AN3359
Application note

Low cost PCB antenna for 2.4GHz radio: Meander design

1 Introduction

This application note is dedicated to the STM32W108 product family from STMicroelectronics.

One of the main reasons to use a PCB antenna is the reduced overall cost of the radio module. Well designed and implemented PCB-printed antennas have a similar performance to the SMD ceramic equivalence. In general, the footprint for a ceramic SMD antenna is smaller than that for a PCB-printed variant. For a PCB-printed antenna solution, the increased size of the PCB in relation to space required for the antenna means that the radio module is larger cost of the PCB increased. The increased cost of the PCB is smaller and less expensive than a SMD ceramic antenna.

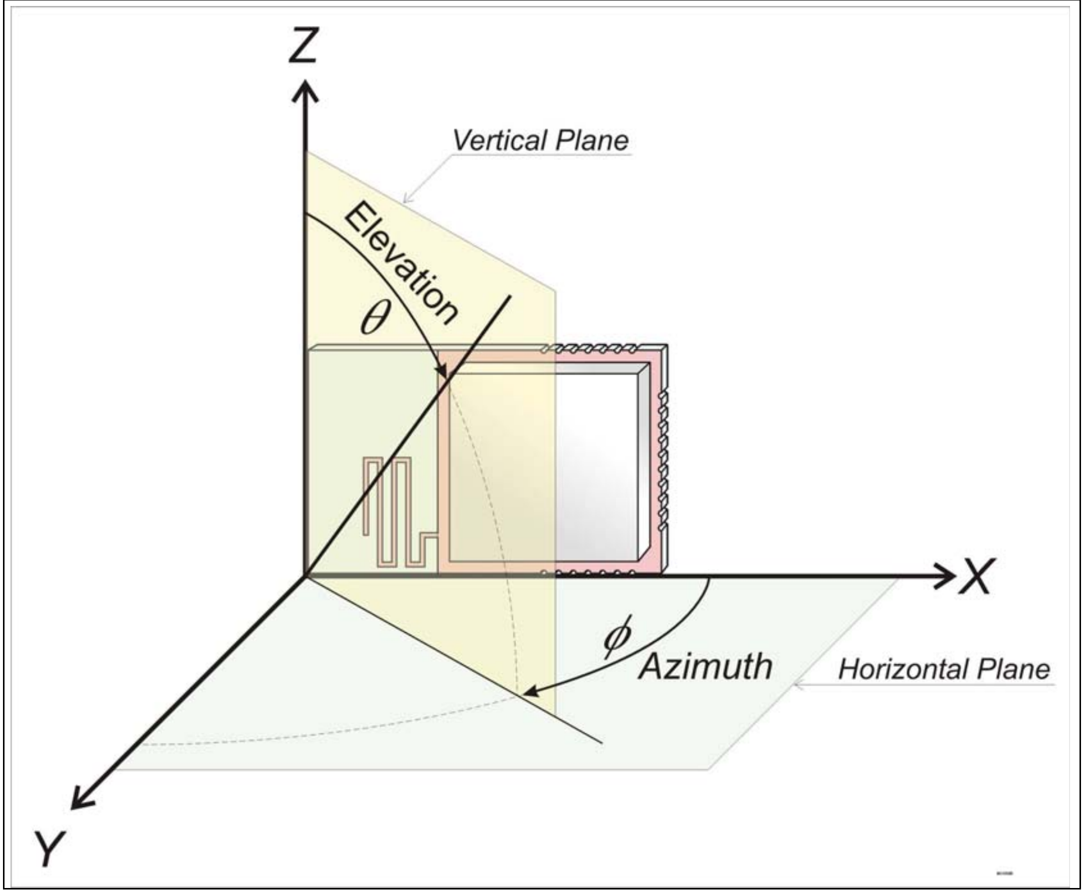
The STM32-RFCKIT RF control kit is based on an STM32W108xx RF microcontroller. It implements a PCB-printed antenna to perform RF communications.

Contents

1 Coordinate system

For the purpose of this document, the spherical coordinate system illustrated in *Figure 1* is used.

Figure 1. Spherical coordinate system

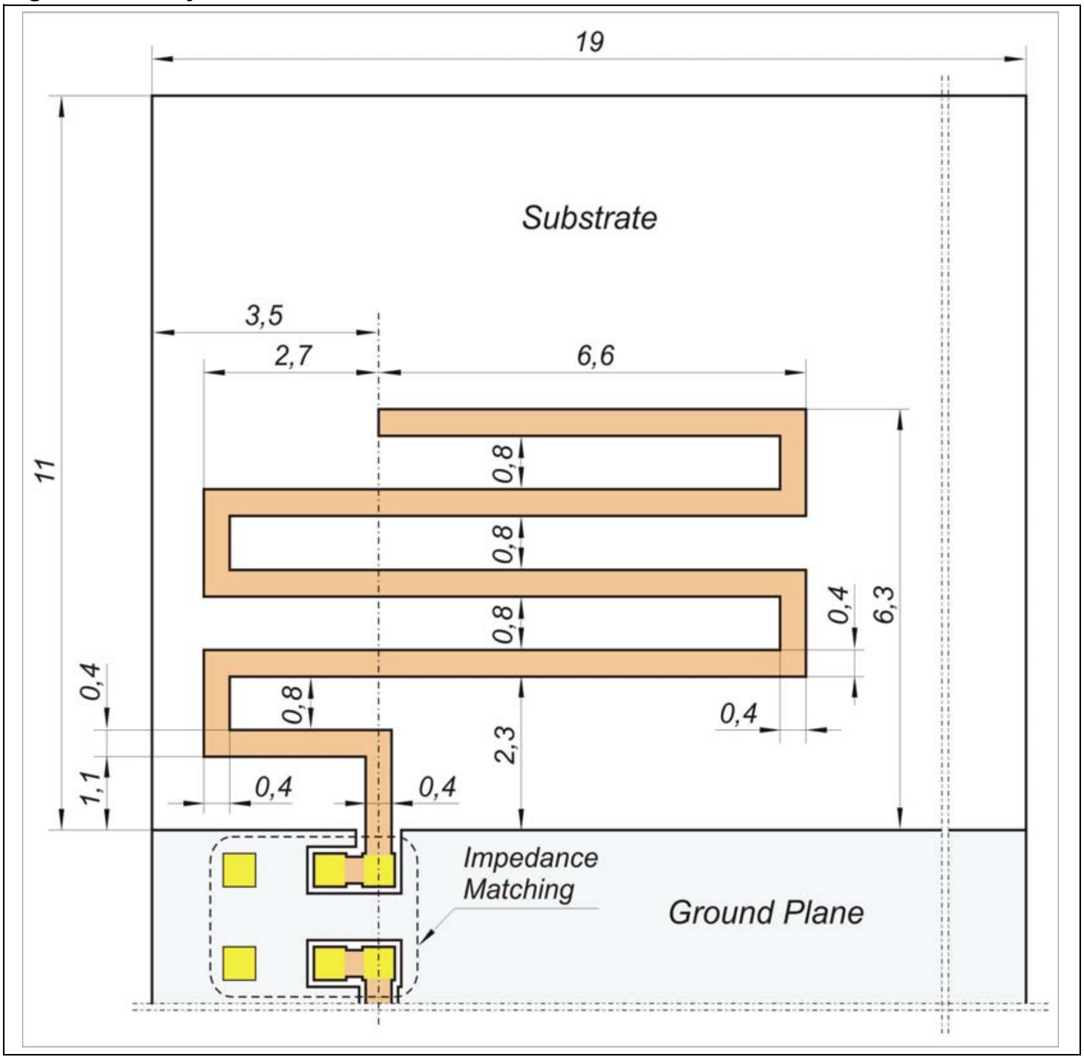


The PCB module is orientated vertically (plane X-Z), and located in proximity to the origin of the coordinate system. The azimuth angle radiates from the X-axis towards the Y-axis, and the elevation angle radiates from the Z-axis towards the horizontal plane, X-Y. Sometimes, as with geographical and navigational systems, the X-axis is called the "Nord-axis", the Y-axis is called the "East-axis" and the Z-axis is called the "Zenith-axis".

