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Design and Fabrication of Fully Fabric Embroidered Monopole Antennas with Different Stitch Patterns for Wearable Application

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ABSTRACT: In this paper, a stitch monopole antenna has been designed, fabricated and measured. The evaluation of the resonant frequency on the stitching density has also been studied. Meshed monopole antenna design using etched copper conductors were create as a transition to the stitched monopole antennas using the embroidery method. The antennas were designed to operate in 850-950 MHz band. This meshed antenna was compared with unmeshed (solid) monopole of the same dimension. The study suggests that the greater the number of stitches better impedance bandwidth at -10 dB depending on stitch patterns. The stitched triangular pattern is a valid alternative to solid conductors with optimal stitch density. This paper also addresses the issue associated with stitch patterns using conductive thread for fabrication of antennas.

KEYWORDS: Stitched antennas, computer embroidery, antennas, resonant frequency meshed monopole.

I. INTRODUCTION

In the recent years' attention has been given to transparent devices such as smart window display and augmented reality. The transparent and conductive materials received attention in the field of transparent electronics [1]. The optically transparent devices are integrated with clear display panels, smart windows, smart glass and transparent mobile devices. Requirement for materials used for design of transparent mobile device include transparency, conductivity and ability to exhibit high optical transparency.

Microstrip patch antenna has been used by several authors [1]-[3] for mesh analysis and transparency of electronic devices. Meshed designs of transparent antennas also resulted in a lower gain than the solid patch [2]. The effects of meshing patch antennas and their ground plane were examined by [3]. They reported that meshing of patch antennas gives opportunities for improving the bandwidth of the antenna.

In this work a meshed and stitched monopole antenna were proposed but microstrip patch antenna is generally used. RF passive components such as antenna was fabricated using computer embroidery. The resonant characteristics of the proposed meshed and stitched monopole antenna were compared with unmeshed monopole antenna. This work proposes a novel stitched monopole structure that reduces the usage of conductive thread, with optimal performance.

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II. MATERIALS AND METHOD

The investigations of meshed monopole antenna properties are carried out using CST Microwave Studio. The interaction of the paralell and orthogonal lines in TM_{010} current path was examined. The structure of proposed meshed monopole antenna is shown in Fig.1(a). Meshed monopoles consist of two sets of mesh lines. The radiating element of the monopole antenna is mesh and represented by a length of $\lambda/4$ with strip width of the radiating element W_S. A coaxial cable with an inpedance of 50 Ω is used to feed the antennas. Meshed ground plane is given by $W_S \times L_g$. The distance d_L and d_W between the strip can be calculated by $(L - w_l)/(N_{v,h} - 1)$. The line width w_l of the strip is taken as 0.2 mm and variables N_v and N_h represents the number of vertical lines and horizontal lines respectively. The transparency $T_{Monopole}$ is given as the ratio between the non-metal area and the total area of the solid structure (1) [4]. The total number of vertical lines are fixed to five and length of the radiating segment is fixed to λ_g.

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$$T_{transparency} = \frac{L.W_S - W_t.N_P.L - W_t.N_O.W_S + W_S^2.N_O.N_P}{L.W_S} \quad (1)$$

The monopole is meshed and printed on PCB replaced with fabric materials. The meshed monopole antenna has no ground plane behind the radiating element. The printed meshed monopole designed using equation (2). The meshed monopole antenna samples with 1.6 mm thickness ground plane fabricated on $FR4$ substrate with relative dielectric constant of 4.3 and loss tangent of 0.025. The meshed lines were etched on a PCB substrates.

$$\lambda = \lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{reff}}} \quad (2)$$

Where $\lambda_0 = c/f$ free space wavelength, λ_g guided wavelength in FR4 substrate and ε_{ff} is the effective dielectric constant which is applied microstrip transmission line. Equation (3)[5] was used to roughly computed as approximately 1.6783.

$$\varepsilon_{reff} = 1 + \frac{\varepsilon_{FR4} - 1}{2}\left\{1 - \left[\frac{w_s/h}{1 + w_s/h}\right]\right\} \quad (3)$$

The pure copper of thickness 0.035mm was used and line width 0.2 mm. The meshed monople antennas were placed on solid ground plane of 60 mm. The meshed monopole consists of vertical $(N_v) = 5$ and horizontal lines $(N_h) = 68$ width a radiating length 68 mm. In this study a line width of 0.2 mm was used but the line width affects the transparency of the meshed monopole antennas. The reflection coefficient (S_{11}) response of the antenna sample 20 (uniform meshed monopole) was simulated and measured compared with the unmeshed monopole antenna. The spacing between uniform mesh is 1mm both with ground plane and radiating element.

