Small Size 2.4GHz PCB Antenna-AN043

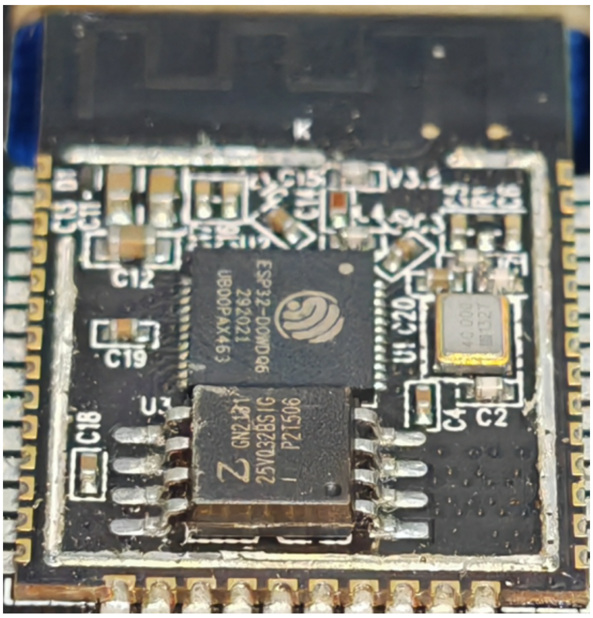
1 KEYWORDS

- PCB antenna
- Average Gain 2dBi
- ESP32
- IOT application
- 2.4 GHz
- Inverted F Antenna

2 INTRODUCTION

The PCB antenna described in this application note is now used on ESP32 module reference design. However, it can also be used in all 2.4 GHz designs, especially small space is required for the antenna.

This application note describes the antenna dimensions, the RF performance and considerations for complying with regulatory limits when using this design.



The suggested antenna design requires no more than 15.2 x 5.7 mm of space and ensures a VSWR ratio of less than 2 across the 2.4 GHz ISM band when connected to a 50 ohm source.

Figure 1: ESP32

3 ANTENNA DESIGN

The PCB antenna on the ESP32 Module reference design is a meandered Inverted F Antenna (IFA). The

IFA was designed to match an impedance of 50 ohm at 2.45 GHz. Thus no additional matching components are necessary.

3.1 Design Goals

The reflection at the feed point of the antenna determines how much of the applied power is delivered to the antenna. A reflection of less than -10 dB across the 2.4 GHz ISM band, when connected to a 50 ohm source, was a design goal. Reflection of less than -10 dB, or VSWR less than 2, ensures that more than 90% of the available power is delivered to the antenna. Bandwidth is in this document defined as the frequency band where more than 90% of the available power is delivered to the antenna. Another design goal was to fit the size of the PCB antenna on the esp32 Module and to obtain good performance also when it is used in IOT applications.

3.2 Simulation

IE3D from Zeland, which is an electromagnetic simulation tool, was used to design the antenna. The accuracy of the simulation is controlled by the mesh. An increase of the mesh increases the simulation time. Thus, for initial simulations mesh = 1 should be used. When a fairly good result is achieved a higher mesh should be used to obtain more accurate results. Comparison of simulation and measurement results shows that the measured reflection is between the result obtained with mesh = 5 and mesh = 1; see Figure 2 for details.

