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Design and Optimization of Wideband Multilayer Printed Antenna Arrays

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***Abstract*— The presentation will give an overview of ONERA recent research work in the field of wideband printed antenna arrays. A special focus will be given to the comprehensive analysis and design optimization of multilayered printed arrays for wide bandwidth and wide scan angle operation.**

I. INTRODUCTION

In recent years, the need for versatile active phased array antennas with large bandwidth, polarization diversity and beam steering capability, particularly for multifunction RF applications with physical size constraint, makes it desirable to develop compact printed antenna arrays. A large number of wideband array technologies have emerged, based on various techniques and topologies.

Tapered slot antenna arrays such as Vivaldi [1] or bunny-ear arrays [2], connected dipole arrays [3], long slot apertures [4] and self-complementary antenna arrays [5] are candidates for broadband and wide-angle beam steering performances.

Vivaldi array [1] is the most well-known wideband array with its 10:1 bandwidth and its scan angle up to 45° in all planes. However, it is not a low profile solution since the element depth reaches 2-3 λ at the highest operation frequency. Furthermore, high cross polarization levels are apparent with scanning. Arrays with reduced-height may be observed with bunny-ear elements [2] (0,56 λ depth is obtained at the highest frequency).

Connected dipole arrays [3] and long slot apertures [4] offer planar arrays with a constant input impedance over a wide bandwidth (typically 5:1) when radiating in free space. However, the bandwidth is reduced when the array is placed above a PEC ground plane which is essential in order to prevent backward radiation toward the electronic system.

A similar ground plane effect can be observed with self-complementary antenna arrays [5], although they theoretically provide a constant input impedance over a wide frequency range in free space.

Our study focuses on the analysis of multi-layered tightly coupled dipole arrays backed by a ground plane [6] and their wideband optimization thanks to a new equivalent circuit model.

II. DIPOLE ARRAY OPTIMIZATION

While inter element couplings tend to be minimized in most of array designs, Munk's approach [6] uses them to overcome the ground plane effect. In fact, the ground plane inductance at low frequencies is offset thanks to a capacitive coupling between two adjacent elements (see Fig. 1(a) with interdigital capacitors). Following this approach, a 5:1 bandwidth array was already presented in [6].

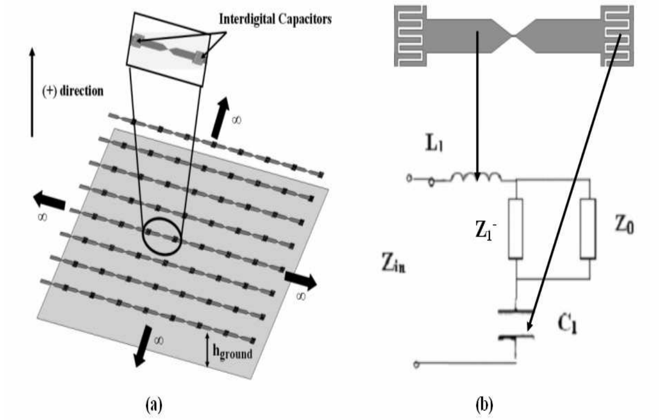

Fig. 1. (a) Munk's infinite tightly coupled dipole array with a ground plane and its equivalent circuit (b).

Moreover, dielectric slabs may also be placed above the radiating panel to increase the bandwidth and avoid scan blindness which may appear for some scan angles [6].

A. A new equivalent circuit for printed dipole arrays

In [6], Munk provides an equivalent circuit for the input impedance of an infinite array of tightly coupled dipoles (see Fig. 1(b)). Nevertheless, this model is only valid for Hertzian dipoles (i.e. dipole length << λ). In Fig. 1(b), L_1 is the dipole's self-inductance, C_1 is the interdigital capacitor, Z_0 denotes the radiation resistance of the array located in an infinite medium and, finally, Z_1^- represents the input impedance of an equivalent Transmission Line (TL) looking toward the ground plane.

