

A LOW-PROFILE UNIDIRECTIONAL CAVITY-BACKED LOG-PERIODIC SLOT ANTENNA

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Abstract—A low-profile unidirectional cavity-backed coplanar waveguide-fed uniplanar log-periodic slot antenna suitable for the ultra-wideband applications (3–18 GHz) is presented. Due to the inherent balanced structure compared with the unbalanced antennas, such as dipole or loop antenna, the impedance matching and radiation performances of the proposed antenna are quite stable and satisfactory. There is a potential advantage for low profile ultra-wideband unidirectional antennas, and this paper demonstrates a technique for transforming the bidirectional beam into a unidirectional beam by using a special cavity in this ultra-wideband antenna. Meanwhile, the multi-resolution time domain (MRTD) method is applied to analyze this antenna. Experimental results reveal that the cavity has a small affect on the S -parameter of the origin antenna, and remains the perfect reflection property within the desired operation band.

1. INTRODUCTION

Since the approval of ultra-wideband (UWB) by the Federal Communications Commission (FCC) in 2002 [1], the UWB technology has gained more and more popularity and become an important candidate for short-range high-speed indoor data communication applications [2, 3]. Nevertheless, the antenna design for these systems still encounters several distinct challenges, including relative wide operation band and nearly invariable inband performances. However, with the non-resonating structures, most UWB antennas have bidirectional beams [4–11]. For unidirectional communications, the bidirectional beams must be transformed into unidirectional ones or choose a new antenna form as vivaldi antenna [12]. The transformation

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can be easily achieved with a cavity [13–16], which reflects the negative direction wave from the antenna at the bottom and re-radiates out to combine with the wave radiated directly from the antenna toward free space.

Two techniques, one based on the method of moments (MoM) and the other one based on the finite-difference time-domain method (FDTD), are primarily used for antenna analysis. The MoM is suitable for analyzing an arbitrarily shaped finite-length wire antenna, where a free-space Green's function is used to obtain the current distribution, while the FDTD is powerful for analyzing a finite-size plate antenna with or without a conducting cavity. Detailed information on these methods can be found in the literature [17–21]. As new time-domain numerical methods, multi-resolution time domain (MRTD) method [22, 23] presents many advantages, such as lower consumption of computer memories, high efficiency, and it is regularly utilized to design antennas and circuits and has a good performance [24–28].

In this paper, we propose a coplanar waveguide (CPW)-fed log-periodic slot antenna with a special cavity for transforming the bidirectional beam into a unidirectional beam at the desired frequency band. Different cavities have been discussed to choose the best one. A special cavity and a loss dielectric material are adopted for low-profile design in this paper. Meantime, the multi-resolution time domain (MRTD) method is used to analyze this antenna, and measured results is illustrated and compared with the simulated results. Experimental results reveal that the cavity affects little on the S -parameter of the origin antenna, and remains the perfect reflection property within the desired operation band.

2. ANTENNA DESIGN

Considering a structure whose size is magnified (or lessens) by a factor K , if the resulting structure is the same as the original one, the antenna structure is called a self-similar structure. An antenna that has a self-similar structure is called a self-similar antenna. Therefore, this log-periodic slot antenna is a self-similar antenna which has the broadband characteristic in essence.

The geometry of the proposed CPW-fed log-periodic slot antenna is depicted in Fig. 1. The dimension of this antenna is annotated in the front view Fig. 2. This antenna possesses a simple structure with only one metal covered dielectric substrate layer. The successive slot lengths and distances are in the common ratio M .

$$\frac{L_{n+1}}{L_n} = \frac{l_{n+1}}{l_n} = \frac{D_{n+1}}{D_n} = \frac{d_{n+1}}{d_n} = M \quad (1)$$

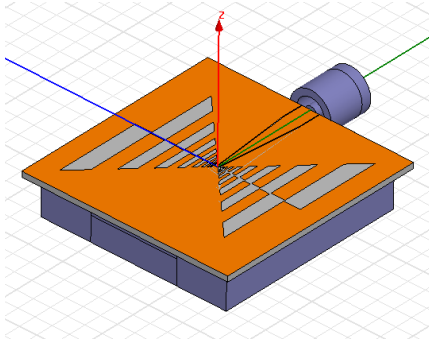


Figure 1. Geometry of unidirectional cavity-backed log-periodic slot antenna fed by a CPW.

