

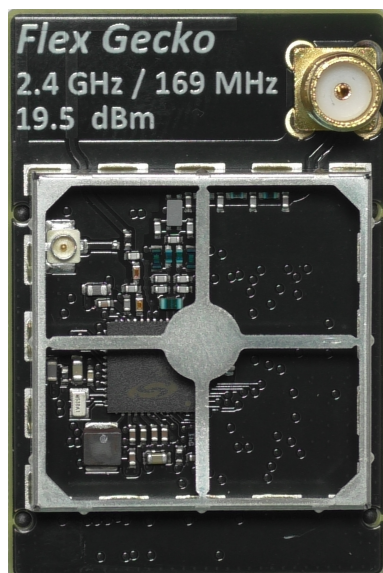
EFR32FG 2.4 GHz / 169 MHz Dual Band 19.5 dBm Radio Board BRD4251D Reference Manual



The EFR32FG family of Wireless SoCs deliver a high performance, low energy wireless solution integrated into a small form factor package.

By combining high performance sub-GHz RF and 2.4 GHz RF transceivers with an energy efficient 32-bit MCU, the family provides designers the ultimate in flexibility with a family of pin-compatible devices that scale from 128/256 kB of flash and 16/32 kB of RAM. The ultra-low power operating modes and fast wake-up times of the Silicon Labs energy friendly 32-bit MCUs, combined with the low transmit and receive power consumption of the sub-GHz and 2.4 GHz radios result in a solution optimized for battery powered applications.

To develop and/or evaluate the EFR32 Flex Gecko the BRD4251D Radio Board can be connected to the Wireless Starter Kit Mainboard to get access to display, buttons and additional features from Expansion Boards.



RADIO BOARD FEATURES

- Wireless SoC: EFR32FG1P133F256GM48
- CPU core: ARM Cortex-M4 with FPU
- Flash memory: 256 kB
- RAM: 32 kB
- Dual band transceiver integrated in the Wireless SoC: EFR32
- Operation frequencies: 2.4 GHz + 169.4 MHz
- Transmit power: 19.5 dBm
- 2.4 GHz: Integrated PCB antenna.
- 169.4 MHz: Single SMA connector both for transmit and receive
- Crystals for LFXO and HFXO: 32.768 kHz and 38.4 MHz.

1. Introduction

The EFR32 Flex Gecko Radio Boards provide a development platform (together with the Wireless Starter Kit Mainboard) for the Silicon Labs EFR32 Flex Gecko Wireless System on Chips and serve as reference designs for the matching networks of the RF interfaces.

The BRD4251D Radio Board supports dual-band operation with its integrated sub-GHz ISM band and 2.4 GHz band transceivers. The sub-GHz section is designed to operate in the European ETSI 169.4-169.475 MHz band with an external whip antenna, the 2.4 GHz section is designed to operate at the 2400-2483.5 MHz band with the on-board printed antenna. The matching networks are optimized to 19.5 dBm output power.

To develop and/or evaluate the EFR32 Flex Gecko the BRD4251D Radio Board can be connected to the Wireless Starter Kit Mainboard to get access to display, buttons and additional features from Expansion Boards and also to evaluate the performance of the RF interfaces.

2. Radio Board Connector

2.1 Introduction

The board-to-board connector scheme allows access to all EFR32FG1 GPIO pins as well as the RESETn signal. For more information on the functions of the available pin functions, we refer you to the EFR32FG1 Datasheet.

2.2 Radio Board Connector Pin Associations

The figure below shows the pin mapping on the connector to the radio pins and their function on the Wireless Starter Kit Mainboard.

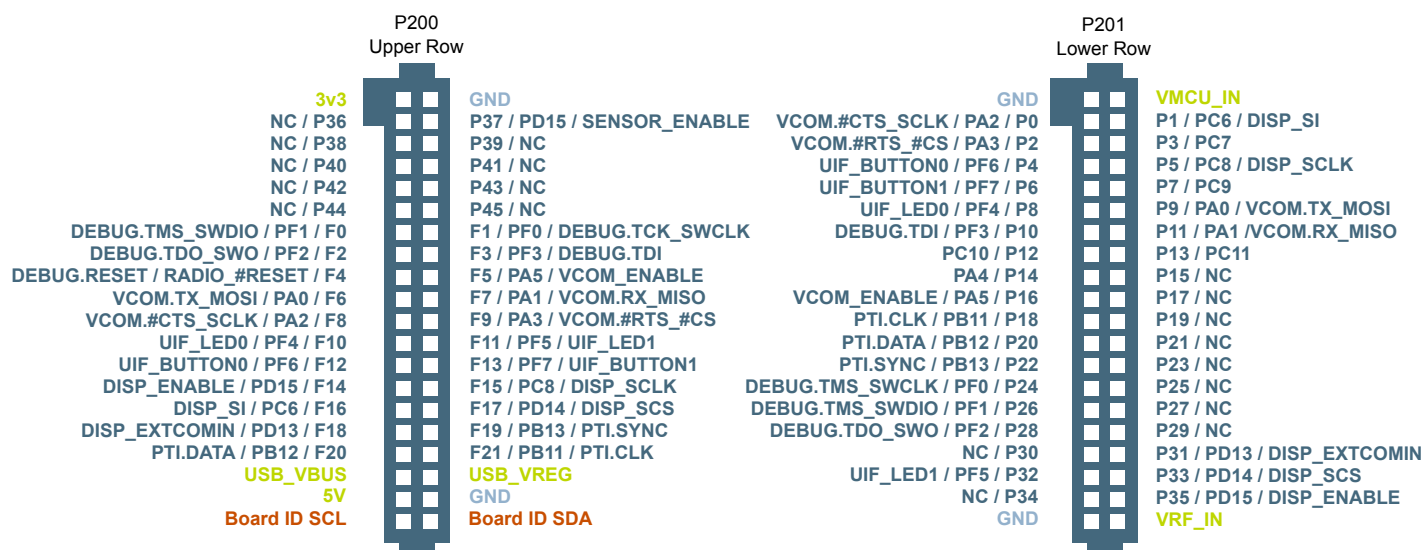


Figure 2.1. BRD4251D Radio Board Connector Pin Mapping

3. Radio Board Block Summary

3.1 Introduction

This section gives a short introduction to the blocks of the BRD4251D Radio Board.

3.2 Radio Board Block Diagram

The block diagram of the BRD4251D Radio Board is shown in the figure below.

