38 GHz HIGH-DIRECTIVITY PLANAR LEAKY-MODE ANTENNA ARRAY

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This paper resents a high-directivity planar microstrip antenna array operating at microwave frequency. The antenna array consists of 48 sub-arrays, and each sub-array comprises 4 elements. The radiation mechanism of the single element, by exciting the first higher order mode (EH_1 mode), can be estimated by the full-wave analysis. Through appropriately arranging and feeding these 192 single elements, the radiated characteristic of the antenna performs narrow radiation beamwidth both in azimuth (AZ) and elevation (EL), thus achieving high directivity. The planar microstrip antenna array prototype is built and tested at 38GHz by traditional printed circuit board (PCB) fabricating process. The measurement result indicates the high directivity of 22.3dB and the 3-dB beamwidth of 8°/12° (AZ/EL) at the elevated angle 30.2° away from the broadside direction.

1 Introduction

Recently, the high-directivity antenna arrays are extensively applied to wireless applications such as car warning system [1], indoor WLAN (wireless local area network) [2], space communication [3] to detect the targets precisely or transmit the signal for farther distance. Prior to the development of high-directivity antenna, several approaches had been successfully developed such as waveguide array [2,4], reflector array [3], multiple dielectric layer structure [5], etc. Regarding these techniques, the waveguide structure shows high efficiency due to its low loss characteristics [2,4], and the inflatable reflector array displays the advantages of low mass and high packaging efficiency [3]. However, the three-dimensional structure will need relatively complicated and expensive mechanical fabrication process [2,4] and the non-planar feeding structure enlarges the dimension of the antenna [3].

This paper presents a planar high-directivity microstrip antenna array, which is designed to build entirely on a printed circuit board by PCB fabricating process, including the feeding structure. As shown in Fig. 1, the antenna array consists of 6×8 sub-arrays, each of which comprises 4 leaky microstrip lines, and the parallel-serious feeding structure, performing compact size of 8cm×8cm. Moreover, the radiated characteristics of the single element, by exciting the first higher order mode, can be predicated easily by the full-wave analysis, so according to the linear array approach [6],the arrangement of the elements can be confirmed. The displacement between elements and the power distribution can be determined to accomplish the directional pattern. The planar microstrip antenna array prototype is designed and built at 38GHz on a low-cost RO3203^{TM} substrate with thickness of 20 mils. The measurement results of the proposed antenna reveal the narrow 3-dB beamwidth and the high-directivity. Thus, the planar antenna array provides the advantage of low-profile, low-cost, and high integration, therefore, suitable for wireless application.

2 Single Element Design

The single element functions as a unit radiation source through exciting the first higher order mode of the microstrip. As shown in Fig. 2, it consists of a short microstrip line for excitation and a matched balun feed network for supplying power. The matched balun network, employing the half-wave length delay line, provides the current feeding out of phase to the short microstrip line for excite the EH_1 mode, which cross electrical field is odd symmetric. Considering the width (W) of the leaky microstrip line, a strong factor to determine the propagation characteristics of the EH_1 mode, the full-wave analysis is utilized to estimate the relationship between the width (W) of the leaky microstrip line and the propagation characteristics of the EH_1 mode. As shown in fig. 3, the normalized complex propagation constant of the EH_1 mode on the microstrip (W=2mm), which is obtained by the full-wave analysis, showing the normalized propagation constant (β/k_0) of 0.9 and the normalized attenuation constant (α/k_0) of 0.13. For a microstrip transmission line long enough, the power radiation should be toward a angle (64°) away from the broadside ($\theta \cong \sin^{-1}(\beta/k_0)$). However, if the length (L) of the leaky microstrip line is chosen a short distance as 3 mm (about 1.5 λ_g), according to the following approximate equation:

$$\text{Power Radiation}(\%) = (1 - e^{-2\alpha L}) \times 100\%$$

,where the L is the distance of the wave propagating

,the power radiating percentage is 46.8%. That means almost half power could be reflected from the end of the microstrip line, thus transforming the main beam radiated toward a high elevated angle. The analyses of the radiation characteristics employing the full wave simulator demonstrate the radiated angle of the maximum gain at the elevated direction of 21.5° away from the broadside.

According to the linear array design approach, the radiation pattern of an array is a function of the field of the individual elements, their orientations, their geometrical arrangement, and the amplitude and phase of the currents feeding them. When the maximum array factor, which is determined by the arrangement and excitation of the elements, points to the same direction with the radiated field of the single element, a directional radiation pattern will be produced effectively. Thus, for the well-designed pattern multiplication, the radiated beam peak of the single element will almost determine the beam position of the array.

