Full Wave Analysis of Substrate Integrated Structures

E. Arnieri, G. Amendola, L. Boccia and G. Di Massa
DEIS Università della Calabria Rende (CS) ITALY
amendola@deis.unical.it

Abstract In this paper the full wave analysis of substrate integrated structures will be presented. The magnetic dyadic Green's function of a parallel plate waveguide with circular metallic posts will be firstly derived. The presence of radiating or coupling slots will be included in the analysis solving the corresponding integral equation. Simulated results will be presented and compared with results known in literature.

Introduction

Substrate integrated circuits [1] are an effective alternative to metallic waveguide structures. They are realized with standard PCB technology inheriting its advantages like simplicity of the fabrication process and reduced costs. The basic device is the substrate integrated waveguide (SIW) shown in fig. 1. This structure is built realizing, in a conventional board of laminate, a waveguiding channel with an array of metallic via holes. SIWs have many of the characteristics of metallic waveguides, like high power capacity and low dispersion, and combine them with the integration capability typical of microstrip structures. Recently many SIW based devices like filters and antennas have been presented [2],[3]. The analysis of SI structures has been carried out with several methods [4],[5]. In [6] the EFIE integral equation has been solved considering unknown filamentary currents flowing on the metallic posts. In this paper a different approach to the full-wave analysis of substrate integrated structures is proposed. The cylindrical wave expansion of the magnetic dyadic Green's function for the parallel plate waveguide is firstly considered. Then the scattering from the metallic posts is included to obtain the Green's function of the post walled structures. In the present analysis only magnetic current sources have been considered. Radiating slots can be easily taken into account considering the equivalent magnetic current distributions, imposing the continuity of the field along the slot and solving the resulting integral equation with the Galerkin method of moments. In the following a brief account of the derivation of the dyadic Green's function is given and the solution of the radiating slots on a SIW is briefly outlined. Results for a significant case will be also reported and commented.

Theory

The magnetic Green's function for a circular parallel plate waveguide with a thickness d can be expressed as a series of vector wavefunctions and in a more compact form [7] as

$$\bar{\bar{G}}_{PPW} = -\frac{1}{k^2}\hat{z}\hat{z}\delta(\boldsymbol{R}-\boldsymbol{R}') + \sum_{m,n}\frac{j(-1)^m}{2k_{\rho m}^2 d}(1-\frac{\delta_{m0}}{2})$$

$$\begin{Bmatrix} \boldsymbol{M}_n(k_{\rho m},k_{zm},\boldsymbol{\rho},(d-z))\boldsymbol{M}_n{}'(k_{\rho m},k_{zm},\boldsymbol{\rho}',z') \\ \boldsymbol{M}_n(k_{\rho m},k_{zm},\boldsymbol{\rho},z)\boldsymbol{M}_n{}'(k_{\rho m},k_{zm},\boldsymbol{\rho}',(d-z')) \end{Bmatrix} + \tag{1}$$

$$+\begin{Bmatrix} \boldsymbol{N}_n(k_{\rho m},k_{zm},\boldsymbol{\rho},(d-z))\boldsymbol{N}_n{}'(k_{\rho m},k_{zm},\boldsymbol{\rho}',z') \\ \boldsymbol{N}_n(k_{\rho m},k_{zm},\boldsymbol{\rho},z)\boldsymbol{N}_n{}'(k_{\rho m},k_{zm},\boldsymbol{\rho}',(d-z')) \end{Bmatrix} \qquad \begin{matrix} z > z' \\ z < z' \end{matrix}$$

where $\boldsymbol{R} = \boldsymbol{\rho} + z\hat{z}$ and:

$$\boldsymbol{M}_n(k_{\rho m},k_{zm},\boldsymbol{\rho},z) = \begin{cases} \nabla\times(J_n(k_\rho\rho)e^{-jn\phi}\cos k_{zm}z\hat{\boldsymbol{z}}) & \boldsymbol{\rho}\le\boldsymbol{\rho}' \\ \nabla\times(H_n^{(2)}(k_\rho\rho)e^{-jn\phi}\cos k_{zm}z\hat{\boldsymbol{z}}) & \boldsymbol{\rho}>\boldsymbol{\rho}' \end{cases}$$

