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NOVEL PLANAR ANTENNA WITH A BROADSIDE RADIATION

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Abstract—This paper presents a novel low-profile antenna with a broadside radiation. The proposed design strategy consists in modifying the layout of a classical Vivaldi antenna, thus resulting in compact dimensions and a broadside radiation pattern. Two different ways of implementing the proposed design approach are presented and discussed. More specifically, experimental data referring to two prototypes on a FR4 substrate with an operating frequency of 2.45 GHz are reported. The first layout has approximately the same dimensions of a Vivaldi antenna and a directivity of about 7 dBi, the second one has more compact dimensions (the dimensions are smaller than the ones of a standard patch antenna) and a directivity of about 5 dBi.

1. INTRODUCTION

The conventional Vivaldi antenna introduced by Gibson [1] comes under the Tapered Slot Antenna (TSA) with an exponentially tapered profile etched on a thin metallization [2, 3]. A traveling wave propagating along the surface of the slot with a phase velocity less than the speed of light (i.e., $v_{ph} \leq c$) results in an endfire radiation [3, 4].

Although Vivaldi antennas have been extensively used in many applications, especially in ultrawideband systems [5–8], the original layout has suffered from several design problems mostly related to poor and inconsistent gain, limited operational bandwidth and large dimensions.

Several design approaches have been proposed in the literature in order to improve the bandwidth and/or the directivity or to obtain more compact dimensions. Among these, a microstrip-to-slot transition adopting a quarter-wave circular slot and a quarter

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wave radial stripline stubs was introduced in order to achieve a wider bandwidth than the one obtained with the straight stubs [9, 10].

To improve the antenna directivity, a zero-refractive index metamaterial and a photonic band-gap substrate was used in [11] and in [12], respectively.

In [13] the traditional slotline-to-microstrip feed transition of a Vivaldi antenna was replaced with a microstrip-to-parallel stripline. The Antipodal Vivaldi Antenna (AVA) obtained this way overcomes the practical limitations of a conventional Vivaldi antenna exhibiting a very wide operation bandwidth.

Balanced Antipodal Vivaldi Antenna (BAVA), consisting of a balanced stripline structure with two layers of metallization, was introduced by Langley, Hall and Newham in [14] in order to overcome the high cross-polarization levels of a typical AVA.

Various AVA and BAVA designs with more compact size and better radiation properties have been proposed in the literature [15–18]. For example, in order to improve the directivity, the inclusion of a "director" implemented by means of a profiled piece of higher dielectric constant material or a negative-index metamaterial was suggested in [17] and in [18], respectively.

In this paper the layout of a classical Vivaldi antenna is modified in order to obtain a broadside radiation. Numerical and experimental results referring to two prototypes optimized for operation at 2.45 GHz are presented and discussed.

2. GEOMETRY OF THE PROPOSED ANTENNA

The geometry of the proposed antenna is illustrated in Fig. 1; it was optimized by means of simulations performed with CST Microwave Studio [19]. It consists of a conventional Vivaldi antenna fed by a microstrip-to-slotline transition and loaded with an Epsilon Negative Medium (ENG). The exponential taper profile is defined by the opening rate R and the two points $P_1(x_1, y_1)$ and $P_2(x_2, y_2)$ [20]:

$$y = C_1 e^{Rx} + C_2 \tag{1}$$

where

$$C_1 = \frac{y_2 - y_1}{e^{Rx_2} - e^{Rx_1}}, \quad C_2 = \frac{y_1 e^{Rx_2} - y_2 e^{Rx_1}}{e^{Rx_2} - e^{Rx_1}} \tag{2}$$

The ENG medium is placed on the back-side of the tapered slot and consists of an array of copper strips resonating at the operating frequency of the antenna. More precisely, each strip is designed with a physical length (L_s) of $\lambda_0/2$ so as to have a phase shift of 180° at $f_0 = 2.45\,\text{GHz}$. The area occupied by the antenna is $(72.17 \times 75)\,\text{cm}^2$.

