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INNOVATIVE DIRECTIONAL ULTRA-WIDE BAND MEDICAL IMAGING ANTENNA

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ABSTRACT

A directive ultra wide band antenna with small aperture area is presented in this paper. The antenna is in the form of parabolic planar reflector with circular radiating patch. The parabolic reflector improves its directivity and reduced backward radiation and improves forward radiation. The antenna is designed to operate in ultra wide band range of 3.1 GHz to 10.6 GHz but in fact it gives a very good return loss performance in below 3.1 GHz and above 10.6 GHz frequency range also. This antenna has average gain of 3.52 dBi in the Ultra wide band range. The distortion is negligible in both the domains for this antenna, hence such antenna is suitable candidates for medical imaging applications where there is a pulse transmission & reception is applicable. The human body is a made up of thick layers of fat, muscles and skin layers, for such application such directive antenna are suitable to focus the radiated power into the human body to study and reflection received from the body layers. Where such type of antenna can exhibit a very good fidelity being directive and compact in size when it works in free space. For other kind of non directive antennas the fidelity factor decreases when it comes for human body pulse reception. Hence such antenna is proposed to be used for microwave medical applications.

Categories and Subject Description: Antenna and radiation used for Human medical applications such as microwave medical applications where the human body tissue health is examined depending upon the quality of reflections from human body.

General Terms: Radiating patch, Radiation, Ultra wide band, Directivity, Return loss, Impedance bandwidth Operating bandwidth

Keywords *Substrate, VSWR, S11, Front to back ratio, end-fire, broadside*

1. INTRODUCTION

Because of good penetration of Ultra Wideband (UWB) frequency range (3.1 to 10.6 GHz) it is appropriate frequency range using which biomedical applications such as microwave imaging can be used to detect cancerous tissues in human body. The coming section of the concept of UWB cancer detection using the major difference in dielectric properties which is about 2:1 between normal and cancerous tissues. This method has proved to be a hopeful performance in detecting breast cancer anomalies [1]. A narrow pulse transmitted by UWB antenna penetrates a human body tissue, which gets scattered by the various layers of the human body acting as boundary of mediums. These scattered waves received upon a UWB antenna to examine the human body skin and tissue layers condition. The accuracy of the antenna hence depends upon the resolution and range of frequency range in the short pulse, in addition to the structure, size and directivity of the transmitting and receiving antenna.

Major work in this category of literature is on Omni directional radiation which hence exhibits low gain and lot of distortions in received signal [2]. Omni directional UWB antennas are generally suitable for short range low gain applications. But in medical microwave imaging applications a high gain directional antenna are beneficial. Very negligible distortion is desired for this short pulse transmission during reception in impedance bandwidth with return loss of the 11 dB. This distortion less reception will ensure the high resolution in locating the cancerous tissue location in human body. The directional ultra wide band already invented and presented in literatures [3] obeys the criteria such as bandwidth, impulse response and directivity with cost of huge space requirements in the system. The increased directivity with reduced size is a design appeal which can be implemented in this presented design with broad band width, directivity and high resolution performance. There are plenty of designs proposals available with small space and less distortion in this topic [4] which are not perfectly fulfilling the requirements in medical applications thoroughly. While some of bulkier in size and remaining planar antennas are having low directivity and gain parameters. The weak radiation efficiency is the major pitfall of most of the antennas that limits sensitivity of system to detect weakly scattered signals from the tumor.

A compact planar reflector UWB antenna is investigated in this proposed work. The calculation of different values of the antenna parameters is also discussed.

A planar type reflector is used here to improve directivity and gain of the system. This reflector improves its gain and reduced back radiation but may sometimes affect the precision of the imaging systems. The simulated results of the proposed antenna exhibit a sufficient gain and distortion free trans-receiving system operation.

2. DESIGN AND MODELING

The design in this paper is proposed for skin tumor and cancer detection. The directional single antenna will be used for imaging application in this case. The same antenna will act as a transmitter and receiver on time sharing basis. During reception the receiver antenna will collect the scattered signal.

The scattered signal will be measured and stored, the procedure is iterated and scattered signal is collected again. The process may be repeated several times depending upon the quality of received signal. This will help in generating clear image of the part under examination.

The proposed design of antenna is shown in figure 1. It is like a parabolic reflector antenna with planar semicircular reflector ground fed by circular shape planar ultra wide band antenna.

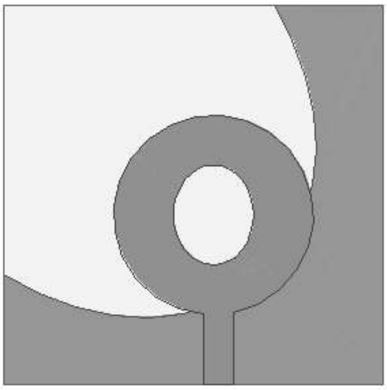

Figure 1 : Proposed antenna structure

The elliptical slot circular element planar structure act as a radiating element. The FR4_epoxy substrate with 4.4 relative permittivity is used in the structure with thickness of 1.6 mm. The parabolic reflector is used in the ground structure is used to increase the front to back ration and thus improves the detection ability of the imaging system. The structure is desired to get a directional radiation with bandwidth requirement of the ultra wideband range. 3.1 to 10.6 GHz. The design steps are given in the following sections.

