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طراحی یک آنتن ویوالدی پهن باند تراهرتز با بهره و سمت گرایی بالا

میترا میرصالحی، زهرا کاوه وش و مهدی فردمنش

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چکیده- در این مقاله یک آنتن ویوالدی پهن باند برای بازه فرکانسی ۰/۵ تا ۳ تراهرتز طراحی و با نرم افزاری مبتنی بر روش المان محدود شبیه سازی شده است. ابعاد این آنتن ۱۰/۲×۴۰۰×۴۳۲ میکرو متر، بستر آن کوارتز و لایه های هادی به کار رفته در آن از جنس طلا است. آنتن مذکور سمت گرا بوده و میزان سمت گرایی آن در بازه فرکانس فوق بین حداقل۴/۵۳ دسی بل تا حداکثر ۹/۴۰ دسی بل است و همچنین، بیشترین میزان بهره و بازدهی آن به ترتیب۸/۵۰ دسی بل و ۸۴/۴۳ درصد در شبیه سازی به دست آمده است. آنتن طراحی شده در مقایسه با پژوهش های مشابه منتشر شده دارای مشخصات تشعشعی بهتری است. با توجه به مشخصات آنتن مذکور در بازه تراهرتز می توان از آن در تصویر برداری و طیف سنجی به جهت شناسایی و تفکیک مواد استفاده کرد.

کلید واژه- آنتن تراهرتز، آنتن ویوالدی، آنتن پهن باند، بهره زیاد، سمت گرایی زیاد.

Design of a wideband, high-gain and high-directivity THz Vivaldi antenna

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Abstract- In this paper, a wideband Vivaldi antenna is designed for the frequency range of 0.5-3 THz and simulated by a software package based on the finite element method. The antenna has dimensions of 432µm × 400µm ×10.2µm, its substrate is quartz, and the conducting layers are made of gold. The designed antenna is highly directive; its directivity in the above mentioned frequency range is between the minimum of 4.53 dB and the maximum of 9.40 dB. Also, from simulation results, its maximum gain and efficiency were found to be 8.50 dB and 84.43%, respectively which make it superior to similar antennas reported in the literature. The proposed antenna can be used in THz imaging and spectroscopy to detect materials that have THz signatures in this region.

Keywords: THz antenna, Vivaldi antenna, wideband antenna, high gain, high directivity.

1. Introduction

Terahertz (THz) spectrum, which lies between infrared and microwave regions, has been of great interest recently due to the impressive developments in the THz generation and detection techniques, and also due to finding potential applications of THz spectroscopy and imaging in quality control, medicine, and safety [1]. Generation of THz waves can be achieved by using femtosecond lasers or electronic systems. In the former technique, an optical pulse is used to generate THz waves using photoconductivity phenomenon [2], while in the latter, they are created by propagating a relatively low-frequency signal in a nonlinear transmission line [3]. An important issue in both techniques is the design of efficient antennas [2,3].

Different types of antennas have been proposed for THz systems, such as dipole antenna, patch antenna, and metamaterial antenna. Among them, Vivaldi antenna has suitable features, including wide bandwidth, high directivity, simple fabrication, planar structure, and linear polarization. Vivaldi antenna was first introduced by Gibson in 1979 for radar and ultra-wideband systems. Because of its features, it has also been designed for mm and THz systems [4,5].

In this paper, we have designed a THz Vivaldi antenna operating in the range of 0.5-3 THz which can be used in the detection of materials that have spectral signatures in this region. The structure of the paper is as follows: Section 2 is devoted to the design of the Vivaldi antenna. The specifications of the antenna, such as directivity, efficiency, gain, and return loss are provided in Section 3 and compared with previously published papers. Finally, Section 4 is devoted to Conclusion.

2. Antenna design

As it is shown in Fig. 1, the proposed antenna consists of two thin film gold layers of thickness t printed on both sides of a quartz substrate of 10µm height with relative permittivity $\varepsilon_r = 3.78$ and electric loss tangent $\tan\delta_e = 0.0001$. The gold layers are micro striplines on the top and bottom of the substrate. In simulation, the Drude model for relative permittivity of gold was used:

$$\varepsilon_r = \varepsilon_{re} + i\varepsilon_{im} = \varepsilon_\infty - \frac{f_p^2}{f^2 + if\Gamma} , \tag{1}$$

where ε_∞ is the relative permittivity at infinite frequency, f_p is the plasma frequency and Γ is the damping frequency. The values of these parameters are 1, 2.184 PHz, and 6.45 THz, respectively [6].

