International Journal of Current Trends in Engineering & Research (IJCTER)
e-ISSN 2455–1392 Volume 2 Issue 3, March 2016 pp. 197 - 203
Scientific Journal Impact Factor : 3.468
http://www.ijcter.com

Quadrature Branch-line Hybrid Coupler With Two Stages

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Abstract—A quadrature branch-line hybrid directional coupler is designed to operate in the S band i.e. in the frequency range of 2GHz to 4GHz with a centre of 2.4GHz. Since, 3dB coupling is used the input power is equally divided between the through port and the coupled port with a 90 degree phase difference. Negligible power is supplied at isolated port. The various calculations regarding the coupler design are performed and the s-parameters of the two stage coupler is measured by simulation using the Advanced Designing System (ADS) software. The two stage coupler shows decent values of s-parameters over the frequency range of 1.2 GHz. At the end a comparative study is presented with reference to the single stage coupler on the basis of coupler parameters and performance and finally the conclusion completes our discussion.

I. INTRODUCTION

The ability to distribute and combine signals is a very fundamental and important function in many microwave systems, this is particularly useful and if it can be done over a frequency range and with phase shifted signals. Directional couplers, are indispensable passive components used in several microwave systems, i.e., mixers, modulators and antenna beam-forming networks-[5]. A directional coupler is a 4-port network that is designed to divide and distribute power. Although this would seem to be a particularly mundane and simple task, these devices are both very important in microwave systems, and very difficult to design and construct-[4]. The various ports of a directional coupler are;

Port 1: Input Port Port 2: Through Port

Port 3: Coupled Port Port 4: Isolated Port

Quadrature hybrids are 3 dB directional couplers with a 90◦ phase difference in the outputs of the through and coupled ports. This type of hybrid is often made in microstrip line or strip line form and is also known as a branch-line hybrid. Other 3 dB couplers, such as coupled line couplers or Lange couplers, can also be used as quadrature couplers. Besides these, waveguide couplers can also be used but avoided as they occupy more space.The phase difference between S21 and S31 becomes 90 degrees for an even number of slots, but deviates from 90 degrees for an odd number. However, it tends to approach 90 degrees as the number of slots and the coupling factor increase-[3]. The various s parameters which are calculated are return loss(S11), insertion loss(S21), coupling loss(S31) and isolation (S41).

The coupler can consist of a single or a multiple stages. A single stage coupler has a relatively narrow bandwidth, at least in terms of its directivity and return loss. Although a higher bandwidth may be achieved using a coupled line configuration instead of a branch line one, coupled line hybrids are difficult to realize-[2]. However, if the coupler is designed with a series of coupling holes i.e. by increasing the number of stages the extra degrees of freedom can be used to increase this bandwidth-[4], as well as, an improvement in s parameters can be achieved. The use of a pair of slots repeated n times at λ/4 intervals along the common broad wall of parallel waveguides can be designed to have perfect directivity at a selected frequency f0, and have flat coupling at this frequency. With additional such pairs spaced λ /4 along the waveguides, the coupling can be increased while, at the same time, the bandwidth for high directivity increases-[1].Thus the project aims at developing a two stage coupler to increase the operating bandwidth in terms of return loss thereby increasing VSWR at the operating frequency of 2.4GHz. The branch line hybrid also has the advantage that it may be realized using slot lines in the ground plane of a microstrip circuit. In this case the hybrid requires virtually no additional real estate on the chip-[2].

II. DESIGN & CALCULATIONS

The geometry of a two stage coupler is shown below.

