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Wideband and High-Gain Aperture Coupled Feed Patch Array Antenna for Millimeter-Wave Application

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ABSTRACT

Millimeter-wave (mmW) antenna is one of the most important parts of the fifth-generation (5G) systems because of its advanced characteristics, for example, wideband and high transmission rate. In this paper, an mmW 4x1 array antenna with high gain and wideband based on an aperture coupled feeding patch (ACFP) antenna is presented. The proposed array antenna operates at 28-GHz frequency. The antenna has a wide operating bandwidth of around 12.6 % at -10 dB bandwidth that covers 26.65 GHz to 30.35 GHz. The peak gain of the array antenna is approximately 13 dBi at 28 GHz and kept maintained in all interested frequency band. The proposed antenna is designed using a 0.127-mm thick Duroid 5880 substrate with a compact substrate of dimensions of 25 mm x 48 mm x 0.754 mm.

1 Introduction

Fifth-generation (5G) communication system has recently drawn increased attention for supporting tens to hundreds of times more capacity compared to the current 4G cellular network [1]–[4]. A bigger system capacity with wide bandwidth and high frequency is required to mitigate the higher path loss at mmW frequencies for a 5G system [5]. Furthermore, the shorter wavelengths of mmWs from installation perspectives are conducive to the reduction of antenna size that allows the incorporation of multiple patches or arrays in compact devices. Therefore, wide bandwidth and high transmission gain are two popular problems of mmW antenna design.

Several types of antenna have been recently proposed for mmW 5G system, such as dielectric-loaded planar inverted-F antenna [6, 7], microstrip leaky-wave antenna (LWA) [8]–[10], arrays of half-width microstrip LWA [11, 12], etc. In most cases, the bandwidth is narrow. In this paper, an aperture coupled feeding patch (ACFP) antenna is proposed to improve the bandwidth of the microstrip antenna. The ACFP antenna is an indirectly feeding method for the resonant patch that includes two substrates separated by a ground plane [13, 14]. To increase the transmission gain, a 4x1 array ACFP antenna is designed to obtain around 13 dBi gain at 28 GHz frequency with a compact size of 25 mm x 48 mm x 0.754 mm.

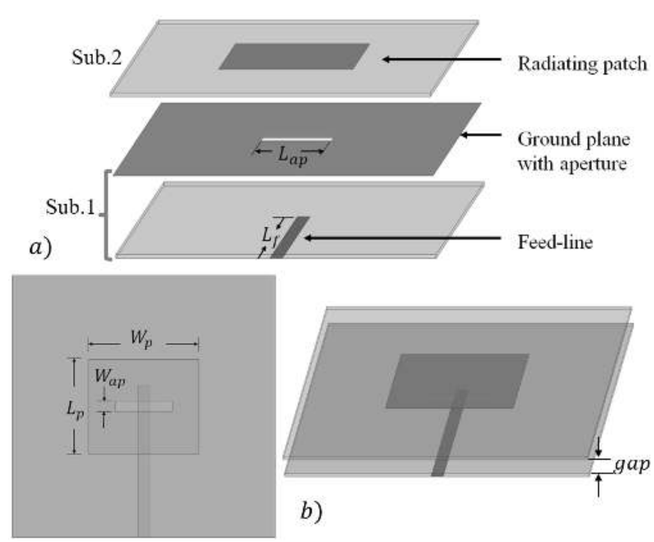

Figure 1: Single ACFP antenna structure: (a) separated components view; (b) top view and perspective view.

The organization of this paper is presented as follows. The proposed antenna's structure is described in Section II. The fabrication

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and experimental results are presented in Section III.

2 Array Antenna Structure Design

Figure 1(a) shows the single ACFP antenna structure that has two substrates separated from each other. The top substrate has the radiating patch antenna element with a dimension of L_p = 3.6 mm and W_p = 4.2 mm, and the bottom substrate has a transmission feed line with a thickness of 0.4 mm and a length L_f = 4.5 mm. A small aperture is slotted in the ground plane to create coupling from the open-circuited feed line to the radiating patch. A rectangular aperture is generally placed in the patch central to maximize the coupling and generate the symmetric radiation pattern, which has a length L_{ap} = 2.2 mm and width W_{ap} = 0.4 mm. In this design, two substrates are separated by a ground plane and a small *gap* of 0.5 mm that can enhance the bandwidth and reduce the interference from the feed network to the main radiation pattern. A tapered line feed network is designed to array four ACFP antenna elements with small mutual coupling and internal reflections. With a conventional array antenna, radiating elements are normally separated by smaller half-wavelength. If the element spacing between two adjacent antennas is larger than a half-wavelength, the antenna gain decreases, and the grating lobe increases [15]. However, the element patch width is usually used in the order of 0.4-0.5 λ_0, which is conducive to a small remaining distance between the adjacent elements. This small distance would cause high mutual coupling. With the ACFP array antenna, the distance between the adjacent patch elements is chosen to be higher than a half wavelength [16]–[18].