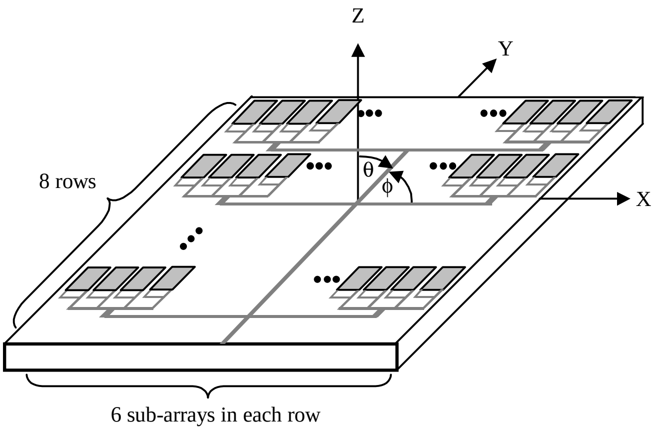

Fig. 1 The configuration of the planar antenna array consisting of 6×8 sub-arrays

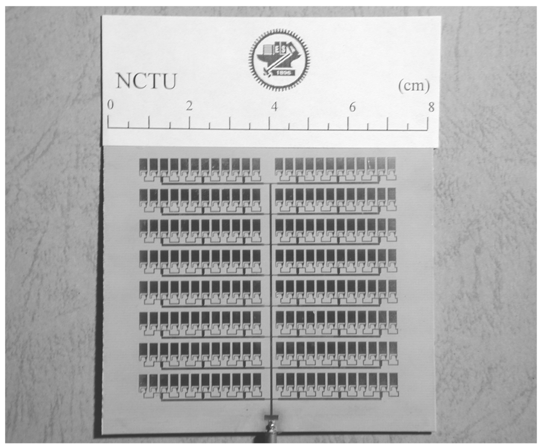

Fig. 2 Photograph of the leaky-mode antenna array involving 192 elements depicts the antenna size about 8cm×8cm

3 Microstrip Antenna Array Design and Measurement

This antenna array consists of 6×8 sub-arrays, where each sub-array is composed of four elements and a 1-to-4 ports parallel-series feed network, as shown in Fig. 2. The distance between the centers of the four adjacent elements is about 0.32 free-space wavelength. The 1-to-4 ports parallel-series feed network provides uniform power (equal amplitude and equal phase) to each element. Under the condition of equally spaced arrangement and uniformly excited, a maximum array factor occurs at ϕ=

90° (on the E-plane). To enhance the directvity, 6 sub-arrays in the same row are needed as configured in Fig. 1. Through the 1-to-6 ports parallel-series feed network, the 6 sub-arrays are fed uniformly, thus also obtaining the maximum array factor at ϕ= 90°. Besides, on the H-plane, the distance of 0.95 free-space wavelength and the out of phase excitation exist between the 8 adjacent rows. Therefore, the maximum array factor of the H-plane points at elevated angle 30°. As a consequence, the 192-elements antenna array consists of 24 elements in each row on the E-plane and 8 rows on the H-plane, as shown in Fig.2, showing the antenna size about 8cm×8cm.

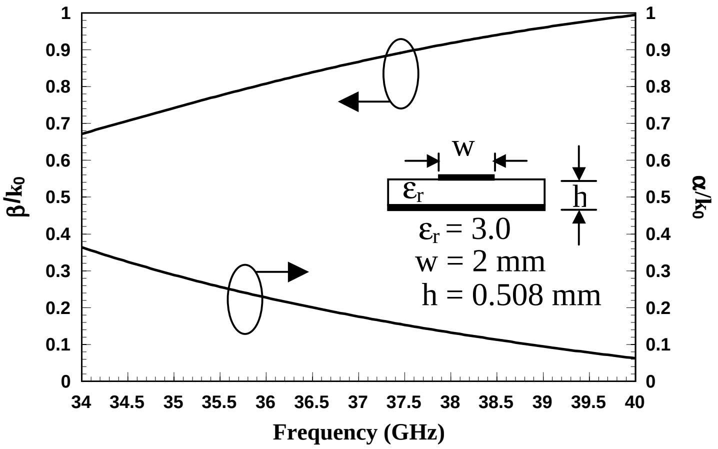

Fig. 3 The normalized complex propagation constants of the first higher-order leaky mode in the leaky region

Fig. 5 illustrates the measured radiation pattern of the proposed planar microstrip array at the design frequency of 38 GHz, showing the position of the main beam at elevated/azimuthal angle of 30.2°/0.8°. Fig. 7 also depicts the azimuth patterns with 3-dB beamwidth of 8°. The elevation pattern, as shown in Fig. 6, indicates the beam peak at 30.2° with 3-dB beamwidth of 12°. Furthermore, the measured directivity is 22.3 dB, and the antenna gain is 15.4 dB.

