A Novel Miniaturized Vivaldi Antenna Using Tapered Slot Edge With Resonant Cavity Structure for Ultrawideband Applications

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***Abstract*—In this letter, a novel tapered slot edge with resonant cavity (TSERC) structure is adopted to improve the design of a planar printed conventional Vivaldi antenna. The proposed modified structure has the capacity to extend the low-end bandwidth limitation. In addition, the directivity and antenna gain of the TSERC structure Vivaldi antenna has been significantly improved when compared to a conventional Vivaldi antenna of the same size at lower frequencies. Compared to the conventional Vivaldi antenna, the TSERC structure lowers the gain at the higher frequencies. A prototype of the modified Vivaldi antenna was fabricated and tested. The measured results were found to be in good agreement with the simulated, which validates the feasibility of this novel design.**

***Index Terms*—Miniaturized, tapered slot edge with resonant cavity, Vivaldi antenna.**

I. Introduction

Ultrawideband (UWB) antennas have been increasingly applied in wireless communication, biomedical detection, and radar system in recent years [1]–[4]. The Vivaldi antenna is one of the best candidates for the UWB technology due to its broad bandwidth, low cross polarization, and highly directive radiation patterns [5].

The Vivaldi antenna belongs to the class of endfire traveling wave antennas, which has theoretically infinite bandwidth [6]. However, the Vivaldi antenna requires a large antenna size to achieve excellent performance in the low-end working band [7]–[8]. According to the research work in [9] the width of a Vivaldi antenna should reach at least one half-wavelength for effective radiation to occur. A Vivaldi antenna presented in [10] utilized a tapered slot edge (TSE) structure to extend the low-end frequency limitation for miniaturizing the antenna size. Though the low-end cutoff frequency can be decreased by employing this technique, the antenna gain and radiation characteristics at lower frequencies are not improved obviously.

In this letter, a modified Vivaldi antenna is designed and measured. The structure of tapered slot edge with resonant cavity (TSERC) is applied to improve the antenna performance. Compared to the TSE structure, the low-end cutoff frequency of the TSERC structure is further reduced with the same antenna size. Simulation and measured results show that relative bandwidth has been increased by nearly 17%. The directivity of proposed modified Vivaldi antenna has also been improved. This letter is organized as follows: In Section II, the structure of the antenna is presented. Simulation and measured results are provided in Section III, which is followed by conclusion in Section IV.

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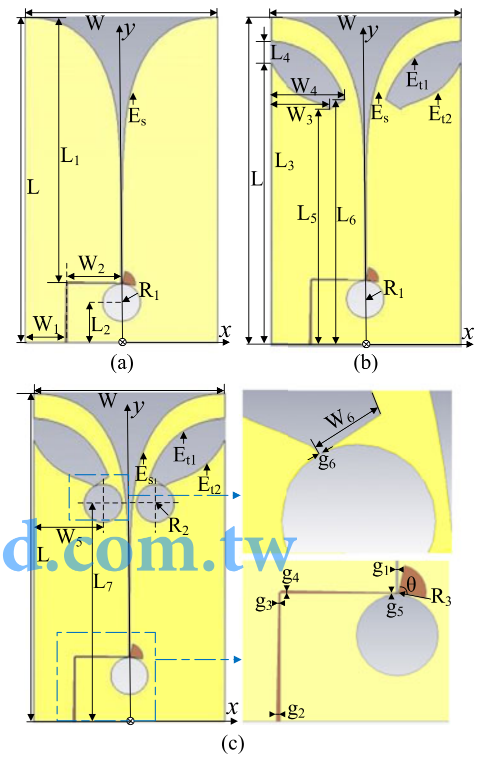

Fig. 1. Configurations of the three Vivaldi antennas: (a) CVA. (b) TSE structure Vivaldi antenna. (c) TSERC structure Vivaldi antenna.

