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Design of A Patch Antenna with Three Bands for Vital Signs Monitoring Devices

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Abstract: Vital signs monitoring is an essential part of protecting human well-being because it represents an indicator of any health abnormality. For this reason, a patch antenna of three bands is proposed in this article. This antenna is made up of two sides of copper with a thickness of 0.035 mm, isolated by a layer of FR-4 substrate material with a thickness of 1.6 mm, and a dielectric constant of 4.3. The antenna showed three resonance frequencies of (3.90) GHz, (6.38) GHz, and (8.64) GHz, respectively. The proposed antenna design was simulated by CST microwave studio software. Since The suggested antenna works at VHF and UHF bands, it is a probable candidate to be utilized in the fields of WBC image enhancement, biomedical sensing applications, and biomedical temperature monitoring.

Keywords: Monitoring, Vital signs, Patch, Antenna, Three bands.

1. Introduction

Prior to hospital diagnosis and again after recovery, it is crucial and advantageous to monitor patients' vital signs (VS) [1]. For a range of remote monitoring circumstances, from monitoring patients to identifying geriatric fall risks, human activity, and physiological data are crucial. The most crucial indications for assessing and tracking human health are vital signs [2]. Continuous health monitoring improves the flow of information for monitoring, treatment, and recovery while also giving the patient a greater understanding of their status [3] The accuracy of vital signs is crucial [4]. because they are significant since they signal clinical worsening [5] The risk of lifestyle illnesses like diabetes, hypertension, and cardiovascular disease is rising as a result of the hurried pace of modern living. Thus, it is crucial in the realm of medicine to monitor physiological signals for the quick detection of such disorders. Key metrics of interest in these applications (BR) are frequently heart rate (HR) and respiratory rate (RR) [6], also the body temperature. Vital Signs are also closely related to non-cardiovascular diseases such as stroke and sudden death [7]. Vital signs must also be monitored during acute care [8].

Although the electrocardiogram (ECG) is a popular way to measure heart rate, it has a number of limitations, such as restricted movement [10], the inability to reliably identify when a patient's heart rate is too slow [9], and the possibility that its electrodes can irritate burned skin [10]. When a patient has an infectious disease like COVID-19, checking their vital signs frequently necessitates coming into contact with them or their secretions, which can lead to coming into contact with personal protective equipment (PPE) that has live virus residue on it. The danger of infection is significantly increased by this situation [11].

Although offering daily health monitoring, non-contact (wireless) monitoring lessens issues and discomfort [2, 4]. Using a wireless vital sign monitor, they can automatically enter measured vital signs into the electronic medical record (EMR), saving time and effort [4]. A comparison between our approach, and the conventional approaches is clarified in Table 1.

Wireless systems cannot function without antennas. The patch antenna (which is the subject of this paper) is known for its compact size, support for multiple resonant frequencies [17], lightweight [12-14], low profile [13, 15, 16], simple manufacture, [14, 16-18], low cost [13, 14, 18, 19], ease of mass produce, ease of install, adaptability to horizontal and non-horizontal floors [13, 14] of small size and thickness, capability of integrating discrete elements [14] and scalable accessibility [19].

Microstrip patch antennas are essential in the field of wireless communication networks today. They can act as the foundation for many applications that operate over a variety of frequency bands [19].

The integration of UWB communication for handheld and portable devices is the subject of extensive patch antenna research [2, 20, 21].

Radar life detectors are built using the electromagnetic wave reflection principle [21]. In both military and civilian settings, radar has a wide range of potential applications, including patient monitoring during medical treatment, seeking for survivors in the ruins following an earthquake or landslide, and looking for wounded on a battlefield following combat [22, 23]. The two most common types of radar for detecting non-contact vital signs are CW radar and UWB radar [24].

The UWB radar vital sign extraction approach has become the primary application technology for life detection and monitoring [24].

CW radar has drawbacks when it comes to long-range target localization. For non-contact real-time signal monitoring and live detection, UWB radar is a crucial instrument. Ultra Wideband (UWB) radars perform noticeably better than continuous wave (CW) UWB is more effective and has a wider detection range than millimeter wave radar [23].

