Full-Wave Analysis of Coplanar Discontinuities Considering Three-Dimensional Bond Wires

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Abstract

The analysis of a simple coplanar band-reject filter based on open ended stubs using the finite difference time-domain (FDTD) method is presented. The influence of bond wires for grounding the side conductors of the coplanar lines is investigated. A comparison of the obtained results with accurate measurements is shown. Results are used for the discussion of the effect on coplanar circuit design.

Introduction

The coplanar line has some advantages in monolithic microwave integrated circuit design. However, it has not achieved high dissemination yet because of missing design tools. With the exception of single or coupled line structures the knowledge of coplanar elements is not comparable with that of microstrip components. There are some facts which make circuit design more easy in coplanar technique. These are essentially the small dispersion of the coplanar line, the simple realization of short circuited ends and the simple integration of lumped elements or active components. Parasitic effects are also much smaller for coupled structures where the ground capacitance is unwanted, as in spiral inductors. On the other hand, the grounding of the side-conductors of the coplanar line sometimes causes trouble, a problem that is hardly considered up to now. If grounding is assured the coplanar structures can be analyzed with quasi-static methods [1]. The effects due to mode conversion can be analyzed with nearly all planar analysis techniques such as the spectral domain analysis or the method of lines. However, the influence of bond wires or air bridges on grounding the side conductors can only be analyzed using a true three-dimensional full-wave analysis technique.

The FDTD Method

The three-dimensional FDTD method applied to planar microwave circuits is well introduced in [2]. A transient analysis in the time-domain is used to determine the S-parameters of the investigated structure. Therefore a single computation run is sufficient to deliver the complete frequency response. First applications of the FDTD method to coplanar lines have been reported in [3]. In this publication the main emphasis is put on the accurate description of the fields in the coplanar line in order to investigate the current distribution, the corresponding characteristic impedance and the propagation constant. Therefore a fine mesh for spatial discretization is used. But with the application of the FDTD method to coplanar discontinuities a coarse mesh must be used to receive an acceptable computational expense. Despite the rough discretization the dynamics of the coplanar structures can be analyzed with good accuracy.

Pulse Excitation

A retarded gaussian pulse of the form

$$g(t) = e^{-\left(\frac{t-t_0}{T}\right)^2} \qquad (1)$$

is excited at one port of the investigated structure using the matched source technique introduced in [4]. The field distribution in the excitation plane is only the electric field at the dielectric interface between the center electrode and the side electrodes. A more detailed field distribution as e.g. the quasi-static solution only leads to faster stabilization of the physical pulse form, but does not change the result. The pulse duration has been set with the time constant T in such a way that the pulse width is about 60 space elements whereby the threshold is 5 percent of the maximum. The time delay turns on the pulse with a distance of

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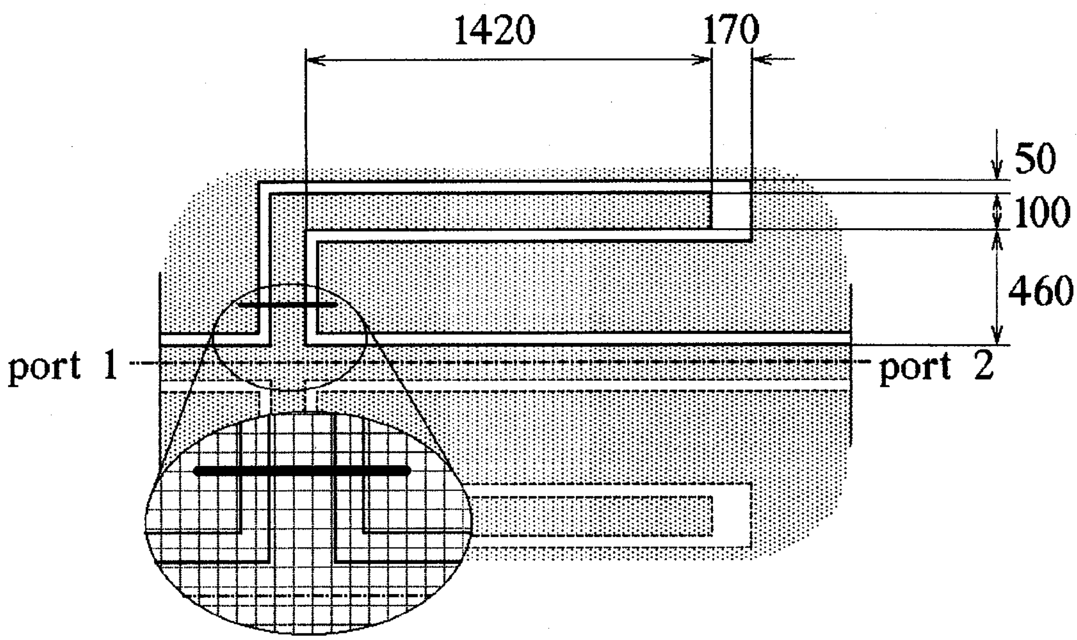

Figure 1: The coplanar band-reject filter.

also 60 space elements from the center of the pulse. Therefore the frequency range of the excited pulse is from dc up to about 130 GHz with the used discretization.

