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New Kind of Textile Transmission Line with an Impedance of 50 Ohms

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Abstract
The article describes a new kind of textile transmission line which might be widely used, among others, in smart clothing. This line consists of a textile substrate in the form of fabric, sewn with paths made from electrically conductive fabric. The arrangement of electrically conductive paths in the line proposed makes it easy to obtain the possibility of impedance changes in a wide range of its values (potentially giving the possibility to obtain an impedance equal to 50 Ω), regardless of the type of fabric used as a substrate. The paper presents examples of measurement results of characteristic impedance of the line affecting its transmission properties. It also presents an impact study of the type of stitches fastening electrically conductive paths and the inaccurate creation of the line on the value of the characteristic impedance. The studies presented are based on real measurements and computer simulation using CST Studio software.

Key words: *textile transmission line, textile signal line, smart garment, characteristic impedance.*

Introduction

Recent years have seen the rapid development of smart materials applicable for the construction of intelligent clothing. Possible applications of such garments are enormous, ranging from, for example, the implementation of an mp3 player or GSM phone to a garment and monitoring systems of physiological parameters that are applied to personal protection systems against various types of threats, and finally to application in medical systems (***Figure 1***).

Textiles equipped with various sensors of physiological parameters and radio system for sending measurement data can also be used to continuously monitor the health of patients, also enabling continuous medical supervision for people when they are out of hospital. Numerous studies of the systems described above have been carried out by a number of institutions around the world [2 - 6]. These systems require numerous connections between electronic modules, which in future solutions will be made from textile materials. For connections (lines) which transmit digital signals at high frequencies, such as data buses for future textile computers (wearable computer) and feed lines for high-frequency signal textile antennas, it is important to know some parameters characterising the properties of the transmission line. One of these is the value of the characteristic impedance of the line, which must be matched (ie. equal) to the impedance of the transmitters and receivers of the systems transmitting the signal. Otherwise the lack of the impedance's match will cause reflections and distortions of the transmitted signal. In extreme cases, this may result in a lack of proper reception of the signal transmitted by the line. The value of charac-

Figure 1. *Example of intelligent wear for medical applications [1].*

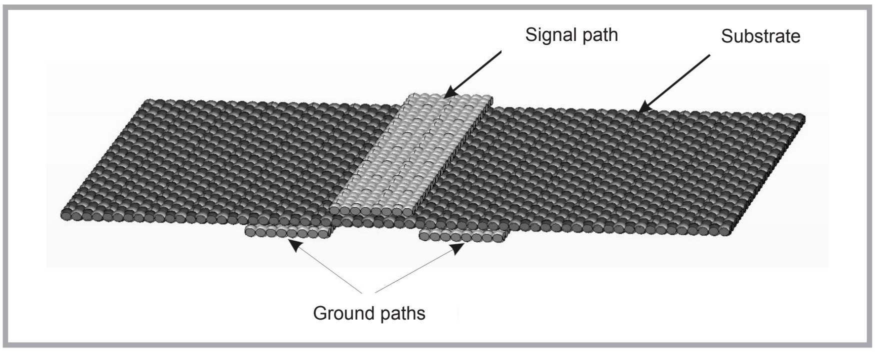

Figure 2. New kind of textile transmission line [9].

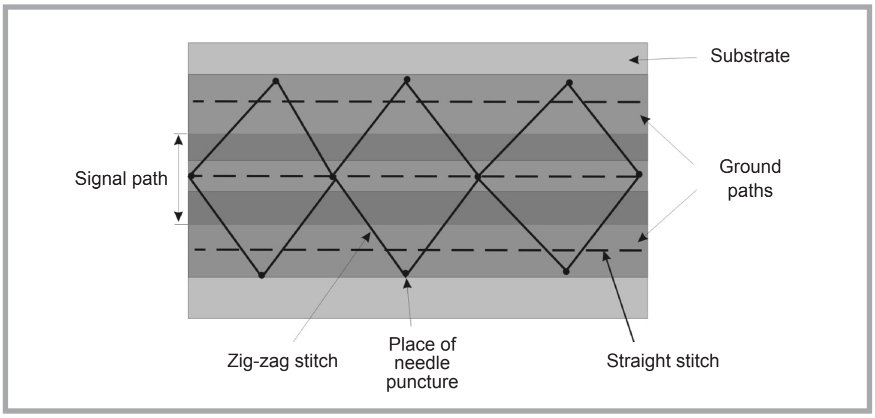

Figure 3. Sewing of electrically conductive paths [9].