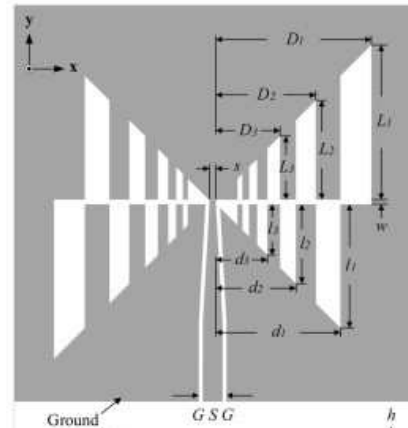


Figure 2. The dimension of the proposed antenna.

and

$$\frac{l_n}{L_n} = \frac{d_n}{D_n} = \sqrt{M} \quad (2)$$

Which makes the spacing between any two adjacent vertical slots on the same quadrant of the antenna equals to the geometric mean of their widths. Each of the slot paths from the feeding terminals to the oblique edges of vertical slots equals uniquely a half guided-wavelength of the slot line resonating at the corresponding in band frequency, and the lower frequency limit of the operating band can be determined by the total path length from the terminal to the tip of the outermost vertical slot.

The wave radiated in the negative direction from the slot antenna is reflected at the bottom of the cavity and is reradiated out of the cavity (free space), superimposing with the wave radiated directly from the slot antenna toward free space, and thus the radiation from the antenna becomes unidirectional, as desired. However, the depth of traditional cavity needs to be a quarter maximum wavelength or its multiple for superimposing inphase.

To keep impedance input and radiation characteristics constant as much as possible, an absorbing strip (ABS) is attached to the vertical wall of the cavity, and two layers cavity backed structure is shown in Fig. 3. The ABS is specified by thickness t , relative permittivity ϵ_r , and conductivity σ .

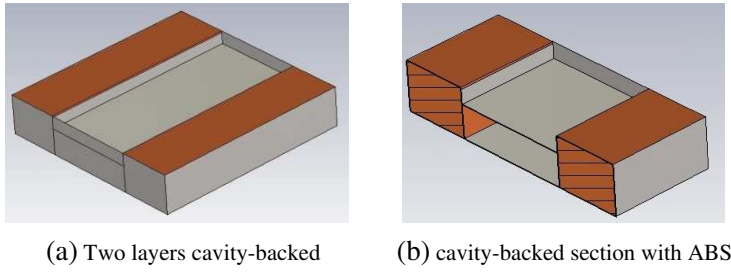


Figure 3. The proposed cavities.

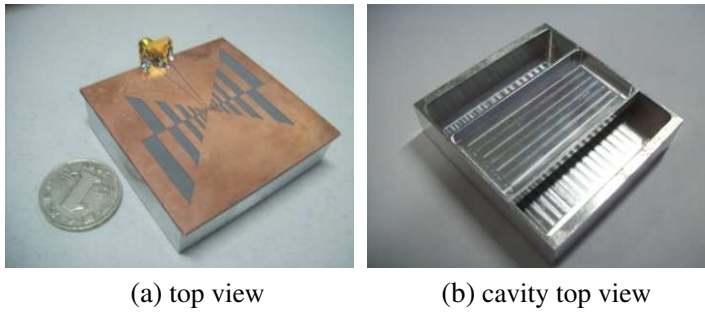


Figure 4. Antenna photos.

3. ANTENNA SIMULATION AND EXPERIMENTAL RESULTS

Both the original and the cavity back log-periodic slot antennas fed by the CPW are implemented. They are fabricated on the same substrate with dielectric constant 2.2, loss tangent 0.0015, and thickness 1.5 mm. The widths of the strip and gap of the 50 Ω CPW feed line S and G are chosen to be 5.0 and 0.2 mm, respectively. To simplify the design process, D_n is assumed to equal L_n ; and consequently, d_n equals l_n . The detailed parameters are listed as follows:

$$L1 = 24 \text{ mm}; w = 0.4 \text{ mm}; M = 0.63; s = 0.4 \text{ mm};$$

The slot number on one quadrant of the proposed antenna is eight.

The exterior size of this proposed cavity is designed as $54 \times 54 \times 12 \text{ mm}^3$. The depth of the larger cavity is 12 mm, which is eight times to the maximum wavelength. The second layer cavity size is $54 \times 25 \times 3.5 \text{ mm}^3$, which is located at the center of the larger cavity and the longer side is parallel to the slots.

