NSLS2 Injector Timing

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Contents

1 Overview

This document describes the machine timing configuration and user controls for Booster commissioning.

2 Requirements

1. Support independent operation of Linac for testing at 1, 2, 5, and 10Hz.
2. Support independent testing of Booster timing.
3. Support Booster operating modes: 1Hz, 2Hz, and stacking.
4. Provide a single shot (push for beam) mode.
5. The single shot mode should effect only the electron source and beam diagnostics. Ofther devices should always receive triggers.
6. Provide a control to select which Storage Ring RF bucket should received the first bunch from the Booster.

2.1 Process Variables

The following are the minimum set of PVs which would be provided.

1. Provide a single timestamp for each booster cycle which can be used to simplify later retrieval.
2. Provide the timestamp of the previous cycle for diagnostics with long readout latency.
3. Provide the number of PSC clock ticks in the 1Hz and 2Hz cycle periods.
4. Allow operators to select Linac timing modes. This will consist of several individual controls
   (a) Select Linac Mode: Off, 1Hz, stacking, 2Hz, 5Hz, or 10Hz.
   (b) Select Booster Mode: Off, 1Hz, stacking, or 2Hz.
   (c) Load selected modes.
   (d) Select between CW and Single Shot operation.
5. Provide status:
   (a) Currently running modes for Linac and Booster
   (b) Current modes compatible with injection of beam into booster.
   (c) If selected next modes can be loaded (based on current machine state).
   (d) Timing operation status (running, stopped).
   (e) Cycle counter.

3 Cycle Definition

For the purposes of configuration an injector cycle is viewed on a 1 cycle scale (see figure 2). Here 1 cycle is defined as as 127281000 ticks of the Timing System clock or equivalently 509124000 ticks of the ~500 MHz RF reference clock. This is broken down into two periods of 63640500 timing ticks, and further into 10 periods of 12728100 timing ticks.

These numbers are selected to satisfy the constraints imposed by the necessity that the cycle periods should be multiples of the clocks shown in figure 1. The divider N gives the ~10Hz period. The constraints placed on N can be expressed as:

$$\begin{aligned} N &= 6 \cdot M \\ N &= \frac{14}{3} \cdot P \\ N &= 12540 \cdot Q \\ N &= \frac{25}{2} \cdot R \\ N &= \frac{5}{2} \cdot S \end{aligned}$$

Given that M (LN 500MHz LLRF), N (Timing System), P (LN 3GHz LLRF), Q (Orbit feedback and ring revolution clocks), R (BR LLRF), and S (BR LLRF) must be integers, it can be seen that the first divider N which produces a frequency $\leq 10Hz$ is $N = 12728100$. The others parameters are then $M = 2121350$, $P = 2727450$, $Q = 1015$, $R = 1018248$, $S = 5091240$.

The number of 10 KHz PSC (Power Supply Controller) clock ticks during each 1 Hz cycle is thus 10150.

Assuming an RF clock frequency of exactly 499.68 MHz, one second is 124920000 ticks. So the time duration of the 1 cycle is 1.018900096 seconds ($\frac{127281000}{124920000}$).

4 Event Codes

The event codes allocated for use in the injector are:

