Electromagnetic Model of All-Metal Reflectarray Antennas with Non-Resonant Elements

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***Abstract* - This paper presented the electromagnetic modeling to design the reflectarray antenna by using metallic non-resonant elements. An example of implementation at 38GHz of millimeter wave is presented to demonstrate the feasibility, where criss-cross elements are used. The use of non-resonant type element in reflectarray exhibits broader the bandwidths in the practical implementation than the conventional approaches of reflectarray antennas. The design methodology and examples are presented.**

***Index Terms* — Reflectarray**

1.   Introduction

The increasing interest of communications at millimeter waves (mmW) [1] makes it desirable to use high-gain antennas, where the reflectarray antennas [2]-[4] are attractive for its low profile and simplification in the beam forming networks (BFC) by using the relative phase differences between elements to compensate these of propagation in air. Due to the high energy loss in the substrate at mmW, all-metal reflectarray antennas [3],[4] attracted much effort.

This paper presents the electromagnetic modeling of metal reflecting elements with non-resonant characteristics. In this case, the reflecting behavior of non-resonant elements [3] exhibits broad-band characteristics of radiation except the cause by the change of elemental period due to frequency sweep. In particular, we present a simple implementation strategy to realize such reflectarray antennas, which is very useful for practical applications in the initial design stage. Design examples by using criss-cross shapes of elements will be presented to validate the concepts.

2.   The Description of Non-Resonant Type Elements

The metallic reflecting elements with non-resonant characteristics are convex elements with properly defined shapes of cross-section. The relative phase variation is created by the relative height differences with respect to a reference plane at the bottom of reflectarray. The definition of cross section shapes is important to govern the polarizations of scattering fields, where, for example, a liner thin strip is useful for a linearly polarized incident field. For dual-polarized radiation, Figure 1 shows a criss-cross shaped

element, where the parameter, h_2, is employed to create the desired phase variations. In Fig. 1, the elements are periodically distributed by w_1 in an infinite array configuration to simulate the scenario of reflectarray, where the Floquet port is set on the single element with periodic boundary conditions to simulate the illumination of plane wave incidence. The relative phase variations with respect to h_2 are found from the reflection coefficients of plane wave incidence. For a thin element, normal incidence of plane wave can be assumed. However, it is worthy to mention that the change of h_2 will also change the location of element's top surface that is used to measure the distance to the feed antennas. Thus when the relative phase differences between adjacent elements are computed by the related height difference, the distances to the feed antenna and to the direction of maximum fields need to be measured from the reference plane at the bottom instead of from the top of the elements. Fig. 2 shows the relatively linear phase variations at 38GHz, where the period is a half wavelength.
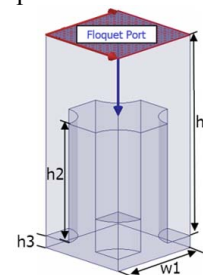

Fig. 1. Illustration of non-resonant elements with a criss-cross shape of cross-section.
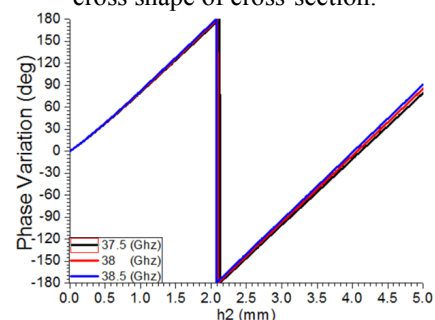

Fig. 2: The phase variation with respect to the change of height

3.   The Implementation of Reflectarray Antennas

The non-resonant elements exhibit characteristics of ray optics in the phase compensation. Fig. 3 illustrates the related difference of path delay that directly results in the phase difference, when a feed is placed to illuminate the reflectarray. In this case, to obtain an equal-phase superposition of scattering fields along $\hat{r}_d = (a_1, a_2, a_3)$, h_2 is selected to satisfy the following condition:

$$k(\ell_{nm} - \bar{r}'_{nm} \cdot \hat{r}_d - \ell_o) = 2p\pi , \qquad (1)$$

where the parameters of distances are illustrated in Fig.3. Here in (1), the index p is selected to minimize the value of h_2, which can be found in closed-form by

$$h_2 = \begin{cases} \dfrac{\ell_{nm,o}^2 - (\ell_o + p\lambda)^2}{2(z_{fo} + \ell_o + p\lambda)}; & a_3 = 0 \\[2ex] \dfrac{(z_{fo} + Aa_3) \pm \sqrt{(A + z_{fo}a_3)^2 - (1-a_3^2)(\ell_{nm,o}^t)^2}}{(1-a_3^2)}; & a_3 \neq 0 \end{cases}, \quad (2)$$

where

$$A = p\lambda + \hat{r}_d \cdot \bar{r}'_{nm,o} + \ell_o , \qquad (3)$$

and

$$\ell_{nm,o}^t = \sqrt{(x_{fo} - x'_{nm})^2 + (y_{fo} - y'_{nm})^2} . \qquad (4)$$

with $\bar{r}'_{nm} = (x'_{nm}, y'_{nm}, h_2)$.

