# Highly Directional Microstrip Ultra Wide Band Antenna for Microwave Imaging System

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## Abstract

This paper presents a novel highly directive ultra-wide band antenna for using in microwave imaging systems. Defected Ground Structure (DGS) is incorporated in the top and side of the ground plane to enhance the bandwidth impedance matching. Subsequently, for the further improvement in the bandwidth, gain and directivity staircase slot and square slot is etched at the bottom and top edge of the square patch plane. The low-frequency performance of the proposed antenna can be achieved by adjusting the gap between the ground and patch plane. The proposed microstrip antenna is fabricated on a Flame Retardant (FR4) plate of laminate substrate with dielectric constant of 4.3. The result shows that a directivity of 2.2-8.4dBi is achieved across a bandwidth from 1.43-8.92GHz. Furthermore, gain, directivity, radiation pattern characteristic and reflection coefficient have also been analyzed at the different resonant frequency.

**Keywords:** Microstrip antenna, microwave imaging systems, ultra-wideband.

## 1. Introduction

Nowadays, microwave imaging system is largely applied for medical imaging applications like breast cancer detection, lung cancer detection, detect the damaged brain tissue and brain tumor detection etc. [1-5]. Generally, this imaging system is assembled by a planar rectangular or circular cylindrical microwave antenna array for detecting tumor tissue. Usually, for microwave imaging application ultra-wideband signal is used which has high resolution and penetration characteristics.

In microwave imaging system, highly directional and ultra-wideband antennas are commonly used to transmit and receive the pulse. These pulses are transmitted into the breast tissues using a single antenna or array of antenna. The tumor is detected in the breast tissue on the basis of the considerable dielectric contrast between normal and malignant tissue. High scattering of electromagnetic signal produced in the tumor tissue due to the difference in the dielectric properties such as permittivity and conductivity.

Ultra-wideband (UWB) system can operate in very large bandwidth range by using the signals in short pulse duration. This very short pulse duration of the UWB signal makes it enhanced in spatial resolution and short-range competency. Thus when the signal is applied in radar-based microwave imaging application; the increase in bandwidth really allows the UWB radar imaging system to obtain more facts about the targets. The down-range resolution is associated to the wavelength of the pulse [6]. Usually, the UWB pulse is in 1 ns of pulse period, which is equal to 30cm of wavelength in free space, so that the down-range resolution is 15 cm. For traditional narrow band radar imaging system, the pulse duration is 1 μs, is equal to 300 m of wavelength in free space, therefore the down-rage resolution is 150m. Clearly, the reduction of the pulse duration increases the down-range resolution. In the meantime, if the wavelength of the pulse is larger than the size of the tumor, then the return signal will provide little information about the target [7-8].

There are two approaches for microwave image namely, microwave tomography [9] and radar-based microwave imaging [10-11]. In the radar-based technique, breast is illuminated by a microwave transmitter and the scattered waves are received by the receiver and then reconstructed into an image. In tomography, the received scattered waves are examined to reconstruct the permittivity distribution of the breast tissues. Absolutely in microwave imaging process, the antenna is the key part to radiate and receives signals to or from neighboring scattered objects.

A number of designs of ultra-wide band antenna have been proposed to image the breast tissue using microwave imaging systems [12-17]. T-slots are placed in the corner of the parabolic ground plane with an elliptical slot in the circular patch have been established for microwave breast cancer imaging [12]. A circular disc with L-shape ground plane is proposed for UWB microwave imaging system which has unidirectional radiation pattern [13]. Two semi-elliptical-ended arms with shorting bride configuration are proposed for microwave imaging system [14]. An exponentially tapered Vivaldi antenna with corrugations at the edges of the flaring unit is presented for cancer detection system [15]. Further, rotated E-shaped slot [16] and L-shaped slot [17] in the ground plane with square shaped radiating patch is presented for UWB breast cancer detection.

The above-reported microstrip antennas [12-17], demands for UWB microwave imaging systems have the bandwidth at high frequency (>3GHz) and also the directivity is not in the acceptable level.

