Tracking Frequency Reference Phase Changes at Point of Use Based on BPM Measurements.

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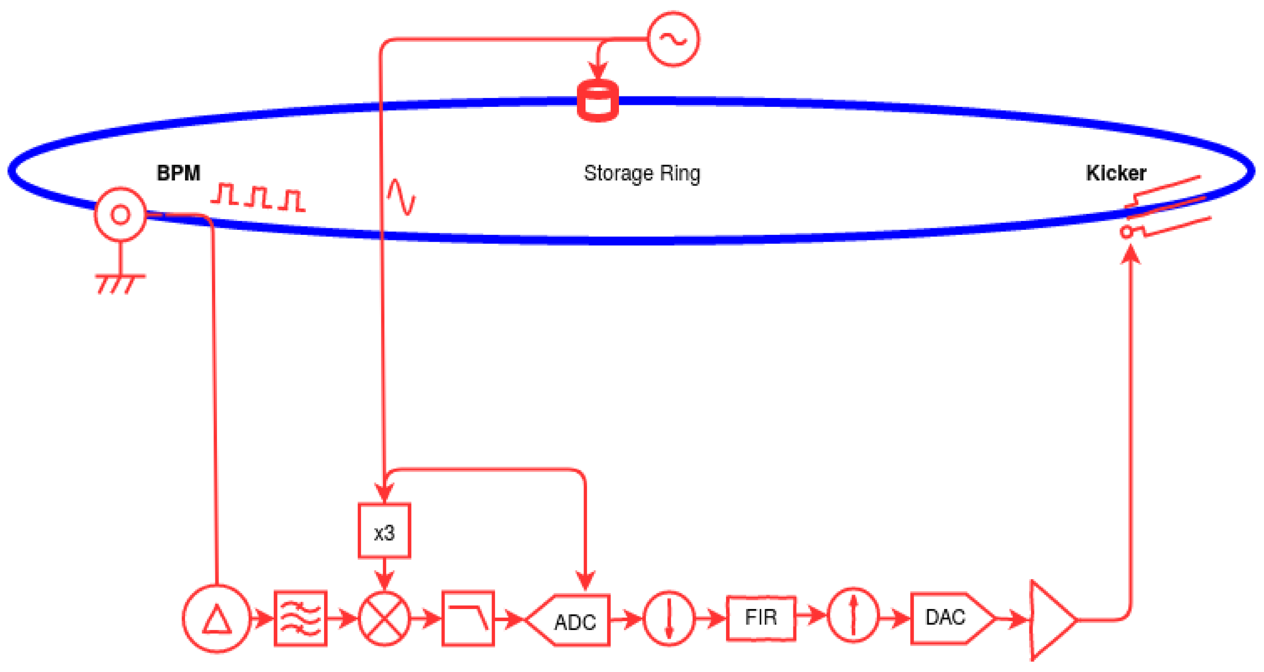
Abstract

Multi-bunch Feedback systems in Diamond use the RF reference signal to homodyne down-convert the 3rd harmonic of BPM signals and sample the detected output. Uncertain reference phase variations due to upstream adjustments to the RF system previously necessitated regular manual realignment of the reference phase. Implementation of a local carrier recovery and symbol synchronizer at the BPM output by locking the local reference phase to the measured beam phase has been shown to significantly improve the stability and robustness of the system and remove the dependence on absolute RF phase. The system has been successfully deployed on the storage ring at Diamond and has been operating live since October 2019.

