HIPPI Work Package 4 (WP4): The RAL† Fast Beam Chopper Development Programme
Progress Report for the period: July 2005 – December 2006

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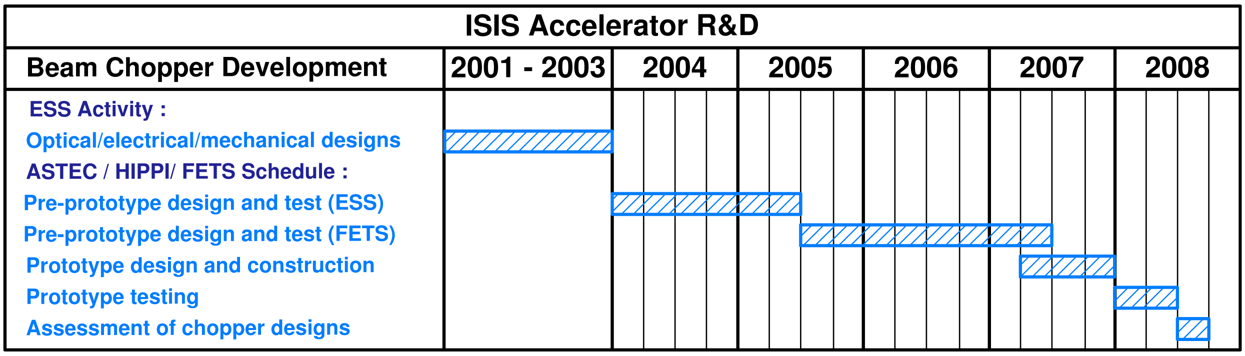
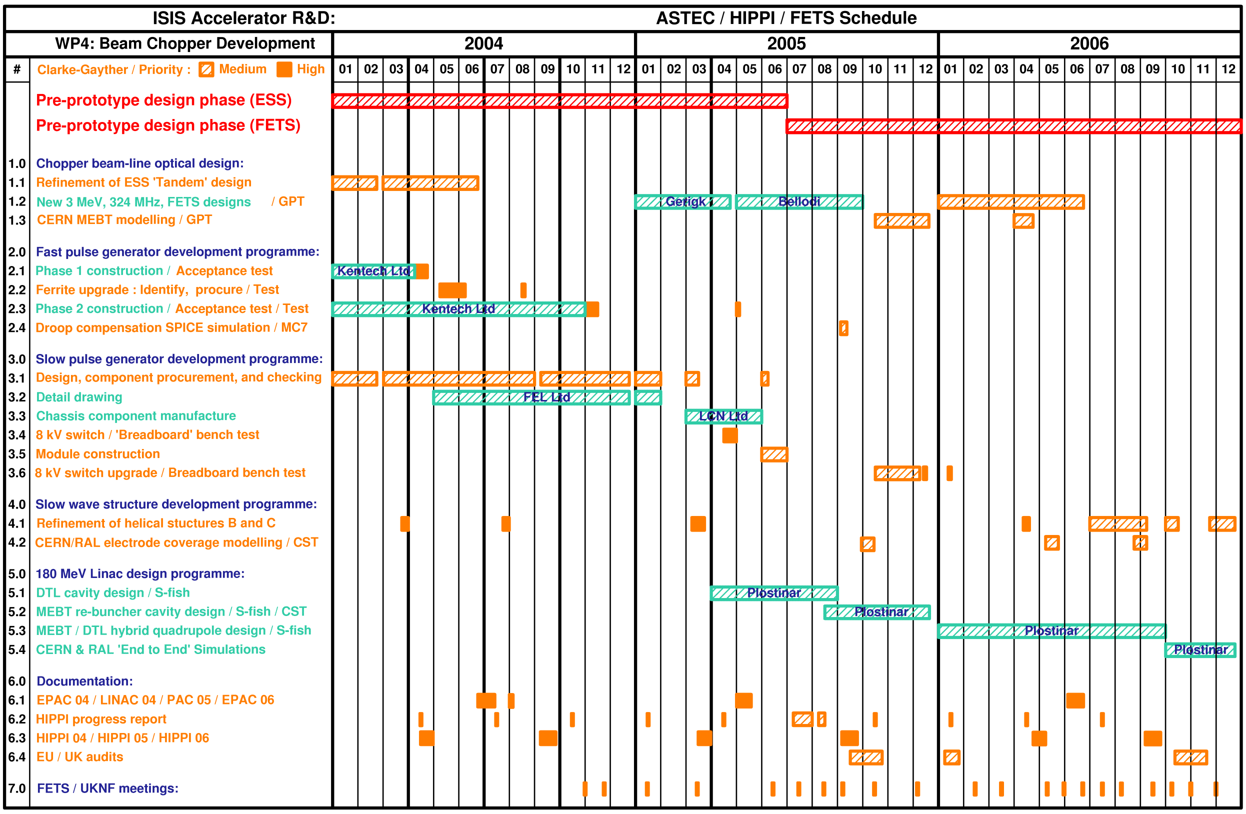
Abstract

The CCLRC Rutherford Appleton Laboratory (UK) joined the European High Intensity Pulsed Proton Injector (HIPPI) collaboration in January 2004, and acknowledges the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395). This report describes the progress made on the development of a fast beam chopper for next generation high power spallation sources (WP4), during the period: July 2005 – December 2006.

Project plan / Overview:



Project history / Detail:



WP4 Prototype design and Construction phase (RAL FETS)

RAL effort is divided into the following key areas of activity:

1.0 Chopper beam line optical design
2.0 Fast pulse generator (FPG) development programme
3.0 Slow pulse generator (SPG) development programme
4.0 Slow wave structure development programme
5.0 Conference activity
6.0 HIPPI meeting activity

Description of WP4 activities and status for the period July 2005 – December 2006

1.0 Chopper beam line optical design

During the period July 2005 – December 2006, an alternative optical design (‘scheme B’) for the RAL Front-End Test Stand [1] MEBT line was developed by G. Bellodi [2], based on the previous, ‘scheme A’ design, developed by F. Gerigk [3]. Both schemes utilise the optical ‘amplification’ of beam deflection provided by a defocusing quadrupole, placed immediately downstream of the chopper electrodes, to significantly lower the chopper field requirement. In addition, beam aperture has been increased, and dedicated beam dumps have been included. These preliminary designs, developed in the IMPACT, MaryLie, and PATH codes, and the ‘tandem’ design for the ESS [4] were subsequently refined by M. Clarke-Gayther in the GPT code [5]. This work formed the basis of a paper submitted to EPAC 2006 [6].

1.1 Extract from reference [6]: RAL FETS MEBT Chopping Schemes

The FETS project [1], 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. The key components, as shown in Figure 1 are: an upgraded ISIS ‘Penning’ ion source, a three solenoid Low Energy Beam Transport (LEBT) line, a high duty factor 324 MHz Radio Frequency Quadrupole (RFQ), a novel ‘Fast-Slow’ 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 [7], respectively.

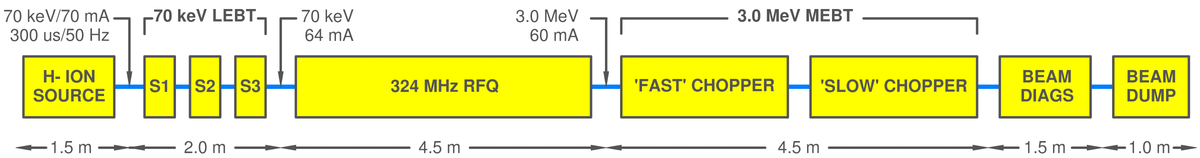


Figure 1: FETS beam line block schematic

Table 1: Key FETS Parameters

Parameters		Parameters	
Ion species	H^-	RF frequency	324 MHz
RFQ output energy	3.0 MeV	Pulse repetition frequency	50 Hz
Pulse duration	0.3 - 2 ms	MEBT chopper field transition time (10-90 %)	2 ns
RFQ input energy	70 keV	Chopped beam duration	0.1-100 μs
Beam current	60 mA	Chopper pulse repetition frequency	1.3 MHz

The RAL ‘Fast-Slow’ chopping scheme for the 2.5 MeV, 280 MHz, ESS MEBT [4] is evolving to address the requirements of the 3.0 MeV, 324 MHz, FETS project. Three candidate optical designs have been identified, and two of these, schemes A and B, make use of the optical amplification of beam deflection in a downstream defocusing quadrupole, to significantly lower the chopper field requirement, a key feature of the proposed Linac 4 MEBT design at CERN [8]. The preliminary FETS schemes A, and B, and the ESS scheme C, have been refined in the GPT code [5], and are shown in Figures 2, 3, and 4, respectively. In each of these Figures, three plots, scaled in the z-plane to a schematic of the component layout, show simulated beam trajectories for the conditions of no chopping, ‘fast’ chopping, and ‘slow’ chopping, respectively. Input and output doublet matching sections, and CCL type re-bunching cavities [9] control emittance growth in the transverse and longitudinal planes. Plots of simulated beam distributions in phase space, at the input and output of all three schemes, are shown in Figure 5.

FETS Scheme A

In this case, the configuration of the ‘fast’ and ‘slow’ choppers is symmetrical, each operating independently and each followed by a defocusing quadrupole and a dedicated beam dump. ‘Fast’ and ‘slow’ chopping fields are uniformly low, but emittance growth is higher than in scheme B.

