UWB, Wide Angle Scanning, Planar Arrays Based on Connected Dipoles Concept

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***Abstract*— In this paper the impedances of connected arrays of slots and dipoles are presented. The study is based on the rigorous Green's Functions (GF) of the two structures in infinite array environments. The preliminary investigations indicates that the potentials of the connected slots when scanning are limited, due to the excitation of a leaky wave mode that can propagate between the continuous and the slotted metallic planes. The connected dipoles do not suffer from any such poles.**

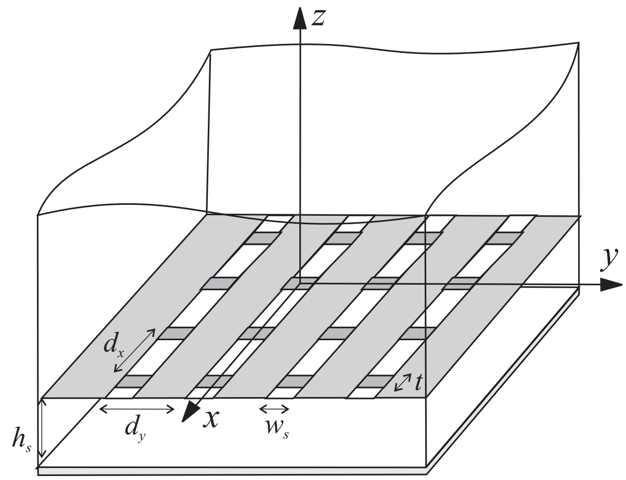
I. Introduction

A number of applications recently arising require high directivity and wide band widths as well as low profile and low cross polarization. These applications range from the radars for military or security environments in X band, to communication applications in Ku band, from earth based deep space investigation (Square Kilometer Array, [1]) to satellite based sub-mm wave instrumentation (SPICA, [2]). Connected arrays are now arising as one of the most promising antenna solution for such applications. While their origin probably stems from the concept of self complementarity in [3], [4], [5], recently it was B. Hansen [6] that brought the concept of connected array of dipoles to the attention of the antenna community. In [7] the connection concept was extended to the slot based configurations. In [8] and [9] the Green's function of a long slot array was derived and presented in analytical form, for both finite and infinite arrays, starting from a spectral representation of the field in each slot [10]. The availability of such Green's function greatly facilitated the design steps and eventually the first functioning demonstration of a planar connected array was presented in [11]. This 4x8 connected array of slots, radiating at broadside with reasonable efficiency thanks to a backing reflector, operated on an enormous band-width that spanned from 150 MHz to 650 MHz.

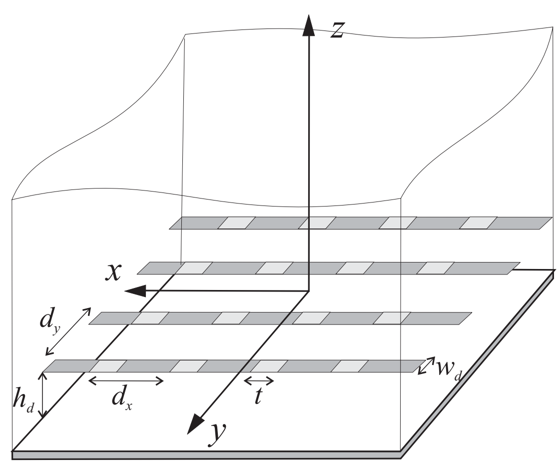
To the knowledge of these authors scanning capabilities of connected arrays have been not been demonstrated via measurements of hardware yet. In this article we will first demonstrate analytically that the Green Function of connected arrays of slots, as the one in [11], supports a disturbing leaky wave, propagating between the slots plane and the backing reflector, that significantly alters the performances of the array as the scanning angles increase. We will then show that in an equivalent dipole based structure such a leaky wave is not supported. This implies better scanning behavior.

