Design of Serial-Fed Bend-Array and Measured Results

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***Abstract*—For the next generation mobile system (5G), a cylindrical lens antenna is developed for mobile base station application. As for the feed radiator for this lens antenna, bend-array configuration that produces a bifurcated beam is also developed. The bend-array configuration consisting of four rectangular patch array elements with serial feed network. In previous work, achievement of the bifurcated beam by bend-array configuration was shown by electromagnetic simulations. In this paper, a practical bend-array composed of four numbers of patch elements is fabricated. To verify the radiation characteristics, measured results of antenna input characteristic and radiation pattern are compared with the designed results. Through good agreement of measured and designed results, achievement of practical antenna is ensured.**

***Index Terms*—Bifurcated Beam; Bend-Array; Cylindrical Lens Antenna; Mobile Base Station Antenna.**

I. Introduction

For the next generation mobile system (5G), multi beam capability and multi frequency band shall be requested in the mobile base station [1]. The objectives of the multi beam are to maximize the minimum gain over the coverage region and to maximize the pattern roll-off outside the spot-beam area and to minimize the side lobe radiation in order to maximize the frequency reuse [2]. Because of the present base station antenna is designed to achieve one shaped beam, the present antenna cannot be applied to 5G mobile system. As a candidate antenna, a cylindrical lens antenna shown in Figure 1 is proposed [3]. The lens is formed cylindrically around the vertical axis (z-axis). For convenience of installation on a base station, the distance between a feed to lens should be designed as small as possible [4]. In order to illuminate all lens area effectively, a shaped beam called bifurcated beam is requested from the feed radiator [5]. For achieving a bifurcated beam, a bend-array configuration is proposed by authors [6]. As for feeding method of the bend-array, serial feed is applied [7].

In this paper, a practical bend-array of four elements configuration is fabricated and measured results are obtained. First, the designed serial feed characteristics are compared with measured results. Next, after achieving the optimum design of the serial feed, a bend-array is designed. The radiation patterns of a bend-array are compared with measured results.

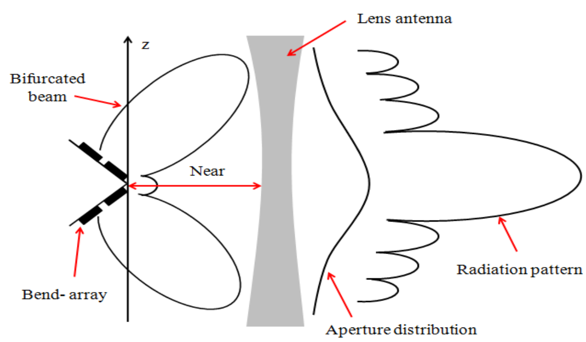


Figure 1: Application of a bend-array

II. Design Method

Figure 2 shows the configuration of the bend-array structure with serial feed line network which is designed as the feed radiator for cylindrical lens antenna system. The design consists of four elements of microstrip patch with serial feed line between each patches. One of the patches is probe-fed by a coaxial cable structure. The bifurcated beam radiation pattern is produced by this antenna design.

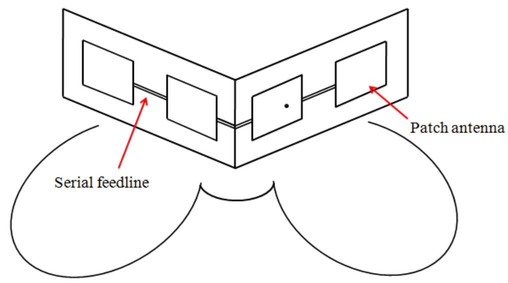


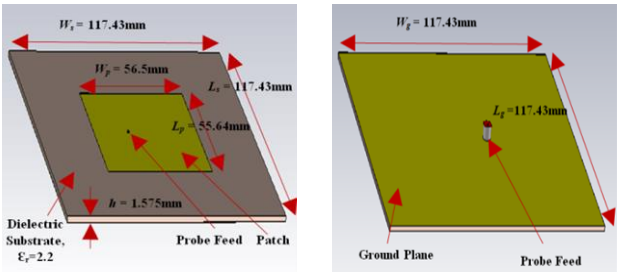
Figure 2: Configuration of bend-array.

