An UHF RFID Reader Antenna made of Materials from Construction Waste

Edmilson Carneiro Moreira and Antônio Sérgio Bezerra Sombra and Giovanni Cordeiro Barroso

***Abstract*— A circularly polarized microstrip metallic patch antenna made reusing and recycling materials from construction debris is proposed, designed, fabricated and validated in this paper. Such device is used in RFID systems operating at the 902-928MHz UHF band allocated for International Telecommunication Union, ITU, Region 2, that includes North and South America. The antenna is composed of two stacked patches, a T junction based on microstrip lines and a ground plane, being those arranged in simple and low cost structure. Experimental and simulation results of this microwave device are presented and discussed.**

***Keywords*— Antennas, RFID, Communication Systems.**

I. Introduction

RFID is an Auto Identification and Data Capture, AIDC, system that carries information around through the use of radio frequency waves. This technology, especially the specified at ISO 18000-6c, has been increasingly adopted in various industry sectors, being really important in supply chain management. Although, as reported by [1], one of the major difficulties of RFID adoption is the expensive costs of the needed infrastructure. Thus, the development of a low cost RFID infrastructure is vital to decrease these costs and, consequently, push the use of RFID worldwide.

Microstrip patch antennas are used in various wireless applications, being present in missiles, aircrafts, spacecrafts and satellites, as stated in [2], for example. These, according to [2] and [3], are lightweight, thin, cheap, easy to manufacture and to polarize circularly and linearly. Microstrip patch antennas presents a narrow bandwidth that decreases the interference in the communication system in debate, and are easily integrated with feeding networks and impedance matching devices. All these features made the above-mentioned radiation device one of the most popular for RFID systems operating in the UHF band, as seen in [4].

The construction industry in Brazil, according to [5], grew by 4,8% in 2011 and will grow 5,2% in 2012. In line with [6], this industry generates a huge amount of waste that it is responsible for somewhere around 41 to 70 % by weight of solid waste produced in the urban environment, as stated in [7]. In [8], is shown the recycling potential in the Brazilian city of Sorocaba. In this city, the Sorocaba Dump Recyclers Cooperative, Cooperent, works in the first two weeks of every month in Sorocaba Inert Waste Landfill, removing and separating 80 tons of construction and demolition waste that instead of buried, will be reutilized or recycled. In these 80 tons, notable amounts of plastics, 2.55%, and metals, 9.84%, can be found. Conductors, like metals, and dielectrics, such as plastics, can constitute microstrip patch antennas. If they are well selected and properly prepared, these materials can be used in the manufacturing of microstrip antennas with the same performance pattern established by those devices made of virgin ones.

It is against this background that comes the idea to conceive a low-cost circularly polarized microstrip patch antenna for RFID systems operating in the UHF band allocated for ITU Region 2 countries, conforming to [9], being it made reutilizing and recycling materials from construction and demolition debris, helping the environment and the RFID field with one single action.

This paper continues with Section II that describes the antenna design, simulation and fabrication, presenting the virtual model made in a software simulator and the the physical prototype. The experimental and simulation results are shown, analyzed and discussed in Section III. Conclusion of this paper and the proposition of a future work are made in Section IV.

II. The Antenna Conception

From the idea to the prototype, several phases were elapsed. The first one is the antenna constitutive matter definition. Once this antenna must be made reutilizing and recycling materials from construction and demolition debris in order to be environmentally friendly, the above mentioned definition process is not a simple task. These materials used must not only be ”green”, but also look for the antenna fabrication and operation. Therefore, the material selection process occur considering the study of properties like stiffness, ductility, fragility, hardness, tenacity, resilience, machinability and electrical conductivity and permissiveness. A study about this specific waste and informal tests performed in the material candidates during visits to construction sites at Fortaleza, Brazil, settle the constituent material of the antenna. The microwave device will be made reusing tinned, paint cans, and galvanized, fences and signs, steel sheets, as conductor, and recycling polypropylene, as dielectric, from civil construction waste, as seen in [8]. Fig. 1 show some examples of materials used in the manufacture of the antenna in question.

