Fermilab

Mu2e Delivery Ring RF Technical Review
Reviewers Responses and Comments

Review Date: November 20, 2015

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Summary:

The Mu2e project has recently received CD-2/3b approval from the DOE (March 2015). The project is in the process of completing the final design and preparations for a CD-3c DOE review in early CY-2016. External peer reviews of key technical elements of the project are a part of this process. The Delivery Ring 2.5 MHz RF System is essential to the operation of the Mu2e experiment. The purpose of the Delivery Ring RF system is to produce an efficient transfer of beam from the Recycler and to preserve a 250 ns bunch structure in the Delivery Ring. Much of the Delivery Ring RF system is being fabricated on the Recycler RF AIP. The Mu2e project is responsible for the low-level system, some longitudinal tracking simulation work, and management effort. This review covers the current technical design of Mu2e for the portions of the Delivery Ring RF System that are within the scope of the Mu2e project.

Responses to Charge Questions:

1. Is the technical design of the Mu2e Delivery Ring Low-Level RF System technically sound? Have all the principle issues of the Recycler to Delivery Ring transfer process been appropriately evaluated, simulated, and calculated?

Principle Issues:

a. The specific timeline for delivering beam to both the Nova experiment and to the Muon Campus experiments.

Findings: For the purposes of this review, a reasonable timeline option was chosen, but at the time of this review the timeline has not been finalized.

Comments: At an early design stage it was thought that the Muon Campus could receive beam during eight of the twenty 66.6 ms time intervals that make up one super-cycle for the Fermi accelerator complex. It was discovered that this plan would not work and a report published in June of 2015 outlined alternate timelines for delivering beam to both the Nova experiment and the Muon Campus experiments, Mu2e and g-2 [1].

For the purposes of this review, a workable timeline option was chosen. A timeline utilizing 21 ticks seems to be most able to meet the beam requirements for Nova and Mu2e. Being able to switch to alternate timelines that would benefit one experiment when the other was offline was discussed. It is felt that the ability to switch between different timelines on an hourly or daily basis is a very desirable feature. The Low-Level RF (LLRF) systems of the Recycler Ring and Delivery Ring presented look to have the capacity and flexibility to implement multiple timelines, but the final base timeline as well as the allowed alternate timelines must be chosen and their implications for the LLRF system considered and incorporated into the system design.

It was noted in the review that there is an interval of time just before the final beam bunch is extracted from the delivery ring that an “end of beam” event is signaled for the Recycler. This event shuts off RF in the Recycler, and with the Delivery Ring LLRF coupled tightly to the Recycler this would mean that RF in the Delivery Ring would be turned off before all of the beam had been extracted to the experiment. Solutions to this situation were proposed.

Recommendations: The final base timeline, as well as any alternate timelines must be specified, worked into the LLRF system design and documented for the CD-3c review.

b. RF manipulation of the beam in the Recycler Ring and transfer from the Recycler Ring to the Delivery Ring must meet the experiments beam requirements.

Findings: The confidence level with regard to successfully accomplishing the accelerator RF manipulations and beam transfer between machines is high, but can be made higher with more simulation and consideration.

Comments: The specifications of the new High Level RF accelerating cavities for the Recycler and Delivery Ring appear to be more than sufficient. Simulations have been done to demonstrate the feasibility of the re-bunching of recycler beam into the 2.5 MHz RF bunches. Simulations were also made of the transfer of the beam from the Recycler to the Delivery Ring. It was requested in the review that further simulation be made varying the phase and energy of the beam injected into the Delivery Ring and determine limits on such errors. The simulations have been documented, but this documentation will need to be updated for the CD-3c review [2][3].

Recommendations: Additional simulations should be performed to include the phase and energy variations. Simulations using the Recycler Ring model should be performed with the inclusion of the cavity impedances. The effects of the Higher-Order Modes of the cavities should be investigated. The documentation of the simulations needs to be updated for the CD-3c review.

c. Implementation of the new LLRF electronics.

Findings: The preliminary design of the VXI electronics appears to be capable of managing the various accelerator states and timing, as well as accurately generating and manipulating the require frequency and phase of the Low-Level RF to the Recycler and Delivery Ring. However, there are still questions as to whether both the Recycler and Delivery Ring RF should be controlled from a single or separate front-end systems.

Comments: For normal operation, following the established timeline for beam acceleration, transfer and extraction to the experiment there are benefits to having the Recycler and Delivery Ring tightly coupled within the same system module. However, for bunched beam studies within the Delivery Ring, decoupling the Delivery Ring LLRF from the operation of the Recycler becomes necessary. For this the presenters felt that separate LLRF systems would be necessary.

