19CCE383 ELECTROMAGNETIC SIMULATION LAB

B.Tech CCE – Semester VI

Academic Year: 2022-23

Even Semester: Feb. 2023 – May 2023

Experiment Manual

Department of Electronics and Communication Engineering
Amrita School of Engineering
Amrita Vishwa Vidyapeetham
Coimbatore – 641112

BASIC COURSE DETAIL*

Course Objectives:

- To get hands on experience in building the RF circuits and analyze its performance
- To practice the tools used for simulations and its parameters and syntax in the circuit design
- To become the expertise in RF design and performance analysis

Course Outcomes:

CO1: Ability to understand the concepts of RF signal transmission through waveguides
CO2: Ability to analyze the scattering parameters of RF devices
CO3: Ability to apply the RF design concepts and characterize using simulation tools
CO4: Ability to design and analyze RF circuits using simulation tools

Course Outcome – Program Outcome Mapping:

	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10	PO 11	PO 12	PSO 1	PSO 2
CO 1	3	3	3	3	3	-	-	-	-	-	-	3	3	3
CO 2	3	3	3	3	3	-	-	-	-	-	-	3	3	3
CO 3	3	3	3	3	3	-	-	-	-	-	-	3	3	3
CO 4	-	2	-	-	-	-	-	-	3	3	-	3	-	-

Syllabus:

1. Characterization of waveguide based microwave setup.
2. Measurement of radiation pattern of horn antennas.
3. Measurement of return loss and insertion loss of any selected microwave component.
4. Characterization of materials using two-antenna method.
5. Electromagnetic simulation and scattering parameters study on microstrip lines.
6. Electromagnetic simulation and characterization of rectangular microstrip antenna.
7. Electromagnetic simulation and characterization of circular microstrip antenna.
8. Electromagnetic simulation and characterization of microstrip power dividers .
9. Electromagnetic simulation and characterization of rectangular microstrip resonator.
10. Electromagnetic simulation and characterization of hybrid ring couplers.

Evaluation Pattern:

Assessment	**Internal**	**External**
Continuous Assessment	80	
End Semester		20

***As per Curriculum – Syllabus Document – 2019 Regulation**

HFSS BASED EXPERIMENTS

Exp.No:1 **Design and Simulation of Microstrip Line Structure**

Date:

Aim of Experiment: To design and simulate a 50Ω Microstrip transmisssion line

Specification:

Dielectric constant (ϵ_r) =

Dielectrice Height (h) =

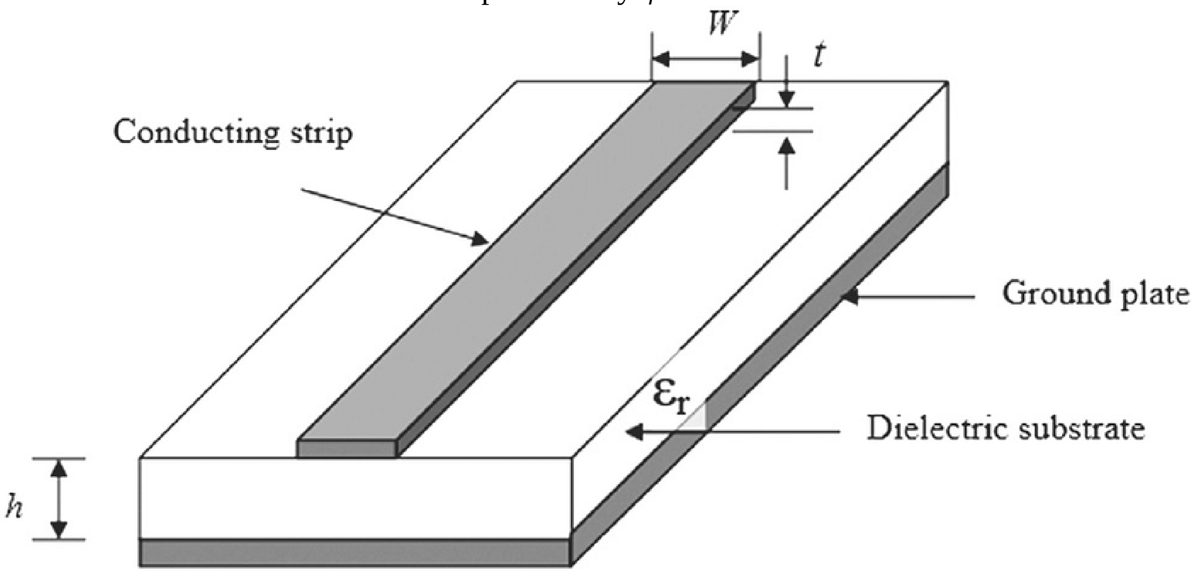
Operating frequency (f) =

Software Requirement:

- Ansys HFSS, Python

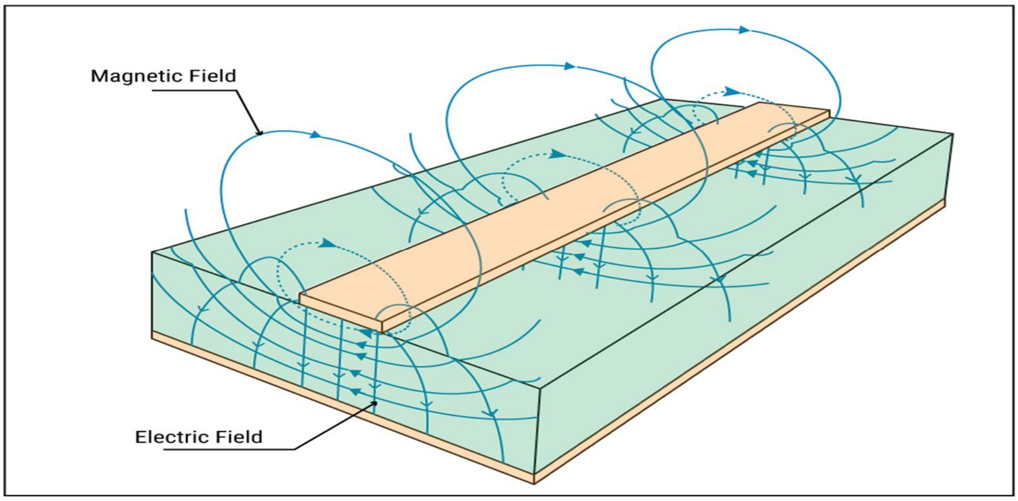
Theory:

A microstrip is a type of planar transmission line that consists of a conductor fabricated on dielectric substrate along with a grounded plane. It consists of a conductor of width W, a dielectric substrate of thickness d and permittivityϵ_r.



It is used to carry Electromagnetic waves (EM waves) or microwave frequency signals and also to design and fabricate RF and microwave components such as directional coupler, power divider/combiner, filter, antenna, MMIC etc.

A micro strip can be fabricated by photolithographic processes, can be easily miniaturized and can also be easily integrated with both passive and active microwave devices.



Magnetic field – concentric circles around the micro strip.
Electric field – starts from the top of the strip (high potential) and ends perpendicularly to the ground plane (low potential).
As you can see the above the figure, electric field and magnetic field are present in two asymmetric mediums, therefore the microstrip does not support a pure TEM wave. They support hybrid TM-TE wave.
Therefore, in a micro strip the dominant mode of propagation is Quasi-TEM (Transverse electromagnetic) due to which the phase velocity, characteristic impedance and field variation in the cross-section become frequency dependent.
The electric energy stored in the microstrip arrangement lies in both air and the dielectric, so the effective dielectric constant will satisfy the relation $0 < \epsilon_{eff} < \epsilon_r$.