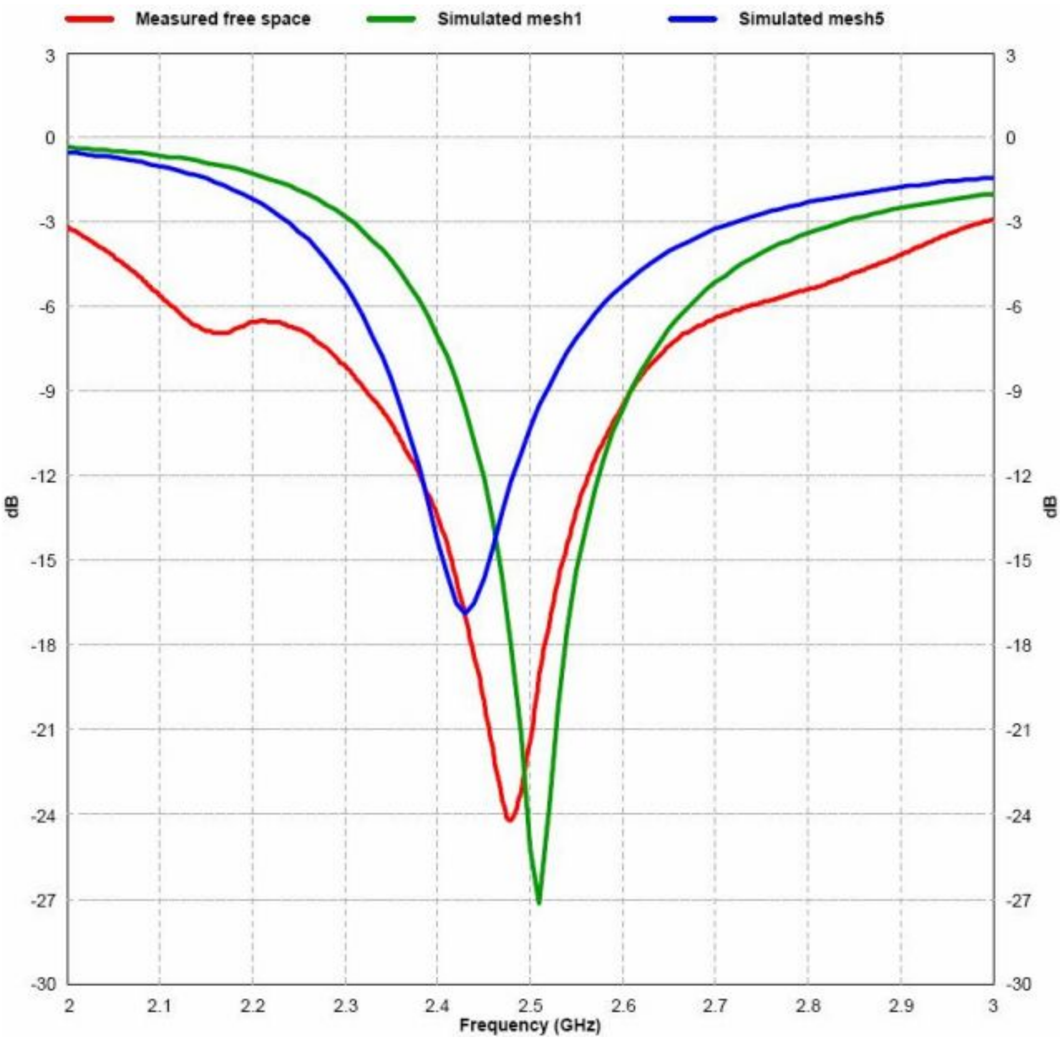


Figure 2: Comparison of Simulation and Measurements Results

3.3 Layout and Implementation

Small changes of the antenna dimensions may have large impact on the performance. Therefore it is strongly recommended to make an exact copy of the reference design to achieve optimum performance. It is also recommended to use the same thickness and type of PCB material as used in the reference design. To compensate for a thicker/thinner PCB the antenna could be made slightly shorter/longer.

