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# Phase delay through slot-line beam switching microstrip patch array antenna design for sub-6 GHz 5G band applications

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**ABSTRACT**

Two, four, eight, and sixteen-element patch array antennas for beam switching are presented in this study. For a 1×2 array, an aperture-coupled feeding mechanism is used to feed patches while a slot line on the ground plane provides the phase delay between antenna elements. The 1×2 array is used to create the 2×2, 4×2, and 8×2 arrays, and an equal power divider provides the signal for each. For applications in the 5G sub-6 GHz frequency spectrum, the antennas are modeled. With -37.14 dB, -17.85 dB, -21.51 dB, and -26.03 dB return loss for two, four, eight, and sixteen-element array antennas respectively the simulation demonstrates that the antennas are properly matched at the resonant frequency. The antennas can switch its radiated beam to ±24°, ±24°, ±28°, and ±26° with gains of 8.97 dBi, 11.19 dBi, 13.23 dBi, and 16.24 dBi, respectively at the resonance frequency. The directivity of the proposed antenna is found to be 9.17 dBi, 11.20 dBi, 13.40 dBi, and 16.45 dBi respectively. The antennas are constructed with two 0.8 mm-thick Teflon substrate layers. The ground plane between the two substrate layers contains the aperture and the slot line that generates the phase delay.



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## 1. INTRODUCTION

Antenna designers encounter several design challenges such as interference improvement, channel capacity, power efficiency, and assuring better transmission and reception for enhanced wireless communication, including 5G applications. And, in those instances, beam-switching antennas can be effective because they have the capacity to guide a radiated beam in a certain direction, which is very important in this high data throughput, high user mobility communication age [1]–[6]. Directing an antenna's radiated beam in a desired direction can be accomplished mechanically or electronically using horn antenna, spiral antenna, lens antenna, patch antenna, or other antennas [7]–[12].

Beam switching by means of a microstrip patch antenna has various advantages such as ease of installation, ease of manufacture, and lightweight. A number of recent research demonstrate the advancement in the beam-switching microstrip antenna that beam switching may be done by a single element or by a microstrip patch array. In most general instances, using diodes in a single patch or patch array may cause the emitted beam to tilt in a given direction by controlling the diode configuration as they can manipulate the current distribution over the patch surfaces. The beam-switching action is also accomplished through the use of switches as well as a butler matrix circuit to produce a phase difference between patch array components can result in a tilted beam [13]–[18]. By adjusting the current route on the patch, a center patch with four parasitic patches and rectangular slots with diodes inside each patch can switch the beam. A maximum of 16 degrees of beam diflection can be configured by turning ON and OFF the diode of various parasitic patches [19]. In addition to utilizing diodes to control the radiated beam by patch array antenna, using a parasitic strip next to the patch can create a new mode in analysis along with the broadside mode, which allows the parasitic patch to serve as a director and ultimately deflect the main radiated beam but only in one direction [20]. In [21], the port feeding determines the fundamental modes, which causes the parasitic patch to function as a reflector and, ultimately, causes the beam to tilt in two different directions along a plane. However, beam switching in positive and negative direction by mode switching requires two different dielectric constants, which reduces the overall antenna size.

This work designs and simulates a phase delay via slot line on the ground plane of a two-, four-, eight-, and sixteen-element microstrip patch array for high gain beam switching capabilities for sub-6 GHz 5G frequency band applications. The ground plane's slot line creates the phase difference between patches to achieve the necessary beam tilting and also takes advantage of both sides of the microwave integrated circuit (MIC), which, in the end, results in a very simple and compact antenna design [22]–[25]. The essential idea behind this constructed array is depicted in Figure 1. The phase difference between the patches as seen in the picture is caused by the slot line on the ground plane and is indicated by $\Delta\Phi$. The beam is right-tilted if the signal is applied to port #1, and it is left-tilted if the signal is applied to port #2. As the signal propagates from either source #1 or source #2, the other patch radiates with a delay and the beam gets deflected either way.

