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# Compact Cascaded Branch Line Coupler using T-Sections Conversion

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## ABSTRACT

The branch line coupler has many applications such as phase shifters, vector modulators, amplifiers and mixers and etc. The conventional branch line coupler consists of four arms each have λ/4 length with different impedances. To broaden the bandwidth, the couplers need to be cascaded, but due to the cascading, the overall size will be very large. To minimize the overall size, a T-section conversion was used instead of each of the quarter wave length arms. The new cascaded coupler occupies 33.5% of the area needed for the conventional cascaded coupler. Added to the size reduction, the new cascaded branch line coupler has nearly the same frequency response and fractional bandwidth as the conventional cascaded branch line coupler.

***Keywords**: branch line coupler, coupling, insertion loss, isolation, T-section, and photolithographic*

## I. INTRODUCTION

The branch-line coupler is one of the most basic circuit components in various fields of microwave engineering. The branch-line couplers (sometimes called quadrature hybrids) are 3-dB directional couplers with a 90$^o$ phase difference in the two outputs ports which are the through and coupled ports. It is usually constructed using the quarter-wave (λ/4) transmission line sections, which limit the coupler operation around a single frequency and some spurious responses at the odd harmonic frequencies, Fig.1 (a). The branch line coupler [1-2] has many applications in devices such as phase shifters, vector modulators, amplifiers and mixers for achieving good return loss, as well as spurious signal rejection. However, due to the inherent narrow-band nature of the conventional single section branch line coupler that is based on single section quarter-wavelength transmission lines; its application to wide-band and multiband systems is thus limited. Over the past years, various reports concerning bandwidth enhancement [3], size reduction [4]–[6] techniques and lumped parameters [7] have been published in these literatures.

In this article, the idea of converting the quarter wave length sections into corresponding T-section will be used. This idea was used previously by the one of the authors as stepped impedance stubs to make a size reduction for a single section branch line coupler [8] and for dual band ring coupler in [9]. The same idea was used for dual band branch line and rat race couplers in [10]. Here we will use the cascaded branch line coupler to improve the overall bandwidth, but the overall size of the coupler will be large, so to minimize the size, we will convert each quarter wave section to it corresponding T-section. Also how to use the correct T-Section shunt element length to prevent overlap between shunt elements with each other will be described in details.

## II. CASCADED BRANCH LINE COUPLER

The branch line coupler with one section is a quite fundamental structure; however, it causes a narrow bandwidth. By employing the phase inverter [11], attaching four λ/4 open circuited coupled lines [12], or adding four single-section quarter wave transformers [13], bandwidth of the coupler with the one- or two-sectioned branch lines can be increased by utilizing open/short-circuited coupled-transmission lines [14] for the loose coupling (-10dB) branch line coupler; or by a circuit construction using series capacitances and short-circuited stubs freeing from shunt capacitances is employed [15]. In general, to broaden the bandwidth, the increasing of couplers' section numbers is a regular method adopted for waveguide structures [14]. Hence, several design techniques [17]-[23] have been reported for bandwidth enhancement and size reduction of branch line coupler. The small bandwidth can be overcome by adding additional sections to have multi section which, in theory, is an acceptable technique for broad banding [24]-[26]. In fact most of the cascaded branch line coupler suffers from large size. To have small size, each λ/4 section may be converted to its corresponding T-section or π-sections. Here we will focus our work on the T-section corresponding only.

### A. The T-section conversion

In this section we will convert each quarter wave length to its corresponding T-section, as shown in Fig 2a. The ABCD matrix for the single section Zo, Fig. 2(a) is given, by [8-10]:

$$M_1 = \begin{vmatrix} 0 & jZ_o \\ jY_o & 0 \end{vmatrix} \tag{1}$$

Where Zo, Yo are the transmission line characteristic impedance and is its admittance, respectively. The ABCD matrix for the T-shaped transmission line section of Fig. 2b is