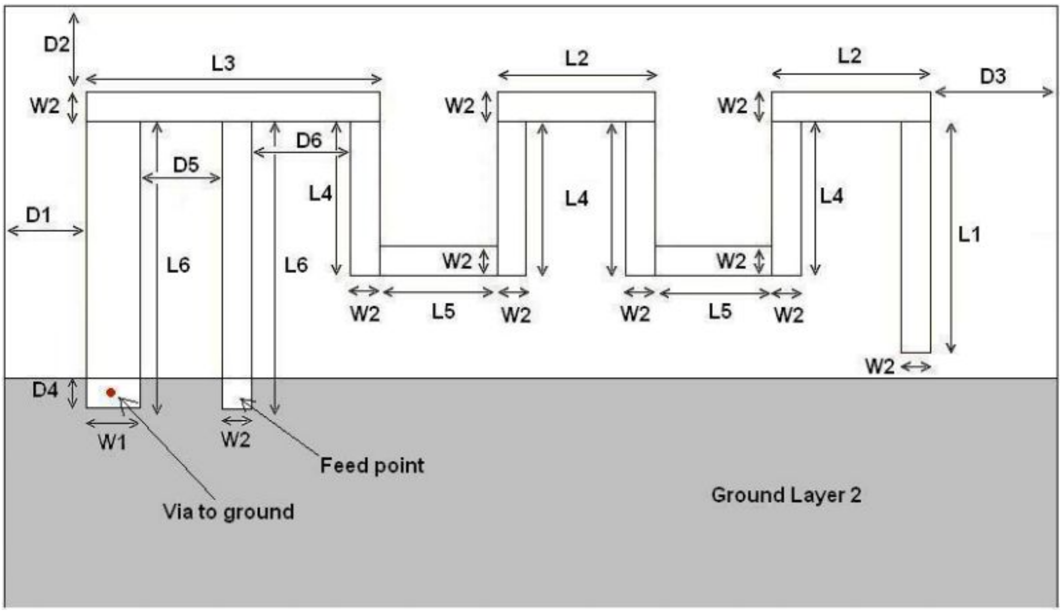


Figure 3: Antenna Dimensions

L1	3.94
L2	2.70
L3	5.00
L4	2.64
L5	2.00
L6	4.90
W1	0.90
W2	0.50
D1	0.50
D2	0.30
D3	0.30
D4	0.50
D5	1 .40
D6	1 .70

Table 1: Antenna Dimensions

4 TEST RESULTS

Reflection, radiation pattern and variation of output power across a wide frequency band were measured to verify the performance of the PCB antenna.

4.1 Reflection

All the reflection measurements were performed with a network analyzer connected to a semi-rigid coax cable, which was soldered to the feed point of the antenna. Because of the small size antenna and the small ground plane this kind of measurements is heavily affected by the presence and placement of the coax cable. This influence can result in a small uncertainty in resonance frequency and measured reflection. Typically different placement of the semi-rigid coax cable could change the resonance frequency with 5 -10 MHz and the reflection with 3 - 4 dB.

