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DESIGN OF DIPLEXER USING WAVEGUIDE TECHNOLOGY

by

Jatin Tandukar

A THESIS

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APPROVAL PAGE

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The thesis entitled "**Design of Diplexer using Waveguide Technology**", submitted by Mr. Jatin Tandukar in partial fulfillment of the requirement for the award of the degree of "Masters of Science in Information and Communication Engineering" has been accepted as a record of work independently carried out by him in the department.

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Abstract

The rapid growth in wireless network has created a massive demand for concise frequency selective components. Diplexers are key components in varieties of communication systems. They are passive devices which implement frequency domain multiplexing and allow various frequencies to share common channel. A novel diplexer is a frequency selective device. It has three ports and six resonators where common junction is replaced by one of the resonator. The diplexer forms an all-resonator based structure and is designed and simulated in the CST Microwave Studio. The diplexer is designed using standard dimensions for rectangular cavity to operate in the X-band and it is based on the synthesis of coupling matrix of a three port coupled resonator. The completed design consists of three ports; one input port with centre frequency of 10 GHz and two output ports with centre frequencies 9.7 GHz and 10.3 GHz respectively with bandwidth approximately around 400MHz .The response of the designed diplexer is carefully studied and the response is good as compared to the response of the ideal diplexer.

Keywords – Diplexer, Novel Topology, Resonator, Coupling matrix, Quality Factor, Iris, Coupling Coefficient, Scattering Parameter

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CHAPTER 1

INTRODUCTION

1.0 Introduction

The fast pace of advances in communication technologies is forcing to deploy new devices around the world. The commercial success of new devices has stimulated the quick development of modern communication systems. The rapid growth in wireless network has created a massive demand for concise frequency selective components. Diplexers are key components in varieties of communication systems, including radio transmission, cellular radio, satellite communication systems, and broadband wireless communications. They are passive devices which implement frequency domain multiplexing and allow various frequencies to share common channel. Diplexers are often used as front end equipment in communication systems and, typically connected between antenna and equipment. Diplexers allow a transmitter and a receiver operating on different frequencies to share common antenna with a minimum interaction between the transmitted and received signals. Novel diplexer is a three port frequency selective device where common junction is replaced by one resonator. The diplexer forms an all-resonator based structure and designs using coupling matrix approach for coupled resonator filters. This novel topology produces more compact diplexers than the conventional topology does. It reduces volume and mass due to the use of a single antenna, which is used for simultaneous transmission and reception of signals. They are also used in industrial settings and domestic system such as television and telephone. Further, the wide utilization and rapid growth in technology cause diplexers to be more cost effective.

1.1Background

The increasing development over the years of communication systems has stirred the need for compact and better performance diplexer. To achieve these requirements, large numbers of research are carried out for filter design on the basis of coupled resonator which significantly decreases coupling loss and provides reliable solution over conventional diplexer. A conventional diplexer consists of common junction and two channel filters with stringent requirements on selectivity and isolation. The channel filters and the junction are usually designed separately before being joined together. The conventional approach can be very time consuming for large diplexer structures [1]. Physical structure of conventional waveguide based diplexer where two separate channels are connected with common junction and shared input is fed in the common junction is shown in the figure 1.1.

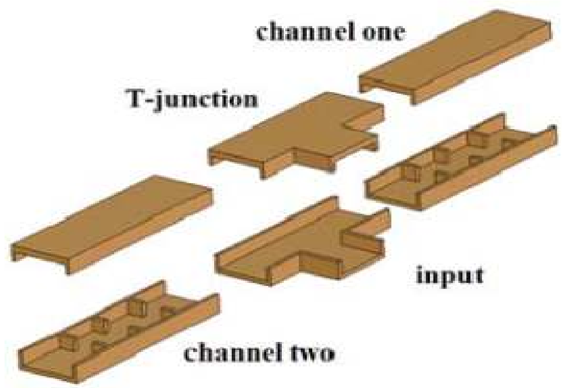


Figure 1.1: Conventional Diplexer

The proposed Novel diplexer is based on optimization of coupling matrix of multiple coupled resonators representing three port networks, and it widely employs waveguide technology. Novel topology has been introduced where common junction is replaced by one resonator and diplexer forms single structure having group of rectangular cavities with suitable dimensions.

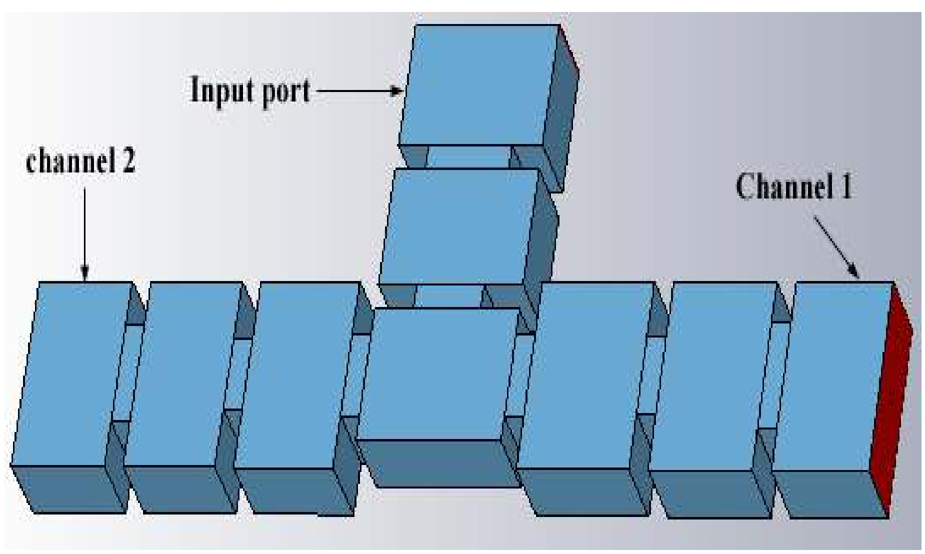


Figure 1.2: Novel Diplexer

1.2 Principle of Diplexer

Waveguide cavities called resonator works as band pass filter, it allows signal within pass band and attenuate outside the pass band. Circle represents a resonator whereas short line between resonators indicate internal coupling. The linking between resonators and ports represent external coupling. The leading part having resonator 1 and 2 is called stem, and two branches are coupled with stem. The operating frequency is around 10 GHz. The signal coming from any source is fed into port1; the output of resonator 2 with pass band centre frequency of 10 GHz is fed into resonator 3 and 4.

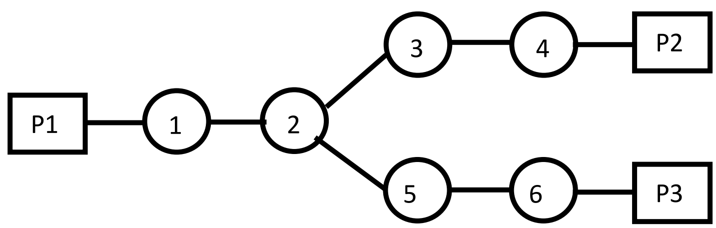


Figure 1.3: Topology of novel diplexer

The resonators 3 and 4 permit pass band centre frequency of 9.7 GHz and completely stop other band of frequencies. Similarly, resonators 5 and 6 allow centre frequency of 10.3 GHz centre and block other range of frequencies. The topology of novel diplexer is flexible, which can be changed by altering size of the resonators. Using proper mathematical model, the shape, size, and distance between resonators are calculated to get the desire output. Novel diplexer is designed to operate at X-band range from 8-12 GHz, P1 acts as input port and, P2 and P3 work as two outputs with different pass band frequency as shown in figure 1.3.

1.3 Scope

Diplexer acts as a multiplexer and its three ports connect two networks operating at different frequencies. It enables transmitter and receiver to use common antenna at the same time, therefore diplexer reduces volume, mass and cost of the communication systems. The scope of this thesis is to use in wireless communications systems as a front end equipment to separate transmitting and receiving channel. Generally, the transmitter generates signals with relative high power, so transmitter should have high power amplifier to handle power. But it requires high level of stop band attenuation in order to reject noise generated by power amplifier. In contrary, receiver detect very weak signals and RX filter is required to have high attenuation in the transmit band in order to protect noise coming from receiver. The appropriate isolation should be maintained to protect transmitter and receiver circuit [1].

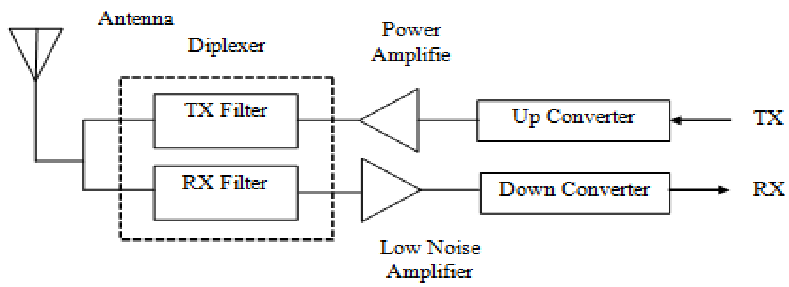


Figure 1.4: RF front end of a base station

The latest technological innovations offer for compact size and low cost diplexers, many researches have been done to meet the requirement of increase demand. The maximum utilization of diplexers is easily seen in cellular radio systems, which employ diplexers in their transceivers as a front end component. Waveguide based diplexers are mostly used in the communication systems where quality is much more concern. Diplexers are critical in satellite communication systems, and multiport diplexers are used to increase capacity and to maximum utilize limited bandwidth.

1.4 Aims and Objectives

The aims and objectives of this thesis are to develop novel all resonator based diplexer with improved performance using waveguide technology. The individual rectangular cavity in the diplexer functions as frequency selective components.

- To develop a design procedure for three port diplexer at X-band frequency.
- To study possible opportunities of realization of filters using rectangular cavities.
- To design novel diplexer with improved performance, this can be achieved due to improved isolation between resonators.

CHAPTER 2

LITERATURE REVIEW

2.1 Electromagnetic Theory of Rectangular Waveguides

Rectangular waveguides are widely used in various communication systems due to their numerous benefits such as high Q-factor values and high power handling capacity. The basic electromagnetic theories with regards to propagation in rectangular waveguides are derived and analytical expressions of Maxwell's equations are introduced to know the field in rectangular waveguide.

