International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 7.101

# Design and Implementation of a Class E Resonant Source for Generate Cold Plasma

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**Abstract:** ***Cold plasma, recognized as the fourth state of matter, requires high voltage and high-frequency power sources tailored to the type of gas and intended application. This work presents the design and implementation of a 1000 Vp, 50 W Class E resonant power source operating at 24 kHz for generating cold plasma. The system was developed for applications such as biomedical sterilization and material treatment. The design incorporates a PWM-controlled driver, MOSFET-based Class E amplifier, and resonant tank, validated through both simulation and physical testing with helium and argon gases. Results demonstrate stable operation, adjustable frequency ranges from 5 kHz to 60 kHz, and effective plasma generation suitable for experimental and applied research in plasma-based technologies.***

**Keywords:** High frequency, cold plasma, Class E amplifier, ionization, biomechanical applications.

## 1. Introduction

Plasma is considered the fourth state of matter, with a presence similar to a quasi-neutral ionized gas containing charged and neutral particles, which exhibit collective behavior and can be obtained when a gas is exposed to high temperatures and when high voltages are applied to it [1], [2]. There are different types of plasma, however, essentially a potential difference needs to be applied to a gas, which means that the energy applied to the gas through the electric field will excite the electrons in such a way that ionization of the atoms or molecules of the gas used occurs [3], [4]. The chemical species produced by the aforementioned process will be useful for mainly biological applications. Plasma is present in our environment, and we can see it in lightning during a storm, in the ionosphere and in the polar auroras, some of its applications in industry and daily life [5] include lighting in energy-saving bulbs [6], televisions, electric arc welding under gas protection, among others. One of the most common ways to generate plasma is through an electrical discharge, for this there are different ways to do it such as: dark discharge, discharge, arc discharge, glow discharge and dielectric barrier discharge [7]. To achieve discharge, it is necessary to excite with one or more sources which can be direct current (DC), alternating current (AC), radio frequencies (RF), microwaves and multifrequency. One of the means by which the treatment of parts is carried out to improve their properties through plasma is a reactor [8], in which controlled fusion and fission is carried out, it is achieved under conditions of low pressure and vacuum. Plasma reactors are used in industries such as aeronautics, metalworking, biomedical, telecommunications, textiles, among others, to generate the necessary voltage to ionize the gas and produce the plasma. An electronic converter will be designed to provide signals with the voltage levels and frequency required so that it can be tested in a plasma reactor [9].

The primary objective of this work is to design, implement, and validate a Class E resonant power source for generating cold plasma suitable for biomedical and industrial applications.

## 2. Design and Simulation

The development of the source followed a theoretical-experimental methodology.

The switched-mode power supply (SMPW) allows the use of high frequencies necessary to generate cold plasma.

Figure 1 shows the block diagram of the power supply design, which starts with a PWM signal generator block and subsequently provides the signal to the block formed by the gate driver, which in turn will be responsible for providing the activations of the MOSFETs that make up the Class E Amplifier block.

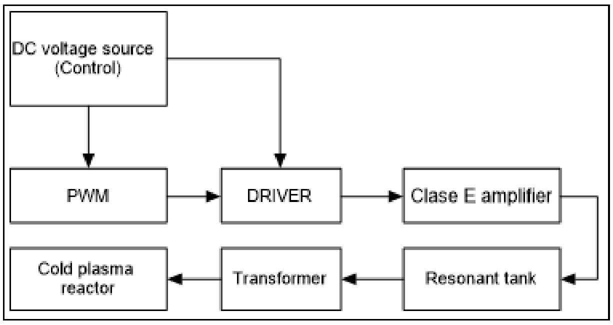


**Figure 1:** Block Diagram of the Source. Prepared by the authors.

The PWM and DRIVER blocks provide the output signal to activate the MOSFET gate.

