the performance is clearly improved in both bandwidth and loss characteristics in the final synthesis.

IV. Conclusion

As part of our effort in developing the microwave planar circuit theory, we have demonstrated a fully computer-aided synthesis of a planar circulator for wide-band operation. As a result, a circulator better than a six-sided (irregular hexagonal) circulator is synthesized. We believe that the preliminary synthesis of an initial pattern and the evaluation of pattern simplicity make our synthesis reasonable. The optimized circulator performance may be improved by adding external matching circuits to each circulator arm.

We hope the method of synthesis shown in this paper will be useful in the design of a circulator.

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On Mode Classification in Rectangular Waveguides Partially Filled with Dielectric Slabs

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Abstract —**Arguments are given for the designation of the lowest order longitudinal-section magnetic mode in a dielectrically loaded rectangular waveguide as LSM_{01} rather than LSM_{11}.**

Although the theory of dielectrically loaded rectangular waveguides is well established [1], [2], some inconsistency in the classification of the modes still remains. In particular, the lowest order longitudinal-section magnetic mode is designated as LSM_{11} [3], [4] instead of LSM_{01}. The present short paper provides arguments for the latter designation.

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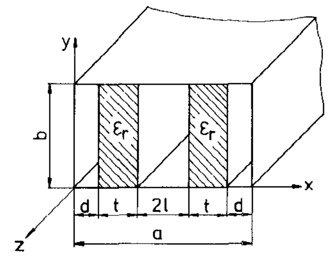

Fig. 1. A configuration under discussion.

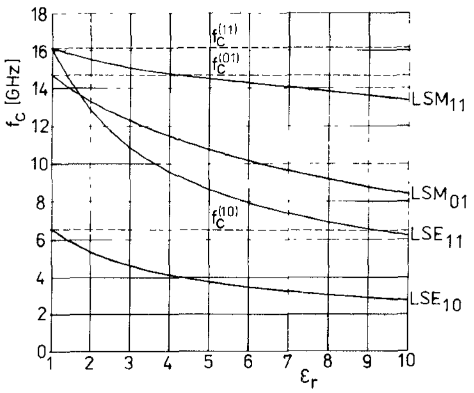

Fig. 2. The cutoff frequencies of several LSE and LSM modes in a waveguide with the dimensions $a = 22.86$ mm, $b = 10.16$ mm, $l = 0$, $2t = 6$ mm.

A typical and fairly general representative of the waveguides under discussion is shown in Fig. 1.[1] The guide can support longitudinal-section electric (LSE_{mn}) and longitudinal-section magnetic (LSM_{mn}) waves. The subscripts m and n are equal to the number of the field variations along the x and y axes, respectively. In an empty waveguide, the field can also be expressed in terms of LSE_{mn} and LSM_{mn} modes; these are, however, appropriate linear combinations of the commonly used TE_{mn} and TM_{mn} modes (transverse to the z axis) with the same subscripts m and n. It is therefore logical to require that the modes in a loaded waveguide be provided with subscripts m and n in such a manner that, approaching $\epsilon_r \to 1$, their field distribution becomes identical with that of equally designated modes in an empty guide. This "correspondence principle" is generally observed for the LSE modes. In a special case of no field variation along the y axis ($n = 0$), the LSE_{m0} modes have the electric field oriented in the y direction and approach the empty guide TE_{m0} modes (transverse to z).

However, it is as a rule not recognized [3], [4] that in the limit $\epsilon_r \to 1$, the lowest order LSM mode[2] becomes the TE_{01} (transverse to z) rather than the TM_{11} mode (a reason for this is probably intuitive connecting the lowest order LSM mode with the lowest order empty guide TM mode, i.e., TM_{11}). Hence, the LSM modes should be classified as

$$LSM_{mn}, \qquad m = 0,1,2,\cdots, \quad n = 1,2,3,\cdots.$$

It is beyond the scope of this paper to provide complete analysis, but a simple numerical example for a single centered slab ($l = 0$) readily confirms the above argument. In Fig. 2, cutoff frequencies

[1] Solution for a waveguide with one assymetrically placed slab, as well as for that with an H-plane slab, can be derived directly from the solution of the waveguide according to Fig. 1.

[2] This mode can be the dominant one for $a < b$ and ϵ_r near to unity.

of various modes are plotted as functions of relative permittivity ϵ_r of the slab (a method for computing the characteristics of the modes with prescribed m and n has been described in [5]). It is seen that when $\epsilon_r \to 1$, the cutoff frequencies of the LSE_{mn} and LSM_{mn} modes approach the empty guide values

$$f_c^{(mn)} = (c_0/2)\sqrt{(m/a)^2 + (n/b)^2}$$

(c_0 is the free-space light velocity). The cutoff frequency of the lowest order LSM mode approaches the value of $f_c^{(01)}$ rather than $f_c^{(11)}$.

