THE DEVELOPMENT OF A FAST BEAM CHOPPER FOR NEXT GENERATION HIGH POWER PROTON DRIVERS

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Abstract

The Front End Test Stand (FETS) project at RAL will test a fast beam chopper, designed to address the requirements of high-power proton drivers for next generation pulsed spallation sources and neutrino factories. The RAL chopping scheme for the ESS 2.5 MeV, 280 MHz, Medium Energy Beam Transport (MEBT) line [1] is evolving to address the requirements of the 3.0 MeV, 324 MHz FETS project. The recent adoption of a more efficient optical design for the FETS MEBT [2] will result in a useful increase in beam aperture and permit an important reduction in the amplitude of the chopper E-fields. A description is given of 'state of the art' high voltage pulse generators, designed to address the FETS chopper requirement. Measurements of output waveform and timing stability are presented.

INTRODUCTION

Proton driver specifications for the next generation of spallation neutron sources, neutrino factories, and waste transmutation plants, call for more than an order of magnitude increase in beam power, typically from ~ 0.16 to ~ 5 MW [3]. For the linac-accumulator or linac-synchrotron schemes, beam loss at ring injection and extraction, and the consequent activation of components, can be minimised by a programmed population of ring longitudinal phase space, produced by 'chopping' the linac beam at low energy. The 'chopper' is required to produce precisely defined gaps in the bunched linac beam, and the chopping field must therefore rise and fall within, and be synchronous with, bunch intervals that are typically just a few nanoseconds in duration .

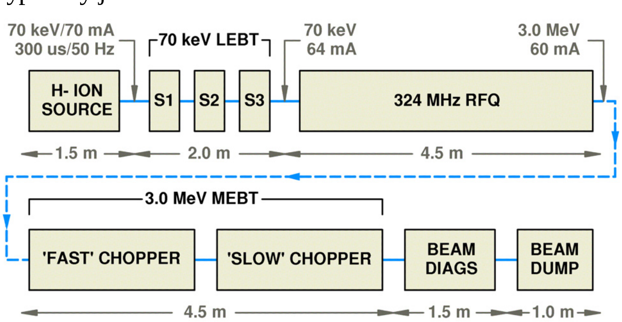

Figure 1: FETS beam line block schematic.

The FETS project, a UK based collaboration involving RAL, Imperial College London, and the University of Warwick, will test a fast beam chopper in a high duty factor MEBT line [4]. The key components, as shown in Figure 1 are: an upgraded ISIS 'Penning' ion source, a three solenoid Low Energy Transport (LEBT) line, a high duty factor 324 MHz Radio Frequency Quadrupole (RFQ), a novel two stage beam chopper, and a suite of beam diagnostic instruments. The specification, as shown in Table 1, calls for significant technical development in attempting to address the generic, and specific requirements for a next generation proton driver and a 0.16 to 0.5 MW upgrade for ISIS [5], respectively.

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Table 1: FETS Parameters

Parameters		Parameters	
Ion species	H^-	RFQ input energy	70 keV
RFQ output energy	3.0 MeV	MEBT beam current	60 mA
Beam pulse duration	0.2 - 2 ms	RF frequency	324 MHz
Beam pulse repetition frequency			50 Hz
MEBT chopper field transition time (10-90 %)			2 ns
Chopped beam duration			0.25-100 μs
Chopper pulse repetition frequency			1.3 MHz

TWO STAGE CHOPPING

A block and timing schematic of the proposed two stage chopping scheme as developed for the European Spallation Source (ESS) [6, 7], is shown in Figure 2. This novel configuration addresses the conflicting chopping field requirements of fast transition time (~ 2 ns) and long duration (~ 0.1 ms), with the tandem combination of 'fast' transition time short duration, and slow transition time long duration, fields. The upstream chopping field is generated by a pair of AC coupled 'fast' transition time

