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MICROSTRIP ANTENNA DESIGN BASED ON STACKED PATCHES FOR RECONFIGURABLE TWO DIMENSIONAL PLANAR ARRAY TOPOLOGIES

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Abstract—In this work, a probe fed microstrip antenna design for the implementation of two dimensional arrays with individually fed radiating elements is presented. The performance of the antenna element, both isolated and in a 4×4 fixed array topology, is analysed using ADS and HFSS simulation software. Prototypes of the antenna element and of the array are manufactured and measured for the experimental validation of the design.

1. INTRODUCTION

Antenna arrays have been widely employed in a great variety of applications, taking advantage of their beamforming [1], conformation [2] and pattern nulling [3] possibilities. Additionally, the behaviour of the array can be modified in real time by separately tuning the feeding signals of the different individual radiators, providing adaptive solutions [4, 5].

Microstrip technology has become a widespread option for the implementation of antenna arrays, owing to its well-known advantages, such as low profile, conformability, ease of fabrication and low cost, especially after the development of different enhancement techniques, aimed at counteracting the traditional drawbacks of this technology (limited bandwidth, spurious radiation of the feeding lines, ...).

In reconfigurable implementations of antenna arrays, the feeding signals of the radiating elements must be separately controlled, which requires these signals to be individually conducted from each of the

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tuning circuits to its corresponding radiating element. Although this is straightforward in linear arrays, by simply extending the feeding lines of the antenna elements to the edge of the circuit board [6], the transmission line layout process might become a challenging task for two dimensional arrays, especially for applications where a large number of elements is required [7]. This is overcome in [8], with a topology based on quasi Yagi antennas, in which the tuning circuits for each row of the array are placed in a perpendicular plane. Similarly, in microstrip technology, probe feeding techniques are more appropriate than others based on microstrip transmission lines for these cases, as the connectors associated to the individual patches can be installed in the ground plane, where the necessary circuitry is connected (Fig. 1).

Although probe fed microstrip antennas present inherently reduced operating bandwidths ($|S_{11}| < -10\,\mathrm{dB}$), in the order of 1–2% at low frequencies [9], multiple works can be found in the literature, focused on improving the impedance bandwidth of these structures. Bandwidths around 4% can be obtained by introducing short circuited parasitic elements [9], or with an H-shaped radiating patch [10], providing circular polarisation. Further improvements can be achieved using thick air substrates with L-shaped probes [11] (26.5%), T-shaped probes [12, 13] (33–40%) or with stacked patches on thick dielectric layers [14] (up to 60%). However, besides the usually reduced mechanical stability of designs with air substrate layers, thick substrates generally give rise to high coupling levels between patches, which make them inappropriate for array designs.

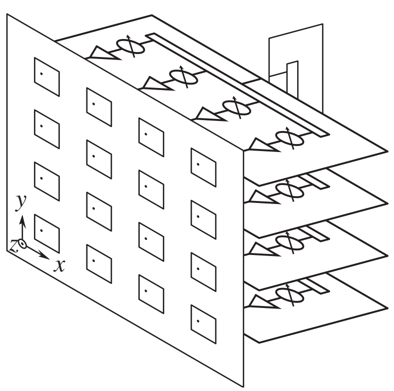

Figure 1. Topology of the two dimensional antenna array with individually fed radiating elements.

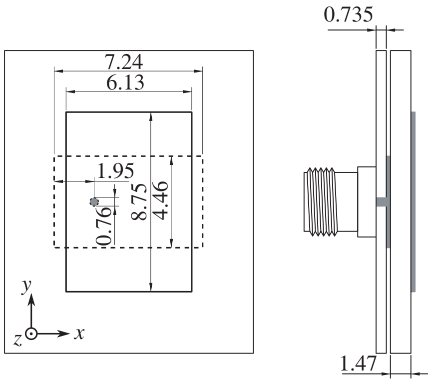

Figure 2. Proposed microstrip antenna. Dimensions in millimetres.

The purpose of the present work is the development of a probe fed antenna design operating at 10 GHz for the implementation of radiation pattern reconfigurable two dimensional array topologies (Fig. 1), for mobile military communications. A solution based on stacked patches is proposed, in order to avoid the commented drawbacks of some of the referenced work, in terms of reduced robustness and excessive coupling levels.

