Knitted, textile, high impedance surface with integrated conducting vias

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An experimental, microwave high impedance surface (HIS) manufactured from a combination of both conducting and insulating yarns using commercial, computerised flat-bed knitting machines is presented. The HIS consists of a knitted, conducting ground plane, a polyester spacer layer and a knitted, conducting patterned top surface. The structure also contains vias that link the conducting elements of the top layer to the ground plane. The entire structure (including the vias) is knitted in one continuous process that is both low cost and highly efficient in terms of manufacturing time. Measurements of the surface wave transmission properties of the knitted, textile HIS are made and data are presented that show that the HIS prevents surface wave transmission over a band of frequencies between 4 and 5GHz.

Introduction: Passive electromagnetic structures and components are often manufactured using conventional printed circuit board techniques. However, over the past decade new materials and manufacturing techniques have been developed that permit the creation of electromagnetic structures, such as antennas, frequency selective surfaces (FSSs) and transmission lines using conducting textiles [1–4].

Electromagnetic structures based on conducting textiles have certain advantages over equivalent structures constructed from conventional materials. Textile structures offer advantages such as low 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 3D 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 [5]. The disadvantage of this approach, particularly when applied to complex structures such as FSSs, 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. In this Letter we investigate the use of computerised flat-bed knitting to manufacture a specific type of conducting textile electromagnetic structure – a high impedance surface (HIS).

A typical HIS design consists of a two-dimensional planar grid of periodically arranged conducting patches separated from a conducting ground plane by a dielectric substrate material. Additionally, in many HIS designs the conducting patches on the top surface are electrically connected to the ground plane by conducting pins, or vias. This type of HIS design is particularly useful for suppressing electromagnetic surface, or creeping wave, propagation and is exemplified by the classic Sievenpiper ‘mushroom’ HIS [6]. However, the manufacture of a mushroom-type HIS employing conducting vias is a non-trivial process and typically requires many holes to be drilled through the HIS structure and conducting pins to be inserted and soldered to form the electrical connections between the patch elements of the top layer and the ground plane. It is in the creation of conducting vias between the conducting surface elements and the ground plane of a HIS that the proposed manufacturing process based on flat-bed knitting excels. In particular, the flat-bed knitting process is used to create such a structure in one continuous process which is highly efficient in terms of manufacturing cost and time.

Variations of the HIS are also known as artificial magnetic conductors (AMCs) and electromagnetic bandgap (EBG) structures and applications include: AMC ground planes which permit the design of efficient low-profile planar antennas that can be placed in close contact to electrically conducting surfaces; the suppression of surface wave transmission to reduce inter-element coupling in array antennas, and the use of EBGs to design various microwave components and structures. In this Letter we report experimental details of a unique knitted HIS which incorporates integrated conducting vias and present results of reflectivity phase and surface wave transmission measurements.

Knitting process: Flat-bed knitting machines consist of two needle beds positioned opposite to each other and set at an angle of between 90° to 104° giving the appearance of an inverted V. Each bed has a set number of knitting needles which actively form the knitted loops with yarn that is introduced during the knitting process. In flat-bed knitting, a single feed of yarn can be progressively fed from one needle to the next in a continuous process which binds the knit loops together, thus creating the fabric [7]. During this knitting process it is possible to selectively choose which needles are knitted and also to control the choice of fibre used. Of all methods of knit manufacturing computerised flat-bed knitting is the most versatile with the potential to develop complex 3D structures which can have embedded, at predetermined areas, yarns and structures with different core properties and functionalities [7]. Flat-bed knitting is a proven industrial technology capable of producing complex fabrics over 2 metres wide in a continuous roll.

Experimental knitted HIS: The HIS structure was knitted as a spacer material (Fig. 1) with a conductive ground plane using a Shima Seiki SWG091N (gauge 15) computerised flat-bed knitting machine. The non-conducting spacer yarn was polyester and the conducting yarn (≃4Ωcm−1) was formed by embedding silver nanoparticles on the surface of a 235 Denier 34 filament Polyamide 6.6 yarn [8]. To create the conductive patches on the front of the structure the non-conductive polyester was selectively knitted to create the negative shape of the conductive patch which was then filled by using the conductive yarn from the back (ground plane) and knitting it on the front (non-conductive layer). By moving the yarn from the back layer to the front a via was created connecting the front conductive patches to the ground plane layer (Fig. 2).