$\bar{r}'_{nm} = (x'_{nm}, y'_{nm}, h_2)$
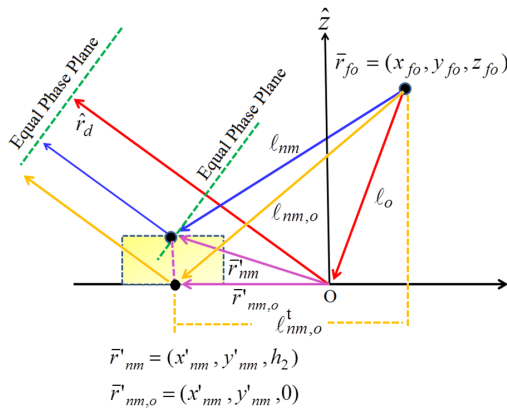$\bar{r}'_{nm,o} = (x'_{nm}, y'_{nm}, 0)$

Fig. 3: The illustration of phase differences due to the difference of path delay.

4. Demonstration Examples

The examples consider the radiation of pencil beam at 38GHz of mmW. The reflectarray is offset by 15 mm from the feed to avoid the blockage, and has dimensions of 10×9.6cm with $w_l = 4$mm to distribute 25×24 elements. The feed is located at the bottom of reflectarray at a distance of 65 mm to the reference phase plane of reflectarray as shown in Figure 4, whose radiation boresight points toward the array center by 45 degrees. In this case, the feed's radiation has a beamwidth of roughly 70 degrees.

The radiation pattern on the horizontal cut is shown in Fig. 5, which was obtained by using HFSS, a commercial code developed by Ansys [5]. It is observed that the gain is 29 dBi with a sidelobe level of nearly -20dB from the peak. The radiation is linearly polarized, where the cross-polarization level is very low in the main beam region.

5. Conclusions and Discussion

The presented results demonstrate the advantages of non-resonant elements in forming the reflectarray antennas with distinguished radiation characteristics. Experimental results will be presented in the conference presentation.
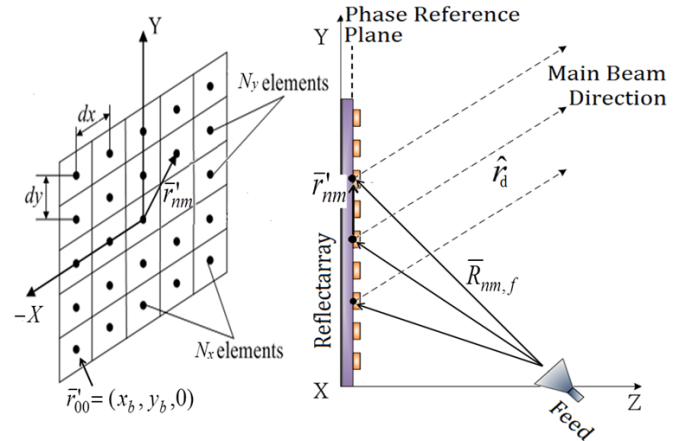

Fig. 4: Illustration of reflectarray antenna and the related parameters, which consists of non-resonant elements of criss-cross elements.
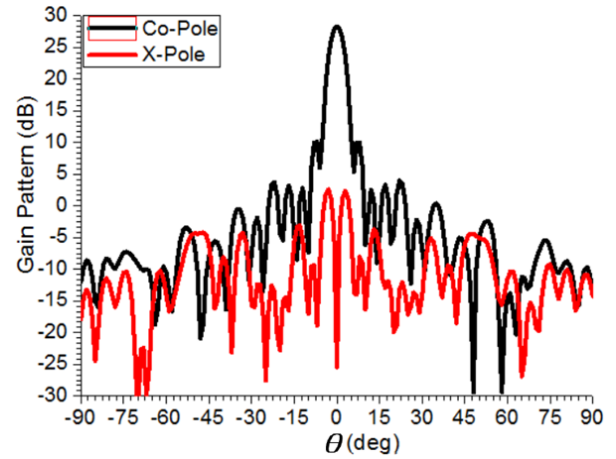

Fig.5. Simulation result of reflectarray antennas at mmW.

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