teristic impedance of the textile transmission line depends on many factors, the most important of which are the electric permittivity of the substrate, the width of electro-conductive paths, the mutual position of the electro-conductive paths and the distances between these paths and the substrate. Works described so far in literature [7, 8] have not led to the development of a textile transmission line with a small value of characteristic impedance, for example equal to 50 Ω. Generally most of the values of impedance obtained significantly exceed a value of 50 ohms and can be only slightly changed by the designer of the line. Actual technological capabilities in textronics causes that conventional electronic circuits are often used in it. The development of a textile transmission line in which we can easily obtain impedance values adopted from standard transmission systems (eg. 50, 75 ohm, etc.) is a key factor in the proper transmission of signals with a wide frequency spectrum, using commercially available conventional systems for transmitting and receiving, without the need for additional matching circuits. As a result of this work, such a line was developed and is described in this article. The value of the impedance of the line taken in the work presented is 50 ohms. The choice of this value was dictated by the desire to use the proposed line not only in high-speed transmission systems of digital signals but also as an antenna feed line often used in smart clothes. The impedance of most antennas used in smart clothing is 50 ohms, which is also a standard value for inputs and cables in systems for measuring the parameters of transmission systems. This choice, therefore, also facilitated accurate measurement of transmission parameters of the line. Naturally the structure of the line allows to obtain different impedance values in an easy way, as is required.

New kind of textile transmission line

A view of the textile transmission line proposed is shown in ***Figure 2***.

This line consists of a signal path, substrate and two ground paths placed on the opposite side of the substrate. An electrical, transmitted signal flows through these paths. Ground paths are arranged at a distance from each other. By changing this distance, the characteristic impedance of the line can be varied over a wide range. The signal path and ground paths are made from electro-conductive fabric with a width of 5 mm. This width is a compromise between the ability to make a line of strict size and the possibility of correct transmission of high frequency signals. The substrate of the line is made from a flat, non-conductive textile product, for example from conventional fabric. Because the characteristic impedance of the line depends on the degree of adhesion to the substrate of electrically conductive paths of lines, the way they are sewn has a significant effect on its value. ***Figure 3*** shows the method of sewing of electrically conductive paths proposed.

All electrically conductive paths are sewn with a straight and zig-zag stitch. It is important here that the needle while sewing is not passed by both through the signal and ground paths, which is to ensure the avoidance of short circuits caused by electro-conductive fibres torn by the needle and dragged to the other side of the substrate.

Measurements of new textile transmission lines

In studies of transmission properties of the line proposed, measurements of the impedance profile were made. For impedance profile measurement, a DSA8200 Digital Serial Analyser with Iconnect software from Tektronix (USA) was used. This software allows to obtain a so-called true impedance profile, i.e. taking into account the effect of multiple reflections in the line of the signal transmitted. The profile impedance represents the value of characteristic impedance of the line as a function of the distance from the beginning of the line. More information about the measurement of the characteristic impedance of the line can be found in [10 - 12].

In order to make measurements, textile transmission lines with a substrate from different fabrics were made. Parameters of the exemplary fabric used as a substrate are shown in ***Table 1***. Electro-conductive paths were made from fabric named Ponge, from the firm Soliani (Italy). Basic characteristics of that fabric are shown in ***Table 2***. For more information on electro-conductive textile materials, see, for example, [13].

The appearance of the exemplary transmission line analysed is shown in ***Figure 4***, while its profile impedance is in ***Figure 5***.

As can be seen from ***Figure 5***, the value of characteristic impedance obtained for a substantial part of the line reaches 50 Ω. For the remaining sections of the line, deviation from a value of 50 Ω is not significant, caused by the quality of workmanship of the line. Similar results of the characteristic impedance of the line were obtained in the case of a line on a substrate made from other fabrics tested.