Fig. 1 *Example 3D spacer fabric with two knit layers interconnected by spacer material*

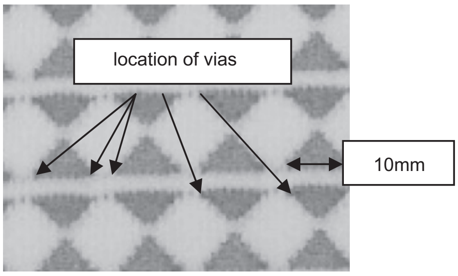

Fig. 2 *Top surface of conducting textile HIS*

White area is knitted from polyester yarn, dark regions are knitted from conducting yarn. Integrated vias connect top conducting surface to ground plane at base corners of triangular patches

Measurements: To characterise the properties of the knitted textile HIS, two separate types of measurement were made: a free-pace reflectivity phase measurement and a surface wave propagation measurement. The free-space 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 (36 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 surface wave propagation measurements were made using a test rig based on the system described in [6]. Surface waves are launched and received using broadband conical monopole antennas (TM mode). The test rig was used in conjunction with an Agilent E5071 network analyser. A ‘thru’ (S21) calibration was made using the uncovered, conducting surface (aluminium) of the test rig as the reference standard. The conducting surface of the test rig was then replaced by the knitted HIS surface and the resulting S21 data were recorded. Both the reflection phase and the surface wave propagation measurements were made over a frequency band between 2 and 6GHz

Results: The free-space reflection phase measured from the knitted HIS for normally incident illumination is shown in Fig. 3. The surface exhibits the classic bandgap reflection phase response with zero phase reversal at approximately 4.7GHz and with a +/−90^o bandgap of approximately 750MHz. The measured surface wave propagation properties of the textile HIS are shown in Fig. 4 where it is observed that the HIS shows a distinct, sharp propagation cutoff at around 4GHz and a bandgap between approximately 4 and 5GHz.

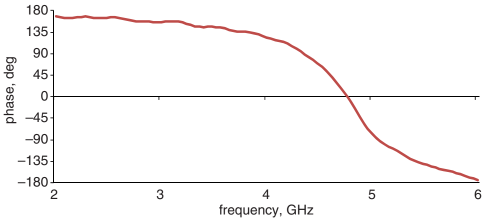

Fig. 3 *Measured reflection phase response of knitted HIS at normal incidence*

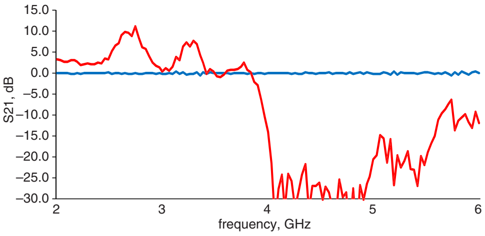

Fig. 4 *Measured S21 surface propagation (TM mode) response of knitted HIS and reference conducting surface*

Conclusions: An experimental, textile HIS knitted from conducting yarns on a computerised flat-bed knitting machine has been presented. The textile HIS is a variant of the classic Sievenpiper mushroom design and contains conducting vias linking the conducting elements of the surface layer to the ground plane. The entire HIS structure was knitted in one continuous and efficient manufacturing process. Experimental data from free-space phase reflectivity and surface wave propagation measurements have been presented to show that the knitted HIS exhibits a bandgap response between 4 and 5GHz. No simulated data are presented in this Letter as, currently, we do not have accurate models to describe the highly complex electrical interactions and contact processes between the individual conducting yarns in the knitted structure. This topic is an area of ongoing research which will be reported at a later date.

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One or more of the Figures in this Letter are available in colour online.

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