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RADIATION PATTERN OF THE WULLENWEBER TYPE PHASED ARRAY ANTENNA ALLOWING FOR MUTUAL COUPLING EFFECT

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1. INTRODUCTION

A study has been made on the consideration of the mutual coupling effects between elements of the Wullenweber type array antenna(1)and a theoretical calculation has been made on some specific examples.

In this paper, it is considered that, since the diameter of the cylindrical metallic conductor is fairly large with a smooth curvature, it may be approximated to an infinite plane of perfect conductor as far as several adjacent antenna elements are concerned, and also the mutual coupling effects of the other antenna elements away from those mentioned above is negligible due to their curvature which could not be approximated by a perfect plane.

2. RADIATION IMPEDANCE OF THE WULLENWEBER TYPE ANTENNA CONSIDERING MUTUAL COUPLING EFFECTS

As the first example, an approximate calculation has been made to get the mutual coupling effects between five adjacent antenna elements designated as #I to #V in Fig. 1, neglecting those elements located at a distance.

Fig. 1 (a) shows the original system while Fig. 1 (b) shows the approximate system for analysis. In order to obtain the self-and mutual impedance of the five vertically polarized wave half-wave length antenna elements arranged with a spacing of d, and with a distance of a from the infinite plane, the method of Improved Circuit Theory(2)has been applied by setting images of these antenna elements.

Supposing that $D=10\lambda$, $S=0.25\lambda$, and N=90pcs. and also the diameter of the two antenna elements being $a=\lambda/150$ with the distance between them $d=0.3665\lambda$, a calculation has been carried out.

On the other hand, a measurement has been made by using a partial model of the Wullenweber type antenna having a diameter of 3m to obtain the self-and mutual impedance at an experimental frequency of 1 GHz band for the distance d varied from 0 to 1.2λ.

These results are shown in Fig. 2 which shows that the agreement between the calculated and the measured values is fairly good, and that the value of the mutual impedance between the two antenna elements becomes smaller as the distance between them becomes larger, resulting decreased coupling effects.

In Fig. 2 the self impedance of #III and the mutual impedance between #III and #II in the arrangement of Fig. 1 (b) are also shown. Based on this result, an approximate calculation concerning the actual Wullenweber type antenna has been made, considering the mutual impedance between five antenna elements, the element being considered and the two on either side, neglecting those farther away.

3. THEORETICAL ANALYSIS OF RADIATION PATTERN OF THE WULLENWEBER TYPE ANTENNA CONSIDERING MUTUAL COUPLING EFFECTS

The antenna elements to be excited are 2n in number consisting of # 1 to # n and # 1′ to # n′; the other elements not to be excited must be taken into consideration for their effects. For this reason analysis has been made on

condition that the four antenna elements adjacent to # n and # n′ which are to be excited: # n+1, # n+2 and # n′+1, # n′+2 are terminated through a resistance of 50 Ω each, in order to take their effect into consideration.

The fundamental formula, given the consideration of the mutual coupling effects due to each of the multi-element antenna, and the impedance matrix be given by

$$\begin{pmatrix} 0 \\ 0 \\ V_n \\ \vdots \\ V_1 \\ V_{1'} \\ \vdots \\ V_{n'} \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} Z_{11}+50 & Z_{12} & Z_{13} & & & & & & & \\ Z_{21} & Z_{22}+50 & Z_{23} & Z_{24} & & & & & & \\ Z_{31} & Z_{32} & Z_{33} & Z_{34} & Z_{35} & & & 0 & & \\ & Z_{31} & Z_{32} & Z_{33} & Z_{34} & Z_{35} & & & & \\ & & & & & & Z_{31} & Z_{32} & Z_{33} & Z_{34} & Z_{35} \\ & & & & & & & Z_{31} & Z_{32} & Z_{33} & Z_{34} & Z_{35} \\ & & & & & & & & Z_{42} & Z_{43} & Z_{44}+50 & Z_{45} \\ & & 0 & & & & & & & Z_{53} & Z_{54} & Z_{55}+50 \end{pmatrix} \begin{pmatrix} I_{n+2} \\ I_{n+1} \\ \vdots \\ I_1 \\ I_{1'} \\ \vdots \\ I_{n'+1} \\ I_{n'+2} \end{pmatrix} \qquad (1)$$

which represents 2 (n + 2) sub-formulae.

In this formula, Ii = Ii′ and Vi = Vi′, because a symmetrical excitation is to be made. If the driving voltage to each antenna element is determined, it becomes possible to obtain each antenna current I_1 to I_n, the current flowing through the adjacent parasitic antenna element I_{n+1} to I_{n+2} and the voltage produced in the terminal resistor connected to the parasitic antenna V_{n+1} to V_{n+2} by solving the simple simultaneous equation with 2 (n + 2) unknowns.

As an example, the characteristics of the Wullenweber type antenna have been calculated for the conditions where D=10λ, s=0.25λ, N=90pcs., 2n=32pcs. and d=w=0.3665λ.

