Pulsed Electromagnetic Gas Stimulator: Design and Suggestions for Rapid Prototyping

ILIAS CHRYSOCHERIS, MARIOS KOLANIS, EVANGELOS C. PAPAKITSOS,
CHRISTOS DROSOS, ELENI SYMEONAKI, NIKOLAOS LASKARIS
Department of Industrial Design and Production Engineering, School of Engineering,
University of West Attica,
12241 Athens,
GREECE

Abstract: - This paper discusses the development of a pulsed stimulation system designed to interact with specific sections of gas molecules within a chamber made of insulating material. The primary aim is to design a suitable chamber that can contain the gas under stimulation and to develop an electronic pulse generator capable of delivering appropriate voltage pulses to the chamber's electrodes to interact with the gas. Various chamber designs are explored, highlighting their advantages and limitations. From the perspective of pulse generation, the objective is to create a simple, yet effective, generator to meet the system's requirements. The proposed design employs an ATMEL™ ATMega328P microcontroller, for its ease of use and programming, which are features well-suited for rapid prototyping.

Key-Words: - Gas stimulation, pulsed electric field, pulse generator, stimulation chamber, high voltage pulses, rapid prototyping.

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1 Introduction

In recent years, our planet has been experiencing increasingly severe environmental phenomena. Human activity across various sectors has contributed to a climate crisis previously unforeseen. Sudden, extreme weather changes now have a significant impact on our daily lives.

A substantial body of research is focused on addressing this issue, aiming to mitigate the effects of climate change and restore environmental balance. Ongoing studies span a wide range of fields, including energy [1], [2], environmental science, transportation, and food processing, [3].

In many of these areas, physics and chemical research play a crucial role, as in [4] a way is investigated to split CO_2 to C and O_2 at room temperature, using surfaces of inorganic electride $[Ca_{24}Al_{28}O_{64}]^{4+}(e^{-})_4$. Other studies aim to activate the CO_2 molecules using UV laser beams targeting bond braking to produce C and O_2 (photodissociation, [5]).

A broad body of research on pulsed electromagnetic fields focuses on biological tissues. The researchers in [6] examined the role of pulsed electromagnetic fields in enhancing the differentiation of mesenchymal stem cells into bone and cartilage tissues. Similarly, an overview has been provided in [7] of how pulsed electromagnetic fields influence tissues by generating molecular forces and modulating signaling pathways, while the researchers in [8] investigated the influence of pulsed electromagnetic field stimulation on muscle activity during cycling exercises.

Ongoing research explores the concept of stimulating gas bonds using electromagnetic fields. The aim is to supply the necessary energy to break these bonds, leading to the decomposition of molecules, such as the decomposition of CO_2 into C and O_2. To explore new solutions and technologies, such as gas stimulation using a pulsed electric field, specialized tools are essential. In particular, studying gas properties under pulsed electric fields requires a properly designed stimulation chamber powered by a high-voltage pulse generator. This setup enables researchers to investigate the behavior of gases under controlled conditions, contributing to environmental research and innovation.

The current study contributes to the field of gas stimulation research by focusing on the rapid prototyping of a pulsed high-voltage generator and its integration with a specialized stimulation chamber. While previous studies have explored the decomposition of gas molecules under electromagnetic fields, as well as the application of pulsed electric fields for activating molecular bonds, this work advances the tools required for such investigations. By leveraging a microcontroller-based design and modular construction, the developed system provides a versatile platform for controlled and customizable pulsing of electric fields, enabling the researchers to investigate gas properties under precise and reproducible conditions. This contribution not only facilitates future studies in gas stimulation but also supports broader applications in environmental research and innovation, particularly in the context of developing sustainable technologies for molecular decomposition.

2 Pulsed Electromagnetic Field Usage

Pulsing electric fields are used in many ways. Numerous projects aim to affect fluid or gaseous substances, such as water, as studied by [9], [10], [11], [12], [13], [14], [15] and [16]. All of them aim to dissolve water molecules to produce hydrogen and oxygen. The products of their processes can be used as fuel (in most cases) by driving high-voltage pulses into various devices that hold the water. Puharich uses a thermodynamic device (as he calls it) where current pulses pass through water to dissolve its molecules, similar to simple electrolysis, but using a pulsed system instead, [13].

