Feasibility of Dual-Polarization Operation in a Slot Array by Multi-Layer Full-Corporate Waveguide Feeds

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1. Introduction

Hollow waveguide slot antennas, which have the features of low transmission loss and high cross-polarization discrimination (XPD), have been widely employed in communication and radar systems. The fabrication technique called "diffusion bonding of laminated thin metal plates" [1, 2] has been introduced in the realization of multi-layer waveguide structures with high mass-productivity. The diffusion bonding is a process to realize stable surface bonding by applying diffusion motion of atom in the neighboring etched plates. It is conducted under the condition of high pressure and high temperature (~1000°C) in a protective atmosphere or vacuum. As is well known, etching of thin plates is the process of high precision around 20μm at low cost. The number of etching patterns is only five for a double-layer waveguide slot array [2]. Relatively long processing time of the diffusion bonding is not serious if a large number of antennas are processed simultaneously.

Actually, waveguide slot antennas are also characterized as operating at narrowband and beam squint to disadvantage. A double-layer corporate-feed waveguide slot array antenna [3], where the feeding circuit is located in the bottom layer underneath the radiating waveguides in the top layer has been developed for wideband operation and to avoid the beam squint. A 16×16-element array is designed and fabricated by diffusion bonding of laminated thin copper plates in 60 GHz band. A high gain of 32 dBi as well as a wide bandwidth of 8 % for the high efficiency of more than 80 % is achieved.

Compared to reflector antennas, waveguide slot array antennas have the advantages of low profile and high XPD, and simultaneously have the disadvantages of less flexibility in beam scanning, dual-polarization operation etc. Dual-polarized waveguide slot antennas are almost absent from literature. In most previous works [4, 5], the sub-arrays with orthogonal linear polarizations are interlaced side by side. The development of dual-polarized radiating elements in common as well as corresponding exciting networks is awaited to enhance the aperture efficiency by twice. Moreover, a wider bandwidth in feeding circuit rather than the simple series feed [4] also deserves more expectations. In this paper, a multi-layer full-corporate waveguide feeding structure is proposed to excite a slot array in dual-polarization operation sharing common radiating units. The coupling cross-slot is demonstratively designed at 60 GHz, while a high isolation of more than 53 dB as well as a high XPD of more than 37 dB is realized. The structure and the principle of operation will be explained in detail.

2. Approach to Dual-Polarization and Feeding Structure

Fig. 1 shows the configuration of the 16×16-element double-layer waveguide slot array [3] in a bird's-eye view. A 2×2-element slot array in the upper layer is designed as the radiating unit, which is fed in-phase and in parallel by the full-corporate waveguide feeding structure placed in the lower layer through the coupling slot. Fig. 2 shows the exploded perspective view of the radiating unit with 2×2 slots on a waveguide cavity with two sets of walls in the *x* and *y* directions.

In Fig. 3, the arrows and the arrowed circles in dashed lines show the magnetic field distribution inside the waveguide cavity. The upper four radiating slots are excited in same single linear polarization through the coupling slot located underneath the cavity. To realize a dual-polarization operation in the radiating unit, all radiating slots are changed into square shapes, and the rectangular coupling slot is changed into a cross-slot as illustrated in Fig. 4. Moreover, the structure of cavity is also reshaped into an axis-symmetric one in both longitudinal and transverse directions. Two orthogonal linear polarizations will be realized, if the magnetic fields in both longitudinal and transverse directions can be excited independently with a high XPD in radiation and a high isolation in feed.

