EFR32BG22 Bluetooth Tag Design Reference Manual

Silicon Labs provides customers with a reference design for BLE tag solutions in a CR2032 coin cell battery size with EFR32BG22 and sensors. This document describes this tag reference design including RF test data as well. Also, design files including schematic and layout CAD designs, BOM, PDF, ASCII files and Gerbers, are available under Silicon Labs website at www.silabs.com.

The tag design utilizes an EFR32BG22 chip in a QFN32 package.

The design is pre-compliance tested and appeared to be fully compliant with CE and FCC regulatory standards.

The BLE tag reference design includes the following circuit components:

- EFR32BG22C224F512GM32
- Built-in PCB antenna
- Tactile switch as button
- Detachable 10-pin mini-simplicity debug connector
- CR2032 coin cell battery
- LED
- Barometer for height detection (Infineon DPS310)
- Accelerometer for motion detection (Bosch BMA400)

KEY POINTS

- Brief description of EFR32BG22 QFN32 BLE Tag reference design
- RF test data provided, including antenna impedance, gain and efficiency, conducted and radiated fundamental and harmonics EIRP data, radiation patterns
- Design files are available for customers reference at www.silabs.com

1. Introduction

The EFR32BG22 QFN32-based BLE tag reference design is virtually provided for customers, since design files, including schematic and layout CAD design files, BOM, PDF, ASCII files and Gerbers, are available under www.silabs.com but there is no orderable part number for the board design itself.
The design is also pre-tested by Silicon Labs and is fully compliant with CE and FCC regulatory standards at the TX output power level of +6 dBm. At the output power level of +8 dBm, i.e. maximum rail power setting of raw 127, the module is apparently also compliant with the main regulatory standards, like CE and FCC, however this +8 dBm TXP from the EFR32BG22 part is not guaranteed over temperature and process variations.
The module utilizes 4 electrical layers and an on-board printed antenna, and it runs from a CR2032 coin cell battery. The entire module dimension (circular design with ~26 mm diameter) is not even significantly larger than the size of a coin cell battery.
The module has the so-called 10-pin mini-simplicity header for programming and debugging purposes (see connection details in AN958 application note), and this part of the PCB can easily be removed and broken apart once the device has been flashed and programmed.
The on-board printed antenna is tuned when the coin cell battery is being inserted into, but no plastic enclosure is considered. So, for design implementations with plastics, Silicon Labs recommends checking the antenna impedance since some fine-tuning (probably only BOM change) might be required in its final environment.
The photo of the tag reference design is shown in the Figure 1.1 below.

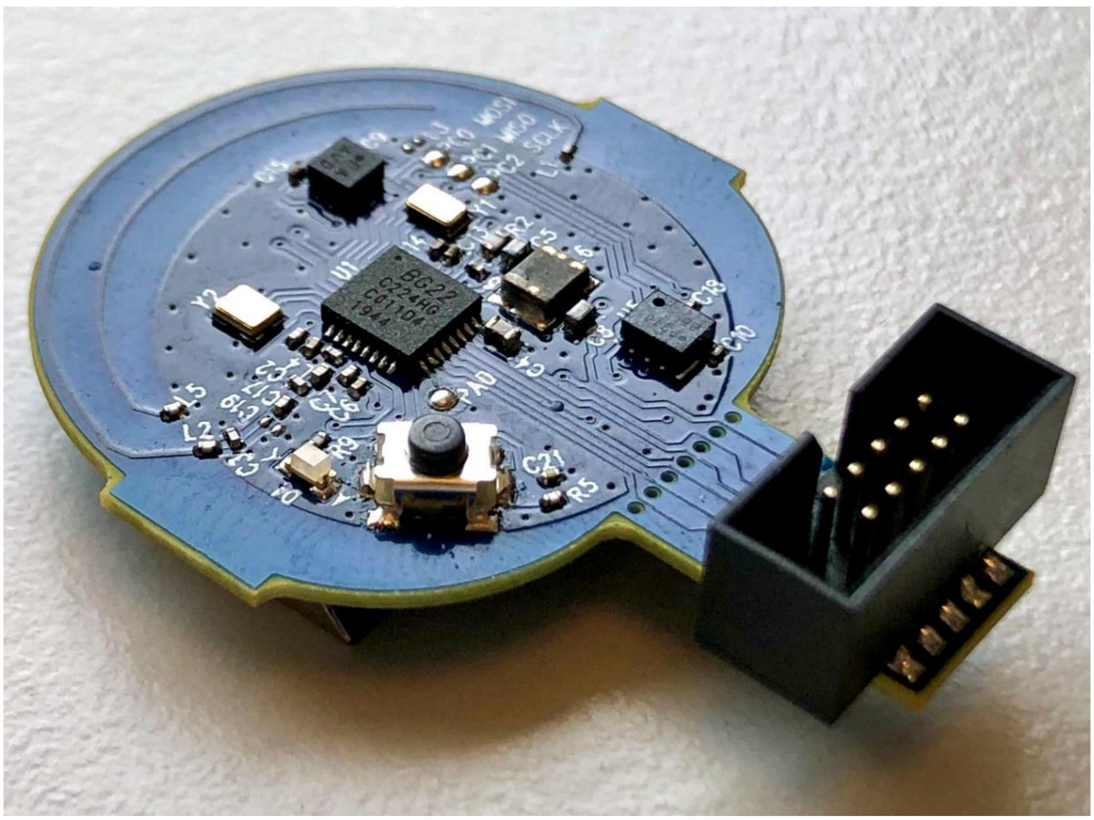


Figure 1.1 EFR32BG22 BLE Tag Design

2. Schematic Design

The complete schematic design of the EFR32BG22-based tag reference module can be found in the full design pack provided by Silicon Labs and is also available under www.silabs.com. Since this reference manual focuses on the RF design part of the module, this section shows the RF focused schematic part of the entire design.
The EFR32BG22 RF part of the schematic is shown in the Figure 2.1 below.

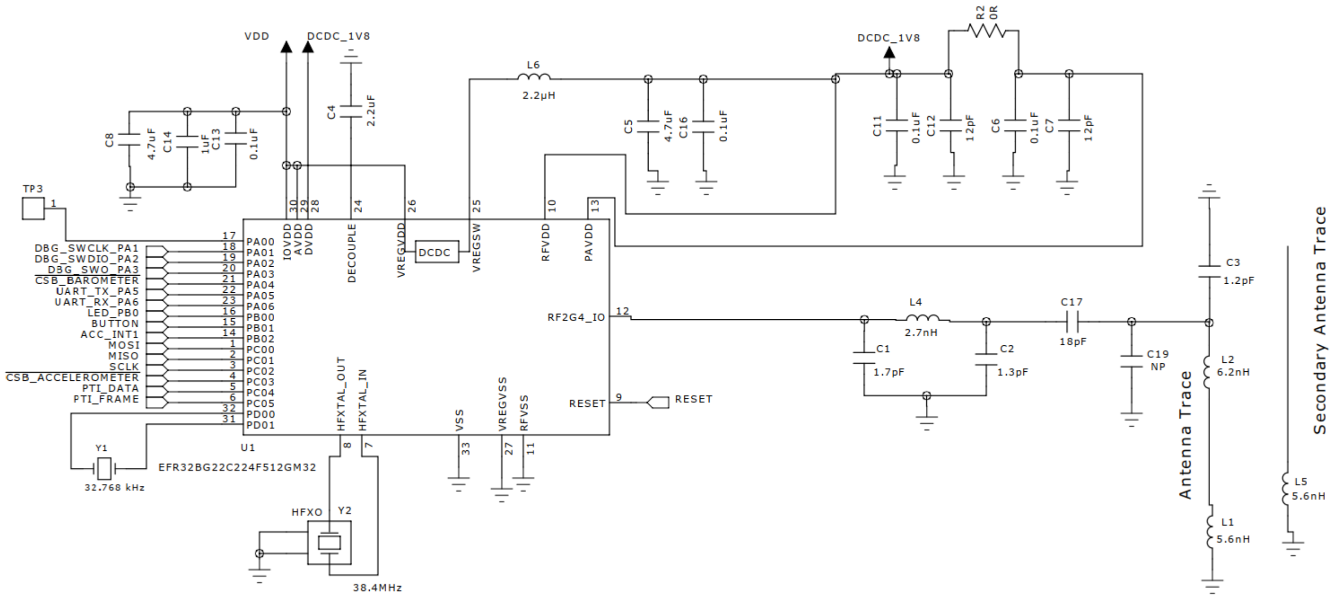


Figure 2.1 RF part of the BLE tag schematic design

As the RF schematic shows above both low- and high-frequency crystals and the on-chip DCDC converter are being utilized. Both RFVDD and PAVDD nets are connected to the internal DCDC converter's output to minimize the current consumption and thus maximize the battery life. The RF front-end path can be divided into two separate parts: EFR32BG22 matching network including components C1, L4, C2, C17 and C19; printed antenna and antenna matching network including components C3, L2, L1 and L5. The printed antenna also consists of two parts: a main, primary antenna trace which is connected to the RF output port of the EFR32BG22 matching network and another, secondary antenna trace which is coupled with the primary antenna trace and connected to the GND through an inductor. The 50-ohm point in the RF-FE path is between the EFR32BG22 and antenna matching networks, i.e. the common point of components C17, C19, C3 and L2. So, conducted measurements can be performed by sniffing the RF-FE path at that region.
The RF matching network elements are realized by SMD 0201-sized components, capacitors from Murata GRM0335C and inductors from Murata LQP03TN series.
The recommended maximum TX output power level is +6 dBm, but the module is also capable of transmitting up to +8 dBm however power levels above +6 dBm cannot be guaranteed over temperature and process variations.

