Compact Wideband Quadrature Hybrid based on Microstrip Technique

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***Abstract*—This paper introduces a new compact quadrature hybrid for wideband applications. Using the conventional technique of cascading two sections in a quadrature hybrid we designed a broadband coupler at a central frequency of 1.8 GHz. To improve the performance of this coupler and reduce its size we used the artificial transmission line concept, microstrip line loaded with shunt open ended stubs, and meandering lines. A size reduction of about 31% was achieved compared to the conventional one. The proposed design has a relative bandwidth of 41.6%, return loss and isolation loss are both better than 18 dB on all the entire band. The design was simulated using the CST Studio suite.**

Keywords—Quadrature hybrid, broadband coupler, miniaturization, CST Studio suite

I. INTRODUCTION

Many microwave and millimeter-wave components have been designed and fabricated using microstrip technology. Among these components are the branch-line hybrid couplers which are 3 dB directional couplers with a 90◦ phase difference in the outputs of the through and coupled arms [1]. This device is a very important circuit element in microwave and millimeter-wave systems and subsystems such as balanced amplifiers, phase shifters, mixers, array antennas and many others. Applications of this coupler, however, are limited by a relatively narrow bandwidth due to the quarter-wave length requirement. For modern communication systems and due to the growing of the ultra-wideband technology, broadband and compact size characteristics are two main goals which researchers are aim to fulfill. However, very good characteristics have been obtained for hybrid couplers using developed structures during the last decade [2]-[9]. In this paper a new compact wideband quadrature hybrid based on cascading two sections branch-line coupler has been designed and simulated, and its characteristics are presented.

II. ANALYSIS AND DESIGN

A. Conventional Coupler

Figure 1 shows the schematic diagram of the conventional two sections branch-line coupler where all transmission lines are quarter-wavelength long at the center frequency, and have three sets of characteristic impedances, namely Z_1, Z_2, and Z_3. Using the even- and odd-mode analysis, expressions for these impedances can be obtained [10] and may be written in the following form as

$$Z_1^2 = Z_0\, Z_3 \frac{k}{\sqrt{1+k^2}} \quad (1)$$

$$Z_2 = Z_0 \frac{k}{-1+\sqrt{1+k^2}} \quad (2)$$

where Z_0 is the port impedance (the system impedance), and k^2 is the output port power ratio,
i.e. $k^2 = P_3/P_2 = |V_3|^2/|V_2|^2$. Equations (1) and (2) can also be written in terms of the coupling coefficient C,
$C = |V_3|/|V_1|$. Since the coupler is assumed to be ideal, hence $P_1 = P_2 + P_3$ or $|V_1^2| = |V_2^2| + |V_3^2|$
which gives the following relation

$$k = \frac{c}{\sqrt{1-c^2}} \quad (3)$$

Using this relation, equations (1) and (2) can be written as

$$Z_1^2 = Z_0\, Z_3 C \quad (4)$$

$$Z_2 = Z_0 \frac{c}{1-\sqrt{1-c^2}} \quad (5)$$

These equations, (4) and (5), can be used to design the two sections branch-line coupler with a given coupling coefficient C, where Z_1 or Z_3 can be chosen arbitrarily. However, choosing $Z_1 = Z_3$ gives a maximum bandwidth [10]. Hence, equation (4) reduces to $Z_1 = Z_0\, C$.

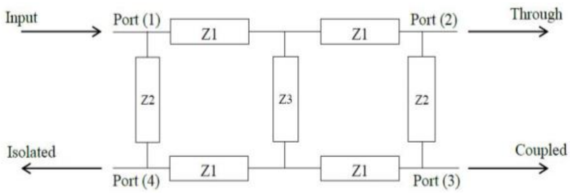

Figure 1: Schematic diagram of the conventional two sections branch-line coupler.

