Simulation Study of Partly Excited Parasitic Elements for an Aperture Array

Damri Radenamad [1], Taizo Isono [2], Tadashi Takano [1,3]
[1] *The University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-8656 Japan, E-mail:damri_r@yahoo.com, damri@radionet.isas.ac.jp*
[2] *Tokyo University of Science, 1-3, Kagurazaka, Shinjuku, Tokyo 162-8601 Japan*
[3] *The Institute of Space and Astronautical Science / JAXA, 3-1-1 Yoshino-dai, Sagamihara 229-8510 Japan, Email: ttakano@radionet.isas.ac.jp*

Abstract

Parasitic elements of half wavelength dipoles were proposed to be loaded between two apertures in the configuration of an array antenna with element apertures. Its objective is to bury the gaps, and to adjust the phase relation between the directly radiated wave from the element apertures and the scattered illumination wave by the dipoles.

In this paper, the equivalence of an incident wave and voltage sources in infinitesimal gaps is deduced to clarify the aforementioned phenomena. The validity of the proposed idea will be shown through the simulation study of partly excited parasitic elements in various perspectives and through the comparison with experimental results. It will be greatly useful to the design of ultra-large antennas in the future to study partly excited parasitic elements by simulation method in addition to experiment.

1. INTRODUCTION

Ultra-large antennas with a diameter of several 100 m or even 1 km are required for several applications [1]. The array antennas with element apertures are one of the promising concepts to construct an ultra-large aperture. The element apertures should have mechanical gaps between the adjacent element apertures for the tolerance against thermal expansion or manufacturing margin. However, the gaps cause the growth of grating lobes and the reduction of antenna gain.

In [2], they proposed to load parasitic elements of half wavelength dipoles between two apertures as shown in Fig.1 in order to bury the gaps, and to adjust the phase relation between the directly radiated wave from the element apertures and the scattered illumination wave by the dipoles by changing the length of the dipole [3]. The experiment results in [2] and [3] concluded that the gain of the array antenna with two parabolic reflectors can be increased by adding parasitic elements between the reflectors. Therefore, the mechanical and electrical gap between the reflectors is expected to be buried.

The objective of this paper is to clarify the phenomena which parasitic elements of half wavelength dipoles are partly excited by the incident wave from two apertures. Pocklington's integrodifferential equation is mathematically modified together with proposing the idea that that the effect of incident wave is equivalent to the voltage source in infinitesimal gap along the excited area. Its validity will be shown through simulation. By using this equivalence, this paper shows the simulation results to convince the accuracy of simulation model in analysing the situation that parasitic elements are partly excited by the incident wave. Interestingly, the phase dependency on the dipole length is also clarified.

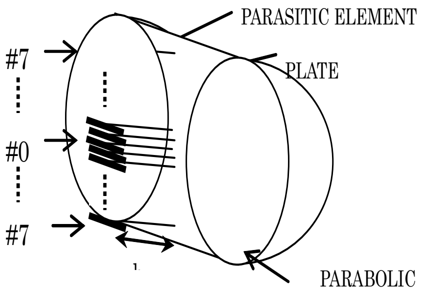

Fig. 1: Parasitic elements between two apertures

2. POCKLINGTON'S INTEGRODIFFERENTIAL EQUATION

As shown in Fig.1, let us consider 1 parasitic element. This parasitic element is partly excited by incident waves from two apertures. The incident wave induces the current on the parasitic element which makes this parasitic element reradiates a wave as illustrated in Fig.2.

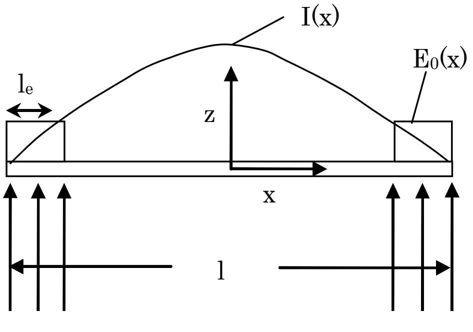

Fig. 2: A parasitic element partly excited by incident wave

As shown in Fig. 3, let us assume that a parasitic element is very thin. The equation that explains the relation between the incident wave and the current on the surface of a parasitic element is given as follows[4] :

