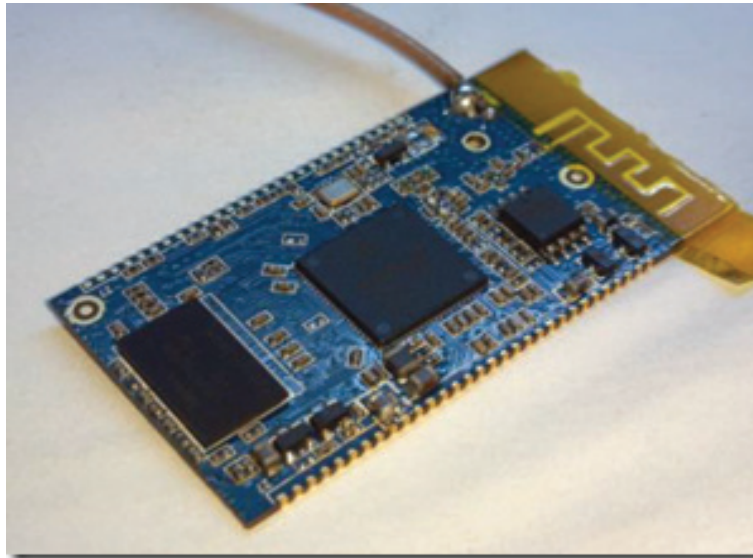


## Small Size 2.4 GHz PCB antenna

By Audun Andersen

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- 2.4 GHz
- Inverted F Antenna



Oolite V1 module router module Spec

# 1 ANTENNA DESIGN

The PCB antenna on the AR93331-V1 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.

## 1.1 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 USB dongle and to obtain good performance also when the dongle is connected to a computer.

## 1.2 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.

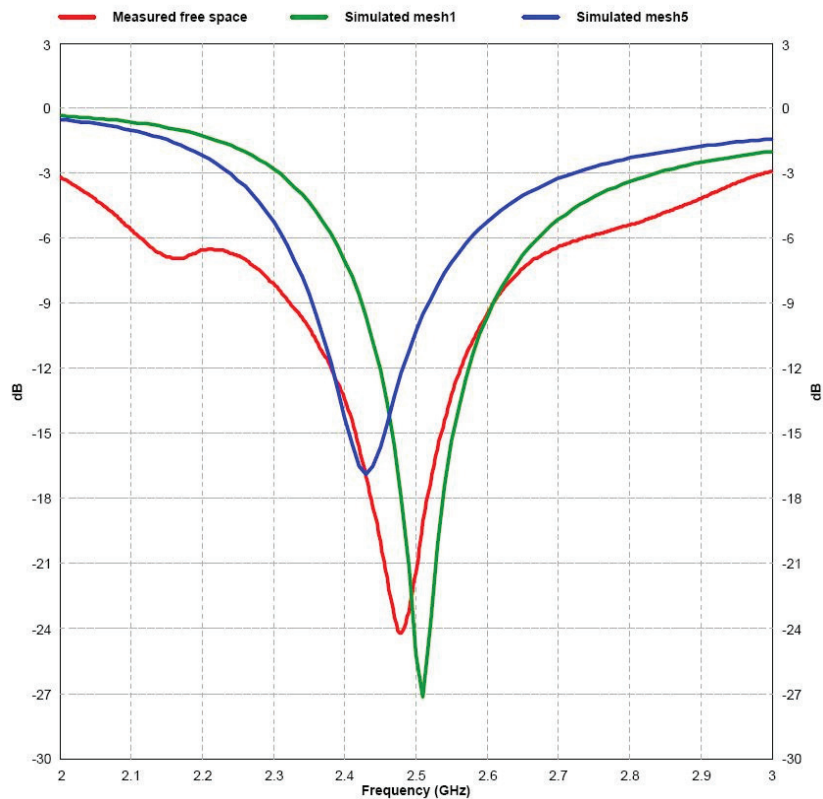


Figure 2: Comparison of Simulation and Measurements Results

### 1.3 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 IFA\_USB.spl and IFA\_USB.dxf respectively and are included in the AR93331-V1 dongle reference design available from [oolite@oolite.com](mailto:oolite@oolite.com). The imported file can be used as a template when drawing the antenna. By using this procedure it should be possible to make an exact copy. If the PCB CAD tool being used does not support import of DXF or gerber files, Figure 3 and Table 1 should be used to ensure correct implementation. It is recommended to generate a gerber file for comparison with IFA\_USB.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, on top of IFA\_USB.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.

