Microwave Link Phase Compensation for Longitudinal Stochastic Cooling in RHIC

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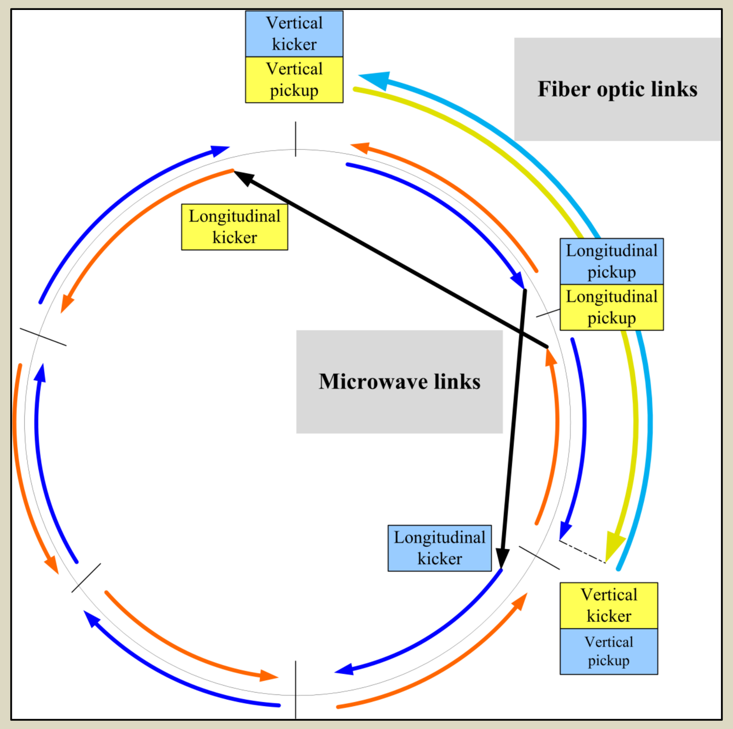
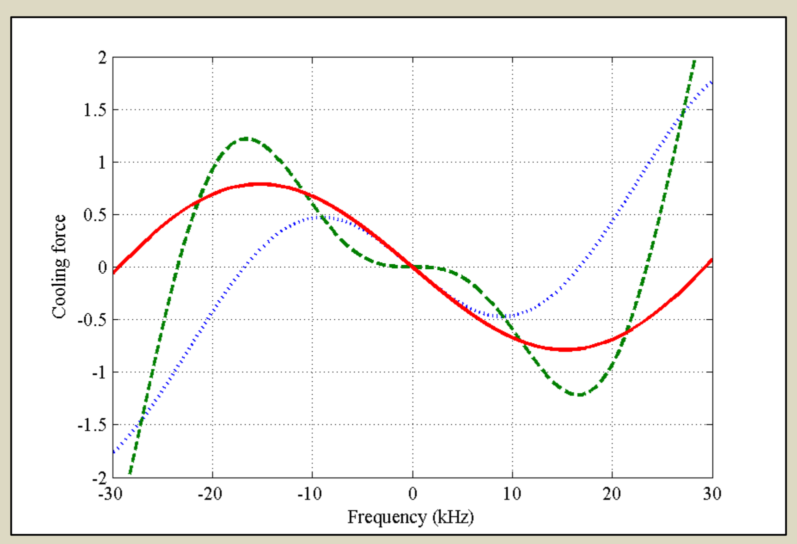
A new microwave link has been developed for the longitudinal stochastic cooling system, replacing the fiber optic link used for the transmission of the beam signal from the pickup to the kicker. This new link reduces the pickup to kicker delay from 2/3 of a turn to 1/6 of a turn, which greatly improves the phase margin of the system and allows operation at higher frequencies. The microwave link also introduces phase modulation on the transmitted signal due to variations in the local oscillators and time of flight. A phase locked loop tracks a pilot tone generated at a frequency outside the bandwidth of the cooling system. Information from the PLL is used to calculate real-time corrections to the cooling system at a 10 kHz rate.

