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OPTIMISED SYNTHESIS OF MICROSTRIP BRANCH-LINE COUPLERS TAKING DISPERSION, ATTENUATION LOSS AND T-JUNCTION INTO ACCOUNT

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ABSTRACT

Directional couplers are fundamental components for MIC's up to millimeter-wave range. The paper presents an optimised synthesis technique of the microstrip branch-line type, that takes microstrip dispersion, conductor loss and T-junction discontinuity effects into account.

The good agreement between measured and computed S parameters of two experimental 3-branch couplers proves the complete model reliability up to 20 GHz. Finally a brief analysis of sensitivity versus geometrical dimensions of the coupler is made.

INTRODUCTION

Directional couplers are fundamental components for MIC's up to millimeter-wave range. The equal power-split (3 dB) coupler is often used for balanced-type components such as amplifiers and mixers. Among the planar structures the branch-line coupler seems to be most suitable for coupling values in the range of 3 to 6 dB.

In fact the parallel-line coupler is quite difficult to be manufactured at very high frequencies and for tight coupling values because of the narrow gap between the microstrip lines. Furthermore the wire-bondings between the coupler fingers behave as distributed parameter transmission lines for very high operating frequencies, making coupler performance worse.

Rat-race hybrid has the output arms not adjacent and a crossover connection may be needed while branch-line couplers are structures completely planar with output ports adjacent and 90° out of phase.

The Levy exact synthesis [1] is good for ideal loss less branch-couplers; however this does not take T-junction discontinuities into account and the microstrip impedances are not always realizable. Muraguchi optimised synthesis [2] allows to achieve impedance values compatible with microstrip technology, but the coupler is still considered lossless and without discontinuity effect; anyway the results obtained are very good in C-band. Finally Celliers and Malherbe [3] take discontinuities into account but the design is limited only to strip-line two-branch coupler and experimental results are given up to 10 GHz.

This paper presents an optimized synthesis technique of microstrip branch-line couplers with any number of branches, taking dispersion, conductor attenuation and T-junction effects into account. Furthermore this design procedure allows the solution with optimum electrical performance and manufacture feasibility to be achieved. It is also shown that, while microstrip dispersion affects coupler performance particularly at higher frequencies, T-junction effects make performance worse also at very low frequencies (1 GHz).

With this design technique two 3-branch 3 dB couplers have been designed and manufactured on alumina substrate, to be operating at 1.6 and 20 GHz.

Measured S parameters well agree with computed values up to K-band proving that a complete model of the microstrip structure has to be used. The good experimental results obtained at 20 GHz show microstrip branch-line couplers to be well working also at very high frequencies. Finally a sensitivity analysis is made in order to find the most critical geometrical dimensions of the structure.

DESIGN PROCEDURE

The branch-line coupler structure is shown in Fig. 1. The microstrip coupler design procedure is carried out through three steps. First branch impedance values of the coupler, assumed as an ideal, lossless reciprocal four-port, are obtained minimising a suitable objective function, so that the coupler theoretical performance, computed according to the analysis developed by [2], agrees as well as possible with the required electrical specifications.

For a 3 dB coupler a standard objective function is:

$$F = P_1 \sum_{n=1}^{N} |S_{11}(f_n)|^2 + P_2 \sum_{n=1}^{N} |S_{41}(f_n)|^2 + P_3 \sum_{n=1}^{N} (|S_{21}(f_n)|^2 - 0.5)^2 + P_4 \sum_{n=1}^{N} (|S_{31}(f_n)|^2 - 0.5)^2$$

where:

S_{11}, S_{41}, S_{21}, S_{31} are the S parameters computed at the n-frequency point

N is the number of frequency points where the device response is calculated

P_1, P_2, P_3, P_4 are weight constants which values depend on the parameters to be optimised.

In this first optimisation phase, bounds to branch impedance values are set, so that a microstrip structure phisically feasible is achieved. All branch lengths are assumed to be a quarter of wavelength long at the band-centre frequency. Of course it's possible to take full advantage of the symmetries existing in the frequency response, about the frequency centre, and in the planar structure of the branch-coupler, respect to the x and y planes as shown in fig.1, in order to achieve a simpler and faster optimisation in order to achieve.

In the second step the microstrip line widths and lengths are computed taking taking dispersion, attenuation loss, T-junction discontinuity effects into account. Attenuation loss sets a bound to high impedance microstrip line manufacture, while dispersion and discontinuities let branch-line lengths to be changed enough. In fact the propagation constant and then line lengths vary versus the line impedance while T-junction [4] produces a reference plane shift and a parallel susceptance. The dispersion and attenuation are calculated according to [5] and [6]. At last in the third step the geometrical dimensions of all the structure branches are optimised in order to achieve optimum electrical performance of the coupler. The starting point of this optimisation is the result obtained in the second step. The rapid convergence of the optimisation algorithm allows only a desk computer to be used. Weighting suitably the several contributes in the objective function to be minimised, various optimum solutions can be achieved.

