OPEN ACCESS

2nd International Electronic Conference on Sensors and Applications
15–30 November 2015

www.mdpi.com/journal/sensors

Development of Substrate Integrated Waveguides with Textile Materials by Manual Manufacturing Techniques

Catarina Lopes [1,3], Caroline Loss [1,2,3], Rita Salvado [1], Pedro Pinho [3, 4], Sam Agneeessens [5] and Hendrik Rogier [5]*

[1] University of Beira Interior, UMTP/FibEnTech, [2] CAPES, [3] Instituto de Telecomunicações, [4] Engineering Institute of Lisbon (ISEL), [5] Ghent University

Contents

Introduction

When developing smart textile systems for wearable applications it is necessary to construct structures that are conformable to the body shape, and comfortably and unobtrusively integrated[1].

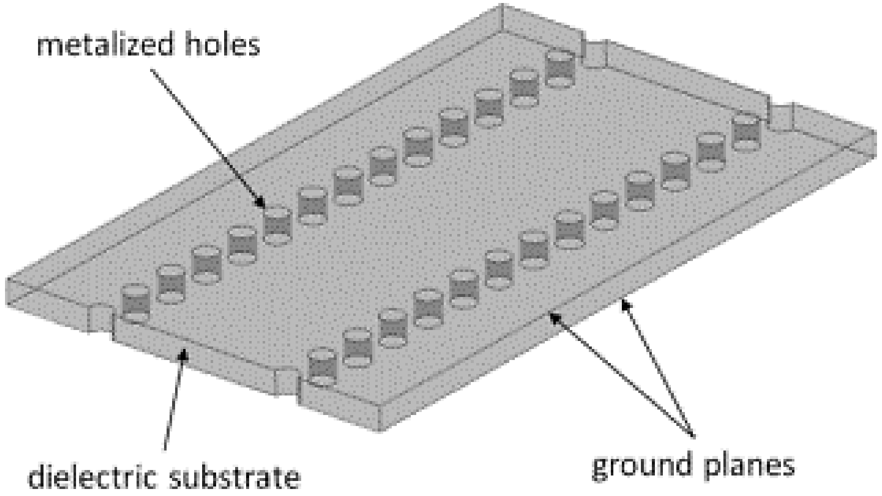
In this context of wearables, the substrate integrated waveguide (SIW) technology is suitable for implementation into clothing and wearable textile systems, as this topology improves the isolation of the electromagnetic fields from its environment, being mainly from the human body[1-3,5].

[1] R. Moro, *et al.*, *IEEE Trans. Microw. Theory Tech.*, vol. 63, no. 2, pp. 422–432, 2015., [2] S. Agneessens and H. Rogier, *IEEE Trans. Antennas Propag.*, vol. 62, no. 5, pp. 2374–2381, 2014., [3] S. Agneessens, *et al.*, *Electron. Lett.*, vol. 48, no. 16, pp. 985–987, Aug. 2012., [5] S. Lemey, *et al.*, *IEEE Antennas Wirel. Propag. Lett.*, vol. 13, pp. 269–272, 2014.

Introduction

In general, the SIW technology implements two metallized rows of conducting cylinders or slots embedded into the dielectric. These vias connect two metal parallel plates [5-8].

Figure 1. Geometry of a straight substrate integrated waveguide (SIW) interconnect[6].



