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Materials Today: Proceedings 4 (2017) 5030–5038

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13th International Conference on Nanosciences & Nanotechnologies & 9th International Symposium on Flexible Organic Electronics

Microstrip antenna from silver nanoparticles printed on a flexible polymer substrate ☆

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Abstract

This work describes the use of inkjet printing technology to fabricate a flexible microstrip antenna. The antenna is printed on a flexible PET foil (Polyethylene terephthalate) using silver nanoparticles. Silver nanoparticles were synthetized by the solvothermal precipitation technique. The diameter of the prepared silver nanoparticles ranges from 20 to 200 nm measured with the help of the SEM analysis. In addition, the ink formulation for printing of a homogenous and electrically conductive layer was further prepared using silver nanoparticles. The printed antenna operates in two frequency bands of 2.02 GHz (–16.02 db) and 2.3 GHz (–19.33 db). The antenna is flexible and weigh is only 0.208 g and is suitable for electronic devices of a very low weight, such as wearable electronic devices.

Selection and peer-review under responsibility of the Conference Committee Members of NANOTEXNOLOGY2016 (13th International Conference on Nanosciences & Nanotechnologies & 9th International Symposium on Flexible Organic Electronics).

Keywords: antenna; silver nanoparticles; PET, wearable electronics

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2214-7853
Selection and peer-review under responsibility of the Conference Committee Members of NANOTEXNOLOGY2016 (13th International Conference on Nanosciences & Nanotechnologies & 9th International Symposium on Flexible Organic Electronics).

1. Introduction

The electronic devices use the passive antennas for information transfer between a user and a network, or the devices exchange information with each other without any intervention by the user, for instance M2M (Machine to Machine) technology. These so-called passive antennas are used in a large number of electronic devices, especially in portable devices. They are most frequently used in mobile phones, tablets, laptops, navigations and last but not least in wearable electronics. Wearable electronics place high demands on the flexibility of materials used.

In general, the passive antenna can be made from a large number of electrically conductive materials. Nevertheless, not all electrically conductive materials that are used in electrical engineering are suitable for the production of antennas of low weight and high flexibility [1]. Nowadays, the so-called microstrip antennas are being used. For these antennas many varieties of shapes of copper materials are mostly used, such as copper foils, copper strips, and layers on different substrates, for example a well-known FR-4 substrate or ceramic substrates [2,3]. In some types of communication devices one can find other types of antennas, such as those constructed from meander stainless steel provided with plastic covers. The choice of the basic material for construction has a decisive influence on the characteristics of the antenna [4]. Materials being used nowadays in antenna technology contain the applicable parameters; however, mounting these antennas into polymer substrates is difficult. This article describes the antenna attached to the (Polyethylene terephthalate) PET substrate. This solution is new and unique by making it possible to produce antennas using a conductive layer of prepared silver nanoparticles and consequently, it is possible to make additional reproductions without changing the geometry of the antenna. Silver nanoparticles are applied to the PET substrate using inkjet printing technology so as to incorporate them directly into plastic casings used for the protection of wearable electronics [5-9]. The presented solution for printing the antenna by means of the inkjet printing on the basis of silver nanoparticles is unique because a low weight flexible microstrip antenna is produced using a polymer stabilized silver nanoparticles ink obtained by the solvothermal synthesis method that has not been used in any previous research.

2. Experimental methods

The antenna was formed using an inkjet printer FUJIFILM Dimatix DMP-2800 (Fig. 1). To prevent oxidation of the silver layer the printer was positioned in a glove box (Jacomex) with an inert atmosphere N_2 with < 1 ppm O_2 and < 1 ppm H_2O during the whole printing process. The material used for the printed electronics was applied to the PET substrate (Novacentrix novele IJ-220) that was 150 μm thick.

