# Two-Section Branch-Line Coupler for Wireless Application

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**Abstract – The proposed design is of two 3-dB wide-band multi-section branch line couplers where the couplers are compared with small optimization The double-section branch line coupler is also called as the double box branch line coupler or multi-section branch line coupler. The double box branch line coupler is intended for the reduction of the size, improving the bandwidth and the return loss of the $S_{11}$ parameter should be over -10dB. A double-section branch line coupler is designed in microstrip configuration. Optimization of the design is carried out in Advanced Design System software (ADS) to meet the required specifications using the layout window. The proposed double-section branch line coupler is designed with the operating frequency of $S_{11}$ parameter is 2.4GHz for the wireless applications. The power divided at the output should be $90^0$ in phase difference. The FR-4 material is used for the fabrication of the double-section branch line coupler in printed circuit board (PCB).**

**Index Terms – Double-section branchline coupler; ADS; FR-4; 2.4GHz; S11, S12, S13 parameters.**

## 1. INTRODUCTION

The compact size and the high performance are demanded in many microwave communication systems. The important component widely applied in microwave circuit design is the 3dB branch line coupler. It is typically used in high frequency transmission and low frequency transmission. The branch line coupler has many applications in the design of microwave devices like balanced amplifiers, mixers and phase shifters. The branch line coupler helps in the power combining and power dividing functions which is suitable for the low-cost fabrication.

However, the size of the conventional branch line coupler is very large at the low frequencies. Therefore the reduction in size of this device is highly desirable for modern communication systems. The dimensions of the branch line coupler is reduced then the bandwidth will also be reduced. However ,the increase in dimension causes the frequency to decrease and the low width of the branch line coupler causes the permittivity to increase. Therefore to reduce these issues we use flame retardant (FR-4) substrate which is called as the lossy substrate. Hence, by decreasing the size the bandwidth is improved.

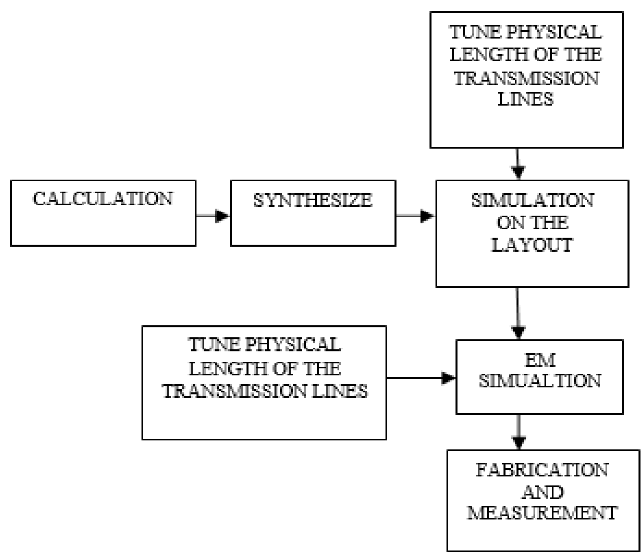


Figure 1 Block diagram for the design and process of the branch line coupler

The figure 1. shows that the proposed design needs the process of calculating the dimensions by using the frequency in which the design is going to operate which is also called as the operating frequency and helps in synthesizing the design by simulating on the layout. The proper output can be obtained by tuning the physical length of the transmission lines only to a limit the design is capable of and this process is further lead by EM simulation process and check the output according to the operating frequency and tune the physical length of the transmission lines till obtaining the respective values for the parameters and then the design is fabricated and tested using the network analyzer.

## 2. $90^0$ DOUBLE-SECTION BRANCH LINE COUPLER

The branch-line coupler dwelt of two lateral communication channels palpably buckled all at once with multiple branch lines betwixt them. Dispersed branched lines are λ/4 apart and represent sections of a multi-section filter design in the same way as the multiple sections of a coupled line coupler except that here the coupling of each section is controlled with the impedance of the branch lines.

