Characteristics of Feeding-Guide Slot Array Antenna

Wen-Kuan Su[1] and Jin-Hwa Ju[2*]

[1] *Front Department of Electronic Engineering, Chung Cheng Institute of Technology, National Defense University*
[2] *Combined Logistics School*

ABSTRACT

This paper is mainly aimed at the X-band standing-wave slot array radar antenna design and characteristics. Today, the large-scale radar network for the individual-soldier, combat-vehicles, micro-aircraft or small-ship is still with lack of effective battlefield reconnaissance equipment. A new antenna structure, simple and suitable for mass production, is proposed in this study to be applied to radar systems. The radiation patterns are the shape of conical beam and its directivity is high. The polarization characteristics are investigated to enable the circularly polarized radiation, and the experimental results fit well with theory. With a commercial simulation tool, HFSS (High Frequency Structure Software) from Ansoft, we designed and fabricated the whole antenna and its feeding system on a single substrate, taking advantages of small size, low profile, and low cost, etc.—the design process and experimental results of a line slot array antenna at X-band are presented. The RWSA (Radial Waveguide Slot Array) antenna is investigated as a low profile, lightly weight, simple but effective, easy to design and fabricate with reasonable cost efficiency with a prototype of the antenna designed, fabricated and successfully tested.

Keywords: slot antenna, high frequency structure software, bandwidth, X-band

饋入式波導縫隙陣列天線之特性

蘇文寬[1]　朱景華[2*]

[1]前國防大學理工學院電機工程學系
[2]聯合後勤學校

摘　　要

本論文之重點在於 X 頻段雷達天線設計及特性探討；現今大型雷達網對於單兵、戰鬥車輛、微飛行器或小型船艦等，仍欠缺有效率的戰場偵蒐裝備。探討製造結構簡單的天線，在應用雷達系統方面可提出來做研究，其輻射場型是非常集中之波束，而且指向性很高，其場型特性走向電流性的極性輻射，且實驗的結果可以完全結合理論，使用高頻結構模擬軟體工具，大家可以設計與建立整個天線以及其單一基板所注入之系統。優點有尺寸小、低旁辦與低成本等，可以展現出一個 X 頻段之縫隙陣列天線整個設計與實驗成果。輻射波導縫隙陣列天線持續研究，就好比其有低旁辦、重量輕與結構簡單但有效率，容易去建立有效成本設計天線類型，並可以圓滿成功量測實驗結果。

關鍵詞：縫隙天線，高頻結構模擬軟體，頻寬，X 頻段

文稿收件日期 100.12.1 文稿修正後接受日期 101.5.30;*通訊作者
Manuscript received December 1, 2011; revised May 30, 2012;* Corresponding author

I. INTRODUCTION

To simplify the feed system and reduce the feeding line loss, the method of series feeding is adopted to excite the radiating slots. As such, a ten-slots array, operating at 9.375GHz, is designed and its characteristics are examined, with measured results emerging to validate the numerical evaluation. A waveguide slot array antenna is a promising candidate for high gain in millimeter-wave wireless communication systems due to its unique features such as lower loss in comparison with microstrip antennas, and a simpler structure than reflector antennas are [1-3]. The slot antenna proposed here features attributes to overcome difficulties other types of antennas face. More important is that “Feeding-Guide Technology” can achieve wideband performance suppressing the backward radiation simultaneously. Fig.1 reveals the geometry of slot waveguide array system. Waveguide slot array antennas play an important role in microwave-antenna field for numerous applications such as radar and communication systems, which require radiation patterns of narrow-beam or shaped-beam. The slot spacing of such an array is one-half guide wavelength at the design frequency with slots locating at the standing-wave peaks. Antenna designers, however, are always searching for ways to improve existing designs or introduce novel ones in order to fulfill desirable radiation characteristics, reduce the size and weight, which are mandatory requirement for antennas used in microwave and thus make antennas more cost efficient[4-6]. The conventional rectangular waveguide-fed slot array antennas present the advantages of low loss and high power handling capacity; nevertheless, their incompatibility with slab components creates a hurdle for their extended applications in microwave and millimeter wave circuits.

