# Compact Branch Line Coupler using Step Impedance Transmission Lines (SITLs)

**S. H. Sedighy [1] and M. Khalaj-Amirhosseini[2]**

[1] School of New Technologies,
Iran University of Science and Technology, Tehran, Iran
sedighy@iust.ac.ir

[2] School of Electrical Engineering,
Iran University of Science and Technology, Tehran, Iran
khalaja@iust.ac.ir

***Abstract*** **─** A compact branch line coupler is proposed by using the optimized step impedance transmission lines (SITLs). The proposed branch line coupler has an area reduction of more than 50% at 1 GHz. The measured results of the fabricated coupler are in good agreement with the simulation results.

***Index Terms*** **─** Branch line, compact, coupler, and step impedance transmission line.

## I. INTRODUCTION

Branch line couplers are among the important components in the microwave circuits, which have wide applications in balanced mixers, image rejection mixers, balanced amplifiers, power combiners, and power dividers. The convenience of design and implementation, compact size and high-performance of this coupler is highly demanded in microwave integrated circuits. The conventional branch line coupler is composed of four uniform quarter-wavelength transmission lines. This coupler has narrow bandwidth and large size around a single frequency [1-7].

Some efforts have been done to compact the conventional branch line couplers. Lumped elements can reduce the coupler size [8], but real lumped components are far from ideal, which resulted in some practical problems especially at high frequency. Moreover, the lumped element values are discrete and include some tolerances commercially, which limit the designer to achieve the desirable specs. The series and shunt stubs embedded in the ground or signal lines have been used in [9] to reduce the size of a branch line coupler. Also, four coupled transmission lines have been presented in [10] to reduce the size of a branch line coupler. Each quarter wavelength branch in the conventional coupler has been replaced by an equivalent circuit composed of four coupled transmission lines and two single transmission lines. A compact slow-wave microstrip branch line coupler with four microstrip high-low impedance resonant cells periodically placed inside the branch-line coupler was introduced in [11]. Another effective way to reduce the size of a branch line coupler is the replacement of straight transmission lines segments by space-filling curve segments with the same electrical characteristics [12, 13]. Moreover, nonuniform transmission line (NTL) can be used instead of the quarter wavelength uniform transmission lines to reduce the size of branch line coupler [14]. In this method, the normalized width function of the NTLs expanded in a truncated Fourier series and an optimization method applied to obtain the optimum values of series coefficients. Two unequal-length high impedance transmission lines paralleling with each other have been used in [15] instead of the branch line coupler arms to reduce the size of the branch line coupler. Planar artificial transmission line concept is another option to reduce the physical length of a transmission line. In this method, a transmission line incorporated with microstrip quasi-lumped elements is capable of synthesizing microstrip

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lines with reduced physical length, which can be used to reduce the size of branch line coupler [16]. Also, defected ground structures and composite right/left handed (CRLH) transmission-line have been used in [17, 18] to design a compact branch line coupler.

Step impedance transmission lines and step impedance resonators (SIRs) are other ways to reduce the size of microstrip components [19]. In this paper, step impedance transmission lines (SITLs) are used to compact the conventional branch line coupler. The proposed branch line coupler is realized by the microstrip step impedance transmission lines instead of the uniform quarter wavelength branches. The impedance ratio of SITLs is considered as a variable and written as the total electrical length of the line. This additional design parameter gives us a higher degree of design freedom, which is useful to design a reduced size branch line coupler. Moreover, the folded lines are used for more size reduction. Finally, the proposed branch line coupler is fabricated. The measurement results have a good agreement with the simulation results.

## II. STEP IMPEDANCE TRANSMISSION LINES (SITLs)

Generally, step impedance transmission line is a non-uniform transmission line, which can be used in microstrip circuits for size reduction, shift the spurious pass band to the higher frequency and even to suppress the multiple spurious pass bands [20, 21]. Figure 1 shows a step-impedance transmission line with three segments: $Z_2$ line with the electrical length of $\theta_2$ and two $Z_1$ lines with electrical length of $\theta_1/2$. For equaling this SITL and uniform $Z_0$ transmission line with the length of $\pi/2$ at $f_0$ frequency, two independent elements of the ABCD matrices of both SITL and uniform line have to be equal to each other at the design frequency, $f_0$. Consequently, the optimum values of $k_z=Z_2/Z_1$ and $Z_1$ to achieve the minimum discontinuity in the SITL with total length, $\theta_t$ , can be expressed as follows [12],

$$k_{z1} = \cot^2(\theta_t/2) + \sqrt{\cot^4(\theta_t/2) - 1} \qquad (1)$$

$$k_{z2} = \frac{1}{k_{z1}} = \cot^2(\theta_t/2) - \sqrt{\cot^4(\theta_t/2) - 1}\,, \qquad (2)$$

