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DUAL BAND BRANCH LINE COUPLER USING T AND Π SECTIONS

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Abstract

A dual band branch line coupler is designed using the conversion of the quarter wavelength transmission line sections into its corresponding T or Π- sections. The relations and some designed curves for the operation of dual band branch line coupler are given for both types of T and Π-sections conversion. The simulation results give a good results for the design at the two GSM bands (925-960 MHz), (1930-1960 MHz). As an example, the dual band branch line coupler using the Π- sections was realized and the measured results are in good agreement with the simulated results.

1. 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. 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 design 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.

Dual-band components are devices that exhibit certain functionality at two different frequencies. Such devices are of interest for modern microwave and wireless communication systems such as GSM, Bluetooth, WLAN, and WiMAX which required to support multiple wireless standards. In [8], the author present the design of branch-line coupler that can operate at two arbitrary frequencies 900/2000MHz, where all branch lines are only a quarter-wavelength long which evaluated at the mid-frequency of the two operating bands, but the authors use four short circuit stubs at the connections of the four quarter wave section external to the coupler structure, added to the limited frequency ratio range (R=1.5 to 3) Lin et al [9] present compact dual-band branch-line coupler operated at 900/2000MHz that was designed using E-shaped dual-band transmission lines. In [10], the authors construct the dual band branch line coupler operated at 2.4/5.8GHz with using stepped-impedance with additional stepped-impedance stubs to branches. Another types of a dual band branch line couplers were done using different configurations such as, the left-handed transmission lines [11], the cross-coupled branch-line structure [12], the rectangular patches [13], and the use of stub lines at the input ports [8] or stubs at the center of the branches [14-15].

In this article, the design was an extension to the previous work done by the author that was presented at [16-17] for the dual band Wilkinson power divider. Here, each (λ/4) section of the conventional branch line coupler is converted to T or Π sections. The relation of such conversion are given and some designed curves are presented. Two branch line couplers using the T and Π-sections was designed and simulated at GSM bands (925-960 MHz) and (1930-1960 MHz). As an example, the dual band branch line coupler using the Π-sections was realized on RT/Duroid (ε_r =2.2, h=0.7874 mm) and the measured results are in good agreement with the simulated results.

2. The Dual Band Conversion

The dual band operation for the branch line coupler can be done using the T or Π sections conversion as will be illustrated in the following subsections:

2.1 Dual Band Operation using the T-Section Transmission Line

Each quarter wave length section (λ/4) of the conventional branch line coupler of Fig. 1(a) will be converted to T-shaped transmission line section, Fig.1c. The equivalence between the (λ/4) transmission line section, Fig. 1b and the T-section is investigated utilizing the ABCD matrices [18]. The ABCD matrix for the original transmission line, which has (λ/4) length shown in Fig. 1b is given by

$$M_1 = \begin{vmatrix} 0 & jZ_1 \\ jY_1 & 0 \end{vmatrix} \quad (1)$$

Where Z_1, Y_1 are the transmission line characteristic impedance and is its admittance, respectively.

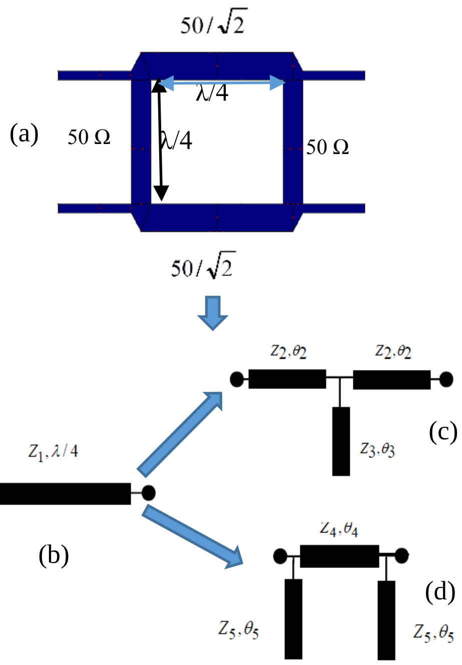


Fig.1 The branch line coupler and its corresponding of T and Π-sections

The ABCD matrix for the T-shaped transmission line section of Fig. 1c is

$$M_T = M_2 M_3 M_2 \quad (2)$$

Where M_2 and M_3 are the ABCD matrices for the series and shunt elements of the T-section which are:

$$M_2 = \begin{vmatrix} \cos\theta_2 & jZ_2\sin\theta_2 \\ jY_2\sin\theta_2 & \cos\theta_2 \end{vmatrix} \quad (3)$$

$$M_3 = \begin{vmatrix} 1 & 0 \\ jY_3 Tan\theta_3 & 1 \end{vmatrix} \quad (4)$$

Where Z_i, Y_i and θ_i (i=2,3) 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:

$$\tan\theta_3 = 2(Z_3/Z_2)\cot(2\theta_2) \quad (5)$$

When equating the B element of the ABCD matrix in both of Eqs. (1-2), and with substituting of Eq. (5) result in:

$$Z_1 = Z_2\tan\theta_2 \quad (6)$$

For the purpose of dual band operation, the necessary conditions implied by satisfying Eq. (6), [14] are:

$$Z_2\tan\theta_{2f1} = \pm Z_1 \quad (7.a)$$

$$Z_2\tan\theta_{2f2} = \pm Z_1 \quad (7.b)$$

Where θ_{2f1} and θ_{2f2} are the electrical lengths of the series stub at the two operating frequencies $f_1$and f_2 respectively, where ($f_2 > f_1$). The solution for Eq. (7) is given by:

$$\theta_{2f2} = n\pi \pm \theta_{2f1} \qquad n=1, 2, 3\ldots \quad (8)$$

$$\theta_{2f2}/\theta_{2f1} = f_2/f_1 = R \quad (9)$$

Based on Eq. (5) and Eq. (9), the following conditions can be deduced:

$$\theta_{3f2} = m\pi \pm \theta_{3f1} \qquad m=1, 2, 3\ldots \quad (10)$$

$$\theta_{3f2}/\theta_{3f1} = f_2/f_1 = R \quad (11)$$

For practical small size transmission line, choose

$$n=m=1 \quad (12)$$

The design procedure for branch line coupler that operates at dual bands using T-sections can be presented as follows:-

- The value of the frequency ratio R is found from Eq. (9)
- The corresponding electrical length of the series transmission line will be:

$$\theta_{2f1} = \pi/(R+1) \quad (13.a)$$

$$\theta_{2f2} = R.\theta_{2f1} \quad (13.b)$$

- The corresponding electrical length of the shunt stub will be:

$$\theta_{3f1} = 2\pi/(R+1) = 2\theta_{2f1} \quad (13.c)$$

$$\theta_{3f2} = R.\theta_{3f1} = 2\theta_{2f2} \quad (13.d)$$

- The values of impedances Z_2 and Z_3 can be calculated as follows:

$$Z_2 = Z_1/\tan\theta_{2f1} \quad (13.e)$$

$$Z_3 = 0.5Z_2\tan^2(2\theta_{2f1}) \quad (13.f)$$

The variation of the frequency ratio (R) against the electrical lengths (θ_2, θ_3) is shown in Fig.2. The variation of the characteristic impedances (Z_2, Z_3) of the T-sections against the frequency ratio (R) for the 50Ω and $50/\sqrt{2}$ impedances is shown in Fig.3. Due to the fabrication tolerance, the practical ranges for the microstrip impedance is limited to the range

(20<Z<160Ω), so the available frequency ratio ranges for both impedance together are (1.9<R<2.32) and (4.72<R<8) which corresponding to the electrical lengths ranges $(54.22 < \theta_{2f1} < 62.07)$ and $(20 < \theta_{2f1} < 31.47)$, respectively. Due to limited ranges for the microstrip impedance, another article under study will overcome such problem with using the defected ground structures techniques, to make large impedance values can be realized.

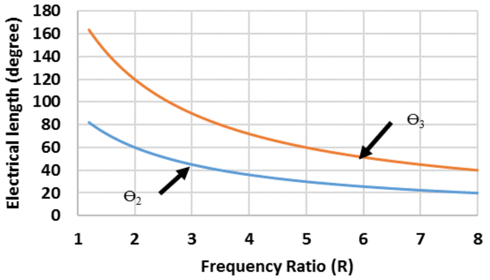


Fig.2 The variation of the electrical lengths against the frequency ratio (R)

