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Analysis of the power transfer and electrical performances of an embroidered textile loop antenna for near field communication (NFC) application

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Abstract. We present a new class of wearable textile antenna and analyse their performances through an electrical study. The developed prototypes have been realized by an embroidery process and are made of conductive twisted copper/polyester yarns on a cotton substrate. These antennas aim to transfer power and data thanks to the NFC technology, so the operating frequency is 13.56MHz and the maximal reading distance is around 10cm. The strong resistance of the yarn ($4.20\Omega/m$) make us overlap three yarns to reach satisfactory electrical characteristics. Antennas are composed of a textile plan circular coil to which we add a usual capacitor. The study of coils electrical characteristics highlights a linear evolution of coil resistance and inductance in function of embroidery geometrical parameters. Also, these data show the feasibility of such antennas, especially through quality factor values reaching 45.

1. Introduction

The use of textile materials for wireless communication and energy harvesting is supposed to improve communications around human body and to interconnect users within new concept of Internet of Clothing (IoC). Nowadays, there are different ways to develop wearable antennas, as patches or prints [1], [2]. This concept is also under development throughout French ANR CONTEXT project funded by National Ministry of Research. The main objective focuses on body-centric communication and energy and data transfer. It aims also at development of power supply for textile structures embedded electronic components such as low consumption sensors, actuators and processing and communication electronic modules. Therefore, NFC 13.56MHz wireless communication will be used for energy transfer from smartphones to connected clothing and for data transfer from connected clothing to a smartphone [3]. Data collected could be sent to a cloud for further processing, analysis and if necessary decision making.

ANR CONTEXT project aims also to solve the problem of unreliable connections among



sensors, actuators and processing and communication electronic modules, by using textile metamaterials as surface wave guides at ISM band (2.4GHz) for communications purposes [4]. This project should have repercussions in the telemedicine field, security, sports and leisure, etc. [5].

The NFC technology is a short-range radiofrequency identification system operating at 13.56MHz. It uses the magnetic induction principle to transfer power and data between two antennas, i.e. to transform an electric current into an electromagnetic field and vice versa.

In the field of usual radio frequency identification antennas are composed by very conductive materials as copper or silver, and their electromagnetic characteristics, such as inductance, capacity or emitted magnetic field, are well known by the literature [6]. It is also possible to make accurate simulation to forecast antennas behavior. Nevertheless, the transition from usual materials to textile materials reconsiders theories mentioning previously. Indeed, the complex structure of textile materials, in particular yarns, makes previous equations very inaccurate. So, it is necessary to understand evolution of electromagnetic characteristics under several parameters, in particular geometrical, for textile antennas.

An experimental study of this subject could enables to make textile antennas resonating at the desired frequency repeatedly. Also, the electromagnetic characteristics knowledge is necessary to make efficient and optimize the power and data transfer.

2. Materials and method

2.1. Materials

This study is dedicated to energy and data transfer using NFC protocol. First step of this study aims to design an RLC resonant circuit at 13.56MHz compatible with textile structures composed of textile flat loop coil on a fabric support made by embroidery and an adapted capacitor. The use of textile conductive yarn, instead of classic conductive yarn, involves an increasing of the circuit resistance. In order to prevent power and transfer issues, the coil has been made by overlapping three textile conductive yarns “DataTrans” from TibTech Innovation to reduce the total circuit resistance. This yarn is composed of twisted polyester, polyamide and four copper micro filaments and its electric characteristic is presented in table 1.

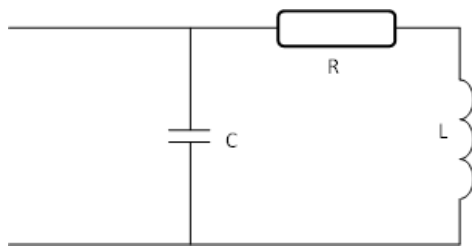
Table 1. Electric characteristic of TibTech Datatrans yarn

Yarn	Resistivity [Ohms/m]	Tex [g/m]	Outer wall [m]	Max Voltage [V]
TibTech - Datatrans	4.20	0.18	2.8e-7	48

