

Two Element Phased Array Dipole Antenna

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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.

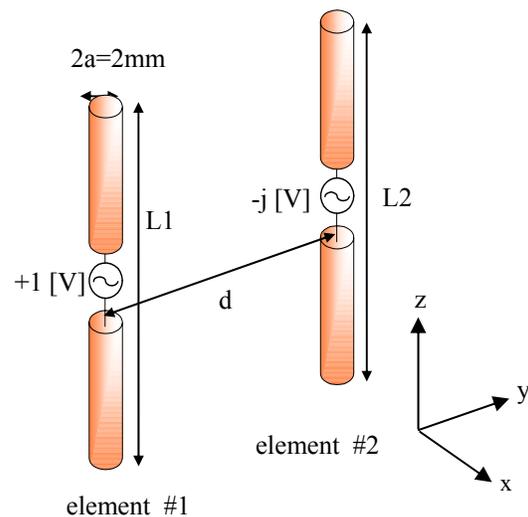


Fig. 1. Structure of proposed antenna.

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 Γ at the input port of the hybrid phase shifter is expressed in terms of the reflection coefficients Γ_2 and Γ_3 seen from ports 2 and 3 toward the load [5].

$$\Gamma = \frac{1}{2}(\Gamma_3 - \Gamma_2). \quad (1)$$

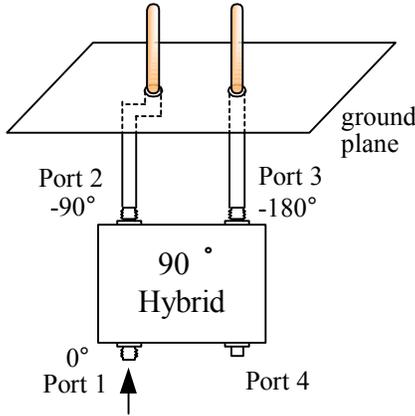


Fig. 2. Experimental model.

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 λ_c is the wavelength at the design frequency 2.45 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 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 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 dB at 2.45 GHz and becomes highest at 1.9 GHz . Figure 5 shows the maximum front-to-back ratio calculated in the frequency band from 1 GHz to 3 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 .

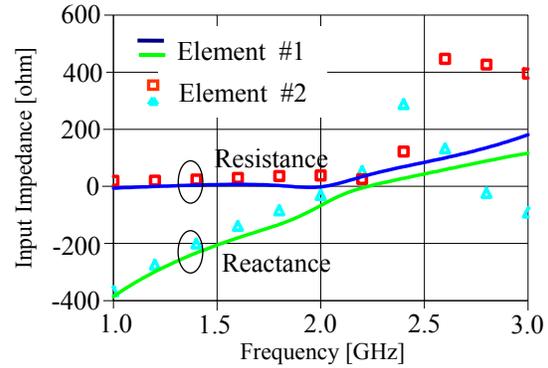


Fig. 3. Calculated input impedance at feed point of each element, $d=30.6 \text{ mm}$, $L_1=L_2=61.2 \text{ mm}$.

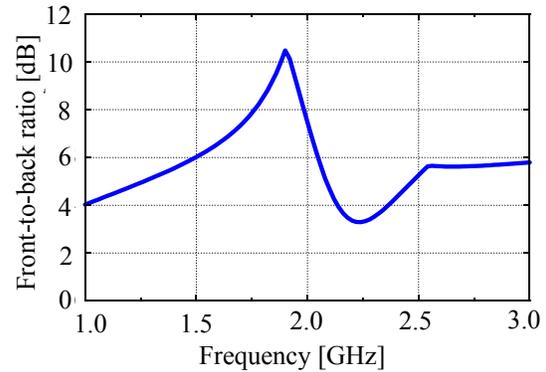


Fig. 4. Calculated front-to-back ratio characteristics, $d=30.6 \text{ mm}$, $L_1=L_2=61.2 \text{ mm}$.

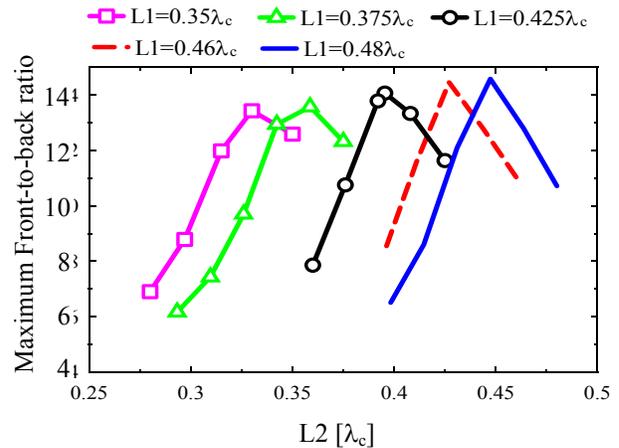


Fig. 5. Calculated maximum front-to-back ratio.

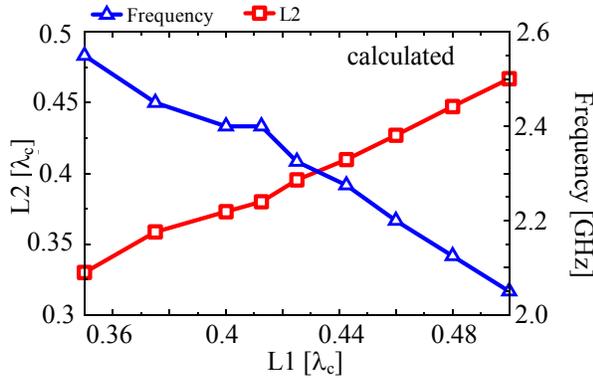


Fig. 6. L2 for maximum front-to-back ratio and its frequency.

