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Research paper

Design of 2x6 Butler Matrix for Smart Antennas

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Abstract

In this paper a 2x6 butler matrix is designed forswitched beam smart antenna array. This work describes system design and optimization which is based on the elimination of some component (such as: crossover, phase shifter) which are used in basic structure of butler matrix generally and utilization of the output ports of hybrid coupler to make it 10log (1/3) dB coupler. This design increased the number of ports at the output of beam forming network array and miniaturized the area of butler matrix circuit. Proposed model is designed for ISM band of frequency with well accepted simulation results. This model is quite suitable in microwave devices as a low cost, high performance beam forming network in wireless communication system.

Keywords: *butler matrix, hybrid coupler, MIMO*

1. Introduction

The principle of beam forming is based on feeding a signal into an array of antennas with equal power and phase difference. The Butler matrix is a widely used beam forming technology characterized by its simplicity and low power loss.Butler matrix array is introduced as a key component of the switched beam system. Basically the design of butler matrix array result in six fixed overlapping beams which will cover the designated angular area that we require. It is an MxN passive feeding network with N radiation elements. The output ports of the butler matrix feed the antenna elements. It consists of four dB couplers, two crossovers, and two 450 phase shifter .

When a signal is excited on one input port while the others are terminated, the signal will go through the output antennas generating equal power with progressive phase shifts. However, the Butler matrix has area penalty because the length of the 3-dB coupler is quite long, especially at low frequencies. This leads to an increase in cost and makes it harder to be implemented in applications where only a small area is available .

2. Design Process

Butler matrix has been implemented with various techniques such as waveguide, micro-strip, multilayer micro-strip, suspended micro-strip lines, CPW (coplanar waveguide), IPD(integrated passive device) etc. Micro-strip technique is widely used in butler matrix due to its numerous advantages as low profile, easy fabrication and low cost. So we use microstrip technique to implement the butler matrix array. To design the butler matrix with planner microstrip lines technology first it is chosen the type of substrate material. Depending upon cost of the substrate, technology used (thin or thick), frequency range, thermal conductivity and mechanical strength we choose the type of material. Since butler matrix is the combination of its components used, to realize the butler matrix first we have to design its basic components after that all the components are connected with no loading effect. To design the particular component first we have to calculate the characteristics impedance of the lines used in the device. Then lengths and widths of microstrip lines involved in the design of components are calculated by using the values of impedance calculated effective permittivity of material used and frequency which is taken for a particular application .

After getting all the dimensions we can design it on the printed circuit board and remove all the redundant part of metal, and we get an array of butler matrix ready to feed any antenna array.

2.1 10LOG (1/3) db Asymmetric Coupler

It is an asymmetric coupler consists of five ports (two are input port and three are output ports). Structure of branch hybrid coupler and 10log (1/3) dB asymmetric coupler are alike except 3 ports at output of asymmetrical coupler (upper two are connected by a branch line). In this structure design ports of branch line coupler are utilized to divide the power further. If the power is applied to input port 1, first it will divide in the ratio of 2:1 (only one third power will be coupled to lowest part, two third of the power will be in the main branch). Two third power will be divided further at upper two ports (upper two ports connected with an extra branch line will do function as a hybrid coupler). Therefore power will be divided equally into three parts.

In the construction of 10log (1/3) dB asymmetric coupler power is divided in the ratio 1:2 and this power ratio depends on coupling coefficient ‗k'. Width of a micro-strip can be calculated after calculating the impedances of the particular branch. The equations given below, main line and branch line impedance can be calculated with the help of coupling coefficient.

$K = S_{31}/S_{21}$ where K is coupling coefficient.

Coupling coefficient k should be selected equal to 0.5 so that power gets divided in the ratio of 2:1. Port impedances (Z_{01}/Z_{02}) are taken equal to 50Ω. Using above values the values of first branch line impedance Z_{c1}, second branch line impedance.

