60GHz Slot-Array Antenna Design Based on Gap Waveguide Cavity and Gap Waveguide Feed Layer

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Abstract— **We propose a multilayer layer 32x32 slot array antenna realized in gap waveguide technology. The antenna has three metal layers: the first layer is the radiating slots in the form of 16x16 subarrays of 2x2 slots, the second defining an air-filled cavity below each subarray, and the third layer forms the distribution network for the 16x16 subarrays. Both the cavity layer and distribution network layer have been designed using gap waveguide technology. Thus the problem of good metal connection between all these layers is completely avoided. The proposed antenna is operating over 11% relative bandwidth covering 58 - 65GHz with -10dB reflection coefficient. The simulated directivity of the 2×2 slot subarray is 13dbi at the center of the band. We present also a T-junction 3-dB power divider for the distribution network designed in groove gap waveguide technology. The reflection coefficient for the designed T-junction is well below -15dB over the band of interest.**

Index Terms— ***Double-layer structure, cavity-backed slot antenna, waveguide slot-array, corporate feed network.***

I. Introduction

Waveguide slot array antennas are expected to provide high aperture efficiency and also high gain at mm-wave frequencies due to the lower losses in the distribution networks [1-2]. Waveguide slot array antennas can be series-fed or parallel-fed. Series-fed slot array antennas have a simple geometry but suffer from narrow operational bandwidth due to long-line effects [3-4]. Also, in a single layer distribution network, it is normally not possible to feed each radiating element in parallel with a fully corporate distribution network because of the space limitations associated with keeping the element spacing smaller than one wavelength (λ_o) to avoid grating lobes. On the other hand, multiple layer cavity-backed slot array antennas can have lower loss as well as wider bandwidth. However, the key challenges with multi-layer antenna structures are higher fabrication cost and the manufacturing complexity associated with achieving good electrical contacts between the distribution layer, cavity layer and radiating slot layer. Such a tripple-layer slot array with corporate distribution network designed in rectangular waveguide technology is described in [5]. It was not possible to realize such antenna with conventional milling technique. On the other hand, the authors realized the antenna by using expensive diffusion bonding of laminated thin metal plates and the antenna worked over 11% relative bandwidth with 80% efficiency.

Apart from the proposed diffusion bonding technique, another common practice in rectangular slot array antennas is to use dip-brazing to achieve very good electrical contact between several metal layers forming distribution networks in conventional rectangular waveguides for slot array antennas. In reality, both diffusion bonding and dip-brazing techniques are employed for ensuring good electrical joints and apparently dictate the electrical performance of the rectangular waveguide fed slot array antennas.

To overcome this problem of good electrical contact associated with mechanical assembly, the gap waveguide technology can be successfully employed. The gap waveguide technology presented in [6-7] uses the cut-off of a PEC/PMC parallel-plate waveguide configuration to control desired electromagnetic propagation between the two parallel plates without the requirement of the electrical contact. This is quite advantageous and is very suitable for the mechanical assembling of the multilayer slot-array antennas mentioned before. Also, the Q-factor analysis confirms that the losses in ridge gap waveguide and groove gap waveguide structures are comparable to that of standard rectangular waveguide [8-9]. Therefore, the feed network losses will be quite low for gap waveguide antennas, and the radiation efficiency of gap waveguide slot array antenna will be high and will be comparable to that of rectangular waveguide based slot array.

Till now, few papers on antennas realized in gap waveguide technology have been published. Initial slot array work in single hard-wall waveguide has been described in [10]. Recently, a 4×1 slot array design in ridge gap waveguide was published [11]. We should also mention the multi-layer phased array antenna and dual mode horn array based on related technology presented in [12-13]. Recently, series-fed groove gap waveguide slot array having inclined slots in narrow wall has also been reported [14]. However, this slot array was narrow band (5% BW). Apart from the above-mentioned works, a Ku-band 2×2 element ridge gap waveguide based slot array has also been described in [15].

In this work, we present a prototype of a limited 60GHz multilayer 2×2 cavity backed slot-array antenna excited by groove gap waveguide. The spacing between the slots at the top radiating layer is kept 4.0 mm, corresponding to about 0.87λ at the highest operating frequency of 65GHz. Thus, the problems associated with grating lobes will be minimized within the frequency range of interest. The design is made in an infinite array environment using periodic boundaries, so that we will be able to realize a larger final 32x32 slot array later.

