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LOW DISPERSION NOTCH FILTER FOR MULTI-GHZ FREQUENCIES USING FIBER OPTICS DELAYS

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Summary

Although their designs appear simple and straightforward, notch filters for application in stochastic cooling systems are frequently difficult to construct with acceptable characteristics. Problems arise because the components are less than perfect, coaxial cables have loss plus dispersion and other necessary hardware has limitations. Usually it is the delay line, typically a high quality coaxial line, which is the source of most problems.

Filter configurations have been produced in many styles. Their purpose is to provide a transmission coefficient with (nearly) zeroes at harmonically related frequencies over a large bandwidth. Specifics of the notch shape (and thus the phase) depend upon the particular filter design. Low dispersion of the notch distribution, that is, the deviation of notch frequencies from ideal, is often difficult to achieve. This is especially true as the operating bandwidths of cooling systems expand. The stochastic cooling systems used in FNAL's TEV-I operate in the 1-2 and 2-4 GHz bands, but future systems at CERN'S ACOL or even an upgraded TEV-I will extend to 8 GHz.

A filter developed at FNAL[1] solves the dispersion problem by using a small superconducting coaxial cable as the long delay element. Laboratory measurements of its characteristics indicate it to have excellent parameters. Nevertheless it requires substantial support in the way of cryogenic and control equipment for its operation. This filter is the one chosen for use in the initial operation of the TeV-I pbar accumulation system.

We report in this paper on the developement of a notch filter which uses a laser diode/fiber optic delay line instead of a coaxial cable. Measurements of its properties indicate it to be a possible alternative to other designs. Bandwidth, dispersion, notch depth, dynamic range and intermodulation are each within the bounds of typical cooling system requirements.

Filter Design

Filter type

The filter type developed is what is commonly referred to as a "corellator". Figure 1 illustrates the basics of this filter type. As indicated in Fig. 2, the long delay line of the new filter has been changed from a coaxial cable to a fiber optic link.

Component choice

The choice of components was determined by the operating parameters of the FNAL pbar source and by availability. The 10 milliwatt GaAlAs laser diode chosen has a nominal operating frequency range up to 6 Ghz. Because we were designing a 1-2 Ghz filter we chose to use 50 micron, multi-mode fiber with a 1.6 GHz-Km bandwidth. For the 1.6 microsecond delay appropriate for the 0.6 (approximate) frequency spacing, the 326 meter long fiber is usable to beyond 4 GHz.

The PIN receiving diode chosen is advertized as having an 8 GHz upper (3 db) frequency limit-adequate for our use.

We point out at this time that lasers, fibers, diodes, and techniques such as permanently coupling fibers to lasers is developing rapidly and that components with much better characteristics than those we used are already available.

Normally, one expects the relatively low thermal expansion coefficient of glass not to produce noticeable notch dispersion. The particular fiber selected for this project was clad with a plastic buffer for mechanical protection. The expansion of the plastic buffer overwhelmed that of the glass fiber producing an effective coefficient for the fiber much larger than that of glass alone.

Temperature regulation of the fiber optic notch filter system to $\pm 0.2°$ C provided adequate notch frequency temperature stability. The entire fiber optic notch filter is housed behind a 14" rack panel which includes a commercial temperature controller that claims $\pm 0.1°$ C temperature regulation.

Measured performance

Notch depth

Typical cooling systems require notch depths of at least 25 db. Depths are determined by parameter adjustment (eg balance between branches of the filter) and by dynamic range limits of the laser. To measure the available range, we first recorded the amplified output of the fiber optic link with no input drive and with the input terminated. Next a 1-2 Ghz bandwidth noise spectrum with total power of 0 dBm was connected to the input and the output recorded. The 0 dBm level corresponded to about the maximum power level the laser can handle without risk of mirror damage. The difference between the two output spectra indicates the maximum practical depth that could be expected without noise flooring. There are reasons to believe that the indicated value of about 25 db, shown in Fig. 2, is about the lower limit one should get because the particular laser we have appears to be unusually noisy.

Figure 3 shows the envelope of single frequency notches across the 1-2 GHz band.

Dispersion

The frequencies of notches were measured across the 1-2 GHz band and analyzed in the following way.

Define the dispersion as:

$$\delta = \frac{f_n - nf_o}{nf_o}$$

where

f_n = frequency of n^{th} notch

f_o = fundamental frequency or spacing

Figure 4 is a plot of this function for the 1-2 GHz band. The rms value is 6E-6. Included in the dispersion function are the imperfections of various elements such as the power combiners. By removing the output combiner of the filter and feeding the signals from the two branches of the filter into a network analyzer we measured "zero" phase crossings. These results are shown in Fig. 5. Note the improved rms dispersion, 3E-6.

Intermodulation

Third order intermodulation products produced by input frequencies of 1.0 and 1.4 GHz were measured at various input power levels. The 1.8 GHz term is shown in Fig. 6. As can be seen, IM is low for power inputs less than -6 dBm.

Stability

Long term stability of the complete filter was carefully monitored over a 10 hour period during which the the environment was changed. For normal room environment of 72 degrees F and the fiber operating at 65 degrees F the fundamental frequency deviated less than 1 ppm. Introducing a step adjustment to the temperature controller indicated about 1.5 hr time constant

Conclusions

We consider the fiber optics based filter to be a demonstration that useful filters of this type can be built. Newer, higher performance components can no doubt result in even better characteristics than those of the filter reported here. We also realize that there may be some applications in which the low power handling capabilities are not acceptable. On the other hand, there are many situations in which this filter would work well.

Currently available improved components include 15 GHz antireflective coated PIN diodes. Also promised is a 10 GHz laser with pigtailed 5 micron fiber. These components suggest that an 8 GHz system could easily be built.

