Special Issue Millimeter-Wave Radar for Automotive Applications

特集

Research Report

Millimeter-Wave Microstrip Array Antenna with High Efficiency for Automotive Radar Systems

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自動車レーダ用高効率ミリ波マイクロストリップアレーアンテナ

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Abstract

We propose the microstrip array antenna with high efficiency for automotive radar systems. The proposed antenna consists of a straight feeding microstrip line and rectangular radiating elements connected directly to the microstrip line at their corners without dividers and impedance transformers in order to realize lower feeding line loss and linear polarization inclined 45 degrees. The radiation coefficient of the rectangular radiating elements is investigated by the finite element method. It is shown that the radiation coefficient is controlled from 1 % to 23 %, which is wide enough to set aimed amplitude distribution of an array antenna. The array antenna having 2 × 37 radiating elements is developed as one subarray of an electrical beam scanning array antenna for automotive radar systems. As a result of experiment, high efficiency of 53 % with high gain of 22.5 dBi is obtained at the design frequency of 76.5 GHz. The efficiency of the developed antenna is higher than that of conventional millimeter-wave microstrip array antennas.

Keywords Automotive radar systems, Millimeter-wave, Linear polarization inclined 45 degrees, Microstrip array antenna, High efficiency

要　旨

自動車レーダ用高効率マイクロストリップアレーアンテナを提案している。提案したアンテナは，直線状のマイクロストリップ線路と方形の放射素子で構成される。給電損失の低減と斜め45度直線偏波を実現するため，方形の放射素子は，分岐やインピーダンス変換器を介さずに，直接，そのコーナー部で直線状のマイクロストリップ線路に接続されている。有限要素法による解析により，放射素子の放射係数制御範囲は1%～23%と広く，アレーアンテナの所望の振幅分布を形成するのに十分な制御範囲であることを示している。自動車レーダ用ビームスキャン型アレーアンテナの1サブアレーとして2×37素子のアレーアンテナを試作，評価した結果，設計周波数76.5GHzで効率53%，利得22.5dBiを達成し，従来のマイクロストリップアンテナにない，高い効率を実現した。

キーワード 自動車レーダシステム，ミリ波，斜め45度直線偏波，マイクロストリップアレーアンテナ，高効率

1. Introduction

Automotive radar systems utilizing the millimeter-wave band have been developed[1, 2] since they can detect targets even in bad weather. In the automotive radar systems, linear polarization inclined 45 degrees is utilized in order to avoid mutual radio interference between them[3]. The antenna for the automotive radar systems is required to have high efficiency, which means high gain against for an aperture area determined by the size of a radar sensor, in order to detect the targets at a long distance. In addition, low profile is required not to spoil the appearance of a car. Ease of manufacturing is also one of the significant factors in order to install the automotive radar systems in popular cars.

As candidate antennas for the automotive radar systems, a slotted waveguide array antenna[4] and a triplate-type array antenna[5] have been studied. These antennas have low profile and high efficiency

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characteristic in the 76 GHz band, but, in general, they have a difficulty in mass production. A lens antenna with advantages of both high efficiency characteristic in the 76 GHz band and ease of manufacturing has also been studied[6], but it is too thick for our aimed radar sensor. A microstrip array antenna is known to have advantages of low profile and ease of manufacturing. However, there is a problem that efficiency of the microstrip array antenna with a large aperture is degraded due to feeding line loss [7]. We have decided to eliminate dividers and impedance transformers used in the feeding lines of the microstrip array antenna in order to solve the problem.

In this paper, we propose a microstrip array antenna with high efficiency for automotive radar systems[8, 9]. In Chapter 2, a configuration of the proposed microstrip array antenna is presented. Design method for the proposed antenna is described in Chapter 3. Performance of the developed antenna is presented in Chapter 4. This paper is concluded in Chapter 5.