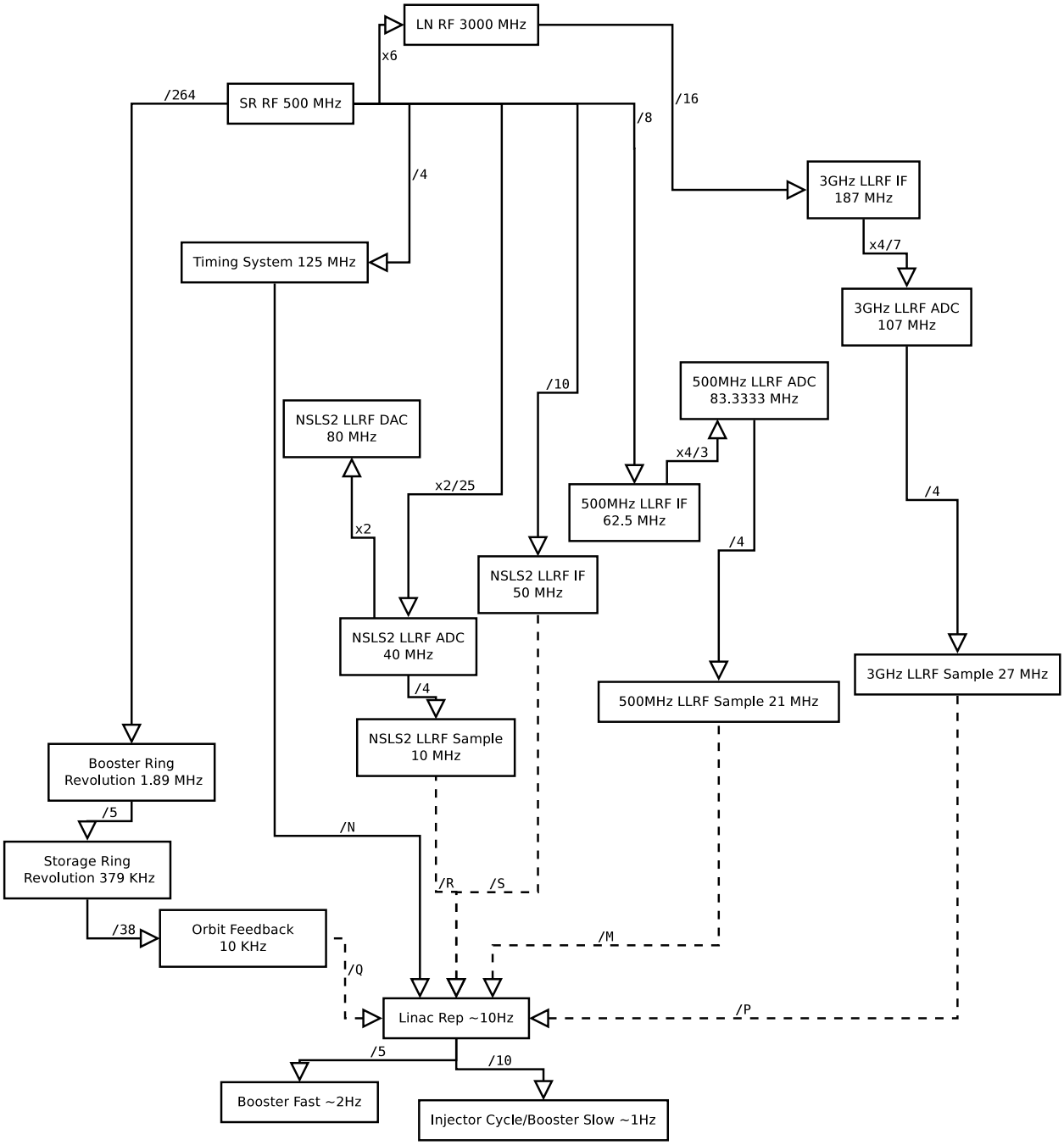

Figure 1: Constraints on the selection of the 10 Hz period

Event #	Function	Beam Only?
10	Injector fine delay 0 buckets	
11	Injector fine delay 1 buckets	
12	Injector fine delay 2 buckets	
13	Injector fine delay 3 buckets	
15	Linac pre-trigger	
16	Linac e^-source trigger	
20	BR SLM	Yes
21	BR Injection #1 (all modes)	
22	BR Injection #2 (stacking mode)	
23	BR Charge IS kickers	
25	Booster T0	
26	Booster Extract	
27	Booster PSC Sync	
28	BR Charge XS kickers	
47	SR first turn diag.	Yes
55	Linac pre-trigger (Beam)	Yes
56	Linac e^-source trigger	Yes
65	Booster T0	Yes
66	Booster Extract	Yes

The "Beam only" events will only be sent with cycles when beam is requested.