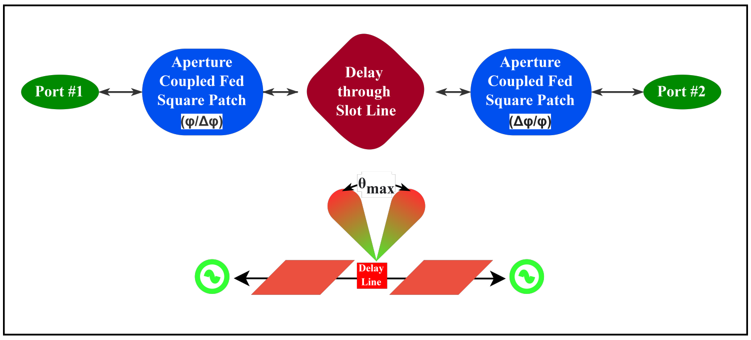


Figure 1. Basic diagram of the proposed beam-switching array antenna

The advanced design system (ADS) software from keysight technologies is used throughout the entire simulation. The format for the other sections of the paper is as follows: section 2 lists the specifications for the suggested antenna's design. Section 3 discusses the simulated results, and section 4 presents the conclusion.

## 2. ANTENNA DESIGN

In this section, the beam switching antenna's design specifications, construction, and operating principle are discussed. In subsection 2.1, 1×2 and 2×2 array antenna structures are described whereas subsection 2.2 contains the specification of the array antenna along with 8×2 element array structure. How beam switching is realized by the proposed array antenna is described in subsection 2.3 elaborately.

### 2.1. Basic structure

Figure 2 shows the top view along with cross-sectional view of the proposed 1×2 microstrip patch array antenna.The antenna is designed so that both of the proposed array's elements can use the aperture coupled feeding technique. The antenna's two substrates each have a relative dielectric constant of 2.15 and are composed of Teflon glass fiber. Both substrates height are 0.8 mm and separated by a ground plane where the aperture slot is cut. The microstrip feed line is attached below the lower substrate and the square microstrip patches are set above the upper substrate. The phase delay between the patches (which will be discussed later in subsection 2.3.) is given by the slot line has also been cut on the ground plane between the two substrates. The slot line is cut on the ground plane in C shape. The C shape slot line is placed above the microstrip line in such a way that the open arms of the slot line is extended by a quarter wavelength long surpassing the microstrip line's middle axis.

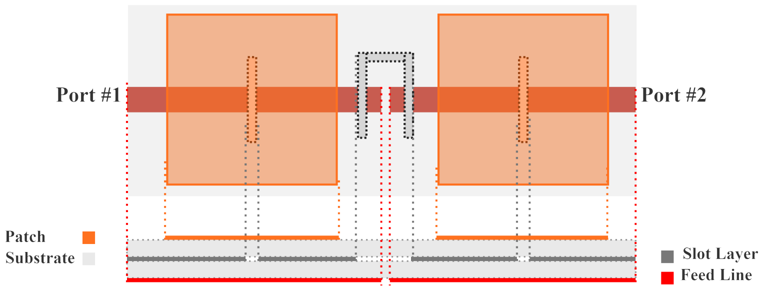


Figure 2. Basic structure of the proposed beam switching 1×2 array antenna

A 2×2 beam switching microstrip patch array is depicted in Figure 3. This structure has a symmetry along the port line. The four elements are fed by a common port, port #1 which then divide equally into two feed line.

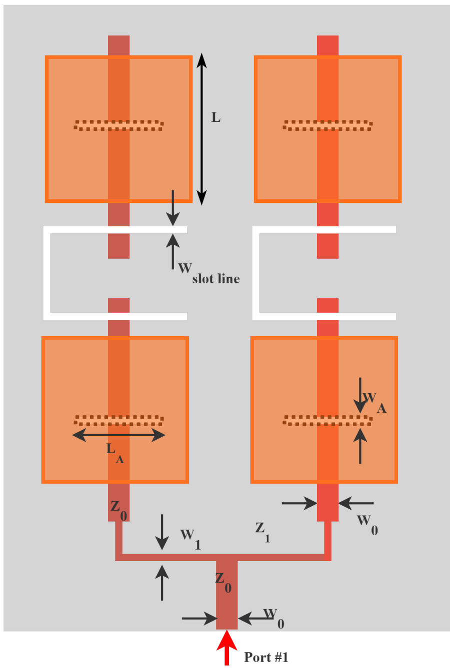


Figure 3. Basic structure of the proposed beam switching 2×2 array antenna with configuration

### 2.2. Configuration of the array

As shown in Figure 3, for a 2×2 array antenna, input signal is fed in port #1 of 50 Ω microstrip line. Then the signal is split into two equal signal, propagtes through 70.35 Ω which is fed to two 1×2 array through aperture coupled 50 Ω microstrip lines. Though a 4×2 array antenna structure is not shown in this paper, in Figure 4, a 8×2 array antenna structure is depicted.