Meyer develops a water capacitor, [14]. The water, subjected to a pulsed electromagnetic field, enters a container that forms a tubular capacitor. This capacitor is formed by the electrodes of the container, one at its center and another around its outer radius. By applying high-voltage pulses to the capacitor's electrodes, the water molecules in the container begin to resonate until their bonds break. The capacitor forms part of the resonating circuit.

Eccles created a fracture cell [9], where two pairs of electrodes are used to pulse the water subject to high voltage.

To stimulate a gaseous subject, there must be an appropriate chamber that encloses the gas under stimulation, and a way to apply an electric field to it. The ability to alter field strength, pulse frequency, bursting, and other related factors is crucial to study in depth the phenomena that occur on different gaseous subjects. Some electrodes placed around the chamber are those that, when high-voltage is applied, produce the required electric field. Since the voltage is high, appropriate measures must be taken to prevent corona arcs, especially during changes in field polarity.

3 Pulse Stimulator Design

The main goal is to design and manufacture a pulse generator with the following characteristics:

- Two pulsed outputs that produce pulses complementary to each other.
- Controllable frequency, duration, and dead time between the two outputs.
- An option to produce bursts of pulses with a variable number of pulses and variable duration between consecutive bursts.
- An output voltage of up to 1KV, with adjustable output voltage being desirable.
- The system can be attached to a single or double-electrode chamber to apply the generated pulsed electric field to the gas subject.

3.1 Stimulating Chamber

In order to stimulate a gas under an electromagnetic field, we have to use a chamber with proper specifications. The chamber must be a water-tight enclosure, possibly open at its upper end to allow the products of the stimulation to escape, and/or have a gas input pipe at the bottom to refill the chamber with new gas. Depending on the type of stimulation needed, there can be chambers with the following features:

- One pair of parallel electrodes. In this configuration, a pulsed voltage is applied directly to the electrodes, producing an electric field that stimulates the gas under test. The pulsed voltage can be either direct current (DC) or alternating current (AC). The generator requires only one output to drive the electrodes.
- Two parallel pairs of electrodes. The first pair is used to create an electric field in one direction, while the second pair is used to create an electric field in the opposite direction to the first. To create an alternating electric field through the gas being stimulated, only one pair of electrodes is driven by voltage at a time. The gas resides in the common area between each pair of electrodes.

The type of electrode system needed forces the shape and size of the chamber. Figure 1 and Figure 2 present various types of stimulating chambers.

In Figure 1 a circular chamber utilizing one pair of electrodes is shown. Although the chamber is depicted as open, it can be fitted with a cap to enclose the gas being stimulated, if needed. The problem with using this kind of chamber is that it is impossible to visually observe the subject.

Additionally, high voltage A.C. can produce large currents in the driving circuit due to capacitance inherent to the chamber design.

Fig. 1: An example of a circular chamber featuring one pair of electrodes

In order to avoid the issue of visually observing the gas under stimulation, a chamber like the one shown in Figure 2 could be used. By utilizing one pair of electrodes on the presented device, we can achieve similar results to those of the circular one.

In this figure, a section cut of the chamber is presented for a better representation of the electrodes' placement. Two pairs of electrodes are utilized to overcome the problem of high discharging currents during high-voltage pulsing. By using two pairs of electrodes, one pair is pulsed when there is a need to produce an electric field in one direction, and the second pair is pulsed when there is a need to produce an electric field in the opposite direction. The two pairs are pulsed one after the other, with a dead time in between, to avoid corona discharge phenomena. In Figure 3 the produced pulses that drive the two high-voltage switches are shown. Each channel drives one pair of electrodes.

For the experiments conducted, all stimulating chambers were designed using a parametric 3D application (FreeCAD) and 3D printed. This approach allows for various sizes, materials, and chamber properties to enable more in-depth experimentation.