Electric and magnetic fields that vary with time are governed by physical laws described by a set of equations known collectively as Maxwell's equations [2]. The general form of time varying Maxwell's equations can be written as:

$$\nabla x\vec{E} = -\frac{\partial \vec{B}}{\partial t}, \qquad (2.1.1a)$$

$$\nabla x\vec{H} = \frac{\partial \vec{D}}{\partial t} + \vec{J}_s, \qquad (2.1.1b)$$

$$\nabla x\vec{D} = \rho_e, \qquad (2.1.1c)$$

$$\nabla x\vec{B} = 0, \qquad (2.1.1d)$$

Where the variables involved are described as:

$\vec{E}$ (V/m)-Electric field intensity;

$\vec{H}$ (A/m)-Magnetic field intensity;

$\vec{D}$ (C/m^2)-Electric flux density;

$\vec{B}$ (W/m^3)-Magnetic flux density;

$\vec{J}_s$ (A/m^2)-Electric current density;

ρ_e(C/m^3)-Electric charge density;

Faraday's Law is expressed by the equation (2.1.1a), means that variations of magnetic flux with time or/and fictitious magnetic current play the role of sources of circulating electric field. Ampere's Law is expressed by the equation (2.1.1b), which means that time variations of electric flux or/and electric current generate circulating magnetic field. The Gauss's Law is expressed by the equation (2.1.1c), which shows that electric charges are sources of electric field and the Gauss's Law for magnetic field is expressed by the equation (2.1.1d).

Another set of equations describes relationships between the above parameters in any medium in terms of its permittivityε, permeability μ and conductivity [3].

$$\vec{D} = \varepsilon\vec{E}$$

$$\vec{B} = \mu\vec{H}$$

$$\vec{J} = \sigma\vec{E},$$

Where, $\varepsilon = \varepsilon_r\varepsilon_0$, $\mu = \mu_r\mu_0$, Here ε_r and μ_r are the relative permittivity and relative permeability of the propagation medium respectively; ε_0 and μ_0 permittivity and permeability in vacuum.

2.2 Coupling Matrix

Coupling matrix is an important means for design and analysis of coupled resonator diplexer which is also used to improve the precision of filters. The coupling matrix of 'n' coupled resonators in a diplexer is calculated from the formation of impedance matrix for magnetically coupled resonators or electrically coupled resonators [4]. A general normalized coupling matrix [A] in terms of coupling coefficients and external quality factors has been derived as:

$$[A] = [q] + p[U] - j[m]$$

$$
= \begin{bmatrix} \frac{1}{q_{e1}} & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & \cdots & \frac{1}{q_{e2}} & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & \frac{1}{q_{e3}} \end{bmatrix} + p \begin{bmatrix} 1 & \cdots & 0 & 0 \\ \vdots & \ddots & \vdots & \vdots \\ 0 & \cdots & 1 & 0 \\ 0 & \cdots & 0 & 1 \end{bmatrix} - j \begin{bmatrix} m_{11} & \cdots & m_{1(n-1)} & m_{1n} \\ \vdots & \ddots & \vdots & \vdots \\ m_{(n-1)1} & \cdots & m_{(n-1)(n-1)} & m_{(n-1)n} \\ m_{n1} & \cdots & m_{n(n-1)} & m_{nn} \end{bmatrix} \quad \text{..... (2.2a)}
$$

Where [U] is the n×n identity matrix, n is the number of the resonators, p is the low-pass prototype frequency, [m] is the coupling matrix and entry mij is the normalized coupling coefficient between resonators i and j, [q] is an n×n matrix with all entries zero except for $q_{mm}=\frac{1}{q_{eM}}$ (m refers to resonators connecting to ports) where q_{eM} is the scaled external quality factor of resonator m to port M.The scattering parameters derived from the general coupling matrix are as follows:

$$
S_{11} = \pm\left(1 - \frac{2}{q_{e1}}[A]_{11}^{-1}\right) \quad S_{M1} = 2\frac{1}{\sqrt{q_{e1} \cdot q_{eM}}}[A]_{M1}^{-1} \quad \text{............................. (2.2b)}
$$

2.3 External Quality Factor

The coupling that connect filter to the outside world is called external coupling and is often represented as Q_e value. Quality factor is dimensionless parameters, which gives a resonator's bandwidth relative to its centre frequency. Higher Q_e shows a lower rate of energy loss relative to the stored energy of the resonator; the oscillations die out more slowly [5].

External quality factor can be calculated using following formula:

$$
Q_e = \frac{f_0}{\Delta f_{3\ dB}} = \frac{f_0}{(f_2 - f_1)_{3\ dB}} \qquad (2.4a)
$$

Where, f_0 is the maximum resonant frequency and Δf is the bandwidth 3 dB below maximum resonant frequency.

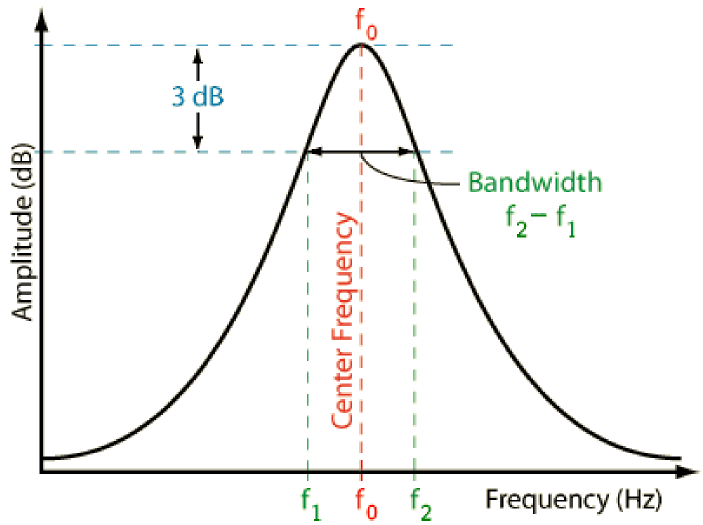


Figure 2.1: Frequency response for loaded resonator (Courtesy: Kwok & Liang, 1999)

2.4 Scattering Parameter (S-Parameter)

Scatter parameters describe the input-output relationship between ports or terminals in an electrical system. S-parameters are important in microwave design to quantify RF energy propagation through a multi-port network and to work with at high frequencies than others network parameters. S-parameters are linear by default and, they are conceptually simple, analytically convenient and capable of providing detail insight into a measurement and modelling problem. S-parameters are complex (magnitude and phase) and refer to RF voltage out versus voltage in. The number of rows and columns are equal to the number of ports available in network. Generally, S_{NM} represents the power transferred from port M to port N in a multi-port network where M and N act as source and destination respectively. In the network, port can be defined as any place where voltage and current deliver. General scattering matrix for three port network is depicted below:

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \qquad (2.5a)$$

2.5 CST Microwave Studio

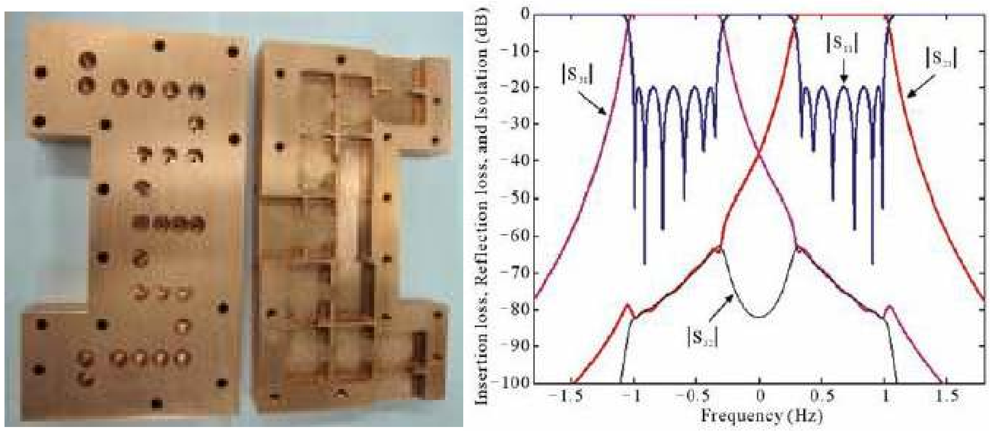
CST (Computer Simulation Technology) is the world's largest pure electromagnetic simulation software company, founded in 1992, headquartered in Darmstadt, Germany. CST Microwave Studio is a specialist tool for the 3D electromagnetic simulation of high frequency components. It is one of the most effective and accurate professional simulation software and generally used in frequency passive device simulation. CST enables the fast and accurate analysis for the devices such as antennas, filters, couplers, planar and multi-layer structures. It gives wide range of flexibility through the variety of available solver technologies. The software also covers the entire electromagnetic band, provides the complete time domain and frequency domain full wave algorithm. It has a bundle of software integrated in single package. CST Microwave Studio Suite 2014 is one of them.

2.6 Diplexer

Researches are carried out on diplexers and components based upon waveguides. Waveguide based diplexers are widely used where quality much more concern and, they have high power handling capability and high Q-factor. However, conventional diplexers based on waveguide are bulky and unsuitable for density integration and, which create problem of waveguide miniaturization. Now, drawbacks exist in conventional diplexers are mitigated by employing variation in waveguide cavities.

2.6.1 Diplexer Based on Waveguide Technology

Increasing demand in miniaturization and reducing complexity of diplexer design, novel topology has been employed with multi-port coupled resonator. It utilizes coupling matrix optimization techniques. The waveguide cavities in the diplexer act as band pass filter and response is Chebyshev filter [1]. Desired frequencies are selected using group of resonators and the composite frequency is fed into common port. The external junction exists in conventional diplexer is removed, so that the size of coupled resonator diplexer is miniaturised in comparison to the conventional diplexer. The design approach makes optimization of whole structure easier and provides a very good starting point for the optimization of the whole structure [7]. However, large design consumes more time.

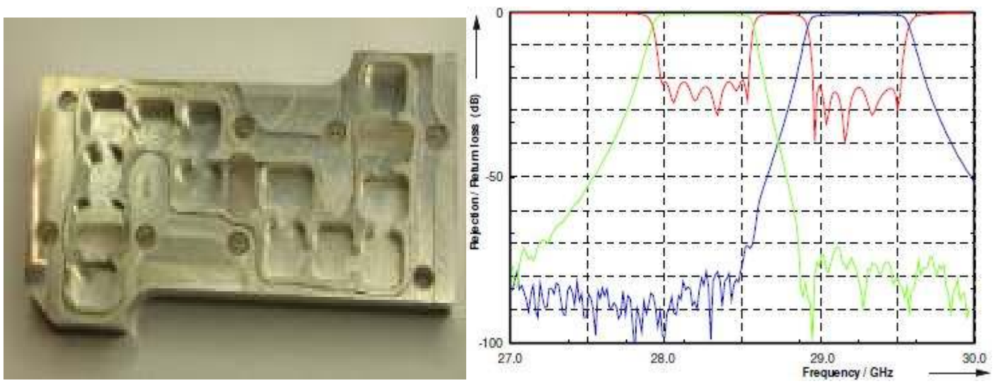


(a) (b)

Figure 2.2: 12-resonator diplexer (a) Photograph of diplexer (b) Diplexer response (Courtesy: Skaik, 2011)

The resonator circuit operates in X-band frequency (8-12 GHz). Similar techniques have been used to develop microwave diplexer using novel approach [8]. This diplexer consists of three junctions; two junctions for transmitter and receiver filters, one junction for common port, depending on the operating frequency, several structures can be implemented; H-plane T-junction and E plane T-junction network. Diplexers employs coupled cavity where common node is realized by adding an extra resonator. Although, it is suitable for the channels having small separation, which is the most challenging case for diplexer design. The proposed synthesis approach offers design flexibility employing TX and RX filters with arbitrary topology. The interaction between RX and TX filters are taken into account during the synthesis and best performances are obtained when the two channels are very close. However, design becomes more inaccurate as the channels space increases.