2 Layout specification

PCB antennas, including the electrical parameters of PCB materials used, are layout sensitive. STMicroelectronics recommends using a layout as close as possible to that shown in *Figure 2*.

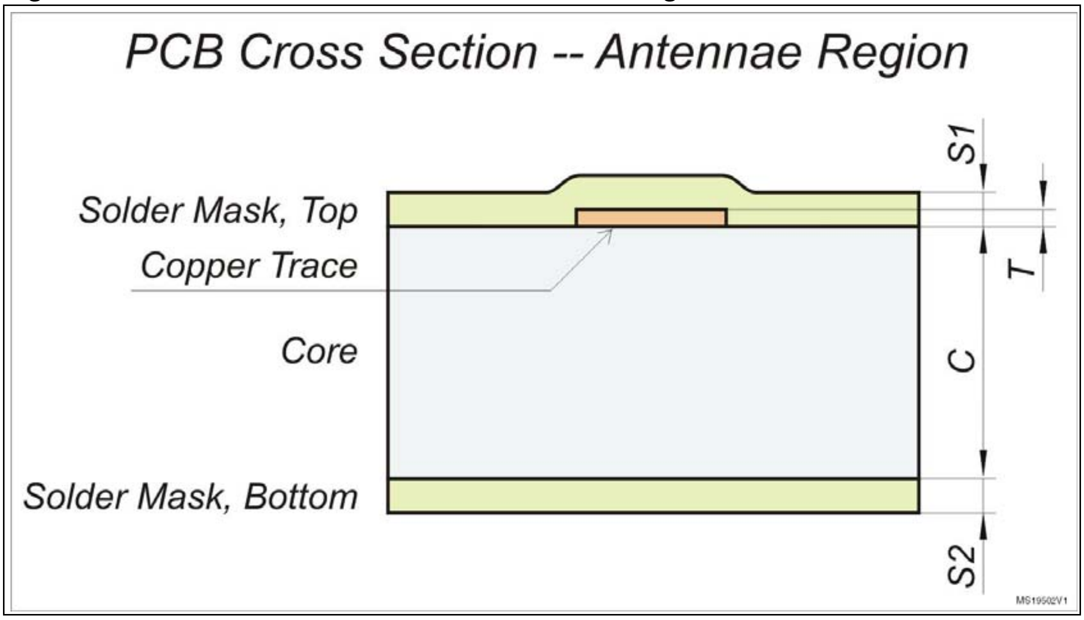
Figure 2. Layout of Meander-like PCB antennae



The electrical parameters and performance of the PCB antenna are also determined by the substrate used, in particular the thickness of the core and dielectric constants ε_R.

Figure 3 illustrates a typical cross-section of the substrate in a PCB-antennae area.

Figure 3. Cross section of the PCB at antennae region



A substrate with the parameters in *Table 1* is recommended:

Table 1. Specification of the recommended substrate

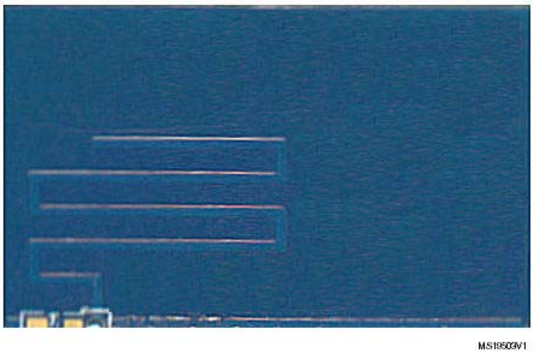
Pos.	Layer	Dimension					Dielectric Constant ε_R
		Label	Value	Unit	Value	Unit	
1	Solder Mask, Top	S1	0.7	mil	17.78	µm	4.4
2	Copper Trace	T	1.6	mil	40.64	µm	---
3	Core	C	28	mil	711.2	µm	4.4
4	Solder Mask, Bottom	S2	0.7	mil	17.78	µm	4.4

3 Impedance matching

Meander-like PCB antenna can be tuned to the required 50 Ohm impedance by matching the impedance circuitry with the π topology. In *Figure 2* the impedance matching area is marked with a dashed line. Under nominal conditions, this antenna should exhibit impedance very close to the required nominal impedance (50 Ohm).

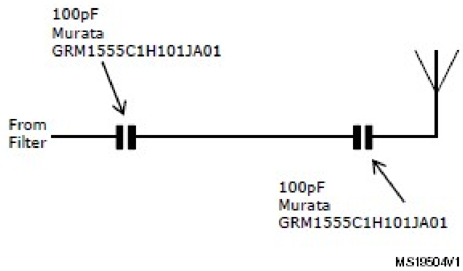
To check the performance of this design, a sample antenna was manufactured (according to the specifications covered by this document). *Figure 4* shows this antenna.

Figure 4. Part of the ZigBee module's PCB with Meander-like antenna (around scale 4:1)



Assuming that the manufactured sample exhibits the expected performance (no impedance matching necessary), the impedance matching circuitry was bypassed by two 100 pF capacitors connected in series, as shown in *Figure 5*:

Figure 5. Bypassing impedance matching circuitry - direct RF connection



All electrical parameters of the meander-like antenna have been measured at connection to the Band Pass Filter with the frequency span covering frequencies from 2.4 GHz to 2.5 GHz.

Complex impedance of the antenna is shown in the Smith diagram in *Figure 6*:

Figure 6. Complex impedance of the Meander-like antenna on Smith Chart

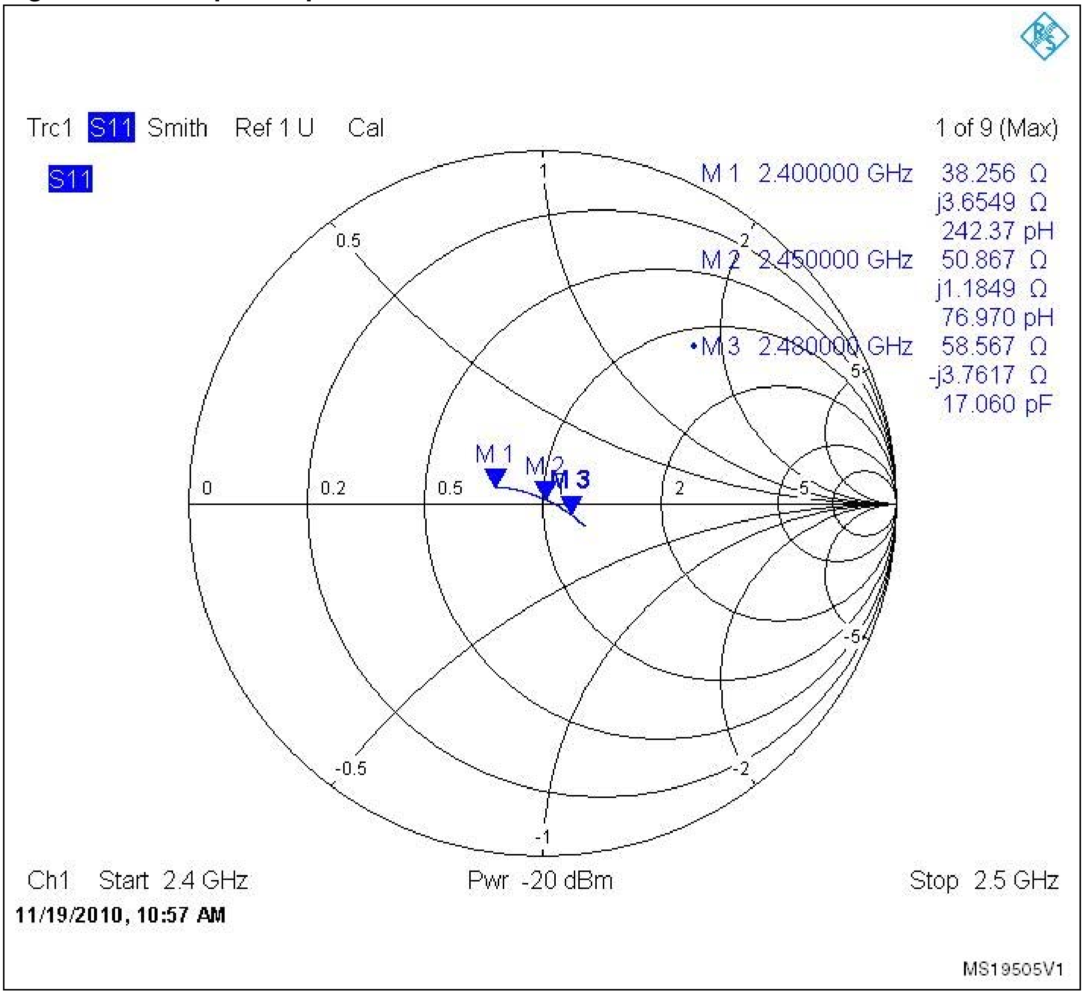


Figure 7 shows the magnitude of the S11 parameter (in log scale).