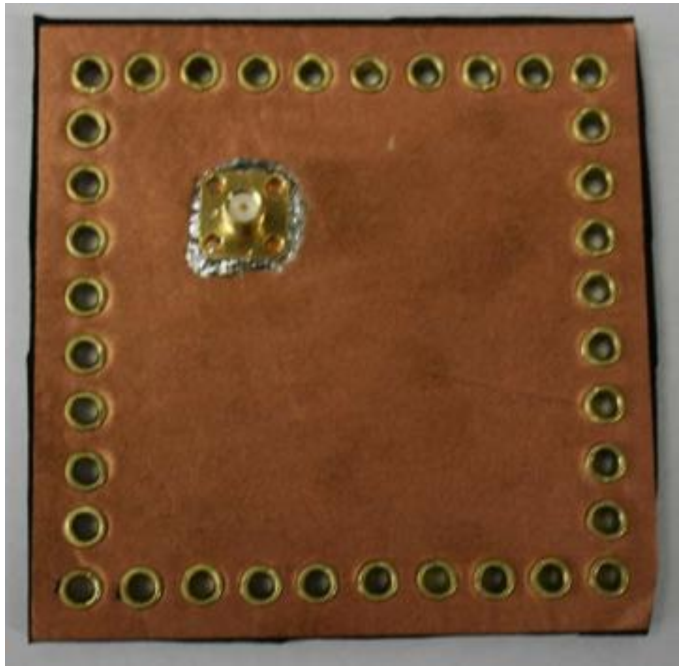
[5] S. Lemey, *et al*., *IEEE Antennas Wirel. Propag. Lett.*, vol. 13, pp. 269–272, 2014., [6] M. Bozzi, *Asia Pacific Microw. Conf. Proc.*, vol. 4, no. 7, pp. 788–790, Dec. 2012., [7] M. Bozzi, *et al*., *IET Microwaves, Antennas Propag.*, vol. 5, no. 8, p. 909, 2011., [8] M. Bozzi, *et al*., *Radioengineering*, vol. 18, no. 2, pp. 201–209, 2009.

Introduction

Currently, the SIW technology has been implemented in flexible materials, using mainly foam as a dielectric substrate and conductive copper fabrics laminated to this substrate to create the parallel plates [1-3,5].

In these works, the cavities were constructed using metallic eyelets with a diameter of 4 mm.

Figure 2. Example of SIW structure in flexible materials[1]



[1] R. Moro, *et al.*, *IEEE Trans. Microw. Theory Tech.*, vol. 63, no. 2, pp. 422–432, 2015., [2] S. Agneessens and H. Rogier, *IEEE Trans. Antennas Propag.*, vol. 62, no. 5, pp. 2374–2381, 2014., [3] S. Agneessens, *et al.*, *Electron. Lett.*, vol. 48, no. 16, pp. 985–987, Aug. 2012., [5] S. Lemey, *et al.*, *IEEE Antennas Wirel. Propag. Lett.*, vol. 13, pp. 269–272, 2014.

Introduction

SIW is thus a cost-effective solution for millimeter and microwave components, enabling the fabrication of passive components, active circuits and antennas for wireless systems embedded into flexible materials, including textiles.

Therefore, this technology serves as a platform for wearable applications, enabling the integration of different components in the same substrate, paving the way to a system-on-textile, similar to the concept of system-on-substrate[6-8].

[6] M. Bozzi, *Asia Pacific Microw. Conf. Proc.*, vol. 4, no. 7, pp. 788–790, Dec. 2012., [7] M. Bozzi, *et al*., *IET Microwaves, Antennas Propag.*, vol. 5, no. 8, p. 909, 2011., [8] M. Bozzi, *et al*., *Radioengineering*, vol. 18, no. 2, pp. 201–209, 2009.

Experimental Study

MATERIALS AND TESTED PROTOTYPES

Materials

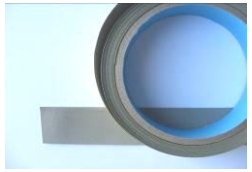
For all developed MTL prototypes, a protective closed-cell expanded-rubber foam [1] was applied as dielectric substrate, for the substrate of the textile antenna a spacer fabric [2] was used.

For the conductive layers a pure copper polyester conductive fabric[3], was glued to the substrate with a thermal adhesive interlining sheet.

The conductive textile materials that were used to fabricate the shorting vias are presented in the following table.

