MULTICONDUCTOR PLANAR TRANSMISSION-LINE STRUCTURES FOR HIGH-DIRECTIVITY COUPLER APPLICATIONS

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ABSTRACT

The spectral domain technique is used to analyze multiconductor printed transmission-line structures containing layered dielectric substrate. Starting from general analytical formulation a useful modification of the procedure is suggested for accurate description of multiconductor interdigitated microstrip circuit with equally dimensioned conductors. Frequency dependent numerical results for some new microstrip and coplanar structures with more than two coupled lines are shown and discussed with respect to high-directivity multiconductor coupler applications.

INTRODUCTION

In recent years, an increasing interest has been observed in the field of accurate description of the behaviour of multiconductor printed transmission-line systems (1-5). This problem takes important place not only in microwave engineering but also in high-speed computer units using microstrip or coplanar strip-lines as a transmission paths for logic information signal (5). For microwave circuitry the knowledge of the transmission behaviour of various multiconductor printed lines is needed to indicate theoretical limitations in the designing of topology of MIC and MMIC layouts /with respect to the prediction of the possibility of the greatest density packaging/ as well as to determine transmission property of novel composed waveguiding structures.

The effect of coupling between nonadjacent lines and propagation characteristics of various multimode systems of edge-coupled conductors with single-layer substrate have already been reported in literature (1-5). The transmission behaviour of layered lines, however, is generally not exactly explained to date. Recently, it was shown that frequency characteristics of three-line microstrip directional coupler can be remarkably improved for both interdigital (6) and three-mode (7) operation. In this paper, therefore, some new alternative microstrip and coplanar structures filled with combined double-layer dielectric substrate are considered for possible application in high-directivity multiconductor coupler design.

In the calculations, the spectral domain technique /SDT/ is used to provide phase constant characteristics of various multiconductor-line structures. This method, comparing with other realisations, has not necessarily lead to unacceptable increase of analytical complexity in case of multimode systems even with multilayered substrates and always results in the well-known set of coupled algebraic equations easily and efficiently solved by numerical techniques.

REMARKS ON ANALYTICAL PROCEDURE

Comparing various realisations of the SDT one can conclude that the most important and sensitive stage of this method lies in the proper choice of the analytical description of unknown field-quantities at the nonuniform boundary-condition cross-sectional interfaces interrelated by the spectral domain Green's function components involving the associated hybrid-mode boundary-value problem. The latter, in case of layered dielectric media, can be directly and simply obtained by inspection of equivalent transverse transmission-line circuits for TE- and TM-waves (8). Although, from the theoretical point of view we have always two possible descriptions of the transmission-line, in terms of impedance or admittance matrices of spectral Green's function components, in practice the manner of analytical description is determined by variables defined over finite intervals in space-domain (4),(9) to avoid unnecessary computational effort.

In order to analyze general nonsymmetrical structures the unknown field-quantities are expanded in double-closed series-type representation in terms of assu-

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med set of known expansion functions(1), (9). This procedure, however, may be too complicated in many practical cases when the symmetry with respect to vertical mid plane exist or the knowledge of only some chosen modes of the structure is required as the resulting dimensions of a uniform system of homogeneous equations to solve are increased linearly with both the number of lines and of expansion functions used in the calculations. In this case, the method can be significantly improved allowing more efficient numerical calculations of various multiconductor printed line structures like, for example, interdigital microstrip circuit with two fundamental modes corresponding to magnetic wall in the plane of symmetry in structures with odd number of strips and to magnetic and electric wall in these with even (10), respectively. Assuming equally dimensioned strip and spacing slot widths relatively simple for numerical implementation functional factors appearing in the spectral representation of the expansion functions are obtained:

$$F_{q-e} = \begin{cases} \sum_{n=1}^{\frac{N}{2}} \cos\left[(2n-1)\alpha \frac{s+w}{2}\right], & N-\text{even} \\ 1+2\sum_{n=1}^{\frac{N-1}{2}} \cos\left[n\alpha(s+w)\right], & N-\text{odd} \end{cases}$$

$$F_{q-o} = \begin{cases} \sum_{n=1}^{\frac{N}{2}} (-1)^{\frac{N}{2}+n} \sin\left[(2n-1)\alpha \frac{s+w}{2}\right], & N-\text{even} \\ (-1)^{\frac{N-1}{2}}+2\sum_{n=1}^{\frac{N-1}{2}} (-1)^{\frac{N-1}{2}-n} \cos\left[n\alpha(s+w)\right], & N-\text{odd} \end{cases}$$

with subscripts q-e and q-o corresponding to quasi-even and quasi-odd mode, respectively, α - being the Fourier transform variable and N the number of strip conductors. Thus, arbitrary system of N equally dimensioned interdigital microstrip lines can be exactly analyzed even with matrices 2×2 if expansion functions are correctly chosen.

