# Experimental Study of a Ka-Band Waveguide-Fed Longitudinal Slot Phased Array

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***Abstract*-A Ka-band waveguide-fed longitudinal slot array designed as a phased array to achieve a ±8° E plane beam scan is presented. A three-layer structure, which is easy to fabricate, has been applied to produce the array. The measured results show that, the array possesses a high gain of more than 34.5dBi in the entire scan range and shows an aperture efficiency of more than 54%. The measured E plane side lobe level is below -16.5dB while the beam scans in the angle range.**

## I. INTRODUCTION

Lots of works about electronically scanned slot arrays had been published during the past decades [1-4]. Most of them had applied edge slot arrays as their scan elements [1, 2, 4], since narrow element spaces could be applied to avoid the grating lobes in a wide scan angle range. However, the operation bands of the edge slot phased arrays were usually below the K-band. Because in higher frequency bands, such as the millimeter wave (MMW) band, high fabrication accuracy of individual waveguides and the edge slots on them will be needed, which can hardly be achieved and will be extremely expensive.

As well known, the waveguide-fed longitudinal slot arrays had got precise and efficient design method [5] which can sufficiently consider the mutual coupling effect, and had already been widely applied to design high gain and high efficient slot array antennas in MMW band [6, 7]. Single layer structures were usually applied to construct the arrays, since it could be fabricated by die-casting technique with enough fabrication accuracy needed in the MMW band and at very low cost [8].

However, only a few of waveguide-fed longitudinal slot arrays have been applied in phased arrays, because wide scan angles will not be achievable due to the scan blindness and the grating lobes caused by the big element spaces and serious E plane mutual coupling factors. In [9], a large Ka-band longitudinal slot array was designed and analyzed for digital beam-forming application. The beam-forming was achieved in the H plane to avoid the serious E plane coupling. However, there were no experimental results of the scanned beam patterns or beam-forming patterns in the article. In [10], a method was proposed for analyzing the performance of the phased longitudinal slot arrays. The E plane scan pattern of a phased longitudinal slot array in K-band was calculated, yet no experimental results were provided.

This paper presents a Ka-band waveguide-fed longitudinal slot array designed as a phased array to achieve a ±8° E plane beam scan. The experimental results show that the array maintains a high gain performance of more than 34.5dBi in the required scan range. Good radiation pattern performances have been achieved in the entire scan range.

## II. DESIGN OF THE SLOT ARRAY

### A. *Slot Element*

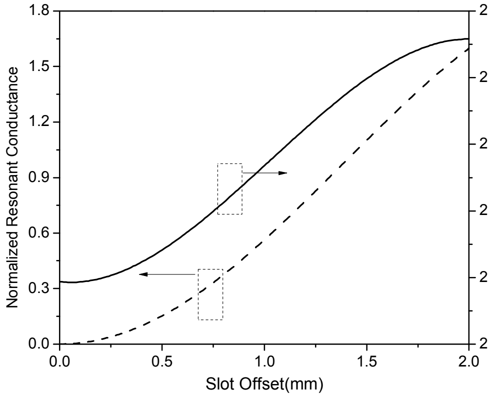


Figure 1. Normalized resonant conductance curve and resonant length curve versus slot offset at the center frequency $f_0$.

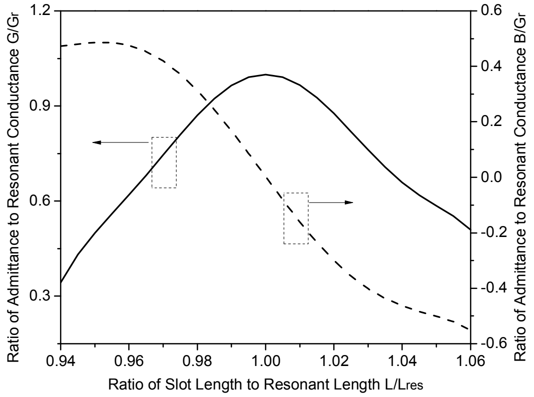
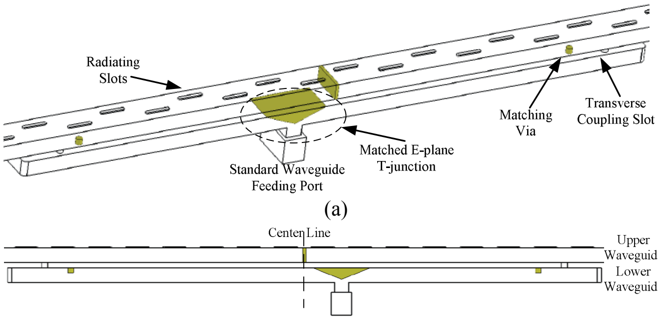


Figure 2. Normalized self-admittance components of the shunt slot at $f_0$.