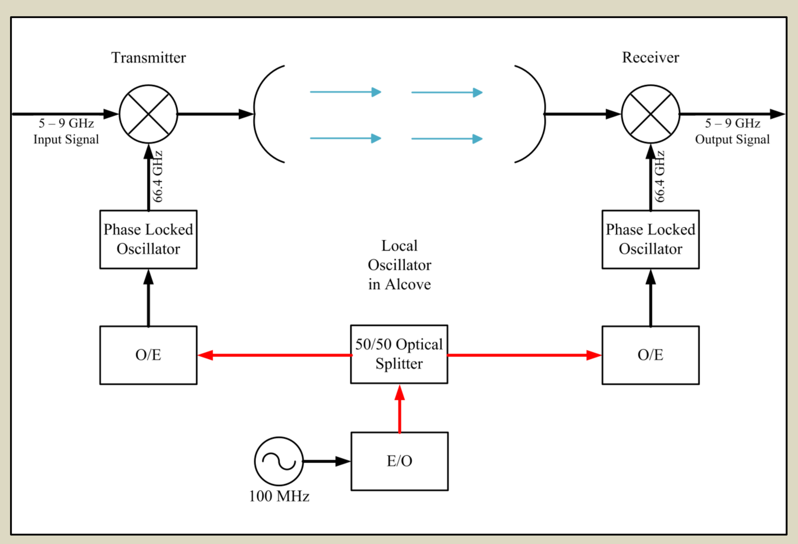


The longitudinal pickups are located at IR2. The Blue longitudinal kicker is in IR4, and the Yellow longitudinal kicker is in IR12. The vertical pickups are in IR4 (Blue) and IR12 (Yellow), and the vertical kickers are in IR12 (Blue) and IR4 (Yellow). In the left figure, the dark blue and orange arrows indicate the direction the beams travel.

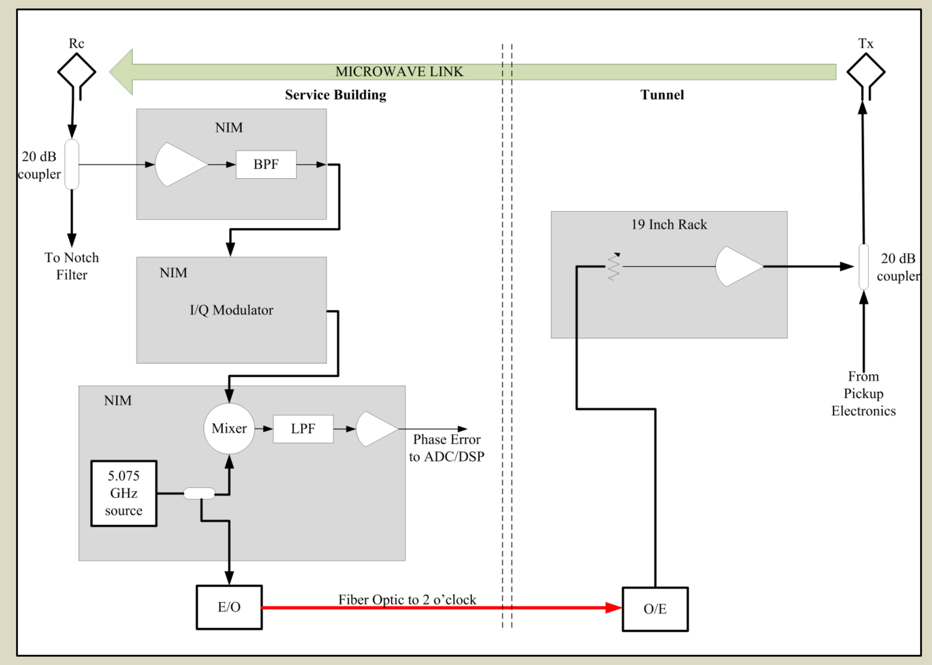
The microwave links transmit across the center of the RHIC ring, cutting the chord between the pickup and kicker and reducing the delay to 1/6 of a turn. The transmitters are located on the berm above the beamline. The Yellow transmitter is shown in the foreground of the photograph on the right with the receiver in the distance. The Yellow receiver and electronics shack, located on the berm above the kicker, are shown in the inset photograph. The Blue receiver is on the roof of the RF service building, with the electronics in the attic above the RF control room.

