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A novel very compact ultra-wide band double ridge horn antenna

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Abstract – *In this article, a new wideband double-ridge horn antenna with very compact dimensions is presented. The structure of the proposed Antenna includes a double ridge, cavity back, and corrected sidewalls. In this paper, the dimension of the horn antenna has been compacted and the bandwidth improved by using FR4 dielectric substrate sidewalls and deforming upper and down metal walls. For designing this entire horn antenna, three-dimensional electromagnetic field simulation software Ansoft HFSS based on the finite element method is applied. To experimentally verify the performance, a prototype of the antenna is fabricated and measurement is performed. The dimensions of the antenna are 95 * 85 * 68 mm3. The bandwidth of this antenna is between 1.7 and 20 GHz and the antenna gain are between 5.5 and 15.5 dBi. Also, the antenna radiation pattern is directional without deterioration in total bandwidth. The proposed antenna can be used in direction finder systems and noise jammers.*

Keywords: *compact dimension, double ridge and ultrawide band.*

1. Introduction

The evolution of electromagnetic theory and antenna technology has fueled the demand for antennas in various applications, including RF target simulation systems, electronic countermeasure systems, and electronic reconnaissance systems [1-3]. Broadband antennas have become indispensable components in high-speed wireless transmission equipment such as high-sensitivity radar, radio frequency interference (RFI) mitigation systems, and electromagnetic compatibility (EMC) test setups [4]. UWB antennas encompass a diverse range of designs, including monopole and dipole antennas, reflector antennas, horn antennas, spiral antennas, and logarithmic periodic antennas, each suited for specific applications based on their geometrical properties [4, 5]. Horn antennas have gained widespread adoption in telecommunication systems due to their exceptional characteristics, including high bandwidth, excellent impedance matching, relatively simple feeding mechanisms, high gain, and exceptional directivity [6]. Among broadband horn antennas, double-ridged horn (DRH) antennas have emerged as a popular choice due to their wide bandwidth and suitable radiation patterns [7]. In 1973, John Kerr made a significant contribution to the field with the introduction of a DRH antenna design for operation within the 1-12 GHz frequency range [7]. Since then, extensive research has been conducted, leading to the development of various DRH models for operation across diverse frequency bands [8]. However, a major limitation of traditional DRH antennas is the deterioration of their radiation pattern beyond 12 GHz, often resulting in the splitting of the main beam into two distinct lobes [8]. Achieving both optimal impedance and radiation characteristics simultaneously in antenna design can be challenging. For instance, reference [11] demonstrates that employing a lens in front of horn antennas can enhance the radiation pattern but compromises impedance matching, ultimately reducing the antenna's bandwidth. Despite utilizing various techniques, the gain of the antenna in this example remains below 10 dBi, as reported in reference [12]. While miniaturization is crucial for antennas, attaining all desired features in a compact radiating element poses a significant challenge. This paper addresses these challenges by proposing a novel DRH antenna design that offers a large bandwidth, optimal radiation patterns, and a compact form factor. Our design is based on theoretical analysis that provides design guidelines, and it has been validated through simulations and a fabricated prototype. This paper aims to design a compact wideband horn antenna with a suitable radiation pattern across the entire bandwidth. To achieve this objective, the following techniques are employed:

1. Waveguide cavity back antenna.
2. Double ridges loaded on the antenna.
3. Modification of the sidewalls.

The paper is organized as follows: Section II: Antenna Design Procedure. This section details the design process, including the waveguide cavity back antenna, theoretical relations of the double-ridged antenna, the effect of a dielectric slab in the antenna wall, and an investigation of circular cuts in the antenna sidewalls. Section III: Field Distribution - This section presents the field distribution within the antenna structure. Section IV: Results and Discussion - This section discusses the results obtained from simulations and experimental measurements. Section V: Conclusion - This section summarizes the key findings and contributions of the paper.

