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Textile Antenna for Personal Radio Communications System – Materials and Technology

Abstract

Development in the field of electronic circuit technology has resulted in the miniaturisation of radio transceiver integrated circuits. This gives the possibility of embedding radio transceivers directly into a garment. The product obtained (garment + electronic transmitter) can have new functions that significantly expand the basic functionality of textiles. To combine radio equipment with clothing, the electronic elements should be as flexible and lightweight as possible. The textile antennas that are being developed in many research institutions have constructions that combine high performance in radio communication together with a flexible and lightweight construction. The authors of this paper propose a vee-type textile antenna that can be used for wireless transmission in a 2.4 GHz band. The concepts of the electrical design of this antenna as well as the antenna structure and design methodology were discussed. The aim of this paper is to present textile materials and textile manufacturing technologies that were used for this design.

Key words: *textile antenna, conducting fibres, nonwovens, composite textile materials, e-textiles, smart clothes.*

Introduction

Modern electronic circuits can realise very complex functions, and yet have a small package and low energy consumption. Significant progress can be observed in digital circuit technology of increasing complexity and computational capabilities every year. Recent development in electronic technology resulted in the miniaturisation of radio transceivers that are now placed in one package with programmable circuits. The small size of such integrated circuits and their low power consumption offers new fields of application for electronics. Examples of this are e-textiles (electrotextiles, intelligent textiles) that combine textile technology with electronics to produce a garment with enhanced features.

E-textiles present enormous potential for the creation of a new generation of flexible, unobtrusive, multifunctional structures for many applications. Therefore the development of new fibrous forms of sensors, electrical connectors and antennas exploring the potential resulting from materials science is possible. For example, health condition monitoring clothes can be created using multifunctional fabrics, often referred to as electronic textiles (e-textiles) or smart textiles. Such materials allow to integrate sensing, actuation, electronics and power functions. These wearable devices can be flexible and remain unobtrusive to the human body. E-textiles are important for progress in biomedicine as well as for several health-focused disciplines, such as bio-monitoring, rehabilitation, telemedicine, tele-assistance, ergonomics and sport medicine.

An example of e-textile application is smart clothes for remote body sensing, developed at the Technical University of Lodz to monitor the physiological parameters of firefighters. The structure of the system and the connection of the antenna is presented in ***Figure 1***. It consists of a remote monitor unit that is capable of receiving data via radio from smart clothes equipped with sensors, a radio transmitter and antenna. The wearable elements are designed to be light and flexible, which was accomplished by their miniaturisation. However, the miniaturisation of the antenna has a disadvantage. It significantly reduces antenna performance, which can be observed in the case of so called chip-antennas, which have very low gain. In the smart clothes project, to achieve user comfort and simultaneously greater antenna gain, instead of antenna miniaturisation, a flexible textile antenna was designed.

In recent years, growing research interest in the investigation of textile material interaction with electromagnetic waves has been observed [4 - 7]. Textile materials can be used to construct microwave transmission lines [6] or flexible electromagnetic shields [7]. Another application of textile electromagneticis materials textile antennas [8 - 11]. Such an antenna can be made with the use of conducting and dielectric textile materials or a thin metal

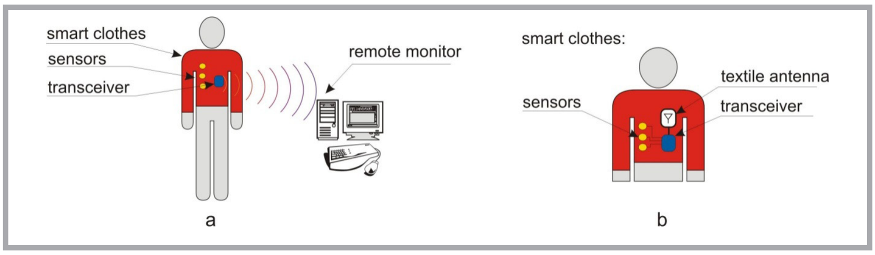

Figure 1. *Antenna in wireless smart clothes: a – system , b – antenna connection.*

