CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

RF and Microwave Technology generally have the frequency range of 100MHz -1000GHz, where RF Frequencies covers the range from VHF to UHF, on the other hand Microwave Frequencies covers the range from 3-300GHz which have the electrical wavelength ranging from centimeter to millimeter and because of the millimeter wavelength these waves refers to millimeter waves [1].

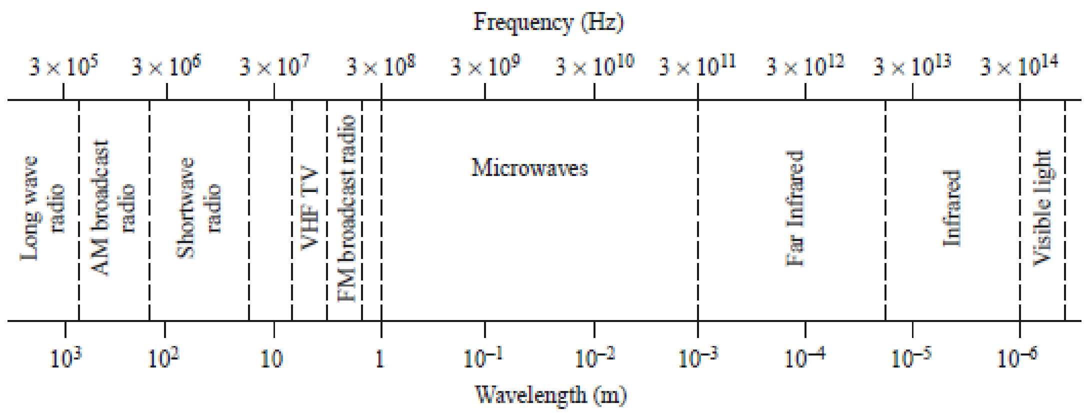


Figure: 1

At high frequencies like Microwave frequencies a normal circuit theory can't be used to solve the network problems of the microwave because at Microwave frequencies Microwave components acts as distributed elements since the size of the components at microwave frequencies is comparable to the electrical wavelength and the phase of the voltage/currents changes significantly over the physical dimensions of the device hence the circuit theory which is an approximation of the electromagnetic theory can't be applied. At low frequencies the wavelength of the signal is large as compared to the physical dimensions of the device therefore the phase variation does not occur.

1.2 Applications of Microwave Engineering

As described above analysis and design of microwave devices and systems are difficult because of the high frequencies and small wavelengths but these disadvantages of microwave engineering give opportunities for the applications. Some of the advantages and applications are given below:

- At microwave frequencies more antenna gain could be obtained from a given dimension and this give advantage while implementing microwave systems.
- At higher frequencies one can have large bandwidth as for 1% bandwidth at 1GHz 10MHz bandwidth can be realized and this directly affects the data rate.
- Because of the LOS (Line of Sight) property of microwave signals they do not reflect or refract by the ionosphere, so they are important for the satellite communication.
- Because of the resonance at high frequencies millimeter waves and microwaves are used in the application of remote sensing, medical treatment etc.
- Microwave frequencies are also preferred for the radar systems because radar cross-sectional area is directly related to the electrical size of the target.

In today's world, RF/ Microwave frequencies are very important for wireless communication system s and other systems like remote sensing and medical.

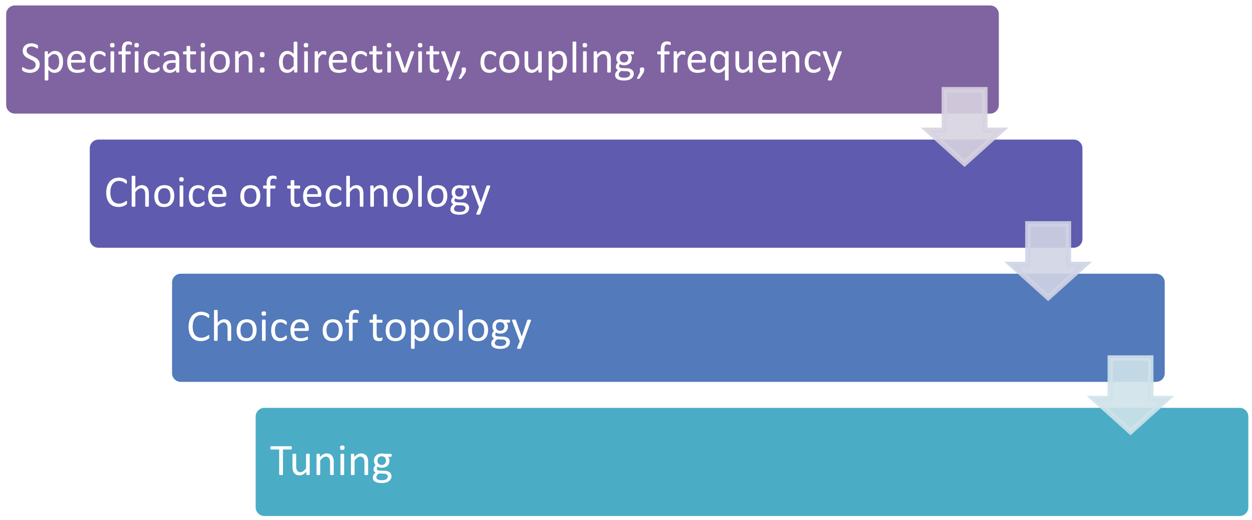
1.3 Design Flow Chart

For designing of a Directional Coupler some basic points for Directional coupler should be kept in mind. In case of Directional Coupler there is a trade-off between factors like directivity, coupling, isolation, bandwidth and insertion loss etc. And based on these parameters previously we have discussed different topologies for the Directional Coupler. In this work we have selected Ring Resonator based topology because this technique provides some important advantage over other techniques as described in the further chapter. Ring Resonator based topology is one of the useful techniques as the device with this topology is easy to design and give better isolation, bandwidth and coupling.

Flow chart of the Directional coupler describes the design flow of the microstrip directional coupler. It starts with the some basic parameter values which are required for any application like coupling, frequency of operation and scattering parameters. Second step is to choose a particular technology for the design of the Directional Coupler. Next step is to choose the technique i.e.

topology which we can choose depending our requirement or application. Fourth step is to tune our circuit depending upon our requirement to set the coupling level and other parameters.

FLOW CHART



1.4 Motivation and Problem Statement

Directional couplers are very important tools which are used in the microwave field for isolating, dividing and to combine the signal. They have wide variety of applications like power monitoring, to isolate the signal sources, source leveling, to measure the reflections and transmission. It very important device in measuring the power level because it couples a definite amount of power to one port so accurate measurement can be easily done without disturbing the output load condition or the operation of the system. In this work my aim is to design a Directional Coupler at a frequency of 2.4 GHz.

1.5 Objective of Present work

The main objective of the research work presented in this project is to Design a Directional Coupler for applications like wireless communication, frequency measurement, power monitoring etc. The goal of this project is to understand the concepts of RF design mainly microstrip lines such as directivity, coupling, isolation etc that are very important for Directional Couplers.

In today's world in the field of microwave technology directional coupler has become very important measurement tool. They provide a very simple, more accurate and convenient means for sampling microwave energy which require no adjustments and movement of parts as other method needs coupling loops and probes. They also give the advantage of separating forward wave from reflected waves.

1.6 Thesis Structure

This work has been divided into six chapters, where each chapter has enough information for learning about this project work. All the areas are explained fully in all the chapters as:

Chapter 1**:** in this chapter the back ground of the RF/Microwave engineering and its applications along with the objective of the research work of Microstrip Directional Coupler has been discussed.

Chapter 2**:** introduces the concept of Microstrip lines and the Directional Coupler along with their applications, advantages and disadvantages and the parameters of the Directional Coupler.

Chapter 3**:** discussed the Directional Coupler and also deals with the details of the research work that has been done in the period of time.

Chapter 4**:** discussed about the techniques chosen which is best suited for the design of Microstrip Directional Coupler along with the Design Equations.

Chapter 5: discussed about the design of the microstrip directional coupler, its simulation, and analysis result of the Microstrip Directional Coupler.

Chapter 6**:** discussed about the result.

Chapter 7: conclusion and future work.

CHAPTER 2

MICROSTRIP LINES & DIRECTIONAL COUPLER

2.1 Microstrip Lines

Microstrip line is transmitting medium which can be used to transmit microwave frequency signals and it can be manufactured using printed circuit board technology. It consist of three materials namely conducting strip, a ground plane and a dielectric layer which separates other two medium and is known as the substrate. All the microwave components including directional couplers, power dividers, filters, antennas etc. can be fabricated using microstrip technology and is very easy to fabricate because entire device can be formed from the pattern of metallization on the dielectric substrate. Microstrip was invented at ITT laboratories to give competition to strip lines. It is similar to the coplanar waveguides and strip-lines also these three can be integrate on the same dielectric substrate. Microstrip lines can also be fabricated into Monolithic Microwave integrated circuits on a small scale. In case of high speed digital designs on PCB where distortion, cross talk, and radiation in not allowed when routed from one part to another microstrip lines can be used.

2.1.1 Inhomogeneity

The presence of dielectric substrate which does not fill the region above the microstrip line complicates the analysis of the microstrip line. In case of strip line all field remain within the homogeneous dielectric medium but in microstrip line some field lines are present between the conductor strip and the ground while some are present in the air due to this microstrip line do not support pure TEM mode. Hence microstrip line will have phase velocity $c/\sqrt{\epsilon_r}$in the dielectric medium while in air the phase velocity of TEM wave will be ***c.*** Therefore it is impossible to have phase-matching condition at the interface of dielectric region and air [1].

Further consequences of Inhomogeneity in microstrip lines:

- Microstrip line will not support a pure TEM wave because at non-zero frequencies E and H both fields have longitudinal components so it will possess a hybrid mode and since these components are small so the dominant mode will be now referred as a quasi-TEM mode.

- Because of the inhomogeneity the microstrip line has dispersive nature. As the frequency increases effective dielectric constant of microstrip line increases to the dielectric constant of the substrate, which reduces the phase velocity. This is also true with the non-dispersive substrate.
- Characteristic impedance of the microstrip line changes with the frequency, as the frequency increases characteristic impedance first increases then decreases and again increases or vice-versa. Characteristic impedance with the low frequency limit is called as quasi-static characterisitic impedance and it remain same for all definitions.
- Wave impedance also varies at the cross-section of the microstrip line.

So, as microstrip line supports quasi-TEM mode because of the fact that electrically diectric substrate is very thin and we can obtained the expressions for characteristic impedance, phase velocity and propagation constant from the quasi static analysis. Phase velocity and propagation constant can be derived as:

$$v_p = \frac{c}{\sqrt{\epsilon_e}}$$

$$\beta = k_0\sqrt{\epsilon_e}$$

Where ϵ_e= effective dielectric constant of the microstrip line

$$1 < \epsilon_e < \epsilon_r$$

Effective dielectric constant is given by:

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12\frac{h}{W}}} \qquad (1)$$

Effective dielectric constant can be considered as the dielectric constant of the homogenous medium which is equivalent to the air and dielectric substrate. When the dimensions of the microstrip line are given than we can calculate the characteristic impedance as:

$$Z_o = \begin{cases} \frac{60}{\sqrt{\epsilon_e}}\ln\left(\frac{8h}{W} + \frac{W}{4h}\right) & W/d \le 1 \\ \frac{120\pi}{\sqrt{\epsilon_e}\left[\frac{W}{h} + 1.393 + 0.667\ln\left(\frac{W}{h} + 1.44\right)\right]}, & W/d \ge 1 \end{cases} \qquad (2)$$

Where W/d can be calculated as

$$\frac{W}{h} = \begin{cases} \dfrac{8e^{A}}{e^{2A}-2} & for W/h < 2 \\ \dfrac{2}{\pi}\left[B-1-\ln(2B-1)+\dfrac{\in_{r-1}}{2\in_r}\left\{\ln(B-1)+0.39-\dfrac{0.61}{\in_r}\right\}\right] & for W/h > 2 \end{cases} \quad (3)$$

Where,

$$A = \frac{Z_o}{60}\sqrt{\frac{\varepsilon_r+1}{2}}+\frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23+\frac{0.11}{\varepsilon_r}\right) \quad (4)$$

$$B = \frac{377\pi}{2Z_o\sqrt{\in_r}} \quad (5)$$

2.1.2 Advantages of Microstrip Line

- Light
- Compact
- Less expensive because whole device can be formed by microstrip line and it exist as the pattern of metallization

2.1.2 Disadvantages of Microstrip Line

- Microstrip line has lower power handling capacity and more losses than waveguide.
- Microstrip line is more susceptible to cross-talk and radiations because it is not enclosed like waveguide.

