Bulk Acoustic Wave (BAW) Devices for Stochastic Cooling Notch Filters

Ralph J. Pasquinelli

Fermi National Accelerator Laboratory*
Batavia , Illinois 60510

INTRODUCTION

Recursive notch filters have been in use for Stochastic Cooling in the Antiproton Source at Fermilab since its commissioning in 1985. They are important parts for providing the proper gain and phase shaping for the Stochastic Cooling feedback systems. Figure 1 is a simplified schematic of a typical "correlator" notch filter. It consists of a long and a short delay whose time of flight difference sets the recurrence period of the filter's notch.

$$f_{notch} = \frac{1}{T_{long} - T_{short}}$$

In the past, two different types of filters have been successfully implemented using superconducting coaxial cable and single mode optical fiber. [1,2] Both have provided reliable performance. The reason for looking into a new technique of notch filters using BAW devices is one of long term stability and economics.

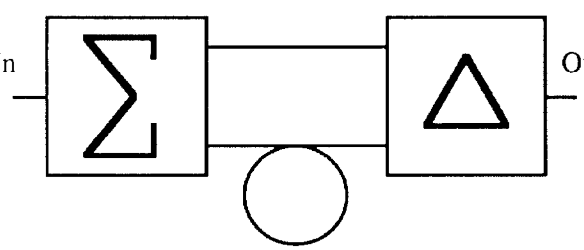

Figure 1. Simplified schematic of correlator notch filter.

Very low insertion loss and long term stability has been very good with the use of superconducting coax delay lines.[3] This is attributable to the fact that they are superconducting and passive devices. On the other hand, there is an economic burden with their usage. Liquid Helium is required to keep these delay lines in a superconducting state. Although liquid Helium is used extensively at Fermilab for the Tevatron, its only use in the Anti-proton Source are these filters. There was an initial cost for installation of a special transfer line plus the added annual expense of maintaining three 100 liter Dewars full of liquid Helium. Elimination of these cryogenic filters and replacing them with BAW units will save an estimated $150,000 annually in operating costs.

Long delays using fiber optic links have been our other solution to making notch filters. Here the cost of cryogens has been eliminated but at the penalty of inserting several active devices in the filter, i.e. a laser and photodiode. Long term amplitude and phase stability contribute to overall filter performance. Although wideband optical transmitters have been improved over the years by the addition of peltier coolers on the laser, they do not attain the same level of amplitude and phase stability as a passive device. The present cost of a state of the art optical link is on the order of $20,000.

In recent years the reappearance of BAW delay lines has largely been spurred by advances and requirements of radar systems. Some of the features of BAW delays are :

Frequency of operation........................500 MHz to 16 GHz

Bandwidth..up to one octave

Delay times.......................................200 nanoseconds to 30 microseconds

Delay tolerance.................................+/- 0.001* delay, +/- 10 nanoseconds

Delay stability................................. 27 ppm/deg C

Attenuation stability...........................2 dB -54 to +71 C

Phase stability..................................+/- 10 degrees

* Operated by Universities Research Association Inc. under contract with the United States Department of Energy

0-7803-0135-8/91$01.00 ©IEEE

HARDWARE IMPLEMENTATION OF FILTER

Work is proceeding on replacing all existing notch filters in the PBAR source with BAW notch filters. Three filters have already been designed and built for the Debuncher thus eliminating the Fiber Optic filters. These have been installed since the fall of 1990. New filters for replacing the super conducting filters in the Accumulator are now under construction.

The delay stability of the BAW device is on the order of 27 ppm per degree centigrade for a sapphire crystal. Maintaining notch frequency spacing requires a constant temperature environment hence the entire unit is mounted in a oven. The tolerance of the notch spacing is so tight that temperature alone is insufficient for keeping the delay time constant. The addition of a phase locked servo system is employed to achieve the required stability. A crystal stable microwave reference signal is split then injected on the long line and phase detected against the same reference signal. Any phase change is due solely to delay change in the BAW device. This phase error signal is used to drive a "trombone" (variable transmission line) in series with the BAW delay to keep the error voltage zero hence constant delay time. Figure 2 is a photo of the BAW delay and associated hardware installed in a temperature controlled oven.

