# Modification of Vivaldi Antenna for 2-18 GHz UWB Application with Substrate Integration Waveguide Structure and Comb Slots

**Ferdows B. Zarrabi [1], Navid P. Gandji [2], Rahele Ahmadian [3], Hamed Kuhestani [3], and Zahra Mansouri [3]**

[1] School of Electrical and Computer Engineering
Tarbiat Modares University, Tehran, Iran
ferdows.zarrabi@modares.ac.ir

[2] Electrical and Computer Engineering Department
Michigan Technological University, MI, USA
npourram@mtu.edu

[3] Faculty of Eng., Science and Research Branch
Islamic Azad University, Tehran-Iran
zm.mansouri@gmail.com, h.kuhestani@srbiau.ac.ir, raheleahmadian@gmail.com

***Abstract*** **─** In this paper have been developed two new Vivaldi antenna for UWB application at 2-18 GHz with SIW structure for linear phase center labeled as antenna I and antenna II. The proposed antennas have high gain and directional patterns with symmetric radiation pattern in phi=0 and phi=90 planes. The SIW structure is combined with Vivaldi antenna in order to improve the gain, pattern and phase center linearity. Similarly, for gain improvement at lower frequencies for SIW antenna and with less divergence in the gain, slots with comb models are proposed. The prototype antenna is printed and fabricated on Roger 4003 with $\varepsilon r = 3.45$ and thickness of 1.5 mm. The antenna's total dimension is 120 mm × 160 mm. The simulation and experimental VSWR and the gain of antenna I and II is less than 2.5 and 6 dBi - 15 dBi, and 2.4 for 2.17-18 GHz and 8.2 dBi - 15.5 dBi in the entire frequency range of 2-18 GHz respectively. Likewise, the Vivaldi antenna phase center is investigated and finally the linear characteristic of the antenna phase center is presented with linear variation.

***Index Terms*** **─** Substrate integration waveguide, UWB, Vivaldi antenna.

## I. INTRODUCTION

Nowadays, broadband systems are designed for faster communication and more data transfer, so it is required to design ultra-wideband (UWB) and multiband antennas in order to support all protocols of wireless applications [1-2]. UWB radio is a transmission technology that is based on short pulses, and this technology usually covered more than several GHz. UWB systems because of their wide bandwidth and economics advantages have been used in communication systems, radio communication, and medical imaging such as breast cancer radar [3-4]. All the above-mentioned applications require small sized, easily feed and low cost antennas. Microstrip compact antennas can be used in mobile communication, WLAN, radar and microwave imaging systems [5-6]. Microstrip circular, elliptical, and spiral models of patch antenna are being used for designing UWB structures for omni directional applications. CPW circular patches and small ground are two methods, which are used for increasing the antenna impedance bandwidth [7-8]. However, the circular and elliptical CPW (coplanar waveguide) patch has a semi omni-directional pattern and cavity back spiral antenna have limited gain. Therefore, it is proposed to design new UWB antenna with high gain and directive pattern. For this reason, some types of quasi Yagi and Log periodic antennas with high gain and directivity have been introduced up to now. On the other hand, Vivaldi antennas are much more noticed than other types of directional antennas because of its advantages such as improved inner band characteristic, large bandwidth, good directional radiation pattern in the entire frequency band, favorable symmetrical end-fire radiation characteristic and high gain in the central frequency band [9-11]. Too many models of Vivaldi antennas are being considered in many researches and they divided this antenna into different groups such as antipodal and tapered slot Vivaldi. All types of Vivaldi

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antenna have sufficient gain and bandwidth for radar application and they also use for breast cancer thermotherapy and microwave imaging [12-18]. Phase center is the point which the electromagnetic radiation spreads spherically outward, which the phase of the signal being equal at any point on the sphere. In the proposed antenna, the phase center Vivaldi antenna is investigated and linear characteristic of the antenna phase center is presented. The phase center location of antennas is important for pulse transmission/reception, as the movement of the phase center will distort the signal. The most conventional method for finding phase center is measuring the phase pattern of the antenna under test (AUT) [16]. The position of the antenna phase centre is not necessarily the geometric centre of the antenna. The phase centre is defined as the apparent source of radiation. If the source is ideal it would have a spherical equiphase contour, but the real case is slightly different, because the equiphase contour is irregular and each segment has its own apparent radiation origin. Phase center distance from antenna shows the radius of curvature in the equal-phased polar plot and it uses to calculate the phase center [17].

