Broadband Lumped-element 180-degree Hybrids Utilizing Lattice Circuits

Tadashi KAWAI, Yoshihiro KOKUBO, and Isao OHTA

Department of Electronics, Faculty of Engineering, Himeji Institute of Technology
2167 Shosha, Himeji-shi, Hyogo 671-2201 Japan
Tel&Fax : +81-792-67-4873, e-mail : kawai@elnics.eng.himeji-tech.ac.jp

Abstract **This paper suggests a novel lumped-element 180° hybrid utilizing lattice circuits. The present hybrid possesses a wide-band property differently from ordinary lumped-element hybrids composed of Π or/and T networks. The bandwidth ratio is 2.4 for a regular type and can be increased to 7.13 by adding a lattice type impedance transformer at each port. The validity and usefulness of this idea also are demonstrated by electromagnetic simulation for a uniplanar circuit pattern.**

INTRODUCTION

The hybrid coupler is one of the important circuit components in microwave and millimeter-wave systems. As a 180° hybrid, a rat-race circuit composed of three 1/4-wavelength line sections and one 3/4-wavelength section is usually used. Since the physical dimensions of the standard hybrid ring are proportional to the wavelength at a center frequency, the decrease of an operating frequency drives MMIC chip larger size and higher cost. Therefore, a lumped-element structure has attracted our attention because of its small size. Generally, lumped-element circuits have been constructed by replacing a $\lambda/4$ and $3\lambda/4$ line section with a Π and/or T network because of its simplicity. The equivalent is guaranteed only at the center frequency, and the frequency dependence is relatively sensitive. For this reason, many efforts have been expended to develop a broadband structure [1]-[7].

In this paper, first, a lumped-element design technique using the symmetrical lattice circuits is described. Then, a very broadband lattice type 180° hybrid is designed by modifying the values of lumped-elements. The hybrid exhibits a broadband performance over a bandwidth ratio of about 3.4 for –20 dB return loss. Furthermore, a ultra-wideband hybrid with a bandwidth ratio of 7.13 is proposed by inserting impedance transformers of a lattice circuit at each port. Finally, the validity and usefulness of the present design concept are shown by electromagnetic simulation of a broadband hybrid.

CIRCUIT STRUCTURE

A rat-race circuit is composed of three $\lambda/4$ line sections and $3\lambda/4$ line section with normalized impedance of $\sqrt{2}$. We derive a lumped-element lattice circuit equivalent to the transmission line segment by equating the image impedance and transfer constant for the transmission line to those of the lumped-element lattice circuit at a design frequency. Fig. 1(a) shows a lossless transmission line, where electrical length and characteristic impedance of a line are described herewith, and Fig. 1(b) a symmetrical lattice circuit con-

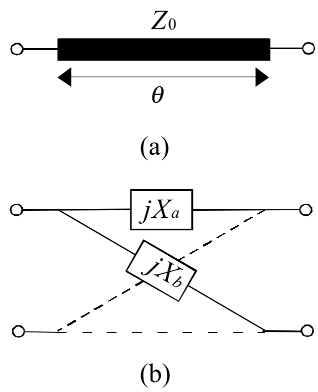


Fig.1 Schematic diagrams of (a) a lossless transmission line and (b) a lossless symmetrical lattice circuit.

0-7803-6540-2/01/$10.00 (C) 2001 IEEE

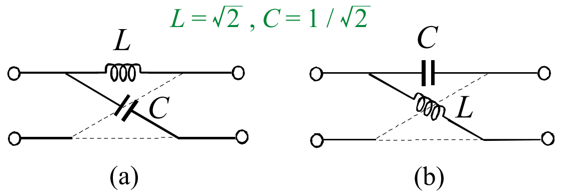


Fig.2 Circuit configurations of symmetrical lattice circuits corresponding to (a) $\lambda/4$ transmission line and (b) $3\lambda/4$ transmission line. The values of L and C are normalized with both a center frequency and a port-impedance.

