Journal of Engineering Research

Volume 7
Issue 5 *This is a Special Issue from the Applied Innovative Research in Engineering Grand Challenges (AIRGEC) Conference, (AIRGEC 2023), Faculty of Engineering, Horus University, New Damietta, Egypt, 25-26 October 2023*

Article 18

2023

A Compact Low Frequency Vivaldi Antenna for Ground Penetrating Radar

Amr Hussein, Ahmed M. Elshenawy, Ahmed M. Elkhawaga

Journal of Engineering Research (ERJ)
Vol. 7 – No. 5, 2023
©Tanta University, Faculty of Engineering

ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

A Compact Low Frequency Vivaldi Antenna for Ground Penetrating Radar

Amr H. Hussein[1, 2], Ahmed M. Elshenawy [1], and Ahmed M. Elkhawaga[1]
[1] Electronics and Electrical Communications Engineering Dept., Faculty of Engineering Tanta University, Tanta, Egypt.
[2] Electronics and Communications Engineering Dept., Faculty of Engineering, Horus University, New Damietta, Egypt.
Email: amrvips@yahoo.com, ahmed.elshenawy182014@gmail.com, a_yasser2012@yahoo.com

***Abstract*- One of the most important parts in ground penetrating radar (GPR) system is the antenna. To transmit the waves to deep depths, the operating frequency should be decreased as possible. A compact Vivaldi antenna is proposed with operating frequency of $0.4\,GHz$ and dimensions of $(0.26\lambda_o \times 0.21\lambda_o \times 0.002\lambda_o)$, where λ_o is the free-space wavelength at the operating frequency. To increase the gain of the Vivaldi antenna, the length of antenna should be increased. The conventional Vivaldi antenna length should be greater than λ_o. In order to improve the gain of the Vivaldi antenna while maintaining a compact size, a triple slot line structure is proposed. The Vivaldi antenna is etched on a thin economic substrate (FR4) with permittivity of $\varepsilon_r = 4.4$ and thickness of $h = 1.6\,mm$.**

***Keywords*- Ground penetrating radar, Vivaldi Antenna, tapered slot antenna, low frequency.**

I. INTRODUCTION

The basic idea of ground penetrating radar (GPR) is to emit an electromagnetic wave into ground direction, then the reflected wave from buried objects is received by the antenna system [1]. The antenna element has a significant role for GPR system performance. To detect deep buried targets, the operation frequency is needed to be low. Designing a compact antenna with low frequency is a challenging problem. Many types of antennas are proposed for GPR systems, such as horn antennas [2], resistively loaded dipole [3], bow-tie antenna [4], spiral antenna [5], double exponentially tapered slot antenna [6] and half-ellipse antenna [7]. The Vivaldi antenna which first introduced by Gibson [8], exhibits a good radiation characteristic with advantages of light weight, compact size, low fabrication cost and endfire radiation. For these advantages, Vivaldi antenna is a good choice for GPR applications [6]. Vivaldi antenna belongs to the family of travelling-wave antennas. Travelling-wave antennas are divided into two main classes, first class called "surface-wave antennas" that use a travelling wave structure, where the phase velocity V_{ph} is less than or equal the velocity of the plane wave propagating in free space, which the main beam direction is an endfire, second class called "leaky-wave antennas", where the phase velocity V_{ph} is greater than the velocity of the plane wave propagating in free space, which the main beam direction is not an endfire [9]. Plus, the low sidelobes and endfire radiation, Vivaldi antenna can produce a symmetric beam in (E-plane and H-plane), the E-plane is parallel to the substrate and H-plane is perpendicular to the substrate. Increasing the length of this antenna increases the antenna gain and narrows the beamwidth [10].

In this paper, a compact triple slot line Vivaldi antenna (TSLVA) with multistage structure is proposed. The design is very simple and low cost to fabricate. The gain of this design is higher than a conventional Vivaldi antenna with the same size due to the multistage structure with triple slot line make the field distribution more uniform [11]. The proposed TSLVA is proposed for low-frequency ground penetrating radar applications. The TSLVA offers improved gain and beam characteristics compared to conventional Vivaldi antennas of similar size. The simplicity and cost-effectiveness of the design, along with the enhanced performance, make the TSLVA a promising choice for GPR systems operating at low frequencies. Further experimental validation and optimization of the antenna design are recommended for future research.