3. Layout Design

The complete layout design of the EFR32BG22-based tag reference module, in CAD format as well, can be found in the full design pack provided by Silicon Labs and is also available under www.silabs.com.

Snapshots from the layout design of EFR32BG22 BLE tag module are shown in the Figures 3.1 and 3.2 below.

The board design follows the generic RF layout recommendations as much as possible on this space-constrained design. The top layer consists of all components, excluding the coin cell battery which is placed on the bottom layer of the module. The first inner layer ensures the low-impedance return path for the RF part of the design by having continuous and unbroken ground pour on it. The board area of the 10-pin mini-simplicity header is removeable from the rest of the PCB once the device has been programmed or flashed. The printed antenna design consists of two separate traces, one of them is connected to the RF port of the EFR32BG22 matching path and is top-loaded by an inductor to the GND (main resonator), while another trace (secondary resonator) is being connected to the GND through also an inductor and EM-coupled with the main antenna trace. This antenna configuration appeared to provide better antenna efficiency and pattern properties, compared to a single-trace antenna design in this small form factor. The antenna has a separate area on the PCB as well as shown in the figures below and placed away from the coin cell battery as much as possible to avoid any possible shielding effects of it.

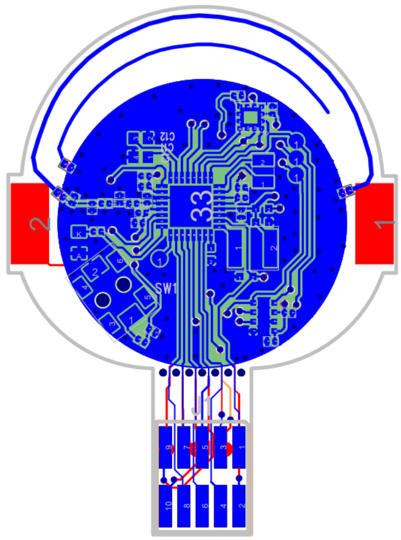


Figure 3.1 BLE tag layout design: top view of all layers with ground stitching vias

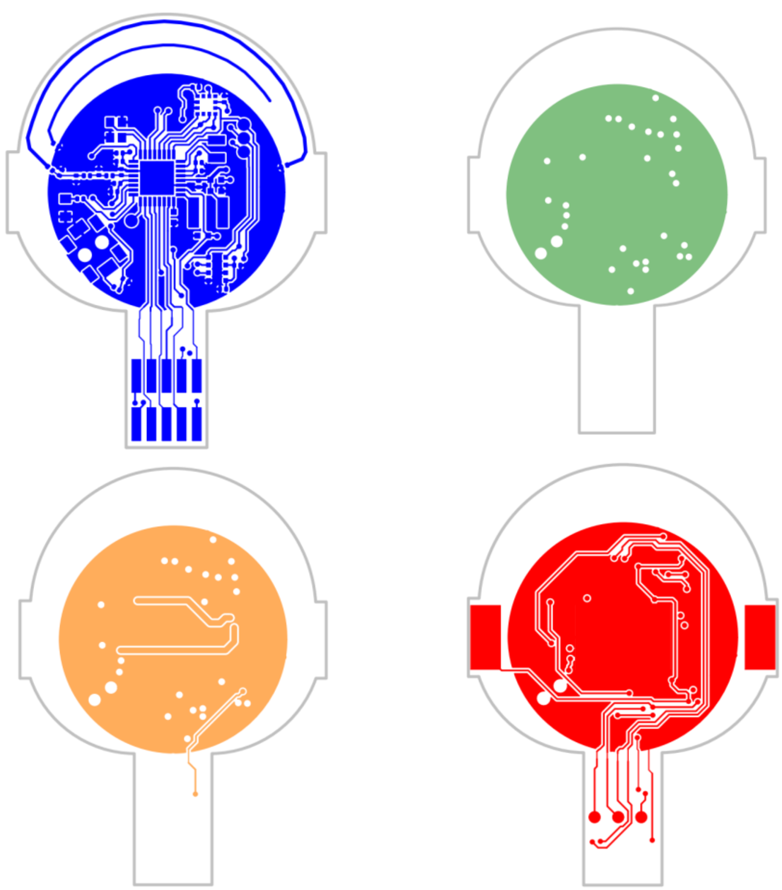


Figure 3.2 BLE tag layout design: top, first and second inner, and bottom layers

4. Antenna Simulations

The RF path and antenna designs have been simulated in a 3D EM simulator, in CST. The simulated antenna structure and PCB is shown in Figure 4.1 below.

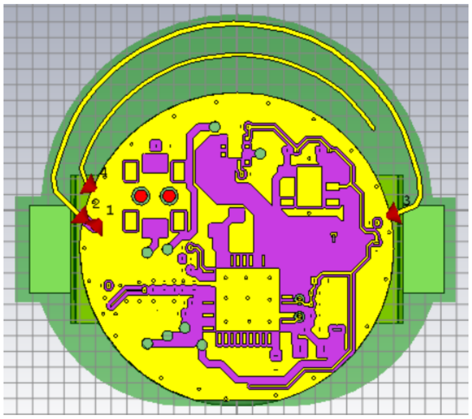


Figure 4.1 EFR32BG22 BLE Tag Design – Simulated structure in CST

The simulated antenna parameters are plotted in the following figures below.

