Washing Durability: A Study on Brush Painted Jute Material based Monopole Antenna for On-body Communication Applications

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Abstract. This work is intended for developing a miniaturized wearable textile antenna on the jute fabric of dimensions 20×16 mm². The proposed antenna operates at 3.5, 4.9, and 5.8 GHz with circular polarization in all the operating bands. As part of the user's outfit, the antenna must be flexible and accommodate the wearer's clothing; for this purpose, the jute fabric in felt form is selected as a suitable substrate because of its durability and flexibility. The proposed antenna is built to withstand regular washing in the machine wash. The prototype is subjected to recurrent machine wash tests under different waters, such as soft water, hard water, and saltwater. After each wash cycle, the antenna is tested for validation. The results from all different washing conditions reveal that the antenna functions with minimal variations in the resonating frequencies. The proposed antenna's lifetime after frequent machine washing in different water conditions is also calculated using the electrochemical workstation; the results show the propounded textile antenna's robust performance.

Keywords: Jute material, textile antenna, recurrent washing.

1. Introduction

From the past decade, there was a particular interest shown in the research of wearable antennas, which were made up of textiles. This developing interest is because of the drastic increase in wearable wireless devices. Textiles are versatile materials that are formed by the network of artificial or natural fibers. The antennas developed from these textiles materials are known as textile antennas, unlike the conventional antennas made of rigid materials [1]. These textile antennas are highly potential, flexible, and are designed to work at various frequency bands for different applications [2]. These antennas play a vital role in launching an active communication link between wearable devices and are easy to integrate with garments [3]. These textile antennas have become the priority choice for realizing a wearable device; they worked with minimal variations in operating bands due to deformation like bendings and twisting and showed good performance in various climates compared to conventional antennas made of inflexible materials [4].

While developing a textile antenna, the essential factor to look for is the polarization technique. There are two types of polarization: circular polarization and linear polarization [5]. Circular polarization has a good probability of establishing a successful link between the receiver and transmitter [6-7]. Various textile antennas are designed using different methods, such as stitching and embroidery [8]. The
conductive textile yarn is used to knit or weave patterns on non-conductive textile substrates. Inkjet printing and Screen printing fabrication methods are useful for manufacturing wearable antennas with simple designs in large quantities [9]. Recently, antennas are also fabricated using SIW technology, a cost-effective technique known for its laminated waveguide technology.

As a part of everyday clothing, the textile antennas accumulate dust and other body fluids of the wearer, such as the user's sweat. For cleaning the textile antenna, it must be washed frequently. The wash cycles put more stress on the textile fibers, and frequent laundry cycles disturb the fibers [10]. So, wearable antennas must be designed in such a way that it can resist the washing conditions. Even after many washing cycles, the antenna must function in the same way as before. So special attention needed while developing the antenna [11]. The quality of the water used for washing also significantly vary the wearable antennas' performance. As a part of the wearer's outfit, the antennas are being washed in machine washes, with different water types, which changes from region to region. So we have experimentally examined the consequence of washing on the textile antenna's performance by considering three types of waters (hard water, soft water, and salinity water). Due to the antenna's frequent washings, there may be an effect on the operating frequencies, so we tested the antenna's resonating frequencies before and after washing. We also analyzed the proposed antenna's lifetime after frequent machine washing in different water conditions using the electrochemical workstation.

2. The Textile antenna topology and Fabrication

This work is intended to design a natural fiber-based textile antenna that can withstand the repetitive washing cycles; for that purpose, jute material with a thickness of 1.5mm is selected as a suitable substrate. The jute material is investigated with the scanning electron microscope [12]. As illustrated in Fig. 1a, the fibers' active intervention is demonstrated, and as shown in Fig. 1b, the diameters of the fibers are measured, ranging from 20 to 30 micrometers.

