A HIGH VOLTAGE SEMICONDUCTOR SWITCHED E-FIELD BEAM KICKER FOR THE ISIS SURFACE MUON FACILITY

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Abstract

A proposal to upgrade the Isis Surface Muon Facility at the Rutherford Appleton Laboratory calls for a new large aperture muon beam kicker and associated pulsed power supply. A description is given of a fast switched E-field kicker, and an associated bipolar, ± 40 kV, pulsed power supply. The high voltage, discharge mode power supply design is simplified by the utilisation of novel fast switching high voltage MOSFET stacks.

1 INTRODUCTION

The ISIS Surface Muon Facility, as commissioned in 1987 , delivered a beam of positive muons with a mean momentum of 26.5 MeV/c, and a double pulse time structure of 82 ns pulse width at half maximum (fwhm), and 320 ns peak separation, to a single user area, at a pulse repetition frequency (prf) of 50 Hz.

In 1989, the periodic gaps in the range of available frequencies for muon spin resonance (μSR) measurement, arising from the double pulse structure, were eliminated, (with a consequent loss of beam intensity), by the addition of a fast E-field beam chopper (Uppset), that removed the interfering second beam pulse [1].

A major facility upgrade, funded by the CEC large facilities program and commissioned in 1994, was prompted by a three-fold over-subscription for beam time, and utilised a fast switching E-field kicker-chopper to distribute the muon pulse pair to three user areas, each capable of simultaneous single pulse operation at a prf of 50 Hz [2].

A recent proposal [3], prompted by the need to address the impact on the existing facility of the planned 200 to 300μA ISIS upgrade , and the current interest in the use of low energy muons for the study of thin films and multi-layers , identified the following objectives and the actions required to achieve them:

(a) To provide a new source of low energy (slow) muons (10eV - 20 keV), by adding a large aperture E-field kicker, septum magnet, beam-line, and user area to the existing facility.

(b) To maintain or increase the muon transmission to the three existing user areas (‘MuSR’, ‘EMu’, and ‘DeVA’) by replacing selected beam-line quadrupoles with a larger aperture design (CERN type M9).

(c) To increase the upper cut-off frequency for μSR measurements in the existing user areas by using the existing, but slightly modified EC muon kicker, in a new chopper-kicker mode.

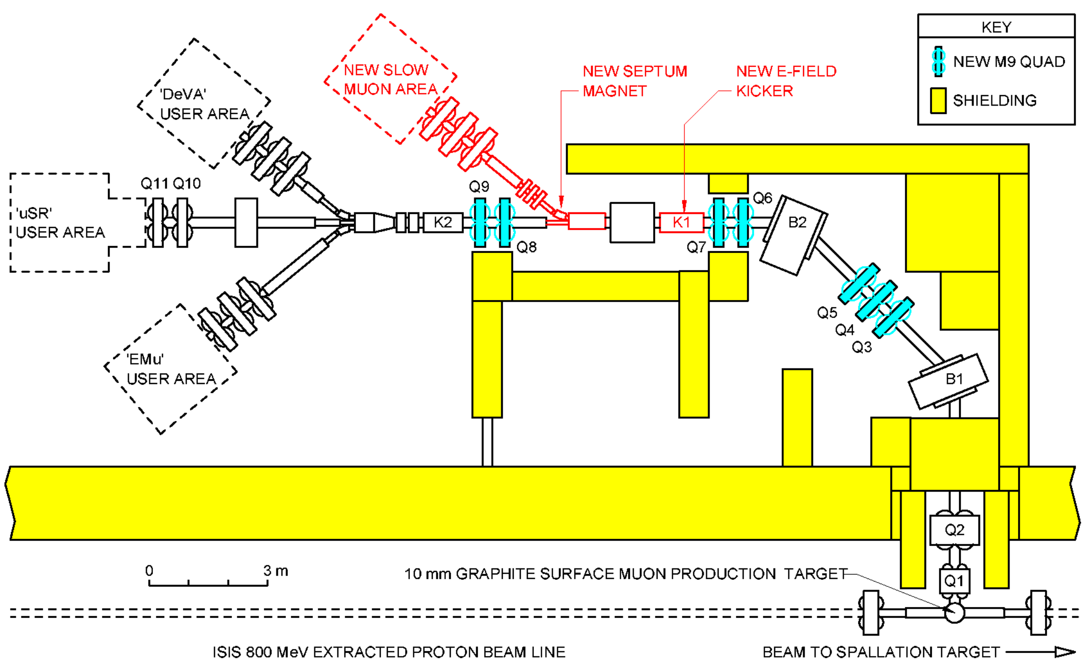

Figure 1: ISIS Surface Muon Facility

2 MODE OF OPERATION

A plan view, and schematic of the upgraded muon facility are shown in figures 1, and 2(a), with the new, and existing kickers labelled as K1 and K2, respectively. Operation of the facility is shown schematically in figure 2(b). Note that beam transit time has been ignored, to simplify the figure.

