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Chapter

Design of a UWB Coplanar Fed Antenna and Circular Miniature Printed Antenna for Medical Applications

Adnane Latif

Abstract

Breast cancer is the second deadly cancer for women; for more efficiency and an early detection, the biomedical field need new systems that should be safe, comfortable, and sensible. The medical field already has its methods to detect breast cancer. In this chapter, a new ultra-wide band (UWB) planar antenna is presented for microwave imaging, the antenna is designed to operate in a frequency band from 2.9-10.8GHz. The antenna was designed to be adaptable for multi-viewing imaging due to it simple form, low cost and ease to be manufactured. The simulation results of the new ultra large band antenna and a performance comparison with other UWB antennas. We also offer a circular miniature printed antenna that satisfies the UWB characteristics in terms of bandwidth and reflection coefficient. This antenna is intended for a system for detecting malignant tumors by microwave imaging. The antenna made has a patch on a FR-4 type substrate with ε_r = 4,3, thickness h =1.575 mm and dimensions l_s = 25 mm, and w_s = 25 mm. A rectangular slot is inserted on the radiating element ensuring its miniaturization. The latter is powered by a microstrip line width wm with matching impedance at 50 Ohm.

Keywords: ultra wide band, coplanar antenna, microwave imaging, CPW (coplanar waveguide) antenna, wireless body area network (WBAN) antennas, BAN communications, UWB antenna, printed antennas, circular patch antennas, wireless communications, radars, microwaves, medical applications

1. Introduction

Since the FCC allows the use of the UWB spectrum, the development of new systems that will adapt to this band has been growing. Much attention has been given to developing new systems that fit with UWB applications as radar detection, biomedical imaging. The proposed UWB antenna is more likely to be used in the biomedical imaging applications as a system to detect breast cancer.

Breast cancer is the second deadly cancer for women, for more efficiency and an early detection, the biomedical field need new systems that should be safe, comfortable and sensible [1, 2]. The medical field already has its methods to detect breast cancer like X-ray mammography, magnetic resonance imaging (MRI), as efficient as those techniques are they are missing between 10 and 30% [2] of very early breast cancer stages.

The UWB microwave imaging is one of the techniques that has been developed, in the Hunt for the next techniques that will detect breast cancer in its early stages. The basis for microwave detection is to compare between the dielectric properties of a normal tissue and cancerous tissue, the result of the comparison gives a prediction of malignant tissue characteristics as it size, shape, placement, … [3].

The second part of this chapter, I present a microstrip antenna that we offer is circular in shape and, a priori, has a low gain and a narrow bandwidth. To meet the requirements of our specifications would be to expand the bandwidth. For this reason, we have developed a design methodology, which has enabled us to develop an antenna capable of meeting these requirements.

The reduction in size is also a consideration to take into account when designing this antenna, which would allow it to be more easily integrated into the system and reduce the size. For this, the certain techniques are used. Among these techniques, we will use the slot insertion at the level of the radiating element.

The design procedure followed consists of three steps:

- The first step is to develop a structure with ULB characteristics.

- The second step is used to optimize the performance of the structure developed in terms of adapting the impedance

- The third step is to develop an antenna network.

2. Design of a UWB coplanar fed antenna

2.1 Ultra wide band

UWB is defined as a system with a very large band, this large spectrum comes usually with some advantages as a low power, high debit of data, high time resolution, low-cost and an ease of implementation, resistance to interference and so on. Those advantages opened a wide range of UWB application to radar detection, biomedical imaging, and HD communication.

The definition of UWB is not a special one, the FCC (Federal Communication Commission) [4] defines it as a system with a bandwidth larger than 500 MHz or larger than 20% if we are working whit the relative bandwidth W/fc (W is the width of the band and fc is the carrier frequency). The UWB is being defined by its very large band that is 7.5 GHz between 3.1 GHz and 10.6 GHz for a limitation of the power emission level −41.3 dBm/MHz [4].

2.1.1 Matching and efficiency

The UWB communication systems uses a very short pulse duration of tens hundreds of nanoseconds, and sense the pulse and the bandwidth are inversely proportional, the shorter pulses is the wider the spectrum is going to be.

Antennas would match the UWB requirements if it have a bandwidth greater than 500 MHz defined at −10 dB according to the FCC, or to have a relative bandwidth more than 20% [4, 5].

Where f_l and f_h are the low and the high frequency respectively.

The efficiency of an UWB antenna can be evaluated by the specter efficiency, the evaluation matching has to be over the whole range of frequencies.

2.1.2 Signal dispertion ans distortion

The signal passing through the UWB antennas is a very short pulse, the shorter the pulse is more likely the UWB antenna's response is going to be distorted and delayed due to the ripple after the pulse called the rippel effect [5].

The rippling effect is caused by the geometry of the antenna, and it causes frequency translation, dispersion or delay on the transition reducing the speed of data transmission [6].

2.2 Antenna design

This section is dedicated to the design and the performance of the proposed antenna. The design proposed is a notched coplanar antenna. The geometry of the antenna consisted of a 25 × 30 mm^2, Rogers RT5850 substrate with ε_r = 2.2 and thickness h = 3.175 mm. The top part of the antenna is a circle with two cutouts of 90° each. The structure of the antenna is shown in **Figure 1**.

The two main characteristics that effect the performance of the antenna was the inner radius of the circle R and the laminate thickness. The gap between the transmission line and the ground structure was optimized so that the antenna's impedance can match a 50 Ω SMA port.

2.3 Performances of the antenna

2.3.1 The return loss S11

Figure 2 shows the return loss or more known as the parameter S11 of the antenna, the spectrum of **Figure 2** contains the UWB frequency band spectrum. The spectrum's antenna range is form 2.8 GHz to 10.9 GHz and contains tow resonate frequencies

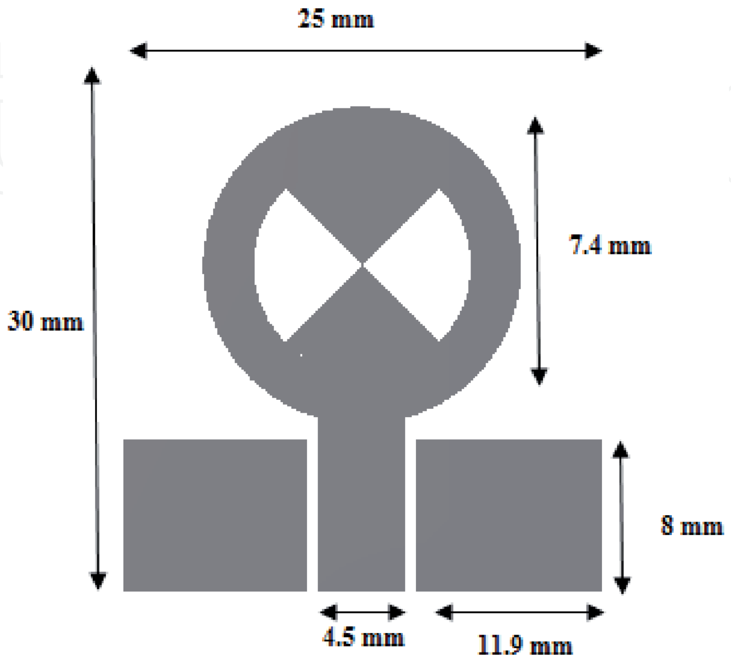


Figure 1.
Geometry of the antenna proposed.