2.2 DIRECTIONAL COUPLER

Directional Couplersand power dividers (power combiners in reverse direction) are passive devices which are used in the area of Radio Technology. Directional coupler couple a fixed amount of power in a line to a specific port which can be further used in another circuit. They couple power which is flowing in one direction only. When power enters through the output than this power will be coupled to the isolated only not to the coupled port.

The coupler/divider can have 3-port, 4-port or more which may be ideally lossless. Power dividers and T-junctions have 3-ports but 4-port circuits are known as directional couplers and hybrids. Power dividers can divide power in equal ratios or unequal ratios but output signals will have the same phase. While directional couplers can be made for arbitrary power division ratio but the output signals have phase shift between them. Hybrid junctions generally have equal power division but they have phase shift of 90° or 180° between the output signals.

2.2.1 Coupled Transmission Lines

Coupled lines are used in directional couplers and also in transmission line filters because of its natural coupling. Coupled line directional couplers are different from the Wilkinson and branch line coupler in a way that it is not DC connected as others. Coupled lines are formed when two parallel microstrip transmission lines are placed very close to each other so that energy can be transferred from one line to other. Coupled lines support two different modes which can be used in many applications like filters, couplers and hybrids.

2.2.2 Coupled Line Theory

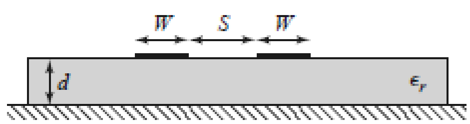


Figure: 2

The above structure of coupled microstrip line can be represented by:

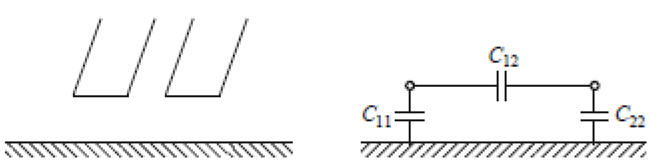


Figure: 3

Electrical characteristics for the coupled microstrip lines can derive from effective capacitances of the line and the propagation velocity by assuming TEM propagation mode.

C_{12} = Capacitances between the two coupled lines

C_{11}, C_{22} = Capacitance between the ground and strip and because of the symmetry of ground and equal size these capacitances will be equal.

There are two types of excitation mode in the coupled lines namely, even mode and odd mode. In even mode the current in the strips flows in same direction and is equal in magnitude while in odd mode current flows in opposite direction but have equal magnitude. For TEM mode phase velocity and propagation constant remain same for both the modes.

$\beta = w/v_p$

$$v_p = c/\sqrt{\varepsilon_r} \quad (6)$$

ε_r =Relative permittivity of the TEM line

In case of even mode no current flows between the two microstrips because of the even symmetry hence C_{12} is open circuited therefore the effective capacitance for even mode will be $C_e = C_{11} = C_{22}$ and characteristic impedance for the even mode will be

$$Z_{0e} = \sqrt{\frac{L_e}{C_e}} = \frac{1}{v_p C_e} \quad (7)$$

But in case of odd mode there is a voltage null between the conductors because of the odd symmetry so effective capacitance and characteristic impedance for odd mode can be calculated as:

$$Z_{0o} = \sqrt{\frac{L_o}{C_o}} = \frac{1}{v_p C_o} \quad (8)$$

The above characteristic impedances are given with respect to the ground plan.

2.2.3 Design of Coupled Line Coupler

From the above definition of characteristic impedances for even and odd mode the analysis of Coupled Line Directional Coupler can be easily done. Fig[4] shows a single section Coupled line Directional Coupler to find the design equation it is assumed to be terminated by Z_0at three ports and one port is connected to the generator with the internal impedance of Z_0. At port 1 we can assume that excitation is the superposition of even mode and odd mode excitation.

For even mode: $I_1^e = I_3^e, I_2^e = I_4^e, V_1^e = V_3^e and V_2^e = V_4^e$

For odd mode: $I_1^o = -I_3^o, I_2^o = -I_4^o, V_1^o = -V_3^o and V_2^e = -V_4^o$

Now, the input impedance at port 1 can be derived as:

$$Z_{in} = \frac{V_1}{I_1} = \frac{V_1^e + V_1^o}{I_1^e + I_1^o} \quad (9)$$

Therefore, input impedance for even mode and odd mode can be given by:

$$Z_{in}^e = Z_{0e}\frac{Z_0 + jZ_{0e}tan\theta}{Z_{0e} + jZ_0 tan\theta} \quad (10)$$

$$Z_{in}^o = Z_{0o}\frac{Z_0 + jZ_{0o}tan\theta}{Z_{0o} + jZ_0 tan\theta} \quad (11)$$

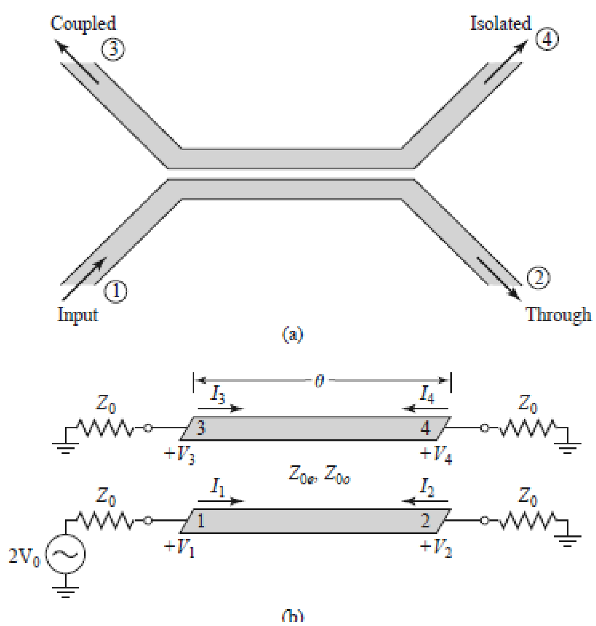


Figure: 4

As we have seen coupled line act as a transmission line for each mode than by using voltage division rule voltage for each mode can be calculated as:

$$V_1^o = V_0 \frac{Z_{in}^o}{Z_{in}^o + Z_o} \tag{12}$$

$$V_1^e = V_0 \frac{Z_{in}^e}{Z_{in}^e + Z_o} \tag{13}$$

$$I_1^o = \frac{V_0}{Z_{in}^o + Z_o} \tag{14}$$

$$I_1^e = \frac{V_0}{Z_{in}^e + Z_o} \tag{15}$$

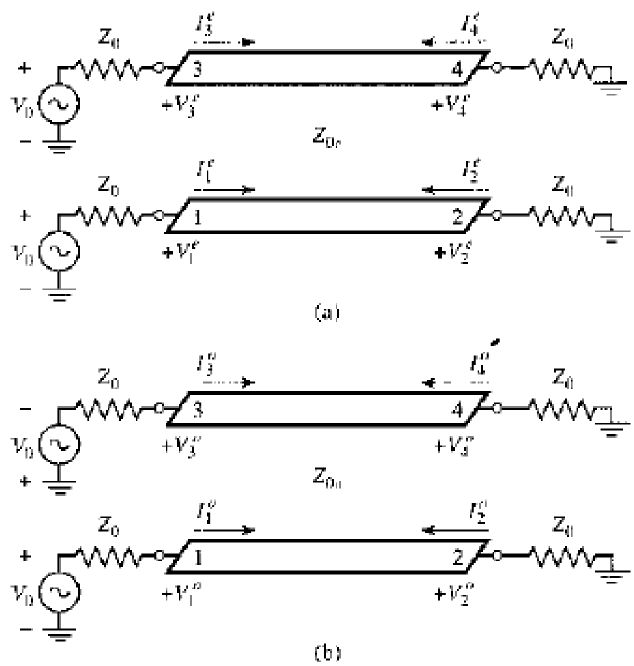


Figure: 5

Using the above results in equation (9) we will get,

$$Z_{in} = \frac{Z_{in}^{o}(Z_{in}^{e}+Z_o)+Z_{in}^{e}(Z_{in}^{o}+Z_o)}{Z_{in}^{e}+Z_{in}^{o}+2Z_o} = Z_0 + \frac{2(Z_{in}^{o}Z_{in}^{e}-Z_0^2)}{Z_{in}^{e}+Z_{in}^{o}+2Z_o} \quad (16)$$

Now, let

$$Z_0 = \sqrt{Z_{0e}Z_{0o}} \quad (17)$$

Then equation 10 and 11 will become

$$Z_{in}^{e} = Z_{0e}\frac{\sqrt{Z_{0o}}+j\sqrt{Z_{0e}}tan\theta}{\sqrt{Z_{0e}}+j\sqrt{Z_{0o}}tan\theta} \quad (18)$$

$$Z_{in}^{o} = Z_{0o}\frac{\sqrt{Z_{0e}}+j\sqrt{Z_{0o}}tan\theta}{\sqrt{Z_{0o}}+j\sqrt{Z_{0e}}tan\theta} \quad (19)$$

Hence, $Z_{in}^{e}Z_{in}^{o} = Z_{0e}Z_{0o} = Z_0^2$ and equation (16) will reduce to

Z_{in}=Z_0

Hence if equation (17) is satisfied port1 will be matched and by the symmetry condition all other ports will be matched. So, if Z_{in}=Z_0 then $V_1 = V_0$ by voltage division method. Now, at port voltage will be calculated as by using equation (12, 13):

$$V_3 = V_3^{e} + V_3^{o} = V_1^{e} - V_1^{o} = V_0\left[\frac{Z_{in}^{e}}{Z_{in}^{e}+Z_o} - \frac{Z_{in}^{o}}{Z_{in}^{o}+Z_o}\right] \quad (20)$$

Now from equations (10, 11, and 17):

$$\frac{Z_{in}^{e}}{Z_{in}^{e}+Z_o}=\frac{Z_0+jZ_{0e}tan\theta}{2Z_0+j(Z_{oe}+Z_{0o})tan\theta} \quad (21)$$

$$\frac{Z_{in}^{o}}{Z_{in}^{o}+Z_o}=\frac{Z_0+jZ_{0o}tan\theta}{2Z_0+j(Z_{oe}+Z_{0o})tan\theta} \quad (22)$$

Now the port 3 voltage equation (20) is reduced to:

$$V_3 = V_0 \frac{j(Z_{oe} - Z_{0o})tan\theta}{2Z_0 + j(Z_{oe} + Z_{0o})tan\theta} \tag{23}$$

After the calculation of port voltages and mode impedances, “Coupling coefficient” can be defined as,

$$C = \frac{Z_{oe} - Z_{0o}}{Z_{oe} + Z_{0o}} \tag{24}$$

Now defining, $\sqrt{1 - C^2} = \frac{2Z_0}{Z_{oe} + Z_{0o}}$, so that

$$V_3 = V_0 \frac{jC \tan\theta}{\sqrt{1 - C^2} + j \tan\theta} \tag{25}$$

Similarly port voltages for V_4 and V_2 can be given by:

$$V_4 = V_4^e + V_4^o = V_2^e - V_2^o = 0,$$

$$V_2 = V_2^e + V_2^o = V_0 \frac{\sqrt{1 - C^2}}{\sqrt{1 - C^2}\cos\theta + j \sin\theta} \tag{26}$$

Voltages at port 2 and 3 can be utilize to plot the voltages at coupled port and through port, at frequencies with very low value having θ less than $\pi/2$ all power is transmitted through port2 with no coupled power. At an angle of $\pi/2$ coupling power will be maximum and generally directional couplers are operated at this postion so that the size of the device is small with minimum losses. For, $\theta = \pi/2$, the coupler will have a size of quarter wavelength and the equation for port2 and port 3 will reduce to

$$\frac{V_3}{V_0} = C \tag{27}$$

$$\frac{V_2}{V_0} = -j\sqrt{1 - C^2} \tag{28}$$

The results obtained above satisfy the power conservation theorem as $P_{in} = (1/2)|V_0|^2/Z_0$, and output powers at coupled port and through ports are given by:

$$P_2 = (1/2)|V_2|^2/Z_0 = (1/2)(1 - C^2)|V_0|^2/Z_0 \tag{29}$$

$$P_3 = (1/2)|C^2||V_0|^2/Z_0 \tag{30}$$

And $P_4 = 0$ so that $P_{in} = P_2 + P_3 + P_4$ and output ports are out of phase by 90° so we can say that it will behave as a quadrature coupler. If the characteristic impedance Z_0 and coupling coefficient is defined than the characteristic impedance for even and odd mode can be calculated by using equation (17, 24) as:

$$Z_{0e} = Z_0\sqrt{\frac{1+C}{1-C}} \quad (31)$$

$$Z_{0o} = Z_0\sqrt{\frac{1-C}{1+C}} \quad (32)$$

Till now the propagation velocity for both modes namely even and odd is assumed to be same but in case of microstrip coupled lines we don’t have a pure TEM mode so this condition do not satisfy and because of this Directivity of the coupler become poor. Difference in the phase velocities for both modes can be explained from the fig [fringing] from this figure we can see that fringing field for even mode in less in the air region as compared to the odd mode because of this the effective dielectric constant for even mode is should be higher which indicates that its phase velocity will be less as compared to the odd mode. So many techniques have been identified to equalize the phase velocities of even mode and odd mode.

