CAVITY BACKED PRINTED DIPOLE ARRAYS WITH SUBSTRATE MODE CONTROL USING VIA-HOLE TECHNOLOGY

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I. INTRODUCTION

Millimeter-wave systems are employed in applications such as high resolution radars, landing systems in adverse weather and imaging through clouds and fog. Unfortunately, current millimeter-wave systems are waveguide based and this has limited their widespread use due to their high-cost. In this paper an efficient planar antenna structure is investigated which is compatible with high-speed solid-state devices. The antenna consists of a cavity backed strip-dipole printed on a Si or GaAs wafer. The cavity behind the dipole can either be a rectangular machined cavity or a pyramidal cavity which is anisotropically etched in silicon and metallized with gold [1]. The basic configuration of the antenna structures under examination is shown in figure 1. Surface-waves are suppressed in the substrate wafer by synthesizing a waveguide

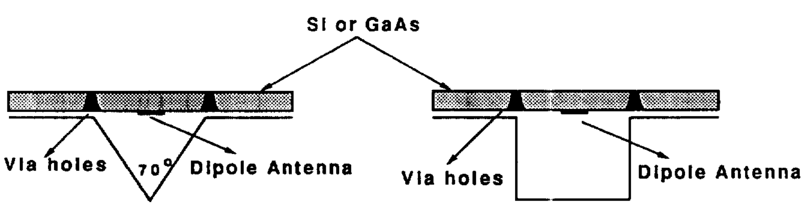

Figure 1: Cavity backed printed dipole elements isolated using metallized via-holes.

environment around the dipole using closely spaced metallized via-holes fabricated by micromachining techniques [2]. This also provides the required isolation between adjacent dipoles in phased array applications for avoiding severe scan blindness effects [3]. The via-hole approach has been used before in the form of shorting pins inserted manually in "soft" substrates at microwave frequencies [3, 4]. However, the shorting pin approach is not compatible with millimeter-wave antennas on "hard" substrates such as GaAs or Silicon wafers.

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II. ANALYSIS

For the determination of the element pattern and of the corresponding active input impedance of the feed-dipoles in a two-dimensional array environment, the Green's function of the array (assumed infinite) is first determined. For this purpose, the feeding strip-dipoles are considered infinitesimal and excited by voltage sources bearing a linear phase taper of the form:

$$V_{st} = V_{00} e^{-j(s\psi_x + t\psi_y)} \quad (1)$$

where $V_{s,t}$ is the amplitude of the applied voltage at the terminals of the $(s,t)th$ strip-dipole. Also ψ_x and ψ_y are the fixed incremental phase-shifts from element-to-element in the x and y directions, respectively. The phasing of the strip-dipoles results in a main beam radiated in the direction (θ_0, ϕ_o) defined by:

$$\psi_x = (ka)\sin(\theta_o)\cos(\phi_o) \quad (2)$$

$$\psi_y = (kb)\sin(\theta_o)\sin(\phi_o) \quad (3)$$

where $k = 2\pi/\lambda$ is the free-space wavenumber and $a \times b$ is the aperture size of one element. This kind of excitation allows to represent the free space fields $(z > 0)$ in their Floquet mode expansion [3]. Subsequently, the Floquet spectrum is matched to the modal representation of the fields inside the synthesized dielectric waveguide and the backing cavity. In the case of the pyramidal cavity the geometry is approximated by a staircase waveguide discontinuity which is analyzed using the mode matching technique through the implication of generalized scattering matrices [1]. The whole process leads to the determination of the Green's function for the array which enables to set up an integral equation (IE) for the feeding strip-dipole current. The (IE) is solved by Galerkin's technique thus yielding the active input admittance of the feeding strip-dipoles. Without loss of generality the active input admittance for the (0,0) element is defined below in terms of the element mutual admittance coefficients Y_{oost} and the scan direction (θ_o, ϕ_o):

$$Y_{actoo}(\psi_x, \psi_y) = \sum_{s=-\infty}^{\infty} \sum_{t=-\infty}^{\infty} Y_{oost} e^{-js\psi_x} e^{-jt\psi_y} \quad (4)$$

Furthermore, for determining the element pattern of the array the relative amplitude of the radiated field is recorded at each scan direction.

