Design of a Taper Slot Low Profile Vivaldi Antenna for Ultra-Wideband Microwave Breast Imaging Applications

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***Abstract*— This paper presents parametric study and design of a taper slotted low profile Vivaldi antenna for ultra wide band near field microwave breast imaging applications. A phantom enclosed in a dielectric container of size 150mm*150mm*150mm at a center frequency of 2.5GHz with low dielectric constant of 9 and conductivity of 0.4. The phantom is scanned with the proposed antenna of size 62.8mm*36mm*2.82 mm at center frequency range of 1 to 4GHz. Stimulated results indicate that the proposed antenna is a good candidate for the breast imaging applications.**

Keywords— cancer detection; microwave imaging; near field imaging; ultra-wideband; ultra-wideband antenna; vivaldi antenna .

I. INTRODUCTION

Breast cancer is one of the prominent diseases affecting women globally, causing a quite number of deaths annually [1], it is therefore imperative for its early detection for effective prevention and screening medically. Medical imaging currently depends on various techniques, including X- ray mammography, magnetic resonance and echography. However, these techniques witness some impediments and hence more effective approaches are desired. The use of microwave subsurface radar (MWR) as a medical imaging technique for breast cancer screening offers several benefits over other imaging methods [2]. MWR techniques detects the contrast in the dielectric properties between normal and tumor tissue in a more efficient, effective, safe and accurate manner which are achieved through advanced imaging technologies [3].

Furthermore, Non-ionizing and non-invasive features of MWR offers an interesting alternative when compared with X-ray mammography which is highly ionizing due to the electron beam used for the scanning coupled with the false negative/positive finding [4]. Additionally, MWR does not require breast compression when compared with X-rays which is very uncomfortable for patients. Low cost is also another advantage of MWR when compared with magnetic resonance that requires an extremely large and costly machine, thus limits its use for large scale screening.

Ultrasound echography is also strongly dependent on the physician's capability which will in turn yield adjustable success rate and hence a disadvantage when compared to microwave imaging [5].MWR allows non-destructive assessment of the breast tissue based on the variations of the dielectric properties of the tissue and thus creates an images of the electrical properties of the breast tissue. The normal breast tissue is transparent to microwaves with lower water content, but the malignant tumor has high water content which has electrical properties that varies from the normal tissue [6]. Consequently, the reflected signal will be used to reconstruct the image of the region when microwave hit the malignant tumor tissue. This method is closely related to the principle of ground penetrating radar used for targeting and imaging landmine but operating in a high frequency range.

Microwave imaging of breast tissue can be either tomography or radar based. The tomography based require a single transmitter radiating Electromagnetic waves (EM) waves into the breast while a number of receiving antennas would be placed around the breast to receive any scattered wave. On the other hand, the based used short-pulsed signal employing mono-static configuration transmitted from a single Ultra-wide band (UWB) antenna into the breast and receives any back-scattered signal from the same antenna. The radar based approach method is used in this simulation. The method will be repeated within the breast in different locations and the travel time of the transmitted and received signal will be recorded, computed and analyzed to predict the location of the tumor. This type of technique does not require any image reconstruction algorithm to yield any imaging information as compared to the tomography based microwave imaging.

UWB systems has become one of the most interesting technologies in this development owing to its high speed transmission rates, low power features which allows frequency recycle and simple hardware configuration over conventional wireless communications technologies. Several UWB antennas for medical applications have been addressed in [7-9], where high frequency ranges are used from 3 to 10 GHz while others exhibit Omni-directional radiation pattern with low gain [10- 12]. For this reason, UWB Vivaldi antennas are more desirable since they possess directional radiation pattern, relatively wider band width and easy integration with MW devices.

Vivaldi antenna is an UWB antenna originated by Gibson [13] which belongs to the class of end fire travelling wave antennas design and conventionally used in many wireless communications systems [14-17]. These applications are utilized in military radar imaging, security screening, detecting tumor especially in early detection of breast cancer due to its non-destructive effects on healthy tissues [18-20] and through the wall imaging [21-26]. These milestones have encouraged and motivate many researchers to exploit the potential of this technology so that more breakthroughs could be achieved.

However, these antennas also witnesses' challenges such as larger sizes and limitation of high losses associated with high frequency bands. To correct this variance, different kinds of Vivaldi antenna for breast cancer imaging have been developed and reported. For example, coplanar Vivaldi antenna [27], a balanced antipodal Vivaldi antenna [28] is studied and their sizes and operating bandwidths are things of concern. Although in [29] the operating bandwidth is desired for the imaging application, the size of the antenna is a challenge to consider. In our design, size and the frequency of operation are put into consideration which have wider bandwidth and yielded high directive performance.

UWB antenna designs on low frequencies are more desirable for the medical detection to guarantee the deep penetration of the signal inside the breast tissue. Additionally, the use of low frequency would guarantee an improve resolution and reduction of losses associated with high microwave bands. In this paper, the proposed antenna would be operating at low frequency range covering 1GHz -4 GHz. Following the design guidelines and principles of an effective and efficient UWB antenna in [30, 31], an improved UWB Taper Slot Low Profile Vivaldi antenna is designed and tested for the imaging scenarios.