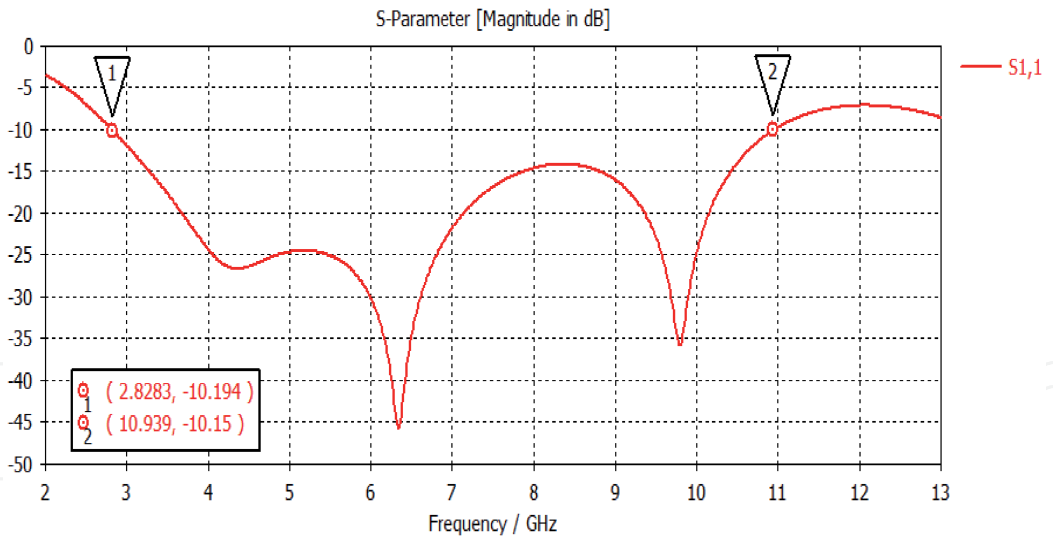


Figure 2.
The return loss S11 as a function of frequency.

6.1 GHz and 9.8 GHz with their S11 parameters −46 dB and −35 dB respectively. The antenna can be easily used in the UWB (3.1 GHz – 10.6 GHz) applications [4].

2.3.2 Voltage standing wave ratio (VSWR)

VSWR is a parameter that describes the power that is reflected by the antenna. It is a function of the reflection parameter.

Figure 3 shows the graph of the VSWR of the antenna proposed, we can tell from the graph that the VSWR is under tow in all the bandwidth so the VSWR can be considered as good.

2.3.3 Radiation pattern

The main focus of the chapter is to design a UWB antenna that can be easily implemented in UWB application with a small dimension and a larger frequency spectrum. **Figure 4** shows the radiation pattern of the antenna proposed for the frequency of 9.8 GHz, the color red defined the higher range of the gain and the green refers to the lower part [7].

2.4 Paramertic study

The parametric study is done in two parts the first part was to choose the laminate and then the value of the radius of the patch.

2.5 Comparison with others UWB antennas

The antennas that was compared to the antenna proposed in the chapter is: a coplanar microstrip antenna with defected ground structure for UWB applications [7]. A printed UWB antenna with full ground plane also for WBAN applications and CPW-fed slot patch antenna [8–10]. The study is to compare the proposed geometry on tree different Rogers laminates. **Table 1** shows the characteristics of the tree laminates.

Figure 5 presents the return loss of the antenna with the different laminates, according to the results of **Figure 5**, the laminate Rogers with a thickness of 3.175 mm was chosen to complete the parametric study. The variation of the radius is

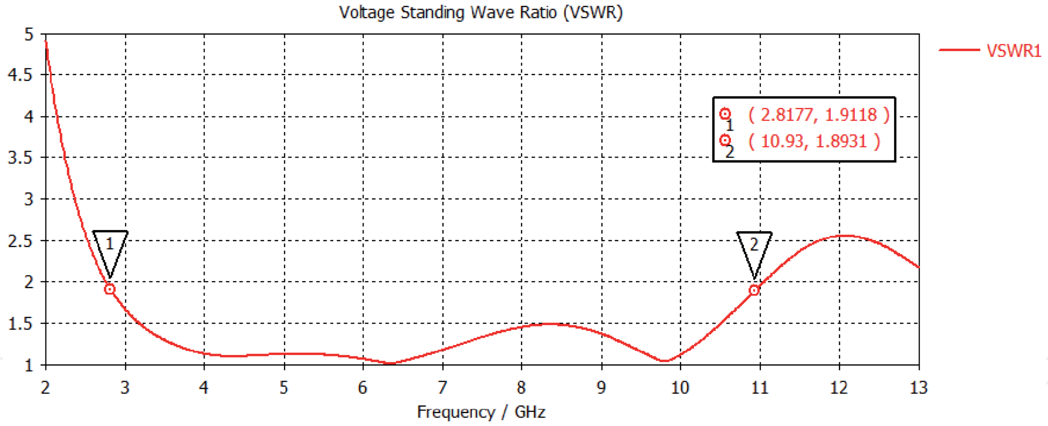
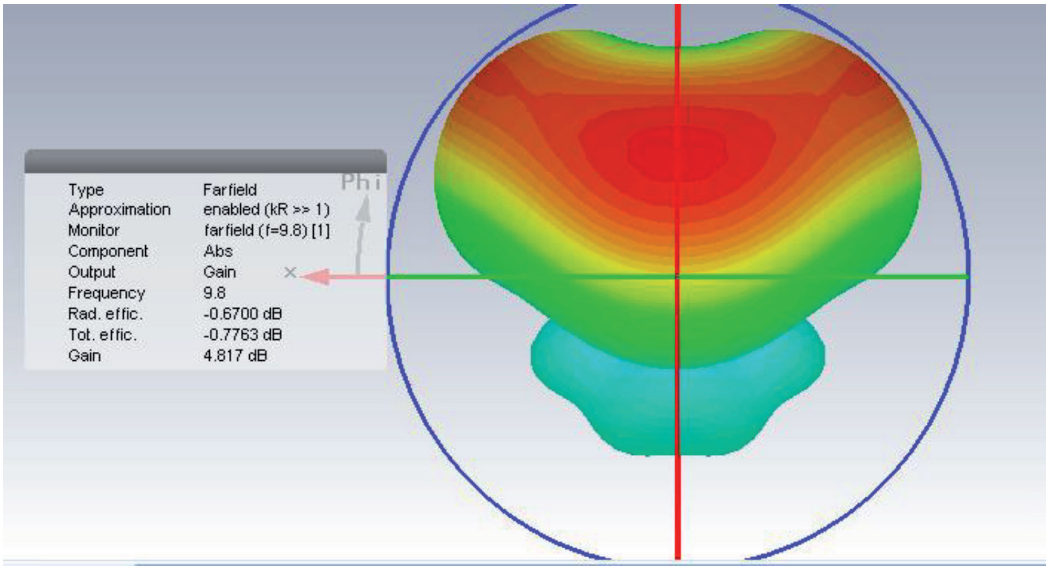


Figure 3.
VSWR as a function of frequency.



Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=9.8) [1]
Component Abs
Output Gain
Frequency 9.8
Rad. effic. -0.6700 dB
Tot. effic. -0.7763 dB
Gain 4.817 dB

Figure 4.
Radiation pattern of the proposed antenna.

Laminates	Laminate characteristics	
	Standard thickness	Standard copper cladding
Laminate 1	0.787 mm	35 μm
Laminate 2	1.57 mm	35 μm
Laminate 3	3.175 mm	35 μm

Table 1.
Standard laminales characteristics.

altered around the theoretical radius to optimize the performance of the antenna. The patch of the antenna is separated into two parts, first where the cutouts are and the second part is the ring that contour the cutouts, this parametric study consisted on varying the inner radius of the patch, the radius of the circle that contain the cutouts. **Figure 6** shows a relation between the radius and the depth of the return loss, R = 4.8 mm shows a better S11 parameter.

Table 2 shows the difference between four UWB antennas, the proposed antenna has a wider band, includes all UWB frequencies, the highest gain is around 5.6 dBi.

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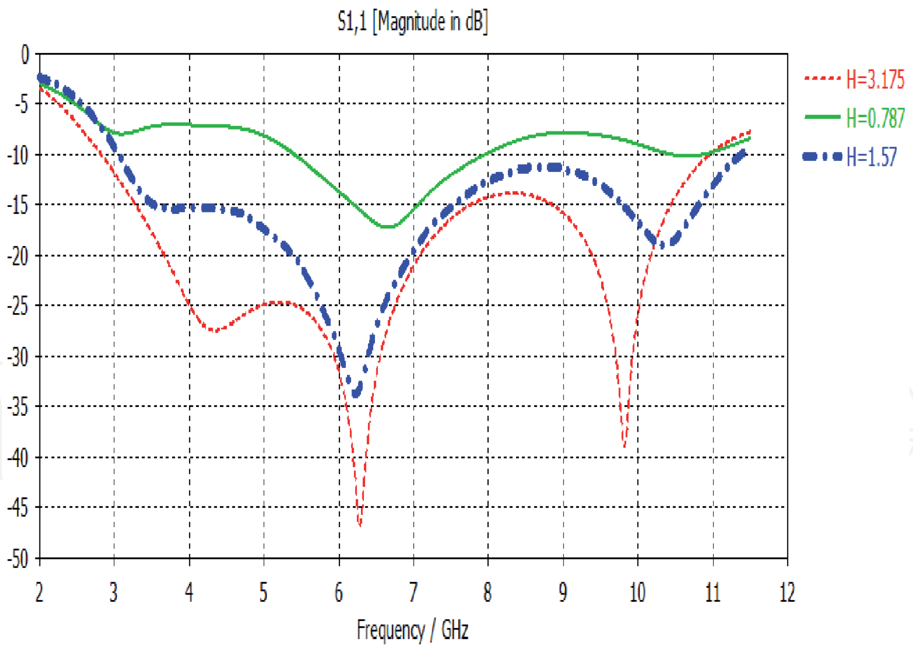

Figure 5.
Effect of the thickness of the substrate.

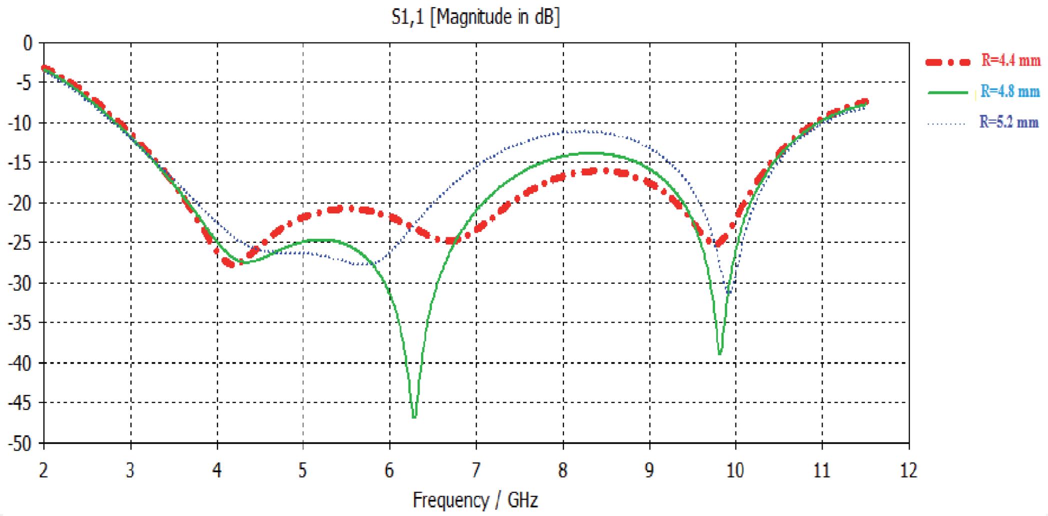

Figure 6.
Effect of the inner radius on the antenna.

Antennas	Characteristic of the antennas		
	Dimension (w × L)	**Bandwidth**	**Gain**
Antenna proposed	25 mm × 30 mm	2.7–10.98 GHz	3.5 dBi
Antenna [7]	30 mm × 32 mm	3.1–9.9 GHz	—
Antenna [8]	75 mm × 85 mm	4–9.5 GHz	—
Antenna [9]	24 mm × 30 mm	4.82–8.87 GHz	3.9 dBi

Table 2.
Performance comparison.

3. Design of a UWB circular miniature printed antenna

3.1 Design of circular miniature printed antenna

3.1.1 Antenna geometry

The patch of radius (r) is produced on a substrate of the FR-4 type (dielectric permittivity ε_r = 4.3, thickness h = 1.575 mm) and of dimensions ls = 25 mm and w_s = 25 mm. A rectangular slot is inserted on the radiating element (u × s) ensuring its miniaturization. The latter is supplied by microstrip line of w_m east width in order to adapt it to a 50 Ω supply [11, 12]. **Figure 7** shows the proposed antenna.

From **Table 3** values, we perform a simulation on the CST software [13].

3.1.2 Simulation results

3.1.2.1 S_{11} parameter

The parameter S_{11} is the coefficient that most concerns designers of printed antennas because it represents the reflection coefficient which plays the role of disturbance on data transmission [14]:

We see that the coefficient S is around −22.35 dB for a resonant frequency of 3.8 GHz, the bandwidth is 3.17–15 GHz, as shown in **Figure 8** [15].

