45-Degrees Linearly Polarized Array Antenna Consisting of Printed Slots Arranged in Both Sides of Microstrip Line

Takahiro Ishigaki[1], Manabu Yamamoto[1], Toshio Nojima[1] and Kiyohiko Itoh[2]

[1] Graduate School of Information Science and Technology, Hokkaido University
Kita 14, Nishi 9, Kita-ku, Sapporo, 060-0814, Japan
E-mail: yamamoto@ice.eng.hokudai.ac.jp

[2] Tomakomai National College of Technology
Nishikioka 443, Tomakomai, 059-1275, Japan

1. Introduction

Millimeter-wave systems are gradually becoming more attractive for wireless applications. Automotive collision avoidance radar system is one of such systems, and has been developed actively in recent years. For this system, 45-degrees linearly polarized antennas are often required in order to reduce interference from other radars installed at oncoming cars. Many types of antennas with 45-degrees inclined linear polarization have been proposed up to now. A Slotted waveguide array [1] has capability to achieve high efficiency at millimeter-wave bands. But its structure is bulky and is not suitable for large-scale production. A post-wall waveguide-fed slot array [2] is low profile, and has mass-producible geometry. However, the need for fabricating many posts may leads to high manufacturing cost. A microstrip patch array with series feeding [3] has the same advantages as those of the post-wall waveguide slot array. The potential drawback of this geometry is that antenna characteristics are strongly affected by the errors in the manufacturing process because of narrow-bandwidth behavior of the microstrip patch antenna. One of promising solutions to this problem is to adopt a printed slot antenna [4], [5] instead of the patch antenna as a radiating element.

Taking these backgrounds into consideration, authors have proposed a 45-degrees linearly polarized printed slot array antenna with microstrip line feed [6], [7]. In the previously developed structure, radiating slots are arranged in one side of the microstrip line. However, from the viewpoint of antenna efficiency, it is desirable that radiating slots should be placed in both sides of the feedline. For this case, we can make the total length of the feedline being half in comparison with the array in which radiating slots are arranged in one side of the feedline. This results in the reduction of feeding loss and the improvement of the radiation efficiency.

Thus, in this paper, we develop a 45-degrees linearly polarized array antenna consisting of printed slots arranged in both sides of microstrip line. First, the performance of a slot pair coupled to a microstrip line is analyzed by the spectral domain moment method to investigate the proper arrangement of the radiating slots. Based on obtained results, a 16-element array antenna consisting of 8-slot pairs is designed, and its characteristics are revealed by the analysis. Measured results of the prototype antenna are also presented to confirm the effective performance of the designed array.

2. Antenna Structure

Fig. 1 shows the whole structure of the array antenna studied in this paper. On the ground plane of a dielectric substrate with a thickness of d and a relative permittivity of ε_r, N pairs of radiating slots with a length of l_s and a width of w_s are arranged at a spacing of l. A microstrip line having a width of w_f is printed on the bottom of the substrate. All of the slots are inclined at an angle of 45 degrees with respect to the microstrip line, and are excited by the microstrip line through electromagnetic coupling. Both of the

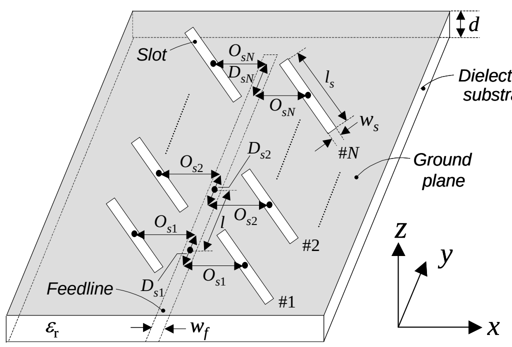


Fig. 1: Whole structure of array antenna.

ISBN: 89-86522-79-9 94460©KEES

slots in the n-th pair are offset along the x-axis by O_{sn} from the microstrip line, and are separated with a length of D_{sn} along the y-axis.

In the following considerations, the design frequency of the antenna is fixed at 11.85GHz. Assuming a substrate with ε_r = 2.17 and d = 0.762mm, the width of the microstrip line is chosen to be w_f = 2.4mm. The characteristic impedance for this case is 50Ω. The dimensions of the slots are set to l_s = 10mm and w_s = 1.2mm. These values are selected so that the slots are in resonance at the design frequency mentioned above. It is assumed that substrates and ground plane are infinite in extent in the lateral dimension.

