Miniaturized UWB Microstrip Antenna for Microwave Imaging

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Abstract: - This article presents the design of a miniaturized microstrip antenna for microwave medical imaging applications. We propose a miniature rectangular printed antenna that meets the UWB characteristics in terms of bandwidth and reflection coefficient. This antenna is designed for a system to detect malignant tumors by microwave imaging. We use certain techniques of miniaturization and expansion of bandwidth in order to achieve our intention. The antenna has an ordinary rectangular radiating patch, therefore displays a good omnidirectional radiation pattern. The proposed antenna exhibits good UWB characteristics and has the capability of operating from 2.68GHz to 12.06GHz.

Keywords:- UWB, microstrip antenna, miniaturized, microwave medical imaging

1. Introduction

Ultra Wideband Radio is a potentially revolutionary approach to wireless communication. The advances in ultra wideband (UWB) systems and applications are progressing at a rapid rate. Microwave Ultra-Wide Band imaging is currently a very promising technology for wireless communications son very high speed, high precision radars and imaging systems [1]. This application involves transmitting UWB signals through the breast tissue and records the received signals from different locations.

Since the acceptance of unlicensed use of the UWB technology in the range between 3.1GHz and 10.6GHz in the USA (FCC, 2002) and more recently between 3.4GHz and 8.5GHz in Europe (ETSI, 2008), the realization of low-cost UWB wireless systems is considered a fundamental research goal both for military and commercial applications [2-3]. The commission has established some regulations regarding the frequency bands and transmission power limits allocated to different UWB applications. UWB is defined as any wireless scheme that occupies either a fractional bandwidth greater than 20% or more than 500MHz of absolute bandwidth [4].However, for radar systems, such as a UWB microwave imaging system for detection of tumor in woman's breast, a moderate gain directional antenna is advantageous [5].The use of UWB signals in microwave imaging applications in addition to wireless communications requires suitable antennas as transducers between UWB transceivers and the propagating medium. One of the major challenges in antenna technology is the design of ultra wideband compact omnidirectional antenna with constant gain and minimum group delay [6]. The microstrip antennas seem to be ideal candidates and are frequently encountered in UWB applications, including medical imaging. This is due to their low profile, low cost and ease of integration [7].

This paper focuses on designing an ultra-wideband microstrip antenna for Microwave Imaging System applications. This UWB structure will be included in a system for detecting breast cancer. The microstrip antenna that we propose is miniaturized rectangular shape and has desirable performance for UWB antennas. The interest is to achieve increased bandwidth. The reduction in size is also a consideration to be taken into account in the design of this antenna, which would be more easily integrated into the system and reduce clutter. For this some techniques are used [8-11]. Among these techniques, we will use the technique of slots at the radiating element [12]. The use of a partial ground plane promotes the enlargement of the bandwidth [13]. Insert a notch in the partial ground plane can also have a significant effect on the performance of our antenna [14-15].

The proposed antenna is simulated with HFSS and CST software's and satisfies the VSWR<2

requirement from 2.68GHz to 12.06GHz. The designed antenna has a simple configuration with an ordinary square radiating patch and small size.

2. Rectangular microstrip patch antenna

Before designing a rectangular microstrip patch antenna, there are several parameters needed to be considered which will affect the antenna bandwidth as well as the resonant frequency [16].
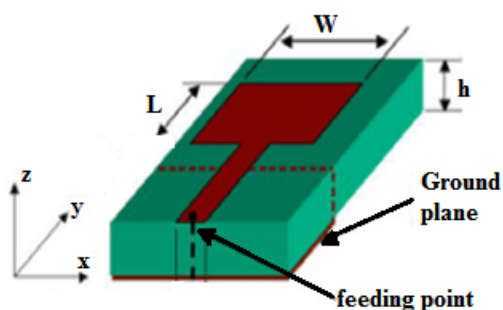
2.1 Patch Length & Width

Fig.1. Geometry of the patch antenna

The shape of the patch is its main parameter and naturally affects most of the antenna characteristics. However, the patch width has a minor effect on the resonant frequency and radiation pattern of the antenna. So a larger patch width increases the power radiated and thus gives decreased resonant resistance, increased bandwidth and increased radiation efficiency. The patch width should be selected to obtain good radiation efficiency if real state requirements or grating lobe are not overriding factors. It has been suggested for patch dimension that $1 < W/L < 2$ [17]. The patch length determines the resonant frequency, and it is critical parameter in the design, however the patch length L for TM_{10} mode is given by:

$$L = \frac{C}{2f_r\sqrt{\varepsilon_r}} \qquad (1)$$

Where f_r is the resonant frequency.

