Analysis of a Novel Ka Horn Antenna with Low Cross-Polarization

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Abstract **─** A Ka combined horn antenna with low cross-polarization is presented in this paper. The antenna consists of an edge-slotted waveguide linear array, a metallic-grid plane in the horn throat and a horn. The effects of metallic-grid and single-ridged waveguide to the cross-polarization are analyzed. Three kinds of 62-element Taylor linear array at Ka band are fabricated and measured and the measured cross-polarization level is less than -35dB in operating bandwidth. The proposed antennas are benefit for fabrication and fixation with low cross-polarization and can be extensively used in radar and communication systems.

Index Terms **–** Cross-polarization, edge slot, horn, ridge waveguide, and waveguide array.

I. INTRODUCTION

Due to many advantages, such as simple feeding, easy manufacture, high efficiency, low cost, precise controlling of aperture distribution and low loss, the rectangular slotted waveguide arrays have been found wide applications in radar and communication systems [1-3]. In some slotted waveguide array applications, edge-wall slots are preferred to their broad wall counterparts mainly due to their ability to electronically scan a wider angular sector without introducing a grating lobe, thanks to its smaller element spacing [3, 4]. And a number of investigations have been presented on the analysis of the edge-slotted structures [5-9]. The horns are often attached to the edge-slotted waveguide linear arrays to decrease the vertical (in elevation) beamwidth of the antenna, and to increase the gain [10, 11]. However, the most common edge-slotted waveguide arrays are composed of inclined shunt slots, which have severe cross-polarization problems due to the inclined field vectors with respect to the vertical plane at the slot aperture [3]. In [12-14], non-inclined slots on the edge wall of a rectangular waveguide have been implemented to reduce the cross-polarization. However, both of these structures are mechanically challenging especially for the application in the Ka band. In this paper, infinite array characterization technique is applied to the two-slot cell and using this characterization data, an edge-slotted waveguide array can be designed effectively. In [15], a modified double-ridged antenna for 2 GHz – 18 GHz was designed. In order to decrease the cross-polarization effectively, we adopt a symmetric rectangular single-ridged slotted waveguide, where longitudinal metallic grid is located on the right side-wall and the radiated slots connected to the radiation waveguide on the left side-wall. Using this technique, the cross-polarization can be improved about 20dB compared to the case of without grid. And a combined horn antenna with low cross-polarization level and narrow beamwidth is designed for the FMCW radar system operating at the Ka band. The proposed combined horn antenna whose aperture is 343 mm × 76 mm in the orthogonal section is analyzed, so are the effects of the metallic grid on the horn throat and the single-ridged waveguide to the cross-polarization in this paper. All the simulations presented here are carried out by commercial software Ansoft HFSS and compared with measurement results.

II. SLOT CELL DESIGN

The cross-section view profile of the proposed antenna is shown in Fig. 1 (a). The slot cell comprises two cross-inclined edge-slots as shown