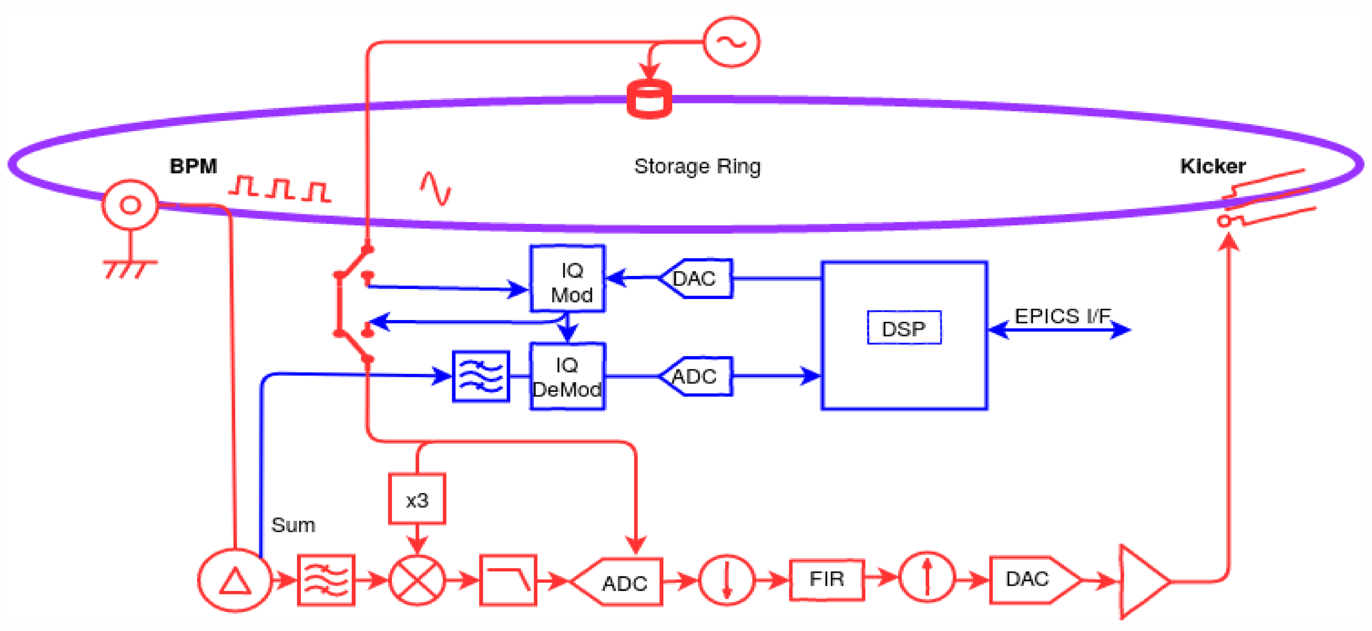


The original MBF Architecture

Introduction

The Diamond Multi-bunch Feedback system [1] uses the Libera Bunch by Bunch Front End to recover a 1.5 GHz local oscillator for homodyne detection of the BPM signal and a 500 MHz sampling clock. During operation, the adjustment of the RF subsystems cause significant deviations in the measured phase requiring regular manual realignment of the phases within the front end. The mean time between realignment was typically 20 days. To improve this situation a beam locked carrier recovery loop was investigated as shown below to lock the phase of the MBF clock to the beam.

In order to phase align the 500 MHz reference clock to the clock component in a BPM output a digital Beam Locked Loop (BLL) using an IQ Modulator and demodulator was chosen because of its low additive phase noise and continuous phase detection and adjustment range. The use of IQ modulators and demodulators for phase detection and phase shifting is well established [2]. The block diagram of the Beam Locked Loop integrated with the MBF is shown below.



