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RESEARCH ARTICLE - ENGINEERING

A Simulated Model of a Triple Band Patch Antenna Proposed for Vital Signs Monitoring Equipment

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Abstract

In the modern lifestyle, an increase in psychological pressures was observed, leading to an increase in various diseases, which increased the need for diagnosis and treatment, (i.e., increased demand for) equipment to monitor vital activities, Therefore, a microstrip patch antenna was suggested as the topic of this article because it is popular in wireless systems due to its low cost, lightweight, and thin profile. The proposed design is made of FR-4 as a substrate material, and copper for the patch and the ground. The reader can notice that our proposed antenna owns the following resonance frequencies: (3.68), (6.48), and (7.93) GHz respectively. The gain values for the previous resonance frequencies were respectively (27) dBi, (11.1) dBi, and (4.19) dBi, while the values of directivity were (32.17) dBi, (15.70) dBi, and (7.984) dBi. The radiation efficiency values were (-5.179) dB, (-4.561) dB, and (-3.789) dB, while the values of the total efficiency were (-5.207) dB, (-4.631) dB, and (-3.799) dB The operating bandwidths were: (0.1146) GHz, (0.2764) GHz, and (0.3641) GHz. The design was simulated with CST software.

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Keywords: Triple; Band; Vital Signs; Patch; Antenna.

1. Introduction

The danger of lifestyle problems like diabetes, hypertension, and cardiovascular diseases is rising with the busy pace of modern living. As a result, the healthcare industry has significant applications for the assessment of vital indicators for the early showing up of those illnesses. Heart rate (HR) and breathing rate (BR) are two crucial components of human bodily well-being. They are frequently vital indications of interest in these applications. Vital signs' ability to predict clinical deterioration [1], to decrease secondary harm, and enhance patient outcomes, early detection, and treatment of adverse events (AEs) are crucial [2]. The accuracy of vital signs is crucial since they can change before a patient's condition worsens [3]. Vital signs are very important measures for the tracking of the health of a person, human activity and physiological data are essential for a variety of remote monitoring scenarios, from patient monitoring to elder fall detection [4], and it has a strong connection to sudden death, stroke, and other diseases that are not cardiovascular [5]. Vital sign monitoring is also important during intensive care [6], Post-operative care [2], Before receiving a diagnosis from the hospital, it is crucial and helpful to keep an eye on patients' vital signs and does so again during their recovery [7]. Monitoring the parameters of the vital signs of the patients in the isolation wards provides an early alarm which is very important in the case of health deterioration [8, 9]. The significance of vital sign detection is also highlighted in COPD Detection (Chronic obstructive pulmonary disease). (COPD) is a Breathlessness brought on by a progressive, fatal lung condition that, if not identified and treated in time, results in death.

Although continuous monitoring has been used for many years in intensive-care units, its use in the ward is hampered by a lower nurse-to-patient ratio, a lack of critical care teaching for nurses, and more active patients [2]. The sensing probes for the majority of traditional devices which measure vital signs must be in physically contacted with the patient and the device. This limits the subject's ability to move [10]. With some limitations, contact sensors have primarily been used as a standard monitoring reference to demonstrate their effectiveness. The main drawbacks are the stress, pain, and irritability brought on by contact with delicate skin in burn patients and newborns [1]. Using electrocardiography electrodes, and the devices which are worn are all currently used in systems to monitor heart rate variability (HRV). Oronasal sensors, which detect changes in the pressure of air brought on by respiration, can be used to manually measure breathing rate [5].

Nomenclature

ECG	Electrocardiography	C	The Light Speed in Free Space: 3×10^8 meter/second
PPE	Personal Protective Equipment	f	The Resonance Frequency
EMR	Electronic Medical Records	H	The Substrate's Thickness
RADAR	Radio Detecting and Ranging	L	The Patch's Length
UWB	Ultra- Wide Band	W	The Patch's Width
HR	Heart Rate	ε_r	The Dielectric Constant
ΔL	The Difference Between the Substrate's Length and The Patch's Length	ε_{eff}	The conventional Microstrip patch Antenna's Effective Dielectric Constant
BR	Breathing Rate	COVID-19	Coronavirus Disease of 2019
AEs	Adverse Events	SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
RBM	Random Body Movements	US Army	United States Army
HAR	Human Activity Recognition	HRV	Heart Rate Variability
COPD	Chronic Obstructive Pulmonary Disease		

Particularly when used for ambulatory monitoring, these conventional techniques can be uncomfortable for users and inaccurate due to random body movements (RBM) [11]. Electrode-type chest impedance scanning techniques are currently used for respiratory detection devices. When the respiratory detection device is operating normally, the test subject's body experiences a tiny current [12]. When the patient's heart rate is too slow, the ECG is not always able to tell. Furthermore, there is a chance that the electrode pads will stick to the skin if the device is used for an extended period. Patients with skin damage should not use this type of device [12]. Strong propagation characteristics are present in COVID-19. When medical professionals and volunteers track the vital signs of a patient, they frequently get in touch with patients or secretions, which can lead to (PPE) interface residue encounter of active viruses.

The risk of infection is greatly increased by this circumstance [13]. When tracking infants, patients with burnt skin, or sleep, the contact measurement techniques may be uncomfortable, disconnect because of cable kinks, and strip epidermis [13]. Electrocardiography (ECG) is the conventional technique for measuring heart rate. However, due to its mobility limitations and inconvenience, it is not suitable for long-term monitoring [5].

Additionally, in a pandemic situation, such as the recent SARS-CoV-2 pandemic, It is now beyond dispute that respiratory parameters can be monitored without contact [11]. A wireless monitor of vital signs saves time and effort by automatically entering the determined vital signs into (EMR) the electronic medical records with no need for materialist input [3]. Non-contact (wireless) sensing, as opposed to contact devices, like an electrocardiogram, and photoplethysmograph (PPG), is not just cozy but also offers health tracking daily [4]. Antennas are a very crucial part of the wireless system. They are favored due to their small dimensions and support for multiple resonance frequencies, lightweight [14], high efficiency [15], low profile [16], and simple manufacturing [16, 17].

