Radio Frequency Performance and Strain Testing of an Iron-On Fabric Shielded Stripline

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***Abstract*—A shielded stripline structure made from commercially available fabric and fleece has been produced using iron-on fabrication techniques and its radio frequency performance evaluated over the range of 10 MHz to 7 GHz. Presented are the simulated and measured return loss and forward transmission characteristics. Also investigated are attachment techniques by which SMA connectors are bonded to the flexible shielded stripline. Four bonding techniques; three solder and one epoxy were evaluated by being subjected to precise mechanical loading. Copper laden solder provided the best bond strength.**

Index Terms*—Stripline, Iron-On, fabric, fleece, strain test, wearable.

I. Introduction

With the growing number of wireless enabled devices for military, law enforcement and emergency services personnel, there comes the need for integrated body-worn solutions providing not only the interconnection of the requisite devices but also flexible transmission lines and antennas [1] [4] [5]. The optimum location of the antennas is high up on the wearer and could be embedded within the personal clothing or within an additional carrier. The sensing or transceiver equipment is more likely to be distributed around the individual and for typical deployed or operational scenarios, will require it to be worn for extended periods necessitating the freedom of location for personal comfort. To accommodate these requirements requires highly flexible radio frequency distribution transmission lines and robust interconnections. These interconnections need to survive repeated attachment and detachment with minimal performance degradation. Motivated by the wearable shielded stripline produced by Kaufman *et.al* [2], the fabrication of a similar shielded stripline using iron-on fabrication techniques and the evaluation of its measured radio frequency performance over the range of 10 MHz to 7 GHz was investigated. Presented are the simulated and measured return loss and forward transmission characteristics.

Also investigated are attachment techniques by which SMA connectors are bonded to the flexible shielded stripline. Four bonding techniques; three solder and one epoxy were evaluated for bond strength by being subjected to precise mechanical loading. A total of sixteen strain tests were undertaken with the mean force to failure and standard deviation reported for each approach.

II. Shielded Stripline Design

The transmission line presented in this paper, as shown in Figure 1, has been fabricated using fleece for the substrate plane and an "iron-on" rip-stop metal plated nylon fabric for the conductive plane. Fleece is a commonly used fabric for clothing, is easily available and relatively inexpensive. The conductive iron-on fabric is known as "Shieldit Super" [3] and is made by weaving Nickel and Copper plated nylon threads. The manufacturer specified conductivity of the "Shieldit Super" fabric is 0.5 $\Omega/\square$. A hot-melt adhesive has been applied to one side of the woven conductive fabric. The adhesive activates at 130C and is well suited to being ironed onto the fleece.

Fig. 1. Flexible shielded stripline fabricated using "Shieldit Super" and fleece.

A. Iron On Fabrication

The stripline was fabricated by ironing a narrow conductive strip onto the centreline of a length of fleece. Another fleece strip was placed on top sandwiching the conductive strip. The structure was shielded by ironing a single sheet of "Shieldit Super" onto the outer surface. To seal the conductive ground layer, the sheet was wrapped over onto itself and ironed up the seam, as shown in Figure 2. An electrical connection bridging the length of the seam is not necessary as shown by the excellent radio frequency performance in Section II-B.

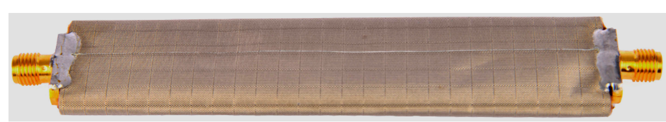

Fig. 2. Shielded stripline ironed seam.

