60-GHz Sequentially-Rotated 1×4 Circular Patch Array Antenna Fed by Microstrip Line

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Abstract

This paper presents a 60-GHz sequentially-rotated 1×4 circular patch array antenna fed by a microstrip line. Design of the antenna is based on both the sequential rotation technique and a system requirement of antenna width. The prototype antenna exhibits not only high-gain but also broadband characteristics. The measured performances agree well with those simulated.

1. INTRODUCTION

Due to the ability to reduce multipath reflections and several kinds of interferences, circular polarization has been widely used in many applications of microwave frequencies recently. Circular polarization is particularly useful in radar, satellite communication, and navigation systems because of the behavior it exhibits upon reflection from regular objects of reversing the hand of circularity to produce predominantly orthogonal polarization [1]. A further attribute is that in a communication system using circularly-polarized (CP) radiation, the rotational orientation of the transmitter and the receiver are unimportant in relation to receiver signal strength, whereas with linearly-polarized signals there will be only very weak reception if the transmitter and receiver orientations are nearly orthogonal.

In our CP array design, the edge-fed circular patch antenna is chosen as the fundamental element due to the several desirable characteristics, such as high directivity, low profile, light weight, and simple structure. However, the major disadvantage of patch antennas is the inherent narrow bandwidth, which seriously limits their applications [1]. To overcome this, the feeding technique of sequential rotation [2]-[4] is adopted in our CP array design. In this paper, a 60-GHz sequentially-rotated 1×4 circular patch array antenna is presented to possess higher peak gains and a wider bandwidth.

2. ANTENNA GEOMETRY AND DESIGN RESTRICTION

Fig. 1 shows the configuration of a microstrip line-fed 1×2 circular patch array antenna using the sequential rotation technique. The two circular patches are the radiating elements, and are properly notched to obtain circular polarization at the element level. The physical orientations of the notched circular patches and the phases of their feeding signals are determined according to the sequential rotation design rule with M = 2 and p = 1 [4]. Consequently, the length difference between the two branches of the feeding microstrip line of the patches l_d must provide a phase delay of 90° at 60 GHz. The line width of both branches w_1 is chosen such that the corresponding characteristic impedances equal approximately 100Ω to match for the high input impedance of the notched circular patches. These two branches are then shunt to a 50-Ω microstrip feed line of width w_2 forming a matched T-junction. In the next paragraph, we will use this sequentially-rotated 1×2 circular patch array antenna as a building block for the 1×4 array design.

The geometry of the proposed sequentially-rotated 1×4 circular patch array antenna is depicted in Fig. 2. Similarly, the four notched circular patches are the radiating elements and capable of CP radiation individually. The patches are collinearly placed with equal spacing *D*. Also note that the physical orientations of the circular patches and the phases of their feeding signals are determined according to the sequentially-rotated case with M = 4 and p = 2 [4]. One can observe that regardless of the feeding network, this 1×4 design can be divided into two congruent 1×2 array antennas illustrated in Fig. 1. The only distinction between them is the relative rotational orientation of 180°.

On the other hand, the CP antenna presented in this paper will be employed in an antenna system, which imposes extra restrictions on the antenna width. Recently, we have been working on a 60-GHz switched-beam antenna system, in which eight replicas of the CP 1×4 circular patch array antenna will be connected to an 8×8 Butler matrix with equal spacing S = 147.6 mil (0.75λ_0 at 60 GHz). In order to reduce the mutual coupling effects in the switched-beam system among neighboring array antennas and their feed lines, the width of the patch array antenna W must be properly chosen. Since the diameter of the circular patch d is predetermined by the operating frequency of the antenna, namely 60 GHz in our design, all we can do is to carefully design the feeding network of the circular patch array antenna to narrow the total antenna width while making the inter- and intra-element mutual coupling effects insignificant. After making some trade-offs, the layout of the proposed feeding network of the 1×4 sequentially-rotated patch array antenna is obtained and illustrated in Fig. 2. The 50-Ω microstrip feed lines of the two congruent 1×2 array antennas are respectively connected to the two vertical 70.7-Ω quarter-wavelength transformers ($l_q \times w_q$) such that the input impedances at the ends of both branches are equally 100Ω. And then they are directly shunt to the central T-junction making the input impedance of the 1×4 array antenna equals about 50Ω, namely the desired system impedance.