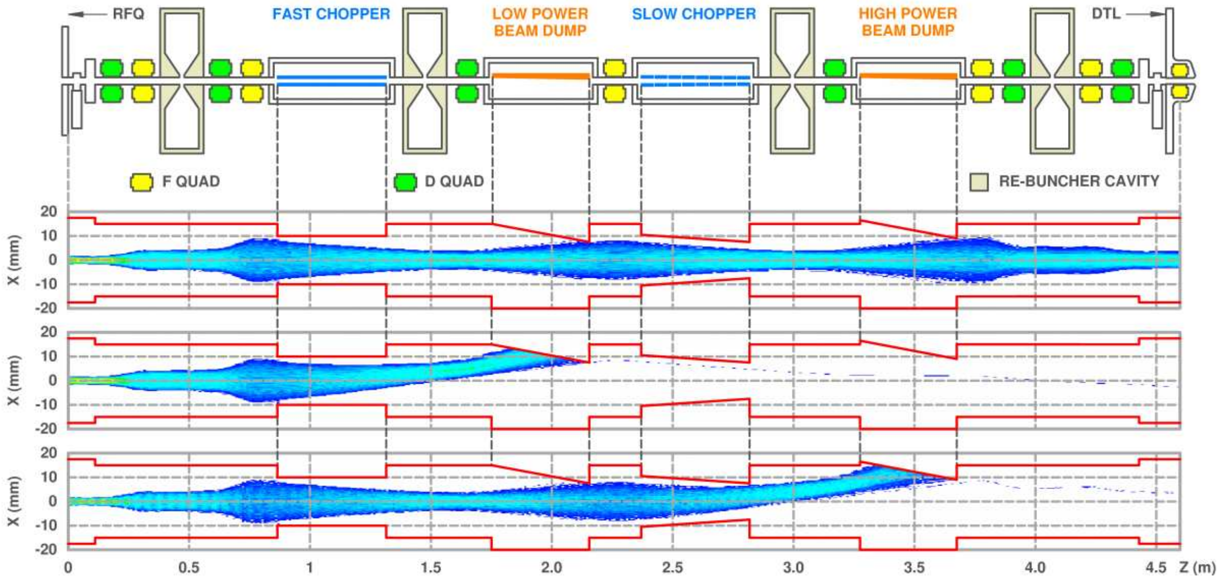


Figure 2: FETS scheme A / Beam-line layout and GPT trajectory plots

FETS Scheme B

In this scheme the configuration of the ‘fast’ and ‘slow’ choppers is asymmetrical, with the ‘slow’ chopper functioning as a low duty cycle beam dump for the ‘fast’ chopper. However, chopper fields are synergistic, and as a result the fast chopping field is minimised. Emittance growth is lower than scheme A, and similar to scheme C.

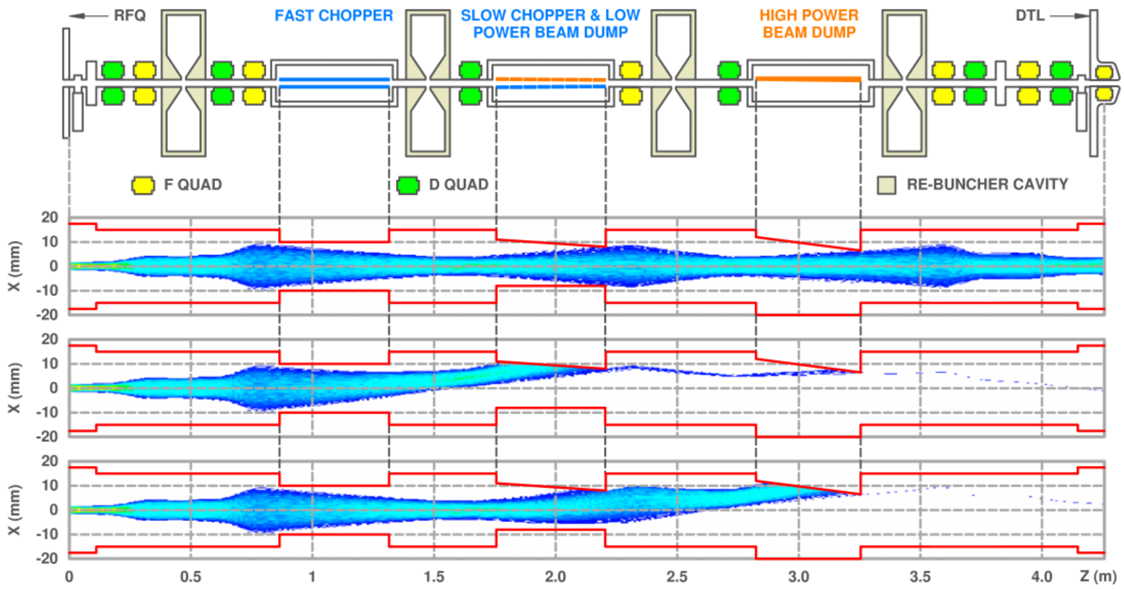


Figure 3: FETS scheme B / Beam-line layout and GPT trajectory plots

FETS Scheme C

The configuration of the ‘fast’ and ‘slow’ choppers is, in this case, similar to the original ESS chopper design, with the ‘slow’ chopper functioning as a low duty cycle dump for the ‘fast’ chopper, and a high duty cycle dump for the ‘slow’ chopper. The slow chopping field is significantly higher than that in schemes A and B.

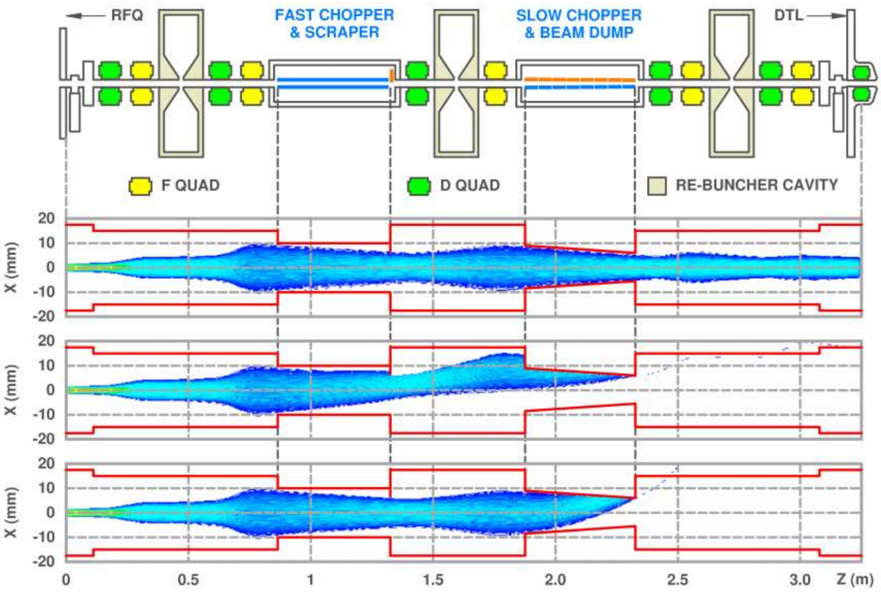


Figure 4: FETS scheme C / Beam line layout and GPT trajectory plots

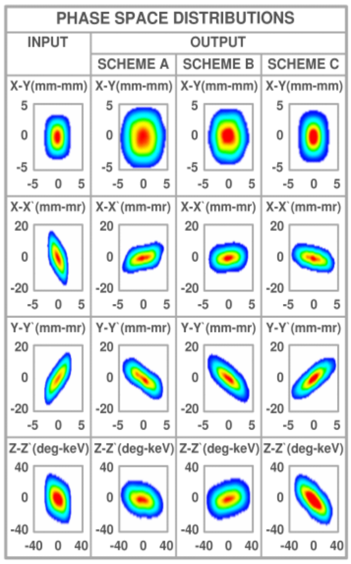


Figure 5: FETS phase-space plots

MEBT line parameters used in GPT simulations of schemes A, B, and C are shown in Table 2.

Table 2: FETS MEBT line parameters (GPT simulations)

Parameters	Scheme A	Scheme B	Scheme C	Parameters	Scheme A	Scheme B	Scheme C
Beam line length (mm)	4600	4260	3250	Fast chopper electrode effective length & gap (mm)	450 x 0.82 20	450 x 0.82 20	450 x 0.82 20
Beam current (mA)	40	40	40	Fast chopper potential (kV)	± 1.3	± 1.2	± 1.4
RMS input emittance in X/Y (π-mm-mr) & Z planes (π-deg-MeV)	0.25 / 0.25 0.18	0.25 / 0.25 0.18	0.25 / 0.25 0.18	Slow chopper electrode effective length & gap (mm)	450 x 0.85 18	450 x 0.85 18	450 x 0.85 14
RMS emittance growth in X/Y & Z planes (%)	6 / 13 2	4 / 8 0	5 / 8 0	Slow chopper potential (kV)	± 1.5	± 2.0	± 5.0
Quadrupole length / aperture (mm)	70 / 35	70 / 35	70 / 35	Beam dump length (mm)	2 x 400	2 x 450	450
Cavity field max. (keV/mm) / gap (mm)	4.5 / 21.5	4.5 / 21.5	5.0 / 21.5				

1.2 Summary

Candidate optical designs for the FETS MEBT chopper line have been identified, and refined. Schemes A and B address three weaknesses in the original ESS MEBT optical design, these being: the high chopper field requirement, the absence of a dedicated chopper beam dump, and an overly compact component layout. The results of these studies are encouraging, in that they indicate that schemes A and B can address the above mentioned weaknesses without incurring excessive emittance growth in the MEBT line.

