A DESIGN METHOD FOR ARRAY ANTENNAS

TAKING INTO ACCOUNT OF MUTUAL COUPLING BETWEEN ELEMENTS

----- DIPOLE ARRAY ANTENNA ABOVE THE GROUND PLANE -----

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ABSTRACT

An array antenna is generally designed by using the array factor. The designed antenna hasn't been desired characteristics because the mutual coupling between elements isn't taken into account for the design. In this paper a quantitative design method for an array antenna above the infinite ground plane is proposed. The fundamental idea of this method is the input impedance correction of each array element. The each element's length and the each feeding voltages are adjusted. The method takes into account the mutual coupling between elements. The proposed design method has a very simple procedure and is obtained good results.

INTRODUCTION

The principle of pattern multiplication using the array factor is generally used for the design of an array antenna. When an array antenna is designed by using the array factor, the resultant beam width and the side-lobe levels of the array deviate from the desired values, because the design does not take into account the effect of the mutual coupling between elements. The middle elements of the array have symmetrical mutual couplings from the adjacent elements, but both of the end elements have asymmetrical mutual couplings. So the deviation is caused by the difference of the amplitude and the phase of the currents on the end elements from their values of the middle elements of the array. In particular, the realization of the desired pattern is very important for designing the case of pattern synthesis.

Generally, an array antenna is constructed above the ground plane. The basic design method was proposed and examples of the design of the broadside array antenna were also reported [1]. But the end elements of the array had phase error of the current when the array antenna was designed by using the method. The method had a limitation, because the method used only adjustment of elements' lengths.

The new antenna design method has been investigated. In this paper a quantitative design method for an array antenna above the infinite ground plane is proposed. The method takes into account the mutual coupling between elements. The proposed design method has a very simple procedure.

THE DESIGN METHOD

The fundamental idea of this method is the input impedance correction of each array element. As is well known, the input impedance of the element antenna can be obtained from the analytical calculation when the elements' size/shape is given. The current amplitude and the phase on the element directly relate to the input impedance, so the desired current distribution on the array elements with fixed spacing can be realized by adjusting the elements' size/shape.

The paper describes a method for designing the broadside arrays consisting of parallel half wavelength dipoles above the infinite ground plane, as shown in Fig. 1. However, the design of this array is not our purpose, this is first step to reach our final goal of pattern synthesis. In this paper, the electromotive force method (EMF) is applied for analysis of the input impedance and the radiation characteristics.

When the length of an element of the array is varied, the input impedance of this element is changed, but the input impedances of residual elements are changed slightly. The current distribution of the array is directly decided from the input impedance of each element. So the desired current distribution can be realized by adjusting the element length. The concept of the design method is already reported in the reference [1]. At the time the element length of the middle elements of the array is adjusted to suppress reactance component of each element. The resultant radiation pattern has slight difference from the desired value because the end elements have the different amplitude and the different phase of the current from their values of the middle elements of the array.

In this paper all elements' lengths are adjusted in order to suppress the reactance component of each element. Therefore all elements are worked as pure resistance, but they do not have same values. The desired current distribution of the array is obtained by adjusting the exciting voltage of each element because each element has no reactance component. It takes into account the mutual coupling between elements. The proposed array antenna design method is very simple.

RESULTS

Fig. 1 shows the configuration of the 8 element parallel half wavelength broadside dipole array above the ground plane. The parameters are fixed as element spacing: $d=\lambda/2$, height from the ground plane: $h=\lambda/4$ and radius:$\rho=0.005\lambda$, where λ is a wavelength in free space.

Fig. 2 shows the reactance characteristics as a function of each element's length. As all elements' lengths are varied, the reactance component, which is affected by the mutual coupling between elements, is linearly changed. It is found that the reactance component of all elements can be reached to zero by adjusting all elements' lengths.

