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Design of Textile Antenna for Moisture Sensing †

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Abstract: This study reports a design of an e-textile microstrip patch antenna for wireless sensing of the moisture content of a fabric substrate. The microstrip patch antenna with a proximity coupled feeding line is implemented on two layers of polyester felt substrate. The performance of the antennas in terms of the reflection coefficient S11 is measured, indicating that the resonance frequency of the antenna shifts to a lower frequency for moisture contents ranging from 20% to 100%. This is the result of a change in the dielectric constant and the loss tangent of the substrate material caused by the presence of moisture. The proposed moisture sensor exhibits high linearity and higher sensitivity than state-of-the-art textile-based antenna sensors, and is suitable for a variety of applications such as sweat and wound monitoring.

Keywords: antenna sensor; chipless moisture sensor; resonant frequency

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1. Introduction

There has been an increased interest in recent years in designing antenna-based sensors, due to their simple structure, low-cost, battery-free, and wire-free operation [1]. The majority of wireless sensors use the resonant technique to sense a variety of materials from liquid characterisation to temperature sensing, and even crack and strain monitoring. Moisture causes the antenna to detune and introduces losses into the textile antenna. As water has a much higher and more stable dielectric constant, it can significantly change the dielectric properties of the fabric leading to a shift in the antenna resonance frequency. By monitoring the resonant frequency of the antenna, which changes as a function of the water content absorbed by the fabric substrate, a wireless sensor can be realized. Such a moisture sensor can be used for various applications such as for measuring water drops or sweat and fluid loss in wound care.

In Refs. [2,3], a planar inverted F-antenna (PIFA) was implemented by embroidering conductive yarn on a denim textile for moisture sensing. However, non-linearity in the antenna response meant that the sensor did not provide accurate results. Furthermore, the patch was shorted at the end, which required the destruction of the textile substrate. As a result, the antenna was hard to fabricate on textile materials.

This study investigates the performance of microstrip patch antennas in terms of variation in the reflection coefficient in response to different moisture contents. The microstrip patch antennas with proximity coupled feeding lines were implemented in two-layer felt substrates, and the dimensions of the antenna were tuned to resonate at 2.45 GHz. The antennas were tested with different moisture contents and the results showed that the resonance frequency of the antenna shifted to a lower frequency, demonstrating its suitability to be used as a moisture sensor. Compared with alternative textile antenna designs, the proposed antenna designs are more suitable for integration within textiles, and can be easily fabricated.

2. Antenna Design

The geometry of the proximity coupled microstrip patch antenna is shown in Figure 1a. The length and width of the patch are 52 mm and 46 mm, respectively. The patch length can be optimised to tune the antenna's resonance frequency, i.e., increasing the length of the patch will shift the resonance frequency to a lower band. A 50 Ω microstrip feed line, 4.15 mm wide and 31 mm long, was designed and symmetrically positioned under the patch on top of substrate 2. Moreover, a 1-mm-thick polyester substrate with a dielectric constant of (ε_r) of 1.2 and loss tangent (δ) of 0.02 at 2.45 GHz was used to simulate the antenna in CST Microwave Studio [4] in two configurations: (i) polyimide laminates [5], and (ii) copper fabric [6], used for the patch, the microstrip, and the ground plane.

