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Analysis of Branch Line Coupler with Arbitrary Gains and Phase Shifts

Diksha Thakur[1], Salman Raju Talluri[2], Nafis Uddin Khan[3]

[1]*Student, ECE Department JUIT, Waknaghat Distt-Solan (H.P) 173234*
[2]*Assistant Professor (Sr. Grade), ECE Department JUIT, Waknaghat Distt-Solan (H.P) 173234*
[3]*Assistant Professor (Sr. Grade), ECE Department JUIT, Waknaghat Distt-Solan (H.P) 173234*

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Abstract - *This paper presents a new design of the branch line coupler (BLC) that can control the gains and phase difference. It is shown that gains at the output ports can be increased or decreased and phase difference can be decreased by varying series branch length and its impedance. In the proposed design there is change in one branch length and impedance of the conventional coupler and all the other dimensions are kept same. Firstly the mathematical analysis of the coupler is done using even and odd mode analysis and the mathematical results are verified by the full wave electromagnetic simulator. There is good agreement between mathematical results and full wave electromagnetic (em) simulations.*

Key Words: **Branch line coupler, arbitrary gains, arbitrary phase, S parameters etc.**

1. INTRODUCTION

The branch line coupler [1] is a passive microwave component which is used in various microwave and antenna applications. 90° phase difference is obtained at the output ports of branch line coupler with equal division of power. In some applications like antenna feeding system, beamforming networks etc, unequal power division and flexible phase difference is required. There are various methods in literature for arbitrary power divisions like in [2] the electrical lengths of the horizontal branches are varied to change the coupling values and the impedance remains constant. Branch lines are replaced by coupled lines in [3] and centre tapped open and short circuited stubs in [4]. In [5] the length of each feed line is increased by $\lambda = 4$ amount, in [6] series stubs are used, in [7] terminated resistances are used, in [8] vertical and horizontal branches has different line lengths and impedance and in [9] defective ground structures is used in order to achieve desired power divisions.

This paper presents a new design of branch line coupler for arbitrary gains as well as phase shifts. It is shown that the gains and phase differences at the output ports can be controlled by changing the branch lengths and impedances. In the proposed design of the branch line coupler, the length and the impedances of only one branch are varied and the other three branches are kept same. The gains as well as phases are controlled through the length and impedance variations.

The organization of the paper is as follows. In section 2, the mathematical analysis and the formulas for calculation of S parameters for the proposed structure is presented. The mathematical simulations and full wave electromagnetic simulations are presented in section 3 and 4 respectively which is then followed by conclusion.

2. NUMERICAL ANALYSIS

The proposed design of the branch line coupler is shown in the Figure 1. It can be seen from the Figure 1, that only one branch of the conventional branch line coupler is modified and all the other branches are kept same.

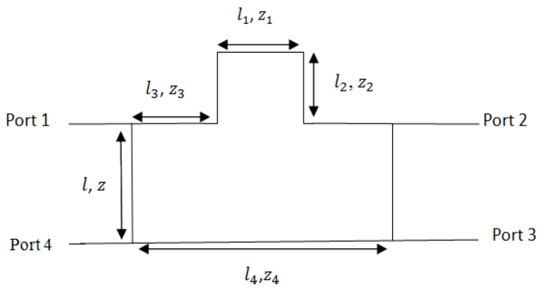

Fig -1: Proposed Branch line coupler

The circuit of the proposed branch line coupler can be decomposed into even and odd mode and the equivalent circuits are excited by different combinations of inputs at port 1 and port 2. In even mode equal polarity power is incident on port 1 and port 2 so the circuit become open circuited at the symmetry line. In odd mode opposite polarity power is incident on port 1 and port 2 so the circuit becomes short circuited at the line of symmetry. Even and odd mode equivalent of the proposed coupler is shown in Figure 2 and 3.

