# TECHNOLOGICAL PECULIARITIES OF THE PRODUCTION OF A WEARABLE ANTENNA WITH INNOVATIVE TEXTILE MATERIALS

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***Abstract:*** *Essentially, textile materials are insulators. This is one of the main reasons to avoid their use in the fabrication of radiating elements of the antenna. Their extremely low value, the development of industrial technologies, as well as the need to design and build antennas on textile materials (embedded in clothing) are the main prerequisites for the ever-expanding use of textile materials (TM) for the fabrication of substrates of wearable antennas. Withal, many questions arise regarding technological factors affecting the effectiveness of textile materials application for antenna fabrication. Today, a number of new textile materials are very intensively developed. The subject of this work is the technological peculiarities of the fabrication of wearable antennas from a new TM registered with an invention patent in recent years.*

***Keywords:*** *modern textile materials, wearable antenna.*

## 1 INTRODUCTION

The development of modern industrial technologies on a global scale is particularly intensive. Setting the scientific basis of problematic engineering tasks is especially important in view of their faster and more efficient solution for optimization of innovative technological processes. The process of application of textile materials for the fabrication of wearable antennas is an extremely up-to-date, interesting and innovative process, which is why its research and scientific analysis is the subject of this work.

Essentially, textile materials are insulators - they have very high electrical resistance. This is one of the main reasons to avoid their use in the fabrication of radiating elements for antenna. Their extremely low value (compared to other materials commonly used for antennas), the development of the industrial technology in recent years (however, electrical loads pass through textile materials), as well as the need to design and build antennas on textile materials (embedded in clothing) [1] are the main prerequisites for the ever-expanding use of textile materials to make substrates for wearable antennas. Wearable antennas made out of conductive fabric on textile substrates were reported in the past [2, 3]. Withal, many questions arise regarding technological factors affecting the effectiveness of TM application for antennas that have not been the subject of scientific treatment or have not been sufficiently and thoroughly studied.

One of the main criteria that determines the applicability of TM for antenna fabrication is its dielectric constant. Studies have been carried out to determine the effect of the degree of filling of capacitor plates with textile material, as well as the influence of the humidity and the temperature of fibers on the dielectric constant [4, 5]. Also, scientific research has been conducted in order to identify the influence of the frequency of the current supplied to the capacitor plates and the chemical structure of the fibers on the dielectric constant [4-6]. In recent years, however, a number of new textile materials have been developed and have entered into mass production. Each of them is with different properties according to its composition and structure. All this requires an expansion and deepening of the studies of dielectric properties of textile materials, taking into account the multicomponent nature of their chemical composition and the complexity of their structure. In the context of the above mentioned, the dielectric properties of an innovative TM (with multicomponent composition and complex structure) registered with an invention patent [7] in recent years, which have not been a subject of scientific research, are of a particular interest.

## 2 DISCUSSION AND ANALYSIS

The purpose of the present work is to investigate and analyze the dielectric constant of an innovative double woven fabric at different technological variants of operation. The double weaving technology enables the front side of the TM to have one type of structure and composition, and the backside of the TM - another type of composition and structure that meets specific requirements for the TM.

### *2.1 Conditions to execute the experiment*

The textile material studied is a double woven fabric (for winter sports, hunting and tourism) "Hunter'12", produced by "E. Miroglio SA" – Sliven, Bulgaria. Flexible textile product is a fabric of multilayer weave type "double fabric". The considered pattern consists of 2 classical twills - 3/1 twill for the face fabric and 2/1 twill for the reverse fabric. Between the face fabric and the reverse fabric there is an intermediate bonding layer of chemical threads. The cross section of weaving contexture that underlies this complex fabric structure is given in Figure 1 [7, 8].

Pure cotton fibers (100%) make the face layer of the fabric and 100% wool fibers make the reverse layer of the fabric. The intermediate layer is made of chemical fibers - polyamide and viscose [8]. General fibrous composition of the face fabric is characterized by the linear density of warp threads (c: 1, 3, 5, 7, 8, 10, 12 and 14) Tt = 20.0x2 tex Sirospun, 70/18/7/5% Cotton/Viscose/PES/PA6, while the linear density of weft threads (t: 3 and 10) is Tt = 16.1 (8.3 + 7.8 Ply twisted) tex, 52/48% Viscose/PES. General fibrous composition of the reverse fabric is characterized by the linear density of warp threads (c: 2, 4, 6, 9, 11 and 13) Tt = 16.1 (8.3 + 7.8 Ply twisted) tex, 52/48% Viscose/PES, while the linear density of weft threads (t: 1 and 8) is Tt = 40x1 tex, 100% Wool.

It was the multicomponent composition, the complexity of the structure and the exceptional applicability of the above-described TM that aroused interest in exploring its potential for wearable antenna fabrication.