II. Antenna Design

Configurations of three Vivaldi antennas, namely, the conventional Vivaldi antenna (CVA), the TSE structure Vivaldi antenna, and the TSERC structure Vivaldi antenna, are shown in Fig. 1, where the dimensions of all antennas are 258×150 mm^2 with structural parameters in Table I. All the three have already been optimized. The dielectric substrate used in this letter is chosen as FR4 with a thickness of 0.8 mm, a dielectric constant of 4.6, and a tangent loss of 0.01. The structure of the CVA is shown in Fig. 1(a). The exponential profile curves E_S employed in this

TABLE I
STRUCTURAL PARAMETERS OF DESIGNED ANTENNAS

Parameter	Value (mm)	Parameter	Value (mm)
W	150.0	L_5	185.2
W_1	31.1	L_6	193.0
W_2	43.3	L_7	172.2
W_3	47.0	g_1	1.0
W_4	58.9	g_2	1.5
W_5	54.5	g_3	0.5
W_6	13.7	g_4	0.9
L	258.0	g_5	0.2
L_1	206.2	g_6	0.5
L_2	36.0	R_1	15.0
L_3	221.8	R_2	15.0
L_4	17.3	R_3	10.0

design can be described by

$$y = 88.7(e^{0.0007x} - 0.85e^{-0.0617x} + 1.87), \quad 2g_1 \le x \le \frac{W}{2}. \tag{1}$$

Fig. 1(b) illustrates the primary modified structure. A pair of symmetrical tapered slots is inserted on the radiation fins inspired by the TSE structure reported by Oraizi and Jam in [8], which was used to reduce the size of the antenna. Using the structure parameters given in Table I, the exponential curves E_{T1} and E_{T2} of the TSE structure can be described using

$$y = 87.3(e^{-0.001x} - 0.46e^{-0.0457x} + 1.9), \quad \frac{W}{2} - W_4 \le x \le \frac{W}{2} \tag{2}$$

$$y = 15.2e^{-}0.013x - 0.044e^{0.085x} + 166.1, \quad \frac{W}{2} - W_3 \le x \le \frac{W}{2}. \tag{3}$$

Configuration of the proposed TSERC structure Vivaldi antenna is shown in Fig. 1(c). A pair of symmetrical resonant cavities is inserted in the terminal of tapered slots for lengthening the effective length of the surface current path.

A microstrip-to-slotline transition structure is used to excite the three antennas. As shown in Fig. 1(c), a tapered microstrip feeding line is adopted for perfect impedance matching. The port width of the microstrip feeding line is fixed to 1.5 mm to achieve 50-Ω characteristic impedance.

III. RESULTS AND DISCUSSIONS

In order to validate the design of the proposed antenna, two antenna prototypes as depicted in Fig. 2 have been fabricated and tested. A 50-Ω SMA connector was used to feed the antenna. The fabricated antenna was measured using an Agilent E5071B programmable network analyzer and ETS-Lindgren measurement system. Simulations were carried out using the CST Microwave Studio. The xoy-plane and yoz-plane represent the E-plane and H-plane.

A. Return Loss

Fig. 3 illustrates the S_{11} variation of the CVA, the TSE structure Vivaldi antenna, and the TSERC structure Vivaldi antenna. As shown in the figure, the lower end $S_{11} \le -10$ dB limitation

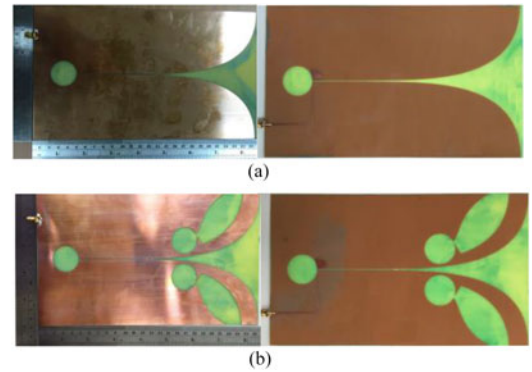

Fig. 2. Photographs of the fabricated prototypes: (a) CVA, (b) TSERC Structure Vivaldi antenna.

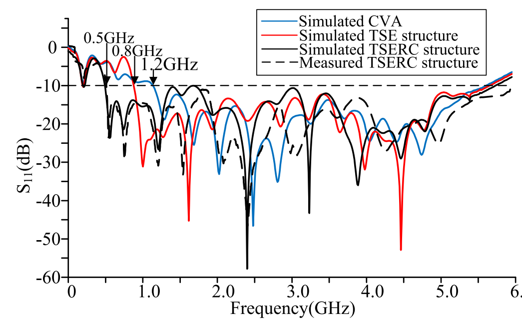

Fig. 3. Return loss of proposed antennas.

