AN5009
Application note

Using the S2-LP transceiver under FCC title 47 part 90 in the 450 – 470 MHz band

Introduction

The S2-LP 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 433, 868, 915 and 920 MHz.

This application note outlines the expected performance when using the S2-LP under FCC title 47 part 90 [2] in the 450 - 470 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 450 - 470 MHz band, please refer to the FCC Title 47 Part 90 regulations [2].

These can be downloaded from:*http://wireless.fcc.gov/index.htm?job=rules_and_regulations.*

Contents

1 Overview and applicability of the FCC part 90 regulation in the 450 – 470 MHz band

An overview of the FCC part 90 main requirements in the 450 – 470 MHz band are here reported. FCC part 90 is only concerned with the performance of the transmitter, and contains no requirements on the receiver performance.

1.1 FCC part 90.205

The maximum allowable station effective radiated power (ERP) is dependent upon the station's antenna height above average terrain (HAAT) and required service area. The standard provides a list of the maximum ERP and reference HAAT as a function of a specific service area radius. For a service area radius of 3 km, the maximum ERP is 2 W, that is +33 dBm. This level will be considered as an upper limit.

1.2 FCC part 90.207

The FCC standard authorizes emissions with a different type of modulation on the transmitter carrier, type of signal modulating the transmitter carrier and type of transmitted information.

The S2-LP implements frequency modulation (F), digital modulation (1) and data, telemetry and telecommand as transmitted information (D). FCC part 90 permits the F1D modulation in the 450 MHz – 470 MHz band.

1.3 FCC part 90.209

The FCC standard provides a table which specifies the channel spacing and bandwidths for each frequency band. Within the 421 MHz – 512 MHz band the required channel spacing is 6.25 kHz. Also, the standard provides the permissible authorized bandwidths. Operations using equipment designed to operate with a 25 kHz channel bandwidth will be authorized a 20 kHz bandwidth. Operations using equipment designed to operate with a 12.5 kHz channel bandwidth will be authorized an 11.25 kHz bandwidth. Operations using equipment designed to operate with a 6.25 kHz channel bandwidth will be authorized a 6 kHz bandwidth.

1.4 FCC part 90.210

Transmitters used in the radio services governed by this part must comply with the emission masks outlined in this section.

A table is provided from the standard where the required spectral emission mask is defined as function of the channel bandwidth. Within the 421 MHz – 512 MHz band the required spectral emission masks are the C, D and E.
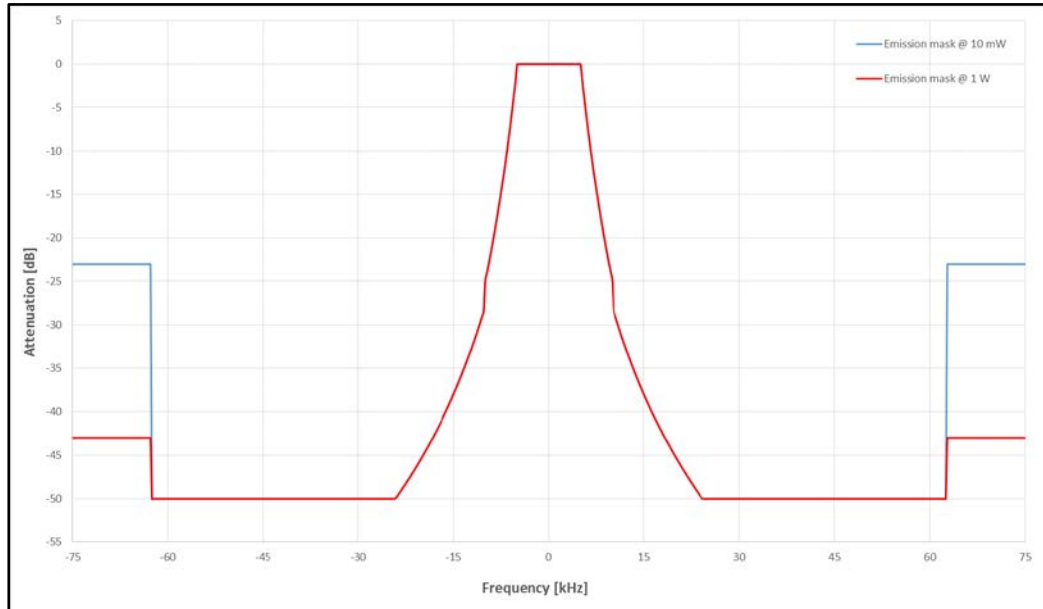
1.4.1 Emission mask C

For transmitters designed to operate with a 25 kHz channel bandwidth and are not equipped with an audio low-pass filter the power of any emission must be attenuated below the unmodulated carrier output power (P) as follows:

1 On any frequency removed from the center of the authorized bandwidth by a displacement frequency (fd in kHz) of more than 5 kHz, but not more than 10 kHz: at least $83*\log(fd/5)$ dB.

