1.0 INTRODUCTION

For the 5G mobile communication system, higher operational frequency and multi-beam radiation are requested at base stations to increase the network capacity [1]. A number of array feeds should be arranged to achieve the multi-beam objective. However, the performance will be affected by mutual coupling that is inversely proportional to the spacing distance between the array elements. The effects can be characterized by mutual impedance, S-parameters, gain, directivity, coupling matrix, or antenna-embedded element pattern performances [2, 3, 4].

Figure 1 shows the multi-beam cylindrical dielectric lens antenna that consists of array antennas as the feed radiators. For this configuration, when the element is placed close to each other, the scattered currents by the nearby element will affect the current antenna distribution; thus, the overall antenna performance will be degraded [5, 6]. From the previous work, a single bent array antenna was designed in convex and concave configurations to compare the bifurcated beam radiation when different configurations were adopted. This process investigated the antenna coupling when multiple array elements were arranged as the feed radiators of the cylindrical lens antenna system. The designed antenna's mutual coupling was also...

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discussed based on its radiation pattern and near-field distribution [7]. Thus, in this research, the feed radiator is designed in a dual bent array structure where each bent array can produce a bifurcated beam radiation pattern. To verify the mutual coupling between them, the distance between each bent array, $s$ is investigated.

Figure 1 Multi beam cylindrical dielectric lens antenna

2.0 RESEARCH METHODOLOGY – BIFURCATED BEAM ARRAY

From the previous research, a bent array structure was designed to operate at 1.72 GHz to produce a bifurcated beam radiation pattern. The researcher also discussed the relations of array element numbers with the beam shape [8]. From [9], a bent array with a serial feed network was designed. The orientation of electric fields and amplitude of currents at each patch element were considered good because they produced uniform current distribution for the bifurcated beam pattern. The bent array configuration consists of four rectangular patches with serial feed networks [10], arranged in convex and concave structures. In order to produce a convex and concave bent array that can obtain an optimum radiation shifting angle, the structure has been extended by $\Delta S$.

Then, in this paper, the dual bent array in convex and concave are arranged as shown in Figure 2. This process is to produce bifurcated beam array, analyze the mutual coupling, and achieve the optimum bent array configuration. Each bent array structure for convex and concave consists of four patches, substrate, and ground. One of the patch elements is probe-fed by a coaxial cable. As shown in the figure, it is also shown that the bending and radiation shifting angles of this antenna structure are indicated by $\theta_w$ and $\theta_s$ respectively. The $\theta_w$ and $\theta_s$ relation are expressed by equation (1):

$$\theta_w = 180 - 2\theta_s \,[\text{deg}], \quad (1)$$

The simulation condition and properties of the substrate used for the designed antenna are shown in Tables 1 and 2, respectively.

Table 1 Simulation condition

| Simulator                             | Frequency, $f$ |
|---------------------------------------|----------------|
| Computer simulation technology (CST)  | 1.72 GHz       |

Table 2 Properties of Rogers Duroid (RT 5880)

| Properties              | Values   |
|-------------------------|----------|
| Thickness, $h$          | 1.57 mm  |
| Dielectric constant, $\varepsilon_r$ | 2.2      |
| $\tan \delta$          | 0.0009   |

2.1 Dual Extended Convex Bent Array

Figure 3 shows the simulation of an extended convex bent array in the top, bottom, and side views. The top layer shows that each array structure consists of four patch elements, and the serial feedlines are designed between each element. The feeding technique used for this antenna is a coaxial probe structure where it is fed at one of the radiating patches. For the bottom view, a full ground plane is used, and it can be seen that the bent array angle of this designed antenna is 90 degrees, as shown in the side view. The two bent arrays are arranged as close as possible. The dimensions of an extended convex bent array antenna are shown in Table 3.
Table 3 Dual extended convex bent array antenna dimension

| Parameter | Dimension (mm) |
|-----------|----------------|
| $W_s$     | 231.565        |
| $L_s$     | 117.43         |
| $W_p$     | 57.75          |
| $L_p$     | 35.00          |
| $d$       | 0.6677$\lambda_0$ |
| $W_{f1}$  | 1.00           |
| $W_{f2}$  | 0.7871         |
| $W_{f3}$  | 1.20           |
| $L_f$     | 58.71          |
| $W_g$     | 229.995        |
| $L_g$     | 117.43         |
| $h$       | 1.57           |
| $t_c$     | 0.035          |

