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

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Abstract

A description is given of the development of slow-wave chopper structures for the 3.0 MeV, 60 mA, H^- MEBT on the RAL Front-End Test Stand (FETS) [1]. 'Helical' and 'Planar' electrode designs [2] have been developed by simulating their high frequency (HF) electromagnetic properties in a commercial 3D code [3], and the manufacture of prototypes has helped to validate the predictive accuracy of the design code, and the selection of suitable machine-able ceramics and alloys of copper and aluminium. A description is also given of a novel abrasive brushing process that enables fine tuning of stripline characteristic impedance by facilitating control of stripline edge radius. The transmission line properties of the previously described 'Helical' test assembly [4] are compared with those of the recently completed 'Planar' test assembly. Finally, the development status of a related prototype high voltage pulse generator is 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 [5]. During critical accelerator tuning procedures, and crucially for the ring based schemes at injection and extraction, beam loss and the consequent activation of components, can be minimised by a programmed population of 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. The UK based FETS project, a collaboration involving RAL, Imperial College London, the University of Warwick, and the University of the Basque Country, will test a fast beam chopper in a high duty factor MEBT line [1]. The key components, as shown in Figure 1 are: an upgraded ISIS 'Penning' ion source, a three solenoid Low Energy Beam Transport 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 [6], respectively.

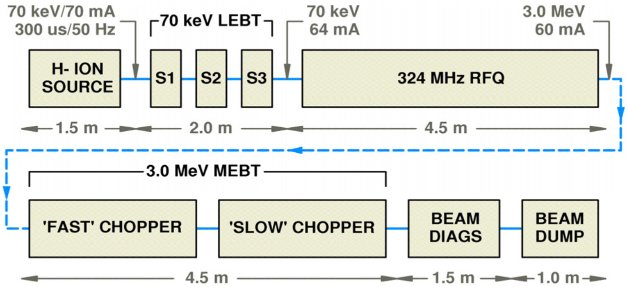


Figure 1: FETS beam line block schematic.

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 schematic of the proposed two stage beam chopper 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 a tandem combination of 'fast' transition time short duration, and slow transition time long duration, fields. The upstream field is generated by a pair of AC coupled 'fast' transition time pulse generators (FPG) that output high voltage, dual polarity pulses into a 'slow-wave' transmission line electrode structure [2], 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

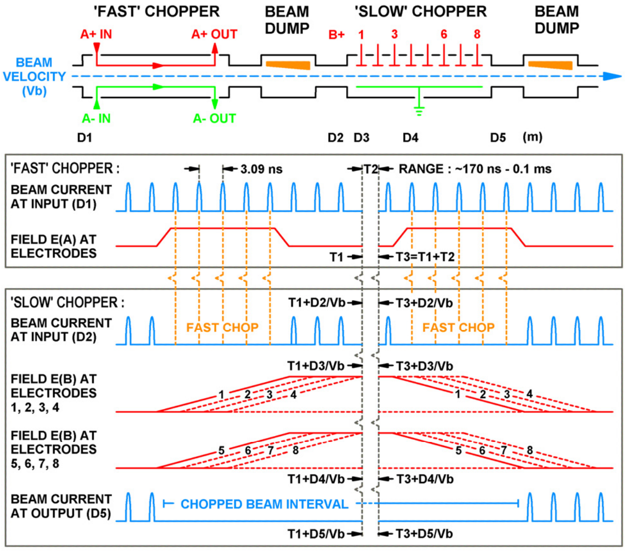


Figure 2: Two stage chopper timing schematic.

chopping of beam bunches is avoided in the downstream 'slow' chopper, whose field is generated by eight DC coupled, 'slow' transition time pulse generators (SPG) that output high voltage 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 onto a downstream beam 'dump'.

SLOW-WAVE ELECTRODES

The RAL helical and planar electrode designs [2] and their key parameters are shown in Table 2.

Table 2: FETS Slow-wave Electrode Parameters

H^- beam energy	3.0 MeV
Beam velocity	2.39032e7 m/s
Beam width / 100%	18 mm
Beam aperture	19 mm
Cell periodicity	19 mm
Stripline width / thickness	14 / 0.5 mm
Cell delay	0.794874 ns
Coverage factor: Centre / Edge	82 / 81 %
Characteristic impedance	~ 50 Ω
Bandwidth	0 – 500 MHz
Breakdown voltage	3 kV

The manufacture of the test assemblies has helped to verify the predictive accuracy of the 3D design code [3], and the selection of suitable machine-able ceramics and alloys of copper and aluminium. The subsequent planar and helical 'short length' prototype structures, will build on the experience gained from the preliminary test assemblies, and should facilitate the choice of a candidate design for the full scale structure, as outlined in the development plan, shown in Figure 3.