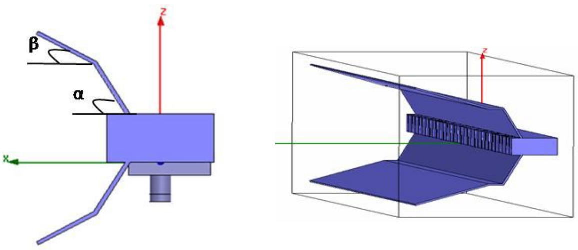

Fig. 1. Geometry of the slot waveguide array system (xz-plane).

II. DESIGN CONCEPT AND THEOREM

In order to accurately predict the radiation pattern of the RLSA (Radial Line Slot Array) antenna, it is necessary to precisely solve the full problem of several slots in the surface of the radial guide, a task which is common but formidable for RLSA (Radial Line Slot Array) antennas. A simple yet accurate model about radiation from the entire set of slots in the surface of the radial guide is applied, in which model no mutual coupling is considered and each radiating slot is replaced by an equivalent magnetic dipole[7-8]. The magnetic current on the conducting plane of the radial slot-containing waveguide or cavity can be written as the cross product of the electric field and the unit vector normal to the surface. Assuming narrow-slots of width less than λg/2, the only component of the electric-field which contributes to the induced magnetic-current is the radial component.

This type of array antenna needs no impedance matching circuits and has very simple circuit configuration, which are mainly due to the excellent performance of the waveguide slot array antenna circuit[3]. The electromagnetic wave fed by waveguide passes through the cavity, wherein the phase and amplitude on each dot are not the same due to the distance difference from feed-point to each slot if slots are equally spaced[9]. The radiating elements are arrayed so that their radiation waveforms are added in phase along the beam direction. The orientation of slots is arranged so as to transmit and receive waves of proper polarization, linear, and have proper coupling inside the cavity[10]. The offset relative to the waveguide centerline of each slot can be calculated by Green’s method, the formula shown as follows:

$$\frac{G_d}{Y_0} = 0.131\frac{\lambda_g}{\lambda} \times \frac{\lambda^4}{A^3 B}\left[\frac{\sin\gamma\cos(\frac{\pi\lambda}{2\lambda_g}\sin\gamma)}{1-(\frac{\lambda}{\lambda_g}\sin\gamma)^2}\right]^2 \qquad (1)$$

where A, B are the widths of the broad wall and the narrow wall, λ is the wavelength in the free space, and λg is the guide wavelength.

The standing-wave waveguide, longitude slot array antenna has been successfully modeled and analyzed. With the equivalent waveguide model[11], an equivalent of waveguide longitude slot array antenna can be designed by using the same slot lengths and offsets, and for such an antenna, Ansoft HFSS is used to extract single slot parameters.

It is obvious that the theoretical results match well with the experiment except that, however, the experimental resultant bandwidth for VSWR ≤ 2° is slightly narrower than theory predicts because of imperfect coaxial adapter in the measurement. Plus, the matching condition of this antenna remains to be improved for further study. The maximum directivity of this antenna is 24.7dBi under the setup of pattern measurements using the standing-wave waveguide circularly polarized antenna with orientation angle of 75°, 18.5° per step, to receive the transmitted wave. It is obvious that the results of elevation-patterns are in good agreement with the theoretical ones. There are some errors expected from the diffraction at the edge of the cavity, imperfect fabrication and test-site situations. The theoretical and experimental results for azimuth-patterns agree very well and they are completely directional [12].

III. EXPERIMENTAL RESULLTS AND DISCUSSIONS

Related parameters of radiation patterns of the antenna on elevation and azimuth planes are tabulated in Table.1. It is evident that the beam pattern is achieved—the elevation-pattern possesses nulls in broadside direction as well as the beam peak directs at 75° and 18.5° in Fig.1 and Table.1, the azimuth-pattern is to have high directivity. The gains of such antenna have been verified through comparison with experimental results for radiation pattern as shown in Table.2.

