G-band Frequency-Scanned Antenna Arrays

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I. Introduction

Beam steering antenna arrays have many applications, from object tracking and localization to landing systems [1]. The main requirements for such a system are usually a wide scanning angle, low beamwidth and constant gain. Beam steering can be obtained electronically, by controlling the relative phase shift between the array elements. This can be achieved by delay elements, as in phased arrays, or by sweeping the carrier frequency [1–4]. The latter are usually easier to implement, but require a wider operating bandwidth for the same scanning angle. In this work, frequency scanned arrays for wide-angle scanning are described. By operating at G-band, the overall size and weight of the antenna can be reduced, thus making it suitable for space applications. Two architectures, based on slotted waveguides and microcoaxial line fed slots, are introduced to provide a wider scanning angle than conventional structures. The devices are fabricated using the PolyStrata process, which enable low-loss feeds at millimeter-wave frequencies. The PolyStrata process involves sequential deposition of copper layers and photoresist on a silicon wafer [5]. Copper layer thicknesses range from 10 µm to 100 µm, with gap-to-height and width-to-height aspect ratios of 1:1.2 and 1:1.5, respectively. After the desired layers are deposited, the photoresist filling is rinsed away ("released") through 200 µm long holes. This process can be used to fabricate air-supported coaxial lines and waveguides at G-band, with slot antennas acting as release holes.

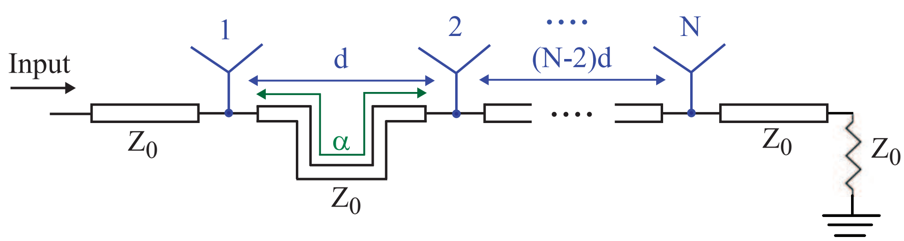

Figure 1: A conceptual sketch of an N-element frequency-scanned antenna array fed by a dispersive line.

A frequency-scanned antenna array schematic is shown conceptually in Figure 1. When the signal frequency is varied, the relative phase between elements changes and as a result the beam steers. The wave travels down the feed line and loses power at each element to radiation. Thus, elements near the feed must couple weakly to the feed line, while elements near the load must couple strongly. Any power remaining in the feedline after the last element is dissipated in the load in this type of array. The phase of each element is determined by the length of the feed line section between the elements, as well as the mutual coupling [6, page 133]. In Figure 1 the antenna array is fed by a line of physical length α between elements

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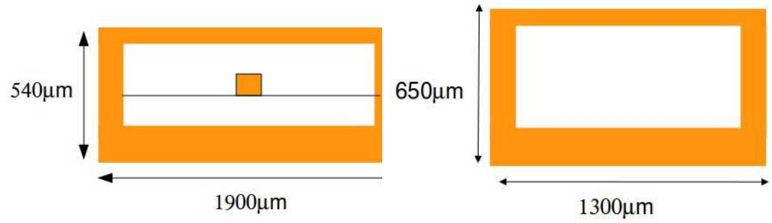


Figure 2: Typical microcoaxial (a) and waveguide (b) cross sections at G-band fabricated with the PolyStrata process.

and propagation constant β, with element spacing of d in air. For a scan angle θ_m, and with m being an integer, the following can be written:

$$\beta_0 d \sin\theta_m = \beta\alpha - 2m\pi, \quad (1)$$

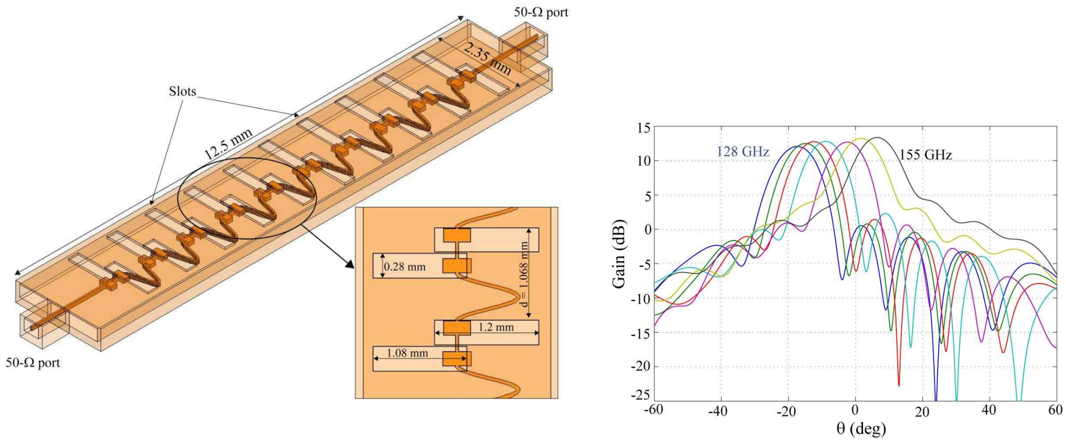
The phase equation can be written as

$$\sin\theta_m = \frac{\alpha\lambda_0}{d\lambda_g} - \frac{m\lambda_0}{d}, \quad (2)$$

where λ_0 is the free-space wavelength and λ_g is the guided wavelength in the feed. It is clear from these equations that both a longer feed line section (higher α/λ_g) and a more dispersive delay line result in a wider beam scan with frequency [3, pages 181–182]. In the remainder of the paper, two types of frequency scanned arrays are presented: (1) an array of slots fed by a micro-coaxial non-dispersive line where the delay is increased by meandering; and (2) a slotted waveguide array designed for the dominant mode at G-band. Both lines can be implemented in the PolyStrata process with cross-section dimensions shown in Figure 2.

