Tapered Slot Antenna for Near-Field Microwave Imaging

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Abstract

This paper presents a tapered slot antenna to be used in a near-field microwave imaging system. The antenna contains a metallization layer to enhance the front-to-back ratio. The proposed antenna is assumed to be immersed in a high dielectric constant medium in order to get a good matching with the irradiated tissues of the human body. Results of simulation indicate that the proposed antenna can cover the ultra wide band from 1.8GHz to more than 12GHz with a high directivity. The time domain behaviour of the antenna is calculated and the antenna is found to have high fidelity.

1. INTRODUCTION

Recently, microwave imaging for medical application has received a considerable amount of interest which can enable the detection and location of malignant tissue in woman's breast [1-6]. A microwave imaging system is considered as a viable alternative to X-ray mammography due to its several advantages such as cost and less side effect. Microwave imaging involves the propagation of very low levels of microwave energy through the breast tissue. The basis for tumour detection and location is the difference in the electrical properties of normal and malignant breast tissue. Normal breast tissue is largely transparent to microwave radiation while the malignant individual contains more water and blood resulting in microwave signal back scattering. This scattered signal can be picked by a microwave antenna and analysed using a computer [5 - 6].

In general, two approaches are used with respect to detecting cancerous tissue. In one approach, known as microwave tomography [1-4], a forward and reverse electromagnetic field problem is solved to detect and locate cancerous tissues in woman's breast.

An alternative approach is microwave imaging where it involves generating and receiving short pulses for the various locations of probe antenna or alternatively by an array antenna [5 - 6]. Such short pulses can be generated in practice by applying a step-frequency pulse synthesis technique. The space or time-domain representation is then achieved using an Inverse Fast Fourier Transform. The processed signals for the various locations of a probe antenna or from array elements are combined to form a two or three-dimensional image showing the location of highly reflecting objects representing a cancerous tissue.

The multiple-frequency tomography approach and the radar technique require the use of ultra-wideband (UWB) antenna elements. Several broadband designs have been proposed for the use in imaging systems [7 - 9]. Each has its own merits and drawbacks. The antennas proposed in [7-8] have a nonplanar structure while the design in [9] has low radiation efficiency (less than 40%) and a low gain. The low efficiency is a major drawback as it limits the dynamic range of the imaging system.

This paper addresses the shortcoming of the previous designs by designing UWB tapered slot antenna that has a high directivity and radiation efficiency. The proposed antenna is to be used in a microwave imaging system as shown in Fig.1.

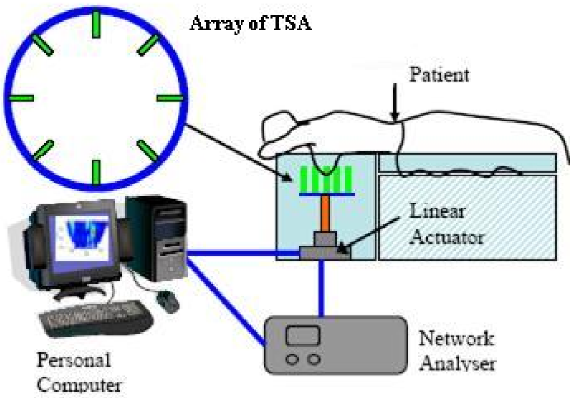

Fig.1: Schematic diagram of the microwave imaging system.

The proposed antenna element is in the form of planar tapered slot in a high dielectric constant substrate material to minimize size and to get a better matching with the medium in which the antenna is immersed and with tissues of the human body. It features a very low loss across the desired band and its radiation efficiency is around 80% with a high gain. By using a metallic layer at the top and bottom radiating structures, the front-to-back ratio of the antenna is increased.

As the proposed antenna is of a small size it allows for forming a circular array with high packing density. The design of UWB antenna as proposed in this paper is accomplished using simple design formulas. This is an advantage with the previously reported UWB antenna designs

[7-9] relying on the trial and error method and simulation tools.
The paper is organised as follows. Section 2 describes the design procedure of an UWB antenna for inclusion in this array. Section 3 shows the performance data of the designed antenna obtained by simulation using finite element analysis. Finally, Section 4 concludes the paper.

