An Optimized design of Wideband Multi-Section Branch Line Coupler at Ka Band

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Abstract
This paper presents the design of 3-dB wide-band branch line coupler. A multi-section branch line coupler is designed in microstrip configuration to cover the frequency band of 26.0 – 40.0 GHz. Optimization of the design is carried out in Ansoft Designer V6.0 to meet the required specifications. Simulated results show 42% bandwidth for a return loss of better than 20dB and amplitude imbalance of 3±1dB over 26-40GHz. Isolation of more than 15dB with a phase imbalance of better than ±3° has been simulated.

Keywords: Branch line coupler, Microstrip, discontinuities, mutual coupling, correlator.

I. Introduction
Branch line couplers offers a 90^0 phase difference with good directivity and equal/unequal power splitting which is useful in large number of RF circuits such as balanced mixer, phase correlator , balanced amplifier, image rejection mixer ,balanced modulator, programmable attenuator, power measurements ,antenna beam forming networks and other microwave instrumentation.

A single section branch line coupler with equal power division is a most popular structure but due to quarter wavelength requirement, its bandwidth is limited to 15%.The band width can be improved to a decade or more by using multiple sections in cascade[1]. There are many circuits that can be used as broadband 90° hybrids such as Lange coupler and coupled line couplers. But Lange coupler involves realization of very narrow lines and spacing apart from wire bonding. 3 dB couplers in edge coupled microstrip configuration are impossible to realize as the coupled line spacing is few microns. And couplers using offset coupled strip lines involve multiple layers and hence not suitable for uniplanar applications. Most of the 3 dB couplers require multi-layered or air-bridged structures for tight coupling and signal routing (crossover) over a wide frequency range. The requirements for air-bridges results in more masks and fabrication processes leading to more manufacturing costs. Moreover, these air-bridges would represent a bottleneck for power handling and that limit the applications of Lange and tandem couplers. The simplest technique to enhance the bandwidth is to use a multi-section cascaded branch line coupler. So, a conventional branch line coupler is cascaded with 5 sections to enhance the bandwidth up to 42%.The main feature of 5-section branch-line coupler is the simplicity in its design and implementation. But, the only disadvantage of the cascaded conventional branch-line couplers is the large area required and little higher insertion loss.

In this paper, a compact, wide band five sections 3.0 dB branch line coupler is designed in 26.0 – 40.0 GHz in Microstrip technology using Ansoft Designer, a Method of moments (MoM) based 2.5D EM simulation software.

II. Design
Generally, branch line couplers are formed by using two quarter wave lines separated by branches of quarter wave length long. Fig.1 shows a conventional single section branch line coupler in planar configuration with Z_1 = 35.35 Ohms and Z_2 = 50 Ohms, for which power in arm 1 divides evenly between arms 3 and 4 with a phase shift of 90^0.

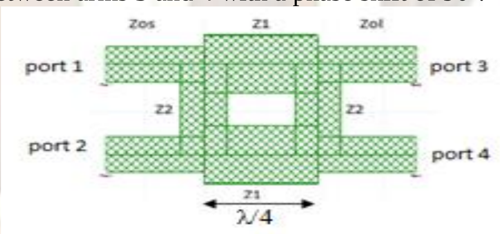

Figure 1. Single Section Branch-line Coupler

No power is delivered to arm 2, because the signal flowing through different paths of lengths λ/4 and 3λ/4 have the same amplitudes and opposite phases at this port [2]. The source impedance Z_{os} and load impedance Z_{ol} are 50ohms.The s-parameters can be calculated by using even and odd mode analysis as shown in figure 2.At the center frequency, the s-parameters of branch line coupler are given by [3]:

$$S_{21} = -j\frac{Z_1}{Z_o} \qquad (1)$$

$$S_{31} = -j\frac{Z_1}{Z_2} \qquad (2)$$

$$S_{11} = 0 \qquad (3)$$

$$S_{44} = 0 \quad (4)$$

Where,

Z_0 represents the impedance of various ports of branch line coupler.Z_1 and Z_2 represents the main and branch line impedances.

