Design of Millimeter Wave Waveguide-Fed Omnidirectional Slotted Array Antenna

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***Abstract*-In this paper the design of a linear array of slots is presented at 38 GHz. The array is fabricated with a total number of 24 slots, 12 on each broad side wall of a WR22 rectangular waveguide, to form an omnidirectional radiation pattern. The offsets of the individual slots are calculated for two cases: when all slots are uniformly excited and when Dolph-Chebyshev synthesis method is used to achieve a radiation pattern with low sidelobe level.**

I. INTRODUCTION

Millimeter wave technology occupies the frequency spectrum from 30 GHz to 300 GHz with wavelength between one and ten millimeters. This technology has attracted a great deal of interest due to its unique features. The millimeter wave frequencies were primarily used in military applications and radio astronomy [1]-[3]. Now, this part of the spectrum is used in a wider range of applications such as medical imaging, collision avoidance radars, inter-vehicle communication, indoor cellular systems, personal area network, high-definition video streaming, point-to-multipoint communication links, multi-gigabit file transmission, surveillance systems and security [4]-[5].

Antennas occupy an important place in millimeter wave systems. Different types of planar, horn, dielectric and lens antennas are used in single antenna and array configurations to achieve the desired features such as gain, beamwidth and sidelobe level at millimeter wave frequencies [10].

Slotted array are popular antennas because of their simple geometry, mechanical strength, high efficiency, high gain and polarization purity. They are used in radar systems, communications and navigation applications. These antennas can provide excellent pattern control at millimetre wave frequencies. In [11], the design and development of a series fed 1 x 12 resonant slotted array antenna is presented. The slot dimensions, their spacing and positions are calculated for broadside radiation pattern.

In this paper, the design of a linear array of slots is presented at 38 GHz. Since an array of slots in one side of a waveguide does not radiate uniformly on both sides, two identical rows of 12 slots are fabricated on the broad side walls of a WR22 waveguide to form an omnidirectional radiation pattern. The offsets of the individual slots are calculated for two cases: when all slots are uniformly excited and when Dolph-Chebyshev synthesis method is used to achieve a radiation pattern with low sidelobe level.

II. THEORY

A waveguide-fed slotted array is usually fabricated by milling a set of rectangular shaped slots in a common wall of a rectangular waveguide. One advantage of a waveguide slotted array is that the radiating aperture and the feed network can be made from waveguides [12]. This makes the design easier since matching networks are not required. The transverse dimensions of the waveguide are chosen so that only the TE_{10} mode can propagate.

The modal fields within a waveguide must necessarily be known to understand how to properly place the slots. Figure 1 shows a longitudinal slot displaced from the center line of an air-filled rectangular waveguide. This slot interrupts x-directed current. The modal fields analysis shows that more displacement causes greater radiation into outer space. The lengths and offsets of the slots must be chosen so that the desired electric field intensity in amplitude and phase is achived in each slot. This will insure the specific radiation pattern. A linear array consists of N slots is shown in Fig. 2. The slots are made by spacing their centers at electrical half wavelength intervals along the waveguide, where the successive slots are placed in the opposite sides of the centerline of the waveguide. The center of the last slot is located at a quarter-wavelength from the closed end of the waveguide. The electrical wavelength in the waveguide, λ_g, is obtained by:

$$\lambda_g = \left[\left(\frac{1}{\lambda_0} \right)^2 - \left(\frac{1}{\lambda_c} \right)^2 \right]^{-\frac{1}{2}} \tag{1}$$

where λ_0 is the wavelength in free space and λ_c is the cutoff wavelength. In the linear array of Fig. 2, the following formulas are used to calculate the slots length and displacement [12]:

$$\frac{Y_n^a}{G_0} = K_1 f_n \sin kl_n \frac{V_n^s}{V_n} \tag{2}$$

$$\frac{Y_n^a}{G_0} = \frac{K_2 f_n^2}{Z_n^a} \tag{3}$$

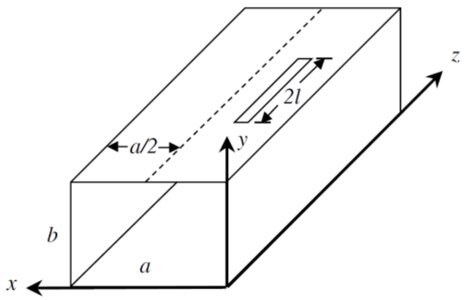


Figure 1. A longitudinal slot displaced from the center line of a rectangular waveguide.

