USING THE FDTD METHOD TO MODEL THE REFLECTION COEFFICIENT OF A VIVALDI TAPERED SLOT ANTENNA FED THROUGH A PLANAR BALUN

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ABSTRACT - **In this paper, the Finite-Difference Time-Domain (FDTD) method was used to determine the reflection coefficient vs. frequency of a Vivaldi Tapered Dual-Slot Antenna fed through a planar balun. The reflection coefficient at the input port of the feed stripline was determined through the separate computation of the reflection coefficient of the antenna section and the scattering matrix of the balun, assuming that the electromagnetic coupling between these sections was negligible. Experimental results, which were obtained on a prototype of this structure, confirmed the validity of the proposed approach and demonstrate that the coupling between the two sections does not affect the accuracy of the model.**

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 traveling 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 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. 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 thus confirming the assumption validity.

Because the coupling between the two sections of the whole antenna can be ignored without adversely affecting accuracy, an FDTD-based equivalent network representation of the whole structure can be than derived which would allow a simple and efficient numerical analysis of the electromagnetic response of these devices. Moreover, this approach allows an accurate refinement of the grid for the two disconnected sections, greatly reducing the need for computational resources thus fully exploiting the capability of the FDTD method.

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:

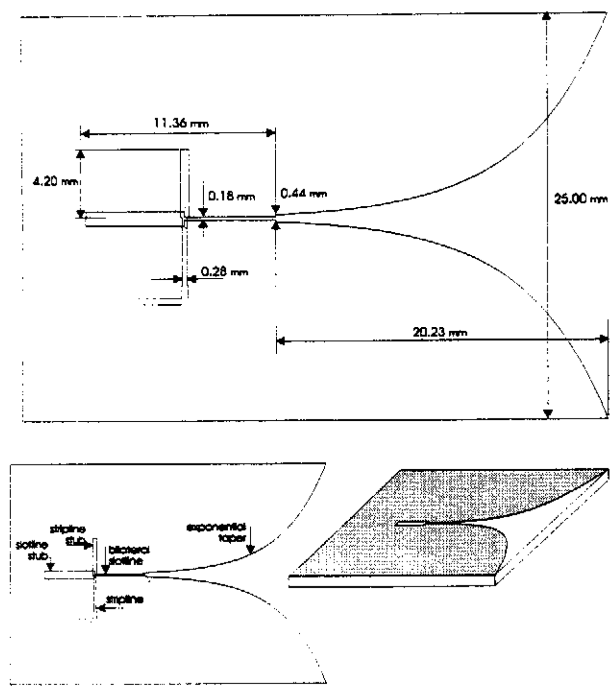


Fig. 1: the Vivaldi antenna and the feeding balun.

a) antenna section

The grid step size was linearly changed through the mesh domain to provide a better tracking of the exponential contour. This means that, in the x direction, $\Delta x' = \alpha\ \Delta x$ where $\Delta x'$, Δx are the step sizes of two contiguous cells and α is a coefficient that would depend on the design parameter of the exponential profile.

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 (see Fig. 2a), 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. With reference to Fig. 2a, this source was located at AA' plane (i.e. the excitation plane) while simulation results were stored in terms of voltage at BB' plane (i.e. the input plane). The distances BB' - AA' and BB' - HH' were properly chosen (20 and 30 cells, respectively) in order to remove the evanescent modes launched at the discontinuity planes. The reflection coefficient Γ_a at the input plane of the antenna was determined according to the following procedure:

a.1 - a first simulation was run with the slotline alone terminated on a matched load. This allowed to sample a clean incident signal (i.e. without antenna reflections) at BB' plane. Litva's second order boundary conditions [9] were used to simulate a matched load at the end of the slotline. Since these conditions require the knowledge of phase velocities at the lower and the upper frequency of the range of interest, other FDTD simulations were run before, in order to compute the propagation constant vs. frequency in the slotline;

a.2 - a second simulation was run for the entire antenna section and the total voltage response detected at the input BB' plane. Since this signal would correspond to the incident one previously computed plus the reflected signal from antenna terminals, the latter was then extracted by subtraction. Litva's conditions were used to simulate a matched load at the slotline end, while Higdon's second order boundary conditions [10] were enforced to absorb the waves radiated from the antenna;