The characteristic impedances of main line (Z1) and branch line (Z2) are calculated by [3]:

$$Z_1 = Z_o * S_{21} \quad (5)$$

$$Z_2 = \frac{Z_1}{S_{31}} \quad (6)$$

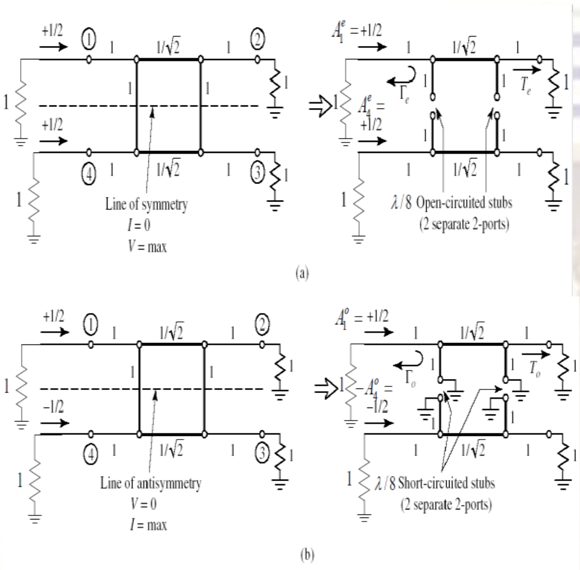

Figure 2. Decomposition of the branch-line coupler into even- and odd-mode excitations. (a) Even mode (e). (b) Odd mode (o).

From equations (5) to (6), the characteristic impedances of main line and branch lines are 50Ω and 35.35Ω.The 3-section branch line coupler is shown in fig.3

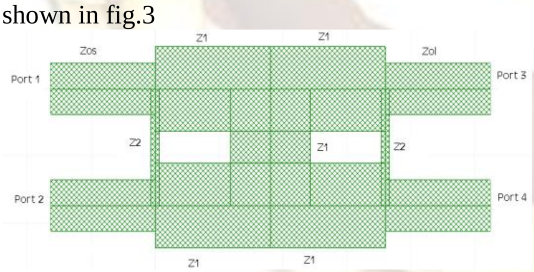

Figure 3. 3-Section branch line Coupler

To design this hybrid with the given impedance transformation ratio 'r' and power split ratio k^2, the branch and the main line impedances can be can be calculated by [4]:

$$Z_1 = Z_{os}\sqrt{r - \left(\frac{r}{t}\right)^2} \quad (7)$$

$$Z_2 = Z_{os}\sqrt{r\left(\frac{t^2 - r}{t - r}\right)} \quad (8)$$

Where, $t = 4\sqrt{1 + k^2}$

For an equal power division when k=1,the condition t= 1.414* r specifies a minimum value of 'r' which is equal to 0.5.However in practice, it is better to choose 'r' in the range of 0.7 to 1.3,in order to provide the physically realizable branch line characteristic impedances for 50Ω input impedance. From the above equations, the characteristic impedances of main line and branch lines are 35.35Ω and 120.7Ω.

The 5-section branch line coupler is shown in figure 4.

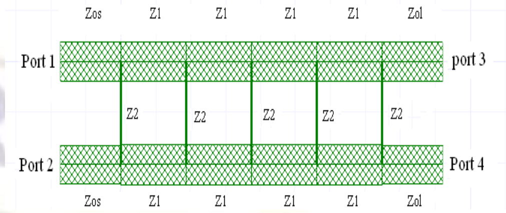

Figure 4. 5-Section Branch line Coupler

The characteristic impedances of main line and branch lines of 5-section branch line coupler can be calculated by using design equations specified in [5].The calculated main line and shunt line impedances are 35.35Ω and 155.7Ω.

At millimeter wave frequencies, the lengths of the microstrip lines can actually get shorter than the widths and the mutual coupling between the input lines and discontinuities at the input increases significantly. This has a direct effect on the input/output match, frequency bandwidth and isolation. To minimize the effect of these problems, the height of the substrate is reduced since the height of the substrate is directly proportional to width.

As multi-sections are cascaded, due to a change in the impedance level at the junction's results in discontinuity effects. These discontinuities lead to increase in the reactance at the junctions leading to poor coupling and return loss. The reactance associated with these discontinuities may be called as parasitic reactance, as they are not introduced intentionally. Some of the effects of discontinuities on circuit performance are:

- Frequency shift in narrow band circuits.
- Degradation in input and output voltage standing wave ratios.
- Interfacing problems in multifunction circuits.
- Lower circuit yield due to degradation in circuit performance.
- Surface waves and radiation coupling may cause oscillations.

The effects of discontinuities become more critical at higher frequencies. These reactances mainly depend on the physical dimensions of the coupler. So in order to avoid these effects, physical dimensions are optimized to compensate the reactances associated with the junctions of the coupler.