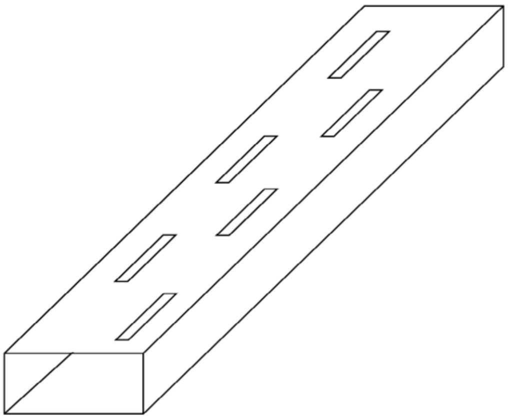


Figure 2. A linear array consists of *N* slots.

where V_n , V_n^s , Y_n^a and l_n are the mode voltage, peak slot voltage, active admittance and length of the n th slot, respectively, G_0 is the characteristic admitance of the equivalent transmission line and k is the propagation constant of the air. Also,

$$K_1 = -j\left[\frac{8}{\pi^2\eta G_0}\frac{(a/b)}{(\beta/k)}\right]^{\frac{1}{2}} \tag{4}$$

$$K_2 = \frac{292(a/b)}{0.61\pi(\beta/k)} \tag{5}$$

and

$$f_n = \frac{\cos\beta l_n - \cos k l_n}{\sin k l_n}\sin\frac{\pi x_n}{a} \tag{6}$$

$$Z_n^a = Z_{nn} + Z_n^b \tag{7}$$

in which

$$Z_n^b = \sum_{m=1}^{N}\frac{V_m^s \sin k l_m}{V_n^s \sin k l_n} Z_{nm} \quad \text{for } m \neq n \tag{8}$$

$$Z_{nn} = \frac{K_2 f_n^2}{Y_n/G_0} \tag{9}$$

where β is the propagation constant in the waveguide, Z_n^a , Z_{nn} and Z_n^b are the active impedance, self-impedance and mutual impedance of the n th equivalent loaded dipole, respectively, Y_n is the isolated self-admittance of the n th slot and Z_{nm} (with $m \neq n$) is the mutual impedance between the n th and m th equivalent dipoles.

The linear array of N slots, shown in Fig. 2, does not radiate uniformly on both sides. In order to have an omnidirectional radiation pattern, identical row of N slots must be fabricated on the opposite broad side wall of the waveguide. The total number of slots, $2N$, is selected to satisfy desired gain and beamwidth.

III. NUMERICAL SIMULATIONS AND RESULTS

Based on the theory presented in the previous section, the design of an omnidirectional array is presented at 38 GHz. The length of each slot is set to $\lambda_0/2$. The array is fabricated on a WR22 waveguide. A total number of 24 slots, 12 on each broad side wall, are positioned on the waveguide to form an omnidirectional radiation pattern. Two cases are considered to calculate offsets of the individual slots. In the first case, all slots are uniformly excited. In the second case, Dolph-Chebyshev synthesis method is used to achieve a radiation pattern with low sidelobe level. In the first case, all slots have an offset equal to 0.5 mm. In the second case, the resulted slot offsets are:

$$x_1 = x_{12} = x_{13} = x_{24} = 0.2976 \text{ mm}$$

$$x_2 = x_{11} = x_{14} = x_{23} = 0.3222 \text{ mm}$$

$$x_3 = x_{10} = x_{15} = x_{22} = 0.4515 \text{ mm}$$

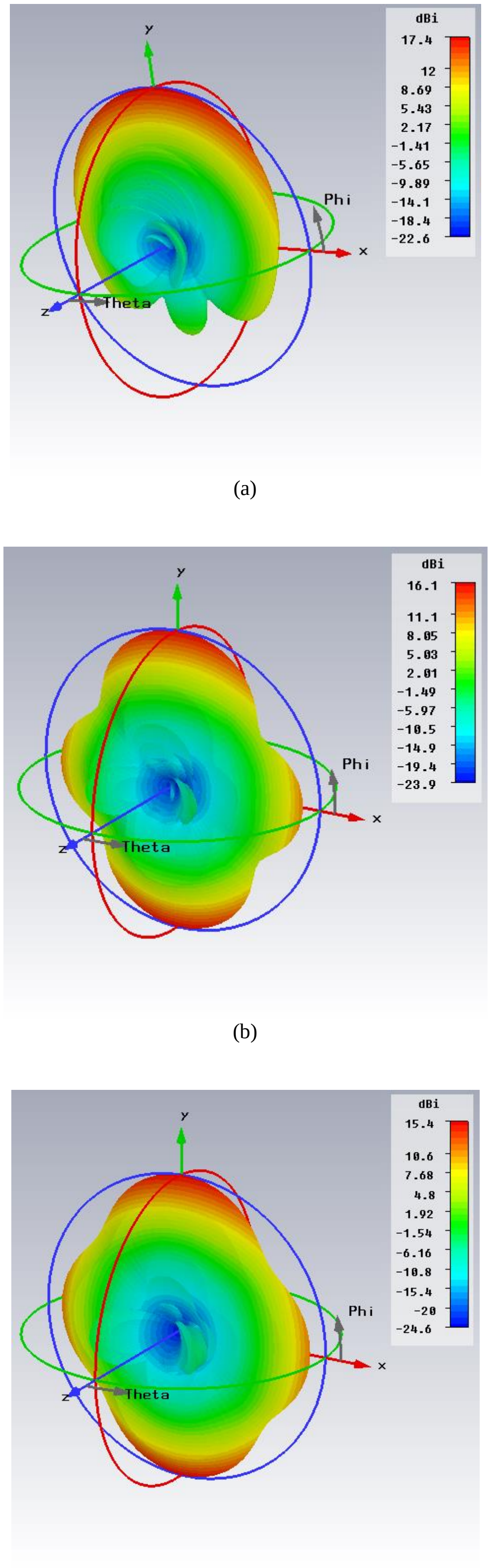
$$x_4 = x_9 = x_{16} = x_{21} = 0.5725 \text{ mm}$$

$$x_5 = x_8 = x_{17} = x_{20} = 0.6676 \text{ mm}$$

$$x_6 = x_7 = x_{18} = x_{19} = 0.7201 \text{ mm}$$

In Fig. 3, we present the three-dimensional radiation pattern of the arrays to compare the omnidirectional radiation property of the 24-slot arrays with the case that only 12 slots are placed on one broad side wall of the waveguide. Furthermore, the azimuth radiation patterns of these arrays are shown in Fig. 4. The azimuth radiation pattern of the 12-slot array shows that this array does not uniformly radiate on both sides of the waveguide. However, both 24-slot arrays provide pretty omnidirectional radiation patterns. Also, Dolph-Chebyshev excitation leads to smaller gain variations over the full 360° azimuth.

The elevation radiation patterns of the 24-slot arrays are shown in Fig. 5. It can be seen that Dolph-Chebyshev synthesis method results in a 5 dB better sidelobe level than the uniform excitation. Figure 6 shows the VSWR of these arrays.



(a)

(b)

(c)

Figure 3. Three-dimensional radiation pattern of the arrays. (a) 12-slot array, (b) 24-slot array with uniform excitation, (c) 24-slot array with Dolph-Chebyshev excitation.

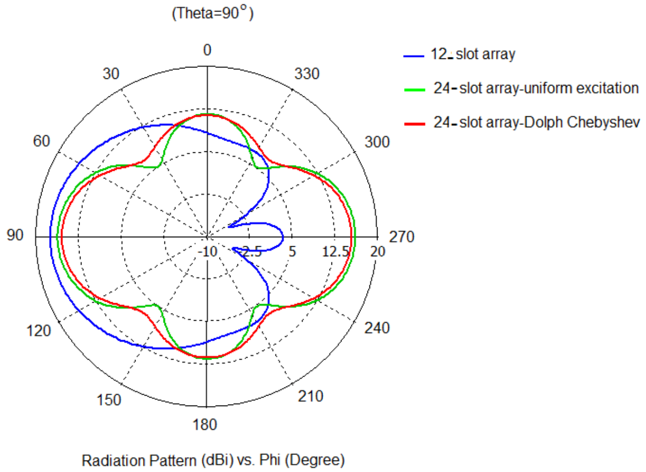


Figure 4. Azimuth radiation patterns of the arrays.

