LABORATORY MANUAL

Subject code: ECC507

Subject name: RF PG Modular Lab-1

Course: M.Tech in RF & Microwave Engineering

DEPARTMENT OF ELECTRONICS ENGINEERING

Indian Institute of Technology(ISM), Dhanbad
Jharkhand, India

CONTENT

Experiment No-1

Aim: To design and implement dual band branch line coupler using stub technique for the operating frequency of 2.4GHz and 3.5GHz.

Software: ANSYS HFSS 14.0

Theory:

Coupler is a four-port device, which couples the power from input ports, while the fourth port is isolated. It is a passive device that divides and distributes power. Couplers have an additional "coupled" port which taps the main signal at a small fraction of the power of the through line. It takes one signal as the input and provides two outputs, one being the regular output and the other being the coupled output. Due to the inherent narrow-band nature of the conventional branch line coupler that is based on single section quarter-wavelength transmission lines, it suffers from narrow bandwidth and large size. In modern communication system, need for dual band operation and compactness possess new requirements. The Characteristics of a coupler are defined as follows:

Transmission factor (T) = 10log(P2/P1)

Coupling factor (C) = 10log(P1/P3) dB

Isolation (I) = 10log(P1/P4) dB

Directivity (D) = 10log(P4/P3) dB

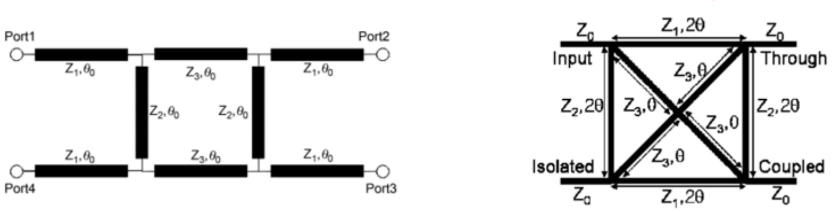


Fig. 1 Dual Band Branch line coupler

Design and observations:

- Design Specifications-: Substrate thickness:1mm, Dielectric Constant: 2.65
- The Geometric parameters of the branch line coupler needs to be calculated by going through the revised formulas: for center frequency 2.4GHz and 3.5GHz.

Table-I Observation Table

	Impedance(Ω)	Length(mm)	Width(mm)
Z_O			
Z_1			
Z_2			
Z_3			

Used Formulas:

For $W/h \leq 2$, $\dfrac{W}{h} = \dfrac{8\exp(A)}{\exp(2A) - 2}$,

with

$$A = \frac{Z_c}{60}\left\{\frac{\varepsilon_r + 1}{2}\right\}^{0.5} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left\{0.23 + \frac{0.11}{\varepsilon_r}\right\} \qquad (5)$$

And for

$$W/h \geq 2,\ \frac{W}{h} = \frac{2}{\pi}\left\{(B-1) - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right\},$$

with

$$B = \frac{60\pi^2}{Z_c\sqrt{\varepsilon_r}} \qquad (6)$$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10}{u}\right)^{-ab} \qquad (7)$$

where $u = W/h$, and

$$a = 1 + \frac{1}{49}\ln\left(\frac{u^4 + \left(\frac{u}{52}\right)^2}{u^4 + 0.432}\right) + \frac{1}{18.7}\ln\left[1 + \left(\frac{u}{18.1}\right)^3\right] \qquad (8)$$

$$b = 0.564\left(\frac{\varepsilon_r - 0.9}{\varepsilon_r + 3}\right)^{0.053} \qquad (9)$$

$$\lambda_g = \frac{300}{f(\mathrm{GHz})\sqrt{\varepsilon_{re}}}\ \mathrm{mm}. \qquad (10)$$

Interpretation and Results:

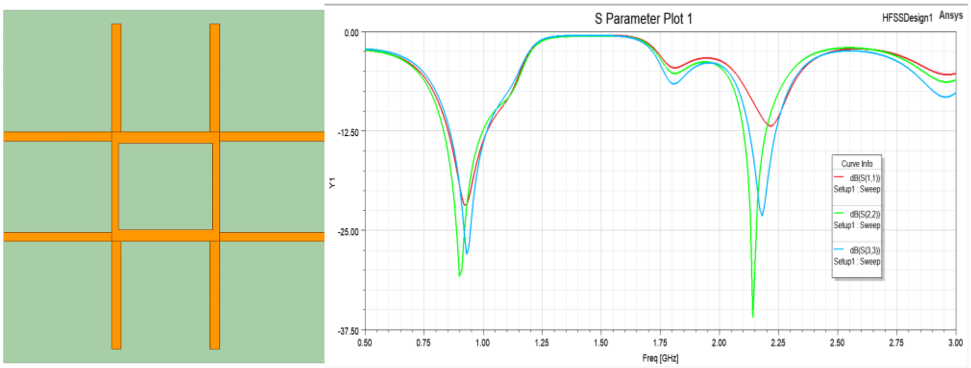
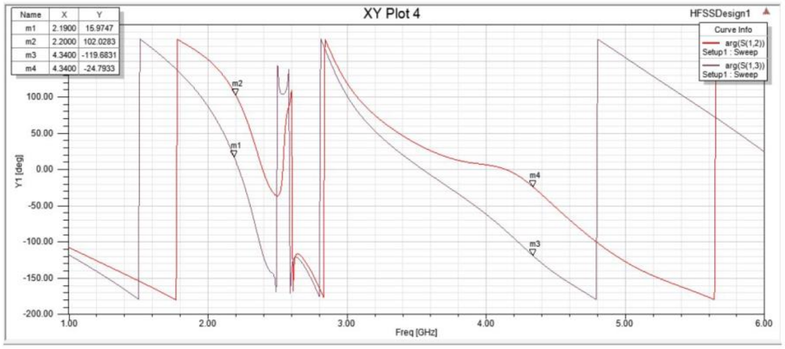


Fig. 2 Designed Layout of dual band coupler and S-parameters



Name	X	Y
m1	2.1900	15.9747
m2	2.2000	102.0283
m3	4.3400	-119.6831
m4	4.3400	-24.7933

Fig. 3 Phase Plot of S_{12} and S_{13}

Conclusion:

The design of dual band coupler has been simulated and results were verified.

