Fabrication and Characterization of a Directional SPIDA Antenna for Wireless Sensor Networks

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***Abstract*—This paper presents the simulation, fabrication and complete characterization of a 2.4 GHz directional antenna designed for Wireless Sensor Network (WSN) nodes, named SPIDA. The use of this kind of antennas empowers the performance of sensor nodes, as they increase the communication range without compromising the power consumption. The antenna was simulated and the results were compared with measurements, obtaining a gain of 6.8 dBi. Also future optimization options for this antenna are discussed, including the use of switched beamforming.**

I. Introduction

Wireless Sensor Networks (WSNs) have increasingly been used to connect the physical and digital world for a large variety of applications. These are composed of small network nodes that contain a microcontroller, a radio transceiver, an antenna and different sensors. These nodes are expected to be of small size, low cost and to have a battery life-time from months to years. These desired characteristics would allow to deploy large networks with a very high node density in order to acquire magnitudes from the physical world with reduced cost of installation and maintenance.

The most widely used protocol for the radio communication in WSNs is the one defined in the IEEE 802.15.4 standard, and for the last decade there has been a large amount of research on how to optimize network protocols in order to improve efficiency and reduce power consumption. Nevertheless, the role of the antenna is often underestimated and left out of the optimization, as commercial nodes come with standard omni-directional whip antennas. The antenna is a decisive element to optimize, as it may provide a higher gain and improve the quality of the network link without increasing the power consumption. Particularly, switched beamforming techniques enable to concentrate the transmitted power in a given direction and increase the communication range of the network nodes without compromising the battery lifetime. The SPIDA antenna [1] is an example of an electrically switched directional antenna that uses switched beamforming techniques designed specifically for WSN nodes. These antennas which take their name from *Swedish Institute of Computer Science* Parasitic Interference Directional Antenna, are of reduced size and low cost, enabling them to be introduced in large deployments.

In this work we describe the complete process to simulate, optimize, fabricate and characterize a SPIDA antenna in the band of 2.4 GHz. This is a simple and complete process to understand and manipulate the performance of these antennas. Later the developed antennas will be used in WSNs, which will allow to evaluate the performance of them in this class of wireless networks. Another advantage for this kind of antennas is that they are quite cheap to fabricate, without needing specialized equipment. On the other hand, it is true that the manual fabrication process takes an important amount of time, which represents a task to optimize.

The rest of this document is organized as follows. In Section II the main characteristics of the SPIDA antennas are introduced. In Section III the results of the simulations are described. Section IV describes the fabrication process, followed by Section V that describes the characterization of the antenna, discusses the obtained results and proposes future work lines. Then, in Section VI, the conclusions are summarized.

II. SPIDA Antenna

SPIDA antenna is a kind of antenna that allows to perform switched beamforming [1], [2]. Being able of controlling the beam direction dynamically is a very useful feature for wireless communication systems also considered in a similar kind of antennas based in this case in Electronically Steerable Passive Array Radiators (ESPAR) [3], [4] and [5]. Comparing SPIDA antennas with ESPAR ones, the first are simpler and cheaper to fabricate, which represents an important advantage. These dynamic beamforming features are a promising alternative to optimize WSNs, reason why several researchers have been developing this area [6], [7], [8].

Fig. 1 presents the fabricated antenna. This antenna has a parasitic element defined as director (the one glued with silicone) and other five parasitic elements defined as reflectors (once they are welded to its corresponding "legs", which are connected to the hexagon and through it to the cable shield). This prototype was used to characterize electromagnetically the performance of this kind of antenna. In a future work, switches will be inserted between the parasitic elements and its corresponding "leg" in order to have dynamic beamforming (controlled by their switches which are able to connect the parasitic element to the "leg" or not).

For this antenna, the dimensions provided in [1] and [2] were strictly followed. The configuration of the elements of this antenna is not accidental, by having the elements diametrically opposed the variation in the input impedance of the active element is decreased [9]. To understand the influence

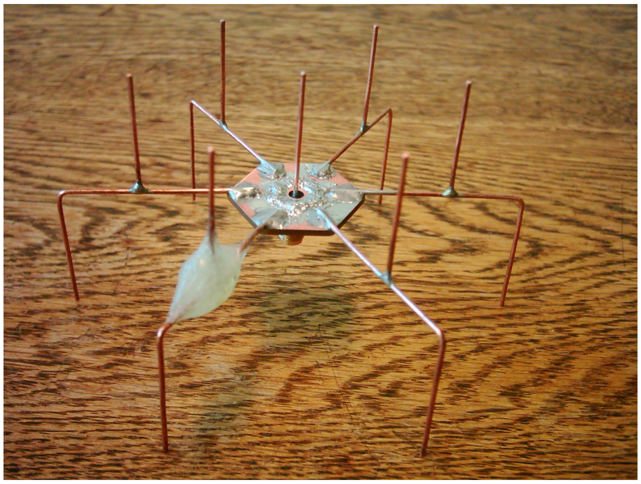


Fig. 1. SPIDA antenna fabricated.