2. DESIGN METHOD

The configuration of a planar tapered slot antenna which is designed for UWB microwave imaging system is shown in Fig.2. The design objective is to have the antenna operate over the bandwidth of 3.1 to 10.6 GHz. In order to reduce the time and effort needed by the trial-and-error strategy adopted by other papers we propose a simple design procedure of this antenna, whose validity is confirmed by electromagnetic simulations. The design steps are as follows.

Step 1: Given the lowest frequency of operation (f_l), which is 3.1GHz for the UWB, thickness of the substrate ($\boldsymbol{h}$) and its dielectric constant (ε_{rs}), the width ($\boldsymbol{w}$) and length ($\boldsymbol{l}$) of the antenna structure, excluding the feeder can be calculated using equation (1).

$$\boldsymbol{w} = \boldsymbol{l} = \frac{\boldsymbol{c}}{\boldsymbol{f_l}}\sqrt{\frac{2}{\varepsilon_{rs} + \varepsilon_{rm}}} \quad (1)$$

where c is the speed of light in free space and ε_{rm} is the dielectric constant of the medium enclosing the antenna structure. The antenna structure is assumed to be in the xy-plane with its dimension $\boldsymbol{w}$ extending along the x-axis.

Step 2: The radiating structure of the antenna is formed from the intersection of quarters of two ellipses. The major and the secondary radii of the two ellipses are chosen according to the following equations;

$$\boldsymbol{r}_1 = \boldsymbol{w}/2 \quad (2)$$

$$\boldsymbol{r}_2 = \boldsymbol{w}/2 - \boldsymbol{w_m} \quad (3)$$

$$\boldsymbol{r}_{s1} = \boldsymbol{k}_1\boldsymbol{l} \quad (4)$$

$$\boldsymbol{r}_{s2} = \boldsymbol{k}_2\boldsymbol{r}_2 \quad (5)$$

Values of the parameters $\boldsymbol{k}_1$ and $\boldsymbol{k}_2$ are in the range 1.2-1.5 and 0.4-0.8 depending on the substrate and the immersing medium characteristics.

Step 3: The width of the microstrip transmission feeder $\boldsymbol{w_m}$ to give the characteristic impedance, $\boldsymbol{Z_o}$ equal to 50Ω can be calculated using the following equations [10];
$w_m / h \leq 1$

$$\boldsymbol{Z_o} = \frac{60}{\sqrt{\varepsilon_e}}\ln\left(\frac{8\boldsymbol{h}}{\boldsymbol{w_m}} + \frac{\boldsymbol{w_m}}{4\boldsymbol{h}}\right) \quad (6)$$

where ε_e is the effective dielectric constant . It is assumed that $\boldsymbol{w_m}/\boldsymbol{h} \leq 1$ because of the use of a high dielectric constant for the substrate and the medium containing the antenna in the microwave imaging system under investigation.

The effective dielectric constant ε_e can be calculated using the following approximate formula;

$$\varepsilon_e = \frac{\varepsilon_{rs} + \varepsilon_{rm}}{2} \quad (7)$$

Step 4: The ground plane of the antenna consists of two parts. The first part is a structure which is similar to that of the radiating element of the antenna. The second part is a tapered shape structure formed from the intersection of a rectangular conductor with two anti-faced quarter ellipses with dimensions $\boldsymbol{r}_2$ and $\boldsymbol{r}_{s2}$. To improve the impedance matching of the antenna, the ground plane is extended by $\boldsymbol{y}_g$.

Step 5: A metallization layer, with a 50Ω/□ surface resistivity is added to the top and bottom radiating structures. Shape of the layers is chosen to be a quarter ellipse with major and secondary diameters equal to $\boldsymbol{r}_2$ and $\boldsymbol{r}_{s2}$ respectively. Location of the layers is shown in Fig.2.

