DESIGN & IMPLEMENTATION OF BRANCH LINE COUPLER USING ADS

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Microwave and Optical Communication

Submitted by

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CERTIFICATE

This is to certify that the thesis report entitled, "**Design & Implementation of Band Branch Line Coupler** " being submitted by **Pooja Sharma** to the *Department of Electronics and Communication Engineering and Applied Physics, Delhi Technological University* in partial fulfilment of the requirement for award of Master of Technology degree in **Microwave and Optical Communication** is a record of bonafide work carried out by her under the supervision and guidance of Dr. Priyanka Jain. The matter embodied in this report has not been submitted for the award of any other degree.

Dr. Priyanka Jain	**Dr. Rajiv Kapoor**
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DECLARATION

I hereby declare that all the information in this document has been obtained and presented in accordance with academic rules and ethical conduct. This report is my own, unaided work. I have fully cited and referenced all material and results that are not original to this work. It is being submitted for the degree of Master of Technology in Engineering at the Delhi Technological University. It has not been submitted before for any degree or examination in any other university.

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Name : POOJA SHARMA

ABSTRACT

Branch line couplers one of the most famous passive circuits used for microwave and millimeter-wave applications. Quadrature hybrids are good examples that gives equal amplitude and quadrature phase outputs at the desired frequency band. They are commonly used in balanced amplifiers and mixers for attaining good return loss, as well as spurious signal rejection. The goal of this project is to design, simulate, and fabricate the Branch Line Coupler operating at microwave frequency by using a software called “Agilent Advance design system (ADS)”. The Branch Line Coupler covers arbitrary band, that frequency decided by area of application.

Todays, a good advancement in wireless communication is done because of increasing demand of users to access data services. To fulfill the data access demand, that only possible by increase spectrum of wireless communication system. But the spectrum given by authority is limited, and ranges also provided in bands e.g. 850MHZ, 900MHZ, and 2000MHZ. Hence, wireless communication system have multiple standards that’s results increasing demand of design multiband system. Therefore in recent year much consideration is given to new design of the couplers, operating at the two arbitrary frequency band.

In this thesis, the design and implementation of a novel planar dual band branch line coupler is introduced. First we discussed Single-Band Branch Line Coupler design and then simulation on Agilent ADS. In order to translate these circuits for dual band, ABCD-parameter is employed. A detailed mathematical analysis of each design is analyzed. The ADS simulations were used to accurate determine the final design.

The designed models are implemented using non-uniform microstrip lines in Agilent ADS and Agilent EMPro. Simulation results shows proposed models as good candidate for wide band microwave application.

Finally, the fabrication of Branch Line Coupler is done using non-uniform microstrip line on a FR4 substrate.

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POOJA SHARMA

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Introduction

1.1 Overview

Branch Line Coupler is one the most famous passive circuit used for microwave & millimeter wave application, and is also known as a “Hybrid Coupler”. Quadrature Hybrid delivers equal amplitude & quadrature phase output at the desired frequency band. They are commonly used in Balanced Amplifiers and mixer for accomplish good return loss as well as spurious signal rejection.

However a good improvement in recent wireless communication system, that has a multiple standards. Branch Line Coupler is a famous passive component as of having arbitrary frequency band that capable to use in different wireless communication standards. But, coupler designed for particular frequency standards, they always be fixed and cannot be changed. Hence wireless communication system works on different frequency standards, results increase the demand of multiband system that supports multimode wireless communication. Therefore in recent year more consideration is given to new outline for the couplers, operating at the two arbitrary frequency band. In this project we represented a new planar structure for the design of a dual band branch line coupler.

The theory required for the design and implementation of the Branch Line Coupler has been gathered from IEEE journals, books, and internet. This report describes the design, simulation and implementation of Single & Dual-Band Branch Line Coupler using microstrip transmission line.

1.2 Motivation and Problem Statement

The motivation for project came while under taking course on RF, Microwave and Millimeter Circuits. The theory on hybrid coupler is very well developed in Microwave. These devices manly work at a single band. Thus, so far the implementation of Branch Line Coupler for multiple band application has been largely ignored. So an idea came to relate the microwave techniques by representations of transmission-line elements in a ABCD-parameter for dual band circuit designing.

1.3 Goals/Scope of present work

The main goals of this project are to get acquainted with microwave circuit designing using tool like Agilent Advanced Design System and EMPro. The present work consists of designing of Branch Line Coupler using microstrip transmission line technology. The scope of this project lies on designing and implementation of other microwave device components like Dividers, Notch filter, Butler Matix etc.
The next section describes the organization of chapters in the thesis.

1.4 Report Organization

The thesis report is divided into seven chapters, each having ample information for comprehending the concepts of this project.

Chapter 1: Presents introduction to project, discusses the motivation and problem statement, goal and scope of present work.

Chapter 2: Literature review and the theory involved in the research work of this project have been presented in this chapter. Here discussed general formulation of S-parameter and overview of Directional Coupler. This chapter also discussed the microstrip technology.meeting with supervisor and lecturers.

Chapter 3: Describes the design methodology of Branch Line Coupler (BLC). The performance of Branch Line Coupler are evaluated by even-odd mode decomposition technique.

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Chapter 4: Illustrates the thorough designing of Branch Line Coupler. Upon using the system functions designed in Chapter 3 corresponding microstrip line configuration is obtained and tuned to derive the characteristic impedance of microstrip sections. Software Simulation performed in Agilent ADS followed by exporting the designed prototype model to Agilent

EMPro. Finally, Plotting of magnitude & phase response of final design schematic circuit of Branch Line Coupler.

Chapter 5: Describes the designing methodology of Dual Band Branch Line Coupler. Mathematical analysis is done to translate a single band branch line coupler into dual band branch line coupler. The designed branch line coupler are analyzed in Agilent EMPro. Lastly, magnitude & phase response of hybrid coupler are presented.

Chapter 6: The detail fabrication process of Dual-Band Branch Line Coupler is illustrated here. The design is fabricated on FR4 substrate having a dielectric constant 4.6 and the final fabricated device port are connected by SMA connectors.

The Final chapter of the thesis (Chapter 7) presents the conclusions and future aspects of this project. The significance and contribution of this work is summarized.

Chapter-2

Literature Review

2.1 Introduction

Branch-line coupler is one of the most famous passive circuits used for microwave and millimeter-wave applications. It provides equal amplitude and quadrature phase outputs at the operating frequency band. They are mostly used in balanced amplifiers and mixers for acquiring good return loss as well as power combining purposes. Branch Line Coupler generally used quarter wavelength due to which it's bandwidths limited to 10-20%. Many attempts have been made to enhance the isolation and return loss over broad bandwidths of the branch line couplers. Many of these involve adding extra branch line section to enhance the bandwidths [8][9]. The physical restraint result a high impedance needed in the branch line section. These techniques even doesn't work at millimeter wave frequencies because of small aspect ratio; one design overcame this problem, by using three quarter wavelength sections in the hybrid. This worked well, but over a limited bandwidth. However, due to the inherent narrow band nature of conventional design, its application to wide band and multi band systems is restricted. In the past years, various reports concerning bandwidth enhancement [3-4] and size reduction [5-6] techniques have been published in the literature. Recently, branch-line couplers based on the use of lumped-distributed-elements [2], were proposed for dual-band systems. However, this kind of proposed circuit exhibited the following drawback:

1. Restricted operating bandwidth (less than 10MHz)
2. Suboptimum return/insertion loss performance
3. Occupies a much large substrate area than the conventional design

Hence, in this project we will introduces a novel planar dual-band branch line coupler that's provides a much wider operating bandwidth (>100MHz) and optimum coupler performance (return & insertion loss).

This chapter reviews several basic but important concepts that are necessary to comprehend the contents of this report. Here we discussed general formulation of S-parameter and overview on directional coupler. This chapter also discussed the microstrip technology and its implementation concept.

2.2 Overview of Directional Coupler

A directional coupler is a passive device. A part of the transmission power couple through main line to couple port when two transmission lines set close enough such that energy passing through one is coupled to the other. Figure2.1 shown the symbol of Directional Coupler, this device has four ports which are input, transmitted, coupled, and isolated. The term ‘main line’ refers to section between port 1 & 2 and 'couple line' refers to section between port 3 & 4. Directional couplers generally use main line for high power operation (or large connectors), while the coupled port designed for a small SMA connectors. Mostly isolated port is terminated with a matched load (typically 50ohms). Directional Coupler is a linear and symmetric device hence; any port can be the act as an input port and the line joined this input port is terminated with transmitted port and the adjacent port become the coupled port, and the diagonal port being the isolated port.

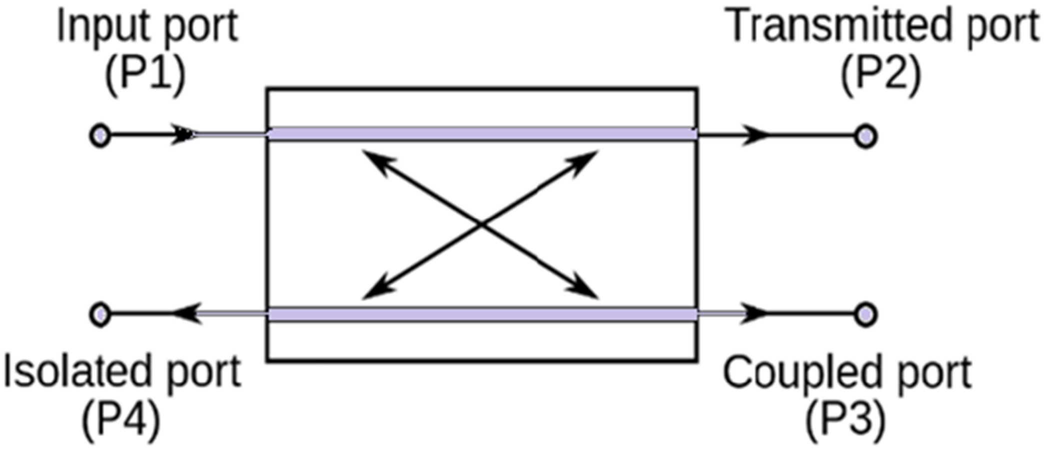


Figure.2.1: Directional coupler

The Couple port most often used in Directional Coupler to obtain information of the signal on main line without interrupting main power flow(except a small power reduction).

The special case of Directional Coupler where power coupled to port 3 (coupled port) is half the input power, also say as 3dB below the input power and power on main transmission line is also 3dB below the input power. This special type of coupler is referred as a 90^0hybrid, or 3dB coupler.

2.3 Performance Characteristics of Directional Coupler

The performance characteristic of directional coupler explained in details as follows:

2.3.1 Coupling Factor

The coupling value is the ratio of the coupled output power (P_3) to the input power (P_1), expressed in decibels:

$$\text{Coupling} = \text{C} = 10\log\frac{\text{P1}}{\text{P3}} \qquad 2.1$$

2.3.2 Insertion Loss

In an ideal directional coupler, the main line loss from port 1 to port 2 due to power coupled to the coupled output port is:

$$\text{Insertion loss (dB)} = 10\log\left[1-\frac{P_3}{P_1}\right] \qquad 2.2$$

2.3.3 Isolation

Isolation is the difference in signal levels in dB between the input port and the isolated port when the two output ports are terminated by matched load, or:

$$\text{Isolation (dB)} = -10\log\frac{P_4}{P_1} \qquad 2.3$$

2.3.4 Directivity

Directivity is define as:

$$\text{Directivity (dB)} = 10\log\frac{\text{P}_3}{\text{P}_4} \qquad 2.4$$

where P_3 is coupled port output power and P_4 is isolated port output power. The directivity should be as high as possible and it cannot directly measurable; it is calculated from the isolation and coupling measurements as:

$$Directivity\ (dB) = Isolation\ (dB) - Coupling\ (dB) \qquad 2.5$$

2.4 S-Parameter (Scattering Matrix)

The scattering matrix is a mathematical construct that specify how RF energy propagates through a multi-port network. The S-matrix allow us to accurately determine the properties of complicated networks as simple "black boxes".

