Design and Performance Analysis of a Tri-Band Coupler for RF Applications

1st Srividhya Ganesan
Department of ECE
Panimalar Engineering College
Chennai, India
srividhyakrishiv@gmail.com

2nd Tamilselvi Durairajan
Department of ECE
Panimalar Engineering College
Chennai, India
kgthangadurai6@gmail.com

3rd Janani Krishnan Srinivasan
Department of ECE
Panimalar Engineering College
Chennai, India
linkjanani2002@gmail.com

4th Kavipriya Ravikumar
Department of ECE
Panimalar Engineering College
Chennai, India
kavipriyamagi@gmail.com

5th Kiruthika Venkataramani
Department of ECE
Panimalar Engineering College
Chennai, India
kirthi474@gmail.com

***Abstract*--The Branch Line Coupler is a four-port network which can divide an input signal into two equal-power with 90º phase difference. This paper presents the design and analysis of a tri-band Coupler. The proposed coupler is operating at frequency ranges of 1.9 / 3.6 / 5 GHz with output ports at 3 dB. The Advanced Design System (ADS) software is used to simulate this tri-band coupler. The Flame Retardant-4 (FR-4) substrate material is used to design this coupler. The proposed tri-band coupler measures 98.3 mm × 30 mm in size. The proposed coupler is designed for L, S, and C bands.**

Index terms- tri-band, microstrip line, branch line coupler (BLC)

I INTRODUCTION

There are four ports on a branch line coupler: Input (P1), Output 1 (P2), and Output 2 (P3). The fourth port (P4) is isolated from the input. Branch Line Couplers are used for splitting or combining the incoming signal. A Branch Line Coupler comprises of at least two parallel transmission lines that are physically connected to one another. The designed coupler has a multi-branch stub in its shunt element, which has been examined using two intuitive solutions: one is through a series LC resonator, while the other is to use an open-ended stub in coupler design [2]. By using an E-shaped network in place of branch lines, the dual-band coupler is created [3]. The designed branch-line coupler has different impedances at its input and output by using two different asymmetries: the input–output asymmetry and the up-down asymmetry [4]. The coupler is designed using a dual-band quarter wave TL structure, which can perform wide frequency ratio operation, but its isolation and return loss need to be improved [5]. The coupler replaces each transmission line with a dual-band impedance transformer, whose characteristic impedances are employed using even-odd mode analysis [6]. The BLC performs dual-band operation by placing open coupled lines in all ports, and tri-band operation is performed by replacing them with short coupled lines [7]. It tends to make the design more complicated because all four of the coupler's TLs that are connected in parallel to the coupled lines make an outer round to the corresponding coupled line [8]. In order to create the branch line coupler, each λ/4 line is replaced by an equivalent pi network made up of a short and high-impedance line with a shunt capacitance at each end of the design [9]. The branch line coupler is designed using circular and stepped impedance resonators [10]. Using multiple asymmetric structures of pi-shape, cross-shape, and T-shape, the two-section branch line coupler is designed

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[11]. The BLC is mainly designed for wireless applications, with a reduction in size and improved return loss [12]. The BLC is designed by substituting a T-shaped structure in the λ/4 transmission line [13].

In comparison to other techniques, the proposed design is in simpler form. This paper proposes a coupler which provides response to three different frequencies for multiband applications. The design of the coupler is executed by adding an extra pair of transmission lines in both the vertical sessions and a pair of open- ended stubs between these transmission lines. The proposed coupler is designed using FR4, which is a low-cost and readily available substrate.

II CONVENTIONAL BRANCH LINE COUPLER

Branch Line Coupler plays a vital role in microwave engineering. It's often built using quarter wave transmission line sections, which confine coupler function toa single frequency. The conventional design of the coupler is shown in Figure 1.

The conventional coupler comprises two quarter-wavelength lines constructed using 50 Ω. The impedance of Series arm is $Z_0/\sqrt{2}$ = 35.35 Ω and impedance of Shunt arm is Z_0 = 50 Ω. The permittivity and thickness of FR-4 substrate in conventional branch line coupler design is 4.4 and 1.6 mm respectively. The design frequency of conventional BLC is 3.5 GHz. Figures 2(a), 2(b), 2(c) & 2(d) shows simulation results for 3.5 GHz of conventional Branch Line coupler.