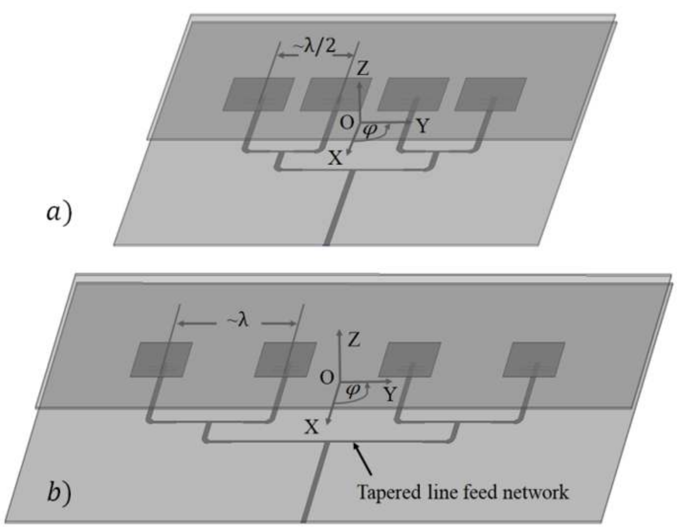

Figure 2: 4x1 ACFP array antenna with a tapered line feed network: a) 4x1 half wavelength spacing (HWS) array antenna; b) proposed 4x1 array antenna.

In this paper, a 4x1 half-wavelength spacing (HWS) array antenna is considered to verify the performance. Besides, a proposed 4x1 array antenna is optimized and compared to the performance with the 4x1 HWS array antenna. The 4x1 HWS array antenna and the proposed 4x1 array antenna are illustrated in Figure 2. Both antennas are designed using Duroid 5880 with the permittivity ε of 2.2 and the thickness of 0.127 mm for both layer substrates. The ANSYS HFSS software (ANSYS Inc. Canonsburg, PA, USA) was used to design, simulate, and optimized the antenna. The return loss S_{11} parameters, radiation patterns, and antenna gains in the simulation for the single antenna, the 4x1 HWS array antenna, and the proposed 4x1 array antenna are shown in Figure 3. The -10 dB bandwidth of the antennas cover the 28-GHz frequency band with almost higher than 12 % bandwidth that is shown in Figure 3(a). The bandwidth of the array antenna is a bit larger and shifted up than the single antenna.

