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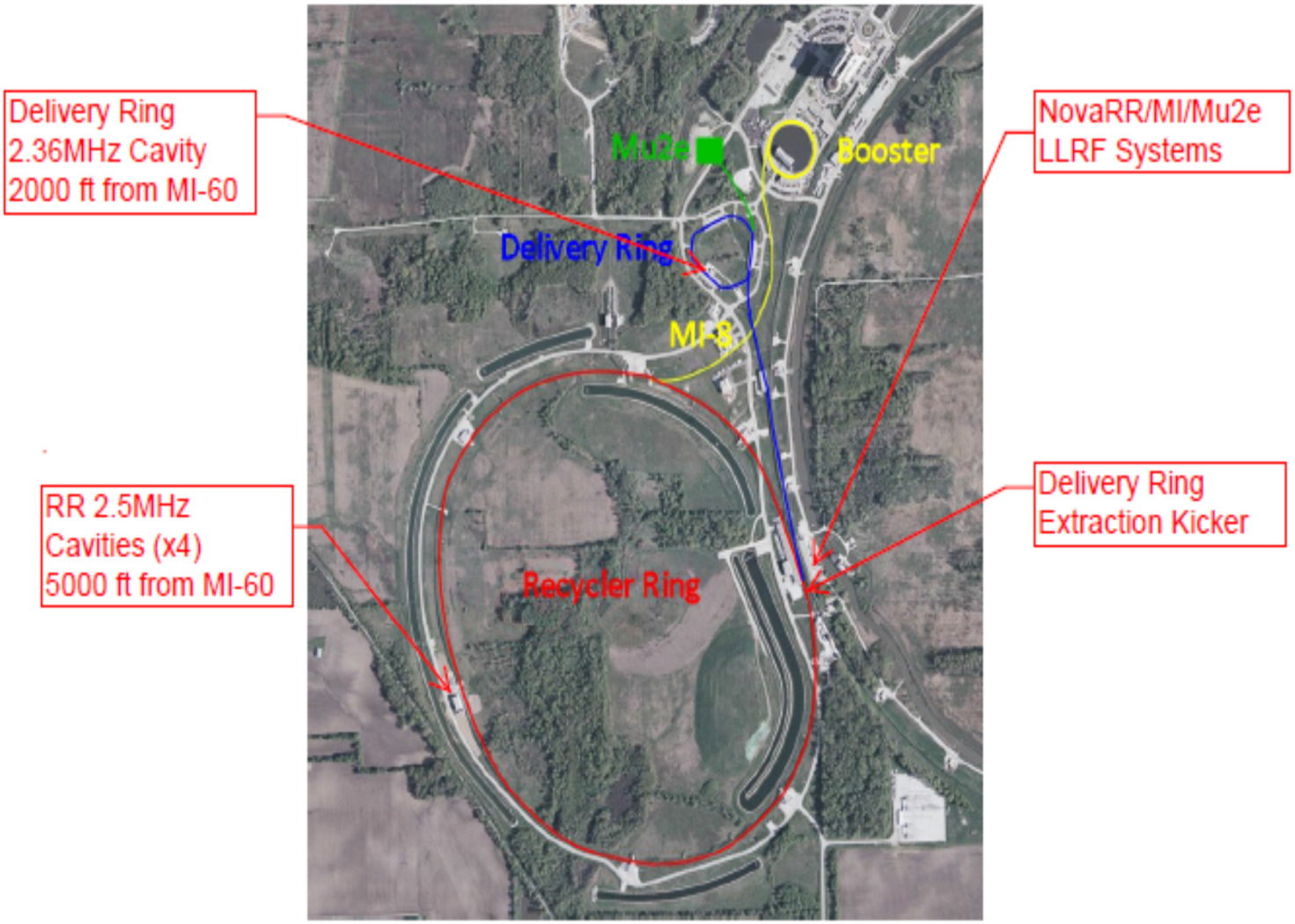
Delivery Ring LLRF system for the Mu2e Project

P. Varghese

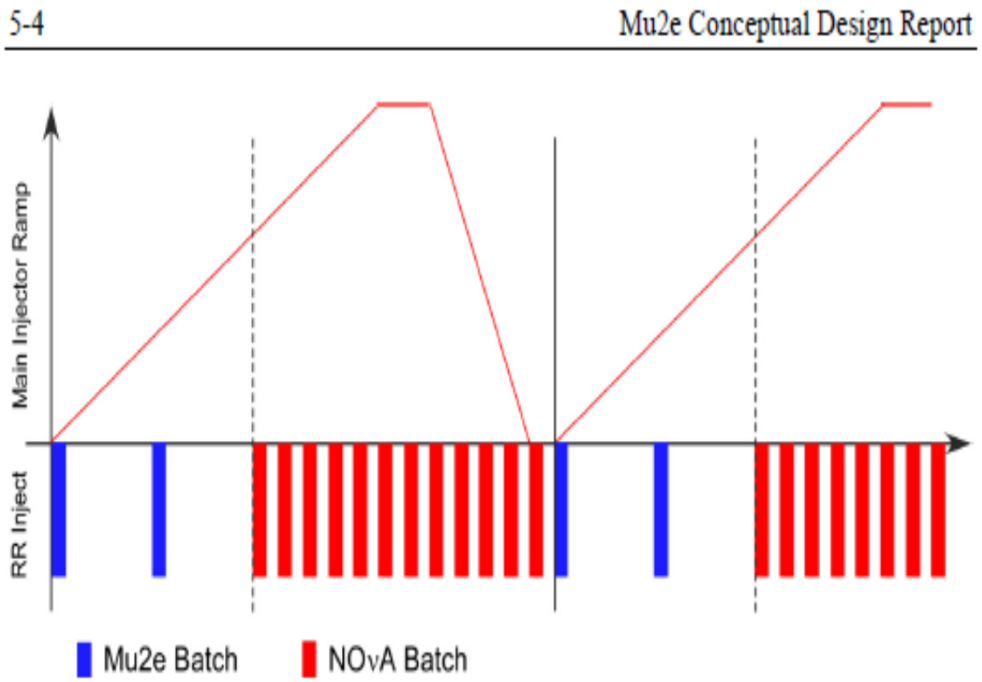
Delivery Ring LLRF system

19 Nov 2015

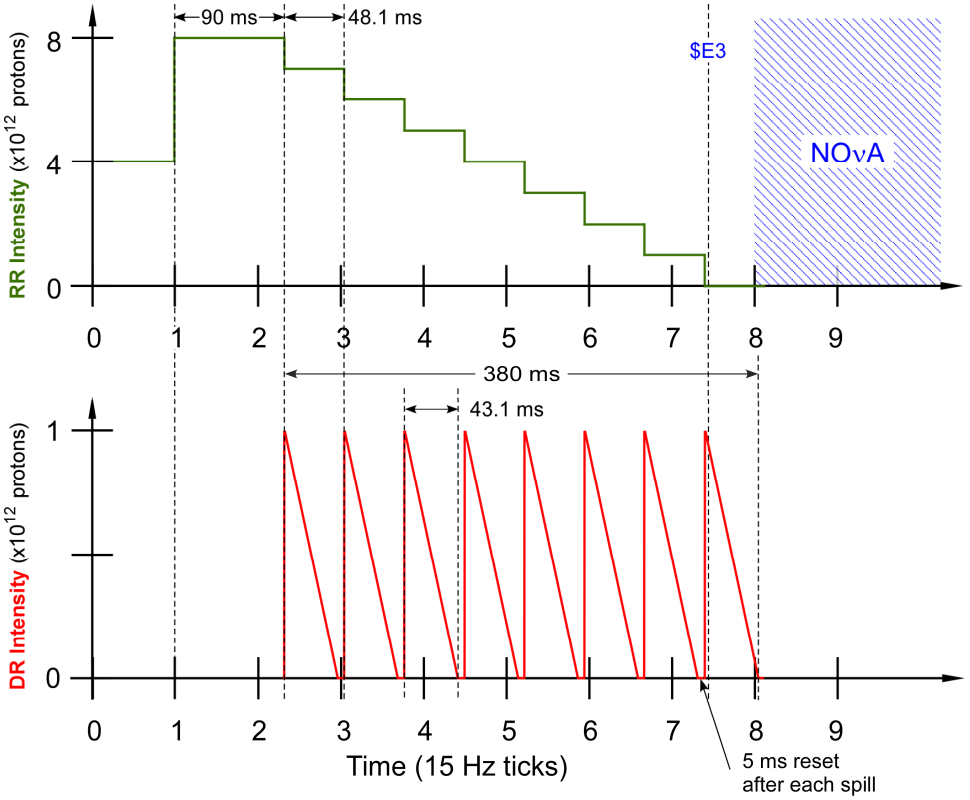
Location of RF components and Delivery Ring LLRF system



