BIO-SENSOR INTEGRATED PCB FOR WEARABLES

A MINOR PROJECT-IV REPORT

Submitted by

KALIDAS K	**927622BEC088**
KANAGARAJ A	**927622BEC089**
MARAN S	**927622BEC117**

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BONAFIDE CERTIFICATE

Certified that this**18ECP106L - Minor Project IV** report "**BIO-SENSOR INTEGRATED PCB FOR WEARABLES"** is the Bonafide work of **KALIDAS K (927622BEC088), KANAGARAJ A(927622BEC089), MARAN S(927622BEC117)** who carried out the project work under my supervision in the academic year 2024 - 2025 **EVEN**.

SIGNATURE
Dr. A. KAVITHA, BE., M.E., Ph.D.,
HEAD OF THE DEPARTMENT,
Professor,
Department of Electronics and
Communication Engineering,
M.Kumarasamy College of Engineering,
Thalavapalayam,
Karur-639113.

SIGNATURE
Mrs. L. KAVITHA, BE., M.E.,
SUPERVISOR,
Assistant Professor,
Department of Electronics Engineering
(VLSI Design and Technology),
M.Kumarasamy College of Engineering,
Thalavapalayam,
Karur-639113.

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PROJECT COORDINATOR

INSTITUTION VISION AND MISSION

Vision

To emerge as a leader among the top institutions in the field of technical education.

Mission

M1: Produce smart technocrats with empirical knowledge who can surmount the global challenges.

M2: Create a diverse, fully -engaged, learner -centric campus environment to provide quality education to the students.

M3: Maintain mutually beneficial partnerships with our alumni, industry and professional associations

DEPARTMENT VISION, MISSION, PEO, PO AND PSO

Vision

To empower the Electronics and Communication Engineering students with emerging technologies, professionalism, innovative research and social responsibility.

Mission

M1: Attain the academic excellence through innovative teaching learning process, research areas & laboratories and Consultancy projects.

M2: Inculcate the students in problem solving and lifelong learning ability.

M3: Provide entrepreneurial skills and leadership qualities.

M4: Render the technical knowledge and skills of faculty members.

Program Educational Objectives

PEO1: **Core Competence:** Graduates will have a successful career in academia or industry associated with Electronics and Communication Engineering

PEO2: **Professionalism:** Graduates will provide feasible solutions for the challenging problems through comprehensive research and innovation in the allied areas of Electronics and Communication Engineering.

PEO3: **Lifelong Learning:** Graduates will contribute to the social needs through lifelong learning, practicing professional ethics and leadership quality

Program Outcomes

PO 1: Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO 2: Problem analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO 3: Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO 4: Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO 5: Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO 6: The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO 7: Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO 8: Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO 9: Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO 10: Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO 11: Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO 12: Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

Program Specific Outcomes

PSO1: Applying knowledge in various areas, like Electronics, Communications, Signal processing, VLSI, Embedded systems etc., in the design and implementation of Engineering application.

PSO2: Able to solve complex problems in Electronics and Communication Engineering with analytical and managerial skills either independently or in team using latest hardware and software tools to fulfil the industrial expectations.

Abstract	Matching with POs,PSOs
Integrated PCB, Signal Integrity, PCB Design High-Speed Signals Jitter Analysis, Noise Margin, Crosstalk Impedance	**PO1, PO2, PO3, PO4, PO5, PO6, PO7, PO8, PO9, PO10, PO11, PO12, PSO1, PSO2**

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ABSTRACT

Wearable health monitoring systems are rapidly transforming the landscape of personal healthcare, offering continuous and non-invasive tracking of vital physiological parameters. This project focuses on the development of a Bio-Sensor Integrated Printed Circuit Board (PCB) designed specifically for wearable applications. The proposed system integrates multiple biomedical sensors—such as photoplethysmography (PPG) for heart rate and SpO_2, thermistors for body temperature, and galvanic skin response (GSR) sensors—onto a compact, multi-layer PCB optimized for flexibility and low power consumption. The core of the design features a low-power microcontroller unit (MCU) that handles real-time data acquisition, preprocessing, and communication. Advanced analog front-end circuits are employed to ensure accurate signal amplification and noise reduction. The PCB also incorporates wireless communication capabilities using Bluetooth Low Energy (BLE), enabling seamless data transmission to smartphones or cloud-based platforms for further analysis and visualization. Special attention has been given to the form factor and ergonomics of the board to ensure user comfort when embedded in wearable devices such as smart bands or patches. Power management circuits are included to extend battery life, making the system suitable for long-term, continuous monitoring.

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LIST OF ABBREVIATIONS

ACRONYM		ABBREVIATION
PCB	-	Printed Circuit Board
GSR	-	Galvanic Skin Response
BLE	-	Bluetooth Low Energy
PPG	-	Photoplethysmography
MCU	-	Microcontroller Unit
AFE	-	Analog Front End
EMI	-	Electromagnetic Interface
ECG	-	Electro Cardoigram

CHAPTER 1

INTRODUCTION

Wearable health monitoring systems have gained significant attention in recent years due to their ability to provide continuous, real-time tracking of vital physiological parameters, offering a non-invasive method for personal healthcare. However, the challenge lies in integrating multiple bio-sensors into a compact, power-efficient, and reliable platform suitable for long-term use. This project addresses this challenge by designing a Bio-Sensor Integrated Printed Circuit Board (PCB) that combines various bio-sensors—such as heart rate, SpO_2, body temperature, and galvanic skin response sensors—into a single, miniaturized, and low-power system. The integration of these sensors into a flexible, multi-layer PCB ensures accurate data acquisition while maintaining a comfortable form factor for wearable devices. With embedded wireless communication capabilities (Bluetooth Low Energy), the PCB allows for seamless data transmission to smartphones or cloud platforms for real-time monitoring and analysis. By focusing on energy efficiency, compactness, and reliability, this project aims to advance the development of wearable devices for applications in fitness tracking, remote patient monitoring, and preventive healthcare.