III. Electromagnetic Simulation Parameters

In order to achieve the bifurcated beam pattern from the feed radiator, a bend-array structure is designed. For the purpose of applying the bend-array with serial feed to the cylindrical lens antenna, patch array configuration in series structure is studied. Table 1 shows the simulation condition for this design. Finite Element Method (FEM) of Computer Simulation Technology (CST) software is used. First, a single element of patch antenna is designed to operate at the frequency of 1.72 GHz. The single patch antenna structure in front and rear view consisting of microstrip element, dielectric substrate and ground are shown in Figure 3 . The patch is probe fed by a coaxial cable structure. For the substrate, Rogers RT 5880 plate of 1.575 mm thickness, dielectric constant of $\mathcal{E}_r$ = 2.2 and tan δ = 0.00009 is used. As a result using small value of dielectric loss, this feed structure can achieve very small losses. The simulated return loss, S_{11} characteristics of single patch antenna is shown in Figure 4. The bandwidth, *BW* at return loss of -10 dB becomes 28.3MHz. Then, an array antenna configuration in serial feed structure is designed. The array antenna design consist of four elements number of patch and one patch is probe-fed by a coaxial cable structure. During the design process of series feed array structure, the orientations of electric fields and the array excitation amplitudes are considered. Next, the bend-array configuration is designed using the previous serial feed structure. The bifurcated beam pattern is produced by the bend-array design. Simulation parameters of serial feed array structures are shown in Table 2. The parameters of feed element consist of the dimension of patch, substrate and connecting serial line between the patch elements.

Table 1
Simulation Condition

Simulator	CST (FEM)
Frequency	1.72 GHz
Array	4 elements
Feed	Serial feeds
Beam	Bifurcated



(a) Front view (b) Rear view

Figure 3: Simulation model of single patch antenna

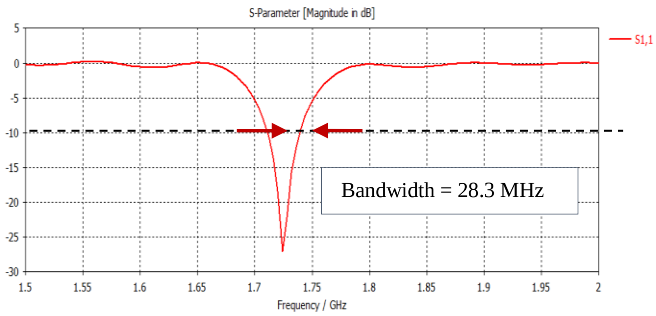


Figure 4: Simulated return loss, S_{11} characteristics of single patch antenna

Table 2
Structures of Serial Feed Array

Element	Parameter	Dimension
	W	57.75 mm
Patch	L	35 mm
	d	$0.6687\lambda_o$
Substrate	h	1.575 mm
	ε_r	2.2
	W_{f1}	1 mm
Series Line	W_{f2}	0.7871 mm
	W_{f3}	1.2 mm
	d_f	58.71 mm

IV. Patch and Feed Line Design

To ensure good and balance performances of an array antenna, the orientation of electric fields and the excitation amplitude of each patch elements in serial feed array structure are considered. Figure 5 shows the simulation model of series feed structure. From the figure, it shows that the antenna design consists of four elements of microstrip patches and one patch is probe-fed by a coaxial cable structure. The dimension of all four patches are similar in size. The connecting serial line between patches is studied for the serial feed structure. The design of the length and width of the serial line determines the amplitude excited at each of the patch surface. The spacing between each patch also are set to have the same distance. The fabricated of serial feed configuration is shown in Figure 6.