Coupled line coupler is best for the application where weak coupling is required, for higher coupling factors lines should e place very close to each other or the even mode and odd mode impedance should have a combination so that coupling can be increased this become non realizable.

2.3 Parameters of Directional Coupler

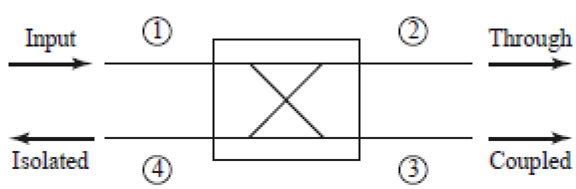


Figure: 6

Directional coupler is characterized by four parameters described below:

- **Coupling:** Coupling factor gives the measure of the part of the input power that can be coupled to the output port and varies with the frequency. It is a negative quantity and it cannot be more than 0dB for a passive device and can be given by:

$$\textbf{Coupling Ratio} = 10\log\frac{P_1}{P_3} \tag{33}$$

- **Directivity:** Directivity gives the indication that how effectively coupler can isolate backward wave and forward wave. This parameter should be as high as possible and it is comparatively more sensitive to frequency as it depends on the two components of the wave. It is measured by:

$$\textbf{Directivity} = 10\log\frac{P_3}{P_4} \tag{34}$$

- **Isolation:** Isolation gives the measure of the power delivered to the isolated port or uncoupled port when the other ports are terminated with the matched loads.

$$\textbf{Isolation} = 10\log\frac{P_1}{P_4} \tag{35}$$

- **Insertion Loss:** This parameter gives the idea about the power delivered to the through port after deducting the power delivered to the coupled port and isolated port.

$$\textbf{Insertion Loss} = 10\log\frac{P_1}{P_2} \tag{36}$$

CHAPTER 3

LITERATURE REVIEW

3.1 INTRODUCTION

Microwave Directional Couplers play a very important role in the passive microwave circuits. They are used for number of applications like power combining/dividing, power monitoring, power sampling, and signal injection in microwave communication sub-systems and radar applications [2]. In such kind of applications they are required to be implemented in planar technology like microstrip lines. Directional Couplers are also an essential part in many circuits like balanced mixers, balanced amplifiers and phase shifters etc [3]. Because of the simple manufacturing process and compatibility with the other planar technology microstrip technology has become very attractive. But due to the inhomogeneity of the substrate and difference in the phase velocities of even and odd mode the coupler fabricated using microstrip line leads to a poor directivity, imbalance in case of baluns, and unwanted mode at first harmonic for the filters [4].

3.2CLASSIFICATION SCHEME

There are different types of technique for different applications which can improve the parameters of the directional coupler as our requirements. Since basic coupled line microstrip directional coupler are widely used in the RF and microwave applications because of their ease of implementation and compatibility with the other devices. Hence there are many methods to improve the limitations of the basic directional coupler.

1. wiggly lines
2. anisotropic substrate structure
3. langestructures
4. single or distributed element compensation
5. tandem structures
6. multilayer couplers
7. solutions based on left hand and right hand

8. artificial lines
9. slotting line couplers
10. dielectric overlay couplers
11. Couplers with phase-compensation capacitors.
12. Pseudo-suspended-substrate couplers.
13. Couplers with phase-compensation matching networks.
14. Equivalent admittance approach

3.2.1wiggly lines

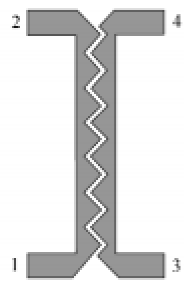


Figure: 7

In [5]-[6] equalization of the phase velocities has been done by wiggling the inner edge of the coupled line which increases the effective propagation length for the odd mode thereby decreasing the phase velocity of the odd mode. This type of topology require higher designing techniques but have better directivity, more power capacity and constant gain as compared to the basic directional coupler.

3.2.2 Anisotropic Substrate Structure, phase compensation matching network

In [7] it's shown that anisotropic substrate can be used to equalize the phase velocities of both the modes. By making permittivity of the substrate greater in the parallel direction as compared to the perpendicular direction odd mode phase velocity can be reduced. This results in the improvement of the directivity. But strong anisotropy is difficult to obtain at higher frequencies.

3.2.3Single or Distributed element compensation, phase compensation matching network

Lumped element compensation technique can be divided into two approaches known as capacitive and inductive compensation techniques. Coupled lines compensated with these approaches are comparatively shorter than the basic structure. Initially because of the requirement of the twisted pair this technique was not that famous for higher frequencies. In [8] an alternative implementation was proposed which has the ability to process the double side substrate requires under board cavity have very narrow bandwidth. To utilize this technique at microwave frequencies coupled inductor was replaced by the ground line inductor having better return loss, better quadrature performance and good isolation. But this also have narrow bandwidth, for wide band application in [9] two designs were proposed. These techniques suffer from the parasitic effects and to remove this problem in [10] periodically loaded microstrip section with the shunt capacitive stubs was proposed.

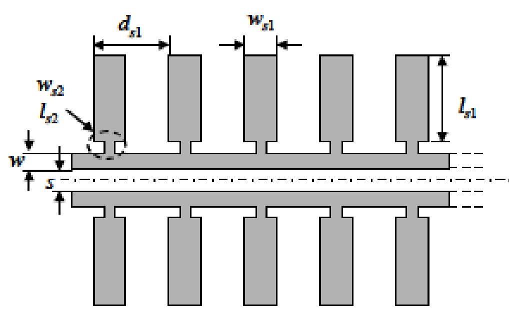


Figure: 8

In this size of the coupler is reduced because of the distributed capacitances and has wider band as compared to other inductive approaches.

In [11] - [12] techniques gives high directivity but matching performance was degraded because of the non-symmetric structure.

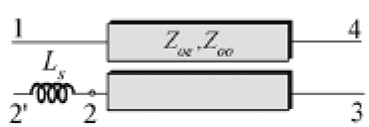


Figure: 9 Single compensated

In [13] instead of series loading shunt loading techniques was presented. In this technique parasitic effects are minimized because of the placement of elements outside the main structure instead of placing them in the gap between the lines.

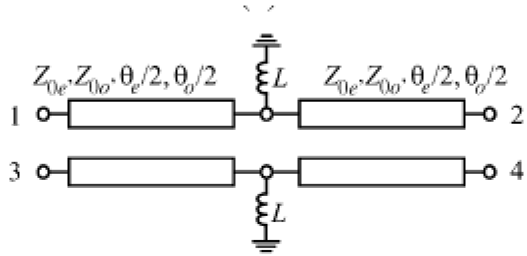


Figure: 10

In [14] trans-directional coupled line directional coupler using periodically loaded coupled is implemented and conditions so that even and odd mode phase velocities and impedances reach to the trans- directional operations are derived. But this is impossible to vary one parameter without changing the other because all parameters depend on the gap between the lines. To rectify this problem coupled lines are replaced by the periodically loaded coupled lines. Conditions required for the trans-directional operation can be derived easily by adjusting the load impedances and periods of the coupled lines. The shunt component added in this technique can be used to adjust the impedance coupling and phase simultaneously as compared to the conventional coupled lines. In [11] – [12] directivity enhancement with series inductor is achieved but coupling level was only 10 dB. In [15] the design based on [13] was investigated to enhance the directivity of the directional coupler loaded with shunt inductors.Among other reactively compensated techniques this method is most practical for directivity enhancement at microwave frequencies for weak coupling levels. To provide the proper performance modeling of the parasitic effect as capacitor is done. In [16] for miniaturization an improved capacitive loading method is proposed for 0 dB forward wave coupler. This method allows the directional coupler to have characteristic impedance which is predetermined after miniaturization. As compared to the other miniaturization method [9] high degree of miniaturization is achieved because extra impedance transformers are avoided and also minimum insertion loss and large fractional bandwidth is achieved. But these techniques like inductive [10], [11] and capacitive stubs [9] for making the different mode impedance identical are remain narrow band. In [17] four port networks are matched to both the modes (even and odd) to compensate their phase velocities. This approach is broadband as compared to the other approach which uses only inductive and capacitive compensation techniques. In [18] a compact forward wave coupler is designed with periodic shunt inductors. Size of the directional coupler is remarkably reduced because the shunt inductors will have different effective inductances for different modes (even and odd) increasing the phase difference between the modes. Input impedance for both the modes can also be matched at the same time by controlling the length of the directional coupler without using additional circuits. The compensation achieved in [5], [15] is narrowband in these methods mostly capacitance is placed between the microstrip coupled lines at every end of the coupler.

But in [19] equations for the design of the coupler with the capacitance placed at random positions are derived maintaining the symmetry along the coupler. The parasitic capacitance of the even mode is taken into account which is assumed that it depends on the capacitance of odd mode instead of being constant. Positions of the capacitance were optimized for the better directivity and bandwidth performance.

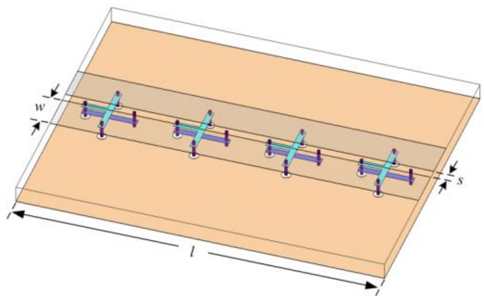


Figure: 11

In [20] a method for designing of microstrip directional coupler alongwith multi-compensated capacitors is proposed. In theory,the method can be employedfor designing a number of multi-compensated capacitors greatlyby notsummingmore area of the coupler.Experimental results showingthe directivity of the couplers alongwith multi-compensated capacitors has remarkably improved compared to the conventional structure. Another technique is presented to resolve the glitches in conventional coupled line couplers & to get tight coupling.In [21] novel re-entrant mode structure has been submitted to microstrip line coupler for applying the high directivities and to achieve tight coupling. Advancement of poor isolation property of a conventional microstrip directional coupler could be gained by using the proposed structure as well as design method. In [22] 3dB coupling and more than -30 dB isolation with tight coupling and high directivity is presented. To equalize each mode phase velocity, they have applied the capacitive compensation technique to the parallel coupled lines and an additional lumped capacitor is made using dielectric substrate. Lumped capacitor of presented structure could be achieved by lowering the difference between the odd and even mode phase velocities of the coupled line. To enhance the directivity property, re-entrant mode structure was used in [23] whereas the structure yields much greaterdirectivity, additional efforts are required to fabricate this typeof directional coupler because ofinsertion of a floating conductor plane.In [24], a directional coupler structurealong with loose coupling factor has been presented with grooved housing for achieving high directivity. It has been shown that a high directivity characteristic couldbe obtained easily by addingan optimized housing structure over the microstripstructure.

3.2.4 Tandem structures

[25], tandem type structures having disadvantage of using large substrate areasoto overcome the disadvantage of using constricted line widths, narrow gaps in between the coupled lines fora tight coupling, and lower power capability depends on substrates, and multiple wire-bonding in [26] N- section tandem structure is suggested. Compared to the traditional tandem coupler [25] – [26], in [27] the advanced tandem coupler has been proposed which gives a broad band with no multi-sectional coupled lines. The technology for remuneration of phase velocity differences in asymmetric and symmetric modes in microstrip parallel coupled lines based on design of saw tooth geometry is suggested in [28] attaining high directionality in a large frequency band, without the use of additional concentrated components and complex manufacturing processes like in [10], [24]. All of the techniques stated/written above are focusing on to decrease the odd mode phase velocity.

