Electronically-Reconfigurable Horizontally Polarized Wide-Band Planar Antenna

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***Abstract*— Antennas are a necessary and critical component of communications and radar systems, but their inability to adjust to new operating scenarios can sometimes limit the system performance. Reconfigurable antennas capable of radiating in only specific desired directions can ameliorate these restrictions and help to achieve increased functionality in applications like direction finding and beam steering. This paper presents the design simulation, fabrication and measurement of a wide-band, horizontally polarized, direction reconfigurable microstrip antenna operating at 2.45 GHz. The design employs a central horizontally polarized omnidirectional active element surrounded by electronically reconfigurable parasitic microstrip elements, controlled by PIN diodes acting as RF switches. Experimental results show that the reconfigurable antenna has a bandwidth of 40% (2-3 GHz), with 3 dB gain in the desired direction and capable of steering over the 360° range.**

Keywords*— reconfigurable antenna; parasitic antenna; wide-band frequency

I. INTRODUCTION

Rapid progress in wireless communication technology has spurred on the need for reconfigurable antennas capable of changing the operating frequency, radiation pattern or polarization and has recently been a very active field of research. These changes are achieved by many different techniques that redistribute the antenna currents and thus alter the electromagnetic fields of the antenna's effective aperture [1].

There is a variety of reconfiguration techniques including antennas based on radio-frequency microelectromechanical systems (RF-MEMS) or electrically reconfigurable devices which employ PIN diodes or varactors to redirect the surface currents [1]. Alternatively, configurability is achieved through photoconductive switching [2], physically altering the structure of the antenna [3] or utilizing smart materials such as ferrites and liquid crystals [4].

In this paper, we use microstrip parasitic elements controlled by PIN diodes as RF switches to electronically redirect the radiation.

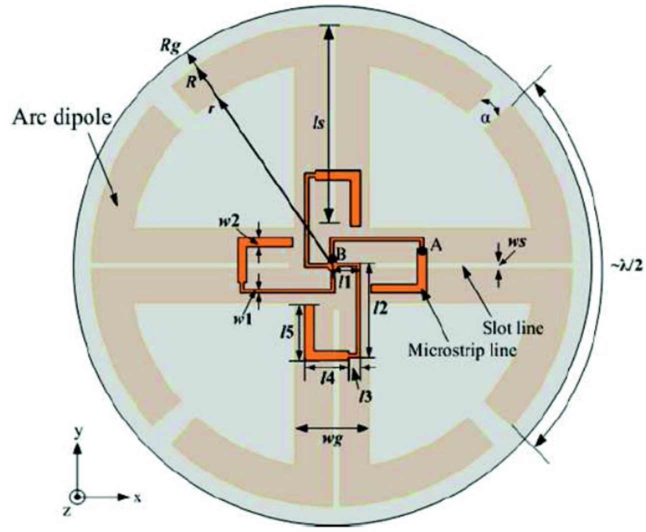

Figure 1- Active element [18]

II. DRIVEN ANTENNA

The reconfiguration capability of an antenna using electrically controlled parasitic elements can be achieved by using a central active element with a consistent omnidirectional pattern and horizontal polarization. The radiation pattern of the active element should ideally present a maximum in the plane of the parasitic elements and have a constant magnitude and phase over the parasitic elements [3]. A suitable candidate for the active element is the Alford-loop antenna, since it has horizontal polarization, an omnidirectional radiation pattern and an invariant electric field [10].

Examples of planar Alford-loop antennas are presented in the literature [11]. The configuration utilized in this paper has a consistent gain over the entire range and a wideband frequency response [12]. The geometry of the driven antenna is shown in Figure 1 [12] and is fabricated using Rogers RO4003 substrate with dielectric constant ε_r=3.55 and thickness h=0.81 mm. The antenna consists of four arced dipoles which are excited by a broadband feeding network. The antenna is fed using a 50 Ω SMA connector with the centre pin connected to the feeding network passing through the substrate and the outer conductor connected to the four arced dipoles acting as the ground for the feeding network.

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The geometric parameters for the broadband horizontally polarized omnidirectional antenna are shown in Table 1.

