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Design and Development of Rectangular Waveguide Based Butler Matrix in X-Band

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***Abstract*—This paper gives the Design and Develop of the Rectangular Waveguide based Butler Matrix (2 x 2) in the X-Band of frequencies. The Butler matrix is type of a beam forming network and will be implemented at center frequency of 10 GHz, depending on which of N inputs is accessed. The waveguide could be a recommended technology for the Beam Forming Network because of its field shielding nature and will follow the WR-90 type waveguide specification. The future scope this research may goes to the space communications and for deep space communications.**

***Index terms*—Butler Matrix, Beam Steering, Rectangular Waveguide, X-band.**

I. INTRODUCTION

The development of Butler matrix in the field of Electromagnetic and Microwave provides steerable beam forming network. The Butler Matrix was first developed by Jesse Butler and Ralph Lowe. It is passive reciprocal network, so it works the same when it transmits the energy as when it receives the energy. It consist of N input port with N output port so forming N x N Butler Matrix. Its function is similar to a phased array antenna system.

Butler matrix has been implemented with various techniques such as waveguide, microstrip, multilayer microstrip, suspended stripline in which the Microstrip technique is widely used in the implementation due to its advantages but the Butler matrix realization from waveguide components results in a very low-loss network and almost all of the source power radiates in a beam that is oriented to a desired space direction therefore, this waveguide network is useful for high-power microwave transmission, moreover the main functionality of multiple beam forming network (the Butler Matrix) is to generate multiple beams from a same radiating aperture. Due to the field shielding nature, Waveguide will be the tool to transfer the electromagnetic energy in the most efficient way at microwave frequencies. Since the electromagnetic fields are completely contained within the waveguide, hence the radiation losses are kept very low.

The Selection of X-band in our research is to implement Beam Forming Network for the satellite communication. The range defined by IEEE is 8 GHz to 12 GHz. Using the X-band, beam formed by butler matrix can be used for satellite communications for up linking and down linking as well as in radar applications for target identification. Shorter wavelengths of X-band allow for higher resolution imagery from high resolution imaging Radars. So the X-band can be used in Radar applications such as target identification and discrimination.

So, taking the advantage of both the terms (Butler Matrix and Rectangular waveguide) in the Specific band of frequency, X-band, our purpose will be to form steerable beam forming network especially in satellite communication.

This could be an another way to improve the performance of mobile phone networks by increasing the angular resolution of the base station antennas; i.e., more than one radiating lobe is used to cover a specific geographic area (the cell). Also, as a key component of a switched beam smart antenna system, the problem of multipath fading, delay and interference, which is caused by reflection or diffraction in wireless communication systems, can be controlled by Smart antenna systems.

II. DESIGN PROCEDURE

Butler matrix will be firstly design in the CST Microwave Studio of CST Design Environment, for its software development. After successful implementation, further work will be carried out for the hardware part. The design of Butler matrix will be initiated by forming the Brick in the form of U.S. standard rectangular waveguide size WR-90 for the X-band. This is shown in Fig. 1. It will be given two ports, one is input and the other is output Fig. 2. For getting the another two port, same Brick will be constructed and will be Boolean add by another waveguide component so as to obtained the four port (2x2) means two inputs and two outputs waveguide ports as shown in Fig. 3.

In the Proposed 2x2 Butler Matrix Physical characteristics, Shorting ports (capacitive and inductive)

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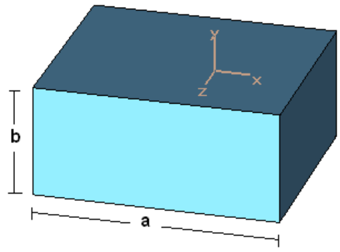
will be added to the structure for matching purpose which is shown in Fig. 4.



a=22.86mm and b=10.16mm
Fig. 1. Brick –A Rectangular Waveguide

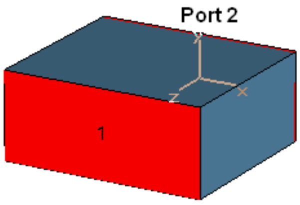


Fig. 2. WR-90 U.S. standard Rectangular Waveguide with port 1 and port 2.