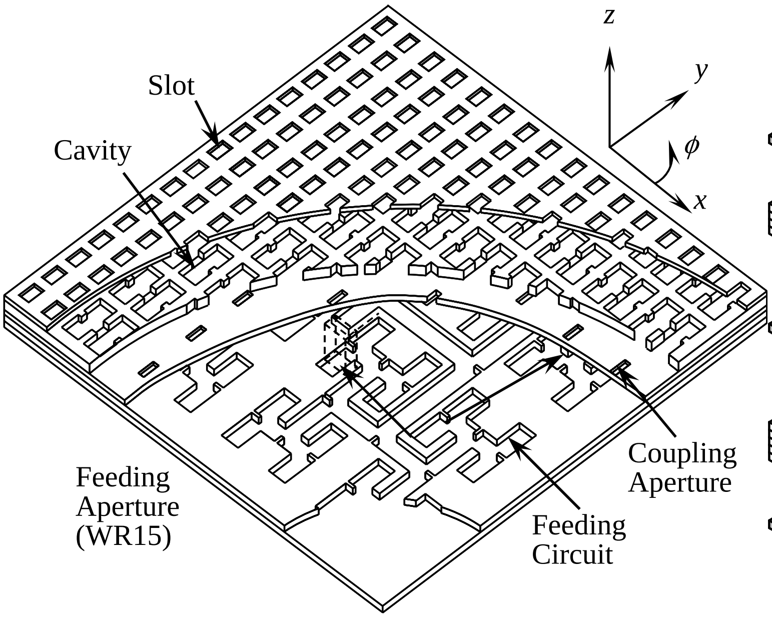
As illustrated in Fig. 5, the longitudinal magnetic field is to be excited by the corporate feeding circuit placed in the fourth layer, which is same with that of the double layer antenna [3]. On the other hand, the transverse magnetic field is to be excited by applying the transverse slot in the second layer. The transverse slots neighbored up and down would be excited in alternating phase, if the third layer was not introduced in Fig. 6 denoted by the dashed lines. The corporate feeding circuit in the third layer is almost identical with than in the fourth layer except the terminations. Therefore, the design of feeding circuit can also be simplified to some extent by adopting same structural parameters. The realization of a high isolation as well as a high XPD is very promising, because the longitudinal slot locates at the waveguide axis in the second layer as illustrated in Fig. 7, where all three layers for the feeding circuits illustrated in Figs. 5 and 6 are laminated together.

3. Design of the Coupling Cross-Slot

As an example, the coupling cross-slot is designed at 60GHz by using the finite element method based simulator HFSS. The first layer for the radiating parts is not included in this initial design, and the external region of the coupling slot is just simplified as a half-free space. The dimensions of the feeding waveguides in all of the second, third and fourth layer are $a(=a_2=a_3=a_4)=4\times b(=b_2=b_3=b_4)=3.53$mm in common. The width w and thickness t of the cross-slot are 1.0mm and 0.3mm, respectively. In the case of incident from Port 1, input matching is realized by optimizing the length and offset of the longitudinal slot at 2.6mm and 0.4mm, and the short position at 1.6mm. On the other hand in case of incident from Port 2, input matching is realized by optimizing the length of the transverse slot at 3.3mm, and the short position at 3.7mm. Fig. 8 shows the frequency characteristics of reflection and transmission coefficients. Even though S_{11} is suppressed below -30dB at the center frequency, the improvement in bandwidth is remained as the future work. Meanwhile, S_{22} is well suppressed below -20dB over the frequency range from 58.25 to 61.75 GHz. The transmission between Port 1 and 2 $S_{21}=S_{12}$ is sufficiently suppressed below -53dB over the whole frequency range from 55 to 65 GHz. There are two principle contributions to this high isolation. The first one is the relative location of the longitudinal slot as explained in the previous section. The second one is that the thickness of the longitudinal slot has to be increased from t to $b+2t$ due to the introduction of the third layer. Therefore, the higher-order mode excited in the longitudinal slot attenuates sufficiently in the long slot thickness region, and the excitation of the transverse slot as well as that in the third layer can also be suppressed effectively. Fig. 9 shows the directivity of the cross-slot in the principle E-plane. A high XPD of more than 37 dB between the two orthogonal lineal polarizations is realized for both incident from Port 1 and 2.

4. Summary

The novel dual-polarization operation of a slot array using three-layer full-corporate waveguide feed has been proposed. The structure of the radiating unit and its principle of operation are explained first for the common use in two orthogonal linear polarizations. The configurations of the full-corporate feeding circuits to independently excite the longitudinal and transverse magnetic fields are illustrated. The initial design of the coupling cross-slot is conducted at 60 GHz. As the simulation results by HFSS, the reflection is suppressed below -30dB at the center frequency and the transmission is suppressed below -53dB over the frequency range from 55 to 65 GHz. A high isolation of more than 53dB and a high XPD of more than 37 dB are realized. As the future work, the design of the radiating unit and the realization of wider bandwidth in the feeding circuit are planned.