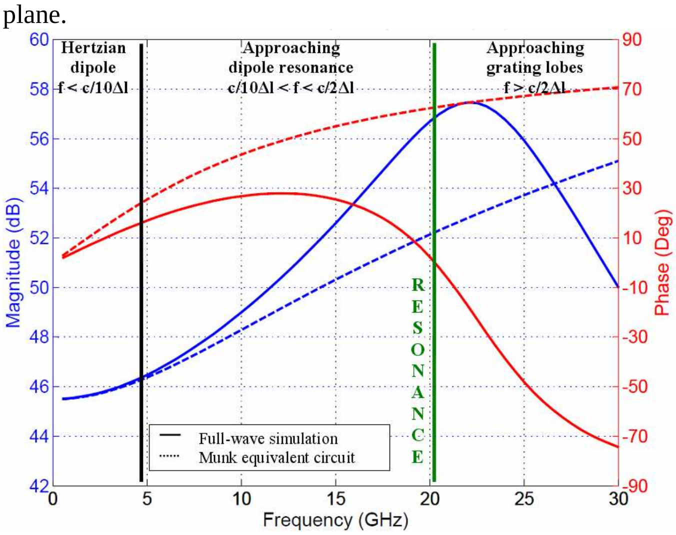

Fig. 2. Input impedance of an infinite connected dipole array (central element with C_1=0) located in free space - Full-wave simulation and its comparison with Munk's equivalent circuit.

The input impedance of the array (central element) calculated using a full-wave simulation and Munk's model are compared in Fig. 2. The simulation was performed using ANSYS-HFSS software considering an array of Δl long dipoles and inter element spacings D_x and D_y ($\Delta l = D_x = D_y$ = 7 mm).

From Fig. 2, we can see that the frequency limit of Munk's equivalent circuit appears around 5 GHz and the array impedance varies quickly as the frequency is close to the dipole self-resonance.

A new equivalent circuit, which is valid from DC to the onset of the first grating lobe, was then developed to model the input impedance of a multi-layered printed dipole array with a ground plane. The use of L-C resonant circuits is the key element which allows to describe the wideband dipole input impedance behaviour. The ground plane and dielectric slabs above the array may also be taken into account in our new model thanks to a TL-based scheme. In Fig. 3, a comparison is made between the input impedance calculated using our new equivalent circuit model and the result from the full-wave simulation for the case where the ground plane distance (h_{ground}) is 6 mm and with a single dielectric slab (h_{slab} = 5 mm, ε_{r1} = 1.5).

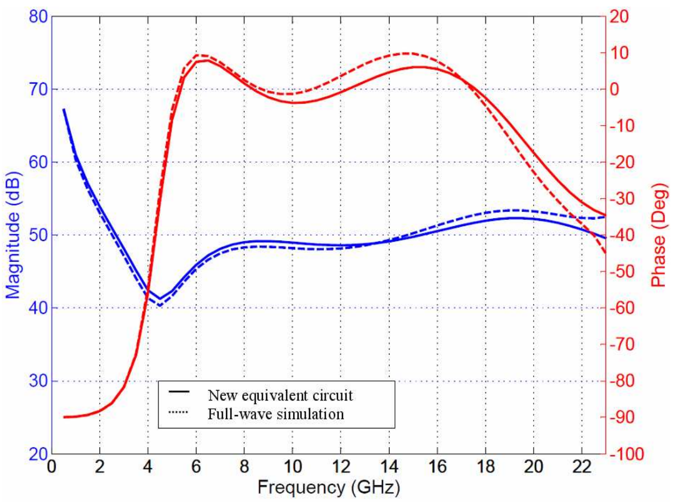

Fig. 3. Input impedance of an infinite array (central element) with a single dielectric slab and a ground plane (h_{ground}=6 mm, h_{slab} = 5mm, ε_{r1} = 1.5, θ = 40° H-plane) calculated using our new circuit model (solid line) and the full wave analysis (dashed line).

B. The design optimization procedure

Thanks to the perfect knowledge of the input impedance behaviour, an optimization procedure based on our new equivalent circuit model was then developed in order to optimize the upper dielectric slabs arrangement (permittivity and thickness) and the array-ground plane distance. The objective was to reach the largest bandwidth and scan angle capability with an active VSWR lower than 2 (for a central element in an infinite array).