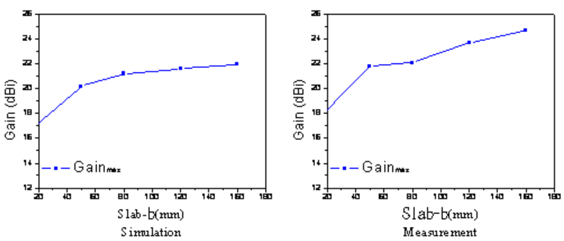

Fig. 2. The antenna gains with simulation and measurement vs. the lengths of slot-slab.

The measured antenna patterns also agree quite well with the simulated results, with the HPBW (Half Power Beam Widths) of E- and H-plane patterns matching well with less than 2°. The relative power levels of the two-slabs for E- and H-plane patterns are approximately 24.7dB, and all the antennas were designed for operation at 9.375GHz.

Table 1. The parameter features of the antenna with lengths of second-slab from 0 to 160mm.

Parameters / Samples	Slot Num	slab-a mm	slab-b mm	α deg	β deg	HPBW	simulated gain(dBi)	measured gain(dBi)
10S	10	44	0	0°	0°	< 2°	15.2	16.0
10S-2-50	10	44	50	75°	18.5°	< 2°	20.2	21.8
10S-2-80	10	44	80	75°	18.5°	< 2°	21.2	22.12
10S-2-120	10	44	120	75°	18.5°	< 2°	21.6	23.7
10S-2-160	10	44	160	75°	18.5°	< 2°	22.0	24.7

Table 2. The comparison of measured gains（dBi）with different antennas.

10-Slot	10-Slot-two-slab	Microstrip	Array 8x8	Waveguide	Annular slot
16.0	24.7	18.2	22.1	15.7	20.3

The RLSA antenna has a more 24.7dBi gain compared with the common slot array antenna. We believe that the improvement lies in the newer slab-structure used on rectangular waveguide slot array antenna, which in turn concludes that using this method to design the pattern for the rectangular waveguide slot antenna array is effective. The measurement was conducted utilizing an HP-8722D vector network analyzer, with the antenna radiating surface aimed at free space or microwave absorbing material separately. Fig.2 illustrates the comparison of gains between the simulation and the measurement of fabricated antenna. Detailed comparison is indicated in Table.1. To perform these simulation analyses, a standing-wave was directed at the surface of the RLSA waveguide antenna and the magnitude and phase of the reflected radiation were calculated. Ansoft's HFSS software was used in these simulations and periodic boundary conditions were used to simulate an infinite array of the RLSA unit slots. For various slab-widths, we tuned the slot length L to enable the resonation at the required frequency.

The prototype antenna was built and measured in the anechoic chamber. Fig.3 shows the antenna simulation and the measured XY-plane patterns corresponding to all of the input ports at 9.375GHz, which shows the best RLSA antenna performance. Where a, b are the lengths of the first-slab and the second-slab. Numerical simulations of all prototypes are performed using Ansoft HFSS. Fig.4 shows the antenna simulation and the measured XZ-plane patterns.

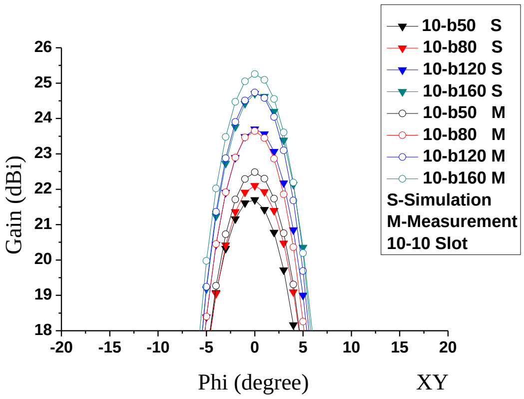

Fig. 3. E-plane (XY-plane) radiation patterns.

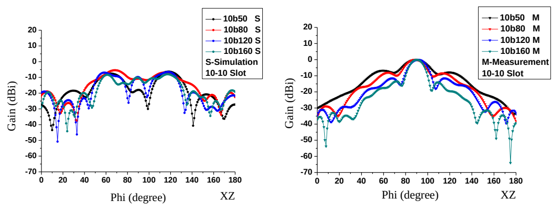

Fig. 4. H-plane (XZ-plane) radiation patterns.