2   On any frequency removed from the center of the authorized bandwidth by a
    displacement frequency (fd in kHz) of more than 10 kHz but not more than 250% of the
    authorized bandwidth: at least 29*log(fd2/11) dB or 50 dB, whichever is the lesser
    attenuation;

3   On any frequency removed from the center of the authorized bandwidth by more than
    250% of the authorized bandwidth: at least 43+10*log(P) dB.
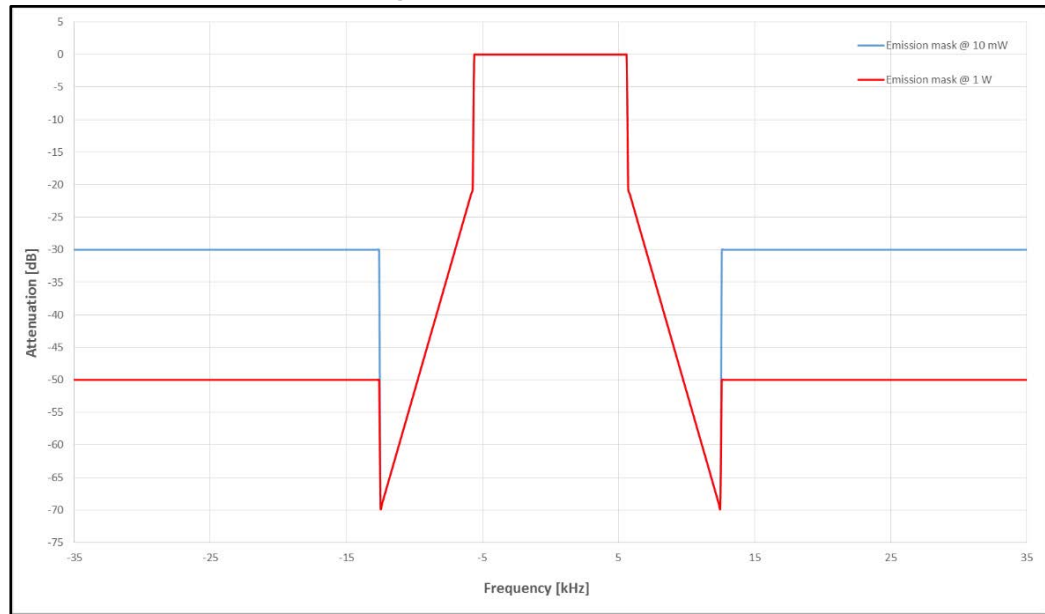
Figure 1: Emission mask C

1.4.2   Emission mask D

For transmitters designed to operate with a 12.5 kHz channel bandwidth any emission must
be attenuated below the power (P) of the highest emission contained within the authorized
bandwidth as follows:

1   On any frequency removed from the center of the authorized bandwidth f0 to 5.625 kHz
    removed from f0: 0 dB;

2   On any frequency removed from the center of the authorized bandwidth by a
    displacement frequency (fd in kHz) of more than 5.625 kHz but not more than 12.5 kHz:
    at least 7.27(fd – 2.88 kHz) dB;

3   On any frequency removed from the center of the authorized bandwidth by a
    displacement frequency (fd in kHz) of more than 12.5 kHz: at least 50 + 10*log(P) dB or
    70 dB, whichever is the lesser attenuation.

4   The reference level for showing compliance with the emission mask shall be
    established using a resolution bandwidth sufficiently wide to capture true peak emission
    of the equipment under test. In order to show compliance with the emission mask up to
    and including 50 kHz removed from the edge of the authorized bandwidth, adjust the
    resolution bandwidth to 100 Hz with the measuring instrument in a peak hold mode.

Figure 2: Emission mask D

1.4.3 Emission mask E

For transmitters designed to operate with a 6.25 kHz or less bandwidth, any emission must be attenuated below the power (P) of the highest emission contained within the authorized bandwidth as follows:

1   On any frequency removed from the center of the authorized bandwidth f0 to 3 kHz removed from f0: 0 dB;

2   On any frequency removed from the center of the authorized bandwidth by a displacement frequency (fd in kHz) of more than 3 kHz but not more than 4.6 kHz: at least 30 + 16.67(fd – 3 kHz) dB or 55 + 10*log(P) or 65 dB, whichever is the lesser attenuation;

3   On any frequency removed from the center of the authorized bandwidth by more than 4.6 kHz: at least 55 + 10*log(P) dB or 65 dB, whichever is the lesser attenuation.

4   The reference level for showing compliance with the emission mask shall be established using a resolution bandwidth sufficiently wide to capture true peak emission of the equipment under test. In order to show compliance with the emission mask up to and including 50 kHz removed from the edge of the authorized bandwidth, adjust the resolution bandwidth to 100 Hz with the measuring instrument in a peak hold mode.

