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Citation for the original published paper (version of record):
Liu, J., Vosoogh, A., Uz Zaman, A. et al (2016). Design of a Cavity-backed Slot Array Unit Cell on Inverted Microstrip Gap Waveguide. International Symposium on Antennas and Propagation (ISAP)

Design of a Cavity-backed Slot Array Unit Cell on Inverted Microstrip Gap Waveguide

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***Abstract*—Inverted microstrip gap waveguide is advantageous for millimeter wave application because of its low-loss, self-packaging characteristics and cost-effectiveness. In this work a planar gap waveguide slot array is presented. It is fed by a corporate distribution network realized in inverted microstrip gap waveguide. The structure consists of three layers. The top layer contains subarrays of 2 × 2 radiating slots. This is backed by an air-filled groove gap waveguide cavity. This cavity layer is fed by the inverted microstrip gap waveguide distribution network formed in the air-gap between the middle and bottom layer. The paper presents a design of the 2 × 2 subarray, i.e. the unit cell using simulations in an infinite array environment. The simulation results show that the S_{11} is below -11 dB over 57-66 GHz frequency band covering 14% bandwidth, and the simulated directivity is about 39 dBi when evaluated for a 32 × 32 element slot array antenna.**

I. INTRODUCTION

Gap waveguide technology constitutes a new type of guiding structure that shows lots of potential to overcome the issues of conventional technologies, and become a suitable technology at millimeter wave frequencies [1-3]. The gap waveguide technology is based on the cutoff of electromagnetic fields when a metal plate is placed at a distance on top of textured surface - working as an Artificial Magnetic Conductor (AMC). The AMC establishes a high impedance boundary condition that ensures the removal of any parallel-plate mode, cavity mode, surface waves or radiation leakage within a certain frequency band called the stopband [4]. This novel conception states that a local quasi-TEM mode is allowed to propagate between a PEC plate layer and a high impedance layer which supplies a parallel-plate stopband over a specific frequency range. Therefore, this quasi-TEM wave can be used for microwave and millimeter wave circuits. An example of particular case is distribution networks feeding a slot array [5-6]. AMCs are realized by periodic structures comprising metal pins or other geometrical shapes. So far, four different versions of gap waveguide technology have been proposed: the groove, ridge [7], inverted microstrip [8] and microstrip-ridge gap waveguides [9], as sketched in Fig. 1. In this work the inverted microstrip gap waveguide technology is utilized for feed networks. The corresponding dispersion diagram is illustrated in Fig. 2, which clearly shows that a quasi-TEM wave propagates over the stopband from 48 - 72 GHz.

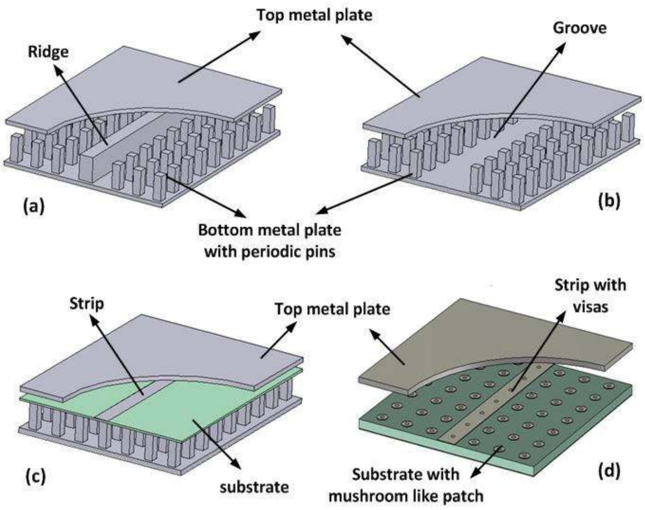

Fig. 1. Four realized versions of gap waveguide technology. (a) Ridge gap waveguide. (b) Groove gap waveguide. (c) Inverted microstrip gap waveguide. (d) Microstrip-ridge gap waveguide.

Slot array antenna has been widely applied in radar

This work has been supported by European Research Council (ERC) via an advanced investigator grant ERC-2012-ADG_20120216, and Sweden's innovation agency VINNOVA within the VINN Excellence Center Chase at Chalmers.