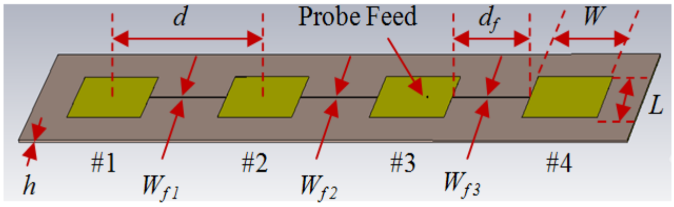


Figure 5: Simulation model of serial feed structure

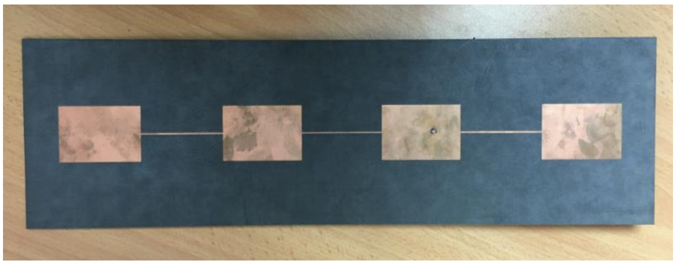


Figure 6: Fabricated of serial feed configuration

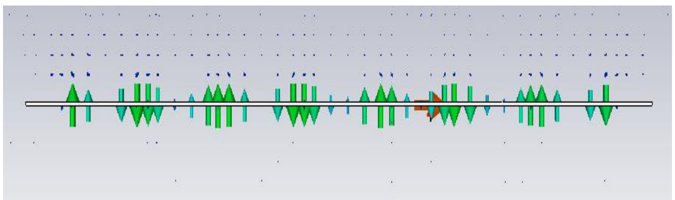
The length of connecting serial line impedance, d_f between patches is calculated by the given Equation (1),

$$d_f = 0.5\lambda_g \quad (1)$$

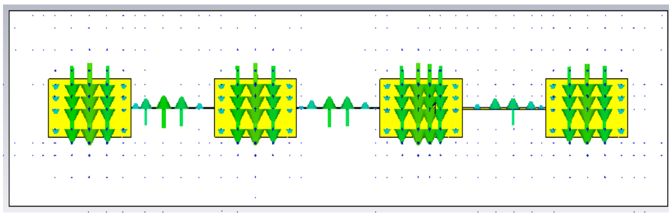
and, λ_g is given by Equation (2).

$$\lambda_g = \frac{\lambda_o}{\sqrt{\varepsilon_r}} \quad (2)$$

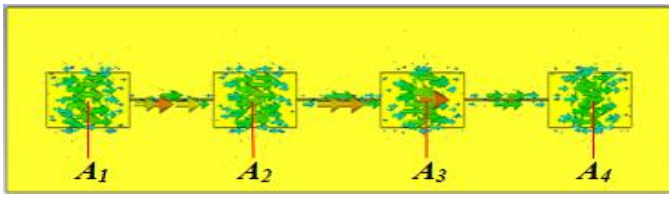
For the calculations of the antenna simulation results, Figure 7 shows the calculation results of field components and current distribution for the array antenna configuration in serial feed structure. Figure 7(a), Figure 7(b) and Figure 7(c) show the electric field, magnetic field and surface current distribution respectively. From this design, it shows that the surface current is in the same orientation.



(a) Electric field (side view)



(b) Magnetic field (front view)



(c) Surface current (front view)

Figure 7: Calculation results of field components and current distribution

Figure 7(c) shows the radiation amplitudes of current distribution for all elements, labeled as A_1, A_2, A_3 and A_4. From the graph of Figure 8, it shows the difference in current amplitude for the serial feed configuration when using similar and optimized serial line width dimension, W_{f1}, W_{f2} and W_{f3}. Before the optimization process of the connecting line between patches which is using similar line width dimension, the surface current is not uniform. However, after optimizing the line width of the connecting line, the amplitudes of current distribution becomes uniform, which is important in the implementation of bifurcated beam for lens antenna in order to ensure that the radiated beam of the bend-array structure is balance. From this optimization process of serial feed array, it shows that the amplitudes of current distribution can be controlled through optimization of the serial line width dimension, which are W_{f1}, W_{f2} and W_{f3}. The result of reflection coefficient or return loss characteristic of the proposed antenna for simulated and measured results are shown in Figure 9. The calculated bandwidth, *BW* at return loss, S_{11} of -10 dB for simulated result becomes 9.497 MHz operate at frequency of 1.72 GHz while for measured result, the bandwidth, *BW* becomes 10.17 MHz at frequency of 1.736 GHz. From this result, it shows that the frequency for measured result is shifted about 0.016 GHz which has small percentage difference, 0.93%. The result also shows that the measured bandwidth for this antenna design becomes better than the simulated bandwidth with increment of 7.09%.

