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AN INEXPENSIVE RECONFIGURABLE PLANAR ARRAY FOR WI-FI APPLICATIONS

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Abstract—This work presents the results of the synthesis of a light-weight inexpensive reconfigurable planar array antenna. The antenna structure is based on four circular patches. The sources points and some discontinuities on the patches can be electronically reconfigured by means of radio-frequency (RF) switches in order to modify the radiation pattern. In particular, the main lobe could be steered towards a desired direction to obtain an optimal management of wireless resources. An experimental prototype has been realized and tested. Numerical and experimental results are reported and compared to assess the reconfigurable capabilities of the proposed antenna prototype.

1. INTRODUCTION

Nowadays one of the main challenges in the design of telecommunication systems is connected to miniaturization. Modern mobile telecommunications systems, such as mobile smart phones and laptops, offer multimedia applications and different services that require an high degree of re-configurability in spite of the limited dimensions of the devices. Moreover, the impressive growth of wireless applications has forced designers to develop suitable methodologies to optimize the use of the transmitting channel, maximizing the signal to interference plus noise ratio (SINR). Another field of applications deals with space

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telecommunications that require reconfigurability over the satellite lifetime, usually longer than ten years. The use of reconfigurable antennas arrays, with fully adaptive properties [1–4], could dramatically improve the performances of a telecommunication system in particular if it is combined with a reconfigurable digital back end processing unit. Such a kind of antennas, commonly used in several fields such as airport surveillance, missile detection and tracking, are unfortunately too complex and expensive to be used for commercial applications. Also, for more dedicated tasks they are still to be integrated and controlled simultaneously with their digital processing circuits and developed at microwave frequencies to perform microwave software defined radio (SDR) [8, 9]. Another interesting application could be the transmission of signals from room temperature to the cryogenic stage of cryocoolers to feed signals to superconducting imagers with low thermal loss. For low cost applications, the use of switched beam antennas is generally adopted instead of adaptive arrays. Recently, a new kind of reconfigurable parasitic antennas, able to electronically select different configurations of the radiation patters [5–7], or to change the working frequency as in [6], has been successfully adopted for different practical applications. Such antennas offer a good compromise between the fully adaptive arrays and the switched beam solution. This work presents the design of a reconfigurable antenna array based on four planar circular microstrip patches, and the phase of each element can be electronically modified by means of radio frequency switches. The obtained results seem to have the reconfigurable capabilities of the proposed antenna prototype. The main innovation introduced in this paper is the phase shift strategy that is not based on well-known pin diode phase shifters, but has been obtained by electronically changing the antenna structure. In particular, the positions of the feeding microstrips and suitable perturbations, placed on the top of the antenna, have been changed by means of RF switches. To the knowledge of the authors, this technique has never been used before.

2. ANTENNA DESIGN

Let us consider the example of the array shown in Fig. 1. The antenna architecture is composed by an active (bottom view) and a passive (top view) reconfigurable part, respectively. The passive reconfigurable part consists of four circular patches, and eight rectangular discontinuities are located on each patch. These discontinuities can be activated or removed by using suitable RF switches. By activating the RF switches, the discontinuities are removed (see Fig. 2 for details). The discontinuities are introduced to keep the circular polarization

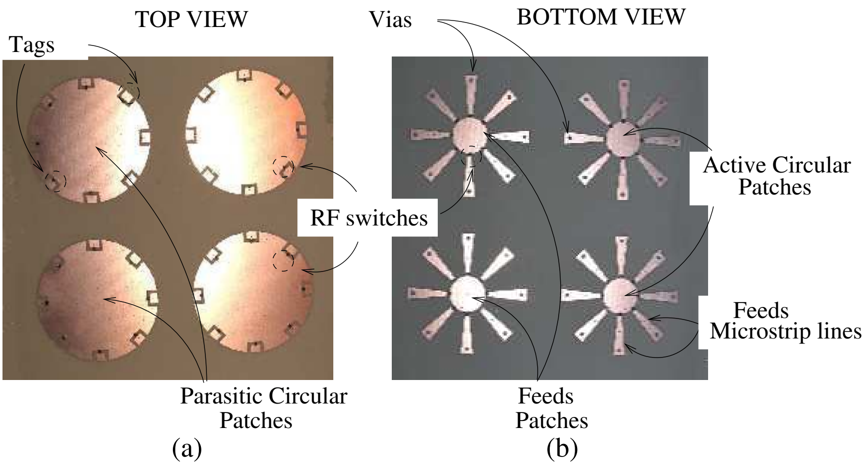

Figure 1. Photograph of the antenna prototype.