foil. The major advantage of using textile materials for antennas is the elasticity and light weight of the final product, which can be integrated into clothing. Such an antenna is then unobtrusive to the wearer and has no influence on their comfort [8]. The authors of this paper designed a textile body-worn exponentially tapered Vee antenna for the 2.4 GHz frequency band [1 - 3]. The antenna is suitable for operation in the proximity of the human body. The advantage of the antenna designed as compared t standard patch antennas lies in its greater flexibility and immunity to deformation or exposure to liquids. The concepts of the electrical design of this antenna as well as the antenna structure and design methodology were discussed in [1 - 3]. The aim of this paper is to present textile materials and textile manufacturing technologies that were used for this design. Measurement results of antenna parameters are presented to illustrate the influence of materials used on the antenna parameters.

Antenna design

For the smart clothes radio system, an antenna was designed that can be made with purely textile materials and technology. The configuration of the antenna is presented in ***Figure 2***. It is a modified Vee dipole antenna adapted for manufacturing in textile technology [1 - 3]. The antenna has a symmetrical structure as its radiators are formed by two arms of the dipole (in the shape of the letter V) that are exponentially tapered to increase the impedance bandwidth. The antenna is symmetrically fed by a two wire line. As typical transmitters have an asymmetrical coaxial port, the antenna is equipped with a balun (balanced-unbalanced converter) to match the standard output from the transmitter. For the purpose of antenna measurements, the balun was made with a quarter wave coaxial line that uses a small connector (3.5 mm diameter). The antenna radiators are made of yarn based textile conducting materials of low resistance. In order to provide sufficient mechanical support for thin radiators, the flexible conducting elements were placed on textile material of high electric resistivity and low dielectric loss (base material). The covering material (of similar parameters to the base material) is placed directly on the antenna, which is shown in ***Figure 2***.

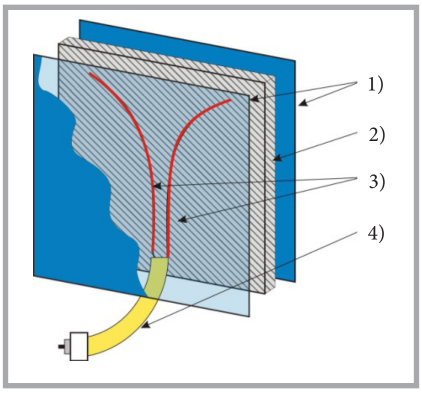

Figure 2. *Antenna structure; 1 - covering material, 2 - base material, 3 - conducting elements, 4 - coaxial feeding cable.*

When the radiator (dipole arms) is placed between the base material and covering material, a shift of resonant frequency can be observed, which is caused by the presence of dielectric material that has greater dielectric permittivity than air. To compensate this shift, before manufacturing, the whole structure was simulated with a computer program using the finite difference time domain method. For this purpose the program XFDTD (produced by Remcom) was applied to optimise the antenna geometry and achieve proper tuning [1 - 3]. The dielectric permittivity values of the nonwovens that had to be defined as simulation parameters were obtained from [12].

Two prototypes of the antenna were elaborated: The first one was made with a radiator formed by copper fibres, and it was tuned to operate in the 2.4 GHz band. Another was fabricated with Bekinox fibres, and it was tuned to work in the 1.7 GHz band.

Table 1. *Characteristics of the material used for the antennas;* ***Explanation****: *- the twisted yarn consisting of 12 continuous fibres with the linear mass of 275 dtex and the number of Z twists equal to 100 t.p.m., ** - twisted yarn consisting of 78 continuous fibres with a linear mass of 18 dtex and the Z twist.*

Symbol	Material description	Manufacturer	Characteristics
Cu	Thin copper wires	DAHMEN	φ = 0.061 mm
Ag	Silver fibres	ELEKTRISOLA	φ = 0.063 mm
Cu-Ni	Wires from nickel-copper alloy	DAHMEN	φ = 0.061 mm
BEKINTEX	Continuous steel fibres	BEKAERT	12 x 275/100Z*
SHIELDEX	Polyamide silver-plated fibres	STATEX	78 f18 dtex Z**

