Bite Force Sensor System – Project Development Report

Extensive Research

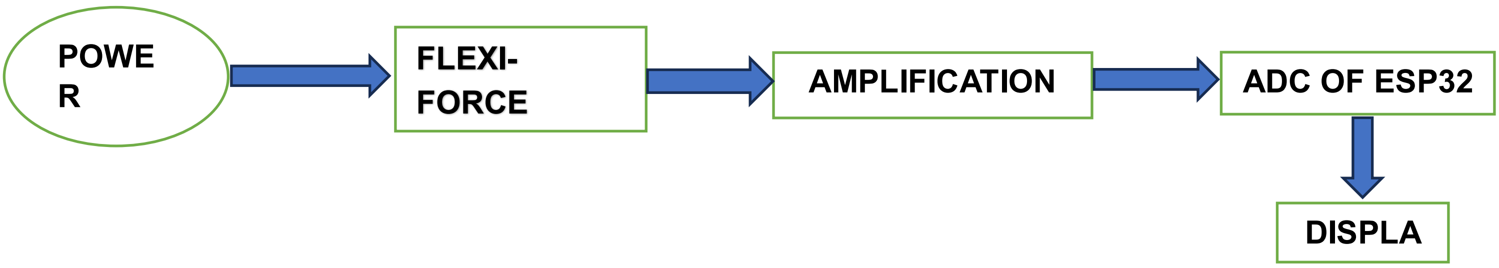
1. Introduction

The product is based on a **Flexi Force** sensor, integrated into a custom-designed electronics system. It aims to provide a cost-effective alternative to existing market solutions while delivering accurate and reliable measurements.

2. Design and Technical Specifications

The product's design is a fully integrated system, housed in a compact enclosure. It includes the following key components:

- **Sensor Unit:** The device uses a **Flexi Force** sensor to measure bite force. This sensor changes resistance in response to applied force. The sensor is integrated into a mechanical bite fork mechanism.
- **Electronics:** Signal conditioning circuit built around a **MCP6004** quad op-amp. This circuit amplifies the minute voltage changes from the sensor and filters out noise.
- **Microcontroller Unit (MCU):** An **ESP32-WROOM-32-N4** microcontroller processes the amplified analog signal from the op-amp circuit, converting it to a digital force reading.
- **Power Management:** A **Li-Po battery** and a **TP4056** charging module provide portable power, while an **MCP1700** voltage regulator ensures a stable 3.3V supply for all components. However, power was supplied via ESP32 to other components. USB cable connected to laptop provided the power during breadboard implementation.
- **User Interface:** A **0.96-inch TFT LCD (ST7735S driver)** displays the measured bite force in real time.



Choice Of MCP6004 as amplification part and force sensor as flexi force sensor is by below reference: **[1]**

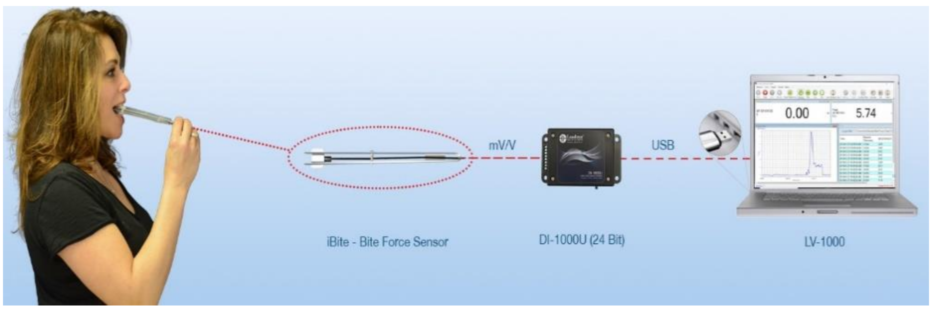
3. Market and Competitive Analysis

The bite force measurement market includes several established products. A comparative analysis highlights the positioning of our device.

- **IDDK Digital Dynamometer:** This device is a high-end solution, capable of measuring up to 1000 N. While effective, its design with a separate bite fork and digital display may be less compact than our integrated solution.

- **Innobyte by Kube Innovation:** Aimed at dental practitioners, this device also measures occlusal force in Newtons. It is used to evaluate conditions like bruxism. Our product offers a similar function but with a focus on affordability and portability.