The ABCD matrix for even mode is calculated by equation 1.

$$\begin{bmatrix} A_e & B_e \\ C_e & D_e \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{Section\ 1} \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{Shunt\ line\ l,Z} \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{Open\ stub\ l,Z_4} \text{................} (1)$$

The S parameters for even mode are calculated by using equations 2 and 3.

$$S_{11e} = \frac{A_e + \frac{B_e}{Z_0} - C_e Z_0 - D_e}{A_e + \frac{B_e}{Z_0} + C_e Z_0 + D_e} \ldots\ldots\ldots\ldots\ldots (2)$$

$$S_{12e} = \frac{2(A_e D_e - B_e B_e)}{A_e + \frac{B_e}{Z_0} + B_e Z_0 + D_e} \quad \ldots\ldots\ldots\ldots\ldots(3)$$

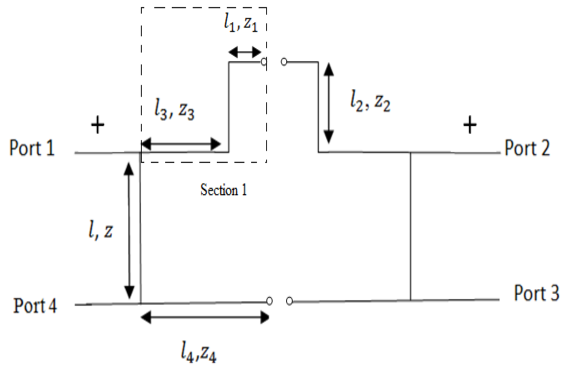

Fig -2: Even mode equivalent of the proposed BLC

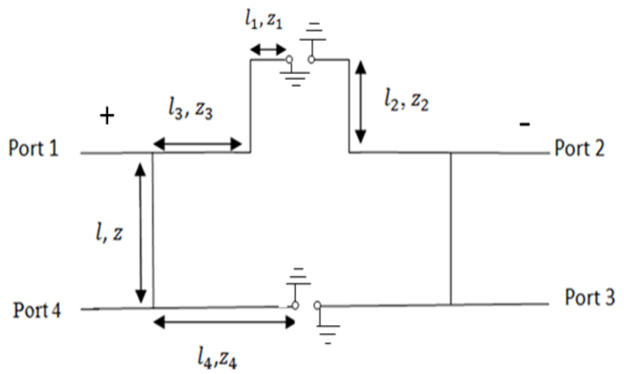

Fig -3: Odd mode equivalent of the proposed BLC.

The S parameters for odd mode are calculated in similar way as calculated for even mode. The complete analysis of the proposed branch line coupler is done by the summation of even mode and odd mode outputs. The four port S parameters are calculated by using the formulas given in equations 4-7.

$$S_{11} = \frac{S_{11e} + S_{11o}}{2} \quad \ldots\ldots\ldots\ldots\ldots(4)$$

$$S_{12} = \frac{S_{11e} - S_{11o}}{2} \quad \ldots\ldots\ldots\ldots\ldots(5)$$

$$S_{13} = \frac{S_{12e} - S_{12o}}{2} \quad \ldots\ldots\ldots\ldots\ldots(6)$$

$$S_{14} = \frac{S_{12e} + S_{12o}}{2} \quad \ldots\ldots\ldots\ldots\ldots(7)$$

3. RESULTS OF NUMERICAL ANALYSIS

The upper horizontal branch of the conventional branch line coupler is divided into three equal parts as shown in Figure 1 and the middle part is modified by changing its branch impedances and lengths in order to get the desired results. The mathematical analysis is done in Matlab [10] and simulations are carried out for different lengths and impedances. All the lengths are expressed in terms of wavelength (λ) and all the impedances are normalized by the characteristic impedance z_0 which is 50Ω. The different lengths l_2 for which the simulations are carried out are $\lambda/20, \lambda/10, \lambda/6.67, \lambda/5, \lambda/4$ and the impedances are ($z_1 = z_2$) 0.5, 0.72 , 0.94, 1, 1.16, 1.38 and 1.6 . Firstly the Impedance z_2 is kept constant and length l_2 is varied and the simulation results are shown in Figure 4 for $z_2 = 1$ and length is varied from $\lambda/20$ to $\lambda/4$.