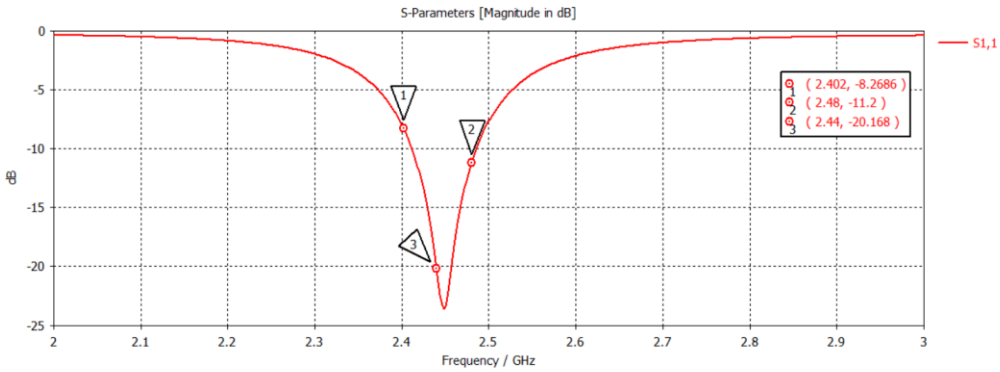


Figure 4.2 Simulated antenna S11

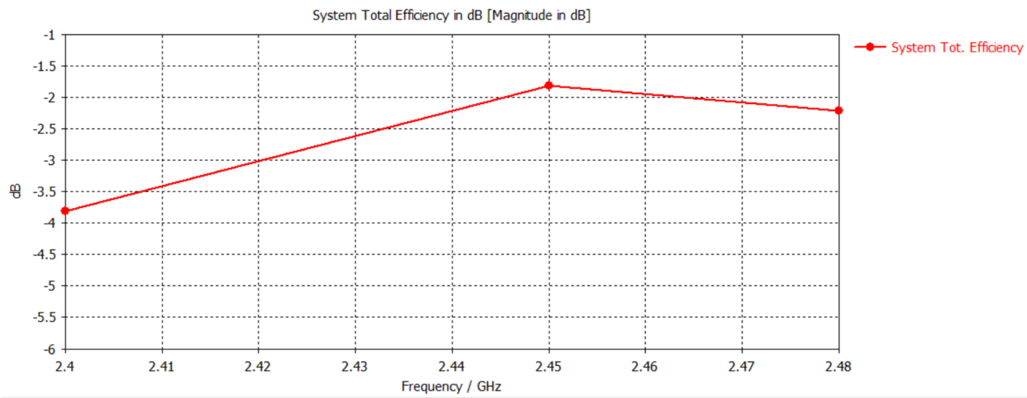


Figure 4.3 Simulated antenna efficiency

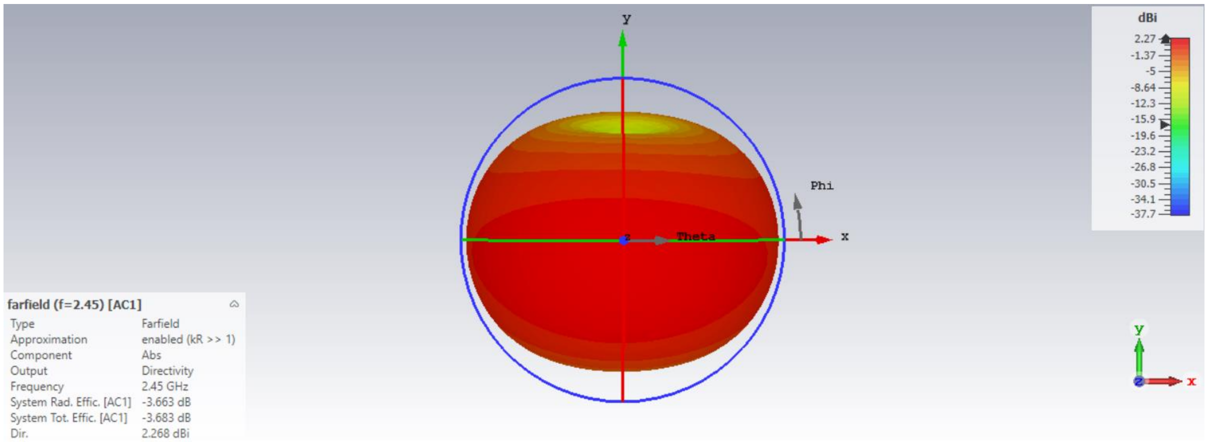


Figure 4.4 Simulated antenna far-field properties

5. Measurement Results

5.1. Conducted TX Performance

The TX conducted performance results taken on two samples are summarized in the table below.

Table 5.1 Conducted TX Performance Results

Power Settings	Frequency	TXP	H2	H3	H4	H5
Max power with 6dBm PA, raw 127	2405 MHz	8.39 dBm	-42.8 dBm	-52.3 dBm	< -70 dBm	-56.3 dBm
	2450 MHz	8.04 dBm	-43.4 dBm	-54.6 dBm	< -70 dBm	-55.6 dBm
	2480 MHz	7.89 dBm	-43.4 dBm	-55.6 dBm	< -70 dBm	-56.9 dBm
'setpower 60' with 6dBm PA, raw 74	2450 MHz	6.81 dBm	-55.0 dBm	-55.6 dBm	< -70 dBm	-59.5 dBm
'setpower 54' with 6dBm PA, raw 59	2450 MHz	6.13 dBm	-62.6 dBm	-56.6 dBm	< -70 dBm	-61.4 dBm
'setpower 0' with 0dBm PA	2450 MHz	-0.82 dBm	-55.3 dBm	-64.5 dBm	< -70 dBm	< -70 dBm

The spectrum plots for these TX conducted measurements listed above are shown in the following figures below.

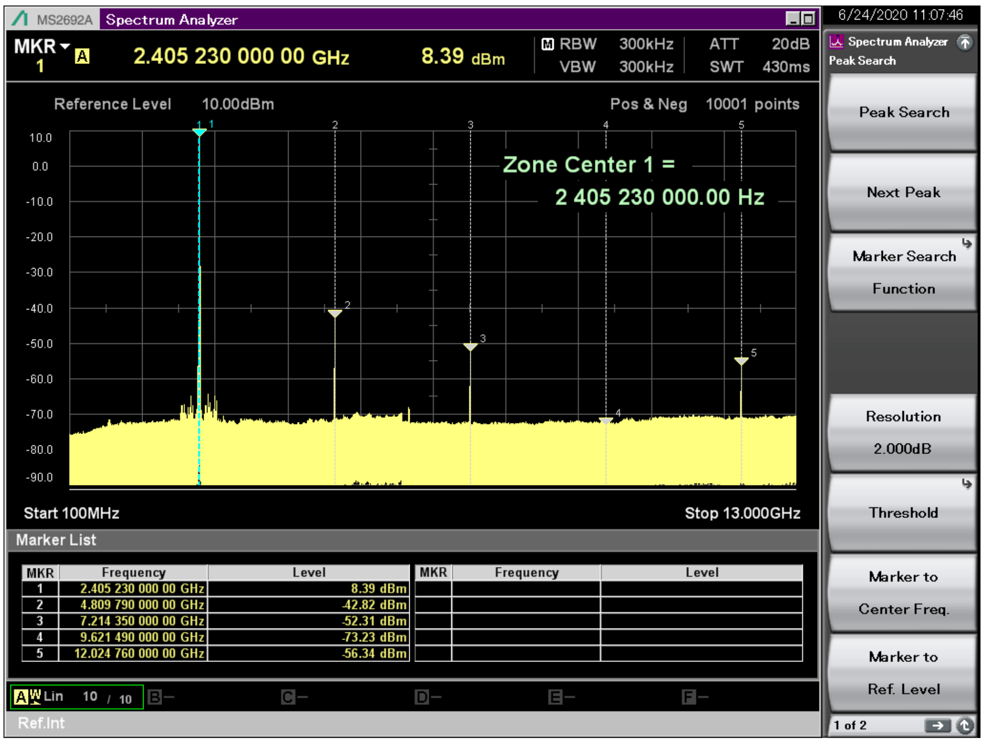
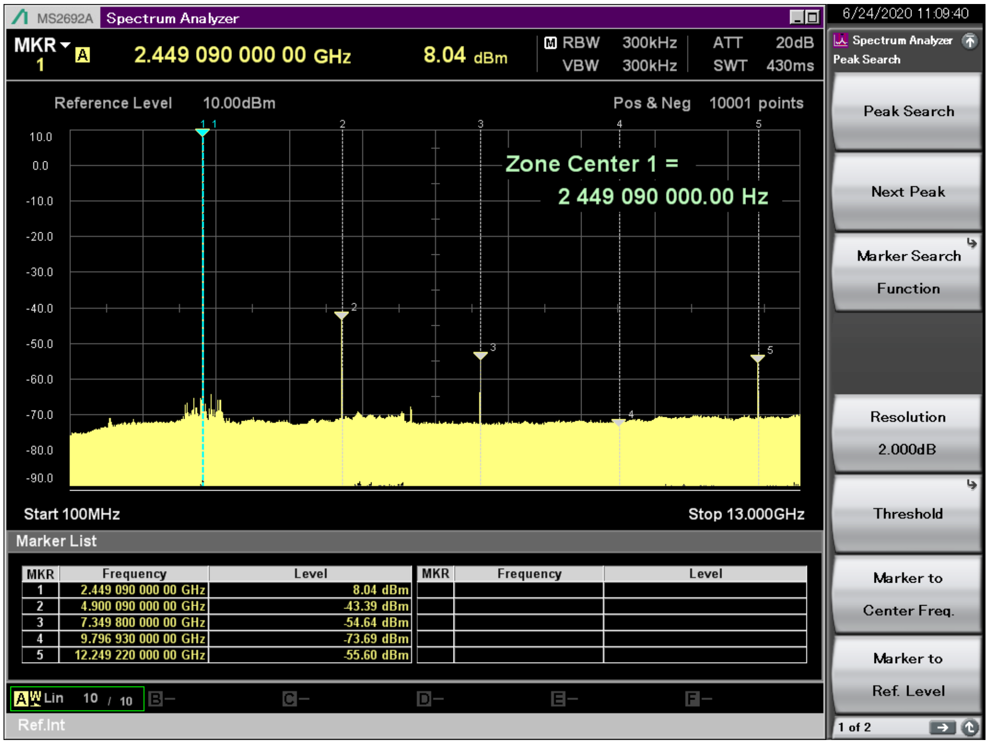
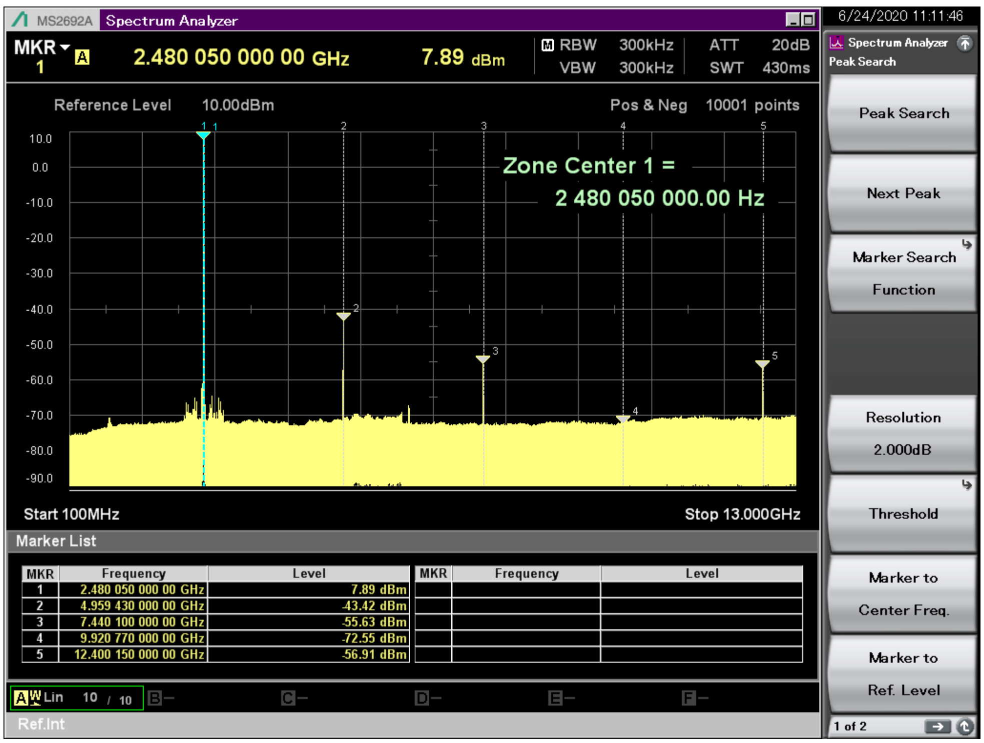