A channel bandwidth of more than 500 MHz (absolute bandwidth) or 20% (fractional bandwidth) is required for UWB, which has a defined frequency range of 3.1 GHz to 10.6 GHz [24, 25]. Because of its enormous bandwidth, UWB provides high-data-rate communications and high-resolution sensing/imaging in a variety of applications, including radar/detection systems, localization/positioning systems, wireless communications networks, and medical imaging, among others [23]. The advantages and features of our proposed antenna compared to other antennas is that, since it is a multiband antenna it fetches several frequency bands, which enables it to be utilized in more than one application. Also, it is an affordable type because the patch antennas are generally cheaper than other types of antennas, especially, because we used the economic material FR-4 to be used as a substrate. Additionally, it has a small size, thin profile, and is lightweight, which makes it practical, and facilitates mass production. Our proposed antenna showed good results compared to other antennas, as will be mentioned in the comparison section, where it has high reflection coefficient magnitudes in the negative part of the S11 plot which means that the transmitted signal will not be affected by the reflected signals.

Our suggested antenna's resonant frequency bandwidths work in the UHF and VHF bands, respectively. Our antenna has a probability of being successful in the aforementioned arena because VHF is used for WBC image enhancement [22] and UHF can be used for biomedical sensing applications, and biomedical temperature monitoring [26].

In this paper, a three bands patch antenna for vital signs monitoring devices was proposed. A comparison between the conventional approaches, and this work was stated. Design and method, main results, the practical part, the characteristics of a vital sign monitoring device, and a comparison between this work, and other studies was mentioned.

2. The conventional approaches, and this work

A Comparison between the conventional approaches, and this work is shown in Table 1. Below:

Table 1. A Comparison between the conventional approaches, and this work

No	Conventional technique	This work
1	Movement limitation	Free movement
2	High ability of infection transfer	The low ability of infection transfer
3	Require physical presence of health care provider	Does not require that
4	Require more time and effort	Saves time and effort

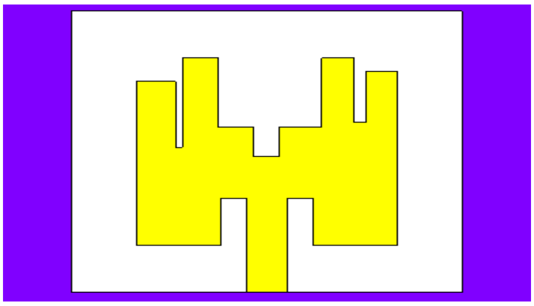
3. Design and method

The recommended antenna was built on an FR-4 substrate with a 4.3 dielectric constant and a 1.6 mm thickness. Copper material with a 0.035 mm thickness was used to make the patch and the ground plane. The patch's relative parameters equations are [27, 28]:

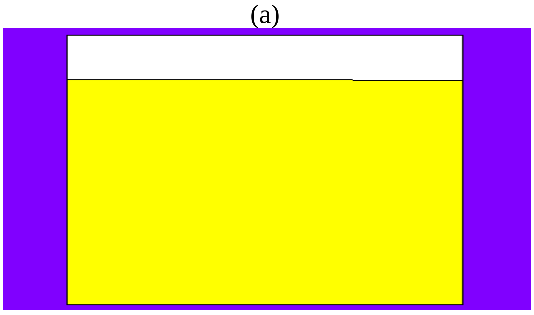
$$W = \frac{c}{2f}\left(\frac{\varepsilon_r+1}{2}\right)^{\frac{-1}{2}} \quad (1)$$

$$\Delta L = 0.412H\,\frac{(\varepsilon_{eff}+0.300)(\frac{W}{H}+0.262)}{(\varepsilon_{eff}-0.258)(\frac{W}{H}+0.813)} \quad (2)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+10\frac{H}{W}\right)^{\frac{-1}{2}} \quad (3)$$