Notation:

N_X Number of ticks in $\frac{X}{1000}$ of the total cycle length. N_{1000} is equal to $10 \cdot N$ as derived in section 3.

R_X Number of ticks in X ms (wall clock) assuming an RF reference clock frequency of exactly 499.68 MHz. ($R_X = 124920 \cdot X$)

T_M Period of machine M ($BR = 66$ or $SR = 330$)

L_Y Time of previous occurrence of event Y in this sequence.

A_Y Time of the next occurrence of event Y in this sequence.

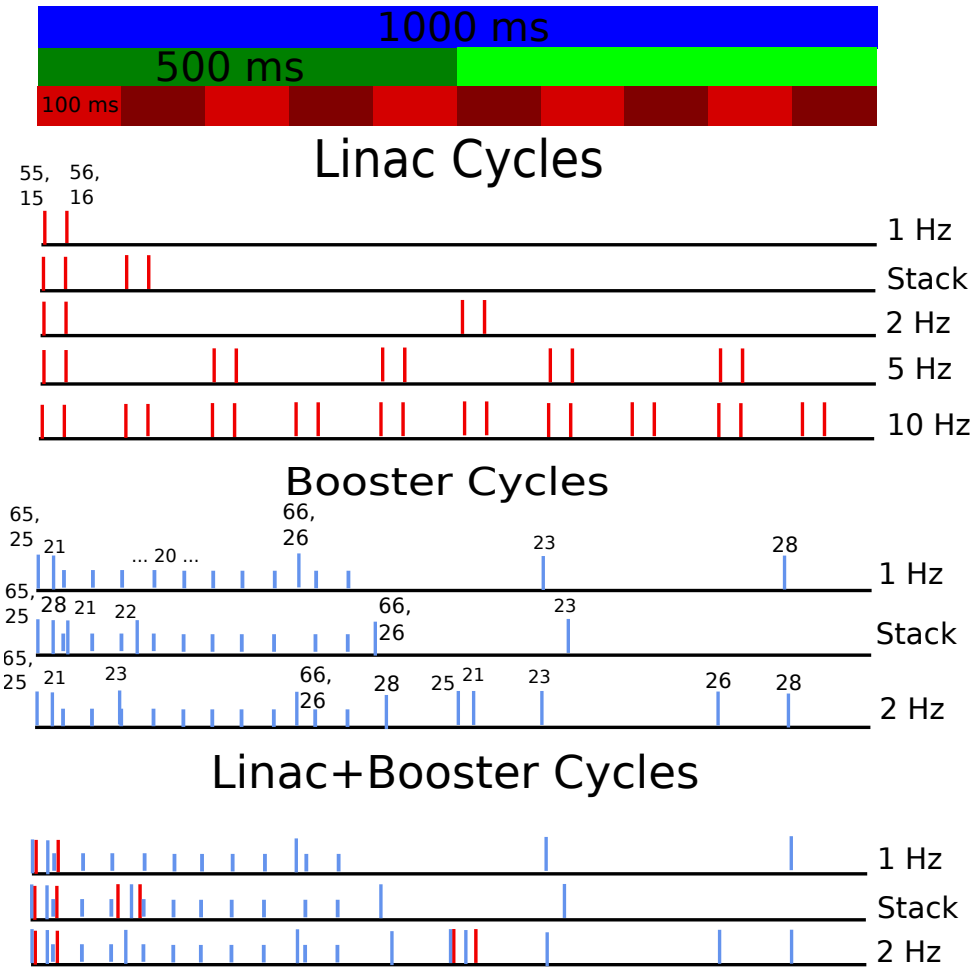

Figure 2: Order and approximate time of injector events

4.1 Linac+Booster 1 Hz cycle

Event #	Delay Calc	Delay Ticks	EGU	Function
47	Reference	8	64 ns	SR first turn beam diag.
65	Reference	10	80 ns	BR beam diagnostics
55	$L_{65}+1$	11	88 ns	LN beam diagnostics
25	$L_{65}+4$	14	112 ns	BR PSCs and device cycle start time
15	$L_{55}+4$	15	120 ns	Start Linac Cycle start
10+P	$L_{15}+2$	17	136 ns	Injection fine delay (P=[1,3])
21	$L_{25}+3030*T_{SR}$	999914	8 ms	Booster injection #1
20	$A_{56}-R_1$	1124291	9 ms	BR SLM #1
56	$L_{55}+R_{10}$	1249211	10 ms	LN beam diag. and egun
16	$L_{15}+R_{10}$	1249215	10 ms	Linac Electron source trigger
20	$L_{20}+R_{40}$	6121091	49 ms	BR SLM #2
20	$L_{20}+R_{40}$	11117891	89 ms	BR SLM #3
20	$L_{20}+R_{40}$	16114691	129 ms	BR SLM #4
20	$L_{20}+R_{40}$	21111491	169 ms	BR SLM #5
20	$L_{20}+R_{40}$	26108291	209 ms	BR SLM #6
20	$L_{20}+R_{40}$	31105091	249 ms	BR SLM #7
20	$L_{20}+R_{40}$	36101891	289 ms	BR SLM #8
66	$L_{65}+T_{SR}*113600$	37488010	300 ms	BTS beam diagnostics