S-parameters describe the response of an N-port network. The first number in the subscript refers to the responding port, while the second number refers to the incident port. Thus S_{31} means the response at port 3 due to a signal at port 1.

2.4.1 S-parameter of Two-Port Network

Figure2.2 shown a two-port network. The incident voltage at port is denoted by "a", while the voltage leaving at the port is denoted by "b".

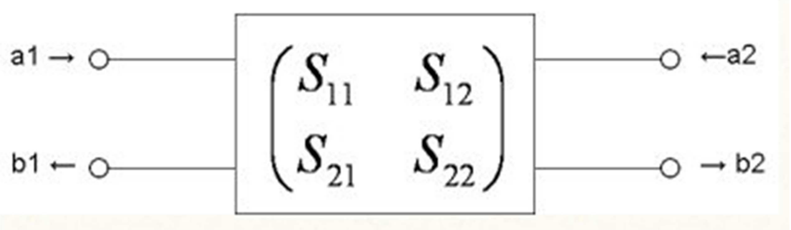


Figure.2.2. The power wave incident and reflect from a 2-port network

The S-parameter matrix of 2-port network is most often used as the basic building block for generating higher order matrices for larger networks. In this case the relationship between the reflected, incident power waves and the S-parameter matrix is given by:

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \qquad 2.6$$

Expanding the matrices into equations gives:

$$b_1 = S_{11}a_1 + S_{12}a_2 \qquad 2.7$$

and

$$b_2 = S_{21}a_1 + S_{22}a_2 \qquad 2.8$$

Each equation indicate the relationship between the reflected and incident power waves at each of the network ports, 1 and 2, in terms of the network's individual S-parameters S_{11}, S_{12}, S_{21}, and S_{22}. Considers an incident power wave at port 1 (a_1) there may result from it waves exiting from either port 1 itself(b_1) or port 2 (b_2).

Let us assume each port is terminated with impedance Z_0, we can define the four S-parameters of the 2-port as:

The S-parameter S_{11}, S_{12}, S_{21}, and S_{22} are:

$S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0}$ = Input reflection coefficient when output port terminated by a matched load

$(Z_L = Z_0 \; sets \; a_2 = 0)$

$S_{22} = \left.\frac{b_2}{a_2}\right|_{a_1=0}$ = Output reflection coefficient when input terminated by a matched load

$(Z_s = Z_0 \; sets \; V_s = 0)$

$S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0}$ = Forward transmission (insertion) gain when output port terminated with a matched load.

$S_{12} = \left.\frac{b_1}{a_2}\right|_{a_1=0}$ = Reverse transmission (insertion) gain when input port terminated with a matched load.

2.5 Microstrip Technology

Microstrip is a kind of transmission line which is fabricated on a printed circuit board (PCB). Device fabricated by microstrip line is far better than waveguide technology. Microstrip line used to fabricate microwave device have light weight, low cost, and compact in size results increasing demand to develop microwave device on microstrip line. Microstrip structure is very simple, it has conductive strip separated from a ground plate by a dielectric layer called substrate. Microstrip line is used to convey microwave signal on it.

2.6 Overview of Microstrip Line

Microstrip is a famous transmission line as in a field of microwave system design. The microwave device designed on microstrip line is far better than waveguide technology especially for microwave integrated circuit and MMICs. Figure 2.3 shows cross section view of microstrip geometry. Microstrip line have a conductive strip of width ‘w’ and thickness ‘t’ and have a wider ground plane. The conductive strip and ground plane separated by a dielectric layer known as substrate having thickness ‘h’.

Microstrip is similar to stripline technology, but has an advantage over strip line as all the active component can be mounted on top of the board. Microstrip line required external shielding to provide high isolation as the requirement of coupler or hybrid design. Microstrip line without external shielding carried electromagnetic wave radiated results an unintended circuit response. A small issue also with microstrip line is its dispersive nature, meaning signal of different frequency travel with different speed.

A transmission line is distribution network parameter, where magnitude & phase of voltage & current changes over a length of transmission line[8]. Microstrip line also used in microwave solid state device. As solid state device very small in size[10] , the technique to provide input and extract output power is by the use of microstrip line where it is easily mounted.

A conducting strip (microstrip line) with a width ‘w’ and a thickness ‘t’ is on the top of a dielectric substrate having relative dielectric constant $\in_r$ and a thickness ‘h’, and the bottom of the substrate is a ground (conducting) plane as shown in figure 2.3.

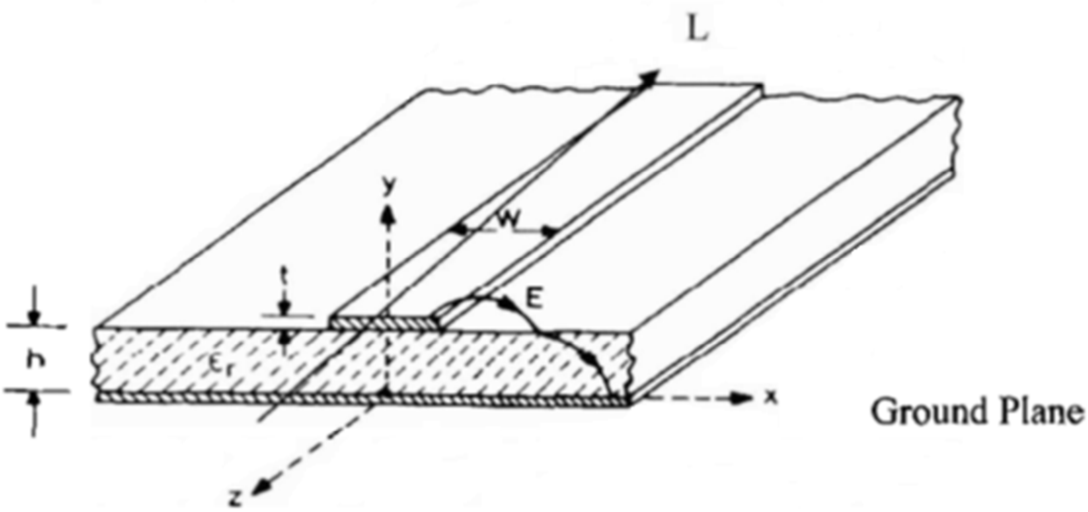


Figure.2.3 Cross-Section view of Microstrip Geometry.

Where:

$\in_r$ = effective permeability of dielectric

h = height of dielectric

t = conductor thickness

E= electromagnetic plane

l = element of length

W= element of width

The electromagnetic wave travels over a microstrip line exits partly in dielectric substrate and partly in air above it. As the result of this, the effective dielectric constant will be different from substrate and air dielectric. The waves travel in an inhomogeneous medium has effective dielectric constant which value lie in between substrate and air dielectric constant values. Due to presence of inhomogeneity medium, the Transverse Electro-Magnetic (TEM) mode is not pure propagate along the microstrip structure. This is what they called quasi-TEM [8]. With the use of thin and high dielectric materials reduces radiation loss of the open structure. As the result of this, the fields are mostly limited inside the dielectric. In this project, we use the Agilent ADS software to find the width and length of the coupler element. The full detailed on how to calculate dimension is disused in next chapters. The Agilent ADS calculate the dimension of physical length of transmission line is totally based on basic formulae of microstrip line [12]

Chapter-3

Branch Line coupler

3.1 Introduction

Branch Line Coupler is a special type of directional couplers having 90^0 phase difference between outputs of through and coupled arms. Branch line coupler also known as 3dB coupler as its output at through and coupler is half of input power supply. This type of coupler is mostly made by microstrip transmission line as shown in Figure 3.1, and is also known as a Quadrature Hybrid[1]. Operation of hybrid coupler can be observe by even-odd decomposition technique.

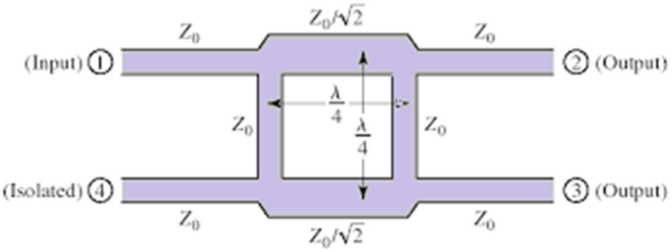


Figure.3.1 Geometry of the Branch Line Coupler

The basic operation of branch-line coupler is that all of their ports are matched and power entering at port 1 is equally divided between ports 2 and 3, with a 90° phase shift between these outputs. No power is coupled to port 4 (the isolated port).

A branch-line coupler has a high degree of symmetry, as any port can be become a input port and output ports will always be on the opposite side of the junction from the input port. The isolated port will be the remaining port on the same side as the input port. This symmetry is also reflecting in the scattering matrix, as each row can be obtained as a transposition of the first row.

3.2 S-parameter of Branch Line Coupler

Branch line coupler is a 3 dB directional coupler, which indicate that $\beta = 1/\sqrt{2}$. The Branch Line Coupler has a 90° phase shift between ports 2 and 3 ($\theta = \emptyset = \pi/2$) when input fed at port

1. The [S] matrix of branch line coupler has mention in equation 3.1, this S parameter matrix shows it is an example of symmetrical coupler.

$$[S] = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & j & 0 \\ 1 & 0 & 0 & j \\ j & 0 & 0 & 1 \\ 0 & j & 1 & 0 \end{bmatrix} \qquad 3.1$$

Now in next section, we will observe the operation of the branch line coupler using an even-odd mode decomposition technique.

3.3 Even-Odd Mode Analysis

Figure 3.2 shown, the normalized form of branch line coupler, where each line represents a transmission line with a characteristic impedance normalized to Z_0. Suppose a wave of unit amplitude $A_1 = 1$ is incident at port 1.