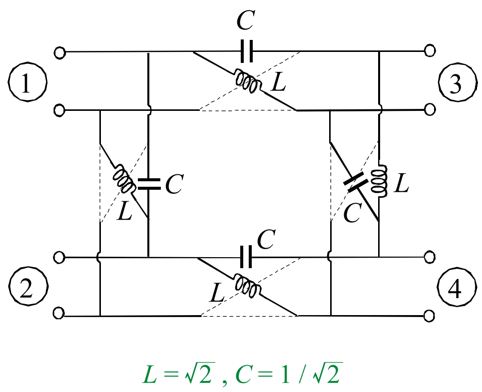


Fig.3 Example of a circuit construction of a 180° hybrid.

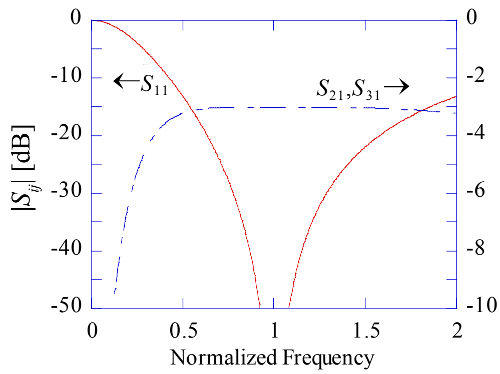


Fig.4 Theoretical frequency dependence of S-parameters for an example of a lumped-element 180° hybrid using lattice circuits.

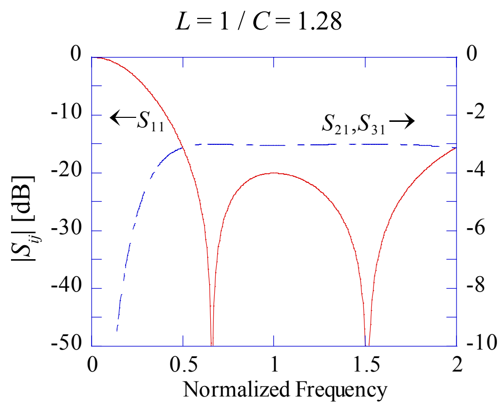


Fig.5 Theoretical S-parameters of a band-broadened 180° hybrid.

sisting of reactances jX_a and jX_b. When the next conditions are satisfied, the above two circuits are equivalent to each other.

$$jX_a = jZ_0 \tan\left(\theta/2\right) \tag{1a}$$

$$jX_b = -jZ_0 \cot\left(\theta/2\right). \tag{1b}$$

For $Z_0 = \sqrt{2}$ and $\theta = 90°$, $X_a = \sqrt{2}$ and $X_b = -\sqrt{2}$ can be derived. Therefore, we can replace this $\lambda/4$ transmission line with the lattice circuit shown in Fig. 2(a). Similarly, $3\lambda/4$ transmission line (θ = 270°) can be substituted as shown in Fig. 2(b). We call these lattice circuits type A and type B, respectively. The phase difference between type-A and type-B circuits is 180° independently of frequency, and the transfer constants are insensible to operation frequency in comparison with Π and T lumped networks. So a broadband 180° hybrid can be realized using three type A (or type B) circuits and one type B (or type A) circuit. Fig. 3 indicates the circuit construction of a 180° hybrid using three type A circuits and one type B circuit. Figure 4 exhibits the frequency characteristics of its scattering parameters of a regular type. A bandwidth ratio is about 2.4 with a return loss of -20 dB. This value is larger than that of a distributed 180° hybrid with an ideal phase inverter.

Figure 5 shows S-parameters of a broadband hybrid with modified lumped-element values. The design parameters in this example are set for a -20 dB return loss at a center frequency. A bandwidth ratio increases

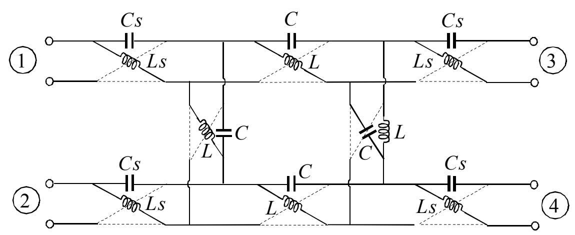


Fig.6 Circuit construction of a broadband 180° hybrid utilizing lattice-circuit impedance transformers.

