A Broadband High-Gain Printed Antenna Array Using Dipole and Loop Patches for 5G Communication Systems

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Abstract—A broadband and high-gain printed antenna array is presented in this paper. Its single antenna element consists of a loop and two symmetric dipole patches, making the element exhibiting broad impedance bandwidth and improved gain at the targeted frequency, which is 28 GHz, one of the 5G mm-wave band, for this design. An 8×3 antenna array fed by a microstrip line feed network was designed and simulated. With a compact size of 98×32.5 mm^2, the array presents a broad -10 dB impedance bandwidth of 6.8 GHz (24.3%) and a high gain of 18 dBi at 28 GHz. Besides, the single-layered array also features low profile, simple geometry, and low cost, making it a good candidate for 5G communication systems.

Keywords—Printed antenna array, loop, dipole, 5G, mm-wave, single-layered.

I. Introduction

It is well known that the fifth-generation (5G) wireless networks are the proposed next telecommunication standards that based on millimeter-wave (mm-wave) communications due to the shortage of frequency spectrum in microwave bands [1]. Despite that the mm-wave bands can realize high-speed transmission [2], the Friis' transmission equation reveals that the high pass loss is a major shortcoming of mm-wave communications [3]. To address the challenge, antenna arrays with pencil beams, i.e., high gain, are widely implemented in 5G communication systems [4]-[5].

In recent years, several 5G mm-wave antenna arrays have been proposed. In [7], the authors presented a compact 2×2 slot antenna array operating at 28 GHz that exhibits a moderate gain of 9.6 dBi but with a narrow -10 dB fractional impedance bandwidth of 5.7%. [8] presents a 28 GHz high gain patch antenna array with 30 elements. The 102 × 96.5 mm^2 array exhibits a peak gain of around 22 dBi, but a fractional bandwidth of only 8.2%. Another mm-wave microstrip patch antenna array presented in [9] has a peak gain of 14.6 dBi, but it also exhibits a narrow fractional bandwidth of only 5.4%.

In general, for antenna arrays, high gain can be easily achieved by simply increasing the number of elements and the size of the array as described in [8]. However, the number of elements cannot be infinitely increased due to the losses raised from discontinuities in the feed network, particularly in high frequencies [10], [11]. On the other side, the gain of arrays will be improved without increasing the array size or the losses from the feed network if the gain of antenna elements can be improved. Besides, the bandwidth of an array can be broadened by some complex techniques such as those introduced in [12]. But antenna arrays that exhibit high gain and wide bandwidth usually do not have simple geometries.

In this paper, based on the authors previous work [10], an 8×3 printed antenna array with broad bandwidth and high gain is proposed. Dipole and loop patches were adopted to design the antenna element, which improves the gain and bandwidth performance of the element. Simulated in the *Ansys-HFSS*[13] commercial software, the array exhibits a broad -10 dB impedance bandwidth of 6.8 GHz and a high gain of 18 dBi at 28 GHz, its targeted frequency in this design. Despite its good performance, the array also has some other attractive features such as compactness, low profile, simple geometry, etc.

II. Antenna Element Design and Discussions

A. Configuration

The antenna element consists of a loop and two dipoles, which has been described in the authors previous work [10]. Its configuration is shown in Fig. 1, the rectangular loop works as a radiator as well as a power divider to feed dipoles. The element is printed on the Rogers RO4003 laminate with relative permittivity of 3.55, dielectric loss tangent of 0.0027, and thickness of 0.203 mm.

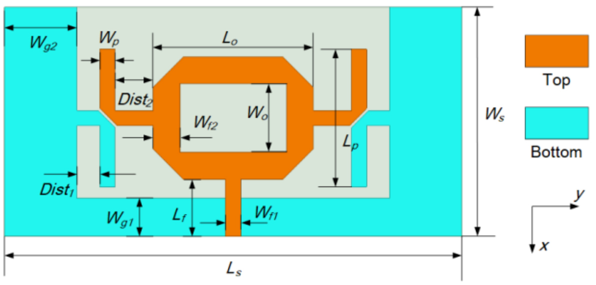


Fig. 1. Configuration of the presented antenna. (L_f = 1.5 mm, L_s = 12 mm, L_p = 3.6 mm, L_o = 4.2 mm, W_s =6 mm, W_{f1} = 0.4 mm, W_{f2} = 0.7 mm, W_o = 1.8 mm, W_{g1} =1 mm, W_{g2} = 1.9 mm, W_p = 0.4 mm, $Dist_1$ = 0.7 mm, $Dist_2$ = 1 mm)