2. Configuration of proposed microstrip array antenna

We propose the microstrip array antenna shown in **Fig. 1**. The proposed antenna consists of a straight microstrip line and rectangular radiating elements printed on one side of a dielectric substrate with a ground plane on the other side of it. The rectangular radiating elements inclined 45 degrees from the straight microstrip line (y axis) are arranged on both sides of the microstrip line and are connected directly to the microstrip line at their corners without dividers and impedance transformers in order to realize lower feeding line loss and linear polarization inclined 45 degrees. The radiation coefficient of each rectangular radiating element can be widely controlled by changing the width W of each rectangular radiating element and is determined to satisfy an aimed amplitude distribution of a linear array antenna. The length L of each rectangular radiating element is chosen to be a half resonant wavelength. Element spacing d_y in the y direction is set as approximately a half guide wavelength so that all of the rectangular radiating elements are excited in phase. The microstrip line is terminated by a rectangular matching element to suppress the reflection of the residual power and radiate it at the end of the microstrip line. The antenna is fed by a waveguide (WR-12) through the microstrip line to a waveguide transition[10] at the opposite end of the microstrip line.

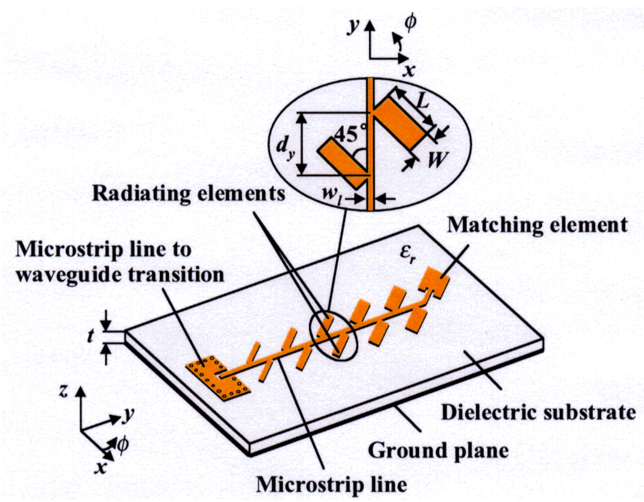

Fig. 1 Configuration of proposed microstrip array antenna.

3. Design method of proposed microstrip array antenna

Controlling widely the radiation coefficient of a radiating element leading to aimed amplitude distribution is required together with lower feeding line loss in order to achieve high efficiency. The radiation coefficient is numerically investigated here. **Figure 2** shows a calculated model of the radiating element and the feeding line. The calculated model consists of a dielectric substrate, the feeding microstrip line, the radiating element inclined 45 degrees from the feeding microstrip line and a ground plane. The calculated dielectric substrate has thickness t = 0.0324 λ_0, relative dielectric constant ε_r = 2.2 and loss tangent tan δ = 0.001. Width w_l of the microstrip line and length L of the radiating element are set to be 0.0765 λ_0 and a half resonant wavelength, respectively. Numerical analysis was carried out by the finite element method.

The electric field intensity distribution of the radiating element in xy plane is shown in **Fig. 3**.

Dimensions of the radiating element are set to be average values of the developed antenna such as L = 0.321 λ_0 and W = 0.11 λ_0. It is observed from Fig. 3 that the radiating element is resonated with a half wavelength along the length L.

The radiation coefficient varied with width W of the radiating element normalized by a wavelength λ_0 = 3.92mm is shown in **Fig. 4**. The calculated result is represented by a solid line. The radiation coefficient is defined as the ratio of the radiation power, which is the power substituting both the transmission power and the reflection power from the input power, to the input power. In order to evaluate the radiation coefficient itself, loss of the straight feeding line is eliminated from the transmission power of the calculated model. Figure 4 clarifies that the radiation coefficient is controlled by changing the width W of the radiating element and that wide control of the radiation coefficient from 1 % to 23 % is achieved with variation of the width W from 0.013 λ_0 to 0.255 λ_0, which is wide enough to realize aimed Taylor amplitude distribution.

4. Performance of developed antenna

The performance of the developed antenna is presented.