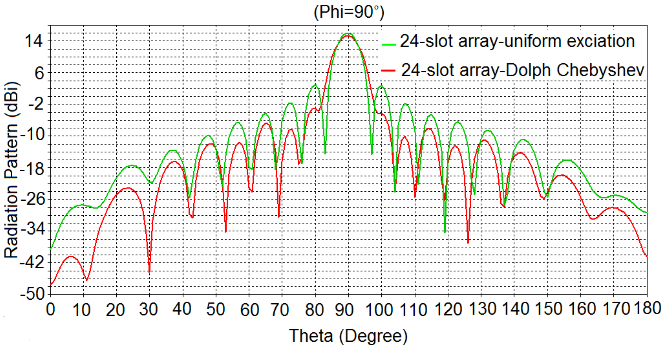


Figure 5. Azimuth radiation patterns of the 24-slot arrays.

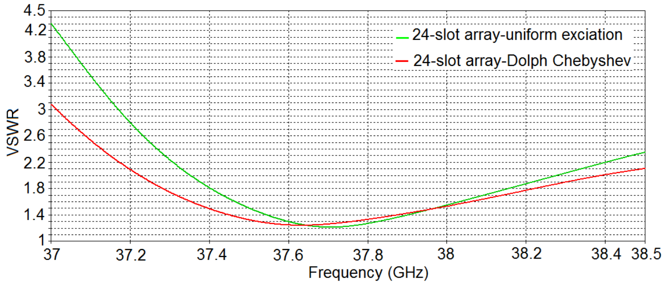


Figure 6. VSWR of the 24-slot arrays.

IV. CONCLUSIONS

A 24-slot waveguide-fed omnidirectional array antenna has been designed at 38 GHz. Two different sets of slot offsets have been calculated for uniform and Dolph-Chebyshev excitations. The last set leads to a radiation pattern with a 5 dB better sidelobe level. It also results in smaller gain variations over the full 360° azimuth.

REFERENCES

[1] C. W. Tolbert, A. W. and C. O. Britt, "Phantom radar targets at millimeter radio wavelengths," *IRE Transactions on antennas and Propagation,* vol. 6, no. 4, pp. 380 – 384, 1958.

[2] J. W. Meyer, "Radar astronomy at millimeter and submillimeter wavelengths," *Proceedings of the IEEE,* vol. 54, no. 4, pp. 484–492, 1966.

[3] F. B. and E. K. Reedy, "Millimeter RADAR at Georgia Tech," in Proc. *S-MTT International Microwave Symposium Digest,* pp. 152, June 1974.

[4] S. S. Ahmed, A. Schiessl, F. Gumbmann, M. Tiebout, S. Methfessel, L. Schmidt, "Advanced Microwave Imaging," *IEEE Microwave Magazine,* vol. 13, no. 6, pp. 26–43, 2012.

[5] S. Futatsumori, A. Kohmura, N. Yonemoto, K. Kobayashi, Y. Okuno, "Small transmitting power and high sensitivity 76GHz millimeter-wave radar for obstacle detection and collision avoidance of civil helicopters," in Proc. *9th European Radar Conference,* pp. 178–181, Oct. 31-Nov. 2, 2012.

[6] D. Gunton, "Millimeter Wave Technology in ITS," in Proc. *6th International Conference on ITS Telecommunications,* June 2006.

[7] H. Ogawa, "Millimeter-wave wireless personal area network systems," in Proc. *IEEE Radio Frequency Integrated Circuits Symposium,* June 2006.

[8] R. Appleby and R. N. Anderton, "Millimeter-Wave and Submillimeter-Wave Imaging for Security and Surveillance," *Proceedings of the IEEE,* vol. 95, no. 8, pp. 1683–1690, 2007.

[9] D. Lockie, D. Peck, "High-data-rate millimeter-wave radios," *IEEE Microwave Magazine*, vol. 10, no. 5, pp. 75–83, 2009.

[10] K. C. Huang and D. J. Edwards, *Millimetre Wave Antennas for Gigabit Wireless Communications,* John Wiley and Sons, 2008.

[11] R. Kumar, P. K. Verma and M. Singh, "Design and Development of a 1 x 12 Series Fed Linear Slotted Array Antenna at 38 GHz," in Proc. *Applied Electromagnetics Conference*, pp. 1–3, Sep. 2009.

[12] R. S. Elliott, *Antenna Theory and Design*, John Wiley and Sons, 2003.