Progress In Electromagnetics Research Letters, Vol. 102, 95–100, 2022

A Super Wideband Washable Antenna Demonstrated on Flannel

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Abstract—In this paper, a textile based fractal monopole antenna is proposed with a defected ground structure for wearable application. The proposed antenna is designed on flannel fabric with a thickness of 1 mm, which is 0.03 at 10 GHz. The total dimensions of proposed antenna is 60 × 40 × 1 mm. The measured fractional bandwidth of the antenna is 110.1%. The proposed flannel based conductive ink antenna is characterized. The results for washable fabric are illustrated. Both simulated and measured results are presented. The concept of application of low cost conductive ink on flannel fabric is demonstrated using conventional screen printing method. The antenna is characterized for commercial wash ability; the measurement results are invariant with the machine wash of the flannel fabric indicating robustness of the proposed method of fabrication of the antenna element.

1. INTRODUCTION

In the last decade, growth in the development of flexible devices which can monitor and transmit vital signals in various body-worn applications such as health monitoring and geo-positioning for rescue applications has led to optimization hardware products compatible with the aforementioned applications. Antennas integrated with these hardware systems are critical for a sustainable ink. Super wideband (SWB) antennas are an important class of antennas, especially in the context of wearable applications. Wideband low power signals could be useful for rescue operations [3–6]. Hence, the research on wearable SWB antennas is an important topic. Several wideband antenna designs have been proposed in the recent past. For instance, the design in [7] presents a monopole realized on cotton. The presented antenna is fabricated using an expensive conductive stitching method. A narrowband end-fire is repeated in [8], realized on cotton fabric. A band notched wideband antenna with a non-flexible substrate is demonstrated in [9]. Monopole antennas on different dielectrics have been demonstrated in [10–13]. From the aforementioned arguments it is clear that a super wideband antenna with washability has not been repeated yet. Hence, a washable super wideband antenna is presented in this paper. The antenna is realized on a flannel fabric and is subjected to conventional machine wash with commercially available detergent. The antenna is characterized for washing and rinsing.

2. PROPOSED ANTENNA

The proposed textile based fractal monopole antenna is designed on flannel fabric with relative dielectric constant of 1.7, loss tangent of 0.025, and these values have been assumed at 10 GHz. The thickness of the fabric is 1 mm, which is realized by stitching two fabric pieces with 0.5 mm thickness each. As flannel is a popular fabric, it is chosen. A planar hybrid fractal microstrip patch antenna based on a

