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| **RESEARCH ARTICLE** |  |

**Pattern-reconfigurable antenna using four-elements dipole array for 5G beam-switching applications**

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# Introduction

Wireless communication demands and the transition from 4G to 5G have increased the focus on smart antennas and their applications.1-7 It is essential to be able to point the waveform in a specific direction based on the user's request. The beam switch antenna is one of the most suitable solutions for such requirements. It allows for energy conservation, reducing multipath fading by directing the desired signal to the appropriate user and enhancing antenna flexibility. In a multi-beam–steering antenna, a beam-forming network should be designed and cascaded with the antenna array. There are several methods for designing a beam switch antenna. For instance, beam switch antennas can be designed using conventional phased array antennas.8-11 However, a phased array antenna needs an active circuit and, in many cases, a digital phase shifter, which makes the antenna complex and expensive. An antenna based on a lens structure shows excellent potential for generating a high directivity radiation pattern.12-14 However, lens antennas are limited in terms of coverage and resolution. A tunable beam-steering antenna with a left-handed phase shifter has been presented.15 However, beam coverage is restricted, despite their high coverage. A miniaturized SIW 8×8 on two layers is presented16, but multilayer structures and vias are undesirable in fabrication. The antenna adds only four new beam patterns, which is especially significant. An 8×8 beam switch Butler matrix antenna with a stripline phase shifter has been reported.17 Although, a better solution can be found, the stripline design is more complicated and costly. In addition, the phase shifter method reported introduces relatively high insertion losses. Over the last two decades, composite right/left-handed transmission lines (TLs) with right-handed and left-handed features have exhibited low loss and extended bandwidth. These TLs have been extensively studied and utilized in radiated-wave circuits and devices.18,19

In this paper, a compact pattern-reconfigurable circular array using four-dipole-element is reported. The antenna achieves a good frequency bandwidth and radiation characteristics in terms of the beam pattern and gain.

This article is organized as follows: Section 2 explains elementary dipole antenna design. Section 3 describes the design of the proposed pattern reconfigurable circular array, and the performances in terms of input impedance mismatch, radiation pattern, gain, and efficiency, are discussed Section 3 concludes the article. Section 4 concludes the article

# Elementary dipole

This section describes the elementary dipole chosen for the antenna array. The simulation and measurement results in terms of reflection coefficient, 3D and 2D radiation patterns, max gain, and efficiency are presented and discussed.

## *ANTENNA DESIGN*

Figure 1 shows a schematic diagram of the proposed antenna. As seen from the figure, the antenna consists of a printed dipole20 with a length of λ/2, and the spacing between the arms of the dipole and the ground plane is approximately λ/4, where λ represents the wavelength at 2.65 GHz. The printed dipole is designed on Teflon glass (TM) with a dielectric constant of 2.17 (tan = 0.001) and a thickness equal to 0.8 mm. The simulations of the elementary dipole and the reconfigurable antenna array were performed by the 3D electromagnetic software ANSYS-HFSS21.

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| (a) | (b) |

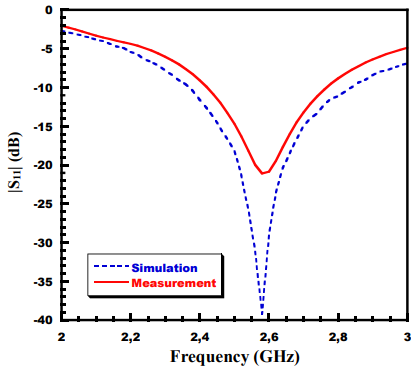


(c)

**Fig. 1.** The elementary dipole: (a) HFSS design, (b) Geometry and dimensions in (mm),   
(c) Photo of the realized prototype.

## *RESULTS*

The simulated and measured reflection coefficient of the elementary dipole is shown in Fig. 2. The obtained resonant frequency is equal to 2.6 GHz with a matched bandwidth around 630 MHz in simulation and 500MHz in measurement.