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° 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.

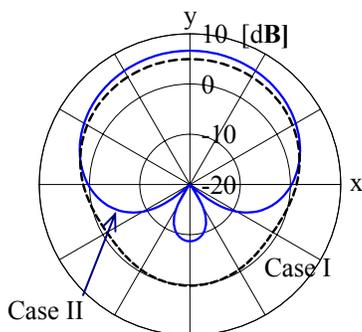


Fig. 7. Calculated electric field radiation patterns in xy plane (vertical polarization) at 2.45 GHz, Case I: $d = 30.6$ mm, $L1 = L2 = 61.2$ mm, Case II: $d = 20.6$ mm, $L1 = 54.6$ mm, $L2 = 50.2$ mm.

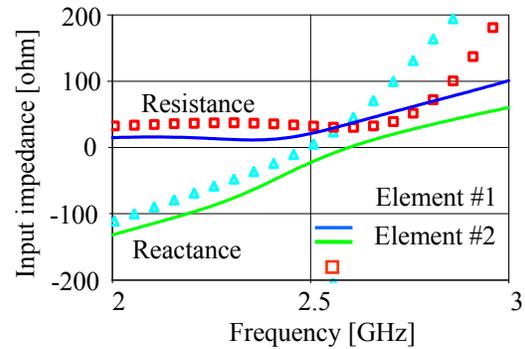


Fig. 8. Calculated input impedance at feed point of each element, $d = 20.6$ mm, $L1 = 54.6$ mm, $L2 = 50.2$ mm.

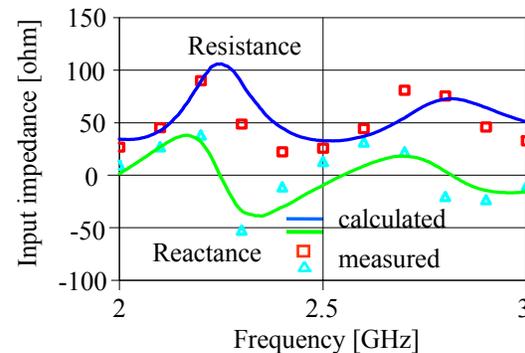


Fig. 9. Input impedance characteristics at input port of 90° hybrid phase shifter, $d = 20.6$ mm, $L1 = 54.6$ mm, $L2 = 50.2$ mm.

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° at 2.45 GHz. Without considering the attenuation along the propagation, the current on the element #2 added by the current #1 with 90° phase delay contributes to the radiation toward $+y$ direction. The current on the

element #1 added by the current #2 with 90° 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° because of the mutual coupling. Therefore the current on the element #1 does not cancel out the current on the element #2 with 90° 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, $L_1 = 54.6$ mm, $L_2 = 50.2$ 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.

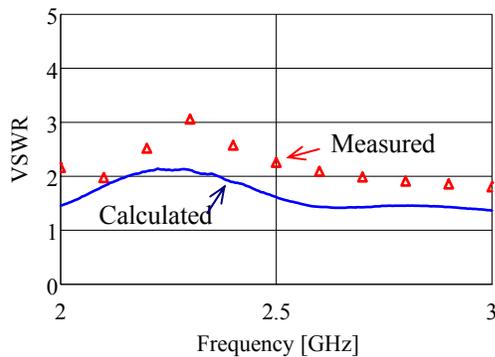


Fig. 10. VSWR characteristics at input port of 90° hybrid phase shifter, $d=20.6$ mm, $L_1=54.6$ mm, $L_2=50.2$ mm.

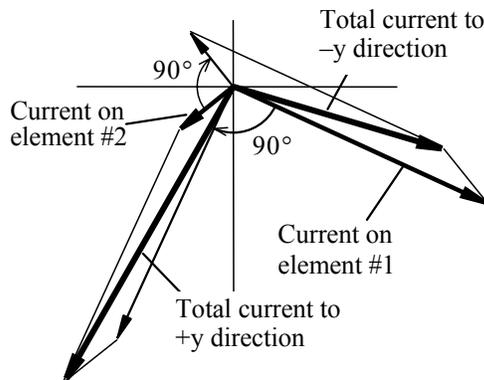


Fig. 11. Current on each element and synthesized currents toward $+y$ and y directions at 2.45 GHz, $d=30.6$ mm, $L_1=L_2=61.2$ mm, FB ratio = 4.8 dB.

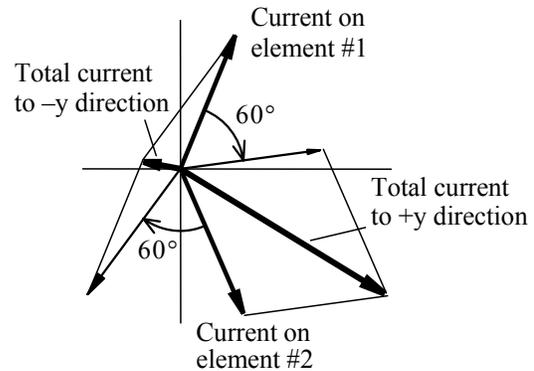


Fig. 12. Current on each element and synthesized currents toward $+y$ and $-y$ directions at 2.45 GHz, $d=20.6$ mm, $L_1=54.6$ mm, $L_2=50.2$ mm, FB ratio = 15.3 dB.

IV. CONCLUSION

Two element phase array of dipole antennas with 90° 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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