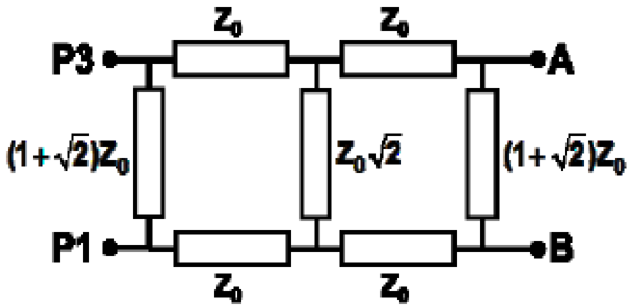


Figure 2 Double-section Branch line coupler

The main and coupled line are $\sqrt{2}$ of the system impedance. The more sections there are in the coupler, the higher is the ratio of impedances of the branch lines. High impedance lines have narrow tracks and this usually limits the design to three sections in planar formats due to manufacturing limitations. A similar limitation applies for coupling factors looser than 10 dB; low coupling also requires narrow tracks. Coupled lines are a better choice when loose coupling is required, but branch-line couplers are good for tight coupling and can be used for 3 dB hybrids. Branch-line couplers usually do not have such a wide bandwidth as coupled lines. This style of coupler is good for implementing in high-power, air dielectric, solid bar formats as the rigid structure is easy to mechanically support.

## 3. RELATED WORK

Azizi,Rahim proposed a reduced size single band semi-lumped element branchline coupler operating at frequency of 5.8GHz has been designed and semi-lumped element is inserted between transmission lines in realizing approximately 50% smaller size of coupler.It is used in butler matrix which is one of the main components in smart antenna [1].

The quasi-∏-equivalent double box is an in effect attitude to reduce the circuit size of a branchline coupler with regard to wideband performance.

The proposed branch line coupler exhibits couplings and phase errors inside −3.75 ± one decibel and 3° and return loss and isolation higher than -15 decibel over frequency from (1.4 GHz ~ 3.4 GHz) with a center frequency at 2.4GHz[2].

Abdelahk presented the simulations of the three branches coupler by the ADS software.The simulation results are presented in S-parameters [Sij] in module and phase at wide band (K and Ku band).The design of this coupler meets the norm of the coupler microstrip technology [3].

Novel transparent BLC design using a self-assembling nano-particle technology based MM film has high transparency, a -10dB measured 38.8% fractional bandwidth and isolation is better than 10dB.This design has high potential to be used as building blocks for BM BFN applications in future IIVWC in ITS to make wireless communication between mobile vehicles to base station a reality and it is a promising candidate for future 5G indoor wireless communications[4].Yongqiang Wang presents a novel approach for designing a coupler with arbitrary division, optional phase difference and alternative input or output impedences[5].

[6] presents a compact branch-line coupler by making good use of the three dimensional layout capability of the low temperature co-fired ceramic(LTCC) substrate and is accomplished by using lumped inductors and lumped capacitors. Zeeshan Qamar implemented a novel compact branch-line coupler using substrate integrated suspended line(SISL) to reduce the size which is composed of high-low impedance lines cascaded in meander line configuration and 62%size reduction has been achieved [7].

Priya Sharma presented a branchline coupler realised by coupled microstrip lines and coupled line fed coupling structures with insertion loss of 1.4 dB and a 3dB fractional bandwidth of 3.5% [8].A two section branchline coupler topology that simultaneously achieves a wide bandwidth operating at a frequency of 3GHz[9].The branch line coupler with the dual band is proposed with combination of Pi and T-Stub lines for global positioning system (GPS) and satellite applications where FR-4 is the substrate used here[10].

A reduced size single band semi-lumped element branchline coupler operating at frequency of 5.8GHz has been designed and semi-lumped element is inserted between transmission lines in realizing approximately 50% smaller size of coupler.It is used in butler matrix which is one of the main components in smart antenna [11]. Bashir Muhammad proposed the new design theory is successfully developed in an attempt to enhance electrical and mechanical performances of hybrid ring coupler and helps in the reduction of size[12].

N.H.A.Rahim developed a branchline coupler using parallel coupled transmission lines on planar microstrip using CST studio Suite 2010 design tool operating at 4GHz to 8GHz with percentage bandwidth of 32.32% [13].Tetsuo Hirota presents the method of reducing the size of the coupler with operating frequency 25GHz and 11GHz and has the advantages of excellent design accuracy even at higher frequencies [14]. The design of miniaturised on-chip quadrature hybrid branch-line coupler is investigated and used in millimetre wave communication is found by Meriam Gay[15].

Kae-Oh Sun implemented the novel compact branch-line coupler that employs discontinous microstrip lines is demonstrated with 1GHz frequency and 60% device size reduction is achieved compared with traditionally fabricated branchline couplers [17].Seungku Lee,Yongshik proposed the wideband branchline couplers with arbitrary coupling levels and by integrating single-section quarter-wave transformers at each port,wideband characteristics with excellent coupling flatness is achieved and reduces the return loss and isolation [19].