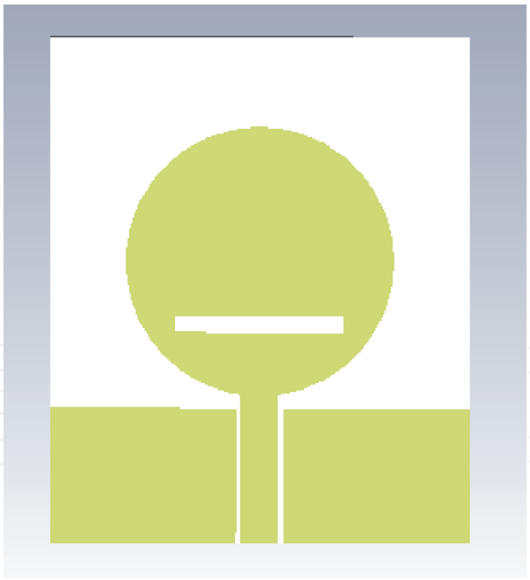

Figure 7.
Antenna geometry.

Parameters	r	l_m	w_m	t_m	lg	u	s	v	g	k
mm	8	9	2.25	0.035	8	1	10	4	0.27	5

Table 3.
The dimensions of the circular miniature printed antenna.

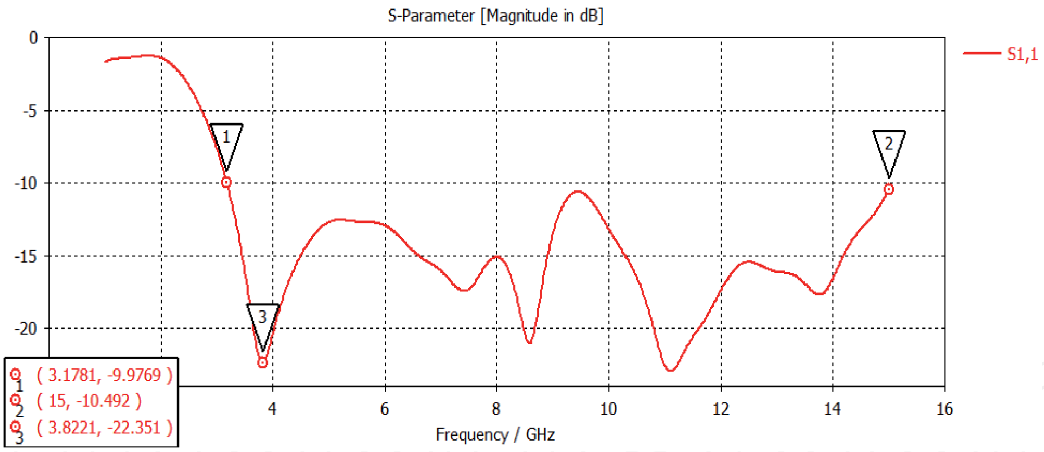

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Figure 8.
Return loss of circular miniature printed antenna.

3.1.2.2 Antenna gain

Figure 9 gives us the variation of the gain of our antenna as a function of the frequency. It happens to be between 2 and 4.87 dBi on the frequency band which interests us, which is 3.1–10.6 GHz. This limitation of the gain could be improved by a possible networking of antennas [16].

3.1.2.3 Radiation diagram

The 3D radiation pattern at the 8 GHz frequency. We can say that the radiation is focused on both sides of the antenna. At the frequency f = 8 GHz the gain of antenna is 4.28 dBi (**Figure 10**) and a directivity of antenna is 4.87 dBi (**Figure 11**).

Figures 12 and **13** show the far-field gain and far-field directivity in plane E. For both the opening of the main lobe at -3 dB for the frequency 8 GHz is 66.9° [16, 17].

3.1.3 Parametric study

We are going to play on three parameters, to see its effect on the behavior of this antenna.

- The parameter effect r (RO) (the radius of the radiating part) on coefficient S_{11} (**Figure 14**) and gain (**Figure 15**):

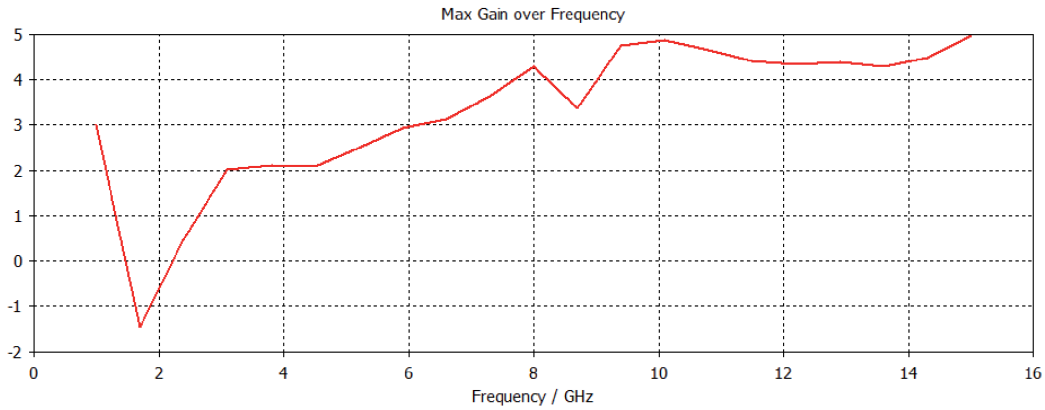
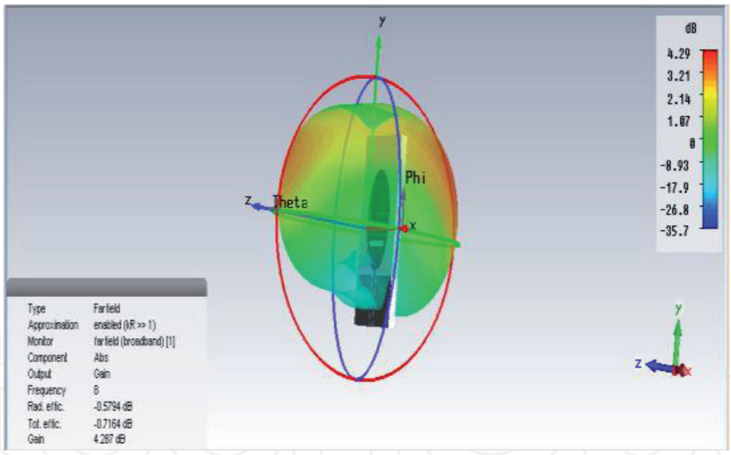
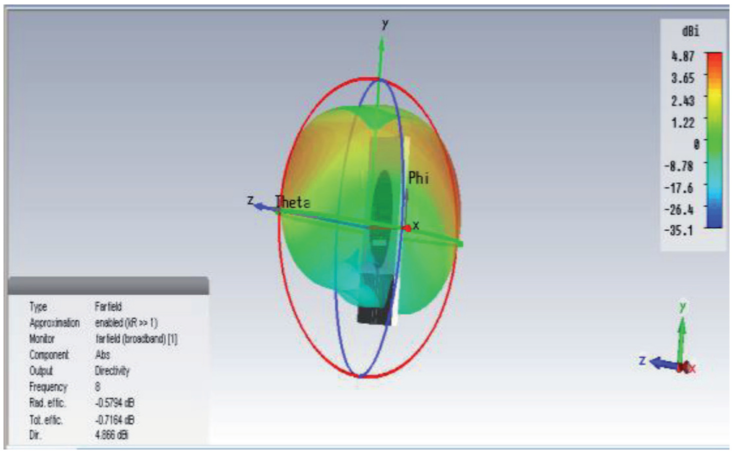


Figure 9.
Gain diagram of circular patch antenna.