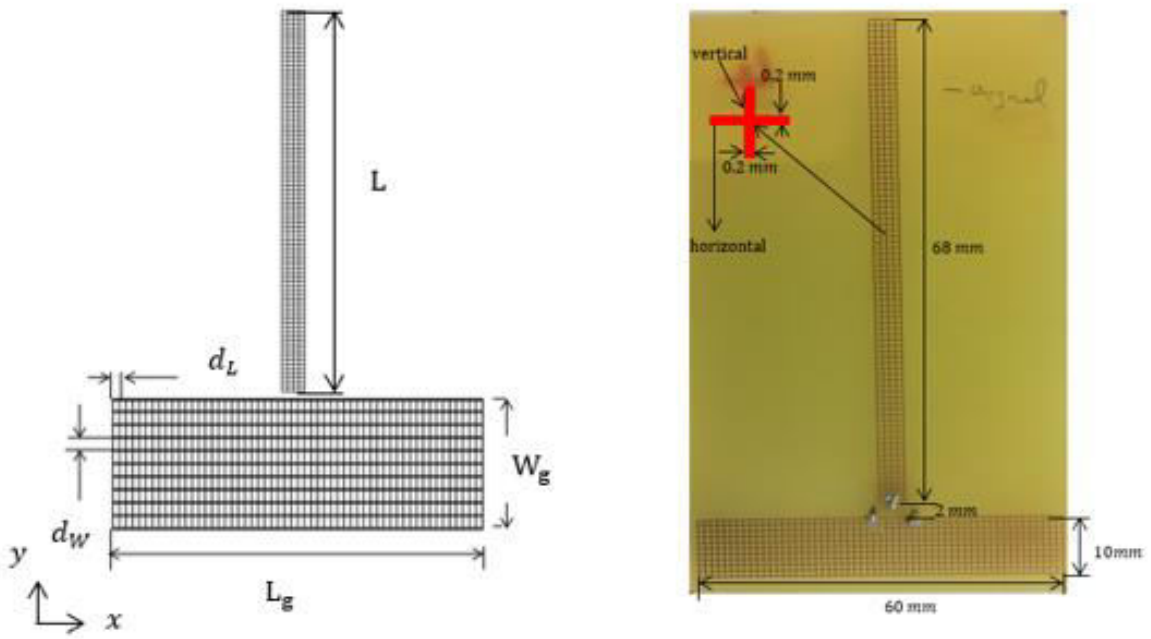

Fig. 1 (a) Meshed monopole antenna layouts and (b) Meshed monopole antenna sample

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III. RESULT AND DISCUSSION

In Fig. 2 is the S_{11} response plot of simulated and measured of meshed and unmeshed monopole antenna sample. The resonant frequency of uniform meshed monopole 20 (measured) is 921 MHz at -32.86dB, -10 dB bandwidth 283 MHzwhile the simulated result is 905 MHz at -16.52 dB, -10dB bandwidth 100 MHz.The impedance bandwidth increased from 11 % (simulated) to 30 % (measured) for the uniform meshed antenna. Unmeshed monopole antenna measured is 866MHz at -28.17 dB, -10dB bandwidth 237 MHz and simulated value is 900 MHz at -14.77 dB, -10 dB bandwidth 85 MHz. Simulation feeding discrete port was placed between the ground plane and the radiating element. Meshing a unmeshed monopole antenna shifted the resonant frequency of the right due to increased current path on the radiating elements and ground plane [6].

In the fabrications of both antennas sample errors were introduced due to placing of the SMA connectors. The mesh space for the uniform monopole antenna is less than 2 mm; a similar resonant frequency is obtained in the unmeshed monopole antenna. The both exhibit similar resonance properties. The measured S_{11} result of sample 25 shown two peak values -27.1 dB at 725 MHz with 96 MHz -10 dB bandwidth and -17.2 dB at 1630 MHz with 40 MHz -10 dB bandwidth. The antenna sample 25 has a good match at the 725 MHz and easily tuneable to desired frequency

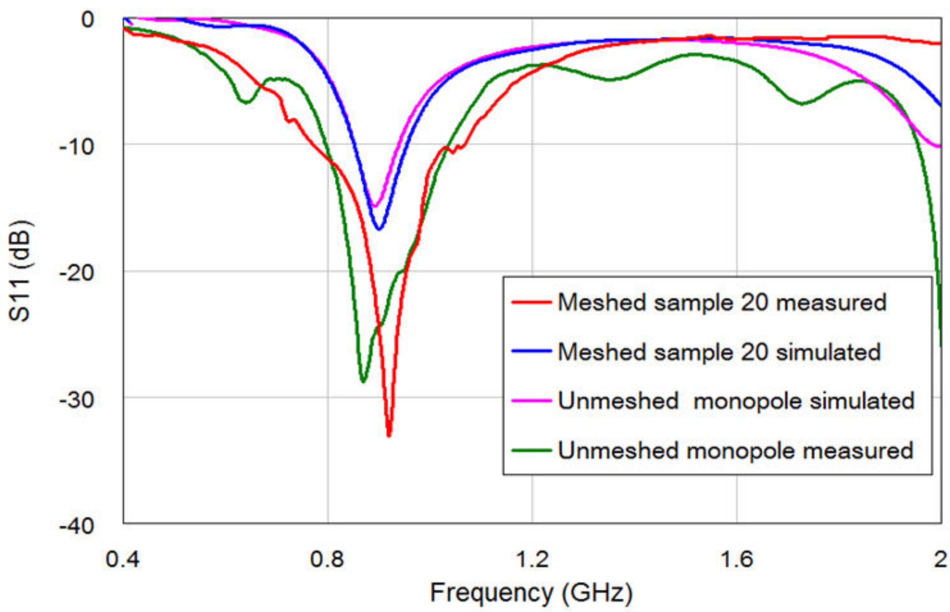

Fig. 2 S_{11} plot of meshed and unmeshed monopole antenna see Table 1 for detail of antenna 20