$$M_T = M_2 M_3 M_2 \tag{2}$$

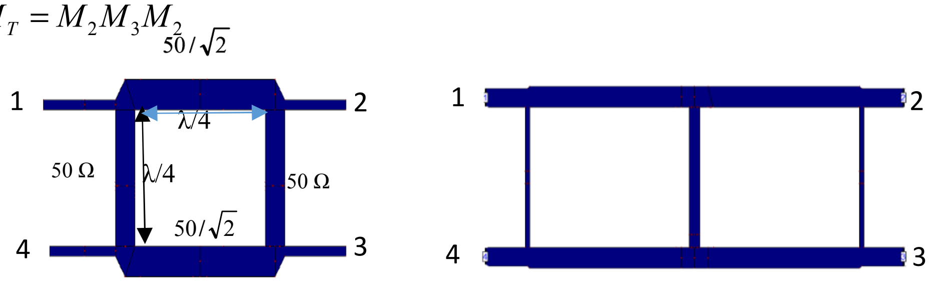



Fig.1 conventional single section and cascaded branch line coupler


Fig.2 The branch line coupler and its corresponding T-section

Where M2 and M3 are the ABCD matrices for the series and shunt elements of the T-section which are:

$$M_2 = \begin{vmatrix} \cos\theta_1 & jZ_1 \sin\theta_1 \\ jY_1 \sin\theta_1 & \cos\theta_1 \end{vmatrix} \tag{2}$$

$$M_3 = \begin{vmatrix} 1 & 0 \\ jY_2 Tan\theta_2 & 1 \end{vmatrix} \tag{3}$$

Where Zi, Yi and θi (i=1,2) are the impedances, admittances and the electrical lengths for the series and the shunt elements of the T-section, respectively. Equating the A element of the ABCD matrix in both of Eq. (1) and Eq. (2), results in

$$\tan\theta_2 = 2(Z_2 / Z_1)\cot(2\theta_1) \tag{4}$$

When equating the B element of the ABCD matrix in both of Eqs. (1-2), and with substituting of Eq. (4) result in:

$$Z_O = Z_1 \tan\theta_1 \tag{5}$$

After some mathematical derivation, we have

$$\tan\theta_1 = \frac{1}{M} \tag{6}$$

$$\tan\theta_2 = 2\frac{\cos 2\theta_1}{\sin 2\theta_1} = \frac{1}{K}(\cot\theta_1 - \tan\theta_1) \tag{7}$$

Where K = ($Z_1/Z_2$) and M = ($Z_1/Z_o$). In this case θ1, and so $\theta_T = 2\theta_1 = 2\cot^{-1}(M)$ depends only on M. The electrical $\theta_1$ can be plotted against M and $\theta_2$ plotted against $\theta_T$ as shown in Fig.3. For symmetrical and compact coupler, it should be noted that $\theta_2$ must be less than $\theta_1$ to avoid overlapping between the four stubs. The unrealizable values of circuit parameters, is that, where θ2 is greater than $\theta_1$.

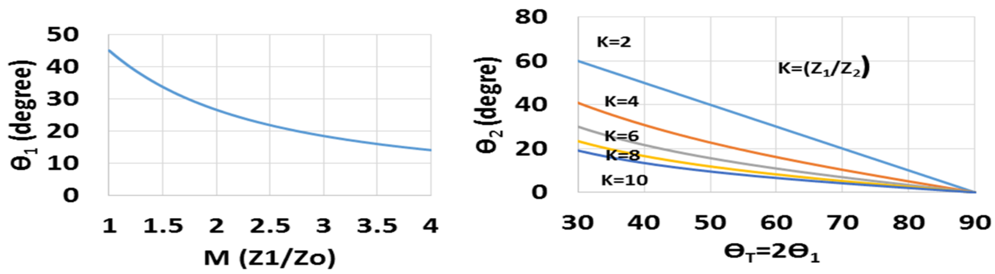



Fig.3 Design curves for the T-section conversion

## B. Conventional cascaded branch line coupler

Based on the tables given by Levy et al [14],[23], the cascaded two sections will have the following impedance values as shown in Fig.4, where $Z_{b1}$=46.33 Ω, $Z_{a1}$=110.01 Ω and $Z_{a2}$=71.43 Ω, where the termination ports will be have $Z_o$=50 Ω.