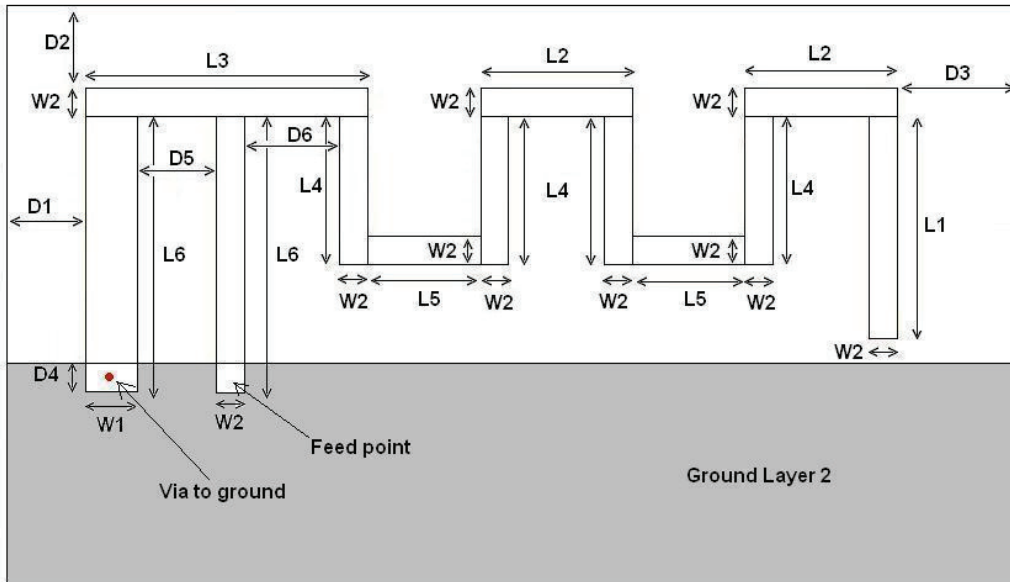


Figure 3: Antenna Dimensions

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

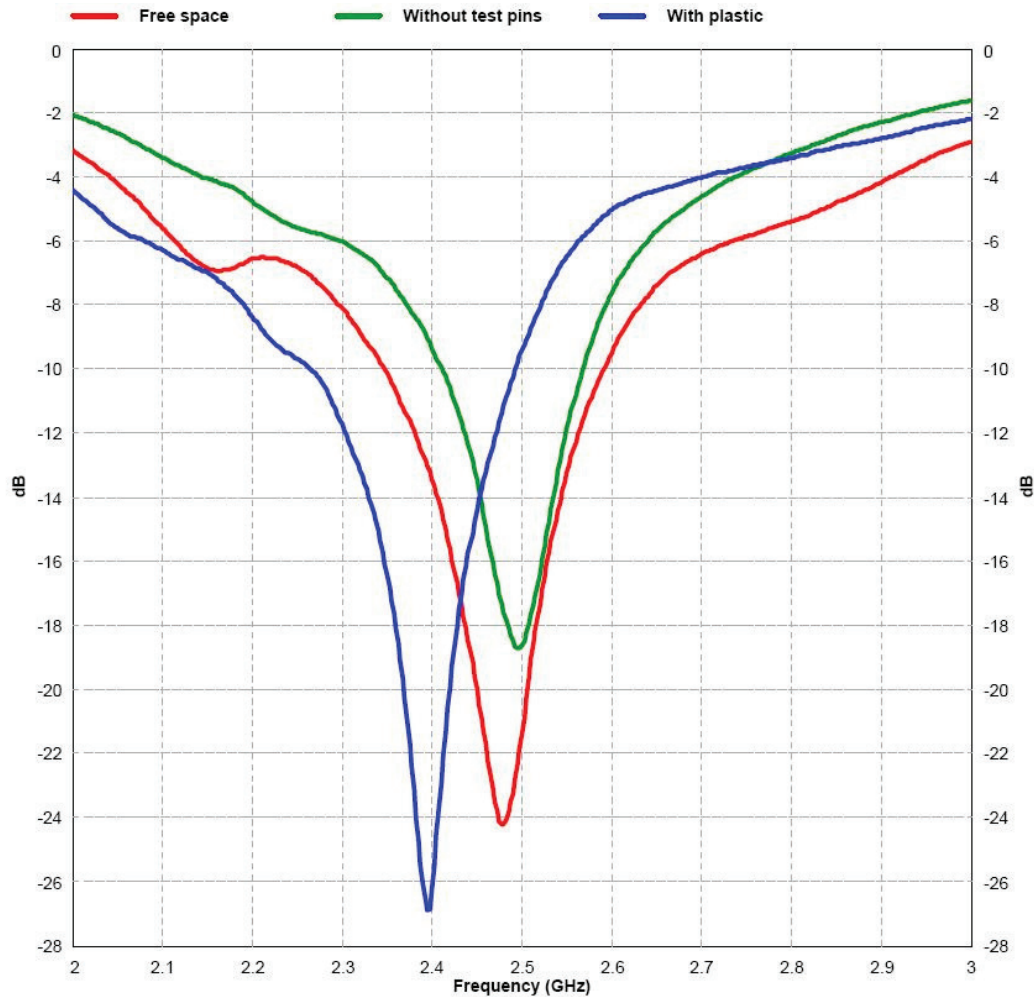
Table 1: Antenna Dimensions

## 2 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 AR93331-1 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.

### 2.1 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.



A small part on the AR93331-V1 PCB is equipped with test pins. These are intended for use during development. This part of the PCB will typically be omitted in a final application. The red and