RADIO FREQUENCY SYSTEM FOR THE EXCITATION OF AN ION SOURCE

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Abstract

The application of a radio frequency device was introduced to reach controlled plasma production with the aim of modify the excitation principle of a neutron generator ion source. A test bench was created which allowed to verify the system functionality in conditions close to real. Indispensable to the system devices were developed, modified or constructed on the base of discrete components. The sustained plasma production was obtaine along widespread test sessions. The system output power was limited according to the system cooling and biasing capabilities, he available reserves to obtain higher levels of radio frequebcy energy were identified. First steps to apply an alternative way of exploitation of our neutron generator were made.

Key words: rf systems, plasma, ion sources, impedance, neutron generators

SISTEMA DE RADIO FRECUENCIA PARA EXCITAR UNA FUENTE DE IONES

Resumen

Se introdujo la aplicación de un dispositivo de radio frecuencia para establecer la producción controlada de plasma con el objetivo de modificar el principio de excitación de la fuente de iones de un generador de neutrones. Se creó un banco de pruebas que permitió comprobar el funcionamiento de este sistema en condiciones cercanas a las reales. Se desarrollaron, modificaron y construyeron todos los dispositivos indispensables para el sistema, utilizando los componentes discretos disponibles. Se obtuvo la producción sostenida de plasma durante largas sesiones de pruebas. Se limitó la potencia de salida del sistema de acuerdo con sus posibilidades de enfriamiento y polarización, identificándose las reservas disponibles para obtener mayores niveles de energía de radio frecuencia. Se dieron los primeros pasos para aplicar una alternativa de explotación del generador de neutrones diferente a la original.

INTRODUCTION

Neutron generators are small accelerators consisting of vacuum, magnetic, electrical and mechanical components; radiation sources, cooling circuits and pneumatic transfer systems.

The low voltage (a few 100 kV) neutron generators [1] produce neutrons by the following reaction:

$$^{2}H(d,n)^{3}He \qquad Q=3.268\ MeV \qquad (1)$$

$$^{3}H(d,n)^{4}He \qquad Q=17.588\ MeV \qquad (2)$$

The large cross section of the $^{3}H(d,n)^{4}He$ reaction permits high yields of fast neutrons to be obtained even at low deuteron energy.

The process of neutron production on this machine begins with the ionization of deuterium in the ion source. Then the obtained ions are extracted from there and accelerated trough the acceleration tube to finally impact over a target after been deviated by a magnet. The target material can be either tritium or deuterium.

According to the manufacturer's specifications at 250 kV it features an output of 10^{12} neutrons/second with an energy range of up to 14 MeV.

Through out the time of our neutron generator exploitation it's been strengthening the need for an alternative way of producing ions. It is well known that there are important experiences in the world, which apply the RF power in order to ionize gases

[2]. Therefore we need for an RF signal to transfer to the gas contained in a volume, enough energy so as to have its particles excited to reach their ionization and to sustain the plasma.

MATERIALS AND METHODS

A wide spectrum of developments and works are been performed but we will refer only to those associated with the RF application.
A device responding for generation and multiple amplification of RF signal is been upgraded and adjusted. See figure1, which pictures the structure of such a system.

According to the international agreements on frequency spectrum usage, the 13.56 MHz channel is world wide utilized for research purposes. In our application this is just the signal frequency range.

The system is mainly based on a 13.56 MHz crystal generator and consists of multiple amplification stages, matching networks, different power supplies and an antenna, which is finally located inside the ion source.

The heart of the RF power amplification track is a 5000 w RF power tube GU-47, see figure 2, its

