Faculty of Electrical Engineering and Information Technology

Chair of Measurement and Sensor Technology

Master Research Project

Design and Realization of Wireless Measurement System for Resistive Sensors

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Declaration of Originality

We hereby certify that we are the sole authors of this research project. This is a true copy of the research project, including any required final revisions, as accepted by our supervisor.

Date : 1-Apr-19

Signature :

Acknowledgement

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Abstract

New sensors are being developed every day for various kinds of measurements. And they are also being improvised for accuracy, reliability, faster response times etc. For this to happen we also require similarly equal measuring system that is accurate, reliable with faster response times, which works same tough weather conditions as well. Recently focus is been on wearable electronics emphasizing on reducing the size of the sensor measuring system making it more and more portable for the users. One such application is where our project revolves around. The idea of this project is based on the previous works in this chair and state of the art references.

Previous work was on wireless measurement of sensor using a voltage follower where the change in resistance is detected by change in the voltage drop across the sensor. Where there eight different channels each equipped with one range of reference resistance. Which means more resistors and more space and increased PCB size.

This project provides a solution in reducing the number of channels to one and finding one suitable reference resistance for a wide range of sensors. Which reduces hardware and in turn reducing the size of PCB.

In this project a measuring system is developed which consists of Analog Front End (AFE) and a wireless communication module. The data obtained is wirelessly transmitted to the remote terminal where it is processed and stored. A graph can be generated in real-time at remote terminal on resistance characteristics of the sensor.

The end product of this project is wearable electronics which can be used for various sensor measurements like pressure sensor, elongation sensor, strain gauge

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Abbreviations

AFE	: Analog Front End
BLE	: Bluetooth Low Energy
EAGLE	: Easily Applicable Graphical Layout Editor
OLED	: Organic Light Emitting Diode
PCB	: Printed Circuit Board
SMD	: Surface Mounted Devices

Formulas

1 Introduction

1.1 Goal

The goal of the designed system is to enable one to measure and characterize the sensor used. Sensors are developed in wide ranges, so when designing a measuring system, it should be capable of measuring wide range of sensors. The motivation behind developing a measuring system is to provide an environment where the sensor’s resistive characteristics can be determined while the sensor is being used.

1.2 Objectives

The objective of the project is to develop a measuring system with following functions:

1. Measuring the resistance of a sensor of any given range from 200kΩ – 6MΩ.

2. Displaying the data through an OLED.

3. Transmitting the acquired data to a remote station.

4. Monitoring the resistance in real-time.

5. Recording the measured data.

1.3 Structure of this work

The first part of the project is to introduce the state-of-the-art references and the circuit is based on the references from the previous works in this chair. The first part of the circuit consists of an analog front end, where a reference resistor is used in conjunction with sensor to be measured in series. The junction is connected to a two-channel amplifier. Another voltage divider is introduced in order to reduce the voltage for the microcontroller. The second part of the circuit contains of a microcontroller and a wireless module to transmit the measured resistance values to a remote location.

The first part of the work is to perform several resistance tests in selecting the suitable reference resistor using a simple ohmmeter circuit. Comparing several amplifiers and selecting the suitable one. The microcontroller used in this work is the reference from the previous works in this chair.

The second part the development of the system is discussed. It focusses on the hardware and software development of the system. In hardware the components used their working and description. Furthermore, in software it focusses on code development on a suitable platform for the software components and the working of the system together.

The third part focusses on the design and development of the PCB and transferring the circuit from breadboard to PCB. Furthermore, it tells about performing the final tests on PCB.

Finally, it focusses on the conclusion and future scope of the project. It includes a summary of the work done in the development of the project and how it can be improved further.

2 State of Art

2.1 Resistance Sensors and Measurement

Resistive sensors can be defined as transducers that have the ability to convert a mechanical change such as displacement or a temperature change into electrical signal. Resistive sensors perform similar to variable resistors the resistance changes with change in sensor input. Sensors such as temperature or pressure sensor has a nominal resistance defined as the resistance at zero input. Also, at minimum and maximum input it provides a minimum and maximum resistance value. The datasheet provided by the manufacturer contains values which are necessary to design the interface circuit of a sensor. Examples of resistance thermometers are NTC Thermistor, RTDs, Thermocouple, Semiconductor-based sensor. A good measurement system is also very important for a well-developed sensor.

2.1.1 Resistance Thermometer

Resistance thermometers are also called Resistance Temperature Detectors or RTDs in short. RTDs consist of fine length wire wrapped around a ceramic or glass core. Wire is usually a pure metal, typically platinum, nickel or copper. A temperature sensor is crucial to many applications. For example, maintaining a specific temperature is essential for equipment used to fabricate medical drugs, heat liquids. These applications require high responsiveness and accuracy detection circuit for quality control.

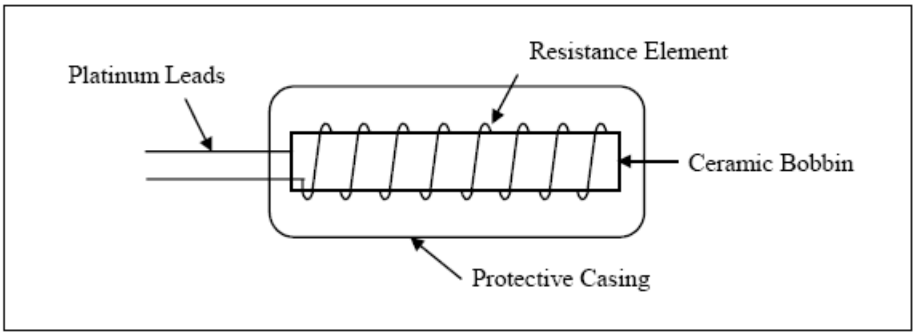


Figure 1: Typical RTD

2.1.2 Bending Sensors

Bending sensors are also known as Soft sensors. Soft sensors are receiving growing attention, due to both global wave of developments in wearable human-centered devices and the recent focus on soft robots. Soft sensors are compatible to the flexible and deformable natures of the human body in wearable device applications. For human motions, soft sensors could provide direct joint-level angle measurements, hence lead to a reconstruction of human body trajectories. For soft robots, soft sensors are required to provide sensory and control

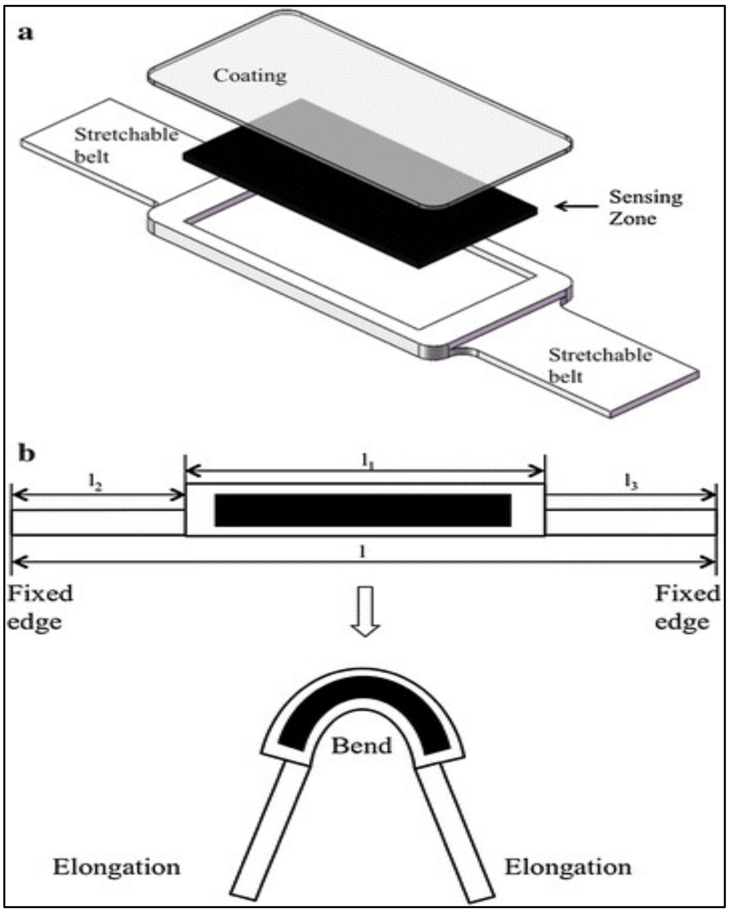


Figure 2: Stretch Sensor

information while not interfering with the primary compliant and adaptive features of the robotic devices. However, for both above application scenarios, bending and stretching are two closely coupled factors. [1-3]

2.1.3 Touch Sensor

A touch sensor is a type of sensor that captures and records physical touch on a device or object. Touch sensors are also called Tactile sensors or Touch detectors and sensitive to touch, force or pressure. They are one of the simplest and useful sensors. The working of a touch sensor can be compared to that of a simple switch. When there is contact with the surface of the touch sensor, the circuit is closed and there is flow of current. When the circuit is opened no current flows.

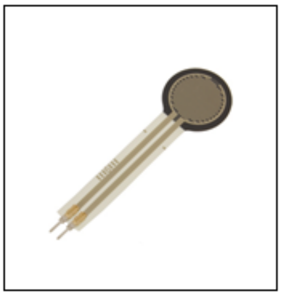


Figure 3:Touch Sensors

2.1.4 Pressure Sensor

A pressure sensor is a device that senses pressure and converts it into an analogue electric signal where the amount depends upon the pressure applied. They can be used to measure the flow of liquid, the weight or force exerted by one object or another, atmospheric pressure or anything else involving force. The pressure sensors based on resistance are called piezo resistive pressure sensors. A Piezo resistive pressure sensor contains several thin layers of silicon embedded between protective surfaces. The surface is usually connected to a

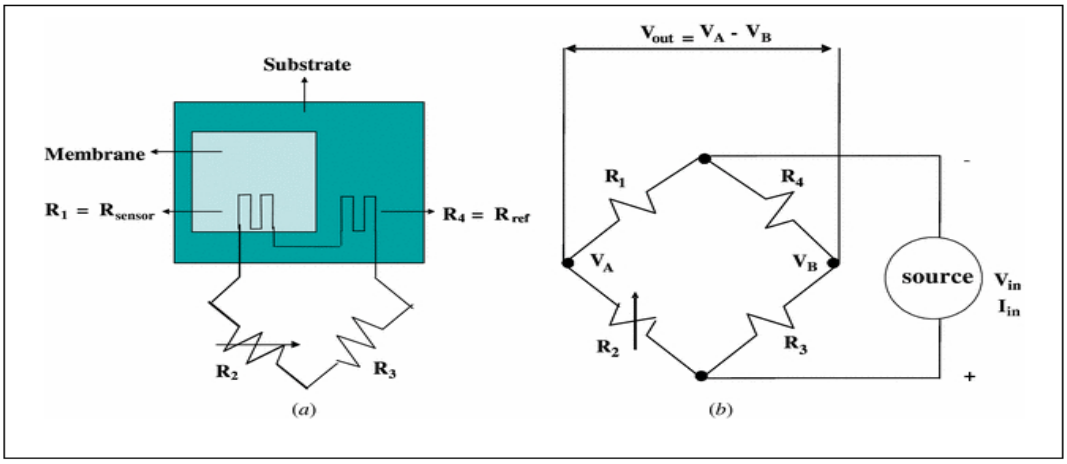


Figure 4: Piezoresistive Sensors

Wheatstone bridge, a device for detecting small differences in resistance. The Wheatstone bridge runs a small amount of current through the sensor. When the resistance changes, less current passes through the pressure sensor. The Wheatstone bridge detects this change and reports a change in pressure [4].

2.2 Resistance Measurement and Signal Conditioning

The current project measures resistance of the sensor through voltage change with respect to mechanical change in the sensor. In all the above-mentioned resistive sensors we are measuring temperature, pressure or touch with the help of resistance change, that is converted into measurable voltage which can be read by the analog to digital converters. There are many possible ways to achieve this, the currently existing and commonly followed methods are 'Voltage Dividers' and 'Wheatstone Bridge'.

Many applications involve environmental or structural measurements, such as temperature, pressure and vibration from sensors. These sensors require signal conditioning before data acquisition is done from a device that can effectively and accurately measure the signal. Signal conditioning is one of the most important components of a data acquisition system because without optimizing real-world signals for the digitizer in use, you cannot rely on the accuracy of the measurement. Signal conditioning needs vary widely in functionality depending on the type of sensor, so no instrument can provide all types of conditioning for all sensors. Most signals require some form of preparation before they can be digitized. Thermocouple signals are very small voltage levels that must be amplified before they can be digitized. Resistance sensors such as RTD's, thermistors, strain gages, and accelerometers require excitation to operate. The common signal conditioning types are Amplification, Attenuation, Filtering, Isolation, Excitation, Linearization, Cold-Junction Compensation, Bridge Completion, Sampling Method.

2.2.1 Excitation for Resistance Sensors

Excitation is required for many types of transducers. For example, strain gages, accelerometers, thermistors and RTD's require external voltage or current excitation. RTD and thermistor measurements are made with a current source that converts the variation in resistance to a measurable voltage. Accelerometers often have an integrated amplifier, which requires current excitation provided by the measurement device. Strain gages, which are very-low-resistance devices, are typically used in a Wheatstone bridge and Voltage dividers with a voltage excitation source [5].