green graph on Figure 4 shows that removing this part of the PCB has a small impact on the performance. Figure 4 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 AR93331-1 to a computer increases the size of the ground plane and thus the performance is affected. Figure 5 shows how the performance is affected when the AR93331-V1 is connected to a laptop. In free space the antenna has a bandwidth of approximately 250 MHz. When the AR93331-1 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.

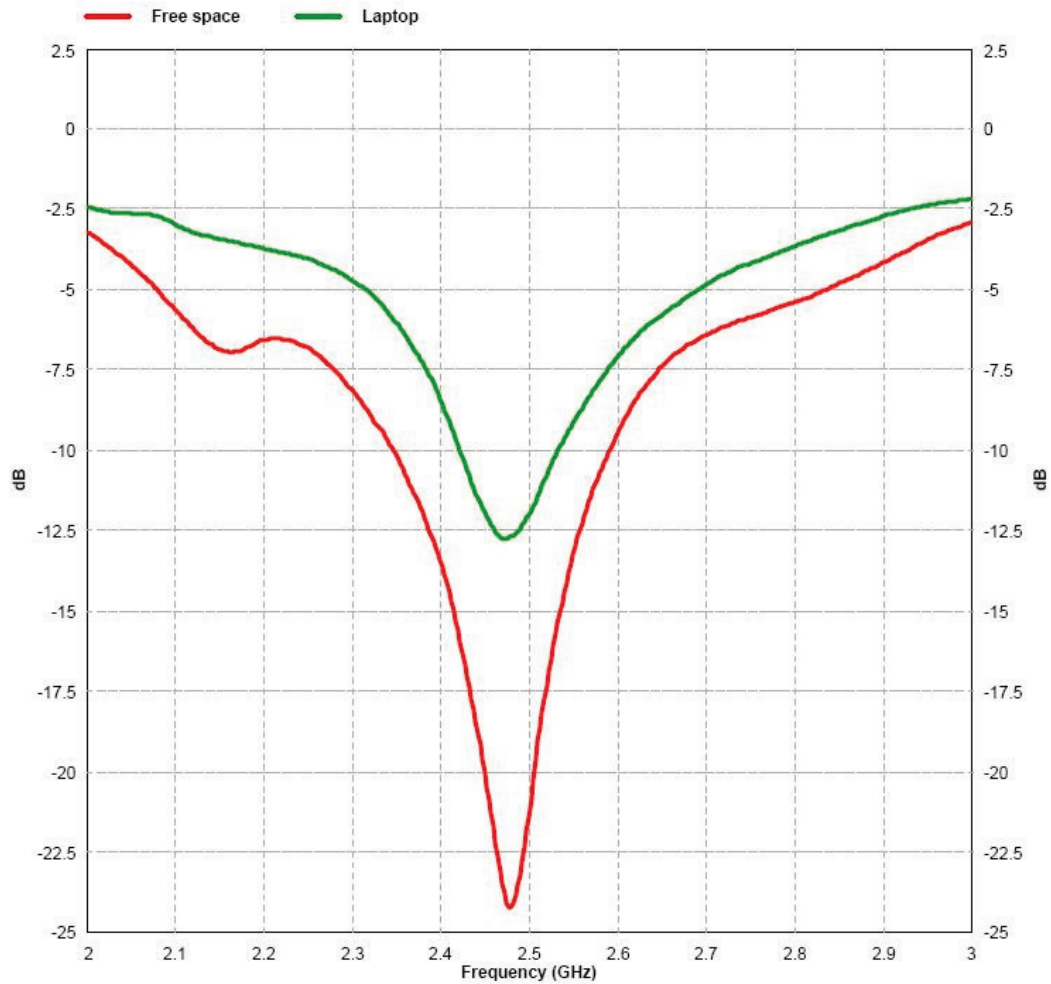
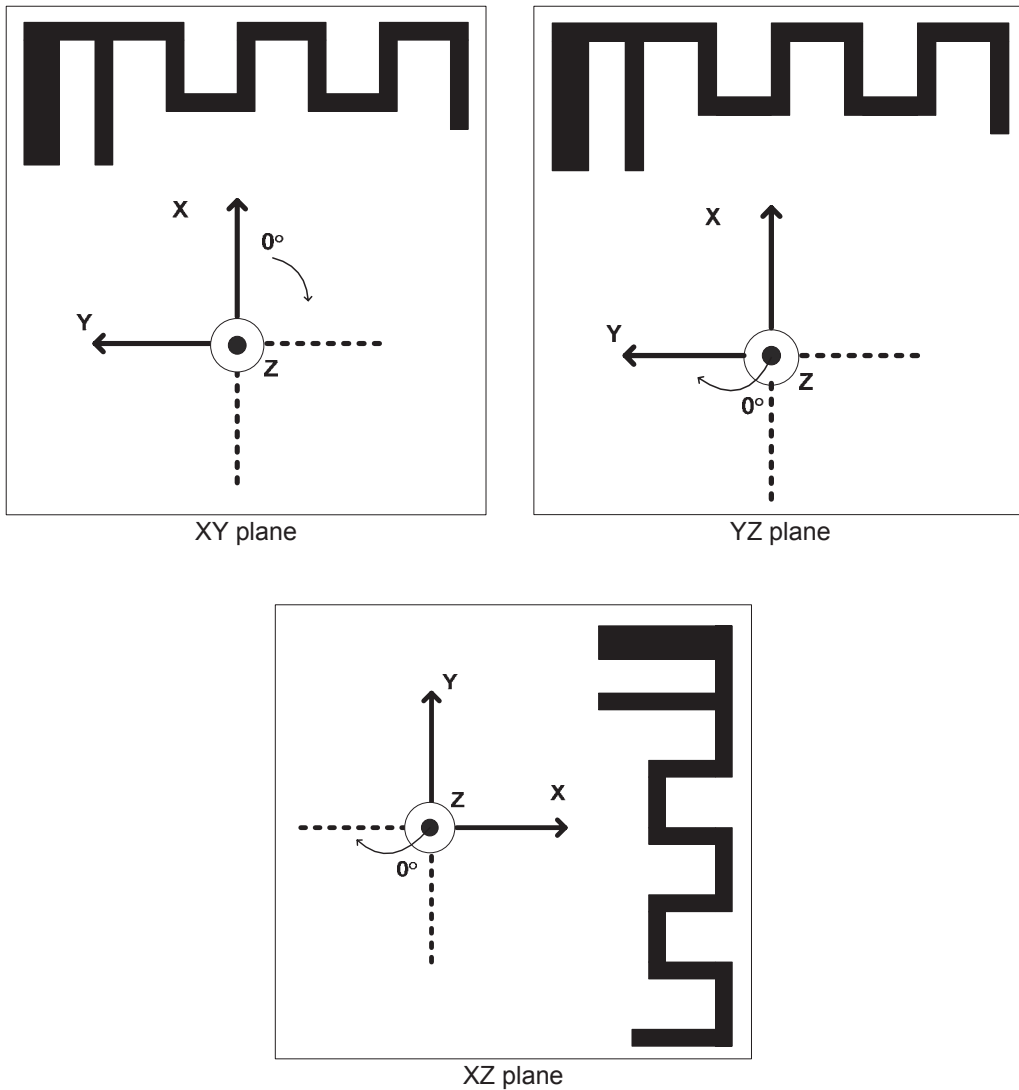