- **I Bite Pro by Loadstar Sensors:** This product is sold as a kit with different interface options (USB, wireless, analog). The inclusion of dedicated software is a key feature. Our product, by comparison, offers a self-contained, ready-to-use device without the need for an external computer or software.



Our product's competitive advantage lies in its all-in-one, integrated design. By using a cost-effective ESP32 and a Flexi Force sensor, we can deliver a portable, compact, and affordable solution that serves the same core function as these market leaders.

4. Manufacturing and Future Improvements

The current design has been successfully prototyped using a breadboard. While this validates the circuit's functionality, future manufacturing will require a professional PCB design adhering to industry standards for **Signal Integrity (SI)**, **Power Integrity (PI)**, and **EMI/EMC** to ensure reliability and robustness in real-world applications.

- **SI/PI:** Proper trace routing and power plane design will minimize signal noise and voltage drops, ensuring accurate sensor readings.
- **EMI/EMC:** Following these standards will prevent the device from being affected by external interference and from interfering with other electronic devices.

5. Conclusion

This report details a fully functional portable bite force measurement device. The prototype successfully demonstrates the core functionality of measuring bite force using a Flexi Force sensor, an ESP32, and an integrated display. With a compact design and a competitive price point, the product is well-positioned to enter the market. Further development should focus on finalizing the PCB design to meet professional standards, ensuring the device is reliable, robust, and ready for mass production.

SPICE Simulation (Circuit Design)

The first design step was to simulate the sensor interface in SPICE. The circuit measures the changing resistance of the FSR (labeled R4) and produces a conditioned analog output (V6) for the microcontroller. The key stages in the circuit are:

- **Input Stage:** An FSR (R4) is placed in series with a fixed resistor (R2) to form a voltage divider. A reference 3.3 V source (from the ESP32) feeds a primary divider (R1 and the pin's internal Rser) and a secondary divider (R4 with R2). As force on the FSR increases, its resistance falls, causing the divider's output voltage to change. This converts force into a proportional analog voltage.
- **Amplification Stage:** Two op-amps (U1, U2, from an MCP6004 quad op-amp) are configured as a differential amplifier to boost the small voltage difference from the FSR divider. The gain is set by resistors (R3 = 100 kΩ, etc.) so that tiny changes (millivolts) become larger (volts). While not a classic three-op-amp instrumentation amplifier, this configuration achieves similar differential gain. Using multiple op-amps in this way allows high gain while maintaining high input.
- **Filter Stage:** The amplifier output (v2) is fed into an active low-pass filter (U3 with R5 = 10 kΩ and C2 = 47 pF). This op-amp filter passes low-frequency signals (the slow bite-force changes) but attenuates high-frequency noise. Active low-pass

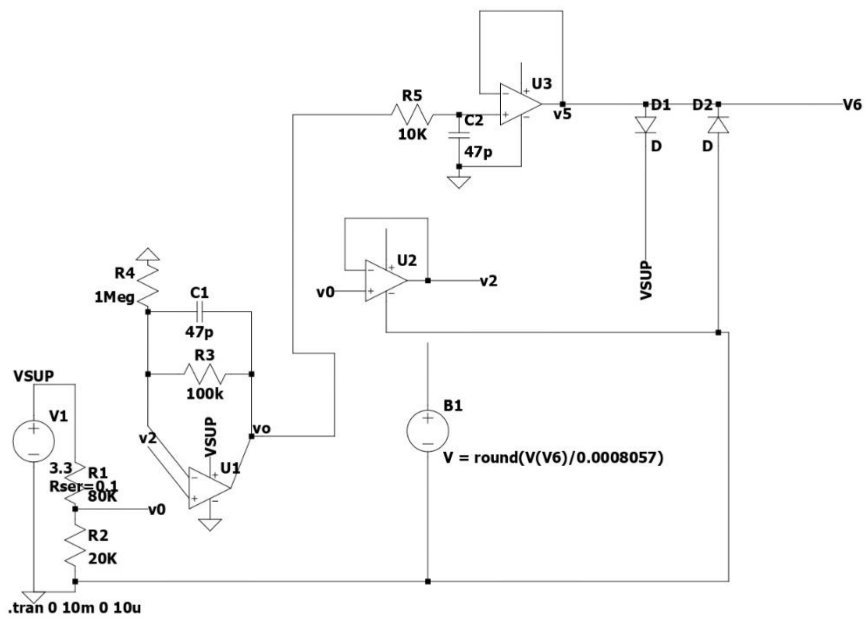
filters like this both amplify and limit the bandwidth of a signal, improving stability and reducing unwanted spikes.

