SUPERCONDUCTING NOTCH FILTERS FOR THE FERMILAB ANTIPROTON SOURCE

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Introduction

Recursive notch filters are a required component in the stack tail momentum cooling system[1]. Fig. 1 is a simplified block diagram showing the location and revolution energy of the filters. The purpose of the filters is two-fold. Stack tail momentum cooling is a high power system of approximately 1600 watts. Deep notches at harmonics of the core revolution frequency "protect" the core from the uncorrelated energy in the stack tail system. At the same time, there is no desired Schottky signal in the stack tail at the core revolution orbit frequency. Placement of notch filters at this revolution orbit enhances the signal-to-noise ratio of the stack tail momentum system. Figure 2 shows what a typical notch filter response and Schottky signal may resemble. The core revolution frequency is approximately 630 kHz. Within the 1-2 GHz band there are some 1600 notches.

Notch Filter Description

The type of filter configuration implemented is the correlator[2] (Fig. 3). This filter was chosen over the shorted $\lambda/2$ stub due to its insensitivity to reflected signals. The long cable is 330 meters (1.6 µsec) in length with the short cable being only centimeters long. When the loss of the two lines is matched, what remains are 2 rotating vectors of equal amplitude. When the vectors are combined in the output hybrid, notches result.

The group delay of a transmission line may be defined as

$$t_d = \frac{\Delta\phi}{\Delta w}$$

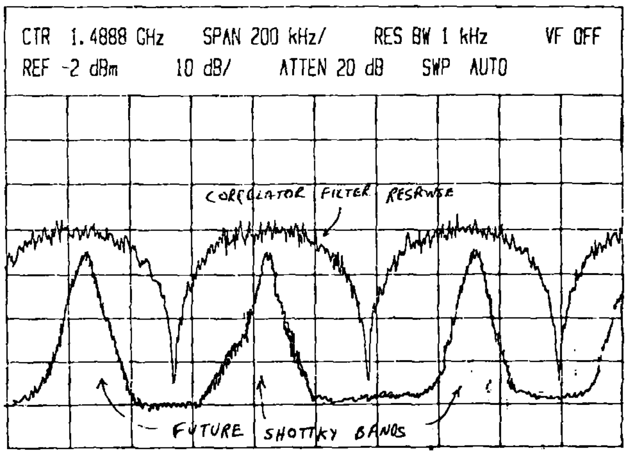

Fig. 2 Spectrum Analyser Response for Typical Filter and Schottky Signals

Notches occur at harmonics of the revoltion frequency when the phase of the long line is $n2\pi$ times the phase of the compensation line (n is an integer). The hybrid provides the extra π phase shift to perform subtraction. Hence

$$\Delta\phi_{\substack{long\\line}} - \Delta\phi_{\substack{comp\\line}} = n2\pi$$

$$\Delta w_{notch}\, t_{\substack{dline\\long}} - \Delta w_{notch}\, t_{\substack{dline\\comp}} = n2\pi$$

$$\Delta w_{notch} = n\,\frac{2\pi}{t_{d_{long}} - t_{d_{comp}}}$$

The time difference between the 2 lines is set to the revolution time of the particles at the core orbit.

