2024 International Applied Computational Electromagnetics Society Symposium (ACES-China) | 979-8-3503-5558-1/24/$31.00 ©2024 IEEE | DOI: 10.1109/ACES-China62474.2024.10699703

Efficient Modeling of Two-Dimensional Infinite Periodic Structures and Its Application to Method of Moments

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***Abstract*—A novel modeling method of two-dimensional infinite periodic structures is introduced, and they are modeled as infinite surfaces whose reflection coefficients are numerically known. In the similar manner as a layered media Green's function (LMGF), a reduced form of Green's function for the two-dimensional infinite periodic structures is obtained. Self/mutual coupling between source and observation point is formulated via method of moments (MoM). Numerical simulation of an antenna over frequency selective surfaces (FSSs) is performed, and it is found that the proposed modeling method works well for including contribution of the FSSs to the numerical results.**

Keywords—Periodic structure, Reflection coefficient, Green's function, Method of moments, Frequency selective surface

I. Introduction

Periodic structures have been widely used for designing practical antennas or scatterers, such as array antennas, FSSs, radio wave absorbers, and reflectarrays [1-3]. For example, array antennas for wireless power transfer systems and wireless communications have been designed as periodic structures[4]-[9]. Radio wave absorbers for radio frequency identification systems have been developed as periodic structures [10, 11]. Reflectarrays for wireless communication systems have been designed as periodic structures of non-identical elements [12-14]. Diagnosis technologies for finding defective elements or unintentional radiation sources using eigenmode currents of periodic array antennas have been developed so far [15-17].

On the other hand, numerical analysis methods are necessary for designing the periodic structures. MoM is well-known as one of the efficient numerical analysis methods for periodic structures [18]. During the numerical analysis of the periodic structures using MoM, two different options are available for their modeling, i.e. modeling as finite ones or infinite ones. Numerical analysis of the finite periodic structures using the MoM requires large computational cost because their size is usually larger than wavelength. Therefore, reduction of computational cost using fast MoM such as iterative solvers or direct solvers is necessary [19-22]. On the other hand, numerical analysis of the infinite periodic

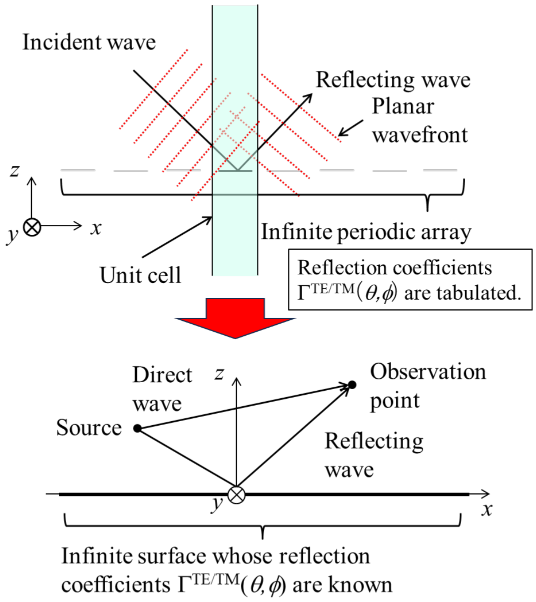

Fig. 1 Concept of the presented method.

structures using the MoM only requires small computational cost because the infinite periodic structures can be modeled as so-called unit cell via a periodic boundary condition (PBC) [23-26].

It is well-known that periodic structures enhance the performance of antennas. For example, an artificial magnetic conductor has been used to design low-profile antennas [27]. Instead of ground planes, bandstop FSSs have been introduced and multiband reflectarrays have been developed [28]. Although the periodic structures can enhance performance of antennas, numerical analysis of antennas with periodic structures is cumbersome.

In this paper, a novel modeling method of two-dimensional infinite periodic structures demonstrated in [29] is presented. The presented method models the infinite periodic structures as infinite surfaces via reflection coefficients. The reflection coefficients of the infinite periodic structures are easily available using PBC. Once the reflection coefficients are obtained, response from the infinite periodic structures can be formulated by a form of Green's function. Self/mutual impedance expression between source and observation points is obtained by MoM formalism. Numerical analysis is performed, and it is demonstrated that the presented method enables to model the infinite periodic structures accurately.

