

# Micromachined travelling wave slotted waveguide antenna array for beam-scanning applications

Mahmud, Rashad; He, Tianhao; Lancaster, Michael; Wang, Yi; Shang, Xiaobang

## *Document Version*

Early version, also known as pre-print

## *Citation for published version (Harvard):*

Mahmud, R, He, T, Lancaster, M, Wang, Y & Shang, X 2014, 'Micromachined travelling wave slotted waveguide antenna array for beam-scanning applications', Paper presented at 2014 10th Loughborough Antennas and Propagation Conference, LAPC 2014, Loughborough, Leicestershire, United Kingdom, 10/11/14 - 11/11/14.

[Link to publication on Research at Birmingham portal](#)

## **General rights**

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

## **Take down policy**

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact [UBIRA@lists.bham.ac.uk](mailto:UBIRA@lists.bham.ac.uk) providing details and we will remove access to the work immediately and investigate.

# Micromachined Travelling Wave Slotted Waveguide Antenna Array for Beam-Scanning Applications

Rashad Mahmud<sup>1</sup>, Tianhao He<sup>1</sup>, Micahel Lancaster<sup>1</sup>

<sup>1</sup>*School of Electronic, Electrical and Computer Engineering  
University of Birmingham  
Edgbaston, Birmingham, B15 2TT, UK  
[RHM112@bham.ac.uk](mailto:RHM112@bham.ac.uk), [TXH166@bham.ac.uk](mailto:TXH166@bham.ac.uk),  
[m.j.lancaster@bham.ac.uk](mailto:m.j.lancaster@bham.ac.uk)*

Yi Wang<sup>2</sup>, Xiaobang Shang<sup>1</sup>

<sup>2</sup>*School of Engineering  
University of Greenwich (Medway campus)  
Chatham, ME4 4TB, Kent, UK  
[Yi.Wang@greenwich.ac.uk](mailto:Yi.Wang@greenwich.ac.uk), [X.shang@bham.ac.uk](mailto:X.shang@bham.ac.uk)*

**Abstract**—A design of travelling wave slotted waveguide antenna array based on micromachined layers operated in the WR-03 frequency band (220-325 GHz) is demonstrated in this paper. The antenna structure remains simple and is designed to be fabricated by using thick SU-8 photoresist technology. Instead of a matched load or a back-short at the termination of the waveguide, a novel H-plane bend followed by a radiating slot is integrated in order to minimise the power reflected to the input port and achieve the travelling wave operation. It also enables broadening of the bandwidth, and keeps the high gain value of the antenna. The 8-slot linear array antenna has shown a simulated gain of 13.5 dBi in the E-plane at 300 GHz, and 30% fractional bandwidth from 240 GHz to 325 GHz. The main beam scans in the H-plane, from  $-25^\circ$  to  $-6^\circ$  over the bandwidth. The scanning feature is attractive for radar applications.

**Keywords**—Beam scanning, travelling array, millimeter-wave waveguides, H-bend radiating slots.

## I. INTRODUCTION

Frequency scanning waveguide antenna arrays have been introduced to radar applications since 1950 [1]–[3]. To achieve frequency scanning in a conventional travelling-wave slotted waveguide antenna array, a matching load at the termination of waveguides is used to absorb the power which is not radiated, and a phase shifter to control the main beam direction [4]. Indeed, a matched load, which does provide wider bandwidth at the expense of antenna gain, is not desirable for radar applications. Also, at the millimeter-wave band, it is difficult to implement matched load and phase shifter for the antennas because of the inefficiency of shifters and the small size of the components [5], [6].

Therefore, in this paper, a novel H-bend feeds a radiating slot replacing the matched load. This H-Bend Radiating (HBR) slot has been integrated with the linear array of the slotted waveguide antenna (Figs 1 and 3) instead of the matched load in order to lower the VSWR and keep the high gain value of the antenna at the designed frequencies (220-325 GHz). Also, it has been realised in this work that with the presence of the HBR slot, in addition to widening the bandwidth, a wider range of beam scanning angle can be achieved.

Due to the complicated three dimensional structure of the waveguide, the slotted waveguide antenna presented in this paper has been suited to be fabricated using 288  $\mu\text{m}$  thick micromachined SU-8 photo-resist layers. Based on the previous work, this technique can confidently be used to make

millimeter-wave devices with dimensional errors of only a few microns and introducing very low losses [7], [8], [9]. It is believed that the design proposed here is the highest operation frequency for any travelling wave slotted waveguide antenna.

## II. DESIGN OF HBR SLOT

A single HBR slot is shown in Fig. 1 and has a length (a) which is about half of a wavelength. Its width is equal to the narrow wall dimension of the waveguide. The simulated reflection coefficient of the HBR slot is less than -20 dB from 220 to 325 GHz as shown in Fig. 2. The HBR slot has been optimised using full-wave simulations (CST), and has a gain of (6.85dBi) at 300 GHz with only 0.8 dBi variation over the whole WR-03 band as depicted in Fig 2. From Figs. 2, it is important to note that the directivity and radiation pattern of the HBR slot are almost frequency independent. This behaviour is similar to half wave dipole antenna as expected [10].

