Two Types of High Gain Slot Array Antennas based on Ridge Gap Waveguide in the D-Band

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***Abstract*—The recent introduced ridge gap waveguide shows huge strengths in array antennas in millimeter and sub-millimeter wave frequencies. Generally, gap waveguide supplies contactless characteristics in order to avoid the good electrical contact between the different metallic layers. Therefore, the gap waveguide structures are relatively simple to be fabricated in Ka-, V-, W-bands. As is well known, the conductor loss increases rapidly versus frequency in millimeter wave and submillimeter wave frequencies. Thereby, the increasing conductor loss above 100 GHz affects the antenna gain. In this work, we compare two types of antennas in the D-band. The full cooperate feed array antenna is wide band, avoiding the offset of main beam. However, the number of T-junction power dividers rapidly increases. Thereby, it is necessary to design a T-junction power divider with ultra-low reflection for a big array in the D-band so that the gain of the big array antenna enhances. On the other hand, a series feed antenna array is also a choice in the D-band. The series feed structure has advantages of less power dividers, easy design. Nevertheless, it is unable to avoid the long line effect, narrow bandwidth and main beam offset. The comparison between two structures has been done in the D-band in this work.**

***Index Terms*–Artificial Magnetic Conductor (AMC), ridge gap waveguide, high efficiency, single layer, millimeter wave and slot array antenna.**

I. Introduction

The upper millimeter-wave (mm-wave) frequency band above 100 GHz has obtained a lot of attention growing in recent years due to the increasing demand for high-speed wireless communication [1]. D-band (110-170 GHz) is able to supply frequency spectrum for the future wireless systems. Given the attenuation of electromagnetic wave and limited output power of RF circuits in those frequency band, high-gain and high-efficiency antenna is the one of the most important component. In the past few years, several different antennas have been reported at D-band [2]-[4]. Nevertheless, low profile, high-gain, high-efficiency and low cost antennas are still needed for some applications.

Recently, a couple of new waveguide structures and transmission lines have been developed. Substrate integrated waveguide (SIW) is a good candidate for mm-wave applications because it is able to integrate with active components. So far, some different types of antennas based on SIW technology have been developed [5][12] in mm-wave. Nevertheless, its dielectric loss becomes problematic if it is applied for designing large high-gain array antennas above 110 GHz. The gap waveguide is another new technology for mm-wave applications recently introduced in [13]. This novel gap waveguide has advantages of low loss properties compared to the microstrip line and the hollow waveguide [14]. In [15]-[22] several different high-gain high-efficiency slot array antennas based on gap waveguide technology have been reported. A novel W-band low-profile monopulse slot array antenna based on gap waveguide has been reported in [23]. In addition, passive filters and novel transition structures based on gap waveguide technology have been reported in [24]-[28].

In this paper, we present both series-fed and corporate-fed array antennas based on ridge gap waveguide in the D-band. The whole structure is organized as follows. In section II a series-fed array antenna is introduced. Section III discusses a full-corporate-fed array antenna. Both of antennas work at 144 GHz. Finally, some detailed comparisons of both antennas are given in section IV.

II. Series-fed Array Antenna

The demonstration of the series-fed slot array antenna is illustrated in Fig. 1. The whole structure consists of 24$\times$16 slot, which has an effective area of 48 $\times$ 42 mm^2. At the bottom layer a groove gap waveguide distribution network feeds all sub-arrays with identical phases and amplitudes. The electromagnetic wave transmits through the coupling holes in the middle layer. Then the series ridge gap waveguide directly feeds the top radiation slots. The similar work has been achieved by ridge waveguide in K-band [29]. The simulated reflection coefficient of the series-fed array antenna is depicted

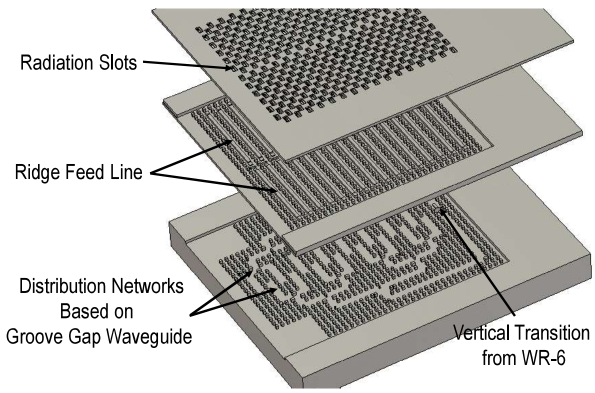

Fig. 1. Configuration of series-fed array antenna.

