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Switch-Beam Vivaldi Array Antenna Based On 4x4 Butler Matrix for mmWave

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Abstract. It will be diffcult to use either omnidirectional or fixed beam antenna due to the high propagation losses caused by atmospheric absorption at mmWave for 5G mobile communication. Several studies have been conducted recently using butler matrix which is part of switchable antenna with some advantages such as simple, minimal cost, low loss, etc. Previous studies also have designed vivaldi array antenna at 28 GHz which provides a fix beam directional radiation pattern with narrow beam that requires real phase setting. However, there has been no research using vivaldi antenna with butler matrix, whereas it has some advantages such as wide bandwidth, high gain, high directivity, etc. This paper proposed 4x4 butler matrix integrated with vivaldi antenna by using phase shift of 45 . The design is developed on a single layer of Rogers RT5880 with dielectric constant 2.2 and thickness 0.254 mm. Best results of simulation were picked for overall system at 28 GHz, and the results of antenna as follows: the return loss was below -10 dB, the realized antennas gain was 10.2 dB with unidirectional radiation pattern and bandwidth antenna of 6 GHz that covers from 25 GHz to 31 GHz. The butler matrix average phase di erent between output port are -44.106^o, 137.38^o, -137.66^o, 43.95^o with phase error of 0.894^o, 2.38^o, 2.66^o, 1.06^o. Antenna array that has been given di erent phase by butler matrix is able to shift radiation pattern on the input port successively with range of beam that can be achieved equal to 185^o.

1 Introduction

One of the challenges in making a 5G antenna is to design a high gain antenna to avoid high pathloss due to the atmospheric absorption of electromagnet waves at higher frequencies[1][2]. The much higher gain that is needed to compensate the higher signal attenuation at mmWave introduces the concept of antenna arrays for cellular phones[3]. But the use of antenna arrays to increase the antenna gain causes the antenna radiation pattern to be directional thus requiring the use of beam steering on the antenna [4][5].

There are two ways to steering beam using smart antenna system such adaptive array system and switched-beam [6][7][8]. Switched beam antenna is choosen because it is less cost and simple to be implement and achieve most of the features of adaptive array including capability to steer the antenna beam [6]. Butler matrix is one of the well-known

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beam forming which can be used in switched-beam smart antenna system [9]. It is plays an important role in the transmitter and receiver for 5G communication with some advantages such as easy implementation [12], simple, minimal cost[10], the loss involved is very small[8][13]. This study was conducted on the basis of research [5][2] on the design of vivaldi antennas for 5G, which integrated with 4 4 butler matrix [6][11] at mmWave. The working frequency of this 5G antenna is 28GHz [13][5][2].

The proposed design of butler matrix and antenna is applied for 5G mmWave mobile communication at 28 GHz. It must be capable of generating phase di erence between the output ports to provide phase di erence to the input port of antenna array. Thus, the antenna array radiation pattern is capable of shifting in certain directions according to the phase difference assigned to each input. Apart from this introductory remark, this paper has additional three sections. Section II describes the design configuration. Section III discusses the results and analysis, the performance in terms of phase di erent in output port and radiation pattern in every input will be discussed. Finally, a conclusion will be drawn in Section IV.

2 Design Configuration

The proposed butler matrix utilized some elements such as 90 hybrid, phased shifter of 45 and crossover. These element consists of transmission lines and calculated using microstrip feedline. It is created by copper strips separated from the ground plane by a Rogers RT5880 substrate layer with dielectric constant 2.2 and thickness 0.254 mm in 28 GHz.

As indicate in figure 1, the proposed design consists of a butler matrix with four inputs and four outputs, each output of the butler matrix serves as a feeding line for the vivaldi antennas and direct the beam to the desired direction according to the selected input port. The phase di erence which will be generated on each output port with the selection of input ports respectively i.e are 45°, -135°, 135°, -45°.

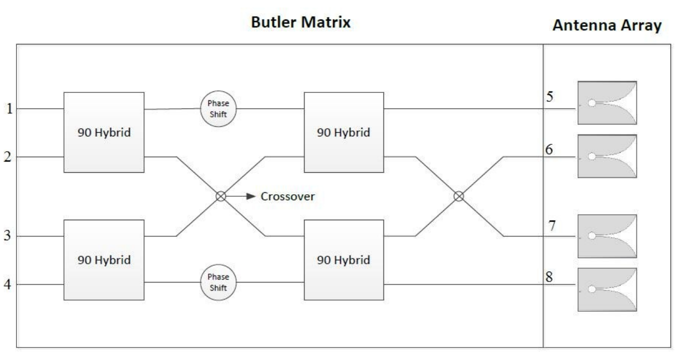


Fig 1. Design of proposed butler matrix and vivaldi array antenna

The first step to design butler matrix is design 90o hybrid which have functions as a power divider with phase margin difference at port 3 and port 4 is 90o caused by the length of each quarter-wavelength transmission line (□/4). The hybrid design consists of two impedance namely Z_o and Zo/□$\sqrt{2}$ withline length for each impedance of λ/4.