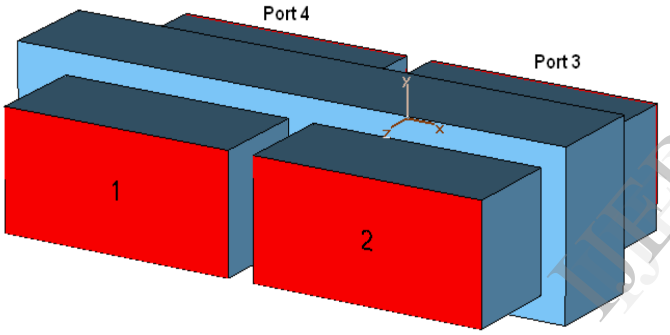


Fig. 3. A 2x2 Butler Matrix model by WR-90 U.S standard Rectangular Waveguide

These shorting ports are nothing but the two small rectangular bricks made up of PEC material. (Perfect Electric Conductor)

For the simulation process to start, some parameters must be specified. For this we will do "Set Units" first which will be given by—.Geometry "mm" , Frequency "GHz" , Time "s, Temperature "Celsius, Voltage "V, Current "A, Resistance " Ohm, Conductance "S, Capacitance "pF, Inductance "nH". Next to set will be Frequency Range —"8" to "12".

Unaltered the default Boundary Conditions and Background Material properties in the working environment, we will proceed to Solver parameters that is the final simulation which will be done by Transient Solver option. With Solver, the conditions to set will be—Calculation Type "TD-S, Stimulation Port "2", Stimulation Mode "1", Steady State Limit "-30", Mesh Adaption "False", .Calculate Modes Only "False", S Para Symmetry "False", Store TD Results In Cache "False", Full Deembedding "False", Use Network Computing "False".

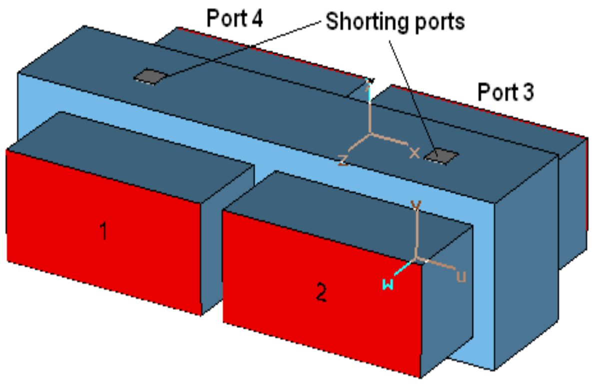


Fig. 4. Butler Matrix structure with Shorting Ports.

This Whole procedure will be implemented in the Vaccum condition in the CST microwave studio for getting the perfect results in the software.

The Proposed 2x2 Butler Matrix Electrical Characteristics will be achieved up to required value when the conditions written below are satisfied.

(A) The bandwidth of the proposed Butler Matrix will be in the range of 200MHz to 800MHz with the center frequency of 10GHz.

(B) The return loss of each Input and output port of the proposed Butler Matrix will be less than -15dB over the entire bandwidth.
That is the S-parameter values S_{11}, S_{22}, S_{33} and S_{44}

(C) The insertion loss of proposed 2x2 Butler Matrix will follow the FFT algorithm, that is the S-Parameters S_{32} and S_{42} should not be greater than -3dB loss.