Figure 7. Magnitude of the S11 parameter in logarithmic scale (Cartesian plot)

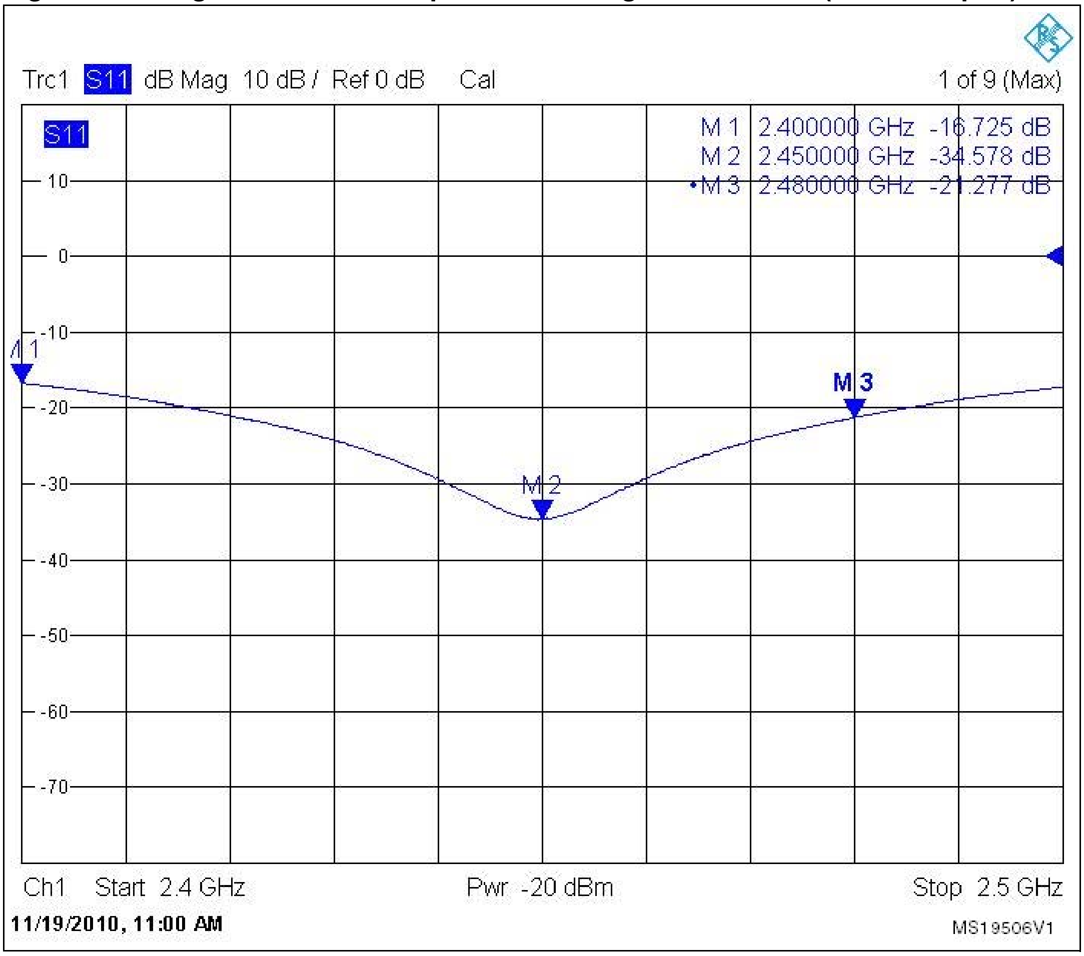
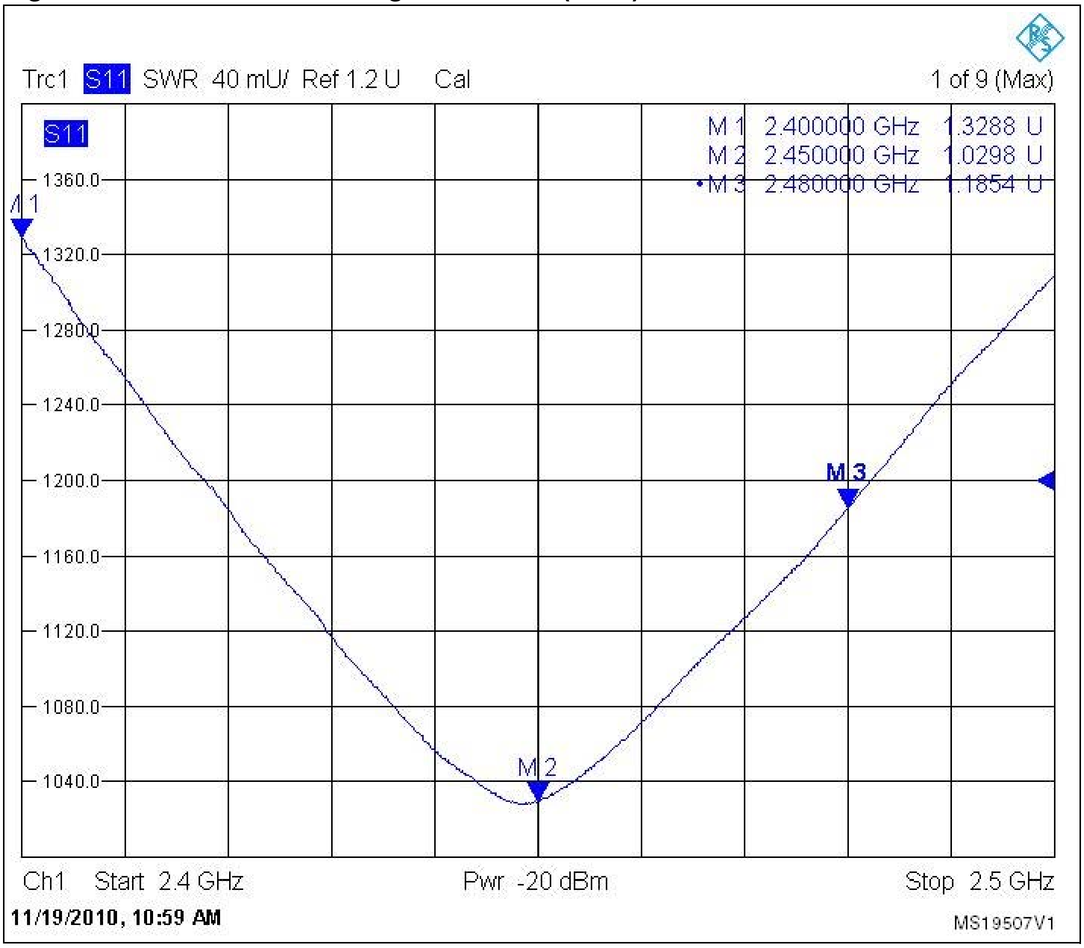


Figure 8 shows the Standing Wave Ratio (SWR).

Figure 8. Antenna's Standing Wave Ratio (SWR)



The following changes will affect the radiation impedance of the PCB antenna:

- slight board size variation
- metal shielding
- use of plastic cover
- presence of other components in proximity of the antenna

The best performance impedance matching circuitry will compensate these effects so that for operating frequencies, the optimum 50 Ohm impedance is achieved.

