DESIGN AND MEASUREMENTS OF A FAST HIGH VOLTAGE PULSE GENERATOR FOR THE MEDAUSTRON LOW ENERGY TRANSFER LINE FAST DEFLECTOR

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Abstract

MedAustron, a centre for ion-therapy and research, will comprise an accelerator facility based on a synchrotron for the delivery of protons and light ions for cancer treatment. The Low Energy Beam Transfer line (LEBT) to the synchrotron contains an electrostatic fast deflector (EFE) which, when energized, deviates the continuous beam arriving from the ion source onto a Faraday Cup: the specified voltage is ±3.5 kV. De-energizing the EFE for variable pulse durations from 500 ns up to d.c. allows beam passage for multi-turn injection into the synchrotron. To maintain beam quality in the synchrotron, the EFE pulse generator requires rise and fall times of less than 300 ns between 90 % of peak voltage and a ±1 V level. To achieve this, a pulsed power supply (PKF), with high voltage MOSFET switches connected in a push-pull configuration, will be mounted in close proximity to the deflector itself. A fast, large dynamic range monitoring circuit will verify switching to the ±1 V level and subsequent flat bottom pulse quality. A prototype will be installed in the injector test stand in 2012; this paper presents the design and first measurements of the PKF and its monitoring circuit.

INTRODUCTION

In the MedAustron Low Energy Beam Transfer line (LEBT) an electrostatic fast deflector (EFE), comprising two electrodes, is used to chop the beam. When energized with a high voltage electric field between the EFE electrodes, the continuous beam arriving from the ion source is deflected onto a cylindrical Faraday Cup. De-energizing the EFE for variable pulse durations from 500 ns up to d.c. allows beam passage for multi-turn injection into the synchrotron. To achieve this, a ±3.5 kV pulsed power supply is used, employing four switches, two in push-pull configuration for each electrode (Fig. 1). The deflector/Faraday Cup assembly has been designed to allow a 90º rotation to sweep the beam in the vertical or horizontal plane if required. This excludes direct mounting of the switches on the EFE feedthroughs, hence the need for the connection cables, *+T2 and −T2*.

During beam transfer to the synchrotron, the values of the beam divergence at the downstream RFQ inlet and the beam displacement at the downstream solenoid must be kept below 255 µrad and 82 µm respectively. This requires that the residual field in the EFE must be below 22.2 V/m, corresponding to less than 2 V potential between the electrodes [1]. In addition, to optimize injection into the synchrotron, the beam must be switched from its position on the Faraday Cup on to the transfer trajectory in less than 300 ns, requiring a demanding voltage fall time from 90 % to ±1 V.

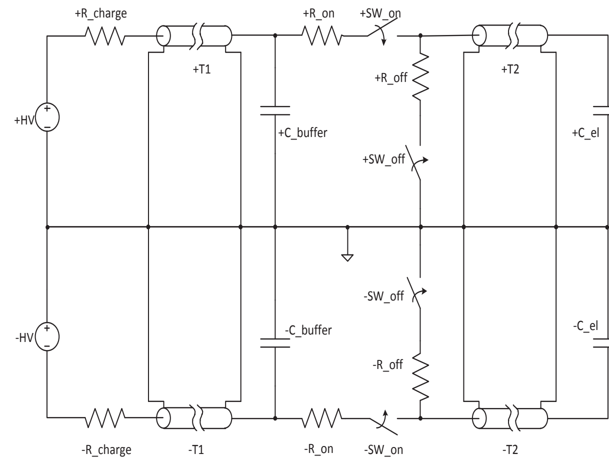

Figure 1: Simplified circuit showing both the positive and negative sections of the bipolar power supply.

Principal performance parameters of the pulsed power supply are shown in Table 1.

