Design of Wideband Directional Couplers Using Three Types of Broadside Coupled-Lines

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Abstract - **Wideband directional couplers using broadside coupled-lines in stripline, suspended stripline, and inverted suspended stripline are systematically designed and compared. The proposed couplers are composed of multi-section broadside coupled-lines. The fabricated couplers have less than 2 dB insertion loss, typical 10–20 dB directivity, and over 15 dB isolation for a wide frequency range of 2 to 18 GHz. Among the proposed couplers, the broadside coupler in stripline showed the best performance.**

Index Terms — **directional coupler, broadside coupled-line, stripline, suspended stripline, multi-section, wideband.**

1. Introduction

Directional couplers with parallel microstrip coupled-lines are conveniently implemented, but possess disadvantages of low directivity and lack of tight coupling. Recently, considerable efforts have been made on the development of wideband RF and microwave couplers in various structures such as stripline, suspended stripline, inverted microstrip line, etc. Among them, broadside coupled-lines[1] are particularly useful in circuits where tight coupling (3–10 dB) is required. Broadside coupled-lines in stripline or in suspended stripline are suitable for tight coupling as well as low attenuation at microwave and millimeter-wave frequencies.

Considerable efforts for the design of directional couplers using broadside coupled-lines have been made and reported. As one of these efforts, the authors in [2] summarized theory and design method for the coupled-line directional coupler. Various types of directional couplers using broadside coupled-lines have been presented in [3]–[5]. These papers suggested practical coupler design approaches with good performance, but still the measured results were good only at low frequencies (< 10 GHz), and the realized couplers had larger size than other structures.

In this paper, we present design methods of directional couplers using broadside coupled-lines in three types of structures (SL: stripline, SSL: suspended stripline, and ISSL: inverted suspended stripline). The proposed couplers are composed of mutli-section broadside coupled-lines. The implemented couplers exhibit good performance with small size, wide bandwidth, and simple configuration. Comparison of the three types of couplers in terms of performance and manufacturing easiness is provided.

2. Directional Coupler Design

The design method of a coupled-line coupler is based on odd and even mode characteristics of the coupled-line. The electrical characteristics of the coupled-lines can be completely determined from the effective capacitances between the lines and the velocity of propagation of the line with assumption of TEM propagation.

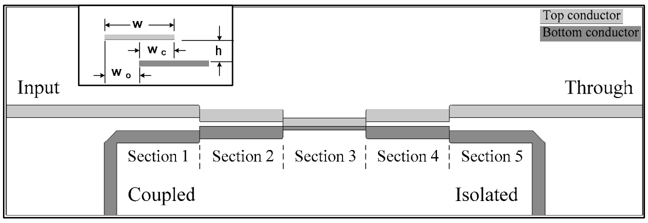


Fig. 1. Layout of the proposed coupler using broadside coupled-lines.

Fig. 1 shows a layout of the proposed directional coupler using broadside coupled-lines. The proposed coupler is composed of 5-section broadside coupled-lines. For the stepped coupler design, the coupling factor changes from section to section by a discrete step. Each section of the coupler is designed with a quarter wavelength line at the center frequency of the desired bandwidth. The coupling of each individual section in the transmission line is defined by the even and odd mode impedances, Z_{0e} and Z_{0o}. With normalization to the characteristic impedance of the input ports, the coupler can be designed to have the desired coupling factor with adequate VSWR and isolation [2].

Tables in [2] showed the even-mode normalized impedance values for five sections of 8.34 dB coupler for a wide frequency band from 2 to18 GHz.

The authors in [6] described the coupler design method using broadside coupled-lines, providing explicit expressions by using conformal transformation. The formulas are divided into two cases: loose coupling and tight coupling. For calculating the parameter of each section, offset position and strip width can be computed by using equations in [6].

3. Implementation and Measurements

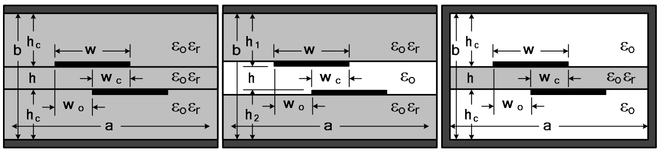
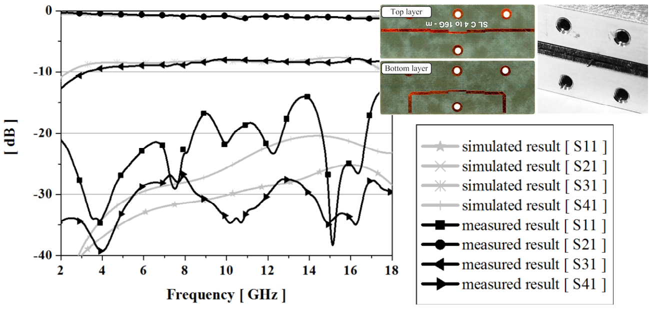