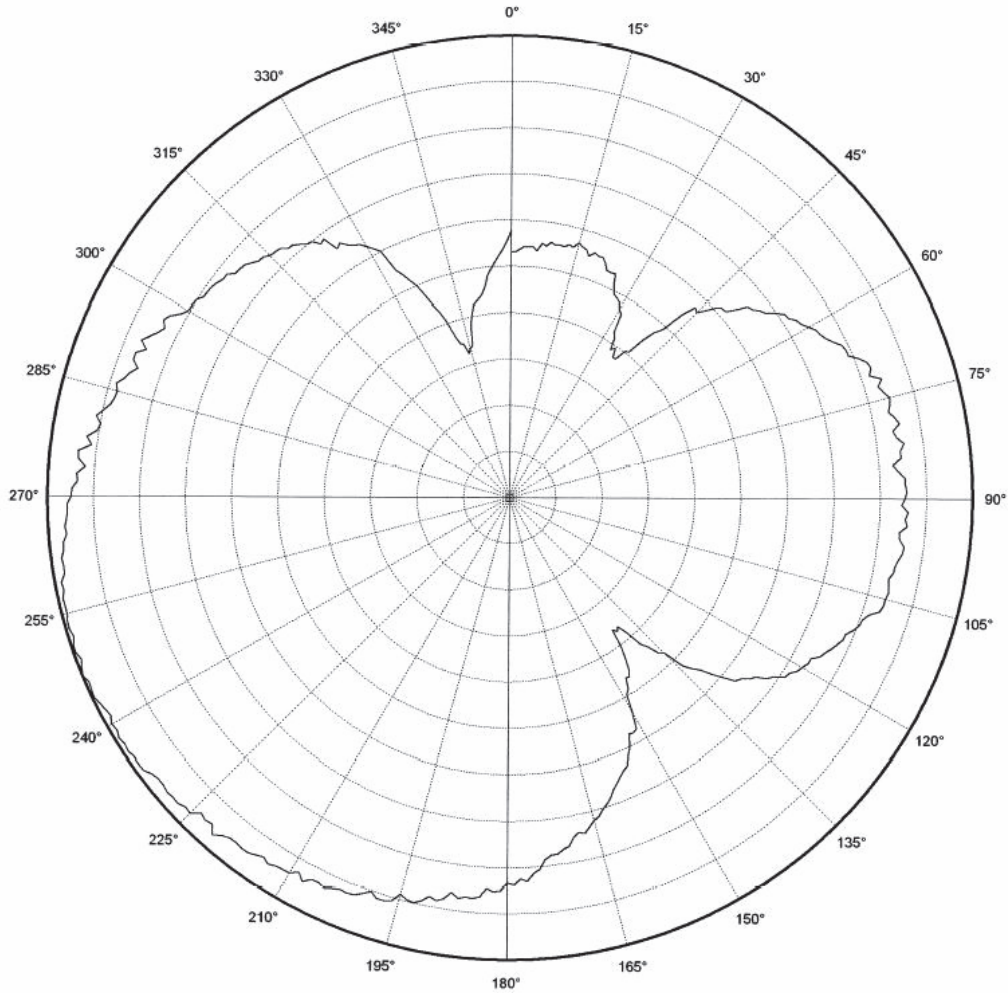
Figure 5: Comparison of Performance

## 2.2 Radiation Pattern

The radiation pattern for the antenna implemented on the AR93331-V1 reference design has been measured in an anechoic chamber. Figure 7 through Figure 12 shows radiation patterns for three planes, XY, XZ and YZ, measured with vertical and horizontal polarization. All these measurement were performed without connecting the dongle to a computer. Figure 13 and Figure 14 shows the radiation pattern when the dongle is connected to a laptop. All measurements were performed with 0 dBm output power. Figure 6 shows how the different radiation patterns are related to the positioning of the antenna.



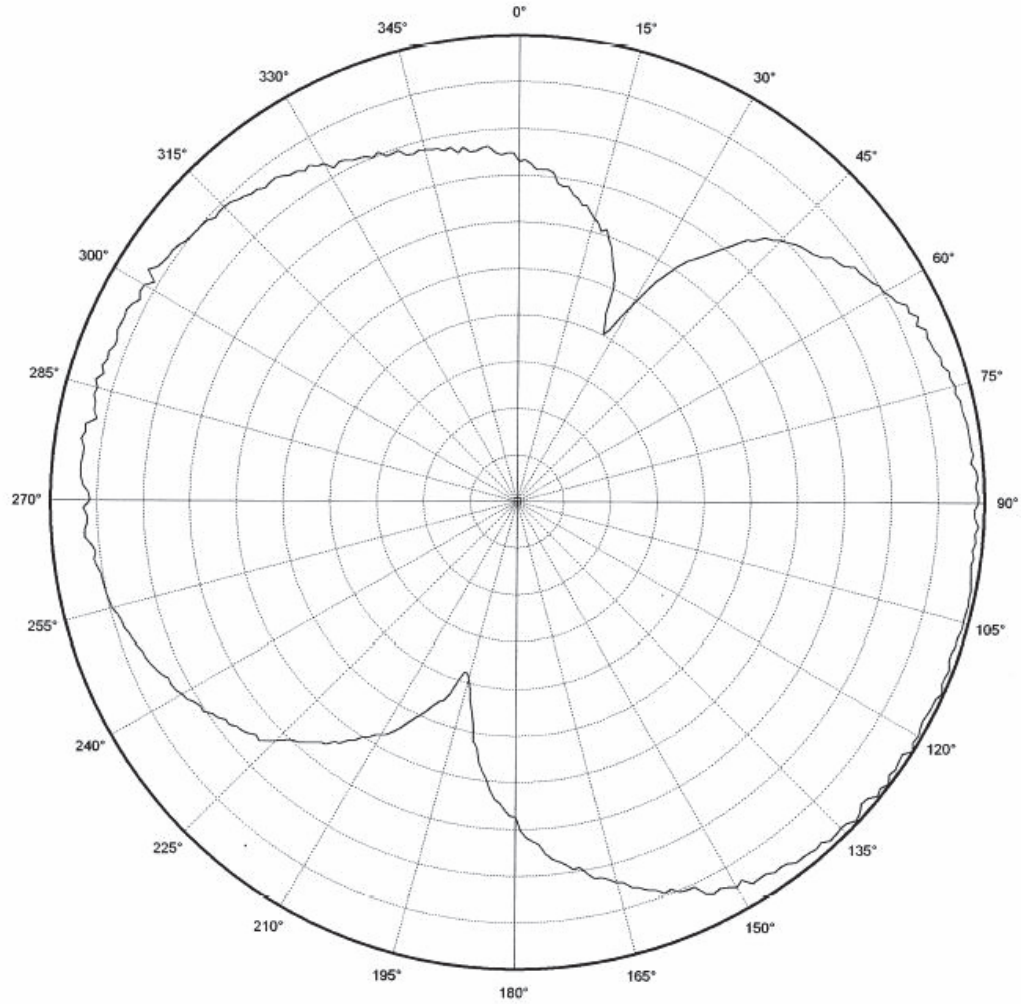
How to Relate the Antenna to the Radiation Patterns