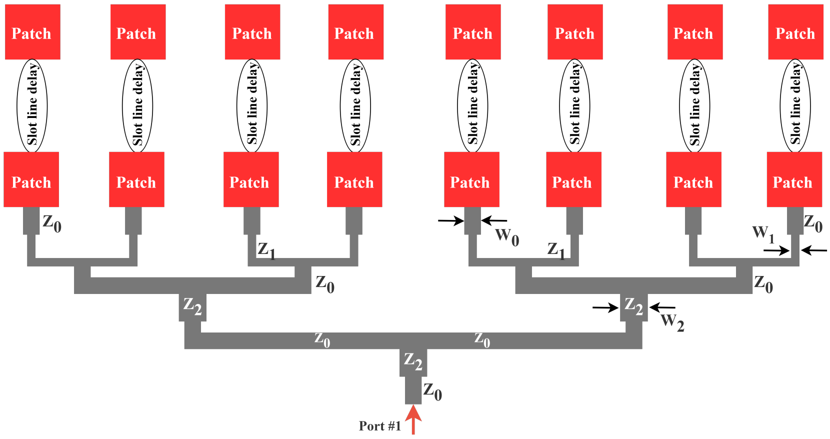


Figure 4. Basic structure of the proposed beam switching 8×2 array antenna with configuration. $Z_0$=50 Ω, $Z_1$=70.35 Ω, $Z_2$=35.7 Ω, $W_0$=2.6 mm, $W_1$=1.4 mm, $W_2$=4.0 mm

In sixteen elements array antenna, the signal is fed through a 50 Ω microstrip line. before splitting into two 50 Ω microstrip lines, the signal is fed through a quarter wave transformer of 35.70 Ω. As the signal propagates through the lines, it's then divides into two and then again into two makes the equal division of port #1 signal into eight signals. Each of eight microstrip lines has two microstrip patch to fed with a slot line delay. $W_m$ and $Z_m$ denoted in Figure 3 as well as Figure 4 are the width and impedance of the feed network respectively, where m represents the whole number. All the design parameters of designs as shown in this section are denoted in Table 1.

Table 1. Antenna design parameters

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Single patch dimension | 27.8×27.8 $mm^2$ | Substrate thickness | 0.8 mm |
| Microstrip line width, $W_0$ | 2.6 mm | Patch thickness | 0.018 mm |
| Aperture width, $W_A$ | 0.2 mm | Relative dielectric constant, $\epsilon_r$ | 2.15 |
| Substrate material | Teflon glass fiber | Quarter wave transformer width, $W_2$ | 4.0 mm |
| Aperture length, $L_A$ | 12.6 mm | Microstrip line width, $W_1$ | 1.4 mm |
| Slot-line width, $W_{slotline}$ | 0.2 mm | Microstrip line impedance, $Z_1$ | 70.35 Ω |
| Microstrip line impedance, $Z_0$ | 50 Ω | Quarter wave transformer impedance, $Z_2$ | 35.70 Ω |

### 2.3. Beam switching realizaion

Figure 5 shows the working principle of the proposed beam switching array antenna. As the signal propagates from port #1 for a 1×2 array antenna, Its get fed into antenna #1 through aperture. The microstrip line coming from port #1 is extended beyond the microstrip patch #1 upto lower arm of C shape slot line. Another microstrip line is set along the first microstrip line from the upper arm of C shape slot line. This microstrip line is for feeding the second element of the array by aperture coupled feeding technique. Thus the signal coming from port #1 reaches the antenna element #2 with a phase delay provided by C shape slot line.