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left(1 + 12\frac{h}{\mathrm{W}}\right)^{-1/2} \text{ for } \frac{W}{\mathrm{h}} \geq 1$$

The phase velocity and propagation constant is given by

$$v_p = \frac{c}{\sqrt{\epsilon_{eff}}}$$

$$\beta = k_0\sqrt{\epsilon_{eff}}$$

If the dimensions of the microstrip line are known, then the characteristic impedance Z_0 is calculated as

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

For a given characteristic impedance Z_0 and dielectric constant ϵ_r, the $\frac{W}{\mathrm{d}}$ ratio can be found as

$$\frac{W}{\mathrm{d}} = \begin{cases} \dfrac{8e^A}{e^{2A} - 2} & \text{for } \dfrac{W}{\mathrm{d}} < 2 \\ \dfrac{2}{\pi}\left[\mathrm{B} - 1 - \ln(2\mathrm{B} - 1) + \dfrac{\epsilon_r - 1}{2\,\epsilon_r}\left\{\ln(\mathrm{B} - 1) + 0.39 - \dfrac{0.61}{\epsilon_r}\right\}\right] & \text{for } \dfrac{W}{\mathrm{d}} > 2 \end{cases}$$

Where,

$$A = \frac{Z_0}{60}\sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1}\left(0.23 + \frac{0.11}{\epsilon_r}\right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}}$$

Attenuation due to dielectric loss:-

$$\alpha_d = \frac{k_0\, \epsilon_r(\, \epsilon_0 - 1) \tan\delta}{2\sqrt{\epsilon_{eff}}(\, \epsilon_r - 1)} \text{ Np/m}$$

Where,
Tanδ = loss tangent of the dielectric.

$$\text{Filling factor} = \frac{\epsilon_r(\, \epsilon_{eff} - 1)}{\epsilon_{eff}(\, \epsilon_r - 1)}$$

The attenuation due to conductor loss is given by

$$\alpha_c = \frac{R_s}{Z_0 W} \text{ Np/m}$$

Where,

$R_s = \sqrt{\frac{w\, \mu_0}{2\sigma}}$ = surface resistivity of the conductor.

Total attenuation constant (α) = $\alpha_d + \alpha_c$.

Theoretical calculation:

-{{Determine the width and length of the microstrip line using python program}}

Procedure:

1. Draw a dielectric box with dielectric constant (ϵ_r), length L, width W and thickness h.
2. Draw a rectangle (of same length) above the dielectric box to get microstrip line.
3. Draw another rectangle (with the same dimensions of the box) to form ground.
4. Now select microstrip line and ground and assign perfect E to their boundaries.
5. Draw another two rectangles along Y-axis to define the lumped ports.
6. Draw another box with radiation boundary whose dimensions are much more than the dielectric box.
7. Add solution setup.
8. Validate, analyze, and simulate all.
9. Go to Results and plot s parameters and impedance Z_0 in the operating frequency.

Results and Conclusion:

- Geometry of microstrip structure
- Plot the magnitudes of the transmission coefficient, reflection coefficient of the design circuits over a frequency range.
- Determine the impedance of circuits in the operating frequency.
- Provide Concluding Remarks

Evaluation		
Component	**Maximum Mark**	**Obtained Mark**
Preparation	20	
Methodology	20	
Results & analyses	30	
Quiz	10	
TOTAL	**80**	

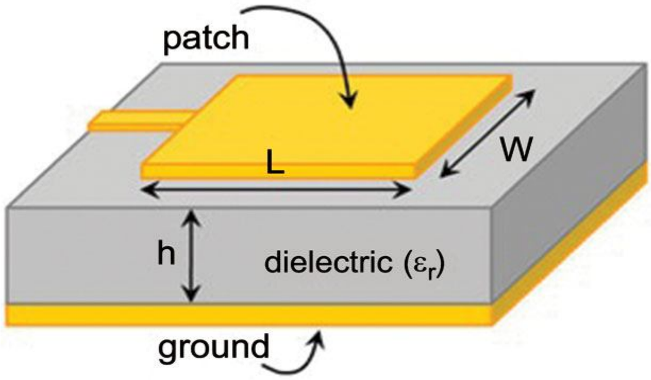
Exp.No:2 **Design and Simulation of Rectangular Microstrip Patch Antenna**
Date:

Aim of Experiment: To design and study the characteristics of Rectangular Microstrip patch antenna.