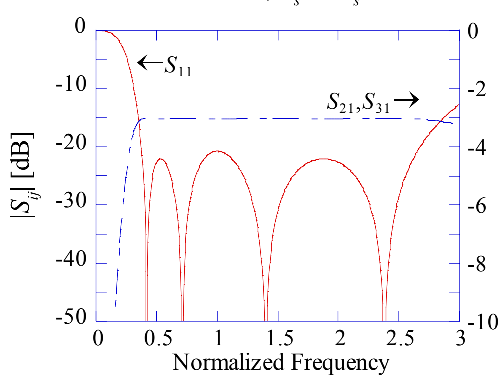


Fig.7 Theoretical S-parameters of ultra-wideband hybrid using impedance transformers as shown in Fig. 6.

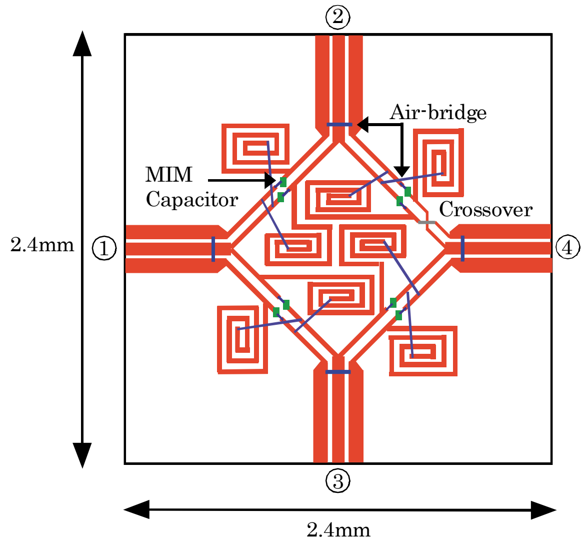
to about 3.4.

FURTHER BAND-BROADENING

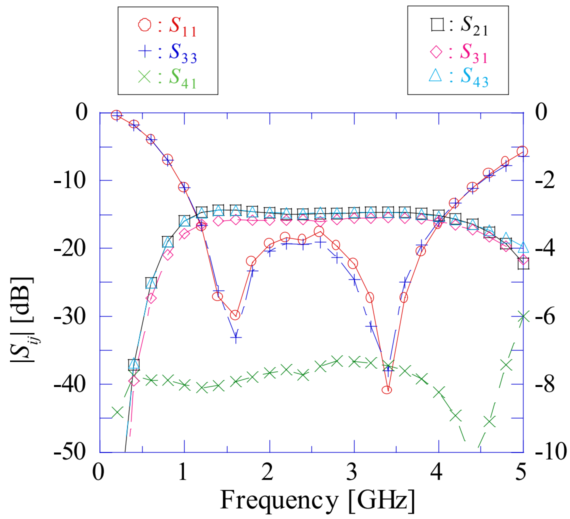
The purpose of this section is to broaden the bandwidth of the above lattice type lumped-element hybrid. We try to broaden the bandwidth of the hybrid by inserting lattice-circuit impedance transformers at each input/output port as shown in Fig. 6. Figure 7 exhibits the theoretical results of the scattering parameters. The bandwidth is surprisingly widened and attains a bandwidth ratio of 7.13.

SIMULATION RESULTS

In order to confirm usefulness of the above circuit design, we simulate the bandbroadened hybrid corresponding to Fig. 5 by an electromagnetic simulator (Sonnet). We treat the hybrid patterned on a uniplanar circuit with consideration for the design of M(H)MICs. As shown in Fig. 8(a), output ports are constructed of a 50 Ω finite-ground-plane coplanar waveguide (FGCPW), and coplanar strips (CPS) are used for connecting with lumped-elements because of easy crossover construction. Lumped-elements (C, L) have been realized by metal-insulator-metal (MIM) capacitors and rectangular spiral inductors, respectively. We assume an alumina substrate with a dielec-



(a)



(b)

Fig.8 (a) A circuit pattern for simulation.
(b) Simulation results.