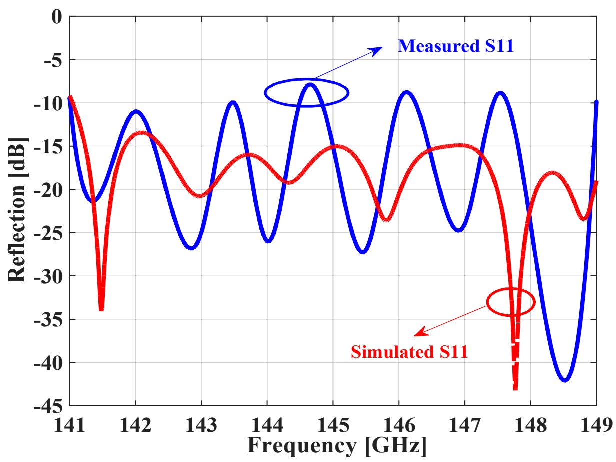

Fig. 2. The simulated and the measured reflection coefficients of the series-fed antenna.

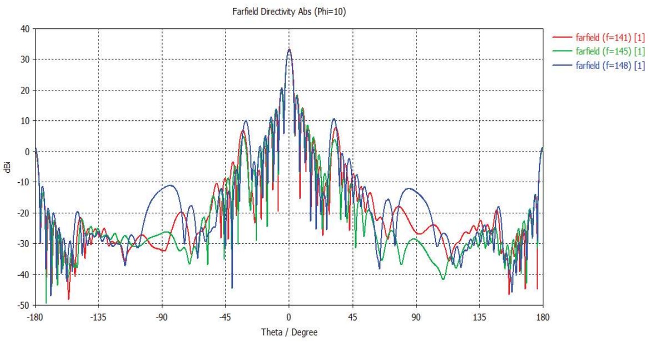

Fig. 3. The simulated E-plane radiation patterns at 141, 145 and 148 GHz.

in Fig. 2. As shown in the figure, the simulated reflection coefficient is below -15 dB from 141 to 149 GHz. The measured reflection coefficient is higher than the simulated one because of fabrication tolerance and misalignment of different layers. The input impedance bandwidth is around 5.6%. Because the bandwidth RF-electronics in D-band is very limited due to its high loss, it is enough for proposed series-fed antenna to realize the 8 GHz bandwidth. The simulated radiation patterns of the proposed series-fed array antenna is illustrated in Fig. 3. As is shown in the Figure, the grating lobes at 45 degree is a little higher than our expectation. The major reason for this phenomena is that the space between two arbitrary slot on the E-plane is bigger than half wavelength. Fig. 4 shows the radiation patterns of proposed series-fed antenna on the H-plane from 141 to 149 GHz. The H-plane radiation patterns characterize the low side lobe performance. In the Fig. 5, the simulated and the measured gains are illustrated. As seen in the figure, the measured gain is around 30 to 31.5 dBi from 141 to 149 GHz. The antenna efficiency of proposed series-fed array antenna is between 40% to 60%. The antenna efficiency at 144 GHz is not so high as that value at 60 GHz since the waveguide loss at 144 GHz is much higher.

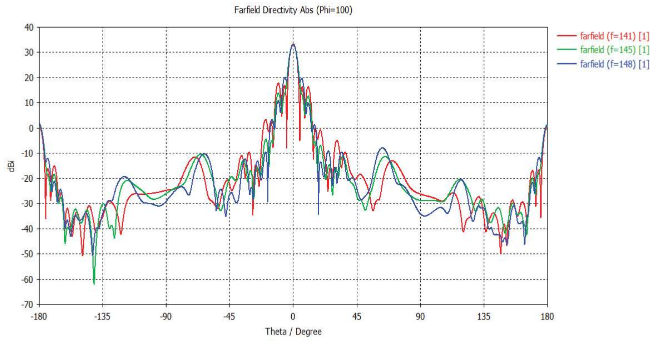

Fig. 4. The simulated H-plane radiation patterns at 141, 145 and 148 GHz.

