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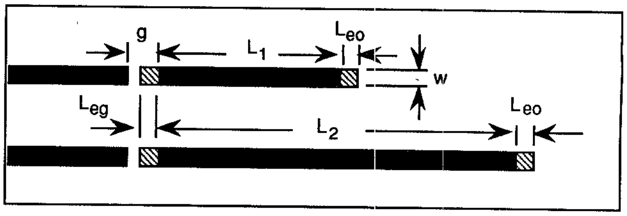

Fig. 1. Gap resonator pair for dispersion measurements. By measuring the resonant frequency of the two resonators end effects can be canceled.

Experimental Evaluation of Existing CAD Models for Microstrip Dispersion

R. A. YORK AND R. C. COMPTON, MEMBER, IEEE

Abstract —**Microstrip dispersion measurements covering a variety of different substrate materials and line impedances were carried out using the gap-coupled resonator pair method. The results were compared against nine microstrip dispersion models. The results indicate two models that are consistently accurate and are therefore recommended for CAD applications.**

I. Introduction

Despite the obvious need, there have been relatively few published measurements of dispersion which have been complete enough to form the basis of a thorough evaluation of the different models. A collection of published dispersion measurements has been compiled by Atwater and compared with various models [1]. However, the errors introduced in extracting data from these published curves are comparable to the errors in the models themselves. With the increasing importance and use of CAD programs, it is necessary to choose from among these models. We have made many measurements of microstrip dispersion, over the range of 1–18 GHz, covering a variety of substrate materials and line impedances. Measurements were made (Fig. 1) using the method of gap-coupled resonator pairs [2].

For convenience, the CAD models chosen for evaluation are designated as follows: Jansen [3], Kobayashi [4], Yamashita [5], Hammerstad [6], Pramanick [7], Getsinger [8], Edwards [2], Carlin [9], and Schneider [10].

II. Experimental Results

Typical measurement results are shown in Fig. 2. The error bars in this figure were calculated using a measurement uncertainty of ± 1 MHz in frequency and ± 0.05 mm in length, corresponding to about 0.8 percent, or ± 0.05 in the measured permittivity. Also given for comparison are calculated effective permittivities using the analysis of Denlinger [11]. In order to compare the various models, a figure of merit was assigned as the average percent difference between the measured data and calculated result.

Extrapolating the measured dispersion curves to zero frequency gave the static effective permittivity $\epsilon_{eff}(0)$, from which

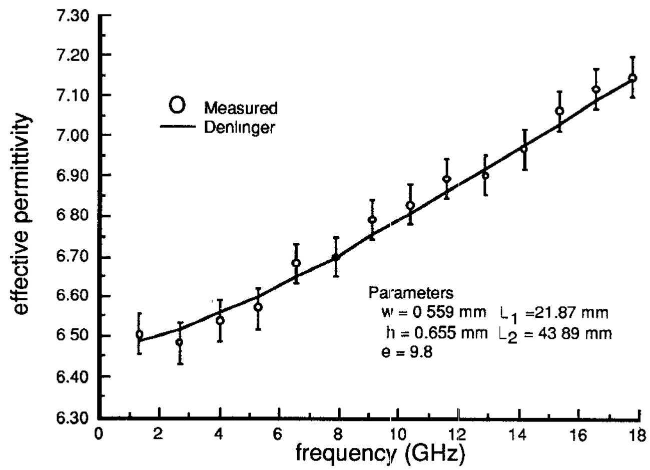

Fig. 2. Typical results of measurement, including theoretical results for comparison. The figure of merit for the Denlinger model in this example is 0.34 percent deviation.

the substrate dielectric constant could be determined. This was important since the substrate permittivity was known to deviate from the manufacturer's specifications.

In all, 18 separate resonator pairs were fabricated and measured, encompassing eight different soft substrate materials and three different line impedances. The physical specifications of each of these are given in Table I. The data were gathered in each case using an HP 8510A and an HP 5343 frequency counter, and the expected experimental error as mentioned earlier was calculated to be $\simeq 0.8$ percent. The models which give the most consistently accurate results are the Jansen [3] and Kobayashi [4] models. In every instance they are within the limits of experimental uncertainty. They yield rms errors of 0.71 percent and 0.73 percent respectively, which are significantly lower than the rms errors of 2.3 percent and 2.5 percent presented in [1]. The larger error values in [1] include errors introduced in retrieving data graphically from published graphs. The Edwards model [2] is fairly consistent also, while the rest show varying accuracy between measurements. A more thorough discussion of the various dispersion models and measurement techniques has been given recently in [12].