[1] http://www.javaux.com | [2] http://www.eschler.com/english/home/home.html | [4] http://www.lessemf.com/

Table 1. Conductive textile materials used to fabricate the shorting vias in the prototypes

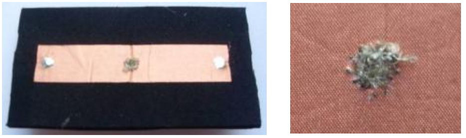
Conductive Materials		Characteristics	Electrical Resistance	Application in prototypes:
YARN 1		High conductivity silver plated nylon, 275 dtex (Ref.: PW018A)[4]	<300 Ω/m	Sample 2 and 5: embroidered circle with and without cavity. All three prototypes of antennas.
YARN 2		Conductive silver plated nylon, 293 dtex (Ref.PW018)[4]	<2 kΩ/m,	Sample 3: embroidered circle with a cavity.
YARN 3		Stainless steel conductive yarn (Ref.ADA-641)[5]	10 Ω/m,	Sample 7: embroidered circle with a cavity.
KNITTED STRING		Tubular jersey [6] with 11 columns, made of Yarn 1 together with polyester yarn	________________	Sample 6: introduced in the circular cavity and sewn to the conductive elements.
FABRIC		Highly conductive fabric tape, 0,5 mm thick, made with Nickel, Copper and Cobalt coated nylon ripstop fabric with adhesive[3]	<0.1 Ω/sq	Sample 4: glued inside the circular cavity and over the conductive elements.

[3] http://www.lessemf.com/ | [4] http://www.plugandwear.com/default.asp?mod=home | [5] http://www.inmotion.pt/store/e-textiles | [6] http://www.logik.pt/site/index.php/pt/loja

Prototypes of Microstrip Transmission Lines (MTL)

Table 2 presents an overview of the several prototypes of MTL with a shorting via, that were fabricated with the materials previously mentioned.

Table 2. Prototypes of Microstrip Transmission Lines and detail of the shorting via.

Sample 1 	Sample 2 	Sample 3 	Sample 4 
Sample 5 	Sample 6 	Sample 7 	

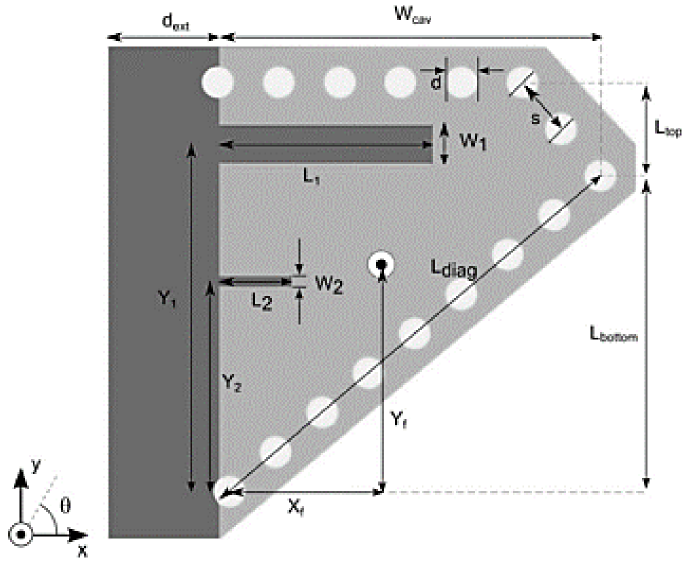
Sample 1 is a reference, as it is based on the already validated technique to produce the SIWs with metallic eyelets.

Antenna implemented in the new SIW technology

Based in the experience obtained in developing the MTLs, we relied on Yarn 1 and embroidering as adopted material and technology, respectively, to produce the antennas in SIW technology.

As antenna topology, we opted for the half-diamond antenna operating in the 2.45 GHz Industrial, Scientific and Medical band, based on the design presented in [2].

