Novel Antipodal Linearly Tapered Slot Antenna Using GCPW-to-SIW Transition for Passive Millimeter-Wave Focal Plane Array Imaging

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Abstract- **In this work, a novel antipodal linearly tapered slot antenna (ALTSA) using grounded coplanar waveguide (GCPW)-to-substrate integrated waveguide (SIW) transition is proposed and demonstrated. The antenna is well designed for using as the feed antenna in the focal plane array (FPA) imaging system. The S11 of the proposed antenna is below -13dB on Ka-band, meanwhile, the E-plane side lobe is almost 15dB down and 40dB down after reflecting by a parabolic antenna when placing along a line on its focal plane, which show us its high availability for passive millimeter-wave (PMMW) focal plane array imaging system.**

Index Terms- Passive millimeter-wave; Focal plane array; Antipodal linearly tapered slot antenna; Grounded coplanar waveguide; Substrate integrated waveguide

I. INTRODUCTION

Passive millimeter-wave (PMMW) imaging method is based on the passive detection of naturally occurring millimeter-wave radiation from a targeted scene. Upon receiving the thermal radiation of an object in contrast to its background, the PMMW imaging would have the ability to produce images during day or night times; in clear weather or in low-visibility conditions--such as haze, fog, clouds, smoke, or sandstorms; and even through clothing [1]. Such capabilities make PMMW imaging of great importance in many civilian and military applications, such as atmospheric research, all-weather landing guidance, non-destructive security check, and also car collision avoidance [2].

A highly popular method for PMMW imaging is the Focal Plane Array (FPA) Imaging where the receiving units are placed along a line on the focal plane of a reflector antenna, resulting in a multi-beam coverage sight. Because of the relatively higher performance and lower cost of the feed units and their associated receivers; the FPA imaging system has become the main method in PMMW imaging. The packing density, the noise figure, and the data handling speed performance of the receivers are main factors determine the spatial sampling rate of the millimeter-wave focal plane array (MFPA) imaging systems [2]. Undeniably, the performances of the feed antenna, such as, better side-lobe level, better S11 and narrower main beam are extremely needed for better accuracy of the imaging.

In this paper, a novel antipodal linearly tapered slot antenna (ALTSA) with grounded coplanar waveguide (GCPW)-to-substrate integrated waveguide (SIW) transition is proposed and its performance is fully analyzed, simulated and proved by measurement results.

II. PLANAR ANTIPODAL LINEARLY TAPERED SLOT ANTENNA

The ALTSA features high-gain, low-cost, low-side lobe, ease of fabrication, light-weight and compact-size as well as a better performance than the conventional feed elements, i.e. the horn antennas.

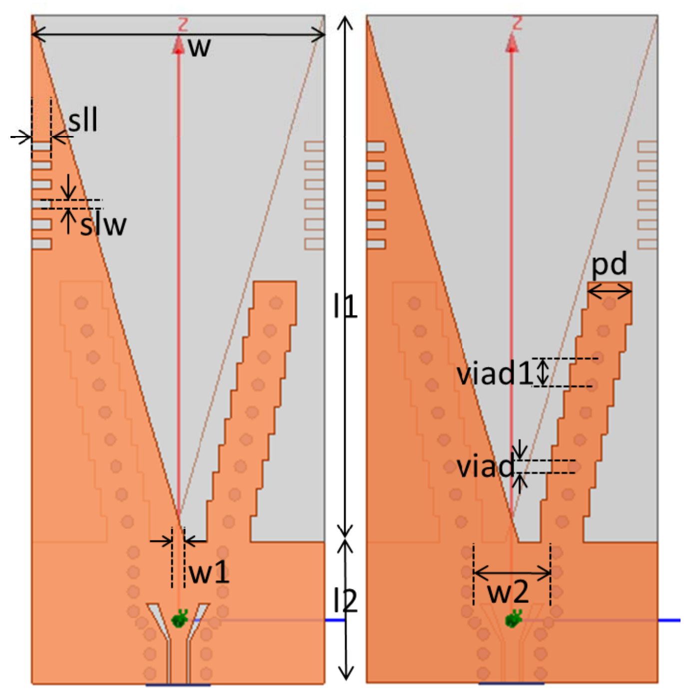


Fig. 1. Modeling of ALTSA (front and ground) in HFSS

The developed ALTSA design is a suitable feed antenna for the reflector for the PMMW imaging system, and covers the Ka-band (32-38GHz). The proposed antenna structure (Fig. 1) is designed using a RT\Duroid6002 substrate with a 2.98 relative permittivity, a dielectric loss tangent of 0.0012, and a 0.508 mm thickness, which is relatively thick for lower SIW conductors' loss.

