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REALIZATION OF A COMPACT BRANCH-LINE COUPLER USING QUASI-FRACTAL LOADED COUPLED TRANSMISSION-LINES

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Abstract—An extremely compact branch-line coupler operating at 900 MHz is presented without the use of via-holes, multilayered technique, or air-bridged. The technique presented here uses the concept of fractals to load a coupled transmission-line in order to realize a compact quarter-wavelength transmission-line, which forms the couplers arms. It is shown that the proposed branch-line coupler's performance is analogous to a conventional branch-line coupler with the benefit of substantially reduced physical dimensions by a factor of 78%. The measured result of the fabricated microstrip branch-line coupler is compared with the simulation data. The agreement of the measurement and simulated confirms the theory and validates the proposed coupler design.

1. INTRODUCTION

Branch-line couplers with compact size and high-performance are demanded in many microwave communication systems. The branch-line coupler has several applications in the design of microwave devices such as balance amplifiers, balance mixers and phase shifters. The

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branch-line coupler employs quarter-wavelength transformers to realize a simple square-shaped configuration that is used for power dividing or power combining functions and is suitable for low-cost fabrication. However, at the low frequencies the size of a conventional branch-line coupler is very large. Hence, the size reduction of this device is highly desirable for modern communication systems.

In order to reduce the size and volume of a branch-line coupler several techniques have been previously reported. For example, combination of short high-impedance transmission-lines and shunt-lumped capacitors has been considered in [1, 3]. In [1] a size reduction of 60% is achieved compared with the conventional design by embedding series and shunt uniplanar stubs inside the main uniplanar line; and in [2] a size reduction of 55% is achieved using rectangular patches within the coupler arms. Other studies have explored different topologies to reduce the size of the conventional branch-line coupler design: however, the consequence of size reduction is detrimental to its bandwidth, which decreases too [4, 5], except for the BLC designed in [6].

Additionally, a microstrip 90 degree coupler has been developed by substituting the quarter wave transmission lines employed in conventional 90 degree coupler with its equal circuits consisting of two oblique stubs and an inductor and capacitors [7]. The size reduction has been reported about 27% by this technique.

Recently we introduced a compact model of a quarter-wavelength transmission-line using a loaded coupled transmission-line [8, 9]. It has been shown in [8] that the use of a cascade of two coupled transmissions-lines provides an effective technique to compensate for the bandwidth reduction resulting from size reduction using previously reported techniques. This model was used to miniaturize a conventional branch-line coupler by a factor of 65% without compromising its operational bandwidth.

In this paper, a novel loaded coupled transmission-line based on [8] is used to realize a highly compact model representing a quarter-wavelength transmission-line by applying a quasi-fractal technique. This technique is used to create extra cascaded coupled transmissions-lines within the main coupled transmission-line model. Hence, a branch-line coupler using this fractal loaded coupled transmission-line is shown to provide a size reduction of 78% with comparable electrical performance to a conventional branch-line coupler. The novel branch-line coupler design operating at 900 MHz was practically verified. It was fabricated on a 0.762-mm-thick RF-35 PTEE/Woven substrate with a relative dielectric constant $\varepsilon_r = 3.5$.

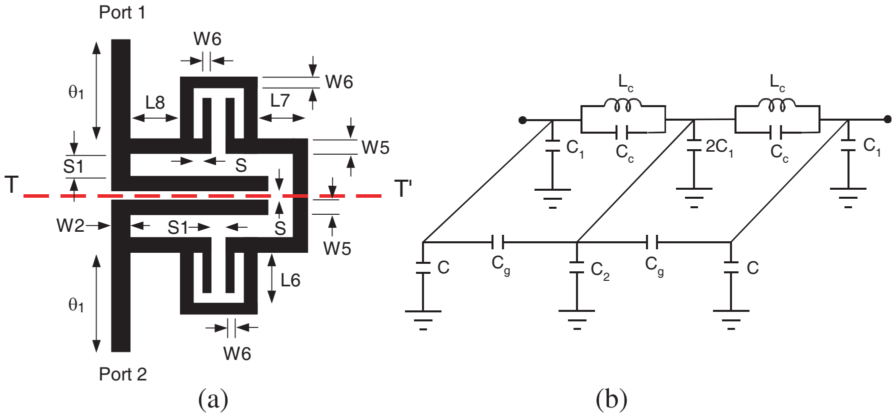


Figure 1. (a) The proposed coupled microstrip transmission-line model using fractal technique; (b) its equivalent circuit model.

