REPORT ON

TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION UNIT

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ABSTRACT

This project focuses on the design and implementation of a Transcutaneous Electrical Nerve Stimulation (TENS) unit using a simple circuit based on NE555 timers, resistors, capacitors, and electrode patches. The device generates square wave pulses with an adjustable frequency range of 50 Hz to 120 Hz and a peak output of 20V, providing effective nerve stimulation for pain relief and muscle relaxation.

The TENS unit operates by utilizing the NE555 timer in an astable configuration to generate electrical pulses. These pulses are precisely controlled by adjusting the resistors and capacitors, ensuring accurate frequency modulation. The pulses are delivered to the skin through electrode patches, stimulating nerves while maintaining safe current levels with the help of resistors. The device is powered by a 12V battery, ensuring reliable and portable operation.

This project demonstrates a practical and affordable solution for pain management using simple electronics. It holds potential for future enhancements, such as integrating digital displays for better control, IoT connectivity for remote monitoring, and rechargeable power options to improve usability and efficiency.

Chapter 1

1.1 INTRODUCTION

Transcutaneous Electrical Nerve Stimulation (TENS) is a widely recognized method for non-invasive pain management and muscle therapy. It operates by delivering low-voltage electrical impulses through electrodes placed on the skin, which stimulate the underlying nerves and interfere with pain signals traveling to the brain. TENS units are compact, portable, and highly versatile, making them suitable for various medical and therapeutic applications, including chronic pain relief, post-surgical recovery, and sports rehabilitation. The below figure 1.11 tells about the gate theory. Figure 1.12 explains how the electrical impulses sent to the skin interferes with the nerves.

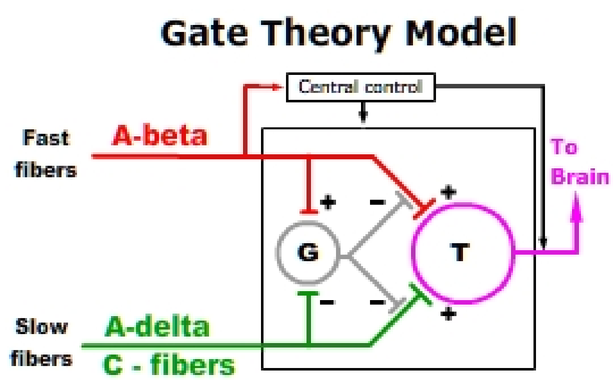


fig 1.11 : Gate theory model

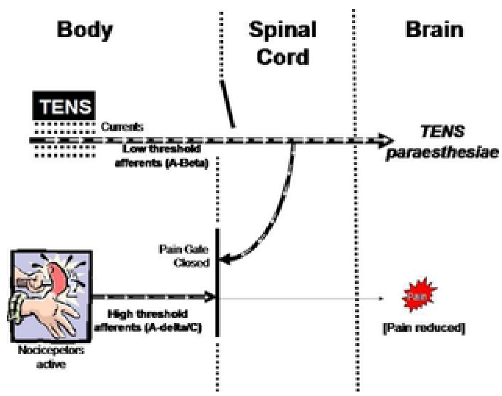


fig 1.12 : Principle of TENS Unit

1.2 MOTIVATION

This project was inspired by the increasing need for accessible and non-invasive solutions for pain management and rehabilitation. Chronic pain, post-surgical discomfort, and muscle injuries are significant challenges in healthcare, often requiring costly treatments or medications that come with side effects. A TENS (Transcutaneous Electrical Nerve Stimulation) unit offers a safe, drug-free alternative for pain relief and muscle stimulation.

Physiotherapists and healthcare professionals often face limitations in providing portable and user-friendly devices that patients can use at home. The design of a reliable, compact, and affordable TENS unit addresses these challenges, empowering individuals to manage their conditions conveniently without constant clinical supervision.

Moreover, the versatility of TENS units in applications such as sports rehabilitation, post-surgery recovery, and chronic pain relief makes them an attractive solution for both medical and personal use. By bridging the gap between advanced technology and user comfort, this project aims to develop a device that enhances the quality of life for individuals while deepening technical expertise in biomedical engineering applications.

1.3 PROBLEM STATEMENT

Pain management and muscle rehabilitation are critical aspects of healthcare, yet many conventional treatments rely heavily on medication or complex clinical procedures, which can be costly, inconvenient, and associated with side effects. For patients dealing with chronic pain, post-surgical recovery, or sports-related injuries, accessing effective, non-invasive therapeutic solutions remains a challenge.

