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Beam Position Monitors for LEReC*

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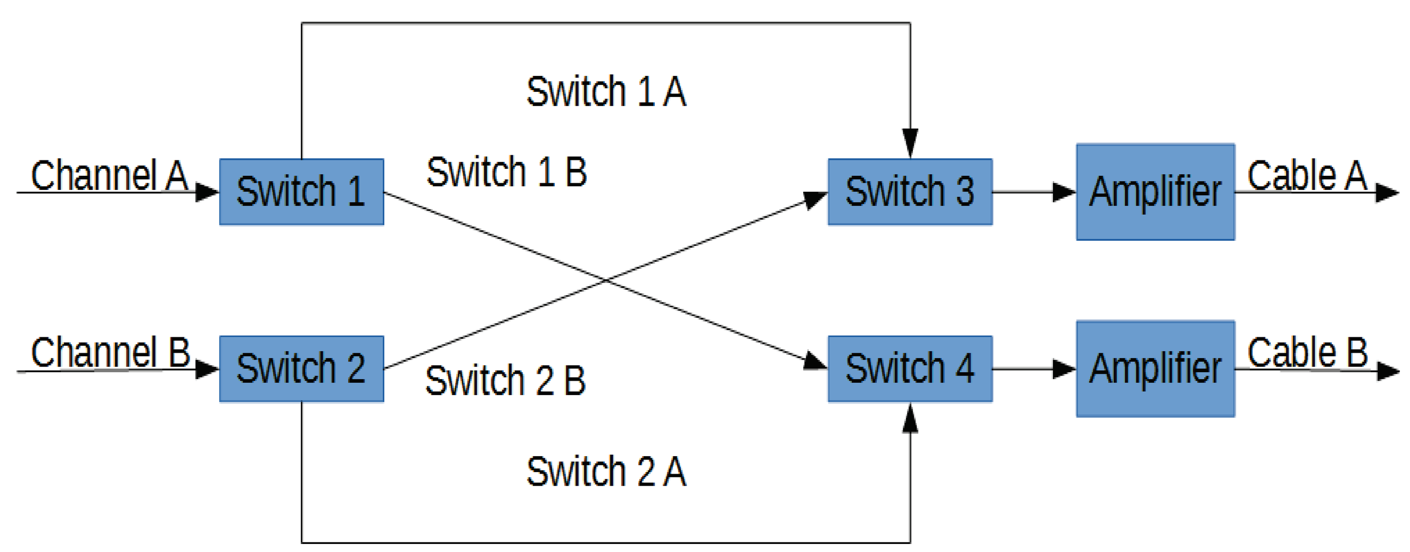
Abstract

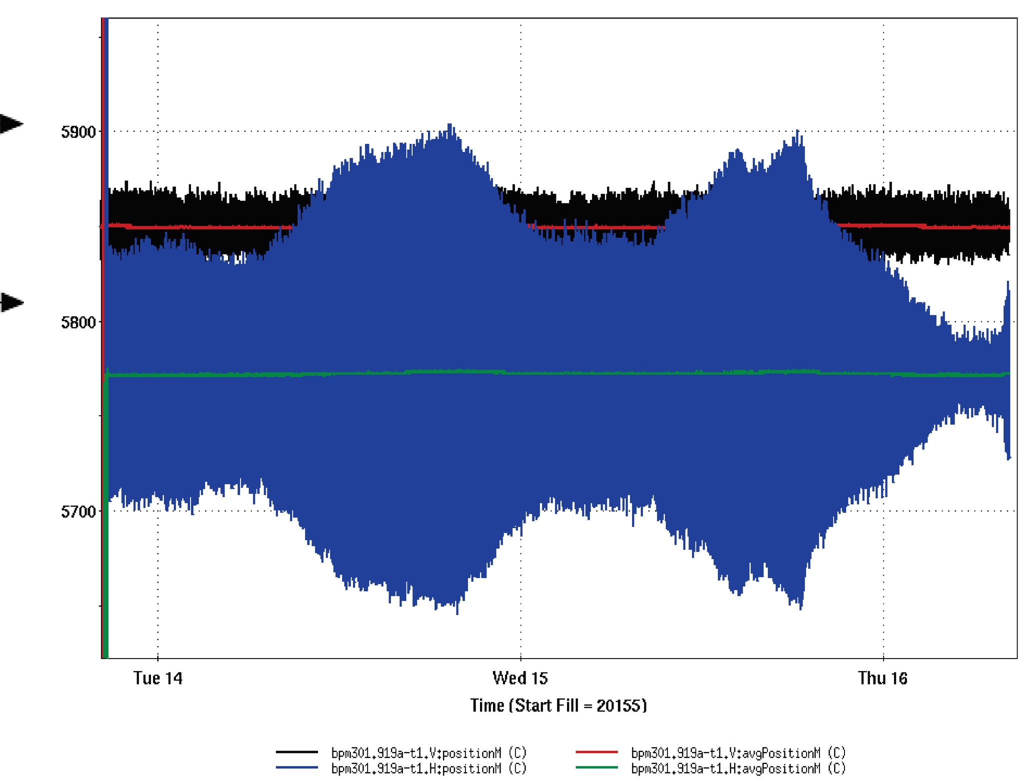
The operating parameters for Brookhaven National Laboratory's Low Energy RHIC Electron Cooling (LEReC) project create a unique challenge. To ensure proper beam trajectories for cooling, the relative position between the electron and the ion beam needs to be known to within 50µm. In addition, time of flight needs to be provided for electron beam energy measurement. Various issues have become apparent as testing has progressed, such as mismatches in cable impedance and drifts due to temperature sensitivity. This paper will explore the difficulties related to achieving the level of accuracy required for this system, as well as the potential solutions for these problems.