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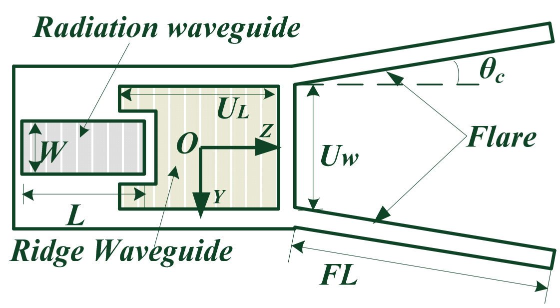
in Fig. 1 (b). The radiated waveguide is a non-standard waveguide (W = 7 mm and L = 3 mm), and a symmetric rectangular single-ridged slotted waveguide (U_W = 7 mm and U_L = 9 mm) with longitudinal grids located on the right side-wall and the radiated slots on the left side-wall is connected to the radiated waveguide. The surface fields on the edge-slotted radiation plane are the superposition field excited by the dominant mode and higher modes. The higher modes transmitting in the single-ridged waveguide will degrade rapidly. The electric field distributions at the slots'-aperture are illustrated in Fig. 2 (a). The electric field E_1 and E_2 can be divided into two orthogonal components (E_{1x}, E_{1y}, E_{2x}, and E_{2y}) along the x-axial and y-axial, respectively. The E_{1x} and E_{2x} are the co-polarization components we needed while the E_{1y} and E_{2y} are the cross-polarization components, which should be restrained. In order to reduce the cross-polarization components, we utilize a single-ridged waveguide with a longitudinal grid (G_W = 3.4 mm and G_X = 2.12 mm) located on the right side-wall of the single-ridged waveguide added outside of the radiated waveguide, as shown in Fig. 1 (a). Due to the existing grid, only small cross-polarization components (E_{1y} and E_{2y}) pass through the grid, and thus are restrained effectively. From Fig. 2 (b), we can observe that many E_y components are generated in the single-ridged waveguide, and the electric field components along the y-axial decline rapidly after passing through the longitudinal grid plane compared to that in the single-ridged waveguide. By choosing proper G_X and G_W, we can obtain the cross-polarization level needed in engineering. For the aperture of the single-ridged waveguide is a bit larger than that of the radiation waveguide, the matching to the free space can be improved. In order to further match the free space, a horn is added along the z-axial outside of the grids shown in Fig. 1 (a) where θ_c is the horn angle and FL is the horn length. The higher modes will be excited again on the grid plane of the single-ridged waveguide, and then degraded after some transmission distance in the horn, but the cross-polarization level has been improved greatly. The reflection caused by the discontinuity between the single-ridged waveguide and the horn can be neglected when θ_c is minor and the problem can be transformed into the radiation of H-plane rectangle horn aperture.

Because the edge-slotted array with horn antenna is usually quite long, its quasi-two-dimensional characteristic allows one to consider it analogous to an H-plane sector horn. By selecting suitable size of G_W, G_X, U_W, and U_L, the dominant mode will propagate in the single-ridged waveguide while the higher modes will cut off. In order to greatly reduce simulation time we utilize infinite array approach to obtain the characterization data of the cross-inclined slot. For the linear array simulations, periodic boundary conditions are applied along the transverse direction to the waveguide. For the combined horn antenna presented in this paper, the main impact factor to the cross-polarization are the grid strip-width G_W and single-ridged waveguide depth U_L. Because the structure is assumed to be two-dimensional, the analysis can be greatly simplified and the influences of the above parameters on the antenna can be acquired, respectively by the full-wave electromagnetic simulation software Ansoft HFSS.



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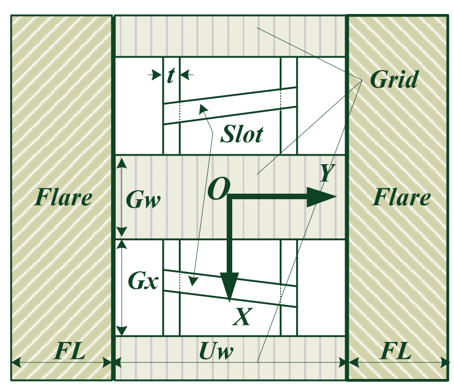

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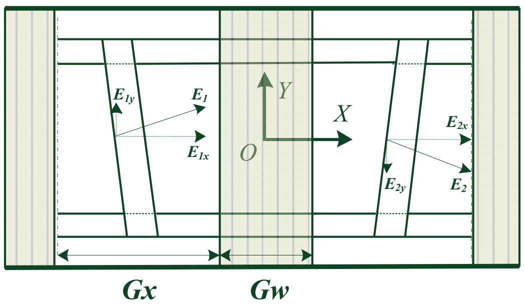
Fig. 1. Geometry of the proposed antenna (a) cross-sectional view and (b) top view.