Existing devices for pain management, such as bulky or overly expensive TENS units, often lack portability and accessibility, making them impractical for widespread use. Additionally, physiotherapists and individuals at home require devices that are user-friendly, safe, and customizable for different types of pain and muscle stimulation.

This project aims to address these challenges by designing a simple and reliable TENS unit with basic components that provides effective pain relief and promotes muscle recovery.

1.4 OBJECTIVE

- Understand TENS Mechanism: Study how electrical impulses relieve pain by interacting with the nervous system.
- Circuit Design: Create a functional circuit for the TENS unit with precise current and signal control.
- Safety Features: Integrate protection mechanisms to ensure safe operation and user safety.
- User Interface: Develop an intuitive interface with adjustable controls for frequency and intensity.
- Effectiveness Testing: Evaluate the device's performance and therapeutic impact through research and testing.

Chapter 2

LITERATURE SURVEY

The development of a Transcutaneous Electrical Nerve Stimulation (TENS) unit involves integrating insights, electronic components, and clinical applications. For this, we have referred a few articles and research papers to make this project a success.

Electronic Design and Timer Components:

The IC 555 timer is a fundamental component for generating the electrical pulses necessary for a TENS unit. Sarkar [1] demonstrated how the 555 and 7555 timers could be utilized for regulating pulse frequency and duration, which are critical parameters for TENS functionality. Similarly, Goyal [2] provided detailed insights into the operation and troubleshooting of the IC 555 timer, offering valuable guidance for its integration into the circuit design. Together, these studies underline the importance of precise timing circuits in ensuring the effectiveness of TENS devices.

Clinical Effectiveness of TENS:
From a clinical perspective, the effectiveness of TENS in pain management and rehabilitation is well-documented. Gozani et al. [3] emphasized the real-world impact of TENS on chronic conditions like low back pain, particularly its role in improving sleep and reducing pain intensity. This evidence underscores the need for adjustable stimulation settings in TENS units to cater to individual patient needs.

Guidelines for Practical Implementation:

Johnson [4] consolidated clinical research on TENS and outlined practical guidelines for its application. These guidelines are instrumental for ensuring the safety and efficacy of TENS devices, particularly in aligning the electrical parameters with therapeutic objectives. The integration of such protocols into the design process is essential for bridging the gap between technical development and clinical utility.

Key Design Considerations

The reviewed literature collectively highlights several critical factors for building a TENS unit:

- Pulse Generation: Use of IC 555 timers for reliable and customizable pulse delivery [1], [2].
- Frequency Modulation: Adjustable frequency and pulse width to accommodate different therapeutic requirements [1], [3].
- Safety Standards: Incorporating guidelines from clinical studies to ensure safe current delivery and patient comfort [3], [4].
- Cost-Effectiveness: Designing a low-cost unit without compromising functionality, as suggested by Sarkar [1].

By synthesizing these insights, our project can was aimed to develop a TENS unit that is both technologically robust and clinically impactful.

Chapter 3

METHODOLOGY

The following steps outline the systematic approach undertaken to design, construct, and test the TENS unit circuit:

1. Identifying Objectives:
   - Defined the primary goal of creating a reliable, safe, and adjustable TENS unit for therapeutic pain relief.
   - Focused on generating adjustable electrical pulses for various applications, such as muscle relaxation and pain management.

2. Performance Criteria Specification:
   - Established parameters such as frequency range (2–150 Hz), pulse width (50–250 µs), and safe current levels for user safety.
   - Ensured ease of use and adjustability for different therapy needs.

3. Technical Research:
   - Conducted a detailed study of pulse generation using NE555 timers and their applications in medical devices.
   - Explored safe electrical pulse delivery methods to ensure effectiveness without compromising user safety.

4. Circuit Design:
   - Designed a dual NE555 timer circuit with the following features:
     - First Timer (U1 in Astable Mode): Generates a continuous square wave to provide base pulse frequency.

        - Second Timer (U2 in Monostable Mode): Produces adjustable pulse widths triggered by the output of U1.
        - Variable resistors (PR1 and PR2) were included to allow fine-tuning of frequency and pulse width.
        - R7 was connected to ground to stabilize the output signal.

