FIN LINE PARAMETERS CALCULATED WITH THE TLM - METHOD

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ABSTRACT

The guided wavelength in fin line is calculated using the Transmission Line Matrix (TLM) method. The resonant frequencies of fin line cavities are evaluated on a computer, yielding the dispersion characteristic of the fundamental and higher order modes of propagation.

Introduction

Various methods for the evaluation of fin-line parameters have been presented by Meier[1], Hofmann[2] Saad and Begemann[3] and Hoefer[4]. In addition, a method for analyzing the transition from fin-line to a below-cutoff waveguide has been reported by Saad and Schuenemann[5]. In the present paper, the application of the Transmission Line Matrix (TLM) technique to the fin line problem is demonstrated for the following reasons:

a) To verify and eventually to refine the various methods mentioned above,

b) To calculate the equivalent lumped element circuit of fin line discontinuities which have not been evaluated to date.

The number of results given in the present paper is rather limited because of the considerable size of memory and the large CPU-time required for the calculation of a given structure.

The TLM - Method

The transmission-line matrix (TLM) method was developed by Akhtarzad and Johns[6] and was applied by these authors to the analysis of three-dimensional resonating structures. The dispersion characteristics of waveguide structures and discontinuities can be obtained by calculating the resonance frequencies of cavities exhibiting the pertinent cross-sectional geometry and containing the discontinuities under investigation. To this end, field propagation in the structure is simulated by the propagation and scattering of impulses in a three-dimensional transmission line lattice characterised by the parameter $\Delta\ell$ (distance between adjacent nodes. Boundaries (electric and magnetic walls) and dielectric interfaces can be simulated by introducing stubs which modify in an appropriate way the impedance across nodes situated at the boundaries or inside the dielectric. Valid results are obtained if the distance between nodes is smaller than $0.1\ \lambda$, where λ is the free-space wavelength corresponding to the resonance frequency of interest. On the other hand, the minimum value for $\Delta\ell$ is limited by considerations of available computer memory.

To start the calculation, one or more nodes (depending on the mode to be investigated) are excited by an impulse. The propagation of the impulses across the three-dimensional network is calculated in real time. After a sufficient number of iterations (forth-and-back trips of impulses across the structure), the impulse response of the structure is picked up at strategic output points, chosen again according to the expected field distribution. Speaking in terms of measurements, the position of the input and output nodes is chosen in the same way as the position of field probes for excitation and detection of modes in a resonator. In the TLM-program, however, the "probes" do not interact with the field and thus are non-perturbing.

From the time domain output, the eigenvalues of the structure in the frequency domain are obtained via Fourier Transform. The number N of iterations must be sufficient to obtain satisfactory resolution in the frequency domain. The finite character of N limits the response in the time domain and thus determines the resolution of maxima and minima in the frequency spectrum.

Features of the Computer Program

The original program published by Akhtarzad[7] has been modified by A. Ros (co-author) and co-workers to gain a factor 5 in CPU-time and a factor 2 in memory size. This has been achieved by incorporating the subroutines into the main program. Still, for the structures calculated in the present paper, considerable memory is required, particularly because fin line structures with relatively thin dielectric and small fin-spacing require at least three nodes within the smallest dimension to yield satisfactory accuracy.

A value of $\Delta\ell = .4$ mm has been chosen for the distance between adjacent nodes. A typical program for a cavity of 20 x 10 x 4 mm requires a memory close to 1 M-octets, and an IBM 360 runs for about 240 CPU-minutes to execute 1000 iterations. These requirements are obviously the major drawback of the TLM-method, but on the other hand, any structure can be handled regardless of complexity of its geometry.

Computations and Results

A rectangular cavity containing a unilateral fin line structure was adopted for TLM computations. Fig.1 defines the parameters of the structure. Resonant modes are characterized, as in empty rectangular cavities, by indices ℓ, m, n representing the number of half-periods in x, y and z direction respectively.