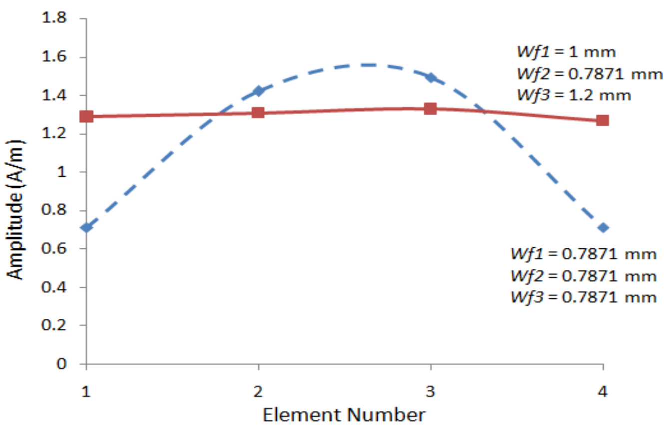


Figure 8: Amplitudes of currents

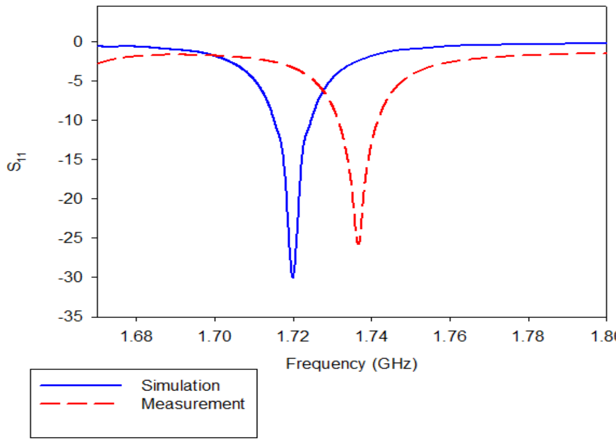


Figure 9: Simulated and measured return loss, S_{11} characteristics of serial feed array configuration

V. MEASUREMENT OF BEND-ARRAY

The bend-array configuration is designed using the previous serial feed structure in CST simulation software. The bend angle (θ_B) of the bend-array structure is 90˚. After achieving the optimum simulation results in terms of reflection coefficient and the radiation pattern for the bend-array configuration, the antenna then is fabricated as shown in Figure 10.

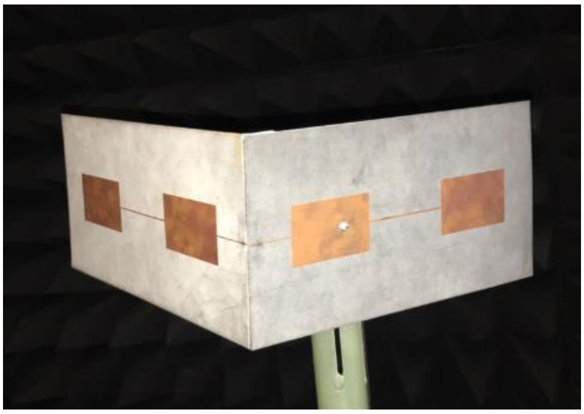


Figure 10: Fabricated of bend-array configuration

A. *Measurement Set-up*

Figure 11 shows the measurement setup of the fabricated bend-array structure. The antenna is measured in an anechoic chamber at Antenna Research Centre, UiTM Shah Alam, Malaysia. In the measurement setup, the instrument used to measure the reflection coefficient or return loss is the Vector Network Analyzer (VNA) [8].

B. *Results*

Figure 12 shows the simulated and measured return loss, S_{11} characteristics of bend-array structure. From the result, it shows that the bandwidth, *BW* of simulated result is 9.46 MHz with operating frequency of 1.72 GHz while the bandwidth, *BW* for measured result is 9.59 MHz with operating frequency 1.736 GHz. The measured frequency is shifted about 0.016 GHz with 0.93% percentage difference. The frequency difference between simulated and measured result is caused by the difference of dielectric constant at the actual substrate. However, the measured bandwidth for simulated result is better compared with the measured result with increment of 1.38%. For the radiation pattern, the simulated and measured results are compared as shown in Figure 13 and 14 for E-plane and H-plane view respectively. For E-plane view, it shows that there are two beams produced from this designed antenna. Figure 13 shows that the simulated and measured results agree very well. It also shows that the four-element patch array configuration has a balanced bifurcated beam characteristic for simulated and measured results. The radiation pattern of the bend-array structure is balance and have similar magnitude shift angle due to the optimization process of current distribution amplitude which can be controlled by adjusting the serial line width dimension between each patches. The gain, *G* produced by this antenna is 7.54 dB and 7.36 dB for simulated and measured respectively. This values correspond to the antenna efficiency of η = 82.39% and η = 74.3% for simulated and measured results respectively. The directivity performances, for simulated result is 8.38 dBi and for measured result, the directivity is 8.65 dBi.

