An Ultra-Wideband 3-dB Quadrature Hybrid with MultiSection Broadside Stripline Tandem Structure

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Abstract. Design of an Ultra-Wideband 3-dB quadrature (90°) Hybrid using ADS and HFSS softwares plus Measurement report are presented. Simultaneous Use of these two softwares lead to fast and accurate design procedure. The coupler is realized in broadside stripline and with the connection of coupled regions in tandem structure. The measured data agrees well with the expected values from simulations, and shows a good ultra wide bandwidth response over the frequency range of 1-10 GHz. Measurements showed an amplitude unbalance of ±1.5 dB, a phase unbalance of 90°±7° , and an isolation and a return loss characteristics of more than 14 dB over the frequency of 1 to 10 GHz.

Keywords: 3-dB quadrature Hybrid, tandem Structure, Ultra-Wideband coupler, broadside stripline, multisection coupling.

1 Introduction

The 3-dB 90°Hybrid is a directional coupler which has two equal amplitude outputs with 90 degree difference in phase, and it is used in many communication devices. Mixers, oscillators, balanced amplifiers, phase array antennas, modulators, etc. are the most famous applications of the 3-dB 90°-Hybrids. Therefore, for realization of an Ultra-Wideband system, here we propose to realize a suitable 3-dB 90°-Hybrid.

It is known that in a TEM system, two parallel coupled lines achieve highest coupling when they are a quarter wavelength long ($\lambda/4$) [1]. The necessity of a quarter wavelength, results in a narrowband width (about 10-20%). Wideband coupling is achieved by cascading several $\lambda/4$ coupled sections together. More broadband response with smaller ripples may be achieved by increasing the number of $\lambda/4$ sections [1]. Crystal and Young have presented detailed design data for this type of device [2]. These tables give the required even mode impedance for each section to produce an equiripple frequency response.

However, the required coupling of the central elements in the multisection couplers is always tighter than that of the overall coupler. Such tight coupling values are

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impossible or very hard to realize in microstrip [3]. For resolving this problem we use broadside stripline structure which can realize such tight coupling. This tight coupling is needed for realization of a half power coupler that as we mentioned the half power coupler use in balanced structure amplifiers for decreasing return loss or in dual quadrature Mixer for reducing LO to RF isolation and reflection coefficient.

One of the other problems about these couplers is jump discontinuities in the coupling coefficient function with corresponding jump discontinuities in the stripline dimensions [4]. To mitigate this effect we should taper the discontinuities.

Beacause of the importance of the hybrids in communication engineering, some papers are reported in the literatures that some of them discuss on the method of design or optimization and some of them present new structure for increase the bandwidth or decrease the size of module[5-10].

In this paper, the design, optimization and realization of a broadside stripline symmetrical multisection quadrature hybrid are reported. The design is started by using tables [2]. Then with the use of LineCalc tool of ADS we obtain dimensions of each section. After that we use broadside stripline coupled lines elements in ADS to optimize these dimensions and confirm our simulation in the momentum environment of ADS. Finally, the main simulation process is made using a famous 3-D analysis program, namely HFSS. So, with simultaneous utilizing of ADS & HFSS we can decrease the essential time for obtaining suitable and accurate simulation results. After fabrication , measurements show good agreements with simulated data.

2 Coupling Structure

Basis of this design is the connection of two symmetrical multisection couplers with crossover in tandem, i.e. the coupled and direct ports of one multisection coupler be connected to the isolated and input ports of another coupler [11]. The use of broadside stripline structure with crossover in each coupler, has the advantage that coupled and directed outputs of each coupler are both on one side, while in structure without crossover, coupled and direct ports are not on one side(Fig. 1 & Fig. 2) and thus there will be need to wire-bonding for tandem connection of two multisection couplers without crossover, so we use couplers with crossover to avoid the wirebonding procedure. A -3 dB coupler is realized by using two -8.34 dB couplers that connected in tandem as in Figure 3 (-3 dB = 20 log sin(π/4), and -8.34 dB = 20 log sin(π/8)). C_1, C_2 and C_N are the coupling coefficients of each individual quarter wavelength coupler stages, and given by:

$$C = \frac{Z_{oe}^{2} - Z_{0}^{2}}{Z_{oe}^{2} + Z_{0}^{2}} \quad (Z_0 = \sqrt{Z_{oe} \times Z_{oo}}) \tag{1}$$

where Zoe and Zoo are even and odd mode impedances of each coupled line respectively and Z0 is 50Ω.

