Asymptotic Analysis of Scattering from Transmitarray for Near Field Focused

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Abstract— This paper presents the asymptotic formulation of ray fields in the decomposition of electromagnetic (EM) scattering mechanisms from a one-dimensional, semi-infinite and periodic array when it is illuminated by a line source. This technique can be applied to analyze the passive FSS (frequency selective surface) type periodic structure with identical elements, the transmitarray type antennas that are phased to radiate EM fields focused in the near zone of the array aperture. The solutions are built up based on the Floquet mode expansion of the scattering fields, and are obtained by asymptotically evaluating the resulted integrals to express the fields in terms of transmitted and edge diffracted fields as previously addressed in the framework of uniform geometrical theory of diffraction (UTD).

1. INTRODUCTION

This paper interprets the mechanisms in terms of ray decompositions based on the concept of uniform geometrical theory of diffractions (UTD). In this approach, the radiations of periodically located current sources are first decomposed into Floquet modes, in which every mode is equivalent to the radiation of continuous current sources with additional linear phase impressions. Fast convergence in the radiation computation can be achieved because relatively few modes will propagate to the target zone with the rest being evanescent. The ray decomposition is performed by asymptotically evaluating the radiation integral of each Floquet mode and interprets the total fields in terms of rays directly radiated from the aperture and diffracted from aperture truncations [1–5]. They have successfully decomposed the fields in terms of ray fields related to the radiation from infinite arrays and diffraction from finite truncations. The works related to the scattering problems of interested in this paper were investigated in [6], where a periodic array of identical elements illuminated by the radiation of a line source was considered. In particular, they examine the reflection type phenomena and focus on the phenomena interpretation according to the basic assumption of known equivalent distribution over the array, which appears not sufficient to become a useful tool in the realistic applications. The works presented in this paper perform a systematic investigation over the scattering problem, and extend the application scope to treat the transmitarray type antenna structures, where the array elements are periodically distributed with different elemental structures to account for the needs of phase changes in the designs of this types of array structure.

2. FORMULATIONS DEVELOPMENT

2.1. Problem Composition of the 2-D Radiation from a 1-D Array

One considers a semi-infinite, linear array of reflecting elements as illustrated in the configurations of Figure 1, where the elements are illuminated by the radiation from a line source. The line source is located at $\bar{\rho}_f = (x_f, z_f)$ and radiates EM fields by

$$u_f(\bar{\rho}) = \frac{1}{4j} I_0 H_0^{(2)}\left(k|\bar{\rho} - \bar{\rho}_f|\right) \cong \frac{e^{-j\pi/4} I_0}{4} \sqrt{\frac{2}{\pi k|\bar{\rho} - \bar{\rho}_f|}}\, e^{-jk|\bar{\rho}-\bar{\rho}_f|}. \tag{1}$$

The scattering field can be expressed as

$$u_s(\bar{\rho}) = \frac{1}{4j} \int_{x_a}^{x_b} u_f(\bar{\rho}_i) Q(\bar{\rho}') e^{j\phi(\bar{\rho}')} H_0^{(2)}\left(k|\bar{\rho} - \bar{\rho}'|\right) dx'. \tag{2}$$

Since the array elements are periodically located, thus substituting (1) into (2) gives

$$u_s(\bar{\rho}) = \left(\frac{I_0 d_x}{8j\pi k}\right) \sum_{n=-\infty}^{N} \frac{e^{-jk\ell_n} e^{-jk\rho_n} e^{j\phi_n^c}}{\sqrt{\ell_n}\sqrt{\rho_n}} G_n\left(k_{r,x}^n - k_{f,x}^n\right) \tag{3}$$

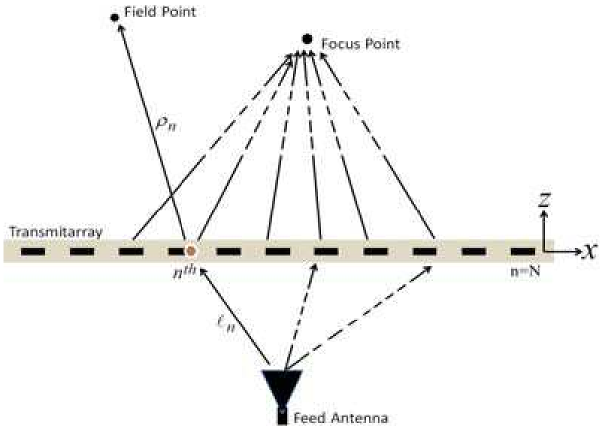


Figure 1: Illustration of 2-D transmitarray scattering/radiation problems. Where the fields are focused in the near zone at $\bar{\rho} = \bar{\rho}_o$.

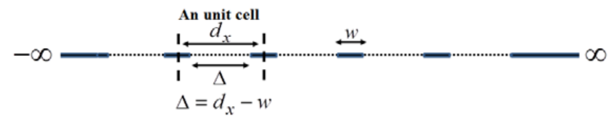


Figure 2: The array of metal strips for the scattering examination for transmitting scattering problem.

where the large argument approximation of Hankel's function has been used in (2), and

$$G_n(\xi) = \frac{1}{d_x} \int_{-d_x/2}^{d_x/2} e^{j\xi x'} Q_n(x') e^{j\phi_n^{\ell}(x')} dx' \tag{4}$$

2.2. Composition of Uniform Asymptotic Formulations

The Floquet modes are obtained by using the Poisson sum formula [7]:

$$\sum_{n=-\infty}^{N} f(n) = \frac{f(N^-)}{2} + \sum_{p=-\infty}^{\infty} \int_{-\infty}^{N^-} f(v) e^{-j2\pi p v} dv. \tag{5}$$