Since most of the probe fed topologies available in the literature operate at somewhat lower frequencies, the design process, as explained in Section 2, relies on simulations carried out using Agilent Advanced Design System (ADS) and Ansoft HFSS (which provides a more complete 3D model of the structure that might lead to more accurate results at this frequency). In Section 3, the performance of this design in a fixed two dimensional array topology is studied, assessing its properties in terms of mutual coupling and radiation pattern. Finally, in Section 4, the measurements of the manufactured prototypes are commented, in order both to evaluate and compare the simulation methods and to validate the design.

2. MICROSTRIP ANTENNA DESIGN

The impedance bandwidth of microstrip antennas is known to be larger for higher values of the substrate thickness and for lower permittivities. However, apart from its impact on the mutual coupling, when the substrate thickness is increased in simple probe fed topologies, the length of the probe is extended accordingly, leading to high inductance values that must be subsequently compensated. The proposed topology, shown in Fig. 2, uses a relatively thin substrate layer through which the probe is connected to the first patch, while the layer between the first and the second can be moderately thickened to improve the bandwidth.

The coaxial connector is soldered to the bottom layer of a 0.762 mm thick ARLON 25N substrate ($\epsilon_r = 3.38$ and $\tan\delta = 0.0025$ at 10 GHz) and the probe is connected to the specified point in the first patch, edged on the top layer or this substrate. The second patch is placed on top of a double layer of ARLON 25N (1.524 mm).

2.1. Simulation and Optimisation

The performance of the proposed design has been studied using the Agilent Advanced Design System Method of Moments (Momentum) electromagnetic simulator. This analysis software, in which the substrate layers are considered infinite, does not support coaxial feeding and, therefore, the simulations have been carried out using an Internal Port, directly placed on the feeding point of the first patch. At the same time, the complete design structure, including the coaxial feeding and the finite substrate layers, has been analysed using the Ansoft HFSS finite element simulator. Using the results of these two methods, the dimensions of the design have been optimised to increase its impedance bandwidth. The results obtained with both simulation methods for the final design are compared in Fig. 3.

The antenna presents a bandwidth ($|S_{11}| < -10\,\text{dB}$) of approximately 1.15 GHz centred at 10 GHz (11.5%). Despite the fact that the probe feeding is not modelled in the ADS simulations, the results obtained with both methods are reasonably similar, yielding analogous values for the frequency of operation and for the impedance bandwidth.

The radiation patterns, evaluated at 10 GHz in the E-plane (XZ plane in Fig. 2) and in the H-plane (YZ plane in Fig. 2), have been calculated using ADS and HFSS obtaining gain values of 5.17 and 6.5 dB respectively. The normalised values of the co-polar (CP) and cross-polar (XP) components are compared in Fig. 4, as a function of the spherical coordinate θ. For the co-polar components, similar results are obtained with both simulation methods, whereas, for the cross-polar ones, noticeably higher values are observed in the HFSS simulations. A very pure linear polarisation is found in the E-plane, with cross-polar levels under -30 dB (under -50 according to the ADS simulation). However, in the H-plane the cross-polar levels are low in the boresight direction and increase with $|\theta|$ (although, in the ADS simulation, the -30 dB level is never reached).

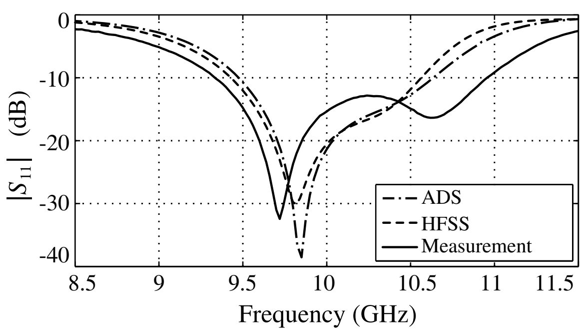

Figure 3. Simulation of the antenna design using ADS (Method of Moments) and HFSS (Finite Element Method), compared to the measurements of the manufactured prototype.