Materials and technology

The Vee type textile antenna requires a textile base material that is dielectric (electrical insulator) and flexible yarns that are good conductors. Conducting yarns form the antenna radiator, should provide very low resistance to the currents that flow in the antenna. The composition of the polyester fibres (PES) and two-ingredient thermoplastic fibres (LMF) was prepared for the production of the needled non-woven destined for the antenna base. The composition was prepared using the following materials: 95% (PES) - 5% LMF, 90% (PES) - 10% LMF, 85% (PES) - 15% LMF, 80% (PES) - 20% LMF, 75% (PES) -25% LMF and 70% (PES) - 30% LMF. All the non-wovens were characterised by a similar surface mass, oscillating around 160 g/m^2, and thickness of about 5 mm. Deviations from the assumed surface mass did not exceed 1%. Then the non-wovens were subjected to thermal processing based on ironing with the use of a clothing press at a temperature of 150 °C for 1.5 min. The thickness of all variants of the non-woven after the thermal processing was equal to 0.5 ± 0.05 mm at a constant surface mass.

The samples of base non-woven material obtained with different compositions of fibres were compared on the basis of mechanical and electrical features. The selection criteria were the smallest impedance shift of the prototype antenna after it was placed on the sample material. Also the maximum rigidity and smallest thickness of the sample were sought. A composition of 75% (PES) and 25% LMF was selected for the production of non-woven base material for the textile antennas. The volume resistance of the ironed non-woven layers was equal to $4.0 \cdot 10^{10} \pm 5 \cdot 10^{9}$ Ω.

The antenna conducting elements (radiators) were made from textile wires formed from the continuous fibres. Different fibre materials were examined: thin copper wires with a diameter of 0.061 mm (as in the prototype elaborated), textile wires made from silver fibres, a nickel-copper alloy, continuous steel fibres and continuous polyamide silver-plated fibres. Symbols of the material used for the wires, their description, and the names of the manufacturers are given in ***Table 1***.

The antenna radiators were hand-formed to keep the shape of the exponential curve conforming to the shape designed with the use of computer simulation. All the textile wires used had a twist equal to 100 t.p.m. and diameter equal to 0.5 mm. The yarns were placed on Teflon foil and attached to it point wise with the use of a temperature resistant adhesive up to 150 °C. In order to avoid deviations in the antenna shape, a specially elaborated pattern made from a teflon plate with a thickness of 1 mm was used. The teflon foil, with the antenna placed on it, was covered with the blended needled non-woven composition, comprising 75% (PES) - 25% LMF. Such a structure was subject to thermal ironing on the clothing press at a temperature of 120 °C for 1.5 min, which caused thermal binding of the wires with the non-woven layer (see ***Figure 3.A***).

The resistance of the wires was measured before and after implementation of the radiators onto the surface. The results are given in ***Table 2***.

The values of electric conductivity of each of the wires after implementation showed that there the wires were not broken.

After the tests of antenna prototype performance under real conditions the technology of production was changed. These changes were implemented to facilitate mass production of the antennas. The electro-conductive fibres of the antenna radiator were placed on the non-woven base material using the sewing technique, with a normal stitch (see ***Figure 3.B***). The shift of stitch of the visible link was equal to 3 mm, and that of the invisible link - also 3 mm. The radiator was connected to the coaxial quarter wave balanced - unbalanced transformer (balun). A standard 3.5 mm connector was used to connect the antenna to the firemen module interface. The layer with wires was placed between those of polyolefin foil covered with layers of the thermal insulation material, as presented in ***Figure 4***. The layers were placed in such a way that the outer surface was the fabric. Then the whole construction was subjected to welding in the clothing press at a temperature of 120 °C for 2 min. In this way the layers were thermoplastic bound, and the antenna is additionally protected from the action of water, due to the fact that polyolefin foil is a waterproof material**.**

Table 2. *Values of the electric resistance R of the wires measured after implementation on the non-woven structure.*

The type of the electric wires	Unit	Resistance before implementation	Resistance after implementation
BEKINOX® VN yarn	Ω	20.3	20.8
Wire from 10 copper wires with a diameter of 0.063 mm each.		0.58	0.68
Copper wire with a diameter of 0.15 mm		0.274	0.27
Copper wire with a diameter of 0.16 mm		0.509	0.50