Levy [1] provided the exact solution for Butterworth and Chebyshev performance couplers with more than two branches; however some theoretically exact solutions are not always realizable with microstrip technology.

The optimised synthesis method proposed here allows, instead, the solution with optimum electrical performance and microstrip manufacture feasibility to be achieved.

DESIGN EXAMPLES AND EXPERIMENTAL RESULTS

The design technique described above has been successfully employed to design and manufacture two 3-branch 3 dB couplers.

The first coupler, operating at 20 GHz, has been manufactured on 10 mils thick alumina substrate. The goals to be attained are a flat transmission response and an input reflection less than -20 dB on a 20 per cent frequency bandwidth.

After the first design step has been carried out, branch impedance values are the following (see Fig. 1):

$z_1=50\ \Omega \quad z_2=44\ \Omega \quad z_{S1}=110\ \Omega \quad z_{S2}=63\ \Omega$

All branches are a quarter of wavelenght long of the band-centre frequency. The length and width values of the branches are obtained with the second step; they are:

$w_1=.24$ mm $w_2=.314$ mm $w_{S1}=.018$ mm $w_{S2}=.142$ mm
$L_2=1.41$ mm $L_{S1}=1.53$ mm $L_{S2}=1.46$ mm

The values of the geometrical dimensions obtained with the final optimisation process are shown in Table 1.

Parameter	20 GHz	1.66 GHz
z_1 (Ω)	50	50
w_1 (mm)	0.240	0.603
z_2 (Ω)	44.8	36.5
w_2 (mm)	0.300	1.092
L_2 (mm)	1.328	17.760
z_{S1} (Ω)	107.7	120.6
w_{S1} (mm)	0.020	0.032
L_{S1} (mm)	1.951	18.436
z_{S2} (Ω)	62.5	38.5
w_{S2} (mm)	0.142	0.996
L_{S2} (mm)	1.951	18.436

Tab. 1 - Coupler design data

Figs. 2a and 2b show the good agreement between theoretical and measured results of the 20 GHz coupler transmission and reflection response. The second 3-branch 3 dB coupler operates at 1.66 GHz and it is manufactured on 25 mils thick allumina substrate. The goals are the same as for 20 GHz coupler.

The final design data are given in Table 1.

As it can be seen the branch impedance values are different for the two couplers, though the electrical specifications are the same. This difference, of course, arises only with the last optimization phase. In both cases the final branch lengths are different from the theoretical starting values assumed to be all a quarter of wavelength.

Theoretical and measured results are shown in Figs. 3a and 3b. All the measurement have been performed with an HP 8510 network analyzer, and for the 20 GHz coupler the time domain gate option has been used to avoid the unwanted effects of the connectors. The small discrepance between computed and measured results is due to the edge effects of gating [7]. In order to verify separately the attenuation dispersion and T-junction effects on electrical performance of the couplers the transmission parameters (S_{21}, S_{31}) have been computed introducing the various effects one at a time. Figs. 4 and 5 show the results fo the 20 GHz and 1.66 GHz couplers respectively. Also experimental results are given for comparison.

While the attenuation and dispersion contribution affects mainly the 20 GHz coupler performance, the T-junction effect is already evident at lower frequencies and it is awfully strong at 20 GHz.

SENSITIVITY

A simple analysis of sensitivity has been carried out on the 20 GHz coupler to achieve a better knowledge about the most critical geometrical parameters of the structure. A 5 µm variation has been assumed on the line widths, due to a possible technological error, while a 50 µm shift has been set on the branch lengths.

Taking these variations one at a time into account, the analysis program supplies the results shown in Table 2.

It can be seen that the parameters which have to be got under control are W_{S1}, width of the first branch-line, and L_2, length of the second branch-line.

In fact W_{S1} variation affects considerable both transmission response and return loss, while L_2 uncertainty acts mainly upon reflection response.

However, it should be pointed out that the parameter variations considered in this analysis are the maximum tolerances allowed in thin film technology.