Specification:
Dielectric constant of the substrate (ϵ_r) =
Thickness of dielectric substrate (h) =
Transmission line Impedance (Z_0) =
Range of Resonant frequency =

Software Requirement:
- Ansys HFSS.

Theory:
An individual micro strip antenna consists of a patch of metal, dielectric and a metal plate for ground. Rectangular patch consists of an extremely thin conducting metallic foil that is deposited on a dielectric material and has got an underlined grounding plane. Together constitute the concept of rectangular patch antenna.
Micro strip antennas are usually fabricated using photolithographic techniques on a printed circuit board (PCB) and are mostly used at microwave frequencies.



The patch antenna, micro strip transmission line and ground plane are made of high conductivity metal (typically copper). The patch is of length L, width W, and sitting on top of a substrate (some dielectric circuit board) of thickness h with permittivity. The frequency of operation of the patch antenna is determined by the length L. The center frequency will be approximately given by,

$$f = \frac{c}{2L\sqrt{\epsilon_r}} = \frac{1}{2L\sqrt{\epsilon_0\epsilon_r\mu_0}}$$

Width of the patch:

$$W_p = \frac{c}{2f_0\sqrt{\frac{\epsilon_r+1}{2}}}$$

Effective dielectric constant (ϵ_{eff}):

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\sqrt{\frac{1}{1 + 10\frac{h}{W_p}}}$$

The extension of length (ΔL):

$$\Delta L = 0.412h \frac{(\epsilon_{eff} + 0.2)(\frac{W_p}{h} + 0.264)}{(\epsilon_{eff} - 0.258)(\frac{W_p}{h} + 0.813)}$$

Effective length (L_{eff}):

$$L_{eff} = \frac{c}{2\, f_0 \sqrt{\epsilon_{eff}}}$$

Physical length of the patch is given by

$$L_p = L_{eff} - 2\Delta L$$

The width W of the micro strip antenna controls the input impedance. Larger widths also increase the bandwidth. By increasing the width, the impedance can be reduced. The width further controls the radiation pattern. The normalized radiation pattern is approximately given by:

$$E_\theta = \frac{sin\left(\frac{kWsin\theta sin\varphi}{2}\right)}{\frac{kWsin\theta sin\varphi}{2}} cos\left(\frac{kL}{2} \sin\theta\cos\varphi\right) cos\varphi$$

$$E_\varphi = -\frac{sin\left(\frac{kWsin\theta sin\varphi}{2}\right)}{\frac{kWsin\theta sin\varphi}{2}} cos\left(\frac{kL}{2} \sin\theta\cos\varphi\right) cos\theta sin\varphi$$

Magnitude of fields is given by

$$f(\theta, \varphi) = \sqrt{{E_\theta}^2 + {E_\varphi}^2}$$

It is the fringing fields that are responsible for the radiation. The fringing fields near the surface of the patch antenna are both in the +y direction. Hence, fringing E-fields on the edge of the micro strip antenna add up in phase and produce the radiation of the micro strip antenna.

Current is usually applied at the point of feed and has got a maximum distribution at the centre of the patch and progressively decreasing value at the strength at the edges of the patch. At the same time the voltages having a certain distribution that is different from the current and its distributions are primarily maximum along the edges. Effectively this in turn realizes the actual fringe field along the edges of the patch region.

<u>Calculation</u>

….{Calculate using python programming:
1. The length and width of the patch calculation using the above expressions
2. Calculation of length and width of the feed line}….

