High Efficiency 2×2 Cavity-Backed Slot Sub-array for 60 GHz Planar Array Antenna Based on Gap Technology

Abbas Vosoogh and Per-Simon Kildal
Department of Signals and Systems, Chalmers University of Technology
Gothenburg, Sweden
{abbas.vosoogh, per-simon.kildal}@chalmers.se

***Abstract*—This paper presents a two layer 2×2-slot element as a sub-array for 60 GHz planar array antenna based on gap waveguide technology. The proposed element consists of 2x2 slots in a gap waveguide cavity where the cavity is fed through a coupling slot from a ridge gap waveguide corporate-feed network in a lower layer. The 2×2-slot sub-array is numerically optimized in an infinite array environment. The designed sub-array shows the relative bandwidth of 11% with reflection coefficient better than -13 dB over 58.2-65 GHz frequency band. A prototype of a 8×8-element slot array antenna is designed and fabricated in order to verify the simulations.**

Keywords—gap waveguide, high efficiency, mmilimeter wave, slot array antenna.

I. Introduction

The unlicensed 60 GHz band gets more attention over the last few years due to the heavily used of the lower frequency bands, which resulting in the interference between the wireless systems, and the rapidly increasing demands for high data rate communication systems. High-gain antenna is one of the most important component of the wireless system links. High gain, high efficiency, low profile, inexpensive and suitable for mass-production are some of the required features of the antenna for these new frequencies. Planar array antennas are good candidate for millimeter wave applications, because of their low volume and weight. The high dielectric loss is a critical problem at millimeter wave. Microstrip and substrate integrated waveguide (SIW) array antennas have a relatively low efficiency specially, when the array dimension becomes large [1], [2]. The double-layer slot array antenna presented in [3] shows high efficiency and wideband performance. However, their fabrication process, i.e. diffusion bonding of laminated thin copper plates, is relatively complicated. An effective and cheap manufacturing method is required in order to mass produce the high-gain antennas at these frequencies.

The gap waveguide technology introduced in [4] and [5] indicates promising characteristics such as low loss, flexible manufacturing, and cost effectiveness in particular at millimeter wave. Four different variety of gap technology, ridge gap waveguide [6], groove gap waveguide [7], microstrip gap waveguide [8], and inverted microstrip-ridge gap waveguide [9], have been already investigated. In these new guiding structures electrical contact between the building blocks is not needed. Therefore, gap waveguide technology can be mass-produced by molding and thereby offers mechanical flexibility and manufacturing advantage, e.g. for the corporate-fed array antennas [10], [11]. In [12] a 2×2-slot element based on inverted microstrip gap waveguide is presented. Four slots in a SIW cavity fed by an inverted microstrip gap waveguide. Because of higher order mode in the cavity and uneven excitation of the slots, the aperture efficiency is reduced due to the high grating lobe. Moreover, the gap waveguide technology can also be used to PMC package active circuits [13], [14].

In this paper a new air-filled 2×2 cavity-backed slot sub-array for 60 GHz planar array antenna is presented. The proposed unit cell consists of two layers. The air-filled cavity excites by a ridge gap waveguide line via a coupling slot. The 2×2-slot sub-array is optimized in an infinite array environment. The simulated results show the high efficiency and wide impedance bandwidth performance of the proposed unit cell. An 8×8-slot array antenna is designed based on the proposed sub-array. The simulated results of the sub-array and the designed antenna is presented.

II. Sub-array Design

The proposed 2×2-slot sub-array is illustrated in Fig. 1. The

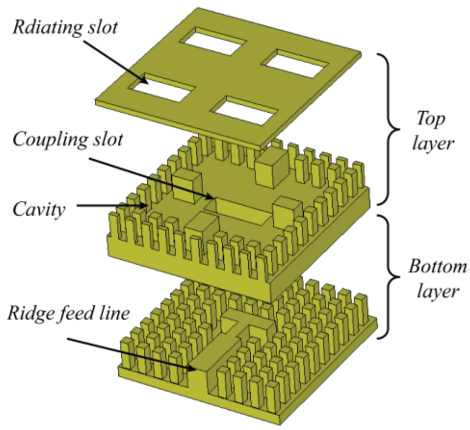

Fig. 1 Distributed view of 2×2 cavity-backed slot subarray.