2.2 Fringing Effect

To account for the fringing effect, an effective dielectric constant ε_{reff} is used. The effective dielectric constant is defined as the dielectric constant of the uniform dielectric material so that:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{w}\right)^{-\frac{1}{2}} \qquad \frac{w}{h}\geq1 \qquad (2)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{w}\right)^{-\frac{1}{2}} + 0.041\left[1-\sqrt{\frac{w}{h}}\right] \qquad \frac{w}{h}\leq1 \qquad (3)$$

2.3 Length and Width

Due to fringing effect, electrically the patch dimensions will be bigger than its physical dimensions. A practical approximate formula to calculate the width and length is shown below. The following equation is used to calculate the width W:

$$W = \frac{C}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \qquad (4)$$

Where f_r is the resonant frequency, c is the free-space velocity of light (c = 3.10^8 m/s) and ε_r is the dielectric constant of substrate. To determine the length (L) of the patch, the following equation is used:

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\varepsilon_0\mu_0}} - 2\Delta L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \qquad (5)$$

Normalized extension of the length ΔL is:

$$\Delta L = 0.412h\frac{\left(\varepsilon_{reff}+0.3\right)\left(\frac{w}{h}+0.364\right)}{\left(\varepsilon_{reff}+0.258\right)\left(\frac{w}{h}+0.8\right)} \qquad (6)$$

3. Principle of MRI

The imaging technique of microwave used in the distribution of signals from an object, when it is illuminated by an electromagnetic signal. The signal broadcast by an object depends on several factors, including the environment, the signal strength, and material properties [18-19].
For a source data signal, the broadcast signal depends on electrical characteristics of the equipment, particularly the dielectric constant and conductivity. This principle is used to detect tumors in the breast using microwave signals.
Breast tumors have very different electrical properties (high dielectric permittivity and higher conductivity), which can be detected by analyzing the broadcast signals [20]. As shown

in Figure 2, the amount of signal transmitted from a breast tumor is higher than that of normal breast tissue. It may be well received by an antenna localized or modification of these emission properties due to broadcast signals can be analyzed and used for the detection of tumors.
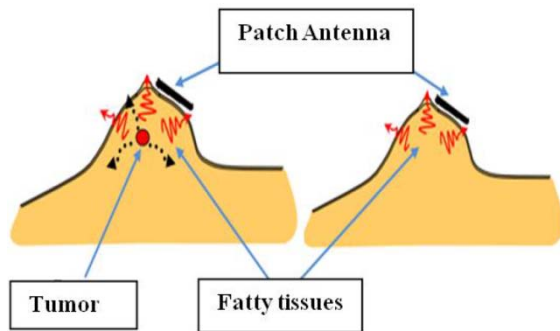

Fig.2. Schematic representing breast, patch antenna and tumor showing signal broadcasting. (a) With breast tumor. (b) Normal breast.

The principle of our study is the detection of breast cancer. We examine the ability to detect tumors by a UWB microstrip antenna operating at a large frequency band. This antenna can be placed in contact with breast in order to give us a clear insight for the concept studied.

4. Model and geometry of the antenna

Figure 3 illustrates the top and bottom views of the geometry of the studied antenna. The antenna is a rectangular patch that has undergone a number of changes in order to overcome the limitation of narrow bandwidth at the origin. The patch is formed on a substrate of FR4_EPOXY (Dielectric permittivity ε_r=4.4, thickness h=1.58mm). Antenna feeding is performed by microstrip line in order to adapt to 50Ω.
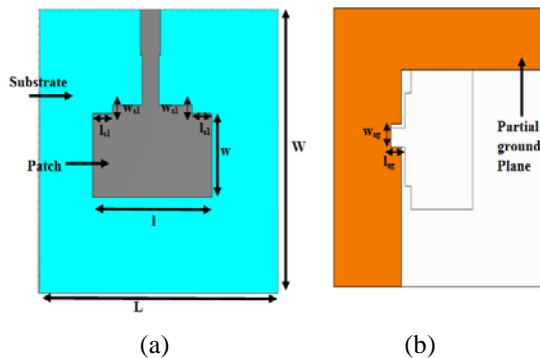

(a) (b)
Fig.3. Antenna Geometry (a) Top view
(b) Bottom view

A simple and effective method by cutting slots in the radiating element and in the partial ground plane under the feed line has been proposed and studied. The number of slots with their dimensions of the length and the width at the entrance of the patch were also discussed using software simulation, in order to obtain a better adaptation. A partial ground plane, which was inserted a slot, is printed on the bottom surface of the substrate. The length and the width of the slot were optimized. All the optimal dimensions of this proposed rectangular patch antenna are listed in table1.