26	$L_{25}+T_{SR}*113600$	37488014	300 ms	Booster Extraction
20	$L_{20}+R_{40}$	41098691	329 ms	BR SLM #9
20	$L_{20}+R_{40}$	46095491	369 ms	BR SLM #10
23	$L_{21}+N_{600}$	77368514	619 ms	BR Charge IS kickers
28	$L_{26}+N_{600}$	113856614	911 ms	Booster XS Kicker Charge

4.2 Linac+Booster 2 Hz cycle

Event #	Delay Calc	Delay Ticks	EGU	Function
47	Reference	8	64 ns	SR first turn beam diag.
65	Reference	10	80 ns	BR beam diagnostics
55	$L_{65}+1$	11	88 ns	LN beam diagnostics
25	$L_{65}+4$	14	112 ns	BR PSCs and device cycle start time
15	$L_{25}+1$	15	120 ns	Start Linac Cycle start
10+P	$L_{15}+2$	17	136 ns	Injection fine delay (P=[1,3])
21	$L_{25}+3030*T_{SR}$	999914	8 ms	Booster injection #1
20	$A_{56}-R_1$	1124291	9 ms	BR SLM #1
56	$L_{55}+R_{10}$	1249211	10 ms	LN beam diag. and egun
16	$L_{15}+R_{10}$	1249215	10 ms	Linac Electron source trigger
20	$L_{20}+R_{40}$	6121091	49 ms	BR SLM #2
20	$L_{20}+R_{40}$	11117891	89 ms	BR SLM #3
23	$L_{21}+N_{100}$	13728014	110 ms	BR Charge IS kickers
20	$L_{20}+R_{40}$	16114691	129 ms	BR SLM #4
20	$L_{20}+R_{40}$	21111491	169 ms	BR SLM #5
20	$L_{20}+R_{40}$	26108291	209 ms	BR SLM #6
20	$L_{20}+R_{40}$	31105091	249 ms	BR SLM #7
20	$L_{20}+R_{40}$	36101891	289 ms	BR SLM #8
66	$L_{65}+T_{SR}*113600$	37488010	300 ms	BTS beam diagnostics
26	$L_{25}+T_{SR}*113600$	37488014	300 ms	Booster Extraction
20	$L_{20}+R_{40}$	41098691	329 ms	BR SLM #9
20	$L_{20}+R_{40}$	46095491	369 ms	BR SLM #10
28	$L_{26}+N_{100}$	50216114	402 ms	Booster XS Kicker Charge