NUMERICAL RESULTS

In this section exemplary obtained results of normalized to the free-space wave number phase constants of various microstrip and coplanar structures with double layer dielectric substrate are shown and briefly discussed. These structures, due to the possibility of the compensation of phase velocities of propagating fundamental modes are especially intended for high-directivity coupler application. The presentation, therefore, is oriented on phase-velocity equalization effect and the methods to achieve this. In numerical calculation the series of sine and cosine functions with Maxwell term have been used as the expansion functions which are proved to be very efficient in many similar field-theory problems.

In Figs. 1, 2 and 3 characteristics of three-line microstrip and coplanar structures resulting from general analytical formulation are shown versus relative dielectric permittivity of lower substrate layer. The first structure - coupled coplanar strip-lines /C-CPS/, can be treated as two edge-coupled slot lines with finite ground planes and designed as typical four port device. The remaining two structures illustrated in Figs. 2 and 3 may be used both as four- and six-port devices. Microstrip version should provide better frequency behaviour due to the smaller differences between permittivities required for the equalization of any two modal phase velocities.

Fig. 4 presents characteristics of interdigital microstrip structure which are obtained in terms of suggested modification of SDT. The plotted curves show that single layer network does not provide the decrease of phase velocity ratio with increasing N. The use of layered substrate results in the equalization of two modal phase velocities. This technique is especially suited for the interdigital structure as the use of crossovers does not allow the efficient use of an overlay techniques commonly employed in conventional two-line microstrip couplers.

REFERENCES

(1) B.Janiczak,"Behaviour of guided modes in systems of parallelly located transmission lines on dielectric substrates", Electron. Lett., 19,1983, pp.778-779

(2) H.Lee,V.K.Tripathi:"New perspectives on the Green's function for quasi-TEM planar structures",IEEE MTT-S Digest,1983,pp.571-573

(3) S.B.Worm,R.Pregla:"Hybrid mode analysis of of arbitrarily shaped planar microwave structures by the method of lines, Vol.MTT-32, pp.191-196

(4) H.Lee,V.K.Tripathi:"Generalized spectral domain analysis of planar structures having semi-infinite ground planes",IEEE MTT-S Digest,1984,pp.327-329

(5) C.Chan,R.Mittra:"Spectral iterative technique for analyzing multiconductor microstrip lines",ibid.,pp.463-465

(6) K.Shibata,H.Yanagisawa,Y.Ishihata:"Three-line microstrip coupler with dielectric overlay",Electron. Lett.,19,1983,pp.911-912

(7) B.Janiczak:"Accurate hybrid-mode approach for computing modes in three-line coupled microstrip structure in overlaid configuration",ibid.,20,1984,pp.825-826

(8) T.Itoh:"Spectral domain immitance approach...", Vol.MTT-28,1981,pp.352-355

(9) B.Janiczak:"On the analysis of multimodes...", Mikrowellen Magazin,Vol.10,1984,pp.157-165