Generally, in microwave imaging system, the resolution is improved for the high frequency of operation but penetration energy is reduced. Hence there exists a trade-off between the energy of penetration and resolution of the image. Therefore, to increase the penetration depth and to decrease the attenuation of the transmitted microwave wave signal, the designated antenna should have ultra-wideband. Likewise, to localize the tumor in the particular location high directional antenna is essential. High frequencies are highly essential for detecting the tumor at the skin level; whereas low frequencies are more effective in detecting the tumor at a deeper level [18, 19]. This motivates a new directional UWB antenna.

To improve the above constrictions, this paper introduces a new directional UWB antenna with staircase and square slot which is etched at the bottom and top edge of the square patch plane, that has a low frequency of operation 1.43GHz, with acceptable directivity, and easier to fabricate.

In section II, the configurations of the proposed antennas are discussed. In section III, simulation result such as reflection coefficient, gain, directivity, radiation pattern and current distribution is discussed. In section IV, measured result of the proposed antenna is discussed.

## 2. Antenna design

The antenna presented in this paper is to be used in a microwave breast imaging system, which may include a three-dimensional (3D) array of the proposed UWB antennas. In a multi-static configuration, each element of the array takes a turn to transmit a microwave signal while the rest of the elements receive the backscatter signals. This process is repeated until all antennas in the array have been used for transmission. Eventually, 3D or 2D images could be formed by analyzing the backscatter data [20, 21].

Fig. 1(a) shows the front view of the square antenna, with the slot of different dimensions in the top and bottom of the patch plane. Different efforts are made in the antenna configuration to improve the bandwidth. First, stair steps are made at the bottom of the radiating patch. Subsequently, square shaped slots are etched at the top of the patch plane. Secondly, to improve the return loss and widening the fringing fields, two slots of width 2.25mm is etched at the side of the ground plane as shown in fig.1 (b).To increase the bandwidth further a rectangular slot was engraved in the top of the ground plane with a length of 1mm and width of 10mm. The ground plane length is 25.7mm from the feed line.

The antenna is fabricated on an FR4 substrate with a relative permittivity of 4.3 and a thickness of 1.6 mm. The feed line has a width of 3.1 mm, which ensures that the antenna is matched to a 50 Ω impedance source. The complete size of the antenna is 63mm x 72mm x 1.6mm. The lower frequency of operation [22] is calculated using the following equation:

$$f_l = \frac{7.2}{2.25 * L + g} \quad (1)$$

Where, L is the length of the patch

g is the gap between patch and ground plane.

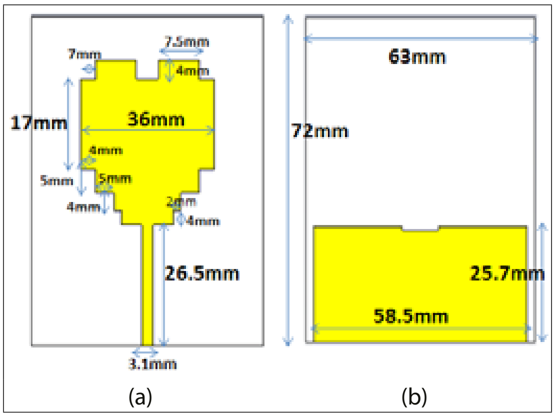


**Fig. 1 configuration (a) Top view (b) Bottom view**

To examine the different antenna properties such as the reflection coefficient, gain, directivity and radiation patterns, the software Computer Simulation Technology (CST) is employed. CST is a professional tool for the 3D electromagnetic simulations of high-frequency devices such as different types of antennas, resonator, filters, couplers, etc. Transient Solver is used to performing the analysis of the different antenna parameters.

## 3. Results and discussion

In the following section, the simulated properties of the proposed antenna such as reflection coefficient, gain, directivity, surface current and radiation pattern of the proposed antenna are explained in detail.