Similarly, Ka-Band Diplexer has also been designed using filter characteristic. It has three ports; two ports are dedicated for filters and common port for composite frequency [9]. Ka-Band diplexer contains cross coupled cavities which are arranged in H-plane structure. The interfacing of the respective cavities is done in E-plane. Cavities arranged in diplexer function as filter and response is Chebyshev. The utilization of quadruplet cavity structures realizes filter characteristics with transmission zeros (TZs). This is a flexible configuration and can be used for others compact design. The proposed diplexer is designed for Ka-band frequency applications. The key benefits of this project are small size and low insertion loss. It also facilitates low cost production in large quantities. However, overall diplexer structure suffers from suitable alignment and position.



(a) (b)

Figure 2.3: Ka-band diplexer (a) Photograph of diplexer (b) Measured Characteristics of the diplexer (Courtesy: Amari S, 2005)

CHAPTER 3

METHODOLOGY

Methodology is the systematic procedure to analyse methods applied to a field of study, which consists of concepts such as theoretical model, phases and quantitative or qualitative techniques. It does not set out solution but drives in a right direction. Research strategy is a step by step plan of the action that gives direction. This focuses on schedule to produce quality results and detailed report.

Design process is the construction of an object or a system using suitable tools. The design of novel diplexer was divided into three sections to reduce the design complexity. The first section called stem was constituted by resonators 1 and 2. Similarly resonators 3 and 4 formed section two; resonators 5 and 6 shaped section three. The quality factor was measured using external port and neighbour resonator. Individual sections were designed in CST Microwave Studio software and the corresponding simulation results were carefully monitored.

The result obtained from simulation was carefully analysed and optimization was done in individual design to make output more concise.

The flow chart of the design process is shown by the figure 3.1. The design process starts by collecting the data and standard design specifications from the literature review. Then the next step is the design of the individual sections if the diplexer. The individual sections are designed and simulated in the CST Microwave Studio. If the Response of the Simulation is satisfactory then we move on to the next step and if the response is not satisfactory we optimize and again simulate the design until we get the desired response. Then the next step is the assembly of the individual sections to form a diplexer having three ports and 6 resonators. Then the assembled diplexer is again simulated. If the response of the design is satisfactory we move on to the next step that is the test and measurement of the design and if it is not satisfactory the design is optimized and simulated in a cycle until we get the desired results.

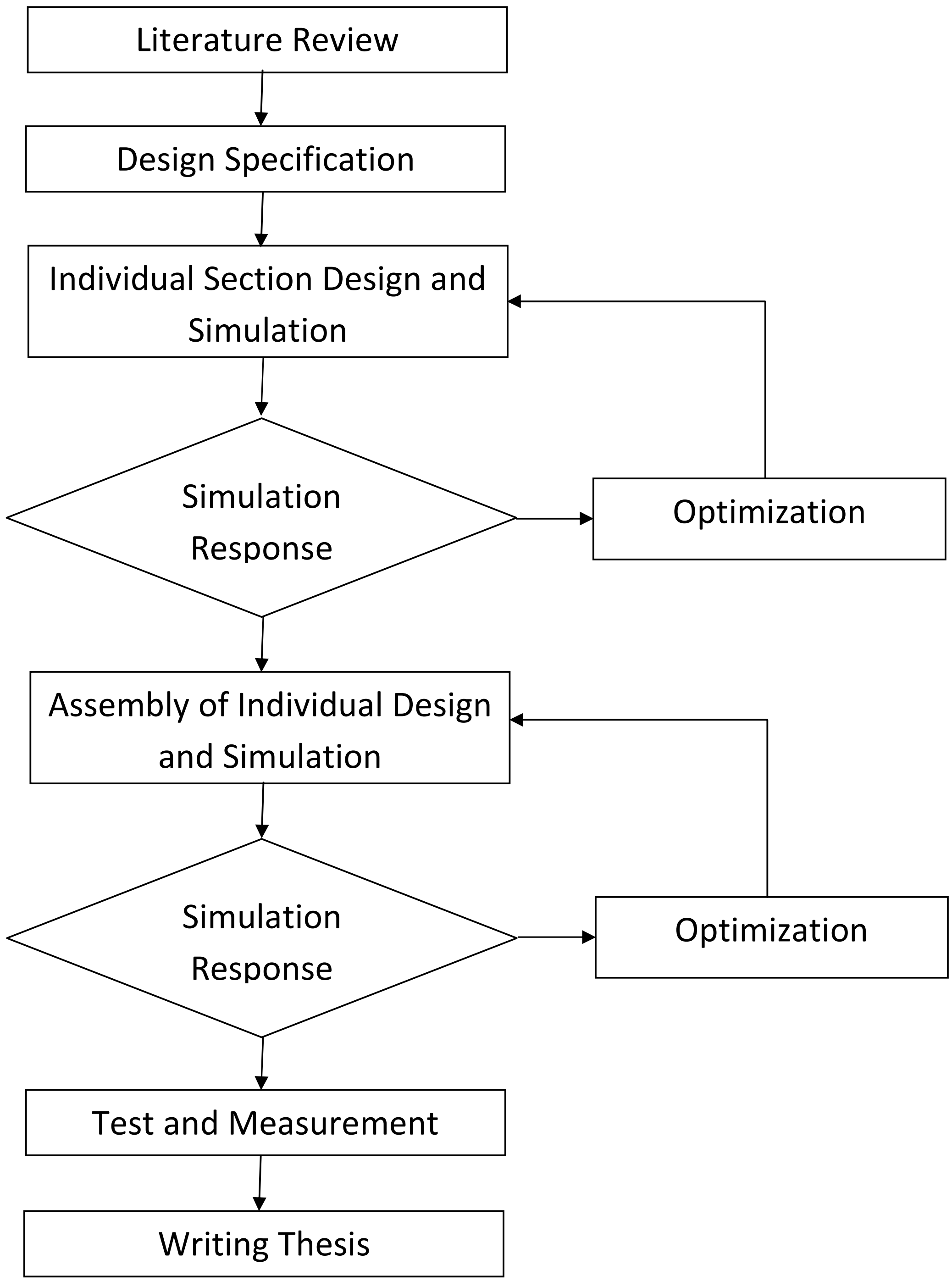


Figure 3.1: Flow Chart of the diplexer design process

CHAPTER 4

DESIGN AND DEVELOPMENT

4.1 Diplexer Design

An X-band 6-resonators diplexer has been designed using waveguide cavity resonators. The resonators are coupled together with irises. The diplexer has pass band centre frequency of 9.7 GHz for channel 1 and 10.3 GHz for channel 2.

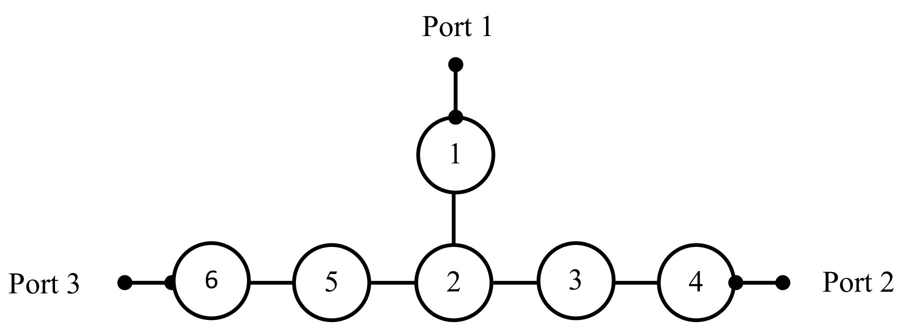


Figure 4.1: Novel diplexer topology

Circular box represents waveguide resonators which is a basic component of waveguide filters. This consists of a short length of waveguide blocked at both ends. Electromagnetic waves passed inside the resonator are reflected back and forth between the two ends. A given geometry or physical dimension of waveguide cavity resonate at a characteristic frequency. Using specific dimension of the resonators for particular frequency, certain selective frequency is passed. Filter structure requires that some wave is allowed to pass out of one cavity through coupling structure.

An iris is a waveguide connector used to couple two resonators. Further, it makes interaction between resonators and, which is highly desirable to get filter response. In this thesis, resonant cavity is coupled to the waveguide cavity through an iris and is tuned to resonate in X-band frequency.

4.2 Coupling Coefficient from physical structure

The coupling coefficient for a selected resonator pair can be determined from the physical structure using CST Microwave Studio simulation.

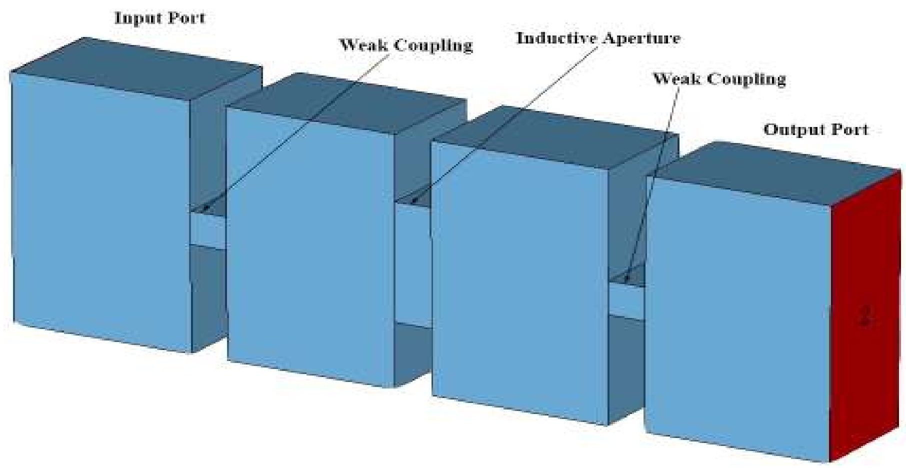


Figure 4.2: Two coupled waveguide resonators

F_Max and f_Min are the two resonant frequencies of the resonators; f_max is the higher frequency whereas f_Min is lower frequency. The two frequencies are in magnitude form of s_{21} response of coupled resonator with port are weakly coupled to the neighbour resonators. The characteristic parameters f_Max and f_Min were determined from CST Microwave simulation.