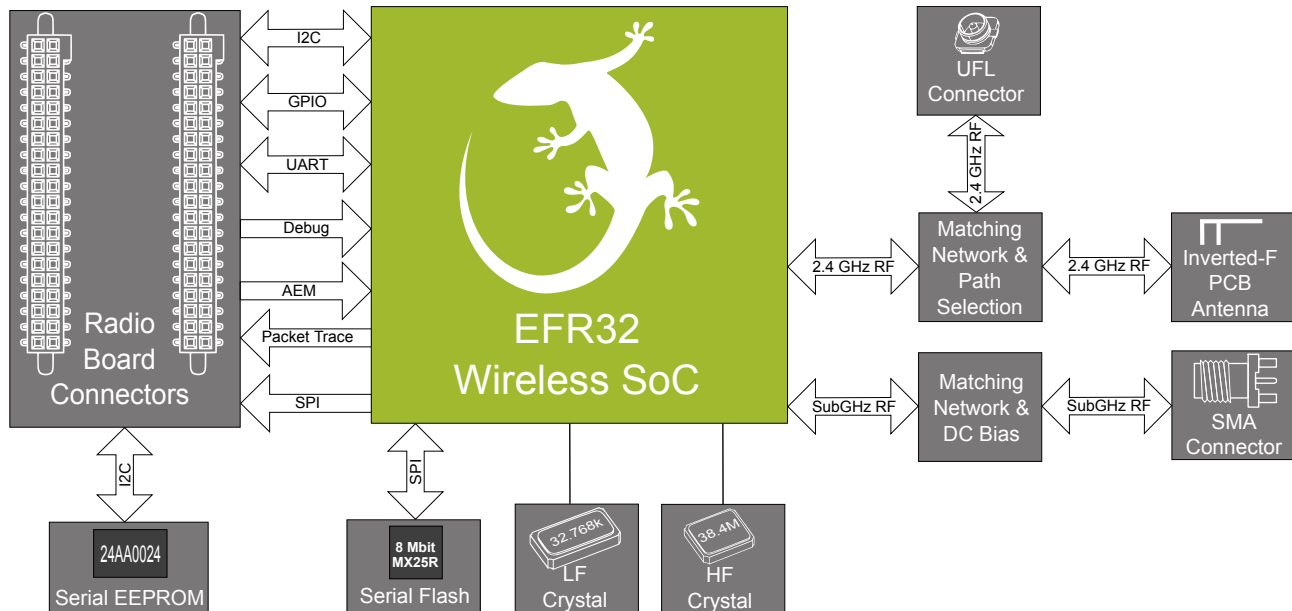


Figure 3.1. BRD4251D Block Diagram

3.3 Radio Board Block Description

3.3.1 Wireless MCU

The BRD4251D EFR32 Flex Gecko Radio Board incorporates an EFR32FG1P133F256GM48 Wireless System on Chip featuring 32-bit Cortex-M4 with FPU core, 256 kB of flash memory 32 kB of RAM, an integrated 2.4 GHz band and an integrated sub-GHz ISM band transceiver with output power up to 19.5 dBm. For additional information on the EFR32FG1P133F256GM48, refer to the EFR32FG1 Data Sheet.

3.3.2 LF Crystal Oscillator (LFXO)

The BRD4251D Radio Board has a 32.768 kHz crystal mounted.

3.3.3 HF Crystal Oscillator (HFXO)

The BRD4251D Radio Board has a 38.4 MHz crystal mounted.

3.3.4 Matching Network for Sub-GHz

The BRD4251D Radio Board incorporates a sub-GHz matching network which connects both the sub-GHz TX and RX pins of the EFR32FG1 to the one SMA connector to be able to transmit and receive with one antenna. The component values were optimized for the 169.4 MHz band RF performance and current consumption with 19.5 dBm output power.

For detailed description of the matching network see Chapter [4.2.1 Description of the Sub-GHz RF Matching](#).

3.3.5 Matching Network for 2.4 GHz

The BRD4251D Radio Board incorporates a 2.4 GHz matching network which connects the 2.4 GHz TRX pin of the EFR32FG1 to the one on-board printed Inverted-F antenna. The component values were optimized for the 2.4 GHz band RF performance and current consumption with 19.5 dBm output power.

For detailed description of the matching network see Chapter [4.2.2 Description of the 2.4 GHz RF Matching](#).

3.3.6 Inverted-F Antenna

The BRD4251D Radio Board includes a printed Inverted-F antenna (IFA) tuned to have close to 50 Ohm impedance at the 2.4 GHz band.

For detailed description of the antenna see Chapter [4.6 Inverted-F Antenna](#).

3.3.7 SMA connector

To be able to perform conducted measurements or mount external antenna for radiated measurements, range tests etc., Silicon Labs added an SMA connector to the Radio Board. The connector allows an external 50 Ohm cable or antenna to be connected during design verification or testing.

3.3.8 UFL Connector

To be able to perform conducted measurements Silicon Labs added an UFL connector to the Radio Board. The connector allows an external 50 Ohm cable or antenna to be connected during design verification or testing.

Note: By default the output of the matching network is connected to the printed Inverted-F antenna by a series component. It can be connected to the UFL connector as well through a series 0 Ohm resistor which is not mounted by default. For conducted measurements through the UFL connector the series component to the antenna should be removed and the 0 Ohm resistor should be mounted (see Chapter [4.2 Schematic of the RF Matching Network](#) for further details).

3.3.9 Radio Board Connectors

Two dual-row, 0.05" pitch polarized connectors make up the BRD4251D Radio Board interface to the Wireless Starter Kit Mainboard.

For more information on the pin mapping between the EFR32FG1P133F256GM48 and the Radio Board Connector refer to Chapter [2.2 Radio Board Connector Pin Associations](#).

4. RF Section

4.1 Introduction

This section gives a short introduction to the RF section of the BRD4251D.

4.2 Schematic of the RF Matching Network

The schematic of the RF section of the BRD4251D Radio Board is shown in the following figure.