As shown in Fig. 3, a ABS is attached to the vertical wall of the cavity and it is specified by thickness $t = 12 \text{ mm}$, relative permittivity $\epsilon_r = 1.1$, conductivity $\sigma = 0.125$, width 14.5 mm, and length 54 mm.

Fig. 4 is the photo of the proposed antenna. Fig. 4(a) is the top view of this antenna, Fig. 4(b) shows the cavity structure.

These antennas are simulated by MRTD method, based on analyzing the EM transmission in CPW. The feeding model of the CPW structure is illustrated in Fig. 5, in which “C” denotes the integral path of the current; “L” denotes the integral path of the voltage at the CPW port. The port impedance can be achieved by Equations (3)–(5).

$$I(z, t) = \oint_C \vec{H}(x, y, z, t) \cdot d\vec{l} \quad (3)$$

$$U(z, t) = \int_L \vec{E}(x, y, z, t) \cdot d\vec{l} \quad (4)$$

$$Z_0(f) = \frac{F(U(t))}{F(I(t))} = \frac{U(f)}{I(f)} \quad (5)$$

where, “F()” denotes the Fourier transform.

The antennas are tested through SATIMO anechoic chamber as shown in Fig. 6.

Simulated and measured return losses of the slot antenna without cavity are shown in Fig. 7. It is clear that the corresponding curve of the original design stays below -8 dB across the entire band from 3.0

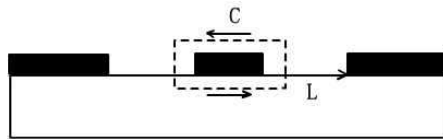


Figure 5. The feeding model of the CPW structure with MRTD.

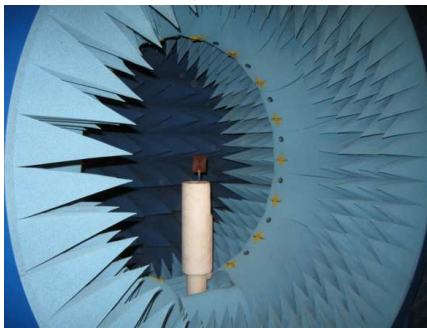


Figure 6. Antennas were tested through SATIMO anechoic chamber.

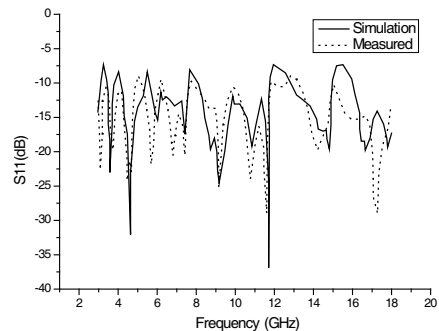


Figure 7. The return losses of the slot antenna without cavity.

