A FAST CHOPPER FOR THE ESS 2.5 MeV BEAM TRANSPORT LINE

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Abstract

Beam chopping requirements in the proposed European Spallation Source (ESS) 2.5 MeV beam transport lines are challenging. Stringent beam loss restrictions in the downstream linacs and accumulator rings dictate that partial chopping of the high current 280 MHz bunched H- beam must be minimised. A description is given of a modulation scheme where the required time dependent chopped beam structure is generated by a fast transition, short duration, pulsed E-field in a distributed element slow-wave chopper, followed by a slower transition, long duration, pulsed E-field in a lumped element slow-wave chopper. Candidate modulator systems are identified.

1 INTRODUCTION

The European Spallation Source (ESS) [1], is the most ambitious of the existing proposals for the next generation of accelerator driven pulsed neutron sources [2]. Designed to address the rapid expansion in the field of condensed matter research, the ESS accelerator will generate intense, fast pulsed, beams of neutrons by delivering up to 10 MW of protons to short pulse (5 MW, ~ 1.2 us), and long pulse (5 MW, ~ 2.0 ms) liquid mercury targets.

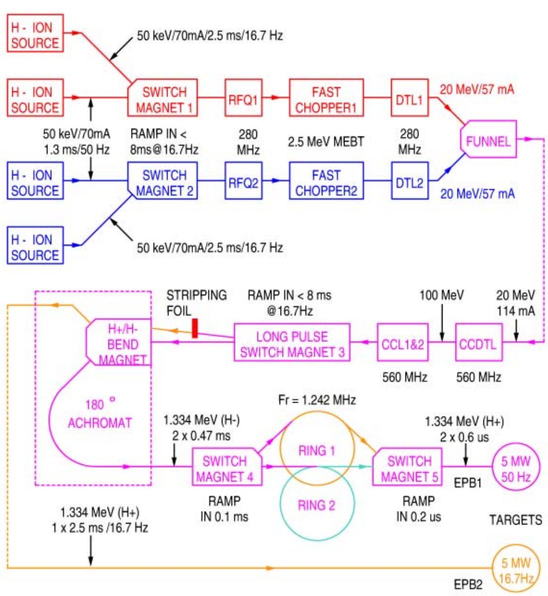

Figure 1: ESS block schematic

Components of the ESS, are shown in schematic form in Figure 1. The low beam loss (< 1 nA/m @ 1.334 MeV) design features a high current H- linac, and twin accumulator rings with sequential charge exchange injection and sequential fast extraction.

The time dependent function of the fast choppers, switching and fast extraction magnets, is shown in Figures 2 and 3, where the 'history' of a beam pulse is traced from RFQ to target, over a linac cycle. The seven short pulse chopping regimes listed in Figure 2, are described in Table 1, and the four long pulse chopping regimes listed in Figure 3, are described in Table 2.

