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AN OPTICAL LINK DELAY ELEMENT IN MICROWAVE NOTCH FILTERS

R. Konecny and J. Simpson

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R. Konecny and J. Simpson
Argonne National Laboratory

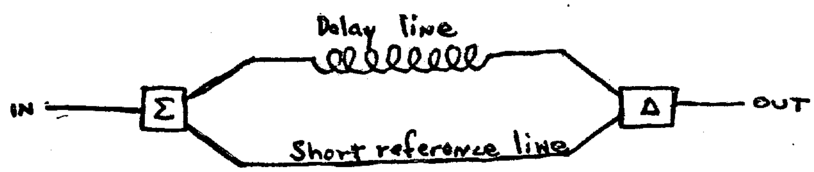
Introduction

We present here design considerations and results of preliminary experiments in which the delay element in a notch filter is an optical-fiber link. The notch filters designed into TeV-I stochastic cooling systems are of the correlator type.[1] In the present design, difficulties encountered if conventional room temperature coaxial cable were used as the delay link[2] have been overcome by the use of superconducting cable. Although this approach appears workable, the required cryogenic support system represents a major capitol investment and potential operational concern.

Recent advances in GaAs laser technology and in fiber performance suggested to us that it may now be feasible to use an optical-link delay line. We have conducted measurements of various component properties and have assembled a rather crude prototype filter whose performance supports our enthusiasm.

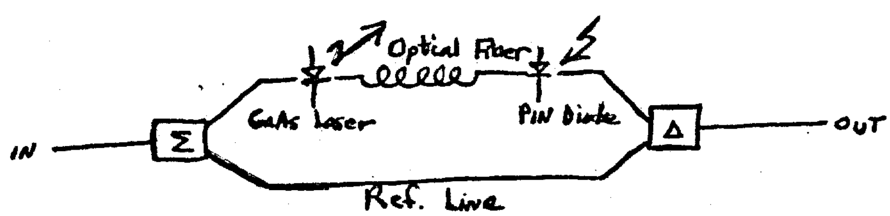
Important Characteristics

A basic correlator filter circuit is shown below.



Such a device produces notches in its transmission function at successive harmonically related frequencies defined by the difference in delay of the two lines.

The long line may be replaced by an optical system as shown below.



Due to present insertion loss in the optical link, the maximum transmission (between notches) is somewhat low (-20 to -25 db typical). Notch depths, on the other hand, can be made very adequate, limited by circuit imperfections, tuning and, in the case of noise spectrum notches, by laser limitations. Laser constraints will be described later.

Laser parameters

Direct-modulated GaAs lasers are now commercially available which produce several milliwatts of infrared power and have several GHZ of modulation bandwidth.[3] Output is primarily limited by the acceptable power density on the lasing cavity mirror, typically about a megawatt/cm^2. Modulation bandwidth and noise output characteristics are rather strong functions of the lasing current. The particular lasers (ORTEL LD53-PMF) we have been using have also been carefully studied in a project at Hughes Research.[4] The Hughes experiments have addressed these noise and bandwidth properties, and calculations have been made to compare the results with theory. We do not have access to a great deal of this work, but Fig. 1 illustrates one of the important laser parameters, the noise enhancement figure (NEF).

At room temperatures, the advertized and measured[5] frequency response extends to ~6 GHZ for lasing plus modulation powers appropriate for notch filters. This response can be extended to >10 GHZ by operating the laser at -50°C according to communications with the manufacturer. Thus an optical link correlator may find application at the (4-8 GHZ) bandwidths being considered for future $\bar{p}$ sources.[6]

Detector diode parameters

The PIN receiving diode we have used (ORTEL model PD050-OM) has response to about 4 GHZ (3db point). However, present technology can extend this far beyond our requirements (the Hughes group used one which is manufactured by them, for them, and which is good to 18 GHZ).

