

# Potential to use Microstrip Patch Instead of Dipole Antennas in 2.4 GHz Wireless Sensor Networks

Marko M. Milivojčević, Nenad D. Tolić, and Mijat I. Štimac

**Abstract** — This paper describes the process of designing, simulating and measuring antenna parameters in order to perform a comparative analysis of the performance of microstrip patch antennas and dipole antennas intended for use in wireless sensor networks. The implemented antennas are designed for the unlicensed ISM band of 2.402-2.480 GHz as one of the most widely used bands for this type of network. The patch antenna was created based on calculation and tested in simulation software, and then adjusted with appropriate measurements to suit the intended purpose. Measurements in real conditions were made to compare the patch and dipole antennas in the same frequency range. The patch antenna was further tested, due to the specificity of the implementation within the WSN, in an enclosed and open enclosure made of a conductive material that simulates the enclosure of wireless sensor network nodes in certain applications. The aim of this paper is to show the possibility of using patch antennas instead of dipole antennas in the enclosures of wireless sensor networks nodes.

**Keywords** — Antenna, patch antenna, dipole antenna, wireless sensor networks, ISM band, WSN.

## I. INTRODUCTION

THE Wireless Sensor Networks (WSN) were initially designed as primitive low-speed networks composed of a large number of nodes equipped with a sensor, a microprocessor, a wireless communication interface, and a power source. Due to the decline in component prices, the increase in processing power and the improvement of communication protocols, they have expanded their application and found a place in almost every segment of modern living [1] [2] [3] [4]. The increasing development of IoT (Internet of Things) is setting ever more strict requirements for WSNs in terms of the speed and reliability of data transmission as well as increasing the distance between nodes [5]. The implementation of these

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requirements would be relatively straightforward without the need for as low power consumption as possible due to the limited power supply of the nodes (battery power) and the application area where there may be a large number of other signals interfering with WSN. The wireless communication interface, i.e., the radio part of the node, has a large contribution to the energy consumption, so its construction can directly influence the "life extension" or increased energy efficiency of the node. This part of the node also greatly affects the quality of the transmitted or received signal and the elimination of interference. An antenna as an integral part of radio interfaces plays an important role in its efficiency, being one of the cheapest parts of the assembly itself, however, designing the antenna itself in WSN networks can be difficult due to limitations in terms of the physical size of the node and its robustness or compactness, respectively, a form that again depends on the specific application of the network. In this paper, a comparative analysis of dipole and microstrip patch antennas intended for WSN nodes was made taking into account the antenna gain, physical shape, and frequency of unlicensed ISM band at 2.4GHz used in the WSN as well as the type of housing where the antenna was mounted. In addition to the design method based on the theoretical model and the simulation results, the measurement results in the laboratory are presented. The idea underlying this work is to provide a comparative representation of the characteristics of the observed antennas to allow the correct selection of the antenna depending on the given application of the WSN network in order to achieve maximum energy efficiency and appropriate signal quality between nodes, and to show the possibility of using microstrip patch antennas instead of dipole antennas if they are constrained by the size of the sensor node body of the sensor network, keeping them on approximately the same physical dimensions.

## II. LITERATURE OVERVIEW

A review of the literature shows that the design of patch antennas is highly prevalent in modern telecommunications, in which, due to increasing coverage, antenna gain does not represent the most important characteristic. The design of the 2.402-2.480 GHz frequency patch antenna is highly developed, however, the performance testing of such antennas used for wireless sensor networks has not been extensively analyzed in the literature. Wireless sensor networks, as networks based primarily on wireless communication, require an antenna as