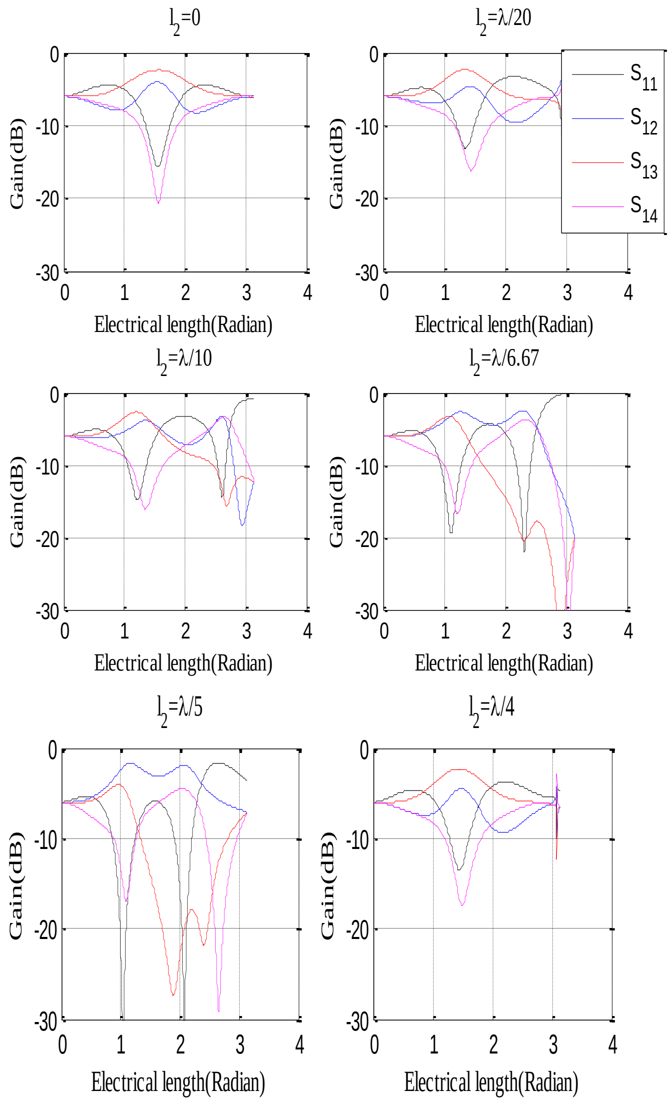

Fig -4: Simulation results of gains of variable length for $z_2 = 1$

The phase variations for $z_2 = 1$ and variable length is shown in Figure 5.

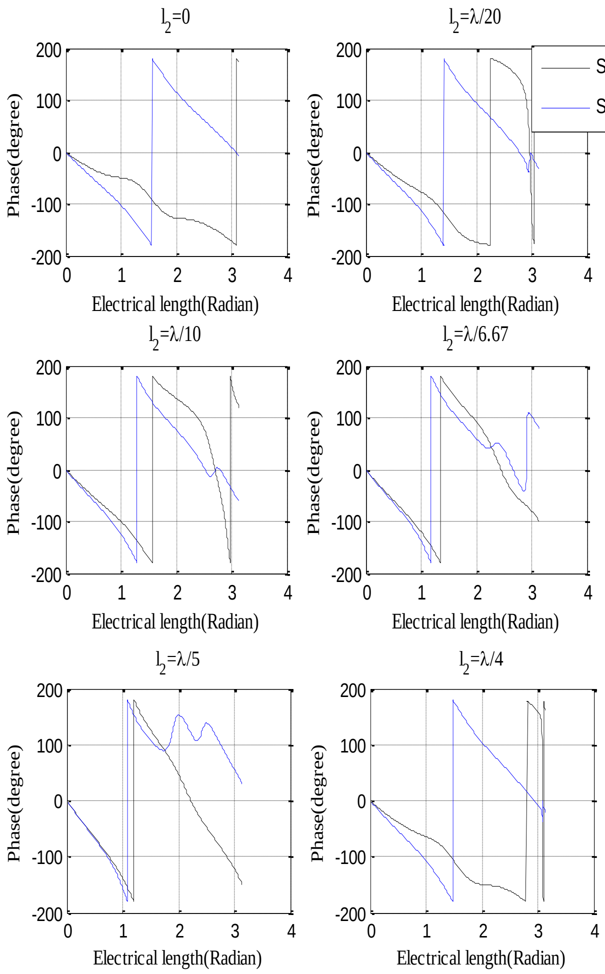

Fig -5: Simulation results of phase of variable length for $z_2 = 1$.