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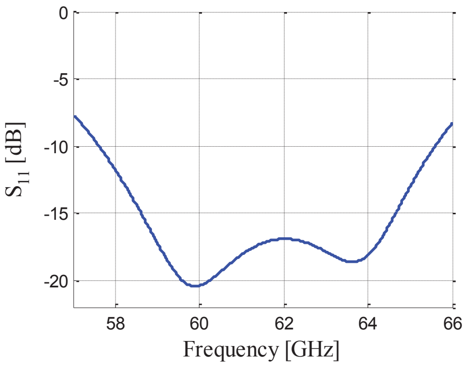
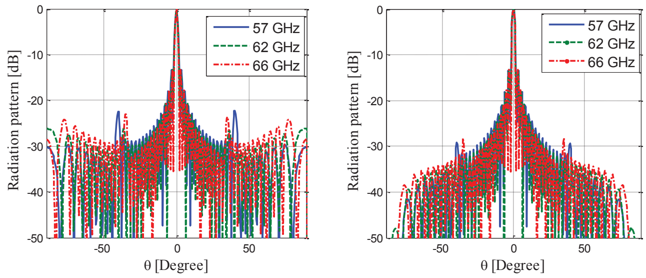


Fig. 2. Reflection coefficient of 2×2-slot subarray in infinite array environment.



(a) (b)

Fig. 3. Normalized radiation patterns of an array with 32×32 slot aperture dimension in (a). E-plane and (b). H-plane. Infinte array approach.

sub-array consists of two layers. An air-filled cavity formed by pins, feeds four radiating slots with spacing smaller, but close to, one wavelength on the top layer. A ridge gap waveguide excites the cavity via a coupling slot on the bottom layer. There is a small gap between each layers and no electrical contact between the different layers is needed. This is a manufacturing advantage of this design. The pins in the top and bottom layers present a stopband for parallel-plate modes. The designed sub-array has 8×8 mm^2 dimensions in E- and H-plane. The sub-array is optimized in the infinite array environment by using CST Microwave Studio where the mutual coupling between subarrays are automatically included.

The simulated reflection coefficient of the designed sub-array in the infinite array environment is shown in Fig. 2. The 2×2-slot unit cell has a relative bandwidth of 11% (58.2-65 GHz) with return loss better than -13 dB. In Fig. 3, the E- and H-plane far field patterns of an array with 32×32 slots over its aperture are illustrated for different frequencies. The proposed sub-array has better radiation pattern than the one presented sub-array in [5]. The directivity vs frequency of an array with the same aperture size is shown in Fig. 4. The dashed lines in the graph show the maximum available directivities with 100% and 90% aperture efficiency, which clearly shows that the designed sub-array has high aperture efficiency.

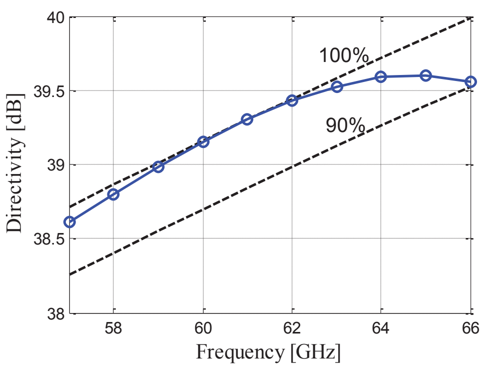


Fig. 4. Directivity of an array with 32×32 slot aperture dimension in infinite array environment. The dashed lines show results for an aperture of the same size when the aperture efficiencies are 100% and 90%.

