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Wideband Tapered Slot Antenna for D-Band Applications

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Abstract—This paper presents a wideband tapered slot antenna for D-band (110–170 GHz) applications. The antenna is fed by a substrate integrated waveguide (SIW) and achieves a simulated gain of 11.1 dBi at 170 GHz. The in-band gain variation is less than 3 dB. The designed SIW is based on a thin aluminium nitride (AlN) substrate with hollow plated vias working as the vertical conductor walls. The substrate is extended and inserted into a tapered slot antenna. The concept of designing SIW-fed tapered slot antenna is described in detail. The assembly structure is illustrated and the antenna radiation pattern is shown. The proposed SIW-fed tapered slot antenna also provides a wideband matching at D-band. The simulated return loss remains better than 18 dB from 110 GHz to 170 GHz which corresponds to a bandwidth of 43% at 140 GHz.

Index Terms—D-band, substrate integrated waveguide (SIW), tapered slot antenna, wideband.

I. INTRODUCTION

With the increasing demand worldwide for high-speed wireless communication, high-resolution imaging, remote sensing, and security applications, millimeter-wave frequency bands above 100 GHz have acquired enormous attention in recent years [1]–[4]. D-band covers the frequencies from 110 GHz to 170 GHz. It becomes attractive due to low atmospheric loss and large bandwidth [5]. Different types of wideband antennas have been investigated for wireless point-to-point communications as well as system integration and packaging at millimeter-wave frequencies [6]–[9]. The challenge for designing such antennas is to achieve a high gain and at the same time a wideband impedance matching. Besides, the in-band gain uniformity needs to be taken into account for transmitting and receiving signals around the same power level at different frequencies.

Fig. 1 shows the overview of the proposed wideband tapered slot antenna for D-band applications. A substrate integrated waveguide (SIW) with an extension on the substrate is inserted into the gap guiding electromagnetic waves from the SIW to the tapered slot antenna and radiating into free space. In this way, the SIW works as the feed of the antenna and makes it compatible for connecting to other circuits as well as components. Compared with conventional rectangular waveguides, SIWs are more compact and versatile especially at millimeter-wave frequencies. The dimensions of the waveguide can be downscaled by a factor of $\sqrt{\epsilon_r}$ in which ϵ_r represents the relative permittivity of the dielectric substrate. Besides, SIW

Fig. 1. Overview of the proposed SIW-fed wideband tapered slot antenna for D-band applications.

is easier to be integrated with the circuits at such high frequencies since they mainly rely on planar structures due to the fabrication processes. The transitions between SIWs and planar transmission lines used for the circuits at D-band can be found in the literature [10], [11].

In this work, a SIW-fed wideband tapered slot antenna for D-band applications is designed and analyzed by using the full-wave electromagnetic simulator from Ansys. In order to validate the concept, a thin aluminium nitride (AlN) substrate is used for designing the SIW while it can be reconfigured for other dielectric materials such as gallium arsenide (GaAs) or indium phosphide (InP). In Section II, the designs of the SIW with extended substrate and the tapered slot antenna are described in detail. The dimensions are shown and the fundamentals are explained. Besides, the assembly structure of the proposed antenna is demonstrated and the potential

Fig. 2. SIW with extended AlN substrate.

way of building an antenna array is discussed. In Section III, the simulated scattering parameters, gain, radiation pattern of the proposed SIW-fed wideband tapered slot antenna are presented.

II. DESIGN PROCEDURE OF SIW-FED TAPERED SLOT ANTENNA

A. SIW with Extended Substrate

Conventional rectangular waveguides have both horizontal and vertical conductor walls forming an air-filled rectangular tube. At millimeter-wave frequencies, SIWs are normally based on thin dielectric substrates due to the downscaled wavelength. Under this circumstance, the top and bottom metal layers work as the horizontal conductor walls while the vertical conductor walls can be realized by adding vias going through the substrate. As the feed of the antenna, a SIW is designed by using an AlN substrate with hollow plated vias. The dissipation factor ($\tan\delta$) and ϵ_r of the AlN substrate are 0.001 and 8.6, respectively. At the end of the SIW, the AlN substrate is extended while its width is reduced gradually forming a triangle termination. The extended substrate helps guiding electromagnetic waves smoothly from the SIW to the tapered slot antenna. The details of the designed SIW is illustrated in Fig. 2.

The material of the top and bottom conductor layers is gold and it has a thickness of 1.2 μm. The vias are located as close to each other as possible in order to prevent the wave leakage from the SIW. By taking into account the requirements of the fabrication processes, both the diameter of the vias and the gaps between the vias need to be kept more than the thickness of the substrate which is 127 μm in this case. Fig. 3 shows the simulated scattering parameters of the designed SIW at D-band. The extension of the AlN substrate is excluded from the SIW simulation structure. The return loss remains better than 27 dB from 110 GHz to 170 GHz with an associated insertion loss of 0.3 dB.