TABLE 1- GEOMETRIC PARAMETERS OF THE DRIVEN ANTENNA

R_g	40 mm	l_2	17 mm
R	32.6 mm	l_3	1.913 mm
R	29.54 mm	l_4	5.7665 mm
w_g	12 mm	l_5	12.3277 mm
l_s	27.575 mm	w_1	0.4235 mm
w_s	0.945 mm	w_2	1.5869 mm
l_1	4.339 mm	α	5.1°

The broadband horizontally polarized omnidirectional antenna element was simulated using CST Microwave Studio 2015. Figure 2 shows the simulated results for the scattering parameters of the active element, while Figure 3 and 4 show the simulated radiation patterns of the horizontally polarized electric field in the H-plane and E-plane.

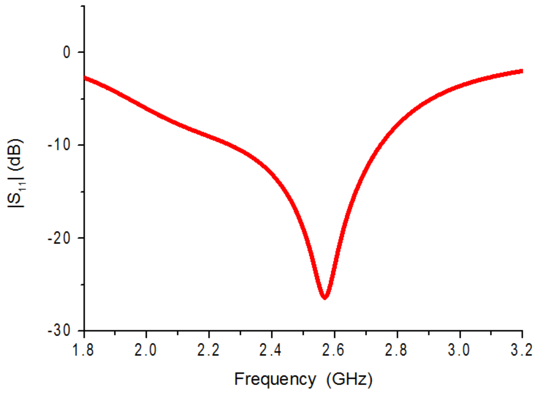

Figure 2- Reflection coefficient of driven antenna

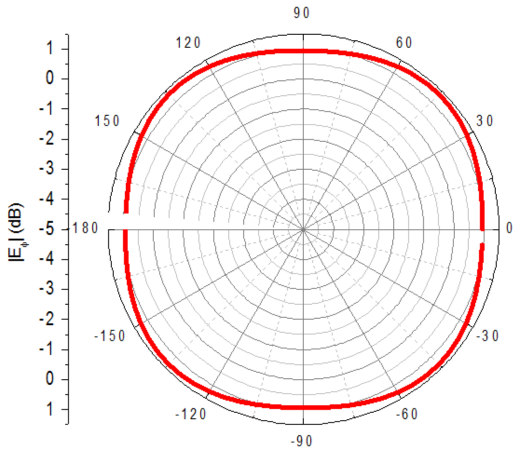

Figure 3- Electric field (H-plane)

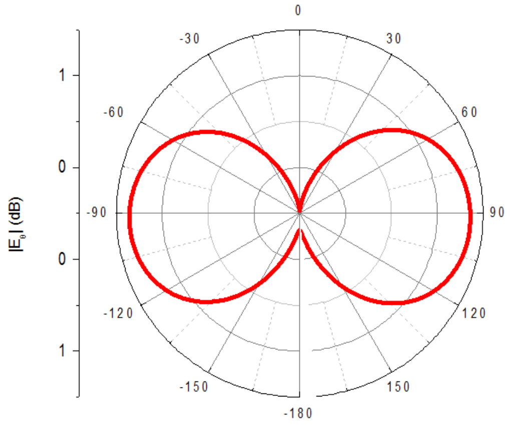

Figure 4- Electric field (E-plane)

These results show good omnidirectional radiation characteristics in the H-plane, and a return loss better than 10 dB across the frequency range from 2.2 to 2.8 GHz can be observed. This makes the central element a good candidate for the implementation of electrically controlled parasitic reflector elements to achieve consistent direction configurability and wide band performance.

III. RECONFIGURATION MECHANISM

The reconfiguration mechanism used in this antenna is based on the commonly used Uda-Yagi scheme [5], [6]. Parasitic elements whose impedance can be changed electronically are placed around an active element to direct the radiating beam [6], [7]. The parasitic elements are arranged in a circle, and each element closed on a passive load to make them act as reflectors, directors or tune them out of resonance [8]. In this design, planar metallic radial sectors have been used as parasitic elements which behave as suppressing elements/reflectors when activated by PIN diodes acting as RF switches [5], [9]. Active element selection plays a crucial role in achieving a consistent gain over the entire 360° range and a wide-band frequency response. Similar work has been done in the past [5], but inconsistent gain achieved over the 360° range in the azimuth plane and a very narrowband frequency response limits its application. The design presented in this paper has a wideband frequency response and achieves a much higher consistency in gain over the entire azimuth plane while using only half the number of active switches.

IV. RECONFIGURABLE ANTENNA DESIGN

The parasitic element structure is composed of sixteen identical, equally spaced copper radial sectors. These sectors are electrically connected using PIN diodes, thus behaving like reflectors or reconfigurable suppressors when activated while showing transparent-like behaviour when deactivated [5], [9].