With the above analysis, we propose a branch-line coupler with reduced size and provides the return loss of S11 is high so as to reduce the loss. The following shows how the branch-line coupler is designed with maximum return loss.

## 4. COUPLER DESIGN

The proposed double-section branch line coupler has four ports where any port can be designated as input port and correspondingly the other port combinations can be determined as this device is totally symmetric and can also acts as a power divider and power combiner. The design is calculated using various equations.

### 4.1. Proposed design

Design considerations

Operating frequency ( $f_0$ ) =2.4GHz

Velocity of light (c) =3x10$^8$m/sec.

Substrate Flame Retardant-4 with relative permittivity ( $\in_r$ ) = 4.4

Substrate thickness(h)=1.6mm

Impedance ( $z_0$ ) = $50\Omega$

Impedance (1+ $\sqrt{2}$ ) $Z_0$ = $2.414\, Z_0$

Impedance $z_0\sqrt{2}$ = $1.414\, z_0$

### 4.2. Calculation for operating frequency

A and B value for $Z_o$ :

$$Z_0 = 50\Omega$$
$$\in_r = 4.4$$
$$A = \frac{Z_0}{60}\sqrt{\frac{\in_r +1}{2}} + \frac{\in_r -1}{\in_r +1}\left(0.23 + \frac{0.11}{\in_r}\right)$$
$$A = 1.5298$$
$$B = \frac{377\prod}{2Z_0\sqrt{\in_r}}$$
$$B = 5.6463z$$

Width calculation for $Z_0$ :

$$Z_0 = 50\Omega$$
$$e = 1.8036$$
$$A = 1.8036$$
$$\frac{w}{d} = \frac{8e^A}{e^{2A} - 2} < 2$$
$$\frac{w}{d} = 1.3932 < 2$$
$$\frac{w}{1.6 * 10^{-3}} = 1.3932$$
$$w = 2.229mm$$

Effective relative permittivity for $Z_0$ :

$$\in_e = \frac{4.4+1}{2} + \frac{4.4-1}{2}\frac{1}{\sqrt{1+12\left(\frac{d}{w}\right)}}$$
$$\in_e = 2.7 + 1.7\left(\frac{1}{\sqrt{1+\frac{12}{3.2717}}}\right)$$
$$\in_e = 3.4868$$

Wavelength for $Z_0$ :

$$\lambda = \frac{c}{f_0\sqrt{\in_e}}$$
$$\lambda = 31.25mm$$

For $Z_0$:

$\frac{\lambda}{4} = \frac{69.358*10^{-3}}{4}$
$\lambda = 17.1242$

A and B value for $\frac{Z_0}{\sqrt{2}}$:

$A = 1.128$
$B = 7.985$

Width calculation for $\frac{Z_0}{\sqrt{2}}$:

$w = 5.234mm$

Effective relative permittivity for $\frac{Z_0}{\sqrt{2}}$:

$\in_e = 3.486mm$

Wavelength for $\frac{Z_0}{\sqrt{2}}$:

$\frac{Z_0}{2} = 66.9mm$

For $\frac{Z_0}{\sqrt{2}}$:

$\lambda = 16.735mm$

| Parameters | $z_0$ | $\frac{z_0}{\sqrt{2}}$ |
|---|---|---|
| A | 1.5298 | 1.1288 |
| B | 5.6463 | 7.985 |
| Width(w) | 3.059mm | 5.2347mm |
| Effective permittivity($\in_e$) | 3.3302 | 3.4868 |
| Wavelength($\lambda$) | 68.497mm | 66.94mm |
| $\frac{\lambda}{4}$ | 17.124mm | 16.735mm |

Table 1 Dimension of branchline coupler

The table.1 shows all the dimensions of the two-section branchline coupler depending upon the impedance of the coupler the length and width of the arms of the coupler differs but the maximum adjustment can be done in length within the limit.

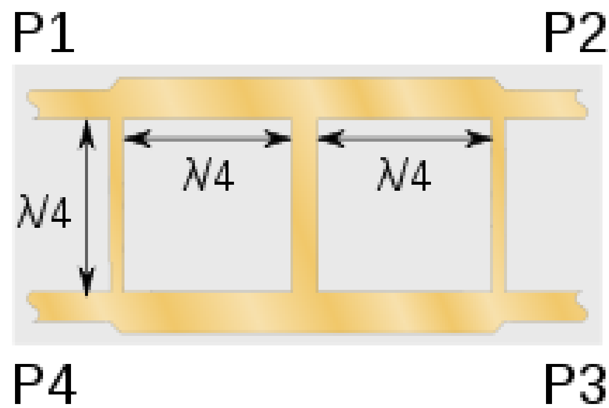


Figure 3 Measurement of double-section branch line coupler

Thus, using above calculations and dimensions, the branchline coupler is designed in layout window of ADS Software and simulated for operating frequency of 2.4GHz which is shown in the figure 3.