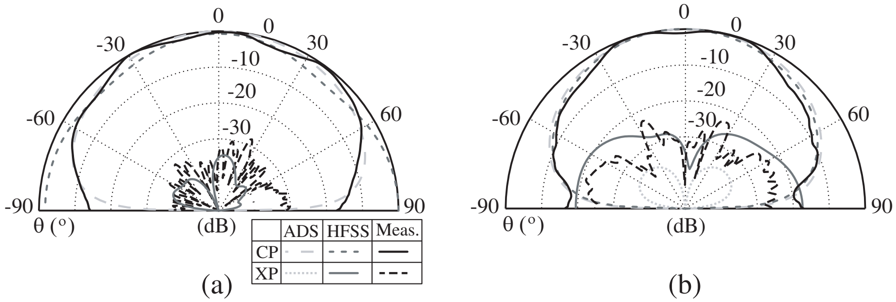

Figure 4. Simulations (using ADS and HFSS) and measurements of the radiation patterns of the proposed microstrip antenna design, as a function of the spherical coordinate θ for: (a) E-plane (XZ plane in Fig. 2), (b) H-plane (YZ plane in Fig. 2). Normalised magnitudes in dB of the co-polar (CP) and cross-polar (XP) components at 10 GHz.

3. TWO DIMENSIONAL ANTENNA ARRAY

A microstrip antenna design for the implementation of two dimensional arrays has been presented and analysed, focusing on its isolated behaviour. In order to complement the previous analysis and to validate the design for the proposed application, its performance in a 4×4 fixed array topology is studied in this section.

The radiating elements are arranged as shown in Fig. 1, so that the array presents horizontal polarisation (its E-plane is the XZ of Fig. 1). The distance between elements is selected to maximise the directivity of the array, while keeping the Secondary Lobe Level (SLL) at least 10 dB under the main beam level, for the scanning angles $|\theta| \leq 20°$. While this requirement is met for a vertical spacing $d_y = 0.7\lambda$ ($\lambda = 30$ mm is the free space wavelength at 10 GHz), only a scanning angle $\theta = 16°$ can be achieved with the same horizontal distance. Thus, the distance $d_x = 0.6\lambda$, has been chosen.

3.1. Mutual Coupling

The mutual coupling between elements of antenna arrays is a potential source of performance degradation in this kind of applications and, therefore, it is a parameter that must be taken into account during the design process. The previously described array topology has been studied using ADS and HFSS simulations to evaluate the isolation levels between the different antenna elements. Since the isolation between consecutive elements with the same alignment, along either their E- or their H-plane (x or y axis in Fig. 1) was found to be highly similar, regardless of the specific pair of elements considered, for the sake of clarity, only one parameter for each arrangement has been represented in Fig. 5.

The isolation is about 5 dB lower between elements aligned along their E-plane, which are separated $d_x = 0.6\lambda$, than between those aligned along their H-plane, which are separated $d_y = 0.7\lambda$. In general, the ADS simulation predicts lower isolation values, although the differences are not particularly significant.

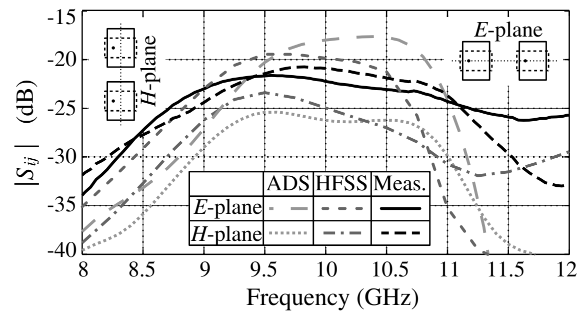

Figure 5. Isolation (S_{ij} parameter) between consecutive elements, aligned along either their E- or H-plane, of the described array configuration. The simulated results obtained with ADS and HFSS are compared with measurements of the manufactured prototype.