In this paper, a combination of Vivaldi antenna with SIW structure is presented. The Vivaldi antenna is known as antenna with UWB characteristic and directional pattern. In this article by using SIW structure we are able to control the field distribution on the surface of the antenna in order to achieve higher gain with symmetric radiation pattern. Antenna I has high gain and directional pattern with symmetric radiation pattern in phi=0 and phi=90 planes.

## II. ANTENNA DESIGN

Figure 1 shows the two prototypes, Vivaldi antenna and fabricated antenna. It was designed and fabricated on Roger 4003 with relative permittivity of 3.45 and loss tangent of 0.0027. Thickness of the substrate is 1.5 mm. The antenna is connected to 50 Ω tapered feed line. L and W are the antenna dimensions and they are 160 mm and 120 mm respectively. The antenna contains two slant rows of via with diameter of 0.6 mm. These vias have connected both sides of antenna together. Table 1 shows the antenna dimensions for both antennas.

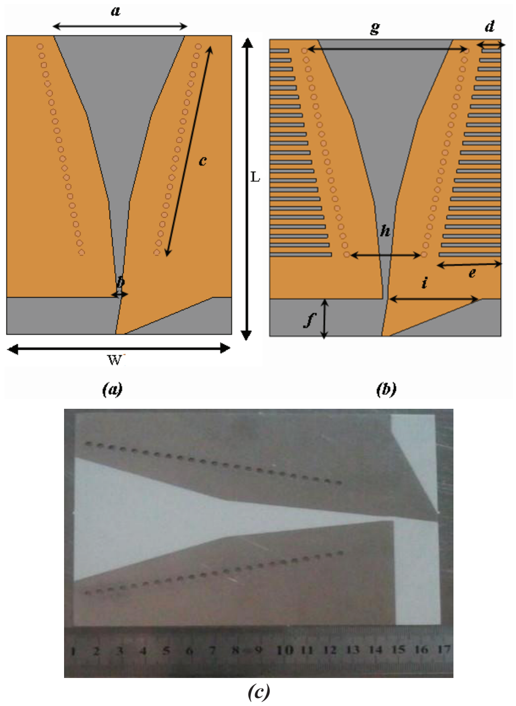
Usually a Vivaldi antenna was introduced by exponential equations and exponentially tapered slot antenna was called Vivaldi antenna [18]. Therefore, it can be defined by equation (1). The maximum and minimum opening widths are calculated based on equations (3) and (4) respectively [19]:

$$y = c_1 e^{Rz} + c_2, \tag{1}$$

$$\lambda_g = \frac{c}{f_{\min}\sqrt{\varepsilon_r}}, \tag{2}$$

$$H_{\max} = \frac{\lambda_g}{2}, \tag{3}$$

$$H_{\min} = \frac{C}{f\sqrt{\varepsilon_r}}. \tag{4}$$



(a) (b)

(c)

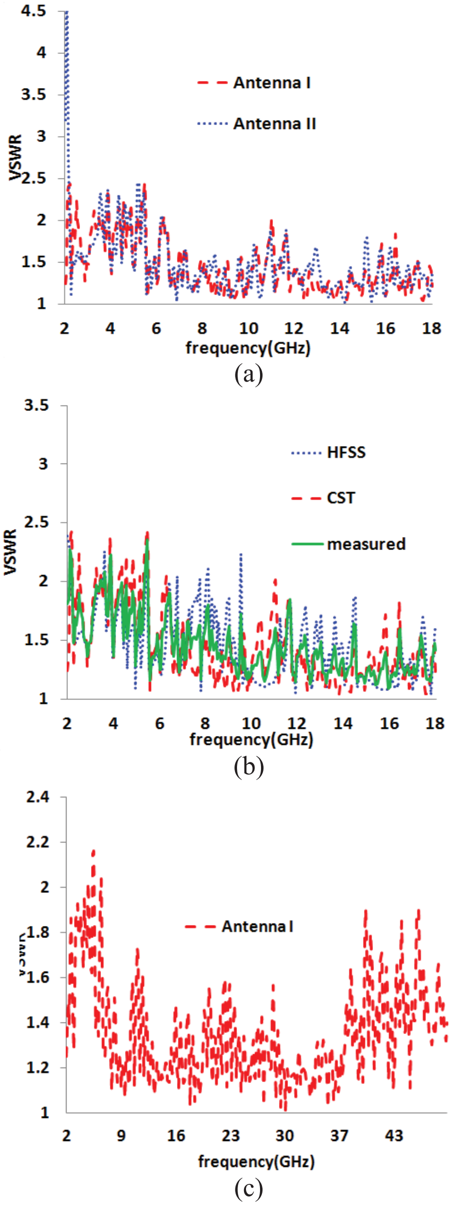
Fig. 1. The prototype Vivaldi antenna: (a) simple model of Vivaldi antenna with SIW, (b) Vivaldi antenna with comb slots, and (c) fabricate antenna.

