To Reduce Side Lobe Level of Slotted Array Antennas Using Nonuniform Waveguides

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ABSTRACT: In this article, a method is presented to reduce the side lobe level of slotted waveguide array antennas while the gain to be constant. In this method, the *H*-plane dimension of the waveguide is considered as the variable rather than constant. The nonuniformity of waveguide walls obviates the need for offset of slots and thereby reduces the side lobe level of radiation pattern. A slotted nonuniform waveguide is designed at frequency 10 GHz and then fabricated and tested. Int J RF and Microwave CAE 26:42–46, 2016.

Keywords: slot array antenna; side lobe level; nonuniform waveguide; Elliott design

I. INTRODUCTION

The slotted waveguide array antennas are very popular and mainly used in navigation problems, such as radars. The reason behind is due to simple feeding, ease of fabrication, precise control of aperture distribution, good mechanical strength, and linear polarization with low cross-polarization and low loss [1–4]. In spite of these advantages, these antennas suffer from the appearance of spurious side lobes out of the principal planes [5, 6], which are arising from that the slots are not collinear and have alternating offset from the center line. The more offsets have to be the higher those side lobes would be. Some efforts have been done to overcome this shortcoming and thereby reducing the side lobe level. The main ideas of some efforts are using probes near the slots [7, 8], using iris exciting [9], using asymmetric ridge waveguide [10, 11], using partially dielectric filled waveguide [12], and using wiggly-ridge waveguides [13–15]. In this article, side walls of a hollow waveguide are made nonuniform to reduce side lobe levels in all radiation planes while the gain to be constant. The nonuniformity of the walls of waveguide enables us to set the slots collinear and without any offset. The nonuniformity of the walls, the length of slots, and also the distance between them are obtained by an optimization procedure. A slotted nonuniform waveguide antenna is designed and measured at frequency 10 GHz and is compared with conventional uniform antenna.

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II. THE PROPOSED STRUCTURE

Without loss of generality, Figure 1 shows the configuration of a slotted nonuniform waveguide antenna whose five slots are located in the center line of the broad wall of waveguide. In this antenna, all slots are collinear and without any offset with respect to center line of waveguide. In fact, by changing the *H*-plane dimension of the waveguide, instead of offsetting the slots from the center line, the axial component of magnetic field becomes non-zero on the center line and thereby on the offset-less slots. Therefore, the collinear slots can cut the route of surface current and consequently, the radiation is caused.

In Figure 1, L is the length of nonuniform section of waveguide, L_is are the length of slots, and and $L_{i,i+1}$s are the distance between two adjacent slots. We can define the profiles of two walls in the form of a truncated Fourier's series as follows.

$$f_1(x)=\sum_{n=0}^{n=N}[a_{n1}\cos(n\pi x/L)+b_{n1}\sin(n\pi x/L)]\ \ [\text{mm}] \quad (1)$$

$$f_2(x)=\sum_{n=0}^{n=N}[a_{n2}\cos(n\pi x/L)+b_{n2}\sin(n\pi x/L)]\ \ [\text{mm}] \quad (2)$$

In Eqs. (1) and (2), N is number of terms and a_{n1}, b_{n1}, a_{n2}, and b_{n2} are unknown coefficients whose optimum values