Table 1: Principal EFE Power Supply Parameters

Maximum electrode voltage	±3.5	kV
Maximum rise time (±1 V to 90 %)	300	ns
Maximum fall time (90 % to ±1 V)	300	ns
Maximum repetition rate	10	Hz
Maximum residual electrode voltage when switched off	±1	V

CIRCUIT DESIGN

Operating Principle

The basic circuit (Fig. 1) consists of a positive and a negative section which charge the positive and negative EFE electrodes, represented schematically as *+C_el* and *–C_el*, respectively. Considering the positive section, a buffer capacitor, *+C_buffer*, is charged to a predetermined voltage by a high voltage d.c. power supply, *+HV*. During non-injection periods the electrodes must be energised, hence the high voltage switch *+SW_off* is opened and the high voltage switch *+SW_on* is closed, so as to maintain voltage on the positive electrode; a similar configuration is applied to the negative section. Immediately prior to an injection, the high voltage switch *+SW_on* is opened, and the high voltage switch *+SW_off* is then closed. *+C_el* then discharges through *+R_off* to ground and, once the residual electrode voltage is in the range of ±1 V, a stable injection condition is achieved. This condition prevails for

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the desired injection period by maintaining this discharge configuration of the high voltage switches.

Once the injection period is finished *+SW_off* is opened and *+SW_on* is then closed. *+C_el* is then rapidly recharged by charge available from *+C_buffer* through the matching resistor *+R_on*.

Circuit Simulation

PSpice™ simulations were made initially with a generic circuit (Fig. 2), using ideal switches and estimates of parasitic inductances and capacitances.

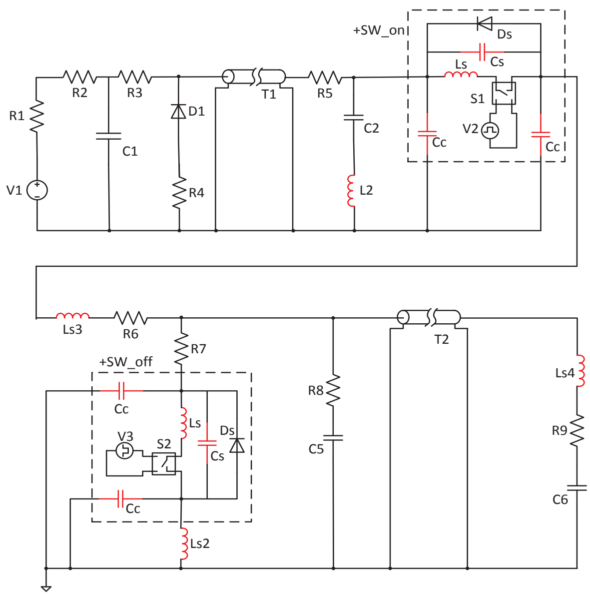

Figure 2: Simulation of generic circuit (positive section).

The coaxial cables used are all 50 Ω and have a delay of 5 ns/m. Figures 3 and 4 below show plots of rise and fall times, respectively, for various *T2* cable lengths: there is a strong dependency of the fall time on the length of the connecting cable *T2*.

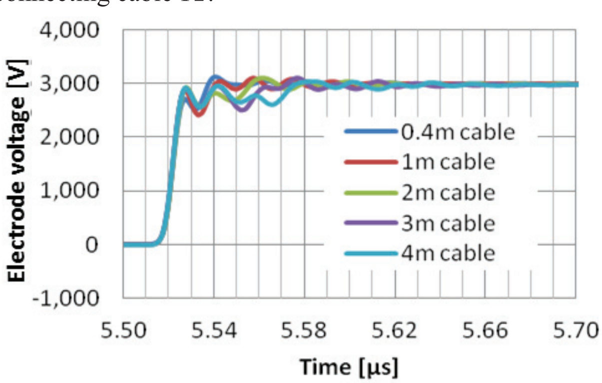

Figure 3: Rise times with varying lengths of *T2*.

Oscillations are present due to imperfect impedance matching of the cable to the load at its terminations, principally caused by the capacitive load (EFE), and the presence of parasitic inductances and capacitances, shown in red in Fig. 2. These oscillations elongate the rise and, particularly because of the critical ±1 V level, the fall times.