a required piece of hardware, and since one of the primary features of these networks is easy scalability, it is very important that antennas are not directional. Another requirement of the WSN is the ability to operate antennas well in a wide variety of housing types, which is also not a prominent topic in the literature, like an analysis of the operation of such antennas in a closed housing, which is often used as sensor node housing in applications such as smart parking where sensor nodes are integrated into the surface of the street and are required to physically withstand the frequent crossing of the vehicle [2]. In paper [6], where the implementation of WSN for traffic monitoring is addressed, it can be clearly observed that the entire node, including the antenna, is placed in the line marker housing on the road. The marker housing is metal, and an already assembled module with a PCB antenna was used. Taking into account the shape and dimensions of the housing, it opens the possibility for designing and testing a better performance antenna, patch antenna, and its operation in similar conditions. An analysis of the available literature did not reveal similar testing, so that motivates the testing in this paper. A review of the literature related to low height antennas that have a good performance in the observed frequency range shows that a potential application in low height housings may have helical antennas [7] or magneto-dielectric antennas [8]. Helical antennas are small in size and have very low production costs, however, the radiation diagram shown in Fig. 1 is not omnidirectional, especially when the antenna position is horizontal, so it is not suitable for most wireless sensor networks whose sensors do not have a predefined fixed position.

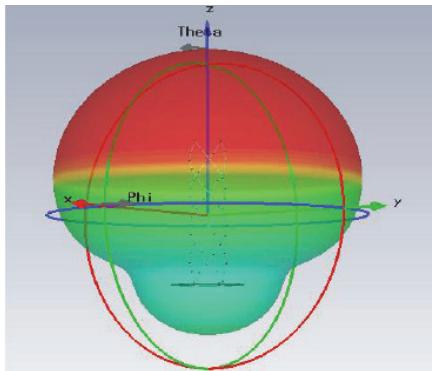


Fig. 1. Helical antenna radiation pattern [7].

Magneto-dielectric antennas are similar in construction to patch antennas, with higher gains [8], but the construction and production are more complex. All these characteristics additionally motivate the examination of the possibility of using simple patch antennas.

### III. METHODOLOGY

#### A. Designing patch antenna

The design of the microstrip patch antenna was realized in the Advanced Design System 2009 software using the parameters for a widely available low cost FR4 substrate that is suitable for antenna fabrication [9]. The characteristics of FR4 substrates are given in Table 1.

TABLE 1: FR4 SUBSTRATE DESCRIPTION.

Dielectric constant	4.36
Loss tangent	0.016
Dielectric thickness	1.55mm
Copper thickness	35μm

The determination of the patch dimensions is based on the following equations [10]:

$$W = \frac{c}{2f_0\sqrt{\frac{(\epsilon_r + 1)}{2}}}; L = \frac{c}{2f_0\sqrt{\epsilon_e}} - 2\Delta l \quad (1)$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[ 1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}} \quad (2)$$

The simulation results using the calculated dimension parameters did not show the resonant frequency of the antenna at a central frequency of 2.44 GHz, but at a slightly lower frequency. The iterative method of changing the antenna dimensions after several dozen attempts resulted in a resonant frequency at the appropriate frequency for the following antenna dimensions  $W=32.4\text{mm}$ ,  $L=27.54\text{mm}$ , and feed line length of 15.01mm (Fig. 2 left)

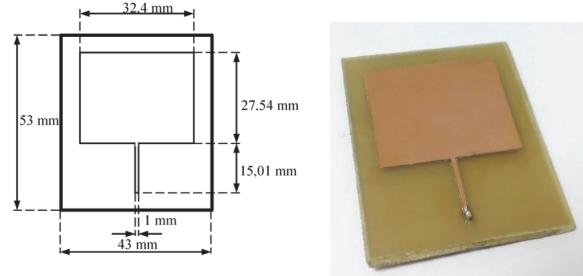


Fig.2. Dimensions and appearance of the realized patch antenna

In order to observe the antenna characteristic and at the resonant frequency environment, a 1-3GHz test was originally selected in the software. As the antenna at this frequency range meets the required selectivity criteria, Fig. 3 and Fig. 4 show the antenna characteristic for the frequency band of interest, i.e., 2.402-2.480GHz.

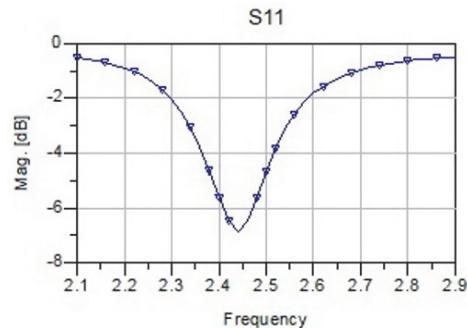


Fig. 3. S<sub>11</sub> patch antenna parameters in 2.1-2.9 GHz range.