The width of the waveguide which contains the radiating longitudinal shunt slots is 5.5mm, and the height is 2.5mm. The width of the radiating slots is set to be 0.6mm, and the shim that contains the slots has a thickness of 0.5mm. The normalized resonant conductance curve and the resonant length curve versus the slot offset at the center frequency $f_0$ have been calculated by using the method of moments (MoM)

[11], and are shown in Fig. 1. The ratio of admittance to resonant conductance curve versus ratio of slot length to resonant length at $f_0$, which is needed in the design process, is also calculated and presented in Fig. 2.

### *B. Structure Of One Linear Array*



(a)

(b)

Figure 3. Structure of one linear slot array, (a) 3D view; (b) side view.

The planar array contains 16 linear arrays, each of which contains 42 radiating slots and has an individual feeding port. The structure of one linear slot array is shown in Fig. 3. It should be noted that, only the air parts of the waveguide and the slot have been shown in the figure to clearly depict the structure. In order to meet a 1% bandwidth requirement, the linear array is equally divided into two sub-arrays, which are separated by a metal plate. The energy will be received by the radiating slots, then coupled to the lower feeding waveguide through the coupling slots, and finally synthesized together by using a matched E plane T-junction to the feeding port thus the receiver. The waveguides in this paper have set to be smaller than the standard BJ320 waveguides. Thus step transmission sections have been applied to transmit the waveguides to the standard ones. To leave enough space for the standard waveguide ports and maintain an opposite phase transmission to the two sub-arrays, the waveguide port is set to have a $\lambda_g/2$ offset from the center line, where $\lambda_g$ denotes the waveguide wavelength of the feeding waveguide at $f_0$.

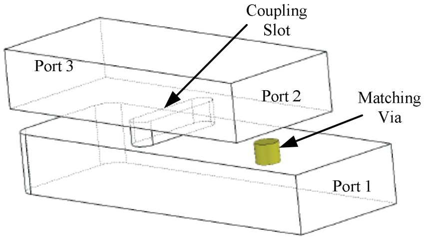


Figure 4. Broad wall transverse coupling slot.

The broad wall transverse coupling slot is depicted in Fig. 4. The thickness of the common wall of the waveguides is 0.5mm. The slot has a width of 0.5mm, a length of 3.4mm, and is $\lambda_g/2$ away from the waveguide shorting end. A metal matching via has been placed 4.5mm before the coupling slot to obtain a good impedance match. The via has a diameter of 1mm, a height of 0.8mm and a offset of 0.7mm from the center line of the waveguide.

The matched E plane T-junction is depicted in Fig. 5. A metal roof-top structure has been added to obtain a good impedance match.

The structures of the broad wall transverse coupling slot and the matched E plane T-junction have been simulated by applying Ansoft's High Frequency Structure Simulator (HFSS). Both of their simulated return losses are below -20dB in the 1% operation bandwidth around $f_0$.

