Optimization of UWB Vivaldi Antenna for Tumor Detection

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Abstract—An UWB Vivaldi Antenna structure is presented and analyzed for tumor detection of brain cancer. Various antenna configurations are considered in this analysis. The radiation is investigated inside a human head phantom with a tumor model. The antenna is designed with FR-4 substrate, and is tested when immersed in background of relative permittivity 40 to achieve good matching with the head tissue. Results show that good performance is obtained for the design size of 329.25x153x1.6 mm, and the antenna is found to operate in the range 100 Mhz to 1.4 GHz.

Keywords—Optimization; Antipodal Vivaldi Antenna; Microwave Imaging; Tumor Detection.

I. INTRODUCTION

Cancer is one of the main health challenges. Statistics reveal that around 13.2 million deaths of cancer are expected in 2030 [1]. Early detection of cancer is an important aspect for effective treatment. Widely used detection techniques include X-ray mammography, magnetic resonance imaging (MRI), and ultrasound technique [2]. Microwave imaging provides an alternative detection technique that requires simple configuration. The objective is to detect the variations in the dielectric properties of a tumor from the surrounding healthy tissue [3]. Recent technologies, particularly the use of ultra wideband (UWB) systems allow resolution enhancement in the detection [4].

Microwave tomography and radar based microwave imaging techniques have been investigated in cancer detection [5-7]. In microwave tomography, the electric field distribution is reconstructed by solving the inverse non-linear function problem. Using radar based microwave imaging techniques, UWB pulses are transmitted from antenna array that surrounds the human head. Analysis of the received scattered signals depending on beamforming techniques can be used to detect anomalies in the tissues [8-10].

This paper aims to investigate various Vivaldi antenna structures for brain cancer detection. Fig. 1, shows the proposed antenna structure, placed close to a human phantom. The return loss parameter $S_{11}$ is observed for as antenna dimensions are changed. This paper is organized as follows: Section II introduces the optimized Vivaldi antenna structure. Simulation results are discussed in Section III. Finally, conclusions are provided in Section IV.

II. ANTENNA DESIGN

Antipodal Vivaldi Antenna is attractive for use in microwave imaging applications. The structure has various advantages including having planar configuration, and being compact with light weight. The antenna can achieve ultra-wideband operation with acceptable efficiency, gain and directivity. Symmetric beam in the E-plane and the H-plane is realizable. UWB Vivaldi antenna presents an attractive configuration for biomedical applications [11-13]. Examples of the usage of antipodal antenna for microwave imaging applications is described in the literature [14, 15].

Figure 1. Illustration of the proposed system Configuration.

In this paper, an UWB Vivaldi antenna is optimized for brain cancer detection. The antenna is designed on dielectric substrate with two-sided metallization, and is fed via a micro-strip line, which leads into exponentially tapered fins [16]. The antenna shown in Fig. 2 has inner and outer edges that are governed by:

$$Y_{outer} = a_1 e^{b_1 x^2} + C_1$$
$$Y_{inner} = a_2 e^{b_2 x^3} + C_2$$

Where x and y refer to the horizontal and vertical dimensions in Fig. 2. $Y_{outer}$ and $Y_{inner}$ represent the outer and inner edges respectively. The constants $a_1, a_2, b_1, b_2, C_1,$ and $C_2$ are used...
such that $a_1 = a_2 = 100$, $b_1 = 200 \times 10^6$, $b_2 = 200 \times 10^9$, $C_1 = -99.25$ mm, $C_2 = -100.75$ mm as described in [16].

The maximum values of $Y_{inner}$ and $Y_{outer}$ are changed to control the vertical and the horizontal dimensions of the antenna $V$ and $H$. Table 1 presents the dimensions of ten considered configurations. The effect of antenna size on performance is investigated.