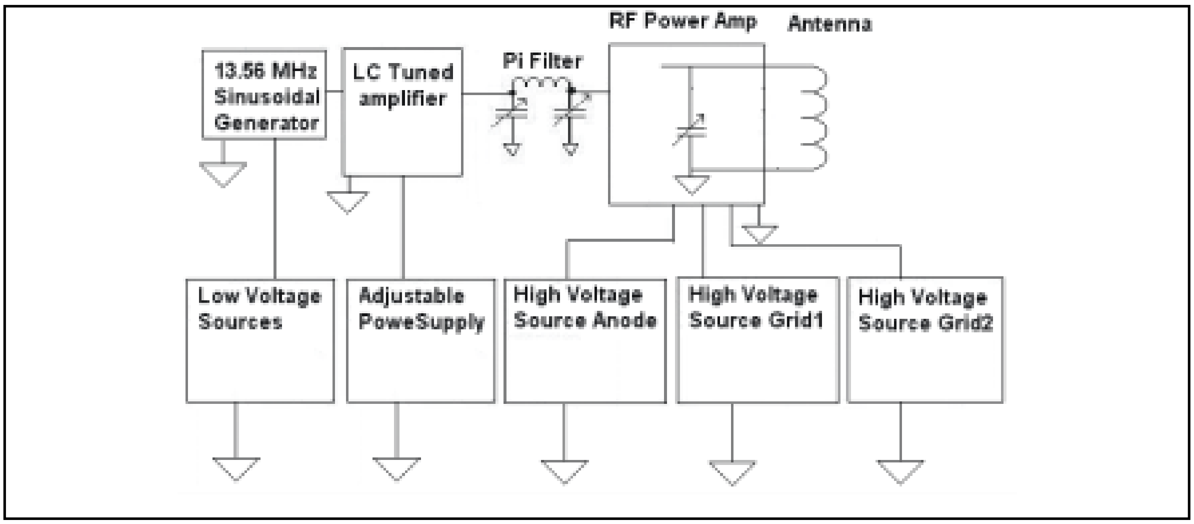

Figure 1. RF amplifying system.

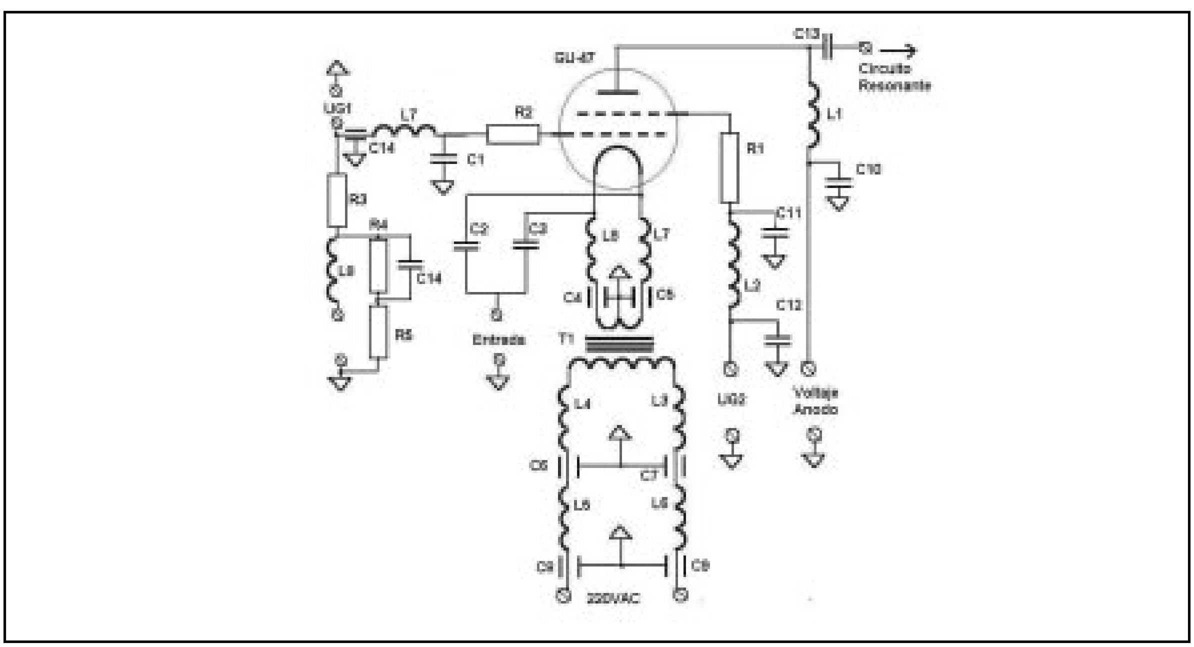

Figure 2. RF Power Amplifier Stage.

performance involves a network of circuits intended to supply and polarize it.

Such a powerful electronic tube requires the use of a robust 1500 volt power supply for anode circuit bias, it was built at our Lab as well as other sources that were designed and constructed to guarantee the polarization of the tube grids. There should be remarked that the working point for this valve was selected so as to ensure a moderated regime of performance what is just a starting point considering that it may happen that more power might be required to obtain the needed output.

Before being feeded to the power stage the signal sinusoidally shaped requires to be amplified in an earlier stage. Originally for such a purpose there was inserted a circuit based on other electronic tube which finally had to be discarded.

