DESIGN AND IMPLEMENTATION OF AN ANALOG FEEDBACK DAMPER SYSTEM FOR AN ELECTRON-PROTON INSTABILITY AT THE LOS ALAMOS PROTON STORAGE RING*

C. Deibele, S. Assadi, V. V. Danilov, S. Henderson, M. Plum, C. Sibley III, SNS-ORNL, Oak Ridge, TN 37831, U.S.A.
D. Gilpatrick, R. J. Macek, R. C. McCrady, J. F. Power, T. Zaugg Los Alamos, NM 87545, U.S.A.
J. Byrd, LBNL, Berkeley, CA 94720, U.S.A.
S. Breitzmann, S.Y. Lee, IUCF, Bloomington IN 47408, U.S.A.

Abstract

The PSR (Proton Storage Ring) at LANSCE has observed an E-P (electron-proton) instability. A wideband analog feedback damper system was designed and implemented that has shown it is possible to correct this instability. The damper system consists of two 180 degree hybrids, low level amplifiers, a delay line, comb filter, power amplifiers, and adjustable delay lines. The system bandwidth is about between 10-300 MHz, and was developed and implemented in stages showing improvement in the e-p threshold of the buncher voltage. The system takes advantage of fiber optic technology for delays as well as for the comb filter. A system description and some measurement results are presented.

SYSTEM DESCRIPTION

A schematic for the wideband damper system is depicted in Fig. 1.

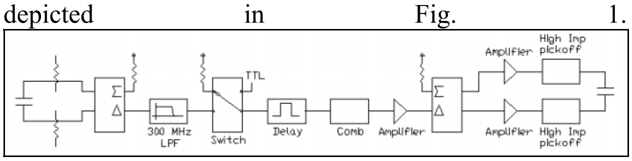

Figure 1: Schematic of the wideband damper system.

The signals from the left side of the schematic on the BPM (beam position monitor) are sent upstairs to a rack in a service building in phase matched cables. The signals are then sent through an appropriate attenuator so that saturation does not occur in any of the downstream electronics, and the level of attenuation is set such that the beam is electrically centered between the electrodes when no instability is present.

A low level RF box manipulates the difference signal from the BPM electrodes and sends out a time delayed signal to kicker electrodes. The signals from the power amplifiers are phase matched and are 180 degrees out of phase from one another, and are sent down to the kicker electrodes on the right hand side of the schematic.

The difference signals are then passed through a 180 degree hybrid (Minicircuits ZFSCJ-2-1) [1]. This hybrid has a bandwidth from 1-500 MHz, and a hybrid with better than 30 dB CMRR was hand selected from a series of measurements across the bandwidth of interest.

Bandwidth Considerations and Power Amplifier

The output of the hybrid is then passed through a 300 MHz low-pass maximally flat time delay filter. This filter was selected because it has a flat phase response with respect to frequency. This is the same as saying that the group delay through the filter is constant versus frequency in the passband. See Fig. 2 for the unwrapped phase measurement of the high power amplifiers. See Fig. 3 for the gain of the power amplifier.

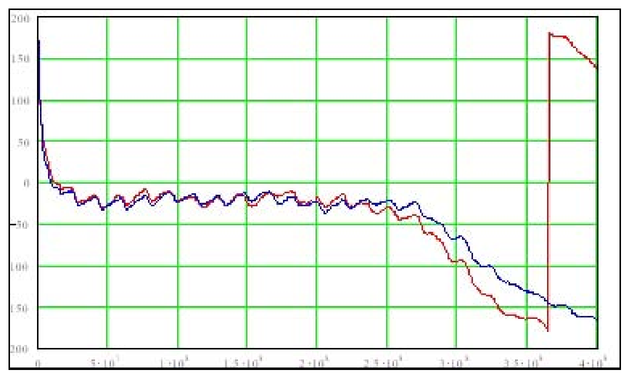

Figure 2: Unwrapped phase through the power amplifiers.