4 Radiation pattern, 3-D visualization

A three-dimensional (3-D) visualization of the radiation pattern (magnitude of the electrical far field |E|) is done for the center ISM band frequency 2.44175 GHz.

Figure 9. Three dimensional (3-D) radiation pattern overview

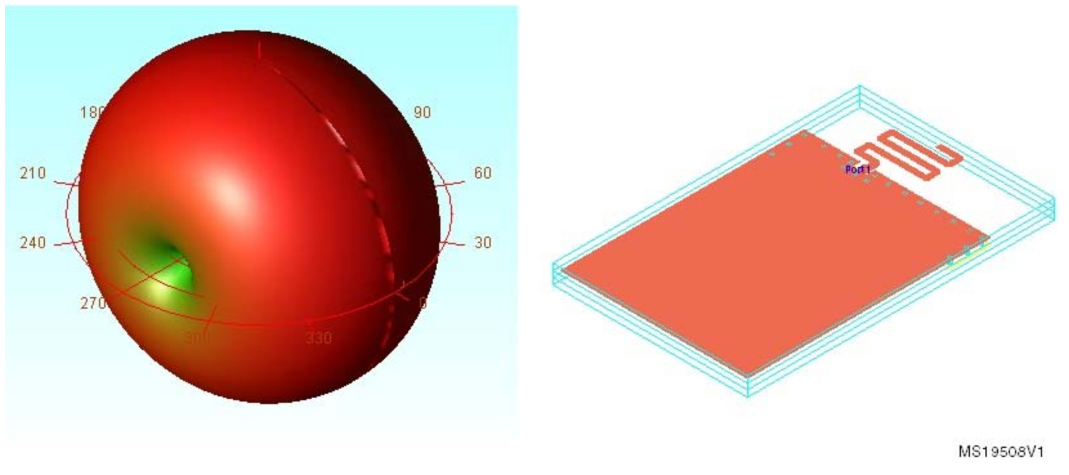


Figure 10. Radiation pattern on Y-Z plane

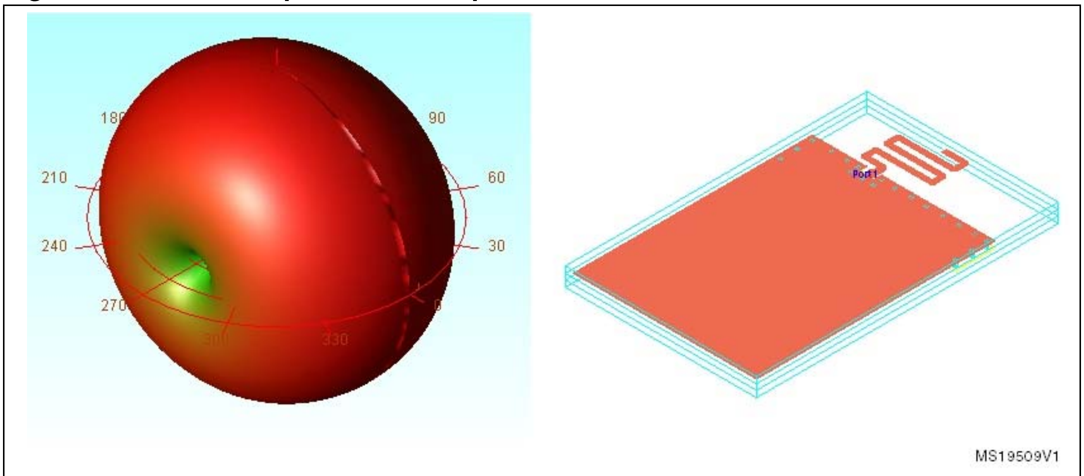
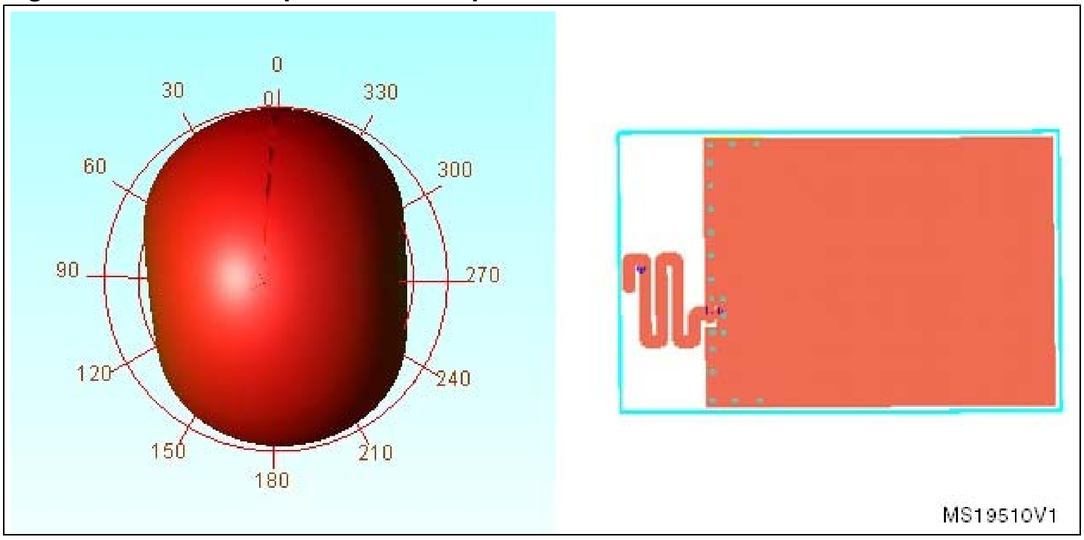


Figure 11. Radiation pattern on X-Z plane



5 Radiation pattern, 2-D visualization

In this chapter all radiation patterns are related to the magnitude of electrical far field E, which is normalized and shown in the logarithmic scale (in dB). This means that the maximum global radiation pattern (maximum magnitude of the electrical far-field E) is represented by 0 dB level. To show antenna radiation patterns in detail, three two dimensional (2-D) major cuts are presented. Consider the orientation of the module in the spherical coordinate system as shown in *Figure 1*.

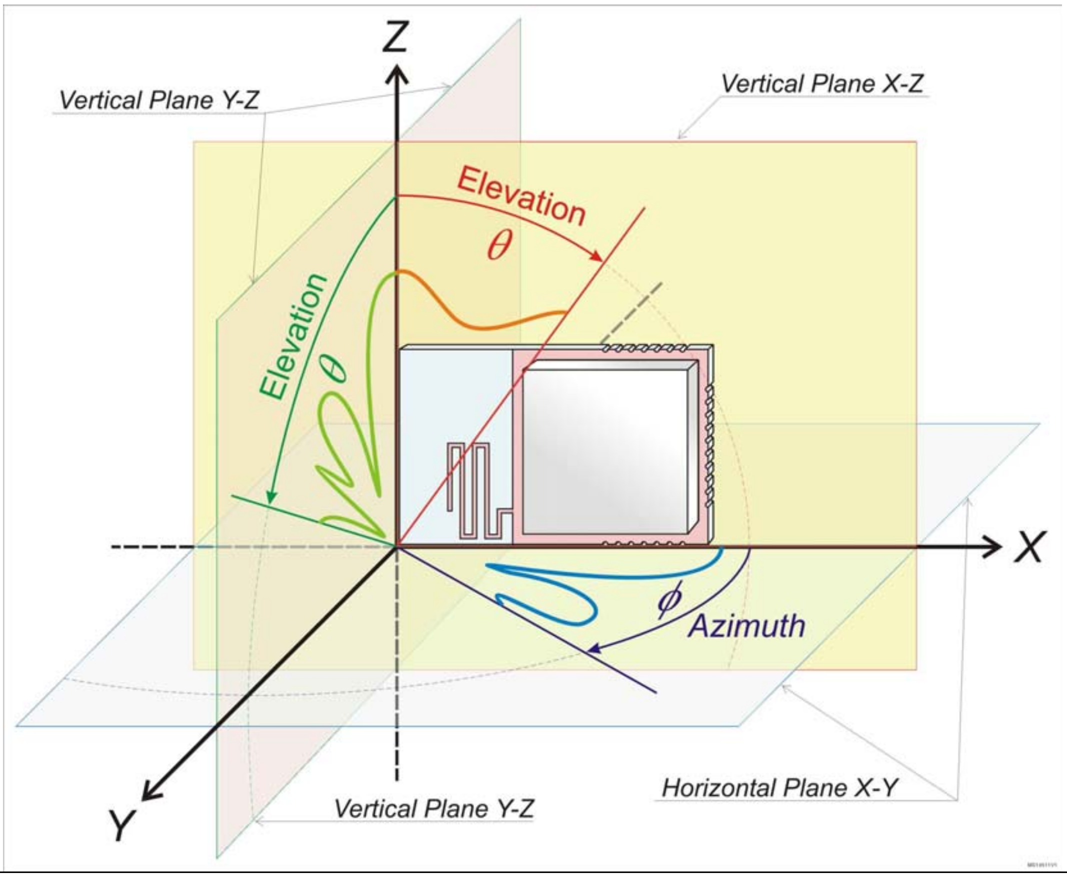
A three dimensional (3-D) far field radiation pattern is visualized as three two dimensional (2-D) cuts through a 3-D pattern. Three major planes are used for these cuts (*Figure 12*):