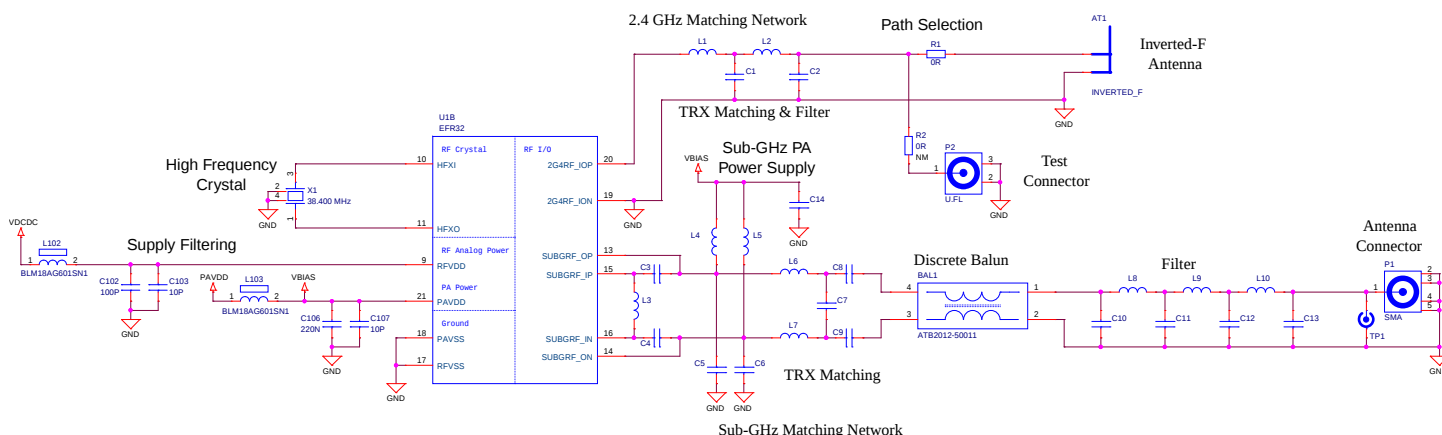


Figure 4.1. Schematic of the RF Section of the BRD4251D

The RF matching comprises two separate TX/RX matching networks: one for the sub-GHz RF path, the other for the 2.4 GHz RF path.

4.2.1 Description of the Sub-GHz RF Matching

The sub-GHz matching network connects the differential TX outputs and RX inputs of the sub-GHz RF port to the SMA connector while transforming the impedances to 50 Ohm. Careful design procedure was followed to ensure that the RX input circuitry does not load down the TX output path while in TX mode and that the TX output circuitry does not degrade receive performance while in RX mode.

The matching includes a differential impedance matching circuitry, a discrete balanced-unbalanced transformer and a filter section. The targeted output power is 19.5 dBm at 169.4 MHz.

4.2.2 Description of the 2.4 GHz RF Matching

The 2.4 GHz matching connects the 2G4RF_IOP pin to the on-board printed Inverted-F Antenna. The 2G4RF_ION pin is connected to ground. For higher output powers (13 dBm and above) beside the impedance matching circuitry it is recommended to use additional harmonic filtering as well at the RF output. The targeted output power of the BRD4251D board is 19.5 dBm thus the RF output of the IC is connected to the antenna through a four-element impedance matching and harmonic filter circuitry.

For conducted measurements the output of the matching network can also be connected to the UFL connector by relocating the series R1 0 Ohm resistor to the R2 position between the output of the matching and the UFL connector.

4.3 RF Section Power Supply

On the BRD4251D Radio Board the supply pin of the radio (RFVDD) is connected directly to the output of the on-chip DC-DC converter while the supply for the sub-GHz and 2.4 GHz power amplifiers (VBIAS) is provided directly by the Motherboard. This way, by default, the DC-DC converter provides 1.8 V for the RF analog section, the Motherboard provides 3.3 V for the PAs (for details, see the schematic of the BRD4251D).

4.4 Bill of Materials for the sub-GHz Matching

The Bill of Materials of the sub-GHz matching network of the BRD4251D Radio Board is shown in the following table.

Table 4.1. Bill of Materials for the BRD4251D 169.4 MHz 19.5 dBm RF Matching Network

Component name	Value	Manufacturer	Part Number
BAL1	Balun	TDK Corporation	ATB2012-50011
C3	3.0 pF	Murata	GRM1555C1H3R0WA1
C4	3.0 pF	Murata	GRM1555C1H3R0WA1
C5	13 pF	Murata	GRM1555C1H130GA01
C6	13 pF	Murata	GRM1555C1H130GA01
C7	10 pF	Murata	GRM1555C1H100GA01
C8	1 nF	Murata	GRM1555C1H102GA01
C9	1 nF	Murata	GRM1555C1H102GA01
C10	15 pF	Murata	GRM1555C1H150GA01
C11	33 pF	Murata	GRM1555C1H330GA01
C12	33 pF	Murata	GRM1555C1H330GA01
C13	15 pF	Murata	GRM1555C1H150GA01
C14	1 nF	Murata	GRM1555C1H102GA01
L3	390 nH	Murata	LQW18ANR39G00
L4	470 nH	Murata	LQW18CNR47J00
L5	470 nH	Murata	LQW18CNR47J00
L6	36 nH	Murata	LQW15AN36NG00
L7	36 nH	Murata	LQW15AN36NG00
L8	51 nH	Murata	LQW15AN51NG00
L9	56 nH	Murata	LQW15AN56NG00
L10	51 nH	Murata	LQW15AN51NG00

4.5 Bill of Materials for the 2.4 GHz Matching

The Bill of Materials of the 2.4 GHz matching network of the BRD4251D Radio Board is shown in the following table.

Table 4.2. Bill of Materials for the BRD4251D 2.4 GHz 19.5 dBm RF Matching Network

Component name	Value	Manufacturer	Part Number
C1	2.0 pF	Murata	GRM1555C1H2R0WA01
C2	1.0 pF	Murata	GRM1555C1H1R0WA01
L1	1.8 nH	Murata	LQP15MN1N8W02
L2	3.0 nH	Murata	LQP15MN3N0W02

4.6 Inverted-F Antenna

The BRD4251D Radio Board includes an on-board printed Inverted-F Antenna tuned for the 2.4 GHz band. Due to the design restrictions of the Radio Board the input of the antenna and the output of the matching network can't be placed directly next to each other thus a 50 Ohm transmission line was necessary to connect them. The resulting impedance and reflection measured at the output of the matching network are shown in the following figure. As it can be observed the impedance is close to 50 Ohm (the reflection is better than -10 dB) for the entire 2.4 GHz band.