The prepared ink was based on a concentrated and stabilized silver nanoparticles suspension; a highly concentrated dispersion of these nanoparticles (~ 25 wt%) was prepared using the solvothermal microwave synthesis by means of the precipitation of the nanoparticles from a solution of silver nitrate, organic precipitant (hexamethylenetetramine) and a polymer additive (polyvinylpyrrolidone) which served as a stabilizer in the reaction mixture. In order to remove any organic residues from the synthesis process the silver particles were washed with ethanol and kept in a stable dispersion solution. The image acquisition of the materials prepared in this way was accomplished using a scanning electron microscope (FEI Nova NanoSEM 450) which revealed the presence of spherical or polyhedral particles with a diameter in the range of 20 to 200 nm (Fig. 2). The next step was the preparation of the ink. Nanoparticles were dispersed in deionized water using an ultrasonic homogenizer UZ SONOPULS HD 2070. To achieve a good dispersion of nanoparticles in the solution 0.1 ml of dispersion stabilizer was added to 10 ml of the dispersion liquid followed by an addition of 25 wt% of nanoparticles; the viscosity of the final ink ranged from 8 to 12 cPs which are suitable values for inkjet printing. A cartridge DMP 2800 was filled with the prepared ink and the antenna was successfully printed on the PET substrate. The print process conditions were set as follows: the cartridge temperature was 35 °C and the substrate temperature was 45 °C in order to achieve a good sintering of a drop on the substrate. After the printing process the antenna was dried in a vacuum oven at 120 °C for 20 minutes in order to sinter the nanoparticles and create a compact layer [10-16].

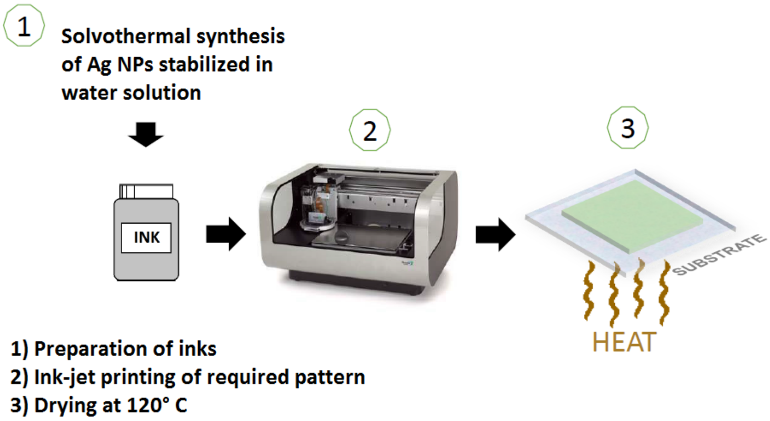

Fig. 1. The process of inkjet printing of a flexible antenna on the PET substrate.