The double-sided-metallization of the substrate is flared linearly in opposite directions with an overlap width (*w1*) to form tapered slots to reduce mismatch losses. The parameters *w1*, *w* and *l1* are optimized to achieve wide band performance. Cylindrical vias with rectangular patch on one side are added to the antenna structure to increase gain especially at the high frequency end, while reduce side lobe level particularly in E-plane [3]. Additional periodic slits (*sll***slw*) are placed on top of the antenna's tapered structure to effectively increase the gain, and decrease the side lobe and cross-polarization levels. The photograph of fabricated antenna with connector is shown in Fig. 2.

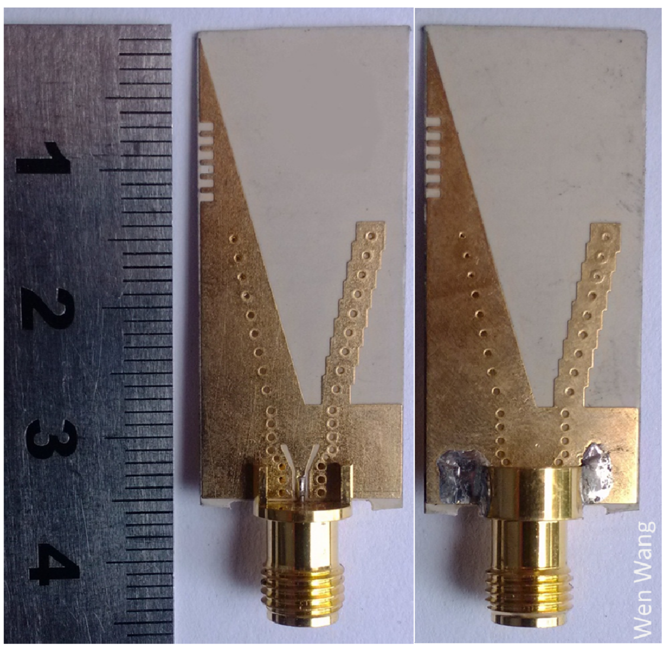


Fig. 2. Photograph of fabricated antenna (front and back with connector)

All optimized antenna dimensions are listed in Table I.

TABLE I
DIMENSIONS OF ALTSA (UNIT:MM)

Symbol	Value	Symbol	Value
l1	27.1	tcsl	2
w	15	tcsw	0.55
w1	0.7	tcsa	62^{o}
l2	7.2	cw	0.8
w2	4	cs	0.15
viad	0.6	cl	2.1
viad2	1	slw	0.5
viad1	1.4	sll	1
pd	2.2	viad3	0.6

III. DESIGN OF GCPW-TO-SIW TRANSITION

For low cost and easy fabrication, compactness, light weight and low loss performance, substrate integrated waveguide technology is utilized, where waveguide side-walls are emulated using rows of metallic vias placed in double-sided substrate for the top and bottom waveguide walls. SIW technology makes it possible to realize the waveguide in a substrate and provides an elegant way to integrate the waveguide with microwave and millimeter wave planar circuits using the conventional low-cost PCB processing technologies [4]. The parameters *w2*, *viad* and *viad2* are calculated by [5] and optimized to make sure that SIW can be replaced by a dielectric filled rectangular waveguide perfectly and good matched to ALTSA.

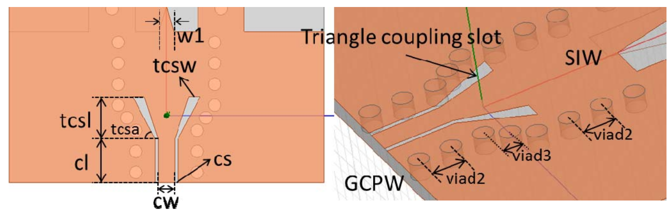


Fig. 3. GCPW to SIW transition (2D and 3D)

It is really a big challenge on how to connect the SIW to coaxial connector. SIW components are typically fed by coplanar waveguide [6], or microstrip-to-SIW transitions [7], here we use the former. In this work, we propose a simple and compact transition (Fig. 3) between GCPW and SIW which can be easily realized on the substrate of SIW circuit with PCB technologies. The sidewalls of the SIW are tapered along the triangle-shaped coupling slot, in such a way that the direction of the electric field on the coupling slot is always perpendicular to the SIW sidewalls. The tapered coupling slot also serves as an impedance transformer to transform any arbitrary impedance line in SIW to the CPWG port impedance. The parameters *viad3*, *tcsa*, *tscl* and *tcsw* are optimized for a smooth transition and perfect match. The optimized length of the coupling slot (*tcsl*) is almost quarter-wavelength of the center frequency in order to achieve a wider bandwidth. Additionally, a 2.92mm connector is utilized in the implement of this transition, while *cl*, *cw* and *cs* are decided by size of the connector and calculated by [8]. All optimized parameters are shown in Table I.

