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Conformal Corrugated Edges for Vivaldi Antenna to Obtain Improved Low-Frequency Characteristics

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Abstract—A novel idea of conformal corrugated edges (CCE) is put forward in this paper for tapered slot antennas to obtain improved low-frequency characteristics. The CCE is realized using conformal slots whose two longitudinal boundary lines are modelled using curvilinear function of the curves that form the tapered slots. So the conformal slots can sufficiently corrugate edges of the tapered slot antennas with one set of structural parameters by comparing with the typical rectangular slot, which makes the corrugated edges design for tapered slot antennas much simpler. Moreover, when used to corrugating edges with the same width of a tapered slot antenna, the conformal slot is longer than the typical rectangular slot, as a result of which the CCE can better improve low-frequency characteristics of the tapered slot antennas. For verification, the CCE using exponential slot is proposed for typical Vivaldi antenna in this paper. Comparisons among antenna structures, port characteristics and radiation characteristics of Vivaldi antennas with the proposed CCE and the typical rectangular slot corrugated edge are carried out, and the Vivaldi antenna with its proposed CCE is fabricated and measured. The remarkable improvement for low-frequency characteristics demonstrates the correctness of the idea.

1. INTRODUCTION

Vivaldi antenna [1], also known as exponentially tapered slot antenna, is one kind of tapered slot antennas (TSA) described as the general class of end-fire traveling wave antennas, including a tapered slot with or without a thin layer of dielectric material. The tapered slot can restrict electromagnetic wave and radiate it while the slot widens. Because of the wideband characteristics, low cross polarization, and highly directive patterns, the Vivaldi antenna has been widely applied to radio astronomy [2], ground penetrating radar [3, 4], ultra-wideband communication systems [5], ultra-wideband imaging systems [6, 7], etc.

When designing a Vivaldi antenna, the input impedance match is good, and the energy can be radiated when final width of the tapered slot is greater than half guide wavelength, and the total length of the tapered slot is greater than one guide wavelength [8]. However, this designing guideline is studied to be right only if the antenna has extra width of more than quarter-guide wavelength outside the tapered slot [9], which makes the Vivaldi antenna larger in size and less in application. In practical applications, corrugated edge is designed to decrease the extra width, which is always realized by etching many rectangular slots at edges of a Vivaldi antenna [10–12]. The major factor that affects the low-frequency characteristics of a Vivaldi antenna is the length of the rectangular slots. Besides, better low-frequency characteristics can be achieved when the edges are fully corrugated using rectangular slots with different lengths, which is complicated for modeling. In this paper, a novel idea of corrugated edges design is proposed by drawing lessons from conformal antennas, according to which the slot that constructs the corrugated edges has its two longitudinal boundary lines modeled using curvilinear function of the

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curves that form the tapered slots. This kind of slot can be simply modeled and sufficiently corrugate the edges of TSAs while this corrugated edge can be referred to as conformal corrugated edge (CCE).

In this paper, the CCE for Vivaldi antennas is designed using exponential slot, also called as exponential slot corrugated edge (ESCE). A Vivaldi antenna with typical rectangular slot corrugated edge (RSCE) is also designed for comparison which shows that the ESCE is modeled simply and can better improve low-frequency characteristics of the Vivaldi antennas. Moreover, the idea about CCE can also be applied in designing corrugated edges for other TSAs. The substrate used in this paper for simulation and fabrication is Teflon with permittivity 2.65, thickness 1 mm and loss tangent 0.0001. Ansoft HFSS is used for simulation here.

2. ANTENNA CONFIGURATION

Figure 1(a) shows configuration of the Vivaldi antenna with the proposed ESCE, and Fig. 1(b) shows configuration of the Vivaldi antenna with a typical RSCE. Structural parameters are listed in Table 1, which have already been optimized. Dimension of the antennas is $50 \times 125\,\text{mm}^2$. The two exponential curves that compose the tapered slot can be described by the equation:

$$y = \pm\frac{g}{2} * \exp\left(\ln(W/g) * x/L\right) \quad (0 \leq x \leq L) \tag{1}$$

where g, W and L are original width, final width and length of the tapered slot, respectively.