2.2.1.1 Balanced constant current excitation

Balanced constant current excitation uses a pair of matched current sources to excite the RTD and a differential amplifier to measure RTD voltage as shown in figure 5. In addition to the measurement sensitivity and linearity advantages the balanced topology provides other measured advantages. We can see in figure below that the two differential amplifier connections are balanced both physically and electrically with respect to the interfering noise source acting upon the RTD and interconnecting cables. With proper attention to cabling and hookup techniques, noise pickup will be nearly equal on the two balanced inputs and therefore greatly reduced by the CMR of the differential amplifier. [6]

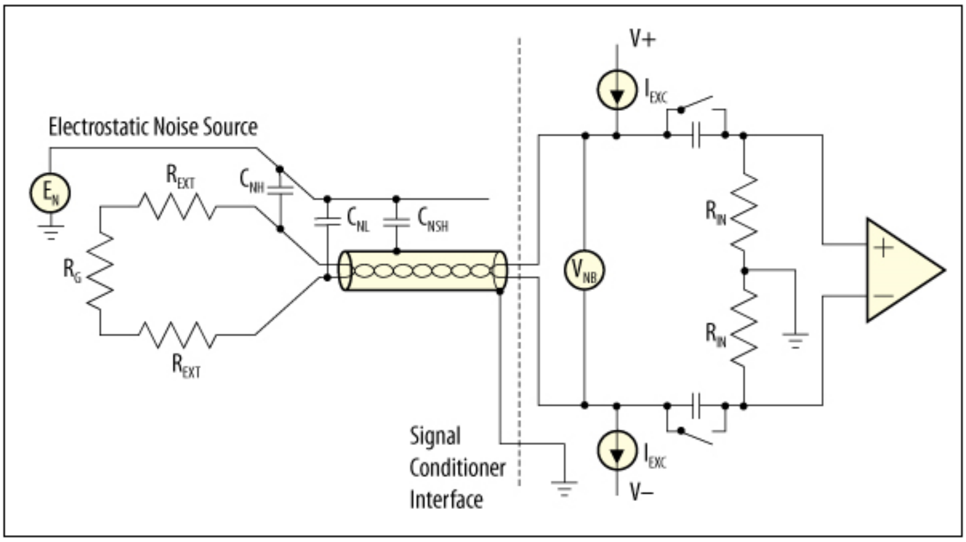


Figure 5: Balanced Constant Current Excitation Circuit

2.3 Wireless protocols

In recent times, factory automation has become an important part of any industry ranging from small-scale to large-scale and has emerged worldwide as one of the most attractive research and development area including control, computer, sensor, actuator, communication, information and so on leading into new solutions, enhanced performances and complete systems. Industrial communication has become one of the frontrunners in factory automation. For interconnection within the factory the factory automation is combined with several other devices like sensors, controllers and heterogeneous machines using a common message specification. Many different network types have been deployed for use on shop floor including control area network (CAN), Process fieldbus (Profibus), Modbus and so on.

If cable connection is one type which is predominant part of communication the other type which has grown into importance in recent decades is establishing connection through wireless. It is one of the fast-growing technologies providing flexibility and mobility and reducing the cable restriction. Other benefits include the dynamic network formation, low cost and easy deployment. In recent times number wireless technologies have been developed for very short distances. These technologies are referred to as 'short-range wireless communication'. Signals in this type of communication travel from a few centimeters to several meters. Examples of short-range wireless communication are Bluetooth, BLE (Bluetooth Low Energy, version of Bluetooth), Infrared, near field communication, Ultraband**,** Zigbee and Wi-Fi.

2.3.1 Standard and Proprietary Short-Range Wireless Protocols

The project focusses on short range wireless communication. Currently the short-range wireless communication is held by four protocols they are Bluetooth over IEEE 802.15.1, UWB over IEEE 802.15.3, ZigBee over 802.15.4 and Wi-Fi over IEEE 802.11a/b/g standards respectively. The IEEE standard defines the Physical (PHY) and Medium Access Control (MAC) layers over the distance range of 10-100 meters. [7]

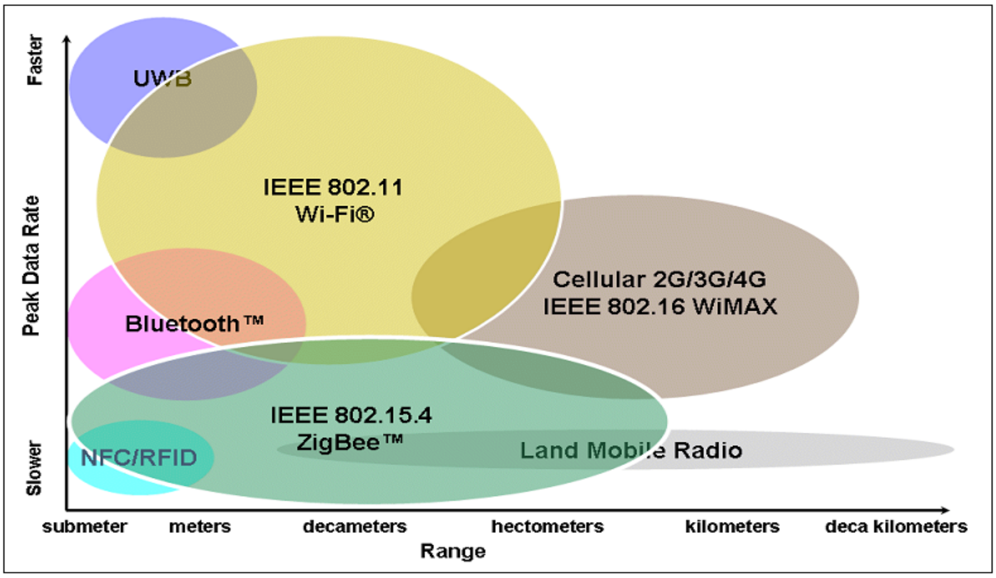


Figure 6: Current Scenario of Wireless Protocols

2.3.2 Comparison of Wireless Protocols

Comparison of the Bluetooth, UWB, ZigBee, and Wi-Fi Protocols				
Standard	Bluetooth	UWB	ZigBee	Wi-Fi
IEEE spec.	802.15.1	802.15.3a *	802.15.4	802.11a/b/g
Frequency band	2.4 GHz	3.1-10.6 GHz	868/915 MHz; 2.4 GHz	2.4 GHz; 5 GHz
Max signal rate	1 Mb/s	110 Mb/s	250 Kb/s	54 Mb/s
Nominal range	10 m	10 m	10 - 100 m	100 m
Nominal TX power	0 - 10 dBm	-41.3 dBm/MHz	(-25) - 0 dBm	15 - 20 dBm
Number of RF channels	79	(1-15)	1/10; 16	14 (2.4 GHz)
Channel bandwidth	1 MHz	500 MHz - 7.5 GHz	0.3/0.6 MHz; 2 MHz	22 MHz
Modulation type	GFSK	BPSK, QPSK	BPSK (+ ASK), O-QPSK	BPSK, QPSK COFDM, CCK, M-QAM
Spreading	FHSS	DS-UWB, MB-OFDM	DSSS	DSSS, CCK, OFDM
Coexistence mechanism	Adaptive freq. hopping	Adaptive freq. hopping	Dynamic freq. selection	Dynamic freq. selection, transmit power control (802.11h)
Basic cell	Piconet	Piconet	Star	BSS
Extension of the basic cell	Scatternet	Peer-to-peer	Cluster tree, Mesh	ESS
Max number of cell nodes	8	8	> 65000	2007
Encryption	E0 stream cipher	AES block cipher (CTR, counter mode)	AES block cipher (CTR, counter mode)	RC4 stream cipher (WEP), AES block cipher
Authentication	Shared secret	CBC-MAC (CCM)	CBC-MAC (ext. of CCM)	WPA2 (802.11i)
Data protection	16-bit CRC	32-bit CRC	16-bit CRC	32-bit CRC

Table 1: Comparison Table

In this section we are going to look at the main differences between the wireless protocols based on IEEE standards as shown in the figure 7. Bluetooth and ZigBee provide a lower data rate whereas UWB and Wi-Fi provide a higher data rate. The Bluetooth, UWB and ZigBee come under WPAN (wireless personal area network) and has a range of 10m and correspond to 802.15 IEEE standard. However, ZigBee can reach 100m in some applications. The technology for WPAN is undergoing rapid development and the operating frequencies are 2.4 GHz. While the Wi-Fi comes under WLAN (wireless local area network) and has a range of about 100m and corresponds to 802.11 IEEE standard. When compared Bluetooth and Wi-Fi their main features and behaviors between them in terms of various metrics including capacity, network topology, security, quality of service support and power consumption the results show that the power difference between them is quite small. Further, the power management of 802.15.3 is better than that of 802.11.e. Comparing Zigbee and Bluetooth in terms of strengths and weaknesses for industrial applications the results showed that ZigBee over 802.15.4 protocol can meet a wider range of real industrial applications than Bluetooth due to its long-term battery operation, greater useful range, flexibility in number of dimensions, and reliability of the mesh networking architecture.

2.3.3 Wireless Communication Using NRF24L01

In this project the module used for wireless transmission of the data is NRF24L01. It is a single chip radio transceiver it operates in 2.4 – 2.5 GHz ISM band worldwide. The transceiver consists of a fully integrated synthesizer, a power amplifier, a crystal oscillator, a demodulator, modulator and Enhanced SchockBurst™ protocol engine. Output power, frequency channels, and protocol setup are easily programmable through a SPI interface. Current consumption is very low, only 9.0mA at an output power of -6dBm and 12.3mA in Rx mode. Built-in Power Down and standby modes make power saving easily. It works on SPI interface, it is standard interface with a maximum data rate of 10Mbps. All configuration of nRF24L01 is defined by values in some configuration registers. All these registers are writable via the SPI interface. The nRF24L01 operates in several modes like RX, TX, Standby, Power Down depending on the level of the following primary I/Os and configuration registers. There are two types of packet handling methods:

1. ShockBurst™ with 1Mbps data rate compatible with nRF2401, nRF24E1, nRF2402 and nRF24E2.

2. Enhanced ShockBurst™

Pin Functions in different modes of nRF24L01 is given in the table 7 below.

Pin Name	Direction	TX Mode	RX Mode	Standby Modes	Power Down
CE	Input	High Pulse >10μs	High	Low	-
CSN	Input	SPI Chip Select, active low			
SCK	Input	SPI Clock			
MOSI	Input	SPI Serial Input			
MISO	Tri-state Output	SPI Serial Output			
IRQ	Output	Interrupt, active low			

Table 2 : Pin Functions of nRF24L01

2.3.4 Bluetooth Low Energy (BLE)

In this project BLE is chosen and implemented because of its performance characteristics including: Energy consumption, Latency, Maximum Piconet Size and throughput have a better trade of than the original Bluetooth model. Bluetooth Low Energy is the recent improvements made in contrast with previous Bluetooth versions developed by the Special Interest Group (SIG). It is a distinctive feature of Bluetooth 4.0 specification. It is an emerging low-power wireless technology developed for short-range control and monitoring applications which plays major role in coming years it is expected to be incorporated in all the high-end devices and technologies which thrive on low battery consumption. BLE represents a trade of between energy consumption, latency, piconet size, and throughput that mainly depends on parameters such as 'connection interval' and 'connection slave latency'. According to theoretical results the lifetime of a BLE device powered by a coin sized battery last anywhere from2 days and 14.1 years. The number of simultaneous slaves per master ranges from 2 and 5917. The minimum latency for a master to obtain a sensor reading is 676µs. [9] Ashok et. al. V3, sep2013

2.3.4.1 Characteristics of BLE

Like the classic Bluetooth the BLE is comprised of two main parts, the controller and the host. The controller comprises of Physical layer and Link Layer and is generally implemented as a small system-on-chip (SOC) with an integrated radio. On the other hand, the host comprises of upper functionality layer they are Logical Link Control and Application Protocol (L2CAP), the Attribute Protocol (ATT), the Generic Access profile (GAP), the Generic and runs on application processor, the Generic Attribute Profile (GATT) and the Security Manager protocol (SMP) and runs on an application processor. Host Controller Interface (HCI) is the standardized communication between the Host and the Controller.

1. **PHYSICAL LAYER**

   Here the BLE operates in the 2.4GHz Industrial Scientific Medical (ISM) band and defines 40 Radio Frequency (RF) channels with 2 MHz channel spacing. It consists of two RF channels: advertising channels which are used for device discovery, connection establishment and broadcast transmission. And the other one is data channels which are used for bidirectional communication between connected devices [9]. The 40 RF channels are divided into 3 advertising channels and 37 data channels respectively.

2. **LINK LAYER**

   When a BLE device wants to broadcast data, it transmits data in terms of advertising packets through advertising channels and is called an advertiser. The transmission of data through advertising channels occur in intervals of time and are called advertising events. Within this advertising event, the advertiser sequentially uses each advertising channel for packet transmission. The scanners are the devices which receive data through these advertising channels. For this Bidirectional communication to happen a connection between these two devices is required and it is an asymmetric procedure.

When the scanner finds an advertiser, it sends a connection request to the advertiser which creates a point-to-point connection. The packets for this connection will be identified by a randomly generated 32-bit access code. [9]

3. **L2CAP**
   The main role of L2CAP in BLE is to multiplex the data from the higher layer protocols, ATT, SMP and Link Layer control signaling with connection. The data from these layers is handled in best-effort approach by L2CAP.

