PROXIMITY EFFECTS OF TRANSMISSION LINE DISCONTINUITIES

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Abstract

The proximity effects of multiple step transmission line discontinuities have been computed by a computer assisted integral equation technique and good agreement with experimental data and exact asymptotic solutions is obtained. New results for typical matching structures and filter geometries are presented.

Introduction

A universal problem in transmission line structures is predicting accurately the interactions of multiple step discontinuities in close proximity. Moreover, these effects are of increasing importance as device complexity and performance increase together with the utilization of higher and wider frequency ranges.

A new approach to the problem is to divide the stepped conducting surface into strips, find the Green's function formulation for any strip, use the Green's function formulation to create a set of linear Fredholm integral equations and numerically solve these equations for charge densities (i.e., capacities) using a digital computer program.

This paper presents the results of applying this technique to yield the proximity effects of both symmetric and unsymmetric step discontinuities for a range of step geometries and separations. Accuracies of better than 6% have been confirmed experimentally and further confirmation is presented for asymptotic solutions for which exact analytical results are available.

Discussion

The problem of finding the discontinuity capacitance for a single step discontinuity has been rigorously solved by conformal mapping and higher order mode expansions.[1-3] A complicated multiple step geometry readily lends itself to solution by integral approximation. With this technique the conducting surface to be analyzed is broken up into several infinitely long strips of width w each carrying an unknown charge density σ. The potential V_k on one of these strips at point P due to all other strips at points Q can be expressed as:

$$V_k = \sum_{j=1}^{N} \frac{1}{W_k} \int_{W_k} \left\{ \int_{W_j} \sigma(Q)\, G(P,Q)\, dQ \right\} dP \, .$$

If the strip widths are small enough to assume the surface charge density is constant on the strip, then $q = \sigma W$ and

$$V_k = \sum_{j=1}^{N} \left\{ \frac{1}{W_k} \frac{1}{W_j} \int_{W_j} \int_{W_k} G(P,Q)\, dP\, dQ \right\} q_j \, .$$

Once this integral expression is evaluated for each strip, the resulting matrix is inverted, yielding the capacitance matrix for the modeled surface.[4]

The capacitance matrix for a particular geometry includes the contributions of all the fields exterior to the conducting surface as well as interior (see Figure 1). To arrive at the discontinuity capacitance C_d the fringing fields C_{f1} and C_{f2} must be separately calculated and subtracted out. $C_{f1} + C_1$ is calculated for a particular geometry by letting $d \rightarrow 0$. At this asymptotic limit C_{f2}, C_2 and C_d all must be zero. C_2 is just the known capacitance between two parallel plates and is directly calculable. C_{f2} is the fringing capacity due to the top of the step and is arrived at by approximating it as the average fringing due to an element of length d/2 on a parallel plate capacitor of length L + d/2 and average height (b + a). The error in this approximation can be made very small, and usually represents an error less than 2% in C_d depending upon b/a and d/a ratios.

Figure 2 shows a plot of discontinuity capacitance versus b/a ratio for the asymptotic case of large d, which is equivalent to two single steps. The exact conformal mapping solution for a single step in plane parallel geometry is also plotted from the formula:[3]

$$C_d = \frac{\epsilon_o}{\pi} \left\{ \frac{1+\alpha^2}{\alpha} \ln\left(\frac{1+\alpha}{1-\alpha}\right) - 2\ln\left(\frac{4\alpha}{1-\alpha^2}\right) \right\} \text{with } \alpha = b/a.$$

Accuracy depends on the number of elements used to model the conducting surfaces and on the aspect ratio L/b. If L is too short, the fringing fields C_{f1} distort the discontinuity capacitance C_d. The range of accuracy is from less than 1% error for small b/a ratios to about 3% for b/a = .9.

Results

For a geometry such as in Figure 1, the net effect of close step proximity is to reduce discontinuity capacitance. This reduction of discontinuity capacitance with decreasing d/a ratio is shown in Figure 3 for three b/a ratios. In each case the discontinuity capacitance is normalized to one for values of d/a approaching infinity. Both curves show a significant reduction in discontinuity capacitance from the single step case for d/a ratios less than one.

The experimental device shown in Figure 4 was constructed in a coaxial APC-7 line of 50 ohms to measure the proximity effect of symmetric discontinuities at microwave frequencies (1.75 to 18.0 GHz). Return loss and reflection phase data were taken on a computerized network analyzer and used to calculate the discontinuity capacitance assuming the circuit model shown. Normalized data taken at 2.5 GHz is shown in Figure 4 which corresponds reasonably with predicted results. However, data taken by the authors at higher frequencies indicate that this simple model breaks down due to the distributed nature of C_d.

The charge distribution for a symmetric, two step discontinuity with a b/a ratio of .3 and d/a ratio of 2.4 is plotted in Figure 5. The fringing field charge distributions on the exterior of the structure have been subtracted out, leaving only the parallel plate and discontinuity charges. It is significant that the maximum charge buildup occurs before the geometric discontinuities (see Figure 5) and that between them the charge is depressed, giving a net inductive effect. Thus, a better circuit model at high frequencies for a step discontinuity would be a short section of line with excess capacitance followed by a section with excess inductance.