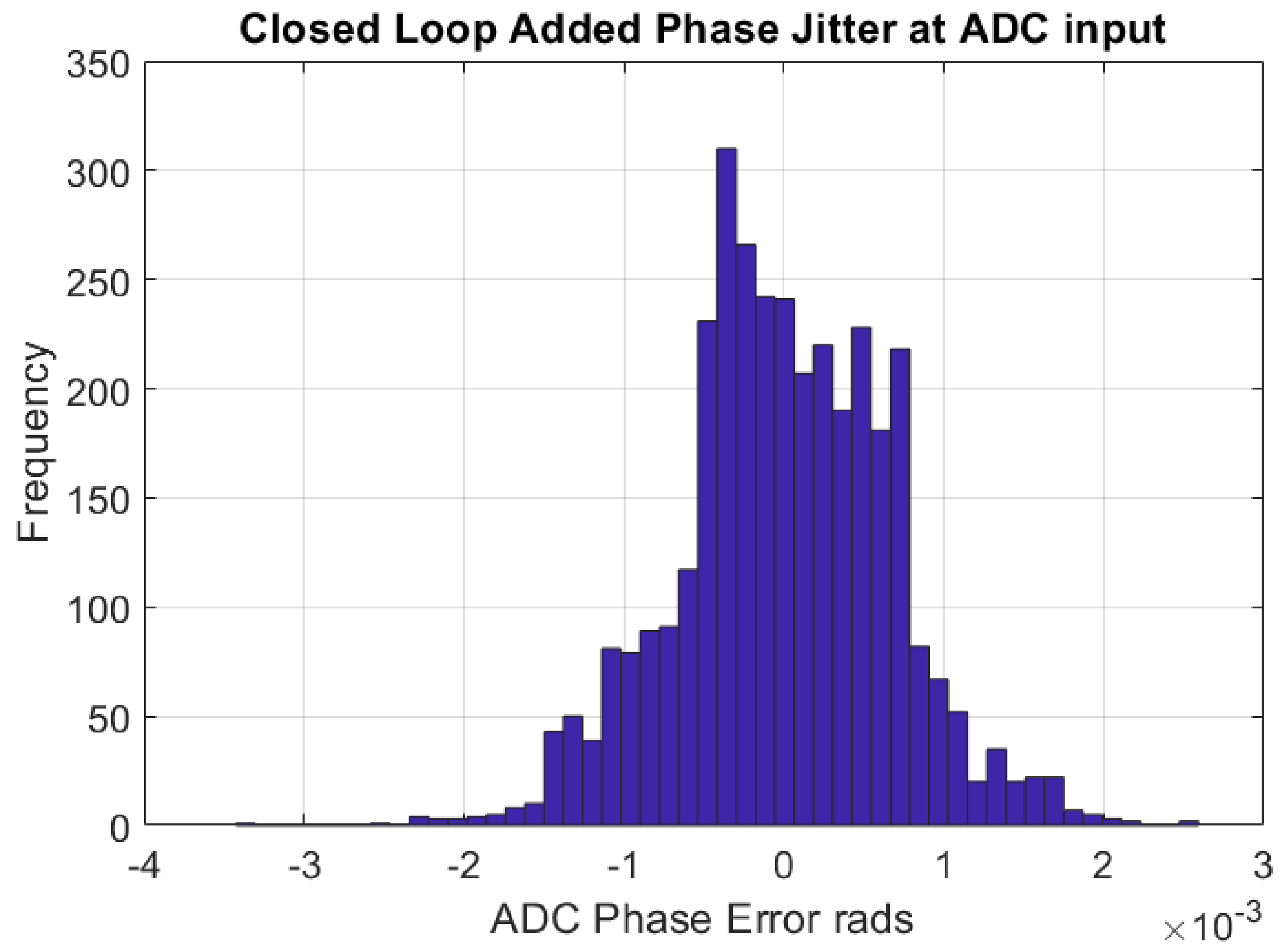
The MBF with BLL added.

Description

The RF reference input is connected to an IQ modulator. By applying a constant modulus I and Q from a pair of DACs any phase shift can be achieved. The output of the modulator is split between a feedback path to an IQ demodulator and an output to the MBF system. The BPM input is band pass filtered using a SAW filter to extract the reference clock component and provide the local oscillator drive to the IQ demodulator. In this configuration the IQ demodulator functions as a full 360 degree range phase detector.

The demodulator I and Q differential outputs are sampled by a pair of ADCs and averaged yielding an IQ update every 10 msec. The IQ data is processed in an ARM Cortex M4 microcontroller to generate a phase feedback signal using a floating point arctan function which is subtracted from the set point value to yield a phase error. The phase error is passed to a discrete time PID controller to drive the phase error to zero. If no BPM signal is present the PID is maintained at its previous value and the modulator is held in a phase holdover mode.