As a result, the pth Floquet mode of (4) can be expressed as

$$u_s^p(\bar{\rho}) = \left(\frac{I_0}{8j\pi k}\right) \int_{-\infty}^{x_e} \frac{e^{-j[k(\ell_v+\rho_v)+\beta_p x_i]} e^{j\phi_v^c}}{\sqrt{\ell_v}\sqrt{\rho_v}} G_v\left(k_{r,x}^v - k_{f,x}^v\right) \cdot e^{-j\beta_p x_i} dx_i \tag{6}$$

According to the UTD framework, (3) can be approximately formulated into the following format:

$$u_s^p(\bar{\rho}) = u_{dir}^p(\bar{\rho}) \cdot U\left(\mathrm{Re}(x_e - x_s)\right) + u_{end}^p(\bar{\rho}) F(ka) \tag{7}$$

where $U(\cdot)$ is the Heaviside step function and $F(\cdot)$ is the UTD Fresnel transition function to assure the uniform field distribution when the field point is across the shadow boundary of incident/reflected fields. The asymptotic solution is given by

$$u_{dir}^p(\bar{\rho}) = u_f(\bar{\rho}_s^p) G_{v_s}\left(k_x^s - k_x^i\right) \frac{j e^{-j\beta_p x_s}}{2k_z^s} \sqrt{\frac{\rho_c}{\rho_v^s + \rho_c}} e^{-jk\rho_v^s} \tag{8}$$

In (7), $u_{end}^p(\bar{\rho})$ is the scattering field due to the truncation effect at x_e. The asymptotic solution is given by

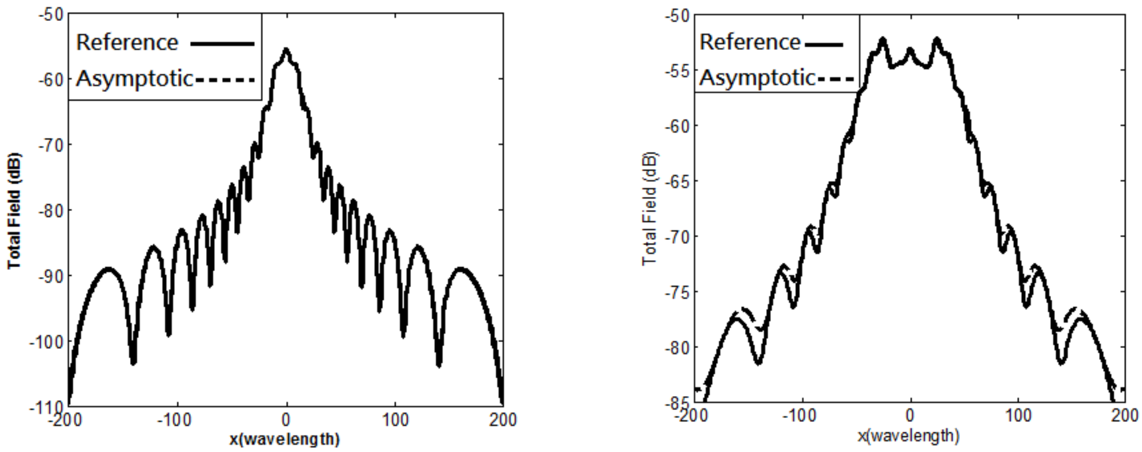
$$u_{end}^p(\bar{\rho}) = u_f(\bar{\rho}_e^p) G_N\left(k_x^e - k_x^{ie}\right) \frac{j e^{-j\beta_p x_e}}{2} \frac{e^{-jk\rho_e}}{\sqrt{\rho_e}} \cdot \left(\frac{e^{-j\pi/4}}{\sqrt{2k\pi}\left(\left(k_x^{ie} - k_x^e\right) + \beta_p\right)}\right) \tag{9}$$

The standard UTD Fresnel transition function is given by

$$F(\chi) = 2j\sqrt{\chi} e^{j\chi} \int_{\sqrt{\chi}}^{\infty} e^{-j\tau^2} d\tau \tag{10}$$

3. NUMERICAL EXAMPLES

One considers a finite array of infinitely thin metal strips as illustrated in Figure 2, where the period is $d_x = 0.3\lambda$, and the size of elemental strip is $w = 0.2\lambda$ at 10 GHz. The elemental structures of the array are selected by the unit cells in Figure 3, where 41 elements are considered in the examination. The line source is located at $(0, -60\lambda)$ and $(0, -80\lambda)$ respectively in front of the array.



(a) (b)

Figure 3: Numerical results to validate the solution developed in this paper. The total fields is considered at various case. (a) Without NF focused ($d_x = 0.3\lambda$). (b) NF focus point $(0, 10\lambda)$, line source located at $(0, -80\lambda)$.

4. CONCLUSIONS

This paper presents the asymptotic formulation of ray fields in the decomposition of electromagnetic (EM) scattering mechanisms from a one-dimensional, semi-infinite and periodic array when it is illuminated by a line source. The paper interprets the mechanisms in terms of ray decompositions based on the concept of uniform geometrical theory of diffractions (UTD). In this approach, the radiations of periodically located current sources are first decomposed into Floquet modes, in which every mode is equivalent to the radiation of continuous current sources with additional linear phase impressions. This technique can be applied to analyze the passive FSS (frequency selective surface) type periodic structure with identical elements, the transmit-array type antennas that are phased to radiate EM fields focused in the near zone of the array aperture.

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