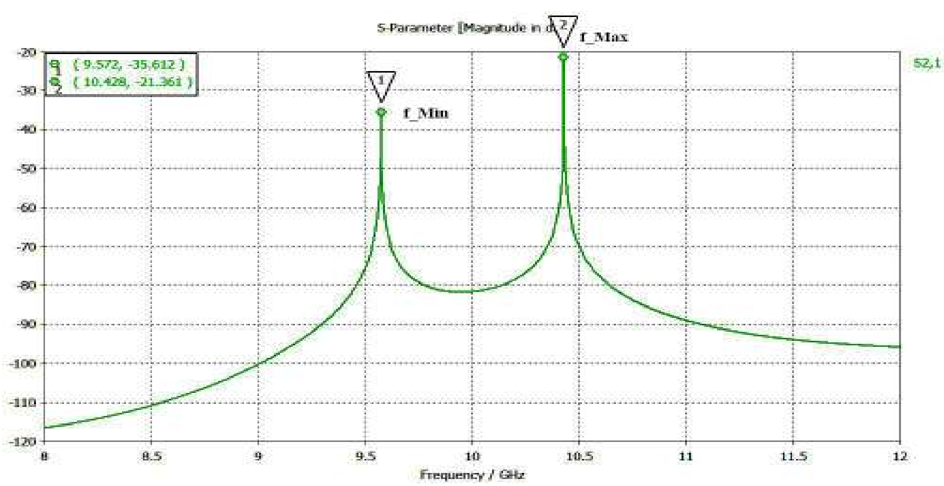


Figure 4.3: S_{21} response of two coupled resonators

The formula is applicable to calculate coupling coefficient for coupled resonators [1].

$$M = \frac{f\_Max^2 - f\_Min^2}{f\_Max^2 + f\_Min^2} \text{.......................................} \quad (4.2a)$$

4.3 External Quality Factor from Physical Structure

The external quality factor (Q_e) is calculated to identify the coupling between port and waveguide cavity. Waveguide cavity is inductively coupled with output port and weakly coupled with input port.

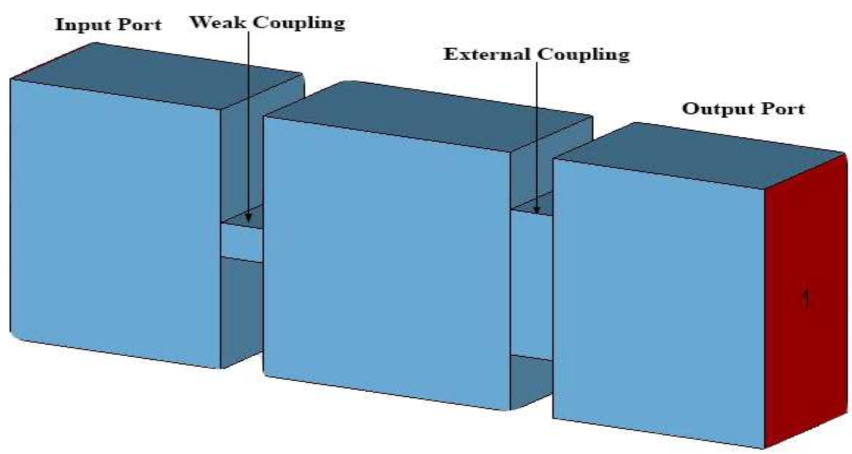


Figure 4.4: Externally coupled waveguide resonator

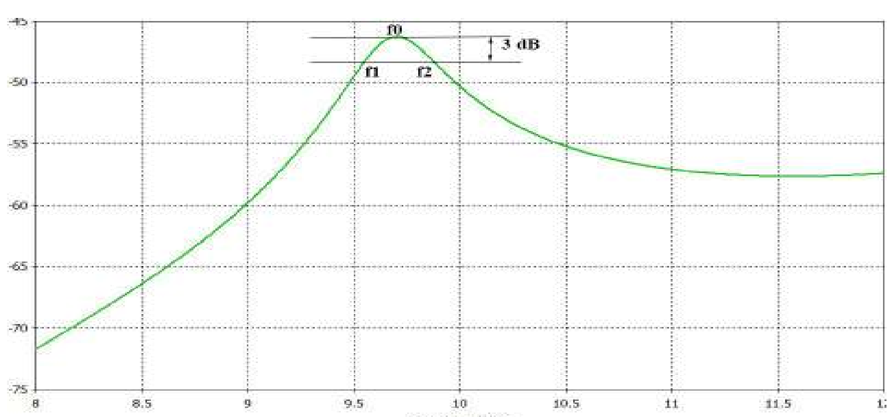


Figure 4.5: S_{21} response of externally coupled waveguide resonator

The S_{21} response of the design to calculate the external quality factor is shown in the figure 4.5. Here f_0 Shows the resonant frequency of the loaded resonator and Δf_{3dB} is the 3 dB bandwidth below from maximum frequency as shown in the graph.

The external quality factor can be calculated from data collected from the simulated s_{21}response using below formula [1].

$$Q_e = \frac{f_0}{\Delta f_{3dB}} = \frac{f_0}{f_2 - f_1} \quad \text{.................................. (4.3a)}$$

4.4 Design and Simulation

The whole design was divided into sections to simplify complexity. Each pair of coupled resonators was simulated separately to find the coupling iris and coupling coefficient. CST frequency domain solver was extensively used to get results. The corresponding simulation results were carefully monitored and optimized to get desire output in each section. The physical dimensions of a=22.86 mm, b=10.16 mm were kept, which are the standard dimensions for rectangular cavity operating at X-band. The weak coupling was set t=3 mm throughout the design.

4.4.1External Quality Factor of Input Port

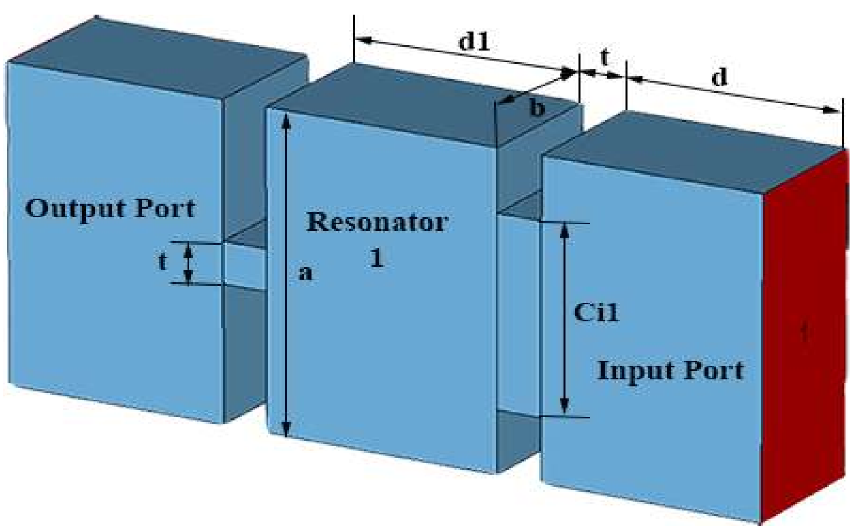


Figure 4.6: Design for external quality factor of input port (*Figure not in scale*)

Input port was connected with resonator 1 via iris, and Output port was weakly coupled with resonator 1. In this design, the variable dimensions were width of resonator 1 (d1) and iris (ci1), and the remaining other parameters were kept standard value of X-band.

Table 4.1: Dimensions of the design for external quality factor of input port

S.N	**Parameter**	**Dimension (mm)**	**Description**
1	a	22.86	Height of resonator
2	b	10.16	Depth of resonator
3	d	15	Width of input port
4	t	3	Width of iris
5	ci1	13.723	Height of iris between input port and resonator 1
6	d1	15.878	Width of resonator 1

From the simulation response, it was observed that the maximum resonant frequency (f_0) was at 10 GHz and bandwidth (Δf) below 3 dB from maximum frequency was 0.848 GHz. External quality factor (Q_e) for input port was calculated to be 11.786. S_{21} response of this design where port 1 works as source and port 2 as output as shown in the figure 4.7.

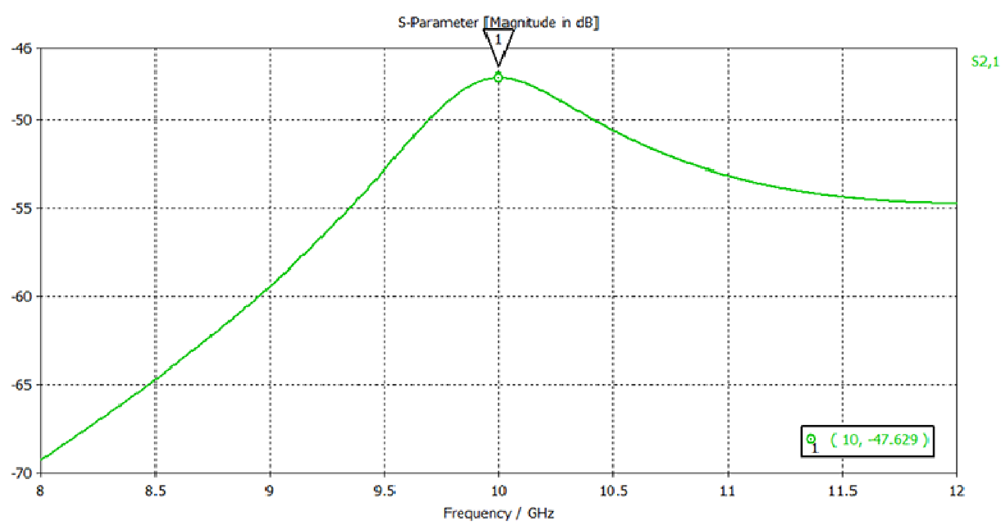


Figure 4.7: S_{21} response of the design for external quality factor for input port

4.4.2 External Quality Factor of Output Port 1

Weak coupling was formed between input port and resonator 4 while as output port 1 was externally coupled with neighbour resonator 4 via iris. The variable parameters in this design were width of resonator 4 (d4) and iris (c40). Initial value of variable parameters were set and then modified using optimization.