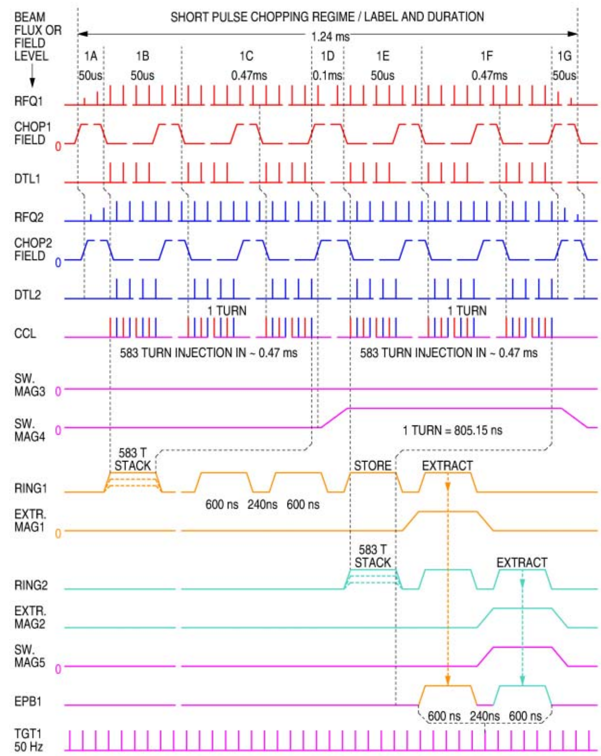

Figure 2: Short pulse beam chopping and switching

Table 1: ESS short pulse chopping regimes

Label (fig.2)	Chopping Regime	Dura--tion	Chopper Duty Cycle		No. of Turns*	Function
			On time	Off time		
A	Ion source transition	50µs	50 µs	0	60	Gates low intensity beam
B	Beam duty cycle ramping	50µs	803.57 ns to 241.1 ns	0 to 563.8 ns	60	Limits linac beam loading transient
C	Ring 1 stacking	0.5 ms	241.1 ns	563.8 ns	583	Gaps for fast extraction
D	Ring switching	0.1 ms	0.1 ms	0	120	Gap for ring switching
E	Beam duty cycle ramping	50µs	803.57 ns to 241.1 ns	0 to 563.8 ns	60	Limits linac beam loading transient
F	Ring 2 stacking	0.5 ms	241.1 ns	563.8 ns	583	Gaps for fast extraction
G	Ion source transition	50µs	50 µs	0	60	Gates low intensity beam

* One accumulator ring revolution period = 803.57 ns

Stringent beam loss requirements dictate that the chopping field in the 2.5 MeV transport line rises and falls within the beam bunch interval of 2.9 ns (1 - 90%). In addition, the field duration must be rapidly programmable in the range 240 ns - 0.1 ms (see Tables 1, 2).

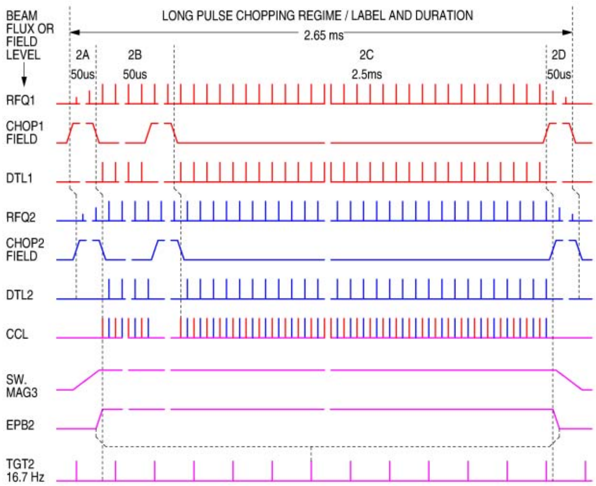

Figure 3: Long pulse chopping and switching

Table 2: ESS long pulse chopping regimes

Label (fig.2)	Chopping Regime	Dura- -tion	Chopper Duty Cycle On time	Chopper Duty Cycle Off time	No. of Turns*	Function
A	Ion source transition	50µs	50 µs	0	-	Gates low intensity beam
B	Beam duty cycle ramping	50µs	805.15 ns to 241.1 ns	0 to 563.8 ns	-	Limits linac beam loading transient
C	Beam to long pulse target	2.0ms	241.1 ns	563.ns	-	Maintains short pulse linac beam loading
D	Ion source transition	50µs	50 µs	0	-	Gates low intensity beam

2 MODULATION SCHEME

Slow wave (E-field) transmission line structures have demonstrated field transition times in the nanosecond regime [3, 4], and an ESS chopping scheme utilising these structures has been identified [5]. The scheme has been refined, following the recent addition of the long pulse target option to the ESS specification, and a block schematic of the proposed chopper beam line is shown in Figure 4. The new beam line design provides space for an additional chopper sub-system that permits a halving in sub-system pulse repetition frequency, and beam dump dissipation.

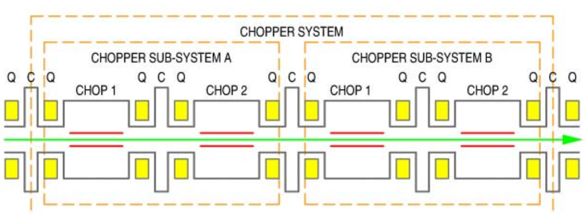

Figure 4: 2.5 MeV Chopper beam line layout

Beam trajectories, and a timing schematic for the proposed scheme are shown in figures 5 and 6 respectively, where slow wave chopper 1, produces a bipolar, pulsed field that deflects just two adjacent bunches through ± 16 mr, to beam dumps 1 and 2 (BD1, BD2), creating two ~ 10 ns duration gaps in the bunch train, at the beginning and end of each chopped beam interval. Modulator peak power is ~ 39 kW, but the low duty cycle results in a mean power requirement of only 25 W.