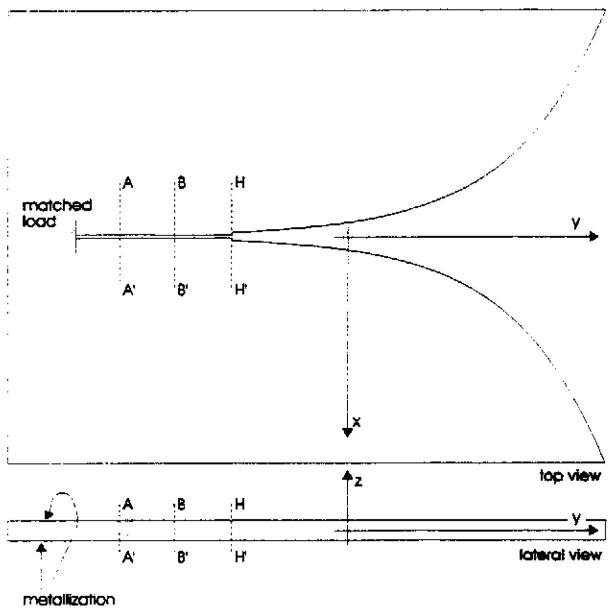
a.3 - finally, the reflection coefficient vs. frequency was computed through the ratio of the FFT of the reflected and incident signals.

b) feeding section

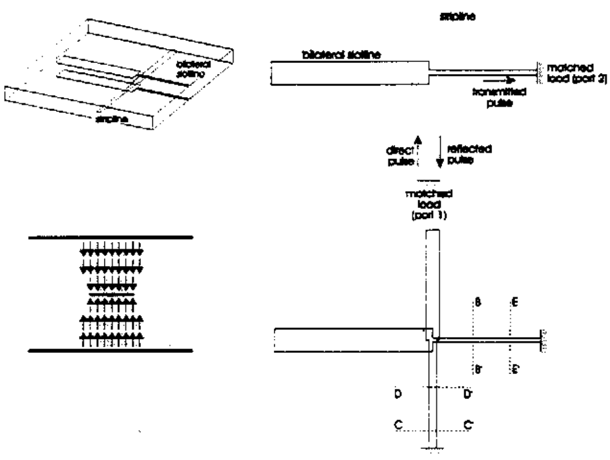
Since the feeding section is a two-port symmetric network with losses, three of the four parameters of its scattering matrix must be determined. With reference to Fig. 2b, this was carried out as follows:

<u>S_{11} and S_{12} parameters:</u> a pulse signal was launched in the stripline by exciting the field distribution shown in the same figure, at the excitation CC' plane. In order to properly compute the voltage of the TEM incident wave at the input DD' plane, a first simulation was run by terminating the stripline with a matched load. Due to the TEM propagation in the line (i.e. normal field incidence on the boundary), matching conditions were obtained by enforcing there Mur's first order absorbing boundary conditions [11]. Then, a second simulation was run for the entire feeding section and voltage signals stored at DD'and BB' planes. Since port 2 of the network corresponds to the slotline end, Litva's absorbing boundary conditions were enforced there to simulate a matched load (see a.1 above). 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 at EE' plane and by storing the total signal at BB' plane, respectively. The determination of S_{22} immediately follows since the incident signal at BB' plane was already known from the previous simulations (see a.1).



(a)



(b)

Fig. 2a,b: schematic view of (a) the Vivaldi antenna and (b) the planar balun. In both figures, the reference planes for FDTD analysis are indicated. In Fig. 2b, the exciting field distribution in the feed stripline is also depicted.

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 DD' plane was determined by using the following equation:

$$\Gamma_{in} = S_{11} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_a}{1 - \Gamma_a \cdot S_{22}}$$

on the assumption that the antenna and the feeding sections were not electromagnetically coupled.