The tabular representation of the magnitude and phase values for $z_2 = 1$ and variable length is shown in Table 1.

Table -1: S parameter values for $z_2 = 1$.

l_2	S_{11} (dB)	S_{12} (dB)	S_{13} (dB)	S_{14} (dB)	f_r (Radian)	$\angle S_{12}$ (°)	$\angle S_{13}$ (°)	$\angle S_{12} - \angle S_{13}$
λ/20	-13.14	-4.757	-2.342	-4.71	1.351	-110.3	-171.7	61
λ/10	-14.87	-4.285	-2.675	-12.65	1.222	-124.8	-165.1	40.3
λ/6.67	-19.55	-3.361	-3.361	-13.19	1.115	-136.9	-165	28.1
λ/5	-34.32	-2.002	-4.335	-15.41	1.002	-146.9	-168.5	21.6
λ/4	-23.07	-1.409	-6.001	-16.76	0.989	-157.3	-175.3	18.4

It can be concluded from the Figure 4 and Table 1, that S_{12} magnitude increases and S_{13} magnitude decreases with the increase in length l_2. For length $\lambda/4$ the magnitude of S_{12} increases by 20% and the magnitude of S_{13} decreases by 29% as compared to the conventional coupler with the return loss of -23.07. From the Figure 5 and Table 1 it can be said that the phase difference between the output ports decreases.

The simulations are also carried out for fixed length and variable impedances. The impedance z_2 is varied by keeping the length l_2 constant which is $\lambda/20$. The simulation results of gain for different impedances are shown in Figure 6.

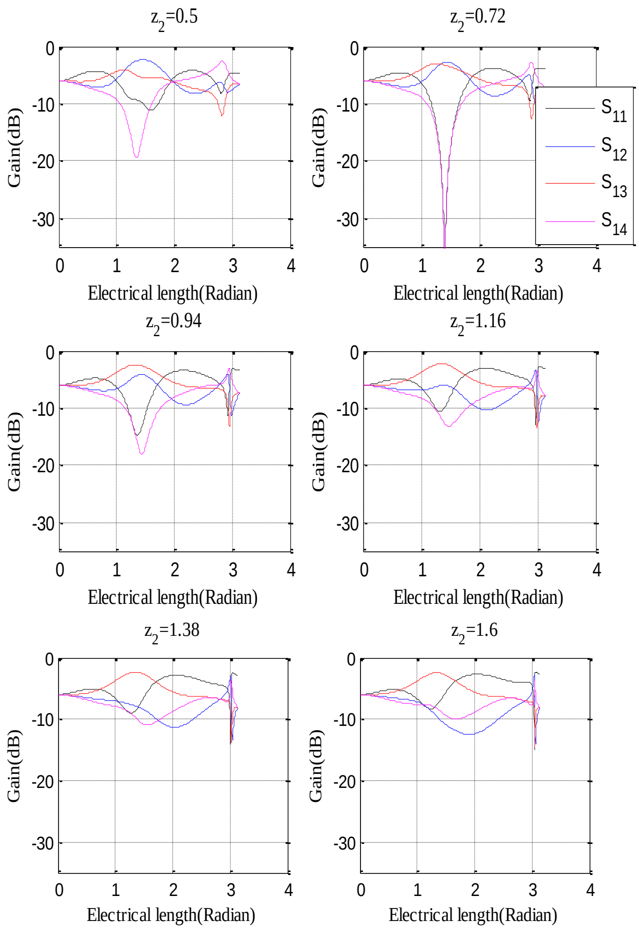

Fig -6: Simulation results of gains of variable impedance for $l_2 = \lambda/20$.

The phase variations for fixed length $l_2 = \lambda/20$ and variable impedance is shown in the Figure 7.