The stripline length and total width (a) Figure 3, were chosen to be 100 mm and 20 mm respectively. The thickness of the conductive fabric (t) minus the hot-melt adhesive is 0.07 mm and the total thickness of the two layers of fleece (b) is 4.6 mm. The relative permittivity (ε_r) of the fleece fabric was determined by measuring the characteristic impedance of a stripline constructed with a 5 mm wide conductive strip. With all the physical dimensions of the stripline known, equation 1, [6] pg. 61, was used to calculate the ε_r of 1.28. A Keysight PNA was used to measure the line's characteristic impedance in the GHz region.

$$Z_o = \frac{377}{4\sqrt{\varepsilon_r}} \left(\frac{1}{\frac{w/b}{1-t/b} + \frac{2}{\pi} \ln\left(\frac{1}{1-t/b} + \coth \frac{\pi a}{2b} \right)} \right) \quad (1)$$

The calculated ε_r was then used to determine that a 5.5 mm wide conductive strip was needed to create a 50 ohm line. A diagram representing the stripline cross section is shown in Figure 3.

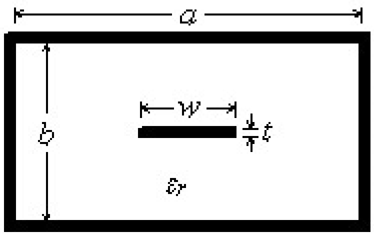

Fig. 3. Shielded stripline cross section design parameters.

B. Simulations and Measurements

To confirm the analytical solution, a 3D model was developed in Ansys HFSS V15 and a numerical analysis conducted. The constructed 50 Ohm stripline model was measured on a Keysight PNA and the measured s–parameters were compared against those obtained in the numerical solution. Figure 4 and 5 present the measured and simulation results for S11 and S21 for the copper laden solder stripline. A DC conductivity of 90000 S/m was applied to the simulation of the stripline model to achieve good correlation between the measured and simulated results. The measured S11 is better than -18 dB and S21 is within 0.2 dB of the simulation from 10 MHz to 7 GHz.

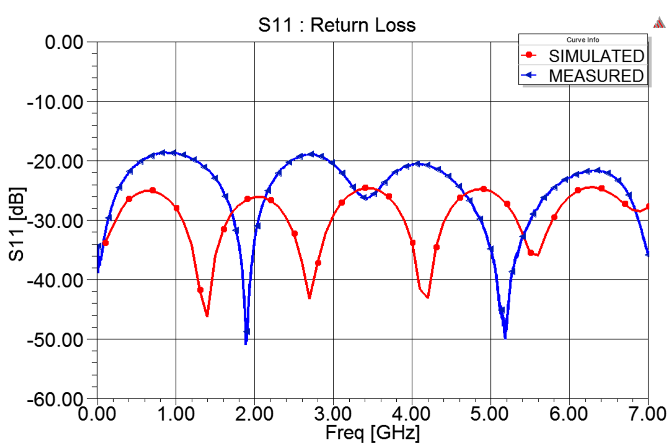

Fig. 4. Shielded stripline simulated and measured return loss.

III. Connector Pull Strain Tests

In order to evaluate the strain of the solder bond between the conductive fabric and the SMA connector, a pull strain test was conducted using the Condor XYZTEC pull measurement unit, see Figure 6. The test was performed by firstly, securing and clamping the transmission line in a vice. Secondly, in order to vertically align the stripline, a male SMA fixture

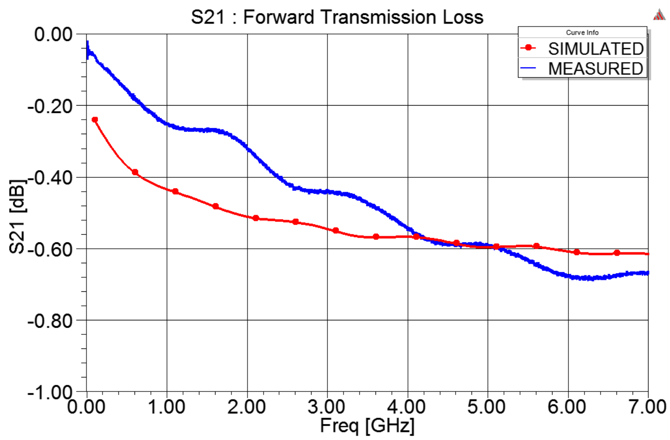

Fig. 5. Shielded stripline simulated and measured forward transmission loss.

was attached to the machine head. Thirdly, the male SMA fixture was screwed onto the female connector of the stripline, Figure 7. During the pull measurement, the unit exerts up to 8800 grams force (gf) over a test distance of 4000 μm in the vertical direction at a velocity of 250 μm/s. The measurement continues irrespective of the connector breaking off the stripline during testing. A peak force is generated from the measurement and is used for comparison.