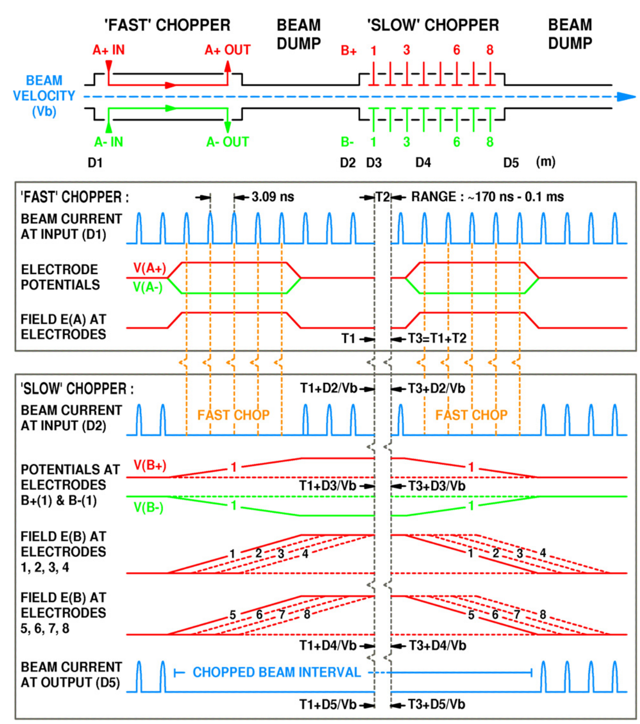

Figure 2: Two stage chopper timing schematic.

pulse generators (FPG) that output high voltage, dual polarity pulses into a transmission line electrode structure [8], where partial chopping of beam bunches is avoided by ensuring that the deflecting E-field propagates at the beam velocity. The 'fast' chopper deflects just five bunches at the beginning and end of each chopped beam interval, creating two ~ 18 ns gaps in the bunch train. These gaps ensure that partial chopping of beam bunches is avoided in the downstream 'slow' chopper, whose field is generated by eight pairs of DC coupled, 'slow' transition time pulse generators (SPG) that output high voltage dual polarity pulses to a set of discrete, close-coupled, electrodes. The 'slow' chopper generates a long duration E-field that deflects the remaining bunches in each chopping interval. Deflected beam is directed to dedicated beam 'dumps' situated immediately downstream of the fast and slow electrode structures

'FAST' & 'SLOW' PULSE GENERATORS

A block schematic of the high voltage pulse generator system for the FETS beam chopper is shown in Figure 3.

FPG Development and Waveforms

The FPG is a high voltage pulse generator, designed and manufactured in the UK [9], to meet the specification for the previous ESS fast chopper [7]. Measured performance parameters as shown in Table 2, and Figures 4, and 5, indicate that the design is generally compliant with the RAL FETS requirements. However, the AC

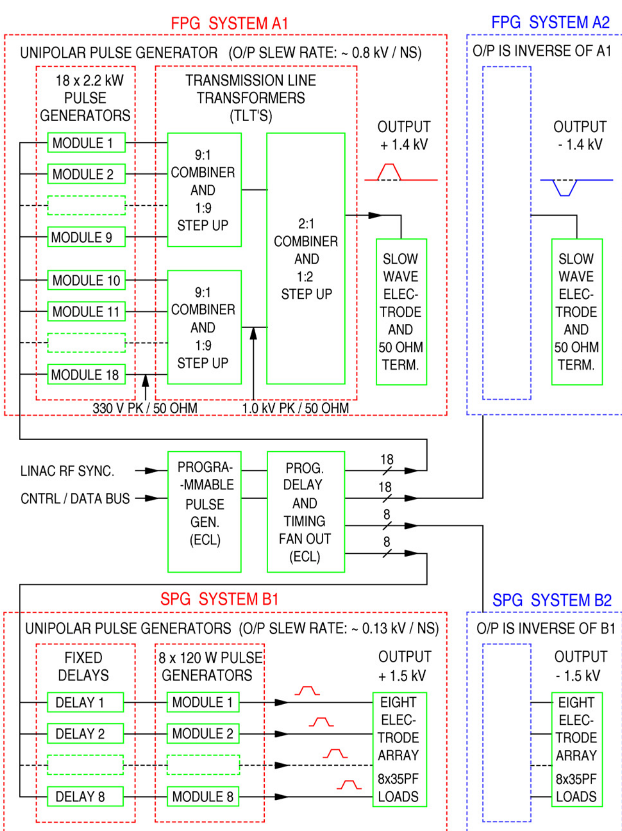

Figure 3: Fast and slow pulse generator block diagram.

Table 2: FPG / Measured performance parameters

Parameters		Parameters	
Pulse amplitude	± 1.5 kV	Pulse repetition freq.	2.6 MHz
Load	2 x 50 Ω	Burst duration	1.5 ms
Duty cycle	0.27 %	Burst repetition freq.	50 Hz
Transition time	≤ 2.0 ns	Timing stability (1 hour)	± 50 ps
Pulse duration	10-15 ns	Burst amplitude stability	+10, -5 %
Pulse droop	2% in 10 ns	Post pulse aberration	± 5 %

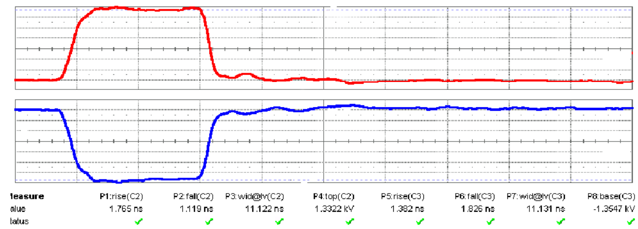

Figure 4: FPG waveforms at ± 1.4 kV peak & 5 ns/div.