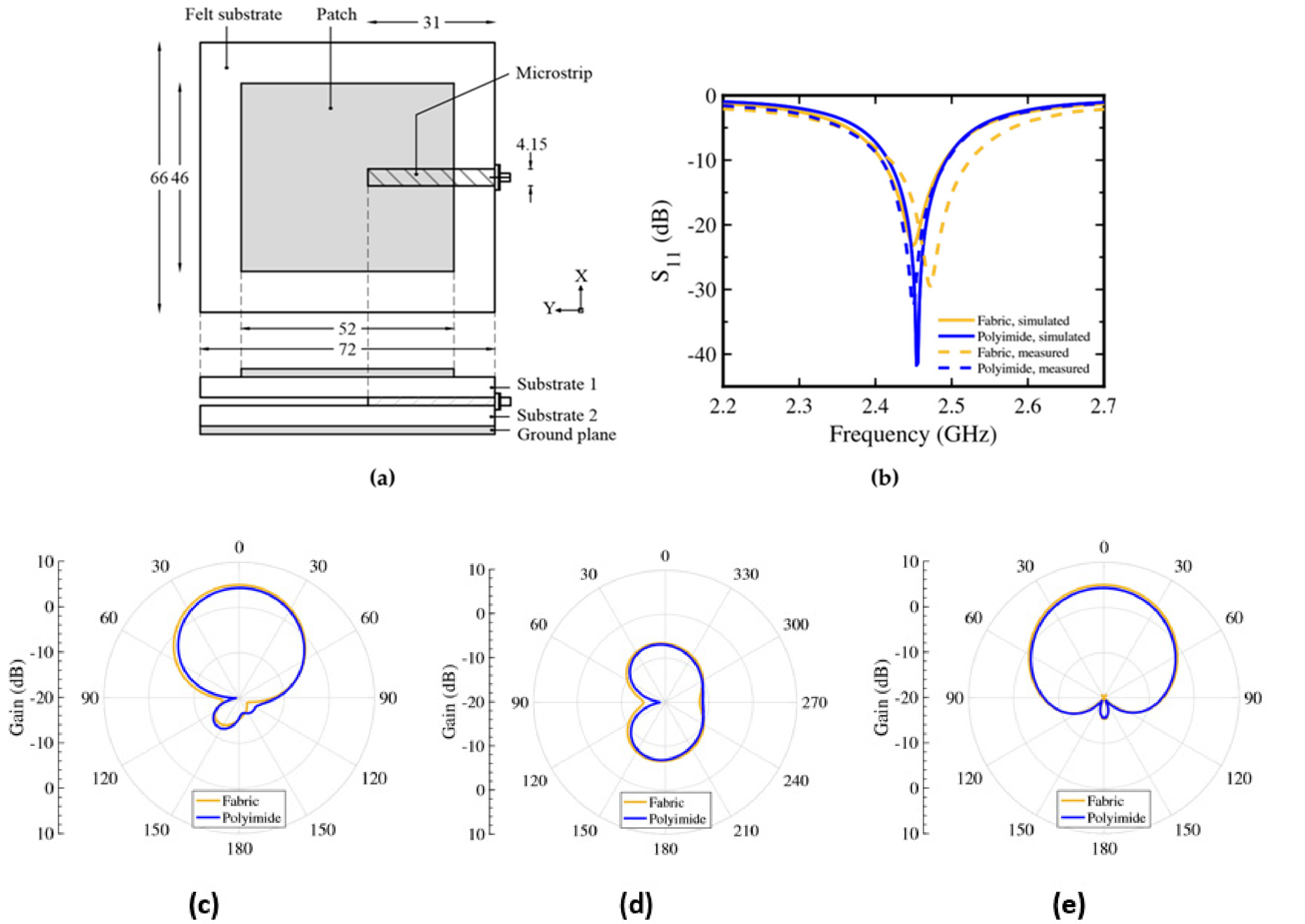

Figure 1. (**a**) Geometry of the proximity coupled microstrip patch antenna; (**b**) simulated and measured reflection coefficient S_{11} of the polyimide and fabric antenna designs; antenna gain in the (**c**) yz–plane, (**d**) xy–plane and (**e**) xz–plane.

The simulated and measured reflection coefficients of the antennas are shown in Figure 1b, indicating that both antennas were well matched (S11 > –10 dB) at 2.45 GHz. There was a slight shift in the measured frequency response of the fabric antenna, which was caused by cutting the patch a little short. Figure 1c–e shows the radiation pattern of the patch in yz-plane, xy-plane and xz-plane, respectively, and it can be observed that both antennas had a gain of about 4.98 dB with a radiation efficiency of 49.5% at 2.45 GHz.

3. Measurements and Results

The antenna (Figure 1a) was fabricated. In the first prototype, a copper laminate was used for the patch, the microstrip, and the ground plane, while a copper fabric was used in the second prototype, realizing a fully textile, breathable, and flexible antenna, as shown in Figure 2a. A repositionable adhesive pray [7] was used to attach the coppers to the substrates. The antenna designs (Figure 2a) were baked in the oven for about 5 hours at 105 °C to dehumidify the substrate, and then the reflection coefficient measurements were performed with a calibrated network analyser, as shown in Figure 2b. Figure 2c,d shows a shift in the resonance frequency as the antenna substrate gradually absorbs more water, where 0% refers to the dry antenna. The amount of the water content absorbed by the fabric was calculated as:

$$Moisture\ content\ (\%) = \frac{m_{wet} - m_{dry}}{m_{dry}} \times 100 \quad (1)$$

where m_{wet} and m_{dry} are referring to the wet and dry weight of the antenna. The results show that the resonance frequency of both antennas shifted to a lower frequency when the different moisture content was applied. It can be observed that the maximum water content for the fabric antenna reached 77%. This was due to the amount of water lost from the substrate through the ground plane, as the fabric was not water-resistant compared to the copper antenna. At the dry state, both antennas resonated at the 2.45 GHz ISM band. On the other hand, when the antennas were fully wet, the antenna made of polyimide resonated at 1.34 GHz, while the antenna made of ohmic sheet resonated at 1.45 GHz. The shifting in the resonance frequency of the antennas determined the moisture content absorbed by the antenna substrate, and hence the sensor response. Comparing with alternative textile antennas, the proposed patch antenna is more suitable for textile applications as it has a more linear response and can be easily fabricated. The results indicated that the fully textile antenna had a higher sensitivity value of 0.532% compared to the copper antenna and the antenna proposed in Refs. [2,3], which had sensitivity values of 0.443% and 0.463%, respectively.

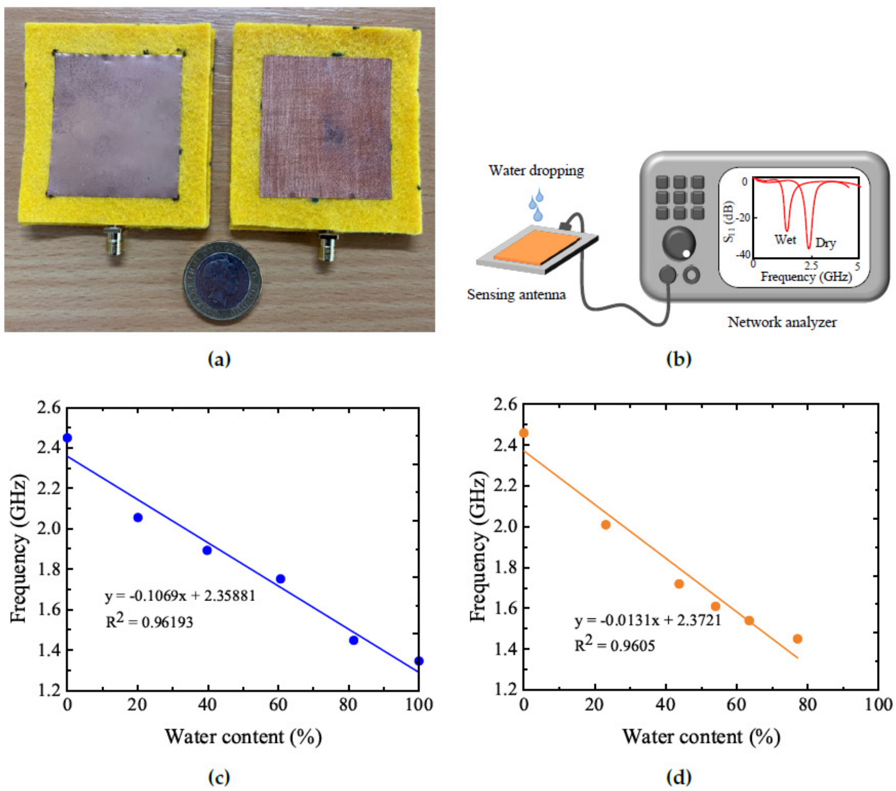

Figure 2. (**a**) Fabricated antennas; (**b**) measurement setup; (**c**) resonance frequency against water content for polyimide antenna; and (**d**) resonance frequency against water content for fabric antenna.

4. Conclusions

Two patch antennas operating at 2.45 GHz have been demonstrated in this paper, enabling low-cost moisture sensing. The resonance frequency of the antenna shifts to a lower frequency band as the antenna absorbs more moisture. This shift in the resonance frequency of the antenna indicates the amount of moisture absorbed by the fabric. It was observed that the full fabric patch antenna design was more sensitive compared to the polyimide antenna. The antennas are flexible, low-cost, easy to fabricate, and can be seamlessly integrated with clothing for on-body applications. The objective of our future work is to investigate different types of fabrics which are more absorbent, such as escalade, cotton and linen.

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