As shown in Fig. 1(b), a typical RSCE is always realized by periodically duplicating a rectangular slot of length l_{ce} and width w_{ce} at edges of the antenna, and the duplication cycle is $2w_{ce}$. d_{ce} is the distance between the first slot and the terminal of the tapered slot, which is used to keep the tapered slot working normally. As a result, there are always blanks left at edges of the antenna. The solution for this problem is using rectangular slots with different lengths, which is complicated for modeling. However, ESCE, the CCE for Vivaldi antennas shown in Fig. 1(a) which is realized by periodically duplicating an exponential slot, leaves no blank at the edges. As shown in Fig. 1(a), boundary lines of the exponential slot is modeled using Equation (1) with x spanning from $L - t_{ce}$ to L. So t_{ce} can be decided by l_{ce} using Equation (1). This is the reason that exponential slots can implement sufficient corrugation at the edges of a Vivaldi antenna. The comparison between configurations of the

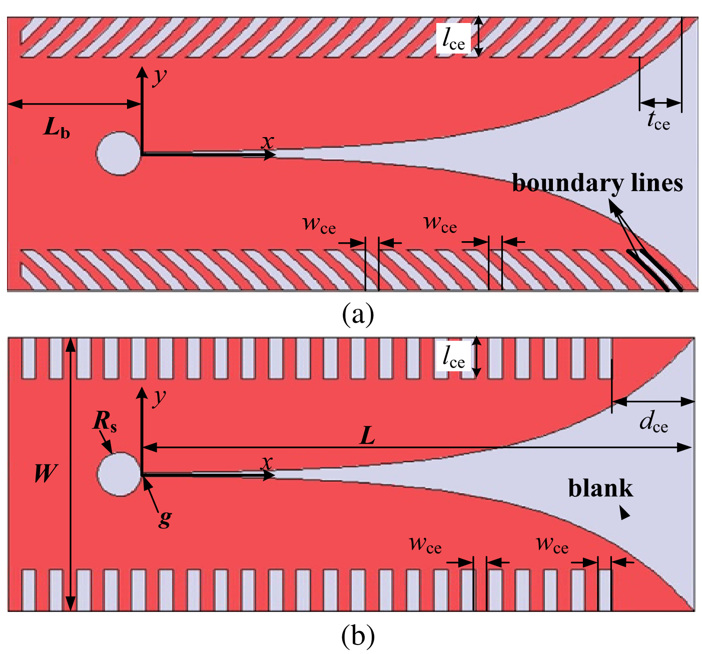


Figure 1. Configurations of the Vivaldi antennas with different CE: (a) Vivaldi antenna with proposed ESCE, (b) Vivaldi antenna with the typical RSCE.

Table 1. Structural parameters of the Vivaldi antennas (mm).

Parameters	Value	Parameters	Value
W	50	L_b	25
L	100	l_{ce}	7.5
R_s	4	w_{ce}	2.5
g	0.5	d_{ce}	15

two Vivaldi antennas describes that the exponential slot has greater slot length than rectangular slot when the edges of width l_{ce} are corrugated. According to [10], CE with longer slots can better improve low-frequency characteristics of the antennas. Additionally, feeding structure used in this paper is the typical microstrip/slotline transition in which the microstrip line is grounded using a metallic hole.

3. RESULTS AND DISCUSSION

For validating effectiveness of the ESCE in improving low-frequency characteristics of the Vivaldi antenna, the antennas shown in Fig. 1 are simulated, and adequate comparisons among the feeding and radiation characteristics are carried out. Finally, the proposed Vivaldi antenna with ESCE is fabricated and measured to verify the simulation. Fig. 2 shows a photo of the fabricated samples. Reflection coefficient of the antenna is measured by a vector network analyzer, and the radiation characteristics are measured in a microwave dark room.

