

10 GHz-100 GHz Compact Double-Ridge Horn Antenna for Ultra-Wideband Millimeter-Wave Biomedical Imaging Applications

Milad Mirzaee, Amir Mirbeik-Sabzevari, and Negar Tavassolian

Department of Electrical and Computer Engineering
Stevens Institute of Technology
Hoboken, NJ, USA

mmirzaee@stevens.edu, amirbeik@stevens.edu, negar.tavassolian@stevens.edu

Abstract— This paper presents the design of a compact double-ridge horn antenna for radar-based ultra-wideband millimeter-wave (mm-wave) biomedical diagnostics. The proposed antenna is composed of a coaxial to double-ridge waveguide (DRW) transition and a free-space matching section. The antenna is designed such that it can be fed using a commercial 1.00 mm coaxial flange launcher. The effect of the ridge profile inside the back-cavity structure of the designed transition is investigated and optimized to achieve an ultra-wideband single-mode bandwidth. Finally, to achieve a smooth transition and a good impedance match to the free-space, exponentially-tapered matching section is employed and optimized. The antenna has small aperture size of 20 mm $\times$ 24 mm and demonstrates stable gain and symmetric radiation patterns across the bandwidth.

Keywords— Biomedical imaging; double-ridge waveguide (DRW); double-ridge horn antennas; millimeter-wave antennas.

I. INTRODUCTION

Attention to microwave and mm-wave spectrum is growing increasingly in the emerging sensing and inspection technologies. In the past few years, tissue imaging at microwave frequencies (300 MHz-10 GHz) has been widely investigated for detection of breast cancer and lung cancer mainly based on the contrast between the dielectric properties of the normal and malignant tissues [1]. Although microwave-imaging systems are cost-effective and can support nonionizing radiation, they are limited by a narrow operating bandwidth and consequently a low spatial resolution. Mm-wave (30-300 GHz) imaging as a possible solution to this problem is studied for skin cancer diagnostics [2]. Antennas are key components in mm-wave imaging systems as their performance will directly affects the accuracy of the obtained results. To attain high resolution images, an ultra-wide imaging bandwidth is required [2]. Double-ridge horn antennas are great candidate for this application since they can provide ultra-wideband bandwidth with directional radiation patterns. Recently different approaches have been proposed for the design of ultra-wideband double-ridge horn antennas [3-5].

In this paper, we present a compact double-ridge horn antenna with only 20 mm $\times$ 24 mm aperture size. The proposed antenna provides an ultra-wideband bandwidth of 10

TABLE I
ULTRA-WIDEBAND DOUBLE-RIDGE HORN ANTENNAS

Reference	Transition structure	Aperture size (mm ²)	Bandwidth (GHz)
[3]	Coaxial to double-ridge	64.7 $\times$ 37.8	10-100
[4]	Coaxial to double-ridge	60.0 $\times$ 38.5	22-129
[5]	Coaxial to double-ridge	61.0 $\times$ 49.0	12.1-63.2
This work	Coaxial to double-ridge	24.0 $\times$ 20.0	10-100

GHz to 100 GHz and can be fed using commercial 1.00 mm coaxial flange launchers. Table I compares the proposed antenna with previously reported ultra-wideband double-ridge horn antennas.

II. ANTENNA DESIGN

Fig. 1 shows the geometry of the proposed antenna, coaxial line, side view of the transition, and cross section of the DRW. To design the broadband millimeter-wave transition from coaxial line to DRW, the impedance matching of the DRW to the coaxial launcher as well as mode conversion from TEM in coaxial line to TE₁₀ in the DRW have been considered. The characteristic impedance of the double-ridge

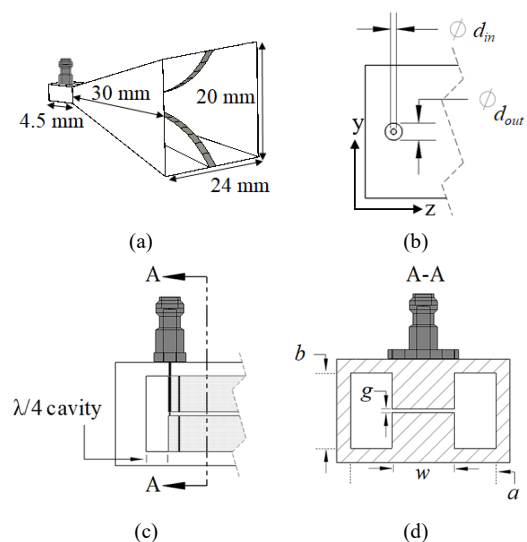


Fig. 1. (a) Geometry of the proposed antenna, (b) coaxial line, (c) transition structure (side view), and (d) cross section of the DRW.

waveguide at any frequency depends on the characteristic's impedance in infinite frequency as [6]

$$Z_0(\omega) = Z_0(\infty) \sqrt{1 - \left(\frac{\lambda}{\lambda_c}\right)^2} \quad (1)$$

Since the DRW is non-TEM transmission line, its impedance is not unique and has several definitions. The choice of definition depends on the application of the waveguide [6]. In this paper, the characteristics impedance in infinite frequency is approximated using the voltage-current definition as follow [6],

$$Z_0(\infty) = \frac{\pi \eta_0 \left(\frac{b}{\lambda_c}\right)}{\left(\frac{b}{g}\right) \sin \theta_2 + \left[2 \left(\frac{b}{\lambda_c}\right) \ln \csc \left(\frac{\pi g}{2b}\right) + \tan \theta_1\right] \cos \theta_2}$$

$$\theta_1 = \frac{\pi}{2} \left(\frac{a-w}{b}\right) \left(\frac{b}{\lambda_c}\right), \text{ and } \theta_2 = \pi \left(\frac{w}{b}\right) \left(\frac{b}{\lambda_c}\right). \quad (2)$$