Figure 3: Emission mask E
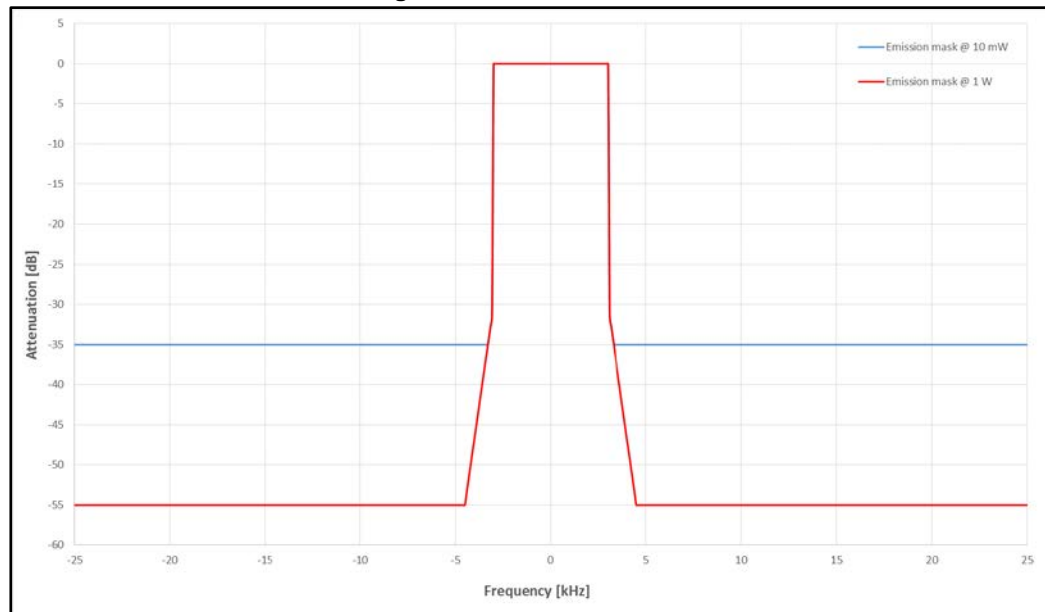
1.5 FCC part 90.213

Transmitters used in the radio services governed by this part must comply with a minimum frequency stability requirement. The requirements for the fixed/base stations and mobile stations are different in the 421 MHz – 512 MHz band.

For the fixed and base stations the following minimum frequency stability is required:

1. +/- 2.5 ppm with 25 kHz channel bandwidth;
2. +/- 1.5 ppm with 12.5 kHz channel bandwidth;
3. +/- 0.5 ppm with 6.25 kHz channel bandwidth.

For the mobile stations the following minimum frequency stability is required:

1. +/- 5 ppm with 25 kHz channel bandwidth;
2. +/- 2.5 ppm with 12.5 kHz channel bandwidth;
3. +/- 1.5 ppm with 6.25 kHz channel bandwidth.

1.6 FCC part 90.214

Transmitters used in the radio services governed by this part must maintain transient frequencies within the maximum frequency difference (from the assigned transmitter frequency) limits during some time intervals of the transmission. The requirements are done as a function of channel bandwidth and transmit output power level.

In the transmitters designed to operate with a 25 kHz channel bandwidth the transient frequency difference has to be lower than:

1. +/- 25 kHz for the first 10 msec (t_1) after turn-on
2. +/- 12.5 kHz for the next 25 msec (t_2) period
3. +/- 25 kHz for the first 10 msec (t_3) after turn-off

In the transmitters designed to operate with a 12.5 kHz channel bandwidth the transient frequency difference has to be lower than:

1. +/- 12.5 kHz for the first 10 msec (t_1) after turn-on
2. +/- 6.25 kHz for the next 25 msec (t_2) period
3. +/- 12.5 kHz for the first 10 msec (t_3) after turn-off

In the transmitters designed to operate with a 6.25 kHz channel bandwidth the transient frequency difference has to be lower than:

1. +/- 6.25 kHz for the first 10 msec (t_1) after turn-on
2. +/- 3.125 kHz for the next 25 msec (t_2) period
3. +/- 6.25 kHz for the first msec (t_3) after turn-off

 If the transmitter carrier output power is 6 watts or less, the frequency difference during the times t_1 and t_3 may exceed the maximum frequency difference for this time period.

1.7 FCC part 90.217

Except as noted herein, transmitters used at station licensed below 800 MHz on any frequency listed in subparts B and C of this part which have an output power not exceeding 120 mW (+20.8 dBm) are exempt from the technical requirements set out in this subpart, but must instead comply with the following:

- For equipment designed to operate with a 25 kHz channel bandwidth, the sum of the bandwidth occupied by the emitted signal plus the bandwidth required for frequency stability shall be adjusted so that any emission appearing on a frequency 40 kHz or more removed from the assigned frequency is attenuated at least 30 dB below the unmodulated carrier.
- For equipment designed to operate with a 12.5 kHz channel bandwidth, the sum of the bandwidth occupied by the emitted signal plus the bandwidth required for frequency stability shall be adjusted so that any emission appearing on a frequency 25 kHz or more removed from the assigned frequency is attenuated at least 30 dB below the unmodulated carrier.
- For equipment designed to operate with a 6.25 kHz channel bandwidth, the sum of the bandwidth occupied by the emitted signal plus the bandwidth required for frequency stability shall be adjusted so that any emission appearing on a frequency 12.5 kHz or more removed from the assigned frequency is attenuated at least 30 dB below the unmodulated carrier.