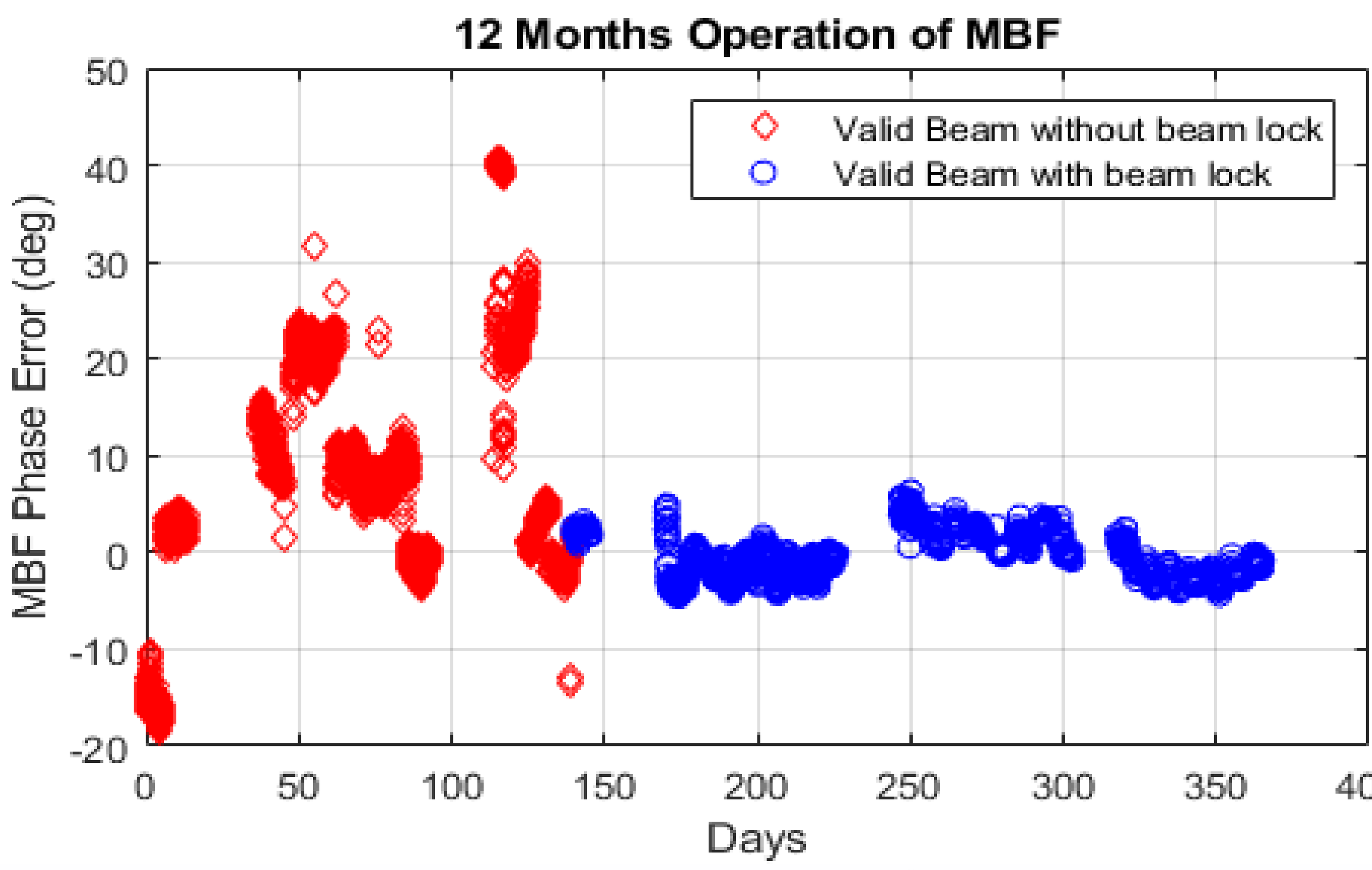
All of the hardware was mounted in a 1U shelf and integrated with the MBF system and EPICs.