The structure as shown in figure 4 is simulated in HFSS whose numerical analysis is based on the finite element method (FEM). Parametric study has been conducted to optimize the design of the antenna.
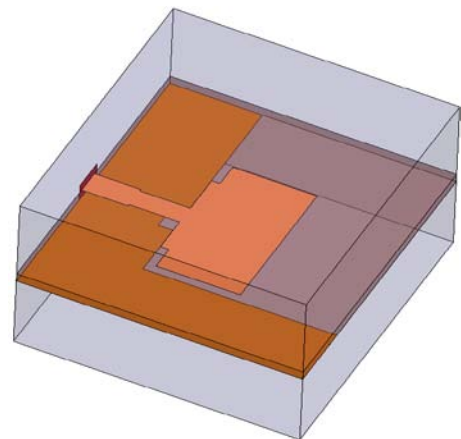

Fig.4. Schematic of the antenna

Table 1. The optimal dimensions of the proposed antenna

ELEMENTS	DIMENSIONS
Substrate	L=36mm ; W=34mm
Patch	l=18mm ; w=11mm
Slots	l_{s1}=3mm ; w_{s1}=1mm
Slot_ground plane	L_{sg}=1.75mm ; w_{sg}=3mm

5. Results and discussions

Figure 5 shows the reflection coefficient of this antenna according to the frequency. The first point is to evaluate the effect of the ground plane on the enlargement of the bandwidth. As shown in figure 5, a partial ground plane allowed us to expand the bandwidth, narrow at the origin, with a full ground plane. The partial ground plane with slot shows better return loss compared to full ground plane on the bottom. The results of simulation show that a slot in ground plane with

proper dimensions placed under the feed line allowed us to increase the bandwidth without affecting much the performance of the antenna.
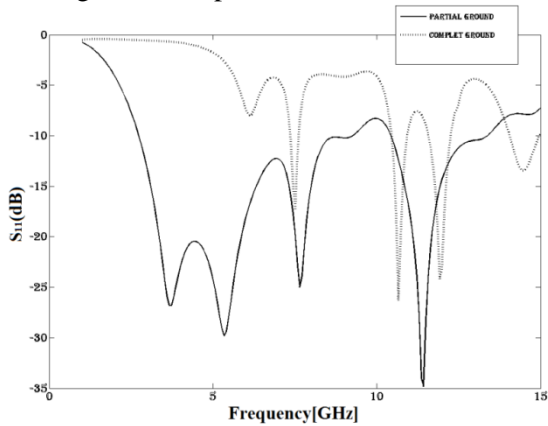

Fig.5. Comparison between the reflection coefficients S_{11} against frequency

Thereafter, we will make an optimization of the dimensions (length, width) of the slot inserted in the partial ground plane, which also allowed us to expand bandwidth and have more resonance frequencies.
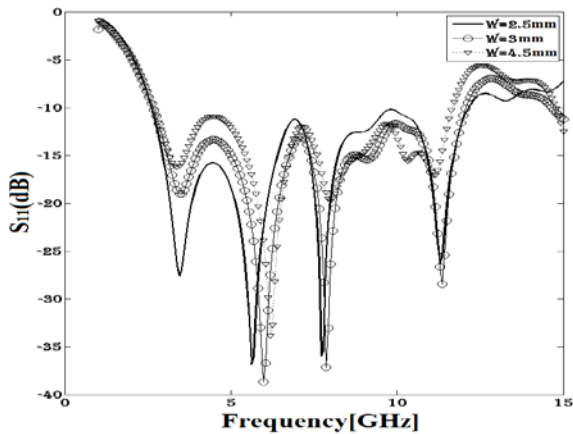

Fig.6. Simulated reflection coefficient for the proposed antenna with various widths in slot of ground plane

