
**Using the BlueNRG family transceivers under ETSI EN 300 328
in 2400 –2483.5 MHz band**

Introduction

BlueNRG family devices are very low power Bluetooth low energy (BLE) devices compliant with Bluetooth specifications.

Bluetooth low energy technology operates in the same spectrum range (2400 - 2483.5 MHz, ISM band) as classical Bluetooth technology, but uses a different set of channels. Bluetooth low energy technology has 40 channels (37 data channels + 3 advertising channels) of 2 MHz band. Within the channel, data is transmitted using GFSK (Gaussian frequency shift modulation). The bit rate is 1 Mbit/s, and the maximum transmit power is 10 mW (10 dBm).

Further details are given in volume 6 part A of the Bluetooth Core Specification V4.0.

The BlueNRG family includes:

- BlueNRG single-mode network processor; Bluetooth v4.0 compliant
- BlueNRG-MS single-mode network processor; Bluetooth v4.1 compliant
- BlueNRG-1 single-mode system-on-chip (application processor); Bluetooth v4.2 compliant
- BlueNRG-2 single-mode system-on-chip (application processor); Bluetooth v4.2 compliant

This application note outlines the expected performance when using the BlueNRG under ETSI EN 300 328 in the 2400 to 2483.5 MHz band.

For details on the regulatory limits in 2400 - 2483.5 MHz frequency band, please, refer to ETSI EN 300 328 V2.1.1 (2016-11).

These can be downloaded from www.etsi.org.

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1 An overview of ETSI regulations

The use of radio equipment in most European countries is regulated through the R&TTE directive. The European Telecommunications Standard Institute (ETSI) is a standardization body that issues the standards for testing and type approval of transmitters and receivers. EN 300 328 covers the 2.4 GHz band and specifies in detail the requirements and test methods to be used for license-free operated radio equipment under class 3a, equipment using wideband modulation techniques (DSSS or FHSS).

The standard defines two categories of equipment based on modulation type:

- Frequency hopping spread spectrum (FHSS)
- Other types of wide band modulation (DSSS, OFDM, etc.)

It also covers both adaptive and non-adaptive equipment.

Adaptive equipment uses an automatic mechanism which allows the equipment to adapt automatically to its environment by identifying frequencies that are being used by other equipment.

ETSI classifies Bluetooth LE as adaptive equipment using DSSS modulation.

ETSI defines different receiver categories with different receiver requirements and/or corresponding limits:

- **Receiver category 1:** adaptive equipment with a maximum RF output power greater than 10 dBm EIRP
- **Receiver category 2:** non-adaptive equipment with a Medium Utilization (MU) factor greater than 1% and less than or equal to 10% or adaptive equipment with a maximum RF output power of 10 dBm EIRP.
- **Receiver category 3:** non-adaptive equipment with a maximum Medium Utilization (MU) factor of 1% or adaptive equipment with a maximum RF output power of 0 dBm EIRP.

Bluetooth LE is classified as adaptive equipment with a maximum RF output power of 10 dBm, so the Bluetooth LE receivers has to be category 2.

2 Technical requirements

RF output power

The RF output power is defined as the mean equivalent isotropic radiated power (e.i.r.p.) of the equipment during a transmission burst.

The max allowed limit is -10 dBW (20 dBm, 100 mW).

Power spectral density

It is the mean equivalent isotropically radiated power spectral density during a transmission burst.

Its value is limited to 10 dBm per MHz.

Occupied channel bandwidth

It is the bandwidth that contains 99% of the power of the signal.

It shall fall completely within the band 2.4 GHz to 2.4835 GHz.

Transmitter unwanted emissions in the out-of-band domain

They are emissions when the equipment is in transmit mode, on frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious.

The transmitter of unwanted emissions in out-of-band domain but outside the allocated band shall not exceed the values provided by the mask in the following table.

Table 1: Transmitter in out-of-band domain

Frequency range	Transmit mask level	Domain
< 2396 MHz		Spurious
2396 to 2398 MHz	- 20 dBm/MHz	Out of Band
2398 to 2400 MHz	- 10 dBm/MHz	Out of Band
2400 to 2483.5 MHz		Allocated Band
2483.5 to 2485.5 MHz	-10 dBm/MHz	Out of Band
2485.5 to 2487.5 MHz	-20 dBm/MHz	Out of Band
> 2487.5 MHz		Spurious

Transmitter of unwanted emissions in the spurious domain

Transmitter of unwanted emissions in spurious domain are emissions outside the allocated band and outside the out-of-band domain (as specified in the previous table), when the equipment is in transmit mode.

The transmitter unwanted emissions in the spurious domain shall not exceed the values given in the following table.

Table 2: Transmitter in spurious domain

Frequency range	Maximum power, e.r.p. (≤ 1 GHz) e.i.r.p. (> 1 GHz)	Bandwidth
30 MHz to 47 MHz	-36 dBm	100 kHz
47 MHz to 74 MHz	-54 dBm	100 kHz
74 MHz to 87.5 MHz	-36 dBm	100 kHz
87,5 MHz to 118 MHz	-54 dBm	100 kHz
118 MHz to 174 MHz	-36 dBm	100 kHz
174 MHz to 230 MHz	-54 dBm	100 kHz
230 MHz to 470 MHz	-36 dBm	100 kHz
470 MHz to 862 MHz	-54 dBm	100 kHz
862 MHz to 1 GHz	-36 dBm	100 kHz
1 GHz to 12.75 GHz	-30 dBm	1 MHz

Receiver spurious emissions

Receiver spurious emissions are emissions at any frequency when the equipment is in receive mode. They shall not exceed the values given in the following table.

Table 3: Receiver spurious emissions

Frequency range	Maximum power, e.r.p.	Measurement bandwidth
30 MHz to 1 GHz	-57 dBm	100 kHz
1 GHz to 12.75 GHz	-47 dBm	1 MHz

Receiver blocking

Receiver blocking is a measure of the ability of the equipment to receive a wanted signal on its operating channel without exceeding a given degradation in the presence of an unwanted signal (blocking signal) at frequencies other than those of the operating band.

The minimum performance criterion is a PER less than or equal to 10%.

Table 4: Receiver blocking

Wanted signal mean power [dBm]	Blocking signal frequency [MHz]	Minimum blocking signal power [dBm]
Pmin + 6 dB	2380	-57
	2503.5	
Pmin + 6 dB	2300	-47
	2583.5	

3 Application circuit

Figure 1: "BlueNRG application daughterboard" shows the BlueNRG-MS daughterboard (STEVAL-IDB005V2D). It holds the BlueNRG-MS device and the circuitry necessary for it to function. The Bluetooth low energy protocol stack (GAP, GATT, SM, L2CAP, LL, RF-PHY) is embedded in the device.

The board is equipped with a 32 MHz XTAL to provide the correct oscillator to the BlueNRG-MS. A low speed crystal oscillator (32.768 kHz) is also mounted and used by the BlueNRG-MS.

An internal SMPS on the BlueNRG-MS drastically reduces power consumption. The SMPS is fed from the battery and provides a programmable voltage to the device (1.4 V typical).

An SMA connector is present to connect the board to an antenna or to an instrument to verify correct operation and to verify standard compliance.

An integrated balun (STM BALF-NRG-01D3) is used for the differential-to-single-ended conversion and to show the correct impedance at the TX/RX of the BlueNRG-MS device. A C-L-C network is included for improved matching and to increase the out of band attenuation.

The daughterboard must be plugged onto a motherboard (see *Figure 2: "BlueNRG application motherboard"*) via two 5 x 2 header connectors.