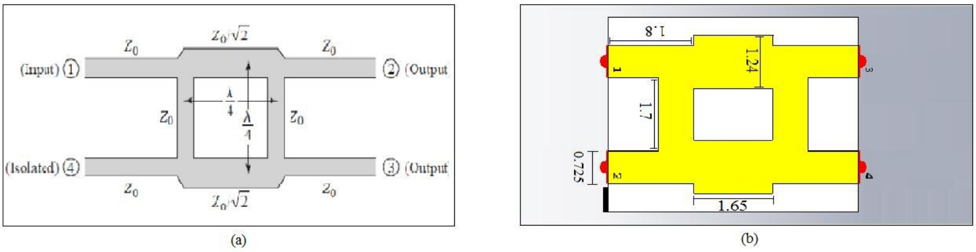


Fig 2. Configuration of 90 hybrid in (a)geometry (b)simulation

Figure 3 shows that insertion loss S(1,3) and S(1,4) of 90 hybrid not exactly -3 dB because loss of feedline. While the isolation of S(1.2) and return loss S(1,1) magnitude -10 dB at 28 GHz frequency. The phase di erence between the output ports S(1.3) and S(1.4) is approaching 90 which has been in accordance with the desired hybrid specification.

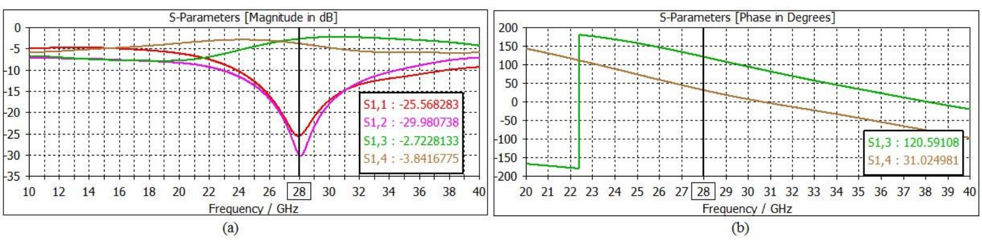


Fig 3. Simulation result (a)insertion loss, return loss and isolation (b)phase di erent

The second step is design and simulate the crossover which used for obtain high isolation between two intersecting lines in order not to connect electrically by combining the 90 hy-brid in series, but it does not give satisfactory performance[11]. Therefore, the geometry used is shown in Figure 4 where mitred bend is used to prevent discontinuity on the crossover.

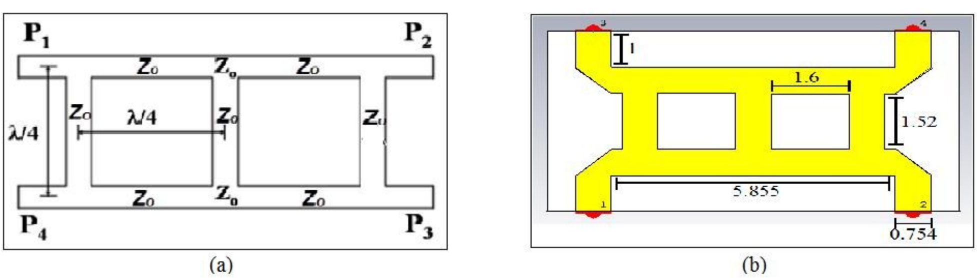


Fig 4. Configuration of crossover in (a)geometry (b)simulation

The result of crossover simulation after optimized is showed in Figure 5, the insertion loss S(1,4) value is about to 0 dB due to channel loss. While the return loss S(1,1) and isolation

S(2,1) and S(3,1) values are less than -10 dB, which means that almost nothing is missed on those ports.

