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Design And Implementation Of Miniaturized Microstrip Patch Antenna For Bio-Medical Applications

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Abstract: The objective is to design a miniaturized microstrip patch antenna with narrow bandwidth and appropriate size for biomedical applications. The targeted design frequency lies between 5.725GHz to 5.825GHz. In this research, a miniaturized microstrip patch antenna with the ground is being developed on a wearable substrate with the required compact and simple structure dimensions. A miniaturized microstrip patch antenna is mostly preferable for biomedical applications like stroke imaging, and tumor detection in breast cancer to characterize malignant, benign, and normal breast tissues, MRI, and PET scanners, etc. We design the antenna using CST studio. The results show that the antenna design can be used for biomedical applications. The simulated antenna will be fabricated with flexible materials like jeans, cotton, tween, neoprene rubber, leather, and fleece fabric. Finally, the fabricated antenna is tested in the network analyzer for the testing results.

***Index Terms* – Microstrip Patch Antenna, CST Studio suite, Biomedical Application, Textile.**

I. INTRODUCTION

Biomedical applications require highly efficient and miniaturized antennas to operate at specific frequencies. In order to cater to the specific characteristics, microstrip patch antennas are an ideal choice due to their simple structure, low profile, and ease of integration with other components. In this paper, we present the design and simulation of a miniaturized microstrip patch antenna for biomedical applications operating in the frequency range of 5.725 GHz to 5.825 GHz. The antenna is designed to be wearable and fabricated with flexible substrates such as jean, cotton, tween, neoprene rubber, leather, and fleece fabric. The proposed antenna design is based on a compact and simple structure, with a ground plane and a patch element. We develop an antenna with a narrow bandwidth and appropriate size suitable for biomedical applications like stroke imaging, tumor detection in breast cancer, characterization of malignant, benign, and normal breast tissues, MRI and PET scanners, etc. The simulation of the antenna is carried out using CST Studio, and the results are analyzed.

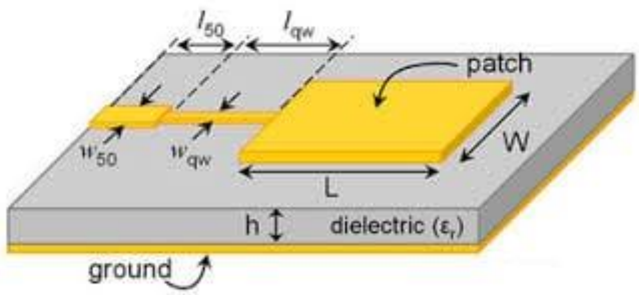

Fig 1 Basic Structure of Microstrip Patch Antenna

II. LITERATURE SURVEY

In recent years, the use of wearable antennas for biomedical applications has gained significant attention. Wearable antennas are preferred for their ability to be attached to the human body without causing discomfort. Among the various types of wearable antennas, microstrip patch antennas have proven to be effective for biomedical applications due to their low profile and ease of integration. There is another study which has its focuses on a circular patch antenna design with a defected grounded monopole patch. This antenna was designed for microwave-based head imaging applications. The antenna was designed to operate in the frequency range of 5GHz to 10GHz and had a compact size with a low profile. The simulation results demonstrated that the proposed antenna achieved a high gain and a low return loss, making it suitable for microwave-based head imaging applications. There is also a study that deals with low profile and low SAR full-textile UWB wearable antenna. This study analyzed WBAN applications using a metamaterial antenna. The antenna was designed on a flexible substrate with a compact size and a low profile. The simulation results demonstrated that the proposed antenna achieved a high gain and a low SAR, making it suitable for WBAN applications. The antennas were designed on various flexible substrates such as silk, cotton, and polyester. The simulation results showed that the proposed antennas achieved high gain and low VSWR, making them suitable for health monitoring systems. A miniaturized multiband antenna for terahertz applications in wireless body area networks was also designed. The antenna was designed to operate in the frequency range of 0.1THz to 1THz and had a compact size with a low profile. The simulation results showed that the proposed antenna achieved a high gain and low return loss, making it suitable for terahertz applications in wireless body area networks. Finally, an ultra-miniaturized antenna using the loading circuit method was designed for medical implant applications. The antenna was designed to operate in the frequency range of 2.4GHz to 2.5GHz and had a compact size with a low profile. The simulation results demonstrated that the proposed antenna achieved a high gain and a low return loss, making it suitable for medical implant applications. Overall, these studies have shown the potential of wearable antennas in various biomedical applications such as brain tumor detection, breast cancer detection, health monitoring systems, tomography, biotelemetry, and more.

