DEMONSTRATION OF LIBERA LLRF AT DARESBURY AND DESY

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Abstract

Libera LLRF was conceived as an industrial digital RF stabilization system. The adopted AMC architecture makes the system extremely compact and flexible at the same time. The high performance RF design fulfills the requirements of the most demanding new generation machines. The system flexibility enables the operation in a broad frequency range (from few MHz up to 12 GHz) and supports different RF system topologies and operation modes. The Libera LLRF system was successfully demonstrated on the field at Daresbury laboratory and DESY. The two machines, EMMA and FLASH, have different requirements in terms of LLRF control and signal processing. The paper takes as example the two cases, explains how the same system can be reconfigured to enable new functionality, describes how the demonstration on site was carried out and the results are presented.

INTRODUCTION

The Libera LLRF digital RF stabilization system was designed having in mind the performance requirements of the most demanding accelerators including fourth-generation light sources, where a high level of RF field stabilization is required. In addition the flexibility of the adopted AMC industrial standards and software structure enables system scalability in order to reconfigure the same system for different LLRF applications.

The first part of the paper briefly describes the Libera LLRF system functionality and capabilities. The second part describes the requirements of the EMMA FFAG 1.3 GHz RF system and reports the results of the Libera LLRF system high power demonstration carried out at Daresbury laboratory in April 2009.

During the same demonstration session at Daresbury, the Libera LLRF system was reconfigured for the operation of the ILC 3.9 GHz SC crab cavity set-up. In a very limited time (only a two hour shift was available), the same Libera LLRF unit used for the EMMA NC 1.3 GHz system was reprogrammed and used to successfully control the RF field of two SC 3.9 GHz cavities.

In the last part of the paper the results of the demonstration carried out at DESY (FLASH) in July 2009 are summarized. The system was configured to control three sections (ACC456) of the FEL in order to stabilize the RF field of 24 SC cavities. Experiments with the cavities loaded by the beam were also carried out, including a beam based vector sum calibration and the machine was also operated in SASE mode when the Libera LLRF system was controlling ACC456.

SYSTEM OVERVIEW

The Libera LLRF system is developed on a modular AMC architecture based on distributed low latency FPGA real time data processing. These data processing resources are integrated with additional computing power provided by the Interconnection Computing Module where a powerful personal computer is implemented. This computing module is also the center of a PCIe star topology network that enables communication among modules. The mentioned data acquisition and computing resources are organized in a layered software structure that makes the Libera LLRF system a standard network attached device that can be easily integrated into any accelerator Control System.

The Libera LLRF system supports operation with various RF systems including pulsed and CW operation modes, SC and NC cavities, vector-sums control of up to 32 cavities, in a frequency range up to 12 GHz.

The basic version of the Libera LLRF application already supports a rich set of sophisticated built-in functions and algorithms. The system automatically performs the RF system response analysis in order to completely describe the RF system by means of analytical models. This model is then passed to the Stability Analysis algorithm, based on the Nyquist criterion, that automatically configures the loop parameters in order to maximize the feedback loop stable region. A robust interlock system implemented inside the Libera LLRF unit constantly monitors the signals for machine protection purposes.

The system also supports beam-based vector-sum calibration, RF system tuning and arbitrary signal shaping at the set-point and the feed-forward levels. The feed-forward signal shaping enables the implementation of beam loading suppression adaptive-feed forward algorithms based on beam transient measurements integrated with the RF system response data. In general, the computing resources and the software architecture also enable the implementation of user specific algorithms running at the computing module level or at the FPGA level.

DEMONSTRATION AT DARESBURY

The Libera LLRF system was demonstrated at Daresbury laboratory on a high power test setup involving two 1.3 GHz NC EMMA FFAG cavities.

The Libera LLRF system was configured in order to arbitrarily set an RF frequency in the 5.5 MHz EMMA RF frequency range and control the field of the RF cavities.