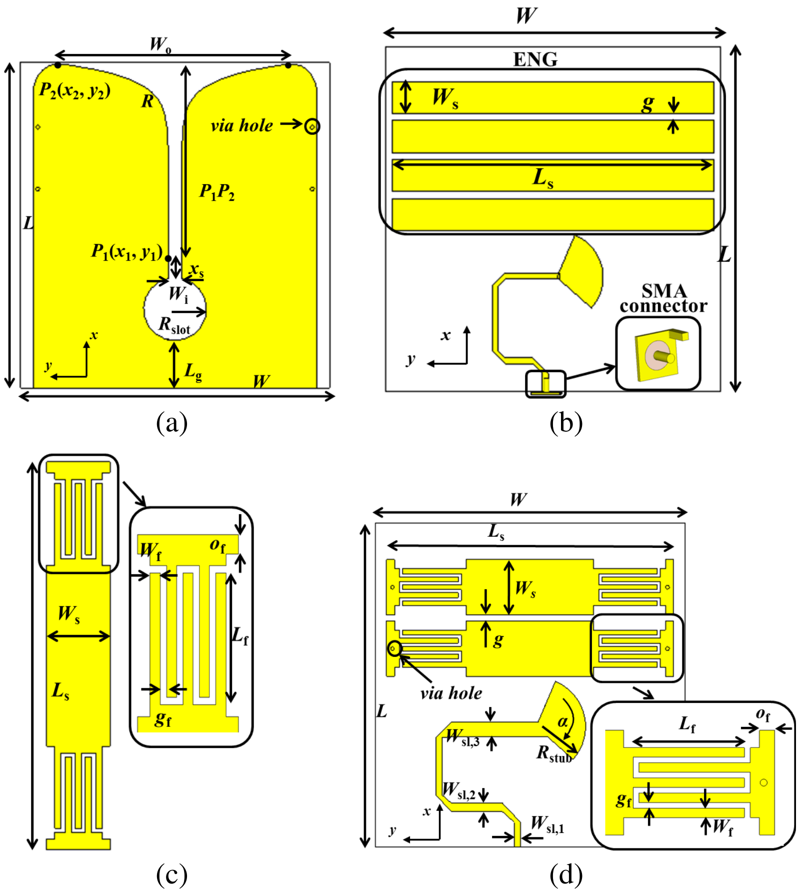
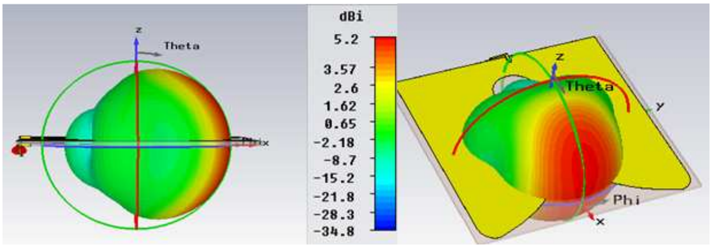


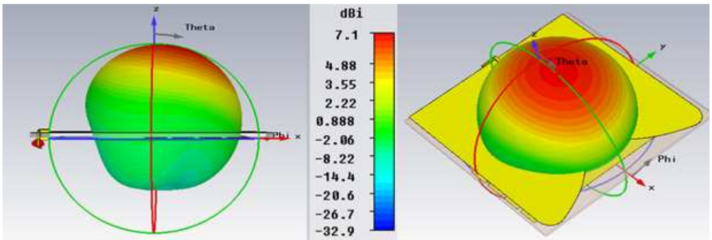
Figure 1. Geometry of the proposed antenna. (a) Front-view, (b) 4-strip ENG back-view, (c) 4-strip CRLH: single strip, (d) 2-strip CRLH back-view.

The purpose of using the ENG medium as a load is to modify the radiation pattern of a classical Vivaldi antenna so to obtain a broadside radiation. This is highlighted in Fig. 2, where numerical results calculated for the radiation pattern of the proposed antenna with and without the ENG medium are illustrated. In Fig. 2(a) the end-fire radiation pattern of a properly designed Vivaldi antenna can be recognized, while from Fig. 2(b) it is evident that in presence of the ENG medium the antenna has a broadside radiation. By comparing Figs. 2(a) and 2(b), it can be also noticed that the directivity increases of about 2 dBi in presence of the ENG medium.

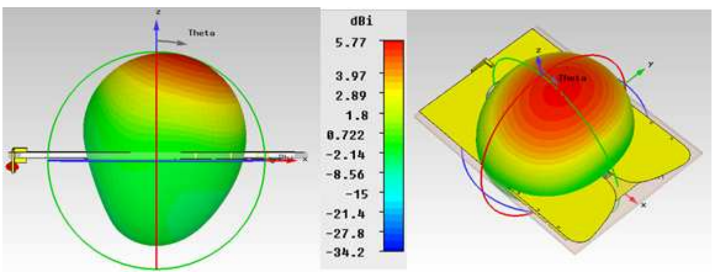
The possibility of reducing the size of the antenna while maintaining good radiation properties was also investigated. More