 The transmitter may be operated in the continuous carrier transmit mode.

1.8 FCC part 90.221

For the frequencies in the 450 MHz to 470 MHz bandwidth, operations using equipment designed to operate with a 25 kHz channel bandwidth may be authorized up to a 22 kHz bandwidth if the equipment meets the adjacent channel power (ACP) limits below. The table specifies a value for the ACP as a function of the displacement from the channel center frequency and a measurement bandwidth of 18 kHz.

The maximum adjacent channel power levels for frequencies in the 450 MHz – 470 MHz band is:

Table 1: ACP requirements

Frequency offset [kHz]	Max ACP for devices ≤ +30 dBm [dBc]	Max ACP for devices ≥ +30 dBm [dBc]
25	-55	-60
50	-70	-70
75	-70	-70

2 Application circuit

An application board has been designed to evaluate the RF performances and to develop the connected firmware of the S2-LP transceiver. It is compatible with the Arduino UNO R3 connector layout and allows expansion of the STM32 nucleo boards. *Figure 4: "S2-LP application daughterboard + STM32 nucleo board"* shows an image of the S2-LP application board + STM32 nucleo board.

The daughterboard is provided with a 50 MHz XTAL to provide the correct oscillator to the S2-LP.

The S2-LP has an internal SMPS that drastically reduce the power consumption making the S2-LP the best in class for the application on this bandwidth. The SMPS is fed from the battery (1.8 V to 3.6 V) and provides to the device a programmable voltage (1.5 V usually). An SMA connector is present to connect the board to antenna or instrumentation to verify the correct functionality and verify the compatibility with the requested standards.

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

To reduce the application cost the S2-LP is designed to work without external antenna switch. This daughterboard is designed to show the S2-LP functionality in this condition. Clearly, an application with antenna switch can be realized, but this is not described in this document.

A dedicated graphical user interface (GUI) has been developed to correctly set the S2-LP, see *Figure 5: "Graphical user interface"*.

