A Small UWB Tapered Slot Antenna Design for Microwave Imaging System

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Abstract: The main challenge present in microwave imaging applications is to retrieve the information that a sensitive microwaves carry. The characteristics of the antenna is known to have a direct impact on the imaging system's performance. In this manuscript, a novel UWB Vivaldi Antenna embedded with rectangular,semicircular slots and a sequence of director elements is designed. Theproposed antenna is designed with the optimized size of 50×48.23mm^2 to achievesatisfactory impedance matchingand good radiation characteristics in the frequency band from 2.9 GHz- 11 GHz. The loading of slots and passive directors helps to concentrate the field towards the radiation aperture and thereby helps in increasing the gain. The antenna exhibits a stable radiation pattern and the gain between 2-7.8 dB in the operating frequency band. Besides, the time domain analysis shows the proposed antenna exhibits a flat group delay and a high-fidelity factor.
Keywords: Vivaldi Antenna, Microwave Imaging, Ultra-Wide Bandwidth

I. INTRODUCTION

The MicrowaveImaging (MWI) system consists of transmitting and receiving antennas that surrounds the object of interest. The antennas are the ultimate part of the system and therefore have a huge impact on the resulting image quality [1]. The type of antenna used in the imaging system is deeply impacted by the frequency range, dielectric characteristics, target, and the immersion medium. The antenna structure should efficiently direct microwave power towards the body for optimum illumination and must have little sensitivity to the environmental interferences [2].The multi-frequency or UWB imaging offers image claritythan the mono frequency approach and the optimum antenna element should maintain a stable characteristic over a large bandwidth as well. The antennas such as Monopoleantenna [3],Dipoleantenna [4], Microstrip antenna [5], Dielectric ResonatorAntenna (DRA) [6] have been studied for applications inside theMWI system.

Vivaldi Antenna is a broadband antenna originally introduced by Gibson [7],which satisfies the requirement of the MWI System with its characteristics such as planar structure, directional radiation pattern, a low distortion in contrast to other antennas. Different Vivaldi antenna structures have been reported in the existing workssuch as A fern fractal-inspired wideband antipodal antenna for the MWI system[8], Vivaldi antenna surrounded by a dielectric material for gain improvement[9], Double-slotted Vivaldi Antenna [10]. This paper details the design of acompact Vivaldiantenna having ultra-wide bandwidth characteristics, the evolution steps of the designed antenna, an investigation into its radiation performance, and thetime domain characteristics.

II. ANTENNA DESIGN

The proposed Vivaldi antenna geometry is shown in Fig.1. The antenna is designed on a 0.8mm thick FR4 substrate with a size of 50 mm ×48.4mm and the structural parameters of the proposed antenna are listed in Table.1. The performances of the proposed antenna are managed by the balanced exponential tapered curves which are represented by Eq.1

$$Y(t) = \alpha \times exp(R \times t) \quad (1)$$

The opening rate R is defined as

$$R = \frac{1}{La} \times \ ln \left(\frac{Wa}{S}\right) \quad (2)$$

Where La, Wa, and S are the aperture length, width, and the spacing of the tapered lines which are optimized to achieve compactness and to have desired radiation characteristics.

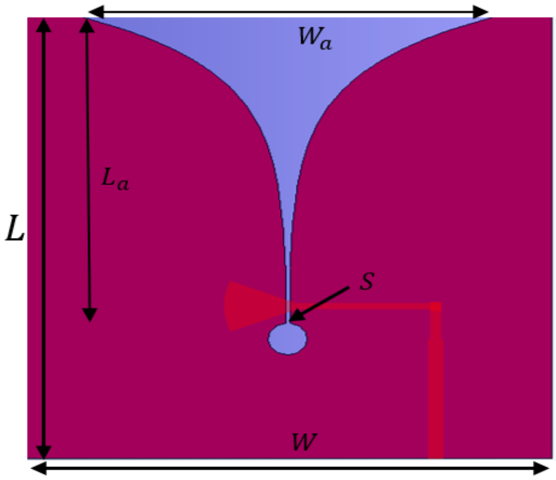

Fig.1.Proposed Vivaldi Antenna

As shown in Fig.1, The microstrip line cascaded with a radial stub has been designed to operate in the UWB range with low insertion loss and used to feed the antenna. The top tapered radiating structure and the bottom feed line are designed orthogonal to each other and the fields are coupled through the crossing.