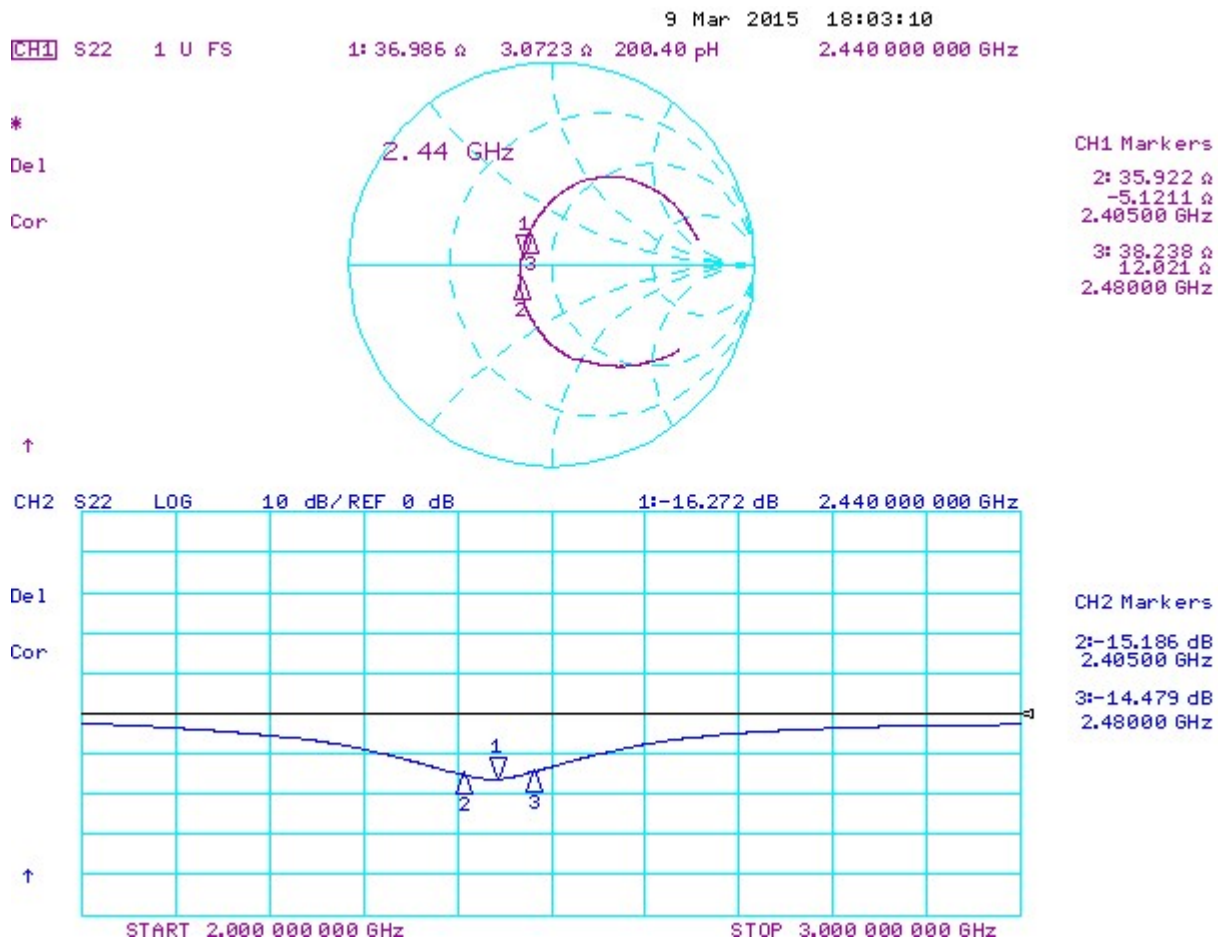


Figure 4.2. Impedance and Reflection of the Inverted-F Antenna of the BRD4251D

5. Mechanical Details

The BRD4251D EFR32 Flex Gecko Radio Board is illustrated in the figures below.

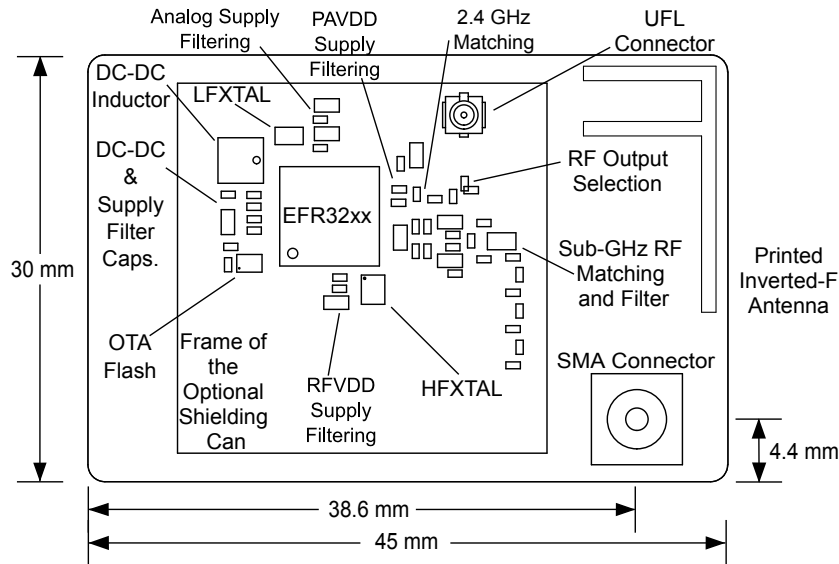


Figure 5.1. BRD4251D Top View

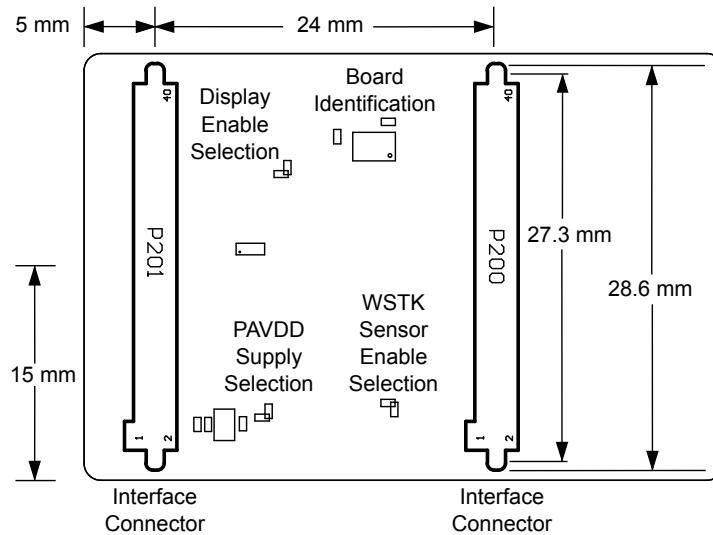


Figure 5.2. BRD4251D Bottom View

6. EMC Compliance

6.1 Introduction

Compliance of the fundamental and harmonic levels is tested at the listed frequencies against the listed EMC regulations:

- 169.4 MHz:
 - ETSI EN 300-220-1
- 2.4 GHz:
 - ETSI EN 300-328
 - FCC 15.247

6.2 EMC Regulations for 169.4 MHz

6.2.1 ETSI EN 300-220-1 Emission Limits for the 169.4-169.475 MHz Band

Based on ETSI EN 300-220-1 the allowed maximum fundamental power for the 169.4-169.475 MHz band is 500 mW (27 dBm) e.r.p. both for conducted and radiated measurements.

Note: Further in this document EIRP (Effective Isotropic Radiated Power) will be used instead of e.r.p. (Effective Radiated Power) for the comparison of the radiated limits and measurement results. The 500 mW e.r.p radiated limit is equivalent to 29.1 dBm EIRP.

For the unwanted emission limits see the table below.