II. ANTENNA STRUCTURE

The structure of the proposed multilayer layer groove gap waveguide antenna is shown in fig.1. The antenna structure consists of a groove gap waveguide feed layer at the bottom. This feed layer can easily be expanded to a bigger corporate feed network with power dividers or T-junctions. The feeding groove gap waveguide excites the gap waveguide cavity in the middle layer via a coupling slot. The coupling slot is placed at the center of the cavity layer. The four radiating slots are placed on the top plate of the cavity and are equally spaced from the coupling structure. Thus these four slots are excited equally in amplitude and phase to give a broadside beam.

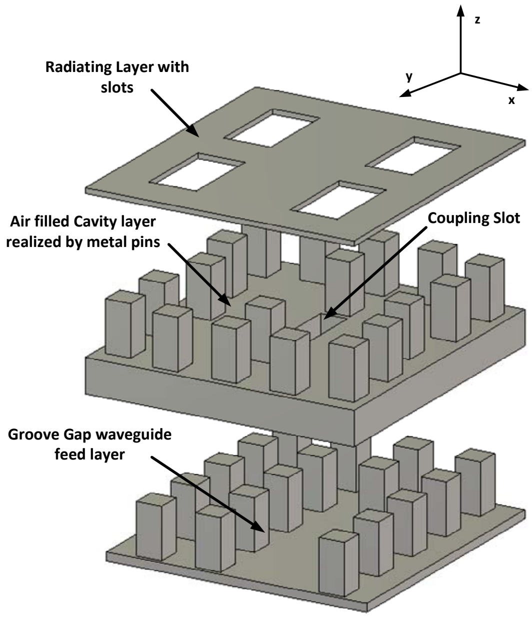

Fig. 1: Perspective view of 2×2 multi-layer slot-array antenna

The pin dimensions in both the cavity layer and groove gap waveguide feed layer are same. The pins have the dimension of $0.75 \times 0.75 \times 1.25 mm^3$. The period of pins used in this design is kept equal to 1mm. The height of the feeding groove gap layer and the cavity height are 1.5 mm, which is due to the pin heights of 1.25mm and the air gap height of 0.25mm between the layers. These dimensions are achieved by looking at the eigenmodes or parallel-plate stop-band obtained for one unit-cell of the periodic pin structure designed in CST microwave studio. The length and width of the radiating slots on the top layer are chosen to be 2.7mm and 1.4mm respectively. The slot-width to slot-length ratio for the radiating slot is kept more than 0.5 for achieving a larger impedance bandwidth as mentioned in [3]. The width and length of the coupling slots are chosen to be 2.825mm and 0.8mm respectively. In this case, the slot-width to slot-length ratio is kept less than 0.5. This helps to stop excitation of unwanted higher order modes in the cavity layer.

III. BANDWIDTH OF MATCHING AND RADIATION PATTERNS

In the simulations, the 2×2 slot-array antenna is excited with a waveguide port at the groove gap waveguide feed layer. The simulated reflection coefficient at the feed waveguide port is shown in fig.2. The simulated bandwidth for -10dB reflection coefficient is found to be 11% within 58-65GHz band.

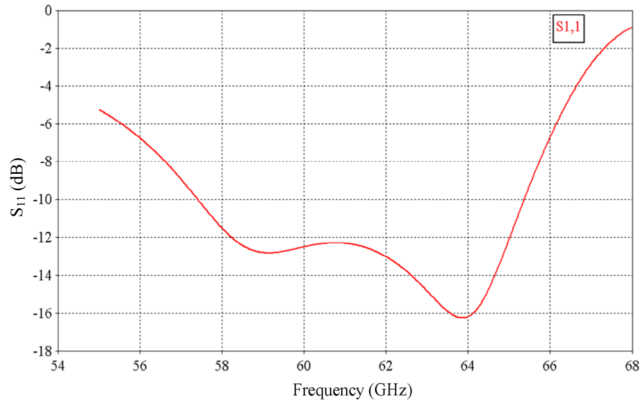

Fig.2 Simulated S_{11} of the 2×2 multi-layer slot-array antenna.