Antenna sample 21 is meshed monopole consisting of horizontal lines $N_h = 8$ and vertical lines $N_v = 5$ Antenna height (H_L) of 84 mm having a radiating width of $4mm$ with $d_L = 1mm$ and $d_w = 10mm$, ground plane length $(L_g) = 60mm$ and width of the ground plane $(W_g) = 5mm$. Antenna sample 24 is meshed having the following dimensions of $N_v = 5$ and $N_h = 17$, $d_L = 1mm$, $d_w = 5mm$, $H_L = 84mm L_g = 60mm$ and $W_g = 5mm$. The line width is $0.2\,mm$ and radiating width of $4\,mm$. S_{11} plots of samples of mesh monopole are shown in Fig. 3. Antenna sample 21 (measured) $894MHz\ at\ -52.32dB$ and $-10\,dB$ bandwidth $(862 - 942MHz)$ while the simulated S_{11} is $899\ MHz$ at $-11.22dB, -10dB$ bandwidth $(878 - 926MHz)$. The Measured and simulated S11of antenna sample 24 are $885MHz$ at $-57.25\,dB, -10dB$ bandwidth $(861 - 927MHz)$ while simulated value is$892\ MHz\ at\ -16.62\,dB, -10\,dB$ bandwidth $(852 - 949MHz)$.

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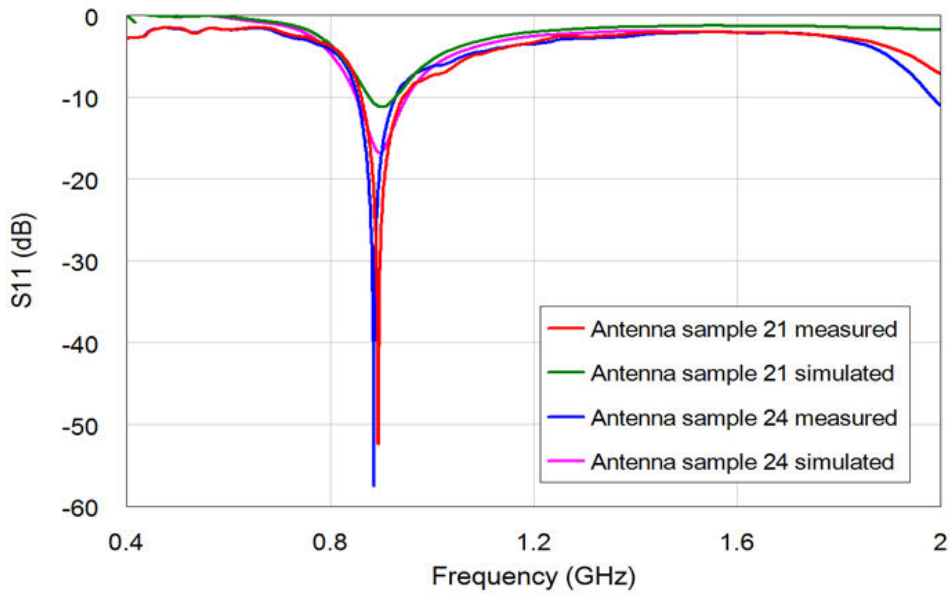

Fig. 3 Measured S_{11} of two size meshed monopole antennas with different mesh parameters on FR4 see Table 1 for detail of antennas

Table 1 Geometry of meshed monopole antennas on FR-4

Meshed monopole type	Meshed monopole dimensions $L \times W$ (mm)	Measured f_0 (MHz)	Measured S_{11} (dB)	-10 dB Bandwidth (MHz)	N_h	N_V	$T_{monopole}$ (%)
Unmeshed monopole	68 by 4	864	-28.14	238	unmeshed		100
Sample 20	68 by 4	920	-32.86	282	41	5	67.59
Sample 21	84 by 4	894	-52.19	71	9	5	73.55
Sample 24	84 by 4	884	-56.40	73	18	5	71.74
Sample 25	84 by 4	721	-27.05	96	3	3	64.57
Sample 26	84 by 4	901	-47.71	80	41	5	67.59
Sample 27	84 by 3	904	-42.20	138	Triangular meshed		

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IV. STITCHED MESHED MONOPOLE

The meshed monopole antenna samples were named as shown in Table 2 (Figure 4(a), (b), (d) and (f) are of the dimensions but different stitching designs. Figure 5 (c) and (e) uses the different square stitched configurations with same dimensions. A digital embroidery machine at the Loughborough University model Brother Pro PR1000e Entrepreneur was use to realise the fabrication of the stitched monopole antennas. The thread used for this study was a Multi-thread conductive yarn Amberstrand Silver 66. One single thread of Amberstrand is made of 66 identical filaments [7]. The diameter of the Amberstrand filament is approximately 17μm. The stitching was performed along the horizontal step and vertical step directions for antennas. The lock stitch method was used where two threads: conductive thread and non-conductive thread for stitched formation. A stitch density of 4.5 lines/mm was used stitching of the ground plane. Current prefers to follow the stitch direction rather jump from one yarn to another.