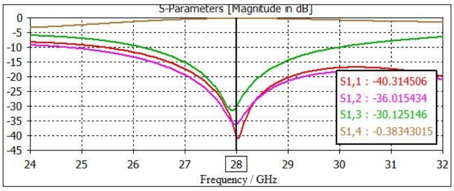


Fig 5. S-Parameter at 28 GHz for crossover

The third step is design and simulate the phase shift which used for steered beam antenna in the desired direction without repositioning the antenna physically [9][10]. The phase out-put at the phase shifter can be seen in figure 6 where at 28 GHz frequency, the phase output is approaching -45^{o}

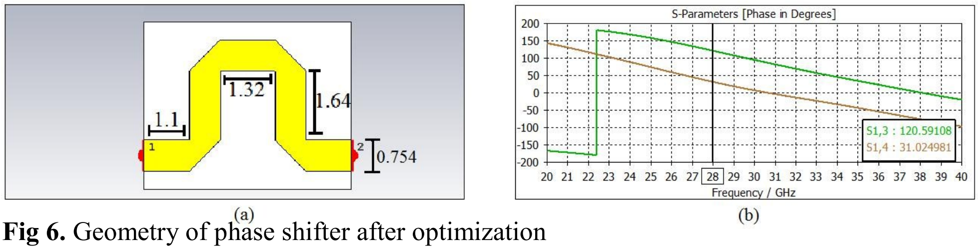


Fig 6. Geometry of phase shifter after optimization

The final step is design and simulate a vivaldi antenna to an array. Vivaldi antenna config-uration is obtained based on [13] and modified the vivaldi input to make distance of vivaldi input as sama as butler matrix. The optimized vivaldi can be seen in Figure 7 where the vivaldi dimension is 6.6 mm 9 mm.

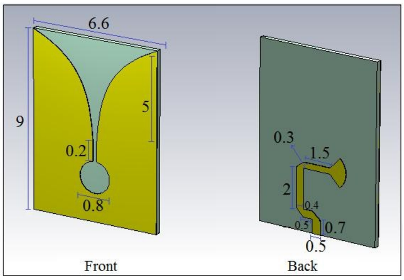
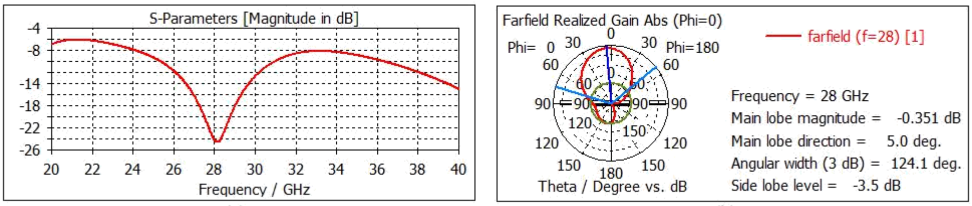


Fig 7. Optimum design of vivaldi antenna at 28 GHz.

The return loss value S(1,1) and radiation pattern of vivaldi antenna is shown in Figure 8. The return loss value at 28 GHz is -24.09165 dB which is less than -10 dB while bandwidth antenna is 6 GHz. It is also has unidirectional radiation pattern with realized gain about 4.13 dB.

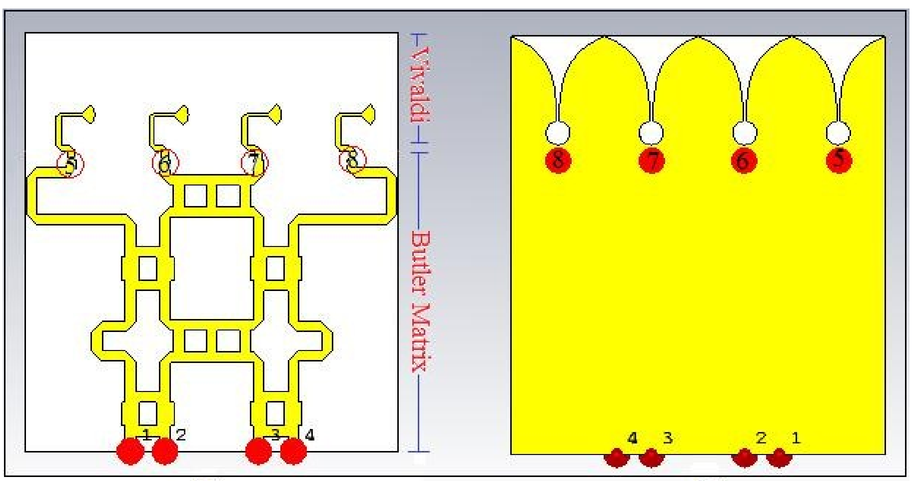


(a) (b)

Fig 8. Result of vivaldi simulation (a)returnloss (b)radiation pattern

3 Result and Analysis

Hereafter, all the individual components of butler matrix are combined on a single substrate together without antenna, it has dimension of 20.52 mm 26.4 mm. After the butler matrix has been designed to provide the output of phase di erence of 45°, -135°, 135°, -45° on the output port, then it was integrated with four vivaldi antennas which has been designed, the final design of butler matrix-antenna array is shown in Figure 9 with dimension of 20.52 mm 29.52 mm.