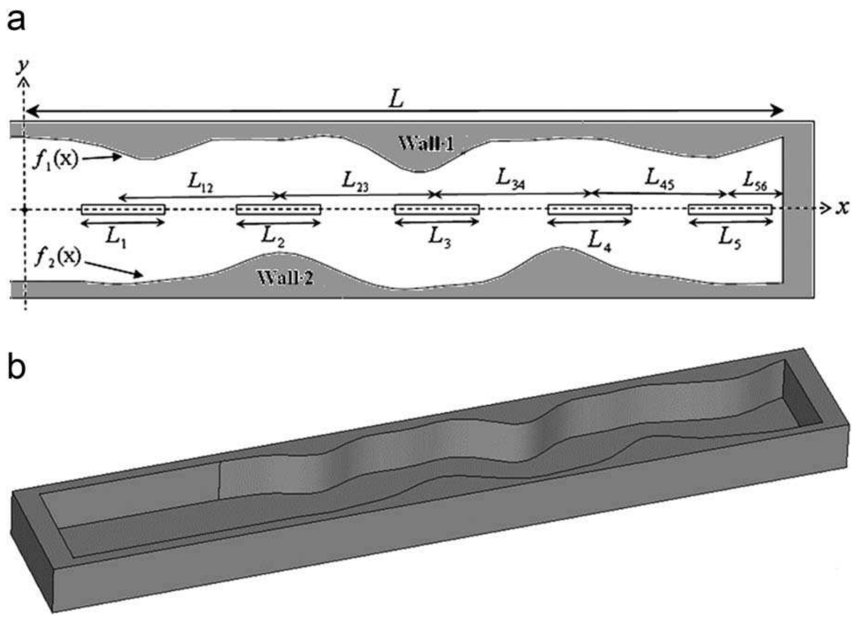

Figure 1 The slotted nonuniform waveguide antenna (a) top view (b) three dimension view.

TABLE I The Optimum Values Related to Slots

N	1	2	3	4	5
L_n (mm)	13.97	13.97	13.97	13.97	13.97
$L_{n,n+1}$ (mm)	25.97	26.49	25.53	23.52	8.78

TABLE II The Optimum Values of Coefficients a_{n1} and b_{n1}

n	0	1	2	3	4	5	6	7
a_{n1}	10.44	−0.049	0.200	−0.035	1.533	−0.100	−0.540	0.094
b_{n1}	0	−0.477	0.174	−0.34	0.067	0.910	0.039	−0.109
n	8	9	10	11	12	13	14	–
a_{n1}	−0.084	0.041	0.249	−0.137	−0.080	0.025	−0.159	–
b_{n1}	−0.01	−0.317	−0.044	0.163	−0.074	0.047	0.104	–

should be obtained. For optimization, the genetic algorithm (GA) method is used by connecting the MATLAB software and full wave analyzer CST STUDIO together.

III. DESIGN, SIMULATION, AND MEASUREMENT

Here, a slotted nonuniform waveguide antenna is optimized and fabricated. This antenna consists of five slots on WR90 waveguide (22.86 × 10.16 mm^2) placed on an infinite perfect conductor. The thickness of two side walls is 5 mm, the thickness of two broad walls is 1.3 mm, and the width of slots is 1.575 mm. Also, $N + 1 = 15$ terms are considered in Eqs. (1) and (2).

The optimization goal is to have side lobe level as low as possible. Also, the constraints for optimization is return loss below −10 dB and the gain equal to the Elliott's

TABLE III The Optimum Values of Coefficients a_{n2} and b_{n2}

n	0	1	2	3	4	5	6	7
a_{n2}	−10.25	−0.069	−0.091	−0.027	0.470	−0.650	−0.375	0.198
b_{n2}	0	0.560	−0.053	0.090	0.010	1.425	0.118	−0.061
n	8	9	10	11	12	13	14	–
a_{n2}	0.061	−0.050	−0.396	−0.150	0.021	0.030	−0.113	–
b_{n2}	−0.160	0.471	0.019	−0.234	−0.134	0.016	−0.15	–

TABLE IV The Peak of Electric Field of Slots for Both Antennas

No. Slot	Elliott [1]	Nonuniform
1	1	1
2	1.02	1.56
3	0.902	2.12
4	1.015	1.94
5	1.031	0.92

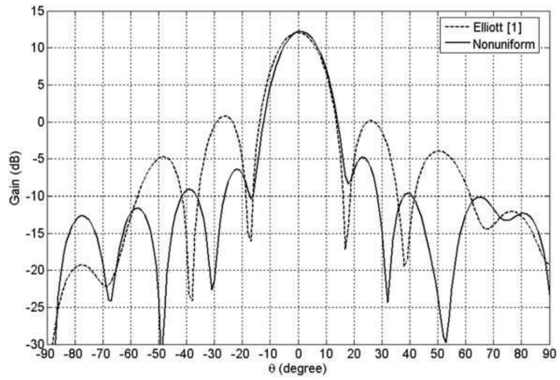

Figure 2 The simulated gain pattern of nonuniform and conventional antennas on the surface $\varphi = 0°$.