and must be symmetrically activated. With reference to Fig. 2, the bottom section of the antenna is formed with a circular active patch and a set of reconfigurable tapered microstrip lines, connected with the central patch with the same RF switches adopted for the upper parasitic section of the antenna. In particular, the tapered microstrip lines are used to change the positions of the feeding points on the upper parasitic circular patches. The microstrip lines can be changed in eight different positions, as shown in Fig. 2, obtaining different feeding configurations and modifying the phase of the source of each antenna elements as a phase shifter. To maintain the circular polarization, a couple of rectangular discontinuities on the top part of the antenna are placed with a 45 deg orientation with respect to the orientation of the reconfigurable feeding microstrip of the bottom part of the antenna. The bottom and top sections of the antenna are assembled into a layered structure as shown in the bottom of Fig. 2, and the result is a compact phased array able to change its radiation characteristics. The electrical connections between the discontinuities and the microstrip feeding lines are physically implemented by means of low cost positive intrinsic negative (PIN) diodes working as electronically driven switches. The use of PIN diodes as switches is based on the direct forward bias characteristic of the diode. In particular, the PIN diodes appears to be a very small and a very large impedance under forward and reverse bias, respectively. To connect the tags of the circular patches and to the source lines, single pole single throw switches SPST have been considered. The schema

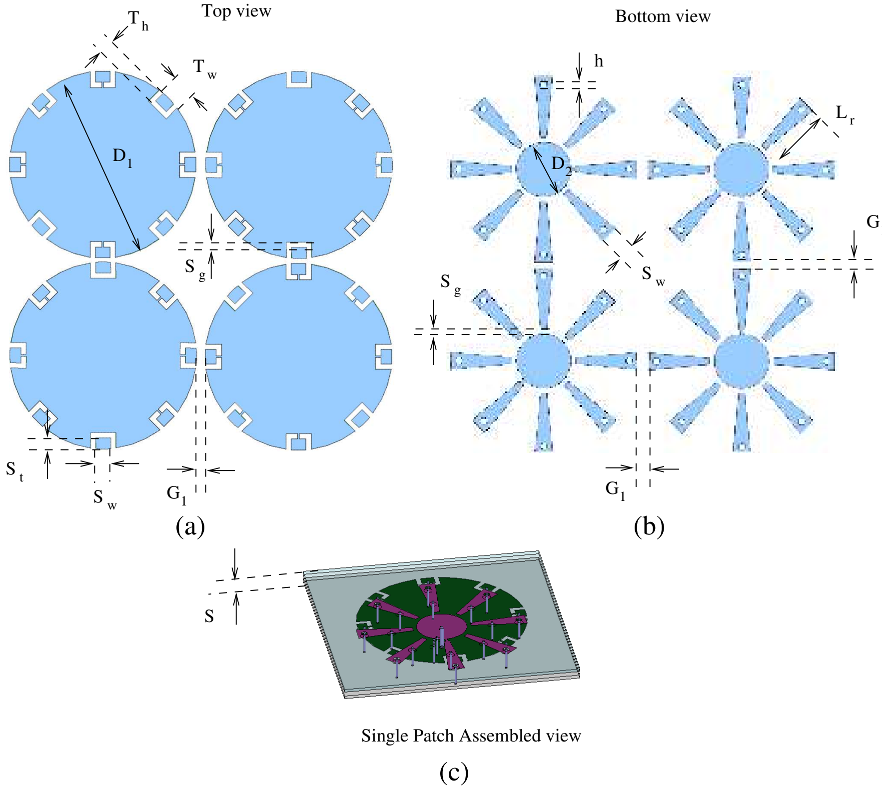

Figure 2. Drawings of the antenna prototype.

and driven circuit of each switch is reported in Fig. 3. Concerning the components for the SPST $L_1 = L_2 = 100\,\mathrm{nH}$ and $C_1 = 0.2\,\mathrm{nF}$, the nonlinear device D1 is a BA5030 from NXP semiconductors.