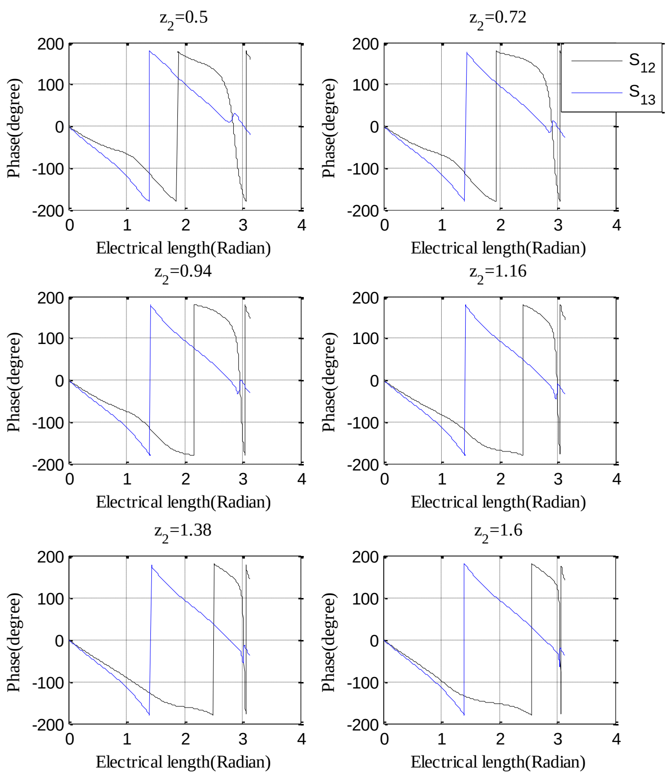

Fig -7: Simulation results of phases of variable impedance for$l_2 = \lambda/20$.

The tabular representation of the S parameter values for $l_2 = \lambda/20$ and variable impedance z_2 is shown in Table 2.

Table -2: S parameter values for$l_2 = \lambda/20$.

z_2	S_{11} (dB)	S_{12} (dB)	S_{13} (dB)	S_{14} (dB)	f_r (Radian)	$\angle S_{12}$ (°)	$\angle S_{13}$ (°)	$\angle S_{12} - \angle S_{13}$
0.5	-11.9	-2.718	-5.454	-9.817	1.618	-147	154	59
0.72	-35.94	-2.799	-3.236	-40.32	1.415	-112.6	179.8	67.6
0.94	-14.78	-4.299	-2.428	-16.32	1.363	-109.3	-172.7	63.4
1.16	-10.61	-6.073	-2.525	-11.51	1.332	-110.9	-168.5	57.6
1.38	-9.024	-7.637	-2.361	-9.024	1.252	-115.7	-158.8	43.1
1.6	-8.334	-8.9	-2.381	-8.21	1.241	-122.6	-151.8	29.2

With the increase in impedance z_2 the gain at port 2 decreases whereas the gain at port 3 increases which is shown in Figure 6 and Table 2. There is an increase of 29% in S_{13} and decrease of 5.157% in S_{12} for z2 = 1:16 with S_{11} less than 10dB. From the Figure 7 and Table 2, it is clear that the phase difference at the output ports decreases with the increase in impedance.

4. FULL WAVE ELECROMAGNETIC DESIGN AND SIMULATIONS

The coupler is designed in full wave electromagnetic simulator [11] to verify the results. It is designed on RT-Duroid 5880 substrate with dielectric constant 2.2 and the substrate height h=0.508 mm. The full wave electromagnetic simulator structure is shown in the Figure 8.

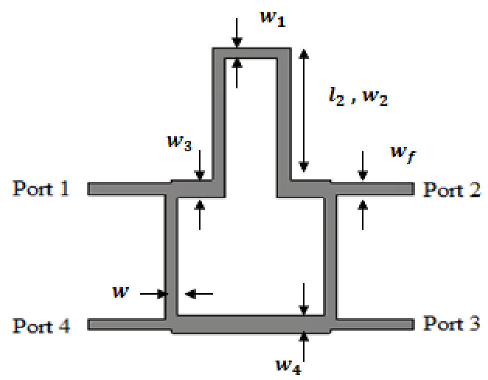

Fig -8: Layout of proposed branch line coupler

The design parameters of the proposed design are shown in Table 3.