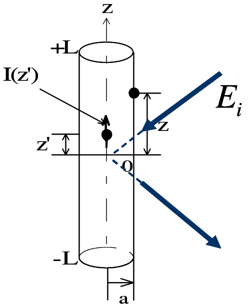

Fig. 3: Pocklington's model

$$\int_{\Delta z} I_z(z') * [\frac{\partial^2}{\partial z^2} + k^2] G(z,z')dz' = -j\omega\varepsilon E_{iz} \quad (1)$$

where I_z : Induced current in parasitic element, Δz : The region excited by plane wave (excitation area) in this case from –L to +L, G(z , z'): Green function, E_{iz} : Electric field of incident wave in z component (electric field tangent to a parasitic element).

However, to clarify the phenomena that a parasitic partly excited by incident wave, it is necessary to modify Pocklington's integrodifferential equation. The objective is to pave the way for a simulation software with an infinitesimal gap and voltage source to be applied to simulate a parasitic partly excited by the incident wave with sufficient accuracy.

A. Modification of Pocklington's Integrodifferential Equation

From equation (1), to solve this equation by the method of moment, the term of current ($I_z(z')$) in this equation should be expanded as follows:

$$I_z(z') = \sum_{n=1}^{N} a_n B_n(z') \quad (2)$$

where a_n : unknown value, $B_n(z')$: basis function (function that has the ability to accurately represent and resemble the anticipated unknown function, while minimizing the computational effort required to employ it).

By substitute the new term of $I_z(z')$ and multiply weighting function ($W_m(z)$) in equation (1), the modified Pocklington's integrodifferential equation can be obtained as follows:

$$W_m(z)\int_{\Delta z}[\frac{\partial^2}{\partial z^2}+k^2]\sum_{n=1}^{N} a_n B_n(z')G(z,z')dz' = -j\omega\varepsilon W_m(z)E_{iz} \quad (3)$$

And also to solve this equation (find the value of a_n , n=1,2,...,N), equation (3) must be changed in matrix form as follows:

$$[b_{nm}][a_n] = [C_m] \quad (4)$$

where $b_{nm} = \iint_{\Delta z} B_n(z')W_m(z)(\frac{\partial^2}{\partial z^2} + k^2)G(z,z')dzdz'$;

n=1,2,…,N; m=1,2,…,N,

$$C_m = -4j\pi\omega\varepsilon \int_{\Delta z} W_m(z)E_{iz}dz \text{ ; m=1,2,…,N.}$$

B. The Equivalence of Incident Wave and Voltage Source in Infinitesimal Gap

After modifying Pocklington's integrodifferential equation, in this step the objective is to show the equivalence of incident wave and voltage source in infinitesimal gap.

First, consider the value of matrix C_m ,

$$C_m = -4j\pi\omega\varepsilon \int_{\Delta z} W_m(z)E_{iz}dz \quad (5)$$

In this case E_{iz} is constant, we select the value of Δz sufficiently small so that $W_m(z)$ is constant, from equation (5) we can obtain value of C_m as follows:

$$C_m = -4j\pi\omega\varepsilon W_m(z_0)E_{iz}\Delta z \quad (6)$$

where $W_m(z_0)$ represents constant value inside Δz . Moreover, by proposing the idea that the incident wave causes voltage source in infinitesimal gap inside Δz ($E_{iz} = V_0\delta(z)$), thus substitute this value in equation (5).

$$C_m = -4j\pi\omega\varepsilon \int_{\Delta z} W_m(z)V_0\delta(z)dz \quad (7)$$

According the characteristic of delta function and $W_m(z)$ (it is constant inside Δz) , equation (7) can be modified as follows:

$$C_m = -4j\pi\omega\varepsilon V_0 W_m(z_0) \quad (8)$$

From equation (6) and (8), they both represent the value of C_m ; therefore, we can conclude their relationship as follows:

$$V_0 = E_{iz}\Delta z \quad (9)$$

To clarify this equation, the physical illustration is represented as Fig.4.