The design synthesis to achieve a fully controllable wideband reconfigurable antenna is a three stage process. The first stage involves optimization of the geometrical parameters of the parasitic structure (i.e. the inner and the outer diameter of the radial sectors D_1, D_2, and the spacing θ_s between each of the radial sectors shown in Figure 5) by means of the Nelder

Mead Optimizer. The aim is to implement the parasitic structure with each parasitic element deactivated while maintaining the omnidirectionality of the antenna. This enables the antenna to still be used as an omnidirectional antenna when all the parasitic elements are deactivated.

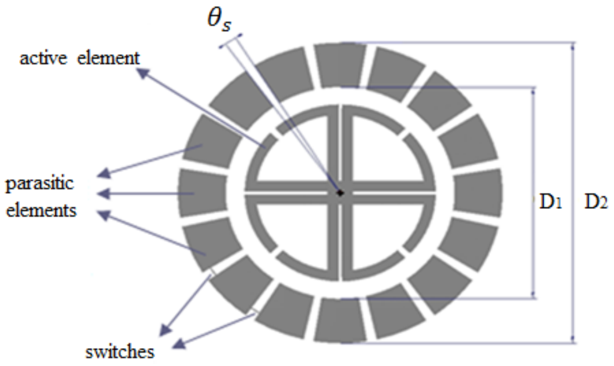

Figure 5- Reconfigurable antenna description

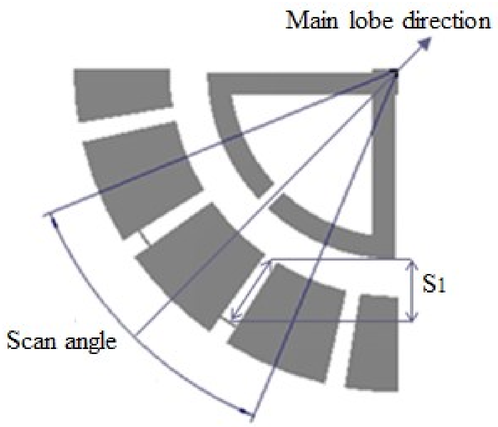

Figure 6- Radiation characteristics

The second stage of the synthesis process aims to achieve configurability of the system. This is obtained by placing proper electrical connections between each radial sector and its neighbour in order to obtain a variable configuration composed of an active element and a variable suppressing/reflecting structure utilizing PIN diodes as electronically driven RF switches. The radial locations of these switches and the number of parasitic elements activated are critical parameters in achieving the desired radiation pattern and scattering parameters. The switches provide a low impedance between these parasitic elements when activated and transparent-like behaviour when deactivated [11].

In the third stage the same optimization technique is used to achieve maximum radiation in the desired direction and the desired frequency response by choosing the number of parasitic elements activated and adjusting the position of the RF switches.

These parasitic elements behave as reflectors, and thus maximum gain is observed in the direction opposite to the mid-point of the activated parasitic sector with respect to the centre of the active element as shown in Figure 6. To achieve finer tuning of the radiation pattern with smaller scan angles, a greater number of parasitic elements can be used.

After the synthesis process, the descriptive parameters of the resulting antenna were, D_1=77.05 mm, D_2=120.16 mm, θ_s=3.92°, number of active switches n=2 and S_1=14.68 mm. Based on these design parameters, a prototype of the reconfigurable antenna shown in Figure 7 was built and tested. An enlarged image of the implemented PIN diode is also shown in Figure 7.

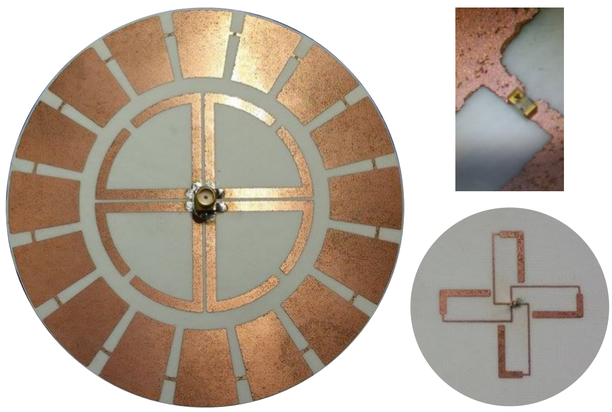

Figure 7- Manufactured model

V. RESULTS

The reconfigurable antenna was modelled and simulated using CST MWS 2015. The manufactured model was tested using a Rhode and Schwarz Vector Network Analyzer in an anechoic chamber where both the radiation pattern and the scattering parameters were measured. In Figure 8, the H-plane pattern of the simulated antenna with all the switches in the off-state is shown. The measured pattern suggests that the radiation pattern of the active element is unaltered in the presence of the parasitic elements with the switches in the off-state.