3.2.5 Meandered lines

The work in [29] uses the meandered line to reduce the circuit size which boosts up the even-mode phase velocity to make it equal to the odd mode. Results from [4–9] shows that high directivity could be obtained by taking a lumped component, and wiggly inside edge. In [4, 5], however, extra material along with the components are required.

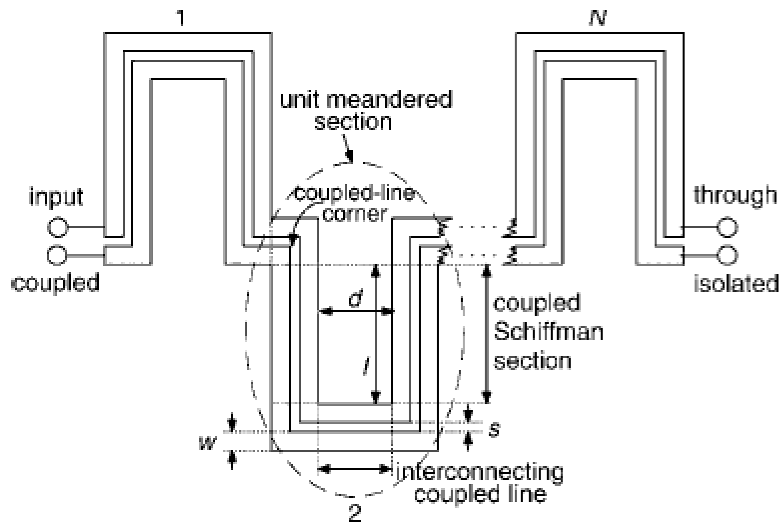


Figure: 12

In [29] by cascading unit meandered sections given in [28] a multi section meandered coupled lines structure was suggested in which noticeable size reduction was obtained also the coupler uses no extra materials, components and manufacturing process. Various couplers have been suggested, like the periodic shunt stubs alongwith the coupled-line [9], the microstrip coupled-line having pattern ground structure [30]. All of these contribute to the phase difference improvement, but they are used onlyin constrictedbandwidth applications due to their monotonously enlarged phase differences. In [31] a proposition ofbroadband as well as symmetrical forward coupler is suggested. The proposed coupler consists of many H-shaped coupled-line structures which associate with each other repeatedly. The input impedance for odd mode and even mode could be matched. The phase difference can be kept unchanged during a frequency range thus attaining a broadband coupling level by acquiring the constant phase difference. An advanced microstrip compressed branch-line directional coupler is proffered in [32], which merged the compact T-model coupler alongside the defected ground structure (DGS). A component's bandwidth performance can be upgraded as well as a branch line coupler’s size can be lessened by the defected ground structure (DGS). The size of the coupler can be reduced more if there is an increase in the phase difference between two modes. Various different structures have been scrutinized to enlarge the phase difference like the coupler designed with periodically loaded shunt stub [9], patterned ground plane coupler [30]. All of them contribute to size reduction, but a lot of them require tapered lines for the matching of impedance and the coupler's total size would be increased. In [35] coupled-line is comprised of duo of microstrip coupled-line along with etched rectangular patterns periodically over the ground plane is suggested. The unit-cell's phase difference is enhanced as even mode phase constant is increased greatly due to slow wave effect. On the basis of this structure, there can be achievement of 3-dB forward-wave directional coupler with a compressed size. Slot line technique is shown in [36] which propose that microstrip 3 dB directional coupler having flat coupling as well as high isolation.

3.2.6 Slotting line coupler

Achievement of good isolation can be attained by using slot line-based capacitive compensation, and by affixing external matching networks at the four ports, the flat coupling is obtained. The tight coupling can be attained employing the Lange [x] or tandem coupler structure [23]–[24]by the use of coupled microstrip lines. However, there is wire crossovers required, which is difficult from the fabrication point-of-view. Additionally, the narrow strips featured in Lange coupler, create furtherfabricationproblems due to thestrict etching tolerances requirements. In order to avoid such problems, the slot-coupling techniquewhich involves a double-sided substrate was proffered. In [36] a class of compressed planar couplers capable of giving coupling between 3–10 dB throughout an ultra-wide band of frequency. The proposed devices are created by a multilayer microstrip structure along with broadside slot coupling. The elliptical shapes of microstrip conductors as well as a coupling slotcontrol the coupling. In [37] to mitigate the need for narrow spacing inbetween the coupled line as spaced ground plane beneath the coupled microstrip lines is utilized. A slotted ground plane was utilized underneath the coupled area in order to relax the need for a narrow slot in between coupled lines. In [38], there is presentation of cavity-coupled microstrip directional couplers. Elliptical coupling slots and microstrip discontinuities are featured in the designs. A circular cavity is selected to provide enough area for the coupling slots by modifying the dimensions of the major as well as minor axes of theslots of elliptical coupling, various coupling can be attained. [39] Combine the technology which is used in [36] and [38] in order to design multi-section ultra-band coupler alongwith low amplitude imbalance as well as phase imbalance. Due to its compressed size, low loss and less weight, it would be widely used in themicrowave subsystem. In [65] ultra-wide band using 2 non-uniform symmetrical TEM-mode slot directional coupler are presented which have frequency range of 3.8 octaves to 28 GHz.

3.2.7 Multilayer couplers

In [40] - [41] there is appearance of Multilayer thick-film technology to point out the requirements of miniaturization, combined with needs for low-cost devices as well as enhanced performance. The circuit size is highly reduced by stacking the conductors; this is a process that also increases opportunities for the progress of new, three-dimensional structures. A particular advantage of this technique is that it makes possible to attain microstrip lines with very tight coupling without the requirement for very fine gaps which are difficult and expensive to fabricate.

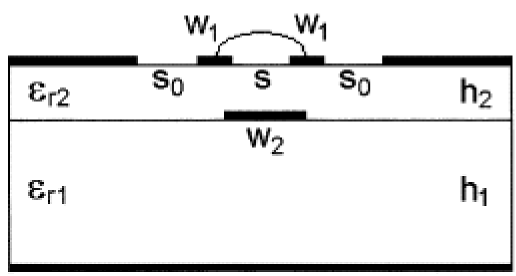


Figure: 13

In [42] the improved re-entrant mode coupler utilizing three-layer microstrip substrate to enhance the performance of the traditional re-entrant mode coupler is suggested. The proffered coupler **is** the traditional re-entrant mode coupler along with the additional layer as well as floating conductor; the advanced re-entrant mode coupler has larger coupling values and finer phase differential characteristics than traditional re-entrant mode coupler. To enhance achievable bandwidth and take benefit of the integration capabilities of the LTCC technologies shown in [42], [43] author in [44] announced a design method for the multi section and multi-layer LTCC stripline couplers. These couplers give extremely wide bandwidth for coupling as well as have a very compact size. Tandem arrangement [22] – [23], a re-entrant coupler type [21] are feasible solutions. The first method needs undesired wire crossovers and latter takes an additional substrate area as two couplers with decreased coupling are associated. In [45] instead of vertical introduced substrate a simple multilayer arrangement is used leading to uncomplicated fabrication process, significant height depletion and a robust structure. In [46] novel multilayer 6-port directional coupler design taking 3 asymmetric coupled lines at very high and ultra-high frequency range is given. The efficiency of the directional coupler is enhanced by using disorderly asymmetric coupled transmission lines with uneven impedance terminations. This enlarged directivity and the bandwidth of directional coupler by retaining the desired coupling level over the bandwidth.

3.2.8 Metamaterial based coupler

Left-handed metamaterials specified by anti-parallel phase and group velocities, are hopeful materials for new kind of microwave structures and components. In [47] a backward-wave coupler build on an LH transmission line was originally presented. This line was later validated to be more commonly composite right/left-handed (CRLH), as it incorporate both LH series parasitic RH series C/shunt L and L/shunt C in its circuit model, concluding in a structure which has LH at lower frequencies while RH at higher frequencies. The mixed C S/CRLH coupler suggested in [47] this is consists of a traditional microstrip RH line edge-coupled along with a CRLH line adopted in its LH range. A similar kind of coupler discussed in [15]. In that a distributed microstrip realistic implementation of the coupler, along with an accurate circuit model for the design, and full-wave/experimental authentication of the model was presented. A novel mixed traditional C S/CRLH coupler with vast bandwidth and tight coupling specifications has been demonstrated. CRLH coupler shown in [48] is considered to be an interesting substitute to broad-band traditional couplers, as it will be presented to be able of randomly tight coupling, over an immense bandwidth (over 30%), while being an economical uniplanar microstrip structure not using bonding wires. Electrical length of directional coupler is zero, the even and odd-mode characteristics are entirely imaginary, the odd and even lines operate in a stop-band, and the coupling level rely on attenuation length of even or odd lines. In [49] Composed Meta materials with using lumped-elements microstrips and L-C is shown, it is feasible to design an asymmetric RWLH backward coupler as well as symmetric structure power divider. At same time, the lumped-elements give some significant advantages: further it is more compact in size, material parameters can be tuned, and method of fabrication is simple. Multilayer microwave circuits developed for decreasing size and weight in the past covered the dual-layer directional coupler (DTC). However, there are still some losses in the earlier reported couplers, such as shorter bandwidth or more volume. In [50], design of DTC with traditional left handed and right-handed transmission line (LH-TL) have been done, respectively. The later possesses immense bandwidth due to multi-aperture, while former occupies lower volume because of bigger phase constant of LH transmission line. Analyzing the DTC in conventional right handed microstrip line, DTC in left handed (LH-TL) is lower than conventional one. In [51], analysis and design of coupled microstrip lines loaded along with an ENG slab have been shown. The presence of the metamaterial offers increasing coupling values well ahead the values obtainable through conventional materials. Poor directivity and less coupling of parallel coupled microstrip lines could be improved by using cascaded interconnecting coupled lines as well as using delay lines [52]. Furthermore, there is enhancement in the bandwidth along with the design area of coupler due to delay line with meta material. Application of Schiffman 'C' section LH transmission lines for coupling improvement of the coupled-line directional coupler's was investigated in [53]. It was proven that tightly coupled directional couplers can be designed using the proposed solution even in single-layer microstrip technology .Also the proposed solution simplifies the design process and it might lower the required manufacturing costs as well as steps. In Wiggly-line couplers [4], [5], dielectric overlay coupler, anisotropic substrate coupler [8], pseudo-suspended-substrate couplers, couplers with velocities-compensation capacitors complicated structures as well as substrate with stated physical constants are needed.

3.2.9. Equivalent admittance approach

In [54] equivalent admittance approach is expected to enhance the directivity of quarter wave micro strip coupler. Equivalent admittance approach is marked by logical design of identical networks for a similar admittance and hence needs only microstrip matching networks for enhancement not like the other techniques asking various ingenious devices.

3.2.10 floating overlay

In [55] for phase velocities compensation a quarter-wave microstrip coupler is designed by a new approach, which makes use of a coupled-microstrip along with periodically floating conductors loading on its inside edges. Features of this coupler are completely planar structure alike wiggly types, realization of tight coupling than the slotting type, and directivity enhancement over the broad bandwidth. In [56] new technique for realization of the coupled-line couplers having floating-plate overlay by applying single-layer technology has been proffered. The suggested coupler is very cost effective because it is made without bond wiring and also without fabrication technology which requires a high resolution along with precision alignment skill. In[9], [23], [40], [47],it can be seen that these techniques lead to the desired coupling improvement, they substantially complicate the design process and also make the fabrication troublesome because of the use of several manufacture levels and bonding wires or via holes.

3.2.11 electromagnetic band gap based

[57] – [58] propose an alternative procedure for enhancing the coupling. It works on the introduction of electromagnetic band gap (EBG) structure. Simultaneously, the directivity is also strongly raised by carefully modifying the device length for achieving a null of energy at isolated port at design frequency. Design procedure is very simple, supported by the use of analytical expressions. Their requirements of fabrication are similar to requirements of classical coupled-line design.

3.2.12 artificial lines

[59] Introduces a 180° hybrid based on the inter-digitally coupled unsymmetrical artificial transmission lines. Output ports are DC-isolated from one-another and are geometrically adjacent. This property addresses DC-biasing points and eliminates the necessity of cross-over structures when implementing the hybrid to uniform mixer, balanced frequency multiplier and the designs of mono pulse comparator. In [60] proffered structure is comprised of mushroom-shaped ground plane and symmetrical microstrip coupled-line. The perturbed ground plane enhances the even-mode phase constant greatly due to slow-wave effect, but has negligible effect for odd-mode phase constant. Along with, the characteristic impedances of the two modes might be designed to 50 Ω to match the impedance. Based on the suggested structure, a high level forward wave directional coupler can be achieved along with a compact size.