The PIN diodes are mounted on the surface of the upper and lower sections of the antenna and driven by means of $h = 0.5\,\mathrm{mm}$ diameter metallic wires placed orthogonally to the array plane in order to minimize the electromagnetic interferences. In the synthesis process, the passive and active parts of the antenna have been designed to operate in the WiFi frequency band from 2.4 GHz up to 2.5 GHz. In more details, an evolutionary optimizer, namely the particle swarm algorithm (PSO) [10–13], has been adopted to minimize a suitable cost function [4] and make synthesis of the antenna. In particular, a suitable cost function that receive as input all the geometrical antenna parameters defined in Fig. 2 (namely D_1, D_2, T_h, T_w, S_g, S_t, S_w, G_1, h, and L_r) has been defined. Then the PSO has been used in

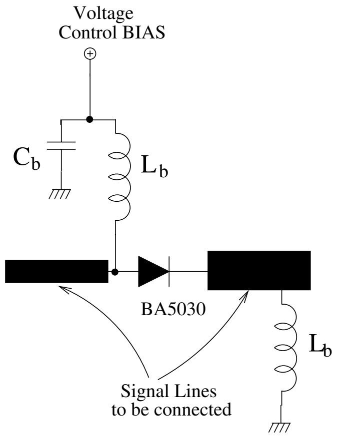

Figure 3. STST switch control circuit.

conjunction with a commercial electromagnetic simulator based on the MoM method (i.e., Ansoft Designer) able to simulate the antenna with an high degree of accuracy and to take into account the presence of the dielectric substrate and all the different components of the antenna structure. The PSO generates a set of trial solutions changing the geometrical parameters of the antenna, and the electromagnetic simulator estimates the performances of the trial solutions used to estimate the cost function permitting the evolution of the population of trial solutions toward the optimal solution. After the synthesis procedure, the following geometrical parameters have been obtained $D_1 = 40\,\mathrm{mm}$, $S_w = 6\,\mathrm{mm}$, $S_t = 4\,\mathrm{mm}$, $T_h = 5\,\mathrm{mm}$, $T_w = 7\,\mathrm{mm}$, and $S_g = 1\,\mathrm{mm}$. Concerning the feeding microstrips, we have $D_2 = 10\,\mathrm{mm}$, $L_r = 14\,\mathrm{mm}$, $S_w = 6\,\mathrm{mm}$, while at the other end, the feeding microstrip has a width equal to 1 mm, the same dimension of the PIN diodes used as RF switches. A prototype of the reconfigurable array shown in Fig. 1 has been fabricated on a ceramic dielectric substrate of thickness $t = 0.8\,\mathrm{mm}$, $\varepsilon_r = 3.38$, and $\tan(\delta) = 0.005$. Due to the thickness of the substrate and the layered structure of the antenna, the thickness of the assembled prototype is $S = 1.6\,\mathrm{mm}$. The output of the four patches are connected with a standard four ways splitter/combiner fabricated with small lumped elements (surface mount devices SMD) to keep the dimensions and weight of the antenna as low as possible. The design of a four ways power splitter/combiner could be difficult considering standard planar fabrication methodologies (e.g., microstrip). Moreover, it can present unrealistic dimensions at frequencies in the low microwave bands where

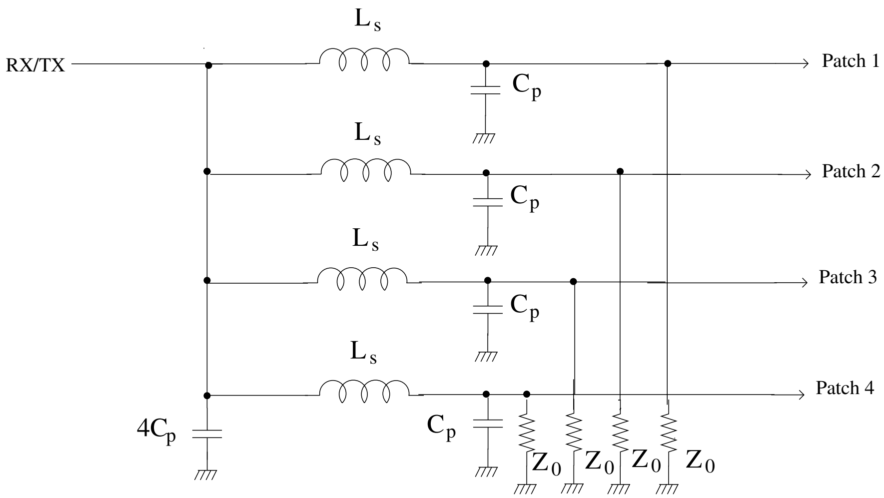

Figure 4. Lumped elements, four ways power splitter.

the wavelength is large, since such a kind of devices usually employs quarter wave transmission line sections. By replacing the quarter wave line sections with an equivalent LC networks, it is possible to obtain a lumped elements version of the power splitter. The circuit of the power splitter is reported in Fig. 4, where $L_s = 1300\,\mathrm{pF}$, $C_p = 3.25\,\mathrm{nH}$ and $Z_0 = 50\,\Omega$. For the fabrication of the splitter standard low-cost 0805SMD components mounted on the same ceramic substrate of the antenna have been considered. The splitter has been equipped with five sub miniature type A (SMA) connectors.