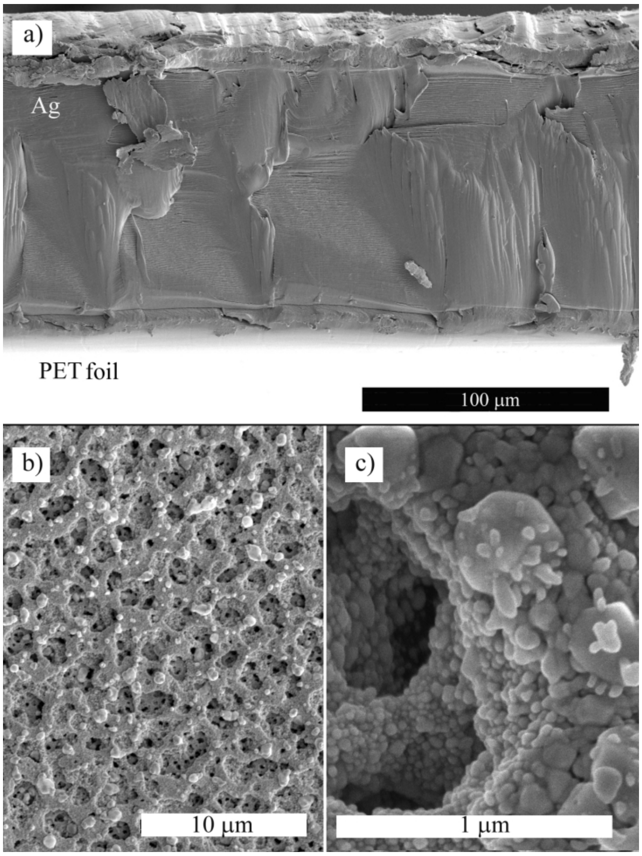

Fig. 2. a) This image depicts a fracture of the PET substrate with a printed silver layer; b) SEM microscopy of the silver ink structure on the PET substrate in a print resolution of 10 μm; c) details of silver nanoparticles; the image shows the way silver nanoparticles are interconnected, which demonstrates a high conductivity of the printed layer, the image is in a resolution of 1 μm.

3. Results and discussions

All measurements of the printed antenna were performed in the anechoic chamber using the N9912A FieldFox Handheld RF spectrum analyzer with a measuring range within 2 MHz to 4 GHz. By means of this spectrum analyzer the parameter S11 was measured; this parameter determines the best frequencies of impedance matching for the antenna. The dimensions of the printed layer of the antenna are 9 × 26 mm (Fig. 4). The total weight of the printed antenna is 0.208 g. The dimensions of the PET substrate are 18 × 36 mm. The ground plane of the antenna is made of FR-4 copper substrate sized 65 × 75 mm. All measured values (Fig. 3) such as two frequency bands of 2.02 GHz, 2.3 GHz and also the weight of the antenna 0.208 g, shows that the PET substrate and silver nanoparticles in combination with inkjet print technology proved to be very promising materials suitable for wearable electronic devices. By combining these materials a very efficient design of the microstrip antenna was achieved.

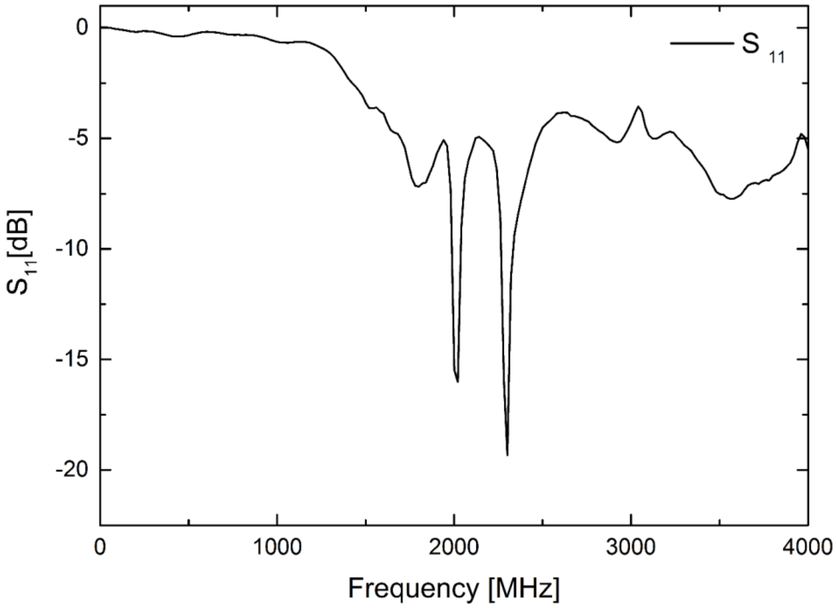

Fig. 3. This graph represents the reflection coefficient S11 (expressed in dB) with dependence on the frequency with impedances to 2.02 GHz and 2.3 GHz.