- **Output/DAC Interface:** The filtered voltage is presented at node V6, the final analog output. Schottky diodes (D1, D2) clamp this output to safe levels, protecting against voltage spikes or swings beyond 0–3.3 V. A behavioral element (B1) models an ADC/DAC step by rounding V6 to a quantized value (V = round(V(V6)/0.0008057)). This simulates the ESP32's 12-bit ADC quantization (0–3.3 V maps to 0–4095) and shows how the microcontroller would interpret the analog signal.

In summary, the SPICE simulation converts bite force (changing R4) into a voltage, amplifies it, filters out noise, and outputs a clean analog voltage (0–3.3 V) for the ESP32's ADC.

Operational Flow (Signal Path)

1. **Force Application:** A bite on the FSR lowers its resistance, changing the divider voltage at the input of U1.
2. **Signal Amplification:** U1/U2 amplify this small voltage difference, producing a larger signal at node v2.
3. **Noise Filtering:** U3's low-pass stage filters v2, yielding a smooth voltage v5 with high-frequency noise removed.
4. **Signal Output:** The filtered signal appears at V6. Schottky diodes clamp it to [0,3.3] V for safety.
5. **ADC Quantization:** The behavioral source B1 rounds V6 to the nearest ADC step (≈0.0008057 V), mimicking a 12-bit ADC. The ESP32 then reads this digital value to update the display.

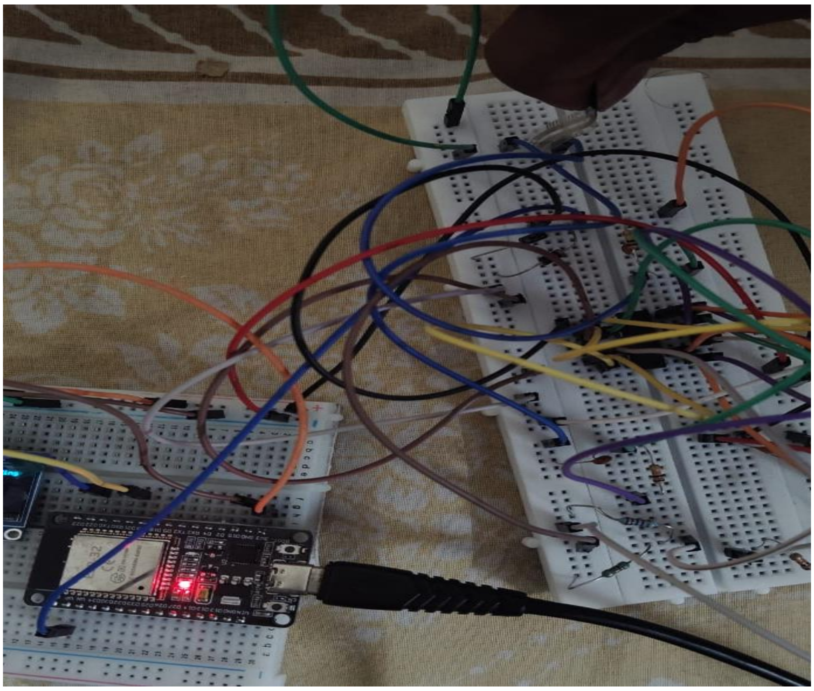


Breadboard Prototyping

The breadboard prototype physically implements the simulated circuit, tuned for the specific FSR used. Its function is to take the tiny resistance change when a student bites the sensor and convert it into a readable voltage for the ESP32. The key elements are:

- **Input Stage (FSR & Divider):** The FSR is wired with a fixed resistor into a divider so that voltage at the midpoint increases as the FSR's resistance falls under bite force. This provides a force-dependent analog voltage.
- **Amplification & Conditioning:** The small voltage from the divider is fed into the op-amp circuit (U1/U2 as before). The gain is adjusted (by R3 and related resistors) so that the full range of expected bite forces maps to the ADC range. If the FSR produces only millivolt-level changes, the op-amps scale it up to volts. This ensures the ESP32's ADC sees a strong signal, improving resolution.
- **Output to ESP32:** The final analog voltage (at the node equivalent to V6) is connected to an ADC pin on the ESP32. Thus the microcontroller directly reads the amplified sensor signal.
- **Data Processing (ESP32):** In software, the ESP32 reads the ADC value (0–4095 for 0–3.3 V) and applies calibration to convert it to a bite force (e.g. newtons or kilograms). A calibration curve or formula (derived from known weights) maps ADC counts to force. The result is then sent to the OLED display. For example, the code might scale and round the raw reading to report force.
- **Protection (Schottky Diodes):** The breadboard also includes Schottky diodes on the signal line to ground and 3.3 V. These clamp any unexpected spikes or negative swings to safe levels, protecting the ESP32's ADC. The ESP32 then uses the digital value from the ADC (after any rounding or mapping) to update the OLED via SPI (using its SCL/SDA pins as clock/data lines).

Overall, the prototype takes the FSR's analog response to biting, amplifies and cleans it, and uses the ESP32's ADC and firmware to compute and display the bite force.



Design and Implementation of a Transcranial Electrical Stimulation (TES) System

Abstract

Transcranial Electrical Stimulation (TES) includes techniques such as transcranial Direct Current Stimulation (tDCS) and transcranial Alternating Current Stimulation (tACS), which non-invasively modulate brain activity using low-intensity scalp-applied currents. This report presents the design of a TES system controlled by ESP32 microcontrollers, featuring programmable waveform generation and constant-current output stages. A comprehensive system architecture was developed, and the core stimulation circuit (Howland current source with HCNR201 feedback isolation) was verified using SPICE simulations. A simplified prototype was built on a breadboard using one ESP32 and a manual potentiometer for amplitude control. The SPICE tests confirmed that the system reliably generates stable DC currents. Measured output currents closely matched the simulation predictions, validating the design.

Introduction

Transcranial Electrical Stimulation (TES) refers to non-invasive brain stimulation methods that deliver weak electrical currents through electrodes placed on the scalp. Common TES modalities are **tDCS** (transcranial Direct Current Stimulation) and **tACS** (transcranial Alternating Current Stimulation). In tDCS, usage of constant current (typically 1–2 mA) between two electrodes (anodal/cathodal) is done. It produces a lasting change in neuronal membrane polarization: anodal (positive) stimulation tends to increase excitability (depolarization), whereas cathodal (negative) stimulation decreases excitability (hyperpolarization). Sessions commonly last 20–30 minutes. tDCS has been studied for enhancing motor learning, reducing depression symptoms, and improving working memory. Effects are often subtle but can be cumulative over repeated sessions [2]. In tACS, application is sinusoidal (or other oscillating) current, often in the range of 0.1–100 Hz. The goal is to interact with endogenous brain rhythms (e.g. alpha, beta waves) by delivering current in-phase with neural oscillations. tACS has been explored for cognitive tasks (e.g. attention, perception) and for clinical effects such as reducing tremor in Parkinson's or alleviating chronic pain. Since tACS has zero net DC offset, it typically feels even less perceptible on the skin [3].

Types:

- Active TES: Delivering electric current for required amount of time to produce actual results. for example, delivering 2mA for 20mins.
- Sham TES: Delivering active stimulation for few seconds to mimic sensations observed in TDCS and keep participants blind from intervention for example, delivering 2mA for 30s and 0mA later 19 minutes [4].
- Anodal TES: Enhancement of stimulated brain area which helps to enhance cognitive functions of brain.
- Cathodal TDCS: Inhibiting brain simulation method to reduce hyperactivity disorders like hypertension.

For anodal simulation, anode is placed over central parietal-5 section of brain according to EEG 10-10 system. similarly for Cathodal simulation, cathode is placed [5].

Literature Review

The history and development of TES can be summarized as follows:

1.Application of electrical discharge of torpedo fish for treatment of head-ache i.e applying live fish directly to affected part of brain which was releasing electric currents to numb the pain.