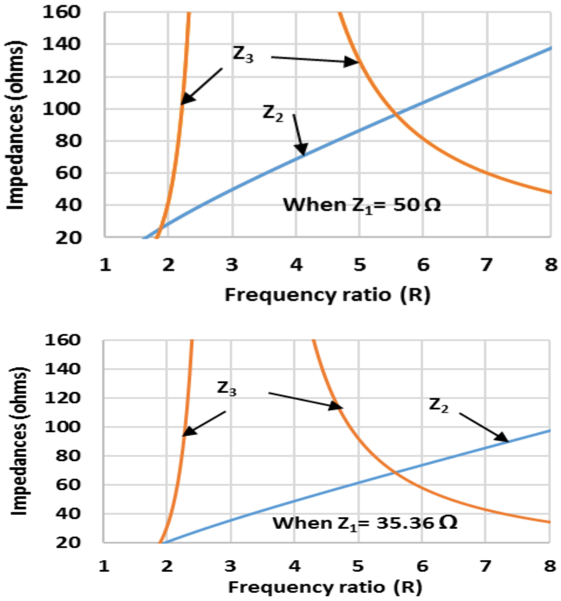


Fig.3 The variation of T- section impedances against the frequency ratio (R)

2.2 Dual Band Operation using the Π-Section Transmission Line

Each quarter wavelength (λ/4) section of the conventional branch line coupler, Fig.1a, will be converted to Π-shaped transmission line model. The Π-shaped transmission line model shown in Fig.1d is consisted of two identical shunt open stubs (Z_5, θ_5) and one series transmission line connecting the two stubs (Z_4, θ_4). The ABCD matrix for the original transmission line is given in Eq.1, while, the ABCD matrix for the Π-shaped transmission line section of Fig.1d is given by:

$$M_T = M_5 M_4 M_5 \tag{14}$$

Where

$$M_4 = \begin{vmatrix} \cos\theta_4 & jZ_4 \sin\theta_4 \\ jY_4 \sin\theta_4 & \cos\theta_4 \end{vmatrix} \tag{15}$$

$$M_5 = \begin{vmatrix} 1 & 0 \\ jY_5 \tan\theta_5 & 1 \end{vmatrix} \tag{16}$$

Equating the A element of the ABCD matrix from Eqs. (1) and (14), results in:

$$\tan\theta_5 = (Z_5 / Z_4).\cot\theta_4 \tag{17}$$

Equating the B element of the ABCD matrix from Eqs. (1) and (14), the following equation is obtained

$$Z_1 = Z_4 \sin\theta_4 \tag{18}$$

For the purpose of dual band operation, it is necessary to modify Eq. (18) as follows:

$$Z_4 \sin\theta_{4f1} = \pm Z_1 \tag{19.a}$$

$$Z_4 \sin\theta_{4f2} = \pm Z_1 \tag{19.b}$$

Where θ_{4f1} and θ_{4f2} are the electrical lengths of the series element of the Π-section at the two operating frequencies f_1 and f_2 respectively, where ($f_2 > f_1$). The solution for Eq. (19) is given by:

$$\theta_{4f2} = n\pi - \theta_{4f1} \qquad \text{n=1, 2, 3,..} \tag{20}$$

The relation between the electrical lengths and the dual band operating frequencies is given by:

$$\theta_{4f2} / \theta_{4f1} = f_2 / f_1 = R \tag{21}$$

Equation (21) can be modified by Equation (20) to the following form

$$\theta_{4f1} = n\pi / (R+1) \tag{22}$$

$$\theta_{4f2} = nR\pi / (R+1) \tag{23}$$

Based on Equation (17) and (21), the following condition can be deduced

$$\theta_{5f2} = m\pi - \theta_{5f1}, \qquad \text{m=1, 2, 3,…} \tag{24}$$

$$\theta_{5f2} / \theta_{5f1} = f_2 / f_1 = R \tag{25}$$

Equations (24) and (25) can be modified to the following relations:

$$\theta_{5f1} = m\pi / (R+1) \tag{26}$$

$$\theta_{5f2} = mR\pi / (R+1) \tag{27}$$

For compact design, *m*, n=1 is chosen. From the above equations it is found that, the design procedure for the branch line coupler operates at dual band can be presented as follows:

- The value of the required frequency ratio *R* is found from Eq. (21);
- The electrical length corresponding to series transmission line is found from Eq. (22), with *n* =1 for compact size;

