Feasibility Study on a Slot Array in the Millimeter-Wave Band Based on a Conformal Waveguide

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***Abstract*—A novel antenna array with over 120 degree coverage in the azimuth plane based on a conformal waveguide is proposed. The 8x8 element array with directivity gain of 15.7dBi at 79GHz is designed and confirmed that the side lobe level by using switching method can be suppressed over 5dB compared to a linear array with 8 branch.**

***Keywords*—slot array; millimeter-wave; conformal; waveguide**

I. Introduction

Millimeter-wave radar technology has proved its ability for automotive application. In [1], traffic surveillance radar systems located at intersection using 79GHz bands is reported. This system as shown in Fig. 1 was required to detect and separate vehicles and pedestrians around intersection concurrently within 40-meter range and 120 degree azimuth field of view. However, the detection area is divided into two sectors due to narrow coverage of a linear array antenna.

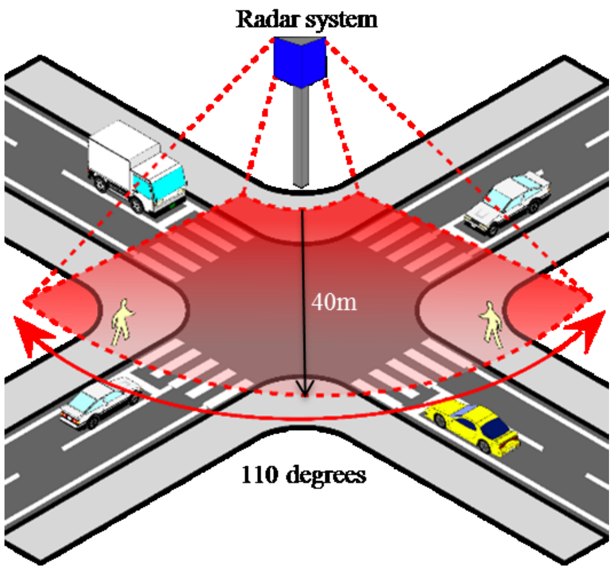


Fig. 1. Use case of a millimeter-wave radar system.

In this paper, a slot array antenna based on a conformal antenna fed by a rectangular coaxial line to realize wide coverage over 120 degrees is proposed. In Section 2, it is confirmed that the angle, which the directivity gain of conformal antenna adopting a switching method with branch separation of 0.65λ is greater than that of a linear array, is 40 degrees. In Section 3, the simulated results of the 8x8-element array band indicate that the directivity gain was 15.7dBi at 79GHz.

II. Basic Study

Figure 2 shows the 2-D model of the conformal array antenna in a horizontal plane. 8-elements of dipole antennas are located on the circumference of radius a at equal intervals in the angular spacing s. In this case, it is assumed that each element only radiate to outward direction of the circle. n-th directivity of an element $g_n(\theta)$ is $\cos^{1.17}(\theta-\theta_n)$ because a beam width of an element in a horizontal plane is assumed as 84 degrees. θ_n is an angle of n-th element as shown in Fig. 2. A directive gain of array antenna is expressed as follow;

$$D(\theta) = \frac{\left|\sum_{n=1}^{N} g_n(\theta) I_n e^{jk\,d_n}\right|^2}{\sum_{n=1}^{N}\sum_{m=1}^{N} r_{nm} I_n I_m^*} \tag{1}$$

$$r_{nm} = \frac{1}{2\pi}\int_0^{2\pi} g_n(\theta) g_m(\theta)\, e^{jkd_{nm}}\, d\theta \tag{2}$$

where, I_n is a complex excitation coefficient, d_n is an optical path difference from the origin point of each element, d_{mn} is an optical path difference between each element and I_n is given as $I_0\, e^{-jkdn}$.

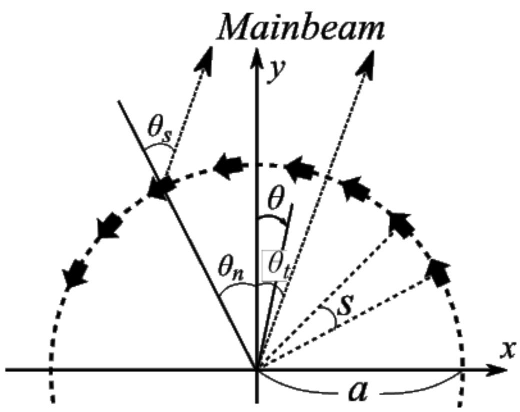


Fig. 2. Analysis model of a conformal array with 8-branch.

The beam tilt angle characteristics of the directive gain of the co-phase exited conformal array and uniform linear array are shown in Fig. 3. The element separations of the linear array *as* are 0.5 and 0.65λ. The radius *a* is set to 1.8 and 2.7λ when *as* is 0.5 and 0.65λ, respectively to realize the directivity gain of conformal array in the front direction is set to be 1dB lower than that of linear array.