2.Giovanni Aldini, was one of the first persons to utilize DC for clinical applications, he cured the patient completely who was suffering from melancholy madness [6].

Case Study

Experiment Setup:

A total of 66 healthy subjects were recruited for the study. Six subjects had to be excluded, two because they were left-handed and four due to technical problems during the measurement.

Application:

- Subjects were divided into three groups with 20 subjects each, receiving either anodal (10 male, mean age 21.5 ± 1.9 years), cathodal (10 male, mean age 23.7 ± 3.2 years) or sham stimulation (10 male, mean age 22.9 ± 2.7 years) at Wernicke's area
- TDCS was delivered by a battery-driven direct current stimulator through a pair of 7 × 5-cm saline-soaked surface sponge electrodes. The NaCl solution concentration was 15 mM since lower concentrations are more likely to be perceived as comfortable during stimulation.

Experiment Procedure:

Two tests are taken which are described below

Lexical decision task: This test consisted of group of string of letters which it was based on how fast the decisions were made by people to decide it as word or not

Motor control task: This test was consisted of arrows and person has to decide the direction of arrow as quickly as possible.

Results:

Side effects: Sensations like itching was found underneath the electrodes.

Reaction Times:

- RTs of the cathodal group were significantly decreased with respect to the sham group.
- Decreased RTs in the anodal group compared to the sham group was observed.

- There was no difference in RTs between the anodal and the cathodal group.

Conclusion:

In summary, our data show that both anodal and cathodal tDCS applied to Wernicke's area improved semantic processing compared to sham stimulation.[7]

Current manufacturers of TES

Soterix medicals:

- Since 2008, across over 180 published trials and 15,000 stimulation sessions, the Soterix Medical 1x1 tDCS is the recognized standard in tDCS research.
- The 1x1 tDCS anchors the 1x1 class of stimulators, with unique features such as RELAX, Smart SCAN, and True Current with exhaustively validated accessories.
- Current intensity from 0.1 to 5 mA, and current duration from 5 to 40 minutes. Higher current performance is made possible by unique accessories, integrated LTE and Adaptive current ramp.[8]

Neuroconn:

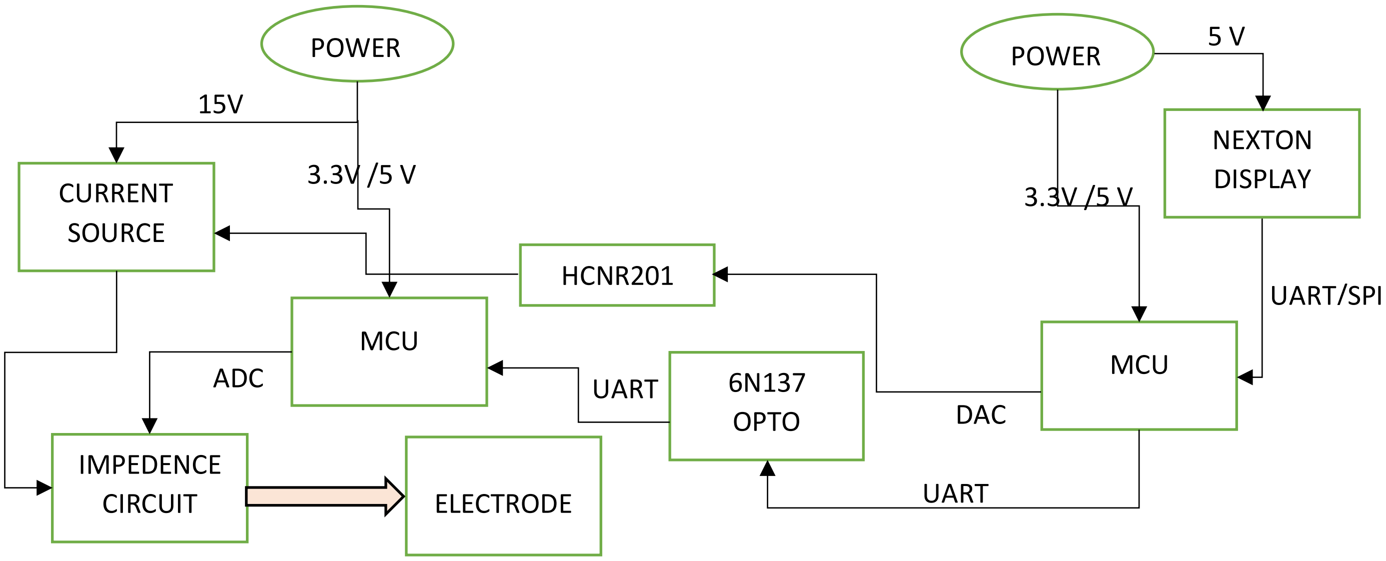
The DC-STIMULATOR MOBILE is a clinical simulator designed to be used in clinics and practices. Using this device, doctors and psychologists can apply transcranial direct current stimulation (tDCS) using weak currents up to 2mA over 15-30 minute.