Fiber characteristics

Optical fibers can be generally separated into single-mode and multi-mode types. The attenuations of these fibers is typically 3.0 db/Km for single-mode and 2.5 db/Km for multi-mode.

The dispersion limited frequency response for single mode fibers is difficult to define, but for simplicity we can say that its at least 50 GHZ-Km.

Graded index multi-mode fibers presently have bandwidths to 1.8 GHZ/km, but are much easier to couple light into and out ofdue to core diameters of > 50 micron. The 50 micron multi-mode fiber we have been using for our experiments (Corning 171132981702) has a dispersion limited response of 1.6 GHZ-Km. The length required to produce a 1.7 μsec delay (TeV-I size) is just over 300 m, hence a link made of this cable has almost a 5 GHZ bandwidth.

ANL Experiments

Our early experiments utilized a single mode fiber link. Micro-positioners and high quality lens systems were employed to couple the fiber to the laser and to the diode. We found (as just about everyone else in the game has found) that this is a difficult task. Adjustments are extremely sensitive to make and subject to vibration and temperature change. We soon opted for a lower bandwidth, multi-mode fiber. Concurrently, a laser assembly became commercially available in which a 50 micron multi-mode fiber is permanently coupled and attached to the laser housing. This simplification meant that we needed only provide optics to couple the fiber to the detector diode, a relatively simple job.

To obtain a quick idea of what notch depth in a noise spectrum would be possible, we imposed -14 dbm of 0.6 GHZ BW noise on a 2 MW lasing output. Fig. 2 shows a spectrum analyzer display of the laser output with and without the 0.6 GHZ BW noise added. Even with the conservative conditions of this test, noise notches in excess of 25 db are possible.

The fiber was scramble wound on a rolled paper core about 8 inches in diameter. A breadboard circuit provided the lasing current and the detector diode voltage. Simple protection circuits were included to protect us from ourselves (i.e. over currents, too fast turn-on, etc). Measurements of notch frequencies are made under control of an HP-85 computer and code. Thus far we have concerned ourselves with the 1-2 GHZ band, but we will soon look at higher frequencies.

A plot of a typical dispersion function $\delta \equiv \frac{f_n - n_{fo}}{n_{fo}}$ is shown in Fig. 3. The r.m.s. δ is about 5×10^{-6}. Shown for comparison in Fig. 4 is a corresponding analysis of a superconducting filter (CYBER file JC3361). An r.m.s. $\delta \lesssim 10^{-5}$ is adequate for the TeV-I tail system. Figure 4 is a network analyzer scan showing the notch depth variation across the 1-2 GHZ band. Bear in mind that this was a quickly assembled and tuned system, and the results do not represent ultimate performance by any means.

Things Still to be Studied

There are a number of parameters yet to be studied. Among these are:

- Temperature stability - there are indications that the link delay is much more temperature dependent than expected from simple thermal expansion. Perhaps mode population depends on temperature. Mode scrambling/stripping might solve such a problem.

- Optimum operating conditions - we have been conservative in the laser powers so as not to damage the device. Notch depths and frequency response are dependent on power.

- Optical reflections - reflected light from fiber joints, exit optics, etc. effects the NIF of a laser. These can be minimized by the use of optical isolators and clever optics (e.g. entering the diode at an angle. This is acceptable since the n.a. of the diode > n.a. of the fiber).

- A PIN diode with a permanently attached input fiber is on order. This will eliminate all external optics and alignments, and is expected to have better overall coupling.

- A laser diode with 5 micron single mode pigtail fiber is planned by the manufacturer which will allow use of 5 micron core single mode fiber with its inherent low dispersion/wide bandwidth characteristics.

Conclusions

Results thus far are very encouraging that an optical-linked filter can be a practical device. This report is intended to provide familiarization with the activity. Future results will be reported as they are obtained.

The idea of using direct modulated laser links (with or without fibers) for transmission of digital, analogue, or rf signals in an accelerator environment is obvious. It appears that the technology is here now or soon will be.