Boundary Treatment

The computation domain is truncated with artificial absorbing boundaries based on Sommerfeld's radiation condition. The used algorithm is mainly based on the super absorption method [5] and is described in [4]. The symmetry plane in the structure (Fig. 1) is replaced by a magnetic wall which reduces the computer memory need and therefore the computation time by half.

The Band-Reject Filter

The coplanar band-reject filter has been designed for application in a frequency multiplier. It should have no transmission for 18 GHz and good transmission for 36 GHz. With the assumption of negligible dispersion and open end capacitance the effective length of the bended stub has been selected to 1780 μm on a 635 μm Al_2O_3-substrate with a permittivity of $\varepsilon_r = 9.8$. The size of the structure was reduced using a bend in the stub. Furthermore the band-reject filter has been realized using a symmetric stub to avoid additional bond wires. The S-parameters of the band-reject filter with bond wires (Fig. 1) are compared with measurement results (dashed lines) performed with a HP 8510 and a CASCADE prober station (Fig. 2).

The essential difference between the measured and calculated results is the absence of attenuation in the calculated results and therefore the sharper resonant phenomenon at about 26 GHz. The measured results also show this effect which must be explained with the interaction of the connected discontinuities together with higher order modes different from the symmetric quasi-TEM mode on the stubs. Each used discontinuity in the structure analyzed separately shows negligible or only a weak frequency dependence in the investigated frequency range.

The position and length of the bond wires take big influence on the resonant frequency of the stubs. They must be positioned as close as possible to the cross junction. Otherwise the resonant frequency of the stubs increases as several simulation results showed. This means that theoretical field approaches that are not able to consider the bond wires have strong restrictions in coplanar circuit design.

The S-parameters of the investigated structure without bond wires are shown in Fig. 3. There is no similarity between the transfer functions of the structure with and without the bond wires. Apparently the structure can now be interpreted as two symmetrically coupled winding slotlines.

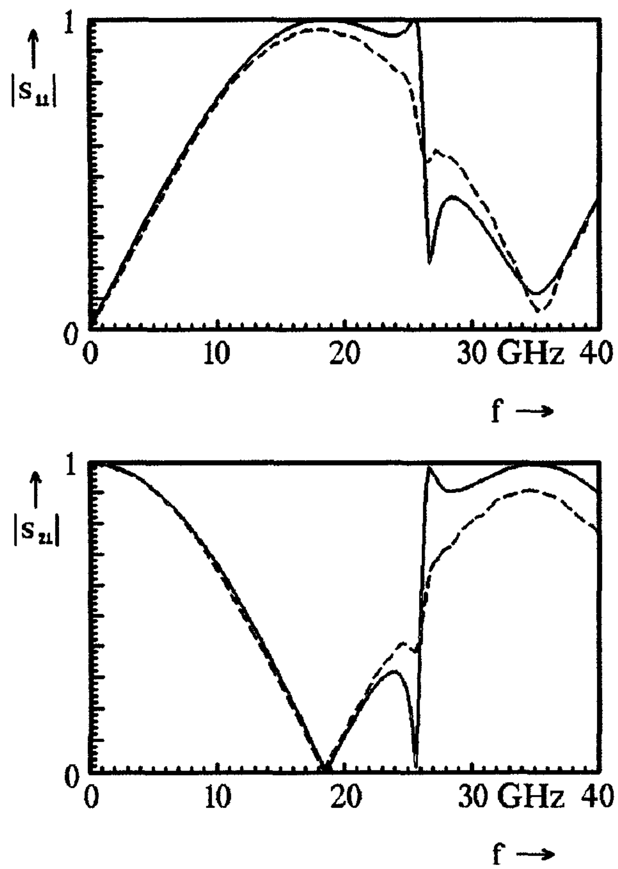

Figure 2: S-parameters of the coplanar band-reject filter with bond wires, theory (solid lines), measurement (dashed lines).