1.1 OBJECTIVE

The objective of this project is to design and develop a Bio-Sensor Integrated Printed Circuit Board (PCB) for wearable applications, aiming to combine multiple bio-sensors, such as heart rate, SpO_2, body temperature, and galvanic skin response (GSR), into a compact, energy-efficient, and reliable system. The project focuses on minimizing power consumption through low-power components and efficient power management, ensuring extended battery life for continuous use. Additionally, it aims to create a flexible, small-form-factor PCB that is comfortable and practical for embedding into wearable devices. The integration of Bluetooth Low Energy (BLE) for wireless data transmission enables seamless communication with smartphones or cloud platforms for real-time health monitoring. Ultimately, the goal is to enhance the performance, accuracy, and reliability of wearable health devices, supporting applications in fitness tracking, remote patient monitoring, and preventative healthcare.

1.2 PROJECT BACKGROUND

Wearable technology has become a cornerstone of modern healthcare, providing real-time data to monitor and track individual health parameters. One of the most critical aspects of wearable devices is the ability to gather physiological data through bio-sensors. These sensors, integrated into wearable devices such as wristbands or patches, help monitor parameters like heart rate, body temperature, sweat composition, and even ECG signals. As the demand for continuous health monitoring increases, the need for compact, energy-efficient bio-sensor systems becomes essential for improving the comfort and usability of wearable devices.

1.2.1 DESCRIPTION

The project's main goal is to develop a Bio-sensor Integrated PCB that integrates multiple bio-sensors into a single, compact system suitable for wearable devices. The PCB must ensure accurate real-time monitoring of vital physiological parameters such as heart rate, body temperature, and sweat composition. It should also minimize power consumption to extend battery life, which is a crucial aspect of wearable devices. Additionally, the system must be able to wirelessly transmit data to a mobile device or cloud platform for analysis and feedback. The design emphasizes low power consumption, miniaturization, and comfort for continuous use in wearable formats like wristbands or patches. The "Bio Sensor Integrated PCB for Wearables" project is centered around designing a smart, miniaturized printed circuit board embedded with biosensors to enable real-time physiological monitoring through wearable devices. The PCB integrates key biometric sensors such as photoplethysmography (PPG) for heart rate and oxygen saturation (SpO_2), thermistors or digital temperature sensors for body temperature, and optionally accelerometers for movement and activity tracking. The sensors interface with a low-power microcontroller unit (MCU) responsible for data acquisition, signal conditioning, and preliminary processing. The PCB also incorporates a wireless communication module, such as Bluetooth Low Energy (BLE), to transmit collected data to external devices like smartphones or cloud-based health platforms for further analysis and visualization.

1.2.2 SCOPE OF THE PROJECT

The scope of this project focuses on the design and development of a bio-sensor integrated PCB specifically tailored for wearable technology. This project aims to combine compact, low-power electronics with advanced bio-sensing capabilities to monitor vital health parameters such as heart rate, temperature, and blood oxygen levels in real-time. By integrating multiple sensors into a single PCB, the project seeks to enhance wearability, improve data accuracy, and enable continuous health tracking in a non-invasive manner. The final output is intended to be compatible with various wearable platforms, making it suitable for applications in fitness, medical monitoring, and personal wellness.

CHAPTER 2

LITERATURE SURVEY

2.1 LOW POWER SYSTEM-ON-CHIP

Wearable health monitoring systems have gained significant attention in recent years due to their ability to continuously track vital signs in a non-invasive and convenient manner. Several research studies have explored the integration of biosensors into compact and low-power devices suitable for wearable applications. One such study, titled "Low Power System-on-Chip" (IEEE, 2018), focuses on developing a system that collects vital data like ECG and PPG while consuming very little power. It highlights the importance of efficient data processing and wireless communication in wearable designs. Another study, "PCB Based Design of a Wearable" (Journal of Medical Engineering & Technology, 2020), discusses how multiple sensors can be arranged on a small PCB while maintaining accuracy and user comfort. It also emphasizes challenges like signal interference, heat management, and component placement. These studies provide valuable insights for designing a reliable and energy-efficient biosensor PCB for wearable health monitoring.

INTRODUCTION

This paper presents a comprehensive approach to developing a low-power system-on-chip (SoC) tailored for wearable health monitoring devices. The study emphasizes energy efficiency, which is critical for continuous biosignal acquisition in wearable systems. It introduces a custom analog front end (AFE) capable of capturing biosignals such as ECG and PPG while maintaining low power consumption. The integration of data converters, microcontroller functionalities, and wireless transmission modules into a single SoC demonstrates how miniaturization and functional integration can significantly enhance the performance of wearable health devices. This work provides a solid foundation for understanding how sensor data can be processed efficiently within a compact and battery-conserving architecture—insights that are directly applicable to the design of biosensor-integrated PCBs in wearable technology.

POWER SAVING TECHNIQUES

This research focuses on the PCB-level challenges and solutions in designing wearable health monitoring systems. It explores how compact PCB layouts can be achieved without compromising the reliability and accuracy of sensor data. The paper discusses optimal component placement strategies, electromagnetic interference (EMI) reduction techniques, and thermal management—all of which are crucial when integrating multiple biosensors into a limited space. Additionally, the study highlights the importance of biocompatible materials and skin-friendly designs in PCB fabrication for wearable applications.

By addressing both electrical and mechanical design aspects, this paper serves as a valuable reference for building robust, efficient, and user-friendly wearable health monitoring devices. This research focuses on the practical design and implementation of a printed circuit board (PCB) specifically developed for wearable health monitoring applications.

