A DESIGN TECHNIQUE FOR RAISING UPPER FREQUENCY LIMIT OF WIDE-BAND 180°HYBRIDS

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ABSTRACT

A design technique combining Rectangular Boundary Division method and Finite-Difference Time-Domain method is proposed for raising upper frequency limit of 180°hybrids. Characteristics of a designed 180°hybrid covering 2 to 26.5GHz are shown as experimental results.

INTRODUCTION

Wide-band 180°hybrids are important as the basic circuit of balanced mixers and antenna feed networks. Fig.1 shows the schematic plan view of a 180°hybrid consisting of tandem-connected 8.34dB tapered coupled-line magic-T's[1]. Fringing capacitances introduced at the magic-T junction as shown in Fig.2 cause phase unbalance of the even- and odd-mode waves and determine the practical upper frequency limit. An air-gap coupled-line section[1] as shown in Fig.2 or a double arrow structure using ground conductors[2] has been used in the magic-T junction to compensate the influence of the fringing capacitances. However, good magic-T performance in the frequency range beyond 20GHz is still difficult to obtain because a systematic design technique for the magic-T junction has not been developed.

We describe, in this paper, a design technique for the magic-T junction with an air-gap coupled-line section. In a conventional magic-T junction, impedance discontinuity between an air-gap section and a full dielectric section causes multiple reflection of waves, therefore a design of the optimum air-gap length for compensating the fringing effects has been difficult. In the proposed technique, a transition without impedance discontinuity between the two sections is designed with the use of Rectangular Boundary Division (RBD) method[3] and the air-gap length is optimized with the use of the Finite-Difference Time-Domain (FD-TD) method[4]. The resulting bandwidth, 2 to 26.5GHz, of a designed 180°hybrid is shown as experimental results.

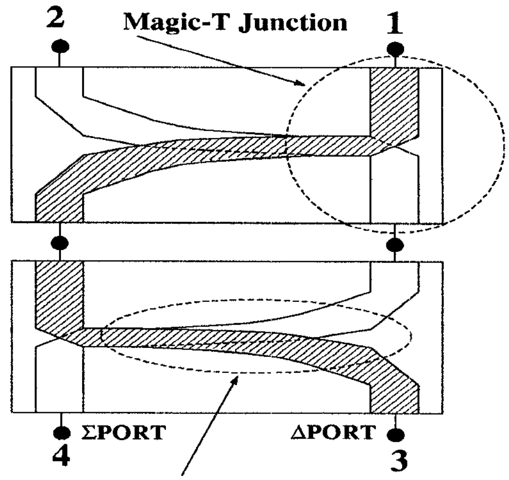

Figure 1: Schematic view of a 180°hybrid consisting of tandem-connected tapered-coupled-line magic-T's

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DESIGN OF TAPERED COUPLED-LINE

Cross-sectional views of the full-dielectric section and air-gap section near the magic-T junction are shown in Fig.2(b) and (c), respectively. The spacings between the strip conductors, S_d and S_a, are different because the strip conductors in the full dielectric section sink by the half of the conductor thickness,t, in the case of soft substrates. The influence of this structural difference is not negligible because electromagnetic waves are strongly coupled in the two sections.

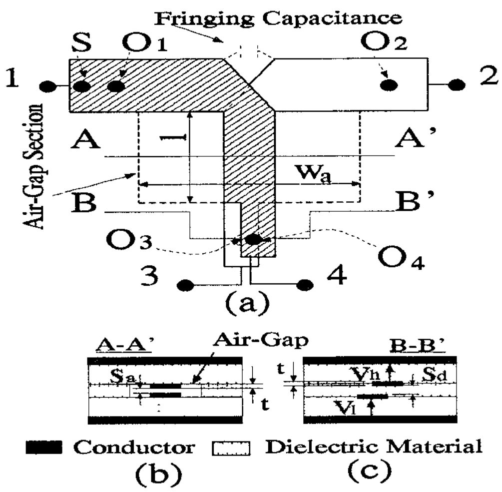

Figure 2: Plan view of the magic-T junction(a) and cross-sectional view of the air-gap section(b)and full dielectric section(c)

The RBD analysis is carried out by considering the strip conductor thickness, so that a design chart[5] for the coupled-line sections is made as shown in Fig.3. The chart provides the cross-sectional dimensions and the coupling coefficient of a coupled-line. Then, the coupling coefficient,K, and the characteristic impedance relation are given as,

$$K = \frac{Z_{even} - Z_{odd}}{Z_{even} + Z_{odd}}, \quad Z_0 = \sqrt{Z_{even} Z_{odd}}$$

where Z_0, Z_{even}, and Z_{odd} denote the characteristic impedance of the isolated strip line, the even-mode, and odd-mode impedance of the coupled-line, respectively.