B. Tapered Slot Antenna

Fig. 4 demonstrates the proposed SIW-fed wideband tapered slot antenna. When the wave propagation is dominated by the TE_{10} mode in the designed SIW, the electric fields exist vertically between the gold conductor layers. As for the tapered slot antenna, the electric waves are excited in the small gap at the end of the slot and guided along the tapered

Fig. 3. Simulation results of the designed SIW.

Fig. 4. Wideband tapered slot antenna.

structure. In order to support a wideband radiation, the length and height of the tapered slot are optimized by three stages. At the beginning, the AlN substrate is inserted into the gap and the slot is extended 100 μm. After that, the gap enlarges vertically while the AlN substrate is terminated gradually. The length of the second and third stages are 1900 μm and 1400 μm, respectively. The connections between the second and third stages are also rounded preventing the possible reflections. The aperture width of the tapered slot antenna is 700 μm and the height is comparable with the free-space wavelengths at D-band.

C. Assembly Structure and Antenna Array

The assembly structure of the proposed SIW-fed wideband tapered slot antenna is shown in Fig. 5. The tapered slot is made by aluminium block and divided into two identical parts for easier fabrication and alignment. The bottom part is connected to a metal carrier which contains an alignment slot with a thickness of 127 μm guiding the SIW to the correct position. During the assembly process, the SIW with extended AlN substrate is aligned with the bottom metal carrier at the beginning. The rest half of the tapered slot is fixed from the top afterwards forming a clamping structure. Two guide pins and two screws are used for accurate assembly.

When higher directivity is required by the system or beamforming technique is involved, it is also possible to

Fig. 5. Assembly of the proposed SIW-fed wideband tapered slot antenna.

Fig. 6. A 1×4 antenna array using the proposed SIW-fed wideband tapered slot antennas.

combine the proposed wideband tapered slot antennas into an array. As is shown in Fig. 6, four identical antennas are lined up forming a 1×4 array. Depending on the applications, it can be fed by either four individual SIW inputs or a SIW power divider splitting the input into four ways. Compared with the free-space wavelength at 140 GHz (λ_0), the proposed 1×4 array exhibits a compact structure. The occupation area is less than $4\lambda_0^2$. The total width and length of the 1×4 array are 4.1 mm and 3.9 mm, respectively.

III. MATCHING, GAIN, AND RADIATION PATTERN

Fig. 7 shows the simulation results of the proposed SIW-fed wideband tapered slot antenna. The blue solid line in Fig. 7 represents the simulated return loss including the feed which remains better than 18 dB from 110 GHz to 170 GHz. If the bandwidth refers to the frequency band where the return loss is better than 10 dB, the proposed SIW-fed wideband tapered slot antenna achieves a bandwidth of 60 GHz. It covers the whole D-band and corresponds to 43% fractional bandwidth at 140 GHz. The red dashed line in Fig. 7 is the simulated antenna gain. The coordinate system for simulating the far-field radiation characteristics is assigned to the center of the antenna aperture. The maximum gain is achieved along the x -axis which is also the direction when θ and ϕ equal 90° and 0° , respectively. A simulated gain of 11.1 dBi is achieved

Fig. 7. Simulated return loss and gain of the SIW-fed wideband tapered slot antenna.

Fig. 8. Simulated far-field radiation pattern of the SIW-fed wideband tapered slot antenna at 170 GHz.

by the proposed SIW-fed wideband tapered slot antenna at 170 GHz. In addition, the antenna provides a good in-band gain uniformity since the difference between the maximum and minimum values is less than 3 dB at D-band.

The simulated far-field radiation pattern with normalized amplitude at 170 GHz is shown in Fig. 8. The maximum radiation is acquired along the x -axis which is perpendicular to the antenna aperture. The half-power beamwidth is 46° on the E-plane (xz -plane) and 60° on the H-plane (xy -plane).

IV. CONCLUSION

The design of SIW-fed wideband tapered slot antenna for D-band applications has been presented. The fundamentals of the SIW and the tapered slot antenna have been explained in detail. The proposed SIW-fed wideband tapered slot antenna can provide a wideband matching and a high antenna gain at the same time. The return loss remains better than 18 dB from 110 GHz to 170 GHz and it corresponds to a bandwidth of 43% at 140 GHz. The far-field radiation pattern has been shown and an antenna gain of 11.1 dBi has been achieved at 170 GHz in the direction perpendicular to the antenna aperture. Besides, the in-band gain variation is less than 3 dB which makes the proposed SIW-fed wideband tapered slot antenna suitable for the future high-speed wireless communication systems. The assembly structure has been addressed using a compact approach and the possibility of building an antenna array has been discussed.

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