Figure 3. Layout of the proposed HMSIW dual-band textile antenna[2]



[2] S. Agneessens and H. Rogier, *IEEE Trans. Antennas Propag.*, vol. 62, no. 5, pp. 2374–2381, 2014

Antenna implemented in the new SIW technology

Three antenna prototypes were fabricated with different types of embroidered SIWs, being:

- circular vias with cavity
- circular vias without cavity
- square vias with cavity

Figure 4. Half Diamond textile antenna with embroidered SIWs **(circular with cavity)**, bottom (a) and top (b) view.

(a)

(b)

Antenna implemented in the new SIW technology

These SIW have the similar diameter size of the metallic eyelets of the antenna presented in [2], which was considered as a reference.

Figure 5. Half Diamond textile antenna with embroidered SIWs **circular without cavity (a)** and SIWs **square shape no cavities (b).**

(a) circular without cavity **(b) square shape no cavities**

Results and Discussions

MICROSTRIP TRANSMISSION LINES

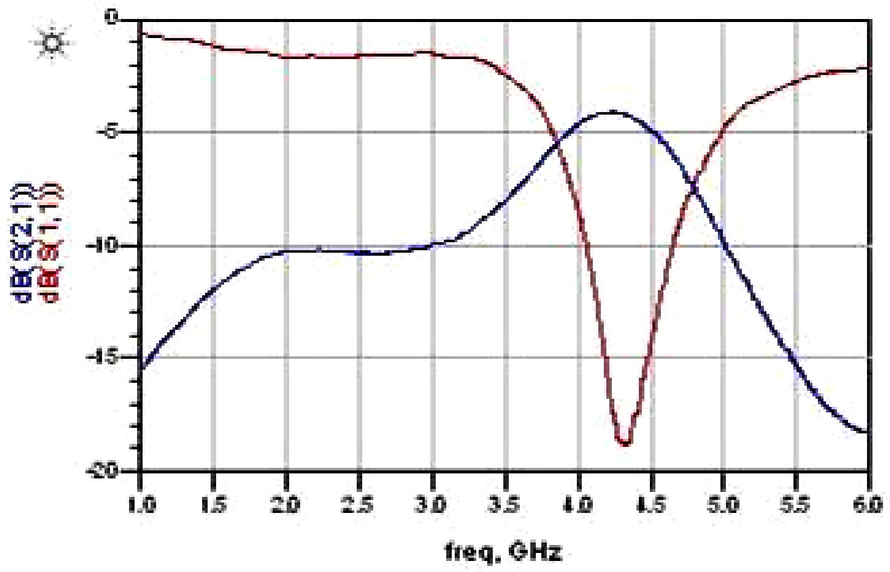
HALF DIAMOND DUAL-BAND TEXTILE ANTENNA WITH EMBROIDERED SIW

Microstrip Transmission Lines (MTL)

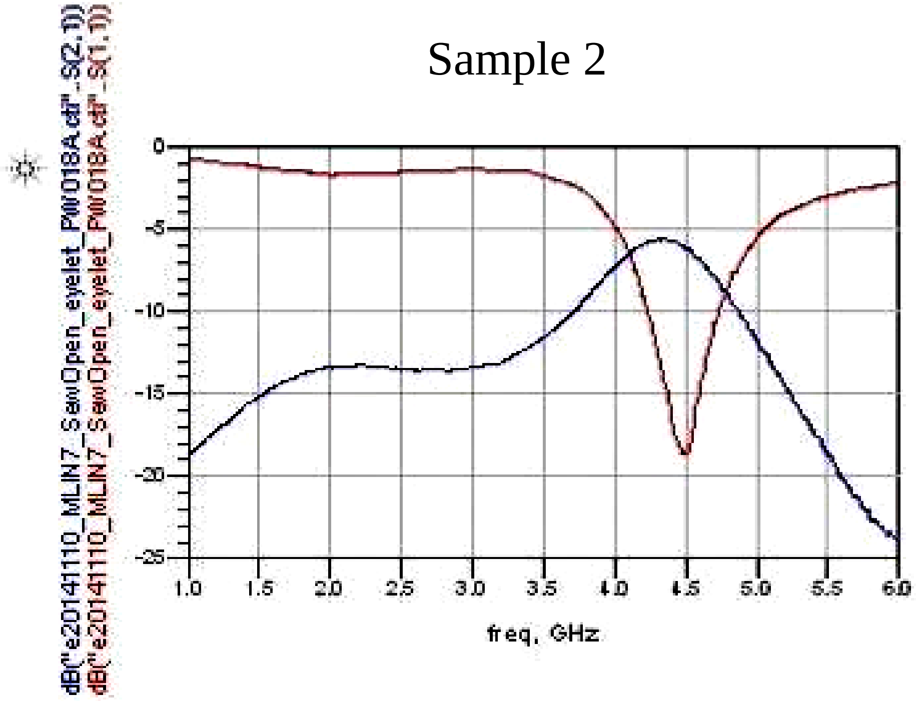
Considering all tested MTLs, sample 2 (made with Yarn 1 through embroidering) showed the best performance, yielding a result comparable to that of reference sample 1, as shown in figure 6.