## 5. DOUBLE-SECTION COUPLER DESIGN

The double-section coupler has four ports like the conventional branch line coupler where the P1 is the input port, P2 is the direct port or also called as through port where direct power flows out of it, P3 is the coupled port where the equal power is biased by 90 degree and the P4 is the isolated port where no power flows through it where here the return loss should be lesser than -10dB.

The double-section coupler here acts as the power divider and the power combiner and the simulated or operating frequency of this coupler is 2.4GHz.

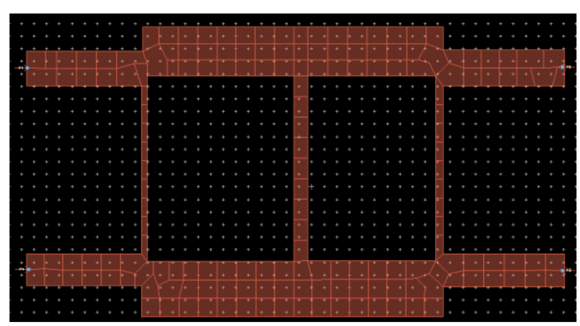

Figure 4 Double-section Coupler design in layout window of ADS Software

There are two sections in the coupler which is therefore made to be called as the double box coupler or double section coupler. The operating frequency is used in the calculation of the dimensions of this coupler with no slots are made but a little optimization in length of the design to a level of adjustment it can be done.

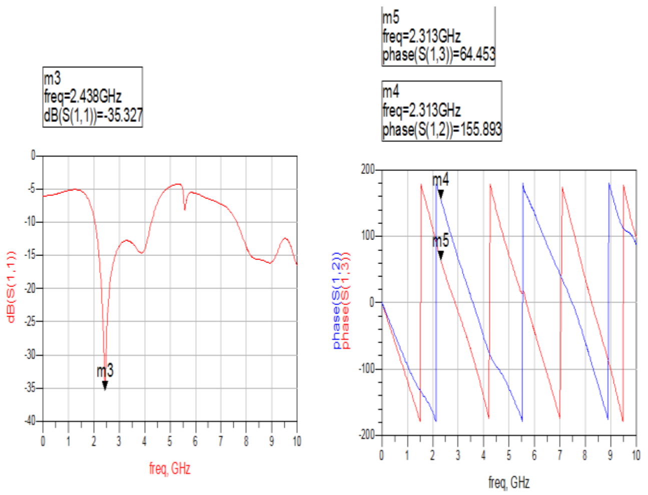


Figure 5 Phase and Return Loss graph for Dual-section branchline coupler

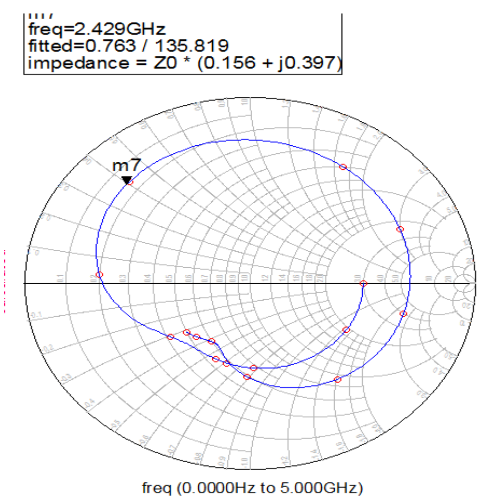


Figure 6 Smith chart for the double-section coupler

Figure 5 shows the graphical representation of the gain and the phase. The gain of the $S_{11}$ parameter of the double section branch line coupler is high with return loss -35dB. The phase difference between the two parameters $S_{12}$ and $S_{13}$ is 90 degree and therefore the power is equally split with phase difference of 90 degree. Figure 6 shows the smith chart where it represents the impedance of the operating frequency of 2.4GHz.

