

# Two Element Phased Array Dipole Antenna

Mitsuo Taguchi<sup>1</sup>, Kotaro Era<sup>2</sup>, and Kazumasa Tanaka<sup>3</sup>

<sup>1</sup> mtaguchi@nagasaki-u.ac.jp

<sup>1,3</sup> Department of Electrical and Electronic Engineering, Nagasaki University  
1-14 Bunkyo-machi, Nagasaki-shi, 852-8521 JAPAN

<sup>2</sup> Presently, Murata Manufacturing Company Ltd.  
10-1 Higashikotari 1-chome, Nagaokakyo-shi, Kyoto 617-8555 JAPAN

**Abstract** — Two element array of dipole antennas with 90 degree phase difference feed is proposed for directional antenna applications. In the numerical analysis, the electromagnetic simulator WIPL-D based on the method of moment is used. At first, the distance between the two elements is fixed to be a quarter wavelengths at the design frequency of 2.45 GHz. The front-to-back ratio is calculated. Then, by adjusting the length of the two elements and the distance between the two elements, a front-to-back ratio of 15.3 dB is obtained. The relation between the front-to-back ratio of this antenna and the feed point currents is discussed. The measured input impedance with 90 degree hybrid phase shifter agrees with the calculated result.

## I. INTRODUCTION

For the short-range wireless communication, a small antenna with unidirectional radiation characteristics is desired. As the directional antenna composed of wire elements, the Yagi-Uda antenna and the Electronically Steerable Passive Radiator (ESPAR) antenna are well known [1], [2]. These antennas consist of single driven element and some parasitic elements. In the Yagi-Uda antenna, the induced currents on the parasitic elements are controlled by adjusting the length of the parasitic elements and the distance between the elements [1]. In the ESPAR antenna, the current of the parasitic elements are controlled by adjusting the reactance loaded at the feed point of them [2]. These antennas are spatially phase controlled antennas. Since only one element is excited in these antennas, the current distribution on each element can be easily controlled by changing the distance between elements or loaded reactance at parasitic elements.

In this paper, two element array of dipole antennas with 90° phase difference feed is proposed for the directional antenna [3]. At first, the distance between two dipole elements is fixed to be a quarter wavelength at the design frequency of 2.45 GHz, and the length of two elements are changed to obtain high front-to-back

ratio. This antenna array configuration is numerically and experimentally analyzed. In the numerical analysis, the electromagnetic simulator WIPL-D based on the method of moment is used [4]. Next, the distance between the two dipole elements and the length of two elements are adjusted in order to obtain highest front-to-back ratio. Finally, the relation between the front-to-back ratio and the feed point current on each element is discussed.

## II. ANALYTICAL AND EXPERIMENTAL MODEL

Figure 1 shows the structure of the two element phased array dipole antenna. The antenna elements are fed with 90° phase difference. The distance between the two elements is  $d$ . The length of the antenna elements #1 and #2 are  $L1$  and  $L2$ , respectively. The radius of each element is  $a = 1$  mm. In the numerical analysis by WIPL-D, antenna elements are excited by the delta-gap generators. The design frequency is 2.45 GHz.

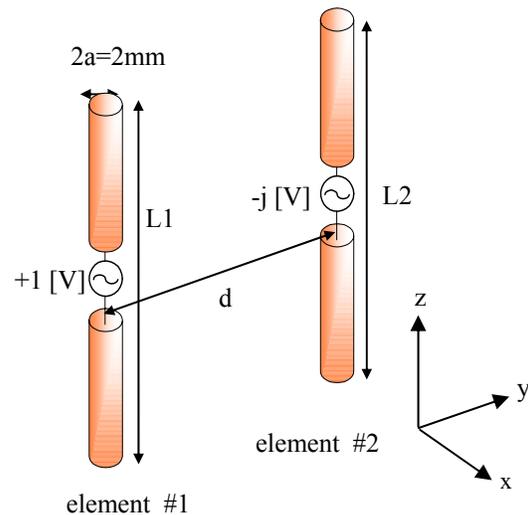


Fig. 1. Structure of proposed antenna.