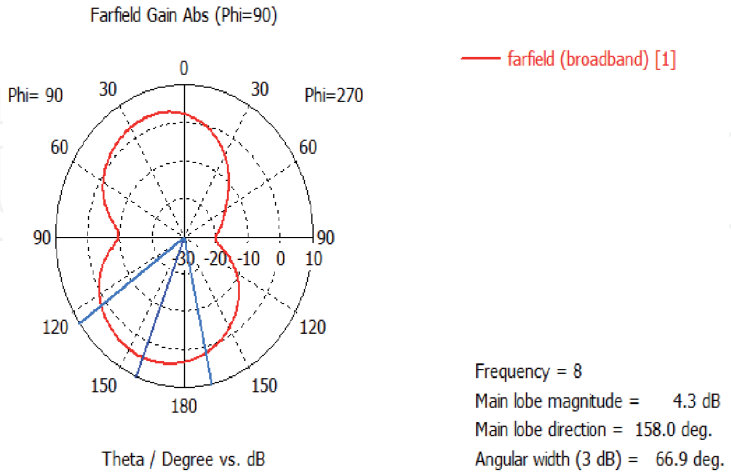
Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (broadband) [1]
Component	Abs
Output	Gain
Frequency	8
Rad. effic.	-0.5794 dB
Tot. effic.	-0.7164 dB
Gain	4.287 dB

Figure 10.
Gain diagram (3D) of circular patch antenna.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (broadband) [1]
Component	Abs
Output	Directivity
Frequency	8
Rad. effic.	-0.5794 dB
Tot. effic.	-0.7164 dB
Dir.	4.866 dBi

Figure 11.
Directivity diagram (3D).



Frequency = 8
Main lobe magnitude = 4.3 dB
Main lobe direction = 158.0 deg.
Angular width (3 dB) = 66.9 deg.

Figure 12.
Far-field gain (2D) of circular miniature printed antenna.

S_{11} parameter:
Gain:

- The parameter effect l_g (length of the ground plane) on coefficient S_{11} (**Figure 16**) and gain (**Figure 17**):

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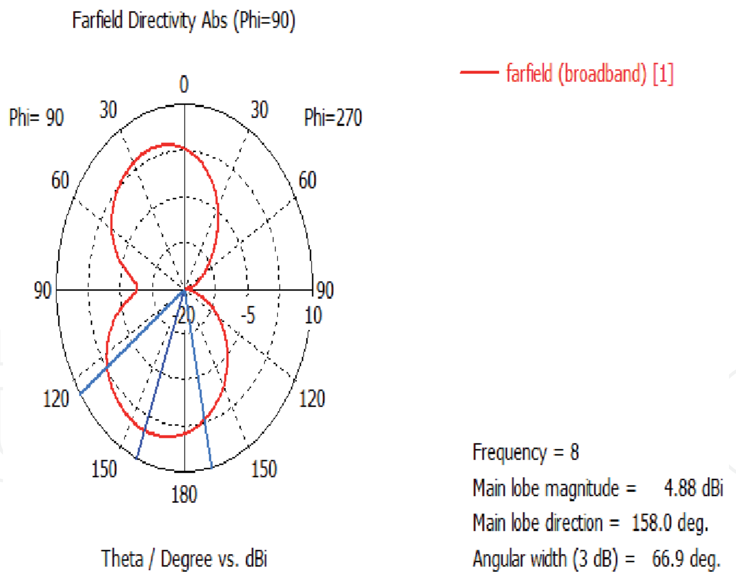


Figure 13.
Far-field directionality (2D).

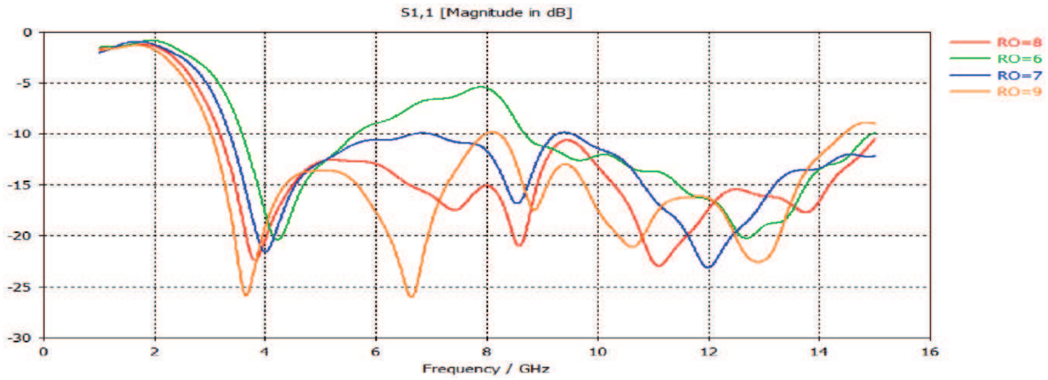


Figure 14.
Return loss with effect of the antenna radius.

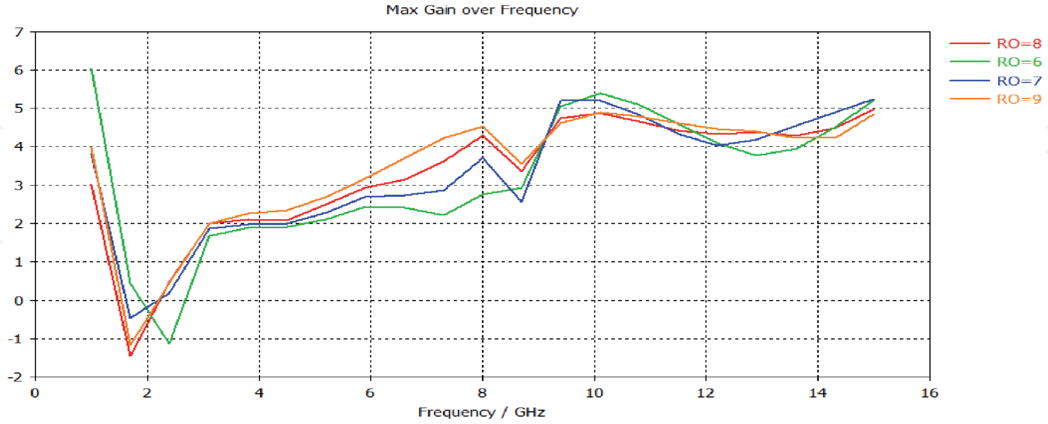


Figure 15.
Gain diagram with effect of the antenna radius.

