

Application Note *F1-18-V1.0*

Small Size 2.4 GHz PCB antenna

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1 KEYWORDS

- *F 1*
- *PCB antenna*
- *2.4 GHz*
- *Inverted F Antenna*

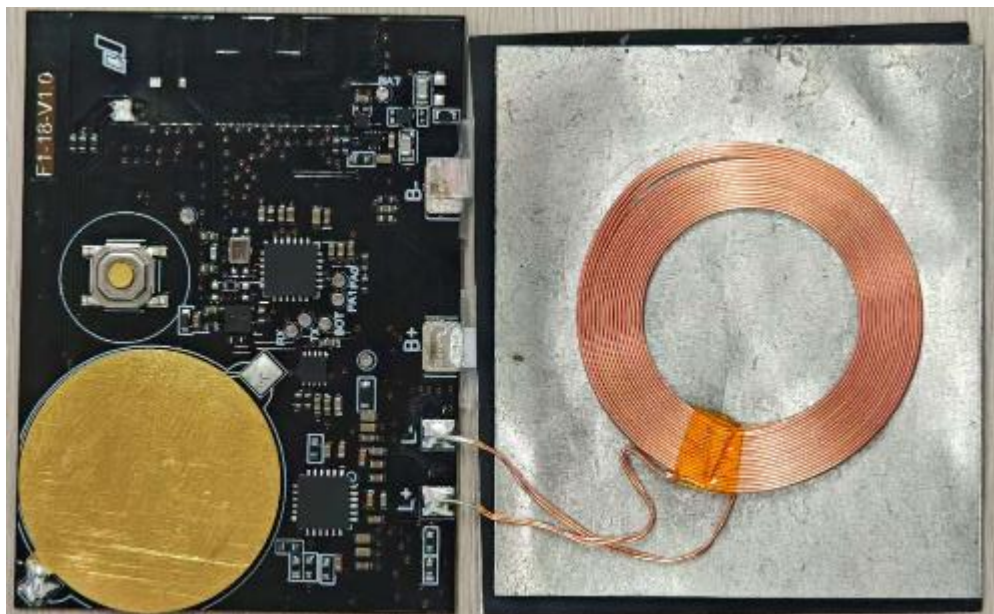
2 INTRODUCTION

The PCB antenna used on the F 1 dongle reference design is described in this application note. It can be used in all 2.4 GHz designs, especially where 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.



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3 ABBREVIATIONS

CAD	Computer Aided Design
IFA	Z-Accel ZigBee Processor Inverted F Antenna
ISM	Industrial, Scientific and Medical
LOS	Line Of Sight
PCB	Printed Circuit Board
PER	Packet Error Rate
VSWR	Voltage Standing Wave Ratio

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4 ANTENNA DESIGN

The PCB antenna on the F1-18-V1.0 dongle 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.

4.1 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 a F1 dongle and to obtain good performance also when the dongle is connected to a computer.

4.2 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

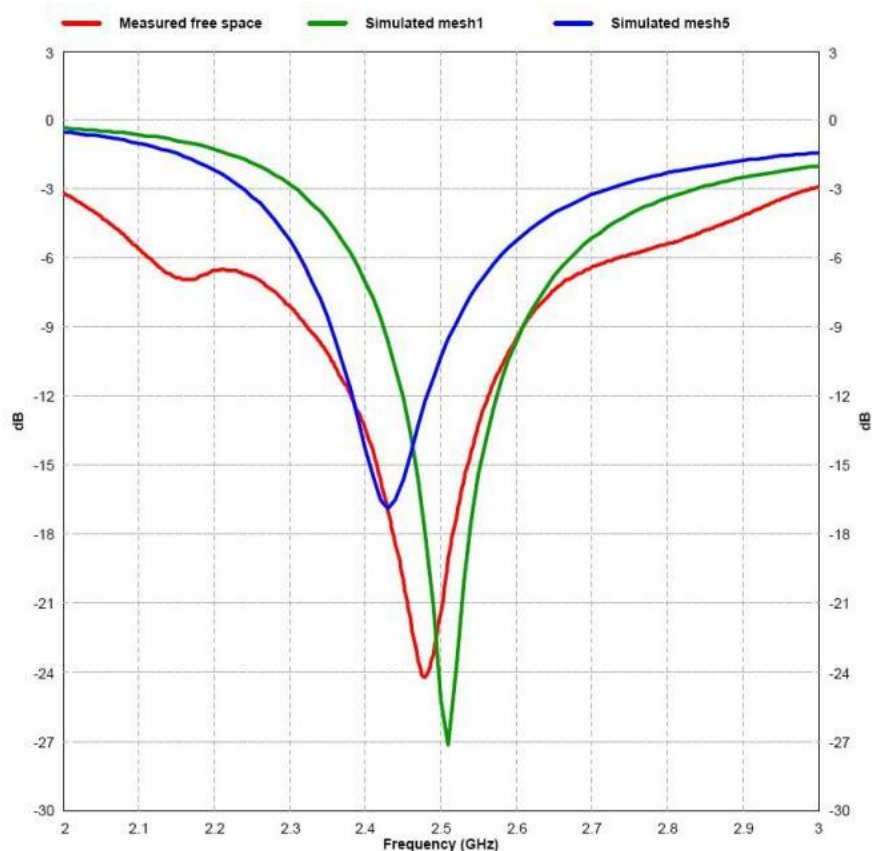


Figure 2: Comparison of Simulation and Measurements Results

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4.3 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. The easiest way to implement the antenna is to import the gerber or DXF file showing the antenna layout. These files are named `F1-18-V1.0_gerber` and `F1-18-V1.0_dxf`. The imported file can be used as a template when drawing the antenna. By using this procedure it is possible to import DXF or gerber files, and implementation. It is recommended to generate a gerber file for comparison with `F1.spl` when making a manual implementation. Most gerber viewers have the possibility to import several gerber files at the same time. Thus by placing the gerber file, showing the manually implemented antenna, `F1.spl` it is easy to verify that the antenna is correctly implemented. It is also recommended to use the same thickness and type of PCB material as used in the reference design. Information about the PCB can be found in a separate readme file included in the reference design. To compensate for a thicker/thinner PCB the antenna could be made slightly shorter/longer.

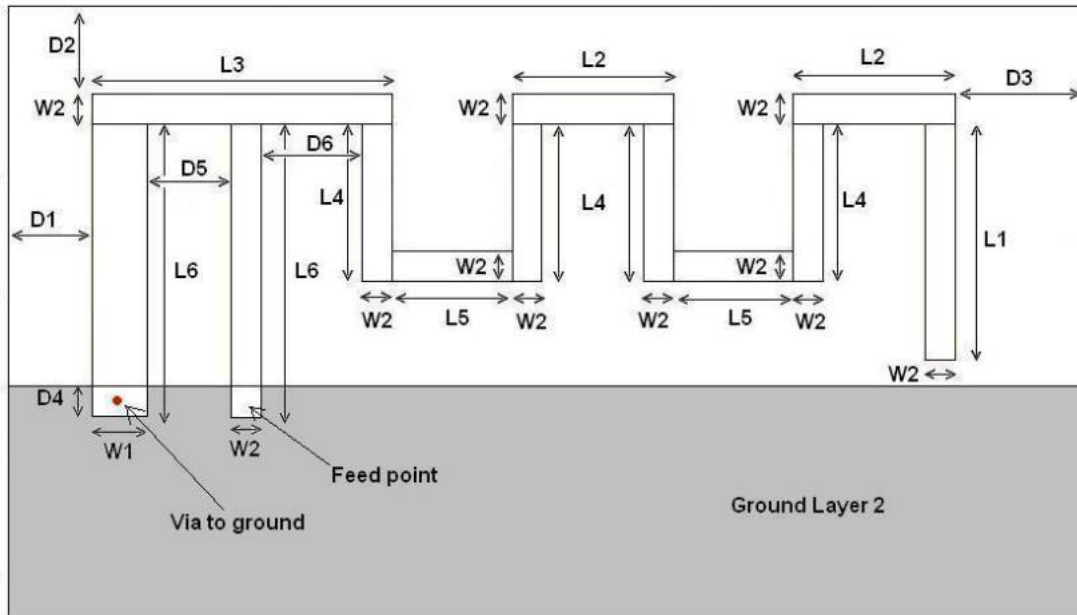


Figure 3: Antenna Dimensions

L1	3.94 mm
L2	2.70 mm
L3	5.00 mm
L4	2.64 mm
L5	2.00 mm
L6	4.90 mm
W1	0.90 mm
W2	0.50 mm
D1	0.50 mm
D2	0.30 mm
D3	0.30 mm
D4	0.50 mm
D5	1.40mm
D6	1.70 mm

Table 1: Antenna Dimensions

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5 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. Measurements of the dongle in free space and when connected to a laptop were performed to verify that the antenna is suitable both for F1 dongle designs and in a standalone application. Free space is in this document interpreted as a measurement performed without connecting the dongle to a computer. In such a measurement the dongle is only powered by a battery.