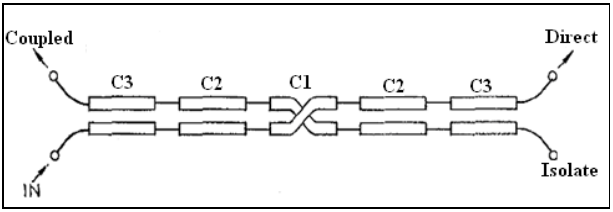


Fig. 1. Symmetrical Five-Multisection Coupler with crossover

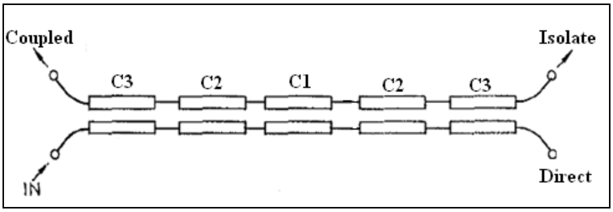


Fig. 2. Symmetrical Five-Multisection Coupler without crossover

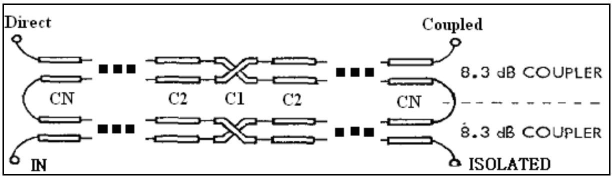


Fig. 3. Tandem connection of two 8.3-dB multisection couplers

3 Realization Environment

Multisection coupler is realized in stripline since - compared to its microstrip counterpart - phase and amplitude dispersion can be much less despite increasing frequency. Along with this structure, “broadside coupling” is selected as realization form for these cascaded couplers because it is well suited for achieving high coupling factors (Fig. 4). This is especially important for the central elements of the structure.

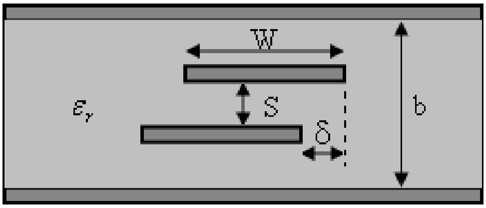


Fig. 4. Stripline Broadside Coupling

For broadside stripline structure if δ=0 we have[12]

$$Z_{0e} = \eta_0 \frac{b-S}{2W\sqrt{\varepsilon_r}}$$
$$Z_{0o} = \eta_0 \frac{1}{2W\sqrt{\varepsilon_r}\,[1/(b-S)+1/S]} \tag{2}$$

Where η_0 is the charectristic impedance of free space and equal to 120π.

Since the bandwidth of the coupler is to be maximized, the highest possible center section coupling coefficient must be achieved. It follows that the separation of the inner conductors must be minimised, and the separation of the two ground planes be maximised to provide maximum coupling. A low dielectric constant maximises the possible coupling as well [11].

Therefore we choose a suitable microstrip board for implementation the coupler realization as indicated in Table1. We select Rogers RT/duroid 5880 with two different thickness of 10 mil for meddle layer and 31 mil for two other layers. Finally to realise a broadside strip line we should sandwich these three layers between two metal plates.

Table 1. Properties of considered substrate

b(mil)	S(mil)	ε_r	Substrate
72	10	2.2	Rogers RT/duroid 5880

4 Simulation Results

It is obvious that selected multisection hybrid requires a structure with corresponding jump discontinuities and hence constitutes a ‘coupling profile’, *k(x)*, which is defined as the value of coupling factor as a function of distance along the coupler's axis of propagation.