Procedure:

1. First, use micro strip patch antenna calculator to find length and width of the patch.
2. Now draw a rectangle whose dimensions are twice the length of the patch and define it as ground.
3. Draw a box to construct substrate whose dimensions are same as of ground and assign its material to dielectric constant (ϵ_r).
4. Now draw a rectangle to construct patch.
5. Use micro strip line calulator to calculate the length and width of the feedline. Draw a rectangle to construct the feedline.
6. To match the impedances of the feed line and patch, draw a rectangle that has the dimensions corresponding to the transmission line impedance and subtract it from the patch.
7. Now use Boolean function ‘Unite’ to combine patch and the feed line.

8. Draw a rectangle to define lumped port.
9. Assign Perfect E boundary to ground and to the geometry 'unite'.
10. Draw another box with radiation boundary (around the geometry) whose dimensions are much larger than the substrate.
11. Add solution setup. Validate, analyze, and simulate all.
12. Add far field setup for $\varphi = 0^\circ$ and 90°, $\theta = 0^\circ$ and 360°.
13. Display vector representation of Electric field and Magnetic field.
14. Go to results and plot radiation pattern for Electric and magnetic fields, plot s-parameters vs. frequency graph and gain vs. frequency graph.

Results and Conclusion:

Plot 1: Design of Rectangular Micro strip patch antenna
Plot 2: S-parameters (S_{11}) (magnitude) vs. frequency (GHz)
Plot 3:
(a) Vector representation and Radiation plot of Electric field.
(b) Vector representation and Radiation plot of Magnetic field.
Plot 4: Gain (dB) vs. frequency (GHz)

Provide your concluding remarks

Evaluation		
Component	**Maximum Mark**	**Obtained Mark**
Preparation	20	
Methodology	20	
Results & analyses	30	
Quiz	10	
TOTAL	**80**	

Exp.No:3 **Design and Simulation of 90 degree Hybrid Directional Coupler**
Date:

Aim of Experiment: Study the characteristics of 90^0 hybrid coupler and its s-parameters

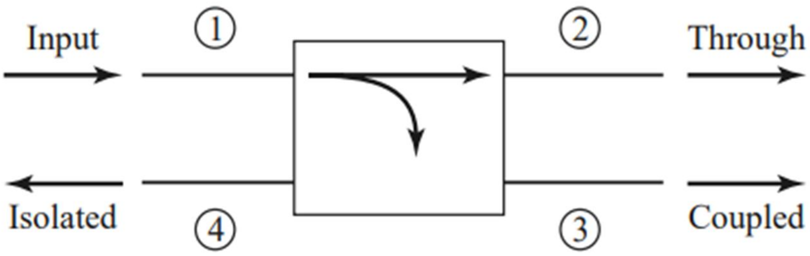
Specification:

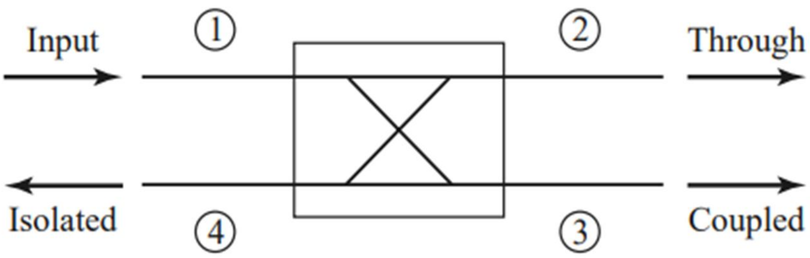
Dielectric constant:
Dielectric height (h): -----mm
Frequency: ------GHz

Software Requirement:
- Ansys HFSS

Theory:

Directional couplers are four-port circuits where one port is isolated from the input port. They are passive reciprocal networks. All four ports are (ideally) matched, and the circuit is (ideally) lossless. Directional couplers can be realized in micro strip, strip line, coax and waveguide. Representation of the directional coupler:





Properties of ideal directional coupler:

1. In an ideal directional coupler, all the four ports are perfectly matched. Therefore, no power reflects to the port.
$$S11 = S22 = S33 = S44 = 0$$
2. Ports 1, 4 and ports 2, 3 are perfectly isolated with each other. Therefore,
$$S14 = S41 = 0, \; S23 = S32 = 0.$$
3. Directional coupler exhibits symmetry property, therefore
$$S12 = S21, \; S13 = S31, \; S14 = S41$$
$$S23 = S32, \; S24 = S42, \; S34 = S43$$
4. A portion of the wave is coupled to port 3 but not coupled to port 4 which is traveling from port 1 to port 2. Similarly, a portion of the wave traveling from port 2 to port 1 is coupled to port 4 but not to port 3.
5. The coupling between port 1 and port 4 is like that between port 2 and port 3, and the degree of coupling depends on the structure of the coupler.
6. The outputs are always in phase quadrature; that is, they exhibit a phase difference of 90^0. For this reason, a directional coupler is called a *quadrature-type hybrid.*

There are 4 parameters associated with directional coupler.

1. Coupling factor
2. Directivity
3. Isolation
4. Insertion loss

By choosing $S_{12} = S_{34} = \alpha$; $S_{13} = \beta\, e^{j\theta}$ and $S_{24} = \beta\, e^{j\varphi}$

Coupling factor (C): The coupling factor of a directional coupler (DC) is defined as the ratio of the incident power (P_i) to the forward power (P_f) measured in dB. It indicates the fraction of input power coupled to the coupled port.

$$\mathrm{C} = 10\log\left(\frac{\mathrm{Pi}}{\mathrm{Pfc}}\right) = 10\ \log\left(\frac{\mathrm{P1}}{\mathrm{P3}}\right) = -20\log\beta\ \ dB.$$

Where, P_1 = power incident at port 1 and P_3 = power coupled at port 3

Directivity (D): It is defined as the ratio of forward power (P_f) to the back power (P_b) expressed in dB. Directivity is the ability to isolate coupled (port 4) and backward (port 3) ports.

$$\mathrm{D} = 10\log\left(\frac{\mathrm{Pfc}}{\mathrm{Pb}}\right) = 10\ \log\left(\frac{\mathrm{P3}}{\mathrm{P4}}\right) = 20\log\left(\frac{\beta}{|\mathrm{S14}|}\right)\ dB.$$

Isolation (I): It is defined as the ratio of power incident (P_i) to the power coupled in the isolated port (P_b) and is expressed in dB.

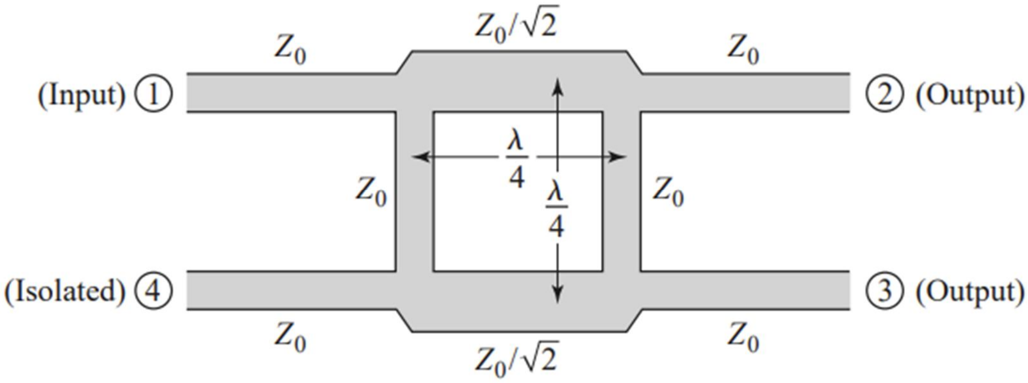
$$\mathrm{I} = 10\log\left(\frac{\mathrm{Pi}}{\mathrm{Pb}}\right) = 10\ \log\left(\frac{\mathrm{P1}}{\mathrm{P4}}\right) = -20\log|\mathrm{S14}|\ dB.$$