The main LLRF controller VXI module is referred to as the SOC MFC. The module uses a daughter card for the memory, processor and FPGA functions. Memory and FPGA components get bigger and faster every year. With the start of the Mu2e experiment several years out, this approach could be beneficial. The SOC MFC module is expected to be able to work as a stand alone device connected directly to the Ethernet. This will reduce installation costs when implementing the module in the Delivery Ring as DAQ for cavity voltage, radial position and beam phase measurements

Recommendations: The beam studies that the experiment and the Accelerator Division would like to be capable of performing must be specified and the final configuration of the LLRF system must be determined and reviewed.

Considerations for beam study modes must also include radiation shielding limits.

2. What are the technical risks of the design? Have all of the technical risks associated with Mu2e Delivery Ring RF System been accounted for? Have these risks been properly evaluated and mitigated?

   The technical risks of the design include:

   a. The risk that the Mu2e proton beam requirements of time structure to include the specified out-of-time extinction factor, bunch intensity and beam size will not be met.

      Finding: A good effort has been made to mitigate this risk. More design work is still to follow this review.

      Comments: Experienced accelerator RF engineers expressed a high level of confidence, with no one raising strong concerns with the results of the beam simulations performed to date. There is a desire for additional simulation work to provide additional confidence margin. The specifications of the RF cavities and the Low Level RF control electronics designs appear to be very capable of meeting system demands.

   b. The risk that production and commissioning of the RF cavities and the Low Level RF control electronics will not be on-time and adversely impact project schedules or compress time desired for production testing and commissioning.

      Finding: The LLRF systems are not currently on the critical path and there is ample time for design, production and testing. This assessment does require that decisions over whether the Recycler and Delivery Ring have a common or separate controller be decided and reviewed soon.

      Comments: Mainly due to the requirements of the beam studies that the experiment and the Accelerator Division would like to be capable of performing, there is a question as to whether it would be necessary for the Recycler and Delivery Ring Low Level RF controls and associated collection of accelerator timing and operational states be separated. If made separate, this would require the development, procurement and testing of more equipment.

   c. The risk that the final system design will not have the flexibility to implement the accelerator beam studies desired.

      Finding: This risk has not yet been dealt with.

      Recommendations: Recommendations are found elsewhere in this reviewers' response.

d. The risk that provisions for the final requirement of the RF system interlocks, beam permit logic and other safety systems are not provided in the Low Level RF system.

   Finding: How these equipment and personnel safety systems will impact the Low Level RF system were not presented.

   Recommendations: Investigation on the requirements on the Low Level RF system in regard to RF system interlocks, beam permit logic and other safety systems should be considered and reviewed.

3. Will the Low-Level RF System be configurable to accommodate the beam studies necessary for Mu2e commissioning and normal beam operations?

   Findings: Beam studies still need to be specified and the requirements on the Low Level RF system considered. There are still questions as to whether both the Recycler and Delivery Ring RF should be controlled from a single or separate front-end systems.

   Comments: For normal operation, following the established timeline for beam acceleration, transfer and extraction to the experiment there are benefits to having the Recycler and Delivery Ring tightly coupled within the same system module. However, for bunched beam studies within the Delivery Ring, decoupling the Delivery Ring LLRF from the operation of the Recycler becomes necessary. For this the presenters felt that separate LLRF systems would be necessary.

   Recommendations: The recommendation here is the same as in 1.c. above.

4. Is the technical design of the Mu2e Delivery Ring RF System on track to satisfy the requirements for a DOE CD-3c review in early CY 2016?

   Findings: Yes, the technical design is on track but, there is a significant amount of work to be done before being ready for the DOE CD-3c review.

General Comments:

None.

Acknowledgements:

The review committee would like to thank the presenters and their colleagues for the time and effort in preparing for this review. An impressive amount of work has been accomplished and the RF system looks to be very capable of meeting the needs of the Muon Campus and the experiments.

References:

[1] E. Prebys, et al., “Modified Operating Scenarios for the G-2 and Mu2e Experiments“, Beams-doc-4854, June 2015.

[2] S. Werkema, “Mu2e Proton Beam Longitudinal Structure”, Mu2e-doc-2771, March 2014

[3] S. Werkema, “Proton Beam Longitudinal Structure -- An Addendum to Mu2e-doc-2771”, Mu2e-doc-4044, April 2014