Embroidered textile antennas based on hybrid sewing thread

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Introduction

This paper presents a research focused on textile antennas which are made embroidered from a novel hybrid conductive sewing thread. Thanks to embroidery, which has been recognized as one of the most promising manufacturing techniques for integrating antennas into clothing, the antennas are more robust, more flexible, fully washable and comfortable for wearing. These properties are important due to the increasing demand for smart textiles products in sport wear, medical or military segment. The objective of this research is to develop a wearable textile antenna optimized to the frequency of 868 MHz. Two different patterns of antennas, i.e. dipole and fractal dipole antenna were designed and investigated. The prototypes of embroidered antennas were realized with the novel brass hybrid sewing thread on a flame-resistant fabric substrate. The thread, which is composed of two strands each containing 48 polyester (PES) fibers and 4 brass microwires, was developed by the UVB Company in close cooperation with University of West Bohemia in Pilsen and it is protected is protected by Czech utility model CZ 28603. The final optimized antenna could be used for applications such as RFID, personal protective clothing or IoT (Internet of Things) networks [1][2].

Material and technologies

A brief overview of the materials and technologies which were used for the research is given bellow.

- **DuPont NOMEX® aramid Fabric** – A flame-resistant fabric (93% NOMEX/5% KEVLAR/2% Carbon) which is commonly used for firefighter and petro-chemical protective suits.
- **Brass hybrid conductive sewing threat** - The hybrid conductive sewing thread is composed of two strands each containing 48 polyester (PES) fibres and 4 brass microwires, linear resistance (nominal value @ 20°C) 8,9 $\Omega \cdot m^{-1}$, tenacity (textile strength) 21,81 cN·tex-1, breaking extension 10,16 %.
- **Embroidering machine** – Bernina QE750.
- **Measurement** – Signal Integrity Network Analyzer SPARQ-3002E.

Experiment

Dipole antennas are an elementary type of antenna which has become the basis for most of other antennas. The length of the arms is determined by the wavelength for which the antenna is designed, the length of both arms should correspond to half of the wavelength, and the length of one arm should then be logically a quarter of the desired wavelength. The proposed antenna has been designed to resonate at the 868 MHz UHF Band and with the input impedance of 50 Ω. During the antenna design the fact, that the antenna input impedance strongly depends on the ratio of the antenna length to the wavelength, was strongly considered, because considerable matching problems can occur if the antenna is operated on another than its resonant frequency. The antenna was calculated as follows: first step was the frequency conversion to wavelength. The wavelength λ is equal to the light velocity ratio c to given frequency f *(see equation 1).*

$$\lambda = \frac{c}{f} \qquad (1)$$

Fig. 1 *Example of embroidered dipole antenna*

$$\frac{\lambda}{2} = \frac{c}{2*f} = \frac{299\ 792\ 458}{\mathbf{2*868*10^6}} = 0.1736\ m => 17.36\ cm \qquad (2)$$

The result of the equation 2 is the length of both arms, for one arm the length is then 8.68 cm. For the embroidered dipole antenna (see fig. 1) the length of one arm was set to 8.67 cm.

As the second type of the embroidered antenna the fractal dipole type antenna was chosen. The fractal antenna is an antenna that uses a fractal, self-similar design in order to increase the range of frequencies which the antenna is able to receive [5]. The fractal design of antenna is becoming to be useful in cases where the limits of conventional antennas dimensions are encountered. The main difference between fractal and conventional antennas is that conventional antennas are designed to work in a narrow bandwidth, typically 10-40% around a center of the main frequency and fractal antennas can be operated as multiband while maintaining almost the same dimensions [4].

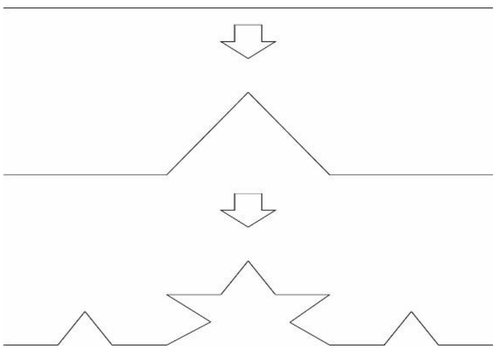

Fig. 2 *An example of Van Koch dipole.*

Fig. 2 shows how to create a fractal antenna from a conventional antenna with using principle of Van Koch curve. The first step is to cut the original line into 3 equal parts and to build a triangle in the middle part (the length of the arms are 1/3 of the original line). The next step is similar to the first step i.e. to cut the straight lines and build a triangle there again. In this experiment just two steps were made due to a limitation in embroidering process. Fig. 3 shows the embroidered sample of the fractal dipole antenna. The length of one arm was 9.072 cm.

Fig. 3 *Example of embroidered fractal dipole antenna*

Results

Fig. 4 shows the reflection characteristics of the embroidered dipole antenna, where the dependence of the parameter S11 on frequency is displayed. The parameter S11 shows how much power is reflected from antenna. In case that S11 = 0 dB, all the power will be reflected and nothing will be radiated out from antenna. The full line depict reflection characteristic of the antenna fastened in a holder for measuring and the dashed line depict reflection characteristic when the antenna was attached to the human body. The table 1 shows main peaks of the both realized antennas.