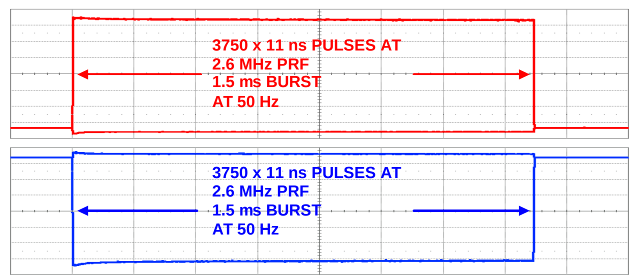

Figure 5: FPG waveforms at ± 1.4 kV peak & 0.2 ms/div.

coupled unipolar nature of the FPG, places an upper limit on output pulse duration, and introduces a low frequency (LF) cut-off and duty cycle dependent shift in baseline potential, as shown in Figure 6. A scheme to compensate

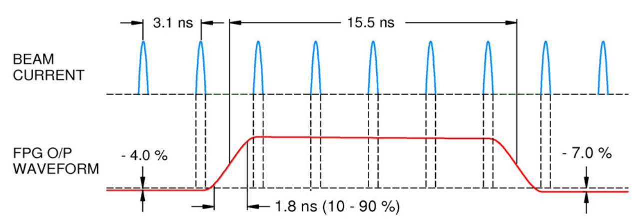

Figure 6: FPG baseline shift for five bunch chopping.

for the duty cycle induced baseline shift, for the case of a fixed or slowly varying duty cycle, has been described [10], and indicates that the resulting residual baseline shift due to LF cut-off can be balanced around the zero volt level, giving values of ± 1.5 % for five bunch chopping in the FETS MEBT. For the case of a rapidly varying duty cycle, duty cycle induced baseline shift can be eliminated, by utilising an FPG with a bipolar output pulse, resulting in alternate beam bunches, or sets of beam bunches, being deflected, in opposite directions [11].

SPG Development and Waveforms

The FETS SPG is a DC coupled high voltage pulse generator, based on an 'off the shelf', 'push-pull' high voltage MOSFET switch module [12]. Previous measurements of the performance of an 8 kV rated switch had shown that when operated at 6 kV, pulse transition times increased, and durations decreased, during the first 20 us of the burst, characteristics that were significantly non-compliant with the ESS SPG specification [10]. However, the new ‘Scheme A’ optical design for the FETS MEBT significantly lowers the SPG voltage requirement from ± 6.0 to ± 1.5 kV, and consequently, the most recent measurements have been made on a lower voltage, 4 kV rated MOSFET switch [12]. Measured parameters as listed in Table 3, and output waveforms as shown in Figures 7, and 8, show that the switch performance is generally compliant with the FETS specification at a burst repetition frequency (BRF) of 25 Hz. A power supply and cooling upgrade should enable testing at the full BRF of 50 Hz. Measurement of pulse duration during the burst, as shown in Figure 9, indicates that there is a step change in the pulse duration between the first pulse in the burst and subsequent pulses, and that the change in duration between the second pulse in the burst and subsequent 500 pulses is then, less than ~ 1 ns. Although these shifts in pulse duration are not compliant with the required specification, they can be corrected by a programmable compensation technique.

Table 3: SPG / Measured Performance Parameters

Parameters		Parameters	
Pulse amplitude	4.0 kV	Pulse repetition freq.	1.3 MHz
Load	20 pF & 50 nH	Burst duration	1.0 ms
Duty cycle	1.7 %	Burst repetition freq.	25 Hz
Transition time	≤ 12.0 ns	Timing stability (1 hour)	± 0.3 ns
Pulse duration	0.17-100 µs	Burst amplitude stability	< +10, -5 %
Pulse droop	DC coupled	Post pulse aberration	< ± 5 %

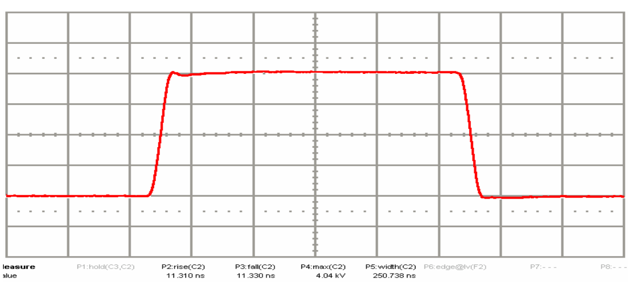

Figure 7: SPG waveforms at 4.0 kV peak & 50 ns /div.