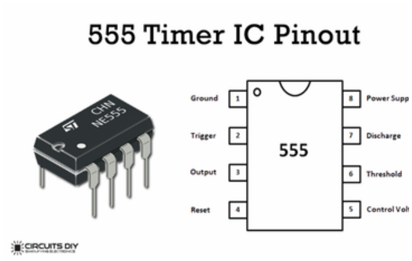
            - The output signal from U2 was directly connected to electrode patches for therapeutic application.
            - formulae: Frequency of Oscillation $f=1.44/(R1+2R2)\times C1$
            - R1 and R2 are the resistors connected to the NE555 and C1 is the timing capacitor.
            - Duty Cycle $D=(R1+R2)/(R1+2R2)$

5. Prototype Assembly:
    - Assembled the designed circuit on a breadboard using NE555 timers, resistors, capacitors, and potentiometers.

6. Testing and Calibration:
    - Connected an oscilloscope to monitor the output waveform.
    - Adjusted PR1 and PR2 to achieve desired frequency and pulse width ranges.
    - Conducted tests to evaluate the effectiveness of the pulses for different therapy modes.
        - Low-frequency (2–10 Hz) for muscle relaxation.
        - High-frequency (80–150 Hz) for pain relief.

3.1 COMPONENT SPECIFICATION

1.



The **NE555** is a widely used integrated circuit designed for precise timing, pulse generation, and oscillator applications. It is capable of operating in monostable, astable, and bistable modes. In this project, the NE555 timer is used to generate electrical pulses with controlled frequency and pulse width, ensuring reliable operation in the TENS unit for nerve stimulation based on our needs. Its versatility and ease of configuration make it a vital component in the circuit.

2.

The **Potentiometer** is a three-terminal variable resistor that provides adjustable resistance. It functions as a voltage divider and is widely used for calibrating or fine-tuning circuits. By rotating its knob, users can change the resistance value, thereby altering the electrical parameters such as voltage or current in the circuit. We have used 1M and 25K potentiometer to vary frequency and pulse width respectively.

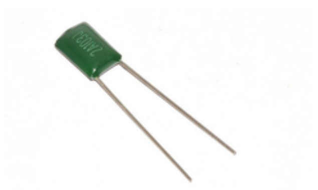
3.

The **12V battery** is a power source that provides a stable and sufficient voltage supply to operate the TENS unit and its components. In this project, the 12V battery powers the NE555 timer circuit, resistors, capacitors, and other components, ensuring consistent and reliable operation of the device. Its portability enhances the usability of the TENS unit

4.

A **Resistor** is a passive electronic component that opposes the flow of electric current, converting electrical energy into heat. In this project, resistors play a crucial role in defining the timing and pulse characteristics of the TENS unit, as well as protecting sensitive components by controlling the current flow within safe limits. Their precise resistance values ensure reliable and stable circuit operation.

5.



A **Capacitor** is a passive electronic component that stores and releases electrical energy in the form of an electric field. It consists of two conductive plates separated by a dielectric material. In this project, capacitors are employed to shape the timing and frequency characteristics of the electrical pulses generated by the NE555 timer. They also help smooth voltage fluctuations and stabilize the circuit.

6.

Electrode patches are conductive interfaces that deliver electrical stimulation from the TENS unit to the user's skin. These patches are typically made of flexible, biocompatible materials with a gel coating to ensure optimal contact with the skin and reduce resistance. In this project, the electrode patches serve as the medium for transmitting electrical impulses to the targeted nerve regions.

3.3 CIRCUIT

INITIAL APPROACH USING AURDINO

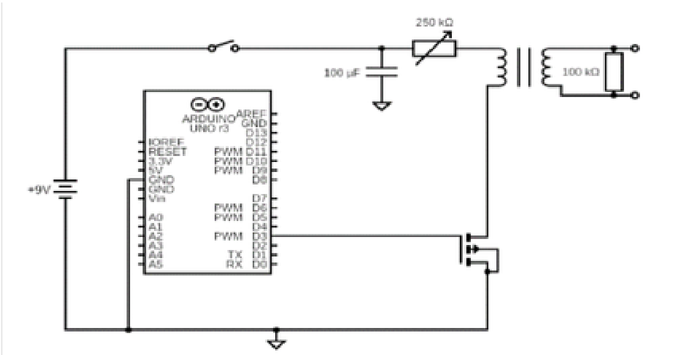


fig 3.1 : TENS UNIT using Arduino

Initial Approach Using Arduino-Based Circuit:

At the outset, we explored using an Arduino Uno to build the TENS unit circuit, leveraging its PWM capabilities to generate the necessary stimulation signals. The goal was to control the signal output efficiently while maintaining flexibility for experimentation. However, the results were unsatisfactory for several reasons:

1. Inadequate Signal Control:
2. While the Arduino could produce PWM signals, achieving the precise voltage and current levels required for effective muscle stimulation was challenging without extensive signal conditioning.
3. Noise and Stability Issues:
4. Environmental noise interfered with the smooth operation of the circuit. The lack of proper filtering and shielding led to unstable signal outputs.
5. Insufficient Output Power:
6. The circuit struggled to produce the desired stimulation intensity due to limitations in the voltage levels achievable with the onboard components.

Drawbacks of the Arduino-Based Circuit for TENS Units

- Complex Signal Processing Requirements:
- Additional components like op-amps and filters were required to condition the PWM signal, complicating the circuit design.
- Power Inefficiency:
- The need to step up voltage and stabilize the current resulted in higher power consumption.
- Limited Practicality:
- While the circuit worked in principle, the output was inconsistent and inadequate for effective transcutaneous stimulation.

This approach demonstrated the need for simpler, more direct methods of achieving the desired output, leading to further exploration and refinement in the design process.

NEXT ATTEMPT: CIRCUIT USING 555 TIMERS, MOSFETS, AND TRANSFORMERS

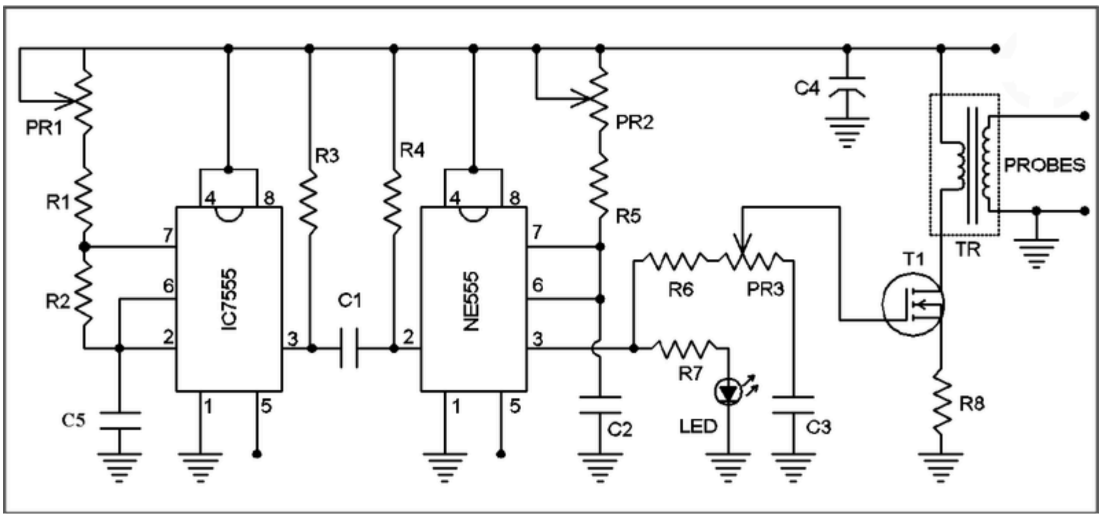


fig 3.2 : TENS UNIT using 555 timer

In the next iteration, we implemented a circuit utilizing two 555 timer ICs (IC7555 and NE555), a MOSFET (T1), and a transformer (TR) to generate the desired TENS output signal. The design focused on producing precise timing pulses and amplifying them for transcutaneous electrical stimulation. While the circuit performed well during simulations in LT spice, practical implementation faced significant challenges:

Challenges Encountered:

1. Distorted Output Signal: The final signal at the NMOS output was distorted and failed to match the desired waveform characteristics for effective TENS application.
2. Simulation vs. Practical Discrepancies: While the circuit yielded acceptable results in LT spice simulations, practical testing revealed inconsistencies. This highlighted potential issues with component tolerances or unexpected interactions in the physical setup.
3. MOSFET Operation Instability: The MOSFET exhibited instability in switching, possibly due to improper gate drive or noise interference, further distorting the output.
4. Transformer Behavior: Due to unavailability of transformer and also due to distorted output at NMOS itself, the output was taken directly from the second timer.

