EE 611 : Microwave Integrated Circuits
Course Project
4x4 Butler Matrix Circuit Design

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1 Given Problem Statement:

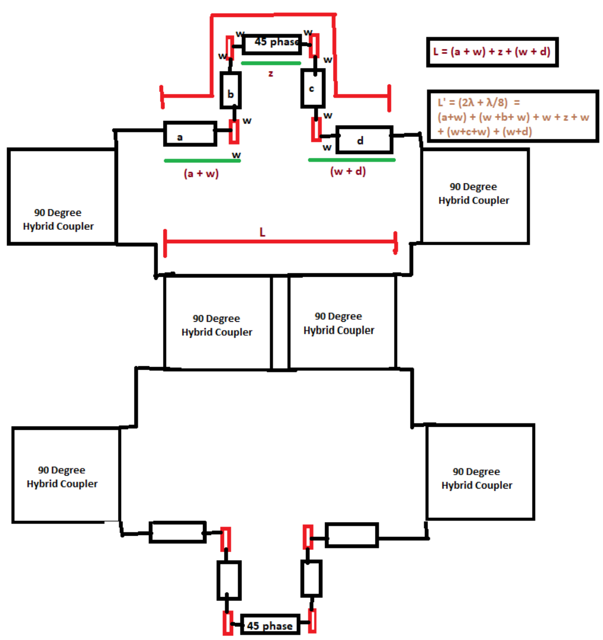
Design a Broadband 4X4 Butler Matrix Circuit Using Microstrip Transmission line at the frequency of operation 5.4 GHz. The design is to be fabricated on FR − 4 substrate with $\epsilon_r = 4.4$, h = 1.6 mm, tan $\delta = 0.02$.

2 Basic Theory

A **Butler matrix** is a network which is in general beam forming network used to feed a phased array of antenna elements.Its objective is to control the direction of a beam,or of radio transmission.
It work on the microwave frequencies range.Butler matrices can be used with both transmitters and receivers. Since they are passive and reciprocal, the same matrix can do both – in a transceiver for instance
The essential components required to build a Butler matrix are hybrid couplers and fixed-value phase shifters. In our design, we build circuit for 4x4 Butler matrix, which consists of (4 + 2) 90^o hybrid couplers and two 45^o phase shifter in between.
In this, we have 4 input port i.e. port 1,2,3,4 and 4 out port i.e. port 5,6,7,8.
Quadrature couplers are needed in four places, we chose to use the branchline coupler; it is comprised of four lines forming a box, with the vertical elements at impedance equal to Z0, and the horizontal elements at Z0/[sqrt(2)]. Two 45 degree fixed phase shifters are needed, here these are series lines sized to provide 45 degrees in length. Note that two crossovers are required, so the Butler matrix requires some type of 3D interconnect. when port 1 is the input, the four outputs are linearly phased in 45 degree increments (port 5 is at zero phase angle). When port 2 is the input, the phase increment is now 135 degrees, with

port 5 now at 90 degrees. When port 3 is the input, the phase increment is 270 degrees (port 5 is at 45 degrees). When port 4 is the input, the outputs are phased at 315 degree increments (port 5 is now at 135 degrees). We apply power to input ports and it gives output which having different phase difference at the output port which are to be used to transmit this powers to antenna connected at its output ports.
The Butler matrix circuit is used to feeds power to the elements with a progressive phase difference between elements such that the beam of radio transmission is in the desired direction.The beam direction is controlled by switching power to the desired beam port
Practically, it can be implemented in micro strip on a low-cost pcb.
Application:
(i.) to keep the beams pointing towards the mobile users from base staations of mobile networks.
(ii.) to produce a scanning beam are used in direction finding applications in general by linear antenna arrays driven by Butler matrices.

3 Our circuit Design Logic



Our 4x4 Butler Matrix circuit design logic for Length calculation

We are working on frequency of **5.4 GHz** so our wavelength calculated be $\lambda =$ **26.48507mm**.