More complicated geometries can be analyzed using this integral approximation technique. An example of an unsymmetrical geometry with four step discontinuities is shown in Figure 6. For this case, the discontinuity capacitance variation as a function of the spacing d between the unsymmetrical steps is plotted for step ratios $b_1/a = .5$ and $b_2/a = .75$. Exact values for the asymptotic cases with separation approaching zero and infinity are also plotted. The large variation of capacitance with spacing demonstrates the necessity for compensating this effect with spacing and impedance changes in filter and transformer designs. Charge distribution studies indicate that in this case each step has a different proximity factor. The discontinuity capacitance in the region of the shallow step ($b_2/a = .75$) is depressed much more rapidly with decreasing separation than in the corresponding symmetric case.

Conclusion

A new method for calculating discontinuity capacitance and charge distribution for complex multiple step geometries by the use of an integral equation technique has been presented. This method has been applied to both symmetric and unsymmetric geometries. Good agreement with exact solutions to single step discontinuities for asymptotic cases has been shown. The curves of Figure 3 indicate that for geometries with small d/a ratios a large reduction in actual discontinuity capacitance occurs when compared to the single step cases. Charge distribution indicates that a lumped equivalent circuit model for discontinuity capacity has limitations. An extension of this method to treat inhomogenous dielectrics and more complicated multiple step discontinuities is currently under investigation by the authors.

References

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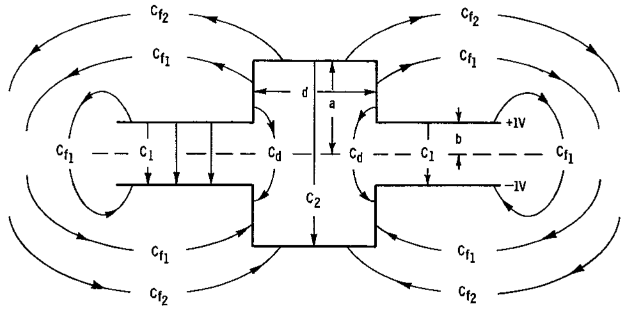