Figure 2. Fabricated samples of the Vivaldi antenna with ESCE.

3.1. Reflection Coefficient

Figure 3 shows simulated reflection coefficients of the antennas. It is observed that cutoff frequencies of the Vivaldi antenna without CE, Vivaldi antenna with RSCE and Vivaldi antenna with ESCE are 5.1 GHz, 4.5 GHz and 3.2 GHz, respectively. It is observed that the CE can obviously improve port characteristic of the Vivaldi antenna at low side of the band. The comparison among the simulated reflection coefficients reveals that the proposed ESCE performs better than the typical RSCE which corrugates edges of the same width, and the reason is that the ESCE has longer slot than the RSCE. Fig. 4 shows the measured and simulated reflection coefficients of the Vivaldi antenna with ESCE, which depicts that the measured cutoff frequency is almost the same as the simulated one.

3.2. Radiation Characteristics

Figure 5 shows the simulated radiation characteristics of the three Vivaldi antennas in the frequency range from 3 GHz to 15 GHz, including the side-lobe level (SLL) both in E-plane and H-plane, the

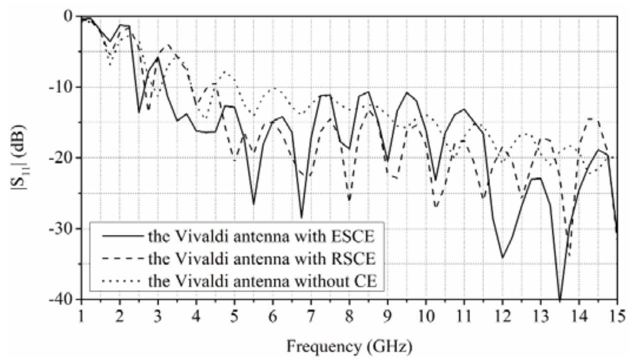


Figure 3. Simulated reflection coefficients of the Vivaldi antennas.

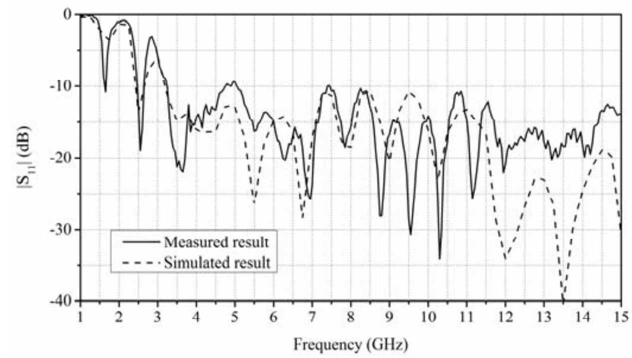


Figure 4. Measured and simulated reflection coefficients of the Vivaldi antenna with ESCE.

