Application of Impedance Extension Method to 2D Large-scale Periodic Array Antenna with Faulty Elements

Keisuke Konno[1], Qiang Chen[1], Kunio Sawaya[1], and Toshihiro Sezai[2]

[1] Department of Electrical and Communication Engineering, Graduate School of Engineering, Tohoku University 6-6-05 Aramaki Aza Aoba, Aoba-ku, Sendai, Miyagi, 980-8579, Japan

[2] Japan Aerospace Exploration Agency, Tsukuba Aerospace Center 2-1-1 Sengen, Tsukuba, Ibaraki, 305-3505, Japan

1 Introduction

The impedance extension method (IEM) has been proposed so far, as a method for analysis of a huge-scale periodic array antenna for power transmission from space solar power systems (SSPS) to the earth[1][2]. Since the IEM is an approximate method based on active impedance properties of elements in the periodic array antenna[3], the IEM can only be applied to the periodic array antenna. However, periodicity of the array antenna can not be kept in the areas where antenna elements are broken due to the trouble in feeding circuits or feeding cables. In this paper, it is reported that the IEM is extended to be valid to a two-dimensional large-scale periodic array antenna with faulty elements.

2 Local Admittance Compensation

The IEM is an approximate analysis method for a huge-scale periodic array antenna. In the IEM, active impedance of elements in a small array is extended to that of a huge array. It is supposed for the IEM that all elements in the huge-scale periodic array antenna are operating. However, some faulty elements may exist in the huge-scale array antenna due to cable disconnection and damage of a feeding circuit. It is thought that current distribution on faulty elements and elements around faulty elements is considerably different comparing with that of the normal elements. Therefore, the IEM must be improved for accurate analysis of the huge-scale array antenna including faulty elements.

As shown in Fig. 1, the local admittance compensation (LAC) technique is proposed to improve the IEM for analysis of the array antenna with faulty elements. In the IEM/LAC, analysis of all types of a small array having one faulty element is carried out and difference of active admittance from the small array fully consists of operating elements is calculated. Then, the active impedance is extended from the small array to the huge array, in similar to the conventional IEM. Finally, current distribution of elements around the faulty one is compensated locally by using the difference of the active admittance and feeding voltage. Since the LAC is based on the principle of superposition, the huge-scale array antenna having faulty elements on random position can be analyzed.

3 Numerical Results

3.1 Active Impedance

A two-dimensional periodic array antenna with ground plane, shown in Fig. 2, is analyzed by the IEM/LAC. Size of a small array and huge array is $N_x^s = N_y^s = 50$ and $N_x^h = N_y^h = 200$, respectively. Feeding amplitude distribution is given by 10dB-tapered Gaussian distribution and feeding phase is controled to realize main beam direction to $(\theta_{\text{main}}, \phi_{\text{main}}) = (10°, 0°)$. Almost 10

% faulty elements are randomly distributed in the huge array. Size of a local array where active admittance of elements is compensated is $N_x^l = N_y^l = 9$.

Absolute value of the active impedance of each element obtained by the IEM/LAC and conventional IEM is compared with that of the full-wave analysis in Fig. 3. The absolute value of the active impedance obtained by the IEM/LAC agrees well with that obtained by the full-wave analysis. On the other hand, the absolute value of the active impedance obtained by the conventional IEM is different from that obtained by the full-wave analysis.

3.2 Error estimation

Error estimation for mainlobe and the first sidelobe of actual gain obtained by the IEM/LAC is carried out. Error of amplitude and direction is estimated by following equation.

$$\text{Mean relative error of amplitude} = \frac{1}{M_{\text{trial}}} \sum_{m=1}^{M_{\text{trial}}} \frac{\left| \left| E_m^{\text{exact}} \right| - \left| E_m^{\text{approx}} \right| \right|}{\left| E_m^{\text{exact}} \right|} \tag{1}$$

$$\text{Mean absolute error of direction} = \frac{1}{M_{\text{trial}}} \sum_{m=1}^{M_{\text{trial}}} \left| \theta_m^{\text{exact}} - \theta_m^{\text{approx}} \right| \tag{2}$$

where, $\left| E_m^{\text{exact}} \right|$, $\left| E_m^{\text{approx}} \right|$ are the amplitude obtained by the full-wave analysis or IEM/LAC, respectively. θ_m^{exact}, θ_m^{approx} are the direction obtained by the full-wave analysis or IEM/LAC, respectively. M_{trial}, number of trials is 100.

