New Coplanar-Like Transmission Lines for Application in Monolithic Integrated Millimeter-Wave and Submillimeter-Wave Circuits

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Abstract

In monolithic microwave integrated circuits (MMICs) for application at millimeter-wave and submillimeter-wave frequencies, new transmission lines with low loss and low dispersion are needed. An additional requirement is that these transmission lines can be produced using conventional MMIC technology. In this paper two new coplanar-like transmission lines which fulfill the above mentioned requirements are analyzed using a finite difference time domain (FDTD) analysis and a quasi-static finite difference method (FD). It will be shown that transmission lines with a low value of the effective dielectric constant, with low dispersion and low losses can be easily produced.

I. Introduction

Microstrip transmission lines exhibit a considerable dispersion at higher frequencies and therefore circuit design at higher frequencies is not easy using these transmission lines. For frequencies above 60 GHz even coplanar waveguides suffer of a certain dispersion and for frequencies higher than 100 GHz new waveguide structures which can be used as a basis for the design of monolithic integrated circuits are desirable. The additional requirement for these new waveguide structures is that they can be produced in a compatible manner as the semiconductor elements which are monolithically integrated into the circuit layout. In this paper two new coplanar-like transmission lines with an elevated center conductor, produced by airbridge technologies, are analyzed and investigated with respect to their applicability for the above mentioned purpose. Using field theoretical analysis techniques it will be shown that these lines show the wanted properties up to highest frequencies.

II. Analysis

The two waveguide structures which are analyzed are shown in Fig. 1. Fig. 1a) and 1b) show a coplanar-like waveguide with an elevated center conductor as it first was proposed for application in sampling circuits and sub-picosecond transmission lines by Bhattacharya et al. [1].

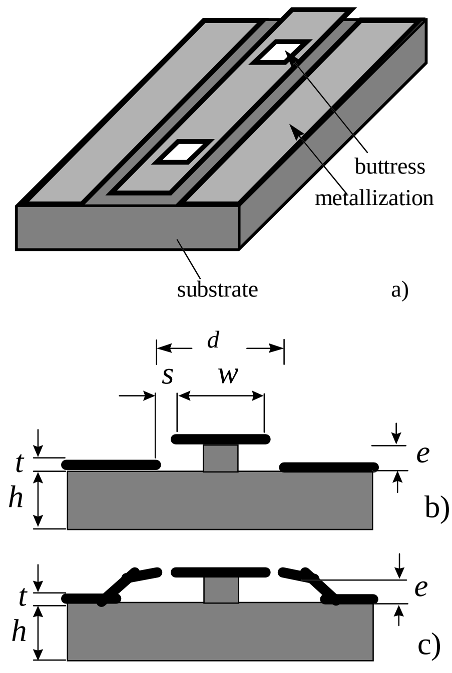

Fig. 1: A quasi-coplanar waveguide a) in a three-dimensional figure, b) cross-section of the line with an elevated center conductor and c) with an elevated center conductor and elevated ground planes.

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Fig. 1c) shows a similar structure where additionally the groundplanes in an area near the center conductors are elevated into the same height as the center conductor. This form of a coplanar waveguide for the first time was used in a similar form as a capacitively loaded waveguide by Koßlowski [2].

Both types of coplanar-like waveguides can be easily produced using conventional airbridge technologies which are normally available in a MMIC production technology. The elevated center strip is carried by buttresses which are placed in a certain distance (10 µm to 200 µm or even larger) under the center strip along the transmission line as shown in Fig. 1a.

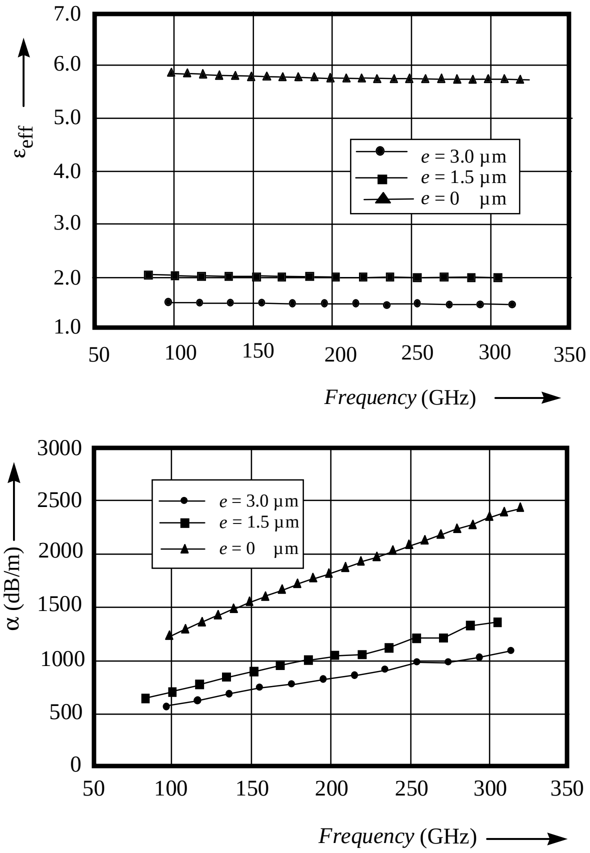


Fig. 2: The effective dielectric constant and the attenuation coefficient of the line structure shown in Fig. 1a/b in dependence on the frequency. Parameters of the waveguide: w = 8 µm, s = 5 µm, t = 2 µm, different elevation heights e = 0, 1.5 and 3.0 µm, substrate GaAs.