4. **ATT**
   ATT defines how a server exposes its data to a client and how it is structured. There are two roles within ATT the Server and the Client. The Server is device which exposes the data it controls or contains. It is the device that accepts incoming commands from a peer device and sends responses, notifications and indications. Client is the device that interfaces with the server to read or receive the data sent by the client and control the server's behavior. The data exposed by the server is structured as attributes. Services and characteristics are the examples attributes. They are made up of: Attribute type (Universally Unique Identifier or UUID), Attribute Handle, Attribute Permissions. [10]

5. **GATT**
   The three important concepts in BLE that should be known are the Services, Characteristics and Profiles. These specifically are used to allow hierarchy in the structuring of the data exposed by the server. The GATT defines the format of the services and the characteristics and the procedures that are used to interface with these attributes such as service discovery, characteristic reads, characteristic writes, notifications and indications. [10]

As shown in the figure above, we can see the different attributes the service is made up of:

- One or more include services
- One or more characteristics

6. **SECURITY**

   BLE offers range of security services for protection of the data that is being transmitted between the connected devices. The supported security services are expressed in two mutually-exclusive security modes called LE Security Mode 1 and Mode 2. These two modes provide functional security at Link Layer and the ATT layer respectively. The BLE Link Layer supports encryption and authentication by using the Cipher Block

Chaining-Message Authentication Code (CCM) algorithm and a 128-bit AES block cipher.

2.3.4.2 Comparing Bluetooth and BLE

Bluetooth is been around for a while now and we all have used it through mobiles, tablets, PC's and other high-end smart devices. Bluetooth was largely used for networks requiring exchanging data wirelessly as well as other consumer devices including headset, watches etc. BLE is used for applications such as mobile payment, healthcare, ticketing or access control and so on. The detailed differences in terms of technical specifications can be seen in the figure below.

Technical Specification	Classic Bluetooth technology	Bluetooth low energy technology
Radio Frequency	2.4GHz	2.4GHz
Distance/Range	10m	10m
Over the air data rate	1–3 Mbit/s	1 Mbit/s
Application throughput	0.7–2.1 Mbit/s	0.2 Mbit/s
Active slaves	7-16,777,184	Unlimited
Security	64/128bit and application layer user defined	128bit AES and application layer user defined
Robustness	Adaptive fast frequency hopping, FEC, fast ACK	Adaptive fast frequency hopping
Latency (from a non-connected state)	Typically 100 ms	6 ms
Total time to send data	100 ms	<6 ms
Government Regulation	Worldwide	Worldwide
Certification Body	Bluetooth SIG	Bluetooth SIG
Voice capable	Yes	No
Network topology	Scatternet	Star-bus
Power consumption	1 as the reference	0.01 to 0.5 (depending on use case)
Peak current consumption	<30 mA	<15 mA
Service discovery	Yes	Yes
Profile concept	Yes	Yes
Primary use cases	Mobile phones, gaming, headsets, stereo audio streaming, automotive, PCs etc.	Mobile phones, gaming, PCs, watches, sports and fitness, healthcare, security & proximity, automotive, home electronics, automation, Industrial, etc.

Table 3: Comparing BLE and Bluetooth

3 Development

3.1 Hardware Development

3.1.1 Architecture

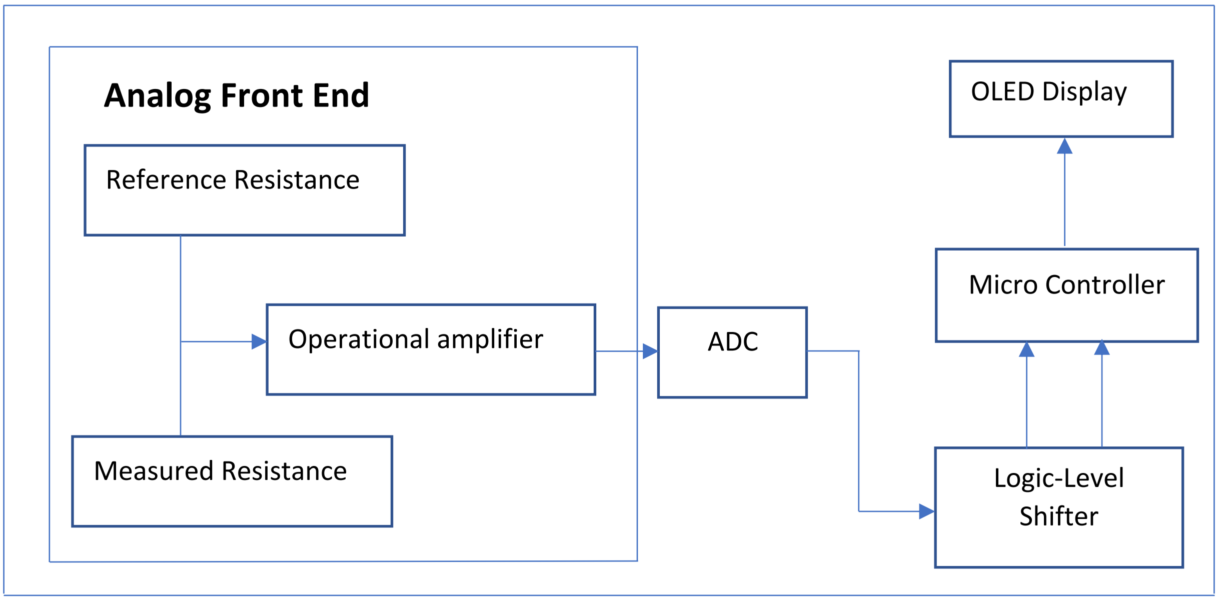


Figure 7: Block Diagram

The analog front end (AFE) consist of the reference resistance, the measured resistance and the operational amplifier.

The measured resistance and the reference resistance together act as a voltage divider. The output voltage is given to an operational amplifier. The op-amp used here is a non-inverting type. The voltage follower output is then given to an analog-digital converter (ADC). The logic level shifter is used to overcome the voltage difference at the pins of ADC and the microcontroller. The measured value is displayed on the OLED screen or can be transmitted to a computer or hand-held device using Bluetooth or wi-fi.

3.1.2 Component Selection

3.1.2.1 Reference Resistor

The reference resistance was decided after testing the circuit with different resistance values according to the below tables.

R_{ref} = 470kΩ			
Sl No:	R_{act}	R_{mes}	% Error
1	677	681	0.59
2	1354	1353	0.07
3	2031	2049	0.89
4	2708	2804	3.55
5	3385	3474	2.63
6	4062	4113	1.26
7	4739	4937	4.18
8	5416	5622	3.8
9	6093	6246	2.51

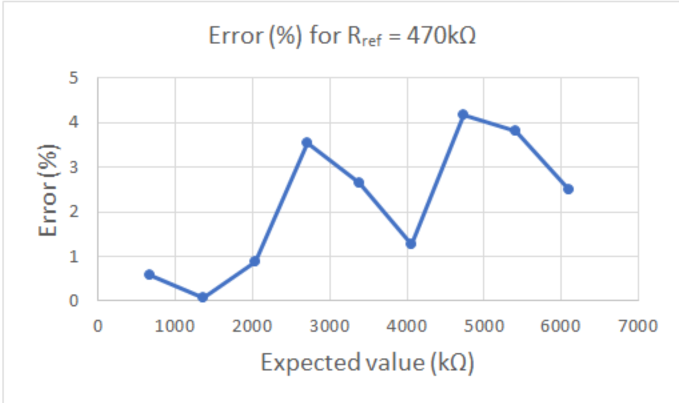


Table5: Rref = 470kΩ, and Error (%) Graph Respectively

R_{ref} = 677kΩ			
Sl No:	R_{act}	R_{mes}	% Error
1	677	677	0
2	1354	1355	0.07
3	2031	2063	1.58
4	2708	2738	1.11
5	3385	3400	0.44
6	4062	4137	1.85
7	4739	4739	0
8	5416	5512	1.77
9	6093	6186	1.53

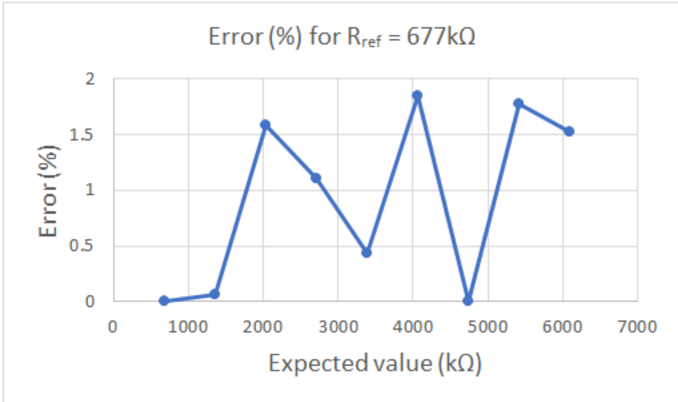


Table4: Rref = 677kΩ, and Error (%) Graph Respectively

R_{ref} = 1800kΩ			
Sl No:	R_{act}	R_{mes}	% Error
1	677	660	2.51
2	1354	1308	3.4
3	2031	1984	2.31
4	2708	2622	3.18
5	3385	3289	2.84
6	4062	3960	2.51
7	4739	4655	1.77
8	5416	5282	2.47
9	6093	5912	2.97

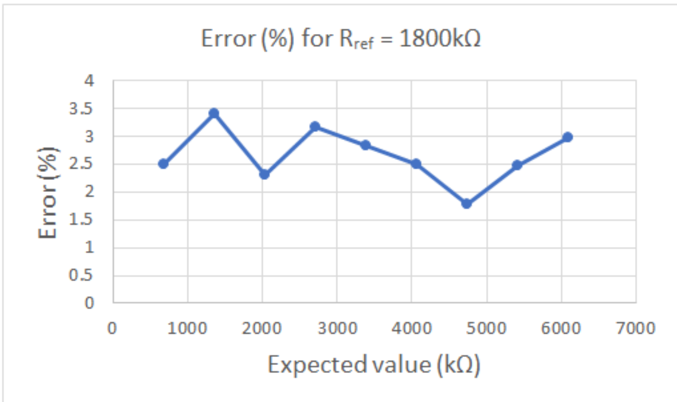


Table 6: Rref = 1800kΩ, and Error(%) Graph Respectively

***all resistance values are in kΩ**

Formula used to calculate percentage error: $(((Rmes - Ract)/Ract) * 100)$

Formula 1: Percentage error

Where,

- R_{mes} : measured value
- R_{act} : actual value

After comparing the results, the better option was using a 677kΩ resistor for reference.

Two types of resistors were considered

- SMD
- DIL

Figure 8: SMD resistor example

SMD stands for surface mounted device. This device is used along with surface mount technology. They were developed to meet the desire for PCB's to use smaller, faster and cheaper. SMD's are useful when both the sides of the PCB are to be used. It avoids drilling of holes as in traditional method. They are often square, rectangle or oval in shape.

The most commonly used code systems are Electronic Industries Alliance (EIA) code, EIA-96 and three- and four-digit systems. The first 2 or 3 digits specify the resistance in terms of numerical values and the last digit specifies the power of 10 by which it should be multiplied

Example: 1733 : 173 * 10^3= 173kΩ

The 0805 represents the package dimensions 0.08* 0.05 inches. [11]

Figure 9:DIL type resistors

DIL stands for Dual in-line. Through hole resistors have long pliable leads which can be used on a bread board or for prototyping. Usually called plated through-hole (PTH) type.

Example: 0204/5

02 * 05 shows the body dimensions in millimeters and the number after “/” shows the grid, the distance between the2-solder holes in millimeters.

3.1.2.1.1 Power Rating

To avoid the resistance from heating up too much, the power across the resistor should be kept below the maximum value.

$$P = \frac{V^2}{R}$$

Formula 2 : Power Rating

Where,

- P = power across the resistor
- V = Voltage
- R = Resistance

The power rating is usually between 1/8W and 1W. The power ratings of SMD are usually judged by the package sizes.

Example: 0805 can take up to 1/10W

For testing on bread board DIL type resistor was used. To minimize the physical size of the final board it is recommended to use SMD components.

3.1.2.2 Decoupling Capacitor

Figure 10 : SMD Capacitors

A capacitor is used in the circuit. The decoupling capacitor is connected between the Voltage source and ground to reduce noise. It provides a low impedance path that allows AC components in the DC power line to pass to the ground. The ideal location to place bypass capacitor is as close as possible to the supply pin of the component.

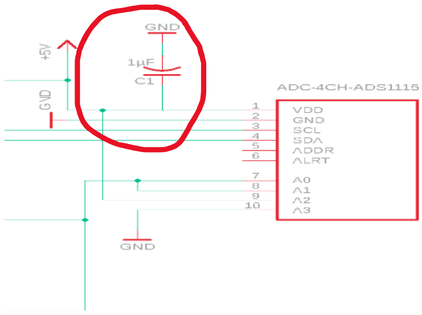


Figure 11: Decoupling Capacitor

In the experimental set-up, the decoupling capacitor is connected across the V_{DD} and GND pin of the ADC.

A 2.2µF through-hole type capacitor was used in the experimental set-up.

3.1.2.3 Voltage Divider

The below circuit is an example for a basic voltage divider. The output voltage (V_{out}) is made a fraction of the input voltage (V_{in}). The voltage gets divided among the different components connected.

In sensor measurement, the sensor and the reference resistance are connected in series and the output voltage is taken out of the center tap point of the resistors. In this case, the voltage divider is used along with a microcontroller to measure the resistance of a sensor. The output voltage is connected to the ADC to measure the voltage.

The reference resistance is selected in such a way that the circuit can measure the resistance in the range of 200kΩ and 6MΩ.

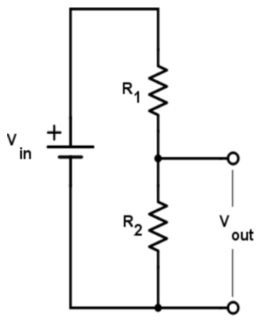


Figure 12: Voltage Divider

The basic equation used to calculate the output voltage is as given below

$$Vout = Vin * \frac{R2}{R1 + R2}$$

Formula 3 : Output Voltage

The maximum sensitivity is when $R_1 = R_2$

For measuring direct current and low frequencies a voltage divider made of resistors is sufficient.