- One horizontal X-Y plane
- Two vertical planes: X-Z plane and Y-Z plane.

For the colors of the plots in *Figure 12*:

- The "Blue" plot is drawn on the horizontal X-Y plane, where azimuth ϕ radiates from 0° on the X-axis towards the Y-axis until it reaches 360° on the X-axis.
- The "Red" plot is drawn on the X-Z plane, where elevation θ radiates from 0° on the Z-axis towards the positive part of the X-axis until it reaches180° on the negative part of the Z-axis. In this plot (cut by X-Z plane), elevation θ is negative for $X < 0$.
- The "Green" plot is drawn on the Y-Z plane, where elevation θ radiates from 0° on the Z-axis towards the positive part of the Y-axis until it reaches 180° on the negative part of the Z-axis. For this plot (cut by Y-Z plane), elevation θ is negative for $Y < 0$.

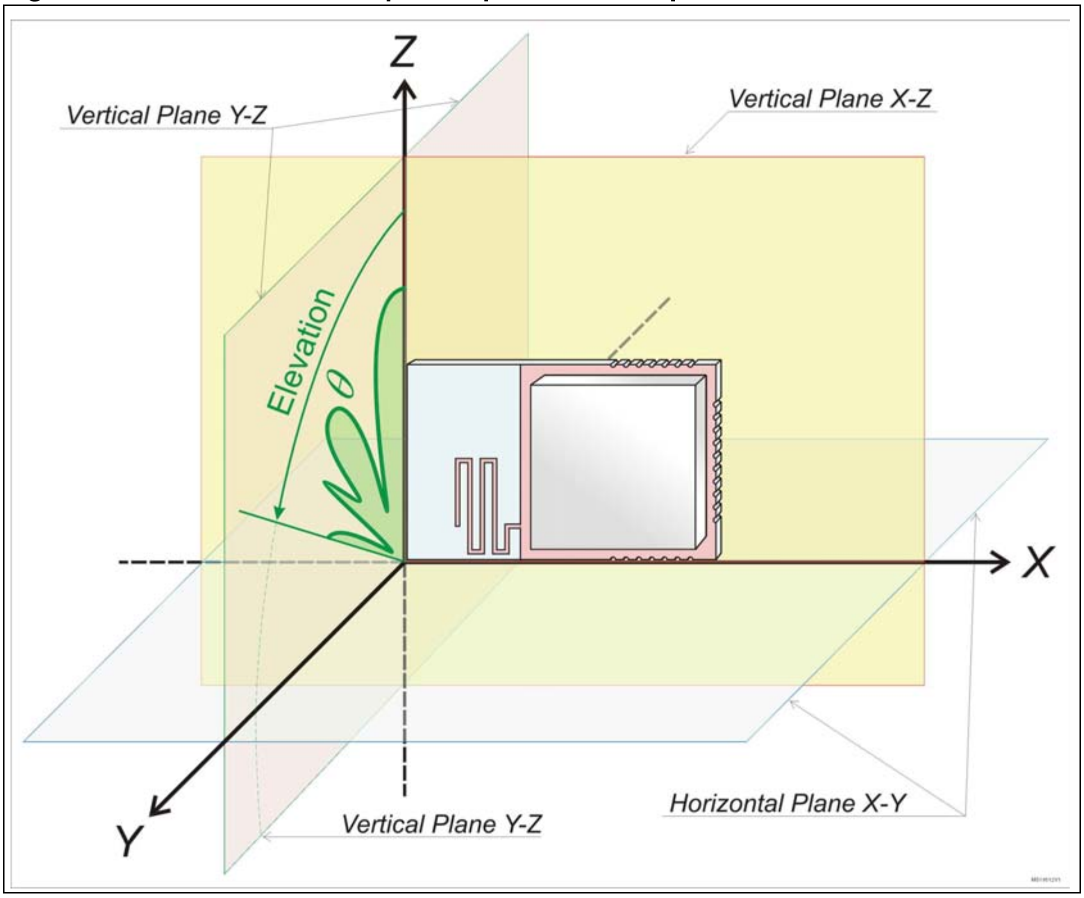
Figure 12. Major planes used to visualize 3-D radiation pattern using 2-D plots



This chapter uses short dipole for comparison and clarification purposes only.

The first radiation patterns in *Figure 14* and *Figure 15* show a normal electrical field radiation pattern |E| (far field) on the Y-Z plane. The module orientation versus Y-Z plane and this plot is shown in *Figure 13*.

Figure 13. Far field radiation pattern plotted on Y-Z plane



Notice the nearly constant level of the radiation—nearly omni-directional radiation on this plane. For a vertically orientated dipole, this pattern is equivalent to the horizontal radiation.

Figure 14. normalized radiation pattern on Y-Z plan (Polar plot)