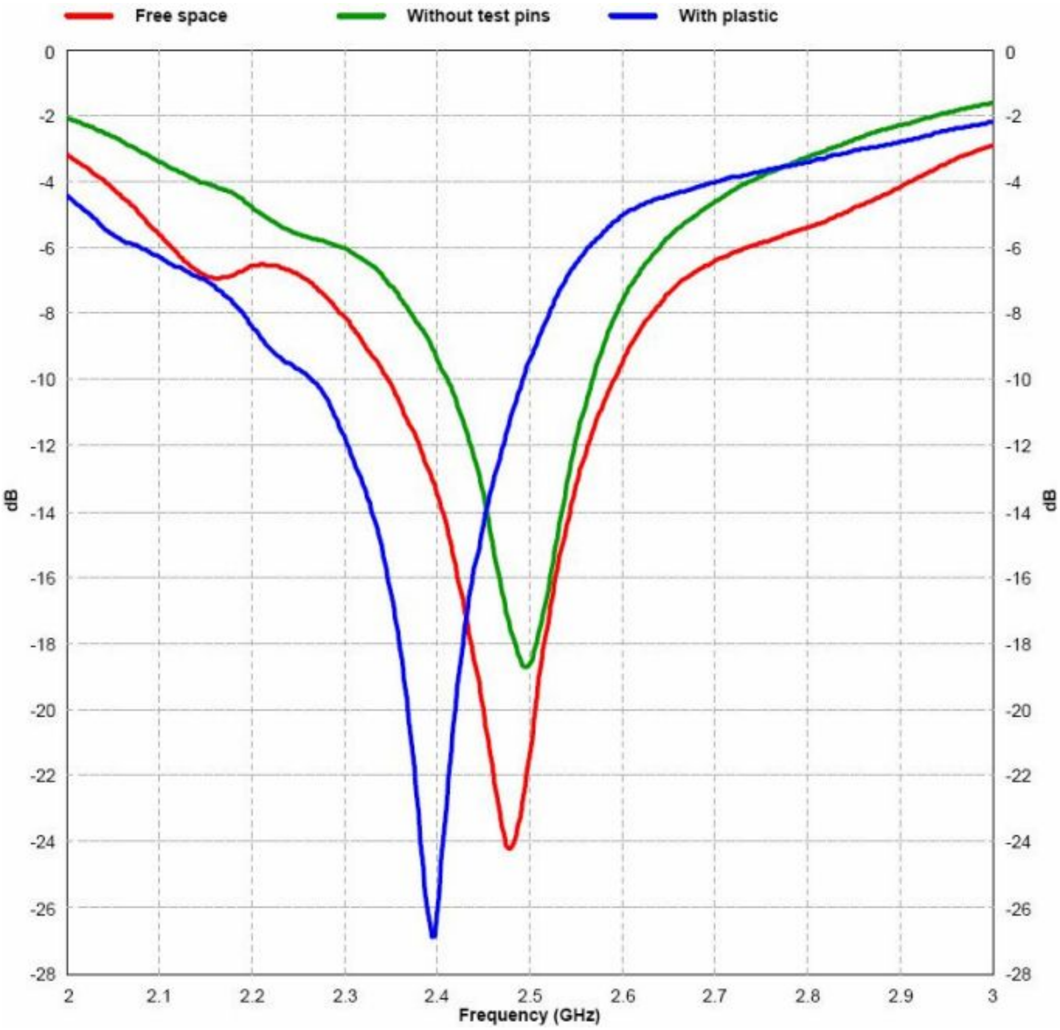


Figure 4: Influence of Plastic Encapsulation and Test Pins

The size of the ground plane affects the performance of the PCB antenna. Soldering esp32 to a test board increases the size of the ground plane and thus the performance is affected. However, bandwidth still can be enough to cover the whole 2.4 GHz ISM band.

4.2 Radiation Pattern

The radiation pattern for the antenna implemented on the esp32 reference design has been measured in an anechoic chamber. Figure 6 through Figure 11 shows radiation patterns for three planes, XY, XZ and YZ, measured with vertical and horizontal polarization. All measurements were performed with 0 dBm output power. Figure 5 shows how the different radiation patters are related to the positioning of the antenna.