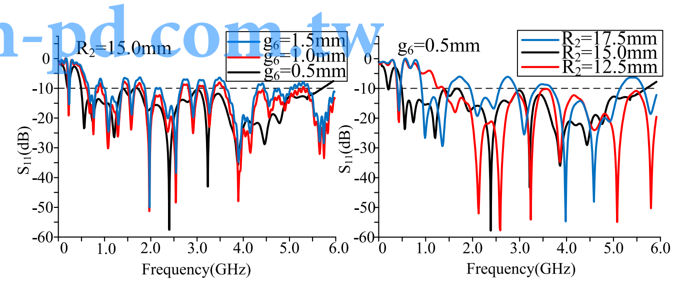

Fig. 4. Simulated return loss of different resonant cavity parameters.

of the CVA is 1.2 GHz, while the TSE structure Vivaldi antenna lowers it to 0.8 GHz. The TSERC structure Vivaldi antenna further reduces the limitation to 0.5 GHz. It means that the TSERC structure is able to miniaturize the size of the CVA by means of lowering the minimum working frequency [11]. The measured S_{11} variation with frequency is also plotted in Fig. 3. It is observed that the measured result is in excellent agreement with the simulation proving the effectiveness of the proposed design. The difference between the simulated and measured results is possibly due to the effect of the SMA connector and the inaccuracy during manufacturing.

Simulated S_{11} variation is obtained by changing the joint width (g_6) and radius (R_2) of the symmetrical resonant cavity as given in Fig. 4. It is observed that the operation bandwidth of the TSERC structure Vivaldi antenna depends on the designed parameters of the resonant cavity. Lowering the joint width (g_6) resulted in the reduction of low-end cutoff frequency. Meanwhile, the radius (R_2) of resonant cavity plays a vital role in return loss characteristic of the proposed antenna. In the proposed antenna, the joint width (g_6) and radius (R_2) of resonant

TABLE II
MEASURED HPBW OF PROPOSED ANTENNAS

Frequency	0.5 GHz	1 GHz	1.5 GHz	2 GHz
CVA	–	89.7°	121.1°	60.5°
TSERC structure	89.5°	77.0°	55.6°	48.7°
Frequency	3 GHz	4 GHz	5 GHz	6 GHz
CVA	48.3°	53.8°	72.2°	58.1°
TSERC structure	45.1°	54.3°	71.1°	58.6°

cavity is kept at 0.5 and 15.0 mm, respectively, to maintain the lower end $S_{11} \leq -10$ dB limitation at 0.5 GHz.

B. Radiation Patterns

The simulated and measured radiation patterns in E-plane (xoy-plane) and H-plane (yoz-plane) at 0.5, 1.5, 2, 3, and 5 GHz are all depicted in Fig. 5. The proposed antennas have endfire characteristics with the main lobe in the axial direction of the tapered slot (y-direction) with exception of the CVA at 0.5 GHz. The difference between the simulated and measured results is possibly due to misalignment errors between the measured antenna and the reference antenna. Detailed comparisons of the measured half-power beamwidth (HPBW) in E-plane of the CVA and the TSERC structure Vivaldi antenna are shown in Table II. At the lower tested frequencies, i.e., 0.5, 1.5, 2, and 3 GHz, both the simulated and measured results of the TSERC structure Vivaldi antenna show significant improvement in directivity compared to the CVA. When the frequency is higher than 3 GHz, the utilization of the TSERC structure does not cause degradation of the directivity.

Table III lists out the comparison between the proposed antenna and other published related antennas. From Table III, the proposed TSERC structure Vivaldi antenna is smaller in dimensions than the CVAs as reported in [11]–[15]. In addition, the comparative results show the improvement in directivity of the proposed antenna at 1 and 2 GHz.