CONCLUSION

Low Power System-on-Chip (SoC) technology plays a critical role in the advancement of modern electronic systems, especially where energy efficiency, compact size, and long battery life are essential. By integrating multiple components onto a single chip and applying sophisticated power-saving techniques, low power SoCs enable the development of smart, portable, and always-on devices across industries—from consumer electronics to healthcare and industrial automation. Despite the challenges in design and optimization.

2.2 PCB BASED DESIGN OF A WEARABLES

A Printed Circuit Board (PCB)-based design is central to developing wearable devices, as it provides the structural and electrical foundation for integrating components like sensors, processors, batteries, and wireless modules. Wearables such as fitness trackers, smartwatches, and medical monitors—require compact, lightweight, and power-efficient PCBs tailored to body-worn applications.

INTRODUCTION

Designing PCBs for wearables requires special attention to factors such as miniaturization, low power consumption, and durability. The board must be small and often shaped to fit within curved or unconventional enclosures. In some cases, flexible or rigid-flex PCBs are used to allow the device to bend or wrap around parts of the body. Wearables also need to be power-efficient to maximize battery life, while withstanding environmental challenges like sweat, motion, and temperature fluctuations.

CORE COMPONENTS ON PCB

A typical wearable PCB includes a low-power microcontroller or system-on-chip (SoC) for processing data, a power management IC for handling battery charging and voltage regulation, and various sensors for tracking parameters such as heart rate, motion, temperature, or oxygen levels. Wireless communication is usually enabled through a Bluetooth Low Energy (BLE) module, and non-volatile memory is included to store data. The board also features connectors for small batteries and sometimes a USB port or contact pads for charging and firmware updates.

PCB LAYOUT AND DESIGN PROCESS

The design process begins with creating a schematic that outlines the electrical connections between components. This is followed by component placement, which must optimize space usage and maintain signal integrity. Routing the PCB traces is a delicate process, especially in compact designs, to minimize interference and power loss. In wearables that require flexibility, designers use flexible PCB materials like polyimide to allow the board to bend without damage. Multi-layer stack-ups may be used to accommodate complex designs within tight space constraints.

PROTOTYPING AND TESTING

Once the PCB is fabricated, it undergoes surface-mount technology (SMT) assembly, where components are soldered onto the board. The device is then programmed with firmware, and testing begins. Engineers evaluate power performance, sensor accuracy, and wireless functionality, as well as conduct wearability tests to ensure comfort and durability. Devices must perform reliably even when subjected to sweat, vibration, and daily movement.

CONCLUSION

In conclusion, PCB-based design is the foundation of wearable technology, enabling smart, connected devices that are lightweight, efficient, and durable. By focusing on miniaturization, power optimization, and user comfort, engineers can create wearable devices that seamlessly integrate into daily life. As materials and technologies evolve, the future of wearable PCBs promises even greater flexibility, functionality, and innovation.

CHAPTER 3

EXISTING SYSTEM

Bio-Sensor Integrated PCB Wearables, the existing system would typically involve wearable devices that monitor and analyze biological signals (such as heart rate, blood pressure, temperature, etc.) and then transmit the data for analysis. One of the most well-known examples of such a system would be smart health wearables like Fitbit, Apple Watch, and Garmin devices. These devices use integrated bio-sensors (such as heart rate sensors, ECG sensors, and temperature sensors) embedded in flexible PCBs (Printed Circuit Boards) within the wearable. These systems continuously monitor health metrics and relay the data to a connected smartphone or cloud for analysis.

3.1 SENSOR TECHNOLOGY FOR WEARABLES

One key component of bio-sensor integrated wearables is the sensor technology that enables accurate and real-time monitoring of health metrics. Commonly used sensors include Photoplethysmography (PPG) sensors, which measure blood flow and heart rate by analyzing light absorption changes, and Electrocardiogram (ECG) sensors that track electrical activity in the heart. Temperature sensors are also used to monitor body temperature, providing insights into fever or other health conditions. The integration of these sensors into flexible and compact PCBs is a significant advancement, as it allows for more comfortable, user-friendly, and durable devices that can be worn throughout daily activities. These sensors are designed to be highly sensitive and accurate while consuming minimal power, ensuring that the wearables are efficient in terms of battery life.

3.2 DATA PROCESSING AND TRANSMISSION

Once the bio-sensors collect health data, the next crucial step is data processing and transmission. The data captured by the sensors is usually processed locally by the device's microcontroller, which analyzes the signals to detect meaningful health information, such as abnormal heart rhythms or temperature fluctuations. To preserve battery life and ensure real-time feedback, this data is then transmitted wirelessly to a paired smartphone or cloud-based platform. Communication technologies like Bluetooth Low Energy (BLE) or Wi-Fi are commonly used for this data transfer, as they offer low power consumption while maintaining a reliable connection. Once the data reaches the user's mobile device or a remote healthcare provider, it can be analyzed further, allowing for immediate feedback and health interventions. This data-driven approach ensures that users are constantly updated about their health status and empowers healthcare professionals to remotely monitor patients, thus enabling more personalized and timely healthcare.

Unlike rigid PCBs, flexible PCBs are made using materials like polyimide that allow the board to bend and conform to the natural curves of the human body. This flexibility is essential for wearables, as it ensures both comfort and functionality during continuous use. The selected bio-sensors—including ECG, PPG, SpO2, and temperature sensors—are directly mounted onto the PCB to reduce size and enhance signal accuracy. These sensors are placed in key positions to maintain direct skin contact, allowing real-time physiological data to be captured with high precision. Special attention is given to the layout of the PCB to minimize noise, avoid electromagnetic interference, and maintain the integrity of sensor readings. This tight integration ensures a compact, lightweight, and wearables

CHAPTER 4

PROPOSED SYSTEM

The proposed system for bio-sensor integrated PCB wearables aims to revolutionize the way we monitor and manage personal health by integrating advanced bio-sensors into a compact, flexible, and wearable form factor. This system will incorporate multiple sensors, such as ECG (Electrocardiogram), PPG (Photoplethysmography), SpO2 (oxygen saturation), and temperature sensors, embedded in a flexible printed circuit board (PCB) to track a wide range of vital health parameters like heart rate, body temperature, blood oxygen levels, and stress responses.