Technical specs:

- Power consumption: Max. 0.25 W
- Power supplied by a built-in, rechargeable, leakproof battery within the Storage Module.
- Recharges via USB runs continuously for around 90 min (dependant on stimulation mode and battery condition)
- Graphical display, 1 button.[9]

System Architecture

It has two separate circuitry which are relied on two isolated power supply and ground. 1st circuit consists of the nextion display and main MCU and power supply is for nextion display and MCU. In 2nd circuit separate power and ground for the current source and secondary MCU is present. Here totally 2 optocoupler is used as bridge for connection between the circuits. 1st optocoupler is HCNR201 connected between waveform mode circuitry and current source. 2nd one is used between two MCU's for the UART communication and the isolation. Power 15 V power supply will be given to the constant current source circuitry and 5V for MCU. Nexton display is where we give the current intensity and duration or TDCS/TACS modes which all are adjusted by just tap on the screen. Now MCU will generate the voltage waveform based on command given in nexton display. DAC of MCU is connected to HCNR201 and the input voltage waveform is adjusted to give the output constant current required which is set by digital pot present in current source block. We have the impedance circuit which detects the impedance of brain by use ADC of MCU.[10]



Core Components:

Waveform Mode Selection:

1. Nexton Touchscreen Display: This display has the options like changing the current amplitude and dc or ac mode dualities. (Just Research Not validated on hardware.)

2. ESP32 MCU: Brain of the entire device which is responsible for the waveform generation either dc or ac.

Optocoupler Circuitry:

1. Two 6N137 optocouplers in between the MCU for the isolation and UART communication. (Just Research Not validated on hardware).

2. One HCNR201 optocoupler for the isolation between the waveform mode circuitry and the howland's current source circuitry.

Constant Current Source Circuitry:

1. Digital Pot: which works digitally through the Nexton via MCU. (Used one resistance to simulate the exact characteristics).

2. Howland's Current Source: This block converts the voltage waveform to required current waveform which consists of 3 op-amps and 4 resistors.

