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FDTD ANALYSIS OF THE REFLECTION COEFFICIENT OF A VIVALDI TSA FED THROUGH A STRIPLINE

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1. Introduction.

Vivaldi tapered slot antennas (TSAs) consist of tapered slots etched in the metallization of a dielectric substrate with an exponential contour for the slot edges [1],[2]. These travelling wave antennas provide a symmetric endfire beam with appreciable gain and low sidelobes. Moreover, they offer a wideband performance and are characterized by a very low profile. Single sided or bilateral antennas can be realized with the feeding section integrated on the same dielectric substrate. However, owing to the broadband characteristics of Vivaldi TSA, a proper matching section must be used to couple the antenna with the feeding transmission line.

In this work, the FDTD method was used to determine the reflection coefficient at the input port in the feed stripline of a dual-slot Vivaldi's TSA. A planar balun was used to couple the antenna section to the stripline [3],[4]. The FDTD analysis was carried out by splitting the problem in two separate ones: the determination of the reflection coefficient of the antenna section and of the scattering matrix of the balun. Then, assuming that the feeding and radiating sections of the antenna were not electromagnetically coupled, the reflection coefficient at the input section of the stripline was computed. This approach allows an accurate refinement of the grid for the two disconnected sections, greatly reducing the need for computational resources. Results were successfully compared with a few experimental data obtained at Elettronica S.p.A. (Rome) where a prototype of this antenna was built up.

2. Antenna configuration.

A schematic view of the antenna section with the feeding transmission line and the planar balun is depicted in Fig. 1. The balun was designed according to the scheme proposed in [4]. Basically, it consists of a stripline-to-slot transition realized by using two stubs, i.e. one terminating the stripline and the other the slotline which directly feeds the antenna. The overall dimensions for the antenna and the feeding sections are reported in the same figure. This antenna is expected to properly operate in the 6 -18 GHz frequency range.

3. FDTD analysis.

The FDTD method [5],[6], consists of the numerical solution of Maxwell's equations in time domain through a finite difference approximation of the partial derivatives which appear in curl operators. A numerical scheme analogous to that of Yee's formulation [7] was implemented, except for a variable grid step size that was introduced to properly describe field behavior in the various parts of the structure. In each simulation, a Gaussian-shaped signal was used as time-varying excitation source. Since simulations were run separately for the antenna and the feeding sections, a brief description of the approach used in each case here follows:

a) antenna section

The grid step size was linearly changed through the mesh domain to provide a better tracking of the exponential contour. A stair casing approximation was used to describe this contour according to the fact that a conformal approach is not expected to give a significant improvement in the results [8]. Due to the symmetries of this dual-slot configuration, the FDTD mesh domain was reduced to a quarter of the total domain by enforcing an electric and a magnetic wall in the x=0 and z=0 planes, respectively. The minimum and maximum grid step sizes along the x direction were 90 μm and 130 μm, respectively. On the other hand, in the y and z directions, a constant grid step size of 110 μm along y and 102 μm along z was used. A grid with 161 x 296 x 41 nodes along x,y,z, respectively, was obtained. Since the maximum step size is about $\lambda/50$ at 40 Ghz, a reasonable accuracy in the results is expected at least up to that frequency.

A voltage source excited pulse propagation in the slotline. The reflection coefficient Γ_a at the input plane of the antenna was determined through the ratio of the FFT of the reflected and incident signals. The incident signal was sampled by running a simulation with the slotline alone terminated on a matched load. Litva's second order boundary conditions [9] were used to simulate this load. Second order Higdon's conditions [10] were instead used to absorb waves radiated from the antenna.

b) feeding section

Since the feeding section is a two-port symmetric network with losses, three of the four parameters of its scattering matrix must be determined. This was carried out as follows:

S_{11} and S_{12} parameters: a pulse signal was launched with the stripline terminated in a matched load in order to properly computing the voltage of the TEM incident wave at the storing plane. Matching conditions were obtained by enforcing Mur's first order absorbing boundary conditions [11] at the end of the stripline. Then, a second simulation was run for the entire feeding section with Litva's absorbing boundary conditions enforced to simulate a matched load at the end of the slotline (i.e. at port 2 of the network). S_{11} and S_{12} vs. frequency were computed through the ratio of the FFT of the reflected and transmitted signals with the incident one.

S_{22} parameter: with the stripline terminated in a matched load a simulation was run by launching a pulse signal in the slotline and by storing the total signal in the stripline. The determination of S_{22} immediately follows since the incident signal plane was already known from the previous simulations (see *a)* above)

The same FDTD grid was used in each simulation. The minimum and maximum grid step sizes were 70 μm and 115 μm along the x direction and 90 μm and 120 μm along the y direction. Again, a constant grid step size of 102 μm along the z direction was used. A grid with 110 x 110 x 41 nodes along x,y,z, respectively, was obtained.

The total reflection coefficient Γ_{in} at the stripline input plane was then determined on the basis of the generalized scattering matrix of the feeding section and the reflection coefficient of the antenna section, with the assumption that the two sections were not electromagnetically coupled.

4. Results.

In Fig. 3, the reflection coefficient amplitude vs frequency for the antenna section is shown. Results indicate the broadband behavior of this kind of antenna up to 40 GHz, with the appearance of local maxima and minima due to the antenna finite dimensions and the dielectric truncation at its far end.