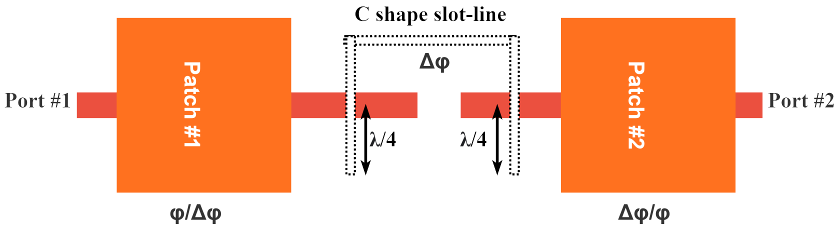


Figure 5. Working principle of the proposed array antenna

Both open arms of the slot line are extended by a quarter wavelength beyond the microstrip line so that the isolation of the signal gets improved. As the two elements of the proposed array have a phase delay between them because of C shape slot line, the radiated beam gets tilted by an angle. When the port #2 signal is in work the radiated beam tilts in the opposite direction of the previous angle. Thus Beam switching is realized by a two-element array antenna. For 2×2, 4×2, and 8×2 element array antenna the beam tilts in the same manner, only the gain of the antenna gets improved which will be shown in the next section.

## 3. SIMULATED RESULT ANALYSIS

Four array antennas are designed and simulated. In this section, different parameters of those antennas are represented and discussed. Figure 6 shows the simulated return loss of the proposed beam switching array antenna for two, four, eight, and sixteen elements. The reflection coefficient of the antenna shown in the figure simulated only for port #1. it has been seen that for port #2, the simulated return loss is the same as for port #1. The graph shows a return loss of -37.14 dB for 1×2 array antenna. Its -10 dB return loss frequency range is 3.46 GHz to 3.53 GHz. For four and eight-element arrays, the return losses are -17.85 dB and -21.51 dB respectively at their resonance frequency. Their -10 dB return loss ranges from 3.48 GHz to 3.55 GHz and 3.490 GHz to 3.70 GHz respectively. And the 8×2 array shows a -26.03 dB return loss and has a -10 dB return loss from 3.48 GHz to 3.58 GHz. All the return losses in the figure show clearly that the proposed array antennas resonate in the Sub-6GHz frequency band around 3.5 GHz.

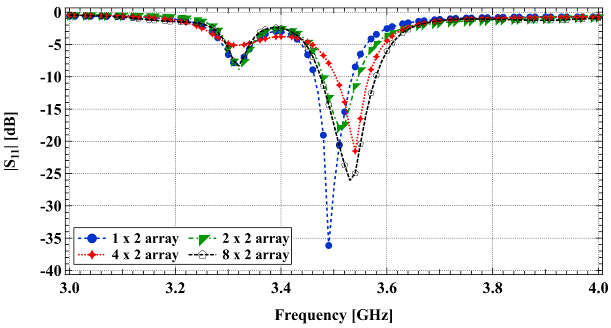


Figure 6. Simulated return loss of the proposed beam switching antenna

The simulated 3D radiation pattern of the four array antennas is displayed in Figure 7. The three-dimensional radiation patterns are shown in pair for four array antennas. 1×2 array antennas radiation beam pair is displayed in the left top and 8×2 array antennas radiation beam is in the right bottom of the figure. It can appear from the figure that, the tilt angle of the radiated beam for port #2 is in the opposite direction of that of port #1.

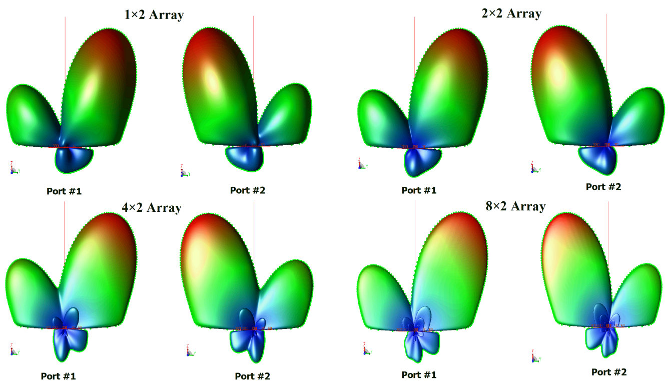


Figure 7. Simulated 3D radiation pattern of the proposed beam switching antenna

Figures 8 and 9 shows the 2D radiation pattern of the array antennas for port #1 and port #2 respectively. It is clear from the Figure 8 that for port #1, the radiated beam get deflected along phi=90° plane for $\theta$ =+28°. Figure 9 shows 2D beam deflection for port #2 of the array antennas. The radiation beam is tilted in the opposite direction as of the beam for port #1. The switching of $\theta$=-28° is achieveable by those antennas when port #2 is feeding the signal. So it is clear that the antennas are capable of achieving maximum beam switching of $\pm$28°.