The coupled-line should be designed so that the impedances are continuous in the junction between the full dielectric section and the air-gap section. Since the cross-sectional dimensions, W and W_c, for the same coupling coefficient defined by the mode impedances is different as shown in the design chart, a step discontinuity is provided in the junction as shown in Fig.2 in order to keep the impedances constant in the two sections. The influence of the structural discontinuities and the fringing capacitances at the magic-T junction is characterized and the length of air-gap section,l, is optimized to compensate the discontinuity effects with use of the FD-TD method.

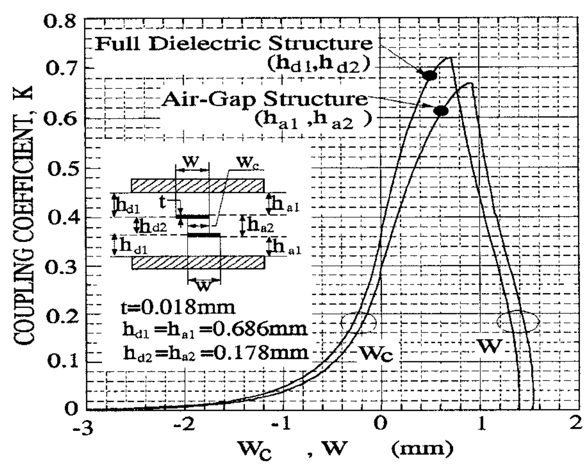

Figure 3: Design chart for the coupled-line sections

OPTIMIZATION OF AIR-GAP LENGTH

The FD-TD method is suited to characterize wide-band magic-T's because the wide-band performance can be efficiently analyzed by using pulse excitation and Fourier transformation[6]. The Yee algorithm[4] is used here with the Cartesian grids and the Mur's first order boundary condition[7] combined with the super-absorption technique[8].

The Gaussian pulse, excited at the source plane, S, propagates toward the observation points, $O_i(i = 1, 2, 3, 4)$, in the magic-T junction as shown in Fig.2. The mitered right-angle bends at the magic-T junction are approximated with the staircases(a) and (b) in Fig.4. The FD-TD analysis is carried out for both staircases and the mean value is used as the result of analysis. Convergence for the number of staircase grids was examined by calculating the coupling characteristics, $|S_{21}|$, of the magic-T junction as shown in Fig.4. In our analysis, 16 staircase grids were used.

The even- and odd-mode pulses, V_e and V_o, at O_3 and O_4 can be obtained by decomposing the observed electrical potentials, V_l and V_h, as shown in Fig.2(c), as,

$$V_e = \frac{1}{2}(V_l - V_h), \qquad V_o = \frac{1}{2}(V_l + V_h).$$

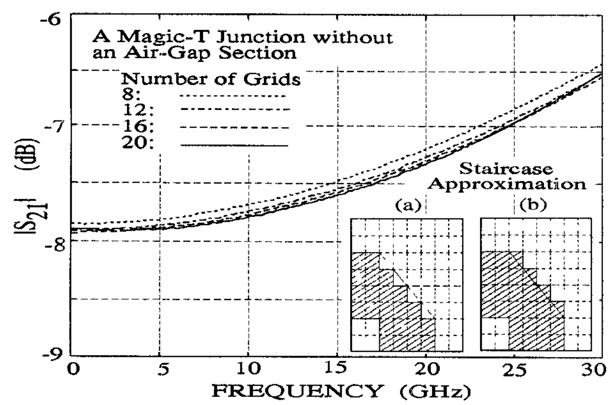

Figure 4: Coupling characteristics, $|S_{21}|$, of the magic-T junction for the approximations, staircase(a) and (b)

These pulses are Fourier-transformed and the phase difference between the two mode pulses is shown in Fig.5. The graph shows that the phase difference caused by the fringing capacitance can be decreased by tuning the air-gap length,l. For the cases of l≥2mm, the phase difference is beginning to show dispersion emerges from inhomogeneous media at the air-gap section. The air-gap length of l=2.5mm is, therefore, the optimum value.

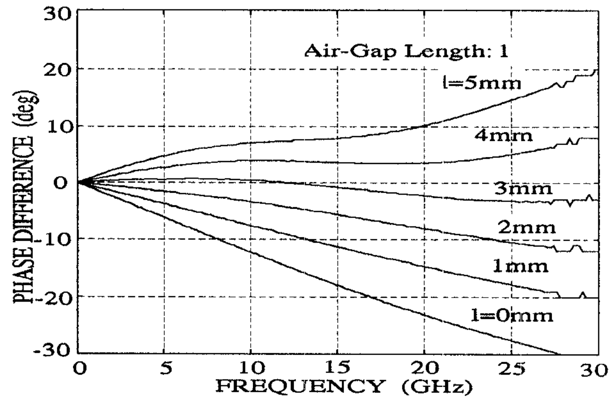

Figure 5: Phase difference between the even- and odd-mode pulses

EXPERIMENTAL RESULTS

A 180°hybrid was designed and fabricated as the triplate strip line structure consisting of soft substrates(RT/Duroid 5880). Cross-sectional dimensions of the designed coupled-line are denoted in Fig.3 and the air-gap width,w_a, is 2.0mm.