5.1 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.

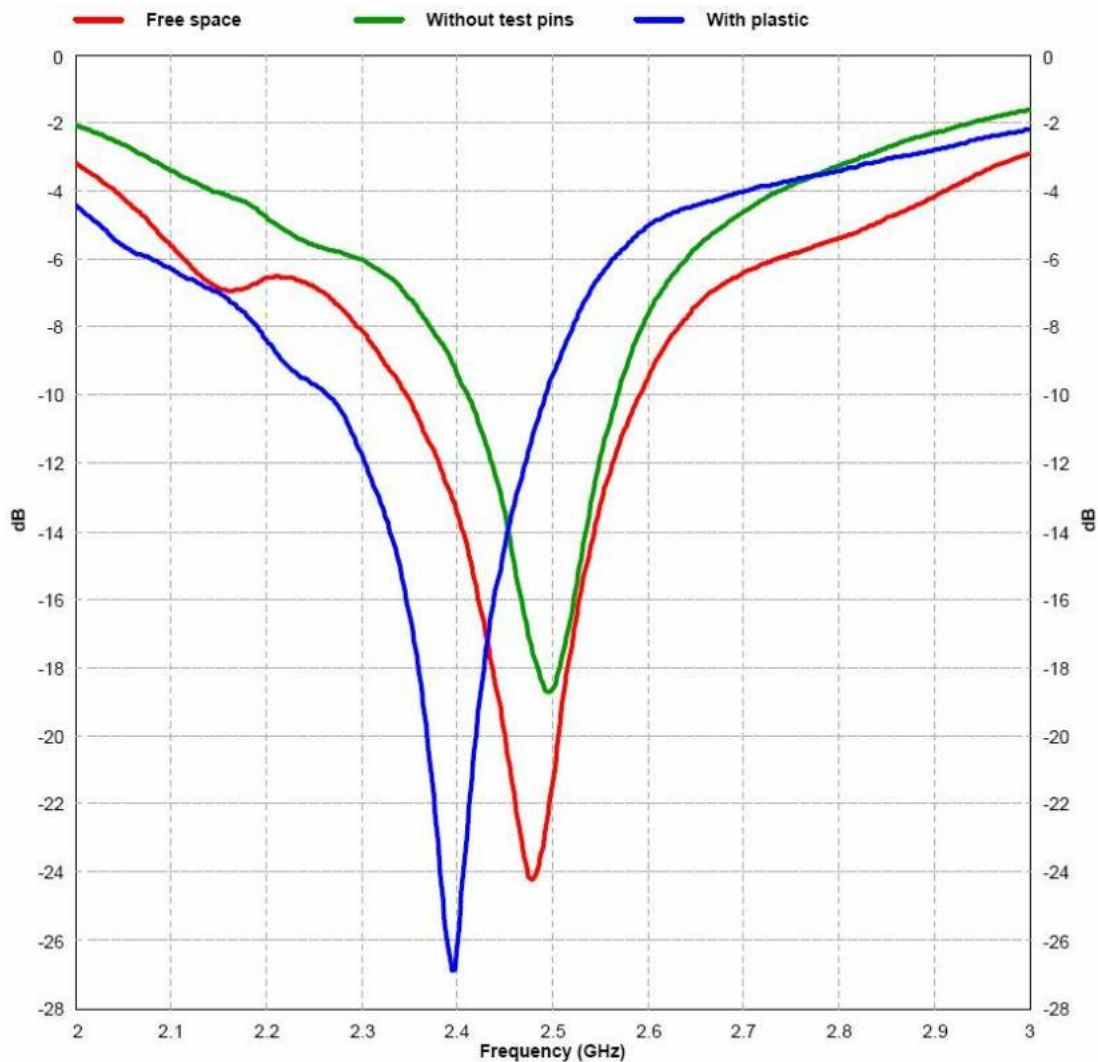


Figure 4: Influence of Plastic Encapsulation and Test Pins

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A small part on the F1 dongle PCB is equipped with test pins. These are intended for use during development. It typically will be omitted in a final application. The red and green graph on shows that removing this part of the PCB has a small shift in the resonance frequency. It also shows that plastic encapsulation of the dongle will shift the resonance frequency to a lower frequency. This can be compensated by making the antenna slightly shorter.

The size of the ground plane affects the performance of the PCB antenna. Connecting the ground plane of the laptop to the ground plane of the dongle affects the performance. In free space the antenna has a bandwidth of approximately 250 MHz. When the F1 dongle is connected to the laptop the bandwidth is reduced to around 100 MHz, which still is enough to cover the whole 2.4 GHz ISM band.

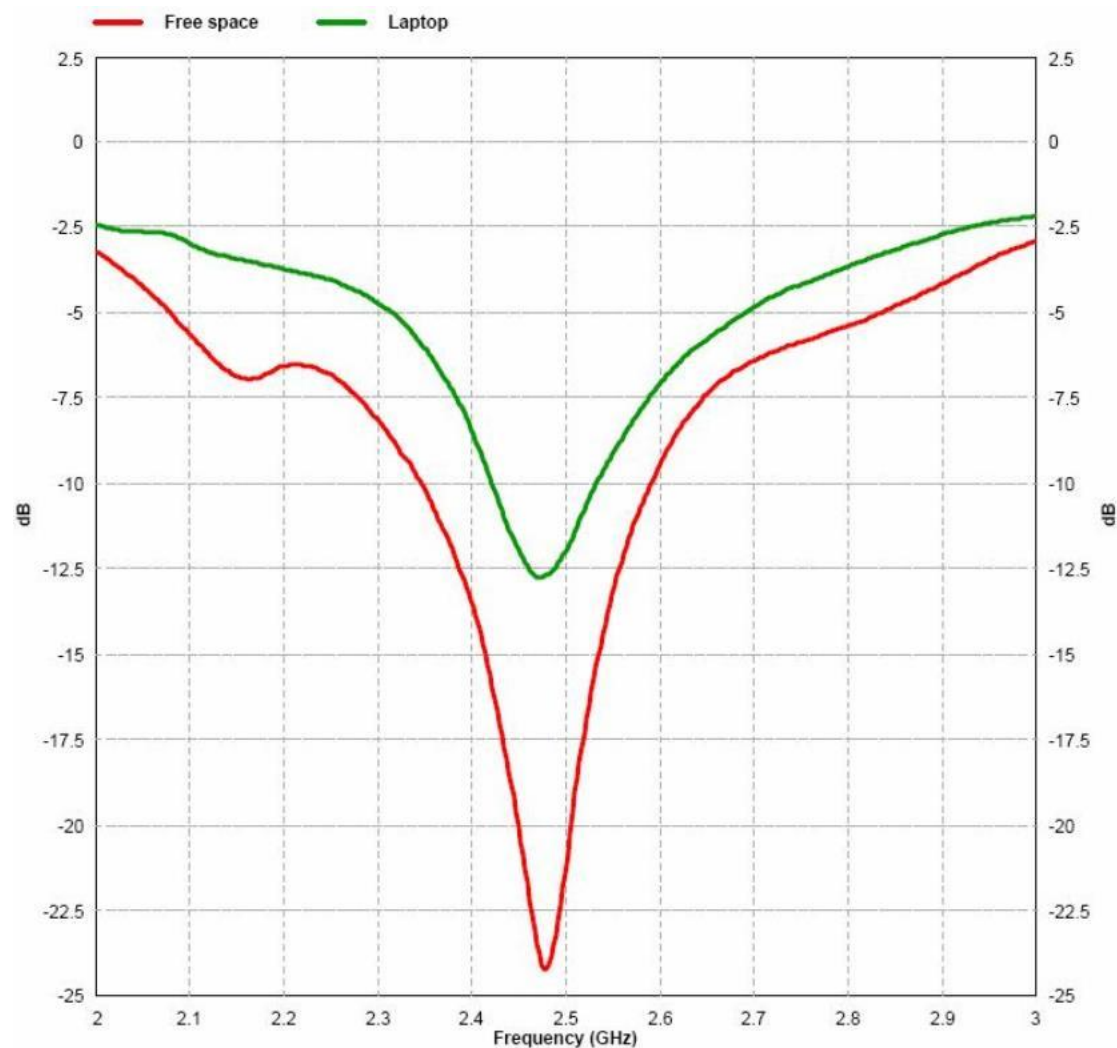


Figure 5: Comparison of Performance

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5.2 Radiation Pattern

The radiation design has been measured in an anechoic chamber. The radiation patterns for three planes, XY, XZ and YZ, measured with vertical and horizontal polarization, are shown below. The measurements were performed without connecting the dongle to a laptop. All measurements were performed with the antenna connected to a laptop. The different radiation patterns are related to the positioning of the antenna.