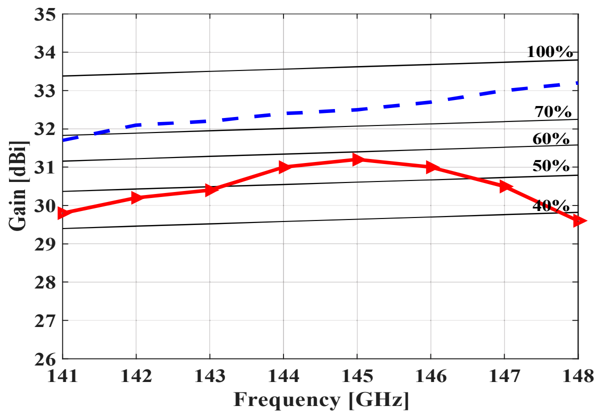

Fig. 5. The simulated and the measured gains of proposed series-fed antenna. Blue-dash line indicates the simulated gain, and red line indicates the measured gain.

III. Corporate-fed Array Antenna

Fig. 6 shows the configuration of the proposed 32 $\times$ 32 slot array antenna. The antenna consists of three unconnected layers, radiation layer, cavity layer and the flange layer. A corporate feed networks of ridge gap waveguide is applied

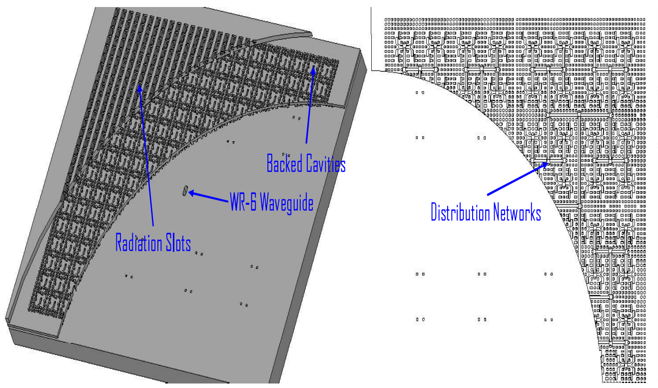

Fig. 6. Configuration of corporate-fed array antenna.

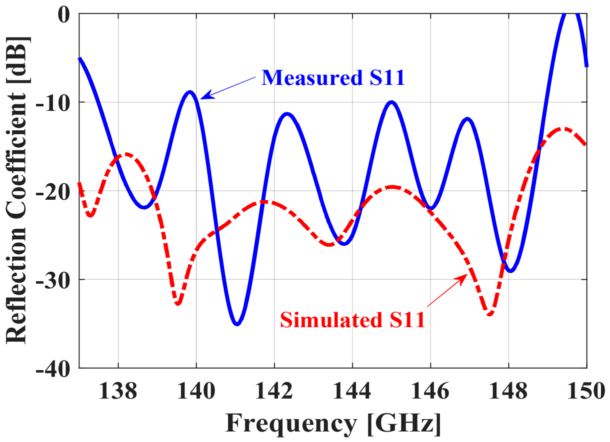

Fig. 7. The simulated and the measured reflection coefficients of the corporate-fed array antenna.

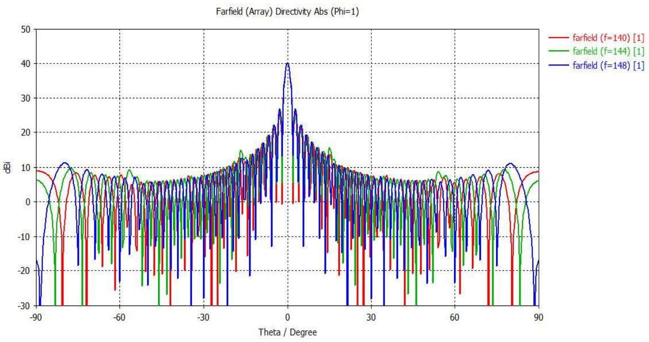

Fig. 8. The simulated E-plane radiation patterns at 140, 144 and 148 GHz.

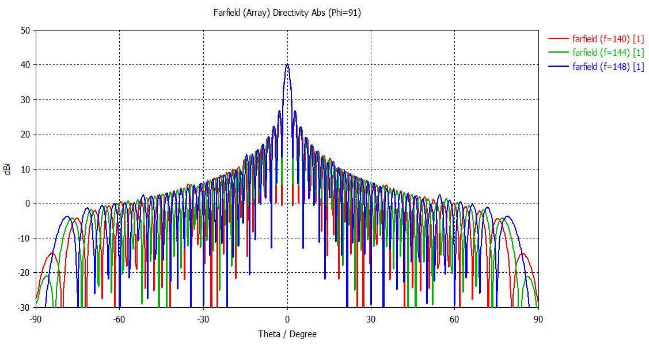

Fig. 9. The simulated H-plane radiation patterns at 140, 144 and 148 GHz.

