

Electrodynamic Coplanar/Slotline Structure Analysis With 3-D Components Based On A Surface/Volume Integral Equation Approach

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Abstract—This paper deals with the electrodynamic analysis of coplanar (M)MIC and submm-wave structures based on a surface/volume integral equation method. The slot areas and additional 3-D components are modeled by magnetic and electric surface currents and polarization volume currents. High accuracy and efficiency is achieved by applying complete analytical solutions for the asymptotic system matrix combined with adaptive database strategies.

I. INTRODUCTION

In the last years an increasing interest regarding to the design and application of coplanar and slotline structures can be observed. Coplanar circuit technology allows the design of compact hybrid or monolithic integrated circuits for implementations in terrestrial and satellite based mobile communication, navigation and remote sensing systems etc.. Due to the only weak excitation of surface waves within coplanar structures they are especially well-suited for new receiver concepts in the radioastronomy and satellite based earth observation programs at THz frequencies. Despite of the large application range of coplanar structures, there still exists a lack of appropriate analysis and design software. From the small number of commercial software tools in this field mainly the program HP-Momentum [9] and the CAD-tool COPLAN [8] have found a larger popularity. The program HP-Momentum is based on a surface integral equation method modeling the slot areas with the duality principle whereas the tool COPLAN is based on a circuit library combined with a quasi-static Finite Difference circuit analysis. Full-wave approaches in an open environment like HP-Momentum are appropriate for the analysis of coplanar (M)MICs also comprising

radiating elements like slot antennas, whereas CAD-tools like COPLAN are well-suited for the design of large circuits at moderate frequencies. Since a general full-wave analysis of coplanar components based on local methods like FDTD or FDFD are very storage and time consuming, integral equation based methods seem to be most appropriate and versatile for the characterization of coplanar/slotline circuits and antennas.

For this goal we have developed a concept based on a surface/volume integral equation. Due to a combined formulation of an electric field surface integral equation for planar metallizations, a magnetic field surface integral equation for planes with slot areas and a volume integral equation for vertical metallizations and additional finite dielectric areas, each circuit component can be modeled with a minimum of discretization effort. The structure discretization is performed by rectangular subdomain basis functions with asymmetric segmentations and different approximations transverse to current flow allowing a flexible nonuniform meshing [5].

The computation of the system matrix elements is performed in the spectral domain after the analytical evaluation of space domain integrations with respect to the vertical structure components. The spectral domain integrations are performed using a general asymptotic subtraction technique applying complete analytical solutions for the asymptotic system matrix, presented first for microstrip and symmetric coplanar structures in [3]. The remaining numerical integrations are strongly accelerated by means of adaptive integration and database techniques. By the further development of algorithms for the search of identities within the system matrix, redundant computations are completely suppressed. First approaches have been presented in [4], they have recently been extended and improved for the combined coplanar/microstrip structure

analysis.

It could be already shown in context with submm-wave antennas and mixers [7] and other special field problems, that the flexibility and reliability of the developed approach is often decisively higher in comparison with comparable commercial software packages.

II. FORMULATION

The considered structures can consist of an arbitrary number of planes containing slot areas within an infinite ground metallization and planes with planar microstrip/stripline components, embedded in a multilayered environment. Furthermore an arbitrary number of volume current basis functions can be arranged within the layers for modeling of vertical interconnects or dielectric fillings and coatings. For solving the corresponding field problem of the structure, we have to fulfill on one hand the surface impedance boundary condition

$$\vec{E}(x, y, z_{le})|_{tan} = Z_{tot}(x, y, z_{le})\vec{J}(x, y, z_{le}) + \vec{E}^{imp}|_{tan} \quad (1)$$

on the planes $z = z_{le}$ carrying microstrip/stripline components, where Z_{tot} is a space-varying surface or line impedance, $\vec{E}^{imp}$ comprising the excitation by Δ -gap sources or external fields, and on the other hand we have to fulfill the boundary condition for the magnetic field

$$(\vec{H}^+(x, y, z_{lb}) - \vec{H}^-(x, y, z_{lb}))|_{tan} = \vec{J}_{imp} \quad (2)$$

on the groundplanes $z = z_{lb}$ with the slot areas. $\vec{J}_{imp}$ are impressed electric currents, $\vec{H}^+$ and $\vec{H}^-$ are the magnetic fields above and below the slot plane, respectively. Additionally we have to fulfill the condition for the electric field within the areas of vertical interconnects and finite dielectric regions:

$$\vec{E}(\vec{r}) = \frac{\vec{J}_V(\vec{r})}{j\omega(\epsilon(\vec{r}) - j\kappa(\vec{r}))/\omega - \bar{\epsilon}}, \quad \vec{r} \in \text{volume current areas} \quad (3)$$

where $\epsilon(\vec{r})$ and $\kappa(\vec{r})$ describe the space-varying permittivity and conductivity of these areas, $\bar{\epsilon}$ is the permittivity of the surrounding dielectric layer wherein the areas with polarisation currents $\vec{J}_V$ are embedded.