Experiment No -2

Aim: To design and implement Hybrid ring using stub technique for the operating frequency of 0.9GHz and 2GHz.

Software: ANSYS HFSS 14.0

Theory:

Rat race coupler consists of angular line of proper electrical length to sustain standing waves, to which four arms are connected at proper intervals by means of series or parallel junctions. The 180° Hybrid coupler (sometimes known as the “ring”, “rat-race”) is a lossless, matched and reciprocal 4-port device. This coupler is likewise a 3dB coupler: the power into a given port (with all other ports matched) is equally divided between two of the three output ports. But the relative phase between the outputs, however, is dependent on which port is the input. Like the quadrature hybrid, it is simply made of lengths of transmission lines. However, unlike the quadrature hybrid, the characteristic impedance of each line is identical ($\sqrt{\mathbf{2}}$Z0), but the lengths of the lines are dissimilar. This 4-port device can be analysed in the same way by using one plane of bilateral symmetry and performing even/odd mode operation. However, we must perform two separate analyses: one using sources on Port-1 and -3. While the other uses sources on Port-2 and -4.

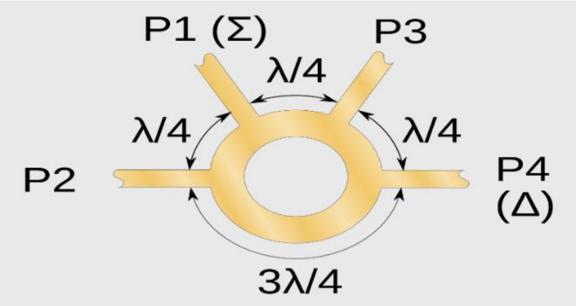


Fig. 1 Rat-Race coupler

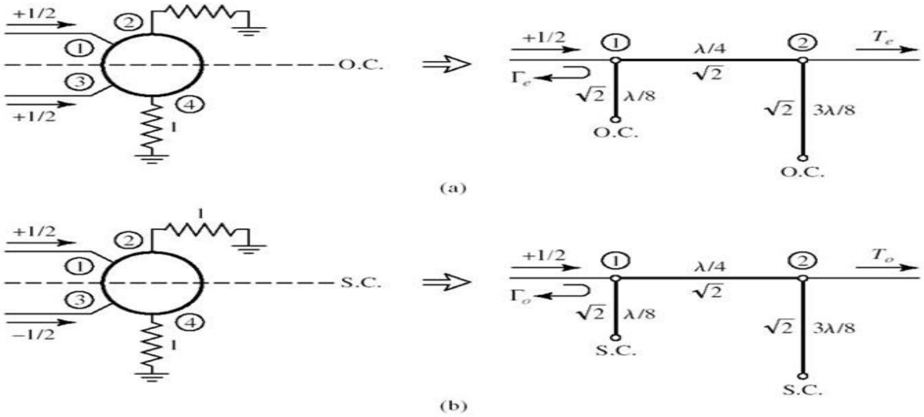


Fig. 2 Even-odd mode analysis of Rat-Race coupler

Applications:

Hybrid Coupler is a 4-Port network widely used in RF and microwave Circuits.

- Balanced Mixers
- Balanced Amplifiers.
- Power Multipliers and dividers
- Antenna feeding networks.
- Duplexers

Design and observations:

- Design Specifications-: Substrate thickness: 0.8mm, Dielectric Constant: 3.38
  The Geometric parameters of the hybrid ring needs to be calculated by going through the revised formulas: for centre frequency 0.9GHz and 2GHz.

Table-I Observation Table

	Impedance(Ω)	Length(mm)	Width(mm)
Z_O			
Z_1			
Z_2			
Z_3			

Interpretation and Results:

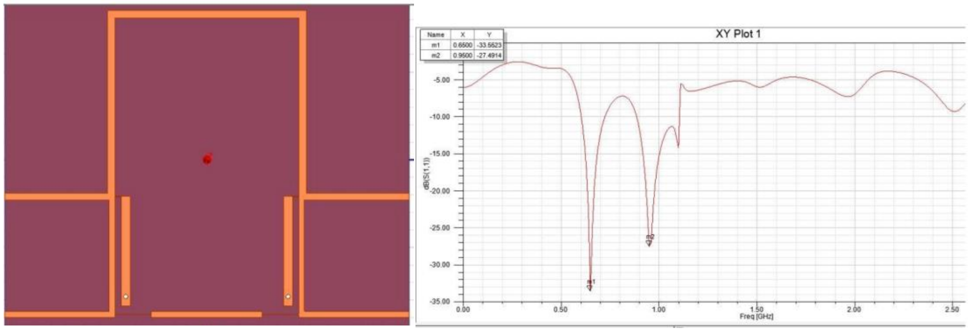
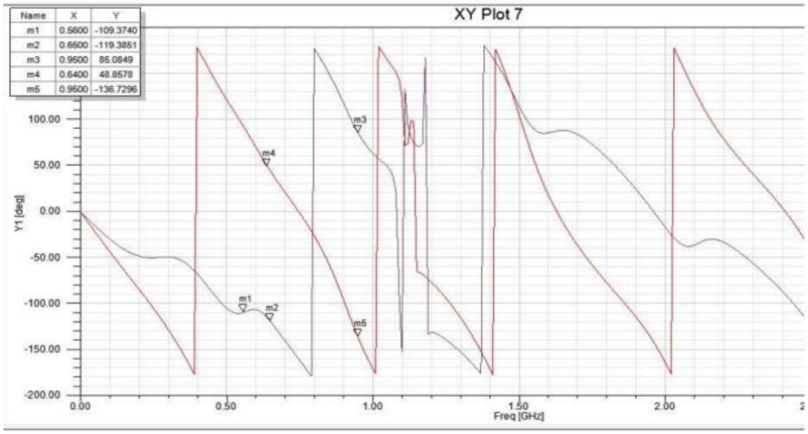


Fig. 2 Designed Layout of rat-race coupler and S-parameters



Name	X	Y
m1	0.5600	-109.3740
m2	0.6500	-119.3851
m3	0.9500	85.0849
m4	0.6400	48.8578
m5	0.9500	-136.7296

Fig. 3 Phase Plot of S_{12} and S_{13}

Conclusion:

The design of rat-raace coupler has been simulated and results were verified.