The motherboard includes an STM32L152VBT6 microcontroller to program the transceiver; the microcontroller is programmed with firmware developed for the BlueNRG application.

A graphical user interface (GUI) is available to help program the BlueNRG-MS.

Figure 1: BlueNRG application daughterboard

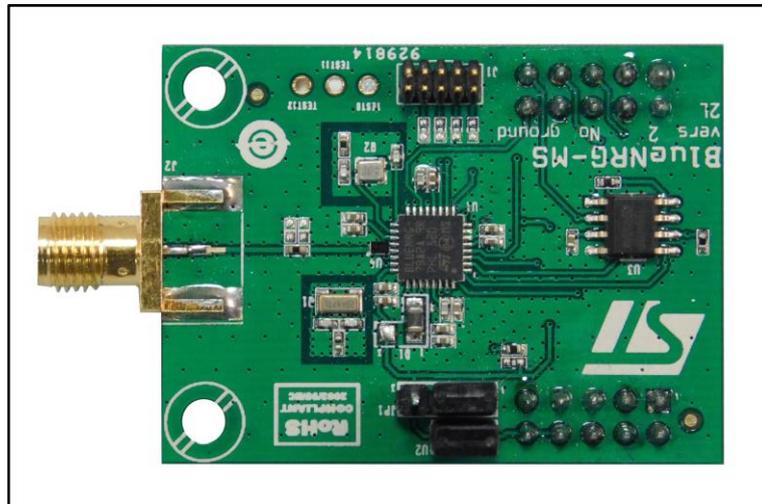


Figure 2: BlueNRG application motherboard

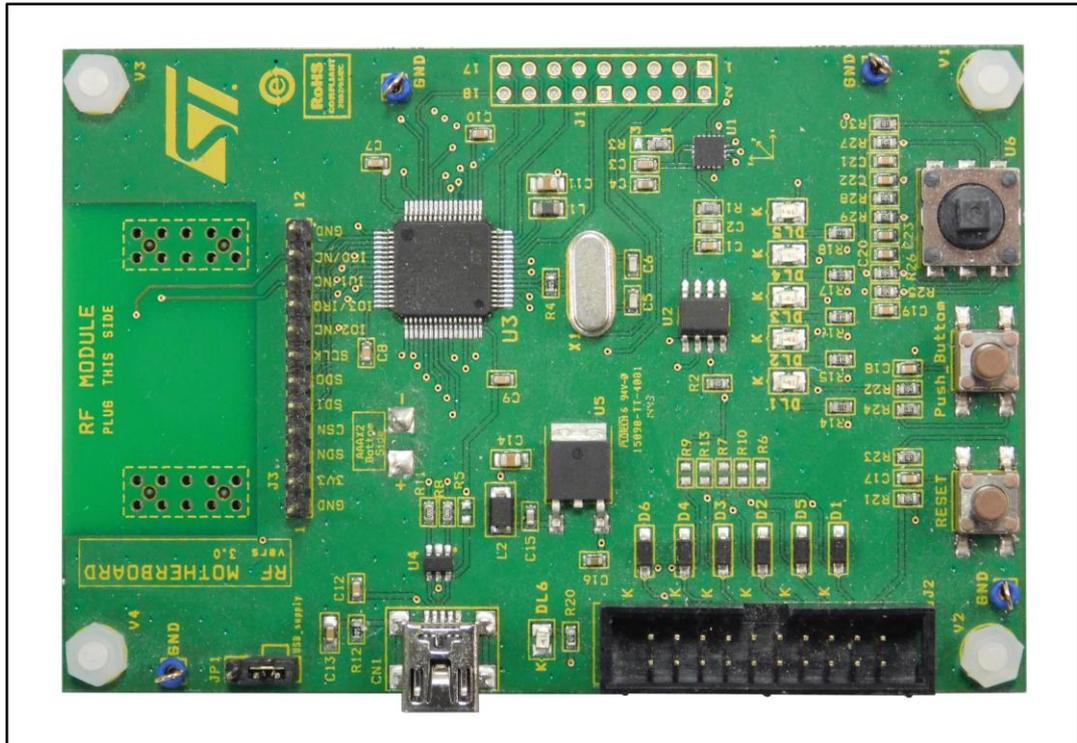


Figure 3: "BlueNRG-1/2 application board" shows the BlueNRG-1/2 (STEVAL-IDB007V1 and STEVAL-IDB008V1) evaluation platform.

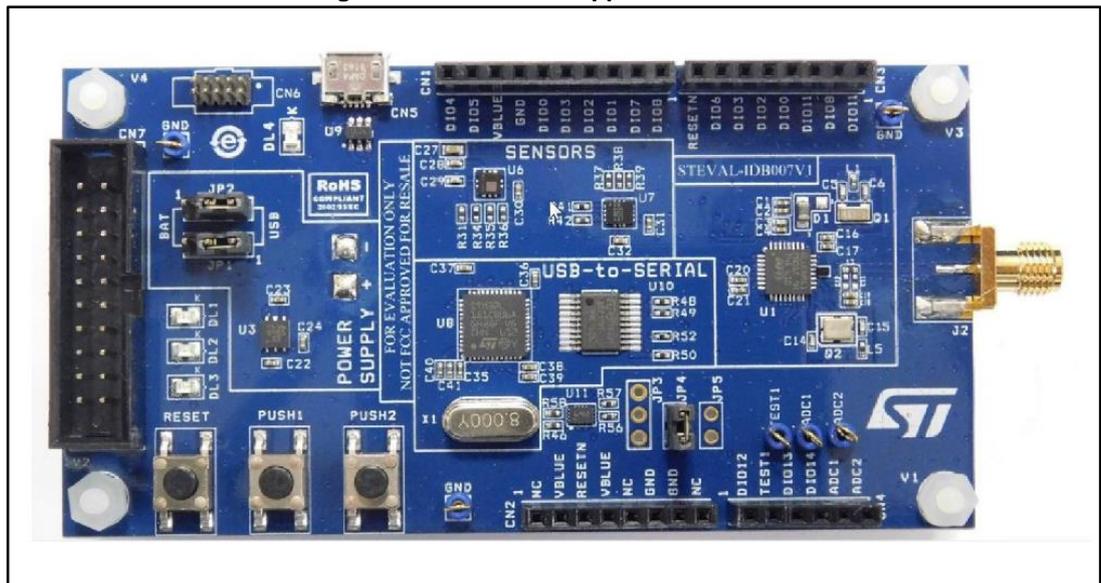
The two platforms also provide a set of hardware resources for implementing a wide range of application scenarios: sensor data (accelerometer, pressure and temperature sensor), remote control (buttons and LEDs) and debug message management via USB virtual COM.

Three power options are available (USB only, battery only, external power supply + USB) for high application development and testing flexibility.

An SMA connector is present to connect the board to an antenna or to an instrument to verify correct operation and to verify standard compliance.

An integrated balun, STM BALF-NRG-01D3, is used for the differential-to-single-ended conversion and to show the correct impedance at the TX/RX of the BlueNRG-1/2 devices. A C-L-C network is included for better matching and to increase the out of band attenuation.

Figure 3: BlueNRG-1/2 application board



4 Transmitter parameter

The measurements that follow are taken at $T_C = 25\text{ }^\circ\text{C}$, $V_{dd} = 3.3\text{ V}$, $f = 2402\text{ MHz}$ (lower useful bandwidth frequency), unless otherwise specified.