8 Booster cycles in MI cycle used for Mu2e



Modified Operating Scenario



MODIFIED OPERATING SCENARIOS FOR THE G-2 AND MU2E EXPERIMENTS

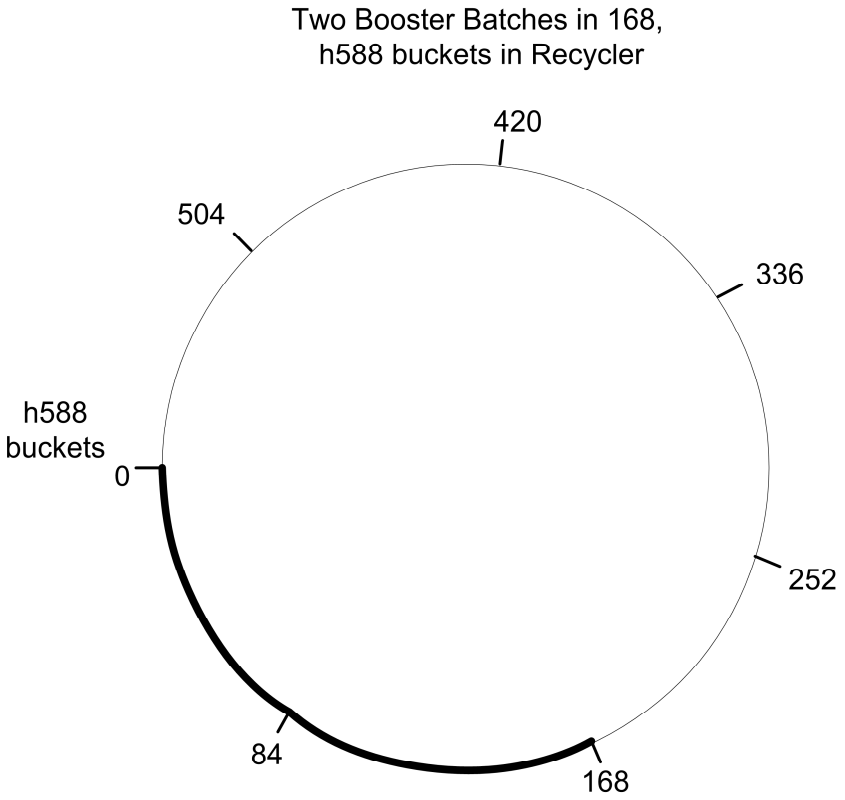
Version 1.4

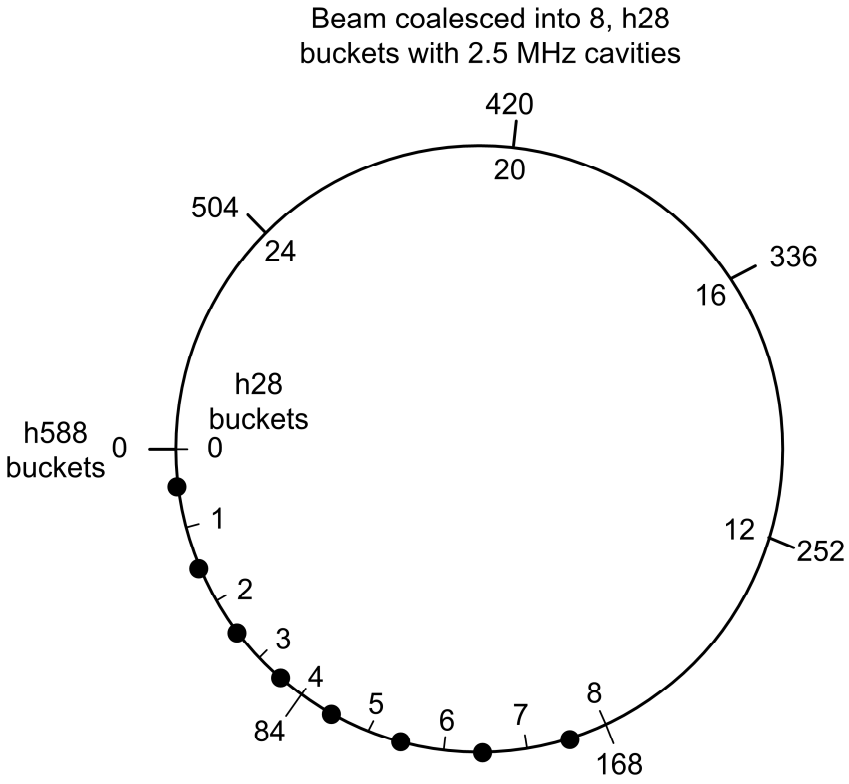
June 17, 2015

Beams-doc-4854

Mu2e				
Total ticks	NOvA Batches	Relative Mu2e total rate[1]	Relative NOvA rate[1]	Peak Detector Rate Factor[2]
20	12	100%	100%	1.61
20	11	100%	92%	1.27
20	10	100%	84%	1.04
21	12	95%	95%	1.27
21	11	95%	87%	1.04
22	12	91%	91%	1.04

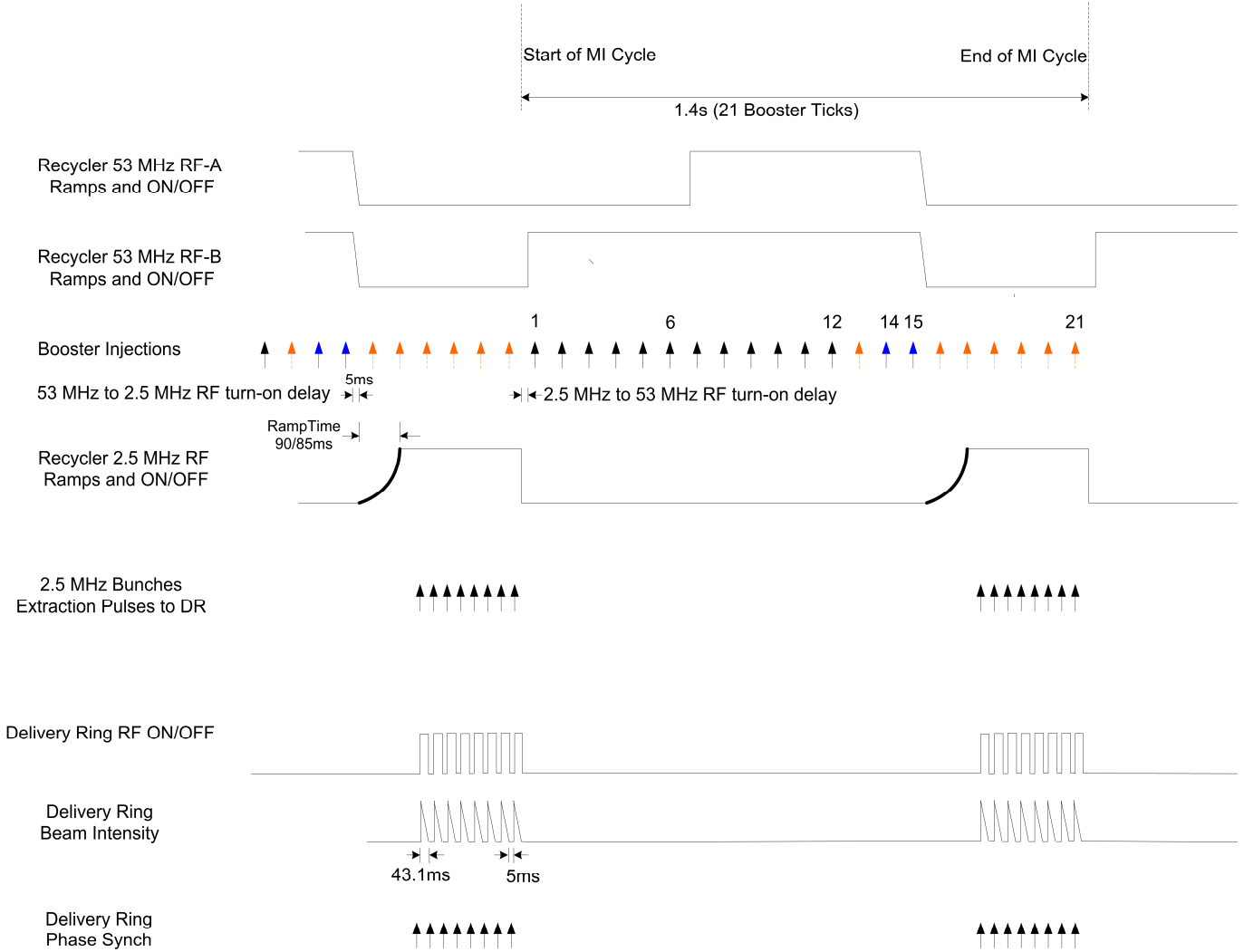
Recycler Beam Manipulation for Mu2e



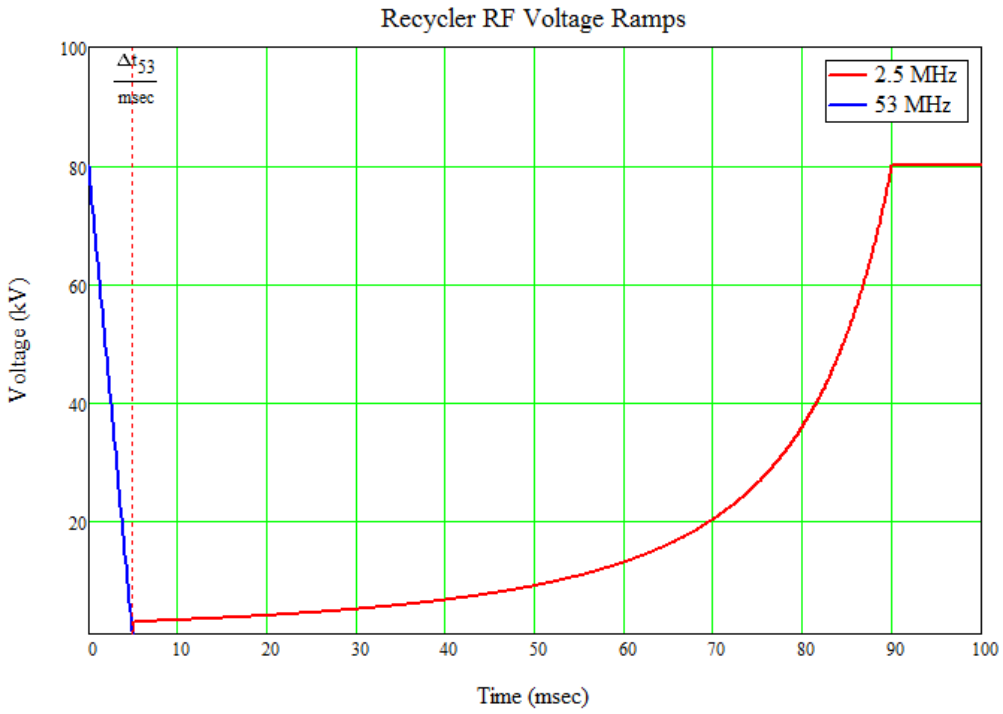


- 2.5 Mhz and 53 Mhz buckets are aligned

Nova/Mu2e Timeline



Recycler RF Voltage Ramps for Beam Manipulation



- 53 Mhz RF linearly ramped down over 5 ms interval
- 2.5 Mhz RF adiabatically ramped from 3 – 80 kV over an interval of 90 ms for coalescing

