FINITE DIFFERENCE QUASI-TEM MODE ANALYSIS OF COUPLED COPLANAR LINES USED IN (M)MIC DIRECTIONAL COUPLERS

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ABSTRACT

An accurate and efficient quasi-static Finite-Difference field calculation is applied to multiple coupled coplanar lines. The characteristics of propagating quasi-TEM modes are derived from the charge and surface current distribution on conductors. Coplanar couplers of different center frequencies and coupling factors are designed and realized on ceramic and GaAs substrates. The scattering matrix of couplers is calculated utilizing the characteristics of quasi-TEM modes propagating along the coupled coplanar lines. Numerical results are compared with measurements showing good agreement.

INTRODUCTION

One of the most important advantages of coplanar transmission lines is the fact that line dimensions are almost independent from substrate thickness. As a result, very small structures can be realized in this technique. But in case of distributed elements such as transmission line couplers the conductor losses restrict the size minimization of the components. On the other hand very narrow gaps between the coupled lines are necessary in order to achieve higher coupling. Alternatives are branch-line and rat-race couplers [1] or the use of multilayer technique [2,3]. But the analysis of such complicated multilayer structures is very time consuming so that an interactive design and optimization of the structure is not possible. This letter presents a solution for the realization of coplanar directional couplers of 3dB to 10dB coupling using conventional (M)MIC technique. An analysis method with CAD capability was developed for the fast and accurate simulation of coupled coplanar lines. The presented method allows the consideration of finite substrate and metallization thickness as well as the influence of air bridges used for the suppression of higher order modes. In order to demonstrate the accuracy and efficiency of applied method, two coplanar directional couplers for different applications (power detection at 1GHz and power splitting/combining at 20GHz) are designed and realized in different techniques (hybrid and MMIC).

APPLIED ANALYSIS METHOD

Fig. 1 shows the schematic description of the used analysis method based on the theory of multiconductor systems. A quasi-static finite difference method [4] is applied to the system

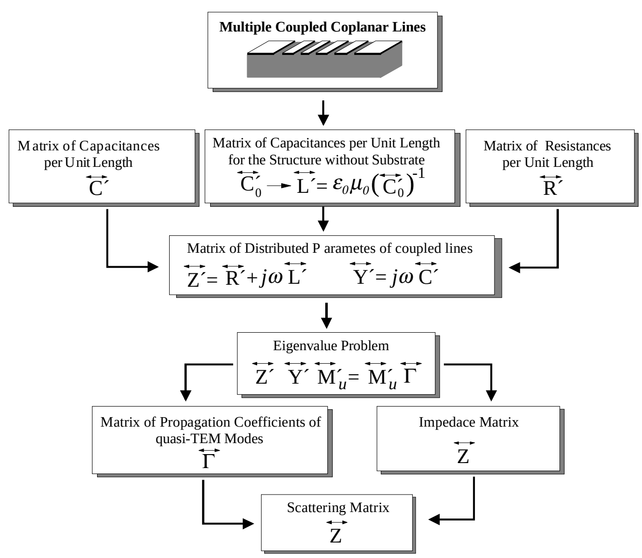
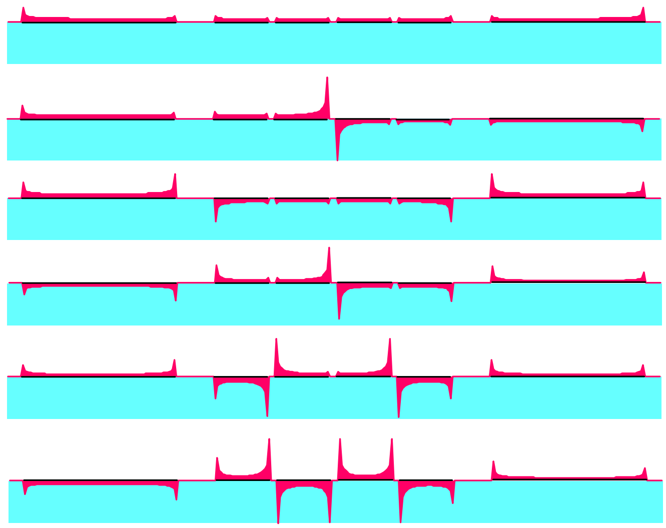


Fig.1 - Quasi-TEM mode analysis of coupled lines



Quasi-TEM Modes	Surface Current Distribution	$\varepsilon_{r,eff}$	α @1GHz dB/m
1st Even Mode		7.263	4.042
1st Odd Mode		6.772	8.118
2nd Even Mode		6.649	15.129
2nd Odd Mode		6.088	24.967
3rd Even Mode		6.388	27.830
3rd Odd Mode		6.190	29.758