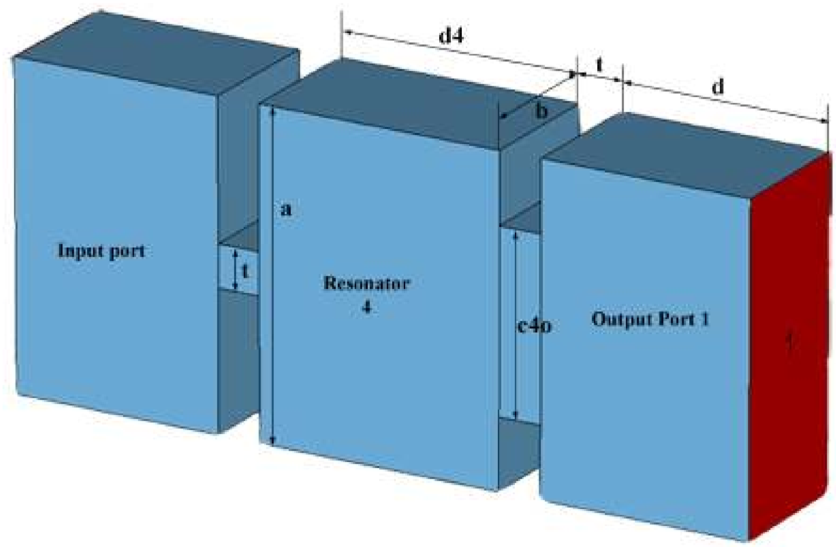


Figure 4.8: Design for external quality factor of channel 1(*Figure not in scale*)

Table 4.2: Dimensions of the design for external quality factor of channel 1

S.N	Parameter	Dimension(mm)	Description
1	a	22.86	Height of resonator
2	b	10.16	Depth of resonator
3	d	15	Width of output port 1
4	t	3	Width of iris
5	c4o	12.788	Height of iris between output port 1 and resonator 4
6	d4	17.497	Width of resonator 4

The simulation result showed that the maximum resonant frequency (f_0) was at 9.696 GHz and bandwidth (Δf) below 3dB was 0.425 GHz. Therefore, external quality factor (Q_e) for output port 1 was obtained as 22.798. S_{21} response of this design is shown in the figure 4.9.

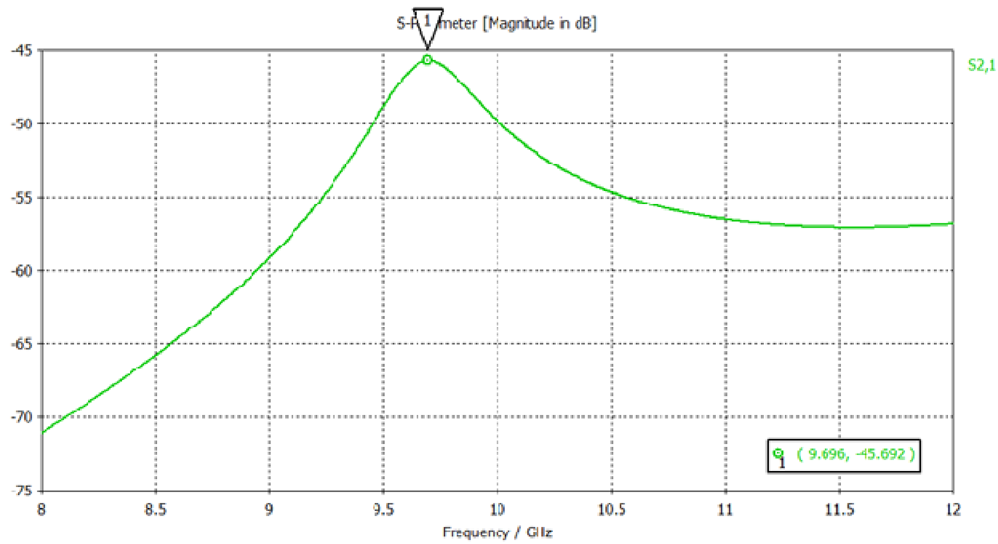


Figure 4.9: S_{21} response of the design for external quality factor of channel 1

4.4.3 External Quality Factor of Output Port 2

Resonator 6 was externally coupled to the output port 2 via inductive iris, and weakly coupled to the input port. The variable parameters width of resonator 6 (d6) and iris (c6o) were optimized to calculate external quality factor.

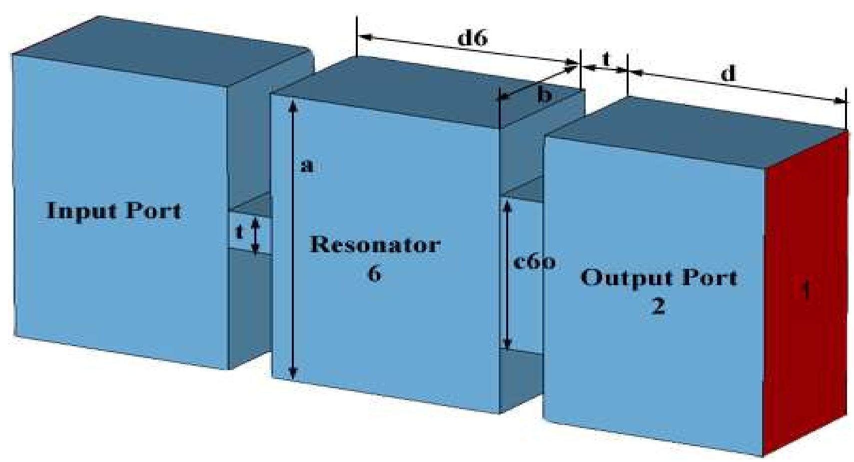


Figure 4.10: Design for external quality factor of channel 2 (*Figure not in scale*)

Table 4.3: Dimensions of the design for external quality factor of channel 2

S.N	Parameter	Dimension (mm)	Description
1	a	22.86	Height of resonator
2	b	10.16	Depth of resonator
3	d	15	Width of output port 2
4	t	3	Width of iris
5	c6o	12.170	Height of iris between output port 2 and resonator 6
6	d6	15.777	Width of resonator 6

From the (s_{21}) response of this design, it was measured that the maximum resonant frequency (f_0) was at 10.3 GHz and bandwidth (Δf) below 3dB was 0.452 GHz. Therefore, external quality factor (Q_e) for output port 2 (High Frequency Band) was calculated as 22.798. S_{21}) response of this design is shown in the figure 4.11.

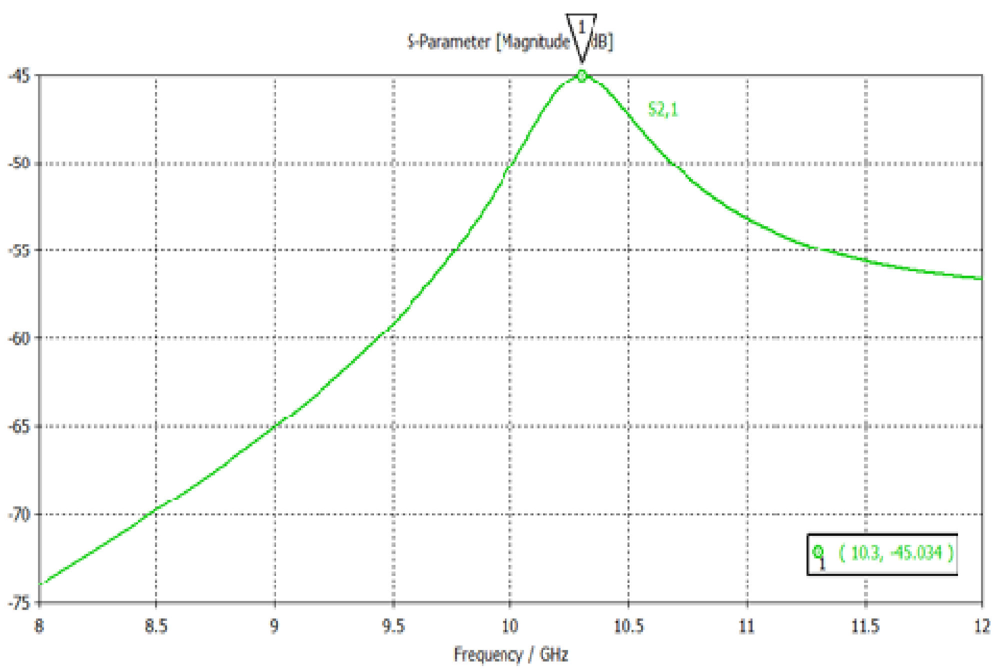


Figure 4.11: S_{21} response of the design for external quality factor of channel 2

4.5 Design and Simulation Response of Coupling Coefficient

4.5.1 Coupling Coefficient of Iris between Resonator 1 and 2

Two outputs were taken out from resonator 2, and two resonators 1 and 2 coupled with iris (c12). Input port was externally coupled with resonator 1 via iris (ci1). The physical dimensions of iris (ci1) and resonator width (d1) were obtained from an external quality factor design. Two variable parameter iris (c12) and resonator width (d2) were tuned using optimization technique.

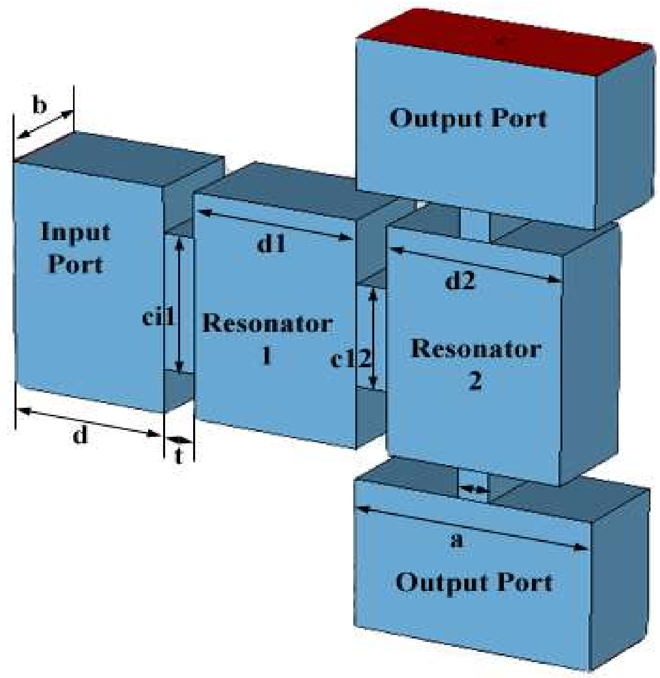


Figure 4.12: Design to calculate coupling coefficient between resonator 1 and 2 (*Figure not in scale*)

The S21 response in simulation result showed by the figure 4.13, from the response we can see that first and second highest frequencies were at 9.576 GHz and 10.424 GHz respectively. Centre frequency was at 10 GHz. With these parameters coupling coefficient is calculated as 0.0846.