Some applications of voltage divider are:

- Sensor measurement
- High voltage measurement
- Logic level shifting

3.1.2.4 Operational Amplifier – ADA4622-1ARZ

Operational amplifier is used as a buffer to protect the microcontroller. A non-inverting type voltage follower is used in this case.

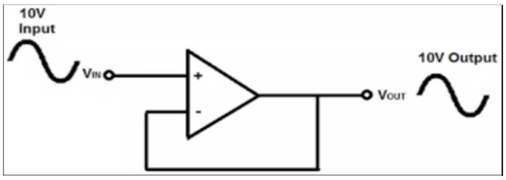


Figure 13 : Voltage Follower

The operational amplifier used is ADA4622-1ARZ.

„The ADA4622-1/ADA4622-2 are the next generation of the AD820 and the AD822 single-supply, rail-to-rail output (RRO), precision junction field effect transistors (JFET) input op amps. The ADA4622-1/ADA4622-2 include many improvements that make them desirable as an upgrade without compromising the flexibility and ease of use that makes the AD820 and the AD822 useful for a wide variety of applications.

The input voltage range includes the negative supply and the output swings rail-to-rail. Input EMI filters increase the signal robustness in the face of closely located switching noise sources." [12]

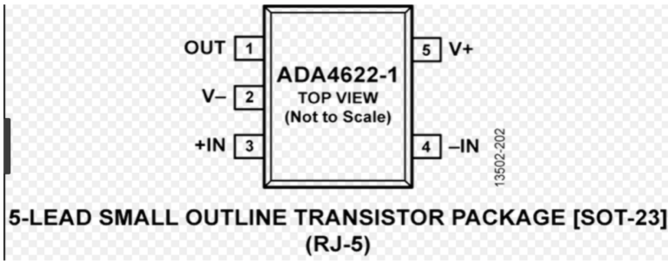


Figure 14 : Pin – Outs

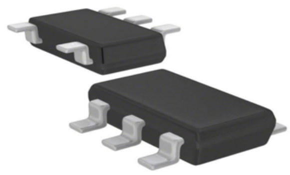


Figure 15 : ADA4622-1ARZ1

Some of the benefits of ADA4622 are: [13]

- Rail to rail output
- High slew rate
- Low input bias current
- Low offset voltage
- Low offset voltage drift

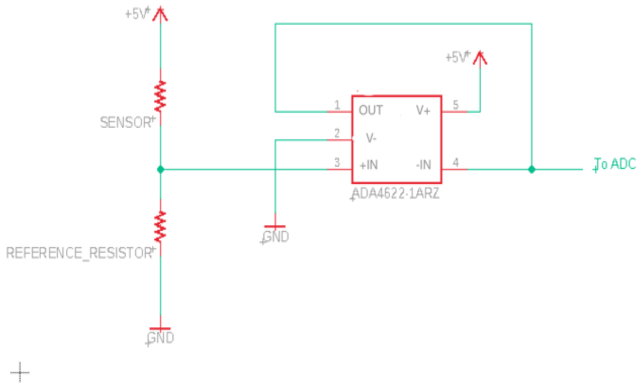


Figure 16 : Op-amp connected to Voltage divider

The voltage taken out of the central tap of voltage divider is given to pin 3(+IN) of the ADA4622-1ARZ. To make the op-amp a non-inverting type, pin 4(-IN) is connected to pin 1 (OUT). Pin 2 (V-) is connected to the ground. A supply of +5V is given to pin 5 (V+)

3.1.2.5 ADC

The output of op-amp is given to an analog-digital converter. The main advantage of using a separate ADC is that it gives technology independence and makes the circuit future-proof.

When only the ADC of microcontroller is used then the entire circuit is dependent on a particular type of microcontroller. So, by using an additional ADC, different microcontrollers can be used along with the same circuit without making any alterations in the circuit, thus making it user-friendly.

The ADC used in the circuit is ADS1115. It is manufactured by Texas Instruments and belongs

Figure 17: ADS1115

to the family ADS1113, ADS1114, ADS1115 (ADS111X). These devices are precision, low-power, 16 -Bit, I^2C compatible analog to digital converters.

Applications

- Portable instrumentation
- Battery Voltage and current monitoring
- Temperature measurement systems
- Consumer electronics
- Factory automation and process control

The ADS111X consist of a low drift voltage reference and an oscillator. The ADS1115 also incorporates a programmable gain amplifier (PGA) and a digital comparator. They also have a wide range of operation supply range. These factors make them suitable for power and space constrained sensor measurement systems.

It operates in either continuous mode or single – shot mode. The devices are automatically powered down after one conversion in a single shot mode, therefore power consumption is significantly reduced during idle periods. [14]

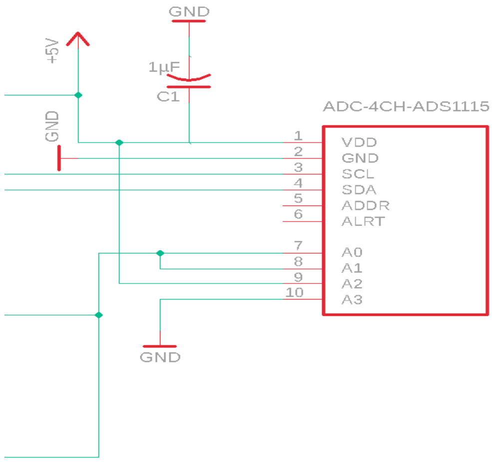


Figure 18: ADS1115 in circuit

3.1.2.6 Microprocessor

Two options were used:

- Teensy 3.2
- D-Duino 32

3.1.2.6.1 Teensy 3.2

The Teensy board is a bread-board friendly development board. The Teensy USB development board is a complete USB based microcontroller system. Teensy 3.2 is a direct, 100% fully compatible replacement for Teensy 3.1. It is manufactured by PJRC and designed by Paul Stroffregen (co-owner).

Teensy 3.2 features a 32-bit ARM processor.

Teensy 3.2 comes pre-flashed with a boot-loader, so that we can program it using on-board USB connection. [16]

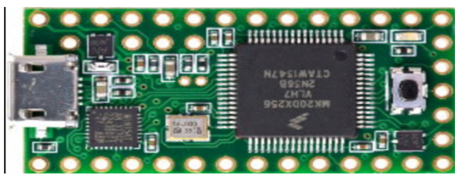


Figure 19 : Teensy 3.2_ Top View

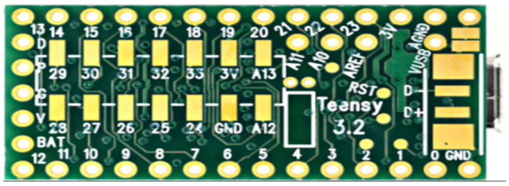


Figure 20: Teensy 3.2_ Bottom View

When Teensy 3.2 is used as a microcontroller, then two additional components are required in the circuit.

- Transceiver – NRF24L01
- OLED display (optional)

3.1.2.6.1.1 Transceiver – nRF24L01

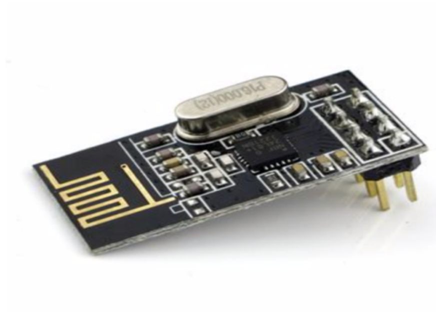


Figure 21: nRF24L01

When Teensy 3.2 is used, a communication interface is required. For this a nRF24L01 module is required.

It is manufactured by Nordic Semiconductor and is a single chip 2.4 GHz transceiver. It consists of a fully integrated frequency synthesizer, a power amplifier, a crystal oscillator, a modulator, demodulator and Enhanced ShockBurst™ protocol engine.

Output power, frequency channels and protocol setup easily programmable through a SPI interface.

Some of the advantages of this module are current consumption is low and built-in Power down and standby modes makes power saving easy.

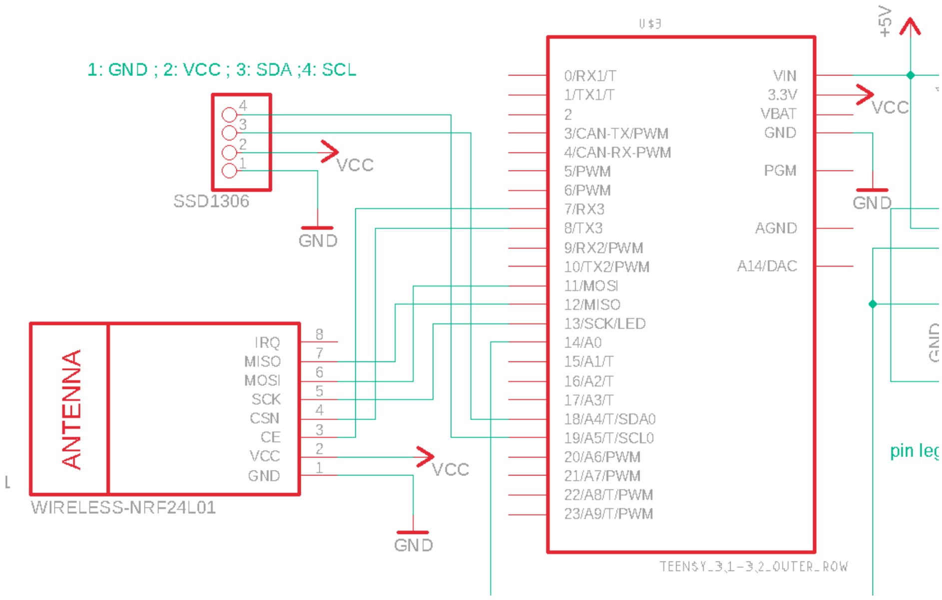


Figure 22: nRF24L01 and OLED connections to Teensy 3.2

3.1.2.6.1.2 OLED Display

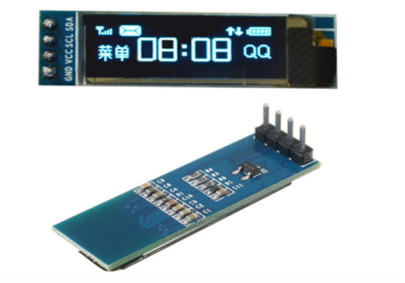


Figure 23: SSD1306 _ 0.91inch OLED

An OLED display can be used to read from Teensy 3.2. A SSD1306 type with 128x32 resolution was used.

The advantages of using OLED are:

- To read output directly
- Low power consumption
- Clear display
- Easy to interface
- Dimensions

The OLED connections are as shown in figure 22, above.

3.1.2.6.2 ESP32

The second option we tested is to use as a microcontroller, is ESP D-Duino 32.

D-duino stands for display-duino. It is a project of ESP8266 and ESP32.It is a low-cost developer board with a 0.96-inch OLED display.

The advantages and features make this an exciting proposition for the future. It features Wi-Fi, Bluetooth and BLE modules. These features enable them to be used in a wide range of applications. It is ideal for battery operated and wearable electronics.

An additional component required when using a D-duino 32 is a level shifter.

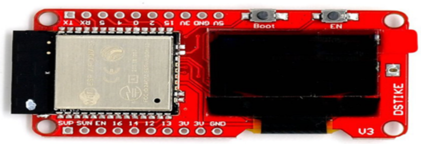


Figure 24: D-Duino 32

3.1.2.6.2.1 Level Shifter

A level shifter is also called as a logic-level shifter. It is used to translate signals or voltages from one level to another. They are used to resolve the voltage incompatibility between various parts of a system. They can be:

- Uni directional
- Bi-directional

In the experiment it is used to bridge the voltage in-compatibility between the ADC and microcontroller.

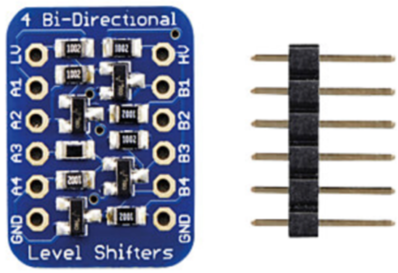


Figure 25:Bi-directional Level Shifter Module

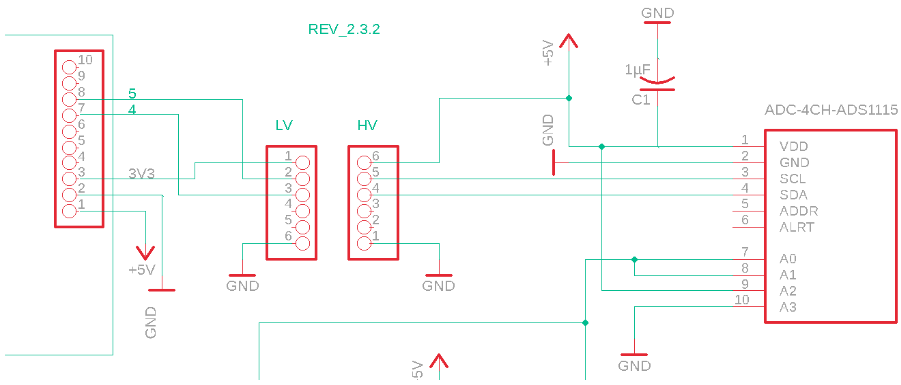


Figure 26: Logic Level Shifter connections

A bi-directional level shifter module was used in the experimental set-up.