The figure 6 shows the variation of the S_{11} parameters as a function of the width of the slot in ground plane. Note that the variation of the width (w_{sg}) between 2.5mm and 4.5mm provides a shift of S_{11} parameter as shown in the figure below.
The antenna is able to operate as a UWB antenna. The reflection coefficient of the antenna improves noticeably when the width of slot ground increases gradually. However, it is observed that the best result is obtained at the width of 3mm.
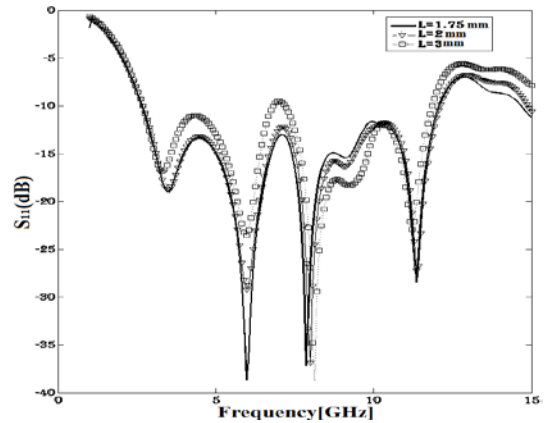

Fig.7. Simulated reflection coefficient for the proposed antenna with various lengths in slot of ground plane

The figure 7 shows the variation of the S_{11} parameters as a function of the length of the slot in ground plane. Note that the variation of the length (l_{sg}) between 1.75mm to 3mm gives a shift of S_{11} parameter as shown in the figure below. The antenna is able to operate as a UWB antenna. The reflection coefficient of the antenna improves noticeably when the length of slot ground plane reduces gradually. However, it is observed that the best result is obtained at the length of 1.75mm.
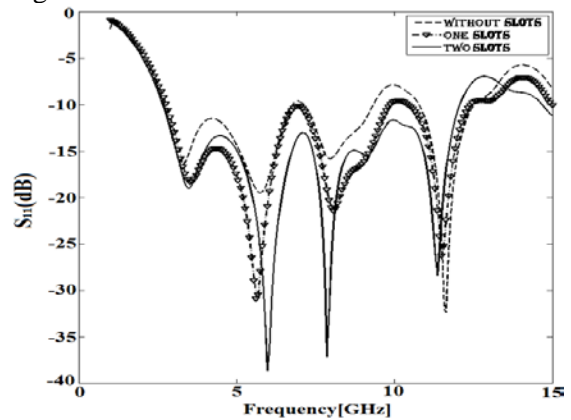

Fig.8. Simulated reflection coefficient for the proposed antenna as a function of numbers of the slots in the patch

In the second axis, we will study the importance of technical insertions of slots in the radiating element on the performance of our antenna. We compare this result to the case of a one slot and two slots in the patch and without slots as shown in figure 8. We thus show the influence of these parameters on the behavior of the structure. Bandwidth narrow for a patch without slots increase noticeably when we insert the first slot and considerably when we insert the second slot, we note also an increase in the level of S_{11}.

We can conclude that the presence of the slots in the partial ground plane and in the radiating element allowed us to greatly expand the frequency band and the level of S_{11} and hence get a better structure UWB.

Figure 9 shows the final result of S_{11} accorded to final structure of our antenna after optimization of various parameters that allow us to expand the bandwidth, with two slots in the patch and slot in the partial ground plane with length of 1.75mm and width of 3mm.This result shows the presence of resonance frequencies at 3.45GHz, 5.97GHz, 7.86GHz and 11.36GHz with a maximum level of S_{11} parameter at -38.7dB. Bandwidth measured at -10dB ranges from 2.68GHz to 12.06GHz, presenting a width of 9.38GHz.
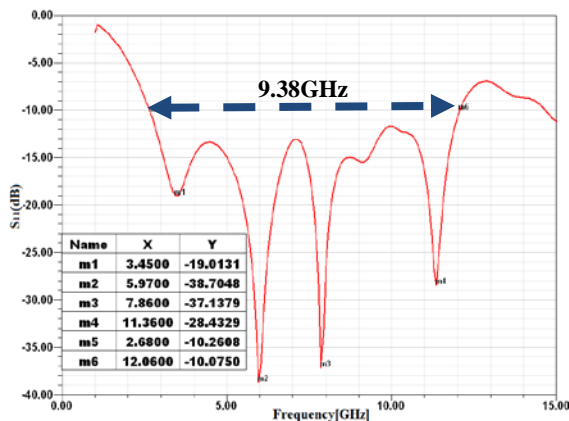