Figure 2 shows the experimental model. Two monopole elements are mounted on a ground plane of dimensions 87 cm by 87 cm. This antenna is driven through the 90 degree hybrid phase shifter. The reflection coefficient  $\Gamma$  at the input port of the hybrid phase shifter is expressed in terms of the reflection coefficients  $\Gamma_2$  and  $\Gamma_3$  seen from ports 2 and 3 toward the load [5].

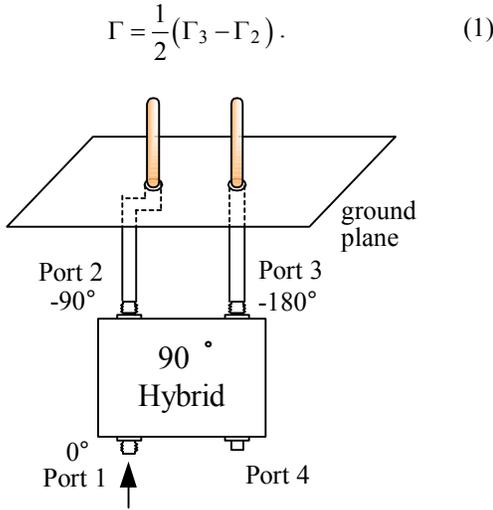


Fig. 2. Experimental model.

### III. RESULTS AND DISCUSSION

#### A. Case I: $d = 0.25 \lambda_c$

At first, the distance between two dipole elements  $d$  is fixed to be  $30.6 \text{ mm} = 0.25 \lambda_c$ , where  $\lambda_c$  is the wavelength at the design frequency  $2.45 \text{ GHz}$ . Figure 3 shows the calculated input impedances at feed points of each element for  $L_1 = L_2 = 61.2 \text{ mm} = 0.5 \lambda_c$ . At the frequencies less than  $2.1 \text{ GHz}$ , the input resistance on the element #1 becomes small compared with the single dipole antenna. This phenomenon is similar to the horizontal dipole located above the infinite ground plane. The difference of impedances between two elements at higher frequencies is observed from  $2.45 \text{ GHz}$ [6]. Since each element is excited with  $90$  degree phase difference, the mutual coupling is different at each element. Therefore this difference occurs.

Figure 4 shows the front-to-back ratio characteristics. The front-to-back ratio is  $4.8 \text{ dB}$  at  $2.45 \text{ GHz}$  and becomes highest at  $1.9 \text{ GHz}$ . Figure 5 shows the maximum front-to-back ratio calculated in the frequency band from  $1 \text{ GHz}$  to  $3 \text{ GHz}$ . Figure 6 shows  $L_2$  and the frequency when the maximum front-to-back

ratio is obtained. The maximum front-to-back ratio is obtained for the ratio of  $L_2$  to  $L_1$  from  $0.93$  to  $0.95$ .

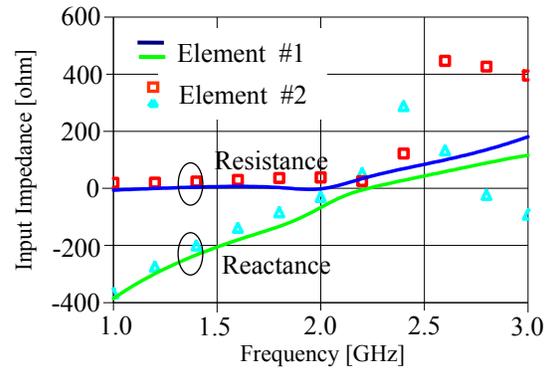


Fig. 3. Calculated input impedance at feed point of each element,  $d=30.6 \text{ mm}$ ,  $L_1=L_2=61.2 \text{ mm}$ .

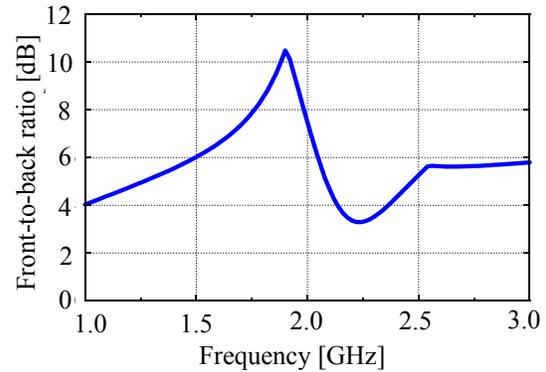


Fig. 4. Calculated front-to-back ratio characteristics,  $d=30.6 \text{ mm}$ ,  $L_1=L_2=61.2 \text{ mm}$ .