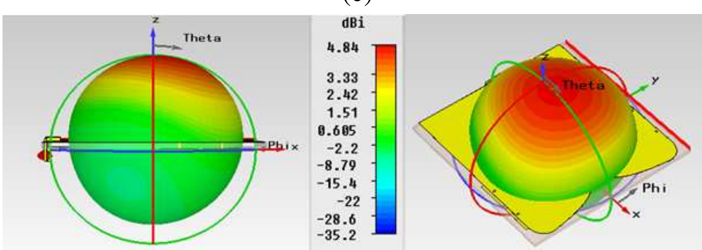
(a)



(b)



(c)



(d)

Figure 2. 3D simulated radiation pattern of the proposed antenna: (a) conventional Vivaldi, (b) 4-strip ENG illustrated in Fig. 1(b), (c) 4-strip CRLH, (d) 2-strip CRLH illustrated in Fig. 1(d).

specifically, we analyzed the possibility of implementing the ENG medium by means of copper strips loaded by a Composite Right-Left Handed (CRLH) cell consisting of a series interdigital capacitor and a via-hole working as a shunt inductor [21, 22] (see Fig. 1(c)). The presence of the CRLH unit cell allows to obtain a phase shift of 180° with a smaller physical length, thus resulting in the possibility of reducing the dimensions of the antenna along the y-direction (see Fig. 1). In particular, by using the dimensions of the CRLH unit cell given in Table 1(d), the size of the antenna along the y-direction can be reduced from 72.17 cm to 50.08 cm. The corresponding radiation pattern, calculated by means of full wave simulations, is illustrated in Fig. 2(c). It can be noticed that the size reduction does not affect the broadside radiation, except for the directivity which, with respect to the layout of Fig. 1(b), lowers of about 1.3 dBi still remaining higher than the one of a conventional Vivaldi antenna (see Fig. 2(a)).

Table 1. Antenna parameters (dimensions in mm).

(a) 2-strip CRLH front-view.

P_1P_2	L_g	R_{slot}	x_s	W_i	W_o
32.75	7.8	5	2	2	36.38

(b) 4-strip ENG back-view.

L	W	L_s	W_s	g
75	72.17	69	7	1.5

(c) 4-strip CRLH: single strip.

L_s	W_s	g_f	o_f	L_f	W_f
46.4	8	0.7	1.3	9	0.8

(d) 2-strip CRLH back-view.

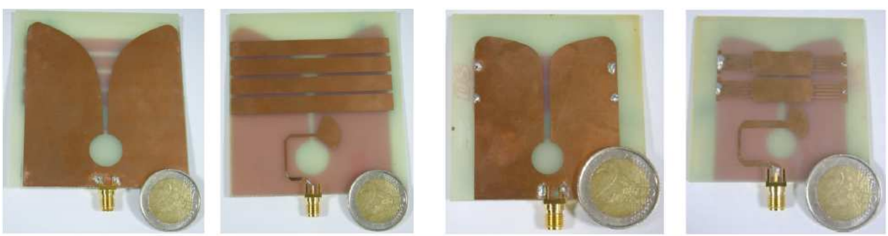
L	W	L_s	W_s	R_{stub}	$W_{sl,1} = g$
52.8	50.08	46.4	9	8	1
$W_{sl,2}$	$W_{sl,3}$	g_f	o_f	L_f	W_f
1.4	2.36	0.5	1.3	9.5	0.8

In order to verify the possibility of reducing the antenna size also along the x-direction, we investigated the performance of the antenna when the number of loading strips is reduced to three and two. Fig. 1(d) illustrates the layout of the proposed antenna optimized for the case of only two CRLH-strips on the back-face; the corresponding radiation pattern is given in Fig. 2(d). It can be seen that the antenna preserves a broadside radiation even though with lower values of the directivity. More specifically, with respect to the layout of Fig. 1(b), the one of Fig. 1(d) allows to obtain a size reduction of about 50% (the antenna size is $(50.08 \times 52.8\,\text{cm}^2)$) while the directivity lowers of about 2 dBi. It is worth underlining that a conventional microstrip antenna designed on the same substrate exhibits very similar radiation properties and occupies an area of about $(68 \times 60)\,\text{cm}^2$.