in this work. Because there is no enough space to layout the distribution networks, the novel T-junction power divider is designed in this work. The simulated reflection coefficient is shown in Fig. 7. The reflection is below -15 dB from 137 GHz to 148 GHz. The measured reflection coefficient is from 138 GHz to 148 GHz with reflection coefficient below -10 dB. The proposed antenna has good radiation patterns from 138 GHz to 148 GHz. Fig. 8 and Fig.9 illustrate the simulated radiation

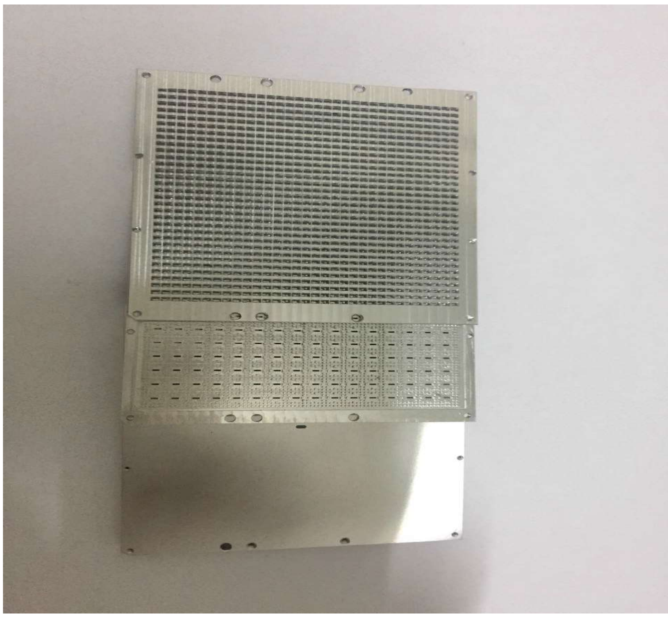

Fig. 10. Fabricated array antenna in this work.

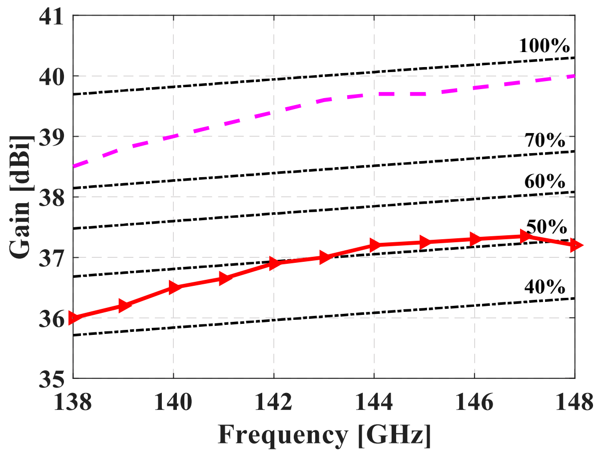

Fig. 11. The simulated and the measured gains of the corporate-fed array antenna in this work.

patterns on the E-plane and H-plane, respectively. The first side lobe is 13.4 dB below the main beam. The final fabricated array antenna is depicted in Fig. 10. Since we have selected bulk pins in the design, the fabrication process is still CNC machine.Fig. 11 illustrates the simulated and the measured gains from 138 GHz to 148 GHz. The measured gain is about 37 dBi in the operating frequency band. The antenna efficiency is around 50% over the operating frequency band.

IV. Conclusion

In this paper two types of array antennas at 144 GHz have been introduced. The series-fed array antenna is usually limited by the bandwidth because of long line effect. However, it is convenient to apply unequal power divider and taylor distribution method to synthesize the radiation patterns. The corporate-fed array antenna has a couple of advantages. Firstly, the bandwidth is very well improved compared with the series-fed array antenna since it is able to avoid the long line effect. Secondly, the main beam offset is able to be avoided compared with the series-fed array antenna. However, the corporate-fed array antenna still has some disadvantages. The number of the T-junctions increases quickly. If their reflection coefficients are not well designed, the insertion loss of whole antenna would be affected. On the other hand, since the corporate-fed array antenna is usually fed by a way of equal power and identical phase, the radiation patterns on the E-plane are usually very bad. Given the limited layout space of corporate-fed distribution networks, it is very difficult to do array synthesis, such as Chebyshev or Taylor method. For mm-wave back-hauling applications in the future, low side lobes radiation pattern, wide bandwidth stable gain and low cross polarization levels are still major challenge.

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