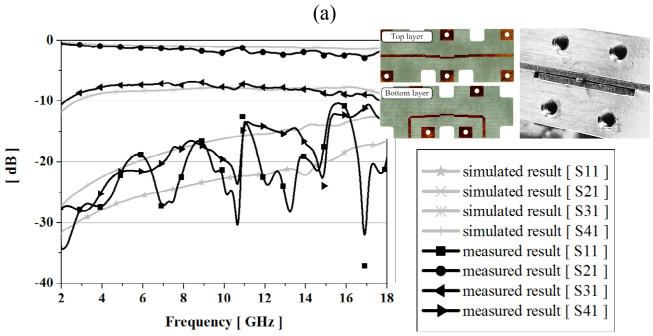
Fig. 2. Structures of the broadside coupled-lines in SL, ISSL, and SSL.

The proposed couplers were designed in three types of structures as shown Fig. 2. The couplers were realized on a Rogers Duroid 5880 substrate with ε_r=2.2, thickness h=0.13 mm, and cover height of h_c, h_1, h_2=0.51 mm.

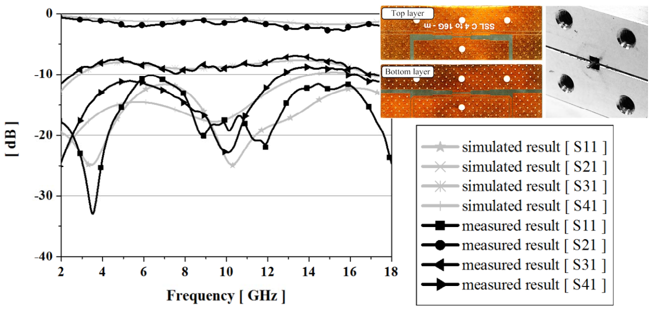
Fig. 3(a) shows pictures of the fabricated coupler in stripline. The fabricated coupler is 29 mm by 3 mm in size, except for the connectors and extra space for the measurement. Length of each line section is 5.08 mm. Fig. 3 (a) compares the simulated and measured results of the fabricated coupler in stripline. The simulation was performed with the CST Microwave Studio simulation software. It is observed that the stripline coupler has less than 1 dB insertion loss, typical 20 dB directivity, and over 20 dB isolation for a wide frequency band from 2.6 to 18.8 GHz.



(a)



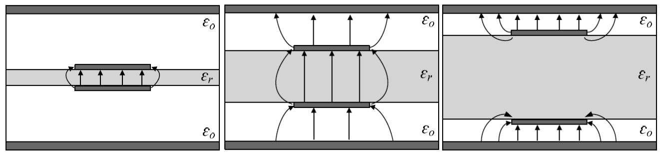
(b)



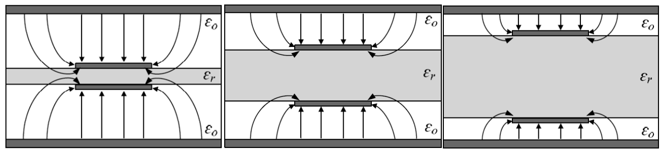
(c)

Fig. 3. Pictures and performances of the fabricated coupler in (a) SL, (b) ISSL, and (c) SSL.

Figs. 3(b) and 3(c) show picture of the fabricated couplers in inverted suspended stripline and suspended stripline. The fabricated couplers are 30 mm by 3 mm in size. Also, Figs. 3(b) and 3(c) compare the simulated and measured results of the fabricated couplers. It is observed that the implemented couplers have less than 2 dB insertion loss, typical 10 dB directivity, and over 15 dB isolation for a wide frequency band from 2 to 18 GHz. Contrary to expectations, the designed coupler on suspended stripline showed slightly higher insertion loss than the stripline coupler. With the suspended stripline coupler, it is observed that most of the propagated signal energy is transferred through air rather than through the dielectric layer of the substrate in the suspended stripline structure; i.e., the odd-mode field is not properly formed as shown Fig. 4. When the cover height is low ($h_c < 50*h$), the odd-mode field is similar to the even-model field. When the cover height is high enough, the designed circuit becomes much larger.



(a)



(b)

Fig. 4. Field distributions for a substrate height variation on SSL : (a) odd mode and (b) even mode.

The fabricated couplers in three types of structures are compared with each other in terms of performance and manufacturing easiness. The implemented coupler in stripline form demonstrated the best performance, and the suspended stripline coupler has an advantage at manufacturing easiness.

4. Conclusion

In this paper, design methods of wideband directional couplers using broadside coupled-lines in SL, SSL, and ISSL are presented. The proposed couplers are composed of multi-section broadside coupled-lines. The fabricated couplers have less than 2 dB insertion loss, typical 10–20 dB directivity, and over 15 dB isolation for a wide frequency range of 2 to 18 GHz. The fabricated coupler is 29 mm by 3 mm in size, except for the connectors and extra space. The proposed couplers exhibit broader frequency bandwidth in a smaller size with comparable performance as compared with the previously reported research results.

Acknowledgment

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