4.3 Linac+Booster stacking cycle

Event #	Delay Calc	Delay Ticks	EGU	Function
47	Reference	8	64 ns	SR first turn beam diag.
65	Reference	10	80 ns	BR beam diagnostics
55	$L_{65}+1$	11	88 ns	LN beam diagnostics #1
25	$L_{65}+4$	14	112 ns	BR PSCs and device cycle start time
15	$L_{25}+1$	15	120 ns	Start Linac Cycle start
28	$L_{15}+1$	16	128 ns	Booster Extraction Kicker Charge
10+P	$L_{15}+2$	17	136 ns	Injection fine delay (P=[1,3])
21	$L_{25}+3030*T_{SR}$	999914	8 ms	Booster injection #1.
20	$A_{56}-R_1$	1124291	9 ms	BR SLM #1
56	$L_{55}+R_{10}$	1249211	10 ms	LN beam diag. and egun #1
16	$L_{15}+R_{10}$	1249215	10 ms	Linac Electron source trigger
20	$L_{20}+R_{40}$	6121091	49 ms	BR SLM #2
20	$L_{20}+R_{40}$	11117891	89 ms	BR SLM #3
55	$L_{55}+N_{100}$	12728111	102 ms	LN beam diagnostics #2
15	$L_{15}+N_{100}$	12728115	102 ms	2nd Linac Cycle start
22	$L_{21}+N_{100}$	13728014	110 ms	Booster injection #2
56	$L_{56}+N_{100}$	13977311	112 ms	LN beam diag. and egun #2
16	$L_{16}+N_{100}$	13977315	112 ms	2nd Linac Electron source trigger
20	$L_{20}+R_{40}$	16114691	129 ms	BR SLM #4
20	$L_{20}+R_{40}$	21111491	169 ms	BR SLM #5
20	$L_{20}+R_{40}$	26108291	209 ms	BR SLM #6
20	$L_{20}+R_{40}$	31105091	249 ms	BR SLM #7
20	$L_{20}+R_{40}$	36101891	289 ms	BR SLM #8
20	$L_{20}+R_{40}$	41098691	329 ms	BR SLM #9
20	$L_{20}+R_{40}$	46095491	369 ms	BR SLM #10
66	$L_{65}+T_{SR}*151418$	49967950	400 ms	BTS beam diagnostics
26	$L_{25}+T_{SR}*151418$	49967954	400 ms	Booster Extraction
23	$L_{21}+N_{600}$	77368514	619 ms	BR Charge IS kickers

4.4 SR First Turn Diagnostics (#47)

While part of the injection sequence, this event is not time shifted to target a particular SR RF bucket. Thus it has a stable phase relation to the SR revolution clock. Requested for BPM turn-by-turn and SR fill pattern monitor (when not storing beam).

4.5 Booster PSC Update Event (#27)

This is a special software (asynchronous) event to signals all Booster PSCs to switch their ramp tables at the next start trigger. This event may not be sent for every cycle.

5 Storage Ring Filling

The function of the injector is to place electrons in the storage ring. During booster extraction, the first electron bunch to leave to booster will be placed into one of the 1320 RF buckets of the storage ring. A

Device	Function	Res.
cPCI-EVRTG-300	Electron source trigger	1 ns
Cryoelectra DRFM 500	Linac prebuncher LLRF	48 ns
Cryoelectra DRFM 3000	Linac other LLRF	37 ns
BINP ADC200	BR kicker diagnostics	8 ns
SIS3302	SR kicker diagnostics	16 ns
PSC	Ramping power supplies	98,522 ns
BNL CFC	Booster LLRF	100 ns
BNL BPM	Transverse beam position	2640 ns

Table 1: Effective trigger resolution of devices in the injector

control which allows operator selection of this SR RF bucket is implemented by time shifting the all injector events.