Table -3: Design parameters of proposed coupler

Width(mm)	Impedance(Ω)	Length(mm)
$w_1 = w_2 = 1.52$	50.39	λ/4=19.2
$w_1 = w_2 = 1.20$	57.89	λ/20=3.8
w_3 =2.51	35.35	λ/12=6.4
w =1.52	50.39	λ/4=19.2
w_4=2.51	35.35	λ/4=19.2

The simulation results of Matlab and full wave electromagnetic simulator are compared for $l_2 = \lambda/4$ and z_2=1 as well as for $l_2 = \lambda/20$ and z_2=1.6 which are shown in Figure 9 and 10 respectively.

The mathematical simulations and the full wave electromagnetic simulations for $l_2 = \lambda/4$ and z_2=1 are almost same with the error of 0.295GHz in the resonant frequency and approximately 5 dB in S_{11} magnitude.

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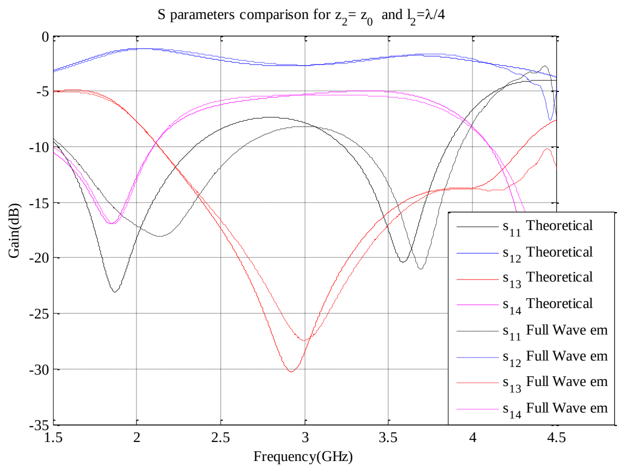

Fig -9: Comparison of mathematical and full wave em simulations for l_2= λ/4 and z_2=z_0 .

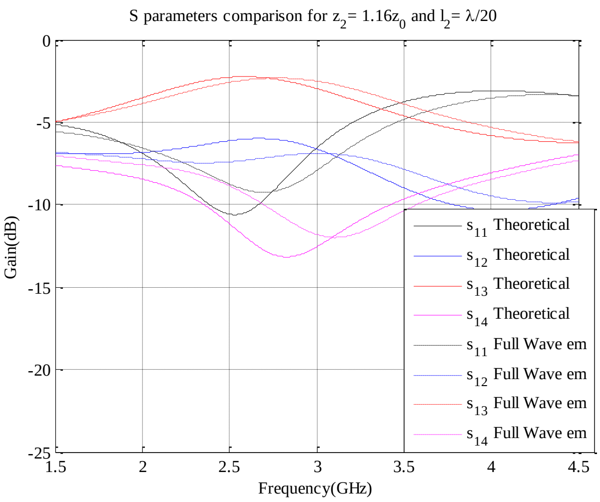

Fig -10: Comparison of mathematical and full wave em simulations for l_2= λ/20 and z_2=1.6z_0.

The mathematical simulations and the full wave electromagnetic simulations for l_2= λ/20 and z_2=1.6z_0 shows good agreement with the error of 0.154GHz in the resonant frequency, 2 dB in S_{11} magnitude and 3 dB in S_{14} magnitude.

4. CONCLUSION

A new method is presented to control the gains and phases of the branch line coupler. In the proposed coupler the branch length and impedance of branch line coupler is varied in order to control the gains and phases. If the gain at the output port 2 is desired to increase and gain at output port 3 is desired to decrease then the branch length is increased by keeping the impedance fixed. On the other hand if branch impedance is increased with fixed length then gain at the output port 3 also increases and gain at output port 2 decreases. In both the cases the phase difference between the output ports decreases.

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