In formulating the conditions and methods for conducting the experiment, principles of the morphological method for analysis and synthesis of methods are applied [9]. The analysis of technological methods for the production of wearable antennas shows that the most common technological variants are with one layer and two layers of TM given in Figure 2. A wearable antenna can be made on a single layer of TM as given in Figure 2, positions 2 and 5.

A number of reasons may require the concealment of the wearable antenna. Therefore, this antenna can be inserted between the details of the sewing article. For example, between the base textile material and the outer sewn pocket (Figure 2, position 1) between the two layers of TM in the manufacture of connecting seams of the article (Figure 2, positions 3 and 4), between the two layers of TM in the manufacture of hemmed seams of the article and a number of others.

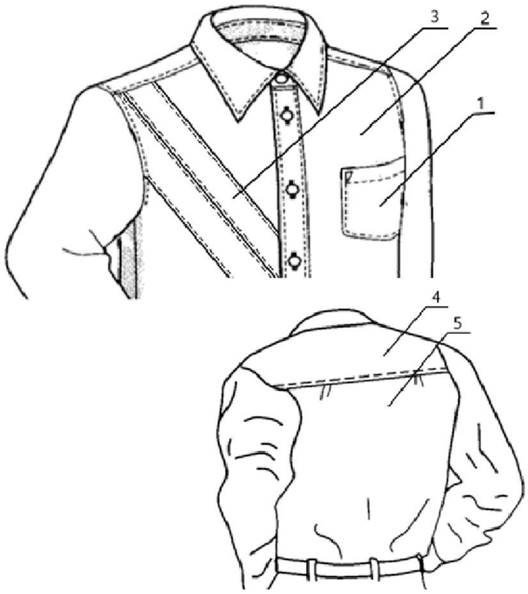


**Figure 2** Scheme of an example placement of a wearable antenna on a men's shirt

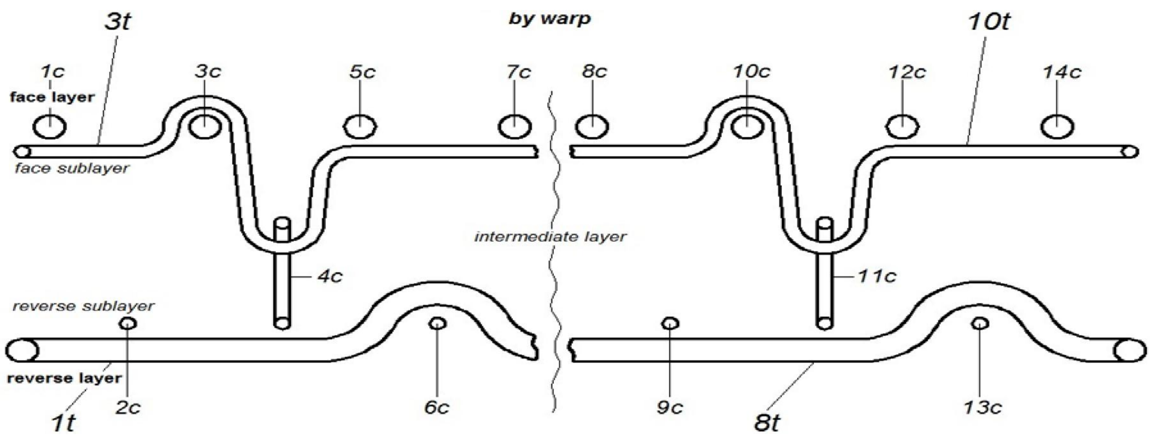


**Figure 1** A cross section of weaving contexture that underlies a double woven fabric “Hunter'12”

Possible technological solutions are by using a special thread to connect the antenna to the basic TM or by using a polymeric binder. In this regard, two experiments were conducted to investigate the dielectric constant of the described TM. For each experiment, 2 variants were examined according to the number of TM layers - with one layer and two layers.

The tests in Experiment I were performed with TM without a polymeric binder.

The tests in Experiment II were performed with a TM with a polymeric binder.

The dielectric constant of the material was measured by the resonant perturbation method described in [10] at frequency of 2.564 GHz.

### *2.2 Experimental results*

The results obtained from the implementation of Experiment I and Experiment II are given in Tables 1 and 2. It is important to note that in the initial conduct of two experiments, 3 repeated trials were made for each point in the experiment plan (*m* = 3). In doing so, it was found that the studies for Experiment II were not reproducible. This is why the number of repeated trials at one point in the experiment plan for Experiment II is increased to 4 (*m* = 4 for Experiment II).