**Fig. 2.** Simulated and measured reflection coefficient of the elementary dipole.

As shown in Fig 3, the elementary dipole exhibits omnidirectional radiation around the y-axis as expected. The maximum gain is 4.92 dBi for simulation and 4.81dBi for measurement. The measured radiation patterns in the H-plane (OXY) and E-plane (OXZ) at an operating frequency of 2.65 GHz are plotted in Figure 4. We can note an omnidirectional behavior in the H plane and the E plane E gives a “null” of radiation in the Y axis which corresponds to theta = 90 °. This result is expected because the two arms of the dipole are oriented along the y-axis. All the radiation measurements in terms of gain and efficiency are performed in the anechoic chamber Stargate 32 from SATIMO.

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| (a) | (b) |

**Fig. 3.** 3D-radiation pattern (Gain) for the simple dipole at 2.6GHz.   
(a) : simulated results and (b) : measured results.



**Fig. 4.** Measured 2D radiation patterns in the E plan and H plan of the elementary dipole.

We obtain a maximum measured efficiency of 83% and a measured peak gain of around 4.81 dBi at the 2.6 GHz frequency as shown in figure 5.

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| (a) | (b) |

**Fig. 5.** Elementary dipole (a) Measured efficiency (b) Measured peak gain.

# PATTERN-RECONFIGURABLE CIRCULAR ARRAY

The proposed array consists of a circular network of 4 printed dipoles positioned every 90° 22,23. Then, in order to ensure the reconfigurability of the structure, four open circuits used as switches S1, S2, S3, and S4 were loaded on the top face of the substrate as shown in Figure 6. The main idea of reconfiguring the array antenna is to control the array radiation pattern to change the shape of the beam and change the side lobe levels.

## *ARRAY DESIGN*

To demonstrate the reconfigurable dipole array developed in this work, a design for approximately 2.6 GHz was fabricated and measured. The substrate is circular with a radius size of 45 mm, Teflon type (TM) of 0.8mm height, and with a relative permittivity of 2.2 (the same substrate used for the elementary dipole). Figures 6-a and 6-b illustrate respectively the HFSS design and realized prototype reconfigurable antenna array.

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| --- | --- |
| Top  Bottom  Switches  **S1**  **S2**  **S3**  **S4**  (a) | |
| Top view | Bottom view |

(b)

**Fig. 6.** Proposed circular antenna array: (a) HFSS design  
(b) Fabricated prototype.

## *OPERATING modes*

Four radiation modes were selected depending on the choice of dipole activation for reconfigurability with a single-powered dipole.

**Table 1.** Mode Configurations by Switches ON/OFF Conditions.

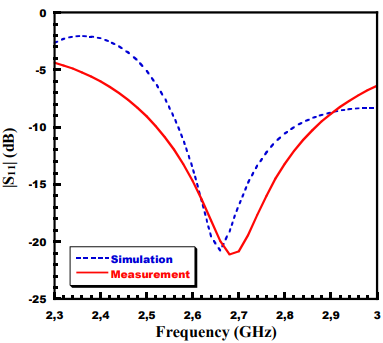
|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Mode** | **S1** | **S2** | **S3** | **S4** |
| **M1** | ON | OFF | OFF | OFF |
| **M2** | OFF | ON | OFF | OFF |
| **M3** | OFF | OFF | ON | OFF |
| **M4** | OFF | OFF | OFF | ON |
| **M5** | ON | OFF | ON | OFF |
| **M6** | OFF | ON | OFF | ON |

The first mode M1 presents the activation of dipole 1 and the deactivation of the other dipoles (2, 3, and 4). Mode M2 shows the activation of dipole 2 and the deactivation of the other dipoles (1, 3, and 4). Mode M3 shows the activation of dipole 3 and the deactivation of the other dipoles (1, 2, and 4). Mode M4 presents the activation of dipole 4 and the deactivation of the other dipoles (1, 2, and 3). For the reconfigurable network with two powered dipoles, two radiation modes were selected. Mode 5 is set when dipoles 1 and 3 are energized and the rest of the dipoles are deactivated (2 and 4). Mode 6 is set when dipoles 2 and 4 are energized and the rest of the dipoles are deactivated (1 and 3). These modes are detailed in table 1.