2. ANALYSIS LOADED COUPLED TRANSMISSION-LINE

In [8], the conventional quarter-wavelength transmission-line is replaced by an equivalent transmission-line model comprising of two pairs of parallel-coupled lines, which can be considered as a load for the input/output transmission-lines with the electrical length θ_1. In order to further reduce the size of the loaded coupled transmission-line model in [8] a fractal technique is applied here. The resulting coupled transmission-line, shown in Figure 1, is loaded with an additional pair of identical coupled transmission-lines at the top and bottom of the structure.

The characterizing parameters of the equivalent circuit model, shown in Figure 1(b), can be derived as in [10, 11]. As discussed in [12], the equivalent circuit inductors and capacitors shown in Figure 1(b) are given by:

$$C_1 = 1/Z \tag{1}$$

$$C_c = -1/2Z \tag{2}$$

$$L_c = 2Z \tag{3}$$

According to Eq. (2), the series capacitor C_c in the Figure 1(b) is a negative capacitor, and the series capacitor C_g must be increased to compensate for the negative capacitors, so that

$$C_g = C_1 + 1/L_c \tag{4}$$

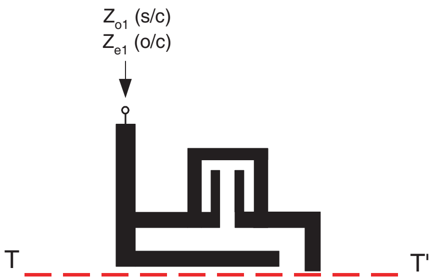


Figure 2. Bisected proposed coupled transmission-line.

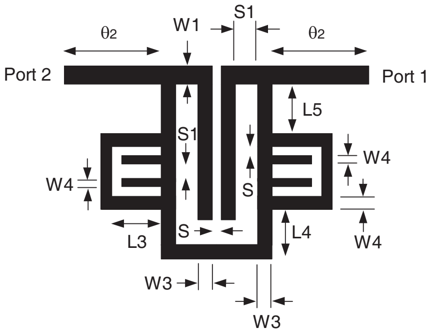


Figure 3. The horizontal coupled transmission-line in the branch-line coupler.

While the parallel capacitors are decreased,

$$C = C_1 - 2/L_c \tag{5}$$

$$C_2 = C_1 - 4/L_c \tag{6}$$

Even- and odd-mode analysis of the structure in Figure 1(a) is used here to evaluate the performance of the branch-line coupler. In the odd-mode analysis the symmetry the plane T-T′, in Figure 1(a), is replaced by an electric wall (i.e., a short-circuit), as illustrated in Figure 2. Then the total impedance at Port 1 as a function of the input impedance Z_1 is given by:

$$Z_{o1} = Z_o \frac{Z_1 + jZ_o \tan(\theta_1)}{Z_o + jZ_1 \tan(\theta_1)} \tag{7}$$

If the symmetry plane T-T′ in Figure 3 is replaced by a magnetic wall (i.e., an open-circuit) and, similarly, if the input impedance is assumed to be Z_2, then, the total impedance at Port 1 is given by:

$$Z_{e1} = Z_o \frac{Z_2 + jZ_o \tan(\theta_1)}{Z_o + jZ_2 \tan(\theta_1)} \tag{8}$$

Once Z_{e1} and Z_{o1} are known the physical dimensions of the coupled transmission-line can be determined.