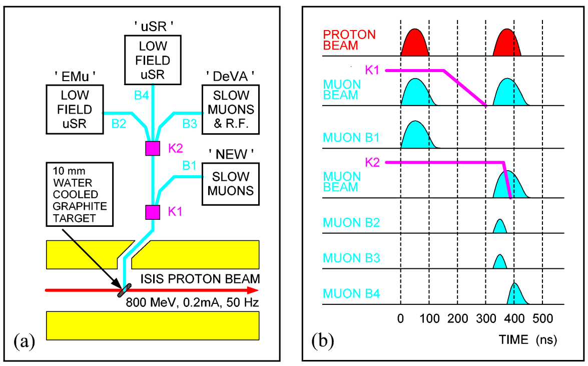

Figure 2: Facility schematic and mode of operation

At t = 0ns, K1 and K2 are at full field level. During the period t = 0 to 120ns, the first muon pulse is deflected by K1, and transported by beam-line B1 to the 'NEW' slow muon area. At t = 120ns, the field at K1 starts to decay, and reaches ~ 0.2% of the initial value at t = 320ns. During the period t = 320 to 450ns, the second muon pulse passes through K1 un-deflected. During the period t = 320 to 360ns, the first half of the second muon pulse is bisected and deflected by K2, and transported by beam-lines B2 and B3 to the 'EMu' and 'DeVA' areas. During the period t = 360 to 380ns, the field at K2 decays, and the last half of the second muon pulse passes through K2 un-deflected, via beam-line B4 to the uSR area. A recent test in the 'uSR' user area, with K2 operating in the new chopper-kicker mode, showed that the upper frequency limit for μSR measurements was increased from ~8 to ~14 MHz.

Existing and upgraded ISIS facility μ+ beam characteristics are shown in table 1.

Table 1: ISIS facility μ+ beam characteristics

ISIS User Area	Pulse Width fwhm (ns)		μSR cut-off Freq. (MHz)		μ+ / pulse (@ 50 Hz)	
	Now	Upgd	Now	Upgd	Now	Upgd
NEW	-	80	-	8	-	3.5e4
EMu	80	30	8	20	0.5e4	0.7e4
DeVA	80	30	8	20	0.5e4	0.7e4
uSR	80	45	8	14	1.0e4	1.4e4

3 KICKER DESIGN

The key specifications shown in table 2 were obtained after optimisation of the muon facility beam line design, to provide a minimised beam width at the input and output of the kicker and at the downstream septum magnet, and application of the standard equations for field (E) and transverse displacement (y), where q is the electronic charge, V is the muon velocity, m_0 is the muon rest mass, x is the electrode length, and θ is the required deflection angle,

$$E = \tan\theta \cdot m_0 \cdot \frac{V^2}{q \cdot x} \text{ , and } y = \frac{q \cdot E \cdot x^2}{2 \cdot m_0 \cdot V^2}$$

Table 2: Kicker specification

			x (cm)	y (cm)
Beam size at kicker input (100%)			14	24
Beam size at kicker output (100%)			9	22
Beam size at septum input (100%)			8	8
Deflection (mrad)	70	Electrode length (m)	0.9	
Displacement (cm)	3.2	Electrode gap (m)	0.15	
Field (MV/m)	0.49	Electrode height (m)	0.3	
Potential (kV)	73.0	Capacitance (pF)	53	

A preliminary mechanical layout for the proposed large aperture kicker is shown in figure 3. The parallel plate design is configured for bipolar drive at ± 36.5 kV, and presents a load capacitance of ~ 53 pF on each electrode. In-vacuum components, subject to high electric fields will be designed to reduce field level to less than 5 MV/m. Base mounted discharge mode power supplies will limit load capacitance to the level required for successful high voltage MOSFET switch application.

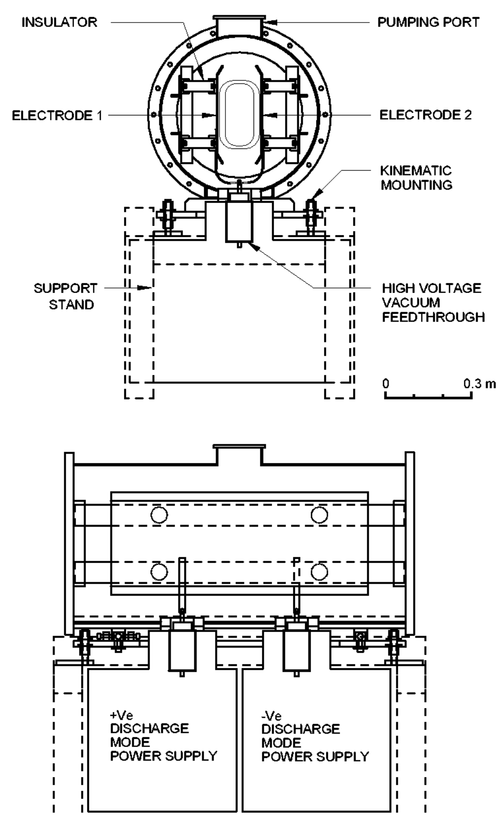

Figure 3: Large aperture kicker (end and side views)