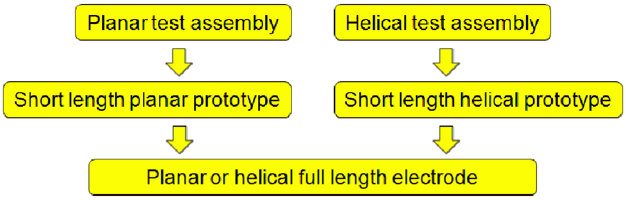


Figure 3: Development plan.

Helical & Planar Test Assemblies

The helical test assembly [4] consists of a demountable input and output coaxial assembly, and a short piece of stripline supported at each end by a captive ceramic disc, in a configuration that models a single cell of the proposed short length helical prototype structure as shown in Figure 4. A key feature of the helical design is the adjustable nature of the demountable coaxial delay lines. However, for the full scale structure, many high quality coaxial to stripline transitions are required, and current effort is directed toward the optimisation of a radiation hard, vacuum compatible design using a boron nitride (BN) machine-able ceramic [7] support disc, and a silicon dioxide ($\mathrm{SiO_2}$) insulated coaxial cable [8]. The planar test assembly as shown in Figure 5, models a section of the proposed short length planar prototype structure as shown in Figure 6, where the delay line is integral to the continuous stripline structure, and as a consequence the total delay is non-adjustable. In this design, the stripline is supported at intervals by capacitively compensated BN pillars, and is comprised of identical 'J' shaped sections joined end to end by spring loaded sliding joints, that permit stripline thermal expansion due to beam heating.

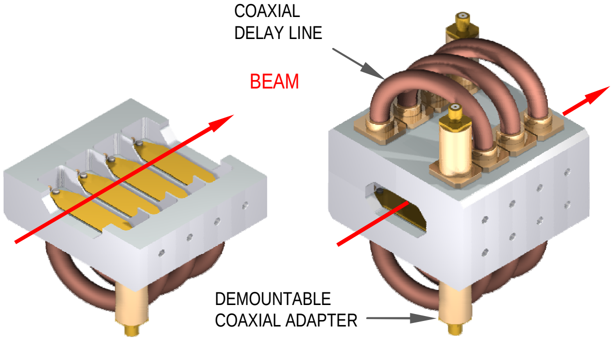


Figure 4: Short length helical prototype.

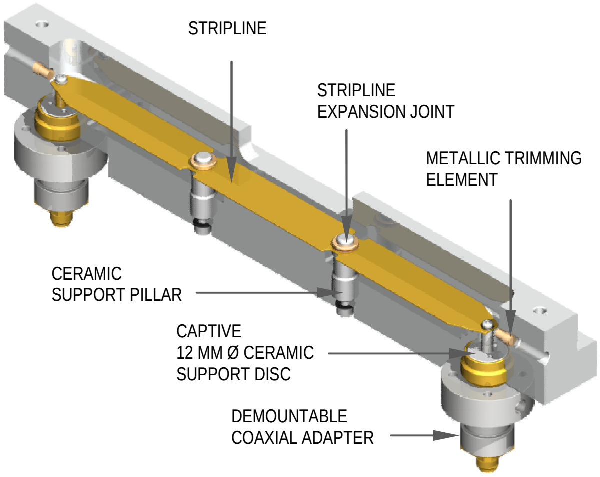


Figure 5: Planar test assembly.

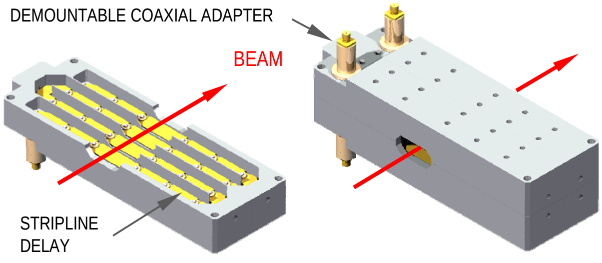


Figure 6: Short length planar prototype.

Measured transmission (S21) and reflection (S11) parameters for the helical and planar test assemblies, as shown in Figure 7, are in reasonable agreement with

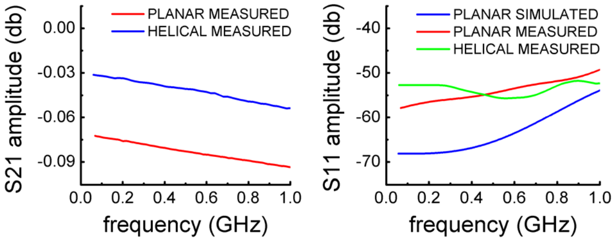


Figure 7: Test Assemblies / S parameters.

simulated parameters from the 3D models, and indicate that transmission loss and reflected amplitude are at an acceptably low level.