The current of each antenna element has been calculated from formula (1) on condition that the uniform amplitude (unit voltage of 1 V) co-phase voltages with V_1 to V_{16} are fed.

Using the current distribution in each antenna element, the radiation pattern has been calculated as shown in Fig. 3. In the same figure is shown the result when neglecting the mutual coupling effects between each antenna element and feeding with a current of co-phase and uniform amplitude.

No great difference can be recognized between these two radiation pattern, but care must be taken when such an exact requirement as side-lobe suppression is specified.

4. FEED SYSTEM OR SCANNING OF A SIDE LOBE SUPPRESSION FOR MUTUAL COUPLING EFFECTS

This section treats the horizontal radiation pattern of an electronic scanning antenna using a vertically polarized wave to make scanning over a range of a medium angle of plus and minus some tens of degrees within a horizontal plane, and the radiation pattern for the case when side-lobe suppression is made. As shown in Fig. 4, N of vertical half-wavelength antenna element numbered by # i along a part of a cylindrical metallic conductor were arranged with an angular separation of Φ degrees and the direction of the radiation pattern of the main beam Φ_m could be directed to the left or right of the forward direction.

As shown in Fig. 4, if the diameter of the cylindrical metallic conductor composing the Wullenweber type antenna is D and the angular separation between

each antenna element is Φ, their total number becomes $N = 360/\Phi$, among which the antenna groups fed in common are designated as # 1 to # $\bar{N}/2$ and # 1′ to # $\bar{N}'/2$, making $\bar{N}$ in all $\bar{N}$ is generally less than one third of N.

The formula for calculating the electric fields due to the current distribution is:

$$I_i(z_i) = a_i^{(1)} \frac{\sin k(h_i - |z_i|)}{\sin kh_i} + a_i^{(2)} \frac{1-\cos k(h_i - |z_i|)}{1-\cos kh_i} \qquad (2)$$

$$E = j60\frac{e^{jkR}}{R}\sin\theta\left\{\sum_{i'=1}^{N'/2}\left[a_{i'}^{(1)}\frac{\cos(\pi/2\cos\theta)}{\sin^2\theta} + a_{i'}^{(2)}\left\{\frac{\sin(\pi/2\cos\theta)}{\cos\theta} + \frac{1}{\sin^2\theta}(\cos\theta\sin\overline{\frac{\pi}{2}\cos\theta} - 1)\right\}\right] \times M(\theta, \phi_m - (i' - \tfrac{1}{2})\Phi) + \sum_{i=1}^{N/2}\left[a_i^{(1)}\frac{\cos(\pi/2\cos\theta)}{\sin^2\theta} + a_i^{(2)}\left\{\frac{\sin(\pi/2\cos\theta)}{\cos\theta} + \frac{1}{\sin^2\theta}(\cos\theta \times \sin\overline{\frac{\pi}{2}\cos\theta} - 1)\right\}\right] M(\theta, \phi_m + (i - \tfrac{1}{2})\Phi)\right\} \qquad (3)$$

$$M(\theta\phi_m) = \sum_{n=0}^{\infty}\varepsilon_n e^{j\frac{\pi}{2}n}\cos n\phi_m\left[J_n(k\overline{\tfrac{D}{2} + s}\sin\theta) - H_n^{(2)}(k\overline{\tfrac{D}{2} + s}\sin\theta)\frac{J_n(k\frac{D}{2}\sin\theta)}{H_n^{(2)}(k\frac{D}{2}\sin\theta)}\right] \qquad (4)$$

5. FORMULATION FOR NUMERICAL CALCULATION

In this paper, the mutual coupling effects have been taken into consideration to calculate the various characteristics. At this time two antenna elements are provided at both outside and terminated through a resistance of 50 Ω.

Fig. 5 shows the radiation pattern of the case where the main beam was shifted in direction in 4° steps over the range from 0 to 60 degrees.

As is seen from Fig. 5, the larger the directional angle of the main beam becomes, the larger its side lobe; the driving voltage to each antenna is changed in its amplitude in a modified cosine distribution and the computed result of application of the gradient method(3) (Amplitude Dependent Algorithms (ADA) method) is shown in Fig. 6.

As is seen from the figure, the side lobe level has been suppressed while the half-power beam widths and the gain have been decreased.

6. CONCLUSIONS

This paper has analysed the mutual impedance between each antenna element and has determined the quantitative degree of the variation especially the variation of the characteristics due to the mutual coupling effects during scanning within a medium angle. A study has also been made on the change of the radiation pattern due to mutual coupling effects when the side lobe level is suppressed, a change which becomes considerably large in the co-phase feed system. The Wullenweber antenna pattern attained characteristics good enough for practical use.