3. Prototype Antennas and Results

Two prototype antennas, including the 1×2 and the 1×4 patch array antennas, are designed and implemented. Both are fabricated on the Rogers RT/Duroid 5880 dielectric substrate with dielectric constant ε_r = 2.2, loss tangent tanδ = 0.0009, and thickness h = 5 mil. The design parameters are listed as follows: d = 72 mil, W = 143 mil, D = 146 mil, w_2 = 15 mil, w_f = 15 mil, and the perturbation of the circular patch is ΔS = 1.2% of the circular patch area. All the microstrip line bends are mitered to mitigate the discontinuity. In order to apply the sequential rotation design rules, the difference between L_1 and L_2 equals a half guided-wavelength of the microstrip line at 60 GHz, whereas l_d equals approximately a quarter guided-wavelength. Although the prototype antennas presented in this paper radiate right-handed circularly-polarized (RHCP) wave, they can be easily designed to radiate left-handed circularly-polarized (LHCP) wave. Throughout the design process, all the simulations are carried out using the package software Ensemble from Ansoft Corporation.

The simulated and on-probe measured input return losses of the 1×2 and 1×4 prototype antennas are compared and plotted in Figs. 3 and 4, respectively. Radiation performances of the prototype antennas were measured in the millimetre-wave anechoic chamber after assembly with a testing fixture and the 1.85-mm connector. The measured and simulated axial-ratio responses and the RHCP peak gains of the 1×4 prototype antenna are shown in Figs. 5(a) and (b), respectively. In Fig. 5(a), although the measured axial ratios are slightly higher than those simulated, both the measured and simulated axial-ratio responses exhibit wideband characteristics. Also note in Fig. 5(b) that the simulated gain response remains about 1-2 dB higher than the measured one within the 59-62 GHz band. The difference may be attributed to the mismatch introduced by the testing fixture and the connector. The simulated maximum RHCP peak gain is 12.8 dBic, while the measured one is 11.3 dBic. In addition, the normalized x-z and y-z plane patterns at resonance are plotted in Figs. 6(a) and (b), respectively. The simulated and measured results agree well. The mainbeam with a narrower beamwidth can be observed in the x-z plane pattern. The cross-polarized radiation or the LHCP component is relatively low in both principal planes.

4. Conclusion

Design of the 60-GHz sequentially-rotated 1×4 circular patch array antennas has been demonstrated in this paper. It is based on the sequential rotation technique and the antenna width restriction. Both the 1×2 and 1×4 array antennas are implemented and tested. In addition to the CP radiation, they are presented to have relatively wide bandwidth and high gains. The proposed sequentially-rotated 1×4 patch array antenna meets all the specifications of the 60-GHz switched-beam antenna system being developed in our group.

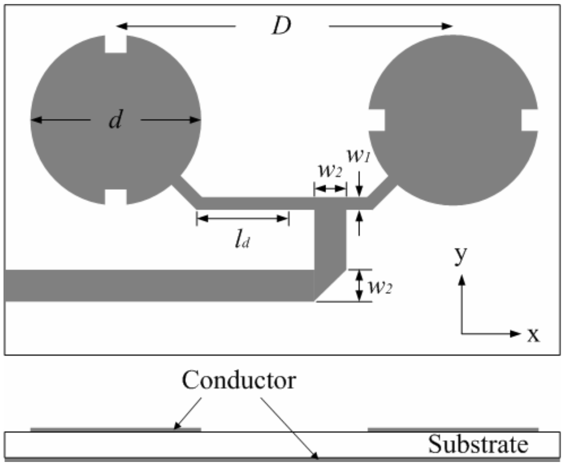


Fig. 1: Configuration of the 1×2 sequentially-rotated circular patch array antenna fed by a microstrip line.

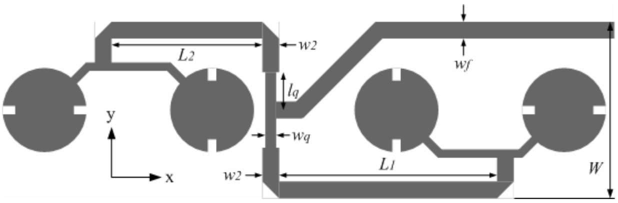


Fig. 2: Geometry of the proposed 1×4 sequentially-rotated circular patch array antenna fed by a microstrip line.

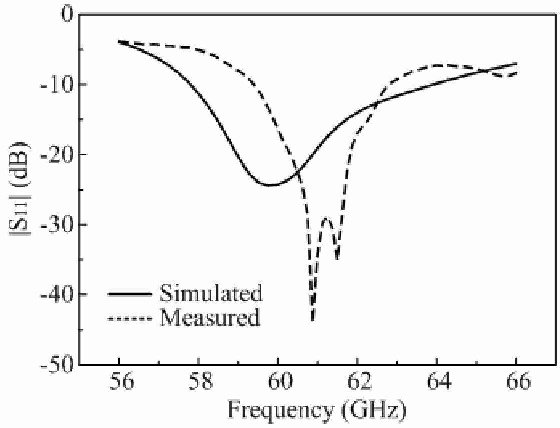


Fig. 3: Measured and simulated input return losses of the 1×2 sequentially-rotated prototype antenna.