This attempt underscored the importance of refining the final stages of the circuit, particularly focusing on the MOSFET's switching behavior and transformer coupling, to achieve a clean and effective output signal.

Final Design:
To address the limitations encountered in earlier designs, the final TENS unit circuit was successfully implemented by simplifying the output stage. Instead of relying on transformers, the output was taken directly from Pin 3 of the second 555 timer. This design delivered a stable and effective output voltage, suitable for therapeutic use in mild pain relief and muscle relaxation.

Circuit Description:

1. Dual 555 Timer Configuration: The circuit used two 555 timer ICs to generate precise timing pulses. The first timer(U1) was able to produce pulses and its frequency could be varied with potentiometer. The second timer(U2) produced varying pulse width to the pulses based on out applications using potentiometer.
2. Direct Output to Electrodes: The output from Pin 3 of U2 was connected directly to electrode patches for delivering the stimulation signal. This design ensured a clean and stable output voltage without requiring additional amplification or transformers.
3. Output Voltage of 20V:The circuit produced an output of approximately 20V, a level found to be effective for mild TENS therapy applications.

Features of the Final Circuit:

1. Simplified Output Design: By eliminating the transformer and MOSFET stages, the circuit reduced complexity and potential signal distortions.
2. Effective Stimulation: The 20V output was sufficient for providing mild therapeutic effects, suitable for relaxation and pain management.
3. Compact and Reliable: The design relied on simple components, ensuring a lightweight and portable device while maintaining reliability.

4. Noise Resistance: The stable operation of the 555 timers and direct output configuration minimized issues caused by noise and external interference.

5. Cost Efficiency: Removing the need for high-power components like transformers overall circuit cost.

This streamlined approach provided a reliable and effective solution for TENS therapy, overcoming the challenges of earlier attempts and delivering practical results in both simulation and real-world testing.

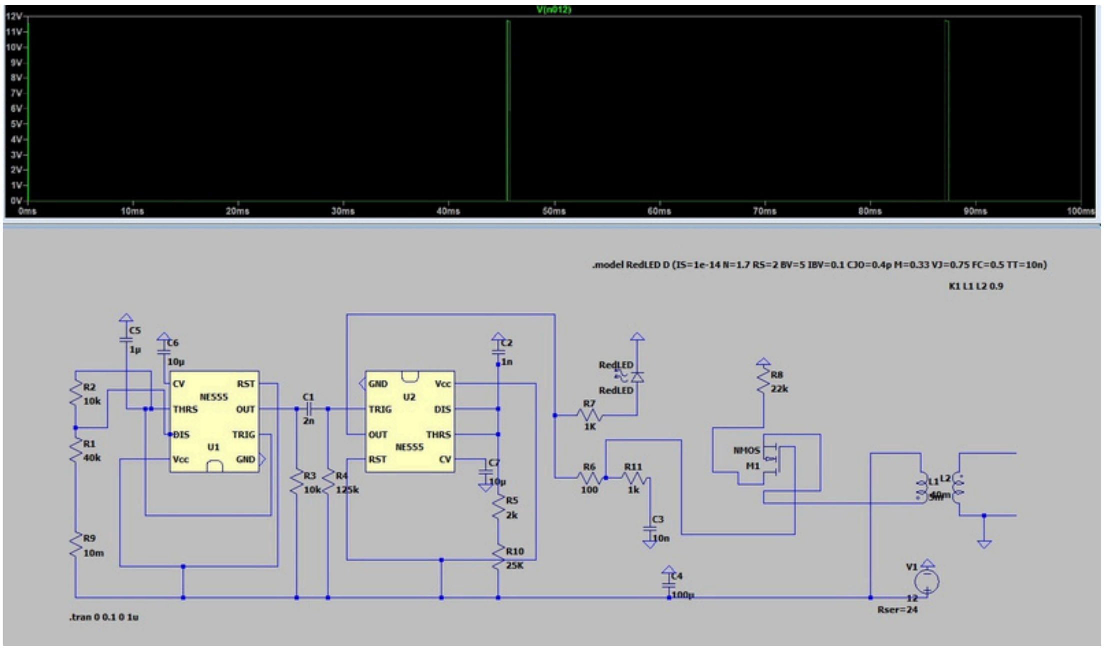


fig 3.3: Circuit with mosfet and transformer: gave results in LT spice but practically output was distorted