Insertion loss (L): Insertion loss accounts for the input power delivered to the through port diminished by power delivered to the coupled and isolated ports.

$$\mathrm{L} = 10\log\left(\frac{\mathrm{Pi}}{\mathrm{Pf}}\right) = 10\ \log\left(\frac{\mathrm{P1}}{\mathrm{P2}}\right) = -20\log|\mathrm{S12}|\ dB.$$

$$I = D + C\ \ dB.$$

Quadrature hybrids are 3 dB directional couplers with a 90◦ phase difference in the outputs of the through and coupled arms. This type of hybrid is often made in microstrip line or stripline form as shown in Figure. It is also known as a branch-line hybrid.



With all ports matched, power entering port 1 is evenly divided between ports 2 and 3, with a 90◦ phase shift between these outputs. No power is coupled to port 4 (the isolated port). The scattering matrix has the following form:

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

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

Procedure:

1) First, draw two squares of inner and outer dimensions as per the requirement.
2) Then use Boolean subtract to subtract two squares.
3) Now draw field lines using rectangles around near the four corners of the square.
4) Draw a rectangle so that all the previously drawn rectangles and squares are filled in it and name it as ground and use Boolean “unite” to combine all the geometry drawn.
5) Draw a substrate (box) which has same dimensions as of ground and assign the material with dielectric constant (ϵ_r).
6) Assign Perfect E boundary to ground and to the geometry ‘unite’.
7) Draw 4 rectangles along X and Z- axis to define the lumped ports.
8) Draw another box with radiation boundary (around the geometry) whose dimensions are much larger than the substrate.
9) Add solution setup. Validate, analyze, and simulate all.
10) Go to results and plot s-parameters vs. frequency graph

Results and Conclusion:

Plot: Simulated S-parameters (S_{11}, S_{12}, S_{21} and S_{22} only) (in dB) vs frequency (GHz)
Calculate: Coupling factor(dB); Directivity(dB); Isolation(dB); and insertion loss(dB)
Calculation:
Coupling factor (dB) = -20 log ß = -20 log | S_{13} | = .
Directivity (dB) = $20\, log \frac{ß}{|\, S14\, |}$ =
Isolation (dB) = -20 log | S_{14} | =
Insertion loss (dB) = -20 log | S_{12}

Provide your concluding remarks

Evaluation		
Component	**Maximum Mark**	**Obtained Mark**
Preparation	20	
Methodology	20	
Results & analyses	30	
Quiz	10	
TOTAL	**80**	

Exp.No:4 **Design and Simulation of Microstrip Ring Resonator**
Date:

Aim of Experiment: Study the characteristics of microstrip ring resonator its s-parameters

Specification:

Dielectric constant:
Dielectric height (h): -----mm
Frequency: ------GHz

Software Requirement:
- Ansys HFSS

Theory:

Microstrip resonators have been widely used for the measurements of dispersion, phase velocity, discontinuities, and dielectric constant. Microstrip resonators are used either as signal components, i.e., as frequency determining parts of oscillator circuits, or in coupled form for the realization of filters, couplers and other microwave circuits. The two configurations that are most often used are linear and ring resonator. The ring resonator has two advantages: it is free of open-ended effects and its curvature effects can be made negligible if its diameter is large enough with respect to the line width. The basic circuit of a microstrip ring resonator shown in Figure 1. The microstrip ring resonator has a wide range of applications, for this reason, the paper will make the design easer by using the curves and tables for calculate the mean radius, the length, and the width of the feed lines of the resonator.

