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Stitched Transmission Line for Broadband Operations

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Abstract

Wearable stitched transmission lines made from stripped RG174 and textile materials are introduced for broadband operations. The stitched transmission lines which are 150 mm long consists of an inner conductor surrounded by a tubular insulating layer. For shielding purposes, the structures are stitched into a denim material with conductive threads. The performances of the stitched transmission lines with three different stitch patterns, Double Overlock, Flatlock stitch and Ric-Rac stitch were investigated and results obtained confirm that Ric-Rac stitched transmission line has fewer DC losses than the three stitched transmission lines for frequencies up to 1 GHz. However, beyond that up to 2.4 GHz and above, it was observed that the Flatlock stitched transmission line and the Double Overlock stitched transmission line have fewer radiation losses compared to the Ric-Rac stitched transmission line. Similarly, the performance of the stitched transmission line when bent through curved angles of 90° and 180° was considered, and a much better S_{21} was observed with a curved angle of 180° for frequencies below 2.1 GHz, with radiation loss increasing afterwards. Finally, the sensitivity of the design to manufacturing tolerances, with changes in cross-sectional dimensions of the stitched transmission line and the transmission characteristics with different textile substrates were both considered. While simulated results showed that the stitched transmission line is sensitive to small variations in its circular dimensions, measured results conversely showed that Denim and Felt materials can be used as a substrate without any significant effect on its propagation characteristics.

Keywords: Stitched transmission line; stripped RG174; conductive threads; curved angles; manufacturing Tolerance

I. INTRODUCTION

The increasing demand for wearable electronics from industries such as fashion and entertainment, medical and healthcare, protection and safety, sports and fitness, and consumer electronics has led to the rapid miniaturisation of electronic devices that are mobile, convenient and accessible in both their physical form and applications. To connect wearable devices operating at radio frequencies, efficient transmission lines, which are lightweight with low fabrication cost, flexible and capable of providing shielding from the ingress and egress signals are vital components of such a system [1].

Textile transmission lines have been developed and used as means for transmitting signals to and from wearable devices, with extensive use in wearable computing [2] - [3]. Embroidery techniques used in fabricating transmission lines have been considered in [4], while the use of twisted copper yarns made with yarn covering process, used to transmit signals and power has been studied in [5]. Screen-printed textile lines [6], textile-shielded strip lines [1] and e-textile metamaterial transmission lines [7] have also been proposed for broadband operations. Similarly, the development of textile-based transmission lines using conductive yarns and a study on textile-based signal lines using ultrasonic welding technology were presented by [8] and [9], while an analysis of characteristic impedance of Microstrip and coplanar textile signal lines was presented in [10].

In this study, the novel stitched transmission line proposed in [11]-[12], is being presented for broadband operations within a measured frequency range of 0.04 GHz to 4 GHz (limited by measurement set-up). The research primarily focuses on the propagation characteristics of three different stitch types as well as the robustness of the stitched transmission line with two different bending conditions. The sensitivity of the design to manufacturing tolerance and its propagation characteristics with two different substrates, Denim and Felt were also considered.

II. NUMERICAL AND EXPERIMENTAL RESULTS

The stitched wearable transmission line was simulated using CST Microwave Studio Suite, while measurements were carried out with Anritsu $MS46524A$ $7GHz$ Vector Network Analyser.

A. Stitch types

The stitched wearable transmission line was fabricated with three different stitch types as presented in Fig. 1.