II. Modeling of Infinite Periodic Structures

Fig. 1 shows concept of the modeling of the infinite periodic structures via the reflection coefficients. The presented method models the infinite periodic structures as a surface whose reflection coefficients are numerically known. The reflection coefficients of the infinite periodic structures are obtained using MoM with PBC. In the similar manner as the LMGF, electromagnetic response between source and observation points can be described as summation of free-space Green's function corresponding to direct wave and TE/TM components of dyadic Green's function corresponding to reflection wave [30-33]. Once the electromagnetic response between source and observation points are described, self/mutual impedance between them can also be described using MoM. According to the presented method, mesh-free modeling of the infinite periodic structures is available. This point is a big advantage of the presented method. Rigorous description on the presented method is omitted here due to the limitation of the pages but is found in a previous publication [29].

III. Numerical Analysis

Here, performance of the presented method is demonstrated via a numerical example. Numerical analysis of a rectangular loop antenna over FSS composed of circular loop elements shown in Fig. 2 is performed.

Directivity of the rectangular loop antenna over the FSS is shown in Fig. 3. As a reference, Fig. 3 includes the directivity of the rectangular loop antenna over finite FSS composed of 7 x 7 circular loop elements. It is found that directivity of the rectangular loop antenna over the infinite FSS obtained using the presented method agrees well with that over the finite FSS. At this frequency band, it has been confirmed that the FSS demonstrates similar reflection performance as a ground plane [29]. Therefore, direct wave from the rectangular loop antenna and reflection wave from the FSS are in-phase at broadside direction. As a result, directivity of the rectangular loop antenna over the FSS becomes maximum at the broadside direction.

TABLE I shows CPU time for numerical analysis. The CPU time corresponds to 61 points of frequency response from 100 MHz to 400 MHz. It is found that CPU time of the presented method is much shorter than that of Full-wave analysis. As have been mentioned earlier, the presented method enables mesh-free modeling of the FSS and the total number of unknowns is only 44. On the other hand, full-wave analysis (i.e. conventional MoM) requires mesh modeling of the FSS and the total number of unknowns is 2249. Such difference of the total number of unknowns results in significant difference of the CPU time.

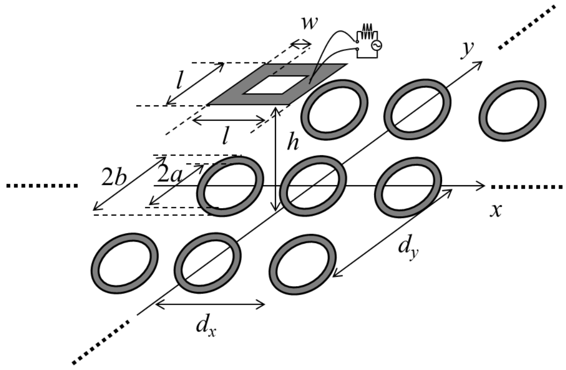

Fig. 2 Rectangular loop antenna over circular loop FSS

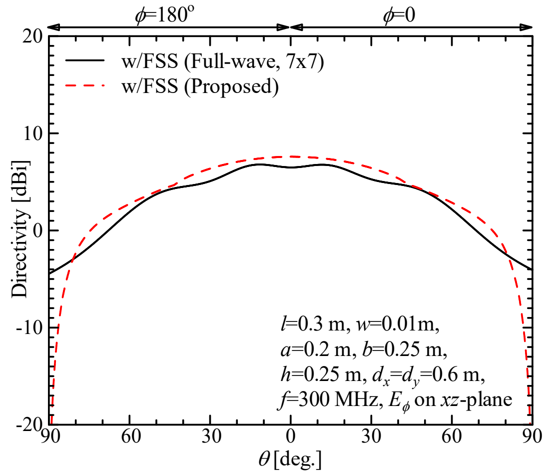

Fig. 3 Directivity.

TABLE I. CPU time

Method	CPU time [sec.]
Full-wave	21454
Presented	210

IV. Conclusions

In this paper, a novel modeling method of two-dimensional infinite periodic structures was presented. The presented method enables mesh-free modeling of the two-dimensional infinite periodic structures using their reflection coefficients. Numerical simulation was performed, and it was demonstrated that the presented method reduces computational cost without degrading accuracy.

Acknowledgment

This research was partly supported by the Ministry of Internal Affairs and Communications in Japan (JPJ000254). Discussions with the members of the Cooperative Research Project Program of the Research Institute of Electrical Communication, Tohoku University, were helpful for this work.

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