Table 6.1. ETSI EN 300-220-1 Spurious Domain Emission Limits in e.r.p. (and EIRP)

Frequency	47 MHz to 74 MHz	Other frequencies below 1000 MHz	Frequencies above 1000 MHz
	87.5 MHz to 118 MHz		
	174 MHz to 230 MHz		
	470 MHz to 862 MHz		
Operating	4 nW (-54 dBm e.r.p. = -51.8 dBm EIRP)	250 nW (-36 dBm e.r.p. = -33.9 dBm EIRP)	1 uW (-30 dBm e.r.p. = -27.9 dBm EIRP)
Standby	2 nW (-57 dBm e.r.p. = -54.8 dBm EIRP)	2 nW (-57 dBm e.r.p. = -54.8 dBm EIRP)	20 nW (-47 dBm e.r.p. = -44.8 dBm EIRP)

The above ETSI limits are also applied both for conducted and radiated measurements.

6.3 EMC Regulations for 2.4 GHz

6.3.1 ETSI EN 300-328 Emission Limits for the 2400-2483.5 MHz Band

Based on ETSI EN 300-328 the allowed maximum fundamental power for the 2400-2483.5 MHz band is 20 dBm EIRP. For the unwanted emissions in the 1 GHz to 12.75 GHz domain the specified limit is -30 dBm EIRP.

6.3.2 FCC15.247 Emission Limits for the 2400-2483.5 MHz Band

FCC 15.247 allows conducted output power up to 1 Watt (30 dBm) in the 2400-2483.5 MHz band. For spurious emissions the limit is -20 dBc based on either conducted or radiated measurement, if the emission is not in a restricted band. The restricted bands are specified in FCC 15.205. In these bands the spurious emission levels must meet the levels set out in FCC 15.209. In the range from 960 MHz to the frequency of the 5th harmonic it is defined as 0.5 mV/m at 3 m distance (equals to -41.2 dBm in EIRP).

Additionally, for spurious frequencies above 1 GHz FCC 15.35 allows duty-cycle relaxation to the regulatory limits. For the EmberZNet PRO the relaxation is 3.6 dB. So practically the -41.2 dBm limit can be modified to -37.6 dBm.

In case of operating in the 2400-2483.5 MHz band the 2nd, 3rd and 5th harmonics can fall into restricted bands so for those the -37.6 dBm limit should be applied. For the 4th harmonic the -20 dBc limit should be applied.

6.3.3 Applied Emission Limits for the 2.4 GHz Band

The above ETSI limits are applied both for conducted and radiated measurements.

The FCC restricted band limits are radiated limits only. Besides that, Silicon Labs applies those to the conducted spectrum i.e. it is assumed that in case of a custom board an antenna is used which has 0 dB gain at the fundamental and the harmonic frequencies. In that theoretical case, based on the conducted measurement, the compliance with the radiated limits can be estimated.

The overall applied limits are shown in the table below.

Table 6.2. Applied Limits for Spurious Emissions for the 2.4 GHz Band

Harmonic	Frequency	Limit
2nd	4800~4967 MHz	-37.6 dBm
3rd	7200~7450.5 MHz	-37.6 dBm
4th	9600~9934 MHz	-30 dBm
5th	12000~12417.5 MHz	-37.6 dBm

7. RF Performance

7.1 Conducted Power Measurements

During measurements the BRD4251D Radio Board was attached to a Wireless Starter Kit Mainboard which was supplied by USB. The voltage supply for the Radio Board was 3.3 V.

7.1.1 Conducted Measurements in the 169.4 MHz band

The BRD4251D Radio Board was connected directly to a Spectrum Analyzer through its SMA connector. The supply for the radio (RFVDD) was 1.8 V provided by the on-chip DC-DC converter, the supply for the power amplifier (VBIAS) was 3.3 V provided by the Motherboard (for details, see the schematic of the BRD4251D). The transceiver was operated in continuous carrier transmission mode. The output power of the radio was set to 19.5 dBm.

The typical output spectrum is shown in the following figure.

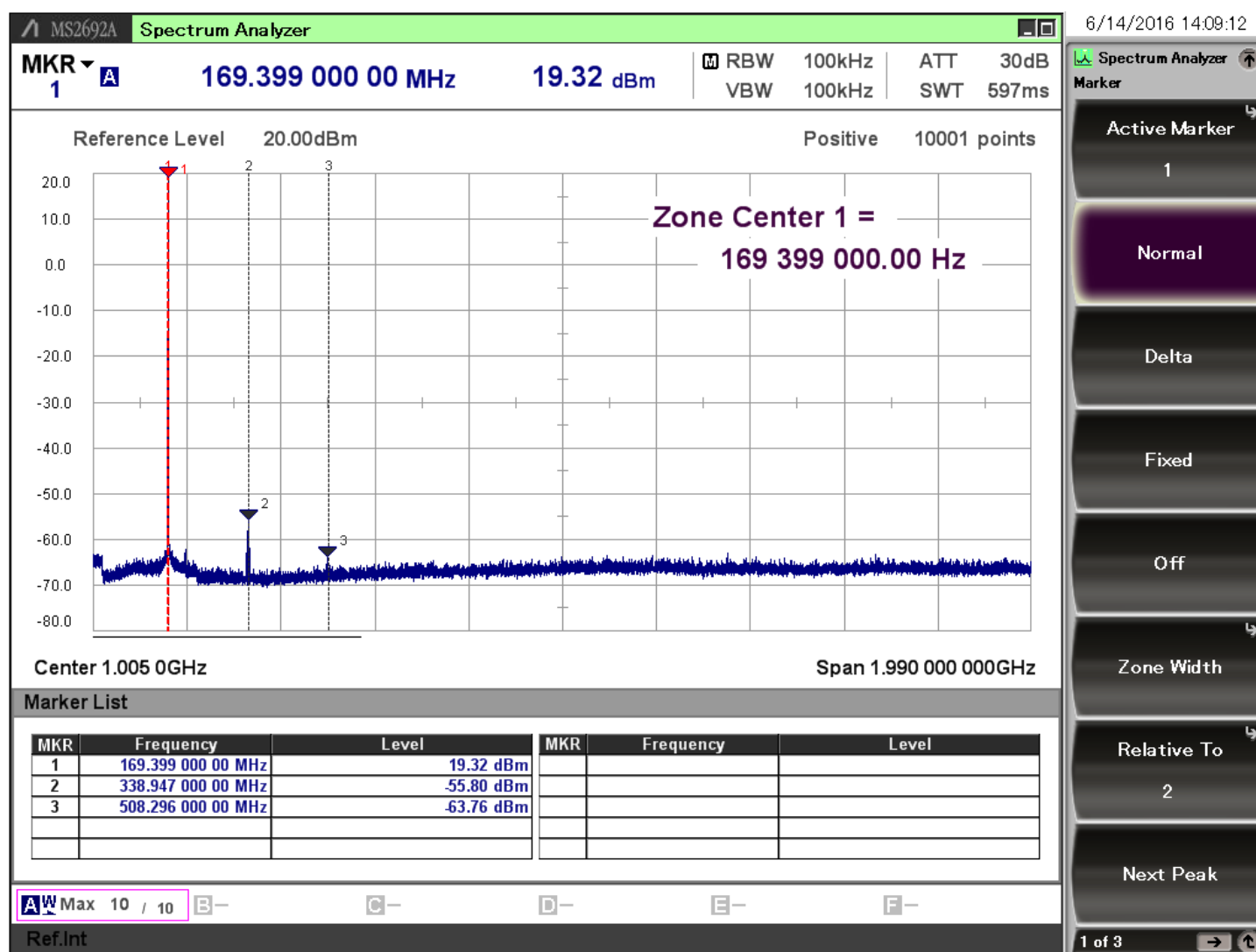


Figure 7.1. Typical Output Spectrum of the BRD4251D

As it can be observed the fundamental is close to 19.5 dBm so it is compliant with the 29.1 dBm fundamental limit, unwanted emissions are under their corresponding limit so the conducted spectrum is compliant with the regulation limits.