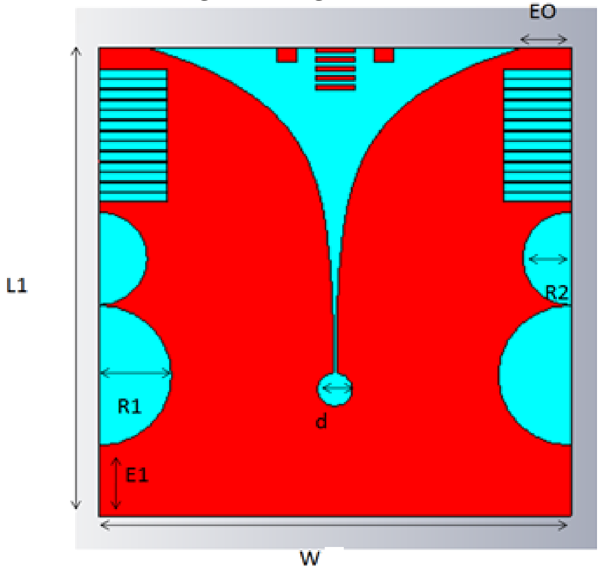

Fig.2a. Top View of Proposed VARSCD design

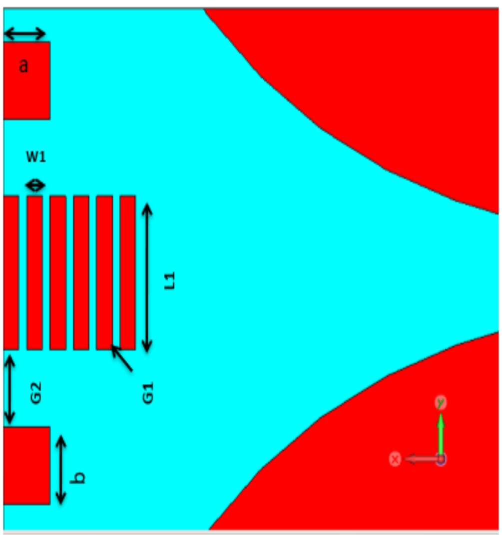

Fig.2b. Geometry of the Director Elements

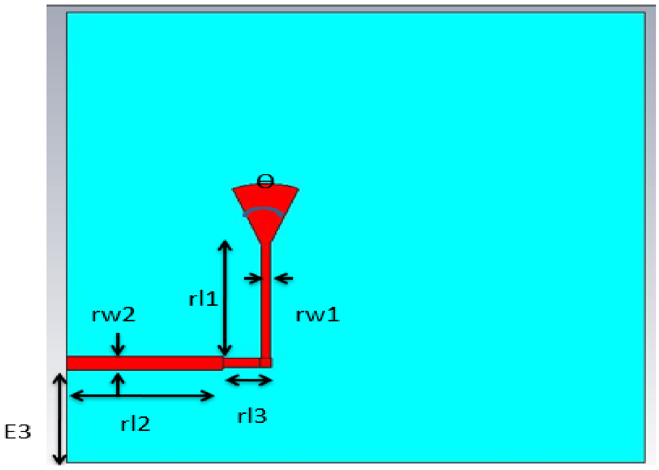

Fig.2c. Geometry of Bottom View with Radial Stub Feeding

Two semicircular slots of radius 7.5 mm and 5 mm, a string of rectangular slots of length 6 mm, width 0.5 mm, and the gap of 0.3 mm between the rectangular slots are selected and the slots are etched on both sides of the antenna. The addedslots focus the energy towards the aperture center and assist to maximize the antenna gain. Then the dimensions of the director's elements are optimized and added in the aperture regionfor improving the gain, efficiency, directivity and reduce E Plane Beam tilt further. The dimensions of the director are displayed in fig.2b and the optimized values are listed in Table.1