Due to the fact that this control must provide single bucket (2 ns) resolution, it can not be implemented solely by changing the event delays in the EVG. Some change must be made to the EVR delay channels with better resolution. As events can only be shifted by a multiple of 4 RF buckets, some extra information must be sent to allow the fine delay (target bucket modulo 4) to be computed in each EVR. This is accomplished by sending one of 4 special event codes (10-13).

5.1 Trigger resolution

Not all devices will follow trigger changes of 8 ns. Devices with an external clock typically use it to sample their trigger. In these cases the trigger resolution is limited by the clock period.

Table 1 lists triggered devices in the injector and gives effective trigger resolution (limited by device or EVR). This includes some devices which are not sensitive to start time (eg. integrating).

6 Device Timing

6.1 Booster Kicker Magnets

The Booster kicker magnet power supplies expect two electrical trigger inputs. One trigger begins the charging process, the second triggers a discharge. The timing for these signals in the CW operating modes is shown in figure 3. The PSC start trigger is the time reference.

The start discharge triggers for IS kickers 1 and 2 are mapped to event 22 only. IS kickers 3 and 4 are mapped to both events 21 and 22. The XS kickers are mapped only to event 26.

The charge triggers Kicker charging supplies must be triggered 400 ms before a discharge.

An example configuration for the EVent Receiver (EVR) channels would be

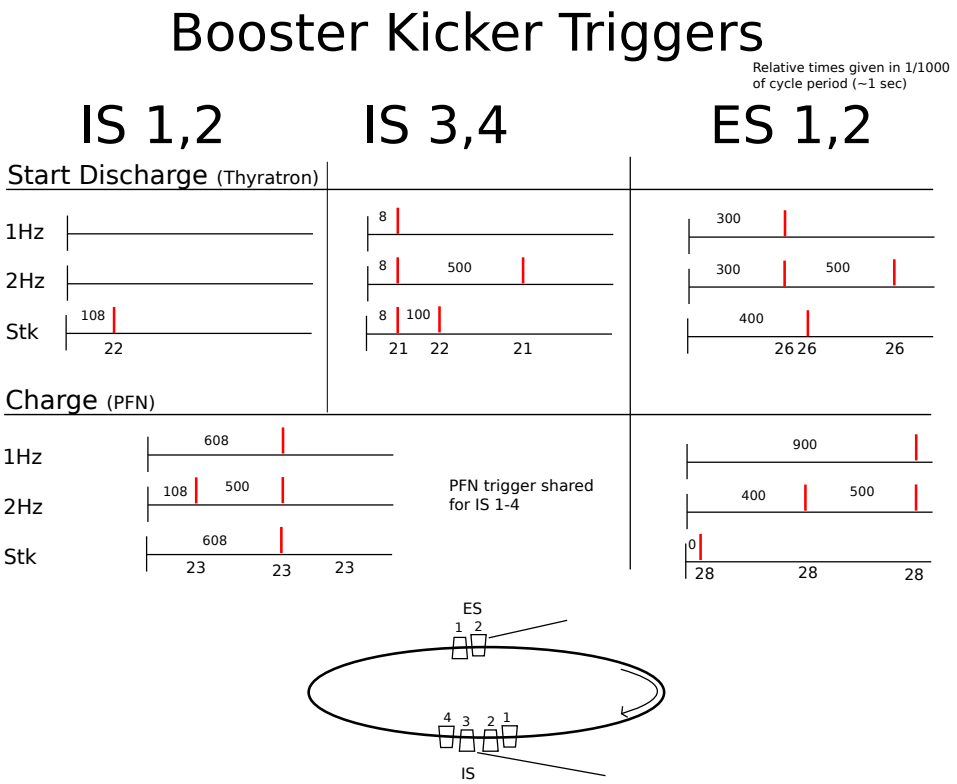

Figure 3: Electrical trigger signals for kicker PS types in each Booster mode

Name	Event(s)	Delay from Event	Pulse Width
IS 3,4 Start Discharge	21,22	2 ms	20 us
IS 3,4 Charge	23	0 ms	20 us
IS 1,2 Start Discharge	22	2 ms	20 us
IS 1,2 Charge	23	0 ms	20 us
XS Start Discharge	26	2 ms	20 us
XS Charge	28	0 ms	20 us

6.2 Booster Synchrotron Light Monitor

The Booster SLM camera needs a burst of trigger pulses during the fill, ramp, and extraction. The triggers should come no more often than every 40 ms (25 Hz CW).