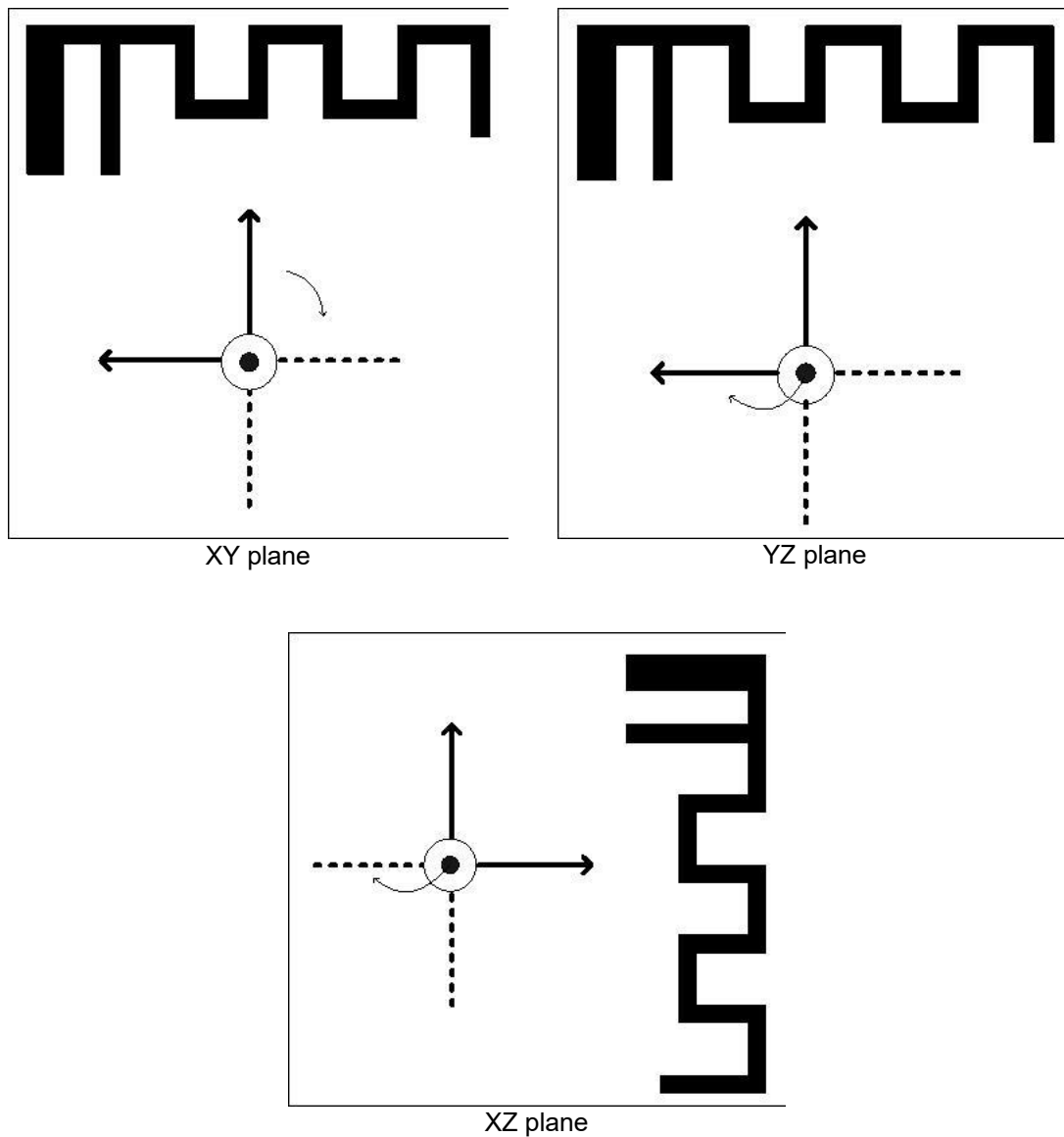


Figure 6: How to Relate the Antenna to the Radiation Patterns

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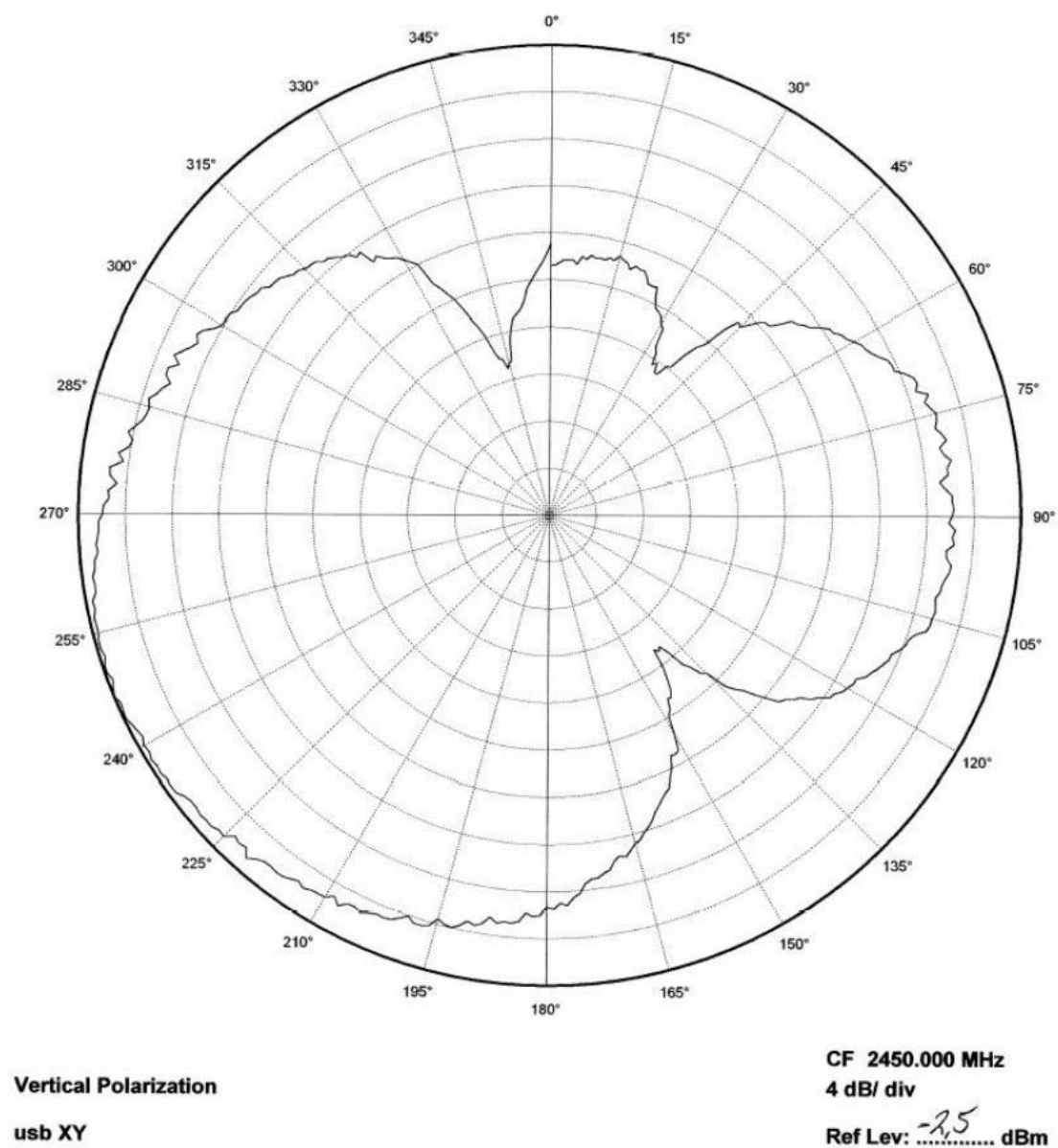