Table 1: Optimized Physical Parameters Values

Parameter	Values	Parameter	Values	Parameter	Values
L	50	a	1.5	rl1	12.25
W	48.4	b	2	rl2	13.5
R1	7.5	G1	0.25	rl3	4.2
R2	5	G2	2	rw1	0.75
EO	5	L1	4	rw2	1.5
d	3.6	W1	0.5	ϴ	45
E1	7.5	E2	11.69	E3	9.95

III. RESULTS AND DISCUSSIONS

The proposed antenna designs have been analyzed and optimized with the help of CST Microwave Studio software.The comparison of S_{11}(dB) results of the proposed Vivaldi Antenna (VA), the VA with Semicircular Slots (VASCS), the VA with Rectangular Slots and Semicircular Slots (VARSCS) and the VA with Rectangular Slots, Semicircular Slots and passive Directors (VARSCD) are plotted in Fig.3.

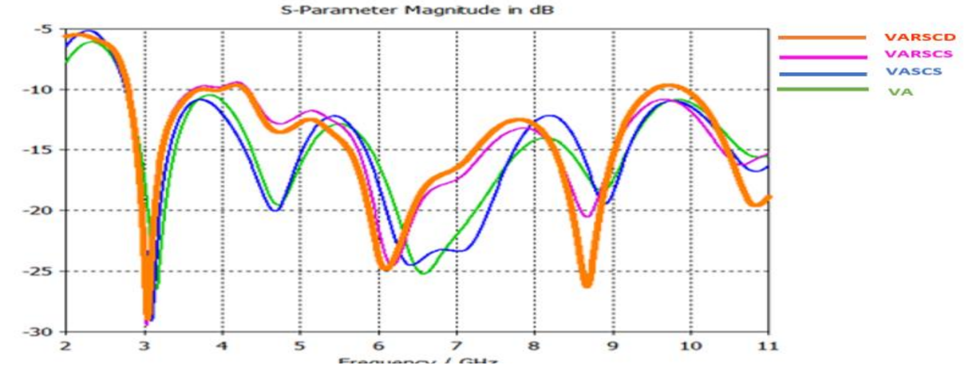

Fig.3. The simulated S_{11}(dB) results of the designed antenna geometries

It is obvious from Fig.3 that, the -10 dB operating bandwidth of all the proposed antenna geometry lies between (2.9-11) GHz. The impedance matching of the VARSCD antenna decreases compared to the other proposed antennas because of the director loading. However, the sizes ofpassive directors are optimized to maintain the S_{11} (dB) level of VARSCD antenna below -10dB.

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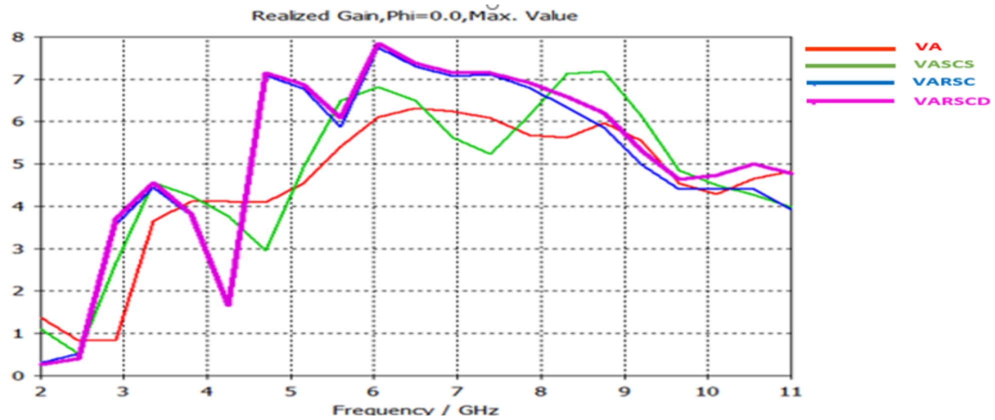

Fig.4 The simulated gain(dB) of the designed antennas

Fig.4 compares the gain of all the proposed geometry which shows that further addition of rectangular slots and the passive directors to the dual semicircular slots enhance the gain over a large bandwidth. It can be clearly seen from fig.4 that, the VARSCD antenna exhibits a gain more than 2 dBi over the desired bandwidth and the peak gain of 7.8 dBi at a frequency of 6 GHz.

