Element-Independent Design Technique for Wide Angle Impedance Matching Material

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***Abstract*—This paper presents a design technique for a wide angle impedance matching network material which does not require the knowledge of the analytical form of the scan impedance of the radiating element. The design procedure is therefore applicable for any type of array element and it is based on a Floquet-mode expansion. The presented approach is applied to the design of a multilayer Wide Angle Impedance Matching (WAIM) material for a phased array of patch elements.**

Keywords— phased arrays, impedance matching, wide angle impedance matching. radome.

I. INTRODUCTION

The variation of the main beam direction in a phased-array can lead to losses in the system with a consequent degradation of the antenna performance. These losses, which are usually referred to as scan losses, can be mainly associated with two phenomena. The former is the reduction of the antenna aperture with the increase of the scan angle whereas the latter is dependence of the active impedance of the radiating element on the scan angle. In fact, the mutual coupling between the radiating elements varies as the array beam is tilted off the boresight and this can lead to a significant reduction of the transmitted power at some scan direction [1]. Consequently, there is an impedance mismatch between the active impedance of the array and the characteristic impedance of the feeding network. This phenomenon determines a drastic reduction of the radiated power of the array at some scan angles. This problem can be resolved with a tunable feeding network. However, this solution increases the complexity and cost of the phased-array. An alternative and more cost-effective solution to the tunable feeding networks is represented by the WAIM technique. It consists of employing a properly-designed stackup of dielectric or more complex materials above the array in order to compensate the impedance mismatch between the array and the feeding network.

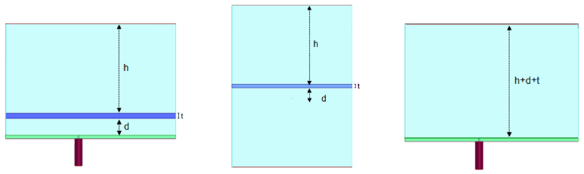
Most of the works available in the open literature provide the WAIM design for phased arrays comprising radiating elements for which the analytical form of their active impedance is well-known (*i.e.* dipoles and open waveguides). One of the first works shows how the scan blindness can be reduced to a problem of impedance mismatch [2]. In fact, the authors show how the scan blindness can be reduced by modifying the active impedance of the radiating element. In this work, however, an array of circular waveguides is considered. Later, by using this approach, studies aimed to match the active impedance of the radiating element of a phased array on a wide band by loading it with dielectric materials have been conducted [3]. More recently, WAIM surfaces realized with metamaterial have been proposed in order to improve the performance achievable with dielectric WAIM. For example, in [4], the design of a metamaterial is adopted in the case of an array of circular waveguides whereas the analysis and characterization of a WAIM surface for the case of an array of dipoles is performed in [5]. The system composed of the unit cell of the array and the dielectric layer is analysed with an equivalent transmission line approach. This model has been obtained by considering the equivalent transmission line for each Floquet mode employed in the analysis. However, a common drawback of these approaches is the required knowledge of the analytical form of the scan impedance.

The purpose of this paper is to present a WAIM design approach, which does not require the knowledge of the analytical formula of the scan impedance of the radiating element. The proposed approach can be applied to any type of radiating element. The method is based on the modal description of the radiant element in terms of a Floquet-mode expansion. A similar expansion is used to describe the WAIM layer. The two GSM are then opportunely cascaded to obtain the overall response of the system. This approach does not rely on any homogenization techniques since the periodicity of the WAIM layer is comparable to that of the radiating element.

II. ELEMENT-INDEPENDENT WAIM DESIGN TECHNIQUE

In the cases where the analytic form of the scan impedance of the radiating element is unknown, the entire system can be characterized through the Floquet mode GSM (Generalized Scattering Matrix) [6]. By assuming that the planar array is infinite, the Floquet modal expansion of the electromagnetic fields can be performed.