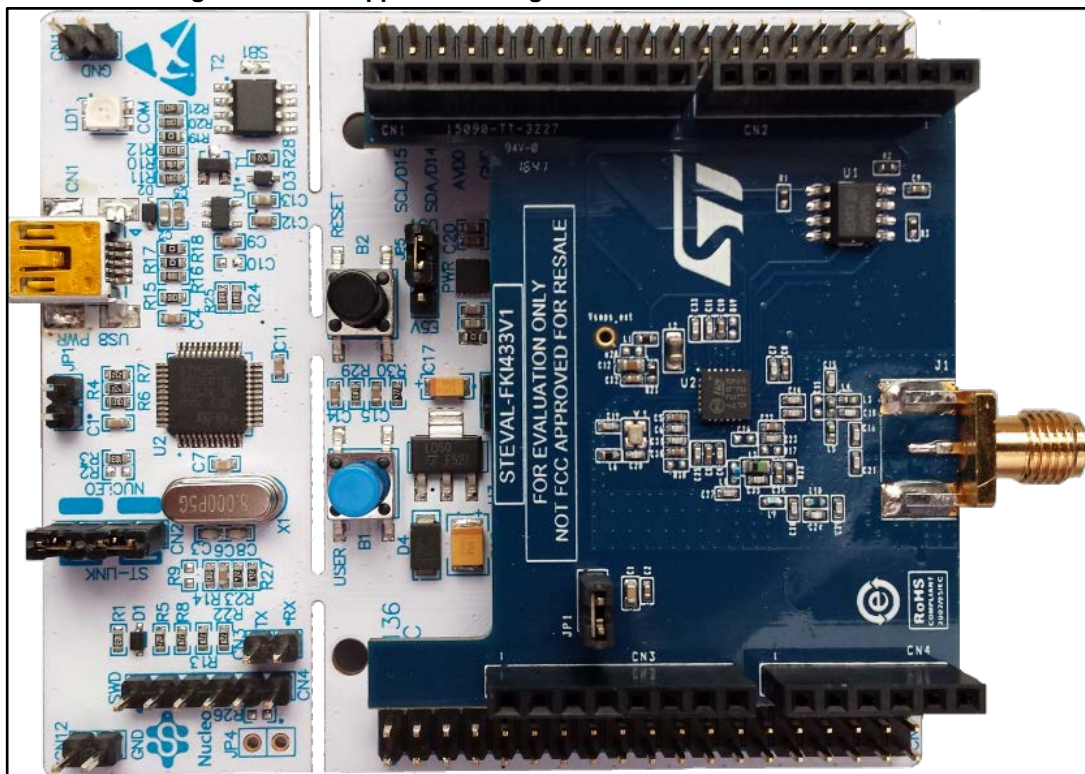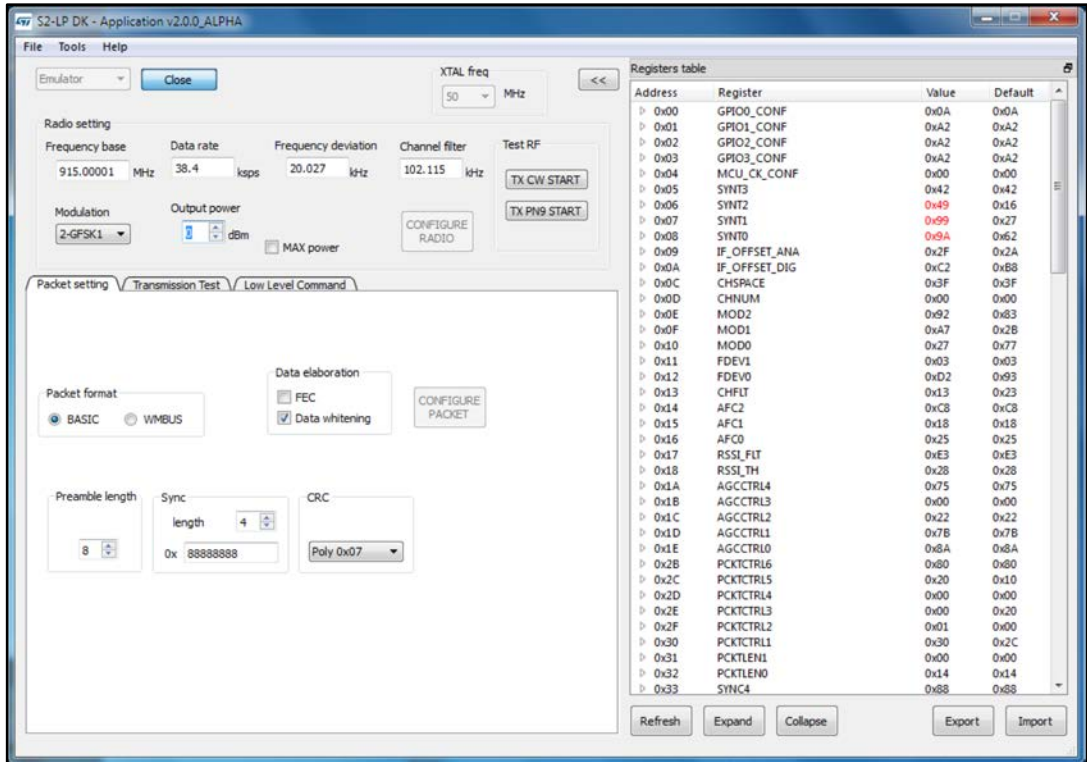**Figure 4: S2-LP application daughterboard + STM32 nucleo board**

Figure 5: Graphical user interface

3 Measurements report

All of the measurements reported here are measured using the following parameters: Tc = 25 °C, Vdd= 3.3 V, f = 460 MHz, unless otherwise specified.

3.1 FCC part 90.205

The +33 dBm has to be considered as upper limit of this specification. In this case the maximum S2-LP output power is +16 dBm, so the specification is fully met.

3.2 FCC part 90.207

S2-LP implements frequency modulation (F), digital modulation (1) and data, telemetry and telecommand as transmitted information (D). FCC part 90 permits the F1D modulation in the 450 MHz – 470 MHz band. So this specification requirement is fully met.

3.3 FCC part 90.209

The FCC standard provides a table which specifies the channel spacing and bandwidths for each frequency band. Within the 421 MHz – 512 MHz band the required channel spacing is 6.25 kHz. Also, the standard provides the permissible authorized bandwidths. Operations using equipment designed to operate with a 25 kHz channel bandwidth will be authorized a 20 kHz bandwidth. Operations using equipment designed to operate with a 12.5 kHz channel bandwidth will be authorized an 11.25 kHz bandwidth. Operations using equipment designed to operate with a 6.25 kHz channel bandwidth will be authorized a 6 kHz bandwidth.

The standard does not specify the measurement method to evaluate the bandwidth of the signal. In this case, the occupied bandwidth is measured using the 99% power calculation method.

The 99% occupied bandwidth of the cases used in the following parts of this application note are reported *Table 2: "Occupied bandwidth"*.

Table 2: Occupied bandwidth

2-GFSK, BT = 0.5 Data rate [kbps]	Frequency deviation [kHz]	99% occupied bandwidth [kHz]	FCC part 90 limit [kHz]
9.6	4.8	16.3	20
4.8	2.4	8.1	20 / 11.25
2.4	1.2	4.1	11.25 / 6
1.2	1	3.1	6

3.4 Emission mask

Transmitters used in the radio services governed by this part must comply with the emission masks outlined in this section.