Table 1 - Main peaks of antennas

	f [MHz]	**S11 [dB]**
dipole 50 Ω	878	-15,2451
dipole 50 Ω hand	895,125	-17,3779
fractal dipole 50 Ω	855,5	-25,6162
fractal dipole 50 Ω hand	897	-36,1831

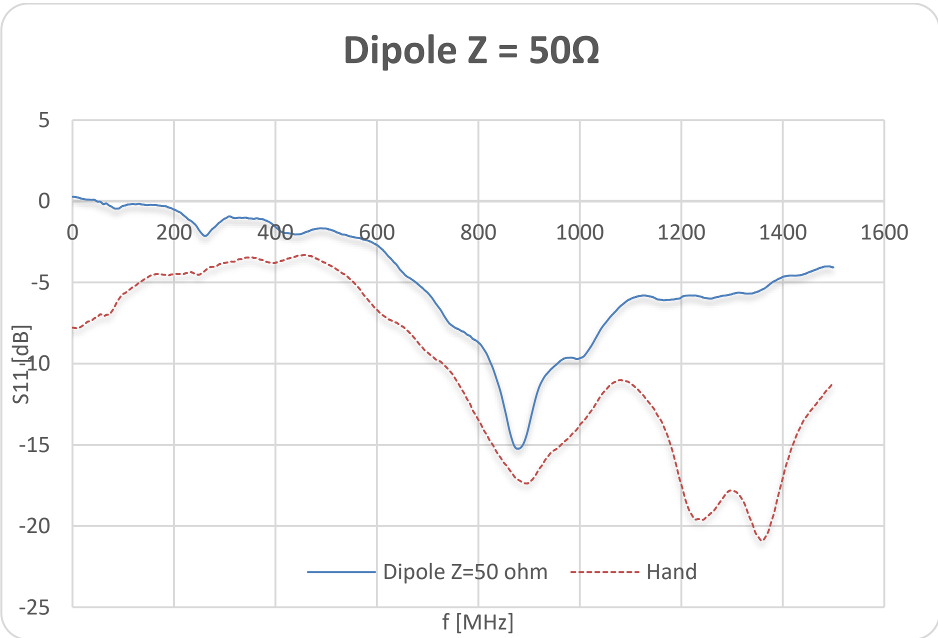

Fig. 4 *Coefficient (S11) vs frequency plot of the embroidered dipole antenna*

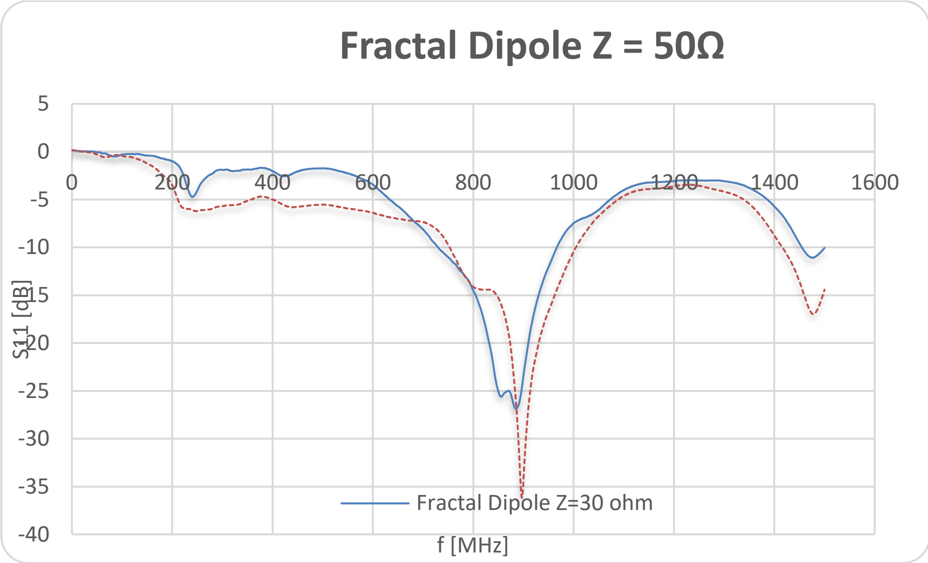

***Fig. 5** Coefficient (S11) vs frequency plot of the embroidered fractal dipole antenna*

Fig. 5 shows the reflection characteristics of the embroidered dipole antenna. The full line depict reflection characteristic of the antenna fastened in a holder for measuring and the dashed line depict reflection characteristic when the antenna was placed to a human body – on a arm.

Conclusion

In the frame of the research two different types of embroidered antennas were designed and realized. Both of them were optimized for input impedance of 50 Ω and the aim was to reach resonance frequency of 868 MHz. The promising results were obtained. The main measured parameter was the S11 coefficient which depends on frequency. The results show that if the dipole antenna was attached to a human body the frequency shifted from 878 MHz to 895,125 MHz and S11 changed from -15,2451 dB to -17,3779 dB. When the fractal antenna was in the measuring holder the peak was 855,5 MHz (S11 = -25,6162 dB) and after attaching to the body the peak was 897 MHz (S11 = -36,1831 dB). The parameter S11 and the uplink frequency shift will be improved by attaching the antenna to the human body. Future work will focus on optimization of the proposed antennas, analysing their radiation patterns when they are placed on the body and automated washing tests.

Acknowledgement

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