A new stage was developed and built on a single MOSFET transistor IRF 830. The new circuit fulfilled the requirements of the previous one. A different approach for the signal amplification was utilized taking advantage of a more efficient configuration like the tuned LC one as it can be seen below in the figure 3.

Such configuration is useful when the operating frequency is confined to a narrow range and guarantees a signal free of distortions with no harmonics [3].

This has several advantages:

- Higher single stage gain, since the load presents high impedance at the signal frequency while allowing arbitrary quiescent current.
- Elimination of the undesirable loading effects of capacitance, since the LC "tunes out" any capacitance by making it part of the tuned circuit capacitance.
- Simplified interstage coupling, since an LC circuit can be tapped or transformer –coupled to achieve any desired impedance transformation.
- Elimination of out-of-band signals and noise owing to the frequency selectivity of the tuned circuits.

The stage recives a 24 Vpp signal at the input giving out a 200 Vpp sinusoidal signal. It should be commented that there is inserted between this amplification stage and the next a so called Pi filter, see figure 1 in order to have the outcoming and incoming impedances matched so as to ensure the less significant RF energy losses.

The above mentioned amplifying stage requires an adjustable power supply which was designed and constructed on discrete components, at our Lab too. See it in the figure 4. It meets the following requirements:

- Adjustable from 1. 25 V to 140 volts. It is one of the provided ways of controlling the system output power.
- At maximum output voltage it supplies up to 300 mA. The circuit is over current protected.
- The circuit features soft start and short circuit protection.
- The dc source is RF protected so as to have no RF noise at its output level.

The possibility of utilize the LM 117 family regulators in the floating mode makes them ideal for the operation at high voltages considering its availability it was a good choice in our application.

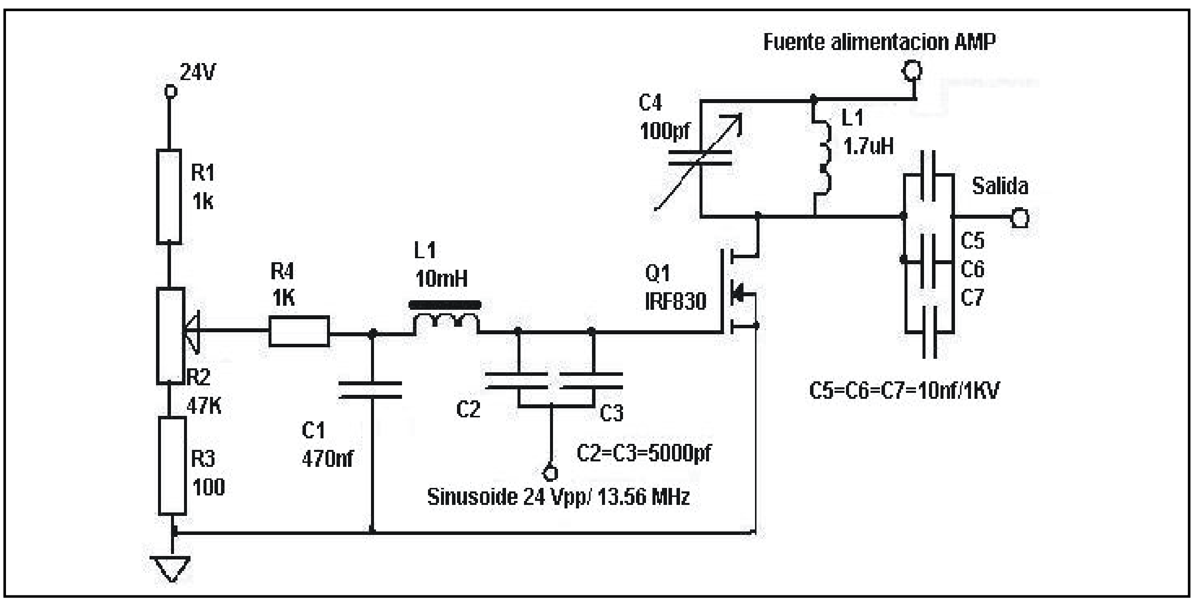

Figure 3. Tuned LC amplifier.