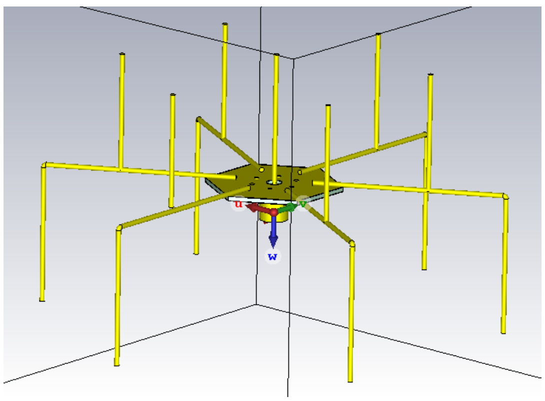


Fig. 2. SPIDA antenna model used in the simulator.

of a parasitic element close to an active element, the reader can see [10]. There it is explained that the influence of the parasitic element over the radiation pattern is grater when the parasitic element is closer to the active element.

III. Simulation

Computer Simulation Technology (CST) tool was used to simulate the antenna [11]. This electromagnetic simulator was used to obtain the S_{11} parameter as well as the radiation pattern corresponding to the introduced model.

Fig. 2 shows the antenna model used for the simulation. This model represents carefully the fabricated antenna. E.g., the vias used to connect both faces of the hexagon were also considered in this model.

Fig. 3 presents the S_{11} parameter obtained by simulation for a frequency between 2 GHz and 3 GHz, using the simulation model shown in Fig. 2. In this figure the S_{11} parameter allows to observe how the input impedance varies with the frequency between 2 GHz and 3 GHz. Later when this parameter was measured a similar behavior was found.

Fig. 4 shows the Radiation Pattern obtained by simulation for this antenna model (Fig. 2). As it can be seen in Fig. 4,

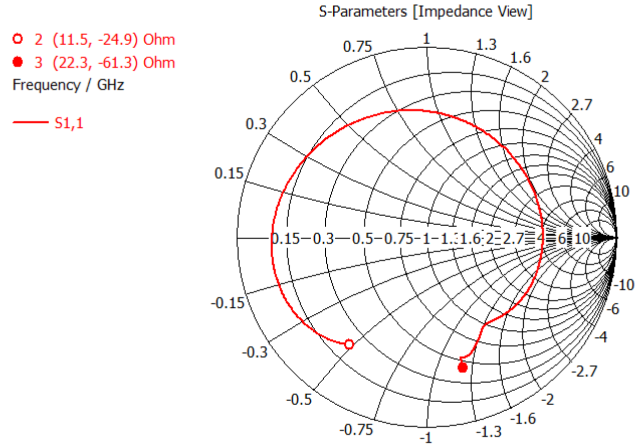


Fig. 3. Simulation of the S_{11} parameter using the SPIDA antenna model.

the main lobe of this antenna is in the direction of the director element. At this figure some small variations of the radiation pattern can be appreciated when the frequency is varied; e.g. the Front to Back Ratio (FBR) is better for $f = 2.4200$ GHz than for the other two cases.

As it is shown in Fig. 5, a maximum gain of 6 dBi could be obtained for this antenna according to the simulation.

IV. Fabrication

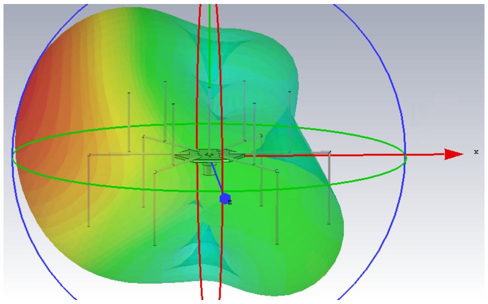
The elements were made using copper wire of 1 mm^2 of section (the dielectric shield was removed). The central hexagon was made of standard 1.6 mm FR4 PCB board of 35 μm of copper thickness. Later both copper layers of the hexagon were connected using vias of 1 mm^2 of section, welded with tin (the vias placement can be seen in Fig. 2). A SMA connector was welded to the lower copper layer of the hexagon to feed the antenna through it. The active element of the antenna (the central element) is connected through the SMA connector to the central wire of the coaxial cable used to feed the antenna. A coaxial cable with SMA connectors was used to feed the antenna.

