R&D Proposal - LARP Program

Modelling of LLRF Limitations on LHC Performance
Digital RF controllers and impedance control architectures for next-generation colliders, damping rings, and light sources

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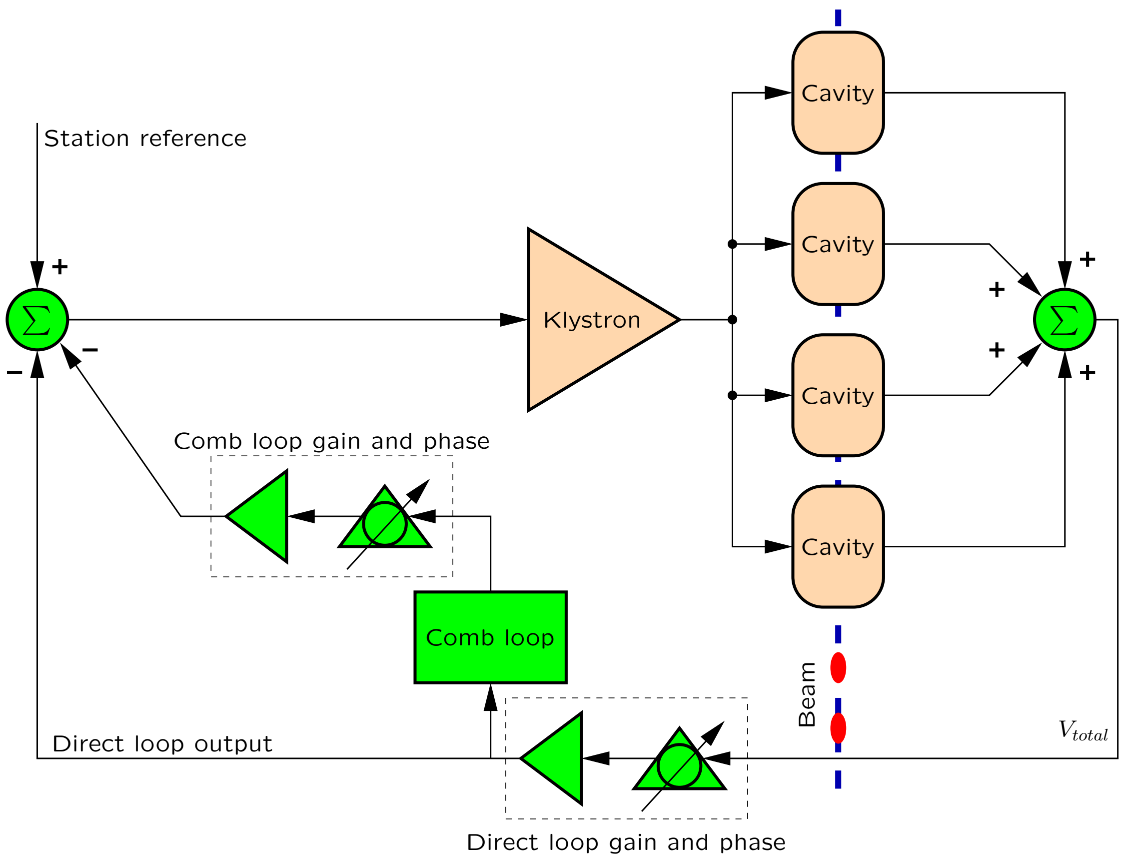
Background:

The stable operation of high beam loaded colliders and light sources requires the control of higher-order mode impedances as well as the precise control of the accelerating fundamental impedance. The PEP-II systems define the state of the art for direct and comb loop feedback techniques and are implemented in a mix of Analog, RF and Digital technologies. The LHC LLRF systems are very similar in topology and in the basic technology of implementation.

Our group has identified the limitations on PEP-II operations from non-linear effects in the high power klystron and RF drive components via the use of RF-Beam simulation models and machine measurements (ref PRST V10/e022801). These effects have limited the stable operating currents in PEP-II. We also have insight into the operational difficulties with critical configuration and adjustment of the Direct and Comb Feedback. This impedance control RF architecture is subject to numerous drifts, offsets and imperfections from the analog circuit implementation.



The figure shows the topology of direct and comb feedback to minimize the cavity fundamental impedance. This proposal aims to evaluate new, more stable, implementations of these techniques.

Initial LARP Task:

We propose to expand the existing LLRF- Beam Dynamics simulation model to look at effects in the LHC, and to expand the beam model to look for the impact of additive noise and other technical imperfections on the longitudinal phase space, other impacts besides strictly impedance-driven growth rates and operational limits. This expanded model would then be used to study the limits and impacts of the existing LHC LLRF implementation, as well as specify and study the performance of alternative architectures.

Follow-On LARP Task:

We propose to build on our understanding via investigation of a new form of all-digital RF impedance control architectures, replacing the analog circuit based techniques. This will require a novel form of a very low group delay processing architecture. From our experience producing the wide-band digital feedback systems, including the low group delay woofer, we expect that a "Digital RFP" is feasible and should allow a much more stable, reproducible, and configurable LLRF systems.

We anticipate investigating two new approaches to the LLRF processing. The existing approaches use analog complex heterodyning to mix the RF signals down to I&Q baseband analog channels - we propose to investigate a direct digital sampling and down/up conversion scheme. Similarly, we would design and evaluate a low group delay all digital processing channel. One critical aspect of this effort would be the use of the group's nonlinear RF/beam simulation models to understand the necessary noise and non-linearity performance of the sampling and processing functions, as well as the robustness of the controlled system to perturbations.

Relevance:

Such precise RF control would directly translate into better operating efficiency, high currents, and higher luminosity in the various facilities which use these techniques. These digital RF control techniques would be directly applicable to numerous light sources and other accelerators (such as the ILC damping rings), and because of the reprogrammable digital technology would be especially available for transfer to other labs and facilities. LHC is a very realistic potential facility to study these limits and possibly use these techniques. They are interested in a collaboration with us investigating the noise and imperfections in these impedance control architectures (the LHC technology is essentially identical to the existing PEP-II implementation, with many of the same potential difficulties). While it is unlikely that PEP-II would be investing in new LLRF architectures, the insight gained from this work might well help with operation and configuration strategies.

Funding Request:

Initial LLRF Modelling study (time frame 6 - 8 months):

- This is proposed new activity (Fox, Rivetta et al). Goal is to model impact of LLRF imperfections in LHC using the expanded PEP-II RF model. Contact at CERN is F. Pedersen/P. Baudrenghien
- 2 visits x 2 weeks/visit, establish contacts, collect parameters, collaboration on dynamics model expansion

0.5 FTE junior salary, to be covered by LARP
0.15 FTE senior salary, covered by SLAC

Initial Hardware modelling and lab study materials:

Time frame - after initial modelling study, roughly 6 - months duration

Using the insight from the dynamics model, possible digital architectures can be mocked-up for lab measurements on existing Xlinix Vertex-II evaluation boards (Our existing design and simulation tools will be used in this project.). This proposal is intended to evaluate the technical feasibility and estimate the performance of this approach. Based on these critical technology studies a follow-on research project would actually design and evaluate a fully-functional processing channel.

M&S $15K for evaluation modules, critical sampler components (in addition to ongoing SLAC R&D contribution).

0.5 FTE Senior Salary, covered by SLAC
0.5 FTE Junior Salary, covered by LARP

Travel - 2 visits x 2 weeks/visit, machine measurements and comparisons with simulation models. Discussion of initial study results.