Fig.9.   Simulated reflection coefficient S_{11} against frequency

The figure 10 presents the proposed antenna gain. The maximum value obtained is approximately 6.48dB. The peak gain decreases slightly from 1GHz to 5GHz before returning to growth from 5GHz to 9GHz.
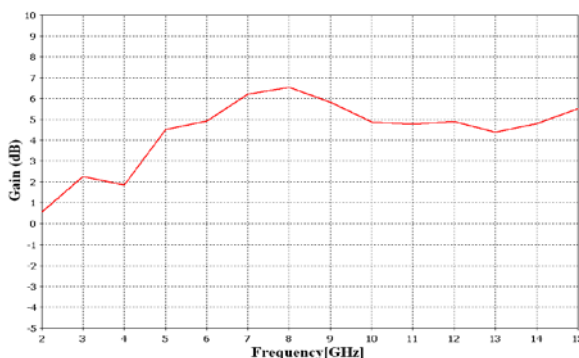

Fig.10.   Gain in dB against frequency

Figure 11 shows the variation of voltage standing wave ratio of the antenna according to the frequency. We observe that the value of VSWR in the band is less than the value 2,

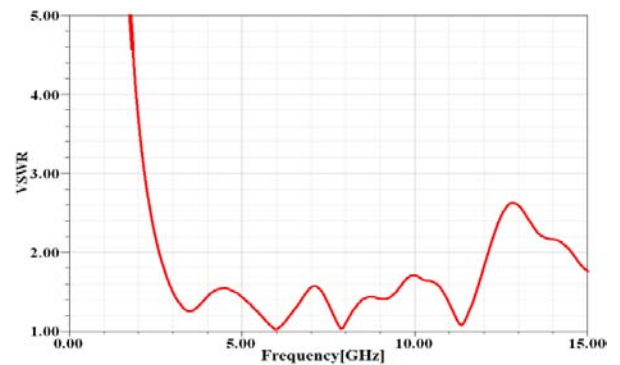which is sufficient to cover the band allocated by the FCC.

Fig.11.   Variation of the VSWR against frequency

To validate our use of design software HFSS, we designed and simulated the same structure as CST whose numerical analysis is based on the method of finite integration technique (FIT).

Figure 12 illustrates the reflection coefficient and VSWR obtained by both simulation tools for the optimized structure of the antenna with two slots in the patch and slot in the partial ground plane with length of 1.75mm and width of 3mm. We note a good agreement between the simulated results. There is a slight difference if we consider the resonant frequency, that is, in terms of bandwidth results are very comparable. As shown in table 2.
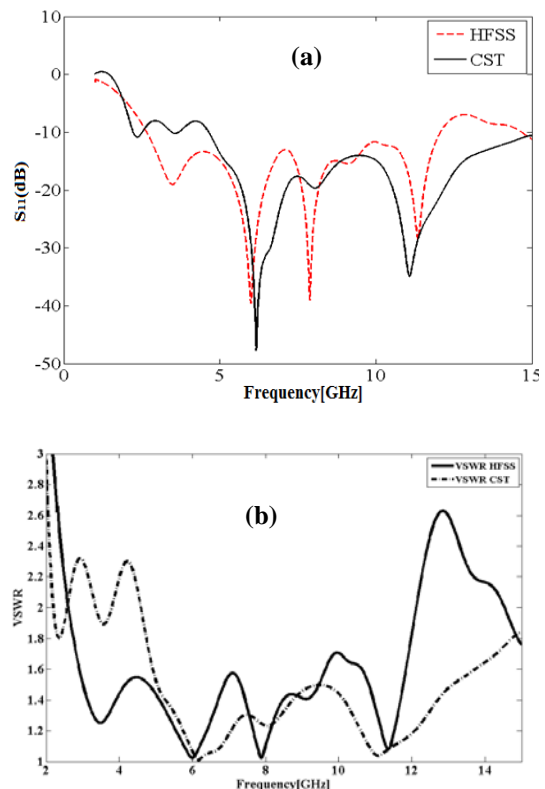