4.1 RF output power

For RF output power measurement, the equipment must be connected to a fast power sensor suitable for 2.4 GHz and capable of a minimum 1 MS/s.

The measurements were performed using a spectrum analyzer with the following settings:

- Center frequency: 2402 MHz (ch 0), 2440 MHz (ch 19) and 2480 MHz (ch 39)
- Span = 4 MHz
- RBW = 1 MHz
- VBW = 1 MHz
- Detector = peak
- Trace = max hold
- Sweep time = auto

The equipment is programmed to provide a single tone. The marker is set to max.

The following table shows the measurement results.

The BlueNRG family fully satisfies the ETSI max. permitted output power specification of +20 dBm.

Table 5: RF output power

Frequency (MHz)	Channel	Output power [dBm]	ETSI spec [dBm]
2402	37	7.4	+20
2442	18	7.3	
2480	39	7.2	

4.2 Power spectral density

The measurement shall be performed at the lowest, the middle, and the highest channel on which the equipment can operate.

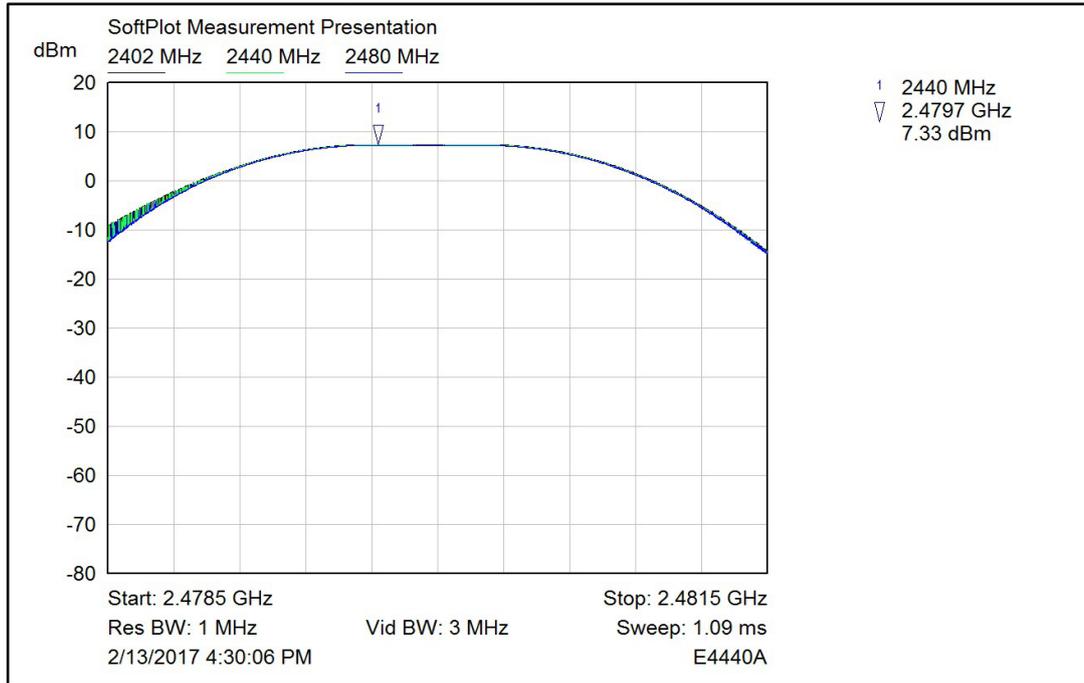
The transmitter shall be connected to a spectrum analyzer with the following settings:

- Center frequency: 2402 MHz (ch 37), 2440 MHz (ch 18) and 2480 MHz (ch 39)
- Span = 3 MHz
- RBW = 1 MHz
- VBW = 3 MHz
- Detector = peak
- Trace = max hold
- Sweep time = auto

Find the peak value of the trace and place the analyzer marker on this peak. This level is the highest mean power (power spectral density) in a 1 MHz band.

The measurements in the three channels show a value in line with the limit: 10 dBm/MHz.

Figure 4: Power spectral density Ch 37



4.3 Occupied channel bandwidth

The measurement shall be performed at the lowest, middle and highest frequencies within the stated frequency range.

The spectrum analyzer must be set with:

- Center frequency: 2402 MHz (ch 37), 2440 MHz (ch 18) and 2480 MHz (ch 39)
- Span = 2 x nominal channel bandwidth (2 MHz), that is 4 MHz
- RBW = $\geq 1\%$ of the span
- VBW = 3 x RBW
- Detector = RMS
- Trace = max hold
- Sweep time = 1 s

Find the peak value of the trace and place the analyzer marker on this peak.

Use the 99 % bandwidth function of the spectrum analyzer to measure the occupied channel bandwidth of the equipment under test.

The measurements show a value equal to 1 MHz for all channels; completely within the 2.4 - 2.4835 GHz band.

Table 6: RF output power

Frequency (MHz)	Channel	Channel bandwidth [MHz]
2402	37	1.05
2442	18	1.05
2480	39	1.05

4.4 Transmitter unwanted emissions in out-of-band domain

The measurement shall be performed at the lowest and the highest channel on which the equipment can operate.

The spectrum analyzer must be set with:

- Center frequency: 2484 MHz
- Span = 0 Hz
- RBW = 1 MHz
- VBW = 3 MHz
- Filter mode = channel filter
- Detector = RMS
- Trace = max hold
- Sweep time = continuous
- Sweep points = sweep time [s] / (1 us) or 5000 whichever is greater
- Trigger mode = video trigger; in case video triggering is not possible, an external trigger source may be used
- Sweep time = > 120 % of the duration of the longest burst detected during the measurement of the RF power

For the segment 2483.5 MHz to 2485.5 MHz (2483.5 MHz to 2483.5 MHz + BW):

- Adjust the trigger level to select the transmissions with the highest power level.
- Set a window (start and stop lines) to match with the start and end of the burst and in which the RMS power shall be measured using the time domain power function.
- Select RMS power to be measured within the selected window and note the result which is the RMS power within this 1 MHz segment (2483.5 MHz to 2484.5 MHz).
- Compare this value with the applicable limit provided by the mask.
- Increase the center frequency in steps of 1 MHz and repeat this measurement for every 1 MHz segment within the range 2483.5 MHz to 2485.5 MHz. The center frequency of the last 1 MHz segment shall be set to 2485.5 MHz - 0.5 MHz (which means this may partly overlap with the previous 1 MHz segment).

For the segment 2485.5 MHz to 2487.5 MHz (2483.5 MHz + BW to 2483.5 MHz + 2BW):

- Change the center frequency of the analyzer to 2486 MHz and perform the measurement for the first 1 MHz segment within range 2485.5 MHz to 2487.5 MHz. Increase the center frequency in 1 MHz steps and repeat the measurements to cover this whole range.
- The center frequency of the last 1 MHz segment shall be set to 2487.5 MHz - 0.5 MHz.