1.3 GPT code verification

As a precursor to the work on the refinement of the FETS MEBT schemes, a comparison of the new GPT, and original TraceWin [10] simulations of the CERN Linac 4 MEBT line [8] was made, with good agreement between codes being demonstrated [11]. Selected results from the GPT simulation of the CERN MEBT line are shown in Figures 6, and 7.

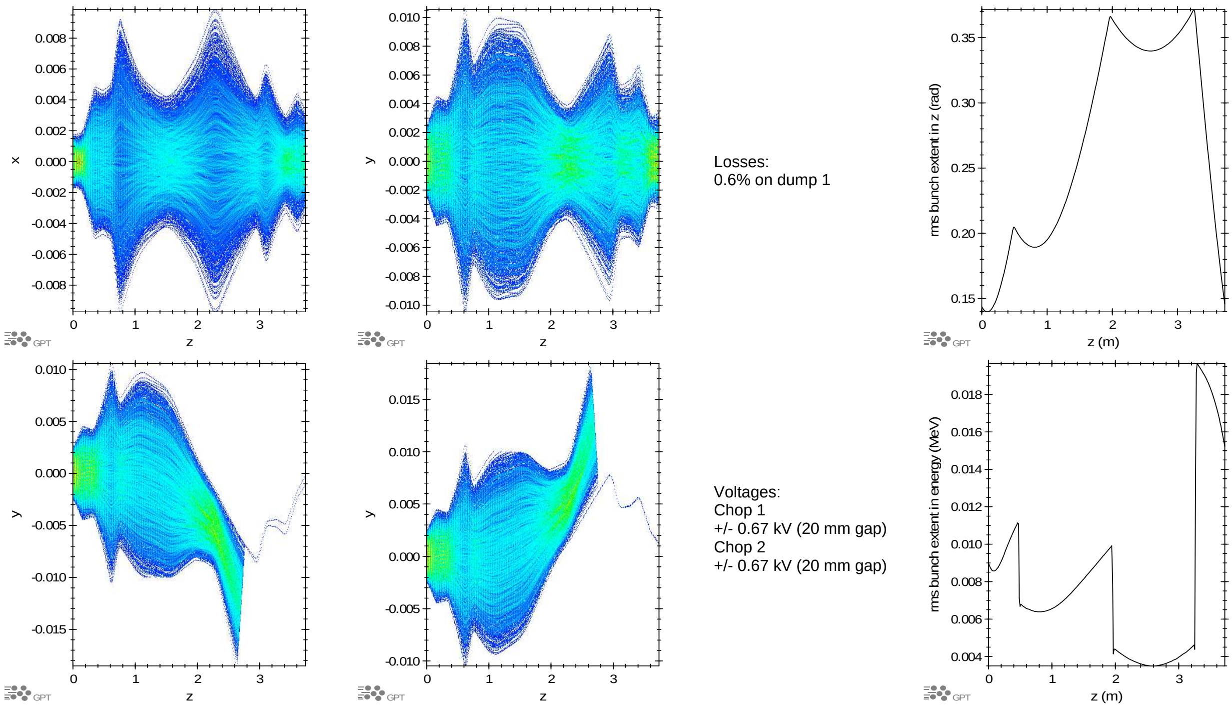


Figure 6: CERN MEBT / Trajectories & rms bunch parameters in z plane (GPT)

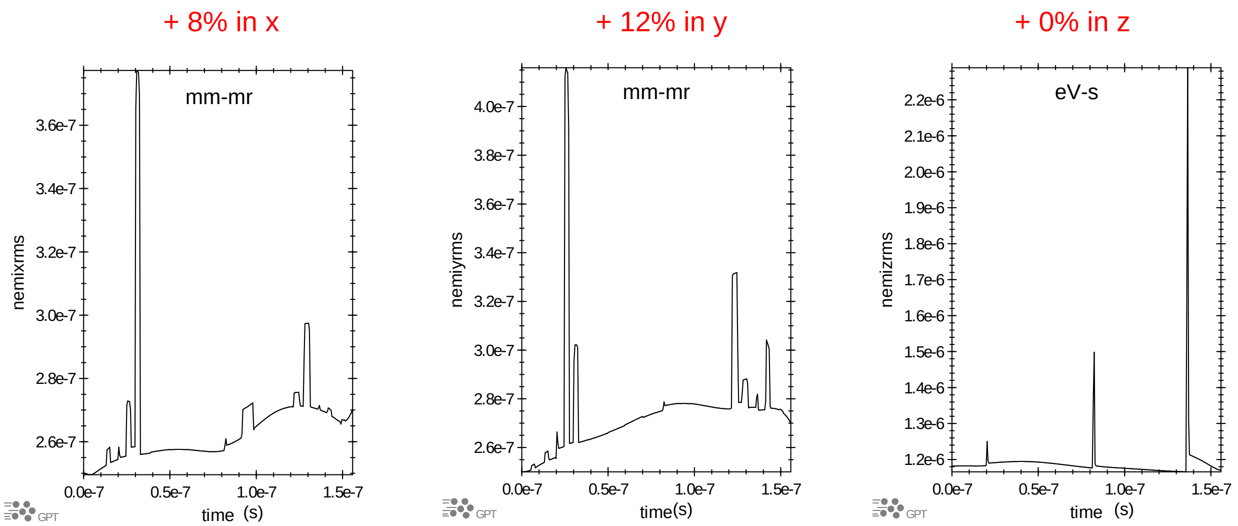


Figure 7: CERN MEBT / Emittance growth (GPT)

1.4 RAL chopper tests on the CERN MEBT line

Following the successful verification of the GPT code [11], a study was initiated, to investigate the possibility of conducting preliminary 'in beam' tests of the RAL choppers on the CERN MEBT line. A modified optical scheme for the CERN MEBT was subsequently developed [11]. Selected results from the GPT simulation of this modified scheme are shown in Figures 8, and 9.

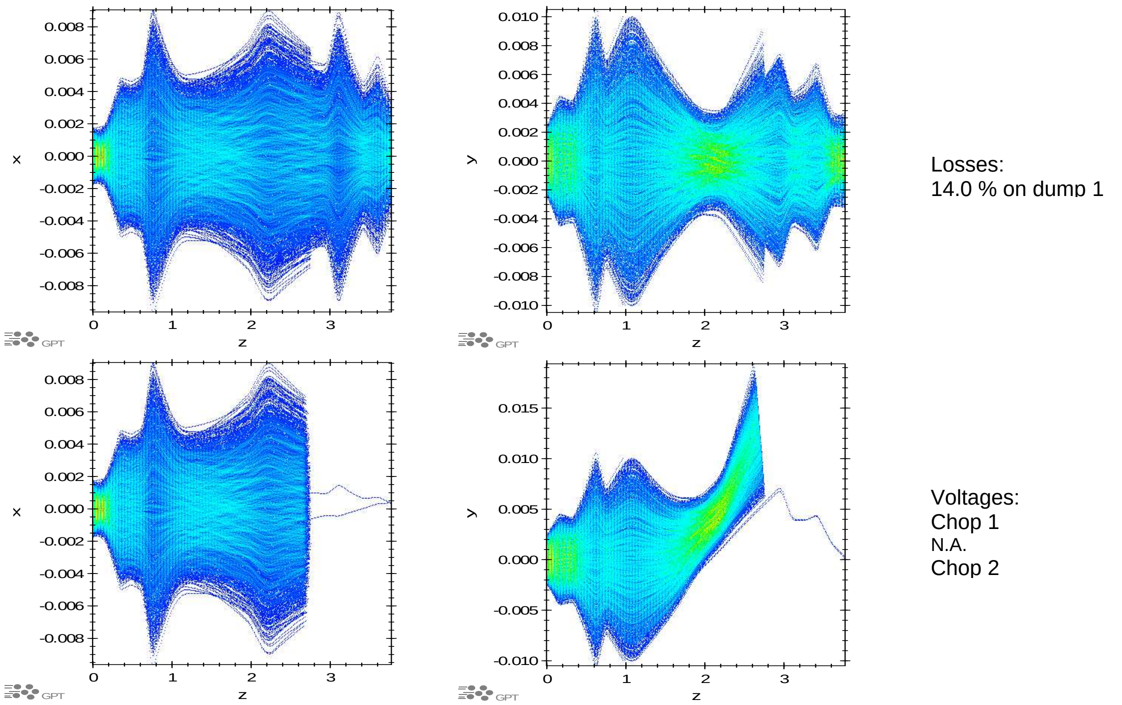


Figure 8: CERN MEBT / RAL set-up /Trajectories (GPT)

