**ICAST2013: 24th International Conference on Adaptive Structures and Technologies
October 7-9, 2013, Aruba**

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Knitted Electromagnetic Textile Surfaces

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Abstract

We report a commercially attractive approach to manufacturing conducting textiles which is based on computerised flat-bed knitting technology using conducting yarns. We examine how flat-bed knitting can be used to manufacture large area samples of functional electromagnetic structures such as frequency selective surfaces (FSS). In addition we show how the knitting process can be adapted to allow the integration of conducting vias into a 3-D knitted spacer structure to form an electromagnetic high impedance surface (HIS).

1. INTRODUCTION

Passive and active electromagnetic components are usually manufactured from sheet metal or using lithographic techniques for printed circuit boards. However, over the past decade new materials and manufacturing techniques have been developed that permit the creation of electromagnetic structures, such as antennas and transmission-lines using conducting textiles [1,2].

Electromagnetic structures based on conducting textiles have certain advantages over equivalent structures constructed from conventional materials. Textile structures offer advantages such as light weight, flexibility, softness, and high-strength-to-weight ratios. A unique advantage of electromagnetic structures based on textiles is that they can be integrated into clothing to provide functions such as on-body and off-body communications. Functional conducting textiles may also be integrated into composite structures where they provide a light weight and flexible alternative to conventional structures based on circuit-board technology. Advanced textile manufacturing techniques, such as computerised flat-bed knitting, can also be used to create a variety of 3-D and conformal structures to prescribed geometries [3]

Much of the previously published work on conducting textiles at RF frequencies considers structures constructed from combinations of traditional (non-conducting textiles) with commercially available conducting textiles, such as Zelt to form hybrid structures [4]. The disadvantage of this approach, particularly when applied to complex structures such as Frequency selective surfaces (FSS), is that the conducting textile needs to be “cut-to- shape” and then attached to the non-conducting textile substrate using adhesive or some other means. This is obviously a time consuming process that is not amenable to mass manufacturing and alternatives are sought. One alternative technique that has been investigated is the use of computerised embroidery in which a conducting yarn is used to embroider conducting features, such as a patch antenna, onto a non-conducting textile base, or substrate, layer [5]. Although, computerised embroidery is a step forward with regard to efficient manufacturing, it is still a relatively slow process and the conducting surfaces created often suffer from poor continuous conductivity.

In this contribution we investigate the use of another textile manufacturing process – knitting – to fabricate conducting textile structures. Knitting is a very old and traditional process that has been revolutionised over the past few decades to allow the efficient, commercial manufacture of a wide variety of textile products using advanced, large-scale, flat-bed knitting machines under computer control and driven by advanced CAD software interfaces [6]. The computerised flat-bed knitting process can easily be used to manufacture of large area textile structures with repeated patterns and is therefore ideally suited to the manufacture of periodic structures such as FSS and meta-material surfaces. FSS typically consist of a grid of periodically arranged conducting patches on a dielectric substrate. At microwave frequencies, FSS can act as transmission or reflection filter elements and can be configured for low-pass, high-pass, band-pass or band-stop operation. Applications of FSS include dichroic sub reflectors for multi-band reflector antennas, radomes, electromagnetic shielding, and as components in radar absorbers and electromagnetic bangap (EBG) structures.

2. TEXTILE MANUFACTURING TECHNOLOGY

Textiles have a major role to play in strategically important areas and offer many advantages over traditional materials such as support for technologically advanced products, flexibility, softness, and high-strength-to-weight ratios. The highly developed mass production techniques that characterise the textile sector facilitate the path for the development of new products and their cost effective manufacture for aerospace applications. In particular modern computerised flat-bed knitting technology is one of the most technologically advanced textile production methods.

Flat-bed knitting machines are precisely engineered with two primary needle beds of hardened steel that are arranged in an inverted V-form. In the needle beds, latch or compound needles are placed inside needle tricks. This arrangement facilitates the movement of needles individually and linearly during the knitting process. It is this unique combination of needle tricks and latch needles that has paved the way for the creation of complex 3D knitted structures on these machines.

On current machines the technology used to select needles is based on electro-mechanical principles and microprocessors control. This has resulted in the development of CAD/CAM systems for generating pattern information for needle selection and storing it on workstations. The development of holding-down sinkers has complemented the existing methods of knitted loop control (yarn loop in the needle hook), including fabric take-down and presser foot technology. These developments allowed for the creation of previously un-knittable structures and shapes. On a modern computerised flat-bed knitting machine needles of the two needle beds can also be selected individually to form stitches, tuck loops and floats, which are the three primary elements of knitted structures. The technology for transferring knitted loops between the needle beds has also been perfected.

