Pattern Synthesis of a Waveguide Slot Array Antenna for a Fixed Wireless Access System

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1. Introduction

Rather than reflector antennas, the development of waveguide slot antennas [1], which have advantages of low profile and low transmission loss, are also undergoing for their application in high gain (39dB ~) and high frequency (26GHz ~) Fixed Wireless Access (FWA) systems. The radiation pattern envelope (RPE) generally with suppressed sidelobes is an important design parameter when introducing the antennas into a practical communication or radar system. For example, the European Telecommunications Standards Institute (ETSI) [2] and Japan Ministry of Internal Affairs and Communications [3] have determined the specifications of wireless system in certain frequency band. In this paper, the synthesis of radiation pattern for a 32×64-element waveguide slot array is studied based on the Woodward-Lawson method [4]. Moreover, the Modified Edge Representation (MER) method [5][6] is also introduced when investigating the effects of a finite ground plane on the radiation especially in the back side of antennas.

2. Pattern Synthesis Method

2.1 2D Array model

Figure 1 shows the two dimensional model of a 32 × 64-element waveguide slot array. Here, 32 slots are arranged in the H-plane with a figure-eight-shaped pattern for the elements and 64 slots are arranged in the E-plane with a uniform pattern for the elements. Two 32x64 element arrays are separately used for transmission and reception. According to the hollow waveguide adopt as the transmission line, the slot spacing *dx* and *dy* in both the *x* and *y* direction are set to be $0.8\lambda_0$, where λ_0 is the wavelength in free space. Therefore, the aspect ratio of a single transmitting or receiving antenna is about 1/2, and the shape of the two antennas arranged side-by-side is close to a square when operating as a wireless terminal. The offset of the slot away from the waveguide axis in the broad wall is *p*, and the size of a ground plane outside of the slot array is *w* when investigating the effect of the finite ground plane.

2.2 Pattern Synthesis Procedure

The synthesis of radiation pattern is conducted by using the following formula originally given from the Woodward-Lawson method [4]. Total array factor of a discrete linear array ($AF(\theta)$) can be written as follows.

$$AF(\theta) = \sum_{m=-M}^{M} b_m \frac{\sin\left[\frac{N}{2}kd\left(\sin\theta - \sin\theta_m\right)\right]}{N\sin\left[\frac{1}{2}kd\left(\sin\theta - \sin\theta_m\right)\right]}$$

Here, b_m is the excitation coefficient of the array element at the sample point θ_m. N is the number of elements and d is the identical element spacing. k is the wave number in free space at the design frequency. Original Woodward-Lawson method has the most appealing property that the excitation coefficients b_m at the sample points are equal to the value of the desired array factor at the sampler points according to the orthogonality of composing functions. However, one limitation is that the sample points have to be restricted at $\cos\theta_m = (2m \mp 1)\cdot\lambda/(2Nd)$ $m = \pm 1, \pm 2, \ldots$ for even samples and can to be chosen arbitrarily. In this study, this restriction on sample points is lifted and on the contrary an iterative procedure to determine the appropriate b_m is indispensable.

The iterative procedure for the pattern synthesis is illustrated as follows:

Step1. The radiation pattern with uniform excitation in both amplitude and phase is calculated as the initial pattern, and is compared with the desired radiation pattern envelope.

Step2. The angles and levels of sidelobes which exceed the RPE are specified. A pattern with uniform amplitude and a linear phase taper to cancel out the excess values in sidelobe level at the specified direction is added in order from the boresite to the end-fire direction. It is noted that the local maximum direction of the sidelobe will change after adding the patterns together, because the orthogonality in the original Woodward-Lawson method is sacrificed in exchange for arbitrary sampling as mentioned above.

Step3. Step 2 is repeated until the synthesized pattern satisfies the specified radiation pattern envelope.