- The electrical length corresponding to shunt stub is found from Eq. (26), with m =1 for compact size;
- The values of impedances Z_4 and Z_5 can be calculated as follows:

$$Z_4 = Z_1 / \sin\theta_{4f1} \tag{28}$$

$$Z_5 = Z_4 . \tan\theta_{4f1} . \tan\theta_{5f1} \tag{29}$$

Figure 4 illustrates the variations of electrical lengths Θ_{4f1} (Θ_{5f1}= Θ_{4f1}) against the frequency ratio (R), while Fig.5 illustrates the variation of the characteristic impedances Z_4 and Z_5 against the frequency ratio R. For practical realization of microstrip lines, the characteristic impedance should be bounded in the region (20<Z<160Ω), so the corresponding practical frequency ratio must be in the range $(1.8 < R < 5.8)$ for both impedances (Z_1=50Ω, $Z_1 = 50/\sqrt{2}$) which is corresponding to $(26.47^o < \theta_{4,5} < 64.28^o)$.

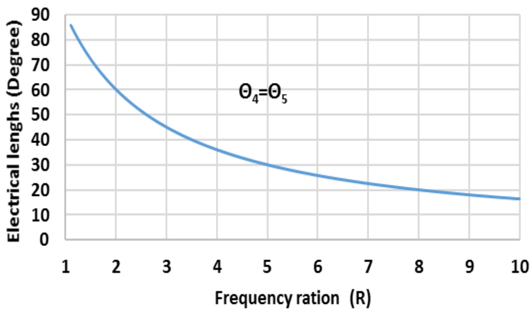


Fig.4 The variation of the electrical lengths against the frequency ratio (R)

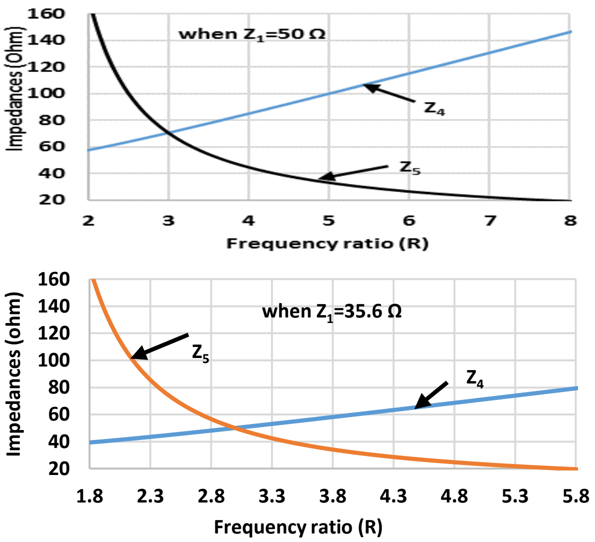


Fig.5 The variation of Π-impedances against the frequency ratio (R)

3. Simulation Results

The dual band branch line coupler using T-sections or Π-sections was simulated using the readymade IE3D software package as follows:

3.1 Simulation for Dual Band Branch Line Coupler using T-Sections

The dual band branch line coupler is designed to operate at the GSM-bands (925-960MHz) and (1930-1960MHz). The required operating frequencies are 942.5 MHz and 1945 MHz, so, the frequency ratio will be R=2.064. Each λ/4 branch of the conventional branch line coupler is replaced by its corresponding T-section. The values for $\theta_{2f1}, \theta_{3f1}$, Z_2 and Z_3 will be 58.75°, 117.51°, 30.34Ω and 56.02 Ω, respectively when Z_1=50 Ω, and will be 58.75°, 117.51°, 21.46Ω and 39.617 Ω, respectively, when $Z_1 = 50/\sqrt{2}$ Ω. The T-section branch line coupler is design on RT/Duroid 5880 $(\varepsilon_r = 2.2, h = 0.7874mm, \tan\delta = 0.00019)$.

The sketch of the designed T-section branch line coupler is shown in Fig. 6. The simulation results are shown in Fig.7, where, for the GSM band (925-960 MHz), the reflection at port-1 is $(S_{11} \le -17.3dB)$, while the coupling coefficients at port-2 and port-3 are $(-3.13dB \le S_{21} \le -2.74dB)$, $(-4.2dB \le S_{31} \le -3.77dB)$ respectively, and the isolation at port-4 and the isolation between the output ports 2,3 are $(S_{41} \le -17.44dB)$, $(S_{32} \le -17.44dB)$, respectively. For the GSM band (1930-1960 MHz), the reflection at port-1 is $(S_{11} \le -15.14dB)$, while the coupling at port-2 and port-3 are $(-4dB \le S_{21} \le -3.4dB)$, $(-3.36dB \le S_{31} \le -3.0dB)$, respectively, and the isolation at port 4 and the isolation between the output ports 2,3 will be $(S_{41} \le -17.53dB)$, $(S_{32} \le -17.51dB)$, respectively.

