TENS device for cervical pain during teleworking controlled remotely by mobile application

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ABSTRACT

Monitoring cervical muscle pain during teleworking, exacerbated by the COVID-19 pandemic and increased remote work, highlights electrotherapy as a crucial physical therapy tool to mitigate muscle pain and promote tissue recovery, addressing ergonomic and occupational health problems that affect the well-being of remote workers. The research proposes to design a transcutaneous electrical nerve stimulation (TENS) device to monitor cervical muscle pain during teleworking, addressing the urgent need for technological solutions to mitigate this problem and improve the quality of life of teleworkers through data acquisition and processing, hardware development, implementation device monitoring, and evaluation software. For this, a TENS device was designed with a graphical interface to treat muscle pain in the neck of teachers who do remote work, dividing it into four stages: signal acquisition and generation, Bluetooth communication with an Android device, signal conditioning, and amplification and protection, following a development scheme that includes circuit design in Proteus and the creation of a mobile application in App Inventor. In conclusion, it was obtained that the power supplies have an average error of less than 1%, indicating good general performance and confirming the consistency and optimal performance of the proposed therapies.

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1. INTRODUCTION

Currently, cervical muscle pain monitoring during teleworking arises in response to the health challenges derived and amplified by the COVID-19 pandemic and the growing adoption of remote work. In this context, electrotherapy stands out as a crucial tool of physiotherapy, used to mitigate muscle pain and promote the recovery of damaged tissues through the application of electrical currents [1], [2]. This approach seeks to relieve pain, inflammation, and prevent chronic muscle conditions associated with a sedentary lifestyle in remote work environments [3], [4].

During 2020, the COVID-19 pandemic significantly increased the demand for teleworking, becoming the preferred option for companies in Latin America, the Caribbean and other parts of the world [5], [6]. This increase brought advantages of flexibility and time optimization, but also technological problems and difficulties and work stress [7], [8]. Occupational risks have been demonstrated due to poor ergonomics, affecting the musculoskeletal and visual levels due to difficult working conditions and the appearance of musculoskeletal disorders (MSDs) [9], [10]. In this context, the International Labor Organization (ILO) specifies that work-related stress was the biggest work-related health problem in countries like the United Kingdom, accounting for 50% of all work-related illnesses [11], [12], while the World Health Organization (WHO) estimates that the frequency of these disorders in the population ranges between 13.5% and 47%, with the main risk factors being sustained, static, uncomfortable, prolonged postures, and repetitive movements with high frequency [13], [14]. Cervical pain has a prevalence between 30% and 90%, where soft tissue problems and low back pain are identified [15]-[18]. Furthermore, in some Latin American countries, it is described that sitting for a long time and using the computer for a long time mainly affects the muscles of the neck, back and shoulders due to inappropriate postures [19], [20]. Finally, the use of non-invasive electrical stimulation using a transcutaneous electrical nerve stimulation (TENS) device would be favorable to monitor neck muscle pain and facilitate rehabilitation [21], [22]. In the review of the literature, it was found that the dependence on imported technologies in some countries for electrical stimulation and a solution is proposed based on a prototype of a TENS and electrical muscle stimulation (EMS) [23], [24]. On the other hand, some works investigate the design of electrostimulation devices for therapeutic purposes, focusing on their adaptation for various patients, using an H-bridge as a generator and a buck [9], [25], [26].

Electrostimulation devices are deployed in real environments, for workers in medical companies and reduction of work stress [27] or use in personnel in hospitals and clinics using devices that control current intensity and a oriented frequency counter [28]. Additionally, among the applications of this technology is the development of an affordable muscle electro stimulator for rural populations [29] and a non-invasive solution to reduce adipose tissue in overweight people [30]. The specific objectives focus on: data acquisition and processing, hardware development, monitoring software implementation, and device evaluation. The components of the proposed solution are: i) acquisition; ii) transmission; iii) conditioning; and iv) amplification and protection stage. It is for this reason that the research justifies its importance by addressing the urgent need for technological solutions to mitigate cervical pain caused by teleworking, while its value lies in offering an accessible device that improves the quality of life of teleworkers.

