TWO-DIMENSIONAL ANALYSIS FOR STRIPLINE/MICROSTRIP CIRCUITS

K.C. Gupta, Rakesh Chadha, and P.C. Sharma
Department of Electrical Engineering
Indian Institute of Technology
Kanpur-208016, U.P., India.

ABSTRACT

This paper discusses two aspects of two-dimensional circuits at microwave frequencies. First part is intended to emphasize that 2-dimensional planar circuit approach may be used to analyze and optimize stripline circuits. The second part describes a new method called 'desegmentation' which extends the applicability of Green's functions technique for planar circuits.

Stripline Circuit Analysis and Optimization

Stripline circuits contain many discontinuities whose rectances lead to degradation of circuit performance. For computer-aided design, it is necessary to determine accurately the effects of discontinuity reactances and of the presence of higher order modes. Stripline discontinuity models are not very accurate at high frequencies, or when neighbouring discontinuities interact with each other. The concept of two-dimensional microwave planar circuits[1] can be used for analyzing such circuits and for optimizing their design. Green's functions for rectangular, circular, and some of the triangular and sectoral shapes are known[2-5]. The segmentation method[2,6,7] can be used to analyze a 2-d circuit with a shape that is made up of shapes whose Green's functions are known. Z-matrices of various segments are obtained using Green's functions. Portions of outgoing lines from the circuit are also modelled as planar rectangular components to take into account any higher order modes excited by the discontinuity at the circuit ports[7].

T-Junctions

T-junctions appear frequently in stripline circuits. Normally, these junctions have a rectangular geometry. In this paper, it is shown that the use of triangular geometry at the T-junction reduces the effect of parasitics. Two types of T-junctions with impedance ratios 1:1:1 and $1/\sqrt{2}:1:1$ have been studied for this purpose.

For T-junctions with impedance ratio 1:1:1, the widths of three outgoing lines are equal and so a junction using equilateral triangular geometry is investigated. The T-junction using triangular geometry is compared (Fig. 1) with the one using rectangular geometry (both analyzed using 2-d analysis) and it is seen that the triangular junction behaves closer to an ideal junction ($|S_{11}| = 1/3$).

For T-junctions with impedance ratio $1/\sqrt{2}:1:1$, the effective widths (between magnetic walls in planar waveguide model) of the three outgoing lines are in the ratio $\sqrt{2}:1:1$ and so use of a right-angled isosceles triangle (in magnetic wall model) is proposed. Such a T-junction using triangular geometry is compared (Fig. 1) with the one using rectangular geometry and it is found that triangular junction behaves closer to an ideal junction ($|S_{11}| = 0.172$).

Improvement using triangular shaped junctions has been verified experimentally for both the cases.

Power Dividers

In-phase 3-db power dividers[8] use T-junctions with impedance ratio $1/\sqrt{2}:1:1$ and their designs can be improved using right-angled isosceles triangular junctions and 2-d analysis for optimization. Three types of power divider circuits that have been considered are : i) a circuit with single matching section ($Z = Z_0/\sqrt{2}$) on the input side, ii) a circuit with single matching sections ($Z = Z_0\sqrt{2}$) on the output sides, and iii) a circuit with matching section ($Z = Z_0/2^{1/4}$) at the input side and matching sections ($Z = Z_0\, 2^{1/4}$) on the output sides.

Optimization. The matching line sections and portions of line lengths on the 3 outgoing transmission lines are modelled as rectangular planar segments. The lengths of various matching sections for the three types of power divider circuits are optimized to minimize the overall $|S_{11}|$.

To reduce output VSWR, an isolation resistance is connected between the two outgoing lines from the T-junction. The values of resistance and its position are obtained to minimize $|S_{22}|$. Power divider circuits, of the three types mentioned earlier, have been designed at 10 GHz center frequency. The frequency variations of the input and output VSWR's are shown in Fig. 2.

The T-junctions discussed above are also used in circuits like branch-line and ratrace hybrids, SPDT switches, etc. Improved designs for these circuits also be obtained by the same technique. The method is applicable to microstrip circuits also.

Desegmentation Method

As pointed out in the above discussion, planar circuits which can be segmented in regular shapes, for which Green's functions are known, are analyzed by the segmentation method[7]. A new method, called desegmentation, for analyzing planar circuits is discussed here. This method extends the application of the Green's function approach to the circuits which can be extended into regular shapes by adding one or more regular

0149-645X/81/0000-0504$00.75

shapes to them.

This method can be formulated in terms of S-matrices or Z-matrices. As computations in terms of Z-matrices are more efficient, this formulation is discussed here.

