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Compact Monopole Antenna for Smart Meter Applications in ISM Band 900 MHz

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Abstract – **A compact monopole antenna for smart meters in Industrial Scientific and Medical (ISM) band 900 MHz is developed in this paper. The antenna was built in low-cost material (FR4), with spirals in P-Shape, and a total area of 4.32 cm^2. The monopole antenna has broadband characteristics, however, the use of a spiral in P-Shape provides a reduction of the bandwidth, making it operate in narrowband. The P monopole antenna presents good relation between simulated and measured results, a difference of 0.32 %, measured bandwidth of 32 MHz (896 - 928 MHz), covering the ISM band 900 MHz (902 - 918 MHz), omnidirectional radiation pattern, without secondary lobes, with simulated HPBW of 107 degrees, the maximum gain of 2.29 dBi, and current density of 387.19 A/m^2.**

I. INTRODUCTION

In the recent years researches in smart grids has been intensive, a difficult is the long distances management of electrical systems distributed in real-time. The smart grids require an intelligent energy management system, an efficient communication infrastructure to estimate and control of distributed energy resources systems demands smart devices controller [1]. The wireless commercial networks, as cellular communications (2G, 3G, 4G), industrial, science and medical applications (ISM), IEEE 802 and your families (Wi-Fi, Wi-Max), and others, with compatibility of machine-to-machine (M2M) technologies are used possibilities for application in smart grids [2, 3]. Machine to machine communications has characterized by automated connectivity among machines or devices without any human intervention, and relationship with Internet of Things (IoT), and others systems [4]. The ISM band ((910 - 928) MHz have intensive use in several communications systems, being a good candidate of use in M2M application for smart grids, thus the antenna operating in this band provide implementation of low cost.

The smart meters are M2M devices used in automatic meter reading systems (AMR), with the function of collecting and transmitting information automatically to a meter data, and management system, for further processing and storage. The project of a smart meters antenna requires some characteristics like compact structure, omnidirectional radiation pattern, low cost, easy reproduction, and operation in the commercial band [5, 6, 7]. The project of antenna for smart meters presented application in various frequencies, such as cellular communications technologies, wireless local area network, Global Positioning System (GPS) and ultra-high frequencies (UHF) [8, 9, 10].

The printed monopole antenna is generally used in ultra-wideband antenna, with interesting characteristics for use in smart meters as, compact structure, low cost, a facility built, the possibility of circular polarization, omnidirectional radiation pattern, wideband, and low effective isotropic radiated power. However, it presents limitations as susceptibility to interference by metallic plates and other electromagnetic devices near to the ground plane, and the possibility of group delay, i.e., the signal sent may be delayed by the receiver, depending on its position relative to the antenna [11, 12]. The use of the spiral in a monopole antenna provides a reduction of the bandwidth, making the narrow band antenna. A spiral antenna has the following attributes: lightness, quick assembly and compatibility with microwave circuit. Thus, it has essential features in many wireless communication applications. The spiral structure makes the antenna lighter and provides broadband action [13].

This paper presents the design of the compact spiral monopole antenna, the total area of 4.32 cm^2, with P-Shape, operating in ISM band 900 MHz, low cost, and omnidirectional radiation pattern, with a comparison of simulated and measured results. This paper is composed of three parts before this introduction. Section II present the materials and methods used, section III the results, and the conclusions in section IV.

II. MATERIALS AND METHODS

The design method for the P antenna, was developed by steps:

1. The definition of the application and determination of operating frequencies, choice of the antenna characteristics suitable for the application;
2. The selection of the conductor and dielectric materials, with a characterization of the properties of the material;
3. Simulation and optimization of the antenna, where some adjustments are done targeting the desired resonant frequency, with the construction of the antenna, and comparison of the measured and simulated results.

The electrical characterization, was performed with the measurement of the permittivity, loss tangent, and thickness of the dielectric, were performed in the laboratory of the Federal Institute of Paraiba, the campus of João Pessoa, Paraiba, by probe process with the software Dielectric Probe 85070, using the Vector Network Analyzer (VNA) of Agilent Technology model E5071C (300 kHz - 20 GHz). The results of the dielectric characterization are shown in Fig. 1.

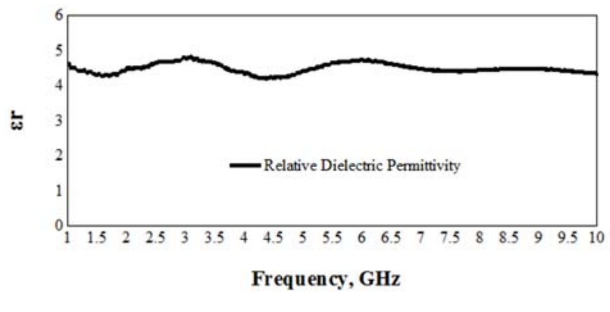

Fig. 1. Fiberglass permittivity of dielectric characterization.