An improved stitching design minimises the conductive thread usage and the antenna performance is enhanced. The design of stitched monopole with low stitch density makes the antenna light and flexible thereby reducing the cost of antenna production. The major aim of this design was reduced cost of embroidered antennas design by using minimal stitches for optimal performance [8]. In Fig. 5 gives a results of different stitch formation and design for fabrication of stitched monopole.

Table 2Parameters of stitched monopole antennas

S/No	Antenna samples (Dimensions in mm)	Stitch pattern	Fabric
1	M01: ground (70 × 10) radiating element (84 × 4)	Cross stitch	Felt
2	M04: ground (70 × 10) radiating element (84 × 4)	Square stitch	Denim
3	M05: ground (70 × 10) radiating element (84 × 4)	Cross stitch	Denim
4	M4: ground (70 × 10) radiating element (84 × 4)	Cross stitch	Felt
5	M1: ground (68 × 10) radiating element (83 × 4)	Triangular	Felt
6	M2:ground (70 × 10) radiating element (84 × 4)	Cross stitch	Denim
7	M03: ground (65 × 5) radiating element (84 × 4)	Square with diagonal	Denim
8	M3: ground (68 × 10) radiating element (84 × 4)	Square stitch	Denim
9	M02: ground (70 × 10) radiating element (84 × 4)	Running stitch	Denim
10	M5: ground (70 × 10) radiating element (84 × 4)	Fill stitch	Denim
11	M6: ground (70 × 10) radiating element (84 × 4)	Fill stitch	Felt

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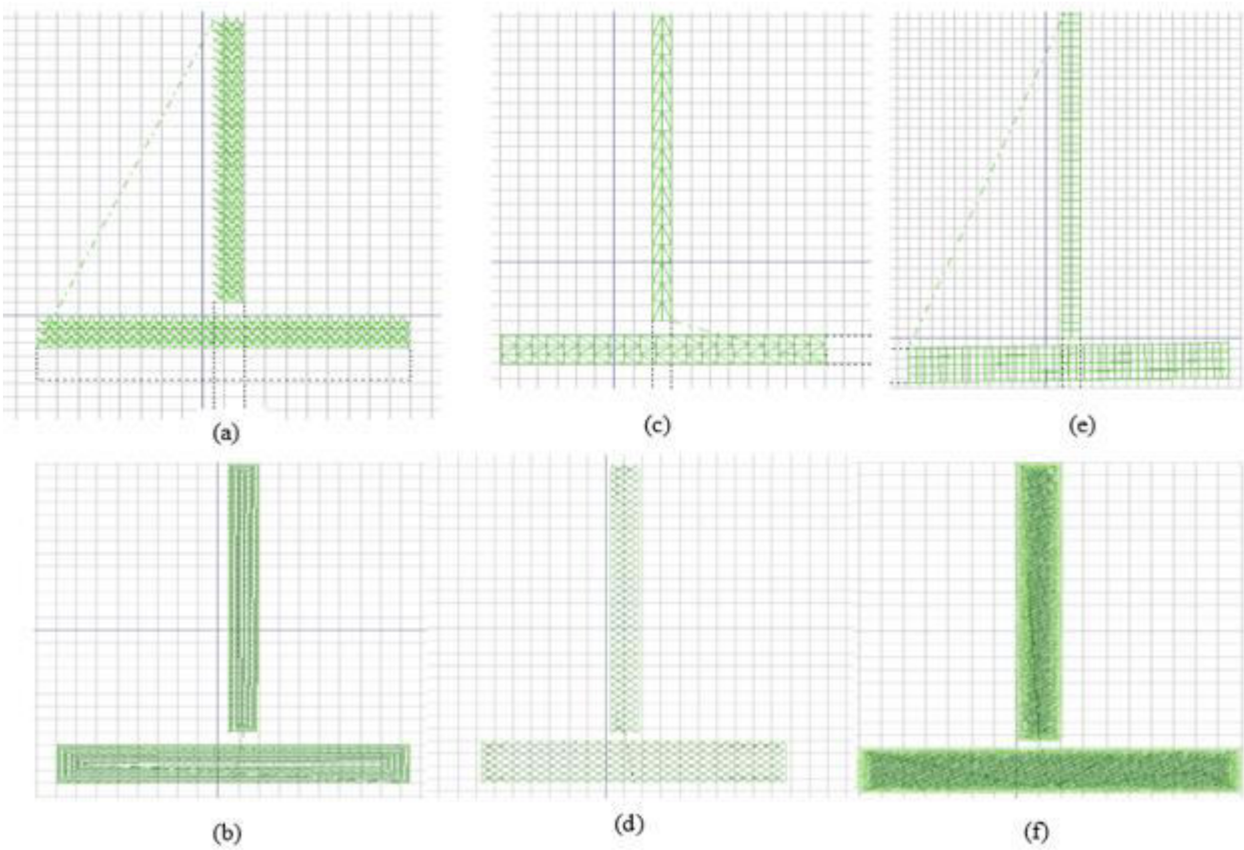
In Fig. 4 shows six different stitching patterns for embroidery software and the parameters are in Table 3. The fabricated geometry is stitched with a better precision than 1mm and the lengths are different due to nature of pattern realisations. Using the monopole dimensions, six different types of stitch were considered: running stitch, cross stitch and fill stitch, square and triangular stitched design.The monopole antenna was embroidered onto a felt layer as shown in Fig.5; stitch pattern is a triangular formation. Due to nature of the Amber strand thread which is fuzzing, edges of the triangle were not smooth