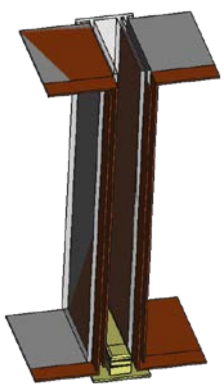

Fig. 1: A sectional cut of an orthogonal-shaped chamber using two pairs of electrodes

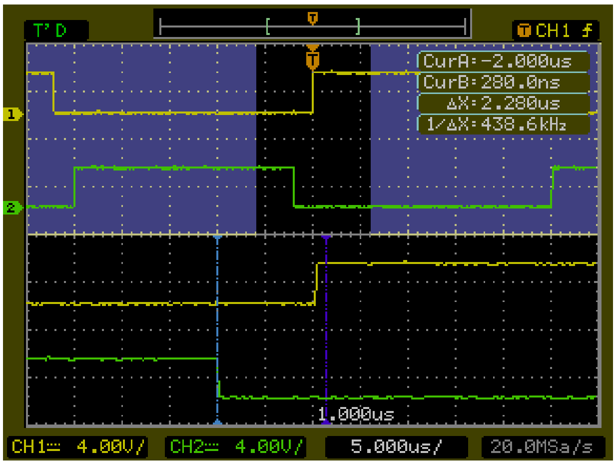

Fig. 2: Two pairs of electrodes being driven, with a focus on the dead time between pulses [1]

3.2 Pulse Generator Design

The pulse generator can take various forms. The idea is to pulse a high-voltage signal to power the chamber's electrodes. The proposed design is based on an ATMEL™ ATMega328P microcontroller, now produced by MicroChip™. The microcontroller controls one or two inverters and high-voltage switches at the required frequency and duty cycle, managing the dead time between the two channels, if a second one is used. For a chamber with a single pair of electrodes, only one high-voltage inverter is needed.

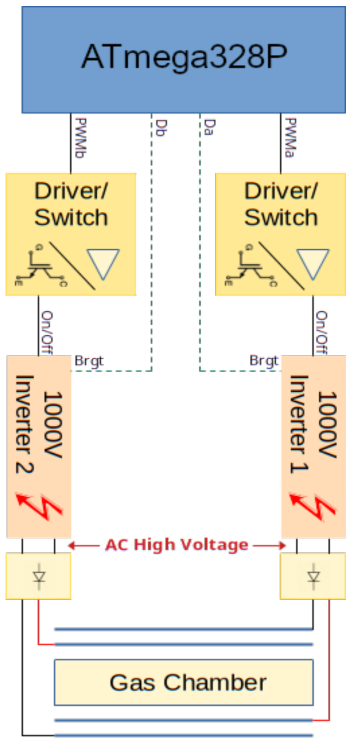

Fig. 4: Generator Block Diagram: Driving the On/Off inputs of the inverters to generate high-voltage pulses, [1]

Two block diagrams describe the two possible modes in which the function generator operates. The first is shown in Figure 4. In this mode, the pulse generator activates and deactivates the two inverters to produce the necessary pulses in the stimulating chamber. The chamber shown in this diagram is depicted as having two pairs of electrodes.

In this mode, the produced frequency is low and depends on the delay required for each inverter to switch on and off after receiving the on/off command. The microcontroller drives the two inverter modules through electronic driver/switches while also controlling their "brightness" input to adjust the output voltage. Each inverter outputs an alternating voltage, requiring a rectifying circuit. The resulting DC voltage is applied at the electrodes of the stimulating chamber. It is crucial to connect the electrodes in a specific configuration, as shown in the diagram.

Another capability of this topology is the ability to control the slew rate of the generated pulses. When a high slew rate is not desirable, the brightness input of the inverter circuits can be adjusted to achieve a slower slew rate.

A second operating mode is possible, and it is shown in Figure 5.

If higher frequency pulsing is required, switching the inverters on and off is insufficient. In this case, the output voltage must already be generated and pulsed to the targeted electrodes. Higher voltages require more demanding circuits. Circuits designed for pulsing high voltages require high-voltage switching devices, such as MOSFETs [17], driven by an appropriate driving circuit (Figure 6).

The same principle can also be implemented using IGBT devices [18]. These devices can be used in high-voltage, high-frequency pulsing circuits, as described by [19]. High-voltage pulsing circuits also require careful design to function optimally, [20].

The switching devices must be connected either in parallel to achieve higher current [21], or in series to control very high voltage pulses, [22]. These two topologies are shown in Figure 7 and Figure 8. Figure 7 illustrates only the portion of the circuit with switching devices connected in parallel, which is used to control the primary side of the high-voltage transformer, rather than the entire diagram of the referenced project.