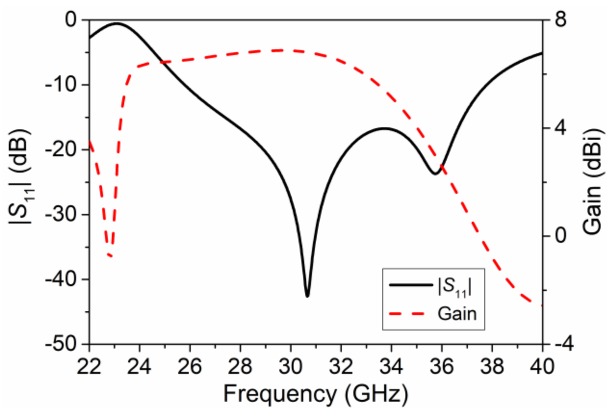
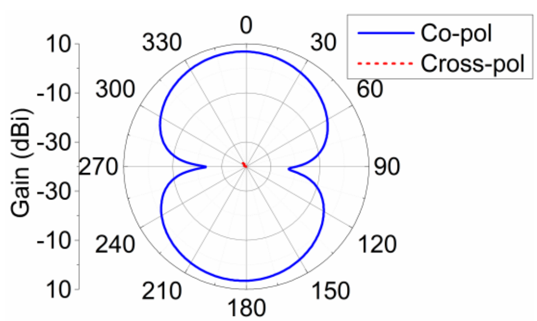
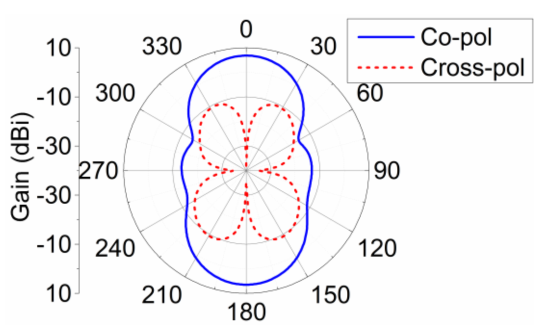


Fig. 2. $|S_{11}|$ and gain of the proposed antenna element.



(a).



(b).

Fig. 3. Radiation patterns of the presented antenna at 28 GHz. (a). *xz*-plane and (b). *yz*-plane.

B. Performance

The antenna element has a -10 dB impedance bandwidth of 12 GHz (25.8-37.8 GHz), i.e., a fractional bandwidth of 42.9% as shown in Fig. 2. Besides, its gain is stable and has an average value of 6.5 dBi in the frequency range of 24-32 GHz, but it decreases sharply beyond the frequency range mainly due to mismatch loss and deformation of the radiation pattern.

Fig. 3 shows the radiation patterns of the element. It presents directional radiation patterns with a peak gain of 6.8 dBi at 28 GHz and a low cross polarization level especially at *xz*-plane. More surprisingly, the size of the antenna is only 12×6 mm^2 due to the proper arrangement of the loop patch and the dipole patches. In fact, achieving such a high gain with $1.12\lambda_0 \times 0.56\lambda_0$ is satisfying.

III. Antenna Array Design and Discussions

A. Configuration

Fig. 4 shows the configuration of the proposed 8×3 planar array. Fed by a microstrip line feed network, the size of the array is only 98mm×32.5mm. The 24 elements are fed uniformly and in phase.

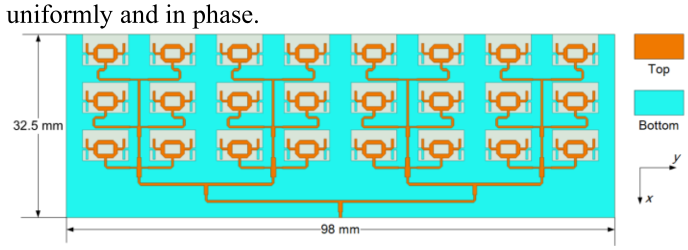


Fig. 4. Configuration of the proposed antenna array.