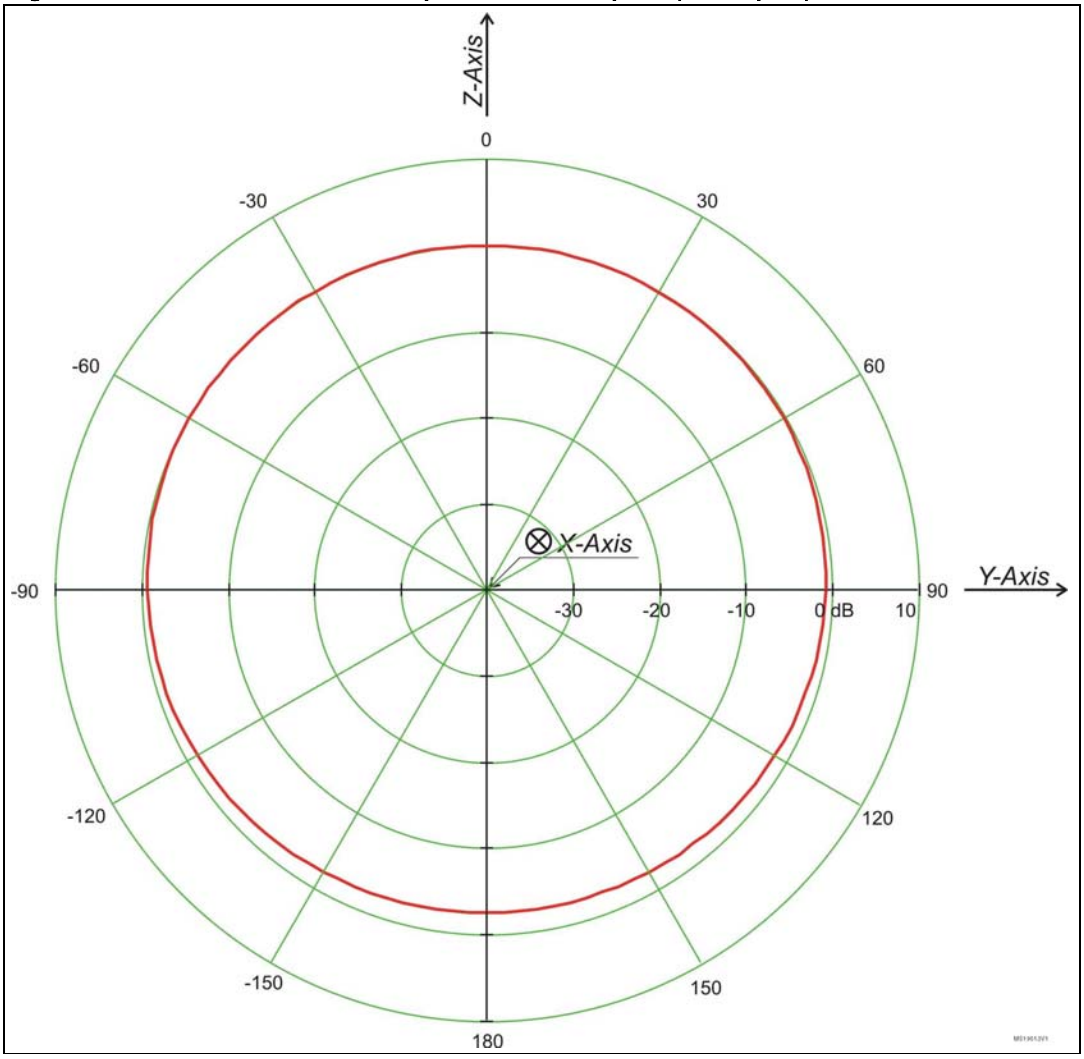
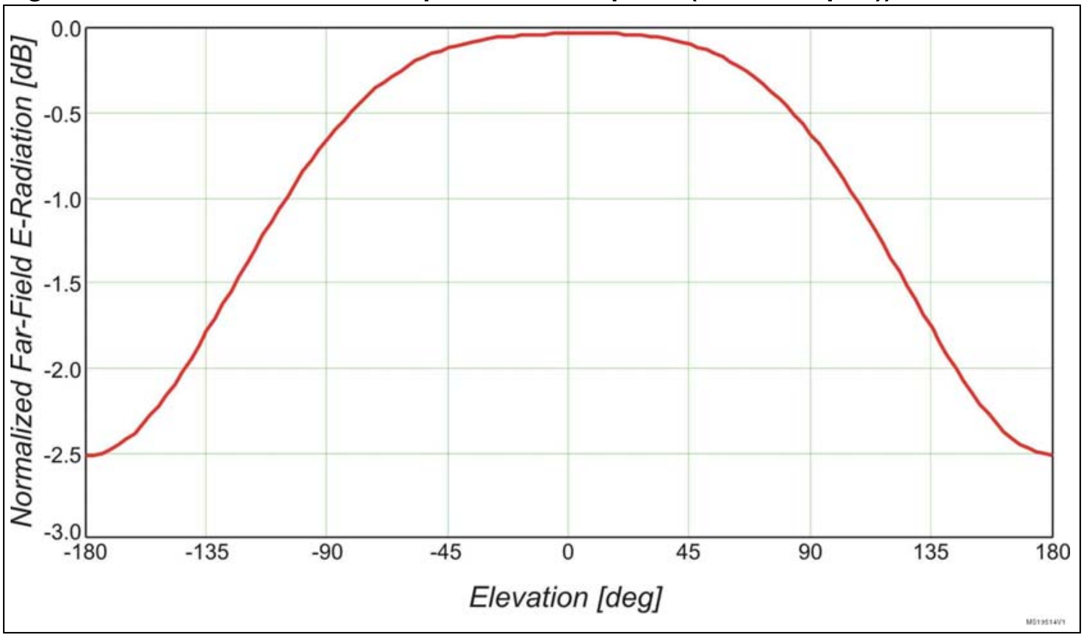


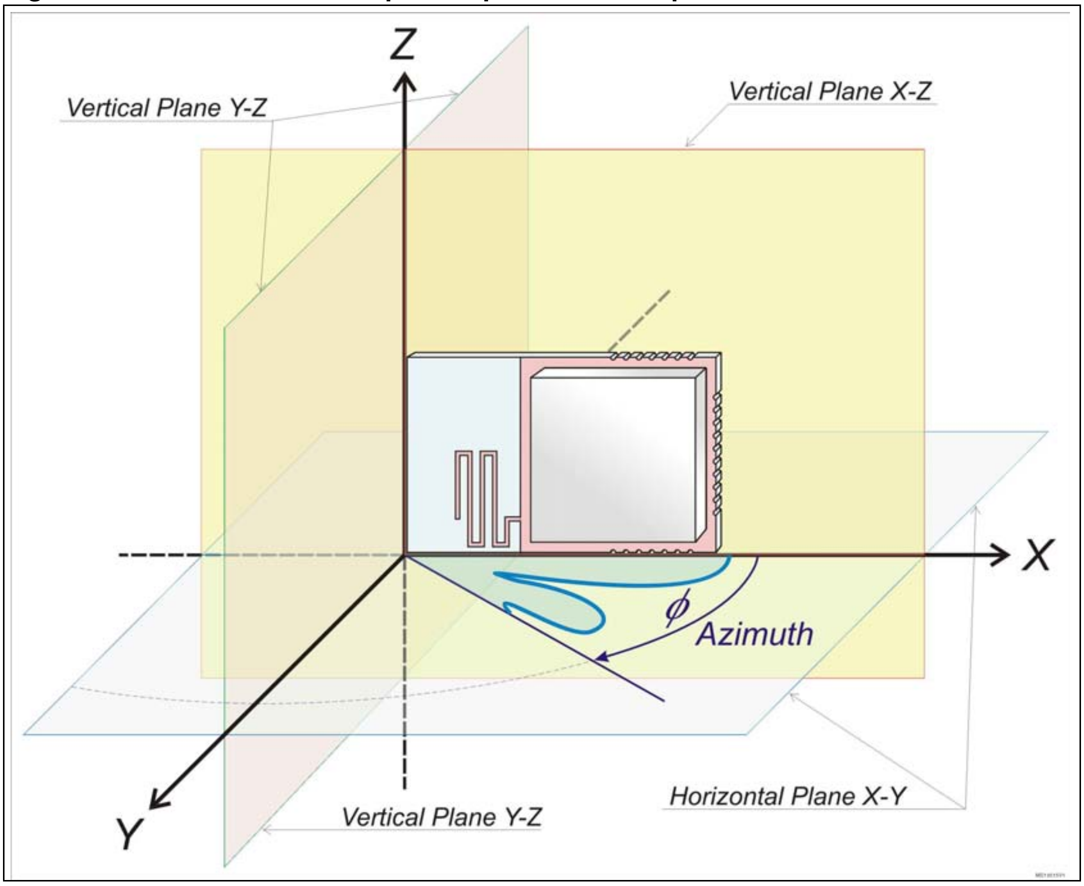
Figure 15 shows the same radiation pattern as in *Figure 14*, presented as a Cartesian plot.

Figure 15. normalized radiation pattern on Y-Z plane (Cartesian plot))



The second far-field radiation pattern (*Figure 17* and *Figure 18*) represents a normalized magnitude of the electrical field |E| plotted on the X-Y plane. The module orientation versus the X-Y plane and this plot is shown in *Figure 16*.

Figure 16. Far field radiation pattern plotted on X-Y plane



For a vertically orientated dipole, this pattern is equivalent to the vertical radiation. Note that the "dips" (between -10 and -14 dB) are much less critical than for the dipole.