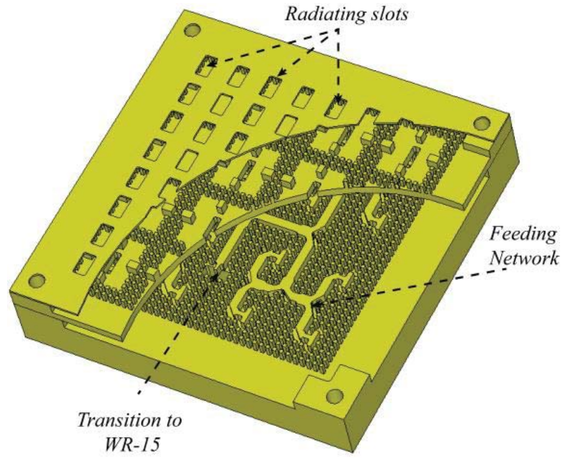


Fig. 5. Configuration of the double layer corporate-feed 8×8 slot array antenna.

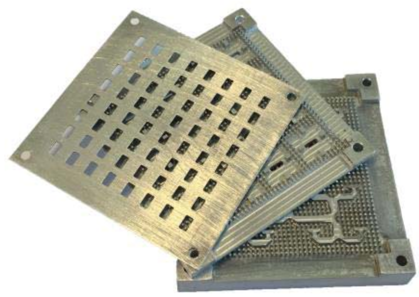


Fig. 6. Fabricated 8×8 slot array antenna.

III. 8×8-ELEMENT SLOT ARRAY ANTENNA

The proposed sub-array is used to design an 8×8-element slot array antenna. The configuration of the antenna is shown in Fig. 5. A corporate feed network formed by ridge gap waveguide is used to excite 4×4 subarrays with equal phase

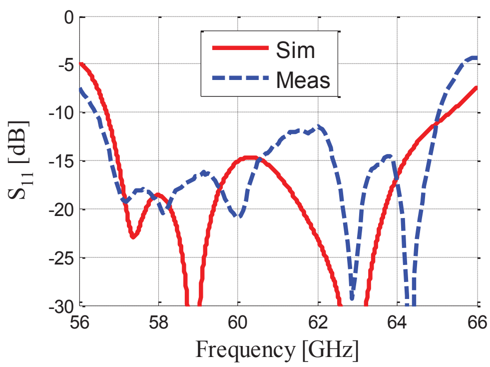


Fig. 7. Comparison of simulated and measured reflected coefficient of sub-array and 8×8 slot array.

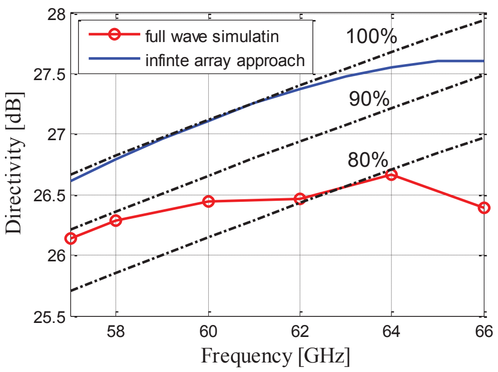


Fig. 8. Simulated directivity of 8×8 slot array antenna. The dashed lines show results for an aperture of the same size when the aperture efficiencies are 90% and 80%.

and amplitude. A simple transition is designed to match the distribution network to WR-15 rectangular waveguide. The fabricated antenna is shown in Fig. 6. The measured and simulated reflection coefficient of the 8×8-element slot array antenna are shown in Fig. 7. The simulations are here done with full wave approach. There is a good agreement between simulated and measured results. The measured reflection coefficient of the slot array antenna is below -15 dB from 56.8-65 GHz except from 60.5-62.3 GHz which is below -12 dB. The simulated directivity of the array antenna is shown in Fig. 8. The directivity of an array with the same aperture dimension in infinite array environment is also presented. The aperture efficiency is reduced compared to the 32x32 slot array case, due to the smaller size of the aperture which affects the full wave simulations.

IV. Conclusion

We present an air-filled 2×2 cavity-backed slot sub-array for high-gain 60 GHz planar array antenna based on recently introduced gap waveguide technology. The proposed sub-array consists of two layers, i.e. cavity and feeding network layers, without need of electrical contact between layers. This presents manufacturing advantages in particular at millimeter wave. The sub-array shows better radiation pattern and higher aperture efficiency than presented unit cell in [5]. A corporate-feed 8×8-slot array antenna is designed with proposed sub-array. The simulated and measured results of the array antenna show wide impedance bandwidth.

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