Table 4.4: Dimensions of the design to calculate coupling coefficient between resonator 1 and 2

S.N	Parameter	Dimension(mm)	Description
1	a	22.86	Height of resonator
2	b	10.16	Depth of resonator
3	d	15	Width of input port
4	t	3	Width of iris
5	ci1	13.717	Height of iris between input port and Resonator 1
6	c12	10.228	Height of iris between resonator 1 and resonator 2
7	d1	15.872	Width of resonator 1
8	d2	16.722	Width of resonator 2

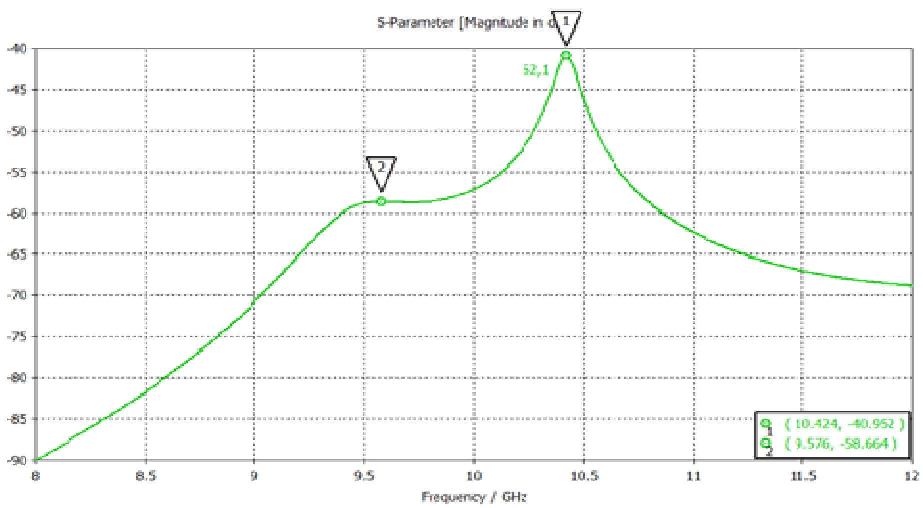


Figure 4.13: S_{21}response of the design to calculate coupling coefficient between resonator 1 and 2

4.5.2 Coupling Coefficient of Iris between Resonator 3 and 4

Input port and output port were coupled with resonator 3 and 4 respectively. External quality factor for inductive iris (c40) and width of the resonator 4 were used same dimensions as obtained in external factor calculation for output port 1. Resonator width (d3) and an iris (c34) were tuned using optimization to get best result.

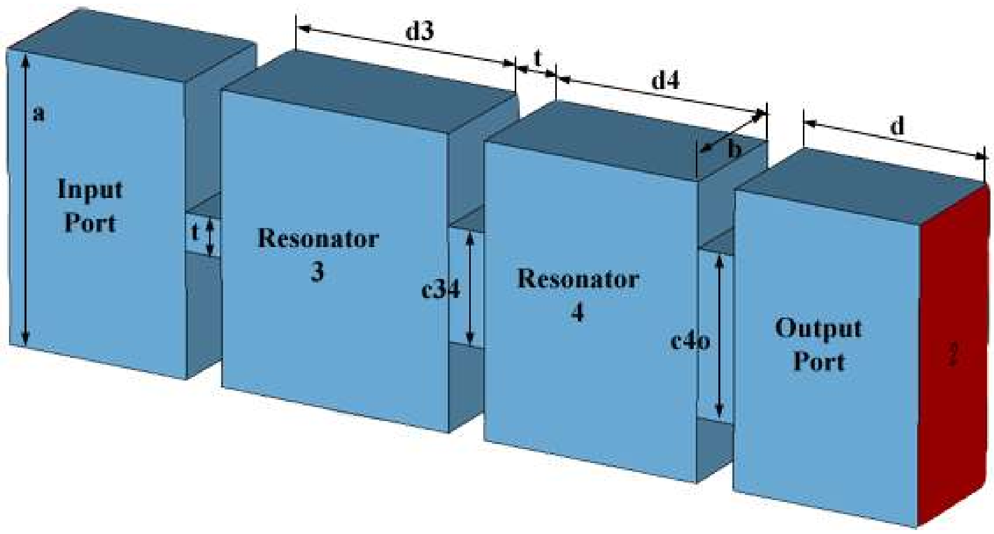


Figure 4.14: Design to calculate coupling coefficient between resonator 3 and 4 (*Figure not in scale*)

Table 4.5: Dimensions of the design to calculate coupling coefficient between resonator 3 and 4

S.N	Parameter	Dimension (mm)	Description
1	a	22.86	Height of resonator
2	b	10.16	Depth of resonator
3	d	15	Width of Output port
4	t	3	Width of iris
5	c4o	12.788	Height of iris between output port and resonator 4
6	c34	8.814	Height of iris between resonator 3 and resonator 4
7	d3	18.959	Width of resonator 3
8	d4	17.497	Width of resonator 4

The S21 response in simulation result showed by the figure 4.15, the graph obtained from simulation showed that first and second highest frequencies were at 9.504 GHz and 9.9 GHz respectively. Centre frequency was at 9.702 GHz. With these parameters coupling coefficient is calculated as 0.0407.

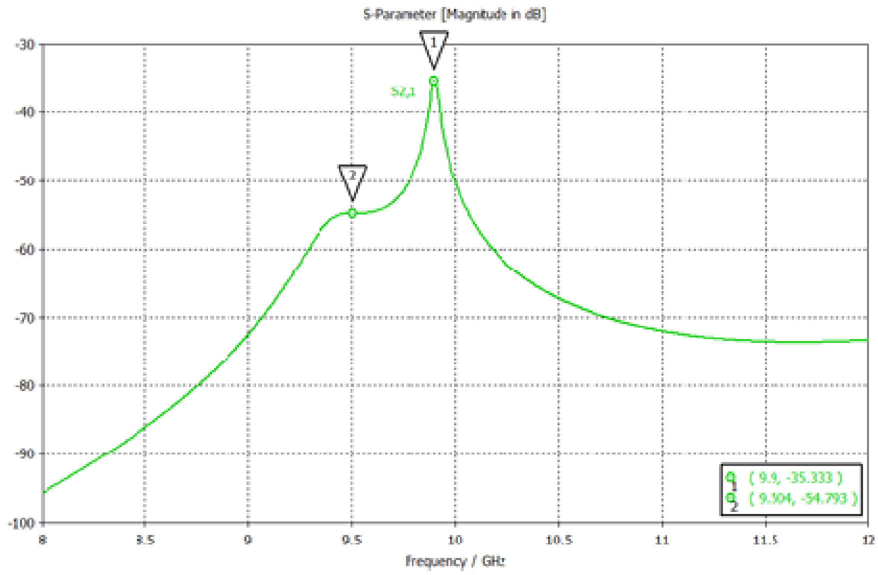


Figure 4.15: S_{21} response of the design to calculate coupling coefficient between resonator 3 and 4

4.5.3 Coupling Coefficient of Iris between Resonator 5 and 6

Resonator 5 was weakly coupled with input port; similarly resonator 6 was externally coupled with output port.

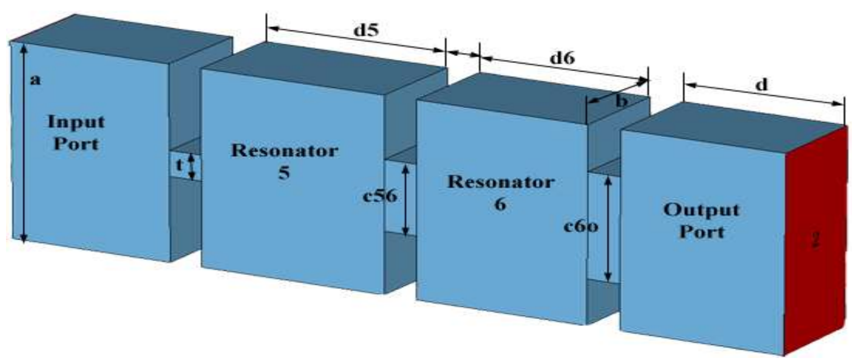


Figure 4.16: Design to calculate coupling coefficient between resonator 5 and 6 (*Figure not in scale*)

Two resonators interacted via iris (c56) and the physical dimension of an iris (c6o) and width (d6) were kept same as obtained from external quality factor calculation for output port 2. Here the width (d5) and an iris (C56) were variable parameters, which were tuned and optimized.

Table 4.6: Dimensions of the design to calculate coupling coefficient between resonator 5 and 6

S.N	Parameter	Dimension (mm)	Descriptions
1	a	22.86	Height of resonator
2	b	10.16	Depth of resonator
3	d	15	Width of output port
4	t	3	Width of iris
5	c6o	12.170	Height of iris between output port and resonator 6
6	c56	8.195	Height of iris between resonator 5 and resonator 6
7	d5	17.140	Width of resonator 5
8	d6	15.777	Width of resonator 6

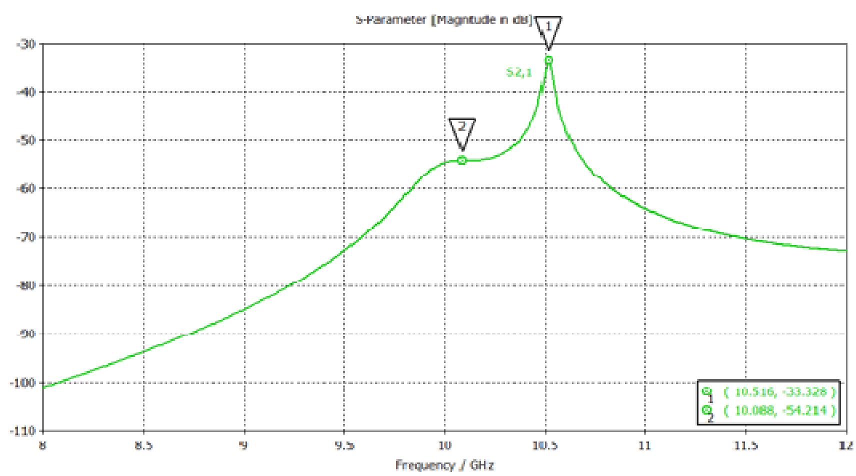
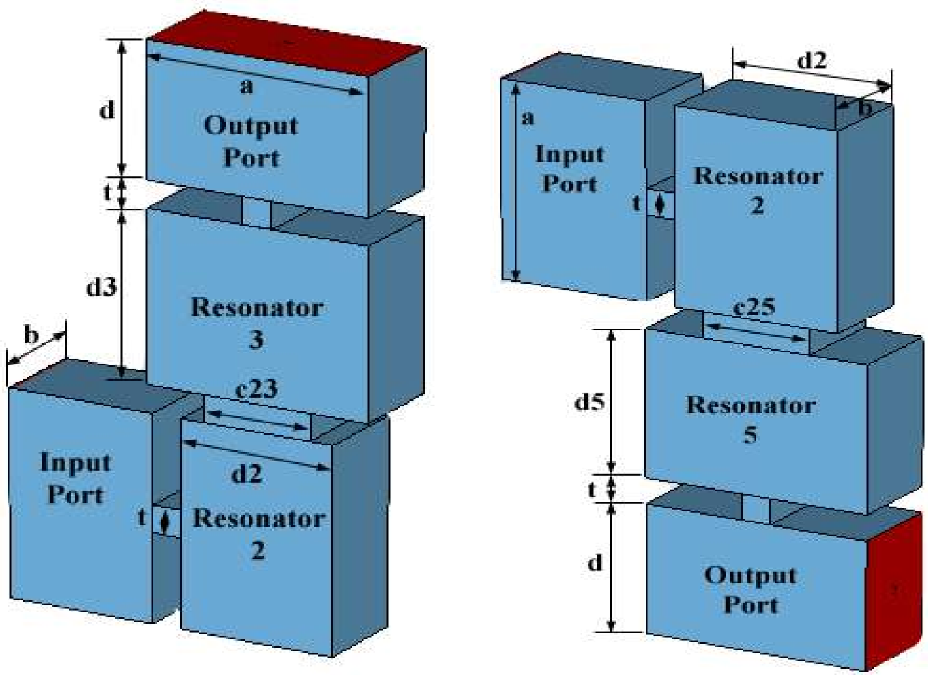


Figure 4.17: S_{21} response of the design to calculate coupling coefficient between resonator 5 and 6

The S21 response in simulation result showed by the figure 4.17, from the graph, it was observed that the first and second highest frequencies were at 10.088 GHz and 10.516 respectively. Centre frequency was at 10.302 GHz. With these parameters coupling coefficient is calculated as 0.0415.