7.1.2 Conducted Measurements in the 2.4 GHz band

The BRD4251D Radio Board board was connected directly to a Spectrum Analyzer through its UFL connector (the 0 Ohm resistor was removed from the R1 position and was soldered to the R2 position). The supply for the radio (RFVDD) was 1.8 V provided by the on-chip DC-DC converter, the supply for the power amplifier (VBIAS) was 3.3 V provided by the Motherboard (for details, see the schematic of the BRD4251D). The transceiver was operated in continuous carrier transmission mode. The output power of the radio was set to 19.5 dBm.

The typical output spectrum is shown in the following figure.

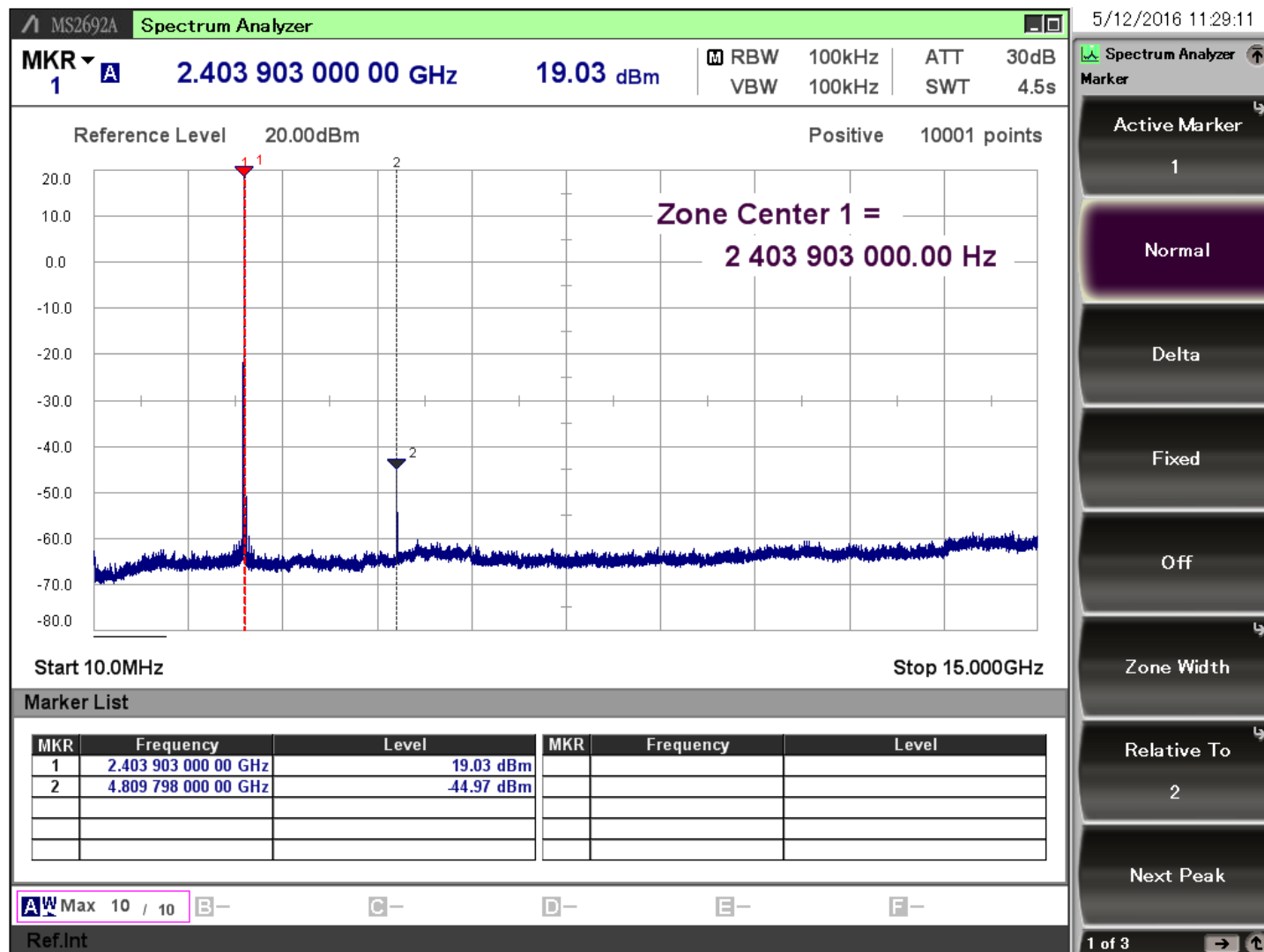


Figure 7.2. Typical Output Spectrum of the BRD4251D

As it can be observed the fundamental is slightly lower than 19.5 dBm limit and the strongest unwanted emission is the double-frequency harmonic but with its -44.97 dBm level it is under the -37.6 dBm applied limit with ~7 dB margin. So the conducted spectrum is compliant with the applied limits.

Note: The conducted measurement is performed by connecting the on-board UFL connector to a Spectrum Analyzer through an SMA Conversion Adapter (P/N: HRMJ-U.FLP(40)). This connection itself introduces approx. 0.3 dB insertion loss.

7.2 Radiated Power Measurements

During measurements the BRD4251D Radio Board was attached to a Wireless Starter Kit Mainboard which was supplied by USB. The voltage supply for the Radio Board was 3.3 V. The radiated power was measured in an antenna chamber by rotating the DUT in 360 degree with horizontal and vertical reference antenna polarizations in the XY, XZ and YZ cuts. The measurement axes are as shown in the figure below.