For the segment 2398 MHz to 2400 MHz (2400 MHz - BW to 2400 MHz):

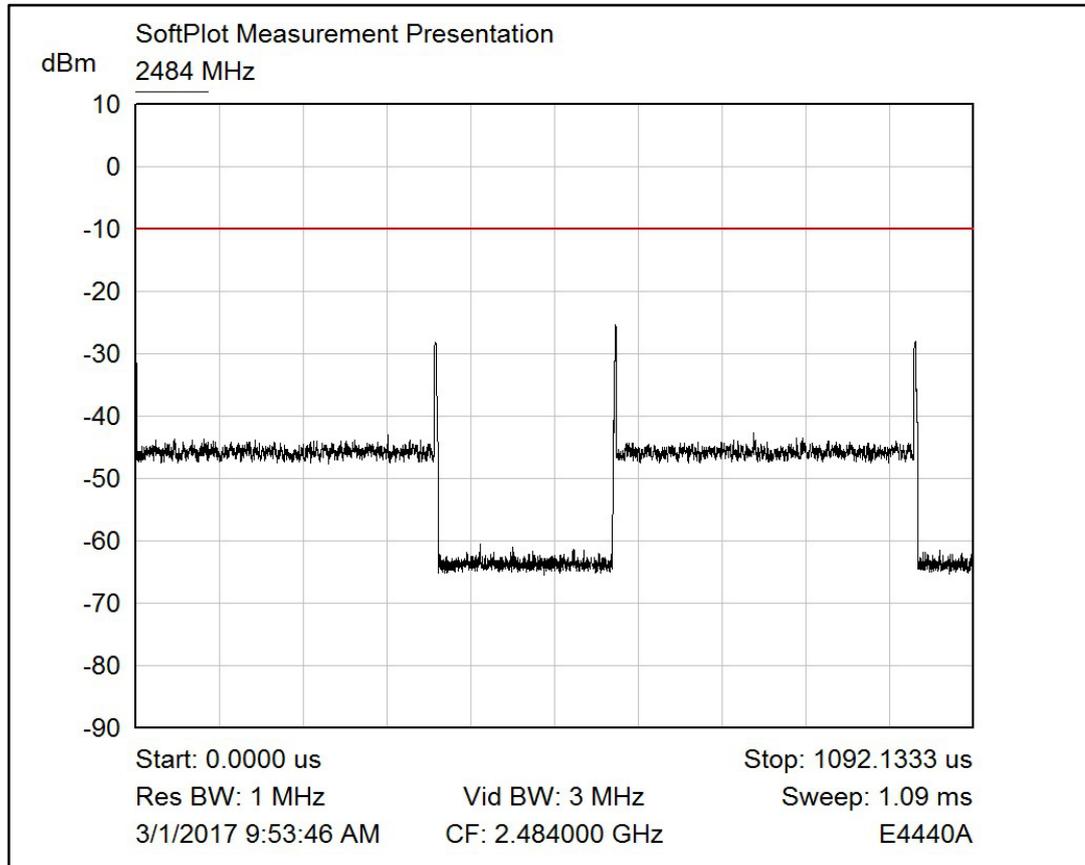
- Change the center frequency of the analyzer to 2399.5 MHz and perform the measurement for the first 1 MHz segment within range 2398 MHz to 2400 MHz.
- Reduce the center frequency in 1 MHz steps and repeat the measurements to cover this whole range.
- The center frequency of the last 1 MHz segment shall be set to 2398 MHz + 0.5 MHz.

For the segment 2396 MHz to 2398 MHz (2400 MHz - 2BW to 2400 MHz - BW):

- Change the center frequency of the analyzer to 2397.5 MHz and perform the measurement for the first 1 MHz segment within range 2396 MHz to 2398 MHz. Reduce the center frequency in 1 MHz steps and repeat the measurements to cover this whole range.
- The center frequency of the last 1 MHz segment shall be set to 2396 MHz + 0.5 MHz.

Following the detailed analysis in all the ranges specified by the mask; the BlueNRG easily satisfies the requirement.

Figure 5: Out-of-band emission 2484 MHz



Follows the detailed analysis in all the ranges specified by the mask; the BlueNRG meets the requirement with large margin.

Figure 9: Out-of-band emission 2399.5 MHz

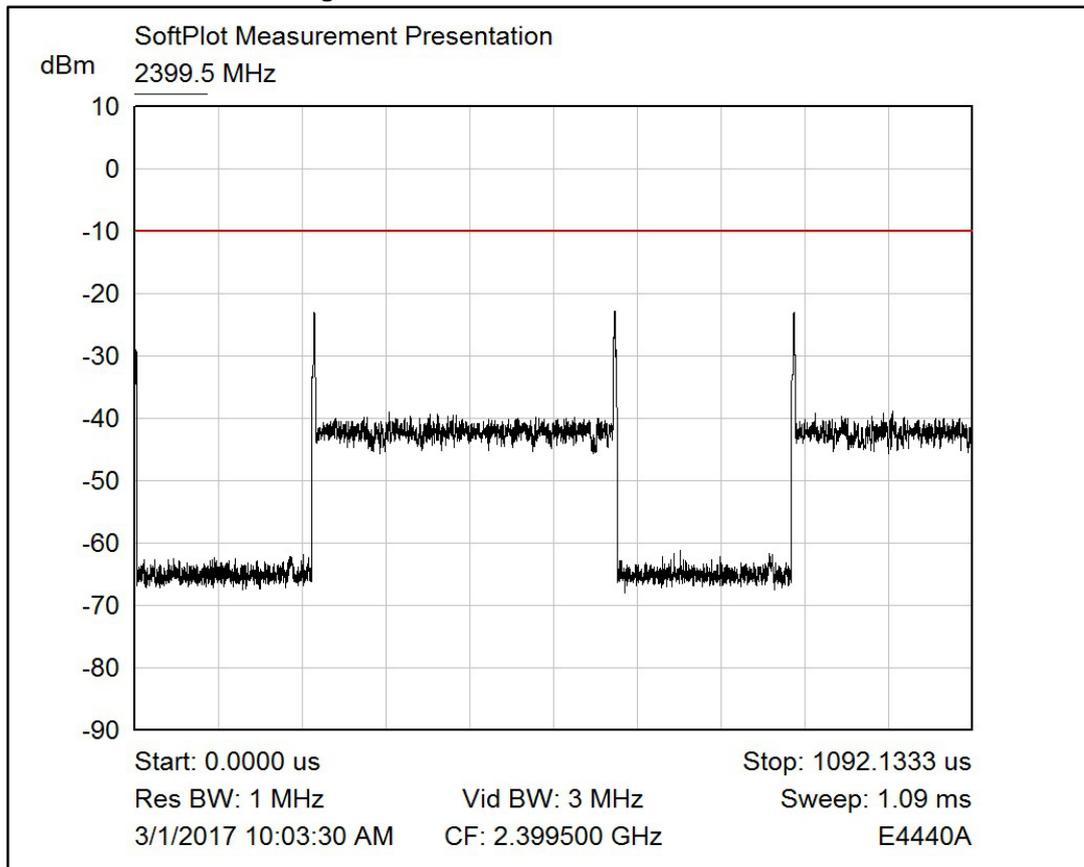
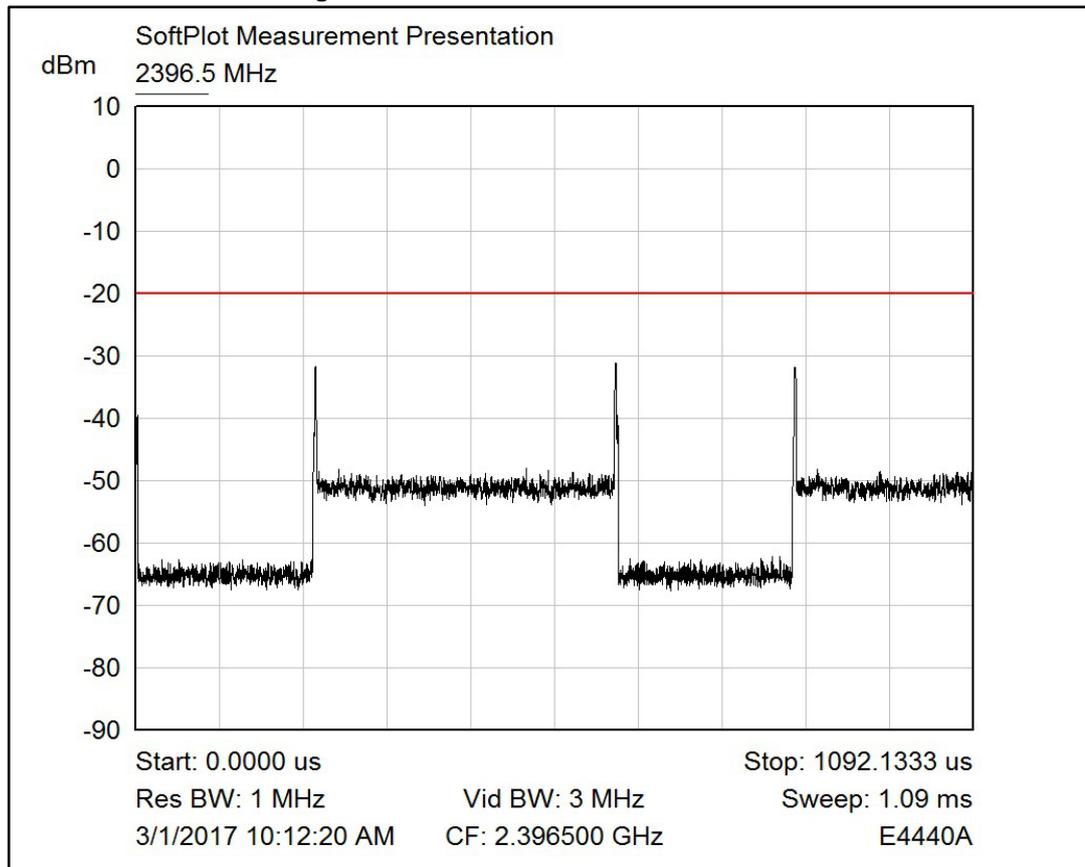