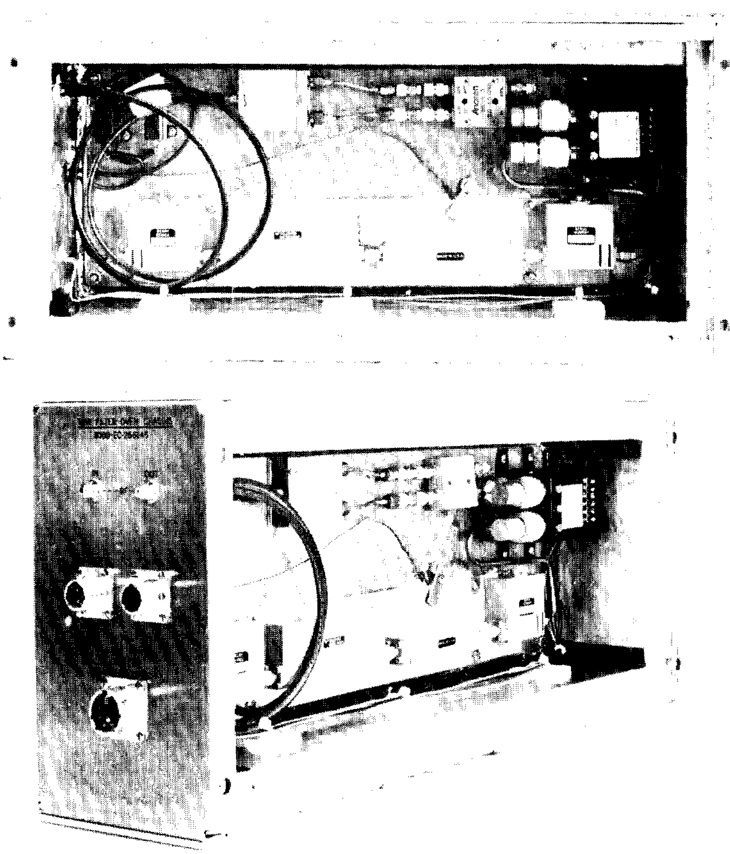

Figure 2. BAW delay and associated components installed in oven.

Teledyne Microwave was awarded the bid to make specific units for Fermilab. In addition to some of the above mentioned parameters, the units would be octave bandwidths 1-2 GHz for the Stacktail systems, 2-4 GHz for the Debuncher systems. Delay times are 1.6 microseconds (one revolution period) and 3.2 microseconds (two revolution periods). The shorter time for momentum cooling and the longer for transverse cooling.Input/output matching required the addition of microwave circulators as well as a custom equalizer to meet overall amplitude and phase specifications. The insertion loss of the delay line can be considerable (40 to 50 dB) but is comparable to that of the Fiber Optic filters. The insertion loss stems from the fact that launching an acoustic wave onto a bulk medium is very inefficient. This inefficiency also produces an unwanted side effect in that the mismatch of the transducers leads to a triple travel feed through. This can be observed in the time domain as shown in Figure 3. If this undesirable response is not minimized the end result will be a notch filter that does not have uniform notch depth. Our units were specified to have a minimum of 20 dB suppression of this spurious response.

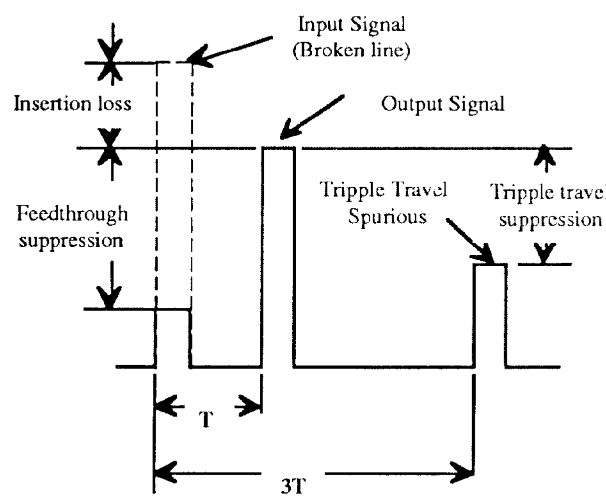

Figure 3. Time Domain Transmission mode of BAW delay line.

SYSTEM PERFORMANCE

The two main specifications for the notch filters are notch depth and notch frequency dispersion. Dispersion is defined as

$$\text{dispersion} = \frac{f_{notch} - N^*f_{rev}}{N^*f_{rev}}$$

where f_{notch} is the measured notch frequency, f_{rev} is the notch frequency spacing and N is the harmonic number of the notch. Matching of amplitude and phase characteristics over the octave bandwidths is critical. To achieve 25 dB deep notches with +/- 10 ppm notch dispersion requires an amplitude match of 1 dB and a phase match of 5 degrees across the frequency band of interest. A special equalizer was designed to compliment the amplitude and phase response of the long leg hence providing the required match. Figure 4 shows notch depth envelope and dispersion for one of the filters installed in the Debuncher Horizontal system. The fine grain ripple noticeable in the plots is a result of triple travel suppression (TTS). Because the suppression is not infinite, large excursions in notch depth can be seen. If the TTS was worse than 20 dB it would be impossible to have a minimum notch depth envelope of greater than 20 dB.