Requirements for Mu2e Delivery Ring LLRF

1. 8 booster cycles in MI cycle used to provide beam to the Delivery Ring
2. Two batches are captured in 53 MHz buckets. 53 MHz RF is ramped off and 2.5 MHz RF is ramped to 80 kV over 90ms
3. 8, 2.5 Mhz bunches are transferred - one bunch at a time to the Delivery Ring
4. Extraction synch pulses provided for each bunch
5. Delivery Ring frequency of 2.36MHz is non-harmonically related to the RR 2.5 MHz.
6. The frequency drop must be handled by the LLRF system while providing phase alignment at transfer

Recycler 2.5 MHz Cavity Parameters

Parameter	Value	Units
Harmonic Number	28	
Frequency	2.515	MHz
Peak Voltage	80	kV
Number of Cavities	6	
R/Q	400	Ω
Q	125	
Bandwidth	18.8	kHz
Time Constant τ	16.9	μs
90% Rise Time w DRF FB	7.3	μs
Cavity Power Loss	1.0	kW
SS Amplifier Output	6x5.0	kW

- 5000 ft , ½ ” Heliax LDF4-58 cable from MI-60 to cavity
- Cable attenuation 5.1 dB

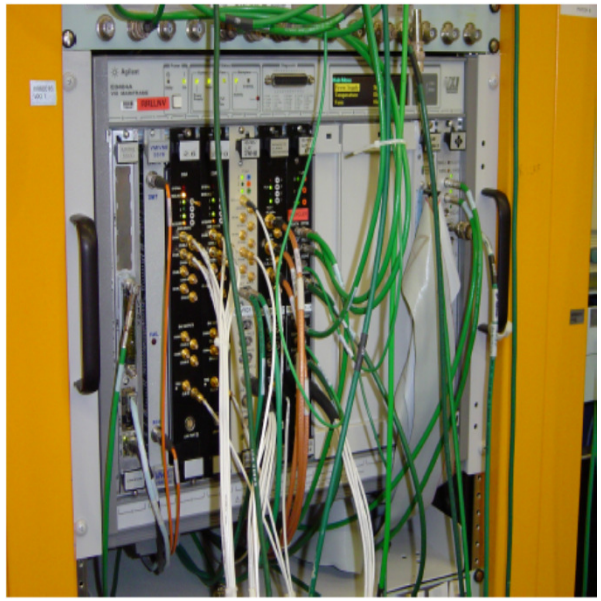
Delivery Ring Cavity Parameters

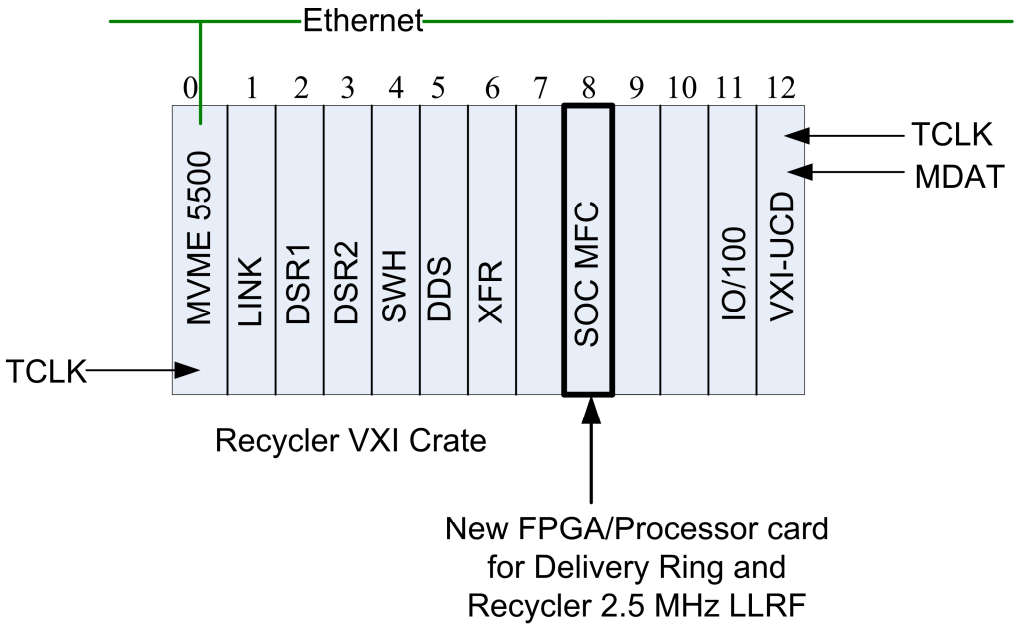
Parameter	Value	Units
Harmonic Number	4	
Frequency	2.360	MHz
Peak Voltage	10	kV
Number of Cavities	1	
R/Q	400	Ω
Q	125	
Bandwidth	18.8	kHz
Time Constant τ	16.9	μs
90% Rise Time w DRF FB	7.3	μs
Cavity Power Loss	1.0	kW
SS Amplifier Output	8.0	kW

- 2000 ft , ½ ” Heliax LDF4-58 cable from MI-60 to cavity
- Cable attenuation 2 dB