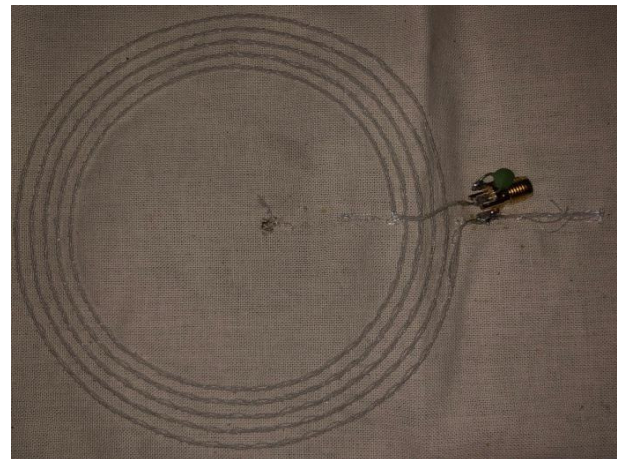
Different designs of textile flat loop coil are made by a ZSK industrial machine on a cotton fabric support to study the impact of geometrical parameters, such as the radius, the number of turn and the distance between two current lines, on electrical parameters. The figure 1 shows the ZSK embroidery machine (a), and a zoom on needle during an embroidery process (b).



Figure 1. Photography of the ZSK embroidery machine (a) and a zoom on needles during an embroidery process (b).



(a)



(b)

Figure 2. Schematic of a RL circuit in series with the capacity C in parallel (a) and photography of the antenna (b).

The embroidery process requires the use of two yarns: the sewing yarn, which is delivered by the needle, and the bobbin yarn, which is delivered by the bobbin under the fabric support. Prototypes have been realized by using the conductive yarn as a bobbin yarn and a thin cotton thread as sewing yarn. This setup enables to get a flat positioning of the conductive yarn, so a better linearity of the coil. Indeed, during the embroidery process, the sewing yarn go through the fabric support, moreover the bobbin can deliver larger and stiffer yarn.

Then, once flat coil prototypes are made, it is necessary to provide a way to connect them to measurement devices. The presence of copper filaments in the conductive yarns enables to solder them on a SMA connector.

2.2. Methods

In order to evaluate performances of our antennas, it is necessary to measure coils electrical characteristics first. The resistance, the inductance and the quality factor are measured by a calibrated impedance analyzer Agilent 6945A. Coils are simply connected to the impedance analyzer with a coaxial cable via the SMA connector. The influence of the coaxial cable is included into the preliminary calibration. So, only the SMA connector will lightly influence the measurement.

From these data, the inductance is calculated to adapt the capacity value in order to create 13.56MHz resonant antennas thanks to the equation 1, with f_0 is the resonant frequency, L the inductance and C the capacity.

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

Then, antennas' electrical parameters measurements have been realized through the calibrated impedance analyzer Agilent 6945A in order to evaluate its resonant frequency and quality factor. The antenna is built as in the figure 2: a schematic of a RL circuit in series with the capacity C in parallel (a) and photography of the antenna (b).

3. Results

First electrical parameters results obtained show that the coil resistance is directly dependent on the length of the embroidery, so coil radius and number of turn are two influent parameters. Indeed, intrinsic yarn linear resistance contribute to a resistance evolution. Figure 3 highlights the resistance evolution in function of the number of turn, at constant radius (a) and the radius, at constant number of turn (b)