Figure 5 shows a photograph of the developed antenna, which corresponds to one subarray of an electrically beam scanning array antenna for

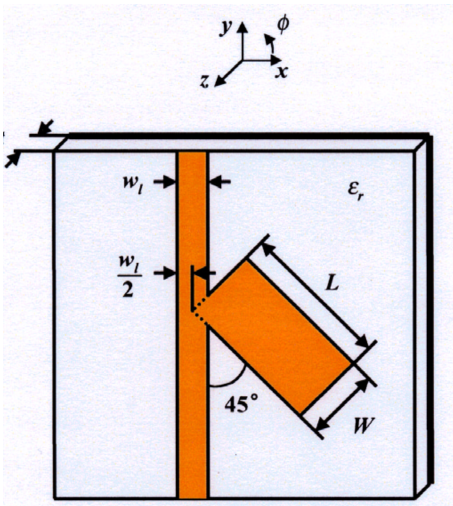

Fig. 2 Calculated model of radiating element and feeding line for calculation of radiation coefficient.

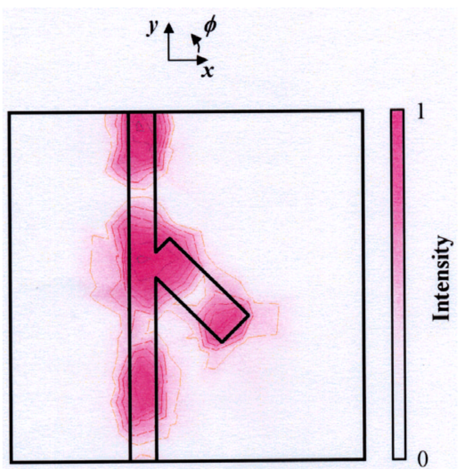

Fig. 3 Electric field intensity distribution of radiating element and feeding line in xy plane.

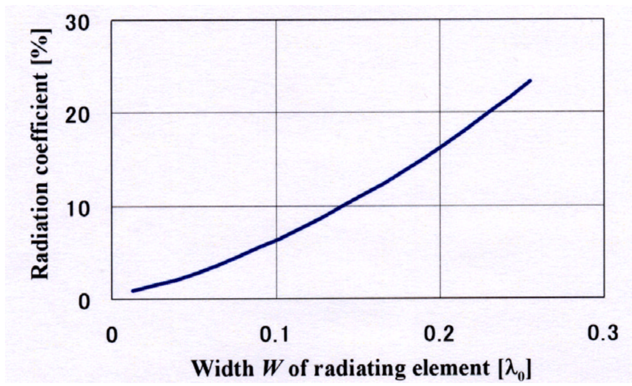

Fig. 4 Radiation coefficient versus width W of radiating element normalized by a wavelength λ_0 = 3.92mm.

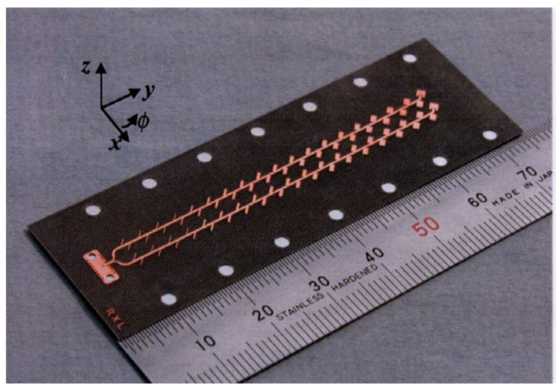

Fig. 5 Photograph of developed antenna having 2 × 37 radiating elements as one subarray of electrically beam scanning array antenna.

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automotive radar systems. Assuming that the dimensions of the array antenna including feeding circuits and the microstrip line to waveguide transition are approximately 2 $\lambda_0 \times 16 \lambda_0$, the array antenna is composed of 2 linear arrays having 37 radiating elements.

The measured reflection coefficient of the developed antenna at the input port is shown in **Fig. 6.** Since there are no impedance transformers in the proposed antenna, reflection is suppressed by tilting the main beam. Reflection is –18.7 dB at 76.5 GHz, which is small enough to ignore the gain reduction. Bandwidth of reflection below –10 dB is 2.98 GHz and sufficient for automotive radar systems allowing for margin of errors in manufacturing.