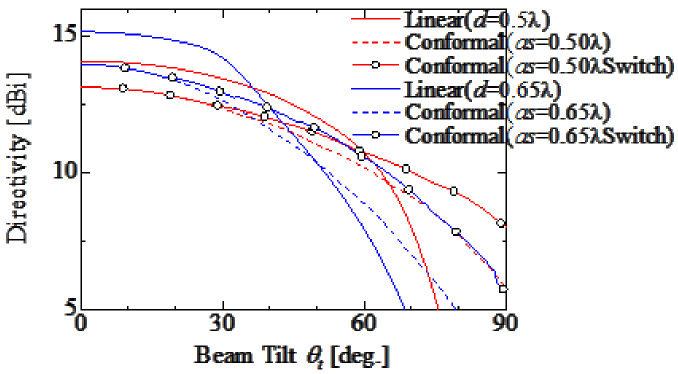


Fig. 3. Characteristics of tilt angle of directivity gain for a conformal array with 8-element compared to those for a linear array.

Increasing *as* is the advantageous in terms of enhancing the directivity gain by reducing number of branches, the effect is greater at high frequencies such as millimeter wave band. As shown in Fig. 3, it is confirmed that the angle θ_c, which the angle where the directivity gain of conformal array is greater than that of linear array, becomes smaller by increasing *as*.

The reason for the reduction of the directivity gain at wider angle for conformal array is that the side lobe level in the opposite direction to the main beam is increased. This side lobe is radiated from the elements apart from the main beam direction. Then, the elements whose angles are larger than switching angle θ_s should be turned off to reduce the side lobe level of the array. θ_s shown in Fig. 3 in the case of 0.5 and 0.65 λ is obtained to minimize the angle θ_c where the directivity gain of conformal array is larger than that of linear array. θ_c is reduced to 60 degrees from 65 degrees when θ_s is 81 degrees in the case of *as* = 0.5λ. Similarly, θ_c is reduced to 40 degrees from 50 degrees when θ_s is 67 degrees in the case of *as* = 0.65 λ.

Figure 4 shows the directivity characteristics of the conformal array and linear array when *as* is 0.65λ and θ_t = 50 degrees. It is observed that the reduction of the side lobe level at the opposite direction from main beam direction for the conformal array. It is confirmed that the further suppression of the side lobe level by using switching method.

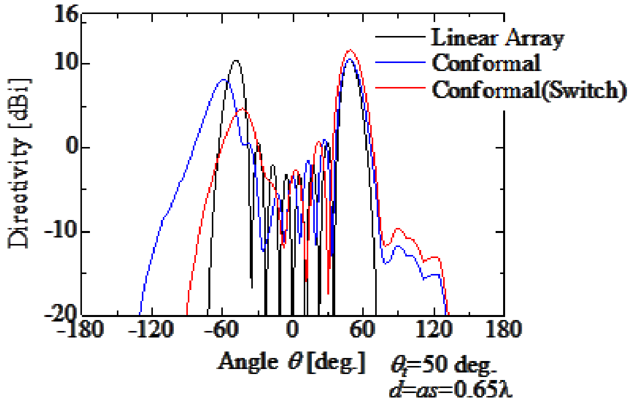


Fig. 4. Directivity characteristics of a conformal array and a linear array with 8-element when *as* is 0.65λ and θ_t = 50degrees.

III. Design of the Radiation Slot

Figure 5 shows the configuration of the conformal array. Slot antennas are excited from rectangular coaxial lines located on a thin resin film such as PET sheet. Each branch is fed by waveguide from printed circuit board. ε_r, tanδ and thickness *t* of a resin film are set to 3.2, 0.002 and 0.1mm, respectively. The width of Broad walls and narrow walls are 1.6 and 0.7mm, respectively. The cut off frequency of TE_{10} mode as higher mode is 88.5 GHz. The loss of transmission line at 79 GHz is 0.045 dB/cm, the leakage from the resin partial at side wall is 0.53dB/cm. The 45-degree linearly-polarized slots are located on the broad wall at the interval of about 1λ in the rectangular coaxial line. The step structure on the internal conductor can improve the reflection characteristics of the conformal array.