Now, that the antenna's constituent material matter is defined, is time to focus in electromagnetic engineering of

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(a) Tinned steel samples.

(b) Galvanized steel samples.

(c) Polypropylene samples.

Fig. 1: Antenna constitutive matter

the antenna. As stated in [2], the rectangular patch, is the most easy to fabricate and analyze, and can be used from the simplest to the most demanding applications. The use of two stacked patches, a main and a parasite, allows a wider impedance bandwidth that, by it self, increase circular polarization band, as cited in [10]. Circular polarization is really important to several RFID applications. The use of a T junction is, using two feeds, the simplest and cheaper way to excite two resonant, orthogonal and *quasi*-degenerate modes needed to make the antenna radiation to be circularly polarized. A impedance matching network influence directly the overall efficiency and bandwidth. A tapered three dimensional transition is a microstrip line that connects the feeding network to the rectangular patch and makes the impedance matching. Thus, the antenna is specified as circular polarized square microstrip patch with a ground plane, a polypropylene and a air substrate layers, a main and a parasite patch, a microstrip feed line working as a T junction and a three dimensional transition impedance matching device that binds the principal patch with above mentioned feeding network. The main and parasite patches side length are represented by Lp and Lm, respectively. The patches were separated by an air substrate layer, where four cylindrical apparatus made of polypropylene, with Hp of height, gives the mechanical support to the parasite patch. The ground plane has square edges with a value of Lg and is separated from the main patch by a truncated polypropylene substrate layer with Hm of height, being it that gives mechanical support to the main patch.

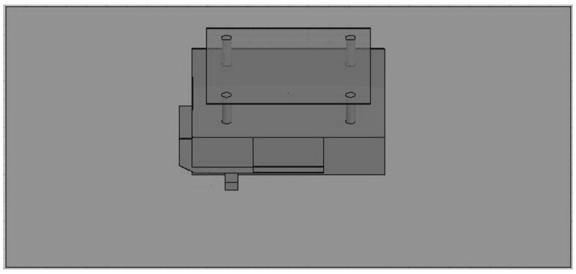


Fig. 2: Proposed antenna configuration.

Now, that the basic model of the antenna is conceived, its exactly dimensions must be determined in order to operate as needed. Initially, the physical and mathematical tools showed in [11], [12], [10] and [2], allowed the specification of these preliminary antenna dimensions. Then, a virtual model based on the proposed antenna configuration with their preliminary dimensions is designed into a CAD simulation software that uses the finite element method called Ansoft HFSS^{TM}. With this virtual model, several parametric studies were conducted based on analysis using the cavity and transmission line models and a systematic design method presented in [13]. These studies resulted in a final optimized antenna virtual model, based on the proposed configuration that works as required in the 902-928MHz UHF band. Fig. 3 shows the refined model of the antenna.

The table I illustrates the antennas most relevant dimensions of this final model.

TABELA I: *Important antenna parameters.*

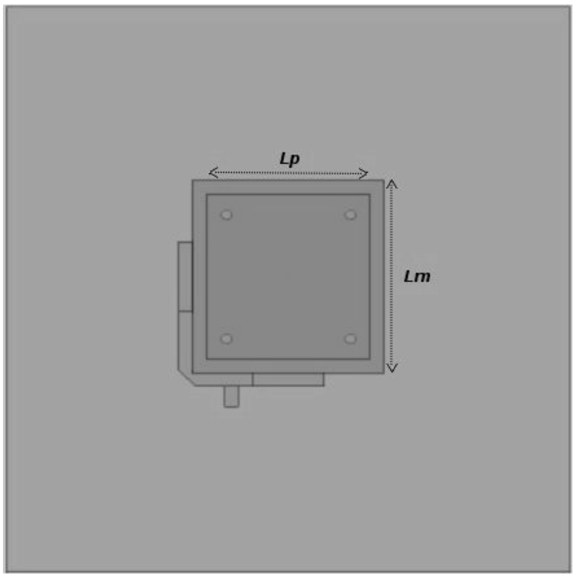
Parameter	Lg	Lm	Lp	Hm	Hp
Length(mm)	280	96	65	18	12

Once defined an antenna blueprint, its prototype is then manufactured, being this process presented in a nutshell. First, the used steel sheets are reworked in order these to became flat as virgin ones. Than, the metal pieces, such as patches and transmission lines, are cut using paper templates and plastic parts are made machining a recycled polypropylene block. Finally, some metallic pieces are welded together, if needed, and all manufactured parts assembled as a one, forming the antenna itself. It's important to emphasize that 4 antennas where made through this process, and all of them showed very consistent results. The "green"antenna prototype is presented in Fig. 4.