Experiment No. 3

Experiment Name: Design a compact planar Rat- Race coupler.

AIM: Design a compact planar Rat- Race coupler using ATL Technology at 2GHz.

Software used: HFSS

Theory: Both 90 and 180 hybrids find numerous applications in microwave systems. The 180◦ hybrid junction is a four-port network with a 180◦ phase shift between the two output ports. It can also be operated so that the outputs are in phase. A signal applied to port 1 will be evenly split into two in-phase components at ports 2 and 3, and port 4 will be isolated. If the input is applied to port 4, it will be equally split into two components with a 180◦ phase difference at ports 2 and 3, and port 1 will be isolated. When operated as a combiner, with input signals applied at ports 2 and 3, the sum of the inputs will be formed at port 1, while the difference will be formed at port 4. Hence, ports 1 and 4 are referred to as the sum and difference ports, respectively.

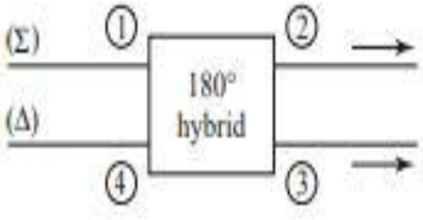


Fig 3. Symbol for 180◦ hybrid junction

The Artificial Transmission Line (ATL) concept has been applied to reduce the physical size of planar circuits.

Design

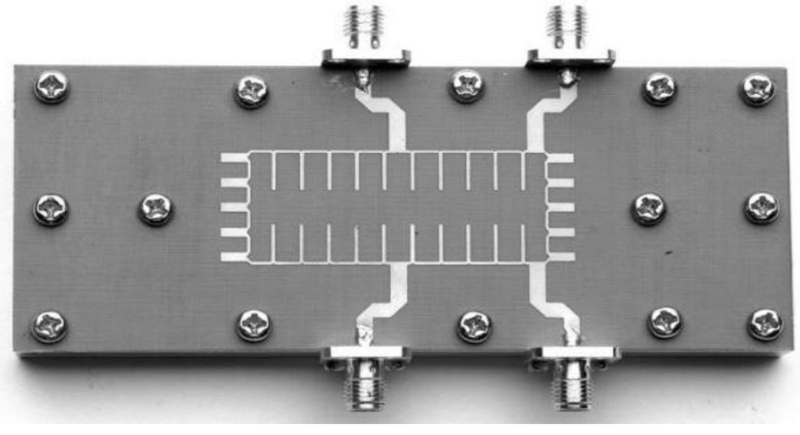


Fig3.2 Photograph of fabricated 1.8-GHz compact rat-race hybrid.

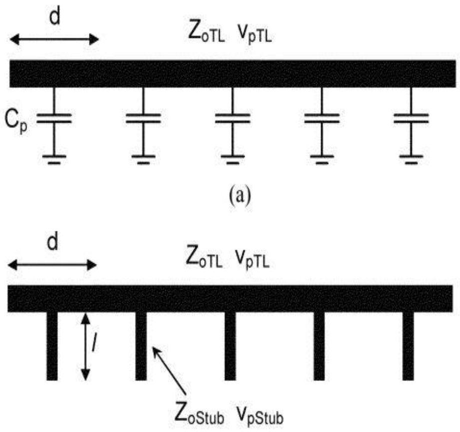


Fig 3.3 ATL assembled from: (a) transmission line and shunt capacitances and (b) transmission line and open-circuit shunt stubs.

CALCULATIONS:

The ATL comprises N (integer) unit cells and, hence, for an **N** section ATL, its electrical length (ϕ_{ATL}) is given by:

$$\phi_{\mathrm{ATL}} = \frac{N d \omega_o}{v_{p\mathrm{ATL}}} = N d \omega_o \sqrt{L\left(C + \frac{C_p}{d}\right)} \quad \textbf{(1)}$$

$$d = \frac{Z_{o\mathrm{ATL}} \phi_{\mathrm{ATL}} v_{p\mathrm{TL}}}{Z_{o\mathrm{TL}} N \omega_o} \quad \textbf{(2)}$$

$$C_p = \frac{\phi_{\mathrm{ATL}} \left({Z_{o\mathrm{TL}}}^2 - {Z_{o\mathrm{ATL}}}^2\right)}{N \omega_o {Z_{o\mathrm{TL}}}^2 Z_{o\mathrm{ATL}}}. \quad \textbf{(3)}$$

$$Z_{o\mathrm{ATL}} = \sqrt{\frac{L}{C + \frac{C_p}{d}}}$$

$$v_{p\mathrm{ATL}} = \frac{1}{\sqrt{L\left(C + \frac{C_p}{d}\right)}} \quad \textbf{(4)}$$

Where ω_o is the angular frequency of interest. For the case of the hybrids considered in this study (ϕ_{ATL}) is either π or $\frac{\pi}{2}$, as the case may be. **L** and **C** can be obtained by solving above equations, hence, **d** and C_p can be solved for a given transmission line. Length of the transmission line **Nd**.

DESIGN PROCEDURE:

70.7 Ω ATL (stubs pointed inward)	**Calculated(mm)**	**Optimized(mm)**
W_{TL}		
d		
W_{Stub}		
L		
N		

70.7 Ω ATL (stubs pointed outward)	**Calculated(mm)**	**Optimized(mm)**
W_{TL}		
d		
W_{Stub}		
L		
N		

Observation:

1) Observe S_{11}, S_{12} ,S_{13} ,S_{14} of the conventional design.

2) Observe S_{11}, S_{12} ,S_{13} ,S_{14} of the ATL design.