The simulated far-field patterns at 58, 60 and 65GHz are also presented in fig.3 (a) and fig. 3(b). As expected, we find that- the sidelobes in the E-plane patterns are higher than those of the H-plane patterns. In a bigger array, this sidelobes will be lower and will remain below the acceptable level. The simulated directivity of this 2×2 slot-array antenna is found to be around 13dBi at the center of the band.

IV GROOVE GAP WAVEGUIDE T-JUNCTION

To be able to design a fully corporate distribution network, we need a T- junction realized in groove gap waveguide. In this section, we present a T-junction with equal power division. The layout of the groove gap waveguide T-junction is shown in fig.4 (a) and the simulated results for the designed T-junction is shown in fig. 4(b). The T-junction is designed by placing a pin in the junction of three groove gap waveguide sections. As shown in fig. 4(b), the designed T-junction is quite wideband in nature, and the T-junction is operating over more than 25% relative bandwidth.

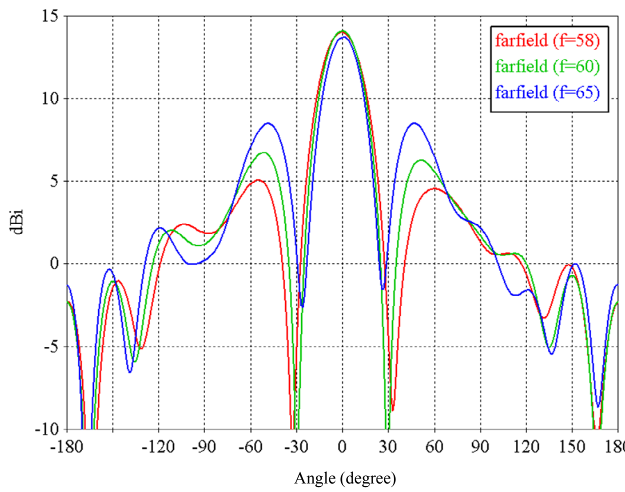

Fig.3 (a) Simulated E-plane patterns for the slot-array antenna.

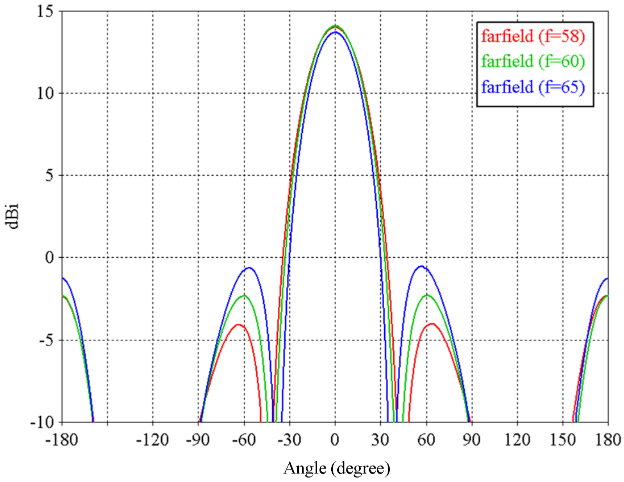

Fig.3 (b) Simulated H-plane patterns for the slot-array antenna.

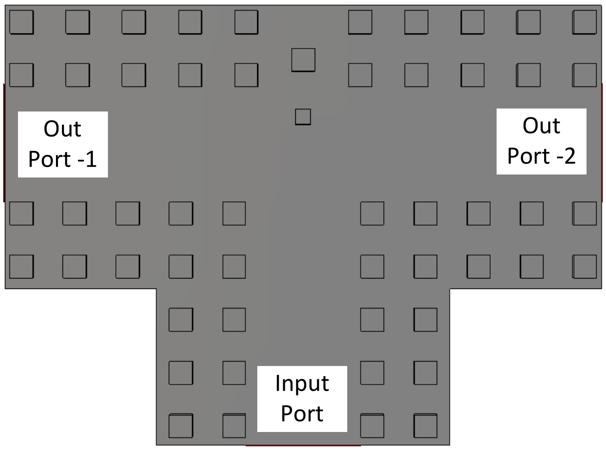

Fig. 4(a) Top view of the designed T-junction.