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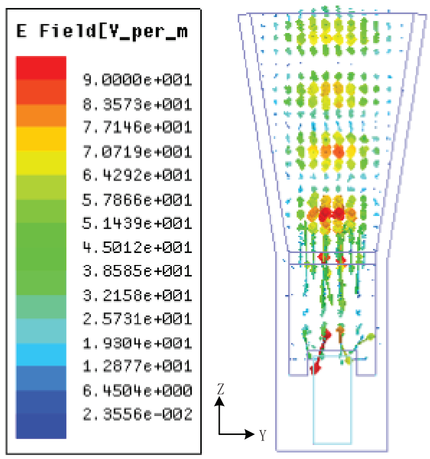

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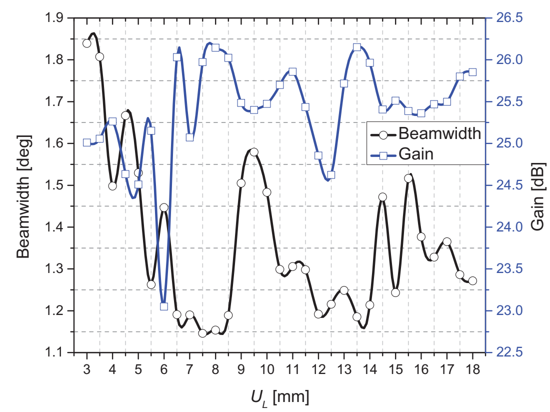
Fig. 2. (a) Electric field at the slots aperture and (b) electric field in the structure.

III. ARRAY DESIGN

The edge-slotted waveguide linear array feeds the horn antenna. The elements in the linear array are arranged along the x-axis and the polarization of the antenna is the same as the direction of x-axis, and the slot elements have Taylor distribution, which is designed for a -27 dB side-lobe level (SLL). In order to reduce the influence of cross-polarization, the effects of different single-ridged waveguide depth U_L and grid strip-width G_W to cross-polarization are studied in this paper.

A. Effects on cross-polarization for different U_L

Figure 3 (a) illustrates that the beamwidth and the gain change with U_L periodically. Due to the higher mode's attenuation and fundamental mode's propagation in the single-ridged waveguide, a minimum value can be obtained every about $\lambda_0/2$ (λ_0 is the wavelength in free space). The peak gain curve of the cross-polarization in E- and H-planes for different U_L is shown in Fig. 3 (b). Evidently, the periodical variation trend is almost coherent between E-plane and H-plane while the cross-polarization in E-plane is at least 10 dB larger than that in H-plane. The results shown in Fig. 3 depict that we can acquire specific antenna performances easily by choosing proper U_L, which satisfies the special needs in engineering projects. For the proposed antenna, we choose the U_L = 9 mm to satisfy the requirement of low cross polarization level, high radiation gain, and narrow beamwidth.



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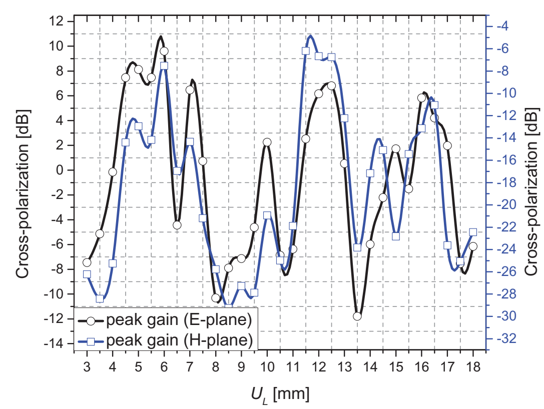

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Fig. 3. (a) Beamwidth / gain versus U_L and (b) cross-polarization versus U_L.

B. Effects on cross-polarization for different G_W

The grid on the horn throat has great influence on the cross-polarization in the E-plane. As can be seen from Fig. 4 (a), when $G_W \leq \lambda_0/2$, the beamwidth increases with G_W and the gain decreases with U_L. The peak gain level of the cross-polarization in the H-plane is smaller than that in the E-plane as shown in Fig. 4 (b). For the purpose of meeting the low cross-polarization requirement, the grid strip-width (G_W) should be chosen reasonably to compromise the cross polarization in the E- and H-planes. According to the curves illustrated in Fig. 4, we set G_W = 3.4 mm to obtain low cross-polarization for the designed antenna, whose peak gain level of the cross-polarization is -15.2 dB and -24.4 dB in the E- and H-planes, respectively.