II. PROPOSED ANTENNA DESIGN

The proposed antenna is designed and simulated using HFSS software package. Shown in Fig. 1 (a) the top view of the proposed TSLVA, the bottom view of the proposed TSLVA is shown in Fig .1 (b). The dimensions of the antenna are set to be $(20 \times 16 \times 1.6)\ mm^3$ which equivalents to $(0.26\lambda_o \times 0.21\lambda_o \times 0.002\lambda_o)$. Presented in Table 1, the structure parameters of the antenna. The antenna is printed on low cost FR4 substrate with permittivity of 4.4 and thickness of 1.6 mm. The utilized curves equations are described as follows:

$$y_1 = \pm 0.3e^{0.3x} \qquad 0 \le x \le 9\,(cm) \qquad (1)$$

$$y_2 = \pm 0.2e^{0.4x} + 5 \qquad 0 \le x \le 9\,(cm) \qquad (2)$$

$$y_3 = \pm 0.2e^{0.4x} - 5 \qquad 0 \le x \le 9\,(cm) \qquad (3)$$

Table 1: The structure parameters of the proposed TSLVA.

Parameter	Value (cm)	Parameter	Value (cm)
Lslot	6	Wf	0.3
g1slot	0.6	Lf	17
g2slot	0.4	EXT	1
L	16	Ledge	3
W	20		

doi: 10.21608/erjeng.2023.237508.1250

ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

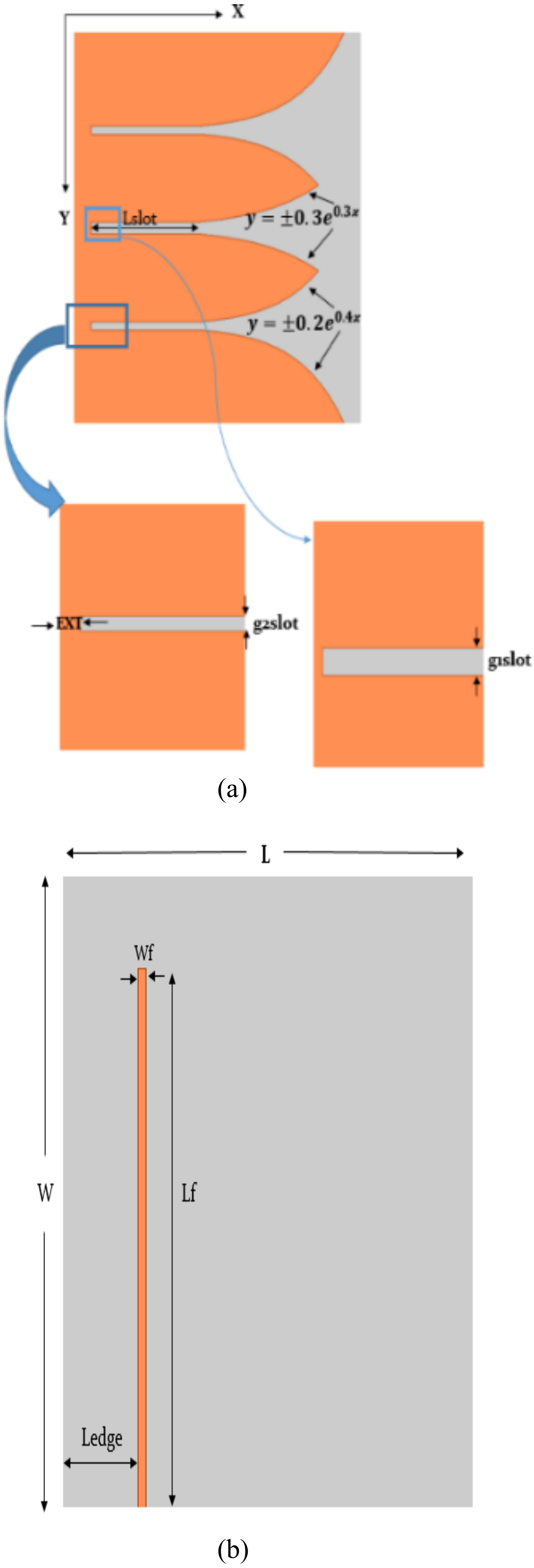


Fig. 1. Proposed TSLVA (a) Top view. (b) Back view.