The three line structure elements as shown in Fig. 1 have been analyzed using a finite difference time domain (FDTD) technique and a quasi-static finite difference method (FD) to calculate the effective dielectric constant, the characteristic impedance and the losses of these new transmission media.

In a first step, a 2-D FDTD analysis technique [3] and a 3-D FDTD analysis technique [4] was used to analyze the waveguide properties of the line structure shown in Fig. 1a for very high frequencies and for different elevation heights of the center conductor. The results are shown in Fig. 2a and 2b.

Fig. 2a shows that the effective dielectric constant of the special waveguide under consideration (see figure inscription) is reduced considerably if the height of the center conductor above the substrate is 3 µm, a value which can be easily realized. The figure also shows that the effective dielectric constant is nearly frequency independent up to highest frequencies. The losses of the waveguide are reduced by a factor two to three compared to the conventional coplanar waveguide due to the smaller current densities in the edges of the center conductor, as can be recognized from the FDTD analysis (see Fig. 4).

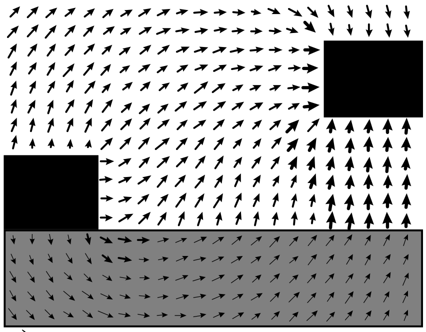
Due to the above mentioned results it appears that the line properties also can be analyzed using a simple quasi-static finite difference method (FD). A comparison between the results of the FDTD analysis and a FD calculation for the same line used in Fig. 2 shows (Table 1) that both results are nearly identical

Elevation	*Parameter*	FD	FDTD	*Diff.*
e = 3 µm	ε_{eff}	1.451	1.452	0.044%
	Z_0/Ω	84.73	84.92	0.22%
e = 0 µm	ε_{eff}	5.57	5.58	0.16%
	Z_0/Ω	41.37	41.43	0.14%

Table 1: Comparison of a FD- and a FDTD-analysis of a waveguide as shown in Fig. 1a. Parameters of the waveguide: w = 8 µm, s = 5 µm, t = 2 µm, elevation height e = 3 µm, substrate GaAs.

and therefore the much simpler quasi-static analysis is well suited for analyzing the complex structures shown in Figs. 1b and 1c.

Fig. 3 shows the distribution of the electric and the magnetic field in a waveguide structure defined in Fig. 1b. Similar results are available for the structure shown in Fig. 1c. From the field distributions of waveguide structures with different line parameters it may be recognized that with decreasing center conductor width a large part of the electric field is concentrated in the air region between the ground planes and the center conductor. In the case of a waveguide with a large center conductor width a considerable part of the field is concentrated under the center conductor which increases the effective dielectric constant with increasing width *w*.


a)

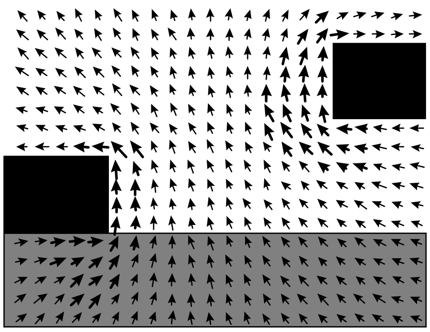

b)

Fig. 3: The electric (a) and the magnetic (b) field distribution between groundplane and the elevated center conductor for a waveguide as shown in Fig. 1b.

As is shown in Table 2, the influence of the buttress under the center conductor leads to an increase of the effective dielectric constant and therefore has a similar influence as a capacitance at the position of the buttress. Using this result for the structures with and without buttresses, a waveguide model can be easily created which describes this new waveguide structure under consideration of the distributed buttresses. Also Table 2 shows that a large range of characteristic impedances can be realized using this coplanar-like waveguide.