The EMMA test setup consisted of a AM87 preamplifier, a 30 kW CPI IOT, a Q-par Angus 3 dB hybrid waveguide distribution section, a phase shifter installed in one of the hybrid output arms and two 1.3 GHz Niowave copper cavities. Additionally, two directional couplers were installed for forward and reflected power monitoring purposes. A high performance Master Oscillator based on Wenzel and Vectron components was used as reference.

The RF system signals were connected to the Libera LLRF unit. The unit was started and the RF system diagnostics was performed in order to completely describe the RF system in terms of response by means of the built in vector network analyser functionality. Figure 1 shows the response analysis of a cavity.

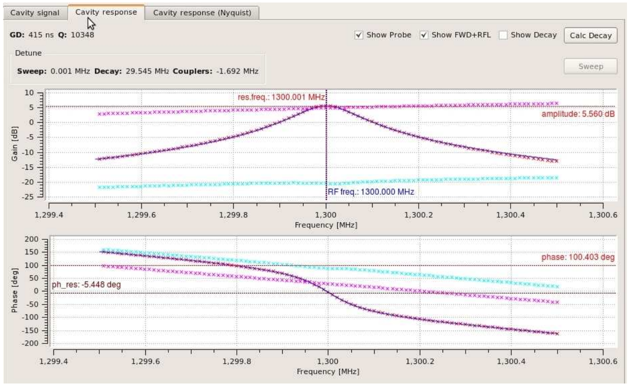


Figure 1: The response analysis of the EMMA cavity. The detuning, the loaded quality factor, the amplitude and phase response and the cabling delays are available from the measurement.

During the demonstration, the response analysis was an indispensable diagnostics tool for the investigation of the mutual coupling between the IOT output cavity and the acceleration cavities.

After that, the response analysis data was passed to the Nyquist stability algorithm in order to automatically configure the loop parameters for stable operation. The loop gain setting was manually increased up to a point where the operation with sufficient stability margin was possible according to stability analysis. The loop was at that point closed and the Libera LLRF system started generating the RF pulses. The RF power from the IOT was progressively increased up to 10 kW, corresponding to a vector sum of 300 kV. Figure 2 shows the global vector sum GUI screen shot at 10 kW.

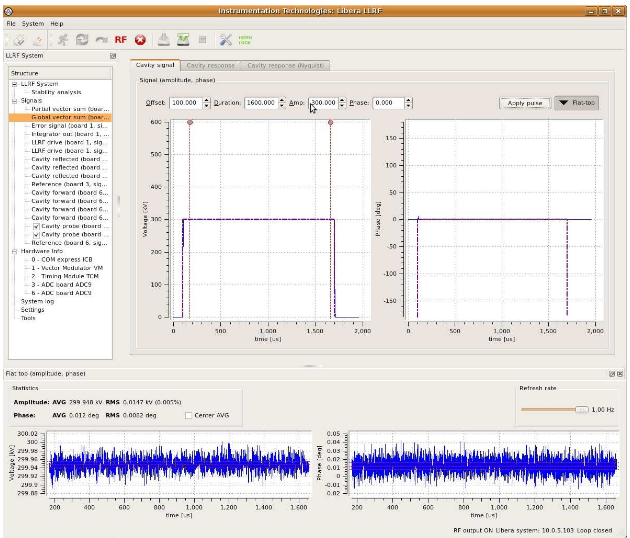


Figure 2: The Libera LLRF controlling 10 kW.

The 300 kV vector sum was stabilized to 0.005 % RMS in amplitude and 0.008° RMS in phase over 1 MHz of bandwidth.

After that also the amplitude and phase response of the IOT versus power was measured.