The impedance of the printed antenna is matched for frequencies of 2.02 GHz, (–16.02 dB) and 2.3 GHz, (–19.33 dB). The measured parameters show that the antenna operates in multiple frequency bands. The precise values of the antenna's performance during the measuring cannot be predicted prior to printing the overall geometry of the antenna. There are many parameters that can greatly affect the efficiency of the antenna. For example, the printed layer has to be sufficiently homogeneous. The homogeneity of the printed layer has a great impact on the quality of the resulting microstrip antenna. On average, achieving a very good homogeneity of thin layers printed with inkjet technology is rather difficult. The solution to this can be found in the preparation of electrically conductive ink of suitable properties such as viscosity and concentration of conductive nanoparticles so that the best possible homogeneous printed structure can be obtained (see micrographs from SEM in Fig. 2). This solution is new and unique in several points: (i) silver nanoparticles used for the preparation of conductive ink were prepared by solvothermal microwave synthesis, which is fast and environmentally friendly approach, (ii) it possible to easily reproduce the manufacturing of the antennas using a conductive layer based on prepared silver nanoparticles and, (iii) this printing technology enables to create printed conductive layers of multiband frequency antenna on flexible substrate. Silver nanoparticles are applied to the PET substrate using the inkjet printing technology so as to incorporate them directly into plastic cases used for the protection of any wearable electronics [17-26].

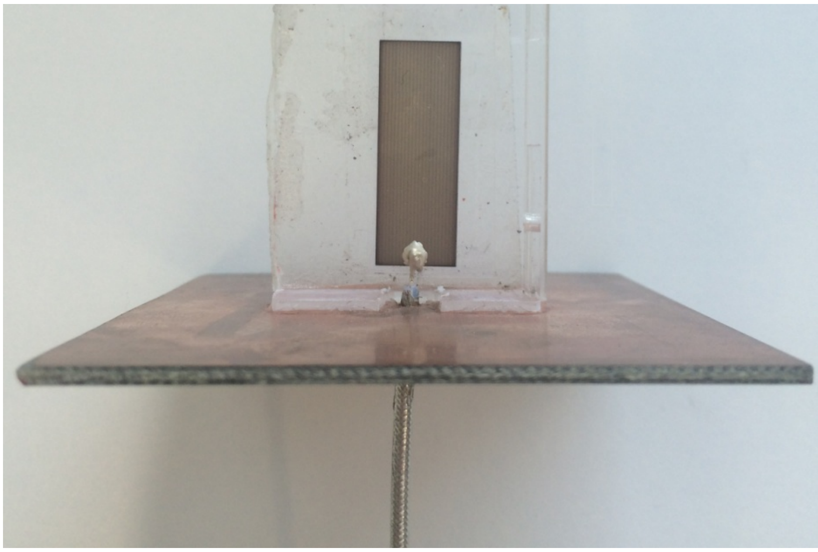

Fig. 4. Photograph of the antenna produced using inkjet printing.

