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DESIGNING, SIMULATING AND ANALYZING OF MICROSTRIP ANTENNA FOR WIRELESS BODY NETWORK USING TWO DIFFERENT TYPES OF SUBSTRATES

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Abstract. Microstrip patch antennas are used in wireless networking due to their flexibility, light weight, and ease of fabrication. This article discusses the designed and simulated microstrip patch antenna for WBAN networks using professional CST Studio Suite 2020 software. The antenna operating frequency was 2.5 GHz, and its substrate was made of FR-4 (lossy) and Rogers RT/Duroid 5880 PCB materials with permittivity of 4.3 and 2.2, respectively. Both materials showed good results, but Rogers RT/Duroid was better with an efficiency of 94.4% because it has excellent performance characteristics that make it more suitable for use in wearable devices. The antenna substrate and ground plane were made of copper with a substrate height of 1.58 mm for Rogers RT/Duroid and 2.8 mm for FR-4. During the research process, an antenna with low return loss and a standing wave ratio value as close as possible to unity was created.

Keywords: microstrip patch antenna, wireless body network, Rogers RT/Duroid material.

Conflict of interests. The authors declare no conflict of interests.

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ПРОЕКТИРОВАНИЕ, МОДЕЛИРОВАНИЕ И АНАЛИЗ МИКРОПОЛОСКОВОЙ АНТЕННЫ ДЛЯ БЕСПРОВОДНОЙ НАТЕЛЬНОЙ СЕТИ С ИСПОЛЬЗОВАНИЕМ ДВУХ РАЗЛИЧНЫХ ТИПОВ ПОДЛОЖЕК

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Аннотация. Микрополосковые патч-антенны используются при построении беспроводных сетей благодаря их гибкости, легкости и простоте изготовления. В статье рассмотрена спроектированная и смоделированная микрополосковая патч-антенна для сетей WBAN с использованием профессионального программного обеспечения CST Studio Suite 2020. Рабочая частота антенны составляла 2,5 ГГц, ее подложка изготавливалась из материалов для печатных плат FR-4 (с потерями) и Rogers RT/Duroid 5880 с диэлектрической проницаемостью 4,3 и 2,2 соответственно. Оба материала показали хорошие результаты, но Rogers RT/Duroid оказался лучше с эффективностью 94,4 %, поскольку обладает превосходными эксплуатационными характеристиками, которые делают его более подходящим для использования в носимых устройствах. Подложка и заземление антенны были изготовлены из меди с высотой подложки 1,58 мм для Rogers RT/Duroid и 2,8 мм для FR-4. В процессе исследований создана антенна с низкими обратными потерями и значением коэффициента стоячей волны, максимально приближенным к единице.

Ключевые слова: микрополосковая патч-антенна, беспроводная нательная сеть, материал Rogers RT/Duroid.

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Introduction

In recent years, Wireless Body Area Networks (WBANs) have emerged as a transformative technology in healthcare. These networks include the use of wearable antennas for transmitting and receiving of the data for healthcare related systems [1]. Microstrip patch antennas are being used more and more for wireless communication because they are lightweight, affordable, easy to manufacture, have flexible feed lines, an omnidirectional, two-dimensional field pattern, and work with solid-state equipment.

Microstrip antennas became very popular in the 1970s primarily for spaceborne applications. Today they are used for government and commercial applications [2]. These antennas are easy to make. A common microstrip antenna consists of a metal radiating plate that is attached to one side of a dielectric substrate. On the substrate's other side, a continuous metal layer is attached to the ground plane. This radiating patch is on one side of dielectric substrate ($\varepsilon_r \leq 10$), which has a ground plane on other side [3, 4].

There are multiple dielectric materials available in the market for printing antennas. Each dielectric have their own special properties, different dielectric constants, different conduction properties, etc. affecting the fringing waves in the patch antenna, and hence enhancing the overall properties of the antenna [5]. Rogers RT/Duroid 5880 and FR-4 are both used in this research as substrates. Some main key performance parameters that need to be considered for Microstrip Patch Antenna are reflection coefficient bandwidth, input impedance, radiation pattern, surface current, VSWR, gain and return loss.