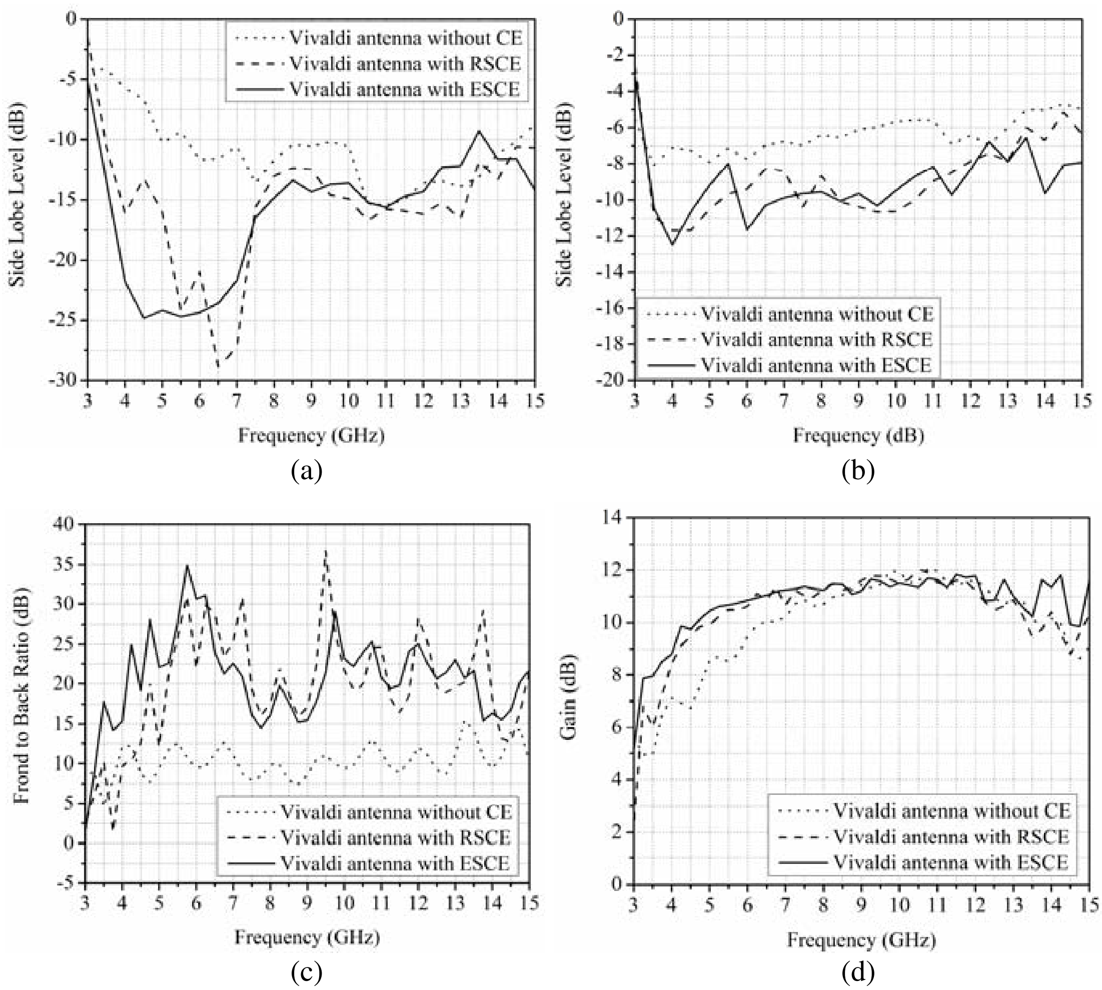
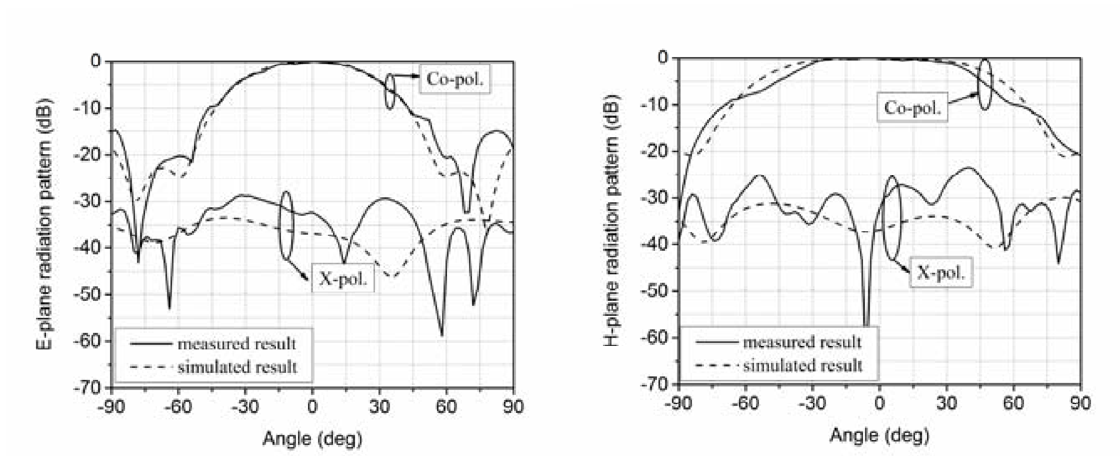
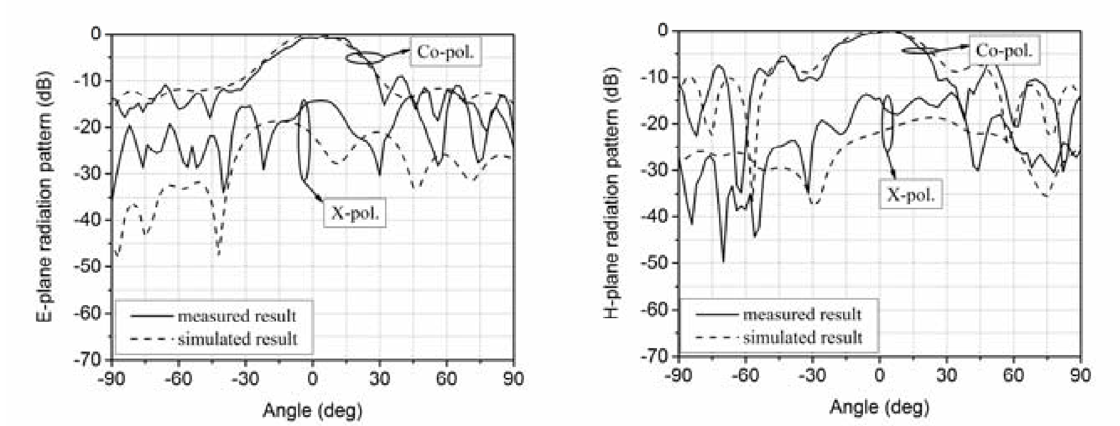