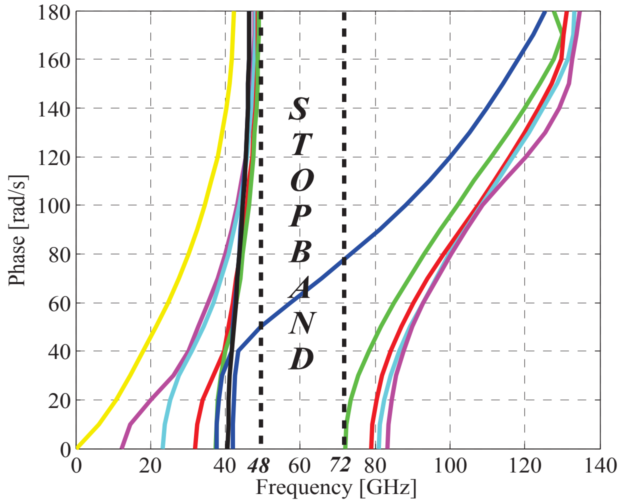

Fig. 2. Dispersion diagram for inverted microstrip gap waveguide utilized in this work and blue curve crossing over the stopband represents the quasi-TEM mode.

communication systems at which high efficiency and high gain are required. So far corporate distribution networks using hollow waveguide can achieve high radiation efficiency. The corporate distribution networks in [9-10] are single layer rectangular waveguide structures and its bandwidth reaches 9.5%. On the other hand, multi-layer distribution networks are possible to provide wider bandwidth, but cost and complexity increase. In [11] slot array antennas with double-layer distribution networks are proposed, providing the bandwidth of 12-15% and efficiency around 75%. However, its cost and manufacturing complexity accordingly increases at millimeter wave frequency range due to the requirement of very good metal contact among different antenna layers. The gap waveguide technology provides manufacturing advantages for multi-layer structures in particular at millimeter waves as no electrical contact is required among the antenna layers.

In [12-13] two directive gap waveguide antennas were presented. In [12] 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 [13] a 2×2 slot element for a 60 GHz antenna array is designed by utilizing two double-sided printed circuit boards (PCBs), PCB - based microstrip-ridge gap waveguide and SIW technologies were used to realize the antenna. In this work we will introduce a new cavity-backed slot array unit cell based on inverted microstrip gap waveguide.

II. ANTENNA CONFIGURATION

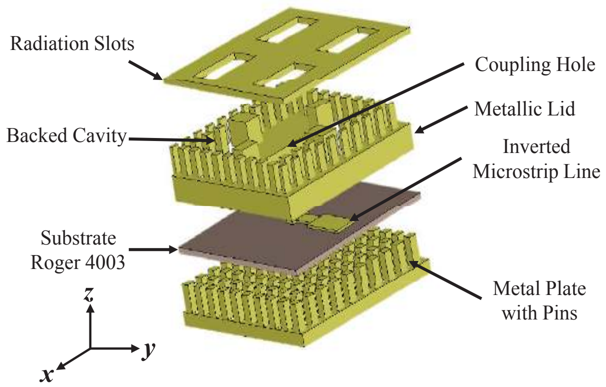

Fig. 3. Detailed 3-D view of slot array unit cell.

The 2×2 slot array unit cell is illustrated separately in 3-D view in Fig. 3. The structure briefly consists of four layers. The top layer contains four radiating slots. These radiating slots are backed by an air filled cavity which locates at the middle layer. Below the cavity layer there is a PCB containing the distribution networks, which have been designed by using the inverted microstrip gap waveguide. Below the PCB, there is a bottom metal layer with a uniform grid of pins. The coupling between the cavity layer and the feed networks is obtained by using a rectangular coupling slot at the center of the metal layer used as the cavity layer. The radiating slots are uniformly spaced in both x and y directions. Their distances are kept less than one wavelength in order to minimize the grating lobe level and at the same time the element spacings are optimized to get the highest possible directivity of a large 32×32 slot array.