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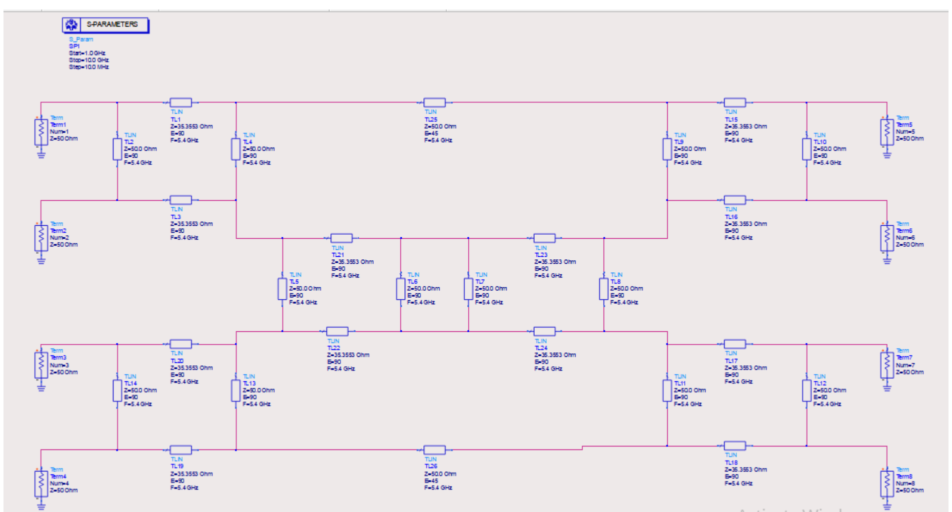
$$2\lambda + \frac{\lambda}{8} = 56.28077$$

In our circuit, we implemented circuit in two different way:
Model 1:
we have taken length such that:
z = 45^o TM-line impedance length after calculation be $\frac{\lambda}{8}$ = 3.77387mm.
w = bends width = 3.1126mm.

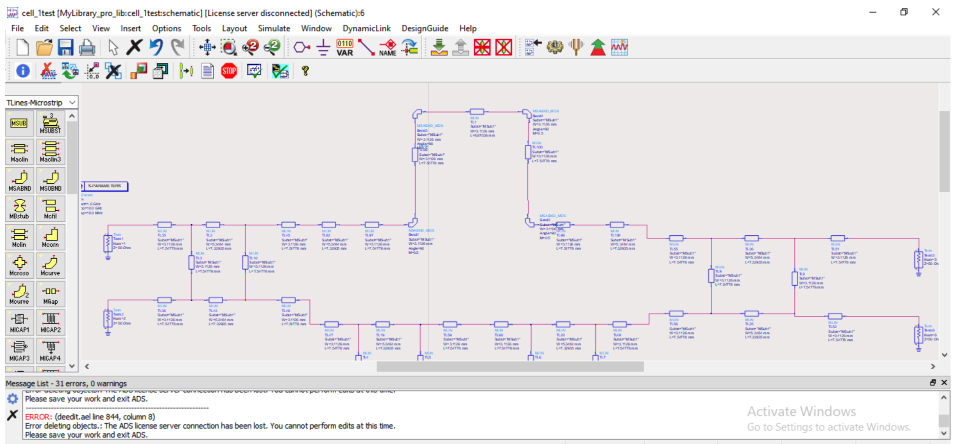
And then adjust the other part of the length (**L'**) such that it will be equal to $2\lambda + \frac{\lambda}{8}$ and simultaneously it will be such that **L = L'** by using the MLIN element of impedance Z_o.

Model 2:
we have taken length such that:
z = 45^o TM-line impedance length after calculation be $\frac{\lambda}{8}$ = 3.77387mm.
w = bends width = 5.660835mm. And then adjust the other part of the length (**L'**) such that it will be equal to $2\lambda + \frac{\lambda}{8}$ and simultaneously it will be such that **L = L'** by using the MLIN element of impedance Z_o.