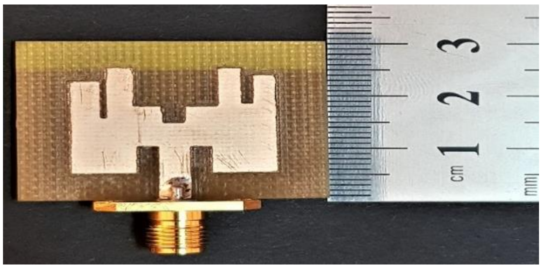


(a)

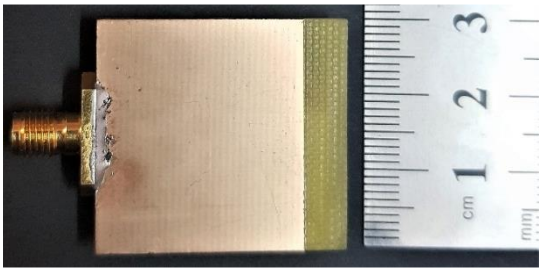


(b)

Figure. 1 The simulated design of the proposed antenna: (a) front view, and (b) back view



(a)



(b)

Figure. 2 The fabricated design of the proposed antenna: (a) front view and (b) back view

$$L = \left(\frac{c}{2f\sqrt{\varepsilon eff}}\right) - 2\Delta L \quad (4)$$

Where W is the patch's width, ΔL is the patch's length minus the substrate's, H is the substrate's thickness, ε_{eff} is a standard microstrip patch antenna's effective dielectric constant and ε_r is the substrate's dielectric constant, and c is the speed of light. The resonant length is L.

Table 1. The dimensions of the proposed antenna

Number	The element	The area dimensions (mm^2)
1	The substrate	30×30
2	The ground plane	25×30
3	The patch	20×20
4	The feeder	3.11×10
5	The two lower slits	2×5
6	The left upper slit	0.52×9.52
7	The middle upper slit	8×7.34
8	The right upper slit	6.89×1

The proposed antenna was designed and simulated using CST software. Fig. 1 below shows the simulated design of the proposed antenna. Note that, the yellow color in (a), and (b) represents the patch, and the ground plane respectively, while the white color in both (a), and (b) represents the substrate layer. In Fig. 2 one can see the fabricated design of the proposed antenna.

The dimensions of the proposed antenna are shown in Table 1.

4. Main results

4.1 The reflection coefficients

The reflection coefficients were as follows: at (3.90) GHz the reflection coefficient was (-30.18) dB, at (6.38) GHz the reflection coefficient was (-36.53) dB, at (8.64) GHz the reflection coefficient was(-25.68) dB. It is obvious from the previous values that, the proposed antenna has excellent reflection coefficients. The plot of the reflection coefficients is shown in Fig. 3 below, where the orange curve represents the simulated values, and the blue curve represents the measured values of the reflection coefficients. Note that, It will be obvious that there is a noticeable difference in magnitudes and a simple frequency shifting when comparing the simulated and measured reflection coefficient curves. This is because, while in the practical test, the antenna is excited using a SMA connector, which has losses influencing the antenna's performance, the simulation uses a typical CST software environment and excites the antenna using a waveguide port, which is also a typical source of excitation. Add to that, the material loss due to commercially available material which may have imperfect characteristics.