Table 1: Geometrical parameters of proposed antenna

| Parameter | mm |
|---|---|
| a | 70 |
| b | 2.6 |
| c | 110 |
| d | 10 |
| e | 32 |
| f | 20 |
| g | 84 |
| h | 40 |
| i | 48.7 |
| L | 160 |
| W | 120 |

## III. SIMULATION RESULT

As previously mentioned, two different full wave methods, FEM and TDM are employed for simulation of the prototype antenna. VSWR comparison between HFSS and CST with experimental results of antenna I and II is presented in Fig. 2 (a). As it can be seen in Fig. 2 (b), the VSWR is less than 2.4 but it is mostly less than 2 for the entire frequency range of 2-18 GHz. Figure 2(a) shows the VSWR of the Vivaldi antenna with comb slots. The VSWR of antenna II is typically under 2.5 for the entire frequency of 2-18 GHz. Figure 2 (c) shows the antenna VSWR simulation for 2-50 GHz, and in Table 2 highlights that in [22] with lower profile frequency range of 6-50 is approachable, so here with size incensement lower is frequency available for prototype antenna without any resistive element. In addition, the feed line effect on the bandwidth of the antenna is studied. As shows in Fig. 2 (d), the feed width in junction to Vivaldi (i) is an effective factor in antenna bandwidth. For difference value of (i), we have compared the antenna VSWR at range of 2-18. For this aim i=40, 50, 60 mm is checked and best result is obtained for 50 mm.



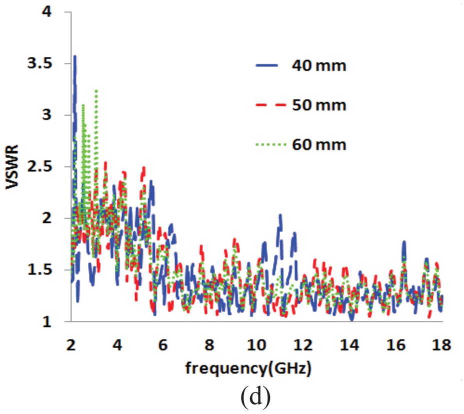
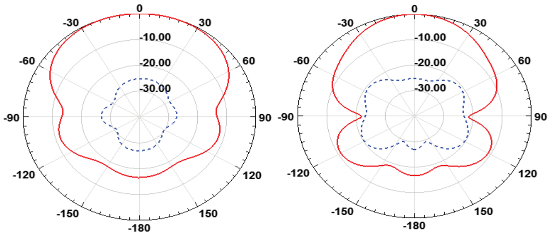


Fig. 2. The simulated and measured VSWR: (a) simulated VSWR by CST for comb slot Vivaldi antenna, (b) simulated and experimental VSWR for first antenna, (c) antenna VSWR simulation 2-50 GHz, and (d) feed line effect on antenna VSWR.

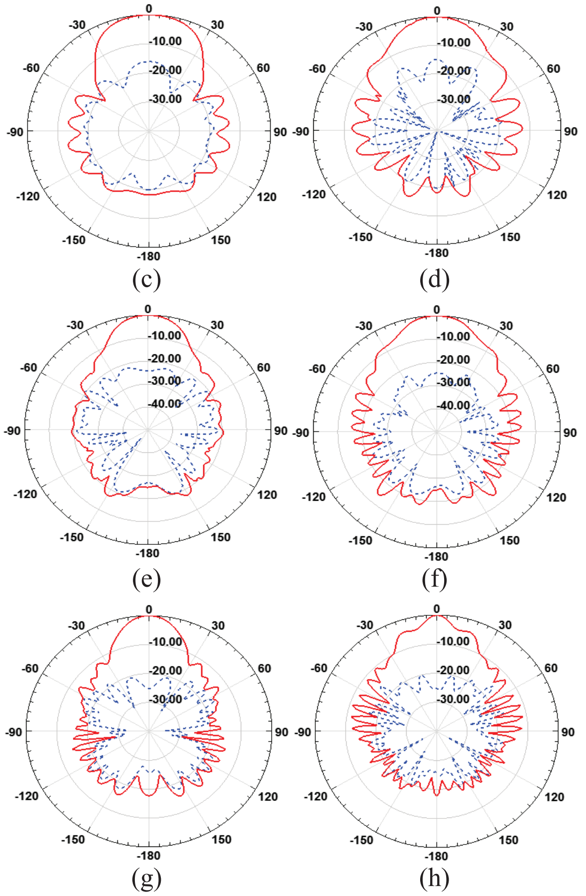
Table 2: Comparisons between current models with previous research