III. Conclusions

Several dispersion models have been evaluated in order to select the most promising for inclusion in CAD programs. It was found that the Kirschning and Jansen [3] and Kobayashi [4]

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TABLE I
AVERAGE PERCENT DEVIATION BETWEEN THE MEASURED DISPERSION AND THE MODELS LISTED IN THE REFERENCES

ϵ_r	Thickness	Z_0	[3]	[4]	[5]	[6]	[7]	[8]	[2]	[9]	[10]
9.80	0.655 mm	50Ω	0.51	0.37	1.56	3.14	1.27	0.70	**0.34**	1.41	1.91
9.80	0.655 mm	50Ω	**0.47**	0.55	1.38	2.95	1.69	0.76	0.62	1.83	2.32
9.80	0.648 mm	35Ω	0.38	**0.28**	1.46	3.07	0.94	1.06	0.69	1.85	3.80
9.80	0.648 mm	50Ω	0.39	**0.32**	1.39	2.92	1.50	0.77	0.43	1.69	2 23
9.80	0.648 mm	70Ω	0.56	**0.55**	1.35	3.00	1.89	0.95	0.65	1.44	0.84
9.80	0.668 mm	50Ω	**0.58**	0.84	1.13	2.71	1.99	0.69	0.95	2.16	2 69
9.80	0.668 mm	50Ω	0.54	0.67	1.04	2.54	1.84	**0.51**	0.74	1.95	2.45
9.80	0.635 mm	50Ω	**0.31**	0.32	1.31	2.95	1.60	0.78	0.47	1.80	2.24
9.80	0.635 mm	70Ω	**0.32**	0.32	1.17	2.80	1.81	0.69	0.41	1.50	1.10
2.20	1.605 mm	50Ω	0.56	**0.51**	0.65	1.18	1.99	2.57	0.78	1.87	2 67
2.20	1.605 mm	70Ω	0.52	0.54	0.41	0.88	1.24	2.49	**0.45**	1.61	2.50
2.20	0.780 mm	50Ω	0.56	0.58	0.54	0.48	0.68	1.01	0.53	**0.39**	1.67
2.20	0.780 mm	70Ω	0.53	0.53	0.56	**0.50**	0.56	1.01	0.76	0.51	0 98
2.33	1.524 mm	50Ω	0.48	0.46	0.50	**0.45**	0.81	1.28	0.61	0.99	1.51
2.33	1.524 mm	35Ω	0.46	**0.43**	0.59	0.51	0.77	1.12	0.86	1.17	1.21
2.17	0.686 mm	50Ω	**0.41**	0.42	0.52	0.41	0.80	1.02	0.75	0.50	1.14
2.33	0.787 mm	50Ω	0.53	0.55	0.57	0.45	0.78	1.10	0.71	**0.44**	1.59
2.50	0.762 mm	50Ω	**0.23**	0.27	0.47	0.41	0.71	1.14	0.63	0.37	1.50

The results for 18 different resonators are given, and the smallest deviation for each case is highlighted

models gave the most consistent results for the substrates ($2.2 \leqslant \epsilon_r \leqslant 9.8$) and line impedances ($35\ \Omega \leqslant \epsilon_r \leqslant 75\ \Omega$) that were tested. Caution should be exercised in extrapolating these conclusions to substrates and line widths outside this range [13].

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A New Wire Node for Modeling Thin Wires in Electromagnetic Field Problems Solved by Transmission Line Modeling

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Abstract—A new three-dimensional wire node for the numerical solution of electromagnetic field problems by transmission line modeling has been developed. The wire node can represent thin wires in a coarse mesh, thus substantially increasing computational efficiency. The scattering matrix for the node is given, together with a simulation result and comparisons with another method.

I. INTRODUCTION

Transmission line modeling (TLM) has been applied extensively to the solution of electromagnetic field, diffusion, and network problems [1]. The use of TLM results in algorithms which are easy to understand and can be efficiently implemented. Knowledge of the electromagnetic fields inside structures such as aircraft and vehicles is useful for EMC studies. Usually of more interest is the calculation of voltages and currents induced on thin wires or antennas within such structures.

In practical cases the small size of these wires and the close proximity of metal boundaries can make the modeling of such a

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