Error estimation results are shown in Fig. 4. From the results, it is found that the actual gain obtained by the conventional IEM includes large error which is proportional to number of faulty elements since the conventional IEM ignores effect of faulty elements. On the other hand, error of the actual gain obtained by the IEM/LAC is small. However, error of the actual gain obtained by the IEM/LAC does not decrease monotonically when the size of the local array increases. From the results shown in Fig. 4, it is known that $N_x^l = N_y^l = 3$ (i.e., $1.5\lambda \times 1.5\lambda$) is enough size of the local array.

4 Conclusion

The LAC technique is proposed to improve the IEM for analysis of a huge-scale array antenna including randomly distributed faulty elements. Validity of the IEM/LAC compared with the conventional IEM is shown from results of numerical simulation.

5 Acknowledgements

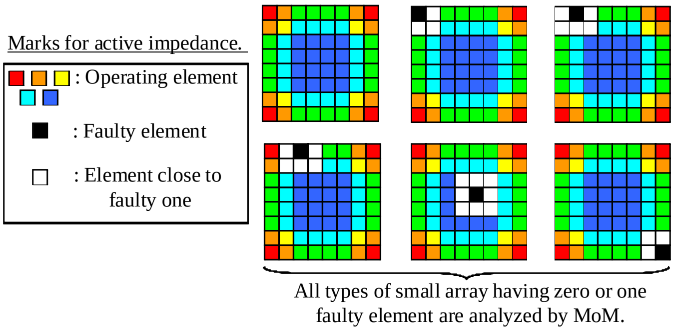
This work was supported by the GCOE Program CERIES in Tohoku University, and SCAT (Support Center for Advanced Telecommunications) Technology Research, Foundation. Supercomputing resources at Cyberscience Center in Tohoku University were used in this research.

References

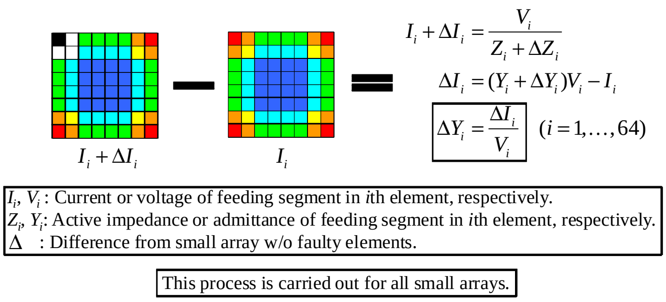
[1]K. Konno, Q. Chen, K. Sawaya, and T. Sezai, “Analysis of huge-scale periodic array antenna for SSPS using impedance extension method,” Proc. IEICE Int. Symp. Electromagn. Compat., pp.33-36, July 2009, Kyoto, Japan.

[2]K. Konno, Q. Chen, K. Sawaya, and T. Sezai, “Analysis of huge-scale periodic array antenna using impedance extension method,” IEICE Trans. Commun., vol.E92-B, no.12, pp.3869-3874, Dec. 2009.

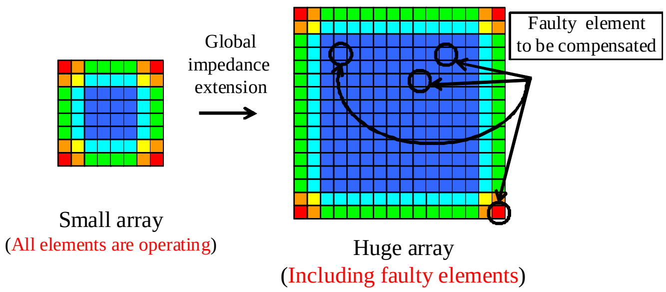
[3]R.C. Hansen, Phased Array Antennas, Sect. 8.3, John Wiley & Sons, 1998.



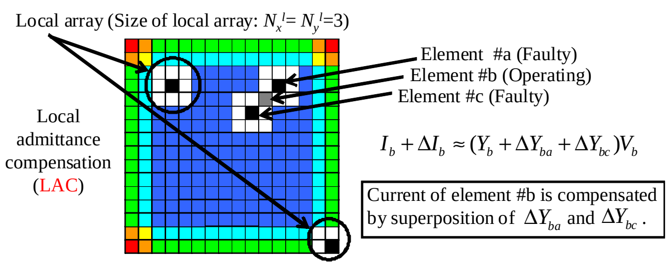
(a) Analysis of all types of small array.



(b) Calculation for difference of active admittance.



(c) Active impedance extension to huge array.



(d) Local admittance compensation.

Figure 1: IEM/LAC from 8×8 small array to 16×16 huge array.