Received 8 December 2021, Accepted 17 January 2022, Scheduled 20 January 2022
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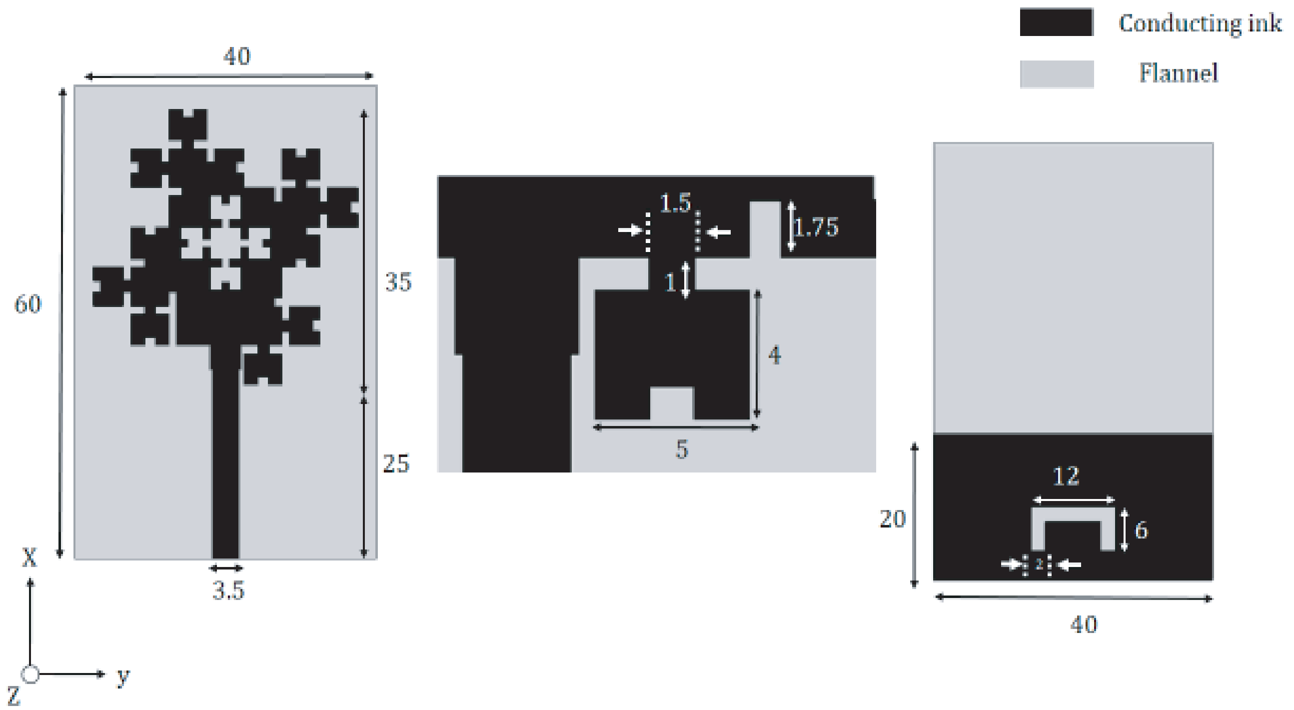


Figure 1. Proposed conductive ink based flannel antenna (units in mm).

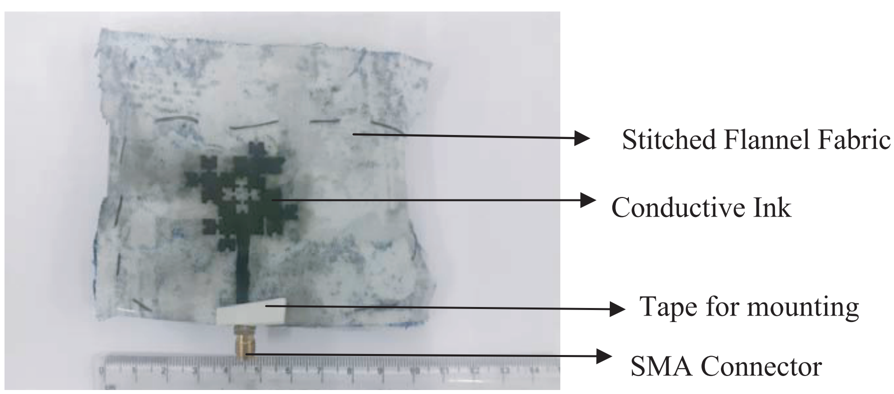


Figure 2. Photograph of the fabricated prototype.