3.2.13 other techniques

[61] Explores an interesting phase relation of the microstrip coupled line couplers. It can be seen that phase difference between coupling as well as the isolation coefficients is pretty close to in the wide band. This is a characteristic which is suitable for directivity improvement using two different techniques proposed in this paper. The needed component values for both the methods

can be calculated by given analytical expressions. In [62] one novel method for enhancing the directivity of the parallel coupled line coupler with a design procedure is shown. It can also be seen that if we use ENG transmission lines in a coupled lines directional coupler it will made odd and even mode phase velocity comparable at desired frequency. This equality will make directivity of the parallel coupled line coupler theoretically infinite. Another approach of tunable and high directivity directional coupler is presented in [64] where directional coupler can be tuned. In [65] multi section Chebyshev coupler along with tandem arrangement is presented which have enhanced directivity but weak coupling. In [67] a design for 4-branch coupler is proposed which remove the problem of high branch impedances and also optimized the design to get high isolation and bandwidth.

3.2.14 Ring resonator based coupler

Ring-based resonators have gained special interest thanks to their attractive features where they can produce dual frequency resonance with transmission zeroes, which lead to high selectivity and circuit compactness Furthermore, the use of parallel coupled-lines to as a feeding method to the rings has led to easy way to control their response through the variation of their line impedances In [63] a quarter-wavelength side-coupled ring is proposed to be the base of a directional coupler. The main advantage of such topology is that the line impedance of its elements can be used to control the response of the coupler. Such way, one can easily choose the coupling ratio of the coupler, simply by varying the even- and odd-mode impedances of the coupled-lines in the ring, or the line impedance of the ring.

3.3 Parameters

	Directivity	**Coupling**	**Isolation**	**BW**	**Size**
1.	-	-	-	-	-
1.	-	-11+(-)1 dB	15	-	-
2.	-	3db	29	-	-
3.	-	-	-	-	-
4.	-	3db	30	20% (6.4 GHz and 1.27GHz)	-
5.	-	3dB	25dB	1-3GHz	-

6.	-	3db	-	50%	Size reduction 18%
7.	50dB	10dB	60dB	50% (0.9GHz)	-
8.	6.5dB more than uncompensated	-	-	-	Size reduction 30%
9.	43dB improvement	10dB	30dB improvement	50%(0.9 GHz)	-
10.	38dB more	10dB	-	0.9GHz	-
11.	-	3dB	-	-	Size reduction
12.	56dB	20dB	-	16.3% (2.4)	-
13.	42dB	0dB		53%(5GHz)	89.4% miniaturization
14.	30dB	15dB	48dB	1.8GHz-2.8	
15.	-	1.1dB	-	-	86% miniaturization
16.	40dB	-	-	100%(2GHz)	-
17.	-	20dB	-	2.5-3.5	-
18.	38dB	-	-	850MHz	-
19.	29/31dB	3/4.7dB		2GHz	-
20.	>30dB	18dB		850MHz	-
21.	-	3dB	15dB	3.6-5.5GHz	-
22.	-	3dB	-	70%(1GHz)	-
23.	>30dB	-	40dB	300MHz-2.5GHz	-
24.	40dBimprovement	10dB		2.4GHz	-
25.		20dB	50dB	0-2GHz	-
26.	58dB	0dB	-	12%(1.5GHz)	-
27.	20dB	1.5dB	-	3-6.6GHz	-
28.	-	-	-	200Mhz(2.4GHz)	30% reduction
29.	-	3dB	-	13%(1.5GHz)	95% size reduction
30.	-	3dB	35dB	2.4GHz	-
31.	-	3-10dB	-	3.1-10.6 GHz	-
32.	-	3dB	14dB	3.8-9.8 GHz	Compact size

33.	-	6/10 dB	-	2.68-11.15 GHz	-
34.	-	3.3dB	20dB	2.5-9.2 GHz	Compact size
35.	35dB		15.4d**B**	1903 MHz (8%)	-
36.	-	3dB	-	3-8 GHz	-
37.	22.5 dB	2dB tighter than reenterant	16dB	1.5GHz	-
38.	-	2.7/3/8.34dB	27dB	-	-
39.	-	3dB	-	5.25 GHz (138%)	-
40.	-	3.4+-1.1dB	14dB	3.1-10.6 GHz	-
41.	-	-	-	-	-
42.	30 dB	0dB	-	53% (2.2-3.8 GHz)	-
43.	20dB	3dB	-	50%(3.5-5.8GHz)	-
44.	-	3dB	-	2.1-2.7GHz (20%)	-
45.	10dB	12dB	-	-	-
46.	-	-3dB	-	-	-
47.	20dB	18dB	-	38%(2 GHz)	-
48.	-	-	18dB	2.6/4.5 GHz	-
49.	-	-	-	-	-
50.	30dB	15dB	-	-	-
51.	-	3dB	-	45%(4.5-7.1GHz)	-
52.	-	3dB	-	1.90	-
53.	51.2dB	1.36dB	-	10GHz	-
54.	-	-	15dB	42%(2.35-3.6GHz)	54% of ring shaped rat race coupler
55	-	-1.6dB	-	2.85GHz	86% size reduction
56.	40 dB	-	-	1GHz	-
57.	40 dB	10 dB	-	8.7% (2GHz)	-
58.	-	3dB	15dB	40%(2 GHz)	compact
59.	40 dB	25 dB	-	250-500MHz	compact

60.	>15 dB	3/8 dB	-	165% (3.8-30 GHz)	-
61.	-	3 dB	-	6-18 GHz	compact
62.	-	-	44 dB	680-1195 MHz	-

CHAPTER 4

RING-RESONATOR

4.1 INTRODUCTION

There are so many applications of ring resonators like they can be used to measure the dielectric constant of the material, for tuning and stabilizing the microwave oscillators, directional couplers and to characterize the superconducting thin films [1]. In today's world microwave communication systems are emerging as the important systems in case of satellite communication and mobile communication, band pass filter having high performance, high selectivity, low insertion loss and linear phase delay and flat group delay in the pass band. Filters can be realized with the required properties using cross coupling but this cross coupling results in the so many alternate paths and this multipath effect will give rise to the attenuation poles [2]. They can be realized by using dielectric resonators or wave guide cavities but they are bulky. But to reduce the size weight and make them cheaper planar structures are used. Ring resonators can be realized as side coupled or edge coupled to the microstrip line.

4.2 Side Coupled Ring Resonator

Microstrip ring resonators are becoming very attractive for the applications as in resonant structures at microwave frequencies/millimeter wave frequencies like filters, directional couplers, and measurement of dielectric constant, phase velocity and dispersion [3] because of their compact size, dual resonance and transmission zeroes in the frequency response.

Microstrip ring resonator is consisting of feed lines, gaps for the coupling and a ring which have a circumference equal to that of guided wavelength. The dual mode property of the resonator can be obtained by introducing a notch or short stub on the ring.

In [3] to remove the requirement of notch or short stub quarter wavelength side-coupled lines are used to couple the microwave power into the ring. In this type of structure dual resonance can be obtained having no perturbation. The advantage of this structure is that parameters like bandwidth, coupling etc. can be easily controlled by adjusting the line impedance of the ring and by controlling the odd mode and even mode impedances of the coupled line.

4.3 Quarter-wave Side-Coupled Ring Synthesis

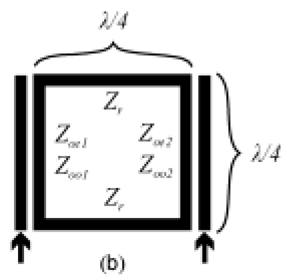


Figure: 14

The ring resonator have the circumference equal to the one wavelength at resonant frequency and input output feedings of the ring is done by using the coupled open ended lines. Characteristic impedance, odd mode characteristic impedance and even mode characteristic impedance are the main factors which controls response of the ring.

4.3.1 Ring Resonator with Identical Coupled Lines

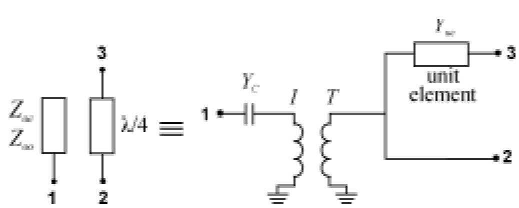


Figure: 15 Equivalent-circuit diagram of a three-port coupled line section.

A) To derive the equations for the ring structure the coupled line structure is simplifies as given above:

$$A_{ue} = \varphi \begin{bmatrix} 1 & \frac{s}{Y_{ue}} \\ sY_{ue} & 1 \end{bmatrix}$$

$$Y_{ue} = Y_{11} - \frac{Y_{12}^2}{Y_{11}}$$

$$\varphi = \frac{1}{\sqrt{1 - s^2}}$$

$$s = j\tan\theta$$

$$\theta = \frac{\pi f}{2 f_o}$$

$$Y_c = sY_{11}$$

$$T = \frac{Y_{11}}{Y_{12}}$$

$$Y_{11} = \frac{(Y_{oo} + Y_{oe})}{2}$$

$$Y_{12} = \frac{(Y_{oo} - Y_{oe})}{2}$$

$$Y_{oe} = \frac{1}{Z_{oe}}$$

$$Y_{oo} = \frac{1}{Z_{oo}}$$

Where Y_{ue} and A_{ue} are the characteristic admittance and the ABCD matrix of the unit element respectively.

Initially consider that both the coupled lines are identical i.e. their even mode and odd mode impedances are equal.

$$Z_{oe1} = Z_{oe2} = Z_{oe}$$

$$Z_{oo1} = Z_{oo2} = Z_{oo}$$

B) Transmission Zeroes Frequency Control

Admittance of the coupling capacitor Y_C controls the out of band response and transformer ratio T is independent of the frequency and controls the magnitude of the out of band response. Transmission zero frequency is controlled by the closed loop of the structure.

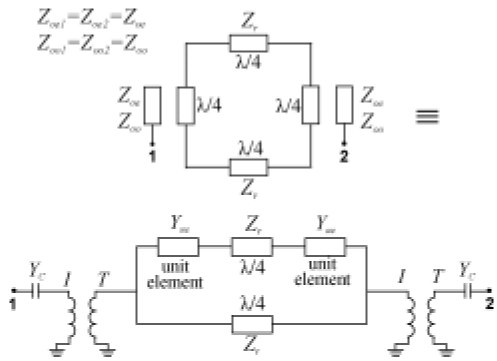


Figure: 16. Simplified diagram of the quarter-wavelength side-coupled ring-resonator.

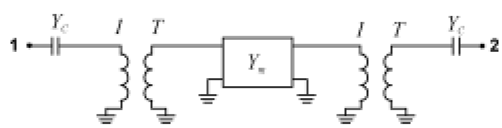


Figure: 17. Simplified diagram of the quarter-wavelength side-coupled ring resonator with simplified middle part.

Y-matrix of the closed loop is given by:

$$Y_m = \begin{bmatrix} Y_{m11} & Y_{m12} \\ Y_{m12} & Y_{m11} \end{bmatrix}$$

Where,

$$Y_{m11} = \frac{\left(B - {Y_{ue}}^2 {Z_r}^2\right)(1 + Y_{ue} Z_r)}{jBZ_r \sin\theta}$$

$$Y_{m12} = \frac{\left(B + {Y_{ue}}^2 {Z_r}^2\right)}{-jBZ_r \sin\theta}$$

$$B=2Y_{ue}Z_r \cos\theta^2 + {Y_{ue}}^2 {Z_r}^2 \cos\theta^2 + \cos\theta^2 - 1$$

One can determine the position of zeroes when Y_{m12} is zero therefore from the above equations

$$2Y_{ue}Z_r\cos\theta^2+{Y_{ue}}^2{Z_r}^2\cos\theta^2+{Y_{ue}}^2{Z_r}^2+\cos\theta^2-1=0$$

From this the length of the first zero will be:

$$\theta_{tz}=arccos\left(\sqrt{\frac{1-Y_{ue}Z_r}{1+Y_{ue}Z_r}}\right)$$

And the frequency can be calculated as:

$$\theta_{tz}=\frac{\pi f_{tz}}{2f_o}$$

Therefore the unit element admittance can be written in the form of resonance impedance Z_r as:

$$Y_{ue}=\frac{\sin\left(\frac{\pi f_{tz}}{2f_o}\right)^2}{\left(1+\cos\left(\frac{\pi f_{tz}}{2f_o}\right)^2\right)Z_r}$$

Now the Y_{oo} can be derived as:

$$Y_{oo}=\frac{Y_{ue}Y_{oe}}{2Y_{oe}-Y_{ue}}$$

4.4 Side-Coupled RING Medium-Band Directional Coupler

Directional Couplers are one of the important components in the RF/Microwave circuits and have applications in the measurement for power sampling and to control the transmitter, they are also used between the mixers or amplifiers as a junction and also in the antenna input circuits [4]-[8]. Ring- based resonators are becoming famous because of their circuit compactness, high selectivity due to dual frequency resonance and transmission zeroes. Also their response can be controlled very easily by just varying the line impedance of the parallel coupled lines [3].