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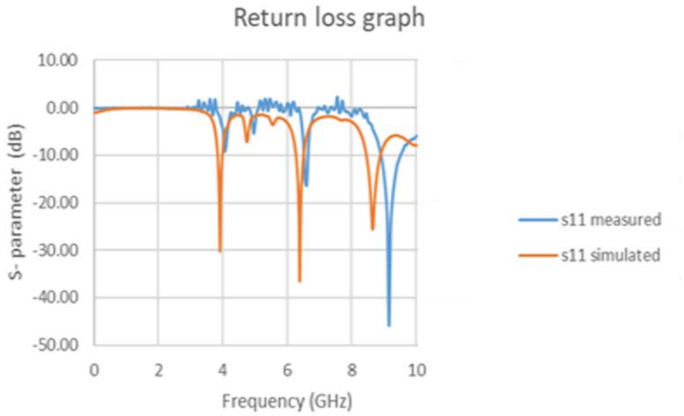
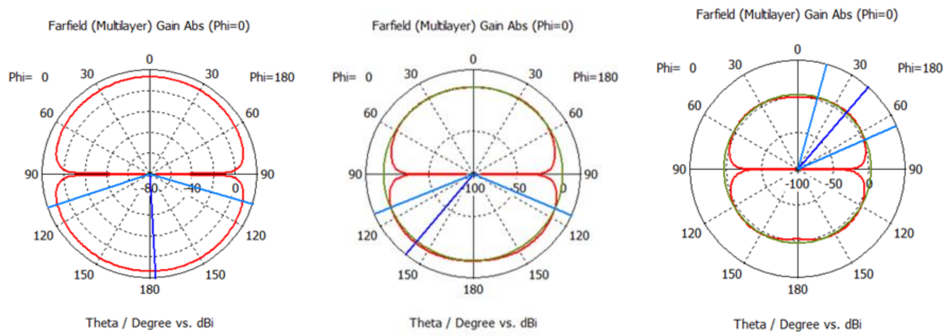
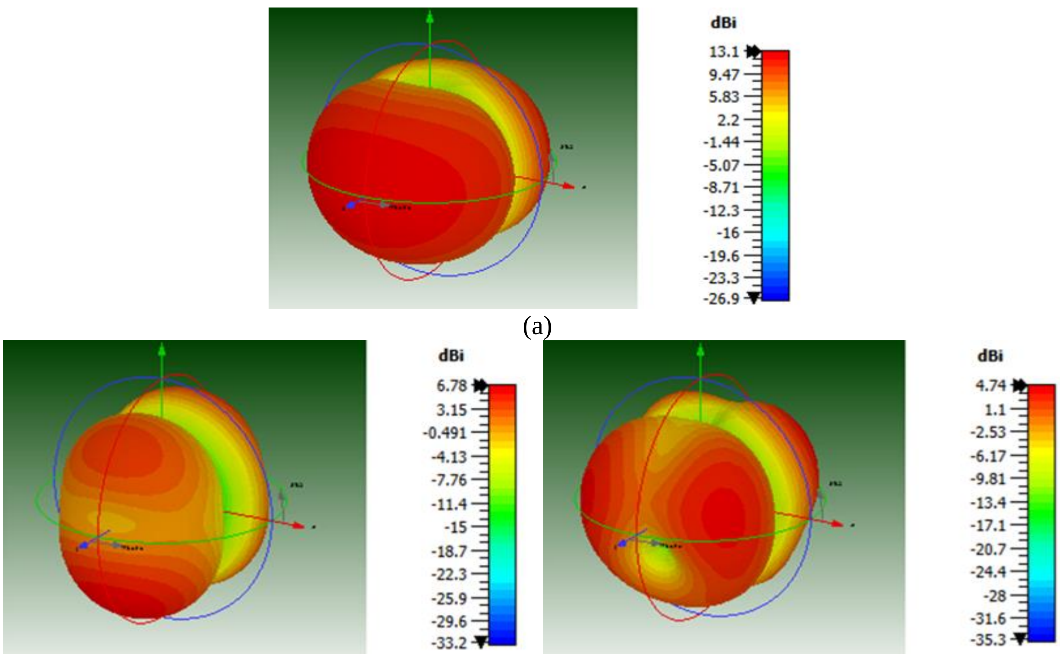


Figure. 3 The simulated and measured reflection coefficients plot of the proposed antenna



(a) (b) (c)

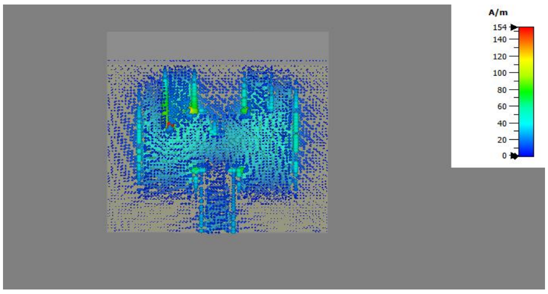
Figure. 4 The proposed antenna's 2D radiation pattern at: (a) (3.90) GHz, (b) (6.38) GHz, and (c) (8.64) GHz respectively