Theoretically, the upper frequency limit of a Vivaldi antenna is infinity while the lower frequency limit is related to the dielectric substrate and the width of the antenna (w) as follows:

$$f_1 = \frac{c}{w}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{2}$$

The length of the antenna and the two major and minor radii of the ellipses in Fig. 1 are calculated by the following equations [7]:

$$l = w \tag{3}$$

$$a_1 = l + c \tag{4}$$

$$b_1 = \frac{w + w_m}{2} \tag{5}$$

$$b_2 = \frac{w - w_m}{2} \tag{6}$$

$$a_2 = 0.6\ \mathrm{b}_2 \tag{7}$$

where c is a controllable variable and is 90µm in this structure. All geometrical parameters of the proposed antenna are depicted in Table I:

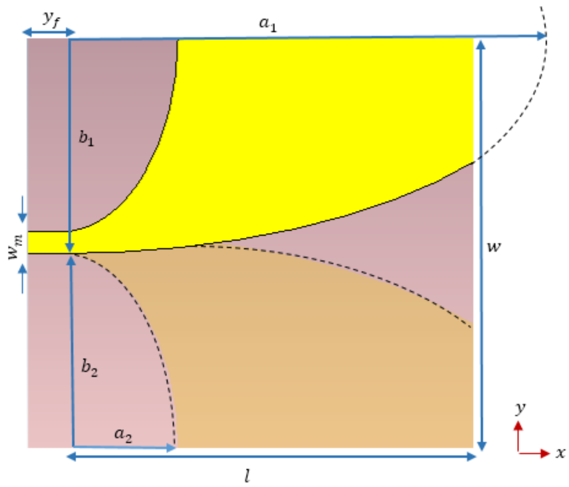

Fig. 1: Geometry of the proposed antenna

Table I. Parameters of the proposed antenna

Parameter	Value (μm)
w	400
y_f	32
w_m	21
t	0.2
a_1	490
a_2	113.7
b_1	210.5
b_2	189.5

3. Results

We used the finite element method (FEM) to analyze the designed antenna. The simulated return loss (S_{11}) of the antenna is plotted in Fig. 2. As it is shown, the acceptable impedance matching ($|S_{11}|<$ -10dB) has a wide bandwidth of about 3 THz. In Fig. 3, both the maximum realized gain and total efficiency of the antenna are depicted. The lowest and highest calculated gains are 3.32 dB at 0.5 THz and 8.50 dB at 2.5 THz, respectively. Also, the total efficiency of the antenna varies from 75.69% at 0.5 THz to 84.43% at 0.7 THz. High efficiency of the proposed antenna implies that the metallic and dielectric losses of gold and quartz at this frequency band have minor effect on the performance of the antenna. The far field pattern in the E (XY) plane and H (XZ) plane at two selected frequencies are shown in Fig. 4. The dark blue lines show the major radiation direction and the light blue lines indicate the 3dB beamwidths which are 77.6° at 0.5 THz and 28.0° at 2.5 THz in the $\theta = 90°$ plane. The

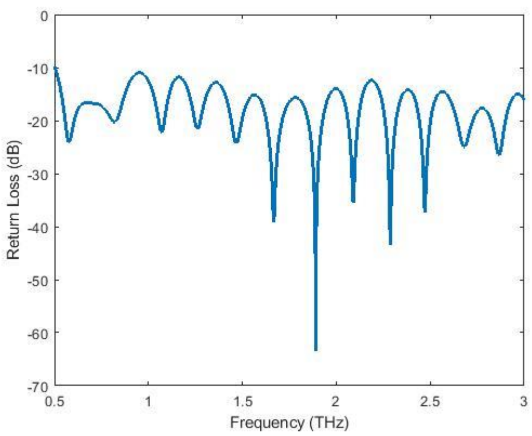

Fig. 2: Return loss of the proposed antenna.

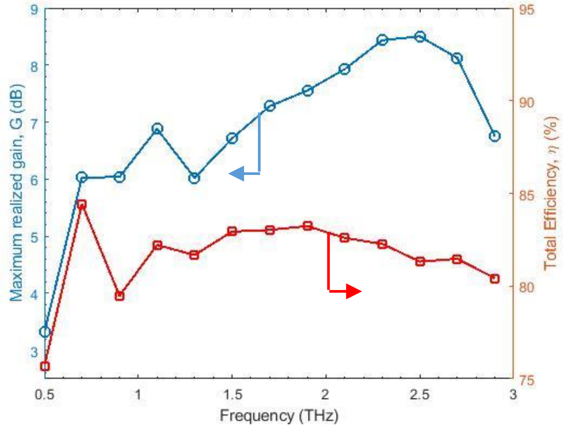

Fig. 3: Simulated realized gain and total efficiency of the proposed antenna.

corresponding values for the antenna pattern in the $\varphi = 0°$ plane are 125.6° and 62.9° as shown in Figs. 4(c) and 4(d). For more detailed information, the directivity of the antenna in the E plane is plotted in Fig. 5. The directivity of the proposed antenna in the E plane, varies from 4.53 dB at 0.5 THz to 9.40 dB at 2.5 THz which satisfies the expected directivity of the patch type antennas.

