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Design Of The Rectangular Microstrip Antenna For E-UTRAN New Radio – Dual Connectivity (EN-DC)

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A B S T R A C T

Wireless communication systems are multiplying, and the high data access and volume have increased yearly. The 3GPP release 15 introduces a technique called E-UTRAN New Radio – Dual Connectivity (EN-DC). This technique allows users to simultaneously utilize 4G and 5G transmissions on a single antenna. The EN-DC antenna requires beamforming capabilities, often achieved using a Butler matrix. Butler matrix can produce an ideal phase difference of -135^0, -45^0, $+45^0$, and $+135^0$, or called $\pm45^0$ and $\pm135^0$. This research discusses the design of microstrip rectangular MIMO 4x4 standalone and the Butler matrix method operation at 2.1 GHz and 2.375 GHz to obtain a phase difference in each antenna element. In this case, the simulation results show that a standalone antenna MIMO 4x4 produces a main phase direction of approximately $\pm171.0^0$ at 2.1 GHz for 4G at elements 1, 2, 3, and 4. At 2.375 GHz for 5G, the main phase direction for the same elements is approximately $\pm25.0^0$. At 2.1 GHz for 4G at elements 1, 2, 3, and 4, the simulation results for the antenna MIMO 4x4 with the Butler matrix indicate a main phase direction of around $\pm1.0^0$. For elements 1 and 4, the primary phase direction at 2.375 GHz is around $\pm19.0^0$, while for elements 2 and 3, it is around $\pm52.0^0$. The simulation results demonstrate that the phase direction of the antenna MIMO 4x4 is significantly improved because of the Butler matrix. In addition, that is a limited phase direction for a standalone antenna MIMO 4x4.

1. Introduction

Wireless communication systems are growing rapidly, and the high data access and volume have increased yearly. The 5G technology presented and claimed will provide better user services and massive connectivity for human to human, machine to machine and human to machine. The 5G services need a large capacity with a fast data speed of 10 to 100 times faster (Huawei, 2019). The 5G requirement for data speed is that the 5G network must have a 3-layer service structure called ultra experience layers, high-capacity layers, and ubiquitous coverage layers (Gemmel et al., 2017). The third layer structure works at high frequencies with a spectrum of sub-6 GHz (below 6 GHz) and a millimetre-wave (mmWave) spectrum, where it works at frequencies of 24 GHz to 40 GHz. The band of this spectrum is the 5G network. However, that spectrum has challenged itself (Uchendu & Kelly, 2016). At millimetre-Wave (mmWave) spectrum can offer more bands for choosing compared with the recent spectrum that uses cellular at this moment, which is under 3 GHz. Meanwhile,

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providing coverage everywhere and a strong signal without obstacles with Line of Sight (LOS) conditions is incredibly challenging for mmWave case because many obstacles are caused by building while for sub-6 GHz (under 6 GHz) still using 3G and 4G (Sheikh et al., 2020).

To keep using 5G and meet the requirement where can provide substantial and significant coverage with high-speed data access, The 3rd Generation Partnership Project (3GPP) release fifteen presented a technology called E-UTRAN New Radio – Dual Connectivity (EN-DC) or Dual Connectivity (DC). This technology promises a 5G system that can improve the data speed access for users (3GPP, 2019).

Applying the EN-DC technology requires a good frequency combination to offer better coverage and data speed access according to the 5G network specification. One of the frequencies that prepare for EN-DC is 2.1 GHz for 4G and 2.3 GHz for 5G (KOMINFO, 2017, 2021).

To support the EN-DC research, one part of the need to research is the antenna field, which includes the beamforming technology to broadcast beams at all bands. An antenna is a device that transmits and receives electromagnetic waves, usually radio waves, to communicate or broadcast information (Balanis, 2005). To produce beamforming beams requires two minimum array antennas. Those two array antennas must support Multiple-Input and Multiple-Output (MIMO) 4-Transmitter 4-Receiver (4T4R) configuration (Huawei, 2019). Beamforming can be done by using the Butler matrix method. Butler matrix is a widely used network beamforming system with phase ideals -1350, -450, +450, and $+135^0$ (Shaikh & Akhade, 2015).

This research discusses the design of a microstrip rectangular antenna for EN-DC operation at 2.1 GHz and 2.3 GHz, simulated using CST Studio Suite 2021. Two scenarios are investigated to evaluate the antenna's phase direction performance: a standalone antenna MIMO 4x4 and an antenna MIMO 4x4 with a Butler matrix.

2. Literature review

This research refers to some previous research done where the title of the article is "Antenna design rectangular array Microstrip for 5G technology at 28 GHz frequency" (Yusup et al., 2021), and also "Switch-Beam Vivaldi Array Based On 4x4 Butler Matrix for mmWave" (Safitri et al., 2018). Both researchers use a MIMO antenna with the Butler matrix method as the beamforming technique to produce the phase difference at mmWave frequency. Based on both papers, each antenna element's phase difference can produce a phase error of $\pm 2.0^0$ for mmWave purposes.

A butler matrix is a microwave circuit with N input and output ports. Change the input on one port into several ports, and a power driver is needed from one port to N ports (Mahardhika et al., 2016). The ideal phase from Butler Matrix 4x4 is -135^0, -45^0, $+45^0$, $+135^0$. There are three main Butler matrix components:

2.1 Hybrid Coupler

A hybrid coupler or 3 dB quadrature coupler can produce a phase signal of 90^0 at the port output (Louati et al., 2018). The hybrid coupler part consists of the main line, which is combined with a secondary line which has the characteristic of a quarter of the wavelength ($\lambda/4$) and the characteristic impedance of each series according to Figure 1 defined as $Zo/\sqrt{2}$ (Idrus et al., 2019).