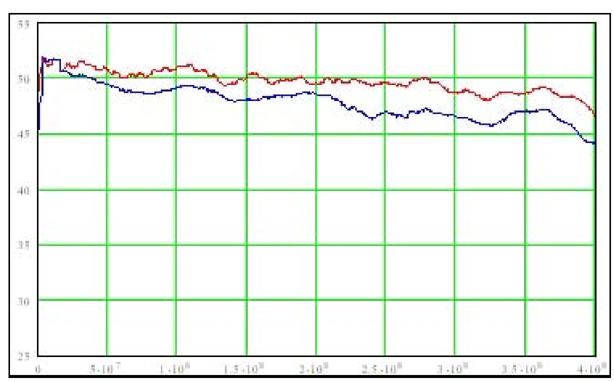

Figure 3: Gain of the power amplifiers. Notice that the gain is constant when the phase starts to drop. This is the reason for the low pass filter.

The corner frequency of the filter was chosen based on the measurement of the high power amplifiers, and these amplifiers begin to be dispersive at about 300 MHz, so the goal is to have attenuation where the system gets dispersive.

ACKNOWLEDGMENTS
Research on the Spallation Neutron Source is sponsored by the Division of Materials Science, U.S. Department of Energy, under contract number DE-AC05-96OR22464 with UT-Battelle Corporation for Oak Ridge National Laboratory.

The power amplifiers are ENI 5100L. These are solid state 100 Watt amplifiers, and each amplifier drives a single plate of the kicker electrode.

TTL RF Switch and Low Level Amplifier

The signal then goes through a TTL RF switch. This switch permits the user to turn the feedback system on or off via the use of simple input TTL gate. The isolation between the outputs of the switch is about 40 dB, and the switch is manufactured by Minicircuits, part number ZYSWA-2-50DR. Use of this switch can, for example, allow one to make grow/damp measurements straightforwardly, or allow the user to turn the feedback system on or off in a simple straightforward manner.

A low level amplifier and variable attenuator is also implemented. The variable attenuator, made by TekScan, can be adjusted in 1 dB steps up to 60 dB, is a tool that was used to dynamically adjust the feedback gain, as well as to effectively turn the feedback off.

Delay Line

The first component is a 3 GHz LBL fiber optic transmitter/receiver pair manufactured by Miteq [2]. The fiber optic delay line was used so that the user could choose delays in groups of 10, 20, 30, 40, and 50 nsec, and then in steps of 50 nsecs: 100, 150, 200, … 950 nsec. The delays were accurate to about 40 psec with a standard deviation of about 40 psec. The delays are selected by the user in a switchboard style. See Fig. 4 for a picture of the switchboard delay box.

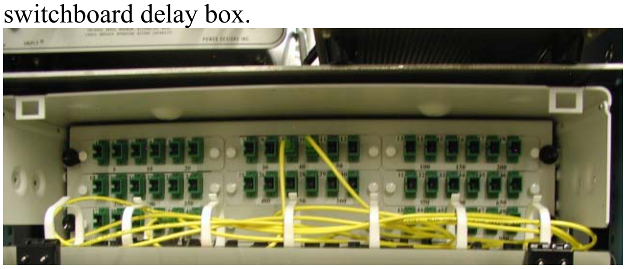

Figure 4: Fiber optic delay box. Users use a fiber to connect specific lengths of fiber.

The second part of the delay is a binary delay tree that is adjusted by turning on specific delay lines. The delays are incremented in powers of 2: 200 psec, 400 psec, 800 psec, 1.6 nsec, 3.2 nsec, 6.4 nsec, and 12.8 nsec. The delays are selected by turning on appropriate RF switches (ZYSWA-2-50DR). A schematic of one section of the binary delay tree chassis is shown in Fig. 5.

The advantage of the binary delay tree is that it is possible to quickly change delays and experiment to find an optimal system delay for differing system configurations. The experimenter takes a shot of data, analyzes measurements from the oscilloscopes, and then modifies the delays. The alternative method was to have a multitude of different cables of different lengths and to manually de-install and re-install these cables.