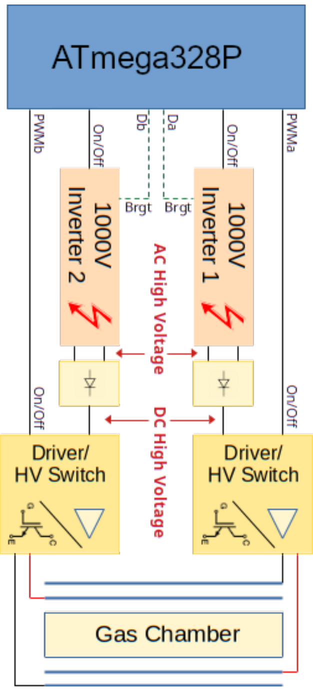

Fig. 3: Generator Block Diagram: Pulsing the inverters' outputs using high-voltage switches to generate pulses, [1]

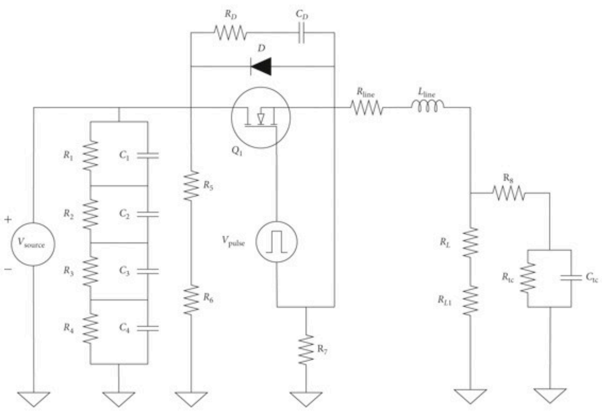

Fig. 4: High-voltage pulsing circuit using MOSFET [17]

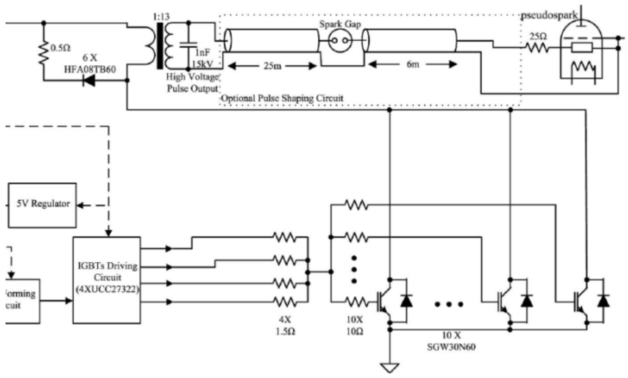

Fig. 5: Switching devices in parallel on the primary side to handle higher current, [21]

To control the parameters of the pulse generator, only a rotary encoder and an OLED display, controlled via an I^2C bus, are needed. A block diagram of the proposed generator's controls is shown next (Figure 9):

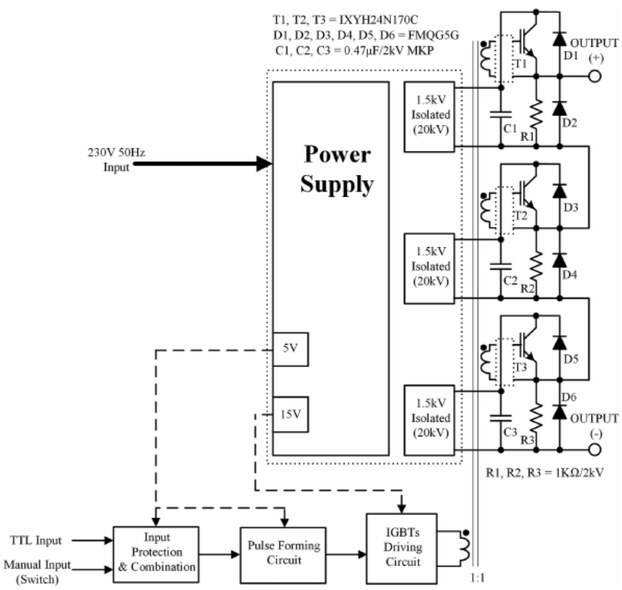

Fig. 6: Series-connected high-voltage switching devices, [23]

The parameters controlled are:

- Frequency: The output frequency of the base pulses. This property can be adjusted according to the gaseous subject under stimulation.
- Dead Time: The time between deactivating the currently activated inverter device and activating the next one. During this period, no output voltage is generated in either pair of plates. This time allows the charges on the formed capacitors to relax and helps prevent corona discharge and sparking. It is also a parameter that can be adjusted to study the movement properties of the gaseous subject.
- Duty Cycle: This parameter depends on Dead Time and Frequency. It is another way to control the dead time described earlier.
- Burst On: The number of pulses to be produced consecutively. The generator can produce a specified number of consecutive pulses, followed by a pause before producing another burst.
- Burst Off: The number of suppressed pulses during the output bursts. If this value is 0, the output is continuous and without bursts.
- On/Off: This parameter allows the generator to either start outputting pulses or remain idle.