III. DESIGN OF BIOMEDICAL ANTENNA

2.1 Overview

The design of a microstrip antenna focuses on parameters such as length, width, input impedance, gain, and radiation pattern. The general structure of a microstrip patch antenna typically comprises a radiating element, referred to as a patch, and a ground plane that is separated by a dielectric substrate. The patch is a conductive element, often in the shape of a square, rectangular, circular, or other geometries, which serves as the radiating element. It is placed on one side of the dielectric substrate. The ground plane, typically on the opposite side of the substrate, provides a reference point for the antenna. This arrangement allows for electromagnetic fields to propagate between the patch and the ground plane, resulting in radiation. The dielectric substrate, positioned between the patch and the ground plane, provides mechanical support and insulation. Together, these components form the fundamental structure of a microstrip patch antenna.

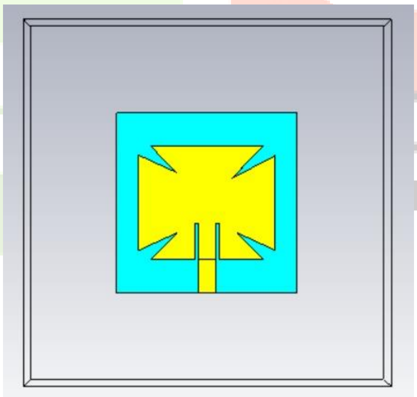

Figure. 2 Front View of the Simulated Antenna

Electronic circuit miniaturization and the large-scale integration revolution helped this concept develop beyond bounds. Early application of microstrip antennas on missiles showed that there was a practical concept for use in many fields. The growth has been rapid since then resulting in various mathematical models, papers, and articles being published. Microstrip antenna designs are most sought after when designing an antenna since they use low dielectric constant substrates which are generally preferred for maximum radiation.

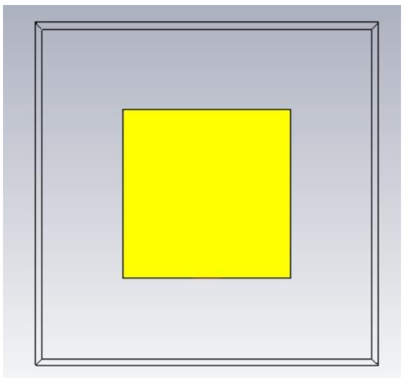

Figure. 3 Ground View of the Simulated Antenna

2.1.1 The basic structure of microstrip patch antenna:

A microstrip patch antenna (MPA) is made up of a ground plane on one side of a dielectric substrate and a conducting patch with any planar or non-planar shape on the other. It is a well-liked printed resonant antenna for semi-hemispherical coverage in narrow-band microwave wireless communications. The microstrip patch antenna has received a great deal of attention and is frequently employed as a component of an array because of its planar configuration and simplicity of integration with microstrip technology. Up until now, many microstrip patch antennas have been researched. There is a complete list of the geometries and their key characteristics. The most basic and widely used microstrip antennas are rectangular and circular patches. The MSA are typically thin metallic patches with a range of forms that have been etched onto dielectric substrates with an h thickness, typically between 0.0032.0 and 0.0520. Typically, the opposite side of the substrate is grounded. The patch's dimensions typically fall between 20/3 and 20/2. The substrate's dielectric constant typically falls between 2.2 and 12. Because they offer greater efficiency and bandwidth, the most popular designs combine relatively thick substrates with lower ones. On the other side, this suggests that the antennas will be greater in size. Typically, photo-etching technology is used to create the microwave circuit and antenna. 2.2 Substrate material

2.2 Substrate material

The substrate material is chosen based on the applications of the antenna. The wearable antenna requires a flexible substrate; high-frequency antennas require a low dielectric constant substrate to reduce the size of the antenna. The first design step is to choose a suitable dielectric substrate of appropriate thickness and loss tangent. In order to get better bandwidth and impedance a thicker substrate is used which would eventually radiate more power and suffer less conductor loss. A substrate with a low dielectric constant creates the fringing field at the patch edge. So, substrates with a dielectric constant of less than 2.4 is favored.