Figure 7 shows measured gain and efficiency of the developed antenna. The vertical axis represents measured gain and the horizontal axis represents frequency from 74.5 GHz to 78.5 GHz. Peaked gain and efficiency are represented by a solid line and a dotted line, respectively. Efficiency η is defined as the ratio of the measured gain G_m to the aperture gain G_a and written as

$$\eta = \frac{G_m}{G_a} = \frac{G_m}{\frac{4\pi A}{\lambda_0^2}} = \frac{G_m}{\frac{4\pi N_x d_x N_y d_y}{\lambda_0^2}} \quad \cdots\cdots\cdots\cdots (1)$$

where A is the aperture area having radiating elements and expressed with the product of numbers N_x and N_y of radiating elements in the x and y directions and spacing d_x and d_y of radiating elements in the x and y directions, respectively. The aperture area A of the developed antenna is 1.78 $\lambda_0 \times$ 14.91 λ_0.

It can be seen from Fig. 7 that high efficiency of 53 % with high gain of 22.5 dBi is obtained at 76.5 GHz. Efficiency and gain are higher than 53 % and 22.4 dBi, respectively from 75.5 GHz to 77.5 GHz, which are high enough for the frequency band from 76 GHz to 77 GHz utilized for automotive radar systems. Loss of the microstrip line to waveguide transition is not included in the measured gain shown in Fig. 7. When loss of the transition as 0.4 dB is included, efficiency and gain correspond to 49 % and 22.1 dBi, respectively.

Measured radiation patterns in both the zx plane and the yz plane of the developed antenna at 76.5 GHz are shown in **Fig. 8** (a) and (b), respectively. As shown in Fig. 8 (a), the radiation pattern is almost symmetrical in the zx plane. Half power beam width and sidelobe level are 26.3 degrees and –10.7 dB, respectively. In the yz plane as shown in Fig. 8 (b), the half power beam width is 4.0 degrees and sidelobe level is suppressed to less than –15.4 dB. The main beam is tilted to 2.8 degrees in the y direction to suppress the overall reflection at the input port.

The main beam of the developed antenna is tilted about 1.6 degree when frequency varies 1 GHz. Since the frequency band utilized for automotive radar systems is 1 GHz, the main beam shown in Fig. 8 (b) is tilted within ±0.8 degrees. In this case, gain reduction at the direction of 2.8 degrees in the

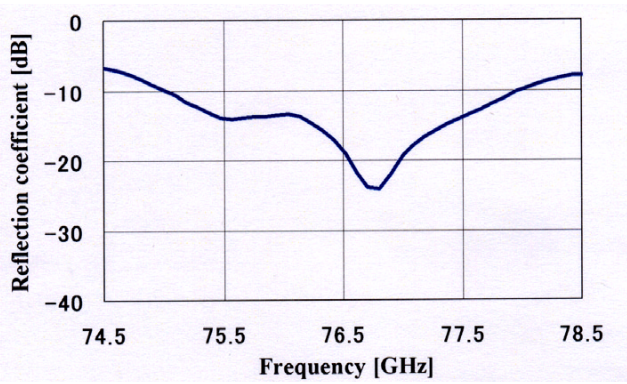

Fig. 6 Measured reflection coefficient of developed antenna.

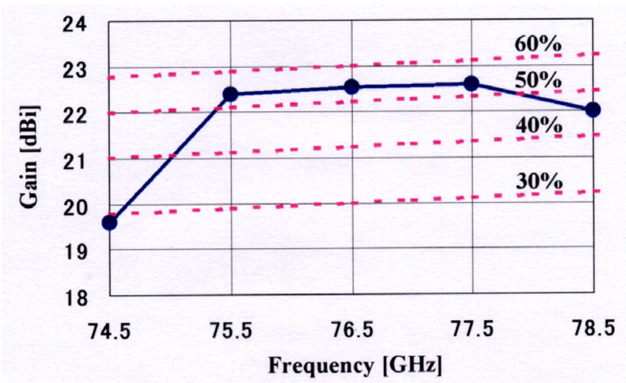

Fig. 7 Measured gain and efficiency of developed antenna represented by a solid line and a dotted line.

yz plane is 0.5 dB.