Figure 5.1 Conducted Spectrum, raw power setting of 127 of 6dBm PA, 2405 MHz



MKR	Frequency	Level
1	2.449 090 000 00 GHz	8.04 dBm
2	4.900 090 000 00 GHz	-43.39 dBm
3	7.349 800 000 00 GHz	-54.64 dBm
4	9.796 930 000 00 GHz	-73.69 dBm
5	12.249 220 000 00 GHz	-55.60 dBm

Figure 5.2 Conducted Spectrum, raw power setting of 127 of 6dBm PA, 2450 MHz



MKR	Frequency	Level
1	2.480 050 000 00 GHz	7.89 dBm
2	4.959 430 000 00 GHz	-43.42 dBm
3	7.440 100 000 00 GHz	-55.63 dBm
4	9.920 770 000 00 GHz	-72.55 dBm
5	12.400 150 000 00 GHz	-56.91 dBm

Figure 5.3 Conducted Spectrum, raw power setting of 127 of 6dBm PA, 2480 MHz

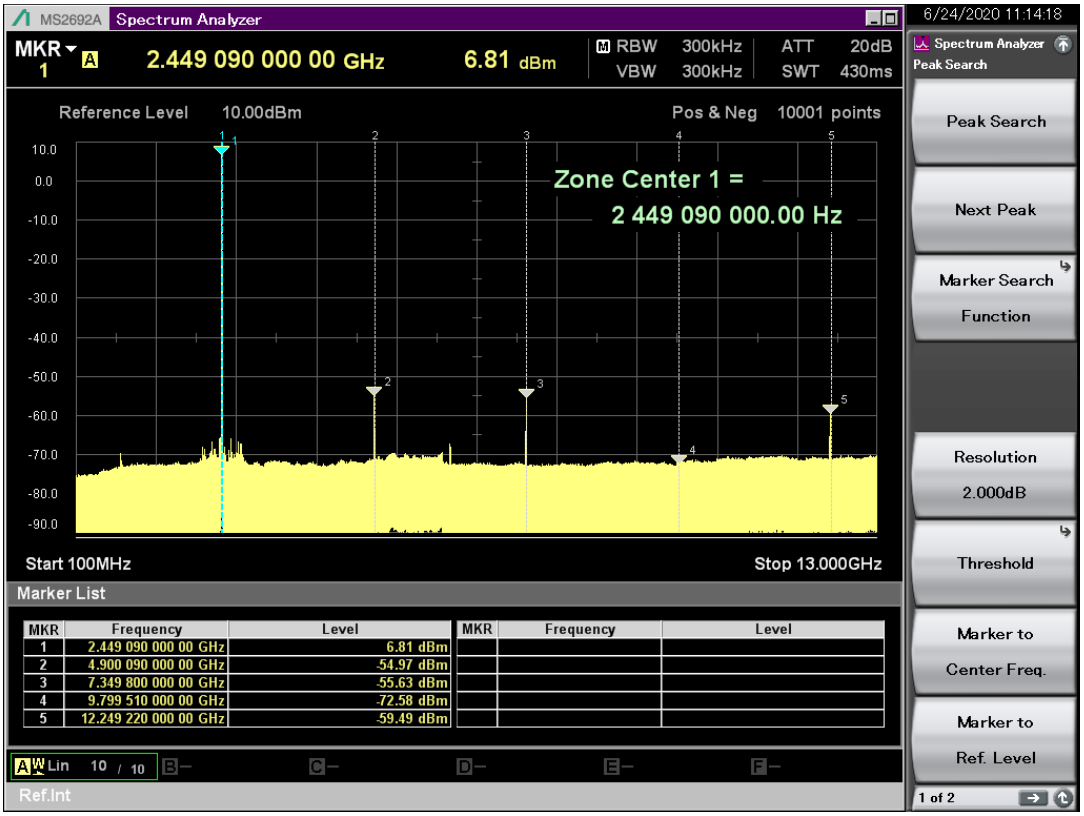


Figure 5.4 Conducted Spectrum, raw power setting of 74 of 6dBm PA, 2450 MHz

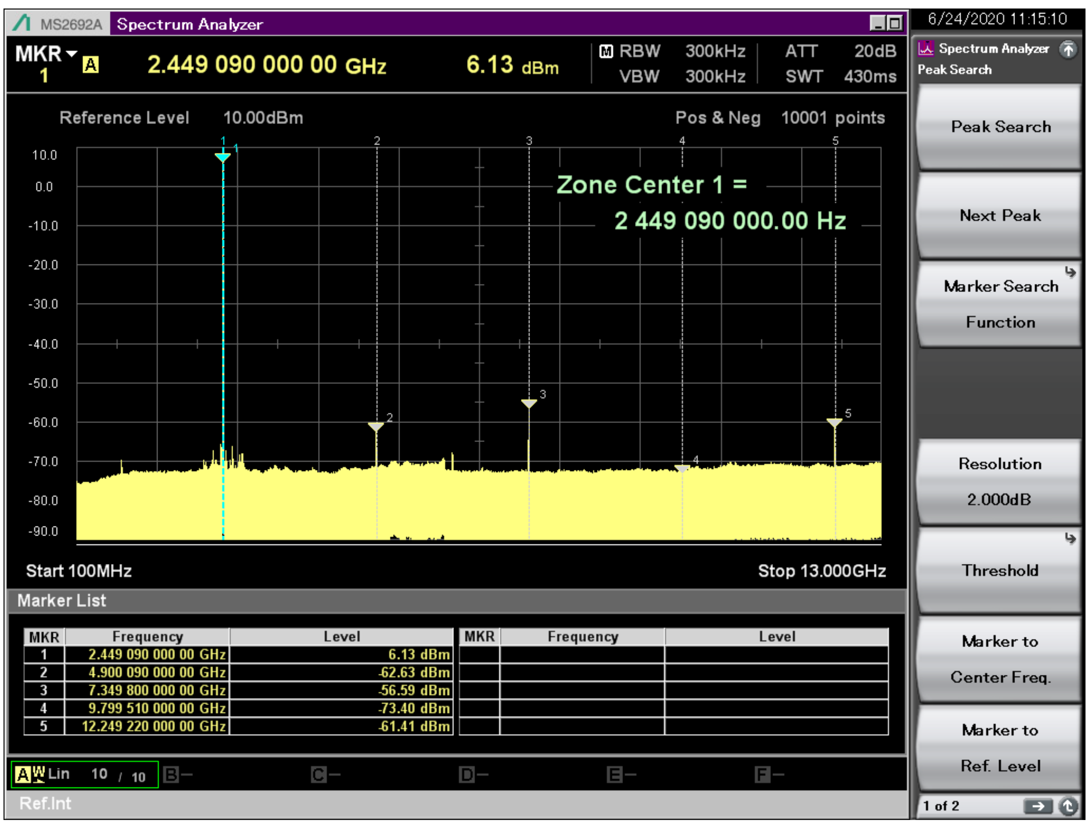
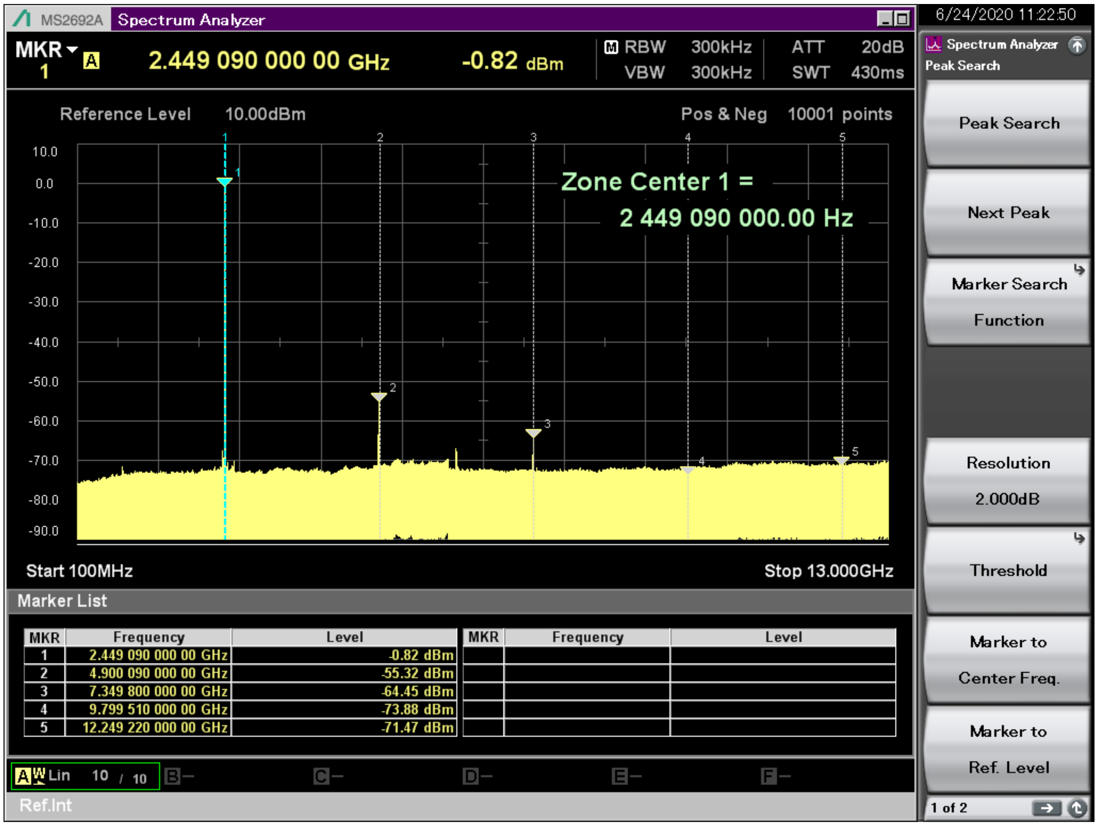


Figure 5.5 Conducted Spectrum, raw power setting of 59 of 6dBm PA, 2450 MHz



MKR	Frequency	Level	MKR	Frequency	Level
1	2.449 090 000 00 GHz	-0.82 dBm			
2	4.900 090 000 00 GHz	-55.32 dBm			
3	7.349 800 000 00 GHz	-64.45 dBm			
4	9.799 510 000 00 GHz	-73.88 dBm			
5	12.249 220 000 00 GHz	-71.47 dBm			

Figure 5.6 Conducted Spectrum, power setting of 0 of 0dBm PA, 2450 MHz

5.2. Conducted RX Performance