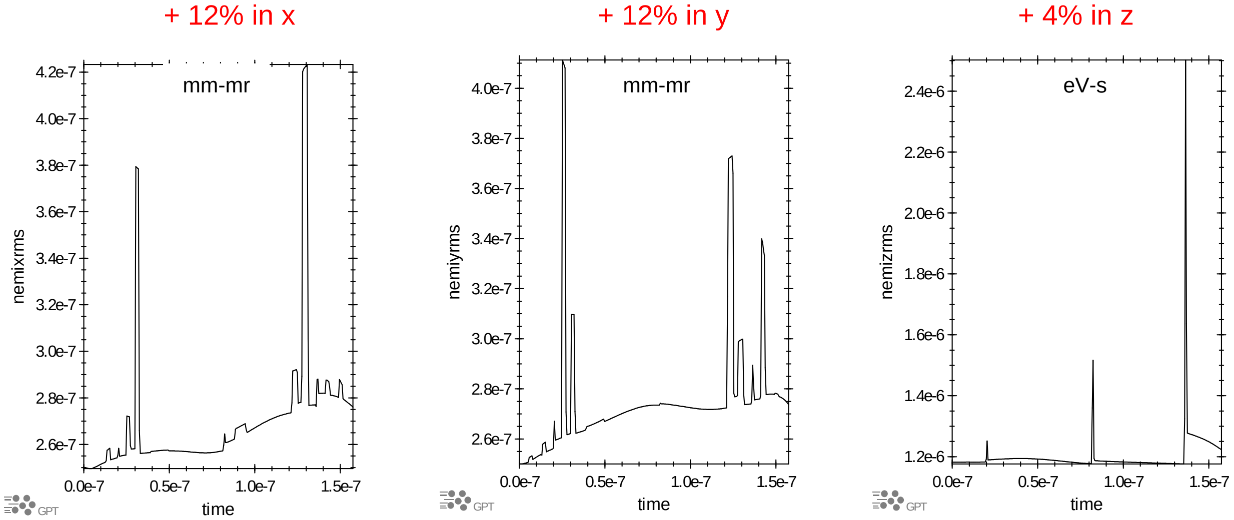


Figure 9: CERN MEBT / RAL set-up / Emittance growth (GPT)

2.0 RAL Fast Pulse Generator (FPG) development programme

The RAL FPG [12] is available for testing slow-wave electrode structures (Z_0=50 Ohm). The range of available pulse amplitudes, and durations are: +/- 200 to +/- 1500 V, and 8 to 15 ns, respectively. FPG layout and output waveforms are shown in Figures 10, and 11, respectively. RAL has offered to conduct high voltage tests on the new CERN meander structures, when they become available. In addition, RAL has received a request to consider the logistics of shipping the RAL FPG to CEA Saclay [13] for preliminary tests of the CERN chopper system, and has made a request for space to be pre-allocated at CEA Saclay for this purpose.

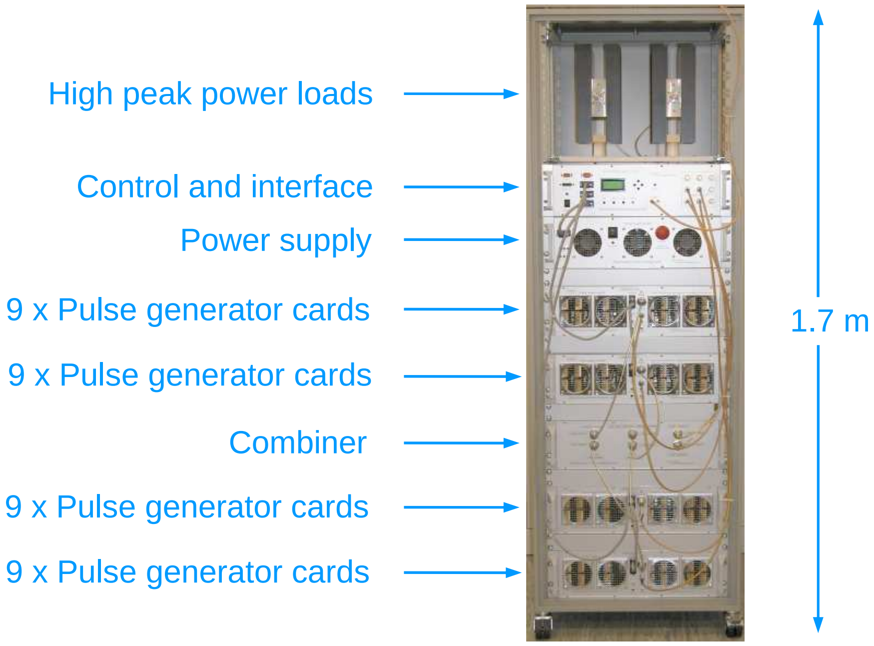


Figure 10: FPG / Front view

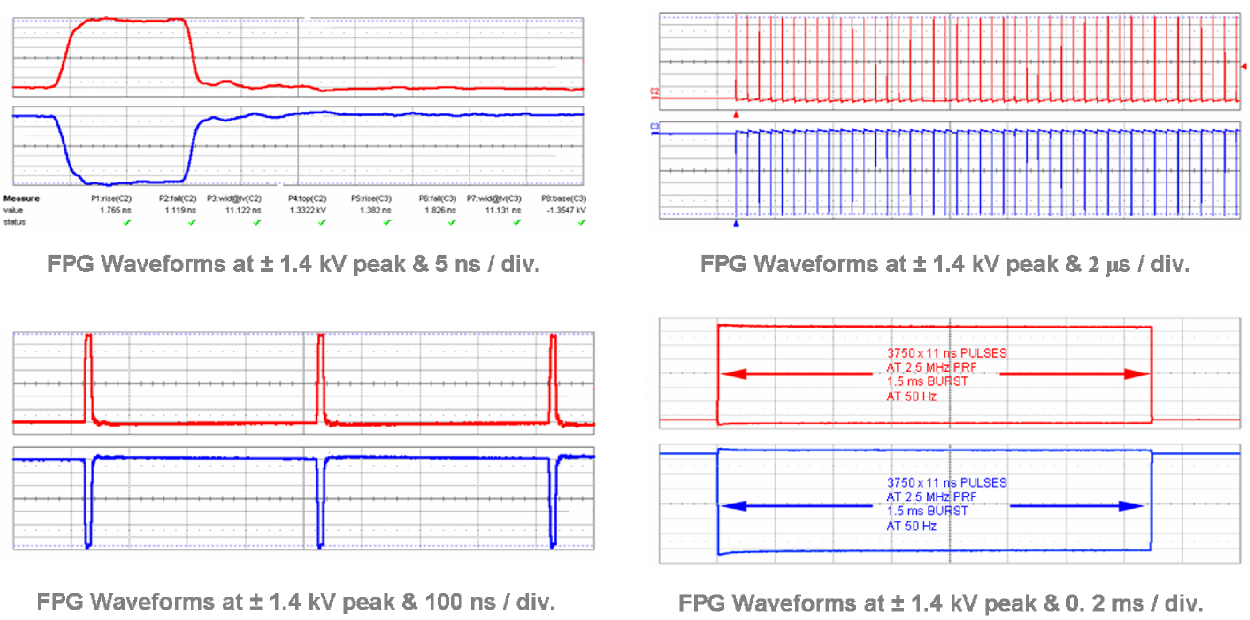


Figure 11: FPG waveforms at ± 1.4 kV peak

Table 3: Summary of measured performance parameters for the 'Phase 2' FPG systems

Pulse Parameter	FETS Requirement	Measured	Compliancy	Comment
Amplitude (kV into 50 Ohms)	± 1.4	± 1.5	Yes	Scalable
Transition time (ns)	≤ 2.0	T_{rise} = 1.8, T_{fall} = 1.2	Yes	10 – 90 %
Duration (ns)	10 - 15	10 - 15	Yes	FWHM
Droop (%)	2.0 in 10 ns	1.9 in 10 ns	Yes	F_{3dB} ~ 300 kHz
Repetition frequency (MHz)	2.4	2.4	Yes	
Burst duration (ms)	0.3-1.5	1.5	Yes	
Burst repetition frequency (Hz)	50	50	Yes	Duty cycle ~ 0.27 %
Post pulse aberration (%)	± 2	± 5	No	Reducible
Timing stability (ps over 1 hour)	± 100	± 50	Yes	Peak to Peak
Burst amplitude stability (%)	+ 10, - 5	+ 5, - 3	Yes	

2.1 FPG / FETS chopping characteristics at 324 MHz

Measurements of the output waveforms of the phase 2 FPG and of an upgraded 8 kV SPG have been made, and the impact of these results on the choice of RF frequency for the RAL FETS has been discussed [14]. A decision to adopt the 324 MHz RF frequency option for the RAL FETS project has now been made, based on the availability of a high power, high duty cycle, pulse rated Klystron [15]. FETS chopper timing schematics, based on slow pulse generator (SPG) transition times of ~ 9 ns and ~ 12ns, are shown in Figures 12, and 13, respectively. These transition times demand FPG pulse durations of ~ 12 ns, and ~ 15 ns, respectively, being determined by the requirement to remove (chop) four, or five bunches at the FETS RF frequency of 324 MHz.