6.3 Injector Fine Delay

The relation of the timing system clock period and RF clock period is $\frac{4}{1}$. This limits delays to a resolution of 4 RF buckets, which is sufficient for most devices. For devices needing single bucket resolution (e^- source) a fine delay of 0, 1, 2, or 3 buckets distributed. The mechanism for this is by sending one of 4 special event codes (10, 11, 12, or 13) each cycle. This special event is sent ~10 ms before the electron source is triggered. Receiving EVR IOCs therefore have ~10 ms to change CML/GTX delay channels before they are triggered.

7 Process Variables

In order to satisfy the requirements stated in section 1 the following PVs are provided.

All injector EVRs will be loaded with local counter PVs to provide Booster and Linac timestamps with minimum delivery latency.

- $(SYS)-TS{EVR:$(EVR)}Cnt:BR-I
- $(SYS)-TS{EVR:$(EVR)}Cnt:BRPrev-I

The relation between the ~10 KHz orbit feedback clock period (used for all PSCs) and the injector repetition clock periods are given available. The values of the first two PVs will remain unchanged unless the timing config is updated. The third will change to reflect the current Booster timing mode.

- BR-TS{}Ratio:10Kto1-I
- BR-TS{}Ratio:10Kto2-I
- BR-TS{}Ratio:10K-I

8 User Interface

The current operator (figure 4) and expert (figure 5) control panels.

The operator panel shows the current timing modes in the center pane. The left pane allows a new timing configuration to be prepared and applied in two separate steps. To do this a user selects from the possible modes for the Linac and Booster. The 'Apply' button will write the new configuration to the Event Generator.