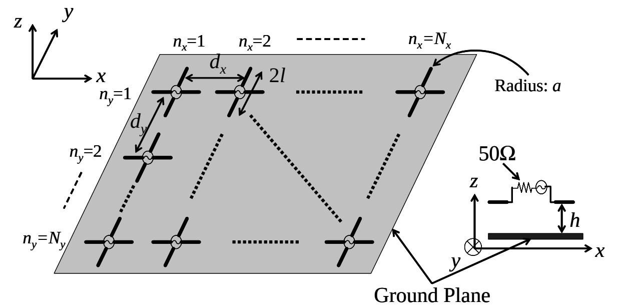


Figure 2: Two-dimensional cross dipole array antenna with ground plane for SSPS.

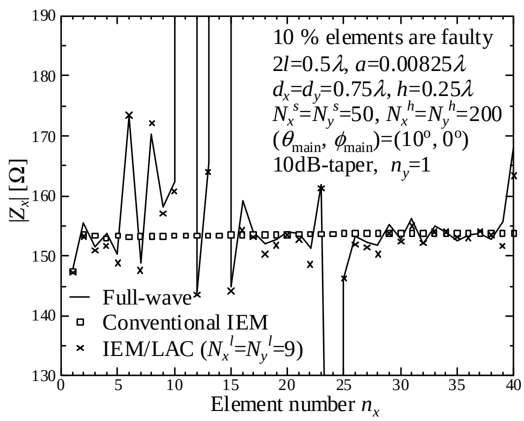
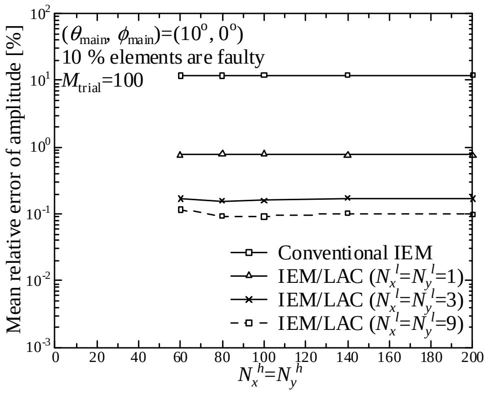
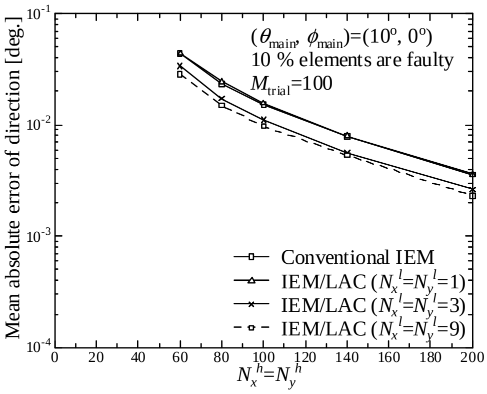


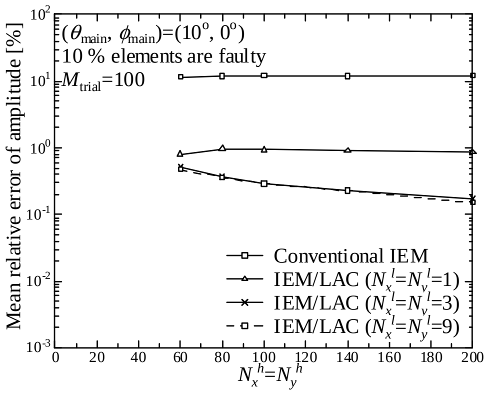
Figure 3: An example of active impedance of each element.



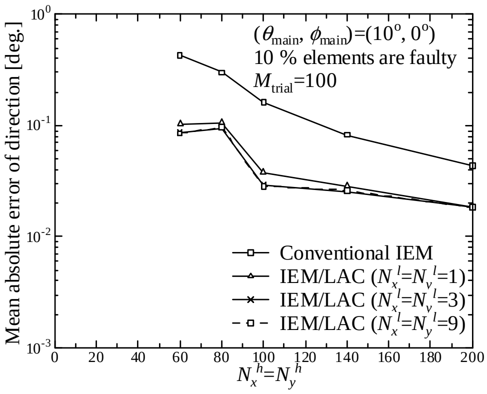
(a) Mean relative error of amplitude of mainlobe.



(b) Mean absolute error of direction of mainlobe.



(c) Mean relative error of amplitude of first sidelobe.



(d) Mean absolute error of direction of first sidelobe.

Figure 4: Error estimation of actual gain.