4 Schematics



Our 4x4 Butler Matrix circuit Schematic using **IdeaL TLIN** elements

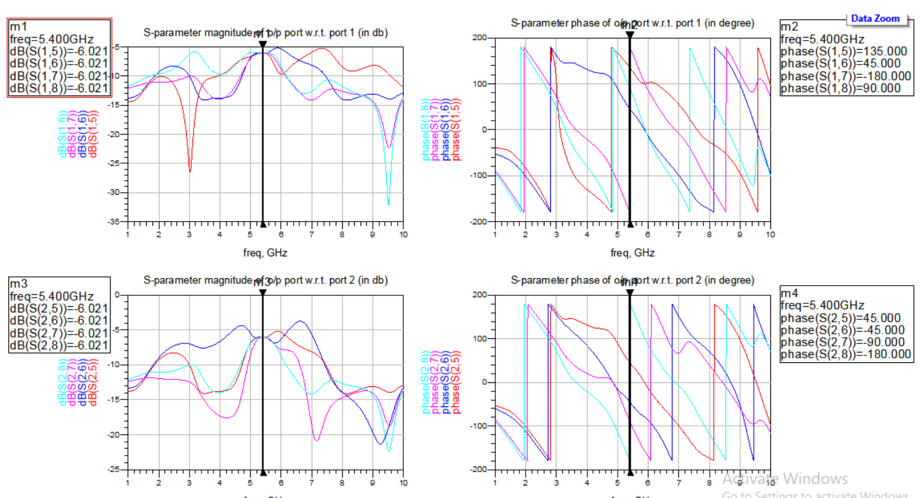


Upper Half of our 4x4 Butler Matrix circuit Schematic using MLIN elements
Lower half of schematic is exactly symmetric w.r.t Bottom axis

**(* I have lost my other schematics and one model simulation folder that I had taken after the licence gets expired.
But all are present in my ADS workspace but cannot access it due to license problem).**

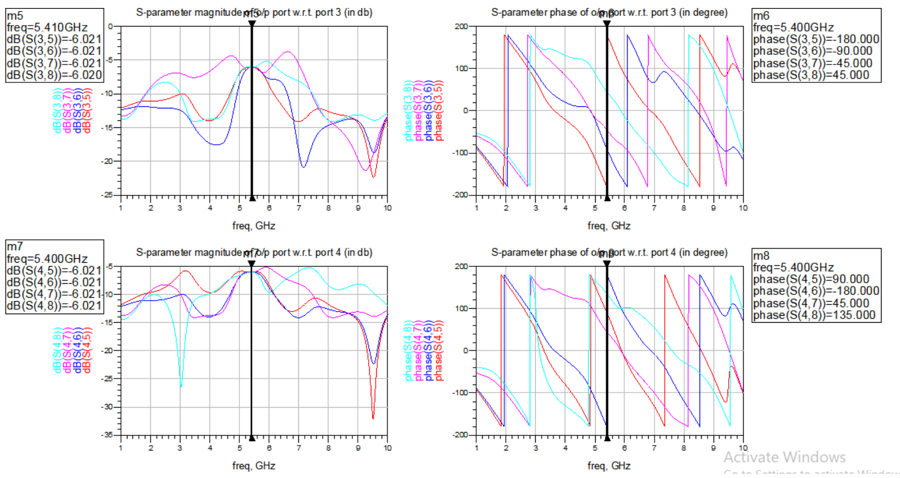
5 Simulation Results

5.1 Simulation Result of circuit using Ideal TLIN elements



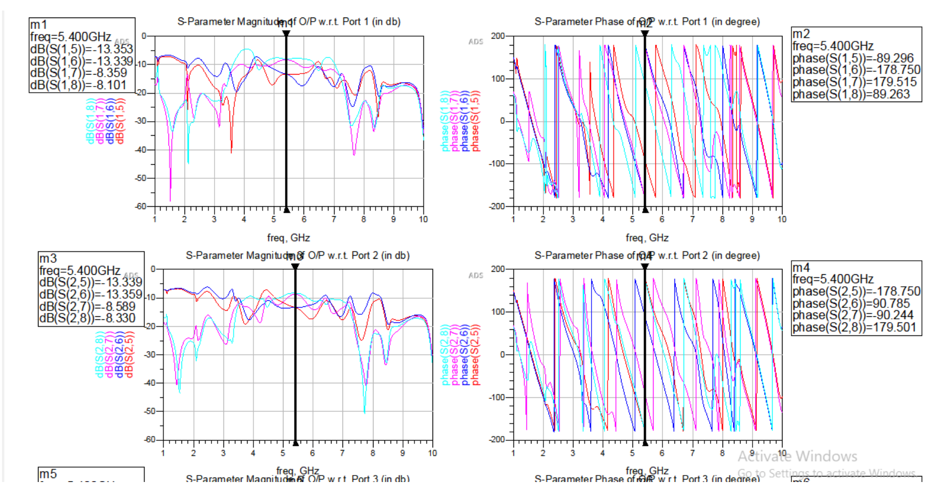
Simulation Plots of butler matrix circuit using Ideal Tlin elements
(Each coupler w/o Terminal TM-line Element)

S-parameter results of i/p port 1 and 2 w.r.t. O/p port(i.e p5,p6,p7,p8)