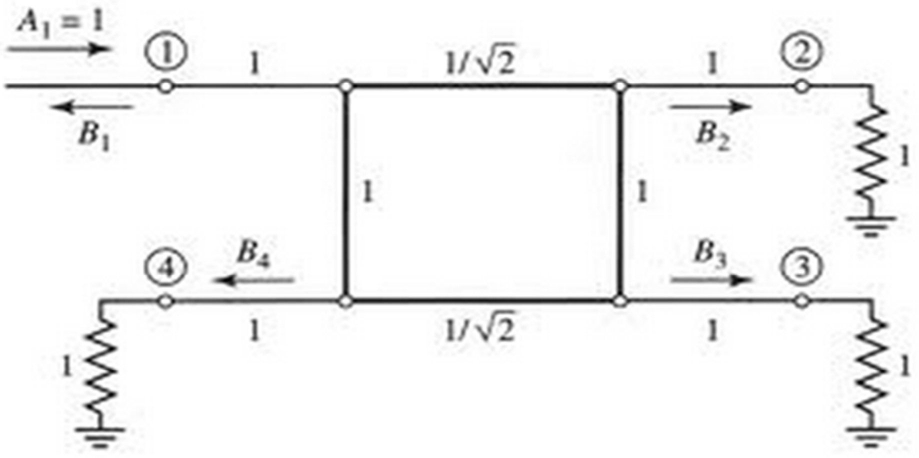
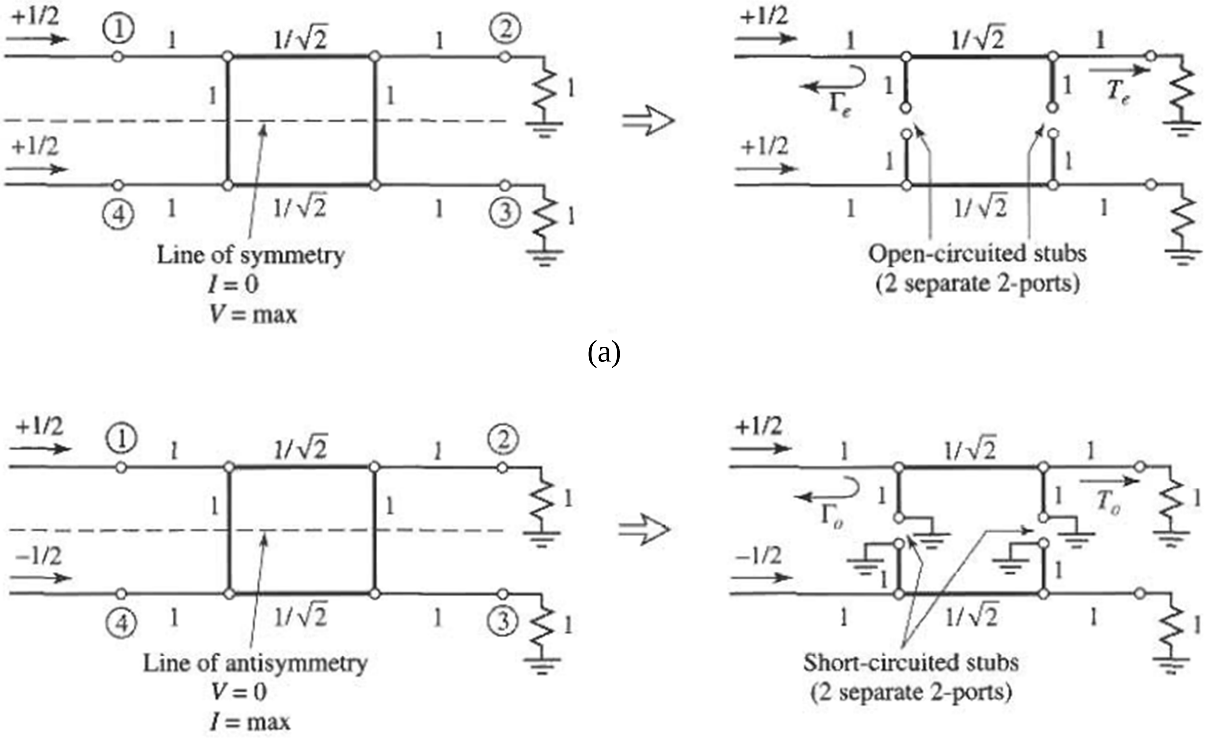


Figure.3.2 Circuit of branch line hybrid coupler in normalized form

The circuit shown above (figure 3.2) can be decomposed into even and odd mode excitation. Because the circuit is linear in nature, so by adding two sets of excitation produce the original excitation and the resultant response can be calculated by the sum of response of even-odd excitations. Because the excitation is symmetry or anti-symmetry in nature, the four-port network will be decomposed into two decoupled two-port networks, as shown in Figure 3.3.



(a)

(b)

Figure.3.3 Branch line coupler decomposed into even and odd mode excitations.
(a) Even Mode (b) Odd Mode

Since the amplitude of incident waves of two-port is $\pm 1/2$, the amplitudes of the emerging wave at each port of the branch line coupler can be represent as

$$B_1 = \frac{1}{2}\Gamma_e + \frac{1}{2}\Gamma_o \qquad 3.2\ (a)$$

$$B_2 = \frac{1}{2}\mathrm{T}_e + \frac{1}{2}\mathrm{T}_o \qquad 3.2\ (b)$$

$$B_3 = \frac{1}{2}\mathrm{T}_e - \frac{1}{2}\mathrm{T}_o \qquad 3.2\ (c)$$

$$B_4 = \frac{1}{2}\Gamma_e - \frac{1}{2}\Gamma_o \qquad 3.2\ (d)$$

where $\Gamma_{e,o}$ and $T_{e,o}$ are reflection and transmission coefficients of two-port networks of Figure 3.3. First we calculate Γ_e and T_e, coefficient, for even-mode two-port network by multiplying the ABCD matrices of each cascade component in that circuit, to give

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & 0 \\ J & 1 \end{bmatrix}}_{\substack{\text{Shunt}\\ Y = j}} \underbrace{\begin{bmatrix} 0 & j/\sqrt{2} \\ j/\sqrt{2} & 0 \end{bmatrix}}_{\substack{\lambda/4\\ \text{Transmission}\\ \text{line}}} \underbrace{\begin{bmatrix} 1 & 0 \\ j & 1 \end{bmatrix}}_{\substack{\text{Shunt}\\ Y = j}} = \frac{1}{\sqrt{2}} \begin{bmatrix} -1 & j \\ j & -1 \end{bmatrix} \tag{3.3}$$

where the individual matrices can be determine from [1]. Now, convert ABCD parameters (defined here with Z_o = 1) to S parameters, which are equivalent to the reflection and transmission coefficients. Thus,

$$\Gamma_e = \frac{A+B-C-D}{A+B+C+D} = \frac{(-1+J-j+1)/\sqrt{2})}{(-1+j+j-1)/\sqrt{2}} = 0 \tag{3.4 (a)}$$

$$\mathrm{T}_e = \frac{2}{A+B+C+D} = \frac{2}{(-1+j+j-1)/\sqrt{2}} = \frac{-1}{\sqrt{2}}\,(1+j) \tag{3.4 (b)}$$

Similarly, for the odd mode we obtain

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \tag{3.5}$$

Hence, the reflection and transmission coefficients of odd mode is

$$\Gamma_0 = 0 \tag{3.6 (a)}$$

$$\mathrm{T}_0 = \frac{1}{\sqrt{2}}(1-j) \tag{3.6 (b)}$$

Then putting 3.4 and 3.6 in 3.2 gives the following results:

$B_1 = 0$ (port 1 is matched), 3.7 (a)

$B_2 = -\frac{j}{\sqrt{2}}$ (half-power, $-90°$ phase shift from port1 to2), 3.7 (b)

$B_3 = -\frac{1}{\sqrt{2}}$ ((half-power, $-180°$ phase shift from port1 to2), 3.7 (c)

$B_4 = 0$ (no power to port 4). 3.7 (d)

The result agrees with the first row and column of the [S] matrix mention in equation 3.1 and the remaining elements can be found by transposition of S-matrix .

Chapter-4

Designing of single Band Branch Line Coupler

4.1 Introduction

This chapter briefly explain the requirements and consideration taken to the develop single band branch line coupler. In this chapter we includes all the mathematical formulae related to design and calculation of responses.

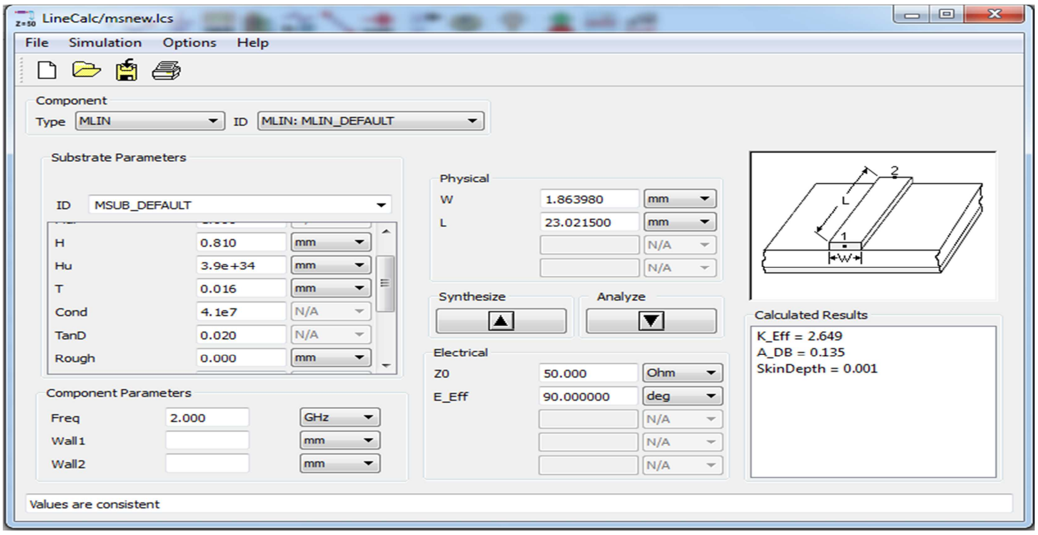
4.2 Objective:

Design a single band branch line coupler at 2 GHz and simulate the performance using Agilent ADS.

4.2.1 Dimension of the coupler

Use Line Calc to determine the physical parameters of the MLINs with the help of characteristic Impedance and Electrical Length.

4.2.2 Agilent Line Calc:



Type: MLIN
ID: MLIN: MLIN_DEFAULT

ID: MSUB_DEFAULT
H: 0.810 mm
Hu: 3.9e+34 mm
T: 0.016 mm
Cond: 4.1e7 N/A
TanD: 0.020 N/A
Rough: 0.000 mm

Freq: 2.000 GHz
Wall1: mm
Wall2: mm

W: 1.863980 mm
L: 23.021500 mm

Z0: 50.000 Ohm
E_Eff: 90.000000 deg

K_Eff = 2.649
A_DB = 0.135
SkinDepth = 0.001

Values are consistent

Figure.4.1 Agilent ADS Line Calc

Corresponding to the value of characteristic impedance of each sections of transmission line is consider and the values of width and length of each section of microstrip is obtained from Agilent Line calc tool as shown in figure 4.1. The dielectric substrate is used having a thickness of 0.81mm and relative dielectric constant of ϵ = 3.38. Table 4.1 tabulates the dimensions of each transmission line section.

4.2.3 Table for the parameters of Transmission Line

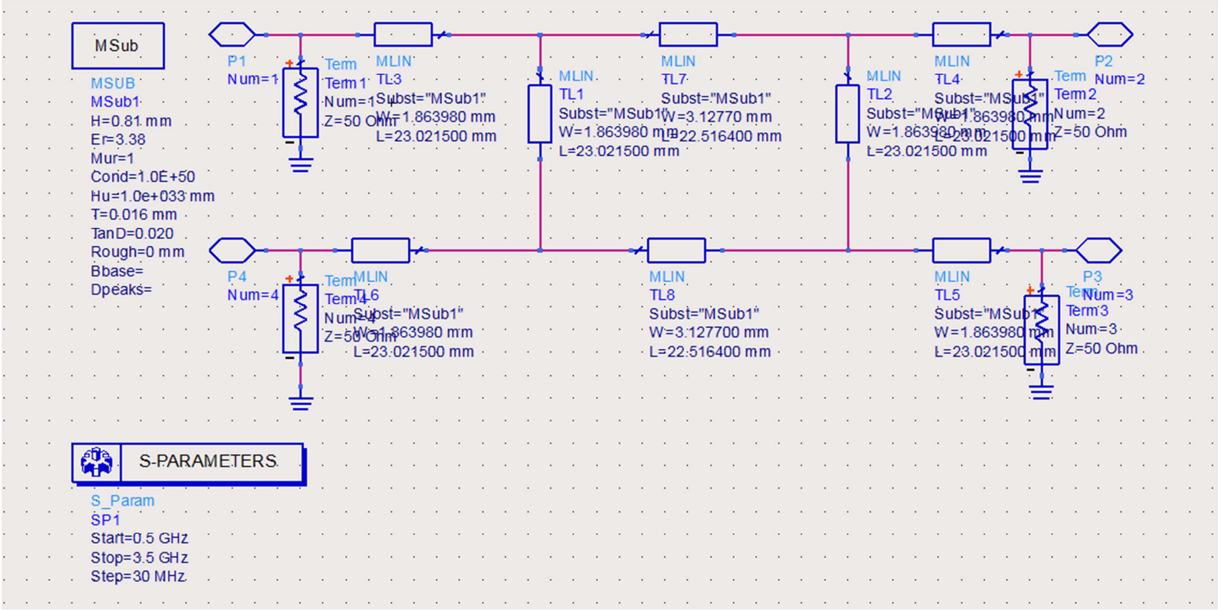
In the following table 4.1 describe the transmission line parameter like width and length for the transmission line. These width and length for transmission line is calculated with the help of line calculation in Agilent Advance design system software. The Agilent ADS use Lincal for the $\lambda/4$ lines with impedance of Z_0 and $Z_0/2$, where Z_0 is a characteristic impedance which values taken as 50 and $50\sqrt{2}$.