Figure 2 shows the part corresponding to the power block and the resonant tank, the MOSFET Q1 is selected according to the nominal power (0-600 W) and the switching frequency (0-150 kHz), so the MOSFET STW25NM60N $V_{DS(MAX)}$=650V, $I_{DS(MAX)}$=20A and $R_{DS(MAX)}$=0.170Ω), is suitable for these characteristics. Cr is a metallized polyester capacitor with a value of 440nF/1000V which together with the magnetizing inductance Lm of the 460uH transformer forms the resonant source.

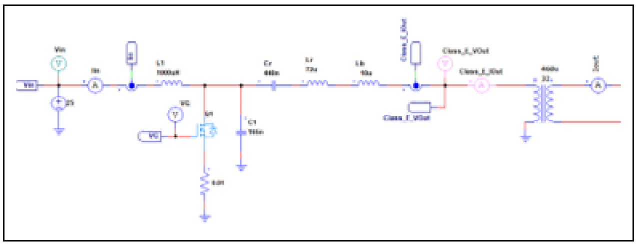

**Figure 2:** MOSFET and Resonant Tank. Own elaboration

The resonant frequency of the tank formed by the capacitor Cr together with the inductance Lm is given by **equation 1,** when applying the values we have a resonant frequency $f_r$= 24kHz.

$$f_r = \frac{1}{2\pi\sqrt{C_r L_m}} \tag{1}$$

Figure 3 corresponds to the block in charge of generating the PWM, the integrated circuit TL494 is used in push-pull configuration which charges the capacitor Ct with a constant current determined by the resistance Rt, this results in a sawtooth waveform, which once it reaches a value of 3V, the cycle is restarted by discharging the capacitor Ct.

The frequency at which the TL494 works in Push-Pull configuration is given by **equation 2** where Rt is made up of a precision potentiometer with a value of 10K, Ct is a capacitor with a value of 100nF resulting in a frequency range from 5kHz to 250kHz.

$$f_{osc} = \frac{1}{2R_t \, X \, C_t} \tag{2}$$

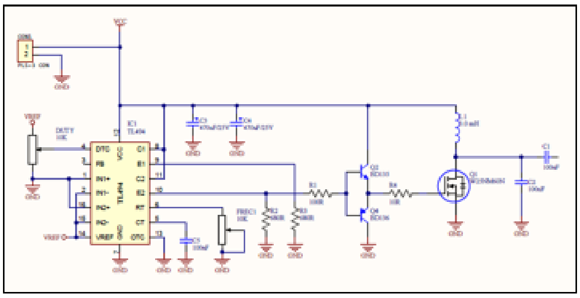

**Figure 3**PWM circuit. Own elaboration

For this purpose, a step-up transformer capable of handling up to 700W of power with a transformation ratio of 1:28 was chosen. The transformer core consists of a Ferroxcube B66395G0000X197 ferrite made of N97 material (Ae=280mm2, ue=1650).

The number of turns required for the transformer primary is obtained from formula 3.

$$n_1 = 10^4 \frac{\lambda}{2\Delta B A_c} \tag{3}$$

Where $\lambda$ corresponds to a voltage-second of 2.42 V-ms, Ac=280mm $^2$ being the area of the transformer core and $\Delta\ B$ which corresponds to the maximum AC flux density considering a value of $\Delta B$=0.23$T$, obtaining a total of 6.71 turns for the transformer primary, and 187.88 turns for the transformer secondary.

A total of 6.71 turns were obtained for the transformer primary, and 187.88 turns for the transformer secondary.

The transformer parameters were physically measured using a B&K PRECISION BK878B LCR meter, obtaining a reading of 1625uH for Lm and Cr of 27nF and a resistance R of 0.820, applying equation 1 to the measured values, a resonance frequency of 24 kHz is obtained.