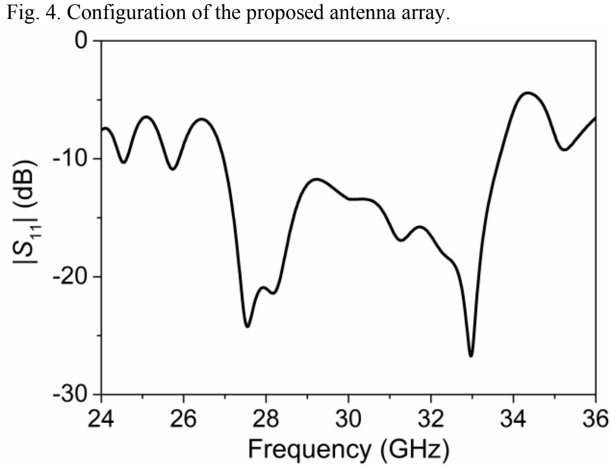


Fig. 5. $|S_{11}|$ of the proposed antenna array.

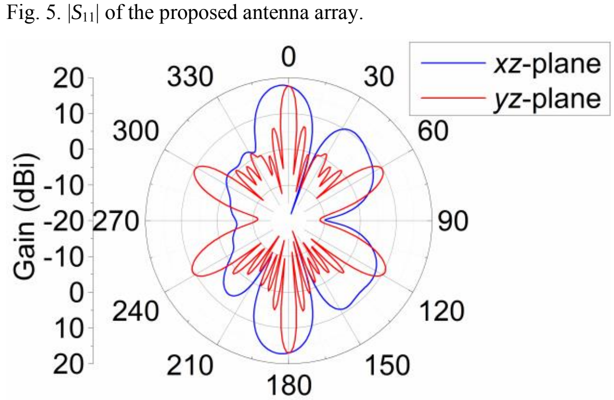


Fig. 6. Radiation patterns of proposed antenna array at 28 GHz.

TABLE I. COMPARISON OF ANTENNA ARRAYS OPERATING AT 28GHZ

Works	Key Parameters				
	Impedance Bandwidth (GHz)	*Peak Gain* (dBi)	*Size* (mm^2)	*Numbers of Elements*	*Complexity*
[7]	1.6	9.5	36.5×32	2×2	Moderate
[8]	2.3	22	96.5×102	5×6	Moderate
[9]	1.5	14.6	78.5×42	4×4	Low
[12]	8	12	—	2×2	High
[14]	1.5	12	17.3×67.1	1×8	Low
[15]	0.5	9.2	—	2×2	Moderate
This work	**6.8**	**18**	**98×32.5**	**3×8**	**Low**

B. *Performance*

Fig. 5 shows that the array has a -10dB impedance bandwidth of 6.8 GHz (26.9-33.7GHz), i.e., fractional impedance bandwidth of 24.3%. The radiation patterns (Fig. 6) illustrate that the gain and the sidelobe level of the array is 18 dBi and -8 dB at 28 GHz, respectively.

C. *Comparison with Existing Mm-wave Antenna Arrays*

In Table I, the proposed design performance is successfully compared to several existing works of antenna arrays operating at 28 GHz. The 2×2 slot array presented in [7] has a gain of 9.5 dBi and a narrow bandwidth of 1.6 GHz. The antenna array proposed in [8] is a microstrip patch antenna array. With 30 elements, it has a high gain of 22 dBi but at the expense of a large size of 96.5×102 mm^2 and a narrow bandwidth. Similarly, the microstrip patch antenna array presented in [9] has a high gain of 14.6 dBi but along with a large size of 78.5×42 mm^2 and a narrow bandwidth of 1.5 GHz. With a complex structure and a large size, the circular polarized antenna array presented in [12] achieved a wide bandwidth of 8 GHz and a gain of 12 dBic at 28 GHz. In [14], a 1×8 linear array with a moderate gain of 12 dBi and a narrow bandwidth of 1.5 GHz is presented. The substrate integrated waveguide patch antenna array presented in [15] exhibits only 0.5 GHz bandwidth and 9.2 dBi gain, moreover, it has a large size.

By comparison, the proposed compact planar array has a broad bandwidth of 6.8 GHz and a simple 2D structure. More importantly, with a compact size of 98×32.5 mm^2, a gain of 18 dBi is achieved, which demonstrates that the gain of a single element can significantly enhance the array performance without increasing its size.

IV. CONCLUSION

In this work, a broadband high-gain planar array using loop and dipole patches for 5G applications is proposed. With a compact size of only 98mm×32.5mm and a simple 2D geometry, the array achieved a high gain of 18 dBi and a broad impedance bandwidth of 6.8 GHz at 28 GHz. The good features of the planar array were demonstrated through successful comparison of its performance with existing designs in terms of bandwidth, gain, dimension, and complexity.

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