Radiation Patterns of Millimeter-Wave Four-Line Microstrip Comb-Line Antennas in Perpendicular Plane of Feeding Line

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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 comb-line antennas (MSCLA) are more advantageous than other millimeter-wave antennas at the viewpoints of low profile and low cost [1]. A comb-line feeding structure is effective for relatively low loss compared with other ordinary microstrip patch array antennas since feeding loss is smaller [2].

Two kinds of four-line planar arrays were developed. One is that radiating elements were connected on the both sides of two feeding lines. The other one is that radiating elements were connected only on one side of four feeding lines. Feeding structure in the former is more simple than the latter. However, design flexibility of radiation pattern in the latter is higher than the former. These two antennas are developed to compare sidelobe characteristics of the radiation patterns in perpendicular plane of feeding line. The difference of the design flexibility is examined in this study.

2. Four-line planar arrays with different feeding systems

Two developed arrays are printed on a dielectric substrate with a ground plane on the back as shown in Fig.1. The dielectric material of the substrate is Fluorine resin (thickness t = 0.127 mm, relative dielectric constant ε_r = 2.2 and loss tangent tanδ = 0.001). The radiating elements are inclined by 45 degrees from the feeding line for the polarization requirement of the automotive radar systems. Reflection-cancelling slit shown in Fig.2 is used to suppress reflection from the radiating element in both antennas [3]. A matching element is designed to radiate in phase all the residual power at the termination of the feeding line. Width and length of the aperture is almost identical between the two antennas to compare the performance. In two-feeding-line array shown in Fig.1(a), the radiating elements are alternately connected at the both sides of the two feeding lines. The element spacing is approximately a half guided-wavelength along the feeding line. On the other hand in the perpendicular direction to the feeding line, element spacing is not constant for the adjacent elements on the same feeding line and on the different feeding line. In four-feeding-line array shown in Fig.1(b), the radiating elements are connected only with the one side of four feeding lines. The element spacing is approximately one guided-wavelength toward the feeding line. Although the element spacing is flexible in the perpendicular plane of feeding line, the antenna requires four-way power divider shown in Fig.3.

3. Design of four-way power divider

One-input four-way power divider is designed for the feeding circuit of the four-feeding-line array. The characteristic impedance of the transmission-line is 60Ω in the five ports. A 1/4 wavelength impedance transformer is well-known for impedance matching applied to the divider as is shown in Fig.4(a). However, the discontinuity of the line perfoms as an obstacle in the transmission line. In order to improve the reflection characteristic, the discontinuous step structure is replaced with a taper structure. Figure 4(b) shows the structure of four-way power divider with taper structure. The feeding line with a different width and different characteristic impedance is smoothly connected by taper structure. The taper dimensions were optimized by using an electromagnetic field simulator to minimize the reflection. Figure 5 shows *S*-parameters of the dividers with and without taper structure. The reflection property was improved to lower than –33.5 dB at the design frequency 76.5 GHz by using the taper structure.

In the four-way power divider, phase difference exists between inner and outer ports. In order to compensate the phase difference, radiating elements are connected to the feeding lines with offset to excite in phase. Figure 6 shows the output phase of the simulated frequency response to the four ports. The phase delay was about 216.7 degrees mainly due to the path length difference at the design frequency 76.5GHz. The required offset of the antenna results in 1.73mm.

4. Experiment

The two arrays are fabricated to evaluate the radiation patterns by experiment at the design frequency 76.5GHz. Figure 1 shows the photographs of the antennas. Two-feeding-line array is fed by Y-junction. Feeding circuit in four-feeding-line array is four-way power divider with the taper structure mentioned in the pervious section. Radiating elements are connected to the feeding lines with offset to excite in phase. Reflection-cancelling slits are used to suppress the reflection from the radiating elements in the antennas.

Figure 7 shows the measured radiation patterns of the two arrays in the perpendicular plane of the feeding line. Sidelobe level of four-feeding-line array is –14.6 dB, which is lower than –11.7 dB of two-feeding-line array. It is because the element spacing of four-feeding-line array is almost constant in contrast to the two-feeding-line array.

Figure 8 shows measured and simulated reflection characteristics of the four-feeding-line array. Measured characteristic includes the characteristic of the microstrip-to-waveguide transition. Measured reflection increased to –10.1 dB from the simulated reflection –17.5 dB at the design frequency 76.5GHz due to the shift of resonant frequency. This could be because effective length of the radiating element becomes short due to rounded corners in fabrication during etching process.

Figure 9 shows the frequency response of gain of two arrays. Peak gain of two-feeding-line array and four-feeding-line array are 20.3, and 20.8 dBi, respectively. They are almost the same between the two antennas. Maximum gain is obtained at the design frequency. Antenna efficiency of two-feeding-line array and four-feeding-line array are 43.5,and 47.1 %, respectively. Antenna efficiency was almost the same between the two antennas.