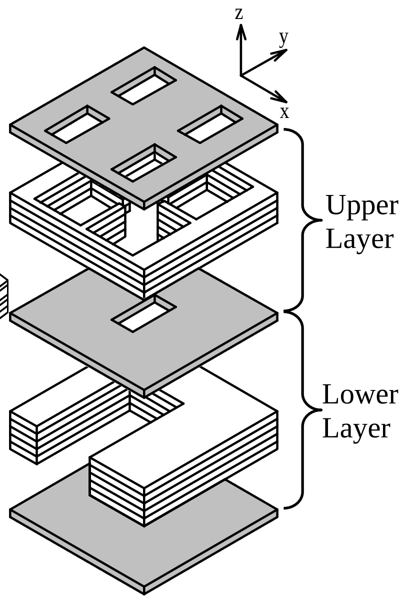
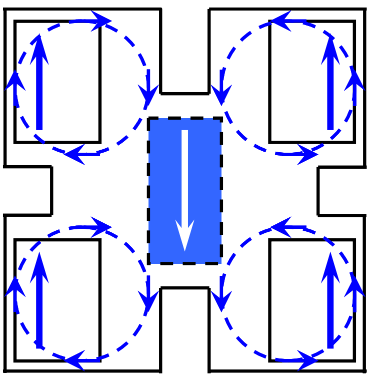


Figure 1: 16×16-Element Double-layer Corporate Array. Figure 2: Radiating Unit of 2×2 Slots.



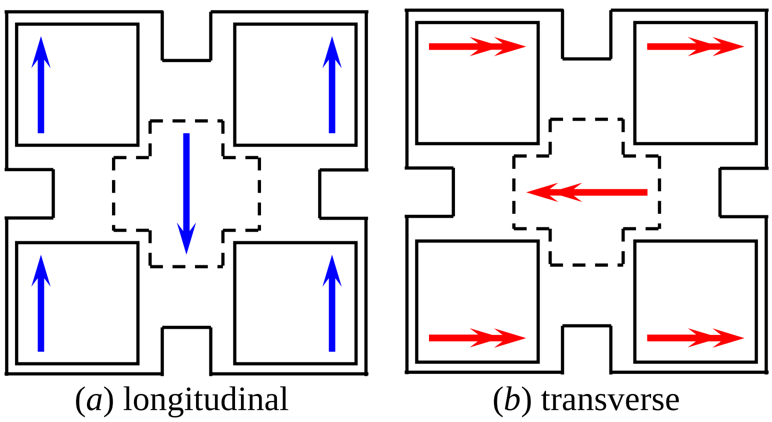
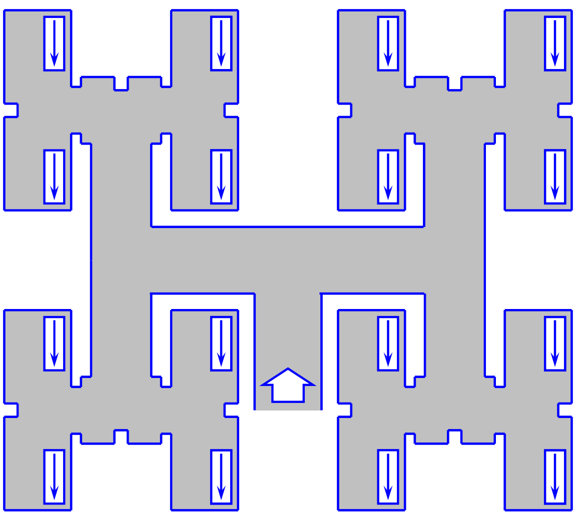


Figure 3: Single Linear Polarization. Figure 4: Dual Polarization – Excitation of Magnetic Fields.