Loss factors of the developed antenna are analyzed in **Table 1** as a reference that the efficiency η equals 100 %. There are two kinds of loss factors such as the loss factors predicted in design and the loss factor caused by fabrication errors. The loss factors predicted in design include feeding line loss factors and directive gain loss factors.

As for the feeding line loss factors, loss of a straight feeding line of the antenna is estimated to be a small value of 0.9 dB since there are no dividers and impedance transformers in the proposed antenna. Loss of T junction for dividing power to two linear array antennas is calculated as 0.3 dB by the finite element method. As for the directive gain loss factors, the ratio of the directive gain in the case of equal amplitude distribution to the aperture gain is 0.4 dB and the ratio of the directive gain in the case of Taylor amplitude distribution with –17 dB sidelobe level to that in the case of the equal amplitude distribution is 0.1 dB. The loss factor of 1 dB caused by fabrication errors is due to degradation of both amplitude and phase distribution and so on. It can be seen from Table 1 that the efficiency η could be up to 68 % after minimizing the fabrication error since the loss factors predicted in design is 1.7 dB.

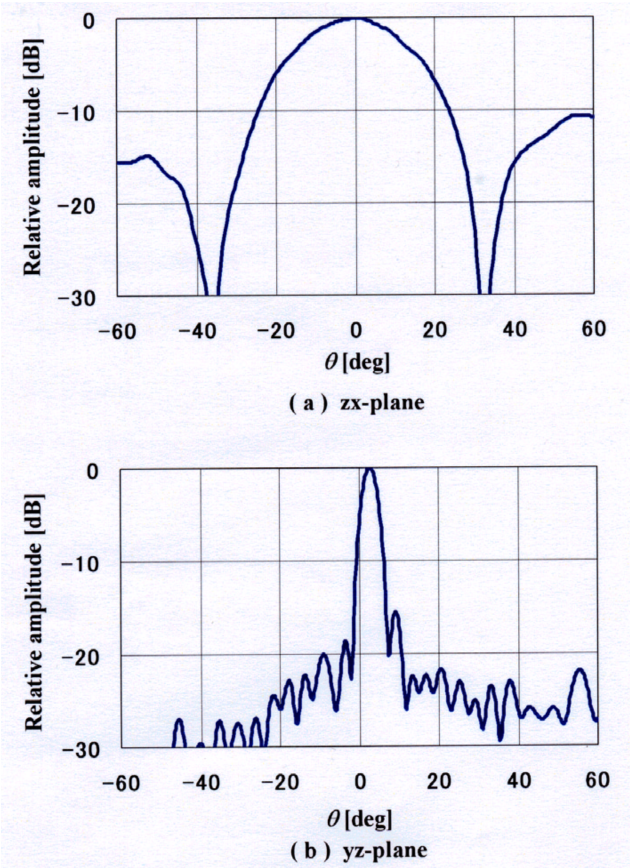

Fig. 8 Measured radiation patterns at 76.5 GHz.

Table 1 Analysis of loss factors of developed antenna.

Design	Feeding line loss	Straight feeding line	0.9dB
		Divider, Bend	0.3dB
	Directive gain loss	Directive gain * / Aperture gain	0.4dB
		Taylor distribution	0.1dB
Error	Degradation of distribution, etc.		1.0dB
Total loss			2.7dB

*In case of equal amplitude distribution

5. Conclusion

A high efficient microstrip array antenna for automotive radar systems has been proposed in this paper. Numerical investigation clarified that the radiation coefficient of radiating elements was varied widely enough to realize aimed Taylor amplitude distribution. The developed antenna with 2 × 37 elements as one subarray of an electrically beam scanning array antenna for automotive radar systems has high efficiency of 53 % with high gain of 22.5 dBi at the design frequency of 76.5 GHz. The antenna developed here will be utilized for automotive radar systems.

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(Report received on April 23, 2002)

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