Figure 7: F1 Dongle XY Plane

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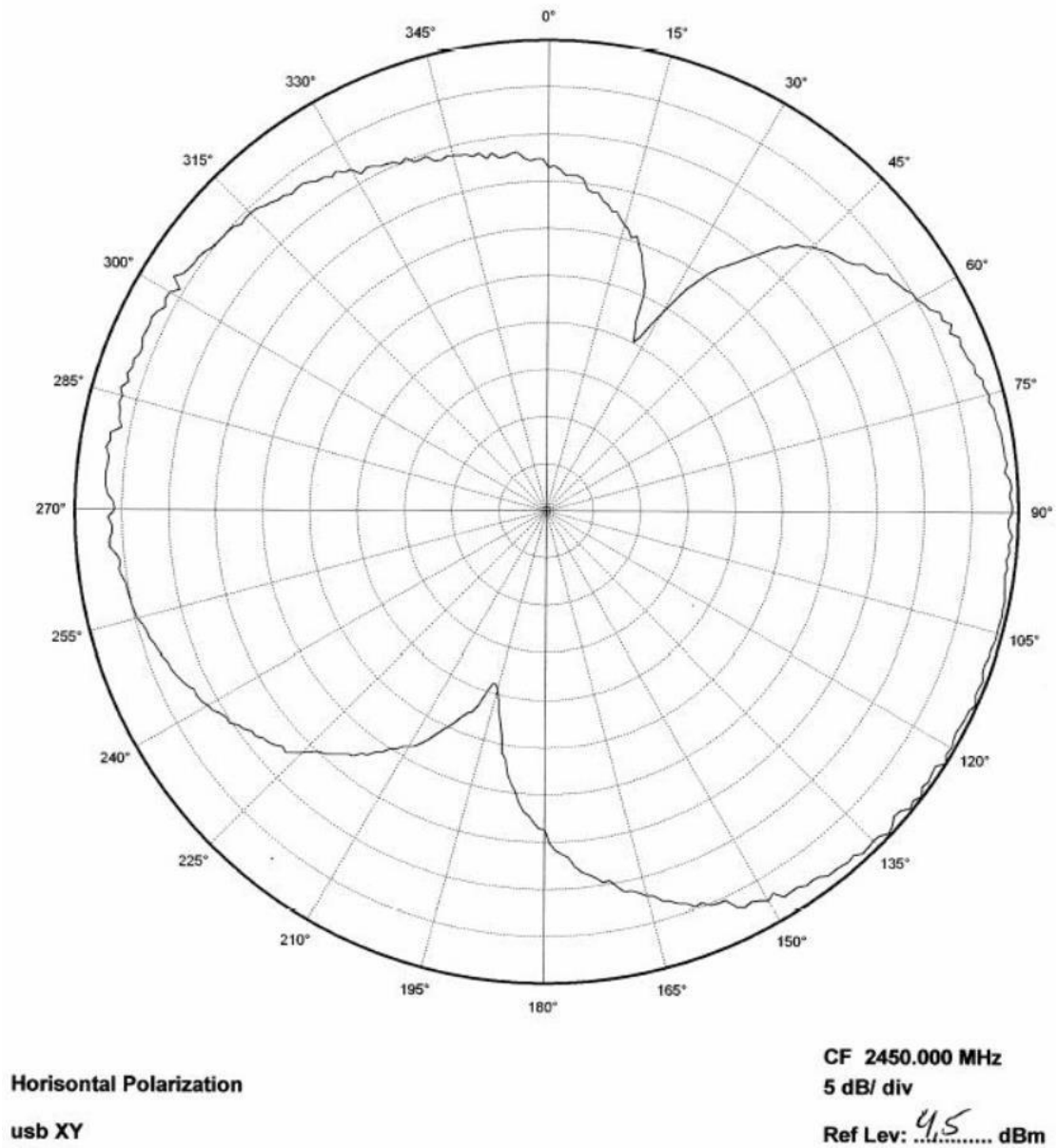


Figure 8: F1 Dongle XY Plane

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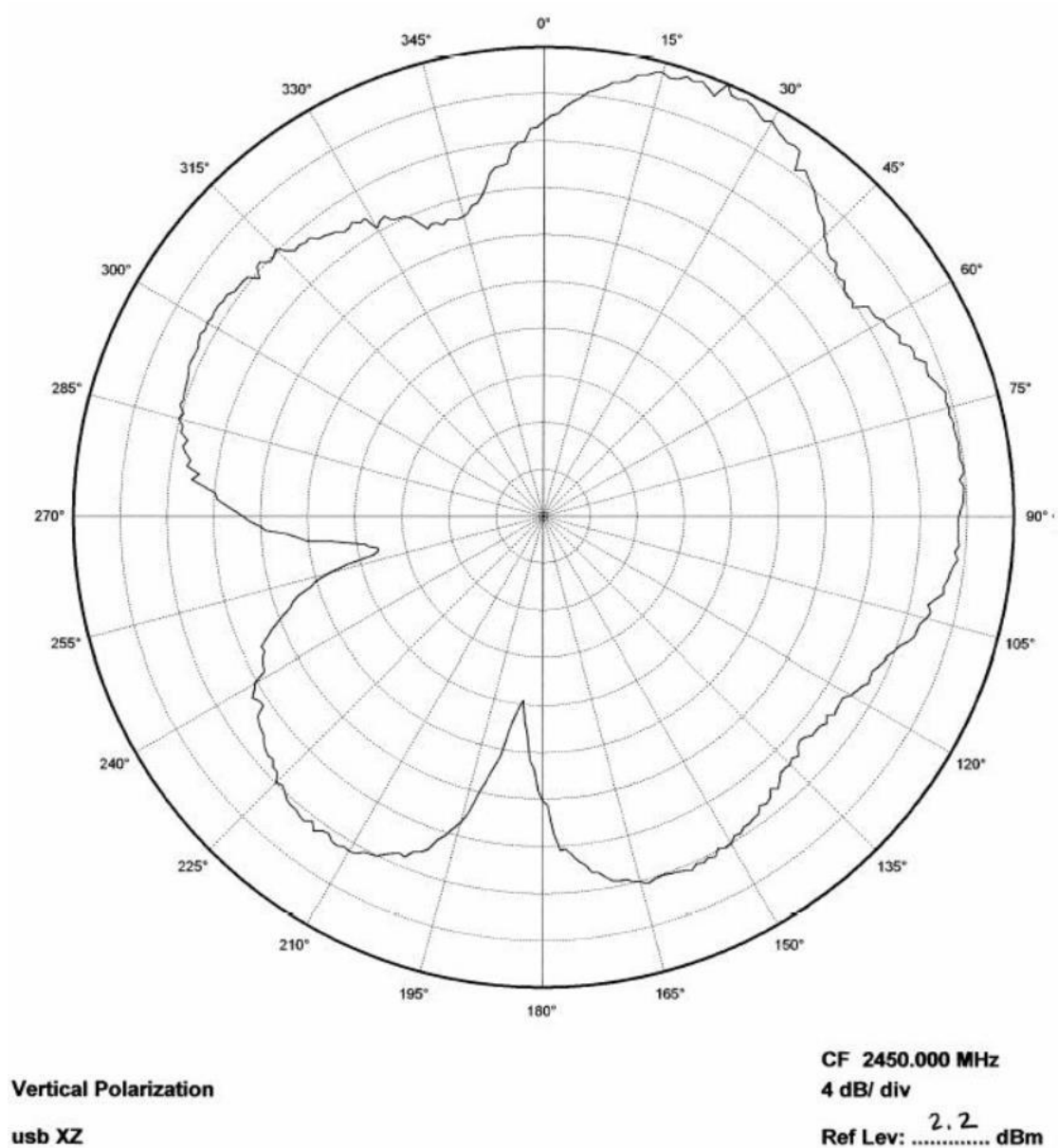


Figure 9: F1 Dongle XZ Plane

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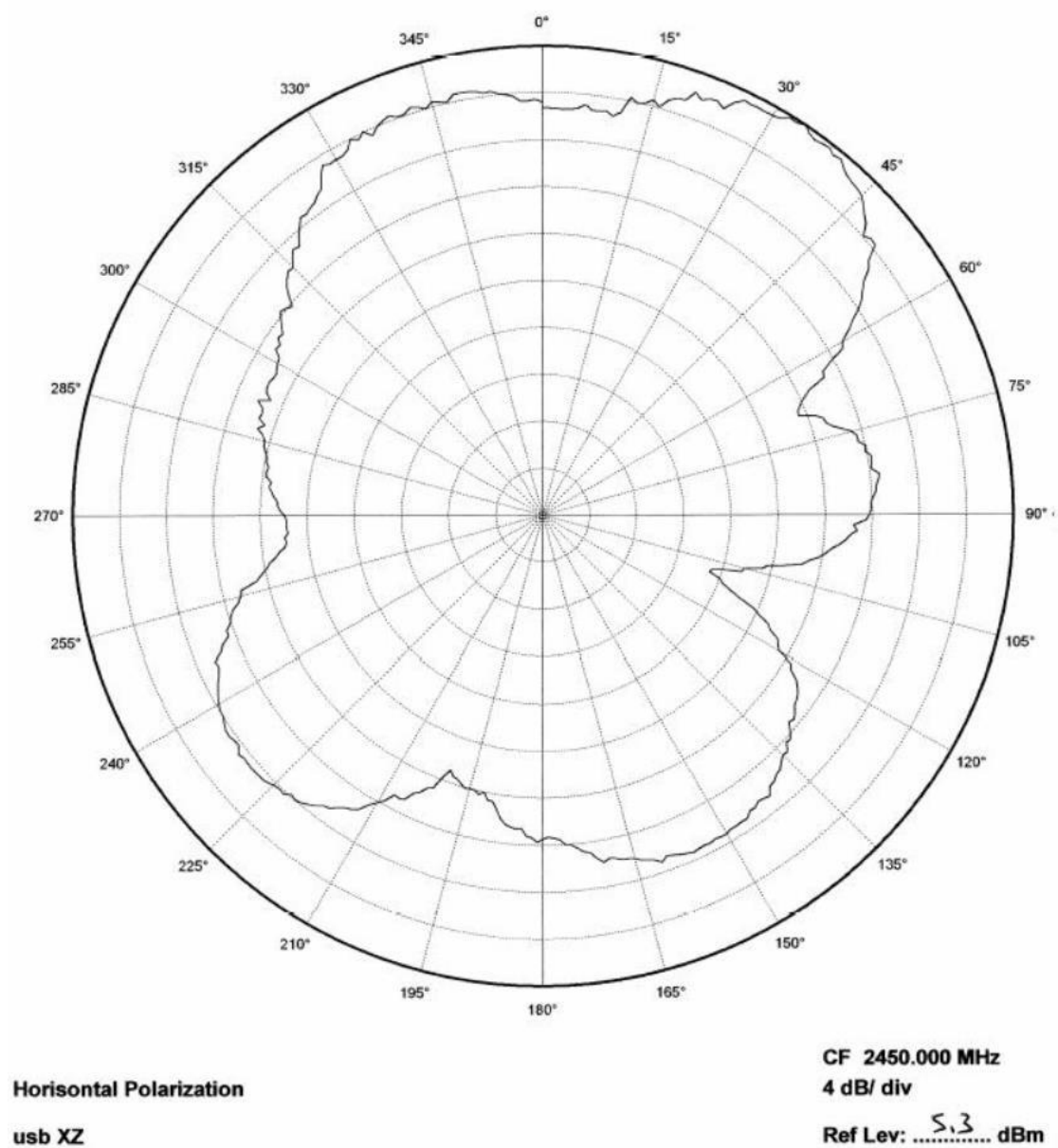


