

# **DESIGN OF MINIATURISED MICRO-STRIP BASED DUAL-BAND BRANCH-LINE COUPLER USING FOLDED STUBS**

*A Thesis Submitted in Fulfilment of the Requirement for the Award of the Degree of*

**MASTER OF ENGINEERING**  
in Wireless Communication

Submitted by

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## DECLARATION

I, Shreya hereby declare that the work presented in this thesis entitled "**Design of miniaturised micro-strip based Dual-Band Branch-line Coupler using folded stubs**" in fulfilment of the requirement for the award of degree of Master of Engineering (WC) submitted at Electronics and Communication Engineering Department, Thapar Institute of Engineering and Technology (Deemed to be University), Patiala is an authentic record of work carried out under supervision of **Dr. Rana Pratap Yadav**, Assistant Professor, ECED and **Dr. R.S. Kaler**, Senior Professor & HOD, EIED. The matter presented in this thesis has not been submitted either in part or full to any other university or institute for the award of any other degree.

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It is certified that the above statement made by the candidate is correct to the best of my knowledge and belief.

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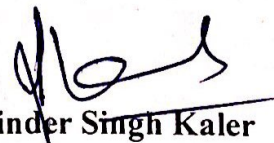


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## ABSTRACT

Modern day communication system poses large number of requirements, such as wide bandwidth, multiple band of operations, compact size etc. in front of us. Branch-line couplers, a very important passive device in communication systems, need to be at par with these requirements. The objective of this thesis is to design a branch-line coupler which has small size and operates on dual band. Here, a dual band branch-line coupler is proposed. Firstly, a dual band coupler is obtained and then the design is modified to reduce its size.

To achieve dual band, stubs are incorporated in the conventional quarter wave-length line. Depending upon the electrical length of the stub, and on the fact whether it is open circuited or short circuited, it can be either capacitive or inductive. Here, the quarter wave-length lines are replaced by equivalent T-shaped lines. So, the proposed coupler has four stubs, one stub centrally tapped at each line of the branch-line coupler. The design formulas are obtained by using ABCD matrix. To reduce size of the coupler, the stubs can be folded inwards. But here, the length of stubs turns out to be quite long. So, right angled bends are introduced in the stubs. Each stub is incorporated with four right angled bends. These bends create discontinuities, which cause the generation of unwanted capacitive and inductive reactance in the design. To compensate for this extra reactance generated, mitring of bends is done. The corners of the bends are adequately cut out to balance the capacitive reactance as the corners lead to charge accumulation, and hence, give rise to capacitance in the design. The two couplers are designed and simulated on CST Microwave Studio.

The performance of the two couplers is analysed and compared. There is a difference in the frequency response of two designs due to presence of extra inductance and capacitance (due to discontinuities) in the modified design. Here, almost 90% reduction in size is achieved with better operating bandwidth and better performance characteristics.

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## LIST OF ABBREVIATIONS

BLC	Branch-Line Coupler
TEM	Transverse Electromagnetic
TE	Transverse Electric
TM	Transverse Magnetic
RF	Radio Frequency
PCB	Printed Circuit Board
VHF	Very High Frequency
MIC	Microwave Integrated Circuit
SIR	Stepped Impedance Resonator
LEDC	Lumped Element Directional Coupler
UHF	Ultra High Frequency



# CHAPTER 1

## INTRODUCTION

Directional Couplers are passive electronic devices which couple a particular amount of electromagnetic power to the output port so that it can be used for other devices. Branch-line couplers, a type of directional coupler, are one of the most important passive devices for millimetre waves and microwave applications [1]. These applications include antenna beam forming, providing feed to antennas, power combination in balanced mixers and combiners etc. [2]. These couplers usually consist of two physically coupled lines having two branches between them each of quarter wavelength and they couple the frequency corresponding to the wavelength. Today, with increasing applications and requirements, the devices having multiple applications in a single unit are more desirable and so is the case with branch-line couplers. Therefore, there is a need to design a branch-line coupler having multiple frequencies of operation so that, a single BLC can be used for multiple applications. Introducing stubs to the design is the most popular method for achieving multiple bands of operation in the branch-line couplers. Other than this, there is one more major constraint that plays an important role in designing of branch-line coupler is size. Lesser is the size, more are the modern day applications and hence, more desirable the device is. Several methods of size reduction in a branch-line coupler such as meandering, using step impedance lines etc. have already been proposed by several researchers.

In this thesis, a dual band branch-line coupler design is proposed. Stubs are introduced to the conventional branch-line coupler so as to obtain dual band of operation. Furthermore, the size of the coupler is reduced by incorporating the stubs with multiple right angled bends [2].

This chapter discusses the basic concepts which form the basis of the proposed design. The discussion starts with an overview of transmission lines and micro strip lines as the micro strip are the most suitable transmission line for our designing purposes. Following that, a brief overview of the concepts related to couplers is given where mainly branch-line coupler is studied. The basic design and analysis is studied and understood using ABCD matrix and even-odd mode analysis of a coupler. The significance and purpose of stubs in transmission line is also discussed later in this chapter.

## 1.1 TRANSMISSION LINES

Transmission line theory plays a significant role in the analysis of microwave devices and circuits as it bridges the gap between analysis of electromagnetic field and basic electronic circuit theory. The major difference between electronic circuit theory and transmission line theory is the electrical size. The transmission line theory deals with the distributed parameters where phase and voltages change continuously along its length while the circuit theory considers lumped elements for analysis where the parameters do not vary significantly over its length. We know that lumped element analysis gives a circuit size much smaller than that of a transmission line as the circuit analysis considers dimensions much smaller than the operating wavelength while for distributed elements the dimensions are of the order of wavelength [1].

Transmission line can be considered as pair of conductors which carry electrical energy from one place to another. Every transmission line is defined by four important parameters. These parameters are resistance, capacitance, inductance and conductance. Resistance and inductance of a transmission line constitute to form impedance of the line whereas; capacitance and conductance together form admittance of the transmission line. These parameters are distributed uniformly along the entire line. Hence, they are also called the distributed parameters of the transmission line.

- Resistance (R): This is the opposition offered to the current flowing through the line by the transmission line. Usually, the value of impedance offered due to other parameters is much greater in value as compared to the resistance of the line which makes the resistance negligible as compared to total impedance.
- Inductance (L): when current streams in the transmission line, it instigates the attractive transition. The attractive transition likewise shifts when current changes in transmission line because of which circuit has an initiated emf. The greatness of instigating emf relies upon the rate of progress of transition. The stream of current in the conductor in transmission line is opposed by initiated emf, and this parameter is called as the inductance of the line.
- Capacitance (C): In the transmission lines, air acts as a dielectric medium. This dielectric medium consists of the capacitor between the channels, which store the electrical vitality, or enhances the capacitance of the line. The nearness of charge per unit of potential distinction is characterized as capacitance of an electric conductor. Capacitance is insignificant in short transmission lines though it is the most essential

parameter in long transmission lines. It influences the effectiveness, voltage control, security and power factor of the framework.

- Conductance (G): Air acts as a dielectric medium between the conveyors. At the point when a substituting voltage connected in a conveyor, some present streams in the dielectric medium as a result of the blemishes in the dielectric. Such a current is known as the spillage current. Spillage current relies upon the climatic conditions (such as dampness) and contamination moisture (like surface stores). Shunt conductance is characterized as spillage current stream between the conductors. It is consistently appropriated along the whole length of the line. It is estimated in Siemens.
- Characteristic Impedance ( $Z_0$ ): All transmission lines possess characteristic impedance, designated as  $Z_0$ . If a load which has a value equal to  $Z_0$  is positioned at the output end of any length of line, the impedance of same value will appear at the input ends of the line. The characteristic impedance tells us the amount of electric current that can flow when a given voltage is applied to a line which is infinitely long.  $Z_0$  is calculated as:

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \quad (1.1)$$

### 1.1.1 ABCD Parameters

Properties of transmission line are usually depicted by the ABCD parameters of the transmission line. In any four port network, we can demonstrate the input voltage and current as a function of output voltage and current but the network should be passive, linear and bilateral for such a case. A transmission line is a four port network and fortunately it is a passive, bilateral and linear network. Therefore, one can easily express input voltage and current of transmission line in terms of output voltage and current [3].

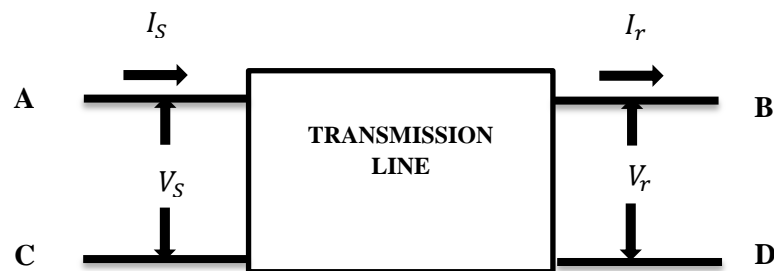


Figure 1.1: ABCD parameters in a transmission line.

The current and voltage in the input and output terminals of a two-port network are given by the following equations

$$V_s = AV_r + BI_r \quad (1.2)$$

$$I_s = CV_r + DI_r \quad (1.3)$$

$V_s$  = Voltage at sending terminal

$I_s$  = Current at sending terminal

$V_r$  = Voltage at receiving terminal

$I_r$  = Current at receiving terminal

A, B, C and D are the constants known as the transmission parameters of a transmission line. We use these parameters for the analysis of electrical networks. They are also used for determination of the performance of input, output voltage and current of the transmission network.

We can write the above equation in form of matrix as:

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix} \quad (1.4)$$

The matrix  $\begin{bmatrix} A & B \\ C & D \end{bmatrix}$  is called the transfer matrix of the network.

If we consider,  $V_s = V_1$ ,  $V_r = V_2$

$I_s = I_1$ ,  $I_r = I_2$

$$A = \left. \frac{V_1}{V_2} \right|_{I_2=0} \quad (1.5)$$

$$B = \left. \frac{V_1}{I_2} \right|_{V_2=0} \quad (1.6)$$

$$C = \left. \frac{I_1}{V_2} \right|_{I_2=0} \quad (1.7)$$

$$D = \left. \frac{I_1}{I_2} \right|_{V_2=0} \quad (1.8)$$

The ABCD matrix for a micro-strip line is:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos \theta_0 & jZ_0 \sin \theta_0 \\ j \sin \theta_0 / Z_0 & \cos \theta_0 \end{bmatrix} \quad (1.9)$$

Where,  $Z_0$  is the characteristic impedance of the line and  $\theta_0$  is the corresponding electrical length.

## 1.2 MICROSTRIP LINE

Micro-strip transmission line is probably the most popular type of planar lines especially because it can be manufactured easily by photolithographic processes and can be effortlessly reduced in size and integrated with both active and passive microwave devices. The figure shows representation of one such line [1].

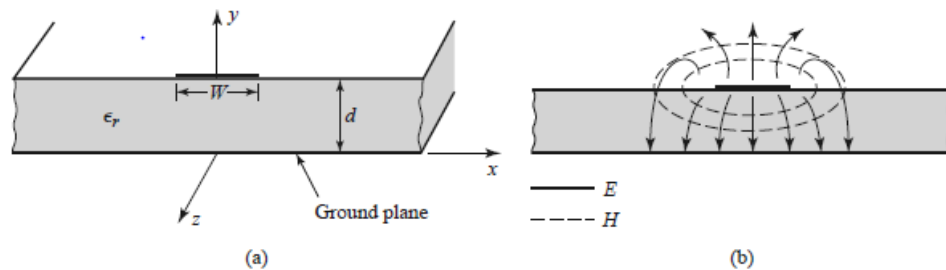


Figure 1.2: Micro-strip line (a) Geometry (b) electric and magnetic fields [1]

Microstrip line is an emerge among the most standard sorts of planar transmission lines basically in light of the fact that it can be made by photolithographic shapes and is easily downsized and composed with both the uninvolved and dynamic microwave contraptions. Figure 1.2 exhibits depiction of one such line. Microstrip has a couple (for the most part most) of its electromagnetic field lines in the dielectric locale between the strip channel and the ground level and some division recognizable all around territory over the substrate. In this manner micro-strip line can't reinforce an unadulterated transverse electromagnetic wave since the stage speed of TEM fields in the region of dielectric would be  $c/\sqrt{\epsilon_r}$ , while the stage speed of transverse electromagnetic fields detectable all around area would be 'c', so a phase planning situation at the dielectric– air interface would be hard to actualize. Truth be told, the right fields of a micro-strip line contain a hybrid TM-TE wave and need additionally created examination strategies than we are set up to oversee in this case. In most even minded requirements, regardless, the dielectric substrate is thin, along these lines the fields are semi TEM. In a manner of speaking, the electromagnetic fields are fundamentally the same as that

of the static (DC) case. At higher frequencies different effects can happen that incite assortments from the semi static results for intense dielectric reliable, trademark impedance, and reducing of micro-strip line. Furthermore, new effects can rise, for instance, higher demand modes and parasitic reactance. Since micro-strip line is definitely not an authentic TEM line, its multiplication reliable is surely not a straight limit of repeat, inferring that the ground-breaking dielectric enduring movements with repeat. The field that exists on micro-strip line incorporates a hybrid coupling of TM and TE modes, obfuscated by the farthest point condition constrained by the air and dielectric substrate interface. Likewise, the current on the micro-strip conductor isn't uniform over the thickness of the micro-strip, and this movement vacillates with repeat. The thickness of the micro-strip conductor in like manner influences the present scattering and hence impacts the line parameters [1].