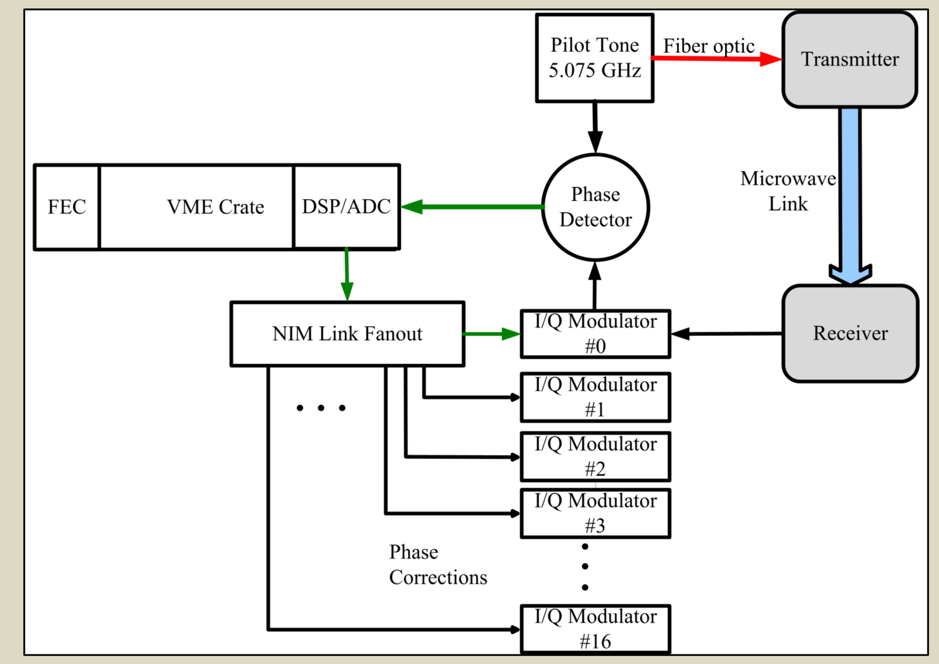


The cooling force for one-turn (blue dots) and two-turn (green dashes) filters with 2/3 turn delay and for one-turn (red) filter with 1/6 turn delay. The reduced pickup to kicker delay from the microwave link allows the operation of the cooling system at higher frequencies with better phase margin.



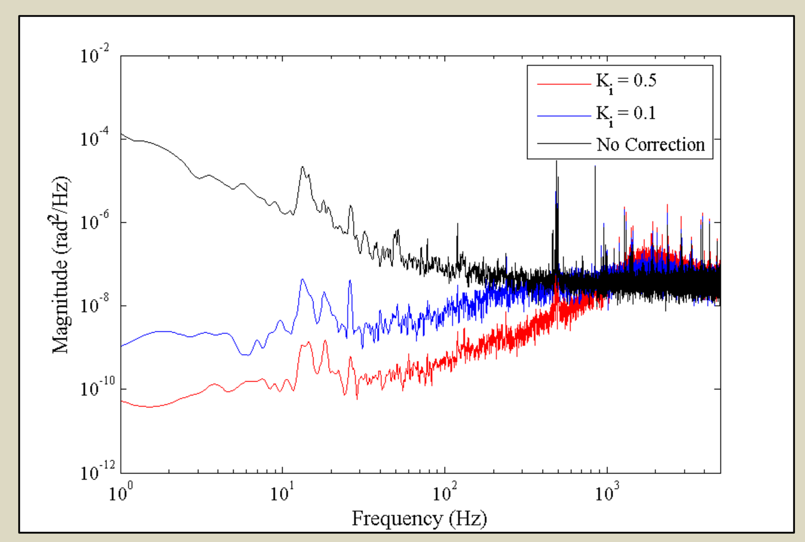
The microwave link introduces phase modulation in the received signal due to variations in the time of flight and differences in the phase of the local oscillator at the transmitter and receiver. We found that the local oscillator was the dominant source of phase shifts.



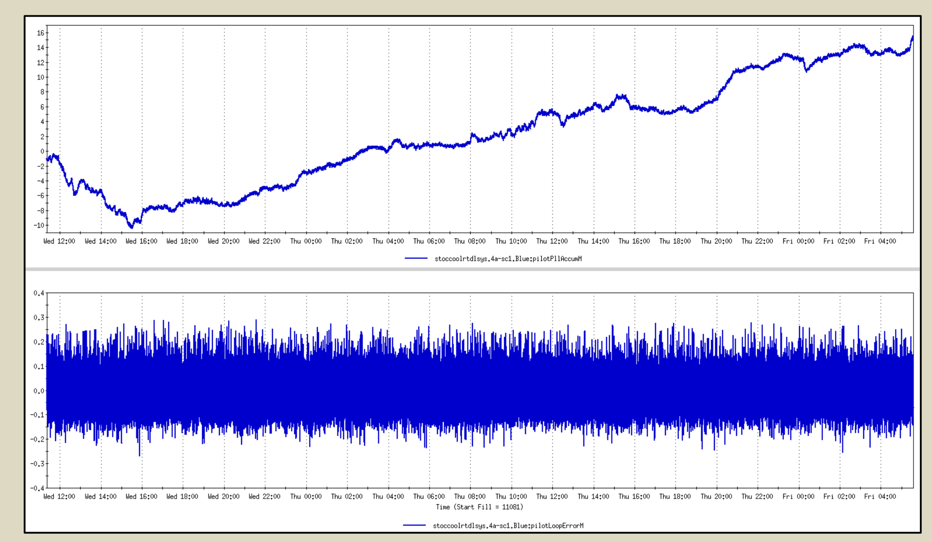


A CW 5.075 GHz tone is generated at the receiver end of the microwave link, sent over a fiber optic link to the transmitter, and added to the pickup signal. This signal received from the link is split, amplified, and filtered before a phase shift is applied by a digitally controlled I/Q modulator. The generated signal and the received signal are connected to a phase detector, whose output is sampled by an ADC on the DSP board.