Figure 10: F1 Dongle XZ Plane

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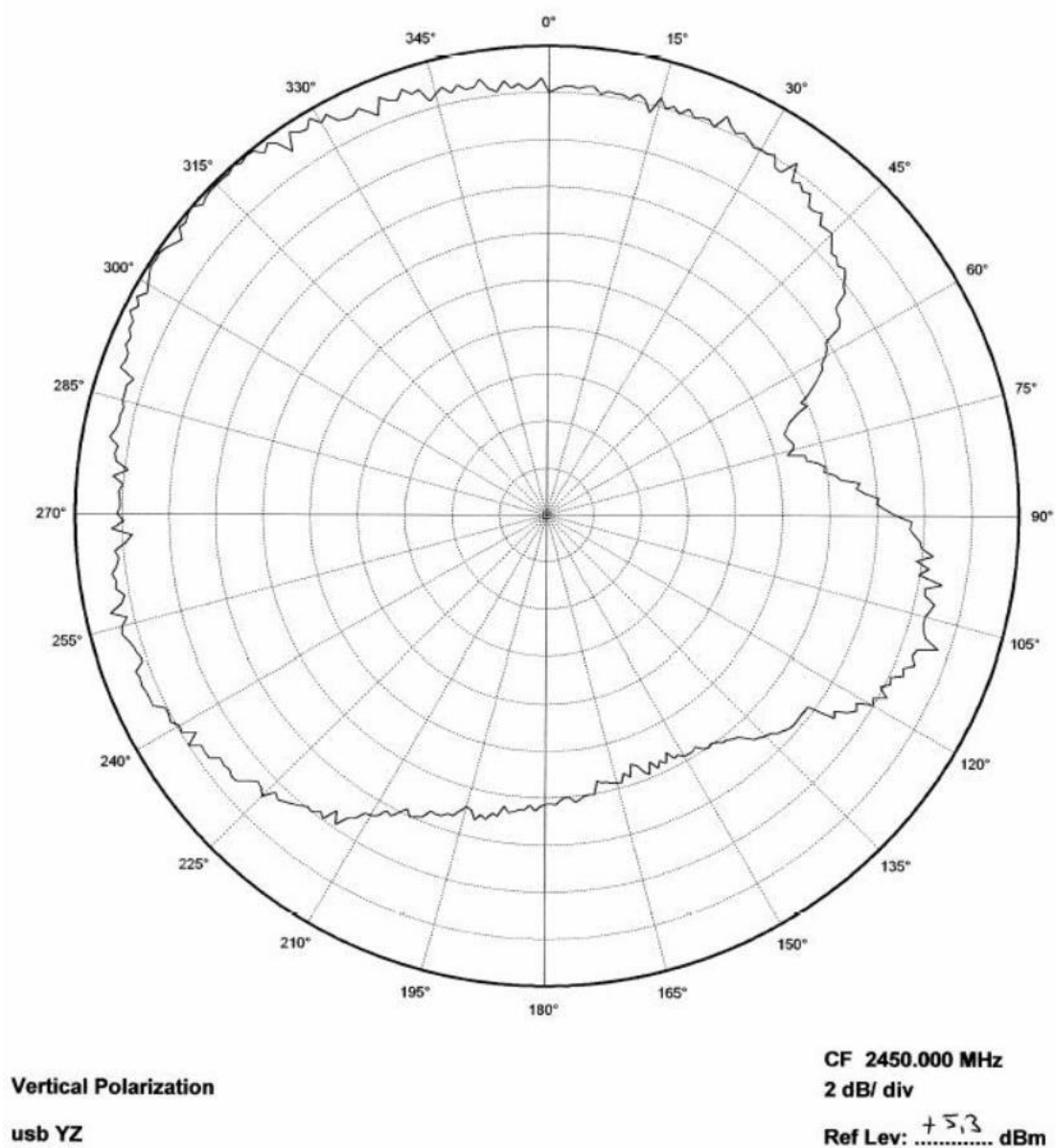


Figure 11: F1 Dongle YZ Plane

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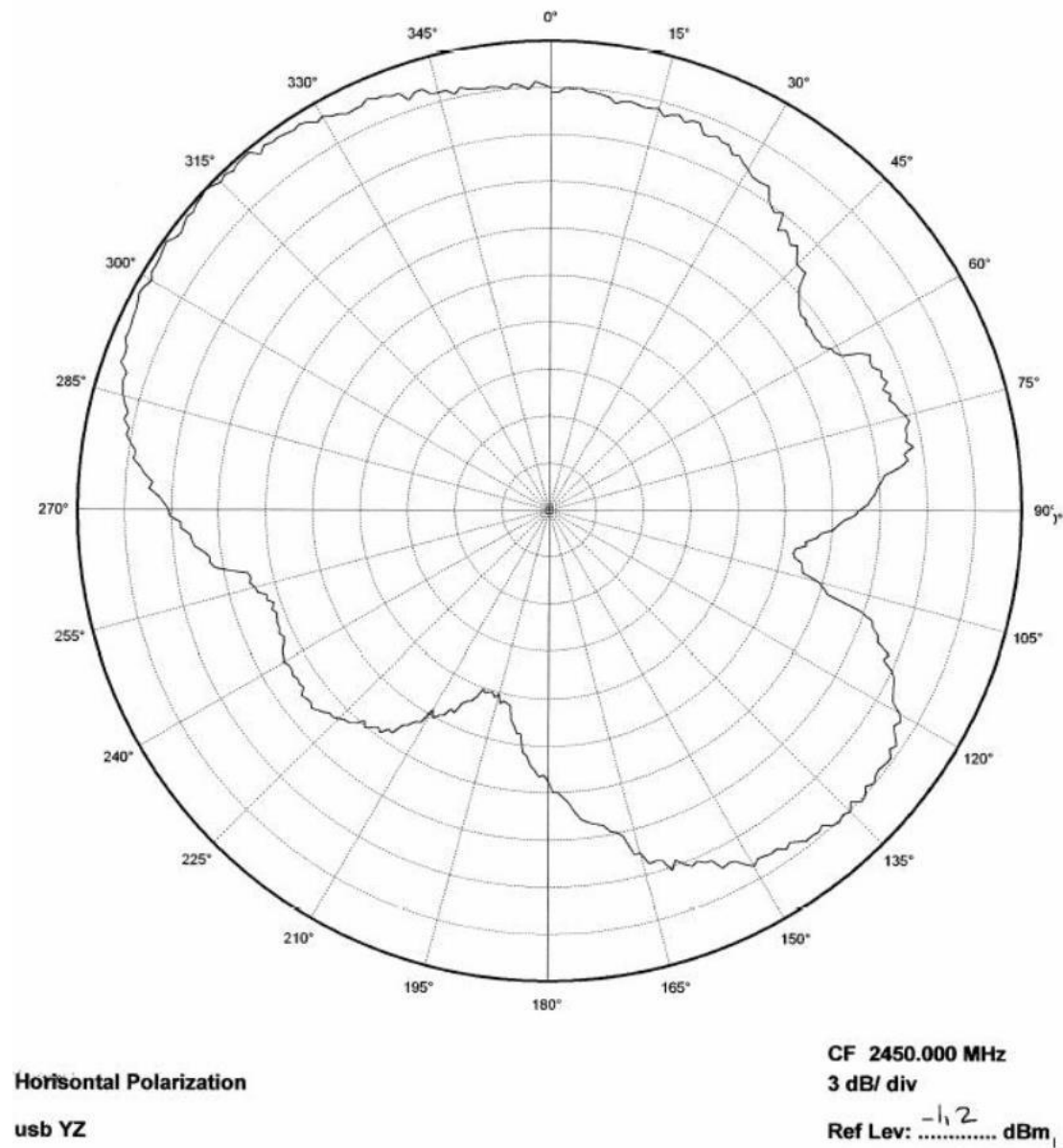