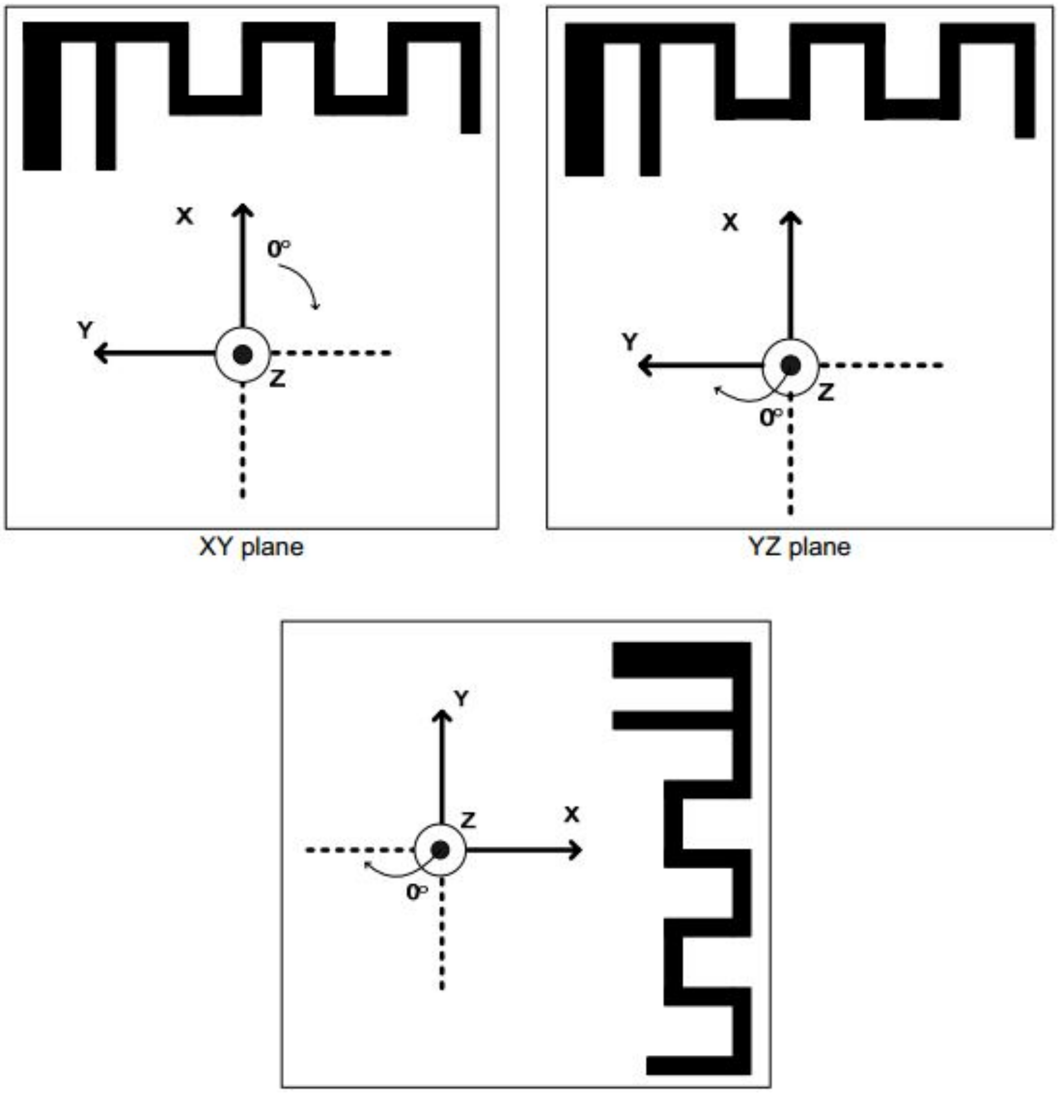


Figure 5: How to Relate the Antenna to the Radiation Patterns

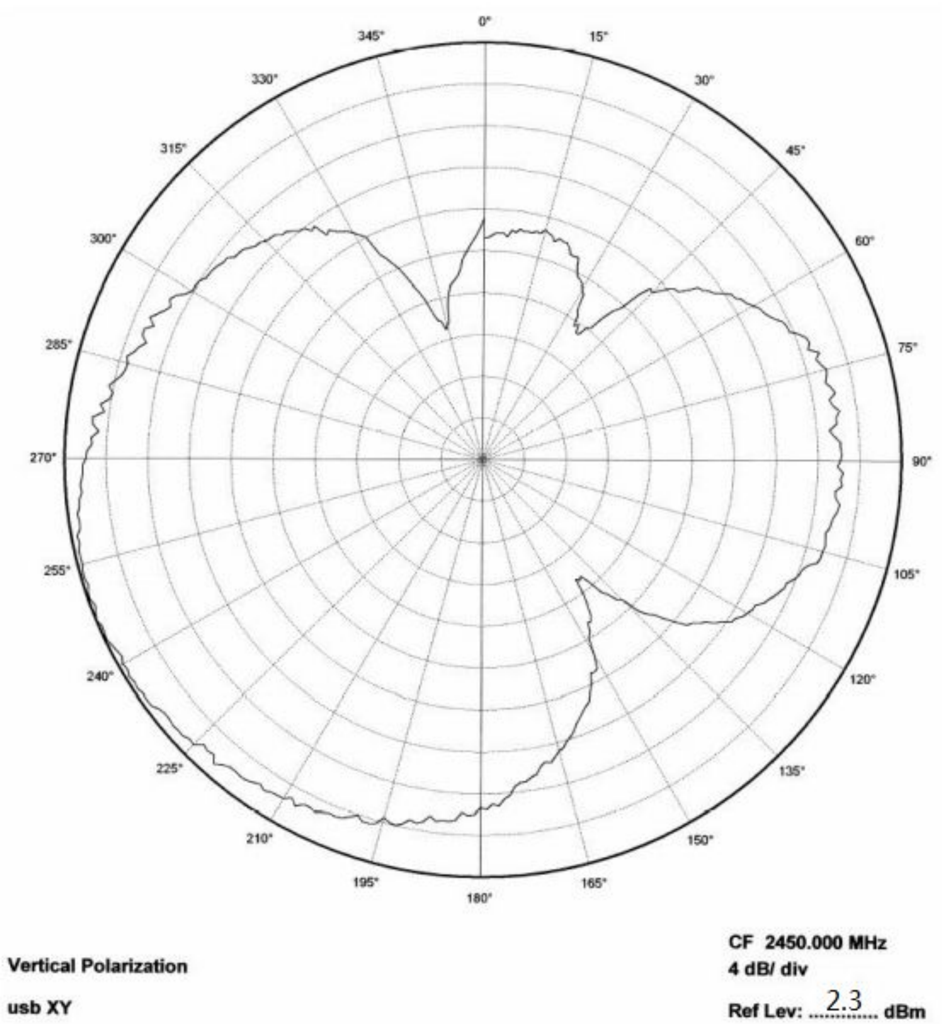


Figure 6:AN043 XY Plane

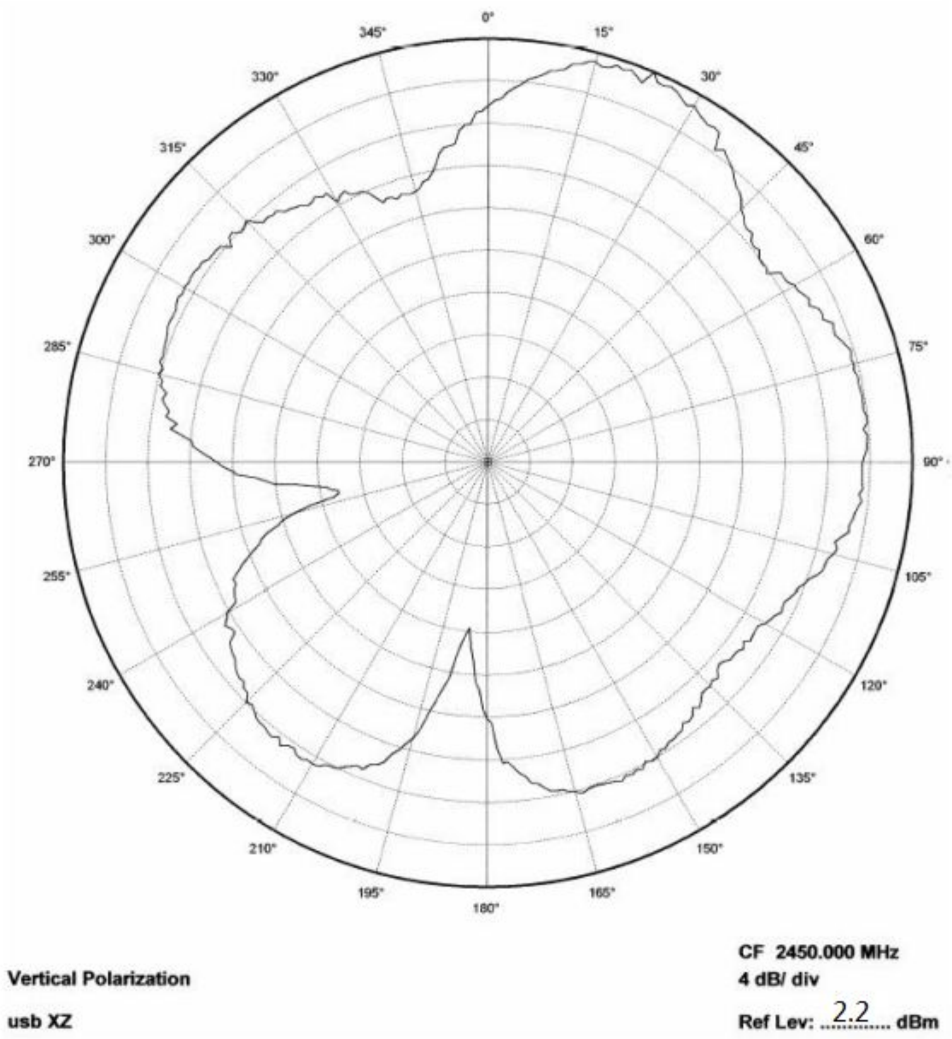


Figure 7:AN043 XZ Plane

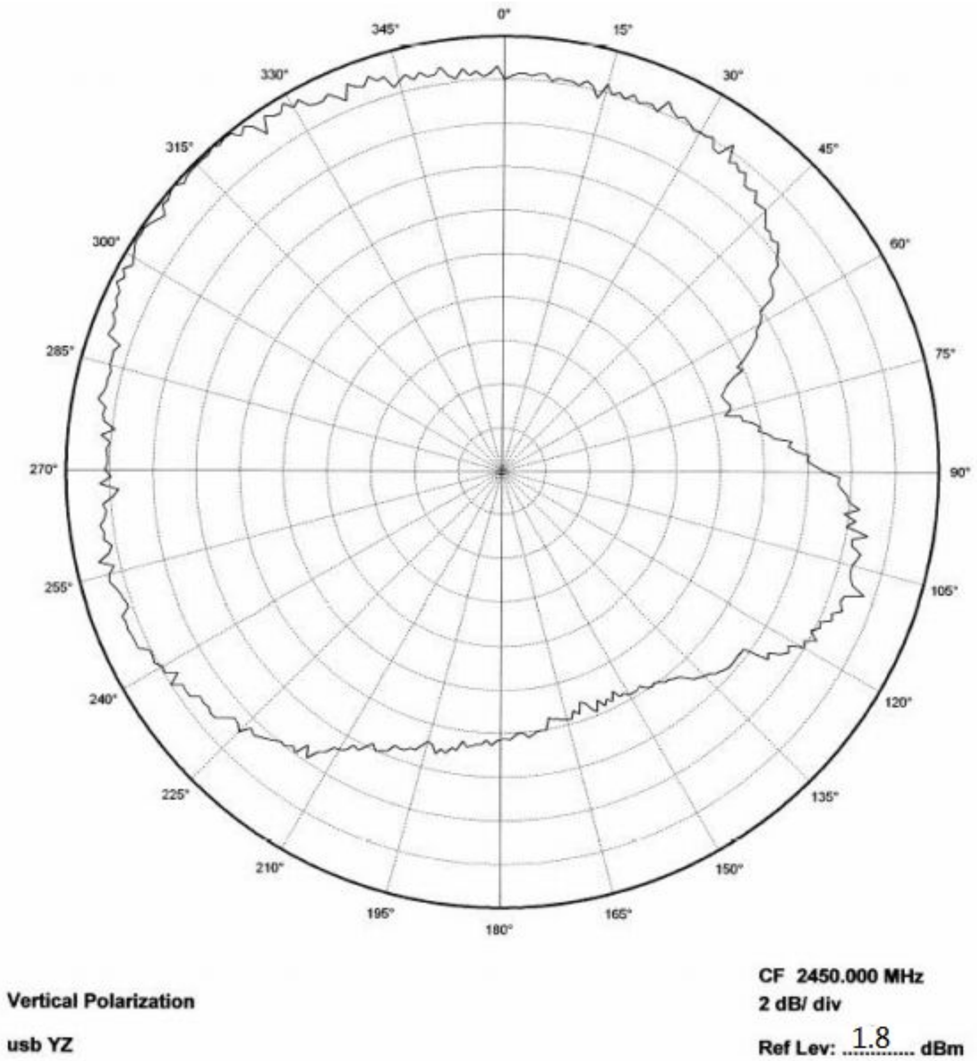


Figure 7:AN043 YZ Plane

4.3 Output Power

To make a realistic bandwidth measurement of the antenna a small test program was used. The test program stepped the center frequency of a carrier from 2.3 to 2.8 GHz. This bandwidth measurement was also done to verify the result from the reflection measurements, described in section 5.1. The output power was measured using max hold on a spectrum analyzer. CC2511 was programmed for 0 dBm output power and the antenna was horizontally oriented and directed towards the receiving antenna. This corresponds to 0° in the XY plane on Figure 6. The bandwidth measurements were not performed with a correction factor on the spectrum analyzer. Thus, the results in Figure 15 and Figure 16 only show the relative changes in output power and not the actual level. Figure 15 shows the bandwidth of the antenna when the dongle is not connected to a computer. The result shows that the antenna has a variation in output power of less than 3 dB across a frequency band of more than 350 MHz. This demonstrates that the antenna has a broadband characteristic. Maximum output power is measured to be at 2.54 GHz. Thus if the same antenna is implemented on a PCB with similar size and if the application is only intended for stand alone usage the antenna could be made slightly longer to obtain best performance at 2.42 GHz.