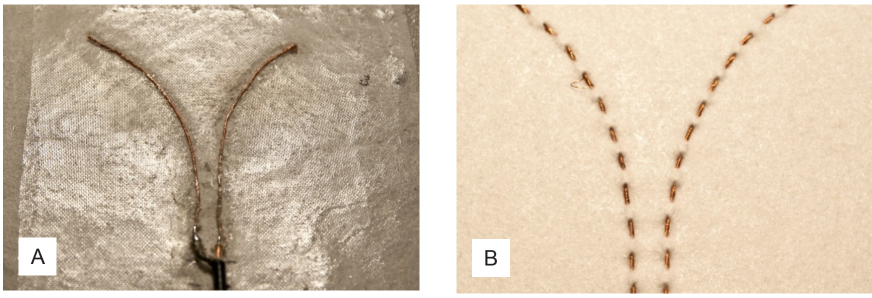

Figure 3. *Base material with: A - thermoplastic layer, B - embroidered radiator.*

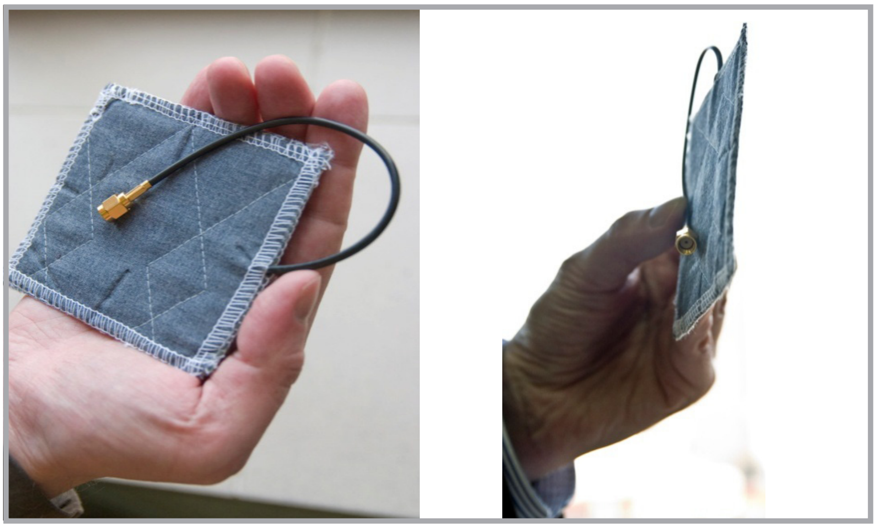

Figure 4. *Textile antenna with burn-proof cover.*

Measurement results

The antenna's performance was verified with measurements of the antenna's input impedance and the radiation pattern for different material compositions. Measurements of the input impedance were carried out using an Agilent E8802 vector network analyser. The input impedance was then recalculated into a Voltage Standing Wave Ratio (VSWR), which measures the impedance shift from the reference value $Z_0 = 50\ \Omega$. Measurements were made both for an open space and the on-body location of the antenna. Measurement results obtained for the cooper base and Bekinox antenna are presented in ***Figures 5*** and ***6*** (see page 132); the input impedance is presented in the form of resistance and the reactance as a function of the frequency.

The impedance bandwidth of the antenna is the frequency range for which the input impedance does not vary much from the reference value. For the purpose of antenna analysis, the reference value was set at $Z_0 = 50\ \Omega$. The impedance shift was analysed with VSWR. The antenna bandwidth was limited by the VSWR = 2. The bandwidth of the copper based antenna measured is from $f_l = 2.377$ GHz to $f_u = 2.578$ GHz. The impedance bandwidth of the Bekinox based antenna was measured as $f_l = 1.67$ GHz, $f_u = 1.8$ GHz.