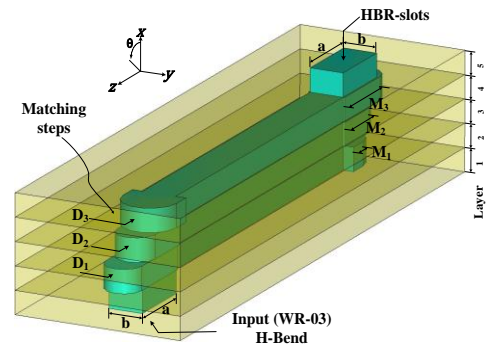


Fig. 1. Diagram of the designed HBR slot with the characterisation of the three matching steps.  $b=0.432$  mm,  $d=0.96$  mm,  $a=0.864$  mm,  $D_1=0.699$  mm,  $D_2=0.499$  mm,  $D_3=0.469$  mm,  $M_1=0.24$  mm,  $M_2=0.60$  mm,  $M_3=0.91$  mm.

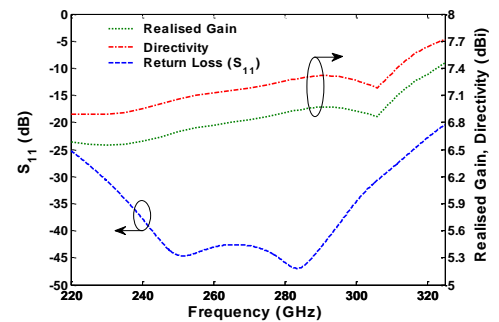


Fig. 2. Variation of  $S_{11}$ , realised gain, and directivity of the HBR slot versus frequency.

### III. DESIGN OF LINEAR ARRAY WITH 8- RADIATING SLOTS AND ITS PERFORMANCE

#### A. Design configuration

The full travelling wave array with 8-slots in the narrow wall of the waveguide is shown in Fig. 3. In the previous design published about a standing wave array [7], the spacing between slots, was chosen to be one guided wavelength in order to feed all the slots in phase. Two grating lobes existed in the radiation pattern of the antenna due to the inter-element spacing ( $\lambda_g$ ) which is larger than the free space wavelength [11]. However, for travelling wave array, the spacing slot does not have to be  $\lambda_g$  [12]-[14]. In this paper, the inter-element space is chosen to be  $d = 0.78 \lambda_g$ . This spacing provides a wide range of main beam scanning. It is worth noting that the slots are not excited in phase here. Thus, a progressive phase shift is generated.

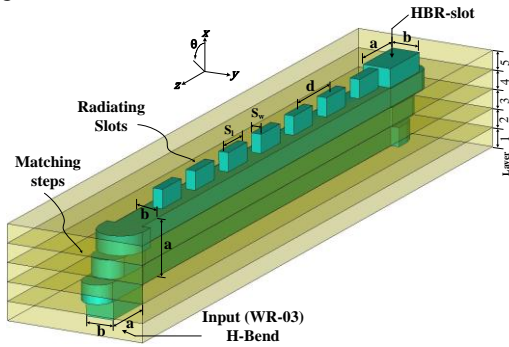


Fig. 3. Layout of an 8-slot travelling array cut in the centre of the narrow wall of the waveguide based on the micromachining layers (equal thickness  $t=0.288$  mm). An H-plane bend is integrated with the structure to interconnect with the waveguide flange (WR-03) precisely, and an H-plane radiating slot is designed in order to cancel the reflected power to the input port. The outstanding structure in the central area represents the hollow waveguide WR-03 and slots, while the surrounding conductors are set to be transparent).  $a=0.864$  mm,  $b=0.432$  mm,  $d=0.964$  mm,  $S_w=0.15$  mm,  $S_t=0.55$  mm.

#### B. Design performance

This section demonstrates the simulated performance of the designed 8-slots linear array antenna operated at 300 GHz. The simulated radiation pattern of the antenna has a main beam in the H-plane which is  $-13^\circ$  scanned towards the input port with the existence of one grating lobe at  $55^\circ$  as shown in Fig. 4. The main beam scans due to the progressive phase shift produced, and the appearance of one grating lobe is because of the spacing ( $0.78 \lambda_g$ ) which is still larger than half of the free-space wavelength. The simulated E-plane radiation pattern of the antenna when ( $\theta_0 = 13^\circ$ ) has shown 13.5 dBi gain. The side lobe level is 13.3 dB in the E-plane which is better than 6.8 dB in the H-plane. A very good matching below -10 dB from 240 to 325 GHz is observed in Fig. 5. This large bandwidth (30%) provides a wide range of beam scanning.