S_{11} parameter:
Gain:

- The parameter effect v (slot location) on coefficient S_{11} (**Figure 18**) and gain (**Figure 19**):

S_{11} parameter:
Gain:

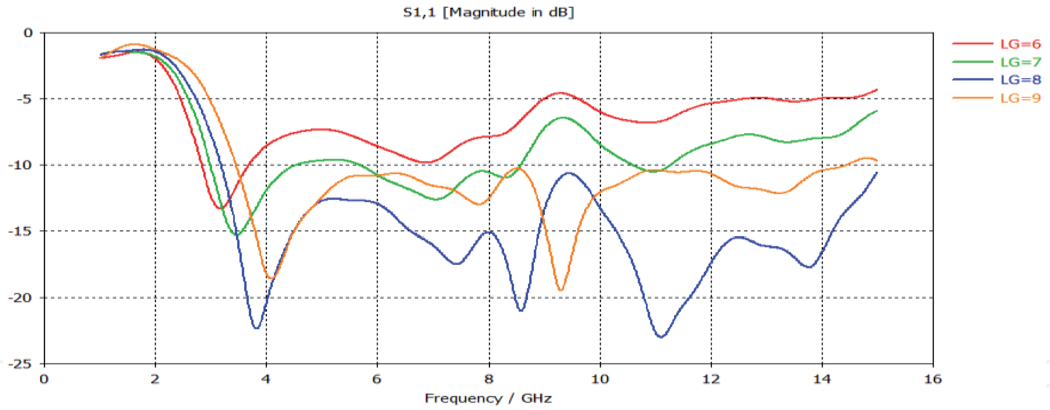


Figure 16.
Return loss with effect of the length of the antenna ground plane.

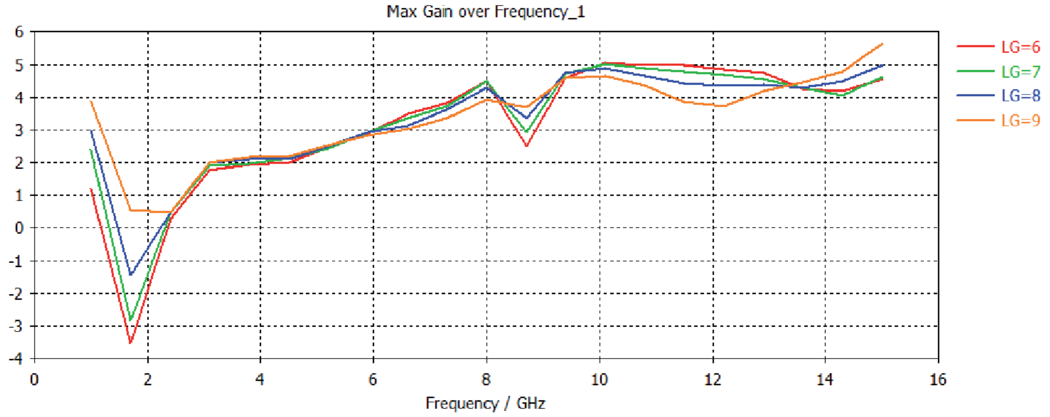


Figure 17.
Gain diagram with effect of length of the antenna ground plane.

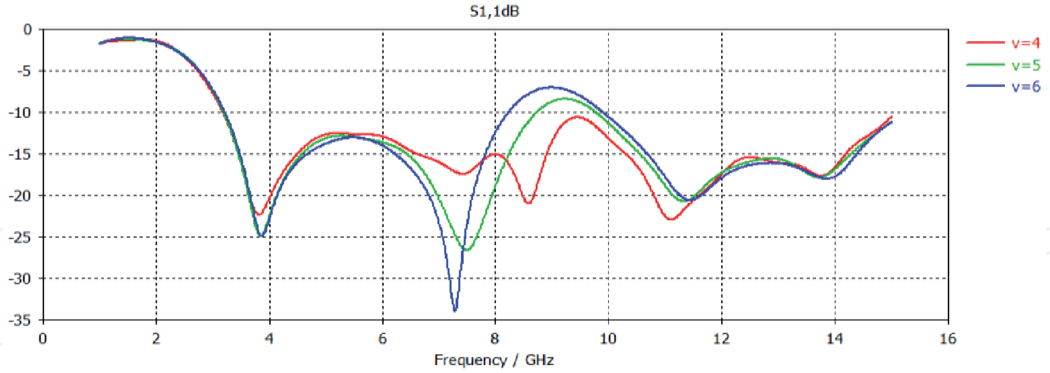


Figure 18.
Return loss with effect of the antenna slot location.

3.2 Design of array of circular miniature printed antenna

3.2.1 Antenna array geometry

We are going to make our antenna network (**Figure 20**) from the previous antenna with some modifications in terms of the parameters and its values in order to have the desired results (**Table 4**).

3.2.2 Simulation results

S11 parameter:

In **Figure 21,** we see that the coefficient S_{11} is of the order of −42 dB for a resonant frequency of 6.08 GHz, we obtained exactly the bandwidth that interests us, which is [2.7 10.6 GHz] [18].

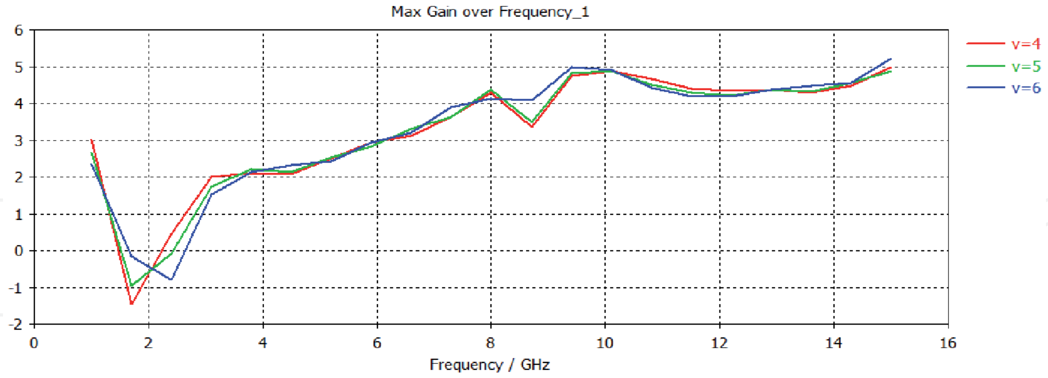


Figure 19.
Gain diagram with effect of the antenna slot location.