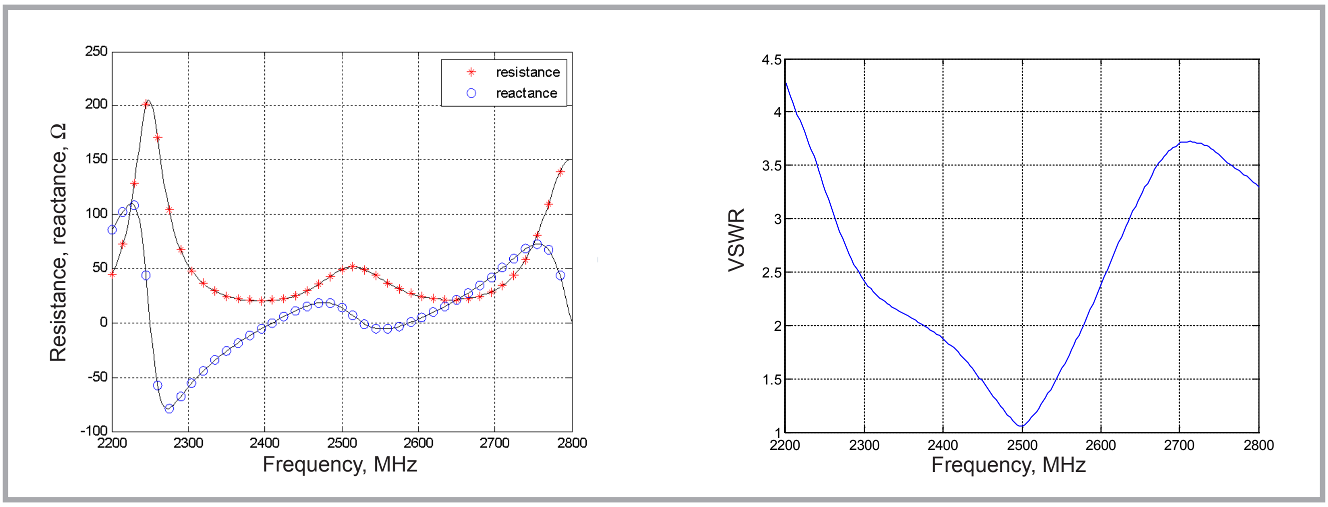

Figure 5. *Copper fibre antenna input impedance and VSWR.*

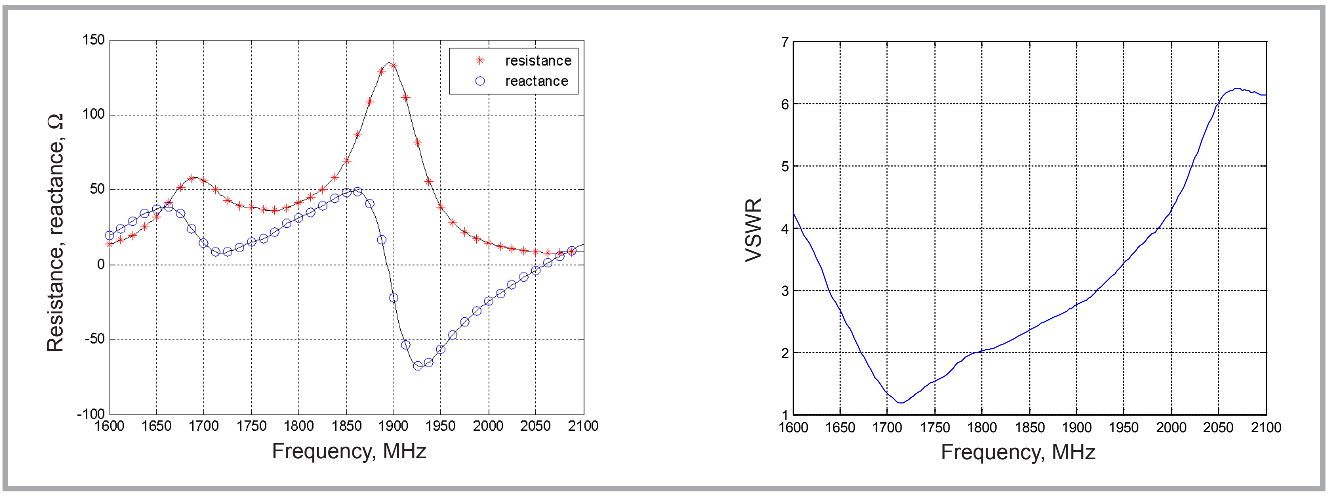

Figure 6. *Bekinox fibre antenna input impedance and VSWR.*

The textile antenna is designed to be placed close to the human body, hence measurements of the antenna radiation pattern were performed in similar conditions on an anthropomorphic phantom (***Figure** 7*). The phantom is made of thin fibreglass filled with liquid (a water solution of sucrose and kitchen salt) of electrical properties similar to human tissue. The electric constant was equal to $\varepsilon \approx 52$ and the conductivity -to $\sigma \approx 1.8$ S/m. These values are close to the parameters of human tissue [13]. Electric parameters of the liquid were measured and adjusted using an open transmission line test set and Agilent E8802 vector network analyser.

The antenna under measurement was fastened to a T-shirt on the phantom (***Figure** 7*). The phantom with the antenna attached was placed on a turntable in an open area test site for radiation pattern measurements. Due to the geometry of the test site, the radiation pattern was measured over a conducting ground only in the horizontal plane. The results of the measurements are presented in ***Figure 8***. The maximum gain of the copper based antenna for the vertical polarisation is equal to 4 dBi. The prototype made with Bekinox has a smaller gain, equal to approximately 0 dBi, which is caused by the resistance of conducting fibres being greater in this case.

Conclusions