The conducted RX measurement results are demonstrated with the following charts. The receiver performance has been checked with Bluetooth LE 1 Mbps PHY, while the sensitivity limit is PER < 30%, which basically corresponds to BER < 0.1% for the same BLE 1 Mbps MSK signal.

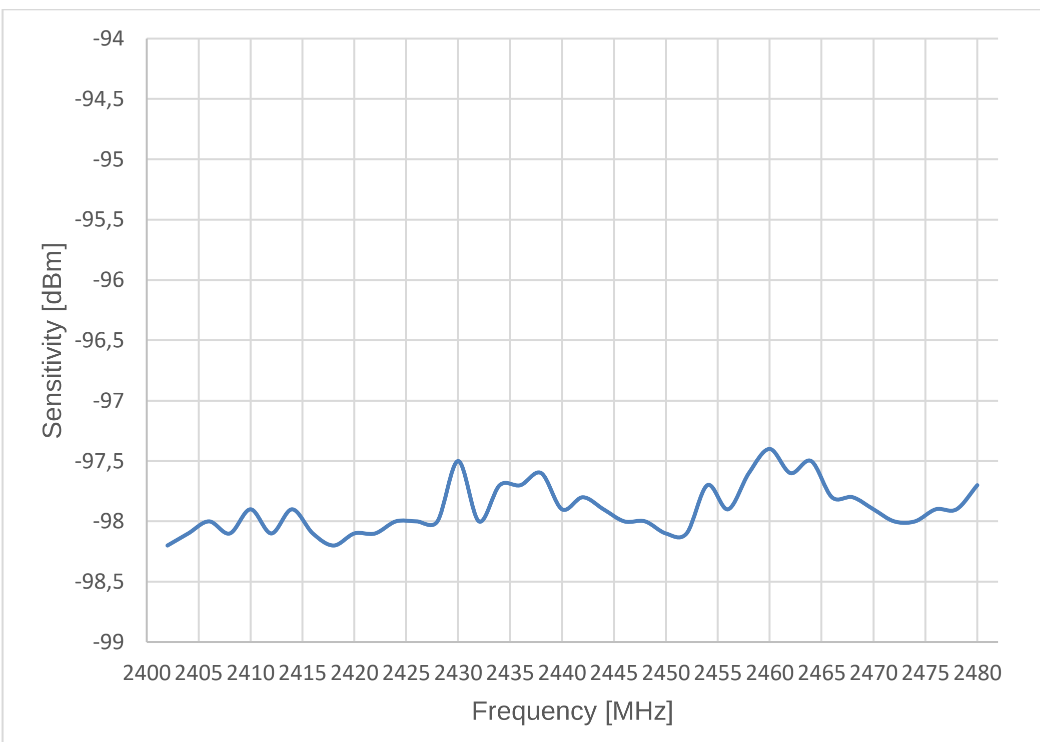


Figure 5.7 Conducted Sensitivity vs. Frequency, BLE 1 Mbps, PER < 30%

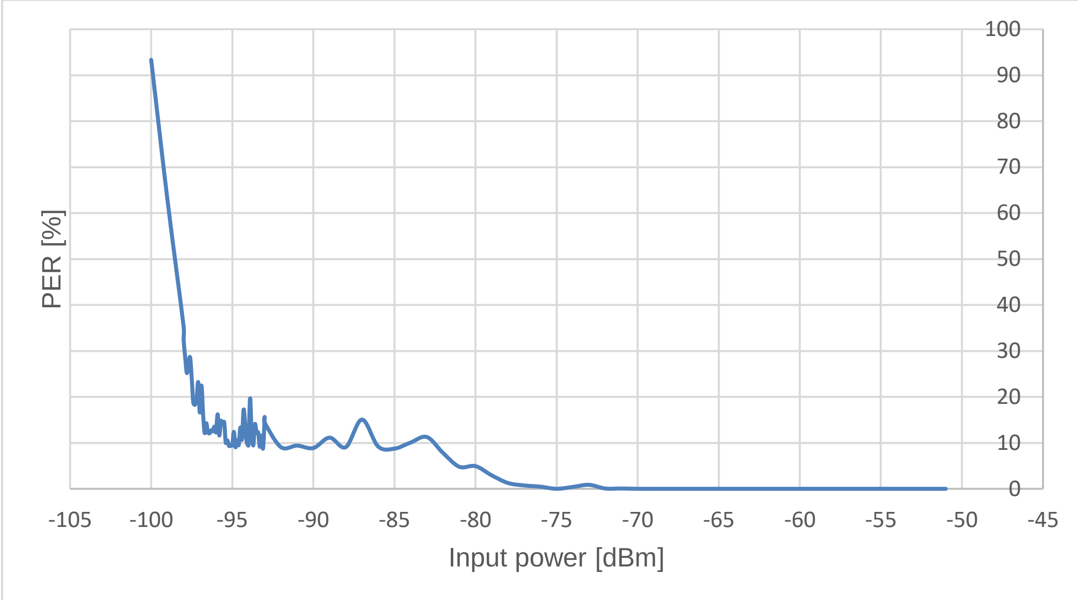


Figure 5.8 Conducted PER waterfall curve, BLE 1 Mbps, 2440 MHz

5.3. Antenna Impedance

The measured antenna impedance of the BLE tag module's printed antenna is shown in the figure below.
The measured S11 of the antenna is below -7dB in the frequency band of interest (2.4 – 2.48 GHz) which is basically acceptable and good for this application also considered the small board size which is a limiting factor in impedance bandwidth. The antenna impedance has been checked by using a sleeve balun connected as well in order to avoid current leakage through the connected RF pig-tail cable which would deteriorate the measurement results. Additionally, the antenna impedance tuning has been performed when the coin-cell battery was being inserted into, but without plastic enclosure. So, designs with plastic housing applied might need some further fine-tuning of antenna to achieve the best RF performance.