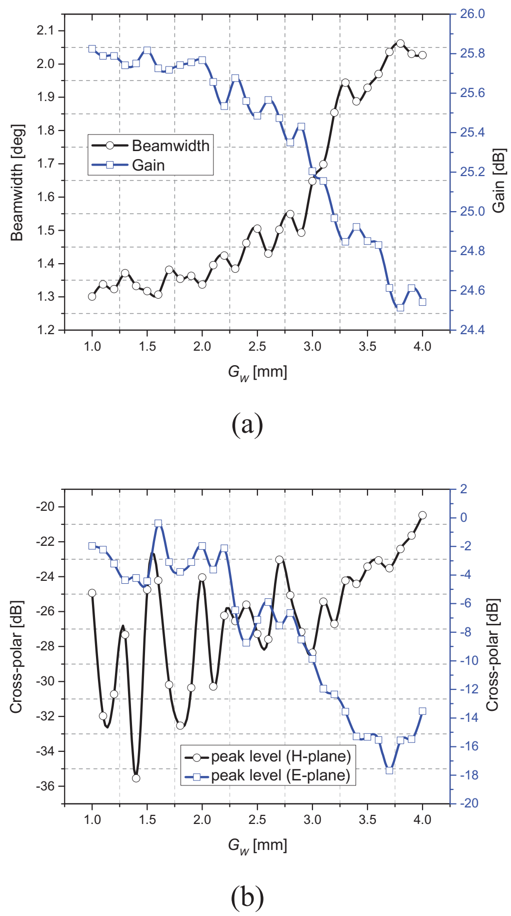


Fig. 4. (a) Beamwidth / gain versus G_W and (b) cross-polarization versus G_W.

In order to study the cross-polarization, we present three kinds of experimental models shown in Fig. 6. The measured results in Fig. 5 illustrate the comparison of the radiation pattern in E- and H-planes between *Case A* (without grid) and *Case B* (with grid). From Fig. 5, we can observe that the grid structure on the horn throat makes a bit improvement to the cross-polarization in the H-plane and a great enhancement in the E-plane while the co-polarization reduces slightly. The use of the grid makes it possible to acquire lower cross-polarization for the proposed antenna.

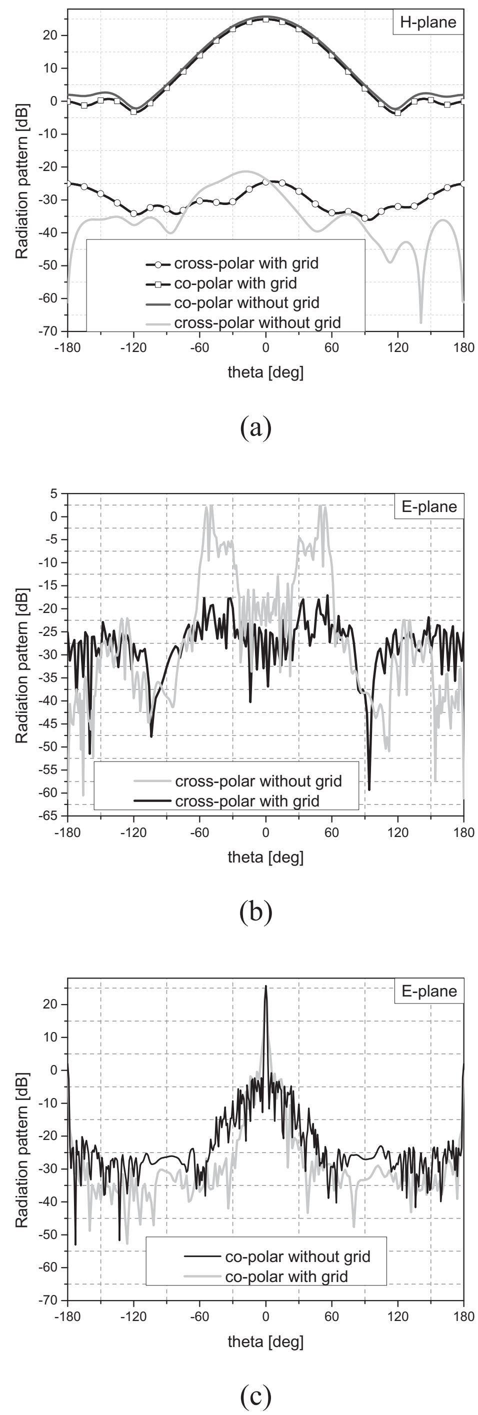
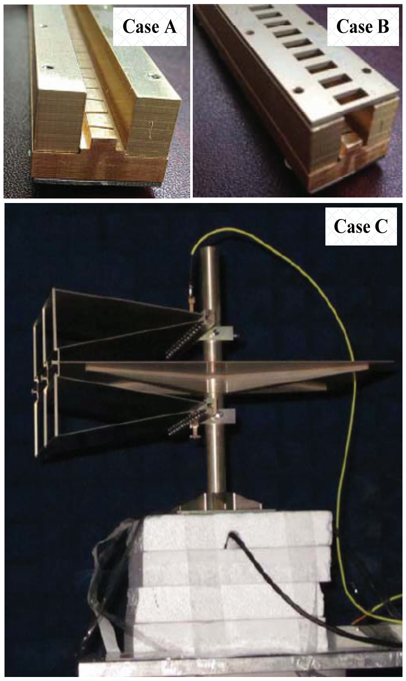