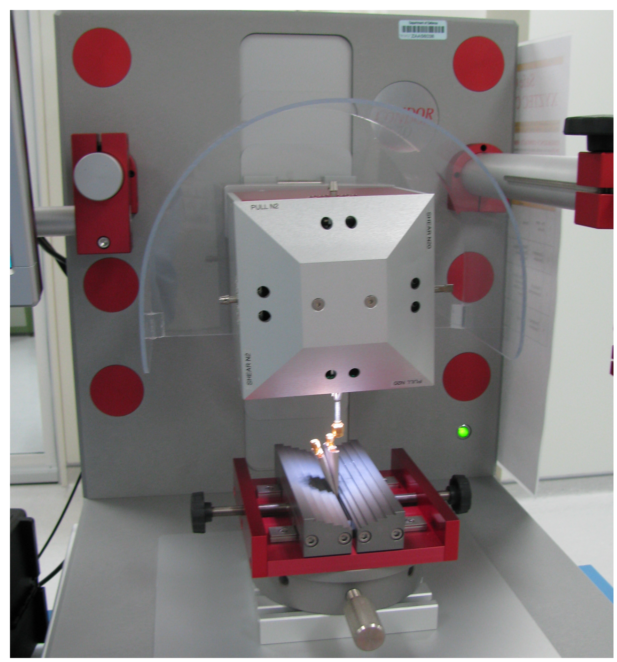

Fig. 6. Condor load pull configuration.

These tests were performed on transmission lines bonded with Tin-Lead solder, Indium solder, conductive Silver epoxy and Copper laden Tin-Lead solder. The bonding agents were applied using the manufacturer's guidelines for their respective application. A total of 16 tests were performed. Each bonding agent was applied to four of the SMA stripline connections. The mean and standard deviation of the results have been tabulated in Table I for each of the bonds.

From Table I, the Copper laden solder demonstrates the

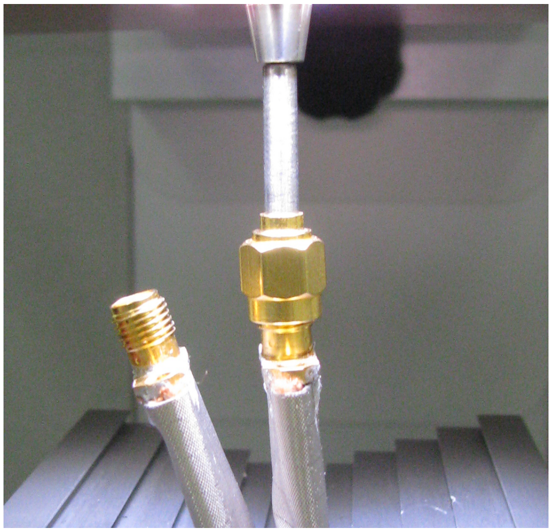

Fig. 7. Condor load pull jig.

Bonding Agent	Mean Force Applied (gf)	Standard Deviation (gf)
Tin Lead Solder	6152	1571
Indium Solder	6311	3090
Silver Epoxy	6607	1302
Copper Laden Solder	7379	1825

TABLE I. PULL STRAIN TEST RESULTS.

strongest average bond to the iron-on conductive fabric. This has been attributed to the solder being laden with copper. This minimises the dissolution of the copper atoms from the thin metallic plating on the fibres of the "Shieldit Super" during the application of heat whilst the solder was in the liquid state [7]. The electron microscope photo clearly depicts the excellent bond attachment, Figure 8.

