Long Slot Arrays - Finite Array Effects and Multilayered Configurations

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Abstract- This work focuses on the properties of a long slot array fed by a finite number of periodically located feeds spaced at "Nyquist" interval. In particular it addresses two key design aspects that were neglected in the original Green's Functions (GF) derivations: a) the end effects of the finite length slots, and b) the dielectric loading of a multi-layer radome to improve the array's front to back ratio. Numerical details and recent findings will be presented.

1. Introduction

In [1] an innovative wide band antenna structure composed of an array of long slots periodically fed at "Nyquist" interval (Fig. 1) has been reported. A prototype test array was manufactured and tested, showing its potential for multi-function radar applications. The potential lies in the fact that the observed band-width is extremely large and the polarization purity appears to be outstanding with respect to other standard wide band radiators. The principle of long slot array is similar to the concept of a "connected" dipole array, which was discussed in [2] and [3]. In [4] the theoretical derivation of the Green's function was presented for the simplest long slot configuration: an infinite long slot array in free space. In this presentation, the Green's function analysis is extended to cover important details of the design such as the edge effects of a finite array and dielectric loading of a multi-layer radome.

Here we present the final analytical expression for the magnetic currents over the long slots embedded in the (aperture) ground plane, assuming an infinitely extended array. Then the (end) effects of the finite number of feed points are discussed concerning its significant impact on the matching properties of the array structure. As in [4], this analytic study provides a direct solution in the form of the GF of the array structure.

2. Magnetic Current in Infinite Array Configuration.

The geometry under investigation consists of an infinite set of infinitely extended (x-oriented) slots which are etched out in a ground plane between two different half spaces, with each side loaded by different infinite planar stratifications, an example being the multilayered radome in Fig.1. The long slots are uniform along the x-direction, centered at $y_n = n_y d_y$. The cross section width of each slot is w_s and it is small in terms of a wavelength at the maximum frequency of interest. Each of the slots is excited by an array of y-oriented electric current elements of the same length of w_s, periodically located at $x_n = nd_x$. Each of these δ sources is assumed to have finite width t.

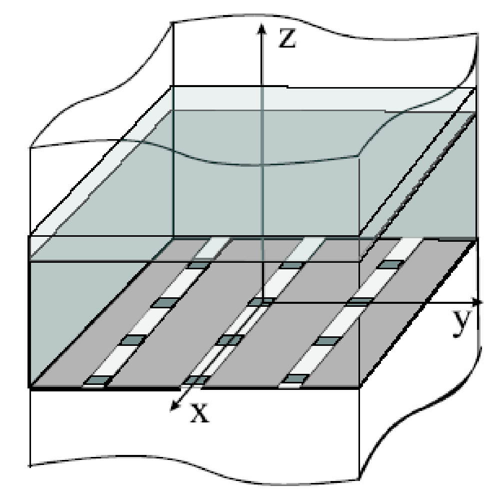

***Figure 1**. Geometry of the infinite long slot array, excited at "Nyquist" interval in the presence of a dielectric stratification (multi-layer radome).*

Generalized to the case with stratified dielectric loading, as presented in [4], the equivalent magnetic current distribution associated with the long slots can be assumed to be perfectly polarized along *x*, ***m***=$\boldsymbol{m}_x$. One can also assume that the currents are characterized by a separable space-dependence with respect to x and y; i.e, the magnetic currents are represented as (1)

$$m(x', y') = \sum_{n_y=-\infty}^{\infty} m_{n_y}(x', y')$$

with (2)

$$m_{n_y}(x', y') = v_{n_y}(x') \cdot m_t(y' - n_y d_y) = v_0(x') e^{-jk_{yo} n_y d_y} \cdot m_t(y' - n_y d_y)$$

where the y component is periodic and the excitation is uniform in amplitude and progressive in phase. Finally the transverse y-dependence, m_t, of the magnetic current in each slot is required to satisfy the quasi-static edge-singularities. The result is that it is possible to derive analytically the expression for v_0, the magnetic current in the zero-*th* cell, leading to an explicit spatial expression (3)

$$v_0(x) = \frac{d_y}{d_x} \sum_{m_x=-\infty}^{\infty} \frac{e^{-jk_{xm}x}}{\sum_{m_y=-\infty}^{\infty} G_{xx}(k_{xm}, k_{ym}) M_t(k_{ym})}$$

where M_t is the Fourier transform of the magnetic current m_t while G_{xx} is the Fourier transform of the superposition of two Green's functions representing the x- oriented magnetic field radiated into the half space above and below the ground plane ($z=0^{\pm}$) by an elementary x- oriented delta magnetic current source.