Fig.2 - Propagation Characteristics ($\varepsilon_{r,eff}$, α) of quasi-TEM modes of six coupled strips used in 3dB Coplanar Coupler on GaAs

of multiple coupled coplanar lines that forms the coupler cross section. The use of a smart non-equidistant discretization as well as the utilization of the successive over relaxation (SOR) for the solution of the Laplace's difference equation leads to a very fast numerical determination of charge and surface current distribution on conductors. From these quantities, the distributed parameters of coupled lines, it means the capacitance, inductance and resistance matrices per unit length (C´, L´ and R´) can be calculated. The matrix of series impedance as well as the matrix of the shunt admittance per unit length of coupled section are used for the solution of the eigenvalue problem which delivers the propagation coefficients of propagating quasi-TEM modes and the impedance matrix of the coupled line system. Fig. 2 shows the propagation characteristics (effective dielectric constant $\varepsilon_{r,eff,}$ attenuation α and surface current distribution) calculated for the six possible quasi-TEM modes of the 3dB MMIC coupler of Fig. 5. Using the normalized impedances at ports, the scattering matrix of the coupled lines can be calculated. The parasitic effects of bridge construction between the ports of the coupler and the coupled line section can not be neglected at high frequencies. These effects are considered in a network of coplanar lines and air bridges (see Fig. 6), which are calculated using the 3D-Finite Difference Method [5]. The methods presented in [4] and [5] are implemented as a complete CPW-Library [6] in the HP-EEsof Series IV (Libra).

NUMERICAL RESULTS

The first structure investigated is a 10 dB coplanar coupler for the center frequency of 1 GHz used for power detection. Fig. 3 shows the layout of the coupler.

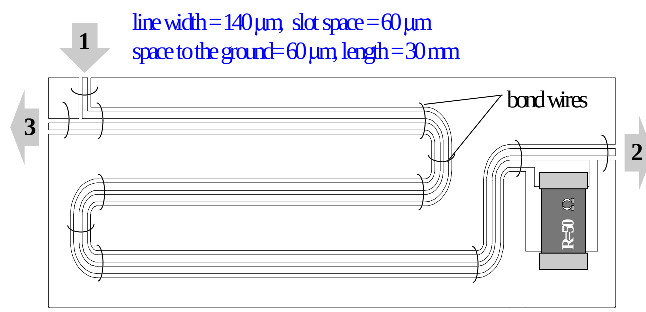


Fig.3 - Layout of the 10 dB coplanar coupler on ceramic substrate

In order to minimize the size of the coupler, the coupled lines are folded several times. Bond wires are used to suppress the parasitic higher modes which could be excited at the bends. The port 4 is terminated using a 50 Ω SMD resistor.

The scattering parameters plotted in Fig. 4 show very good agreement between the calculated and measured results indicating the accuracy of the applied method even beyond the first and second resonance frequencies. The coupling of 10 dB is already achieved. The input matching is better than 20 dB and the isolation is more than 30 dB.

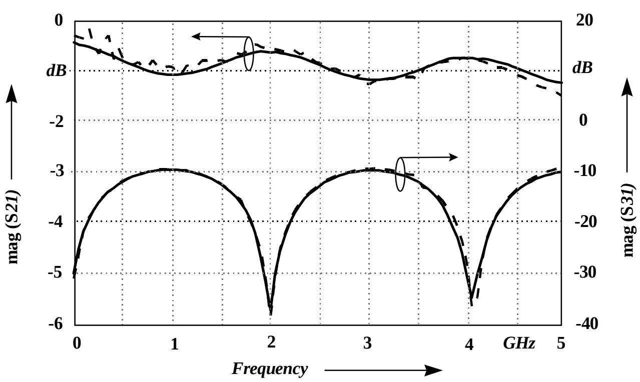


Fig.4 - Measured (dashed lines) and calculated (solid lines) scattering parameters of the 10 dB coplanar coupler on ceramic substrate.

In the next step a 3dB coplanar coupler for center frequencies of 20 GHz is designed and realized on GaAs-substrate (substrate height = 500 µm). The main goal was to realize a small sized coupler for an application as power divider/combiner. In order to reach as much coupling as possible, four coupled lines with a line width of 35 µm and a line spacing of 5 µm are needed. The use of more than four lines leads to much greater losses. The distance between the coupled lines and ground planes is 25 µm and the total length of the coupled section if 1.45 mm.

Fig. 5 shows the photo of the coupler realized. Air bridges at ports suppress the excitation of higher order modes. Two further air bridges are necessary for the connection of coupled lines at the both ends of coupling section. The complete coupler is simulated using *COPLAN* [6], a CPW-Library within Libra (see Fig. 6). The results are plotted in Fig. 7. The maximum achievable coupling is 4.18 dB (Direct=4.06 dB). The input matching and Isolation of 10.6 dB is not sufficient. The main reasons is the bridge construction at the ports an the connection between the lines at the end of coupled line section. The phase balance is within ±5° from 15-25 GHz. The excellent agreement between the simulation and measurement, specially in case of S-parameter angles indicates the validity of quasi-static analysis up to relatively high frequencies.