$$\boldsymbol{M}_n{}'(k_{\rho m},k_{zm},\boldsymbol{\rho}',z') = \begin{cases} \nabla\times(J_n(k_\rho\rho')e^{-jn\phi'}\cos k_{zm}z'\hat{\boldsymbol{z}}) & \boldsymbol{\rho}>\boldsymbol{\rho}' \\ \nabla\times(H_n^{(2)}(k_\rho\rho')e^{-jn\phi'}\cos k_{zm}z'\hat{\boldsymbol{z}}) & \boldsymbol{\rho}\le\boldsymbol{\rho}' \end{cases}$$

$$\tag{2}$$

$$\boldsymbol{N}_n(k_{\rho m},k_{zm},\boldsymbol{\rho},z) = \begin{cases} \frac{1}{k}\nabla\times\nabla\times(J_n(k_\rho\rho)e^{-jn\phi}\sin k_{zm}z\hat{\boldsymbol{z}}) & \boldsymbol{\rho}\le\boldsymbol{\rho}' \\ \frac{1}{k}\nabla\times\nabla\times(H_n^{(2)}(k_\rho\rho)e^{-jn\phi}\sin k_{zm}z\hat{\boldsymbol{z}}) & \boldsymbol{\rho}>\boldsymbol{\rho}' \end{cases}$$

$$\boldsymbol{N}_n{}'(k_{\rho m},k_{zm},\boldsymbol{\rho}',z') = \begin{cases} \frac{1}{k}\nabla\times\nabla\times(J_n(k_\rho\rho')e^{-jn\phi'}\sin k_{zm}z'\hat{\boldsymbol{z}}) & \boldsymbol{\rho}>\boldsymbol{\rho}' \\ \frac{1}{k}\nabla\times\nabla\times(H_n^{(2)}(k_\rho\rho')e^{-jn\phi'}\sin k_{zm}z'\hat{\boldsymbol{z}}) & \boldsymbol{\rho}\le\boldsymbol{\rho}' \end{cases}$$

and $k^2 = k_{\rho m}^2 + k_{zm}^2$, $k_{zm} = \frac{m\pi}{d}$. The presence of the metallic posts is taken into account considering the field given in (1) as primary field and computing the scattering from the metallic posts.

The total field given by a magnetic current distribution $\boldsymbol{J}_M(\boldsymbol{\rho}',z')$ is given by

$$\boldsymbol{H}_{TOT}(\boldsymbol{\rho},z) = -j\omega\varepsilon\int d\boldsymbol{\rho}'dz'\bar{\bar{\boldsymbol{G}}}_{PPW}(\boldsymbol{\rho},\boldsymbol{\rho}',z,z')\cdot\boldsymbol{J}_M(\boldsymbol{\rho}',z') + \boldsymbol{H}_{CYL}(\boldsymbol{\rho},z) \tag{3}$$

where $\boldsymbol{H}_{CYL}(\boldsymbol{\rho},z)$ is the field scattered from the posts is expressed as:

$$\boldsymbol{H}_{CYL}(\boldsymbol{\rho},z)=\begin{cases}\displaystyle\sum_{l}\sum_{n,m}\begin{bmatrix}\boldsymbol{M}_n^H(k_{\rho m},k_{zm},\boldsymbol{\rho}-\boldsymbol{\rho}_l,d-z)A_{l,m,n}^M+\\ \boldsymbol{N}_n^H(k_{\rho m},k_{zm},\boldsymbol{\rho}-\boldsymbol{\rho}_l,d-z)A_{l,m,n}^N\end{bmatrix} & \text{for } z>z'\\ \displaystyle\sum_{l}\sum_{n,m}\begin{bmatrix}\boldsymbol{M}_n^H(k_{\rho m},k_{zm},\boldsymbol{\rho}-\boldsymbol{\rho}_l,z)A_{l,m,n}^M+\\ \boldsymbol{N}_n^H(k_{\rho m},k_{zm},\boldsymbol{\rho}-\boldsymbol{\rho}_l,z)A_{l,m,n}^N\end{bmatrix} & \text{for } z<z'\end{cases} \tag{4}$$