Radar systems use scattered signals coming from the person's body to analyze vital signs and activity data since they are unaffected by light and temperature conditions. Additionally, radar systems perform exceptionally well in the following areas: personnel identification, people counting, gait classification, human activity recognition (HAR), and tracking of vital signs [4]. The development of the radar life detector follows the reflection principle of electromagnetic waves. Radar has many possible applications in military and civilian settings, including patient monitoring during medical procedures, searching for survivors from a rubble following landslide or earthquake, and searching for the injured on the battlefield following a conflict [19]. For vital signs detection of the wireless type, continuous wave radar and ultra-wideband radar are the most common types of radar [20].

The UWB frequency range of the RADAR is where our suggested antenna operates. The US Army first used ultra-wideband (UWB) radar in the 1970s, and companies like Time Domain and Xtreme Spectrum began to market it in the late 1990s [9]. There is a definition of the Ultra-wideband which is the radar in which the sent signal owns a fractional bandwidth (FBW) of more than 0.25 [2]. Due to its advantages over other current tools, the UWB radar sensor has high-speed broadband [12], low power consumption [12, 13], high penetration [12, 13, 18], strong anti-interference ability [13], high resolution [13, 18], good electromagnetic compatibility, and low average transmitting power [18]. Over the past few years, it has been widely used in the relief of quake disasters, military medicine, home monitoring, and many other fields. Since then, UWB technology has been adopted gradually. Numerous facets of life have benefited from the use of UWB technology (e.g., tracking of physical signals, tracking the movement of an object, and indoor positioning while detecting through walls). By detecting the tiny movements that breathing and heartbeat cause to the surface of the body, UWB radar can locate human targets. The radar transmitter emits electromagnetic waves, which travel through the propagation medium until they reach the human body. The human body also scatters electromagnetic pulses, producing corresponding echo signals that travel via the medium to the radar receiver. The receiver then receives the signals and samples them for data [17]. The vital sign extraction techniques of UWB radar have gradually become research hotspots and the primary technology for the detection and monitoring of vital signs [18]. Although radar of continuous waves has many benefits for recognition of frequency domain, processing signals, and other areas, it has limitations for target positioning at a distance. Ultra-wideband radar is a crucial technology for life-detecting or non-contact vital signal monitoring. UWB (ultra-wideband) radar owns significant benefits over continuous wave radar in terms of distance and frequency data. The echo signal is guaranteed to be accurate and sensitive by significant improvements in resolution, interference capabilities, and power usage. On the other hand, UWB performs better and has a wider detection range compared to millimeter-wave radar [19]. Since its standardization in 2002, In a variety of applications, an ultra-wideband (UWB) technology has drawn constant interest. With a channel bandwidth of higher than 500 MHz (absolute bandwidth), or 20% (fractional bandwidth), UWB's assigned range of frequency is 3.1 GHz to 10.6 GHz. UWB provides high-data-rate communications, and high-resolution sensing/imaging in many applications, including localization/positioning systems, radar/detection systems, medical imaging, and wireless communications networks, among others, because of its large bandwidth [20]. In this article, many paragraphs will be covered, such as design and method, which illustrate the dimensions of the proposed design, and the materials of its layers. Also, the results such as operating bandwidths, the values of reflection coefficient, gain, radiation efficiency, far-field results, and current distribution. Finally, there will be the conclusion section, which illustrates the summary of all the previous sections.

2. Problem Statement

The need for monitoring devices increased as a result of our fast-paced way of life to identify and treat illnesses. Due to its usability, wireless monitoring systems are recommended. It was determined that this thesis would concentrate on the antenna because it is essential to these devices. To provide the three-band patch antenna as a suggested solution for use in the field of wireless monitoring systems, research on it was conducted.

3. Design and Method

First of all, a square patch antenna with an area of (30×30) mm^2 was designed. Then, to improve the matching, two slits were placed in the lower part of the patch to extend the feed point connection to the patch. With the trial and error approach, two slits at the upper part of the patch were embedded after the best reflection coefficient (S11) magnitude signal was reached. The dimensions and geometry of our proposed design are given in Figs. 1 &2 and Table 1.

