A 30 GHz slot array with artificial dielectrics to enhance radiation characteristics

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***Abstract*—In this work, we present a design of an array of cavity backed slots in the presence of an artificial dielectric superstrate to enhance the scan range. Spectral domain representations are used for the analysis of the leaky waves propagating within the stratification. The artificial dielectric superstrate loaded cavity supports leaky waves that can be optimized to enhance the gain in a specific angular region or to enlarge the array field-of-view. By controlling the amplitude and phase of the antenna elements, the proposed concept is used to realize an adaptive array, that can reconfigure its radiation pattern.**

***Index Terms*—artificial dielectrics, leaky waves, mm-wave phased arrays, slot antennas.**

I. Introduction

In millimeter wave communication and radar applications, radiation pattern diversity has become an attractive property for the antenna systems. For example, base stations in wireless cellular networks will comprise antenna arrays that can switch between narrow or wide beams to achieve optimal capacity for different user distributions [1]. Multi-mode operation of antennas that can dynamically change the radiation beamwidth is useful due to the limited number of output channels of mm-wave integrated circuits (ICs), which in turn limits the available number of antennas to be connected to an IC. Another advantage of implementing a single antenna system with the two modes, is the smaller area usage compared to two separate antennas.

In order to achieve a wide field-of-view, we investigate the radiation performance of single and multiple slot antennas, loaded at a designed distance by artificial dielectrics layers (ADLs) to achieve pattern reconfigurability and scan gain enhancement. The analysis is based on closed-form expression to describe artificial dielectrics in the spectral domain [2]. The artificial dielectric superstrate loaded cavity [3] supports leaky waves that can be optimized to enhance the gain in a specific angular region or to enlarge the array field-of-view. By controlling the amplitude and phase of the antenna elements, we propose an approach to realize adaptive arrays, that can dynamically change their radiation beamwidth.

II. Antenna Design

The geometry under consideration is shown in Fig. 1(a) and consists of an x-oriented, electrically narrow slot in the presence of a two-layer ADL superstrate. Each ADL is realized as a doubly periodic array of electrically small patches.

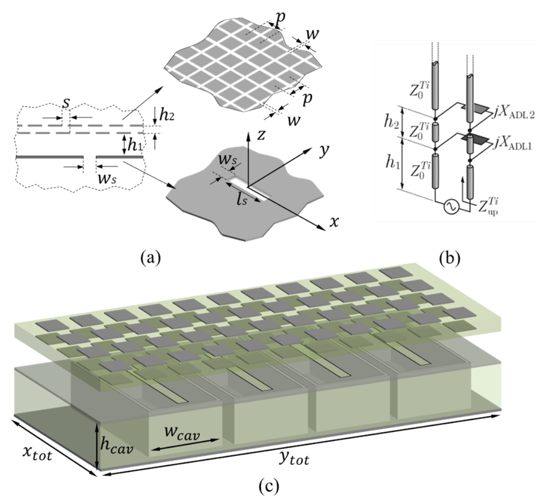
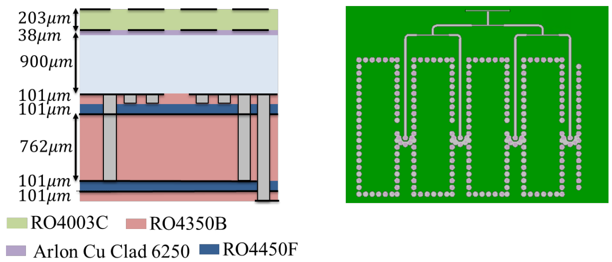


Fig. 1. (a) Slot in the presence of an ADL superstrate. (b) Transmission line equivalent circuit of a source in the presence of two ADLs, for both TE and TM waves. (c) Array of cavity backed slots with ADL superstrate.

The propagation of a generic plane wave impinging on the ADL superstrate can be represented with an equivalent transmission line model, where each layer is described by an equivalent reactance [2], as shown in Fig. 1(b). The value of the reactances X_{ADL1} and X_{ADL2} are expressed in closed-form and depend on the geometrical parameters of the ADL. Z_0^{Ti} is the characteristic impedance of the transmission lines for either transverse magnetic (TM) or transverse electric (TE) components of the wave.

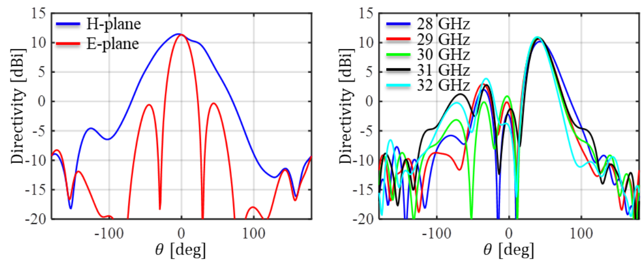
When the ADLs are illuminated by a near source rather then a plane wave, the procedure presented in [4] can be used to evaluate the far field of the source in the presence of the ADLs. By expanding the radiated field from the source in a spectrum of plane waves, we use the equivalent transmission line model for each plane wave. The voltage generator is related to the amplitude of a specific plane wave. This allows to define the spectral dyadic Green's function of the ADL stratification, which significantly speeds up the design process as the radiation patterns can be calculated analytically.

