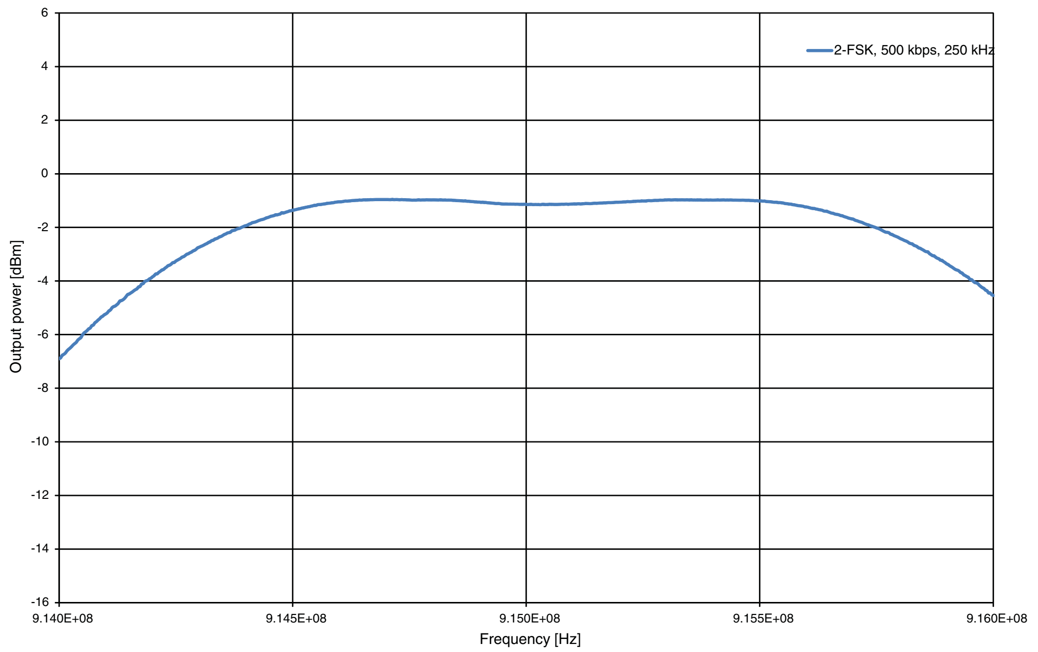
3.3 Part 15.249 measurements

3.3.1 Peak output power

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

To perform this measurement on the SPIRIT1, the cases with 2-FSK modulation, 500 kbps data rate and 250 kHz frequency deviation are chosen. The span is set to 2 MHz, the RBW is set to 1 MHz, and the VBW equal to the RBW. The measured SPIRIT1 output power is -1 dBm. This output power is the maximum permitted output power in accordance with FCC part 15.249 requirements.

Figure 19. Peak output power at -1 dBm measurement



3.3.2 Conducted harmonics and other harmonics emissions

The maximum permitted field strength of harmonic components for the device working on the 902 - 928 MHz band is 500 µV/m at 3 m distance: this equates to a conducted power level of about -41 dBm.

Emissions radiated outside the specified frequency band, except for harmonics, must 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 has the lesser attenuation. According to part 15.33, for an intentional radiator operating below 10 GHz, the frequency range of measurements must be until the tenth harmonic of the highest fundamental or to 40 GHz, whichever is lower. The SPIRIT1's highest fundamental frequency is 928 MHz, so the tenth harmonic is 9.28 GHz which is the frequency range of measurement.

In *Figure 20* and *21* the harmonics and other harmonics conducted emissions are shown. The FCC emission mask in accordance with part 15.249 and 15.209 requirements is also reported. The carrier is modulated with a 2-FSK modulation with a data rate of 500 kbps and a frequency deviation of 250 kHz. The SPIRIT1 fully complies with the conducted spurious emission requirements. Pay attention to *Figure 21* as it may seem that the 2nd harmonics doesn't meet the specification. The requirement for this spurious level is -41 dBm as the maximum level, the spurious level is -43 dBm, so the specification is met.