Resonant frequencies were calculated with the TLM-method and compared with results obtained by solving transverse resonant conditions as shown by Hoefer[4]. Several special cases for which exact analytical solutions exist, were chosen to verify the accuracy of the TLM-program.

Since the TE_{10} fin line mode is of particular interest, the c-dimension should ideally be the longest dimension in order to separate it well from the other modes. However, this would require excessive computer memory, and shorter lengths $c < a,b$ had to be chosen.

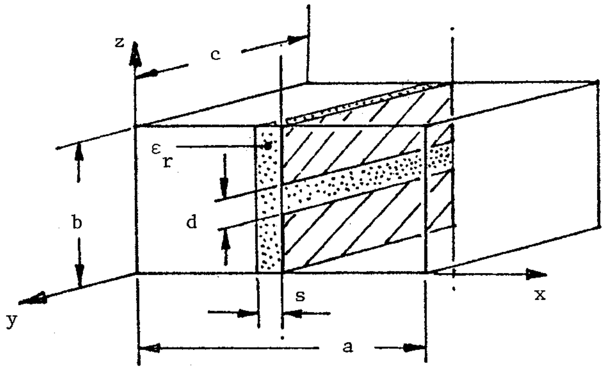

Fig. 1 Rectangular cavity containing unilateral fin line

CONFIGURATION 1: Empty Cavity

a = 20 mm   d = b = 10.4 mm
b = 10.4 mm ε_r = 1
c = 7.2 mm

Mode	Resonant Frequency (GHz) TLM	Exact	Error
TE_{110}	16.22	16.257	-0.2%

Table 1 Resonant frequency of empty cavity. Comparison of TLM and exact solution.

CONFIGURATION 2: Dielectric-Filled Cavity

a = 20 mm   d = b = 10.4 mm
b = 10.4 mm   s = a = 20 mm
c = 7.2 mm ε_r = 2.22

Mode	Resonant Frequency (GHz) TLM	Exact	Error
TE_{110}	10.91	10.911	0%

Table 2 Resonant frequency of dielectric-filled cavity (ε_r = 2.22).
Comparison of TLM and exact solution .

CONFIGURATION 3: Cavity with Dielectric Slab

a = 20 mm   d = b = 10.4 mm
b = 10.4 mm   s = 2 mm
c = 4 mm ε_r = 2.2

Mode	Resonant Frequencies (GHz) TLM	Exact	Error
TE_{101}	33.52	31.866	5.2%
TE_{301}	44.67	41.522	7.6%
TE_{501}	52.40	50.567	3.6%
TE_{102}	59.42	57.673	3 %
TE_{701}	63.39	62.026	2 %

Table 3 Resonant frequencies of cavity with dielectric slab (ε_r = 2.2). Comparison of TLM and exact solutions.

CONFIGURATION 4: Cavity Containing Centered Thin Fins

a = 20 mm   d = 1.6 mm
b = 10.4 mm ε_r = 1
c = 7.2 mm

Mode	Resonant Frequencies TLM	Hoefer[4]	Effective Diel. Constant $\varepsilon_{eff} = (\lambda/\lambda_g)^2$ TLM	Hoefer[4]
TE_{110}	20.63	20.60	n/a	n/a
TE_{101}	23.25	21.473	0.80	0.94
TE_{301}	29.20	27.033	n/a	n/a

Table 4 Resonant frequencies of cavity with centered fins. Comparison of TLM solutions and solutions obtained using transverse resonance conditions. TE_{101} is the fundamental fin line mode.