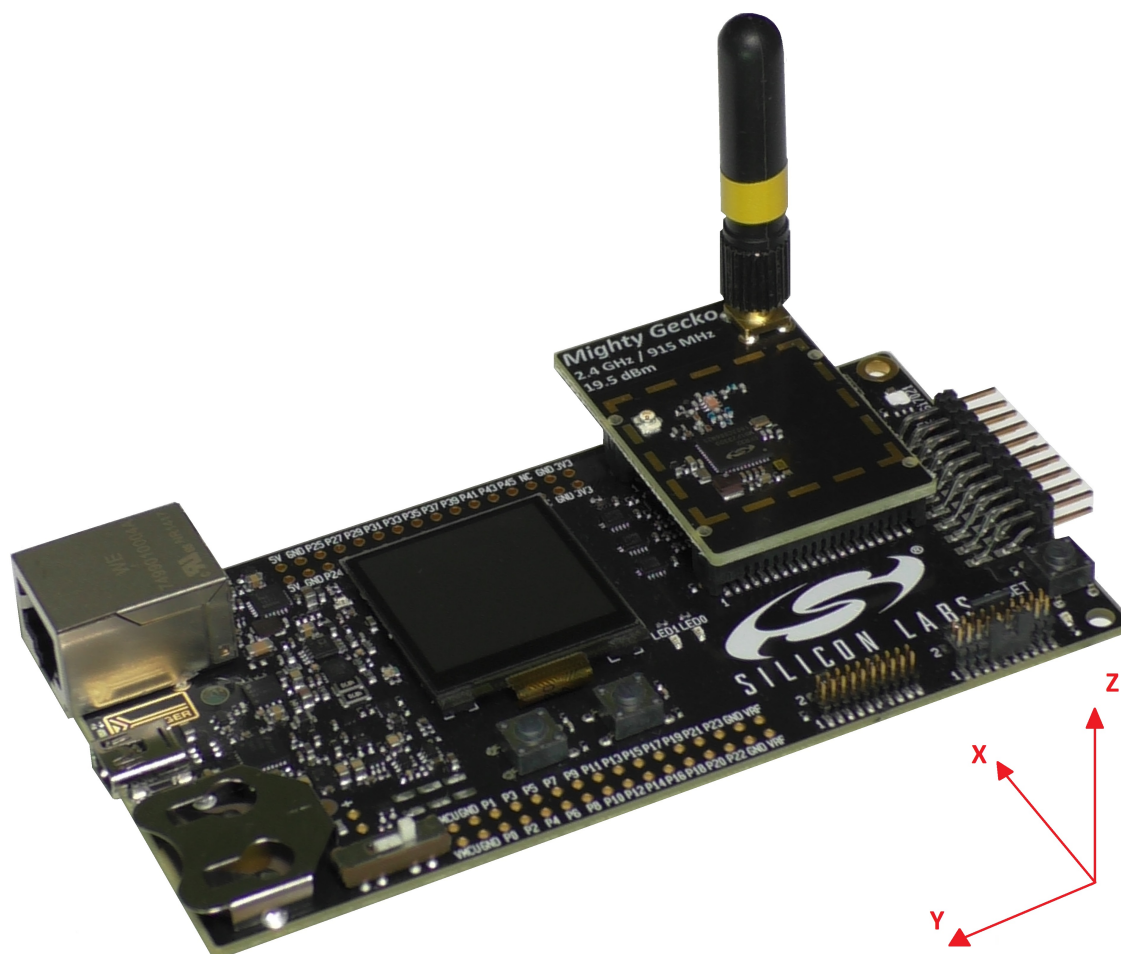


Figure 7.3. DUT: Radio Board with the Wireless Starter Kit Mainboard (Illustration)

Note: The radiated measurement results presented in this document were recorded in an unlicensed antenna chamber. Also the radiated power levels may change depending on the actual application (PCB size, used antenna etc.) therefore the absolute levels and margins of the final application is recommended to be verified in a licensed EMC testhouse!

7.2.1 Radiated Measurements in the 169.4 MHz band

For the 169.4 MHz radiated power measurements an external whip antenna (P/N: EXH-170-SM (Laird Technologies)) was used as a transmitter antenna. It was connected to the SMA connector of the BRD4251D Radio Board. The supply for the radio (RFVDD) was 1.8 V provided by the on-chip DC-DC converter, the supply for the power amplifier (VBIAS) was 3.3 V provided by the Motherboard (for details, see the schematic of the BRD4251D). The transceiver was operated in continuous carrier transmission mode. The output power of the radio was set to 19.5 dBm.

The initial investigations showed that although the conducted spectrum is compliant with the regulation limits, for the radiated compliance in the sub-GHz band mounting a shielding can is required due to the unwanted harmonic radiation through the matching network components and PCB traces.

The measured radiated powers are shown in the table below.

Table 7.1. Maximums of the Measured Radiated Powers of BRD4251D at 169.4 MHz

169.4 MHz	EIRP [dBm]	Orientation	Margin [dB]	Limit in EIRP [dBm]
Fundamental	6.8	YZ/H	22.3	29.1
2nd harmonic	-48.5	XZ/V	14.6	-33.9
3rd harmonic	-63.6	XY/H	11.8	-51.8
4th harmonic	-55.6	XZ/H	3.8	-51.8
5th harmonic	-58.2	XZ/H	6.4	-51.8
6th harmonic	-58.3	XZ/H	30.4	-27.9
7th harmonic	-52.9	YZ/V	25.0	-27.9
8th harmonic	-50.2	YZ/V	22.3	-27.9
9th harmonic	-62.8	XY/H	35.1	-27.9
10th harmonic	-64.9	YZ/V	37.1	-27.9
* Signal level is below the Spectrum Analyzer noise floor.				

As it can be observed with mounted shielding can the fundamental and all of the harmonics are compliant with the limits. Unfortunately the chosen antenna together with the relatively small ground area (compared to the wavelength) provided by the BRD4251D Radio Board and the Wireless Starter Kit Mainboard results very poor antenna gain thus the radiated power of the fundamental is relatively low. The harmonic emissions are compliant with the limits.

7.2.2 Radiated Measurements in the 2.4 GHz band

For the 2.4 GHz radiated power measurements the on-board printed Inverted-F antenna of the BRD4251D Radio Board was used (the R1 resistor was mounted). The supply for the radio (RFVDD) was 1.8 V provided by the on-chip DC-DC converter, the supply for the power amplifier (VBIAS) was 3.3 V provided by the Motherboard (for details, see the schematic of the BRD4251D). The transceiver was operated in continuous carrier transmission mode. The output power of the radio was set to 19.5 dBm. During the measurement the sub-GHz antenna (P/N: EXH-170-SM (Laird Technologies)) was attached to the SMA connector. The radiated performance was measured with and without mounted shielding can.

The results are shown in the tables below.

Table 7.2. Maximums of the Measured Radiated Powers of BRD4251D at 2.4 GHz without Shielding Can

2.4 GHz	EIRP [dBm]	Orientation	Margin [dB]	Limit in EIRP [dBm]
Fundamental	21.2	XZ/H	8.8	30
2nd harmonic	-41.3	YZ/V	3.7	-37.6
3rd harmonic	<-50*	-/-	>10	-37.6
4th harmonic	<-50*	-	>30	-30
5th harmonic	<-50*	-	>10	-37.6

* Signal level is below the Spectrum Analyzer noise floor.