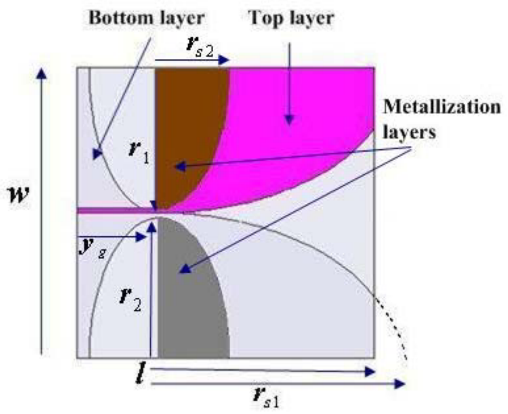

Fig.2 Configuration of the proposed antenna

3. RESULTS AND DISCUSSIONS

The validity of our method is tested by designing an antenna covering the UWB frequency band from 3.1 GHz to 10.6 GHz. The design assumes Rogers RT6010LM substrate featuring a dielectric constant of 10.2 and a loss tangent of

0.0023, 0.64mm thickness plus 17µm thick conductive coating. The antenna is considered to be immersed in a medium with dielectric constant equal to that of the biological material to be irradiated in order to get the best matching with the human body. Here, dielectric constant of the medium enclosing the antenna is assumed to be 9. The proposed antenna is compact with dimensions of 35mm×35mm. The return loss and radiation pattern of the designed antenna is verified using a Finite Element Method design and analysis on a personal computer with dual Xeon 2.8GHz processors and 3.5GB of RAM.

Fig 3 shows the simulated return loss of the proposed planar tapered slot antenna. As can be seen from the figure, the antenna operates from 1.8 GHz to over 12 GHz.

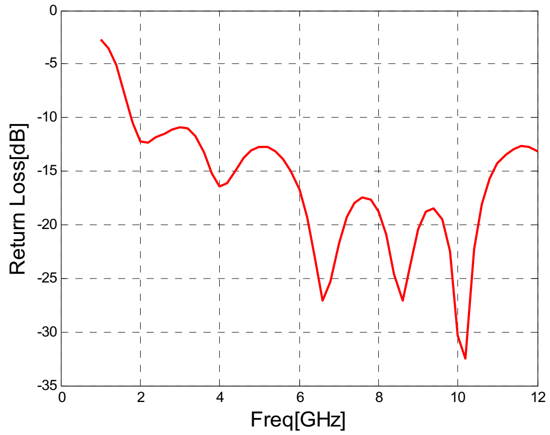

Fig.3: Return loss with frequency for the designed antenna.

In order to verify this antenna capability to support transmission and reception of narrow pulses in distortionless manner, the time domain impulse response of the antenna is calculated using inverse discrete Fourier transform. In this case, two the same type antennas are used, which are aligned for the best transmission. The results are shown in Fig. 4. It is clear that this two antenna arrangement supports almost distortionless transmission. This is an important issue in microwave imaging systems where the received signal should not support the detection of ghost targets.

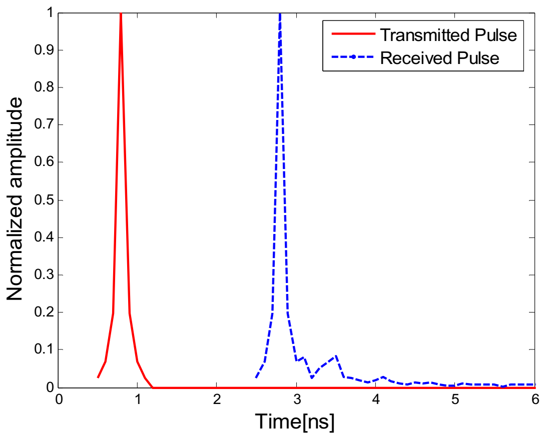

Fig.4: The impulse response of the designed antenna.