Components	Z_0 Impedance of Transmission Line	Electrical Length(βl) In degree	Width (mm)	Length (mm)
MLIN1	50	90	1.863980	23.021500
MLIN2	50	90	23.021500	23.021500
MLIN3	50	90	1.863980	23.021500
MLIN4	50	90	1.863980	23.021500
MLIN5	50	90	1.863980	23.021500
MLIN6	50	90	1.863980	23.021500
MLIN7	35.35	90	3.127700	22.516400
MLIN8	35.35	90	3.127700	22.516400

Table.4.1: Transmission Line parameter from Line Calc width and length for each transmission line.

4.3 Schematic of Single Band Branch Line using Agilent ADS

Figure 4.2 represents the schematic of Single Band Branch Line Coupler using Agilent ADS. Calculate the physical parameters of the Branch Line Coupler from the electrical parameters by using above given design procedure. S-Parameter palette is used for S-parameter analysis of proposed branch Line Coupler.



MSUB
MSub1
H=0.81 mm
Er=3.38
Mur=1
Cond=1.0E+50
Hu=1.0e+033 mm
T=0.016 mm
TanD=0.020
Rough=0 mm
Bbase=
Dpeaks=

P1
Num=1

Term
Term1
Num=1
Z=50 Ohm

MLIN
TL3
Subst="MSub1"
W=1.863980 mm
L=23.021500 mm

MLIN
TL1
Subst="MSub1"
W=1.863980 mm
L=23.021500 mm

MLIN
TL7
Subst="MSub1"
W=3.12770 mm
L=22.516400 mm

MLIN
TL2
Subst="MSub1"
W=1.863980 mm
L=23.021500 mm

MLIN
TL4
Subst="MSub1"
W=1.863980 mm
L=23.021500 mm

Term
Term2
Num=2
Z=50 Ohm

P2
Num=2

P4
Num=4

Term
Term4
Num=4
Z=50 Ohm

MLIN
TL6
Subst="MSub1"
W=1.863980 mm
L=23.021500 mm

MLIN
TL8
Subst="MSub1"
W=3.127700 mm
L=22.516400 mm

MLIN
TL5
Subst="MSub1"
W=1.863980 mm
L=23.021500 mm

P3
Num=3

Term
Term3
Num=3
Z=50 Ohm

S_Param
SP1
Start=0.5 GHz
Stop=3.5 GHz
Step=30 MHz

Figure.4.2 Agilent ADS Schematic of single band branch line coupler

4.3.1 Substrate definition of microstrip

A substrate in EM simulation describes the media where a circuit exists. To demonstrate the proposed design methodology, the brach line coupler simulated using microstrip line build on a Duroid substrate with a thickness of 0.81mm, loss tangent of 0.020 and relative dielectric constant of $\epsilon = 3.38$.

4.3.2 Layout diagram of a Branch Line Coupler in ADS

Based on the schematic diagram (figure 4.2) the layout for Branch Line Coupler is generated in Agilent ADS. For characterization of designed Branch Line Coupler meshing is performed and analysis is done in FEM simulation. An FEM simulation mesh is a part of the entire 3D problem domain, which is divided into a set of tetrahedra (or cells). The pattern of cells is based on the geometry of a layout so each layout has a unique mesh calculated for it. The mesh is then applied to the geometry to compute the electric fields within each cell. It also helps to identify any coupling effects in the layout during simulation. From these calculations, S-parameters are then calculated for the layout.

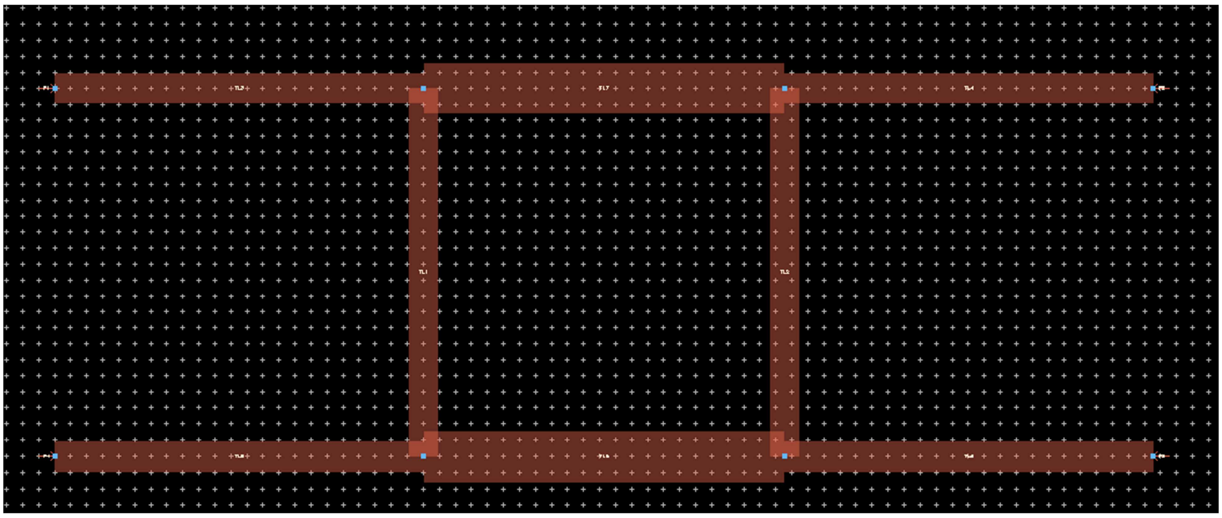


Figure.4.3 Layout diagram of a single-band branch line coupler

4.3.3 Agilent EMPro layout

Figure 4.4 represents the final microstrip Branch Line Coupler prototype build in Agilent EMPro software.

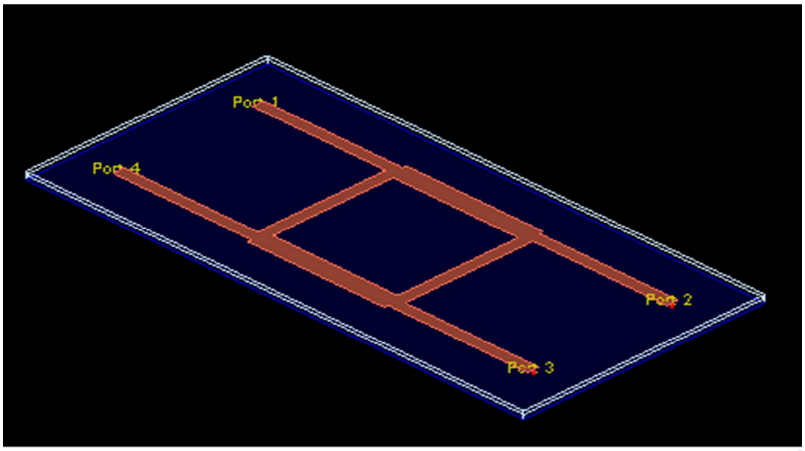


Figure.4.4 3D Agilent EMPro Preview

4.3.4 Magnitude Response

The calculated frequency response is potted for characterization of Branch Line Coupler, reflection coefficient S_{11}, transmission coefficient S_{21} , coupling coefficient S_{31} and isolation coefficient S_{41} parameters have been plotted as shown in figure 4.5. It can be seen that ports 2 and 3 has perfect 3dB power division. Also, perfect isolation and return loss at ports 4 and 1, respectively, at the designed frequency 2GHz. All the parameters, however, degrade quickly as the frequency departs from 2GHz.

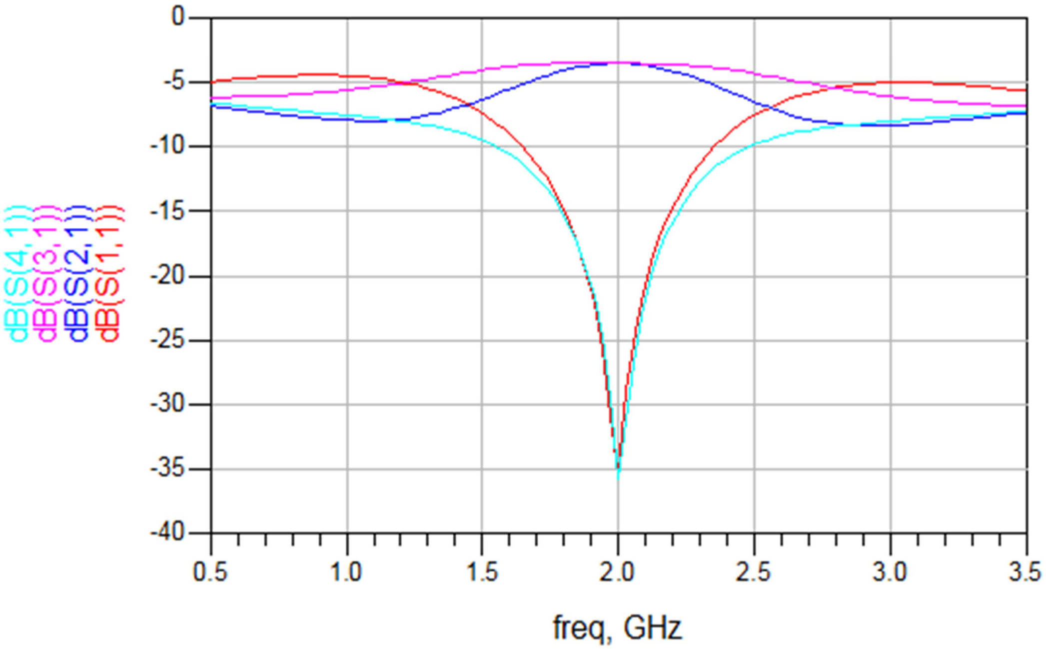


Figure.4.5 Magnitudes versus frequency response of Branch line Coupler

4.3.5 Phase Response

The phase response of Branch Line Coupler plotted against frequency for transmission coefficient S_{21} & coupling coefficient S_{31}as shown in figure 4.6. The calculated phase response S_{21} at 2GHZ is90.003^0 and S_{31} at same frequency is 179.779^0. Now, the phase difference of S_{21}& S_{31} is 89.994^0 that satisfy the Branch Line Coupler specification.