$$\frac{Z_1}{Z_0} = \left\{ \begin{array}{l} \sin(\theta_1)\cos(\theta_2) + \\ \quad [k_z \cos^2(\theta_1/2) - k_z^{-1}\sin^2(\theta_1/2)]\sin(\theta_2) \end{array} \right\}^{-1}, \qquad (3)$$

where $\theta_1 = \theta_2 = \theta_t/2$. Figure 2 shows the $k_{Z1}$, $k_{Z2}$ and $Z_1/Z_0$ versus the total electrical length, $\theta_t$. As shown in Fig. 2, increasing the impedance ratio, $k_{z1}$, which is equal to decreasing of $k_{z2}$, decreases the total electrical length of the SITLs and result in more compactness in the SITL. Also, it resulted in very low $Z_1$ and very high $Z_2$ (by chosing $k_{z1}$) or very high $Z_1$ and very low $Z_2$ (by chosing $k_{z2}$). In other words, very low (ideally zero) and very high impedances (ideally infinity) are needed in the SITL configuration to acheive maximum of compactness (ideally $\theta_t=0$). Although practical limitations to achieve very high impedance lines ($w/h<<1$) and very low impedance lines ($w/h>>1$) can limit the selection of very low and high impedance ratios. In addition, very high and low impedance ratios cause high discontinuity effects and high mode excitation in high frequency.

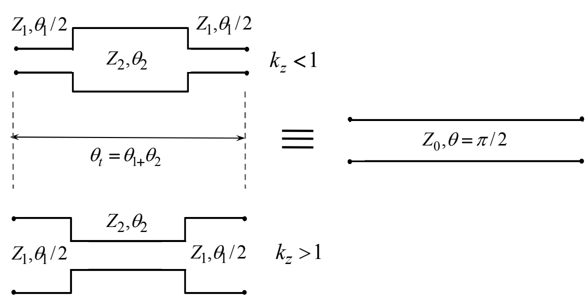



Fig. 1. The step impedance transmission line configuration (SITL).

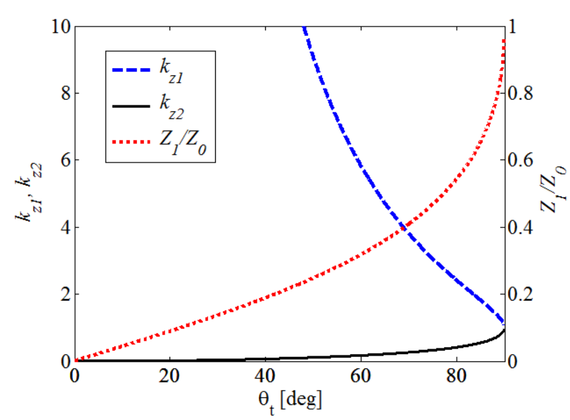



Fig. 2. Impedance ratio ($k_{z1}$ and $k_{z2}$) and normalized impedance $Z_1$ versus total electrical length of SITL, $\theta_t$.

## III. DESIGN AND RESULTS

The conventional branch line coupler is composed of the uniform transmission lines with $Z_1$=35.34 Ω and $Z_2$=50 Ω for the horizontal and vertical branches, respectively, and the electrical length of 90 degrees for all branches. Based on section II, design of branch line coupler is started to reach the desired size reduction. Step impedance transmission lines are replaced with $\lambda/4$ uniform transmission lines in the branch line coupler structure. The total electrical length of the vertical and horizontal lines are selected as $\theta_t=67.5°$. Therefore, the impedance ratios, $k_z$, which are calculated from equations (1) and (2), are $k_z$=4.24 for the vertical branches and $k_z=1/4.24$ for the horizontal ones. Then, the $Z_1$ impedance can be calculated using equation (3). The circuit layout of the proposed branch line coupler is shown in Fig. 3. The $Z_{V1}$, $Z_{V2}$, $Z_{H1}$, and $Z_{H2}$ are 19.16 Ω, 81.3 Ω, 21.74 Ω, and 92.28 Ω, respectively. The designed coupler is fabricated by using a dielectric substrate RO4003 with a relative dielectric constant of 3.5 and a thickness of 30 mils for operation at 1 GHz. Therefore, the line widths of the SITL segments are 6.36 mm and 0.7 mm for vertical SITL and 5.45 mm and 0.53 mm for horizontal SITL.

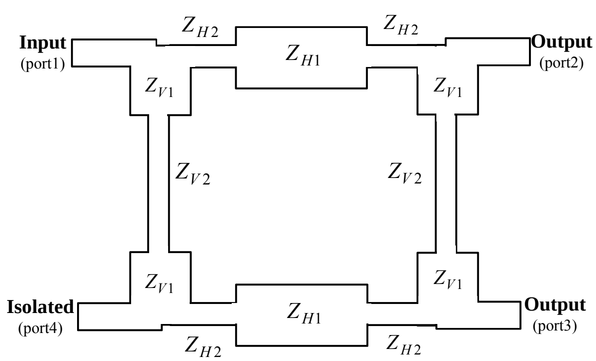



Fig. 3. Layout of the proposed SITLs branch line coupler.