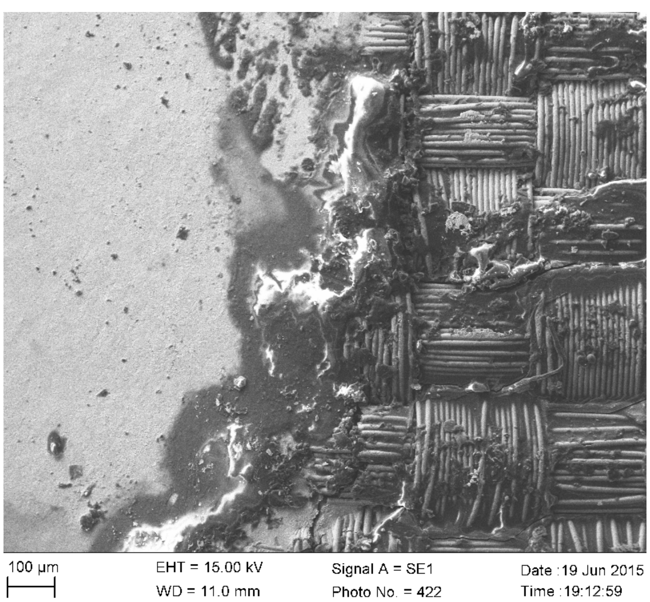

Fig. 8. Copper laden solder bond.

The weakest is the standard Tin-Lead based solder due to the copper dissolution thinning the fibre plating, Figure 9. The Indium bond demonstrated significant variation in the applied force-to-failure measurement. There was difficulty in the application of the Indium solder paste due to a large flux to solder ratio. Figure 10 clearly shows the residual flux from the soldering process. This flux had wicked into the absorbent fleece during soldering, carrying with it micro particles of solder, shorting out the centre pin of the SMA connector.

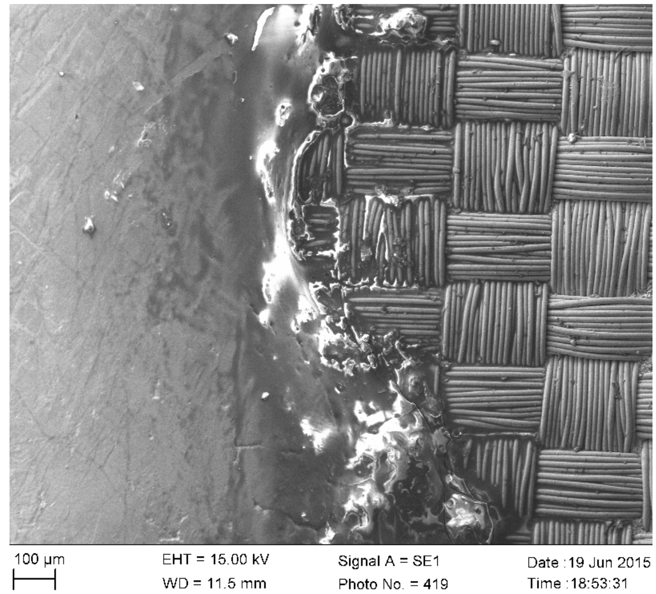

Fig. 9. Tin Lead solder bond.

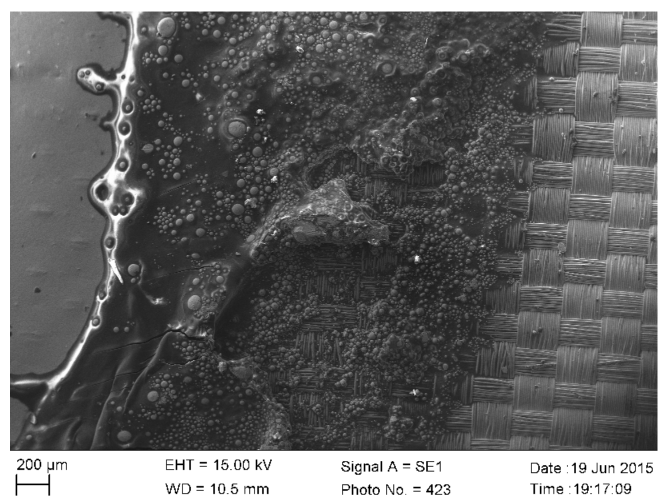

Fig. 10. Excessive indium solder flux residue with micro particles of solder visible in suspension.