To validate the proposed design, the PSIM v9.1 software was used, obtaining because of the simulation of the circuit in figure **2** the graphs shown in figure **4.**

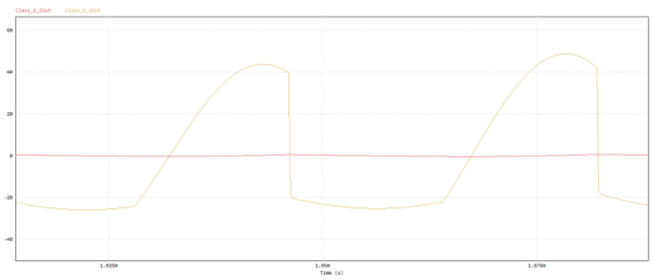

**Figure 4**Class E amplifier waveform. Own elaboration

## 3. Fountain Manufacturing

For the creation of PCB, it was decided to use the Altium Designer software for the creation of the PCB (figure 5) which contains the PWM, Driver and Class E Amplifier blocks while the resonant bridge part was created separately.

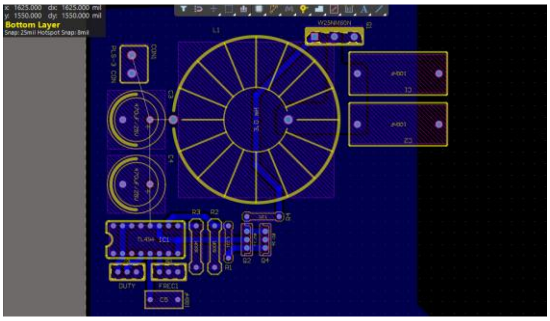

**Figure 5**PCB design. Own elaboration

The final design of the class E amplifier is observed in figure 6 showing the power part (MOSFETs) in the lower left part is the TL494 in charge of generating the PWM as well as the BD135 and BD136 drivers.

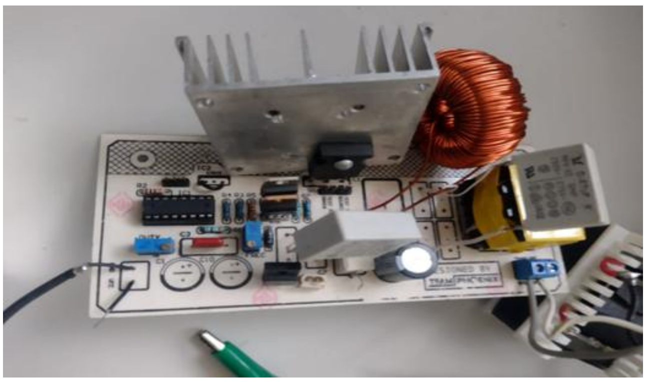

**Figure 6**Class E amplifier. Own elaboration



Paper SR25811081207 DOI: https://dx.doi.org/10.21275/SR25811081207

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The modeling of the plasma generation process was carried out in a design software for this case SolidWorks was used first to model the plasma reactor as shown in the figure, likewise the elements that intervene in the generation of plasma are modeled as seen in figure 8