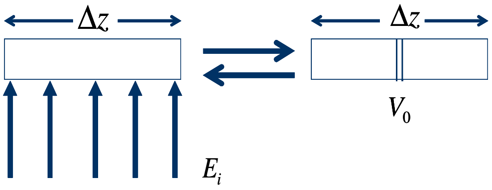

Fig. 4: The equivalence of incident wave and voltage source in infinitesimal gap inside Δz

3. SIMULATION RESULT

From the relationship above, it is implied that if one want to create the simulation model in order to analyse the case that any parasitic elements are partly or fully excited by incident wave, one can substitute the incident wave by voltage source which has its value according to equation (9).

As mentioned earlier related to the value of $W_m(z)$, its value should be sufficiently small so that simulation model will provide high accuracy.

Therefore, before using the relationship from equation (9), first it is necessary to validate the value of $W_m(z)$.

In this paper, all the simulation results will be carried out by using the simulation software namely, MMANA-GAL[5], which is available on the Internet.

A. *Validation of Δz Value*

To validate the size of Δz, a parasitic element was created, assume the excitation area is fixed, varying value of Δz. In this simulation, the length of a parasitic element is 75 mm which is half wavelength of feeding voltage frequency 2 GHz. The radius of a parasitic element is 2.2 mm. Both sides of a parasitic element were assumed to be excited. Each side has excited length 25 mm. Therefore, voltage sources are created along both sides. According to equation (9) and assume E_{iz} is 1 V/m, their magnitude vary according to the size of Δz (in this case 2, 4, 6, 8, 10 mm). Hence, the current of a parasitic element was observed case by case as shown in Fig. 5.

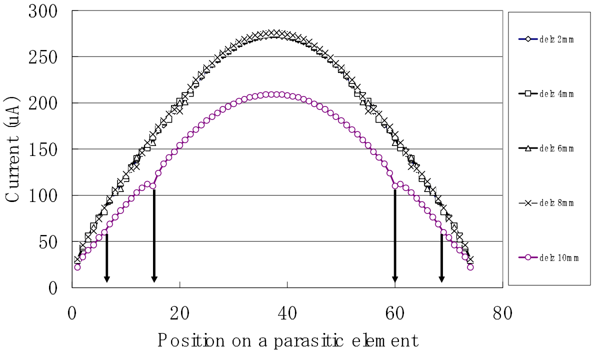

Fig. 5: Current distribution on a parasitic element and positions of voltage sources (the arrows)

From Fig.5, if the current at the center of a parasitic element is observed and thus plotted case by case as Fig.6, this information is useful to analyse the validity of equation (9).

From Fig.6, this information indicates that the length of Δz up to 8 mm gives constant current which means the same current distribution and radiation pattern. Furthermore, it also implies that the equation (9) is valid with sufficient accuracy up to 8 mm.

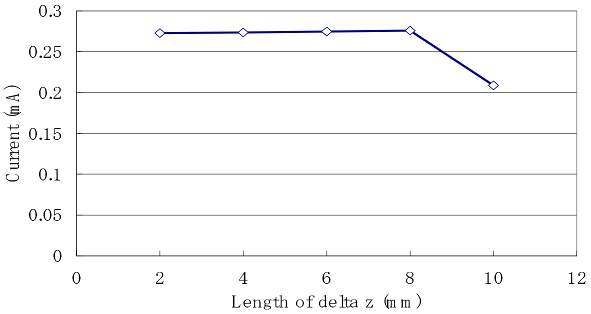

Fig. 6: Current distribution at the center of a parasitic element by varying the value of Δz

Next simulation, the relationship between excitation length and the magnitude of induced current will be investigated.

B. *Excitation Length Versus Current Distribution*

In this section, configure a parasitic element the same length, radius, and feeding voltage frequency as the previous section. Also, assume E_{iz} is 1 V/m. By using the value of Δz 2 mm, this simulation increases the excitation length each side of a parasitic element step by step from 2mm to 26 mm. Hence, the current at the center of a parasitic element was investigated case by case. The result is illustrated in Fig.7.

Fig. 7: Current at the center of a parasitic element versus excitation length

The result indicates that increasing excitation length of a parasitic element provides increasing induced current on a parasitic element and also increasing gain of this parasitic element.

C. *Simulation of A Partly Excited Parasitic Element on Perfectly Electric Conductor (PEC)*

In this section, the effect of the location above PEC of a parasitic element was observed. By comparing between two cases, quarter wavelength and non-quarter wavelength, both cases will be observed in light of radiation pattern. After obtaining the result, it will be extended to study the case that array of parasitic elements located quarter wavelength above PEC.