Table 1: Calculated values of width and length of the micro-strip line

Parameters	Calculated values (in mm) (Using analytical methods)	Simulated values
Width of 50Ω line	3.06	3.06
Width of 35.355Ω line	5.13	5.06
Width of 100Ω line	1.54	1.48
Width of 28.86Ω line	6.22	6.30
Length of λ/4 line	15.70	14.98
Length of λ/8 line	7.85	7.49

By putting these values of characteristic impedances in the equations of W/d ratio (second equation) the width of particular branch can be calculated.
After getting divided the power in the ratio 2:1, throughput port will be treated as the main line of hybrid coupler and its calculations would be like that of hybrid coupler and power will be divided into two parts further.

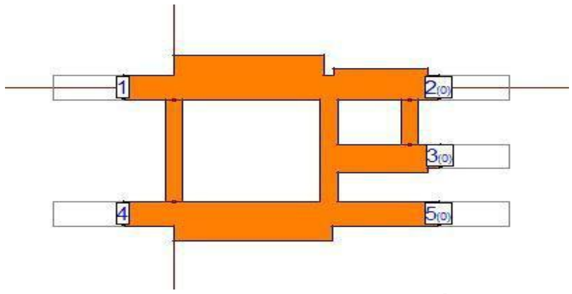

Fig. 1: 2X3 Asymmetric coupler

1.2. Simulation Result of 10LOG (1/3) db Asymmetric Coupler at Frequency 2.5 Ghz

Transmission coefficient S(1,2), coupling coefficients S(1,3), S(1,5) are -5.08dB, -4.85dB and -5.02dB respectively. These coefficients are almost equal in magnitude therefore power at output ports would be equal. Isolation coefficient S(1,4) is - 18.78db and return loss coefficient S(1,1) is -21.68db. These results are acceptable.

Angle of output at port 2, port 3 and port 5 are

ang[S(1,2)]=172.52, ang[S(1,3)]=128.01, and ang[S(1,5)]=83.27 respectively. Difference of phase of all output ports is calculated as 44.51 degree and 44.74 degree which is quite acceptable.

Table 2: Magnitude in s-parameters in dB for 10log (1/3)dB asymmetric coupler

Parameters	Magnitude in dB
S(1,1)	-21.68
S(1,2)	-5.08
S(1,3)	-4.85
S(1,4)	-18.78
S(1,5)	-5.02

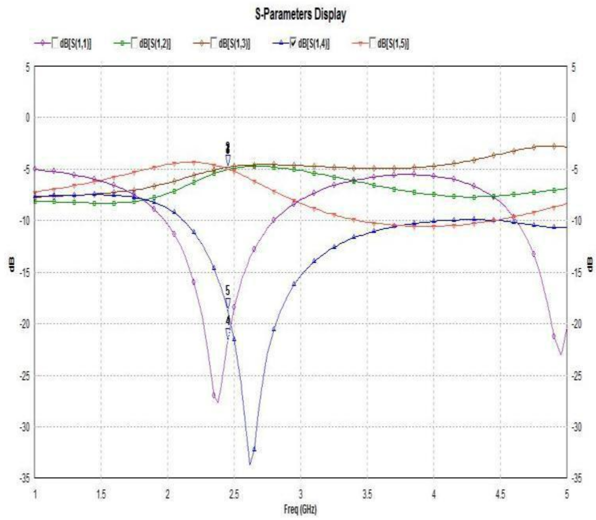

Fig 2: Magnitude plot 10 log (1/3) dB symmetric coupler

Table 3: Values of angles at output of 10log (1/3) dB asymmetric 2x3 coupler in degrees

Parameters	Angle in degree
Ang [S(1,2)]	172.52
Ang [S(1,3)]	128.01
Ang [S(1,5)]	83.27

3. 2x6 Butler Matrixes

Two asymmetric couplers are connected to the outputs of the hybrid coupler and this design consists of two inputs and six outputs. Geometry of 2x6 butler matrix is shown in figure 3.