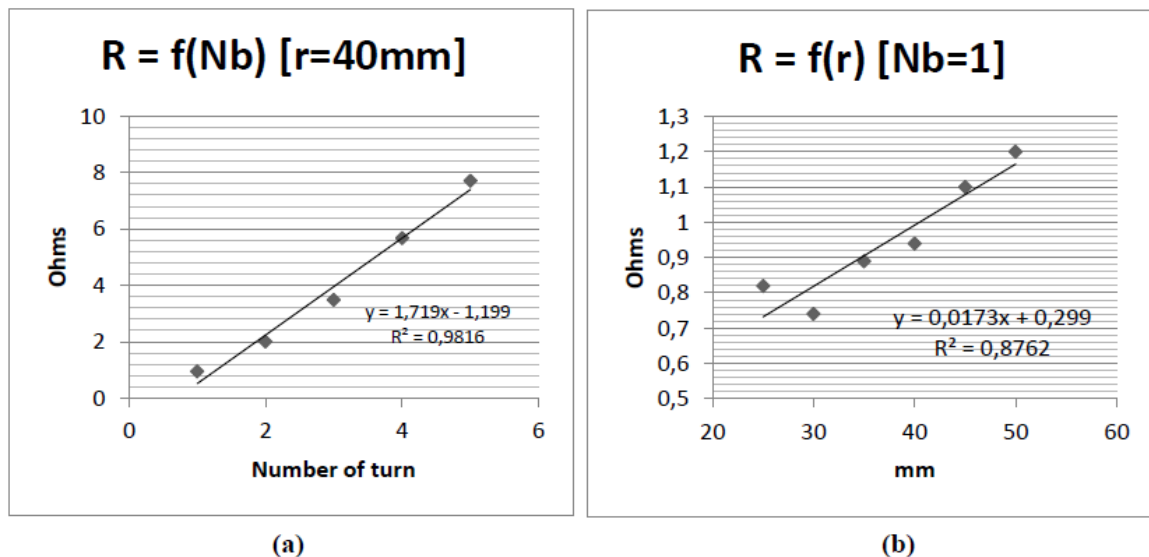


Figure 3. Evolution chart of the resistance in function of the number of turn, at constant radius (a) and the radius, at constant number of turn (b)

Then, the coil inductance values are a slight increase from $1.97e-7H$ to $3.7e-7H$ when the radius of the coil increases from 25mm to 50mm. The most influent parameter is the number of turns, indeed the inductance values increase from $2.85e-7H$ to $3.18e-6H$ with number of turn of the coil increase from 1 to 5. The figure 4 represents charts of the inductance evolution in function of the radius, at constant number of turn (a) and in function of number of turn at constant radius (b).

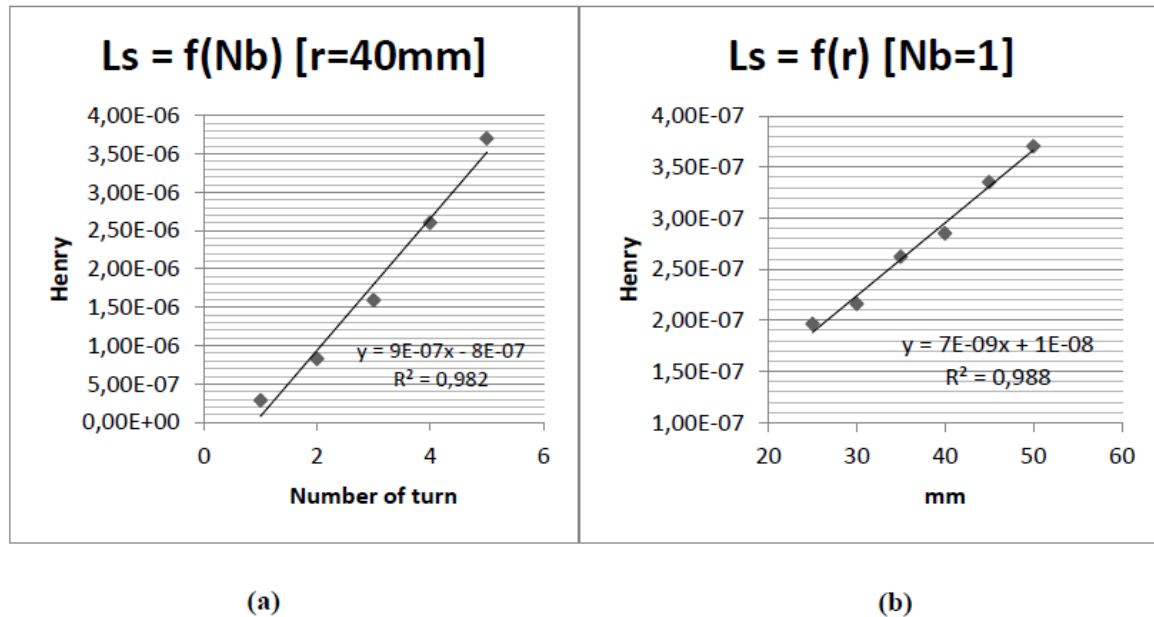


Figure 4. Evolution charts of the inductance in function of the number of turn, at constant radius (a) and the radius, at constant number of turn (b).