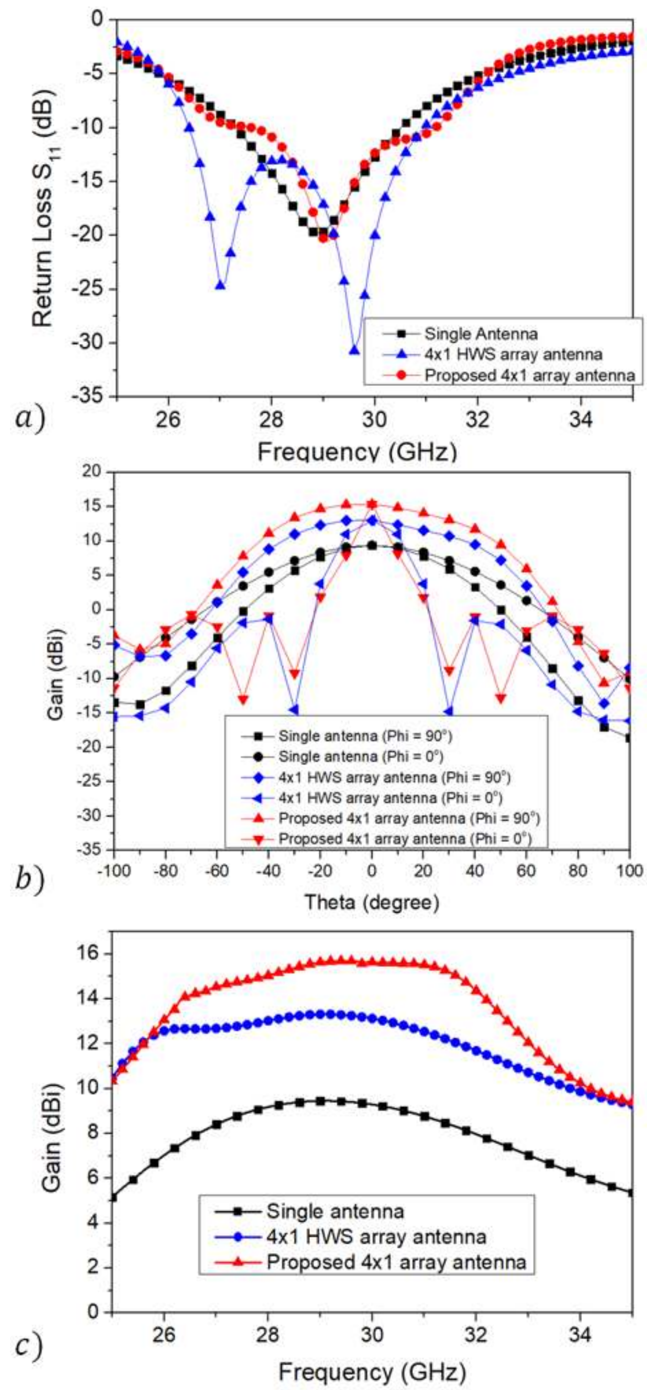

Figure 3: Simulation results of the single ACFP antenna, the 4x1 HWS array antenna, and the 4x1 array antenna: a) S_{11} parameters; b) radiation patterns; c) antenna gains.

A comparison of the radiation pattern and the realized gain between the single antenna, the 4x1 HWS array antenna, and 4x1 array antenna was demonstrated in Figure 3(b) and Figure 3(c) with the single antenna gain of around 9.45 dBi, the HWS array antenna of 13 dBi and the array antenna gain of 15.37 dBi. Because the tapered line feed network presented a good power divider with a small reflection, then the array can obtain a significant gain enhancement compared to the single. However, the radiation pattern of the array antennas is sharper and thinner at the plane of Phi = 0^o than the one of the single antenna. Normally, an HWS array antenna presents a better side lobe level (SLL) compared to a larger spacing array antenna. However, the SLL of the 4x1 HWS array antenna shows a worse value than the one of the optimal 4x1 array antenna with the element spacing around wavelength. In detail, the SLL of the HWS array antenna is -14.34 dB, while the SLL of the proposed optimal array antenna is -16.54 dB. Furthermore, the antenna gains on the overall interested frequency band of the optimal array antenna are significantly higher than the one of the HWS array antenna with almost 2dB on overall frequency band as shown in Figure 3(c).

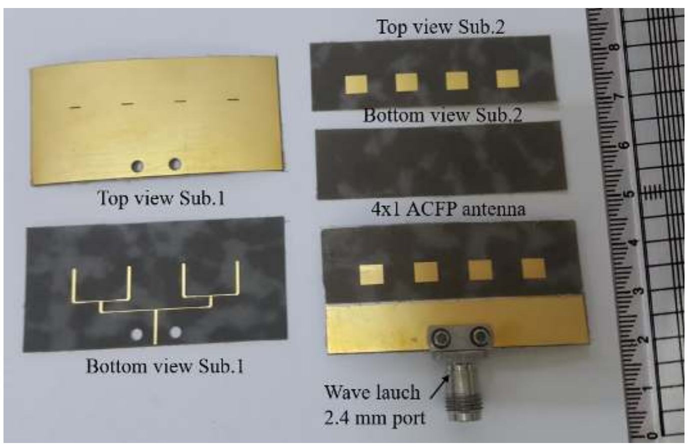

Figure 4: Fabrication of the 4x1 array antenna with the top view and bottom view of each layer substrate.

3 Array Fabrication and Measurement Results

Based on the analysis and design of the above section, the proposed array antenna was fabricated and measured to validate the performance, as demonstrated in Figure 4. The proposed antenna is printed on a 0.127-mm thick Duroid 5880 substrate. The bottom substrate contains a tapered line feed network on the bottom side and a ground plane with four aperture slots on the top side of the substrate, and the size is 25 mm x 48 mm. The top substrate has four radiating patches on the top side of the substrate. There is a small gap of 0.5 mm between two substrates that is an important factor to enhance the bandwidth of the antenna. A thin Styrofoam material was inserted between two layers to straight the antenna and fix the small gap between them. The antenna was connected to a Wave launch 2.4 mm port that can work at 28 GHz frequency band with low loss, wideband, and the terminal impedance of 50 Ω. This port has two screws to firm the antenna with the port. Therefore, two small holes are drilled nearby the feeding network, as shown in the view of Sub. 1. The radiation pattern and antenna gain were measured in a far-field chamber with the configuration setup as shown in Figure 5. The return loss was measured using an 8510C Vector Network Analyzer. The measured S_{11} parameter of the 4x1 array antenna is shown in Figure 6(a). The -10 dB bandwidth for the antenna frequency covers 26.65 GHz to 30.35 GHz, which is slightly different from the one in the simulation result. However, the proposed antenna still covers the interested frequency band. The radiation pattern of the proposed antenna at 28 GHz frequency is shown in Figure 6(b). There is a good agreement between the simulation and measurement results of the radiation pattern. The antenna gain at 28 GHz frequency in the measured result is slightly lower than the simulated gain because of the fabricated tolerance and losses in the measurement process. From the measured radiation pattern, the antenna presents a good performance with the side lobe level (SLL) of approximately -13.2 dB. The antenna gain is also measured in the overall wideband from 26 GHz to 30 GHz, which is depicted in Table 1. It can see that the antenna gain is kept unchanged around 13 dBi on all frequency bands. A comparison between the proposed array antenna and the related works in some important factors, such as overall size, the -10 dB bandwidth, and antenna gain are presented in Table 2. Both array antennas in [16, 17] were based on the ACFP structure which was arrayed 4x1 in series. From this Table, it is obvious that the proposed array antenna is significantly compact size, wider bandwidth, and higher gain compared with the referred antennas.