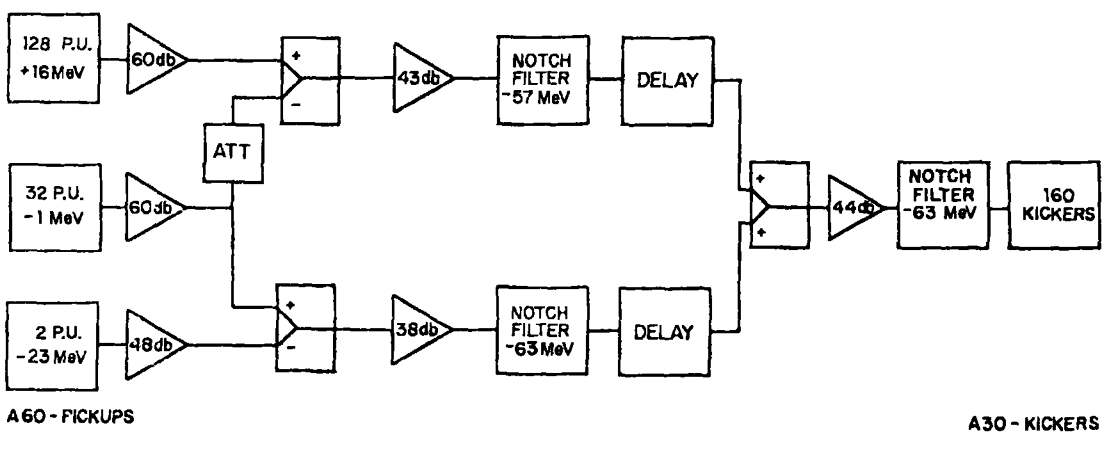

Fig. 1 Block Diagram Stacktail Momentum Cooling System

Why Superconducting?

The long line in the diagram is a 330 meter length of superconducting 50 ohm coaxial transmission line[3]. The choice of superconducting lines over conventional transmission lines is based on three things: 1) the insertion loss of this cable is only 0.2 dB @ 1 GHz and 0.4 dB @ 2 GHz. This very small gain slope makes matching the loss of the compensation line very simple. It also means no special gain equalization for the cooling system. 2) The line can be very small, 1.6 mm diameter. It is also in a very well controlled temperature environment, liquid helium. 3) The excessive insertion loss of conventional lines must be made up with more gain. The stack tail momentum system already has 180 dB of gain using superconducting filters. As a comparison, a length of standard 1/2" diameter foam heliax cable of the appropriate length for a filter has an insertion loss of 36 dB @ 1 GHz and 57 dB @ 2 GHz.

Notch Filter Implementation

Three filters are shown in Figure 1. Two of them are passive, i.e., no amplifiers or other active devices are used. The third filter is in the output stage and must allow a notched power spectrum to be delivered to the kicker electrodes.[5] The traveling wave tube (TWT) amplifiers used to provide microwave power are very nonlinear devices. The higher order odd intermodulation products they produce would "fill in" the notches with unwanted signal, thus "heat up" the core particles. Placing a filter after the TWT's means putting high power through them. There would also be a need for an additional 19 filters in that case.

The arrangement in Figure 4 places the TWT's (40 of them, operating at 40 watts each) within the correlator hybrids. This method drastically reduces the odd order intermodulation products at the notch frequencies.

A further note is that all three filters have a phase lock subsystem to keep $t_d\text{long} - t_d\text{comp} = \text{constant}$. The length of the superconducting line is sensitive to pressure and helium levels.

Figure 5 presents the cryogenic setup for the long line. Presently only one line is in the dewar. Lines for different filters may be put into one dewar to save on space and liquid helium aparatus.

Filter Specifications

The filters have three main specifications: 1) Notch frequency dispersion must be better than ±10 ppm. Dispersion is defined as

$$\delta = \frac{(f_{notch} - nf_{core\ revolution})}{nf_{core\ revolution}}$$

and is a measure of notch frequency variation from true harmonic behavior. 2) Notch depths of all notches in the 1-2 GHz band must be 30 dB minimum with 40 dB preferable. A 40 dB notch requires an amplitude balance of 0.1 dB between the 2 lines. 3) Long term drift of the notch frequencies must be less than ±10 ppm to conform to requirement 1. Sources of notch drfit are dewar pressure, helium level, length of time the line has been cold.