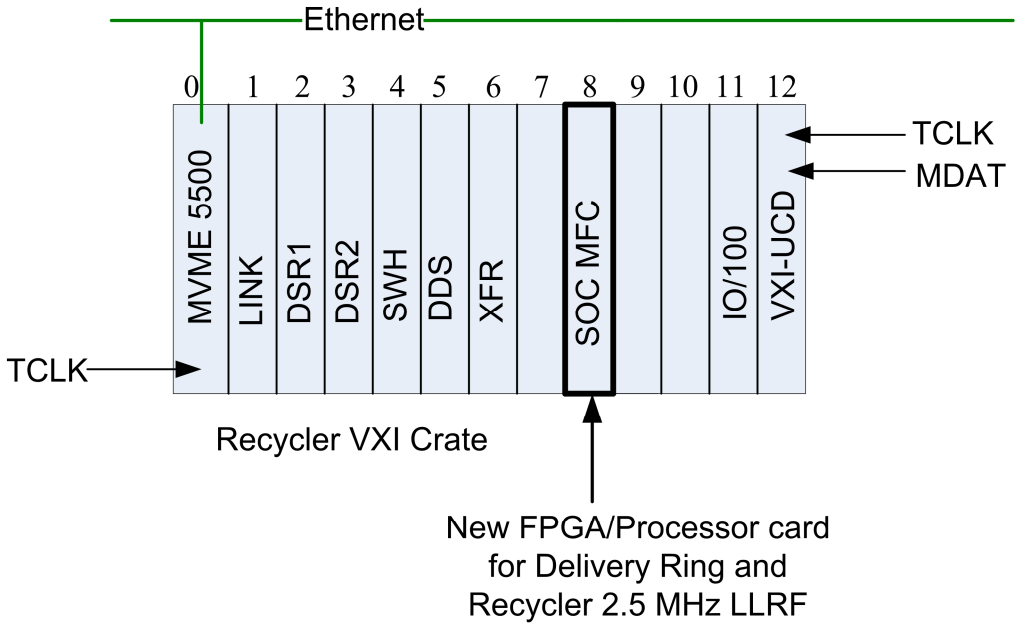
Recycler Nova/Mu2e LLRF system

Nova Recycler LLRF system



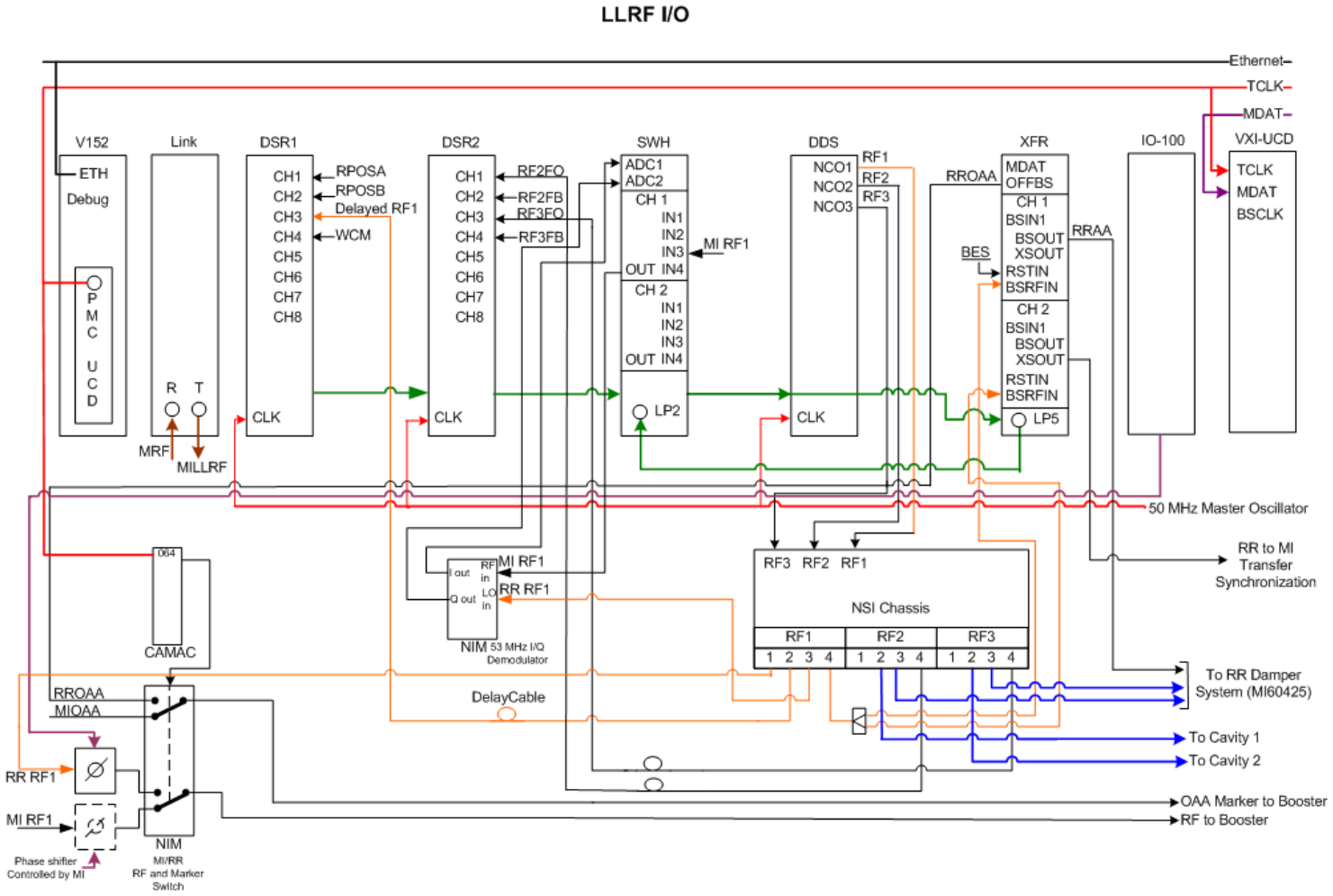


Integration of DR LLRF Card into the Recycler VXI Crate

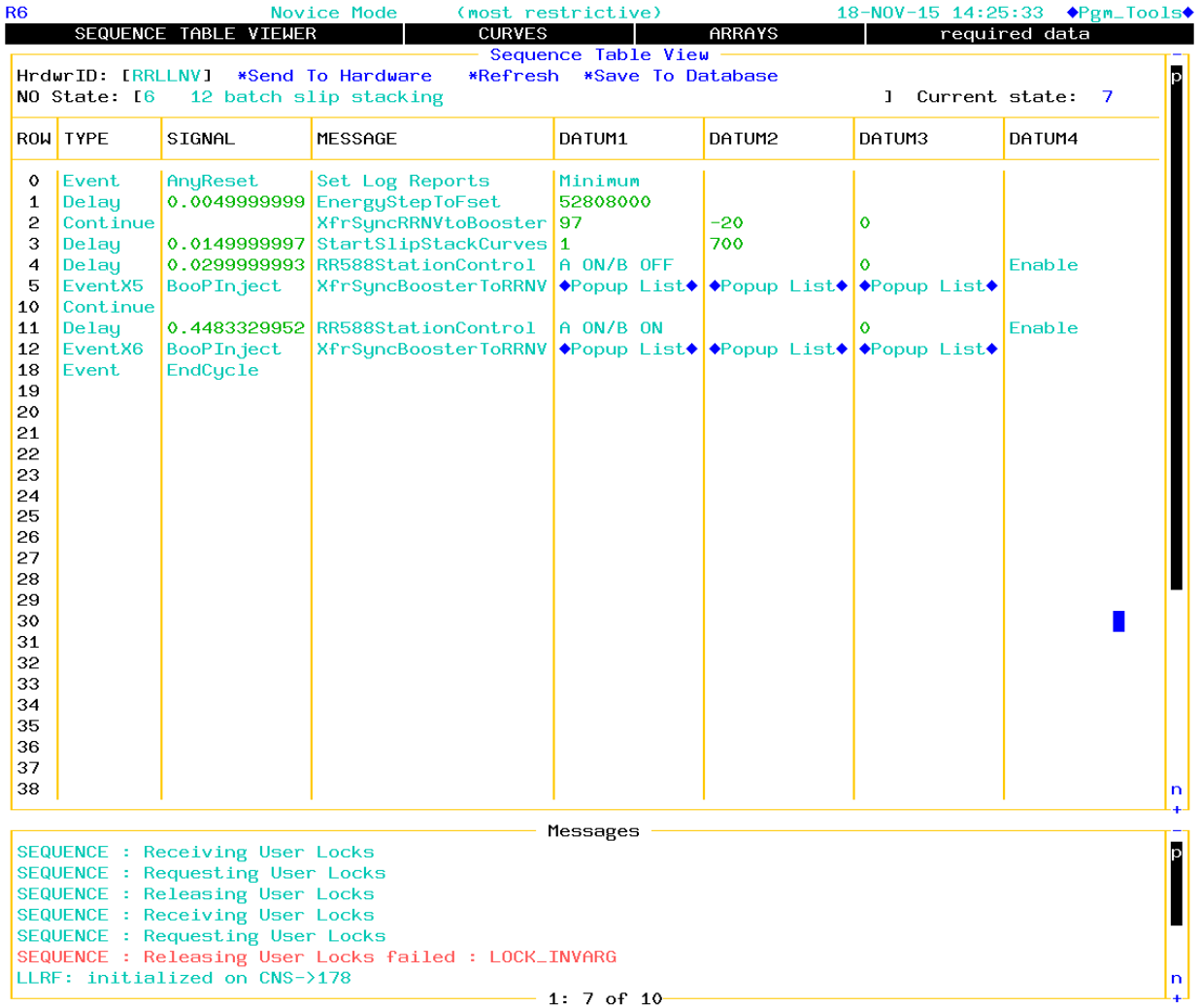


- Backplane access to the ACNET control system for parameter settings and data acquisition
- One crate permits tight co-ordination of RR-DR LLRF timing
- Trigger Lines in backplane for timing signals
- Mu2e specific sequence table messages in R6 PA

Nova Recycler VXI LLRF system



R6 User Interface for Various Operational Sequences



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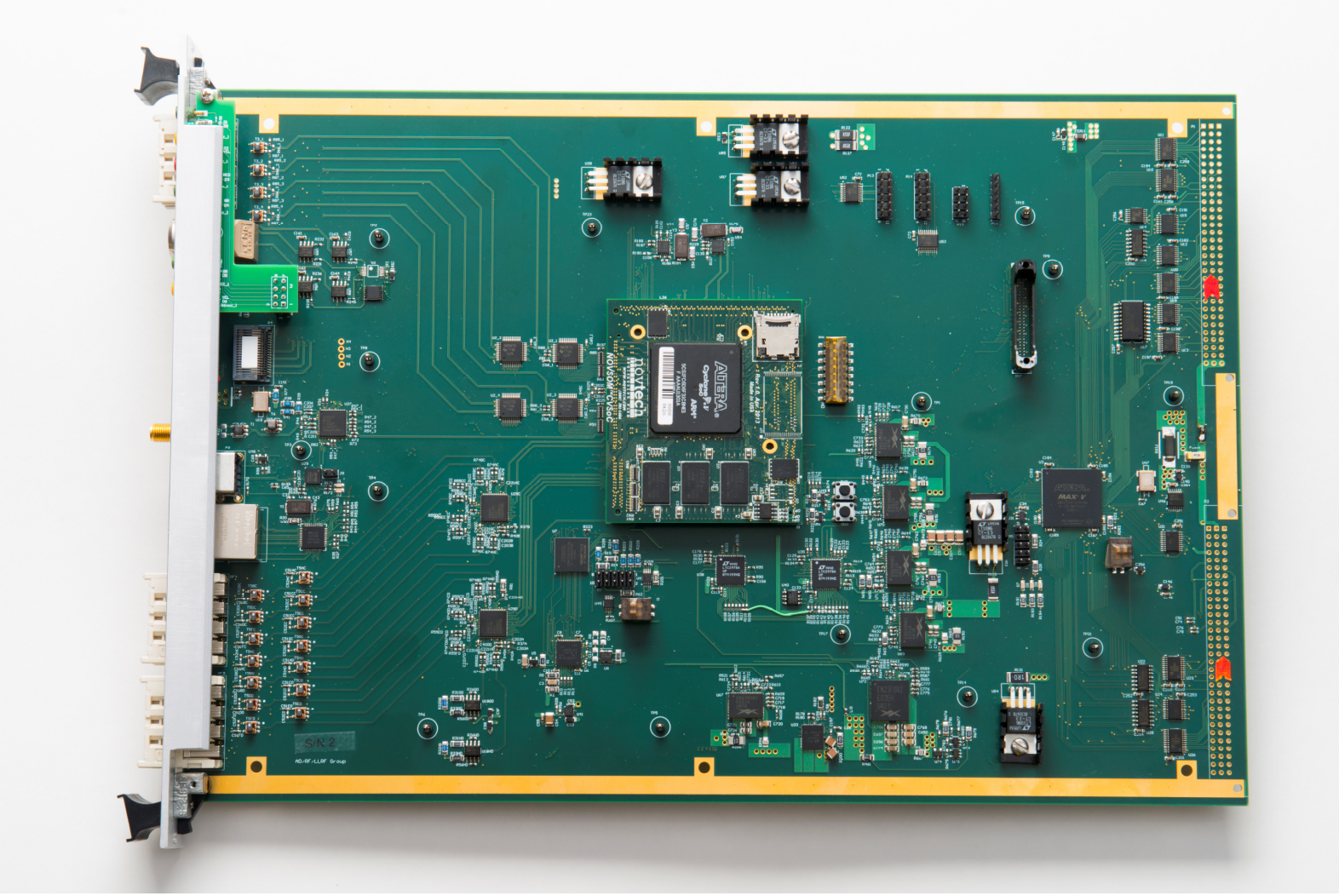
SOC MFC VXI FPGA Board



