Contents

Chapter 1

Electric characterization

1.1 Electric scheme and description

The development of electric components used to produce the Plasma Coagulation Controller is highly influenced by the need of flexibility in settings and mobility for wound treatment. To produce plasma as DBD, in air with Helium or Argon as ignition gasses, it is necessary to apply high electric fields in little space, to permit easy medical application the design of the head must be compact with particular attention to electric safety measuraments. It is common to produce electric fields with fast voltage pulses for various usage, including jet or DBD plasma production ([5], [3], [2]), the scheme used here outputs a voltage pulse with an amplitude up to 10 kV and frequencies up to 60 kHz.

A rappresentation of power and signal lines is in figure 1.1. The circuit is divided mainly in two parts : the controller, with alimentation and settings controls, and the head, where the discharge happens and plasma is emitted.

The line divides in:

- **Alimentation** : the 220 V DC power line goes in a transformer that gives a 22 V tension to the head, passing through a diode bridge. This tension aliments the Driver Circuit on the head.

- **Arduino and trigger** : the power line is reduced to 12 V necessaries to aliment an Arduino controller and a laser. From an analogical output of the Arduino a PWM wave goes to the laser trigger, it transmits information on the wave, frequency and duration, with an optical fiber that ends with a photodiode installed on the driver circuit. Wave frequency is setted by the Arduino, wave duration is setted giving the opening time of the MOSFET that passes the signal to be amplified and sent to the head's transformer. With this setup the high-voltage line is entirely decopuled from the controller, so there are not problems of signal reflection on the power line or the Arduino.

- **Head** : the Driver Circuit receives a power line of 22 V and an optical trigger that defines frequency and duration of the voltage pulse. When the trigger gives the start

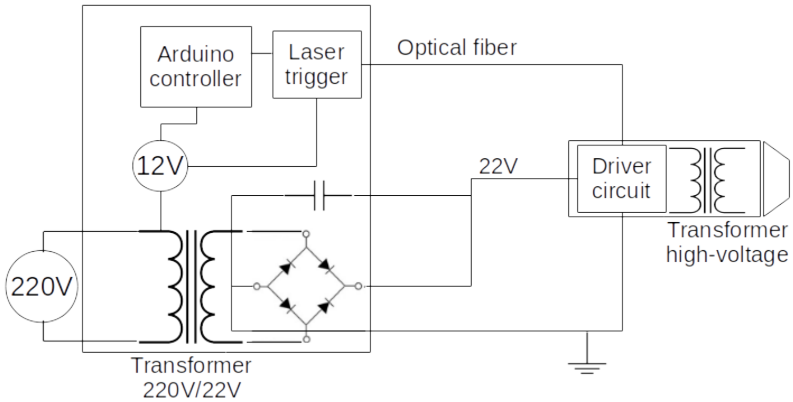


Figure 1.1: Scheme of the general electric line to produce high voltage, the controller on the left and the head on the right.

signal, the transformer on the head receives on primary circuit a voltage of hundreds V and outputs from secondary circuit a voltage of thousends V. Connected to the ouput there is the electrode inside a capillary tube of dielectric material.

To understand signal propagation is presented a simulation in figure 1.2, obtained with a simplified scheme with Spice. As shown, once the PWM trigger starts, tension on the primary goes from alimentation value to 0, when the PWM signal ends (after 6 µs, it has a pulse with amplitude of 150 V (width of 1.2 µs) and a pulse of −5000 V at the output of secondary circuit. A longer PWM implies a longer charging time, so an higher pulse. Ultimately, amplitude of the pulse is proportional to the width of the PWM signal and to know working conditions of the source it is necessary to study the relation between opening time and amplitude output on the actual circuit.

During this thesis study were built two sources, with two controllers and heads, the first one will be called source A, the second one source B. From an electrical perspective the two models are almost identical, the second one comes with a low-pass filter on the driver circuit (to diminish high frequencies noise) and slightly higher amplitude capabilities. The characterization of electric features is made measuring output tension and current with different settings for the pulse.

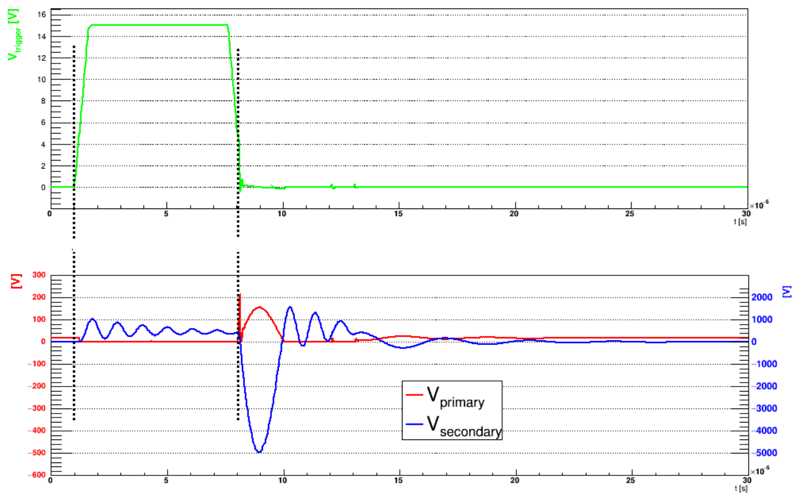


Figure 1.2: Scheme of signal propagation. Up, in green, there is the optical trigger, down, in red, the voltage of primary circuit in the head with axis on the left, in blue, the voltage of secondary circuit with axis on right.