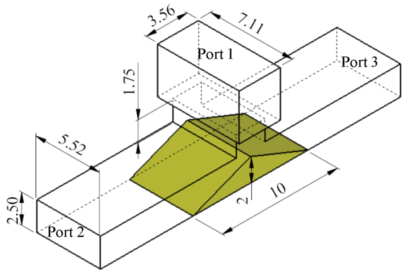
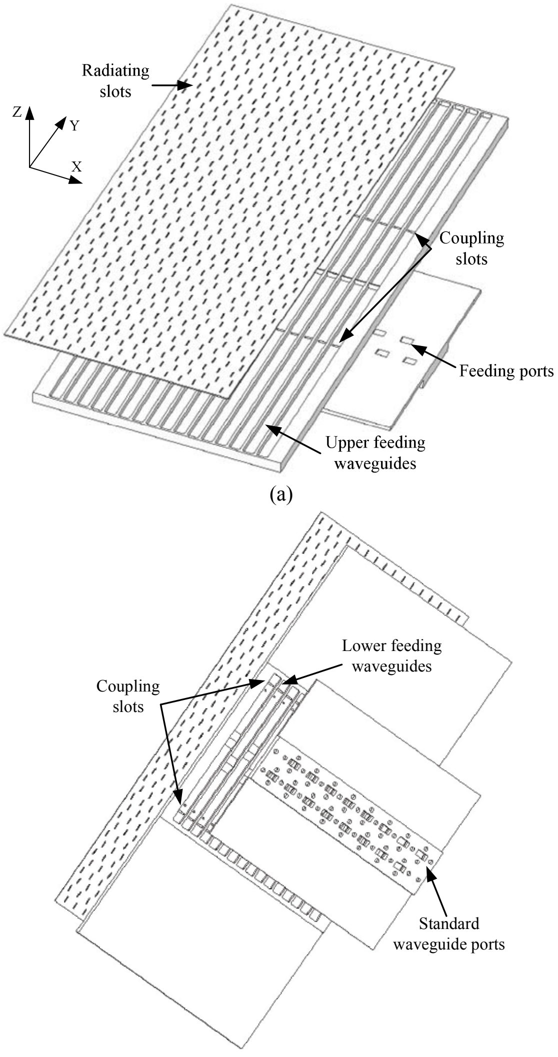


Figure 5. Matched E plane T-junction.

### *C. Structure Of The Planar Array*



(a)

(b)

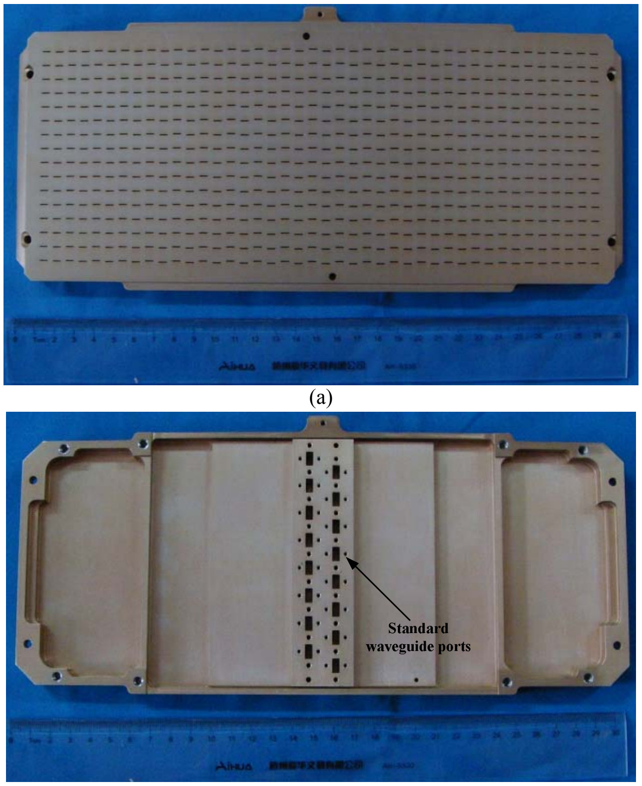
Figure 6. Structure of the planar slot array, (a) top view; (b) bottom view.

The planar array is shown in Fig. 6. It mainly includes three parts: the shim part that contains the radiating slots, the waveguide part and the plate that contains the feeding waveguide ports. At last, the three parts are welded together to construct the final array. This three layers structure can be fabricated by die-casting technique with enough fabrication accuracy and at very low cost, thus suitable for mass production. The element space at the X direction is 0.81$\lambda_0$, which is decided by the waveguide width and the thickness of the metals wall which construct the waveguides. Noted that, the standard waveguide ports besides each other have an opposite offset from the center line to leave enough space for the receive modules.

### *D. Slot Array Design Method*

By using the property curves of the single slot in Fig.1 and Fig. 2, the Elliott's method [5] has been applied to design the planar slot array, which accurately considers the mutual coupling of the total planar array and insures the far field pattern performance. The array distribution has set to be a Taylor distribution, with a -30dB side lobe level in H plane (YZ plane) and a -25dB in side lobe level E plane (XZ plane).