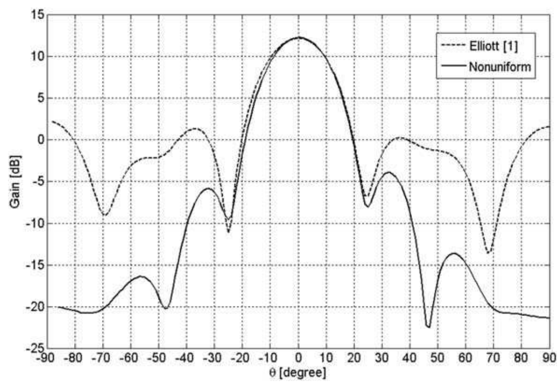

Figure 3 The simulated gain pattern of nonuniform and conventional antennas on the surface $\varphi = 45°$.

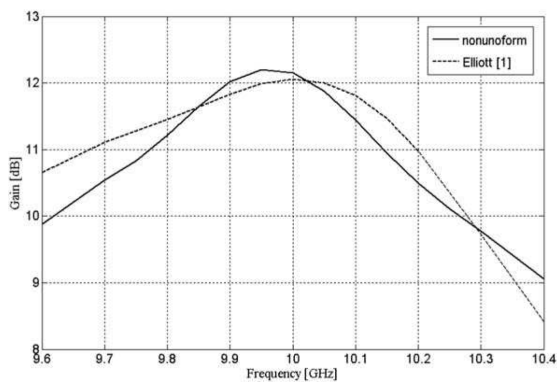

Figure 4 The simulated gain of both antennas versus frequency.

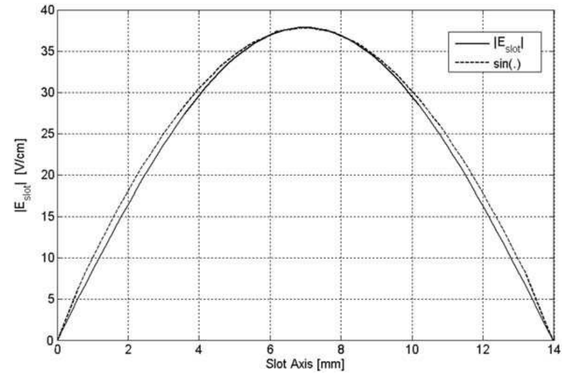

Figure 5 The magnitude of electric field distribution along the length of the first slot for 1.0-W input power.

design (about 12.1 dB) both in frequency of 10 GHz. The initial values of slot lengths and the distances between them are chosen the same as those obtained by Elliott's design. The optimum values related to the slots are given in Table I. Also, the values of unknown coefficients are tabulated in Tables II and III.

The simulated gain pattern of both nonuniform waveguide antenna and the conventional antenna designed by Elliott's formulas on the surfaces $\varphi = 0°$ (x-z) and $\varphi = 45°$ are shown in Figures 2 and 3, respectively. We see that both designed antennas have almost the same gain as about 12.1 dB. However, the side lobe level of

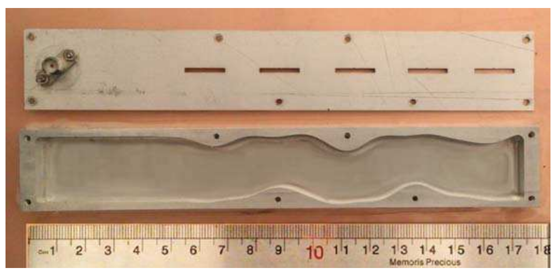

Figure 6 The fabricated nonuniform antenna.