(a) (c) (e) (b) (d) (f)

Fig. 4 Stitching patterns (a) triangular stitch (b) running stitch (c) square with diagonal stitch (d) cross stitch (e) square stitch (f) fill stitch

Simulation and measurement were carried out over frequency range of $0.4-2.0\,GHz$ in each caseusing an Anritsu 37397D VNA for measuring scattering parameters (S_{11}) of the designed antennas. The measurements were conducted on a test bench, experiments showed the environment had little influence on the results. Measured S_{11} results are shown in Fig.6. It is shown that all the two monopole antennas are well matched at their resonant frequencies; S_{11} of M03 is $-28.9\,dBat\,909\,MHz$, with $57\,MHz\ -10\,dB$ bandwidth. The antenna $M03$ has two peaks at $909\,MHz$ and $1804\ MHz\ at\ -13.3\,dB$ width $100\ MHz\ -10\ dB$ bandwidth.

Some stitched antenna parameters for both ground and radiating element, M3 =390: Total antenna height = 84.20 mm, radiating element of monopole 83 mm and width of ground plane =10 mm, length of ground plane =68 mm. Sample $M03$ uses a total number of stitch 1280 but a square stitch pattern design with MATLAB. Parameters for embroidered monopole antennas height = 84mm and width of the ground =70mm. As shown in Fig. 6 the S_{11} of $M1\ =\ -23.3\,dB$ at 919 MHz and -10 dB bandwidth 77 MHZ ranging from 888 $MHz\ to$ 966 MHz while $M2$ presented $S_{11} = -26.75\ dB$ at 937 MHz and $-10\,dB$ bandwidth of 128 MHz ranging from 888 $MHz\ to$ 1016 $MHz.M2$ and $M1$ are all fully textile monopole antennas. $M2$ has a larger bandwidth than $M1$ becausethe ground plane is of larger dimension. In both designs, the bandwidth is larger to cover the entire GSM 900.

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Table 3 Measured results for stitched monopole antennas same nominal dimensions in all cases

Antenna design	Running (Denim) M2	Square with diagonal (Denim) M3	Fill stitch (Denim) M5	Square (Denim) M03	Triangular (Felt) M1	Fill stitch (Felt) M4	Cross stitch (Felt) M01
Measured f_0 (MHz)	935	880	937	909	919	937	951
Measured S_{11} (dB)	-26.81	-31.71	-31.39	-28.96	-23.29	-31.39	-20.56
-10dB Bandwidth (MHz)	114	81	120	57	85	122	83
Number of stitches	1254	390	1254	1280	1254	1254	1547
$Antenna\ length\ (mm) \times width(mm).$	84×4	84×4	84×4	84×4	84×4	84×4	84×4