2.1 **Conductive knitted spacer structures**

A knitted spacer fabric (3D textile structure) is a double layer fabric with both of its layers separated by a defined distance due to the use of a stiff spacer yarn, usually a monofilament, knitted in between the two outer layers. The gap between the two outer layers of the fabric is defined by the stiffness of the spacer yarn and its length between the two layers (Figure 1).

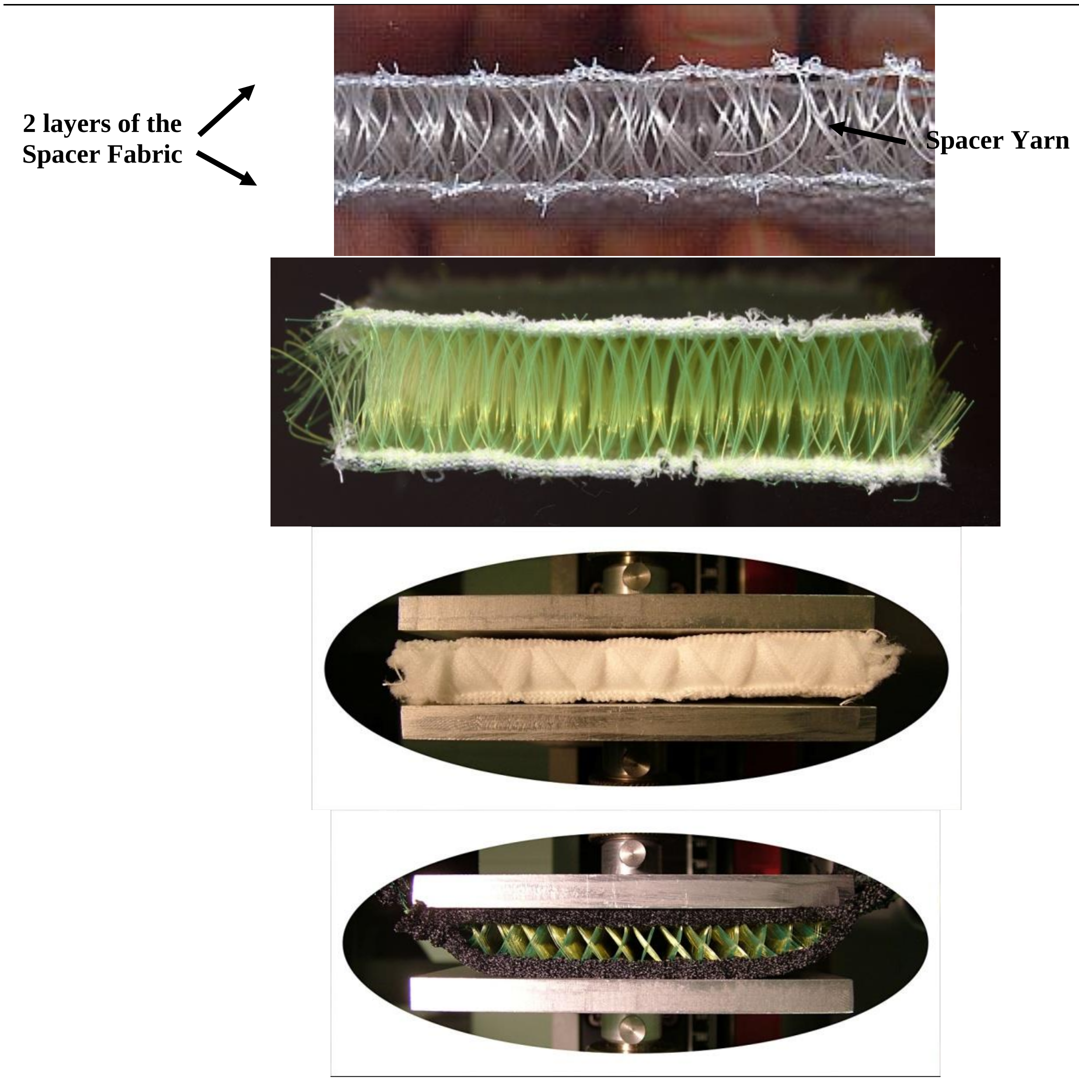

Figure 1. Examples of knitted spacer fabric

During the last few years Nottingham Trent University (NTU) has developed the technique of producing spacer structures on computerised flat-bed knitting machines. The spacer yarn is anchored into the fabric layers using the different combinations of the binding elements (stitches, tuck loops and floats). Structural modifications are also possible using loop transfer and racking techniques**.**