The silver epoxy samples showed, after the pull test, that the epoxy did not bond well to the conductive fabric leaving little indication of the epoxy ever being applied. The silver epoxy failed to adhere to the conductive mesh, Figure 11, yet adhered to the gold plating of the SMA connectors.

IV. CONCLUSION

A method for creating an iron-on shielded stripline transmission line constructed from fleece and an iron-on conductive

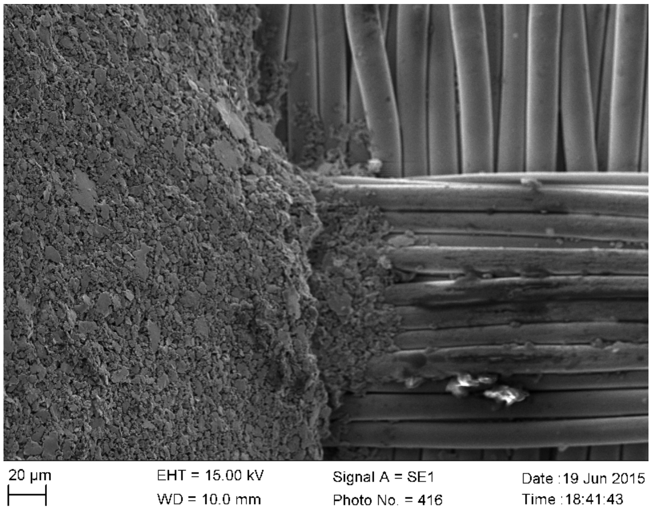

Fig. 11. Photo of the poorly bonded silver epoxy.

fabric has been demonstrated. The stripline is capable of broadband operation to 7 GHz and demonstrates a low insertion loss of 0.063 dB/cm at 7 GHz. The bond strength tests carried out have indicated that conductive fabric can be bonded to a connector using solder. The strength of the bond is dependent upon the solder or epoxy used. It has been shown that using a Copper laden solder produces a bond that requires a mean force of 7379 gf to break the joint and demonstrated to be the preferred method of bonding. Finally, further examination of all solder bond methods under the electron microscope, revealed that a large amount of flux had been left behind during the soldering process. Care needs to be taken during the soldering process to ensure that the flux does not wick into the fleece altering its permittivity at that location and hence creating a localized change in the characteristic impedance of the line. The conclusion has been drawn that the conductive Silver epoxy is not compatible with the nickel and copper content of the plating on the nylon threads thus preventing adequate bonding.

ACKNOWLEDGMENT

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REFERENCES

[1] L. Buechley and M. Eisenberg. Fabric pcbs, electronic sequins, and socket buttons: techniques for e-textile craft. *Journal Personal and Ubiquitous Computing*, 13(2):133–150, February 2009.

[2] T. Kaufmann and C. Fumeaux. Wearable textile shielded stripline for broadband operation. *IEEE Microwave and Wireless Components Letters*, 24(8):566–568, August 2014.

[3] LessEMF. Shieldit super. http://lessemf.com/fabric.html#1220.

[4] J. Matthews and G. Pettitt. Development of flexible, wearable antennas. In *3rd European Conference on Antennas and Propagation*, 2009.

[5] R. Salvdo, C. Loss, R. Goncalves, and P. Pinho. Textile materials for the design of wearable antennas a survey. *Sensors*, 12:15841–15857, 2012.

[6] B. C. Wadell. *Transmission Line Design Handbook*. Artech House, 1991.

[7] P.-Y. Yeh, J.-M. Song, and K.-L. Lin. Dissolution behavior of cu and ag substrates in molten solders. *Journal of Electronic Materials*, 35(5), 2006.