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High Performance Flexible Fabric Electronics for Megahertz Frequency Communications

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***Abstract*— This paper investigates the concept of using conductive threads for fabricating electronics including antennas at microwave frequencies. A number of commercial conductive threads have been considered. Digital embroidery has been used to create samples with different stitch types. This paper will provide a wide range of practical advice about fabricating samples using such materials. The threads have been examined by assessing their DC resistances at rest and while under physical strain and also the RF performance of transmission lines. The results show there is a wide range in performance between different conductive threads.**

I. Introduction

Wearable electronics and antennas have been a popular issue for several years. Consumers demand that new products become smaller, lighter and be wireless. While other electronic components are becoming smaller, it is not always easy to reduce the size of the antenna without compromising the electromagnetic performance; therefore the integration of the antenna into clothing would allow larger and higher performance antennas to be employed without adversely affecting the textile characteristics of clothing [2]. There are many applications for wearable antennas including; first responders, remote patient monitoring, military personnel, athlete tracking, pet and child tacking and main stream consumer and fashion products [3]-[7].

Other researchers have considered flexible antennas which are generally composed of flexible conductive patches of material [8]-[10]. The normal fabric antennas were soft and exhibit easy of bending. The effects of varied fabric antenna geometry (i.e. bending) on RF performance were discussed by Salonen et al [11].

In this work we aim to replace these continuous materials by using flexible conductive threads. Characteristics and RF performances of the electronic textiles have been discussed in [12] and [13]. The advantages of adopting conductive fibres will be explained below. The user will not feel any local stiffness or discomfort. Antenna and electronic designs can be incorporated into clothing using modern computerised embroidery machines – this has the potential to save considerable costs at the mass-manufacturing stage. It also removes the need for the antenna to be attached using glue or other adhesives and this will improve the long term durability of the product. Furthermore, there will be aesthetic advantages as the design will add to the cosmetic appeal rather than being a patch that needs to be hidden.

There are numerous challenges that must be overcome which include; sourcing the optimal materials; investigating the effect of different stitch types and stitch densities, assessing the most cost effective design, assessing the effects of mechanical deformation of the fabric antenna during its use and issues related to connectivity.

II. Embroidery Equipment at NTU

Nottingham Trent University (NTU) is currently developing fabric antenna systems using computerised embroidery machinery – see Fig. 1. The research is focused on the exploration of the embroidery technology to create fabric antenna systems by using conductive threads and analysing their performance during manufacture.

Although computerised embroidery systems are widely utilised within domestic and industrial environments, the machinery is not designed for use with conductive threads. When processing these non traditional materials the technical operative is met with a host of new challenges. Whilst the primary aim is to produce fabric antennas, establishing the mechanical and material limitations and overcoming these are key to the development of the research and the viability of all possible applications.

Fig.1. Barudan embroidery machine at NTU

Having an understanding of the computerised embroidery process is fundamental to overcoming the boundaries encountered by the threads. Antennas are created to specification using embroidery software. The software has a set of CAD/CAM tools providing fast, flexible and efficient productivity. Images can be scanned or imported for use as a backdrop for digitising as a guide or you can manually create the shapes you require. These designs are composed of what is known as ‘embroidery objects’. These objects can be manipulated independently. Each object has a set of defining characteristics such as colour, dimension and arrangement; however the most essential consideration is the stitch type. In relation to the outcome required digitising can be done manually in a point-and-stitch manner or through the use of fill stitches that automatically transform shapes into ‘embroidery objects’ filled with the desired stitch type.

There are a variety of different stitch types but the stitch formation predominantly utilised in our research is the lock stitch which is the most commonly used stitch type in embroidery. The stitch construction is created with a top thread and a looper thread. The top thread runs through a tension system, take-up lever and the eye of the needle. The looper thread is wound onto a bobbin which is inserted into a casing and used in the lower half on the machine. Due to the use of two individual threads which are interloped during the embroidery process lock stitching is durable and secure – see Fig. 2.

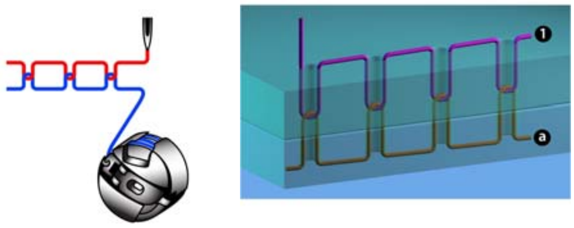

Fig.2. Lock stitch formation

The difficulties arise when using conductive threads. These have characteristics that make the embroidery process difficult. Our findings so far indicate hairy finer threads have to be processed at slower speeds in order to reduce thread breakages which may have an impact on the production cost. Stiff threads and fine metal wires cannot go through the tension devices, and cannot be wound onto the looper wheel or allow the looper wheel to sit securely within the casing. We also found coarser conductive threads and threads containing abundant filaments are also problematic as they have a tendency to become wrapped around the tension devices and may not fit through the eye of the needle. Generally, polymer based conductive threads are easy to process due to the familiarity shared with traditional embroidery threads.