Other Components

1. Precision Resistors, Capacitors and Schotky Diodes: for the noise filter, current limiting and clamping purpose.

2. OLED Display: for the output current view which can be good for validation.

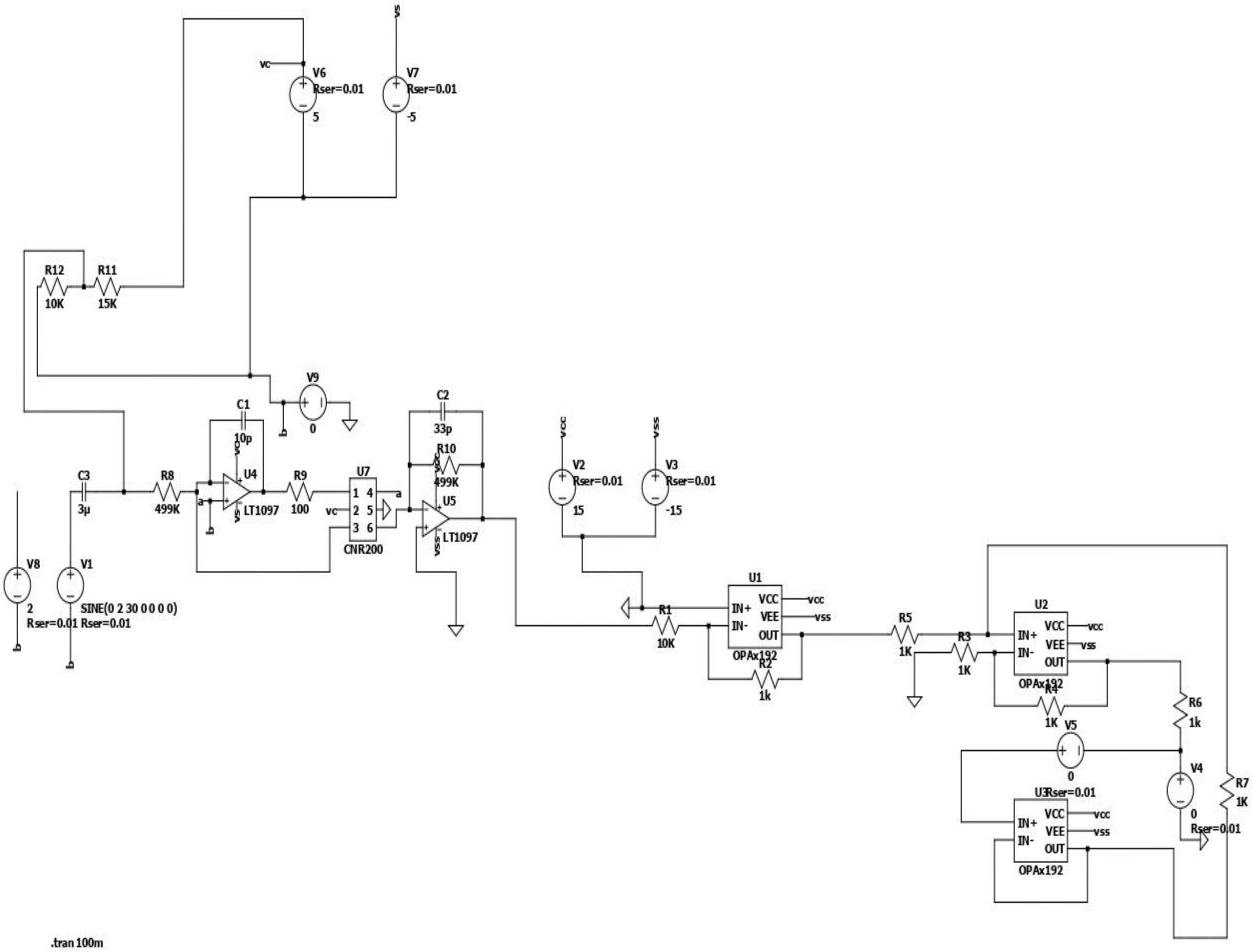
3. Buzzers Or Led: for Indication of alarm or other purposes.
4. Power Supply: To have the portable power supply which is having the capability of giving power.
5. Perfect Electrode Sponges for the brain and the wires for the connection.[11]

SPICE Simulation

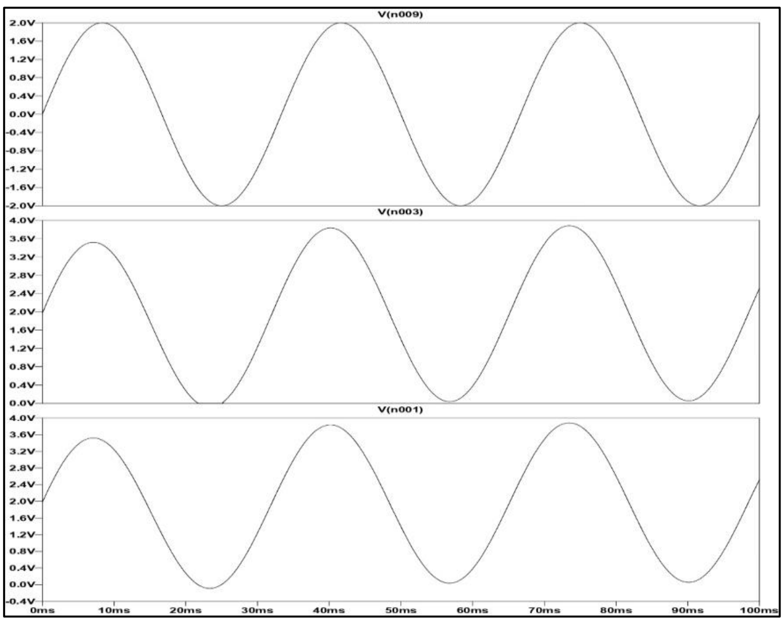
The designed circuit was validated using SPICE simulation to ensure correct performance before hardware implementation. The Howland current source was implemented in SPICE with ideal op-amps and matched resistors. The ESP32's DAC was modelled as a programmable voltage source (with a series resistor to emulate output impedance). The HCNR201 analog optocoupler was included by modelling its LED and dual photodiodes, allowing simulation of an isolated feedback path. The power supplies were set to ±15 V to provide sufficient compliance.