2. METHOD

A TENS device with a graphical interface is designed to treat muscle pain in the neck of teachers who telework. The device has been divided into four stages: signal acquisition and generation; the stage of communication via Bluetooth with an Android device. Signal conditioning uses operational amplifiers to create biphasic waves from a microcontroller output. Finally, in the amplification and protection stage, a push-pull circuit in Darlington configuration is used to supply 150 mA of current. The development of the project follows a diagram of steps that includes the definition of each stage, the design of circuits in Proteus and the creation of the mobile application (Figure 1).

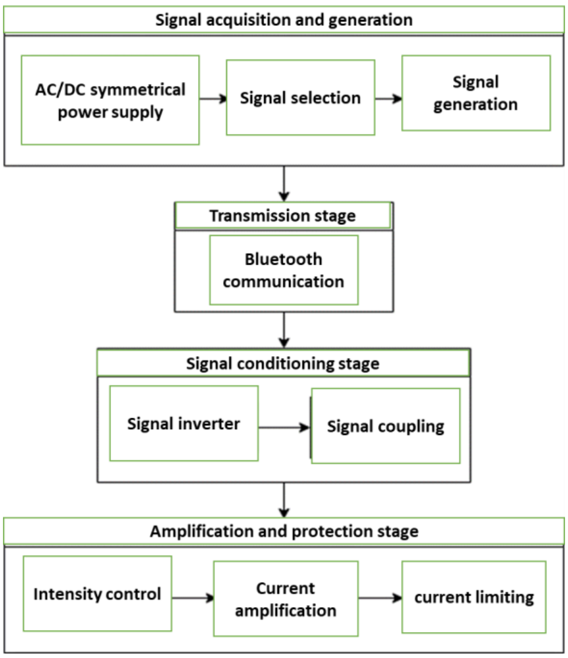


Figure 1. General diagram of TENS device design

2.1. Acquisition and signal generation stage

This section discusses the acquisition and generation of electrical signals for TENS. Figure 2 illustrates the procedure that ensures the accuracy and safety of signals in the treatment of various conditions using TENS stimulation. Given the context of the project, which focuses on monitoring cervical muscle pain during teleworking exacerbated by the COVID-19 pandemic and the increase in remote work.

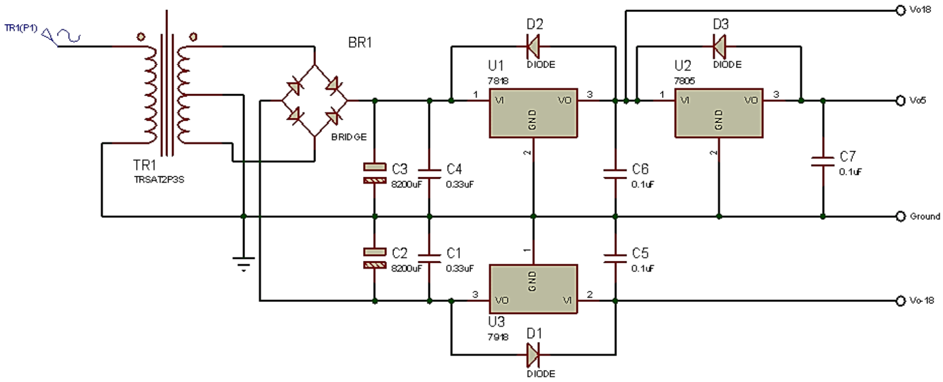


Figure 2. Symmetrical power supply

2.1.1. Design and implementation of a symmetrical AC/DC power supply

In this stage, the alternating current is converted into direct current to have voltage availability for the operation of the TENS therapy. To achieve this, a transformer is used along with rectifier diodes and voltage regulators, accompanied by capacitors, with the aim of having a stable power supply (Figure 2). After having the voltage rectified and filtered, it is applied to a 7,918 voltage regulator, generating a rectified value that ranges between 17.3 Vdc and 18.7 Vdc.

2.1.2. Signal selection

The process involved in choosing stimulation patterns in TENS therapy is illustrated by a flow chart showing the operation of the software, along with the use of three buttons: "ENTER", "botomas", and "botomenos". These controls allow for customizing therapy, allowing users to select and adjust stimulation parameters to their needs (Figure 3). The signals used in TENS treatment are produced for alternating bipolar and Burst type therapy. In the first case, conventional TENS therapy and PG pain reduction are considered using a pulse width of 80 and 500 usage respectively. In the case of the burst current, deconstructing therapy is considered with a pulse width of three ms and frequency of 3 Hz (Table 1).