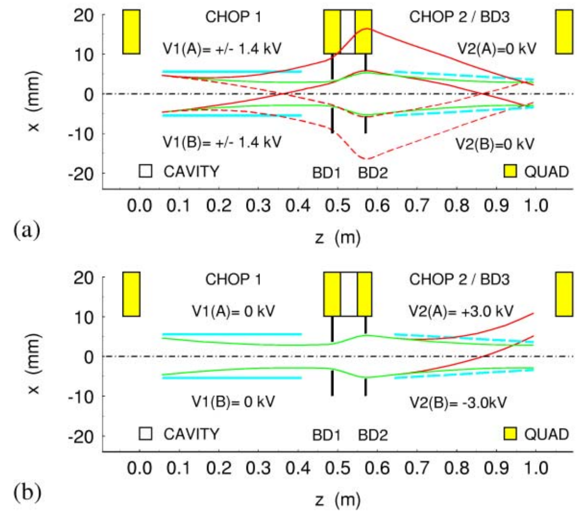

Figure 5: Beam trajectories
(a) Fast transition pre-chopping - beam to BD1&2.
(b) Slower transition chopping - beam to BD3.

The chopper 2, slow wave, lumped element array (6 pairs of 6 cm long electrodes), produces a unipolar, pulsed field that deflects the beam through 47 mr to a water-cooled electrode / beam dump array (BD3).

The chopper 2 modulators (12 x switch modules) are limited to transition times of ~ 8 ns. Pre-chopping in chopper 1 ensures that no partially chopped bunches result from the slower field transition time of chopper 2. Each switch module will dissipate ~ 60 W mean, with chopper 1 electrodes, BD1, 2, and 3 dissipating beam powers of ~ 27, ~ 78, ~ 27, and ~ 3530 W, respectively.

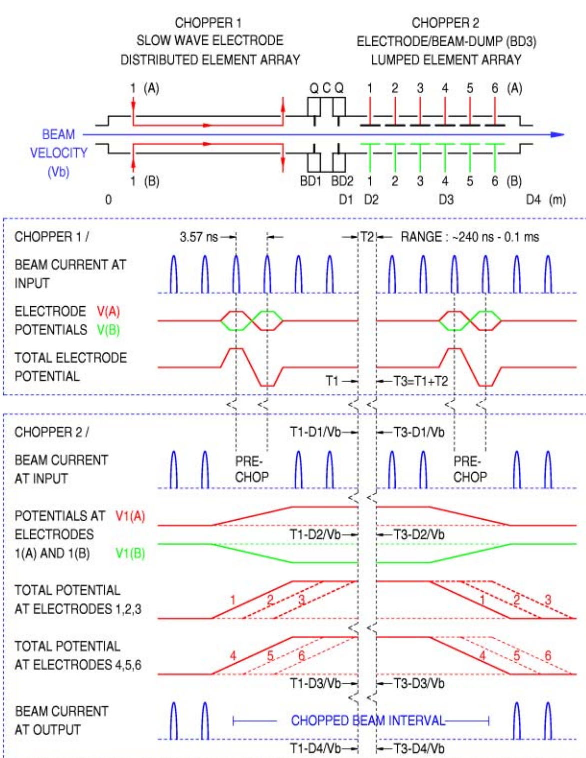

Figure 6: Timing schematic

3 MODULATOR DESIGN

A block schematic of the proposed fast chopper modulator system, is shown in Figure 7. Systems 1A and 1B drive chopper 1A and 1B distributed slow wave electrodes (see Figure 6), and output fast transition (~ 2 ns), quasi-trapezoidal, bipolar high voltage pulses (± 1.4 kV) into a 50 Ω load. The modular configuration makes extensive use of high power transmission line transformers (TLT) to match impedance, and combine, the outputs from 32 solid-state high voltage pulse generators.