References

1. Design Report, Tevatron I Project, September 1983.

2. Correlator Filters for Stochastic Cooling, $\bar{p}$ Note 247, S. L. Kramer.

3. For Example, Ortel Corporation, Alhambra, California.

4. Private communicatioon, Hank Blauvelt, Hughes Research Lab, Malibou, California.

5. Unpublished measurements performed at ANL and at FNAL (by Brian Hyslop).

6. To be published in the proceedings of the February, 1984, Chicago Workshop on $\bar{p}$ Options for the SSC.

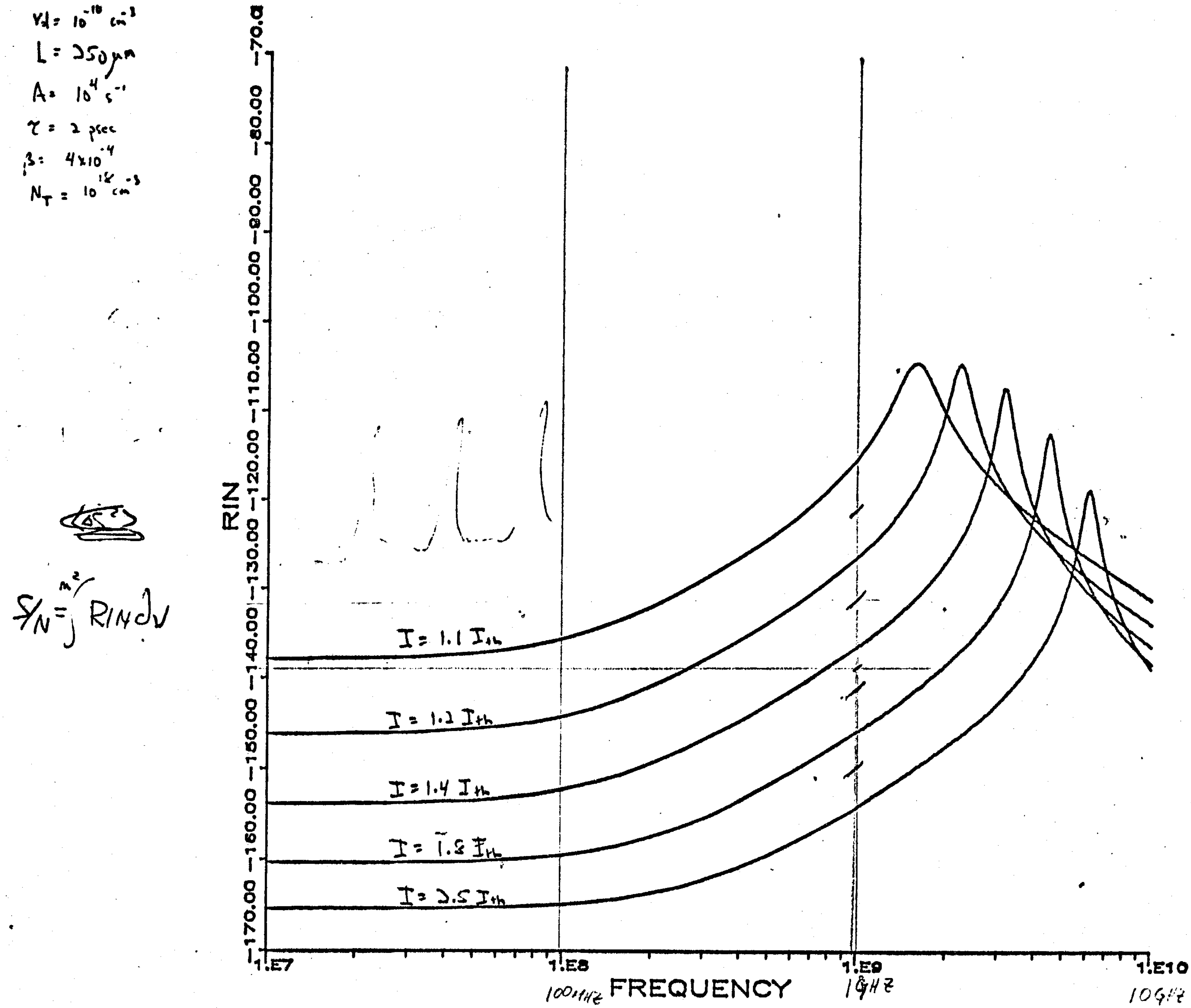


Fig. 1. Calculated Noise Enhancement Figure vs. Frequency for Various Laser Powers

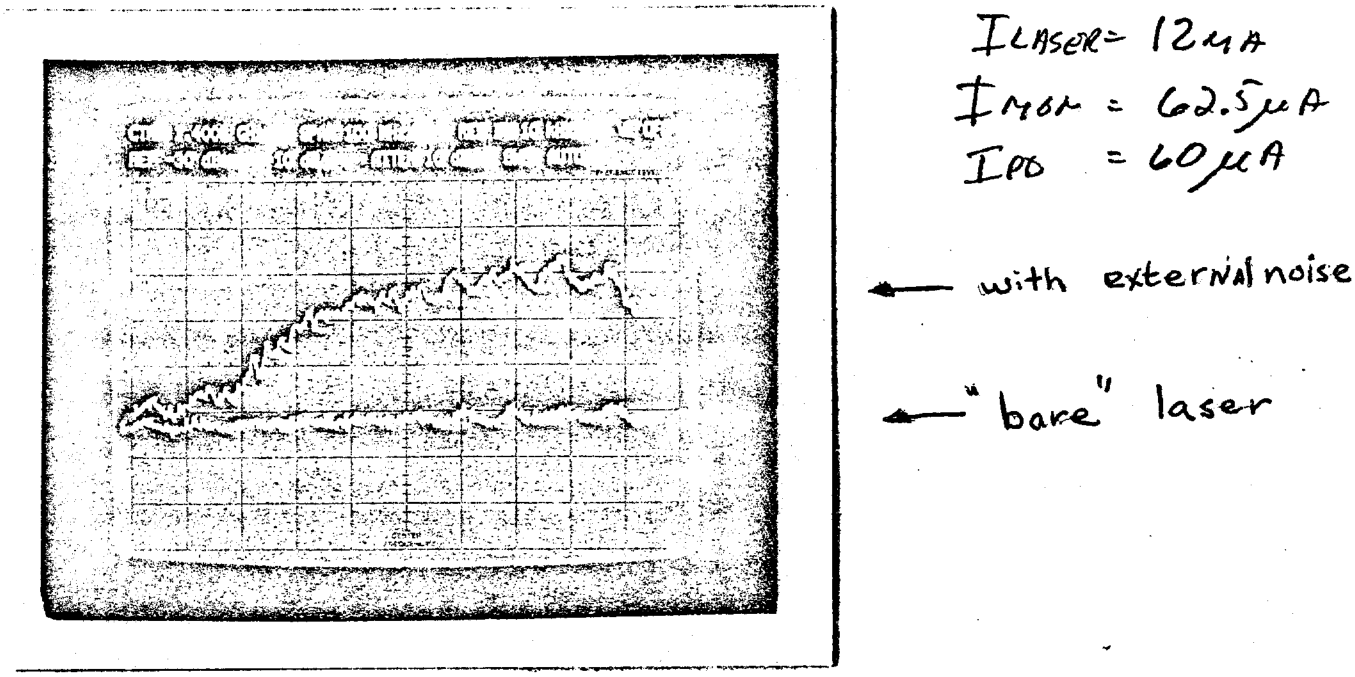


Fig. 2. Power Density Spectra of Laser Output With and Without Additional 0.6 GHZ bandwidth, -14 dbm Noise