The prototype of the proposed generator (excluding the high voltage inverters and OLED screen module) is depicted in Figure 10.

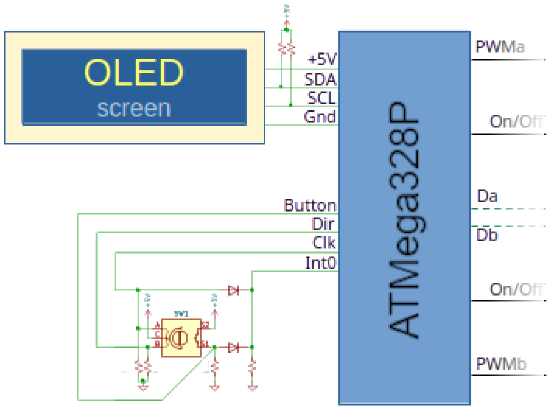

Fig. 7: Block diagram of the control system and display screen

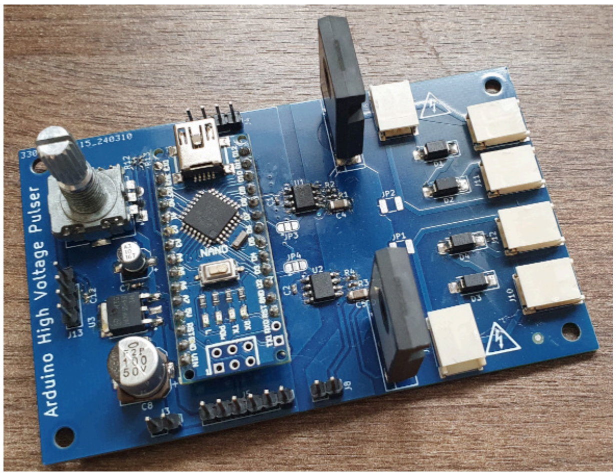

Fig. 10: Proposed generator prototype

3.3 Microcontroller Firmware

ATMega328P is an 8-bit microcontroller offering a wide range of features. Programming the microcontroller is straightforward through various Integrated Development Environments (IDEs) in C/C++, and it also supports AVR assembly and inline intrinsics within the code. This microcontroller gained popularity with the advent of the Arduino™ platform. The platform is open source and is supported by an active community of enthusiasts. Community-built libraries facilitate compatibility with a wide variety of external hardware. Over time, the Arduino platform has grown significantly, supporting many different microcontrollers and making rapid prototyping easy, which aligns with the goals of the proposed generator.

In the case of the described generator, the firmware is explained in parts, as there is a lot of detail required in the critical sections of the code. The remaining sections consist of simple code that needs no further explanation other than a flowchart.

The main code basically consists of two parts: one being the `setup()` (Figure 11) and the other being the `loop()`(Figure 14). The `setup()` function is the entry point of the code. It executes when the microcontroller is powered on. All the initialization is performed in it (Figure 11).

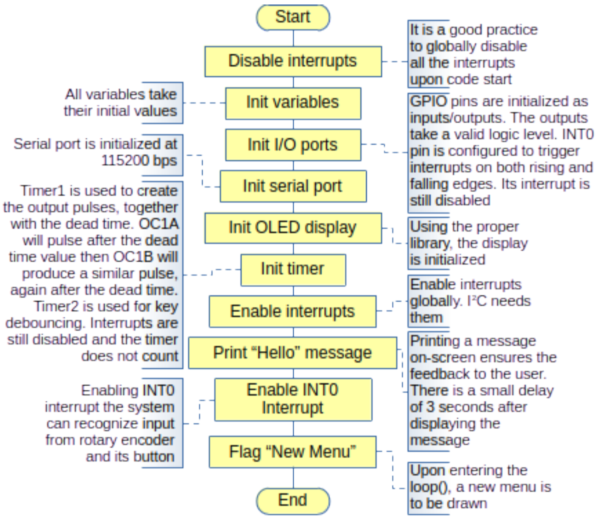

Fig. 11: setup() flowchart

When there is a key press or a rotation of the rotary encoder's handle, an interrupt is triggered at the INT0 input of the microcontroller. This happens whether at the rising or falling edge of the applied signals, which are processed by the OR logic gate constructed with two diodes and their respective resistors, shown in Figure 9. The flowchart of the code triggered by INT0 is located in the INT0 ISR vector (`INT0_vect`) and shown in Figure 12.