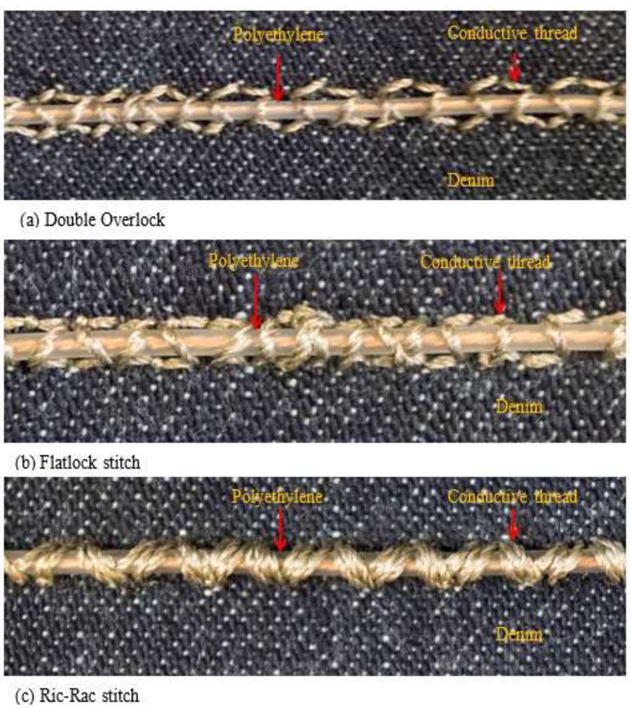

Fig. 1 Zoomed-in view of constructed stitched transmission line with three different stitch types

The measured scattering parameters for a frequency range of 0.04 to 4 GHz for the straight 150 mm long stitched transmission line is shown in Fig. 2. The measured reflection coefficients S_{11} are below -9 dB for both Double Overlock and Flatlock stitch, and -10 dB for Ric-Rac stitch in most of the operation band, while the transmission coefficients S_{21} are better than -13 dB for both Double Overlock and Flatlock stitch, and 10.5 dB for Ric-Rac stitch. The Double Overlock stitch has a better shield coverage of the three stitch types, thus fewer radiation losses.

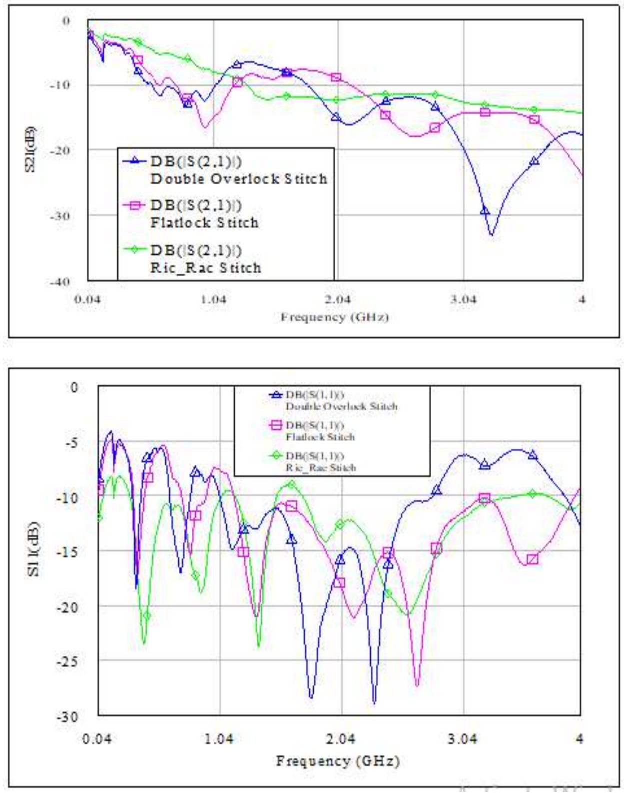

Fig. 2 Measured S-Parameters of stitched wearable transmission line with three different stitch types

The DC losses are observed to be more for Double Overlock stitch and Flatlock stitch, which have higher stitch densities and a more complex geometry compared to Ric-Rac stitch, for frequencies up to 1 GHz (see Fig. 2). The resistive losses are dominant at lower frequencies, while radiation losses are more dominant at higher frequencies. The DC losses are mainly influenced by the stitch geometry which is characterised by the hierarchical structure of the stitch and density, which is also characterised by the distance between individual stitches in a column or row. Fig. 3 further buttress the fact that the Ric-Rac stitch has fewer losses of the three for frequencies up to 1 GHz. However, beyond that up to 2.4 GHz and above that, it was observed that the Flatlock stitch and the Double Overlock stitch have fewer losses respectively. The choice of the best stitch to use will ultimately depend on the range of the frequency of transmission.