Investigation of the effect of the build quality of the line on the value of its characteristic impedance

The implementation of textile transmission lines due to the flexibility of textile materials used to make them poses many difficulties. Lines intended to carry signals with a wide spectrum of frequency or high frequency must be made with great precision. Inaccuracies appearing in the reproduction of the line geometry can cause a significant deterioration in its transmission properties. Therefore an attempt was made to split possible inaccuracies in the reproduction of the line geometry and to assess their impact on the transmission properties of the textile transmission line.

Inaccuracies in the reproduction of the line geometry can be divided into:

- those caused by poor adhesion of electro-conductive paths to the substrate of the line ($a \neq 0$, ***Figure 6*** (see page 54),
- ground paths position errors relative to each other (error of the distance between them, $c \neq$ const., ***Figure 6***),
- position errors of the upper signal path relative to ground paths ($b_1 \neq b_2$, ***Figure 6***).

To show the effects of poor adhesion of the tracks on the value of characteristic impedance of the line, measurements were made for a line where the electrically conductive paths were sewn exclusively with a straight stitch. Then paths were additionally sewn with a zig-zag stitch, as shown in ***Figure 3***. Impedance measurement results are shown in ***Figure 7*** (see page 54). As shown in this drawing, appropriate sewing of paths ensures their proper adhesion to the substrate and decreases the line's characteristic impedance and unevenness of impedance.

This shows that errors caused by the poor adhesion of electro-conductive paths to the substrate are closely related to the method of sewing, which means the type of stitch used, its pitch, position etc. Insufficient fixing of paths to the substrate results in the formation of air gaps between them and the substrate. Due to the difficulty in measuring the differences between the electro-conductive paths and the substrate, in order to quantitively test the effect of such errors, additional simulations of the line were performed in CST Studio software. CST Studio is software for simulation of electromagnetic properties of any 3D model of electric circuits and components including transmission lines.Results of the simulation are shown in ***Table 3*** (see page 54).

Asymmetric sewing of the top central signal path relative to ground paths de-

Table 1. *Parameters of selected, exemplary fabric used as a substrate of the line.*

Stuff	Weave	Thickness, mm	Aerial mass, g/m^2	Density, thread/cm		Relative permittivity f = 2 MHz, -	Tangent of loss angle f = 2MHz, -
				warp	weft		
cotton	twill	0.62	287	30	19	1.825	0,049

Table 2. *Parameters of electro-conductive fabric used to construct paths of the line*

Thickness, mm	Weave, -	Conductivity, S/m	Stuff, -
0.15	Plain	221100	nickel metallised polyester

Figure 4. *Example of the new kind of textile transmission line (top and bottom view).*

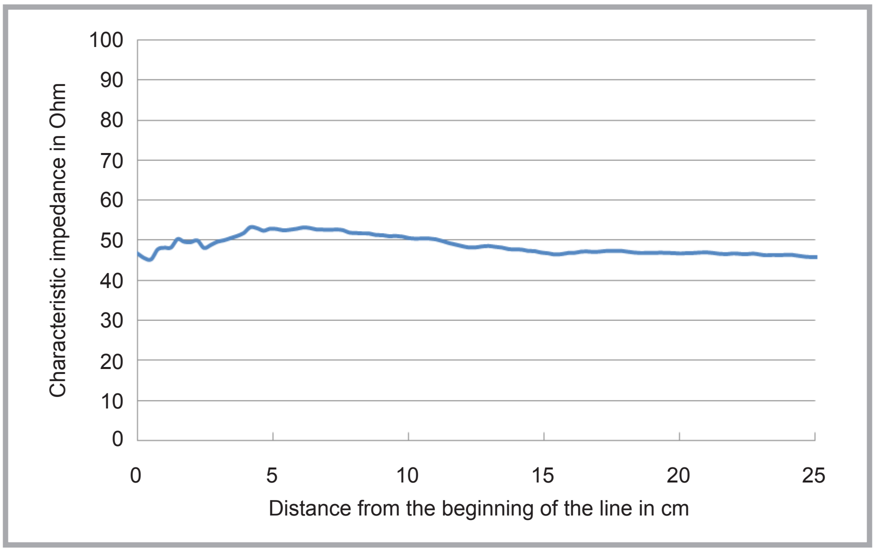

Figure 5. *Example of a characteristic impedance profile of the new kind of textile transmission line.*