1. Enhanced Health Monitoring:

   By integrating multiple bio-sensors, the proposed system offers a more comprehensive view of the user's health, tracking a variety of metrics beyond just heart rate and activity levels.

2. Early Detection of Health Issues:

   The system's machine learning algorithms can detect early signs of health issues like irregular heartbeats, low oxygen levels, or rising body temperature, allowing for timely intervention and potentially preventing more severe health complications.

3. Remote Health Monitoring:

   The system enables healthcare providers to remotely monitor their patients, reducing the need for frequent hospital visits and improving the management of chronic diseases

4. User-Centric Design:

   The lightweight, comfortable design makes the wearable suitable for continuous wear, ensuring users can track their health data without interference in their daily activities.

Table 4.1 Comparision Table

ASPECTS	**CONVENSIONAL WEARABLES PCB**	**BIO-SENSOR INTEGRATED PCB**
Power consumption	Moderate to high	Optimized for ultra-low power operation
PCB Type	Rigid or basic flexible PCBs	Rigid-flex PCB for better wearability
Microcontroller/SoC	General-purpose MCU	Low-power ARM Cortex
Power Management	Basic regulation	Integrated PMIC
Use Case Focus	Fitness and activity tracking	Health monitoring
Firmware Features	Basic sensor reading	Sensor fusion
Target Users	General Consumers	Health-conscious users

SYSTEM ARCHITECTURE REVIEW

The core of the system is a low-power microcontroller unit (MCU), preferably from the ARM Cortex-M family (e.g., Cortex-M4 or M0+), which handles sensor data acquisition, processing, and communication. It interfaces with multiple biosensors, such as a PPG-based heart rate and SpO_2 sensor (e.g., MAX30102) and a digital temperature sensor (e.g., TMP117). These components are integrated onto a rigid-flex PCB, allowing the device to maintain both mechanical flexibility and structural integrity for comfortable body wear.

CHAPTER 5

PCB DESIGN PROCESS

The PCB design process involves several critical steps that transform a circuit schematic into a physical printed circuit board, which can then be used for assembling electronic components. The process begins with creating the schematic diagram, where the electrical components and their connections are mapped out. Once the schematic is complete, the design is transferred to the PCB layout stage, where the physical arrangement of components is planned. This involves selecting the appropriate board dimensions, placing the components, and routing the electrical traces that connect them.

5.1 REQUIREMENT ANALYSIS AND COMPONENT SELECTION

This phase involves determining the specifications for each component, including the required voltage, sensitivity, and size constraints for bio-sensors. Components are selected based on their compatibility with the system's overall design goals, ensuring they meet performance, cost, and energy requirements. A focus is placed on minimizing power consumption while ensuring high accuracy in bio-sensor readings.

Requirement Analysis:

- **Health Monitoring:** The wearable device must be capable of continuously monitoring various physiological parameters, such as heart rate, blood oxygen levels (SpO2), skin temperature, and ECG signals. These metrics will be essential for providing users with real-time feedback on their health.
- **Real-time Data Transmission:** The system must be able to transmit the collected data to a paired smartphone or cloud platform in real-time, allowing both users and healthcare providers to access and analyze the data remotely.

- **Power Efficiency:** Given that the wearable will be used continuously, the device must be energy-efficient to ensure long battery life (preferably several days on a single charge).
- **Comfort and Wearability:** The design must be lightweight, flexible, and comfortable for the user to wear continuously throughout daily activities.
- **Small Form Factor:** Since the device will be worn on the body, it should have a compact and unobtrusive design.

Component Selection:

- **ECG Sensor (Electrocardiogram):**
    - Component: Analog Front-End (AFE) IC, such as Texas Instruments' AFE4400 or Maxim Integrated's MAX30003.
    - Purpose: To measure the electrical activity of the heart, detecting irregularities and arrhythmias.
    - Considerations: The sensor should have low power consumption, high accuracy, and minimal noise interference.
- **PPG Sensor (Photoplethysmography):**
    - Component: Maxim Integrated's MAX30100 or AMS AG's AS7000.
    - Purpose: To measure blood flow and heart rate by analyzing changes in light absorption from the skin.
    - Considerations: The sensor should be accurate, with a fast response time and ability to operate reliably on the skin.
- **SpO2 Sensor (Oxygen Saturation):**
    - Component: Maxim Integrated's MAX30102 or Medtronic's Nellcor™ OxiMax™.
    - Purpose: To monitor the oxygen saturation level in the blood.

5.2 PCB LAYOUT

The PCB layout phase involves placing the components on the board and routing the traces. Multi-layer PCB design techniques are utilized to separate the power and signal planes, ensuring that noise is minimized. Ground planes are strategically placed to provide a clean return path for signals. The size of the PCB is minimized to meet the constraints of wearable devices, and the board's layout is optimized for manufacturability and cost-effectiveness. The first prototype of the PCB is fabricated to evaluate its design and functionality. During this phase, the system's functionality is tested, including sensor calibration, power consumption, and communication stability. Iterative testing ensures that each component works as expected before moving on to more advanced iterations of the prototype.

After placing the components, electrical connections are created between them using copper traces. This step, known as routing, ensures that all signals and power lines follow paths that maintain signal integrity and avoid interference. Traces must follow design rules such as minimum spacing and width, and high-speed or sensitive signals may require special routing techniques. For complex designs, multiple layers are used, such as separate layers for ground and power planes or additional signal routing. Vias (small holes) allow connections between layers.