TABLE I: REFERENCED VIVALDI ANDTHE PROPOSED VIVALDI ANTENNA

Ref.	Dimensions in mm	Operating BW in GHz	ε_r	Directivity in dBi
[27]	70 x 64	0 - 8	4.3	7.05
[28]	122 x 150	2 - 12	4.4	6.45
[29]	145 x 50	0.75 – 2.75	6.15	6.65
Proposed	62.8 x 36	1 - 4	2.33	7.11

II. ANTENNA DESIGNS

Antenna design is one of the main challenges in the modeling, analysis and design of microwave imaging system for medical diagnostics. The main challenge is to be able to design an effective and efficient compact antenna with high sensitivity, low loss and stable radiation pattern over the whole frequency band. The layout geometry of the proposed antenna shows the antenna dimensions as 62.8 mm x 36mm fabricated on Rogers RT/ Druid 5870 substrates with dielectric constants of 2.33 and loss tangent of 0.0012. The 3-D plot radiation properties of the antenna are determined by a set exponential curves, Cavity diameter, tapered rate, back wall offset, edge offset, feeding position and slot width. The exponential curve of the Vivaldi antenna is defined as:

$$\chi = C_1 e^{RZ} + C_2 \quad (1)$$

$$Where\ C_1 = \frac{x_2 - x_1}{(e^{RZ_2} - e^{RZ_1})} \quad (2)$$

$$and\ C_2 = \frac{x_1 e^{RZ_2} - x_2 e^{RZ_1}}{(e^{RZ_2} - e^{RZ_1})} \quad (3)$$

TABLE II. DESIGN PARAMETERS OF THE PROPOSED ANTENNA

Constructional Parameters	Dimensions in mm
Flare Height (H_f)	35.00
Flare Length(L_f)	62.80
Taper rate (T_r)	1.1
Slot Width (S_w)	0.5
Back wall off set ($B\ wall\ off$)	1
Strip line Width (SL_w)	2.5
Strip line length (SL_l)	27.5

TABLE III. SUBSTRATE DETAILS USED FOR THE DESIGN

Substrate Parameters	Values
Name	Rogers RT 5880
Relative Permittivity	2.2
Electrical Conductivity	0.0009
Substrate Height	62.8
Substrate Width	36
Substrate Thickness	2.82
Copper Height	0.035

TABLE IV. BREAST TISSUE ELECTRICAL PROPERTIES

Layers	Skin	Breast
Thickness	2	100
Relative Permittivity	36	9
Equivalent Conductivity/ Sm^{-1}	4	0.4

A parametric simulation of the proposed antenna was carried out indicating the top and bottom view in Figure 1and 2 respectively. Different antenna parameters were considered at the operating bandwidths which are required to obtain the desired gain. Relevant parameters including the antenna size, feeding position, slot width, substrate type, and the Micro strip line size were also measured. To check the influence of these parameters on the impedance band width, parameters were varied one after the other during the parameterization task. Simulation result indicates the effect of these parameters variation on the resonant frequency and the return loss. The geometric model of the antenna with the tissue model is in figure 3.

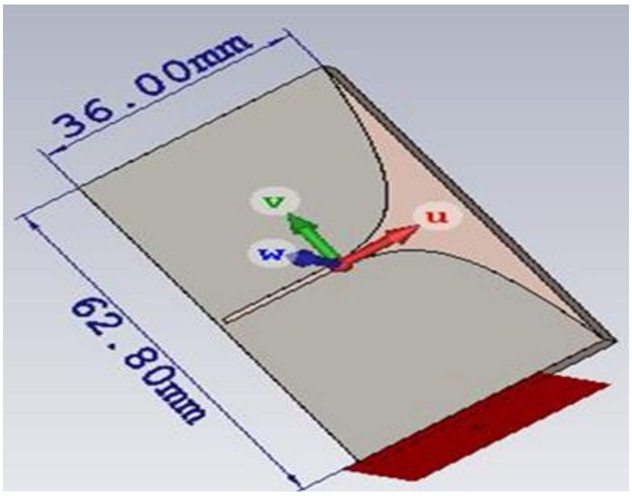

Fig.1. Top view of the proposed antenna.

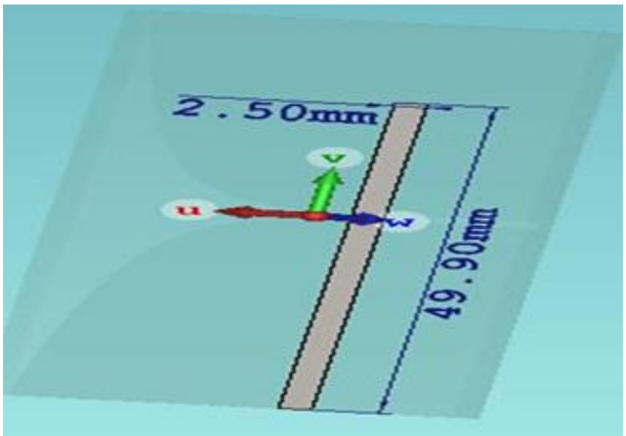

Fig.2. Bottom view of the proposed antenna.