### Modes: M1, M2, M3, and M4 –Directive beam

In this section, we present and discuss the simulated and measured results obtained for the four modes M1 to M4 in terms of reflection coefficient, gain mode, and overall efficiency. These results are then summarized in Table 2.

The measured and simulated reflection coefficient corresponding to Mode 2 of the proposed antenna array is plotted in Fig. 7. As can be seen, the antenna operates at 2.65 GHz according to the measured result with a matched bandwidth of around 350 MHz. The simulated result is in good agreement with the measured result at the resonance frequency.

 **Fig.7.** Simulated and measured reflection coefficient of the antenna array   
corresponding to the mode M2.

The measured and simulated radiation patterns of mode M1 at the frequency of 2.65 GHz are shown in Fig. 8. The measured radiation patterns of the antenna array at 2.65 GHz are shown in Fig. 8 (b) and are in close agreement with the simulated patterns shown in Fig. 8 (a).

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| (a) | (b) |

**Fig. 8.** 3D gain pattern of the array related to the mode M2 at 2.65GHz:   
(a) Simulated result (b) Measured result.

As can be seen, the antenna focuses its radiation towards the positive Y axis as expected. Additionally, in this mode M1, the maximum simulated gain is approximately 3.12 dB and approximately 2.40 dB for the measurement at the operating frequency. We note a good agreement between simulated and experimental results for radiation patterns. The simulated and measured 2D radiation patterns of the antenna array are given in Fig. 9.



**X**

**Y**

**Fig.9.** Simulated and measured 2D-radiation pattern at 2.65 GHz   
corresponding to the mode M2.

We can notice that the radiation pattern of the M2 mode is directional to the working frequency Fr = 2.65 GHz and that the beam is oriented towards the Y direction positive as seen with the 3D radiation pattern. We note a good agreement between simulated and experimental results for 2D radiation patterns.

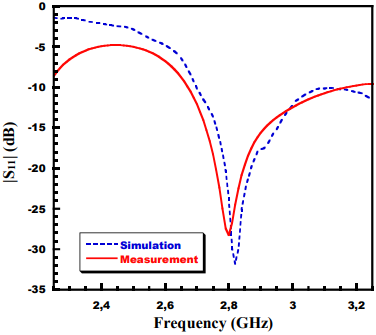
We obtain a maximum measured efficiency of 77% and a measured peak gain of around 2.2 dBi at the 2.65 GHz frequency as shown in figure 10.

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| (a) | (b) |

**Fig. 10.** Mode M2 of the dipole array: (a) Measured efficiency (b) Measured peak gain.

### Modes: M5 and M6 –DUAL beam

In this section, we present and discuss the simulation and measurement results obtained for the M6 ​​mode in terms of reflection coefficient, gain mode, and efficiency. The reflection coefficient for mode M6 is plotted and shown in Fig.11 for both simulation and measurement results at the operating frequency Fr = 2.8 GHz.