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The above equations have been used to design a two sections branch-line quadrature hybrid, where the power splits equally in port 2 and port 3, i.e. $C = 1/\sqrt{2}$. In this design, the central frequency is 1.8 GHz , Z_0 = 50 Ω , Z_1 = Z_3 = 35.35 Ω , Z_2 = 120 Ω , and a substrate with a dielectric constant of 2.2 and a thickness of 0.7874 mm has been used as it is available in most fabrication centers. The dimensions of the $\lambda_g/4$ series and parallel branches have been calculated using the line calculator tool in the ADS software and are shown on the layout in Figure 2. The designed coupler has been simulated using the CST software, and results for the magnitude and phase of its S-parameters are shown in Figures 3 and 4, respectively. These figures show acceptable frequency response within a bandwidth of about 400 MHz.

B. Proposed Coupler

Due to the transmission lines with quarter wavelength, the conventional two sections branch-line coupler occupies a significant amount of circuit area. The artificial transmission line concept [11] is a popular technique to reduce the physical size of the transmission line circuits which is an important factor for planar integrated circuits. In this section we introduce a design based on the artificial microstrip transmission line technique to reduce the size of the designed hybrid coupler in the previous section.

Figure 5(a) shows a layout of an artificial microstrip line which is a normal (main) microstrip line loaded with shunt open ended stubs. Figure 5(b) shows a unit cell of the periodic shunt stub. The steps of the design can be summarized as following:

1. For any arm, series or shunt of the Z_1 and Z_3 arms (Figure1), the characteristic impedance Z_{0TL} and the phase velocity v_{pTL} of the main microstrip line can be obtained at the operating frequency (1.8 GHz) by setting a certain value for its width W_{TL} in the range of 0.4 to 4.5 mm (which is a realizable value). The substrate, as mentioned before, has $\varepsilon_r = 2.2$ and $h =$ 0.7874 mm.

Using the values of Z_{0TL} and v_{pTL}, the length of the unit cell d and the shunt capacitance C_p introduced by a stub to the main line can be calculated by the following relations [11]

$$d = \frac{Z_{0ATL}\ \phi_{ATL}\ v_{pTL}}{Z_{0TL}\ N\ \omega_0} \quad (6)$$

$$C_p = \frac{\phi_{ATL}\ (Z_{0TL}^2 - Z_{0ATL}^2)}{N\ \omega_0\ Z_{0TL}^2\ Z_{0ATL}} \quad (7)$$

where Z_{0ATL} and ϕ_{ATL} are the characteristic impedance and the electrical length, respectively, of the artificial microstrip line which contains N cells, and ω_0 is the angular center frequency. In the calculations Z_{0ATL} is 35.35 Ω and ϕ_{ATL} is $\pi/2$ for Z_1 and Z_3 arms.

3. Using the value of d, the width of the stub line W_{Stub} in a unit cell can be obtained from the condition $d - W_{Stub} \geq 3h$ which reduces the coupling between adjacent stubs. Again with the value of W_{Stub} , the characteristic impedance Z_{0Stub} and the phase velocity v_{pStub} of the open stub microstrip line can be obtained as in step 1 (by the Line Calc in the ADS).

4. Finally, using the obtained above values for C_p, Z_{0Stub}, and v_{pStub}, and using the relation of the input admittance of an open stub, $Y_{in} = j\,Y_0 \tan \beta l$, the length of the open stub L_{Stub} can be obtained as

$$L_{Stub} = \frac{v_{pStub}}{\omega_0} \tan^{-1}(\omega_0\ C_p\ Z_{0Stub})$$
$$\text{where} \quad \frac{\omega_0\ L_{Stub}}{v_{pStub}} < \frac{\pi}{4} \quad (8)$$

Based on the above steps, the conventional two section hybrid coupler, shown in Figure 2, has been redesigned using the same characteristic impedances and on the same substrate.