Figure 12: F1 Dongle YZ Plane

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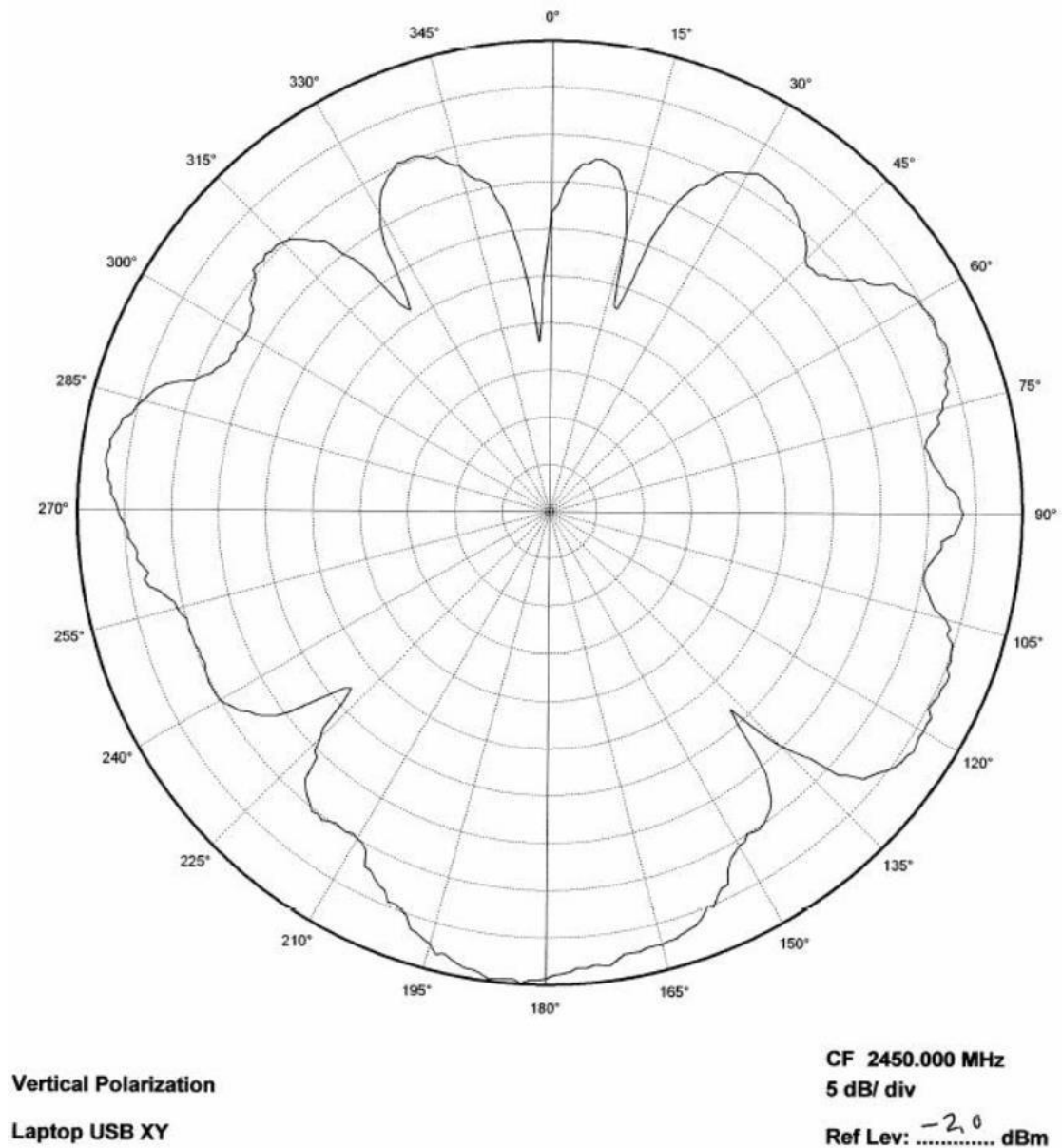


Figure 13: F1 Dongle in Laptop XY Plane

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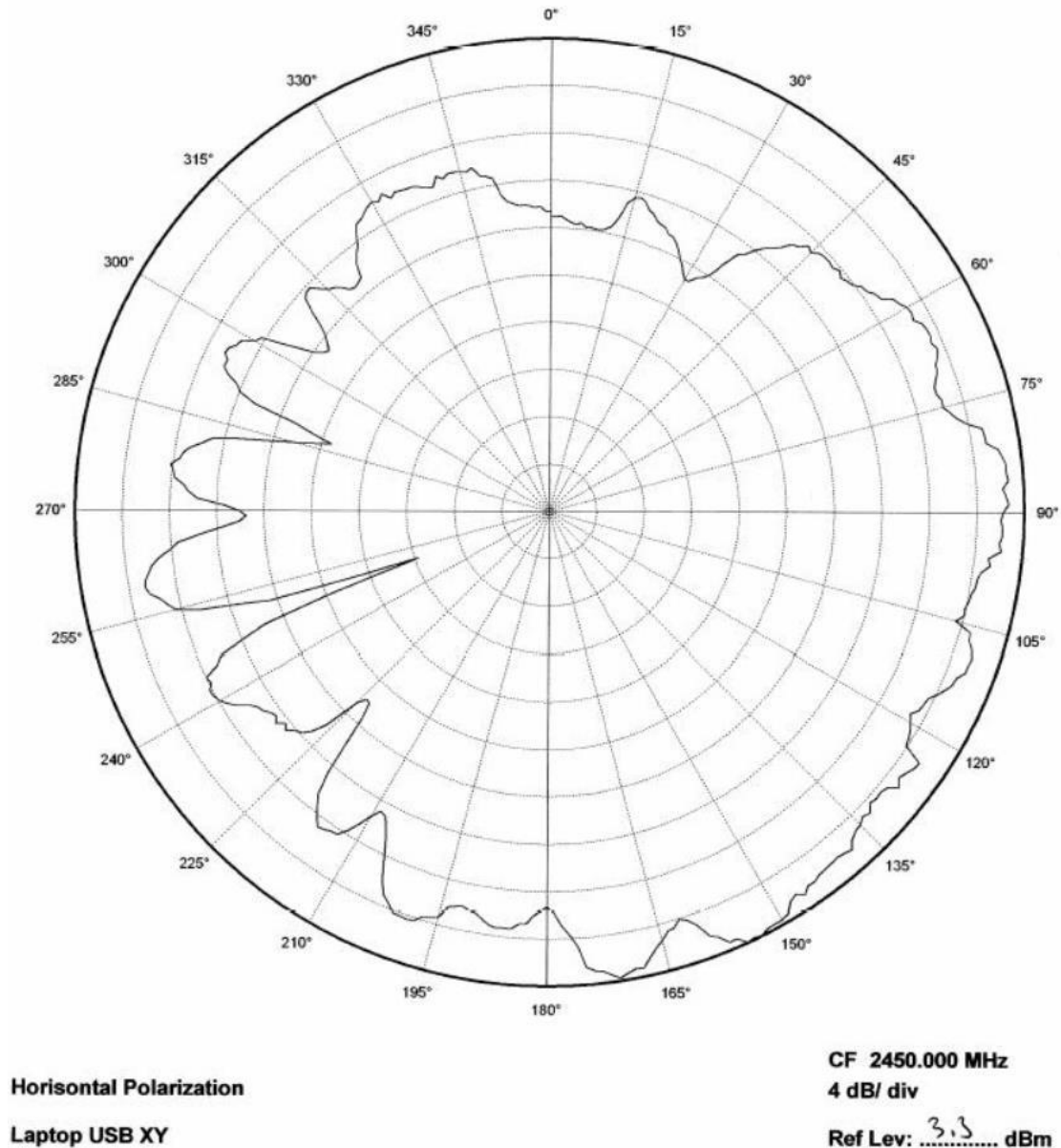


Figure 14: F1 Dongle in Laptop XY Plane

5.3 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 result from the reflection measurements, described in was measured using max hold on a spectrum analyzer. F1 was programmed for 0 dBm output power and the antenna was towards the receiving antenna. This corresponds to 0° in the XY plane on correction factor on the spectrum analyzer. Tonly show the relative changes in output power and not the actual level.

enna 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

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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.