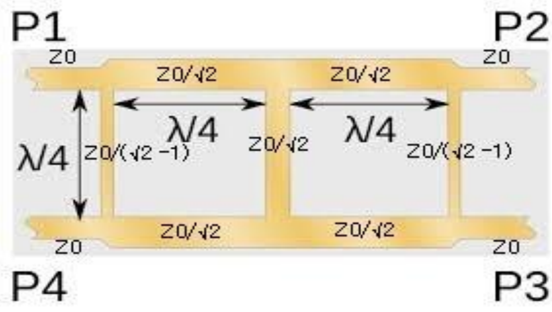

Fig 1: Geometry of a two stage Branch-line Coupler

The figure shows different values of impedances at the various arms of the coupler. In accordance to the impedances the length and width of the various arms changes. As we see, from the figure 1, the three different values of impedances are present on different arms of the coupler, thus, we have 3 different lengths and widths for these three values of impedances. As we are using a characteristic impedance(Z0) of 50 ohms, The other two values of impedances namely (Z0/ √2) and (Z0/ (√2 -1)) are calculated using this value of Z0. We get their values as 35.3553 ohms and 120.7106 ohms. Thus we have to calculate the lengths and widths for each of these impedances. There are two methods of calculating the length and breadth: (1) using formulae and (2) using line calculator

Discussing the second method first, the line calculator is an inbuilt calculator in ADS used for the calculation of length and width for a particular impedance associated coupler arm. The parameters required for the calculation includes substrate height, cover height, conductor height and conductivity, permittivity, loss tangent, electrical length etc. Regarding the first method, we use the various formulae to calculate the length and width as follows;

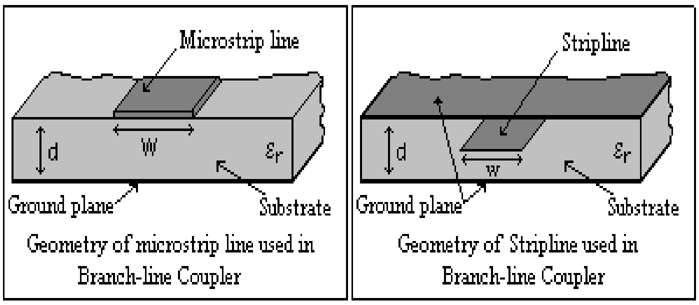

Fig 2: Geometry of microstrip line

The w/d ratio can be obtained as below;

$$\frac{w}{d} = \frac{8e^{A}}{e^{2A}-2}$$ for w/d<2.....................................eqn [1]

$$\frac{w}{d} = \frac{2}{\pi}\left[B - 1 - ln(2B-1) + \frac{\varepsilon r-1}{2\varepsilon r}\left\{ln(B-1) + 0.39 - \frac{0.61}{\varepsilon r}\right\}\right]$$ for w/d > 2....................................eqn [2]

Where, $A = \frac{Z0}{60}\sqrt{\frac{\varepsilon r+1}{2}} + \frac{\varepsilon r-1}{\varepsilon r+1}\left(0.23 + \frac{0.11}{\varepsilon r}\right)$ ....eqn [3]

$B = \frac{377\pi}{2Z0\sqrt{\varepsilon r}}$ ....eqn [4]

Taking substrate height as 1.6mm,

1) for Z0=50 ohms

ε_r= 4.4, f= 2.4GHz,

Assuming W/d ≤ 2, we get A=1.5713

W_1/d=1.8193

Which means our assumption was right,

W_1=2.910mm

2) for Z0=35.35 ohms

Assuming W2/d ≥ 2, we get,

B=7.7261

W2/d=3.0571

Which means our assumption was right

W2 = 4.8913mm

For the calculation of width the following formula can also be used; $w = \frac{7.48h}{e^{Z0\sqrt{\frac{\varepsilon r+1.41}{87}}}} - 1.25t$ ....eqn[5]

We may also note that the length for the impedances 120.7 ohms and 35.35 ohms are different by more than 1mm, but owing to the geometry of the coupler in figure 1, we conclude that if these two lengths are taken different, the layout of the coupler is disturbed affecting the result. Thus we take this length same for both the impedances and compensate this change in length by adjusting the width. Finally we obtain the length and width of the impedances as follows;

Impedance	Length	Width
50 ohms	17.13900 mm	2.986770 mm
35.3553 ohms	17.58097 mm	5.113680 mm
120.7106 ohms	17.58097 mm	0.3355921 mm

Table 1: Length & Width for available coupler arms

III. SIMULATION

For the purpose of simulation the software used is Advanced Designing System (ADS). Beginning with the simulation the very first step involves developing the schematic by connecting the various impedances associated with the coupler arms and terminating each of the ports with matched terminations to perform the simulation.