The effective dielectric constant of a micro-strip line is given approximately by

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} - \frac{1}{\sqrt{1 + 12d/W}} \quad (1.10)$$

Given the dimensions of the micro-strip line, the characteristic impedance can be calculated as:

$$Z_0 = \begin{cases} \frac{60}{\sqrt{\epsilon_e}} \ln \left( \frac{8d}{W} + \frac{W}{4d} \right) & \text{for } W/d \leq 1 \\ \frac{120\pi}{\sqrt{\epsilon_e} \left[ \frac{W}{d} + 1.393 + 0.667 \ln \left( \frac{W}{d} + 1.444 \right) \right]} & \text{for } W/d \geq 1 \end{cases} \quad (1.11)$$

Approximate formulas were initially developed at the time when CAD tools for RF and microwave engineering were not usually available. These design tools usually provide precise results for a wide range of parameters and now days, these tools are usually given preference over closed-form approximations.

### 1.3 COUPLERS

Directional couplers are passive components which are used for division and combining of power in microwave devices. In power division, the input signal is split into two or more number of output signals of lower power, while a power combiner intakes two or more number of input signals combines them and forwards it at an output port. The coupler can have any number of ports (three, four or more) or may be lossless (in ideal conditions) depending on the application and requirement [3].

Directional couplers are generally fabricated from two coupled lines placed near enough to each other in such a way that energy being passed from one line is coupled to the other one. This method is preferred for the frequencies in microwave range where a number of circuit elements are implemented using transmission line designs [4]. However, at lower frequencies in telephony applications devices consisting of lumped components are also possible. Also, at microwave frequencies, especially the high frequency ranges, waveguide based structures can be utilised. Properties that are commonly required for all directional couplers are wide bandwidth, high directivity, and fair impedance matching at all ports when all the other ports are terminated with matched loads. These performance characteristics of directional couplers are self-explanatory. Early research in electromagnetic wave propagation over a system of transmission lines led to the development of directional couplers. Research on directional couplers was chiefly worried about getting their characteristics and giving the outline parameters required to their development.

Directional couplers were at first used to test energy along transmission lines to decide the characteristics of the line under working conditions. With expanding innovation, directional couplers were developed utilizing structures, for example, coaxial lines and strip-lines. All waveguide couplers were produced for use with that sort of transmission framework. The hybrid coupler, which utilizes both, lumped and distributed components, is utilized at microwave frequencies. Lumped component couplers are being utilized at microwave frequencies. At frequencies in the GHz extend, the lumped components are physically sufficiently little to be incorporated with an integrated circuited package which may contain other electronic circuitry or hardware. Some investigation has been performed on lumped component directional couplers. The investigation utilizes a matrix approach and gives a decent broad theoretical discussion of lumped component couplers. Design techniques and experimental results are still lacking for low frequency lumped component directional couplers.

A directional coupler is a four port device where port1 and Port 2 are primary ports and port 3 and 4 are called secondary ports. There is a direct coupling between Port 1 and Port 2 therefore transmission occurs. There is no transmission from port1 to port 3. Also, the amount of coupling between port1 and port4 or port2 and port3 depends upon the structure and design of the coupler.

Characteristics of a coupler are defined in terms of the Coupling, Directivity, Isolation and Insertion of the Coupler. Where coupling factor is written as:

$$\text{Coupling (dB)} = 10 \log_{10}(P_1/P_3) \quad (1.12 \text{ a})$$

$$\text{Insertion Loss (dB)} = 10 \log_{10}(P_1/P_2) \quad (1.12 \text{ b})$$

Coupling factor is the measure of ratio of power levels in primary and secondary transmission lines. Insertion loss is ratio of power levels at the input and through ports.

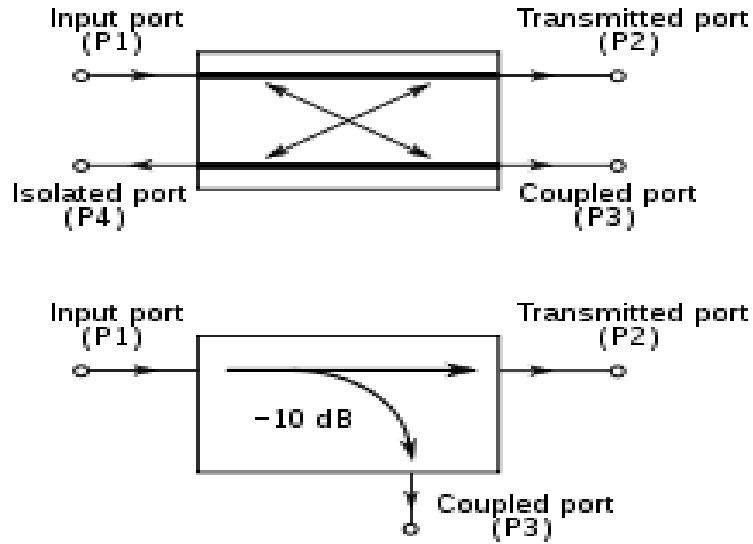


Figure 1.3: Directional coupler

Directivity of a coupler is the measure of how properly the forward travelling wave in primary waveguide couples only to a particular port of a secondary waveguide. The directivity that we obtain in the practical cases is generally in between 30 to 35 dB.

The directivity of the coupler can be written as:

$$\text{Directivity} = 10 \log_{10}(P_3/P_4) \quad (1.13 \text{ a})$$

$$\text{Isolation} = 10 \log_{10}(P_1/P_4) \quad (1.13 \text{ b})$$

Where,

$P_1$ : Power input at port 1

$P_2$ : Power Output at port 2

$P_3$ : Output power at port 3

$P_4$ : Output power at port 4

Note that port2, 3 and 4 always terminate in characteristic impedance.

A coupler is analysed by the help of its S matrix. An S matrix or Scattering Matrix is used for analysis of any device having multiple ports. The circuit is analysed in form of power not in terms of current and voltages when we use S matrix analysis. Power descriptions bring in the values of scattering parameters. It is convenient to take voltage and current values at lower frequencies so, we consider this matrices only for analysis of circuits having high frequency. For an ideal Directional Coupler, all the four ports of the network are considered to be completely matched. Therefore,  $S_{11}=S_{22}=S_{33}=S_{44}=0$  (which shows complete matching). As we know, that there is no coupling between Port1 and Port3 also, no coupling between Port2 and Port4 so,  $S_{13}=S_{31}=S_{24}=S_{42}=0$ . Therefore, the S matrix becomes

$$S = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & 0 \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{bmatrix} \quad (1.14)$$

This matrix can be further reduced. So, we get

$$S_{12}S_{23}^* + S_{41}S_{43}^* = 0 \quad (1.15)$$

Also, from unity property,

$$S_{12}S_{12}^* + S_{14}S_{14}^* = 1 \quad (1.16)$$

These can also be written as,

$$|S_{12}||S_{14}| = |S_{32}||S_{34}| \quad (1.17)$$

$$|S_{21}||S_{23}| = |S_{41}||S_{43}| \quad (1.18)$$

Since  $S_{12}=S_{21}$ ,  $S_{23}=S_{32}$ ,  $S_{34}=S_{43}$ , we get,

$$|S_{12}| = |S_{34}| \quad (1.19)$$

$$|S_{14}| = |S_{23}| \quad (1.20)$$

Let,  $|S_{12}| = |S_{34}| = p$

$$|S_{23}| = |S_{41}| = jq \quad (1.21)$$

$$p^2 + q^2 = 1 \quad (1.22)$$

The S matrix of directional coupler can be concluded to:

$$S = \begin{bmatrix} 0 & p & 0 & jq \\ p & 0 & jq & 0 \\ 0 & jq & 0 & p \\ jq & 0 & p & 0 \end{bmatrix} \quad (1.23)$$

### 1.3.1 Branch-line Coupler

The branch-line coupler comprises of two lines placed parallel and coupled physically together with at least two shunt lines in between them. The branch lines are divided, separated by quarter wave length and represent segments of a multiple section filter similarly as the multiple section of a coupled line coupler aside from that here the coupling of each segment is controlled with the impedance of the branch lines. The fundamental and coupled lines are  $\sqrt{2}$  of the impedance of the system. The more is number of sections in the coupler, the higher is the ratio of impedances of the branch lines. High impedance lines have restricted tracks and this for the most part constrains the outline to three segments in planar organizations because of fabrication limitations. A comparable bar applies for coupling factors inferior than 10 dB; less coupling likewise has requirement of limited tracks. Coupled lines are a superior decision when free coupling is needed, yet branch-line couplers are useful for compact coupling and can also be utilized for 3 dB hybrids. Branch-line couplers generally don't have so much wide bandwidth as compared to coupled lines. Such a structure of coupler is useful for implementations in high-control, air dielectric, strong bar arranges as the inflexible model is anything but difficult to support in mechanical manner [6]. Conventional branch-line directional coupler (BLDC) is widely utilized as a power divider or power combiner in the circuit of balance mixer, image-rejection mixer, balance amplifier, sensor, etc. The basic element of the BLDC is a quarter-wavelength transmission line that results in large area of the coupler, which limits the application of it, especially in system severely requiring for dimension. Therefore, size-reduction techniques are investigated in many studies [7].

For distributed elements, the applications of a coupler are limited to Very High Frequency (VHF) band and above due to large physical size required for the frequencies below VHF. As the size of a distributed element coupler is of orders of wavelength so, as the wavelength increases, the size of the branched line coupler increases. So, we sometimes use lumped elements to remove the size constraint on the couplers. Both lumped and distributed components are used for the applications at microwave frequencies. These circuits are known as Microwave integrated circuits (MIC).

The basic structure of a branched line coupler comprises of four quarter-wavelength transmission lines with different characteristic impedances. The structure can be depicted as:

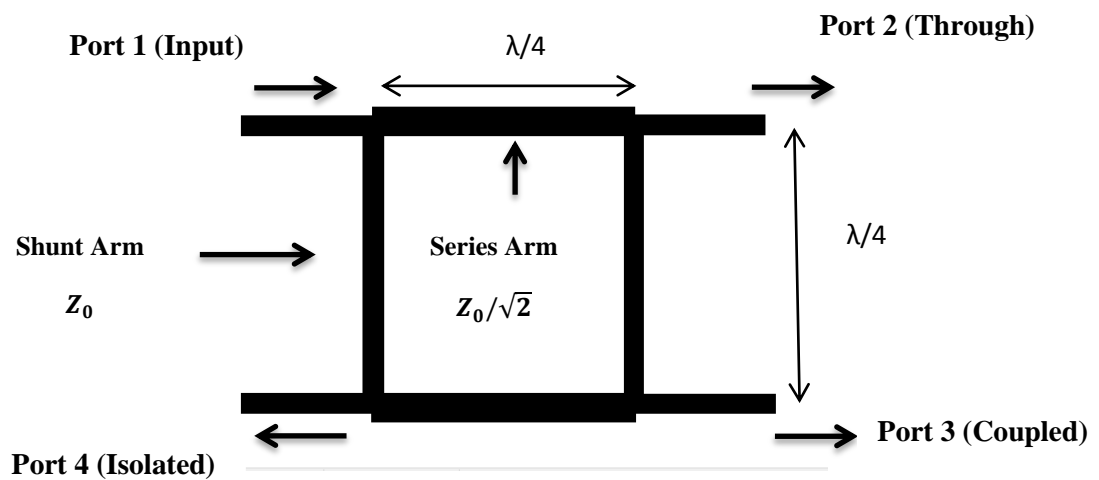


Figure 1.4: Branch-line coupler

### 1.3.1.1 Even-Odd mode analysis of a branch-line coupler

To analyse branch-line couplers we usually use even odd mode analysis. Even-Odd mode analysis makes the realisation of a distributed circuit quite easier. Here, we divide the branch-line coupler symmetrically into two parts. Because the excitation has the symmetry or anti-symmetry, we can decompose the four port network into a set of two decoupled two-port network. Here is the representation of a branch-line coupler cut into two equal halves by the line of symmetry [8].

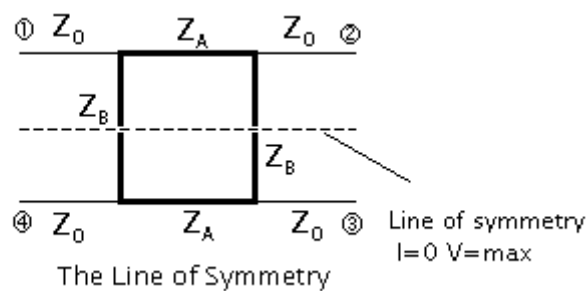


Figure 1.5: Line of symmetry of BLC

In the even mode analysis, the two cut arms are left open ended. They now act as two open-circuited stubs as shown in figure.