Vertical Polarization  
usb XY

CF 2450.000 MHz  
4 dB/div  
Ref Lev: *-2.5* dBm

XY Plane



Horizontal Polarization

usb XY

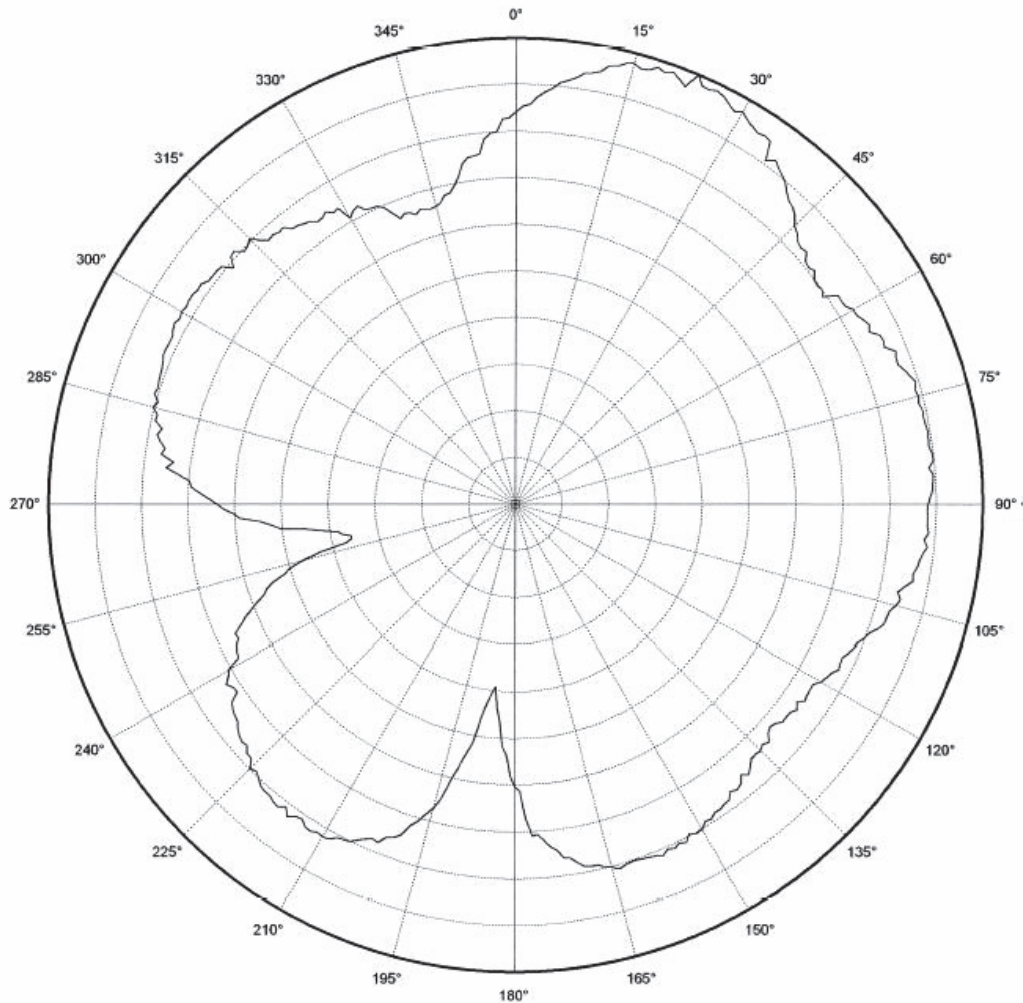
CF 2450.000 MHz

5 dB/ div

Ref Lev: 45 dBm

XY Plane





Vertical Polarization

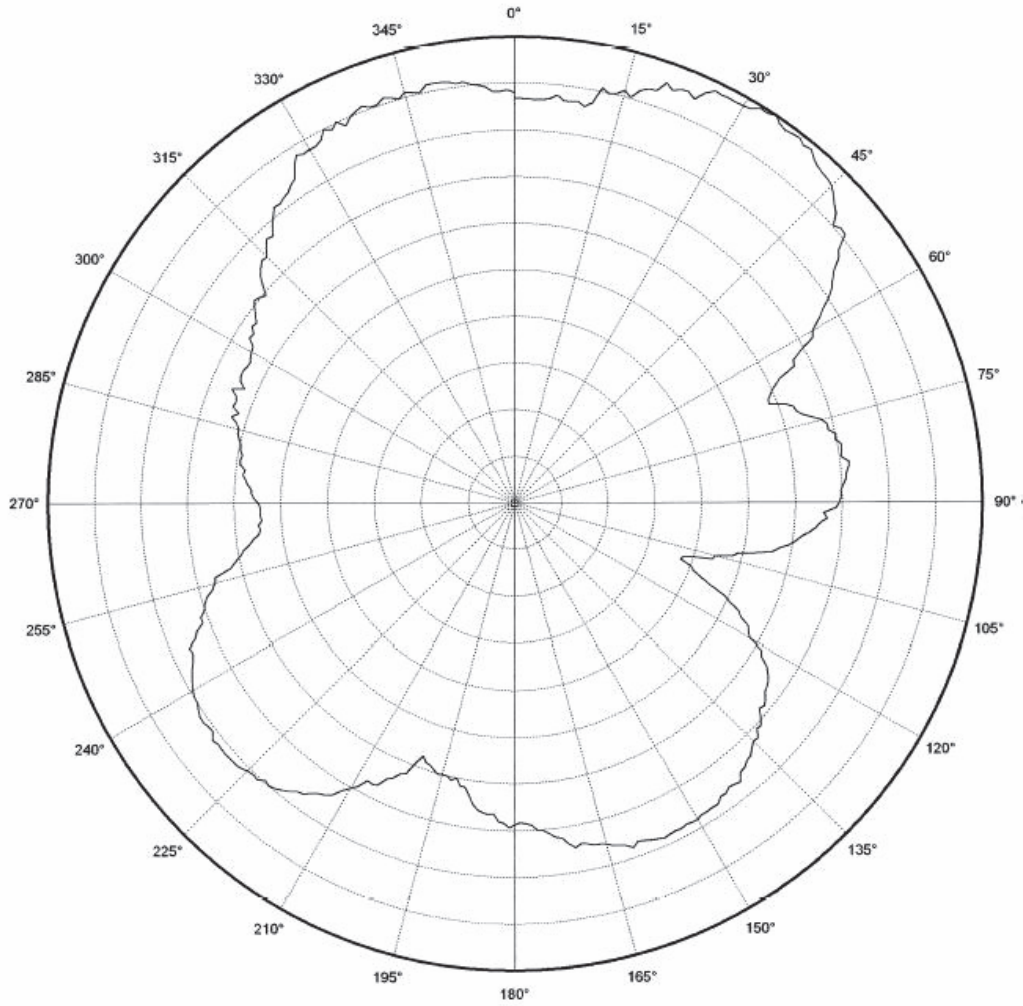
usb XZ

CF 2450.000 MHz

4 dB/ div

Ref Lev: 2.2 dBm

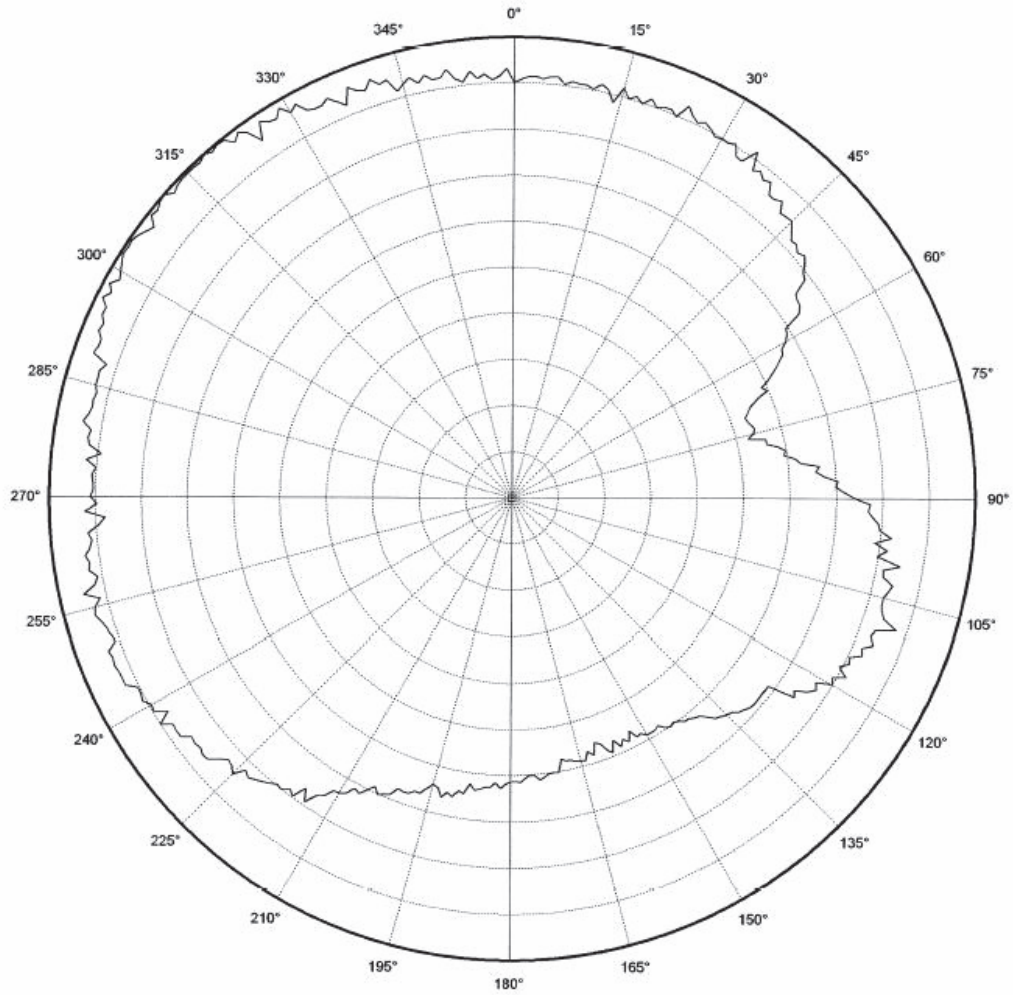
XZ Plane



Horizontal Polarization  
usb XZ

CF 2450.000 MHz  
4 dB/ div  
Ref Lev: 5.3 dBm

XZ Plane



Vertical Polarization

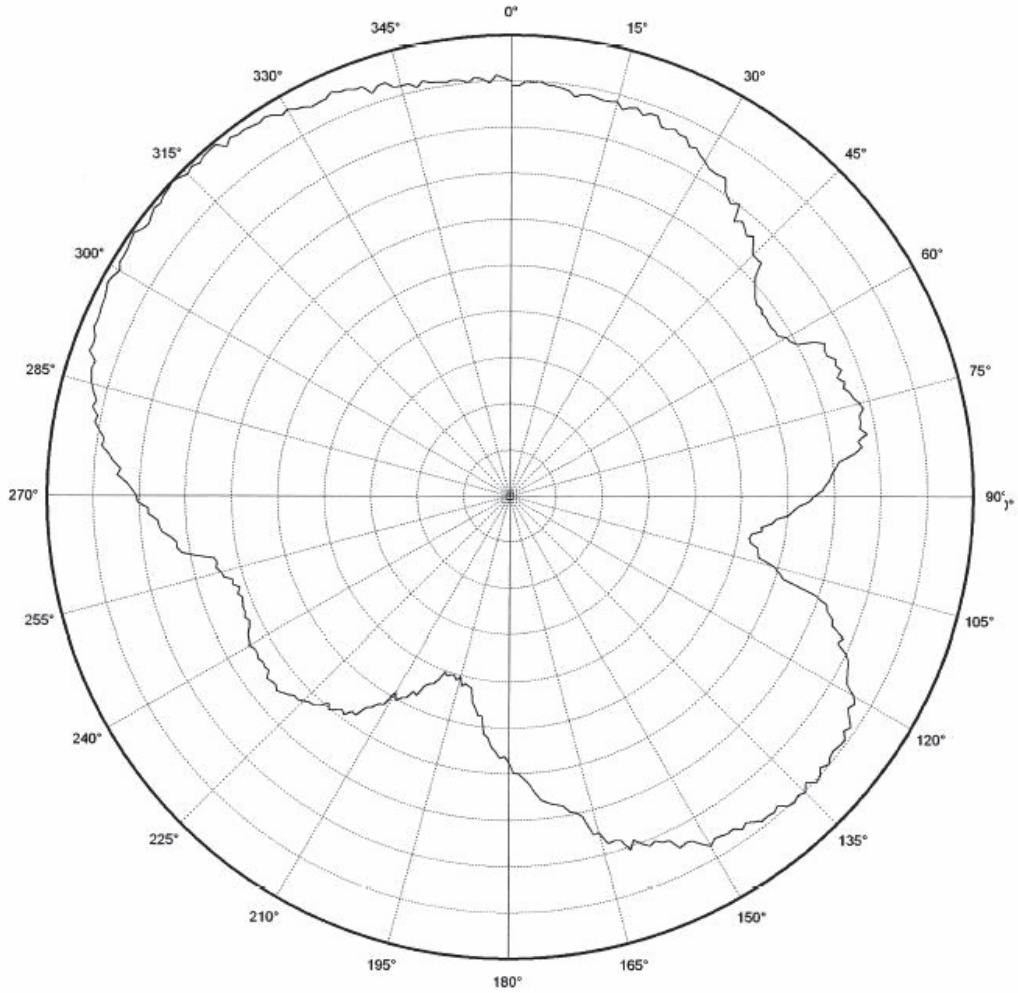
usb YZ

CF 2450.000 MHz

2 dB/ div

Ref Lev: +5.3 dBm

YZ Plane



Horizontal Polarization

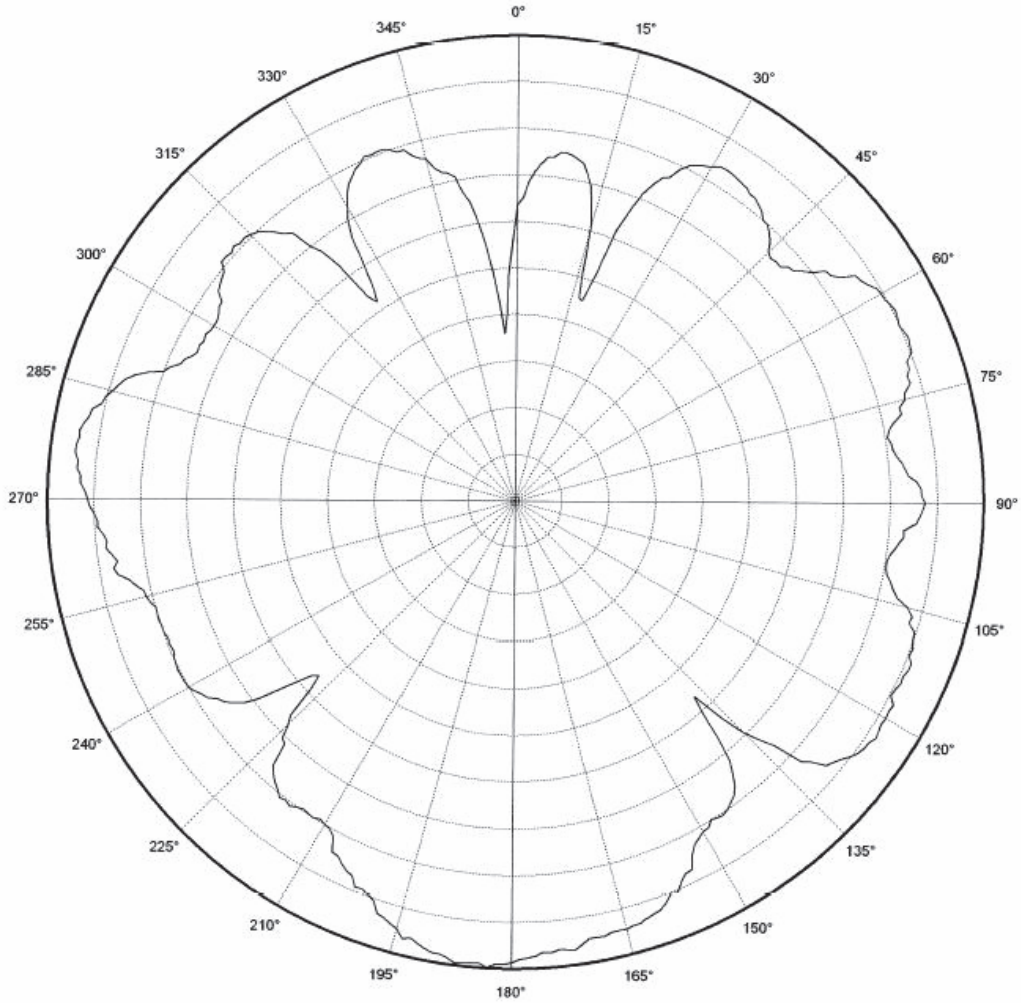
usb YZ

CF 2450.000 MHz

3 dB/div

Ref Lev: <sup>-1,2</sup> ..... dBm<sub>1</sub>

YZ Plane



Vertical Polarization

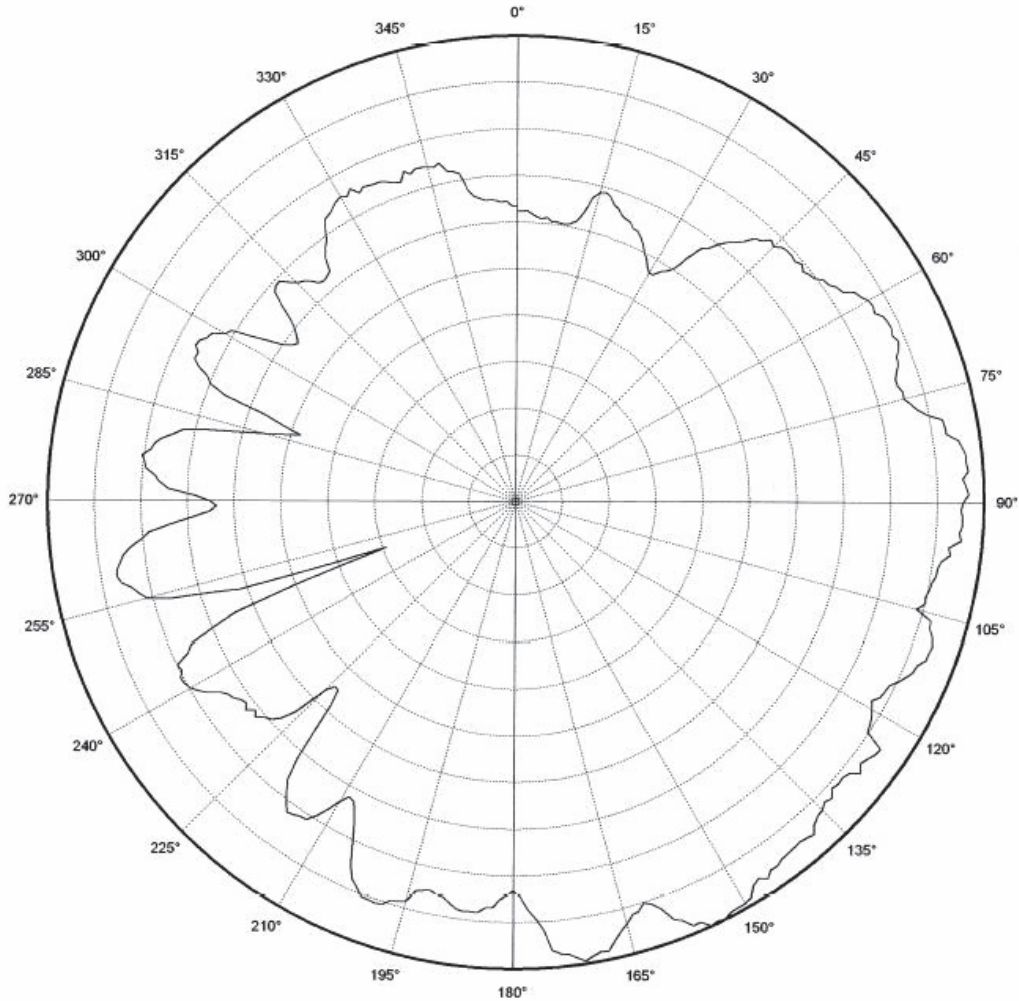
Laptop USB XY

