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Power Supplies for Tetrode High Power Amplifiers at FREIA

ESS TDR Contribution

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Abstract

This paper select the topology of the power supplies to the RF power amplifier to one spoke cavity to be tested at FREIA Uppsala University. The power supplies are thought to fulfill the requirements of ESS in Lund.

The amplifiers pulsed operation will have a strong impact of the choice of topology. The RF amplifier will have two tetrodes in the final stage.

The anode power supply is studied for different topologies and number of anodes to supply.

Storing the energy for pulse current to the anodes at high voltage or at low voltage is considered.

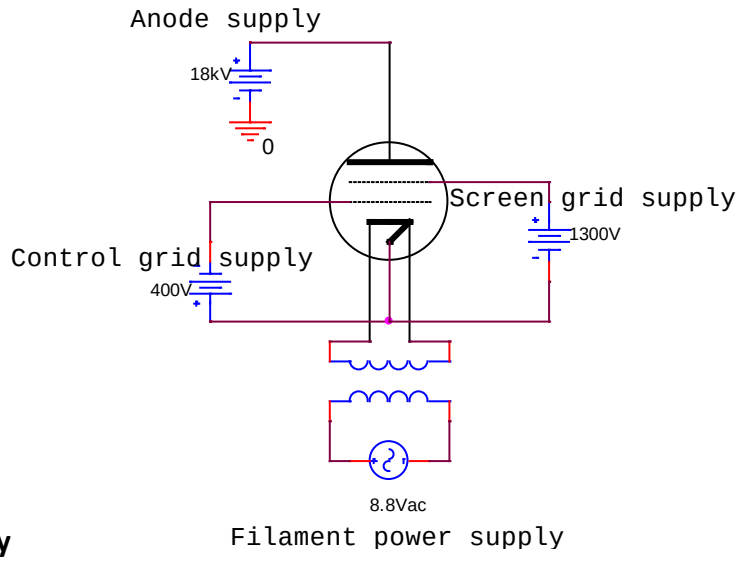
The short circuit protection can be with a crowbar or a series switch. The series switch is selected for reasons of short interrupts in case of temporary short circuits.

The grid and filament supplies are thought to be standard of the shelf power supplies.

Cost estimate and comments on maintenance in the end of the paper.

1. Introduction

The purpose of this document is to show the available setups to power the TH595 tetrodes in terms of power supplies (anode, filament, screen and control grid) and number of outputs per anode power supply. The RF- power amplifiers will have two tetrodes TH 595.



2. Topology

Figure 1: Simple sketch of the tetrod DC and filament connections.

2.1 Anode power supply

The general requirements for the anode power supply are:

1. Positive output voltage max. 18 kV.
2. Pulsed output current 18 A during 3.3 ms at 14 Hz.
3. Bank capacitor: due to the pulsed operation mode of the amplifier with high peak power of 539 kW and low average power 31 kW[1], the power supply needs to store energy: a capacitor is a good choice for that purpose. As the tetrode amplifier is not sensitive to anode voltage droops during the pulse, the capacitor does not need to have a very high capacitance. A voltage droop up to 1000 V in the pulse can be tolerated.
4. A mechanical switch to short circuit the capacitor during service shall be provided.
5. A current limiting resistor and/or inductance is needed to limit current if an arc occurs.
6. The output of the power supply can be directly connected to the capacitor or via a step-up converter.

There are two alternatives (see figure 2): crowbar or series-resonant circuit. The first option with the crowbar (*Alternative 1*), implies that there is high voltage at every point in the circuit and that if an arc occurs, a fast switch response of the crowbar is necessary to avoid damage. The advantages of such setup are that components are readily available and have been known and in use for years
No oil for insulation is needed, the power supplies may be dry insulated.

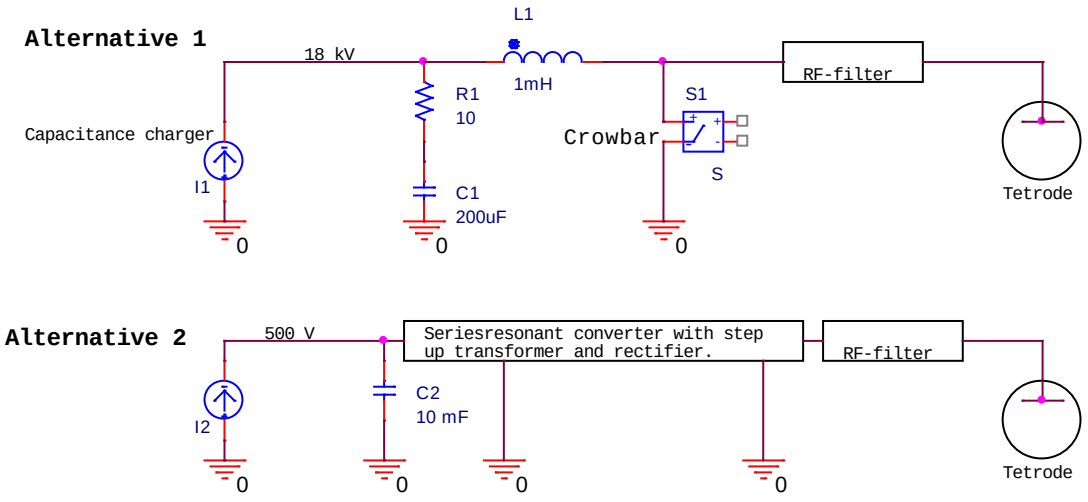


Figure 2: Studied alternatives for the anode power supplies to power the tetrodes.