These antennas can provide constant, discreet monitoring and sensing of several parameters in and on human bodies, including temperature, blood pressure, ECG, EEG, and PH, and other medical applications. But unlike antennas embedded in portable devices, wearable antennas are designed to work in the complicated body-centric environment. Antenna performance near to human body is different than antenna placed in free space [6]. In the future, it is envisaged that each person is going to be wearing multiple sensors on their body being a part of a Body Area Network (BAN) [7].

This research examines the design and structure of a microstrip patch antenna for Wireless Body Antenna (WBAN) applications, focusing on its planar structure and conformability to the human body, utilizing the 2.5 GHz ISM frequency band.

This study explores microstrip patch antenna design principles, including substrate selection, patch shape optimization, and feeding technique. It analyzes performance parameters like return loss, radiation pattern, efficiency, and gain, to design an antenna that works in wireless body area networks, improving health monitoring system efficiency and reliability.

Simulated antenna design

The designed antenna is a microstrip patch antenna (MPA). It is designed to match the WBAN demands such as observing the human vital signs. The MPA simulation was done using the CST software. During the designing process, a systematic approach has been followed, considering various factors such as frequency range, bandwidth requirements, VSWR (Voltage Standing Wave Ratio) requirements, RL (return loss) and physical constraints. Fig. 1 shows the design of the antenna using the simulation software CST.

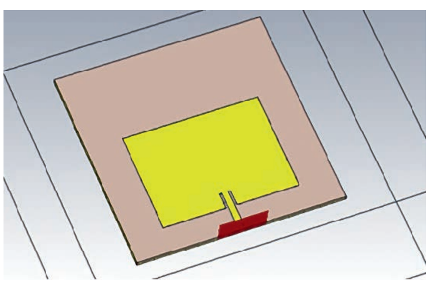


Fig. 1. The antenna's design using CST

Patch design specifications

The proposed wearable patch antenna is designed with microstrip line inset feeding technique. The operating frequency of the antenna is at 2.5 GHz because it can be used in WBAN applications.

A 50 Ω input impedance is used to feed the patch antenna. Two antennas were implemented on two different materials substrates. The first substrate is Rogers RT/Duroid 5880 material and the other one is FR-4 (or FR4). The Antennas' geometrical parameters such as patch length L_p and patch width W_p have been computed using the following steps and formulas mentioned below.

1. Calculate the patch width

$$W_p = \frac{c}{2 f_0 \sqrt{\dfrac{\varepsilon_r + 1}{2}}},$$

where c is the light speed; f_0 is the operating frequency; ε_r is dielectric constant.

2. Calculate the effective dielectric constant

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}},$$

where ε_{eff} is the effective dielectric constant; h is the substrate thickness; w is the patch width.

3. Calculate the effective length

$$l_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{eff}}}.$$

4. Calculate the extension length

$$\Delta L = 0.412h\frac{\left(\varepsilon_{eff} + 0.3\right)\left(\dfrac{w}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right)\left(\dfrac{w}{h} + 0.8\right)}.$$

5. Calculate the patch length $L_p = l_{eff} - 2\Delta L.$

Antenna and substrate specifications

The dimensions of the patch antenna play an essential role to make the antenna design effective in terms of desired results. The parameters of the antenna are presented in Tab. 1.

Table 1. Antenna design parameters

Parameter	Symbol	Parameter value	
		Rogers RT/Duroid 5880	FR-4
Operating frequency	f_0	2.5 GHz	2.5 GHz
Patch dimension along x	L_p	38.857 mm	28.04 mm
Patch dimension along y	L_p	52.177 mm	36.85 mm
Substrate thickness	h	1.58 mm	2.8 mm
Substrate dimension along x	L_s	80 mm	80 mm
Substrate dimension along y	W_s	80 mm	80 mm
Inset gap	G	0.8 mm	4.5 mm
Feeding line length	L_f	10 mm	20 mm
Feeding line width	W_f	2.5 mm	3 mm
Dielectric constant of substrate	ε_r	2.2	4.3
Input impedance	Z_0	50 Ω	50 Ω