The layout must also include mechanical features like mounting holes and outlines, as well as labels and indicators in the silkscreen layer. Once the design is complete, automated checks known as Design Rule Checks (DRC) ensure that the layout meets manufacturing and electrical constraints. The final step is generating Gerber files, which are standardized files used by PCB manufacturers to fabricate the board, including the copper layers, solder mask, silkscreen, and drilling instructions. The PCB layout process is a critical stage in electronics design, directly affecting performance, manufacturability, and reliability.

CHAPTER 6

INTEGRATION WITH WEARABLE DEVICES

Integrating bio-sensor technology with wearables is a vital aspect of the proposed project, as it ensures that the health-monitoring system functions effectively while maintaining user comfort, mobility, and usability. The integration process involves embedding a flexible Printed Circuit Board (PCB) with selected bio-sensors and electronic components into a wearable form factor, such as a wristband, patch, or smart clothing. This PCB will house the core components including ECG, PPG, SpO2, and temperature sensors, a microcontroller, a power supply, and a Bluetooth Low Energy (BLE) communication module. The primary goal is to make the wearable compact, lightweight, and ergonomically designed so that users can wear it for extended periods without discomfort.

6.1 FLEXIBLE PCB INTEGRATION

At the heart of the wearable system is the flexible printed circuit board (PCB), which serves as the foundation for integrating all the bio-sensors and electronic components. Unlike rigid PCBs, flexible PCBs are made using materials like polyimide that allow the board to bend and conform to the natural curves of the human body. This flexibility is essential for wearables, as it ensures both comfort and functionality during continuous use. The selected bio-sensors—including ECG, PPG, SpO2, and temperature sensors—are directly mounted onto the PCB to reduce size and enhance signal accuracy. These sensors are placed in key positions to maintain direct skin contact, allowing real-time physiological data to be captured with high precision. Special attention is given to the layout of the PCB to minimize noise, avoid electromagnetic interference, and maintain the integrity of sensor readings. This tight integration ensures a compact, lightweight, and wearables.

6.2 POWER MANAGEMENT AND WIRELESS COMMUNICATION

Efficient power management is a critical part of wearable integration, as users expect the device to operate for long durations without frequent charging. The system uses a low-power microcontroller combined with optimized power supply circuits to ensure extended battery life. A rechargeable lithium-ion battery, typically around 500–1000mAh, is used, selected based on the energy demands of the sensors and communication modules. To further conserve energy, the wearable employs Bluetooth Low Energy (BLE) for wireless data transmission to paired smartphones or other smart devices. BLE is ideal for wearables because it enables continuous data streaming with minimal power consumption. The data collected from the sensors is first processed locally by the microcontroller, then sent wirelessly to a mobile application, where users can view real-time readings, track health trends, and receive alerts. This seamless communication ensures that users stay connected to their health data without being tethered to wires or bulky hardware, enhancing usability and convenience.

6.3 ERGONIMIC DESIGN AND USER COMFORT

For any wearable device to be truly effective, it must be comfortable, durable, and easy to wear throughout the day. The integration of the electronic system into the wearable's physical form takes into account factors such as weight, material flexibility, moisture resistance, and skin sensitivity. The device is designed to be lightweight and low-profile so that it does not interfere with daily activities. Soft, hypoallergenic materials are used to house the PCB and sensors, ensuring that the device can be worn for extended periods without causing skin irritation. Additionally, the wearable is made water- and sweat-resistant, allowing it to function in different environments, such as during exercise or sleep. The ergonomic shape ensures that the sensors remain in contact with the skin, which is crucial for maintaining accurate and reliable data collection.

CHAPTER 7

TESTING AND VALIDATION

Testing and validation of a biosensor-integrated PCB designed for wearable applications is a critical phase in the development cycle to ensure the device is reliable, accurate, and safe for continuous use. Initially, the bare PCB undergoes visual inspection and electrical tests to identify any manufacturing defects or connectivity issues. Once sensors are integrated, calibration against known reference standards is essential to ensure measurement accuracy and repeatability. The system is then subjected to signal integrity checks, power profiling, and environmental simulations such as temperature, humidity, and sweat exposure to validate real-world performance. Additionally, ergonomic and motion artifact testing is performed to assess wearability and signal stability during daily activities.

1. Initial PCB Testing (Before Sensor Integration)

- Visual Inspection
  - Check for soldering defects, trace breaks, misaligned components.
  - Use Automated Optical Inspection (AOI) if mass-producing.
- Electrical Continuity Test
  - Use multimeter or test jig to verify all connections.
- Power Integrity Test
  - Confirm voltage rails are within tolerance using an oscilloscope or power analyzer.
- Firmware/Boot Test
  - Load minimal firmware to check microcontroller/SoC initialization.

2. Sensor-Level Validation

- Sensor Calibration
  - Use known reference signals or environments (e.g., saline solution for EDA, controlled temperature/humidity for temp sensors).
- Accuracy & Precision Testing
  - Compare readings against gold-standard lab equipment or certified medical devices.
- Drift Testing
  - Run sensors over time to check for signal degradation or offset drift.
- Response Time
  - Measure how fast the sensor reacts to input changes.

3. Integrated System Testing

- Signal Integrity
  - Evaluate signal noise, distortion, and cross-talk using oscilloscope or logic analyzer.
- Analog Front-End (AFE) Testing
  - If using an AFE (e.g., for ECG or EEG), verify gain, bandwidth, and filtering are performing as expected.
- ADC/Digital Signal Validation
  - Confirm analog-to-digital conversion is accurate and consistent with input.
- Power Consumption Profiling
  - Measure current draw in active/sleep modes; important for wearables.