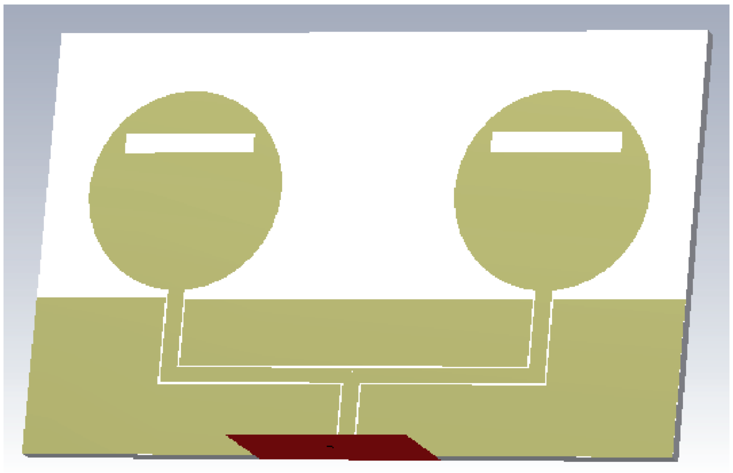


Figure 20.
Antenna array structure.

Parameter	r	L_m	w_m	t_m	lg	w_p	lp	s	u	v	g	k
mm	9	7	1.5	0.035	6	4	9	12	1.8	13	0.18	5

Table 4.
Dimensions of the array antenna.

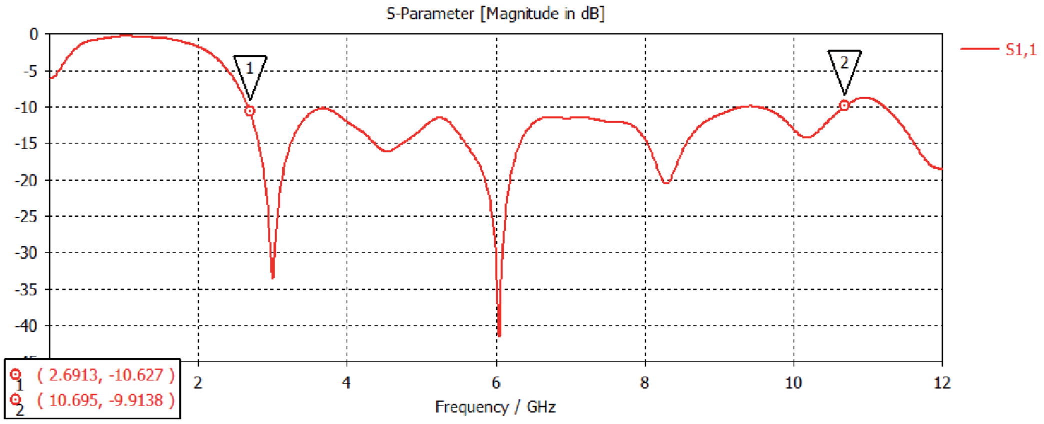


Figure 21.
Return loss of array antenna.

Gain:

Figure 22 gives us the variation of the gain of our antenna as a function of the frequency. Note that the gain has increased to 7.6 dBi on the frequency band [3.1–10.6 GHz]. This networking of antennas has allowed us to increase the gain [19].

At the frequency of 6.14 Hz in **Figure 23** (Gain Diagram) and **Figure 24** (Directivity Diagram), we can say that the radiation is focused on both sides of the

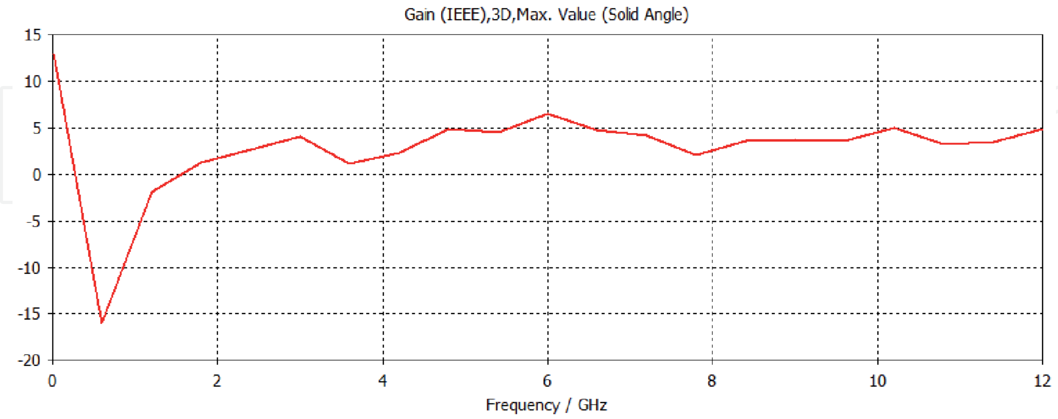
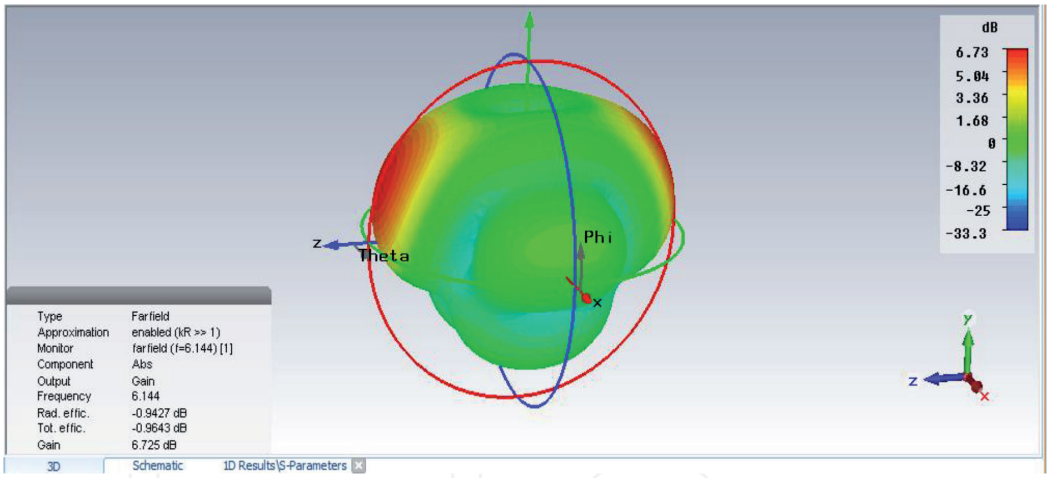


Figure 22.
Gain diagram of array antenna.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=6.144) [1]
Component	Abs
Output	Gain
Frequency	6.144
Rad. effic.	-0.9427 dB
Tot. effic.	-0.9643 dB
Gain	6.725 dB

Figure 23.
Gain diagram of array antenna.