The idea at the basis of the element-independent WAIM design technique is to divide the entire system into more simple subsystems. In this way, it is possible to perform the full-wave simulations of the radiating element and of the WAIM superstrate separately. For example, this procedure can be applied to the structure shown in Fig. 1 (a). A patch array is loaded with a dielectric of thickness t placed at a distance d from the array. This system (Fig. 1a) is split into the two subsystems constituted by the dielectric layer (Fig. 1b) and by the unloaded patch (Fig. 1c).



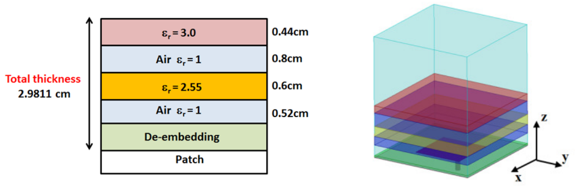
(a) *(b)* *(c)*

Fig. 1 - Cross section view of the unit cell of an array composed by a printed patch loaded with a dielectric layer (a), subdivision of the dielectric loaded array into subsystems: dielectric (b), unloaded patch (c).

Both the GSM of the radiating element and of the WAIM superstrate are computed separately. The response of the overall system is easily obtained by opportunely cascading the two matrices. This approach allows to significantly reduce the computational time with respect to that needed for a full-wave analysis of the entire combined structure. Indeed the radiating element GSM can be computed only once at the beginning of the design process and hence stored. Finally, by recurring to the cascaded GSM matrix technique above described, an evolutionary GA-based search algorithm is applied for optimizing the WAIM superstrate within a given scan angle interval and frequency range. This approach allows an accurate WAIM design independent from the type of radiating element adopted by the phased array. A design example is shown in the remainder of the paper.

III. NUMERICAL RESULTS

The proposed method has been applied to the case of a patch array, working at 2.415 GHz. The unloaded array is initially designed for broadside operation. The aim of the WAIM superstrate to be optimized is to improve performance while scanning off-broadside up to 60 degrees in the plane $\phi=0°$. The layout of the WAIM stack-up obtained at the end of the optimization process is shown in Fig. 2 (a). In this case, the WAIM superstrate has been initially realized only with dielectric material. They have been selected from a database of materials available for the manufacturing process of the prototype. The performance of the superstrate have been verified by simulating only a single unit cell of the array antenna and exploiting the periodic boundary conditions. The simulated stackup is reported in Fig. 2 (b).



(a) *(b)*

Fig. 2 - Layout of the single radiating element of the array loaded with the multilayer WAIM superstrate (a); WAIM stack-up (b).

WAIM superstrate is verified by computing the transmittance from input port of the antenna to the fundamental Floquet mode as a function of the scan angle. When the curve approaches to the unity, the antenna will be perfectly matched. The computed curves in presence and in absence of the WAIM layer have been shown in Fig. 3. The accuracy of the GSM approach is proved by the comparison against the full-wave FEM simulation.

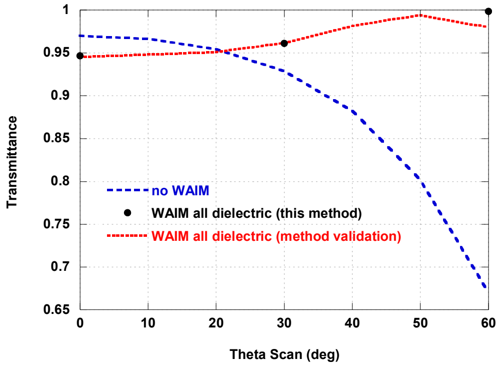


Fig. 3 –Transmittance of the array in function of the scan angle .

The transmittance as a function of the scan angle for the case of the unloaded array (no WAIM-curve) has been calculated with a FEM-based (Finite-Element Method) full-wave solver. The transmittance for the case of the array loaded with the WAIM obtained at the end of the design procedure (this method-curve) has been compared against the transmittance calculated through the FEM solver for the case of the array loaded with the multilayer WAIM superstrate (method validation-curve). As can be seen from Fig. 3, the WAIM superstrate is able to reduce the scan loss effect. The method is straightforwardly applicable also to FSS-loaded WAIM layers.

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