HIGH FREQUENCY PORTABLE PLASMA GENERATOR UNIT FOR SURFACE TREATMENT EXPERIMENTS

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This paper documents the design of an RF plasma demonstration unit. The paper shows that there are significant challenges associated with the generation of high frequency plasma under atmospheric pressure, but it yields some interesting results and a simple and elegant design. The generator makes use of a standard power MOSFET in a modern switching amplifier design to produce the required RF power and drive the resonator to produce the high frequency discharge.

Key words: high-frequency plasma, atmospheric pressure plasma.

1. INTRODUCTION

Over the last decade, the interest in plasmas generated at atmospheric pressure has increased. Atmospheric plasmas offer high excitation selectivity and energy efficiency in plasma chemical reactions [1]. They are sources of UV, Vis and IR radiation, free radicals such as O, OH and ozone that can play important roles in various techniques. This simplified RF plasma unit was built for several reasons: to prove that it could be done, despite many technical difficulties, to see how the appearance and behavior of the electrical discharge differ at MHz frequencies, compared to “traditional” DC or low frequency corona discharge, to make the system compact and portable, easy to set up and use for demonstrations. The operating frequency of 4 MHz was chosen because it is sufficiently far into the RF spectrum so that the generated discharge will have a different behavior than the low frequency corona.

2. THE CIRCUIT EXPLAINED

The plasma unit presented in this paper was built using only general purpose components that are easily available. However, there are real challenges associated with getting standard switch-mode power MOSFETs to switch efficiently at
4 MHz. At this frequency it is difficult to drive the gate with fast edges due to its large capacitance. The system diagram can be broken down into the following functional blocks: power supply, internal oscillator, auxiliary signal driver, high current MOSFET driver, MOSFET power stage, Tesla resonator, fault protection module. The block diagram is shown in figure 1 and the full schematic of the generator is shown in figure 2. The power supply has three outputs: +5 V for the crystal oscillator, +12 V for the driver stage, fault protection module and auxiliary signal input module and +250 V for the MOSFET power stage. The two low voltage outputs are filtered and stabilized by IC3 and IC4 (fig. 2). The high voltage output is filtered by a π type L-C cell formed by C6-L2-C7 (fig. 2). The internal oscillator module is based on a 7405 type integrated circuit (CDB405 – hex inverter with open collector gate outputs) connected in a crystal oscillator configuration. The first two inverting gates of the circuit (IC1A and IC1B, fig. 2) form the oscillator, driven by the Q1 crystal (fig. 2). The remaining 4 gates (IC1C…IC1F, fig. 2) are connected in series and their job is to improve the shape of the output square wave signal. Resistors R2, R4…R8 are the collector load
resistors for the gate outputs. The output signal is a standard TTL square wave at gate IC1E (fig. 2) and is converted to 12 V\text{pp} at gate IC1F. This 12 V signal is then fed to the input of the high-frequency MOSFET driver I.C (TPS2814P, fig. 2).

The auxiliary drive signal can be connected through connector JP1 (fig. 2), and the transistor T1 (fig. 2) forms the 12 V\text{pp} square wave necessary to command the MOSFET driver I.C. The output signal which is connected to the gate of the power transistor Q2 (fig. 2) has a maximum intensity of about 1.2 A, limited by R9 (fig. 2). Such a high intensity signal is necessary to drive the highly capacitive load of the MOSFET’s gate terminal at MHz frequencies, because the gate has an internal capacitance of about 200 pF. L1 (fig. 2) is used as an RF choke to prevent the signal from the power transistor to feed back into the power supply. The fault protection module is based on a LM393N type integrated circuit and has two comparators with hysteresis. (IC2A and IC2B, fig. 2). This module protects the power stage and the power transistor Q2 by blocking the drive signal in two circumstances: if the peak voltage at Q2’s drain exceeds 600 V or the drain current of the power transistor exceeds 2 A. The drain voltage is sensed on resistor R16 (fig. 2) and the source current intensity is sensed on resistor R10 (fig. 2). The reference voltages for the comparators are +5 V and +1 V obtained from the divider formed by R29 and R30 (fig. 2). An extra hysteresis of 100 mV was added to the comparator circuit (figure 3) using the following method: [2] first, the value for R3 was selected. The current through R3 is:

$$I_{R3} = \frac{U_{REF} - U_{OUT}}{R3}$$

(1)