## 6. DOUBLE-SECTION COUPLER DESIGN WITH THE TRIANGULAR CUTS ON FOUR SIDES

The double section branch line coupler with the triangular cuts on four sides is of same as the coupler design in fig .4 except the cuts on four sides. The ports are aligned as before where the P1 as input port, P2 as through port , P3 as port of coupling and the P4 as the isolated port. The difference between the two design is in Figure 5 the four triangular cuts are made to increase the return loss of the $S_{11}$ Parameter. The triangular cuts are made equally on all four sides of the double- section branch line coupler for better radiation operating at 2.4GHz frequency as the radiation will not get into the corners and confine within.

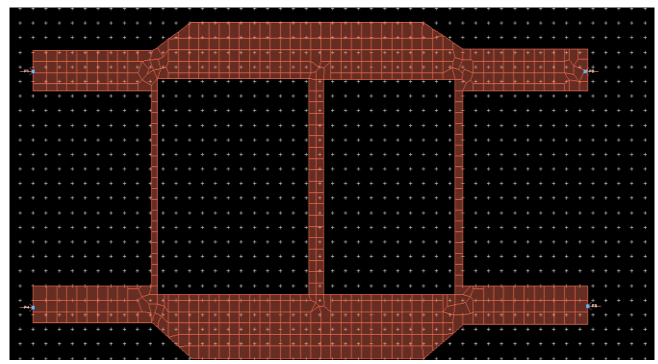

Figure 7 Double-section Coupler design with a triangular cut in layout window of ADS Software

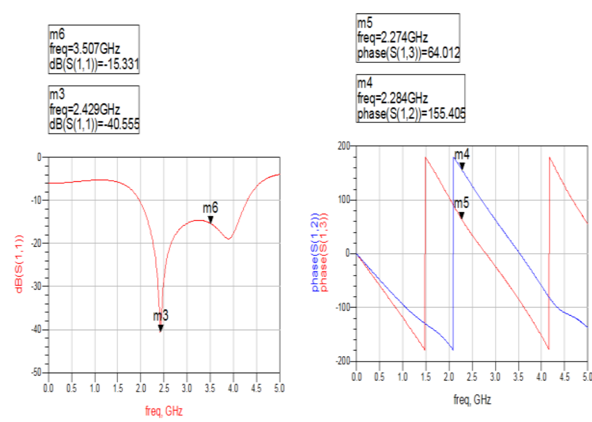


Figure 8 Phase and Return Loss graph for two-section branchline coupler with the cuts on four sides

The figure 7 shows the little increase in the return loss by -40.565dB with the operating frequency of 2.4GHz and it also shows that at 3.5GHz, the return loss is -15.331dB.The phase graph shows that the $S_{12}$ and the $S_{13}$ parameters of phase are 155.405 and 64.012 which gives a 90 degree phase difference. By the drastic optimization of the double section branch line coupler there is an increase in the return loss of the two-section branch line coupler.

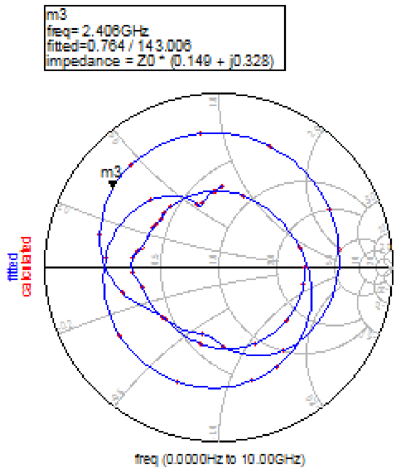


Figure 9 Smith chart with the cuts on four sides of the double-section coupler

Figure 9 shows the smith chart where it represents the impedance of the operating frequency of 2.4GHz.

## 7. RESULTS AND CONSULTATION

Figure 4 shows the simulation result of branchline coupler operating at 2.4GHz which is used for wireless applications. The parameter S12 is also analyzed and obtained as -14.067dB for operating frequency of 2.4GHz.Thus,it is evident that S above -10dB is achieved.

## 8. CONCLUSION

In this paper, a branchline coupler using transmission line designed for wireless applications operating at 2.4GHz was proposed. Using Advanced Design Software in layout window, compact branchline coupler were designed and fabricated using low-cost substrate Fr-4.While reducing the size of the coupler, preserving favourable conductance in terms of balance betwixt the coupled ports (gain & phase of S31&S21), isolation part (S41) ,reflection coefficient S11 & the S21 obtained as -14.067dB which is above -10dB.Thus,the proposed branchline Coupler is cost effective and reduction in size enhanced the bandwidth.

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