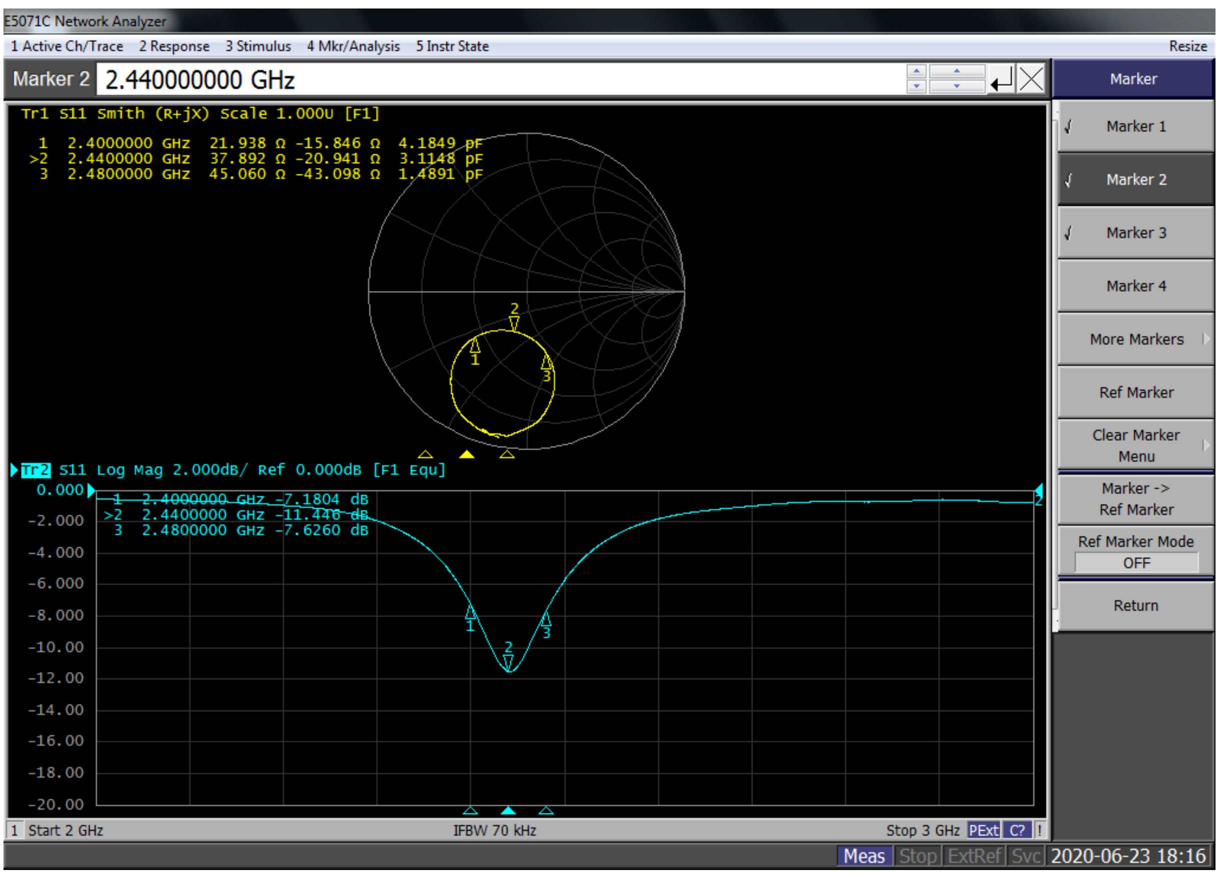


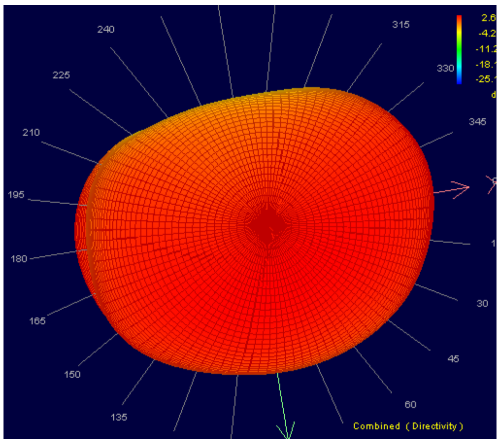
Figure 5.9 Antenna Impedance

5.4. Antenna Efficiency

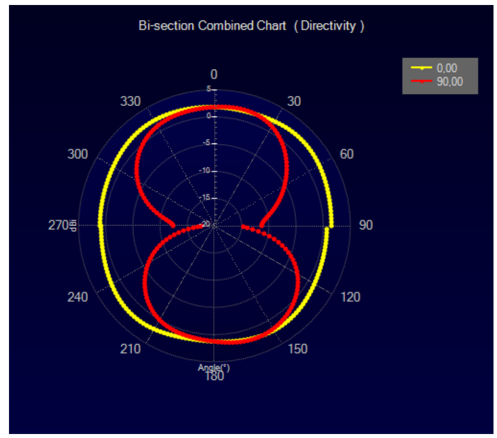
The antenna efficiency of the on-board printed antenna and the total radiated power of the BLE tag module have been measured by using the RFxpert measuring equipment. It also plots the realized gain and maximum EIRP values, but these parameters have also been checked in radiated measurements in an anechoic RF chamber and will be presented later in this document. The antenna efficiency looks pretty good for this small RF module and in-line with the simulation results. The TRP has also a nice flat characteristic across the entire frequency band of interest.

Table 5.2 RFxpert measurement results

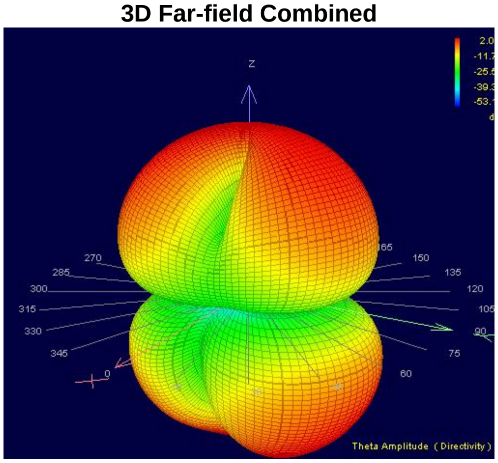
Power Settings	Frequency	Antenna Efficiency	Realized Gain	TRP	EIRP
Max power with 6dBm PA, raw 127	2405 MHz	**-3.15 dB**	-0.63 dBi	**5.24 dBm**	7.76 dBm
	2450 MHz	**-2.75 dB**	-0.1 dBi	**5.29 dBm**	7.94 dBm
	2480 MHz	**-1.91 dB**	1.63 dBi	**5.98 dBm**	9.52 dBm