Figure 20. Spurious conducted emission below 1 GHz measurement

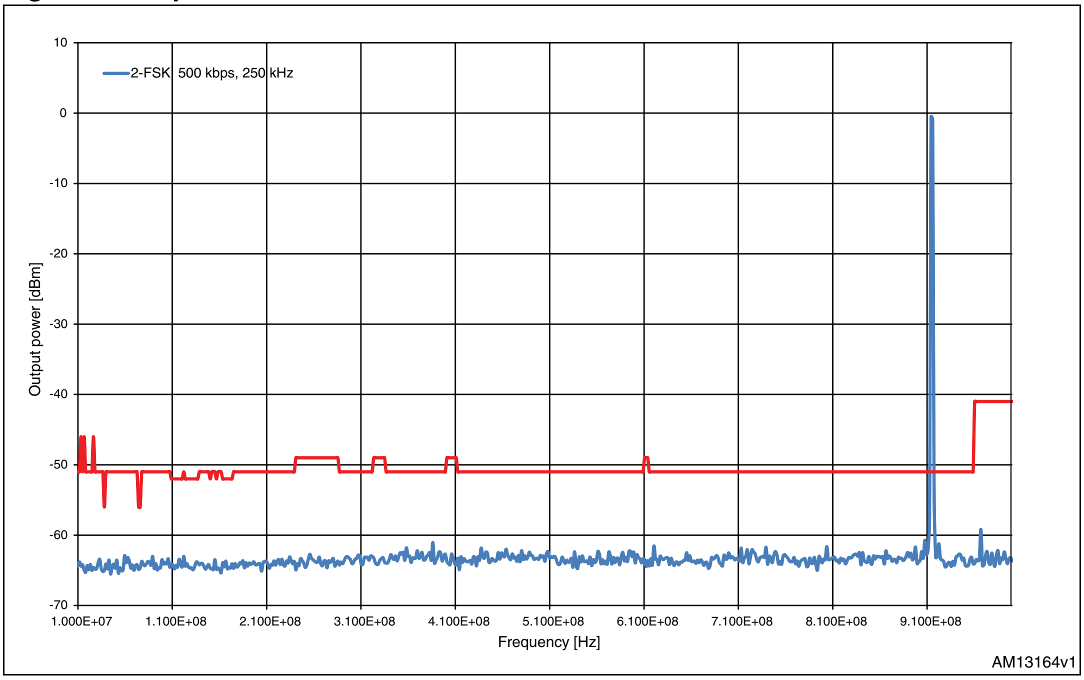
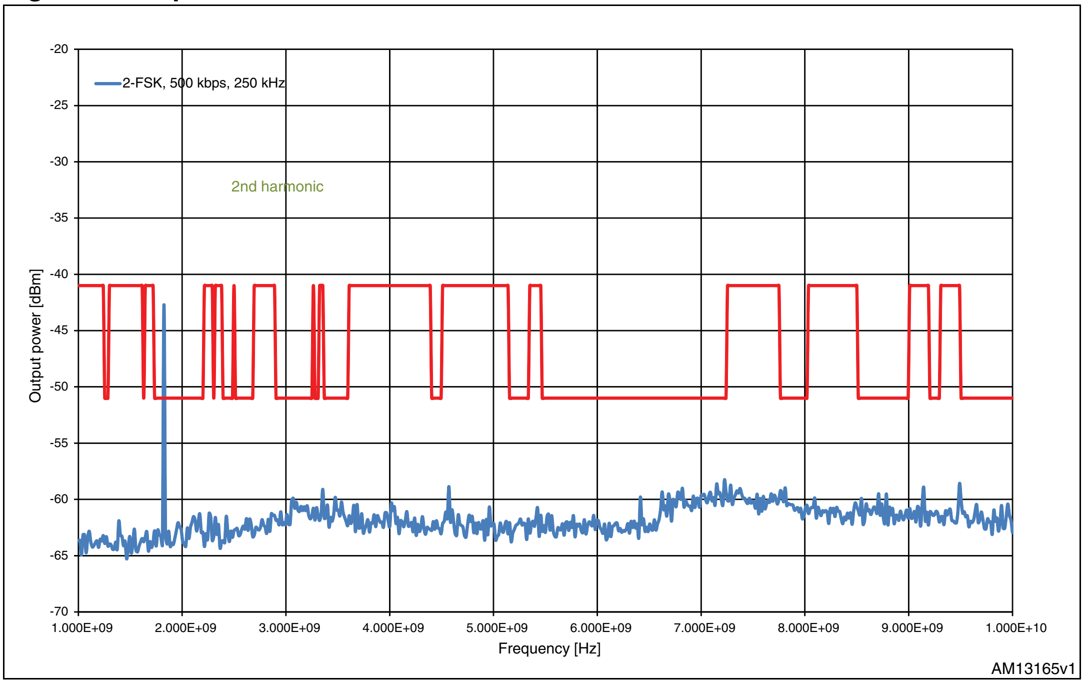


Figure 21. Spurious conducted emission above 1 GHz measurement



4 Receiver parameter

No specific requirements are defined for FCC compliance of the receiver in the US FCC title 47 part 15 [2] in the 902 to 928 MHz band. No measurements were done for the receiver.

5 Reference

1. SPIRIT1 datasheet
2. FCC title 47 part 15: “Radio frequency devices”

6 Revision history

Table 3. Document revision history

Date	Revision	Changes
02-Aug-2012	1	Initial release.