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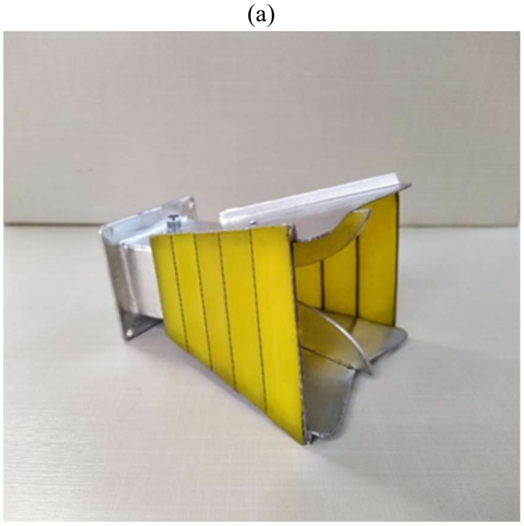

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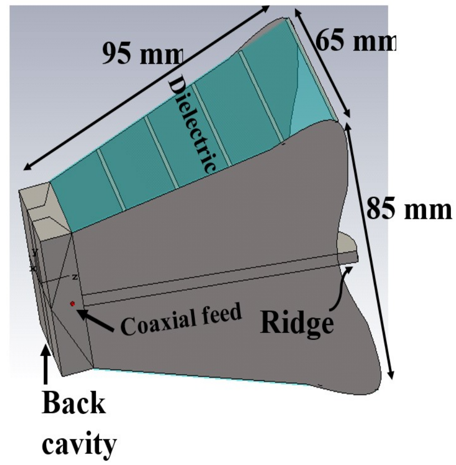


(c)

Fig. 1. Proposed ultrawide band horn antenna. (a), (b) manufactured antenna, (c) Dimension of structure

2. Antenna design procedure

In this section, the components of the UWB antenna will be discussed separately. The photograph of the fabricated antenna along with its dimensional details is shown in Fig. 1.

A. The cavity back waveguide antenna

The internal conductor of the coaxial feed passes through lower blade of the UWB horn and connected to the upper baled one. The external conductor of the feed coaxial is connected to the lower blade [7]. At the back of the feeding area is a space called the cavity back. By using this technique (cavity back), the return loss of the antenna can be significantly improved specially in first of bandwidth. In [14] a type of waveguide cavity back was introduced. Problem of its work was pattern deterioration because of excitation of other modes.

In this work, the structure of cavity back of previous work [14] has been improved. Our proposed and traditional waveguide cavity back structure antenna are presented in Fig.2 b and a, respectively.

By changing the walls of the waveguide and reducing the distance between the walls and the antenna feed, it is possible to support waves with a frequency lower than the cut-off frequency without attenuation. Therefore, as shown in Fig. 2, the proposed structure for the waveguide consists of a number of triangular metal pieces that gradually turn the antenna cavity back into the waveguide.

One of the advantages of this type of cavity over its traditional counterpart is that it prevents the creation of unwanted modes that cause the pattern to deteriorate at certain frequencies. It is also easier to build and assemble this structure.

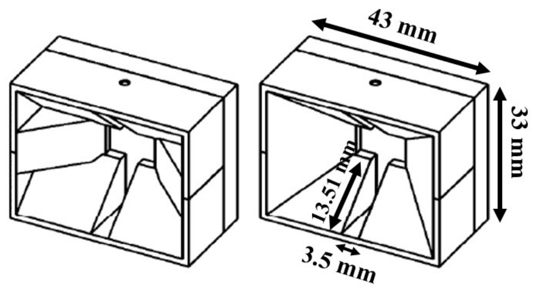


Fig. 2. Waveguide launcher sections (a) Traditional (b) Proposed new structure

B. Double ridge

One of the best ways to increase impedance bandwidth is to add two longitudinally symmetrical blades in the middle of the antenna [15-16]. The added blades act as wide reactive loads, reducing the cut-off frequency of the main mode and also increasing the cut-off frequency of higher modes, leading to improved impedance bandwidth. In the article, exponential ridge based on the following formula are used. The slope of this line is typically 0.02 [7]. According to this point, the suggested feature for this part is the following form [17]:

$$z(y) = 0.02y + z(0)e^{ky} \qquad (0 \le y \le L) \tag{1}$$

Where z is the distance of each point from the axis of longitudinal symmetry of the antenna, y is the horizontal distance of each point from the beginning of the blade, L is the axial length of the antenna and k is a constant calculated as follows, shown in Fig. 3 [17]:

$$k = \frac{1}{L}\ln\left(\frac{z(L)}{z(0)}\right) \tag{2}$$

The initial distance between the blades is 0.5 mm. Reducing this distance improves the impedance adaptation at low frequencies but at medium frequencies destroys the antenna return loss characteristics.