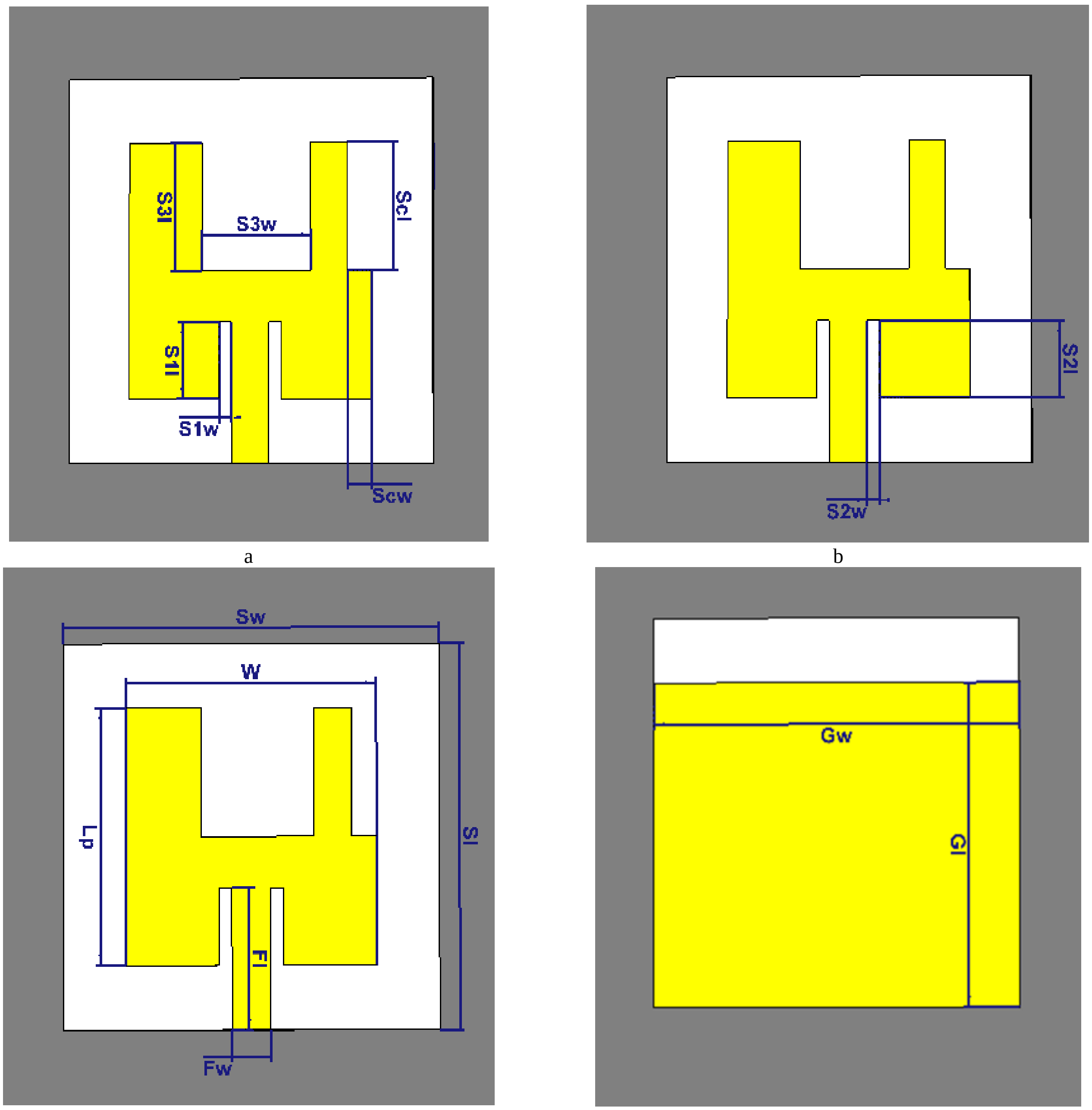


Fig. 1. The suggested triple band patch antenna geometric configuration (a), (b), and (c) front view, and (d) back view

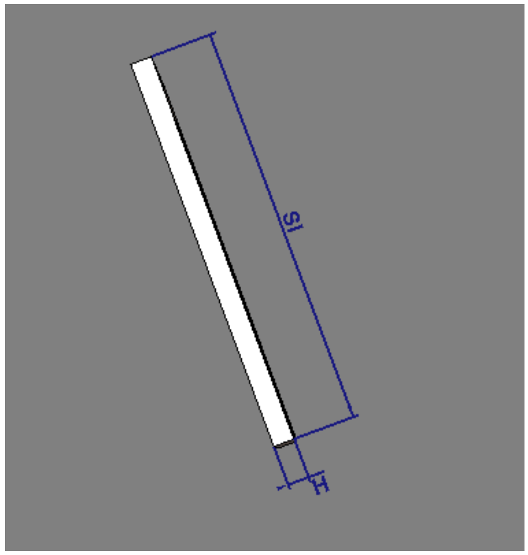


Fig. 2. The suggested triple band patch antenna' geometric (the third dimension)

Table 1. The Proposed Antenna's Dimensions

No	The element	The element's abbreviation	The dimensions (mm)
1	Substrate length	Sl	30
2	Substrate width	Sw	30
3	Ground length	Gl	25.05
4	Ground width	Gw	30
5	Patch length	Lp	20
6	Patch width	W	20
7	Feeder length	Fl	11
8	Feeder width	Fw	3.11
9	Slit1 length	S1l	6
10	slit2 length	S2l	6
11	Slit 1 width	S1w	1
12	slit2 width	S2w	1
13	Slit 3 width	S3w	9
14	Slit 3 length	S3l	10
15	Side cut length	Scl	10
16	Side cut width	Scw	2
17	Substrate's thickness	H	1.6

The patch is extended to create a strip feed line. Both the patch and the ground plane were built of copper with a thickness of 0.035 mm, and the suggested antenna was designed on a substrate of FR-4 of thickness 1.6 mm and dielectric constant of 4.3. The ground plane's length and width are said to be 25.05 and 30 millimeters, respectively. The substrate material has a length and width of both 30 mm. The CST studio suit was utilized to imitate the antenna's functionality. One significant rectangular slit is located in the center of the patch's primary shape, also, there is a side cut on the right. The antenna was designed according to the following equations [21- 23]:

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

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

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

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

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \quad (5)$$

$$L_p = L_{eff} + \Delta L \quad (6)$$

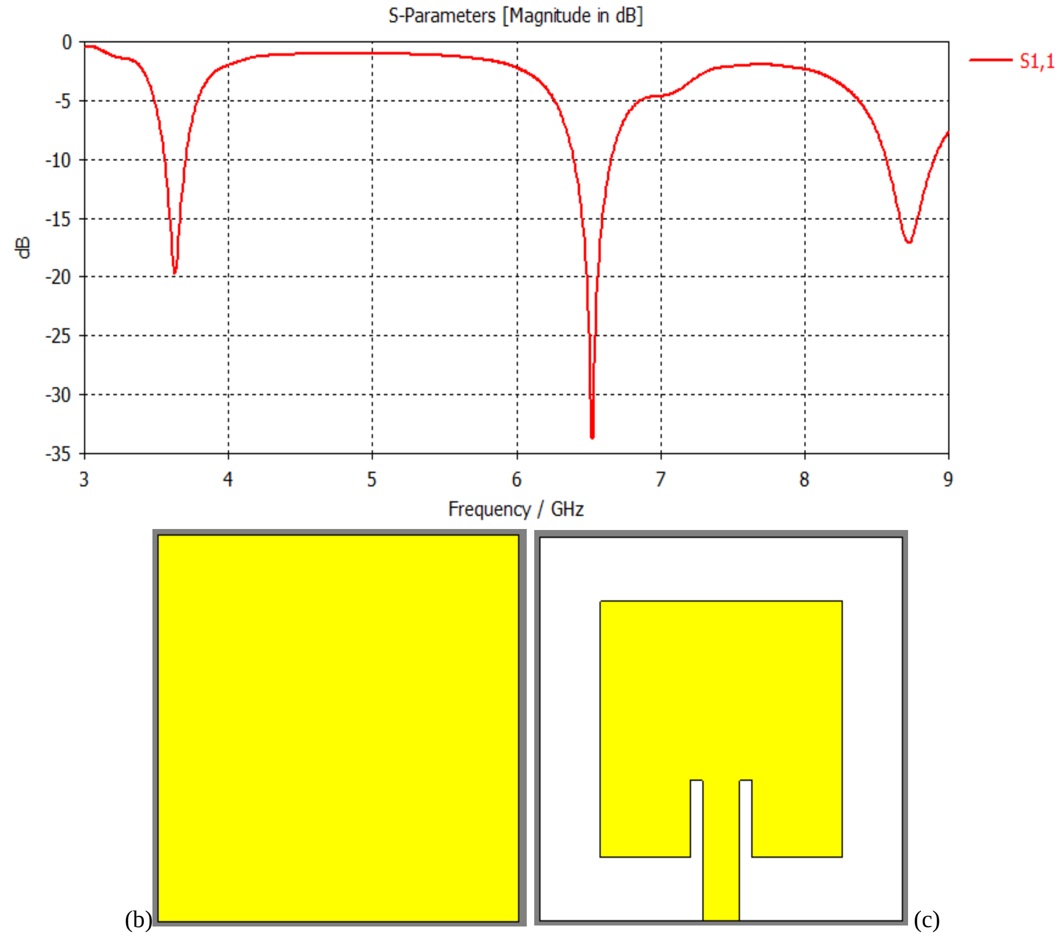
$$Z_a = \frac{90\,\varepsilon_r^2}{\varepsilon_r-1}\left(\frac{L}{W}\right)^2 \quad (7)$$

where W represents the patch's width, ΔL represents the difference between substrate length and patch length, H stands for the thickness substrate's thickness, ε_{eff} is a conventional microstrip patch antenna's effective dielectric constant, ε_r is the substrate's dielectric constant, f is the frequency, c is the speed of light, L the resonant length, L_{eff} is the effective length, L_p is the actual length of the patch, and Z_a is the impedance of the radiating patch.

3.1. Design levels

3.1.1. The first level

The shape of the patch was made as s square that has two slits on both sides of the feeder. The purpose of the slits is to improve the matching. The ground plane has covered the full area of the substrate. Fig. 3 shows the design of the first level, and the shapes of the obtained bands included in the reflection coefficient plot.



(a) (b) (c)

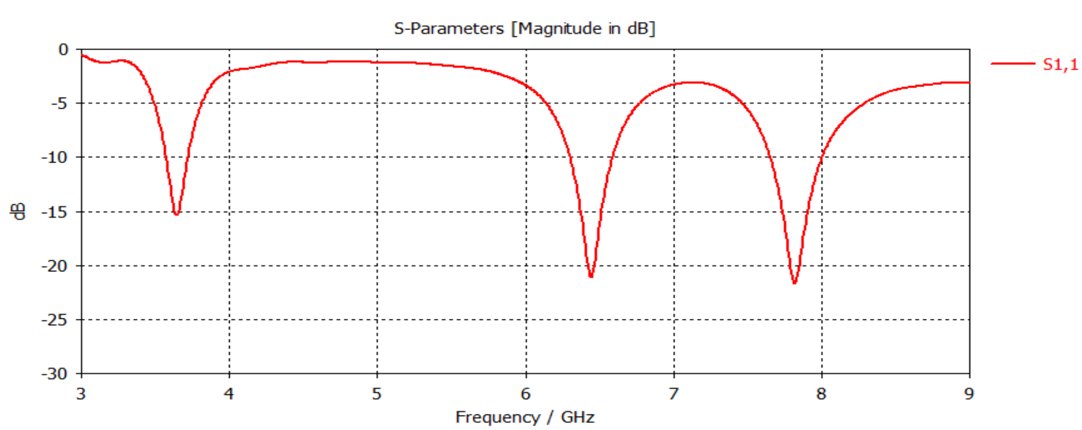
Fig. 3. The level one of the designing process; (a) The reflection coefficient plot, (b) The ground plane, and (c) the Front view of the design

3.1.2. The second level

A slit was cut in the top middle of the patch to enhance the performance of the antenna, and a portion of the ground plane was removed to lower the back lobe radiation of the antenna by suppressing surface wave diffraction from the antenna ground plane's borders. Fig. 4 clears this level's design and the reflection coefficient plot.

3.1.3 The third level

A slit on the right top side of the patch was made to enhance the antenna performance. It is clear now that the antenna has three satisfying magnitudes of ferlection coefficient for each band, as shown in Fig. 5.