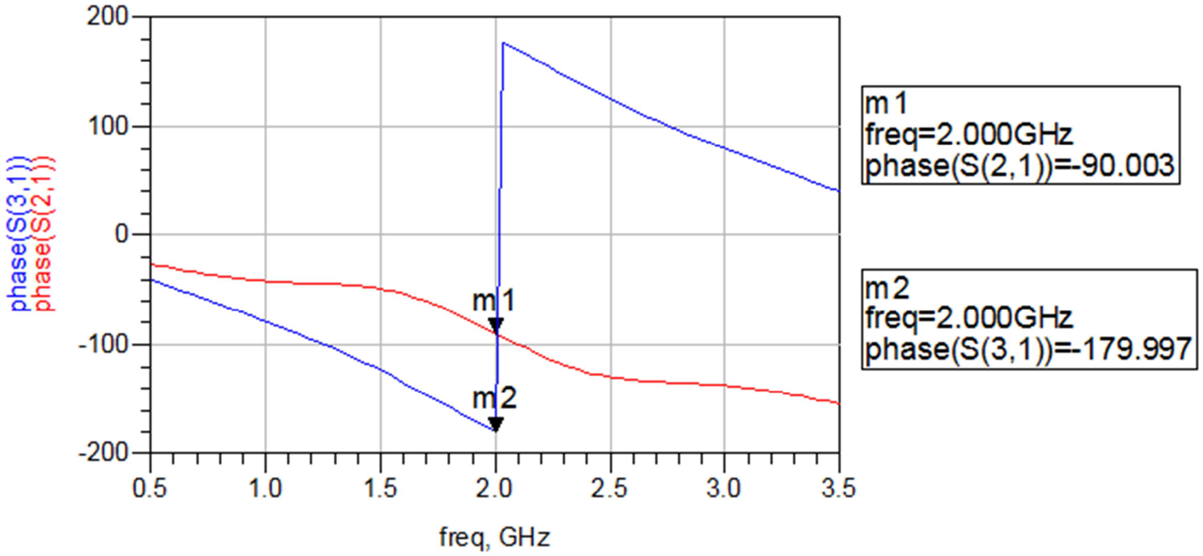


Figure.4.6 S-parameter Phase versus frequency for the Branch line Coupler

4.4 Need to design dual-band branch line coupler

As, from the above designing & simulation results we conclude that Branch Line Coupler can have arbitrary frequency band that band can be decided by area of application. But, coupler is designed for particular frequency standards, they always be fixed and cannot be changed. Hence dual band attracted much attention as it support dual mode of operation and that also save cost of circuit. Hence, in next chapter a mathematical analysis is done to convert single-band branch line coupler to dual-band branch line coupler.

Chapter-5

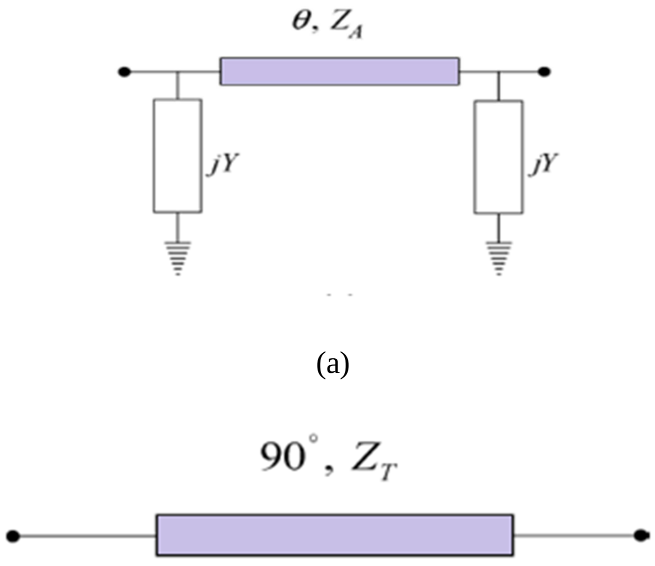
Designing of Dual Band Branch Line Coupler

5.1 Introduction

In this chapter the designing methodology and implementation of dual band branch line coupler discussed. In the proposed design, all the branches are only a quarter wavelength long. Dual band branch line coupler operated at two arbitrary bands, so the evaluation done at mid frequency of the two operating bands. Moreover, in comparison to lumped distributed element circuit, it provides a much wider operating bandwidth (>100 MHz) and optimum coupler performance (return/insertion loss and port isolation).

5.2 Mathematical Analysis of Dual Band Branch Line Coupler

The main idea of dual band branch line coupler is that entire structure of figure5.1 (a) can be equivalent to structure in figure5.1 (b) at the two frequency by setting property value of Z_A and Y.



(a)

(b)

Figure 5.1: (a) Proposed equivalent structure, (b) Quarter- wavelength branch line

Figure5.1 (a), an equivalent circuit for quarter wavelength transformer is introduced, which consists of a branch line having an electrical length of θ and the characteristic impedance of Z_A, connected to a pair of shunt element (jY).

By applying a matrix formulation, the ABCD-parameters of the proposed structure shown in Figure 5.1 (a) can thus be derived as

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ jY & 1 \end{bmatrix} \begin{bmatrix} cos\theta & jZ_A sin\theta \\ jY_A sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} 1 & 0 \\ j & 1Y \end{bmatrix} \tag{5.1}$$

which leads to

$$\begin{bmatrix} cos\theta - Z_A Y sin\theta & jZ_A sin\theta \\ jY_A sin\theta(1 - Z_A^2\, Y^2 + 2Z_A Y cot\theta) & cos\theta - Z_A Y sin\theta \end{bmatrix} \tag{5.2}$$

the above expression can further be simplified to

$$\begin{bmatrix} 0 & jZ_A sin\theta \\ j\frac{1}{Z_A sin\theta} & 0 \end{bmatrix} = \begin{bmatrix} 0 & \pm jZ_T \\ \pm j\frac{1}{Z_T} & 0 \end{bmatrix} \tag{5.3}$$

by setting

$$Z_A sin\theta = \pm Z_T \tag{5.4}$$

$$Y = \frac{\cot\theta}{Z_A} \tag{5.5}$$

Equation 5.3 implies that the introduced structure equivalent to a transmission line with characteristic impedance of Z_T and electrical length of $\pm 90°$. Similary, for dual-band operation, the essential conditions may simply be stated as

$$Z_A sin\theta_1 = \pm Z_T \tag{5.6}$$

$$Z_A sin\theta_2 = \pm Z_T \tag{5.7}$$

where θ_1 and θ_2 are electrical lengths of the branch-line calculated at the center frequencies of the lower f_1 and f_2 upper bands. The general solutions of 5.6 and 5.7 can then be represent as

$$\theta_2 = n\pi - \theta_1 \tag{5.8}$$

where n = 1,2,3,4……, and with the fact that

$$\frac{\theta_1}{\theta_2} = \frac{f_1}{f_2} \qquad 5.9$$

one obtains

$$\theta_1 = \frac{n\pi}{2}(1-\delta) \qquad 5.10$$

$$\theta_2 = \frac{n\pi}{2}(1+\delta) \qquad 5.11$$

$$\delta = \frac{f_2-f_1}{f_2+f_1} \qquad 5.12$$

Furthermore, by substituting 5.10 and 5.11 into 5.4 and 5.5, we have

$$Z_A = \frac{Z_T}{\left|\cos\left(\frac{n\delta\pi}{2}\right)\right|} \qquad 5.13$$

$$Y = \begin{cases} \frac{\tan\left(\frac{n\delta\pi}{2}\right)}{Z_A}, & f = f_1 \\ -\frac{\tan\left(\frac{n\delta\pi}{2}\right)}{Z_A}, & f = f_2 \end{cases} \qquad 5.14$$

for n= 1,3,5,…..,and

$$Z_A = \frac{Z_T}{\left|\sin\left(\frac{n\delta\pi}{2}\right)\right|} \qquad 5.15$$

$$Y = \begin{cases} -\frac{\cot\left(\frac{n\delta\pi}{2}\right)}{Z_A}, & f = f_1 \\ \frac{\cot\left(\frac{n\delta\pi}{2}\right)}{Z_A}, & f = f_2 \end{cases} \qquad 5.16$$

for n= 2,4,6,……

The general expression for the design of the dual band coupler is analytically determined. There exist multiple solutions, which include the choice of n and the different ways of finding the shunt element with its input admittance, as defined by 5.14 and 5.16. Let us consider, a circuit topologies have n=1(compact size).

Using 5.10 and 5.11, accordingly stub’s input admittance can be derived as

$$Y = \begin{cases} \dfrac{\cot\left(\frac{\delta\pi}{2}\right)}{Z_B}, & f = f_1 \\ -\dfrac{\cot\left(\frac{\delta\pi}{2}\right)}{Z_B}, & f = f_2 \end{cases} \qquad 5.17$$

where Z_B is the characteristic impedance of the stub. Hence, by combining 5.14 and 5.17, we get

$$Z_B = \frac{Z_T}{\sin\left(\frac{\delta\pi}{2}\right)\tan\left(\frac{\delta\pi}{2}\right)} \qquad 5.18$$

Figure5.2 shows the final structure (by merging paralleled shunt stubs) of the dual-band coupler with all branch lines replaced by the introduced circuit (Figure 5.1).

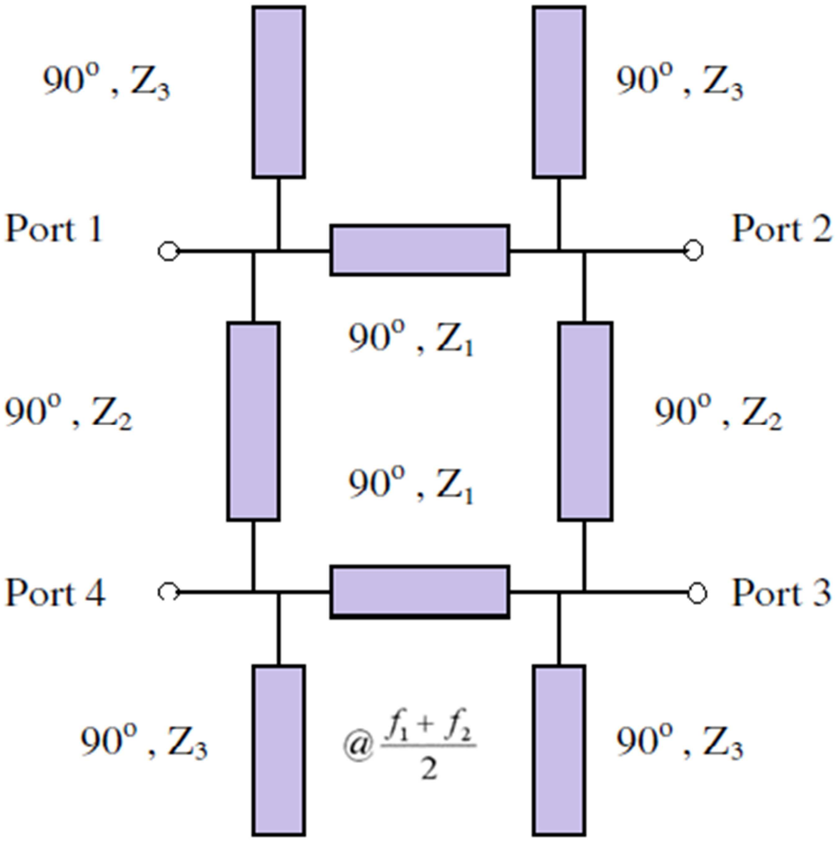


Figure 5.2: Final structure of the proposed Hybrid Coupler with open-circuit stubs

As a result, the value of Z_1, Z_2, and Z_3 may be determined by the following formulas:

$$Z_1 = \frac{Z_0}{\sqrt{2}} \cdot \frac{1}{\cos\left(\frac{\delta\pi}{2}\right)} \qquad 5.19$$

$$Z_2 = Z_0 \cdot \frac{1}{\cos\left(\frac{\delta\pi}{2}\right)} \qquad 5.20$$

$$Z_3 = \frac{Z_0}{1+\sqrt{2}} \cdot \frac{1}{\sin\left(\frac{\delta\pi}{2}\right)\tan\left(\frac{\delta\pi}{2}\right)} \qquad 5.21$$

5.3 Objective:

Design a dual band branch line coupler operating at 900/2000MHz and simulate the performance using Agilent ADS.