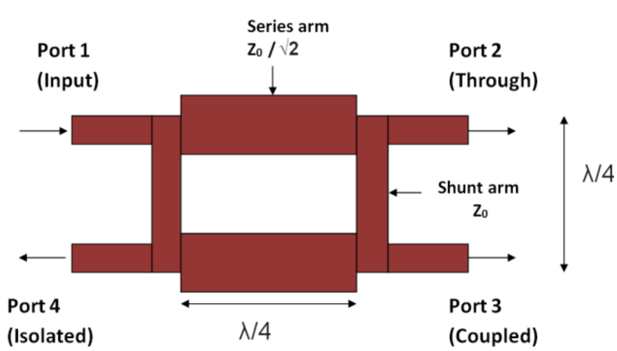

Fig 1. Design of conventional Branch Line Coupler

A. Design considerations

Operating frequency (f) = 3.5 GHz

Velocity of light (c) =$3x10^8$ m/sec

Relative permittivity (∈r) = 4.4

FR-4 Substrate thickness (d) = 1.6 mm

Impedance (z_o)= 50 Ω

For the above requirements, the w/d ratio must be evaluated for the width of shunt and series arms. Here are the design equations for the w/d ratio.

$$W = d\left\{\frac{8e^A}{e^{2A}-2}\right\}$$

Where,

$$A = \frac{Z0}{60}\sqrt{\frac{\varepsilon r+1}{2}} + \frac{\varepsilon r-1}{\varepsilon r+1}\left(0.23 + \frac{0.11}{\varepsilon r}\right)$$

The length of the shunt and series arms are given by

$$L = \frac{\lambda}{4} = \frac{c}{4f\sqrt{\varepsilon eff}}$$

Effective relative permittivity (ε_{eff})

$$\varepsilon_{eff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1+12\,\frac{h}{w}\right]^{-0.5}$$

TABLE I. DIMENSIONS OF THE CONVENTIONAL BRANCH LINE COUPLER

IMPEDANCE (Ohm)	A	WIDTH (mm)	LENGTH (mm)
Z_0=50 Ω	1.529	3.059	11.742
$Z_0/\sqrt{2}$ = 35.35 Ω	1.128	5.241	11.475