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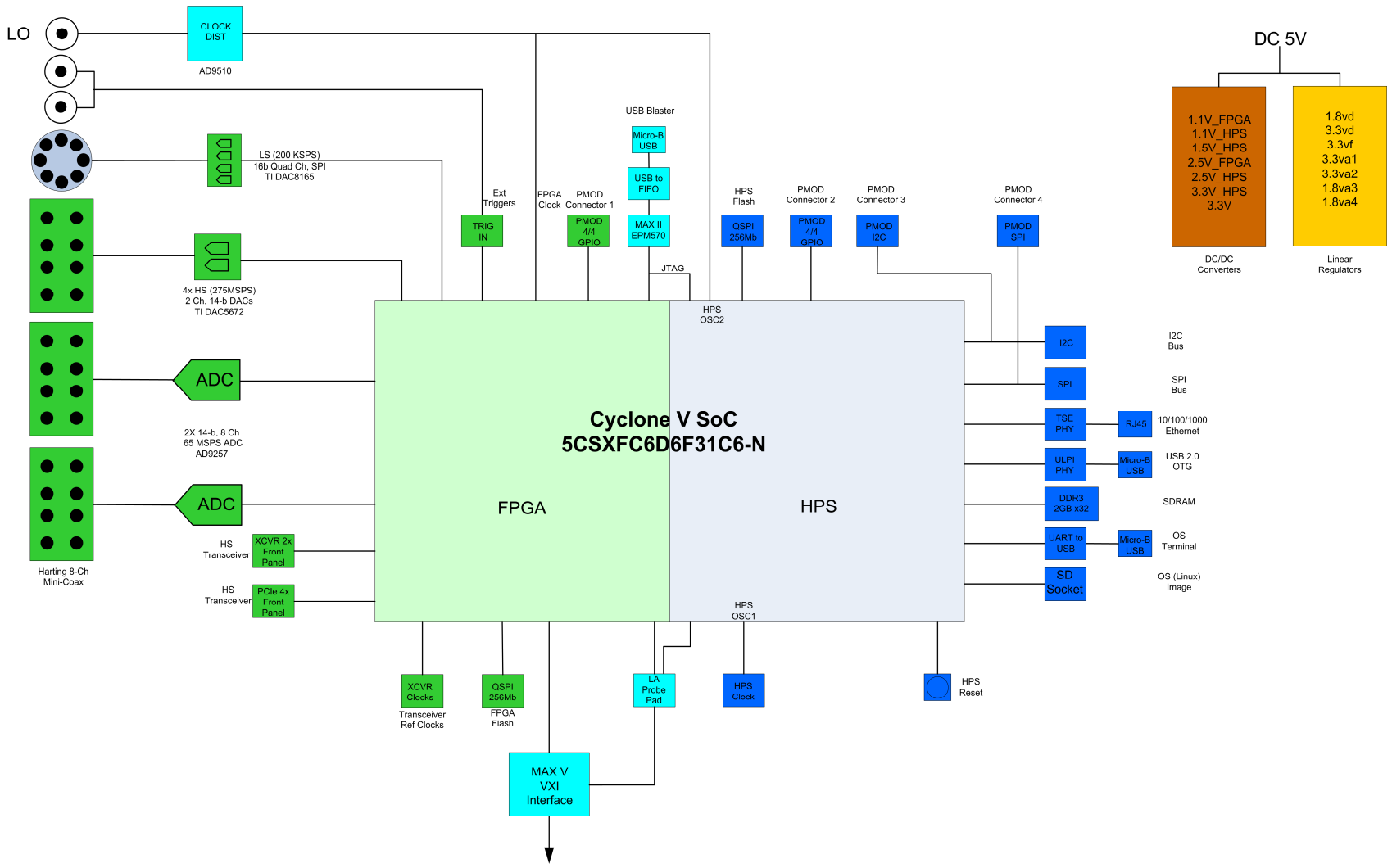
SOC MFC – LLRF card based on SOC FPGA



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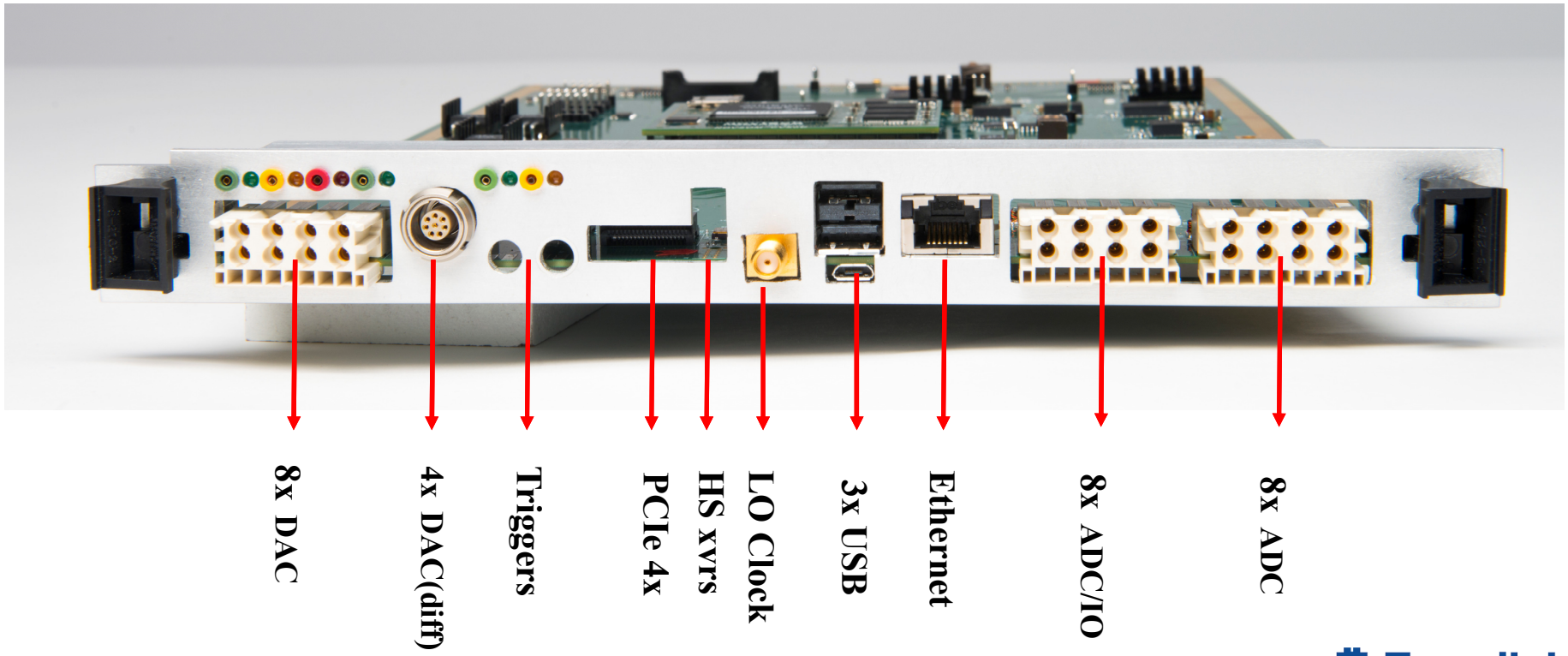
PVx11