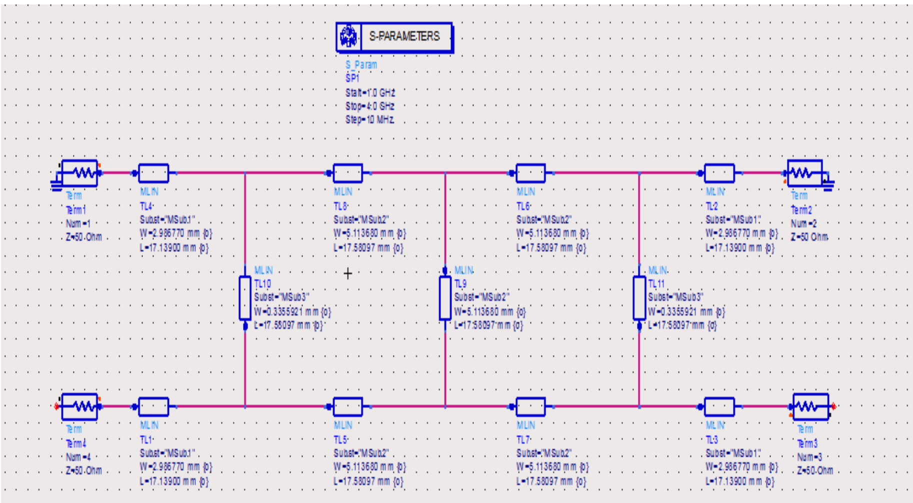

Fig 3: Schematic of the two section hybrid coupler

The various results are obtained for the magnitude of s parameters. Also the phase difference between S(3,1) and S(2,1) is obtained. The various results obtained after the simulation are shown below;

