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RCS Evaluation of Reflectarray Antennas by Using the Asymptotic Technique

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***Abstract*-The radar cross section (RCS) of a reflectarray antenna is investigated, where the reflectarray antenna is phased to radiate a directional beam focused in the far zone for long-range applications communications or radar system. The RCS is simulated by considering a plane wave illumination on the reflectarray. This study focuses on the RCS investigation of the reflectarray while the effect of feed antenna is excluded for simplification. In particular, the UTD-type decompositions in terms of scattering and diffracted rays are employed to interpret the scattering mechanisms.**

***Index Terms* —Reflectarray Antenna, Radar Cross Section, Floquet Modes.**

1. Introduction

The reflectarray antennas are popularly used to produce high directive radiations for a variety of microwave applications including long-distance communications, satellite communications and military applications. In the military applications, the radar cross section (RCS) of antennas is an important consideration at the design stage to retain a low profile of system in the electromagnetic aspect. In general, a tradeoff between the RCS and antenna performance has to be considered. In this case, the understanding of scattering mechanisms will provide a good base for the justification of tradeoff.

This paper numerically investigates the RCS of reflectarray by considering a plane wave illumination over a reflectarray that is designed to radiate directional beams focused in the far zone. In particular, the UTD-type scattering field decomposition is performed to investigate the scattering mechanism, where the scattering fields are addressed in terms of directly scattered fields and truncation diffracted field. Due to the existence of phased elements, the RCS is greatly different from the scattering from conventional flat structures. Numerical examples will be presented in the conference.

2. Overview of RCS Prediction for the Reflectarray Antenna

Figure 1 illustrates the configuration of a reflectarray antenna, which is consisted of $N_x \times N_y$ reflecting elements for simplification. The elements are periodically located at $\bar{r}'_{nm} = (x_b + nd_x, y_b + md_y, 0)$ on the $z = 0$ plane with the index ranging by $(n = 0 \sim N_x - 1, m = 0 \sim N_y - 1)$, where d_x and d_y are the periods along the x- and y-dimensions, respectively.

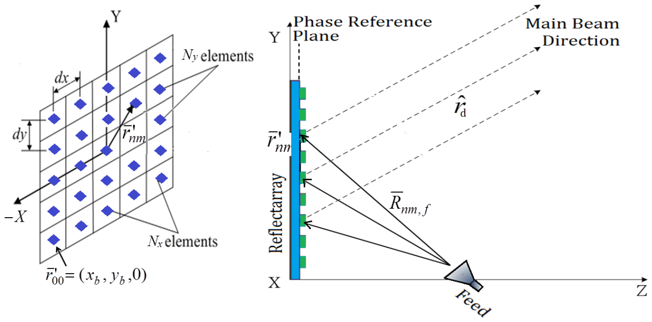


Fig. 1 The configuration of a reflectarray antenna, where the location parameters are also shown.

It is assumed that the reflectarray antenna is designed to radiate a directional beam pointing to the direction of $\hat{r}_d = (\sin\theta_d \cos\phi_d, \sin\theta_d \sin\phi_d, \cos\theta_d)$ for long-range microwave applications, where (θ_d, ϕ_d) is the direction of beam peak in the spherical coordinate system. Thus the reflecting elements are required to provide the following phase compensation:

$$\Phi_{nm} = k\left(R_{nm,f} - \bar{r}'_{nm} \cdot \hat{r}_d\right) - \Phi_{ref}\,, \tag{1a}$$

where

$$\Phi_{ref} = k\left(R_{00,f} - \bar{r}'_{00} \cdot \hat{r}_d\right) \pm 2\pi N\,. \tag{1b}$$

The RCS of the reflectarray antenna is afterward investigated by considering an incident plane wave illumination. In the current study, the effects of feeding antenna to the RCS are not considered for simplification. Thus only the RCS of reflecting elements are investigated. In particular, the scattering mechanisms are examined by performing the UTD-type ray decomposition over the overlapped Floquet modes of field transformation, which addresses the mechanisms in terms of direct scattering and truncation diffracted fields. Thus one considers the far fields scattered from the reflecting elements by the following solution:

$$\bar{E}_s(\bar{r}) = \frac{e^{-jkr}}{r} \sum_{m=0}^{N_y-1} \sum_{n=0}^{N_x-1} \bar{E}_i(\bar{r}'_{nm}) \cdot \left(\bar{\bar{Q}}(\bar{r}'_{nm}) \cdot \bar{\bar{\Gamma}}_A(\bar{r}'_{nm})\right), \tag{2}$$
$$e^{j\Phi_{nm}} e^{jk\left(\hat{r} \cdot \bar{r}'_{nm}\right)}$$

where the term inside the bracket is related to the scattering coefficients of the reflectarray. The incident field in (2) is the plane wave to illuminate the reflectarray. In order to perform the UTD-type analysis, the evaluation of (2) is alternatively performed via the decomposition of Floquet modes, which is achieved by using the following Poisson sum formula:

$$\sum_{n=N_1}^{N_2} f(n) = \frac{f(N_1^+)}{2} + \frac{f(N_2^-)}{2} + \sum_{p=-\infty}^{\infty} \int_{N_1^+}^{N_2^-} f(v) e^{-j2\pi pv} dv . \qquad (3)$$