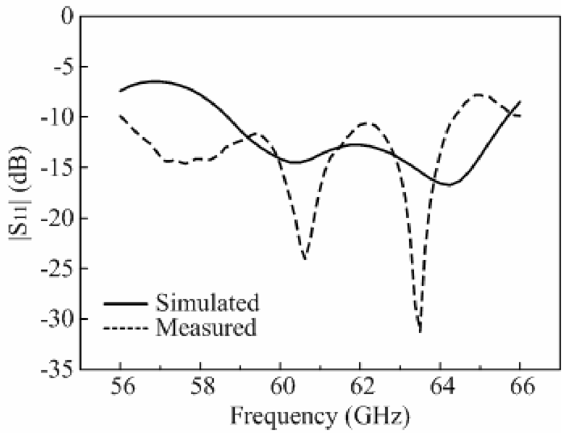
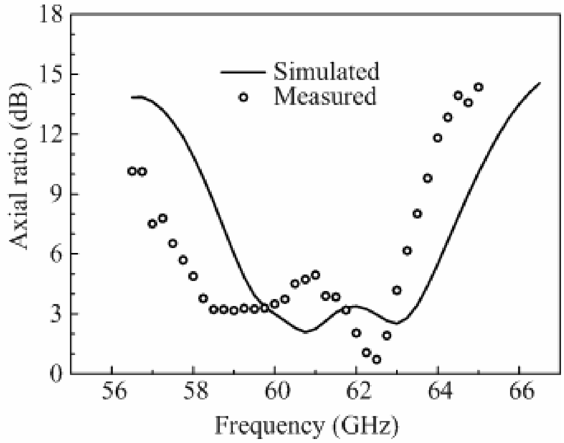
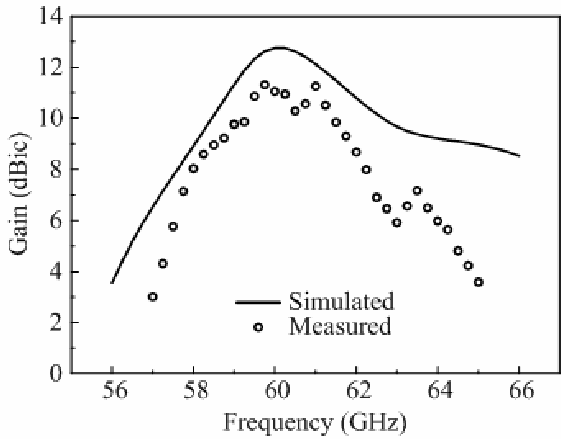


Fig. 4: Measured and simulated and input return losses of the 1×4 sequentially-rotated prototype antenna.

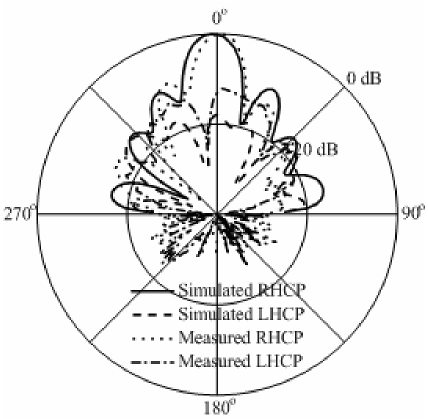


(a)

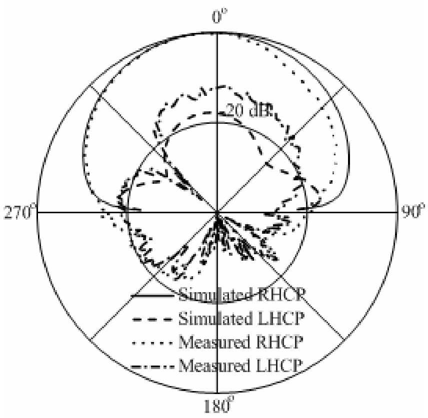


(b)

Fig. 5: Measured and simulated (a) axial ratios and (b) RHCP peak gains of the 1×4 sequentially-rotated prototype antenna.



(a)



(b)

Fig. 6: Measured and simulated radiation patterns of the 1×4 sequentially-rotated prototype antenna. (a) x-z and (b) y-z plane patterns.

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