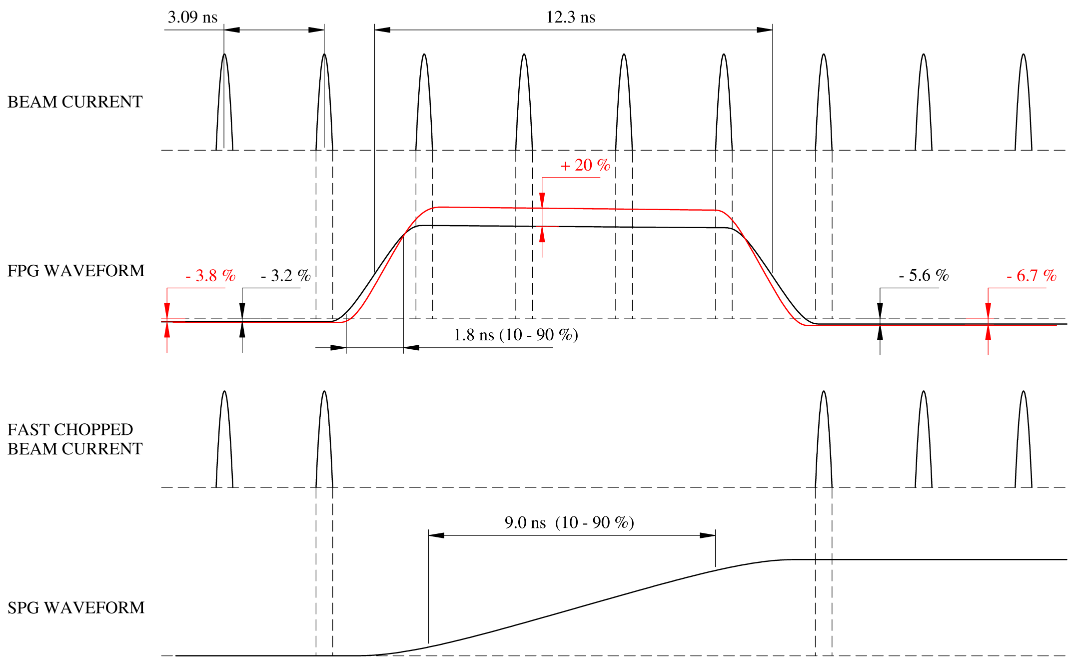


Figure 12: Timing schematic for 324 MHz FETS chopping scheme with 4 kV (9 ns) SPG

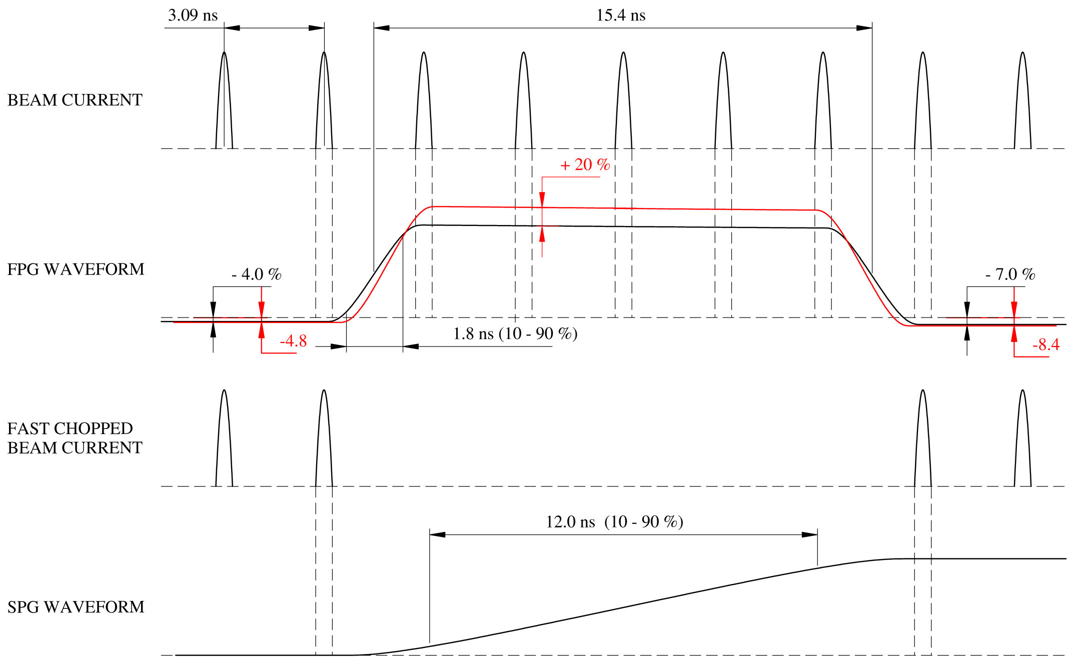


Figure 13: Timing schematic for 324 MHz FETS chopping scheme with 4 kV (12 ns) SPG

Figures 12, and 13 indicate that the FETS RF frequency of 324 MHz is only marginally compatible with measured FPG transition times. A strategy for improving transition time compatibility is shown in red but this strategy calls for an increase in pulse amplitude and results in an increase in the effective amplitude of the baseline shift and pulse top droop.

2.2 FPG duty cycle induced baseline shift compensation

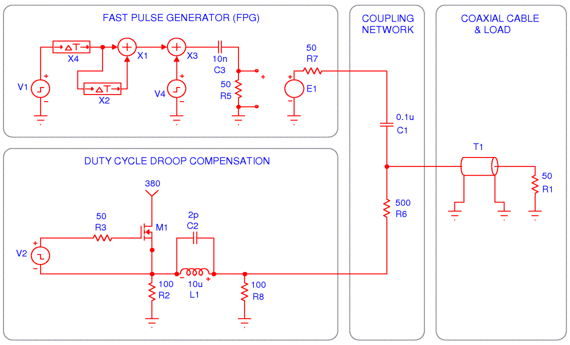
Calculated values of duty cycle induced baseline shift, and low frequency (LF) cut-off induced pulse top droop are shown in Table 4, for the 324 MHz FETS chopping schemes, where the FPG pulse length is determined by 4 kV SPG transition times of 9 ns or 12 ns (10 -90%).

Table 4: FPG duty cycle and LF droop for the 324 MHz FETS chopping schemes

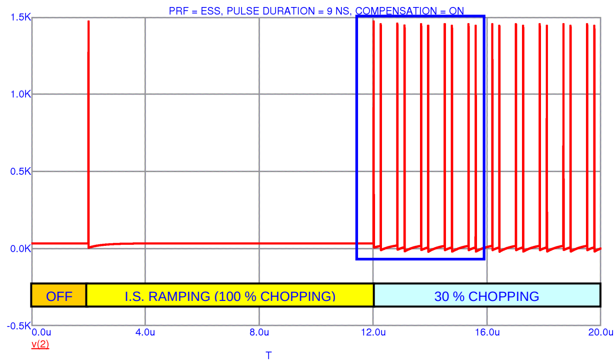
	RFQ	Ring	FPG										
	RF	RF	Pulse				Duty cycle droop		LF cut-off			Total droop	
			PRF	Period	Duration				τ	Droop			
	MHz	MHz	MHz	ns	ns		%		μs	%		%	
					†	††	†	††		†	††	†	††
FETS	324.0	1.3	2.6	384.5	12.3	15.4	3.2	4.0	0.5	2.4	3.0	5.6	7.0

† Assumes 4 kV SPG with ~ 9 ns transition time (10 – 90 %)
†† Assumes 4 kV SPG with ~ 12 ns transition time (10 – 90%)

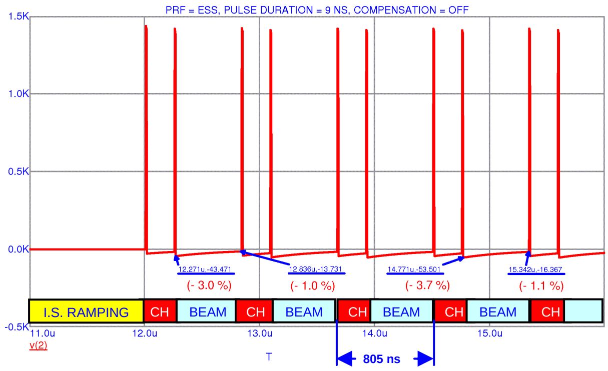
A scheme to compensate for the duty cycle induced baseline shift as shown in Figures 12, and 13 has been described [16]. The resulting residual baseline shift due to LF cut-off can be balanced around the zero volt level, to give values of ± 1.2 %, and ± 1.5 % for 4, and 5 bunch chopping, respectively. Accurate compensation can only be achieved for fixed or slowly varying chopper duty cycles.



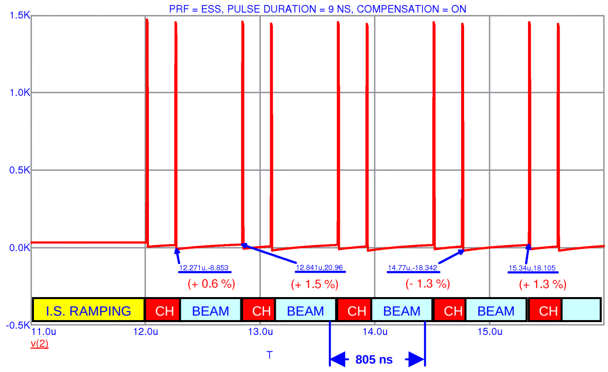
Circuit schematic: Duty cycle droop compensation



Timing schematic: Compensation 'on' @ 20 µs & 0.5 kV/div



Timing schematic: Compensation 'off' @ 1 µs & 0.5 kV/div



Timing schematic: Compensation 'on' @ 1 µs & 0.5 kV/div

Figure 14: FPG duty cycle induced baseline shift / Compensation scheme

3.0 RAL Slow Pulse Generator (SPG) development programme

Work on the RAL SPG has been delayed, as a higher priority has been given to the development of new optical schemes for the FETS MEBT line, and effort that would have been available for the SPG task has been re-directed to the optical design task. However, progress has now been made with the optical work [6], and so it is likely that effort will be directed back to the SPG design task. Preliminary testing of an upgraded 'off the shelf' 8kV SPG MOSFET switch [17] has shown that pulse transition times increase, and durations decrease, during the first 20 us of the burst. However, the new RAL MEBT optical designs (schemes A & B) appear to halve the ESS SPG voltage requirement, and so the direction for the new SPG development will be revised towards a lower voltage (< 4 kV), custom designed switch, that should significantly reduce the above mentioned initial shift in observed pulse transition time and duration.