CONCLUSION:

Area of Compact Rat Race coupler = mm^2

Area Of Conventional Rat Race coupler= mm^2

% Reduction in the Area = %

Experiment No. 4

Experiment Name: Design a compact planar Branch line coupler.

AIM: Design a compact planar Branch line coupler using ATL Technology at 2GHz.

Software used: HFSS

Theory: Quadrature hybrids are 3 dB directional couplers with a 90◦ phase difference in the outputs of the through and coupled arms. 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).

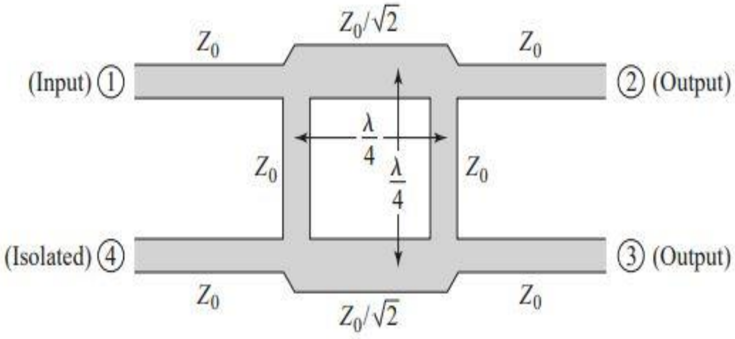


Fig. 4.1 Geometry of a branch-line coupler

The Artificial Transmission Line (ATL) concept has been applied to reduce the physical size of planar circuits.

Design:

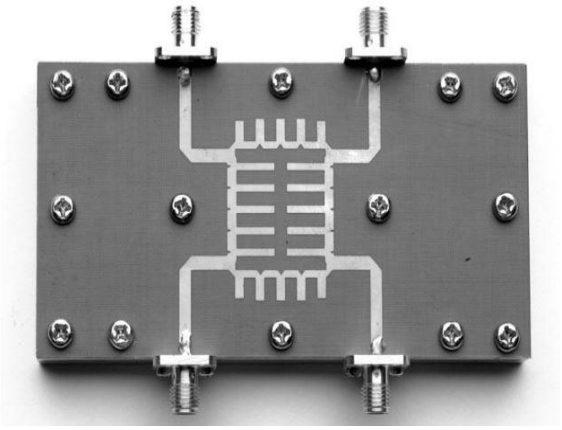


Fig 4.2 Photograph of fabricated 1.8-GHz compact branch-line hybrid.

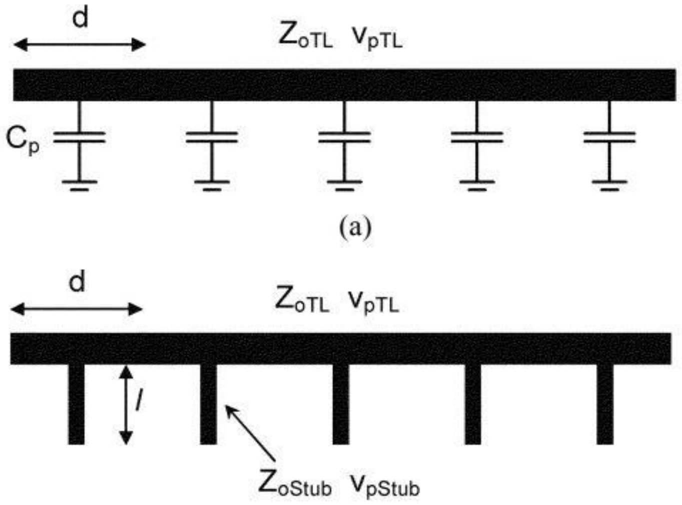


Fig 4.3 ATL assembled from: (a) transmission line and shunt capacitances and (b) transmission line and open-circuit shunt stubs.

CALCULATIONS:

The ATL comprises N (integer) unit cells and, hence, for an **N** section ATL, its electrical length (ϕ_{ATL}) is given by:

$$\phi_{\mathrm{ATL}} = \frac{Nd\omega_o}{v_{p\mathrm{ATL}}} = Nd\omega_o\sqrt{L\left(C + \frac{C_p}{d}\right)} \qquad (1)$$

$$d = \frac{Z_{o\mathrm{ATL}}\phi_{\mathrm{ATL}}v_{p\mathrm{TL}}}{Z_{o\mathrm{TL}}N\omega_o} \qquad (2)$$

$$C_p = \frac{\phi_{\mathrm{ATL}}\left({Z_{o\mathrm{TL}}}^2 - {Z_{o\mathrm{ATL}}}^2\right)}{N\omega_o {Z_{o\mathrm{TL}}}^2 Z_{o\mathrm{ATL}}}. \qquad (3)$$

$$Z_{o\mathrm{ATL}} = \sqrt{\frac{L}{C + \frac{C_p}{d}}}$$

$$v_{p\mathrm{ATL}} = \frac{1}{\sqrt{L\left(C + \frac{C_p}{d}\right)}} \qquad (4)$$

Where ω_o is the angular frequency of interest. For the case of the hybrids considered in this study (ϕ_{ATL}) is either π or $\frac{\pi}{2}$, as the case may be. **L** and **C** can be obtained by solving above equations, hence, **d** and C_p can be solved for a given transmission line. Length of the transmission line **Nd**.

DESIGN PROCEDURE:

50 Ω ATL (stubs pointed inward)	**Calculated(mm)**	**Optimized(mm)**
W_{TL}		
d		
W_{Stub}		
L		
N		

35 Ω ATL (stubs pointed outward)	**Calculated(mm)**	**Optimized(mm)**
W_{TL}		
d		
W_{Stub}		
L		
N		

Observation:

1) Observe S_{11}, S_{12} ,S_{13} ,S_{14} of the conventional design.

2) Observe S_{11}, S_{12} ,S_{13} ,S_{14} of the ATL design.

CONCLUSION:

Area of Compact Branch Line coupler = mm^2

Area Of Conventional Branch Line coupler= mm^2

% Reduction in the Area = %

Experiment No-5

Aim: Design and Implementation of open stub low pass filter.