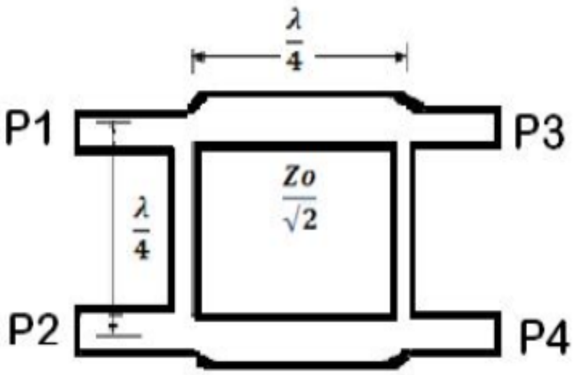

Figure 1. Hybrid coupler (Yusup et al., 2021)

2.2 45^0 Phase Shifter

A phase shifter provides a phase shift to the signal by using the length of line (l) calculation as 1 and 2 (Yusup et al., 2021). Before calculating the length of the line (l), the first steps must calculate the length of the wave line (λg).

$$|\varphi| = \frac{2\pi}{\lambda g} l \qquad \text{.....1)}$$

$$\lambda g = \frac{\lambda_0}{\sqrt{\varepsilon_{reff}}} \qquad \text{....2)}$$

Where,

l : Length of line

φ : Phase value

λg: Length of the wave line

λo: Length of wave

ε_{reff}: Relative dielectric constant

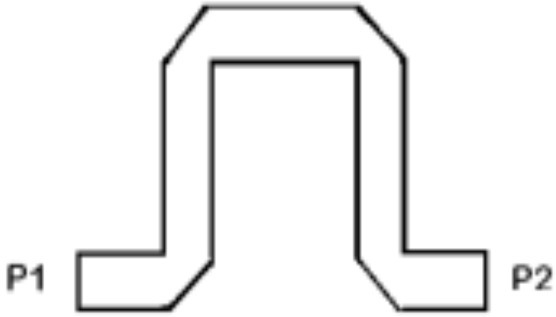

Figure 2. Phase Shifter (Yusup et al., 2021)

2.3 Crossover

Crossover is a network consisting of four symmetrical ports, where two are input ports and the other are output ports. The crossover is perfectly designed to make all ports adjacent to the coupler isolated from each other (Cerna & Yarleque, 2018). Port 1 fed with the output signals of ports 2 and 4 must be zero, the same as port 4 fed with signals of ports 1 and 3 must also be zero

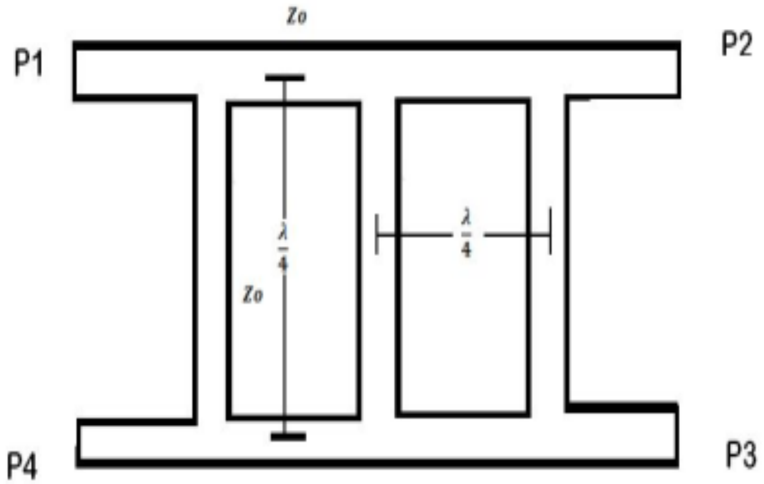

Figure 3. Crossover (Yusup et al., 2021)

3. Method

This research will discuss the MIMO 4x4 antenna design without the Butler matrix and the MIMO 4x4 antenna design with the Butler matrix. Moreover, since this research uses frequencies 2.1 GHz and 2.3 GHz, the bandwidth is one concentrated; therefore, to enhance the bandwidth, will use the Slot (Ardianto et al., 2019) and Defected Ground Structure (DGS) method (Khandelwal et al., 2017), and for dual frequencies use the insert feed methods (Ramesh, & Kb, 2003). In addition, parameter optimization is conducted on the antenna dimension size and the feeder to achieve the best antenna specifications (Deriko & Rambe, 2015). This research uses software antenna simulation CST 2021. Figure 4 describes the detailed steps for this research.

3.1 Antenna Material Specifications

The material specification of the antenna is presented in Table 1 below.

Table 1. Antenna material specification

Material	specification		
	Permittivity Relative (Ɛr)	Thickness (h)	Dielectric Loss Tangent (tan δ)
Copper	1	0.035 mm	-
Rogers RT Duroid 5880	2.2	3.175 mm	0.0009