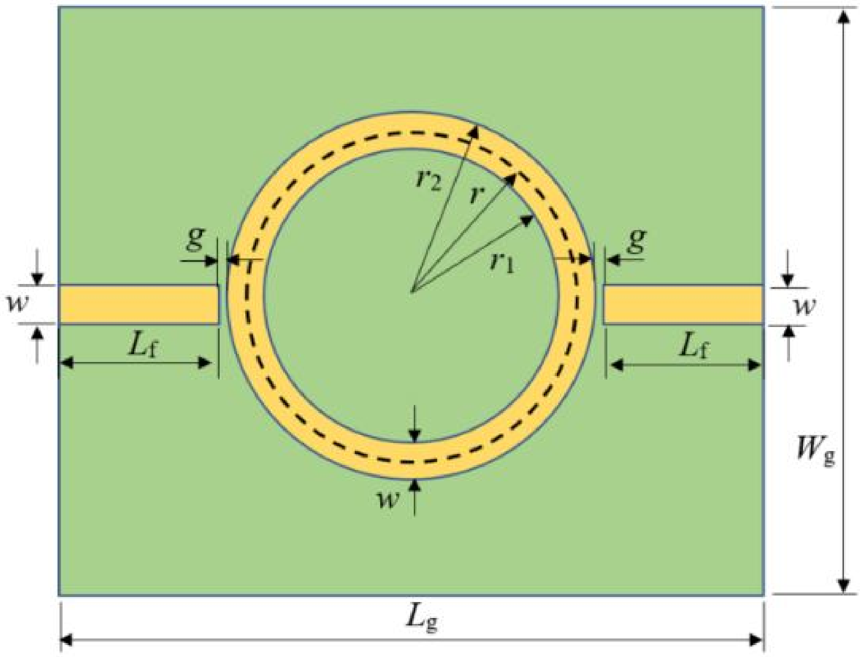


Fig.1 Layout of Microstrip Ring Resonator (MRR)

Design of Ring Resonator:

For the PCB substrate height h, we take that $w/h > 1$ holds, which is typically the case, for which w can be found by iteratively solving the two coupled Equation (1) and (2)

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{w}\right)^{-1/2} \tag{1}$$

$$Zo = \frac{120\pi}{\sqrt{\epsilon_{eff}}\left[\frac{w}{h} + 1.393 + \frac{2}{3}\ln\left(\frac{w}{h} + 1.444\right)\right]} \tag{2}$$

When the mean circumference of the ring resonator is equal to an integral multiple of a guided wavelength, resonance is established. This may be expressed as:

$$2\pi r = n\lambda_g \; for \; n = 1,2,3 \tag{3}$$

Where n is the mode number, λ_g is the guided wavelength and r is mean radius of the ring that equals the average of the outer and inner radius. This relation is valid for the loose coupling case, as it does not take into account the coupling gap effects. From the Eq (3), the resonant frequencies for different modes can be calculated since λ_g are frequency dependent.

For a microstrip ring resonator, λ_g can be related to frequency by

$$\lambda_g = \frac{\lambda_o}{\sqrt{\epsilon_{eff}}} = \frac{1}{\sqrt{\varepsilon_{eff}}} * \frac{c}{f} \tag{4}$$

Where c is the speed of light, ϵ_{eff} is the effective dielectric constant, λ_o is the free space wavelength and f is the resonant frequency.

Equation (3) becomes

$$r = \frac{nc}{2\pi f\sqrt{\varepsilon_{eff}}} \; for \; n = 1,2,3 \tag{5}$$

The feed line that is placed to the left and right of the ring is set to have its length L_f equal to

$$L_f = \frac{\lambda_g}{4} \tag{6}$$

While the value of the inner and the outer ring radii are

$$r_1 = r - \frac{w}{2} \tag{7}$$

$$r_2 = r + \frac{w}{2} \tag{8}$$

Results and Conclusion:

Plot: Simulated S-parameters (S_{11}) (in dB) vs frequency (GHz)
Simulated Impedance (Z11) (Real and Imag) vs frequency (GHz)

Provide your concluding remarks

Evaluation		
Component	**Maximum Mark**	**Obtained Mark**
Preparation	20	
Methodology	20	
Results & analyses	30	
Quiz	10	
TOTAL	**80**	