Measured Performance of Millimeter-Wave Microstrip Comb-Line Antenna using Reflection-Canceling Slit Structure

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1. Introduction

Millimeter-wave antennas have been developed for various applications such as broadband high-speed wireless communication systems and automotive radar systems. Microstrip antenna is more advantageous than other millimeter-wave antennas at the viewpoints of low-profile and low-cost. A comb-line feeding structure is effective for relatively low loss compared with other ordinary microstrip patch array antennas since feeding loss is smaller [1]. When element spacing is just one guided wavelength for broadside beam of traveling-wave excitation, reflections from all the radiating elements are in phase. Therefore, return loss increases significantly. Furthermore, radiation due to the reflection wave from the element degrades the design accuracy for required radiation pattern. Reflection characteristic is improved in the conventional design by beam-tilting of several degrees, where reflections from all the elements are canceled out of phase [2]. Admitted beam-directions are limited by some specific phase differences in which reflections are canceled. We propose the way to improve the reflection characteristic of the antenna with arbitrary beam directions including just broadside direction. In order to suppress the reflection, we propose reflection-canceling slit structure installed on the feeding line around each radiating element. A 27-element linear array antenna with broadside beam is developed at 76.5 GHz. Measured performance is evaluated in the millimeter-wave band.

2. Configuration

A microstrip comb-line antenna is composed of several rectangular radiating elements directly attached to a straight feeding line printed on a dielectric substrate (Teflon, thickness \( t = 0.127 \) mm, relative dielectric constant \( \varepsilon_r = 2.2 \) and loss tangent \( \tan \delta = 0.001 \)) with a backed ground plane as shown in Fig. 1. The radiating elements are inclined 45 degrees from the feeding microstrip line for polarization requirement of automotive radar systems. The radiating elements are arranged on the both sides of the feeding line, which forms interleave arrangement. Element spacing \( d_n \) is approximately a half guided wavelength so that all the elements are excited in phase. Reflection-canceling slit is installed on the feeding line and is closely located at each radiating element. An ordinary patch antenna is connected for a matching element at the termination of the feeding line in order to radiate all the residual power in the microstrip line.

3. Design

Figure 2 shows the analytical structure of a radiating element with a slit. The distance between the slit and the radiating element is \( D_s \). Length and width of the slit are defined as \( L_s \) and \( W_s \), respectively. These three parameters are optimized to suppress the reflection lower than \(-30\) dB by using the electromagnetic simulator. Reflection characteristic is shown in Fig. 3 for the element with slit whose coupling power is \( 7.4\% \). Reflection coefficient of the element with slit is \(-42.3\) dB at 76.5 GHz. Therefore, it is
confirmed that the reflection from radiating element is canceled sufficiently with the reflection from the slit.

Microstrip comb-line antenna is designed to operate in traveling wave excitation. The input power is gradually radiated from all the radiating elements during transmission from the input port toward the termination. Array design is implemented for Taylor distribution with sidelobe lower than −20 dB. Required coupling power is designed to be small near the input port and to increase toward the termination. The required variety of coupling is 2.0 ~ 49.8 %. Radiation from the elements is controlled by variation of the width $W_n$ of the elements where $L_n$ is the resonant length. A 27-element linear array antenna with broadside beam is designed for experiments.

4. Experiments

Figures 4 (a) and (b) show photographs of the fabricated antenna. Width of radiating element is small near the input port and it is large near the termination. Slit is cut on the feeding line at the opposite side of each radiating element. Figure 5 shows measured reflection characteristics of fabricated antennas. Reflection-canceling slit is not used in the conventional antenna. Instead, return loss is reduced by ordinary beam-tilting technique. Reflection coefficient of the proposed antenna is −17.2 dB at the design frequency 76.5 GHz and is almost the same level with the conventional antenna although the proposed antenna is a broadside array. Thus, the effect of reflection-canceling slit is confirmed. Figure 6 shows measured radiation pattern and array factor of design in $yz$-plane at 76.5 GHz. The measured radiation pattern almost agrees well with the array factor. However, some errors are observed in the sidelobe level and the beam direction. To clarify this cause, the aperture amplitude and phase distribution are shown in Figs. 7 (a) and (b), respectively. Growing sidelobe is due to error of amplitude distribution. Figure 7 (b) shows the measured phase distribution and the calculated phase distribution for beam direction of −2 degrees. These phase distributions almost agree with each other. Therefore, error of beam direction is due to phase distribution. We have already confirmed by using electromagnetic simulator that the fabrication error of the etching process affects the phase perturbation in transmission through the radiating element. Figure 8 shows frequency characteristics of gain and antenna efficiency. Since aperture lengths of proposed and conventional antennas are slightly different depending on the design, directivities are different. The maximum gain is obtained at the design frequency for both antennas. Efficiency of proposed antenna is almost the same level with that of conventional antenna. Consequently, it is confirmed that the loss due to the slit structure is extremely small.

5. Conclusion

To suppress the reflection from each radiating element, we propose the reflection-canceling slit structure. A 27-element linear array antenna with broadside beam is designed and fabricated. Reflection coefficient of proposed antenna is almost the same level with the conventional antenna with beam-tilting technique although broadside array is designed for the proposed antenna. The measured radiation pattern almost agrees well with array factor. However, beam direction of measured antenna is −2 degrees. It is confirmed that the fabrication error of the etching process affects the beam direction. We estimate gain and antenna efficiency. It is confirmed that the loss due to slit structure is extremely small. As a result, microstrip comb-line antenna with arbitrary beam direction can be designed without increasing return loss by using reflection-canceling slit structure.

References


Figure 1: Configuration of the proposed antenna

Figure 2: Analytical structure of n-th radiating element

Figure 3: Reflection characteristics of analytical structure

Figure 4: Photographs of the fabricated antenna
Figure 5: Measured reflection coefficient of array antenna

Figure 6: Measured radiation pattern in the yz-plane

(a) Amplitude distribution

(b) Phase distribution

Figure 7: Measured amplitude and phase distribution on the aperture

Figure 8: Measured frequency characteristic of gain and efficiency