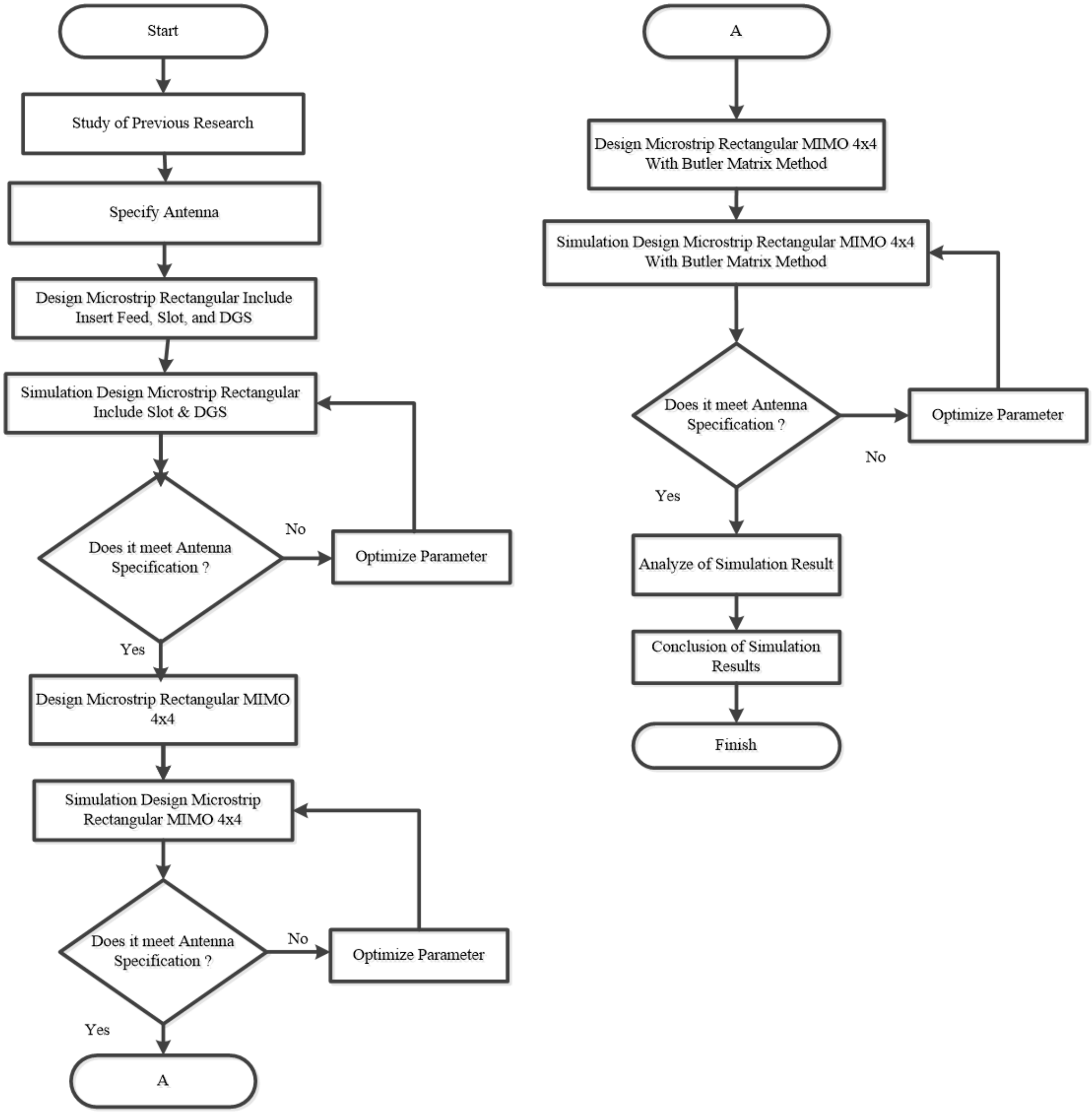

Figure 4. Flow chart of research

3.2 *Antenna Dimension Parameters*

The dimensions of the antenna are shown in Table 2.

Table 2. Antenna dimension parameters

Variables	Dimension (mm)	Descriptions
Ws	300	Width of substrate/ground plane
Ls	210	Length of substrate/ground plane
W	108.67	Width of patch
L	90.55	Length of patch
Wd	155.91	Width of DGS

Variables	Dimension (mm)	Descriptions
Ld	170.51	Length of DGS
Sh	60.77	Width of slot
Sv	5	Length of slot
Ih	3.87	Width of insert feed
Iv	10.57	Length of insert feed
D	131.43	Distance each patch
Lf	27.19	Length of feeder 100Ω
Lf2	51.50	Length of feeder 50Ω
Wf2	5.46	Width of feeder 50Ω
Wm	1200	Width of antenna MIMO
Lm	210	Length of antenna MIMO
Da	56.93	Distance each antenna

3.3 *Microstrip Rectangular 1x2 Include Inset Feed, Slot, and DGS.*

Figure 5 shows a microstrip rectangular 1x2 including insert feed, slot, and DGS with dimension size 300 mm x 210 mm. The antenna patch is 108.67 mm x 90.55 mm, the inset feed size is 3.87 mm x 10.57 mm, the slot size is 60.77 mm x 5.00 mm, and the DGS size is 170.51 mm x 155.91 mm. The distance of each patch is 131.43 mm. The dimension is used according to the table 2.