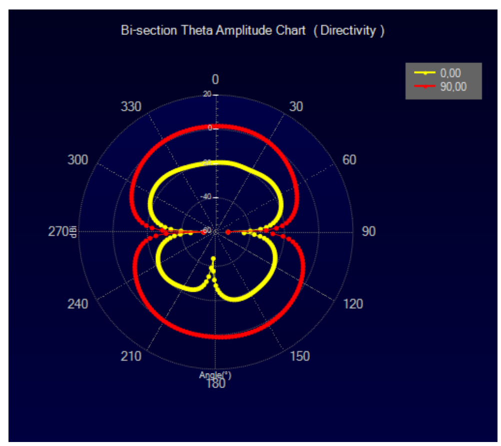
3D Far-field Combined



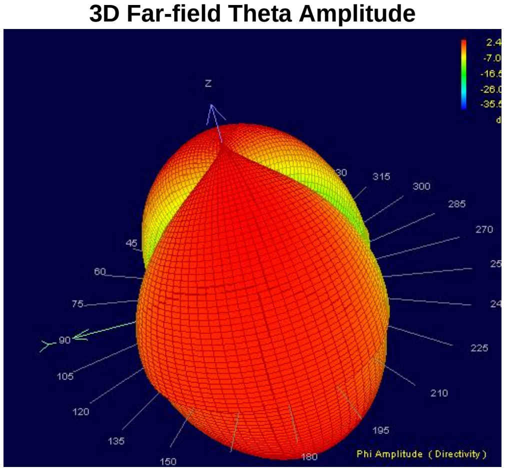
Bisection Far-field Combined



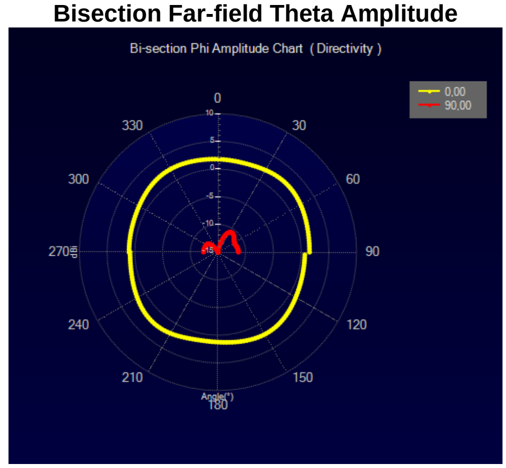
3D Far-field Theta Amplitude



Bisection Far-field Theta Amplitude



3D Far-field Phi Amplitude



Bisection Far-field Phi Amplitude

Figure 5.10 RFxpert Far-field plots at 2450 MHz

5.5. PCB Orientations and Cuts

The following figure shows the orientations and cuts of the PCB module for reference for the radiated measurements.

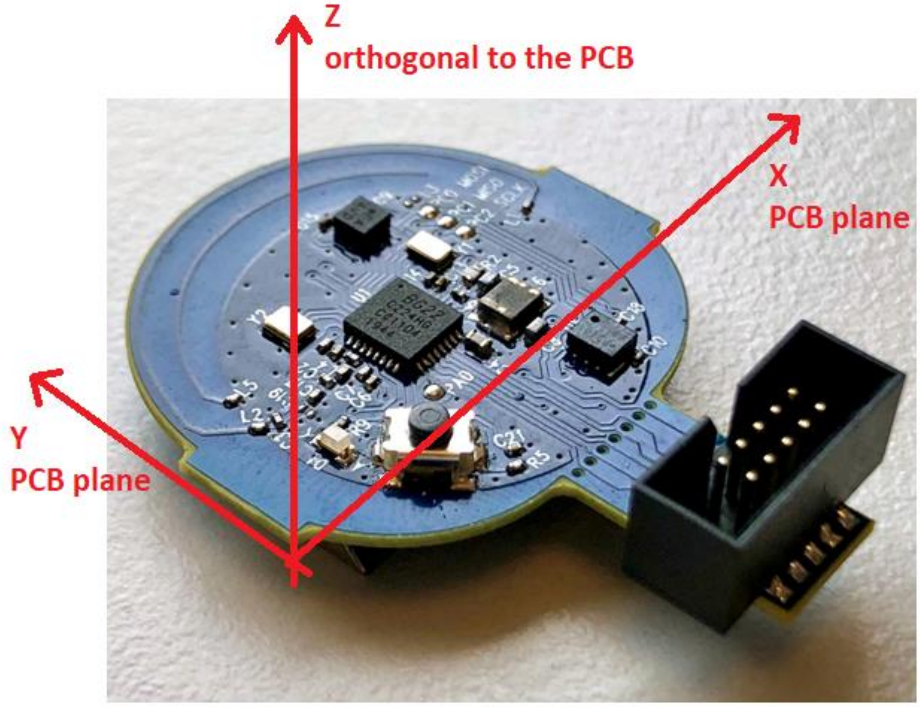


Figure 5.11 PCB orientations for cuts reference in radiated measurements

5.6. Radiation Patterns

The radiation patterns of the module have also been measured in an anechoic RF chamber, and the following plots represent the results. The radiation pattern plots are normalized to the absolute maximum radiated power.

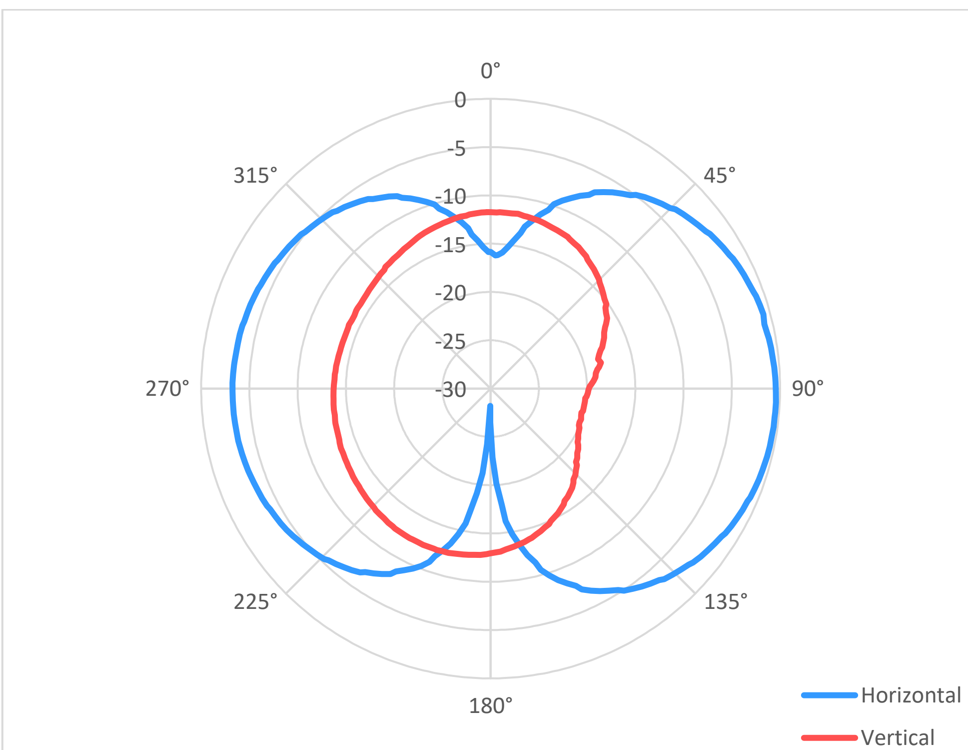


Figure 5.12 Normalized Radiation Pattern, XY cut, zero degree at Y axis, at 2450 MHz

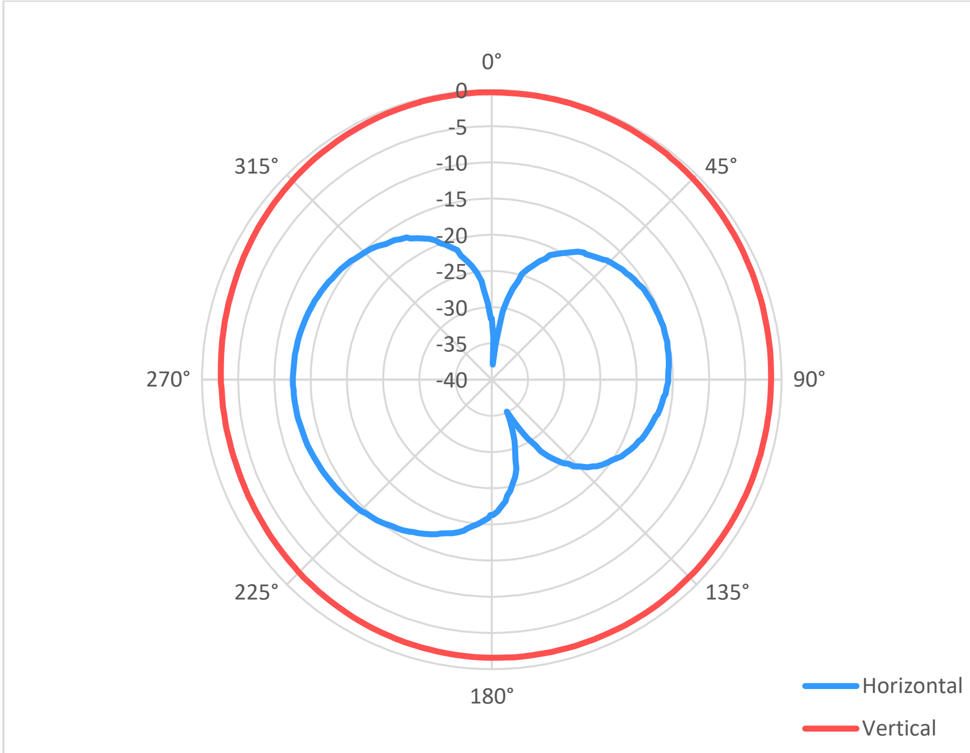


Figure 5.13 Normalized Radiation Pattern, XZ cut, zero degree at Z axis, at 2450 MHz