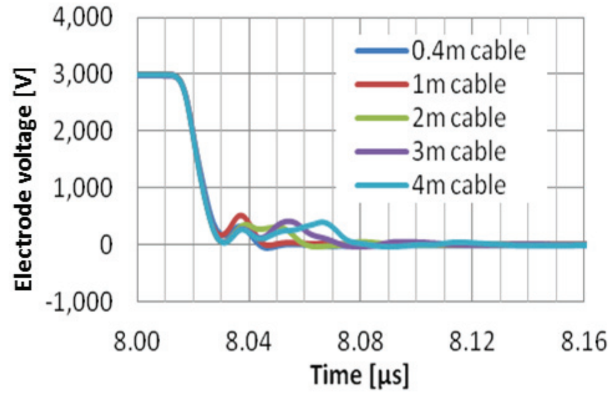

Figure 4: Fall times with varying lengths of *T2*.

Figure 5 shows a summary of the values of these rise and fall times versus cable length. For a fall time of less than 300 ns the cable length must be restricted to a maximum of approximately 4 m.

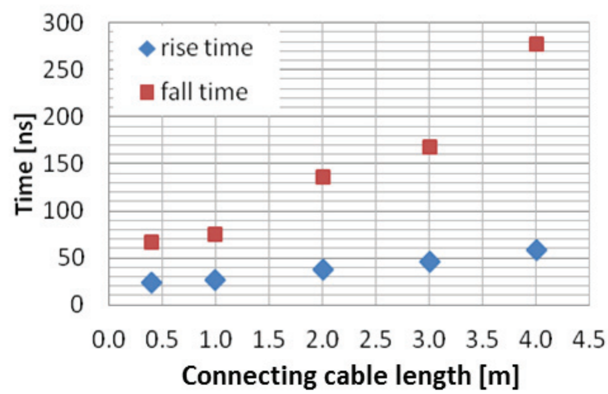

Figure 5: Rise and fall times vs. *T2* cable length.

MEASUREMENTS

Prototyping

A prototype circuit, using Behlke™ HTS 51-06 MOSFET devices as high voltage switches, has been constructed (Fig. 6). Individual switch packages have been chosen, rather than a push-pull switch package, to retain maximum flexibility in sequencing of the switch events.

A strong effort was made to reduce the stray inductance of the circuit, whilst respecting the necessary insulation distances to avoid high voltage tracking, in order to optimise the pulse integrity. A ground plane was used, wherever possible, on the printed circuit board (PCB). Nevertheless first measurements were dominated by electrical noise which required careful placement of the ground returns of the various measurement probes.

No detailed PSpice™ model was available from the manufacturer for the Behlke™ switches, however measured waveforms concur well with those given by simulations using a voltage controlled switch with an inductance of 20 nH in series and a parallel capacitance of 140 pF for the switch models.

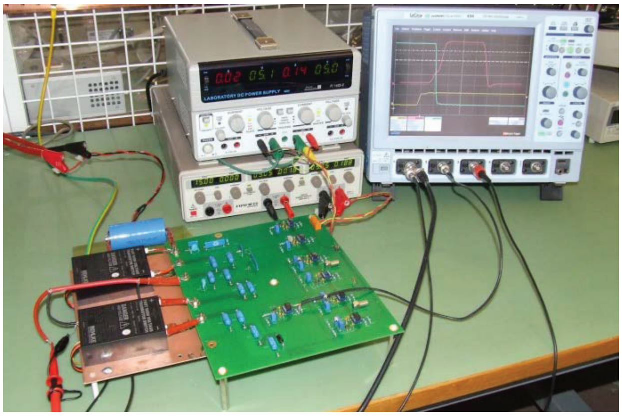

Figure 6: Configuration in laboratory with proper ground plane and simulated load (15 pF capacitor).

Monitoring of Pulse Flat Bottom

Measurement of the residual voltage on the electrodes, to a level of ±1 V during the pulse flat bottom, is required to ensure that the rise and fall times, and the stability of the flat bottom itself, are within specifications.

The dynamic range of the required measurement, ±3.5 kV to ±1 V, is very large and a number of methods to accomplish this were investigated. One idea was a high impedance voltage divider whose ratio could be switched dynamically between a high and a low value during the pulse rise and fall times to allow precise measurement of the ±1 V threshold crossing and subsequent flat bottom stability. This solution was not retained due to difficulty in implementing a switch to give an acceptable commutation time of less than 50 ns.

