A NEW METHOD FOR DISCONTINUITY ANALYSIS IN SHIELDED MICROSTRIP

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Abstract-. A new integral equation method is described for the accurate full-wave analysis of shielded microstrip discontinuities. The integral equation is derived by an application of reciprocity theorem, then solved by the method of moments. Numerical and experimental results are presented for open-end and series gap discontinuities, and a coupled line filter.

I. INTRODUCTION

The development of more accurate microstrip discontinuity models, based on full-wave analyses, is key to improving microwave and millimeter-wave circuit simulations and reducing lengthy design cycle costs. In most applications, radiation and electromagnetic interference are avoided by enclosing microstrip circuitry in a shielding cavity (or housing) as shown in Figure 1. The effect of the shielding is significant, and requires accurate modeling, at high frequencies. Shielding effects are not adequately accounted for in the discontinuity models used in most available microwave CAD software.

To address these inadequacies, a new method was developed for the full-wave analysis of discontinuities in shielded microstrip [2]. This method accurately takes into account the effect of the shielding enclosure. The theoretical contribution, as compared to previous work [3]-[5], is in the novel way that reciprocity theorem, the method of moments, and transmission line theory are combined to solve for discontinuity parasitics. As illustrated in Figure 2, the coaxial feed is modeled using an equivalent magnetic "frill" current [6,7]. To the authors' knowledge, this is the first time that the frill current approach has been applied to microstrip circuit problems.

To demonstrate the method, numerical results are presented for open-end and series gap discontinuities, and a four resonator coupled line filter. These results are compared to other full-wave analyses, to data from *Super Compact* and *Touchstone* [1], and to measurements. The measurements were performed using a variation of the TSD de-embedding technique [8,9].

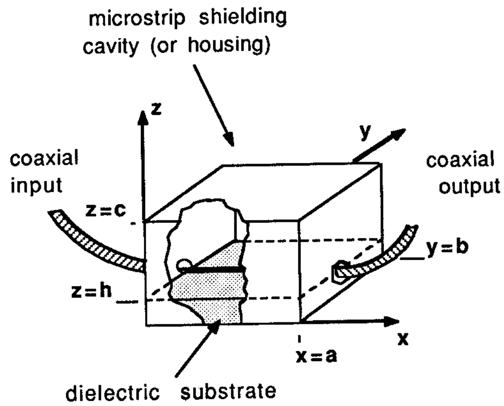

Figure 1: In most practical designs, microstrip circuitry is enclosed in a shielding cavity whose effects must be accurately modeled at high frequencies.

II. SUMMARY OF THEORETICAL METHOD

In the theoretical derivation [2], an application of reciprocity theorem results in an integral equation relating the magnetic current source $\bar{M}_s$, and the electric current on the conducting strips $\bar{J}_s$, to the electromagnetic fields inside the cavity. A Galerkin's implementation of the method of moments is employed by first dividing the strips into N_s subsections. The current is then expanded according to [1]

$$\bar{J}_s = \psi(y) \sum_{p=1}^{N_s} I_p \alpha_p(x) \hat{x} . \qquad (1)$$

[1] *Super Compact* and *Touchstone* are microwave CAD software packages available from Compact Software and EESOF respectively.

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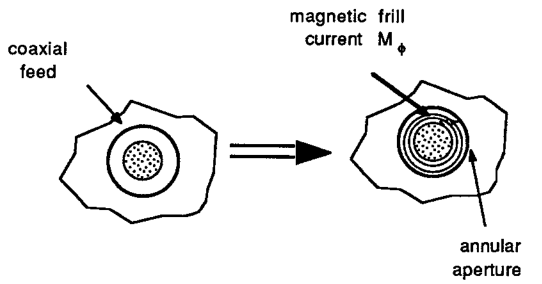


Figure 2: The coaxial feed is represented by an equivalent magnetic frill current $\bar{M}_s = M_\phi \hat{\phi}$; this is used as the excitation mechanism for computing the microstrip current.

where $\psi(y)$ describes the variation of the longitudinal current in the transverse (i.e. y) direction, and $\alpha_p(x)$ are sinusoidal subsectional basis functions.

The resulting equation may be expressed as

$$\sum_{p=1}^{N_s}\left[\int\int_{S_p} \bar{E}_q(x=h)\cdot\psi(y)\,\alpha_p(x)\,\hat{x}ds\right] I_p \;=\; \int\int_{S_f} \bar{H}_q \cdot \bar{M}_s ds \qquad (2)$$

where S_p is the surface area of the p^{th} subsection, S_f is the surface of the coaxial aperture, and $\bar{E}_q, \bar{H}_q$ are the electric and magnetic fields respectively, associated with a test current $\bar{J}_q$ existing over the q^{th} strip subsection.

