Optical Correlator Notch Filters for Fermilab Debuncher Betatron Stochastic Cooling

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INTRODUCTION

One of the proposed upgrades to the Fermilab colliding beam physics program is an increase in antiproton production. Part of this improvement requires faster antiproton production cycles. This will be achieved by running the Main Ring accelerator in multi-batch mode. The present cycle rate is 2.6 seconds, the proposed rate is as fast as 1.5 seconds. The stochastic cooling systems in the original machine would not be able to cope with this faster cycle time. The cooling rate depends on the number of particles, the system bandwitdth, and signal to noise ratio (S/N). Increased antiproton production rates will further degrade the cooling time of the existing hardware. The system bandwidth is to remain the same which leaves S/N ratio as the only variable.

The transverse cooling systems in the Debuncher are power limited, (i.e. operating below the optimum gain) with the output amplifiers operating at saturated power levels. The system gain can be increased at fixed traveling wave tube power output by increasing the betatron signal to thermal noise ratio.

There are several ways of improving the S/N ratio: 1) add more pickups to obtain more correlated signal power, 2) cool the pickups to liquid helium temperature (they are already cooled to liquid nitrogen temperature) thus reducing the system thermal noise, 3) insert a device to improve S/N ratio. Adding pickups to the lattice is difficult due to space restrictions and expense. Cooling pickups to liquid helium temperature is prohibitively expensive requiring not only plumbing changes but complete redesign of the entire pickup. We are left with adding a filter to improve the system characteristics.

Optical correlator notch filters have been installed in the Fermilab Antiproton Debuncher ring. Their main function is the improvement of system signal to noise ratio without degradation of system gain and phase parameters. This in turn yields faster cooling times that are compatible with the more rapid antiproton production cycles proposed for future operation. A brief discussion of cooling techniques will be covered showing the importance of the filters. In addition, the actual hardware implementation and performance results will be presented.

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TRANSVERSE COOLING IN THE DEBUNCHER

The Debuncher ring has two betatron cooling systems[1,2], one for each plane. Antiproton production yields approximately one antiproton for every 10^5 incident protons on target. The end result is a very low current of antiprotons on the order of a few micro-amperes (10^7 particles at the 590 KHz revolution frequency is very close to one micro-ampere). The Schottky signals generated by the beam in the stochastic cooling pickups have a very small signal to noise ratio of the order 0 to -6 dB. Figure 1 shows what the Schottky signals look like on a spectrum analayzer for a 10 micro-ampere proton beam. The cooling system is concerned only with the betatron sidebands. Longitudinal signals and thermal noise between bands degrades the system S/N ratio. If a filter could be added to suppress these unwanted signals, system S/N ratio could be improved.

It is imperative that any filter added to the system have the same absolute phase characteristic at each Schottky band location. The tune of the Debuncher is very close to the quarter integer hence the Schottky bands will occur at the middle of the filter passbands. What results are the filter vector characteristics in Figure 2. Linear gain and phase requirements for the cooling system can be maintained only if such a filter has excellent notch depth, gain flatness, and notch bottom dispersion. Figure 3 shows the change in S/N ratio of the Schottky signal with such a filter on and off.

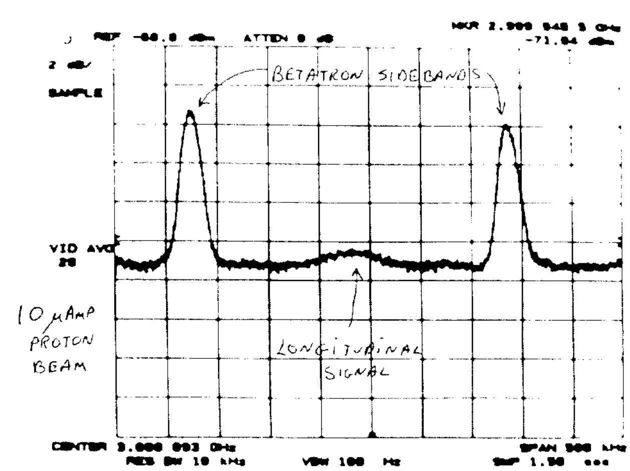

Figure 1: Sample of Schottky signals for 10 uamp proton beam.

