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An Air-filled Cavity-backed 2×2 Slot Sub-array Fed by Inverted Microstrip Gap Waveguide

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***Abstract*— A wideband 2×2-slot element for a 60 GHz antenna array is designed by making use of air filled cavity fed by inverted microstrip gap waveguide. The designed element is a triple layer structure in which the upper layer contains four radiating slots backed by an air-filled cavity. The cavity is excited by a coupling slot fed by an inverted microstrip gap waveguide formed in the air-gap between the middle and lower layers. The designed 2×2-slot element is considered in an infinite array environment. A sample 32×32 slot array aperture is simulated using infinite array approach. The results show that the mismatch is better than -15 dB and the directivity larger than 38 dBi over 56.3-67.9GHz frequency range, i.e. 20.7 % bandwidth.**

Index Terms—gap waveguide, slot antenna array, soft and hard surfaces, EBG surface, substrate integrated waveguide (SIW), Cavity backed.

I. INTRODUCTION

Slot array antennas are an interesting type of antennas that has been widely used in radar and communication applications at which high gain and narrow radiation patterns are required. By using hollow waveguide corporate distribution network, high radiation efficiency can be achieved since the transmission loss is very low [1-5].

The corporate distribution networks in [2-3] are single layer rectangular waveguide structures and the bandwidth of at most 9.5% is achieved. By a multi-layer distribution network it is possible to provide wider bandwidth, but cost and complexity increase. In [4-5] slot array antennas with a double-layer distribution network are proposed, providing the bandwidth of 12-15% and efficiency of around 80%.

In all the structures presented in [1-5], the great challenge was the cost and difficulty of antenna fabrication at high frequencies. In particular, at high frequencies it becomes difficult to achieve good conductive contact between the metal parts used to realize the hollow waveguide structure.

The gap waveguide technology was introduced in 2009 as an alternative to hollow waveguides and microstrip lines at high frequencies with performance close to rectangular waveguides [6-8]. The gap waveguide technology represents a manufacturing advantage for multi-layer structures in particular at millimeter waves since there is no need for electrical contact between different structure layers.

In [9-10] two directive gap waveguide antennas were presented. In [9] a 4×4 horn array with corporate feed network in inverted microstrip gap waveguide backed by a uniform grid of metal pins is introduced. In [10] 2×2-slot element for a 60 GHz antenna array is designed by making use of two double-sided printed circuit boards (PCBs). In [9] PCB-based microstrip-ridge gap waveguide and SIW technologies were used to realize the antenna.

The structure in [10] is expensive to manufacture because of all the via holes and the expensive low loss substrates in the two PCB layers. Therefore, we investigate alternative electrical designs that can enable other manufacturing approaches.

In this paper we introduced a new 2×2-slot sub-array for a 60 GHz antenna array using air filled cavity and inverted microstrip gap waveguide. The proposed antenna is a triple layer structure. The upper layer contains four radiating slots backed by an air filled cavity. The mid-layer is a metal lid with a rectangular slot at the center through which the fields are coupled to the cavity. The rectangular slot is excited by the inverted microstrip gap waveguide formed in the air gap between mid-layer and the lower one. The lower layer contains a PCB backed by uniform grid of metal pins as shown in Fig. 1.

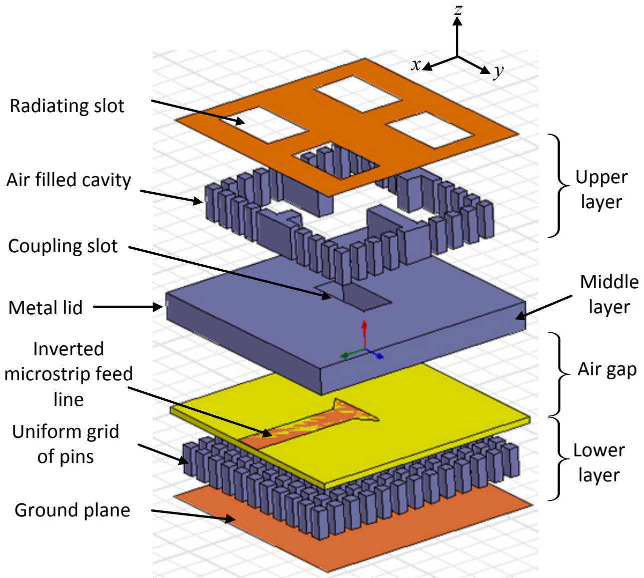


Fig. 1. Distributed 3-D view of 2×2-slot subarray.