COMPONENT LIST FOR TENS CIRCUIT				
S. No.	Component	Component Type	Values	Comments
1.	PR1	Potentiometer	1 MΩ	1.4 Hz – 100 Hz
2.	PR2	Potentiometer	25 kΩ	40 uS – 270 uS
3.	PR3	Potentiometer	5 kΩ	Output Drive
4.	R1	Resistor	10 kΩ	
5.	R2	Resistor	2.2 Ω	
6.	R3	Resistor	10 kΩ	
7.	R4	Resistor	100 kΩ	
8.	R5	Resistor	400 Ω	
9.	R6	Resistor	100 Ω	
10.	R7	Resistor	1 kΩ	
11.	R8	Resistor	22 kΩ	Min. 3 Watt
12.	C1	Capacitor	1 nF	
13.	C2	Capacitor	10 nF	
14.	C3	Capacitor	10 nF	
15.	C4	Capacitor	100 µF, 16V	For Rectifying
16.	C5	Capacitor	1 µF	
17.	7555	IC		
18.	NE555	IC		
19.	T1	MOSFET	IRF9640	
20.	LED	Red LED		Indicator
21.	TR	Transformer	8 Ω (impedance)	Audio Trans.
22.	IN1	Input System	12VDC, 500mA	

fig 3.4: Components list

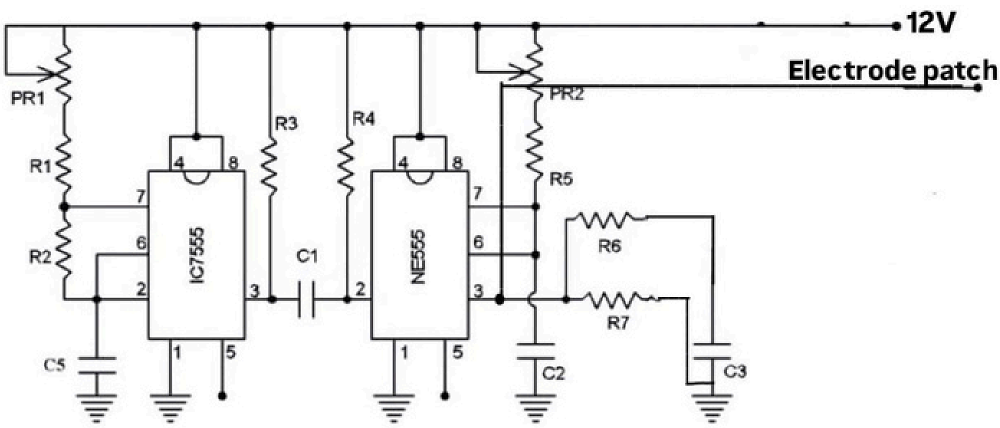


fig 3.5: Final circuit

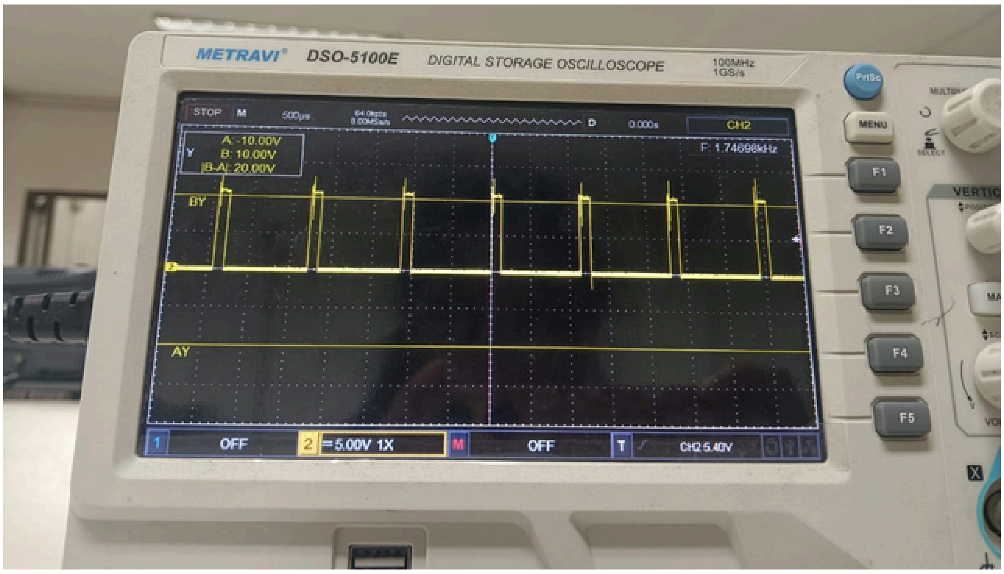


fig 3.5: Final waveform obtained

Chapter 4

RESULTS OBTAINED

After implementing the final circuit design for the TENS unit using NE555 timers and passive components like resistors and capacitors, the following results were achieved:

1. Pulse Generation for Nerve Stimulation
   - The NE555 timer successfully generated electrical pulses with an output voltage of **20V**, meeting the requirements for effective nerve stimulation.