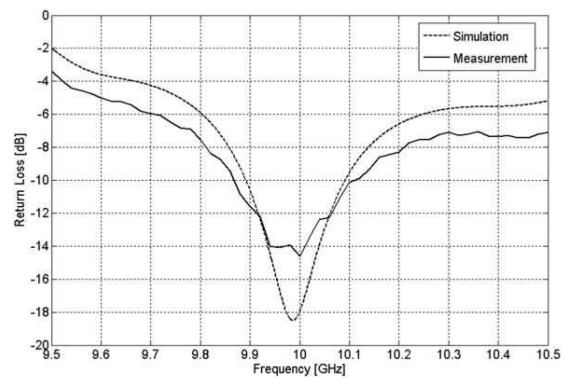

Figure 7 The simulated and measured reflection coefficient of nonuniform antenna versus frequency.

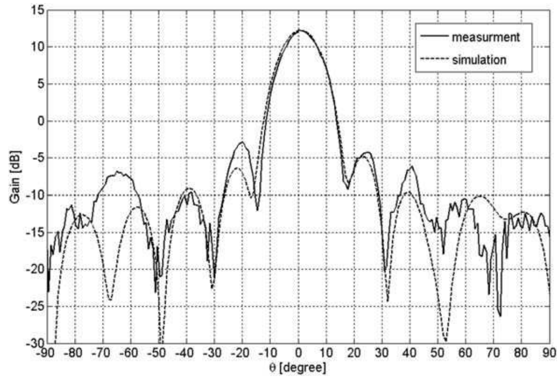

Figure 8 The simulated and measured gain pattern of nonuniform antenna on the surface $\varphi = 0°$.

nonuniform antenna has been reduced about 5.7 dB on surface $\varphi = 0°$ and about 6.6 dB on surface $\varphi = 45°$ in comparison to conventional antenna designed by Elliott's relations. Figure 4 shows the simulated gain of both antennas versus frequency. The 1-dB bandwidth of the nonuniform antenna is about 420 MHz and that of conventional antenna is about 550 MHz.

Figure 5 illustrates the magnitude of electric field distribution along the length of the first slot for 1.0-W input power. The other slots have very similar distribution, too. One sees that the magnitude of electric field distributions on the slots is nearly sinusoidal. The peaks of electric field of slots are tabulated in Table IV for both nonuniform and uniform antennas. It is seen that the variation of maximum electric field of nonuniform antenna is much more than that of uniform one.

The optimized nonuniform antenna was fabricated using a typical milling machine on an aluminum profile. Figure 6 shows the fabricated antenna containing its nonuniform walls and its slotted broad wall attached on a cupper ground with dimensions 25 × 10 cm^2 ($8.33\lambda \times 3.33\lambda$). One sees that the slots are collinear but two nonuniform walls are approaching the slots alternately. The fabricated antenna was tested for validation. Figure 7 shows the simulated and measured reflection coefficient

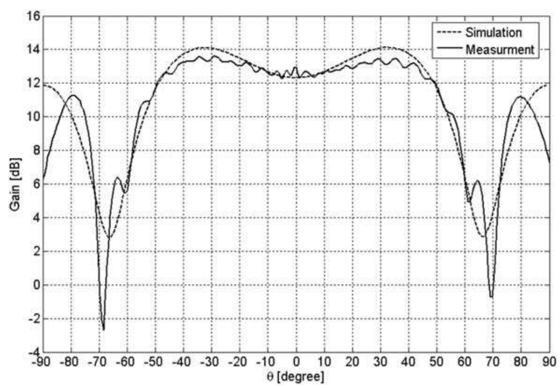

Figure 9 The simulated and measured gain pattern of nonuniform antenna on the surface $\varphi = 90°$.

versus frequency. It is seen that the −10 dB bandwidth of the fabricated antenna is approximately 200 MHz. Figures 8 and 9 compare the measured and simulated values of gain pattern on the surfaces $\varphi = 0°$ (*x-z*) and $\varphi = 90°$ (*y-z*), respectively. As it is seen, there is a good agreement between the results of simulation and measurement. Deep dips at φ=90° and θ=±69° are due to presence of ground and the created images of slots below it. Some disagreements are observed which can be related to construction problems and may be occurred for conventional uniform antennas as well. For example, the shallow dips at boresight (φ=90° and θ=±90°) exist only in measurement which may be due to finite dimensions of the actual ground.