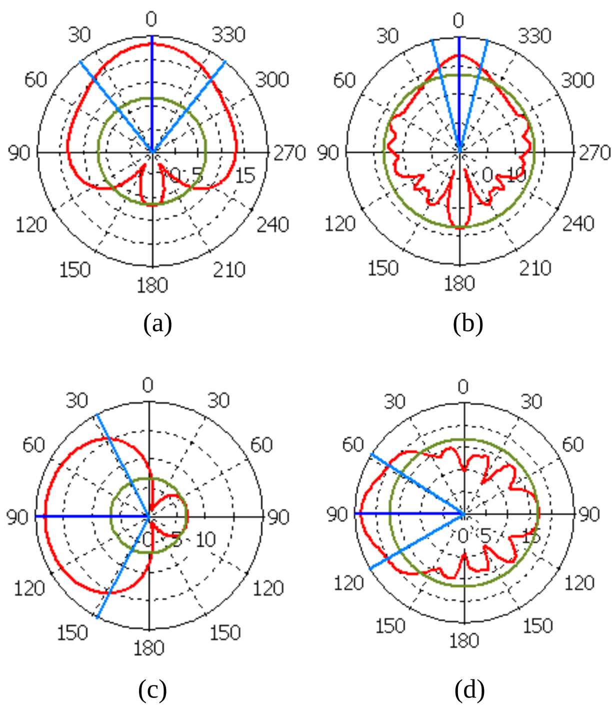

Fig. 4: Far field pattern of the E field in the XY plane ($\theta = 90°$) at (a) 0.5 THz (b) 2.5 THz and in the XZ plane ($\varphi = 0°$) at (c) 0.5 THz and (d) 2.5 THz

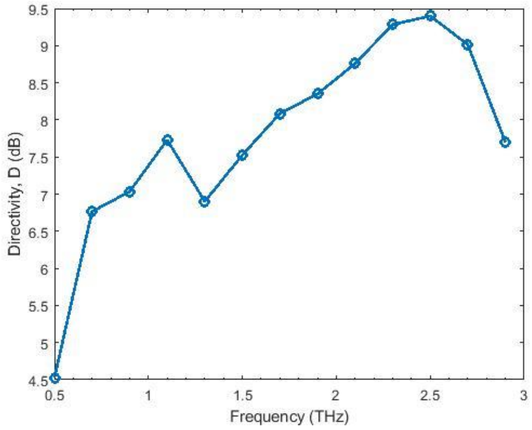

Fig. 5: Simulated directivity of the proposed antenna in the E plane

For comparison, the radiation specifications of the proposed antenna and two THz antennas reported in [4,8] are provided in Table II. As it is shown, the maximum gain (G_{max}) of the proposed antenna has 10 dB and 3.8 dB improvement compared with [4] and [8], respectively. Significant increment of almost five times for the maximum efficiency (η_{max}) of the proposed antenna is achieved in comparison to [4] at the specified spectrum. Also, the superiority of the proposed antenna in the maximum directivity (D_{max}) is shown in the same table.

Table II. Comparison of the proposed antenna with the antennas in [4] and [8]

	Proposed Antenna	**[4]**	**[8]**
Antenna model	Vivaldi	Vivaldi	Log Spiral
Frequency Range (THz)	0.5-3	0.1-6	0.1-3
G_{max} **(dB)**	8.50 @ 2.5 THz	-1.60 @ 5.5 THz	4.72 @ 2.2 THz
η_{max} **(%)**	84.43 @ 0.7 THz	16.30 @ 5.25 THz	81.50 @ 1.38 THz
D_{max}**(dB)**	9.40 @ 2.5 THz	7.80 @ 6.0 THz	5.61 @ 2.05 THz

4. Conclusion

In this paper, we designed a wideband terahertz Vivaldi antenna operating in the range of 0.5THz to over 3THz which is suitable for THz spectroscopy and imaging. The antenna has superior radiation characteristics such as higher efficiency (η_{max}= 84%), increment in gain (G_{max}= 8.50 dB) and more directivity (D_{max}= 9.4 dB). We have utilized the proposed antenna in detecting specific materials which will also be reported in near future.

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