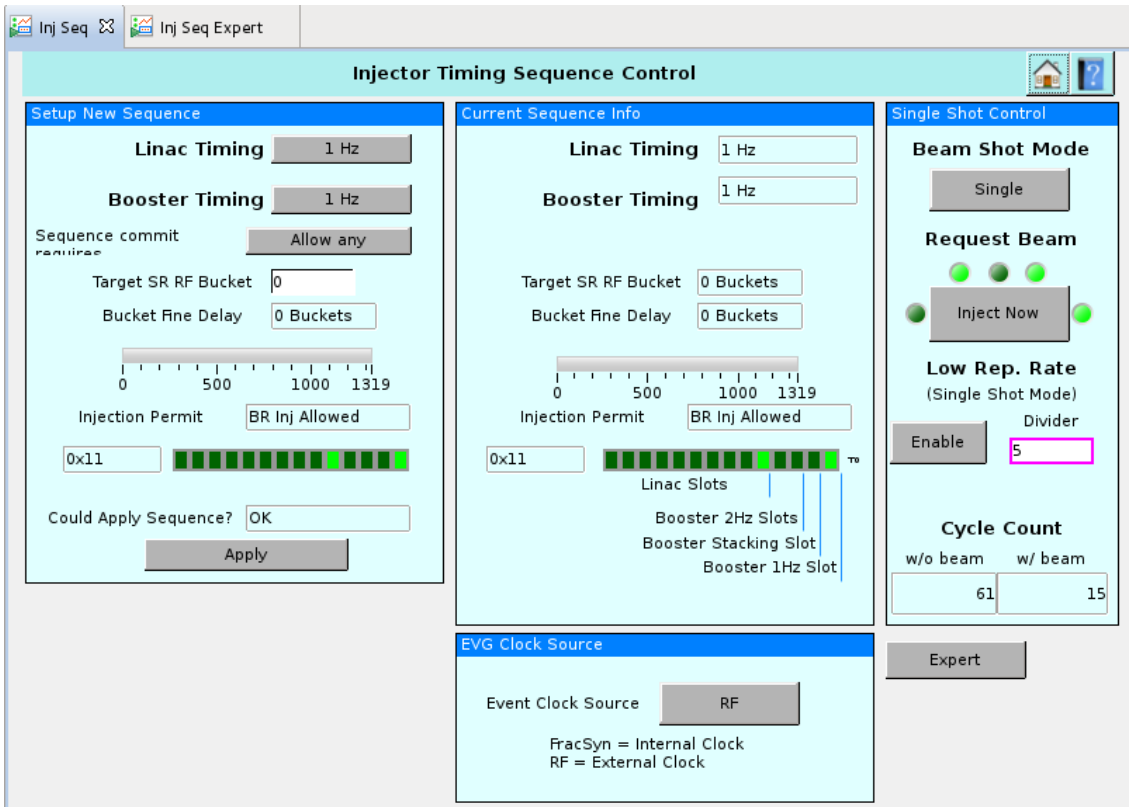

Figure 4: Operator Injector Timing Panel

The 'Sequence commit requires' selection allows the operator to place restrictions on the selectable modes. Currently selections are 'Allow any' and 'Require BR Inject'. The second allows only modes which a compatible with injection from Linac to Booster. If an invalid selection is made then clicking the 'Apply' button has no effect.

The right pane contains the single shot controls. A selection can be made between 'Single' and 'CW' modes. In 'Single' mode the 'Inject Now' button is pressed (write 1) to request a single injection. Alternately the low repetition rate controller can be enabled to give beam on every Nth cycle.

The expert display contains some diagnostic information and two bit masks which can be used to prevent certain modes from being selected.

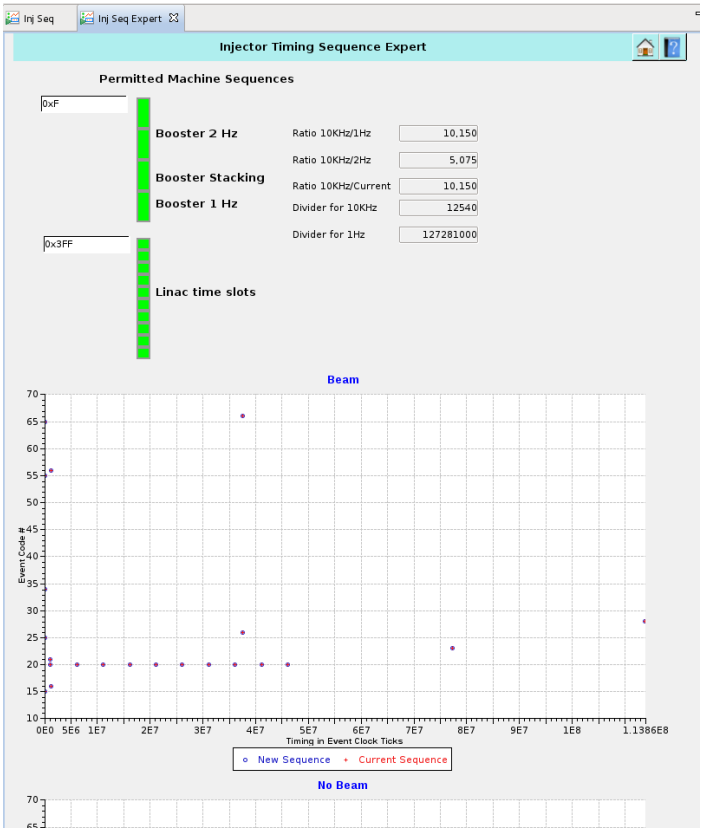

Figure 5: Expert Injector timing display