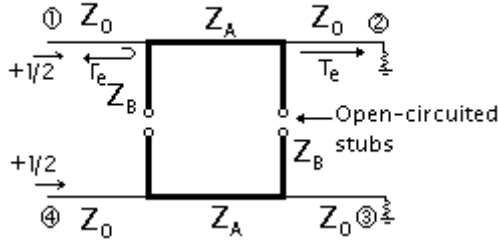


Figure 1.6: Even mode

Furthermore, we use ABCD parameters for the even odd mode analysis. So, when we consider the lines as open circuited stubs, the equations comes out to be:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = [T_{stub}][T_{line}][T_{stub}] \quad (1.24)$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_e = \begin{bmatrix} 1 & 0 \\ jY_B & 1 \end{bmatrix} \begin{bmatrix} \cos\beta l & jZ_A \sin\beta l \\ jY_A \sin\beta l & \cos\beta l \end{bmatrix} \begin{bmatrix} 1 & 0 \\ jY_B & 1 \end{bmatrix} \quad (1.25)$$

Since we have,

$$l = \lambda/4 \quad (1.26)$$

We know that,

$$\beta l = \left(\frac{2\pi}{\lambda}\right) * \left(\frac{\lambda}{4}\right) = \left(\frac{\pi}{2}\right) \quad (1.27)$$

Therefore  $\cos \beta l = 0$  and  $\sin \beta l = 1$  and the ABCD matrix is following:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ jY_B & 1 \end{bmatrix} \begin{bmatrix} 0 & jZ_A \\ jY_A & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ jY_B & 1 \end{bmatrix} = \begin{bmatrix} -Y_B Z_A & jZ_A \\ j(Y_A - Y_B^2 Z_A) & -Y_B Z_A \end{bmatrix} \quad (1.28)$$

Now, for the Odd mode analysis, the line of symmetry divides the coupler into two equal parts but now, the stubs are considered to be short circuited. So, the equation for ABCD parameters becomes the product of ABCD matrices of the two stubs (which we are considering short circuited for odd mode) and the transmission line [9].

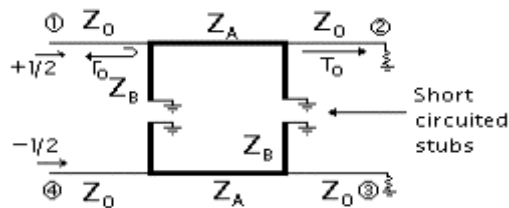


Figure 1.7: Odd mode

The equation now becomes as:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = [T_{stub}][T_{line}][T_{stub}] \quad (1.29)$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_o = \begin{bmatrix} 1 & 0 \\ -jY_B & 1 \end{bmatrix} \begin{bmatrix} \cos\beta l & jZ_A \sin\beta l \\ jY_A \sin\beta l & \cos\beta l \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -jY_B & 1 \end{bmatrix} \quad (1.30)$$

Since we have,

$$l = \lambda/4 \quad (1.31)$$

We know that,

$$\beta l = \left(\frac{2\pi}{\lambda}\right) * \left(\frac{\lambda}{4}\right) = \left(\frac{\pi}{2}\right) \quad (1.32)$$

Therefore  $\cos \beta l = 0$  and  $\sin \beta l = 1$  and the ABCD matrix is following:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ jY_B & 1 \end{bmatrix} \begin{bmatrix} 0 & jZ_A \\ jY_A & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ jY_B & 1 \end{bmatrix} = \begin{bmatrix} Y_B Z_A & jZ_A \\ j(Y_A - Y_B^2 Z_A) & Y_B Z_A \end{bmatrix} \quad (1.33)$$

Now, we can find  $\Gamma_e, \Gamma_o, T_e, T_o$  by using following equations:

$$\Gamma_e = \frac{(A - D) + (BY_o - CZ_o)}{(A + D) + (BY_o + CZ_o)} \quad (1.34)$$

$$\Gamma_o = \frac{(A - D) + (BY_o - CZ_o)}{(A + D) + (BY_o + CZ_o)} \quad (1.35)$$

$$T_e = \frac{2}{(A + D) + (BY_o + CZ_o)} \quad (1.36)$$

$$T_o = \frac{2}{(A + D) + (BY_o + CZ_o)} \quad (1.37)$$

On solving above equations with parameters of even and odd mode ABCD matrices at centre frequency where:  $f = \frac{np}{\lambda} = \frac{np}{4l}$

$$\Gamma_e = \frac{Z_A^2 Y_0^2 - Z_0^2 (Y_A - Y_B^2 Z_A)^2 - j(2Y_B Z_A (Z_A Y_0 - Y_A Z_0 + Y_B^2 Z_A Z_0))}{4Y_B^2 Z_A^2 + (Z_A Y_0 + Y_A Z_0 - Y_B^2 Z_A Z_0)^2} \quad (1.38)$$

$$\Gamma_o = \frac{Z_A^2 Y_0^2 - Z_0^2 (Y_A - Y_B^2 Z_A)^2 - j(2Y_B Z_A (Z_A Y_0 - Y_A Z_0 + Y_B^2 Z_A Z_0))}{4Y_B^2 Z_A^2 + (Z_A Y_0 + Y_A Z_0 - Y_B^2 Z_A Z_0)^2} \quad (1.39)$$

$$T_e = \frac{-4Y_B Z_A - j(2(Z_A Y_0 + Y_A Z_0 - Y_B^2 Z_A Z_0))}{4Y_B^2 Z_A^2 + (Z_A Y_0 + Y_A Z_0 - Y_B^2 Z_A Z_0)^2} \quad (1.40)$$

$$T_o = \frac{4Y_B Z_A - j(2(Z_A Y_0 + Y_A Z_0 - Y_B^2 Z_A Z_0))}{4Y_B^2 Z_A^2 + (Z_A Y_0 + Y_A Z_0 - Y_B^2 Z_A Z_0)^2} \quad (1.41)$$

We can now calculate the values of S parameters from these equations;

$$S_{11} = \frac{\Gamma_e + \Gamma_o}{2} \quad (1.42)$$

$$S_{12} = \frac{T_e - T_o}{2} \quad (1.43)$$

$$S_{13} = \frac{\Gamma_e - \Gamma_o}{2} \quad (1.44)$$

$$S_{14} = \frac{T_e + T_o}{2} \quad (1.45)$$

And the scattering matrix of Branch-line coupler is

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{23} & S_{24} \\ S_{13} & S_{23} & S_{33} & S_{34} \\ S_{14} & S_{24} & S_{34} & S_{44} \end{bmatrix} \quad (1.46)$$

## 1.4 STUBS IN TRANSMISSION LINES

In microwave and RF building, a stub or full stub is a segment of transmission line or waveguide that is associated toward one side as it were. The free terminal of the stub is either left open circuited or (dependably on account of waveguides) short circuited [10]. If we ignore losses in transmission line, depending upon the electrical length of the stub, and on the fact whether it is open circuited or short circuited, the input impedance of the stub is reactive, and that is, it can be either capacitive or inductive. In this manner, Stubs may in this manner work as capacitors, inductors and resonating circuits.

Stubs operate by methods for standing convergences of radio waves along their length. Their responsive properties are controlled by their physical length in association with the

wavelength of the radio waves. Thus, stubs are most typically used as a piece of UHF or microwave circuits in which the wavelengths are adequately short that the stub is supportively little [11]. Stubs are commonly used to substitute lumped components like capacitors and inductors in the circuits in light of the fact that at UHF and microwave frequencies these lumped components have poor performance because of the parasitic reactance [12]. For a lossless short circuited stub line, the input impedance is:

$$Z_{SC} = jZ_0 \tan \beta l \quad (1.47)$$

Where,  $j$  is imaginary complex number,  $Z_0$  is the characteristic impedance of the given line,  $\beta$  is phase constant (where,  $\beta = 2\pi/\lambda$ ) and  $l$  denotes the line's physical length. The value of  $\tan \beta l$  decides if the stub is inductive or capacitive. If it is positive, the stub has inductive effect. If it is negative, the stub has capacitive effect. Similarly, for a lossless open circuited line,

$$Z_{OC} = -jZ_0 \cot \beta l \quad (1.48)$$

Where,  $j$  is imaginary complex number,  $Z_0$  is the characteristic impedance of the given line,  $\beta$  is phase constant (where,  $\beta = 2\pi/\lambda$ ) and  $l$  denotes the line's physical length. The value of  $\cot \beta l$  decides if the stub is inductive or capacitive. If it is positive, the stub has capacitive effect. If it is negative, the stub has inductive effect.

## CHAPTER 2

### LITERATURE SURVEY

For every researcher, reading and analysing the studies which have been done before is very important. This enables the researcher to learn different aspects of the work being done and gives them better approach to solve the problem. This chapter presents some of the work done in the Branch-line coupler and related approach.

**H. Zhang *et al.*** [2] This paper presents a stub tapped branch-line coupler for dual-band applications. In this design, the quarter wavelength lines are replaced with T-shaped lines. Both the length of the proposed branch lines the characteristic impedance are adjusted accordingly as per the dimensions of conventional branch-line structure. ABCD matrix is used to derive the design equations. A conventional branch-line coupler consists of four quarter wavelength transmission line segments at the centre frequency, therefore with the decrease in the value of frequency of operation the size of coupler increases. Also, the conventional structure works on a single frequency band while now a day's multiple band operation is more desirable. Stubs seem to be a suitable option in this regard. Depending upon the electrical length of the stub, and on the fact whether it is open or short circuited, the input impedance of the stub is reactive, that is, it can be either capacitive or inductive. And due to the reactive effect stubs, when added to a coupler, can help us achieve multiple bands in a single design. This paper discusses about obtaining the dual band operation by converting the quarter wavelength line into T-shaped line. To verify the design concept, a micro-strip coupler operating at 0.9 and 2 GHz is fabricated and measured on a Rogers' RO4003 board.

**C. W. Tang *et al.*** [13] In this paper, the author proposes a design of a modified branch-line coupler that operates on multiple pass bands. Open stubs are added to the ports of conventional branch-line coupler in a process to obtain multiple pass bands. The length of the stubs has been chosen carefully by properly calculating all the design equations with the help of the most common method of solving ABCD matrices. The branches are induced with the stubs at the corners giving a pi shape to the lines (both branch and through). To miniaturize the coupler, the stubs have been folded inwards by a certain angle to fit in. Further, to reduce the size even more, the branches have been folded inwards with help of  $90^\circ$  bends. Each branch consists of four bends and those bends are mitred accordingly to cut out the unwanted reactance caused in the coupler because of the bends. Hence by the overall design, a coupler

having quadruple and sextuple band of operation can be obtained depending on the length of stubs being used in the design.

**F. L. Wong** *et al.* [14] Proposed is the micro-strip branch-line coupler with different pass-bands; additionally, the outline conditions are given in the paper. With a specific end goal to get different pass-bands, open stubs are incorporated to the ordinary branch-line coupler ports. In expansion, these impedance and electrical length of open stubs require to be legitimately picked. The suggested couplers can be effortlessly manufactured on the PCB with no lumped component. The understanding between estimated comes about and the hypothetical forecast approves the possible design of the suggested coupler. For check, a dual band micro-strip branch-line coupler working at 900 and 1500 MHz was planned and mimicked. In light of the computed estimation, a particular coupler topology was chosen for execution. The ideal estimations of both impedance were observed to be roughly  $38 \Omega$  and  $70 \Omega$ , individually. For enhanced precision, the frequency response of the entire structure including intersection discontinuities and substrate impact was advanced by utilizing a circuit test system. For explanation, the coupler was constructed utilizing Duriod substrate having 2.94 as dielectric constant. S parameter estimations were carried out utilizing Agilent 8510C system analyser over the 0.1 to 4 GHz of frequency range. The estimated execution of the coupler which have the inside frequencies of the two working groups were observed to be 915 MHz and 1530 MHz are demonstrated.

**I. Sakagami** *et al.* [15] This paper, one of the firsts of its kind, represents an approach to reduce the size of a branch-line coupler by substituting the conventional quarter-wave line by its equivalent stub loaded circuit. The coupler now contains in total of eight stubs. All these stubs are further modified into their equivalents to further reduce the size of the coupler. To modify the stubs, the stubs are converted by method of combination of step impedances, where a transmission line is converted into a series combination of high and low impedance lines. The calculations have been done by the help of ABCD matrices and the series and parallel combination of the transmission lines. It was observed after the designing that, the size of new coupler was now reduced to 25% of its original size. Even in such compact design, it was observed that appreciable frequency characteristics were obtained, other than slight shift in the frequency. Also, it's not tedious to adjust the relocation in centre frequency in practical and experimental circuits. There are the sharp slurt characteristics or spurious notch in theoretical and experiments due to the mild change in the circuits and the choosing of the line impedance of the preliminary stage transmission line of the new dual-step stubs. Therefore, recent branch-line couplers without sharp slur characteristics became future topics

for further studies. The method shown in this paper can be applied to high-frequency areas where thin substrates can be used.