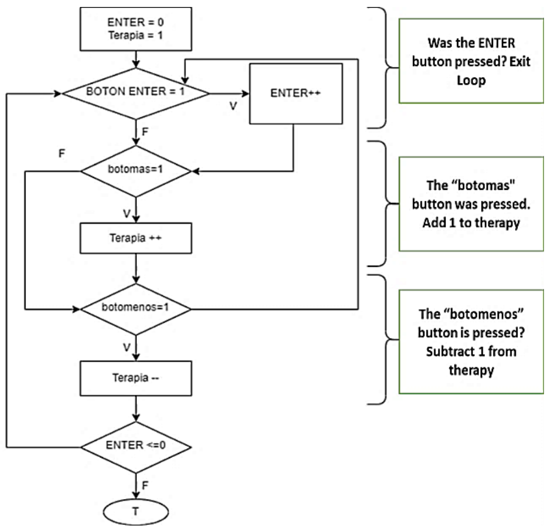


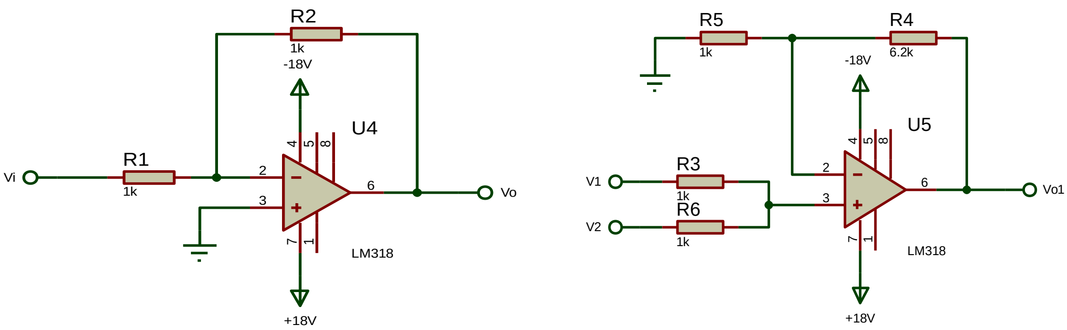
Figure 3. Diagram of the therapy choice menu

Table 1. Summary of therapies

No	Therapy	Theoretical pulse width	Freq. (Hz) theoretical	Npulse
1	Conventional TENS	80.0 μs	100.0	1
2	PG pain reduction (TNS NML)	500.0 μs	10.0	1
3	Decontracting	3.0 ms	3.0	35

2.2. Design of the signal conditioning stage

This stage is responsible for preparing and processing the electrical signals before their transmission and application through an inverter circuit and then a signal coupling stage uses the LM318 as its main component (Figure 4). One of the signals previously generated by the ATmega328P microcontroller is inverted, guaranteeing that the inverter circuit has a gain equal to 1, considering that the voltage output of the microcontroller are pulses that vary between 5 Vdc and 0 Vdc (Figure 4(a)). For signal coupling, the two signals are combined in parallel, which come from the PB0 output of the ATmega328P microcontroller and the inverter stage, using the LM318N operational amplifier (Figure 4(b)).

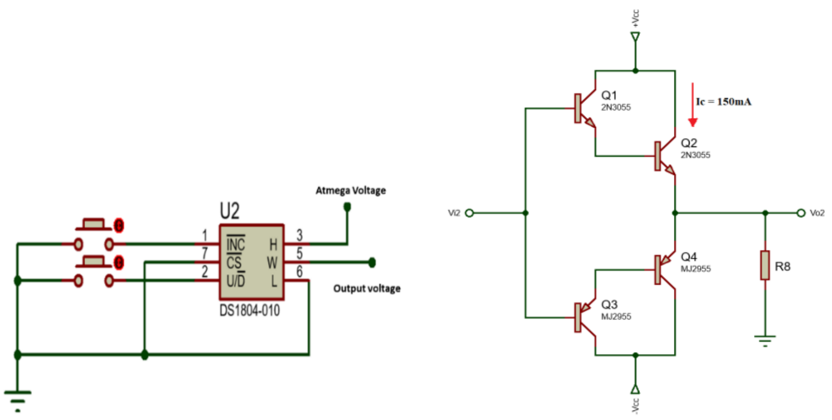


(a) (b)