2.3 Design of the Antenna

A rectangular patch antenna's attributes are affected by all of its parameters (L, W, h, permittivity). As a result, in order to comprehend the design process, this page provides a general overview of how the parameters affect performance. First, the length of the patch L influences the resonance frequency. This is true for all microstrip antennas, even the more sophisticated ones that wrap around the longest path of the microstrip to control the lowest operational frequency. The patch length and resonance frequency are related by the following equation:

$$f_c = \frac{1}{2L\sqrt{\varepsilon_r \varepsilon_0 \mu_0}} \longrightarrow 1$$

Where,

εr=relative permittivity
$\varepsilon 0$=vacuum permittivity
$f c$=operating frequency
$\mu 0$=permeability

The width W determines the input impedance and the radiation pattern (the radiation equations are available here). The lower the input impedance, the wider the patch becomes. The permittivity εr of the substrate controls the fringing fields - lower permittivity's have wider fringes and therefore better radiation The bandwidth of the antenna is also increased by decreasing permittivity. Efficiency is increased when the permittivity value is lower. Higher permittivity results in an increase in the antenna's impedance. [6] Higher permittivity levels allow for "shrinking" of the patch antenna. Designers are given extremely little room in cell phones and want the antenna to be a half-wavelength long. One method is to employ a substrate with extremely high permittivity. To demonstrate this, answer the equation above for L:

$$L = \frac{1}{2\sqrt{f_c \varepsilon_r \varepsilon_0 \mu_0}} \longrightarrow 2$$

As a result, increasing the permittivity by a factor of four reduces the length required by a factor of two. Higher permittivity values are widely used in antenna miniaturization.

The bandwidth is also controlled by the height of the substrate h; raising the height increases the bandwidth. The general notion that "an antenna occupying more space in a spherical volume will have a wider bandwidth" can be used to explain why increasing the height of a patch antenna increases its bandwidth. [1] The same logic holds true when noting that increasing the thickness of a dipole antenna increases its bandwidth. The antenna's effectiveness also rises with its height. Height increases do cause surface waves to propagate into the substrate (unwanted radiation that may link to other components). The following equation approximates how bandwidth scales with given parameters:

$$B \,\alpha\, \frac{\varepsilon_r - 1}{\varepsilon_r^2} \frac{W}{L} h \longrightarrow 3$$

The following steps are taken to design a rectangular micro strip patch antenna.

Step1: Calculation of width of the Antenna (W):

The width of the micro strip patch antenna (Copper Material) is given by the equation as
W – Width of the patch.
C - Light's velocity in free space, 3 x 10^8 m/s.
$f0$ -The resonance frequency.
εr - The dielectric substrate's relative permittivity.

$$W = \frac{c}{2f_0\sqrt{(\varepsilon_r+1)/2}} \longrightarrow 4$$

Step 2: Calculation of the Effective Dielectric Constant of the Antenna:
Based on the patch antenna's predicted width, height, and dielectric constant of the dielectric.

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \longrightarrow 5$$

Step 3: Calculation of the Effective length of the Antenna L:

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}} \longrightarrow 6$$

Step 4: The length extension of the Antenna L is calculated as follows:
The length extension is provided by the following equation:
h - Thickness
W- width

$$\Delta L = 0.412h\,\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \longrightarrow 7$$

Step 5: Calculation of actual length of the patch of the Antenna:
L – Length of the patch.

$$L = L_{eff} - 2\Delta L \longrightarrow 8$$

IV. ANALYSIS OF ANTENNA

4.1 GAIN

Gain is a measure of the ability of the antenna to direct the input power into radiation in a particular direction and is measured at the peak radiation intensity. Gain, often known as 'absolute gain,' is defined as a comparison of radiation intensity in a specific direction to radiation intensity produced if the antenna's absorbed power disappeared isotropically. An isotropic antenna radiates in all directions equally. An isotropic radiator is thought to be completely efficient. A real antenna's gain improves power density in the direction of peak radiation. The gain of the antenna is related to its directivity.