Considering the small size and relative simplicity of this design, it deserves consideration as an alternative to conventional filter designs.

References

[1] R. Pasquinelli, Proceedings of the 12th International Conference on High Energy Accelerators, 584 (1983).

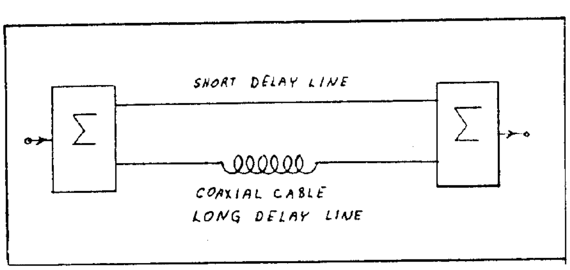

Fig. 1 Basic Elements of a "Correlator" Notch Filter Utilizing Coaxial Transmission Line.

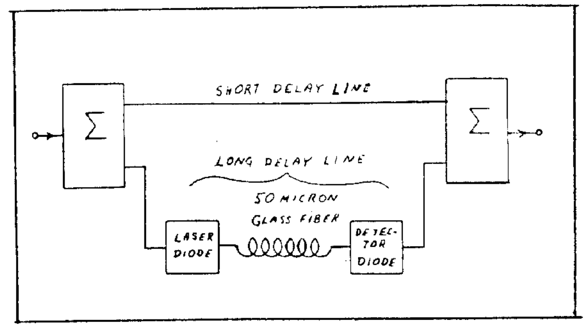

Fig. 2 "Correlator" Notch Filter with Wide Band Fiber Optic Link Replacing Coax Cable in Long Delay Line.

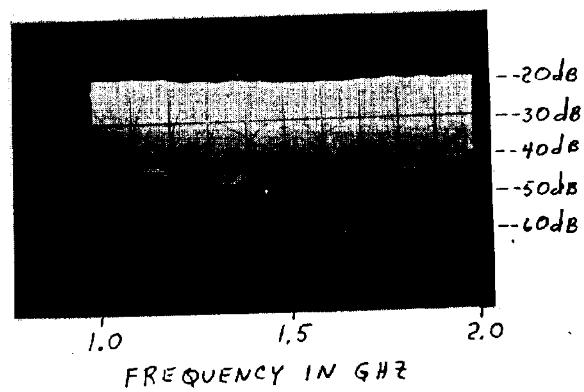

Fig. 3 "Correlator" Notch Filter Swept Over Frequency Range of 1-2 GHz Showing Notch Depths as Function of Frequency.

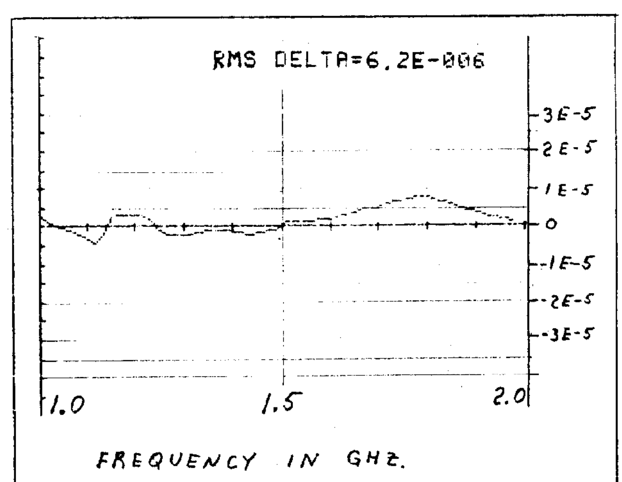

Fig. 4 Dispersion of Notch Filter with Two Combiners.

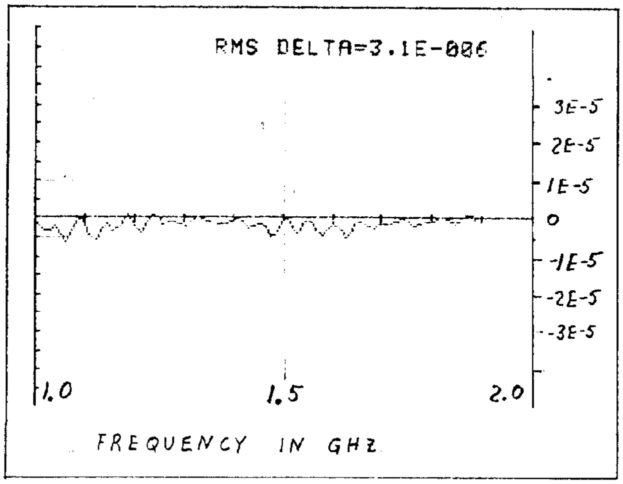

Fig. 5 Improved Dispersion After Removal of One Combiner.

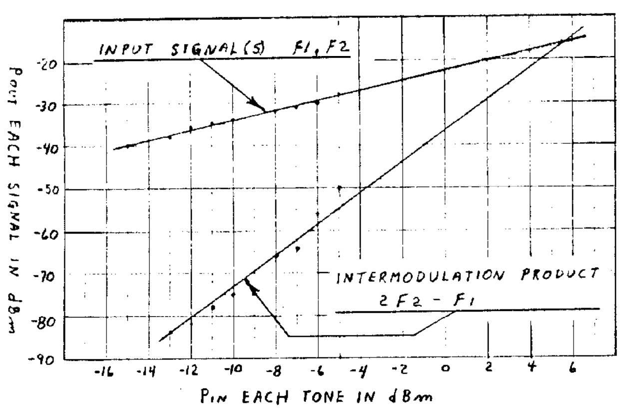

Fig. 6 Intermodulation Products for Various Input Power Levels.