We propose to design a 3-dB 90° hybrid over the frequency of 1-10GHz. By this pourpose to increase the reliabilty of response in practice, we design and simulate the coupler over the frequency range of 1-18GHz.

Using tables of [2],[13] we can find that ninghteen-section coupler can have proper results for our purposes. Even mode impedances and corresponding coupling coefficient of each section are obtained easily from [2],[13]. After that, we use LineCalc tool to find the dimensions of each section. The optimization of these quantities is performed in ADS. Then we use these optimized dimensions to perform our final design and simulation in the HFSS.

Figure 5 displays the ninghteen-section tandem structure coupler in the HFSS enviroment. Ninghteen-section means ten sections at right, ten sections at left and one section at the center that make a ninghteen-section coupler. Notice that, each multisection coupler with cross over is symmetric.

According to Fig 5, if port1 is to be the input port, then port 2,3,4 will be direct, coupled and isolated ports respectively. The final optimized values of the length, line width(W) and offset between up and down line (δ) in broadside structure of each section of our multisection coupler are given in Table 2.

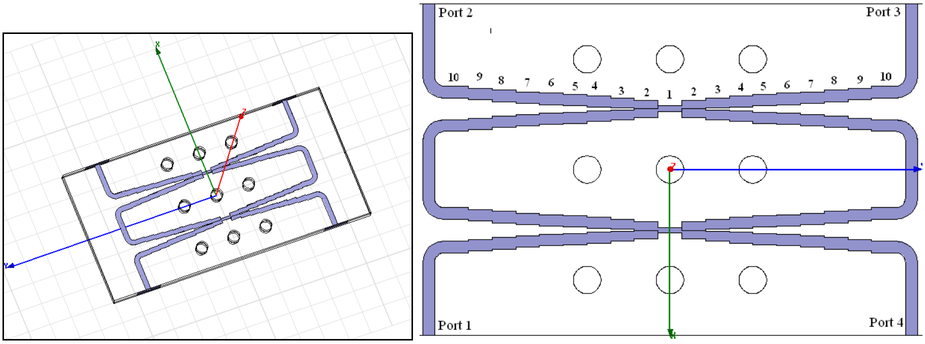


Fig. 5. Ultra-Wideband 19-section tandem structure coupler in HFSS

Table 2. Length, offset and width of each section of coupler

W1(mm)	1.05	δ1(mm)	0	L(mm)	4.3
W2(mm)	1.59	δ2(mm)	1.58		
W3(mm)	1.83	δ3(mm)	2.15		
W4(mm)	1.99	δ4(mm)	2.65		
W5(mm)	2.03	δ5(mm)	3.3		
W6(mm)	2.07	δ6(mm)	3.58		
W7(mm)	2.09	δ7(mm)	4.09		
W8(mm)	2.09	δ8(mm)	4.73		
W9(mm)	2.1	δ9(mm)	5.45		
W10(mm)	2.16	δ10(mm)	6		

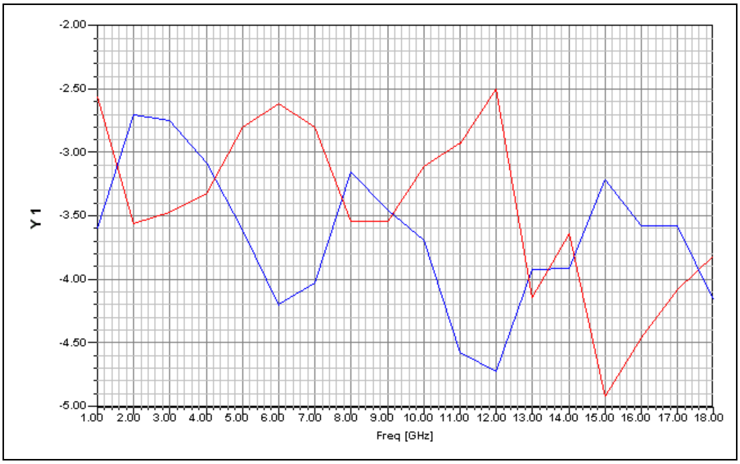


Fig. 6. The direct and coupled insertion loss in HFSS

Figure 6-8 show the results of simulation that were obtained in the HFSS. The direct and coupled insertion loss (S21(dB) and S31(dB)) are showed in Fig6.