With the conditions eqs.(1), (2) and (3) we can formulate a system of coupled surface/volume integral equations, which is solved with the Galerkin Method of Moments. Due to the various current basis functions and

metallization planes, different classes of system matrix entries occur, which are finally formulated and evaluated in the spectral domain.

In the case of coplanar circuits the main part of the system matrix consists of admittance entries $Y_{mn}(lb, lb')$, describing the interactions of the magnetic current basis functions containing the composite Green's function $\vec{G}_M^H(k_\rho, \varphi, lb) = \vec{G}_{M,lb-1}^H(k_\rho, \varphi) + \vec{G}_{M,lb}^H(k_\rho, \varphi)$ in the case $lb = lb'$, where $\vec{G}_{M,lb}^H$ and $\vec{G}_{M,lb-1}^H$ are the Green's functions of the multilayered media above and below the slot plane $z = z_{lb}$, respectively. Additionally we have e.g. impedance entries $Z_{mn}(le, le')$ due to planar electric basis functions, entries $ZY_{mn}(le, lb')$ without dimension due to electric/magnetic current interactions and finally $Z_{mn}(lv, lv')$, $Z_{mn}(le/lb, lv')$ due to interactions of magnetic/electric currents with volume basis functions.

For the generation of the system matrix we apply a general asymptotic subtraction technique combined with strategies for a complete analytical evaluation of the asymptotic system matrix for all relevant matrix entries, what guarantees maximum accuracy for all kinds of basis functions and lateral distances.

The method is based on the partly analytical solutions regarding to the variable k_ρ we have already presented in [5, 4, 6] for planar microstrip components. Due to an appropriate assembling of part integrals and a special treatment of removable integrand singularities, also the integration with respect to φ can be done analytically. The method has recently been extended to microstrip components with vertical circuit components as presented in [3] and has been complemented now for the characterization of combined coplanar/slotline and microstrip structures with 3-D components. Due to these techniques, we typically get a much better efficiency compared with full-wave FDTD/FDFD methods.

Further details of the techniques and of the database/identity search procedures are given in the oral presentation.

III. APPLICATIONS

The first example shows the scattering behavior of coplanar MIM(Metal-Insulator-Metal) capacitances. Figure 1 left shows the configuration of the structure, consisting of a center conductor of width w_c deposited with a thin dielectric film with $\epsilon_r \approx 6$ and thickness $t_d \approx 0.2\mu m$ ($s = 15\mu m, w = 20\mu m$). On top of the dielectric film a second metallization plane is mounted and connected with the center conductor by an air-bridge ($l_g = 15\mu m$).

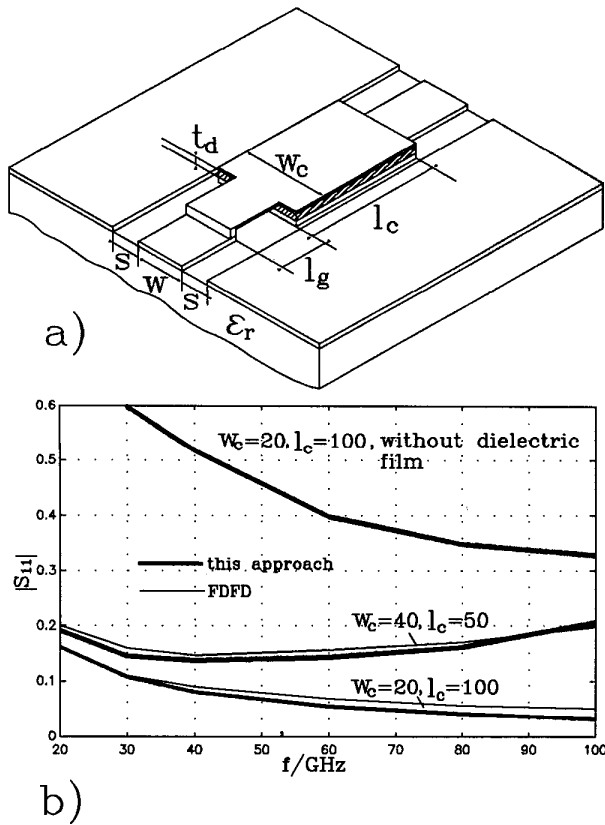


Figure 1. a) Configuration of coplanar MIM capacitances. b) Reflexion factor. All dimensions in μm .