4.5.4 Coupling Coefficient of Iris between Resonator 2 and 3, and Resonator 2 and 5

These two designs were accomplished to determine coupling coefficients between Resonator 2 and 3 (M23), and between resonator 2 and 5 (M25). The widths of resonators 2 and 3 in figure 4.18 (a) were used same as calculated in earlier design. Similarly, the widths of resonator 2 and 5 in figure 4.18 (b) were also obtained from previous design. The variable dimensions were inductive irises c23 and c25.



(a) (b)

Figure 4.18: Design to calculate coupling coefficient (a) between resonator 2 and 3 (b) between resonator 2 and 5 (*Figure not in scale*)

Table 4.7: Dimensions of the design to calculate coupling coefficient between resonator 2 and 3, and resonator 2 and 5

S.N	Parameter	Dimension (mm)	Description
1	a	22.86	Height of resonator
2	b	10.16	Depth of resonator
3	d	15	Width of output port
4	t	3	Width of iris
5	c23	12.788	Height of iris between resonator 2 and resonator 3
6	c25	8.814	Height of iris between resonator 2 and resonator 5
7	d2	16.722	Width of resonator 2
8	d3	18.959	Width of resonator 3
9	d5	17.140	Width of resonator 5

4.6 Assembly of Individual Sections

The individual sections with their respective dimensions were assembled together to form diplexer. Low frequency band (channel 1) was constiuted using resonator 3 and 4, and high frequency band (channel 2) was formed using resonator 5 and 6. Three ports diplexer was designed to operate at X- band frequency (8-12 GHz) having two diffrent outputs. All the rectangular cavities were non-contiguous and intracted each other via inductive irises.

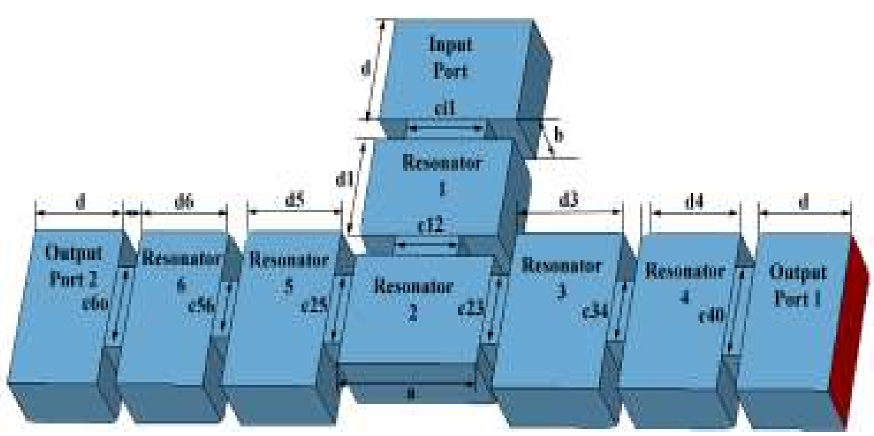


Figure 4.19: Design of novel diplexer (*Figure not in scale*)

Table 4.8: Initial and optimized dimensions of the novel diplexer

S.N	Parameter	Initial Dimension (mm)	Optimized Dimension (mm)
1	a	22.86	22.86
2	b	10.16	10.16
3	d	15	15
4	t	3	3
5	ci1	13.717	13.236
6	c4o	12.788	12.944
7	c6o	12.170	11.935
8	c12	10.228	10.637
9	c23	12.788	10.125
10	c25	8.814	10.107
11	c34	8.814	9.220
12	c56	8.195	8.534
13	d1	15.872	14.207
14	d2	16.722	16.087
15	d3	18.959	17.568
16	d4	17.497	16.082
17	d5	17.140	15.758
18	d6	15.777	14.632

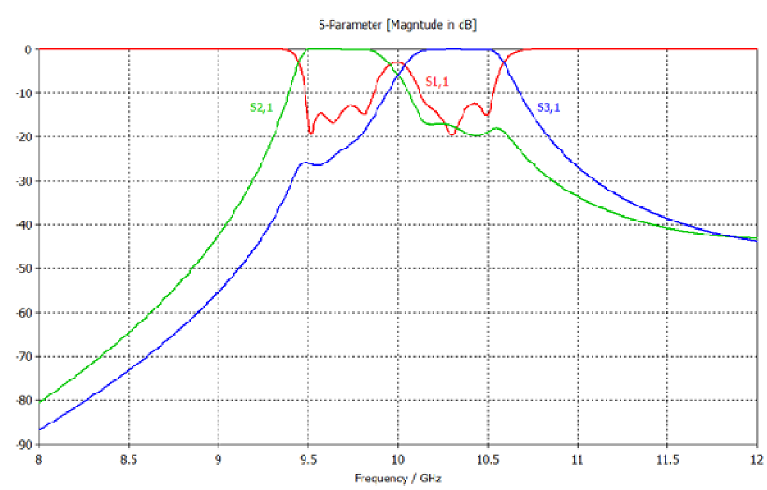


Figure 4.20: $S_{21}, S_{31} and S_{11}$ response of novel diplexer

The $S_{21}, S_{31} and S_{11}$ response of novel diplexer as shown in the figure 4.20 shows two pass bands; channel 1 with pass band centre frequency 9.7 GHz, channel 2 with pass band centre frequency 10.3 GHz and return loss is around -15 dB. Also the bandwidth of the pass band is approximately measured to be around 400 MHz.

Chapter 5

Design Performance

Novel diplexer had been designed using waveguide cavity resonators. The first step in the design was to determine an appropriate coupling coefficients and external quality factors, and which was identified by dividing whole design into various sections. The next step was to construct a structure using individual sections together by inductive irises. The diplexer in figure 5.1 operates at X-band frequency range from 8-12 GHz. The output port 1 (channel 1) allows pass band centre frequency of 9.7 GHz and output port 2 (channel 2) permits pass band centre frequency of 10.3 GHz.

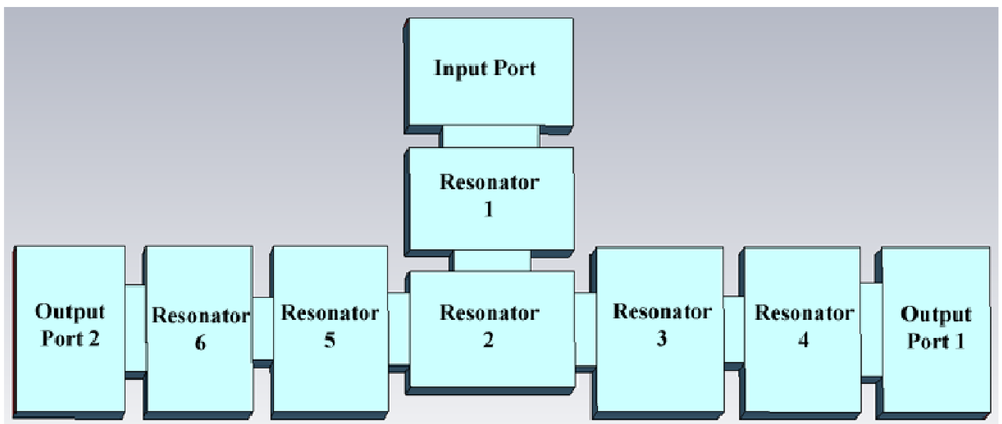
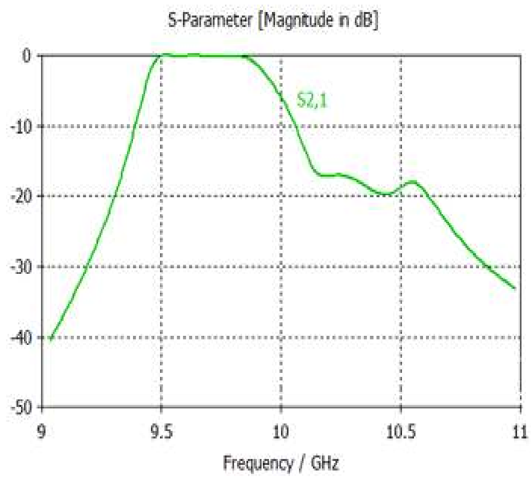


Figure 5.1: Novel all resonator based diplexer at X-band

5.1 Performance Measurement Using Simulation Response

5.1.1 Performance of $S_{21} and S_{22}$ Parameter

S-Parameter (S_{21}) represents output response at channel 1, and S_{22} shows reflection at Channel 1. Resonator 3 was inductive coupled with resonator 2, and output port was externally coupled with adjacent resonator 4. Rectangular cavities associated with channel 1 were especially designed to pass centre frequency of 9.7 GHz. Figure 5.2 illustrates flatter pass band response of channel 1 from 9.5 GHz to 9.9 GHz, but S_{22} response within same bandwidth is drastically reduced to below -13 dB as shown in figure 5.3. From these two responses, it can be analysed that the decrease S_{22} response signifies the better is pass band response at channel 1.