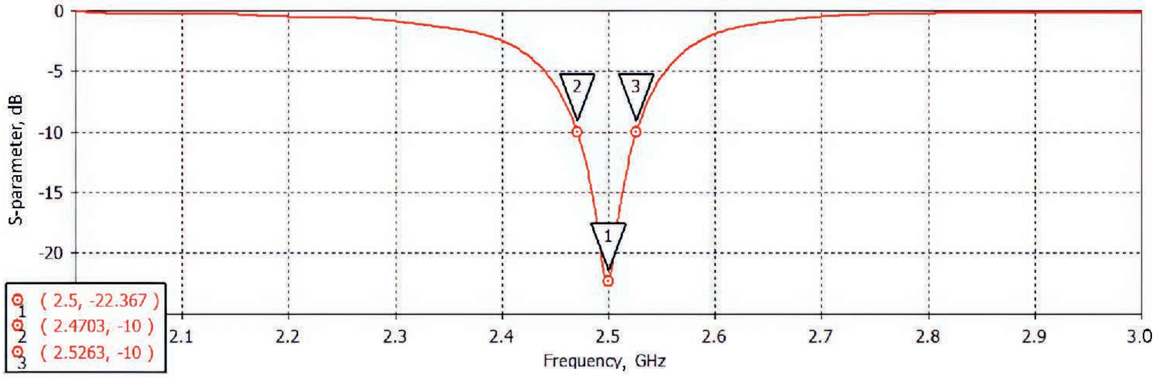
The substrate of the antenna is made from Rogers RT/Duroid 5880 and from FR4. The materials' characteristics are listed in Tab. 2.

Table 2. Substrate parameters

Parameter	Symbol	Parameter value	
		Rogers RT/Duroid 5880	FR-4
Dielectric constant	ε_r	2.2	4.3
Loss tangent	σ	0.0009	0.035
Substrate thickness	h	1.58 mm	2.8 mm

Results and discussion

Fig. 2 represents the amount of power at the input port of the antenna which is reflected back and the remaining power which is radiated by the antenna. The value of return loss is less than or equal to –10 dB at a particular frequency band for the antenna to work efficiently for practical applications [8].



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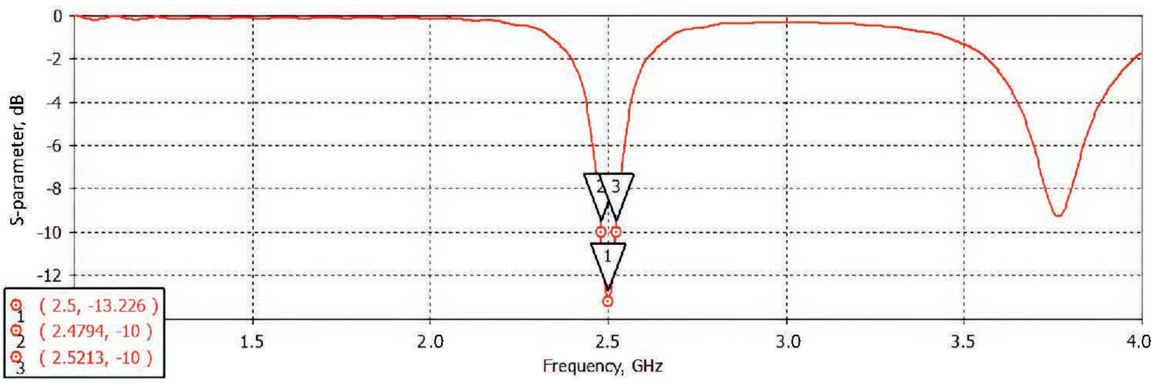