Figure 5. Simulated radiation characteristics of the three Vivaldi antennas: (a) Side-lobe level in E-plane; (b) Side-lobe level in H-plane; (c) Frond-to-back ratio; (d) Gain at the main direction.

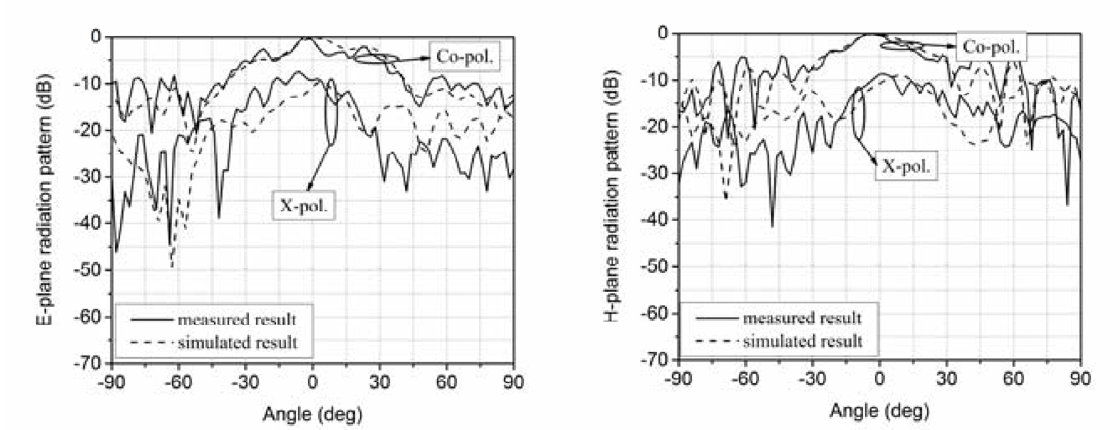
frond-to-back ratio (FBR) and gain at the main direction. Compared with the Vivaldi antenna without CE, Vivaldi antennas with ESCE and RSCE can get their radiation characteristics at low frequencies improved. The two Vivaldi antennas with different CEs have similar radiation characteristics at the higher frequencies (more than about 5.5 GHz). However, because ESCE has longer slots than RSCE, when both them are realized at the edges of the same width l_{ce}, the Vivaldi antenna with ESCE performs better on the SLL in E-plane, the FBR and the gain in the low-frequency band (from 3 GHz to 5.5 GHz), as shown in Figs. 5(a), (c) and (d). Additionally, because edges of the two Vivaldi antennas are corrugated using different CEs but within the same width, effects of the two types of CEs on the tapered slot for bounding slow waves are similar, and the SLLs in H-plane of the two Vivaldi antennas have little difference from each other.