The visible region for the array with an infinite ground plane is defined as $|kd\sin\theta| \le \pi$. According the sampling theorem, the controllable range θ in pattern synthesis is $-90° \sim 90°$, if the element spacing is no larger than $0.5\lambda_0$,. However, the controllable range θ in the pattern synthesis is only $-38.7° \sim 38.7°$ when the element spacing is $0.8\lambda_0$, which is adopted in this study as a general value in waveguide slot arrays. Therefore, the undesired grating lobes will appear in the invisible region of $|38.7° \sim 90°|$ and can not be controlled directly. The affects of the ground plane size and the slot offset value will be investigated for suppression. The element pattern in the H-plane is also taken into account.

2.3 Modified Edge Representation (MER)

The modified edge representation (MER) method is applied to investigate the diffraction effects due to the finite ground plane of the antennas. The infinitesimal dipole arrays are excited with the coefficients determined above. The effect varying the size of the ground plane is investigated in detail for the sidelobe suppression especially in the back region $|90° \sim 180°|$. Changing the edge shape of the ground plane or installing a choke structure is also known as the effective way to reduce the current flowing into the edge of the ground plane so as to suppress the sidelobe levels in the back side of the antennas.

3. Pattern Synthesis Results

Figures 2 and 3 show the synthesized E-plane and H-plane radiation patterns to satisfy the ETSI specifications of Class 3. Here the element spacing is $0.8\lambda_0$ in common and an infinite ground plane is considered. The H-plane radiating pattern satisfies the specification by including the element pattern of a half-wavelength dipole. E-plane radiation pattern does not satisfy the specification in the region of $|38.7° \sim 90°|$. Figures 4 and 5 show the distribution of excitation coefficients, which is symmetrical in both the principle E- and H-planes. The elements located at the array center are excited most strongly, and the elements at the periphery are weakly excited. The larger taper in amplitude of the excitation coefficient is necessary for smaller element number. Figure 6 shows the radiation patterns especially for $\theta > 60$ degrees with different sizes of the finite ground plane. It is confirmed that the radiation patterns for $\theta < 60$ degrees are not strongly influenced due to the edge diffraction of the finite ground plane. The siderobe levels decreases by applying a larger ground plane for $w<6\lambda_0$ as illustrated in Fig. 7, where the local maximum value at the neighborhood of 90 degrees are plotted. There is an optimum size of the ground plane, which is also a function of the operation frequency and the element spacing. It should be noted that a large ground plane will lead to the degradation of aperture efficiency. Figure 8 shows the radiation pattern with the effects slot offset taken in to account. The siderobe levels decrease at the absence of non-zero slot offset. Figure 9 shows the local maximum value at the neighborhood of 90 degrees as a function the slot offset. There is an optimum offset for suppressing sidelobes. Figure 10 shows the radiation patterns when numerically changing the level electric currents flowing at the edge of the ground plane. The back radiation levels after 90 degrees decreases by decreasing the electric currents artificially. The suppression of edge currents can be realized by reshaping the ground plane or by installing a choke. This subject is remained as a future work. A combination of optimum values of the slot offset and the ground plane size provides us with a suitable radiation pattern to nearly satisfy the specifications as shown in Fig. 11.

4. Conclusion

The pattern synthesis of a 32×64-element waveguide slot array for FWA systems is conducted by applying the modified Woodward-Lawson method with arbitrary sampling points. The H-plane radiation pattern with 32 elements and element pattern satisfies the ETSI specification of Class 3. The E–plane radiation pattern with 64 elements does not satisfy the specification in the region of $|38.7° \sim 90°|$ because the large element spacing of $0.8\lambda_0$ is adopted here. The effects of the slot offset and the finite ground plane size are investigated in suppressing the sidelobe levels in the region of $|38.7° \sim 180°|$. A combination of optimum values of the slot offset and the ground plane size provides us with a suitable radiation pattern to nearly satisfy the specifications.