$Z_0 = 50$

$f_1 = 900MHz$

$f_2 = 2000MHz$

$$f_c = \frac{f_1 + f_2}{2} = \frac{900 + 2000}{2}$$
$$= 1450MHz$$

$$\delta = \frac{f_2 - f_1}{f_2 + f_1} = \frac{2000 - 900}{2000 + 900}$$
$$= 0.38$$

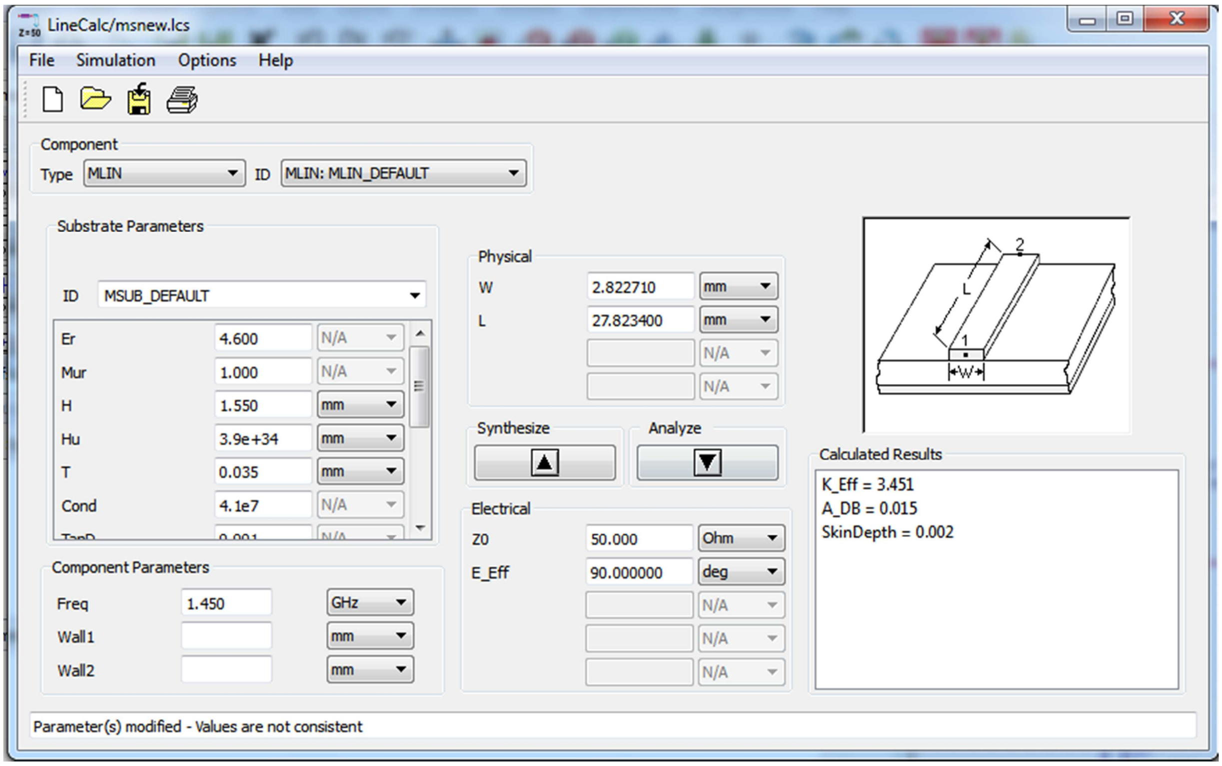
$$Z_1 = \frac{Z_0}{\sqrt{2}} \cdot \frac{1}{\cos\left(\frac{\delta\pi}{2}\right)} = \frac{50}{\sqrt{2}} \cdot \frac{1}{\cos\left(\frac{0.38 * \pi}{2}\right)} = 42.7\ ohm$$

$$Z_2 = Z_0 \cdot \frac{1}{\cos\left(\frac{\delta\pi}{2}\right)} = 50 \cdot \frac{1}{\cos\left(\frac{0.38 * \pi}{2}\right)} = 60.4\ ohm$$

$$Z_3 = \frac{Z_0}{1+\sqrt{2}} \cdot \frac{1}{\sin\left(\frac{\delta\pi}{2}\right)\tan\left(\frac{\delta\pi}{2}\right)} = \frac{50}{1+\sqrt{2}} \cdot \frac{1}{\sin\left(\frac{0.38 * \pi}{2}\right)\tan\left(\frac{0.38 * \pi}{2}\right)} = 54.4\ ohm$$

All the length of the branch is equal to $\lambda/4$ at f_c.

5.3.1 Agilent Line Calc



Component

Type MLIN

ID MLIN: MLIN_DEFAULT

Substrate Parameters

ID MSUB_DEFAULT

Er	4.600	N/A
Mur	1.000	N/A
H	1.550	mm
Hu	3.9e+34	mm
T	0.035	mm
Cond	4.1e7	N/A

Component Parameters

Freq	1.450	GHz
Wall1		mm
Wall2		mm

Physical

W	2.822710	mm
L	27.823400	mm

Electrical

Z0	50.000	Ohm
E_Eff	90.000000	deg

Calculated Results

K_Eff = 3.451
A_DB = 0.015
SkinDepth = 0.002

Parameter(s) modified - Values are not consistent

Figure 5.3: Agilent ADS Line Calc

Corresponding to designing variables Z_1, Z_2 , & Z_3 and its values obtained as from above mathematical analysis. According to the characteristic values of each section of transmission line, the width and length of each section of microstrip is obtained from Agilent Line calc tool as shown in figure 5.3. The FR4 material is used as dielectric substrate having a thickness of 1.55mm and relative dielectric constant of ε = 4.6. Table 5.1 tabulates the dimension of each transmission line section. The device each port terminated with Z_0 = 50Ω transmission line in order to impedance matching at all the ports.

The dimension of each branch line is found by using transmission line:

	Impedance (ohm)	Width (mm)	Length (mm)
Z_0	50	2.822710	27.823400
Z_1	42.7	2.373510	31.395400
Z_2	60.4	1.352170	32.129800
Z_3	54.4	1.618970	31.900600

Table.5.1: Transmission Line parameter from Line Calc width and length for each transmission line.

5.4 Schematic of Dual Band Branch Line Coupler using Agilent ADS

Figure 5.4 represents the schematic for Dual Band Branch Line Coupler elements using Agilent ADS. Calculate the physical parameters of the Branch Line Coupler from the electrical parameters like Z_1 , Z_2, Z_3 and set all the electrical length of branches $\lambda/_4$ at f_c using the above given design procedure explained in section 5.3. All the electrical length of branches are 90°. S-Parameter palette is used for S-parameter analysis of proposed branch line coupler. The simulation is performed with linear sweep of frequency from 0.5 to 3.5GHz.

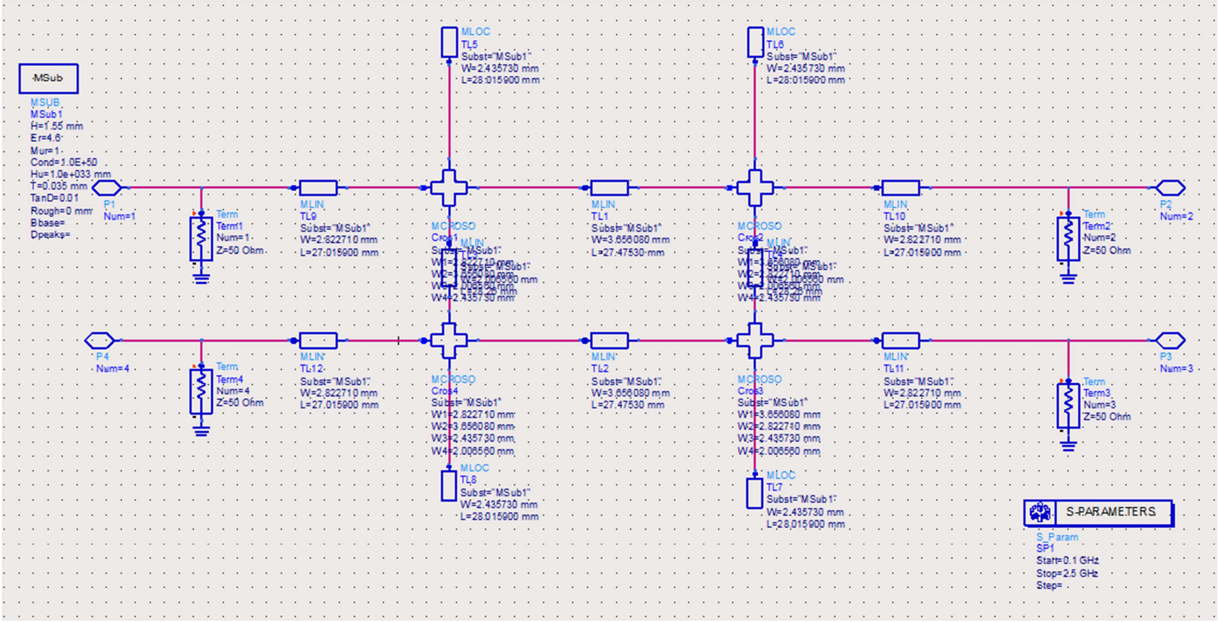


Figure.5.4: Agilent ADS Schematic of Dual Band Branch Line Coupler

5.4.1 Substrate Definition of Microstrip

A substrate in EM simulation describes the media where a circuit exists. To demonstrate the proposed design methodology, the microwave Branch Line Coupler is simulated using microstrip line build on a substrate FR4 with a thickness of 1.55mm, loss tangent of 0.01 and relative dielectric constant of $\epsilon = 4.6$.

5.4.2 Layout diagram of a Branch Line Coupler in ADS

As we discussed schematic diagram of branch line coupler in section 5.4, based on schematic diagram a layout for dual band branch line coupler is generated is show in figure 5.6. For characterization of designed coupler meshing is performed. To generate an electromagnetic field solution from which S-parameter can be computed.