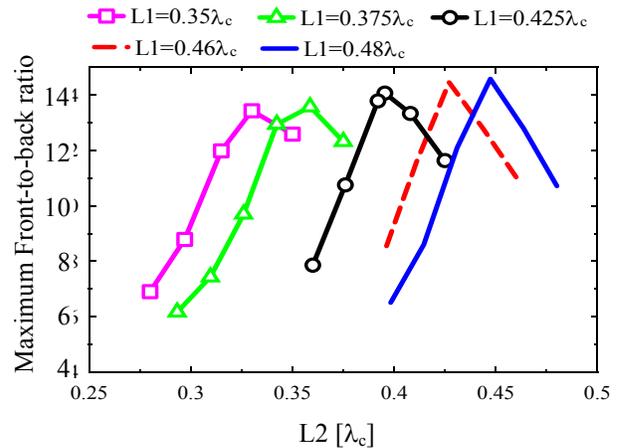


Fig. 5. Calculated maximum front-to-back ratio.

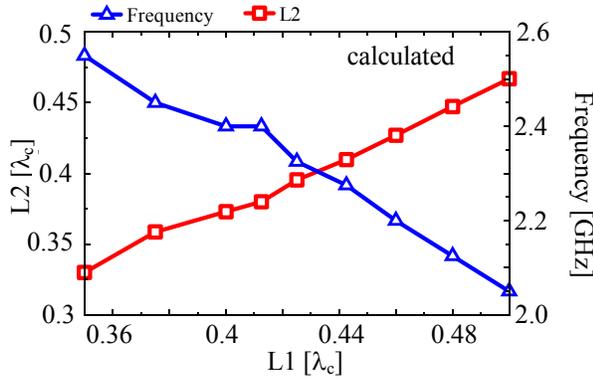


Fig. 6. L2 for maximum front-to-back ratio and its frequency.

**B. Case II:**  $d \neq 0.25\lambda_c$

By adjusting the distance between both elements  $d$  and the length of two elements  $L1$  and  $L2$ , the maximum front-to-back ratio is obtained at the design frequency 2.45 GHz. The maximum front-to-back ratio of 15.3dB is obtained in the case of  $d = 20.6$  mm,  $L1 = 54.6$  mm, and  $L2 = 50.2$  mm.

Figures 7 and 8 show the electric field radiation pattern in  $xy$  plane at 2.45GHz, the input impedance characteristics at the feed point of each element in this case, respectively. In Figure 7, the electric field radiation pattern in the Case I is also shown for comparison.

Figure 9 shows the calculated and measured input impedance characteristics at the input port of the  $90^\circ$  hybrid phase shifter. In the calculation, the attenuation and the phase delay in the coaxial cable between the phase shifter and the antenna element is considered. Figure 10 shows the VSWR characteristics of this antenna. The VSWR less than 3 is obtained near the design frequency 2.45 GHz.

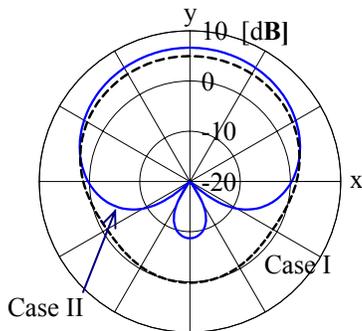


Fig. 7. Calculated electric field radiation patterns in  $xy$  plane (vertical polarization) at 2.45 GHz, Case I:  $d = 30.6$  mm,  $L1 = L2 = 61.2$  mm, Case II:  $d = 20.6$  mm,  $L1 = 54.6$  mm,  $L2 = 50.2$  mm.