II. Slot Based Connected Array

The reference connected slot array that we consider is shown in Fig. 1a, together with the pertinent reference system



(a)



(b)

Fig. 1. Geometries of 2D connected arrays with backing reflector a) long slot array, b) long dipole array

and characterizing parameters. The Green's Function (GF) of this array of long slots periodically fed and in the presence of the backing reflector was derived in [9]. From the GF the input impedance was also derived. The impedance can be expressed explicitly as follows:

$$z_{slot}^{br} = \frac{k_0 \zeta_0 d_y}{d_x} \sum_{m_x=-\infty}^{\infty} sinc^2(k_{xm} t/2) \cdot \qquad (1)$$
$$\frac{1}{(k_0^2 - k_{xm}^2) \sum_{m_y=-\infty}^{\infty} \frac{J_0\left(k_{ym} \frac{w_s}{2}\right)}{k_{zm}} (1 - jcot(k_{zm} h_s))}$$

The double spectral summation of the Floquet waves modes is nested with the summation of the Floquet waves associated to the direction parallel to the slots, m_x, being external. Since the dominant mode in such summation is $m_x = 0$ and $k_{x0} = k_0 sin\theta cos\phi$, it is useful to investigate the singularities of the spectrum in k_x when the array is radiating for $\phi = 0$ ($k_{y0} = k_0 sin\theta sin\phi$=0). Branch point singularities appear in $\pm k_0$. Polar singularities emerge from the dispersion equation that is obtained equating to zero the denominator in equation 1. The dispersion equation can be solved approximately using a first order Newton method, with a procedure similar to the one used in [10]. Fig.2 shows the results of the dispersion analysis for $-k_0 < Re[k_x] < k_0$ and $-k_0 < Im[k_x] < k_0$. The continuous curves, as a function of the slots widths, w_s, and parameterized for different heights, h_s, of the antenna with respect to the backing reflector, indicate the location of pole singularities, k_{xp}^s, of the GF. The array is characterized by $d_x = d_y = 0.5\lambda_0$, with $\lambda_0 = frac2\pi k_0$.

The poles represented in Fig.2 are of the leaky wave type, in the sense that they are characterized by a propagation, $Re[k_{xp}^s]$ and by an attenuation constant, $Im[k_{xp}^s]$, this latter associated to radiation losses. It appears that for smaller heights, h_s, the poles present an increasingly larger imaginary part and, most importantly, much wider dispersivity as function of the frequency.

The intuitive reason for the lower dispersivity when the backing reflector is farther away from the radiating slots is that the propagating mode of the slot is quasi TEM mode, travelling almost parallel to the slot direction, k_{xp}^s. As the backing reflector comes closer the modes fields distributions are much more affected by its presence and thus the propagation becomes more frequency dependent.

An increasing width of the slots is also associated to increased dispersivity. In fact, as the slot becomes wider, the field is less tightly bound to the slots and feels the presence of the ground plane.

However, since the width of the slots is essential for a large radiation bandwidth, [9], and t is only associated to a minor increase or decrease of an inductive localized series reactance, [10], the only parameter left to a wide band array designer is the backing reflector's height, h_s. Fig. 3 shows the real parts of the input impedance of connected slot arrays, over a broad frequency range. Named λ_c the wavelength

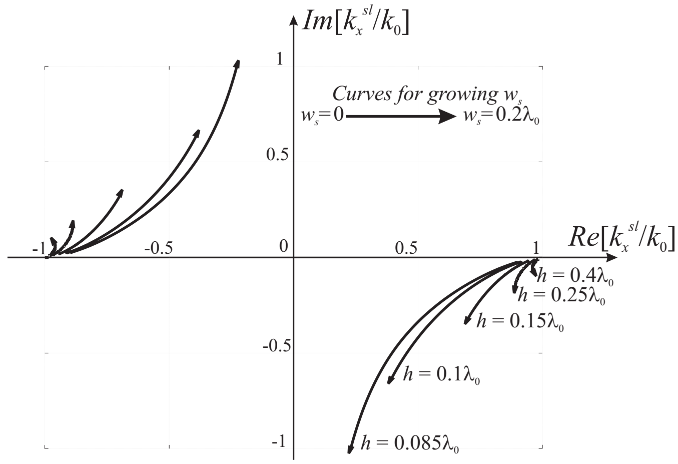


Fig. 2. Polar singularities in the complex k_x/k_0 plane when the array is pointing broadside. The dimensions are $d_x = d_y = 0.5\lambda_0, t = 0.1\lambda_0$, while w_s and h_s are varying.