Figure 12: Out-of-band emission 2396.5 MHz



4.5 Transmitted unwanted emissions in spurious domain

The measurement shall be performed at the lowest and the highest channel on which the equipment can operate.

To identify potential unwanted emissions, a pre-scan is performed.

The spectrum analyzer settings for the range 30 MHz to 1000 MHz are:

- Resolution bandwidth = 100 kHz
- Video bandwidth = 300 kHz
- Detector mode = Peak
- Trace Mode = Max Hold
- Sweep Points: ≥ 19400 ; for spectrum analyzers not supporting this high number of sweep points, the frequency band may be segmented

The spectrum analyzer settings for the range 1 GHz to 12.75 GHz are:

- Resolution bandwidth = 1 MHz
- Video bandwidth = 3 MHz
- Detector mode = Peak
- Trace Mode = Max Hold
- Sweep Points: ≥ 23500 ; for spectrum analyzers not supporting this high number of sweep points, the frequency band may be segmented

Any emissions identified during the sweeps above that fall within the 6 dB range below the applicable limit or above, shall be individually measured using the following procedure:

- Measurement mode = time domain power
- Center frequency = frequency of the emission identified during the pre-scan
- Resolution bandwidth = 100 kHz (< 1 GHz) / 1 MHz (> 1 GHz)
- Video bandwidth = 300 kHz (< 1 GHz) / 3 MHz (> 1 GHz)
- Frequency span = zero span
- Detector mode = RMS
- Sweep mode = single sweep
- Sweep time = > 120 % of the duration of the longest burst detected during the measurement of the RF output power
- Sweep Points sweep time [us] / (1 us) with a maximum of 30000
- Trigger = video (burst signals) or manual (continuous signals)

The spectrum analyzer used for this measurement has a maximum number of sweep points of 8192, so the frequency band is so segmented:

- 30 MHz to 500 MHz
- 500 MHz to 1000 MHz
- 1 GHz to 4 GHz
- 4 GHz to 8 GHz
- 8 GHz to 12.75 GHz

No emission is identified during the pre-scan phase with the level above the 6 dB range below the applicable limit or above, so no other measurements are necessary.