(a)

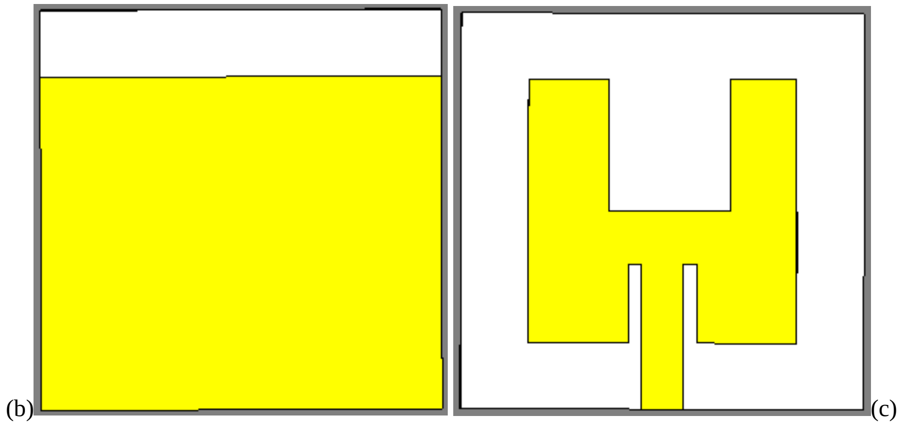


Fig. 4. The level two of the designing process (a) The reflection coefficient plot, (b) The ground plane, and (c) the Front view of the design

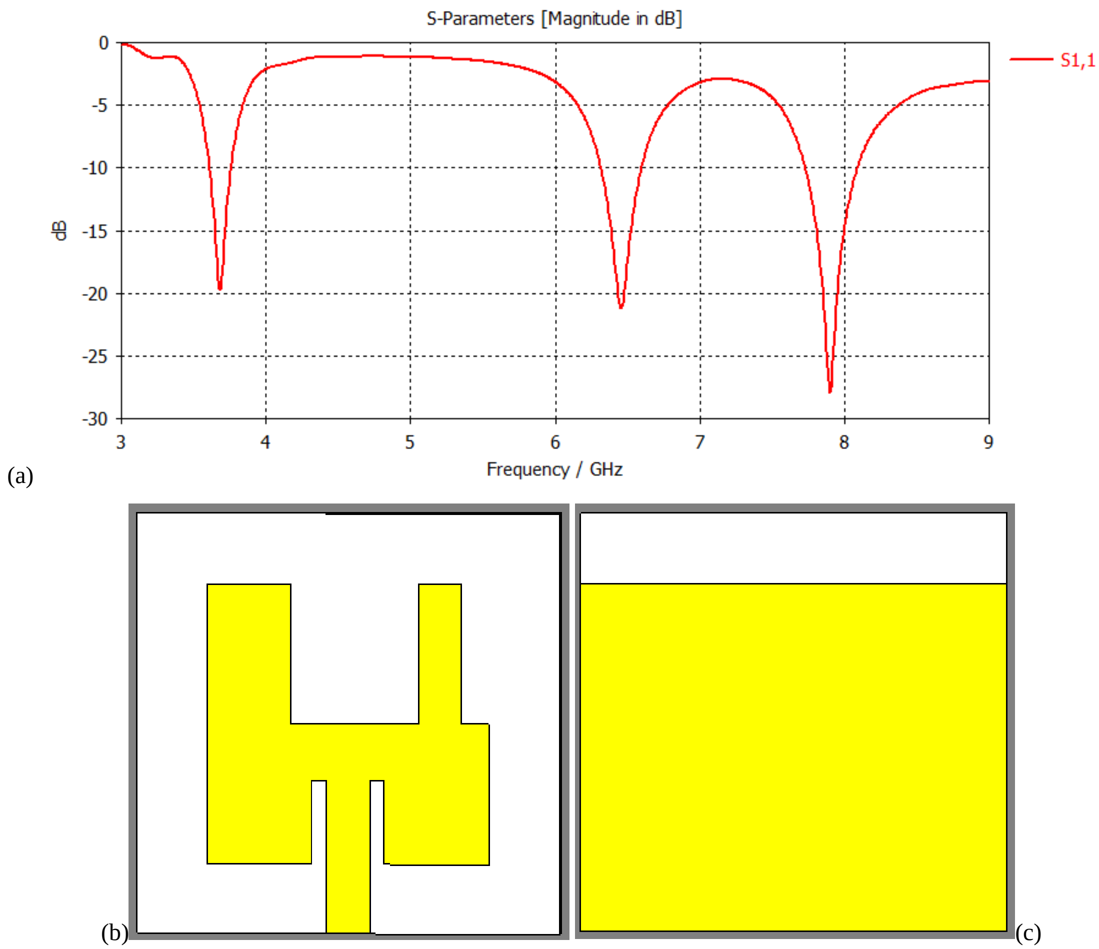


Fig. 5. The level three of the designing process (a) The reflection coefficient plot, (b) The ground plane, and (c) the Front view of the design

4. Results

4.1. Bandwidth, reflection coefficient, and gain

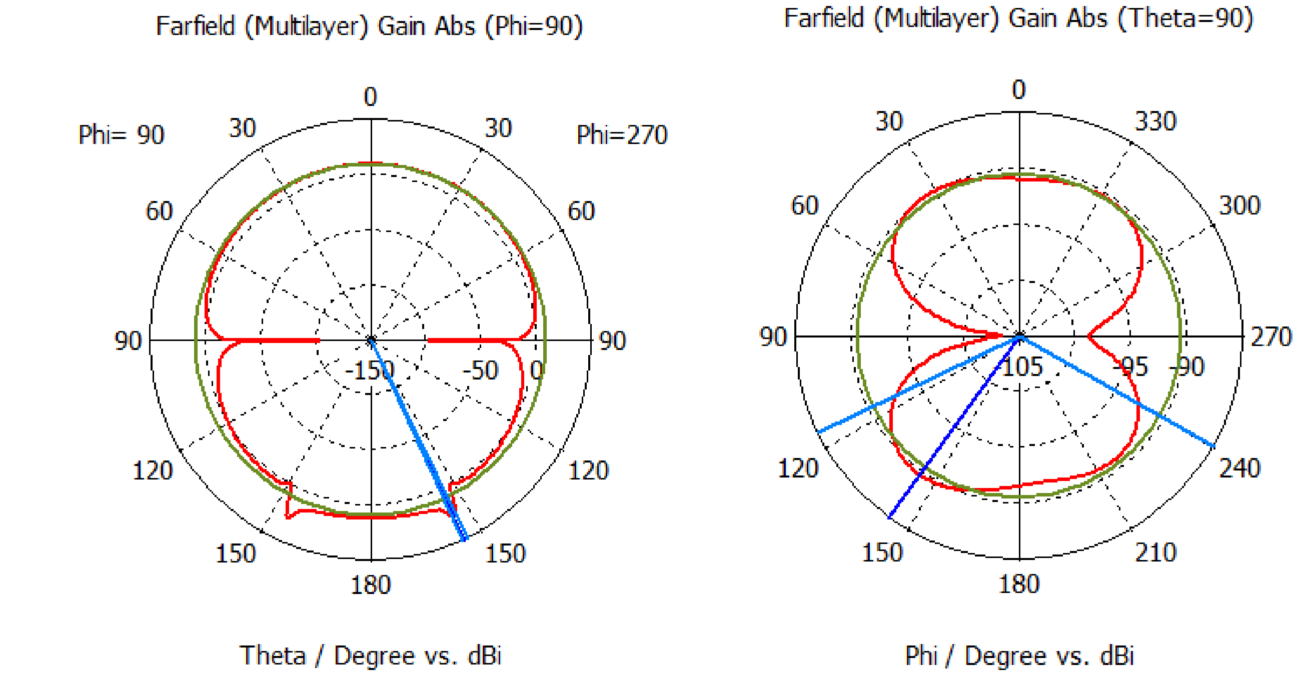
The values of operating bandwidth, gain, and reflection coefficient magnitudes are listed in Table 2.

