Design of Compact Flexible UWB Antenna Using Different Substrate Materials for WBAN Applications

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Abstract— In this paper, the design process of compact flexible ultra-wideband (UWB) antenna using various substrate materials such as FR4, Kapton, and Rogers RT5880 is discussed and experimentally investigated. The proposed antenna is structured as a flexible model that can conform to suite the human body surface to be suitable for wireless body area network (WBAN) applications. The performance parameters of the antenna have been evaluated by using CST Microwave Studio software and very similar results have been achieved by applying FR4, Kapton, and Rogers RT5880 substrates, but latest layer provides the optimized results. Therefore, the Rogers RT5880 substrate was chosen to be experimentally tested for antenna realization and validating the simulated results. It was exhibited that very good agreement between the simulated and measured results have been obtained. It is shown that, the proposed antenna with advantages of miniaturized dimensions of $22 \times 28 \times 1.6\,\text{mm}^3$, dual band capability to operate over 4.8–5.3 GHz, and 7.0–8.6 GHz spectrums, high gain above 5.5 dBi for both bands, omnidirectional radiation patterns, simple layout, ease of manufacture, and cost effective can be good nominate for wireless applications such as wireless body area network (WBAN).

1. INTRODUCTION

WBANs are a type of wireless network that are used to monitor and collect physiological and environmental data from the human body [1]. It has received considerable attention in recent years as a result of its potential applications in the healthcare industry [2]. Antennas are essential in WBAN applications for transmitting and receiving signals [3]. The physical dimensions, substrate material, and surrounding environment all have an impact on the antenna's performance [4]. As a result, designing a compact and efficient antenna for WBAN applications is a difficult task [5]. Because of their high bandwidth and low power consumption, ultra-wideband (UWB) antennas are well suited for WBAN applications [6]. However, the performance of the UWB antenna is determined by the substrate material used [7].

With the use of a fabric that has a lower dielectric constant and decreases losses associated with the antenna's surface wave, impedance and bandwidth of the antenna can be significantly improved [8]. Through simulations, various antenna structural parameters were found to be effective in achieving the directionality required for various wireless applications [9]. A new design of a smaller, highly directional antenna with an added reflector is presented [10].

Wideband (WB) patch antennas, WB monopole antennas, slotted antennas, mutilated patch UWB antennas, tapered slotted geometry, meta-material-based UWB antennas, elliptical printed monopole UWB antennas, and adjustable, on-body UWB antennas used for wireless communication are among the antenna geometries that are being taken into consideration [11]. The realization of the antenna is contrasted in terms of size and uses for portable communication devices [12].

Designing a compact flexible UWB antenna for WBAN applications requires careful consideration of various factors such as size, bandwidth, flexibility, and performance. Here is a general guideline for designing such an antenna:

1- Determine the desired frequency bandwidth, gain, and flexibility [13].
2- Select the antenna to suit the proposed application.
3- Select the type of the flexible substrate with low dielectric loss.
4- Determine the antenna dimensions.
5- Optimize the geometry by adjusting the parameters to the required specifications.
6- Consider the applicable feeding techniques to the desired impedance matching.
7- Incorporate a ground plane geometry.
8- Perform the simulations and optimizations process.
9- Fabricate and test the antenna prototype by measuring the return loss, radiation pattern, and gain.

In this paper, we present the design and comparative analysis of a compact flexible UWB antenna for WBAN applications using various substrate materials. The proposed antenna has a flexible structure that allows it to conform to the surface of the human body, making it suitable for WBAN applications. The antenna's performance is evaluated using various substrate materials such as FR4, Rogers RT5880, and Kapton, but finally the antenna is fabricated and experimentally validated by applying the Rogers RT5880 substrate.

2. SIMULATION PROCESS

The proposed antenna is simulated using the CST Microwave studio software package. A modified planar inverted-F antenna (PIFA) with a rectangular patch and a tapered ground plane is used in the proposed antenna design to enhance the bandwidth [14]. The proposed antenna has dimensions of $22 \times 28 \times 1.6\,\text{mm}^3$ as seen in Fig. 1.