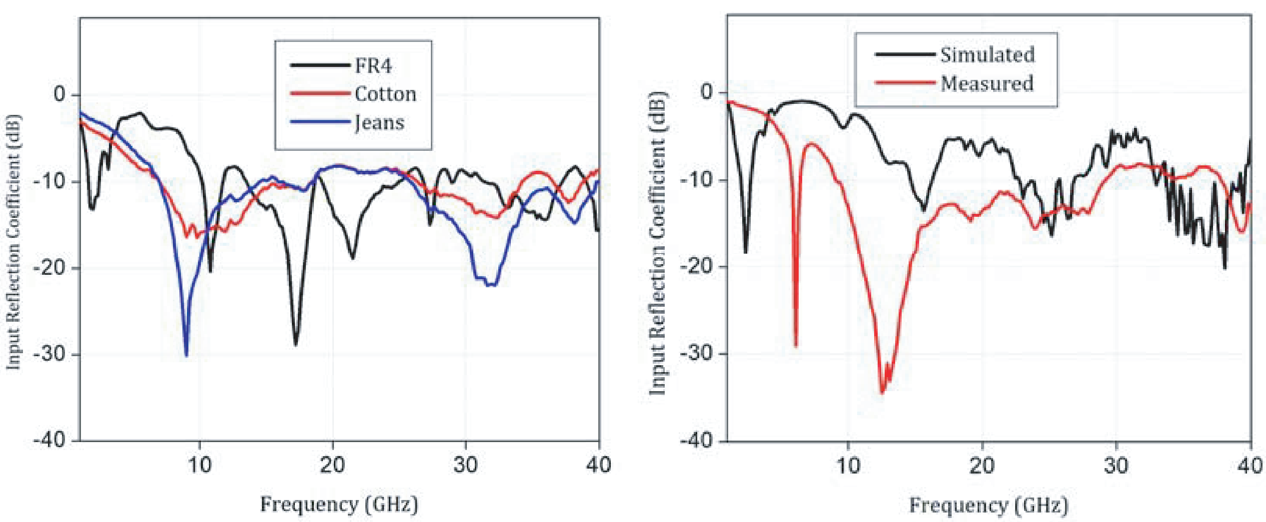
plus-shaped fractal geometry and Hilbert curve has been amalgamated for the design. The schematic of the proposed textile fractal antenna is illustrated in Figure 1.

Overall, the size of the antenna is $60 \times 40 \times 1$ mm. Figure 2 illustrate a photograph of the fabricated prototype antenna. Conductive ink is used for antenna design on a flannel substrate. The conductive ink [10] has an electrical conductivity of $55\,\Omega\text{m}^{-1}$. Even though the conductivity is sacrificed, when the ink is smeared onto the fabric, its conductivity and flexibility are retained. Conductive ink based RFID (Radio Frequency Identification) tags have been illustrated in [14–16]. These fabrication processes are complicated, and the concept of wash ability has not been explored in these articles. A large cut copper foil would be stiff and hence loses the flexibility, when being tested with the fabric. Hence, conductive ink is an ideal choice for flexibility and water solubility. The antenna is fabricated by screen printing method where in 110 Mesh Silk Screen Printing Mesh is used which can achieve a fabrication resolution up to 150 μm. As the dimension in the proposed design is 1 mm, the aforementioned fabrication process is feasible in this context.

Post screen printing with conductive ink, the realized antenna was tested for its performance metrics for washability with commercial detergent. It is soaked with moderately dilute soapy water for ten minutes and then washed in a commercial washing machine. The ink dyes are attracted to the detergent molecules, allowing the detergents to surround and lift the ink molecules from the cloth, in much the same way as detergents removing dirt from clothes, but in the proposed case the conductive ink is water resistant, so ink does not spread after the antenna is washed. Hence, the concept of conductive ink works well with washability. The SMA (subMiniature version A) connector is placed with the fabric antenna. Soldering cannot be performed with this fabric, as the fabric would be burnt with the solder/molten lead. Foam is attached to the backside of antenna which acts as a scaffolding to the electrically thin and fragile fabric. The fractal dimensions enhance the electrical length of the antenna's radiating aperture; the same concept could be realized with meandering or any similar geometry.