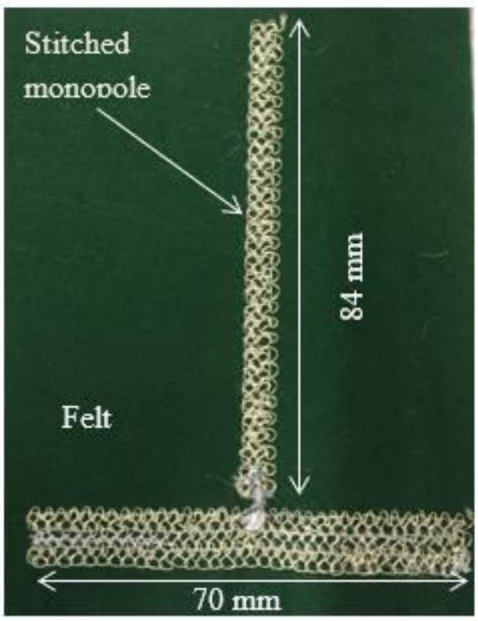

Fig.5 Triangular stitched pattern of monopole antenna

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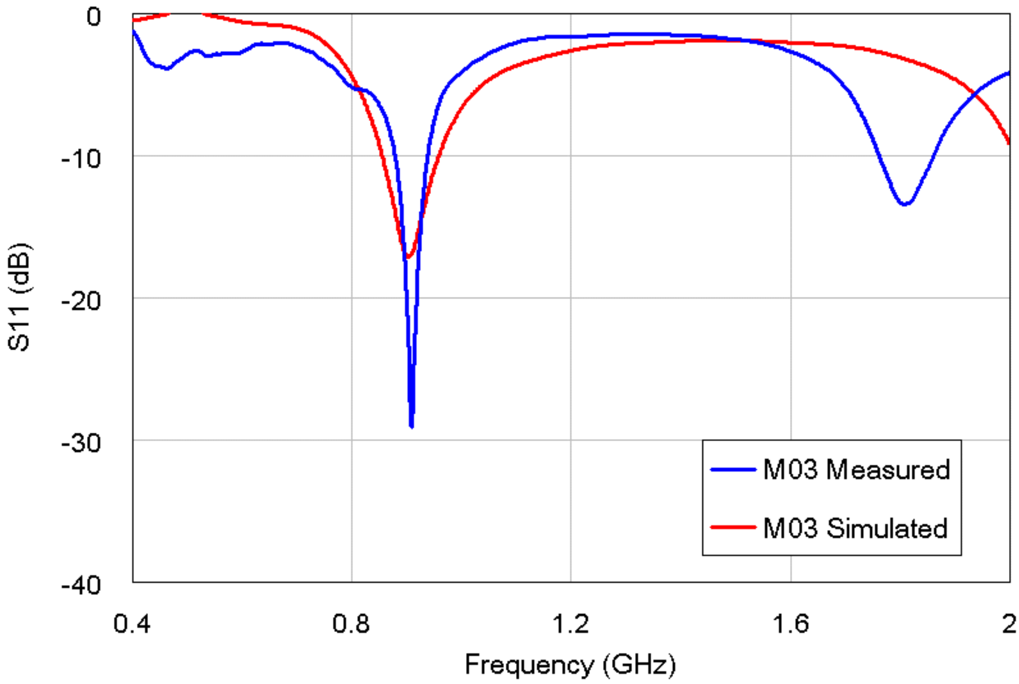

Fig.6 S_{11} plot of antenna sample M03 employing denim fabric

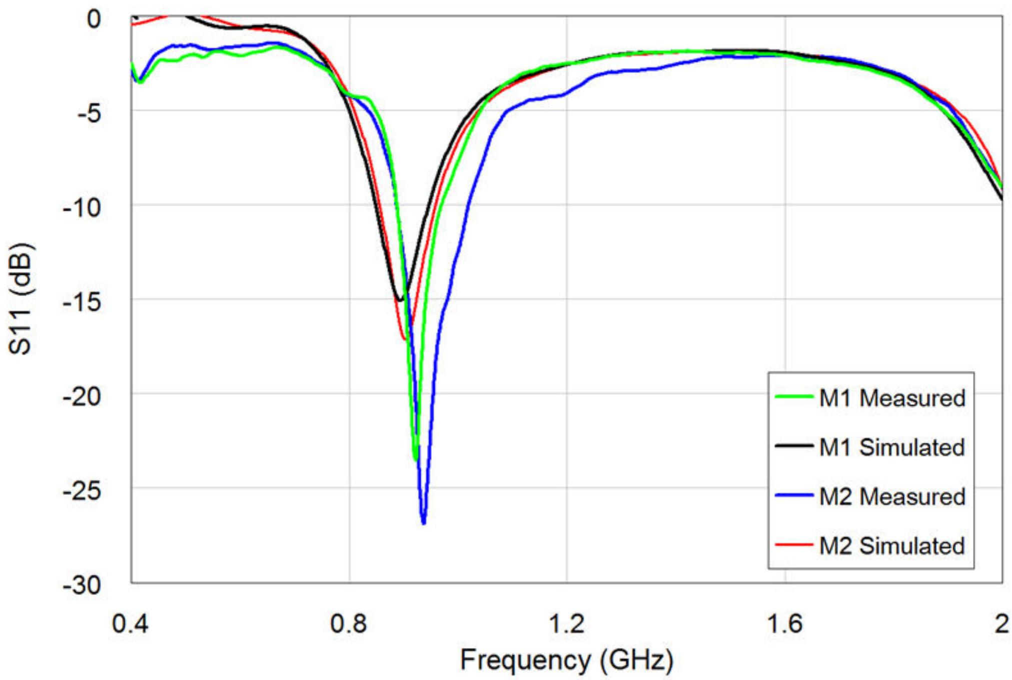

Fig.7 S_{11} plot of measured meshed stitch antenna samples on denim

The meshed monopole antenna $(M6)$ employing the fill stitch in realisation has a stitch count of 1254 antenna height = 84 mm and ground plane antenna width =70 mm. The simulated and measured S_{11} results are shown in Fig. 8. S_{11} of $M5$ (simulated) is -16.96 at 906 MHz with -10dB bandwidth of 93 MHz ranging from 856 $MHz\ to$ 953 MHz while measured S_{11} given as $-34.57\ dB\ at$ 918 MH, $-10\ dB$ bandwidth 120 MHz (871 $MHz -$ 991MHz).Simulated and