We may express (2) by the matrix equation

$$[\mathbf{Z}]\,[\mathbf{I}] = [\mathbf{V}]\ . \qquad (3)$$

Here, [**Z**] is the impedance matrix, [**V**] is the excitation vector and [**I**] is the unknown current vector comprised of the complex coefficients I_p.

Finally, after evaluating the elements of [Z] and [V], the matrix equation is solved to compute the current distribution. Based on the current, transmission line theory is used to derive scattering parameters, and (if desired) an equivalent circuit model, to characterize the discontinuity [1,2].

III. RESULTS

An open-end can be represented by an effective length extension L_{eff}, by a shunt capacitance c_{op}, or by the associated reflection coefficient Γ_{op} (= S_{11}). The plot of Figure 3 compares L_{eff} results to those of Jansen et. al. [3] and Itoh [4]. Also shown is the cut-off frequency f_c, which is defined as the lowest frequency where non-evanescent waveguide modes can exist within the cavity. The new results are almost identical to those obtained by Jansen et. al. for frequencies above 8 GHz, but show a reduced value for lower frequencies.

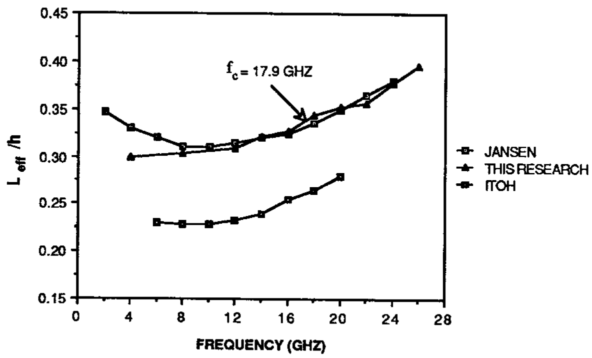


Figure 3: Effective length extension of a microstrip open-end discontinuity, as compared to results from other full-wave analyses (ϵ_r = 9.6, W/h = 1.57, b = .305″, c = .2″, h = .025″).

The results shown in Figure 4 illustrate that shielding effects are significant at high frequencies. The normalized open-end capacitance c_{op} is plotted for three different cavity sizes. The results show that reducing the cavity size raises f_c (as expected), and it lowers the value of c_{op}. For comparison, data obtained from *Super Compact* and *Touchstone* are included.

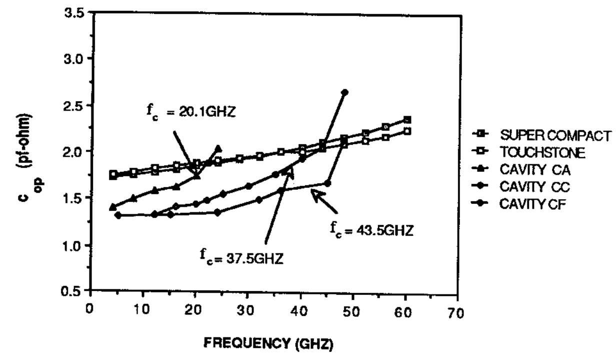


Figure 4: A comparison of the normalized open-end capacitance for three different cavity sizes shows that shielding effects are significant at high frequencies (ϵ_r = 9.7, $W = h$ = .025″; cavity CA: b = c = .25″, cavity CC: b = c =.01″, cavity CF: b = c =.075″).

In the remaining examples, numerical results from the new method are compared to measurements. Figure 5 shows results for the angle of S_{11} of an open-end, and Figure 6 contains results for the magnitude of the transmission coefficient $(/S_{21}/)$ for a series gap discontinuity. In both cases, the agreement between the numerical and experimental data is very good.

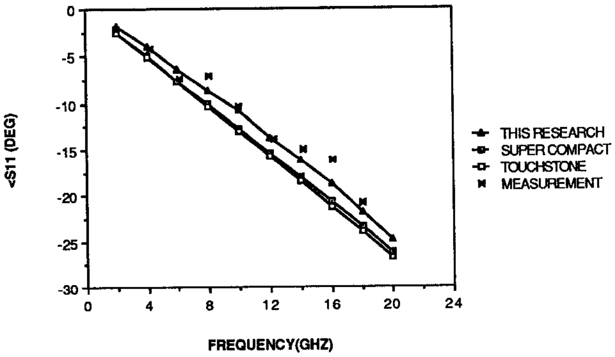


Figure 5: Numerical and measured results show good agreement for the angle of S11 of an open circuit (ϵ_r = 9.7, W = h =.025″, b = c =.25″).