### *Reflection coefficient*

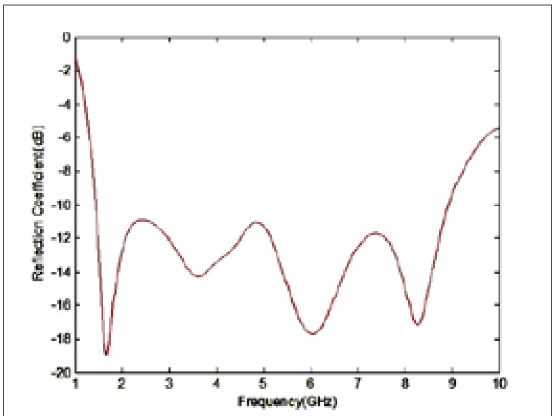


**Fig. 2 Simulated reflection coefficient curve of the proposed antenna**

The reflection coefficient characteristics of the proposed UWB directional antennas are shown in fig. 2. It is observed from the figure that the proposed antenna covers the bandwidth from 1.43GHz to 8.92GHz which indicates the better impedance matching between the transmission line and antenna.. It is observed that three different resonant frequencies occur at 1.67GHz, 6GHz, and 8.25GHz. It is observed that very low frequency (<1.5GHz) is obtained in the proposed antenna which is very useful for deep penetration in microwave imaging application.

### *Gain and Directivity*

The gain variation plot of the proposed antenna is shown in fig. 3. It is observed that the maximum gain 6.06dB occurs at 6.4GHz. The directivity of the proposed antenna with respect to frequency is shown in fig. 4. It is noticed that directivity increases as the frequency increases and the maximum directivity 8.37dB are obtained at a frequency of 9.8GHz.

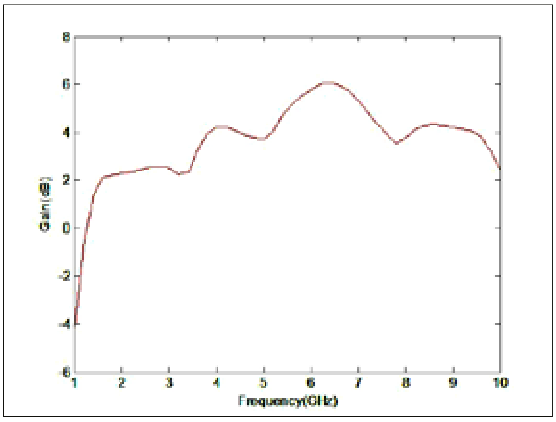


**Fig. 3 Simulated gain of the proposed antenna**

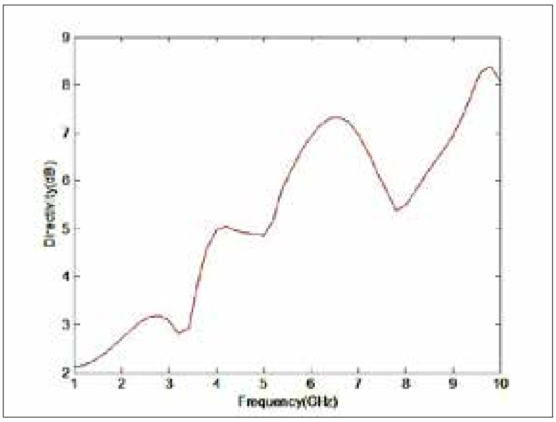


**Fig. 4 Simulated directivity of the proposed antenna**

### *Radiation pattern*

The simulated radiation patterns in x-z plane (H-plane) and x-y plane (E-plane) at different frequencies is shown in Fig. 5. The main aim of the radiation patterns is to illuminate the antenna actually radiates the electromagnetic signal over a wide range of frequency band.

In 3D Radiation Pattern, the entire field distribution with respect to a spherical coordinate system (x,y,z) is analyzed. Whereas in 2D Radiation Pattern, cutting a plane at the center evaluate the rectangular coordinate system. The H-plane radiation pattern is roughly in dumb-bell shape, whereas the pattern in the E-plane is butterfly as expected. As frequency is increased the main lobe is becoming more and more directive and it is narrower with an increase in the number of side lobes. The side lobes have increased in number with a corresponding decrease in their magnitude levels. The directions of the lobes also change with frequency, increasing in elevation.