Table I DC resistance of the shield

Stitch Type	Measured DC Resistance of Shield (Ω)
Double Overlock stitch	30.3
Flatlock stitch	26.7
Ric-Rac stitch	22.4

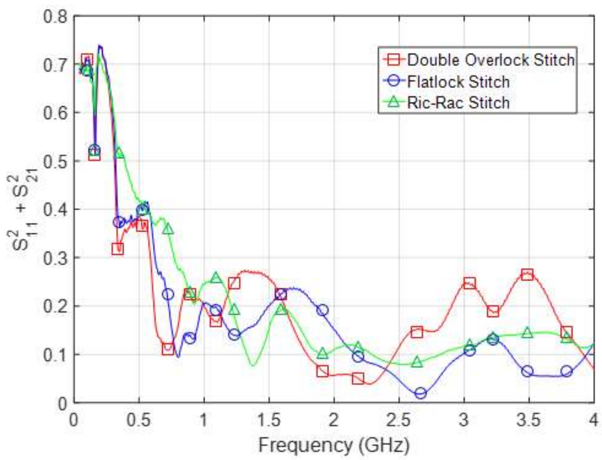

Fig. 3 Plot of $S_{11}^2 + S_{21}^2$ against frequency with three different stitch types

B. Impact of bending

The convenience, robustness, flexibility and operational reliability of the stitched transmission line for various bending positions are very important, as it is stitched or embedded into cloths and worn by humans. With the RG174 braided coaxial cable having a bend radius 10 times its diameter [13], the measured scattering parameter for the fabricated stitched transmission line for 90° and 180° curved bending conditions (see Fig. 4), with a bending radius of 75 mm is presented in Fig.7. Compared with the straight stitched transmission line, the results revealed that the structure maintains reflection coefficients S_{11} below $-10dB$ for both bending conditions of $90°$ *and* $180°$. The equivalent transmission coefficients S_{21} are better than $-10dB$ and $-12dB$ for both 90° and 180° respectively over the considered frequency band from $0.04 - 4GHz$. A much better S_{21} is observed with a curved angle of 180° for frequencies below 2.1 GHz, with the radiation loss increasing afterwards. Discontinuity such as a bend, periodic apertures [14], changes in current locations and not changes in current distribution are responsible for radiation losses from the stitched transmission line [15].

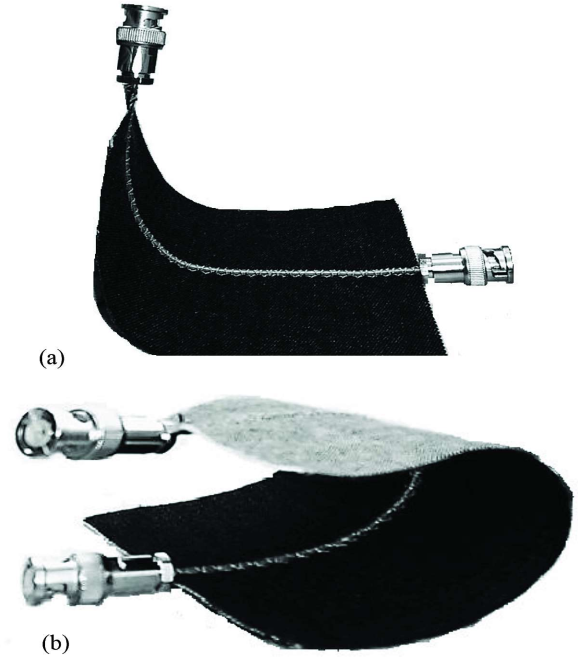

Fig. 4 Stitched transmission line with different curved bending angles at (a) 90º (b) 180º

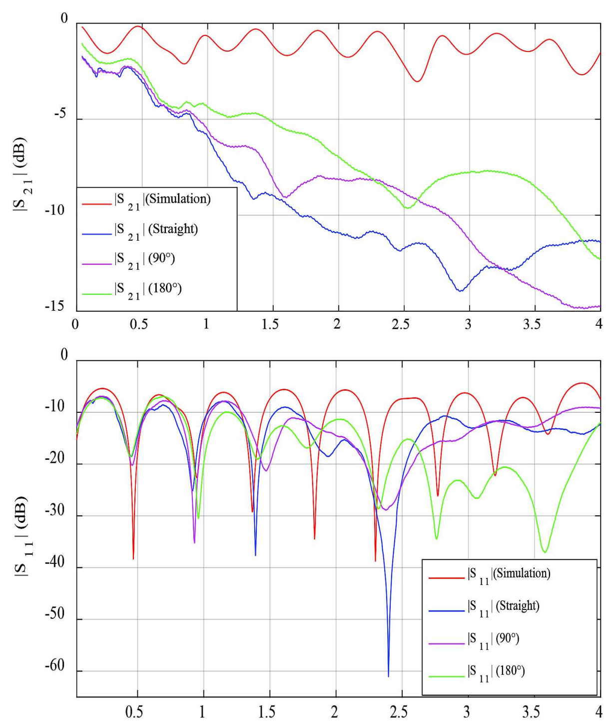

Fig. 5 Measured S-Parameters with two different bending conditions compared with straight fabricated and simulated stitched transmission lines