The chosen solution is similar; however it differs crucially in that use is made of the matching resistance of the turn-off switch branch to implement a low impedance voltage divider which is used in conjunction with a Transient Voltage Suppressor Diode (TVSD) to provide commutation of the divider ratio (Fig. 7).

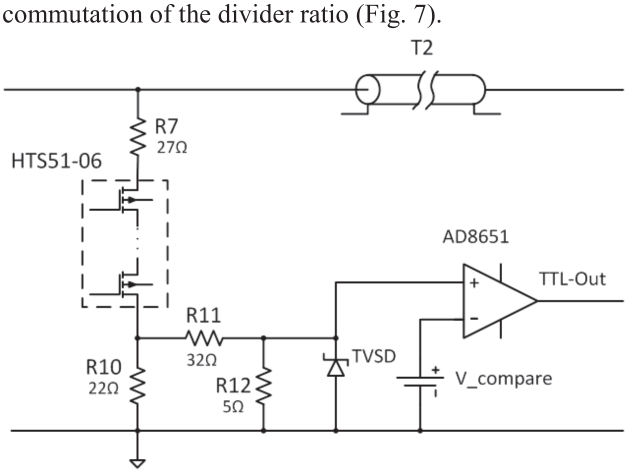

Figure 7: Section from schematic showing measurement circuit for flat bottom.

During turn-off, the EFE discharges through the voltage divider formed by *R7*, *R10*, *R11* and *R12*. The TVSD clamps the positive comparator input to a maximum of 8 V until the pulse amplitude on the EFE is below a value of 200 V, at which time the TVSD comes out of conduction and the comparator input voltage starts to decline in proportion to the electrode voltage. By setting the negative comparator input, *V_compare* to approximately 40 mV the +1 V level on the electrode can be detected. The TVSD, a 1N5908, has a typical response time of 1 ns, surge current rating of 200 A and a typical, linearized, capacitance of 9.5 nF: the value of *R12* is chosen as 5 Ω in order to keep the time constant below 50 ns.

The voltage divider also serves as the matching resistor for the transmission line *T2*. The on-state resistance of the HTS 51-06 is current dependent, the datasheet gives a range of 5 Ω to 11 Ω, hence the matching resistance for *T2* is non-linear. However, PSpice™ predictions show acceptable ripple in the post pulse period. The measured fall time is 319 ns (Fig. 8): this is outside the 300 ns specification, however the measured value is increased due to the presence of a filter circuit with a 50 ns time constant (not shown in Fig. 7) on the comparator input.

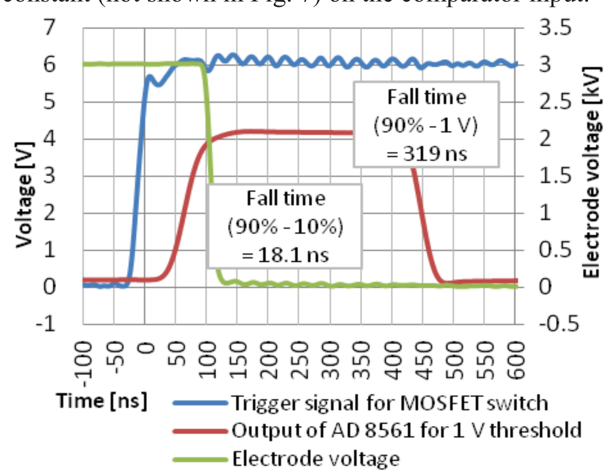

Figure 8: Measurements for circuit shown in Fig. 6.

Confirmation of the fall time using an independent measurement has proved to be difficult: all fast high voltage probes tried to date exhibit some measurement aberrations at very low amplitudes.

CONCLUSION

The electrical design for the high voltage circuit and the monitoring for the PKF of the EFE is completed. Tests and measurements are in good agreement with the simulations and the requirements are met. The PCB will be redesigned to minimize the overall size and reduce stray inductances. Further efforts are still required to independently verify and calibrate the fall time obtained from the comparator circuit. First tests of the EFE device with the power supply will be made in the MedAustron test stand during 2012.

REFERENCES

[1] J. Borburgh, T. Fowler, A. Prost, T. Kramer, T. Stadlbauer, "Design of electrostatic septa and fast deflector for MedAustron", Proc. IPAC'11.

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