III. Results and discussions

The proposed antenna is designed and simulated using HFSS software package. The simulated scattering parameter S_{11} is shown in Fig. 2. It is clear that the antenna has an operating frequencies of $0.4\ GHz$. The Bandwidth of the proposed antenna is narrow. The wideband is not critical for GPR applications as detecting deep targets (like landmines) is more important than the resolution. Fig. 3 describes the simulated gain of the proposed antenna versus frequency in the frequency range from $0.2\ GHz$ up to $1\ GHz$. It provides a maximum gain of $4.8\ dB$ at $1\ GHz$. while the gain at the first resonance frequency $0.4\ GHz$ equals $2.9\ dB$. With a compact size of the antenna at low operating frequency, this moderate gain could be acceptable.

The simulated radiation efficiency of the proposed antenna versus frequency is shown in Fig. 4. The antenna has a very high radiation efficiency, about 94% at $0.4\ GHz$. The simulated two-dimensional radiation patterns in E-plane and H-plane at $0.4\ GHz$ are illustrated in Fig. 5. While Fig. 6 shows the three dimensions radiation patterns of the proposed antenna at $0.4\ GHz$ which demonstrates an endfire antenna.

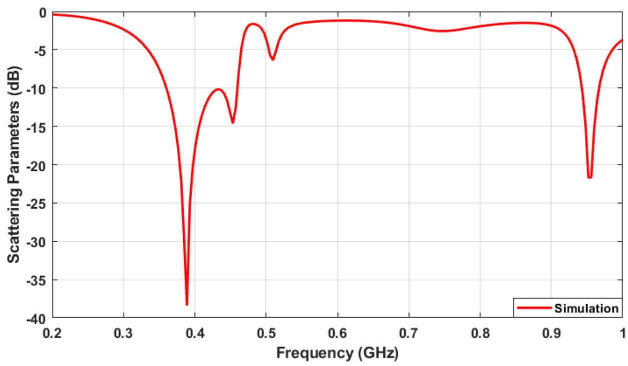


Fig. 2. Simulated scattering parameter S_{11} of the proposed antenna versus frequency in frequency range from 0.2 GHz up to 1 GHz.

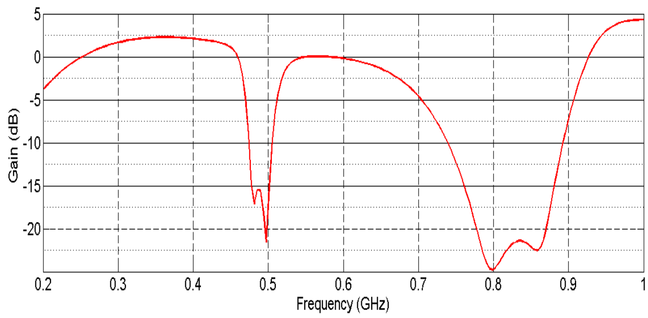


Fig. 3. Simulated gain of the proposed antenna versus frequency in frequency range from 0.2 GHz up to 1 GHz.

doi: 10.21608/erjeng.2023.237508.1250

Journal of Engineering Research (ERJ)
Vol. 7 – No. 5, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

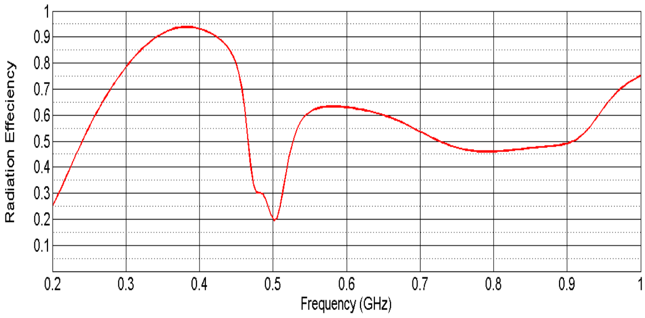
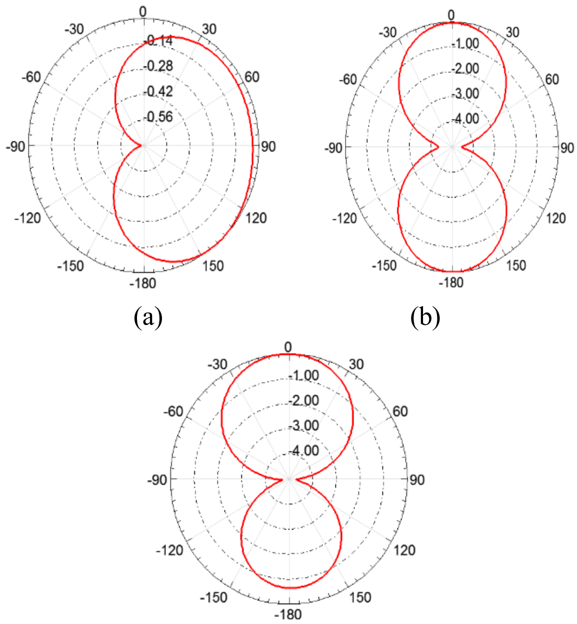