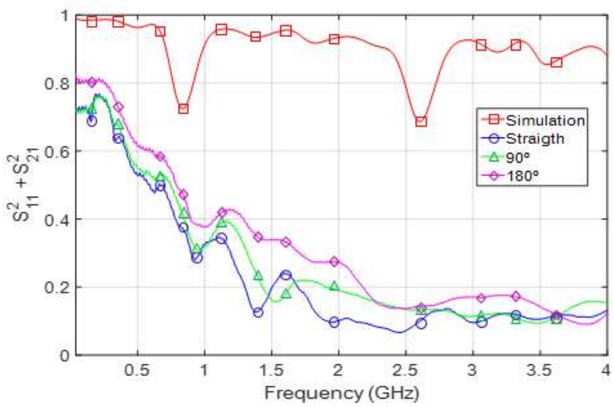

Fig. 6 Plot of $S_{11}^2 + S_{21}^2$ against frequency with two different bending conditions and a straight stitched line compared with a straight simulated line.

C. Sensitivity of Design to Manufacturing Tolerances

With the focus on the production of the stitched wearable transmission line for large-scale use or sale, the robustness of the design is being considered for deficiencies. Two features are being investigated using CST Microwave Studio Suite and measurements using an Anritsu $MS46524A$ $7\,GHz$ Vector Network Analyser; the sensitivity of the characteristic impedance with changes in cross-sectional dimensions of the stitched transmission line, and the transmission characteristics with different textile substrates were both considered.

First, it was observed from simulated results that the characteristic impedance of the stitched transmission line is sensitive to variations in cross-sectional dimensions when the outside diameter of the inner conductor, as well as the inside diameter of the stitched shield, are decreased or increased by $0.2mm$, as can be seen in Table 2. Hence, strict adherence to the dimensions of the stitched transmission line is necessary to maintain a relatively constant impedance during large-scale production.

Table II Simulated characteristic impedance of the stitched wearable transmission line for different cross-section dimensions

Outside diameter of Inner Conductor (mm)	Inside diameter of the shield (mm)	Referenced Characteristic Impedance (Ω)
0.08	1.12	101.72
0.48	1.52	45.52
0.88	1.92	30.84

Lastly, the stitched transmission line was fabricated with two different substrates Denim and Felt with relative permittivity $\varepsilon_r = 1.6$, loss tangent 0.05 and $\varepsilon_r = 1.38$, loss tangent 0.023 respectively. The measured scattering parameters are as shown in Fig. 8, with the results indicating both transmission lines maintained reflection coefficients S_{11} below $-10dB$. The corresponding transmission coefficients S_{21} are seen to be better than $-12dB$ for Denim and $-10dB$ for Felt. Results obtained indicated that the losses with the Denim material are more compared with the Felt which has a smaller loss tangent compared to the Denim. Nonetheless, these losses can be seen to be quite insignificant, especially at lower frequencies.