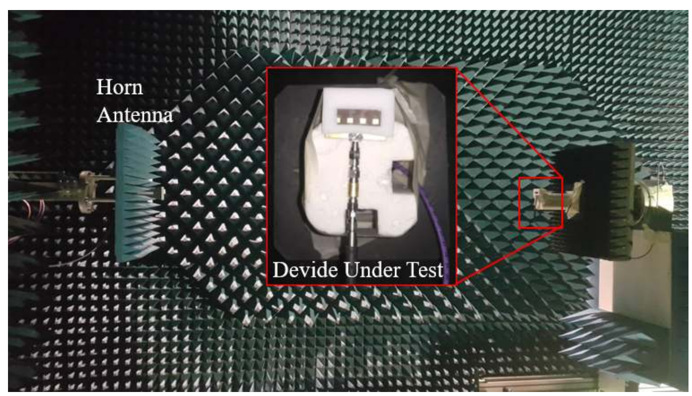

Figure 5: Configuration setup of the proposed array antenna for the measurement process.

Table 1: The measured antenna gain in the interested frequency band.

Freq. (GHz)	26.5	27	27.5	28
Gain (dBi)	12.2	12.86	13.03	13.06
Freq. (GHz)	28.5	29	29.5	30
Gain (dBi)	13.32	13.3	13.69	13.34

4 Conclusions

In this paper, a 4x1 array antenna using an ACFP antenna structure has been presented. The proposed antenna has a compact size of 25 mm x 48 mm x 0.754 mm and is printed on a Duroid 5880 substrate with a thickness of 0.127 mm for both layer substrates. A wideband and high gain of the antenna is obtained with around 12.6 % bandwidth and approximately 13 dBi, respectively.

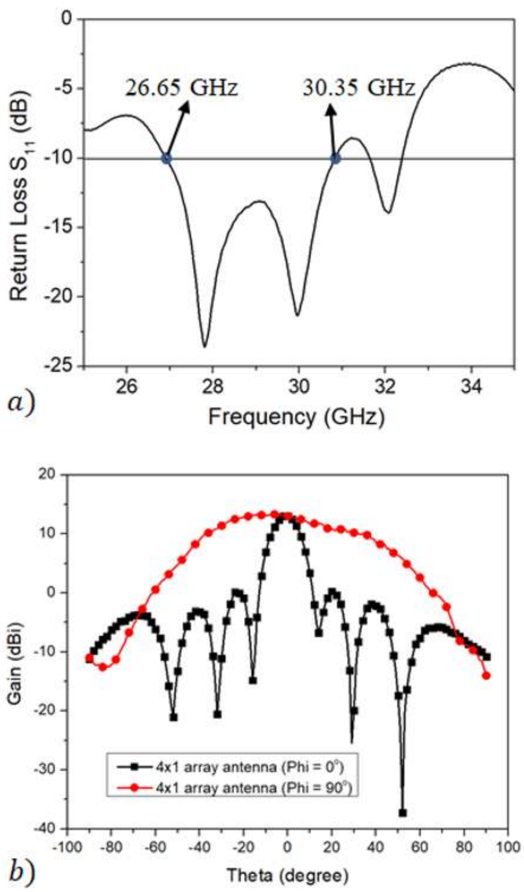

Figure 6: Measured results of the 4x1 array antenna: a) S_{11} parameter; b) radiation pattern and gain at 28 GHz frequency.

Table 2: Comparison of the proposed antenna with those of related works.

Ref.	Substrate	Overall Size (λ_0)	BW (%)	Gain (dBi)
[16]	0.127 mm thick Rogers 6002 28 GHz	2.8 x 0.93 x 0.088	~ 7.1	13.5
[17]	0.127 mm thick Rogers 5880 60 GHz	5 x 3 x 0.076	~ 6.7	12.5
This work	0.127 mm thick Rogers 5880 28 GHz	2.33 x 4.48 x 0.07	~ 12	13.69

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