3. NUMERICAL RESULTS AND EXPERIMENTAL ASSESSMENT

In this section, the synthesized antenna array has been numerically and experimentally tested. The experimental assessment has been carried out in an anechoic chamber where both the radiation pattern and VSWR values have been measured. In the following, the configurations (activated elements in black and deactivated elements in white color) and the corresponding performances in terms of radiation patterns concerning three different configurations are reported. Fig. 5(a) shows the simulated and measured beam patterns when the activated elements (reported on the left of the graph) are configured in order to produce a null phase shift between the patches. As can be observed, the main lobe is directed along the mechanical bore sight of the array,

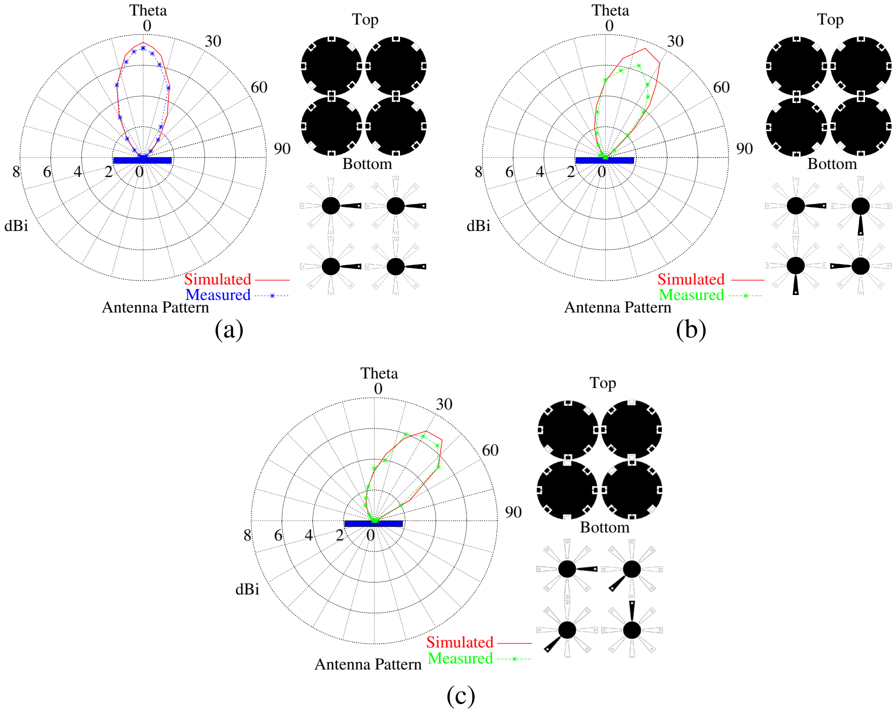

Figure 5. Simulated and measured normalized patterns in correspondence with different configurations of the RF switches. (a) 0 degree, (b) 90 degree and (c) 135 degree of phase shift between patches.

and the measured gain is about $G = 7.2\,\text{dBi}$. Fig. 5(b) reports the beam pattern obtained with the microstrips shifted by 90 deg. As can be noticed, the main beam is steered along $\theta = 25\,\text{deg}$ with respect to the bore sight of the array, with a maximum gain of about $G = 6.1\,\text{dBi}$. In the last considered configuration, the microstrips have been configured with a phase shift of 135 deg as reported in Fig. 5(c). In this configuration, the main beam is steered along $\theta = 35\,\text{deg}$ with respect to the bore sight of the array, and the maximum measured gain is $G = 6.1\,\text{dBi}$. Whatever the different considered configurations are, there is a satisfactory agreement between experimental measurements and numerical simulations. The measure of the axial ratio is equal to 0.98 while the cross polarization has a maximum value of $-23\,\text{dBi}$ (considering the whole set of possible configurations of the antenna). The VSWR measurements have been performed by varying the positions of the discontinuities on the upper part of the antenna and the positions of the feeding microstrips. The range of variations of the VSWR values turned out to be between 1.62 and 2.10 as confirmed by Fig. 7, where the plot of the measured values over the range from 2.4 GHz up to 2.5 GHz are shown for the configurations reported in Figs. 5(a), (b) and (c). In the last check, the circular polarization has been assessed. In particular, the axial ratio has been measured considering the co-polar and cross-polar components of the electromagnetic field, and an axial ratio $A_x = 0.98$ has been obtained confirming the efficiency of the tags placed on the parasitic patches and of the proposed antenna array. For the sake of completeness, Figs. 6(a), (b) and (c) show the cross-polar patterns in correspondence of the same configurations of Fig. 5. The cross-polar patterns have been obtained considering the perpendicular direction of the antenna plane. As can be noticed from the obtained results (see Fig. 5), the antenna is able to steer the main beam covering an angular range from -50 up to 50 degrees with a precision of about 10 degrees.