Simulation results obtained for the scattering parameters of the matching network allow to determine its operational bandwidth and then, on the basis of the results in Fig. 3, the overall bandwidth of the entire structure. As an example, the amplitude of the S11 scattering parameters vs frequency are reported in Fig. 4. Data in the Figure allow to recover the expected 6-18 Ghz operating frequencies with a strong mismatching appearing out of that frequency range.

Results obtained for the reflection coefficient at the input section of the stripline with the antenna loading are shown in Fig. 5. In the same figure, the experimental results measured by using a Network Analyzer are reported. The agreement between them is quite satisfactory and validate the assumption of the electromagnetic decoupling between the radiating flare and the feeding network.

5. Conclusions.

In this work the FDTD method was used to analyze the electromagnetic behavior (i.e. in terms of scattering parameters and reflection coefficients), of a Vivaldi tapered dual-slot antenna fed through a planar balun.

Despite of the complexity of the entire structure, a suitable approximation was made which allowed to separately analyze the radiating section and the planar balun. Numerical results did show the intrinsic broadband characteristics of the Vivaldi antenna and allowed to determine the bandwidth of the balun. Experimental data for the reflection coefficient at the input port of the feed stripline did agree with simulation results, thus indicating the powerfulness of FDTD in dealing with these complex radiating structures and the validity of the proposed approach.

Further investigations will concern the analysis of the scattering matrix of more complex planar baluns and the determination of the electromagnetic coupling between a few adjacent radiating elements, i.e. a subarray of two. three or four Vivaldi antennas.

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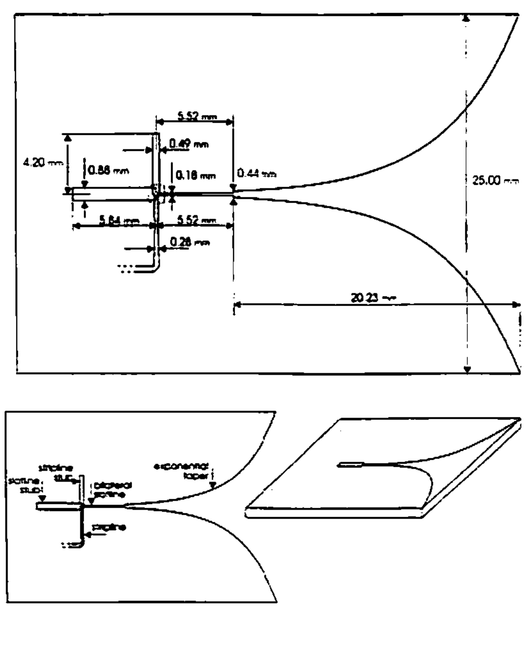

Fig. 1: the Vivaldi antenna and the feeding balun.

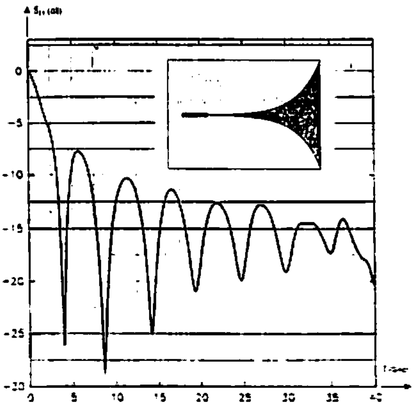

Fig. 2: amplitude vs. frequency of the reflection coefficient of the Vivaldi antenna at the storing plane in the slotline.

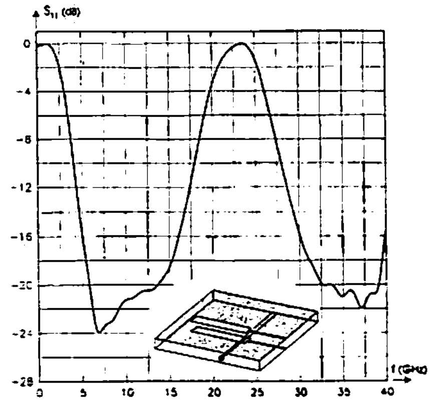

Fig. 3: amplitude vs. frequency of the S_{11} scattering parameters of the planar balun.

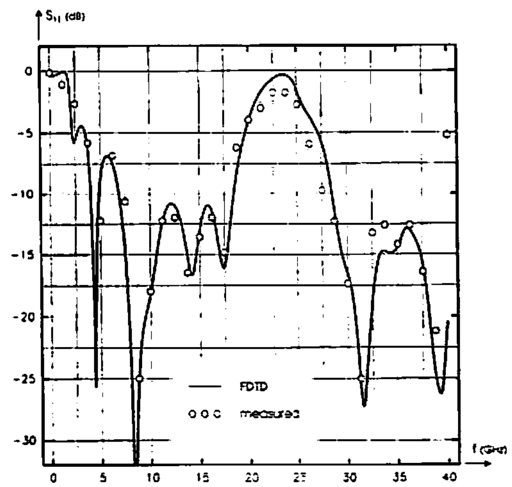

Fig. 5: reflection coefficient of the Vivaldi antenna with the planar balun at the input plane in the stripline: continuous line - numerical results, circles - measured data.