The input impedance of each element is shown in Fig. 3 after all elements' lengths are adjusted. Each element has the resistance of different values (dotted line) but reactance components (solid line) are zero. When the each element is fed different voltages, the mutual coupling between elements is changed. Therefore all each element's lengths are readjusted and then the feeding voltages of all elements are reevaluated to suppress the reactance component. The amplitude and the phase of the current of the each element are shown by solid lines in Fig. 4, when the iterative adjustment is achieved. After adjustment, all elements have the same amplitude and the same phase of the current. Resultant elements' lengths are shown in Table 1. From the result, however the reactance component is still remained at the 2nd and 7th terminals, the phase error of the current is only caused less than 0.1 degrees. The resonance of all the elements can be achieved by further iterative computation. In this case, the feeding circuit without phase control circuit can easily be realized by using the ordinary power dividing design method.

Fig. 5 shows the resultant radiation patterns. Initial radiation pattern (dotted line) is deviated from desired pattern because of the mutual coupling between elements. The radiation pattern (dot-dash-line) of the array with adjusted elements' lengths is identical to the desired pattern (solid line). So the proposed antenna design method taking into account the mutual coupling between elements has simple procedure and can be obtained good results.

Next, the frequency characteristics of the designed antenna are examined. Fig. 6 and 7 show the frequency characteristics of the resistance component and the reactance component, respectively. From the result, the resistance and the reactance component are changed when the frequency is shifted. It is noted that the reactance component is varied about ±11 ohms when the frequency is shifted about ±2 % from center frequency, but the resistance component is shown results approximately similar to the reactance component.

Fig. 8 shows the radiation pattern when the frequency is shifted. The each side-lobe level almost keeps constant, but the maximum angles of side-lobes are changed. The main reason of deviation of these maximum angles is caused by the change of spatial phase between elements.

The radiation pattern is shown in Fig. 9 when the frequency is shifted ±1% from the center frequency. The results show that the radiation pattern is practically not affected due to frequency shift within this range.

Finally the characteristic of the return loss is examined when the array has values of Table 1. Fig. 10 shows that the array has a relatively wide bandwidth of return loss characteristics. Therefore the designed array by using the method is obtained the desired pattern and a useful bandwidth.

CONCLUSION

The design method for array antennas taking into account the mutual coupling between elements is proposed. The main point of the method is the suppression of the reactance component of each element by adjusting all elements' lengths and to feed the voltages proportional to the resistance component of each element. This leads the simple structure of feeding circuit, because all elements are pure resistance. The designed array antenna is obtained the identical pattern to the desired pattern, and a useful bandwidth. The method has a very simple procedure.

REFERENCE

[1] K. Sakaguchi and N. Hasebe, "A Design Method for Array Antennas Taking into Account of Mutual Coupling Between Elements," 2001 IEEE AP-S, Vol.3, pp828-831, 2001.

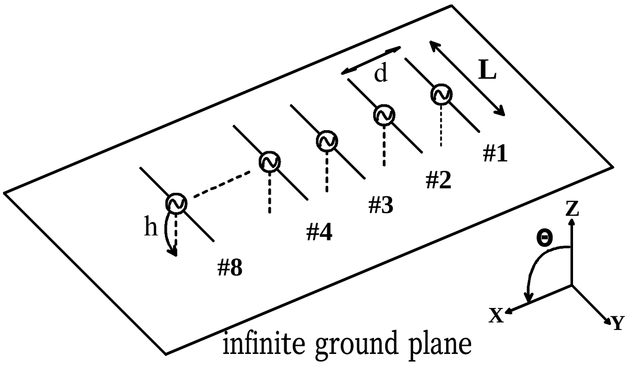

Fig. 1 Configuration of the parallel half wavelength dipole array above the ground plane