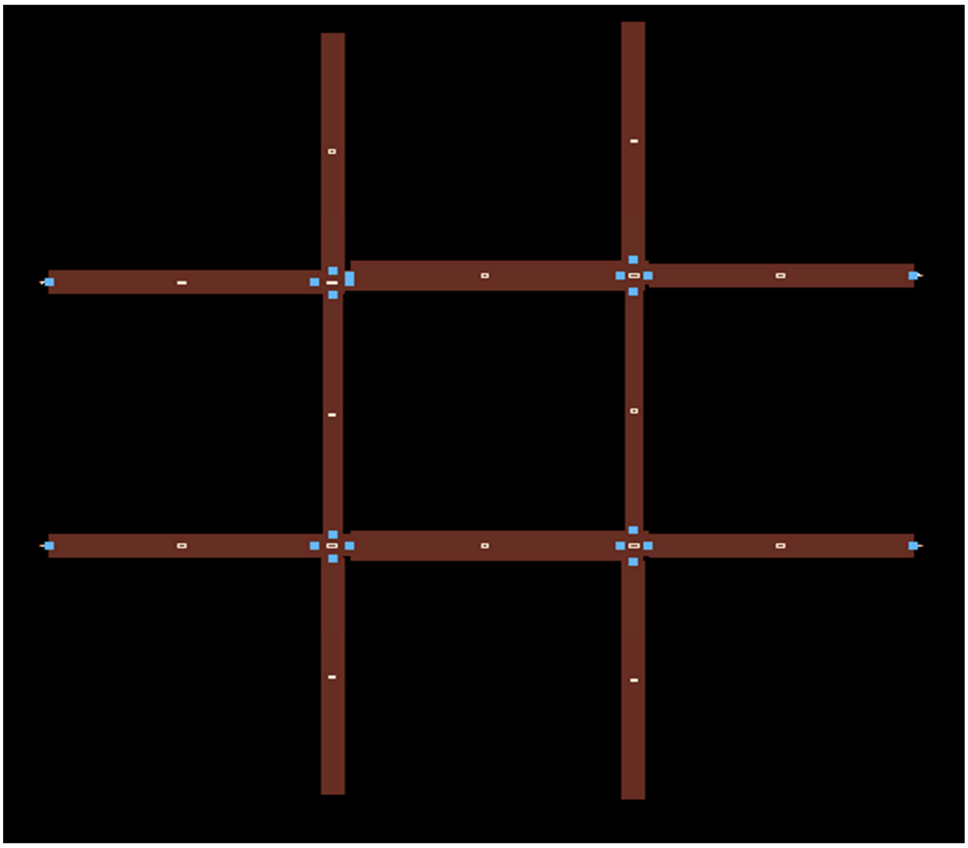


Figure.5.5: Layout diagram of a Dual band branch line coupler

5.4.3 Agilent EMPro layout

Figure 5.6 represents the final microstrip branch line coupler prototype build in Agilent EMPro software.

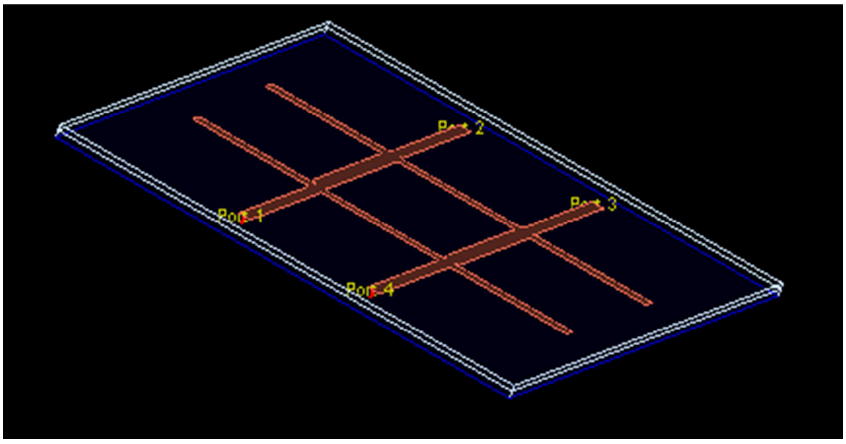


Figure 5.6: 3D Agilent EMPro Layout of Dual Band Branch Line Coupler

5.4.4 Magnitude & Phase Response

The calculated response is potted for characterization of Branch Line Coupler reflection coefficient S_{11}, transmission coefficient S_{21} , coupling coefficient S_{31} and isolation coefficient S_{41} parameters have been plotted. Figure 5.7 shown magnitude response of Dual Band Branch Line Coupler.

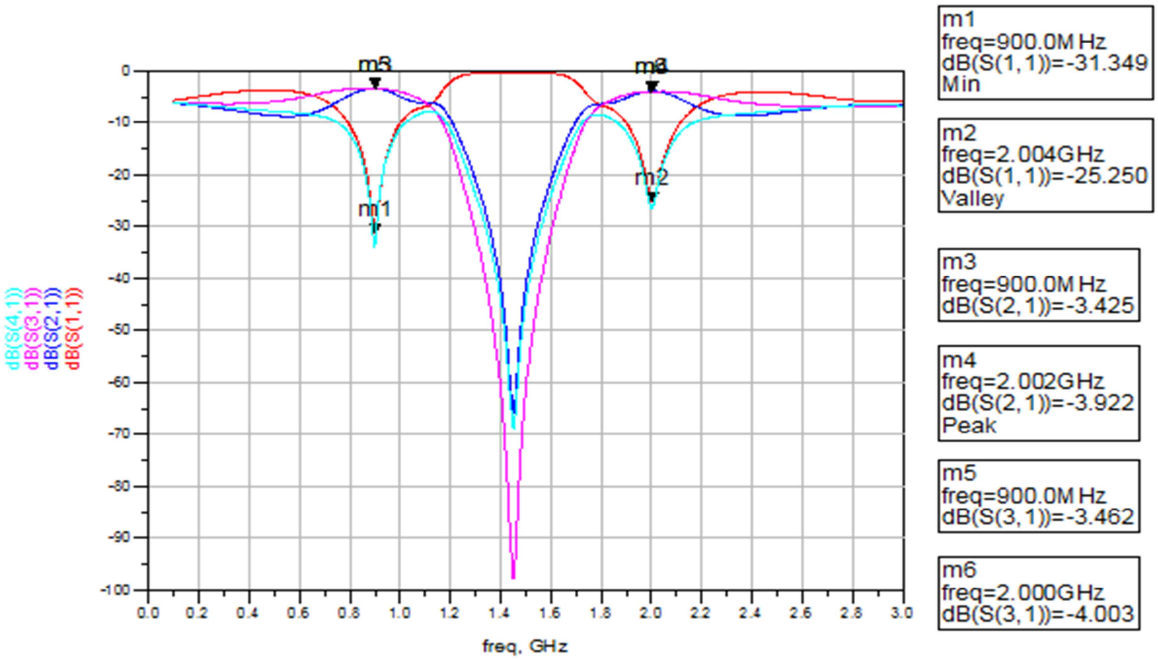


Figure.5.7: S-parameter magnitudes versus frequency for the Dual Band Branch line Coupler

Frequency (MHz)	S_{11}	S_{21}	S_{31}
900	-31.34	-3.45	-3.46
2000	-25.25	-3.92	-4.00

Table.5.2: The S-parameter for Dual Band Branch Line Coupler

The phase difference between port 2 and port 3 of Branch Line Coupler is shown in figure 5.8. Table 5.3 tabulates the phase difference of Hybrid Coupler.

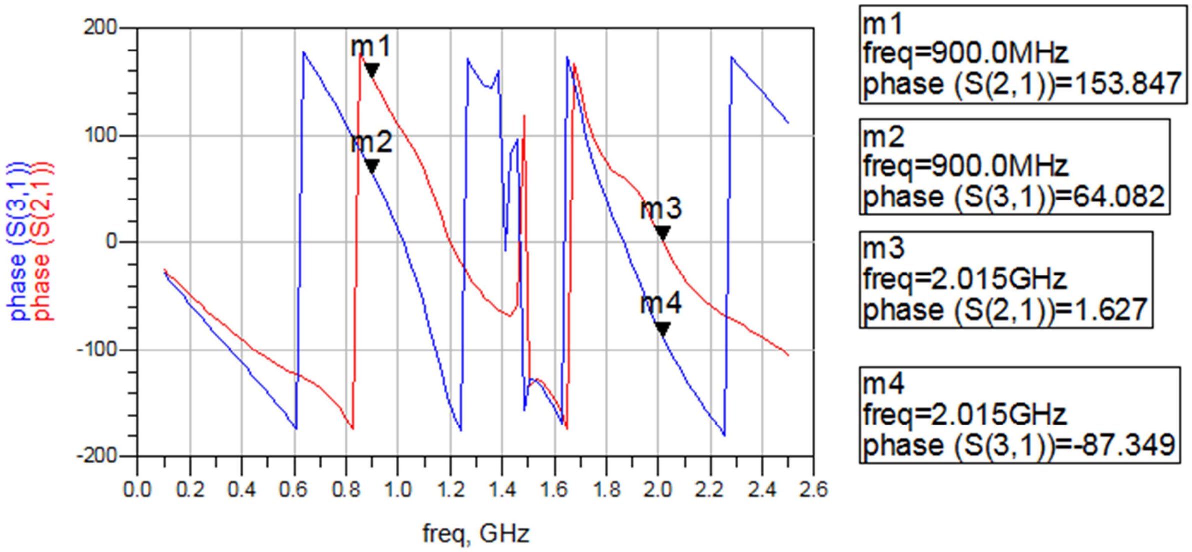


Figure.5.8: The measured phase difference for port 2 & 3of Branch Line Coupler

Frequency (MHZ)	Phase(S(2,1)) (Degree)	Phase(S(3,1)) (Degree)	Phase Difference (degree)
900	153.847	64.082	89.765
2000	1.627	-87.349	88.976

Table.5.3: Measured Phase of the Dual Band Branch Line Coupler

For frequency ranges from 800MHz to 1000MHz and the 1900MHZ to 2100MHz, S_{21} and S_{31} of the branch line coupler are between $-3dB$ to$-4dB$. The isolation and return loss are better than 10 dB in the respective frequency ranges. Also, the Phase difference between two output port are around 90 degree in the two frequency bands as shown in figure 5.8. Hence, branch line coupler covers two frequency bands.

Chapter 6

Fabrication of Dual Band Branch Line Coupler

6.1 Introduction

In recent year most of super semiconductors is fabricated in mass production, by using high technology machines. Machines are supported by computerize programming and hence, fabricated products has high precision, high quality and satisfied guarantee of consumers. Designing based on computer software becoming a priority among engineer or designer.

ADS is using for microstrip circuit design. The circuit created on schematic window and layout of design is then created using layout window of ADS Momentum. After momentum simulation export that program of ADS files into *.DXF or *.garber extension file and then converted into iCAD module. Open Circut CAM and select the area to be rubout and control outing is done. Export the file, automatically Board Master is open. The Board master command Proto-Mat S machine to fabricate the Coupler. According to layout they change milling tools automatically.

6.2 Fabrication Procedure

To be more systematics in fabrication the following step by step procedure are done to make microstrip Dual Band Branch Line Coupler:

Step 1: ADS software are used to design & simulate Branch Line Coupler (BLC). The layout created on layout window of ADS momentum.

Step 2: ADS layout can be directly used to export into *.DXF or *.garber format. *.DXF format produced from the layout is shown in figure 6.1.

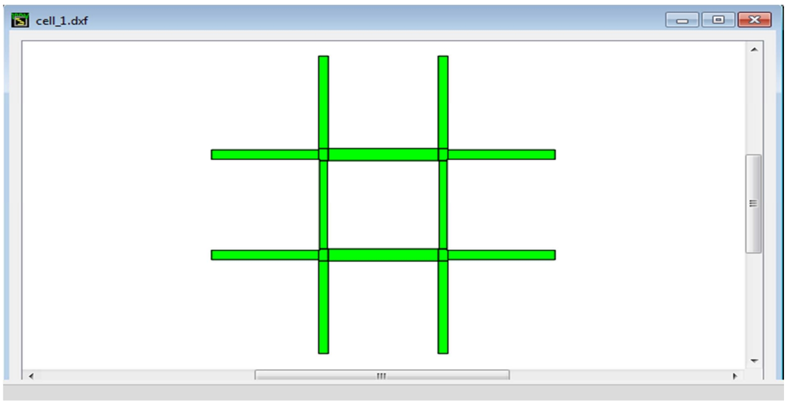


Figure.6.1: *.DXF format for Dual Band Branch Line Coupler (BLC)

Step 3: Draw the outer boundary of the structure for that we should calculate dimension of coupler.