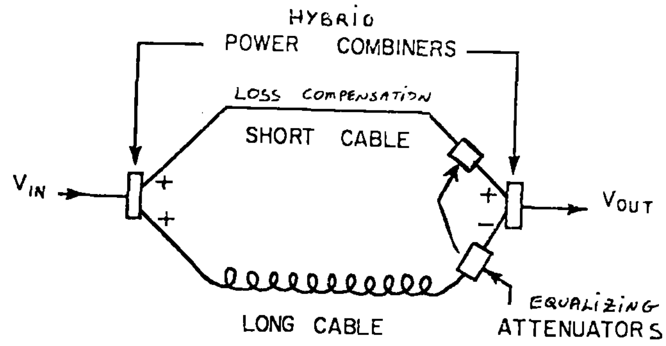

Fig. 3 Basic Correlator Block Diagram

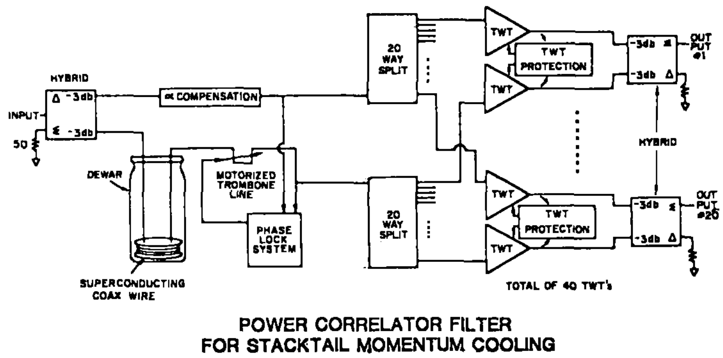

Fig. 4 Power Correlator Block Diagram

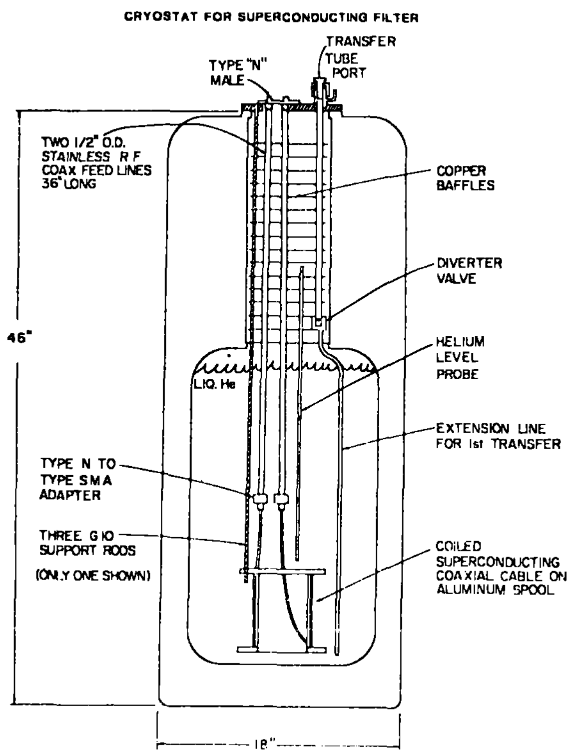

Fig. 5 Cryostat Confirguration for Lone Line

Experimental Results

Figure 6 is a computer simulation of the core stacking density vs energy with a notch dispersion of ±10 ppm. The flux leaving the core is ~50 particles/eV. Higher filter dispersion values increases flux out of core and decreases flux into core. A δ of ±40 ppm equalizes the flux into and out of the core, hence no stacking.

Figures 7 and 8 show dispersion values for the passive and power correlators respectively. The excessive dispersion on the power filter is due to excess phase ripple in the TWT's. Manufacturers of TWT's are presently reducing this phase ripple.

Figure 9 is a plot of notch depth vs frequency for a passive filter. The 30 dB spec has been met. Work is now proceeding to attain 40 dB notches.

Summary

Progress on superconducting notch filter research has shown that they are feasible and reliable for implementation in the Fermilab Antiproton Source.

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References

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5. J. Marriner, Fermilab $\bar{p}$ Note 267, internal document, unpublished. (January 1983).

