Wideband High-Gain Planar Antenna for Millimeter-wave Applications
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Abstract- A novel wideband high-gain planar antenna is presented in this paper. The antenna element is composed of a Substrate Integrated Waveguide (SIW) cavity-backed patch and a stepped waveguide horn. Based on the proposed antenna element, a 2×2 subarray with element spacing larger than a wavelength is designed. A groove, which worked as secondary radiation source, is etched between the elements to improve the gain and suppress the high sidelobes of the 2×2 sub-array. By taking the advantage of the groove, the 2×2 subarray achieves a maximum boresight gain of 17 dBi and an -10 dB impedance bandwidth of 21.8% from 70-87 GHz. For further enhancing the gain, a prototype including 16×16 elements is manufactured and measured. Experimental results confirm that the proposed antenna achieves an -10 dB impedance bandwidth of 22.4% from 71 to 88.5 GHz as well as a peak gain of 28.8-30.9 dBi.

I. INTRODUCTION

Millimeter-wave (MMW) technology was recently proposed to enable broadband access and backhauling in the 5G wireless networks [1]-[2]. The antennas for such applications are typically required to have high gain, wide operating bandwidth, and low cross-polarization. Compared with traditional reflector antennas and horn antennas, planar antennas are more attractive for the MMW wireless communication applications, due to their lower profile, lighter weight, and easier installation. Recently, planar array antennas with broad bandwidths and high gains were investigated based on planar waveguides [3]-[4], substrate integrated waveguides (SIWs) [5]-[7], gap waveguides [8], and some composite structures [9]-[10].

In this paper, a 16×16 elements planar antenna array covering the frequency range of 71-86 GHz is proposed. The antenna array is mainly composed of an SIW feeding network, the SIW cavity-backed patches, the stepped rectangular waveguide horns, and the grooves. The SIW cavity-backed patches are worked as wideband waveform and impedance transformers to excite the stepped waveguide horns on the upper layer. The stepped waveguide horns are employed to enhance the gain of the antenna element by increasing the radiation aperture. The grooves are employed to reduce the coupling between the adjacent antenna elements by suppressing the surface wave propagation. More importantly, the grooves, working as secondary radiation sources, can improve the gain and sidelobes by reradiating the surface wave energy. The unique combination of the above features renders this work a high-performance in operating bandwidth and realized gain.

II. ANTENNA CONFIGURATIONS

A. 2×2 Elements Subarray

Fig. 1 shows the configuration of the wideband 2×2 subarray, which composed of three layers. The top layer consists of four stepped waveguide horns and a groove with a depth of λ/4. The middle layer consists of two pairs of oppositely placed SIW cavity-backed patches. The bottom layer is a one-to-two power divider. The full-wave simulator HFSS is employed to optimize the proposed 2×2 subarray.
The simulated reflection coefficient and maximum gain of the 2×2 subarray are shown in Fig. 2. The simulated results show that the proposed 2×2 subarray exhibits a wide -10 dB impedance bandwidth of 21.5% from 70.2 to 87 GHz. The simulated maximum gains are from 14.6 to 17 dBi. By taking advantage of the groove, an improvement of about 6.5 dB compared to the antenna element can be achieved in the operating bandwidth. The radiation patterns at 75, 80 and 85 GHz are depicted in Fig. 3. It can be observed that although the spacing between the antenna elements in the high frequency band exceeds one wavelength, the radiation pattern of the 2×2 subarray still achieves a lower sidelobes over the whole operating bandwidth with the help of the groove. The cross-polarizations of the radiation patterns in the two planes are lower than -40 dB.

B. 16×16 Elements Array Antenna

Fig. 4 shows the configuration of the wideband 16×16 elements antenna array. The overall structure of the proposed antenna array occupies 3 layers and consists of the stepped waveguide horns, the SIW cavity-backed patches, and the SIW feeding networks. The upper layer is a 16×16 stepped waveguide horn array with a dimension of 59mm×78mm. The spacing between the stepped waveguide horns of the 16×16 antenna array is the same as that of the 2×2 subarray. The middle layer is the 16×16 SIW cavity-backed patch array, which is formed with 128 pairs of oppositely placed SIW cavity-backed patches and printed on the single-layer PCB Rogers 4003c. The lower part is the 1-to-128 SIW feeding network, which is printed on the single-layer PCB Rogers 5880 (εᵣ = 2.2, tan δ = 0.0009 at 10 GHz) with a thickness of 0.508 mm and excites the SIW cavity-backed patch array by couple slots.

III. EXPERIMENTS

To verify the proposed design, a prototype of 16×16 elements array antenna with a dimension of 59mm×78mm (the dimensions of the radiating aperture are 49mm×69mm) was fabricated. The photographs of the fabricated prototype are shown in Fig. 5. The feeding layer and the middle layer are fabricated in Rogers 5880 and Rogers 4003c by the standard single-layer PCB technology, respectively. The stepped waveguide horns with grooves are fabricated in aluminum by milling process. The three layers are separately fabricated and then stacked using metal screws. To create a good electrical contact between the layers of the dielectric substrates and the stepped waveguide horns, a bottom metal plate with a thickness of 4.0-mm is introduced to create a sandwich structure as shown in Fig. 5(b). However, the 4.0-mm thickness for the bottom metal plate is not required for the antenna operation.

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A wideband high gain millimeter-wave antenna array has been proposed and verified in this paper. The measured results show that the proposed antenna achieves an impedance bandwidth of 22.4% from 71 to 88.5 GHz and a peak gain varying from 28.8 to 30.9 dBi. The proposed antenna array demonstrated wide bandwidth, high gain, and simple structure, which make it suitable for mass production and practical applications.

IV. CONCLUSION

The reflection coefficient is measured using Rohde&Schwarz vector network analyzer ZVA40 with the extender from 60 to 90 GHz. The simulated and measured reflection coefficients of the fabricated 16 × 16 elements antenna array are presented in Fig. 6. The measured impedance bandwidth for |S11|<-10 dB is 22% (range from 71 to 88.5 GHz), which agrees well with the simulated value.

The gains and radiation patterns of the proposed 16 × 16 elements antenna array are measured using the far-field antenna measurement system in an anechoic chamber. Fig. 7 compares the simulated and measured gain versus operating frequency. The results indicate that the measured gains are in the range of 28.8-30.8 dBi, which are about 2.2 dB lower than the simulated ones. The corresponding antenna efficiencies are about 36%. The discrepancy mainly comes from the unknown dielectric loss tangent of the substrate at the E-band.

The simulated and measured radiation patterns of the proposed 16×16 elements antenna array at 71 and 86 GHz in E- and H-planes are depicted in Fig. 8. It can be seen that the measured patterns agree well with the simulations. Due to the secondary radiation of the grooves, the measured sidelobe levels (SLLs) are around -13 dB over the entire operating bandwidth. The measured cross-polarization levels are below -40 dB and the simulated ones are less than -60 dB.

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REFERENCES


