

Meander-Slot and U-Slot Antenna Arrays for Wide-Band Spatial Power Combiners

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Abstract—In this letter, we present a multilayered waveguide transition containing several interacting printed antenna arrays for spatial power combining applications. Narrow-band resonant rectangular slot antennas used in earlier designs are replaced by meander-slot antennas and their modifications, in order to increase the frequency bandwidth and efficiency of the system. Numerical results for finite arrays of meander-slot and U-slot antennas show significant advantages in scattering characteristics in comparison to traditionally used rectangular slot antenna arrays.

Index Terms—Meander-slot antenna, method of moments, spatial power combining, U-slot antenna, waveguide transition.

I. INTRODUCTION

MODERN wireless communication and radar systems operating at microwave and millimeter-wave frequencies require high power levels which can be achieved by combining the power produced by many individual solid-state devices [1]. In traditional power combining circuits which utilize waveguide and printed-circuit power dividers/combiners, there is an upper limit on the number of elements used due to high conductor and material losses at these frequencies. Alternatively, increased power output levels and power combining efficiencies can be achieved using a spatial power combining where the power produced by the amplifier array is combined in free space.

In this letter, we present a waveguide transition consisting of several interacting printed antenna arrays placed at dielectric interfaces of an oversized multilayered waveguide (Fig. 1). This passive antenna module serves as an integral part of waveguide-based amplifier arrays (for example, aperture-coupled patch antenna array presented in [2], [3]). In earlier designs, we have used narrow-band resonant patch and slot antennas [3], [4]. In the present study, these are replaced by tapered meander line [5], [6], microstrip loop [7], U-slot patch antennas, and their modifications, in order to increase the frequency bandwidth and efficiency of the system and provide operation in multiple band regimes. In particular, the emphasis of this letter is on the finite arrays of meander-slot and U-slot antennas operating at X-band in a rectangular waveguide environment. Numerical results are presented for a 2×3 interacting meander-slot and patch antenna array, and a 5×5 array of interacting U-slot and U-strip

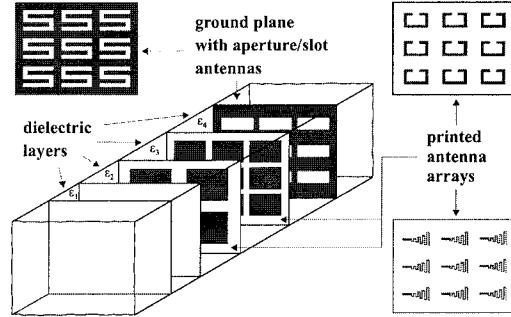


Fig. 1. Multilayered waveguide transition containing interacting printed antenna arrays.

antennas, illustrating advantages of their utilization in a waveguide-based power combining system.

II. THEORY

To model the multilayered waveguide containing electric and magnetic-type antennas (Fig. 1), a method of moments integral equation formulation is utilized for the discretization of electric and magnetic induced surface current densities. A coupled set of integral equations is obtained by enforcing a boundary condition for the tangential components of the electric field on the metal surface of printed antennas and a continuity condition for the tangential components of the magnetic field across the surface of magnetic-type antennas in a ground plane (similar formulations have been implemented in [3], [4], [8], and the other techniques for modeling amplifier arrays can be found, for example, in [9], [10]). In this formulation, magnetic potential dyadic Green's functions due to an arbitrarily oriented point source in a multilayered rectangular waveguide are obtained as the solution of the system of dyadic Helmholtz equations subject to appropriate boundary and continuity conditions. The analytical form of Green's functions provides physical insight into resonance and surface wave effects occurring in overmoded layered waveguides.

III. NUMERICAL RESULTS AND DISCUSSIONS

To investigate the scattering characteristics of meander-slot and U-slot antennas, examples of 2×3 interacting meander-slot and patch antenna arrays, and a 5×5 array of interacting U-slot and U-strip antennas in overmoded waveguide transitions will be considered. The correctness of the full-wave numerical code has been checked extensively by comparison to experimental results and numerical data obtained by other methods (see [2]–[4], among others).