Table 7.3. Maximums of the Measured Radiated Powers of BRD4251D at 2.4 GHz with Shielding Can

2.4 GHz	EIRP [dBm]	Orientation	Margin [dB]	Limit in EIRP [dBm]
Fundamental	21.9	XZ/H	8.1	30
2nd harmonic	-42.0	YZ/V	4.4	-37.6
3rd harmonic	<-50*	-/-	>10	-37.6
4th harmonic	<-50*	-	>30	-30
5th harmonic	<-50*	-	>10	-37.6

* Signal level is below the Spectrum Analyzer noise floor.

As it can be observed, thanks to the ~2-3 dB gain of the on-board Inverted-F antenna, the level of the fundamental is higher than 19.5 dBm. The harmonic levels are compliant with the applied limits with and without shielding.

8. EMC Compliance Recommendations

8.1 Recommendations for 169 MHz ETSI EN 300-220-1 compliance

As it was shown in the previous chapter the conducted spectrum BRD4251D EFR32 Flex Gecko Radio Board is compliant with the emission limits of the ETSI EN 300-220-1 regulation with 19.5 dBm output power. For the radiated compliance mounting a shielding can is required due to the unwanted harmonic radiation through the matching network components and PCB traces. With mounted shielding can all of the unwanted emissions are compliant with the regulation limits.

8.2 Recommendations for 2.4 GHz ETSI EN 300-328 compliance

As it was shown in the previous chapter the radiated power of the fundamental of the BRD4251D EFR32 Flex Gecko Radio Board with 19.5 dBm output power exceeds the 20 dBm limit of the ETSI EN 300-328 regulation due to the high antenna gain so reduction of the fundamental power is required by approx. 2 dB in order to comply. The harmonic emissions are under the -30 dBm limit with large margin even with 19.5 dBm output power. Mounting a shielding can is required due to the sub-GHz compliance but it is not required for the 2.4 GHz compliance.

8.3 Recommendations for 2.4 GHz FCC 15.247 compliance

As it was shown in the previous chapter the BRD4251D EFR32 Flex Gecko Radio Board is compliant with the emission limits of the FCC 15.247 regulation with 19.5 dBm output power. Mounting a shielding can is required due to the sub-GHz compliance but it is not required for the 2.4 GHz compliance.

9. Document Revision History

Table 9.1. Document Revision History

Revision Number	Effective Date	Change Description
1.0	20.05.2016	Initial release.
1.1	14.06.2016	Updating frontpage board photo; updating spectrum plot.

10. Board Revisions

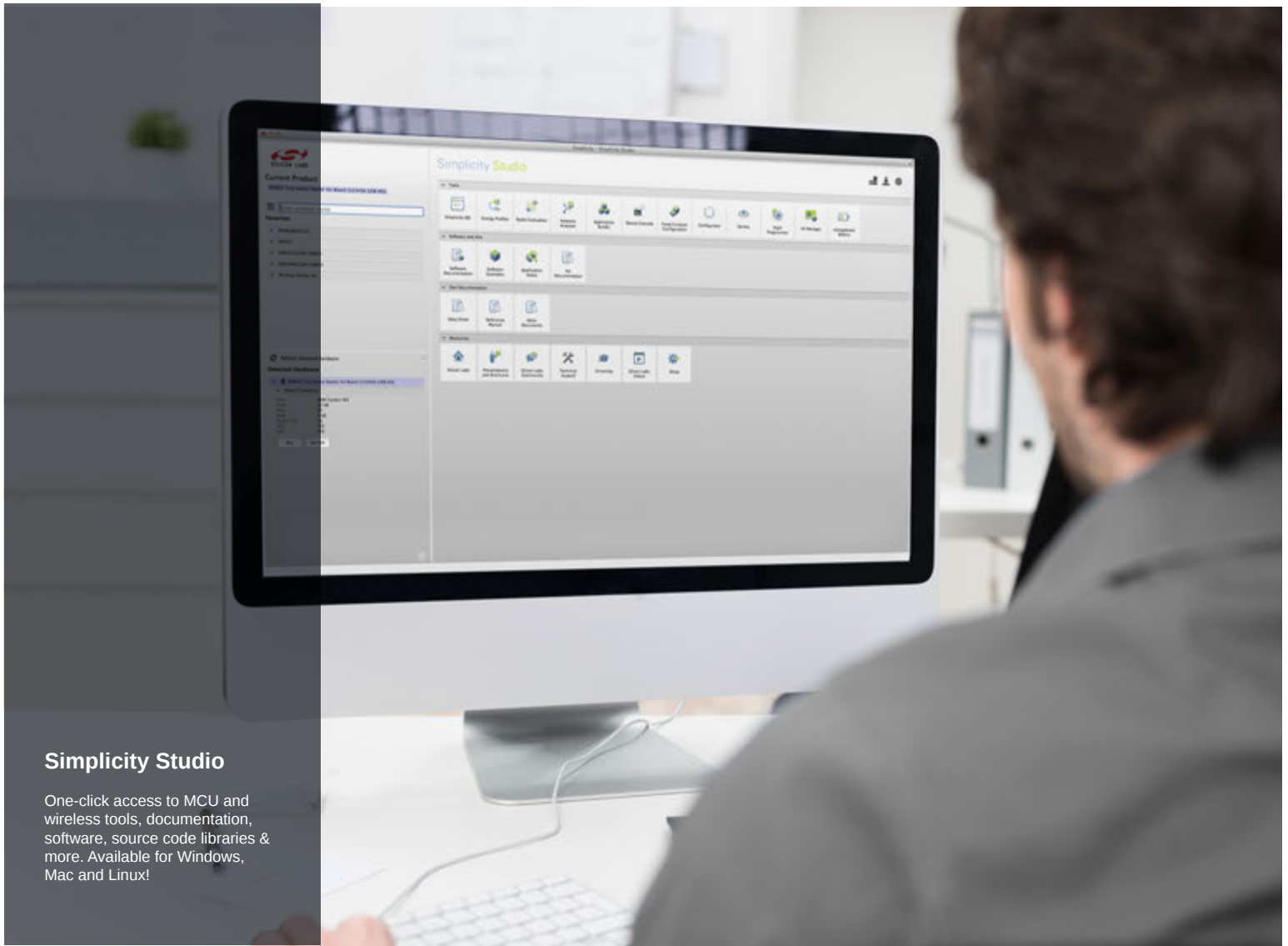
Table 10.1. BRD4251D Radio Board Revisions

Radio Board Revision	Description
B00	Initial release.
B01	Sub-GHz PA supplied from VBIAS (filtered PAVDD).
B02	Mounting shielding can to improve harmonic radiation.

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