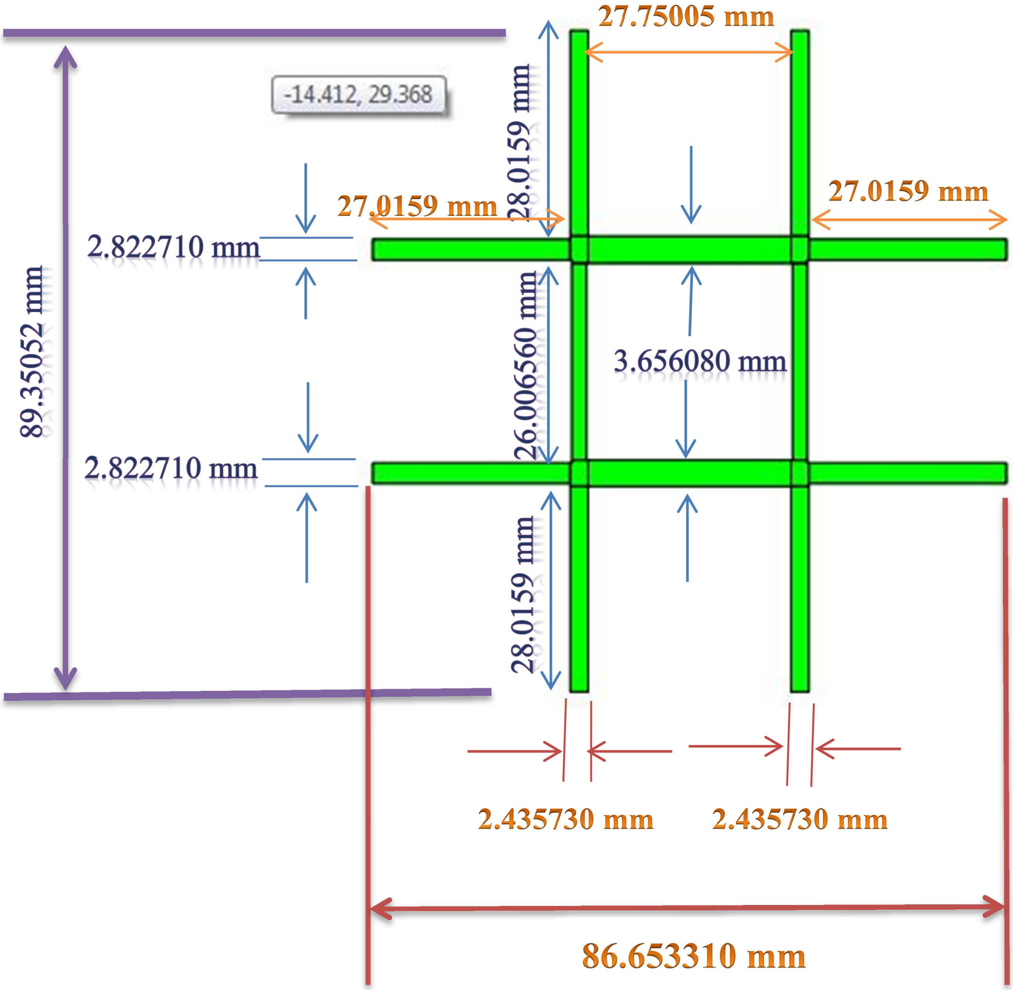


Figure.6.2: Calculate the Dimension of Dual Band Branch Line Coupler

Dimension			
	Length (mm)		Width (mm)
	27.015900		28.015900
	2.435730		3.656080
	27.750050		26.006560
	2.435730		3.656080
	27.015900		28.015900
Total	**86.653310**		**89.35052**

Table 6.1 Calculate the Dimension of Dual Band Branch Line Coupler (BLC)

The calculated complete dimension of coupler W X L is 89.35052 X 86.653310 mm.

Step 4: Open iCAD software and make a rectangular box having dimension of length equal to the length as calculated above i.e. 86.653310 mm (this length exactly equal to *.DXF demission because SMA connector are connected so dimension of PCB so that connector must connect properly microstrip line) and width equal to extended 5mm margin of the width of *.DXF file (on width side no SMA connector are connected).

Step 5: Put the *.DXF file on the defined box and save it as a DXF file.

Step 6: Open the Circuit CAM and import the saved DXF file. Identified the area to be rub out. Do the Insulation by this the rubbing area is selected and also control outing is done to cutoff the boundary.

Step 7: Export the resultant file, by this automatically Board Master is open. Board Master is a software that command Proto-Mat S machine. Proto Mat S produces complex printed circuit board very fast and professionally. The high grade of automation as e.g. automatic exchange of milling tools, head illumination make the ProtoMat S extremely comfortable in its operation. Hence, the required microstrip design fabricated.

Figure 6.3 (a) shown the Board Master where we can adjust the area to fabricate the required design on the PCB. Figure 6.3 (b) shown ProtoMat S machine that work on the command of Borad Master. Here as the ProtoMat machine milling the PCB that also shown on Board Master.

ProtoMat S machine have different categories of milling tool, depend upon design machine automatically choose the tool and fabricate the Branch Line Coupler.

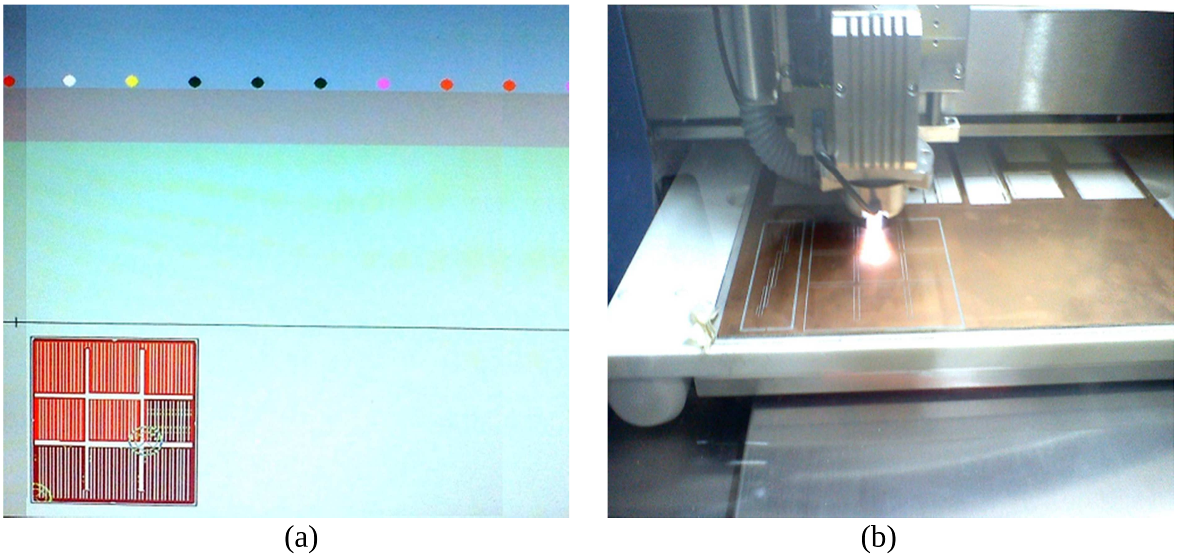

(a) (b)

Figure6.3 : (a) Board Master. (b) ProtoMat S Machine

Step 8: Once the microstrip circuit is prepare, SMA connectors are soldered into microstrip circuit. Ensure that soldering process is neatly done to avoid effect of resonance on the circuit.

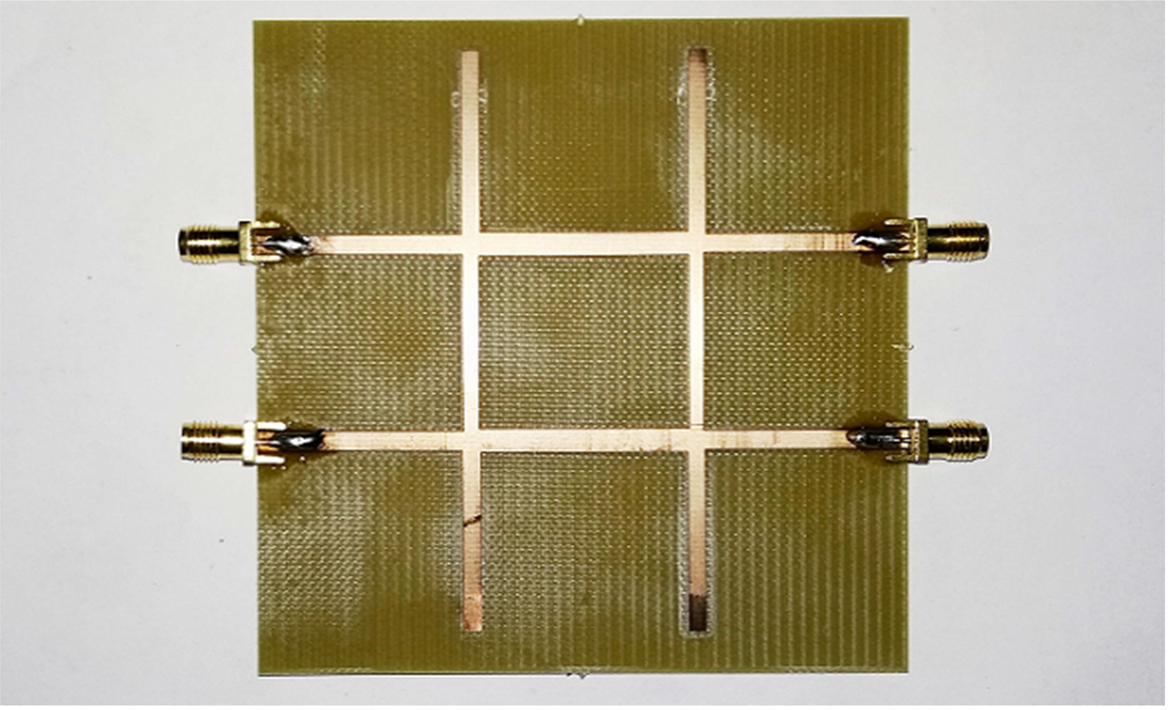


Figure 6.4: Fabricated Dual Band Branch Line Coupler

Chapter 7

Conclusions

7.1 Conclusions

- Firstly, Single Band branch line coupler designed and simulated on ADS and S-parameter are verified.
- Now, a novel planar Dual Band Branch Line Coupler is introduce at operating frequency 900/2000MHz. Simulation is done on ADS and frequency response are verified. After verification, layout is used to fabricate device with all specification are similar to design specification including given material and dimensions.
- In both design, we consider the effects of conductor and dielectric losses. Hence, ADS is accurately arriving at final design. But in the designing process design limitations are consider and ensures that there should be minimum human error. There must be some deviation in practical and Layout result that must be in an acceptable limit and fulfill all the expectations as required.

7.2 Future Scope of present work

As in the project, we discussed the technology & obtained the simulation result for dual band branch line coupler. We can design & simulate the project on the different material available and compare the simulation result for the purpose of cost effective & comprehensive design. We found that simulation result for FR4 ($\epsilon_r = 4.6$) material show the cost effective performance with small tolerance and also easily available in market. Finally, after choosing fabricating material, we proceed for fabrication process using material FR4($\epsilon_r = 4.6$).

The future extension of this project shall be in implementation of Butler Matrix that act as a beam forming network and this network used to feed antenna array and build multiport amplifier Branch Line Coupler also used in implementation of integrators & differentiator and Different types of filters for high frequency application.

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