Position Measurements

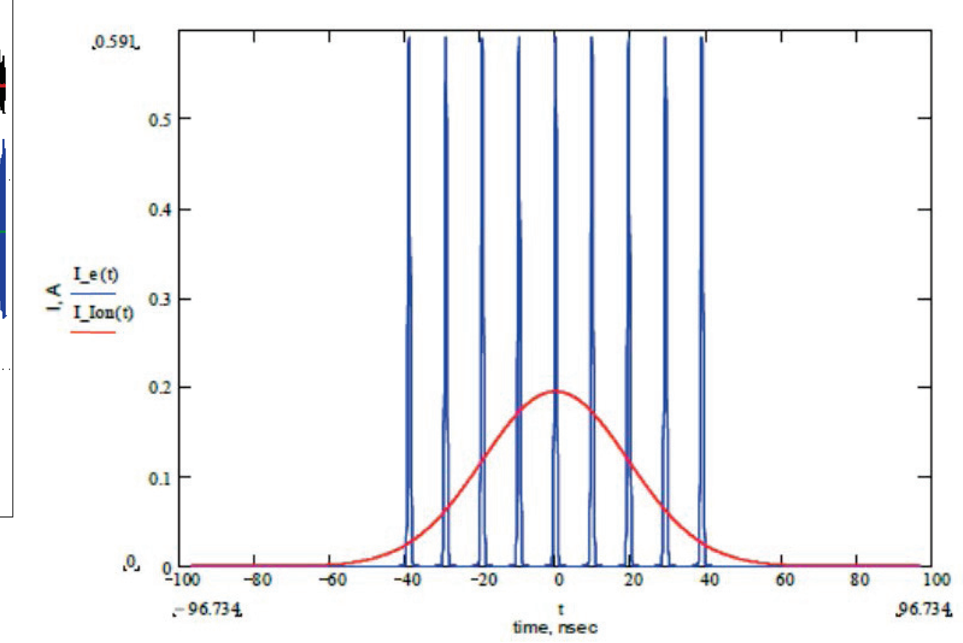
To ensure sufficient cooling, the position of the electron beam with has to be measured with 50 µm accuracy with respect to the ion beam. The challenge with this level of accuracy is the vast difference between the repetition rates of the two beams. The ion beam has a repetition rate of 9 MHz and the electron beam has a repetition rate of 704 MHz. This large difference in frequencies creates disparate responses between the two sets of electronics that are designed to handle the signals from each beam. To ensure that the beam positions are close enough to each other, either a relationship must be established during calibration between the two sets of electronics, or the position measurement must be absolute (from the center of the beam pipe).