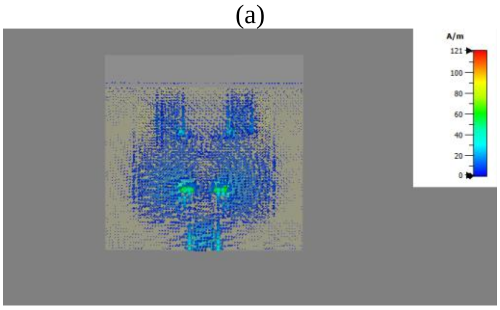
(a)

(b) (c)

Figure. 5 The proposed antenna's 3D radiation pattern at: (a) (3.90) GHz, (b) (6.38) GHz, and (c) (8.64) GHz respectively



(a)



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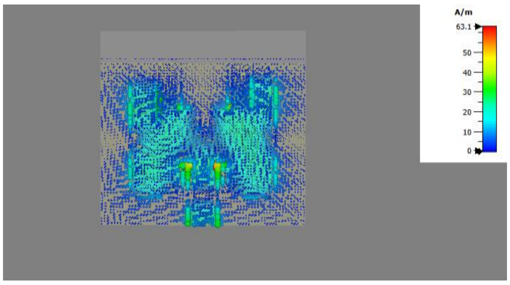

(c)

Figure. 6 Clears the surface current distribution of the proposed antenna

4.2 The 2D radiation pattern

Fig. 4 shows the 2D radiation pattern at each resonance frequency. It is clear that each radiation pattern is omnidirectional at each resonance frequency.

4.3 The 3D radiation pattern

Fig. 5 shows the 3D radiation pattern of the proposed antenna at each resonance frequency.

4.4 The surface current distribution

At (3.9) GHZ, the current was of a magnitude of 154 dB (A/m). while it is noted that at (6.38) GHZ, the current distribution was of a magnitude of 121 dB (A/m). We can see that the current distributed was of a magnitude of 63.1 dB (A/m) at (8.64) GHZ. Fig. 6 clears the surface current distribution of the proposed antenna.

5. The practical part

5.1 Software

Arduino software was used to get the readings of the body parameters.

5.2 Hardware

The following Arduino pieces were used to get Real human body parameters:

1- Thermometer Sensor.
2- heart rate pulse sensor.
3-Jumper wires.
4- Bread board.
5-USB cables.
6-Laptop.
7-Transmitter and receiver antennas.

5.3 Procedure and readings

The above hardware pieces were connected as shown in Fig. 7 below:

The Arduino code, and the temperature and heart rate readings are shown in Fig. 8 below:

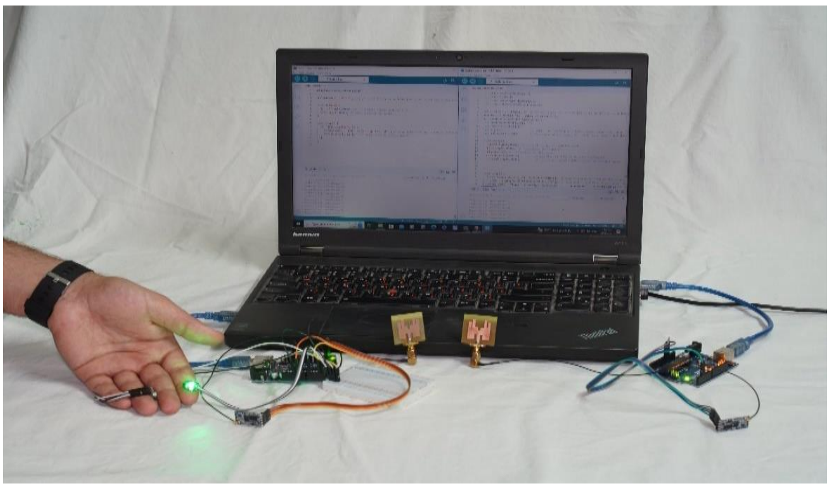

Figure. 7 The hardware pieces of the vital signs monitoring system

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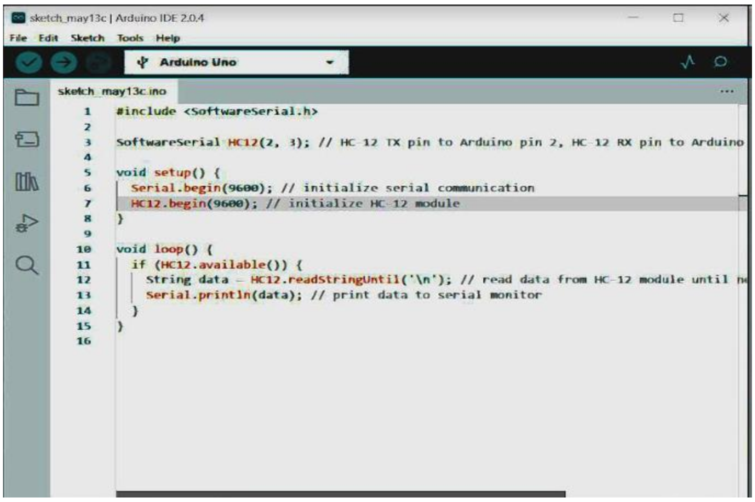
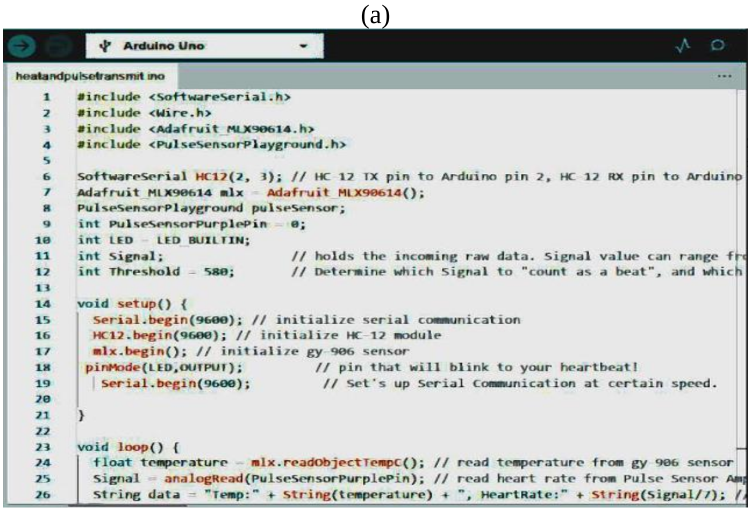
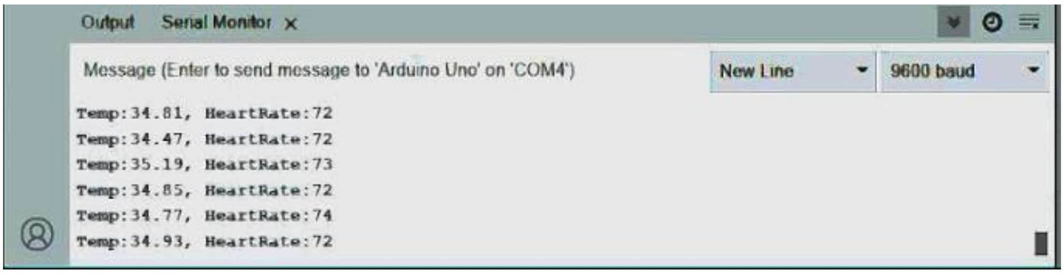


(a)