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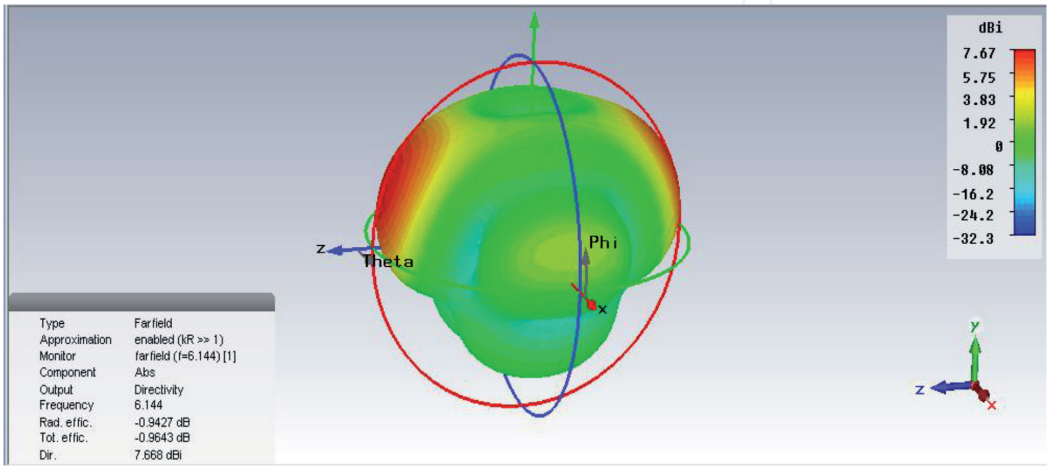


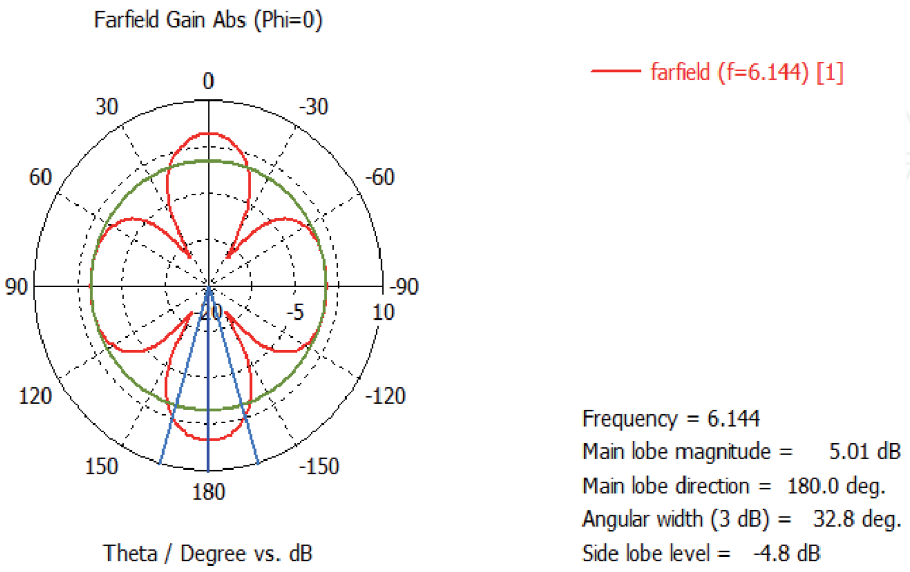
Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=6.144) [1]
Component	Abs
Output	Directivity
Frequency	6.144
Rad. effic.	-0.9427 dB
Tot. effic.	-0.9643 dB
Dir.	7.668 dBi

Figure 24.
Directivity diagram.

antenna but this time we have side lobes. With a gain of 6.7 dBi and a directivity of 7.6 dBi at f = 6.14 [20, 21].

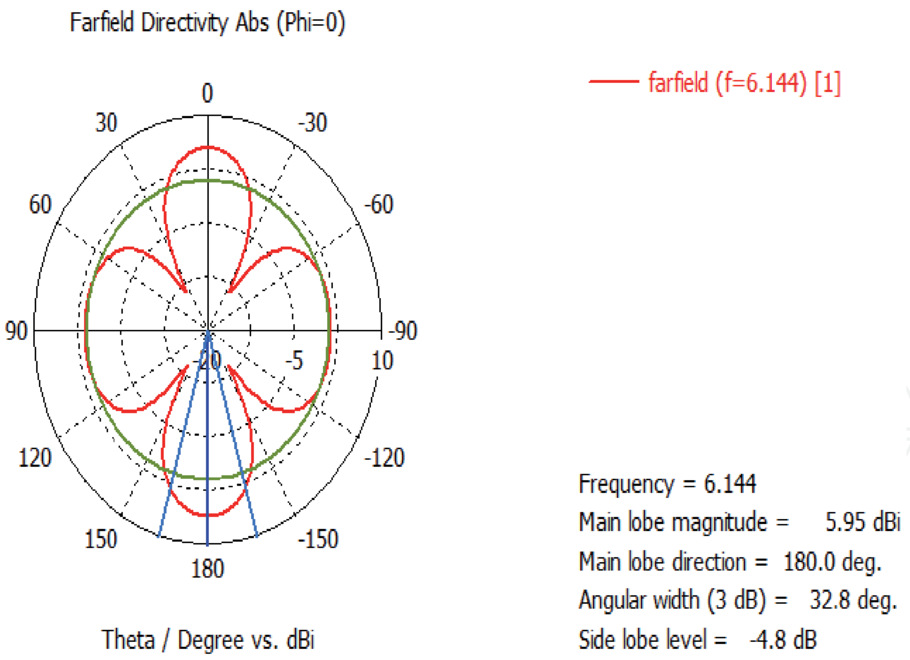
Radiation diagram:

Figures 25 and **26** show respectively the far-field gain and far-field directivity in plane E. The opening of the main lobe at -3 dB for the frequency 6.14 GHz is 32.8° [22–25].



Frequency = 6.144
Main lobe magnitude = 5.01 dB
Main lobe direction = 180.0 deg.
Angular width (3 dB) = 32.8 deg.
Side lobe level = -4.8 dB

Figure 25.
Farfield gain.



Frequency = 6.144
Main lobe magnitude = 5.95 dBi
Main lobe direction = 180.0 deg.
Angular width (3 dB) = 32.8 deg.
Side lobe level = -4.8 dB

Figure 26.
Farfield directivity.

4. Conclusion

In the first part of this chapter, the new coplanar antenna with cutouts on a circular patch demonstrate advantages: larger frequency spectrum, a good VSWR, improved parameter S11. The geometry of the patch was calculated and design with CST microwave studio. The antenna was design for UWB application more likely the microwave imaging in the range from 3.1 GHz to 10.6 GHz. Moreover the antennas are smaller than traditional antennas, and as a coplanar it can be easy to implement. Also, enhancing gain will be a good improvement by making this antenna in an array due to its small size.

In the second part of this chapter, we proposed a miniature circular patch antenna intended for an application in medical imaging.

The antenna network satisfies the imposed requirements satisfactorily and exhibits ultra broadband (ULB) behavior. In fact, the simulations under CST resulted in a reflection coefficient at −10 dB between 2.6 GHz and 10.7 GHz.

We have shown by this study that the dimensions and shape of the ground plane could have a significant impact on the bandwidth of the structure.

Future work includes the fabrication of a prototype of the antenna, as well as measurements in anechoic chamber to verify the agreement between the measured and simulated results.

Due to the complexity of each human tissue, our antenna should be tested in different parts of the body to determine is the optimum distance of 20 mm is valid wherever the antenna is placed within the body. The implementation of an array of antennas will be also evaluated in future studies.

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