III. Results

The circular polarized microstrip square patch in question is validated by the simulated and experimental obtained results of return loss, impedance, axial ratio and gain . The simulation, as mentioned earlier, was made with Ansoft's HFSS^{TM}. The

(a) Side view of the model.



(b) Top view of the model.

Fig. 3: Final antenna model

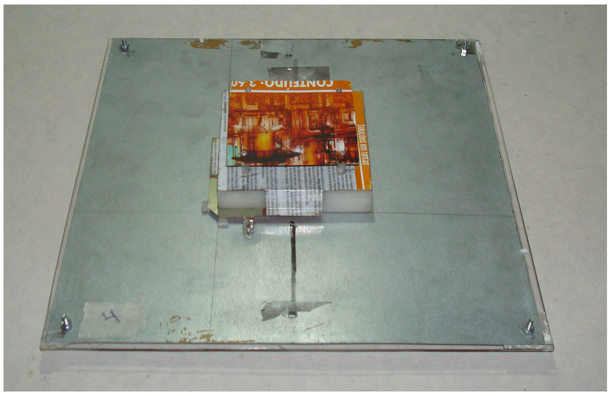


Fig. 4: Prototype.

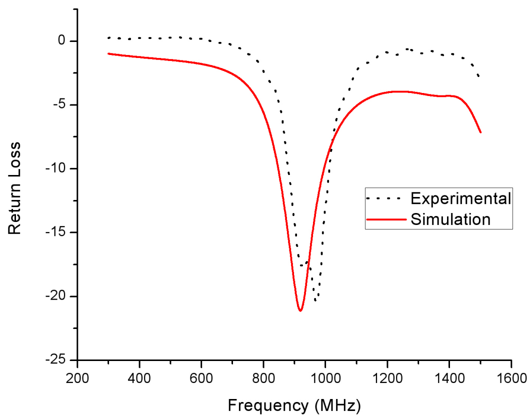


Fig. 5: Return loss.

experimental results of the specific radio frequency device obtained directly from a network analyzer Agilent 8510C.

Fig. 5 shows the return loss of simulated and experimental measured from the antenna. The simulation results shows minimum value of -21.11dB at 918.9MHz. The center frequency of UHF band defined by ITU for its region 2 to RFID systems, 915MHz, the recorded value is -21.00 dB. The return loss bandwidth, which includes values less than -10dB, as [14], is 147.08MHz and is located between 847.65MHz and 994.79MHz. The return loss experimental measurements presented a minimum of -20.39dB at 969.8MHz. At center frequency of 915MHz, the return loss showed a experimental value of -16.85dB. The range of 879.32MHz and 1011.56MHz hosts the return loss band obtained experimentally, with a value of 132.24MHz.

Figs. 6 and 7 shows the simulated and experimental values of real and imaginary impedance parts, $Re[Z]$ and $Im[Z]$, respectively. The values justify the good results of return loss, since, at 915 MHz, the antenna has experimental real impedance of 43.57Ω that is really close to 50Ω present in the feed line.

The antenna's Smith Chart, illustrated in Fig. 8, compile those impedance informations in Figs. 6 and 7 together, showing that the simulation and experimental result are not identical, like presented in [16] and [17] , but very similar. This is probably due to the difficulty to model some parts of the prototype, such as screws and welds, leading to some inaccuracy among the simulated and experimental results. A very small loop can be seen close to the center of the Smith Chart, in both lines: the experimental and the simulated. This little loop indicates that two resonant, orthogonal and *quasi*-degenerate modes are excited at close frequencies, according to [18], making possible CP radiation.