Figure 6. S_{11} (red line) and S_{21} (blue line) parameters measured for the MTL samples 1 and 2.

Sample 1



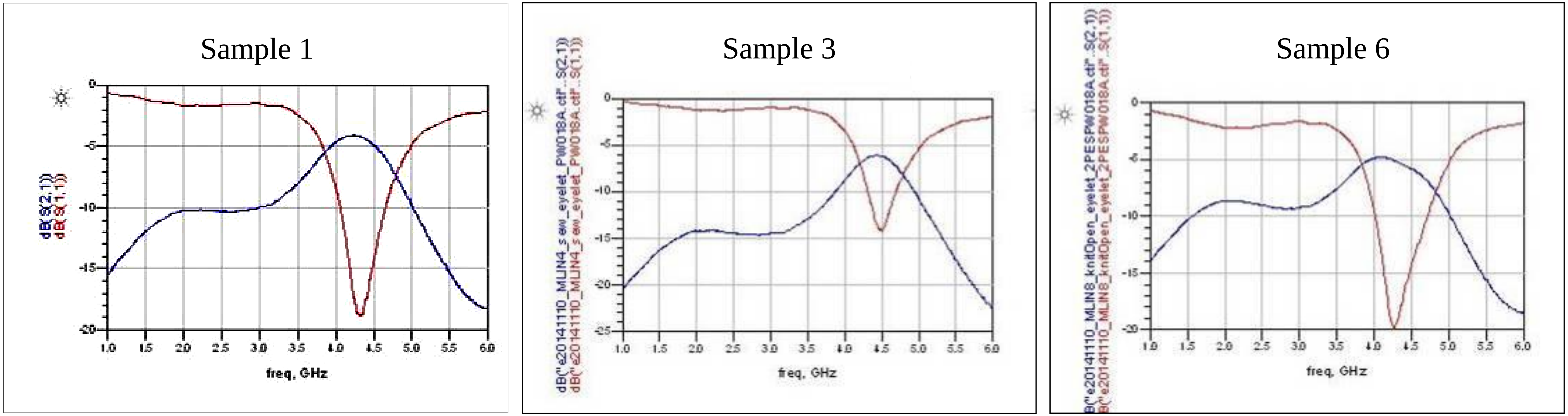
Sample 2



Microstrip Transmission Lines (MTL)

Samples 3 and 6 also exhibit good performance in terms of S_{11} and S_{21} parameters, the Yarn 3 applied in sample 3 has a lower conductivity and the conductive string used in sample 6 is difficult to manipulate by hand. Therefore, these samples were discarded.