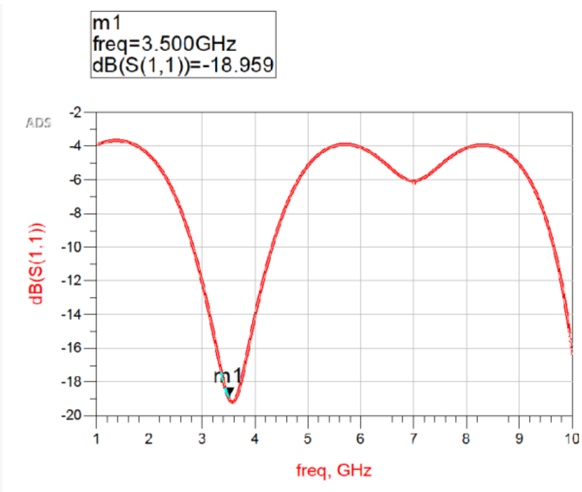

Fig 2(a). S-Parameter (S_{11}) of conventional Branch Line Coupler

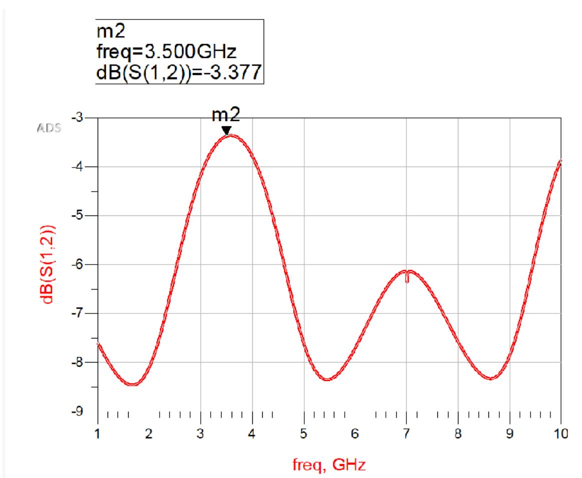

Fig 2(b). S-Parameter (S_{12}) of conventional Branch Line Coupler

The above mentioned conventional Branch Line Coupler provides 3 dB insertion losses for 3.5 GHz frequency only. Thus, this can be overcome with the help of the proposed tri-band Coupler.

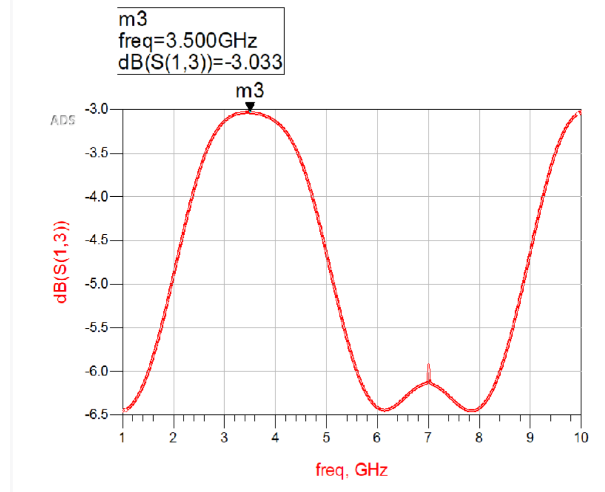

Fig 2(c). S-Parameter (S_{13}) of conventional Branch Line Coupler

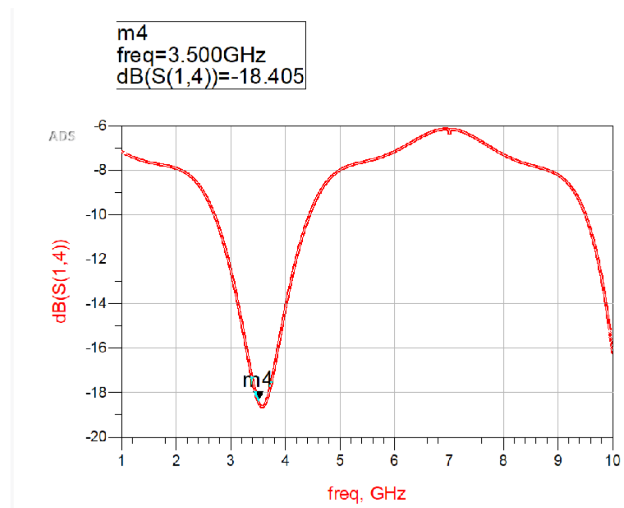

Fig 2(d). S-Parameter (S_{14}) of conventional Branch Line Coupler

III DESIGN & IMPLEMENTATION OF TRI-BAND COUPLER

The proposed tri-band Coupler is shown in Figure 3. The characteristic impedance of the horizontal session is $Z_0/\sqrt{2}$ with $\lambda/4$ wavelength. The characteristic impedance of the vertical sessions is $2Z_0$ with $\lambda/4$ wavelength for the transmission line and $Z_{OC} = Z_0/2$ with λ wavelength for the stub.

The proposed tri-band BLC has been calculated using design formulas. Table 2 provides the computed values for proposed impedances. The thickness and permittivity of FR-4 substrate in proposed tri-band BLC design is 1.6 mm and 4.4 respectively.