References

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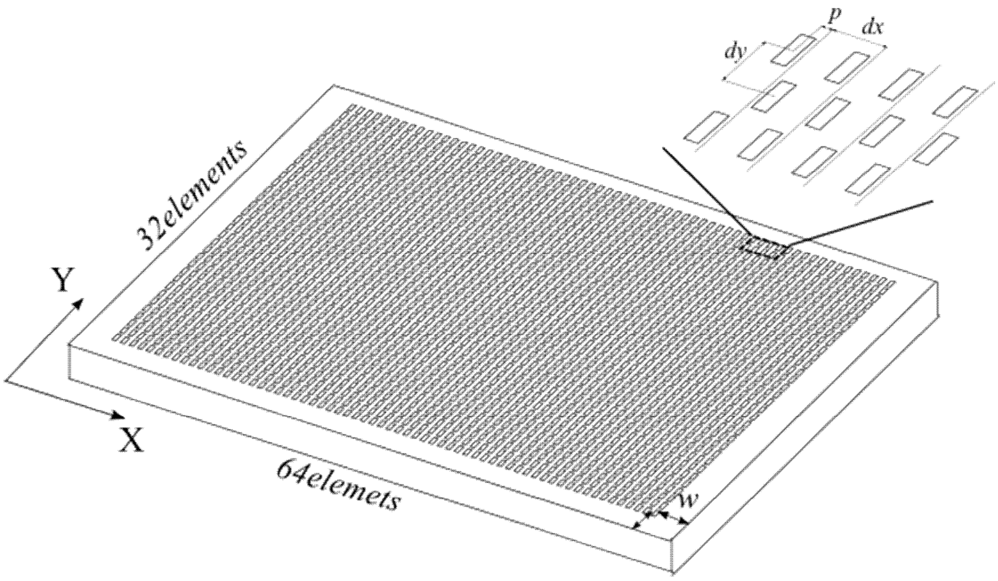

Figure1: Two-dimensional array model(*p*: offset , *w*: ground size, dx and dy :slot spacing)