A table is provided from the standard where the required spectral emission mask is defined as function of the channel bandwidth. Within the 421 MHz – 512 MHz band the required spectral emission masks are the C, D and E.

Two different cases were measured to show the compliance with the three different masks. For different combination of modulation, data rate or frequency deviation dedicated measurements have to be done.

3.4.1 Emission mask C

Transmitters designed to operate with a 25 kHz channel bandwidth have to meet the emission mask C requirements. To show the compliance of the S2-LP two different cases are considered:

Modulation: 2-GFSK with BT=0.5

Data rate: 4.8 kbps

Frequency deviation: 2.4 kHz

Output power: +10 dBm (10 mW)

and

Modulation: 2-GFSK with BT=0.5

Data rate: 9.6 kbps

Frequency deviation: 4.8 kHz

Output power: +10 dBm (10 mW)

Figure 6: "Emission mask C compliance measurements" shows the measurements results. S2-LP device fully meets the emission mask C requirement in the two considered cases.

Figure 6: Emission mask C compliance measurements
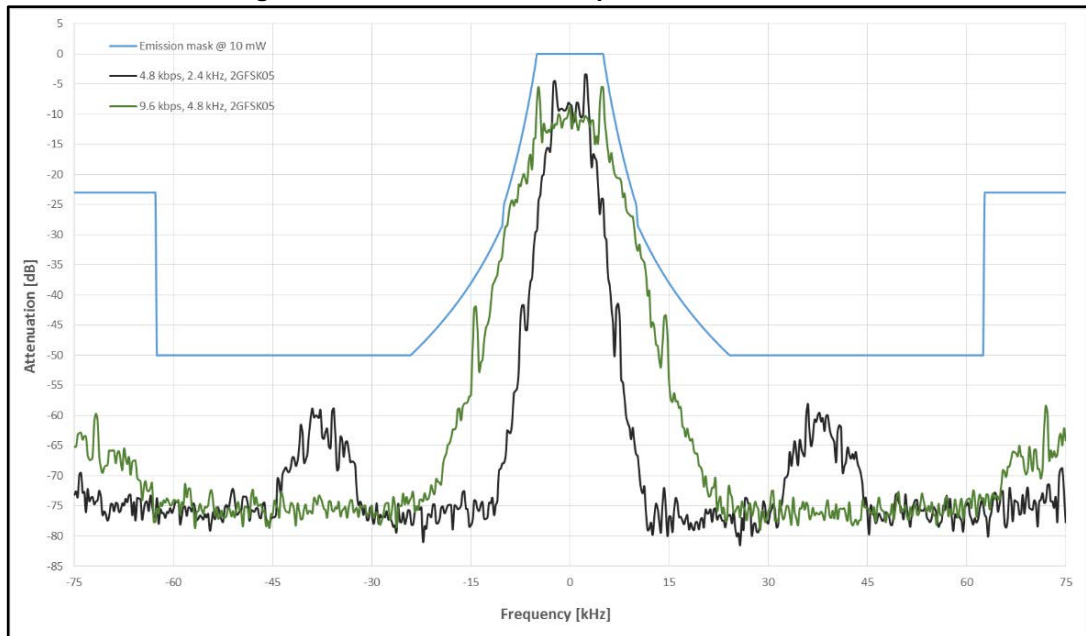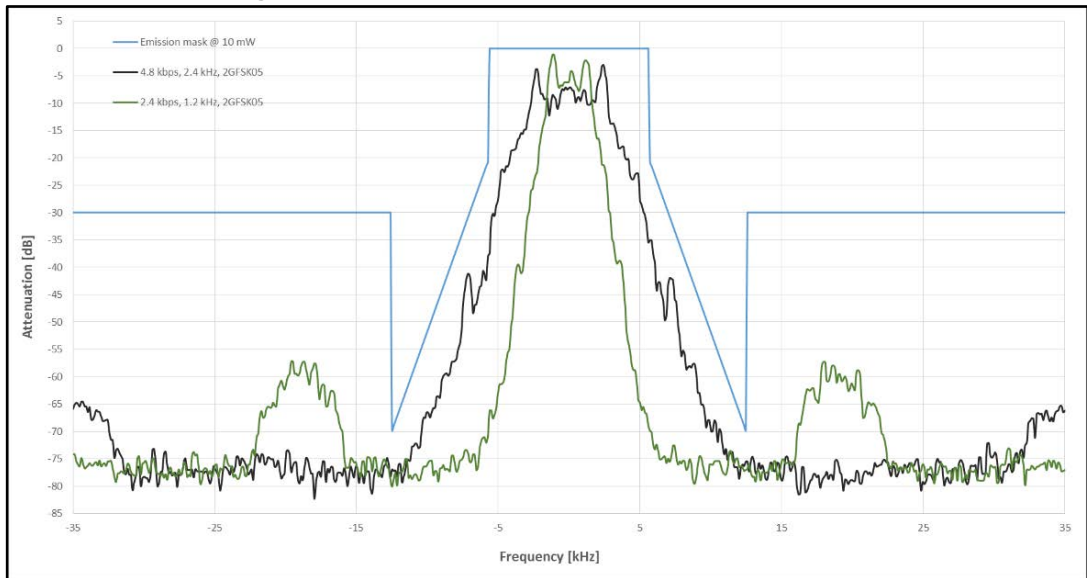