Fig. 4. Simulated radiation efficiency of the proposed antenna versus frequency in frequency range from 0.2 GHz up to 1 GHz.



(a) (b)

(c)

Fig. 5. 10 dB Normalized 2D radiation pattern at 0.4 GHz: (a) 2D radiation pattern $\Phi = 0°$. (b) 2D radiation pattern $\Phi = 90°$. (c) 2D radiation pattern $\theta = 90°$.

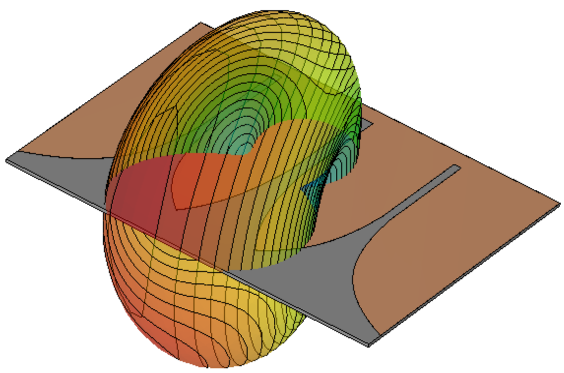
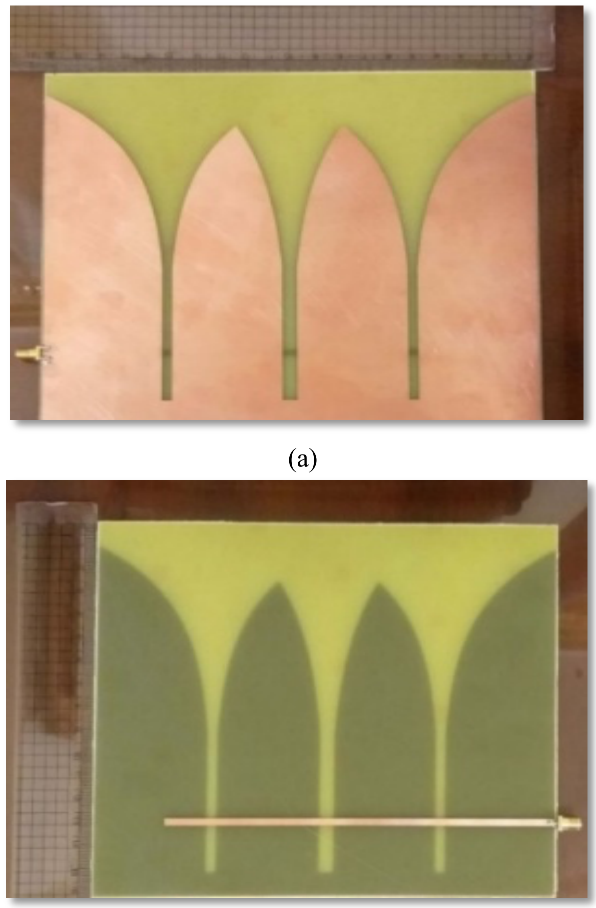


Fig. 6. Three dimensions radiation patterns of the proposed antenna at 0.4 GHz.

IV. FABRICATION AND MEASUREMENTS

The fabricated TSLVA is shown in Fig. 7, the top view shown in Fig. 7 (a) and the back view is shown in Fig. 7 (b). The scattering parameter S_{11} or reflection coefficient is measured using a vector network analyzer (VNA). The comparison between the simulated and measured scattering parameter S_{11} of the proposed antenna indicates a good agreement as shown in Fig. 8. Noticed that there is some little difference between the simulated and measured results due to fabrication tolerance and soldering the SMA connector.



(a)

(b)

Fig. 7. Fabricated TSLVA: (a) Top view and (b) Back view.