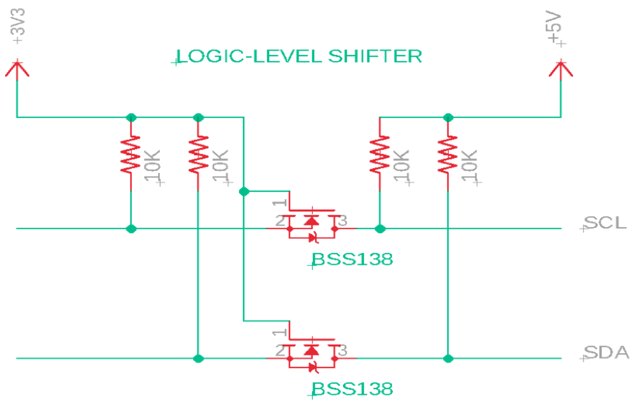


Figure 27 : Level Shifter_ Circuit diagram

A logic-level shifter can also be designed as shown in the above circuit diagram. It requires four 10kΩ resistors and two MOSFET's. The MOSFET used is BSS138.

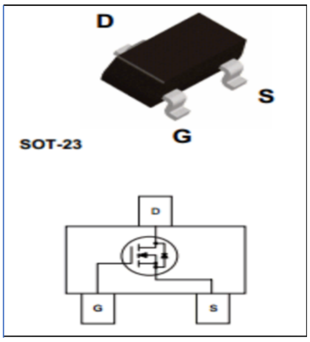


Figure 28: BSS138_n-type MOSFET

3.1.2.6.2.2 BSS138

These n-channel enhancement mode field effect transistors are produced using Fairchild's proprietary, high cell density, DMOS technology. These products have been designed to minimize on-state resistance while providing rugged, reliable and fast switching performance. These products are particularly suitable for low-voltage, low-current applications. [15]

3.1.2.6.3 Comparison between Teensy3.2 and D-Duino 32

Features	Teensy 3.2	D-Duino-32
Processor	MK20DX256VLH7	ESP32-DOWDQ6
RAM	64	64
Bluetooth	No	Yes
Wi Fi	No	Yes
Display	No	Yes
I2C	2	1

Table 7: Comparison Between Teensy3.2 and D_Duino 32

3.2 Prototype in wire board

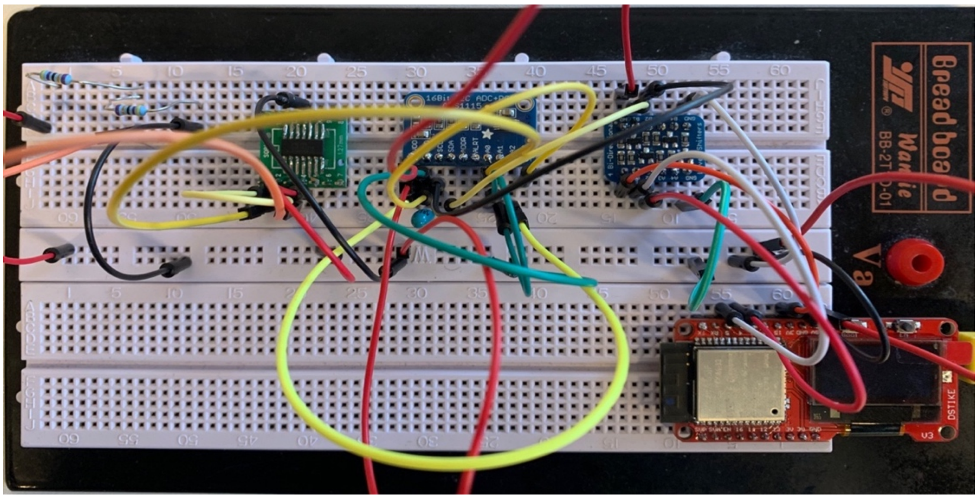


Figure 29: Experimental Set-Up

3.3 Circuit Schematic

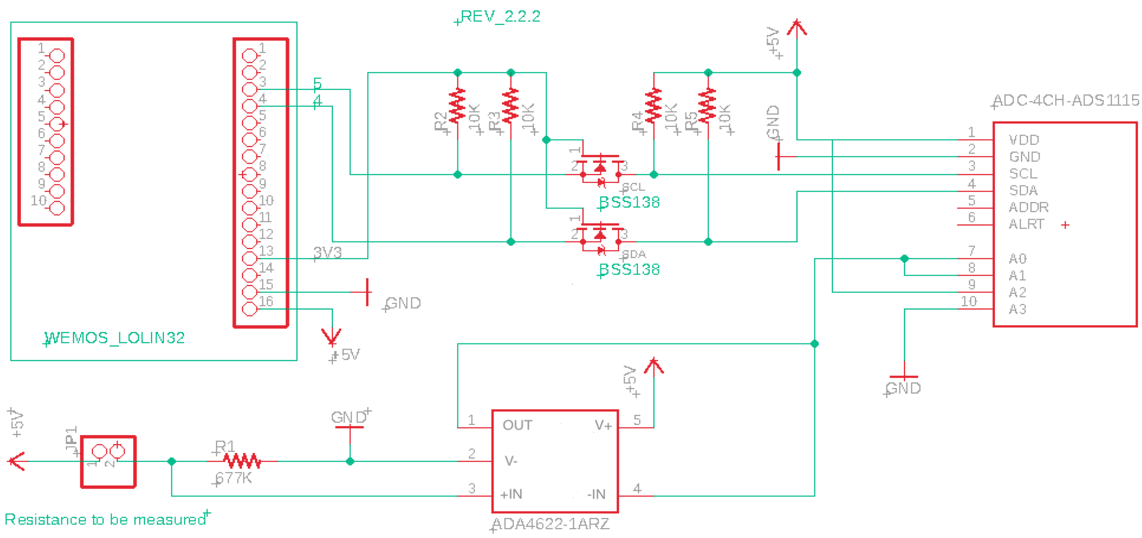


Figure 30 : Circuit Diagram

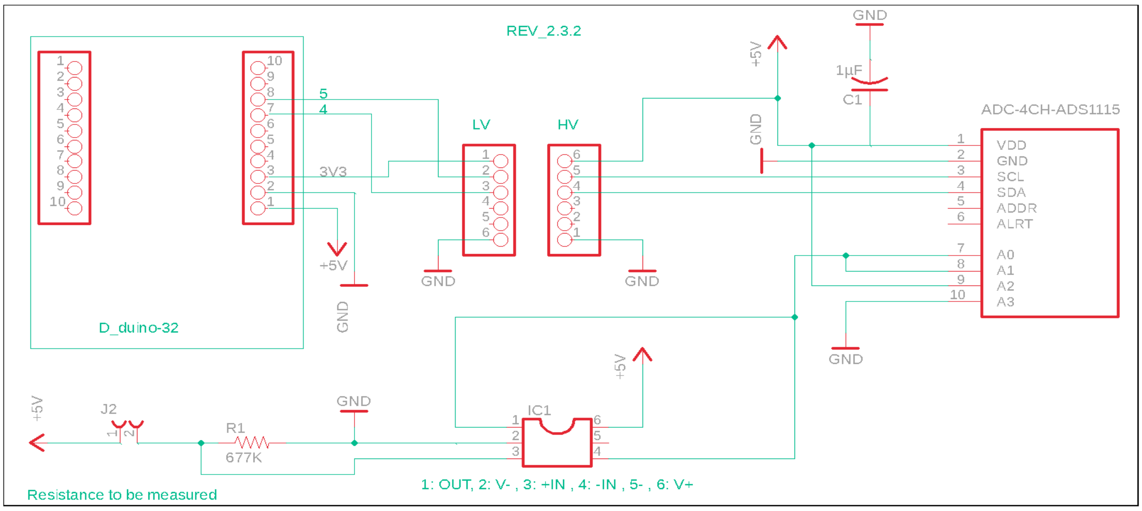


Figure 31: Circuit diagram with a level shifter module

3.4 PCB

3.4.1 PCB Design

EAGLE is an electronic design software developed by Autodesk (previously CadSoft Computer). Some useful features include schematic design, PCB layout, auto-routing, BOM preparation and computer-aided manufacturing. EAGLE stands for Easily Applicable Graphical Layout Editor.

The version used in this project is 9.3.1 (free version). The schematic diagram and the PCB layout was designed using the free version. The free version limits the number of layers that can be used to two layers (top and bottom). The schematics have an extension of *.sch* and the PCB design has a *.brd* extension. The libraries required for the schematic design have the extension *.lbr*

The manual routing method was used to complete the routing procedure.

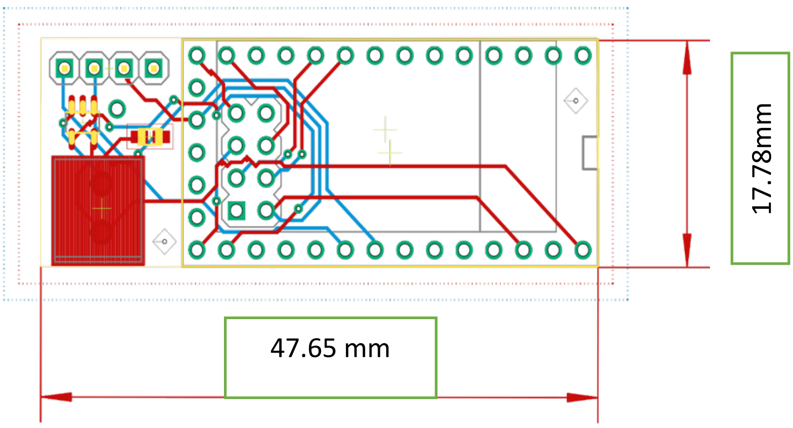


Figure 32 : PCB design with Teensy 3.2

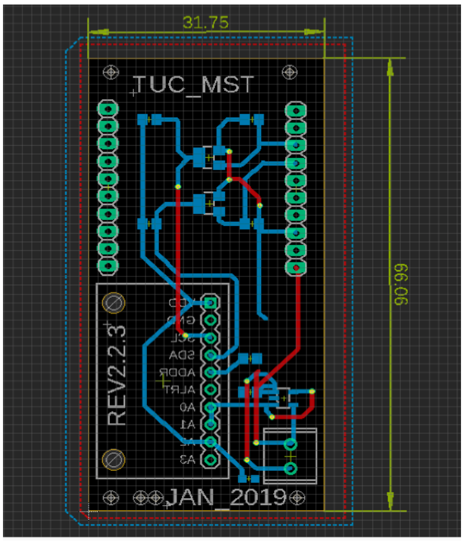


Figure 33: PCB design with D-Duino 32

All the schematics used in this report are drawn using Eagle software.

3.4.2 PCB Etching

An attempt was made to etch the PCB with teensy3.2 in-house. A FR4 Positive Photoresist Pre- Sensitized Board- double side was used for this.

FR stands for Fire Retardant. Boards are protected by a specially-designed light proof blue film. This blue film allows the PCB to be handled in day light. These boards are suitable for use in laboratories.

For in-house etching the method of toner transfer was used.

The *.brd* files saved in Eagle was converted to PDF files with top-layer as mirrored and bottom layer remaining the same.

The layers are printed on glossy paper. The pages of magazine as suitable for this. A glossy paper is used as it is easier to press on to the board and easily washable. Before transferring the layers, the board is treated to remove the photo-sensitive layer.

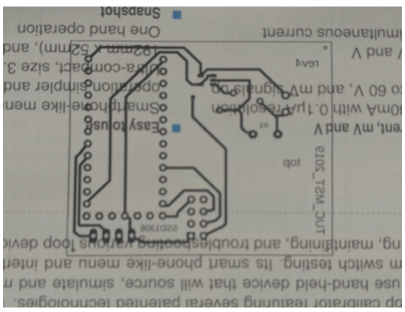


Figure 34: Mirrored Top-layer printed on glossy paper

The printed papers are cut according to the dimension of the PCB required and taped on to the PCB on both sides. Care should be taken to ensure proper alignment of the layers. The circuit is transferred to the PCB using a hot-iron. A hot-iron is used to press down the paper on to the board for approximately 45 seconds. This is repeated for the other side. After that the PCB is doused with cold water and the glossy paper is carefully peeled off the PCB. If any traces are missing it is connected using a black OHP pen.

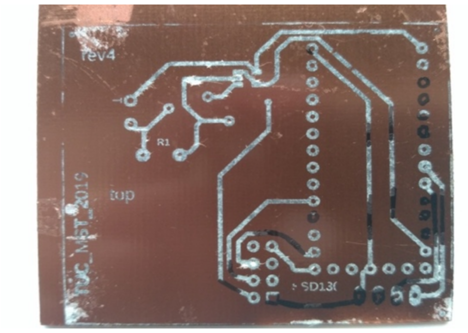


Figure 35 : Top layer transferred to PCB

After transferring to PCB, the boards are ready for etching. Ferric Chloride solution was used for removing the unwanted copper from the board.

Ferric Chloride (Fe Cl_3) is the most commonly used for etching purpose. Care should be taken while handling it as it is both toxic and poisonous.

After etching, the holes are drilled, and the components are placed, and the circuit is tested.

3.4.2.1 Precautions to be taken before the etching process

- Do not handle $FeCl_3$ with bare hands.
- No metal devices or components must be used to handle the solution.
- Use a plastic tray for etching.
- The solution can be reused. It should not be exposed to direct sun-light. A glass or plastic bottle can be used for storing the solution.

Standard procedure has to be followed for disposing of the solution.

3.4.2.2 Etching Process

- Missing tracks, if any are connected using a black OHP marker.
- Ferric chloride solution is heated in a warm water bath. Heated ferric chloride will react faster than in room temperature. The solution should not be directly heated.
- The ferric chloride solution is transferred to a plastic tray and the PCB is immersed in the solution. There should be enough solution to fully immerse the board.
- The actual etching processing time varies. It depends on the size of the board and the concentration of the solution.
- Usually 10-20 minutes is required for fully etching the tracks.