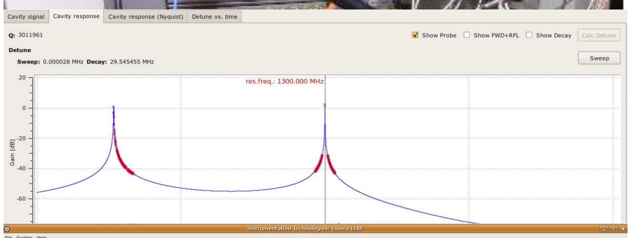
Measurements on 3.9 GHz SRF Crab Cavity

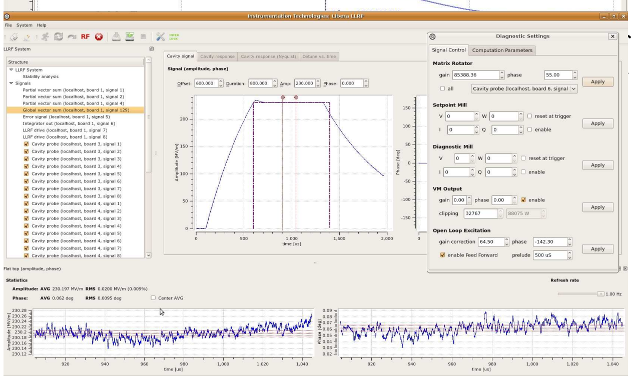
After the tests with the EMMA RF system, the same Libera LLRF unit was reconfigured for operation at 3.9 GHz with small modifications to the hardware. Several tests were performed on the vertical test-stand cooled down to 4K, within the limited time of 2 hours. The regulation of the field with a loop gain up to 80 was applied. A strong correlation between amplitude and phase was observed as a consequence of microphonics. The amplitude and phase were respectively stabilized to 0.07 % RMS and 0.06° RMS over 1 MHz of bandwidth.

DEMONSTRATION AT DESY

The Libera LLRF system was demonstrated at FLASH in July 2009. Three Libera LLRF units were configured in order to process the 24 probe, 24 forward and 24 reflected signals of ACC456. In few hours the three units were installed in one of the racks of FLASH service area, were calibrated with respect to the DOOCS readouts and were ready to acquire in parasitic mode. Figure 3 shows the LLRF setup.

During the tests in parasitic mode the Libera LLRF system detected in ACC6C8 the excitation of the 8/9 π passband mode. Afterwards the Libera LLRF drive output was connected to the Klystron preamplifier in order to measure the RF system response and close the loop. The response analysis algorithm was integrated with additional time domain processing in order to better describe the SC narrowband response and the passband modes. Figure 4 shows the response analysis results for ACC4C4.





Afterwards beam transients measurements were carried out. The ACC456 vector sum flat top was loaded with 30 1.2 nC bunches at the repetition rates of 250 kHz and 1 MHz. From the acquired beam induced transients individual bunch contributions were clearly visible.

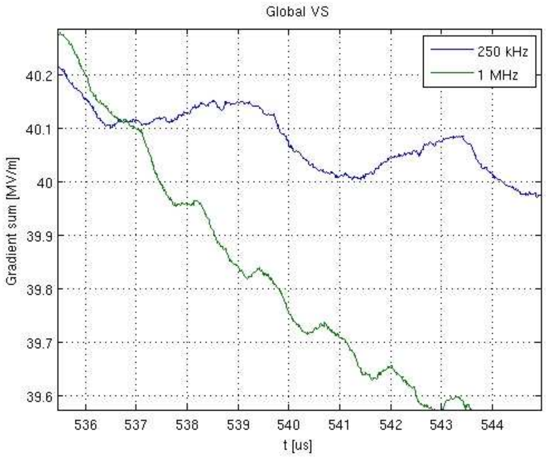


Figure 6: The vector sum beam transient zoom in shows individual bunch contributions for the two bunch repetition rates.

Further beam transient acquisitions were taken in order to perform a beam based vector sum calibration. Furthermore when Libera LLRF was controlling ACC456, FLASH was turned into SASE lasing mode. A stable 10 uJ/pulse radiation was produced.

CONCLUSIONS

The results of the Libera LLRF field demonstrations in the accelerator environment show high performance RF field stabilization integrated in a powerful, easily reconfigurable, robust platform where sophisticated control algorithms can be implemented.

Acknowledgements

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