Fig.6 and Fig.7 show the amplitude and the phase unbalance of the Δ port of the 180°hybrid. Good characteristics are observed for the frequency band, 2 to 26.5GHz. The isolation between the Δ and Σ port and the input port return losses were lower than 15dB.

CONCLUSIONS

A design technique for raising the upper frequency limit of tapered coupled-line magic-T's was proposed. The design procedure which consists of the accurate characterization of tapered coupled-line with the RBD method and the optimization of air-gap size with the FD-TD method is effective for the compensation of fringing capacitance at the magic-T junction. A 180°hybrid designed with this technique provides good performance for the frequency band, 2 to 26.5GHz.

ACKNOWLEDGMENT

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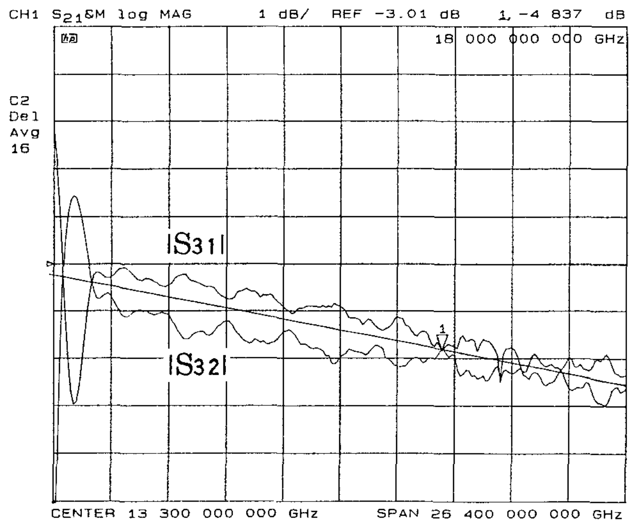

Figure 6: Amplitudes of the Δ port, $|S_{31}|$ and $|S_{32}|$, of the designed 180°hybrid

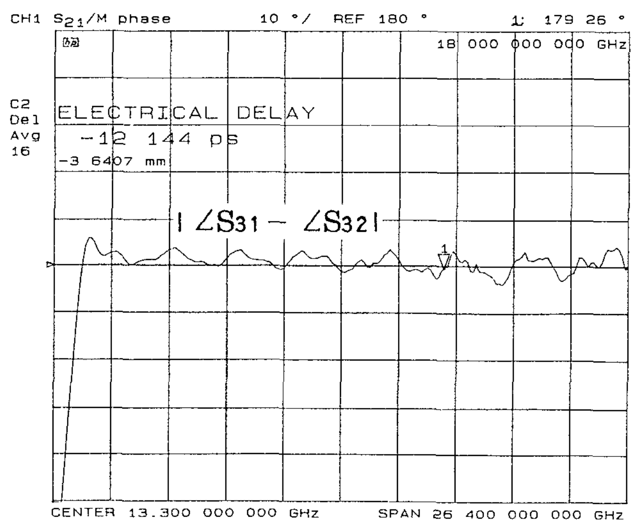

Figure 7: Phase unbalance of the Δ port of the designed 180°hybrid

References

[1] R.H. DuHamel and M.E. Armstrong: "The tapered-line magic-T," *Parallel Coupled Lines and Directional Couplers*, edited by Leo Young, pp.207-233, Artech House, 1972.

[2] "Double-arrow 180 hybrid covers 2 to 18 GHz," *Microwave Journal*, pp.175-177, 1987.

[3] M Nakajima and E.Yamashita: "Rectangular boundary division method", *Analysis methods for electromagnetic wave problems, vol.2*, ch 7, Artech House 1995.

[4] K. S. Yee: "Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media," *IEEE Trans. Antennas Propagat.*, vol.AP-14, pp.302-307, May 1966.

[5] S. B. Cohn: "Characteristic impedances of broadside-coupled strip transmission lines," *IRE Trans., Microwave Theory Tech.*, vol.MTT-8, pp.633-637, Nov. 1966.

[6] X. Zhang and K. K. Mei: "Time-domain finite difference approach to the calculation of the frequency-dependent characteristics of microstrip discontinuities," *IEEE Trans. Microwave Theory Tech.*, vol.36, No.12, pp.1775-1787, Dec.1988.

[7] G. Mur: "Absorbing boundary conditions for the finite-difference approximation of the time-domain electromagnetic-field equations," *IEEE Trans. Electromagn. Compat.*, vol.EMC-23, pp.377-382, Nov. 1981.

[8] K. K. Mei, J. Fang: "Superabsorption-a method to improve absorbing boundary conditions," *IEEE Trans. Antennas Propagat.*, vol.40, No.9, pp.1001-1010, Sep. 1992.