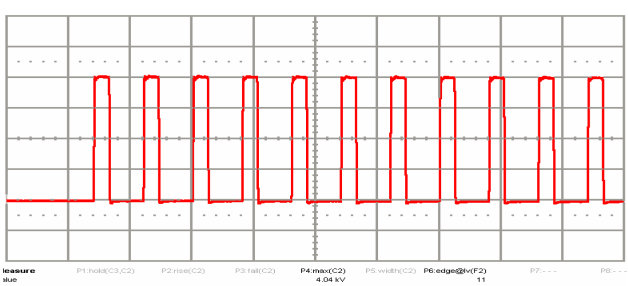

Figure 8: SPG waveforms at 4.0 kV peak & 1.0 µs /div.

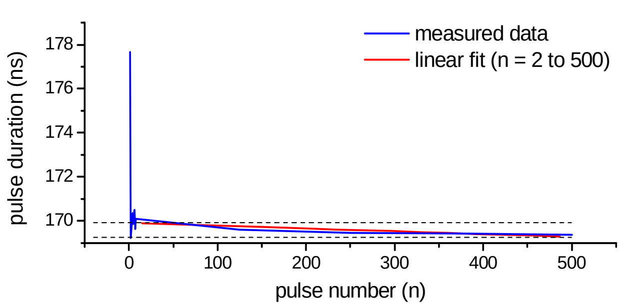

Figure 9: SPG pulse duration vs. pulse number.

SUMMARY

Measured performance parameters, for the FPG as listed in Table 2, indicate that the design is generally compliant with the FETS specification. Passive techniques to reduce post-pulse aberration can be implemented when the precise configuration of the load circuit is determined. A compensation scheme to reduce the duty cycle induced baseline shift in potential to ± 1.5 % of peak pulse amplitude has been identified [10].

Measured performance parameters for the SPG as listed in Table 3, indicate that the 4 kV rated switch is generally compliant with the RAL FETS specification. The new ‘Scheme A’ optical design for the FETS MEBT significantly lowers the SPG voltage requirement to ± 1.5 kV for a bipolar, or 3.0 kV for a unipolar SPG implementation. The results of the 4 kV SPG tests indicate that a unipolar implementation of the ‘slow’ chopper, may now be viewed as a practical possibility.

REFERENCES

[1] M Clarke-Gayther, ‘A Fast Beam Chopper for Next Generation High Power Proton Drivers’, EPAC 04.

[2] M Clarke-Gayther, G Bellodi, F Gerigk, ‘A fast beam chopper for the RAL Front-End Test Stand’, Proc. of EPAC 2006, pp. 300-302.

[3] W Chou, ‘Spallation Neutron Source and other high intensity proton sources’, FNAL Report no. FERMILAB-Conf-03/012.

[4] A Letchford et al, ‘Status report on the RAL front-end test stand’, Proc. of PAC 2007, pp. 1634-1637.

[5] C Prior, ‘Upgrades to the ISIS Spallation Neutron Source’, Proc. of APAC 07, pp. 300-304.

[6] ‘The ESS Project, Volume III Update: Technical Report – Status 2003’, ISBN 3-89336-345-9.

[7] M Clarke-Gayther, ‘‘Fast-Slow’ beam chopping for next generation high power proton drivers’, Proc. of PAC 2005, pp. 3635-3637.

[8] M Clarke-Gayther, ‘Slow-wave chopper structures for next generation high power proton drivers’, Proc. of PAC 2007, pp. 1637-1639.

[9] Kentech Instruments Ltd., Isis Building, Howbery Park, Wallingford, Oxfordshire, OX10 8BA, U.K.

[10] M Clarke-Gayther, ‘HIPPI Work Package 4 (WP4): The RAL Fast Beam Chopper Development Programme / Progress Report for the period July 05 - December 06’, CARE-Note-2007-002-HIPPI.

[11] M Clarke-Gayther, ‘Modulator systems for the ESS 2.5 MeV fast chopper’, PAC 2001, pp. 4062 - 4064.

[12] Model No. HTS 41-06-GSM-CF-HFS, Behlke Electronic GmbH, 61476 Kronberg, Germany.