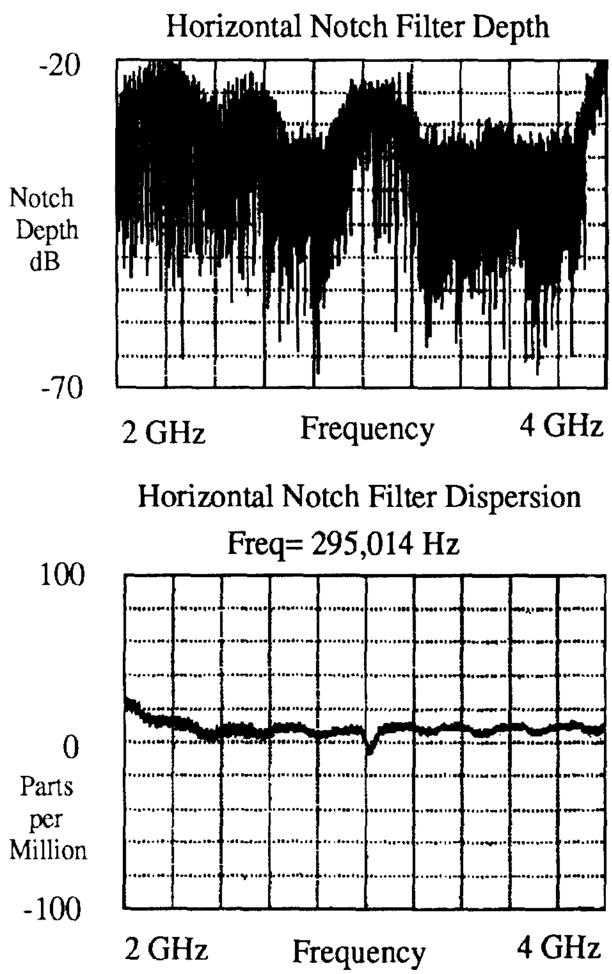

Figure 4. Notch depth (top) and dispersion (bottom) performance for filter installed in Debuncher cooling system.

CONCLUSIONS

A great deal of effort has been put into notch filter development at Fermilab over the years. There is no one technique that can be looked upon as the best choice for all applications. Cryogenic notch filters provided excellent results due to their very low loss, gain and phase flatness, and being totally passive. The cost and complication of liquid helium makes them impractical for new applications.

Fiber optic delays are also still viable solutions. A condition exists at Fermilab were a fiber optic link used in a notch filter is the only practical solution. For Bunched Beam Cooling in the Tevatron[5] a recursive notch filter with notch spacing of 47 kilohertz is required. This corresponds to a time delay of approximately 21 microseconds. To do this in a BAW delay would require a series of delay crystals almost 21 cm long. At this length the insertion loss and bandwidth limitation of the BAW delay become impractical.

As pointed out in this paper, BAW delays are a new, less expensive way to implement recursive notch filters. They can be considered for delays on the order of 1-5 microseconds and provide filter performance comparable to the superconducting notch filters.

ACKNOWLEDGMENTS

I would like to acknowledge the contributions of Dave Peterson, Ernie Buchanan, Wes Mueller, Don Poll and Pete Seifrid for their valuable contributions in realizing and commissioning the hardware.

REFERENCES

[1] R. J. Pasquinelli, "Superconducting Notch Filters for the Fermilab Antiproton Source", Proceedings of the 12th International Conference on High Energy Accelerators, 1983, pp. 584-586.

[2] R. J. Pasquinelli, Kells, Peterson, Marriner, “Optical Correlator Notch Filters for Fermilab Debuncher Betatron Stochastic Cooling”, IEEE Proceedings of the 1989 Particle Accelerator Conference, pp. 694-696.

[3] Kuchnir, McCarthy, Pasquinelli, “Superconducting Delay Line for Stochastic Cooling Filters”, IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1983, pp 3360-3362.

[4] Teledyne Microwave Inc., BAW delay short form catalog.

[5] G. Jackson et al., “A Test of Bunched Beam Stochastic Cooling in the Fermilab Tevatron Collider”, Proceeding of this conference.