3.4.2 Emission mask D

Transmitters designed to operate with a 12.5 kHz channel bandwidth have to meet the emission mask D requirements. To show the compliance of the S2-LP two different cases are considered:

Modulation: 2-GFSK with BT=0.5

Data rate: 4.8 kbps

Frequency deviation: 2.4 kHz

Output power: +10 dBm (10 mW)

and

Modulation: 2-GFSK with BT=0.5

Data rate: 2.4 kbps

Frequency deviation: 1.2 kHz

Output power: +10 dBm (10 mW)

Figure 7 shows the measurements results. S2-LP device fully meets the emission mask D requirement in the two considered cases.

Figure 7: Emission mask D compliance measurements

3.4.3   Emission mask E

Transmitters designed to operate with a 6.25 kHz channel bandwidth have to meet the emission mask D requirements. To show the compliance of the S2-LP two different cases are considered:

 Modulation: 2-GFSK with BT=0.5

 Data rate: 2.4 kbps

 Frequency deviation: 1.2 kHz

 Output power: +10 dBm (10 mW)

and

Modulation: 2-GFSK with BT=0.5

 Data rate: 1.2 kbps

 Frequency deviation: 1 kHz

 Output power: +10 dBm (10 mW)

Figure 8: "Emission mask E compliance measurements" shows the measurements results. S2-LP device fully meets the emission mask E requirement in the two considered cases.

Figure 8: Emission mask E compliance measurements
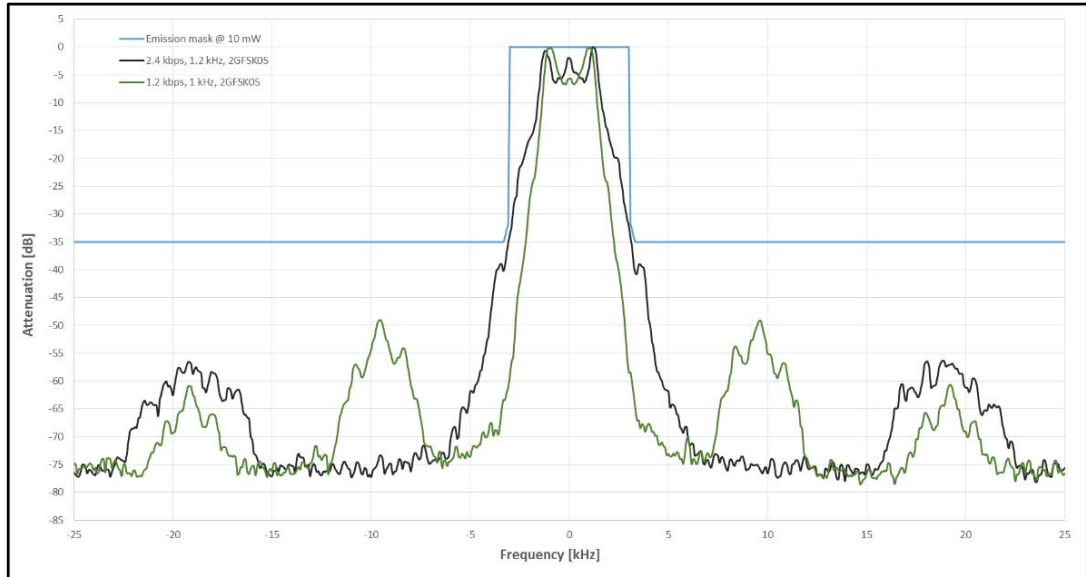
3.5 FCC part 90.213

Transmitters used in the radio services governed by this part must comply with a minimum frequency stability as reported in *Section 1.5: "FCC part 90.213"*.

A TCXO is suggested to be used in the final application to be compliant with the frequency stability requirements.

3.6 FCC part 90.214

Transmitters used in the radio services governed by this part must maintain transient frequencies within the maximum frequency difference (from the assigned transmitter frequency) limits during some time intervals of the transmission. The requirements are done as function of channel bandwidth and transmit output power level. The limits are reported in *Section 1.6: "FCC part 90.214"* of this document.