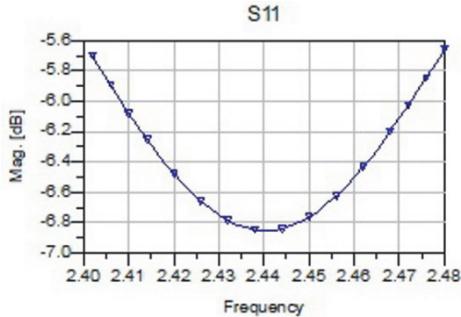


Fig. 4.  $S_{11}$  patch antenna parameters in 2.40-2.48 GHz range.

The antenna radiation diagram is shown in Fig. 5 so it can be observed that the antenna is not directional, which is suitable for the random placement of sensor nodes.



Fig. 5. Patch antenna radiation pattern.

#### B. Designing dipole antenna

Dipole antennas are classified as simple antennas for design and construction. Based on the wavelength it was calculated that the antenna length of 61mm is required. In order to check the calculation, Ansoft HFSS 13 simulation software was used. The simulation results are given in Fig. 6 and Fig. 7.

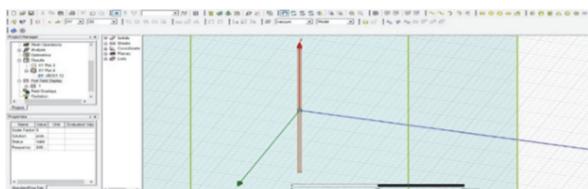


Fig. 6. Appearance of the dipole antenna in Ansoft HFSS 13 software.

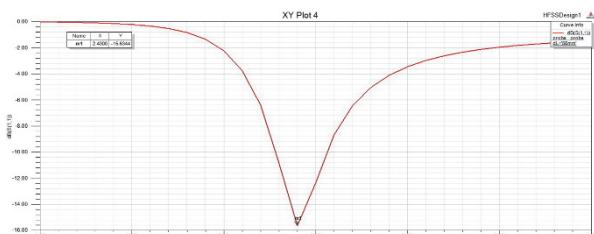


Fig. 7.  $S_{11}$  dipole antenna parameters in 2.40-2.48 GHz range.

Due to the differences in the real material used for antenna fabrication, as well as the excitation site in relation to the simulation model, it was necessary to "trim" the antenna to obtain the appropriate resonant frequency. At realization, the antenna was shortened by about 2mm relative to the simulation model. The dipole antenna is made of a copper wire with a diameter of 1.7mm and an approximate length of 58mm.

#### IV. MEASUREMENTS

Measurements were made in a telecommunications laboratory at the School of Electrical and Computer Engineering of Applied Studies in Belgrade, where there were no ideal measuring conditions or an anechoic room. The aim of the measurement was, among other things, to observe the characteristics of the antenna in real conditions where several wireless networks are operating in the frequency range of interest. During the measurement, the antenna position was changed in several positions, however, this did not affect the measurement results.

The "Agilent E8257D PSG" signal generator, the "R&S® FSV30" spectrum analyzer and the "Mini-circuits ZABDC20-252H-S+" microwave coupler (Fig. 8) were used to test the frequency characteristics of the antennas. A two-line microwave coupler was used to determine antenna  $S_{11}$  parameters based on feedback. A signal generator and antenna were connected to one line and a spectrum analyzer to the other line. The line to which the spectrum analyzer is connected detects a fall in the EM field in the frequency range in which the antenna has reached a resonant frequency, which can be observed on the spectrum analyzer screen. In this way, it was possible to determine and, with additional processing, to reach the required resonant frequency of the antennas.



Fig. 8. Mini-circuits coupler ZABDC20-252H-S+.

Fig. 9 shows the setup used to determine the  $S_{11}$  parameters of the tested antennas.