3. SINGLE LAYER KNITTED FSS

Initially NTU investigated techniques for manufacturing single layer patterned FSS textiles using a combination of non-conducting and conducting yarns to knit textiles with an insulating base-layer and a conducting surface pattern. As an example, Fig. 2 shows samples of two types of textiles: one containing a conducting diamond grid surface pattern and the second containing a triangular conducting patch pattern.

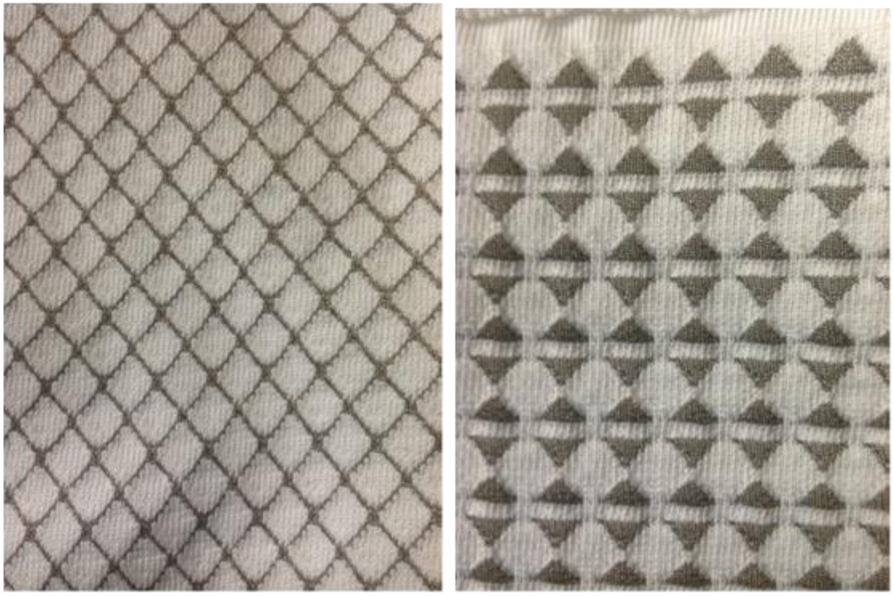

Figure 2a and 2b. Examples of single layer knitted textiles with a conducting mesh pattern

The single layer structures, knitted on one needle bed, were developed on a Shima Seiki SWG 15g 091. The textiles were knitted using both silver and polyester yarns. The silver yarn provided the conductive grid and the high bulk polyester the base structure. When considering the grid mesh design, the grid would normally consist of vertical and horizontal elements which would then intersect at predetermined points along the horizontal and vertical axes. However, to manufacture a square grid would be difficult and could only be realised by a knitting method called intarsia. This is when multiply yarn carriers, which deliver the yarn, are positioned across the length of the fabric being produced to effectively become the vertical elements of the grid. The major limitation of this method is that it is limited by the number of carriers available on a single machine, with dedicated intarsia machines having up to 45 carriers. This technique would therefore become quite limiting in terms of fabric widths that could be produced and also because of challenging and complicated nature of producing intarsia structures.

3.1 Measurements

The knitted textile FSS are inherently flexible structures, but to characterise them they were arranged and measured as flat planar surfaces. To facilitate the measurements the textile FSS were placed over a 30cm by 30cm square, low-loss, polystyrene slab (3cm deep) and gently stretched in both linear dimensions to equalise any distortion and to produce a flat surface with a symmetrical surface pattern. The normal incidence, free-space reflectivity (S11) characteristics of the textile FSS were measured in a fully calibrated NRL arch using an automated measurement system employing an Agilent 8510B Vector Network Analyser. The reference, calibration standard was a flat aluminium plate of equivalent size (30cm by 30cm). The measurements were performed in a dedicated anechoic chamber and a standard time-domain gating procedure was used to remove any spurious returns. Fig. 3 shows the reflectivity response of the single layer knitted textile with the conducting diamond grid pattern. The response is typical of an inductive FSS and is strongly reflective at lower frequencies and non-reflecting (indicating transmission) at higher frequencies. Fig. 4 shows the reflectivity response of the single layer knitted textile with the small triangular conducting patch pattern. The response is typical of a capacitive FSS and is transmissive at lower frequencies and reflecting at higher frequencies.