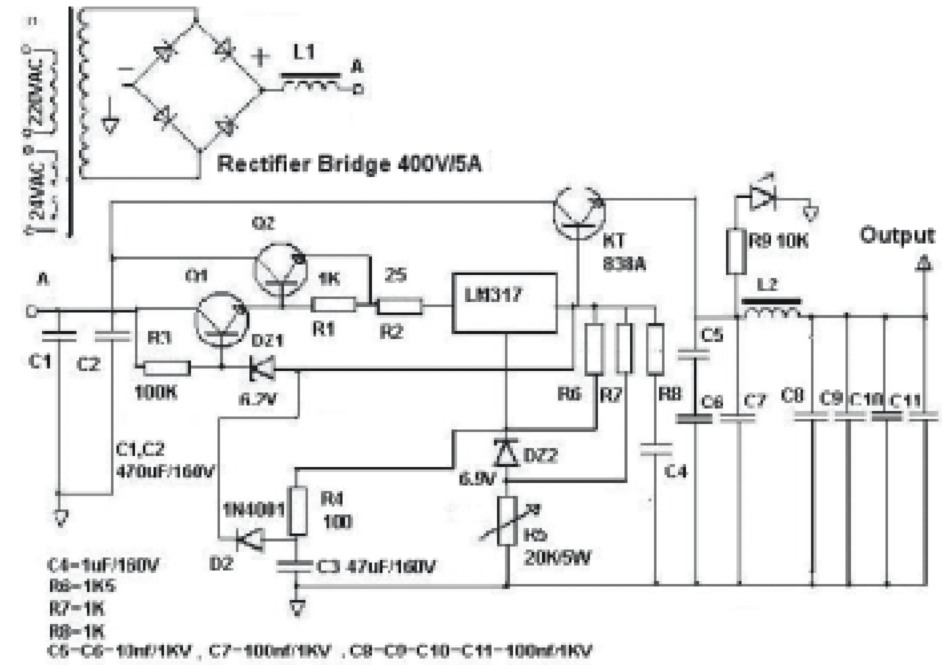

Figure 4. Adjustable power supply.

Such regulator sees only the differential voltage between its input and output, which cannot exceed 40 V what is guaranteed by the 6.2 V zener all over the output range from 1.25 up to 140 V.
Since high voltage transistors by necessity feature low beta a Darlington pair (Q1, Q2) is used to support high voltage. Zener's impedance is low enough so there is no need for connecting capacitors directly to the regulator's input.
To limit the short circuit current to 100 mA there is the 25 ohms resistance. The RC circuits at the output and at the adjusting pin improve the transient response while the 100 ohms resistance and the diode 1N4001 protects the adjusting pin during the shorts. Q2, Q3 are placed on a radiator the last one connected as an emitter follower increases the current output of the source.

Antenna, see figure1, deserves a separate treatment. It is the inductor of a resonant LC circuit which loads the final RF amplification stage. It was calculated so as to achieve the resonance at the working frequency of the output LC circuit in the middle of the adjusting range.

Since the environment it will be surrounded by is plasma it requires to be coated. Such a coating has to be stable at high temperatures, and should be a non conductive substance. At our Lab after several attempts a satisfactory coating substance and application procedure were reached. Temperature generated in the working volume of the ion source requires to be evacuated and the antenna is part of the path followed by an oil flux responsible for heat extracting.

To implement an RF system implies a large number of complex solutions for those appliances and devices it involves. Our paper wants to expose just the first steps and outputs from the experiences arised along the way of upgrading an ion source in our conditions. To pick up in this paper the whole amount of suitable solutions founded and introduced might turn it dense. Available results are better representative of the course we have gone through.

RESULTS

- An installation to check the whole system was obtained, see figure 5.
- The system working point was stablished as well as the procedure to reach it.
- Plasma production was observed in the test bench, see figure 5, every time the experiments were run. With the help of a vacuum pumping system vacuum conditions similar to those the system will work with were previously created in the plasma chamber, the gas of interest, in this case hydrogen, was also supplied to it through a valve. Once the working point was stablished, the system was set up and the RF output power was arised the content of the chamber reached the ionization and plasma could be observed.
- Plasma production, see figure 6, was for many hours sustained along the experiments every time they were run, system supported such severe conditions without showing exhausting signals.
- Required devices like high voltage power supplies, RF stages, low voltage sources,