PARAMETER	VARIATION (mm)	RELATIVE VARIATION %	ΔS_{21} (dB)	ΔS_{31} (dB)	ΔS_{11} (dB)
W_{S1}	+ .005 - .005	±25	-0.19 +0.19	+0.17 -0.20	+1.99 -2.67
W_2	+ .005 - .005	±1.7	+ .05 - .06	- .06 + .06	+ .84 - .95
W_{S2}	+ .005 - .005	±3.5	- .04 + .04	+ .05 - .05	- .68 + .63
L_{S1}	+ .05 - .05	±2.6	- .02 0	0 0	+ .96 - .39
L_2	+ .05 - .05	±3.8	- .01 - .01	- .02 + .02	1.59 - 2.3
L_{S2}	+ .05 - .05	±2.6	- .01 - .02	0 + .01	.44 .26

Tab. 2 - S parameter sensitivity versus physical dimension variation of the 20 GHz coupler

CONCLUSION

An optimized synthesis technique for microstrip branch-line couplers, that allows the solution with optimum electrical performance and manufacture feasibility to be achieved, has been presented. The good agreement between computed and experimental results also at very high frequencies proves that a complete coupler model, taking dispersion, attenuation and T-junction effects into account, has to be used.

Introducing these effects separately, it can be seen that the T-junction affects greatly the coupler electrical performance also at low frequencies. This design technique can be used to design also couplers with unbalanced output power levels and asymmetrical topology.

Finally a sensitivity analysis allows the most critical geometrical dimensions of the coupler to be obtained.

REFERENCES

[1] R.Levy, L.Lind: "Synthesis of simmetrical branch-guide directional couplers" IEEE MTT-16, 1968, n. 2, pag. 80-89

[2] M.Muraguchi, T.Yiukitake and Y.Naito: "Optimum design of 3 dB branch-line couplers using microstrip lines" IEEE MTT-31, 1983, n. 8, pag. 674-678

[3] A.F.Celliers, J.A.G.Malherbe: "Design Curves for 3 dB branch-line couplers" IEEE MTT-33, 1985, n. 11, pag. 1226-1228

[4] E.Hammerstad: "CAD of microstrip couplers with accurate discontinuity models" IEEE MTT-5, 1981, pag. 54-56

[5] R.Jansen, N.Kirschning: "Microstrip characteristic impedance" AEÜ, Vol. 37, pag. 108-112, 1983

[6] E.Hammerstad, O.Jensen: "Accurate models for microstrip CAD" IEEE MTT-5, 1980, pag. 407-409

[7] HP 8510 Network Analyzer Operating and Programming Manual Time Domain Measurements

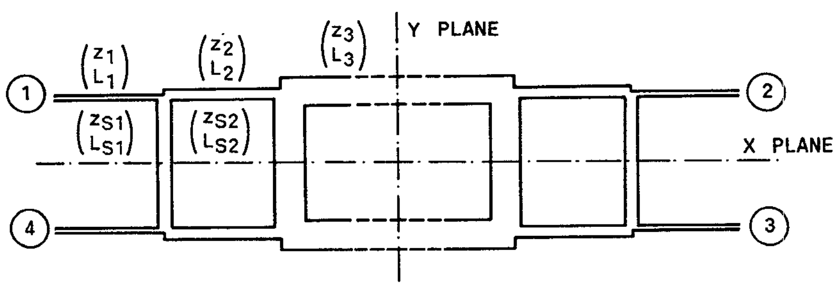

Fig. 1 - Branch-line coupler structure.

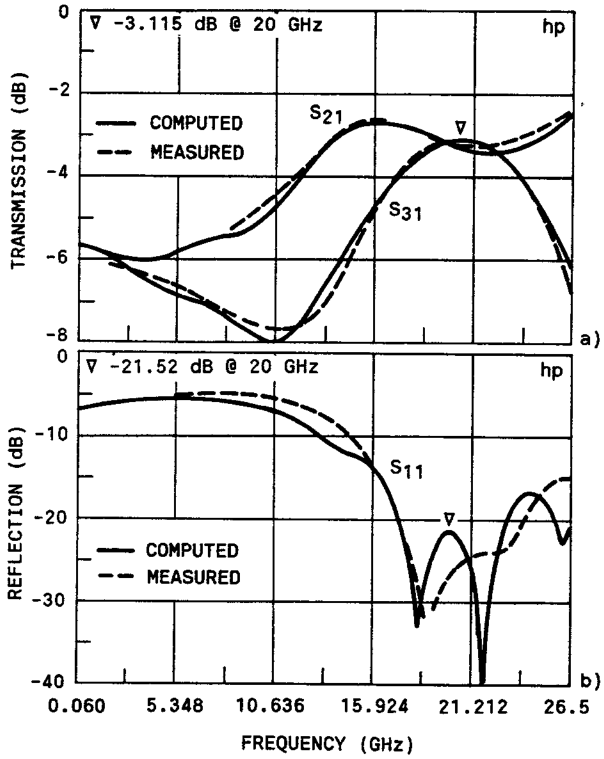

Fig. 2 - Response of the 20 GHz 3 dB coupler.
a) Transmission b) Input reflection.