at the desired maximum operating frequency, the curves are given for $h_s = 0.1\lambda_c$ and $h_s = 0.4\lambda_c$. The remaining array parameters are fixed at $w_s = 0.2\lambda_c$, $d_x = d_y = 0.5\lambda_c$ and $t = 0.05\lambda_c$. The curves are also given for different scanning (broadside and 45^o in the E and H planes). It is apparent that for smaller heights the resonances are shifted toward higher frequencies. More importantly, smaller heights, associated to more frequency dispersive pole singularities, imply the drastic narrowing of the useful band when scanning in the two planes.

It would appear that one should use relatively larger heights. In fact, even if not shown here, it is possible to match to -10 dB over a bandwidth of about 35%, an array characterized by $w_s = 0.2\lambda_c$ and $h_s = 0.3\lambda_c$, and for scanning up to 45^o in the E and H planes. Before moving the attention to connected dipoles, it should be noted that this solution would come at the cost of extreme sampling of the array plane, since the useful bandwidth occurs for lower frequencies. At such frequencies the inter-element periods are about $0.35\lambda_c$.

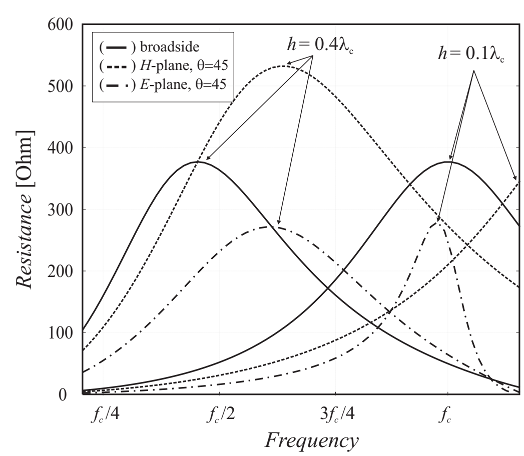


Fig. 3. Active impedance of a connected slot array as a function of the frequency for different heights

III. DIPOLE BASED CONNECTED ARRAY GF

The GF of a connected array of dipoles, with backing reflector as in Fig.1b, can be evaluated following an extension of the procedure derived in [9]. The procedure leads to the following expression for the active input admittance at each feed:

$$y^{br}_{dipole} = -\frac{k_0 d_y}{\zeta_0 d_x} \sum_{m_x=-\infty}^{\infty} sinc^2(k_{xm} t/2) \cdot \frac{1}{(k_0^2 - k_{xm}^2) \sum_{m_y=-\infty}^{\infty} \frac{J_0\left(k_{ym}\frac{w_d}{2}\right)}{k_{zm}(1-jcot(k_{zm}h_d)}} \quad (2)$$

The expression is extremely similar to the one in eq.1 with the important difference that independently from the characteristic array parameters the only pole occurring is located in $\pm k_0$ and corresponds to a micro-strip like TEM pole. Thus, this pole can be essentially neglected also in the design of a scanning array. The behavior of the impedance as a function of the width is more elaborate than in the slot case. Fig. 4 shows real and imaginary part of such impedance as function of the frequency, with a parametric variation with respect to w_d. The reactive energy localized in the feed gaps is growing as a function of the dipoles widths. In circuit terms the characteristic impedance of the micro-strip line, which is slowly varying as a function of the dipoles widths, is in parallel with this feed capacitance. As a consequence both real and imaginary parts of the impedance vary widely with the width.