(10) Y.Tajima,S.Kamihashi:"Multiconductor couplers", Vol.MTT-26,1978,pp.795-801

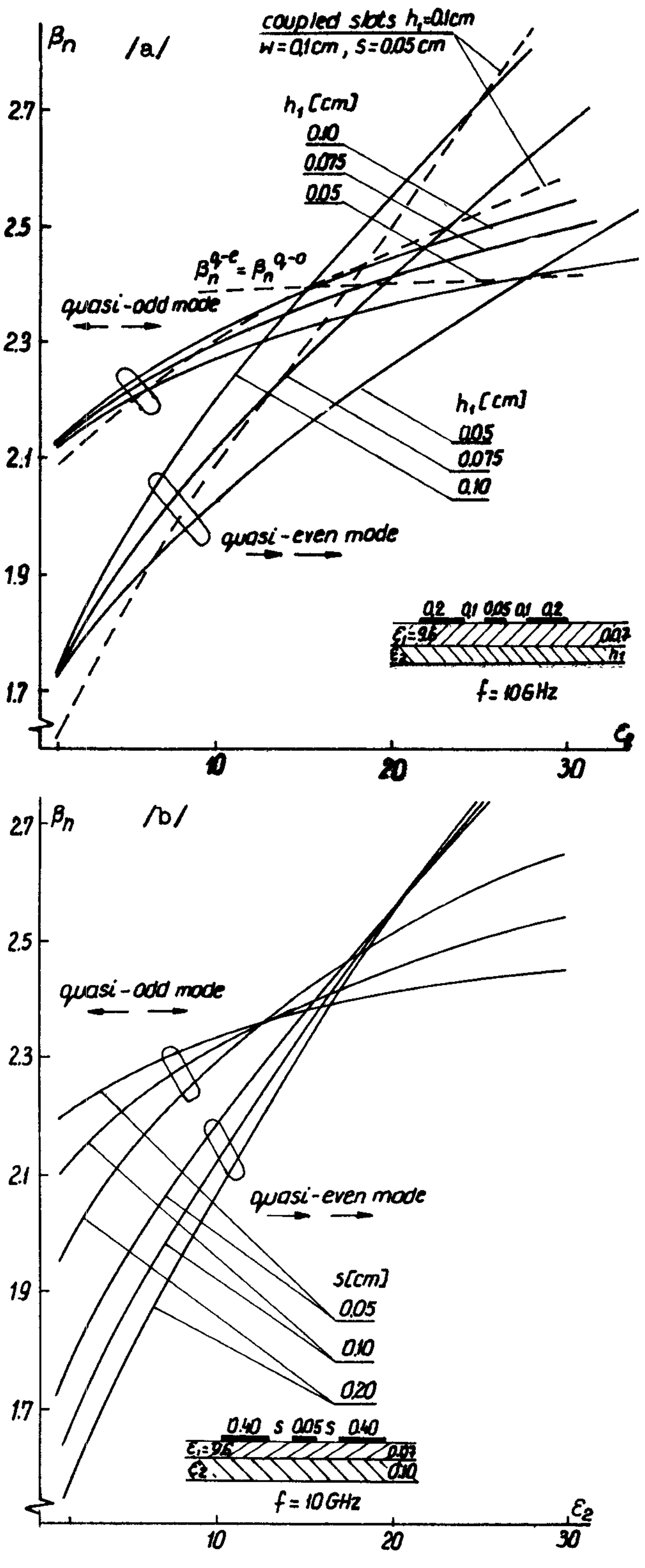

Fig.1 - Characteristics of two modal phase constants of double-layer C-CPS versus the permittivity of lower substrate layer with the thickness of lower layer /a/ and spacing slot width /b/ as a parameter