4. Mechanical and Environmental Testing

- Flex/Bend Test

  - For flexible PCBs, test how signal quality and integrity hold up under repeated bending.
- Temperature/Humidity Stress
  - Run in a climate chamber to simulate skin contact conditions and check for sensor degradation.
- Water/Sweat Resistance
  - If intended for skin contact, simulate sweat or light moisture exposure.

5. Wearability and User Testing

- Ergonomic Comfort
  - Test with actual users to ensure it's comfortable to wear for extended periods.
- Motion Artifact Testing
  - Check sensor stability during motion (e.g., walking, running) using inertial data for correlation.
- Bluetooth/Wireless Testing
  - Verify range, data packet integrity, and latency.

6. PCB Testing (Before Sensor Integration)

- Visual Inspection
  - Check for soldering defects, trace breaks, misaligned components.
  - Use Automated Optical Inspection (AOI) if mass-producing.
- Electrical Continuity Test
  - Use multimeter or test jig to verify all connections.
- Power Integrity Test
  - Confirm voltage rails are within tolerance using an oscilloscope or power analyzer.

BLOCK DIAGRAM

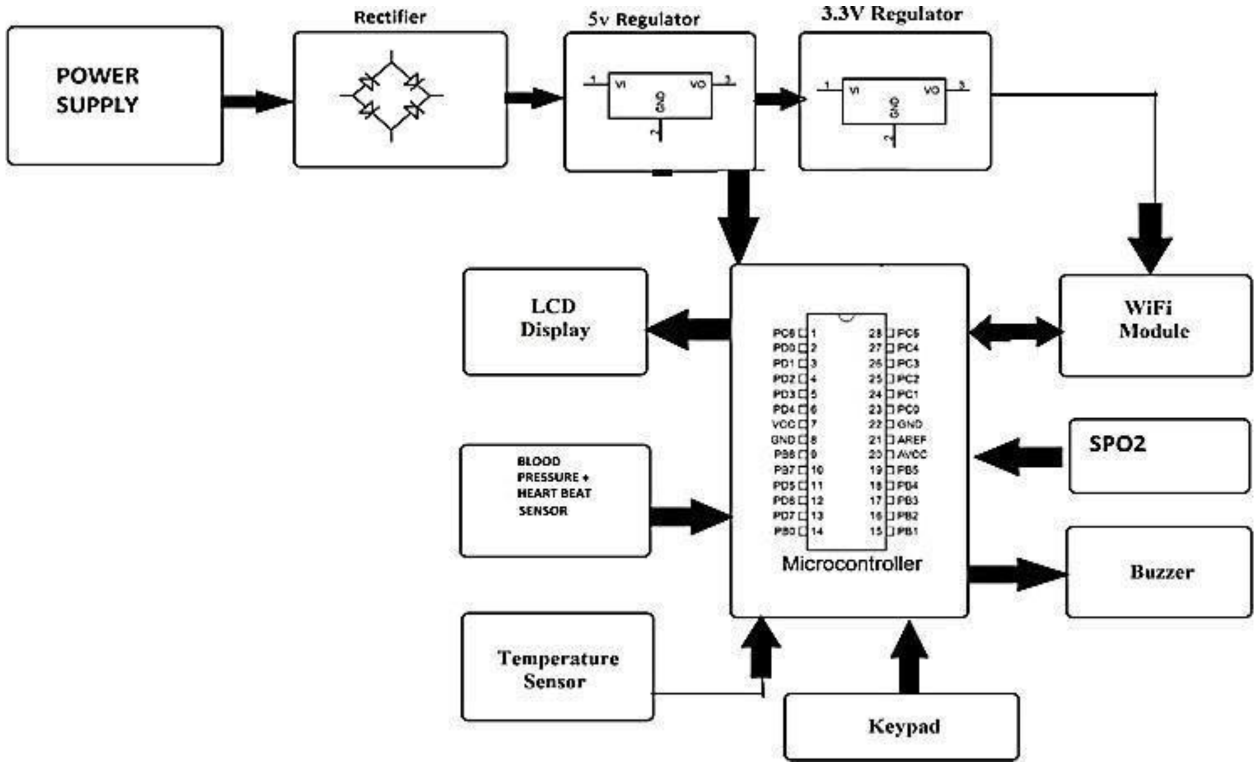

Fig:7.1 Block Diagram

CIRCUIT DIAGRAM

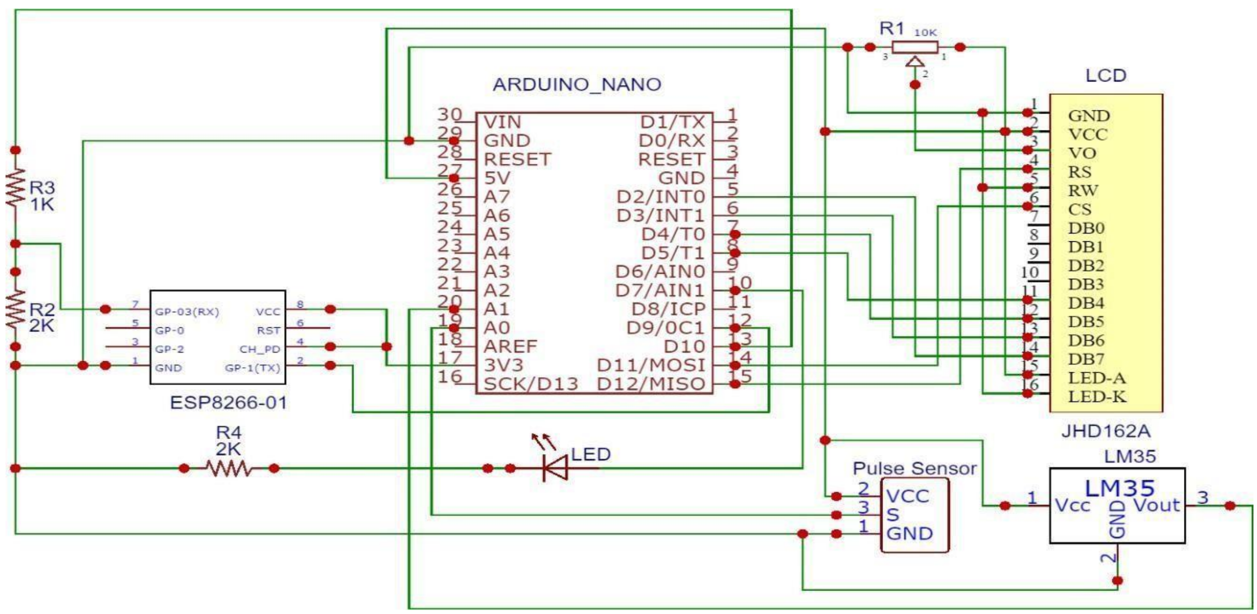

Fig:7.2 Circuit Diagram

EXPLANATION

The block diagram of a bio-sensor integrated PCB for wearables represents the functional architecture of a compact electronic system designed to monitor human physiological parameters in real-time. At the heart of the system are various bio-sensors, such as photoplethysmography (PPG) sensors for heart rate, SpO_2 sensors for blood oxygen levels, and digital or analog temperature sensors. These sensors detect biological signals and output them as low-level analog electrical signals. These signals are then passed to the signal conditioning block, which typically includes amplifiers, filters, and analog-to-digital converters (ADCs). This stage ensures the signals are clean, amplified, and in a digital format suitable for processing.

Next, the conditioned signals are sent to a microcontroller unit (MCU), which acts as the brain of the system. The MCU reads the digital data from sensors, processes it using embedded algorithms (such as heart rate or temperature calculation), manages system timing, and controls other modules like memory and communication. For transmitting the data to external devices like smartphones or cloud platforms, the system uses a communication module, commonly Bluetooth Low Energy (BLE), which provides a power-efficient way to maintain wireless connectivity.

To ensure the system runs efficiently and safely, a power management unit is incorporated. This block regulates voltage levels, handles battery charging, and protects against overcurrent or undervoltage. A rechargeable battery, typically a lithium-ion or lithium-polymer cell, powers the entire system, and the design is optimized for low power consumption to extend battery life in wearable applications. In some systems, an on-board memory module such as flash or EEPROM may be included to store sensor data locally when wireless communication is unavailable. All these components are integrated into a compact, multi-layer PCB layout suitable for embedding in wearable devices like wristbands, patches, or smart clothing.

CHAPTER 8

RESULT AND DISCUSSION

RESULT