Table 2. The Operating bandwidths, Gain, and Reflection Coefficient (S11) values

No	Frequency (GHz)	Operating bandwidth (GHz)	Gain (dBi)	S11 (dB)
1	3.68	0.1146	27	-19.89
2	6.48	0.2764	11.1	-21.25
3	7.93	0.3641	4.19	-28.05

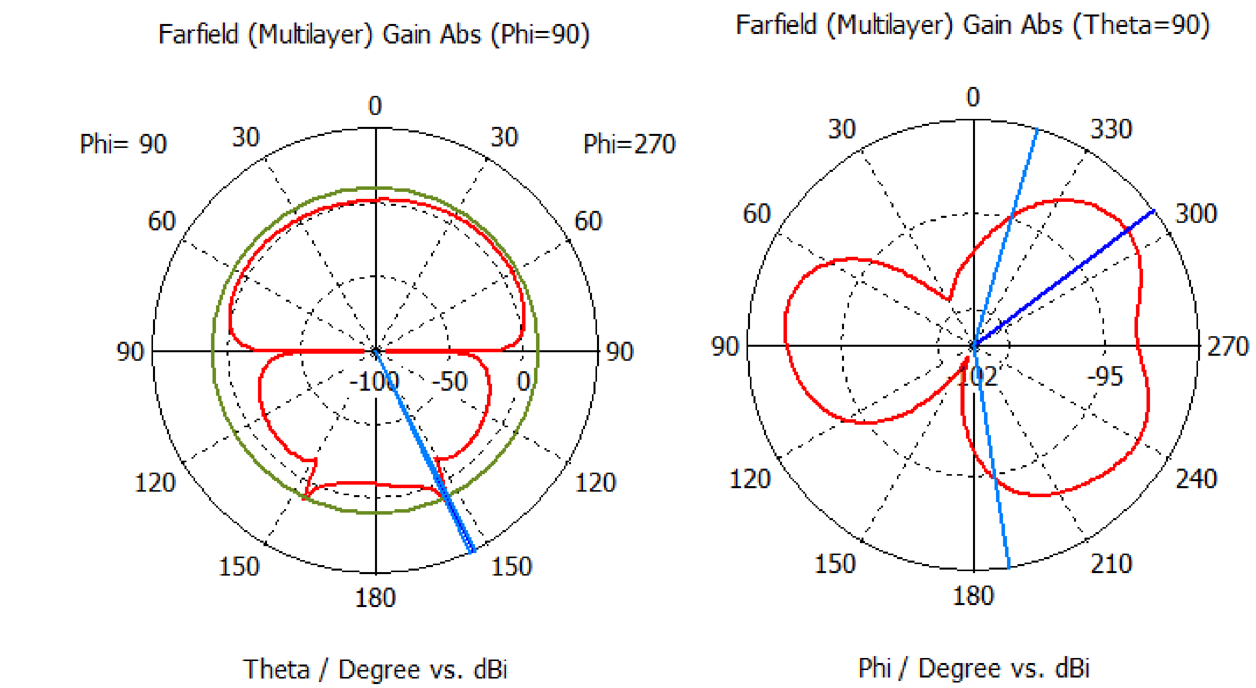
4.2. Far-field results

The 2D far-field plots and 3D far-field plots were observed in Figs. 6, 7, 8, and 9.