For an instance, if the signal of amplitude 1Watt is applied at the Port 2 and looking for the signal to come out at Port 3 and Port 4, then S-parameter values for S_{12}, S_{22}, S_{32} and S_{42} will be first theoretically calculated by using the Scattering matrix properties. For an ideal case, S_{22} and S_{12} value should be zero, which are the return loss values and both the S_{32}, S_{42} values should be 0.707 which indicates that equal power will be divided in to Port3 and Port4. Same calculation can be done for the signal to be applied at other port such as Port1, Port3 and Port4. The calculated values for the Return and Insertion loss, in the case of other port as an input will be identical to that of Port2 calculation.

III. SIMULATION RESULTS

The Fig. 5 indicates the simulated values for the S-parameter (Linear) when the excitation signal is applied at port no 2 and taking the output at port3 and port4 for the frequency of 10 GHz. Similarly, we will apply the excitation signal at other port such as port 1, port 3 and port 4 for which we are getting the values of S-

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parameters as shown in Fig. 6. However, due to the dimension of structure and position of Shorting ports, the obtained values are short of that required one.

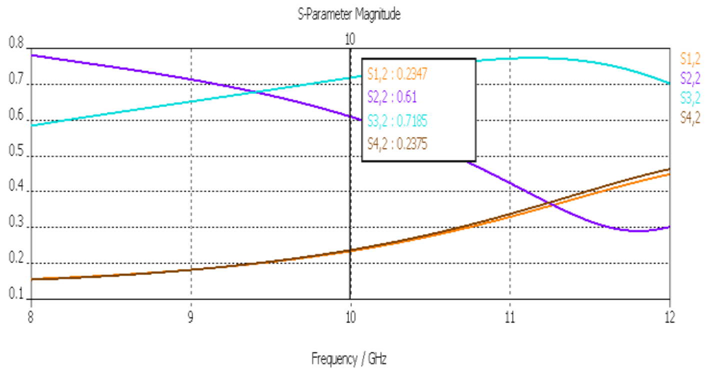

Fig. 5. S-Parameter Values for Port2 as an Input.

TABLE I: S-Parameter Values for Port2 as an Input.

S- parameters	Theoretical values	Measured Practical values
S1,2	0	0.2347
S2,2	0	0.61
S3,2	0.707	07185
S4,2	0.707	0.2375

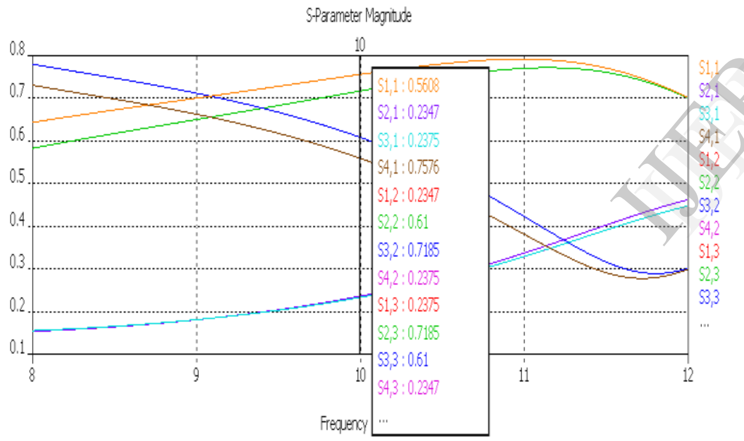

Fig. 6. S-Parameter Values for all Ports as an Input.

TABLE II: S-Parameter Values for All ports as an Input.

S- parameters	Theoretical values	Measured Practical values
S1,1	0	0.5608
S2,1	0	0.2347
S3,1	0.707	0.2375
S4,1	0.707	0.7576
S1,2	0	0.2347
S2,2	0	0.61
S3,2	0.707	07185
S4,2	0.707	0.2375
S1,3	0.707	0.2375
S2,3	0.707	0.7185
S3,3	0	0.61
S4,3	0	0.2347
S1,4	0.707	0.7576
S2,4	0.707	0.2375
S3,4	0	0.2347
S4,4	0	0.5608

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