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measured S_{11} of $M6$ are -14.48 dB at 906 MHz with a -10 dB bandwidth of 135 MHz $(856MHz - 991MHz)$ while measured $S_{11} = -30.28\ dB\ at\ 940\ MHz$, -10dB bandwidth of $124\ MHz\ (890MHz - 1014MHz)$. The both fully textile monopole antennas cover the GSM900. The differences between simulation and measurement results of S_{11} and resonant frequencies may be attributed fabrication error as results of flexible coaxial SMA positions.

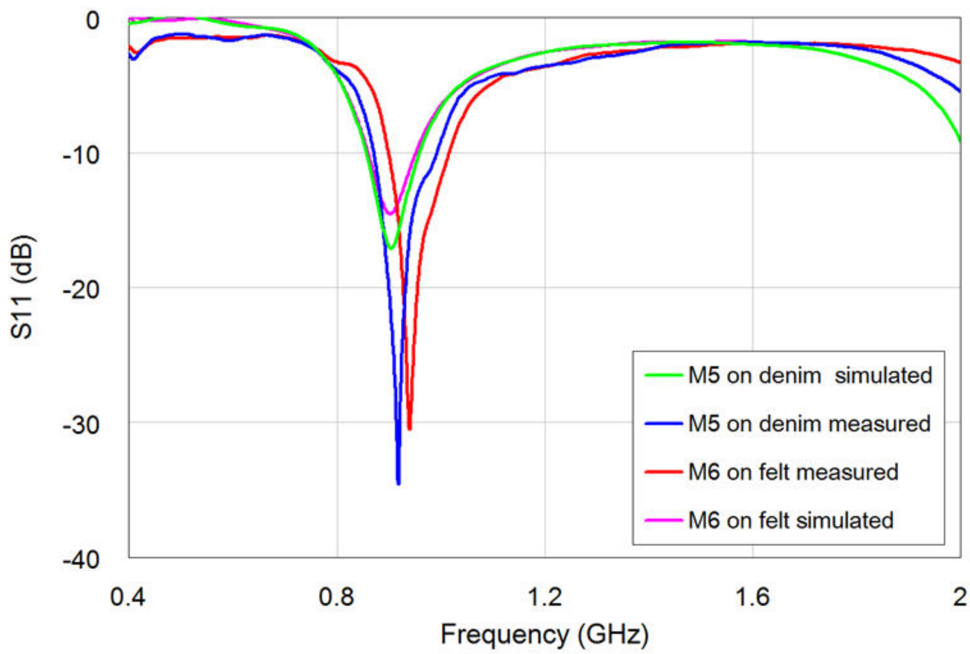

Fig.8 S_{11} plot of meshed monopole antenna employing denim and felt fabric

VI. CONCLUSION

Characterization of the fabric samples were measured using the split post dielectric resonator to determine the dielectric properties of the proposed materials. The wearable monopole was using CST Microwave studio base on the denim and felt fabric with permittivity of 1.97 and 1.2 respectively. A set of stitched antennas were developed made of all textile without rigid copper parts making flexibility and automation of the production process easier using the computer embroidery machine.Based on the results, the number of stitches of meshed monopole antenna is proportional to the bandwidth see Table 3. The greater the number of stitches better impedance bandwidth at -10 dB for different stitch configuration. Using the same dimensions of the antenna but different stitch patterns give differing in impedance bandwidth.The antennas are seamless integrated onto felt and denim substrate which could place on garment and address the requirement of unobtrusiveness of wearable antennas.

A range of test antennas were constructed and fabricated on fabric and FR4. The stitched triangular pattern is a valid alternative to solid conductors with low stitch density. The stitched antennas using MATLAB interface to computer embroidery works comparable to antenna stitched using cross stitch or running stitch of the same dimensions. The measured S_{11} results and simulated samples of the embroidered and meshed monopole antennas exhibits similar resonant frequencies with the same dimensions. Meshing of monopole antenna increases the bandwidth and resonant frequency from the results by one example.

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REFERENCES

[1] Seok Hyon Kang and Chang Won Jung ‘‘Transparent Patch Antenna Using Metal Mesh’’ IEEE transactions on antennas and propagation, VOL. 66, NO. 4, 2018.

[2] E.R. Escobar, N.J. Kirsch, G. Kontopidis and B. Turner ‘‘5.5 GHz optically transparent mesh wire microstrip patch antenna,’’ Electronics Letters, vol. 51 no. 16 pp. 1220–1222, 2015.

[3] G.Clasen and R. Langley ‘‘Meshed Patch Antennas,’’ IEEE transactions on antennas and propagation, vol. 52, no. 6, 2004.