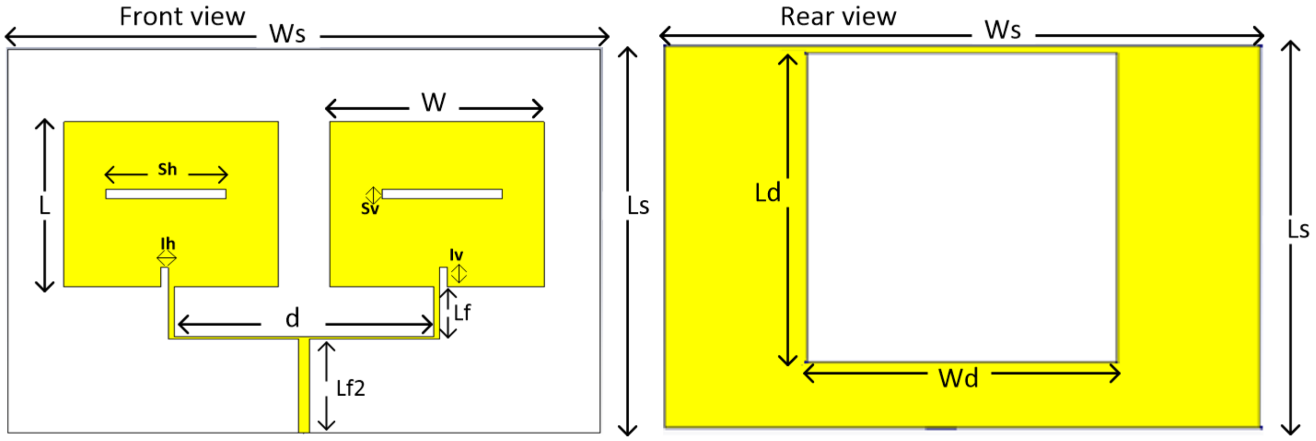

Figure 5. Microstrip rectangular 1x2 including inset feed, slot, and DGS

3.4 *MIMO 4x4 Without Butler Matrix*

Figure 6 shows the microstrip rectangular MIMO 4x4 without Butler matrix with the dimension of whole size defined as variable Wm for width dimension with value 1200 mm, variable Lm for length of dimension with value 210 mm, and variable Da for the distance of each antenna element with value 56.93 mm. Figure 6 also indicated that antenna MIMO 4x4 combines microstrip rectangular 1x2 in Figure 5.

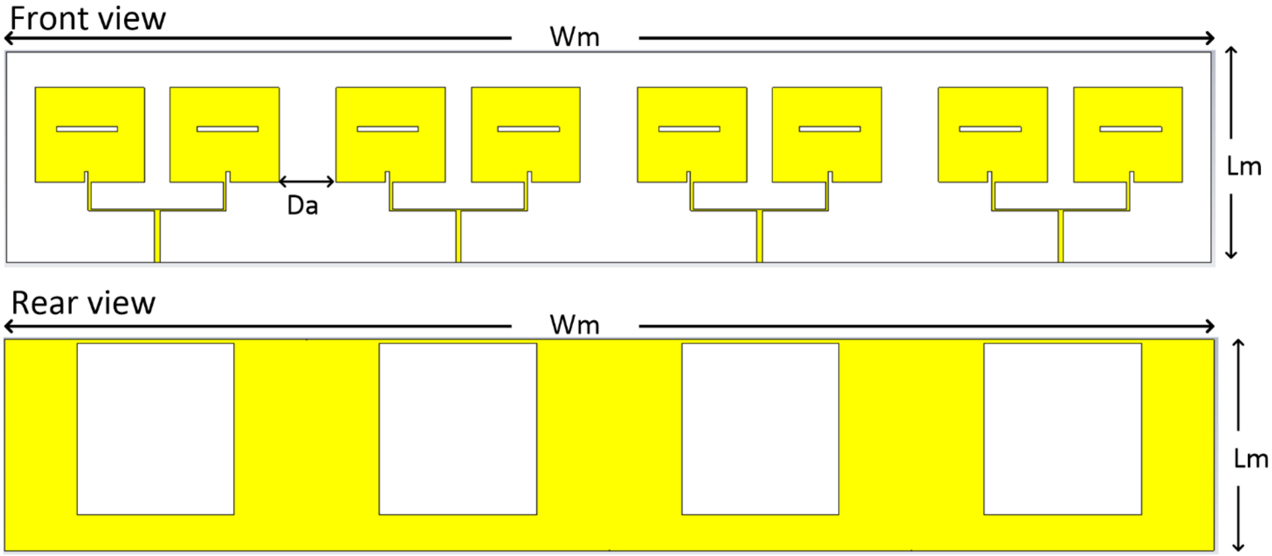

Figure 6. Microstrip rectangular MIMO 4x4 without Butler matrix

3.5 Design of Butler Matrix 4x4

Table 3 shows each component of the Butler matrix where the dimension defined by Zo = 50 Ω and $Zo/\sqrt{2}$ = 35.35 Ω based on 5G frequency at 2.375 GHz. Values in the table mention hybrid coupler, phase shifter and crossover where. The design of them is shown in Figure 7.

Table 3. Dimension of Butler matrix components

Variables	Dimension (mm)	Descriptions
Wh50	40.42	Width of line 50Ω at hybrid coupler
Lh35	11.74	Length line 35Ω at hybrid coupler
Lf	10.89	Length of feeder
Lh50	3.79	Length line 50Ω at hybrid coupler
Wh35	7.52	Width of line 35Ω at hybrid coupler
Wf	3.58	Width of feeder
Wp50	9.48	Width of line 50Ω at phase shifter
Lp45	21.76	Length of line 45Ω at phase shifter
Lc	22.16	Length of line at crossover
Wc	76.06	Width of line at crossover

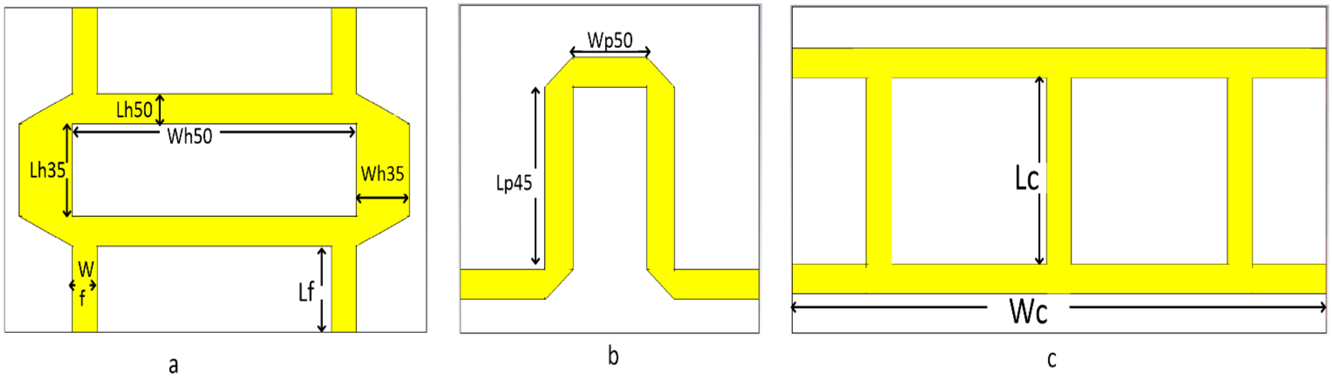

Figure 7. Butler matrix component (a) hybrid coupler (b) 45^0 phase shifter (c) crossover

Figure 8 shows the configuration of each element, which is united and formed as a Butler matrix 4x4. The configuration uses 4 hybrid couplers, 2 phase shifters, and 1 crossover. At the same time, the whole dimension is defined as variable WBm for the width of the Butler matrix with a value equal to 255 mm and variable LBm for the length of the Butler matrix with a value equal to 110.68 mm.