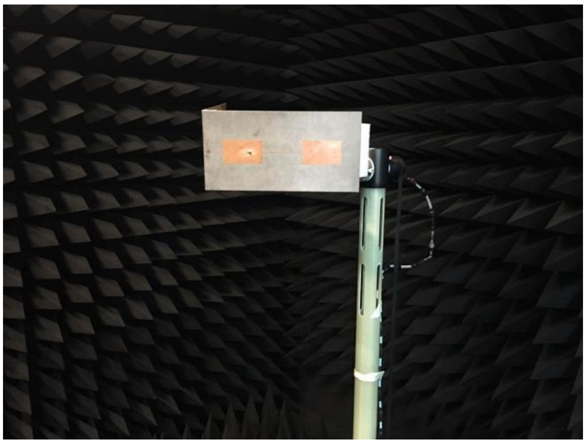


Figure 11: Measurement setup of bend-array structure (side-view)

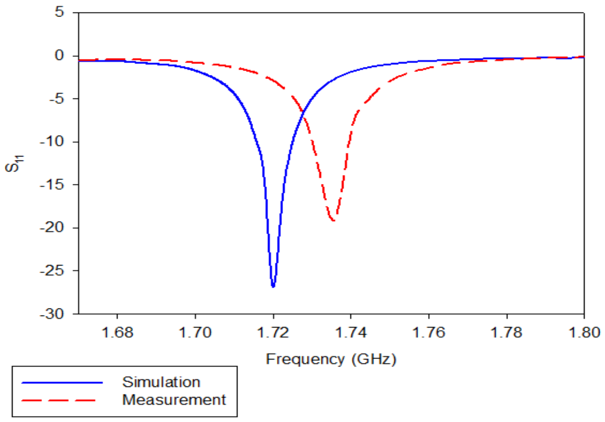


Figure 12: Simulated and measured return loss, S_{11} characteristics of bend-array structure

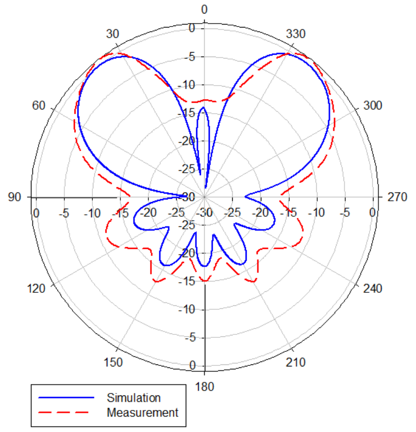


Figure 13: E-plane view for simulated and measured radiation pattern of bend-array structure

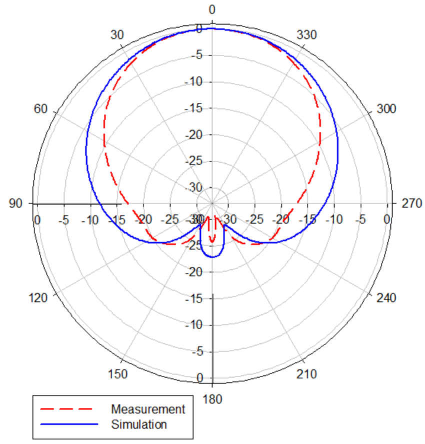


Figure 14: H-plane view for simulated and measured radiation pattern of bend-array structure

VI. Conclusion

In this study, a serial feed of bend-array that can produces balance bifurcated beam pattern is discussed. This antenna is designed for cylindrical dielectric lens antenna. In order to achieve a uniform bifurcated beam, an array antenna configuration is studied to obtain the same orientation of electric fields and array excitation amplitudes. To ensure this, detailed optimization process is performed in series feed array structure. Based on the optimization data, a relation between the serial feed line width and the current distribution amplitude is found. Then, by employing the optimized serial feed of bend-array configuration, it is shown that an excellent bifurcated beam radiation having uniform bifurcated beam characteristics is achieved. The serial feed and bend-array structure performances and total antenna radiation characteristics are confirmed through measurement. Through good agreement of simulated and measured results, achievement of practical antenna is ensured.

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