It is therefore concluded that the modes in rectangular waveguides partially filled with dielectric slabs should correctly be designated as

$$\text{LSE}_{mn} \qquad m = 1,2,3,\cdots, \quad n = 0,1,2,\cdots$$

(this notation was introduced in [3]) and

$$\text{LSM}_{mn} \qquad m = 0,1,2,\cdots, \quad n = 1,2,3,\cdots.$$

This classification is consistent with that for an empty waveguide in the sense that, in the limit $\epsilon_r \to 1$, the equally designated waves become identical. In particular, the lowest order LSM mode is the LSM_{01}.

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Analysis of Some Planar Structures by the Least-Squares Boundary Residual Method

H. BAUDRAND, M. BOUSSOUIS, AND J. L. AMALRIC

***Abstract* —A new approach is proposed to analyze a large class of planar transmission lines such as shielded edge or broadside-coupled striplines and microslots with or without a ground plane. Calculations are carried out, in quasi-TEM and hybrid modes, by the application of a new variant of the least-squares boundary residual method (LSBRM), which is the basis change that allows one not only to improve the precision but also to reduce the computer memory occupation so that smaller computers can be used.**

I. Introduction

The least-squares boundary residual method is used for the solution of a large variety of boundary value problems. It has been successfully applied to the numerical solution of scattering and electromagnetic eigenvalue problems [1], [2], dielectric waveguides [3], and periodic semiconductor and surface acoustic-wave structures [4], [5]. This method is particularly interesting because of its systematic advantage of not introducing spurious solutions such as occurs when the Galerkin's method is used without the appropriate basis functions [6]. In order to accelerate the convergence of the method, some techniques have been suggested, such as the selection of weighting and scaling factors in the basis functions [1], [2], but usually their determination is not easy. In this paper, we propose a new technique in order to reduce the computation time of the LSBRM where a better precision is obtained at the same time. It consists of changing the basis functions to rectangular pulse functions which define and verify the boundary conditions over only one section of the interface. A similar study has been presented by Jansen, where the basis functions are transformed to other sinusoidal forms [7]. The present work introduces a new concept in the formulation of the basis change by the use of a transformation operator. The pulse functions will represent quantities which are zero over this section, such as the tangential electric field for the microstrip and the charge density for a microslot. Here, we have applied the method in order to determine the propagation characteristics of coupled microstrips and slot lines in quasi-TEM and hybrid-modes, respectively (Fig. 1).

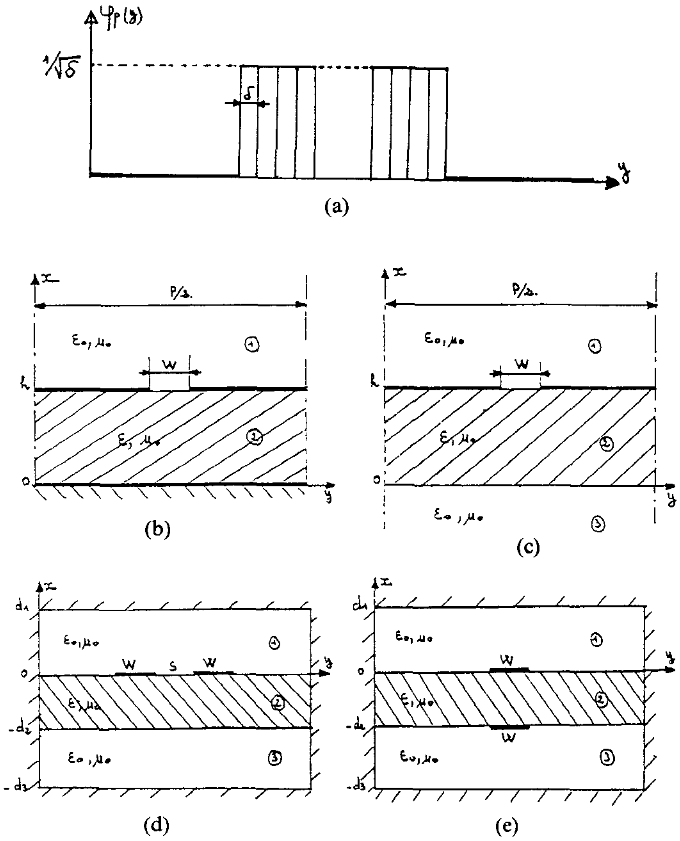

Fig 1 (a) n rectangular pulses representing new basis functions defined in the slot region. (b) Slotline with ground plane (c) Slotline without ground plane. (d) Edge-coupled transmission lines. (e) Broadside-coupled transmission lines.

II. Theory

In this approach, generally the potential of the quasi-TEM wave, or the longitudinal components of the fields in the full-wave analysis, are expanded in space harmonics along the transverse

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