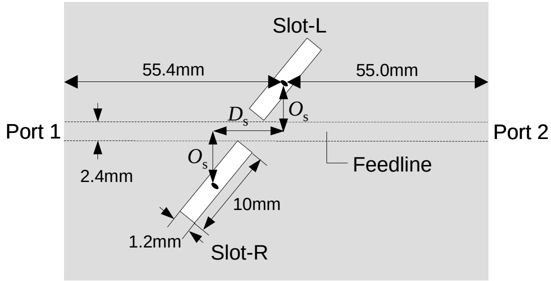


Fig. 2: Analysis model for slot pair.

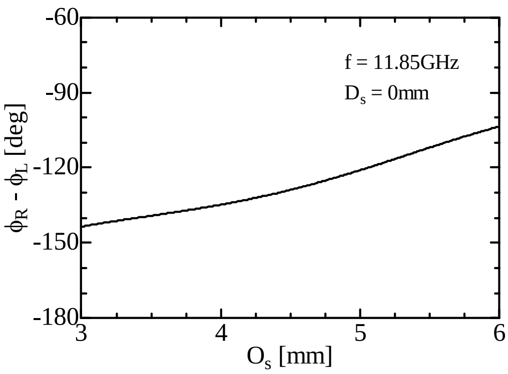


Fig. 3: Difference in excitation phase between two radiating slots.

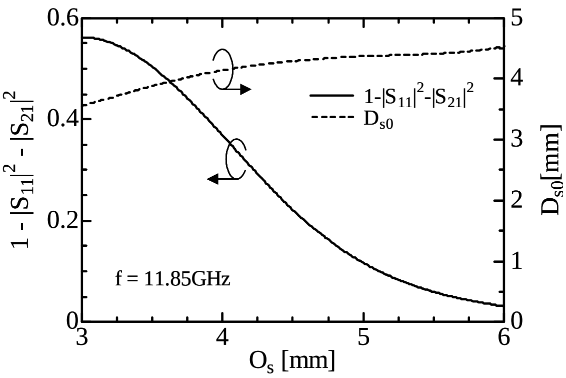


Fig. 4: Coupling coefficient and D_{s0} vs. slot offset.

3. Design of Slot Pair

In order to obtain the data for the design of the array shown in Fig. 1, here we consider a 2-element array antenna whose structure is depicted in Fig. 2. A pair of slots is arranged in both of the microstrip line with an offset length of O_s and a separation of D_s. We investigate characteristics of the array by the analysis using the spectral-domain moment method (SDMM) [8].

In the first place, the array with a separation of D_s = 0mm is analyzed. Fig. 2 shows the difference in excitation phase between two slots. The phase difference of 100° to 150° is observed for this case. In order to make the main beam direction being broadside in the xz-plane, each slot of the slot pair should be excited in phase. For this purpose, the separation D_s is adjusted so that the difference in excitation phase becomes zero.

In addition to the adjustment of the excitation phase, it is necessary to control the coupling level between the slot pair and the feedline so that desired amplitude distribution is obtained. The coupling level can be evaluated by using the ratio of the radiated power from the slot pair to the incident power to the feedline. This ratio can be expressed in terms of S parameters as follows.

$$C_f = 1 - |S_{11}|^2 - |S_{21}|^2 \tag{1}$$

We refer C_f as coupling coefficient in the following discussion. Fig. 4 shows the coupling factor calculated as a function of the slot offset O_s. The separation D_{s0}, with which the difference in excitation phase becomes zero, is also plotted in the same figure. It can be seen that adjusting O_s can control the coupling coefficient, and that each slot can be excited in-phase by setting D_s to a appropriate value, which is a function of O_s.