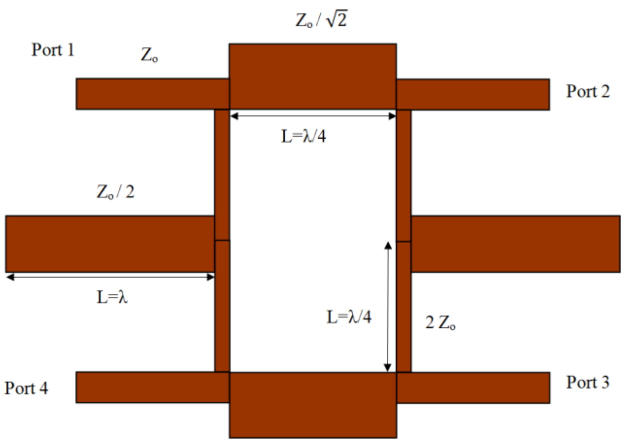

Fig 3. Proposed design Tri-Band Branch Line Coupler

TABLE II. PROPOSED TRI-BAND BRANCH LINE COUPLER

IMPEDANCE (Ohm)	WIDTH (mm)	LENGTH (mm)
Z_0 =50 Ω	3.059	11.75
2 Z_0 = 100 Ω	0.85	12.4
Z_0/2 = 25 Ω	8.4	43
$Z_0/\sqrt{2}$ = 35.35 Ω	5.241	11.475

IV RESULT AND DISCUSSIONS

The results are summarized in Table-3. The results of the simulations indicate that the equal power division (|S12| = |S13|) at port 2 & port 3. Maximum amplitude imbalance of -0.005 dB (A = |S12| |S13|) has been achieved while maintaining -34.424 dB return loss (|S11|) and -34.261 dB isolation loss (|S14|) at the center frequencies of all three frequency bands. A comparative analysis of this tri-band Branch Line Coupler with existing couplers is presented in Table 4.

Better amplitude imbalance has been achieved using a tri-band coupler than most of the previously designed Branch Line Couplers.

All of these results prove the validity of the proposed design approach to designing a tri-band coupler. Figures 4(a), 4(b), 4(c) & 4(d) show the simulated results of proposed tri- band coupler.