Figure 13: Unwanted emission 30 MHz to 500 MHz

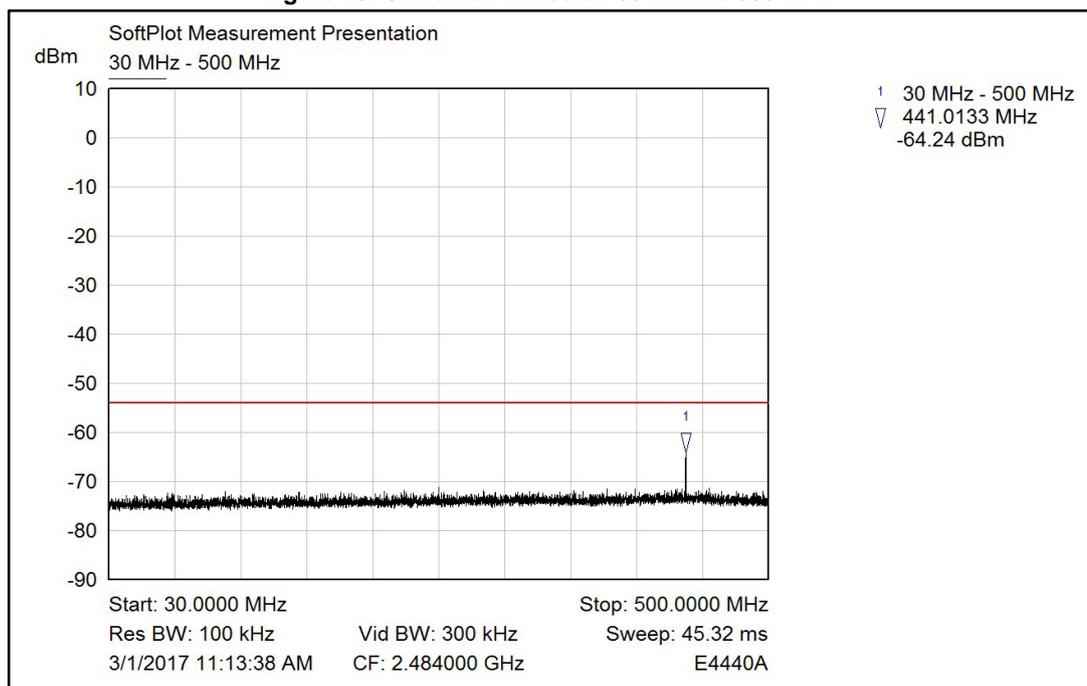


Figure 16: Unwanted emission 8 GHz to 12.75 GHz

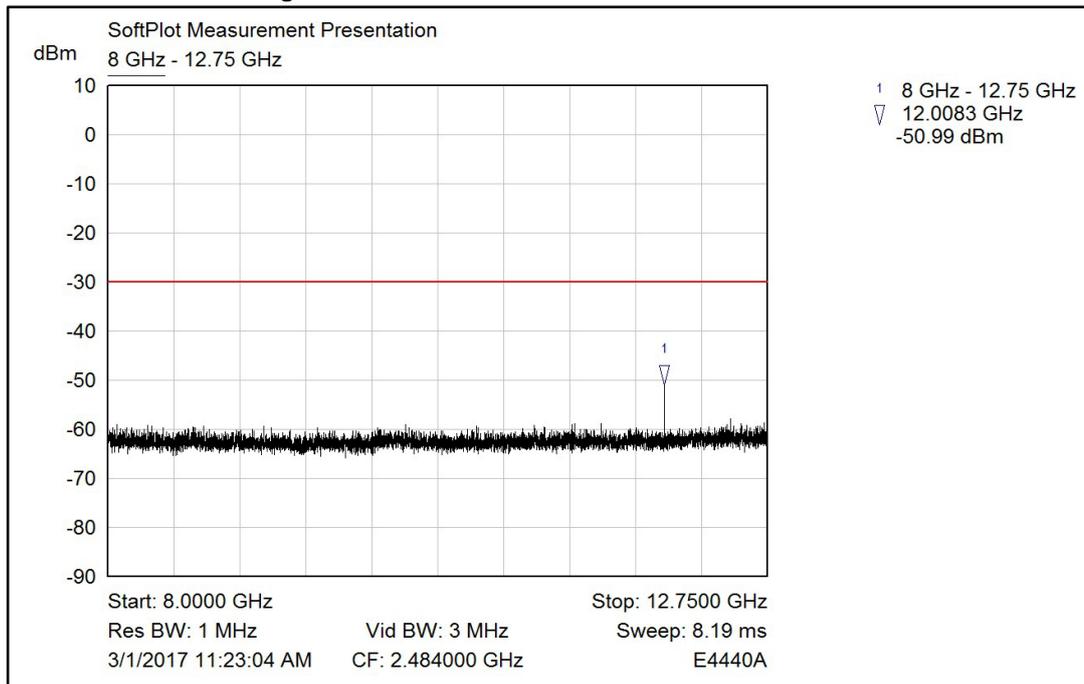
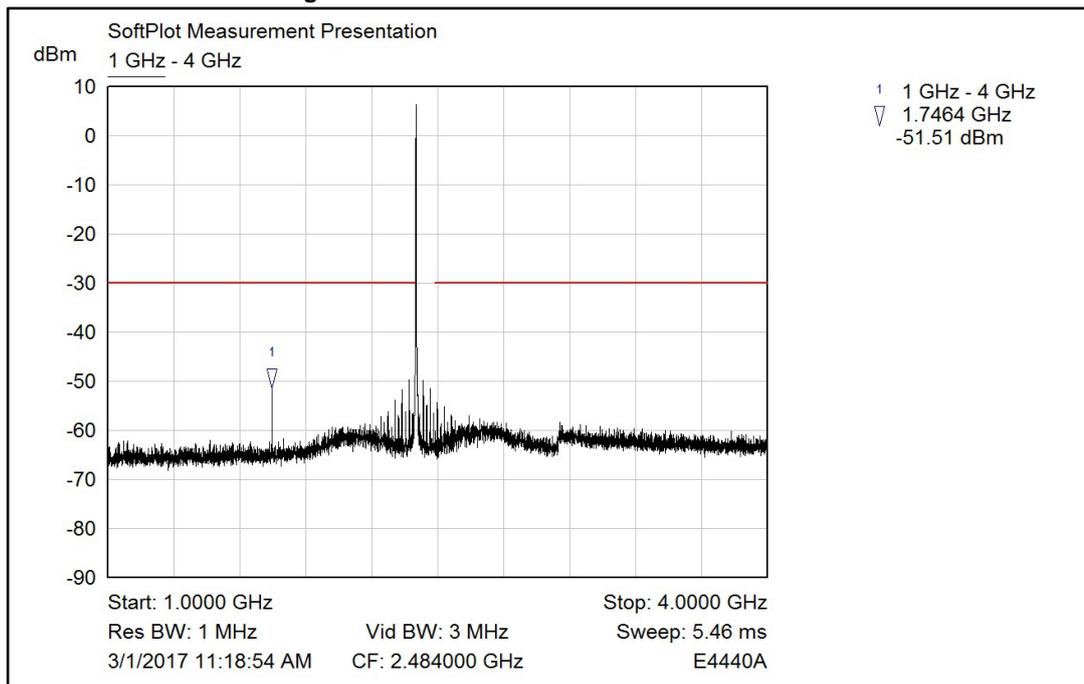


Figure 17: Unwanted emission 1 GHz to 4 GHz



5 Receiver parameter

5.1 Receiver spurious emissions

The measurement shall be performed at the lowest and the highest channel on which the equipment can operate.

Testing shall be performed when the equipment is in a receive-only mode.

The spectrum analyzer settings are equivalent to those used for the transmitted unwanted emissions in spurious domain. No particular problems were encountered for this test.