In this paper, textile materials and textile manufacturing technologies used for antenna design are presented. The antenna uses purely textile materials and techniques which allow to obtain a small, flexible, and lightweight element that can be successfully used in personal radio communication systems. A prototype of the textile antenna presented was successfully verified during tests and measurements. The electrical parameters of the antenna are suitable for antenna application in mobile radio systems, as the antenna's radiation pattern is relatively broad.

The results of the investigation show that the antenna performance is limited by the proper selection of textile materials. For the same antenna geometry the antenna gain depends strongly on the resistivity of fibres used to form the antenna radiator. Bekinox fibre gives a smaller (0 dBi) gain due to resistivity as compared to copper fibre (4 dBi). Antennas made with different fibres had good impedance, equal to 50 Ω (VSWR for both prototypes was very close to 1). As opposed to the antenna gain, this parameter does not characterise the influence of the material resistivity on the antenna's performance.

Further research will be carried out with copper based materials. Also new tech-

Figure 7. Antenna placed on phantom for radiation pattern measurements at open-field antenna test facility.

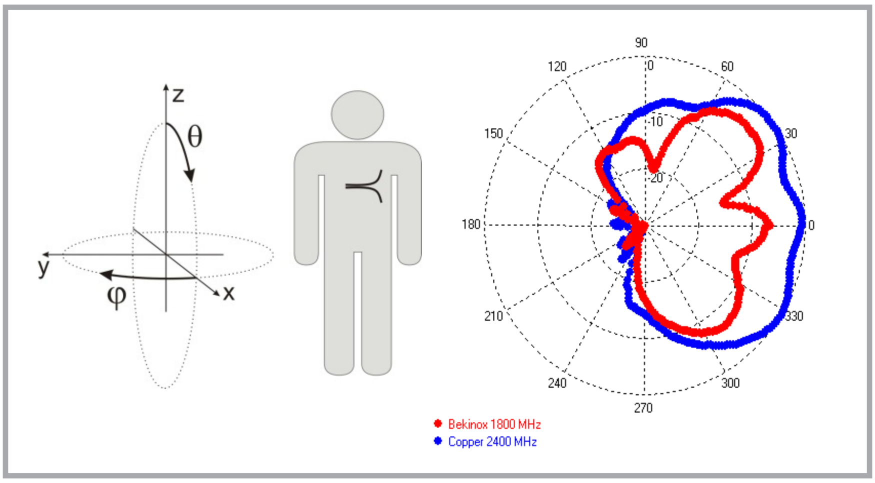

Figure 8. Textile antenna radiation pattern in x-y plane, $G_\theta(\varphi, 90°)$

niques of making inter-layer connections will be examined.

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Received 12.05.2010 **Reviewed 20.03.2012**