We see that both of the direct and coupled insertion loss are about 3dB, that lead to have a 3-dB coupler.

Furthermore Fig 7 shows the phase difference between the direct and coupled port of coupler, that for our quadrature hybrid, it should be about 90 degree.

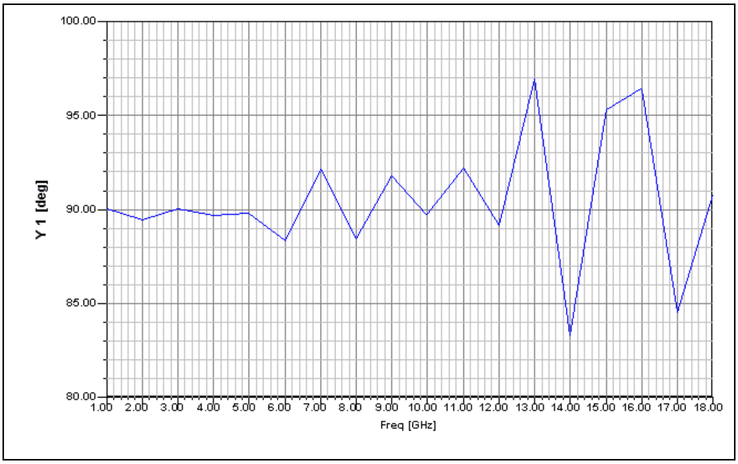


Fig. 7. Phase difference of two outputs in HFSS simulation

Fig 8 shows the return loss (S11(dB)) and the isolation (S41(dB)) of the designed coupler.

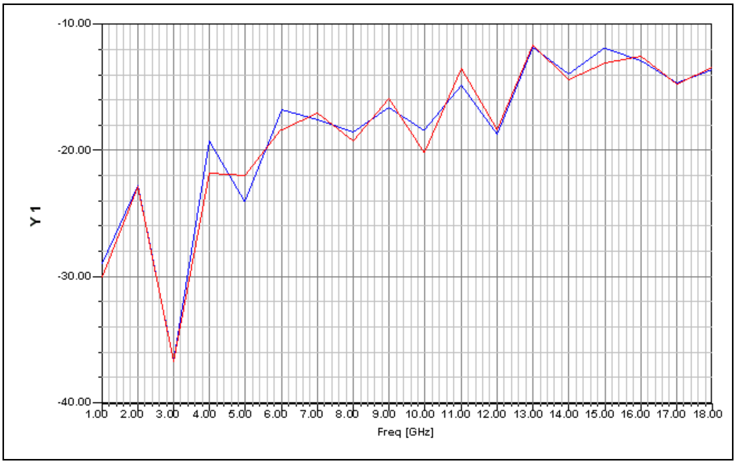


Fig. 8. Isolation and returnloss in HFSS simulation

As seen in three previous figures, in simulation, the amplitude imbalance is ±0.6dB, the phase difference is 90°±6° and the return loss and the isolation are better than 12dB over the frequency of 1-18GHz.

5 Fabrication and the Measurement Results

In the Fabrication, we used a substrate with $\varepsilon_r = 2.2$ and b=72mil and S=10mil. Fig 9 displays the fabricated 3-dB quadrature hybrid. For fabrication of the broadside stripline coupler we pattern the shape of coupler on one side of two thicker layers, then we place another layer between these two layers and sandwich these three layers between two alumunium plates. Dimension of the fabricated quadrature hybrid is 12*4.4*1.3 cm.

