Simple Design Method for Dielectric-Filled Low-Sidelobe Slotted Waveguide Antennas

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Abstract— A simple method for the design of dielectric-filled slotted waveguide antennas (SWAs) with sidelobes below a prescribed level is presented. The existing methods mostly deal with vacuum or air-filled SWAs and resort to numerical techniques or to already available design graphs to deduce the different lengths and positions of the slots. This presented method is based on slots with identical dimensions and uses closed-form equations to compute the uniform length of the slots, their distances from the waveguide's ends, and their offsets from the center line of the waveguide's broad face. The offsets are first computed for a larger air-filled SWA and then scaled for the SWA under design. Examples are given to show the proper operation of the presented design method.

Slotted Waveguide Antennas (SWAs) have been ideal solutions for applications such as radar, communications, and navigation. They benefit from a simple design, since their radiating elements (the slots) are an integral part of the feed system (the wavegude itself), and have the advantages of relatively low weight and small volume, high power handling, high efficiency, and good reflection coefficient [1]. The design of resonant vacuum or air-filled rectangular SWAs is usually based on the use of the graphs produced in 1951 by Stegen for X-band SWAs [2], or on numerical techniques, such as the Method of Moments (MoM). The design goal is to find the slots lengths and offsets to obtain a desired radiation pattern. The design procedure by Elliott [3] computes these slots lengths and offsets after setting the following guidelines: 1) the waveguide is short-circuited at a distance of a quarter-guide wavelength ($\lambda_g/4$) from the center of the last slot, and the inter-slot distance is $\lambda_g/2$.

An advantage of filling a waveguide with a dielectric material is the lowering of its cut-off frequency thus enabling it to operate at a smaller frequency. The cut-off frequency of a dielectric-filled waveguide having a large internal dimension a is given for the TE_{10} mode by:

$$f_{c(10)} = \frac{c}{2a\sqrt{\epsilon_r}}, \tag{1}$$

where c is the speed of light in vacuum, and ϵ_r is the dielectric constant of the material filling the waveguide. The guide wavelength inside a dielectric-filled waveguide is given by:

$$\lambda_g = \frac{1}{\sqrt{\frac{\epsilon_r}{\lambda_0^2} - \frac{1}{4\times a^2}}}, \tag{2}$$

where λ_0 is the free-space wavelength at the frequency of propagation.

Given a dielectric-filled SWA with N slots, where the SWA is shorted at one end and fed at the other end, the center of the first slot is at $n_1\lambda_g/2$ from the feed, and the center of the last slot is at $n_2\lambda_g/4$ from the shorted end, where n_1 and n_2 are integers ≥ 1, and n_2 is odd. The distance between consecutive slots is $\lambda_g/2$ center to center. λ_g is as given in Eq. 2. These are equivalent to the guidelines in Elliott's procedure. The uniform length of the slots is given by:

$$L = 0.98 \times \frac{\lambda_0}{\sqrt{2(\epsilon_r + 1)}}. \tag{3}$$

To find the offsets of the slots, they first have to be computed for a virtual vacuum or air-filled SWA, which can support the same operation frequency, using the method detailed in [4]. Denoting the offset of the n^{th} slot of the virtual SWA by d_{vn}, the offset of the corresponding slot in the dielectric-filled SWA under design will be equal to

$$d_n = d_{vn} \times \frac{a}{a_v}, \tag{4}$$

where a_v is the larger inner dimension of the waveguide making the virtual SWA. The virtual SWA should be designed for the same number of slots, and same desired sidelobe level ratio and distribution as the dielectric-filled SWA.