An array optimization with two dielectric slabs was thus achieved in both E-plane and H-plane. The optimization gives h_{ground} = 5.9 mm, $h_{slab,1}$ = 3.1 mm, ε_{r1} = 2.2, $h_{slab,2}$ = 5.3 mm, ε_{r2} = 1.3 for the multilayer arrangement. Active VSWR in the E-plane for a central element in an infinite array is given in Fig. 4.

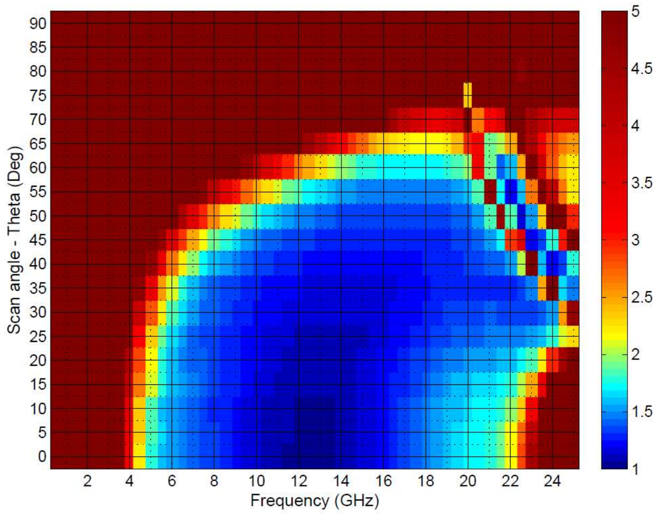

Fig. 4. Active VSWR versus frequency and scan angle in the E-plane of a central element in the optimized infinite array with two dielectric slabs.

III. Design of a coupled dipole array with its feed

One of the key points for broadband arrays is the design of a wideband feeding network. A tightly coupled dipole arrays (Fig. 1) will thus need a broadband and very compact 200 Ω - 50 Ω impedance matching for each cell in the array.

Typical feeding network topologies, including compact balanced and unbalanced solutions, will be reviewed. Usually, a balanced feed is required since the two dipole arms must be fed with signals with equal potentials but with a 180° phase shift between them. It involves to design a balun (balanced to unbalanced transition) to ensure the wideband connection between the coaxial connector (asymmetrical feed) and the symmetrical radiating element (BALanced). Another approach consists in modifying the dipole geometry in order to provide an asymmetrical structure which can be directly connected to the coaxial connector without any balun.

Adding a feeding network generally implies a reduction in the array bandwidth but the results are better with an unbalanced feed and the removal of the restricting balun. Fig. 5 gives the active VSWR versus frequency and scan angle in the E–plane of the optimized array with a wideband impedance adapter (unbalanced feed). The optimize array offers at least a 7 – 20 GHz frequency operation, up to 60° in E-plane and H-plane.

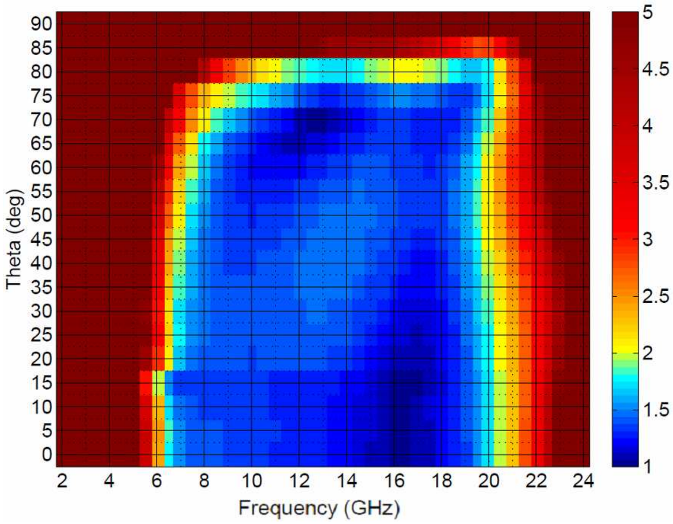

Fig. 5. Active VSWR versus frequency and scan angle in the E-plane of a central element in the optimized infinite array with two dielectric slabs and its 200 Ω -50 Ω wideband adapter.

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