4 PULSED POWER SUPPLY DESIGN

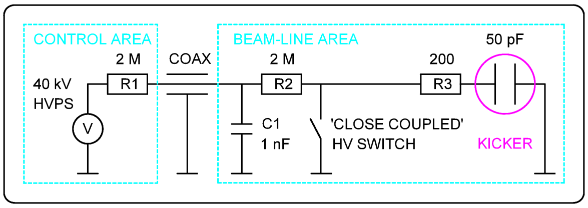

Figure 4: Discharge mode pulsed power supply

The basic elements of the discharge mode circuit are shown in figure 4. The circuit is suitable for low duty cycle kicker applications [4], and uses a 'stock', constant voltage mode, high voltage power supply (HVPS). The 'close coupled' configuration minimises high voltage switch power dissipation and is hence, most suitable for a low power MOSFET switch application [5].

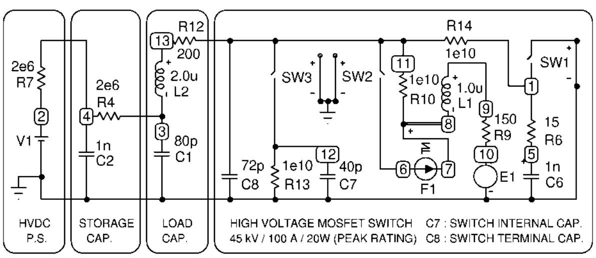

Figure 5: Discharge mode circuit model

A circuit schematic for the discharge mode power supply model is shown in figure 5. The electrode voltage waveform v(3), and switch current I(R9) during discharge, are shown in figure 6. At t = 0ns, the electrode capacitance C1 is charged to ~ V1, and SW1, 2, and 3 are open. At t = 30ns, electrode discharge is initiated by closure of SW1 and 2. The voltage at node 5, initially at ~ V1, decays with MOSFET switch turn-on time constant C6*R6 (15ns). This voltage, mirrored at the output of the dependent source E1, sinks current via the MOSFET series on resistance R9, inductance L1 and current limit F1, from electrode capacitance C1 via external current limiting resistor R12 and inductance L2. At t = 230ns, v(3) has decayed to ~ 0.2% of V1. At t = 300ns, SW1 and 2 open, SW3 closes, and C1 charges via R4, C2, and R7, back to V1. Power loss in the MOSFET switch is ~ 4 W at a prf of 50 Hz .

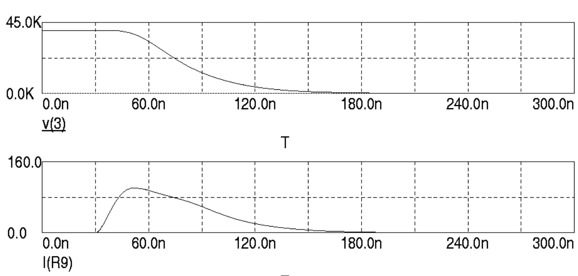

Figure 6: Electrode voltage and switch current

Charging waveforms are shown in figure 7.

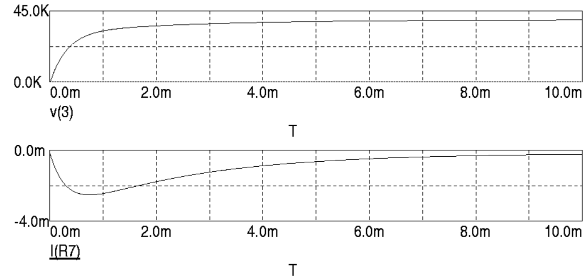

Figure 7: Electrode voltage and HVPS current

5 SUMMARY

A large aperture E-field kicker and discharge mode power supply have been designed to provide a new source of low energy muons at ISIS. The use of commercially available high voltage MOSFET switches in the power supply design, is expected to reduce circuit complexity and cost [6]. A test rig, to determine long term switch reliability, has been designed and will be run in the near future.

In conclusion, it is clear that E-field kicker-chopper technology will make a key contribution to the economic realisation of the next generation of multi-station surface muon facilities [7].

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