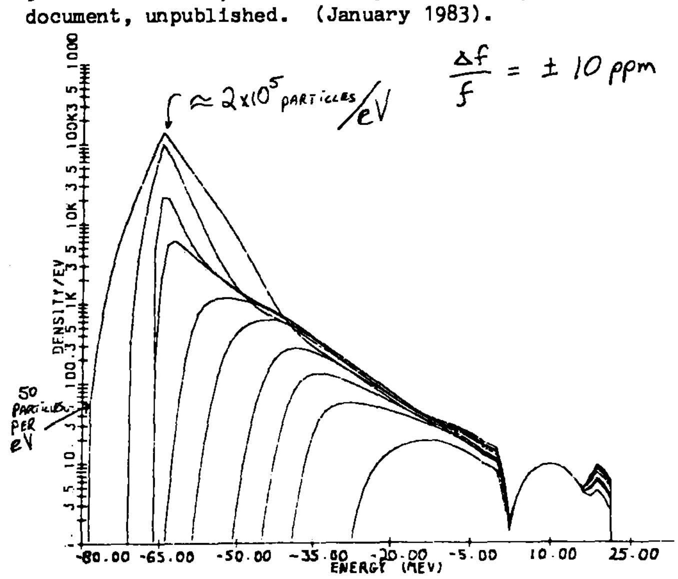

Fig. 6 Computer Simulation of Stacking Density vs. Energy for δ = ±10 ppm

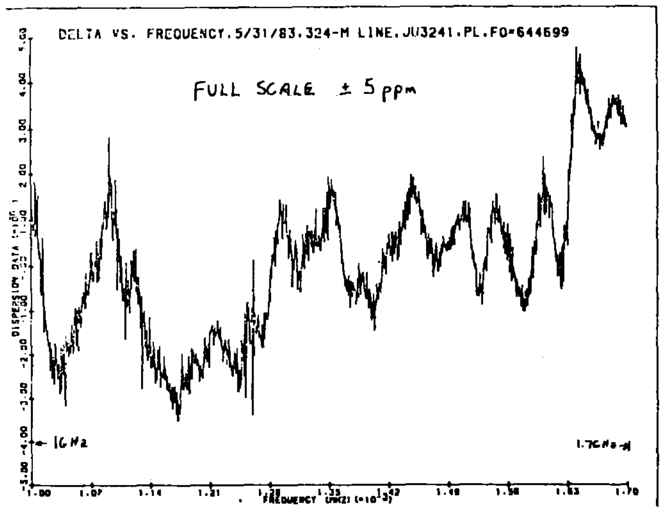

Fig. 7 Passive Filter Dispersion Results

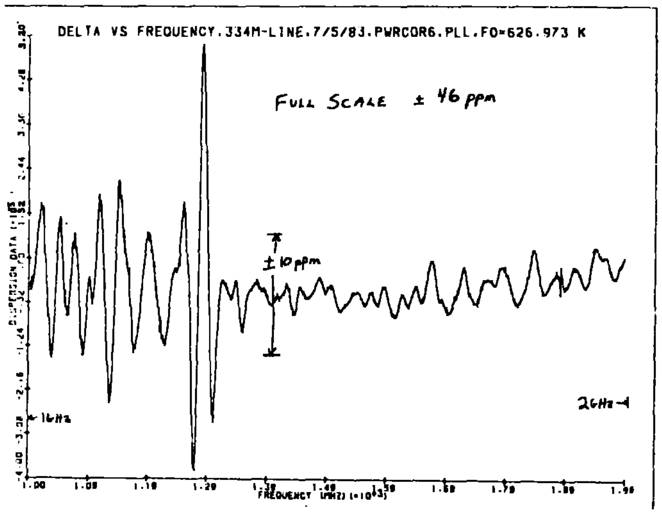

Fig. 8 Power Filter Dispersion Results

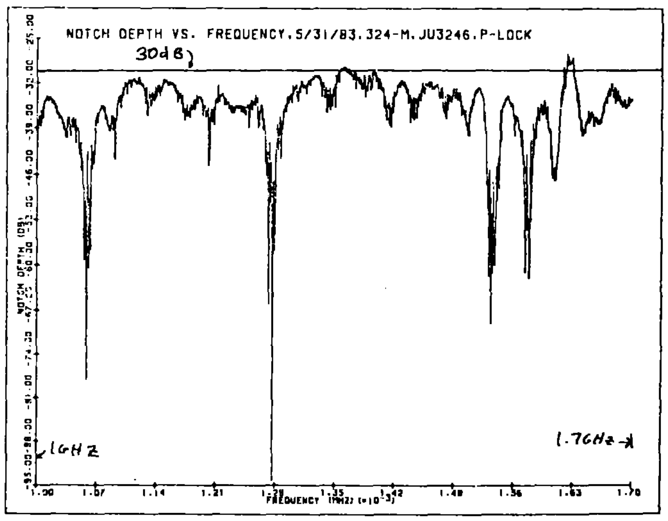

Fig. 9 Passive Filter Notch Depth vs. Frequency