As an example, consider the design of an SWA with 10 rectangular slots based on a WR-284 waveguide filled with a dielectric material having $\epsilon_r = 2.2$. The SWA is to be operated at 2.45 GHz. The virtual SWA uses a vacuum or air-filled WR-340 waveguide, since an air-filled WR-284 is not operable at 2.45 GHz. Hence, $a = 2.84''$ and $a_v = 3.4''$. λ_g is computed from Eq. 2 for the dielectric-filled SWA. The 1^{st} slot is positioned at $\lambda_g/2$ from the feed, and the 10^{th} slot at $3\lambda_g/4$ from the shorted waveguide end. From Eq. 3, the length of each slot is 47.4 mm. The width of each slots is taken as 5 mm. For a sidelobe level ratio $\leq -20dB$, a 35-dB Chebyshev distribution is applied, as explained in [4], to obtain the d_{vn}'s of the virtual WR-340-based SWA. The d_{vn}'s and the corresponding d_n's, computed from Eq. 4, are given in Table 1.

n	1	2	3	4	5	6	7	8	9	10
d_{vn} (mm)	6.22	-9.11	12.10	-14.51	15.88	-15.88	14.51	-12.10	9.11	-6.22
d_n (mm)	5.19	-7.61	10.11	-12.12	13.26	-13.26	12.12	-10.11	7.61	-5.19

Table 1: Offsets of the slots in the virtual air-filled SWA and dielectric-filled SWA

For the resulting SWA, the reflection coefficient and the H-plane gain pattern are plotted in Fig. 1. The plots show the soundness of the presented method. Compared to the uniform-offset case, the designed antenna also operates at 2.45 GHz and has very low sidelobes (more than 20 dB below the level of the main lobe). The back lobe is also lower in magnitude.

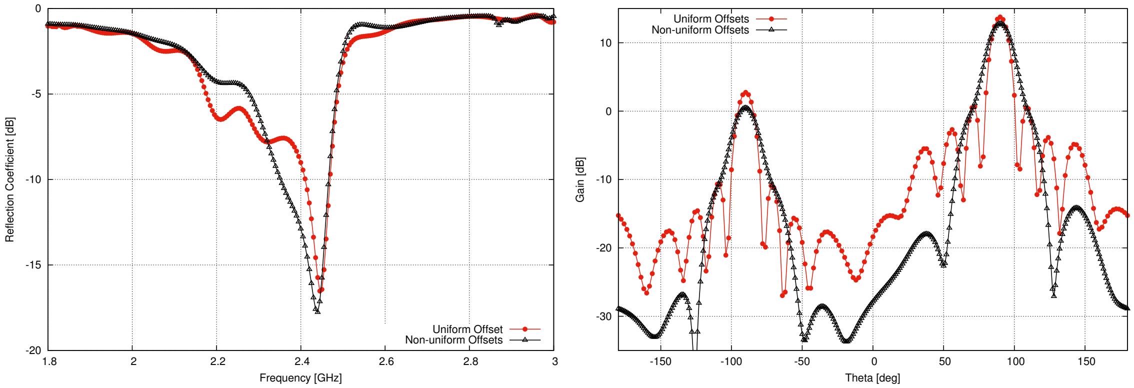

Figure 1: (Left) S_{11} plots and (right) H-plane gain patterns of the uniform- and nonuniform-offset cases

ACKNOWLEDGMENT

This work is partially supported by an Associated Research Unit (ARU) fund from the Lebanese National Council for Scientific Research.

REFERENCES

1. Mailloux, R. J., *Phased Array Antenna Handbook*, Artech House, 2005.
2. Stegen, R. J., "Longitudinal Shunt Slot Characteristics," Hughes Technical Memorandum No. 261, Culver City, CA, November 1951.
3. Elliott, R. S. and W. R. O'Loughlin, "The Design of Slot Arrays Including Internal Mutual Coupling," *IEEE Trans. Antennas Propagat.*, Vol. 34, 1149–1154, September 1986.
4. El Misilmani, H. M., M. Al-Husseini, and K. Y. Kabalan, "Design of Slotted Waveguide Antennas with Low Sidelobes for High Power Microwave Applications," *Progress In Electromagnetics Research C*, Vol. 56, 15–28, 2015.