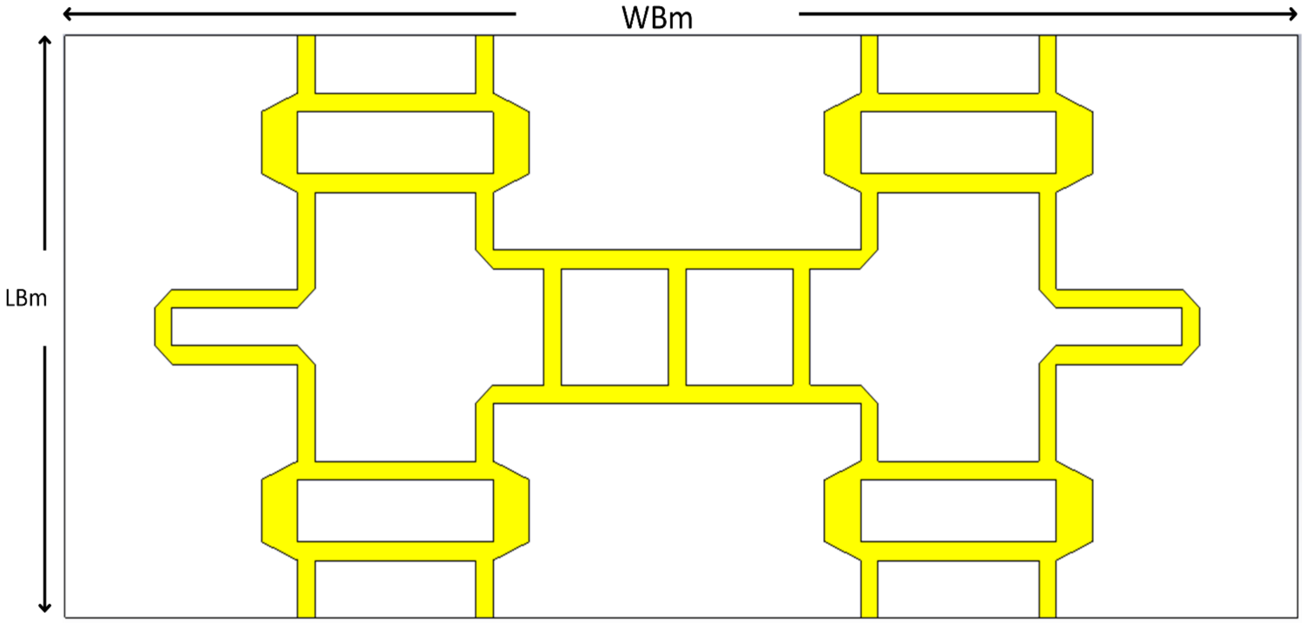

Figure 8. Butler matrix 4x4 configuration

3.6 MIMO 4x4 With Butler Matrix

Figure 9 shows the microstrip rectangular MIMO 4x4 with Butler matrix where the dimension is defined as variable WmBm for the width of MIMO with Butler Matrix 4x4 where value is 1200 mm and variable LmBm for the length of MIMO with Butler matrix 4x4 where value is 375.76 mm. The design presented in Figure 9 combines antenna MIMO 4x4 without the Butler matrix in Figure 6 and the Butler matrix 4x4 configuration in Figure 8.