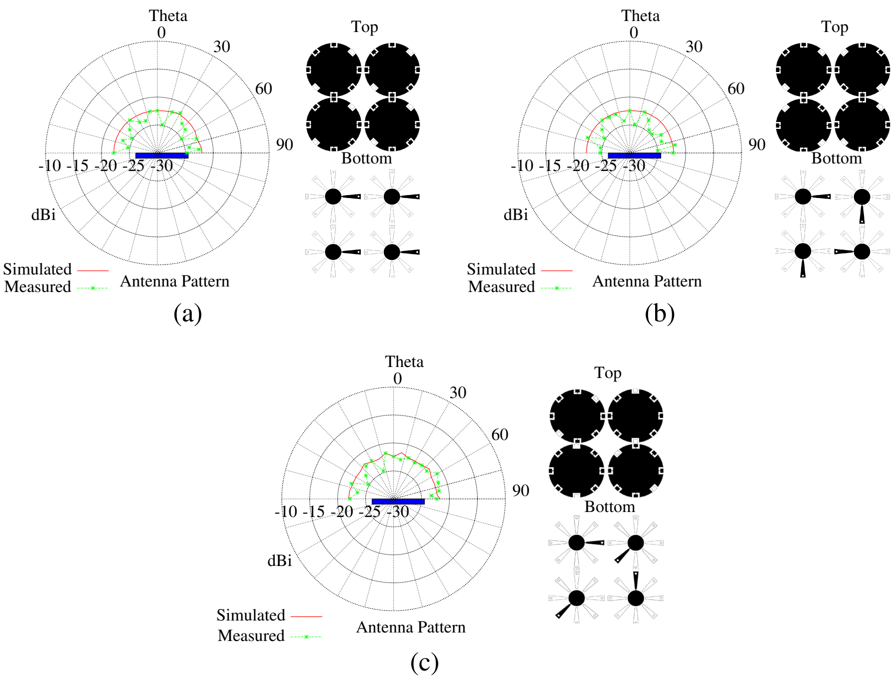

Figure 6. Simulated and measured cross-polar patterns in correspondence with different configurations of the RF switches. (a) 0 degree, (b) 90 degree and (c) 135 degree of phase shift between patches.

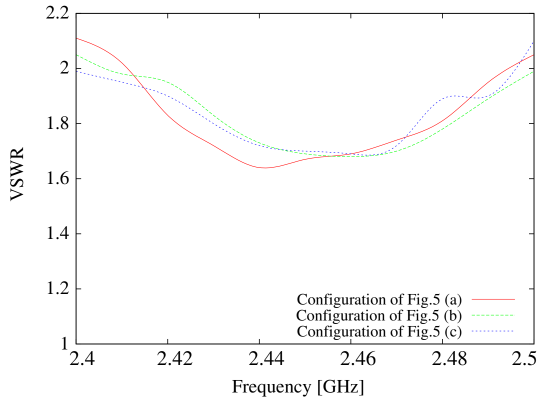

Figure 7. Experimental results. Measured VSWR for the configuration reported in Fig. 2(b) in the whole frequency range.

These characteristics make the proposed antenna particularly suitable for the transmission of signals from room temperature to the cryogenic stage of cryocoolers, since in this practical application it is necessary to move the beam direction by about 20 degrees.

4. CONCLUSION

In this work, the design of an electronically reconfigurable planar antenna array, based on circular microstrip patches and characterized by light weight, low cost, and limited hardware complexity, has been presented. The radiation characteristics of the proposed antenna have been changed by controlling the states of suitable radio frequency switches to modify the source points of each patch and introduce discontinuities to keep the circular polarization. The reported numerical and experimental results confirm the reconfiguration capabilities of the proposed prototype. These first results based on a simple planar antenna array are also of particular interest for several applications at higher frequencies that require SDR systems. In particular, this kind of antenna could be useful for imaging systems, radio astronomy applications and also for security purposes. Moreover, the combination on-chip of reconfigurable antenna systems followed directly by digitizing and processing units will increase the overall system capabilities by a large amount. In particular, the design of superconducting systems based on planar arrays with superconducting active elements used as RF switches and for digital processing is a new way to follow in the near future.

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