5. Conclusion

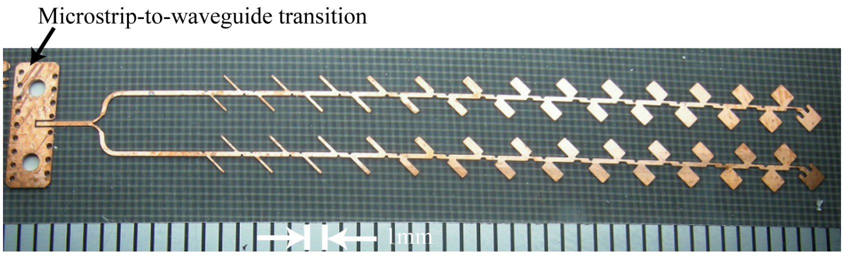
Sidelobe characteristics of the radiation patterns were compared in the two antennas between two-feeding-line array and four-feeding-line array. The design flexibility is examined. Sidelobe level was improved by using four-feeding-line array since arrangement on array element is flexible.

References

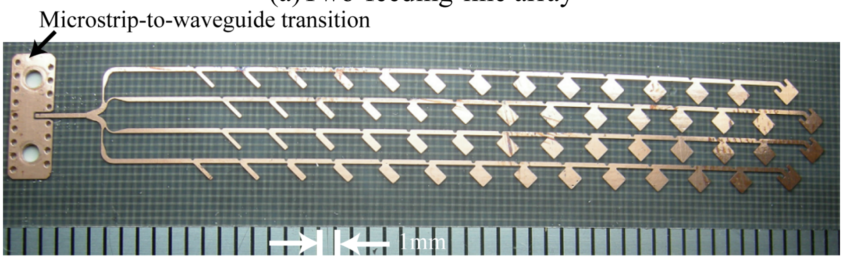
[1] J.R.James, and P.H.hall, *Handbook of Microstrip Antennas*, IEE Electromagnetic Waves Series vol.2, London, UK, Peter Peregrinus Ltd., 1989.

[2] H.Iizuka, T.Watababe, K.Sato and K.Nishikawa, "Millimeter-Wave Microstrip Array Antenna For Automotive Radars," *IEICE Trans. Commun*., Vol.E86-B, No.9, pp.2728−2738, Sept. 2003.

[3] Y.Kashino, K.Sakakibara, Y.Hayashi, N.Kikuma, and H.Hirayama, "Design of Millimeter-Wave Microstrip Comb-Line Antenna Array Beam-Tilting in Perpendicular Plane of Feeding Line"*IEICE Trans. Commum*., Vol.J90-B No.9 pp.864-872, 2007.



(a)Two-feeding-line array



(b)Four-feeding-line array

Fig.1. Photographs of the microstrip comb-line antenna

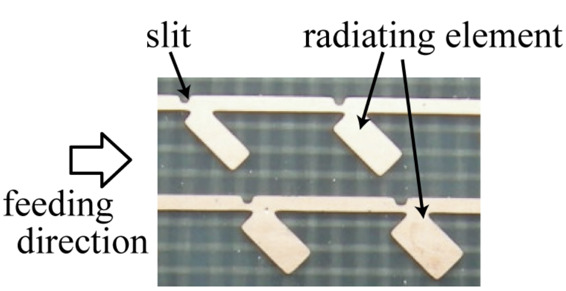


Fig.2. Radiating element

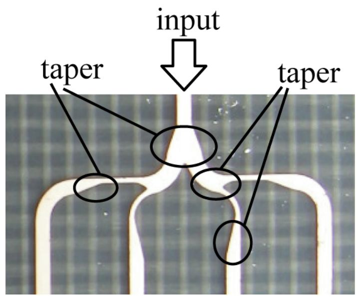
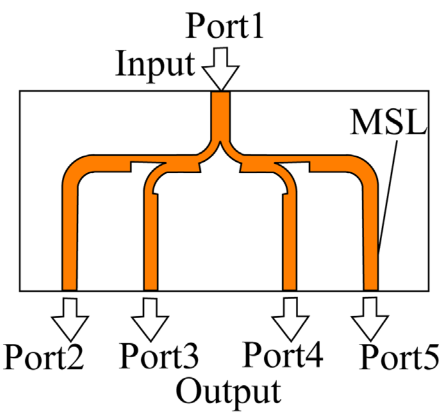
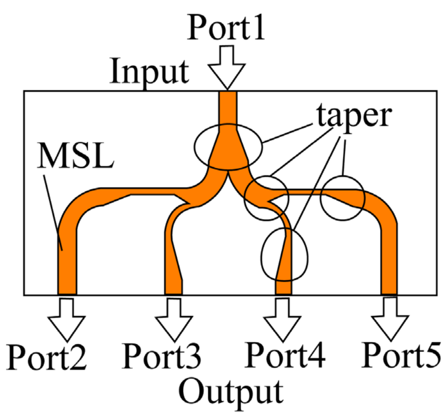