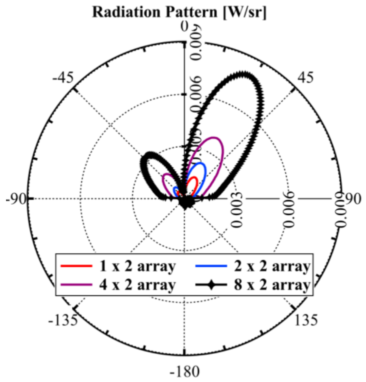


Figure 8. Simulated 2D radiation pattern of the proposed beam switching antenna for port #1. phi=90° plane

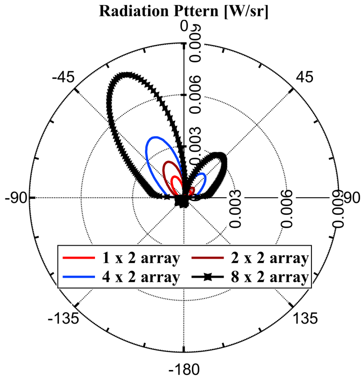


Figure 9. Simulated 2D radiation pattern of the proposed beam switching antenna for port #2. phi=90° plane

Directivity of the proposed array antenna for both port is depicted in Figures 10 and 11. It is seen from Figure 10 that every array either two, four, eight or sixteen element shows maximum directivity at $\theta$=+28°. For port #2 the maximum directivity for all those array antennas are at $\theta$=-28°, as shown in Figure 11. As the element number increases in the array, directivity increases. Side lobe of the directivity curve increases as well. For 8$\times$2 array directivity increaasses upto about 33 dB. Figure 12 shows the directivity versus frequency curve for the proposed antenna. It is seen that directivity for sixteen element array is about 17 dBi at the resonant frequency.

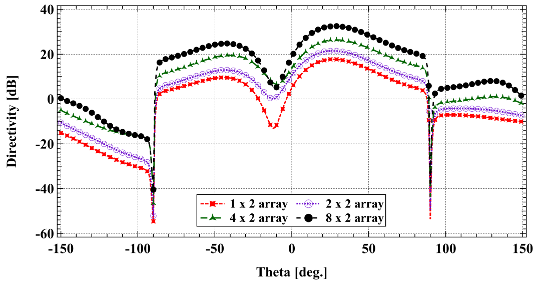


Figure 10. Simulated directivity of the proposed beam switching antenna for port #1. phi=90° plane

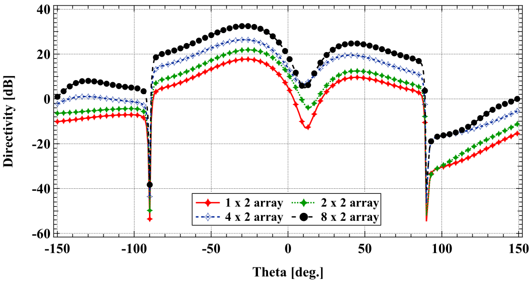


Figure 11. Simulated directivity of the proposed beam switching antenna for port #2. phi=90° plane

Gain of the proposed antenna array is displayed in Figures 13 and 14 for port #1 and port #2 respectively. From the figures it can be said that the antennas can radiate in 56° range along phi=90° plane with high gain. With the increasing number of elements of the array, the gain of the antenna increases along with side lobe gain. For 1$\times$2 and 2$\times$2 array side lobe gain remains under 10 dB, but for eight and sixteen element array antennas side lobe gain surpasses 10 dB. Figure 15 shows the gain versus frequency curve of the array antenna. From the figure it is clear that the array antenna shows excellent gain improvement with element increment at the resonant frequency of 3.5 GHz.