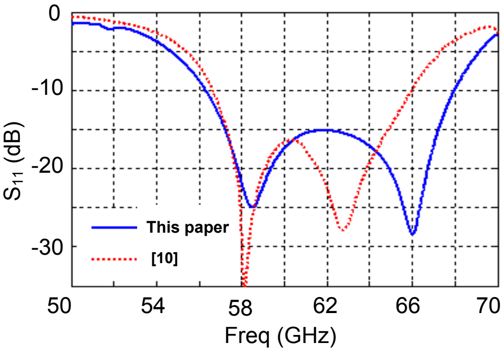
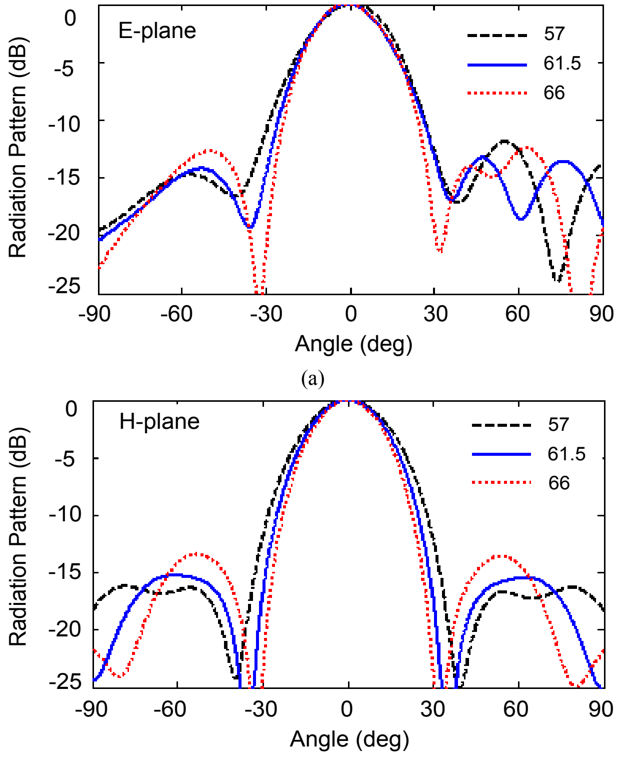


Fig. 2. Reflection coefficient of designed 2×2-slot subarray with periodic walls and its comparison with that obtained in [10]

The present paper presents the numerical design of a 2×2-slot sub-array for operation between 57 and 66 GHz (16%) with $S_{11} \leq -15$dB and for use in large 16×16 or 32×32 slot arrays.

II. ANTENNA CONFIGURATION

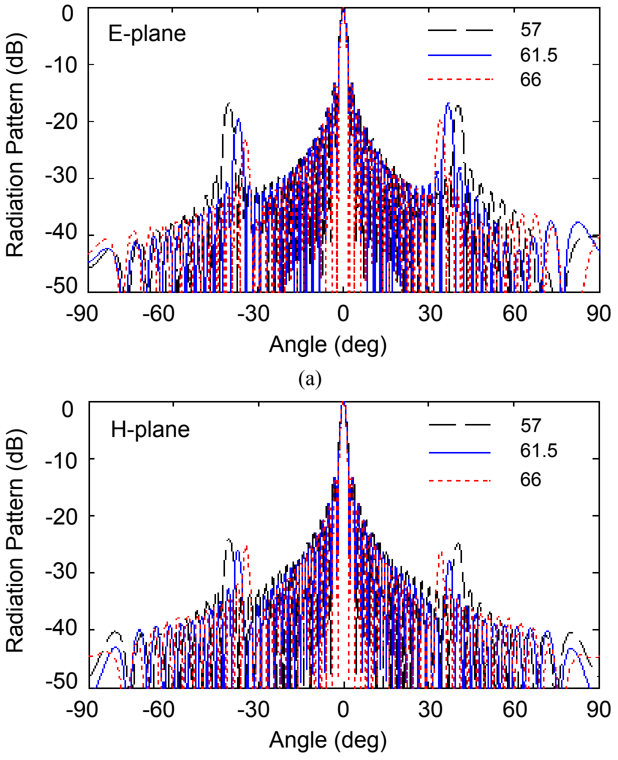
The 2×2-slot subarray is shown in distributed 3-D view in Fig. 1, which clearly illustrates all three layers of the proposed structure. Four radiating slots are backed by an air filled cavity and the distribution network is formed by the inverted microstrip gap waveguide between the middle & lower layers. The coupling between the upper layer and the feed network is provided by a rectangular coupling slot at the center of the metal lid located between the upper and lower layers. The radiating slots are uniformly spaced in both *x* and *y* directions with distances smaller than, but close to, one wavelength, in order to minimize the grating lobe level and get the highest possible directivity of a large 32×32 slot array.



(a)

(b)

Fig. 3. Normalized radiation patterns of proposed 2×2 slot-suarray @ 57GHz, 61.5GHz and 66GHz in (a). E-plane and (b). H-plane.



(a)

(b)

Fig. 4. Normalized radiation patterns of proposed structure with 32×32 slot array aperture @ 57GHz, 61.5GHz and 66GHz in (a). E-plane and (b). H-plane.

In the design of 2×2-slot subarray, we took the mutual coupling between subarrays into consideration by analyzing the 2×2-slot subarray in an infinite two-dimensional array.