Control of Z_0 and Stripline Edge Radius

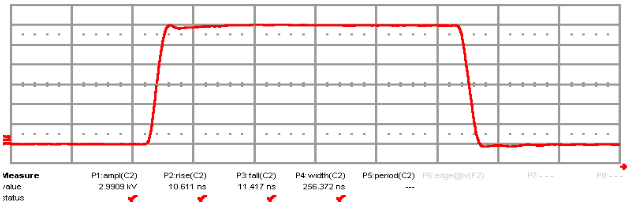
The characteristic impedance (Z_0) of these structures has been shown to be a strong function of stripline width and edge radius. Fine control of these parameters has been achieved by shaping the stripline parts with a numerically controlled (NC) wire erosion machine, and by edge radiusing using a NC abrasive brushing technique in which a miniature abrasive nylon cup brush [9] is programmed to track the convoluted edge of the part.

'SLOW' PULSE GENERATOR (SPG)

The FETS SPG is a DC coupled high voltage (HV) pulse generator, based on an 'off the shelf', 'push-pull' HV MOSFET switch module [10]. Previously described measurements [11, 12] indicated that a power supply and cooling upgrade would be required to enable the SPG to operate at a burst repetition frequency of 50 Hz. Measured performance parameters, as listed in Table 3, and output waveforms as shown in Figures 8, 9, and 10, confirm that the upgraded SPG is now fully compliant with the FETS requirements.

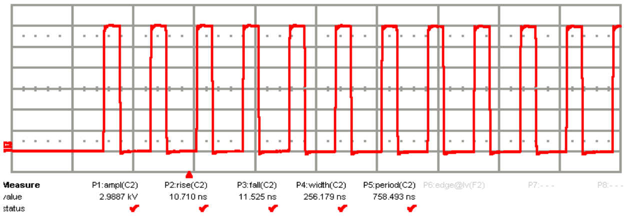
Table 3: SPG / Measured Performance Parameters

Parameters		Parameters	
Pulse amplitude	3.0 kV	Pulse repetition freq.	1.3 MHz
Load	20 pF & 50 nH	Burst duration	1.0 ms
Duty cycle	1.6 %	Burst repetition freq.	50 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 %



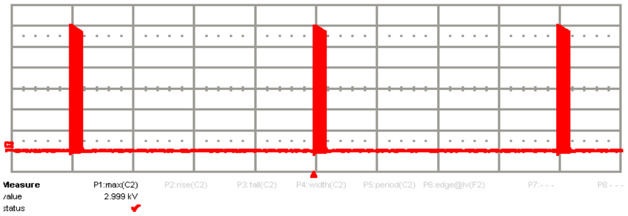
Measure	P1:ampl(C2)	P2:rise(C2)	P3:fall(C2)	P4:width(C2)	P5:period(C2)	P6:edge@lv(F2)	P7:- - -	P8:- - -
value	2.9909 kV	10.611 ns	11.417 ns	256.372 ns	---			
status	✓	✓	✓	✓				

Figure 8: SPG waveform at 3.0 kV peak & 50 ns / div.



Measure	P1:ampl(C2)	P2:rise(C2)	P3:fall(C2)	P4:width(C2)	P5:period(C2)	P6:edge@lv(F2)	P7:- - -	P8:- - -
value	2.9887 kV	10.710 ns	11.525 ns	256.179 ns	758.493 ns			
status	✓	✓	✓	✓	✓			

Figure 9: SPG waveform at 3.0 kV peak & 1.0 µs / div.



Measure	P1:max(C2)	P2:rise(C2)	P3:fall(C2)	P4:width(C2)	P5:period(C2)	P6:edge@lv(F2)	P7:- - -	P8:- - -
value	2.999 kV							
status	✓							

Figure 10: SPG waveform at 3.0 kV peak & 5.0 ms / div.

SUMMARY

Manufacture of the helical and planar test assemblies has helped to validate the selection of materials and machining processes. A novel abrasive method for the production of a uniform stripline edge radius has been tested, and the required degree of control of this critical feature has been demonstrated. Measurements of the HF characteristics of the helical and planar test assemblies are generally in good agreement with the simulated characteristics, and have helped to verify the predictive accuracy of the 3D HF design code [3]. The design and manufacture of the subsequent 'short length' prototypes, will build on the experience gained from the manufacture of the test assemblies, and facilitate the choice of a candidate design for the full scale structure.

Measured performance parameters for the upgraded SPG indicate that it is now fully compliant with the FETS requirements.

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