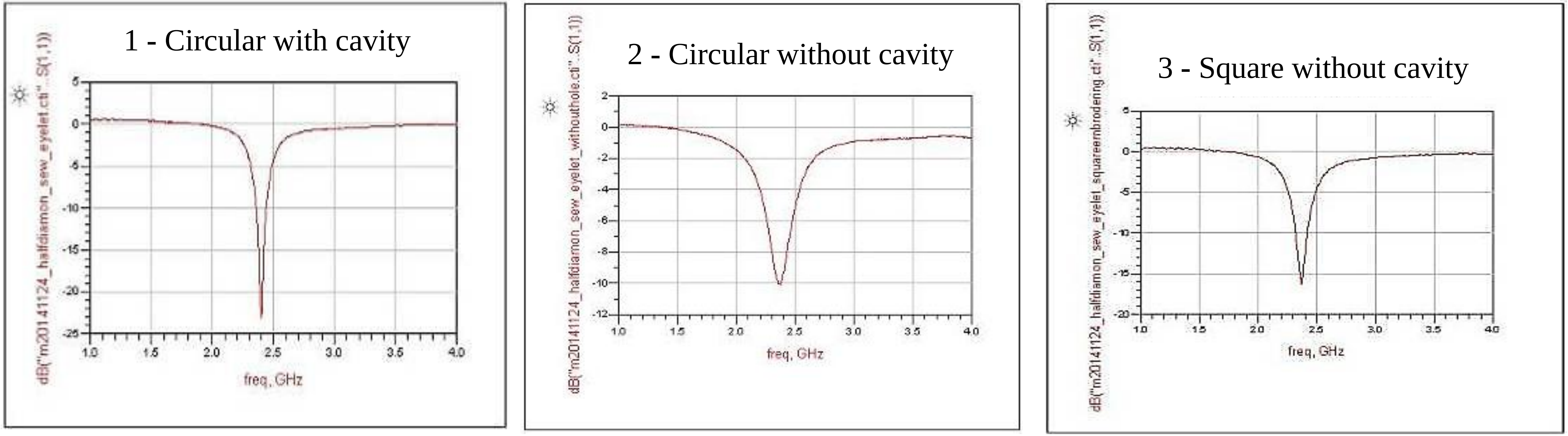
Figure 7. S_{11} (red line) and S_{21} (blue line) parameters measured for the MTL samples 1, 3 and 6.



Half Diamond Dual-Band Textile Antennas with embroidered SIW

Figure 7 shows the S_{11} parameter, in the frequency range of 1GHz up to 4GHz, for the half-diamond textile antennas implemented in SIW technology through embroidering. The resonance peak of the antenna around 2.40 GHz is clearly visible for all samples.

Figure 7. S11 parameters for the textile antennas with embroidered SIWs of types 1, 2 and 3



Half Diamond Dual-Band Textile Antennas with embroidered SIW

These results are very close to the simulation presented in [2] for the antenna with a SIW cavity made of brass eyelets. Clearly, the SIW antenna fabricated using circular vias with cavities (type 1) yields the best matching.

The SIW antenna with vias of type 2 (without cavities), only reaches -10 dB, and the SIW antenna with vias of type 3 (square shape, no cavities), only reaches -15 dB.

Yet, these results are also promising, as such types of vias do not require that the substrate is perforated, and hence, they may be easily produced by an industrial embroidering machine.

Conclusions

We have shown that MTLs and antennas with embroidered cavities yield similar results to the ones made with metallic eyelets.

The embroidering technique is thus a promising technique to fabricate SIW components. It can be used to improve flexibility and reduce weight of several components, mainly when their design requires a large quantity of SIWs.

Conclusions

Moreover, it can be used to produce SIW without perforating the substrate. Therefore, embroidered SIWs may enhance the development of systems-on-textile for wearable applications.

Finally, there exist industrial embroidering technologies that may bring progress in the mass production of such wearable systems.

ACKNOWLEDGEMENTS

The authors thank European COST Action IC1301 WiPE for supporting the COST-STSM-IC1301-21099 mission, the Portuguese company Logik for producing the string with conductive yarns and Santander-Totta/UBI for the financial support given to this investigation work. This work is funded by FCT/MEC through national funds and when applicable co-funded by FEDER – PT2020 partnership agreement under the project UID/EEA/50008/2013.

Thank you for your attention