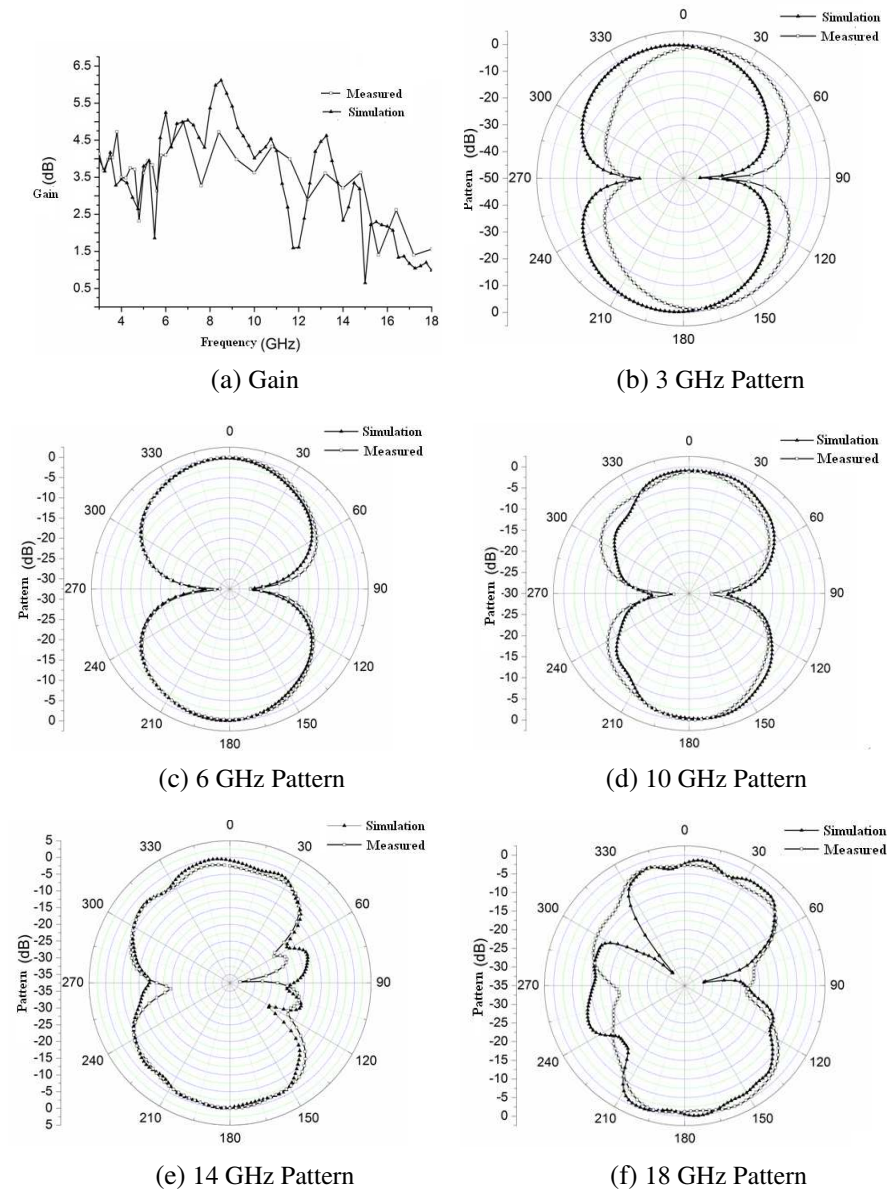


Figure 8. The radiation characteristics of the slot antenna without cavity.

to 18.0 GHz. Fig. 8 shows the comparisons of the patterns obtained from simulation and measurement for the slot antenna without cavity. As this figure indicates, the broadside and bidirectional radiation patterns are quite stable. Furthermore, the measured gains for different frequencies agree with the simulation ones quite well.

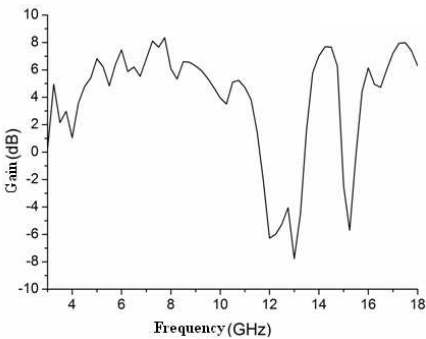
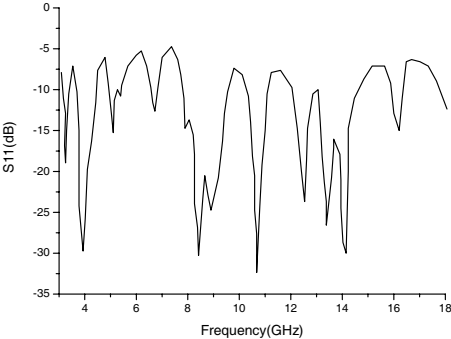
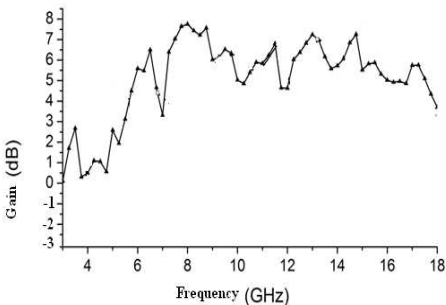


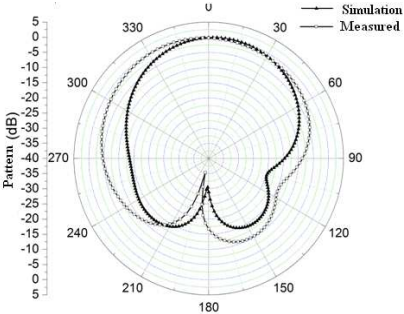
Figure 9. The measured gains of this slot antenna with one layer cavity.