Figure 1 right shows the results for two examples of w_c , where $w_c \cdot l_c = \text{const}$. Despite of the slightly worse convergence due to the very low airbridge, only a few seconds computation time are needed per frequency point. Using a modified asymptotic integrand evaluation for such thin layer structures, the convergence of the coupling integrals can now be decisively improved in these cases as well. Further details in this context are given in the oral presentation. The results are compared with FDFD computations from [1]. The small differences may be due to material and radiation losses, which are not considered by the FDFD analysis.

The second example shows a hybrid coplanar bandstopfilter with bond wire airbridges (Figure 2 left) applied for an 18/36 GHz frequency doubler [2], compared with an FDTD analysis and measurements (Figure 2 right). The parasitic resonance near 26 GHz is due to mode conversions at the still noncompensated bends of the stubs.

The last example shows the simulation of a new satel-

lite based submm-wave receiver concept at 650 GHz (Figure 3 left), which has successfully passed all design steps in context with a current ESA project. A typical magnetic current distribution is shown in Figure 3 right. Former investigations and further analysis concepts in context with this project are given in [7]

IV. CONCLUSIONS

The outlined analysis concept allows the simulation of combined coplanar/slotline and microstrip structures including metallic and dielectric 3-D components in a fraction of time compared to FDTD/FDFD methods due to various acceleration and accuracy improvement strategies. Since it accounts for all radiation and dielectric losses, it is especially well suited for circuit and antenna analysis up to THz-frequencies.

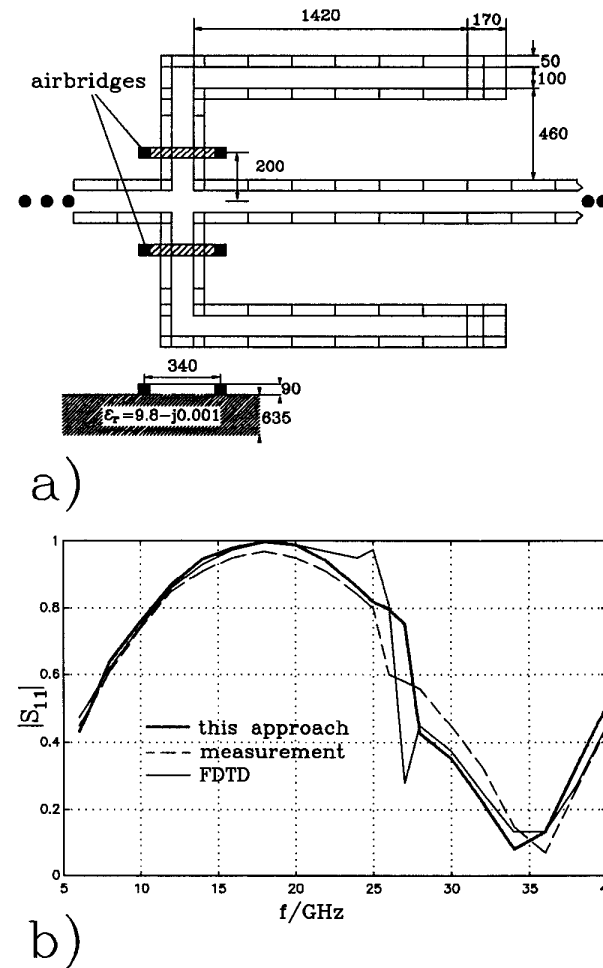


Figure 2. a) Configuration and slot discretization of the coplanar hybrid bandstop filter, b) Reflexion factor. All dimensions in μm .

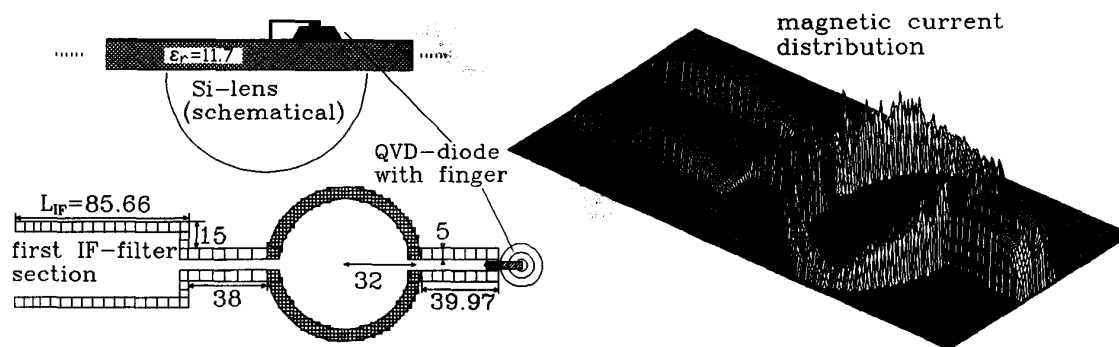


Figure 3. left: Configuration and slot discretization of open structure submm-wave mixer with ringslot antenna, right: magnetic current distribution. All dimensions in μm .

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