Fig.3. Four-way power divider



(a)Without taper



(b)With taper

Fig.4. Structure of four-way power divider

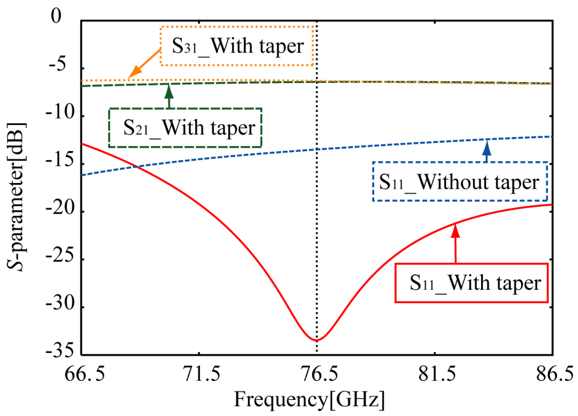


Fig.5. Simulated reflection property of four-way power divider

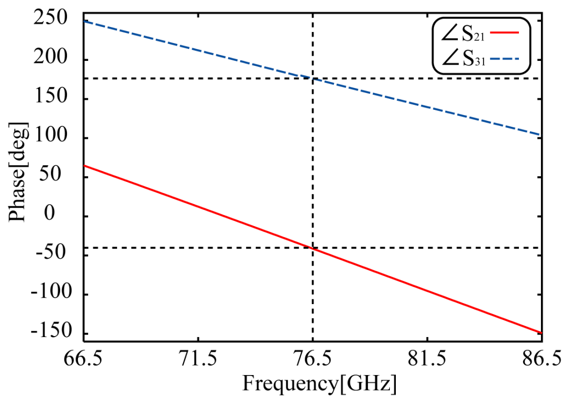


Fig.6. Simulated output phase property of four-way power divider

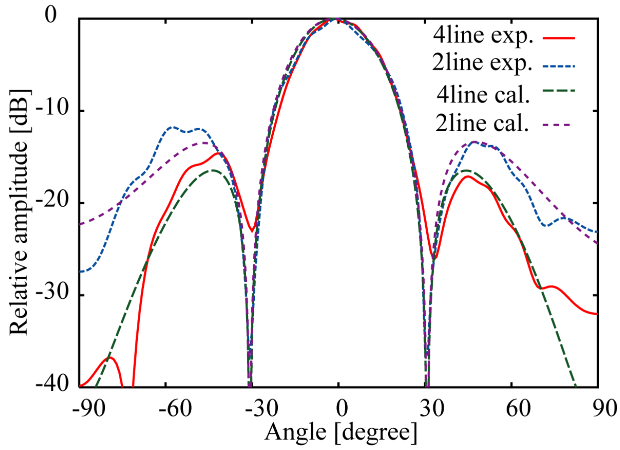


Fig.7. Measured radiation patterns of the microstrip comb-line antennas in perpendicular plane of feeding line

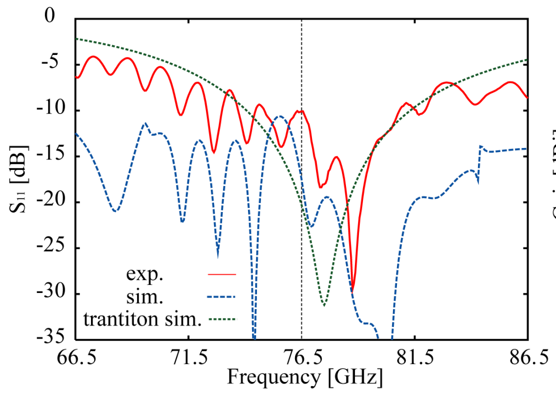


Fig.8. Reflection characteristics of Four-feeding-line array

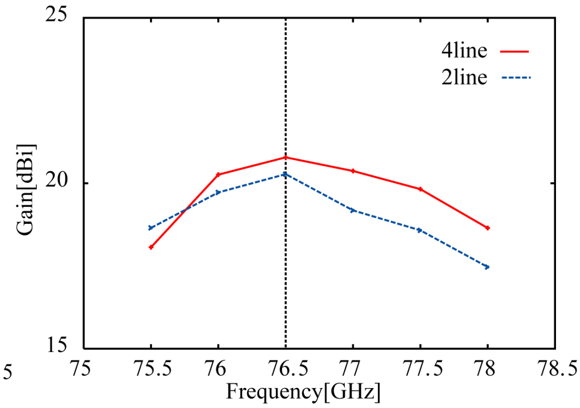


Fig.9. Mesured gains of the Microstrip comb-line antennas