Views of the 8kV SPG MOSFET test set-up are shown in Figure 15. Measured waveforms and parameters, at pulse amplitudes of ± 6 kV, are shown in Figure 16 and Table 5, respectively.

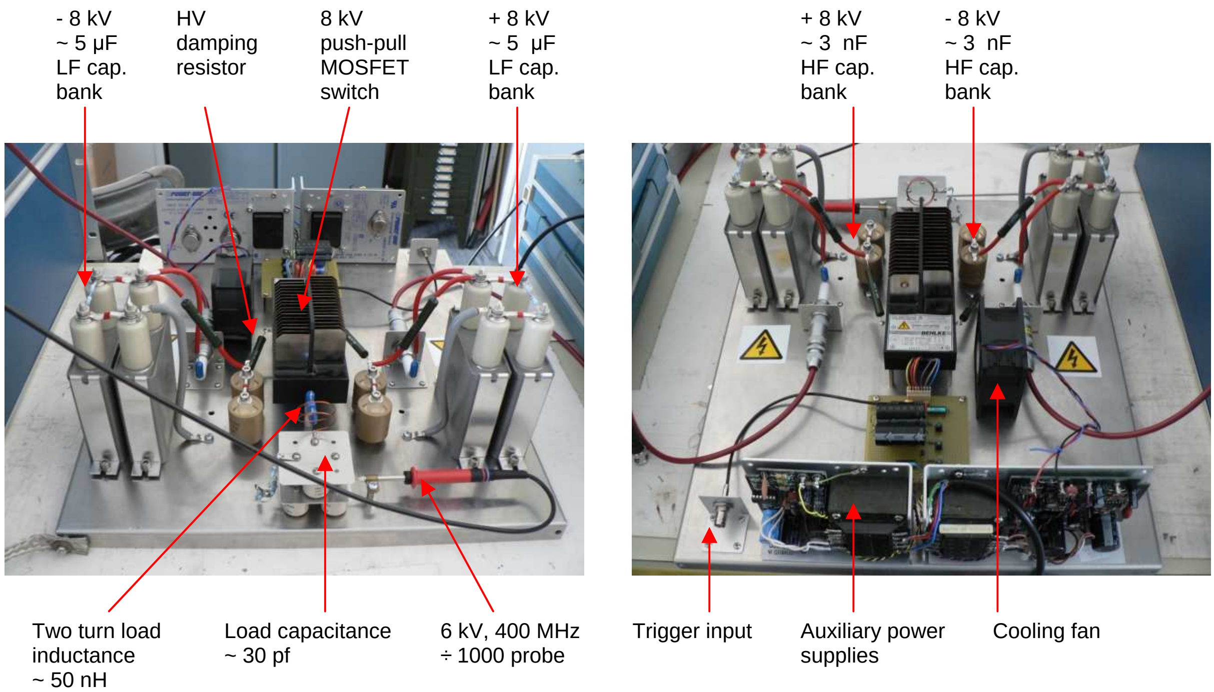


Figure 15: Pre-prototype SPG test set-up

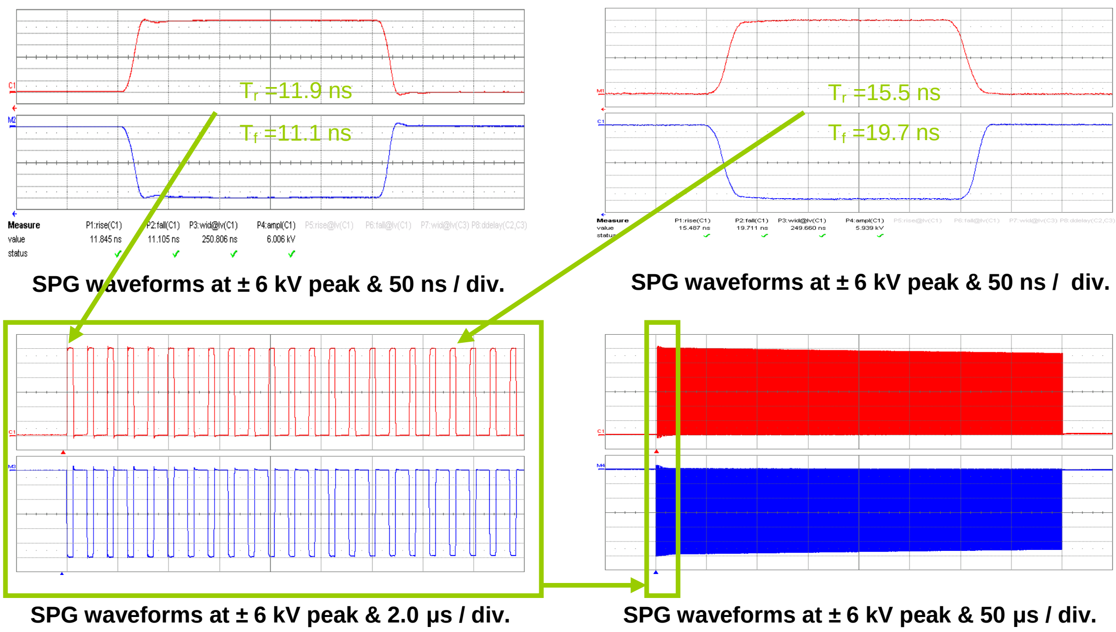


Figure 16: Pre-prototype SPG waveform measurement / HTS 81-06-GSM HFB

Table 5: Summary of measured performance parameters for the pre-prototype SPG

Pulse Parameter	ESS Requirement	Measured	Compliancy	Comment
Amplitude (kV into 50 Ohms)	± 6.0	± 6.0	Yes	± 8 kV rated
Transition time (ns)	~ 12.0	T_{rise} ~ 13, T_{fall} ~ 12	Limited	First ~ 10 pulses in burst
Duration (µs)	0.2 – 100	0.2 – 100	Yes	FWHM
Droop (%)	0	0	Yes	DC coupled
Repetition frequency (MHz)	1.2	1.2	Yes	Note transition time limitation
Burst duration (BD) @ 1.2 MHz	1.5 ms	1.5 ms	Yes	Test limited to BRF < 50 Hz
Burst repetition frequency (BRF) (Hz)	50	50	Yes	Test limited to BD < 1.5 ms
Positive pulse width stability (ns)	± 0.1	- 10	Limited	First ~ 10 pulses in burst
Negative pulse width stability (ns)	± 0.1	≤ ± 0.1	Yes	Note transition time limitation
Post pulse aberration (%)	± 2	≤ ± 2	Yes	Damping dependent
Timing stability (ns over 1 hour)	± 0.5	± 0.4	Limited	First ~ 10 pulses in burst
Burst amplitude stability (%)	+ 10, - 5	< + 10, -5	Yes	@ 0.1 MHz PRF

4.0 Slow-wave structure development programme

During the first half of this reporting period, work on the RAL ‘slow-wave’ chopper structures for the ESS MEBT line (2,5 MeV, 280 MHz) was temporarily frozen, pending the development of new optical schemes for the RAL FETS MEBT line (3.0 MeV, 324 MHz), as described in section 1.0, above. Progress on the development of RAL ‘slow-wave’ structures was further delayed, when effort that would have been available for this task, was redirected to complete the optical design task, following the departure of RAL personnel previously engaged in the development of the preliminary FETS MEBT line schemes [2, 3]. However, good progress was subsequently made with the FETS optical work [6], and as a result, the RAL ‘slow-wave’ chopper structure design work was restarted during the second half of this reporting period. As a precursor to the main task of modifying the ESS structures to meet the new FETS requirements, an analysis of the so called ‘coverage factor’ of the CERN and RAL slow-wave structures was undertaken, prompted by a discussion on the subject, at the annual WP4 meeting [18]. This work was subsequently refined, and formed the basis of a presentation given at the 3rd HIPPI general meeting [19].

4.1 The RAL slow-wave structure development programme / Redefinition of objectives

Objectives for the programme, redefined to meet the new FETS and CERN MEBT requirements, are as follows:

- Modify ESS 2.5 MeV ‘Helical B’ and ‘Planar’ designs to meet the FETS requirement
  - Reduce delay to enable 3 MeV operation
  - Increase beam aperture to ~ 20 mm
  - Maximise field coverage and homogeneity
  - Simplify design - minimise number of parts
  - Investigate effects of dimensional tolerances
  - Ensure compatibility with NC machining practise
  - Optimise choice of materials

- Modify ESS 2.5 MeV ‘Helical B’ design for the CERN MEBT requirement
  - Shrink to fit in 95 mm ID vacuum vessel

Work on this task commenced in July, following the EPAC 06 conference activity, with the modification of the RAL ESS helical B design, initially for the CERN MEBT requirement. This design (Helical B1) was then 'scaled up' to meet the FETS requirement (Helical B2). Engineering drawings of these designs are shown side by side, in Figure 17.