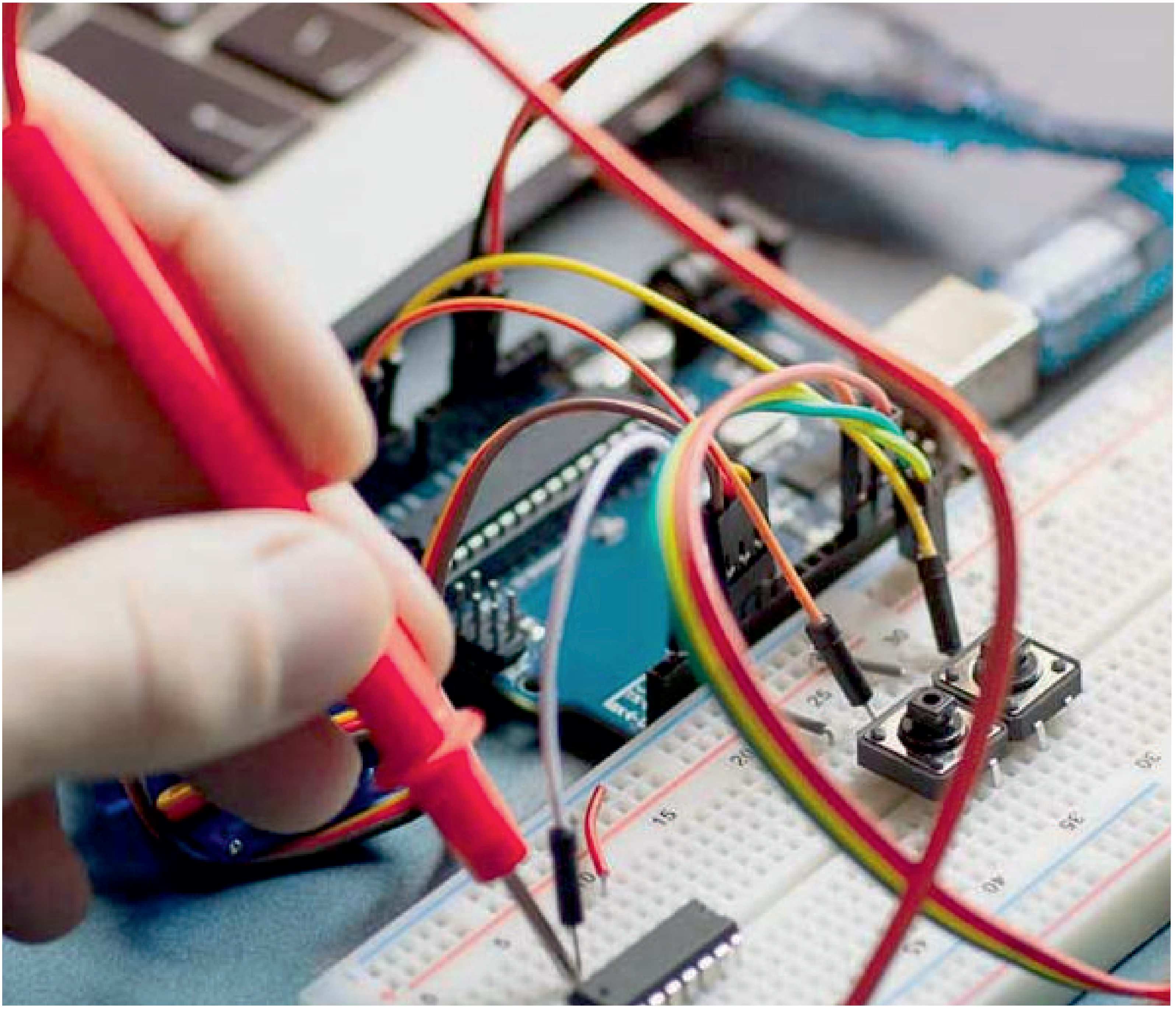
[4] Y. Tursunjan, B. Reyhan, T. Timothy, and A. Jesus, "Analysis and Design of Highly Transparent Meshed Patch Antenna Backed by a Solid Ground Plane," Electrical and Computer Engineering Faculty Publications. Paper 150, 2017.

[5] C.A. Balanis, ‘‘Antenna theory analysis and design,’’ John Willey and Son's Inc., 2016.

[6] A.T. Wiri, ‘‘Automated design, optimization and simulation of stitched antennas for textile devices,’’ PhD dissertation 2019, Loughborough University, Loughborough UK

[7] R. Seager, S. Zhang, A. Chauraya, W. Whittow, Y. Vardaxoglou, T. Acti, and T. Dias, “Effect of the fabrication parameters on the performance of embroidered antennas,” IET Microwaves, Antennas Propagation. vol. 7, pp. 1174–1181, 2013.

[8] S. Zhang, A. Chauraya, W. Whittow, R. Seager, T. Acti, T. Dias, and Y. Vardaxoglou, “Embroidered Wearable Antennas Using Conductive Threads with Different Stitch Spacings,” Loughborough Antennas and Propagation Conference, pp. 6–9, 2012.



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