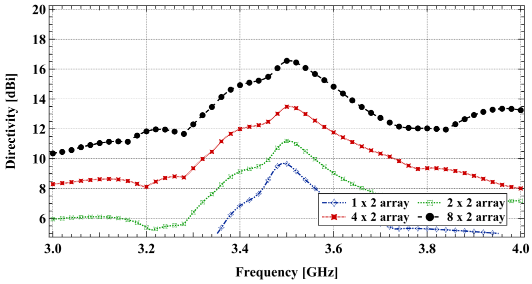


Figure 12. Simulated directivity versus frequency curve of the proposed antenna

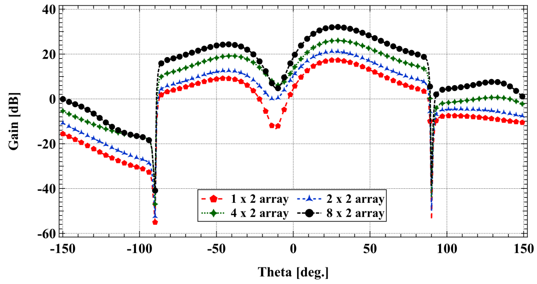


Figure 13. Simulated gain of the proposed beam switching antenna for port #1. phi=90° plane

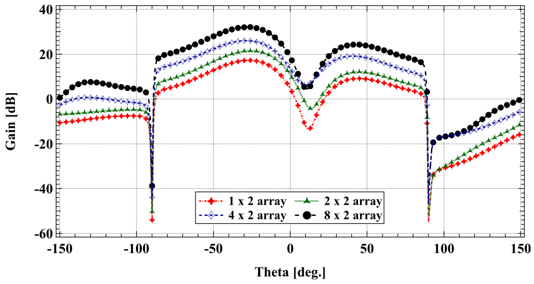


Figure 14. Simulated gain of the proposed beam switching antenna for port #2. phi=90° plane

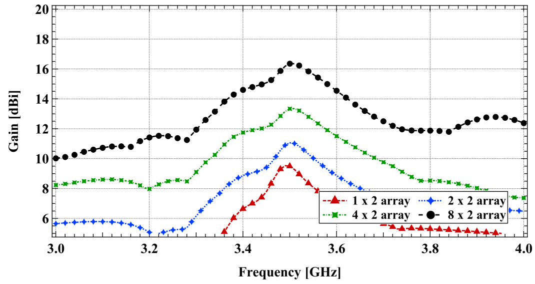


Figure 15. Simulated gain versus frequency curve of the proposed beam switching antenna

The simulated and analyzed values are recorded in Table 2. The table shows maximum gain, directivity, side lobe gain from which it can be said that the antenna is well directed, efficient antenna. It also shows that the antenna is capable of tilting its radiated beam from -28° to+28°. According to the design analysis in Table 2, the antenna is capable of switching its emitted beam to two distinct directions as the slot delays the phase between patches. It is obvious that the suggested antenna is capable of switching the beam to a specific direction regardless of patch element number. Only the gain and directivity rise as the array element count grows. Following the whole study, it is possible to conclude that the antenna demonstrates the proof of the suggested intriguing beam-switching idea. However, According to the design analysis in Table 2, the antenna is capable of switching its emitted beam to two distinct directions as the slot delays the phase between patches.

Table 2. Data analysis of radiation pattern of the proposed array antenna

| Array Config. | Input | Gain (dBi) | Directivity (dBi) | Gain (dB) | SL Gain (dB) | $\theta_{max}$ |
|---|---|---|---|---|---|---|
| 1×2 | Port #1 | 08.97 | 09.17 | 17.94 | 07.92 | +24° |
| | Port #2 | 08.97 | 09.17 | 17.94 | 07.89 | -24° |
| 2×2 | Port #1 | 11.02 | 11.19 | 22.04 | 11.14 | +24° |
| | Port #2 | 11.03 | 11.20 | 22.05 | 11.09 | -24° |
| 4×2 | Port #1 | 13.22 | 13.39 | 26.45 | 18.49 | +28° |
| | Port #2 | 13.23 | 13.40 | 26.47 | 18.45 | -28° |
| 8×2 | Port #1 | 16.24 | 16.45 | 32.47 | 23.81 | +26° |
| | Port #2 | 16.24 | 16.45 | 32.49 | 23.78 | -26° |

## 4. CONCLUSION

For applications in the sub-6 GHz 5G frequency spectrum, four antenna arrays are built and simulated. These antennas can steer the beam to a maximum of -28° to +28°. The antenna displays a maximum gain for sixteen array antennas of 16.24 dBi. In the aforementioned frequency ranges, the antenna exhibits good impedance matching. The results of the simulation demonstrate how highly directional the antennas are. A sixteen-element array's maximum directivity is approximately 33 dB at 26 degrees. As a future refinement of this study, this beam-switching technology might be utilized to generate two-dimensional beam-switching.

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## BIOGRAPHIES OF AUTHORS

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