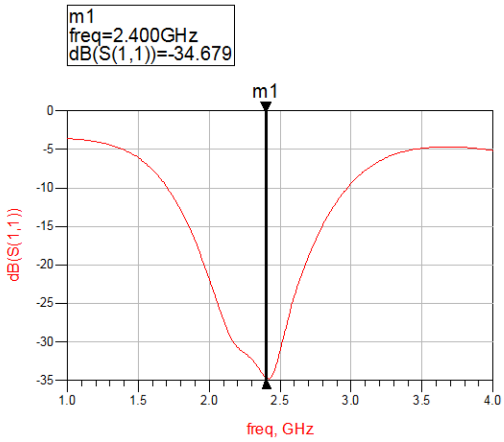

Fig 4(a): Magnitude of S11

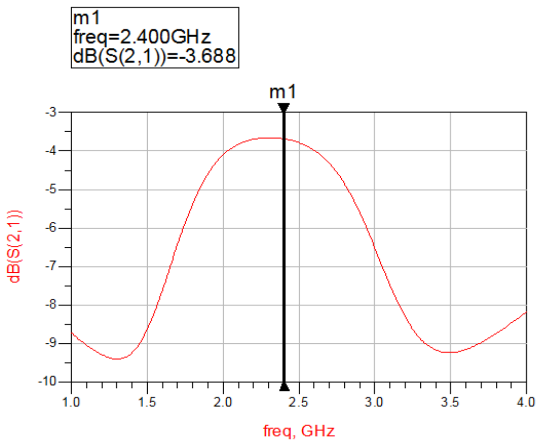

Fig 4(b): Magnitude of S21

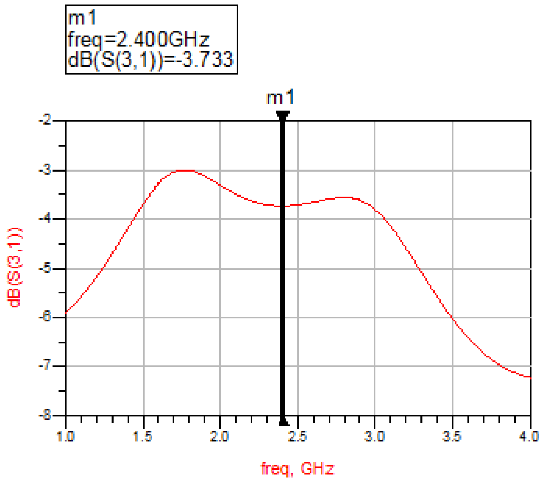

Fig 4(c): Magnitude of S31

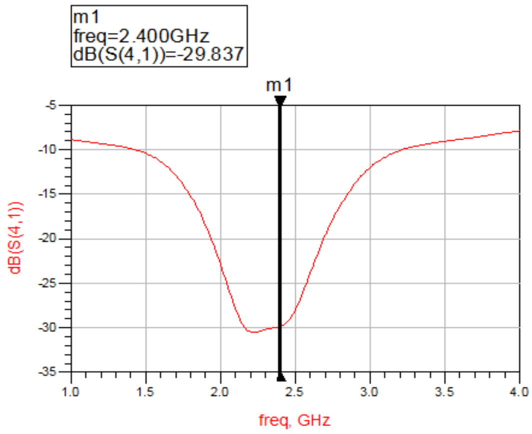

Fig 4(d): Magnitude of S41

The simulation is performed and the various results obtained are presented in figure 4(a), figure 4(b), figure 4(c), figure 4(d). The various results are obtained for the frequency range of 1 GHz – 4 GHz, however, the coupler was designed to operate for a centre frequency of 2.4 GHz and hence the various results are checked for the frequency of 2.4 GHz. The software gives the freedom to plot the equations as per user requirements. We use this feature of the software to plot the phase difference between S31 and S21 shown in figure 5.

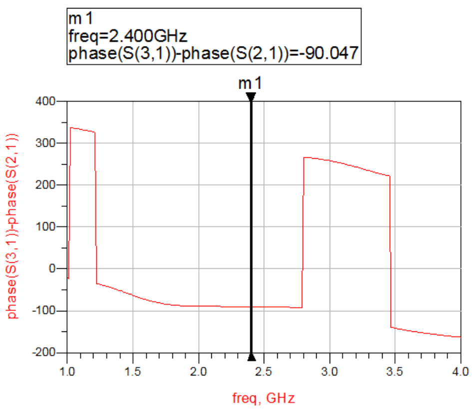

Fig 5: Phase difference between S31 and S21

The figure 6 shown below shows the layout of the coupler which is obtained using the same software. The layout is generated to perform the EM simulation which is a process depicting the real time performance of the coupler under non ideal conditions. The EM simulation was performed using substrate as FR4, substrate thickness as 1.6mm, conductor thickness as 0.035mm, permittivity as 4.4 and the center frequency as 2.4GHz. In real time, a cover is included for the purpose of protecting the substrate from external damage. Hence,in EM simulation the cover is also included and the cover height is also considered and it is taken as 12.8mm. The output of EM simulation is shown in figure 7.