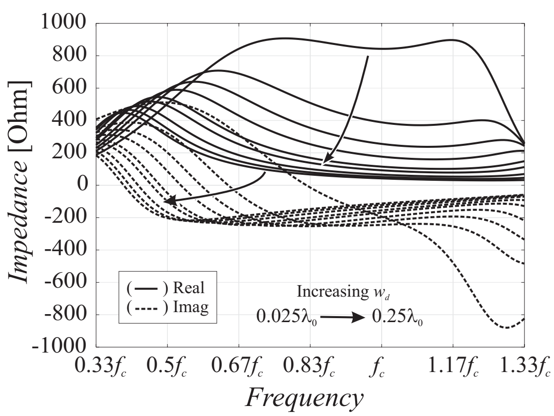


Fig. 4. Active impedance of a connected dipole array array as a function of the frequency for different widths, given $h_d = 0.3\lambda_c$, $t = 0.05\lambda_c$, $d_x = d_y = 0.5\lambda_c$ heights

IV. CONSIDERATIONS

The GF's of connected arrays of dipoles and slots, in the presence of backing reflectors are used to derive analytical expression for the active impedances in scanning configurations. In the slot case the GF is characterized by a leaky wave pole. The presence of this pole limits the useful bandwidth of slot based connected arrays especially when scanning. A mitigation of this degradation is achieved when one resorts to significantly over-sampling of the array. Dipole based connected arrays impedances are much more dependent from the feeding gap reactance than the corresponding slot based structures. The full comparison between the two structure will be discussed in the final version of the paper since some of the conclusions cannot be disclosed yet due to the patenting process.

REFERENCES

[1] D.H. Schaubert, A. van Ardenne, and C. Craeye ”The Square Kilometer Array (SKA) Antenna” *IEEE International Symposium on Pahsed Array Systems and technology* pp. 351-358, October 2003

[2] Core Science Requirements for the European SPICA Instrument, ESIRAL- REQ-0012, Iss. 0.1.

[3] N. Inagaki,Y. Isogai,and Y. Mushiake, “Ichimatsu Moyou Antenna - Self-Complementary Antenna With Periodic Feeding Points”, *Trans. IECE Japan* ,Vol. 62-B, pp. 388-395, April 1979.

[4] C.E.Baum, “Some Characteristics of Planar Distributed Sources for Radiating Transient Pulses”, *Sensor and Simulation Note 100,* AFWL, Albuquerque, 12 March 1970.

[5] M. P. Kesler, J. G. Maloney, and G. S. Smith, “FDTD Analysis of Novel Antenna Array and Substrate Concepts,” *ICAP/JINA Conf. on AP* Davos, April 2000.

[6] R. C. Hansen, “Linear Connected Arrays”, *IEEE Antennas and Wireless Propagation Letters,* Vol. 3, pp.154-156, 2004.

[7] J.J. Lee, S. Livingstone, R. Koenig, “Wide band slot array Antennas”, *Proceeding of AP- S Symposium*, Columbus, Ohio, Vol. 2, pp. 452-455, June 2003.

[8] A. Neto, J.J. Lee, “Infinite Bandwidth Long Slot Array” *IEEE Antennas and Wireless Propagation Letters,* Vol. 4, pp.75-78, 2005.

[9] A. Neto, J.J. Lee, “UWB Properties of Long Slot Arrays” *IEEE Transactions on Antennas and Propagation,* Vol. 56, no. 4, April 2006.

[10] A. Neto, S. Maci, “Green’s Function of an Infinite Slot Printed Between Two Homogeneous Dieletrics. Part I: Magnetic currents”, *IEEE Transactions on Antennas and Propagation,,* Vol. 51, No. 7, pp. 1572-1581, July 2003.

[11] J.J. Lee, S. Livingston, R. Koenig, D. Nagata,L. L. Lai, “Compact light weight UHF arrays using long slot apertures” *IEEE Transactions on Antennas and Propagation,* Vol. 54, No. 7, pp. 2009-2015, July 2006.