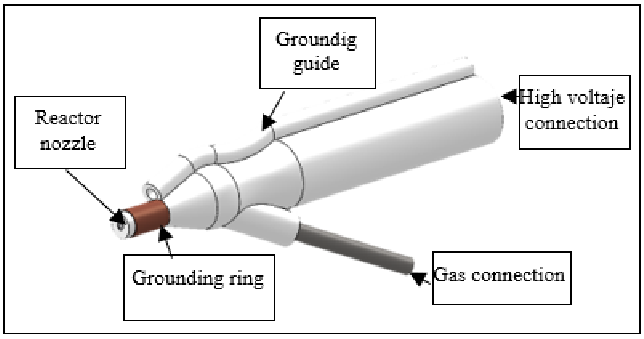


**Figure 7**Cold plasma reactor

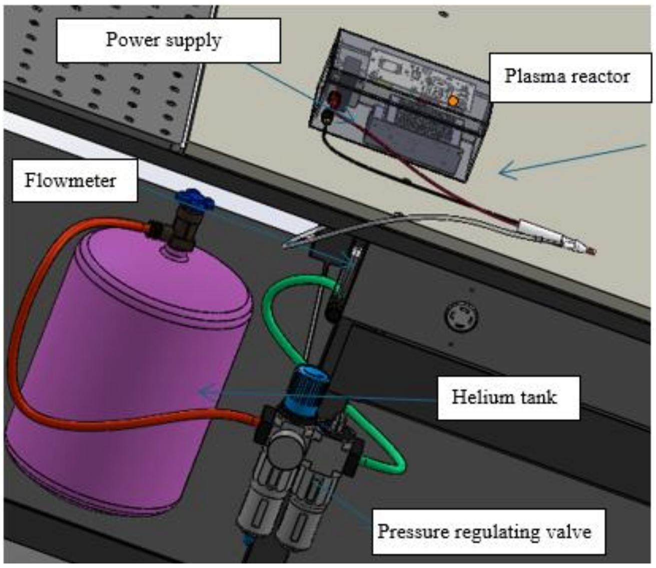


**Figure 8**Elements of the plasma generation process modelled

## 4. Results

The assembly of the source was carried out according to the parameters mentioned in section 2, figure 8 The assembly of the prototype is shown, which contains the PWM, DRIVER and Class E Amplifier blocks, as well as the resonant tank composed of the Cr capacitor and the Transformer. To power the prototype, a commercial HUS-100FG-15 source was used, which can operate at a voltage of 0 to 15V.

**Figure 9**Power supply. Own elaboration

Figure 9 shows the complete plasma generation process, which includes the helium tank, the regulating valve with flowmeter, the power supply, and the plasma reactor.

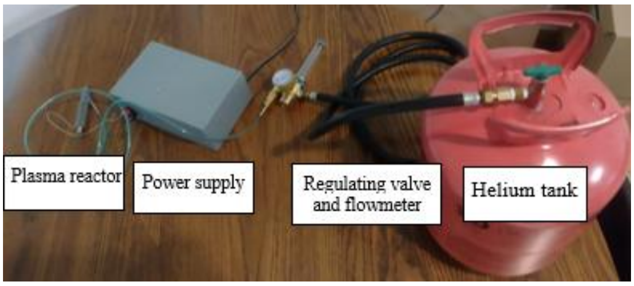


**Figure 10:** Plasma generation process

Using an oscilloscope, measurements are made of the PWM block represented in figure 9, in which the PWM signals generated by the TL494 are seen in yellow, a duty cycle of 50.1% was obtained at a frequency of 40.5 kHz, the waveform corresponding to the activation of the GATE of the MOSFETs Q1 is denoted in blue.

**Figure 11**PWM waveform and MOSFET gate input. Prepared by the authors.

Helium and argon are the most used inert gases for generating plasma and have wide applications in the biomedical field, which is why tests are carried out with these gases. Several tests were carried out with the power supply, first in a vacuum and then with gas, in addition to this the control voltage was varied from 8 VDC to 12 VDC.

The first test was carried out with a control voltage of 8VDC in vacuum with an input current of 540 mA. In figure 10a the shape of the output signal is observed in the gate (yellow) and drain (blue) of the MOSFET and in figure 10b the same signal at an input current of 580 mA using helium at a flow of 1.0 lpm at a pressure of 0.2 Mpa.

**Figure 12ay 10b** Test at 8VDC. Own elaboration

Figure 11a shows the voltage across the capacitor Cr in vacuum and figure 11b with helium.

**Figure 13ay 11b** Voltage in Cr. Own elaboration

Figure 12a shows the voltage across the inductor Lr in vacuum and figure 12b with helium.

**Figure 14ay 12b** Voltage in Lr. Own elaboration

Figure 13a shows the amplifier output in vacuum and Figure 12b with helium.

**Figure 15and 13b:** Amplifier output. Own elaboration

Figure 14a shows the high voltage output in vacuum and figure 14b with helium.

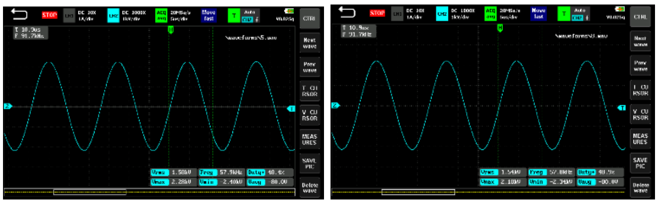

**Figure 14a and 14b:** High voltage output. Prepared by the author.

Comparing the graphs taken in vacuum and with helium, the similarities are almost the same, with minor variations in terms of duty cycle and Vrms voltage.