For *Alternative 2*,the capacitor is charged with a lower voltage and feeding a series resonant converter. The output of the convertor is connected to a step-up transformer and the secondary voltage is rectified to the desired anode voltage. The presence of a step-up transformer permits the voltage to be lower at some points, reducing damage if failure or misuse occurs. In this case, reliability lies on the converter, which has to go out of tune in case of failure.

Table 1 compares both alternatives in terms of basic properties. Following this discussion, the setup chosen for the anode power supply is *Alternative 1*, *i.e.* an electrical circuit with series switch due to the simplicity of the design and the availability and reliability of components.

Table 1: Comparison between a crowbar and a series-resonant circuit, shown in Figure , in terms of basic properties.

No.	Parameter	Alternative 1	Alternative 2
1.	Output ripple	No ripple, just voltage droop	Ripple, but maybe less voltage droop.
2.	Cost	Lower	Higher
3.	Complexity	Low	High
4.	Delivery time	Short	Long
5.	Size	Small	Big

Crowbar versus series switch.
If we use crowbars the anode power supply will be out of service for many pulses after the crowbar has been triggered. The spoke cavity part of the ESS Linac is sensitive for missing RF-pulses and to improve reliability and we prefer to use a series switch instead of a crowbar to protect the amplifier.
The cost of a series switch is higher than for a crowbar.

The next step for the anode power supplies is to choose between single or dual output power supplies. The series-switch, which is a newer technology although still widely known, and will be feasible to use. Semiconductor switches are selected instead of series tubes for reasons of lifetime expectation.

Note that in either topology (single or dual output) an anode power supply wire-test is needed to ensure its correct operation during peak voltage and current values. A copper wire of 0.3 mm in diameter and 11 cm long is foreseen for such test.

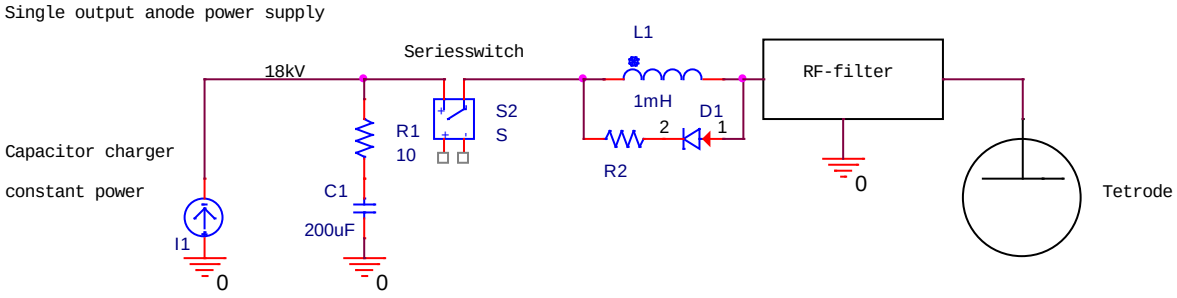


Figure 3: Single output power supply powering only one tetrode

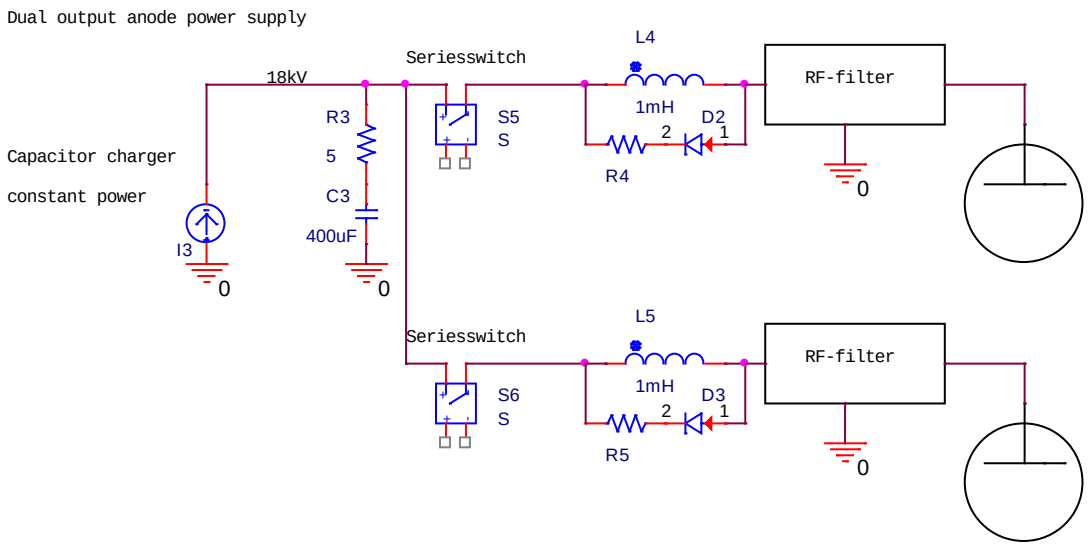


Figure 4: Dual output power supply powering two tetrodes.