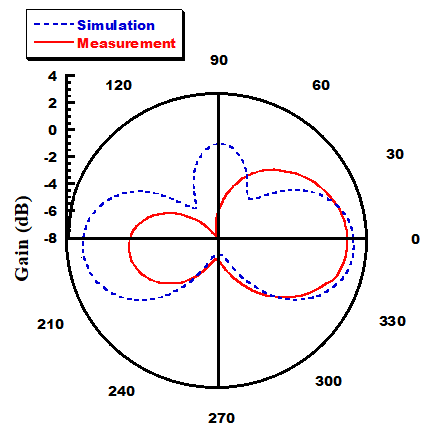


**Fig.11.** Simulated and measured reflection coefficient for the mode M6.

From the plot, it can be seen that the reflection coefficient for simulation results is lower than -30 dB and -27 dB for measurement, which implies a better input impedance adaptation for this mode. At the same time, we have achieved an extremely broad bandwidth, simulated 933.6 MHz and measured 900 MHz, which confirms that the measured data coincide well with the simulated data. Measured and simulated results for the mode M6 2D and 3D radiation patterns at 2.8 GHz are shown in Fig. 12 and Fig. 13. Measured results show that the peak gains are 3 dBi and the maximum simulated gain achieved is approximately 3.52 dBi, [which](https://www.powerthesaurus.org/which_confirms/synonyms) agrees very well with measured ones. Both results show that at the resonant frequency, the radiation pattern is directional in the Y-direction plane of the antenna and has a trough along the dipole axis. This allows us to conclude that the antenna developed in this work achieves extremely wide good characteristics in terms of gain and beam pattern.

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| (a) | (b) |

**Fig. 12.** 3D gain patterns of the array for the mode M6 at 2.8GHz:   
(a) Simulated result (b) Measured result.



**X**

**Y**

**Fig.13.** Simulated and measured 2D-radiation pattern at 2.8 GHz   
corresponding to the mode M6.

We obtain a maximum measured efficiency of 75% and a measured peak gain around 3dBi at the 2.65 GHz frequency as shown in figure 14.

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| (a) | (b) |

**Fig. 14.** 3D gain pattern of the array for the mode M6 at 2.8GHz:   
(a) Simulated result (b) Measured result.

Table 2 summarizes the results obtained from mode M2 to M6 relating to the reconfigurable network developed in this work.

**Table 2.**  Performance Characteristics of the Three Reconfigurable Array Configurations.

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| --- | --- | --- | --- | --- |
| Array configuration | Frequency (GHz) | BW (MHz) | Peak Gain (dB) | Efficiency (%) |
| Directional (Simulated) | 2.65 | 300 | 3.12 | 85 |
| Directional (Measured) | 2.66 | 350 | 2.40 | 77 |
| Bidirectional (Simulated) | 2.81 | 933.6 | 3.52 | 82 |
| Bidirectional (Measured) | 2.80 | 900 | 3 | 75 |

In order to evaluate the work developed in this paper, we have compared the antenna’s performances to the related published works. Table 3 summarizes the results. We can conclude that the proposed structure offers a good compromise in terms of low cost and this is by its simplicity of design, modularity by the possibility of reconfiguring the radiation patterns efficiently, and compactness by reducing the complexity of the design.

**Table 3:** Performance Comparison with Antennas Available in the State-of-the-Art Literature

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| --- | --- | --- | --- | --- | --- | --- | --- |
| **Ref.** | **Size(mm)** | **Actuators** | **States** | **Operating frequency (GHz)** | **Gain (dBi)** | **Modularity** | **Complexity** |
| **[24]** | 60\*60 | 4 open stubs | 3 | 2.53 | 2.03 | Medium | Medium |
| **[25]** | 45×50×1.52 | 5 graphene pads | 6 | 3.5 | 1.8 | Medium | High |
| **[26]** | 150×150 | 4 switchable couplers | 6 | 2.6 | 5.8 | Medium | Medium |
| **This work Mode M2** | 45 | 4 switches | 6 | 2.65 | 3.13 | High | reduced |

# CONCLUSION

This paper presents a circular dipole array with beam-switching capabilities for 5G communications. The beam can switch in four directions by opening or closing short circuits which are used as switches implemented in the antenna arms. Different modes of the antenna can be selected leading to different radiation patterns. Four modes are obtained having a directional beam with a maximum peak gain of 3.11 dBi, and two modes with a bidirectional beam in the H-plane with a maximum peak gain of 3.13 dBi. Simulation and measurement results are reported and they agree well with each other. The reconfigurable pattern properties of this antenna are well demonstrated. The antenna can be used as a compact base station for 5G mobile networks.

CONFLICT OF INTEREST

The authors declared that they have no conflicts of interest to this work. We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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