The pin dimensions in both upper and lower layers are chosen the same. They have the dimensions of $0.377\times0.4292\times1\text{mm}^3$. The period of pins has kept 0.677mm and 0.7292mm in E-& H-planes respectively. The air-gap is also chosen equal to 0.25mm. Rogers Ro3003 with the thickness of 0.25mm is also used as the substrate for inverted microstrip feed line. The thickness of metal lid is 1mm and the coupling slot in it has the size of $3\times1.2\text{mm}^2$. The size of radiating slots in the upper layer is $2.7814\times1.658\text{mm}^2$ and they are apart from each other by nearly 4mm, in both E-& H-planes. The designed unit cell (2×2-slot subarray) has the dimensions of $8.125\times8.1628\text{mm}^2$ in E-& H-planes respectively.

III. SIMULATION RESULTS

The simulated reflection coefficient of designed 2×2-slot subarray in an infinite array environment is shown in Fig. 2 and compared with that obtained in [10] We observe that for the proposed structure in this paper, S_{11} is lower than -10 dB over 56.3-67.9 GHz (20.7%) and lower than -15dB over 57.2-67.2 GHz (17.48%). In [10] these values were 16% and 13% respectively. The simulated far field patterns of designed 2×2 slot-subarray are plotted at 57 GHz, 61.5 GHz and 66 GHz and very low side lobe level can be seen in the entire of bandwidth. We expect even lower sidelobes for larger arrays. The directivity of designed 2×2 slot-subarray was found to be 14.86dBi at the center of band. We computed the radiation patterns for a 32×32 slot array and observed that the grating lobe levels (GL) in E-& H-planes are below -16.7dB and -24dB, respectively, over the whole band. In Fig. 4, the E-& H-plane radiation patterns of the large 32×32 slot array are shown at 57 GHz, 61.5 GHz and 66 GHz, i.e. the two edge and center frequencies of the desired band. We see very low grating lobes in H-plane. In [10], GL value in E-& H-planes is below -10 dB and -16dB respectively. So, we see that the proposed subarray in this paper has better radiation performance than the presented subarray in [10].

In Fig 5 the directivity and aperture efficiency (AE) of the 32×32 slot array aperture are illustrated vs frequency. The AE is defined as the difference between maximum available directivity and the obtained one. So, only the losses due to grating lobes and side lobes were taken into consideration. The largest directivity value is 39.32 dB and minimum value over the band is 1.3 dB lower. This corresponds to aperture efficiencies of -0.86 dB ~ -0.45 dB in the desired bandwidth. The aperture efficiency of the designed antenna is also compared with that presented in [10]. We see that the presented antenna in this paper radiates more efficiently than the antenna introduced in [10], over most of the desired frequency band. In [10] there was a problem of some higher order modes in the coupling slot were excited by the feed line leading to larger grating lobe level. In this paper we could solve this problem by using a thick metal layer between the cavity and the feed line filtering out those higher order modes. So, lower grating lobe level and consequently better aperture efficiency were obtained.

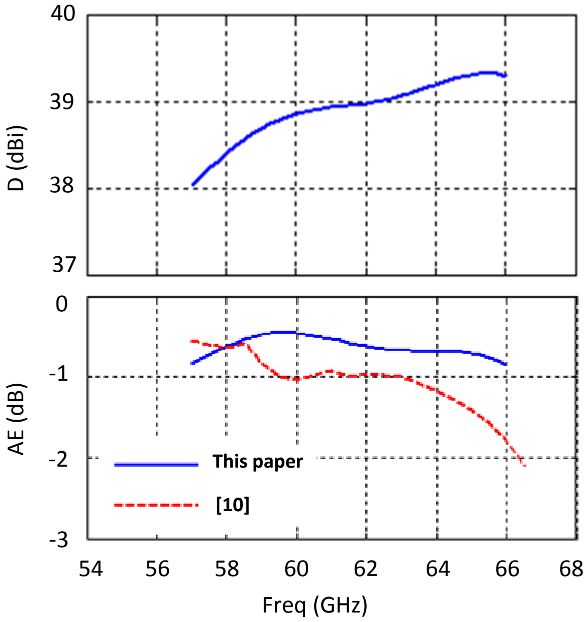


Fig. 5. Directivity and aperture efficiency of proposed structure with 32×32 slot array aperture over the desired bandwidth. The aperture efficiency is compared with that obtained in [10].

IV. CONCLUSION

We have numerically designed the radiating elements of a wideband planar slot array antenna at 60 GHz. We used an air-filled cavity in the radiation layer and inverted microstrip gap waveguide for the feeding. The corporate feed network was not included in the simulations. The design has wider bandwidth and better radiation patterns than the gap waveguide approach in [10]. The idea is to realize the proposed sub-array by using fixed metal posts on the metal plate of the middle plate manufactured by milling, sawing or casting, in the same way as for the lower pin plate. The thin metal plate with the radiating slots will then be soldered to the metal pins by heating the composite structure in an oven. The metal posts can have other cross-sectional shapes than in this paper with no effect on performance. The present rectangular shapes were used to reduce simulation time. Other more rounded shapes may be advantageous for manufacture.

ACKNOWLEDGMENT

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