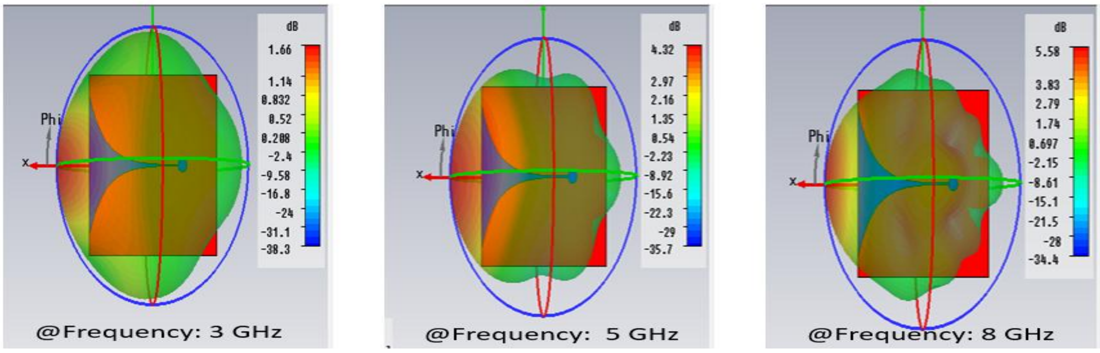

Fig.5a 3D gain pattern of the designed VA structure

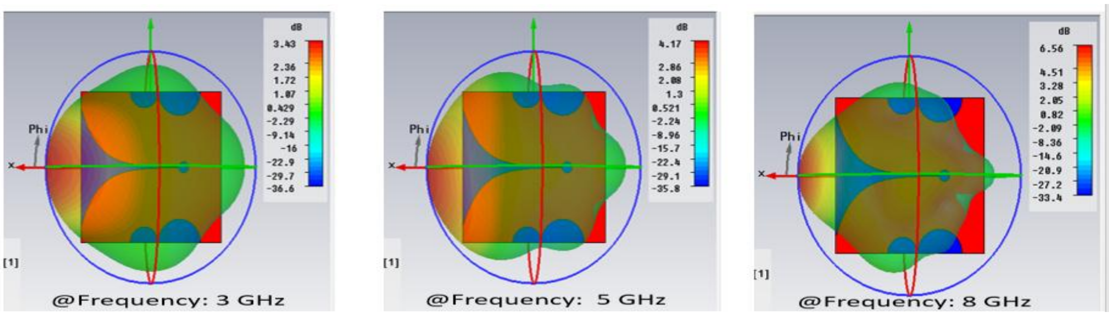

Fig.5b 3D gain pattern of the VASCS structure

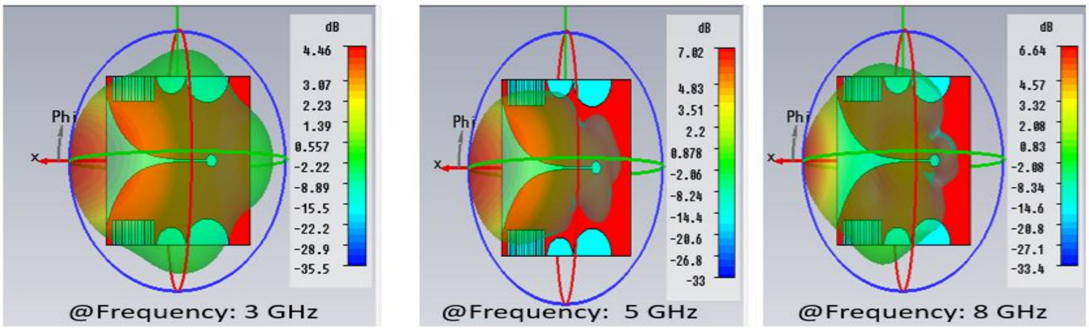

Fig.5c 3D Radiation pattern of the Proposed VARSCS structure

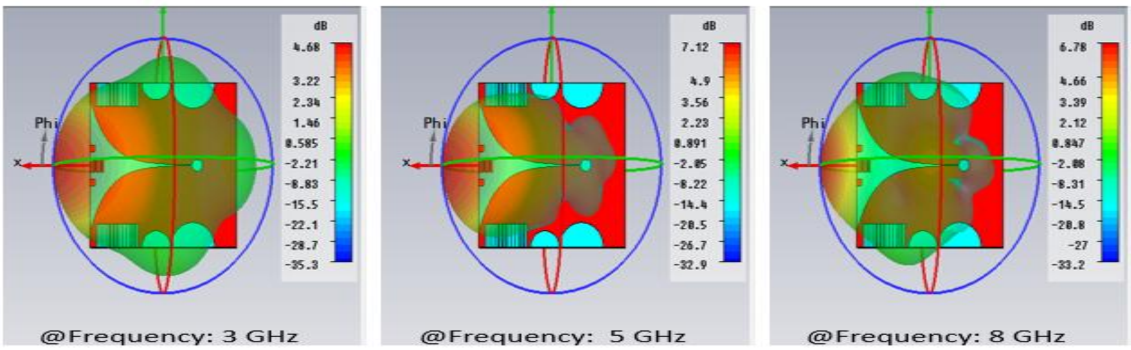

Fig.5d 3D gain pattern of the Proposed VARSCD structure

To further demonstrate the effect of the slots and the director loading, the 3D radiation gain pattern at various frequencies is displayed in fig.5a-5d for all the proposed antenna geometry. It can be clearly observed from the fig.5a-5d that all the antenna exhibits, unidirectional and a stable radiation pattern. It is apparent from Fig.5d that, the VARSCD antenna exhibits a more gain compared to other proposed antenna structures. To study the time-domain performance of the VARSCD, two antennae are placed facing each other with a separation distance of 60mm, and the transmitted signal and received signal are measured and displayed in fig.6a.

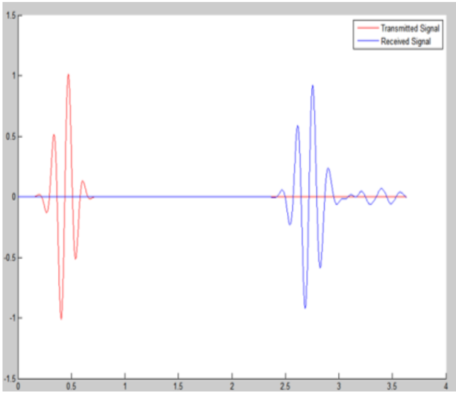

Fig.6a Transmitted Signal and Received Signal

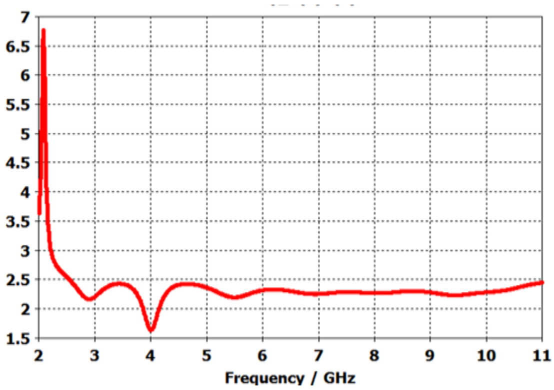

Fig. 6bGroup Delay

The correlation between the signal transmitted and signal received is analyzed by using a fidelity factor. The calculated fidelity factor in boresight direction is 0.96 which shows abetter similarity among the two signals. The group delay is analyzed as well, and it is displayed in Fig.6b. A flat group delay with approximately a 2ns delay with only $\pm 0.5ns$ differencesseen in the operating bandwidth, showing good time-domain characteristics.

IV. CONCLUSION

The design of Vivaldi antenna embedded withthe Rectangular, Semicircular slots and the passive Directors is presented.Compared to other proposed geometries, the VARSCDstructure shows, a significant improvement ofthe fields in theantenna aperturethat consequently supports to maximize the gain. The results showthe presented antenna providesultra-wide bandwidthextending from 2.9 GHz to 11 GHz, with a peak gain of 7.8 dB. The proposed antenna exhibits a stable radiation pattern and a flat group delay over the operating bandwidth. The measured fidelity factor in the boresight direction is 0.96 which revealsa good correlation between the transmitted and the received signals.

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