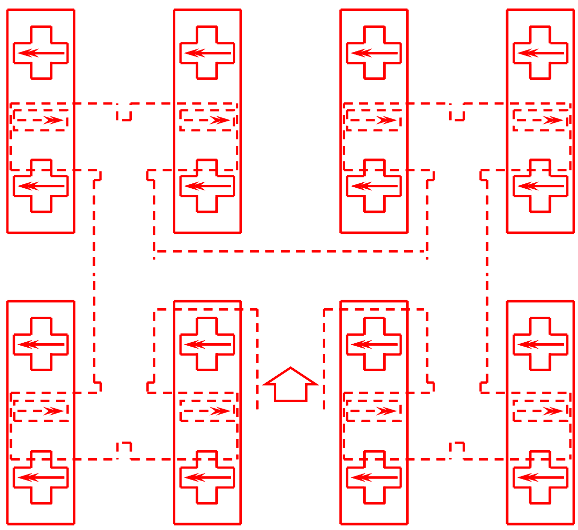


Figure 5: Corporate Feed of 8×8 Slots in 4th Layer to Excite Longitudinal Components.

Figure 6: Corporate Feed of 8×8 Slots in 2nd and 3rd Layers to Excite Transverse Components.

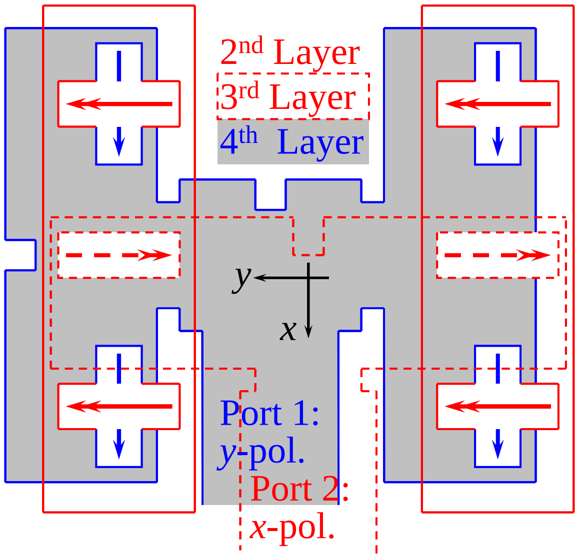
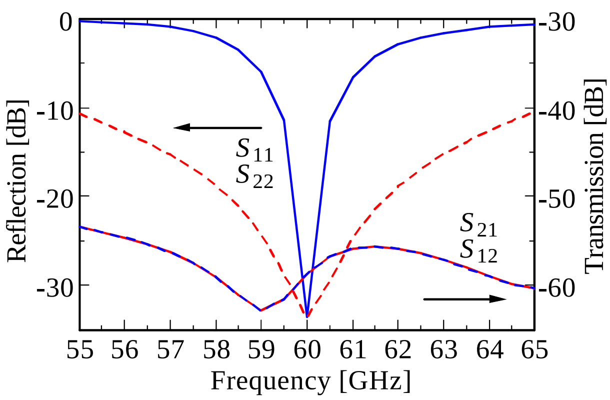


Figure 7: Corporate Feed of 4×4 Slots to Excite both Longitudinal and Transverse Components.



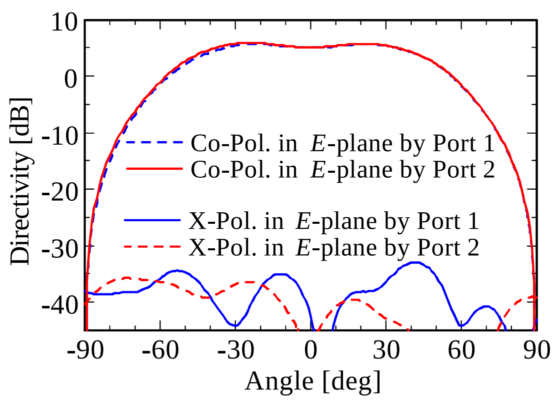


Figure 8: Frequency Characteristics of S-parameters. Figure 9: Directivity of Cross-Slot in E-Plane.

References

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