Figure 18: RX unwanted emission 30 MHz to 500 MHz

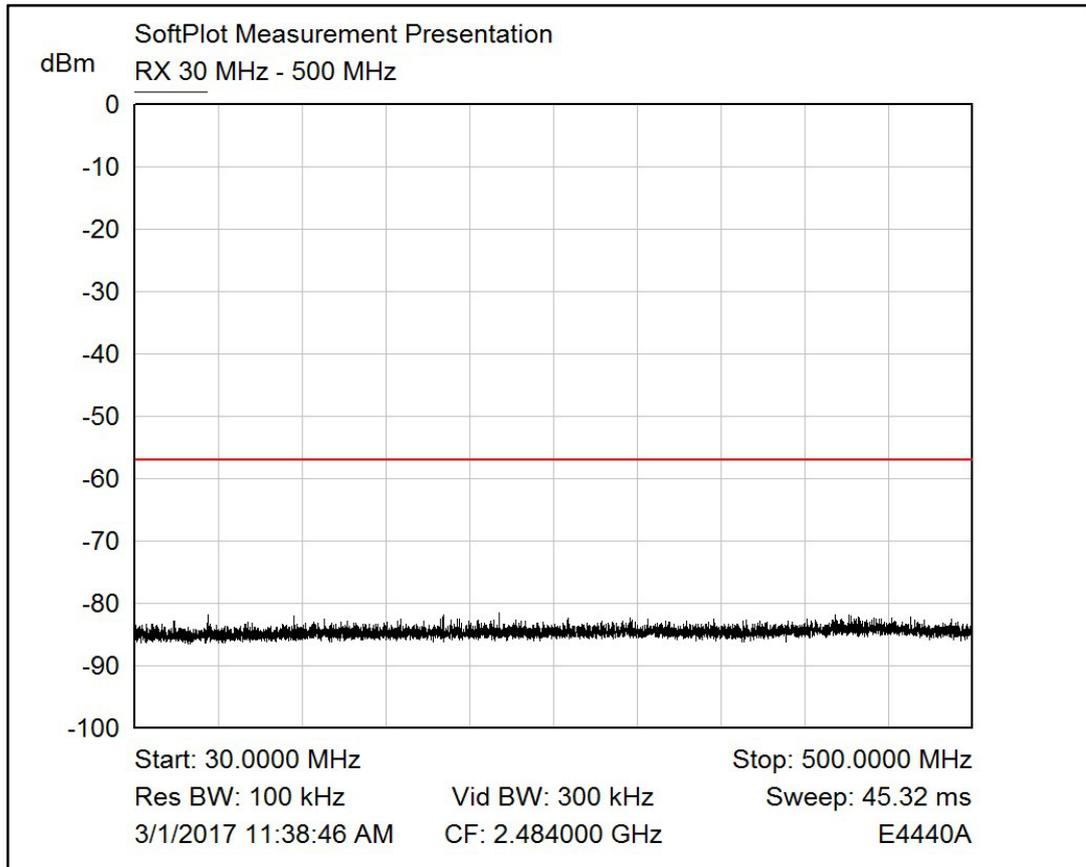


Figure 19: RX unwanted emission 500 MHz to 1000 MHz

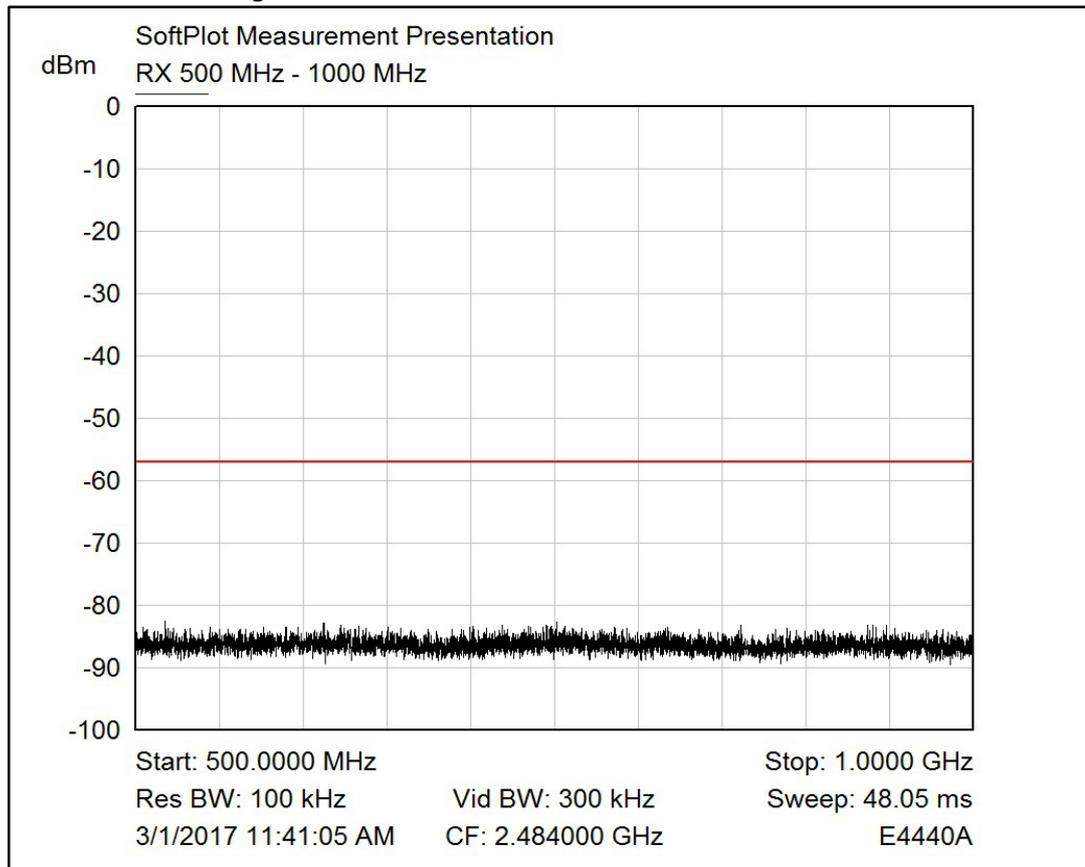


Figure 20: RX unwanted emission 1 GHz to 4 GHz

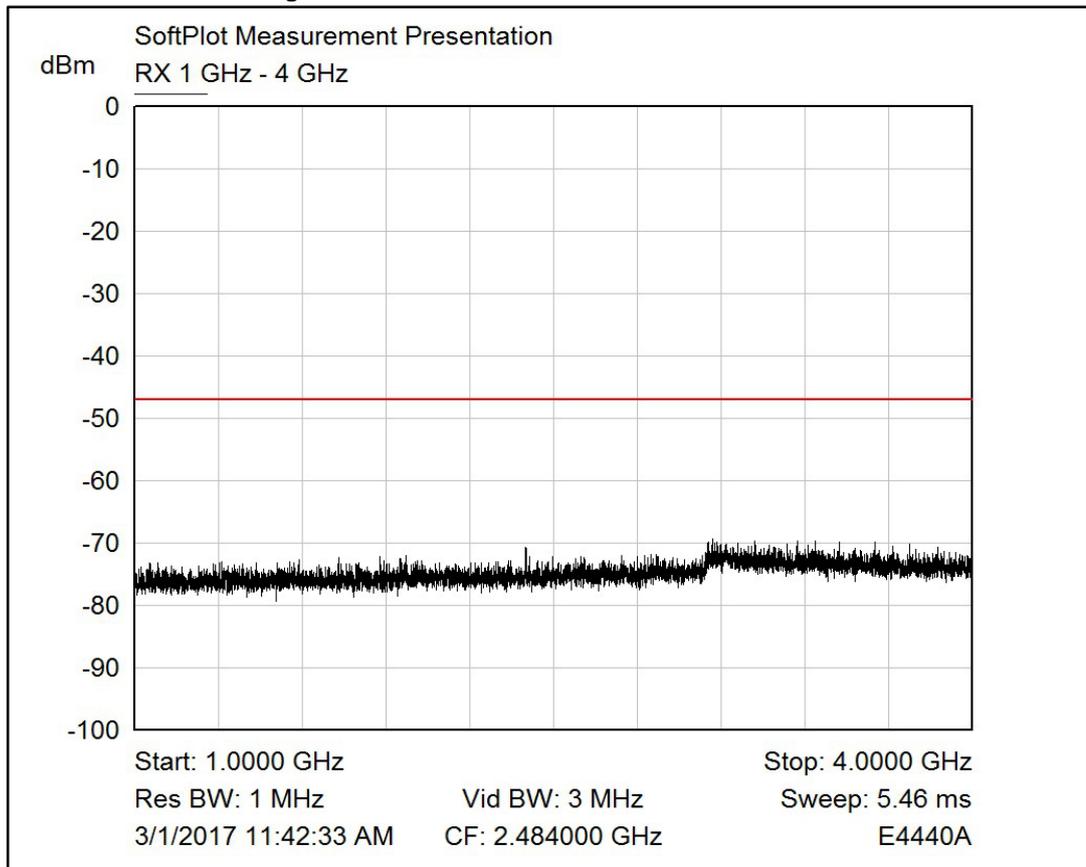


Figure 21: RX unwanted emission 4 GHz to 8 GHz

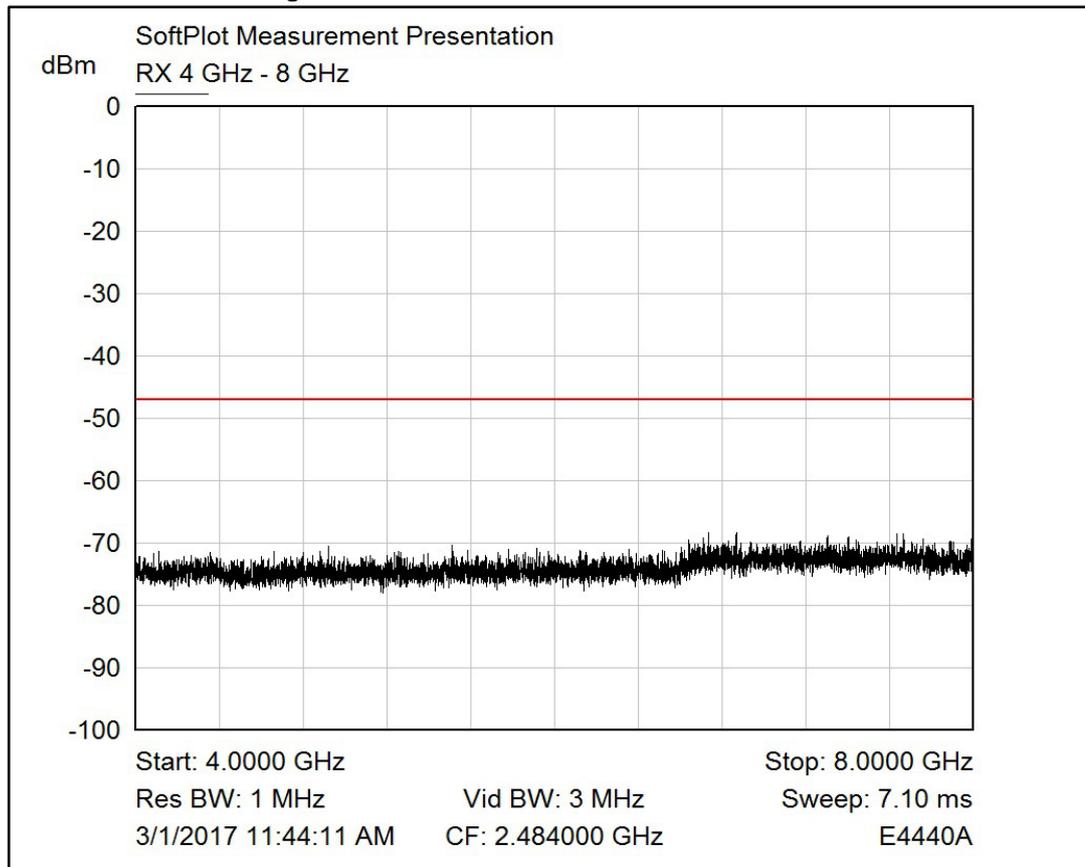
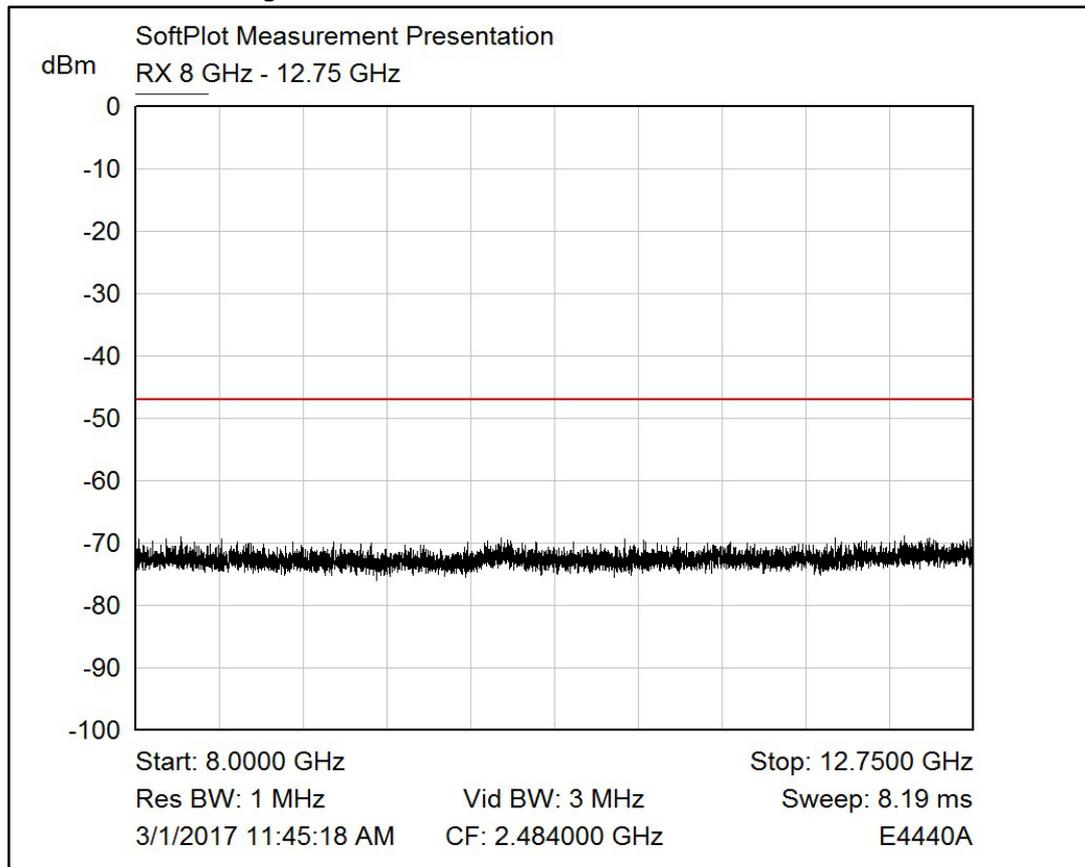


Figure 22: RX unwanted emission 8 GHz to 12.75 GHz



5.2 Receiver blocking

The measurement shall be performed at the lowest and the highest channel on which the equipment can operate.

- The blocking signal generator is set to the first frequency as defined in the appropriate table corresponding to the receiver category and type of equipment
- With the blocking signal generator switched off, a communication link is established. The level at the receiver input has to be reduced until the minimum power level is obtained (P_{min})
- This signal level (P_{min}) is increased by the value provided in the table corresponding to the receiver category and type of equipment
- The blocking signal is set to the level provided in the table corresponding to the receiver category and type of equipment.
- Repeat the same step for each remaining combination of frequency and level for the blocking signal as provided in the table corresponding to the receiver category and type of equipment

The receiver blocking measurements are shown in the table below. The BlueNRG family devices easily satisfy the specification requirements.

Table 7: Receiver blocking measurements

Wanted signal min power [dBm]	Blocking signal frequency [MHz]	Measured blocking signal power [dBm]			Minimum blocking signal power [dBm]