Figure 4. Circuits of (a) the inverter stage and (b) coupling stage

2.3. Design of the amplification and protection stage

In Figure 5 adequate delivery of signals and assurance to patients is guaranteed through a stage that focuses on the control of intensity, amplification, and limitation of current. To carry out the intensity control, a DS1804 integrated circuit is used that controls the resistivity of the circuit, connected to the ATmega328PU microcontroller to modulate the waveform used in TENS therapies. Pins 1 and 2 are used to vary the resistivity in the circuit, pin three is connected to the Atmega328P generating the therapy waveform and port 5 is generating the regulated signal (Figure 5(a)). In the case of amplification, a class B amplifier is designed and is composed of the 2N3055 (NPN) and MJ2955 (PNP) transistors (Figure 5(b)). For current limitation, the use of the LM317 voltage regulator is considered, which restricts the output current to 150 mA.

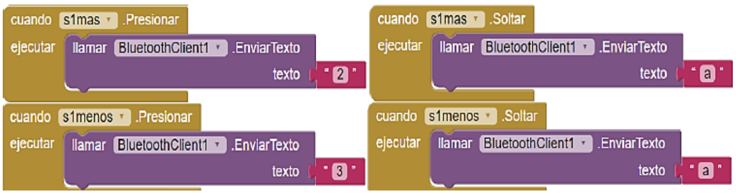


(a) (b)

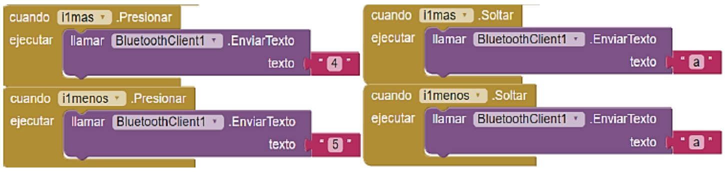
Figure 5. Signal adaptation through (a) a regulatory stage and (b) the signal amplification stage

2.4. Transmission stage design

The transmission of electrical signals for TENS treatment is controlled through a mobile application using Bluetooth communication. Figure 6 shows the programming blocks and commands that are sent to the Atmega328P controller. When the therapy signal is bipolar type, “s1mas” is selected, and a text numbering “2” is sent, obtaining a text response “a”. In the case of a burst type signal, “s1minus” is selected, sending a text numbering “3” and whose operation is verified with a text response equal to the previous one (Figure 6(a)). To control the intensity levels, “i1mas” and “i1menos” are used. The process is like therapy selection, which increases the intensity of the therapy by selecting ‘+’ on the screen and decreases it by selecting ‘–’ (Figure 6(b)). The activities to be conducted are based on the following functions: drop-down menu initialization, start of therapy, therapy selection, and intensity level control.



(a)



(b)

Figure 6. Programming blocks for (a) therapy selection and (b) intensity level control

3. RESULTS AND DISCUSSION

3.1. Analysis of the signal acquisition and generation stage

In the case of the power supply, the theoretical results are compared with those obtained in simulations and experiments. Simulations are performed in Proteus, while actual measurements are performed on all voltage outputs over eleven tests over time (one for every 2 minutes). It is important to highlight the establishment of a maximum allowed error of ±2% for the tests, observing the specific case of the 5 V output in Table 2. The results obtained demonstrate remarkable consistency between simulations and real measurements, validating the precision and stability of the power supply design, important for the operation of the TENS device.

Table 2. Results of the theoretical 5 V source vs simulated vs obtained values

Time (min)	0	2	4	6	8	10	12	14	16	18	20
Theoric value	5	5	5	5	5	5	5	5	5	5	5
Simulated circuit	5	5	5	5	5	5	5	5	5	5	5
Implemented circuit	4.98	4.99	4.98	4.98	4.97	4.99	4.97	4.99	4.98	4.97	4.99

In the case of the 5 V output, a maximum error of 0.6% is obtained in the experimental measurements, which does not impact the circuit, since the microcontroller operates within a safe range of 3.3 V to 5.5 V. Figure 7 shows the asymmetric power supply, highlighting the diodes and capacitors mentioned in the development section, along with the voltage regulators and the diode bridge, as specified and their measurement carried out with the DT830B digital multimeter. During these tests (Table 3) it was observed that the value measured for the frequencies does not exceed the maximum established error range of ±5% for frequencies less than 50 Hz and ±1% for frequencies greater than 49 Hz.