IV. CONCLUSIONS

A simple but accurate model for predicting the radiation patterns of an arbitrarily polarized RLSA antenna with an arbitrary distribution of slots is presented. The validity of the developed model has been verified through comparison with experimental results for the radiation pattern of two-slabs diameter linearly polarized RLSA antenna with less than 2° HPBW achieved in the E-plane at an elevation of lengths from boresight. Good agreement between the theory and experiment has been obtained, showing confidence in the developed theoretical model. It is shown that directivity improvement as much as 9dBi can be reached to improve the antenna radiation patterns.

The design parameters, initial calculation results, simulation tools and antenna design modeling in the software environment have been presented, simulation analysis was performed and the optimum results were obtained for 9.375 GHz LRSA antenna. Each slot corresponds to a different pointing direction and has sufficient bandwidth to recognize targets of a predefined dimension in a security application scenario.

Radiation patterns with low-SLL（sidelobe-level）features have been verified by both simulated and measured results; the proposed slot array antennas are therefore very suitable for high performance communication and radar applications. In principle, better antenna performance and higher operation frequencies can be achieved by using lower loss slot-slab antennas.

REFERENCES

[1] Katayama, M., Yamamoto, M., Nojima, T., and Itoh, K., “Microstrip-Fed Slot Array Antenna Having 45° Inclined Linear Polarization”, Electronics Letters 16th, Vol. 39, No. 21, 2003.

[2] Hwang, J. H. and Oh, Y., “A Single-Layer Waveguide Slot Array Antenna using Diaphragms for Easy Manufacture and High Performance”, IEEE, 2003.

[3] Kodama, K., Nishiyama, E., and Aikawa, M., “Slot Array Antenna using Both-Sided MIC Technology”, IEEE, 2004.

[4] Yan, L., Hong, W., Hua, G., Chen, J., Wu, K., and Cui, T. J., “Simulation and Experiment on SIW Slot Array Antennasy”, IEEE Microwave and Wirekess Component Letters, Vol. 14 , No. 9, 2004.

[5] Abdulrazak, L. F. and Rahman, T. A., “Uni-Omnidirectional Radial Waveguide Slot Array Antenna Design for Wireless Local Area Network”, 19th International Zurich Symposium on Electromagnetic Compatibility, Vol. 19-22, 2008.

[6] Lai, Q. H., Hong, W., Kuai, Z. Q., Zhang, Y. S., and Wu, K., “Half-Mode Substrate Integrated Waveguide Transverse Slot Array Antennas”, IEEE Transactions on Antennas and Propagation, Vol. 57 , No. 4, 2009.

[7] Davis, P. W. and Bialkowski, M. E., “Beam Shaping in Radial Line Slot Array Antennas”, IEEE, 2000.

[8] Noghanian, S. and Shafai, L., “Analysis of Dielectric-Loaded Annular Slot Array Antenna”, Can. J. Elect. Comput. Eng., Vol. 28 , No. 1, 2003.
[9] Jung, K., Lee, H. Y., Kang, G. C., Han, S., and Lee, B., “Cavity-Backed Planar Slot Array Antenna with A Single Waveguide-Fed Sub-array”, IEEE, 2004.
[10] Imran, M. I., Tharek, A. R., Hasnain, A., and Lee, B., “An Optimization of Beam Squinted Radial Line Slot Array Antenna Design”, IEEE International RF and Microwave Conference Proceedings, 2008.
[11] Chen, P., Hong, W., Kuai, Z., Xu, J., Wang, H., Chen, J., Tang, H., Zhou, J., and Wu, K., “A Multibeam Antenna Based on Substrate Integrated Waveguide Technology for MIMO Wireless Communications”, IEEE Transactions on Antennas and Propagation, Vol. 57 , No. 6, 2009.
[12] Monaikrairiksh, C. P. and Ichitakada, J., “Characteristics of A Circularly Polarized Conical Beam Spherical Slot Array Antenna”, IEEE, 2009.