Software: ANSYS HFSS 14.0

Theory:

A filter is a two port network used to control the frequency response at a certain point in an RF and microwave system by providing transmission at frequencieswithin the passband of the filter and attenuation in the stopband of the filter.The filter design includes frequency characteristics of periodic structureswhich consist of a transmission line or waveguide periodically loaded with reactive elements. Usually these criteria are consummated victimization waveguide cavity or stuff resonator loaded cavity filters attributable to their low loss. However, so as to scale back size, weight and value. There has been a growing interest in flattened structures.

Design and Observation:

- Design specifications: substrate thickness: 0.635mm, Dielectric constant: 8
- The geometric parameters of dual band Wilkinson power divider needs to be calculated by going through the revised formulas.

Table – 1 Observation table

	Impedance (Ω)	Length (mm)	Width (mm)
Z_O			
Z_1			
Z_2			
Z_3			

Interpretation And Results:

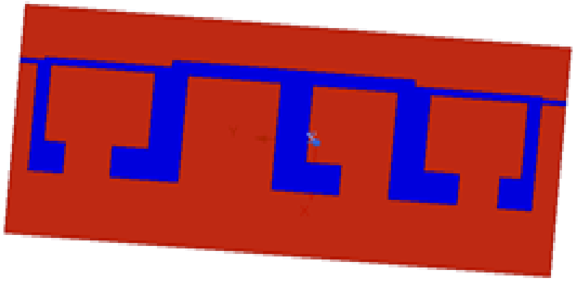


Fig .1 Designed layout of low pass filter

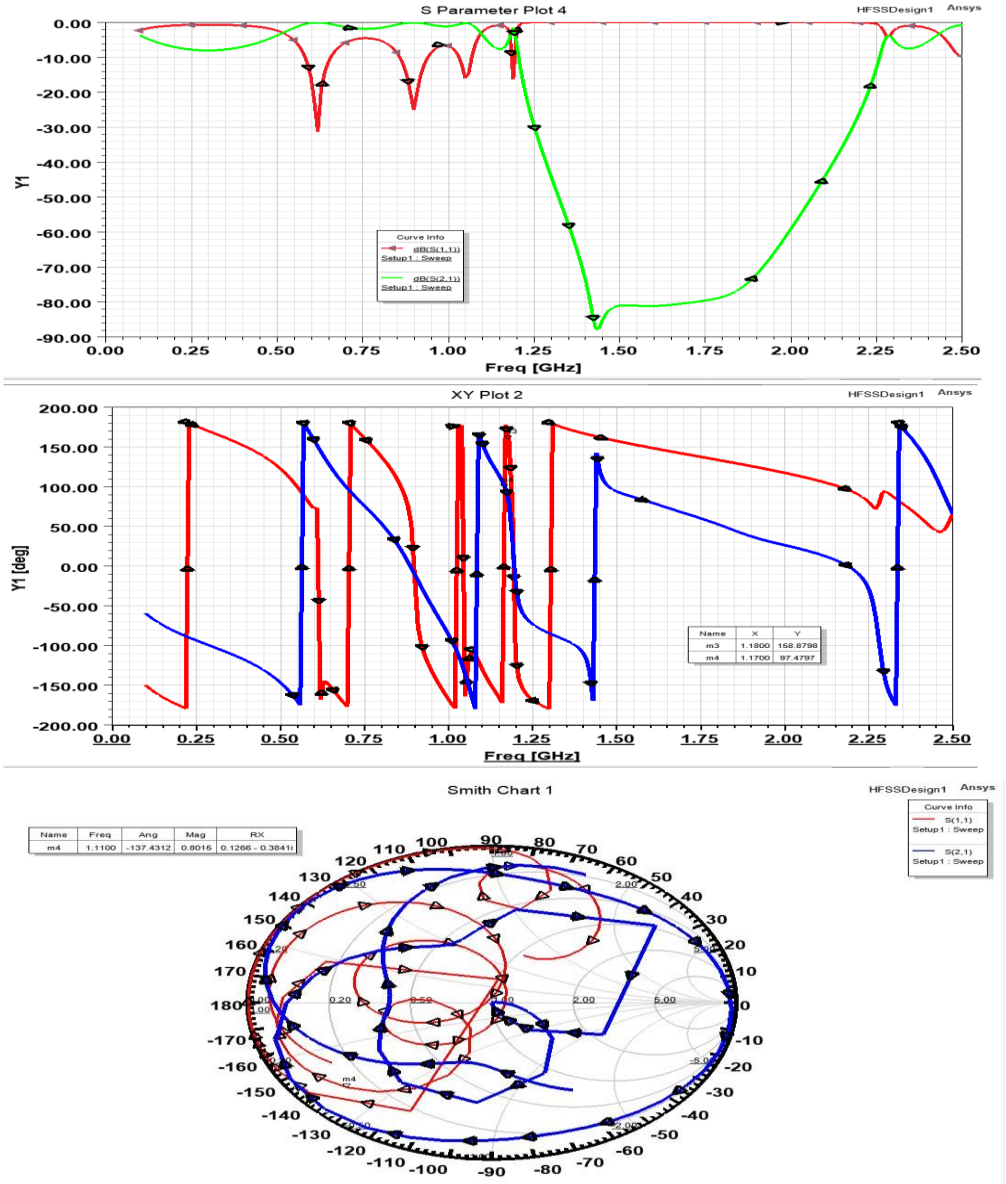


Fig. 2 (a) s parameter (b) phase plot (c) smith chart

Conclusion:

- We successfully designed and verified the performance of the folded open stub Microstrip low pass filter but we need more optimization to get cut-off frequency for 1.4 GHz.
- Microstrip design parameters of a five pole, stub band pass filter withshort circuited stubs.
- The design of open stub low pass filter has been simulated and results are verified.

Experiment No -6

Aim: Design and Implementation of dual band Wilkinson power divider circuit at frequency range 1 to 5 GHz.