Fig.12.   (a) S_{11} comparison between CST and HFSS
(b) VSWR comparison between CST and HFSS

Table 2. Comparison results between CST and HFSS

	Bandwidth	Resonant frequencies	VSWR
HFSS	2.68GHz-12.06GHz (9.38GHz)	3.45GHz (-19.01dB) 5.97GHz (-38.7dB) 7.86GHz (-37.13dB) 11.36GHz (-28.43dB)	< 2
CST	4.6GHz-15GHz (10.4GHz)	6.18GHz (-47.6dB) 110.9GHz (-35.02dB)	< 2

The radiation pattern of the antenna, characterized the variation of the radiation intensity at large distance in the different directions of space. To show the radiation from our antenna, we illustrate in figure 13 the radiation pattern in 3D at frequency of 4GHz and 8GHz. We can say that the radiation is focused on both sides of the antenna.
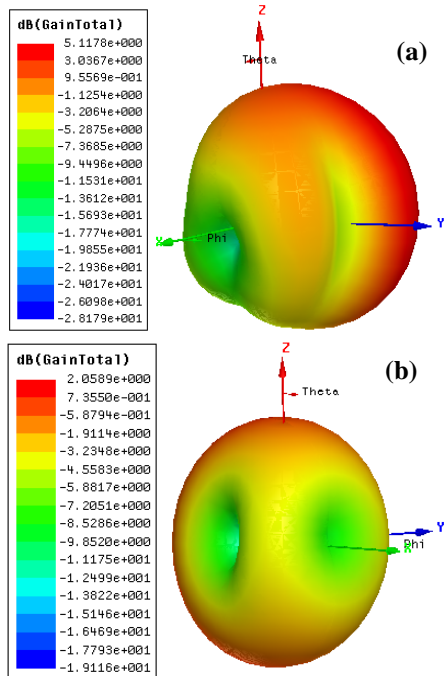

Fig.13.   3D radiation pattern at   a) 8GHz   b) 4GHz

Figure 14 shows the simulated two dimensional radiation patterns (E-plane, H-plane) of the antenna at four frequencies 4GHz, 5GHz, 8.35GHz and 10.1GHz. In the E-plane, the value of azimuth angle φ of 0° and 90° and in H-plane, the value of elevation angle θ of 0° and 90° are taken into consideration.
The radiation is symmetric and bidirectional. The radiation is relatively stable across the frequency band coveted. Also, an omnidirectional, more or less stable behavior can be seen on the whole frequency band.