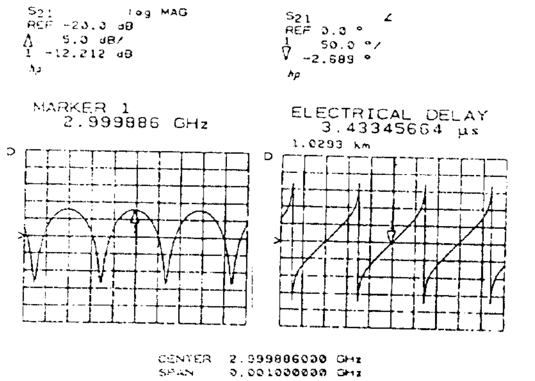

Figure 2: Vector characteristics of notch filter

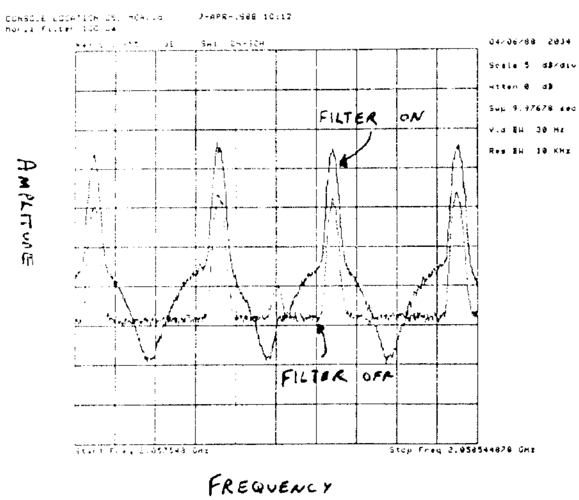

Figure 3: S/N ratio with filter on and off

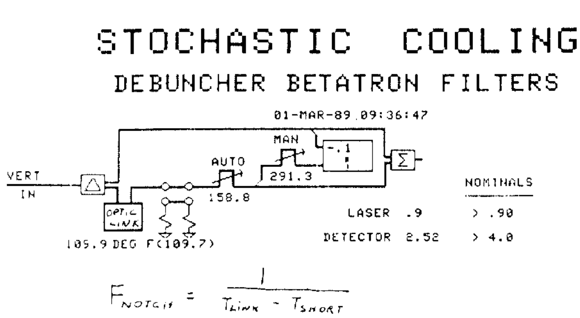

Figure 4: Correlator schematic

HARDWARE IMPLEMENTATION OF FILTER

Correlator filters have been used at Fermilab for the stacktail cooling systems[3]. Figure 4 is a schematic representation of a correlator filter. The requirements for betatron cooling in the Debuncher call for a filter with a recursive notch frequency of half the revolution frequency, i.e. approximately 295 KHz. The filter must be located in the tunnel due to the time of flight timing constraints of the cooling system. Use of a superconducting coax cable[4] for the delay medium as in the stacktail system was not feasible as cryogenic plumbing costs are high. It was decided to test the use of a fiber optic link for the delay[5].

Specifications for the filter are : frequency response 2-4 GHz, notch frequency spacing 295 KHz, 20 dB minimum notch depth, 10 part per million notch bottom dispersion, minimal insertion loss. To achieve these specifications gain match and flatness must be maintained to 1 dB. Group delay variation must not exceed 10 picoseconds out of the 3.3 micro-second delay.

The transmitter/ receiver is an Ortel[6] laser diode/photo diode link. Corning single mode fiber optic is the delay line. The thermal coefficient of the glass fiber is too high for maintaining the required group delay tolerance hence the entire spool of fiber has been oven stabilized to better than one degree Fahrenheit. Even with temperature stabilization an additional phase locked loop was required to hold the delay time requirement. Careful matching of all components in the system yielded the required amplitude performance. The photo in Figure 5 shows the final optical link hardware.