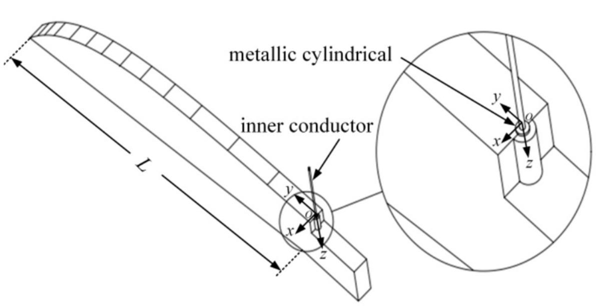


Fig. 3. View of the antenna ridge

C. Dielectric Substrate

One of the most important factors in increasing the gain is the Dielectric Substrate that is placed around the wall. Its presence increases the impedance bandwidth and gain, which we will explain [18]. In a double ridge horn antenna, the energy concentration at high frequencies is mostly between the ridges of the E plane, and the side walls have little effect on antenna performance. Therefore, to reduce the construction costs and reduce the weight of the antenna, the walls of the H plane can be replaced with dielectric Substrate. The boresight gain diagram and impedance bandwidth of the horn antenna with and without dielectric Substrate are shown in Figures 4 and 5. As can be seen, at frequencies below 4 GHz, the VSWR of antenna without dielectric Substrate is slightly higher than 2. Since at a frequency of 4 GHz the wavelength in open space is about 75 mm. We consider the distance between the lines of substrate to be a quarter of the wavelength. For this purpose, the distance between the lines is 16.84 mm and the number of lines in each area is 5, which we achieved this amount of optimization based on trial and error.

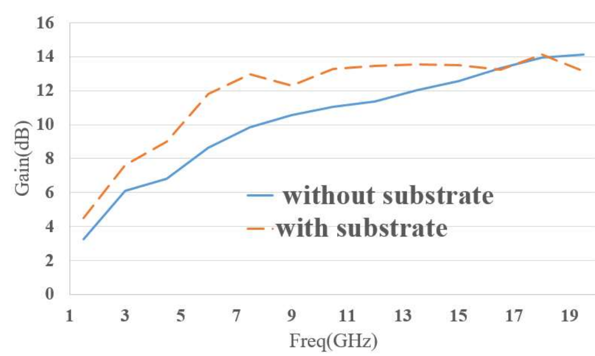


Fig. 4. Result of simulated gain of the proposed antenna in Fig 1

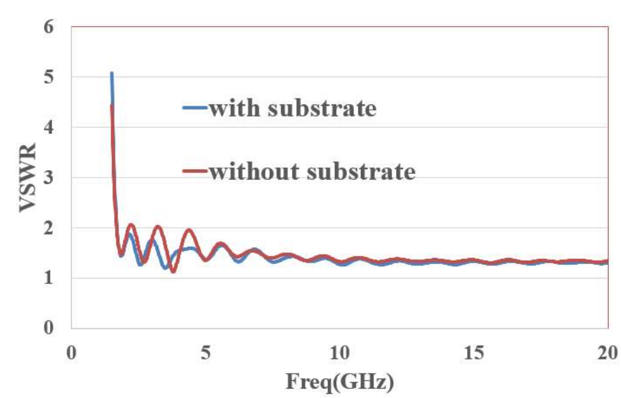


Fig. 5. Result of Simulated VSWR of the DRH antenna proposed in Fig 1

D. Investigation of the effect of circular cut from the side walls of the antenna

Propagate currents density on the upper and lower walls of the antenna is semicircular. As a result, when these currents reach the edge of the antenna, the co-phase plates propagate with different delays, and this will negatively affect the antenna pattern. Therefore, in some commercial models, a circular cut from the end of the side walls removed to allow simultaneous radiation for these phased panels [19]. As we know, the presence of sharp edges in an electromagnetic structure will cause diffraction in the propagation of waves, so as shown in Fig. 6, a small circular curvature at the edge of the upper and lower walls is created to solve the problem of diffraction of the edges.