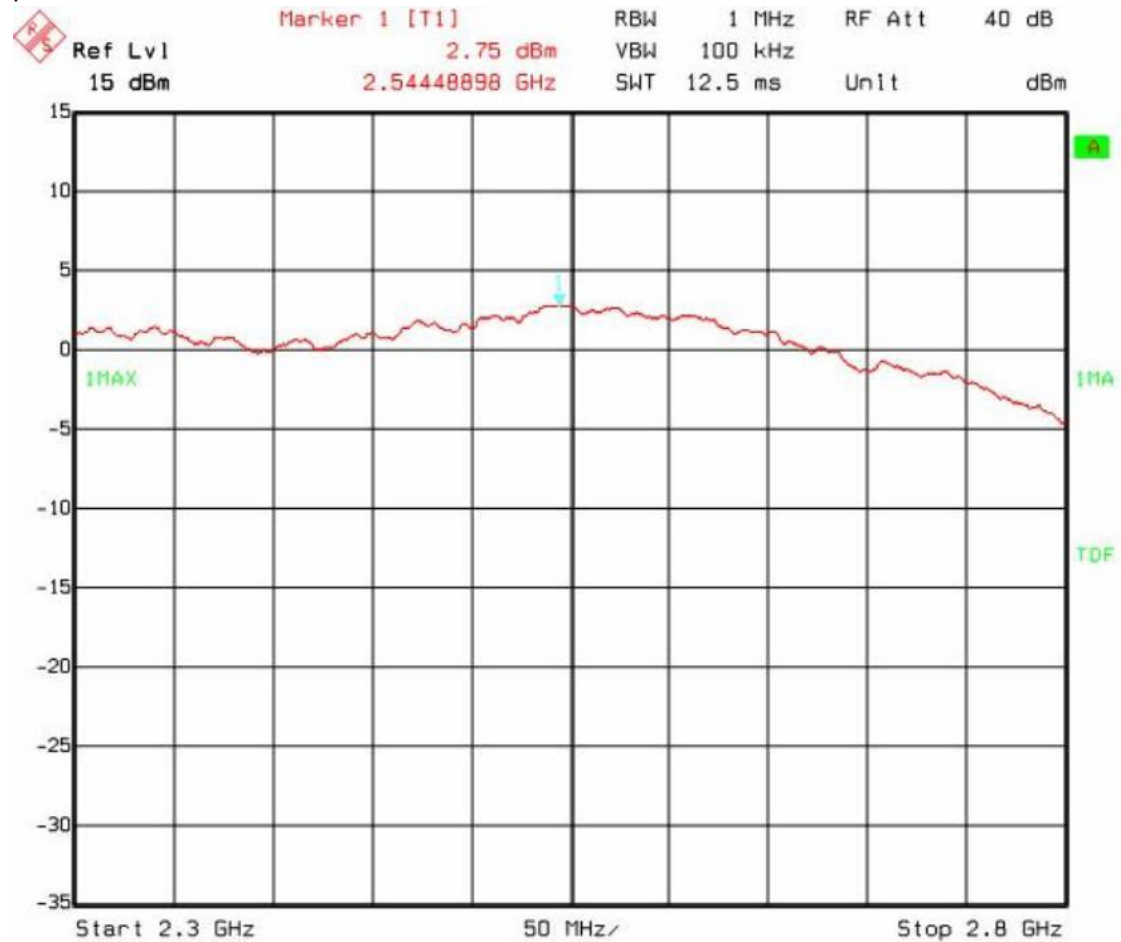


Figure 15: Output Power, F1 Dongle

The reflection
the dongle is connected to a laptop. Comparison of the results
shows that

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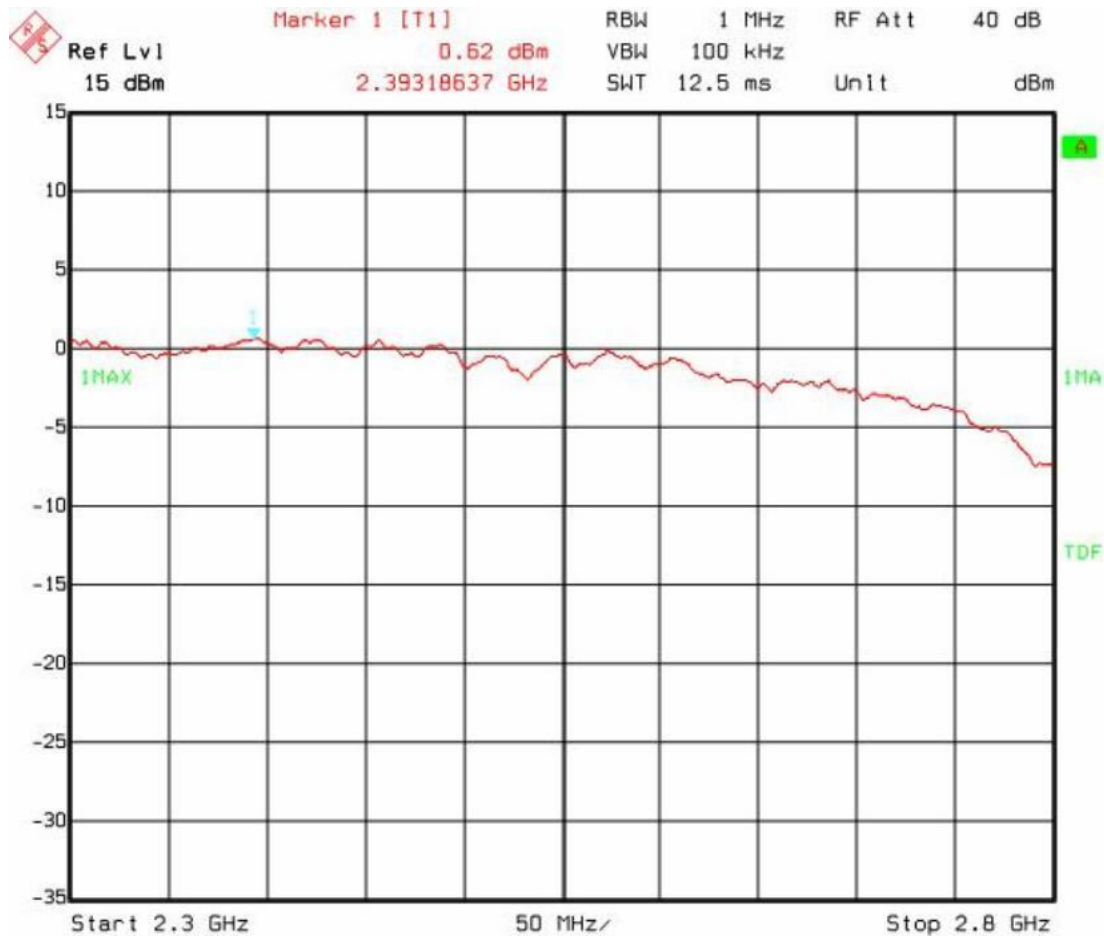


Figure 16: Output Power, F1 Dongle in Laptop

Spurious Emission and Harmonics

ssion at the second harmonic. Above the
no easuring TX emission. This can be seen
measurements were performed according to FCC
requirements. An approximate conversion to dBm can be done by subtracting 95 from the
measured value in dB μ V/m. Since the measurement setup for ETSI and FCC is different this
conversion will not give an exact result, but typically it will give a result that is within 1-2 dB of
the result from a correct ETSI measurement.

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

Table 2: Measured Level of Output Power and Harmonics

ETSI and FCC limits for output power and TX spurious emission are
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 both ETSI and FCC regulation.

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	EN 300 328	EN 300 440	FCC 15.247	FCC 15.249
2.4 – 2.483 GHz	20 dBm	10 dBm*	125 dB μ V/m 116 dB μ V/m**	94 dB μ V/m
2. harm	-30 dBm	-30 dBm	54 dB μ V/m	54 dB μ V/m

*Depends on the power class.