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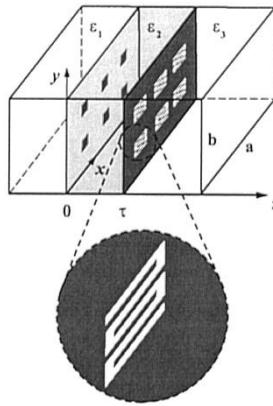


Fig. 2. Geometry of 2×3 interacting meander-slot and patch antenna arrays in a multilayered waveguide transition.

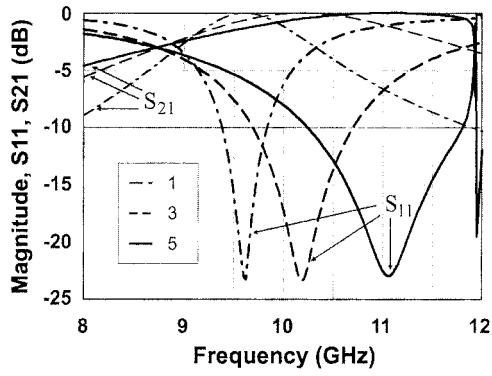


Fig. 3. Magnitude of the reflection S_{11} and transmission S_{21} coefficients versus frequency for the 2×3 interacting meander-slot and patch antenna arrays. A dash-dotted line is for the single-slot (1), a dashed line is for three-slot (3), and a solid line is for five-slot (5) antenna arrays.

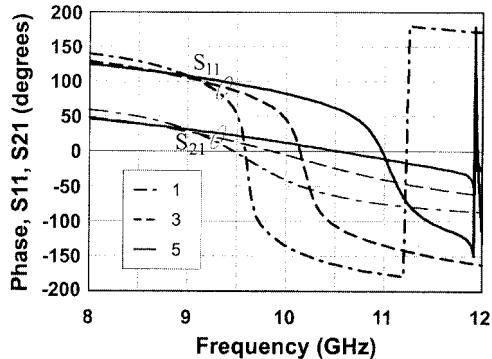


Fig. 4. Phase of the reflection S_{11} and transmission S_{21} coefficients versus frequency for the 2×3 interacting meander-slot and patch antenna arrays. A dash-dotted line is for the single-slot (1), a dashed line is for three-slot (3), and a solid line is for five-slot (5) antenna arrays.

In the first example, numerical results for the magnitude and phase of the reflection and transmission coefficients of the 2×3 interacting meander-slot and patch antenna arrays (geometry shown in Fig. 2), in an overmoded rectangular waveguide transition operating at X-band, are shown in Figs. 3 and 4, respectively. The results are obtained for the following geometrical and material parameters: the rectangular waveguide is $53 \text{ mm} \times 22 \text{ mm}$, the separation between unit cells in the arrays is 15.24 mm in the x -direction and 12.192 mm in the

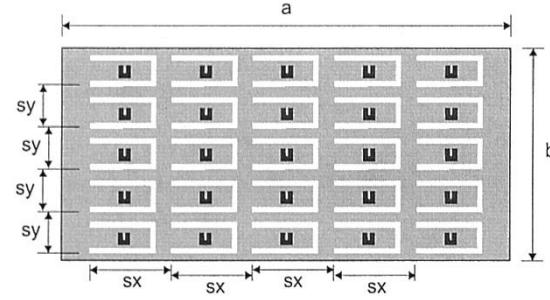


Fig. 5. Geometry of the 5×5 array of interacting U-slot and U-strip antennas in an overmoded rectangular waveguide transition. The parameters are as follows: $a = 84 \text{ mm}$, $b = 39 \text{ mm}$, $s_x = 15.24 \text{ mm}$, and $s_y = 7.62 \text{ mm}$.