Like most UWB planar structures, our antenna behaves like a dipole in viewpoint of radiation (bidirectional in a main plane and omnidirectional in the other) with a gain relatively good and which can be improved by any networking of our antenna.
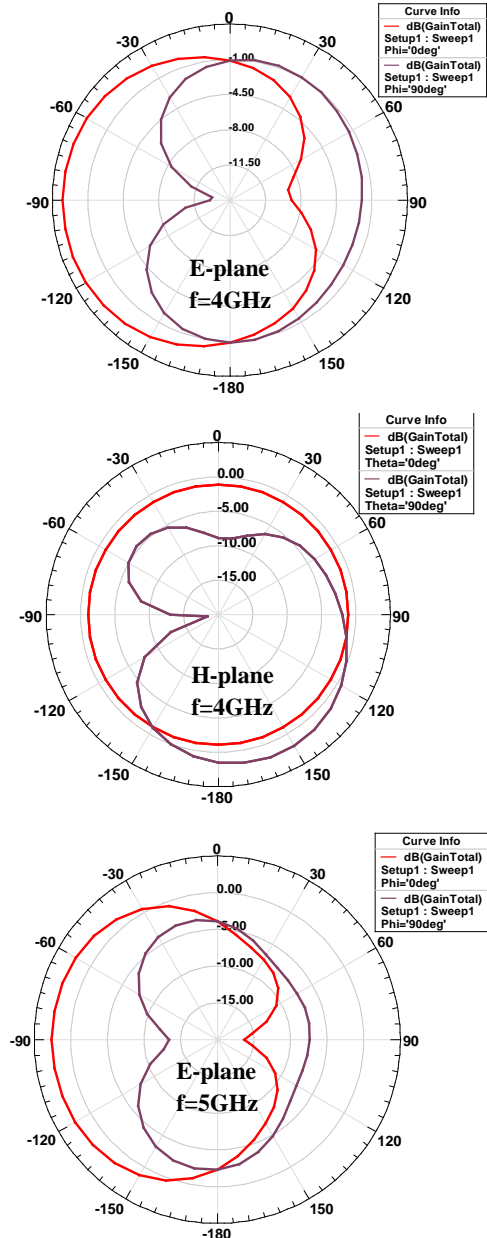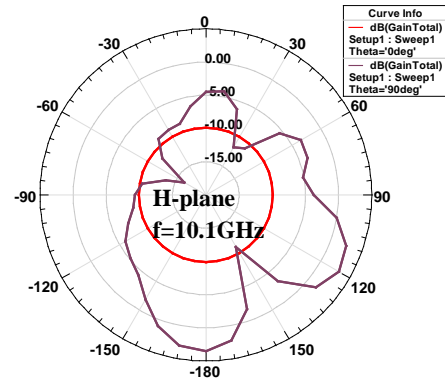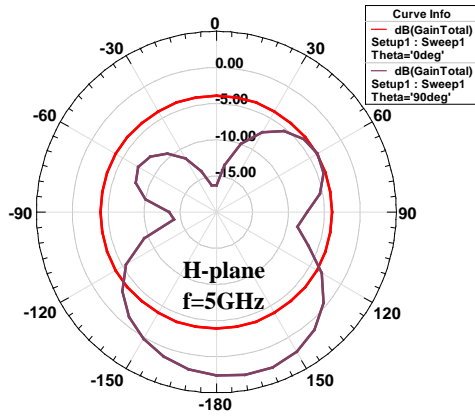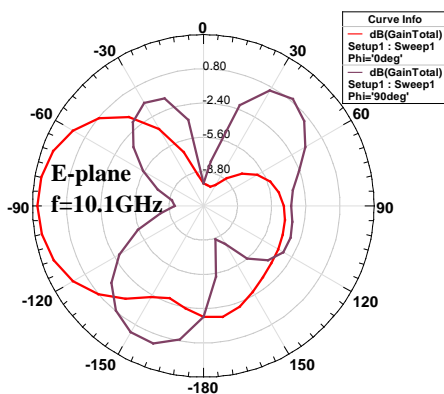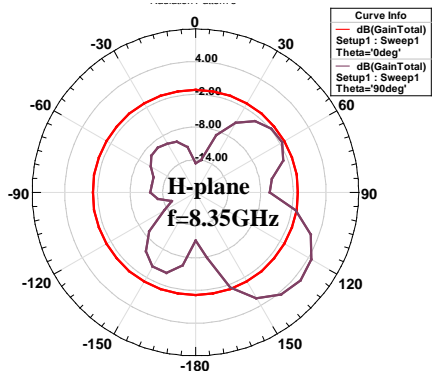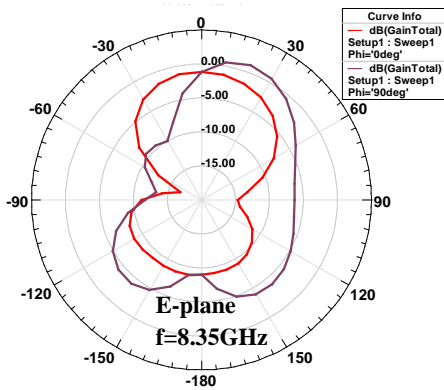
Fig.14.   Simulated radiation patterns of the UWB
patch antenna

6. CONCLUSION

In this paper, a miniature microstrip UWB antenna for application in medical imaging is proposed. The antenna satisfactorily meets the requirements and has an UWB attitude. Indeed, the simulated results show that the antenna has a reflection coefficient of -10dB from 2.68GHz to 12.06GHz in HFSS software and from 4.6GHz to 15GHz in CST with all desired UWB radiation characteristics.

We have demonstrated in this study that the size and shape of the ground plane could have a significant impact on the bandwidth of the antenna. It is the presence of a slot in this ground plane. A good adaptation is obtained between the antenna and its feeding through gradual transition through slots. The radiation of this antenna was analyzed. It has good stability over the entire frequency band coveted and that in the two principal planes E and H. The gain is good and suitable for our intended application. Due to its excellent characteristics like single layer, small size and large bandwidth, this simple, miniaturized antenna structure might be a good application for a system of detection of malignant tumors by microwave imaging.

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