| Parameter | Prototype Model | Ref. (20) | Ref. (21) | Ref. (22) |
|---|---|---|---|---|
| Bandwidth | 2-18 GHz | 1-15 GHz | 6-18 GHz | 6-50 GHz |
| Gain (dBi) | 8-14.9 | 8-13 | 6.8-11.6 | 6.5-16 |
| Efficiency | 73-95.6% | --------- | 93-96% | 94-98% |
| HPBW | 40° to 70° | 24° to 49° | 20° to 80° | 24° to 71° |
| Size (mm) | 120×160×1.6 | 80×140×0.5 | 50×101×1.5 | 64×48×0.78 |

Figure 3 shows the radiation pattern of the prototype of antenna I for four samples in different frequencies at phi=0 and phi=90 for cross- and co-polarization at 2 GHz, 6 GHz, 10 GHz, 14 GHz. As shown in Fig. 3, the antenna patterns for all frequencies are relatively symmetrical. A symmetrical pattern is needed for decreasing the antenna detecting error. Indeed, this symmetrical pattern is very important in identification systems, such as passive radar and microwave imaging for breast cancer detection. In addition, the antenna gain is between 6 dBi and 14.8 dBi and in comparison to other types of the Vivaldi antenna; the prototype antenna has higher gain. As shown in Fig. 3, the half power beam width for 2 GHz occurs around 70° and it reduces to 40° as the frequency increases to 18 GHz.



(a) (b)



(c) (d)

(e) (f)

(g) (h)

Fig. 3. The prototype antenna pattern for phi=0 and 90: (a) 2 GHz at phi=0, (b) 2 GHz at phi=90, (c) 6 GHz at phi=0, (d) 6 GHz at phi=90, (e) 10 GHz at phi=0, (f) 10 GHz at phi=90, (g) 14 GHz at phi=0, and (h) 14 GHz at phi=90.

Figure 4 shows the gain and the efficiency for both antennas I and II in the entire frequency range of 2-18 GHz. The simulated realized gain of antenna I is 6.06 dBi to 14.9 dBi and it is compared with the experimental result in which a good agreement is achieved. Similarly, the simulated realized gain of antenna II is 7.98 dBi - 14.9 dBi. It can be seen that the comb slot has enhanced the gain of the antenna since antenna II has demonstrated higher gain than antenna I in the lower frequency of the antennas.

Actually, the Vivaldi antenna in combination with SIW technology helps to increase the gain and efficiency of the antenna at 2 GHz but at higher frequency, some reduction of the gain and efficiency can be observed. The antenna's efficiency simulated with CST has been presented in Fig. 4 for both antennas. As shown in Fig. 4, the efficiency is between 80% to 91% at 2 GHz - 18 GHz for antenna I, while antenna II the efficiency is between 73% to 95.6%. The efficiency is reduced suddenly at 5 GHz to 80% and 73% for antenna I and II respectively, due to mismatching as shown in the respective VSWR results for both antennas.

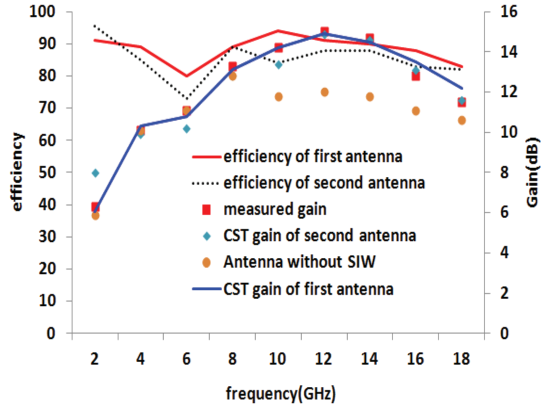


Fig. 4. The prototype antenna gain simulation and experimental for 2-18 GHz and antenna efficiency simulated with CST.

Phase center of antenna has important performance in the time domain. The width of transmitted impulse is about several hundreds of nanoseconds, therefore small change in phase center influences the far field wave dispersion [16]. The phase center for H-plane is calculated in phi-plane. Figure 5 shows the prototype Vivaldi antenna phase center for H-plane. It can be seen that as the frequency increases, the phase center will increase from 9 mm to 109 mm in a linear manner. By comparison of both antennas, it shows the comb slot despite of its effect on gain and efficiency has less effect on antenna phase center.