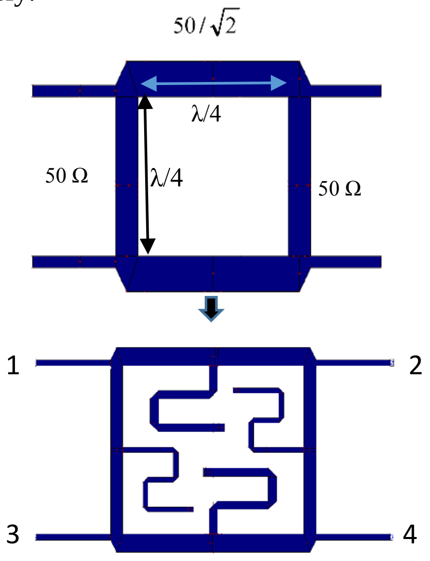


Fig.6 The conventional branch line coupler and its corresponding dual band branch line coupler using the T-section conversion

3.2 Simulation for Dual Band Branch Line Coupler using Π-Sections

The dual band branch line coupler using the Π-section conversion is designed at the same two GSM bands. The values for $\theta_{4f1}, \theta_{5f1}$, Z_4 and Z_5 will be 58.75°, 58.75°, 58.48Ω and 158.83Ω, respectively when Z_1=50 Ω and will be 58.75°, 58.75° , 41.357Ω and 112.33Ω, respectively, when Z_1= $50/\sqrt{2}$ Ω.

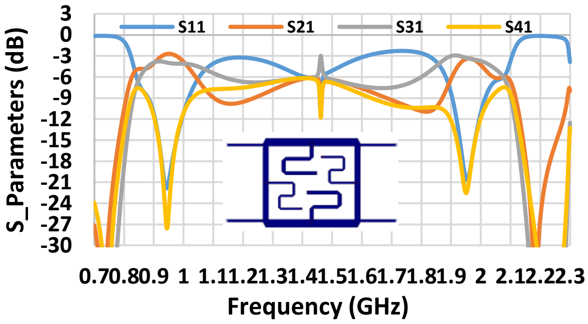


Fig.7 The Simulated (S_{11}, S_{21}, S_{31}, S_{41}) for the dual band branch line coupler using the T-section conversion

The Π-section branch line coupler is design on RT/Duroid 5880 $(\varepsilon_r = 2.2, h = 0.787mm, \tan\delta = 0.00019)$. The sketch of the designed T-section branch line coupler is shown in Fig.8, where each two adjacent shunt open circuit stubs are collect together in parallel as one stub. The design has been investigated using IE3D full wave EM simulator, and the simulation results are shown in Fig.9.

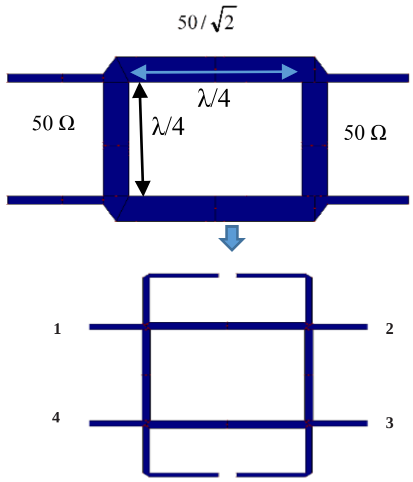


Fig.8 The branch line coupler and its impedance conversion to Π-sections and to the Π- sections

Form the simulation results, it is clear that, the for the GSM band (925-960 MHz), the reflection at port-1 is $(S_{11} \le -23.22dB)$, while the coupling at output port-2 and port-3 are $(-2.93dB \le S_{21} \le -2.77dB)$ and $(-3.53dB \le S_{31} \le -3.42dB)$, respectively, while, the isolation at port-4 and the isolation between the two output ports 2, 3 are $(S_{41} \le -22.67dB)$, $(S_{32} \le -22.67dB)$, respectively. For the GSM band (1930-1960 MHz), the reflection at port-1 is $(S_{11} \le -20.74dB)$, while the coupling at port-2 and port-3 are $(-3.91dB \le S_{21} \le -3.56dB)$ and $(-2.86dB \le S_{31} \le -2.7dB)$, respectively, the isolation at port 4 and the isolation between the two output ports 2, 3 are $(S_{41} \le -22.29dB)$ and $(S_{32} \le -22.29dB)$, respectively.