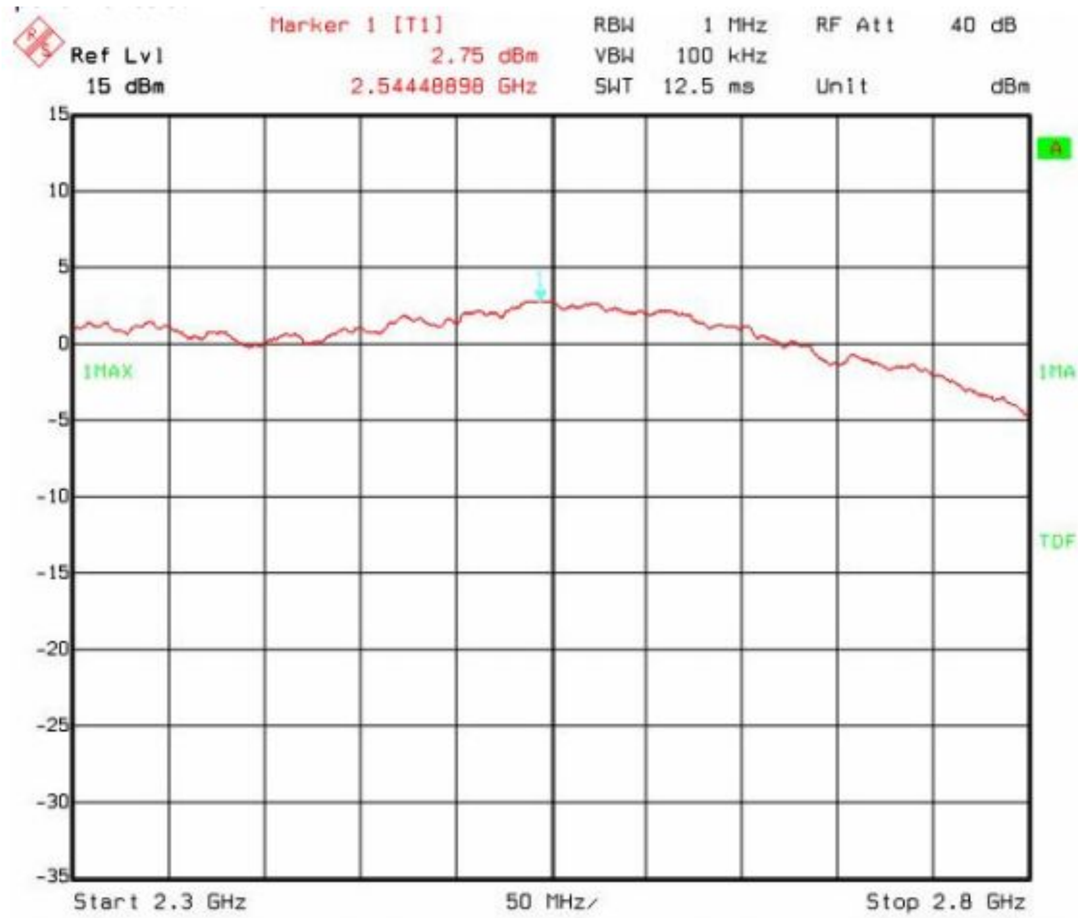


Figure 8:OUTPUT POWER,esp32

5.4 Spurious Emission and Harmonics

Table 2 shows measured output power and emission at the second harmonic. Above the second harmonic no peaks were detected when measuring TX emission. This can be seen from Figure 16 . These measurements were performed according to FCC requirements.

Output power	2.44 GHz	4.88 GHz
1 dBm	96.9 dBµV/m	56.1 dBµV/m
0 dBm	96.1 dBµV/m	54.3 dBµV/m
-2 dBm	93.1 dBµV/m	52.5 dBµV/m

Table 2: Measured Level of Output Power and Harmonics

FCC limit for output power and TX spurious emission are shown in Table 3. FCC allows for up to 20 dB higher emission if duty cycling is used. Thus, it is possible to use the antenna described in this document and be compliant with FCC regulation.

	FCC 15.247	FCC 15.249
2.4 – 2.483 GHz	125 dBµV/m 116 dBµV/m**	94 dBµV/m
2. harm	54 dBµV/m	54 dBµV/m

*Depends on the power class.

** Depends on the number of channels being used.

Table 3: FCC Limits

5 CONCLUSION

This application note shows that it is possible to implement a 2.4 GHz antenna on a small area and still achieve good performance. Table 4 lists the most important properties of the Inverted F Antenna, described in this document. The free line of sight (LOS) range was measured with 250 kbps and 1 % PER.

Gain in XY plane	2.3 dBi
Gain in XZ plane	2.2 dBi
Gain in YZ plane	1.8 dBi
Gain in average	2.0 dBi
LOS range	240 m
Antenna size	15.2 x 5.7 mm

Table 4: IFA Properties (Measured on esp32 Reference Design)

The results provided in section 4 shows that it is possible to comply with FCC regulations when implementing the suggested antenna together with esp32 Module.