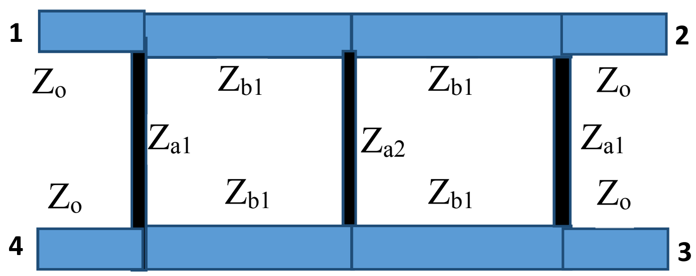
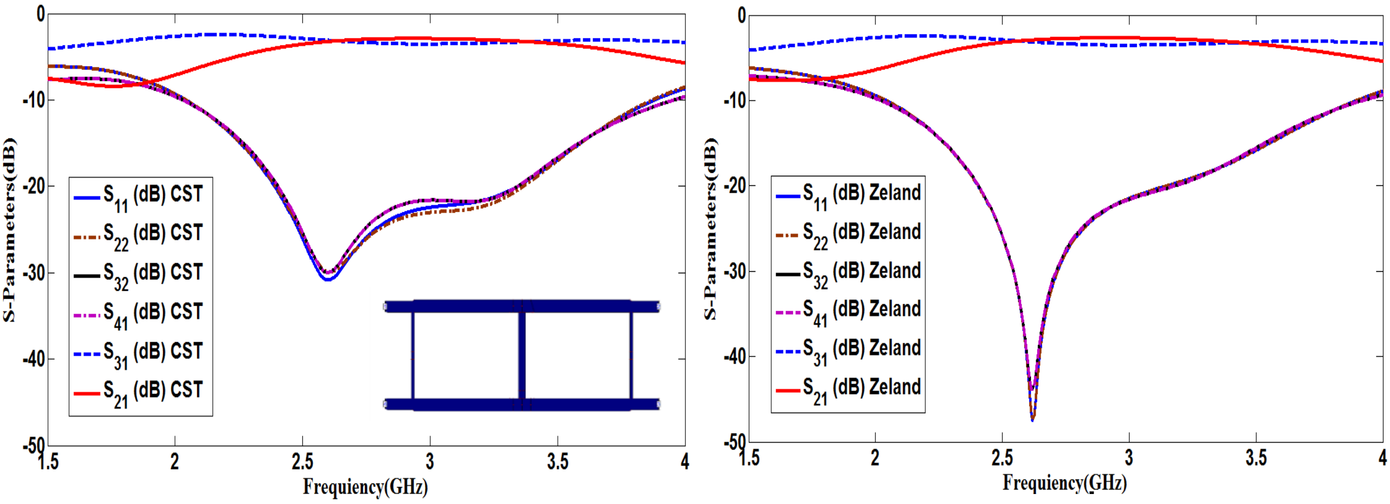



Fig.4 two sections cascaded branch line coupler

The above impedances value were designed on RT/Duriod (εr=2.2, h=0.7874 mm and tan δ=0.00019) at 3GHz as a centre frequency. The widths and the lengths for each of the above impedance will be as in Table 1. The above values are simulated using the IE3D and CST simulators and the Scattering parameters are shown in Fig.5a,b. The return loss S11 and the isolation loss S32 are less than -10 dB through the frequency range 2.428-3.536Hz. The values for the coupling S21 and S31 are equal to -3±0.5 dB in the same range, which achieve a bandwidth of 1.1GHz with 37.15% fractional bandwidth which illustrates that, the cascaded branch line coupler gives broad bandwidth. The circuit overall size is 39.7x31.4 $mm^2$.

Table 1 The arms impedance and its corresponding width and length

| | Impedance (Ω) | W(mm) | L (mm) |
|---|---|---|---|
| $Z_{a1}$ | 110.01 | 0.516 | 20.712 |
| $Z_{a2}$ | 71.43 | 1.315 | 18.62 |
| $Z_{b1}$ | 46.33 | 2.66 | 18.22 |




(a) (b)

Fig.5 The S-parameters for the two section cascaded branch line coupler for both of (a) CST simulators and (b) IE3D Zeland

## C. T-section Conversion cascaded branch line coupler

All the series and shunt λ/4 sections of the described cascaded branch line coupler will be converted to its corresponding T-section with appropriate values for M and K. These values are used to design the cascaded branch line coupler on RT/Duriod (εr=2.2, h=0.7874 mm and tan δ=0.00019) at 3GHz as a centre frequency. The design values are given in Table.2 and its construction is shown in Fig.6.

The T-conversion cascaded branch line coupler is simulated using both of Zeland and CST simulators, where, their S-parameters are given as shown in Fig.7. The overall size of the T-conversion cascaded branch line coupler is 24.43x17.12 $mm^2$, so it occupy 33.5% of the conventional cascaded branch line coupler , so it achieve an area saving by 66.5%. The return loss S11 and isolation loss S32 are less than -15 dB in the operating band 2.38-3.37 GHz which is better than the simulation of the conventional cascaded branch line coupler. The Coupling coefficients S21 and S31 are -3dB±0.5 in the same frequency band. The bandwidth is nearly 1 GHz which achieves a fractional bandwidth of 34.4%.