IV. FOCAL PLANE ARRAY

After perfect design of single antenna, we can use antennas in the focal plane array imaging system. In our PMMW imaging system, the reflector we choose for focal plane array is parabolic antenna, which is proved to be suitable to get a multi-beam coverage sight. In our PMMW-FPA imaging system, each antenna is individually fed and independently connected to a receiver for better spatial sampling rate and imaging, while the whole array is placed linearly along its E-plane

To evaluate the overall performance, we simulated the overall system including parabolic antenna that is fed by the focal plane linear array at 35GHz. In our simulation, we choose 8 antennas for a small and compact system, as well as, a parabolic antenna with a 500 mm focal distance, while its aperture diameter is also 500 mm, which are designed for portable far-distance-imaging system. Fig. 4 shows the model of parabolic antenna with a linear 8x1 array which is placed along a line on the focal plane of the reflector. The off-set angle and distance of each single antenna is calculated and optimized for perfect reflection.

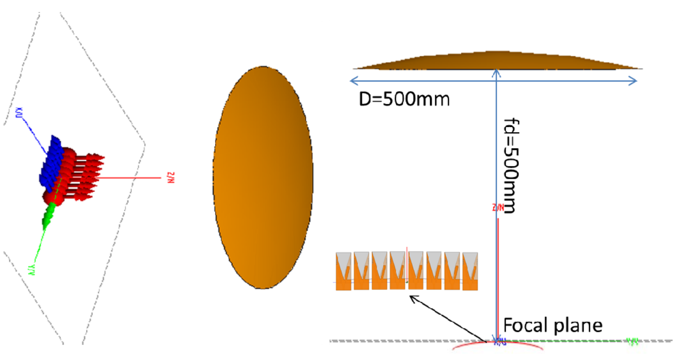


Fig. 4. Modeling of parabolic reflector antenna with a linear 8x1 array in FEKO(3D and 2D)

V. Results

Fig. 5 illustrates simulation and measurement results of the input return loss S11 (32-38GHz) of ALTSA. The S11 of the proposed antenna is below -13dB in a really wide band from 32GHz to 38GHz, especially below -17dB at 35GHz.

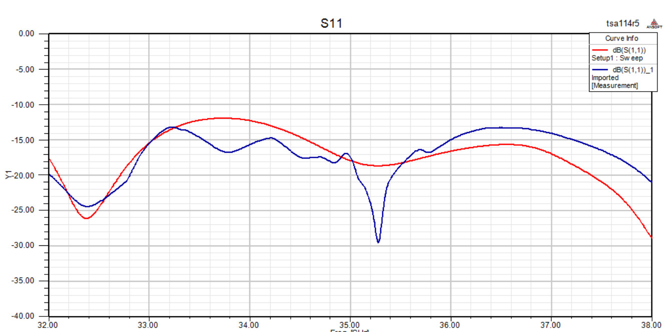
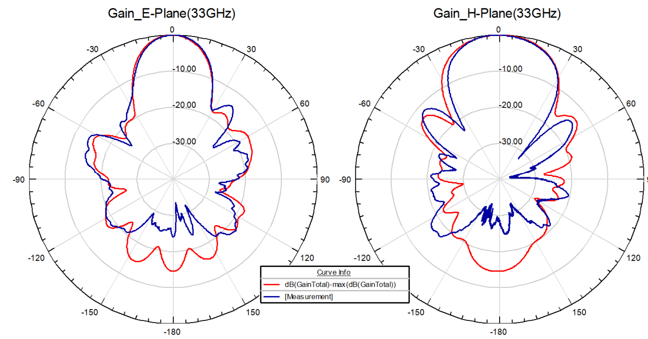


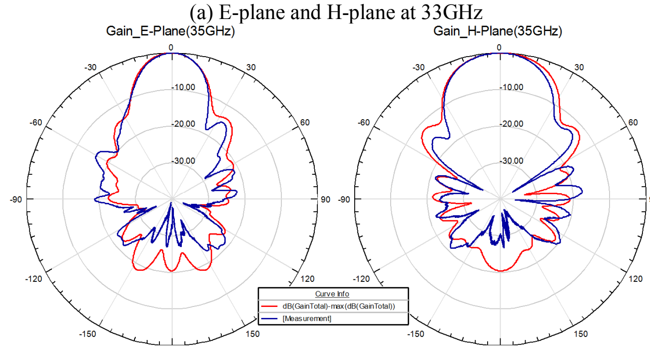
Fig. 5. The S11 (32-38GHz) results of ALTSA
(Red: Simulation, Blue: Measurement)

Fig. 6(a, b, c) show simulation and measurement results of the E-plane/H-plane normalized radiation patterns at 33, 35, 37GHz separately for the ALTSA antenna. It is essential to have low side lobe levels in the E plane to minimize the reception of unwanted noise; given that we arrange the elements in the focal plane along the E- plane. The asymmetric of the side lobe may be resulted by the coupling between the connector and the antenna. Absorbing materials are used to cover the connected coaxial cable during the measurement, which maybe the reason that the measured radiation at the back is lower than simulated one.