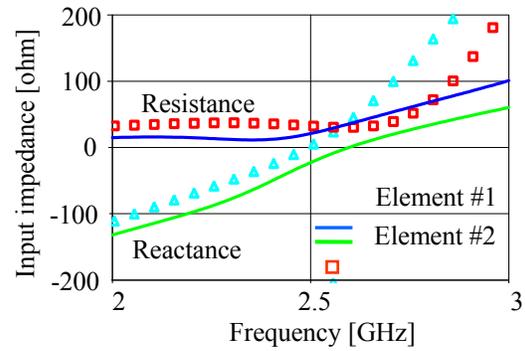


Fig. 8. Calculated input impedance at feed point of each element,  $d = 20.6$  mm,  $L1 = 54.6$  mm,  $L2 = 50.2$  mm.

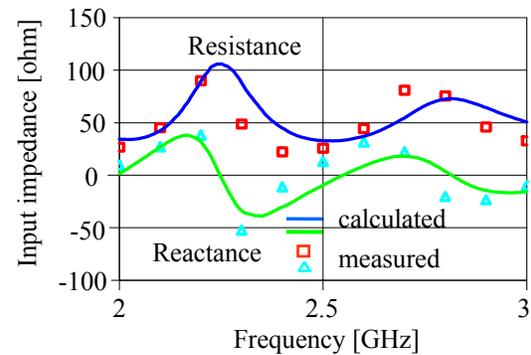


Fig. 9. Input impedance characteristics at input port of  $90^\circ$  hybrid phase shifter,  $d = 20.6$  mm,  $L1 = 54.6$  mm,  $L2 = 50.2$  mm.

**C. Discussion**

The front-to-back ratio of the antenna is 4.8 dB at 2.45 GHz in the case I of  $d = 30.6$  mm, and  $L1 = L2 = 61.2$  mm. On the other hand, the front-to-back ratio becomes maximum (15.3 dB) in the case II of  $d = 20.6$  mm,  $L1 = 54.6$  mm, and  $L2 = 50.2$  mm. The radiation characteristics are determined by the current distribution on each element. Here, the synthesized feed point current vectors including the spatial phase delay between two elements are shown in order to discuss why the front-to-back ratio is different in case I and II. Figure 11 shows the feed point current of each element and the synthesized currents in the  $+y$  and  $-y$  direction in case I of  $d = 30.6$  mm,  $L1 = L2 = 61.2$  mm. The distance between two elements  $d = 30.6$  mm corresponds to the spatial phase delay of  $90^\circ$  at 2.45 GHz. Without considering the attenuation along the propagation, the current on the element #2 added by the current #1 with  $90^\circ$  phase delay contributes to the radiation toward  $+y$  direction. The current on the

element #1 added by the current #2 with  $90^\circ$  phase delay contributes to the radiation toward  $-y$  direction. The amplitude of feed point current on the element #2 is too small compared with that on the element #1, and the phase difference of currents is not equal to the excitation phase difference of  $90^\circ$  because of the mutual coupling. Therefore the current on the element #1 does not cancel out the current on the element #2 with  $90^\circ$  phase delay. As the result, the amplitude of synthesized current toward  $-y$  direction does not become small. Therefore the front-to-back ratio becomes low.

Figure 12 shows the feed point current of each element and the synthesized currents in the  $+y$  and  $-y$  directions in case II of optimized model ( $d = 20.6$  mm,  $L1 = 54.6$  mm,  $L2 = 50.2$  mm). The distance between the two elements  $d = 20.6$  mm corresponds to about  $60$  degrees of the spatial phase delay at  $2.45$  GHz. There is a large difference between the amplitudes of the two synthesized current vectors. Therefore, the front-to-back ratio becomes high.

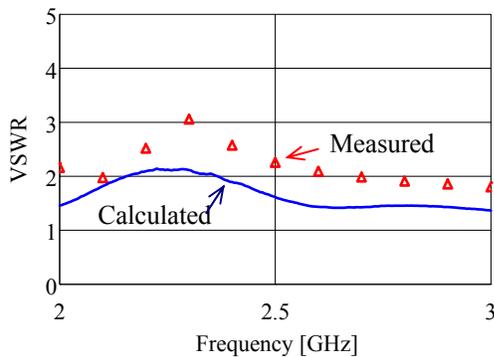


Fig. 10. VSWR characteristics at input port of  $90^\circ$  hybrid phase shifter,  $d=20.6$  mm,  $L1=54.6$  mm,  $L2=50.2$  mm.