		Ch. 37	Ch. 18	Ch. 39	
Pmin + 6 dB	2380	-26	-21	-15	-57
	2503.5	-21	-28	-24.5	
	2300	-21	-21.5	-13.5	-47
	2583.5	-20.5	-22.5	-16	

6 Reference

[1] BlueNRG Datasheets

[2] ETSI EN 300 328 V2.1.1 (2016-11)

[3] "Bluetooth Low Energy Regulatory Aspects", from Bluetooth SIG Regulatory Committee

7 Revision history

Table 8: Document revision history

Date	Revision	Changes
14-Nov-2013	1	Initial release.
07-Apr-2016	2	Updated document title by adding "BlueNRG-MS" <i>Introduction</i> : updated text and added a note <i>Application circuit</i> : updated text and removed 2.0 V to 3.6 V.
11-Apr-2017	3	Throughout document: <ul style="list-style-type: none"> - updated reference to standard ETSI EN 300 328 to V2.1.1 (was V1.8.1) - widened reference to BlueNRG family to include BlueNRG-1 and BlueNRG-2 - minor text and formatting changes In Section 1: "An overview of ETSI regulations" : <ul style="list-style-type: none"> - added ETSI Receiver category In Section 2: "Technical requirements" : <ul style="list-style-type: none"> - added Receiver blocking information In Section 3: "Application circuit" <ul style="list-style-type: none"> - added BlueNRG-1/2 application board details and board photo - removed <i>Figure 3. Daughterboard schematic</i> In Section 4: "Transmitter parameter" : <ul style="list-style-type: none"> - overhauled all content to reflect new measurements and results In Section 5: "Receiver parameter" : <ul style="list-style-type: none"> - overhauled all content to reflect new measurements and results - added Section 5.2: "Receiver blocking"

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