![Fig. 1. SEM analysis of jute material at (a) 500μm, and (b) 100 μm.](image)

The famous Yin Yang symbol inspires the proposed antenna structure. As shown in Fig. 2a, It contains a demilune structure as a patch element, and a similar design is presented on the opposite side as the ground element. In this work, we have used copper paint, which is highly conductive in nature, and this paint is applied through the conventional brush painting technique. Thus developed antenna is resonating at the frequencies of 3.5, 4.9, and 5.8 GHz. The measurement setup of the antenna is illustrated in Fig. 2b.
3. Washing durability analysis

As a body-worn textile antenna, the antenna is attached to the wearer's clothing and subjected to the washing cycles. The type of water used for washing will also affect the antenna's performance. This section presents the impacts of washing in different waters such as hard water, soft water, and saltwater on the proposed antennas' performance. As illustrated in Fig. 3a, the antenna was washed in a standard front load washing machine with a maximum rpm of 1000 rotations. The wash cycle period was 1 hour (40 minutes wash cycle, 15 min rinse cycle, and 5 min dry cycle). In all different washing conditions, the temperature of the waters was at standard room temperature.

3.1. Washing in soft water

The hardness of the water is generally a measure of the ability of water to react with soap. If the mineral depositions (calcium carbonate) in the water are less than 60 mg/l, it is classified as soft water. While realizing the soft water washing, we have taken the soft water with mineral depositions value of 60 mg/l. The antenna is washed for a 1-hour complete wash cycle and sun-dried for 8 hours to ensure no moisture is left inside. Then the antenna is validated in the anechoic chamber. Slight variations in the resonating frequencies are noted and resonating at 3.65, 4.89, and 5.86 GHz, as shown in Fig. 3b.
3.2. Washing in hard water

Natural water is said to be as hard water when it contains minerals such as magnesium and calcium. The hardness value changes from location to location. Water, which contains calcium carbonate that ranges from 60 to 120 mg/l, is treated as moderate hardness. When its value is 120 to 180 mg/l, it's said to be as hard, and for the value greater than 180 mg/l, it is classified as very hard water. In this study, we have taken the hard water of the hardness value 190 mg/l to satisfy all the different hardness conditions. After washing in hard water, the antenna is tested in an anechoic chamber for validation. As illustrated in Fig. 4(a), the antenna operates well in all the three resonating modes with slight variations and operating at frequencies of 3.4, 4.92, and 6.0 GHz.

3.3. Washing in salinity water
Groundwater comprises various types of salts, and if it was dominated by sodium, it's said to salinity. Groundwater also varies from area to area. Salinity is expressed in electric conductivity, and if it's value greater than 15,000 EC, it is said to be as high salinity and is not suitable for irrigation. The proposed antenna is washed in the water of salinity value 15,000 EC. The proposed prototype was then tested, and as shown in Fig. 4(b), it's operating in all the frequencies with minor variations in the center frequency, which are at 3.59, 5.0, and 6.1 GHz.

4. Electrochemical behavior analysis

This section estimates the proposed antenna's lifetime after frequent machine washes in different water conditions. Copper is a metal that corrodes naturally while being exposed to the environment. When the proposed antenna is exposed to a regular machine wash environment, where it was washed with harsh detergents and with different waters, it will initiate the degradation process called corrosion. Corrosion is a natural process, which is an electrochemical reaction between the metal and the surrounding environment. Electrochemical workstations are used to instantly find corrosion values to mimic this natural process, where corrosion is measured as millimeters per year (MMPY.). In this study, the electrochemical workstation Biologic SAS, SP-300 model, was used to find the tafels plot.

![Tafels plot curve of the Jute material washed in various environments.](image)

The proposed antenna is tested for finding its metal degradation after 15 wash cycles in different water conditions, such as soft, hard, and saltwater. The Tafel plot curve is used to determine the corrosion rate, and it's a plot between the current density and current potential. Fig. 5 shows the antenna's Tafels plot curves washed in soft, hard, and saltwater environments. From these results, it's observed that softwater washing shown the least metal degradation, followed by hard water, and saltwater washing showed the maximum corrosion value. However, all these values showed minimal corrosion.

5. Conclusion

This work successfully developed a textile-based wearable antenna, operating at three frequencies of 3.5, 4.9, and 5.8 GHz. A high level of robustness, flexibility, and easy integration to the wearer's garment is achieved by adopting the jute material as the flexible substrate. The antenna is compact, with a size
of 20×16 mm². The proposed wearable antenna withstand the recurrent machine washes with soft, hard, and saltwater through no distortions like cracks, fiber pullouts, and deformation in the fiber’s alignment. After each wash cycle, the antenna is tested in an anechoic chamber for validation. In all the cases, it's working exceptionally well, and the jute active fiber intervention successfully survived the harsh environment of the machine wash recurrently in different waters.

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