Table 2: T-conversion impedance, widths and lengths

| $Z_{b1}$ conversion<br>M=2 and K=4 | | $Z_{a1}$ conversion<br>M=1.4 and K=2 | | $Z_{a2}$ conversion<br>M=2 and K=4 | |
|---|---|---|---|---|---|
| $S_{eries}$=92.7Ω<br>W=0.78mm<br>L=5.273mm | $Z_{series}$=23.2Ω<br>W=6.72mm<br>L=4.04 mm | $Z_{series}$=35.5Ω<br>W=0.174 mm<br>L=7.67 mm | $Z_{series}$=92.7 Ω<br>W=1.142 mm<br>L=3.93mm | $Z_{series}$=100Ω<br>W=0..66mm<br>L=7.49 mm | $Z_{series}$=50 Ω<br>W=2.38 mm<br>L=3.84 mm |

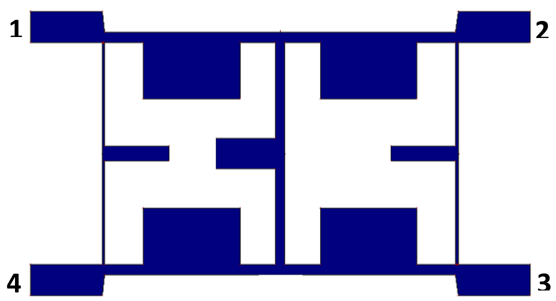
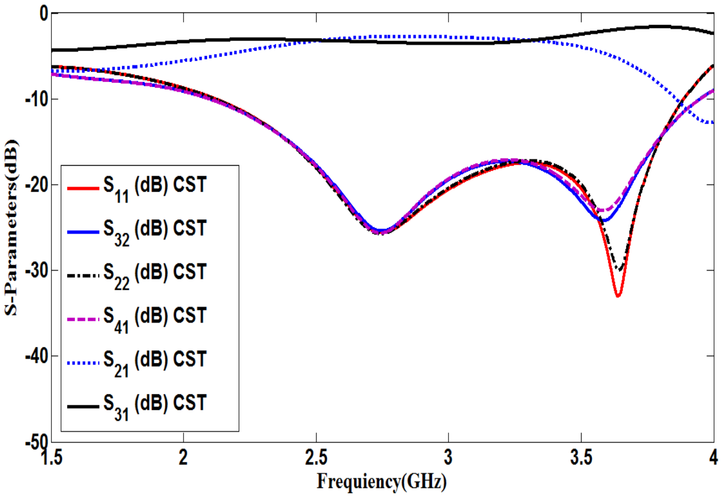
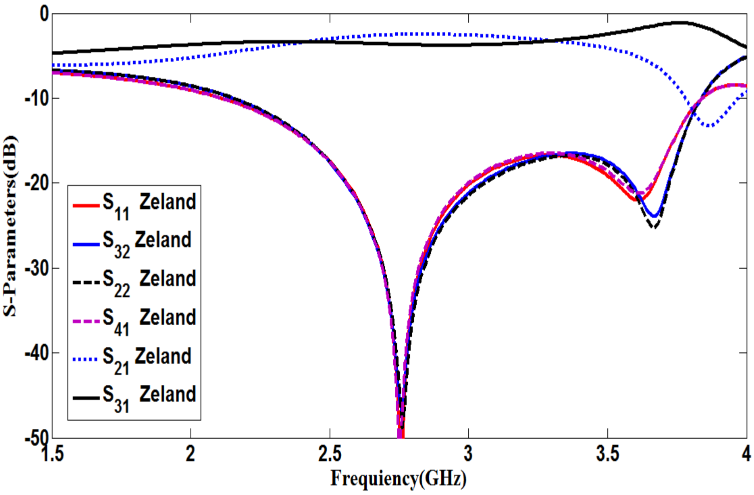



Fig.6 The cascaded branch line coupler with using T-section conversion.