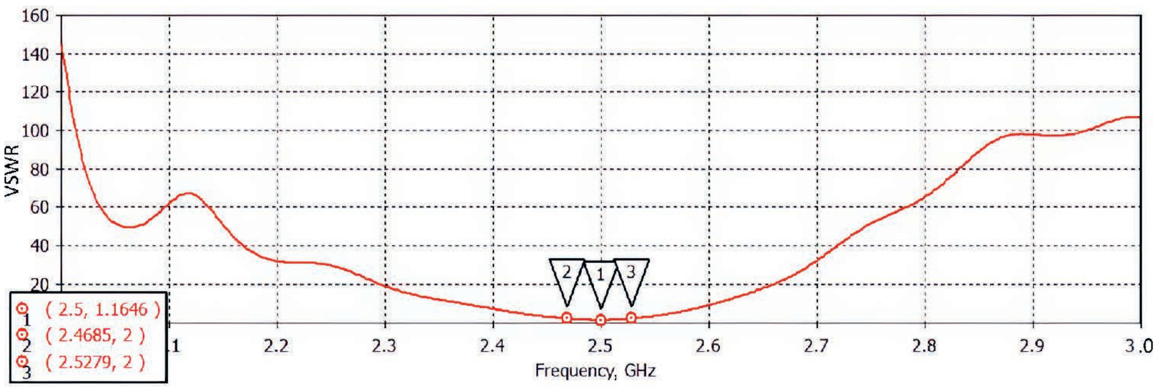
b

Fig. 2. RL result for the antenna with Rogers RT/Duroid 5880 (*a*) and FR-4 (*b*) substrates

The result from Fig. 2 shows the minimum return loss value achieved at 2.5 GHz which is –22.36 dB for Rogers RT/Duroid 5880 and –13.226 dB for FR-4. The value is marked by 1, and the achieved values are acceptable. Bandwidth on the other hand is the difference between the two values of frequency marked by 2 and 3. So, the antenna's BW will be demonstrated to be 0.056 GHz for Rogers RT/Duroid 5880 and 0.0419 GHz for FR-4.

Voltage standing wave ratio (VSWR) indicates how much an antenna's impedance is fitted to the radio or transmission line to which it is linked [9]. The ideal value of VSWR is 1 where maximum power is transferred [10]. Fig. 3 shows the value of the antenna's VSWR at 2.5 GHz. The VSWR is 1.1646 marked with 1 for Rogers RT/Duroid 5880, and 1.5579 for FR-4.

The Gain denotes the amount of power transferred to the main beam [11]. It can also be defined as the ratio of output power (or amplitude) to input power (or amplitude). As can be seen in Fig. 4 the gain of the MPA at 2.5 GHz and 7.296 dBi using Rogers RT/Duroid 5880, and 5.708 dBi for FR-4. For farfield gain the next figures show the polar pattern for the MPA's gain.



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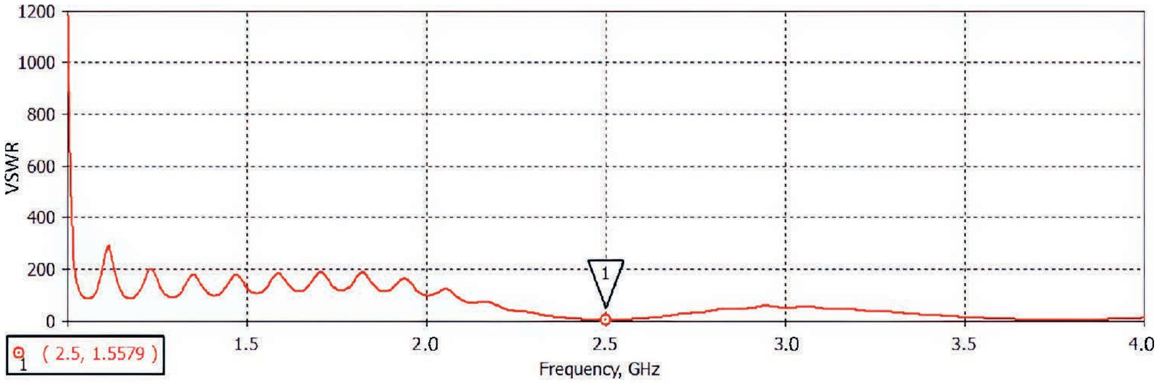