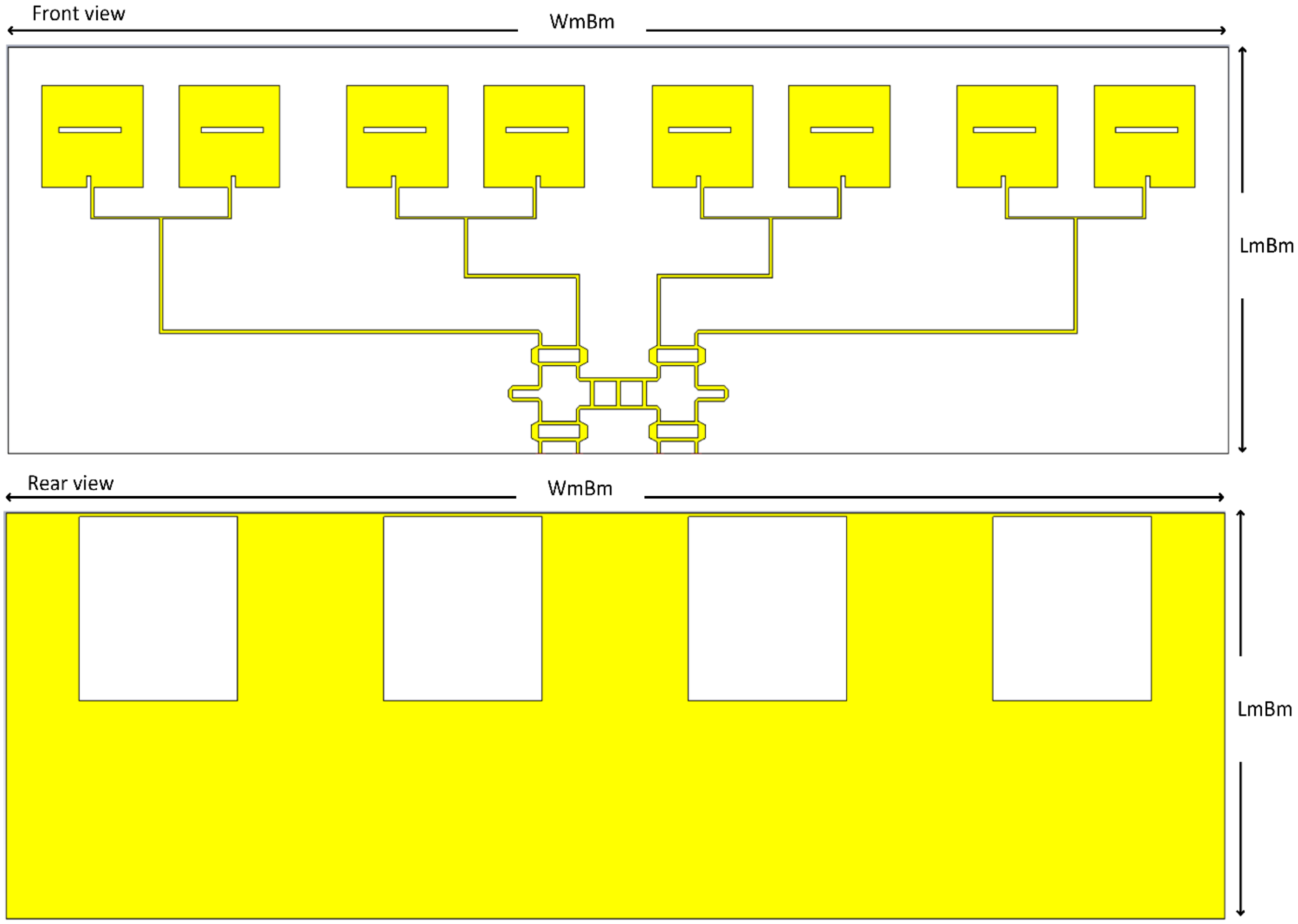

Figure 9. Microstrip rectangular MIMO 4x4 with Butler matrix

4. Result and Discussion

The microstrip rectangular antenna 1x2 includes inset feed, slot, and DGS successfully designed and presented in Figure 5. That figure shows the front and rear views of the antenna. The inset feed and slot are depicted in the front view, while the DGS is shown in the rearview. The microstrip rectangular antenna 1x2, incorporating inset feed, slot, and DGS designs, exhibits S-Parameter values of approximately -16.25 dB at 2.1 GHz and -13.5 dB at 2.375 GHz, as shown in Figure 10. The S-Parameters for both frequencies are below the -10 dB threshold, indicating good performance. The specified limit for the S-Parameter is ≤ -10 dB. The value of ≤ -10 dB is also a standard metric used to define the frequency range over which an antenna operates efficiently. So, in this simulation, the bandwidth value can produce approximately 250 MHz at a frequency of 2.1 GHz and 30 MHz at a frequency of 2.375 GHz. The bandwidth value is determined by locating the two frequency points on either side of the resonance frequency where the S-Parameters reach the -10 dB threshold. At the time, the VSWR value at frequency 2.1 GHz is approximately 1.3, and at frequency 2.375 GHz is approximately 1.5, as shown in Figure 11—the ideal VSWR is approximately 1, good VSWR is approximately 1.5, and acceptable VSWR approximately 2. Therefore, the simulation of a microstrip rectangular antenna 1x2, including inset feed, slot, and DGS, has demonstrated that the design meets all S-Parameters, bandwidth, and VSWR requirements. Consequently, this design is implemented in the antenna MIMO 4x4 configuration, as shown in Figure 6.