Some embroidery stitch patterns and stitch densities have to be processed at lower tensions but this resulted in the top thread looping on the fabric surface or the looper thread being pulled through to the fabric front creating a ‘whip stitch’. This may be acceptable for creative aesthetic value; however it is not acceptable when striving to meet the stringent rules for uniforms, consistency within an antenna formation or durability of the stitches. High stitch density would lead to higher degree of thread breakage.

There are also other factors which could influence the embroidery process. A key factor is the surface characteristics of the conductive threads which will affect their frictional properties as the yarn. This can be resolved by oiling the contact points between the thread and the machine’s thread guides. Higher thread friction could also generate excess heat at each of the contact points at high machine speeds. We also observed needle damages mainly due to the coarse nature of the conductive threads utilised – see Fig. 3.

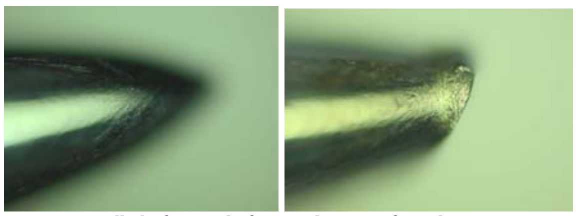

Fig.3.needle before and after production of conductive yarns

III. DC Resistance Measurements

Several conducting threads were sourced and the DC resistance of a 100mm long 3mm wide embroidered transmission line were measured and compared to the equivalent copper strip. There was a great variation in the range of resistances of the transmission lines created with different conductive threads. Many commercial conducting threads are designed for dissipation of electrostatic charges in fabrics and EMC applications such as shielding. These applications only require a low conductivity which stops electromagnetic waves from entering a region and a much high conductivity is required to allow currents to flow on the threads. The DC resistance varied from a fraction of an ohm to several thousand ohms.

Fig. 4 illustrates the variation of the resistances using different threads and stitch types. As a comparison, material No.0 is 100mm x 3mm copper strip with resistance equals to 0.1 ohms. The figure shows that Materials No.1 to No.14 have substantially different DC resistances that vary from 1 to 30000 ohms per unit length. The vertical points for each material represent different stitch types and spacings between each stitch. The figure shows that the choice of thread is crucial to obtain a reasonable conductivity and that furthermore the choice of stitching can be optimised.

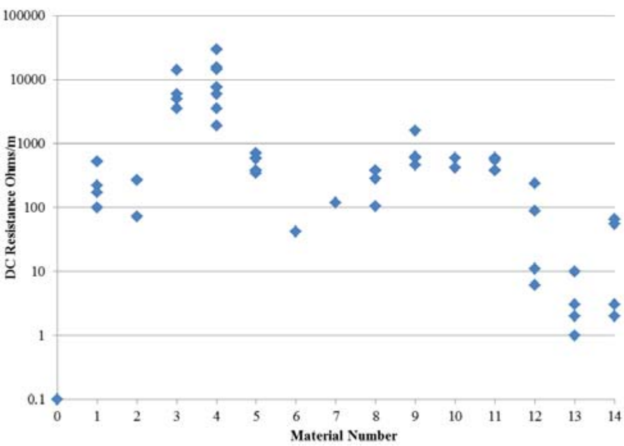

Fig.4. DC resistance of threads material and types of stiches

DC RESISTANCES OF THREADS

IV. DC PERFORMANCE OF STRETCHING

As the samples were stretched, the DC resistance increased linearly – see Fig. 5. The resistance increase was due to the length of the sample increasing. When the tension was removed the threads returned to their approximate resting resistances.

To investigate the long-term durability of the conductive threads, they were subjected to cyclic testing on a Zwick Tensile tester according to ISO2062:2009 standard and the results of four samples are given in Fig 6. In three samples the resting resistance increased each time the material was stretched. This may be due to the formation of micro cracks in the conductive surface of the threads. The fourth sample was relatively robust to repetitive stretching.