1.2 Output characterization

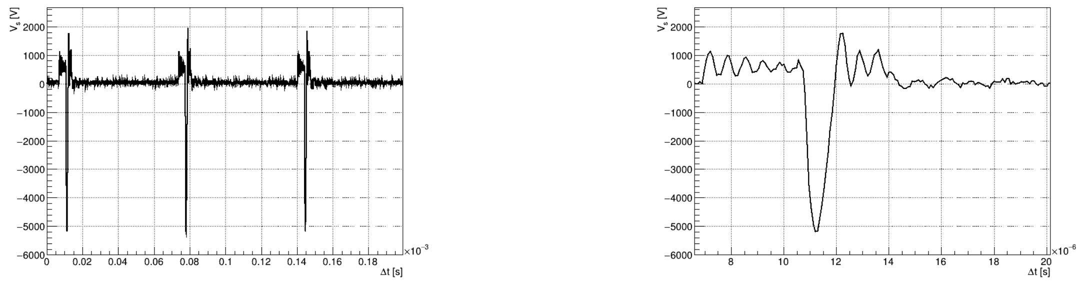
Plasma ignition and discharge features are regolated by electric field generated in the circuit head and power deposition to flowing gas, so the parameters involved are pulse amplitude and frequency arriving on the electrode, settable in the circuit. Medical application of plasma requires low current intensity, in this study it's measured the current flowing on a copper plate targeted by the plasma plume at a certain distance. Ultimately the different parameters for the measures are: Δt, opening time of the trigger that defines amplitude of the pulses, and f, frequency of the pulses.

Voltage signal are taken with an high-voltage probe, attenuation $\times 1000$, current signal with a *Tektronix CT2* probe that gives a 1 mV for a current of 1 mA. All signals are measured with a *Yokogawa DL9040* oscilloscope, from which is saved the waveform of voltage and current.

Measures are taken without gas flowing, to see the output voltage of the circuit, and with an helium flow of 2 L/min, to measure the actual output with different amplitude and frequencies. It's also measured an effective current intensity, i.e. a mean value in a time period, to evaluate plasma application's effects on biological tissues.

1.2.1 Measures without gas

It's used the hv probe to pick tension difference between secondary circuit ouput and ground. Once a work frequency, f, is set, we take voltage wave shape for different values of opening time of the circuit, Δt, in the selectable range. To assure that a voltage pulse ends before another starts, this range is different for different frequencies: higher work frequencies means more pulses in a given time, taking into consideration pulse oscillations



(a) Three pulses

(b) Zoom on one pulse

Figure 1.3: Example pulses with source B for $f = 10\,\mathrm{kHz}$ and $\Delta t = 2\,\mu\mathrm{s}$

time width, proportional to opening time, the range of possible Δt is smaller at higher frequencies. A typical obtained measure is shown in figure 1.3.

The main pourpous of the measures is to study proportionality between amplitude of the peak and opening time, for different frequencies. Those signals are analyzed evaluating their Fourier Transform (using ROOT C++ libraries [4]) and reconstructing the signal without higher frequencies, to exclude noise fluctuations. The reconstructed peak is an asymmetric function as in figure 1.4, it's possible to interpolate it with a Landau function [1] and obtain peak value and position. The error from the fit function is added quadratically to the error given by the cut of high Fourier frequencies, evaluated as the square root of the mean square error between reconstructed and original signal for every point included in the fit range.

Results are shown in figure 1.5 for the two sources. As expected, pulse's maximum absolute value grows almost linearly with Δt, with higher values for source B and a constant behavior for different frequencies. To confirm the hypotesis of constant behavior, the range $0 - 16\,\mu\mathrm{s}$ is fitted with a linear function and the parameters are compared, as shown in figure 1.6. The values are displaced with random distances from the mean value, so it can be concluded that the behavior is not defined by the frequency.