CF 2450.000 MHz

5 dB/ div

Ref Lev: <sup>-20</sup>..... dBm

AR93331-V1 in Laptop XY Plane



Horizontal Polarization

Laptop USB XY

CF 2450.000 MHz

4 dB/div

Ref Lev: 3.3 dBm

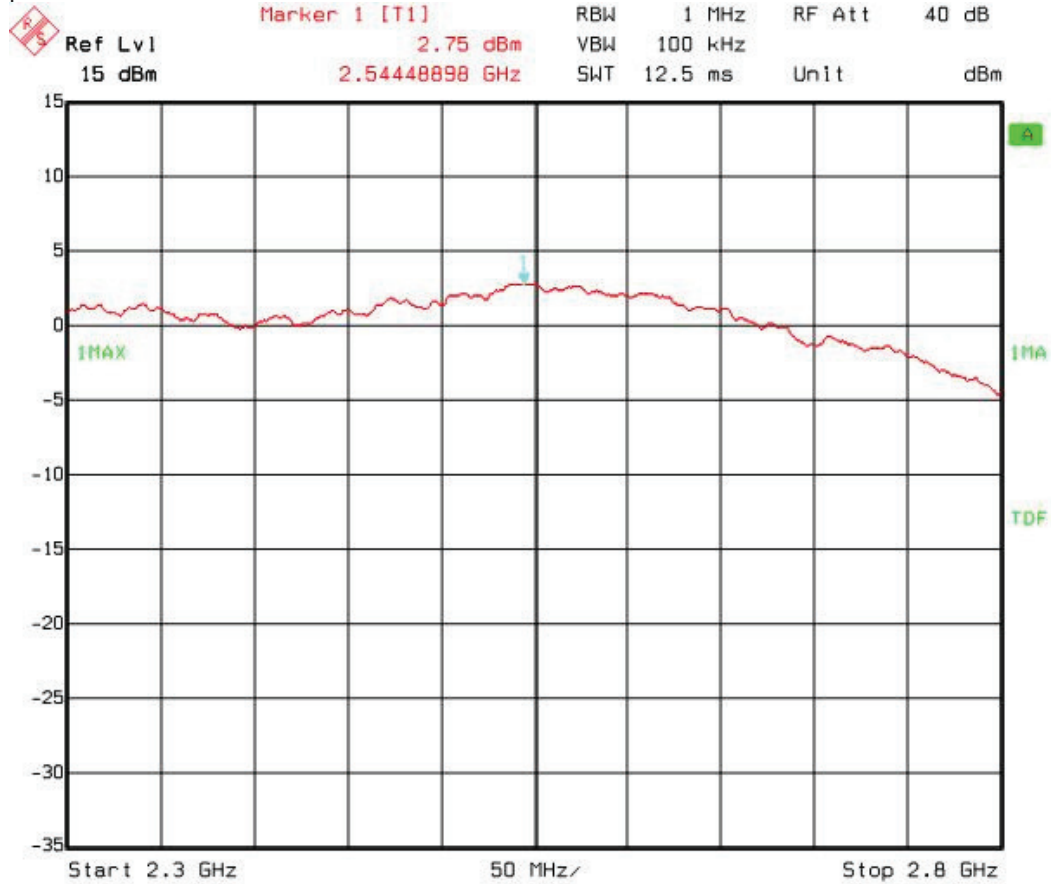
AR93331-V1 in Laptop XY Plane

### 2.3 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. AR93331 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.

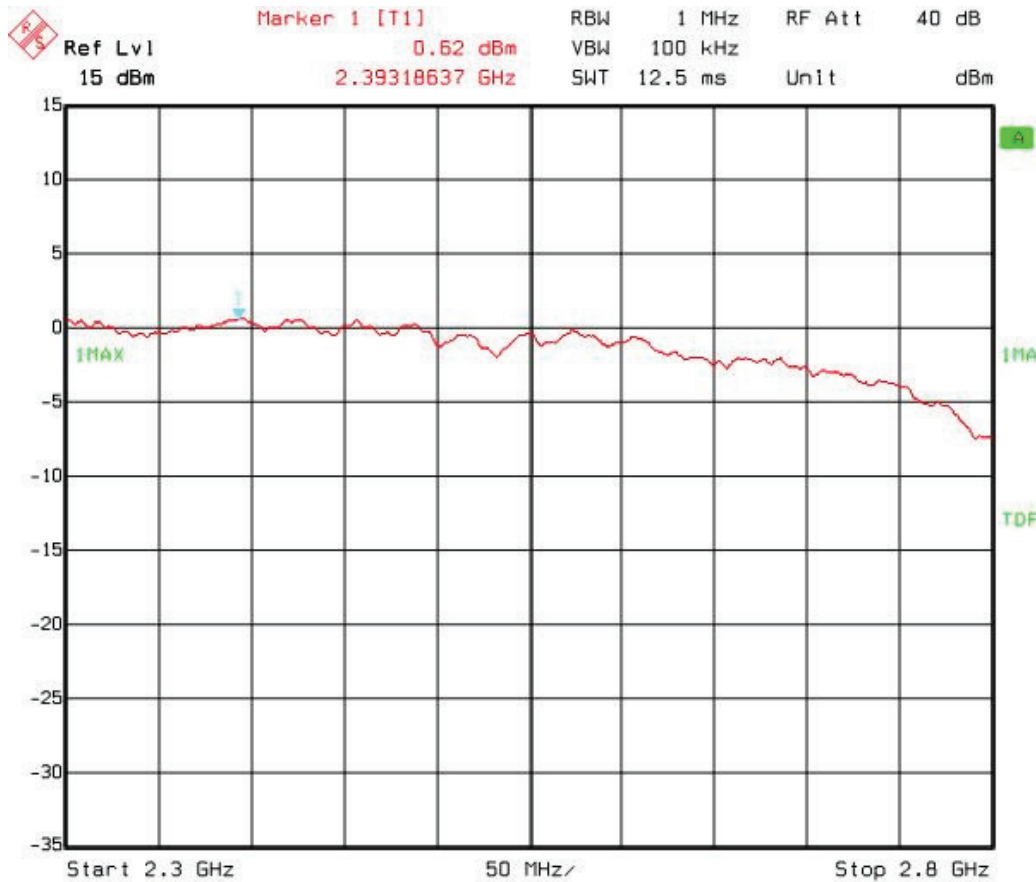
Figure 15 shows the bandwidth of the antenna when the dongle is not connected to a computer. The result shows that the antenna has a variation in output power of less than 3 dB across a frequency band of more than 350 MHz. This demonstrates that the antenna has a

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.



**Output Power, RA93331-V1**

The reflection results in Figure 5 indicate that the output power will be slightly reduced when the dongle is connected to a laptop. Comparison of the results in Figure 15 and Figure 16 shows that the output power is reduced by approximately 2 dB when the dongle is connected to a laptop. This agrees with the results in Figure 5.



**Output Power, AR93331 -V1 in Laptop**

#### 2.4 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 17 and Figure 18. These measurements were performed according to FCC requirements. An approximate conversion to dBm can be done by subtracting 95 from the measured value in dB $\mu$ 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 $\mu$ V/m	56.1 dB $\mu$ V/m
0 dBm	96.1 dB $\mu$ V/m	54.3 dB $\mu$ V/m
-2 dBm	93.1 dB $\mu$ V/m	52.5 dB $\mu$ V/m

**Table 2: Measured Level of Output Power and Harmonics**

ETSI and FCC limits 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 both ETSI and FCC regulation.