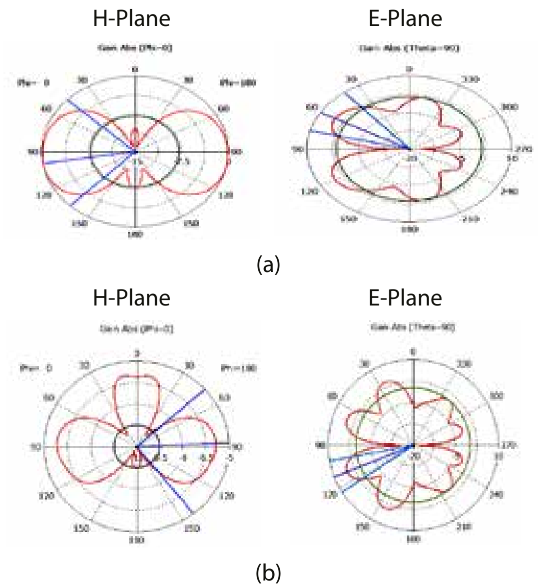


**Fig. 5 Simulated radiation pattern of antenna. (a) 5.5GHz and (b) 8GHz**

The 3-D radiation pattern of the modified square antenna structure is shown in Fig.6.It is noted that the antenna's behavior is same as an omnidirectional antenna in the frequency range below 3.4GHz. The 3-D radiation pattern at 1.4GHz and 2GHz is shown in fig. 6 (a) and fig. 6 (b). The antenna behaves like directional and high gain antenna above 3.4GHz. The 3-D radiation pattern at 5.5GHz and 8GHz is shown in fig. 6 (c) and fig. 6(d). The antenna has high gain and directivity at 5.5GHz while some distortion and low gain at 8GHz.

In order to penetrate through the body a narrow pulse is transmitted from a UWB antenna. When the pulse propagates through different layers of tissues, reflections and scattering of signal will occur at the interfaces. A specific interest is in the scattered signal from a small sized tissue signifying a tumor. The reflected and scattered signals from the breast tissue can be collected by using a UWB antenna, or array of antennas, and used to map different layers of the body. For an exact imaging system with high resolution, the transmitting/receiving UWB antenna should be highly directional.

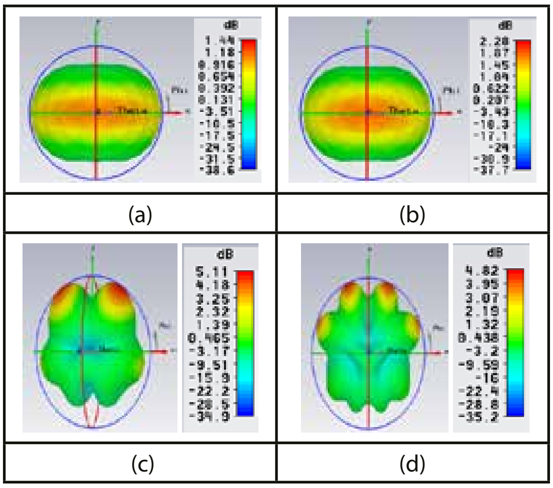


**Fig. 6 3-D radiation pattern (a)1.4GHz, (b)2GHz (c) 5.5GHz and (d) 8GHz**

### *Surface current*

The distribution of current due to simulation surface of the designed patch antennas with microstrip feed line are shown in fig.7 at different resonating frequency of 2.5GHz, 5.5 GHz and 7.5GHz. The flow of Current is visible along the entire surface of the antenna. Distribution of the current is shown for different frequencies such as 5.5 GHz, 7.5GHz, and 3.5GHz. The simulated results show that the antenna surface current distributed mainly on the edge of the metal patch. The operating frequency of the antenna can be reduced by increasing the path length of antenna surface current. There are two ways to increase the path length: increasing the length and width of the metal patch and cutting the edges of the patch plane. As the frequency of operation increases more amount of current flows through the surface of the antenna.