IV. CONCLUSION

A method is presented to reduce the side lobe level of slotted waveguide array antennas in all radiation planes while the gain to be constant. In this method, side walls of a hollow waveguide are made nonuniform. A nonuniform waveguide antenna with five slots is designed at frequency 10 GHz and then fabricated and tested. A significant reduction of side lobe level more than 5 dB is obtained using nonuniform waveguide instead of uniform one.

REFERENCES

1. R.S. Elliott, Antenna theory and design, Prentice-Hall, Upper Saddle River, NJ, 1981.
2. R.C. Johnson, Antenna engineering handbook, 3rd ed., McGraw-Hill, New York, 1993.
3. J.L. Volakis, Antenna engineering handbook, 4th ed., McGraw-Hill, New York, 2007.
4. R.S. Elliott, Antenna handbook, in Y.T. Lo and S.W. Lee, Eds., The design of waveguide-fed slot arrays, Reinhold–Van Nostrand, New York, 1988.
5. L.A. Kurtz and J.S. Yee, Second-order beams of two dimensional slot arrays, IRE Trans Antennas Propag 5 (1957), 356−362.
6. K. Forooraghi and P.S. Kildal, Transverse radiation pattern of a slotted waveguide array radiating between finite height baffles in terms of a spectrum of two-dimensional solutions, IEE Proc H Microwave Antennas Propag 140 (1993), 52–58.
7. H.S. Jones and W.G. Heinard, An improved slot array using post excitation, Microwave J 8 (1965), 69–72.
8. R.E Clapp, Probe-fed slots as radiating elements in linear arrays, MIT Radiation Laboratory Series Report No. 455, 1944.
9. D.G. Dudley, An iris-excited slot radiator in the narrow wail of a rectangular waveguide, IRE Trans Antennas Propag 9 (1961), 361–364.
10. J. Green, H. Shnitkin, and P.J. Bertalan, Asymmetric ridge waveguide radiating element for a scanned planar array, IEEE Trans Antenna Propag 38 (1990), 1161–1165.
11. H. Shnitkin and J. Green, Asymmetric ridge waveguide collinear slot array antenna, U.S. Patent 4638323, 1987.
12. J. Joubert and D.A. McNamara, Analysis of radiating slots in a rectangular waveguide in homogeneously loaded with a dielectric slab, IEEE Trans Antennas Propag 41 (1993), 1212–1221.

13. M. Moradian, M. Khalaj-Amirhosseini, and M. Tayarani, Application of wiggly ridge waveguide for design of linear array antennas of centered longitudinal shunt slot, Int J RF Microwave Comput Aided Eng 19 (2009), 717–726.
14. M. Moradian, M. Khalaj-Amirhosseini, and M. Tayarani, Design of planar slotted array antenna fed by single ridge waveguide, Int J RF Microwave Comput Aided Eng 20 (2010), 593–602.
15. M. Moradian, M. Tayarani, and M. Khalaj-Amirhosseini, Planar slotted array antenna fed by single wiggly-ridge waveguide, IEEE Antennas Wireless Propag Lett 10 (2011), 764–767.

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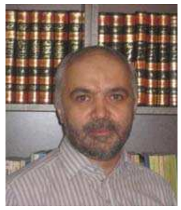
Mohammad khazai was born in Hamedan, Iran. He received the Bachelor of Electrical Engineering degree from the University of Kurdistan in 2011, and the M.Sc. degree in Field of Communication Engineering from Iran University of Science and Technology at Tehran in 2015. His research interests include antennas, scattering, and passive microwave components.



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