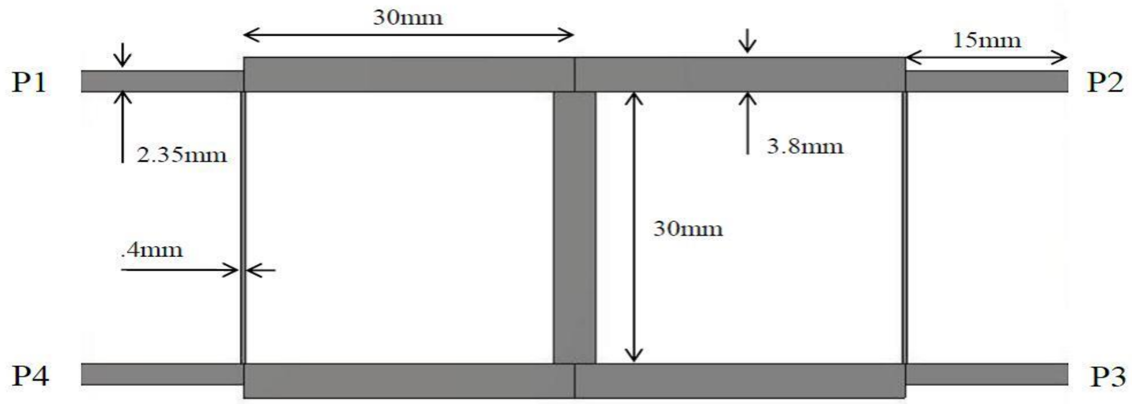

Figure 2: Layout of the designed conventional two sections branch-line coupler.

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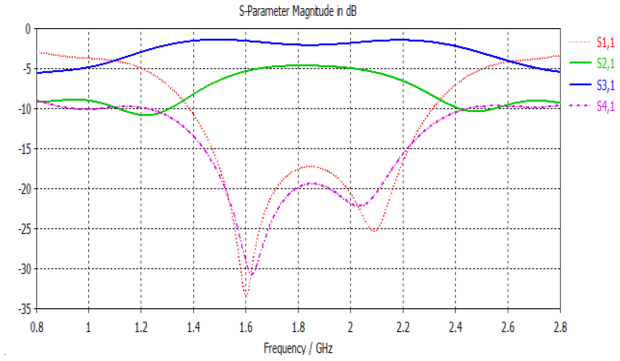

Figure 3: Simulated S-parameters of the two sections conventional coupler.

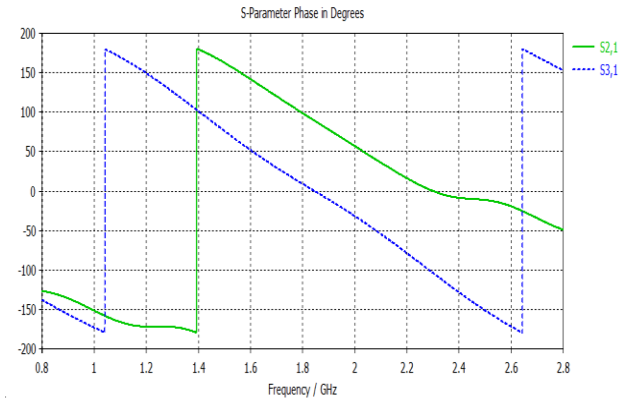

Figure 4: The phase plot of the two sections conventional coupler.

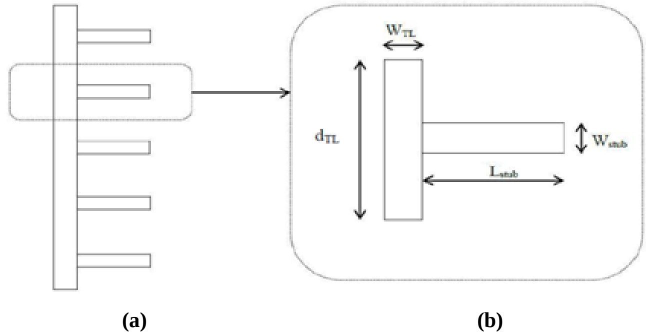

Figure 5: Microstrip line loaded with shunt open ended stubs and its unit cell.