Based on the desired characteristic impedance of 50 Ω and considering a cut-off frequency around 10 GHz, the following relationships are obtained for the structural parameters of the designed DRW indicated in Fig. 1(d)

$$\frac{w}{a} = 0.33 \quad \frac{g}{b} = 0.071 \quad \frac{b}{a} = 0.62 \quad (3)$$

As mentioned above, the launchers are connected to the ridges through 50- Ω coaxial lines to eliminate the need for using any extra impedance transformer. The inner and outer diameter of the coaxial line have been calculated as 0.2286 mm and 0.53 mm to achieve a 50- Ω impedance based on

$$Z_{coaxial} = \frac{\eta}{2\pi} \ln \frac{d_{out}}{d_{in}} \quad (4)$$

To improve the impedance matching and increasing the bandwidth of the transition, the ridge profile was modified inside the back cavity. Fig. 2 shows the chamfered ridge parameters and the effect of chamfering width on the impedance matching. We achieved the desired matching

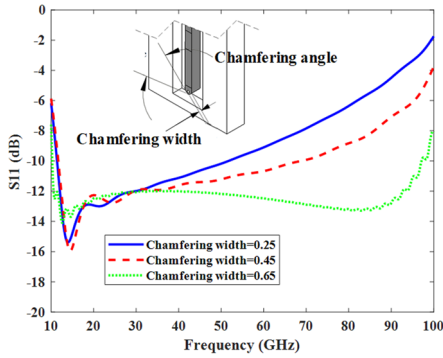


Fig. 2. The effect of chamfering on the impedance matching.

bandwidth with chamfering angle and width of 45° and 0.65 mm, respectively.

The final step for the design of 10 GHz to 100 GHz antenna is the impedance transition from DRW to free-space. For this purpose, a piece-wise exponentially tapered profile was employed and optimized. Fig. 3 (a) and (b) shows the S11 performance of the antenna and normalized 3-D radiation

patterns for different frequencies across the bandwidth. The proposed antenna provides an ultra-wideband matching bandwidth with high gain and stable radiation pattern.

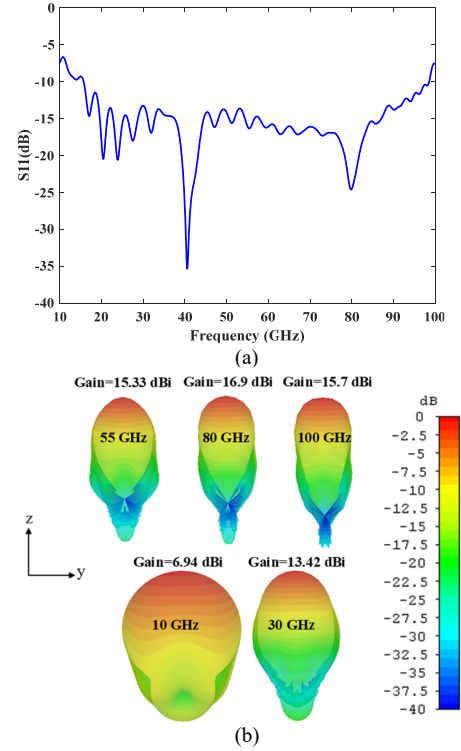


Fig. 3. (a) S11 performance of proposed antenna, and (b) normalized 3-D radiation pattern at different frequencies.

III. CONCLUSION

In this paper, a compact double-ridge horn antenna with the bandwidth of 10 GHz to 100 GHz was presented. The proposed antenna has the aperture size of 24 mm×20 mm and high gain accompanied by stable radiation patterns. These features make the proposed antenna a great candidate for ultra-wideband mm-wave biomedical imaging systems.

REFERENCES

- [1] S. Semenov, "Microwave tomography: Review of the progress towards clinical applications," *Philos. Trans. A Math Phys. Eng. Sci.*, vol. 367, pp. 3021–3042, 2009.
- [2] A. Mirbeik-Sabzevari, E. Oppelaar, R. Ashinoff and N. Tavassolian, "High-contrast, low-cost, 3-D visualization of skin cancer using ultra-high-resolution millimeter-wave imaging," *IEEE Trans. on Med. Imag.*, vol. 38, no. 9, pp. 2188–2197, Sept. 2019.
- [3] M. A. Morgan and T. A. Boyd, "A 10–100-GHz double-ridged horn antenna and coax launcher," *IEEE Trans. Antennas Propag.*, vol. 63, no. 8, pp. 3417–3422, Aug. 2015.
- [4] M. Chung, D. Je and S. Kim, "Development of a wideband double-ridged pyramidal horn for a 22~129 GHz band phase calibration system," in *Global Symposium on Millimeter-Waves (GSMM)*, 2015, pp. 1–3.
- [5] J.-I. Moon and J.-H. Yun, "Double-ridged horn antenna for millimeterwave applications," *Microw. Opt. Technol. Lett.*, vol. 48, no. 11, pp. 2165–2167, April 2006.
- [6] W. J. R. Hoefer and M. N. Burton, "Closed-Form Expressions for the Parameters of Finned and Ridged Waveguides," *IEEE Trans. Microw. Theory Tech.*, vol. 30, no. 12, pp. 2190–2194, Dec. 1982.