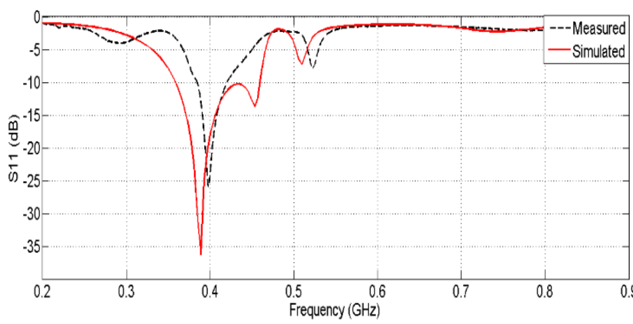


Fig. 8. Comparison between the simulated and measured scattering parameter S_{11}.

doi: 10.21608/erjeng.2023.237508.1250

©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

V. CONCLUSION

Numerous GPR applications need a low-frequency operation in order to find deep objects (like landmines). The proposed TSLVA is designed and manufactured with a compact size of $(20 \times 16 \times 1.6)\ mm^3$, moderate gain of 2.9 dB, and extremely high efficiency of 94 % at a low operating frequency of 0.4 GHz. The TSLVA has a relatively simple construction and affordable manufacturing which makes it a suitable choice for underdeveloped and emerging nations.

Funding: This research has not received any type of funding.

Conflicts of Interest: The author declares that there is no conflict of interest.

References

[1] D. J. Daniels.: ‘Ground Penetrating Radar’, London, U.K.: IEEE, 2nd ed, 2004.

[2] A. Ahmed, Y. Zhang, D. Burns, D. Huston and T. Xia.:‘Design of UWB Antenna for Air-Coupled Impulse Ground-Penetrating Radar’, in IEEE Geoscience and Remote Sensing Letters, , vol. 13, no. 1, pp. 92-96, Jan. 2016.

[3] H. Yang and K. Kangwook.: ‘Ultra-wideband impedance matching technique for resistively loaded Vee dipole antenna’, IEEE Trans. Antennas Propag., , vol. 61, no. 11, pp. 5788–5792, Nov. 2013.

[4]A. A. Lestari, A. G. Yarovoy, and L. P. Ligthart.: ‘RC-loaded bow-tie antenna for improved pulse radiation’, IEEE Trans. Antennas Propag., vol. 52, no. 10, pp. 2555–2563, Oct. 2004.

[5] H. Nakano, T. Igarashi, H. Oyanagi, Y. Iitsuka, and J. Yamauchi.: ‘Unbalanced-mode spiral antenna backed by an extremely shallow cavity’,IEEE Trans. Antennas Propag., vol. 57, no. 6, pp. 1625–31633, Jun. 2009.

[6] F. Zhang, G. Fang, Y. Ji, H. Ju and J. Shao.: ‘A Novel Compact Double Exponentially Tapered Slot Antenna (DETSA) for GPR Applications’, in IEEE Antennas and Wireless Propagation Letters, vol. 10, pp. 195-198, 2011.

[7] X. Li, Y. Ji, W. Lu and G. Fang.: ‘Analysis of GPR Antenna System Mounted on a Vehicle’, in IEEE Antennas and Wireless Propagation Letters, vol. 12, pp. 575-578, 2013.

[8] P. J. Gibson.: ‘The Vivaldi aerial’, in Proc. 9th Eur. Microw. Conf., pp. 101–105, 1979.

[9] K. S. Yngvesson, D. H. Schaubert, T. L. Korzeniowski, E. L. Kolberg, T. Thungren, and J. F. Johansson.: ‘Endfire tapered slot antennas on dielectric substrate’, IEEE Trans. Antennas Propag., vol. 33, no. 12, pp. 1392–1400, Dec. 1985.

[10] K. S. Yngvesson, T. L. Korzeniowski, Y. -. Kim, E. L. Kollberg and J. F. Johansson.: ‘The tapered slot antenna-a new integrated element for millimeter-wave applications’, in IEEE Transactions on Microwave Theory and Techniques, vol. 37, no. 2, pp. 365-374, Feb. 1989.

[11] Y. Wang, G. Wang and B. Zong.: ‘Directivity Improvement of Vivaldi Antenna Using Double-Slot Structure’, in IEEE Antennas and Wireless Propagation Letters, vol. 12, pp. 1380-1383, 2013.

doi: 10.21608/erjeng.2023.237508.1250