## III. EXPERIMENTAL INVESTIGATION


(a)

(b)

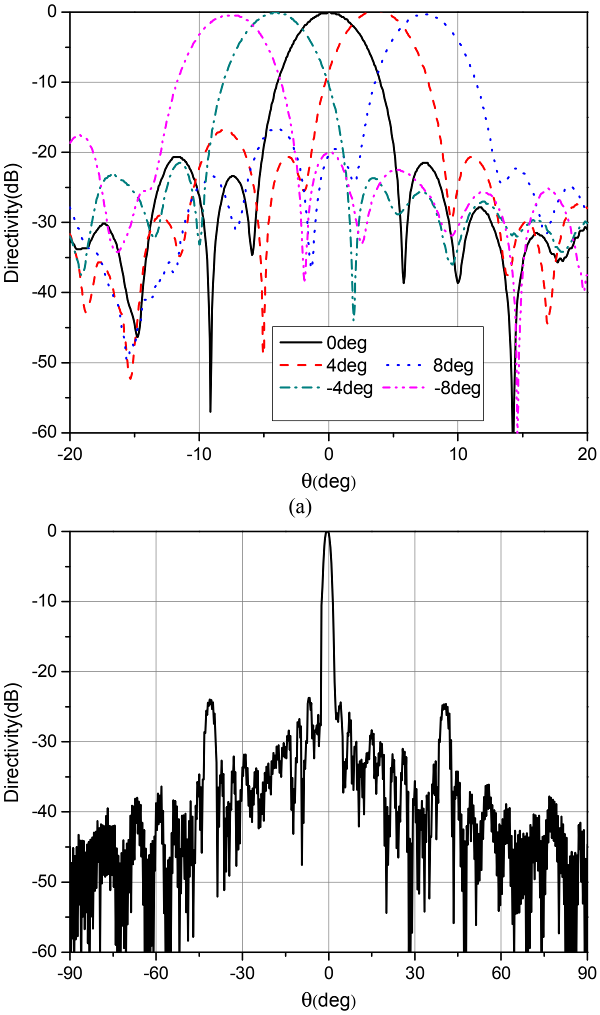
Figure 7. Photo of the slot array, (a) top view; (b) bottom view.

The fabricated slot array is shown in Fig. 7. Its size is about 275mm×110mm×13mm.

The return loss of every linear array has been measured to be below -10dB in a 1.2% bandwidth around $f_0$, under the condition that all the feeding ports of other arrays being matched.

The none-scanned antenna gain at $f_0$ is measured to be 35dBi, which represents that the slot array has gained an aperture efficiency of about 60% at the Ka-band.

The measured E plane radiation patterns are shown in Fig. 8(a). It can be observed that, the array only experiences a slight gain drop as it scans at the E plane, which is at most -0.5dB as it scans to -8°. This means that the array possesses a high gain of more than 34.5dBi and an aperture efficiency of more than 54% in the entire scan range.



(a)

(b)

Figure 8. Measured radiation patterns of the slot array, (a) scan patterns at E plane; (b) none-scan pattern at H plane.

The measured E plane side lobe level is below -21dB as the main beam steering at the broad side. However, the side lobe rises up as the scan angle increases, which even rises to -16.5dB at the scan angle of -8°. This phenomenon can be explained by that, the active admittances of the slots vary when the mutual coupling experienced by the slot elements change as the beam scanned, so the radiation amplitude and the phase of the elements change accordingly.

The measured H plane pattern as the array is steering at the broad side is shown in Fig. 8(b). It can be observed that, the measured H plane side lobe level is below -24dB as the main beam steering at the broad side. However, two side lobes at the angle of ±45° rise up to about -24dB. From the theory in [12], it can be deduced that, there must be at least 0.03mm misplacement at the X direction between the shim which contains the radiating slots and the waveguide plate, thus a periodical amplitude distribution error occurs along the Y direction, which causes the ±45° side lobe. This can be overcome through constructing the radiating slots and the waveguides on one plate or applying a more restrict locating method with less misplacement error.

## IV. CONCLUSION

A Ka-band waveguide-fed longitudinal slot phased array which achieves a ±8° E plane scan range has been presented in this paper. A three-layer structure has been applied to produce the array, which makes the fabrication process accurate and suitable for mass production. The measured results have shown that, the array possesses an extremely high gain of more than 34.5dBi in the entire scan range and shows an aperture efficiency of more than 54%. The E plane side lobe level has been measured to be below -16.5dB in the entire scan range. And the H plane side lobe level has been measured to be below -24dB while the main beam steering at the broad side. The reasons for the side lobe rising of the E plane scanned patterns and the ±45° side lobe of the H plane pattern have been discussed.

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