Fig. 5. Comparison between *Case A* and *Case B* (a) co-polarization in H-plane, (b) cross-polarization in E-plane, and (c) co-polarization in E-plane.



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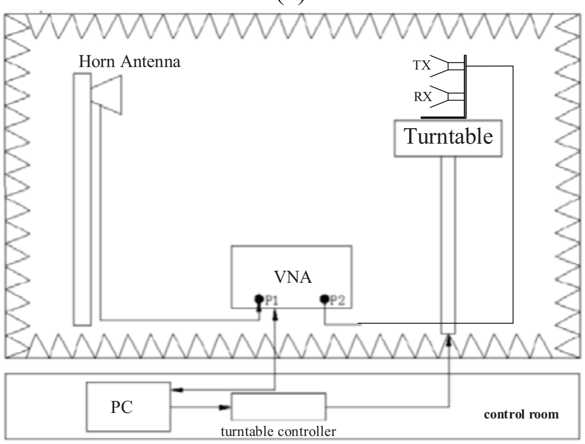
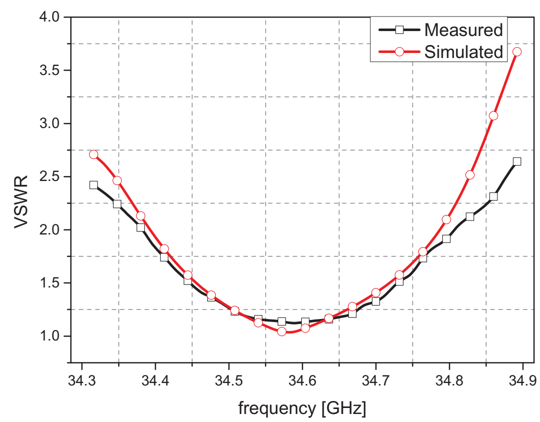


(b)

Fig. 6. (a) Experimental model for the three cases and (b) measurement setup.

For the *Case C* in Fig. 6 (a), the horn length (*FL*) is 220 mm and the horn angle θ_c is 9° whose aperture is 343 mm × 76 mm. The combined antenna consists of the single-ridged waveguide, grid on the horn throat and horn. The structure in *Case C* is made up of the two same combined-antennas and is benefit for fabrication and fixation with low cost, high gain, low side lobe level, and low cross-polarization, which is suitable for application of FMCW radar system. The measured VSWR results are revealed in Fig. 7 (a). Its value in the bandwidth from 34.45 GHz to 34.7 GHz is lower than 1.5. The comparison between simulated and measured normalized radiation pattern of co-polarization and cross-polarization is illustrated in Fig. 7 (b), (c), and (d), respectively. As can be seen from Fig. 7 (b), the measured 3-dB beamwidth of the proposed antenna in the E- and H-planes are 1.5° and 8°, respectively. The simulated and measured results are in good agreement, which indicates that the pretty narrow beam is achieved. Figure 7 (c) and (d) illustrate that the improvement of the cross-polarization mainly concentrated in the E-plane, which improve about 20 dB for the cross-polarization performance. The comparison of the cross-polarization in the E-plane for different types of antenna is listed in Table I.