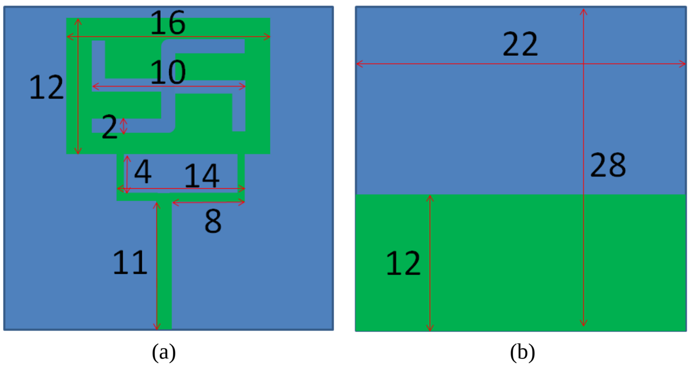
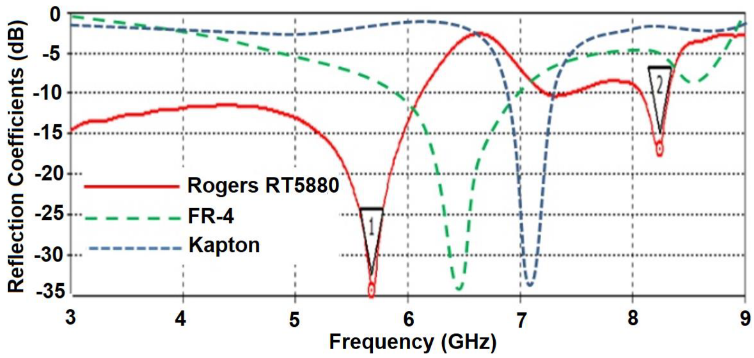


Figure 1: The numerical model of the proposed antenna with all dimensions in mm-scale, (a) top side, and (b) back side.

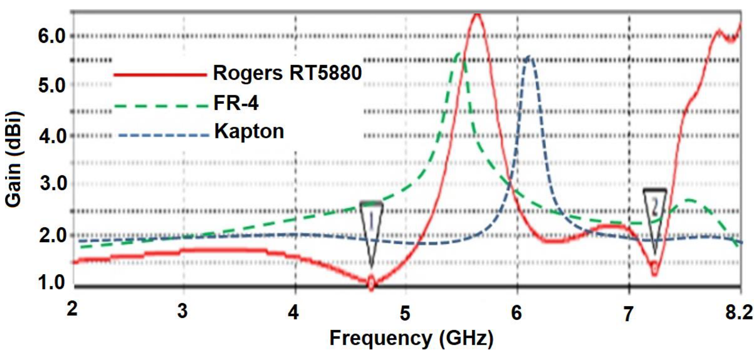
The antenna is designed to operate at frequencies ranging from 3.1 GHz to 8.3 GHz. The simulations are run on three different substrates: FR4, Rogers RT5880, and Kapton. We applied a parametric study based on CST Microwave Studio to optimize the proposed antenna numerically to reach the final design dimensions. We tested the proposed antenna design performance inside CST Microwave Studio by changing the substrate with Rogers RT5880, FR4, and Kapton. According to the obtained simulation results, the proposed antenna with the Rogers RT5880 substrate has the optimized performance in terms of bandwidth, however for the other cases the results are very similar which shows the flexibility of the proposed design than changing the substrate layers.

The proposed antenna implemented on the Rogers RT5880 substrate operates over two frequency bands of 3.0 GHz–6.1 GHz, and 7.2 GHz–8.3 GHz with reflection coefficients below than −10 dB and the resonance frequencies of 5.7 GHz and 8.2 GHz, respectively, as depicted in Fig. 2(a). At the resonating frequencies of the two operating bands, the proposed antenna shows an approximately same peak radiation gain of 6.5 dBi, as depicted in Fig. 2(b). It is also observed in Figs. 2(c) and 2(d) that at both resonating frequencies the antenna exhibits omni-directional radiation patterns.

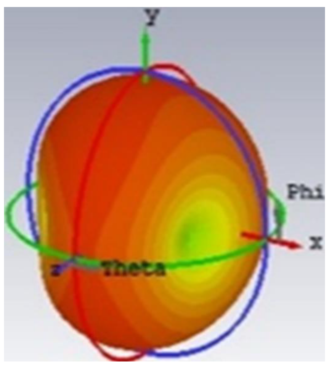
Looking at the results presented in Figs. 2(a) and 2(b), it is clear that by changing the substrate materials the performance parameters of the proposed antenna design are approximately similar with the initial case but with slightly moving around upper frequencies, which highlights the flexibility of the proposed design which can be realized on the various substrate materials with keeping constant its performances.



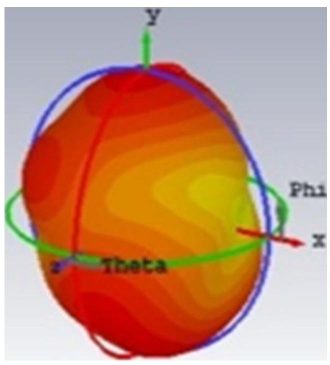
(a)



(b)



(c)



(d)

Figure 2: Performance parameters of the proposed antenna, (a) reflection coefficients, (b) 2D curve of the radiation gain, (c) 3D radiation pattern at 5.7 GHz, and (d) 3D radiation pattern at 8.2 GHz.