The size of the radiating slots is $2.48 \times 1.47\ mm^2$ and the distances between every two slots in x and y directions are 4 mm. The designed unit cell has the dimensions of $8 \times 8\ mm^2$ in both E- and H-planes respectively. The thickness of metallic lid is 1 mm and the coupling slot in the middle has the size of $2.5 \times 1.2\ mm^2$. The pin dimensions in both metal plate and backed cavity have the same dimensions of $0.4 \times 0.4 \times 1.2\ mm^3$. The period of pins has kept 0.8 mm in both E- and H-planes respectively. The air gap between substrate and metallic lid is chosen equal to 0.25 mm. Roger 4003 with the thickness of 0.25 mm is utilized as the substrate for inverted microstrip feed line.

III. SIMULATION RESULTS

In numerical simulation, the 2 × 2 element slot array is excited by a waveguide port at the inverted microstrip gap waveguide. The simulated reflection coefficient of the designed unit cell is shown in Fig. 4. We observe that S_{11} is below -10 dB over the frequency range 57 - 66 GHz. The antenna unit cell has been simulated in an infinite array condition with periodic boundary condition. Simulated far-field patterns of the single unit cell over the operating bandwidth at 57 - 66 GHz are also presented in Fig. 5 and Fig. 6. The simulated directivity of this unit cell is found to be around 15 dBi at the center of band. Then we computed the radiation patterns for the 32 × 32 slot array and corresponding radiation patterns in E- and H-plane. These are shown in Fig. 7 and Fig. 8, respectively. We have observed that the grating lobe levels (GL) in E- and H-planes are below -20 dB and -27 dB respectively at the center frequency of 61.5 GHz. Fig. 9 shows the directivity of the 32 × 32 slot array over 57 - 66 GHz. At center frequency of 61.5 GHz the directivity is around 39.35 dBi.

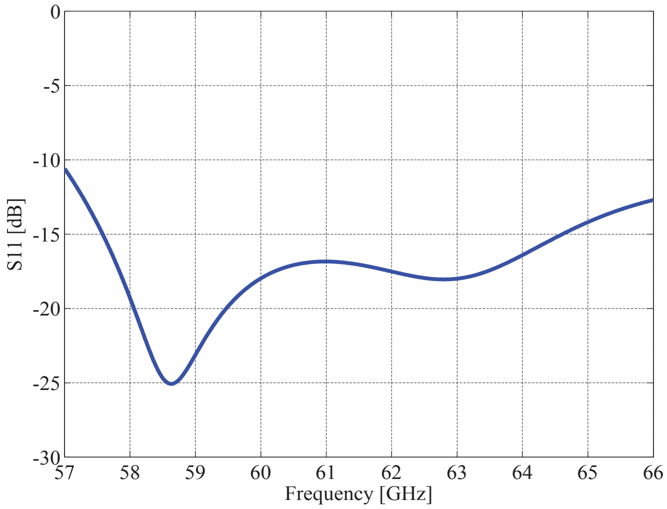

Fig. 4. Reflection coefficient of simulated slot array unit cell.

IV. Conclusion

In this work we have numerically designed the radiating elements of a wide band planar slot array unit cell at 60 GHz. The inverted microstrip gap waveguide is utilized for the feeding. The corporate distribution feed network was not provided in this paper. Full-wave simulated results show promising results over the same bandwidth as the unit cell. The proposed antenna unit

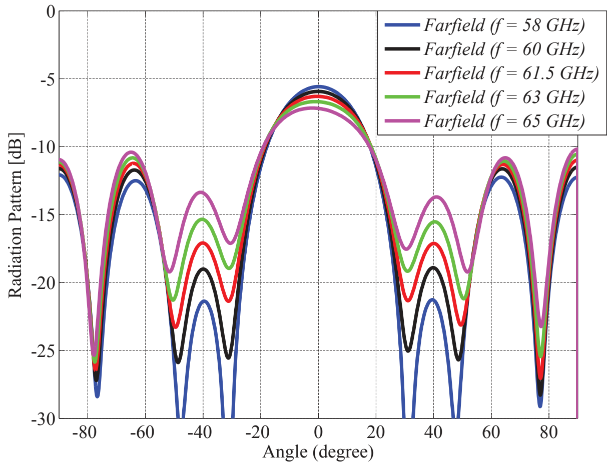

Fig. 5. Simulated E-plane patterns of antenna unit cell.