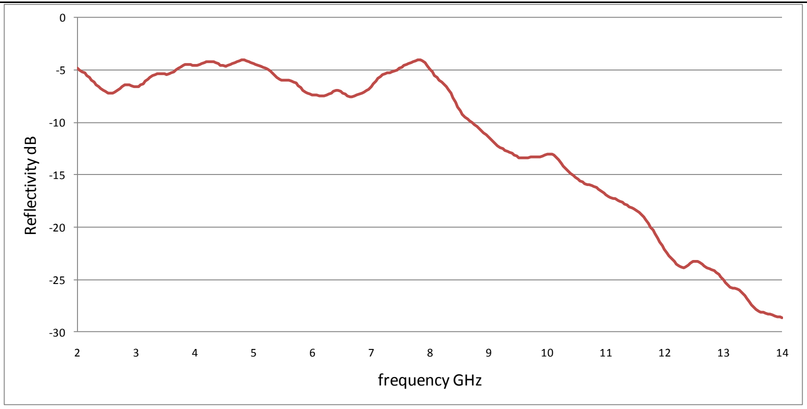

Figure 3. Reflectivity response of the conducting grid knitted FSS measured at normal incidence.

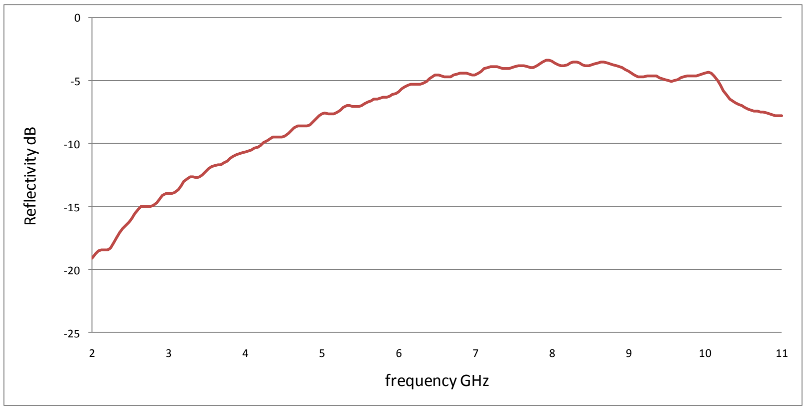

Figure 4. Reflectivity response of the conducting patch knitted FSS measured at normal incidence.

4. DOUBLE LAYER KNITTED FSS

The double layer, 3-D knit structure, knitted on two needle beds, was developed on a Shima Seiki SWG 15g 091. The textiles were knitted using both silver and polyester yarns. The silver yarn provided the conductive triangular patches and the high bulk polyester the base structure and spacer material. The technically challenging and more complicated double layer structure also included vias connecting the conductive ground plate back layer to the triangular patches arranged within a base layer of high bulk polyester. Spacer yarns are normally monofilament and provide a semi rigid separation layer between a double layer structure however these monofilament spacers have many open spaces through which the conductive layers can connect . To minimise this risk and to provide a more robust isolation layer it was decided to use high bulk polyester which would fill the space between layers. The partial knit techniques used in the previous knit sample were again utilised to produce the triangular conductive patches. An example of a double layer FSS (also known as a high impedance surface (HIS)) structure containing vias is shown in Figure 5.

4.1 Measurements

To characterise the properties of the knitted textile HIS a free-pace reflectivity phase measurement was made in an anechoic chamber using a fully calibrated NRL arch system employing an Agilent 8510B Vector

Network Analyser. The reference calibration standard was a flat aluminium plate of equivalent size to that of the HIS (36cm by 36cm). The measurement was made for illumination at normal incidence and a standard time-domain gating procedure was used to remove any spurious returns. The free-space reflection phase measured from the knitted HIS for normally incident illumination is shown in Figure 6. The surface exhibits the classic band-gap reflection phase response with zero phase reversal at approximately 4.7GHz and with a +/-90^o band-gap of approximately 750MHz