3.2. Analysis of the signal conditioning stage

In this stage, inversion, signal coupling and amplification are evaluated up to a maximum of ±18 V. To do this, you have an oscilloscope with a maximum gain of 6 V and a x10 probe is used to obtain values higher than 6 V. Samples were taken that demonstrated an absolute error of ±5%, equivalent to 1.5 V. Figure 8 shows a positive voltage for the case of the voltage of 18.0 V and a negative voltage of -17.8 V, where both are within the margin of error established for the test.

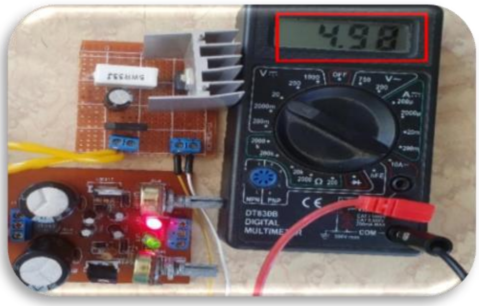


Figure 7. Voltage measured in the 5 V experimental stage

Table 3. Absolute frequency error

No	Therapy	Theoretical value (Hz)	Obtained value (Hz)	Absolute error (%)
1	Conventional TENS	100	100	0.00
2	PG pain reduction (TNS NML)	10.0	10.0	0.00
3	Decontracting	3.0	3.0	0.00

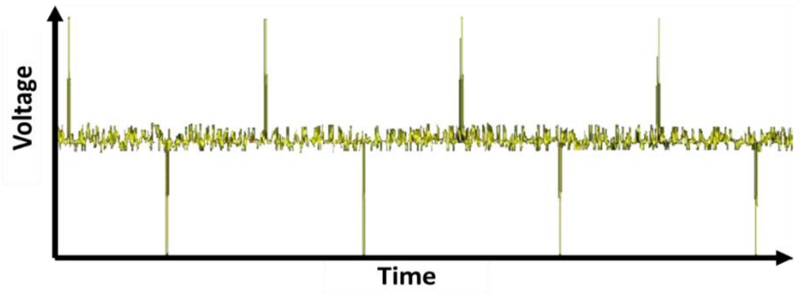


Figure 8. Result of the coupling and amplifier substage for the negative signal

3.3. Analysis of the amplification and protection stage

In the case of the intensity control substage, more than 95 distinct levels are identified, generated by each button press or by each pulse injected into the increment pin (inc). It is obtained that the voltage measured at 0 volts is related to zero pulses while at the level of 4.98 volts there are 95 pulses. Similarly, for 18.1 volts there are 95 pulses considering the limited signal after amplification with the digital potentiometer. On the other hand, to evaluate the current limiting substage, a test circuit is created with a power supply of ±15 V at 2 A in direct current and limit the current output to a maximum of 150 mA. Currents limited to 147.6 mA are obtained (Figure 9), whose value is close to the maximum established value of 150 mA, with a relative error of 2.4 mA. This minimal discrepancy highlights the precision of the circuit design, suggesting that the implemented current limiting is effective and reliable in protecting the device components and ensuring user safety.

3.4. Analysis of the transmission stage

In this phase, the intensity of the signal transmitted by the HC-05 Bluetooth device is evaluated to determine the maximum distance in meters and define the device's operating restriction. For this, software is used to determine signal power. During these tests, both the sending and receiving equipment were in direct line of sight, which means that there should be no objects such as walls or windows that could affect communication between them. It was determined that the signal intensity is -33 dBm at 0 meters, indicating that this is the best signal with which the equipment operates. Furthermore, at 10 meters, the signal strength is no longer optimal for data transmission, and it is recommended that the equipment operator does not exceed the recommended distance of 8 meters (Figure 10).