#### C. Main Beam scanning

This section describes the scanning of the main beam H-plane radiation pattern with respect to frequency. The H-plane radiation pattern from 255 to 325 GHz is investigated, and

shows the main beam scanning from  $-25^\circ$  to  $-6^\circ$ . This means a  $19^\circ$  main beam scanning over 23.3 % BW.

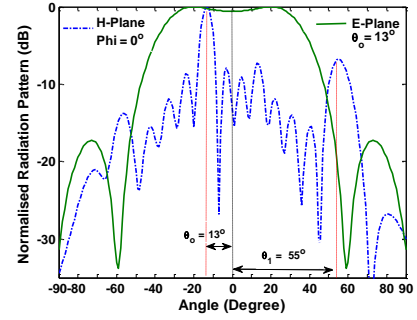


Fig. 4. Simulated radiation pattern of the 8-slots at 300 GHz.

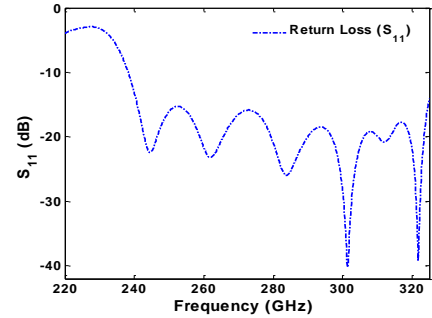


Fig. 5. Variation of return loss of the antenna versus frequency.

### IV. REFERENCES

- [1] R. M. Robertson, Variable Width Waveguide Scanners for Eagle (AN/APQ-7) and GCA (AN/MPN-1): *Radiation Laboratory, Massachusetts Institute of Technology*, 1946.
- [2] L. A. Gustafson, "S-band two-dimensional slot array," Hughes Aircraft Company, Culver City, CA, Tech. Memo 462, 1957.
- [3] A. Derneryd and T. Lorentzon, "Design of a phase/frequency scanned array antenna with non-resonant slotted ridge waveguide elements," in *Antennas Propag. Soc. Int. Symp. AP-S. Digest*, Jun. 1991, vol. 3, pp. 1728-1731.
- [4] R. Hansen, *Phased Array Antennas*, ser. *Wiley Series in Microwave and Optical Engineering*. Hoboken, NJ, USA: Wiley, 1998.
- [5] E. Cullens, L. Ranzani, K. Vanhille, E. Grossman, N. Ehsan, and Z. Popovic, "Micro-fabricated 130-180 GHz frequency scanning waveguide arrays," *IEEE Trans. Antennas Propag.*, vol. 60, no. 8, pp. 3647-3653, Aug. 2012.
- [6] L. Ranzani, D. Kuester, K. J. Vanhille, A. Boryssenko, E. Grossman, and Z. Popovic, "G-Band Micro-Fabricated Frequency-Steered Arrays With 20/GHz Beam Steering," *Terahertz Science and Technology, IEEE Trans. on*, vol. 3, pp. 566-573, 2013.
- [7] Y. Wang, M. Ke, M. Lancaster, J. Chen, "Micromachined 300 GHz SU-8-based Slotted Waveguide Antenna", *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 573-576, 2011.
- [8] M. J. Lancaster, X. Shang, and Y. Tian. "Micromachined terahertz circuits." *Microwave & Optoelectronics Conference (IMOC)*, 2013 SBMO/IEEE MTT-S International. IEEE, 2013.
- [9] X. Shang, M. Ke, Y. Wang, M. J. Lancaster, "WR-3 band waveguides and filters fabricated using SU8 photoresist micromachining technology," *IEEE Trans. Terahertz Science & Technology*, vol. 2, (6), pp. 629-637, 2012.
- [10] M. N. O. Sadiku, "Antennas" in *Elements of electromagnetics*, 3rd ed. New York: *Oxford University Press*, 2001, ch. 13, pp. 588-637.
- [11] A. Mizutani, K. Sakakibara, N. Kikuma, and H. Hirayama, "Grating lobe suppression of narrow-wall slotted hollow waveguide millimeter-wave planar antenna for arbitrarily linear polarization," *IEEE Trans. Antennas Propag.*, vol. 55, no. 2, pp. 313-320, Feb. 2007.
- [12] R. J. Gilbert, "Waveguide Slot antenna arrays," in *Antenna Engineering Handbook*, H. Jasik, Ed. New York: McGraw-Hill Book Company, 2007, ch. 9, pp. 9-1-9-36.
- [13] J. N. Hines, V. H. Rumsey and C. H. Walter, "Traveling-Wave Slot Antennas," *Proc. IRE*, vol. 41, pp. 1624-1631, November 1953.
- [14] Takeshima, T. and Y. Isogai, "Frequency bandwidth of slotted array aerial system," *Electron. Eng.*, 201-204, 1969.