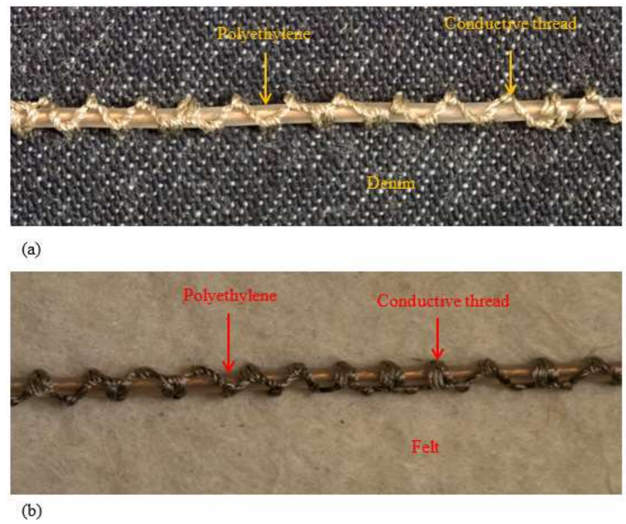

Fig. 7 Stitched transmission line with Denim and Felt used as substrates

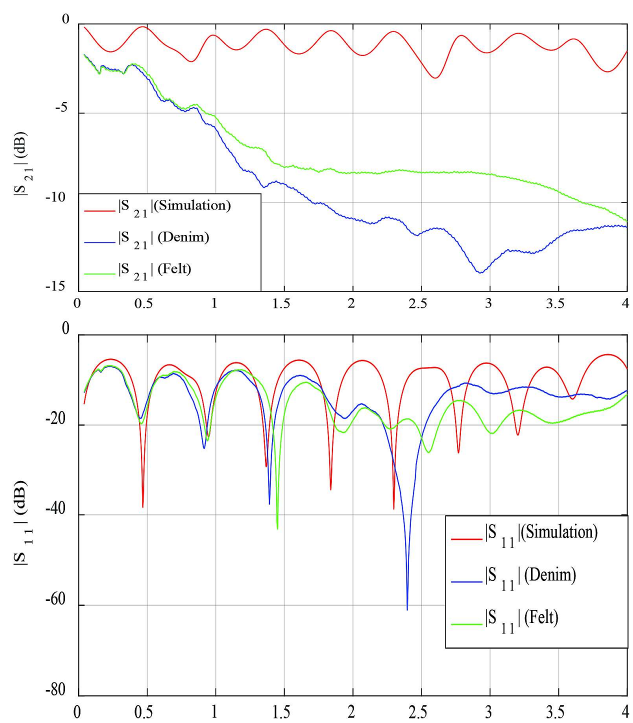

Fig. 8 Comparisons of S-Parameters between Denim and Felt used as substrates

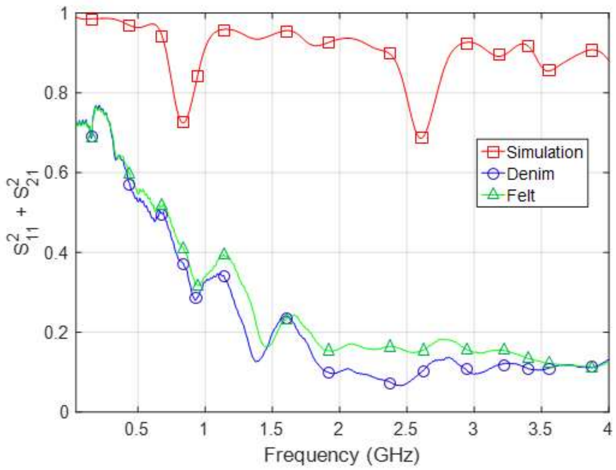

Fig. 9 Plot of $S_{11}^2 + S_{21}^2$ against frequency with Denim and Felt as substrates

III. CONCLUSION

A wearable stitched transmission line has been presented for broadband operations. Measurements on the wearable stitched transmission line for three different stitch patterns, two different curve bending angles and two substrates were considered, while the sensitivity of the line to different manufacturing tolerance was investigated using CST Microwave Studio Suite®. Resistive losses were seen to be more for Double Overlock and Flatlock stitch which has a higher stitch density compared to Ric-Rac stitch; the resistive losses were seen to be dominant at lower frequencies, while radiation losses were dominant at higher frequencies. Compared with the straight stitched transmission line, the stitched transmission lines with curved angles 90° and 180° were seen to maintain reflection coefficients S_{11} below $-10dB$. Conversely, a much better S_{21} was observed for curved bending angles of 180º compared to the straight stitched transmission line and the stitched transmission with a curved bending angle of 90º. The robustness of the design to manufacturing tolerances was demonstrated for different cross-sectional variations and substrates. Results obtained indicate that the impedance of the stitched transmission line is sensitive to variations in cross-sectional dimensions. With Denim and Felt used as substrates, an increased loss was observed with the Denim material compared to Felt, which has a smaller loss tangent compared to Denim. However, these losses can be seen to be fairly insignificant, especially at lower frequencies.

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