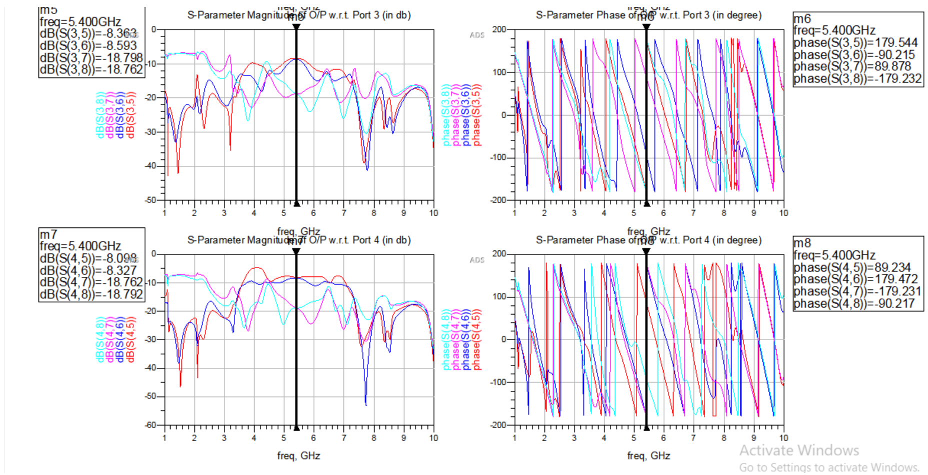


Simulation Plots of Butler matrix circuit using Ideal Tlin elements
(Each Hybrid coupler w/o Terminal TM-line Element)
S-parameter results of i/p port 3 and 4 w.r.t. O/p port(i.e p5,p6,p7,p8)

5.2 Simulation Result of circuit using MLIN elements

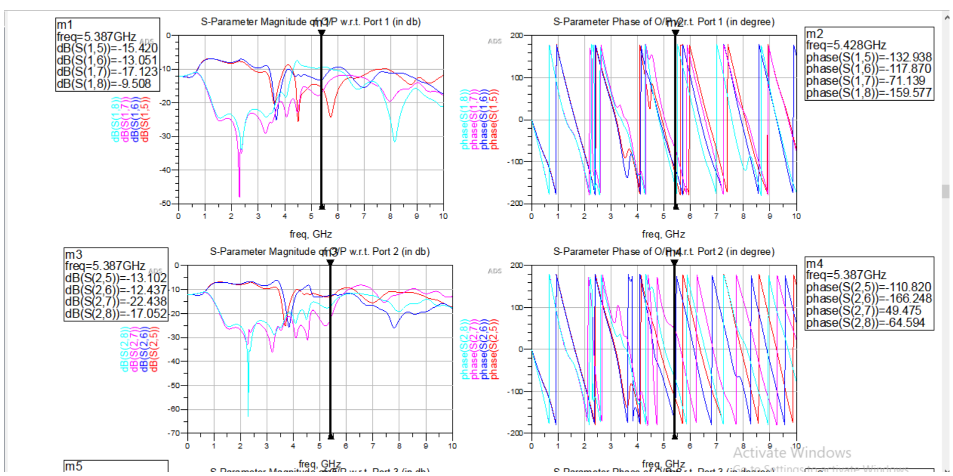


Simulation Plot of Butler circuit using Mlin elements
S-parameter results of i/p port 1 and 2 w.r.t. O/p port(i.e p5,p6,p7,p8)

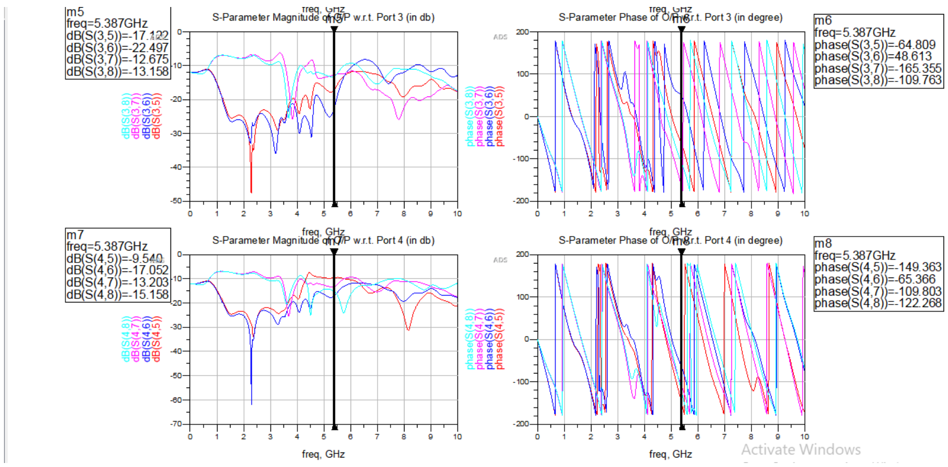


Simulation Plot of Butler circuit using Mlin elements
S-parameter results of i/p port 3 and 4 w.r.t. O/p port(i.e p5,p6,p7,p8)