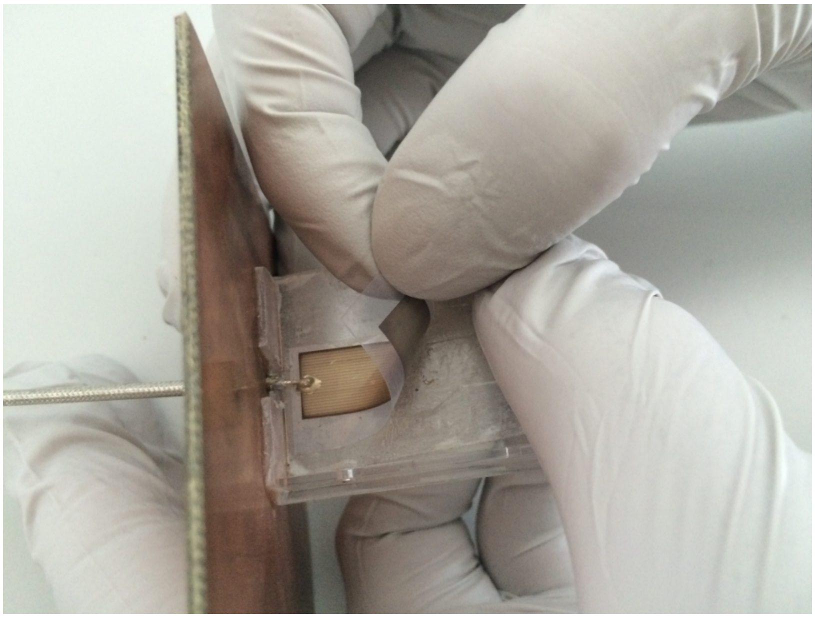

Fig. 5. Demonstration of flexibility of inkjet printed antenna.

The main printed part of the antenna is connected by means of electrically conductive silver paste with a coax cable with an impedance of 50 Ω. This coax cable has a gold-plated micro SMA connector. The joint in the layer of silver nanoparticles is connected by means of the electrically conductive silver paste. Primarily, the main task of the silver paste is to minimize signal loss during transmission between the coaxial line and the actual microstrip antenna. This method of jointing was chosen because PET substrates do not allow tin soldering; the method proved to be efficient, quick and perfectly acceptable for experimental measurements.

The measured values at the frequencies of 2.02 GHz, (–16.02 dB) and 2.3 GHz, (–19.33 dB) make it possible for the antenna to be used in various applications such as mobile devices [27] and SDR (Software Defined Radio) [28]. Also another advantage is the fact that the PET substrate is very thin and the whole antenna is very light. The weight is also one of the most important design criteria so that the antenna could be used for wearable electronics. The reflection coefficient of the antenna was measured in anechoic chamber. The anechoic chamber solution (by Frankonia) used for the measurements was SAC-3 Plus S. This type of anechoic chamber was used for minimized distortion of the results. For the next generation of flexible electronic devices it is necessary to use innovative solutions to ensure low weight and low cost and to minimize the amount of space designated for the antenna inside portable electronic devices, such as mobile phones. The solution presented fulfills these requirements and the main advantage is the potential commercial utilization of the antenna for three frequency bands. Therefore, the designed antenna can replace three different antennas made of copper foil or copper wire. Another advantage of the solution presented is the fact that it meets the requirements for flexibility (Fig. 5) in order to be used in aforementioned electronic applications.

CST Microwave Studio software was used to simulate radiation patterns of antenna. This software uses a mathematical model that works with help of specific variables such as dielectric constant of silver layer, thickness, dissipation factor (tgΔ), and permittivity of PET substrate and finally also an entire geometry of the antenna is taken in account. Some of those parameters were not measured directly and data from literature were used. This is particularly the case of dielectric constant of silver layer when the value only for bulk silver was available. In case of our antenna is silver layer composed of Ag nanoparticles and its real value of dielectric constant will be slightly different from tabled one for used bulk silver.

Further, the PET substrate is modified by the manufacturer by adding of adhesive layer with can have slightly different properties than pure PET substrate. It finally leads to difference in resonance frequency between simulated data and measured one. Following figures (Fig. 6 to Fig. 9) presents simulated electric field radiation pattern from CST Microwave Studio. Figures (7-9) presents advantages of the antenna in XY plane, XZ plane and YZ plane. The results shows simulated antenna is nearly omnidirectional. This factor is one of the advantages of the 2D geometry of the Ag printed layer on the PET substrate.