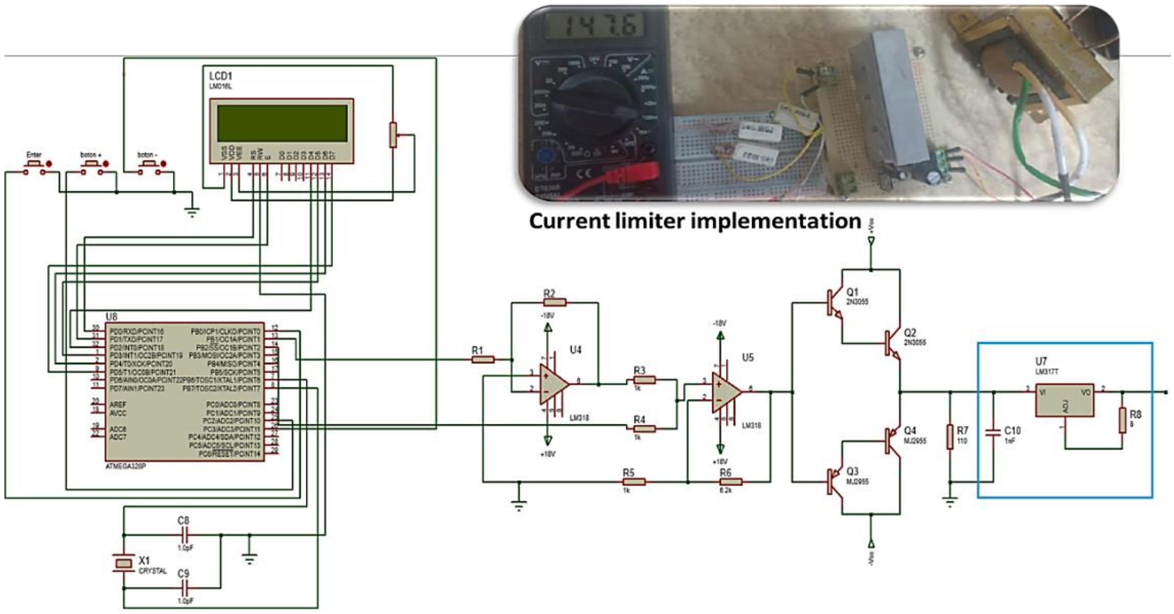


Figure 9. Current limiting substage

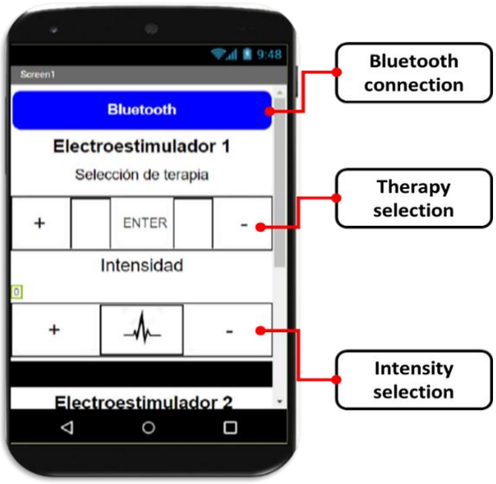


Figure 10. Control interface in mobile application

4. CONCLUSION

It was determined that the 5 V, 18 V, and -18 V sources have an average error of 0.38% for the 5 V source, with a maximum of 0.6%. The 18 V supply showed an average error of 0.36%, with a maximum of 0.5%, while the -18 V supply presented an average error of 0.12% with a maximum of 0.16%, indicating good overall performance of the supplies, ensuring that variations do not compromise the integrity of the system and supporting the viability of the proposed design. In relation to the pulse width and frequency with the oscilloscope, the consistency and optimal performance of the three proposed therapies is confirmed, which is supported by the graphs that show the effectiveness of the system in the emission of pulses and generation of frequencies necessary for the treatment.

The signal conditioning stage contributes to the attenuation of the absolute error, which is related to the quality of the rectified positive signal with voltages close to 5 V and an adequate negative signal, both with a percentage error less than 8%, while the circuit gain resulted in 1.076. Regarding the signal coupler substage, oscilloscope tests with a multiplier probe showed absolute errors of less than 2% for positive and negative voltages of ±18 V, which validate the proper configuration of the circuit. In addition, it is recommended to adjust the resistor value to achieve a higher gain and reduce the percentage error up to 5%, providing voltage levels closer to the theoretical ones. Intensity control in the therapy was achieved with the digital potentiometer, allowing up to 95 distinct levels of pulsations to be generated and adjusting positive or negative voltages as necessary. The reliability of the current limiting circuit was successfully validated in 10 tests, showing a percentage error not exceeding 2% and a maximum limiting current of 147.8 mA.

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