The present formulation is general enough to treat all geometrical configurations including the case with a backing reflector and configurations in which multiple layers of decreasing dielectric constants are used to cover the array. This latter structure is particularly useful as it allows the design of a long slot array using printed circuit board technology to achieve good front-to-back ratios and low active impedances for each feed point.

3. Magnetic Current in Finite Array Configuration

The magnetic current given in (4) was derived by using infinite array hypothesis; however, all practical arrays are finite in dimensions. The impact of the edge effects is especially important for configurations designed for large bandwidth. The edge effects in the present structures are expectedly non-symmetric in the *x* and *y* directions (parallel and orthogonal to the slots respectively).

The truncation effects associated with a finite number of slots are very similar to those found in standard finite arrays [5]. Edge waves present cylindrical spreading, i.e. they decay proportionally to $\rho^{-1/2}$, with ρ being the distance between a scattering point in the edge of the array and the observation point inside the array. A numerical tool is needed in order to quantify these effects. However, having a finite number of sources in each infinitely long slot does not alter the spectral formalism, so the GF spectrum of the long slot array fed by a finite number of feed elements in each slot remains the same analytically. Accordingly, by replacing the spectral summation in m_x with an integral inverse Fourier transform, the x dependence of the voltage distributions on each slot of infinite length slot can be obtained as

(4)

$$v(x) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \frac{I_e(k_x)}{D(k_x)} e^{-jk_x x} dk_x$$

The denominator in (5) represents the same spectral summation in m_y that appears in (4), if the array is composed of an infinite number of periodically phased slots, while the new numerator I_e represents the Fourier transform of the excitation law in x. In the case of a single long slot $D(k_x)$ was derived and given in [6]. Figure 2 presents, as an example, the voltage distribution on a single slot in free space with 20 feed elements spaced at d_x=0.5 λ, each one being excited with unitary electric current (1A, 50V) ? to form a beam in broadside direction. The gap of the slot is w_s=0.1 λ, while the width of the feed element (current source) is t=0.1 λ. The example considered here has a finite number of feeds but the slot is assumed to be infinitely long. The finite array solution oscillates around that of an infinite array. In particular the real part of the voltage oscillates around 50 Volts. These oscillations exhibit a period equal to the wavelength and the peaks do not coincide with the locations of the feed points along the linear array. These oscillations are attributed to the waves emanating from the end-points of the finite feed array. These waves are initially attenuated by a spherical wave spreading as in a standard linear array of discrete elements. However after a small decay the end point contributions remain essentially constant in amplitude and propagate along the entire slot independent of the dimension of the array, because a non-decaying mode is supported by the long slot and it is superimposed on top of the standard spherical wave.

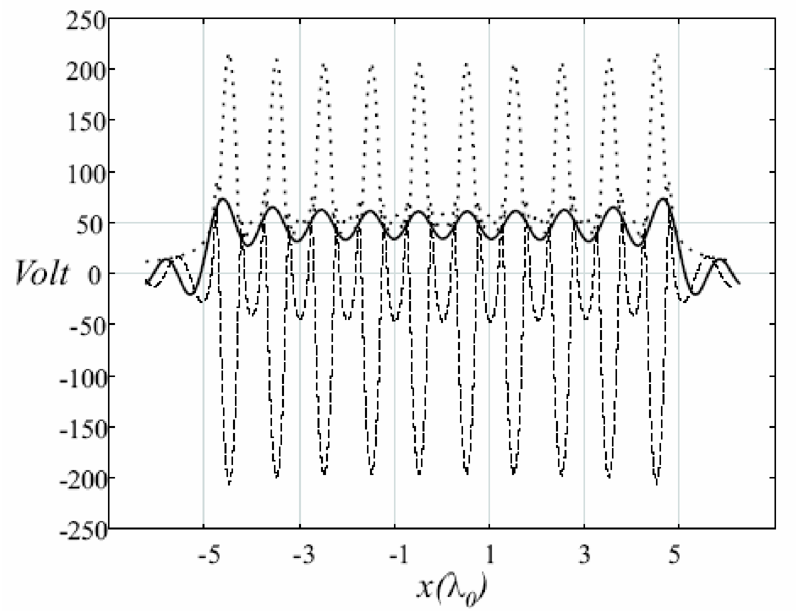

Fig. 2. *Voltage distribution on a single slot in free space with only 20 feed points in an infinitely long slot. The continuous, dashed and dotted lines represent the real, imaginary, and the amplitude respectively.*

Note that the magnitude of the voltage shown in Fig. 2 is very similar to the curve of Figure 6 in [7], representing the electric current on a connected dipole array. This indicates that the long slot and connected dipole array share similar features. For both it is important to refine the infinite array analysis to account for the edge effects, if one desires to rigorously determine the performances of a practical finite array.

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