In this work we have chosen a quarter-wavelength side-coupled ring as the base for realizing a Directional-Coupler. The main advantage for this type of structure is that its response can be easily control from the line impedance of elements of the ring. So coupling ratio of the directional coupler can easily be varied by changing the impedance of the odd mode and even mode of the coupled lines of the ring, or by varying the line impedance of the central ring.

CHAPTER 5

Design and Simulation

5.1 INTRODUCTION

For designing of a Directional Coupler some basic points for Directional coupler should be kept in mind. In case of Directional Coupler there is a trade-off between factors like directivity, coupling, isolation, bandwidth and insertion loss etc. And based on these parameters previously we have discussed different topologies for the Directional Coupler. In this work we have selected Ring Resonator based topology because this technique provides some important advantage over other techniques as described in the further chapter. Ring Resonator based topology is one of the useful techniques as the device with this topology is easy to design and give better isolation, bandwidth and coupling.

5.2 STEPS OF DIRECTIONAL COUPLER DESIGN

Steps of Directional Coupler Design are described in the design flow chart of the Directional Coupler. It starts with the some basic parameter values which are required for any application like coupling, frequency of operation and scattering parameters. Second step is to choose a particular technology for the design of the Directional Coupler. Next step is to choose the technique i.e. topology which we can choose depending our requirement or application. Fourth step is to tune our circuit depending upon our requirement to set the coupling level and other parameters.

5.3 DESIGN SPECIFICATION

A directional Coupler for 2.4 GHz operating frequency is to be designed. For this frequency the ring resonator topology has been selected because of its advantage over other techniques. For the given frequency length of the microstrip lines has been calculated. This technology has so many advantages like small area, low insertion loss, tight coupling and broad bandwidth. The table 5.1 gives the target specification for the Directional Coupler Design.

Table 5.1: Target Specification

PARAMETERS	SPECIFICATIONS	UNITS
Directivity	>30dB	dB
Coupling	-3dB	dB
Isolation	>15dB	dB
Bandwidth	40%(2.4GHz)	MHz

In our work we will try to design a Directional Coupler with the above specification and try to get the netter results we could get.

5.4 MICROSTRIP LINE AS ADESIGNING COMPONENT

Microstrip line has been chosen as the base of the Directional coupler because of its light weight, compact size and less cost as the whole device can be formed by the microstrip line as the metallization pattern.

5.4.1 DESIGN

As discussed earlier we are designing the Directional Coupler using Microstrip Coupled Lines so for that initially we have calculated the length, spacing and width of the coupled lines for the given specifications:

$$\varepsilon_r = 4.5$$

$$H = 1.5\text{mm}$$

$$T = 35 \text{ microns}$$

$$f = 2.4\text{GHz}$$

LineCalc tool available in the ADS (Advance Design System) software is use4d to calculate the physical dimensions of the Microstrip Coupled Lines.

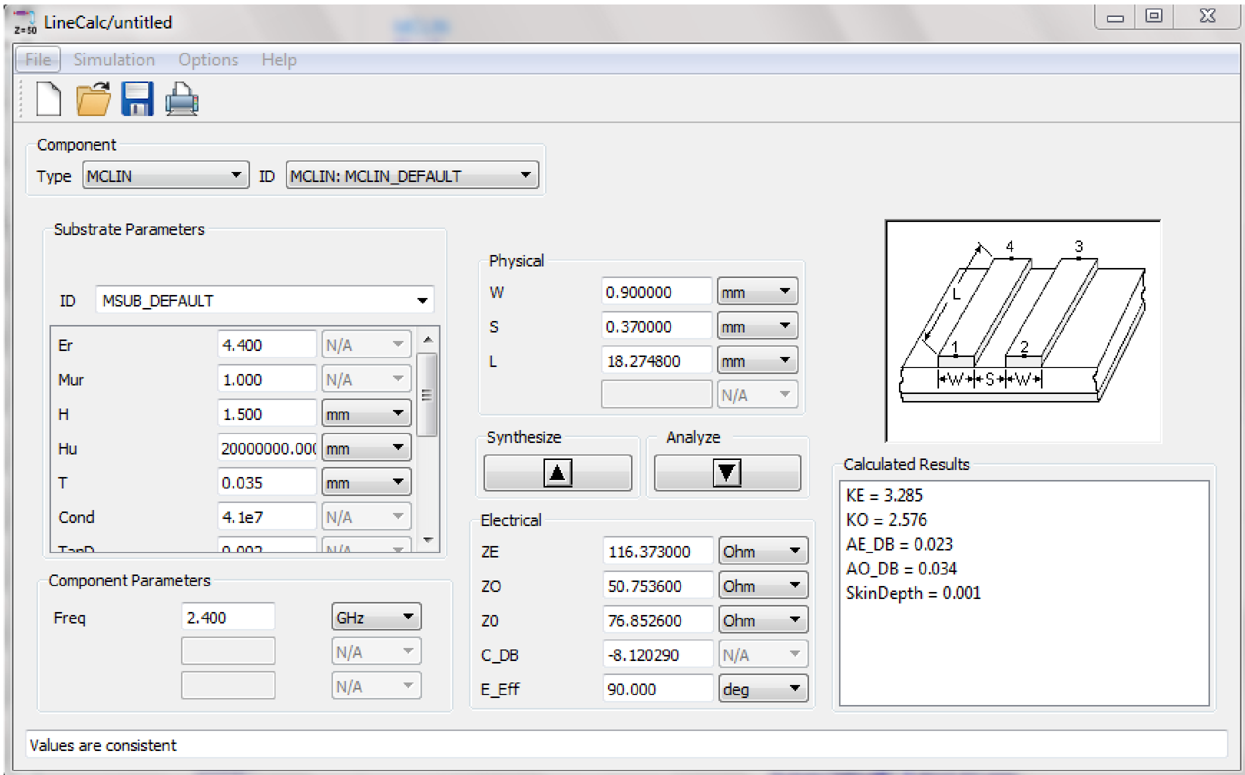


Figure: 18

After calculating the physical dimensions of the coupled lines, length and width of the microstrip transmission lines has been calculated to complete the ring type of structure of the Directional coupler having same substrate as that of the microstrip coupled lines. Again the same tool LineCalc has been used to calculate the dimensions of the transmission line.

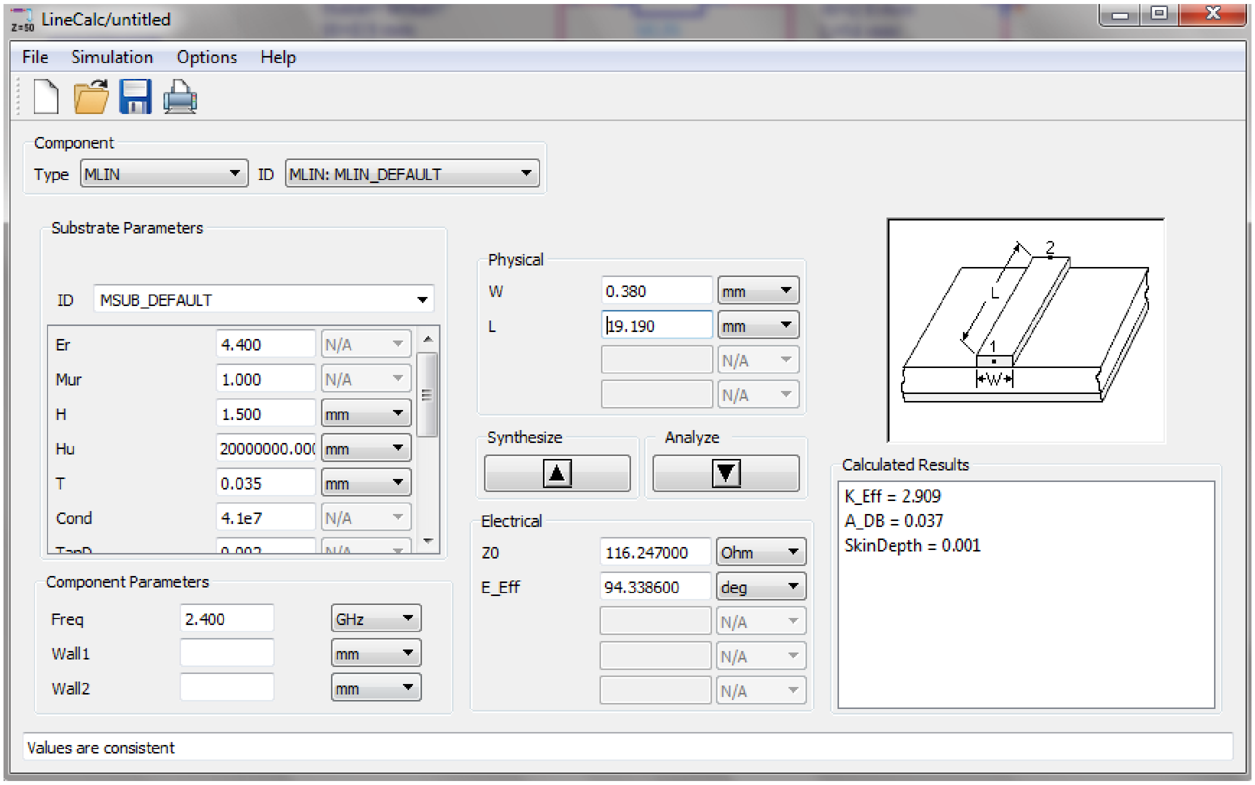


Figure: 19

After calculating the physical dimensions of the components from the LineCalc the components are placed in the schematic as given below.

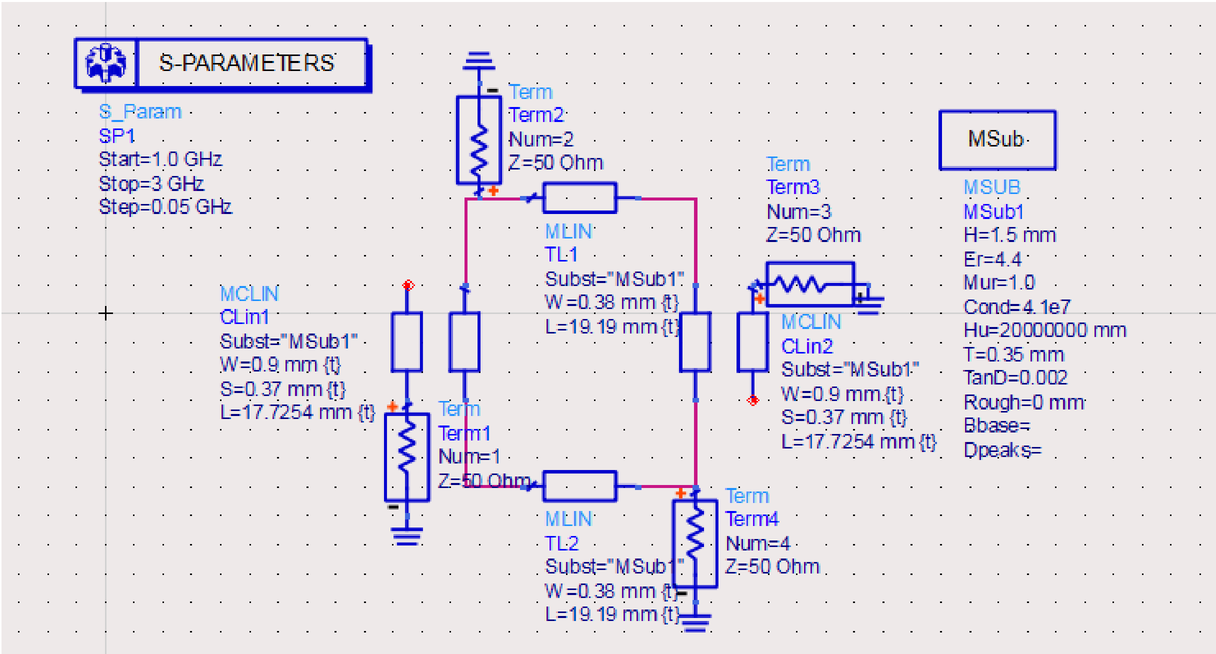


Figure: 20

After simulating the design we have tuned the circuit components to get the accurate result. The tuning has been done at the frequency of operation 2.8GHz, and to get the desired result of the parameters like coupling, insertion loss, isolation bandwidth etc.