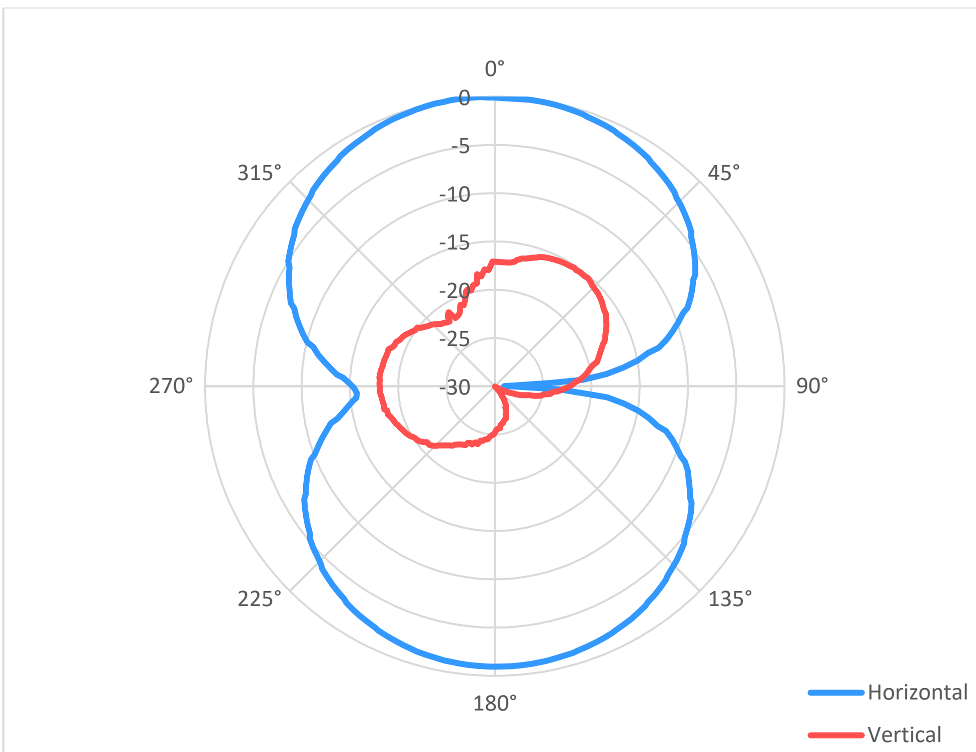


Figure 5.14 Normalized Radiation Pattern, YZ cut, zero degree at Z axis, at 2450 MHz

5.7. Radiated EIRP and Harmonics

The radiated fundamental EIRP and harmonics of the module have also been measured in an anechoic RF chamber, and the following tables represent the results. The module has been measured in its stand-alone operation mode with a CW tone code running on it. The module was being supplied by a coin cell battery.
The tag reference design module complies with CE and FCC regulatory standards based on our pre-certification tests, but the module does not have any official certification ID owned by Silicon Labs.
The tag module's maximum antenna gain based on these radiated EIRP measurements is around -1…-2 dBi, which can be considered as pretty good for this small board size (the RFxpert measurements shown above in section 5.4 a bit overestimate the EIRP and antenna gain values).

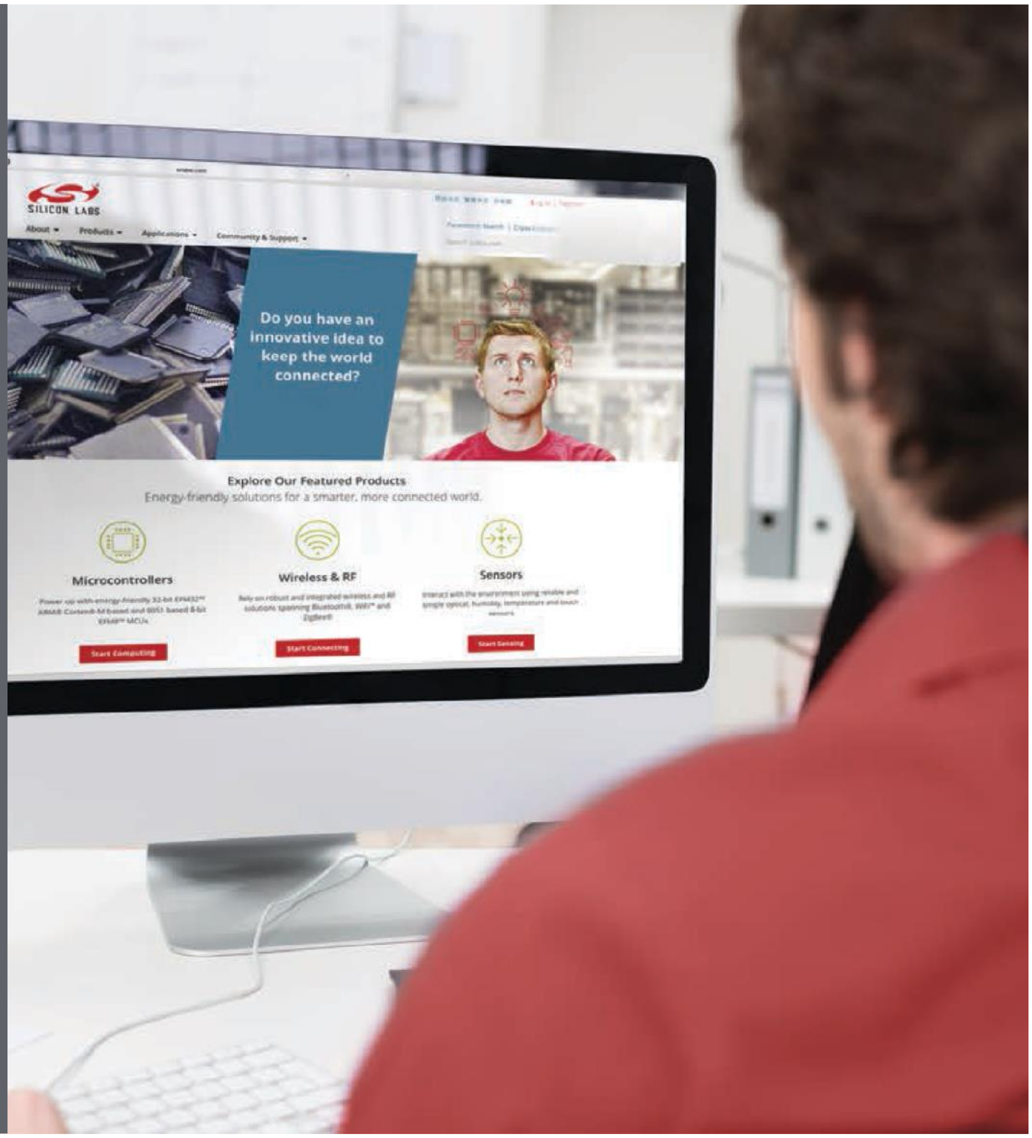
Table 5.3 Radiated EIRP at +6 dBm power settings

2450 MHz +6 dBm	Measured maximums of the radiated power in EIRP [dBm]					
	XY		XZ		YZ	
	H	V	H	V	H	V
Fund.	2.8	-6.5	-10.5	4.0	4.3	-13.3
2nd harm.	-57.0	-56.8	-56.8	-54.7	-54.1	-51.0
3rd harm.	-49.7	-47.4	-44.4	-48.0	-46.7	-44.5
4th harm.	-49.0	-49.0	-49.0	-49.0	-49.0	-49.0
5th harm.	-46.5	-46.5	-46.5	-46.5	-46.5	-46.5

Table 5.4 Radiated EIRP at maximum (+8 dBm) power settings

2450 MHz +8 dBm	Measured maximums of the radiated power in EIRP [dBm]					
	XY		XZ		YZ	
	H	V	H	V	H	V
Fund.	6.2	-11.1	-14.2	7.4	7.2	-13.9
2nd harm.	-49.9	-56.3	-52.1	-53.6	-49.8	-53.7
3rd harm.	-44.0	-45.1	-40.2[1]	-45.4	-41.8	-41.3
4th harm.	-49.0	-49.0	-49.0	-49.0	-49.0	-49.0
5th harm.	-46.5	-44.4	-44.5	-44.1	-43.6	-43.5

Note 1: Based on our pre-certification testing this fails in CW mode (with the possible maximum power settings of raw power 127 in rail) with peak detector by 1 dB but should be compliant with margins (3-4 dB) when applying modulated signal with AVG detector allowed by FCC.
At the output power settings of +6 dBm the module complies with FCC and ETSI regulatory standards even in CW mode.



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