The hexagon was designed using CadSoft Eagle PCB Design Software, and fabricated with a LPKF ProtoMat S63 circuit board plotter. The circuit board plotter features a resolution of 0.5 μm and accuracy of $\pm$ 0.02 mm, allowing a very precise fabrication. This equipment enables the fabrication of identical hexagons for the fabrication of these antennas.

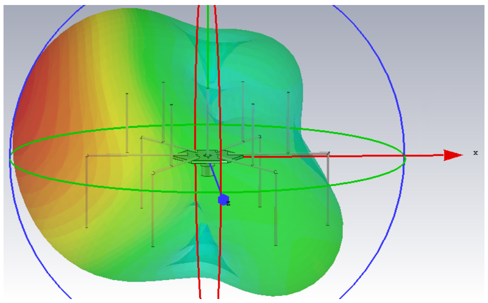
V. Characterization

For the characterization process a vectorial network analyzer (Rohde & Schwarz ZVB 8 Vector Network Analyzer, 300 kHz - 8 GHz), a RF generator (Agilent, E4438C, 250 kHz - 3 GHz, ESG Vector Signal Generator) and a spectrum analyzer (Agilent Technologies, EXA Signal Analyzer, N9010 A, 9 kHz - 7 GHz) were used.

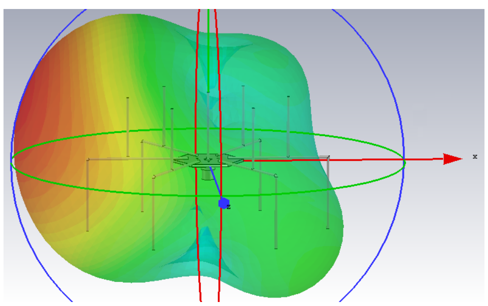
During the antenna characterization the effort was concentrated on S_{11} parameter and the radiation pattern in the H plane and E plane. The measures obtained can be respectively



(a) f=2.4200GHz



(b) f=2.4525GHz



(c) f=2.4850GHz

Fig. 4. Simulated Radiation Pattern for the SPIDA antenna model.

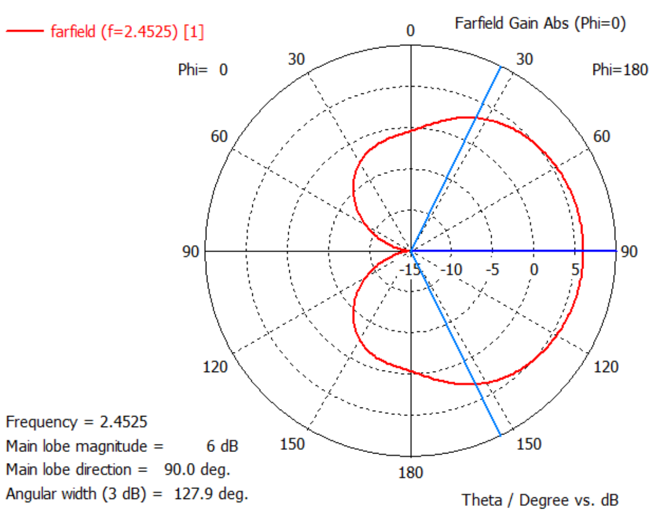


Fig. 5. Simulated gain in H plane for the SPIDA antenna.

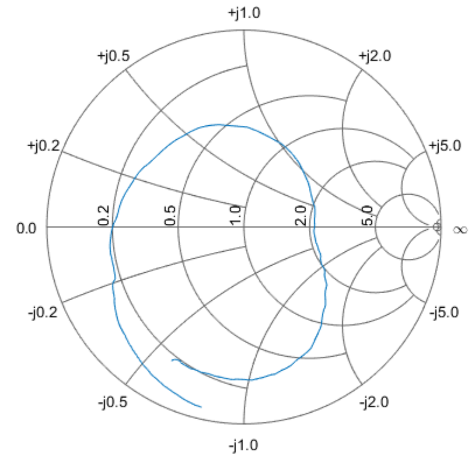


Fig. 6. Measured S_{11} parameter for the SPIDA antenna fabricated.