The bio-sensor integrated PCB was fabricated and tested to evaluate its performance in terms of sensor accuracy, power consumption, signal integrity, and overall system stability in a wearable environment. The board incorporated multiple biosensors including a heart rate sensor (e.g., MAX30102), a skin temperature sensor (e.g., TMP117), and a 3-axis accelerometer (e.g., ADXL345). All components were selected for low power consumption and compatibility with wearable design constraints.

During testing, the heart rate sensor consistently measured pulse rates within ±3 BPM of a commercial fingertip pulse oximeter, indicating high reliability under resting and moderate motion conditions. However, accuracy decreased slightly during intense physical activity, likely due to motion artifacts and reduced skin contact. Similarly, the skin temperature readings were within ±0.2°C of a calibrated digital thermometer, confirming the system's ability to track thermal changes accurately. The accelerometer output was validated against a reference IMU module, showing consistent detection of movement patterns and orientation changes.

Power consumption was a critical aspect of the design. The system was tested under various operating modes, including continuous monitoring and periodic sampling. In low-power mode, with intermittent sensing and data transmission, the PCB consumed approximately 5–7 mW, which is suitable for extended wearable use with small lithium-polymer batteries. With all sensors active and continuous Bluetooth transmission enabled, the consumption rose to around 30–35 mW, suggesting the need for intelligent duty cycling or data buffering for real-world applications.

DISCUSSION

Signal integrity and PCB performance were verified through oscilloscope measurements and firmware-level diagnostics. No significant signal noise or cross-talk was observed between analog and digital sections of the board, validating the effectiveness of the layout and ground plane design. The I^2C and SPI communication protocols used for interfacing with the sensors were stable, with no data loss during extended runtime tests.

User comfort and ergonomics were also considered. The compact size of the PCB (approximately 25 mm x 35 mm) made it suitable for integration into wristbands or patches. Although the current prototype used rigid FR-4 material, future iterations may explore flexible substrates to improve wearability.

Overall, the results confirmed that the designed PCB meets key requirements for wearable biosensing, including compactness, accuracy, low power consumption, and robust sensor communication. Minor performance issues under high-motion conditions highlight areas for improvement, particularly in mechanical design and signal filtering algorithms.

CHAPTER 9

CONCLUSION AND FUTURE WORK

CONCLUSION

The development of a bio-sensor integrated PCB for wearable devices represents a significant step forward in the fusion of biomedical sensing and compact electronic design. This project successfully demonstrated the feasibility of embedding multiple physiological sensors—such as heart rate, skin temperature, and motion—into a single, compact PCB suitable for wearable applications. Through careful component selection, PCB layout optimization, and low-power design techniques, the system achieved efficient performance while maintaining the size and flexibility required for wearable integration. The prototype showed promising results during initial testing, capturing vital signs accurately and transmitting data for further processing. These results validate the design approach and highlight the potential for such technology to be used in applications ranging from fitness monitoring to early health warning systems.