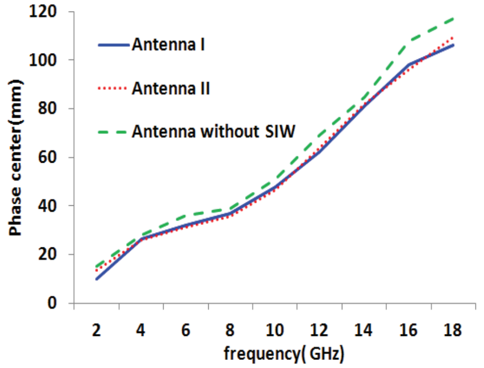


Fig. 5. The prototype Vivaldi antenna phase center for H-plane.

In order to achieve symmetric patterns, it is required to significantly reduce the H-plane beam width, and in here, SIW structure is used for modification of the beam width. Additionally, Vivaldi antennas have an unacceptable phase center variation in the H-plane [16], which may not have significant effects in pulse transmission, but do cause a noticeable error in the high precision localization applications (as indicated in [16]). However, by implementation of linear phase center, the prediction of localization became possible when localization in directional finding application is based on phase calculation.

## IV. CONCLUSION

The VSWR of the antenna is less than 2.3 for 2-18 (up to 50) GHz frequency range, and in this range, the antenna gain is 6 to 15 dBi. The Vivaldi antenna phase center is investigated and the phase center in the prototype bandwidth for H-plane is checked. Finally, the linear characteristic of the antenna phase center is presented. By increase of the frequency, the phase center will increase linearly from 9 mm to 109 mm. Half power beam width for 2 GHz occurs around 70° and will reduce to 40° at 18 GHz. In continue, comb slot is used for gain enhancement. The gain of antenna II is 8.2-15.5 dBi. Antenna I has high gain directional pattern with symmetric radiation pattern in phi=0 and phi=90 planes. The simulation and experimental results are emphasized that the SIW structure combination improved antenna gain and linearity characteristic of phase center.

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**B. Zarrabi** was born in Iran, Babol in 1983. He studied Electrical Engineering at the University of Tabriz in the major of Communication Engineering in 2008 and he is perusing his M.S. at Tarbiat Modares University. His major research interest is designing of antenna for wireless and UWB application for breast cancer detection radar, microwave devices, absorber, metamaterial, plasmonic, nano antenna, cloak, photocell development and THz antenna. He's authored and co-authored more than 33 papers and he published more than 18 ISI and Scopus indexed papers. He is currently work focused on fluid plasmonic and nano chain with statistics optic for bio sensing, based on nano-antenna. He is also invited Reviewer of the Journal of ACES, PIER, Wireless Personal Communication and a few other journals.

**Navid P. Gandji** was born in 1983 in Iran. He received his M.Sc. Engineering from Iran University of Science and Technology (IUST), Tehran, Iran in 2009. He is currently a Research Assistance in Michigan Technological University, Michigan, USA. His area of research includes cancer detection antennas, MRI related patch antennas, conventional microstrip narrow and UWB antennas, microstrip filters, meta-material structures and antenna external wave effect on transmission lines and electromagnetic compatibility (EMC).

**Rahele Ahmadian** was born in Tehran, Iran, in 1984. She received the B.Sc. degree in Electrical Engineering from Semnan University, Semnan, Iran, in 2006 and the M.Sc. degree in Electrical Engineering from Imam Khomeini International University, Qazvin, Iran in 2013. Her major interest is designing of metamaterial shield and absorbers.

**Hamed Kuhestani** was born in Iran, in April 1987. He received the B.S. degree from Islamic Azad University of Mashhad in 2011 and the M.S. degree from Islamic Azad University, Sciences & Research Branch, Tehran, Iran. His current research interests include microwave and millimeter-wave passive circuits, numerical technique in electromagnetic and nano antenna.

**Zahra Mansouri** was born in Zanjan, Iran in 1987. She received her B.Sc. degree in Electrical Engineering (Telecommunication) from Zanjan University, Zanjan, Iran, in 2008 and M.Sc. degree in Electrical Engineering (Telecommunication) from Islamic Azad University, Science and Research Branch, Tehran, Iran, in 2012 where she is currently working on her Ph.D. Her primary research interests are in microwave components such as couplers and power dividers and metamaterials and UWB antenna.