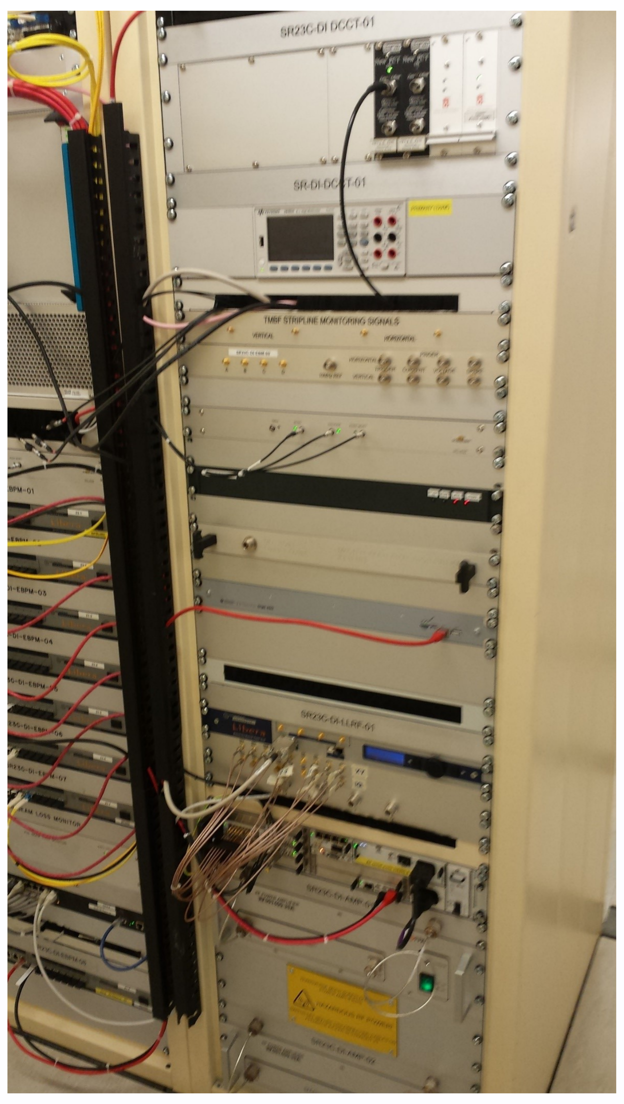
Closed Loop phase Jitter

Results

The prototype hardware has been operating in the Diamond storage ring since October 2019. Closed loop phase error data was collected over EPICS using the serial interface and shows a 0.21psec RMS added output jitter as shown above. The plot of phase alignment over 12 months is shown below. Prior to Oct 2019 (red data points) the reference phase was subject to large shifts during operational adjustments of the RF system periodically corrected by manual phase re-alignment. After Oct 2019 (blue data points) the beam locked hardware was fully operational and the measured phase has remained stable since that time. The vertical transients in the figure are beam loss events.



Operational Results



The Beam Locked Loop (Black 1U shelf) Integrated with the MBF System

Conclusions

A carrier recovery and clock synchronisation system phase locking the 500 MHz MBF reference frequency to a local BPM signal with operating beam current range of 1 to 300 mA has been designed and trialled on the Diamond Synchrotron. With a closed loop bandwidth of 8 Hz the design fully tracks slow phase movements in the BPM phase with low additive phase noise. Whereas previously phase re-alignment would be necessary every 20 days the system now runs without intervention and has so far operated for over 220 days without significant phase shifts. Several prototypes have been built and evaluated. One unit has been installed in the storage ring to provide the timing clock to the TMBF system. The serial management interface has been demonstrated with the EPICS control system to allow complete remote management of the installed hardware

References

[1] M.G. Abbott, G. Rehm, and I.S. Uzun, "A New Transverse and Longitudinal Bunch by Bunch Feedback Processor" in Proc. 16th Int. Conf. on Accelerator and Large Experimental Control Systems (ICALEPCS'17), Barcelona, Spain, Oct. 2017, pp. 1649–1654. doi:10.18429/JACoW-ICALEPCS2017-THPHA115

[2] M. Gaspar, M. Gough, C Mailand, "Phase shifter and IQ demodulator," 7th European Synchrotron Light Source RF Meeting, 10 2003

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