**Table 1** Results of conducted studies for dielectric constant for Experiment I

| **Study №, j** | **Dielectric constant** | | |
|---|---|---|---|
| ***Variant №, i, (number of layers)*** | ***$DC_{i,1}$*** | ***$DC_{i,2}$*** | ***$DC_{i,3}$*** |
| $B_1$ – 1 (one layer of TM) | 1.963022 | 1.963875 | 1.964554 |
| $B_2$ – 2 (two layers of TM) | 1.929429 | 1.924141 | 1.923903 |

**Table 2** Results of conducted studies for dielectric constant for Experiment II

| **Study №, j** | **Dielectric constant** | | | |
|---|---|---|---|---|
| ***Variant №, i, (number of layers)*** | ***$DC_{i,1}$*** | ***$DC_{i,2}$*** | ***$DC_{i,3}$*** | ***$DC_{i,4}$*** |
| $B_1$ – 1 (one layer of TM with one layer polymeric binder) | 1.893409 | 1.890665 | 1.892463 | 1.893318 |
| $B_2$ – 2 (two layers of TM with two layers polymeric binder) | 1.918928 | 1.919031 | 1.918903 | 1.917414 |

### *2.3 Discussion of experimental results*

It is necessary to carry out a process reproducibility check, which is reduced [11, 12] to a variance perseverance check (by Cochran's C test):

$$G_C = \frac{S_{i\max}^2}{\sum_{i=1}^{B} S_i^2}; \tag{1}$$

$$G_T \begin{Bmatrix} f_1 = m-1 \\ f_2 = B \\ r = 0{,}05 \end{Bmatrix} \tag{2}$$

where *m* is the number of repeated trials for each variant, *B* - number of variant, $f_1$ and $f_2$ - degrees of freedom, *r* - significance level.

The C test is used to decide if a single estimate of a variance (or a standard deviation) is significantly larger than a group of variances (or standard deviations) with which the single estimate is supposed to be comparable [11].

The results for the calculated and tabulated value of the Cochran's C test for Experiment I are:

$$G_{C,I} = 0{,}91798; \quad G_{T,I} = 0{,}9750 \tag{3}$$

Therefore, intra-group variance does not differ statistically and the study process for Experiment I is reproducible.

The results for the calculated and tabulated value of the Cochran's C test for Experiment II are:

$$G_{C,II} = 0{,}731019; \quad G_{T,II} = 0{,}9392 \tag{1}$$

Therefore, intra-group variance does not differ statistically and the study process for Experiment II is reproducible. Therefore, it can be summarized that the influence of the number of layers on the dielectric constant has been established. The results in Table 1 show that as the number of layers (without polymer binder) increases, the value of the dielectric constant decreases. The results in Table 2 show that as the number of layers (with polymer binder) increases, the value of the dielectric constant also increases.

As can be seen from the results listed in Tables 1 and 2, the investigated textile material exhibits low dielectric constant. Consequently, textile material can find application as a substrate in wearable antennas for off-body communications in the body area networks, because the low dielectric constant reduces the surface wave losses and improve the impedance bandwidth. From results of two experiments, it can be summarized that the most effective technological variant for making a wearable antenna is variant one ($B_1$) of Experiment II. This motivates the development of numerical and experimental models of a wearable antenna for this technological variant.

Figure 3 illustrates an example for a configuration of a wearable antenna with a substrate from the investigated textile material for one-layer TM with one-layer polymeric binder (variant $B_1$ of Experiment II).

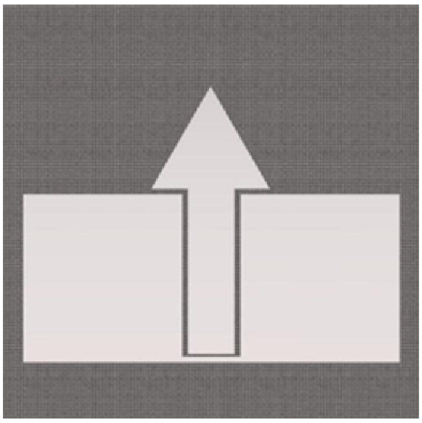

**Figure 3** Configuration of a wearable antenna with a substrate from the investigated textile material

## 3 CONCLUSION

In the present work, the possibility of applying innovative double cloth to the elaboration of a wearable antenna has been investigated. Technological peculiarities for the design of a wearable antenna have been analyzed and considered when carrying out experiments.

The values of the dielectric constant of the investigated TM for different technological variants have been established. The reproducibility of studies carried out has been proven. The applicability of the investigated textile material as a substrate in wearable antennas for off-body communications in the body area networks has been established. A highly efficient technological variant for making a wearable antenna has been established. A configuration of a wearable antenna with a substrate from the investigated textile material has been created.

Researches and analyzes carried out lay on a scientific basis the solution of interdisciplinary engineering problems related to technological peculiarities for the production of a wearable antenna.

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