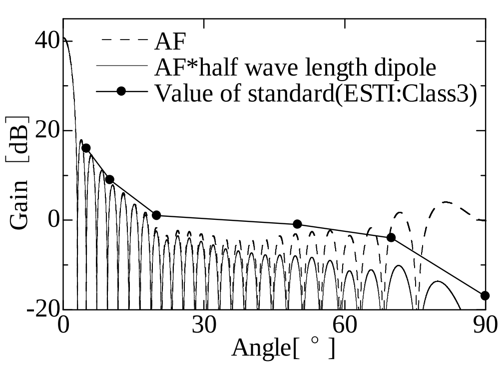

Figure 2: H-plane radiation pattern

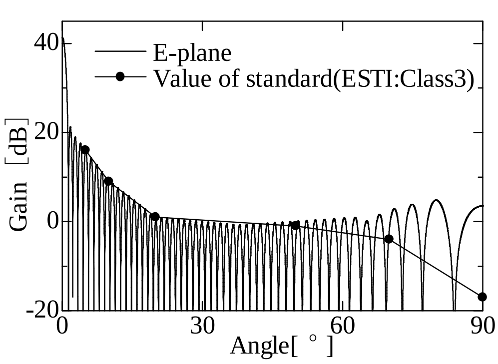

Figure 3: E-plane radiation pattern

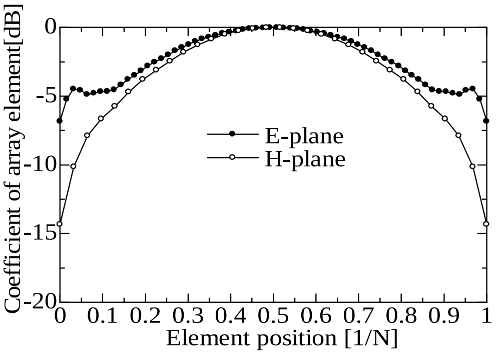

Figure 4: Coefficient of array elements

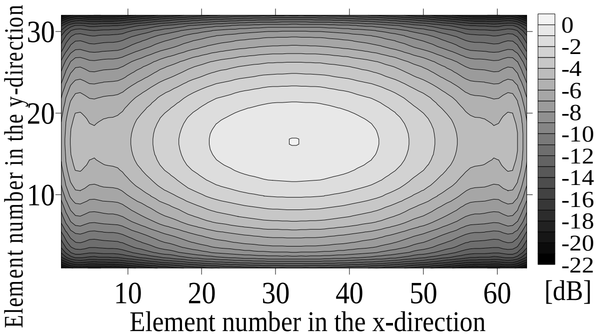

Figure 5: Contour map of excitation coefficients

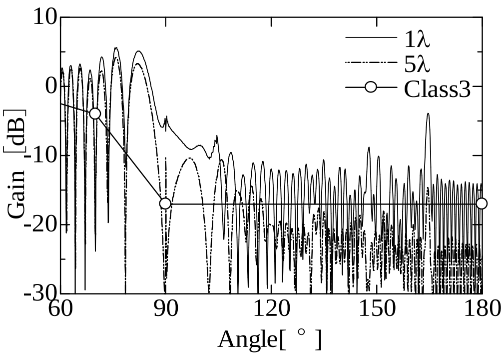

Figure 6: Change of the ground plane size in E-plane radiation pattern

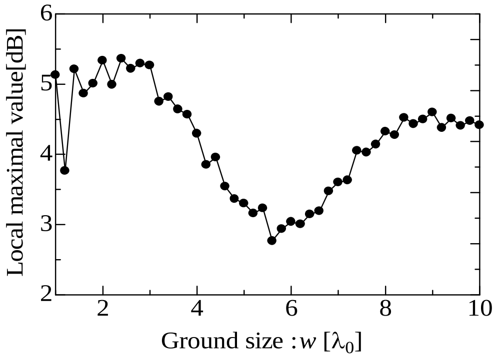

Figure 7: Change of the ground plane size

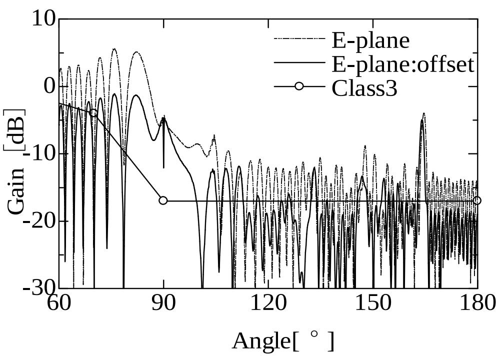

Figure8: Effect of offset on E-plane radiation pattern

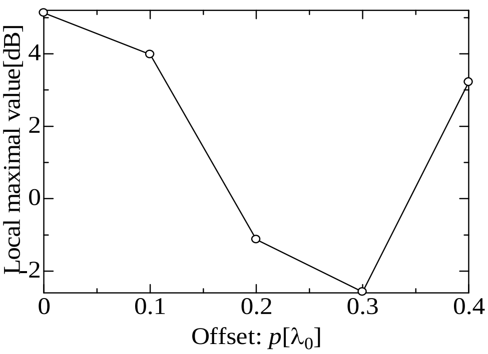

Figure 9: Change of the offset

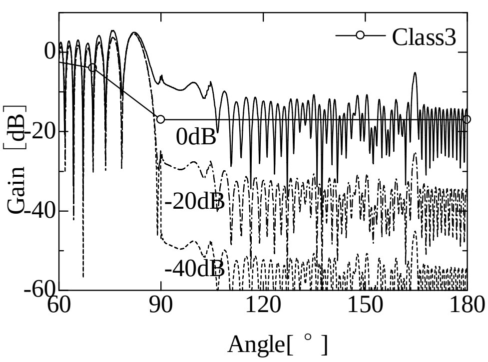

Figure10: Control the electric current of the edge in E-plane radiation pattern

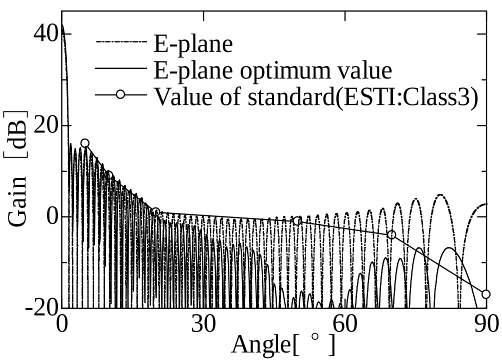

Figure11: Optimal value of the offset and the ground size