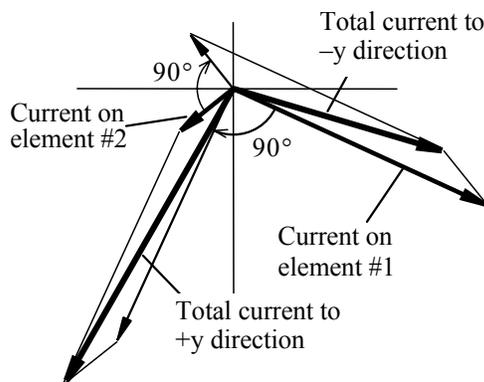


Fig. 11. Current on each element and synthesized currents toward  $+y$  and  $y$  directions at  $2.45$  GHz,  $d=30.6$  mm,  $L1=L2=61.2$  mm, FB ratio =  $4.8$  dB.

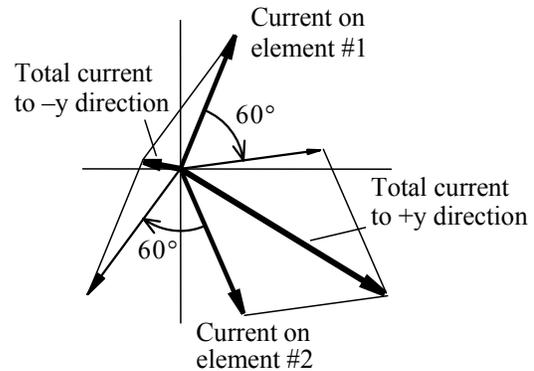


Fig. 12. Current on each element and synthesized currents toward  $+y$  and  $-y$  directions at  $2.45$  GHz,  $d=20.6$  mm,  $L1=54.6$  mm,  $L2=50.2$  mm, FB ratio =  $15.3$  dB.

#### IV. CONCLUSION

Two element phase array of dipole antennas with  $90^\circ$  phase difference feed has been analyzed numerically and experimentally. In the spatially phase controlled antennas such as Yagi-Uda antenna and ESPAR antenna, the feed point current on each element is easily controlled. However, it is difficult in the proposed antenna due to the mutual coupling between two elements. By adjusting the length of each element and the distance between the two elements, the front-to-back ratio of  $15.3$  dB have been obtained.

Although the proposed antenna has a simple structure, it has the unidirectional radiation characteristics. This antenna array configuration can be a promising element antenna for base station antennas of short-range wireless communication systems.

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**Mitsuo Taguchi** received his B. E. and M. E. degrees from Saga University, Japan in 1975 and 1977, respectively, and a Dr. Eng. Degree from Kyushu University Japan in 1986. From 1977 to 1987, he was a Research Associate at Saga University.

Since 1987 he has been an Associate Professor at Nagasaki University. In 1996 he was a visiting researcher at the Department of Electrical Engineering at the University of California, Los Angeles. His research interests are the small antenna for mobile communication and UWB antennas. Dr. Taguchi is a member of ACES, IEEE, the Institute of Electronics, Information and Communication Engineers of Japan, the Institute of Electrical Engineers of Japan and the Institute of Image Information and Television Engineers of Japan.



**Kotaro Era** received his B. E. and M. E. degrees from Nagasaki University, Japan in 2004 and 2006. From 2004 to 2006, he has studied on the directional antenna in the Graduate School of Science and Technology, Nagasaki University. Since 2006, he joined Murata Manufacturing Company, Ltd, Nagaokakyo, Japan.



**Kazumasa Tanaka** received his B. S., M. S. and Dr. E. degrees in Electronic Communication Engineering, in 1965, 1967, and 1975, respectively, all from Kyushu University, Japan. Since 1981, he has been a professor at Nagasaki University. His main areas of interest are the diffraction of optical beams, the detection of optical signals, and optical engineering. Dr. Tanaka is a member of the Japan Society of Applied Physics and Optical Society of America and the Institute of Electronics, Information and Communication Engineers of Japan.