From the comparison table (Table 2), we conclude that a dual output power supply for the anode is most suitable for our purposes, because even though both tetrodes would be inoperable if arcing or any other failure occurs, the reduction in price and space compensates for this loss.

Table 2: Comparison table between single and dual output power supply in terms of basic properties and performance.

No.	Parameter	One big power-supply powering the anodes of 2 tetrodes TH595 (one RF-system for one cavity).	Single power-supply powering the anode of a single tetrode TH595 (half of one RF-system for one cavity).
1.	Anode voltage	18 kV	18 kV
2.	Anode current	2 x 18 A pulsed (2 x 0.9 A CW)	18 A pulsed (0.9 A CW)
3.	Power	31 kW (DC)	16.5 kW (DC)
4.	Pulse width	3.3 ms	3.3 ms
5.	Frequency	14 Hz	14 Hz
6.	Size	1.8 m wide 0.8 m deep 2 m height	1.2 m wide 0.8 m deep 2 m height
7.	Cost	lower	higher
8.	Efficiency	90 %	90 %
9.	Type of series switch	Solid state switch	Solid state switch
10.	Possibility to operate one tetrode during failure of the other one	Worse	Good
11.	Possibility to service one power supply while the other one is faulting	None	Good

2.2 Filament power supply

One filament power supply for each tetrode that gives two for one amplifier system.
The requirements for the filament power supply are as follows:

1. Output voltage: 8.8 V AC 50 Hz single phase. Voltage accuracy better than +/- 2%
2. Output current: 190 Arms shall never exceed 250 A peak.
3. The filament power supply shall be able to work in black-heating mode i.e. 2.5 V output when amplifier is off.
4. The voltage shall be able to ramp the voltage from 0 V to 10 V in 8 minutes.
5. The filament power supply shall monitor the true rms output voltage.

In this case, high current and low voltage will lead to high losses if the current is rectified, therefore an AC output is the best choice. The transformer will be located close to the tetrode. The filament power supply can be voltage, current and power regulated.

2.3 Screen grid power supply

One screen grid power supply for each tetrode, that gives two for one amplifier system.
The screen grid power supply requires:

1. Positive output, voltage regulated and settable current limit.
2. Output voltage: 1300 V voltage regulated. Voltage accuracy +/- 1 %.
3. Output current 0.7 A. Current shall not exceed 1.05 A.
4. The output shall have spark-gap or varistor that limits voltage to 2 kV to ground.
5. A high voltage diode in series with the output and a 2kΩ high voltage resistor in parallel with the diode as the output should be protected from high voltage from the tetrode.
6. Quick shut off shall be possible in case there is a fault in the tetrode or when the series switch has opened.

2.4 Control grid power supply

One control grid power supply for each tetrode, that gives two for one amplifier system.
Finally, the power supply for the control grid needs to have the following characteristics:

1. Negative output voltage: 400 V voltage regulated and current limited.
2. Negative output current: 0.7 A Current (shall not exceed 1.05 A).
3. The output shall have spark-gap or varistor that limits voltage to 1 kV to ground.
4. A high voltage diode in series with the output and a 2kΩ high voltage resistor in parallel with the diode as the output should be protected from high voltage from the tetrode.

2.5 Control system

A common control system for all the power supplies of the type Siemens S7 is needed.

The control system will monitor the cooling with air and water for the amplifiers. An input for a reflected power shall be provided.
The control system will handle the switching on and off sequence of the power supplies and the voltage ramping of the filament voltage, set values for voltages of the power supplies and acquisition of them. Communication to the higher level control system is done via TCP/IP.

2.6 Total cost and time of delivery

(Costs are intentionally removed)

2.7 Maintenance and service

Well designed power supplies with semiconductors do not need regular service. There are no components that had to be replaced at regular intervals except fans. Long life fans can be operating for 200 khours.

The lifetime of the energy storing capacitor may be limited. Experinces show that they can have very long life like 30 years but manufacturer state a much shorter lifetime i.e 10 khours.

Conclusion

The anode power supply will have two outputs supplying two anodes. The short circuit protection will be done by a seriesswitch.

References

1. Rumbhara Yogi et al., 'Selection of RF power source and distribution scheme at 352 MHz for spoke cavities for ESS and at FREIA',2012
2. Thales