Theoretical Formulation

Consider a planar circuit α, as shown in Fig. 3, for which Green's function is not available. The α circuit is extended into a regular shape γ (equilateral triangle) by adding an equilateral triangle β to it as illustrated in Fig. 3. The Z-matrices of β and γ circuits can be evaluated using Green's function[4]. The Z-matrices for α, β, and γ can be, after partitioning into submatrices corresponding to the unconnected and connected ports, expressed as

$$Z_\alpha = \begin{bmatrix} Z_{pp\alpha} & Z_{pc} \\ Z_{cp} & Z_{cc} \end{bmatrix}, \quad Z_\beta = \begin{bmatrix} Z_{dd} & Z_{dq} \\ Z_{qd} & Z_{qq\beta} \end{bmatrix},$$

$$Z_\gamma = \begin{bmatrix} Z_{pp\gamma} & Z_{pq} \\ Z_{qp} & Z_{qq\gamma} \end{bmatrix} \quad (1)$$

where p and q denote the unconnected ports and c and d denote the connected ports of α and β circuits respectively. The q ports are common to β and γ segments. Z_γ can be expressed in terms of Z_α and Z_β using the segmentation method[7]. Comparing the expression of Z_γ so obtained with the corresponding submatrices of Z_γ in (1), Z_α can be evaluated provided $q \geqslant d$. The computations are simplified when q = d and Z_α is given by

$$Z_\alpha = \begin{bmatrix} Z_{pp\gamma} - Z_{pq} Z'_{qp} & - Z_{pq} Z'_{qd} \\ -Z_{dq} Z'_{qd} & -Z_{qd} - Z_{dq} Z'_{qd} \end{bmatrix} \quad (2)$$

where

$$Z'_{qp} = [Z_{qq\gamma} - Z_{qq\beta}]^{-1} Z_{qp},$$
$$Z'_{qd} = [Z_{qq\gamma} - Z_{qq\beta}]^{-1} Z_{qd}.$$

Number of ports of β-segment. One of the methods, of selecting the number of q-ports, which has been used successfully in several cases is as follows. Consider a special case with p=1. Starting with an assumed value of q=1, evaluate $Z_{pp\alpha}$ using (2) which in this case reduces to

$$Z_{pp\alpha} = Z_{pp\gamma} - Z_{pq} [Z_{qq\gamma} - Z_{qq\beta}]^{-1} Z_{qp}. \quad (3)$$

It may be noted that for evaluating $Z_{pp\alpha}$ from (3) we do not need to evaluate Z_{dd}, Z_{dq} and Z_{qd}. Only the evaluations of Z_γ and $Z_{qq\beta}$ are required. The value of the number of q-ports is increased iteratively until the value of $Z_{pp\alpha}$, calculated from (3), converges. This gives the minimum required number of q-ports. The number of c(=d) ports should be at least equal to this value. In the number of examples that have been studied, it is found that this is also the sufficient number of c-ports required for the convergence of Z_α.

Illustrative Example

For illustrating the method of desegmentation the input impedance at port p_1 of the α circuit of Fig. 3 is computed using (3). The value of the input reactance (considering the α-circuit as lossless) as obtained by desegmentation and segmentation method (Fig. 3) are found to be j20.79 and j20.54 ohms respectively, at 3.95 GHz, with $\varepsilon_r = 2.54$, thickness of substrate 1.6 mm, A = 3.1711 cm and a = 0.25 A. The results are thus found to be in good agreement.

There are situations where segmentation method cannot be applied but desegmentation technique can be used. One such example is shown in Fig. 4. The proposed method is useful for analyzing planar microstrip antennas also[9].

References

1. T. Okoshi and T. Miyoshi, 'The planar circuit - an approach to microwave integrated circuitry', IEEE Trans. Microwave Theory Tech., vol.MTT-20, pp.245-252, Apr. 1972.
2. T. Okoshi and T. Takeuchi, 'Analysis of planar circuits by segmentation method', Electronics and Comn. in Japan, vol.58-B, pp. 71-79, Aug. 1975.
3. T. Okoshi et al., 'Planar 3-db hybrid circuit', ibid., pp. 80-90.
4. R. Chadha and K.C. Gupta, 'Green's functions for triangular segments in planar microwave circuits', IEEE Trans. Microwave Theory Tech., vol. MTT-28, pp.1139-1143, Oct. 1980.
5. R. Chadha and K.C. Gupta, 'Green's functions for circular sectors, annular rings, and annular sectors in planar microwave circuits', IEEE Trans. Microwave Theory Tech., vol. MTT-29, Jan.1981 (to appear).
6. T. Okoshi et al., 'The segmentation method - an approach to the analysis of microwave planar circuits', IEEE Trans. Microwave Theory Tech., vol. MTT-24, pp. 662-668, Oct. 1976.
7. R. Chadha and K.C. Gupta, 'Segmentation method using impedance matrices for analysis of planar microwave circuits', IEEE Trans. Microwave Theory Tech., vol. MTT-29, Jan. 1981 (to appear).
8. H. Howe, Jr., Stripline Circuit Design. Dedham MA: Artech House, 1974, ch. 3, p. 95.
9. K.C. Gupta and P.C. Sharma, 'Segmentation and desegmentation technique for analysis of two dimensional microstrip antennas', to be published.