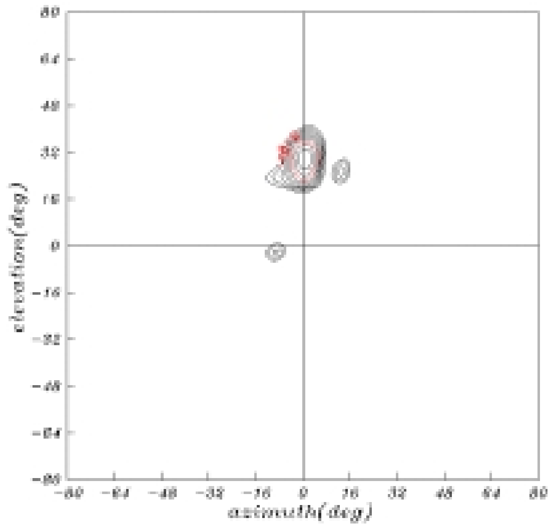

Fig. 5 Measured radiation pattern (at 38 GHz) of the proposed microstrip array pointing at 30.2°/0.8° (EL/AZ)

4 Conclusion

A planar high-directivity microstrip antenna array operating at Ka-band is presented in this paper. The antenna array utilizes the excitation of the leaky EH_1 mode to supply power radiation and the linear array design approach to enhance directivity. The measured performance demonstrates that the narrow beam characteristic (8°/12° (AZ/EL)) can be accomplished on a compact size (8cm×8cm). Furthermore, due to the planar structure, the proposed antenna array has the capability of integrating other planar RF modules without any transition. In addition to high integration, the low-cost manufacture process and the low-profile apperence provide the potential for applying to wireless applications.

Acknowledgements

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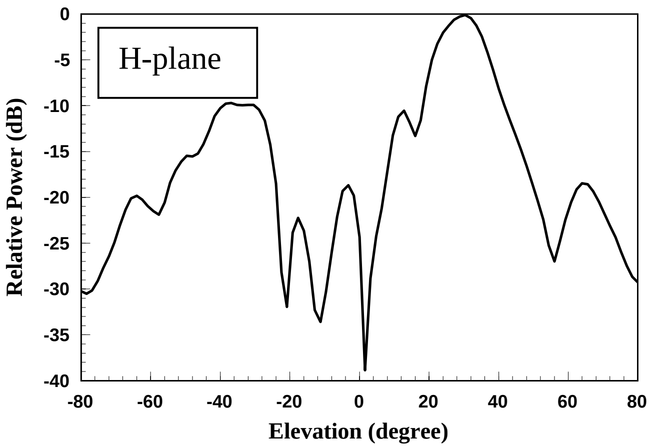

Fig. 6 The elevation pattern of the planar array at 38 GHz shows 3-dB beamwidth of 12°

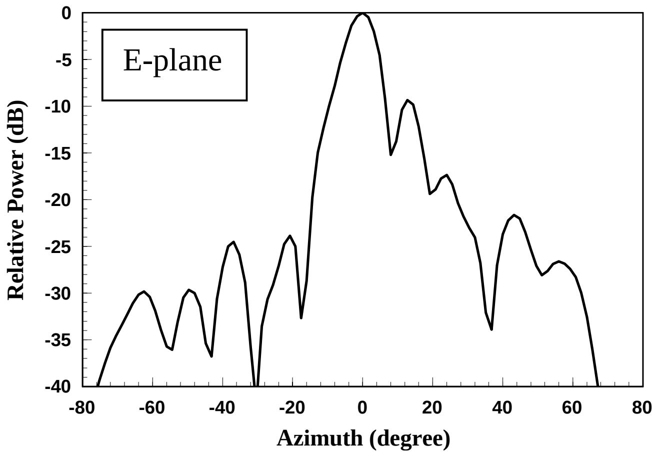

Fig. 7 The azimuth pattern of the planar array at 38 GHz shows 3-dB beamwidth of 8°

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