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Dual Band Branch-Line Coupler Using Stub-Loaded Lines

Heba EL- HALABI
Beirut Arab University

Manal K. FATTOUM
Beirut Arab University

Abstract: This paper describes the design of a center-tapped stub loaded branch line coupler for dual band operation. In this design, the quarter wavelength transmission lines of the conventional branch line coupler are replaced with an equivalent T-shaped transmission lines. Design equations for evaluating the characteristic impedances and the electrical lengths of the coupler arms are derived based on ABCD-matrix. The proposed coupler operates at 2 and 4 GHz corresponding to S-band applications like weather radar and satellite communications. Simulations are done using Agilent ADS software on Roger RO4003 substrate with dielectric constant of 3.38. The simulated results of the S-parameters show that the return loss and isolation loss are well below -20 dB at the designed frequencies. The amplitude imbalance between the two output ports S_{21} and S_{31} does not exceed 0.3 dB. The phase difference between the output ports of the designed coupler is -89.5^o at 2 GHz and -270^o at 4 GHz. Efforts are done on reducing the size of the coupler by folding the stub towards the inner area of the coupler to be ready for fabrication.

Keywords: Branch line coupler, Dual-band, Stub loaded transmission lines

Introduction

Branch-line coupler is a passive microwave component used in various wireless communication systems. It is a four port device constructed from four quarter-wavelength ($\lambda/4$) transmission lines and is used to split/combine microwave signals and provide 90^o phase shift between the output ports (Pozar, 2012). Recently developing a dual-band branch line coupler is drawing a lot of attention. Stub loaded transmission lines is among the popular techniques for obtaining dual-band operation of a branch line coupler. Stubs can be placed at the center of the arms of the branch line coupler (Feng et al., 2020; Zhang et al., 2007), or at their input (Kim, Lee & Park, 2008). A combination of stub loading and unequal arm lengths is also proposed in Kim, et al. (2008) and Park (2009). Other techniques reported to attain dual-band operation of a coupler include: Stepped-impedance stubs (Chin et al., 2010), orthogonal coupled branches (Zhan et al.,2018) and coupled lines (Feng et al.,2018). In this paper, the design of a dual-band center-tapped stub loaded branch line coupler is presented based on the T-network in Zhang & Chen (2007). In Section II, the methodology used for calculating the impedances and electrical lengths values is investigated and verified by the S-parameters simulations conducted in section III. Finally, the paper is concluded in section IV.

Theoretical Analysis of the Stub Loaded Coupler

The structure of the proposed dual-band coupler is shown in Figure 1. To each quarter wavelength arm of the conventional coupler, a stub is attached to the arm center thus transforming the ordinary quarter wavelength transmission line into a T-shaped line. Figure 2 shows the conventional quarter wavelength transmission line and its equivalent T-shaped line, where Z_o, θ_o correspond to the characteristic impedance and electrical length of the conventional (λ/4) coupler arm and Z_1, Z_2, θ_1 and θ_2 correspond to the T-shaped equivalent line. To obtain design equations ABCD-matrix analysis for cascaded network is used.

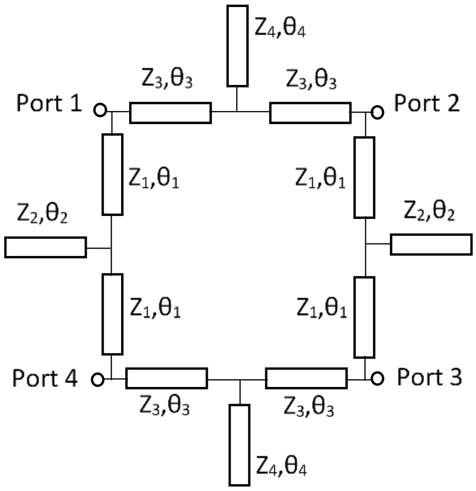

Figure 1. Proposed planar dual-band branch line coupler

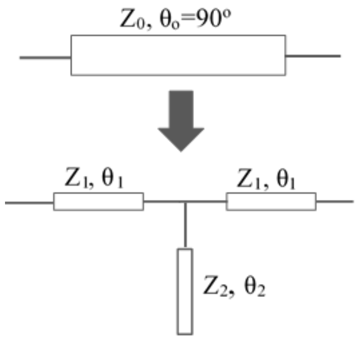

Figure 2. Conventional quarter wavelength line and its T-shaped line Equivalent

The ABCD-matrix of a conventional quarter-wavelength (λ/4) transmission line with characteristic impedance Z_o is:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{\lambda/4} = \begin{bmatrix} 0 & jZ_o \\ \frac{j}{Z_o} & 0 \end{bmatrix} \quad (1)$$