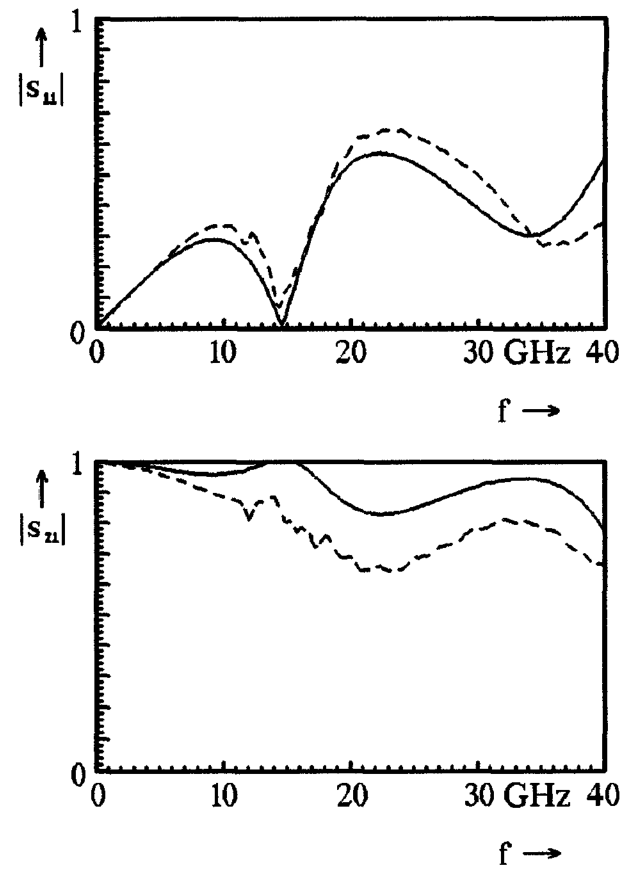

Figure 3: S-parameters of the coplanar band-reject filter without bond wires, theory (solid lines), measurement (dashed lines).

The excitation of the odd mode in the coplanar cross junction for different positions of the bond wires is shown in Fig. 4 in a simulation. u_1^{even} is the voltage of the coplanar incident wave at port 1. u_3^{odd} is the voltage of the unsymmetric outgoing wave at port 3. All the lines connected to the coplanar cross junction are infinitely long. The amplitude of the excited asymmetrical fundamental mode (which is unwanted) increases with increasing distance of the bond wires from the crossing. This means, that best succes in suppressing the asymmetrical mode is obtained by placing the bond wires as close as possible to the discontinuity.

In [6] a T-junction with an air bridge center conductor (Fig. 5) is introduced. This technique is also applicable for cross junctions. The odd mode suppression of the air bridge T-junction is significantly better than that of the conventional one as it is shown in Fig. 6.

Conclusion

Coplanar circuit design requires the use of different air bridges to supress asymmetrical modes excited at several discontinuities. True three-dimensional full-wave simulators are necessary to analyze the influence of such elements. This has been shown in the case of a coplanar band-reject filter using the FDTD method. Measured and calculated results are in good agreement.

Acknowledgement

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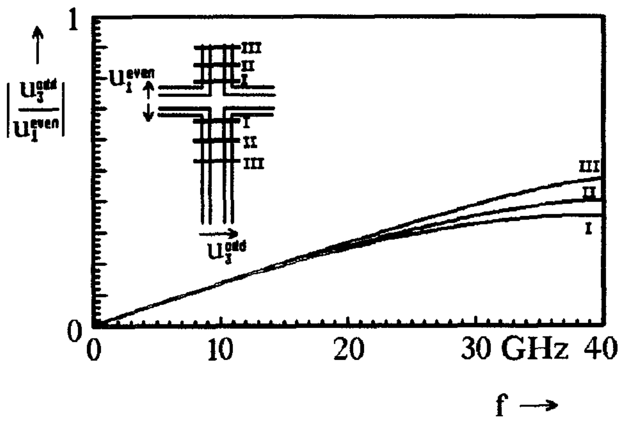

Figure 4: Mode conversion with different bond wire positions.

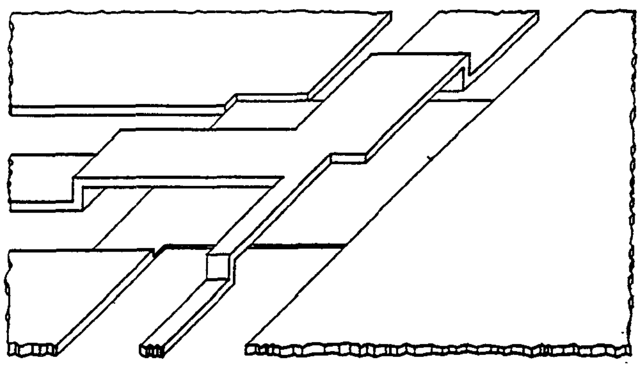

Figure 5: The air bridge T-junction from [6].

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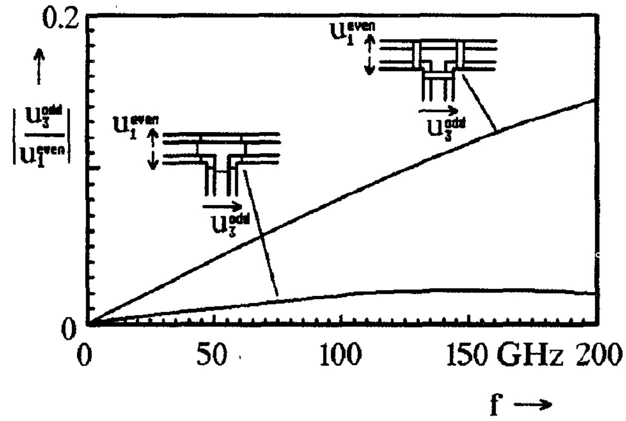

Figure 6: Mode conversion for different T-junctions, $w = 15\mu m$, $s = 10\mu m$, $\varepsilon_r = 12.9$.

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