SOC MFC Front Panel Connectors

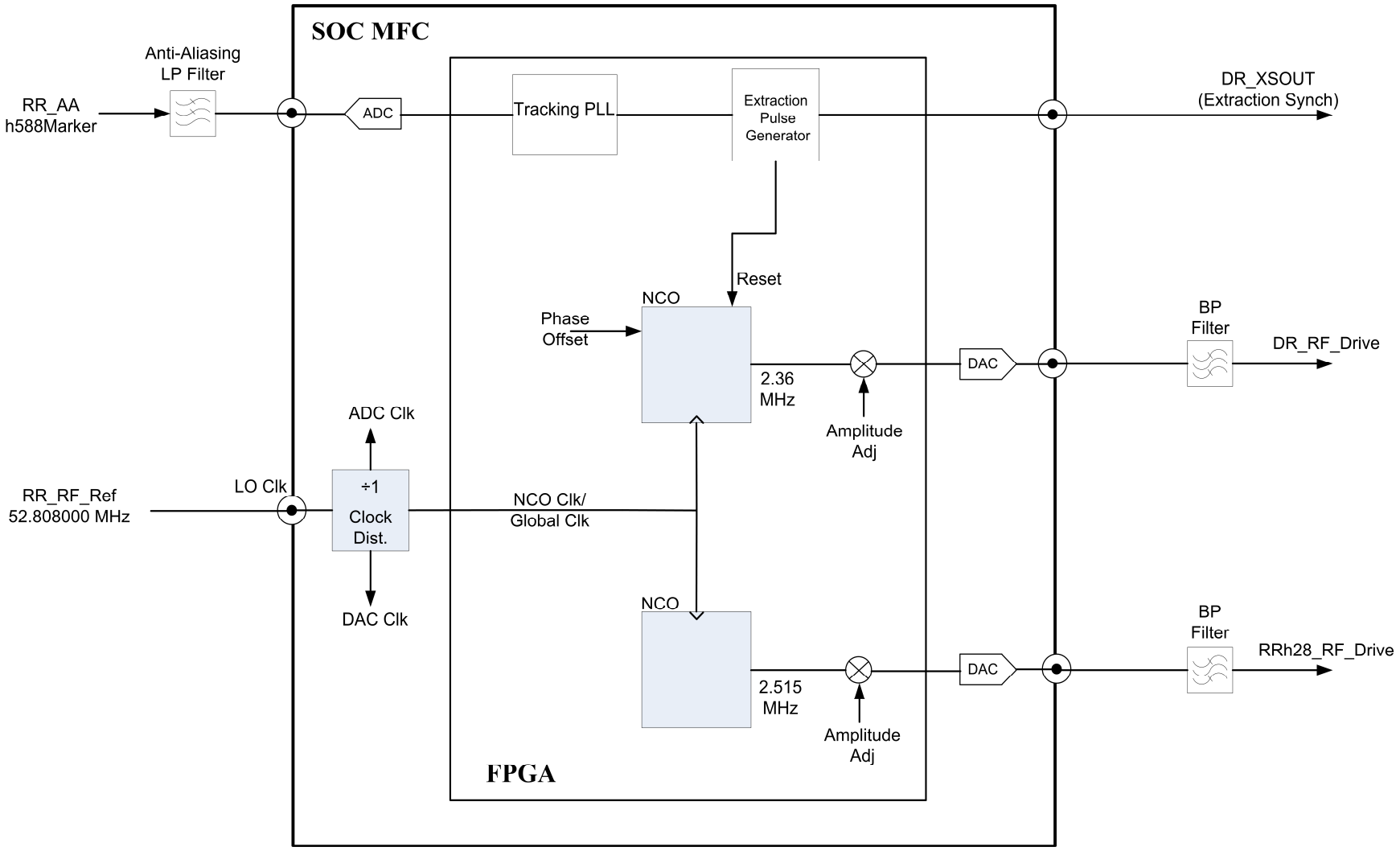
- Board can be used in a VXI crate with a slot0 controller for network access
- Can also be used as a stand-alone NAD (network attached device)



Slide 17

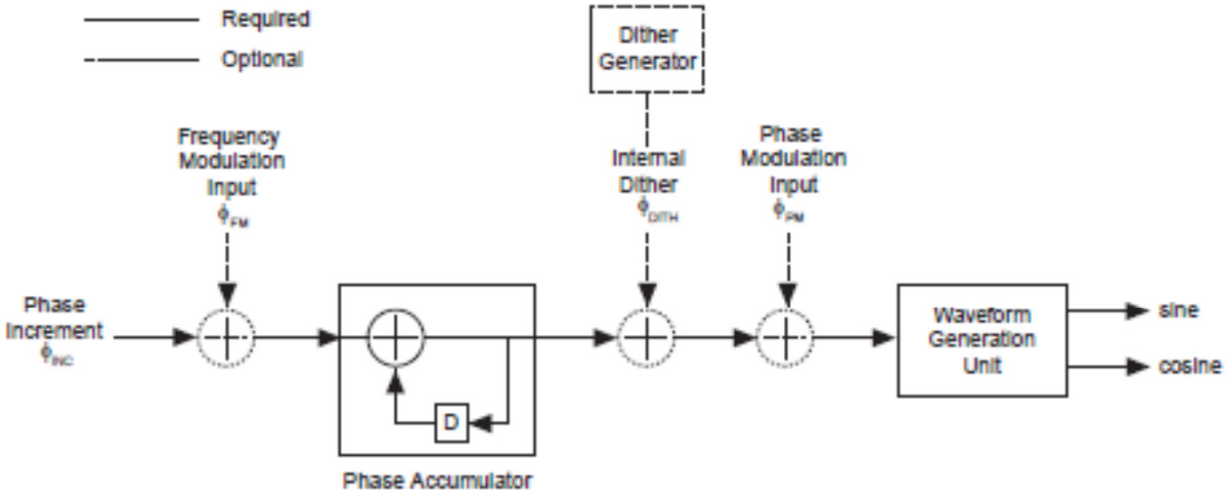
PVx11 Philip Varghese x4803,5689 13675N, 11/11/2015