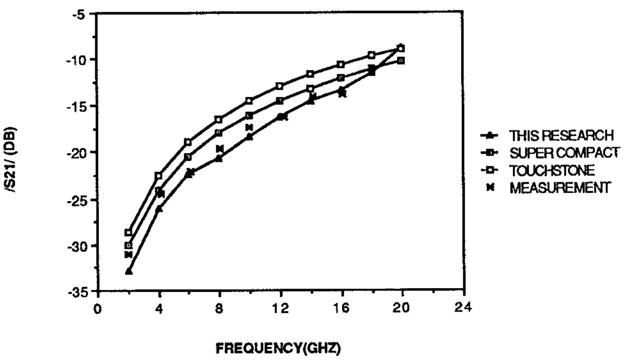


Figure 6: Good agreement with measurements has also been obtained for series gap discontinuities. Shown here is the magnitude of S_{21} for a series gap with a 9 mil gap spacing (ϵ_r = 9.7,W = h = .025″, b = c =.25″).

Finally, consider the four resonator filter of Figure 7. Numerical results for the magnitude and phase of S_{21}, shown in Figure 8, demonstrate excellent agreement with measurements for frequencies below the cutoff frequency f_c. Above cutoff, the filter measurement is distorted due to waveguide moding within the test fixture.

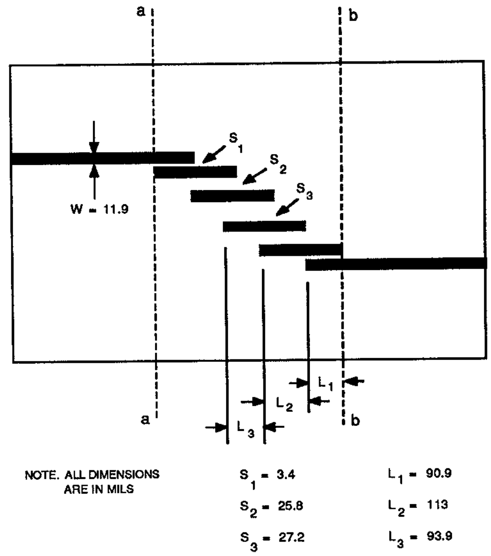
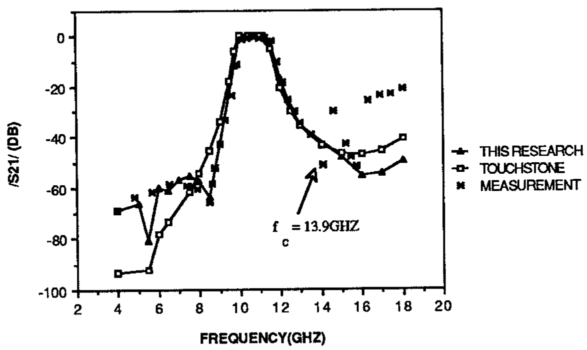
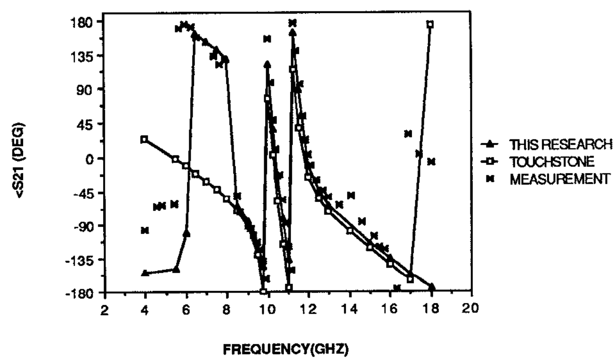


Figure 7: Numerical and experimental results are compared below for this 4 resonator filter (ϵ_r = 9.7, h = .025″, b = .4″, c = .25″).



a. Amplitude of S_{21}



b. Phase of S_{21}

Figure 8: Results for transmission coefficient S_{21} of 4 resonator filter.

IV. CONCLUSIONS

A new analysis method has been described for shielded microstrip discontinuities. Results from this method have demonstrated good agreement with measurements and other numerical results. This method is useful for the evaluation of existing discontinuity models, for the analysis of cases where existing solutions fail –such as when shielding effects are significant–, and for the development of new discontinuity models with improved accuracy for high frequency applications.

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