Software: ANSYS HFSS 14.0

Theory:

The Wilkinson power divider /combiner is one of the most basic components in microwave circuits and system. For the Wilkinson power divider, a dual frequency operation scheme has been proposed using two section impedance transformers and a parallel RLC circuit. In the proposed method, the dual mode operation is achieved by adding a transmission line stub in the middle of the conventional Wilkinson divider structure. The two bands operating frequencies are selected by varying the length and the impedances of the lines. No additional lumped element is needed for dual band operation other than single resistor.

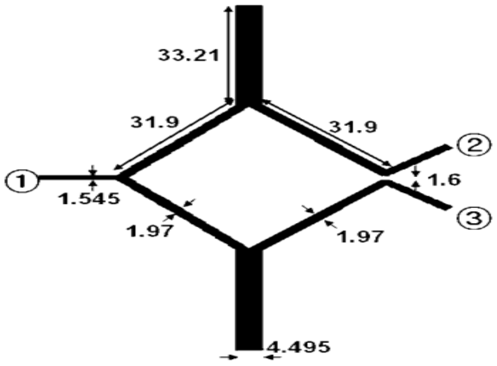


Fig. 1 Dual band wilkinson power divider

Design and Observation:

- Design specifications: substrate thickness: 1.6mm, Dielectric constant: 4.4
- The geometric parameters of dual band Wilkinson power divider needs to be calculated by going through the revised formulas.

Table – 1 Observation table

	Impedance (Ω)	Length (mm)	Width (mm)
Z_O			
Z_1			
Z_2			
Z_3			

Interpretation And Results:

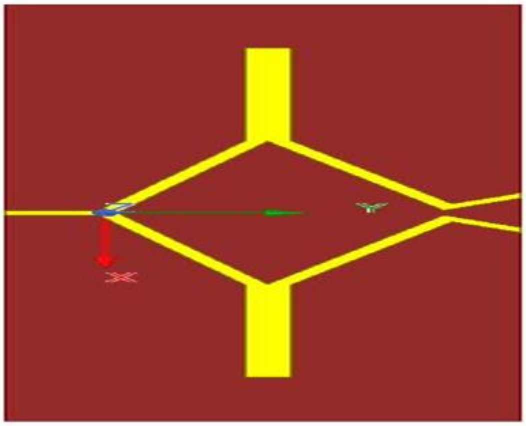
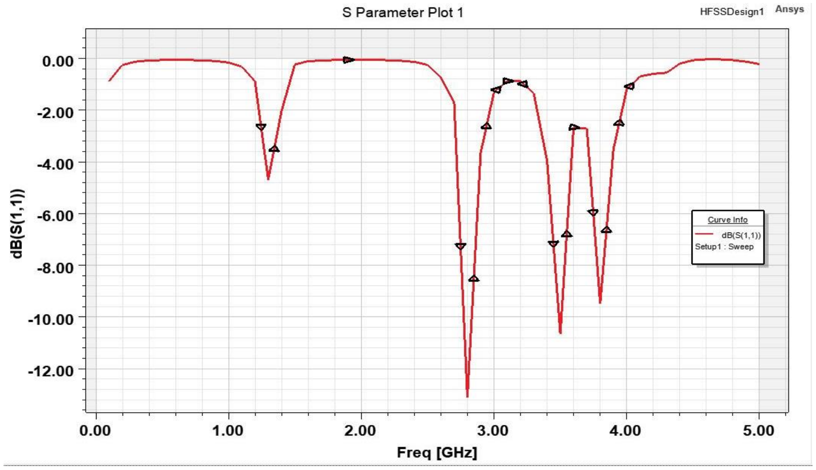


Fig . 2 Designed Layout od dual band wilkinson power divider

Fig. 3 S Parameter



Conclusion:

The design of dual band Wilkinson power divider has been simulated and results are verified.

Experiment no. 7

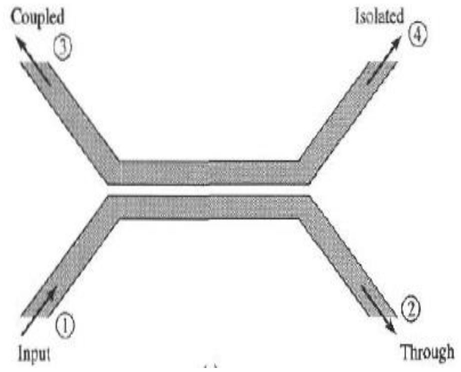
Experiment Name: Dual Band Coupled Line Directional Coupler.

Aim: A dual-band coupled-line coupler with an arbitrary coupling coefficient.

Software used: HFSS Software

Theory:

Coupled line directional coupler is operated based on the power coupling principle between two unshelled transmission lines due to the electromagnetic field interaction of each lines. Such lines are referred to as coupled transmission lines. One can consider this principle as like as the principle of the electrical transformer. A geometry and ports designations of a conventional coupled line coupler is shown in Fig.1.



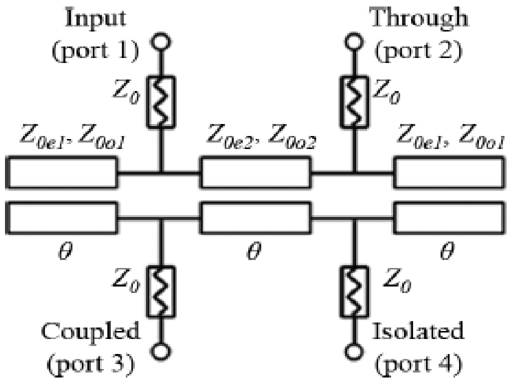


Fig.1. Geometry and port designations of a coupled line coupler. Fig 2. Schematic diagram of designed dual-band coupler.

Design Formulas:

A dual-band coupled line coupler is shown in Fig. 2 with port terminated by the impedance of Z_0.
Other parameters are given as bellow
θ = electrical length of coupled lines.
Z_{0e1} and Z_{0e2}= Even- mode characteristic impedances of coupled lines
Z_{0o1} and Z_{0o2}= Odd-mode characteristic impedances of coupled lines
f_1 and f_2 =designed or required center frequencies.