2.2 Dual Extended Concave Bent Array

Next, a concave bent array configuration is designed to compare the mutual coupling, as shown in Figure 4. This process is to verify whether this configuration can reduce the mutual coupling or not when the dual concave bent array is used as compared to the convex design. At the initial stage of designing the concave structure, all dimensions are similar to the convex structure. Then, however, the antenna is optimized to obtain an optimum result, as summarized in Table 4.
has caused the reduction of the realized beamforming gain, situation happened due to the smaller aperture of the array that will increase when the spacing distance, is decreased. This theoretical study of mutual coupling, where the mutual coupling small middle lobe are produced as expected based on the of the two bent array structures, which are \[12\]. In this paper, the method used is by increasing the distance the mutual coupling between the two bent array structures \[11, 13\]. When the bending angle, \( \theta_w \), of 90 degrees, is used, the expected \( \theta_s \) value is 45 degrees, as given by equation (1). For these three designs, the antenna with \( s = 4\lambda \) produces the closest \( \theta_s \) to the expected \( \theta_w \), which are 42.5 degrees for both ports. Besides that, the results of the gain, bandwidth, and efficiency for the dual convex bent array for both ports are almost similar to the previous work of a single convex bent array \[10\]. The summary of antenna performances for this configuration is shown in Table 5. Other parameters such as gain, efficiency, bandwidth, and \( S_{11} \) seem very stable, with no significant differences observed between all configurations.

### 3.0 RESULTS AND ANALYSIS

#### 3.1 Dual Extended Convex Bent Array

The simulated E-plane radiation pattern for the dual convex bent array with four different \( s \) values for port 1 and port 2 are shown in Figure 5 and Figure 6, respectively. For this designed antenna, the optimization started at \( s = 2.24\lambda \) until \( s = 5\lambda \). The 2.24\( \lambda \) is chosen because this value is the closest spacing distance between the two bent array structures, which directly represents the smallest overall design structure for the proposed cylindrical lens antenna system. The figure also shows that all the designed antennas have a balanced bifurcated beam shape with a middle lobe between the beams. However, when \( s = 2.24\lambda \) is used, the antenna produces a higher middle lobe. This situation happened due to the two bent array structures that are placed very closely, causing the interactions between electromagnetic fields, known as mutual coupling, where the nearby elements have modified the total radiation pattern. Therefore, it is important to reduce the mutual coupling between the two bent array structures \[11, 12\]. In this paper, the method used is by increasing the distance of the two bent array structures, which are \( s = 3\lambda, 4\lambda \), and \( 5\lambda \). The result shows good bifurcated beam radiation patterns with a small middle lobe are produced as expected based on the theoretical study of mutual coupling, where the mutual coupling will increase when the spacing distance, \( s \) is decreased. This situation happened due to the smaller aperture of the array that has caused the reduction of the realized beamforming gain, hence has increased the absorption loss and active reflection in the mutual coupling \[13\]. When the bending angle, \( \theta_w \), of 90 degrees, is used, the expected \( \theta_s \) value is 45 degrees, as given by equation (1). For these three designs, the antenna with \( s = 4\lambda \) produces the closest \( \theta_s \) to the expected \( \theta_w \), which are 42.5 degrees for both ports. Besides that, the results of the gain, bandwidth, and efficiency for the dual convex bent array for both ports are almost similar to the previous work of a single convex bent array \[10\]. The summary of antenna performances for this configuration is shown in Table 5. Other parameters such as gain, efficiency, bandwidth, and \( S_{11} \) seem very stable, with no significant differences observed between all configurations.

![Figure 5](image1)

**Figure 5** Comparison of simulated results of E-plane radiation pattern for dual extended convex bent array antenna with different \( s \) dimension in Cartesian view for port 1

![Figure 6](image2)

**Figure 6** Comparison of simulated results of E-plane radiation pattern for dual extended convex bent array antenna with different \( s \) dimension in Cartesian view for port 2