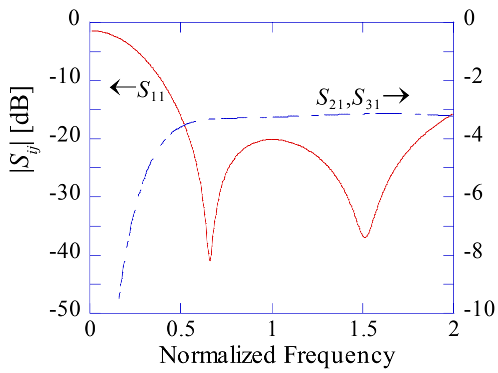


Fig.9 Calculated *S*-parameters of the wideband hybrid with consideration for conductor loss of spiral inductors.

tric constant of 9.9 and a thickness of 254 μm. The substrate size is about 2.4 × 2.4 mm^2. Figure 8(b) shows the scattering parameters calculated by EM simulator. These results nearly agree with the results derived from the lumped-element circuit theory in the previous section.

INFLUENCE OF CONDUCTOR LOSS

We calculated the scattering parameters of the simulated hybrid in Fig. 8(a) with consideration of loss of the spiral inductor [8]. The series resistance is calculated from the conductivity of gold being conductor of the spiral inductor. Fig. 9 exhibits the calculated results of the bandbroadened hybrid shown in Fig. 5. As shown in this figure, the influence of conductor loss for this hybrid composed of lattice circuits are very small.

CONCLUSIONS

We have demonstrated a design technique of a lumped-element 180° hybrid utilizing symmetrical lattice circuits and successfully designed an exceedingly broadband hybrid with bandwidth ratios of 2.4 to 7.13. The verification of the proposed hybrid is shown by EM simulation results (Sonnet). An experimental confirmation would be an important subject to do shortly.

ACKNOWLEDGMENTS

This work was supported in part by Grant-in-Aid for Scientific Research (C) (10650376, 1998-1999) from the Ministry of Education, Science, Sports and Culture, Japan.

REFERENCES

[1] R. K. Gupta and W. J. Getsinger, “Quasi-lumped-element 3- and 4-port networks for MIC and MMIC applications,” *1984 IEEE MTT-S Dig.* 17-1, pp. 409-411, June 1984.

[2] S. J. Parisi, “180° lumped element hybrid,” *1989 IEEE MTT-S Dig.* PP-33, pp. 1243-1246, June 1989.

[3] R. W. Vogel, “Analysis and design of lumped- and lumped-distributed-element directional couplers for MIC and MMIC applications,” *IEEE Trans. Microwave Theory & Tech.*, **40**, 2, pp. 253-262, Feb. 1992.

[4] J. Staudinger and J. Costa, “Lumped-element networks compose wide-bandwidth balun,” *MICROWAVES & RF*, pp.119-126, Sep. 1993.

[5] J. Hogerheiden, M. Ciminera, and G. Jue, “Improved planar spiral transformer theory applied to a miniature lumped element quadrature hybrid,” *IEEE Trans. Microwave Theory & Tech.*, **45**, 4, pp. 543-545, Apr. 1997.

[6] Y. Suzuki, I. Toyoda, T. Ohira, and H. Ogawa, “Wafer-scale MMICs based on new circuit topology for microwave signal processing,” *Technical Rep. of IEICE*, SANE96-91, SAT96-139, pp. 27-33, Feb. 1997 (in Japanese).

[7] T. Ohira, Y. Suzuki, H. Ogawa, and H. Kamitsuna, “Megalithic microwave signal processing for phased-array beamforming and steering,” *IEEE Trans. Microwave Theory & Tech.*, **45**, 12, pp. 2324-2332, Dec. 1997.

[8] E. Pettenpaul, H. Kapusta, A. Weisgerber, H. Mampe, J. Luginsland and I. Wolff, “CAD models of lumped elements on GaAs up to 18 GHz,” *IEEE Trans. Microwave Theory & Tech.*, **36**, 2, pp. 294-304, Feb. 1988.