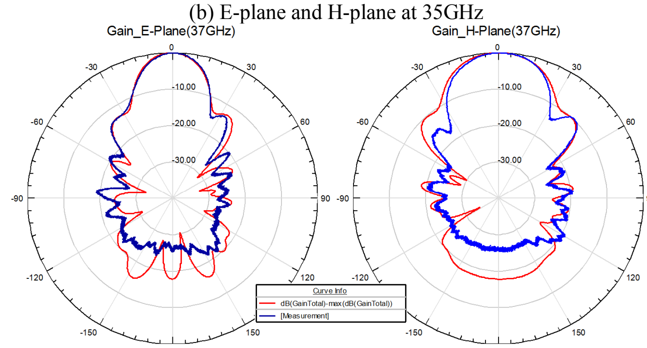
The measured gain of main beam is about 14.5dB, meanwhile, the E-plane side lobe is almost 15dB down, which indicates the ALTSA high potential for high performance in the MFPA imaging system. The measurement results are really close and even better than the simulation results.



(a) E-plane and H-plane at 33GHz



(b) E-plane and H-plane at 35GHz

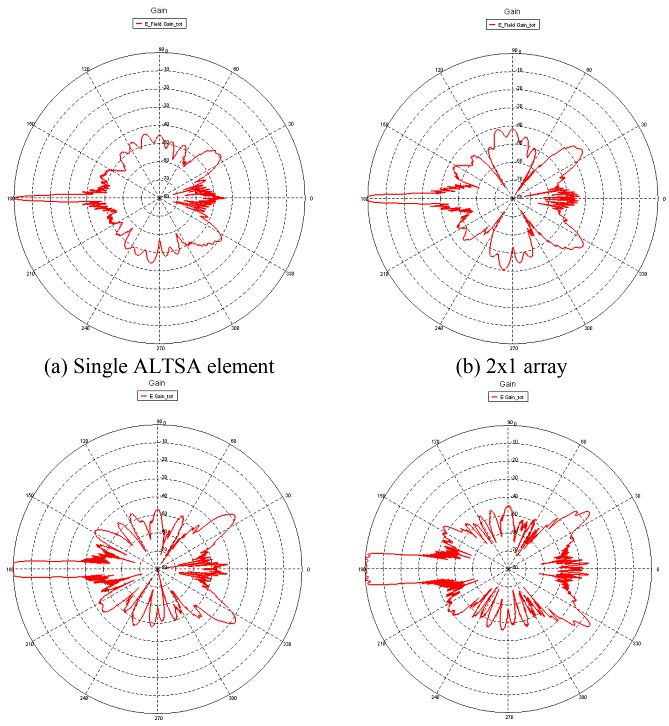


(c) E-plane and H-plane at 37GHz

Fig. 6. The normalized radiation pattern results of ALTSA
(Red: Simulation, Blue: Measurement)

The normalized radiation pattern at 35GHz of a single ALTSA element feeding the parabolic antenna has a side lobe in the E-plane of almost 40 dB down with a 1.3^{o} HPBW (Fig. 7(a)), also the shoulders in the radiation pattern of ALSTA are disappeared after reflector, which illustrates our design is really promising. For the 2x1 array, the side lobe level in the E-plane is almost 37 dB down with the 3^{o} HPBW (Fig. 7(b)), while 4x1 array with almost 40 dB down side lobe level and 7^{o}

HPBW (Fig. 7(c)), lastly, Fig. 7(d) shows almost 38 dB down side lobe level with the 14.5° HPBW for 8x1 array. The high-gain, flat and narrow main beam made by the reflected multi-beam coverage is becoming larger while the number of the ALTSA elements is increasing, which are meaningful for large range and far distance imaging.



(a) Single ALTSA element (b) 2x1 array

(c) 4x1 array (d) 8x1 array

Fig. 7. The E-Plane normalized radiation pattern (35GHz) results of parabolic antenna with linear antenna array placed along a line on focal plane

All of these above theoretical and measurement results are very encouraging and indicates their high availability for PMMW focal plane array imaging.

ACKNOWLEDGMENT

The author--Wen Wang is now a visiting student at The University of Tennessee at Knoxville, which is sponsored by China Scholarship Council.

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