II. Slotted Micro-coaxial Antenna Array

Figure 3 (a) shows a micro-coaxial fed slot array with 10 double slots. Several methods for increasing the scanning bandwidth of the design have been investigated, including meandering the transmission line between the radiating elements, increasing the size of the inner conductor under the slots, changing the width of the slots and using double slots. Meandering the transmission lines between double radiating slots will result in a higher α/d ratio in (2) and thus greater scan angles can be achieved. Increasing the width of the inner conductor under the slots controls the input and output match as well as coupling to each antenna. Using double radiating slots with a slight length difference (10 %) increases the bandwidth. The slot array is matched to the input and output feed coaxial lines characteristic impedance in order to obtain a non-resonant array. Figure 3 (b) shows the simulated beam steering of this array at $\phi = 0°$, as simulated by Ansoft HFSS. A perfect conductor boundary condition was imposed on the sides of the array, while waveports were defined on the input and output. The scanning is 30° from 128–155 GHz, and the gain is within 1.5 dB for all scan angles. However, the pattern degrades at higher frequencies, due



(a) (b)

Figure 3: (a) Double slotted micro-coaxial antenna array. (b) Realized gain vs. θ at $\phi = 0°$, for frequencies 128–155 GHz.

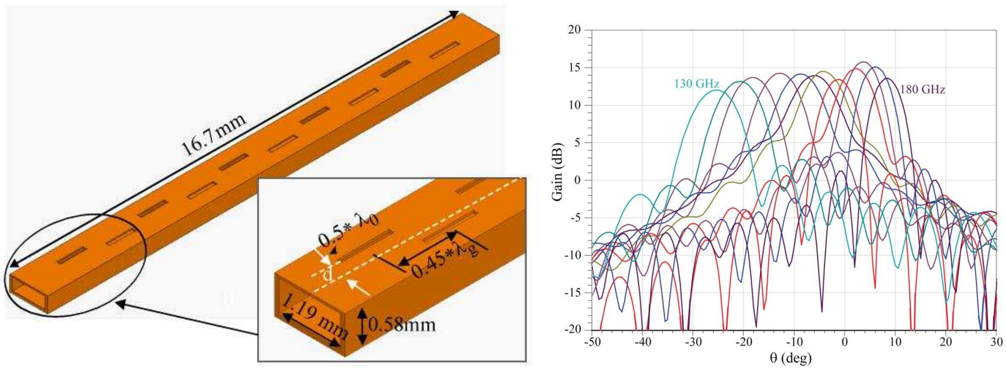
to non-uniform excitation of the slots. Because coaxial lines are purely TEM, they can be more easily scaled to different (lower) frequencies, by scaling the slot length and distance. Moreover a circuit model can be used for design, because TEM lines behave as ideal transmission lines over a wide range of frequencies.

III. Slotted Waveguide Antenna Array

Figure 4 (a) shows a waveguide slotted array with 10 slots. In this case longitudinal slots are used. In order to achieve the greatest possible scan angle and the lowest gain variation over the scanning bandwidth, several parameters, such as the length and width of the slots, the distance between each slot, and the position of the slots from the center of the waveguide were optimized. A non-standard waveguide was designed to operate near the fundamental mode cut-off frequency. In this way high dispersion over the operating bandwidth is obtained. According to Equation (2), the α/d ratio is now equal to 1, but the guided wavelength λ_g is a strong function of frequency thus giving a wider scanning angle than conventional slotted waveguide arrays. Figure 4 (b) shows the resultant simulated beam steering of the final array. With 30° scanning from 140–166 GHz, and corresponding gain variation within 3 dB.

IV. Discussion

In summary, two frequency-scanned slot arrays amenable to the PolyStrata micro-fabrication process are designed to achieve 30° of scanning angle over 26 GHz band-width at G-band. Dispersive slotted waveguides offer low loss at high frequencies [7] and a reduced design complexity compared to the rectangular microcoaxial lines. However, the feeding mechanism for the microcoaxial lines is easier to implement [8] and measurements can be performed more directly than the slotted waveguide array case. In addition, waveguides at lower frequencies, such as W-band, would be



(a) (b)

Figure 4: (a) Slotted waveguide antenna array. (b) Realized gain vs. θ at $\phi = 0°$, for frequencies 140–166 GHz.

more difficult to implement in the sequential copper deposition process due to their increased dimensions. With the PolyStrata process, longer arrays can be fabricated, e.g. 40 mm long lines are demonstrated in [9], corresponding to a 25 element array at G-band. In the presentation a 2D array extension [10] will be discussed.

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