(a) Measured S11



(b) Gain



(c) 3 GHz Pattern

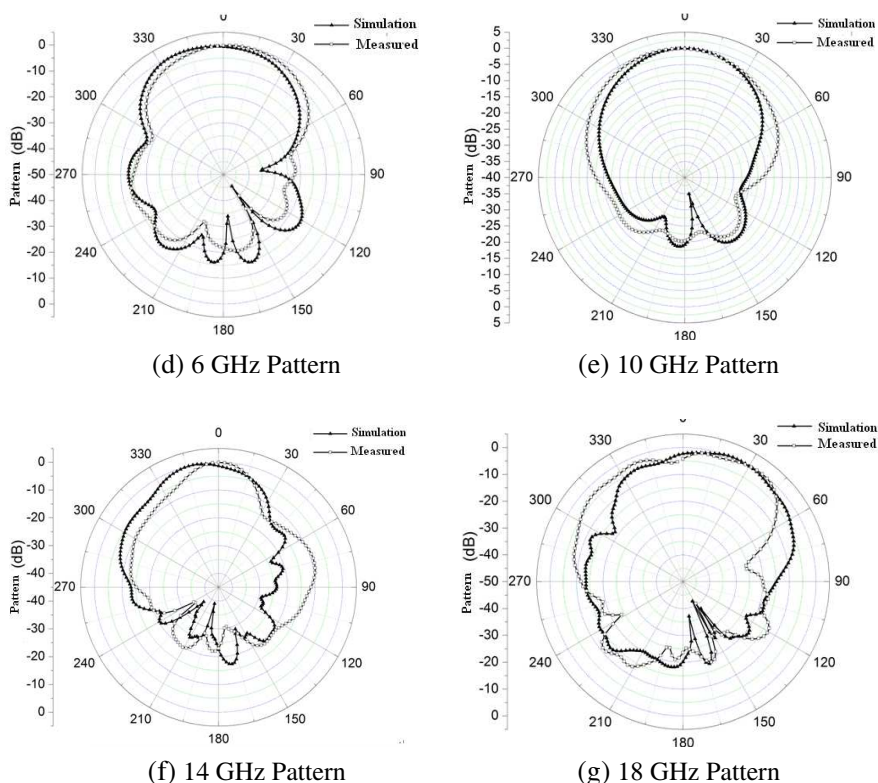


Figure 10. The proposed antenna with two layer cavity and ABS.

The measured gains in the operation band of this slot antenna with one layer cavity are shown in Fig. 9. It is clear that the curve neighboring to 12 GHz exhibits an obvious dropping, because the height of this cavity is close to $\lambda/2$ at this frequency. This is unacceptable in the practical applications.

To solve this problem, a new cavity with two reflectors and an ABS attached to the vertical wall of the cavity is proposed in this paper. The two layer reflectors are used to reflect the EM-wave at low frequencies with the thick cavity and high frequencies with the thin cavity respectively.

With the advanced operation principle of this Log-Periodic Slot antenna, this two layer cavity takes a good performance, which has been shown in Fig. 10. Due to the similarity among the radiation patterns of the three antenna prototypes, only those of the design measured at some in-band frequencies are plotted in Fig. 10. It is

clear that the responsive curve of the original design stays below -6 dB across the entire band from 3.0 to 18.0 GHz. As this figure indicates, the gain is larger than 0 dBi and the broadside and unidirectional radiation patterns are quite stable throughout the operating band too.

4. CONCLUSION

The CPW-fed log-periodic slot antennas with unidirectional back cavity has been proposed and investigated in this paper. Due to the inherent balanced structure compared with the unbalanced antennas, such as dipole or loop antenna, the slot antenna has a potential advantage for low profile ultra-wideband unidirectional antennas. Therefore, a new cavity with two layer reflectors and an ABS attached to the vertical wall of the cavity is presented in this paper. The measured results illustrate that the proposed antenna possesses quite stable unidirectional radiation patterns and acceptable gains throughout the operating band. These characteristics and the simple, compact, and uniplanar configuration make the proposed log-periodic slot antennas highly suitable for applications in the UWB and system detections in military.

ACKNOWLEDGMENT

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