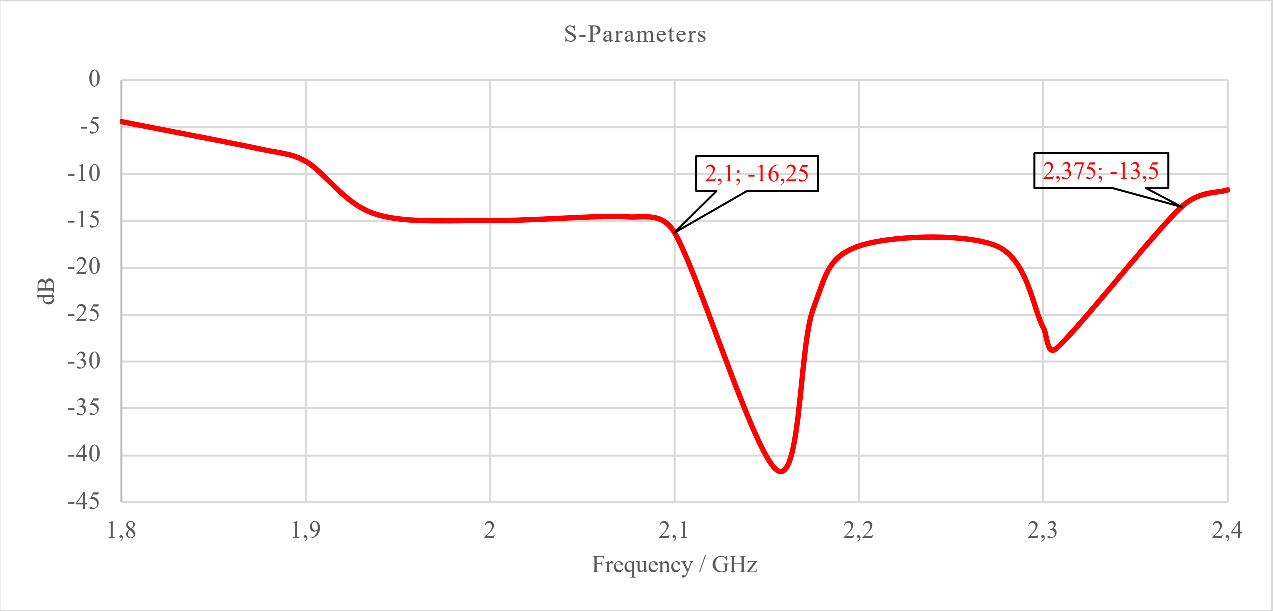

Figure 10. S-Parameter of microstrip rectangular antenna 1x2

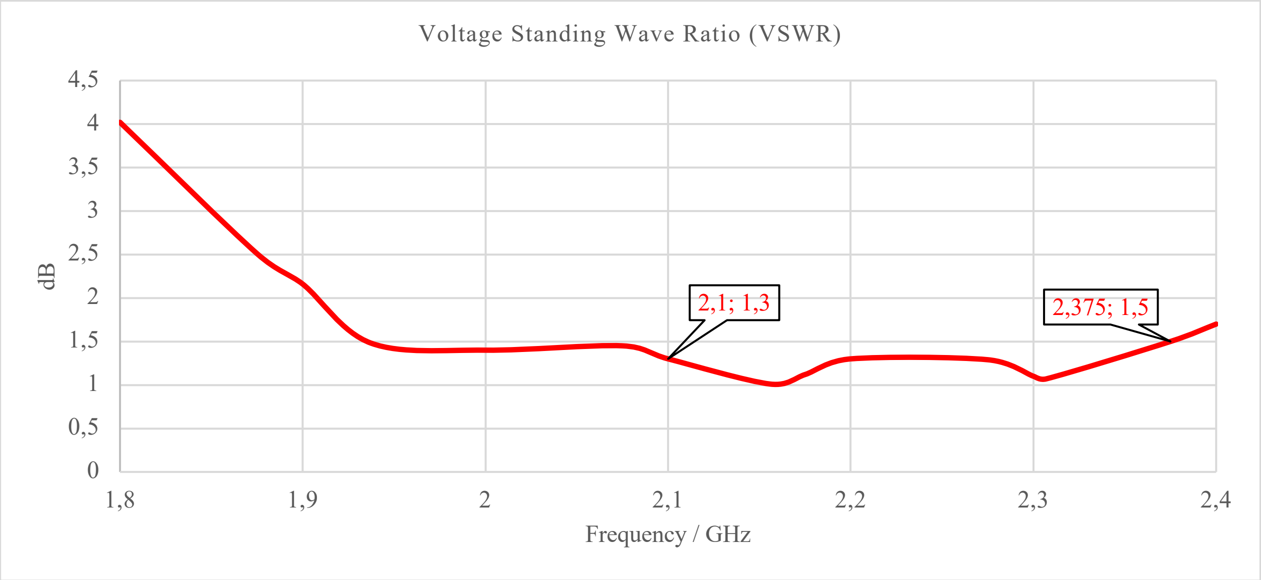

Figure 11. Voltage standing wave ratio (VSWR) of microstrip rectangular antenna 1x2

4.1 Comparison of Phase Difference MIMO 4x4 without and with Butler Matrix Frequency 2.1 GHz

Figure 12 shows the phase difference and radiation pattern of MIMO 4x4 while not using the Butler matrix and Butler matrix for frequency 2.1 GHz operation. The phase difference of the main lobe direction MIMO 4x4 antenna while not using Butler matrix for elements 1, 2, 3, and 4 is approximately $\pm171.0^0$ while the phase difference of the main lobe direction MIMO 4x4 antenna using Butler matrix shown in Figure 13 for elements 1, 2, 3, and 4 is approximately $\pm1.0^0$. There is a difference of $\pm170.0^0$ between the two results. The phase difference for this frequency is insignificant because the frequency 2.1 GHz is used for 4G purposes while the Butler matrix is calculated using 5G frequency at 2.375 GHz.

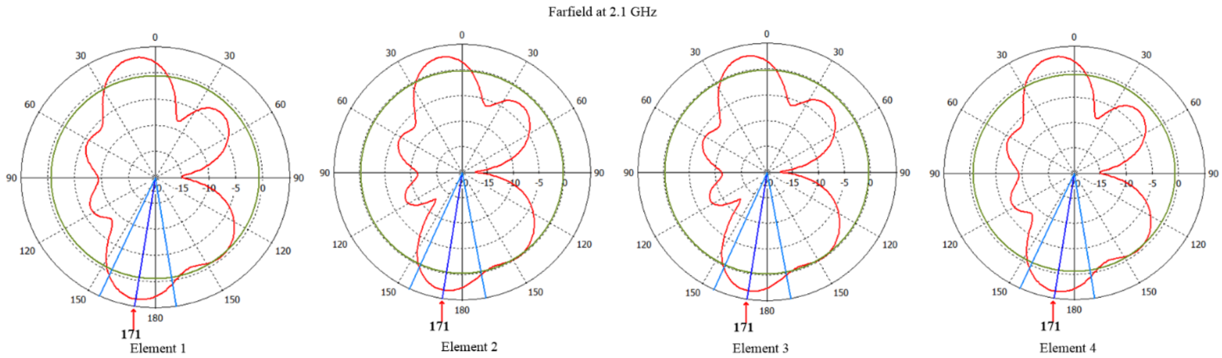

Figure 12. Phase difference MIMO 4x4 antenna without Butler matrix frequency 2.1 GHz