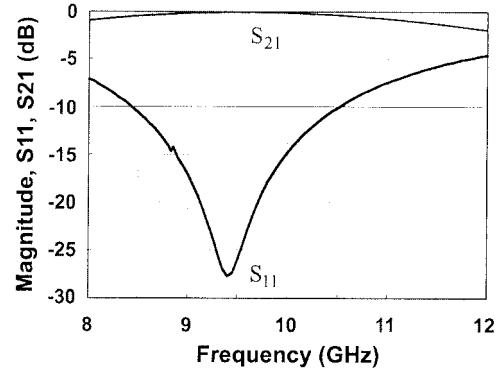


Fig. 6. Magnitude of the reflection and transmission coefficients versus frequency for the 5×5 interacting U-slot and U-strip antennas in the overmoded rectangular waveguide transition.

y -direction, slot length in a meander configuration is 11 mm , slot width is 0.5 mm , slot separation is 1 mm , a metal patch is $2 \text{ mm} \times 2 \text{ mm}$, substrate thickness is 1 mm , $\epsilon_1 = \epsilon_3 = 1$, and $\epsilon_2 = 3$. It can be seen (Fig. 3) that the use of meander-slot antennas in a resonant antenna module results in a significant increase in the bandwidth while maintaining the low return loss at the resonant frequency. In particular, a five-slot meander antenna array (Fig. 2) produces approximately 14.15% bandwidth at -10 dB (solid line for the reflection coefficient in Fig. 3) in comparison to the bandwidth of the traditionally used single slot antenna which is less than 4.7%. Note that the patch antennas are primarily utilized in this design to tune the resonant frequency.

In the second example, a 5×5 array of interacting U-slot and U-strip antennas (Fig. 5) in an overmoded rectangular waveguide transition is investigated for operation at X-band. The numerical results for the S -parameters (reflection and transmission) of the antenna array are shown in Figs. 6 and 7. The results are obtained for the following geometrical and material parameters: the rectangular waveguide is $84 \text{ mm} \times 39 \text{ mm}$, the separation between unit cells in the arrays is 15.24 mm in the x -direction and 7.62 mm in the y -direction, U-strip is $2 \text{ mm} \times 2 \text{ mm}$ with thickness of 0.5 mm , U-slot is $11 \text{ mm} \times 4 \text{ mm}$ with thickness of 0.5 mm , substrate thickness is 1 mm , $\epsilon_1 = \epsilon_3 = 1$, and $\epsilon_2 = 3$. The minimum return loss of -27.72 dB is obtained at the resonance frequency of 9.4 GHz with a remarkable -10-dB bandwidth of 22.13%.

A parametric study of meander-slot antenna array was performed to enhance the operating bandwidth by varying the

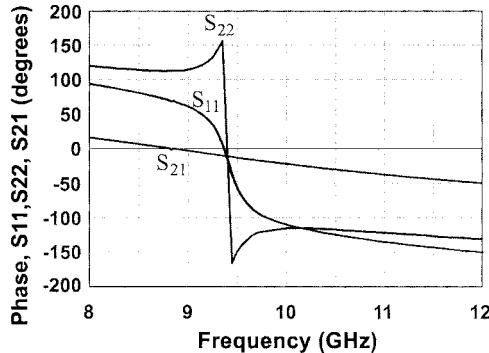


Fig. 7. Phase of the reflection and transmission coefficients versus frequency for the 5×5 interacting U-slot and U-strip antennas in the overmoded rectangular waveguide transition.

spacing between antenna elements and the spacing between outer antenna elements and the waveguide walls. It was observed that a decrease of the waveguide height and an increase of the unit cell separation in the vertical direction enables to achieve a significantly enhanced bandwidth. The detailed results are not included here due to the space limitations and can be found elsewhere [11].

IV. CONCLUSION

In this letter, we present preliminary results for scattering characteristics of finite arrays of meander-slot and U-slot antennas operating at X-band in a rectangular waveguide environment. It is shown that the use of meander-slot and U-slot antennas in waveguide-based transitions results in significant increase of a frequency bandwidth in comparison with traditionally used rectangular slot antennas. These new type antennas

can be utilized in amplifier arrays to achieve a wide bandwidth of spatial power combiners.

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