- **tDCS (DC) Simulation:** A constant input voltage (e.g. +1.0 V) was applied to the Howland circuit. The simulation output current through a 1 kΩ load was monitored. The result showed a stable 1.0 mA output, confirming proper conversion of voltage to current. The output remained constant when the load resistance was varied, demonstrating the constant-current behaviour. The voltage across the load adjusted up to the supply rail as expected.
- **tACS (AC) Simulation:** A 10 Hz sinusoidal input (±0.5 V amplitude, representing ±1 mA through 1 kΩ) was used. The resulting output current waveform was a clean sine of 1 mA peak-to-peak. The simulation confirmed that the output had minimal distortion or phase shift, indicating sufficient bandwidth of the op-amp and filter. The output current precisely followed the input waveform, validating the AC mode operation.
- **Isolation/Feedback:** The HCNR201 model showed that the photodiode output current was linearly proportional to the input LED current, providing an accurate analog feedback signal on the isolated side. This demonstrates that the ESP32 can measure the output current indirectly across the isolation barrier.

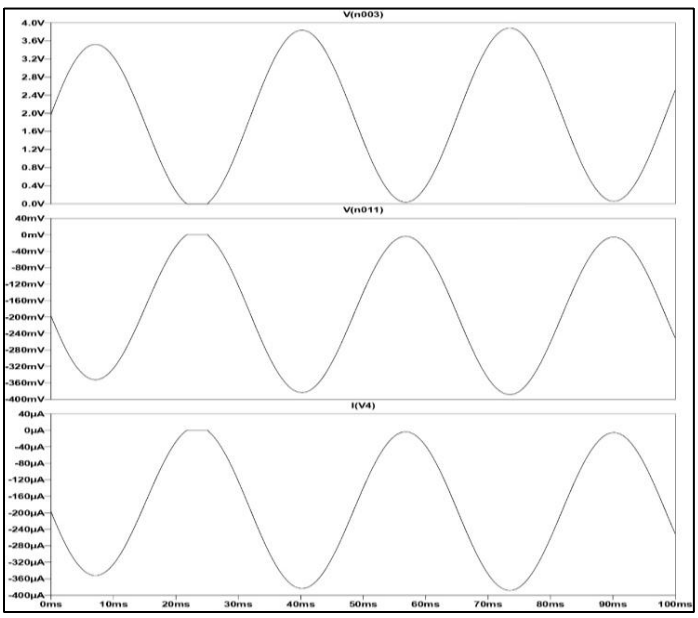
These SPICE results (illustrated in the figure) confirm that the circuit design can achieve the intended performance. The simulations indicated reliable constant-current generation for tDCS and faithful sine-wave output for tACS under ideal conditions.



OPTOCOUPLER SIMULATION



CURRENT SOURCE SIMULATION



Overall, the experimental observations aligned well with design goals. The constant-current source demonstrated high linearity, and the system maintained stable operation under various conditions. simulation confirmed that the architecture is capable of delivering reliable TES outputs.

References:

[1] **Force Integration Guides**

[2],[3] Transcranial electrical stimulation (tES) mechanisms and ...

[4] Active versus sham transcranial direct current stimulation ...

[5] Both anodal and cathodal transcranial direct current ...

[6] Letter to the Editor: Brief history of transcranial direct current ...

[7] Both anodal and cathodal transcranial direct current ...

[8] 1x1 tDCS Device – Transcranial Direct Current Stimulation – Soteri...

[9] neuroConn DC-STIMULATOR MOBILE

[10],[11] **GitHub - Open-Stim/openstim: Open Source Hardware ...**

The Howland Current Pump - Technical Articles

Design and optimization of a high-definition transcranial ...