   - The frequency of the pulses was adjustable within the range of **50 Hz to 120 Hz**, providing flexibility for various therapeutic applications.
2. Signal Conditioning
   - Capacitors and resistors were used to stabilize and shape the output signal, ensuring smooth and consistent pulses delivered to the electrode patches.
3. Ease of Use
   - The simple design ensured the device was easy to operate and maintain.
   - Compact electrode patches provided consistent and comfortable skin contact during therapy sessions.
4. Practical Applications
   - The device effectively delivered low-frequency electrical pulses for pain relief and muscle stimulation, aligning with its intended therapeutic use.
   - It showed potential for use in physiotherapy and rehabilitation settings, particularly for individuals dealing with chronic pain or muscle recovery.

These results confirmed the functionality and practicality of the TENS unit, successfully achieving the project objectives.

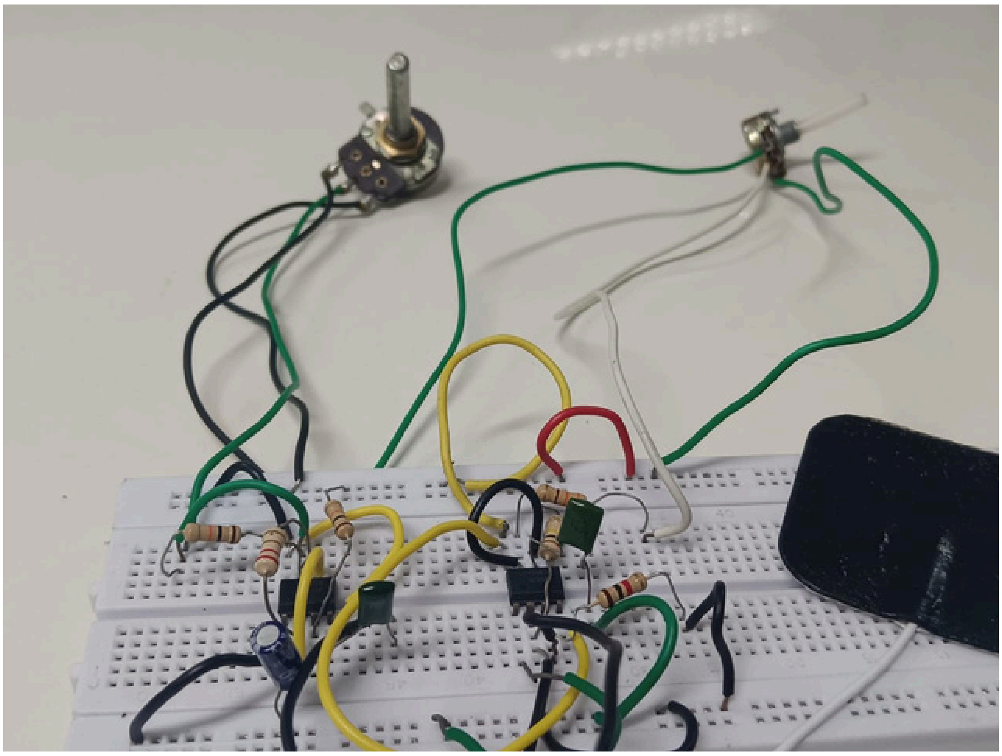


fig 4.1 : Tens unit with 555 timers, potentiometers, capacitors, resistors and electrode patches