In this model, the length of a parasitic is 64.5 mm which is half wavelength of feeding voltage frequency 2.33 GHz. The radius of a parasitic element is 1 mm. The height of a parasitic element is 70 mm for non-quarter wavelength case and 32.25 mm for quarter wavelength case. The value of Δz in this simulation is 6mm. The obtained results were shown in Fig.8 and Fig.9.

As illustrated in Fig.8 and Fig.9, radiation pattern in case non-quarter wavelength above PEC showed undesired shape. However, radiation pattern of a parasitic element located quarter wavelength above PEC provides the same shape as radiation pattern of dipole in free space.

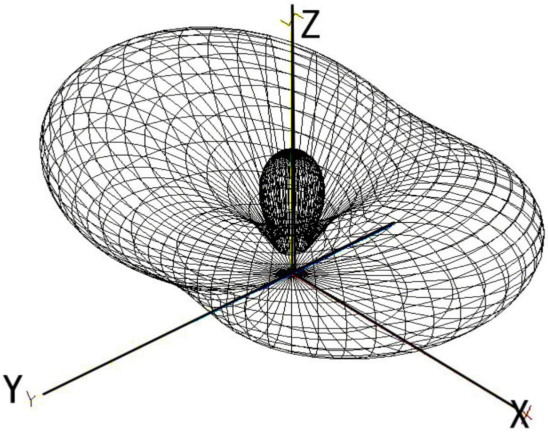

Fig. 8: Radiation pattern in case non-quarter wavelength above PEC

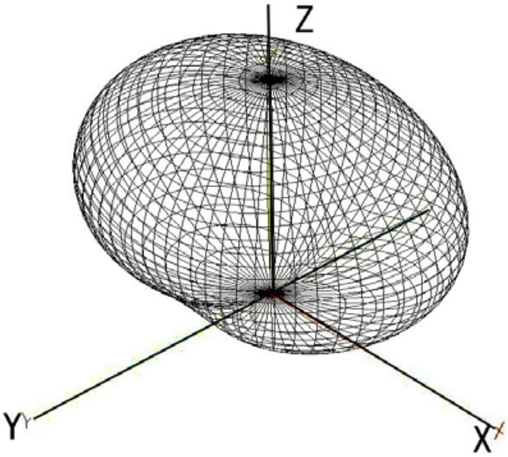

Fig. 9: Radiation pattern in case quarter wavelength above PEC

D. *Simulation of Array of Partly Excited Parasitic Elements Quarter Wavelength above PEC*

According to the previous section, a parasitic element located quarter wavelength above PEC provides desired radiation. Therefore, to extend the result from previous section, we will observe radiation pattern in case of array of partly excited parasitic elements in this section as model in Fig.10. In this model, originally taken from Fig.1, only parasitic element number #0, #1 both sides, #2 both sides, and #3 both sides were partly excited. For the remaining parasitic elements, there is no excitation from incident wave due to the structure of parabolic antennas. The excitation length of parasitic element number #0, #1, #2, and #3 are 27.25, 24.9, 17.8, and 5.4 mm respectively. The parameters of each parasitic element and frequency of voltage source including the value of Δz is the same as previous section. Also, all parasitic elements are located quarter wavelength above PEC.

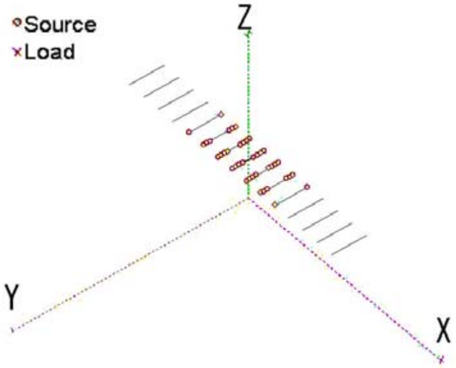

Fig. 10: Simulation model of array of partly excited parasitic elements located quarter wavelength above PEC

The method of simulation is as follows: first create parasitic element number #0, thus observe radiation pattern as done in Fig.9. Next, create parasitic element number #1 in the right side, also observe radiation pattern. Repeat the same step until successfully observe the case of 15 parasitic elements. Fig.11 is the example of radiation pattern in case of 15 partly excited parasitic elements. The distance between each element is quarter wavelength.