#### 3.2 Dual Extended Concave Bent Array

Table 5 Performance summary of dual extended convex bent array structure with different \( s \) dimensions for port 1 and port 2

| Properties                  | Port 1  | Port 2  |
|-----------------------------|---------|---------|
|                             | \( s = 2.24\lambda \) | \( s = 3\lambda \) | \( s = 4\lambda \) | \( s = 5\lambda \) |
|                             | \( s = 2.24\lambda \) | \( s = 3\lambda \) | \( s = 4\lambda \) | \( s = 5\lambda \) |
| Resonant frequency, \( f \) (GHz) | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 |
| Reflection Coefficient, \( S_{11}, S_{22} \) (dB) | -22.15 | -21.87 | -22.09 | -21.96 | -21.96 | -21.39 | -22.14 | -22.26 | -22.22 |
| Bandwidth, \( BW \) (MHz) | 9.29 | 9.32 | 9.33 | 9.31 | 9.32 | 9.41 | 9.34 | 9.36 |
| Gain, \( G \) (dB) | 8.14 | 7.58 | 7.31 | 7.43 | 8.02 | 7.46 | 7.39 | 7.52 |
| Directivity (dBi) | 9.04 | 8.48 | 8.16 | 8.32 | 8.93 | 8.37 | 8.29 | 8.42 |
| Efficiency, \( \eta \) (%) | 81.42 | 81.38 | 81.43 | 81.34 | 81.19 | 81.21 | 81.26 | 81.22 |
| \( \theta_s \) (degree) | 43.00 | 42.00 | 42.50 | 41.50 | 42.00 | 41.50 | 42.50 | 41.50 |

Figure 7 and Figure 8 show the simulated results of the E-plane radiation pattern for dual extended concave bent array antenna with different \( s \) values for port 1 and port 2, respectively. The figures show that the simulated radiation pattern is compared with three different \( s \) parameter values, which are 2.73\( \lambda \), 3\( \lambda \), and 4\( \lambda \). The bifurcated beam shapes for all antennas are almost similar. However, it is observed that the middle lobes between the beams are larger than the convex bent array. It is due to the mutual coupling originating from the arrangement of the two planes, specifically because the radiated waves generated face
the same direction and produce higher mutual coupling. For the concave bent array antenna, the $\theta_w$ is 270 degrees, and the $\theta_i$ value that should be produced is 45 degrees. The $s$ comparison shows that for $s = 3\lambda$, the $\theta_i$ for port 1 and port 2, respectively, which shows a good agreement with the expected shifting angle compared to other $s$ values.

![Figure 7](image_url) Comparison of simulated results of E-plane radiation pattern for dual extended concave bent array antenna with different $s$ dimension in Cartesian view for port 1

![Figure 8](image_url) Comparison of simulated results of E-plane radiation pattern for dual extended concave bent array antenna with different $s$ dimension in Cartesian view for port 2

Table 6 summarizes the simulated results of dual concave bent array antennas. Other parameters such as gain, efficiency, bandwidth, and $S_{11}$ seem very stable, with no significant differences observed between all configurations.

| Properties          | Port 1   | Port 2   |
|---------------------|----------|----------|
|                     | $s = 2.73\lambda$ | $s = 3\lambda$ | $s = 4\lambda$ | $s = 2.73\lambda$ | $s = 3\lambda$ | $s = 4\lambda$ |
| Resonant frequency, $f$ (GHz) | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 |
| Reflection Coefficient, $S_{11}$, $S_{22}$ (dB) | -24.45 | -35.18 | -36.43 | -25.33 | -35.39 | -36.73 |
| Bandwidth, $BW$ (MHz) | 9.92 | 10.24 | 10.21 | 9.99 | 10.25 | 10.23 |
| Gain, $G$ (dB) | 6.63 | 6.20 | 6.43 | 6.79 | 6.38 | 6.30 |
| Directivity (dB) | 7.74 | 7.34 | 7.57 | 7.89 | 7.50 | 7.43 |
| Efficiency, $\eta$ (%) | 77.39 | 77.02 | 76.86 | 77.48 | 77.13 | 77.00 |
| $\theta_i$ (degree) | 47.00 | 45.50 | 42.50 | 47.00 | 44.50 | 47.00 |

4.0 CONCLUSION

This paper compares the performance of the dual bent array antenna between convex and concave structures. The antennas are also designed and studied with different spacing distances between array structures, $s$ to obtain better performance with the lowest mutual coupling. After achieving the optimum result, the $\theta_i$ of each antenna are compared with respect to the $\theta_w$. This study shows that the dual convex bent array antenna can produce a better-bifurcated beam pattern and the middle lobe of the beam shape is also smaller than the dual concave bent array structure. Based on the comparison of many $s$ parameters for a dual convex bent array, the $s = 4\lambda$ is chosen because it produces an optimum and good value of $\theta_i$ for both ports. It is because the dual convex bent array structure with $s = 4\lambda$ produces the closest $\theta_i$ value for both ports to the expected $\theta_i$ (theoretical). Furthermore, the results of this antenna design’s gain, bandwidth, and efficiency are almost similar to the single convex bent array in the previous study.

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