The hysteresis band ($U_{HB}$) chosen being 100 mV, the value for R1 is:

$$R1 = R3 \left( \frac{U_{HB}}{U_a} \right)$$

(2)

The trip voltage for $U_{in}$ rising ($U_{THR}$) is chosen such that:

$$U_{THR} > U_{REF} \left( 1 + \frac{U_{HB}}{U_a} \right)$$

(3)

The value for R2 will be:

$$R2 = \frac{1}{\left( \frac{U_{THR}}{U_{REF} \cdot R1} \right) - \left( \frac{1}{R1} \right) - \left( \frac{1}{R3} \right)}$$

(4)

Finally, verify the trip voltages and hysteresis as follows:
The two diodes D1 and D2 (fig. 2) form an “OR” gate. The output signal from the comparators blocks the drive-signal of the TPS2814P I.C on pins 2 and 3 (fig. 2). The output signal from the comparators blocks the drive-signal of the TPS2814P I.C on pins 2 and 3 (fig. 2). LED1 and LED2 (fig. 2) show the operation of each side of the protection module, lighting up if the fault mode is on. The load for the power stage is a high frequency transformer (1:10) connected in Q2’s drain (fig. 2). The secondary winding of this transformer is connected to the base of the Tesla resonator. The RF corona discharge is generated at the free end of the Tesla coil. This coil was build so that it self-resonates at the desired frequency of 4 MHz. This means that its inductance and stray-capacitance forms a series resonant LC circuit, “tuned” at exactly 4 MHz. The parameters of the resonator coil were calculated using the following equations [3]:

\[
L = \frac{N^2 \cdot R^2}{25.4(9R + 10H)} \quad \text{(Air cored solenoid inductance)}
\]  

\[
C = \frac{(0.29H + 0.41R)}{25.4} + 0.0763 \sqrt{\frac{R^3}{H}} \quad \text{(Medhurst self capacitance for solenoid)}
\]

where: \(L\) is the inductance in \(\mu H\), \(N\) is the number of turns, \(R\) is the radius of the coil in mm, and \(H\) is the length of the coil in mm.

\[
f = \frac{1}{2\pi\sqrt{LC}}
\]

where: \(f\) is the frequency in Hz, \(L\) is the inductance of the coil in H, and \(C\) is the stray-capacitance of the coil in F. The generated corona at 4 MHz is a silent flickering orangey-lillac plasma flame, with a length of about 20 mm, at an input power of 100 W. (Fig. 4)

The samples to be treated in “cold plasma” are placed in a “reactor chamber” working under atmospheric pressure in Helium or Argon gas. Our first treatment tests were performed using a reactor chamber built from microscope glass slides bounded together with acrylic resin. A very important condition for the plasma
column to be stable and homogenous was to maintain a smooth laminar gas flow. The working frequency of the generator coupled to the reactor chamber is 1.6 MHz, because of the reactor chamber’s high self-capacitance.

The waveforms of the current flowing through the reactor chamber and of the electrode voltage are very close to sinusoidal form (fig. 5). The phase angle of 88° with which the current leads the voltage (fig. 5a) suggests the capacitive behavior of the chamber in the absence of the plasma [4].

3. CONCLUSIONS

A high frequency plasma generator - experimental model was designed and built to study the behavior of the corona discharge at MHz frequencies and to experiment with cold plasma effects on some material samples. The generator was built using only general purpose components that are readily available. The unit is portable and easy to set up for demonstrations.
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REFERENCES