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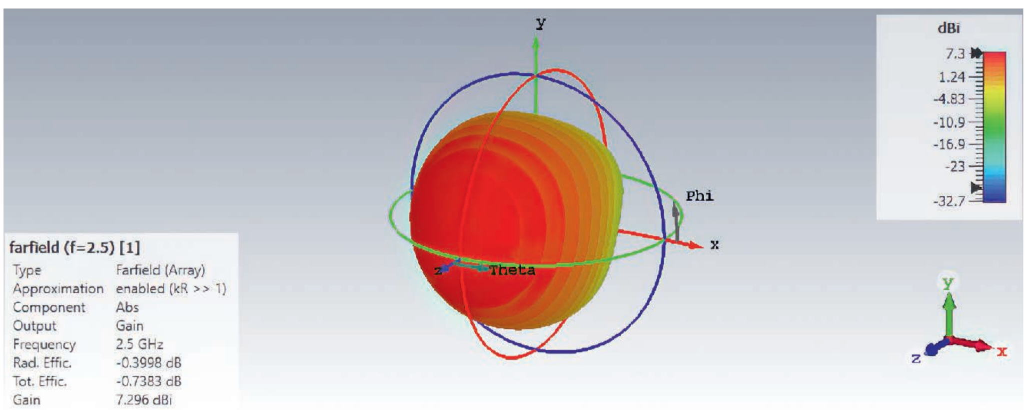
Fig. 3. Voltage standing wave ratio result for the antenna with Rogers RT/Duroid 5880 (*a*) and FR-4 (*b*) substrates



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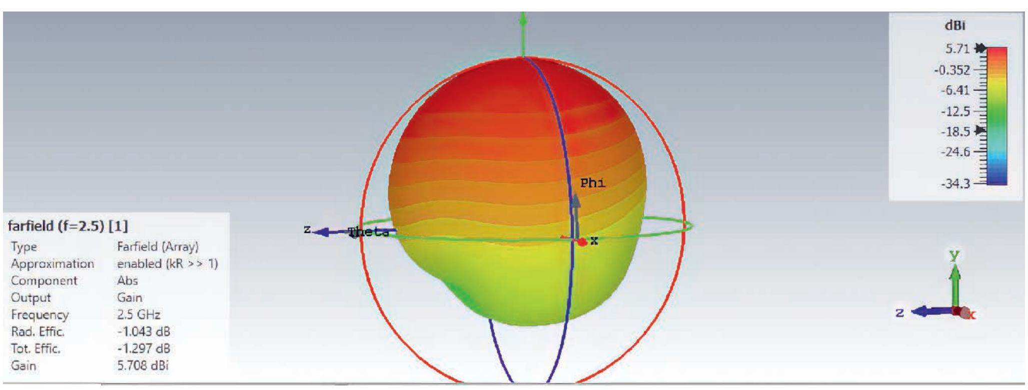
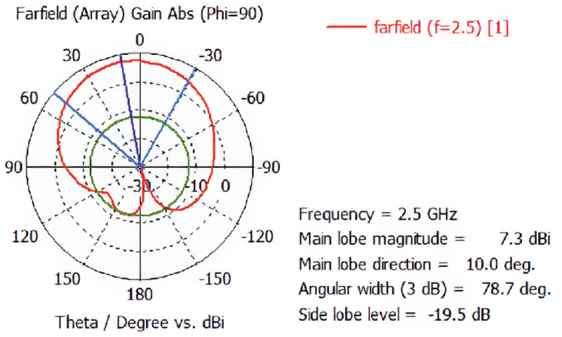


b

Fig. 4. Gain result for the antenna with Rogers RT/Duroid 5880 (*a*) and FR-4 (*b*) substrates

Polar gains pattern result for the antenna are presented on Fig. 5.