Fig. 1 Geometry for Symmetric Double Step Discontinuity

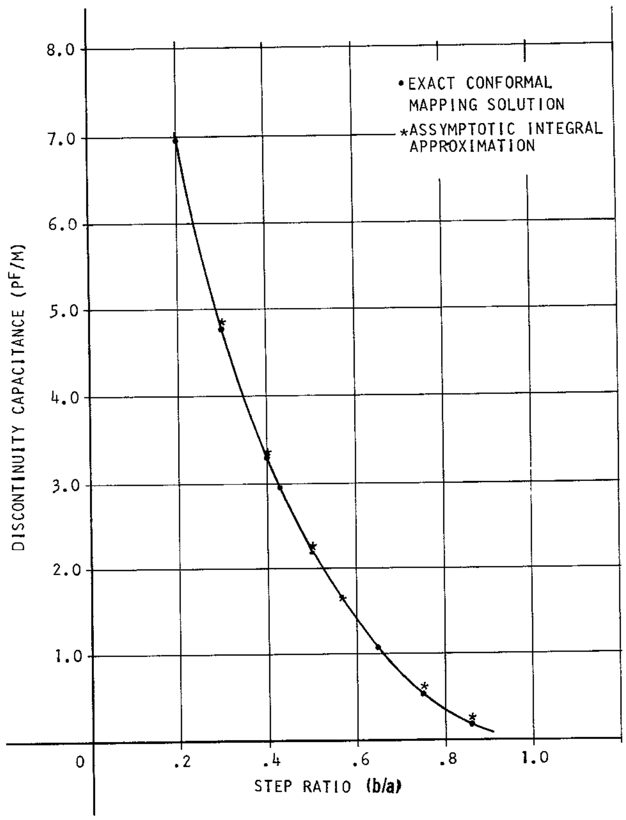

Fig. 2 Step Discontinuity Capacitance

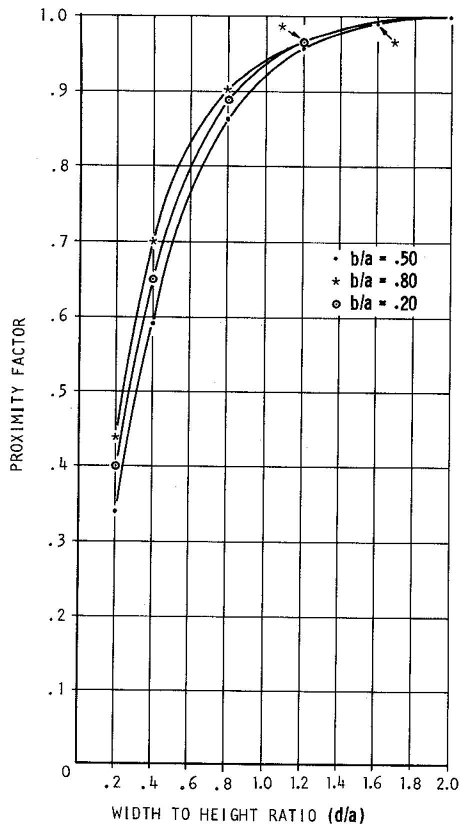

Fig. 3 Proximity Factors for Symmetric Double Step Discontinuity

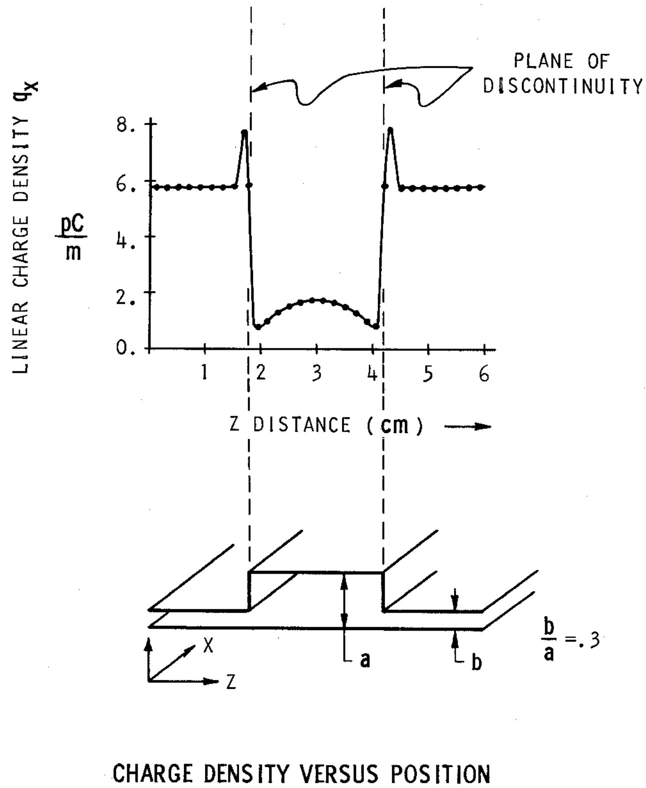

Fig. 5 Charge Density Versus Position for Symmetric Step Discontinuity with Step Ratio of .3

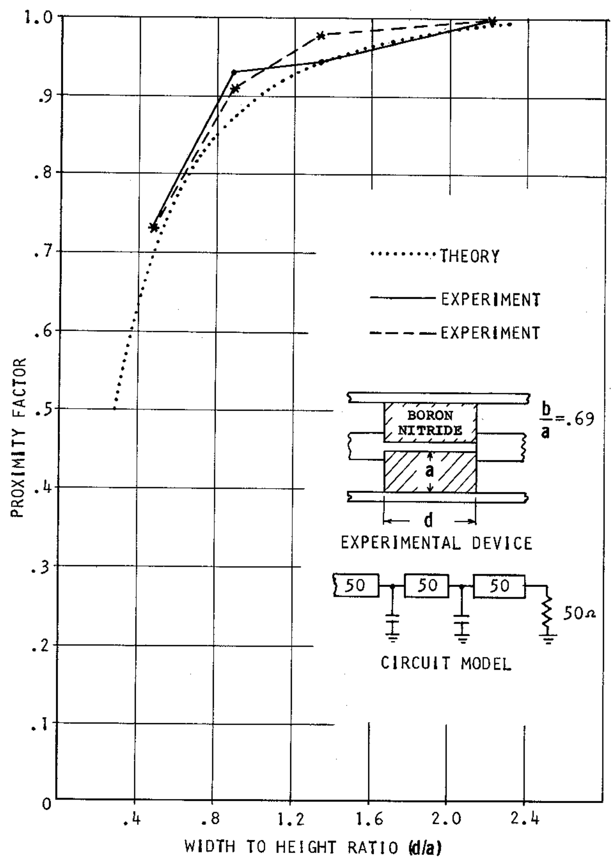

Fig. 4 Experimental Data

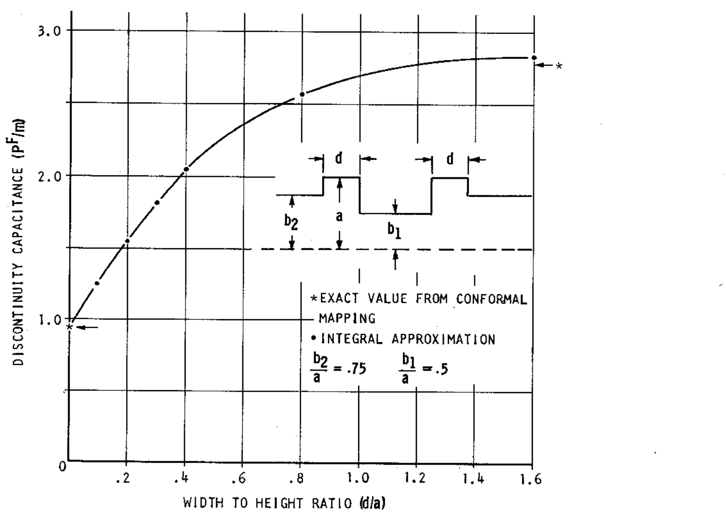

Fig. 6 Proximity Effect for Assymetric Steps