(a)




(b)

Fig.7 The S-parameters for the T-Conversion cascaded branch line coupler for both of (a) CST simulators and (b) IE3D Zeland

## III. Fabrication and Measurements

Both the conventional and compact cascaded branch line couplers were fabricated based on design parameters given in Table 1&2, using thin film technology and photolithographic technique at the microstrip laboratory at the Electronics Research Institute. Figure 8 shows the photograph of the realized compact cascaded coupler and the realized regular cascaded coupler and it is clear that, the size reduction for the new coupler. Both couplers were measured using the Vector Network Analyzer. Figure 9 shows the measured performances of regular cascaded branch line coupler; where; the coupling S21 and S31 are around (-3±0.5) for the operating band from 2.5 to 3GHz only where the isolation S41 is deteriorated above 3 GHz. Figure 9 illustrates the measurement for the compact cascaded branch line coupler; where the coupling S21 and S31 are around (-3dB±1) form 2.4 GHz up to 3.4 GHz. The return loss S11 and the isolation loss S41 are less than -18 dB over all the operating bandwidth. The coupler has a bandwidth with around 1 GHz and centre frequency of 2.9 GHz. The shift in the centre frequency may be attributed to the effect of the open stubs section added to the coupling between adjacent branches.

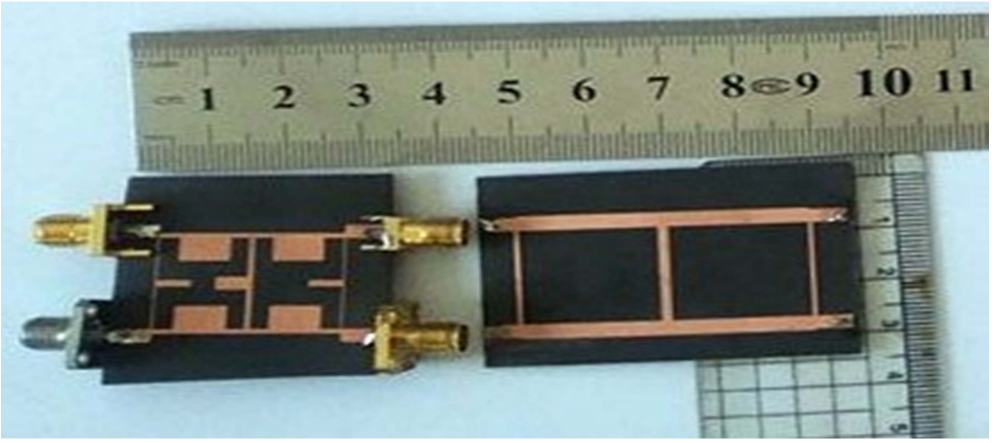


Fig.8 the photo of the realized conventional and cascaded branch line coupler

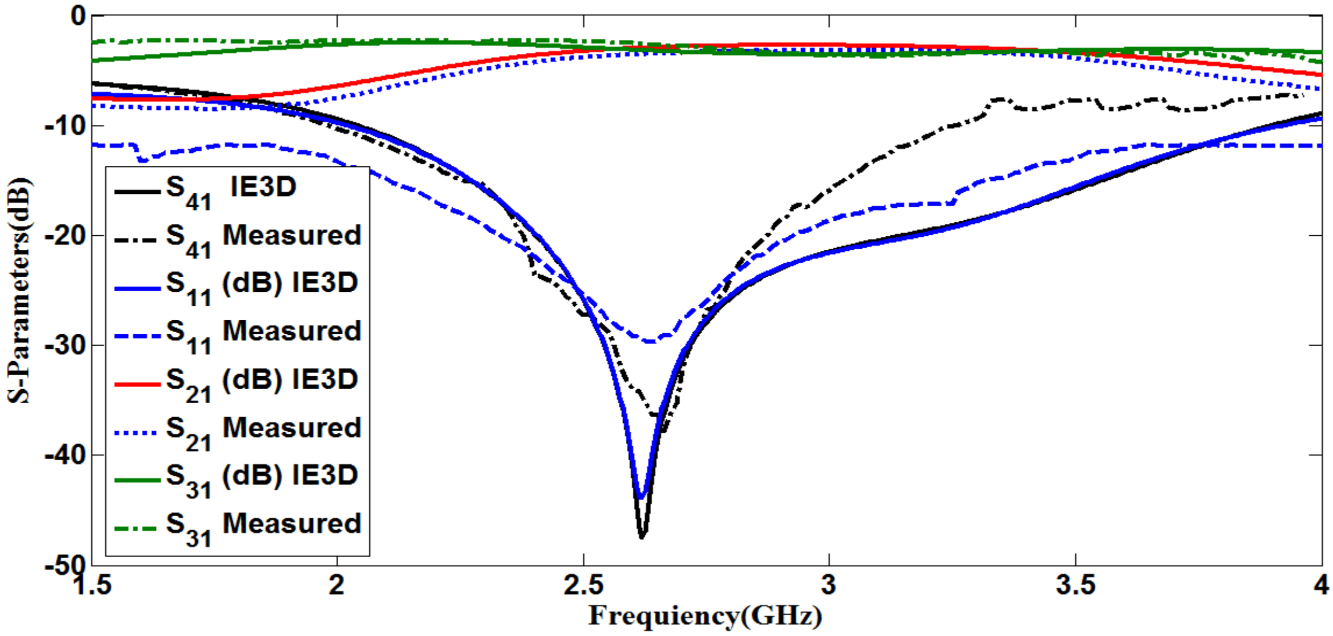



Fig.9 The comparisons between the simulated and measured S-parameters for the cascaded branch line coupler

two section cascaded branch line coupler

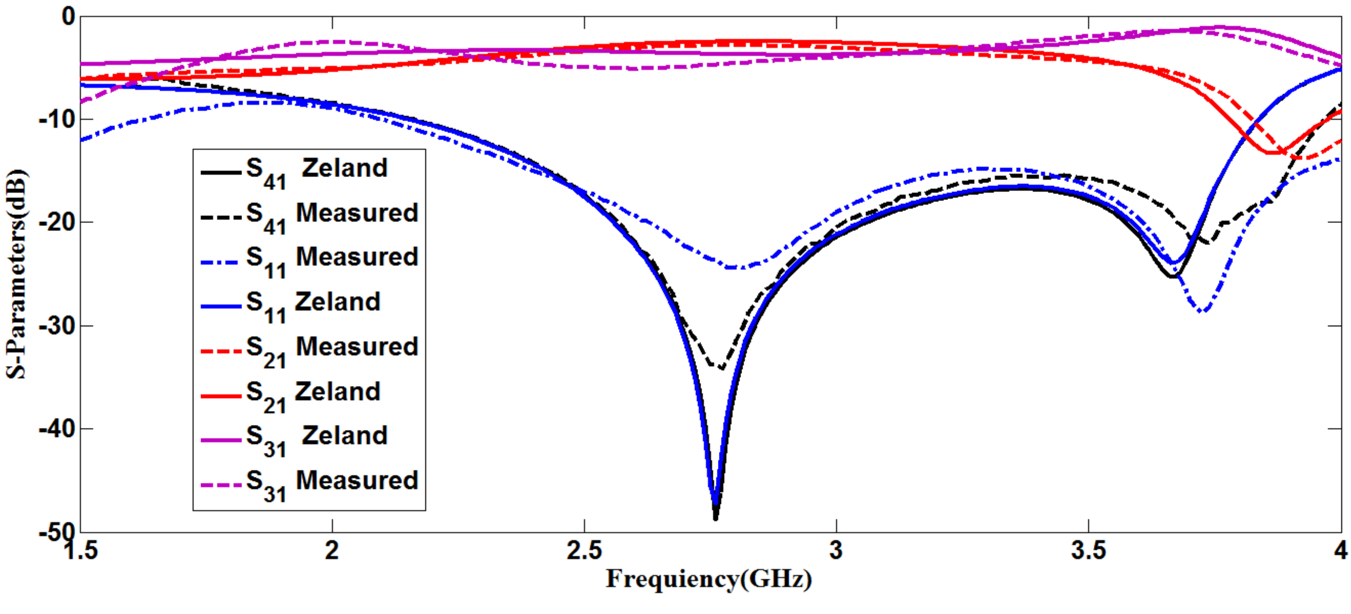



Fig.10. The comparisons between the simulated and measured S-parameters for the realized compact branch line coupler

## IV. CONCLUSION

The conversion of a quarter wavelengths to its corresponding T-section was discussed. A design curves for different values for M and K are given which facilitate the design to any T-conversion ratios. A design were done on RT/Duriod (εr=2.2, h=0.7874 mm and tan δ=0.00019) at 3GHz as centre frequency. The simulated results of the designed T- conversion cascaded branch line coupler are good and have nearly the same frequency response as the conventional cascaded branch line coupler. The new design achieve a 66.5% area saving, while the bandwidth is around 1GHz. The realized compact cascaded branch line couplers have the same frequency response as the simulated couplers.

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