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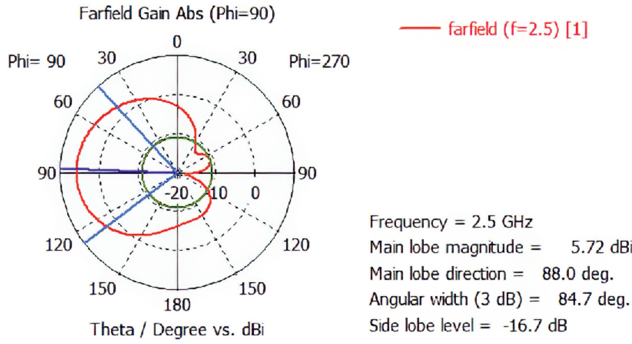
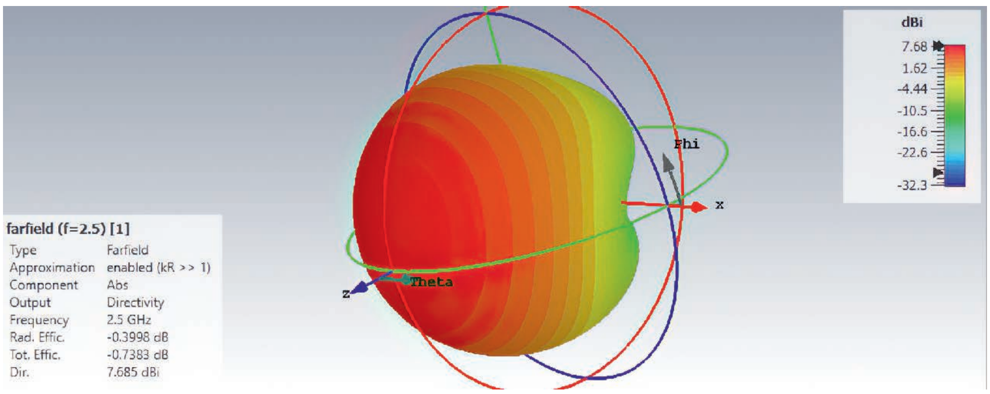


b

Fig. 5. Polar gain pattern result for the antenna with Rogers RT/Duroid 5880 (*a*) and FR-4 (*b*) substrates

The primary lobe of the Rogers RT/Duroid 5880 has an intensity of 7.3 dBi, and main lobe direction is 10.0 degrees. The angle that corresponds to a value of 3 dB is 78.8 degrees. This antenna has a side-lobe level of –19.5 dB on the sidelobe scale. Fig. 5, *b* shows a magnitude of 5.72 dBi in the main lobe and its angle is 88.0 degrees. The angle that corresponds to a value of 3 dB is 84.7 degrees, and the MPA has a side lobe level of –16.7 dB for FR-4 substrate.

The radiation pattern refers to the representation that is graphical of the distribution of radiated energy as a function of direction. Directivity, on the other hand, can measure the quantity of radioactivity for a particular path. The results of the antenna radiation patterns with Rogers RT/Duroid 5880 and FR-4 substrates are shown in Fig. 6.



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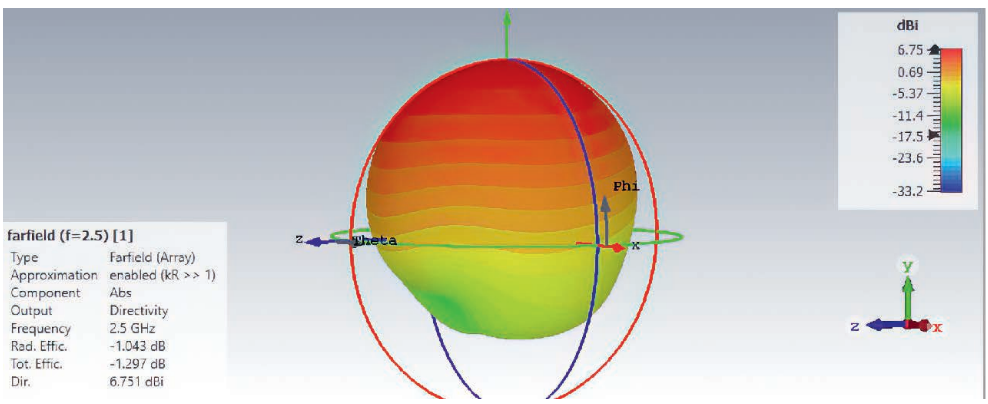
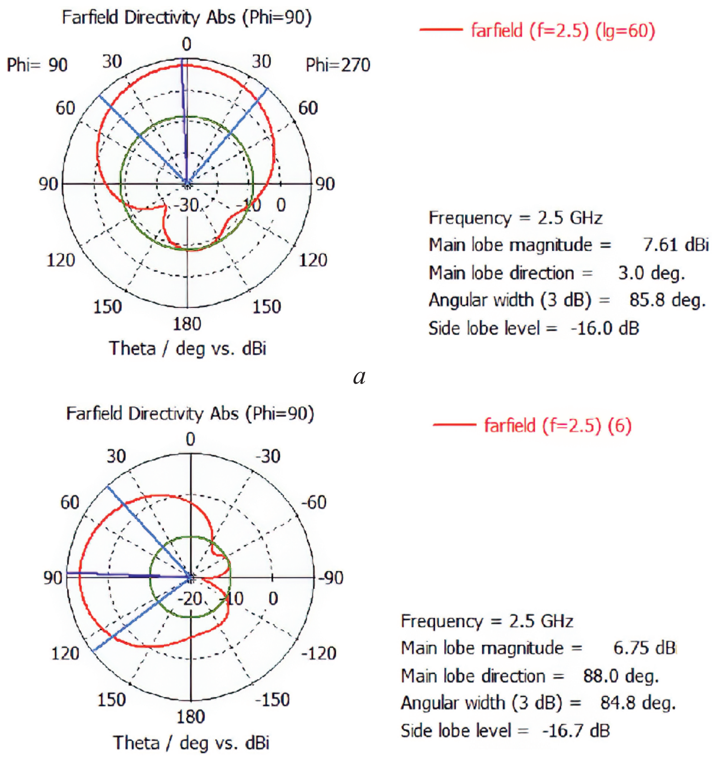