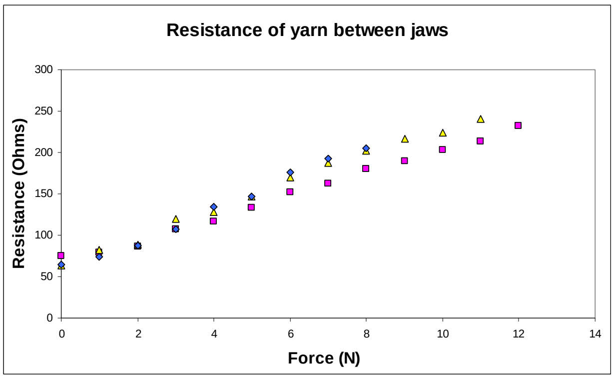

Fig. 5. DC resistance as a function of stretching force

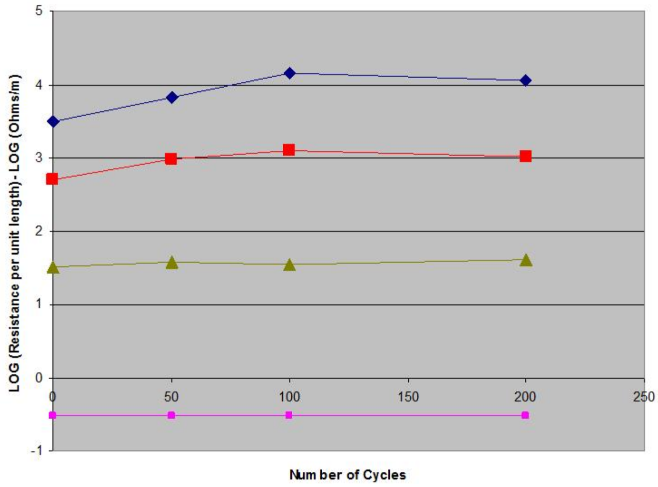

Fig. 6. DC resistance of four conductive threads as a function repeated stretching

V. RF TRANSMISSION LINE MEASUREMENTS

The conductive threads were placed in a measurement jig to form a transmission line (Tx) above an FR4 substrate - see Fig. 7. The jig was designed to enhance the repeatability.

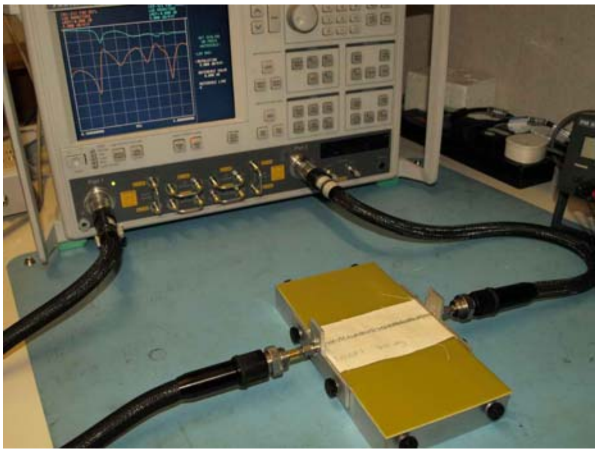

Fig. 7. Conductive thread transmission line in jig above FR4 substrate

The S11 results were very sensitive to the flatness of the sample. However, the S21 exhibited a more repeatable result. The power transmitted to port 2 decreased with frequency, this was also found to be the case with a rigid copper line used as a comparison where the S21 at 6GHz was -3.5dB. The majority of the threads (especially those with a high resistance) had very poor S21 results and would not be suitable for wearable electronic applications. Generally, the DC resistance measurements gave a reasonable indication to the performance of the Tx line. For space limitations, only results with material 12 are included see Fig. 8 and 9. Both the DC resistance and S21 were improved when the stitches were parallel to the Tx line as opposed to perpendicular to them. When the spacing between the stitches was reduced (high stitch density) the conductivity and S21 improved.

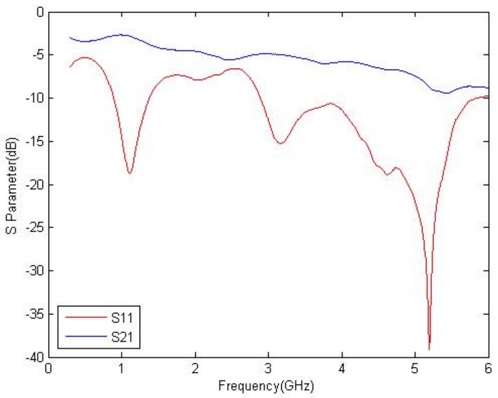

Fig. 8. S11 and S21 of Material No. 12. Stitches are perpendicular to Tx line

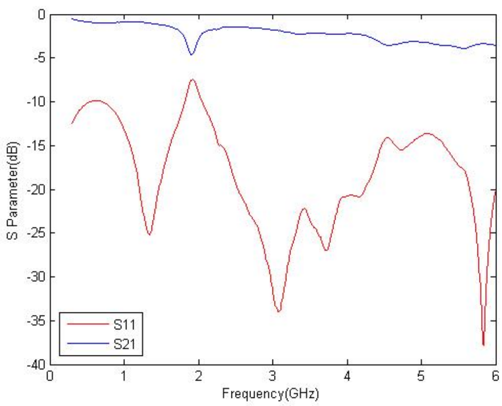

Fig. 9. S11 and S21 of Material No. 12. Stitches are parallel to Tx line

VI. Conclusions

This paper has investigated the feasibility of using digital embroidery and conducting threads to create Tx lines and potentially antennas. There is a wide range of performance between different threads. The RF Tx measurements corroborated the DC measurements which were found to be a reasonable first estimate of RF performance. The conductivity could be improved by stitching along the length of (parallel to) the Tx lines and also by using a higher density of stitching. These results suggest however, that the current has a preference to flow along a single thread rather than traverse from thread to thread. Future research will investigate if the conduction between threads can be improved by pre-processing the threads. The next stage will be to design, fabricate and measure the performance of patch antennas however, it is important to understand the conduction paths and practical implications of geometrically simple one dimensional Tx lines before we can proceed to more complex two dimensional structures.

Acknowledgment

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