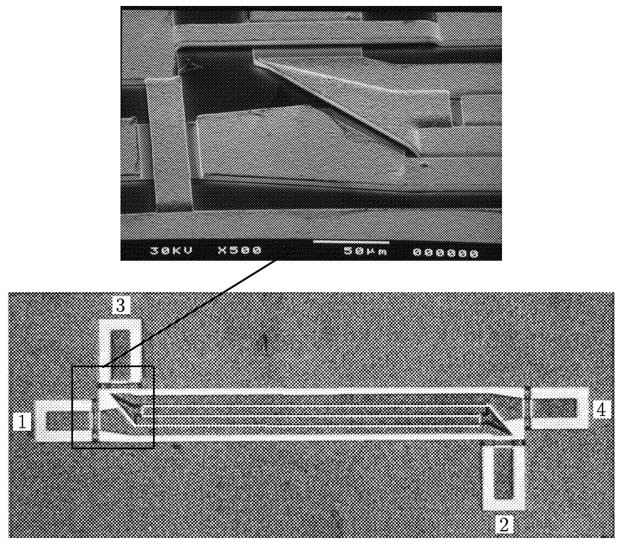


Fig. 5 - Photo of the 3dB MMIC coplanar coupler on GaAs (line width = 35 µm, slot space = 5 µm, space to the ground = 25 µm, length = 1.45 mm).

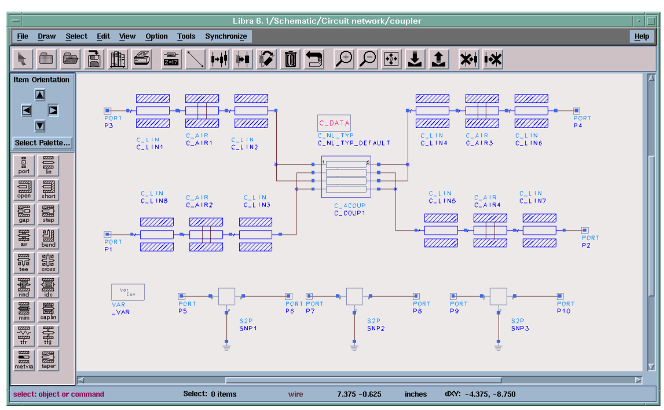


Fig. 6 - Schematic of the 3 dB MMIC coplanar coupler with coupled line section and termination networks consisting of coplanar lines and air bridges.

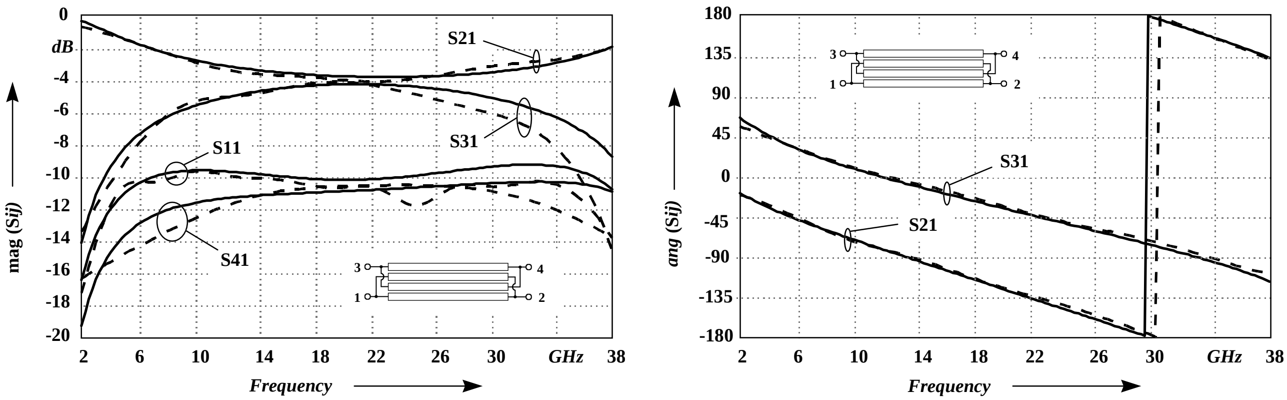


Fig. 7 - Measured (dashed lines) and calculated (solid lines) scattering parameters of the 3 dB MMIC coplanar coupler on GaAs.

CONCLUSIONS

Coplanar directional couplers of relatively small sizes and good performances are presented using conventional (M)MIC. Relatively high coupling is achieved utilizing multiple coupled coplanar lines. An efficient and powerful simulation tool using two- and three-dimensional FDM is used for the fast and accurate simulation of the coupler characteristics. The accuracy of the applied method is verified in a wide range of frequencies using measurements on two coplanar couplers for different applications on ceramic and GaAs substrates.

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