For comparison purposes the patterns of an isolated element, assumed embedded in an infinite ground plane, are also been determined. In this case however the free-space fields are represented in their plane-wave expansion instead of the Floquet-mode expansion [1].

III. NUMERICAL RESULTS

Consider an element of aperture size 0.6λ-square printed on a GaAs wafer ($\epsilon_r = 13$) of thickness 0.15 dielectric wavelengths ($0.15\lambda_d$). The backing cavity is assumed to be anisotropically etched in silicon and therefore its flare angle is fixed to 70^o. For this structure, the patterns of an isolated isolated element embedded in a ground plane are shown in figure 2a. The corresponding patterns in an infinite two-dimensional array environment are shown in figure 2b. It is observed that the array E-plane element pattern is quite different from the E-plane pattern of an isolated element, due to the mutual coupling effects in the array environment. The sharp dips which appear at about $\pm 40^o$ are related to the transition of the $(0, \pm 1)$ Floquet mode from evanescent to propagating (grating-lobe). The active input admittance is examined in the E-plane by defining a corresponding active standing-wave-ratio (swr) given by:

$$swr(\theta_o) = \frac{1 + |\rho|}{1 - |\rho|} \quad (5)$$

$$\text{where: } \rho(\theta_o) = \frac{Y_{actoo}(0^o) - Y_{actoo}(\theta_o)}{Y_{actoo}(0^o) + Y_{actoo}(\theta_o)} \quad (6)$$

The so defined active standing-wave-ratio assumes matched conditions when scanning at broadside. As shown in figure 3 there is a large mismatch around 40^o where the corresponding E-plane pattern dip takes place (see also fig. 2b). This mismatch is a direct manifestation of the mutual coupling effects which make the active input admittance, defined in equation 4, to become a strong function of the scan direction. A comparison between the pyramidal and the rectangular backing cavity will be presented at the conference.

References

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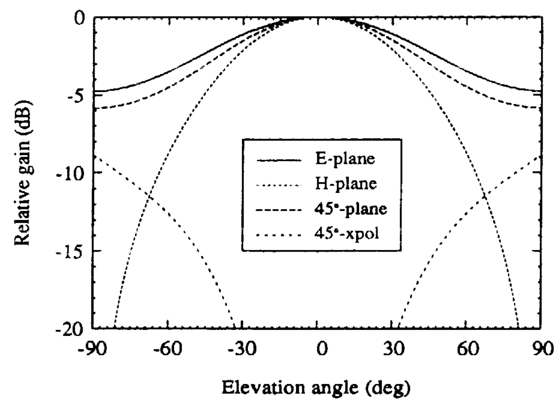

Figure 2a: Patterns in a ground plane.

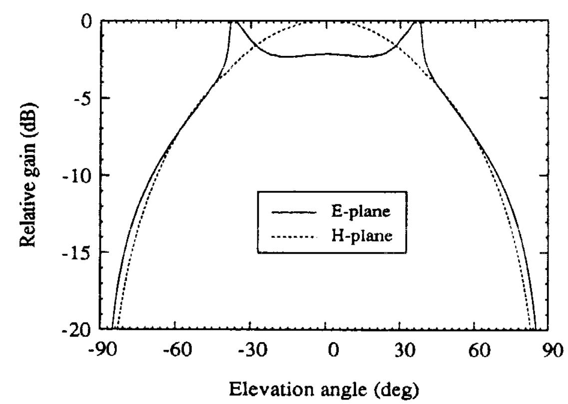

Figure 2b: Patterns in a 2D-array.

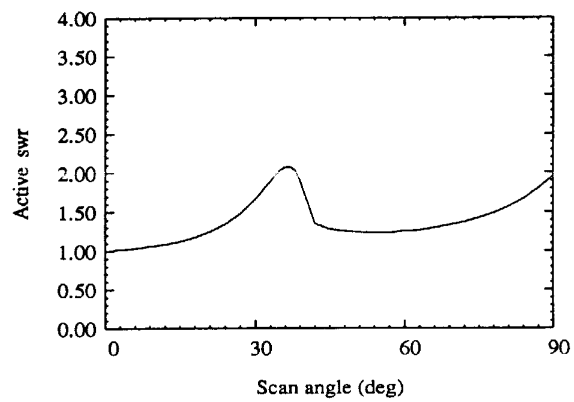

Figure 3: Active standing-wave-ratio in the E-plane.