In this project, we used the printed monopole antenna structure, feeding by a transmission line, and spiral patch element. Fig. 2 shows the antenna design with dimensions (mm), Fig. 3 show the prototype. The simulations were performed in the Radiometry laboratory, Federal University of Campina Grande, in Vector Network Analyzer (VNA) Agilent Technologies, model E5071C (9 kHz - 8 GHz). The antennas was built in FR4, dielectric thickness h = 1.55 mm, dielectric permittivity ϵ_r = 4.34, and loss tangent of δ = 0.002. The transmission line used presented width of 0.5 mm, and length 16.2 mm. The monopole antenna has shaped of "P" with three concentrically spirals, calculated by multiple of guided wavelength (λ_g), thus the width of greater spiral dimension has approximately λ_g/7, length λ_g/15, width spiral core of λ_g/10, and length of λ_g/39, provides total area of 4.32 cm^2. The effective wavelength can be calculated by equation (1),

$$\lambda_g = \frac{c}{f_0\sqrt{\epsilon_r}}, \qquad (1)$$

were ϵ_r is the relative dielectric constant, and f_0 is resonance frequency of antenna. The spacing of spirals used was 1 mm. The matching impedance has obtained by the proximity of spiral terminals. Simulation and adjusts of antenna design were performed by commercial software $Ansys^{TM}$. The Fig.2 and Fig. 3 shows simulated P monopole antenna dimensions (mm) and prototype.

The experimental setup used to measure the antenna response can be seen in Fig. 4: An antenna (1) connected by SMA connector, receiving signals from a coaxial cable 30 cm RG-174 (2) from the VNA (3) , connected by a UBS cable (4) to the computer (5), avoiding movements during measurements. For each measurement, SOL (short-open-load) calibrations were performed.

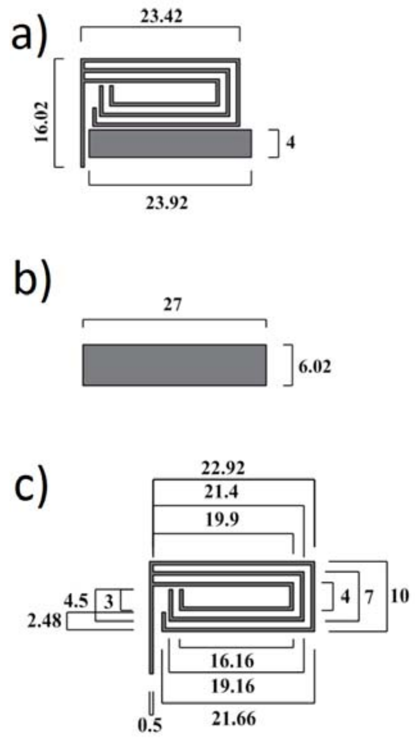

Fig. 2. P monopole antenna: (a) top vision of antenna with dimensions, (b) bottom vision of antenna with dimensions and (c) patch element with dimensions.

Fig. 3. P monopole antenna: prototype top and bottom vision.

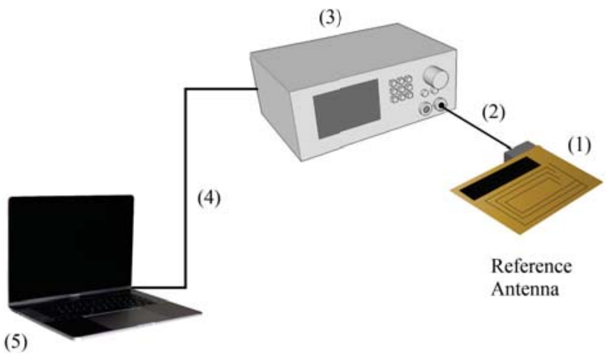

Fig. 4. Schematic of the experimental setup for measurement.

III. EXPERIMENTAL RESULTS AND DISCUSSION

This paper presents the use of spiral P-Shape in a monopole antenna for smart meters operating in ISM band 900 MHz. The use of spiral P-shape in an antenna with broadband characteristics provides a reduction in the bandwidth, making it operate in narrowband. The antenna presented good relation between measured and simulated resonance frequency, difference Δ_f = 0.32 %, measured bandwidth of 32 MHz, compact structure, 4.32 cm^2, omnidirectional radiation pattern, simulated Half Power Beam Width (HPBW) of 107°, the maximum gain of 2.29 dBi, and high current density of 387.19 A/m^2.

Fig.5 shows comparison of return loss ($|S_{11}|$) parameter simulated and measured of P monopole antenna for smart meters. Values has been observe in the Tab. 1 and Tab. 2. The antenna presented good concordance of simulated and measured results, with difference in the resonance frequencies of 0.32 %, return loss S_{11} = -23 dB and bandwidth covering the ISM band.