5.3 Simulation results of em simulation of complete layout



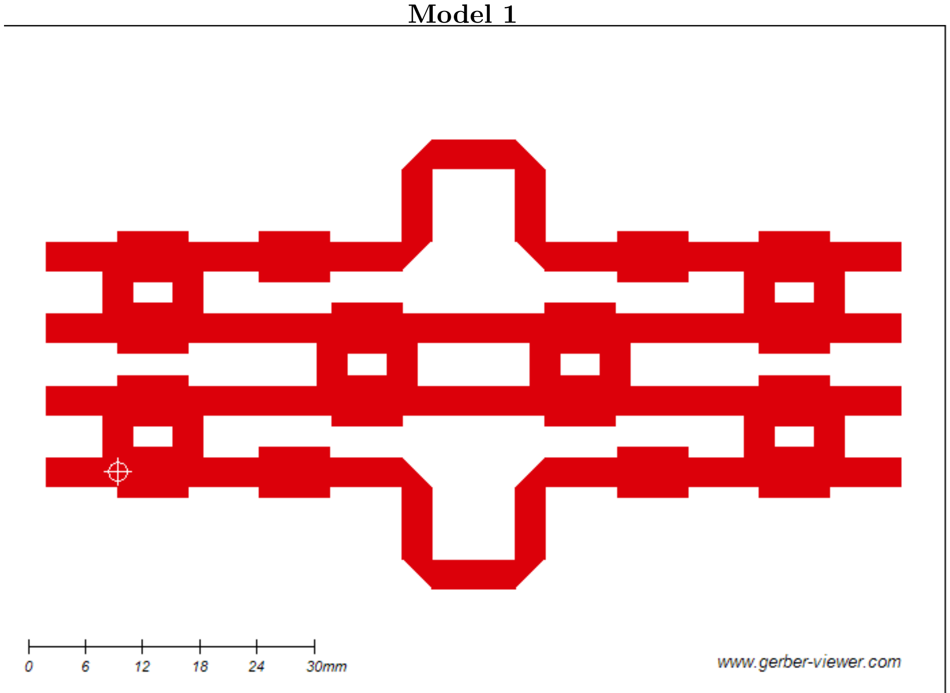
em Simulation Plot of of Completer layout of Butler matrix cicuit
S-parameter results of i/p port 1 and 2 w.r.t. O/p port(i.e p5,p6,p7,p8)



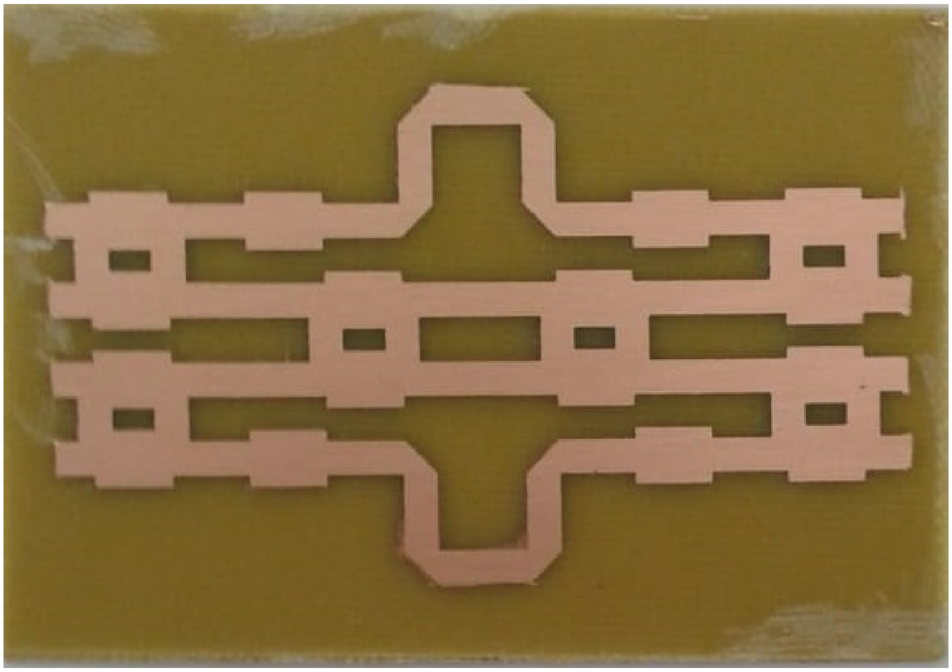
em Simulation Plot of of Complete layout of Butler matrix cicuit
S-parameter results of i/p port 3 and 4 w.r.t. O/p port(i.e p5,p6,p7,p8)