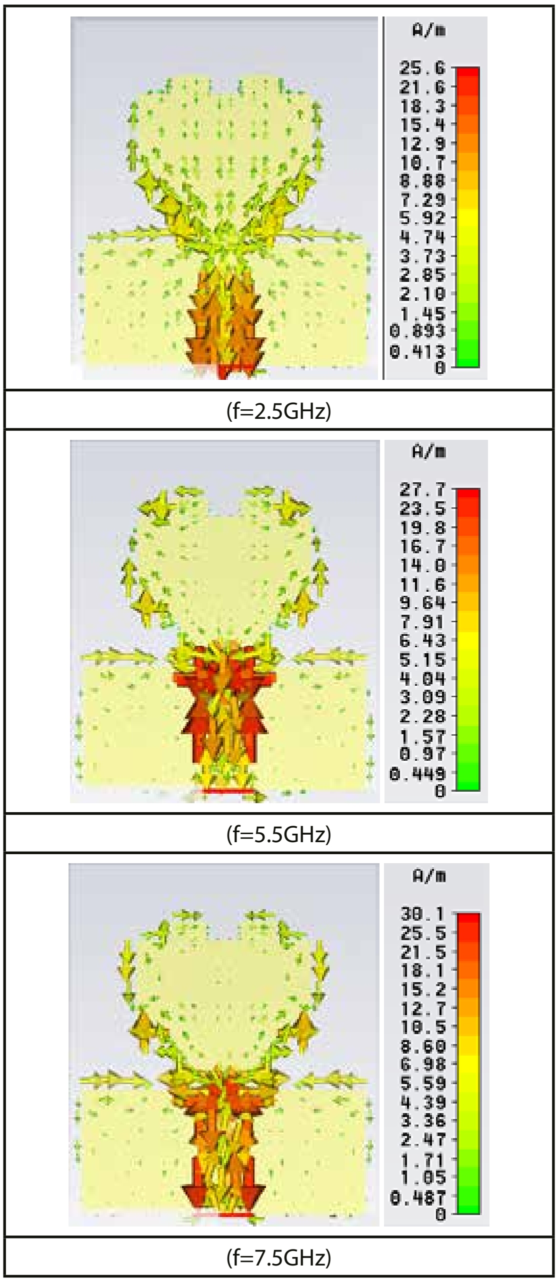


**Fig. 7 surface current of the proposed antenna**

## 4. Fabrication and Measurements

The fabricated antenna is shown in fig. 8. The antenna is fabricated with a height of 1.6mm using a FR4 substrate with 35µm metallization thickness. An SMA connector is soldered at the end of the feed line. The measurement is taken using Vector Network Analyzer having the maximum measurable frequency of 20GHz.

**Fig. 8 Photograph of the fabricated antenna**

Fig. 9 shows the comparison of measured and simulated reflection coefficient of the designed antenna.The fig.9 shows that there is a good correlation between the simulated and measured result.

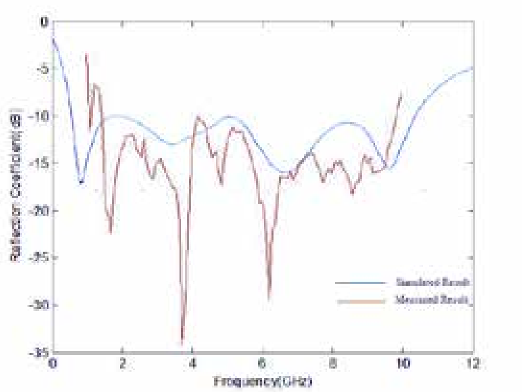


**Fig. 9 Measured and simulated reflection coefficient**

## 5. Conclusion

A stripline feed with staircase UWB directional antenna is presented, showing good measured performances over a wide range of bandwidth. The reported antenna faces the impedance bandwidth from 1.43GHz to 8.92GHz. The maximum gain of the proposed antenna is 6.06dB. It is also observed that directivity increases as the frequency increases and the maximum directivity 8.37dB are obtained at a frequency of 9.8GHz. The radiation pattern, surface current, and VSWR have ensured that the proposed antenna would be a promising candidate for a UWB microwave imaging system.

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