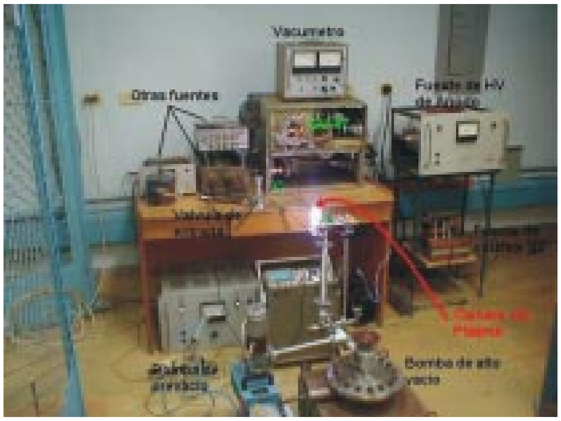

Figure 5. Test bench. Observe plasma chamber containing ionized gas, pre-vacuum pump, high vacuum pump, main amplifying stage, high voltage anode source, high voltage grid 2 source, gas supplying valve, other voltage sources, cooling system is hidden behind the main amplifying block.

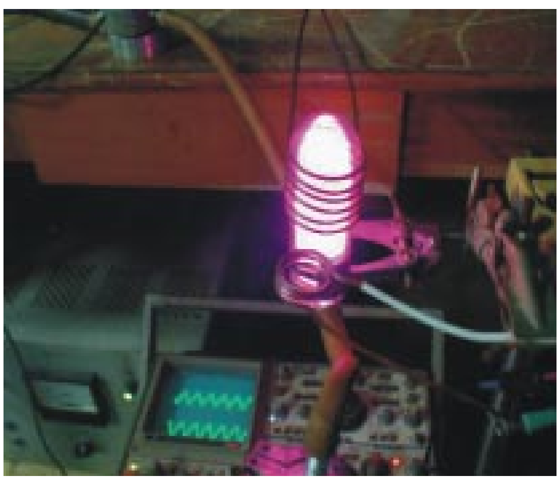

Figure 6. Plasma obtained in a test session. Antenna is coiled around the plasma chamber, an auxiliar antenna allows to observe a signal sample in the oscilloscope.

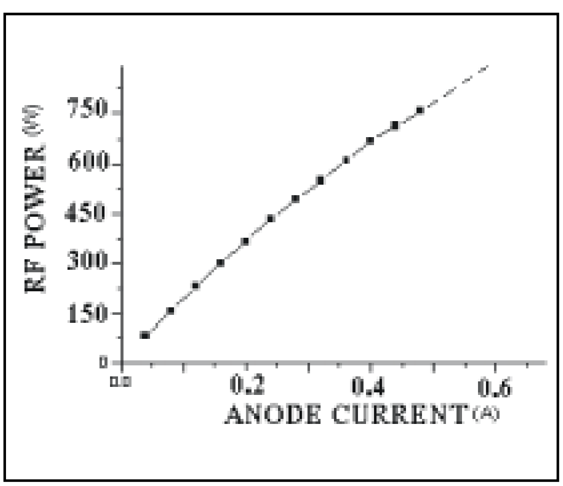

Figure 7. Output RF power vs. anode current.

matching networks, etc. were designed, modified or constructed. That was achieved on the base of discrete components.

- RF power measurements were performed for different RF power measurements were performed for different anode current values. As it can be observed in the figure 7, the output power reached its maximum at 750 W. Considering the poor capacity of the test bench cooling circuit and the HV anode power supply capability system could not support to give out RF power levels beyond such a value. Even though system reserves were well identified.

CONCLUSIONS

- Considering the gas to be excited and the vacuum conditions to be working in, the system was tested in conditions close to those it is expected to be, although there was not possible to simulate all conditions of work the obtained RF field strength showed a significant ionizing capability.
- Control loop most be included so as to guarantee stability.
- System reserves to reach higher levels of RF energy were identified, the rf power tube is not working at its top so there is still an extra source of energy in case it is required to have more of, in this sense it is also requiered to have more power tube cooling capability and a stronger high voltage anode biasing source.
- The system is hand made so it is quite susceptible of being improved. A more efficient design is obtainable utilizing an electronic base closer to the state of art in the field of RF generation, amplification and transmission.
- The main objective of this work was to have available a system with a tangible ionizing capability strong enough to excite the ion source of the neutron generator. First steps in such a direction have been made.
- The original ion source was excited through a thermocathode, the initial power supplied to the gas to be ionized is quantitatively less than the one reached by the present system in the test bench conditions.
- According to the above mentioned facts there are reasons that positively lead us to continue forward in the way of upgrading and/or modifying the neutron generator ion source. RF ion source are been utilized now a day abroad we are just attempting to bring ours to a higher state of art.

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