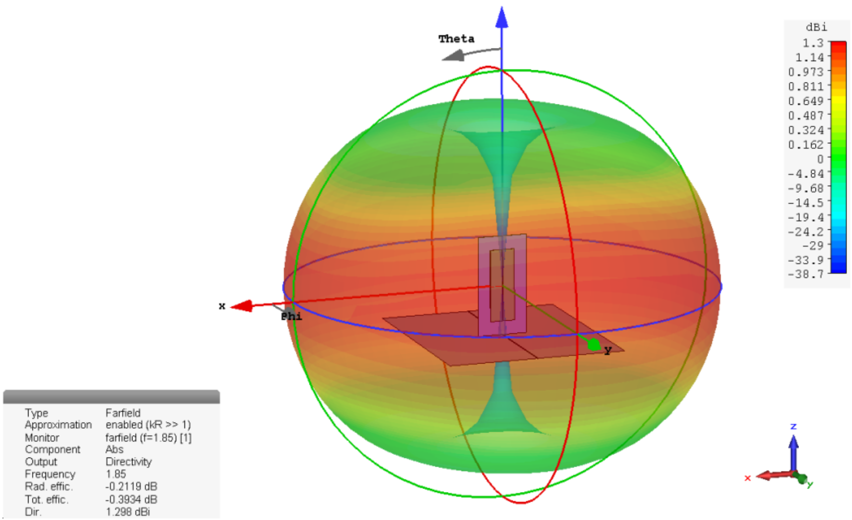

Fig. 6. Simulation of 3D farfield pattern at 1.85 GHz is shown in dBi.

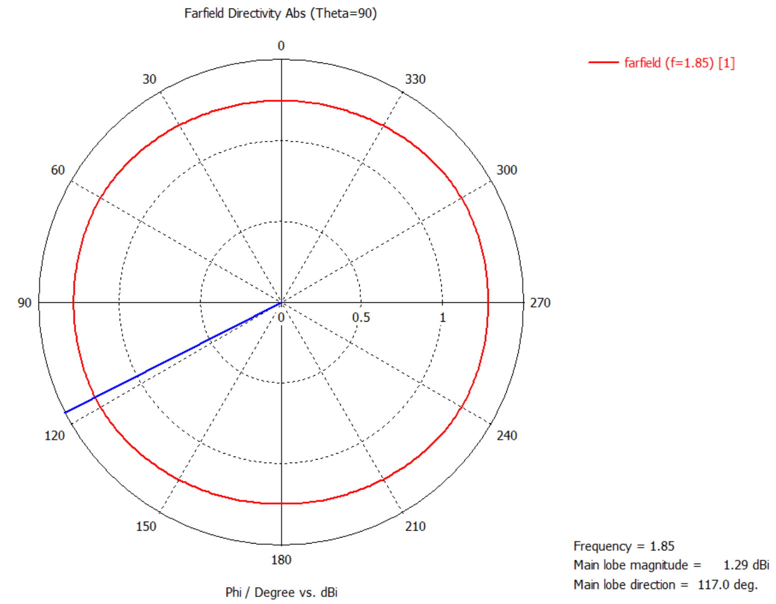

Fig. 7. Simulated electric field radiation pattern at XY plane at 1.85 GHz.