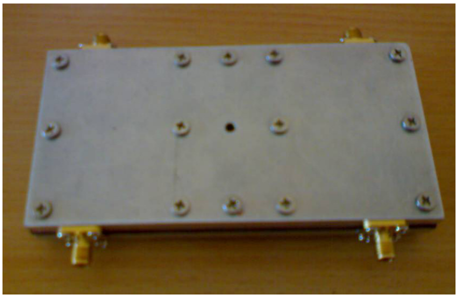


Fig. 9. The fabricated broadside stripline coupler

Figures 10 throw 13 give the measurement results which show an excellent agreement with those of the simulation.

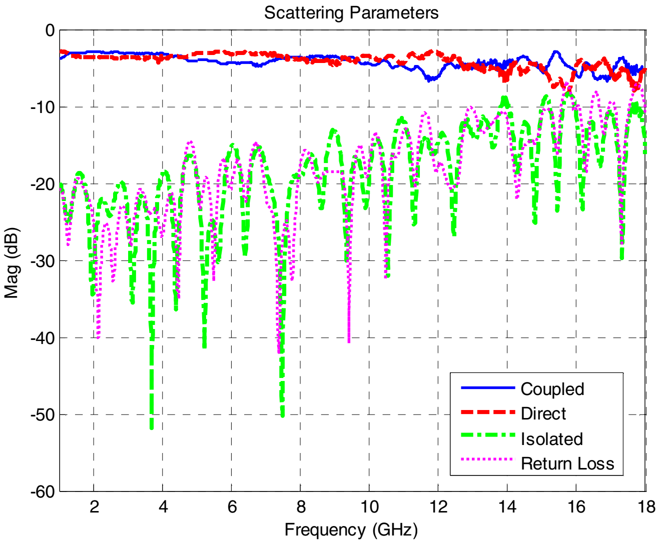
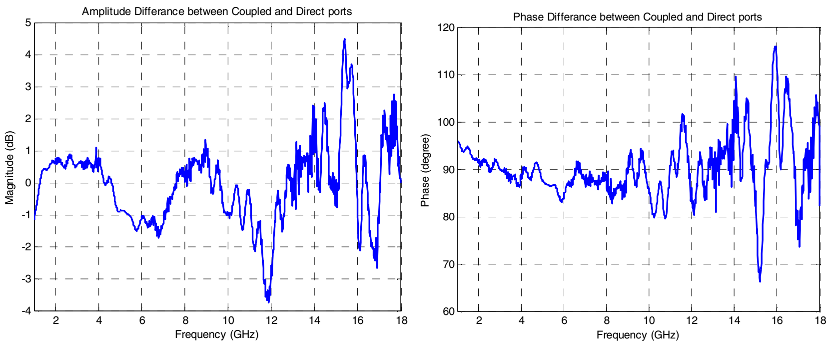


Fig. 10. Measured scattering parameters over the frequency of 1-18GHz



(a) (b)

Fig. 11. Measured **a)** amplitude difference {S21(dB)-S31(dB)} **b)** phase difference (arg(S21)-arg(S31)) between the direct and coupled ports over the frequency of 1-18GHz

We see that fabricated hybrid has suitable response over the frequency of 1-18GHz that are relatively matched with simulation results, and especially its performance is very good over the 1 to 10GHz, that is our desired frequency band.

For better understanding of the response of fabricated coupler over the desired frequency range of 1-10GHz, measurements in this band are separately shown in Fig 12,13.