3. FABRICATION PROCEDURE

To make the proposed antenna designed on Rogers RT5880 suitable for WBAN applications, it is made by a flexible thin material of polyimide film with a thickness of 0.1 mm using the same technology presented in [15]. The copper layer is deposited onto the substrate via sputtering, followed by etching to form the desired pattern. The proposed compact antenna has overall dimensions of $22 \times 28 \times 1.6\,\mathrm{mm}^3$.

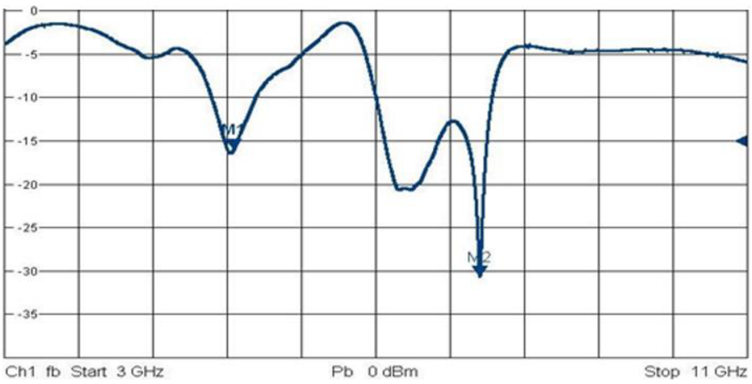
The top- and bottom-views of the fabricated prototype of the proposed flexible antenna have been shown in Figs. 3(a) and 3(b), respectively. The experimental imprudence bandwidth presented in Fig. 3(c) exhibits that this antenna operates through two frequency bands of 4.8 GHz–5.3 GHz and 7.0 GHz–8.6 GHz with resonating frequencies at 5.1 GHz and 8.5 GHz, respectively, which are approximately same in comparison with the simulated ones.

The peak radiation gains of around 5.7 dBi and 5.9 dBi are observed at the resonant frequencies of 5.1 GHz and 8.5 GHz, respectively, which demonstrates good agreements with the simulated results.

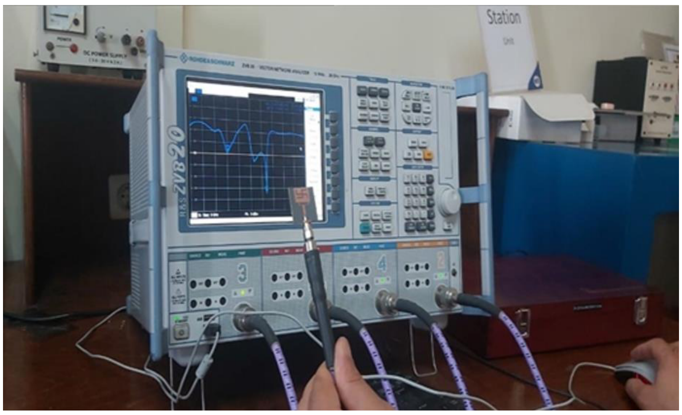
The measurement setup has been presented in Fig. 3(d).

(a)

(b)



(c)



(d)

Figure 3: Experimental results, (a) top view of the fabricated layout of the antenna, (b) its bottom view, (c) reflection coefficient ($S_{11} < -10\,\mathrm{dB}$), and (d) measurement setup.

4. CONCLUSION

The primary goal of this work was to design and realize a compact dual-band UWB antenna using the various substrate layers to cover a wide impedance bandwidth with high radiation gain and required radiation patterns. The results of all simulated models were approximately identical, which shows the flexibility of implementation of the proposed design on various layers with keeping approximately constant its performance parameters. Finally, the Rogers RT5880 substrate layer was chosen for manufacturing test because the optimized results were achieved using this material. It was exhibited that the experimental results have provided a good agreement with the simulate ones. So, the proposed antenna with compact dimensions of $22 \times 28 \times 1.6\,\text{mm}^3$ can operates over two frequency bands of 4.8–5.3 GHz, and 7.0–8.6 GHz, which shows the peak radiation gains of around 5.7 dBi and 5.9 dBi at its resonant frequencies of 5.1 GHz and 8.5 GHz, respectively. The results show that the proposed flexible antenna can be potential candidate for various wireless applications such as wireless body area network (WBAN).

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