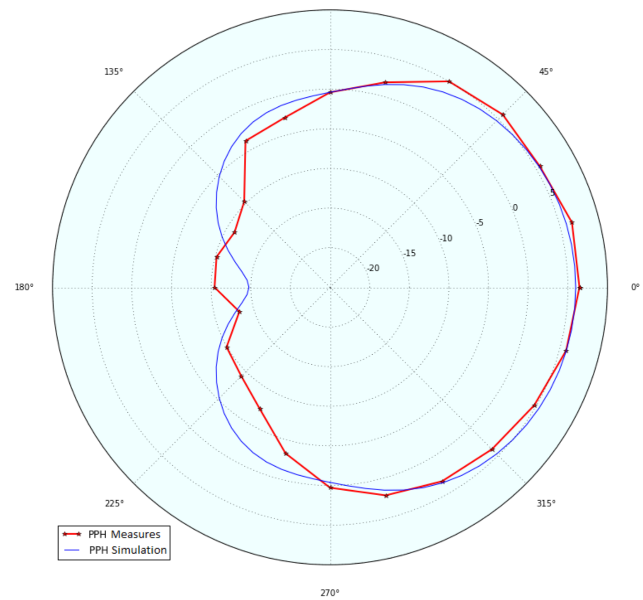


Fig. 7. Measured and simulated gain in H plane for the SPIDA antenna fabricated.

seen in Fig. 6, Fig. 7 and Fig. 8. In Fig. 7 and Fig. 8 the measures and the simulations are superimposed. As it can be observed the measures are quite close to the simulation results.

A maximum gain of approximately 6 dBi (6 dBi according to the simulations and 6.8 dBi according to the measurements) is considered a good result at this step, being a better gain than some previously reported results for similar antennas (e.g. in [3] (5.1 dBi) and in [1] (4.3 dBi)).

These results quantitatively show that these antennas are appropriate for the intended application, opening the path to future work for further improvements. The next efforts will be targeted towards the following aspects. First testing dynamic (switched) beamforming operation. Second, assess the possibility of reducing size and improving mechanical robustness by embedding this antenna in a cylindrical rod of FIK ceramic (as the one used in [4]). Finally, to speed up the

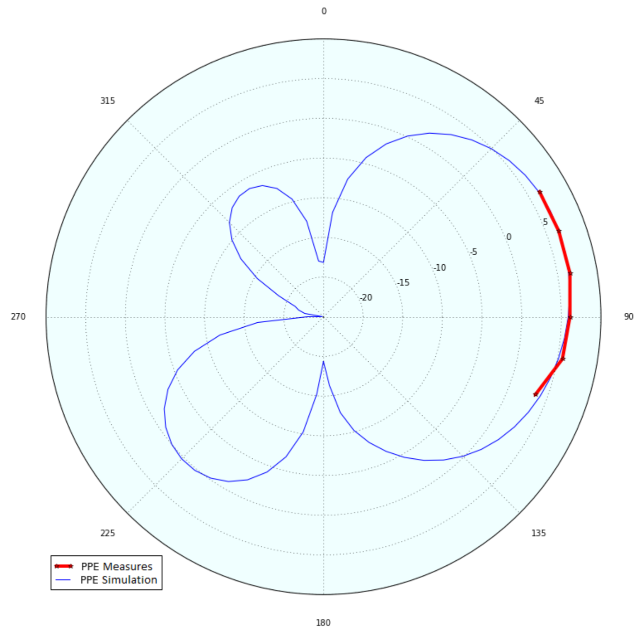


Fig. 8. Measured and simulated gain in E plane for the SPIDA antenna fabricated.

production process and improve repeatability, the substitution of wire elements by PCB elements (like the ones in Fig. 1 in [12]) will be considered.

VI. Conclusion

A six element SPIDA antenna for the 2.4 GHz ISM band was modeled, simulated, constructed and characterized. As far as the authors know, it is the first complete characterization reported of this kind of antenna. It was shown that a simple and cheap fabrication process leads to a directional antenna with very good performance. The measurement and simulation results were in good agreement. The obtained performance is comparable and even better than the best reported for similar antennas.

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