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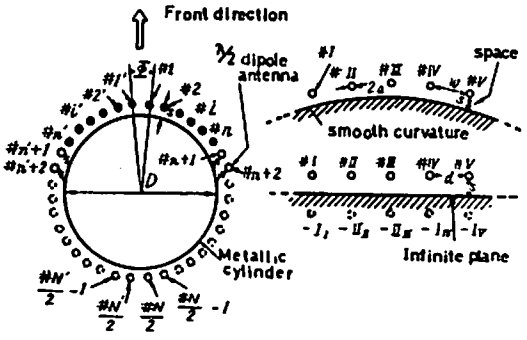

Fig.1 Construction of Wullenweber type antenna

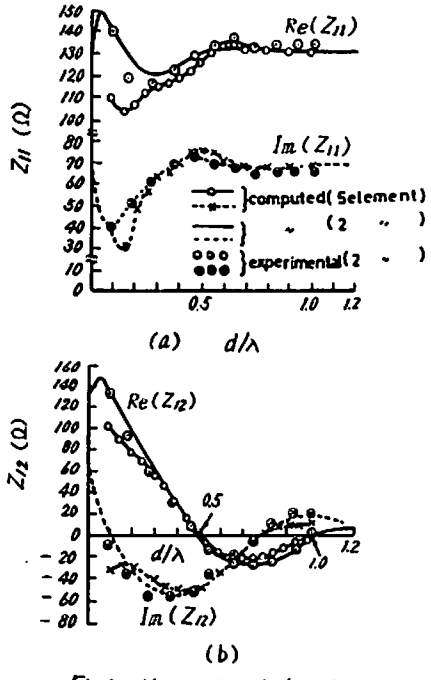

Fig.2 Measured and theoretical self-and mutual impedance

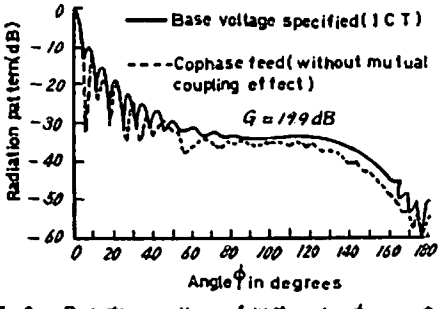

Fig.3 Radiation pattern of Wullenweber type antenna allowing for mutual coupling effect

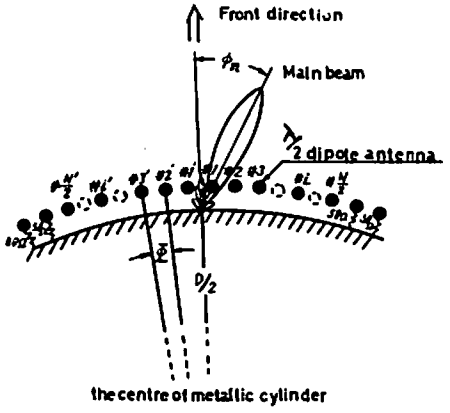

Fig 4 Geometry of Wullenweber type antenna

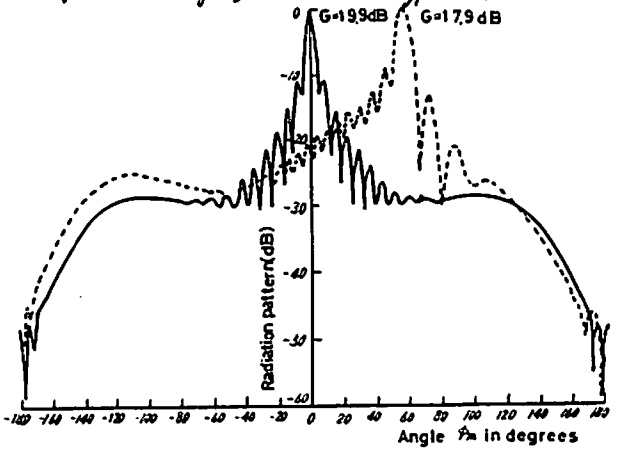

Fig.5 Radiation pattern of Wullenweber electronic scanning antenna

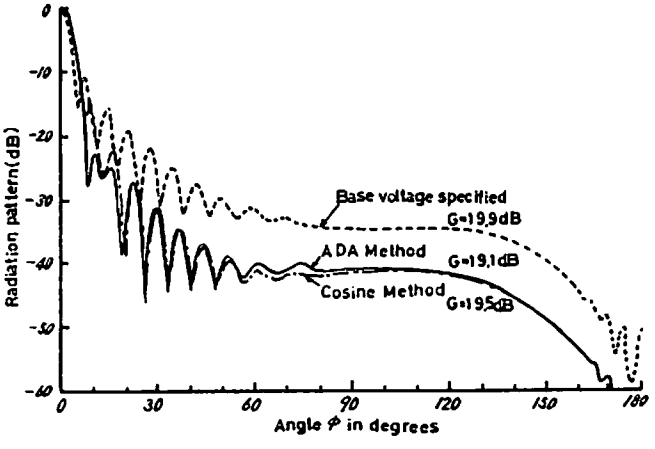

Fig.6 Radiation Pattern of Wullenweber type antenna for side-lobe suppression