Figure 9: "Demodulated packet" shows a demodulated packet with the following parameters:
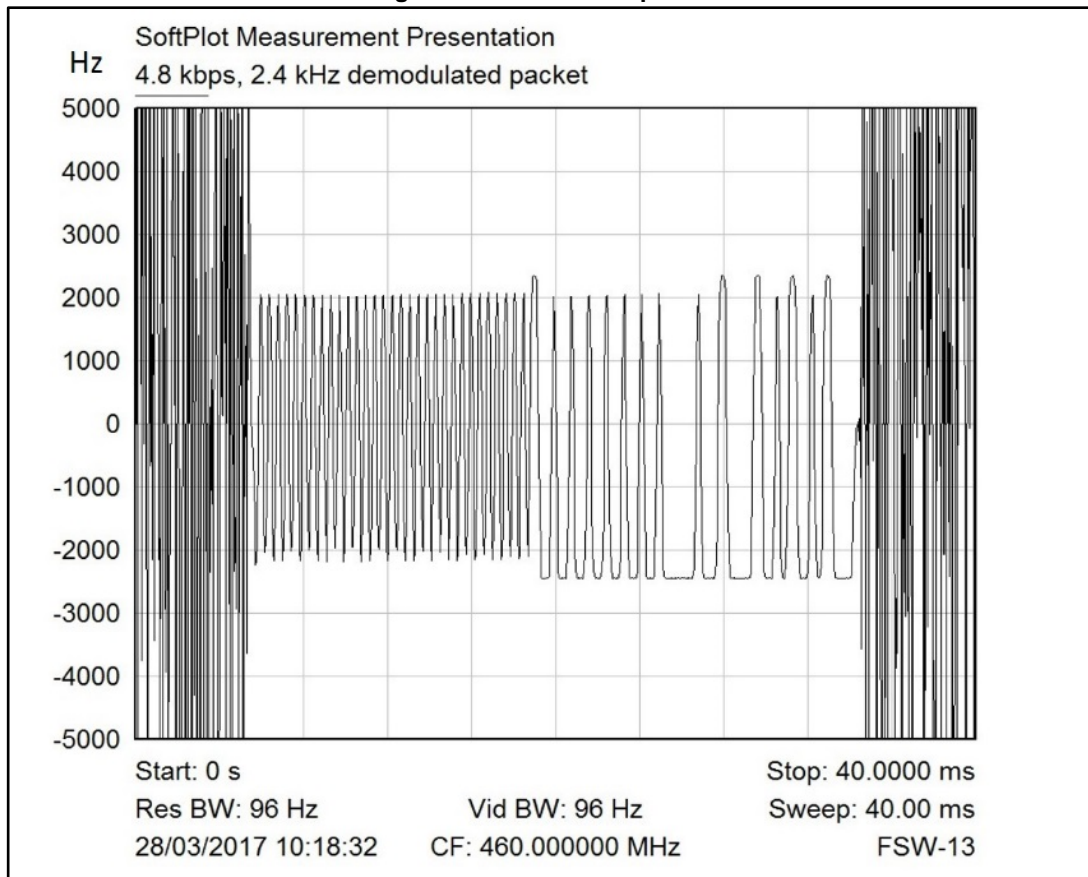
Modulation: 2-GFSK with BT=0.5

Data rate: 1.2 kbps

Frequency deviation: 1 kHz

Output power: +10 dBm (10 mW)

The S2-LP device complies with the requirements of FCC part 90.214 for transient frequency behavior, even for the most stringent requirement of 6.25 kHz channel bandwidth.

Figure 9: Demodulated packet

3.7 FCC part 90.217

Transmitters used at station licensed below 800 MHz which have an output power not exceeding +20.8 dBm (120 milliwatts) are exempt from the technical requirements set out in this subpart, but must instead comply with the limits as defined in the 90.217 as described in *Section 1.7: "FCC part 90.217"*.

The S2-LP device can be used with output power lower than +20.8 dBm, so the compliance with the part 90.217 has to be guaranteed.

A mask with an attenuation of at least 30 dB is defined on a frequency 40 kHz or more for the 25 kHz channel bandwidth, 25 kHz or more for the 12.5 kHz channel bandwidth and 12.5 kHz or more for the 6.25 kHz channel bandwidth removed from the assigned frequency. This measurement should be done using an unmodulated carrier, but from the figures 6, 7 and 8 it is possible to see that more than 30 dB attenuation is already guaranteed using a modulated signal so, for sure, it is guaranteed using an unmodulated carrier. So no further measurements have done to show the compliance with this point.

3.8 FCC part 90.221

For the frequencies in the 450 MHz - 470 MHz bandwidths, operations using equipment designed to operate with a 25 kHz channel bandwidth may be authorized up to a 22 kHz bandwidth if the equipment meets the adjacent channel power (ACP) limits reported in *Table 1: "ACP requirements"*. It specifies a value for the ACP as a function of the displacement from the channel center frequency and a measurement bandwidth of 18 kHz.

The studied cases have an occupied bandwidth lower than 20 kHz, so no specific measurements have to be done.

4 Reference

1. S2-LP datasheet
2. FCC title 47 Part 15: "Radio frequency devices"

5 Revision history

Table 3: Document revision history

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

IMPORTANT NOTICE – PLEASE READ CAREFULLY