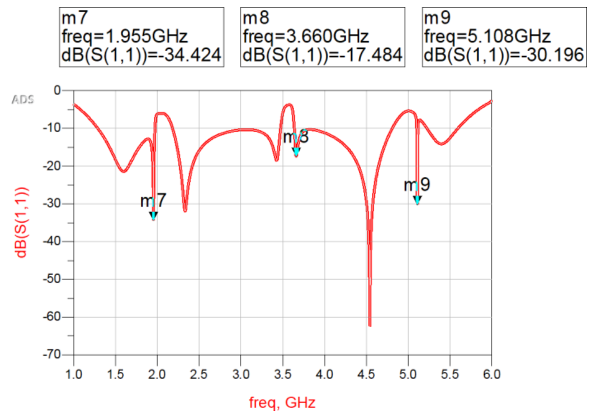

Fig 4(a). S-Parameter (S_{11}) of proposed tri-band coupler

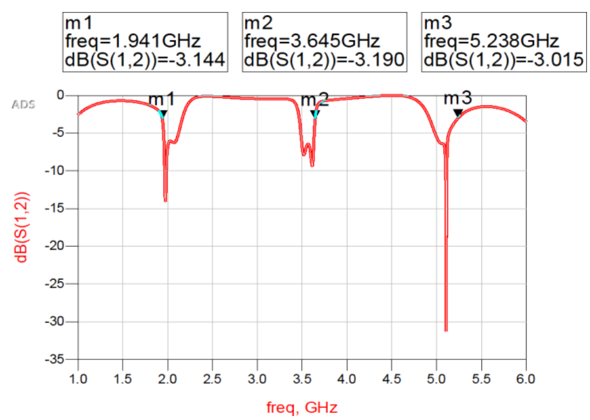

Fig 4(b). S-Parameter (S_{12}) of proposed tri-band coupler

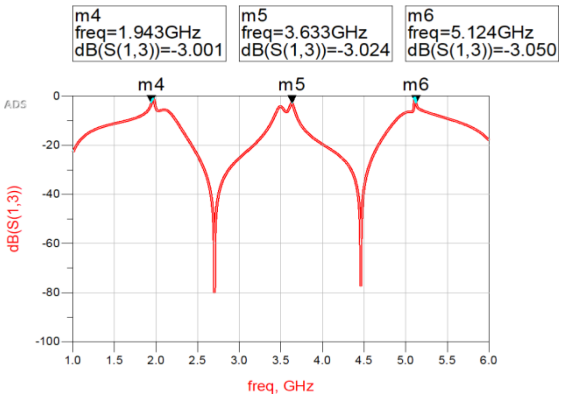

Fig 4(c). S-Parameter (S_{13}) of proposed tri-band coupler

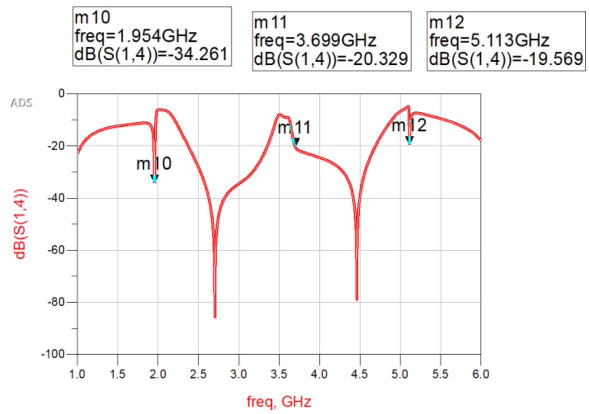

Fig 4(d). S-Parameter (S_{14}) of proposed tri-band coupler

TABLE III. SIMULATED PARAMETERS OF TRI-BAND BLC

FREQUENCY (GHz)	**RETURN LOSS (|S_{11}|) dB**	**ISOLATION LOSS (|S_{14}|) dB**	**INSERTION LOSS(|S_{12}|) dB**	**COUPLING COEFFICIENT (|S_{13}|) dB**	**ΔA (|S_{12}|−|S_{13}|)dB**
1.9	-34.424	-34.261	-3.02	-3.001	-0.019
3.6	-17.253	-20.069	-3.055	-3	-0.055
5	-30.196	-19.569	-3.055	-3.05	-0.005

TABLE IV. COMPARISON OF TRI-BAND BLC WITH OTHER COUPLERS

REF. NO	**FREQUENCY (GHz)**	**SUBSTRATE**	**S- PARAMETER**		
			S11 (dB)	**S12 (dB)**	**S13 (dB)**
[2]	3.52	RO4003C substrate	-18.6	-3.78	-3.24
	4.78		-23.38	-3.51	-3.11
[3]	0.95	Laboratory-available microwave substrate	> -17	-3.35	-3.4
	8		> -17	-3.87	-4.5
[4]	1.5	Diclad	> -15	-3	-3
[5]	0.7	Rogers5870	-13	-3.57	-3.51
	0.9		-12	-3.61	-3.66

[7]	Dual-band 0.75	Dielectric substrate with εr = 2.65, h = 1.0 mm, tan δ = 0.003	> -15	-3.35	-4.0
	1.42		> -15	-3.72	-4.10
	Tri-band 0.736		-3	-3.62	-
	1.02		-3.13	-3.9	
	1.4		-3.06	-3.63	
[8]	0.9	Rogers 5870	-27.74	-3.47	-3.41
	2.4		-26.63	-3.56	-3.78
[9]	3.5	FR – 4	-16.23	-3.58	-3.6
This Work	3.5	FR – 4	-34.424	-3.144	-3.001
			Frequency = 1.9 GHz		
			-17.253	-3.19	-3.024
			Frequency = 3.6 GHz		
			-30.196	-3.015	-3.050
			Frequency = 5 GHz		

V CONCLUSION

For tri-band operation, an open stub branch line coupler that provides high isolation has been proposed. Using the Advanced Design Software, the tri-band BLC was simulated and verified. The proposed coupler was designed using a FR-4 substrate, which is low cost and met the expected result of 3 dB insertion loss at three frequencies of 1.9 / 3.6 / 5 GHz. It offers the advantage of multiband operation and is cost-effective due to the open stub's simplicity in design and ease of fabrication.

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