The ABCD-matrix of a T-shaped line consisting of cascaded sections is:

$$\begin{bmatrix} A_T & B_T \\ C_T & D_T \end{bmatrix}_{T-shaped} = \begin{bmatrix} cos\theta_1 & jZ_1 sin\theta_1 \\ j\frac{sin\theta_1}{Z_1} & cos\theta_1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ j\frac{tan\theta_2}{Z_2} & 1 \end{bmatrix} \begin{bmatrix} cos\theta_1 & jZ_1 sin\theta_1 \\ j\frac{sin\theta_1}{Z_1} & cos\theta_1 \end{bmatrix} \quad (2)$$

In order to match the suggested T-shaped line to the conventional λ/4 line, the parameters of the $[ABCD]_{\lambda/4}$ are equated to the parameters of $[ABCD]_{T\text{-shaped}}$ to get:

$$Z_1 = \frac{Z_o}{tan\theta_1} \quad (3)$$

$$Z_2 = \frac{Z_1}{2} \tan(2\theta_1) tan\theta_2 \quad (4)$$

Since the electrical length θ_1 is function of frequency, θ_1 is defined as $\pi/2$ at f_c , and θ_2 is defined as $2\theta_1$, where f_c is the center frequency of the two pass band frequencies f_1 and f_2 defined as $f_c = (f_1 + f_2)/2$. Then θ_1 equals to $\pi/2 \times f_1 / f_c$ at the lower designed frequency f_1 and $\pi/2 \times f_2 / f_c$ at the upper designed frequency f_2 .

The design steps for the dual band branch line coupler are:

i. Start by evaluating θ_1, θ_2, θ_3 and θ_4 at the designed frequencies
ii. Evaluate Z_1, Z_2, Z_3 and Z_4 where the realizable widths of high impedance transmission lines should be taken into consideration.

Simulation Results and Discussions

Based on the previous discussion, a dual-band coupler is designed and simulated. The coupler is built over Rogers RO4003 substrate having h = 0.813mm, ε_r = 3.38 and tan(δ) = 0.0027. The calculated coupler impedances are Z_1= 28.8 Ω, Z_2= 43.2 Ω, Z_3= 21 Ω and Z_4= 30.6 Ω. The physical dimensions of the designed coupler arms are presented in Table 1.

The simulated S-parameters of the proposed dual-band branch line coupler are shown in Figure 3 and Figure 4 respectively. The center frequencies of the two pass bands are 2 and 4 GHz. Insertion losses S_{21}/S_{31} are -3.3/-3.2 dB and -3.3/-3.6 dB at 2 and 4 GHz respectively. The amplitude imbalance between the two output ports S_{21} and S_{31} does not exceed 0.3 dB. The return loss S_{11} and isolation loss S_{41} are well below –20 dB at the center frequencies.