**C. W. Tang** *et al.* [16] In this paper, a double micro-strip transmission line method has been suggested and implemented to design a new branch-line coupler. The suggested coupler can be conveniently observed on the planar circuits without using the lumped element. The manufactured couplers occupy little space, and also show better circuit outputs as compared to the conventional branch-line coupler design. Good similarities between the theoretical and simulated results have been seen and observed. For fabrication, substrate used is a Rogers RO4003 substrate and the dielectric thickness, dielectric constant, and loss tangent are 0.508mm, 3.38, and 0.0027, respectively. Also, the length and the width of the series transmission lines are 11.5 and 0.29 mm while those of the shunt lines, and, are 16.03 and 0.23 mm, respectively. The layout of the suggested micro-strip branch-line coupler with the double lines is presented and its total size is 11.96 mm X 16.61 mm. The responses of the theoretical and simulation design match considerably. With the calculated phase difference between, the corresponding bandwidth varies from 2.15 to 2.75 GHz. Although there can be undesired coupling effect in the parallel combines transmission line where the two transmission lines are adjusted, the coupling caused would not affect the given circuit much. The bandwidth available for the suggested micro-strip branch-line coupler is just a little bit less broad than that of the conventional coupler.

**C. W. Tang** *et al.* [17] In this letter, an alternate way to develop the micro-strip branch-line couplers is suggested. Compact size and bandwidth are predetermined for the proposed and implemented design. The four quarter-wave length lines for the conventional branch-line coupler can be easily miniaturized using the proposed open stubs with multiple shunts which be realized using either low or high impedances. The fabricated couplers take little space, and show better circuit performances as compared to conventional branch-line response. With this suggested method of equivalent quarter-wavelength lines, six prototypes of reduced size planar branch-line couplers are designed at 2.4 GHz operating frequency. The corresponding equations for the design have been utilized under ideal zero loss conditions. Open stubs having less impedance show performance improved as compared to those having high impedance; also, the more is number of open stubs with low impedance used, the broader will be bandwidth of the device. Also, these couplers can be easily fabricated using the standard PCB process, which could be conveniently applied to the design of microwave integrated circuits.

**K. S. Chin** *et al.* [18] This paper tries to construct stepped-impedance-stub lines for a double-band branch-line coupler design with enhanced pliability in design. The design suggested here explains how dual-band performance and the reduced size are achieved because of supplementary stepped-impedance stubs to the branches. The two degrees of freedom demonstrated in the new synthesis method can be used to reduce size of the circuit and substitute unrealisable impedances with the relatively more practically realizable impedances. Studies also depict the advantages of a wide-spanned practically analysable frequency ratio of double bands. The on-going research in this letter designs three practical dual-band branch-line couplers, which includes a two-section coupler, and has achieved a miniaturization up to 21.7%, in comparison to the conventional branch-line. The measured results confirm considerably good dual-band characteristics at 2.4 and 5.8 GHz with improved bandwidths approximately 21% and 12%, respectively. The paper successfully implements the designed electronic circuit to design and synthesize a rat-race coupler operating on dual band.

**K.V. Phani Kumar** *et al.* [19] Here, the author has proposed, an non-symmetric  $\pi$ -shaped structure to minimize the area and enhance the execution and response of microwave devices such as power splitters and couplers. To prove the miniaturization ability of the designed structure, the author has used multiple asymmetric  $\pi$ -shaped structures to substitute horizontal quarter wave lines of the conventional double section branch-line coupler. The newly developed BLC observes a size degradation of 72.2% .Furthermore, to lessen the coupler size, the shunt branches and the centre shunt branch are replaced by T-structures and cross-structured lines respectively. In this paper, the design has been simulated, fabricated and tested to operate on the frequency of 0.9 GHz. The proposed structure occupies only 23.7% of the area of the original conventional structure. The calculated frequency characteristics depict that the suggested coupler possesses a fractional bandwidth of 44.4%. The simulated and calculated outcomes match each other considerably. The fabricated coupler shows insertion loss superior to 3.6 dB with  $0 \pm 1$  dB as magnitude balance over the frequency range 0.67–1.05 GHz. In supplement to small and miniaturized design, the undesired harmonics are also suppressed up to  $4f_0$  with a value superior than 20 dB. The measured and simulated results match each other considerably.

**B.Li** *et al.* [20] This letter proposes a reduced-size branch-line coupler with suppression of wideband harmonics which is based on a segment of transmission-line section with three stubs. Three transmission zeros are produced due to this fundamental unit and due to the triple stubs wide stop-band response is exhibited. In conventional branch-line coupler, it is utilized to substitute a quarter-wave length segment, leading to reduction in size and

suppression of harmonics of wide-band. The closed form equations are provided for the designing of coupler. For example, a branch-line coupler with frequency of operation 1.0 GHz is developed, fabricated and measured. Measured results match quite well with simulated results, and depict that the suggested branch-line coupler design has now 56% size as compared to the conventional branch-line coupler and achieves suppression of wideband harmonics better than 17 dB in the frequency range from 1.8 GHz to 6.4 GHz. The 2nd, 3rd, 4th, 5th, and 6th harmonics are suppressed to a value better than 34 dB, 19 dB, 30 dB, 17 dB, and 32 dB, respectively. The theoretical analysis and simulated results show us that the suggested design has the benefit of simplified structure, easy analysis and suppression of wide-band harmonics.

**S. S. Liao *et al.*** [21] The proposed is a novel compact branch-line coupler without implementation of any bonding wires and lumped components. In this letter, the area of the suggested design took only 45% of the size of conventional BLC at 2.4 GHz. The performance and response of this device is comparable to that of the conventional coupler design. The component sizes of this design can be implemented effortlessly by simply utilizing standard PCB etching processes. It has very favourable demands in the area of wireless communication systems. The entire simulations are achieved using the full-wave Sonnet EM simulator. The conventional branch-line coupler has characteristic impedances of are  $35\Omega$  and  $50\Omega$ , respectively. By putting a limit to the range of characteristic impedances that are practically realisable one can reduce the effects of radiation loss, conductor loss.

**Q. Wu *et al.*** [22] In this paper, we see that, in printed antenna systems, micro-strip feed circuits can be quite complex, which includes numerous of right-angled bends. While designing the feed networks we must take into account the level of reflections and electrical lengths of the right angle bends. Removing a section of the part in the corner of the bend can compensate for the extra unwanted capacitance occurring due to the bend and lessen the value of reflection in the bend. Full wave simulations are executed for un-mitred and (50%) mitred right angle bends in micro-strip for FR4 and similar substrates in the frequency span of 868MHz – 60GHz. The recreations uncovered that for level of reflections underneath -15dB, up to 10GHz mitring is superfluous. For reflection levels underneath -20dB, mitring should be connected for frequencies more than 2.5GHz. A little adjustment of the centre-line approach for un-mitred twists prompts a comparable electrical length for un-mitred twists with an outright precision of short of what single degree for all frequencies and substrates, where the reference planes might be reverted the distance to the curve. By, applying this alteration to half mitred twists, with the reference planes at  $0.2\lambda_g$  separation from the curve,

$\lambda_g$  being the wavelength in the substrate, prompts a flat out mistake in electrical length of under more than two degrees for all frequencies.

**Y. H. Chun** *et al.* [23] In this letter, a novel plan of a cascaded branch-line coupler with lumped-circulated components which has three branch lines is proposed. This work has its foundations in new improvement of high power RF MEMS switches for which right angled half and halves with high power taking care of capacity are required for planning high power SPDT (single-post twofold through) switches. The required 90 degree cross breed should demonstrate great attributes, for example, return loss and isolation are superior to 20 dB and data transfer capacity is more extensive and a little size on a single layer circuit without utilizing any air-spans. This investigation has prompted the outlining of the cross breed structure. For this outline of coupler, creator has utilized a circuit show based approach. Since an identical circuit may the transmission capacity decrease all in all, and it can be pivotal when it is utilized for outlining broadband application plans, the frequency reactions of the plan of equal circuits have been determined used to choose appropriate broadband circuit applications. Moreover, the reproduced and essentially estimated consequences of the recommended hybrid structure are likewise displayed.

**Y. H. Chun** *et al.* [24] This paper has recommended and examined a reduced wide band branch-line hybrid structure. In reference to this examination following a plan procedure, we have outlined and tried two sorts of wideband hybrids. It is dependable for wide-band applications and high power applications with a structure having single layer. The outcomes got from down to earth demonstrators have recommended that the proposed quadrature coupler hybrid has a more extensive transmission capacity and little size. This hybrid coupler can be effortlessly displayed and manufactured by applying regular solid microwave integrated circuit (MMIC) methods. This could be an especially decent pick for the application in which the working data transfer capacity enhances and the taking care of intensity additionally goes to higher esteem. Moreover, it is trusted that it will help in diminishing the cost of creation and enhance the yields since it doesn't comprise of any component that needs a multi layered structure. For the wide-band trademark and cost viability, a four-branch hybrid has been composed. It has components which are mixed appropriated and lumped distributed. Investigation has been performed deliberately on the identical circuits to get an attractive bandwidth capacity with decreased outline area. The planned hybrids have the fractional bandwidth more prominent than 56% at 2 GHz focus frequency. They likewise delineate up to 55.2% size decrease when contrasted with the ordinary plan of branch-line coupler.

**N. Azimah et al.** [25] The suggested branch line coupler in this paper is designed using two-section couple configuration. Unluckily, this cascaded branch-line coupler with double-section still possesses definite bandwidth. Therefore, an overlapping open circuit quarter wavelength is joined to each port of two-section branch-line coupler. After that, the micro-strip line with slot is utilised to obtain branches of the desired coupler. As the design is made by two-sections, therefore it has quite a large size. Therefore, to achieve size reduction bending technique is applied with regards as reported. The branch-line coupler designs and simulations are analysed using CST software having the frequency band of 2–5 GHz. he diminished area and improved micro-strip space two-area branch-line coupler with covered  $k/4$  open circuited micro-strip line at every port is given the general size of 53.56 mm X 920 mm. The impact of utilizing the two systems has been watched by means of recreation utilizing CST. The investigation on the exhibitions of reflection coefficient, coupling coefficient, the correlation amongst mimicked and estimated S21 and S31 of the suggested model of double section branch-line coupler transmission coefficient, disengagement and stage normal for the outlined couplers has been watched. Where, the data transmission execution has enhanced after the micro-strip space and open circuited transmission lines are utilized on the normal two-segment branch-line coupler plan. While, the suggested two-segment branch-line coupler's size is diminished by utilizing a bowing procedure. In this way, 150 % data transfer capacity change and 31 % estimate decrease have been refined contrasted with the basic outline. Besides, better stage trademark execution of the recommended two-segment BLC has been illustrated. The outline coupler was created and estimated to investigate its wideband performance characteristics from 2 to 5 GHz recurrence band.

**J. Wu et al.** [26] Analysed a 3 dB lumped-component directional coupler (LEDC) in light of subjective terminal impedance portrayed numerically. To fathom the clashed necessity for expansive data transmission and little size in LEDC, another structure of coupler is presented, which can altogether enhance transfer speed and whose size is just 3cm×4 cm on the states of the recurrence area of 410 MHz to 490 MHz. The recreation and measure have been done in the paper. To enhance the data transmission, a novel structure, broadband 3 dB tuneable LEDC has been illustrated, of which the inside recurrence can be balanced in the entire recurrence extend and the measurement has likewise been decreased either. Then again, the varactors are utilized as a part of this paper in the place of tuned circuits. The varactors have generally substantial serial resistors that have caused misfortune, which prompt the

sufficiency unevenness. It is proposed that the littler the serial resistor of the varactor-received, the better it is.

**T. Jayachitra** *et al.* [27] Suggested that Hybrid couplers are generally utilized as a part of microwave circuit plan. The guideline of a mixture coupler is that the info control is part similarly between the coupled and through ports, with a 90 degree stage distinction. The fourth (disconnected) port is ended by a 50-ohm stack. In Wireless correspondence frameworks, the applications in round about polarization reception apparatus are setting imperative part. In this investigation the cross breed coupler is intended for 2.4GHz with impedance ( $z_0$ ) is  $50\omega$ , dielectric steady  $\epsilon_r$  is 4.6 and thickness of dielectric material is 1.6mm. Reproduction is finished by ADS programming. The mixture coupler outlined here works at 2.404 GHz frequency. The half breed coupler was effectively actualized and created. The paper likewise reasoned that The 3 dB half breed coupler can be associated with fix reception apparatus to deliver roundabout polarization.

**R. M. Khattab** *et al.* [28] Presented another minimized quadrature half and half for wideband applications. Utilizing the ordinary system of falling two segments in a quadrature half and half, the creator outlined a broadband coupler at a focal recurrence of 1.8 GHz. To enhance the execution of this coupler and diminish its size we utilized the fake transmission line idea, micro-strip line stacked with shunt open finished stubs, and winding lines. A size decrease of around 31% was accomplished contrasted with the regular one and a relative data transmission over 40.0%. The arrival misfortune (S11) and the separation (S14) of the proposed coupler are superior to 18 dB. The structure configuration proposed in this paper is straightforward, on the grounds that it comprises of a solitary layer with no component that needs a multi layered structure, and does not require lumped segments or through openings which constrain the circuit execution.