Considering the same plane defined when $\theta = 0$ and $\phi = 0$, the $x - z$ plane, the antenna's gain is presented in Fig. 9 and is observed that the device gives a gain higher than 7dBi in the entire UHF band defined for ITU's region 2.

The theoretical radiation pattern of the studied antenna when $\phi = 0$ is presented in Fig. 10. Operating 915MHz, the equipament presented a maximum gain of 7.32dBi. Standard RFID patch antennas presents gain values ranging from 5dBi to 6dBi, according to [15]. Therefore, the results presented Fig. 10 e Fig. 9 confirm that this works antenna has good gain, being it greater than multiple available devices in market.

The simulated values of axial ratio versus frequency can be seen in Fig. 11, as well as the bandwidth achieved considering lower values than 3 dB that in this case is 36.8 MHz. This band is placed in the interval between 895.9MHz and 932.7MHz,

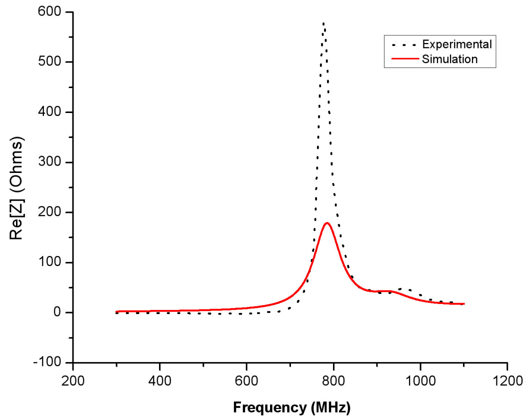


Fig. 6: Real part of the impedance.

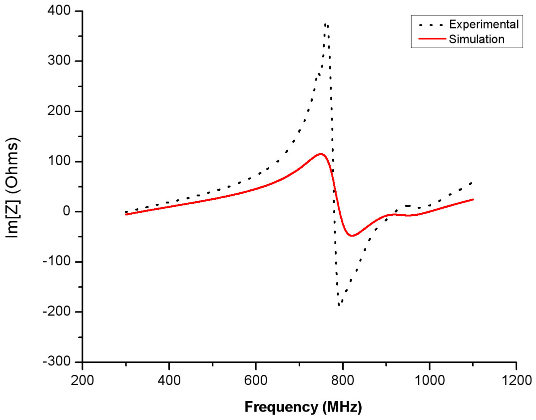


Fig. 7: Imaginary part of the impedance.

with its minimum value being 0.45dB, at 913.6MHz.

The theoretical radiation pattern in three dimensions is shown in Fig. 12 and completes the characterization of the antenna patch. One important thing that can be concluded just by observing this Fig. is that the radiation pattern is quite symmetrical around the z axis.

From the environmental point of view, it is interesting to investigate what impacts this work may bring. Disregarding the mechanical protection need for a real application, the antenna presents a total weight of 0.421 kg, being 0.256 and 0.165 kilograms of steel and polypropylene respectively. As reported in [19], when 1 kg of plastic waste is recycled, 1.3 kg of CO_2 are saved from emission. As stated at [20], the production of 1 kg of steel generates 2,198 kg of CO_2. Consequently, this metal alloy reutilization prevent the atmosphere pollution by all that CO_2. Thus, one "green"antenna save the emission of 0.777 kilograms of CO_2 to the environment. The table II synthesizes the exposed previously.

IV. Conclusion

This work expresses the idealization, design, simulation, manufacturing, testing and validation of an microstrip patch

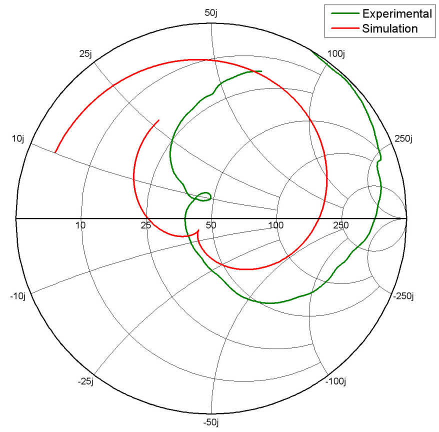


Fig. 8: Input impedance Smith Chart.