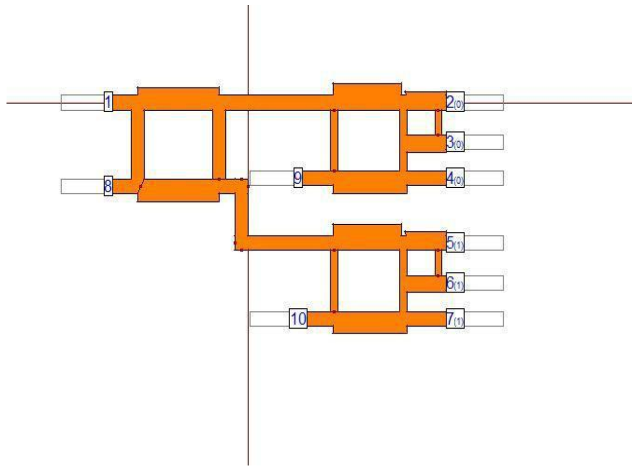
Fig 3: 2x6 butler matrix with the help of 2x2 hybrid coupler and 2x3 asymmetric couplers

4. Simulation Results of 2x6 Butler Matrixes

It is observed that return loss S(1,1) is -20.56 dB, isolation coefficient S(1,8) is -20.23 dB. These values make the system pass the efficient power to output with minimum loss of power at input. Magnitude values of transmission coefficient and coupling coefficients are nearly same as shown in the figure 5. The equality in magnitude of s-parameter indicates the magnitude value of transmitted power is nearly same through the output ports. Magnitude values of s-parameters in dB for 2x6 butler matrix is given in the table 4.

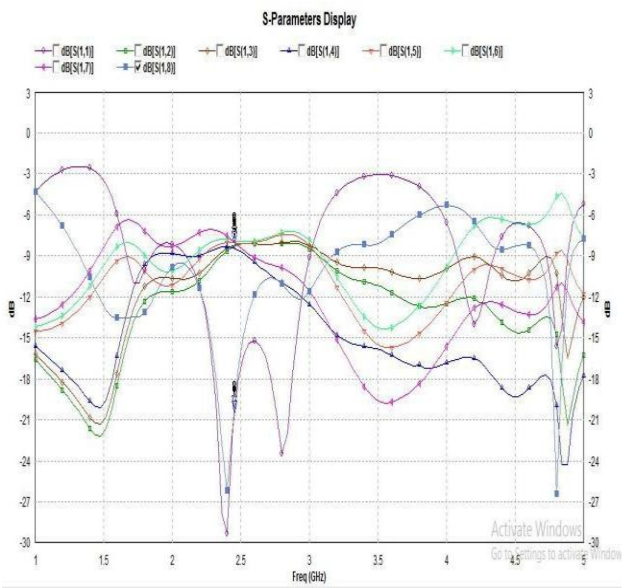

Fig 4: Magnitude plot of 2x6 butler matrix at outputs

Table 4: Magnitude values of s-parameters in dB for 2x6 butler matrix

Parameters	Magnitude in dB
S(1,1)	-20.56
S(1,2)	-8.29
S(1,3)	-8.19
S(1,4)	-8.44
S(1,5)	-8.04
S(1,6)	-7.86
S(1,7)	-8.00
S(1,8)	-20.23

Requirement of phase difference in the consecutive outputs is 45^0. As in the figure 6 given below, the difference in the phase of outputs nearly 45^0 so that output power can be steered in specified directions with equal phase shift between them. Values of angle at output of 2x6 butler matrix in degrees is given in the table 5.

Table 5: Values of angle at output of 2x6 butler matrix in degrees

Parameters	Angle in degree
Ang [S(1,2)]	85.39
Ang [S(1,3)]	130.53
Ang [S(1,4)]	175.26
Ang [S(1,5)]	-140.91
Ang [S(1,6)]	-95.05
Ang [S(1,7)]	-51.10

5. Conclusion

In this paper, a 2x6 Butler Matrix has been calculated, designed and simulated using Zeland software at 2.45GHz frequency. The circuit was compact and has low losses. The proposed system has the advantages of low cost, small volume, light weight and ease of fabrication on a cheap and an available substrate proceed. Thus, it is linearly frequency dependent. The most critical component is the crossovers, it can cause significant amplitude and phase errors and it is eliminated in this design. The proposed Butler Matrix is suitable for wireless applications such as IEEE802.11 technology. The design needs to be verified experimentally. The simulation result shows that the matrix is having good results where both return loss and isolation are better than 20 dB and the coupling provided by the matrix is in the range of 7.8 dB ± 1 dB across the band. Meanwhile, 450± 20 phase differences between the outputs are also achieved across the same band. This couplers are the components that can be used to construct a Butler Matrix for the purpose of the beam-forming MIMO application.

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