In this FDTD-derived equivalent network model the radiating section acts as a lumped, frequency dependent impedance loading the feeding network output terminals.

4. RESULTS

In Fig. 3, the reflection coefficient amplitude vs frequency at the input BB' plane of 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.

In Fig. 4, the amplitude of the scattering parameters vs frequency for the feeding section is reported. Results obtained for S_{11}, S_{12} (S_{12}) and S_{22} (i.e. Fig. 4a, 4b and 4c, respectively) allow to determine the bandwidth of this matching network which covers the 6-18 Ghz operating frequencies. A strong mismatching does appear 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 WILTRON 360 Network Analyzer are reported. Measurements were carried out using a standard SMA connector-to-stripline transition that it was experimentally found to have negligeable effects on results accuracy.

The agreement between simulation results and measurements is quite satisfactory and validate the assumption of electromagnetic decoupling between the radiating structure 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

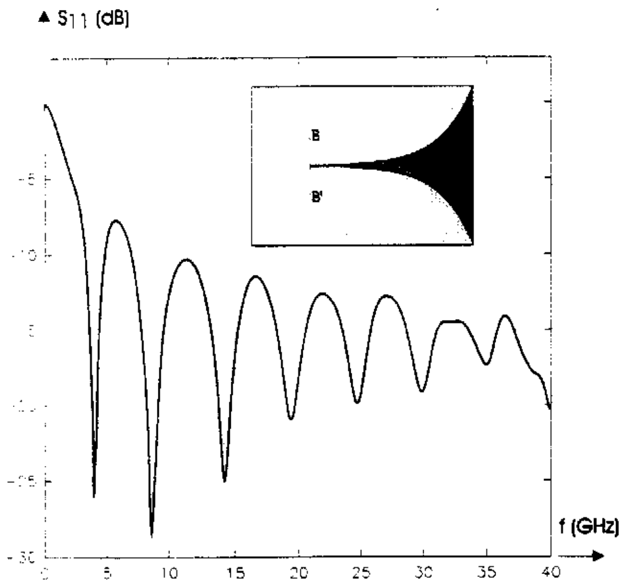


Fig. 3: amplitude vs. frequency of the reflection coefficient of the Vivaldi antenna at BB' plane in the slotline.

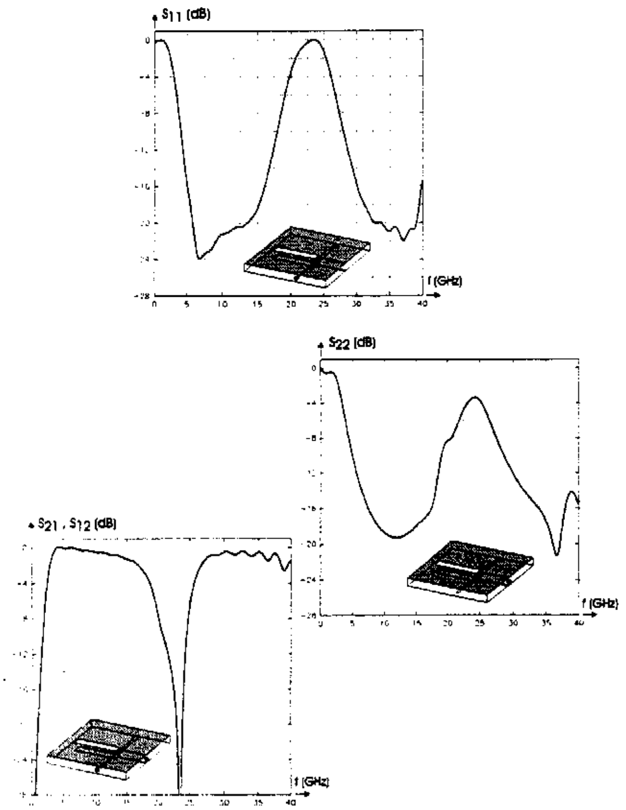


Fig. 4: amplitude vs. frequency of the S_{11}, S_{12} (S_{21}) and S_{22} scattering parameters of the planar balun.