$$Gain = 4\pi\frac{radiation\ intensity}{total\ input\ accepted\ power}$$

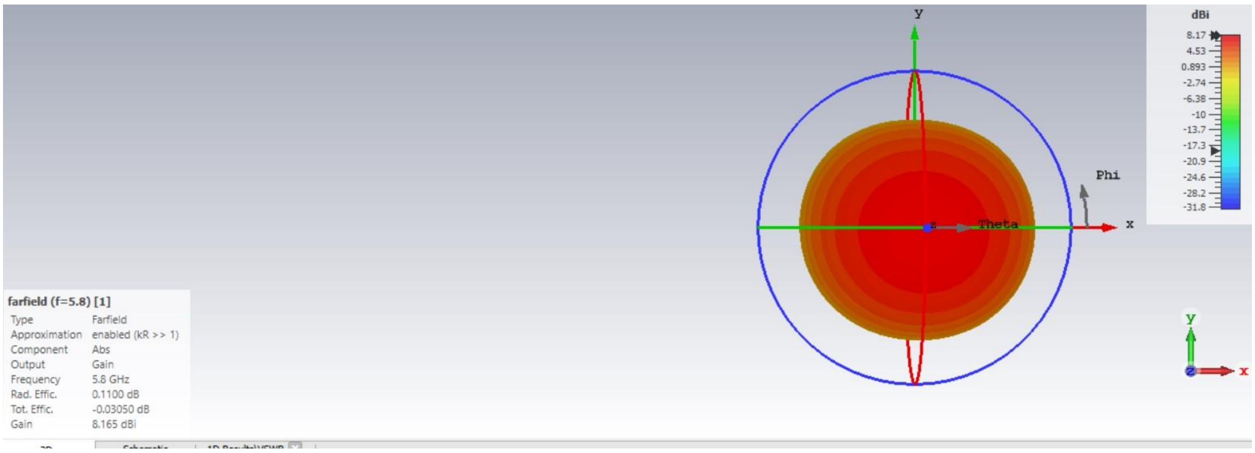

Figure. 4 Farfield at frequency 5.8 GHz of the Simulated Antenna

The figure represents the 3D radiation pattern of gain of the designed antenna with the substrate as Jean. The simulated gain of 8.17 dB is obtained for frequency 5.8GHz (Jean).

4.2 VSWR

VSWR stands for Voltage Standing Wave Ratio and is also referred to as Standing Wave Ratio (SWR). VSWR is a function of the reflection coefficient, which describes the power reflected from the antenna.

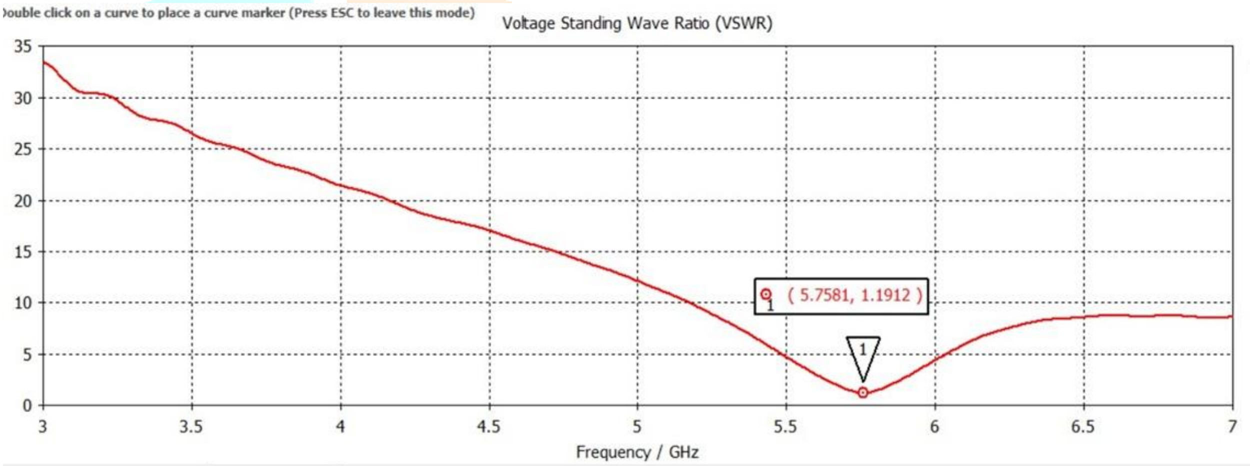

Figure. 5 VSWR of the Simulated Antenna

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \longrightarrow 10$$

where,

Γ- Reflection Coefficient

The reflection coefficient, which describes the power reflected from the antenna, determines VSWR. From the Fig.5 it is seen that the antenna yields a minimum VSWR value of 1.1912 for the frequency 5.8 GHz.