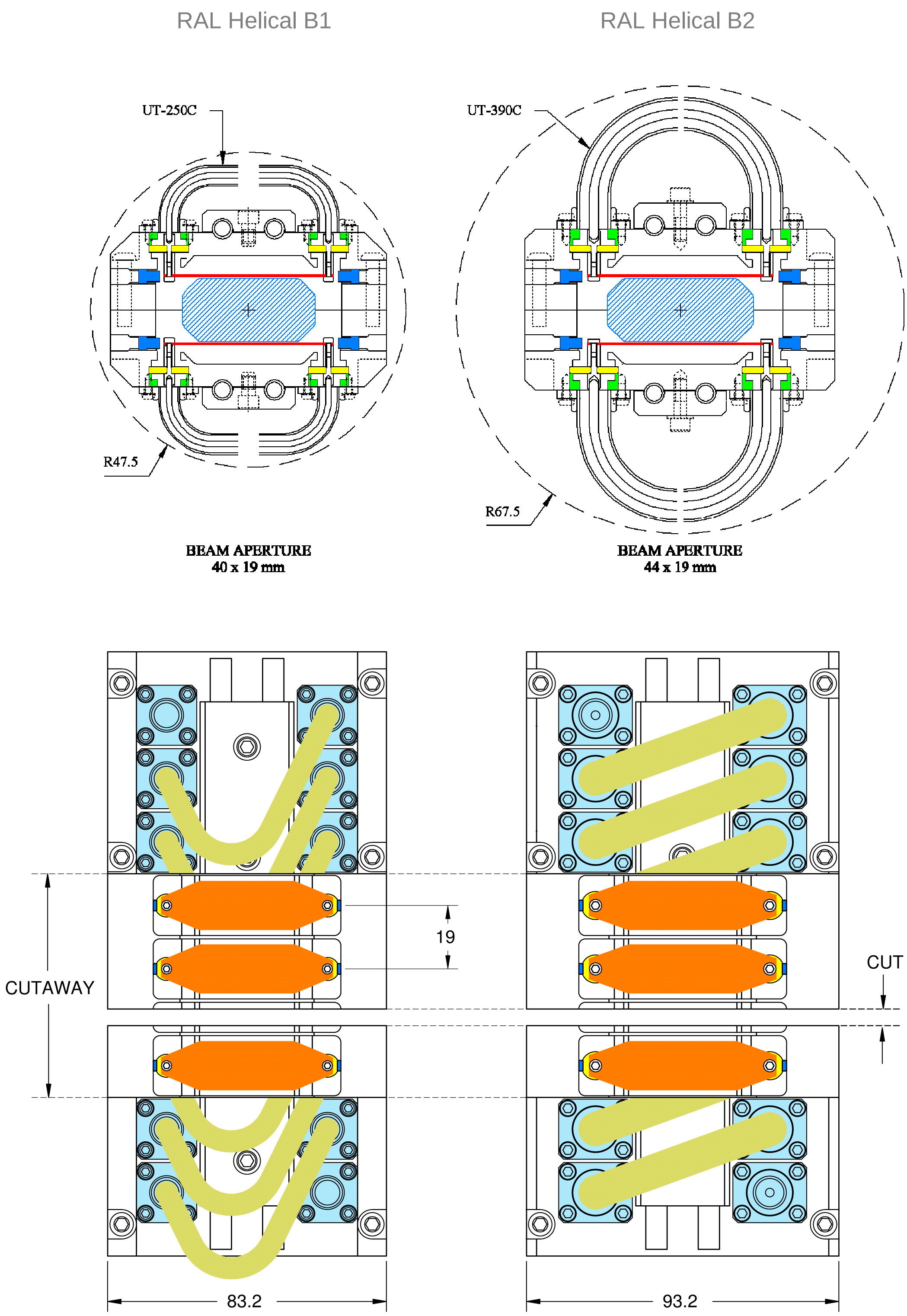


Figure 17: RAL Helical B1 and B2 slow - wave structures / Composite views

4.2 Helical B1 / High frequency modelling

A high frequency 3D model of the Helical B1 structure has been developed and analysed in the CST Microwave Studio code [20]. The model is a development of the earlier RAL Helical B structure for the ESS MEBT [21], and has been designed to meet the objectives listed in section 4.1. Views of the model, where the background material is specified as a perfect conductor, and simulated high frequency characteristics in frequency and time domains, are shown in Figure 18. Further development, and high frequency analysis of these structures is ongoing.

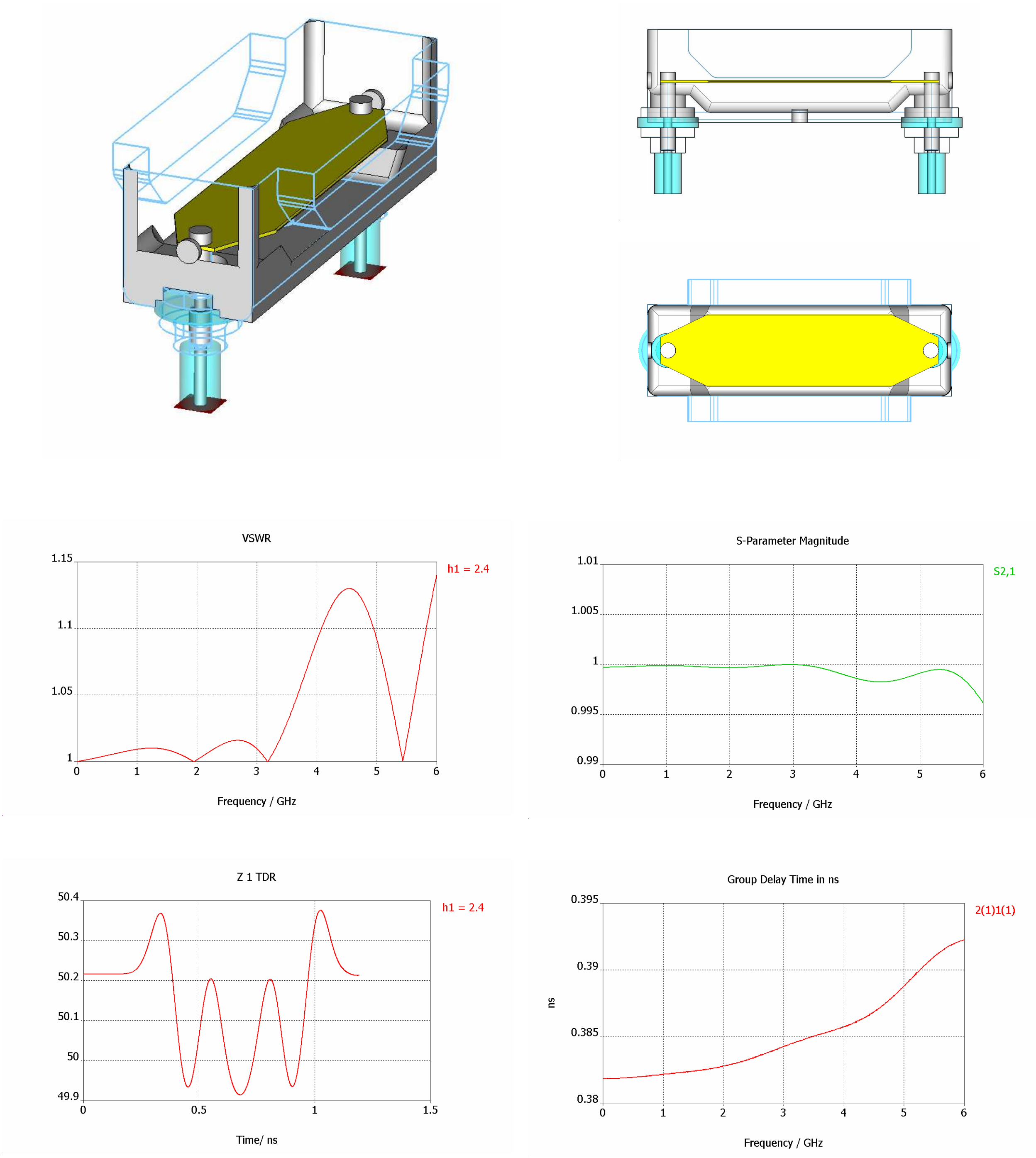
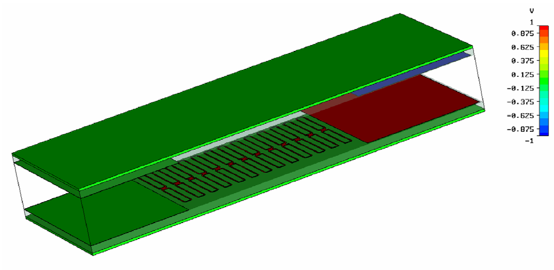


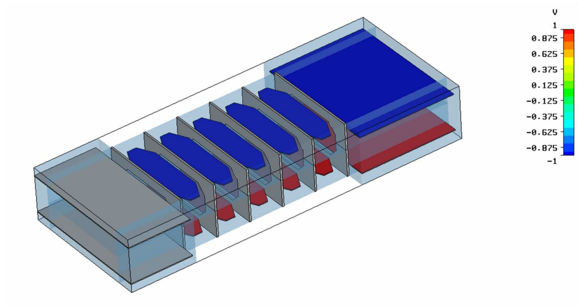
Figure 18: RAL Helical B1 / High frequency model and HF characteristics

4.3 Analysis of slow-wave structure 'coverage factor'

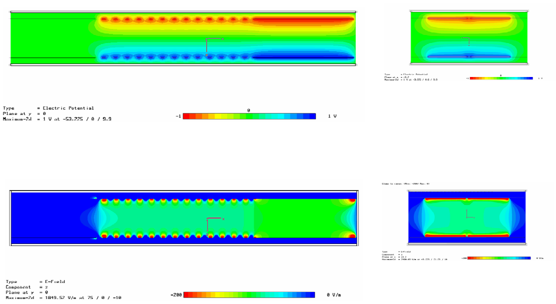
The 'coverage factor' of the CERN and RAL slow-wave structures has been analysed, by simulation of 3D static electric fields in the 'CST EM Studio' code [22]. Extracts from this analysis [19] are shown in Figures 19, and 20.