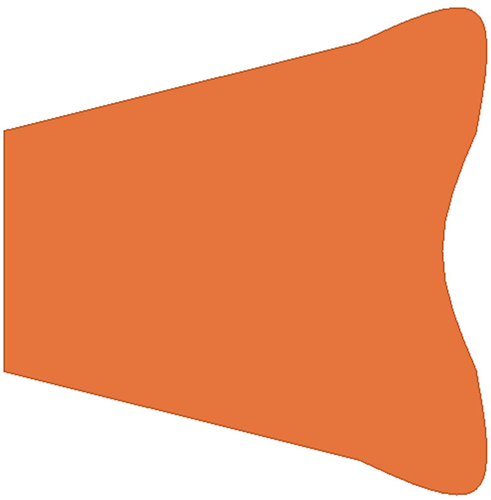
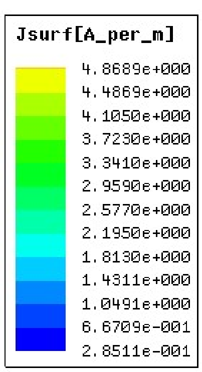


Fig. 6. View of the antenna sidewall

3. Investigation of field distribution in antenna structure

In order to understand the performance of the antenna, we have studied the distribution of the antenna field in several frequencies. As can be seen in the Fig. 7, the middle blades of the antenna have a major current distribution and have a greater impact on the radiant characteristics of the antenna.



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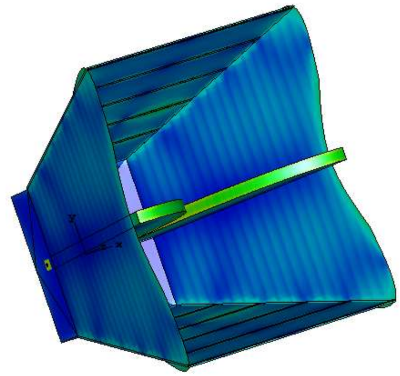

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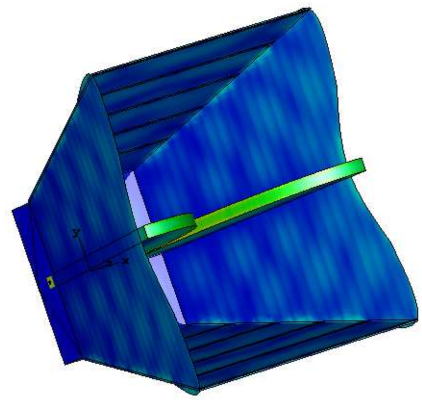

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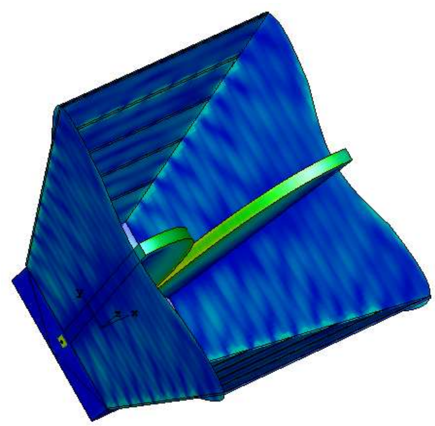


(d)

Fig7. (a) scale of the distribution current on the antenna structure, (b) the distribution current at f=6GHz, (c) f=12GHz, (c) f=18Ghz

4. Results and discussion

The presented antenna is made and measured. The simulation and measurement results of VSWR and boresight gain are shown in Fig. 8, and Fig. 9 respectively. The antenna was measured by using a Vector network analyzer (Agilent E8363E).