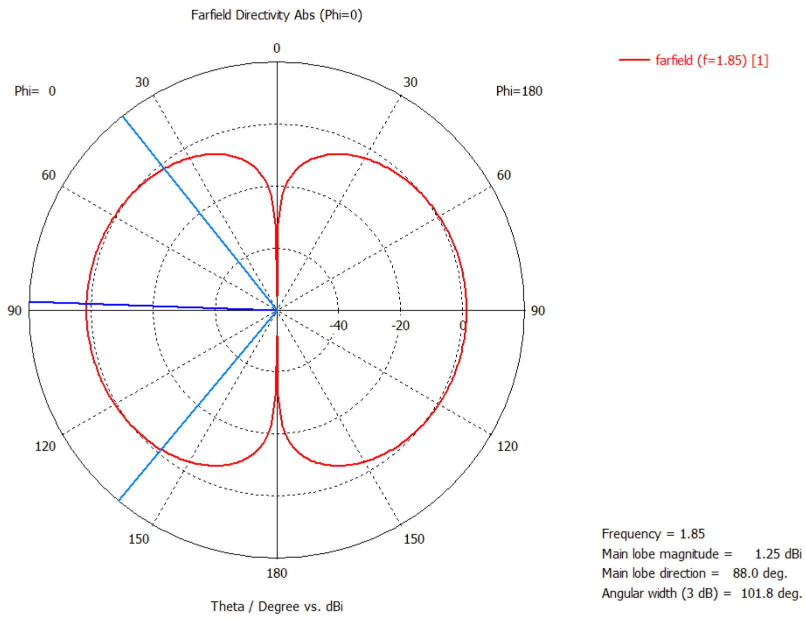

Fig. 8. Simulated electric field radiation pattern at XZ plane at 1.85 GHz.

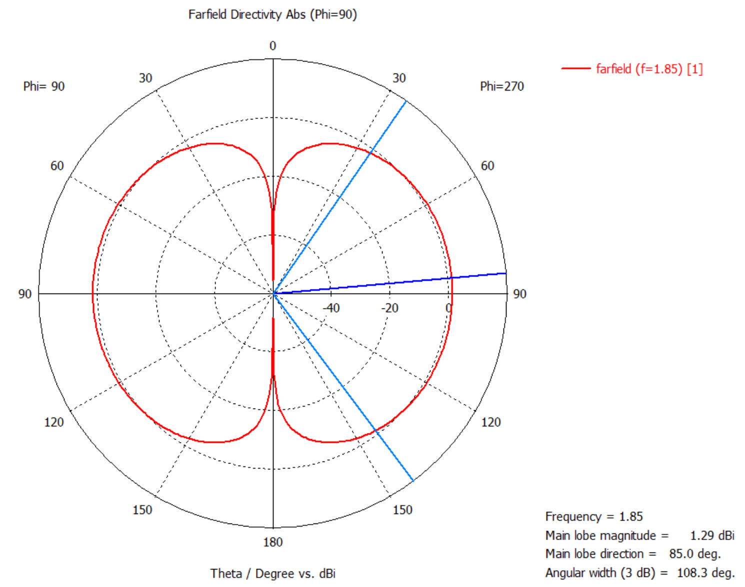

Fig. 9. Simulated electric field radiation pattern at YZ plane at 1.85 GHz.

4. Conclusions

The selected method of the silver ink on the basis of silver nanoparticles used for the construction of the passive microstrip antenna proves that the antenna can be used mainly in applications which place the emphasis on low weight and flexibility. Another advantage of this antenna is the possibility of its implementation in casings based on polymers, where PET belongs as well. This could save space when constructing the device. In addition, the required distance between individual antennas would be maintained. For instance, in MIMO systems the distance of λ/2 for end user of communication devices must be observed. The requirement of the distance of λ/2 among individual antennas puts high demands on the design of the antenna and its miniaturization in order to optimize the use of the limited physical space of the device to which the antenna is to be implemented. For these reasons, the designed antenna is considered beneficial and original. Newly introduced standards for mobile networks, such as Long Term Evolution-Advanced (LTE-A) standard, allow for the possibility of using more antennas, namely 4 x 4 MIMO antennas, which will require optimization of the distribution of individual antennas so as to avoid undesirable interference among them. From practical and economical points of view, it must be noted that the antennas prepared using inkjet printing have an enormous potential on the market with electronic devices due to the possibility of constructing flexible devices of different shapes and different sizes, which can be incorporated into clothes. The next step of the research will be the use of fractal geometry.

Acknowledgements

This article was supported by the Ministry of Education, Youth and Sports of the Czech Republic – National Sustainability Program NPU I (LO1504) and with the support of Operational Program Research and Development for Innovations co-funded by the European Regional Development Fund (ERDF) and national budget of the Czech Republic, within the framework of the project CPS - strengthening research capacity (reg. number: CZ.1.05/2.1.00/19.0409).

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