5.4.2 SIMULATION

In simulation S-parameters are being displayed on the data display unit as given below in the figure.

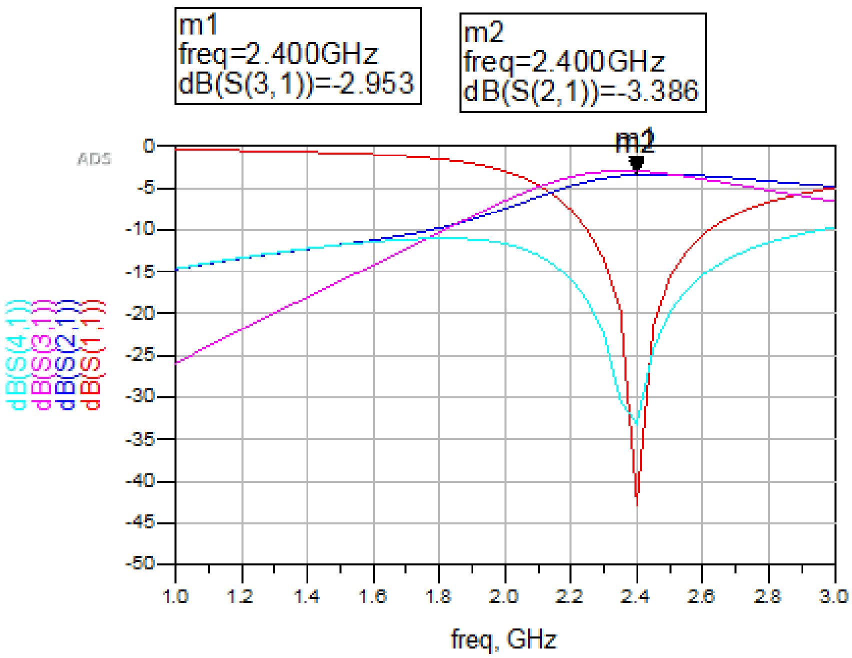


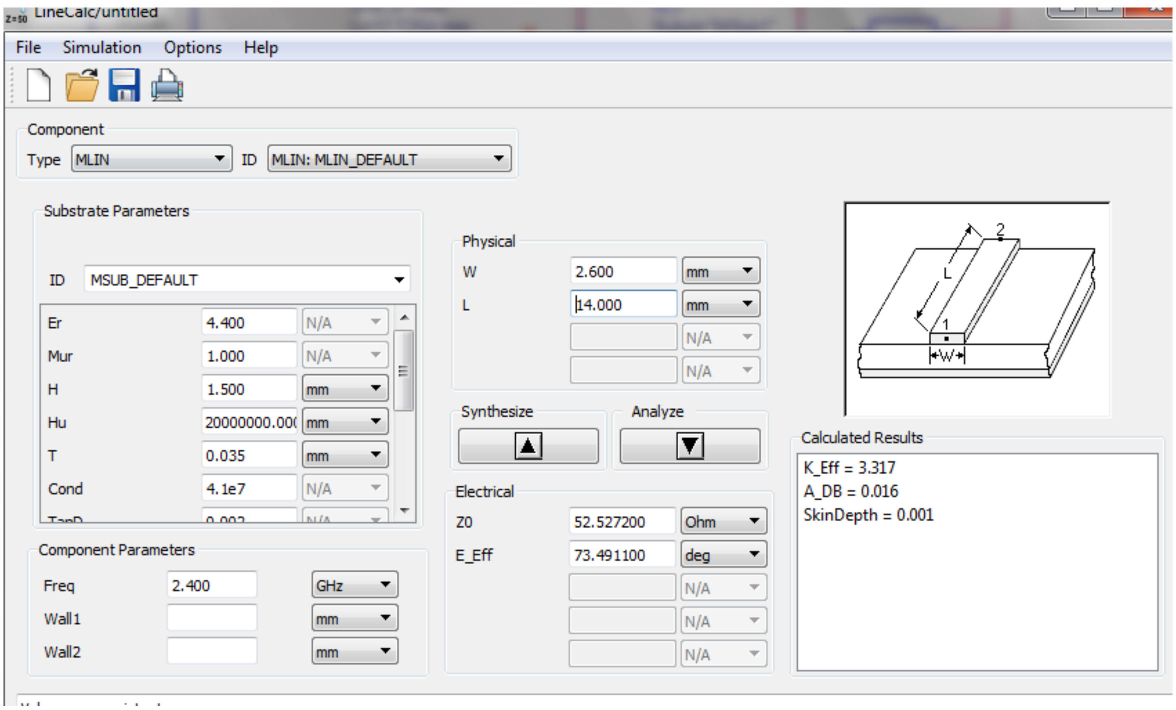
Figure: 21

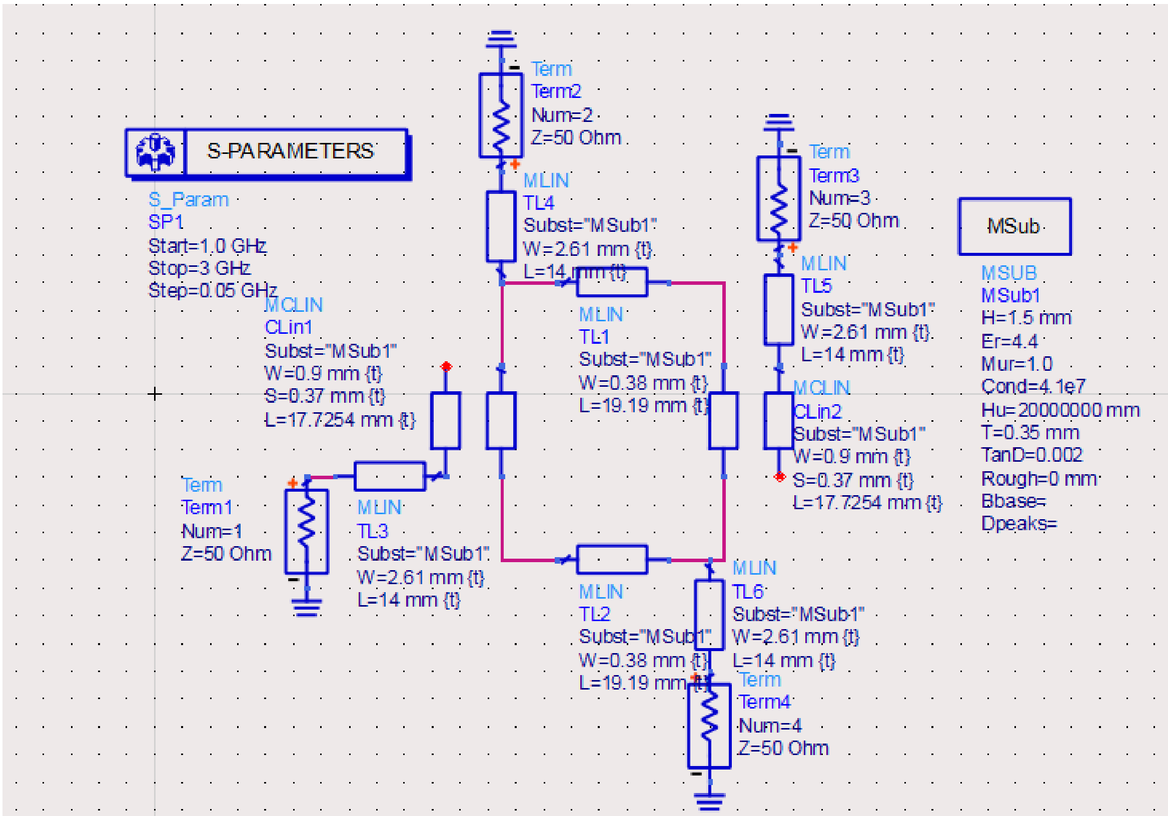
From the simulation of the circuit as we can see we are getting a good through put, isolation and return loss.

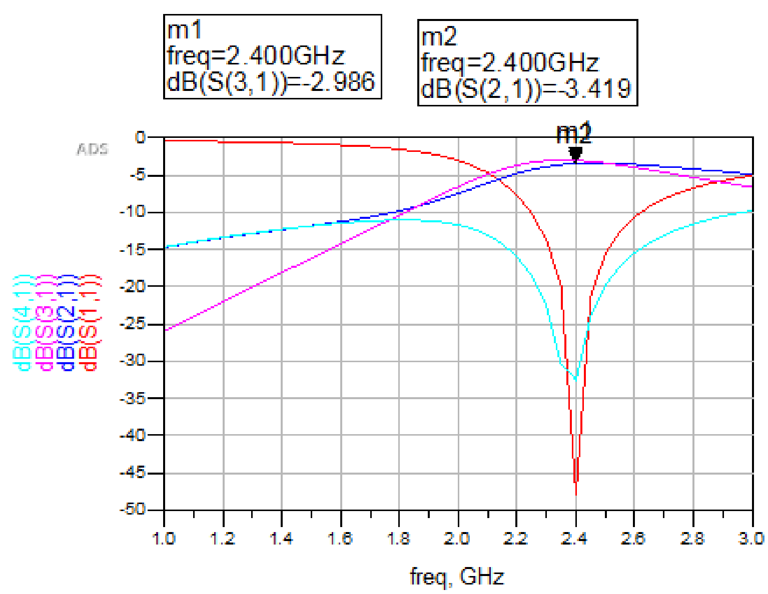
5.4.3 Matching

In our work we are going to fabricate our device which is a Ring Resonator based Directional Coupler so for that we have to add the matched 50Ω lines to connect the connectors. Again to calculate the length and width of the 50Ω line we have used the LineCalc tool of the ADS software. The results are shown in the below figure. But to get the matching condition we have tuned our circuit again so that we get the impedance level which can give the best results.

Now the S-parameters are displayed by simulating the circuit. In data display window we have seen the results which are good in comparison to our requirements.