Mu2e LLRF System Conceptual Design



FPGA NCO Functional Block Diagram

Figure 4–1. NCO Block Diagram

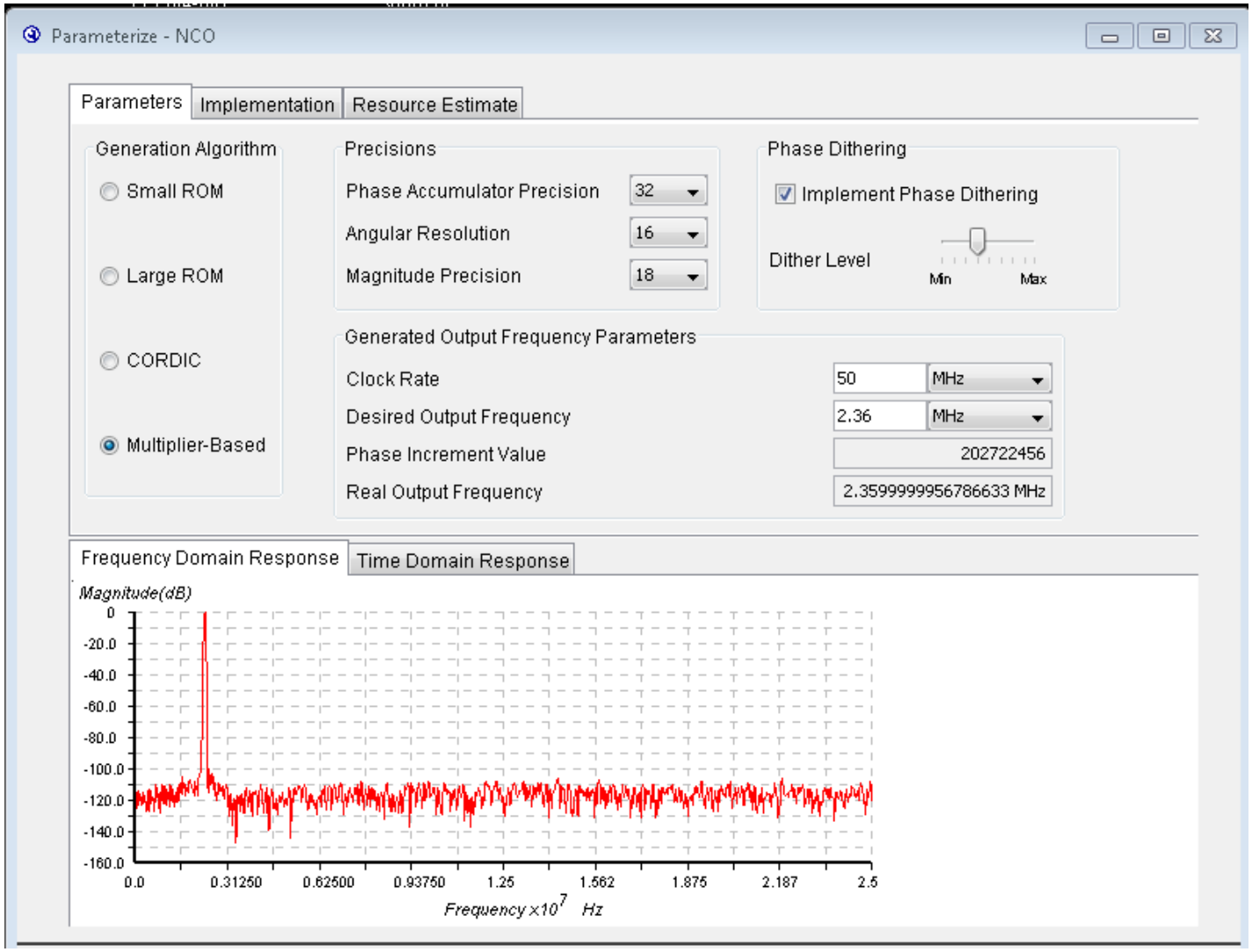


$$s(nT) = A\sin\left[2\pi((f_O + f_{FM})nT + \phi_{PM} + \phi_{DITH})\right]$$

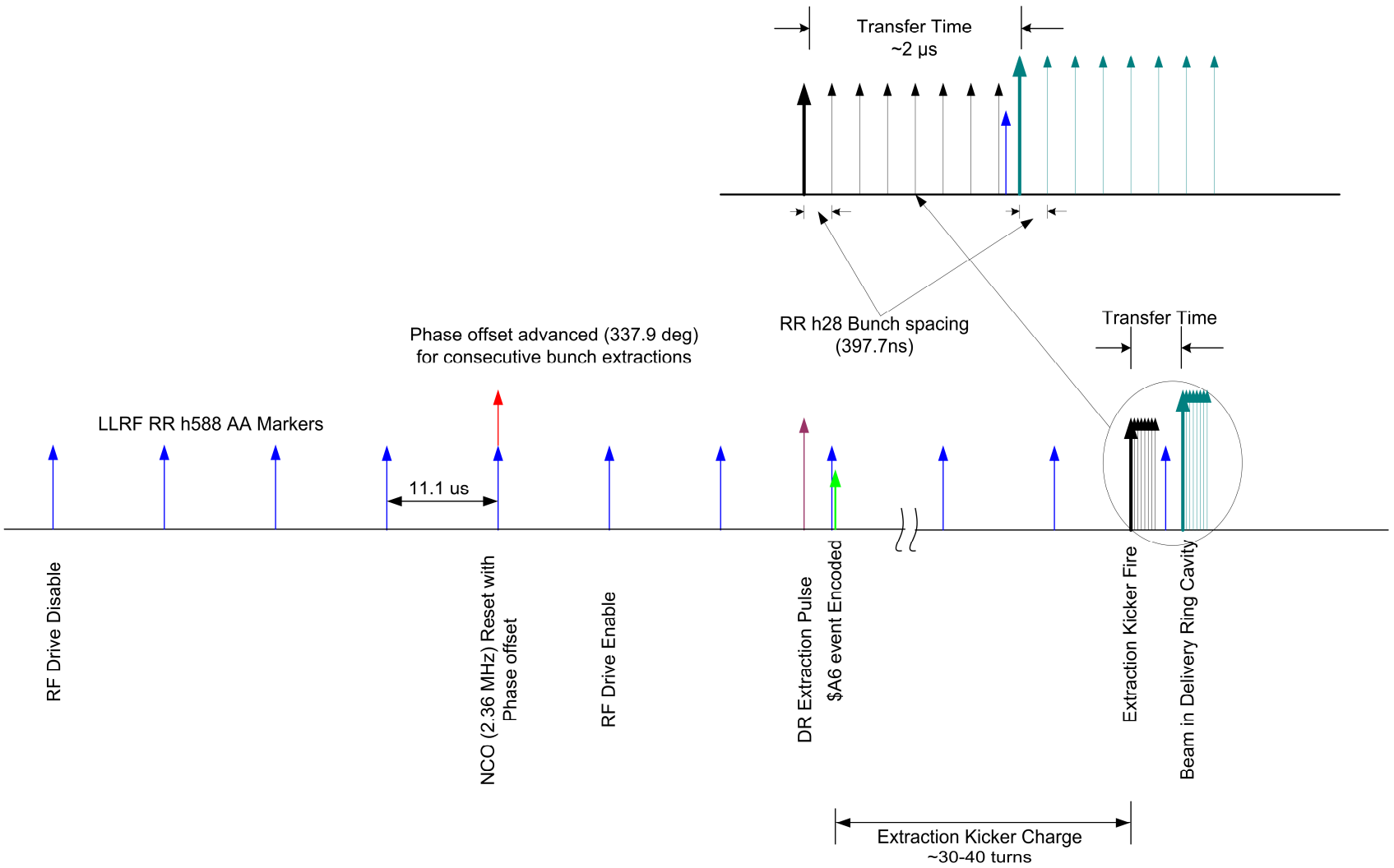
where:

- T is the operating clock period
- f_O is the unmodulated output frequency based on the input value ϕ_{INC}
- f_{FM} is a frequency modulating parameter based on the input value ϕ_{FM}
- ϕ_{PM} is derived from the phase modulation input value P and the number of bits (P_{width}) used for this value by the equation: $\phi_{PM} = \frac{P}{2^{P_{width}}}$
- ϕ_{DITH} is the internal dithering value
- A is 2^{N-1} where N is the magnitude precision (and N is an integer in the range 10–32)

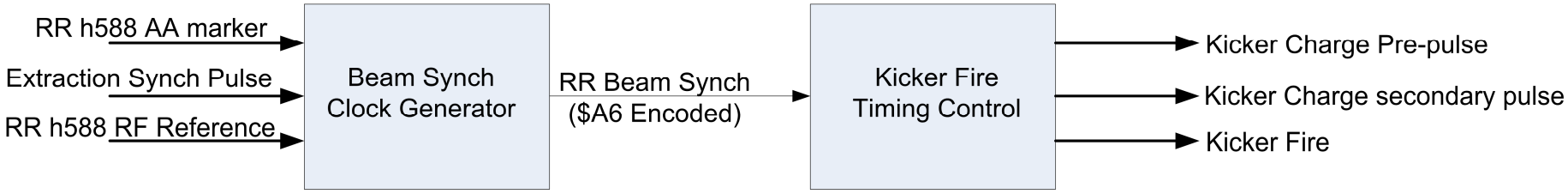
NCO Parameters and Output Frequency Response



Beam Transfer Timing with Phase Alignment

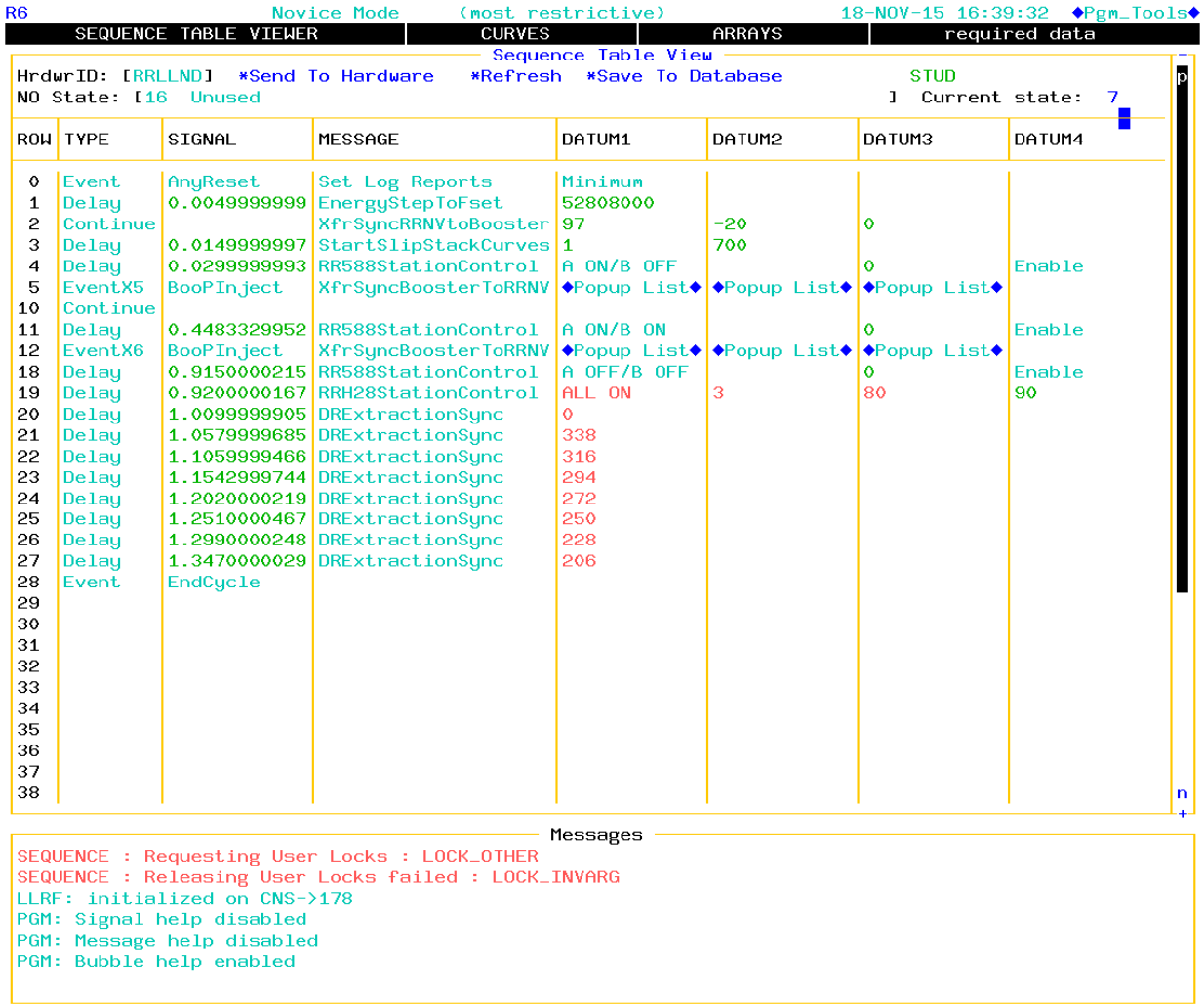


Kicker Fire Sequence



- $A6 Beam extraction event encoded in the beam synch clock at the next AA marker following the extraction pulse
- Kicker fire timing control adjusts timing for the bunch spacing of 397ns between 2.5 Mhz bunches