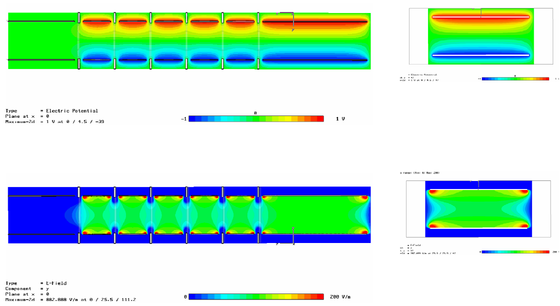
CERN structure / 'CST EM Studio' model



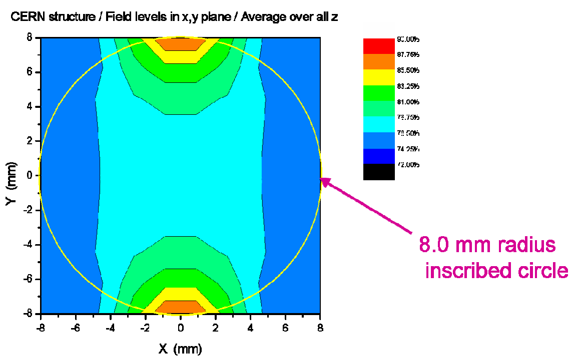
RAL 'Helical B1' structure / 'CST EM Studio' model



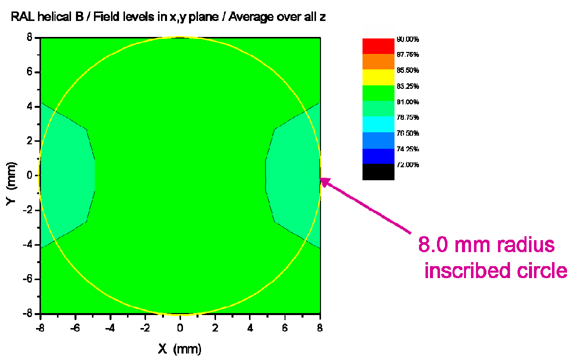
CERN structure / Potential and E field / 2D



RAL 'Helical B1' structure / Potential and E field / 2D



CERN structure / E field integrals in z-plane



RAL 'Helical B1' structure / E field integrals in z-plane

Figure 19: CERN & RAL slow-wave structures /Coverage factor analysis

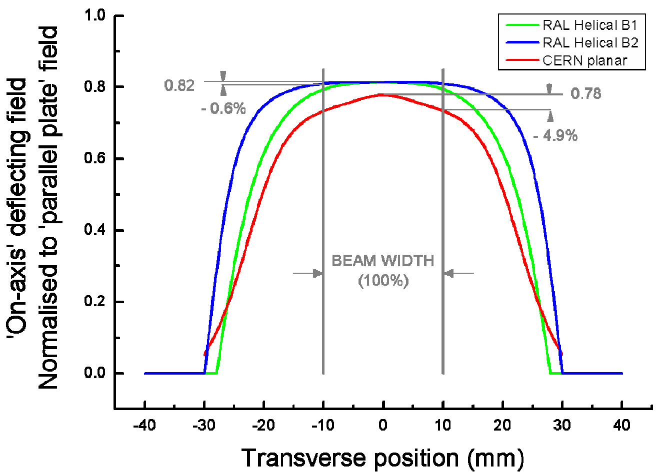


Figure 20: CERN & RAL slow-wave structures / Coverage factor analysis

Table 6: CERN & RAL slow-wave structures / Key parameters & coverage factors†

Design parameter	CERN Planar	RAL Helical B	RAL Helical B1	RAL Helical B2
	Linac 4	ESS	FETS	FETS
H⁻ beam energy (Mev)	3.0	2.5	3.0	3.0
Beam velocity (m/s)	2.39032e7	2.18292e7	2.39032e7	2.39032e7
Beam width / 100% (mm)	20	10	18	18
Beam aperture (mm)	20	11	19	19
Cell periodicity (mm)	6	19		
Cell delay (ns)	0.251012	0.870394	0.794874	0.794874
Coverage factor: Centre / Edge (%)	78 / 73	80 / 75	81 / 79	82 / 81
Characteristic impedance (Ω)	~ 50			
External dimensions (mm)	< 48 radius x 450	< 75 radius x 400	< 48 radius x 450	< 70 radius x 450

† Derived from CST EM Studio analysis

Key parameters and coverage factors for the CERN and RAL slow-wave electrode structures are shown in Table 6. This analysis of coverage factor indicates that the RAL structures (B1 and B2) are expected to produce a higher and more uniform field than the CERN design. However, if the mechanical complexity of the designs is compared, the CERN design appears to be simpler in concept. Field uniformity in the transverse plane has a direct impact on the FPG voltage and MEBT line beam aperture requirements, and on the design of the downstream beam dump. A more comprehensive comparison of these designs will be made when tests on the prototype RAL structures have been completed.

5.0 Conference activity

The following conference papers were submitted during the period July 2005 to December 2006:

2006: **'A fast beam chopper for the RAL Front-End Test Stand'**,
M. A. Clarke-Gayther, CCLRC/RAL/ISIS, Chilton, Didcot, Oxon, UK
G. Bellodi, F. Gerigk, CERN, Geneva, Switzerland.
Proc. of EPAC 2006, Edinburgh, Scotland, UK, 26-30 June, 2006, p.300-302
CARE-Conf-06-005-HIPPI

'Re-bunching RF cavities and hybrid quadrupoles for the RAL Front-End Test Stand',
C. Plostinar, CCLRC/RAL/ASTeC, Chilton, Didcot, Oxon, UK
M. A. Clarke-Gayther, CCLRC/RAL/ISIS, Chilton, Didcot, Oxon, UK
Proc. of EPAC 2006, Edinburgh, Scotland, UK, 26-30 June, 2006, p.306-309
CARE-Conf-06-003-HIPPI

'Design progress of the re-bunching RF cavities and hybrid quadrupoles for the RAL front-end test stand (FETS)'
C. Plostinar, M. Clarke-Gayther, C. Thomas, LINAC2006, Knoxville (USA),
26 July - 2 August, 2006
CARE-Conf-06-048-HIPPI

'The RAL Front-End Test Stand'
A. P. Letchford, D. C. Faircloth, M. A. Clarke-Gayther, CCLRC/RAL/ISIS, &
D. C. Plostinar, CCLRC/RAL/ASTeC, Chilton, Didcot, Oxon, UK
Y. A. Cheng, S. Jolly, A. Kurup, P. J. Savage, Imperial College, London, UK
J. K. Pozimski, CCLRC/RAL/ASTeC & Imperial College, UK
J. J. Back, University of Warwick, Coventry, UK
Proc. of EPAC 2006, Edinburgh, Scotland, UK, 26-30 June, 2006, p.303-305

6.0 HIPPI meeting activity

The following presentations were given during the period July 2005 to December 2006:

2006: **'RAL chopping schemes for next generation high power proton drivers / Progress'** (hippi12)
'RAL Slow-wave electrode designs for a 3 MeV MEBT fast chopper / Progress' (hippi13)
M. A. Clarke-Gayther, 3rd General HIPPI meeting,
Forschungzentrum Julich (FZJ), Julich, GmbH, 27-29th September, 2006

'Re-bunching RF cavity and hybrid quadrupole designs for the RAL FETS project / Progress'
D. C. Plostinar, 3rd General HIPPI meeting,
Forschungzentrum Julich (FZJ), Julich, GmbH, 27-29th September, 2006

'Status of the RAL MEBT and chopper' (hippi10)
'The Front-End Test Stand (FETS) project at RAL' (hippi11)
M. A. Clarke-Gayther, 3rd HIPPI WP4 meeting, Meyrin, CERN,
Geneva, Switzerland, 4-5th May 2006

'Re-bunching RF cavity and hybrid quadrupole designs at RAL'
D. C. Plostinar, 3rd HIPPI WP4 meeting, Meyrin, CERN,
Geneva, Switzerland, 4-5th May 2006

2005: **'Status of the RAL 'Fast-Slow' beam chopper development programme'** (hippi09)
M. A. Clarke-Gayther, 2nd General HIPPI meeting, Coseners House,
Abingdon, UK, 28-30th September 2005

'Design of a re-bunching cavity for the RAL FETS chopper line'
D. C. Plostinar, 2nd General HIPPI meeting, Coseners House,
Abingdon, UK, 28-30th September 2005

7.0 Summary

The project plan for the RAL Fast Beam chopper development programme has been significantly redefined during this reporting period, following a decision to change the MEBT line beam energy from 2.5 to 3.0 MeV, RF frequency from 280 to 324 MHz, and beam aperture in the chopper structures from 12 to 20 mm. A high priority was subsequently given to the development of new optical designs for the FETS MEBT chopper line. These designs have significantly reduced the chopping field requirements, and will consequently ease the pulse generator development task. Development of the RAL slow wave structures was temporarily frozen, but has now restarted, following the redefinition of key parameters. The relocation of office and laboratory space has, inevitably, slowed progress in some areas.

8.0 References

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