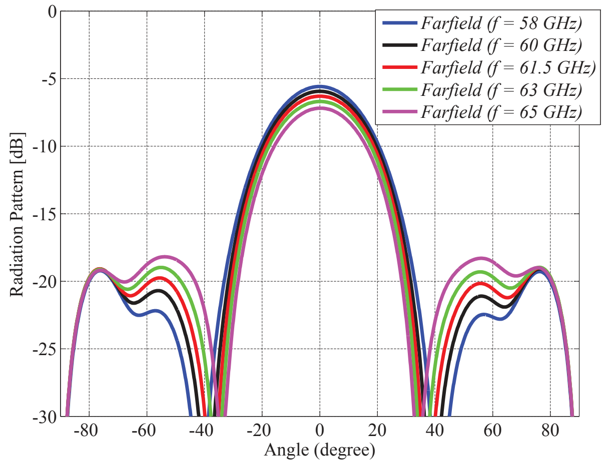

Fig. 6. Simulated H-plane patterns of antenna unit cell.

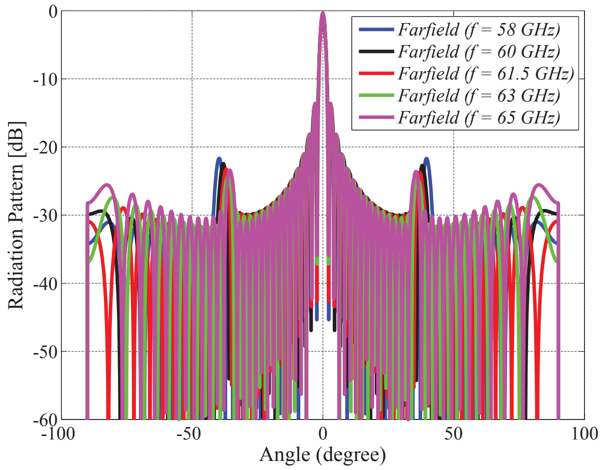

Fig. 7. Simulated E-plane patterns of 32 × 32 array antenna.

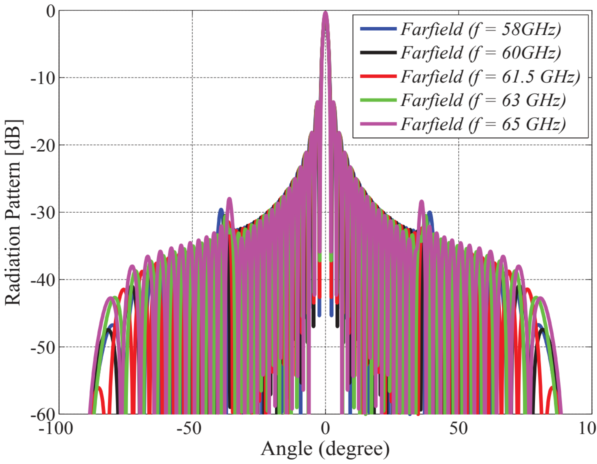

Fig. 8. Simulated H-plane patterns of 32 × 32 array antenna.

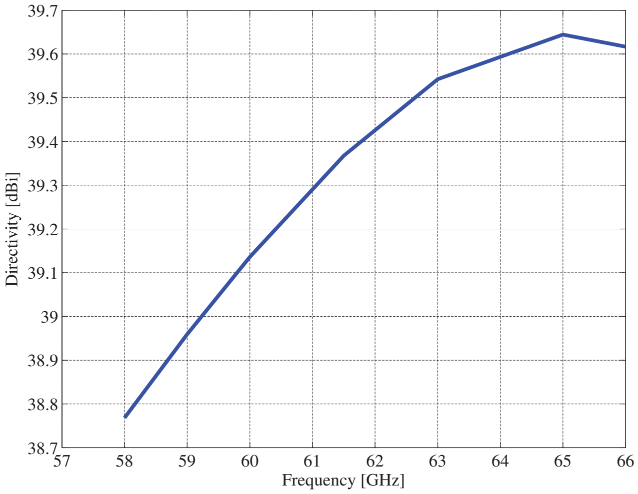

Fig. 9. Directivity of proposed structure with 32 × 32 array antenna.

cell is possible to be a promising choice for 60 GHz applications.

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