C. Surface Current

In order to further understand the operating characteristic of the TSERC structure Vivaldi antenna at the low frequencies, surface current distribution of both conventional and the TSERC Vivaldi antenna at 0.5 and 1.5 GHz are given in Fig. 6(a) and (b), respectively. In region A, it is obvious that the proposed modification is able to enhance surface current along the radiating edges, which can excite the lower frequency electromagnetic wave. On the other hand, by inserting the slots and resonant cavity, significant surface currents are observable in regions B and C along the slot and resonant cavity edges. It means that the effective length of the surface current path on the antenna is lengthened due to the modification. Moreover, part of the surface current along the radiating edges is coupled to the resonant cavity indicating that the performance of the Vivaldi antenna at the lower frequencies is further improved because of the proposed structure. These characteristics of the TSERC structure Vivaldi antenna contribute to extending the lower-end bandwidth. Fig. 6(c) shows the surface current distribution of both antennas at 5 GHz. The surface current in regions A, B, and C showed no significant changes. Therefore, the TSERC structure has not worsened the performance apparently at the higher frequencies.

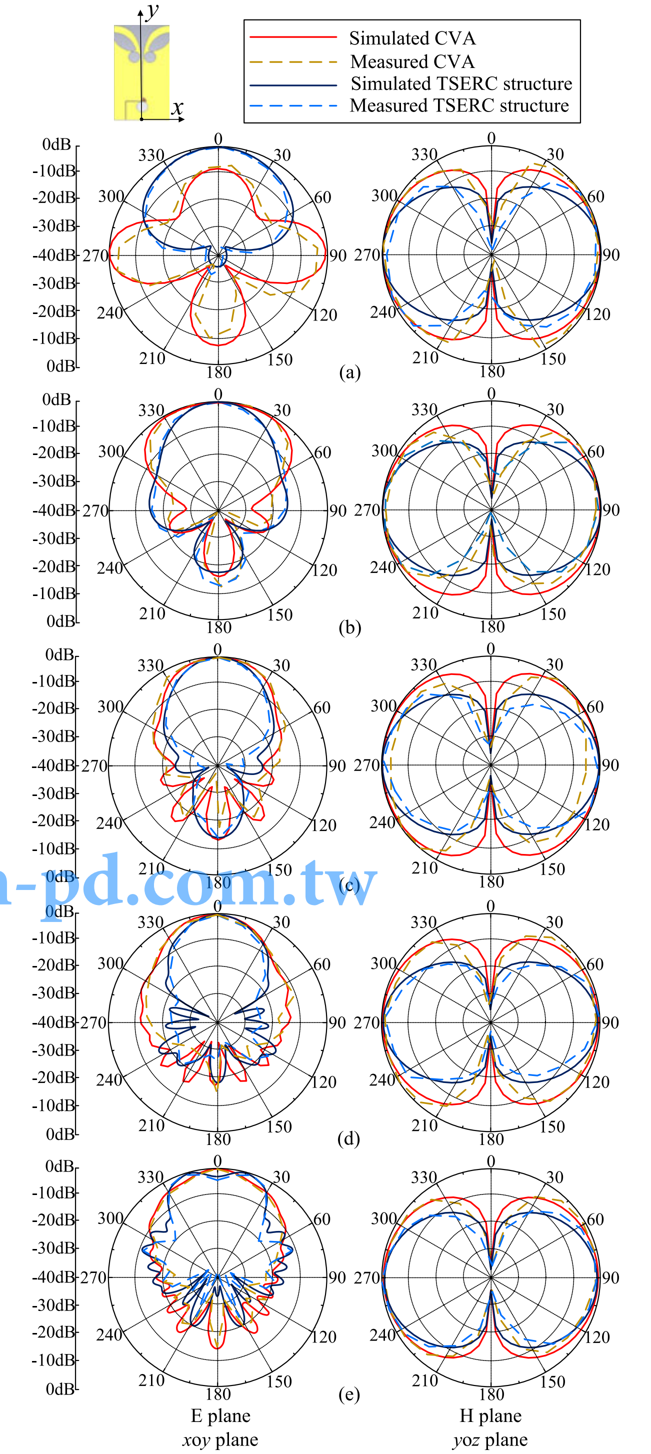

Fig. 5. Simulated and measured radiation patterns of two printed Vivaldi antennas in E-plane (xoy) and H-plane (yoz) at (a) 0.5, (b) 1.5, (c) 2, (d) 3, and (e) 5 GHz.