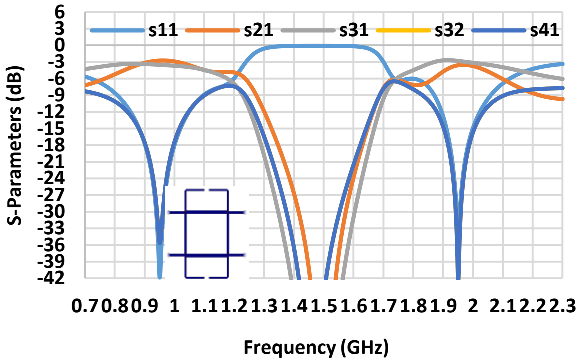


Fig.9 The Simulated (S_{11}, S_{21}, S_{31}, S_{32}, S_{41}) for the dual band branch line coupler using the Π-section conversion

4. Fabrication and Measurement

As an example, the dual band branch line coupler using Π-sections was realized using thin film technology and photolithographic techniques at the microstrip laboratory and the photo of the realized coupler is shown in Fig.10, while the measured S-parameters are shown in Fig.11. Form the measurement results, it is clear that, the for the GSM band (925-960 MHz), the reflection at port-1 is $(S_{11} \le -15.461dB)$, while the coupling at output port-2 is $(-3.97dB \le S_{21} \le -3.51dB)$, and at port-3 is $(-3.53dB \le S_{31} \le -3.42dB)$, while, the isolation at port-4 is $(S_{41} \le -18.75dB)$. For the GSM band (1930-1960 MHz), the reflection at port-1 is $(S_{11} \le -19.32dB)$, while the coupling at port-2 is $(-4.06dB \le S_{21} \le -3.35dB)$, while it at port-3 is $(-3.74dB \le S_{31} \le -3.32dB)$. The isolation at port-4 is $(S_{41} \le -19.50dB)$. The measured results are in good agreement with the simulated results.

Conclusion

A dual band branch line coupler is designed using the conversion of the quarter wavelength transmission line sections into its corresponding T or Π- sections. The relations and curves for the design of dual band branch line coupler are given for both types of T and Π-sections conversion. The dual band branch line coupler using the Π- sections was realized as an example to operate at the two GSM bands and it gives good agreement with the simulated results.

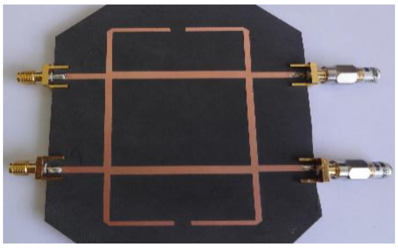
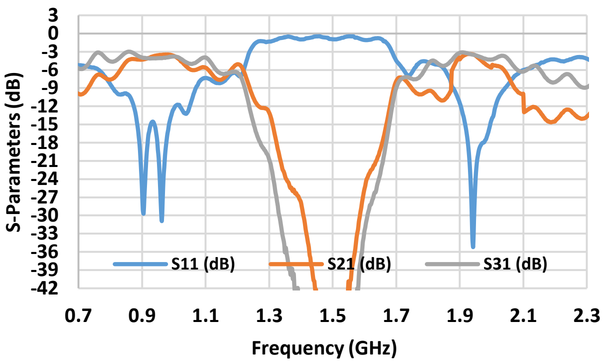


Fig.10 the photo of the realized coupler using the Π conversion



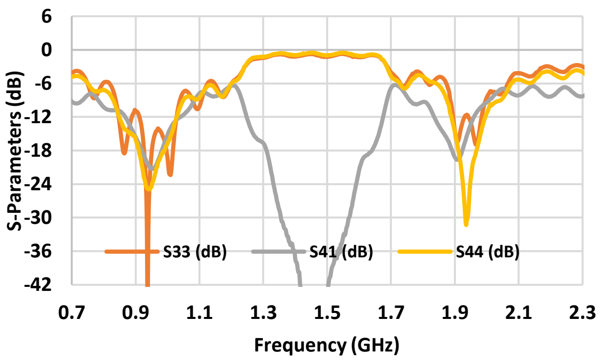


Fig.11 The measured S-parameters of the realized dual band branch line coupler using the Π conversion

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