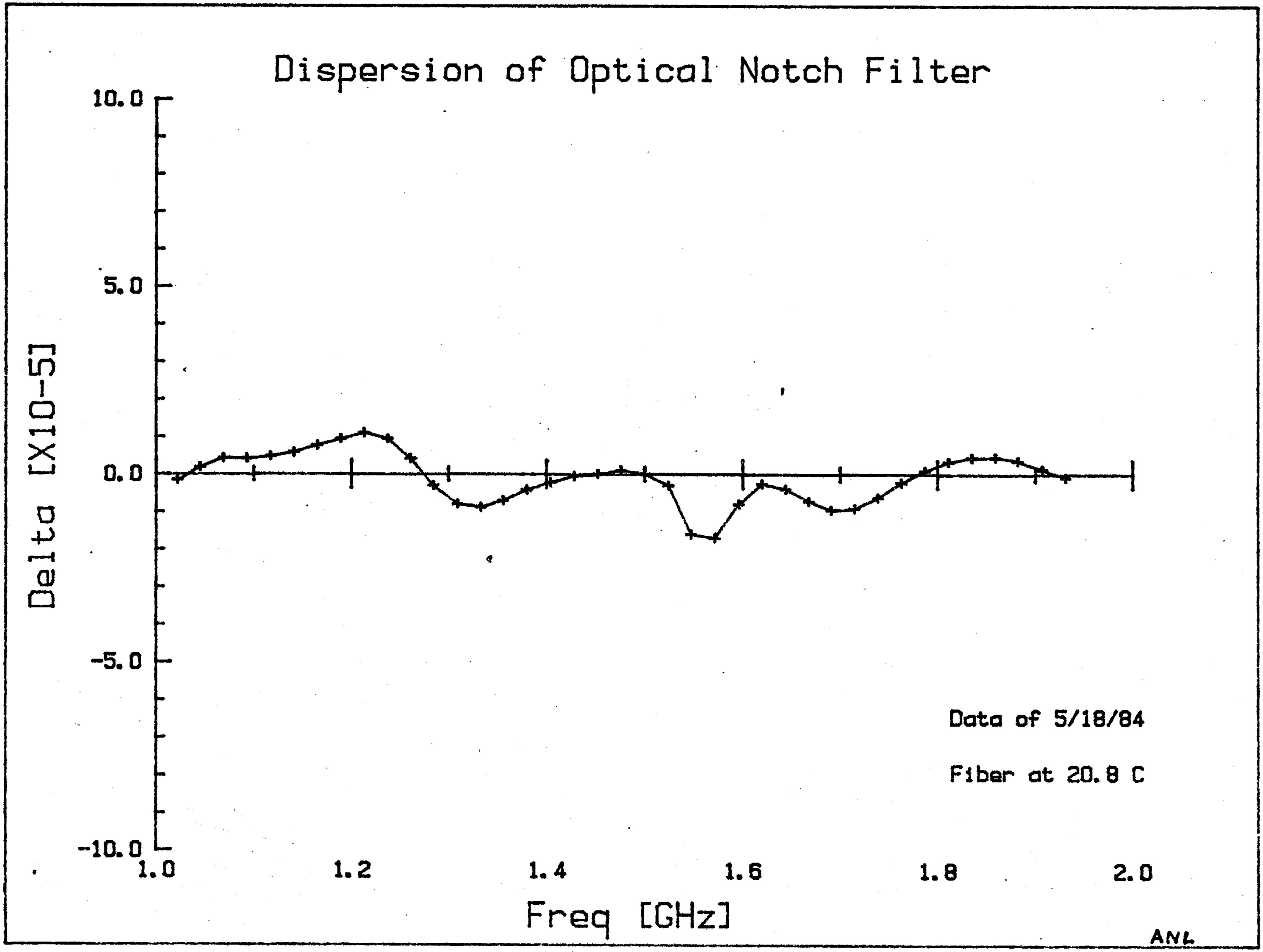


Fig. 3. Dispersion of the First Prototype Notch Filter