The relationship of above parameters are given

$$\theta_1 = \pi - \theta_2 \qquad \frac{f_2}{f_1} = \frac{\theta_2}{\theta_1} \qquad \theta_1 = \frac{\pi}{1 + \frac{f_2}{f_1}}. \tag{1}$$

$$Z_{0e2}Z_{0o2} = \frac{Z_0^2}{\sin^2\theta} \qquad (2)$$

$$C' = \frac{\frac{Z_{0e2}}{Z_{0o2}} - 1}{\frac{Z_{0e2}}{Z_{0o2}} + 1} = \frac{\frac{Z_{0e1}}{Z_{0o1}} - 1}{\frac{Z_{0e1}}{Z_{0o1}} + 1} \qquad (3)$$

$$\frac{Z_{0e1}}{Z_{0e2}} = \frac{Z_{0o1}}{Z_{0o2}} = k \qquad (4)$$

where

$k = \tan^2\theta.$

Design procedure:

1. Take two designed frequencies f_1 and f_2.
2. Calculate θ, sin(θ),tan(θ) using (1) where $\theta=\theta_1$ or θ_2
3. Calculate Z_{0e2} and Z_{0o2} using (3).
4. Calculate Z_{0e1} and Z_{0o1} using (4).
5. Design the structure and verify its results with HFSS software.

Observation:

1. Observe the magnitude and phase of S11 and S41
2. Observe Magnitude and phase of S21 and S31.
3. Observe the phase difference between the two output ports.

References

1. D. M Pozar “Microwave Engineering”, Welly Publication.
2. X. Wang, W. Yin and K. Wu, "A Dual-Band Coupled-Line Coupler With an Arbitrary Coupling Coefficient," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 60, no. 4, pp. 945-951, April 2012, doi: 10.1109/TMTT.2012.2185949.

Experiment No. 8

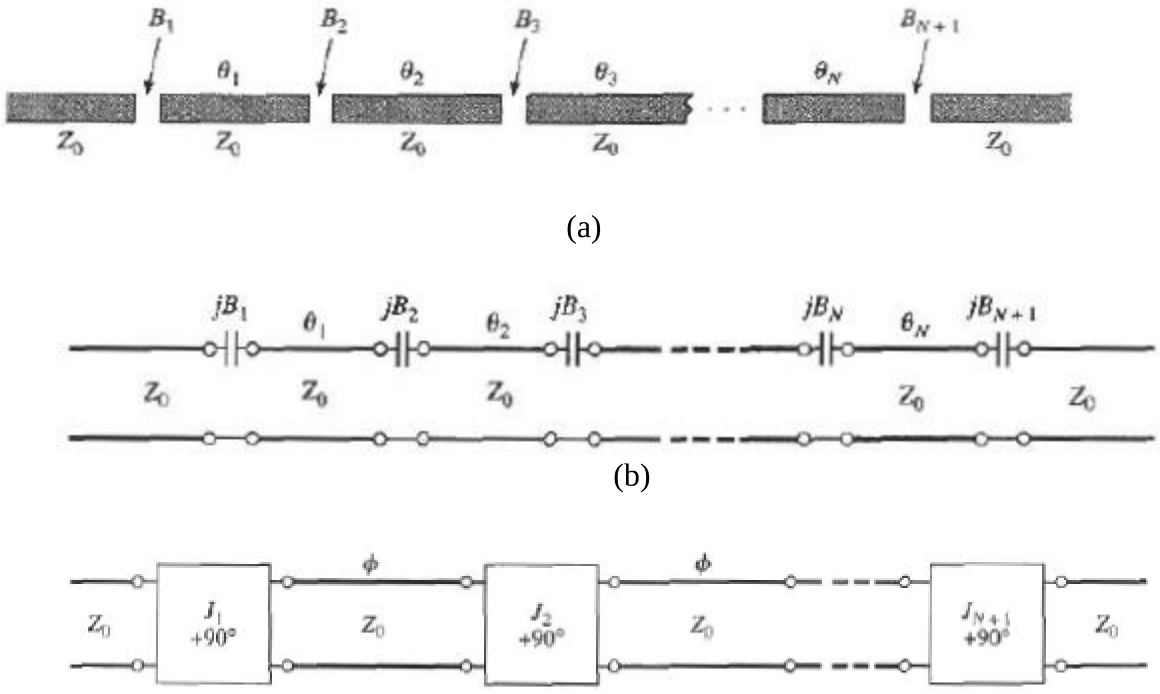
Experiment Name: Band Pass Filter Using Capacitive Coupled Resonator.

Aim: Design a band pass filter using capacitive coupled series resonator.

Software used: HFSS Software

Theory:

The coupling of electromagnetic filed between two unshelled transmissions line stubs are also used to construct many types of filters. Based on this working principle, the filter can be categorized with coupled line filter which is similar to the coupled line coupler while other one coupled resonator type. In this experiment, Coupled Resonator filter will be considered. It is well known that gap between two transmission lines stubs look like series capacitive resonant circuits. These gaps can be approximated as series capacitors. This series capacitors are used to implement the capacitive-gap coupled resonator filter here. A capacitive-gap coupled resonator filter and its equivalent transmission model are shown in Fig.1. An Nth order filter of this form will use N resonant series sections of transmission line with N+1 capacitive gaps between them. The resonators are approximately λ/2 long at the center frequency, ω_0



(a)

(b)

(c)

Fig.1 (a) the capacitive-gap coupled resonator band pass filter. (b) Transmission line model (c) Equivalent circuit using inverter and λ/2 resonator.