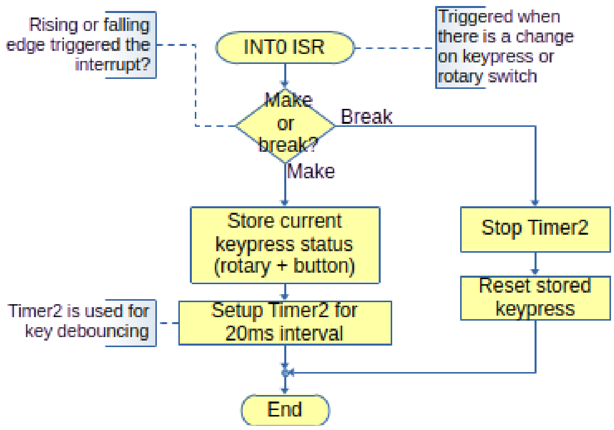

Fig. 12: Interrupt Service Routine for INT0, button triggering

To handle the key debouncing, Timer2 is used. Only when the input of the key and rotary status are stable for 20 ms, then is the action taken into account (Figure 13).

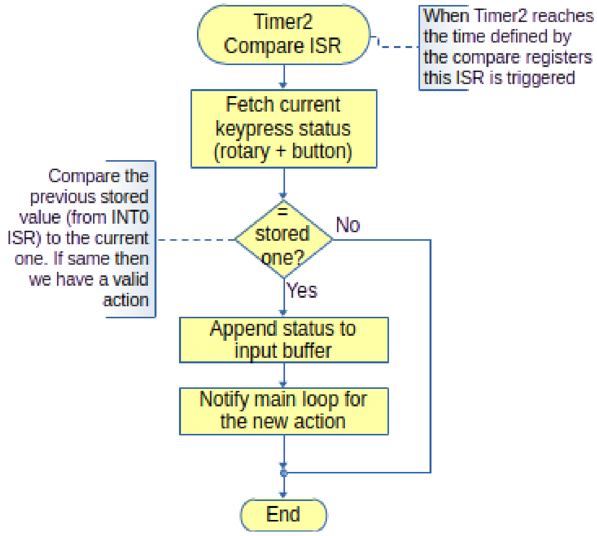

Fig. 13: 20 ms debouncing by using Timer2 Compare ISR

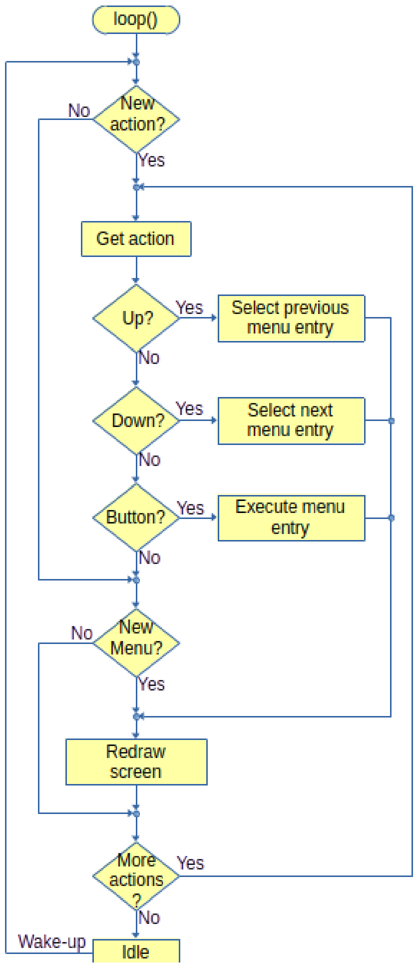

Fig. 14: Main loop flowchart

Finally, another ISR that should be described is Timer1's TIMER1_CAPT_vect vector. To achieve the ping-pong pulsing scheme, the outputs should be toggled one after the other. Every time the TIMER1_CAPT_vect is triggered, the bits COM1A1, COM1A0, COM1B1, and COM1B0 of the TCCR1A register should be toggled.