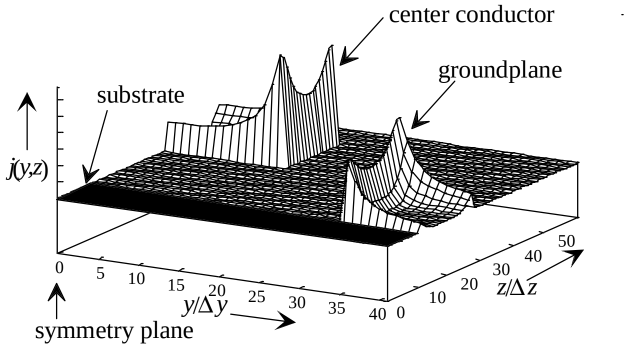


Fig.4: Surface current density distribution in the center conductor and the ground conductor of the coplanar waveguide with elevated center conductor.

w/µm	w/d	b_b/ µm	with buttress		without buttress	
			ε_{eff}	Z_0/Ω	ε_{eff}	Z_0/Ω
10	0.08	4	4.960	96.93	2.577	138.0
24	0.2	6	4.472	76.38	3.009	93.77
36	0.3	6	4.257	68.07	3.218	78.59
50	0.41	10	4.247	58.95	3.342	66.65
60	0.5	10	4.107	54.32	3.375	60.06
72	0.6	10	3.935	49.17	3.358	53.31
84	0.7	10	3.731	44.19	3.276	47.23
100	0.83	10	3.332	37.06	3.009	39.02

Table 2: The effective dielectric constant and the characteristic impedance of a waveguide as shown in Fig. 1c for varying parameters. Substrate: GaAs, h = 350 µm, d = 120 µm, e = 3 µm, t = 3 µm. b_b = buttress width.

The dependence of the effective dielectric constant and the characteristic impedance of the waveguides shown in Fig. 1c with and without buttresses on the *w*/*d*-ratio is shown in Fig. 5a and Fig. 5b, respectively. It may be recognized that the buttresses have a large influence especially on the effective dielectric constant dependence. For small values of the *w*/*d*-ratio and with the buttress-dimensions given in Table 2, the effective dielectric constant of the waveguide with buttress is increasing strongly. Vice versa the effective dielectric constant of the waveguide without buttress is decreasing.

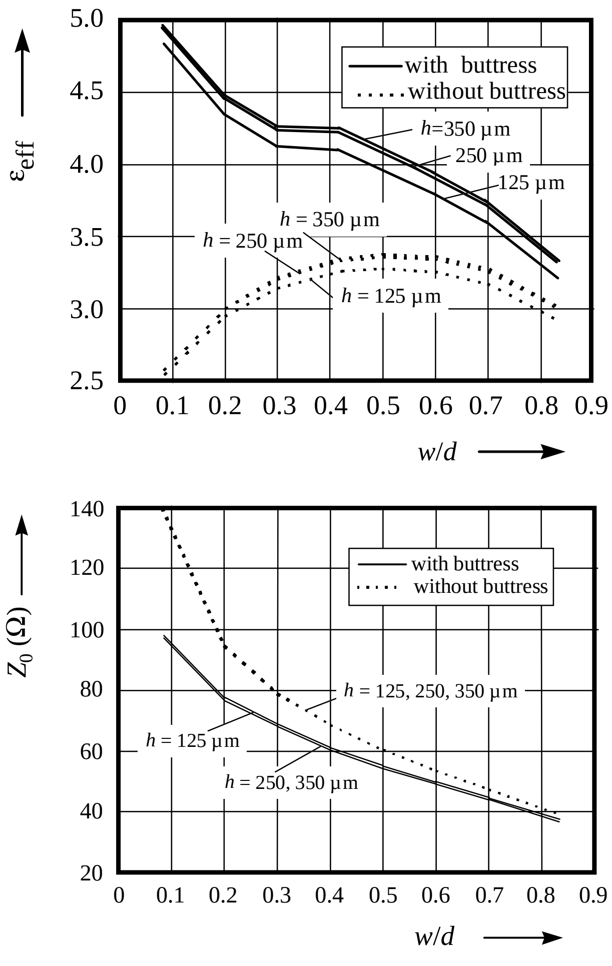


Fig. 5: The effective dielectric constant and the characteristic impedance of waveguide the structure shown in Fig. 1c. Waveguide parameters as given in Table 2, substrate GaAs.

The influence of the substrate height on the effective dielectric constant may be recognized from Fig. 5a). For substrate heights larger than 200 µm it may be neglected. The influence of the substrate height on the characteristic impedance (Fig. 5b)) is nearly not recognizable.

III. Summary

The investigations shortly described above show that the new coplanar-like transmission lines which have been discussed are good candidates for designing millimeter-wave and submillimeter-wave monolithic integrated circuits. They have a low effective dielectric constant which enlarges the dimensions of the circuit elements at these high frequencies, the losses are reduced. Additionally the dispersion of the line properties is low so that circuits can be designed in a quasi-static manner even at submillimeter-wave frequencies. The technology to produce these lines are compatible with the standard MMIC production technique. Comparisons to measured results will be presented in the presentation at the conference.

IV References

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