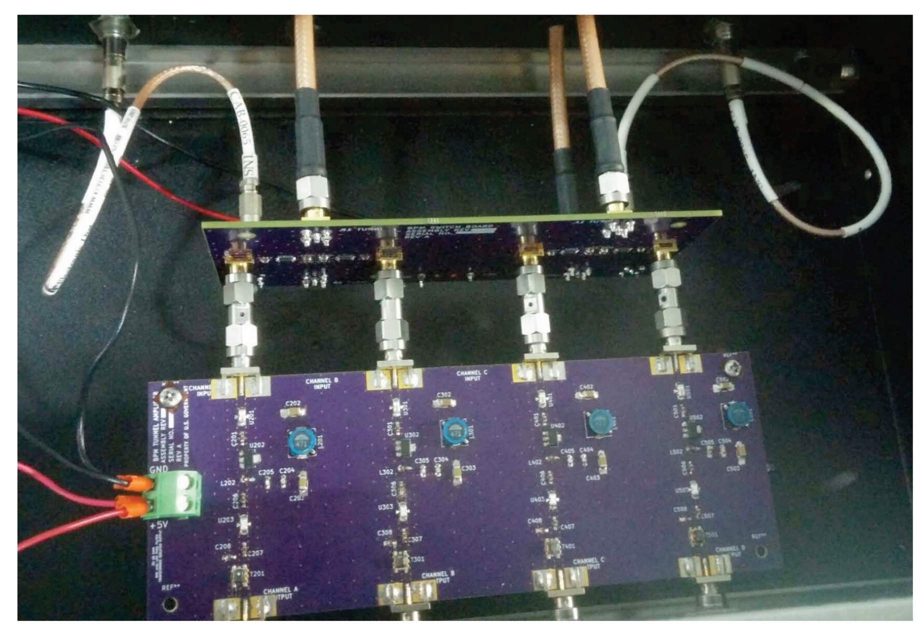
Switch configuration used to eliminate temperature drifts in cables down stream. Amplitude imbalances present in a pair of cables can be detected when the inputs to the cables are swapped.



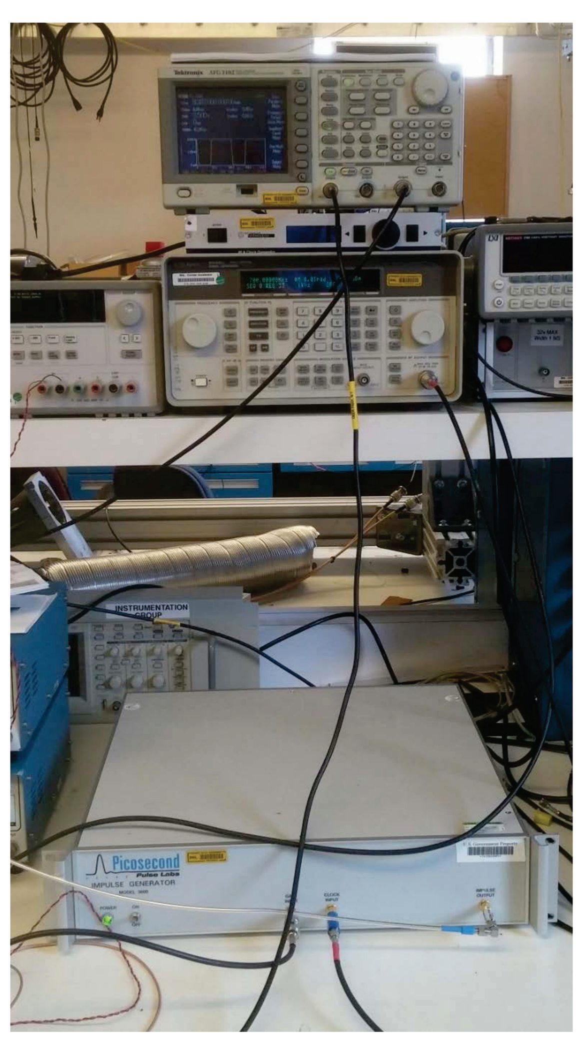
The blue signal is the position calculated from a simulated signal. The signal goes through a switch similar to the one shown to the left. There are several hundred feet of cable between the switch and the rest of the electronics. The scale of the y-axis is measured in microns. Variations in cable losses due to temperature changes can be seen in the envelope of the blue signal. The green signal is a running average of the blue. These results illustrate the effectiveness of including switches as far upstream as possible.