**A. S. Vijayaraghavan** [29] Outlined a lumped component coupler with an inside recurrence of 2.4 GHz utilizing substrate-versatile models for the inductors and capacitors accessible from Modelithics Inc. The reproduction device utilized as a part of this investigation is the Advanced Design System (ADS) from Agilent Technologies. An adaptation of the lumped coupler configuration was manufactured on a FR-4 substrate with a dielectric consistent of 4.3 and estimated. Re-enactment examinations with full-parasitic and in addition glorified models for the surface mount segments are incorporated to exhibit the significance of precise models in programming prototyping. The size and execution of the lumped component coupler are contrasted with a conveyed branch-line 3 dB coupler outlined at a similar

recurrence. A branch-line circulated coupler was outlined at 2.4 GHz for correlation purposes. The length and width of the transmission lines were computed utilizing Linecalc for the perfect plan. The re-enacted reaction was thin band when contrasted with the lumped component reaction. The reaction of this conveyed form is contrasted with the entire lumped component rendition. A Monte Carlo resistance investigation was done to break down the affectability of the lumped component coupler to the thickness of the substrate, dielectric consistent and the part esteem resilience.

**Y. C. Chiang** *et al.* [30] Investigation and plan procedures for planning a lumped-component 3-dB quadrature coupler with wide-band level coupling are proposed for microwave coordinated circuit applications. The proposed plan system can create a coupler with level coupling more than half partial transfer speed, which is more extensive than the customary lumped-component outline strategies. To check the plan idea, A model comprising of a capacitive coupled high-pass organize is planned and created. Estimation and reproduction comes about nearly compare to each other. The estimation of an exploratory model demonstrates the proposed quadrature half and half has a more extensive partial transmission capacity than the ordinary plan system. In delivering a 2.4-GHz model, the greatest inductor and capacitor esteems are for the most part under 3 nH and 2 pF. These inductors and capacitors can without much of a stretch be constructed by applying ordinary MMIC methods. The proposed quadrature half and half ought to have the capacity to discover applications in future MMICs.

**A. Eroglu** *et al.*[31] In this paper, a down to earth and finish strategy to design a symmetrical two-line micro-strip directional coupler is displayed by logically presenting a three-advance outline methodology. The outline technique requires information of the three parameters that are known toward the start of the plan by and by i.e. the port end impedance, the coupling level, and the frequency of operation. The expository outcomes with a planar EM re-enactment apparatus for five unique materials that are broadly utilized as a part of microwave applications are additionally approved in this paper. At that point the expository outcomes for Teflon and FR4 are tentatively checked by the creator. The outline diagrams that give the outline and separating proportions versus diverse coupling levels for five distinct materials that possess relative permittivity between  $2.08 \leq \epsilon_r \leq 9.8$  are displayed. The outline diagrams that demonstrate the physical length of the directional coupler versus recurrence at various level of coupling for the five materials is likewise given. The entire plan of a symmetrical two-line micro-strip directional coupler can be gotten out of the blue with least blunder utilizing the outcomes in this paper.

**A. Cidronali et al.** [32] In this paper the outline procedure for MMIC lumped component directional couplers, in view of self-assertive end impedance, is depicted. Subjective impedance terminations permit coordinating the direct and nonlinear components to the coupler without the necessity of transformer systems. The system's ability is shown through the plan of a solitary adjusted blender model at 1.8GHz the model has been acknowledged on InP substrate. The outcomes demonstrate a decent disengagement between the info ports and a decent coordinating quality. Work is continuous to stretch out the agent recurrence and to exhibit the advantages of such an outline method in nonlinear administration of the electronic capacity. This work is a piece of a task on the uses of quantum utilitarian gadgets to MMICs

**A. Fackelmeier et al.** [33] Show a high-control directional coupler for exact plentifulness and stage estimating of broadband high frequency signals. As opposed to traditional directional couplers, a fundamentally higher weakening of the coupled forward flag can be accomplished with a similar high directivity. These outcomes from another ring coupling structure which relates to a relatively lossless serial association of directional couplers. The higher coupling constriction permits creating directional couplers with emphatically diminished misfortunes and in this way a littler outline on the grounds that no warmth sink is required A high weakening of the coupled forward flag of in excess of 50 dB with a directivity of around 30 dB for a recurrence scope of no less than 300 MHz to 600 MHz has been accomplished. EM field reproductions have demonstrated that a higher coupling constriction can likewise be accomplished by changing the ring measurements and separations dn. By part up the coupling line in at least two sections (utilizing the ring structure), the circuit is significantly more safe to creation resilience and parameter vacillations. The coupler is utilized for the estimation of beat signals with a most extreme intensity of 20 kW and a normal estimation of 2 kW. Reproducibility is affirmed by estimations and in this way no tedious alignment in arrangement generation is required. Besides there is no requirement for extra resistive attenuators, so costly warmth sink measures can be maintained a strategic distance from.

**T. Y. Song et al.**[34] A novel design having lumped equal circuit for a customary parallel directional coupler is suggested. The equivalent electronic circuit and outline equation for the displayed lumped component directional coupler is inferred in view of the even- odd-mode characteristics of a parallel coupled line. By utilizing the determined outline equation, we have composed the 3dB and 10 dB lumped component couplers at the inside recurrence of 100 MHz. Moreover, a chip write coupler has been intended to create with multilayer setups by utilizing the Low Temperature Co-fired Ceramic (LTCC) process. Outlined chip-type

coupler is having a 10dB coupling incentive at the inside recurrence of 2GHz. The plan recipe for the recommended lumped-component coupler has been inferred in view of the even-and-odd-mode characteristics of a parallel-coupled line. Since there are just the self-inductances and capacitances in the displayed coupler of this letter, the suggested lumped-component coupler is substantially simpler to be implemented than the one having the shared coupling components. A few re-enactments and tests have shown that the introduced lumped-component coupler arrangement and outline equation is greatly powerful in planning lumped-component directional couplers. Also, a chip type coupler case has been intended for LTCC applications.

**D. P. Andrews** *et al.* [35] A plan method for wide-band quadrature 3-dB couplers at microwave frequencies is exhibited in this letter, where lumped components are consolidated into a micro-strip circuit. Outline cases for an eight band coupler and a one and-one-half octave-band coupler are introduced. The topologies introduced offer a helpful and financially savvy answer for tight coupling issues, as of now tackled utilizing conveyed circuits. The current plans for wide-band 3-dB quadrature couplers, however unsatisfactory for microwave activity, can be adjusted to give circuits that give great microwave execution. Two outlines have been exhibited: the primary covering a recurrence scope of 1– 2 GHz demonstrates an overabundance loss of 0.2 dB, an information return loss of 31 dB, a confinement of 26 dB, and stage mistake from quadrature of under 1 . With a most extreme abundance lop-sidedness of 1.2 dB, it gives practically identical execution to a solitary area quarter-wavelength coupler. The second covers a recurrence scope of 1– 3 GHz, and demonstrates an abundance loss of 0.4 dB, an information return loss of 21.5 dB, a segregation of 25 dB, and stage mistake from quadrature of under 2 . With a most extreme adequacy awkwardness of 1.7 dB, it gives execution in the middle of a solitary and three-segment coupler. The plans are anything but difficult to actualize and don't require high-accuracy innovation. They are especially proper for hand craft issues, with critical power rating.

**F. Shirkani** *et al.* [36] In this investigation, a novel structure of triple band branch-line coupler is suggested utilizing ventured impedance (SIR) resonator to take control of the recurrence proportion between the second and first reverberation frequencies of such resonator. The basic normal for such resonators, the recurrence proportion between the secondary and primary reverberation frequencies, is focused as a key factor in self-assertive tuning the reverberation frequencies. In light of the first and second misleading reverberation consonant of the SIR, a triple branch-line coupler is outlined and recreated. The proposed

BLC is appeared to exhibit a triple band BLC with focal frequencies situated at 0.9, 2.6 and 4.2 GHz, separately.

**L. Silva *et al.*** [37] In this letter, it is demonstrated that using methods for equations which provide the estimations of the trademark impedances of the quarter-wavelength transmission lines for the ordinary branch-line coupler, is conceivable to discover new characteristics for these lines so that the came about coupler has upgraded electrical execution without modifying drastically its geometry. It will be observed that the primary plan to have the execution enhanced is by just somewhat giving up the normal for having measure up to control division in the focal frequency activity. In spite of the fact that the pick-up in data transfer capacity (in unique the span where  $S_{41} \leq -20$  dB) may not be as incredible as in the examples said previously, the coupler geometry stays basic, easy to actualize and can be utilized to supplant traditional couplers that might be utilized as a part of microwave circuit plans that don't need ultra wideband, yet work better with couplers having a more noteworthy transmission capacity than the ordinary ones, in particular, conceivable situations where is desired that the couplers possesses a better range where  $S_{21} = (-3 \pm 1)$ dB without increment its size or unpredictability of its geometry.

**J. E. Post *et al.*** [38] Analysis of a model used to represent electrical discontinuities toward the finish of the transmission line has demonstrated that the assurance of trademark impedance  $Z_0$  is exceptionally touchy to parasitic impacts, particularly for reduced loss transmission lines. Evacuating the inductive irregularity on account of 168 all inclusive micro-strip lines extraordinarily decreased the vacillations in the subsequent trademark impedance while expelling the capacitive brokenness on account of the 60 all inclusive, 3-mm-length CPW, where the detachment between the ground lines of 156 m showed comparable change. The outcomes from the 60 far reaching micro-strip lines recommend that keeping up a consistent line width so the test cushion setup is vague from the micro-strip transmission line, if conceivable, is ideal. This permit coordinate testing of the micro-strip transmission line without presenting blunder amid the expulsion of test cushion parasitic or remedy for micro-strip width varieties. In both the circumstances, it is conceivable to execute the adjustment examination technique by embedding an impedance transformer to outline reference impedance of the estimation into the reference impedance  $Z_0$  of the different, excess line benchmarks and the accompanying the strategy given in. Examinations keep on determining if following this method brings about a more precise trademark impedance.

## **CHAPTER 3**

### **RESEARCH GAPS AND METHODOLOGY**

Branch-line coupler is an important device in field of microwave technology and a number of researches are being done in this field. Many researchers have performed theoretical and experimental analysis and different design approaches have been proposed on branch-line couplers according to the literature survey.

#### **3.1 GAPS AND PROBLEMS ENCOUNTERED**

- The size of the coupler is one of the major constraints. As, even at slightly lower frequencies, the size of the device becomes large. Especially, for multiple band applications.
- From studies, we find that bandwidth is one of the major issues as narrow bandwidth does not allow a good range of frequencies to be coupled properly. But these days, we need to operate on wider bands of frequency, especially for communication applications.
- The size reduction techniques induce losses and extra unwanted reactance in the device which need to be compensated using proper techniques.

#### **3.2 OBJECTIVES**

- Branch-line couplers are most popularly used passive device in the field of communication systems. And for such applications, the device should operate on multiple frequency bands as it eases antenna deployment. It is intended to design a branch-line coupler that operates on dual band (here, 900 and 1900 band i.e. GSM band)
- Size is a major constraint for any system design as deployment becomes difficult for devices having large size. The devices with smaller size without any significant changes in performance are required. This provides encouragement to reduce the size of the device and optimize the response.

### **3.3 METHODOLOGY**

The various studies show the effect of stubs in a branch-line coupler and their effects according to different applications and techniques to reduce the size of the device. The steps carried out to design the dual band coupler with reduced size are as follows:

- Study of designing and analysis of Branch-line coupler.
- Study and understanding of CST Microwave studio.
- Understanding concept and numerical analysis for obtaining multiple bands in a coupler using different approaches.
- Analysis and implementation of size reduction techniques and compensation of losses occurred because of them.
- Designing of a dual band branch-line coupler by inducing stubs in conventional design.
- Reduction of size of the coupler by incorporating right angled bends in the stubs.

## CHAPTER 4

### DUAL-BAND BRANCH-LINE COUPLER

In modern day communication system, it is desirable for a device to have multiple applications. So, we need a device which operates on more than one frequency. One such design has been implemented in this chapter. The proposed is a dual-band Branch-line coupler where, the dual operation is obtained by introducing stubs to the quarter wavelength line. The calculations have been done by the help of ABCD matrix.

#### 4.1 CALCULATIONS FOR STUB-TAPPED COUPLER

The basic concept for the new design of the coupler is that the conventional quarter wavelength line is replaced by a T shaped line so as to obtain dual band of operation. The design of the presented line is as shown in Figure 4.1.

In the proposed design, dual band of operation is obtained using stubs tapped to centre of each line. A T- shaped transmission line for the proposed coupler has been considered and replaced a quarter-wavelength branch-line section in a coupler with a T-shaped one. A shunt stub is tapped to centre of conventional line where  $Z_a, Z_b, \theta_a$  and  $\theta_b$  represent the characteristic impedances and the electrical lengths of the series and shunt sections [39].