D. Gains

According to the analysis of surface current distribution, the TSERC structure contributes to the radiation of electromagnetic wave at the lower frequencies. However, as shown in Fig. 6(c), part of the surface current along the radiating edges in region C, which can excite the higher-frequency electromagnetic wave, is coupled to the resonant cavity. This characteristic lowers

TABLE III
COMPARISON BETWEEN PROPOSED ANTENNA AND LITERATURE

			HPBW in E-plane	
Ref. no.	Dimension (mm^2)	Operating frequency	1 GHz	2 GHz
[11]	297 × 190	0.6–3.2 GHz	78.3°	51.4°
[12]	300 × 230	0.62–2.6 GHz	247.3°	173.6°
[13]	274 × 282	0.4–9.8 GHz	128.2°	–
[14]	240 × 220	0.68–7.3 GHz	–	–
[15]	260 × 185	0.5–2.0 GHz	115.6°	58°
Proposed	258 × 150	0.5–6.0 GHz	77.0°	48.7°

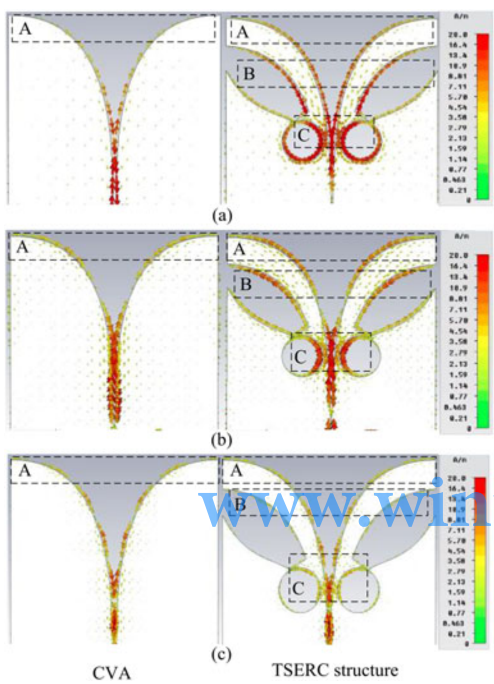

Fig. 6. Surface current distribution of the CVA and the TSERC structure Vivaldi antenna at (a) 0.5, (b) 1.5, and (c) 5 GHz.

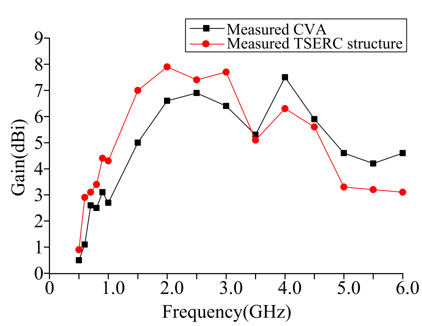

Fig. 7. Measured gain of proposed antennas.

the gain of the main lobe at the higher frequencies [12]. The variations in the measured gain with frequency of the original and proposed antenna are shown in Fig. 7. Compared to the CVA, the measurement results show that the gain of the TSERC structure Vivaldi antenna has increased at the lower frequencies (<3.5 GHz) and lowered at the higher frequencies (≥3.5 GHz) due to the characteristics of surface current distribution. In addition, the reduction of the gain at the higher frequencies of two antennas attributes to the high cross-polarization level [16].

IV. CONCLUSION

In this letter, a TSERC structure Vivaldi antenna is proposed. The lower-end $S_{11} \leq -10$ dB limitation of the proposed antenna is extended to 0.5 GHz from the original 1.2 GHz. The operation bandwidth has been increased by 14.6% and achieved more than 19.5% size reduction compared to CVAs. Simulated and measured results show that the TSERC structure Vivaldi antenna performs with higher endfire directivity compared to the conventional design. In addition, the antenna gain is improved at lower frequencies using the TSERC structure. According to the characteristics, the proposed antenna can be an excellent candidate for the endfire directional UWB radio frequency applications.

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