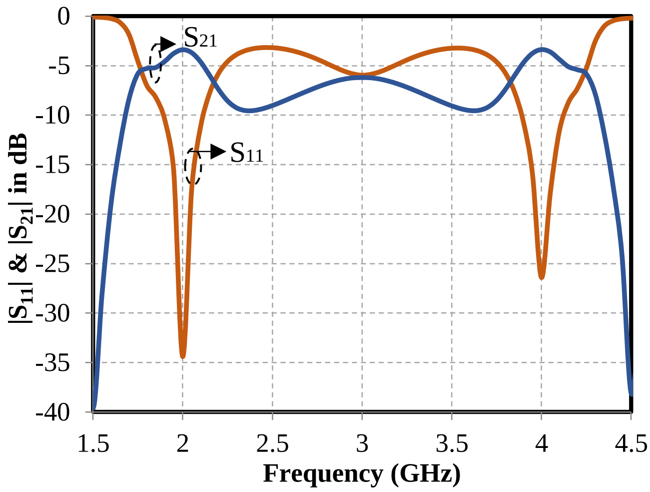

Figure 3. Simulated $|S_{11}|$ and $|S_{21}|$

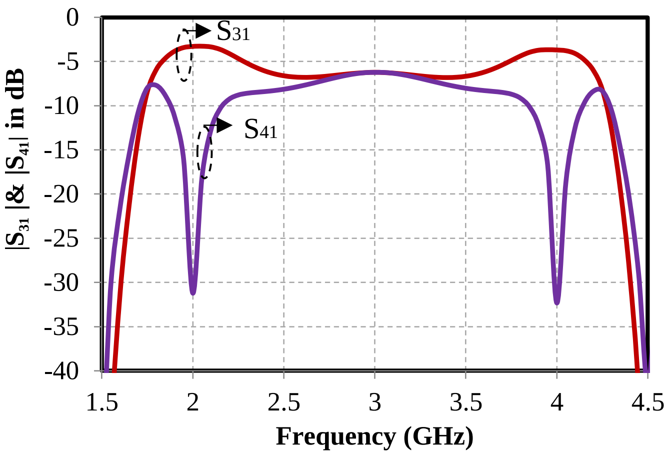

Figure 4. Simulated $|S_{31}|$ and $|S_{41}|$

The phase difference between the output ports of the designed coupler is shown in Figure 5. The phase difference between S_{31} and S_{21} is -89.5^o at 2 GHz and -270^o at 4 GHz.

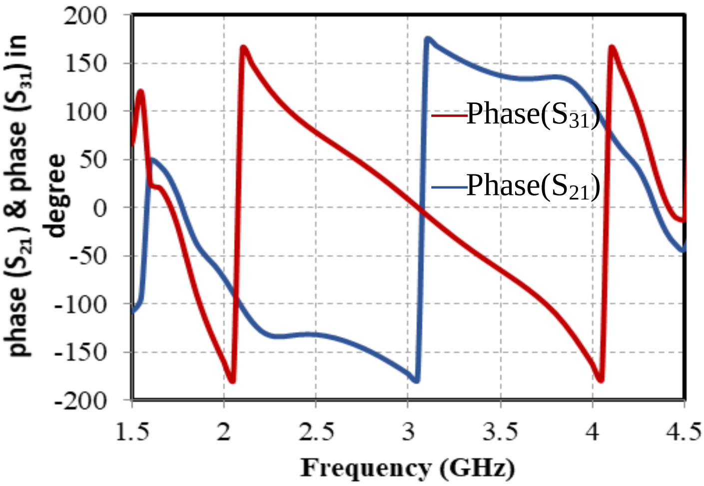

Figure 5. Phase response at the output ports

An ongoing research for obtaining a compact version of the proposed dual-band coupler is in progress. The work includes folding and bending the stubs toward the inner empty area of the coupler to reduce its overall occupied surface area.

Table 1. Dimensions of the dual-band branch line coupler

	$Z_{\lambda/4}$ = 50 Ω		$Z_{\lambda/4}$ = 35.35 Ω	
T-shaped Line	Z_1	Z_2	Z_3	Z_4
	28.8 Ω	43.3 Ω	21 Ω	30.6 Ω
	L_1	L_2	L_3	L_4
	14.8 mm	30.2 mm	14.4 mm	29.5 mm
	W_1	W_2	W_3	W_4
	4.1 mm	2.3 mm	6.2 mm	3.6 mm

Conclusion

A dual-band branch-line coupler based on stub loaded microstrip lines was presented. Design equations are obtained using ABCD-matrix analysis. The simulated results show that the designed coupler has high matching and isolation levels at the two center frequencies. Efforts are done on reducing the size of the coupler by folding the stub towards the inner area of the coupler to be ready for fabrication.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to authors.

Acknowledgements or Notes

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Author Information

Heba EL-HALABI
Beirut Arab University
Beirut, Lebanon
h.alhalabi@bau.edu.lb

Manal K. FATTOUM
Beirut Arab University
Beirut, Lebanon

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