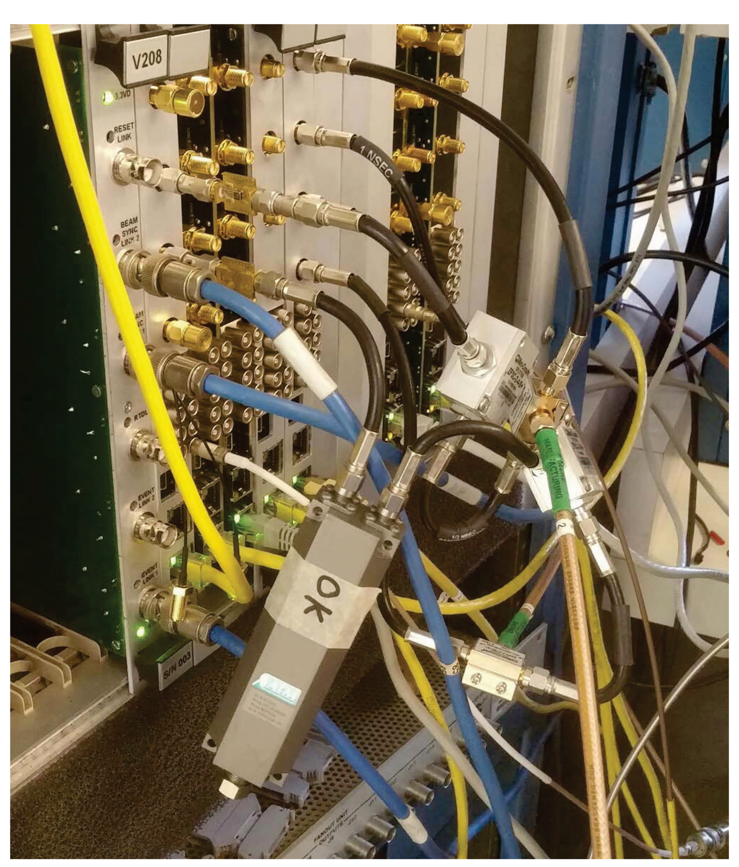
The 704 MHz electron bunches are in blue with a single ion bunch in red.
(Note: This image is for 4.5 MHz RHIC RF) [3]



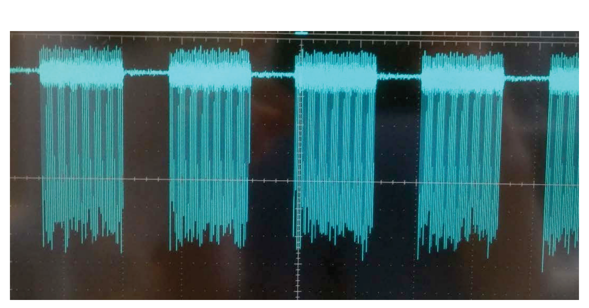
Physical implementation of the switch and amplifier circuit. The perpendicular circuit board contains the switches which are oriented so that the different signal paths are nearly identical to each other.



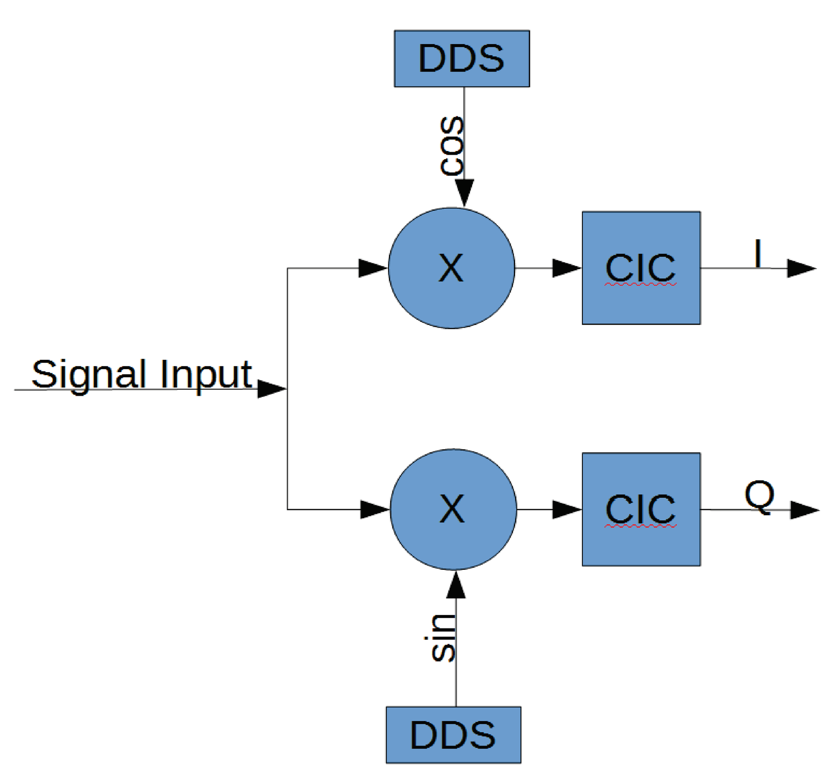
Signal generation for phase measurement testing. Function generator on the top generates a 9 MHz square wave to gate the output of the pulse generator (creating a macro-bunch structure). The function generator in the middle of the picture creates a 700 MHz clock to drive the pulse generator. The pulse generator sitting near the bottom of the picture generator ultimately generates a 700 MHz train of 70ps pulses with a 9 MHz macro-bunch structure.