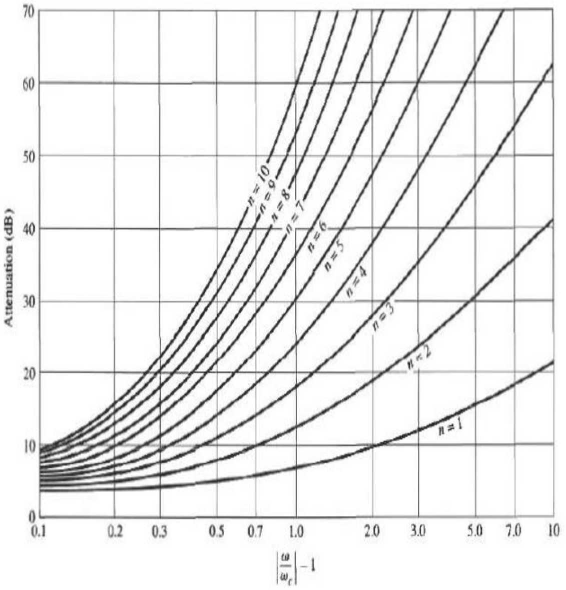


Table. 1

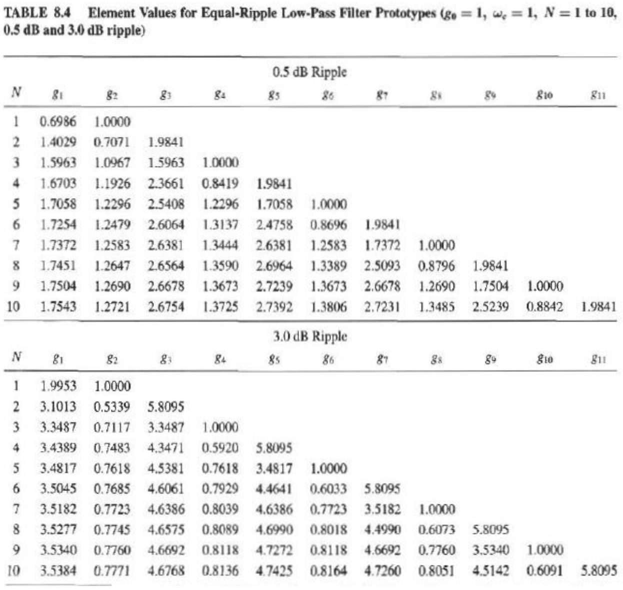


TABLE 8.4 Element Values for Equal-Ripple Low-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 1$, $N = 1$ to 10, 0.5 dB and 3.0 dB ripple)

0.5 dB Ripple

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	0.6986	1.0000									
2	1.4029	0.7071	1.9841								
3	1.5963	1.0967	1.5963	1.0000							
4	1.6703	1.1926	2.3661	0.8419	1.9841						
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000					
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841				
7	1.7372	1.2583	2.6381	1.3444	2.6381	1.2583	1.7372	1.0000			
8	1.7451	1.2647	2.6564	1.3590	2.6964	1.3389	2.5093	0.8796	1.9841		
9	1.7504	1.2690	2.6678	1.3673	2.7239	1.3673	2.6678	1.2690	1.7504	1.0000	
10	1.7543	1.2721	2.6754	1.3725	2.7392	1.3806	2.7231	1.3485	2.5239	0.8842	1.9841

3.0 dB Ripple

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	1.9953	1.0000									
2	3.1013	0.5339	5.8095								
3	3.3487	0.7117	3.3487	1.0000							
4	3.4389	0.7483	4.3471	0.5920	5.8095						
5	3.4817	0.7618	4.5381	0.7618	3.4817	1.0000					
6	3.5045	0.7685	4.6061	0.7929	4.4641	0.6033	5.8095				
7	3.5182	0.7723	4.6386	0.8039	4.6386	0.7723	3.5182	1.0000			
8	3.5277	0.7745	4.6575	0.8089	4.6990	0.8018	4.4990	0.6073	5.8095		
9	3.5340	0.7760	4.6692	0.8118	4.7272	0.8118	4.6692	0.7760	3.5340	1.0000	
10	3.5384	0.7771	4.6768	0.8136	4.7425	0.8164	4.7260	0.8051	4.5142	0.6091	5.8095

Table. 2

Used Formulas:

- ✓ *Normalized frequency*

$$\omega \longleftarrow \frac{\omega_0}{\omega_2-\omega_1}\left(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega}\right)=\frac{1}{\Delta}\left(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega}\right) \tag{1}$$

$$\Delta = \frac{\omega_2-\omega_1}{\omega_0}$$

ω_1; ω_2 =edges of the band pass filter.

ω_0 =Center frequency

Δ =fractional bandwidth

- ✓ *Inverter constants*

$$\begin{aligned} Z_0 J_1 &= \sqrt{\frac{\pi\Delta}{2g_1}}, \\ Z_0 J_n &= \frac{\pi\Delta}{2\sqrt{g_{n-1}g_n}}, \qquad \text{for } n = 2, 3, \ldots, N, \\ Z_0 J_{N+1} &= \sqrt{\frac{\pi\Delta}{2g_N g_{N+1}}}. \end{aligned} \tag{2}$$

- ✓ *Coupling susceptances*

$$B_i = \frac{J_i}{1-(Z_0 J_i)^2}. \qquad (3)$$

- ✓ *Coupling capacitor*

$$C_n = \frac{B_n}{\omega_0}. \qquad (4)$$

- ✓ *Electrical length of the resonator*

$$\theta_i = \pi - \frac{1}{2}[\tan^{-1}(2Z_0 B_i) + \tan^{-1}(2Z_0 B_{i+1})]. \qquad (5)$$

Design procedure:

1. Let X dB attenuation is required at ω GHz.
2. Calculate normalized frequency using (1) for given ω_0 center frequency (GHz) and Δ bandwidth (%).
3. Determine the order (N) of the filter from Table.1 to satisfy the given attenuation specification (X dB) at ω GHz.
4. Determine prototype values from Table.2 for required equal ripple (0.5 or 3 dB).
5. Calculate the inverter constants using (2).
6. Calculate the coupling susceptances using (3).
7. Calculate the coupling capacitor values using (4).
8. Determine the electrical length of the resonator using (5).
9. Design the structure and verify its results with HFSS software.

Observation:

1. Observe the magnitude response, S21 of passband filter(S21)
2. Observe attenuation at ω GHz
3. Observe ripple through the band

References

1. D. M Pozar “Microwave Engineering”, Welly Publication.