In this circuit, the quality factor can be calculated by the equation (2), where Q is the quality factor, L_s the inductance, ω_0 the resonant pulse and R the resistance.

$$Q = \frac{L_s \omega_0}{R} \quad (2)$$

The equation (2) highlights the influence of the resistance and the inductance on the quality factor. Therefore, in order to obtain an antenna that can carry enough electric power in the desired frequency range, it is necessary to establish a compromise between these two values.

According to previous graphs, evolution of the inductance and the resistance can be considered as linear. Moreover, the number of turn appears as the most influent parameters, so it is natural to study the quality factor through this. Diagrams from figure 3 (a) and figure 4 (a) enable to make an equation system, which brings the equation (3) representing quality factor evolution in function of number of turn, with x = number of turns.

$$\begin{cases} R = 1,72(x) - 1,2 \\ L = 9 \cdot 10^{-7}(x) - 8 \cdot 10^{-7} \end{cases}$$

$$Q = \frac{76.64x - 68.13}{1.72x - 1.2} \quad (3)$$

According to this model, the figure 5 represents the quality factor evolution in function of the number of turn.

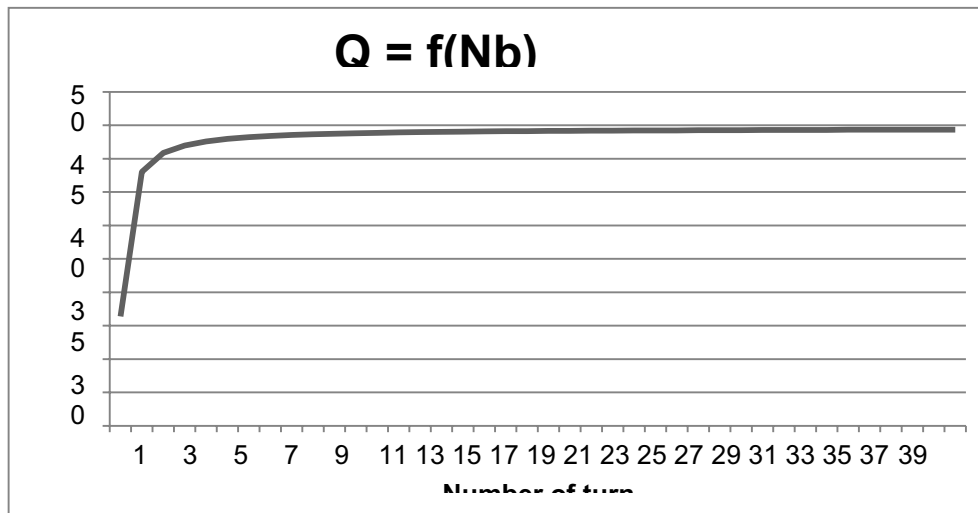


Figure 5. Evolution charts of the quality factor in function of the number of turn, at constant radius $r=40\text{mm}$

Even if this model is only an approximation, it makes it possible to highlight a maximum value of 45 for the quality factor. This maximum is mainly due to the significant resistance of the wire used. Indeed, when increasing the number of turn, increases both the inductance but also the resistance.

4. Conclusion

The fabrication of a new class of textile antennas was made possible by using the embroidery process as printing and overlapping three yarns. Also, the study of electrical characteristics in function of embroidery machine geometrical parameters enables to evaluate antennas performances at the desired frequency, i.e. 13.56MHz. Then, despite the structural complexity of conductive yarn and coil design, the evolution of electrical characteristic is approximately linear, which allows to create a model. So, quality factor and resonant frequency values can be predicted to certain extend by simulation.

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