A design has been made considering four cavity backed slots separated by a distance of $d_y = \lambda_0/2$, where λ is the wavelenght at 30GHz, as shown in Fig.1(c) . Both the array and the ADL superstrate can be fabricated using standard PCB



(a) (b)

Fig. 2. (a) Stack-up of the demonstrator board. (b) Bottom view of the broadside board, showing the feeding network.



(a) (b)

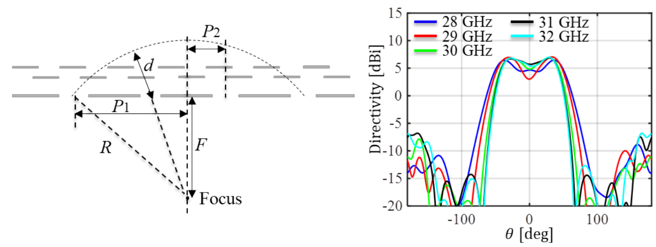
Fig. 3. (a) Gain at 30GHz of the array scanning to broadside direction. (b) Gain at several frequencies of the array scanning to 45° in the E-plane.

technology, while the air gap between the slots and the ADL can be realized with a foam layer.

A fundamental trade off must be made between pattern control and mutual coupling [3]. The leaky waves supported by the ADL superstrate enhance the element gain pattern in certain directions, but also lead to higher mutual coupling since they travel along the array. The increase of mutual coupling causes a deterioration of the active impedance matching when scanning. It is found that more directive element patterns result in higher mutual coupling.

Keeping this trade-off in mind, a design is made with the following geometrical parameters: $l_s = 6.6$mm, $w_s = 0.75$mm and the width of the feeding strip is $\delta = 0.2$mm, $w_{cav} = 3.4$mm. The total sizes of the array in x- and y-directions are $x_{tot} = 7.5$mm and $y_{tot} = 17$mm. The dimensions of the ADLs are $p = 1.2$mm, $w = 0.4$mm and $s = 0$. The stratification of the demonstrator board is shown in Fig. fig:PCB(a). The array is printed on the top metal layer, while on the bottom most layer a feeding network is added for three radiation cases, i.e. broadside, scanning to $45°$ and the wide beam. The broadside feeding network is shown in Fig. 2(b).

Figure 3 shows the gain of the array of four slots, fed with a linear phase shift for scanning in the E-plane. The pattern is shown for broadside and scanning to $45°$. In Fig. 3(b) several frequencies around 30GHz are shown to illustrate the stability of the pattern within the operational bandwidth. The leaky waves characterizing the element patterns enhance the directivity of the array when scanning, so that the broadside gain is approximately equal to the gain while scanning to $45°$.



(a) (b)

Fig. 4. (a) Applying a quadratic phase shift. (b) Gain of the array of four slots with a quadratic phase shift for several frequencies.

To implement radiation pattern reconfiguration, a quadratic phase distribution is applied, as shown in Fig. 4(a). This configuration creates a diverging pattern that realizes a large beamwidth, as shown in Fig. 4. For the four element array, the phase difference between the outer and the inner elements is calculated as $\beta_q = k_0 d$, as depicted in Fig. 4(a), with $F = 0.65\lambda_0$. This is combined with a tapered amplitude of the excitations $[0.6\ \ 1\ \ 1\ \ 0.6]$, to reduce the oscillations in the pattern. Figure 4(b) shows the gain of the array. By applying the quadratic phase shift, the pattern of the array is still wide, however the transmitted power is higher than that of an isolated element.

III. Conclusions

We presented a design of a cavity backed array of slots with artificial dielectric superstrates to realize pattern shaping. Based on the analysis of leaky waves propagating along the artificial dielectric slab, the shape of the element pattern can be manipulated to enlarge the beamwidth. The array shows no scan loss while scanning to $45°$ w.r.t. broadside. The same array can be used also to radiate pattern with large beamwidth by employing quadratic phase excitation.

Applications of this concept can be in the field of mm wave phased array for communication and radar systems, for which adaptive antennas that can reconfigure their radiation pattern are desired.

Acknowledgment

This research is supported by the Dutch Technology Foundation NWO-TTW (WAtt LEvel transmitters at mm-waves (WhALE, 15591)), as part of the TTW-NXP partnership programme “Advanced 5G Solutions”.

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