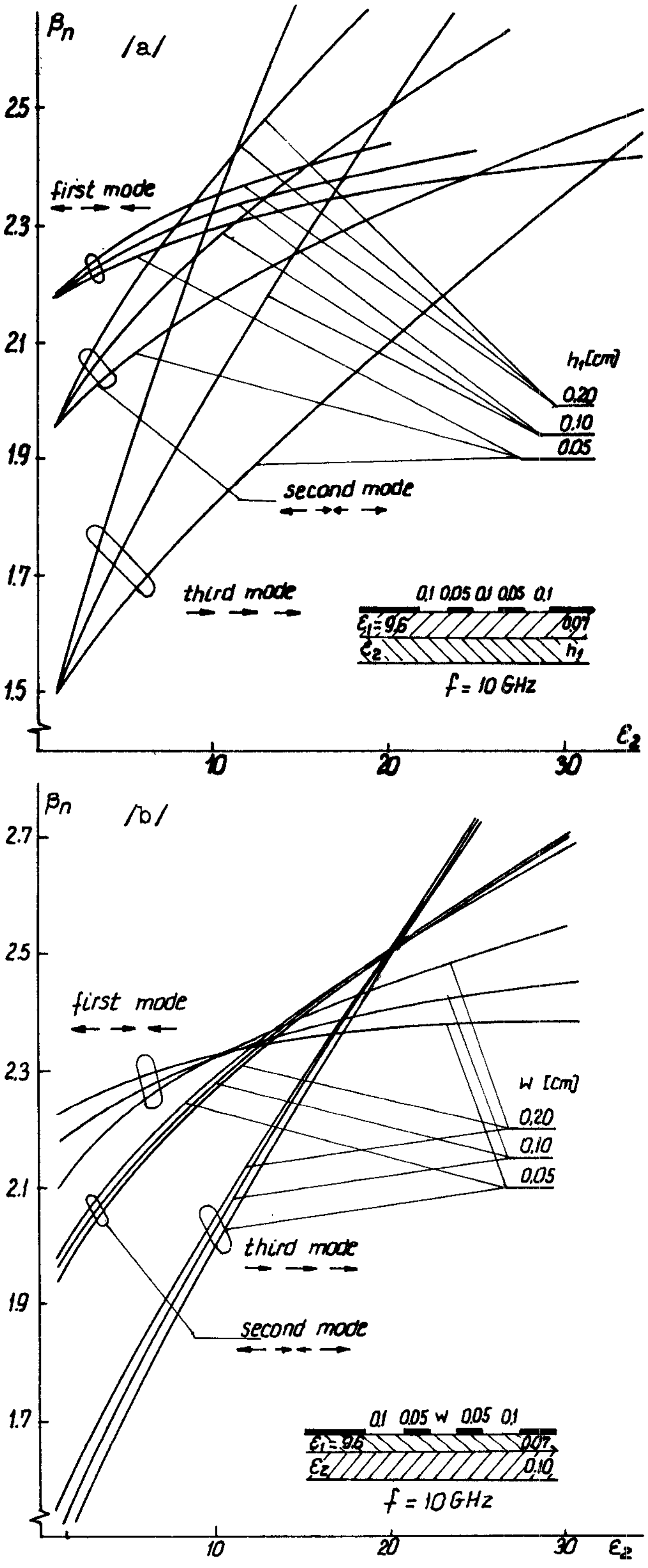

Fig.2 - Behaviour of the modal phase constants of three coupled slot lines with double-layer substrate versus permittivity of lower layer with the thickness of the lower layer /a/ and center slot width /b/ as a parameter