** Depends on the number of channels being used.

Table 3: ETSI and FCC Limits

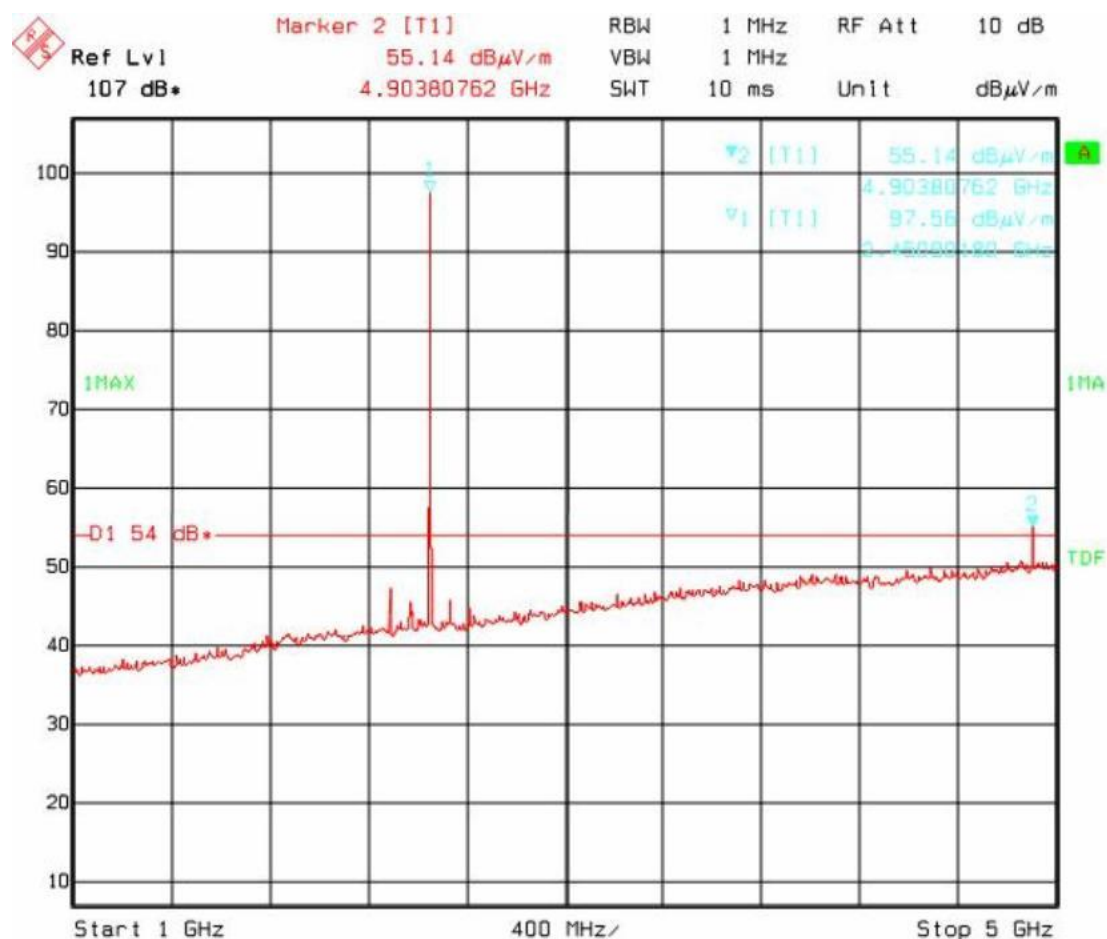
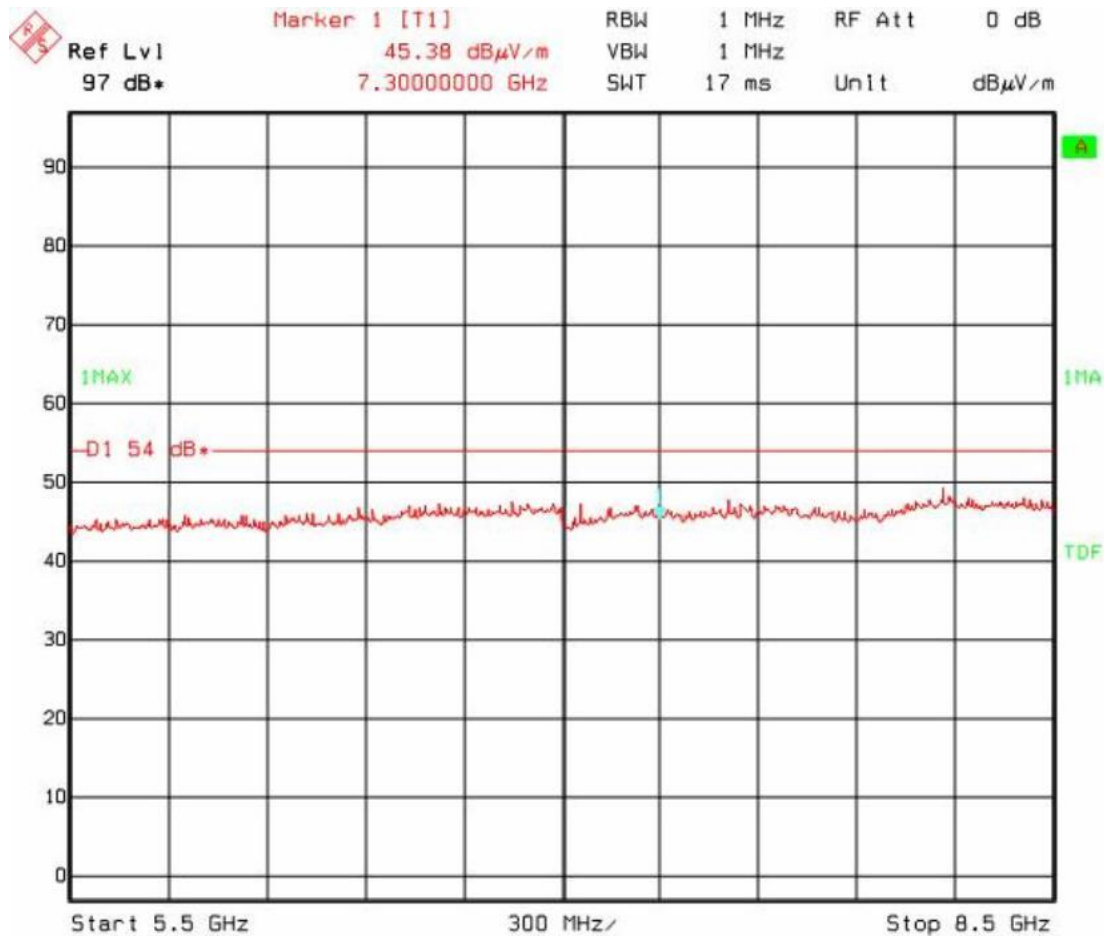


Figure 17: TX Spurious Emission 1 – 5 GHz

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As opposed to FCC, ETSI has specific RX emission the ETSI RX spurious requirements.

	Narrowband spurious emission	Wideband spurious emission
30 MHz to 1 GHz	-57 dBm	-107 dBm/Hz
1 GHz to 12.75 GHz	-47 dBm	-97 dBm/Hz

Table 4: EN 300 328 RX Spurious Requirements

25 MHz to 1 GHz	-57 dBm
1 GHz to 10 times the carrier frequency*	-47 dBm

*Applies for equipment operating between 1 GHz and 20 GHz.

Table 5: EN 300 440 RX Spurious Requirements

The only when measuring RX spurious emission was s that the measured VCO leakage is below ETSI limits.

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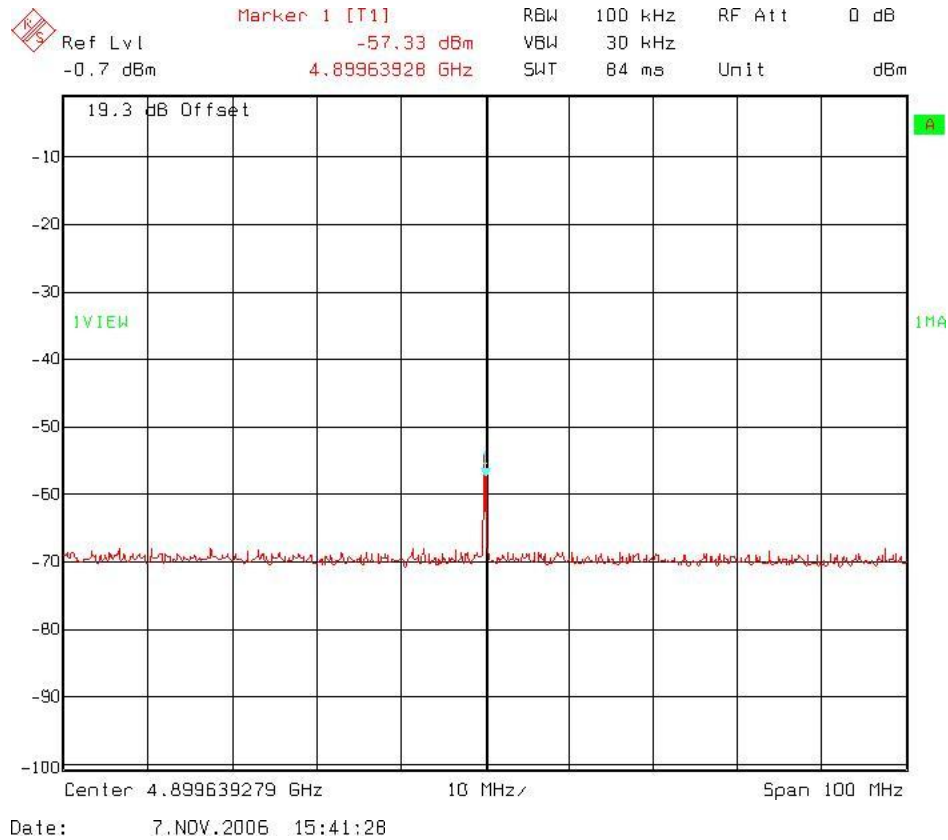


Figure 19: RX Spurious Emission

6 CONCLUSION

This application note shows that it is possible a small lists the most important properties of the Inverted F1 Antenna, described in this document. The free line of sight (LOS) range was measured with 250 kbps and 1 % PER.

Gain in XY plane	4.5 dB
Gain in XZ plane	5.3 dB
Gain in YZ plane	5.3 dB
Gain in XY plane, connected to laptop	3.3 dB
LOS range	240 m
Antenna size	15.2 x 5.7 mm

Table 6: IFA Properties (Measured on F1 Dongle Reference Design)

is possible to comply with both ETSI and FCC regulations when implementing the suggested antenna together with F1

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