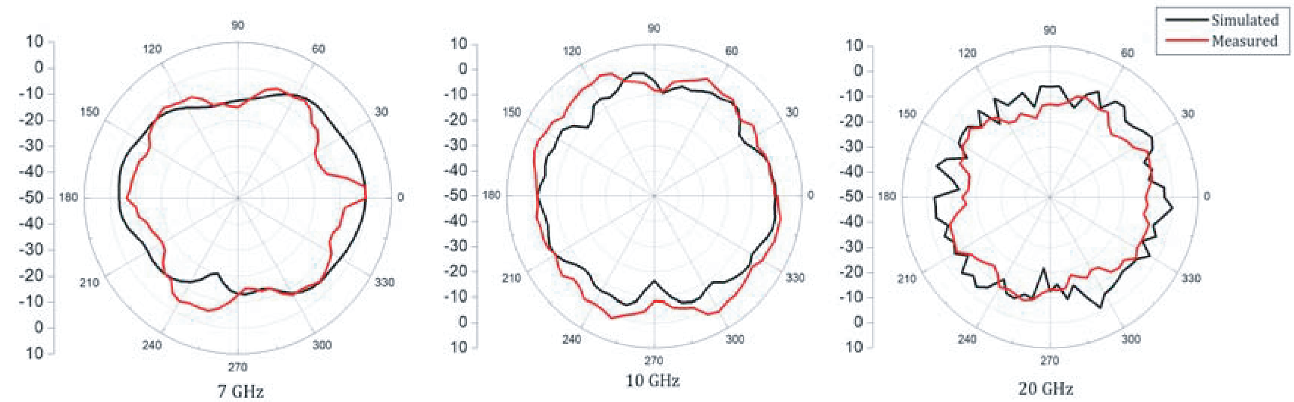
3. RESULTS AND DISCUSSIONS

The designs were simulated in Ansys electromagnetics Suite 19.1. Figure 3 shows the simulated and measured input reflection coefficients for various substrates. The super wideband nature is observed in all the three cases, as the geometry of the monopole mostly decides the super wideband width. It is observed that the impedance bandwidth is from 9.9 to 34.15 GHz as the range of frequencies over which the return loss is −10 dB. After washing the textile antenna, the deviation between simulated and measured curves could be attributed to fabrication and realization errors. The performance of antenna is measured from 1 to 40 GHz. The design for different substrates is also measured as shown in Figure 3(a). The simulated and measured radiation patterns for various frequencies in both the orthogonal planes are illustrated in Figure 4. All the patterns were measured in a standard 700 MHz to 40 GHz anechoic chamber. Additional care was taken to ensure polarization matching between the standard horn and the wearable antenna. These are similar to any standard super wideband antenna. The forward gain of the proposed antenna based on flannel with conductive ink is shown in Figure 5. With the increase of frequency, the gain also increases. Table 1 shows the comparison of different designs. All the characteristics of the antenna are maintained even after the wash, hence the performance of that conductive ink process could be useful for fabrication on textiles.

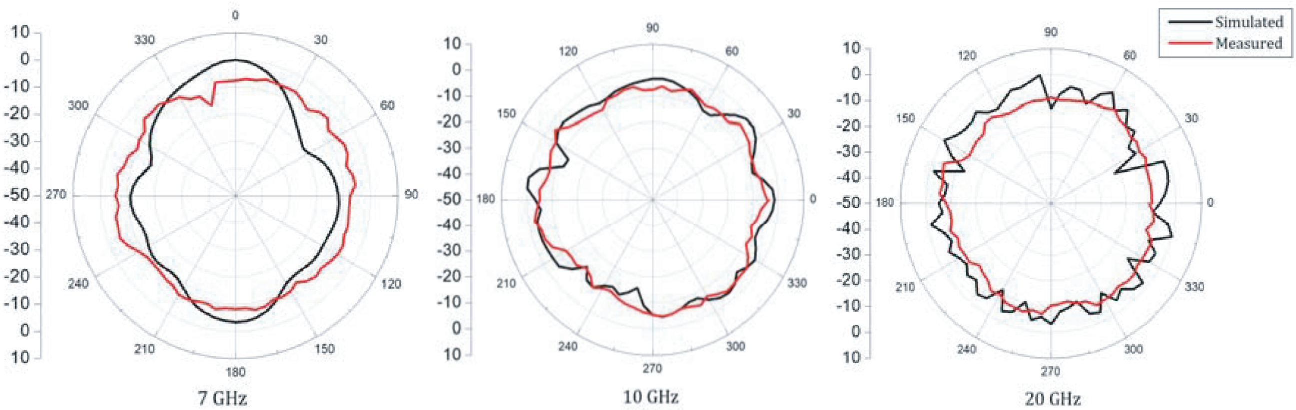


(a) (b)

Figure 3. (a) $|S_{11}|$ of the different materials. (b) $|S_{11}|$ of the textile antenna.