3. DESIGN OF THE PROPOSED BRANCH-LINE COUPLER

Using the even- and odd-mode Eqs. (7) and (8) a series of expressions can be derived that enable the determination of the

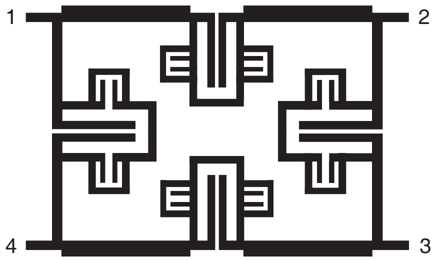


Figure 4. Schematic diagram of the proposed branch-line coupler.

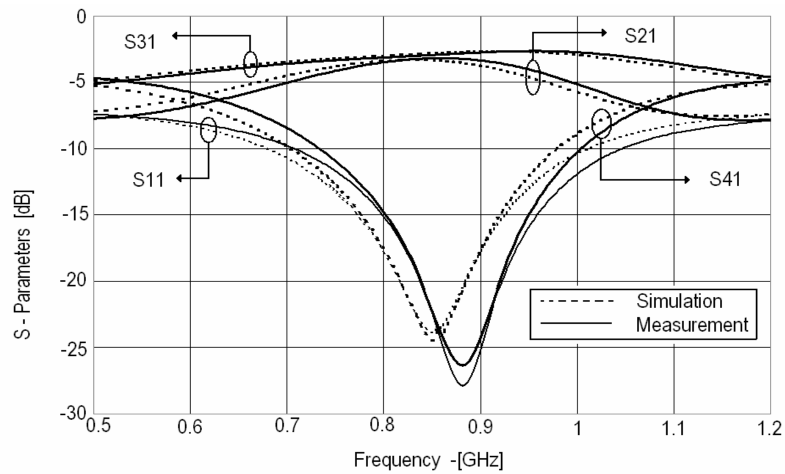
Table 1. The optimized physical values of the proposed branch-line coupler (BLC).

L_7	L_6	L_5	L_4	L_3	θ_2	θ_1
1.9 mm	1.89 mm	1.05 mm	0.7 mm	5.35 mm	7.5 mm	9 mm
W_6	W_5	W_4	W_3	W_2	W_1	L_8
0.7 mm	1.6 mm	0.8 mm	0.9 mm	1.72 mm	2.91 mm	1.4 mm

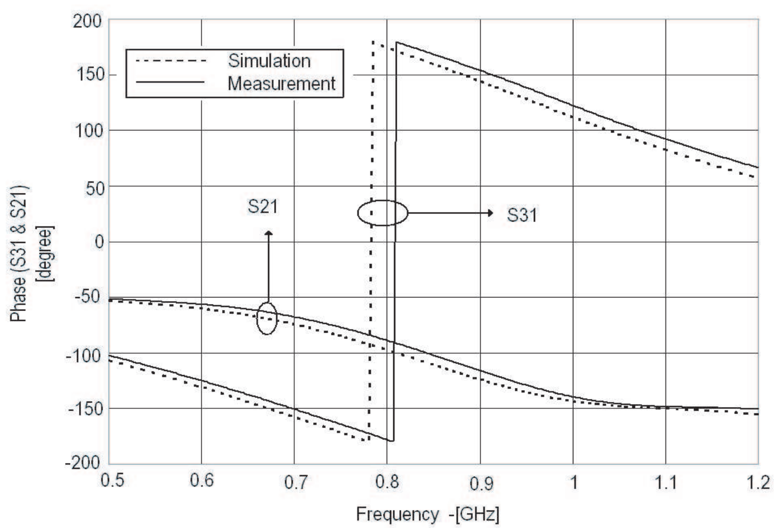
$S = 0.2\,\text{mm}$ and $S_1 = 1\,\text{mm}$

coupled transmission-line's constituent parameters. It is necessary to emphasize that the coupled transmission-line in Figure 1 behaves like a quarter-wavelength arm in the branch-line coupler structure. The values obtained using Eqs. (7)–(8) provide the initial physical parameters of the branch-line coupler design. It was necessary to modify the fractal structure's dimensions to optimize its performance using Agilent's ADS® full-wave electromagnetic simulator. The optimized dimensions of the compact branch-line coupler are given Table 1. The coupled transmission-line at the branch-line couplers vertical arms is defined in Figure 1(a). The coupled line at the branch-line couplers horizontal arms is defined in Figure 3. The schematic diagram of the proposed compact coupler is shown in Figure 4 which occupies its substrate with an area about $20.8 \times 26.6\,\text{mm}^2$. It should be noted that the gap separating the coupled lines on the sides of the main coupled line structure at the top and bottom of the branch-line coupler are closed as a result of the optimization process.