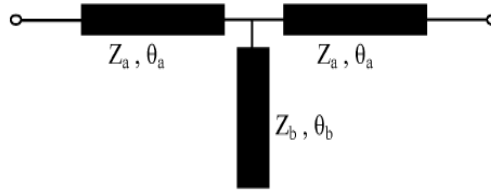


Figure 4.1: Equivalent T-shaped line [2]

We have replaced the quarter wavelength transmission line with an equivalent section, dimensions of which are calculated using ABCD parameters as follows:

When ABCD parameters are taken into consideration, by cascading three different sections of line, we obtain,

$$\begin{bmatrix} A_T & B_T \\ C_T & D_T \end{bmatrix} = \begin{bmatrix} \cos \theta_a & jZ_a \sin \theta_a \\ j \sin \theta_a / Z_a & \cos \theta_a \end{bmatrix} \times \begin{bmatrix} 1 & 0 \\ j \tan \theta_b / Z_b & 1 \end{bmatrix} \times \begin{bmatrix} \cos \theta_a & jZ_a \sin \theta_a \\ j \sin \theta_a / Z_a & \cos \theta_a \end{bmatrix} \quad (4.1)$$

Each element of the matrix is given by

$$D_T = \cos^2\theta_a - \sin^2\theta_a - Z_a \sin\theta_a \cos\theta_a \tan\theta_b / Z_b \quad (4.2)$$

$$B_T = 2jZ_a \sin\theta_a \cos\theta_a - Z_a^2 \sin^2\theta_a \tan\theta_b / Z_b \quad (4.3)$$

$$C_T = \frac{2j \sin\theta_a \cos\theta_a}{Z_a} + \frac{j \cos^2\theta_a \tan\theta_b}{Z_b} \quad (4.4)$$

Since the proposed structure is supposed to be equivalent to a quarter-wavelength transmission line, the ABCD matrix of the new design should be equal to that of a conventional quarter wave-length line [2], yielding

$$\begin{bmatrix} A_T & B_T \\ C_T & D_T \end{bmatrix} = \begin{bmatrix} 0 & \pm jZ_c \\ \pm jZ_c & 0 \end{bmatrix} \quad (4.5)$$

So, by setting  $A_T = D_T = 0$ , we obtain,

$$\tan\theta_b = Z_b (\cos^2\theta_a - \sin^2\theta_a) / Z_a \sin\theta_a \cos\theta_a \quad (4.6)$$

Thus, we obtain,

$$B_T = jZ_a \tan\theta_a \quad (4.7)$$

$$C_T = j / Z_a \tan\theta_a \quad (4.8)$$

Under this condition,

$$\begin{bmatrix} 0 & jZ_a \tan\theta_a \\ 1/jZ_a \tan\theta_a & 0 \end{bmatrix} = \begin{bmatrix} 0 & \pm jZ_c \\ \pm jZ_c & 0 \end{bmatrix} \quad (4.9)$$

By using this, we can obtain the necessary conditions to obtain dual band operation, i.e.

$$Z_a \tan\theta_{af1} = \pm Z_c \quad (4.10)$$

$$Z_a \tan\theta_{af2} = \pm Z_c \quad (4.11)$$

Where  $\theta_{af1}$  and  $\theta_{af2}$  are electrical lengths of lines at the desired frequencies and the solution to above equations can be noted as

$$\theta_{af2} = n\pi \pm \theta_{af1} \quad (4.12)$$

Where the values of  $\theta$  satisfy the relation

$$\frac{\theta_{f1}}{\theta_{f2}} = \frac{f_1}{f_2} \quad (4.13)$$

By this, we can deduce that

$$\theta_{f_0} = n\pi \quad (4.14)$$

Where  $f_0 = f_1 \pm f_2$  and  $\theta_{af_0} = \theta_{af_1} \pm \theta_{af_2}$

Once the frequency of operation is determined, we can easily calculate electrical length of the arms and thus the dimensions of coupler.

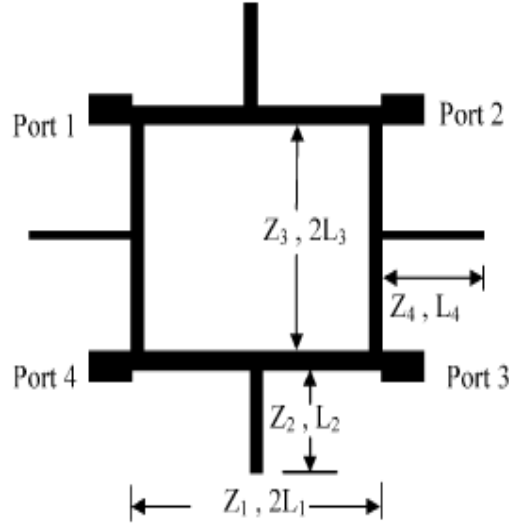


Figure 4.2: Proposed layout of dual band BLC [2]

Figure 4.2 shows the design of the proposed coupler. In the design, there are four stubs, centre tapped at the four branches of the coupler. The stubs are pointing outwards away from the centre. In order to reduce the overall size of the coupler, the stubs are induced with a number of  $90^\circ$  bends which are further chamfered at their corners so that the capacitive effects of corners can be compensated.

## 4.2 MEASUREMENT AND RESULTS

By using the method described in equations 4.1-4.14, the dimensions of coupler can be calculated. The frequencies of operation for the coupler are chosen to be 0.9 and 2 GHz. Based on the above calculations the dimensions turn out to be as shown in table 4.1. Figure 4.3-4.6 shows the results obtained from the simulations and Figure 4.7 shows the combined plot of all the values.

Table 4.1: Dimensions of proposed dual band Coupler

Parameter	Length (mm)	Impedance Parameter	Value( $\Omega$ )
L1	30.3	Z1	24
L2	65	Z2	75.5
L3	30.9	Z3	33.9
L4	66.4	Z4	106.8

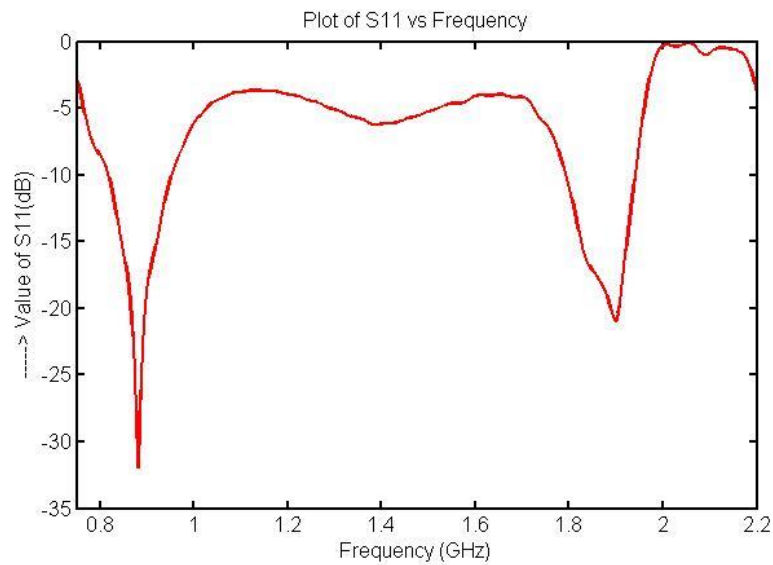


Figure 4.3:  $S_{11}$  Vs. Frequency

The plot of  $S_{11}$  shows the magnitude of power reflected at Port 1 when input is given at Port 1. It is also known as Return Loss. The values, as we know, are measured in dB. More negative the value is, lesser will be the power reflected at that particular frequency. The frequencies where we achieve maximum values (in negative dB) are the frequencies of operation as, at these frequencies there are minimum reflections and maximum power is transmitted to the output port. The plot shown in Figure 4.3 shows the value of  $S_{11}$  to be minimum at 0.88 and 1.92 GHz, which are, -30 dB and -20dB respectively.

The plot shown in Figure 4.4 represents the value of  $S_{21}$  i.e. the output of the Coupler.  $S_{21}$  denotes the output power at Port 2 when input is at Port 1. As maximum power transmission to output port is desirable, the value of  $S_{21}$  should be minimum at the frequency of operation so as to assure that maximum power is transferred from Port 1 to Port 2. Here, 3

dB coupler are designed which splits the power equally between output and coupled port. The graph in Figure 4.4 suggests the value of  $S_{21}$  to be -3.4 dB and -2.7 dB approximately at 0.88 GHz and 1.92 GHz respectively.

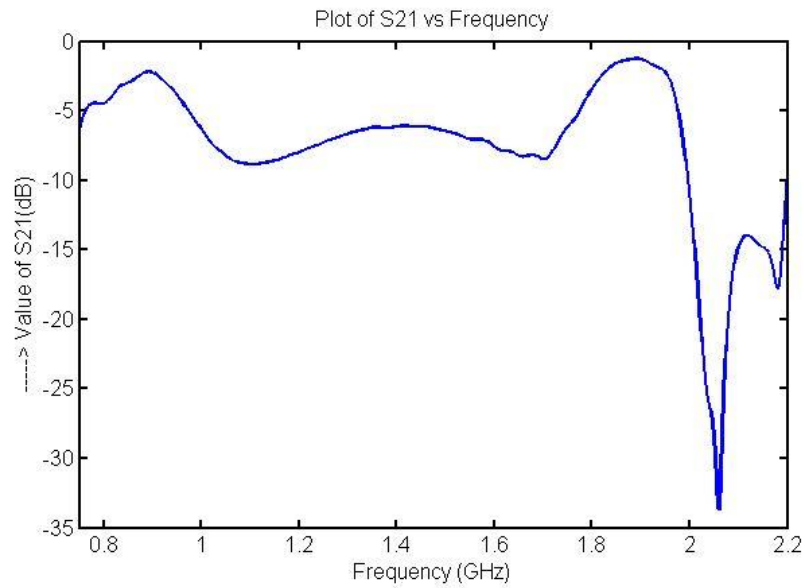


Figure 4.4:  $S_{21}$  Vs. Frequency

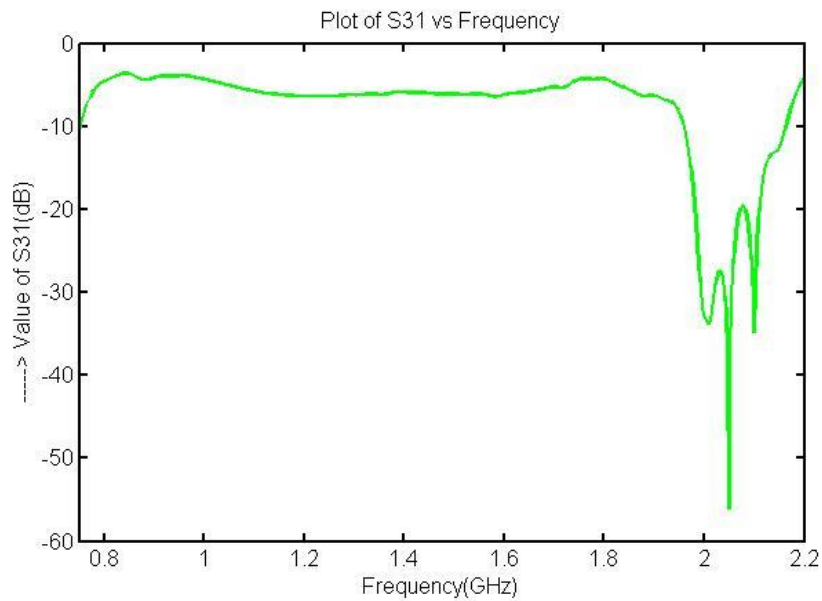


Figure 4.5:  $S_{31}$  Vs. Frequency

Figure 4.5 shows the values of power transferred at Port3 when input is at Port1. For a 3 dB coupler, the power is split equally between Port 2 and Port 3. So, the value of  $S_{31}$  at the

operating frequencies should be near to 3 dB. By the simulated results obtained in Figure 4.5,  $S_{31}$  attains values of -2.8 dB and -3.85 dB at 0.88 and 1.92 GHz respectively.

Isolation, represented by  $S_{41}$  suggests the value of power transmitted at isolated port i.e. Port 4 of the Coupler. Isolated port, as the name suggests, receives minimum power at the operating frequencies and hence, remains isolated. At the operating frequencies of 0.88 and 1.92 GHz the isolation turns out to be -24 dB and -23 dB respectively.