(a) (b)

Fig 9. Simulation of butler matrix array (a)top side (b)bottom side

Table 1. The phase di erence between butler matrix output ports

Input Port	Port(°)			Average(°)	Theoritical Target (°)	Error (°)
	5-6	6-7	7-8			
1	-43.49	-47.02	-41.81	-44.106	-45	0.894
2	150.85	114.63	146.66	+137.38	+135	2.38
3	-146.46	-115.7	-150.83	-137.66	-135	2.66
4	41.82	46.67	43.38	43.95	+45	1.06

It can be seen from Table 1 which obtained through simulation with phase error on the output port of butler matrix respectively are 0.894 , 2.38 , 2.66 , 1.06 . While radiation pattern of butler matrix-vivaldi array antenna in every port are shown in Figure 10.

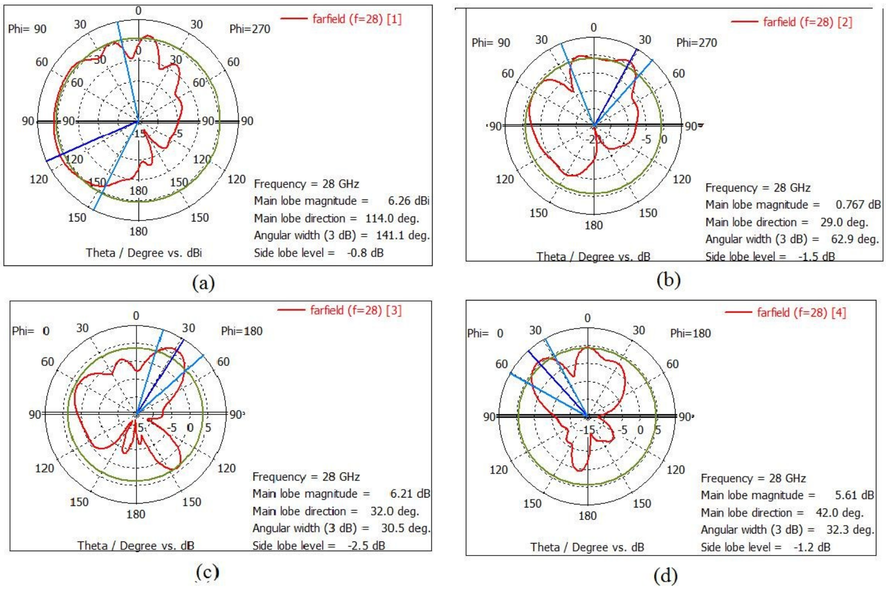


Fig 10. Radiation pattern in every input (a)Port 1 (b)Port 2 (c)Port 3 (d)Port 4

The antenna radiation pattern on each input port when all input ports are combined can be seen in Figure 11. It shows that antenna radiation pattern changes depends on the phase di erence given in each di erent input. The main lobe direction obtained successively on port 1,2,3,4 successively -141.1^o, -29^o, 32^o, 42^o. The main lobe direction which is not symmetrical due to the phase di erence in the output port varies in value. To obtain the sequential beam shift from the data, the sequence of input ports selected are 1, 4, 2, 3 with maximum beam range is 185 in azimuth plane.

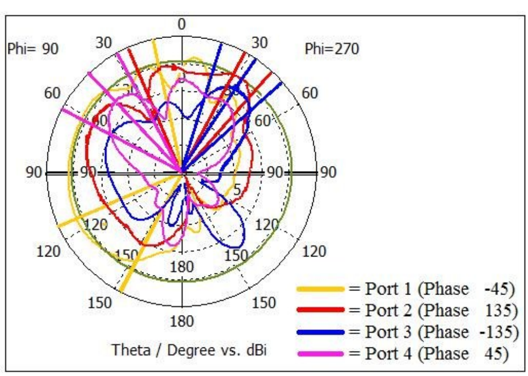


Fig 11. Radiation pattern in every input

4 Conclusion

This paper presents a 4x4 butler matrix using vivaldi array antenna at mmWave for 5G mobile communication. All component of butler matrix such as 90^{o} hybrid, crossover and phase shifter are designed individually. Vivaldi antenna simulation result showed that the antenna can cover from 25 GHz to 31 GHz with the highest array gain performance of 10.2 dBi at 28 GHz. The simulation results of the butler matrix demonstrated a good performance at operating frequency in terms of S-parameters and phase differences in output port. The beam can be switched toward in different directions by switching any of the input ports which will be suitable for 5G mobile communication which would support the future 5G and operate at 28 GHz of frequency. Thus, it has intended to get the butler matrix-vivaldi antennas fabricated and tested to validate the design method. The fabrication will be done in a place where fabrication and measurement equipment are available.

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