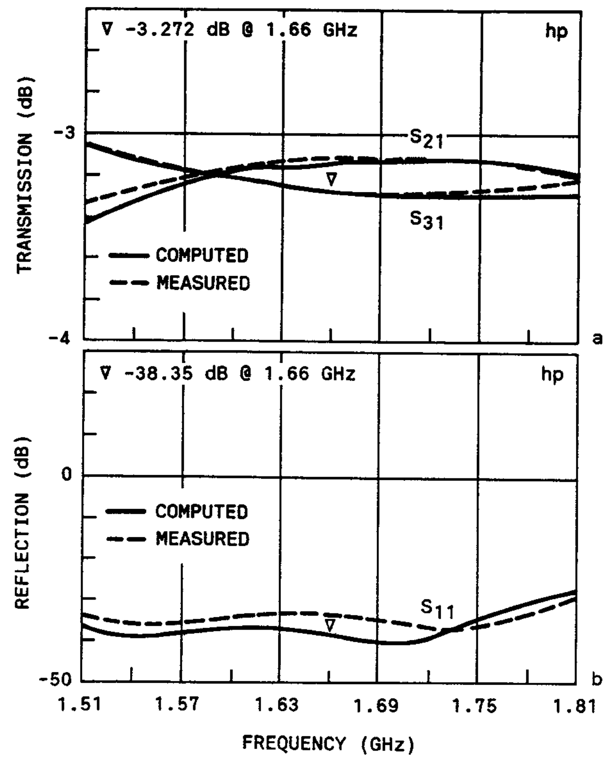

Fig. 3 - Response of the 1.66 GHz 3 dB coupler.
a) Transmission b) Input reflection.

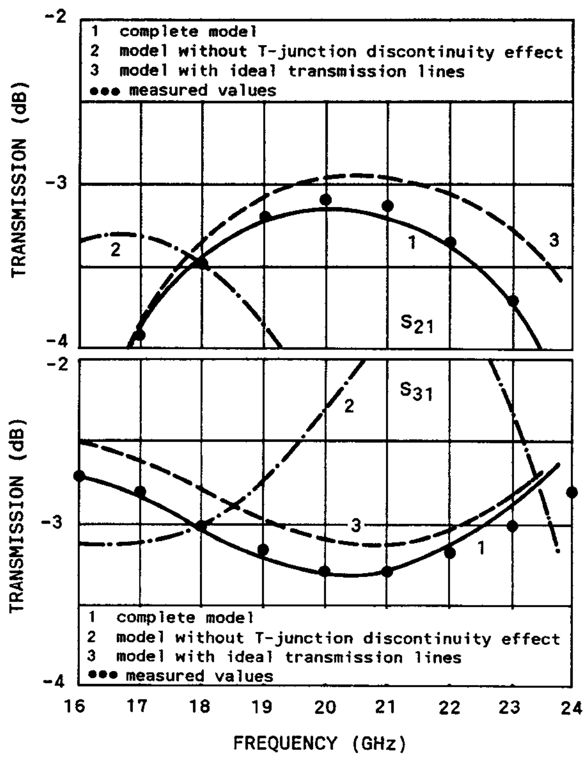

Fig. 4 - Transmission parameters of the 20 GHz coupler.

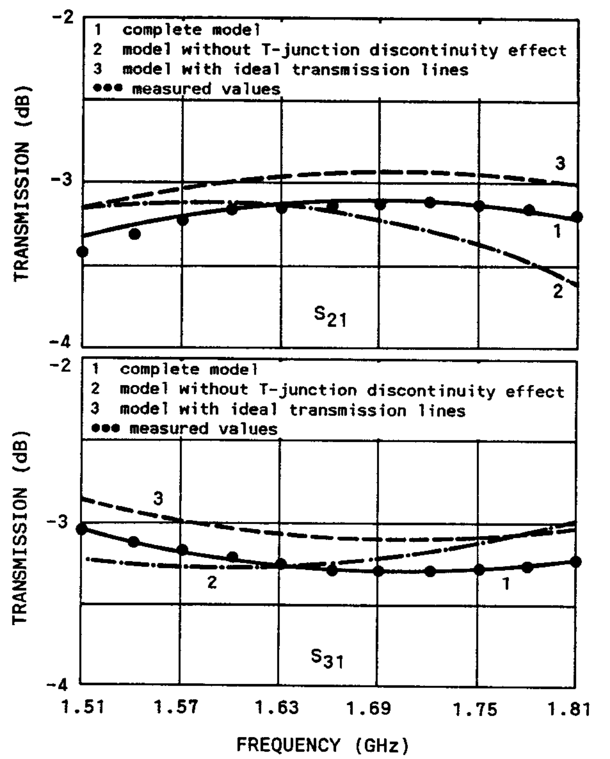

Fig. 5 - Transmission parameters of the 1.66 GHz coupler.