The observed result of this simulation indicates that the number of parasitic elements have the influence on radiation pattern and gain. As the number of parasitic elements increase, radiation beam becomes narrower and also its gain is constant as the number of parasitic elements reaching the value of 5 as indicated in Fig.12.

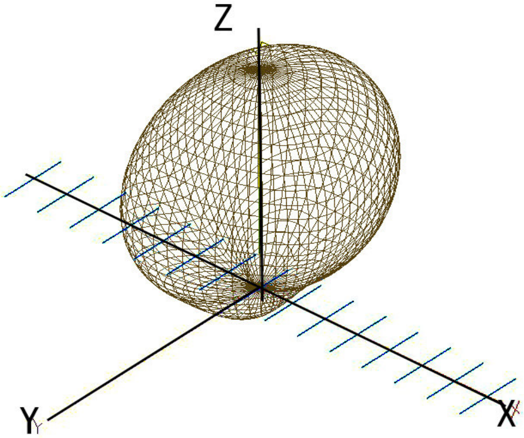

Fig. 11: Radiation pattern of 15 partly excited parasitic elements located quarter wavelength above PEC

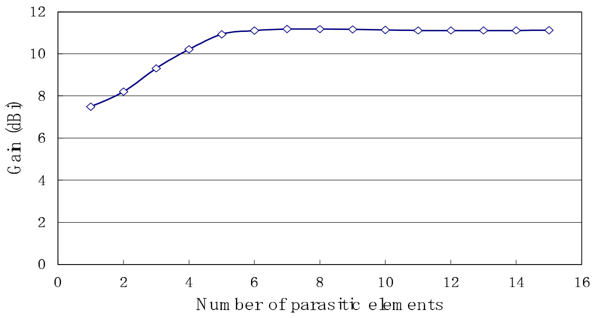

Fig.12: Maximum gain versus number of parasitic elements

E. The Effect of Length of A Parasitic Element

The objective of this section is to observe the effect of length of a parasitic element. The value 64.5 mm is selected as normalized length of a parasitic element. The radius is 1 mm. The value of Δz is 6mm. By changing the length of a parasitic element (increasing excited area on both sides), the observed antenna parameters are gain and the phase of the current at the center of a parasitic element. The result is illustrated in Fig.13.

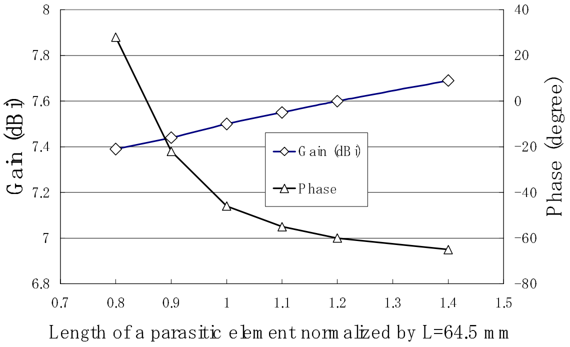

Fig.13: Maximum gain and phase versus the length of a parasitic element

The simulation result points out that the length of a parasitic element has the influence on its gain and phase of the induced current on a parasitic element. By increasing the length of a parasitic element, the phase of induced current on a parasitic element drastically decreases while the gain slightly increases.

4. CONCLUSIONS

An incident wave is equivalent to the voltage source in infinitesimal gap as expressed in equation (9).

From this result, many cases were demonstrated by using equation (9) to create simulation model in software MMANA, all simulation results can be summarized as listed below:

(1) Equation (9) is valid with sufficient accuracy up to $\Delta z = 8$mm.
(2) Increasing the excitation length of parasitic element provides increasing induced current on a parasitic element.
(3) Radiation pattern of a parasitic element located quarter wavelength above PEC provides the desired radiation pattern.
(4) As the number of parasitic elements increase, radiation beam becomes narrower and also its gain is constant as the number of parasitic elements reaching one value (in this case the value is 5).
(5) By increasing the length of a parasitic element, the phase of induced current on a parasitic element drastically decreases while the gain slightly increases.

These simulation results will be useful to the design of ultra-large antenna installed parasitic elements between apertures and also serve as the compared data for experimental observation.

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