b

Fig. 6. Radiation patterns result for the antenna with Rogers RT/Duroid 5880 (*a*) and FR-4 (*b*) substrates

As it can be seen from the previous figures, the given value of the radiation pattern is 7.685 dBi of the MPA using Rogers RT/Duroid 5880. When the value of FR-4 material is 6.751. Fig. 7, *a* shows the polar directivity for Rogers RT/Duroid 5880. The primary lobe has an intensity of 7.61 dBi and an angle of 3.0 degrees. The 3 dB angular value was found to be 85.8 degrees. This antenna has a sidelobe level of –16.0 dB. Fig. 7, *b* shows the FR-4 polar directivity. The primary lobe has an intensity of 6.75 dBi and an angle of 88.0 degrees. The 3 dB angular value was found to be 84.8 degrees. This antenna has a sidelobe level of –16.7 dB.



a

b

Fig. 7. Polar radiation patterns for the antenna with Rogers RT/Duroid 5880 (*a*) and FR-4 (*b*) substrates

Radiation efficiency η is basically defined as the ratio of the total power radiated by an antenna to the net power accepted by the antenna from the connected transmitter. It is given by the next equation: $\eta = G/D$. According to the previous equation radiation levels are 94.9 % for Rogers RT/Duroid 5880 and 84.55 % FR-4. At a frequency of 2.5 GHz, the proposed MPA has a best radiation efficiency of 94.9 %. Tab. 3 displays and summarizes the results of the simulation.

Table 3. Results synopsis

Parameter	Material	
	Rogers RT/Duroid 5880	FR-4
Return loss, dB	–22.36	–13.226
BW, GHz	0.056	0.0419
VSWR	1.1646	1.5579
Gain, dBi	7.296	5.708
Radiation pattern, dBi	7.685	6.751
Efficiency, %	94.9	84.55

Conclusion

1. This paper designed and analyzed a MPA for 2.5 GHz wireless body area networks (WBANs) using FR-4 and Rogers RT/Duroid 5880 substrate materials. The results showed that the choice of substrate material significantly impacts antenna performance. Rogers RT/Duroid 5880 material provided superior performance in bandwidth, radiation pattern, VSWR, gain, and efficiency, making it crucial for the development of efficient WBAN systems and enhancing communication reliability between wearable devices.

2. In summary, the study shed light on the importance of material selection in designing MPAs for WBANs, comparing FR4 and Rogers RT/Duroid 5880 substrate materials. Rogers RT/Duroid 5880 offers superior performance, enhancing communication reliability and efficiency in medical, wearable technologies, and body-centric network applications.

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Authors' contribution

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