Applying (3) to (2) will result in the following equation:

$$\bar{E}_s(\bar{r}) = \frac{1}{4}\sum_{\ell=1}^{4} \bar{E}_\ell^c(\bar{r}) + \frac{1}{2}\sum_{\alpha=1}^{4} \bar{E}_\alpha^e(\bar{r}) + \sum_{q=-\infty}^{\infty}\sum_{p=-\infty}^{\infty} \bar{E}_{pq}^f(\bar{r}) \qquad (4)$$

which transforms the discrete structure scatterings into that of continuous aperture scatterings. The phenomena and analysis of each term are interpreted as corner, edge and Floquet wave contributions, respectively, which is similar to these previously identified in [1]-[5]. In particular, according to the illustration in Figure 2, $\bar{E}_\ell^c(\bar{r})$ are related to the four corner effects, $\bar{E}_\alpha^e(\bar{r})$ are related to the four finite edge effects, and $\bar{E}_{pq}^f(\bar{r})$ are related to the effects of a finite aperture, which are discussed. The asymptotic solutions for these terms have been developed, and will be presented in the conference.

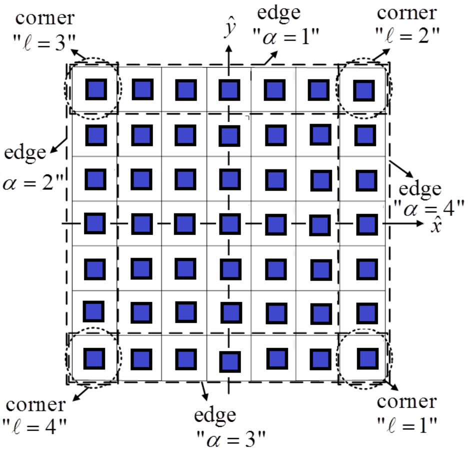
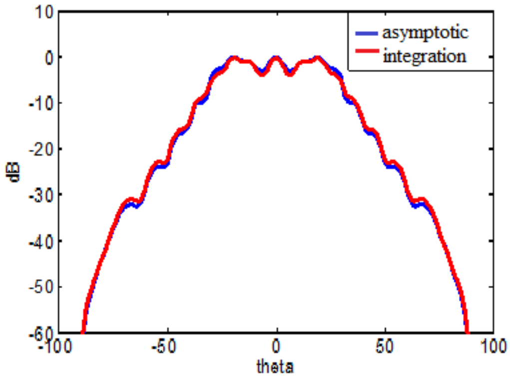


Fig. 2. The indexes of edges and corners to generalize the diffraction mechanism for the finite reflectarray.

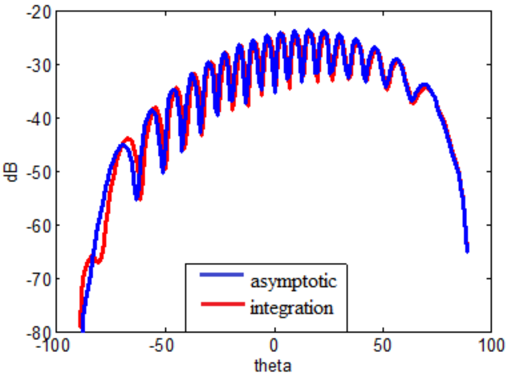
3. Numerical Examples and Conclusion

The Floquet mode phenomena of EM scattering from a reflectarray antenna structure with a plane wave illumination are examined via the asymptotic evaluation of the resulted radiation integrals. The scattering mechanisms in terms of reflected and edge diffracted ray fields are decomposed and evaluated to interpret the scattering fields by examining the local diffraction mechanisms.

Fig. 3 shows the bistatic scattering patterns whose results are compared between the evaluation by the numerical integration and asymptotic formulation. The parameters are given by $N_x = N_y = 20$, the operation frequency is 10GHz and the element spaces are $d_x = d_y = 0.5\lambda$, where the feed is located at (x,y,z)=(0,0,0.189m) with its boresite of radiation pointing toward the center of the reflectarray. It is desired to investigate the RCS of this reflectarray antenna when it is illuminated by an incident plane wave with (θ_i, ϕ_i) being the angle of incidence, and $\bar{r}' = (x', y', z')$ being the position vector of elements. It is assumed that the reflectarray antenna is designed to achieve a maximum far-field directivity in the direction where $(\theta, \phi) = (\theta_d, \phi_d)$ in the spherical coordinate system.



(a) RCS for (p,q)=(0,0) mode



(b) RCS for (p,q)=(1,0) mode

Fig3. RCS investigated for Floquet mode

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