III. Simulation And Discussions

To see the performance of the proposed design ,the return loss,inertion losses and isolation are evaluated in Ansoft Designer microwave Tool.The substrate and electrical characteristics are given below:

Substrate characteristics:

Dielectric constant $\varepsilon r = 2.2$

Height H = 10mil (0.254mm)

Loss tangent $\delta = 0.001$

Electrical characteristics:

Characteristic impedance $Z_0 = 50\Omega$

Electrical length $\beta l = 90$

Design frequency $f_0 = 33GHz$

Based on the line impedances and corresponding substrate and electrical characteristics, the corresponding widths of the lines are calculated using LINECAL in ANSOFT Designer at centre frequency of 33GHz.The electrical length of the line is chosen to be 90^0 and the corresponding physical length of the lines are calculated by using equations (9) and (10):

Electrical length $$\beta l = 90 \quad (9)$$

Where, $$\beta = \frac{2\pi}{\lambda} \quad (10)$$

The physical dimensions of the structure before and after optimization are shown in table 1:

Table 1: Physical Dimensions of the structure

Characteristic impedance(Ω)	Length(mm)	Width(mm)
50	1.64	0.79
35.35	1.61	1.29
155.7	1.71	0.05

After optimization the lengths and widths of the main and shunt lines are as shown in table 2.

Table 2: Physical dimensions after optimization

Characteristic impedance(Ω)	Length(mm)	Width(mm)
50	1.64	0.76
35.35	1.8	0.75
155.7	2.1	0.045

Figure 5 shows the simulated return loss of the designed Quadrature hybrid structures to compare the bandwidth enhancement. As we can see, the results obtained from the designed 5-section branch line coupler has a better bandwidth improvement when compared to the conventional single section and three section branch line couplers.

From figure 6, it can be seen that a return loss of greater than 20dB is achieved throughout the frequency band with a bandwidth of 42%.

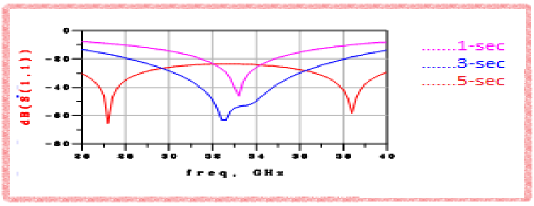

Figure 5: Return loss for 1-Section, 3-Section and 5-section branch line couplers

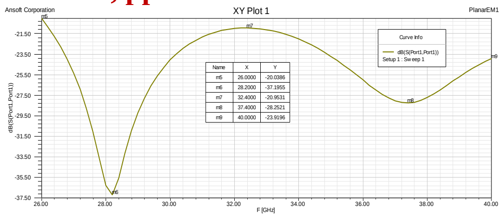

Figure 6: Plot for Return loss (S11)

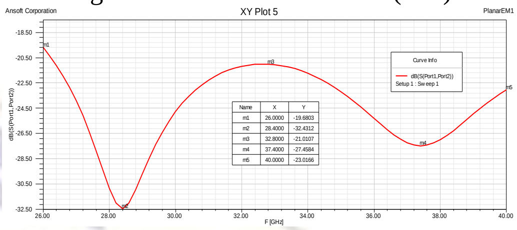

Figure 7: Plot for Isolation (S12)

Figure 7: Plot for coupling in direct (S13) and coupled ports (S14).

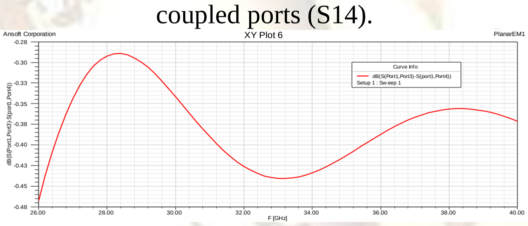

Figure 7: Plot for Amplitude imbalance

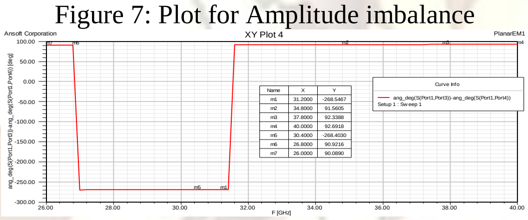

Figure 7: Plot for Phase imbalance

Figure 7 shows isolation with greater than 20dB and figure 8 shows the 3±1dB coupled between the direct and the coupled port and figure 9 shows the difference in coupling between direct and coupled port with 0.5dB.Figure 10 shows the phase difference between the direct and coupled ports. The observed phase was 90^0 with a tolerance of $\pm 3^0$.

IV. Conclusion

This paper has proposed a 3-dB five section branch line hybrid which can operate in wide frequency band using a planar Microstrip configuration with RT Duroid 5880 substrate. The designed band covers frequencies from 26-40GHz.The proposed design was initiated in microwave tool named Ansoft Designer. The proposed design has a bandwidth efficiency of 42% with return loss of 20dB throughout the frequency band. A tight coupling of 3±1dB was achieved with isolation greater than 15dB and with a phase imbalance of better than ±3°.

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