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Citation for published version (APA):

Bruni, S., Neto, A., Maci, S., & Gerini, G. (2005). Non resonant slots for wide band 1D scanning arrays. In *Proceedings of 2005 IEEE Antennas and Propagation Society International Symposium, 3-8 July 2005, Washington D.C.* (pp. 113-116). Institute of Electrical and Electronics Engineers.
<https://doi.org/10.1109/APS.2005.1552596>

DOI:

[10.1109/APS.2005.1552596](https://doi.org/10.1109/APS.2005.1552596)

Document status and date:

Published: 01/01/2005

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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Non Resonant Slots for Wide Band 2D Scanning Arrays

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Abstract

A novel type of broadband integrated array scanning in one plane is proposed. Such arrays are aimed to meet the requirements typically set for airborne Synthetic Aperture Radars, while allowing the highest degree of integration between the T/R modules and radiating elements. The array is composed by broad-band leaky-wave slot elements radiating by means of a wedge shaped dielectric lens. As a preliminary step this paper is focused on a finite number of infinite slots radiating in an infinite medium of the same permittivity of the lens. The problem is studied through a very efficient semi-analytical spectral domain procedure based on the assumption of small width of the slots in terms of a wavelength.

Introduction

Synthetic Aperture Radars for airborne applications are being investigated by many Industries and research centers. Typical performance required for this application include wide bandwidth and wide angle scanning in one plane. Such requirements can be satisfied by resorting to stepped or flared horns. This kind of solution is not however convenient in terms of weight, costs, and BFN, and offers low capability to provide integrated system, since it implies a significant physical separation between the T/R modules and the radiating elements. In this paper, we present a broad-band solution that provides significant integration degree without compromising the system efficiency or the bandwidth. The theoretical basis relevant to the broad band leaky-wave radiating element is given in [1], [2] which present the Green's function (GF) of a thin infinite slot etched on a ground plane that separates two infinite dielectrics. A weakly dispersive leaky-wave radiation is observed in the denser medium which provides a high-directivity conical beam weakly affected beam-scanning with frequency. To show the practical applicability of this concept leaky-wave slot antennas covered by dielectric lenses have been designed to achieve a multi/wide band integrated capabilities, with highly-directive and frequency-independent beam. Such antennas have been manufactured and measured [3-4]. In [3], directivity in the E-plane is provided by means of a conical dielectric lenses with elliptical cross section. This latter study has proved that the integration of slots structures directly into the dielectric lenses leads to broad-band performance.

In the present work the investigation is extended to arrays of long leaky-wave slot elements. Since the directivity in the E-plane is provided by the array factor shaping, the elliptical lens is not necessary, and the effect of leaky radiation into

the denser medium is obtained by covering the array by a dielectric wedge (Fig. 1). The wedge angle is chosen according to the leaky wave beam angle. The flatness of the free-space interface implies advantages in the introduction of planar matching layers to reduce internal reflection. In order to provide prediction of magnetic currents, we provide here the theoretical analysis of a simplified model in which the wedge-shaped region is simulated by a semi-infinite medium. It is indeed assumed that a matching layer will eliminate the reflection from the dielectric-air interface. In a subsequent step (not presented here) the pattern is determined by using the radiated near field in the previous assumption to excite the wedge shaped region.

Fig. 1 Actual configuration of an array of N leaky-wave slots fed by microstrip-coupled radial stubs

Magnetic Currents in Finite Array of Long Slot

In this section we will consider the canonical problem in Fig. 2. It is composed of an array of N periodically displaced slots each one of them fed with a progressive phase and constant amplitude at a single point. In order to derive the equivalent magnetic currents, the width of the each slot is assumed as small in terms of the wavelength so that the separation of variables can be invoked for the space dependence of the current in each slot; i.e.,

Fig.2 Simplified model of slot array radiating in an infinite dielectric medium fed by impressed

$$m_n(x', y') = v_n(x')m_t(y' - nd_y) \quad n = 1, N$$

The transverse function $m_t(y')$ is assumed as independent on the slot index and such as to satisfy the edge singularity conditions while having a closed-form Fourier transform. The functions $m_n(x', y')$ is used as a basis function in a spectral domain method of moments.

Extending the formalism in [1], the spectral domain form of the integral equation which expresses the continuity of the magnetic field through the slots can be expressed by

$$\underline{\underline{D}}(k_x) \cdot \underline{V}(k_x) = \underline{I}(k_x) \Rightarrow \underline{V}(k_x) = \underline{\underline{D}}^{-1}(k_x) \cdot \underline{I}(k_x)$$

where $\underline{V}(k_x) = [\underline{V}_n(k_x)]_{n=1,N}^T$ is a N -element vector with component given by the Fourier transform of $v_n(x')$, $\underline{I}(k_x)$ is spectral vector of the impressed magnetic fields on each slot and $\underline{\underline{D}}(k_x)$ is a $N \times N$ matrix that represent the Green's function of the electric field from the electric sources in presence of the slots. The entries $D_{mn}(k_x)$ of $\underline{\underline{D}}(k_x)$ can be expressed by the spectral k_y domain integration of the double variable (k_x, k_y) spectral Green's function of the layered stratification (with short circuited slot) multiplied by the k_y -spectrum of $m_t(y')$. Possible layered stratifications in the feed region can be included in the GF, as practically useful in designing an actual feeding system (see Fig. 1).

The advantage of such a procedure with respect to a conventional sub-domain MoM is that the fine sub-wavelength details around the feeding points are not meshed, thus avoiding ill-conditioning. Furthermore the resulting size of the problem is of dimension equal to the number of slots, i.e. much smaller than usual.

As a numerical example, Fig.3 shows the currents pertinent to an array of three slots having width $w_s = 0.03 \lambda_0$, distance $d_y = 0.25 \lambda_0$ and mutual phase-shift $k_0 d_y \sin 30^\circ$. The dielectric relative permittivity is 11.7, and the excitation is provided by δ -gap impressed currents with dimensions $0.06 \lambda_0$. The results from this method (inversion of a 3×3 matrix) are successfully compared with those from a conventional sub-domain method with 400 unknowns.

Fig. 3 Currents on an array of three slots: real part (a), imaginary part (b).

The semi-analytical spectral expressions for the magnetic currents provide the tool for investigating the more general dispersion properties of the slots in this array environment. In particular since a different spectral expression applies for

each slot it is possible to study the leaky-wave attenuation and propagation constant of each slot as a function of its distance from the array edges.

Fig.4 presents the S-parameters for an array of two micro-strip excited slots, operating in X-band. It is apparent that this array configuration allows to operate from 8 to 12 GHz with directive elements that are simultaneously well matched and well mutually isolated. The study of the propagation constant and the reason for the isolation between the elements in array configuration will be discussed during the oral presentation.

Fig. 4 S parameter of an array of two slots

Conclusions

A novel array based on the wide band leaky elements is suggested. A simplified model for the current prediction has been formulated by a spectral domain MoM which uses entire domain basis functions synthesizes through the transmission line GF. The results have been validated via comparison with those obtained via a standard element by element MoM analysis. During the presentation, the field obtained by the semi-infinite medium model will be applied to excite the wedge shaped region.

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