Step 1: The lowest frequency, fL in the ultra wide band range is used to calculate thickness of the substrate, h and its dielectric constant, Ꞓr width (W) and length (L) using the equation given as below [5].

$$W = L = \frac{C}{fL}\sqrt{\frac{2}{\epsilon r + 1}} \qquad \text{----------} \qquad (1)$$

In this expression, C is free space velocity of light or electromagnetic waves. It is to be noted that the length and width calculated from above expression are the effective parameters obtained from lower frequency of band of interest.

Step 2: The elliptical slot circular element planar structure act as a radiating element which is formed with ellipse ratio of 1 where major axis is kept at 10mm. the vertical elliptical slot is cut into it which is formed by a shape of ellipse having ratio of 1.25 and major axis of 4mm.

The circular shape is chosen with reference to given expression

$$fo = \frac{8.791}{(a + \frac{h}{\sqrt{\epsilon r}})\sqrt{\epsilon e}}\ \text{GHz} \qquad \text{----------} \qquad (2)$$

Where ‘a’ is a radius of circle, ‘h’ is a height of the substrate given in centimeters. In this model ‘a’ = 10 mm and the height of substrate is 1.6 mm. The parameters of radiating elements are chosen such that the distance between two points on the radiating circular element is approximately equal to the wavelength of the lower operating frequency in ultra wide band range.

Step 3: The feed of width 3 mm and length is 7.05mm used to feed the signal from excited port is chosen to give typical characteristic impedance of 50 Ω. typically it is denoted with notation of Zo in transmission lines and antennas literatures [6] The width wf is calculated using the following expression.

$$wf = \frac{120\pi h}{Zo * \sqrt{\epsilon r}} \qquad \text{-------} \ (3)$$

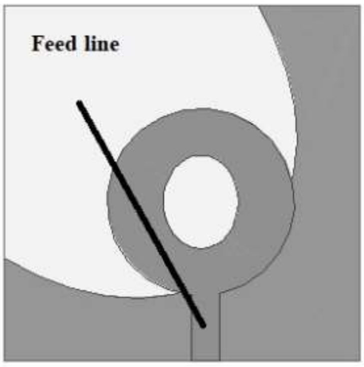

Figure 2: Feed strip line

Step 4: The ground plane of parabolic shape is used as a reflector to increase the front to back ratio of radiation. The parabola of 20 mm major axis is designed with ratio of 1.3. This parabolic shape of major radius 20mm and ratio of 1.3 is then subtracted from the rectangular patch of 38 * 38 mm^2, to form a parabolic reflector as shown in figure 3.

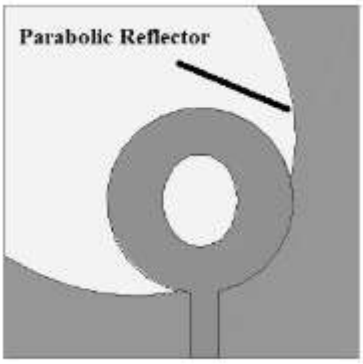

Figure 3: Configuration of parabolic ground reflector

Step 5: Now with circular radiating element and parabolic reflector ground the antenna system has become now the unbalanced transmission line. As the ground plane is not symmetrical about axis of radiating element. The simple coaxial cable feeding will also work here satisfactorily as this coaxial cable is also a unbalance structure of transmission line. The SMA connector will interconnect the antenna feed point with coaxial cable coming from external circuits.

The table for dimensions is given below

3. PERFORMANCE

(a) (b)

Figure 4: Fabricated model of directional antenna

The figure 4 above shows the fabricated model of the innovative directional Ultra Wideband Antenna. The system of antenna for ultra wide band range is utilizing the substrate FR4_epoxy material with relative permittivity, ϵr = 4.4 with thickness, h = 1.6 mm. The total antenna area covers a 38 * 38 mm2 area and volume of 38 * 38*1.6 mm3.

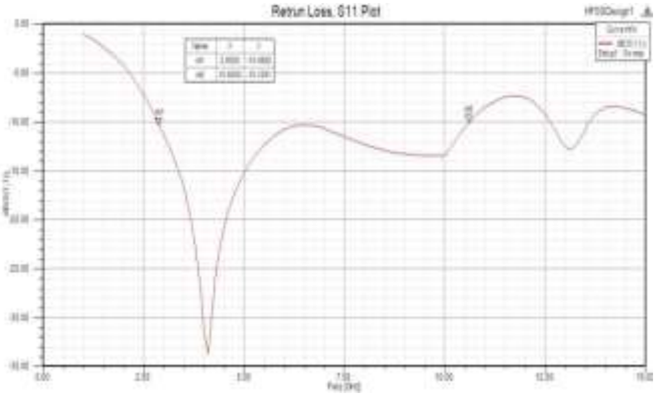

Figure 5: S11 simulated graph, Impedance bandwidth

A analysis of the antenna above shown in performed using Ansoft HFSSv14 shows that the performance of parameter bandwidth is best over the range of 2.9 to10.6 GHz. As shown in above figure the return loss is less than -10dB from the said frequency range. The addition to ground plane parabolic reflector improves the front to back ratio to a value of 12.84 dB.