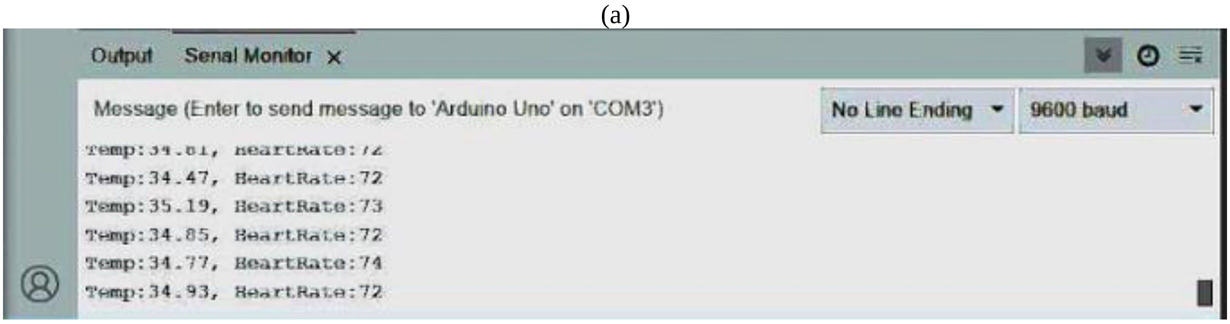


(b)

Figure. 8 The readings are shown in: (a), (b) the Arduino code



(a)



(b)

Figure. 9: (a) and (b) the temperature and heart rate readings

Table 2. A comparison between this work and other works

Reference	Number Of bands	Substrate material	Dimensions	Frequency (GHz)	Reflection Coefficient (dB)	Notes
[28]	4	Rogers (RO4003)	(29×24×1.6) mm^3	13.27, 20.65, 24.98, 28.96	-15.6, -19.5, -17.4, -16.9	
[29]	1	FR-4	17 mm^2	20	-16	Thickness is not mentioned
[23]	1	FR-4	(18×20×1.6) mm^3	~7.2	~-24	Single Antenna Design
[6]	2	LCP	36.5×53×0.1	~23	~-12.9	
This work	3	FR-4	30×30×1.6	3.90, 6.38, 8.64	-30.18, -36.53, -25.68	

The temperature and heart rate readings are shown in Fig. 9 below:

6. The characteristics of a vital sign monitoring device

Our vital signs monitoring device has lightweight and easy to use.

7. Comparison

Below is a table that shows a comparison between this work, and other works.

8. Conclusion

In this paper a triband patch antenna was presented, and its importance in the vital signs wireless monitoring systems was stated. The design and method were mentioned, also the main results. The practical part, and the vital signs readings of human body were presented, while a comparison between this work and other previous works was clarified.

A triband patch antenna has been proposed in this paper. The proposed antenna resonates at (3.90) GHz, (6.38) GHz, and (8.64) GHz with bandwidths of (163.35) MHz (3.83-3.99) GHz (VHF band), (232.26) MHz (6.27-6.50) GHz, (VHF band) and (416.03) MHz (8.45-8.87) GHz (UHF band).

Important parameters such as reflection coefficient, operating bandwidths, and gain have been studied. Therefore, the proposed antenna is a promising design for use as a multiband biomedical communication antenna. The antenna was implemented on FR-4 substrate material with a dielectric constant of 4.3 and a thickness of 1.6mm. The simulation was done with CST software. The antenna showed return loss values of (-30.18, -36.53, and -25.68) dB respectively. The antenna showed gain values of (13.1) dB at (3.90) GHz, (6.78) dBi at (6.38) GHz, and (4.74) dBi at (8.64) GHz. A comparison has been made by comparing the performance of the suggested antenna in this paper with different antenna performances in other papers. In the practical part, one can see that, we used Arduino, to make a sample of our proposed work, and we have got readings for the heart rate, and body temperature. In future, works Rogers can be used instead of FR-4 for further improvement in performance.

Conflicts of interest

The authors declare no conflict of interest.

Author contributions

As the original author and corresponding author, Anfal Shukur Taher typed and edited this work. Rashid Ali Fayadh and Abbas Fadhal Humadi were in charge of supervising the research, keeping track of its advancement, and enhancing its scientific components.

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