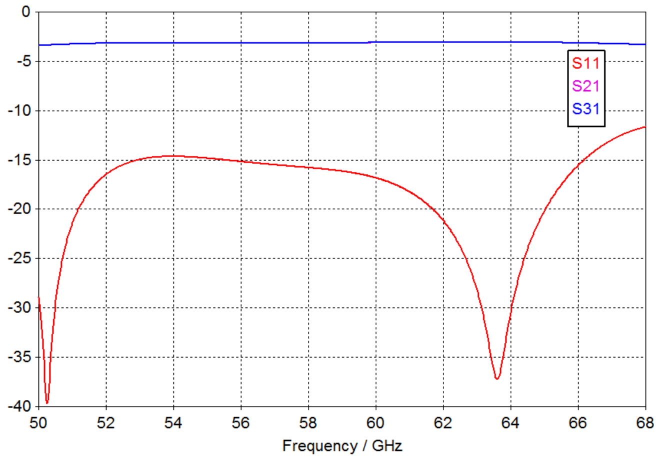

Fig. 4(b) Simulated results of the designed T-junction.

V SUBARRAY IN AN INFINITE ARRAY CONDITION

The presented 2×2 slot array element can be used as a sub-array element to build up much larger antenna with higher gain. Our goal is to build a 32x32 slot array. The element spacing of 4 mm between the adjacent slot elements corresponds to 0.87λ at higher frequency of interest, which is small enough to avoid grating lobes. In order to use the 2x2 array as a subarray in a large array, it has been optimized numerically as a unit cell in an infinite array configuration using periodic boundary conditions, so as to include the effects of mutual coupling between subarrays. The simulated pattern for a 32×32 element large array by using the infinite array approach is shown in fig. 5.

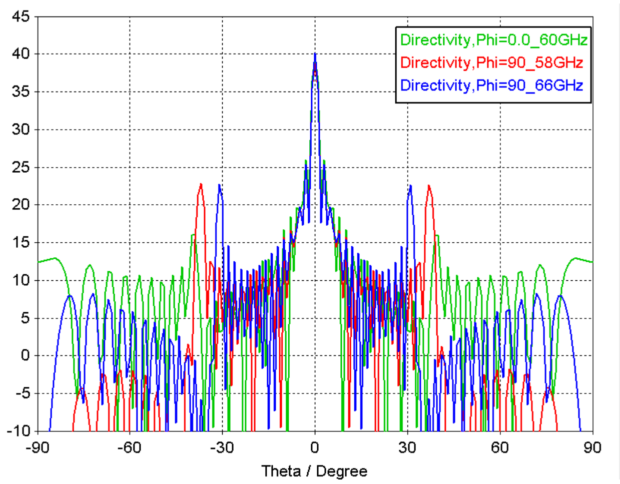

Fig. 5(a) H-plane pattern for the 32×32 element array.

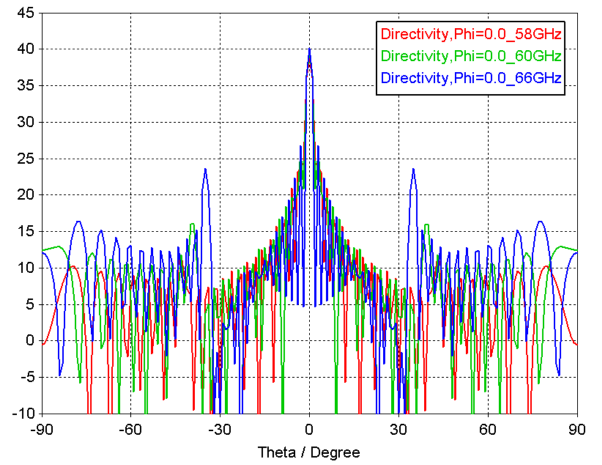

Fig. 5(b) E-plane pattern for the 32×32 element array.

VI CONCLUSION

We present a mechanically flexible multilayer cavity backed slot-array antenna design based on gap waveguide technology. The proposed slot array antenna configuration does not need good electrical contact between the mechanical assembly blocks and therefore, does not require dip-brazing or diffusion bonding during the manufacturing process of the antenna. The simulated results show promising results for the 2×2 array with large impedance bandwidth and good radiation patterns. We also present simulated results for a groove gap waveguide T-junction, which is the key building block for the corporate distribution network. Finally, the 2×2 groove gap slot array element has been used as a subarray unit in an infinite array approach for simulating the patterns of a 32×32 element large array with higher gain. The simulated radiation patterns have grating lobes lower than -17 dB in both principal planes. Thus the reduction in the aperture efficiency due to the presence of grating lobes will be negligible.

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