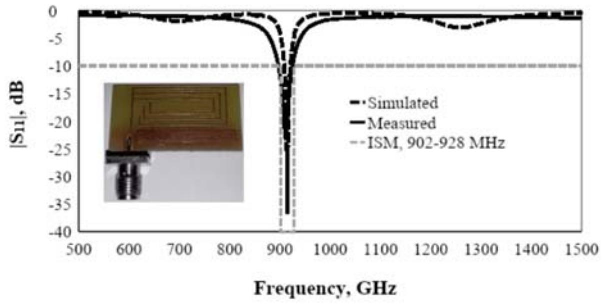

Fig. 5. Result values of P antenna simulated and measured.

Table 1. Result values of P antenna simulated and measured - Frequency

P(antenna)	f_0 (MHz)	f_1 (MHz)	f_2 (MHz)
Simulated	915	909	922
Measured	912	896	928

Table 2. Result values of P antenna simulated and measured - Bandwidth and Return Loss

P(antenna)	Bandwidth (MHz)	Return Loss (dB)
Simulated	13	-36.8
Measured	32	-23

Measured impedance on Smith chart can be observed in Fig. 6. The point 1 indicating the impedance in resonance frequency (912 MHz), with result closed to the input impedance (50 Ω), with Voltage Standing Wave Ratio (VSWR) close to the 1 (one), demonstrating the narrowband operation.

Fig. 7 shows simulated 3D and 2D radiation patterns of the P monopole antenna in resonance frequency, with gain, HPBW, and current density indicated. The antenna presented an omnidirectional radiation pattern, with the maximum gain in broadside direction of 2.29 dBi, the current density of 387.19 A/m^2, HPBW in the patch direction of 97°, and ground plane direction of 107°. The lack of secondary lobes observed in the radiation pattern indicates low group delay, so the signal sent arrives at all points illuminated by the antenna without delay. The high current density is due to the width of the spirals used in the antenna. Current tends to traverse the structure more in the

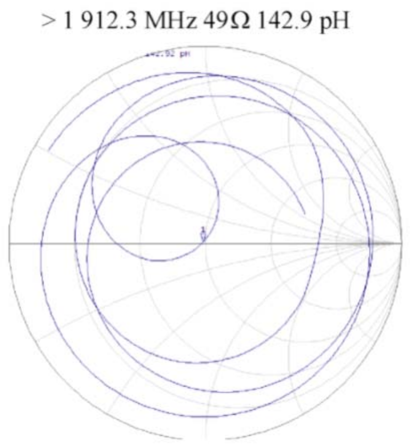

Fig. 6. Smith chart of P monopole antenna with resonance frequency indicating.

edges than in the center of the radiant element [12], thus, the thinner the element, the less difficulty in the passage, and the stronger will be the current on the surface of the antenna.

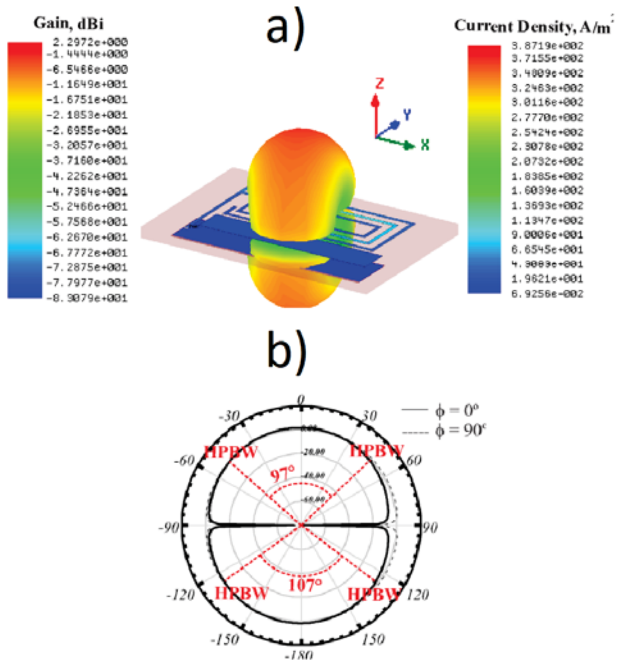

Fig. 7. Radiation pattern of P monopole antenna: (a) 3D with gain and current density, (b) 2D with HPBW.

IV. CONCLUSION

This paper presents the use of spiral P-Shape in a monopole antenna for smart meters operating in ISM band 900 MHz. The use of spiral P-shape in an antenna with broadband characteristics provides a reduction in the bandwidth, making it operate in narrowband. The antenna presented good relation between measured and simulated resonance frequency, difference $\Delta_f = 0.32\,\%$ measured bandwidth of 32 MHz, compact structure, $4.32\,cm^2$, omnidirectional radiation pattern, simulated HPBW of $107°$, the maximum gain of 2.29 dBi, and high current density of 387.19 A/m^2.

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