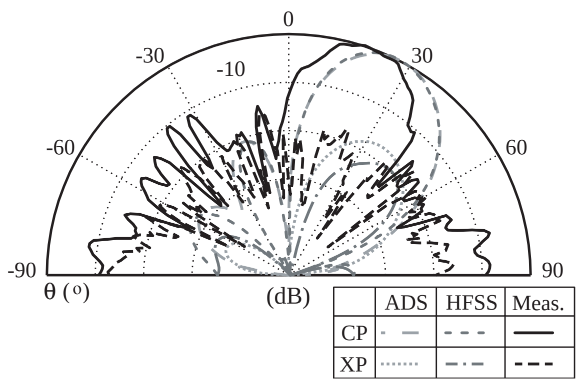

Figure 6. Radiation pattern of the antenna array, evaluated in the plane $\varphi = 45°$ at 10 GHz. The co-polar and cross-polar components simulated with ADS and HFSS are compared with the measurements carried out in the anechoic chamber. Normalised magnitudes in dB.

3.2. Radiation Pattern

In order to evaluate the scanning capabilities of the two dimensional array, the radiation pattern for a progressive phase distribution has been calculated using ADS and HFSS. The phase shift $\Delta\phi$ introduced in the feeding signal of each element is given by $\Delta\phi(i,j) = 80i + 80j - 160\,(^\circ)$, $i, j \in \{1, \ldots, 4\}$, where i is the column in which the element is placed and j the row (the indices grow in the $+x$ and $+y$ directions of Fig. 1, respectively), starting at the lower left element. The normalised simulated radiation patterns are shown in Fig. 6. The gain value obtained with ADS was 16.77 dB and with HFSS 16.15 dB.

4. EXPERIMENTAL RESULTS

Several prototypes have been manufactured for the evaluation of the accuracy of the different simulation methods that have been used in this work. In this section, the measurements of the prototypes are compared to the simulated results.

4.1. Microstrip Antenna Design

A prototype of the microstrip antenna design analysed in Section 2 has been manufactured for the experimental validation of the simulated results. Plastic screws have been used for the alignment of the complete multi-layer structure.

The S_{11} parameter of the prototype, measured with a vector network analyser, has been represented in Fig. 3, together with the simulated results. The isolated antenna is matched to $50\,\Omega$ in the band from 9.33 to 10.66 GHz (16%), which represents a significant improvement with respect to the simulated results.

The radiation patterns of the antenna have been measured in the anechoic chamber at 10 GHz. The co-polar and cross-polar components evaluated in the E- and H-planes are compared to the simulations in Fig. 4. The simulated co-polar components are in good agreement with the corresponding measurements, although the HFSS simulation is slightly different when approaching the endfire directions ($\theta = \pm 90^\circ$) in the E-plane. For the cross-polar component, on the other hand, while neither of the simulation methods provides an accurate estimation, the levels of the HFSS results are somewhat closer to the measured values.

The polarisation purity of the antenna is higher in the E-plane, in which the cross-polar component is under the -30 dB level in almost any direction, whereas, in the H-plane, several oblique lobes of about -25 dB can be found.

4.2. Antenna Array

The array topology with individually fed elements designed and analysed in Section 3 has been manufactured and measured, obtaining approximately the same 16% impedance bandwidth of the isolated element. In agreement with the simulations, the isolation levels between elements with the same kind of alignment is similar and, thus, only one parameter for either alignment is represented in Fig. 5. Similar isolation levels, over 20 dB, have been found for both arrangements.

In order to measure the radiation pattern of the array, a simple fixed feeding network based on 4×1 dividers (Fig. 1), has been designed and manufactured for the phase distribution studied in Section 3. The radiation pattern measured in the anechoic chamber along the plane $\varphi = 45^\circ$ is shown in Fig. 6. The main beam is pointing at $\theta = 21^\circ$, 4 degrees under the value predicted by the simulations, with the $SLL < -10\,\mathrm{dB}$, except when approaching the endfire directions.

5. CONCLUSION

A probe fed microstrip antenna design for the implementation of two dimensional reconfigurable arrays has been presented. The performance of the antenna element, both isolated and in a 4×4 array topology, has been analysed using ADS Momentum and HFSS.

Despite the fact that coaxial feeding is not supported in ADS Momentum and that it considers infinite dielectric layers, the results obtained with both methods are not substantially different in general.

Prototypes of the antenna element and the array with a fixed feeding network have been manufactured and measured, obtaining a 16% impedance bandwidth centred at 10 GHz. The isolation between the elements of the array was found to be higher than 20 dB.

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