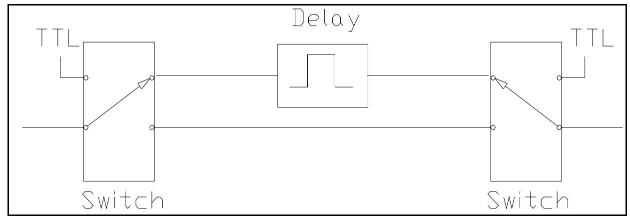

Figure 5: Schematic of binary delay line. The user can select whether to add a delay by giving a high signal to the switches, or remove a delay by giving a low signal to the switches.

Comb Filter

The comb filter was designed to have flexibility [3]. A schematic of the comb filter is depicted in Fig. 6.

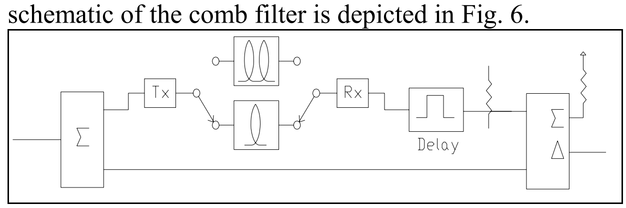

Figure 6: Schematic of the comb filter.

The signal in is split using a resistive splitter (Minicircuits ZFSRC-42). The long leg of the comb filter used a Miteq LBT-HP-10M3G-25-15-M14. This particular transmitter has a bandwidth of about 5 GHz and is temperature stabilized. It is possible to choose the delay (one or two turns of delay) for the long leg by simply choosing the fiber over which to transmit the signal. A trombone by Arra [4] (model number D4428D) was used to fine tune the delays for the different long legs. The resulting signal then goes through a 180 degree hybrid (Minicircuits ZFSCJ-2-1). The hybrids were chosen based on a series of measurements with a vector network analyzer to have the flattest CMRR possible over the band of interest with the flattest phase. This implies that simple attenuation along a single leg would produce a notch filter with the greatest notch depths. A picture of the chassis is shown in Fig. 7.

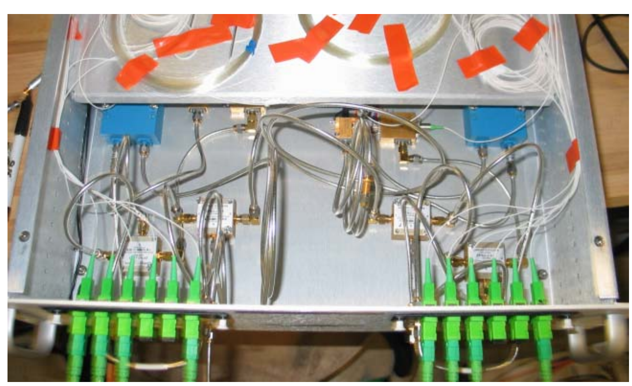

Figure. 7: The comb filter chassis. Two separate filters are included, with the option on each filter to have one or two turns of delay.

It was decided to include two separate notch filters into the system design so that the system could be tested quickly and permit the user to optimize the system because of limited beam time for machine studies. The notch depths for the two systems combined together is shown in Fig. 8.

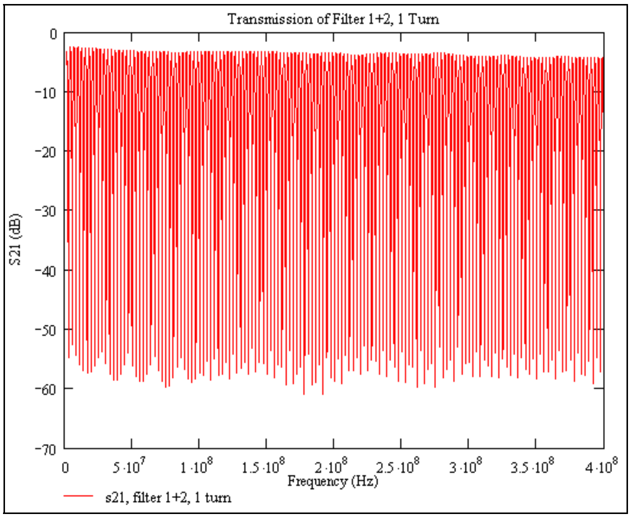

Figure 8: Measurement of notch depths for two notch filters, ganged one after the other, each having a single turn of delay.