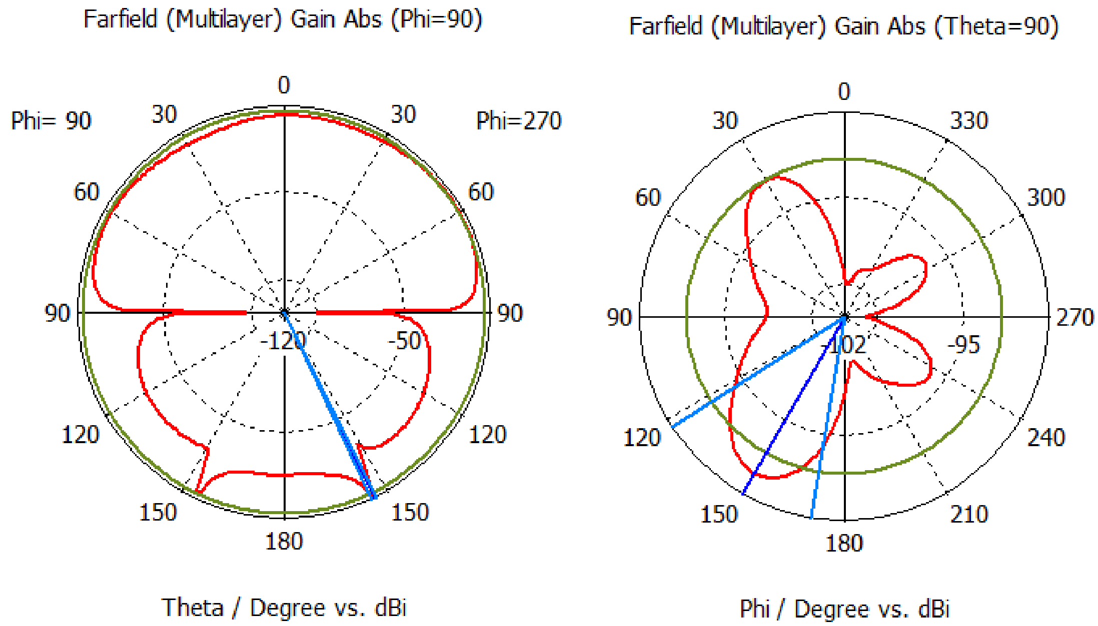
(a) (b)

Fig. 6. 2D farfield plot at 3.68 GHz (a) when phi=90, and (b) when Theta=90



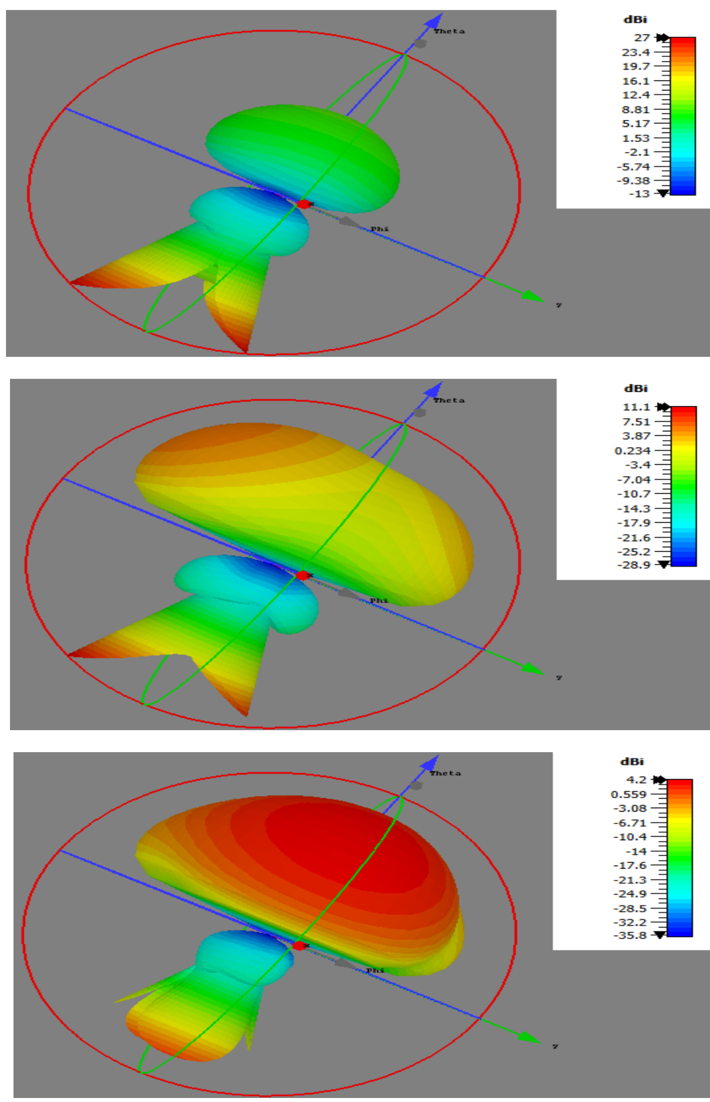
(a) (b)

Fig. 7. 2D farfield plot at 3.68 GHz (a) when phi=90, and (b) when Theta=90



(a) (b)

Fig. 8. 2D farfield plot at 7.93 GHz (a) when phi=90, and (b) when Theta=90



(a)

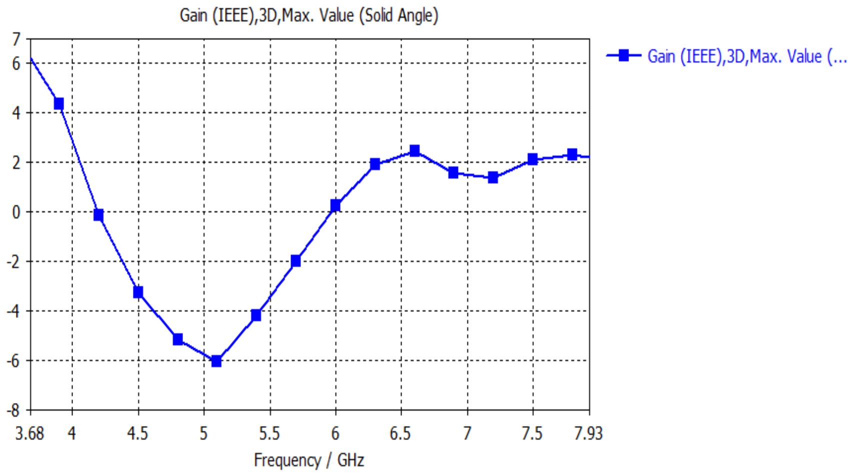
(b)

(c)