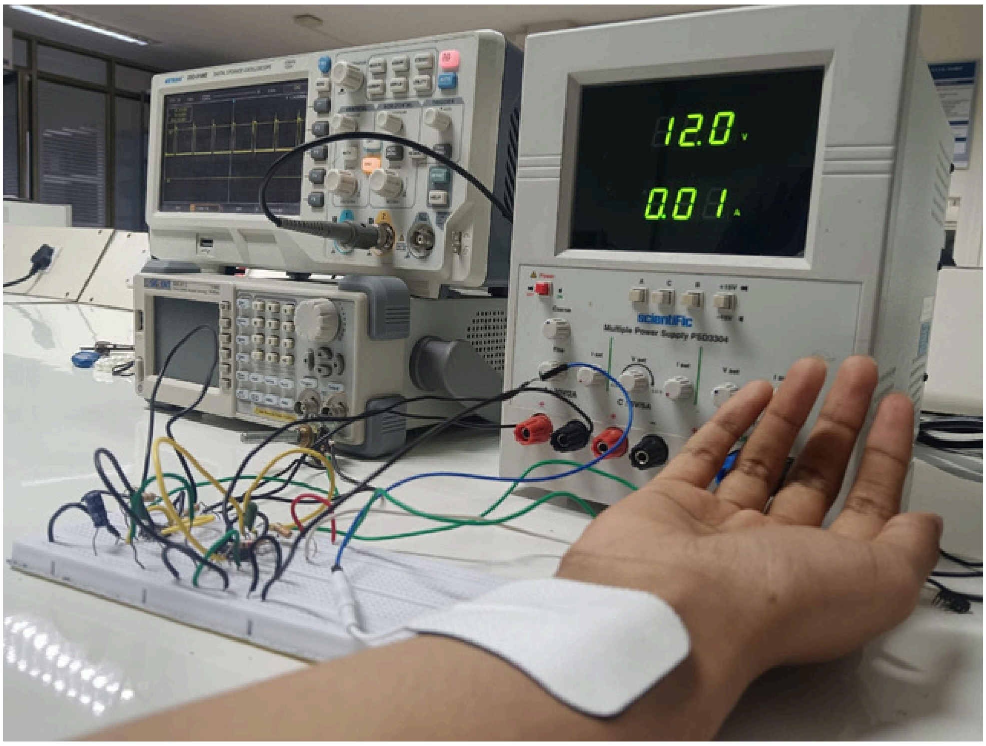


fig 4.1 : The circuit successfully relives mild pain when tested on users

Chapter 5

CONCLUSION

In conclusion, the TENS (Transcutaneous Electrical Nerve Stimulation) unit project successfully utilized NE555 timers and passive components to generate adjustable low-frequency electrical pulses for therapeutic use. The device demonstrated reliable performance, delivering an output voltage of 20V with a frequency range of 50 Hz to 120 Hz, meeting the requirements for nerve stimulation and pain relief applications. The simplicity of the design ensured ease of use, compactness, and low power consumption. This project has shown potential for further development, including advanced control features, portability enhancements, and broader therapeutic applications.

Chapter 6

FUTURE SCOPE

The TENS (Transcutaneous Electrical Nerve Stimulation) unit has significant potential for further development and enhancement in various aspects. Below are some areas where the project can evolve:

1. Portability and Power Efficiency
   - Develop a more compact design by using surface-mount components and energy-efficient circuitry.
   - Incorporate rechargeable lithium-ion batteries to make the device lightweight and suitable for portable use.
   - Explore the use of renewable energy sources like solar charging for remote or outdoor applications.
2. Therapeutic Advancements
   - Expand the range of frequencies and pulse patterns to target a wider variety of conditions, such as chronic pain, arthritis, or post-operative recovery.
   - Conduct clinical trials to validate the effectiveness of different settings for specific medical conditions.
3. Smart Integration
   - Enable Bluetooth or Wi-Fi connectivity to pair the device with a smartphone app for remote control and data logging.
   - Use AI algorithms within the app to recommend personalized therapy settings based on user data and feedback.
   - Incorporate biofeedback sensors to monitor the user's muscle activity or skin resistance and adjust the therapy accordingly.
4. Commercial and Medical Applications
   - Refine the design for commercial production with ergonomic features and user-friendly controls.
   - Collaborate with healthcare professionals to meet medical standards and certifications, making it suitable for widespread use in clinics and hospitals.
   - Explore insurance coverage for the device to increase accessibility for patients.

Chapter 7

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