CONFIGURATION 5: Cavity Containing Unilateral Fin Line

a = 20 mm   d = 1.6 mm
b = 10.4 mm   s = 1 mm
c = 7.2 mm ε_r = 2.22

Mode	Resonant Frequencies TLM	Hoefer[4]	Effective Diel. Constant $\varepsilon_{eff} = (\lambda/\lambda_g)^2$ TLM	Hoefer[4]
TE_{110}	14.49	-	n/a	n/a
TE_{101}	20.19	18.40	1.065	1.282

Table 5 Resonant frequencies of cavity containing unilateral fin line. Comparison of TLM solutions and solutions obtained with method described by Hoefer[4]. TE_{101} is the fundamental fin line mode.

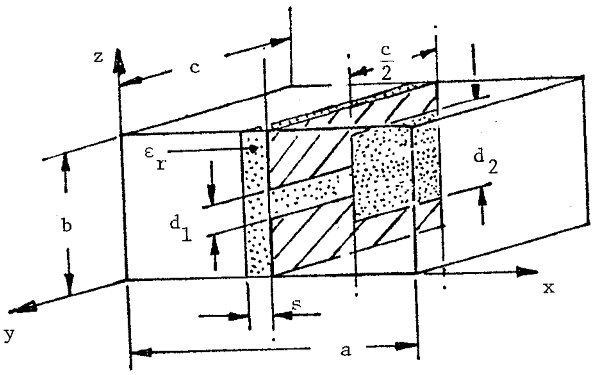

Fig. 2 Rectangular cavity containing a fin line step discontinuity at its centre.

CONFIGURATION 6: Cavity Containing a Fin Line Step Discontinuity at its Centre (See Fig. 2)

a = 20 mm		d_2 = 3.2 mm
b = 10.4 mm	d_1 = 1.6 mm	d_2 = 4 mm
c = 6.4 mm		d_2 = 5.6 mm
ε_r = 1		

Mode	Resonant Frequencies (GHz) obtained with TLM-method			by extrapolation
	d_2=3.2 mm	d_2=4 mm	d_2=5.6 mm	d_2=d_1
TE_{101}	22.82	22.56	21.99	23.40
TE_{102}	45.91	46.13	46.82	45.7

Table 6 Resonant frequencies of cavity containing a fin line step discontinuity. In the TE_{101}-mode, a current node is situated at the discontinuity, while in the TE_{102}-mode, a voltage node occurs at this position. d_1= 1.6 mm.

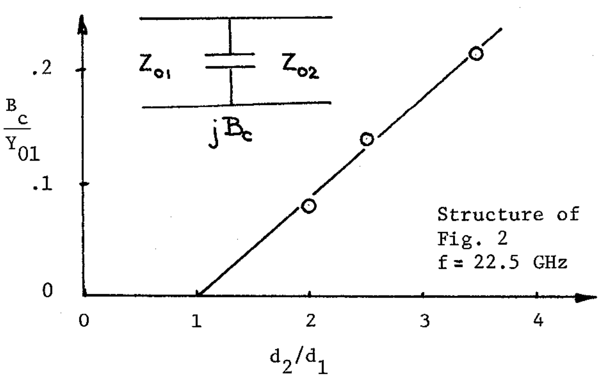

Fig. 3 Equivalent parameters for a step discontinuity of fin line, calculated with the TLM-method.

Fig. 3 shows the calculated equivalent parameters of the discontinuity for the resonant frequency of the fundamental fin line mode TE_{101}, as well as the equivalent circuit itself. The accuracy is estimated to be about ± 10%

Conclusion

The TLM-method yields resonant frequencies of rectangular cavities accurate within ± 0.5%, if the cavities are homogeneously filled with dielectric. In the presence of a centered dielectric slab (ε_r=2.2), the TLM-calculated frequencies are typically 5% too high. If fins are introduced into the cavity, TLM-frequencies are 8% higher than frequencies obtained with formulae for ridged waveguides. Similar discrepancies exist between TLM frequencies for unilateral fin line and frequencies obtained with Hoefer's[4] method. Consequently, the effective dielectric constant ε_{eff} for unilateral fin line is 17% smaller when calculated with the TLM-method. Further study is necessary to determine the reason for these differences.

References

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