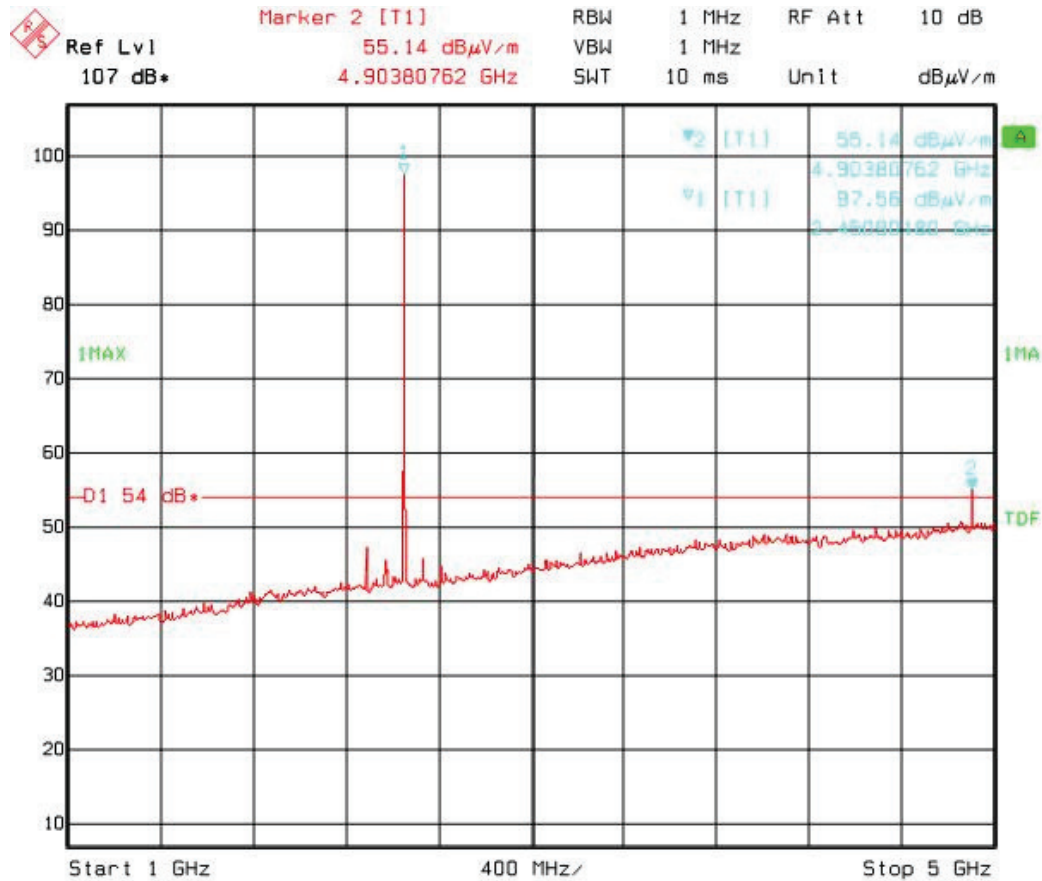


	EN 300 328	EN 300 440	FCC 15.247	FCC 15.249
2.4 – 2.483 GHz	20 dBm	10 dBm*	125 dB $\mu$ V/m 116 dB $\mu$ V/m**	94 dB $\mu$ V/m
2. harm	-30 dBm	-30 dBm	54 dB $\mu$ V/m	54 dB $\mu$ V/m

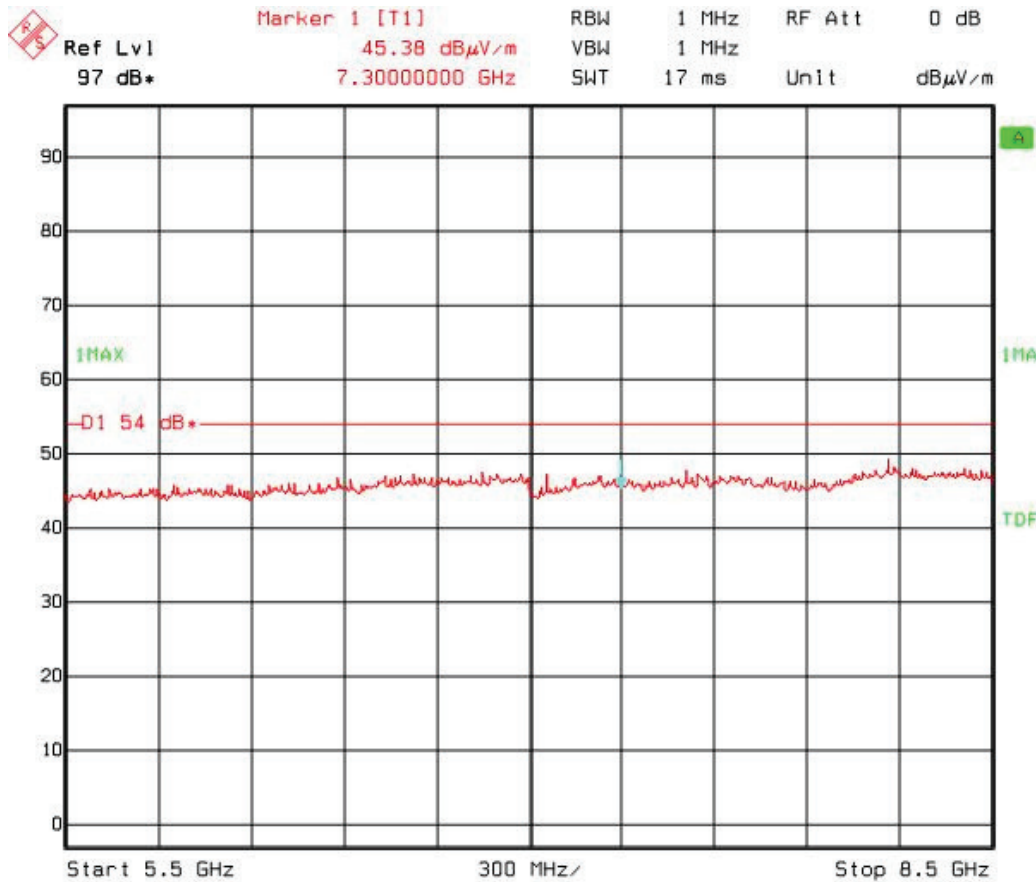
\*Depends on the power class.

\*\* Depends on the number of channels being used.

**Table 3: ETSI and FCC Limits**



**TX Spurious Emission 1 – 5 GHz**



As opposed to FCC, ETSI has specific RX emission requirements. Table 4 and Table 5 list 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

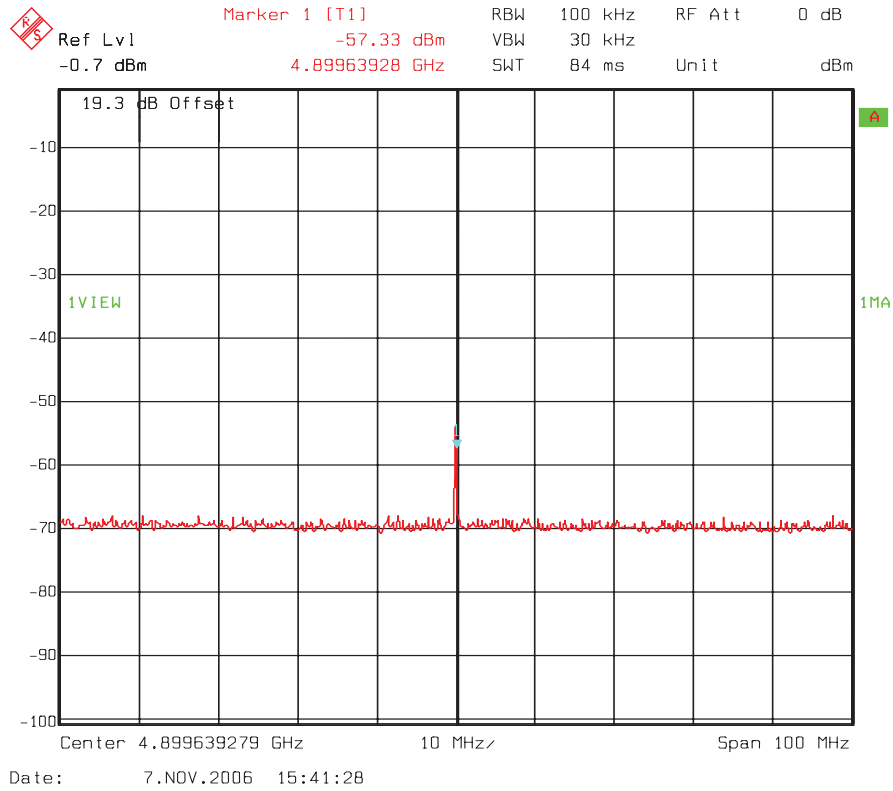
**Table 4: EN 300 328 RX Spurious Requirements**

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 signal detected above the noise floor when measuring RX spurious emission was the VCO leakage at 4.89 GHz. Figure 19 shows that the measured VCO leakage is below ETSI limits.



**RX Spurious Emission**

**3 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 6 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	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 AR93331-V1 Reference Design)**

The results provided in section 5 shows that it is possible to comply with both ETSI and FCC regulations when implementing the suggested antenna together with AR93331-V1 dongle.