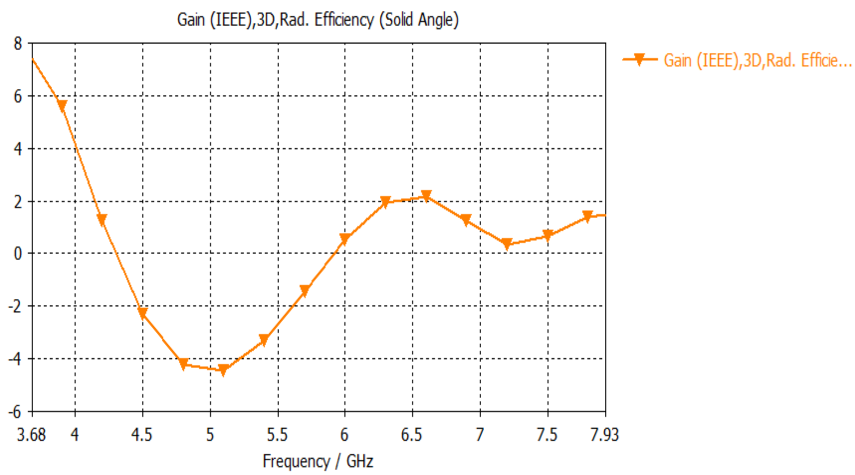
Fig. 9. 3D far-field plots at (a) (3.68) GHZ, (b) (6.48) GHZ, and (c) (7.93) GHZ

4.3. Efficiency, and gain plots

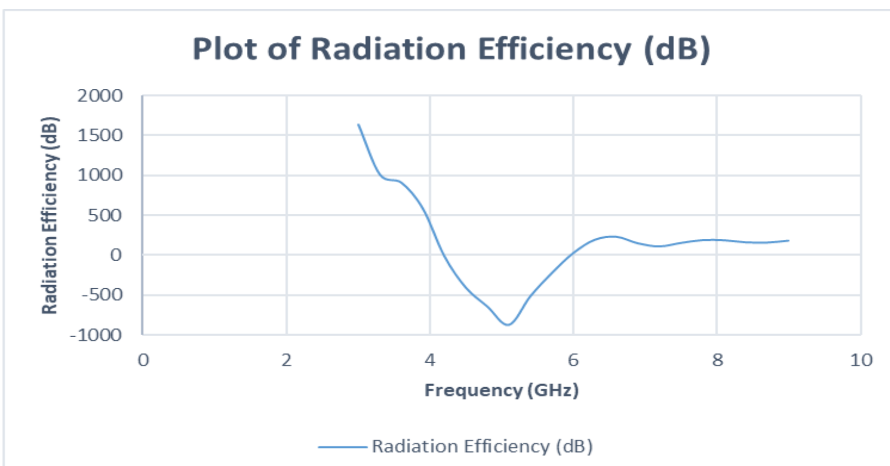
Fig. 10 clarifies the relationship between efficiency and gain with the frequency.



(a)



(b)



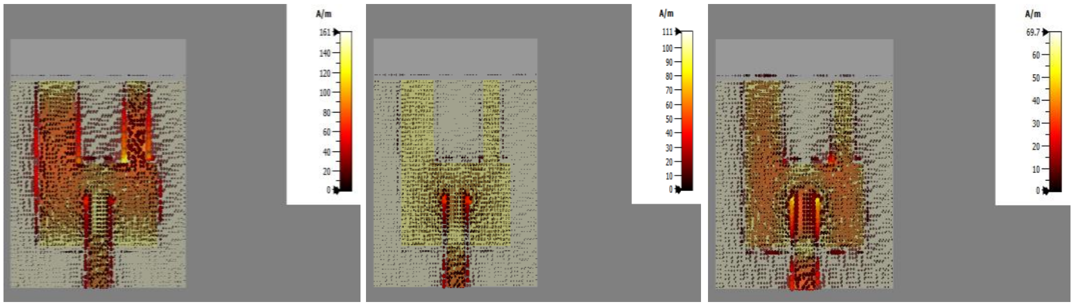
(c)

Fig. 10. The relationship between efficiency, and gain with the frequency (a) the relation between gain and frequency, (b) the relationship between both gain, and the radiation efficiency with the frequency, and (c) the relationship between the radiation efficiency and the frequency

4.4 The current distribution

At (3.68) GHZ, the current distribution was of a maximum magnitude of 161 (A/m), while, at (6.48) GHZ, the current distribution was of a maximum magnitude of 111 (A/m). At (7.93) GHZ, the current distribution was of a maximum amplitude of 69.7 (A/m).

Fig. 11 shows the surface current distribution at each resonance frequency.



(a) (b) (c)

Fig. 11. The surface current distribution at (a) (3.68) GHZ, (b) (6.48) GHZ, and (c) (7.93) GHZ

5. Literature Review

Table 3 is a literature review of some previous works compared to this work.

Table 3. Literature review of previous works with a comparison with this work

Reference	Number of bands	Substrate material	Dimensions (mm^2)	Frequency (GHz)	Reflection Coefficient (dB)	Notes
[24]	4	Rogers (RO4003)	29×24	13.27 20.65 24.98 28.96	-15.6 -19.5 -17.4 -16.9	
[25]	1	FR-4	17 mm^2	20	-16	
[26]	1	Jean cotton	64×71	2.45	-14.2	In free space
				2.48	-14.9	On human phantom
This work	3	FR-4	30×30	3.68 6.48 7.93	-19.89 -21.25 -28.05	

6. Conclusion

In this paper, the triple band patch antenna studies are intended for use in the detection of vital signs. We have developed a simple slitted patch antenna to enhance vital signs monitoring. The results of the antenna's simulation showed appropriate reflection coefficients and very high gain values where the maximum gain was (27) dBi at the resonance frequency (3.68) GHz. The aim and scope of this article are to design an efficient antenna design suitable for use as a part of a wireless monitoring system. As a future work suggestion, a substrate of Rogers is advised to be used instead of the FR-4 substrate material, to get more enhanced results. The suggested design showed appropriate reflection coefficient values and high gain values. The suggested antenna has many advantages as a patch antenna compared to other types of antennas such as lightweight, small size, appropriate price, and commercial availability. For future enhancement, we suggest using Rogers material as a substrate, in case of seeking higher performance regardless concerning the price.

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