The workability of the proposed antenna is confirmed using the Ansys HFSSv14 license version and the results shown over the Vector Network Analyzer. Simulation results can be seen in Figure 4 for the return loss of the antenna 50 Ω characteristic impedance value.

The 3 dimensional far field radiation pattern is derived in the simulation software HFSS. The patterns are plotted for the frequency value of 3.1 GHS, 6.2GHz, 9 GHZ and 10.6 GHz respectively which are shown in figure 5. The average front to back ratio of this system is 12.84 dB across the entire UWB range, which shows its directive property of the designed antenna? Such antennas are a good for imaging applications at microwave frequency.

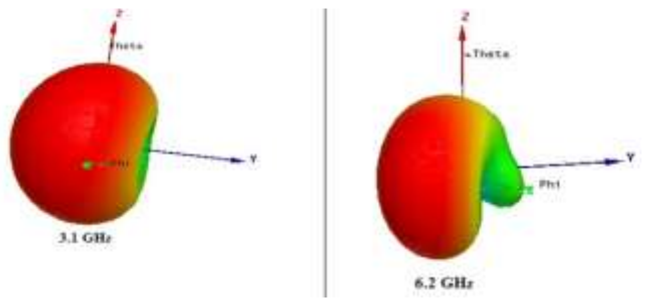

Figure 6: 3D radiation pattern obtained in simulation software.

The peak gain at 3.1 GHz is -1.005 dB and it goes on improving along with the frequency till 12.7 GHz where it reaches 5.69 dB. Figure 6 shows the simulated gain of the antenna, where average gain over the entire frequency band of interest is 3.52 dB. The measurement results can also be compared with standard horn antenna gain. Initially at 3.1 GHz the gain is negative in dB units but later it rapidly increased from the frequency of 3.5 GHz and then continuously goes on increasing. Within the range of 3.5 to 4.6 GHz the gain rose above 2.5 dB. The proposed antenna has improved gain in the class of planar antennas of the same size [7].

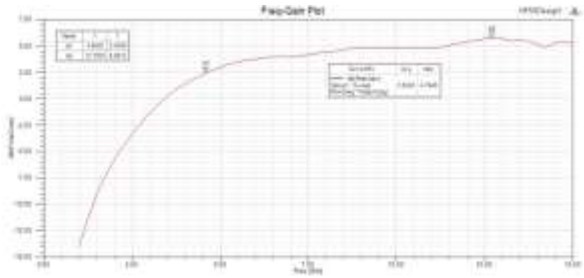

Figure 7: Gain and frequency sweep characteristics

The designed antenna shows a good efficiency, almost ……..% in entire ultra wide band range. In microwave imaging applications this performance is best where 50 % of its efficiency was quoted [8].

The designed antenna has to put near to human body, if we consider the breast for cancer detection then a effect of the human body due to its near presence on its return loss, S11 parameter is also analyzed. Electromagnetic breast model can be represented in two parts in which first 2mm represents skin layer with relative permittivity of 36 and conductivity of 4 S/m, while second layer represents actual breast tissues of 10mm with permittivity of 9 and very less conductivity of 0.4 S/m as compared to skin layer [12]. The effect of human body is simulated as shown in figure 7 to a distance of 10 mm in terms of operational or VSWR bandwidth performance. From results we can conclude that in spite of close distance between human body and antenna of about 10mm, the operational characteristics of the antenna does not exceed critical values.

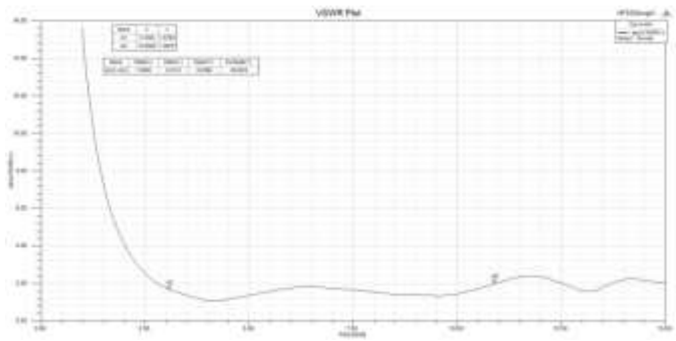

Figure 8: VSWR Plot over Ultra wide band frequency range

4. CONCLUSION

The innovative design of directional ultra wideband antenna is presented in this work. Due to increased directivity of the antenna hence it is used in applications of microwave imaging systems. The antennas directivy has been increased due to presence of parabolic ground plane which acts as a reflector of electromagnetic fields and not allows backward side lobe to form and concentrates power in front direction. The impedance bandwidth and operational bandwidth shows that the designed model is suitable for near body applications like microwave imaging applications where it maintain its bandwidth near human body also. The efficiency of the proposed model is also good as compared to model available in literature presently. The time domain study & fidelity of antenna is under process to show that it transmits and received the very short pulse without much of the distortion.

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