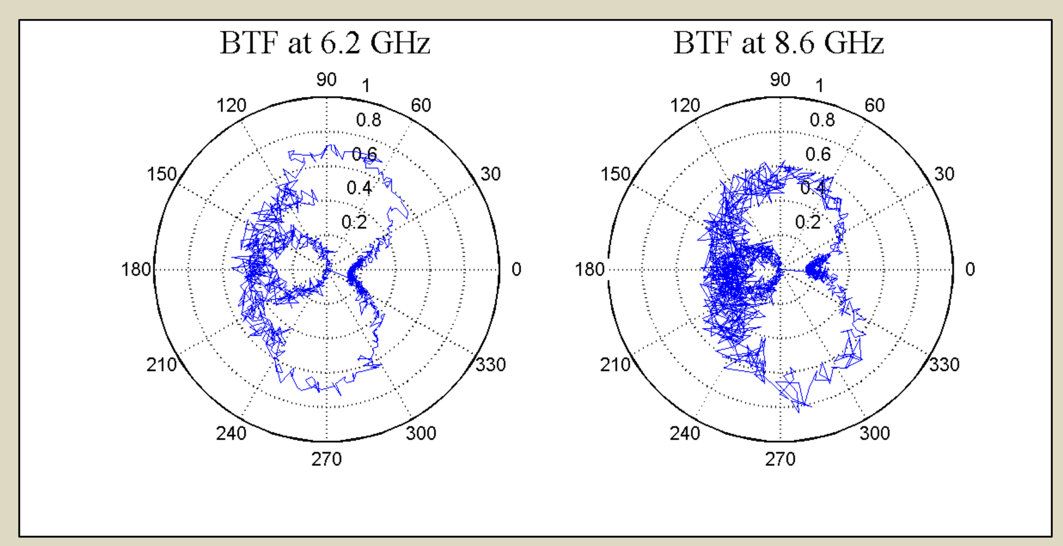
The DSP implements a PLL to cancel the phase shift applied to the pilot tone in the microwave link. It also calculates phase corrections to apply to each of the 16 kicker cavity signals based on the PLL phase. These phase corrections are added to the I/Q gain settings that the cooling system determines from periodic measurements of the beam transfer function, and distributed over a dedicated local serial link.



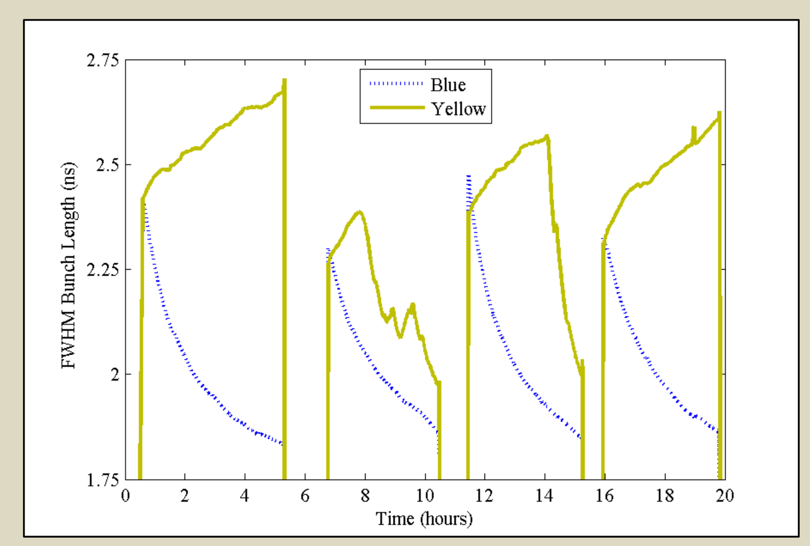
Power spectral density of phase error signal with pilot tone PLL off (black) and on with integral gains of 0.1 (blue) and 0.5 (red).



Evolution of the pilot tone PLL accumulated phase correction (top) and phase error (bottom) over several days.



Beam transfer function measurements for 6.2 GHz and 8.6 GHz cavities. The higher frequency exhibits more noise, consistent with other tests indicating the phase compensation is not as effective due to the uncompensated time of flight variations.



Evolution of the bunch lengths in four RHIC stores. The Blue cooling was on for all stores, Yellow cooling was off for the first and last, and on for parts of the middle two.

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