5.4 layouts of our Butler Matrix circuit

Model 1

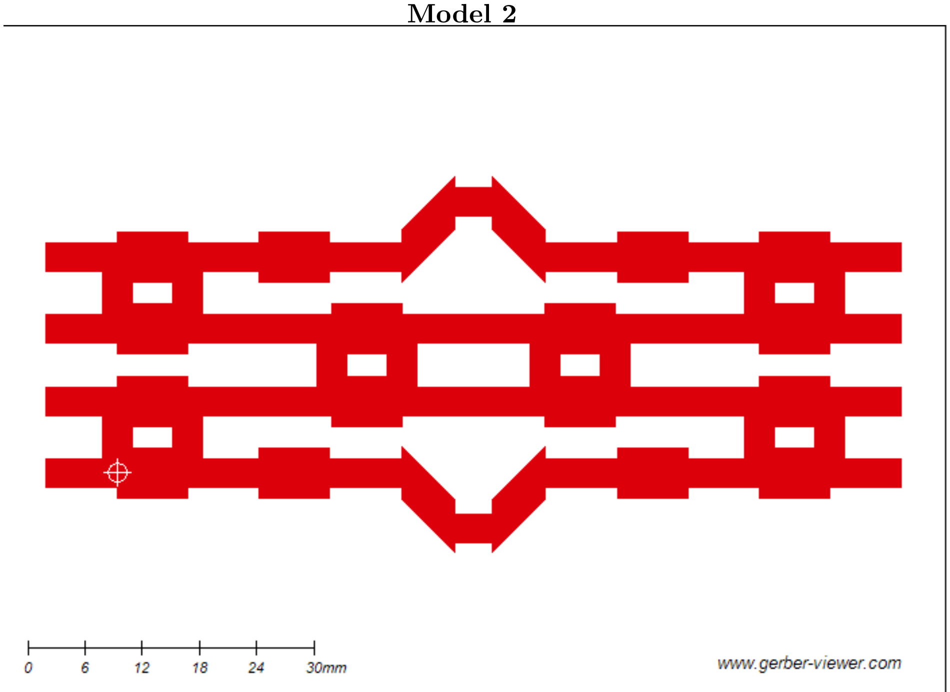


Layout of Butler Matrix circuit for **model 1**

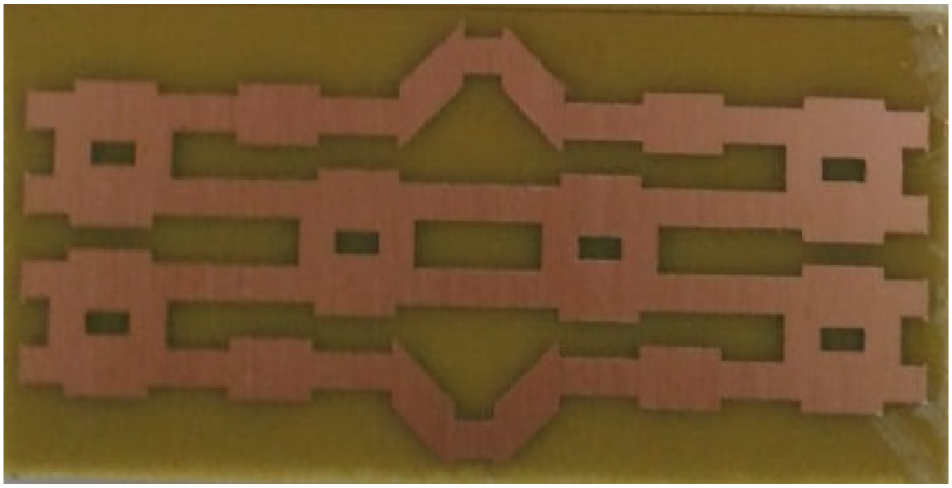


PCB Board Layout of Butler Matrix circuit for **model 1**

Model 2



Layout of Butler Matrix circuit for **model 2**



PCB Board Layout of Butler Matrix circuit for **model 2**