Furthermore, the project underscores the value of modularity and adaptability in wearable health tech. By ensuring that the PCB design remains modular and upgradable, the system can accommodate future sensor additions or firmware improvements with minimal redesign. This adaptability is crucial in the fast-evolving wearables market, where user needs and technological capabilities are constantly shifting. The groundwork laid by this project provides a strong foundation for further innovation and refinement, especially as interest in personalized, real-time health monitoring continues to grow.

FUTURE WORK

Despite the progress achieved, several areas offer opportunities for enhancement and expansion. One important direction for future work involves the integration of additional sensors, such as SpO_2 (blood oxygen saturation), electrocardiogram (ECG), and hydration level monitors. These additions would enable more comprehensive health monitoring and improve the clinical relevance of the wearable device. Another key area is the optimization of wireless communication. While the current prototype employs standard Bluetooth communication, future iterations could benefit from the integration of more advanced protocols like Bluetooth Low Energy (BLE) 5.3 or even long-range, low-power options like LoRa, depending on the intended use case.

Additionally, as wearable technology becomes more intelligent, the inclusion of onboard machine learning algorithms could dramatically enhance the functionality of the device. Real-time pattern recognition, activity classification, or even early disease detection could be enabled by training models on collected physiological data and embedding them directly into the firmware. To support such features, future designs will also need to consider enhanced processing capabilities and efficient power management. Exploring the use of flexible PCBs and biocompatible materials will further improve comfort and usability, particularly for long-term wear. Lastly, moving toward clinical-grade validation and testing with real users will be critical for transitioning the device from prototype to a product ready for medical or consumer markets. This includes adherence to regulatory standards, data privacy compliance, and robustness testing in real-world environments.

APPENDICES

Schematics and Layout

Include detailed PCB schematics and layout designs.

Component List (Bill of Materials)

Provide a comprehensive list of all components used (e.g., resistors, capacitors, microcontrollers, sensors) with their specifications.

Design Software Information

Mention the software tools used for PCB design (e.g., KiCAD, Altium Designer, Eagle PCB).

Testing Procedure

Explain the procedures followed to test the sensors and overall device functionality.

Calibration Data

Include raw data, calibration curves, and equations used for sensor calibration.

Error Analysis

Provide details of any observed inaccuracies and mitigation methods.

Reference Standards

Mention any industry standards followed during PCB or wearable device design

Types of Sensors Used

List the sensors (e.g., heart rate, temperature, accelerometer, SpO2) with specifications such as range, accuracy, and power consumption.

Datasheets

Attach or reference datasheets for the key sensors used.

Integration Details

Explain how the sensors are interfaced with the PCB and microcontroller.

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OUTCOME

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Principal

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BIO-SENSOR INTEGRATED PCB FOR WEARABLES

Mrs .KAVITHA L
Assistant Professor Electronics and Communication Engineering M. Kumarasamy College of Engineering
Karur, Tamil Nadu, India.

MARAN S
Electronics and Communication Engineering
M. Kumarasamy College of Engineering
Karur, Tamil Nadu, India.
927622bec117@mkce.ac.in

KALIDAS K
Electronics and Communication Engineering
M .Kumarasamy College of Engineering
Karur, Tamil Nadu, India.
927622bec088@mkce.ac.in

KANAGARAJ A
Electronics and Communication Engineering
M. Kumarasamy College of Engineering
Karur, Tamil Nadu, India.
927622bec089@mkce.ac.in

***Abstract*—This project presents an efficient Bio-Sensor Integrated PCB Method for enhancing signal integrity analysis in high- speed PCB designs. Bio-sensors are critical for evaluating voltage and timing margins, providing insights into signal quality. The proposed method utilizes advanced computational algorithms to model and predict signal behavior under noise, jitter, and crosstalk conditions, enabling accurate simulation of high- frequency signal transmission. By incorporating adaptive filtering, it isolates key performance metrics such as eye height, eye width, and bit error rates, ensuring detailed analysis with minimal computational effort. Experimental results validate the method's effectiveness in improving design validation efficiency, reducing design cycle times, and enhancing the reliability of high- speed communication interfaces. This scalable approach addresses the growing demands of next-generation electronic systems, offering a practical and cost-effective solution for PCB designers.**

Keywords -Integrated PCB, Signal Integrity, PCB Design High-Speed Signals Jitter Analysis, Noise Margin, Crosstalk Impedance Mismatch.

I. INTRODUCTION

In modern high-speed PCB (Printed Circuit Board) designs, ensuring signal integrity is critical for electronic systems to function properly. As data rates continue to increase and signal frequencies explode, the ability to analyze and mitigate signal integrity issues become more complex and critical. One of the key challenges in this field is the accurate prediction and analysis of signal transmission behavior across a circuit board. Traditional methods of signal integrity analysis, such as time- domain and frequency-domain simulations, often require significant computational resources and may not fully capture the effects of various factors. One promising approach to address these challenges is the use of eye pattern analysis, which provides a clear visual representation of signal quality in high-speed circuits.

An "eye diagram" is a graphical representation of a signal's waveform, where the opening of the "eye" indicates the signal's clarity and the level of distortion or noise. By examining eye diagrams, engineers can identify issues such as timing errors, jitter, inter-symbol interference (ISI), and signal degradation [2].

However, accurate eye diagram generation and interpretation require advanced modeling and estimation techniques that can account for the complex PCB environment and signal transmission paths. This paper introduces a novel eye pattern estimation (EPEM) method for efficient signal integrity analysis in PCB design. The proposed method integrates advanced signal processing techniques and PCB-specific characteristics to predict eye diagram behavior, providing a more accurate and computationally efficient way to evaluate signal quality. By using this methodology, engineers can make more informed design decisions to optimize the performance of high-speed circuits and reduce the chance of signal integrity errors. The remainder of this paper explores the theoretical foundations of eye pattern estimation methods, their application to PCB signal integrity analysis, and their advantages over traditional simulation approaches [3] [4] [5].