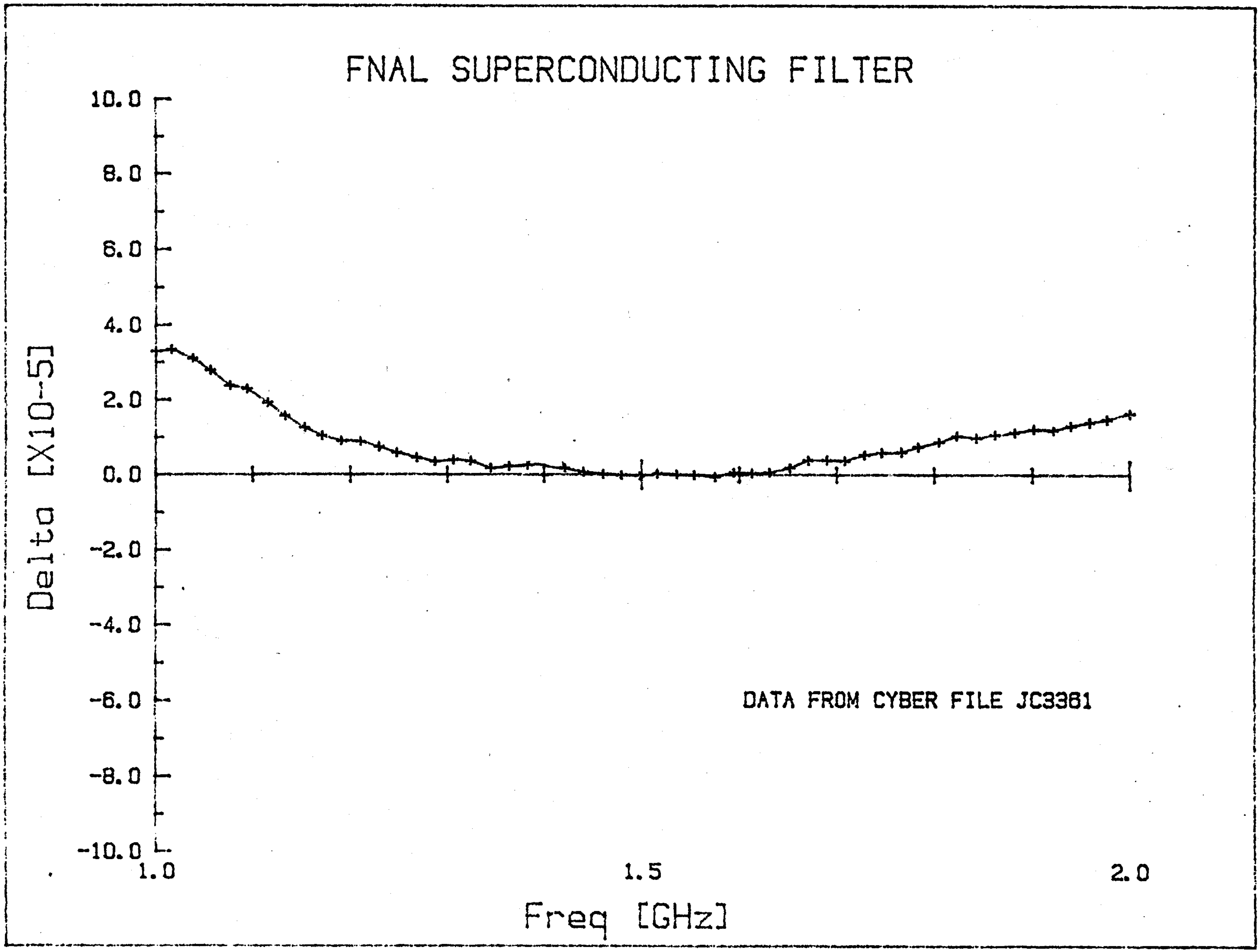


Fig. 4. Dispersion of a Superconducting Cable Notch Filter