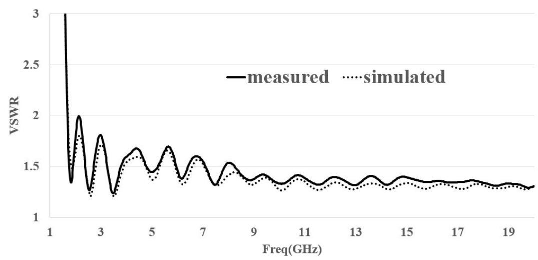


Fig 8. Compression between simulated and measured of VSWR

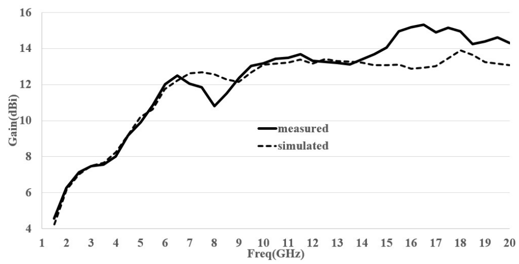
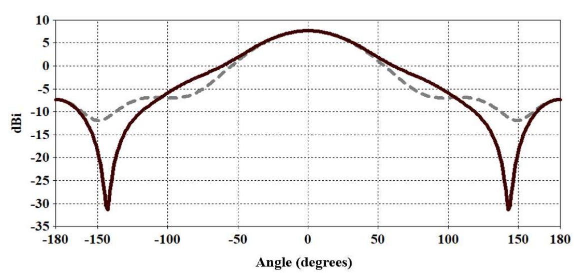


Fig 9. Comparison between simulated and measured of Boresight gain

Fig. 10 shows the radiation patterns of antenna in several frequency. As seen on, the antenna does not have pattern breakup in any frequency in entire band frequency. The performance of antenna in high frequency is perfect. Finally, in order to better express the results, this antenna is compared with similar previous studies in the Table1. As can be seen, this antenna is a desirable antenna for broadband systems compared to other antennas in terms of radiation characteristics. Also, the dimension of antenna is very compact.



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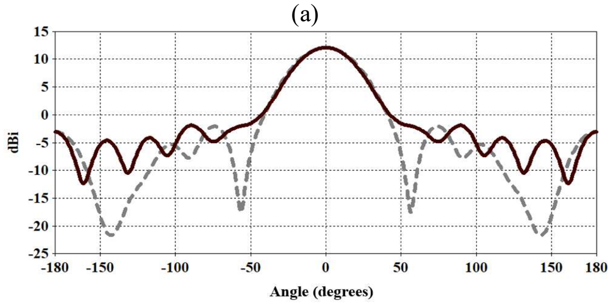

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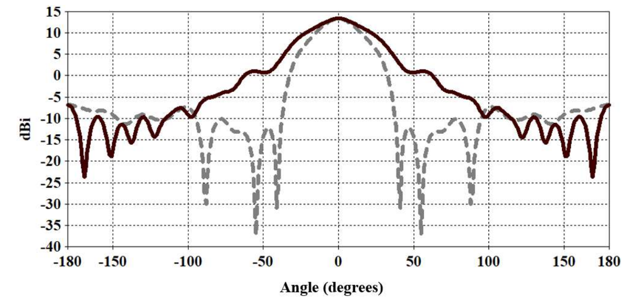

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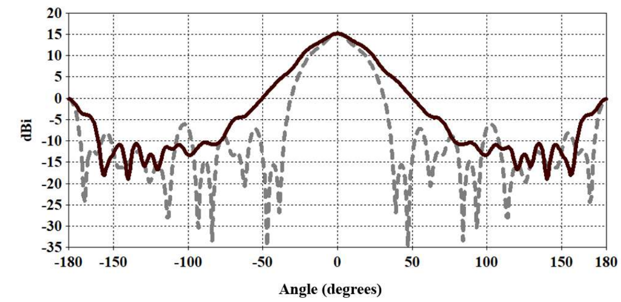

(d)

Fig 10. Radiation patterns of the antenna (- H-plane, -- E-plane) at frequencies (a) f=3GHz, (b) f=6GHz, (c) f=12GHz, (d) f=18GHz

Table1. Comparison with previous researches

reference	dimension (mm^3)	Boresight gain	Band with frequency (GHz)
[20]	264*80*60	0-16	0.5-50
[21]	109.5*60*60	7.1-15	2-18
[23]	285*40*40	7-15.7	2-18
Proposed antenna	95*85*68	14-15	1.7-20

5. Conclusion

In this paper a new ultra-wideband horn antenna with small dimensions was presented. The structure of the proposed Antenna includes a double ridge, cavity back, and corrected sidewalls. In this article, the effects of cavity back waveguide, double ridge, dielectric substrate, and the circular cut from the side walls have been investigated separately. The antenna has an impedance bandwidth of 1.7 to 20 GHz. The proposed antenna has a very high gain and other radiation characteristics of the antenna are also desirable. Also, nulls in the pattern at high frequencies have been prevented. As a result, this antenna can be considered a suitable candidate for a broadband antenna.

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