High Impedance Pickoff

It was desired to measure the signals that the power amplifiers were sending to the BPM electrodes. Typically one uses a directional coupler for this measurement, but since one was not readily available that covered the entire bandwidth of the system, a simple high-impedance pickoff was designed to make this measurement. A schematic of the high-impedance pickoff is shown in Fig. 9.

The amplifier connects to either of the left or right hand SMA connectors. The 1K-ohm resistor is decoupled by about 40 dB, and therefore it does not load the circuit by much. This circuit measures both the outgoing signal from the power amplifier and the beam induced signal on the kicker electrode. The beam induced signal, however, is about 20 dB lower in intensity than the amplifier signal.

MEASUREMENT RESULT

A sample measurement of the system performance is shown in Fig. 10. The red trace is a measurement of a BPM with the feedback on, the blue trace is the same measurement on the same BPM with the feedback off. The ring had 3 uC of charge stored in it. The buncher voltage had a 10% reduction in threshold with the feedback on in this situation. Many of the measurements and discussions of the e-p instability can be found in [5].

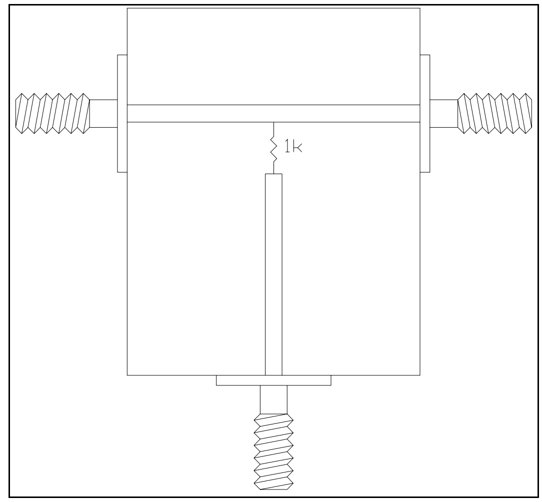

Figure 9: Schematic of high impedance pickoff.

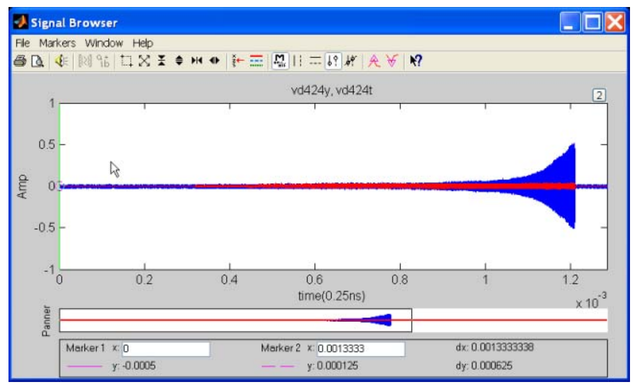

Figure 10: Sample measurement result of BPM signal. Red trace is with feedback on, blue trace is with feedback off.

FUTURE WORK

A mixed-signal feedback system is being developed in collaboration with the University of Wisconsin-Madison for the SNS (Spallation Neutron Source) storage ring. This system will deploy fast digitization and FPGA algorithms that will do some of the signal processing.

ACKNOWLEDGEMENTS

Thoughtful consideration is given to Jeff Ball, William Barnett, Mark Cardinal, Mike Clemmer, Jim Diamond, Tom Hardek, Dale Heidenreich, Syd Murray, Dan Newby, Jim Pogge, Mary Rutherford, Madhan Sundaram, Theresa Thoomey, and Andy Webster for their technical help with system fabrication.

REFERENCES

[1] http://www.minicircuits.com
[2] http://www.miteq.com
[3] R. Pasquinelli, private communication.
[4] http://www.arra.com
[5] R. Macek et al, TUAX04, at HB2006.