![Antenna Configuration](image)

**Figure 2.** Illustration of Antipodal Vivaldi Antenna configuration.

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Maximum Value of $Y_{inner}$</th>
<th>Maximum Value of $Y_{outer}$</th>
<th>Overall Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna 1</td>
<td>80</td>
<td>41.4</td>
<td>88.77x80x1.6</td>
</tr>
<tr>
<td>Antenna 2</td>
<td>100</td>
<td>41.4</td>
<td>88.77x103x1.6</td>
</tr>
<tr>
<td>Antenna 3</td>
<td>100</td>
<td>50</td>
<td>136.74x103x1.6</td>
</tr>
<tr>
<td>Antenna 4</td>
<td>150</td>
<td>69.275</td>
<td>329.25x153x1.6</td>
</tr>
<tr>
<td>Antenna 5</td>
<td>135</td>
<td>41.4</td>
<td>88.77x138x1.6</td>
</tr>
<tr>
<td>Antenna 6</td>
<td>50</td>
<td>41.4</td>
<td>88.77x53x1.6</td>
</tr>
<tr>
<td>Antenna 7</td>
<td>135</td>
<td>55</td>
<td>173.25x138x1.6</td>
</tr>
<tr>
<td>Antenna 8</td>
<td>60</td>
<td>30</td>
<td>46.44x63x1.6</td>
</tr>
<tr>
<td>Antenna 9</td>
<td>50</td>
<td>20</td>
<td>23.65x53x1.6</td>
</tr>
<tr>
<td>Antenna 10</td>
<td>50</td>
<td>30</td>
<td>46.44x53x1.6</td>
</tr>
</tbody>
</table>

With the increase of frequency of operation, the resolution is enhanced, while the energy penetration is reduced. There is thus a trade-off between penetration and resolution. Achieving wideband of operation can provide the advantages associated with both the low and high ranges of operation.

The antenna is designed using FR-4 with relative permittivity of 4.3 and loss tangent of 0.025. The antenna is simulated using CST Microwave Studio [17]. The background material is taken to be of relative permittivity 40 to achieve good matching with the head tissue.

The return loss $S_{11}$ of the antenna are observed for each individual structure. A cylinder is used as a simple human head model. Fig. 3 shows the proposed system. The brain properties is used such that the relative permittivity is 42 and the electrical conductivity is 0.45 S/m. A malignant tumor is inserted inside this phantom with relative permittivity 1.6 times that of the brain value and conductivity that is twice the value of the brain value, as suggested in [18]. Investigation of the performance of these antenna structures is introduced next.

**III. RESULTS**

The geometry of the antenna is varied by changing the two main parameters $V$ and $H$ shown in Fig. 2. Fig.4 shows the return loss parameter $S_{11}$ of antenna-1, where $S_{11}$ is found to be less than -10dB from 0.3GHz to 2.66 GHz. The return loss $S_{11}$ of the antenna is also investigated close to the head phantom in the absence and presence of tumor.

In antenna-2 configuration, the inner length is changed from 80 to be 100 mm. The antenna thus becomes wider and the return loss varies as shown in Fig. 5.

![Proposed Model](image)

**Figure 3.** Illustration of the proposed model.
In order to study the effect of the size of various structures of the antenna, the return loss parameter is investigated for all these configurations. Fig. 6 to Fig. 13 illustrate the return loss $S_{11}$ of the proposed antennas 3 to 10. The $S_{11}$ parameter of antenna 3 is found to be less -10 dB from 0.208 to 2.636 GHz.

Antenna 4 has overall size 136x103x1.6 mm. The structure is found to operate in the frequency band from 0.5 to 1.3 GHz. Antenna 4 has the biggest inner and outer length values. The overall size of this antenna configuration is 329.25x153x1.6 mm as shown in Table I. The antenna is shown in Fig. 4 to operate starting from 0.088 GHz.
Fig. 12 to Fig. 13 illustrate the return loss $S_{11}$ of the proposed antenna-9 and antenna-10. The $S_{11}$ is less -10 dB from 0.75 to 2.5 GHz for antenna-9. Antenna-10, however, gives better penetration depth than antenna-9 because it works from 0.5 GHz.

The specific absorption rate (SAR) is investigated for antenna structure number 3. The IEEE C95.3 method is used [19, 20]. In SAR calculation, a cube is grown around the specific point until it contains the required mass of 1-g of tissue. SAR is calculated corresponding to 500 W source. SAR maps are shown in Fig. 14 to Fig. 17, corresponding to frequency values of 0.25, 0.50, 0.75 and 1 GHz, respectively. Results shows that the SAR depends on the frequency of operation. Less penetration is observed for higher frequency values.
IV. CONCLUSIONS

In this paper, An UWB Vivaldi Antenna is optimized for operation in microwave imaging for tumor detection. Various structures are developed. Simulation provide effective tool to optimize the design of the antenna and thus maximize the energy interaction with the tissues to be detected.

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REFERENCES