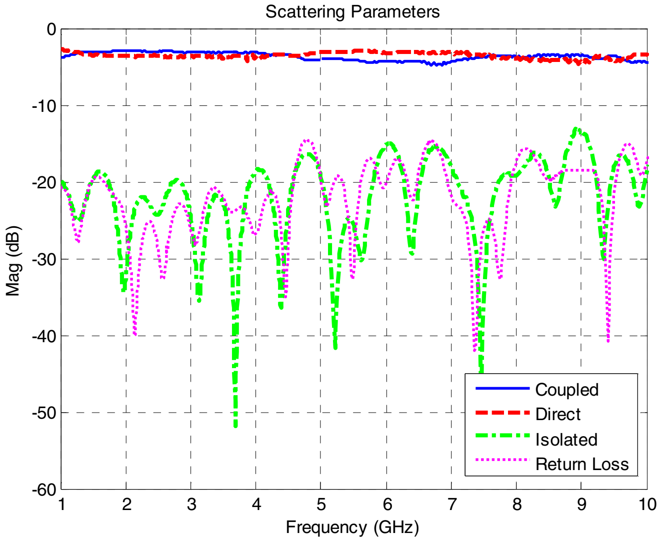
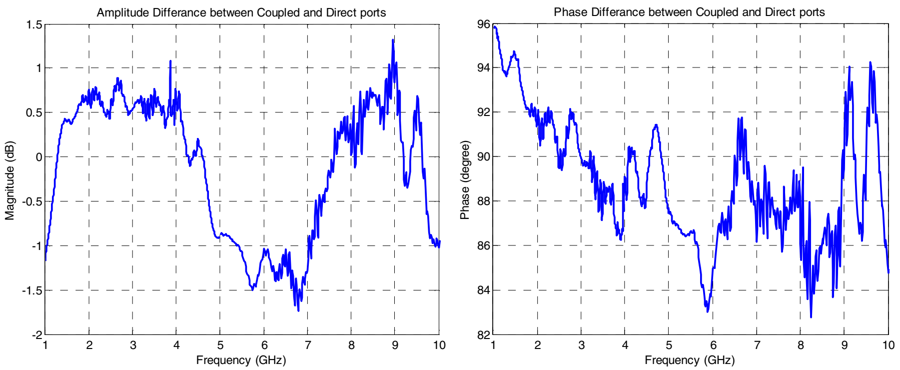


Fig. 12. Measured scattering parameters over the frequency of 1-10GHz



(a) (b)

Fig. 13. Measured a)amplitude b)phase difference between the direct and coupled ports over the frequency of 1-10GHz

Finally, we compare the simulation results with the measurement results over the frequency of 1-10GHz as in Fig 14 that shows good accordance between measurement and simulation results.

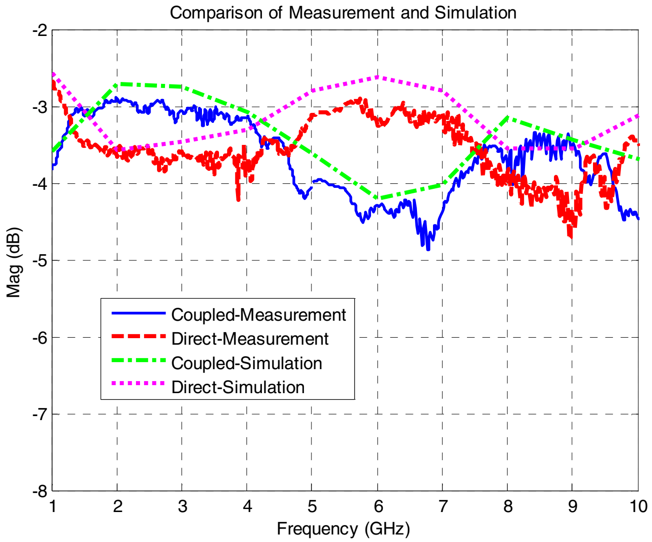


Fig. 14. Comparison the simulation results with the measurement results over the frequency range of 1-10GHz

As seen in above figures, over the frequency range of 1 to 10GHz the measured amplitude imbalance is ±1.5^{dB}, the phase difference is 90°±7° and the return loss and the isolasion are more than 14^{dB} and has a good accordance with simulation results.

6 Conclusion

An Ultra-Wideband 3-dB 90°-Hybrid is designed, simulated and optimizaed in this paper utilizing HFSS and ADS. We implement three conditions for achive Ultra-Wideband response. Multisection coupling, tandem structure and broadside strip line was those issues. We use two ninghteen-section broadside couplers in tandem structure to obtain an Ultra-Wideband response.

The 3-dB quadrature hybrid is fabricated in broadside stripline and the measurements show very good agreement with the simulation results.

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