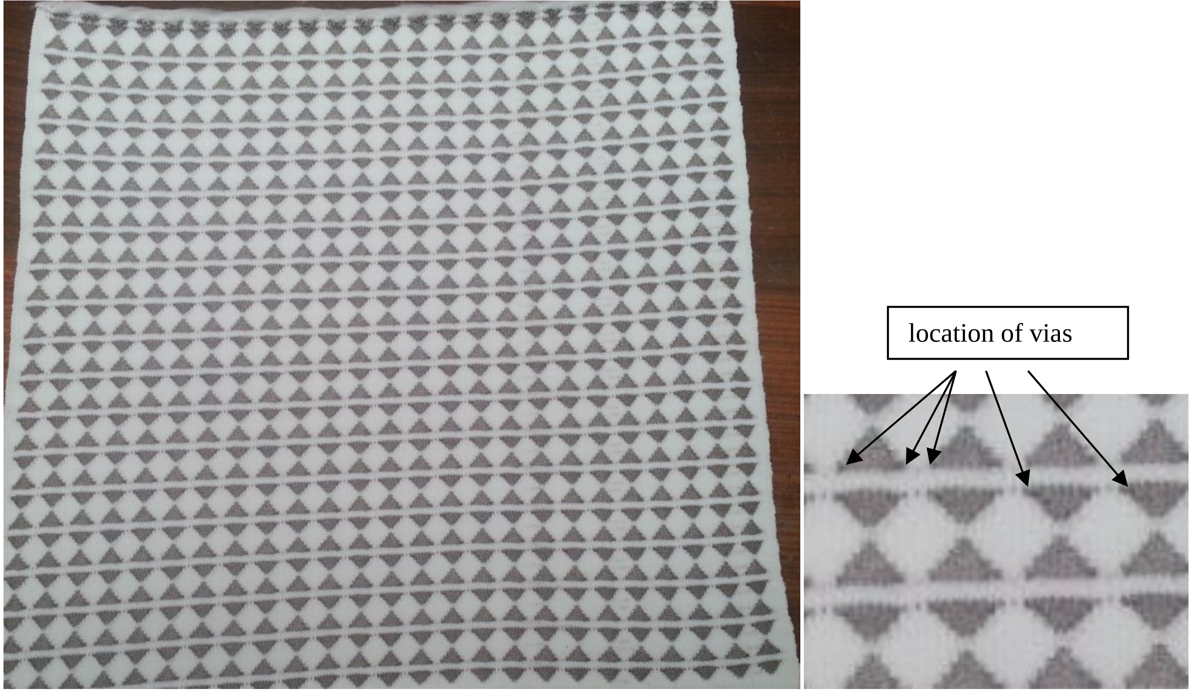

Figure 5. Knitted triangular patch , 3-D sandwich structure with integrated knitted conducting back-plane. Overall sample size approximately 30mm by 30mm. Thickness approximately 3.5mm. This sample contains conducting vias located at the base corners of each triangular patch

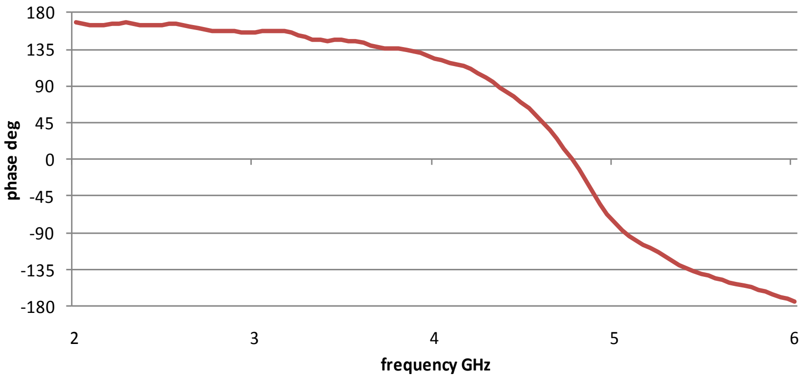

Figure 6. Measured reflection phase response of the knitted HIS at normal incidence.

5. CONCLUSIONS

Several experimental frequency selective surfaces, knitted from conducting yarn on a computerised flat-bed knitting machine have been presented. Two knitted FSS were configured for low-pass and high-pass operation respectively. Measured data shows that the knitted textile FSS exhibit the fundamental characteristics of capacitive and inductive FSS designs and that the HIS exhibits a band-gap reflection phase response. No simulated data is presented in this paper as, of yet, we do not have any accurate models to describe the highly complex interactions and contact processes between the individual conducting yarns in the knitted structure (particularly at microwave frequencies) and this is an area for future research. Other microwave components have been fabricated using the flat-bed knitting process, including 3-D waveguide structures, and these will be reported at a later date.

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