1.2.2 Measures with gas

1.2.3 Time intervals

1.2.4 Effective current

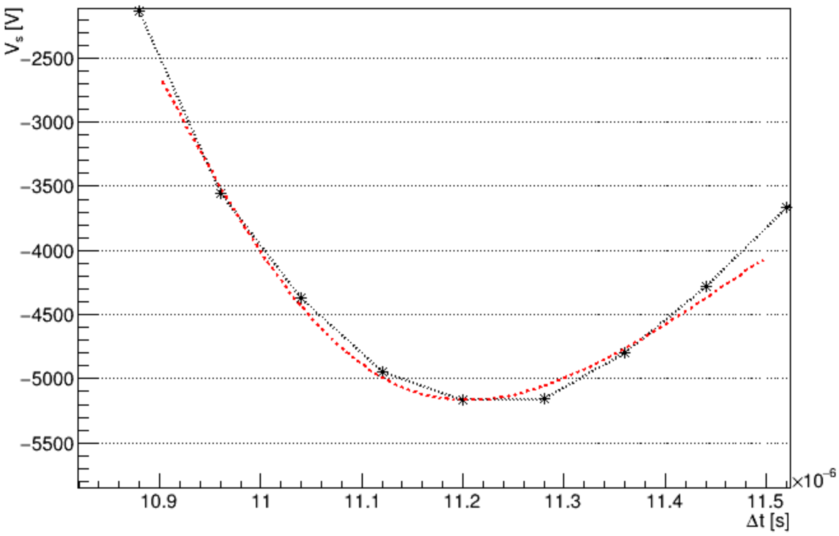
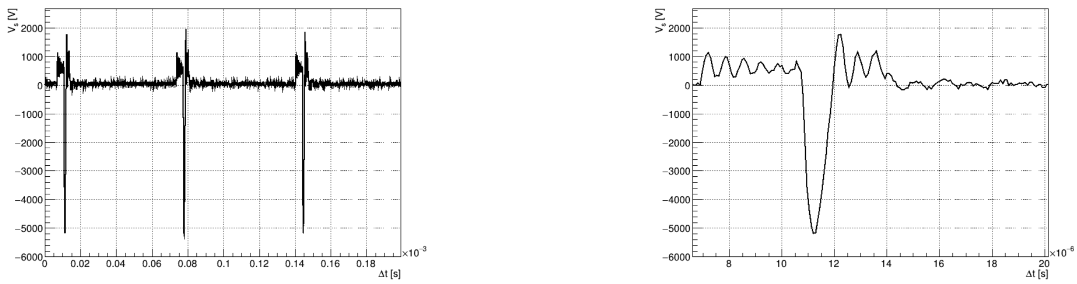


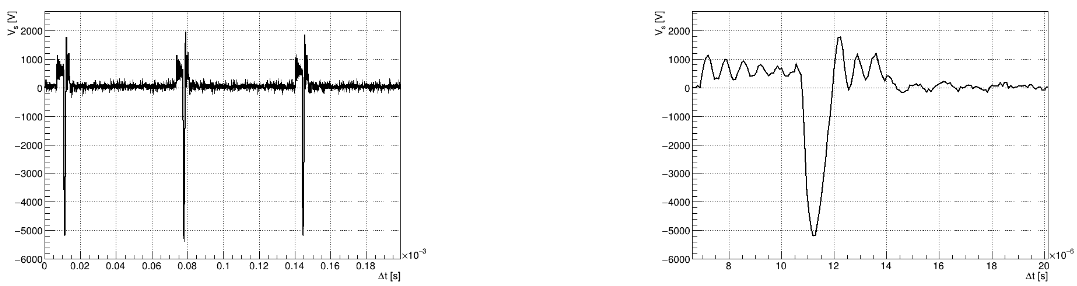
Figure 1.4: Example fit with source B for $f = 10\,\text{kHz}$ and $\Delta t = 2\,\mu\text{s}$



(a) Source A

(b) Source B

Figure 1.5: Absolute value of peak in function of Δt at different f, for both sources.



(a) source A

(b) source B

Figure 1.6: Linear fit parameters of $V_{peak}(\Delta t)$ for $\Delta t = 0 - 16\,\mu\text{s}$, for both sources.

Bibliography

[1] R. Brun. *ROOT documentation for Landau() function.* 1995. URL: https://root.cern.ch/doc/master/namespaceTMath.html#a656690875991a17d35e8a514f37f35d9.

[2] T Darny et al. "Analysis of conductive target influence in plasma jet experiments through helium metastable and electric field measurements". In: *Plasma Sources Science and Technology* 26.4 (2017), p. 045008. DOI: 10.1088/1361-6595/aa5b15. URL: https://doi.org/10.1088%2F1361-6595%2Faa5b15.

[3] Julien Jarrige, Mounir Laroussi, and Erdinc Karakas. "Formation and dynamics of plasma bullets in a non-thermal plasma jet: influence of the high-voltage parameters on the plume characteristics". In: *Plasma Sources Science and Technology* 19.6 (2010), p. 065005. DOI: 10.1088/0963-0252/19/6/065005. URL: https://doi.org/10.1088%2F0963-0252%2F19%2F6%2F065005.

[4] *ROOT documentation for TVirtualFFT class.* URL: https://root.cern.ch/doc/master/classTVirtualFFT.html.

[5] J. Upadhyay et al. "Development of high-voltage pulse generator with variable amplitude and duration". In: *Review of Scientific Instruments* 85.6 (2014), p. 064704. DOI: 10.1063/1.4884883.