The proposed coupler is theoretically simulated using MATLAB. Since the discontinuities are not accurately considered in the MATLAB simulation, we tuned the designed parameters with EM full wave simulation based on the method of moments. Figure 4 shows the photograph of the fabricated branch line coupler. The exact area of the coupler has been shown by black dash line in the figure. Also, the impedance of the vertical and horizontal segments has been added to the figure. In order to achieve more compactness, one-level folded transmission lines have been used in the high impedance segment of the vertical branches.

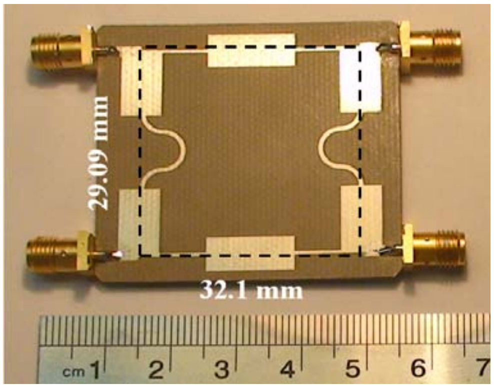
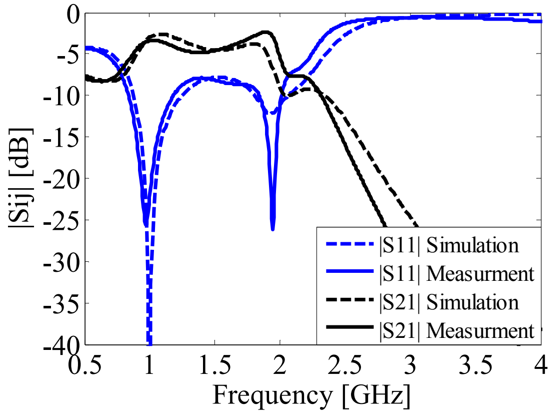



Fig. 4. The photo of the fabricated coupler.

The simulation and measurement results have been demonstrated in Fig. 5, respectively. The required circuit area for the proposed SITLs coupler is 50 % less than the circuit area of the conventional branch line coupler at the operation frequency, 1 GHz. The measured results of the fabricated coupler are in good agreement with the simulation results. There are deep nulls in the return loss and isolation at 1 GHz and the measured |S12| and |S13| are -3.36 dB and -3.4 dB, respectively. Moreover, the measured results show a good performance for the designed coupler at 1.9 GHz.



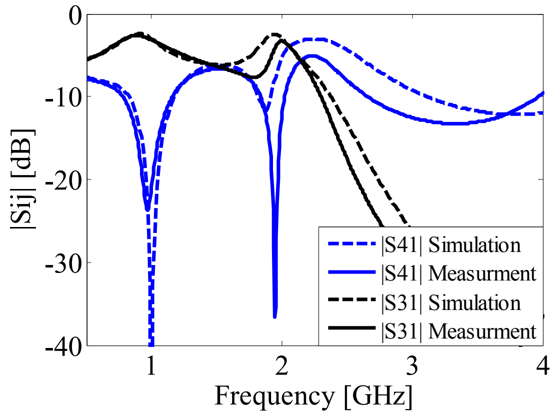



Fig. 5 Comparison of the measurement and simulation results of the branch line coupler.

## IV. CONCLUSION

Branch line coupler is proposed to operate in the reduced size. The proposed structure contains step impedance transmission lines (SITLs) instead of the uniform transmission lines. A branch line coupler has been designed and fabricated at 1 GHz. More than 50 % size reduction is obtained in the proposed branch line coupler, while the coupler performance does not change compared with the conventional one at the design frequency. The measured and simulation results have a good agreement for the fabricated coupler.

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**Seyed Hassan Seddighi** was born in Qaen, South Khorasan, Iran in 1983. He received B.S., M.S. and PhD degrees in Electrical Engineering from Iran University of Science and Technology (IUST) in 2006, 2008, and 2013, respectively. He is currently an Associate Professor in Iran University of Science and Technology, IUST. His current research interests include microstrip antenna, optical transformation, design and application of metamaterials.

**Mohammad Khalaj Amirhosseini** was born in Tehran, Iran in 1969. He received his B.Sc, M.Sc. and Ph.D. degrees from Iran University of Science and Technology (IUST) in 1992, 1994 and 1998 respectively, all in Electrical Engineering. He is currently an Associate Professor at College of Electrical Engineering of IUST. His scientific fields of interest are electromagnetic direct and inverse problems including microwaves, antennas and electromagnetic compatibility.