4. 16-Element Array

Based on the results obtained in the previous section, a 16-element array antenna consisting of

8-slot pairs is designed. In the following description, each slot pair is numbered as shown in Fig. 5. The coupling coefficient K_n for the n-th slot pair can be expressed as

$$K_n = \frac{A_n}{A_n + \sum_{j=n+1}^{N} A_j \exp\{2\alpha(j-n)l\}} \qquad (2)$$

where α is the attenuation constant of the feedline and A_n is the ratio of the radiated power from the n-th slot pair to the incident power to the feedline. Here we design the array with uniform aperture illumination. Assuming α=0, the coupling coefficients are determined as shown in Table 1 by using the equation (2). By referring to the results of Fig. 4, the 1st to 7th slot pair is designed such that these coupling levels are satisfied for each slot pair. The designed O_{sn} and D_{sn} are shown in Table 1. The 8th slot pair is designed so that it acts as a matching slot pair that radiates all the residual power delivered to the pair [9]. The main beam is titled to $\theta = -7^\circ$ in order to cancel the reflection from each slot and to achieve matching at the input port. For this purpose, the spacing between the slot pairs is set to l = 16.7mm as shown in Fig. 6 [5].

We investigate characteristics of the designed array by performing SDMM analysis. Fig. 7 shows excitation amplitude and phase of each slot. For each slot pair, it can be seen that two slots are excited with almost the same phase and amplitude.

Fig. 8 shows frequency response of the return loss, and radiation patterns evaluated at the design frequency of 11.85GHz are shown in Fig. 9. In these figures, solid and broken lines indicate calculated and measured results, respectively. Measured antenna is fabricated on the substrate having the size of $100\text{mm} \times 180\text{mm}$. The return loss at 11.85GHz is observed to be –22dB for the analysis and –10dB for the measurement. The value of the reflection is less than –10dB over the frequency range from 11 to 12.5GHz, thus it can be found that the designed array exhibits broadband characteristics. The difference between the calculation and measurement may be attributed to the error in the fabrication process of the prototype antenna.

As for the radiation pattern, it can be seen from Fig. 9 that calculated and measured results

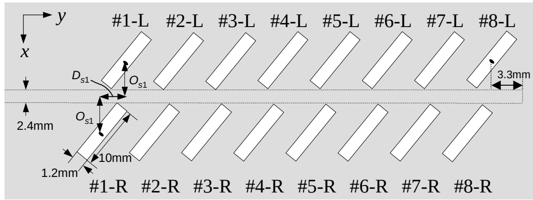


Fig. 5: 16-element array.

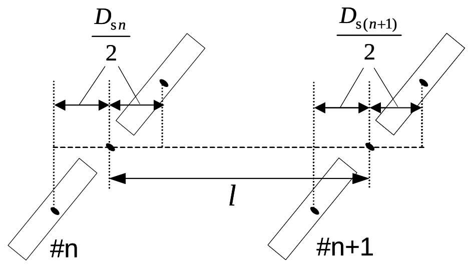


Fig. 6: Arrangement of slot pairs.

Table 1: Parameters for 16-element array.

Slot No.	#1	#2	#3	#4	#5	#6	#7	#8
K_n	0.125	0.143	0.167	0.200	0.250	0.333	0.500	
O_{sn} [mm]	5.0	4.9	4.7	4.6	4.4	4.1	3.5	3.5
D_{sn} [mm]	4.4	4.4	4.3	4.3	4.3	4.2	3.9	3.8

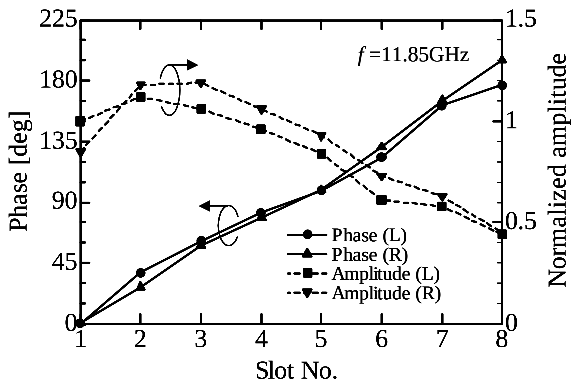


Fig. 7: Excitation amplitude and phase of each slot.