The second test was carried out with a control voltage of 12VDC in vacuum with an input current of 870 mA. In figure 15a the shape of the output signal can be seen in the gate (yellow) and drain (blue) of the MOSFET and in figure 15b the same signal working with Argon at a flow of 0.5 lpm at a pressure of 0.2 Mpa.

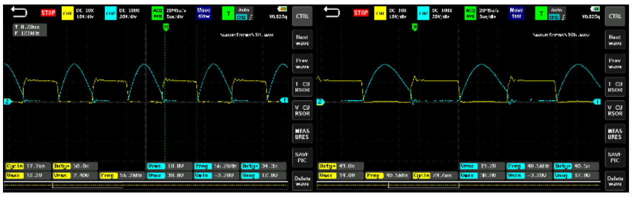

**Figure 15:** 12VDC test. Own elaboration

Figure 16a shows the amplifier output in vacuum and figure 16b with argon.

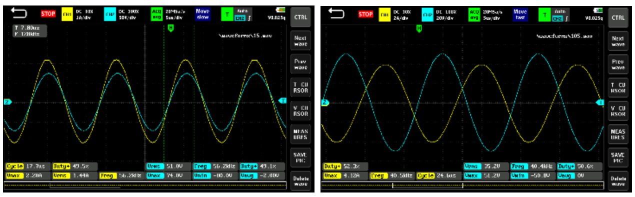

**Figure 16a and 16b** Amplifier output. Own elaboration

In this last graph it can be seen that there is a phase shift in the current signal (yellow) and that it is inverted, this behavior is different from that shown with helium.

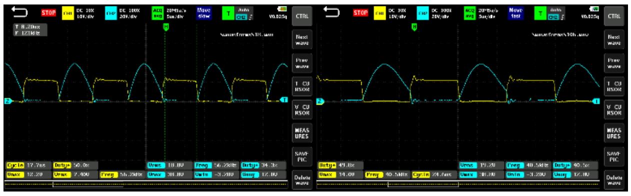

**Figure 17a and 17b 12VDC test. Own elaboration**

The proposed design is of the needle type, allowing for more precise plasma application. The plasma reactor consists of a copper rod, which is the positive feed conductor connected to the power source by a coaxial cable. At the tip, there is a copper ring for the negative feed. On the side, there is an inlet for the gas supply. For this test, argon and helium are used at a flow rate of 2 l/min. Figure 10 shows the test performed with argon.

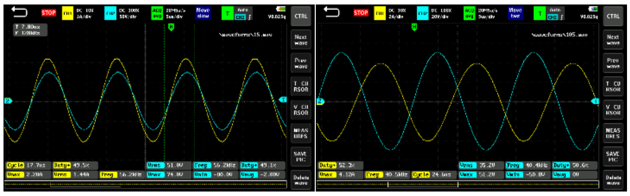

**Figure 18a and 18b** Amplifier output. Own elaboration

**Figure 19** Argon test. Prepared by the authors.

**Figure 20** Helium tests. Prepared by the authors.

## 5. Conclusions and Recommendations

The developed Class E resonant power source demonstrated reliable operation across a frequency range of 5–60 kHz, achieving voltages up to 3 kVpp with minimal switching losses through ZCS operation. Testing with helium and argon confirmed its adaptability for various plasma generation scenarios. These results establish a practical foundation for integrating such systems into biomedical applications, particularly in sterilization and wound treatment, as well as in industrial material processing. Future work should explore optimization for energy efficiency, miniaturization for portable use, and expanded testing with diverse gases and application settings.

**Acknowledgments**

We express our sincere gratitude to the **TecNM: Tecnologico de Estudios Superiores de Jocotitlán** for its invaluable support in the development of this project.

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