The Z_2 arms, Z_2 = 120 Ω, have been redesigned using the meander lines. All the dimensions of the resultant compact hybrid coupler are shown on its layout in Figure 6. The designed coupler has been simulated using the CST software, and the results of its S-parameters, magnitude and phase, are shown in Figures 7 and 8, respectively. As shown in Figure 7, the return loss (S_{11}) and the isolation (S_{14}) both are better than 18 dB. The amplitude imbalance of S_{21} and S_{31} is about ±1.25 dB of the 3 dB level within a relative bandwidth of 41.6 %. Figure 8 shows the phase plot of S_{21} and S_{31}, and the phase difference (≈ 90^0) is shown in Figure 9.

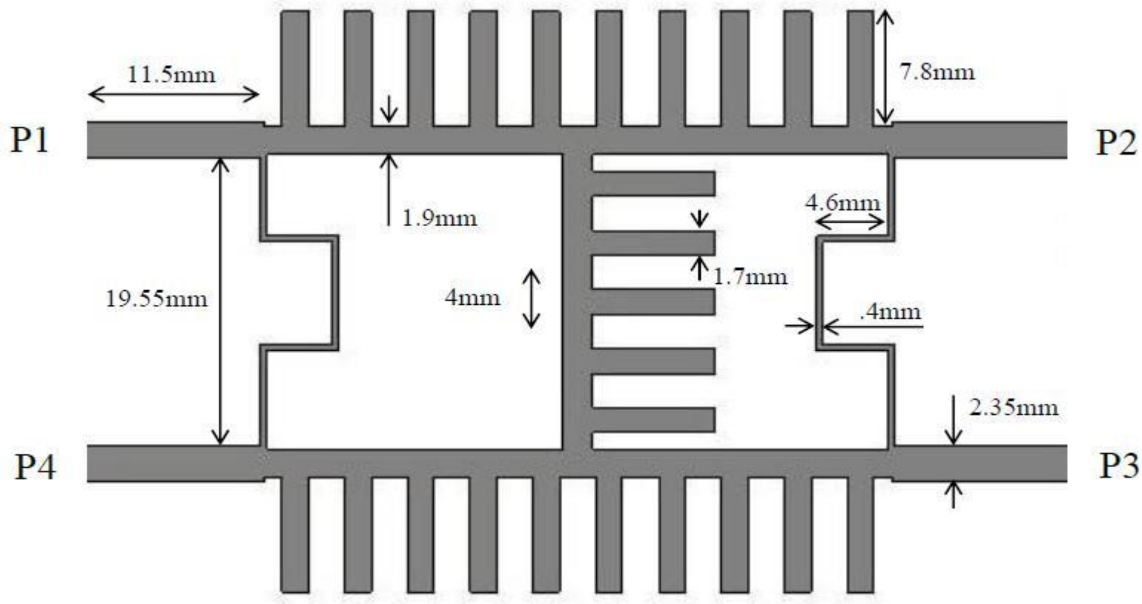

Figure 6: Layout of the proposed hybrid coupler.

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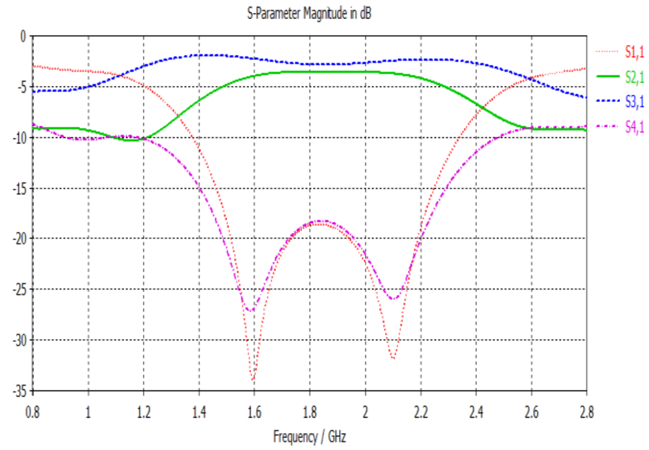

Figure 7: Simulated S-parameters of the proposed coupler.