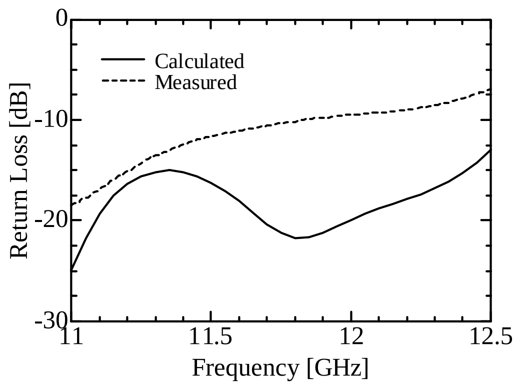
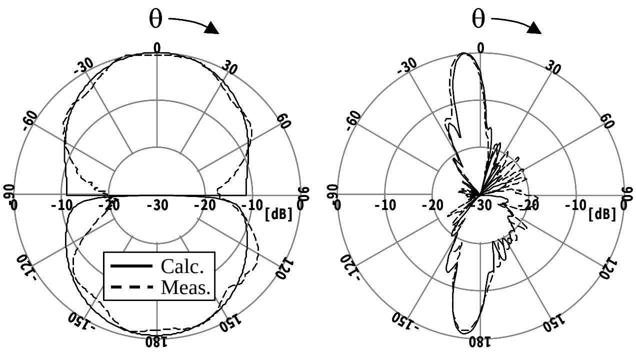


Fig. 8: Frequency characteristic of reflection.

are in good agreement. The calculated and measured gains in the main beam direction are 13.4 and 12.2dBi, respectively. These values are about 2dB higher than those of the 8-element array in which the radiating slots are arranged in one side of the feedline [6], [7]. The half-power beamwidths of the calculated and measured pattern in *yz*-plane are observed to be 10.5° and 11.3°, respectively.



(a) *xz*-plane pattern (b) *yz*-plane pattern

Fig. 9: Radiation pattern of 16-element array.

5. Conclusions

A 45-degrees linearly polarized array antenna consisting of printed slots arranged in both sides of microstrip line has been developed in this paper. First, the performance of a slot pair coupled to a microstrip line was analyzed in order to clarify the proper arrangement of the radiating slot. Based on obtained results, a 16-element array antenna consisting of 8-slot pairs was designed, and its characteristics were evaluated by the analysis to demonstrate the effective performance of the developed array. Measured results of the prototype antenna have been also presented to confirm the validity of the numerical investigations.

Acknowledgement

This work has been supported by Grant-in-Aid for Research 16760284 from the Japan Society for the Promotion of Science.

References

[1] SAKAKIBARA, K., WATANABE, T., SATO, K., NISHIKAWA, K. and SEO, K.: ‘Millimeter-wave slotted waveguide array antenna manufactured by metal injection molding for automotive radar systems’. IEICE Trans. Commun., 2001, E84-B, (9), pp. 2369-2376

[2] HIROKAWA, J. and ANDO, M.: ‘ 45° linearly polarised post-wall waveguide-fed parallel-plate slot arrays’. IEE Proc., Microw. Antennas Propag., 2000, 147, (6), pp.515-519

[3] IIZUKA, H., WATANABE, T., SATO, K. and NISHIKAWA, K.: ‘Millimeter-wave microstrip array antenna for automotive radar systems’. Proc. of the 2000 International Symposium on Antennas and Propagation, Fukuoka, Japan, pp.465-468

[4] GARG, R., BHARTIA, P., BAHL, I. and ITTIPIBOON, A.: ‘Microstrip antenna design handbook’. (Artech House, Norwood, 2001)

[5] YAMAMOTO, M., Ishizaki, K., MURAMOTO, M., SASAKI, K. and ITOH, K.: ‘A planar-type five-sector antenna with printed slot array for millimeter-wave and microwave wireless LANs’. Proc. of the 2000 International Symposium on Antennas and Propagation, Fukuoka, Japan, pp.205-208

[6] YAMAMOTO, M., KATAYAMA, M., NOJIMA, T. and ITOH, K.: ‘A Printed Slot Array Antenna Having 45-Degrees Linear Polarization’, Proc. of 2003 Asia-Pacific Microwave Conference, 2003, 2, pp.1056-1059

[7] KATAYAMA, M., YAMAMOTO, M., NOJIMA, T. and ITOH, K.: ‘Microstrip-Fed Slot Array Antenna Having 45-degrees Inclined Linear Polarization’, Electronics Letters, 2003, 39, (21), pp.1492-1493

[8] SULLIVAN, P.L. and SCHAUBERT, D.H.: ‘Analysis of an aperture coupled microstrip antenna’. IEEE Trans. Antennas Propag., 1986, AP-34, (8), pp.977-984

[9] HIRANO, T., HIROKAWA, J. and ANDO, M.: 'Waveguide matching crossed-slot'. IEE Proc.-Microw. Antennas Propag., 2003, 150, (3), pp.143-146