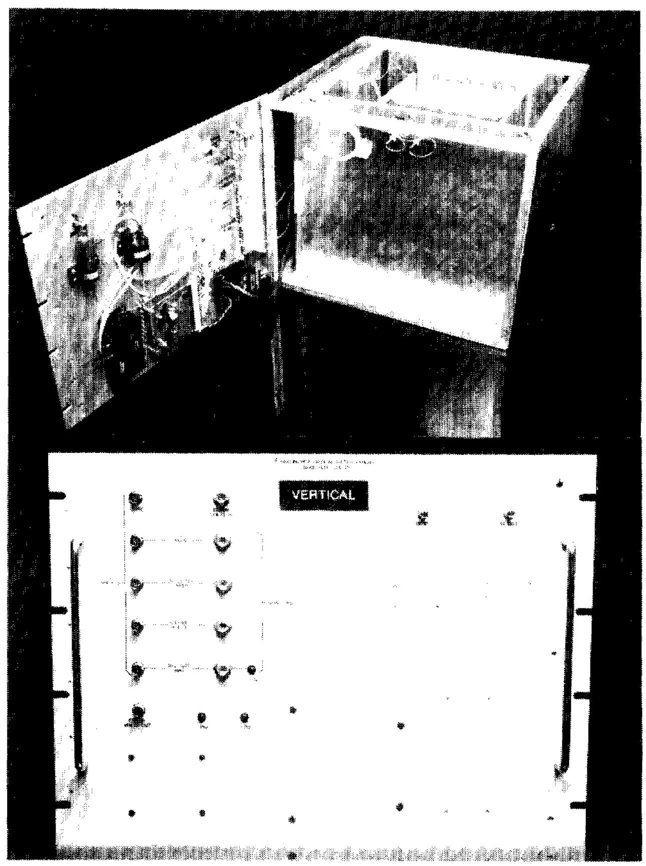

Figure 5: Photo of link hardware and oven

SYSTEM PERFORMANCE

Three filters were built, two filters have been installed and operational for 16 months. Figures 6 and 7 show the notch depth and dispersion characteristics for one of the installed filters. Additional tests were carried out on a 10 micro-ampere proton beam to show improvement in cooling time. The results are in Figure 8. Both curves are asymptotically approaching the thermal noise floor. The difference in initial slopes of the curves is more important. Analysis shows the expected $1/\sqrt{2}$ improvement in cooling time. Studies for multi-batch operation are presently in progress.

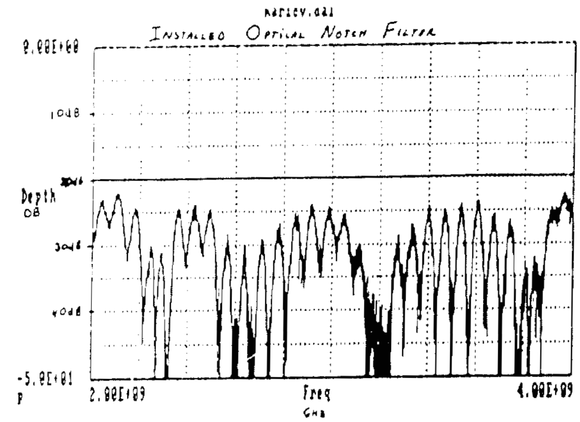

Figure 6: Notch depth envelope from 2-4 GHz

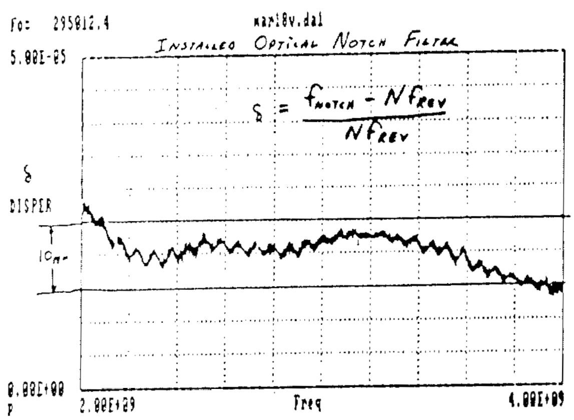

Figure 7: Notch bottom frequency dispersion 2-4 GHz

ACKNOWLEDGMENTS

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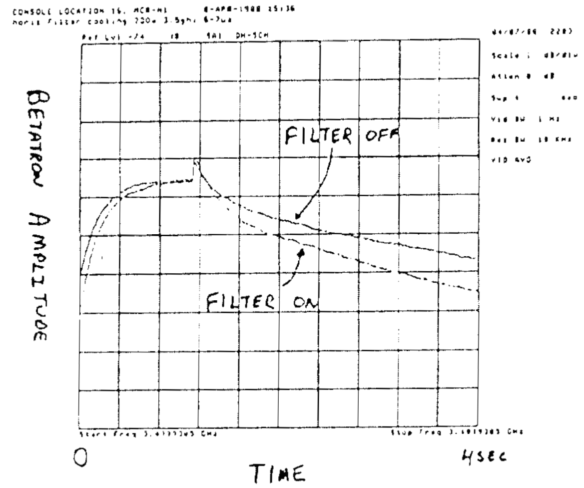

Figure 8: Cooling time with filter on and off

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