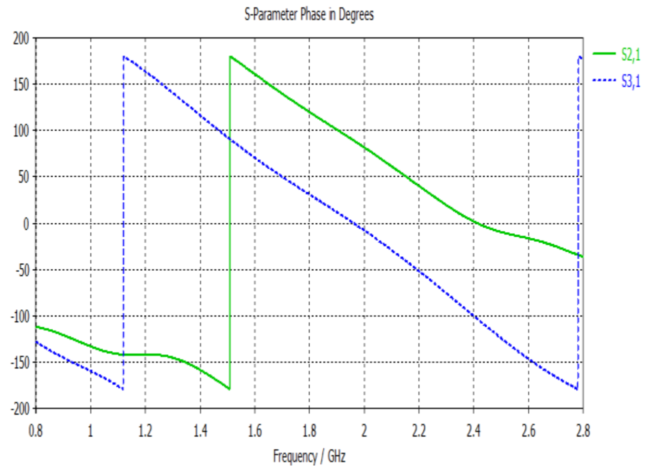

Figure 8: Phase plot of S_{21} and S_{31} .

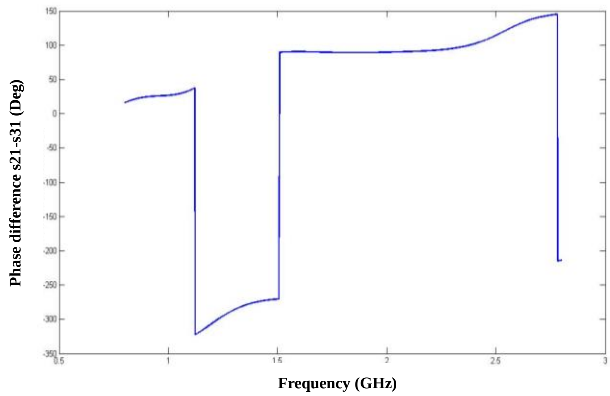

Figure 9: Phase difference between S_{21} and S_{31}.

The quadrature phase imbalance is less than 1^0 over the entire band. The designed coupler is simple and shows broadband and compactness properties with no lumped elements or via holes.

III. EXTENDED COMPARISON

A comparison between the performance of the proposed coupler, the conventional, and some other published data has been made in table 1.

As it is clear from this table, the proposed coupler has very good characteristics compared to the conventional one. This appears from a size reduction by about 31 % and an increasing in the bandwidth by about 19 %, besides to the improvement in the amplitude imbalance of the two outputs. Also, the proposed coupler has comparable results with respect to the other published data.

Table 1 : Comparison of the performance of the proposed coupler and some other published data.

	Conventional broadband	**Proposed coupler**	**Results of [2]**	**Results of [4]**	**Results of [6]**	**Results of [9]**
Frequency (GHz)	1.8	1.8	2	2.5	6	1.8
Return Loss S_{11} (dB)	Better than -17	Better than -18	Better than -22	Better than -16	Better than -20	Better than -20
Isolation S_{41} (dB)	Better than -19	Better than -18	Better than -20	Better than -15	Better than -20	Better than -20
Direct S_{21} (dB)	-4.5	-3.5	-2.5	-2.5±.5	-3.5±.5	-3±.5
Coupling S_{31} (dB)	-1.9 ± .2	-2 ± .5	-4	-4.5	-3.5±.5	-3±.5
Bandwidth (MHz)	400	750	900	1000	2900	400
Fractional bandwidth (%)	22.2	41.6	45	40	49	22.2
Circuit area (cm^2)	22.56	15.6	13.22	8.38	Suspended substrate	7.2
Relative size (%)	100	69	54	43	-	25.7

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IV. CONCLUSION

In this paper a design for a compact wideband quadrature hybrid coupler based on microstrip technology has been presented. We started with a design of a conventional broadband quadrature coupler, and then we used the artificial microstrip line concept and the meander lines to miniaturize and improve the performance of this coupler. The proposed coupler has a size reduction of about 31% compared to the conventional design and a relative bandwidth more than 40.0%. The return loss (S_{11}) and the isolation (S_{14}) both are better than 18 dB. The proposed structure design is simple, because it consists of a single layer with no element that needs a multilayered or air-bridged structure, and does not need lumped components or via holes which limit the circuit performance.

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