The far field radiation patterns of the antenna in the two principle planes, *E*-plane and *H*-plane are shown in Fig.5 at the centre frequency, 6GHz. From the figure, it can be seen that the designed antenna has a high directivity in the endfire direction with a front-to-back ratio better than 13dB.

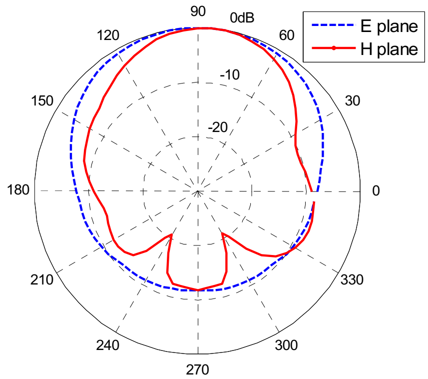

Fig.5: The radiation pattern of the designed antenna at 6GHz.

The variation of the gain for the designed antenna with frequency is shown in Fig.6. The designed antenna has a gain which increases with frequency and the maximum value is 9dBi at 10GHz.

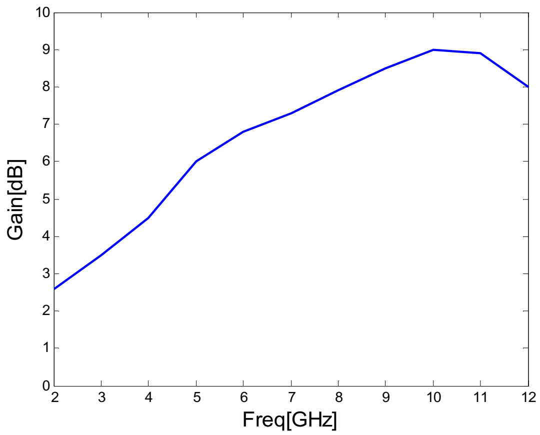

Fig.6: Variation of the gain with frequency for the designed antenna.

Using a metallization layers with the antenna structure could make the radiation efficiency of the antenna to deteriorate. To make sure of the performance of the antenna with respect to this issue, the radiation efficiency was calculated and it is shown in Fig.7. It is obvious that despite the use of those layers to minimize the backward radiation and hence enhance the front-to-back ratio the proposed antenna has a good efficiency which is around 80% across the whole band. This is superior to the recent antennas proposed for the imaging system, described in [9] which have 47% efficiency in its best case.

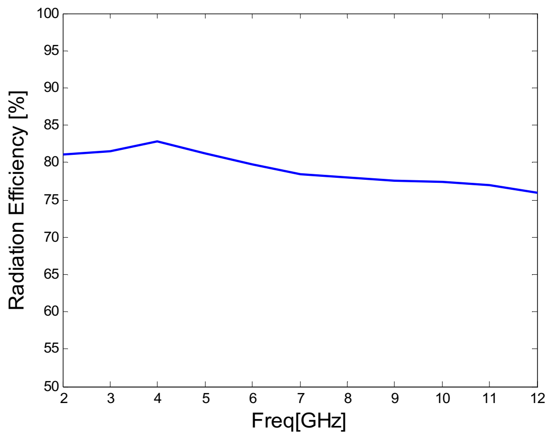

Fig.7: The radiation efficiency oft the designed antenna.

4. Conclusions

A compact UWB antenna suitable for the microwave imaging system has been presented. A metallization layer has been used in the antenna structure to minimize the backward radiation and hence increase the front-to-back ratio. The proposed antenna has been assumed to be immersed in a dielectric medium with a dielectric constant comparable to that of a healthy human body tissue in order to get best matching with the body and to increase the detection capability of the system. The simulated characteristics of the antenna show that the designed antenna covers the band from 1.8GHz to more than 12GHz. It has a good radiation efficiency which is higher that the stated efficiency in the literature for antennas using a metallization layer and designed specifically for microwave imaging systems.

Acknowledgement

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