Figure 17. Normalized radiation pattern on X-Y plan (Polar plot)

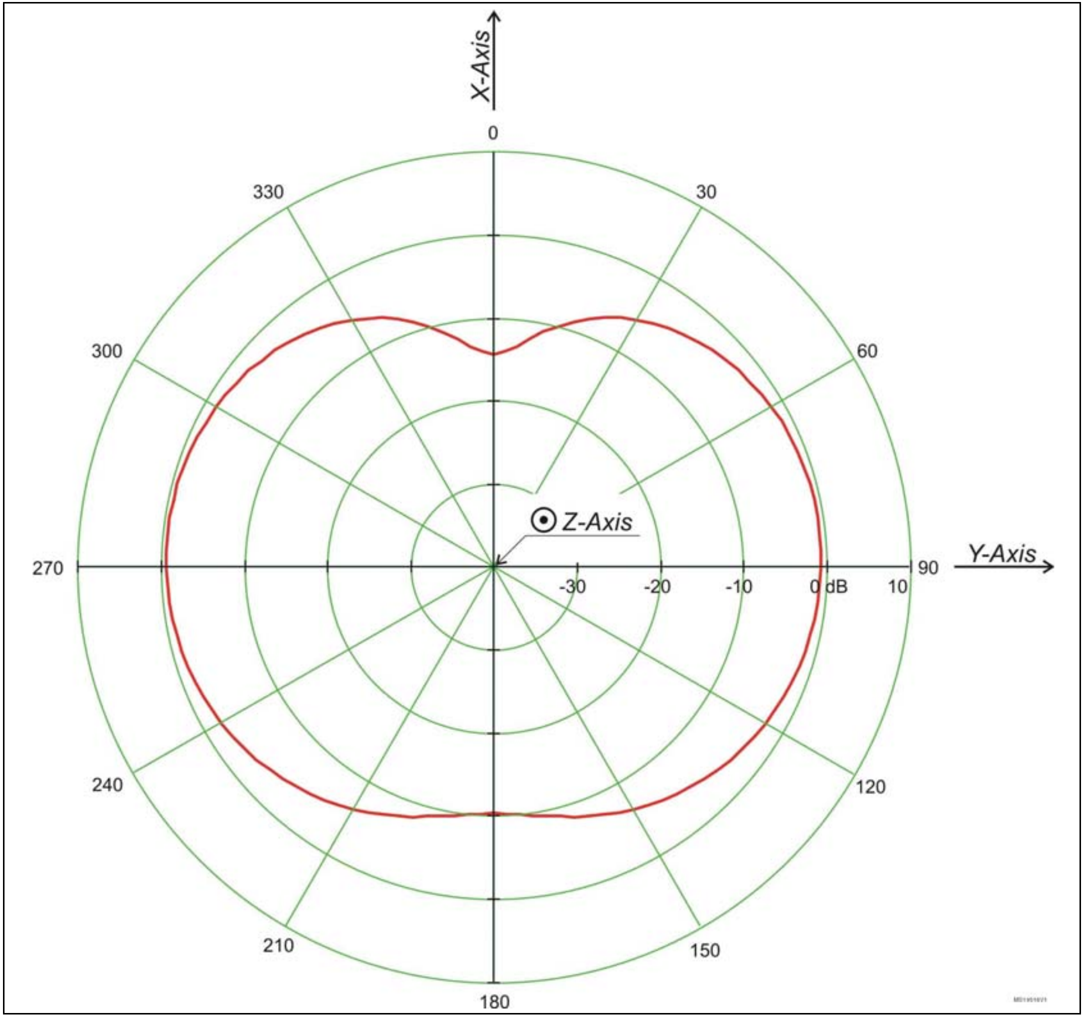
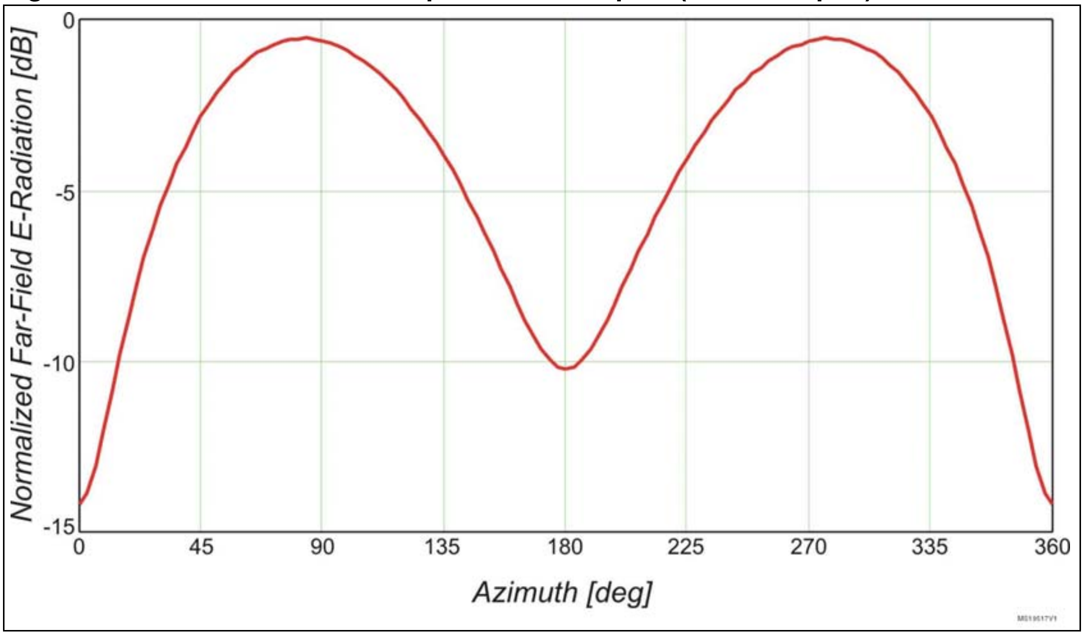


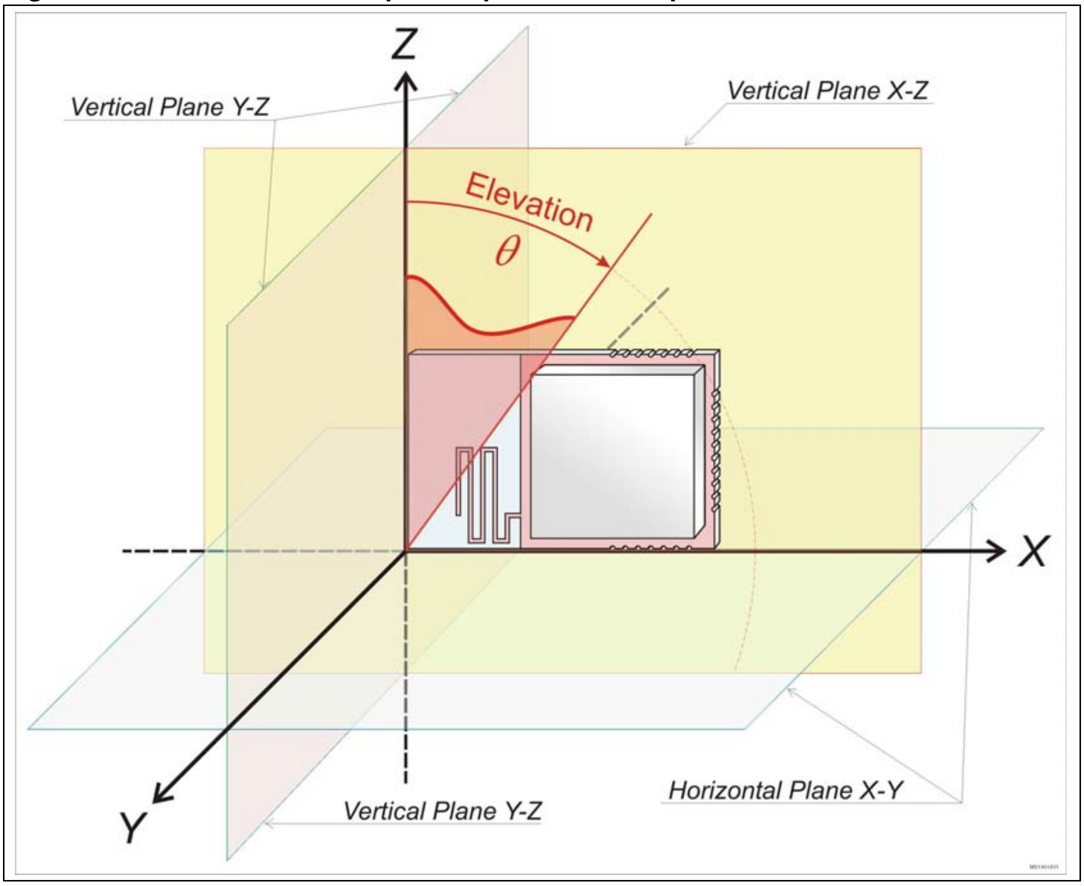
Figure 18 show the same far |E|-field radiation pattern on the X-Y plane as in *Figure 17*, presented as a Cartesian plot.