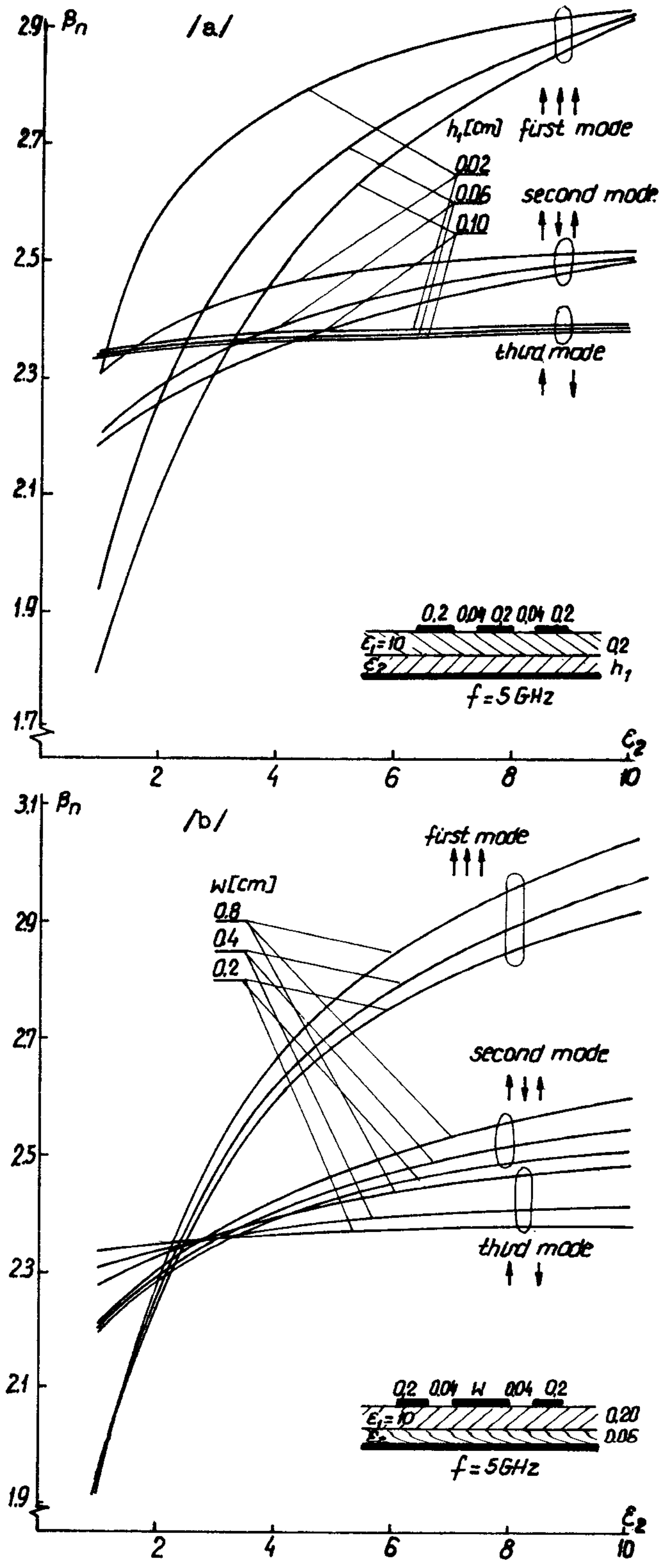

Fig.3 - Phase constant characteristics of three-line coupled microstrip structure in double-layer configuration versus permittivity of lower layer with the thickness of the lower layer /a/ and center strip width /b/ as a parameter

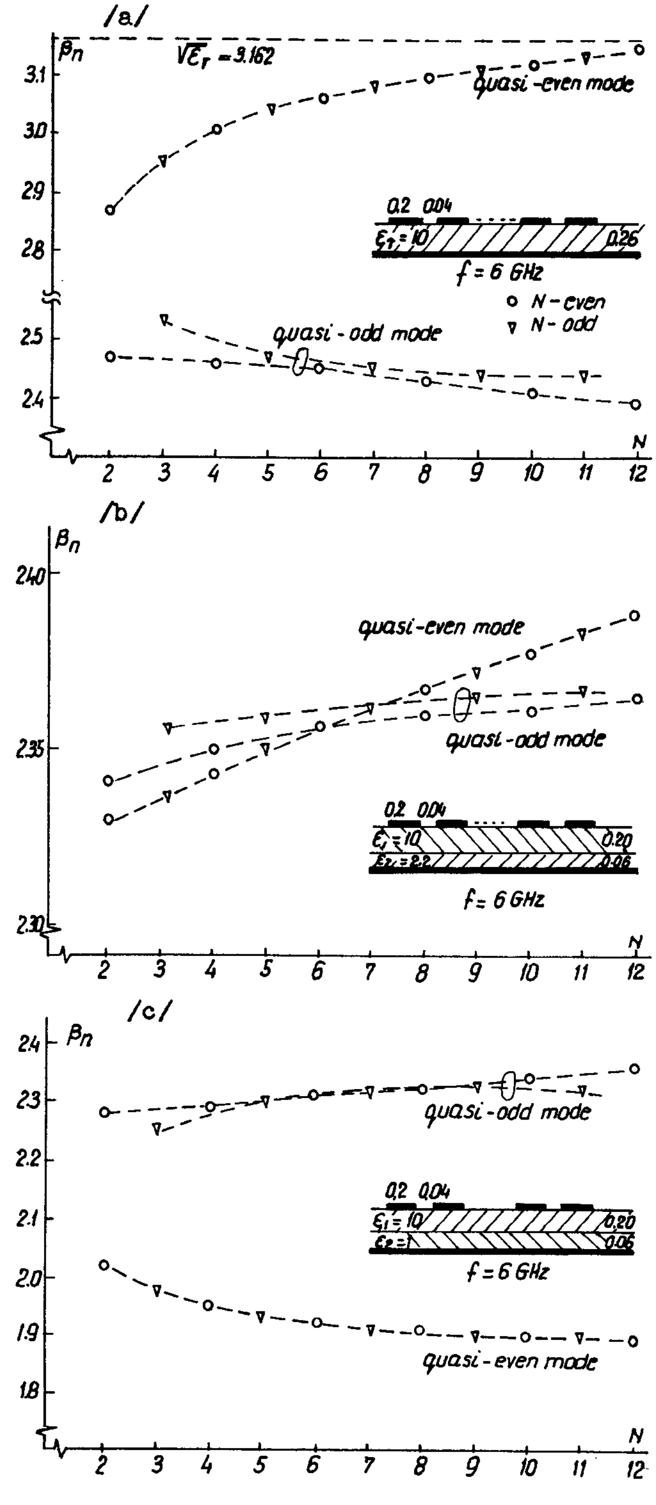

Fig.4 - Characteristics of the quasi-even and quasi-odd mode of interdigital microstrip structure versus the number of coupled strip conductors for single /a/, double /b/ and suspended /c/ substrate