In (4) index l spans over the cylinders, n spans over the number of the circumferential modes and

$$\boldsymbol{M}_n^H(k_{\rho m},k_{zm},\boldsymbol{\rho}-\boldsymbol{\rho}_l,z)=\nabla\times(H_n^{(2)}(k_{\rho m}\left|\boldsymbol{\rho}-\boldsymbol{\rho}_l\right|)e^{-jn\phi}\cos(k_{zm}z)\hat{\boldsymbol{z}}) \tag{5}$$

$$\boldsymbol{N}_n^H(k_{\rho m},k_{zm},\boldsymbol{\rho}-\boldsymbol{\rho}_l,z)=\frac{1}{k}\nabla\times\nabla\times(H_n^{(2)}(k_{\rho m}\left|\boldsymbol{\rho}-\boldsymbol{\rho}_l\right|)e^{-jn\phi}\sin(k_{zm}z)\hat{\boldsymbol{z}}) \tag{6}$$

Coefficients $A_{l,m,n}^M$ and $A_{l,m,n}^N$ are determined from the solution of the two dimensional scattering from the metallic posts under TM and TE illumination. As an example, for the TM case, the coefficients are determined solving a set of the following equations written one for each post q and for the index r spanning over the number of the circumferential modes:

$$-\frac{J_r(k_{\rho m}a_q)}{H_r^{(2)}(k_{\rho m}a_q)}v_{rm}^{MH(q)}=\sum_{l\neq q}\sum_{n}\frac{J_r(k_{\rho m}a_q)}{H_r^{(2)}(k_{\rho m}a_q)}H_{n-r}^{(2)}(k_{\rho m}\rho_{lq})e^{j(r-n)\phi_{lq}}A_{mnl}^M+A_{mrq}^M \tag{7}$$

In the previous equation a_q is the radius of the post q and

$$\begin{aligned}v_{rm}^{MH(q)}=+j\omega\varepsilon\int d\boldsymbol{\rho}'dz'(\frac{j}{2d}\frac{(-1)^m}{k_{\rho m}^2}(1-\frac{\delta_{m0}}{2})\\ \nabla'\times\left[H_r^{(2)}(k_{\rho m}\left|\boldsymbol{\rho}'-\boldsymbol{\rho}_q\right|)\cos(k_{zm}z')e^{jr\phi'}\hat{\boldsymbol{z}}\right]\cdot\boldsymbol{J}_M(\boldsymbol{\rho}',z')\end{aligned} \tag{8}$$

is the excitation coefficient related to a magnetic current excitation $\boldsymbol{J_M}$. The analysis of the radiating slot is carried out by the method of moments using the dyadic Green's function of the post walled structure for the interior region and the free space Green's function for the external region. The slot is modelled with equivalent magnetic currents that are expressed as a sum of entire domain basis functions with unknown coefficients. The coefficients are then computed with the application of a Galerkin procedure.

Results

As a preliminary result the analysis of a SIW structure already presented in literature has been reproduced. In fig.2 is shown a filter obtained inserting posts in a SIW with characteristics reported in [2]. In fig.3 are shown the simulated S_{11} e S_{21}. It is observed that they compare favorably with the measurements published in [2]. In fig.4 a map of the magnetic field is presented. As it can be seen the leakage due to the discontinuous arrays of posts that forms the waveguide is negligible

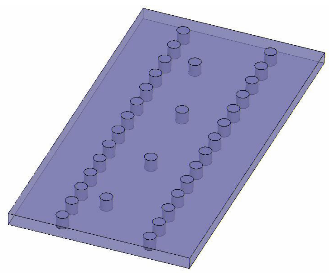

Fig. 1 SIW filters as in [2]

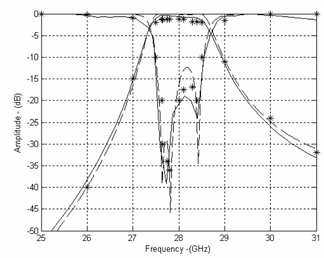

Fig.3 Return losses: full wave simulation (solid line), measurements published in [2] (*),HFSS simulations (---)

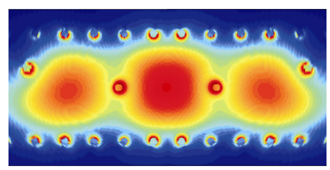

Fig. 2 Magnetic field pattern of the SIW filter

Conclusions

A full wave analysis of substrate integrated waveguides has been presented. It is based on the dyadic Green's function of a parallel plate waveguide which includes the presence of metallic posts. Results on a SIW filter already presented in literature have been shown. The presence of radiating or coupling slots can be also taken into account and more details will be given during the presentation.

References

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