Figure 18. Normalized radiation pattern on X-Y plan (Cartesian plot)



The third and last radiation pattern (*Figure 20* and *Figure 21*) represents a normalized electrical field radiation pattern |E| (far field) on the X-Z plane. The module orientation versus the X-Z plane and this plot is shown in *Figure 20*.

Figure 19. Far field radiation pattern plotted on X-Z plane



For a horizontally orientated dipole, this pattern is equivalent to the vertical radiation. Note that the "dip" (about -18 dB in worse case) is not as deep, in comparison to the dipole radiation pattern.

Figure 20. Normalized radiation pattern on X-Z plane (Polar plot)

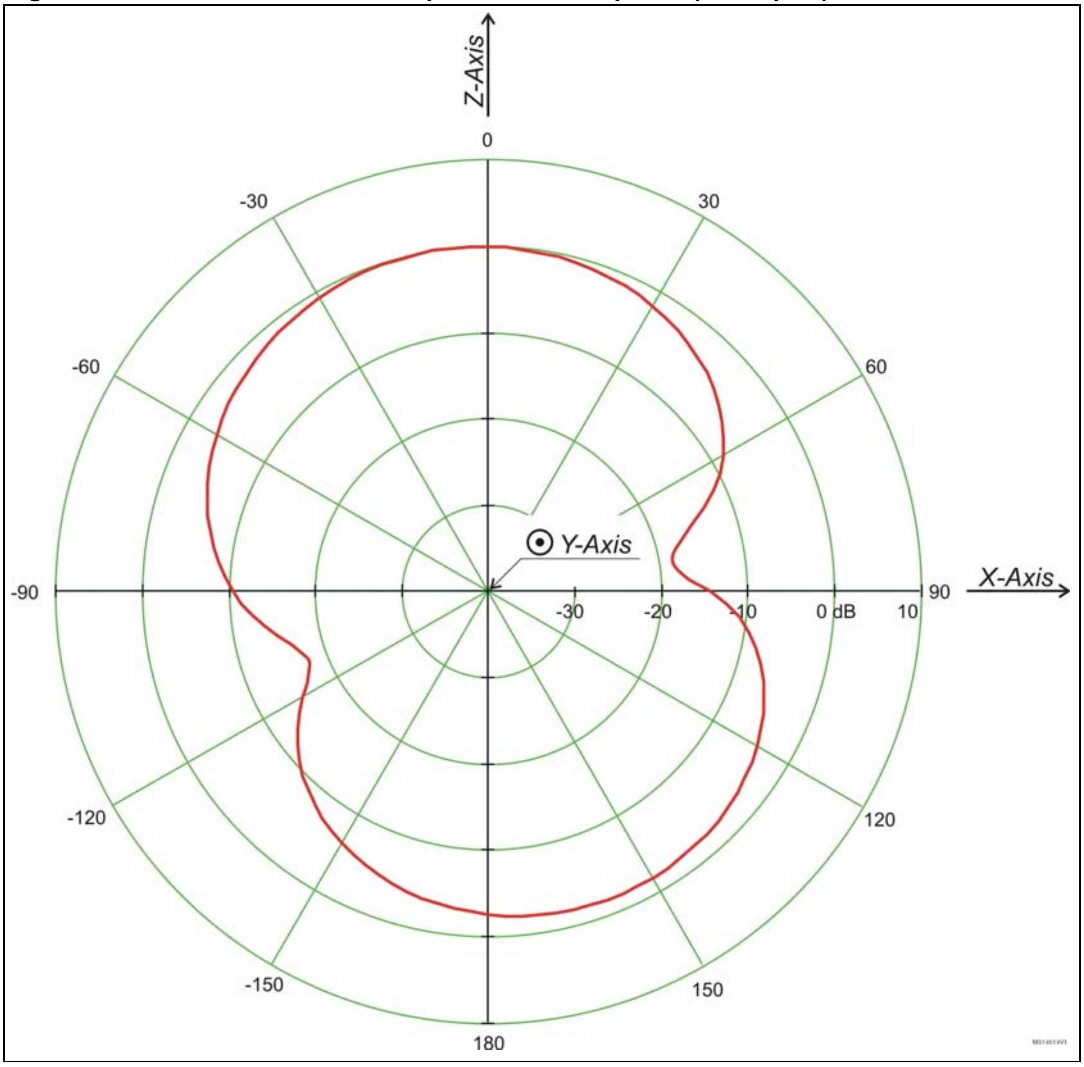
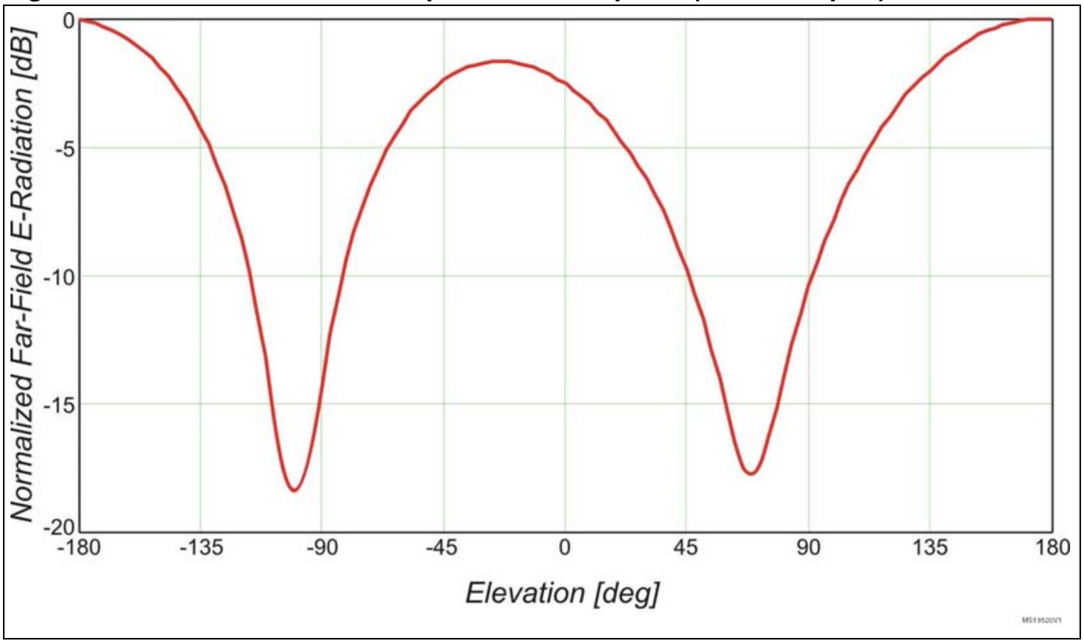


Figure 21 shows the same far electrical field radiation pattern on the X-Z plane (*Figure 20*), presented as a Cartesian plot.

Figure 21. Normalized radiation pattern on X-Z plane (Cartesian plot)



6 Performance

At center ISM Band frequency 2.44175 GHz, antennae show the following key performance parameters:

– Directivity	2.21 dB
– Gain	1.95 dBi
– Maximum intensity	0.125 W/Steradian

7 Summary

The designed antenna occupies a small part of the module's PCB. It is inexpensive and simple to produce and shows very good performances, confirmed by measurements of the manufactured samples. Keeping the manufacturing process as close as possible to the specification detailed in this document produces an antenna that does not need any of the additional components usually required for impedance matching circuitry (cost reduction, increased reliability). In addition, a no tuning procedure or similar is required. The antenna impedance is close to the nominal 50 Ohm value, with excellent SWR < 1.35 together and wideband capabilities, where log (|S11|) < -10 dB is satisfied for more than 150 MHz.

8 Revision history

Table 2. Document revision history

Date	Revision	Changes
17-Mar-2011	1	Initial release.