Example Recycler State for 8 bunch extraction to DR



R6 Novice Mode (most restrictive) 18-NOV-15 16:39:32 ◆Pgm_Tools◆

SEQUENCE TABLE VIEWER | CURVES | ARRAYS | required data

Sequence Table View

HrdwrID: [RRLLND] *Send To Hardware *Refresh *Save To Database STUD

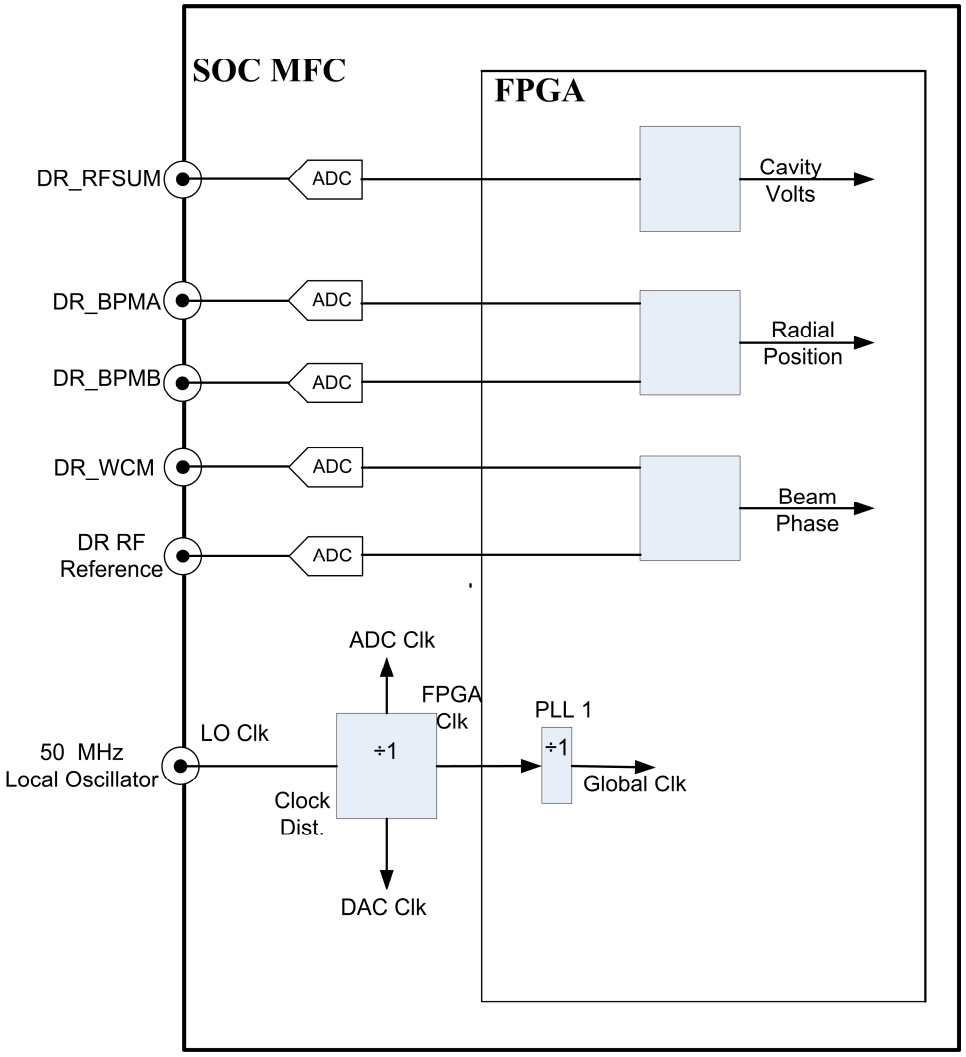
NO State: [16 Unused] Current state: 7

ROW	TYPE	SIGNAL	MESSAGE	DATUM1	DATUM2	DATUM3	DATUM4
0	Event	AnyReset	Set Log Reports	Minimum			
1	Delay	0.0049999999	EnergyStepToFset	52808000			
2	Continue		XfrSyncRRNVtoBooster	97	-20	0	
3	Delay	0.0149999997	StartSlipStackCurves	1	700		
4	Delay	0.0299999993	RR588StationControl	A ON/B OFF		0	Enable
5	EventX5	BooPInject	XfrSyncBoosterToRRNV	◆Popup List◆	◆Popup List◆	◆Popup List◆	
10	Continue						
11	Delay	0.4483329952	RR588StationControl	A ON/B ON		0	Enable
12	EventX6	BooPInject	XfrSyncBoosterToRRNV	◆Popup List◆	◆Popup List◆	◆Popup List◆	
18	Delay	0.9150000215	RR588StationControl	A OFF/B OFF		0	Enable
19	Delay	0.9200000167	RRH28StationControl	ALL ON	3	80	90
20	Delay	1.0099999905	DRExtractionSync	0			
21	Delay	1.0579999685	DRExtractionSync	338			
22	Delay	1.1059999466	DRExtractionSync	316			
23	Delay	1.1542999744	DRExtractionSync	294			
24	Delay	1.2020000219	DRExtractionSync	272			
25	Delay	1.2510000467	DRExtractionSync	250			
26	Delay	1.2990000248	DRExtractionSync	228			
27	Delay	1.3470000029	DRExtractionSync	206			
28	Event	EndCycle					
29							
30							
31							
32							
33							
34							
35							
36							
37							
38							

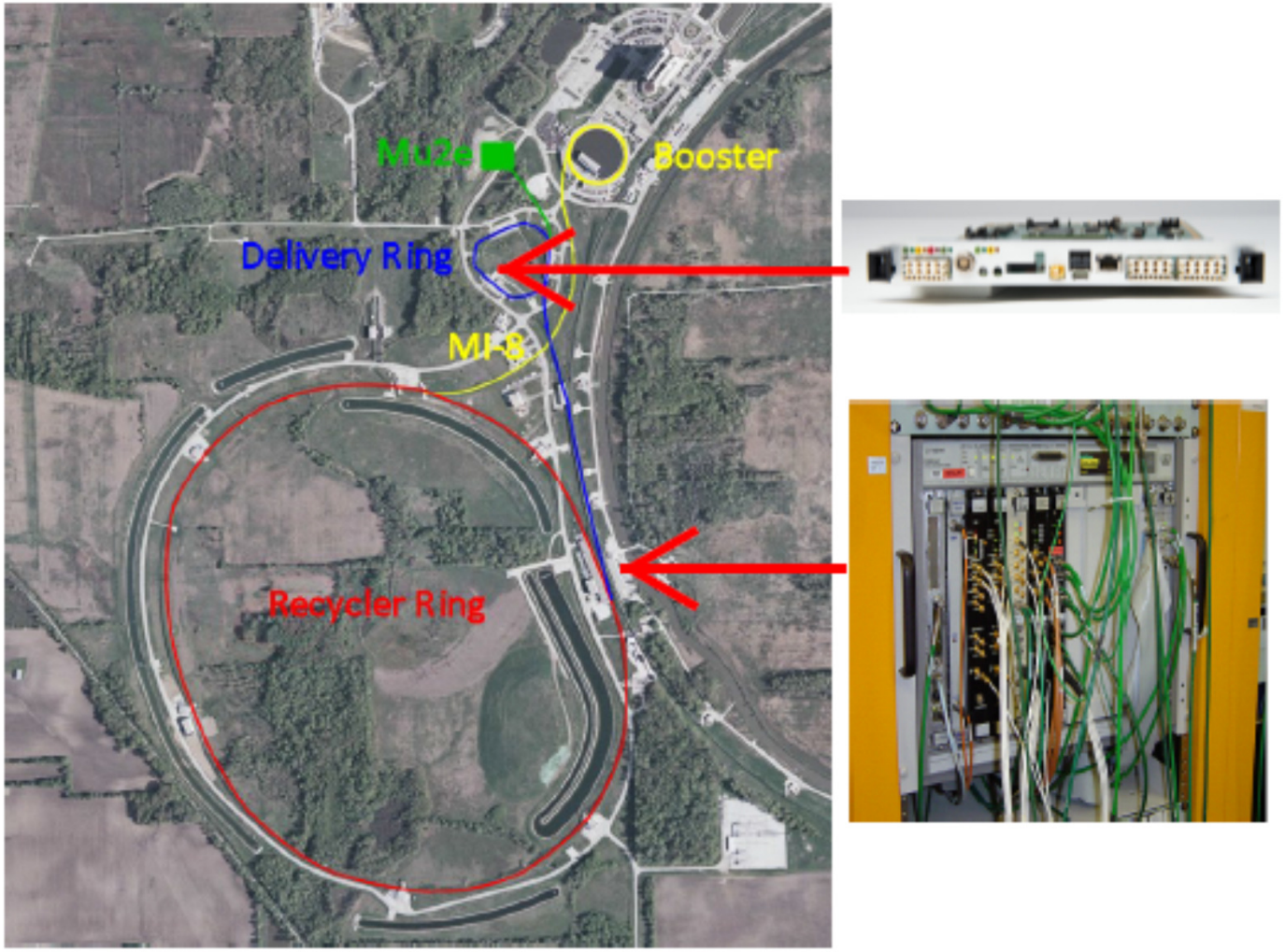
Messages

```
SEQUENCE : Requesting User Locks : LOCK_OTHER
SEQUENCE : Releasing User Locks failed : LOCK_INVARG
LLRF: initialized on CNS->178
PGM: Signal help disabled
PGM: Message help disabled
PGM: Bubble help enabled
```

Beam Phase and Radial Position Measurement



Beam Phase and Radial Position Measurement Hardware



Summary

- Delivery Ring LLRF and the Recycler 2.5 MHz LLRF systems are implemented in one VXI card located in the same crate as the Recycler 53MHz LLRF system

- The Recycler 53MHz, Recycler 2.5 MHz and Delivery Ring LLRF systems are tightly integrated allowing for various operational sequences to be supported.

- The existing ACNET primary application page R6 will include new messages to support machine sequences involving the three LLRF systems