3.5 Flow Chart

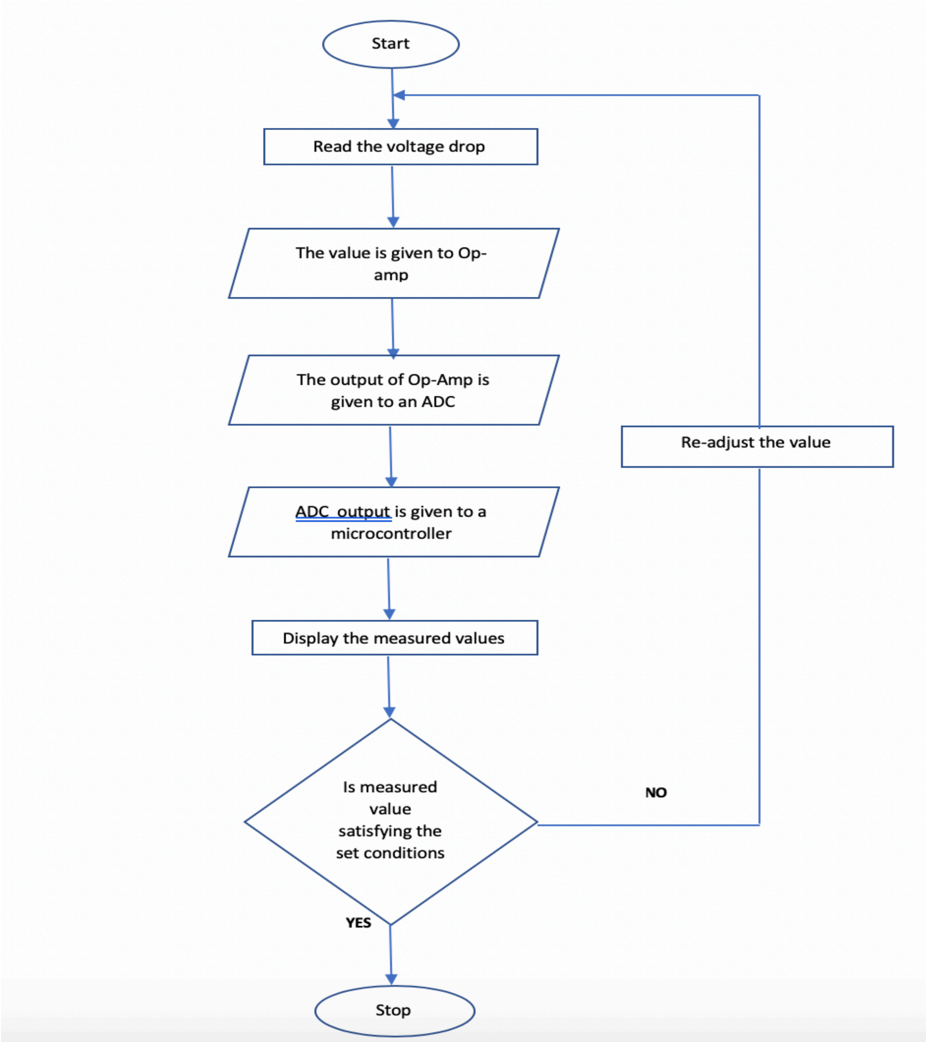


Figure 36: Flow Chart of General Working

The hardware flow process is as follows:

- The unknown value is given as input.
- This value is compared with a reference value.
- This value is given to an Op-amp.
- The output of Op-amp is given to an ADC.
- The final output is given to a microcontroller.
- If the measured value is within the reference range, then the correct value is stored, sent or displayed else the value is adjusted and the process is repeated.

3.6 Software Development

3.6.1 Arduino IDE

The project's software for the board processing was entirely done in Arduino IDE (Integrated Development Environment). It is a cross platform for Windows, Linux and macOS. It is written in Java language. Arduino makes use of C and C++ class libraries. The Arduino IDE doesn't come with ESP32 and Teensy tools built in. The ESP32 tools have to be installed separately. The necessary links required to install are available online and in GitHub as well. The following instructions should be followed:

1. Open the preferences window from the Arduino IDE. Go to **File>Preferences.**
2. Enter this link https://dl.espressif.com/dl/package_esp32_index.json into the 'Additional Board Managers URLs'. Then click ok button.
3. Now go to **Tools>Board>Boards Manager**.
4. Search for ESP32 and press install for the **'ESP32 by Espressif Systems'.**
5. It's installed and ready to use.

3.6.2 App Development

This section of the project is related to ESP32 microcontroller which is part of future scope in this project. The ESP32 board is equipped with BLE. BLE is used as the mode of wireless transmission of the sensor data acquired from the microcontroller. This transmitted data can be received and displayed in two ways one is the android emulator within the desktop and the other is over an android phone where you can track the values remotely where it reflects on wearable electronics. The software used to develop the BLE_App is 'MIT APP INVENTOR'. It's a cloud-based tool i.e. which lets you build the app within the browser for your android device. This tools also helps in live testing of the app while you're building it. To do this you have to download MIT App Inventor Companion app on your device.

3.6.2.1 Building the App

This tool consists of two things mainly:

1. App Inventor 'Designer' where you select components for your app and design the app's user interface using both on and off-screen components. It consists of 'Palette' where you find the components. And 'Properties' where you can modify the component's properties.

2. App Inventor 'Blocks Editor', this is the place where you assemble the program blocks that specify how the components should behave. It consists of Built-in Drawers where you find blocks for general behavior. And Component-Specific Drawers where you find blocks for specific component behavior.

All this process can be tracked live step by step, which helps you test your work as you build. Once you're done building your app you can package your app and prepare a stand-alone application to install on your device. Procedures for which you can find online.

Once done building the app the Designer and the Block Editor look as shown in figure 9 below.

Figure 37 : Designer and Block Editor

3.6.3 Flow Diagram

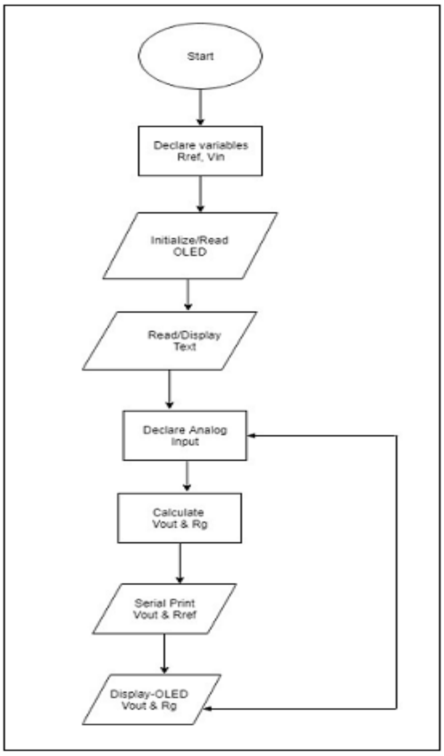
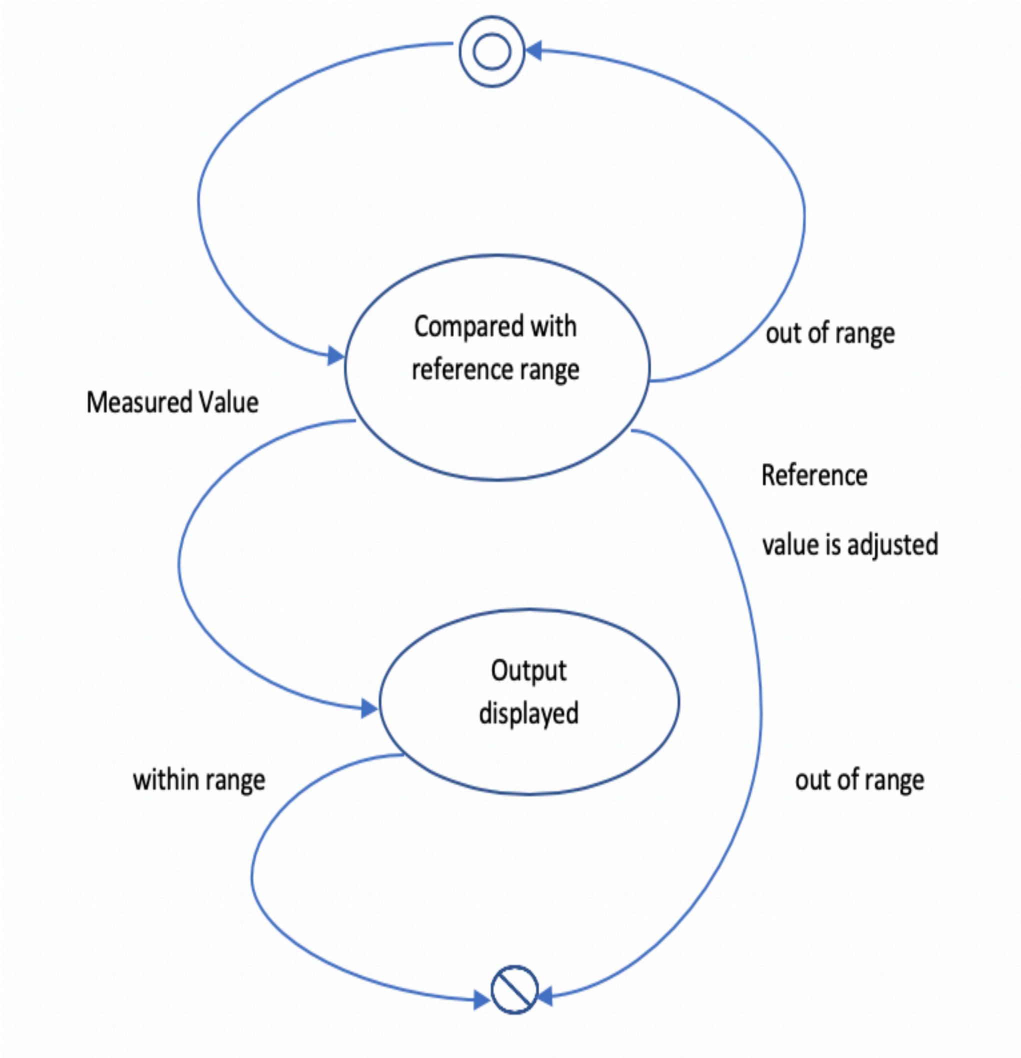


Figure 38 : Flow Diagram

4 State Diagram



The above State Diagram depicts the logic behind designing of such a system. The unknown or the measured resistance is compared with an already fixed reference resistor. If the compared value is within the range of the reference resistance then the value is stored, sent or displayed. If the measured value is below a particular range or above a particular range, then either a random value is generated, or the reference value is adjusted to get a correct value.

5 Test and Discussion

The experimental setup is as shown in the below schematic.

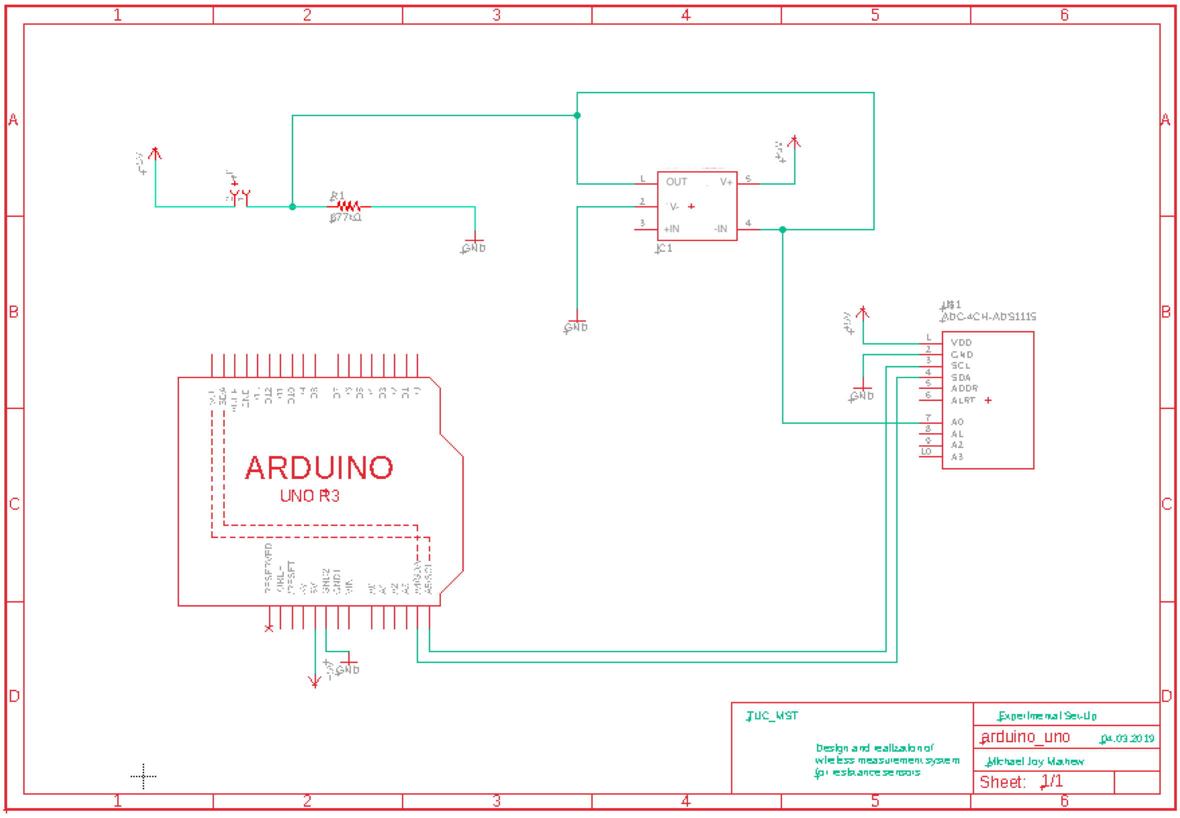


Figure 39: Experimental Setup using Arduino Uno

To reduce the overall size of the circuit the circuit was checked for performance using a 5V supply. The required supply was taken out of the 5V pin of Arduino Uno. Different reference resistors were used to measure a range of resistance from 470kΩ to 6200kΩ.