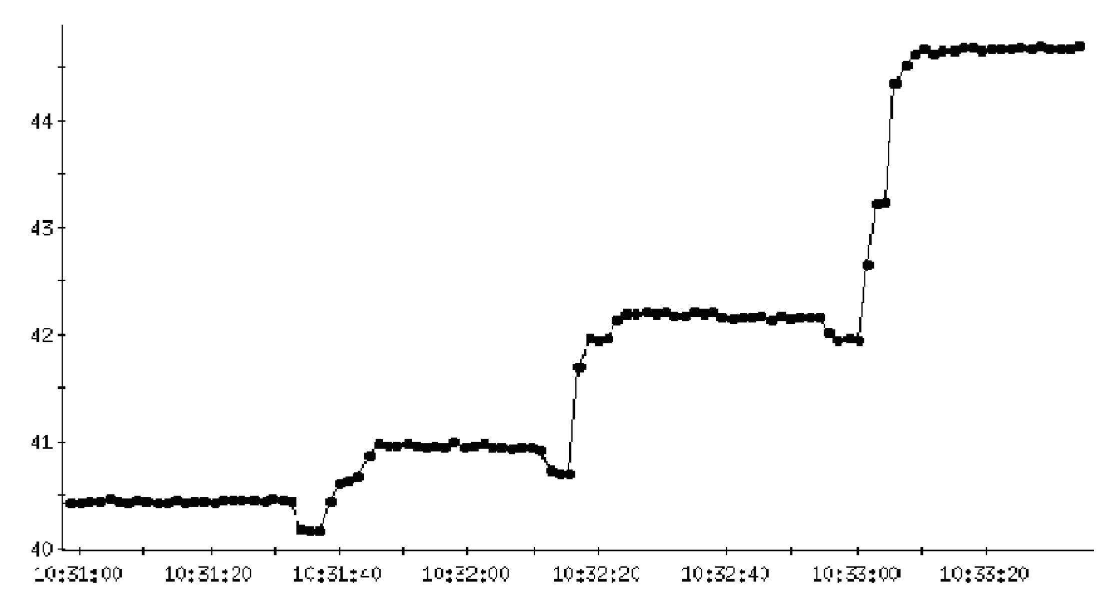
The above setup splits the signal generated in the image to the left and introduces a phase shift on one line using a coaxial phase shifter. The phase could then be adjusted in various steps to test the ability of the V301 electronics to measure relative phase. [1]



Test Signal: 704 MHz pulse train gated with a 9 MHz square wave.



A simple representation of the digital quadrature demodulation that is performed after the signal is sampled. The clock used to down convert the signal is a 400MHz clock that is generated from the 10MHz reference output of the signal generator that was used to create the 700MHz clock. The cascaded integrator comb filters (CIC) low pass the in phase and quadrature signals while also reducing the data rate by a factor of 512. This gives a bandwidth of about 390 KHz which should be sufficient for measuring power supply ripple. The phase can be calculated by taking the inverse tangent of the I and Q outputs.



As an initial test, the phase was varied using the phase shifter with steps of 0.6 degrees, 1.2 degrees, and 2.4 degrees. The results are not exact however as a noticeable shift was created when the screwdriver came into contact with the coaxial phase shifter. This created the dips shown on the chart preceding each increase in phase.

Phase Measurements

Energy measurements are also necessary for LEReC and will be calculated from the time of flight of the electron beam. Time of flight measurements will be achieved by sampling with a clock locked to the global RF clock that is used to generate the 704 MHz clock. The signal will then be digitally down-converted with a digitally synthesized 704 MHz clock to calculate the phase at each BPM.

References

[1] R. Hulsart, et al., "A Versatile BPM Signal Processing System Based on the Xilinx Zynq SoC," IBIC 2016, Barcelona (2016).

[2] T. Miller et al. "LEReC Instrumentation Design and Construction," IBIC 2016, Barcelona (2016).

[3] A.V. Fedotov et al. "Bunched Beam Electron Cooler for Low-Energy RHIC Operation," PAC2013, Pasadena (2013).