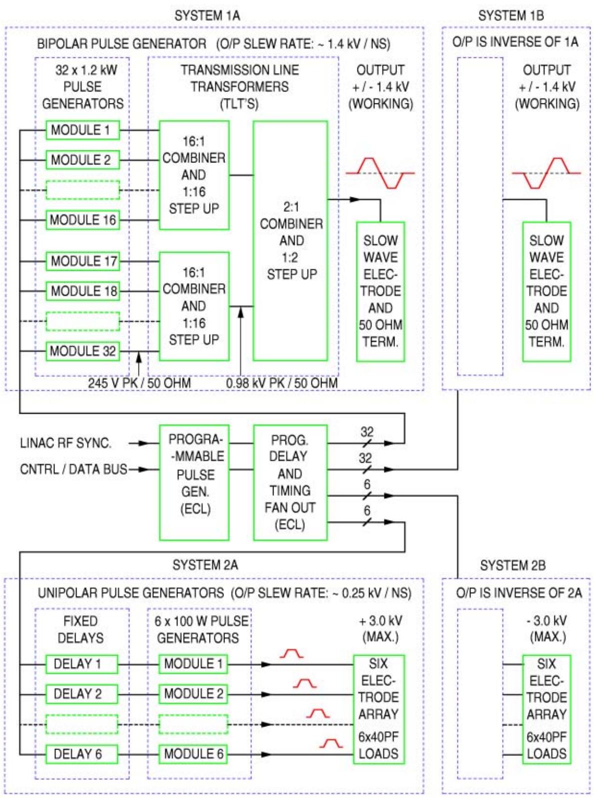

Figure 7: Modulator block schematic

A block schematic of the pulse generator module is shown in Figure 8. The class-D, push-pull, current switching design, outputs ~ ± 245 V (peak) from a 52 V supply, and utilises eight RF power MOSFETs (f_t ~ 2 GHz)

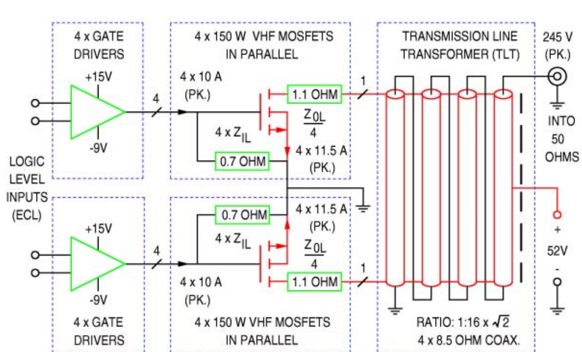

Figure 8: System 1 / Module

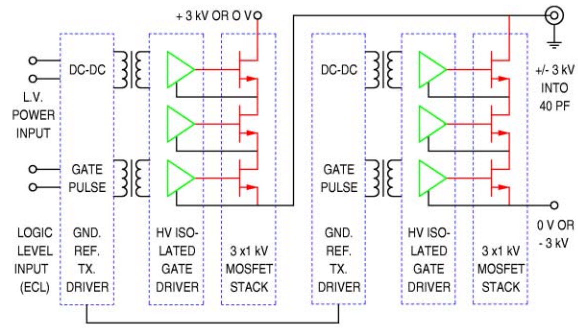

Figure 9: System 2 / Module

and a step up TLT. The module can be very compact, as the average duty cycle for system 1 is ~ 0.12 %, and mean load power per module is only ~ 1 W.

Systems 2A and 2B drive chopper 2A and 2B lumped element, slow wave electrodes, and output ~ 8 ns transition, unipolar, trapezoidal pulses (+3.0 and -3.0 kV) into a 40 pF load. A block schematic of the module is shown in figure 9. The high voltage MOSFET switch has the standard dc-coupled, totem-pole configuration. The 60 W modules will be close-coupled (< λ /10 = < 50 cm) to individual electrodes to preserve signal integrity.

4 SUMMARY

A modulation scheme and a modulator design for the ESS 2.5 MeV fast beam chopper have been identified. The scheme makes use of a new modulation technique that enables the implementation of an elegant, low average power, modulator.

5 ACKNOWLEDGEMENT

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6 REFERENCES

[1] 'The ESS Project Volume III, ', Technical Report, 2002, ISBN 3-89336-303-3.

[2] Spallation Neutron Source, (SNS), ORNL, USA; Japanese Hadron Facility, (JHF), KEK, Japan; Austron, Austria / CERN Switzerland.

[3] S.S. Kurennoy and J.F. Power, 'Development of Meander-Line current structure for SNS fast 2.5 MeV Beam Chopper', Proc. of the 7th European Particle Accelerator Conference, Vienna, Austria, 2000, p.336-338.

[4] J.S. Lunsford and R.A. Hardekopf, 'Pulsed beam chopper for the PSR at LAMPF', IEEE Trans. Nucl. Sci., NS-30, 1983.

[5] M. A. Clarke-Gayther, 'Modulator Systems for the ESS 2.5 MeV Fast Chopper', Proc. of the 2001 Particle Accelerator Conference, Chicago, USA, p. 4062-4065.

[6] C.R. Prior, 'Transverse image effects in the SNS and ESS beam choppers', RAL internal communication.