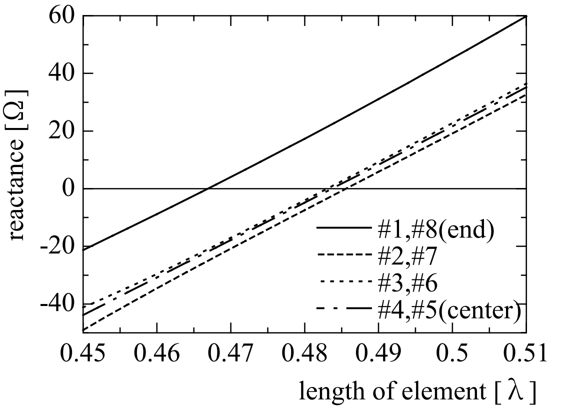

Fig. 2 Reactance component of each element when all elements' lengths are varied

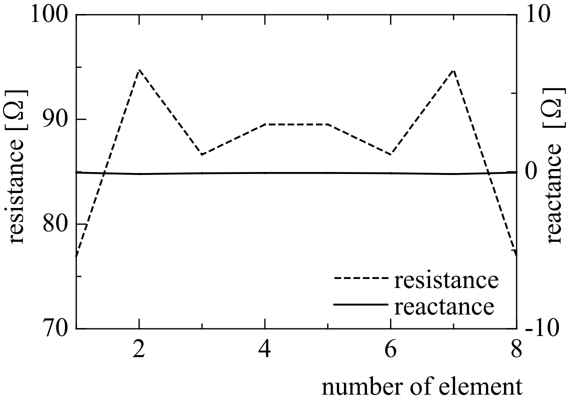

Fig. 3 Input impedance of each element when all elements' lengths are adjusted

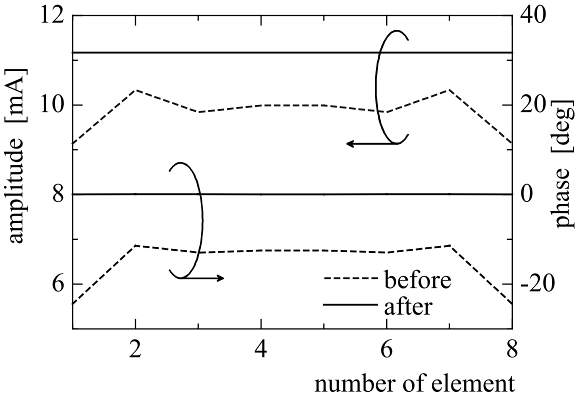

Fig. 4 Amplitude and phase of the current of the each element

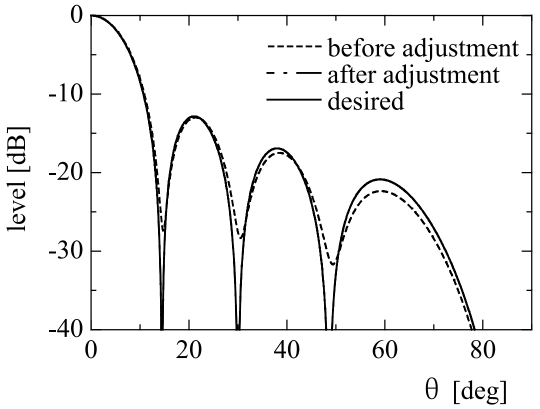

Fig. 5 Radiation pattern of the designed antenna using the method

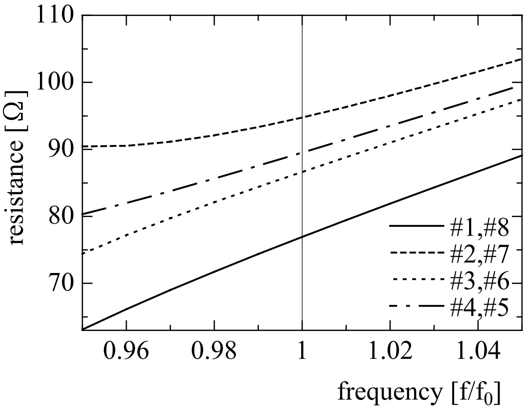

Fig. 6 Frequency characteristics of resistance component of the each element

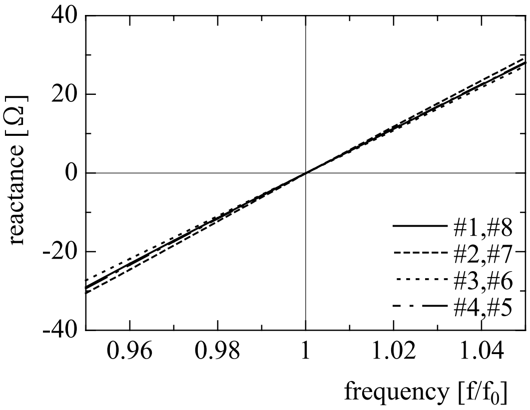

Fig. 7 Frequency characteristics of reactance component of the each element

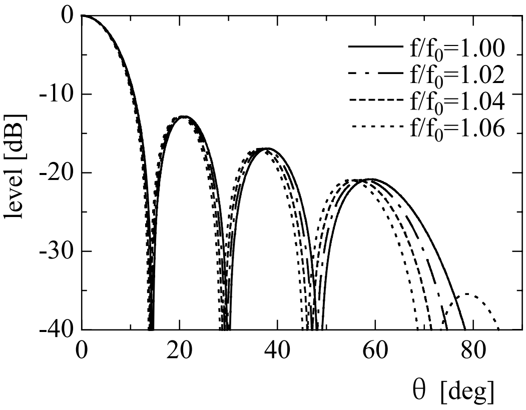

Fig. 8 Deviation of the radiation pattern caused by frequency shift

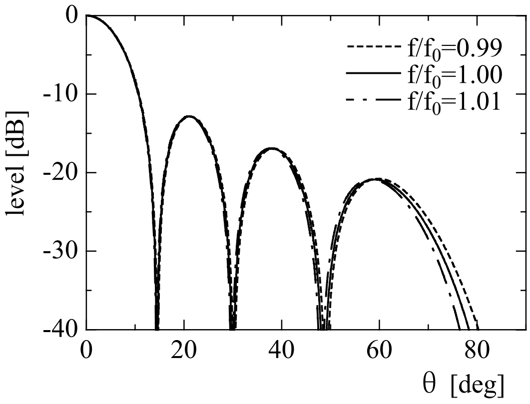

Fig. 9 Radiation pattern when the frequency is shifted ±1% from the center frequency

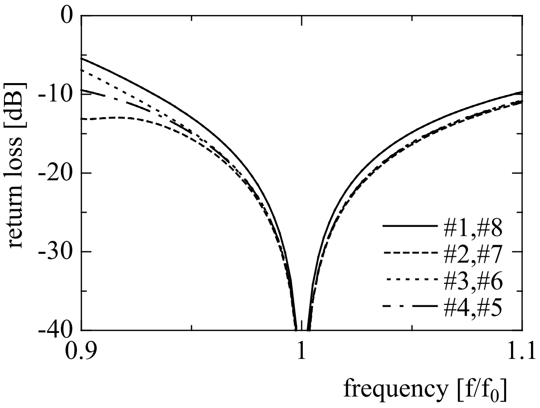

Fig. 10 Return loss characteristics of each element

Table 1 Comparison between initial values and resultant values