4.3 DIRECTIVITY

Directivity measures the power density the antenna radiates in the direction of the strongest emission versus the power density radiated by an ideal isotropic radiator radiating the same total power.

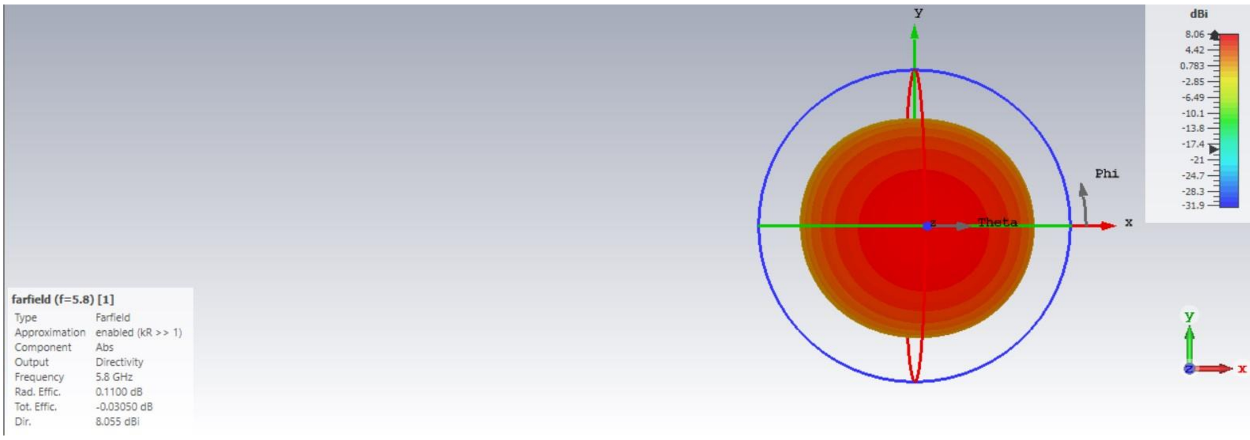

Figure. 6 Directivity of the Simulated Antenna

4.4 RETURN LOSS

The Return loss of the designed antenna indicates that it can be operated at a frequency of 5.80GHz with a return loss of about -21.062 db. Generally, the bandwidth of the antenna is found from the return loss graph. Bandwidth is obtained from the intersection of the return loss graph with 10dB of the graph. The difference between the upper cut-off frequency and lower cutoff frequency gives the bandwidth of the antenna.