(a)



(b)



(c)

Figure 6. Simulated and measured radiation patterns of the Vivaldi antenna with ESCE: (a) 3.2 GHz; (b) 9.0 GHz; (c) 15 GHz.

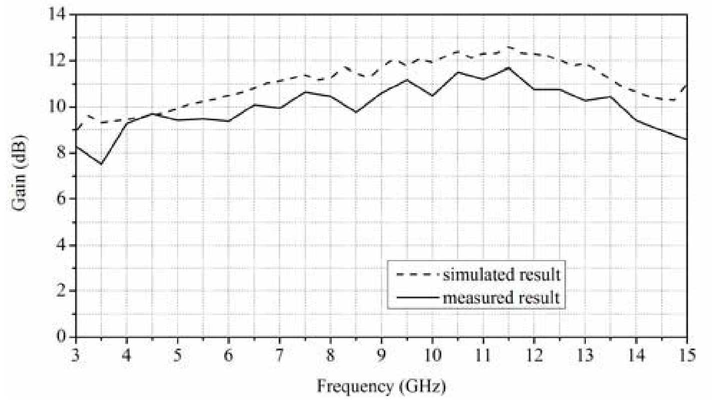


Figure 7. Simulated and measured gain of the Vivaldi antenna with ESCE.

Figure 6 shows the simulated and measured radiation patterns of the Vivaldi antenna with ESCE at 3.2 GHz, 9.0 GHz and 15 GHz, in which a good agreement between simulation and measurement can be achieved. Fig. 7 shows the simulated and measured gains of the Vivaldi antenna with ESCE, from which it can be observed that the antenna has its gain greater than 8 dB from 3 GHz to 15 GHz. The simulated and measured results shown in Figs. 3, 4, 5, 6 and 7 reveal that the proposed ESCE can remarkably improve low-frequency characteristics of the Vivaldi antenna, and the good performances on port matching and radiation make the antenna useful for applications in many fields.

4. CONCLUSION

Corrugated edges are always used to improved low-frequency characteristics of the TSAs. A novel design idea of conformal corrugated edges (CCE) is put forward in this paper, and the CCE for Vivaldi antennas is designed using an exponential slot modeled using curvilinear function of the curves that form the tapered slots. As a result, the exponential slot can sufficiently corrugate edges of the TSAs with one set of structural parameters, which makes the corrugation simpler than the typical rectangular slot. Characteristics of the Vivaldi antennas with CCE and the typical rectangular slot corrugated edges are simulated, and the Vivaldi antenna with CCE is fabricated and measured. The results exhibit that the CCE can improve low-frequency characteristics of the Vivaldi antenna better than the typical rectangular slot corrugated edges. The reason is that the exponential slot is much longer than the rectangular slot when edges of the Vivaldi antenna are corrugated in the same width, which is right for other conformal slots of different TSAs.

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