R_{ref} = 470kΩ

Sl No:	R_{act}	R_{mes}	% Error
1	470	497	5.74
2	562	594	5.69
3	813	846	4.06
4	1864	1924	3.22
5	2334	2381	2.01
6	3578	3681	2.88
7	4707	4895	3.99
8	5377	5593	4.02
9	6190	6246	0.9

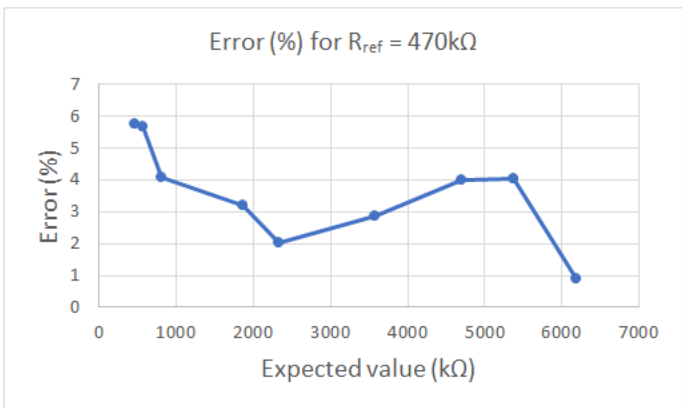


Table 8 : Arduino Uno - R_{ref}=470kΩ and Error Graph (%)

	R_{ref} = 677kΩ		
Sl No:	R_{act}	R_{mes}	% Error
1	470	504	7.23
2	562	591	5.16
3	813	845	3.94
4	1864	1924	3.22
5	2334	2468	5.74
6	3578	3789	5.9
7	4707	4917	4.46
8	5377	5548	3.18
9	6190	6853	10.71

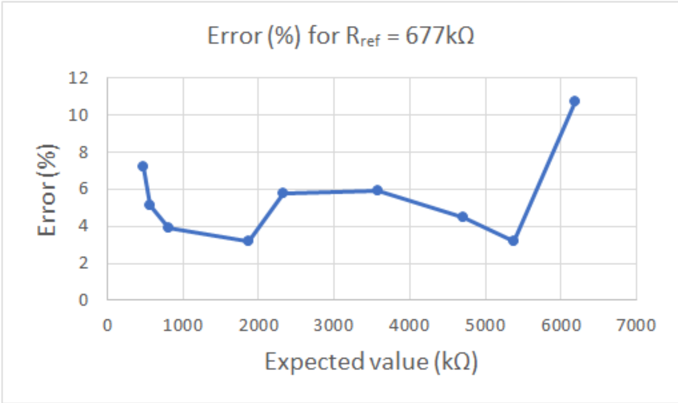


Table 9: Arduino Uno _ R_{ref}=677kΩ and Error Graph (%)

	R_{ref} = 1800kΩ		
Sl No:	R_{act}	R_{mes}	% Error
1	470	534	13.62
2	562	626	11.39
3	813	868	6.77
4	1709	1774	3.8
5	2527	2646	4.71
6	3870	3904	0.88
7	4440	4580	3.15
8	5572	5843	4.86
9	6140	6434	4.79

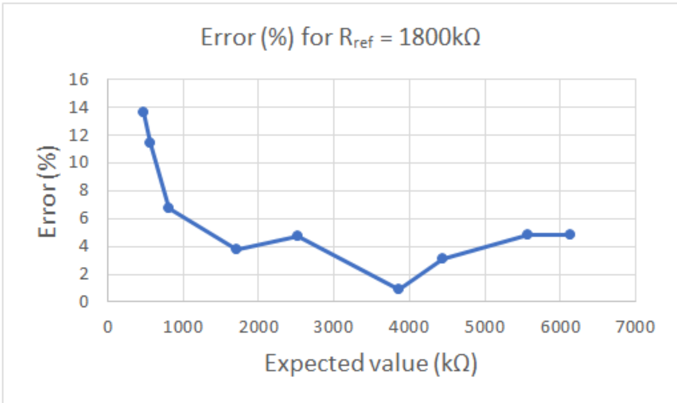


Table 10 : Arduino Uno _ R_{ref}=1864kΩ and Error Graph (%)

***all resistance values are in kΩ**

The unknown resistance was calculated using the formula:

$$Rs = Rref * [\left(\frac{Vin}{Vout}\right) - 1]$$

Formula 4 : Unknown resistance calculation

Where,

R_s : Unknown sensor resistance to be measured

R_{ref} : Reference resistance

V_{in} : Input Voltage

V_{out} : Output Voltage

The output from Arduino was plotted on a serial monitor. The results were tabulated, and the percentage error was calculated. (*using Formula1*)

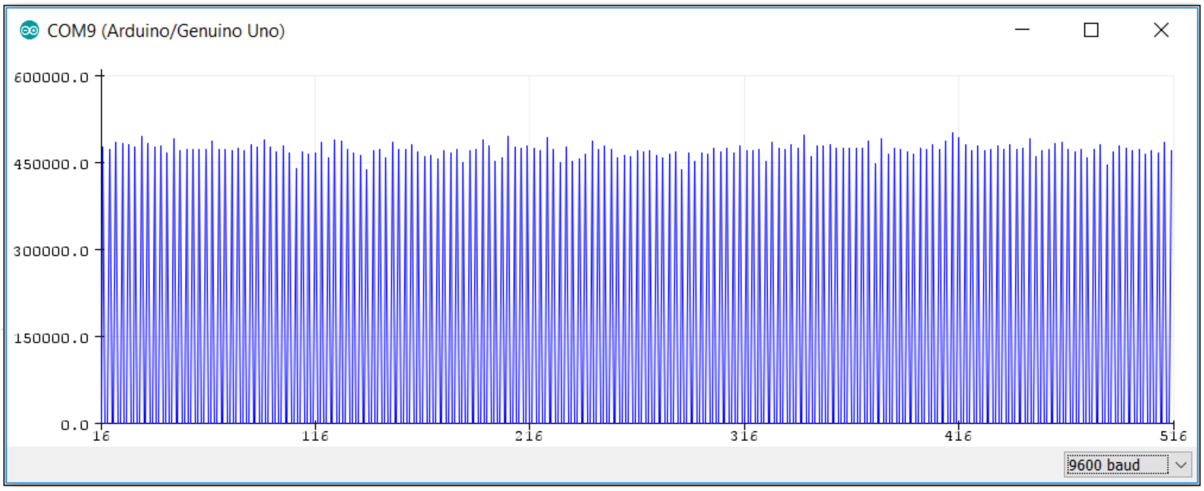


Figure 40:Graph showing R_{mes} with respect to Time

The above graph shows the R_{mes} with respect to time when a reference resistor of 470kΩ was used.

5.1 Data Acquisition Test

The data acquisition test is carried out with three different resistors in the beginning and the one which yields better results is chosen as the reference resistor which is connected in series with the resistive sensor whose measurement should be done. The three different resistors used were 470kΩ, 677kΩ and 1.8MΩ respectively. Initially the programming test is carried out using Arduino UNO microcontroller to check the correctness of the system. The following figure 54 depicts a Bar graph that shows difference between the expected and measured values of sensor calibration when 470kΩ is used as the reference resistance and was tested across the 470kΩ – 6.19MΩ.

Once the logic and working of the system was checked and was fine then it was implemented using the actual requirement i.e. the Arduino UNO microcontroller was replaced with Teensy 3.2 microcontroller. The test was carried out using a reference resistor of 677kΩ cross the range 677kΩ – 6MΩ, and the following results were acquired.

The test results with the above experimental setup showed that the unknown sensor measurement was feasible with the circuit. Next the experiment was repeated with Teensy3.2 as the microcontroller. The same three set of reference resistors were checked to identify the optimum value. From the experiment it was concluded that a reference resistance of 677kΩ can be used to measure an unknow resistance in the range of 470kΩ to 6093kΩ.

	R_{ref} =677kΩ		
Sl No:	R_{act}	R_{mes}	% Error
1	677	677	0
2	1354	1355	0.07
3	2031	2063	1.58
4	2708	2738	1.11
5	3385	3400	0.44
6	4062	4137	1.85
7	4739	4739	0
8	5416	5512	1.77
9	6093	6186	1.53

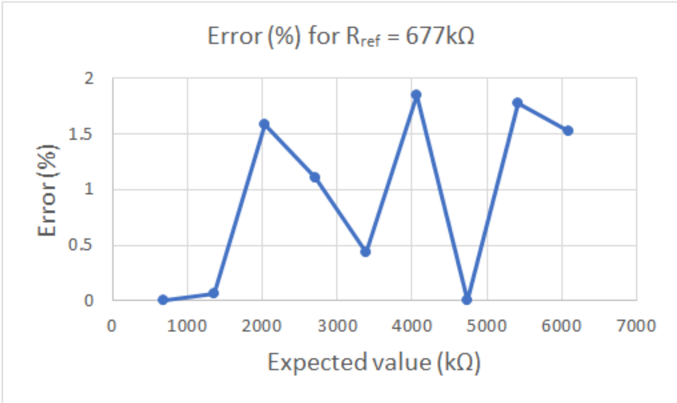


Table 11: Teensy3.2_ R_{ref}=677kΩ and %Error Graph

5.2 Comparison Test

After a series of tests there was one more test carried out with setup involving Arduino UNO microcontroller. In this setup Arduino UNO microcontroller was used and two tests were conducted one with an external ADC ADS1115 and the same test without using an external ADC and using an built-in ADC of the microcontroller. This test was done to see the difference in the values and the amount of deviation generated when an external ADC is used.

	R_{ref} = 470kΩ		
Sl No:	R_{act}	R_{mes}	% Error
1	470	475	1.06
2	562	569	1.25
3	813	816	0.37
4	1864	1877	0.7
5	2334	2374	1.71
6	3578	3643	1.82
7	4707	4761	1.15
8	5377	5446	1.28
9	6190	6264	1.2

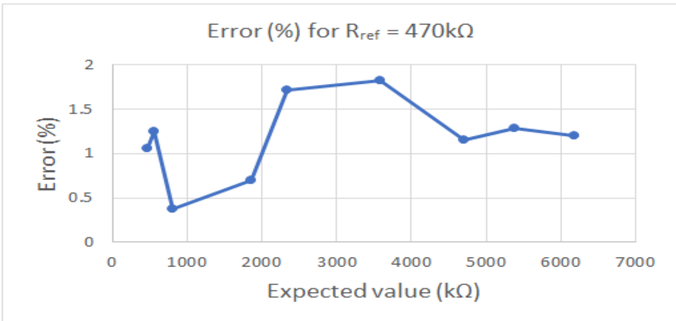


Figure 42: Test Without ADS1115 and %Error Graph Respectively

	R_{ref} = 470kΩ	
Sl.No.	Error(%) with ADC	Error(%) without ADC
1	5.74	1.06
2	5.69	1.25
3	4.06	0.37
4	3.22	0.7
5	2.01	1.71
6	2.88	1.82
7	3.99	1.15
8	4.02	1.28
9	0.9	1.2

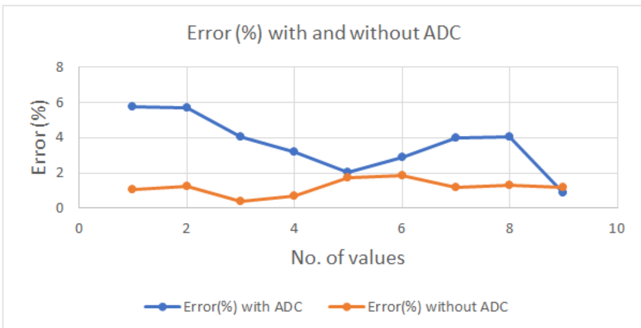


Figure 41: Error (%) with and without ADS1115

6 Application

The main aim of the project is to develop a wearable device. This device can be impregnated to clothes or can be worn on the body and can be used to measure the physical activities. It can be used for movement tracking as well as vibration tracking also. By using a transceiver or via Wi-Fi or Bluetooth the data can be relayed, stored and/or accessed in real time. This device can be used for monitoring health data which in turn can be used for individual centered health care.

By using different combinations of microcontrollers and AFE, this can be tailor-made to fit any purpose according to an individual's needs.

The most important application is in the health-care system.

This can also be used in the development of smart-wearable clothes.

7 Summary

This research project was done to design and realize a prototype for a wireless measurement system for resistance sensor system. The aim was to reduce the overall board size and to develop a circuit which in independent of the microcontroller so that the entire circuit is future-proof.

The state-of-the-art shows the present technologies used in the measurement and communication field. This state of the art provided the initial inputs for designing such a system.

The development chapters separately discuss about the hardware and software developments done. A section by section explanation is given about the different hardware components utilized to realize the circuit. The software development part gives a step by step guideline to implement the prototype. Once the development section is completed, the implementation of the porotype is discussed. The connections using two different microcontrollers are also depicted.

The flow chart and the state diagram are the visual representation of the project aim. The process flow and the logic are shown in them.

The test and discussion section describe about the actual implementation. Difference reference resistance and different microcontrollers were used. The test shows the feasibility of the proposed system.

The application list describes the intended use of such a system in the daily-life and the importance it can play in the future research development of human health-care devices.