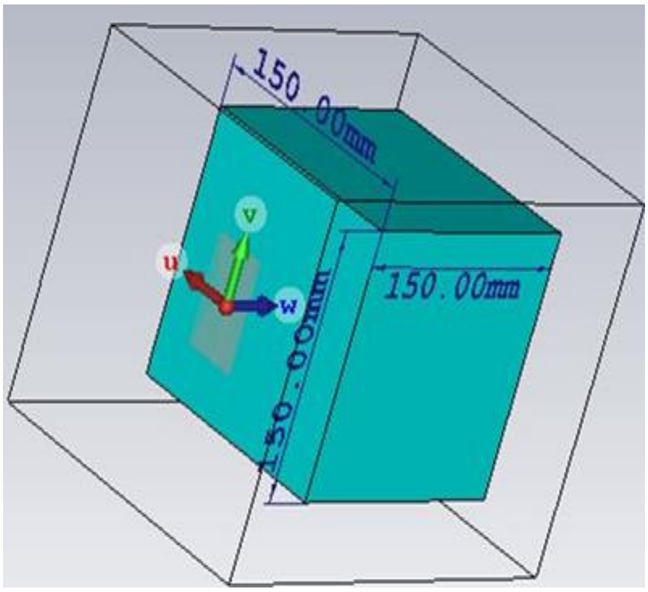

Fig.3. Geometry model of the proposed antenna with the tissue.

III. ANTENNA ANALYSIS

The Proposed antenna has been analyzed using CST microwave studio. The main goal and objective of the design is to measure and analyze the scattered electromagnetic waves due to the transmitted UWB microwave signal penetrating through the breast containing the tumor. To evaluate the antenna design analysis, we evaluate the antenna system by examining the reflection coefficient (S11) and envelope correlation (P_e) which are important parameters of the overall antenna system design as they take into account the mutual coupling effect of the system [32]. The -10 dB impedance bandwidth of the proposed antenna is 2.0228GHz – 3.8441GHz with an UWB of 1.8GHz as indicated in Figure 4. The Far field Directivity of the antenna at 2.5 GHZ is 7.11 dB as indicated in Figure 5.The Return loss of the antenna parameter is affected by the stub angle, substrate type and the cavity diameter while the antenna gain is affected by the stub radius.

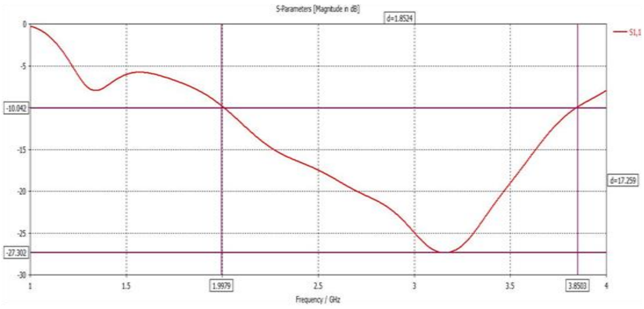

Fig.4. The return loss at less than -10dB with impedance bandwidth of 2.0228GHz – 3.8441GHz.

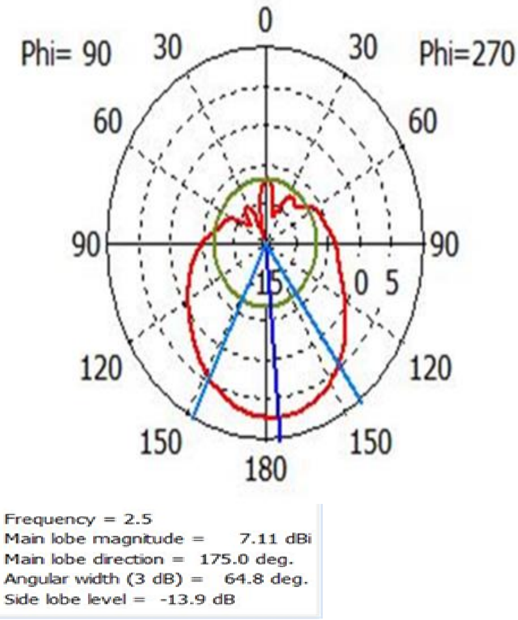

Fig.5. Far field of 7.11 dB at the centre frequency of 2.5 GHz.

IV. CONCLUSIONS

This study has enumerated the importance of using an end fire radiator Vivaldi antenna as an ultra-wide band antenna. Design modeling, analysis has shown that the proposed antenna can achieve a higher performance of deep penetration of electromagnetic signal to transmit the waves through the breast tissue efficiency when compared with other UWB antennas. The simulated results indicate the high directive performance of the proposed antenna.

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