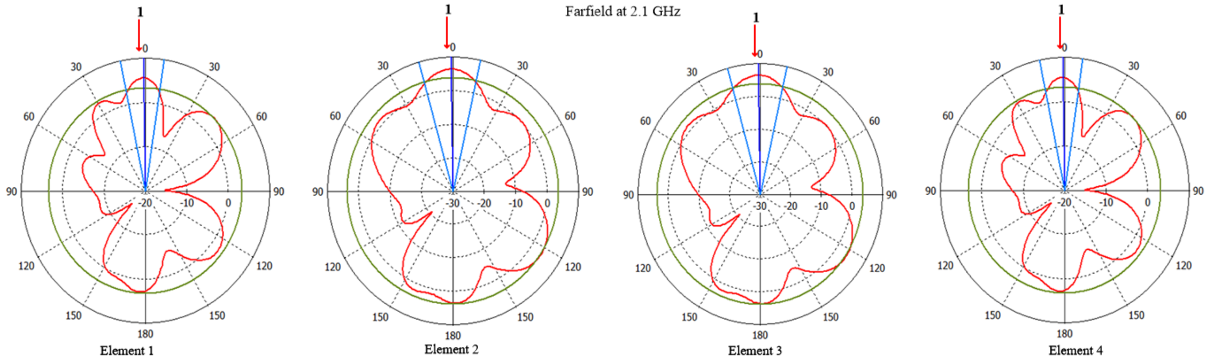

Figure 13. Phase difference MIMO 4x4 antenna with Butler matrix frequency 2.1 GHz

4.2 Comparison of Phase Difference MIMO 4x4 without and with Butler Matrix Frequency 2.375 GHz

Figure 14 shows the phase difference and radiation pattern of the MIMO 4x4 antenna without a Butler matrix at 2.375 GHz, while Figure 15 shows the same for the antenna with a Butler matrix. The phase difference of the main lobe direction for elements 1, 2, 3, and 4 of the MIMO 4x4 antenna without a Butler matrix is approximately $\pm 25.0^0$. With a Butler matrix, the phase difference for elements 1 and 4 is approximately $\pm 19.0^0$, while for elements 2 and 3, it is approximately $\pm 52.0^0$. Based on the results, it can be inferred that the phase difference between the MIMO without the Butler matrix and with the Butler matrix for elements 1 and 4 is approximately $\pm 6.0^0$. For elements 2 and 3, it is approximately $\pm 27.0^0$. The phase difference variations of each antenna element are crucial for 5G applications because the 5G system requires the phase difference of the main lobe direction to vary for each element to meet the antenna standard.

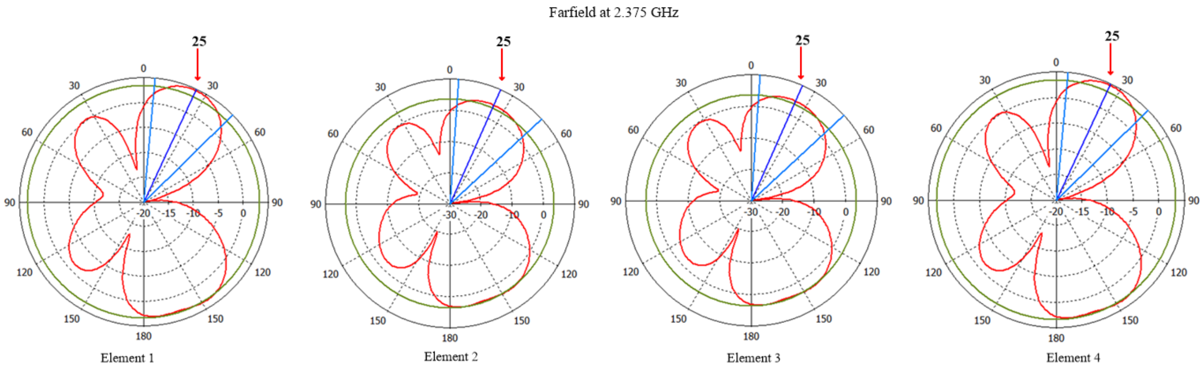

Figure 14. Phase difference MIMO 4x4 antenna without Butler matrix frequency 2.375 GHz

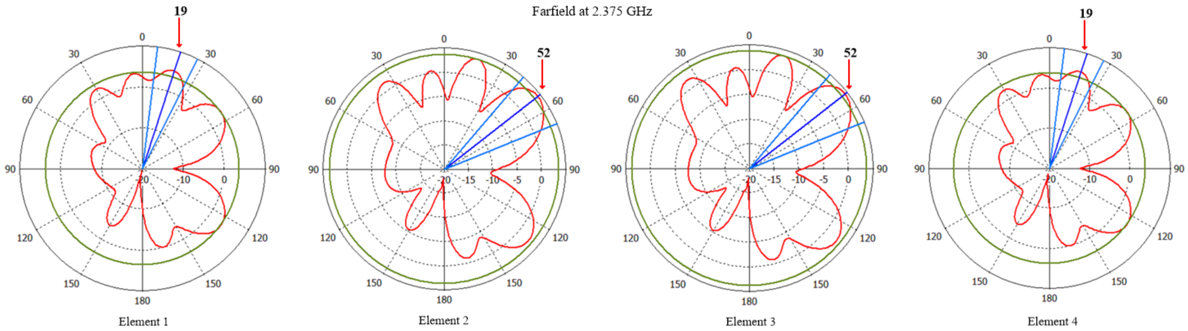

Figure 15. Phase difference MIMO 4x4 antenna with Butler matrix frequency 2.375 GHz

5. Conclusion

Significant phase difference variations have been shown at 2.375 GHz, an important frequency for 5G applications, while comparing the performance of MIMO 4x4 antennas with and without a Butler matrix. The phase differences for elements 1 and 4 are effectively modified to ±19.00 and elements 2 and 3 to ±52.00 by the Butler matrix, which is intended for 2.375 GHz. By comparison, the MIMO 4x4 antenna without the Butler matrix shows a consistent phase difference of about ±25.00 for every element. The phase difference is adequate for 4G applications at 2.1 GHz, where exact phase variation is less significant. This research confirms the ability of the MIMO 4x4 antenna with the Butler matrix to produce phase differences between elements. However, more research is necessary because the results were not sufficiently varied for all elements.

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