8 Conclusion

This project was implemented with the aim of reducing the physical size of the existing wireless measurement system and to reduce the number of measurement channels to one. The range of resistance to be measured was from 470kΩ to 6000kΩ. In addition to that a prototype was developed, so that the circuit is independent of the microcontroller used.

The following requirements were fulfilled by the project at present.

- Realize a resistance measurement system.
- Wireless transmission and reception of the measured values.
- To decrease the number of measuring channels to one.
- To minimize the overall dimensions of the system.
- To make the system independent of the microcontroller.
- To prepare PCB design files for implementing the system in the real world.

The data acquired can be transmitted, stored and/or displayed according to the various requirements.

9 Future Scope

The system was tested using an Arduino Uno and Teensy3.2 boards. The major drawbacks of these boards are absence of Wi-fi or Bluetooth for communication and a screen to display the results. To overcome the short comings as mentioned above, an ESP32_ D-Diuno 32 can be used. It has a built in Wi-fi and Bluetooth along with a 0.96-inch OLED display. This board was also tested, and results were obtained. With further research and experiments the ESP32 can be successfully implemented in the circuit without any major changes to the existing system.

A PCB design was generated for the circuit with ESP32 micro controller. All required files for developing the PCB including the schematics and Gerber files have been created. By outsourcing the actual etching to a PCB fabricating house, a board can be made to implement this system. The design proposed is a stacked version with a double layered PCB. Components are mainly SMD type with the microcontroller being an exception.

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10 Appendix

10.1 Source Code Transmitter

```
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>
#include <Adafruit_SSD1306.h>
#include <Adafruit_GFX.h>
#include <gfxfont.h>
#include<Wire.h>

float Rg = 0.0f;
float Vin = 5.0f;
float Vout = 0.0f;
float Rref = 470000;
float analogInput = 0.0;      //define analog input check for kind of addressing it takes

RF24 radio(7, 8); // CE, CSN

const byte address[6] = "00001";

byte package[32];

#define OLED_RESET 4
Adafruit_SSD1306 display(OLED_RESET);

 unsigned long Time1 = 0;
 unsigned long Time2 = 0;
void setup() {
  // put your setup code here, to run once:
```

```
  //analogReadResolution(10);
  Serial.begin(9600);
  radio.begin();
  radio.setRetries(10, 15);
  radio.setDataRate(RF24_250KBPS);
  radio.openWritingPipe(address);
  radio.setPALevel(RF24_PA_MIN);
  radio.stopListening();

  // setting up OLED

 pinMode(analogInput, INPUT);
 display.begin(SSD1306_SWITCHCAPVCC, 0X3C);//INTIALIZE WITH THE I2C ADDR 0X3C (FOR THE 128X32)
 display.clearDisplay();//clear the buffer
 display.setTextSize(2);//text display voltmeter
 display.setTextColor(WHITE);
 display.setCursor(0,0);
 display.print("W S M\n");
 display.display();
 display.setTextSize(1);
 display.setTextColor(WHITE);
 display.print("Rg = \n");
 display.display();
 display.setTextSize(1);
 display.setTextColor(WHITE);
 display.print("Vout = ");
 display.display();
 Serial.println(" Starting Measurement ");
}
```

```
void loop() {
  // put your main code here, to run repeatedly:
  // code for calculating variable resistance using voltage follower
  float analogInput=analogRead(A1);
  float Vout = (Vin * analogInput)/1024; // 1024 for arduino uno, converting 5v into digital values
  float Rg = (Rref* ((Vin/Vout)-1));//formula for calculating variable resistance

    Serial.println("***starting to send***");//print before copying and transmiting

    memcpy( package, &Rg,  sizeof( Rg ) );//copy data in the form of a package
    radio.write(package, sizeof(package));// write the pacakage into the channel

   Time1 = millis();
   Serial.println(Time1);
  // code for running cotinuous values on OLED
  display.setTextSize(1); //text display voltmeter
  display.setTextColor(WHITE, BLACK);
  display.setCursor(50,16);
  display.print(Rg);
  display.display();
  display.setTextSize(1);
  display.setTextColor(WHITE, BLACK);
  display.setCursor(50, 24);
  display.print(Vout);
  display.display();
  Serial.println(Vout);  Serial.println(Rg);
  Time2 = millis();
  Serial.println(Time2);
  delay(1000);
}
```

10.2 Source Code Receiver

```
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>
RF24 radio(7, 8); // CE, CSN
const byte address[6] = "00001";
byte package[32];
void setup() {
  Serial.begin(9600);
  radio.begin();
  radio.setRetries(10, 15);
  radio.setDataRate(RF24_250KBPS);
  radio.openReadingPipe(0, address);
  radio.setPALevel(RF24_PA_MIN);
  radio.startListening();
  Serial.println("***Starting to receive***");
}
void loop() {
    char text[16] = "";
  float var;
 if (radio.available()) {
     radio.read(&text, sizeof(text));
    radio.read( package, sizeof( package ) );
    memcpy(  &var, package, sizeof( var ) ); //decode
   Serial.println(text);
    delay(100);
    Serial.println( var );
     delay(1000);
  }
}
```

10.3 Data Sheets

30 V, 8 MHz, Low Bias Current, Single-Supply, RRO, Precision Op Amps

Data Sheet **ADA4622-1/ADA4622-2/ADA4622-4**

FEATURES

Next generation of the AD820/AD822/AD824
Wide gain bandwidth product: 8 MHz typical
High slew rate
- **23 V/μs typical (low to high)**
- **−18 V/μs typical (high to low)**

Low input bias current: ±10 pA maximum at T_A = 25°C
Low offset voltage
- **A grade: ±0.8 mV maximum at T_A = 25°C**
- **B grade: ±0.35 mV maximum at T_A = 25°C**

Low offset voltage drift
- **A grade: ±2 μV/°C typical, ±15 μV/°C maximum**
- **B grade: ±2 μV/°C typical, ±5 μV/°C maximum**

Input voltage range includes Pin V−
Rail-to-rail output
Electromagnetic interference rejection ratio (EMIRR)
- **90 dB typical at f = 1000 MHz and f = 2400 MHz**

Industry-standard package and pinouts

APPLICATIONS

High output impedance sensor interfaces
Photodiode sensor interfaces
Transimpedance amplifiers
ADC drivers
Precision filters and signal conditioning

PIN CONFIGURATION

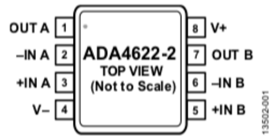


Figure 1. 8-Lead Mini Small Outline Package [MSOP] Pin Configuration (See the Pin Configurations and Function Descriptions Section for Additional Pin Configurations)

GENERAL DESCRIPTION

The ADA4622-1/ADA4622-2/ADA4622-4 are the next generation of the AD820/AD822/AD824 single-supply, rail-to-rail output (RRO), precision junction field effect transistors (JFET) input op amps. The ADA4622-1/ADA4622-2/ADA4622-4 include many improvements that make them desirable as upgrades without compromising the flexibility and ease of use that makes the AD820/AD822/AD824 useful for a wide variety of applications.

The input voltage range includes the negative supply and the output swings rail-to-rail. Input EMI filters increase the signal robustness in the face of closely located switching noise sources.

The speed, in terms of bandwidth and slew rate, increases along with a strong output drive to improve settling time performance and enables the devices to drive the inputs of modern single-ended, successive approximation register (SAR) analog-to-digital converters (ADCs).

Voltage noise is reduced; although the supply current remains the same as the AD820/AD822/AD824, broadband noise is reduced by 25%, and 1/f is reduced by half. DC precision in the ADA4622-1/ADA4622-2/ADA4622-4 improved from the AD820/AD822/AD824 with half the offset and a maximum thermal drift specification added to the ADA4622-1/ADA4622-2/ADA4622-4. The common-mode rejection ratio (CMRR) is improved from the AD820/AD822/AD824 to make the ADA4622-1/ADA4622-2/ADA4622-4 more suitable when used in noninverting gain and difference amplifier configurations.

The ADA4622-1/ADA4622-2/ADA4622-4 are specified for operation over the extended industrial temperature range of −40°C to +125°C, and operate from 5 V to 30 V, with specifications at +5 V, ±5 V, and ±15 V. The ADA4622-1 is available in a 5-lead SOT-23 package and an 8-lead LFCSP package. The ADA4622-2 is available in an 8-lead SOIC_N package, an 8-lead MSOP package, and an 8-lead LFCSP package. The ADA4622-4 is available in a 14-lead SOIC_N and a 16-lead, 4 × 4 mm LFCSP.

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.

ADS111x Ultra-Small, Low-Power, I²C-Compatible, 860-SPS, 16-Bit ADCs With Internal Reference, Oscillator, and Programmable Comparator

1 Features

- Ultra-Small X2QFN Package: 2 mm × 1.5 mm × 0.4 mm
- Wide Supply Range: 2.0 V to 5.5 V
- Low Current Consumption: 150 µA (Continuous-Conversion Mode)
- Programmable Data Rate: 8 SPS to 860 SPS
- Single-Cycle Settling
- Internal Low-Drift Voltage Reference
- Internal Oscillator
- I²C Interface: Four Pin-Selectable Addresses
- Four Single-Ended or Two Differential Inputs (ADS1115)
- Programmable Comparator (ADS1114 and ADS1115)
- Operating Temperature Range: –40°C to +125°C

2 Applications

- Portable Instrumentation
- Battery Voltage and Current Monitoring
- Temperature Measurement Systems
- Consumer Electronics
- Factory Automation and Process Control

3 Description

The ADS1113, ADS1114, and ADS1115 devices (ADS111x) are precision, low-power, 16-bit, I²C-compatible, analog-to-digital converters (ADCs) offered in an ultra-small, leadless, X2QFN-10 package, and a VSSOP-10 package. The ADS111x devices incorporate a low-drift voltage reference and an oscillator. The ADS1114 and ADS1115 also incorporate a programmable gain amplifier (PGA) and a digital comparator. These features, along with a wide operating supply range, make the ADS111x well suited for power- and space-constrained, sensor measurement applications.

The ADS111x perform conversions at data rates up to 860 samples per second (SPS). The PGA offers input ranges from ±256 mV to ±6.144 V, allowing precise large- and small-signal measurements. The ADS1115 features an input multiplexer (MUX) that allows two differential or four single-ended input measurements. Use the digital comparator in the ADS1114 and ADS1115 for under- and overvoltage detection.

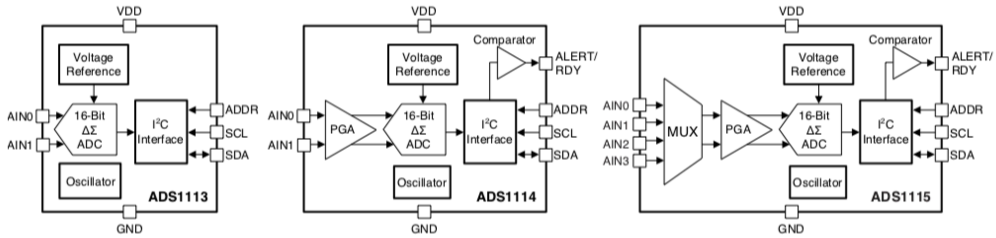
The ADS111x operate in either continuous-conversion mode or single-shot mode. The devices are automatically powered down after one conversion in single-shot mode; therefore, power consumption is significantly reduced during idle periods.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
ADS111x	X2QFN (10)	1.50 mm × 2.00 mm
	VSSOP (10)	3.00 mm × 3.00 mm

(1) For all available packages, see the package option addendum at the end of the data sheet.

Simplified Block Diagrams



FAIRCHILD SEMICONDUCTOR®

October 2005

BSS138

BSS138

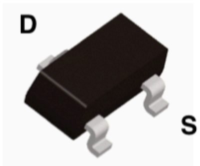
N-Channel Logic Level Enhancement Mode Field Effect Transistor

General Description

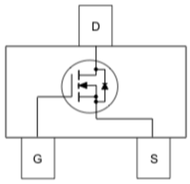
These N-Channel enhancement mode field effect transistors are produced using Fairchild's proprietary, high cell density, DMOS technology. These products have been designed to minimize on-state resistance while provide rugged, reliable, and fast switching performance.These products are particularly suited for low voltage, low current applications such as small servo motor control, power MOSFET gate drivers, and other switching applications.

Features

- 0.22 A, 50 V. $R_{DS(ON)} = 3.5\Omega$ @ $V_{GS} = 10$ V
  $R_{DS(ON)} = 6.0\Omega$ @ $V_{GS} = 4.5$ V
- High density cell design for extremely low $R_{DS(ON)}$
- Rugged and Reliable
- Compact industry standard SOT-23 surface mount package



SOT-23



Absolute Maximum Ratings $T_A=25^oC$ unless otherwise noted

Symbol	Parameter	Ratings	Units
V_{DSS}	Drain-Source Voltage	50	V
V_{GSS}	Gate-Source Voltage	±20	V
I_D	Drain Current – Continuous (Note 1)	0.22	A
	– Pulsed	0.88	
P_D	Maximum Power Dissipation (Note 1)	0.36	W
	Derate Above 25°C	2.8	mW/°C
T_J, T_{STG}	Operating and Storage Junction Temperature Range	–55 to +150	°C
T_L	Maximum Lead Temperature for Soldering Purposes, 1/16" from Case for 10 Seconds	300	°C

Thermal Characteristics

$R_{\theta JA}$	Thermal Resistance, Junction-to-Ambient (Note 1)	350	°C/W

Package Marking and Ordering Information

Device Marking	Device	Reel Size	Tape width	Quantity
SS	BSS138	7"	8mm	3000 units