3. EXPERIMENTAL AND NUMERICAL RESULTS

In order to demonstrate the viability of the proposed design strategy, a prototype of both the layouts illustrated in Fig. 1 was realized on a double-sided copper clad FR4 laminate ($\varepsilon_r = 3.9$, $\tan(\delta) = 0.019$, $h = 1.6$ mm). Photographs are given in Fig. 3; the corresponding measured reflection coefficients are given in Fig. 4 and compared with numerical data. As it can be noticed, for both the prototypes a fairly good agreement between numerical and experimental data was obtained. By observing Fig. 4, it can be also noticed that from experimental data a -10 dB S_{11} relative bandwidth of about 15% ($S_{11} < -10$ dB in the frequency range [2.36, 2.76] GHz) has been obtained for the 2-strip CRLH antenna (i.e., the antenna illustrated in Fig. 1(d)).

As for the radiation pattern, measurements were performed in a large outdoor area at $\varphi = 90°$ (yz-plane) and $\theta = 90°$ (xy-plane). Corresponding results are illustrated in Fig. 5. A good agreement



(a) (b)

Figure 3. Photographs of the fabricated antennas: (a) 4-strip ENG (see Fig. 1(b)), (b) 2-strip CRLH (see Fig. 1(d)).

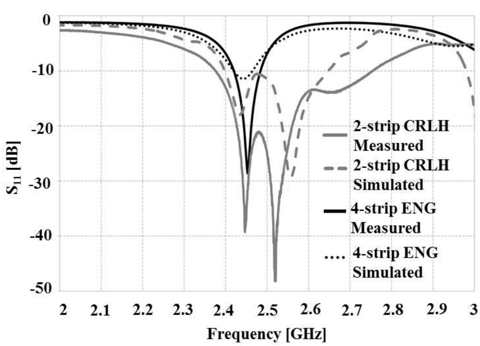
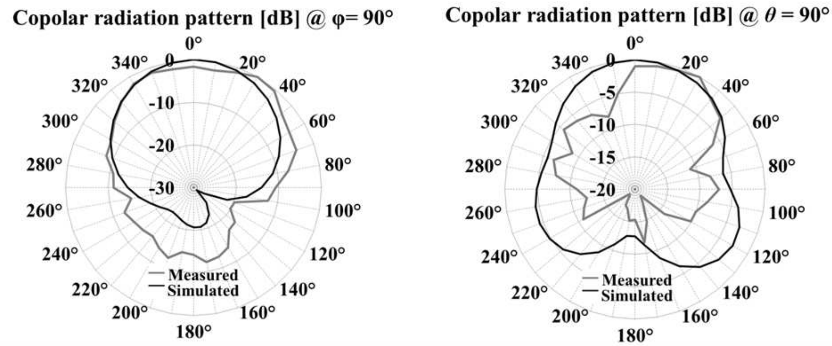
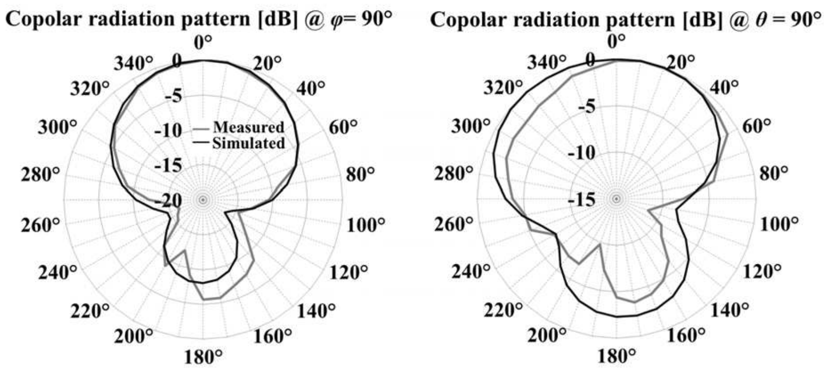


Figure 4. Reflection coefficient of the 4-strip ENG (i.e., the antenna illustrated in Fig. 3(a)) and of the 2-strip CRLH (i.e., the antenna illustrated in Fig. 3(b)).



(a)



(b)

Figure 5. Experimental data obtained for the copolar radiation pattern of the antennas illustrated (a) in Fig. 3(a) and (b) in Fig. 3(b).

between experimental and numerical data can be observed for both the realized prototypes.

4. CONCLUSIONS

A novel planar antenna with a broadside radiation pattern has been presented. It consists of a conventional Vivaldi antenna loaded by an epsilon negative medium. Results referring to two prototypes working at 2.45 GHz have been presented and discussed. It is shown that the proposed antenna is an optimum candidate to be used for broadside radiation. In fact, from experimental data it is demonstrated that the proposed design approach can be customized to design antennas with radiation properties similar to the ones of a conventional microstrip patch antenna but with more compact dimensions.

ACKNOWLEDGMENT

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