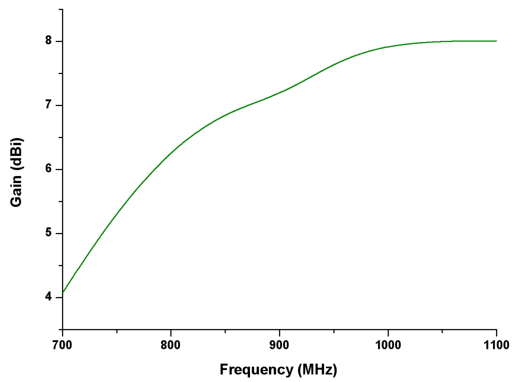


Fig. 9: Gain at boresight.

antenna made for radio frequency identification systems that operates in the UHF band defined by ITU for region 2 countries and made through reuse and recycling of metallic and plastic parts, all coming from the civil construction waste. The equipment confirmed its functionality as an electromagnetic radiator in the above-mentioned band, with gain higher than 7dBi, axial ratio and return loss of less than 3dB and 10db respectively. It's fair to remind that this work antenna presents greater performance than several available devices in the market. The antenna also showed a very good mechanical stability, mainly due to the polypropylene substrate. Environmentally, the microwave device effectively have a positive impact. The SINIAV, Brazilian National System for the Automatic Identification of Vehicles, explained in [21], will use 2.500 antennas to be implement in São Paulo. If were used "green"antennas, 1942 kg of CO_2 would not be emitted to the atmosphere, and 640 kg of steel and 412 kg of polypropylene would be preserved from being made from natural resources.

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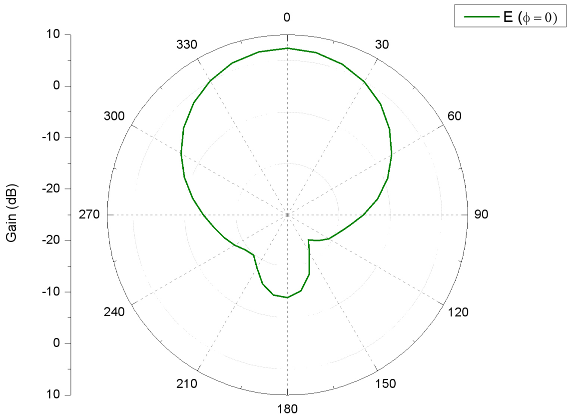

Fig. 10: Radiation pattern.

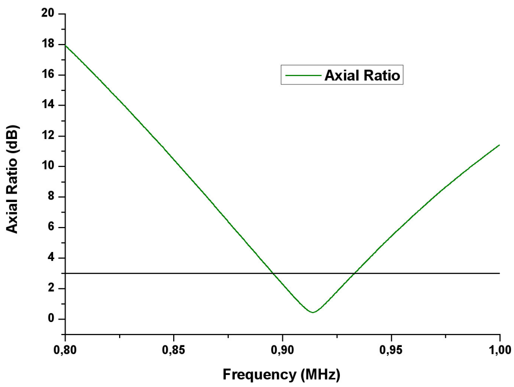

Fig. 11: Axial ratio.

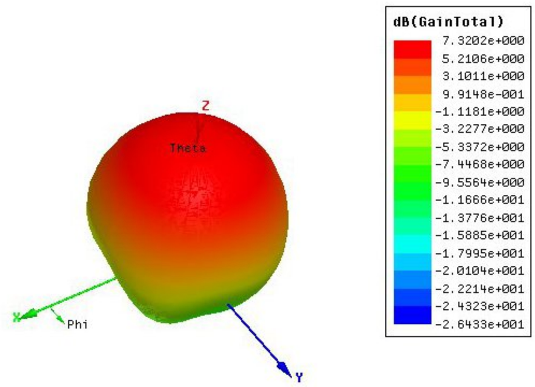

Fig. 12: 3D radiation pattern.

TABELA II: *Environmental benefits of the antenna.*

Material	Process	Weight (kg)	CO_2 Saved (kg)
Steel	Reusing	0.256	0.562
Polypropylene	Recycling	0.165	0.215

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