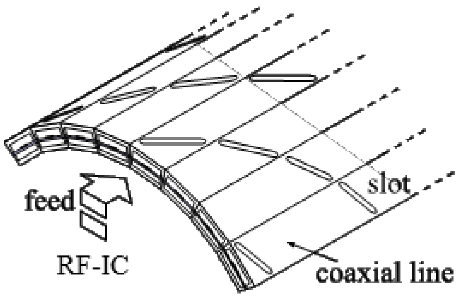
The radiation slot model of the proposed array is shown in Fig. 6. Periodic boundary wall at the side of analytic space in the axis direction is set to take the electro-magnetic coupling effect from adjacent element into account. The center frequency is 79GHz, thickness of outer conductor, width of inner conductor and width of slot are 0.2, 0.5 and 0.5mm, respectively. Thickness of internal conductor is 18μm. First of all, the length of slot l should be determined for mutual coupling. Then, the height and width of the step structure *d* and *w* to realize the same S_{11} characteristic of the single slot antenna. Moreover, offset of the step structure *q* should be determined to suppress the reflection wave. Secondly, the element separation should be fixed. The distance between *n*-th element and *n*+1-th element u_n when elements are radiated in-phase is expressed as following equation;

$$u_n = \lambda_g\left(1 - \frac{\angle S_{31}^{n+1} - \angle S_{21}^{n+1} - \angle S_{31}^{n}}{360}\right) \qquad (3)$$

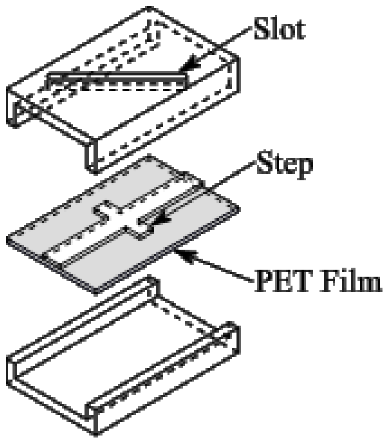
where, $\angle S_{31}{}^{n}$ is the *n*-th radiation phase and $\angle S_{21}{}^{n}$ is the *n*-th tradition phase.

Figure 7 shows the reflection characteristics of each element and 8-element array. The bandwidth of VSWR < 1.5 for 8-elenent array is obtained from 77.7 to 84.1 GHz (8.1%).

Figure 8 shows the radiation pattern in the elevation plane with 8-element array. The direction of the main beam is slightly varied with frequency. The directivity gain at 79GHz is 15.7 dBi.



(a) Antenna array



(b) Rectangular coaxial line

Fig. 5. Configuration of the proposed antenna array.

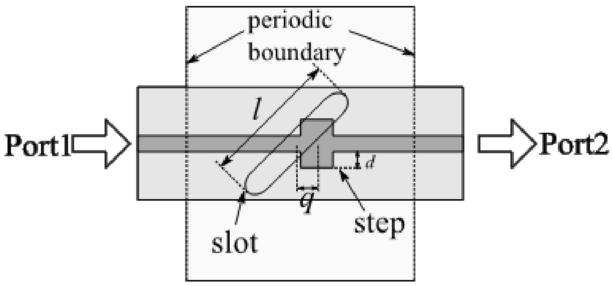


Fig. 6. Simulationon model of a radiation slot for the conformal array.

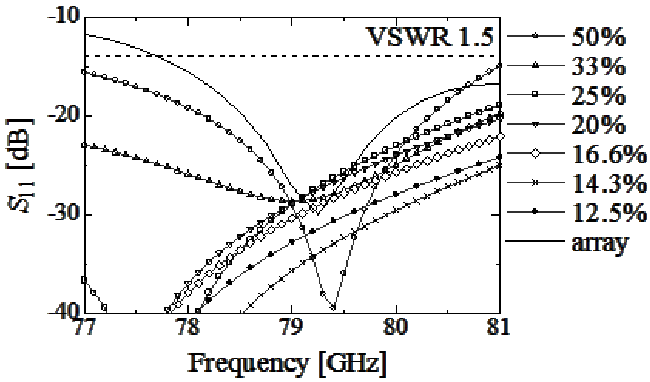


Fig. 7. Reflection characteristics of each element and 8-element array.

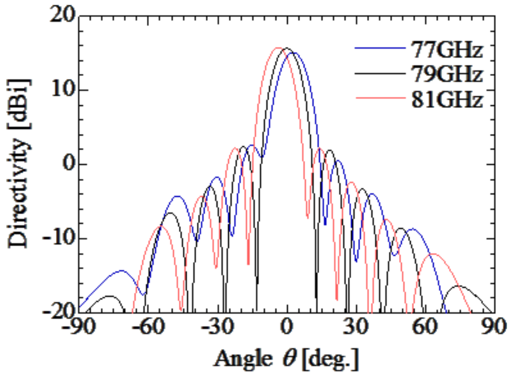


Fig. 8. Radiation patterns of the conformal array with 8x8-element.

IV. Conclution

Feasibility study of the 8x8-element conformal array with over 120 degree coverage in the azimuth plane indicates that the side lobe level by using switching method can be suppressed over 5dB compared to linear array. The directivity gain is 15.7dBi at 79GHz.

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