ICR1 and the prescaler (bits CS12, CS11, and CS10 in the TCCR1B register) of Timer1 should be set at double the needed frequency of the high voltage output. When the frequency is altered using the menu of the device, these values are set accordingly.

OCR1A and OCR1B hold the appropriate value of the dead time. This value should be updated each time the dead time value or duty cycle is altered, or when the prescaler of the timer is changed.

The ISRs should be executed with minimal latency. The rest of the program lies in the loop() function which is executed continuously (Figure 14). Inside it, the menu handling is performed, the variables are altered according to the user's actions, and the timers are adjusted based on newly entered values.

4 Future Work

Several directions for future research within the scope of the presented work are provided. Notably:

1. Exploring High-Frequency Applications: The current system generates low-frequency pulses, up to several kHz. However, the behavior of gases under higher-frequency pulsed electric fields remains an open question. Future research could focus on designing a new generator capable of operating at higher frequencies, potentially by employing a more powerful microcontroller or integrating a DDS (Direct Digital Synthesis) generator.
2. Alternative Chamber Designs: Investigating and optimizing chamber designs for enhanced visibility and performance is another area for future work. For instance, overcoming limitations such as the inability to visually observe the gas during stimulation in current chamber designs could lead to improved experimental setups.
3. Expanding Applications: While the proposed system is designed to stimulate gases, future research could explore its applicability to other fluid types or study the effects of varying field parameters, such as strength, polarity change, and burst configurations.
4. Improved Pulse Generation: Research could delve into refining the pulse generation mechanism to achieve greater precision and flexibility in controlling parameters like duty cycle, dead time, and voltage output.

These directions aim to enhance the system's functionality, broaden its applicability, and deepen our understanding of gas behavior under pulsed electromagnetic fields, contributing to advancements in related fields such as energy, environmental science, and materials research.

5 Conclusion

To effectively study the various properties of gaseous media under pulsed electromagnetic field stimulation, a specialized system is required. This system must include an enclosure to contain the gas being tested, one or more pairs of electrodes forming a capacitor, with the gas serving as the dielectric, and a high-voltage pulse generator to energize the electrodes. Through this configuration, the gas is subjected to a pulsed electromagnetic field, stimulating the medium. Depending on the specific properties being investigated, additional instruments can be used to observe and analyze the stimulation results.

The proposed design, using a microcontroller-driven pulse generator and a 3D-printed stimulation chamber, is intended to apply the necessary fields and facilitate a detailed study of gas stimulation. The current study successfully developed a system capable of applying pulsed electric fields to gaseous media. The design incorporates a microcontroller-driven pulse generator, controlling high-voltage inverters that generate the pulses needed for stimulating gases within the specially designed chamber. By using the ATMEL™ ATMega328P microcontroller and 3D manufacturing of the stimulation chamber, the study benefits from the flexibility and ease of rapid prototyping. This approach allows for quick iterations and adjustments, making it ideal for experimental gas stimulation.

The pulse generator includes key features such as variable frequency, pulse width, and dead time, enabling it to adapt to a variety of experimental conditions. The ability to control these parameters is essential for studying different gaseous subjects and understanding the effects of pulsed electric fields on their behavior. Additionally, the design of the system allows for scalability, with the potential to integrate the microcontroller and associated circuitry directly onto a single PCB. This modularity makes it possible to refine the system further and scale it for more complex experimental setups.

This research contributes to the growing field of gas stimulation, highlighting the role of pulsed electric fields in influencing molecular behavior. By offering a low-cost, customizable system for studying gas properties, the study aligns with ongoing efforts to innovate and improve methods in environmental science and energy research. Future work will likely focus on optimizing the system's performance and exploring its applications in energy production, environmental science, and industrial contexts. Enhancements could include the development of more sophisticated electrode designs, better safety protocols for high-voltage operation, and improved measurement tools to assess the effects of gas stimulation.

In conclusion, this study highlights the system's design, potential applications, and future directions for development, contributing valuable insights to the field of gas stimulation and offering a platform for further research and innovation.

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Declaration of Generative AI and AI-assisted Technologies in the Writing Process
During the preparation of this work the authors used Google Translate services in order to improve the readability and language of their manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Conflict of Interest

The authors have no conflicts of interest to declare.