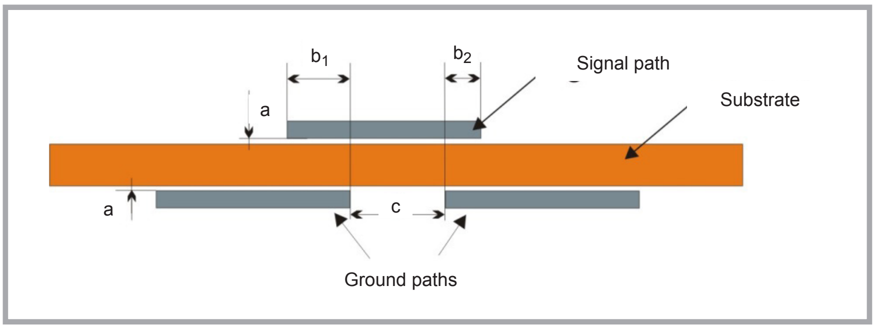

***Figure 6.** Inaccuracies in the reproduction of line geometry (transverse cross-section).*

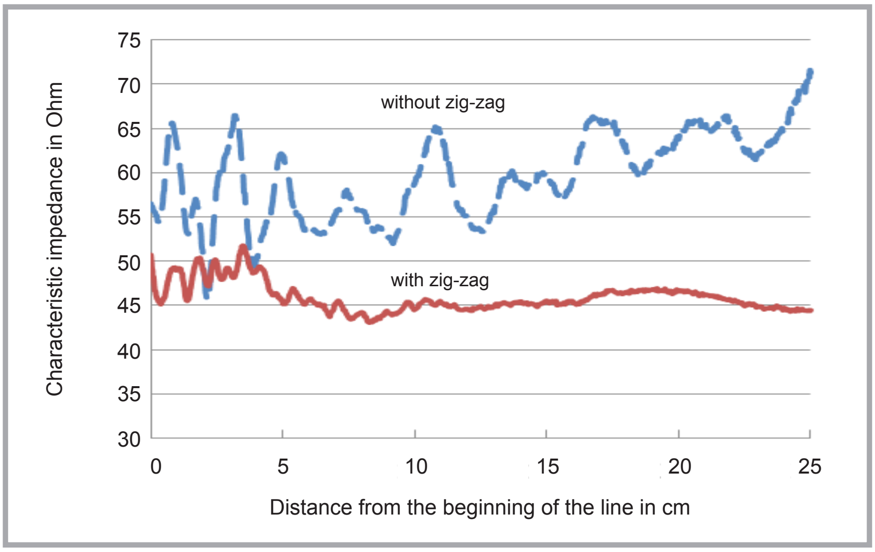

***Figure 7.** Impedance profile of the line with electro-conductive paths sewn with a straight stitch only (without zig-zag stitch) and that of the line with paths sewn with straight and zig-zag stitches (with zig-zag stitch)*

creases the value of characteristic impedance of the line (***Table 3***), while the poor adhesion of electrically conductive paths (the presence of an air gap between the tracks and the ground) causes its increase (***Table 3***).

***Table 3.** Effect of inaccuracies in the reproduction of the line geometry on its impedance.*

Line geometry		Impedance, Ohm
Asymmetry $b_1 - b_2$, (Figure 6)	0 mm	50.4
	1 mm	44.1
Air gap a, (Figure 6)	0 mm	50.4
	0.2 mm	65.5

Conclusions

The new kind of textile transmission line presented in the article allows to obtain different values (including a value of 50 ohms or less) of characteristic impedance, regardless of the type of fabric used as the substrate of the line. This allows to build a textile transmission line which can work correctly with a number of conventional transmitting and receiving devices or conventional radio antennas. From the analysis of the impact of the quality of implementation on the characteristic impedance of the transmission line, it can be seen that the relative position of the top signal path and ground paths and their adhesion properties significantly affect the value of characteristic impedance. Therefore the speed of the top and bottom feeds in the sewing machine during the sewing process should be strictly controlled to avoid stretching of sewn parts and to ensure good adhesion between electro-conductive paths and the substrate. The studies described showed the possibility of implementation of a textile line with characteristic impedance, enabling a proper match of the line with conventional transmission devices.

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