The measurement of the scattering parameters were made using Agilent's 8722D network analyzer over the frequency range from 0.5 to 1.2 GHz. Figure 5 shows the simulated and measured frequency response of the branch-line coupler. This shows the simulated and measured results are in good agreement except that the center frequency of the measured device is slightly below the desired center frequency of 900 MHz by 1.85%, which is be attributed to the manufacturing tolerances. The performance of the proposed coupler has a better return-loss than that obtained by a conventional BLC implemented at the same center frequency using an identical substrate.



(a)



(b)

Figure 5. Measured and simulated frequency responses of the proposed branch-line coupler.

4. CONCLUSION

A novel quasi-fractal branch-line coupler operating at 900 MHz has been designed and implemented on a standard commercial dielectric substrate. This was accomplished using loaded coupled transmission-lines in place of the quarter-wavelength transmission-line arms. The coupler realized is highly compact and is easily manufactured on a single metallization layer of the dielectric substrate to yield a low cost design. Miniaturization with a factor of 78% is achieved with comparable performance as a conventional branch-line coupler.

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REFERENCES

1. Hettak, K., G. A. Morin, and M. G. Stubbs, "Compact MMIC CPW and asymmetric CPS branch-line couplers and Wilkinson dividers using shunt and series stub loading," *IEEE Trans. Microwave Theory & Tech.*, Vol. 53, 1624–1635, 2005.
2. Liao, S.-S. and P.-T. Sun, "A novel compact-size branch line coupler," *IEEE Trans. Microwave Theory & Tech.*, Vol. 15, 588–590, Sep. 2005.
3. Vogel, R. W., "Analysis and design of lumped and lumped-distributed element directional coupler for MIC and MMIC applications," *IEEE Trans. Microwave Theory & Tech.*, Vol. 41, 2116–2125, 1993.
4. Hirota, T., A. Minakawa, and M. Murauchi, "Reduced-size branch-line and rate-race hybrids for uniplanar MMICs," *IEEE Trans. Microwave Theory & Tech.*, 270–275, 2002.
5. Chan, Y.-H. and J.-S. Hong, "Compact wide-band branch-line hybrids," *IEEE Trans. Microwave Theory & Tech.*, Vol. 54, 704–709, 2006.
6. Nosrati, M., "An extremely miniaturized microstrip branch-line coupler," *Microwave and Opt. Tech. Lett.*, Vol. 51, 1403–1406, 2009.
7. Shamsinejad, S., M. Soleimani, and N. Komjani, "Novel enhanced and miniaturized 90° coupler for 3g eh mixers," *Progress In Electromagnetics Research Letters*, Vol. 3, 43–50, 2008.

8. Nosrati, M. and S. K. Valashani, "A novel compact branch-line coupler using four coupled transmission lines," *Microwave and Opt. Tech. Lett.*, Vol. 50, 1712–1714, 2008.
9. Hayati, M. and M. Nosrati, "Loaded coupled transmission line approach of left-handed (LH) structures and realization of a highly compact dual-band branch-line coupler," *Progress In Electromagnetics Research C*, Vol. 10, 75–86, 2009.
10. Nosrati, M. and A. Najafi, "Bandwidth enhancement and further size reduction of a class of elliptic-function low-pass filter using modified hairpin resonators," *Progress In Electromagnetics Research C*, Vol. 5, 187–194, 2008.
11. Nosrati, M., T. Faraji, and Z. Atlasbaf, "A compact composite broad stop-band elliptic-function low-pass filter for ultra wide-band applications using interdigital capacitors," *Progress In Electromagnetics Research Letters*, Vol. 7, 87–95, 2009.
12. Malherbe, J. A. G., *Microwave Transmission Line Filters*, 24–26 and 71–79, Artech House, 1979.