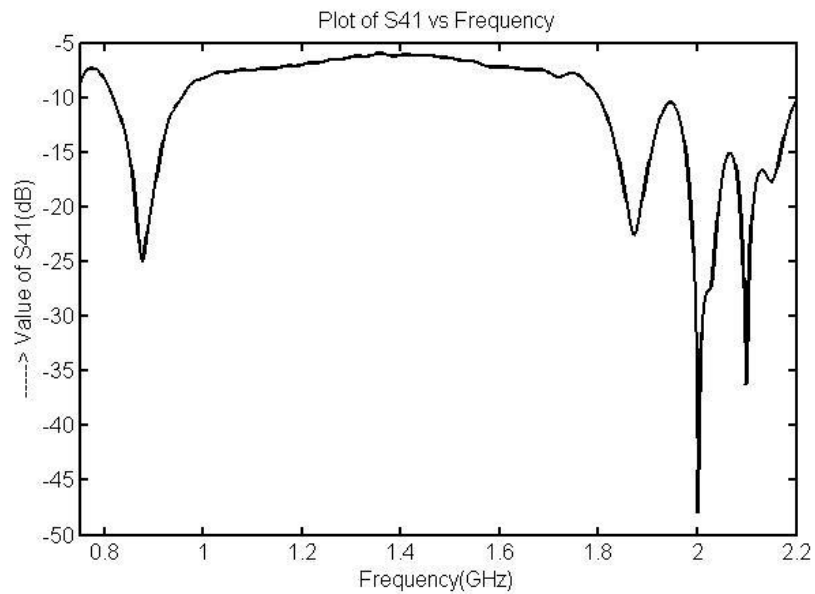


Figure 4.6:  $S_{41}$  Vs. Frequency

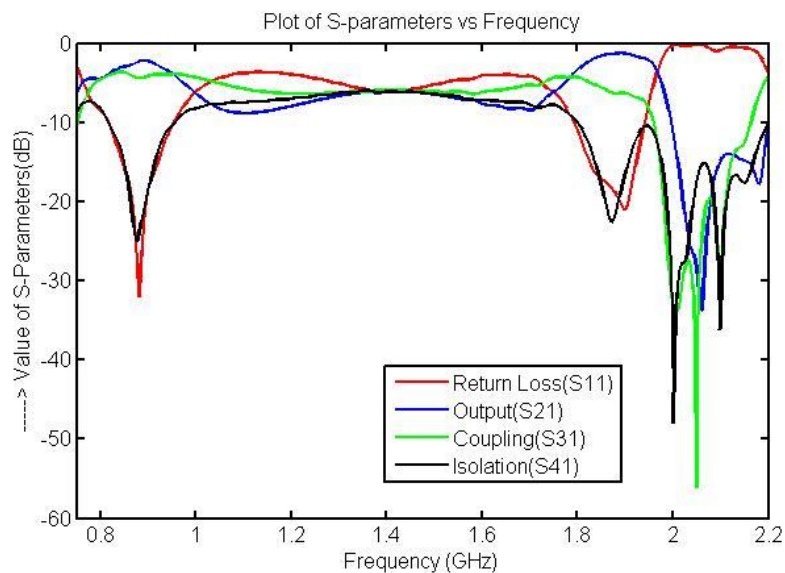


Figure 4.7: S parameters Vs. Frequency

The plot represents the combined values of all the S-parameters for the proposed coupler. It compares the values of  $S_{11}, S_{21}, S_{31}, S_{41}$  and shows that at the operating frequencies, the value of  $S_{11}$  and  $S_{41}$  are minimum while  $S_{21}$  and  $S_{31}$  are at their maximum values. Which suggests minimum power transfer at Port1 (Input Port) and Port 4 (Isolated Port )and maximum power transfer Port 2 (Output Port) and Port 3 (Coupled Port) at the operating frequencies that are 0.88 and 1.92 GHz.

## CHAPTER 5

### MINIATURISED DUAL-BAND BRANCH-LINE COUPLER WITH FOLDED STUBS

Size is among the major constraints that play a crucial role in designing of any device. Numerous methods have been proposed by scholars to reduce size of a device. This chapter presents the utilization of right angled bends in the stubs to reduce its size. The insertion of bends causes discontinuities in the device which gives rise to extra reactance which need to be eliminated.

#### 5.1 FORMULATION FOR RIGHT ANGLED BENDS

The right angled bends are to be incorporated in the stubs. One can determine the electrical length of a right-angled bend in a micro-strip replacing the micro-strip line having the bend with a straight micro-strip line having same equivalent length as the line containing the bend [40].

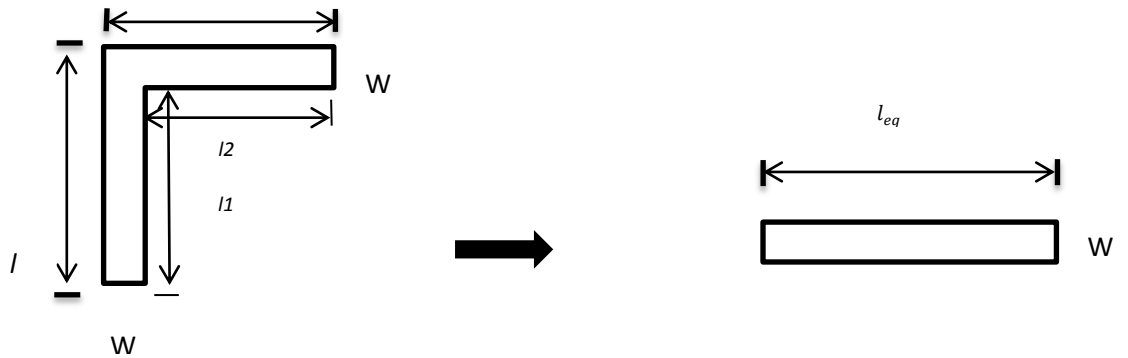


Figure 5.1: Equivalent length of a right angled bend

The equivalent line structure of a right angled bend line to the straight micro-strip transmission line has been shown in figure (3). Here,

$$l_2 = l - W \quad (5.1)$$

$$l_{eq} = l_1 + l_2 + W \quad (5.2)$$

Where,  $l_{eq}$  is the equivalent straight line length of the micro-strip line containing the right angled bend and  $W$  is the width of the microstrip line (for both cases, with or without bend). The bend induces discontinuity in the transmission line causes the generation of extra capacitance and inductance in the transmission line. The equivalent LC circuit of a right-

angled bend in a micro-strip line is determined in Figure 5.2. The bend in the transmission line generates extra capacitance due to charge accumulation at the corner of the bend. While, the abrupt bend causes current interruptions in the line and inductance is induced because of it.

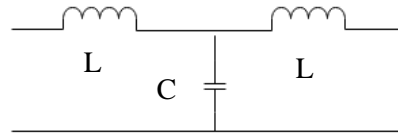


Figure 5.2: Equivalent lumped circuit of a right angled bend

## 5.2 MITRING OF BENDS

Mitring or chamfering is done in such cases to eliminate extra capacitances in the micro-strip line by cutting out the corner of the bend.

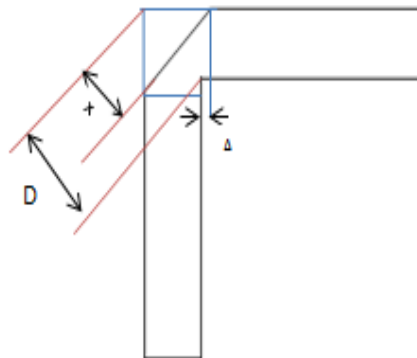


Figure 5.3: Mitring of Bend

$$D = W\sqrt{2} \quad (5.3)$$

$$X = W\sqrt{2} \times (0.52 + 0.65 \times e^{-1.35 \times \frac{W}{h}}) \quad (5.4)$$

$$A = X\sqrt{2} - W \quad (5.5)$$

Where,

W: Width of the line

h: Height of the substrate

D: Diagonal of square mitre

A: compensated length for optimum bend

Mitring is the method to reduce the effects of bend by mitring or curving the transmission lines. As the  $90^\circ$  bend induces a small amount of capacitance to the transmission line, mitring of the bend eliminates those extra capacitances and compensates for it [9]. The method of chamfering the bend is depicted by Figure 5.3.



Figure 5.4: Conversion of straight micro-strip line to line with bend

The transformation of the stub to a right angled line has been shown in Figure 5.4. Four bends have been introduced in the stub and the corners of the bend are removed to compensate for the induced capacitances. These stubs are pointed inwards towards the centre of the coupler to achieve further reduction in size (Figure 5.5).

### 5.3 MEASUREMENTS AND RESULTS

By using the above mentioned method, a modified design has been proposed where, the stubs are folded inwards and then  $90^\circ$  bend is applied to design [41]. For every stub, four bends are incorporated and the corners are cut off i.e. mitring is done to prevent and balance the extra capacitances being induced in the new design. The figure 5.5 shows the coupler as designed on CST Microwave Studio. The proposed model is simulated and the characteristics are observed. Table 5.1 enlists the dimensions of the proposed design. Figure 5.6- 5.10 shows the S-parameters of the proposed design. Figure 5.10 compares all the S parameter values in a single plot and eases the analysis of the performance of branch-line coupler design.

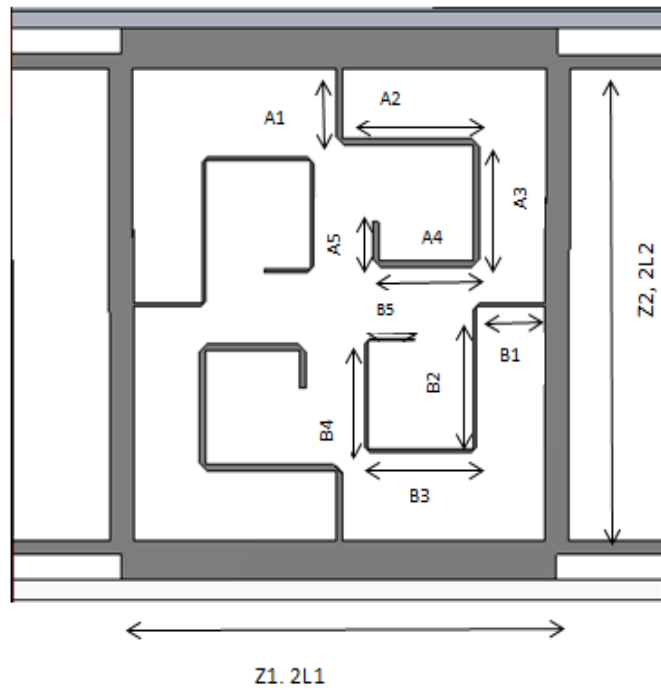


Figure 5.5: Proposed Coupler with stubs bent inwards

Following the procedure and equations described in the previous section, the parameters of the proposed coupler are determined. The table shows the dimensions of the proposed coupler.

Table 5.1: Dimensions of modified design

Parameter	Length (mm)	Parameter	Length (mm)
L1	30.3	A5	5
L2	30.9	B1	10
A1	10	B2	19.09
A2	19.09	B3	15
A3	15	B4	5
A4	5	B5	6.4

The substrate used in the design is Rogers' RO4003 having a dielectric constant of 3.38 and a thickness of 0.81mm. The loss tangent of dielectric is 0.0027. The structure has been designed and optimized on CST Microwave Studio.

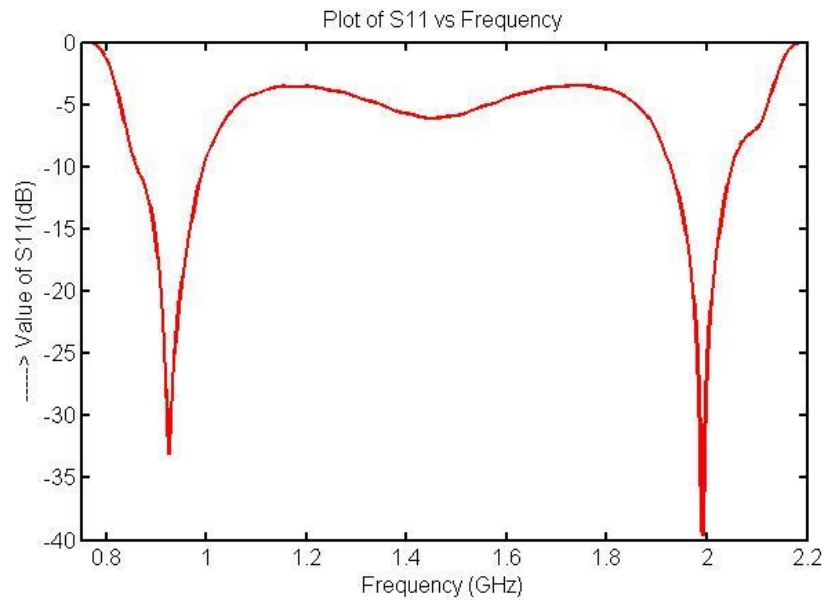


Figure 5.6:  $S_{11}$  Vs. Frequency

The plot shown in Figure 5.6 shows the value of  $S_{11}$  to be minimum at 0.93 and 1.99 GHz, which are, -30 dB and -40 dB respectively. Therefore, we can say that the proposed coupler operates at frequencies of 0.93 and 1.99 GHz.