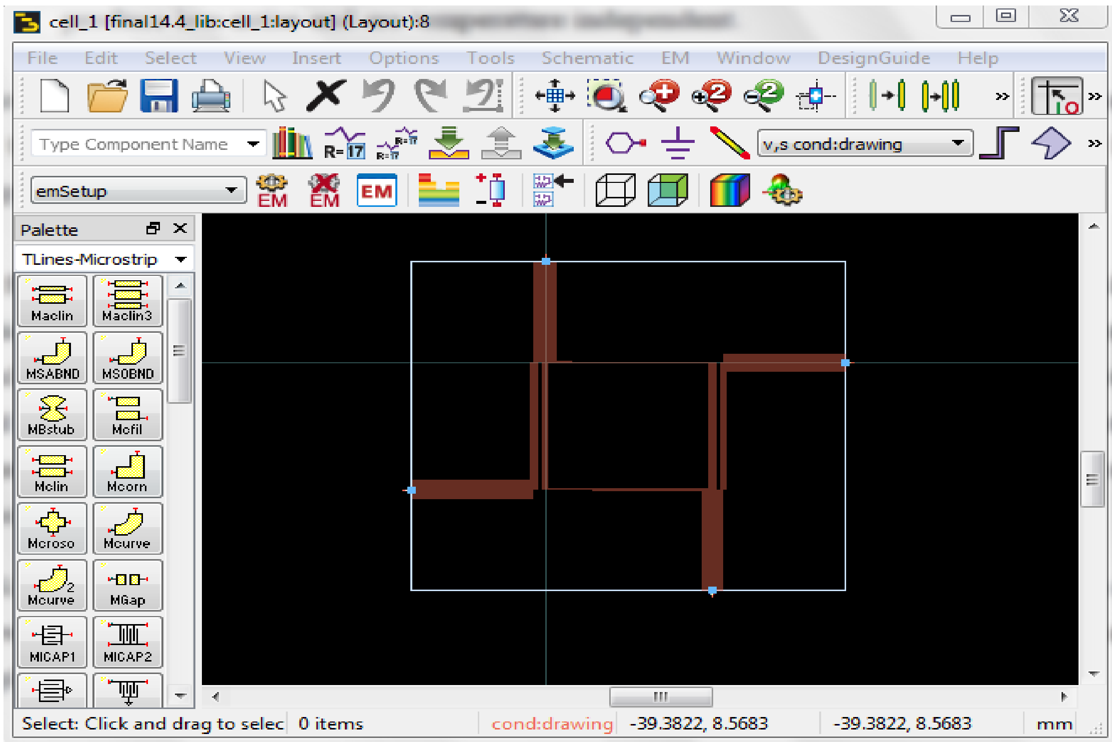

LineCalc/untitled
File Simulation Options Help
Component
Type MLIN ID MLIN: MLIN_DEFAULT
Substrate Parameters
ID MSUB_DEFAULT
Er 4.400 N/A
Mur 1.000 N/A
H 1.500 mm
Hu 20000000.00(mm
T 0.035 mm
Cond 4.1e7 N/A
Component Parameters
Freq 2.400 GHz
Wall1 mm
Wall2 mm
Physical
W 2.600 mm
L 14.000 mm
N/A
N/A
Synthesize
Analyze
Electrical
Z0 52.527200 Ohm
E_Eff 73.491100 deg
N/A
N/A
N/A
Calculated Results
K_Eff = 3.317
A_DB = 0.016
SkinDepth = 0.001


S-PARAMETERS
S_Param
SP1
Start=1.0 GHz
Stop=3 GHz
Step=0.05 GHz
Term
Term2
Num=2
Z=50 Ohm
MLIN
TL4
Subst="MSub1"
W=2.61 mm {t}
L=14 mm {t}
Term
Term3
Num=3
Z=50 Ohm
MSub
MSUB
MSub1
H=1.5 mm
Er=4.4
Mur=1.0
Cond=4.1e7
Hu=20000000 mm
T=0.35 mm
TanD=0.002
Rough=0 mm
Bbase=
Dpeaks=
MLIN
TL5
Subst="MSub1"
W=2.61 mm {t}
L=14 mm {t}
MCLIN
CLin1
Subst="MSub1"
W=0.9 mm {t}
S=0.37 mm {t}
L=17.7254 mm {t}
MLIN
TL1
Subst="MSub1"
W=0.38 mm {t}
L=19.19 mm {t}
MCLIN
CLin2
Subst="MSub1"
W=0.9 mm {t}
S=0.37 mm {t}
L=17.7254 mm {t}
Term
Term1
Num=1
Z=50 Ohm
MLIN
TL3
Subst="MSub1"
W=2.61 mm {t}
L=14 mm {t}
MLIN
TL2
Subst="MSub1"
W=0.38 mm {t}
L=19.19 mm {t}
MLIN
TL6
Subst="MSub1"
W=2.61 mm {t}
L=14 mm {t}
Term
Term4
Num=4
Z=50 Ohm

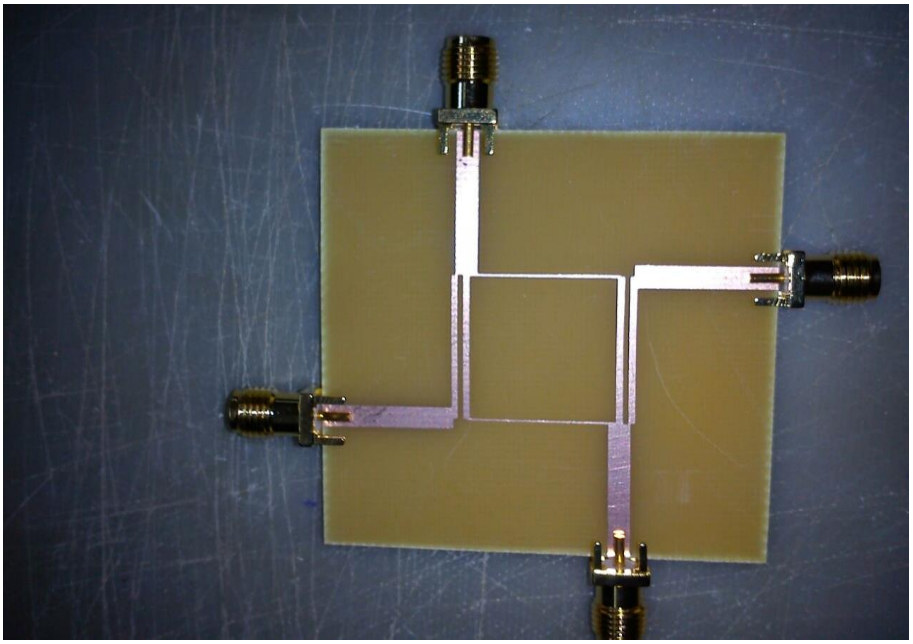

m1
freq=2.400GHz
dB(S(3,1))=-2.986
m2
freq=2.400GHz
dB(S(2,1))=-3.419
m2
m1
ADS
dB(S(4,1))
dB(S(3,1))
dB(S(2,1))
dB(S(1,1))
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
freq, GHz

5.5 LAYOUT

After simulating our design in the ADS (Advance Design System) software we have designed our device in the layout to get the physical look and to fabricate the device. The layout design and the corresponding fabricated device is shown in the below figures.



5.5.1 Fabricated device



CHAPTER 6

RESULTS

The Directional Coupler was designed to operate as 2.4 GHz frequency, and was simulated by using the ADS (Advance Design System) software designed by Agilent technologies. The main issues in the design like return loss, coupling, directivity, isolation and bandwidth was considered.

Directional Coupler using Ring Resonator based technique has been simulated and simulation results are:

Isolation -33dB

Return Loss -48dB

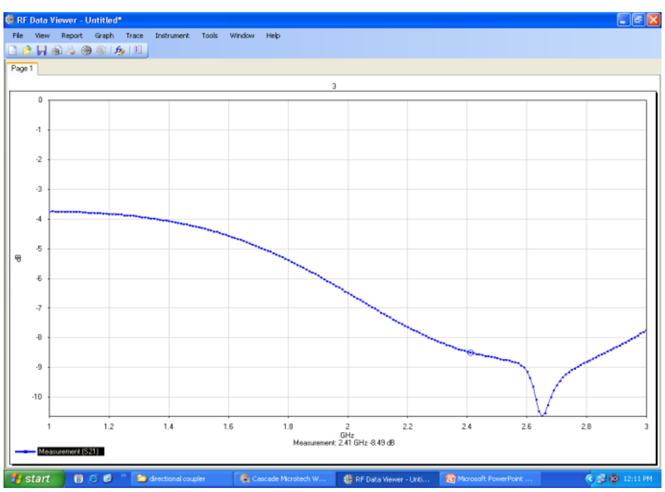
Coupling -3.14dB

Bandwidth 1.96 GHz

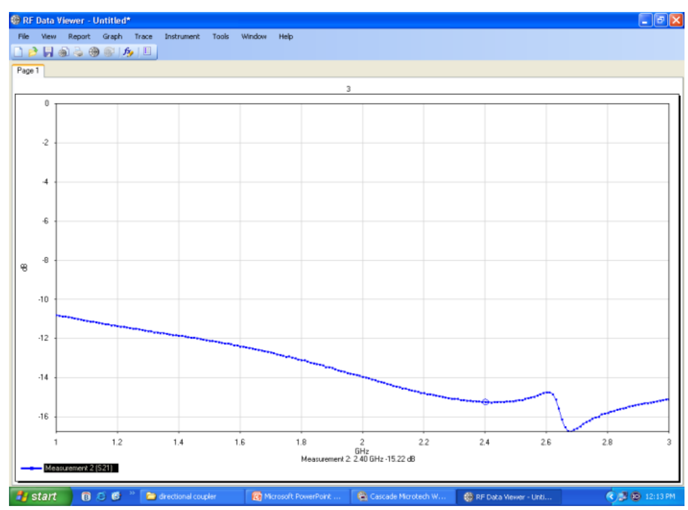
Directivity is around 30dB

The return loss is very low for the simulated circuits and also the isolation of the design is good.

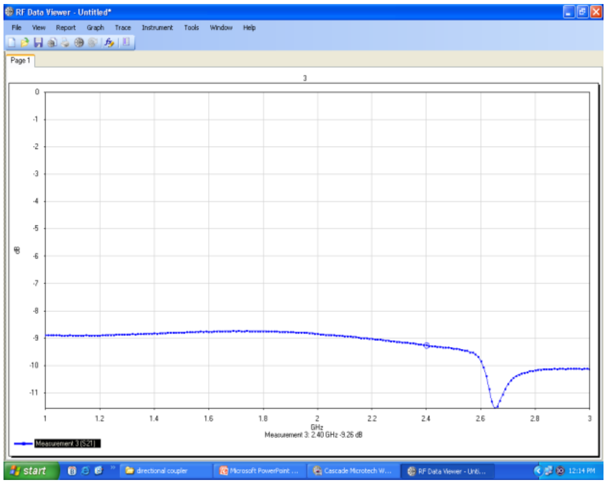
HARDWARE TESTING RESULT:

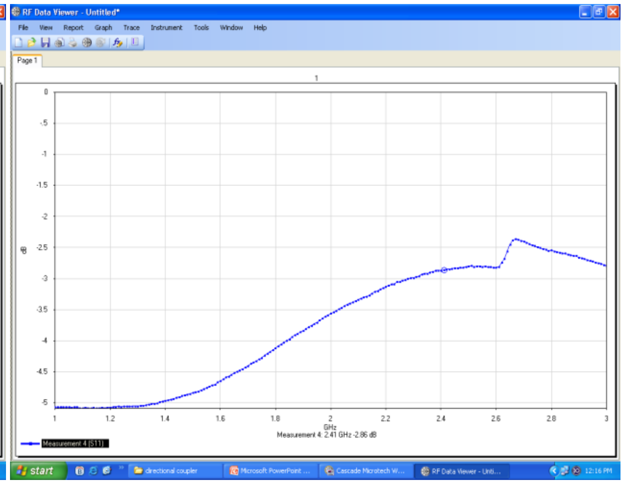


S21



S31





S41 **S11**

CHAPTER 7

CONCLUSIONS

7.1 Conclusion

While trying to design a circuit, it is always good to overcome and remove away the complexity of the process. In this project work we have designed a Directional Coupler for 2.4 GHz frequency range which has applications like in Wireless. This work covers all the important details which are required for the Directional Coupler. A Directional coupler using the said technique is designed and simulated keeping the return loss low and isolation high for the given frequency applications.

In last so many years, lots of work has been reported which focuses on the different parameters like bandwidth, coupling and directivity enhancement where important methods including capacitive compensation, wiggling lines, inductive elements, spurlines, delay lines, stepped impedance, network compensation and resonator based techniques have been presented. But various methods which focus only on the single band cannot be used for today's applications which require multi-bands. A method which keeps away the device from the leakage, cross talk and unwanted modes is also presented where SICL is used to characterize the TEM-mode propagation.

For this project work we have selected the said technique as it is less complex as compared to the other techniques which require high manufacturing complexity also the precision technique. The Microstrip Directional Coupler was designed to operate at 2.4 GHz frequency, simulated by using the software ADS (Advance Design System) designed by Agilent technologies.

The key issue in the design as directivity, coupling, isolation, return loss etc. was considered. After the simulation the design has achieved the

Furthermore, the level of satisfaction of this project work is satisfactory to our level. There are some deviations in the coupling from the expected value in the due to less precision. This project gives a very depth and wide view of all the background theories and designing topologies to the designer.

7.2 FUTURE WORK

After analyzing so many techniques to design and fabricate a Microstrip Directional Coupler. We have found that resonator circuit based technique have so many attractive features like they have can produce dual frequency resonance, high circuit compactness and leads to high selectivity. Also the placement of lines in parallel to couple the power as a feeding network to the ring give an easy way to control the results by varying the line impedance of the parallel coupled lines.

In present work we have not designed a dual mode Directional coupler. In future a Directional Coupler based on the Ring-Resonator technique can be designed for the multi-mode applications. So my future work will be to design a Directional Coupler having dual mode and filtering applications.

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