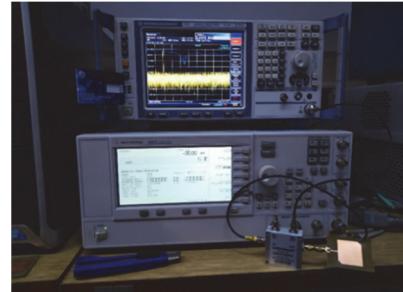


Fig. 9. Device setup when testing antennas.

#### V. RESULTS

The resonant frequency of the patch antenna for the dimensions determined in the simulation (Fig. 1) was measured at a slightly lower frequency than those shown in the software, or 2.38GHz, which can be attributed to the mathematical model of the simulation software, the automatic convergence of the results (Analysis Defaults) and the real characteristics of the material used to fabricate antenna. In order to achieve the desired resonant frequency, the surface of the patch field is reduced by diagonal sections [10] with an iterative method in the form of a right isosceles triangle with cathets of finite dimensions 2.5mm, Fig. 10.

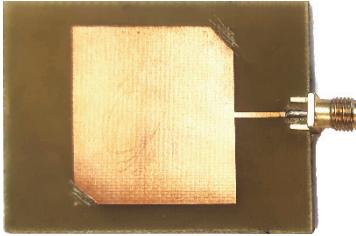


Fig. 10 Realized patch antenna after surface reducing.

Fig. 11, top, shows the resonant frequency of the corrected patch antenna in the 2-3GHz range. It can be observed that the minimum level of the measured signal is at a central frequency of 2.44GHz, that is, the resonant frequency of the antenna. Fig. 11, bottom, shows the  $S_{11}$  parameters of the antenna with the markers placed to observe the antenna characteristics for the entire frequency range of interest.

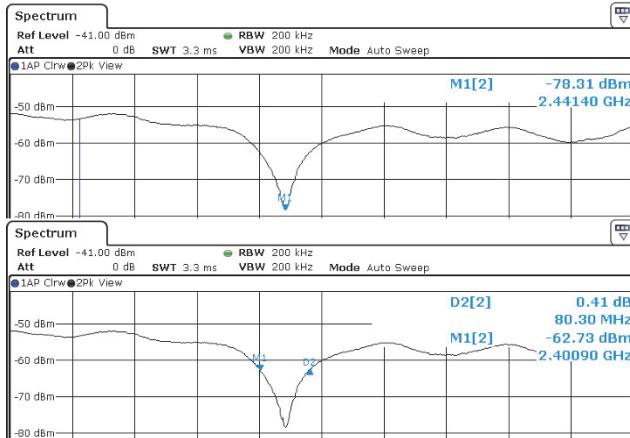


Fig. 11. Frequency characteristic of the corrected and fabricated microstrip patch antenna obtained by measuring in the 2-3 GHz range.

Fig. 12 shows the  $S_{11}$  parameters for a dipole antenna, where the resonant frequency can be clearly observed at 2.40 GHz.

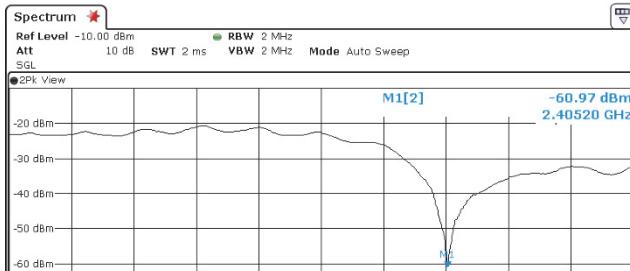


Fig. 12. Measured  $S_{11}$  dipole antenna parameters in the 2-3 GHz range.

In order to examine the performance of the antennas on the receiving side in relation to the housing in which the antenna is located, a reference measurement was performed with two log antennas which were placed at a distance of 2 m and whose declared gains were 9 dBi, Fig. 13, left.



Fig. 13. Setup to measure the signal level on the receiving antenna.

Measurement results on the receiving antenna are given in Fig. 14.