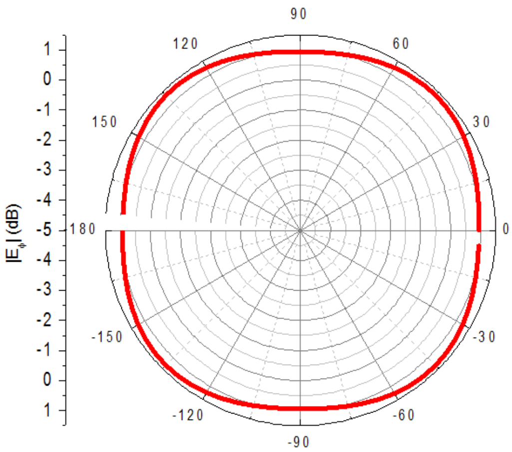

Figure 8- Electric field (H-plane) with all the switches deactivated

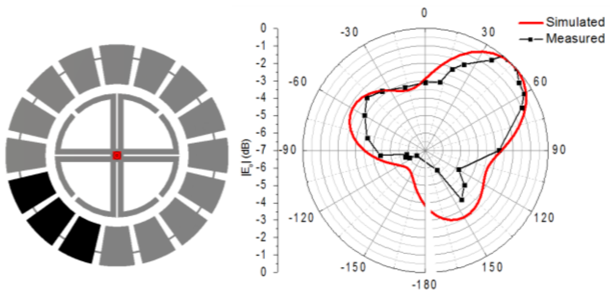

Figure 9- 45° Configuration and simulated vs. measured electric field in the H-plane

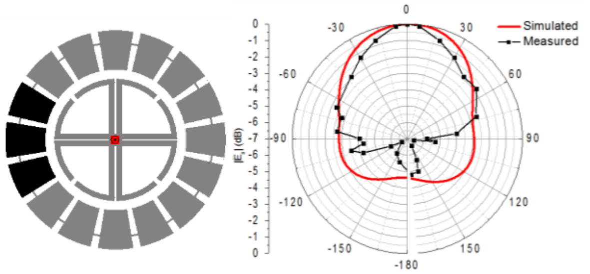

Figure 10- 0° Configuration and simulated vs. measured electric field in the H-plane

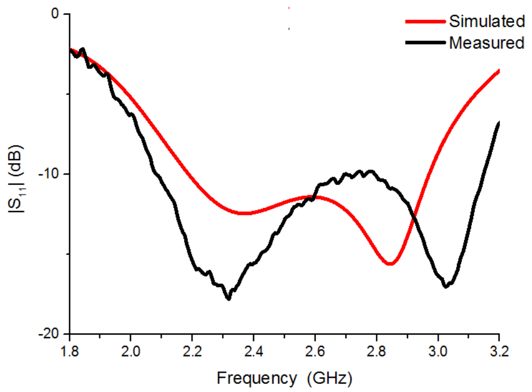

Figure 11- Simulated vs. measured scattering parameters

Figure 9 and 10 show the antenna configuration with the activated parasitic elements highlighted, and compare the simulated and measured reconfigurable antenna patterns with the two switches in the on state, radiating at 45° and 0° respectively. Figure 11 shows the antenna's measured and simulated reflection coefficient. The use of two active PIN diodes for each configuration results in a constant reflection coefficient for both 45º and 0º configurations. The antenna behaves as expected.

VI. CONCLUSION

In this paper, the design for a low cost, electronically controlled, wideband reconfigurable planar antenna based on the Uda-Yagi scheme is presented. By electronically controlling the state of the PIN diodes, the proposed antenna shows a consistent 3dB gain over the entire 360° range within the frequency range of 2-3 GHz.

The reported results demonstrate the reconfigurable properties of the proposed design over a wide frequency range which can be implemented to achieve greater system performance in various applications like direction of arrival detection.

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