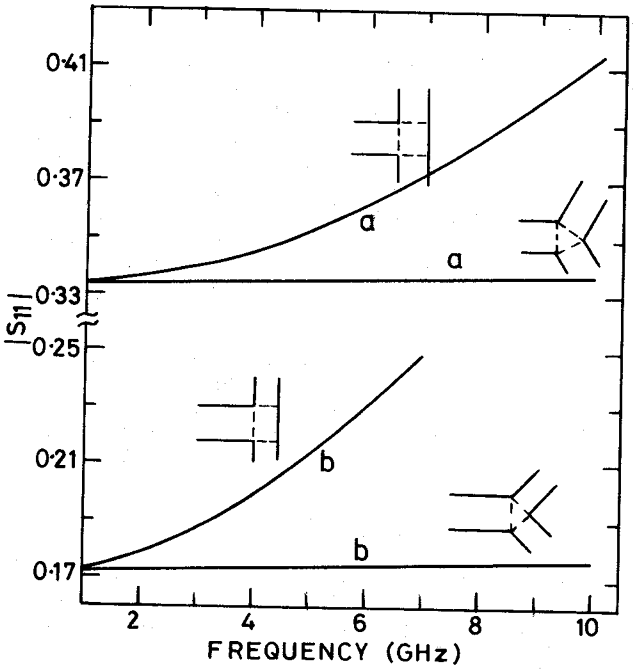

Fig. 1 Comparison of S_{11} for triangular and rectangular T-junctions with impedance ratios (a) 1:1:1 and (b) $1/\sqrt{2}$:1:1.

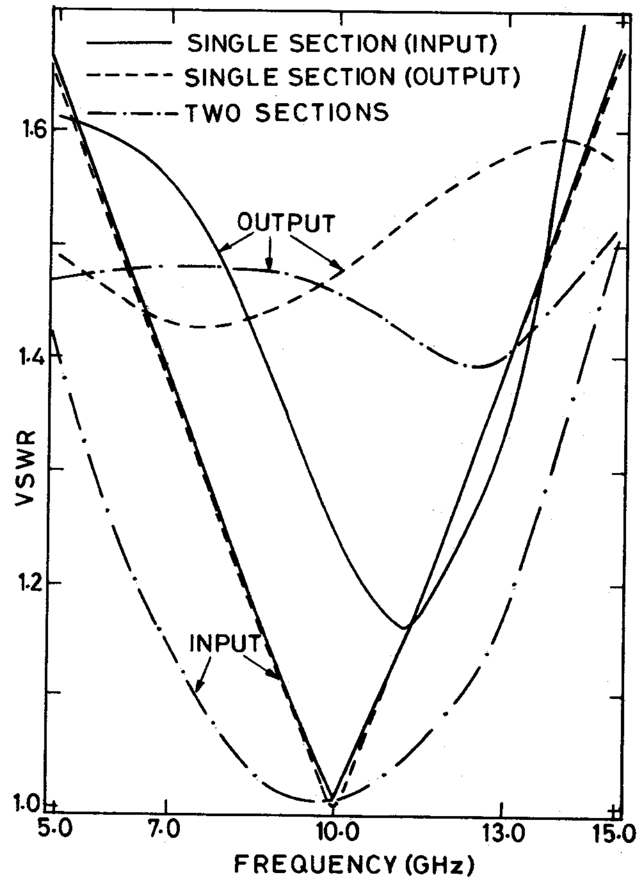

Fig. 2 Frequency variations of the input and output VSWR's for the three types of in-phase power divider circuits.

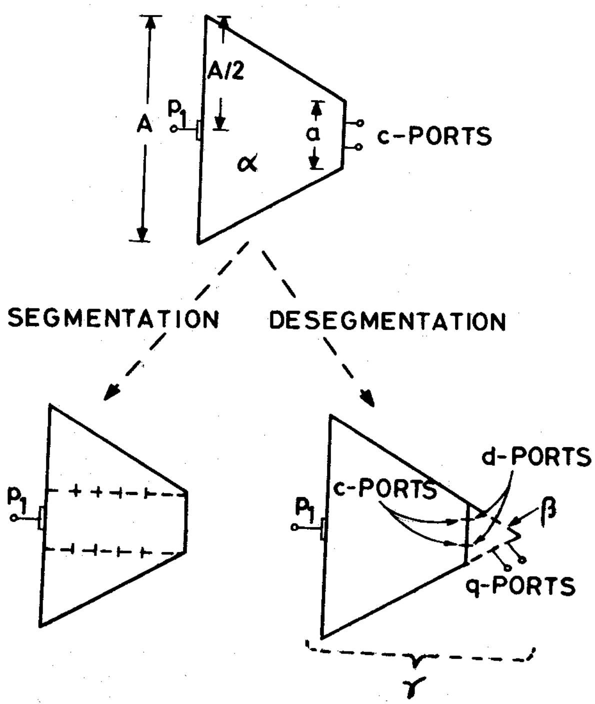

Fig. 3 Segmentation and desegmentation methods as applied to a truncated equilateral triangular circuit.

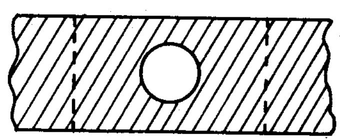

Fig. 4 A round hole in stripline/microstrip as an example of the circuit where the segmentation method cannot be applied.