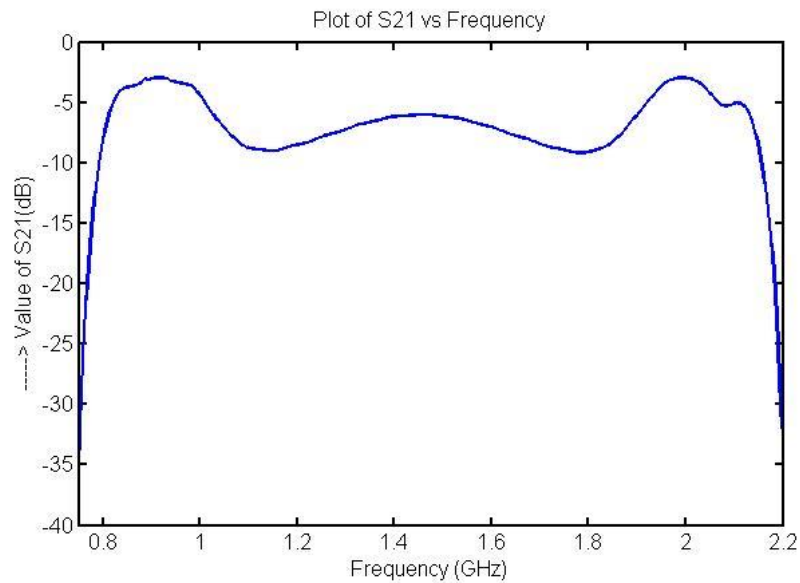


Figure 5.7:  $S_{21}$  Vs. Frequency

The plot shown in Figure 5.7 represents the value of  $S_{21}$  i.e. the output of the Coupler. Here, 3 dB coupler are designed which splits the power equally between output and coupled port. The graph in Figure 5.7 suggests the value of  $S_{21}$  to be -3.04 dB and -2.9 dB approximately at 0.93 GHz and 1.99 GHz respectively.

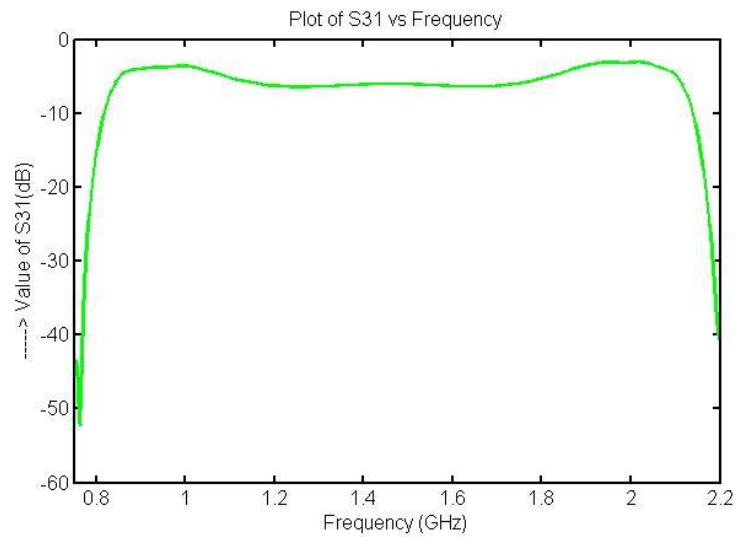


Figure 5.8:  $S_{31}$  Vs. Frequency

Figure 5.8 shows the values of power transferred at Port3 when input is at Port1. For a 3 dB coupler, the power is split equally between Port 2 and Port 3. So, the value of  $S_{31}$  at the operating frequencies should be near to 3 dB. By the simulated results obtained in Figure 5.8,  $S_{31}$  attains values of -3.5 dB and -3.13 dB at 0.93 and 1.99 GHz respectively.

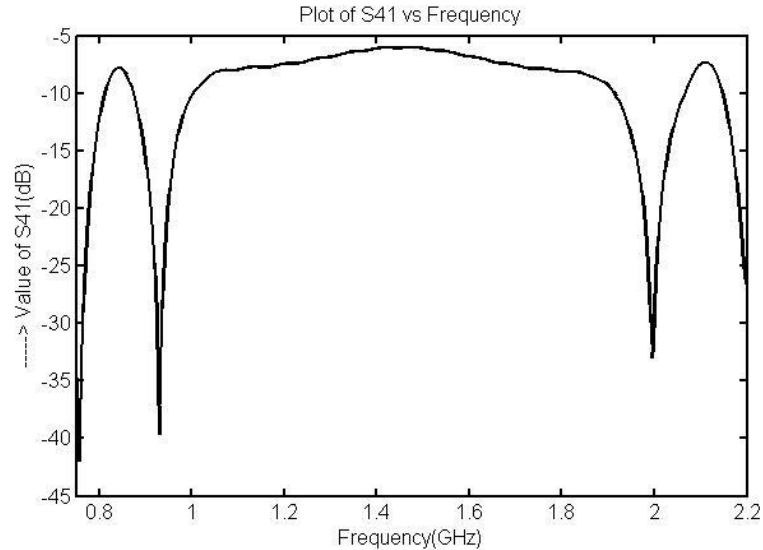


Figure 5.9:  $S_{41}$  Vs. Frequency

Isolation, represented by  $S_{41}$  suggests the value of power transmitted at isolated port i.e. Port 4 of the Coupler. At the operating frequencies of 0.93 and 1.99 GHz the isolation turns out to be -39 dB and -33 dB respectively.

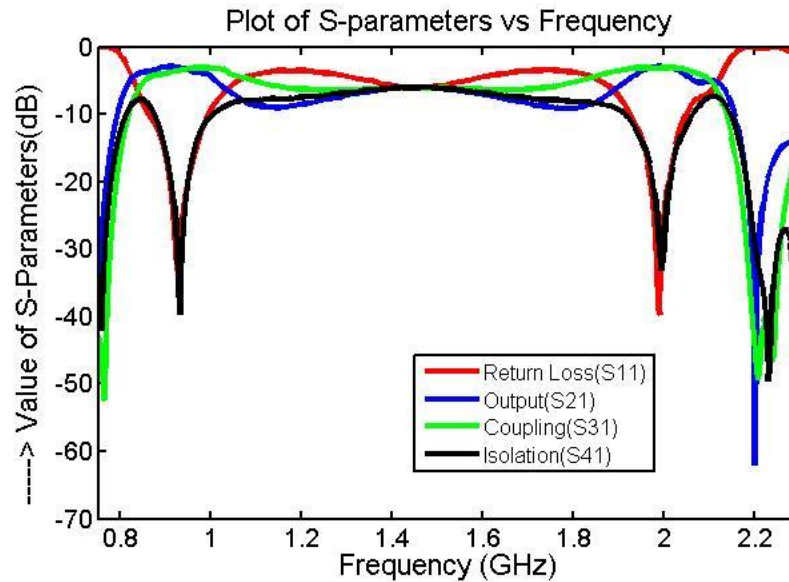


Figure 5.10: S-parameters Vs. Frequency

The plot represents the combined values of all the S-parameters for the proposed coupler. It compares the values of  $S_{11}$ ,  $S_{21}$ ,  $S_{31}$ ,  $S_{41}$  and shows that at the operating frequencies, the value of  $S_{11}$  and  $S_{41}$  are minimum while  $S_{21}$  and  $S_{31}$  are at their maximum values. Which suggests minimum power transfer at Port1 (Input Port) and Port 4 (Isolated Port )and maximum power transfer Port 2 (Output Port) and Port 3 (Coupled Port) at the operating frequencies that are 0.93 and 1.99 GHz .

#### 5.4 COMPARISON OF THE TWO COUPLERS

In the previous sections, dual band branch-line couplers are designed. In the first design, the branches are replaced by equivalent T-shaped lines. To reduce the size of the coupler, bends are introduced in the stubs to reduce the size and are then folded inwards towards the centre of the coupler. When we compare the response of the two designs, we observe that there is difference in the values of S parameters for both the designs. This difference may be due to the extra reactance caused due to the bending of micro-strip line in the stubs. Though, the extra capacitance gets compensated after mitring of bends but the inductances generated due to bends still remain in the coupler. These inductances cause reactance which affects the response of the coupler and a shift in frequencies is observed.

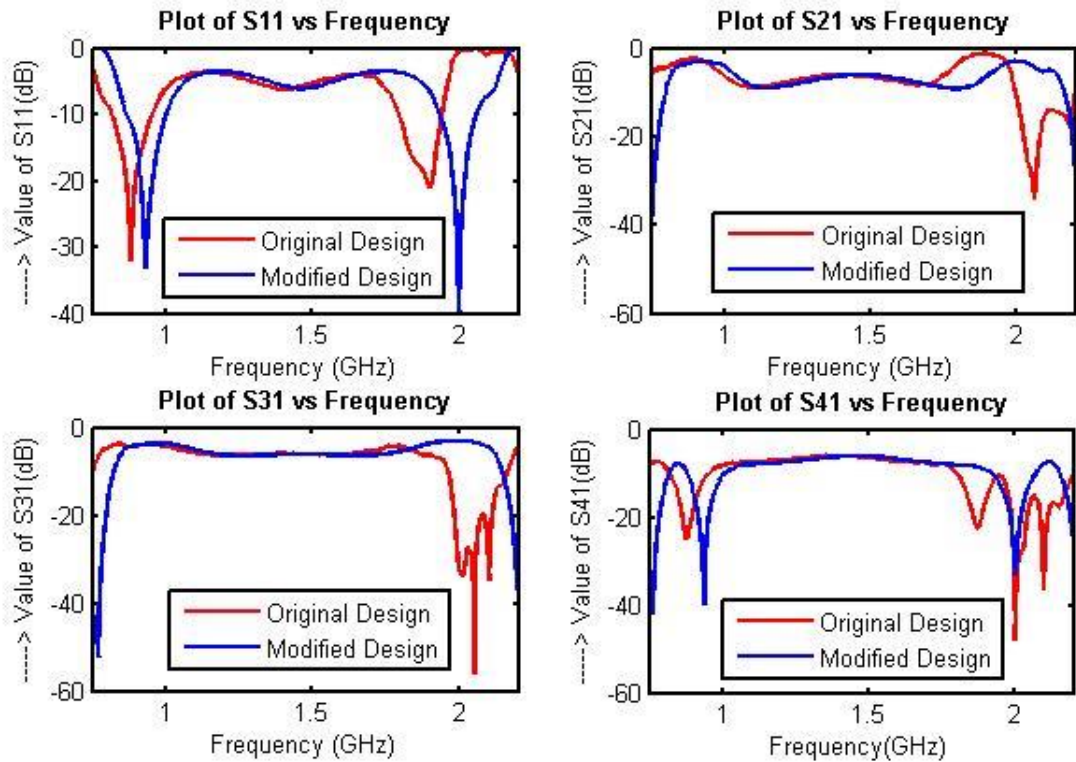


Figure 5.11: Comparison of response of the Couplers

The value of  $S_{11}$  of the two designs has been compared in Figure 5.10. The frequency of operation for first design turns out to be 0.88 and 1.92 GHz. While, for the modified design, it is 0.93 and 1.99 GHz. This shifting in operating frequency is probably due to the extra reactance induced in the coupler because of bends. The values of other S parameters turn out to be approximately similar for both the couplers at their respective frequencies of operation. The modified coupler design shows better response for the operating frequencies i.e. the values of S parameters are better for the modified design.

## **CHAPTER 6**

### **CONCLUSION AND FUTURE SCOPE**

#### **6.1 CONCLUSION**

A Branch-line coupler operating on dual band has been proposed in this report. The study of branch-line coupler is first presented along with the significance of stubs in a coupler. The analysis is done using ABCD matrix. Using this concept, a coupler is designed to operate on dual band. The series and shunt lines of the branch-line coupler are replaced by an equivalent T-shaped line. The design is simulated and characteristics are observed. To miniaturize the coupler, the stubs are then folded inwards and right angled bends are introduced to it. These bends cause discontinuities in the design which leads to generation of extra reactance in the coupler. This reactance has to be removed and mitring is done for the same. The proposed coupler is designed and simulated in CST Microwave studio. On observing the characteristics, the two centre frequencies are found to be 0.93 and 1.99 GHz, which are comparable to the desired values. At both the frequencies, we obtain return loss below -30 dB for 0.93 GHz and approximately -40 dB for 1.99 GHz. Also, the isolation obtained is below -39 dB and -33 dB for 0.93 and 2 GHz respectively. Port 2 and Port 3 have phase difference of -89.29 at 0.93 GHz and 90.66 at 1.99 GHz, which is quite close to that of conventional branch-line coupler. All the results from coupler in Figure 5.5 turn out to be better than the coupler shown in Figure 4.2, which implies that the proposed coupler shows better characteristics. The bandwidth turns out to be 145 MHz and 131 MHz at 0.93 GHz and 1.99 GHz respectively. The area of the proposed design (Figure 5.5) is almost 10% of the area covered by the originally designed coupler (Figure 4.2) which indicates almost 90% reduction in the size.

#### **6.2 FUTURE SCOPE**

In this report, a branch-line coupler design has been proposed to operate on dual band of frequencies. In this design, further size reduction can be achieved using various methods such as incorporation of step impedance in the stubs, use of series and parallel combinations of transmission lines etc. The same design can also be used to work on many other frequencies and thus other applications. As the coupler has been designed on only two frequencies, designs working on more number of bands (triple, quadruple, sextuple or more) can be designed.

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