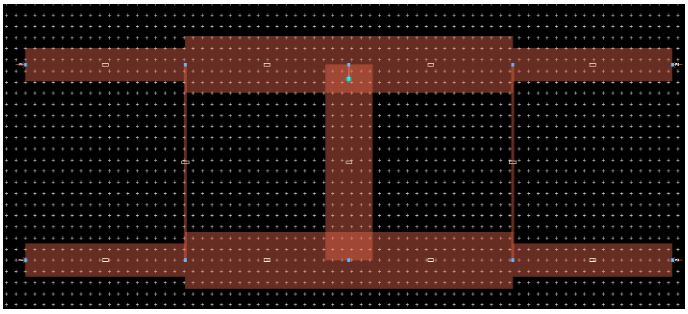

Fig 6: Layout of the Two Section Hybrid Coupler

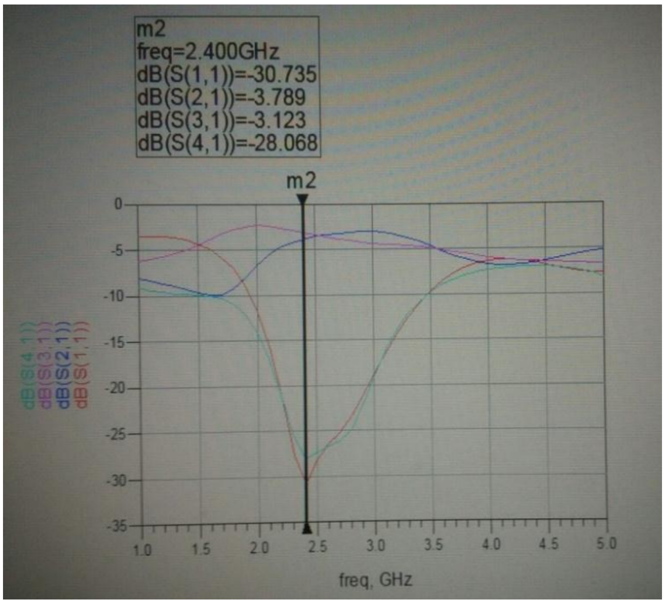

Fig 7: Results of EM Simulation

IV. RESULT AND DISCUSSION

As observed from previous section the various outputs are obtained for normal simulation using the schematic as well as the EM simulation using the layout. The tabular representation of the results are shown;

S parameters	Simulation	EM Simulation
S11	-34.679	-30.735
S21	-3.688	-3.789
S31	-3.733	-3.123
S41	-29.837	-28.068

Table 2: Results of normal and EM simulation

The values obtained for s-parameters in ideal conditions are quite in agreement with the values obtained in real time environment under non ideal conditions. The value of return loss obtained for a two stage coupler is better than the value for single stage coupler, as well as, the other s-parameters of a two stage coupler are also having decent values as compared to a single stage coupler. The operation frequency range is slightly greater than 1.2 GHz which is an increased range as compared to the single stage coupler which has a range of 1 GHz or less than that. Thus the bandwidth increases by more than 20%. Also the phase difference obtained between port 3 and port 2 is -90.047 which was the desirable value. VSWR can be calculated using the value of reflection coefficient which can be obtained using S11 as given below;

Γ= 10^ (S11/20) ……….......................eqn [6]

VSWR= (1+ Γ)/(1- Γ) ………...............eqn [7]

The value of VSWR obtained from above equations is 1.03.

Finally, we present a comparative study between a single stage and two stage directional coupler regarding the performance;

Parameters	Single Stage Coupler	Two Stage Coupler
S11	-30.727	-34.679
S21	-3.661	-3.688
S31	-3.652	-3.733
S41	-35.393	-29.837
VSWR	1.05	1.03

V. CONCLUSION

We have successfully implemented a two stage branch-line hybrid coupler using microstrip technology. The two stage coupler gives an improved value of VSWR as compared to the single stage coupler. The increase in operating bandwidth is another advantage. However, increasing the number of stages increases the area to be occupied. The proposed coupler exhibits low insertion loss, good return loss as well as acceptable quadrature phase shift between output ports. This prototype can be integrated into the design of microwave or millimeter-wave integrated circuits where the compactness of components is crucial.

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