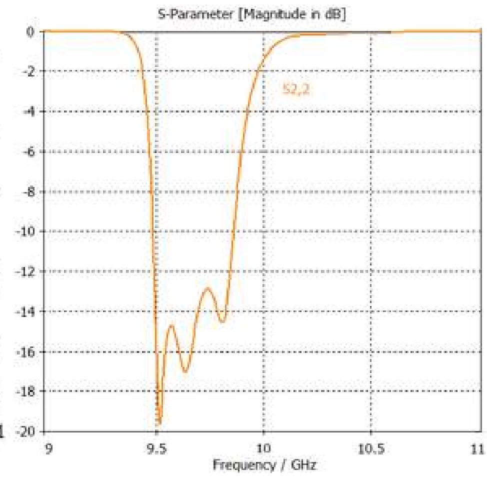
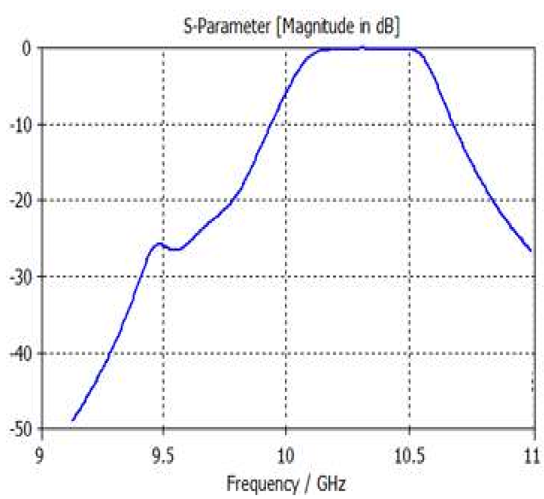


Figure 5.2: S_{21} response at channel 1

Figure 5.3: S_{22} response of reflection at channel 1

5.1.2 Performance of $S_{31} and S_{33}$ Parameter

S-parameter (S_{31}) indicates output response at channel 2, similarly S_{33} shows reflection at channel 2. To achieve pass band centre frequency at 10.3 GHz at channel 2, resonators 5 and 6 were inductively coupled with resonator 2, and externally



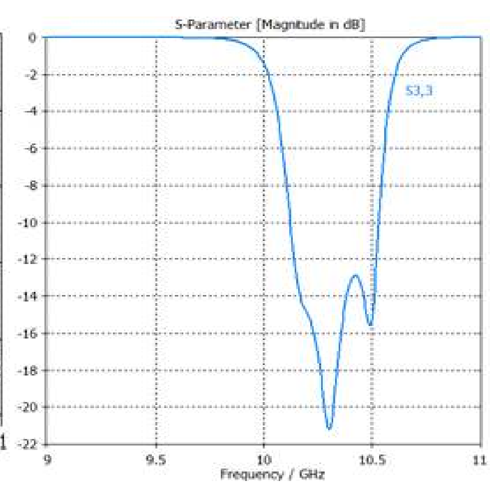


Figure 5.4: S_{31} response at channel 2

Figure 5.5: S_{33} response of reflection at channel 2

coupled with the output port. The variable physical dimensions of waveguide cavities and irises accompanying with channel 2 were very carefully calculated using CST Microwave Studio. Flat response from 10.1 GHz to 10.6 GHz can be observed in figure 5.4 while as S_{33}response is rapidly fall down to below -12 dB within same bandwidth of pass band as shown in figure 5.5. Therefore, it shows better pass band response.

5.1.3 Performance of S_{21}, S_{31} and S_{11} Parameter

The S-parameters S_{21} and S_{31} in figure 5.6 represent lower and upper pass band respectively, and S_{11} shows reflection at port 1. Reflection at port 1 reaches minimum when the pass band frequency is high as shown in figure 5.7. The pass band centre frequency of lower band is at 9.7 GHz and upper band centre frequency is at 10.3 GHz.

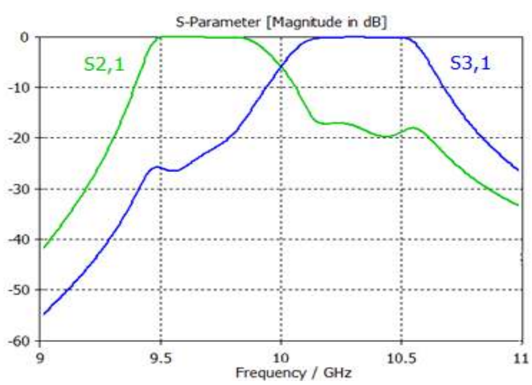


Figure 5.6: S_{21} and S_{31} response at channel 1 and 2

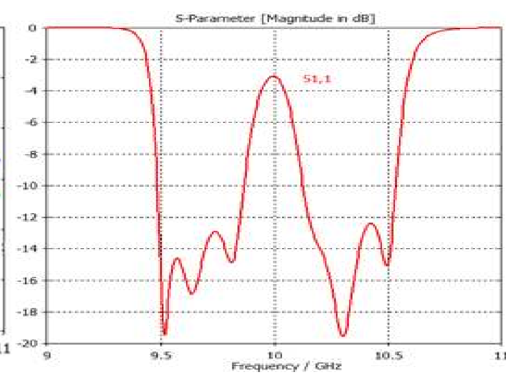
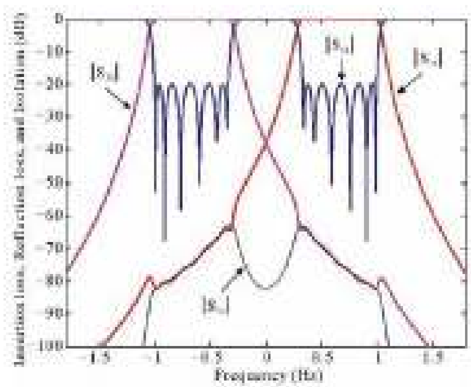


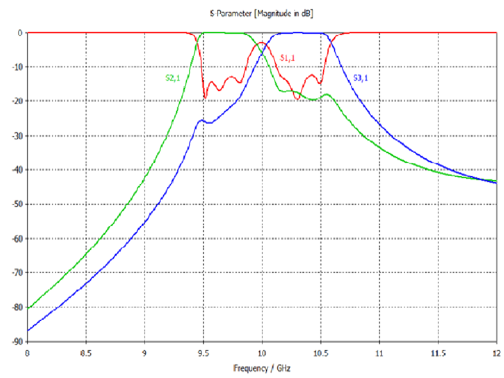
Figure 5.7: S_{11} response of reflection at port 1

From the graph it is observed that channel 1 has the pass band centre frequency of 9.7 GHz and channel 2 has the pass band centre frequency of 10.3 GHz and, the bandwidth of each channel is approximately calculated to be 400 MHz as shown in the figure 5.6.

5.1.4 Comparison with the Response of the Ideal Diplexer

The response of the scattering parameter of the designed diplexer is not perfect as compared to the response of the Ideal Diplexer. The response of the scattering of this work can be improved by further optimizing the design until we get almost perfect response of the scattering parameter. An ideal diplexer response of 12 resonator diplexer [1] is shown in figure 5.8 (a) and the designed response of the 6 resonator diplexer is shown in figure 5.8 (b), which has been design in the CST Microwave Studio. We cannot get the perfect response like in case of the ideal diplexer but with further proper optimization of the design the response of simulation can be improved.





(a) (b)

Figure 5.8: Simulation response of (a) an ideal 12 Resonator Diplexer
(b) Designed 6 Resonator Diplexer

5.2 Analysis of Parameters Variation

5.2.1 Effect of Width Variation

To examine the effect caused by variation of width of the resonator, the width (d) was varied from range 12 to 20 mm. During this process, all other dimensions were kept fixed except width (d). Then the S_{21} responses of four samples were extracted using CST Microwave Studio as shown in figure 5.6.

From the graph it is noticed from figure 5.9 that the resonant frequency decreases with increasing d. It is also noticed that highest resonant frequency occurs at d=12 mm, in contrary lowest resonant frequency obtains at d=20 mm.

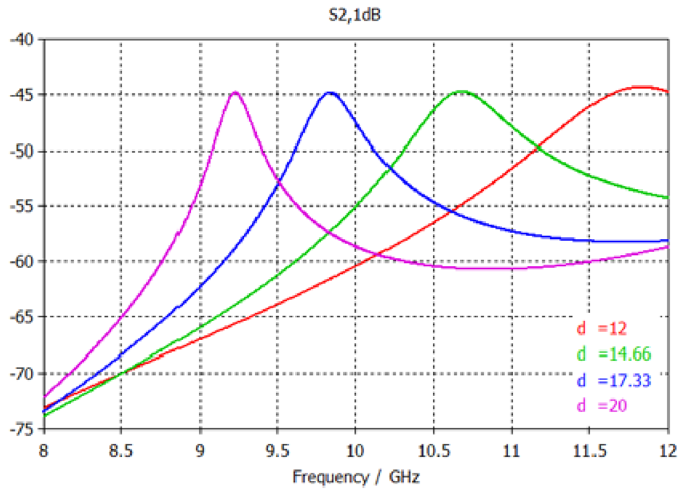


Figure 5.9: Response while varying resonator width

5.2.2 Effect of External Quality Factor

External quality factor characterizes bandwidth of a resonator relative to centre frequency. It varies system to system and introduces performance of the systems. High quality factor implies small range of frequencies oscillation, which is more stable.

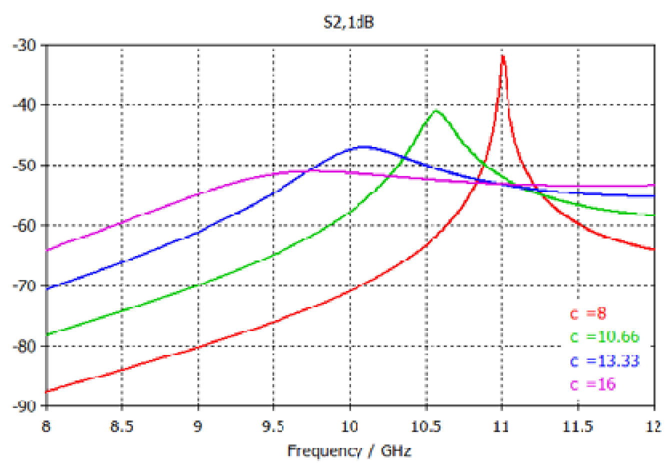


Figure 5.10: Response while varying iris width

From the graph it is noticed that increasing quality factors resonate with greater amplitude but have small bandwidth as shown in the figure 5.10. The highest quality factor occurs at iris width c=8, while as lowest obtains at c=16 which can be calculated using external quality factor formula.

CHAPTER 6

CONCLUSION

The design of novel all-resonator diplexer having three ports and six resonators has been developed using waveguide cavity resonators. The coupling matrix optimization technique is extensively used to find physical dimensions. The design is based on waveguide technology; necessary mathematical calculation is accomplished on the basis of guided wave. It consists of three ports; two ports work as output port filter while as one port is for input. Resonators in the diplexer function as band pass filters (BPF), which are realized using coupling matrix. The design has been implemented to operate in the X-band frequency where the physical dimensions are the standard dimensions for the rectangular cavity operating at X-band. The isolation between resonators is essential parameter for precise filters operation. Overall structure of diplexer forms a single structure, where common junction is replaced by one resonator. So, losses are significantly reduced as compared to the conventional diplexer. CST Microwave Studio has been extensively used to design and to simulate response of the diplexer.

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http://www.cst.com/Content/Products/MWS/Overview.aspx. (Accessed: April 2015).