(a)



(b)

Figure 4. (a) and (b) represent the Radiation patterns at 7, 10 and 20 GHz. (a) E plane. (b) H plane.

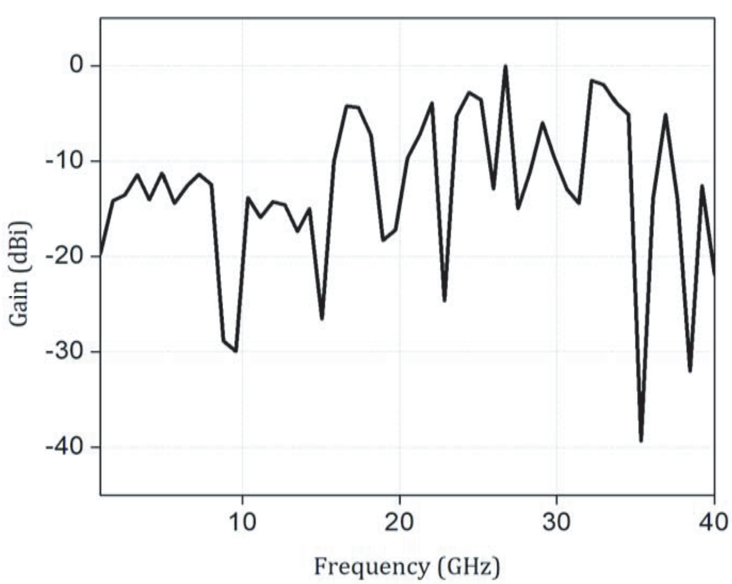


Figure 5. Gain of the textile antenna.

Table 1. Comparison with other designs.

Reference	**Design**	**Substrate with thickness**	**IBW**	**F**	**Size ($\mathbf{l} \times \mathbf{w} \times \mathbf{h}$), mm**	**W**
[1]	Fractal antenna	Jeans (1 mm)	171.6%	yes	$60 \times 60 \times 1$	no
[2]	Monopole antenna	PET paper (0.1 mm)	107.2%	No	$34 \times 25 \times 0.1$	no
[3]	Dipole antenna	Denim (0.8 mm)	124.6%	yes	$49 \times 12 \times 0.8$	no
[4]	dual-polarized embroidered textile antenna	Cotton (1.6 mm)		yes	$45 \times 19 \times 1.6$	no
[5]	Monopole antenna	Cotton (1.5 mm)	165.8%	yes	$50 \times 40 \times 1.5$	no
[6]	Yagi-Uda antenna	Cotton (0.2 mm)	115.6%	No	$26.0 \times 8.0 \times 0.2$	no
[7]	Fractal antenna	FR4 epoxy (1.5 mm)	102.41%	No	$25 \times 25 \times 1.5$	no
[8]	Patch antenna	FR4 (4.4)	115.9%	No	$40.4 \times 18.15 \times 4.4$	no
[9]	Monopole antenna	Jeans (1.25 mm)	112.5% (with notch)	Yes	$90 \times 90 \times 1.25$	no
proposed	**Fractal**	**Flannel (1 mm)**	**110.1%**	**Yes**	$60 \times 40 \times 1$	**yes**

PET: Polyethylene terephthalate, F: Flexible, w: washable

4. CONCLUSION

A textile fractal antenna with an endfire radiation pattern has been designed for wearable application over the entire 1–40 GHz range. The dielectric properties of the textile used as substrate have been characterized. The antenna has been fabricated using a flannel fabric, and its performances are measured. The super wideband characteristics have been observed in both simulated and measured results. The antenna is flexible and compact, and is a very promising solution for wearable application domain. The radiations patterns are omnidirectional in nature. The results show a good agreement between measured and simulated results.

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