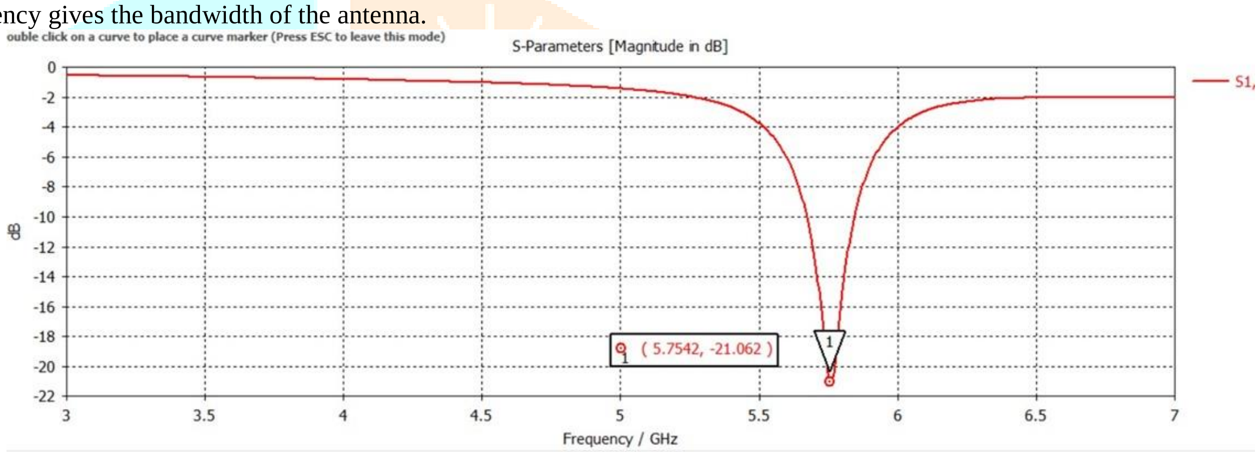

Figure. 7 Return Loss of the Simulated Antenna

Figure 7 shows the S- Parameter (Return loss) of the designed antenna. It indicates that it can be operated at a frequency of 5.8 GHz with a return loss of about – 21.062 dB. Generally, the bandwidth of the antenna is found from the return loss graph. Bandwidth is obtained from the intersection of the return loss graph with - 10dB of the graph. The difference between the upper cutoff frequency and lower cutoff frequency gives the bandwidth of the antenna.

V. APPLICATION

The various bio-medical applications in which the proposed antenna system can be used.

5.1 BRAIN TUMOR DETECTION

Tumors in the brain can be difficult to detect and diagnose, but medical imaging technologies can help identify them. A miniaturized microstrip patch antenna could be used in conjunction with these imaging technologies to improve their accuracy and sensitivity, allowing for earlier detection and more effective treatment.

5.2 BREAST CANCER DETECTION

Similar to brain tumors, breast cancer can also be difficult to detect in its early stages. However, by using a miniaturized microstrip patch antenna in conjunction with imaging technologies such as mammography or MRI, medical professionals can improve their ability to identify and diagnose breast cancer.

5.3 HEALTH MONITORING SYSTEMS

A miniaturized microstrip patch antenna could also be used in wearable health monitoring systems, allowing for the remote monitoring of vital signs such as heart rate and blood pressure. This technology could be particularly useful for patients with chronic conditions, as well as for athletes and fitness enthusiasts.

5.4 TOMOGRAPHY

Medical tomography is a technique used to create images of the interior of the body and is commonly used for diagnostic purposes. By incorporating a miniaturized microstrip patch antenna into tomography systems, medical professionals can improve the accuracy and resolution of the resulting images, leading to more accurate diagnoses and better treatment outcomes.

5.5 BIOTELEMETRY

Bio-telemetry involves the wireless transmission of physiological data from inside the body to an external monitoring system. A miniaturized microstrip patch antenna could be used as a part of these systems, allowing for the accurate and reliable transmission of this data for remote monitoring and analysis.

5.6 WIRELESS CAPSULE ENDOSCOPY

In this application, a wireless capsule containing a miniature camera is swallowed by the patient to capture images of the digestive tract. The images are then transmitted wirelessly to a receiver for diagnosis. Our miniaturized microstrip patch antenna can be used in the wireless capsule to enable the wireless transmission of images.

5.7 BLOOD GLUCOSE MONITORING

This application involves monitoring the blood glucose levels of diabetic patients in a non-invasive manner. Our antenna can be used in a wearable device that monitors the glucose levels in sweat and transmits the data wirelessly to a receiver. The antenna can be used to enable the wireless transmission of data.

5.8 WEARABLE ECG MONITORING

This application involves monitoring the electrical activity of the heart in a non-invasive manner. Our antenna can be used in a wearable device that monitors the ECG of the patient and transmits the data wirelessly to a receiver. The antenna can be used to enable the wireless transmission of data.

5.9 REMOTE PATIENT MONITORING

This application involves monitoring the health status of patients who are located remotely. Our antenna can be used in a remote patient monitoring system that monitors various health parameters, such as heart rate, blood pressure, and oxygen saturation, and transmits the data wirelessly to a healthcare provider. The antenna can be used to enable the wireless transmission of data.

5.10 PROSTHETICS CONTROL

This application involves controlling prosthetic limbs using electrical signals generated by the muscles of the patient. Our antenna can be used in a wireless prosthetic control system that wirelessly transmits the signals from the patient's muscles to the prosthetic limb, enabling the patient to control the prosthetic limb wirelessly.

VI. CONCLUSION

To conclude the proposed microstrip patch antenna design is designed using copper as a patch and jean as a substrate. The proposed antenna is wearable and can be used in various bio-medical applications.

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