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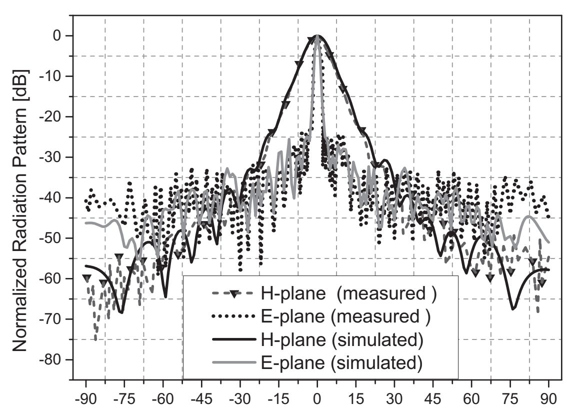

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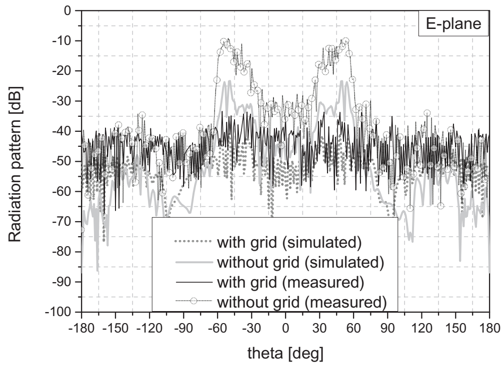

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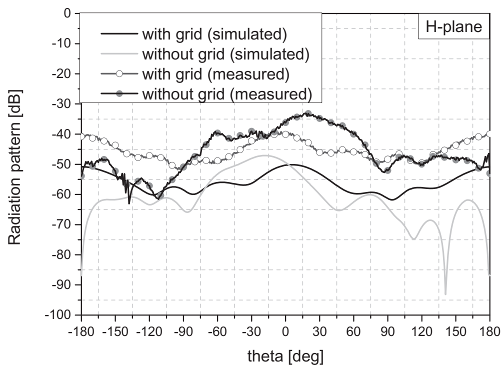

(d)

Fig. 7. Simulation versus measured results (a) VSWR, (b) co-polarization radiation pattern, (c) cross-polarization radiation pattern (E-plane), and (d) cross-polarization radiation pattern (H-plane).

Table I: Comparison of cross-polar in E-plane.

Antenna type	Cross-polar
ANT (with grid)	-40dB
ANT (without grid)	-25dB
ANT in [11]	-25dB
ANT in [12]	-35dB
Edge-slotted waveguide linear array	-28dB

IV. CONCLUSION

In this paper, the combined horn antenna with narrow beamwidth and low cross polarization is presented. The achievement of the key parametric analysis of the proposed antenna conduces to expanding the application field of the antenna. The cross polarization is mainly controlled by the single-ridged waveguide width and metallic grids strip-width and the radiation beam in the H-plane is formed by dominating the horn length (*FL*) and the horn angle θ_c. In the meantime, the horn for the designed antenna has hardly effects on the radiation in the E-plane. Accordingly, it can be realized only by controlling slot parameters in the feed linear array, single-ridged waveguide depth, grid strip-width, and the horn parameters which increase the degree of design freedom. Three kinds of 62-element Taylor linear array at Ka band are fabricated and measured, which show good conformance to the simulated results. The measured cross-polarization level in *Case C* is less than -40 dB and the radiation gain is more than 30 dB at the operating bandwidth. The proposed antenna is benefit for fabrication and fixation with low cost, low cross polarization, and extensive use in radar and communication systems.

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