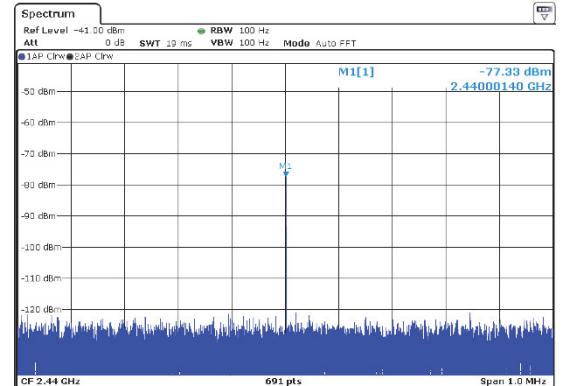


Fig. 14. Receive log antenna signal level.

On the receiving side, the log antenna was then replaced by a patch antenna outside the housing. The obtained results gave a signal level of -82.95 dBm, at a central frequency of 2.44 GHz. Fig. 15, top.

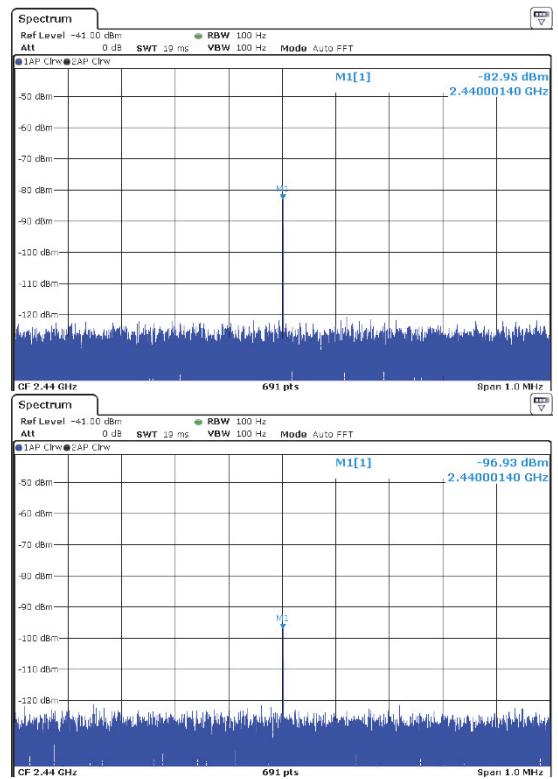


Fig. 15. The signal level of the receiving antenna in the free space (top), and in the metal housing (bottom).

The patch antenna on the receiving side is then placed in a cylindrical metal housing and closed with a metal cover, Fig. 13, right, which can be one of the scenarios when designing WSN nodes. Fig. 15, bottom, shows the measurement result on the receiving side where the signal level is -96.90 dBm at the center frequency.

## VI. CONCLUSION

By analyzing the obtained results, based on the measurements presented in the previous chapter, it can be noticed that the patch antennas in the frequency range 2.402-2.480 GHz are very close in terms of the observed characteristics of dipole antennas of similar dimensions. The given characteristics are selected as primary when observing the application of antennas in wireless sensor networks, where physical dimensions and price are limiting factors. The measured characteristics for the patch antenna were above the expectations for testing in real conditions. In addition, the test carried out in order to analyze the change in performance of the antenna if they are placed in a metal housing, showed that there is no major degradation of the antenna gain and that it can be positioned in this type of housing if required. This set of results indicates the possibility of using patch antennas within wireless sensor networks in a given frequency range instead of standard dipole antennas, which are more expensive to manufacture and physically more complicated to implement, i.e., can complicate the production of sensor nodes and limit their scope. In addition, external dipole antennas usually require at least one more connector relative to the pcb printed patch antenna, mounted on the outer surface of the housing, which, taking into account oxidation and moisture in conditions where WSN can be implemented can reduce the durability and performance of nodes. In the case of the use of pcb printed dipole antennas, considering the radiation diagram, an upright placement of the antenna is required, which initiates a large height of the housing in relation to

the housing with the patch antenna. In the case of the use of helical antennas, the radiation diagram is not omnidirectional, and therefore, despite the high gain and small dimensions, they are not suitable for WSN.

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