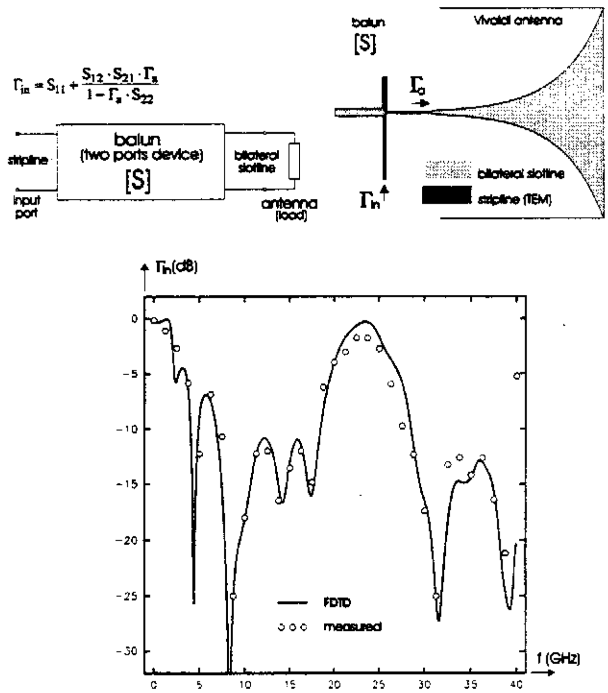


Fig. 5: reflection coefficient of the Vivaldi antenna with the planar balun at the input plane DD' in the stripline: continuous line - numerical results, circles - measured data

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 the determination of 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.

REFERENCES

[1] P.J. Gibson, "The Vivaldi aerial,"in *Proc. 9th European Microwave Conf.* (Brighton, U.K.), 101-105, 1979;

[2] K.S. Yngvesson, T.L. Korzeniowski, Y-S Kim, E.L. Kollberg, J.F. Johansson, "The tapered slot antenna - A new integrated element for millimeter-wave applications, *IEEE Trans. Microwave Theory Tech.*, MTT-37, 365-374, 1989;

[3] N. Marchand, "Transmission-Line conversion," Electronics, vol. 17, 142-145, 1944;
[4] A. Axelrod, D. Lipman, "Novel planar balun feeds octave-bandwidth dipole," *Microwaves & RF*, 91-92, 1986;
[5] A. Taflove, K. Umashankar, "The Finite-Difference Time-Domain (FD-TD) method for electromagnetic scattering and interaction problems," *J. Electromagn. Waves & Appl.*, vol. 1(4), 363-387, 1987;
[6] A. Taflove, "Review of the formulation and applications of the finite-difference time-domain methods for numerical modeling of electromagnetic wave interactions with arbitrary structures," *Wave Motion*, Vol. 10, 547-582, 1988;
[7] K. Yee, "Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media," *IEEE Trans. Ant. Propagation*, AP-14, 302-307, 1966;
[8] E. Thiele, A. Taflove, "FD-TD analysis of Vivaldi flared horn antennas and arrays," *IEEE Trans. Ant. and Propag.*, APS-42, 633-641, 1994;
[9] K.L. Wu, Z.Q. Bi, C. Wu, J. Litva, "A dispersive boundary condition for microstrip component analysis using the finite-difference time-domain (FDTD) method, *IEEE Trans. Microwave Theory Tech.*, MTT-40, 774-777, 1992;
[10] R.L. Higdon, "Absorbing boundary conditions for difference approximations to the multi-dimensional wave equation," *Math. of Comp.*, vol. 47, 437-459, 1986;
[11] G. Mur, "Absorbing boundary conditions for the Finite-Difference approximation of the Time-Domain electromagnetic-field equations," *IEEE Trans. Electromagnetic Compatibility*, EMC-23, 377-382, 1981.