before adjustment

element number	1	2	3	4	5	6	7	8
element length [λ]	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
input voltage [V]	1.000 +j 0	1.000 +j 0	1.000 +j 0	1.000 +j 0	1.000 +j 0	1.000 +j 0	1.000 +j 0	1.000 +j 0
current [mA]	8.319 -j 3.780	10.130 -j 2.050	9.590 -j 2.205	9.755 -j 2.163	9.755 -j 2.163	9.590 -j 2.205	10.130 -j 2.050	8.319 -j 3.780
input impeadance [Ω]	99.63 +j 45.27	94.84 +j 19.19	99.04 +j 22.77	97.71 +j 21.67	97.71 +j 21.67	99.04 +j 22.77	94.84 +j 19.19	99.63 +j 45.27

after adjustment

element number	1	2	3	4	5	6	7	8
element length [λ]	0.4687	0.4863	0.4827	0.4837	0.4837	0.4827	0.4863	0.4687
input voltage [V]	0.860 +j 0	1.058 +j 0	0.969 +j 0	1.000 +j 0	1.000 +j 0	0.969 +j 0	1.058 +j 0	0.860 +j 0
current [mA]	11.180 +j 0.00769	11.163 +j 0.0174	11.184 +j 0.0116	11.170 +j 0.00933	11.170 +j 0.00934	11.184 +j 0.01169	11.163 +j 0.01749	11.180 +j 0.00769
input impeadance [Ω]	76.94 -j 0.0529	94.76 -j 0.1484	86.64 -j 0.0904	89.53 -j 0.0748	89.53 -j 0.00748	86.64 -j 0.0905	94.76 -j 0.1484	76.94 -j 0.0529