

Radio Frequency Notch Filter Utilizing  
Fiber Optic/Laser Diode Delay Line

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Introduction:

A wide band, laser-diode/fiber-optic transmission line (FOL) has been developed which represents a potentially useful stochastic cooling notch filter element. Because of its small size and lack of need for sophisticated support equipment the FOL presents a viable alternative to both conventional and super conducting coaxial line notch filters.

This note summarizes the characteristics of the FOL and of notch filter performance achieved with its use.

The FOL system consists of 1. A 10 milliwatt, GaAlAs, 6 GHz laser diode driving 2. 326 m of 50 micron, graded index, multimode glass fiber coupled to a 3. GaAs, 6 GHz photodetector diode. For temperature stability, the FOL components are housed in an insulated, temperature regulated chamber that is attached to the back of a standard 14" high relay rack panel. Temperature regulation is achieved with use of a thermistor temperature sensor, amplifier and Peltier device. The Peltier device consists of a 1" x 1" x 1/4" series of thermoelectric junctions mechanically placed with one face contacting the inner controlled chamber and the other face contacting the outer thermal sink. Heat energy can be added to or removed from the controlled chamber depending on direction of current flow through the Peltier device. This allows the controlled chamber to be maintained at temperatures above or below ambient.

The following data are measurements made of the FOL as proposed for the ̄ cooling notch filter. The basic FOL components are as shown in Fig. 1.

Frequency response The frequency response of the FOL was measured over the range of 0.5-5.5 GHz using a -10dBm input signal. The response is shown in Fig. 2. Note: Positive spikes are network analyzer artifacts.

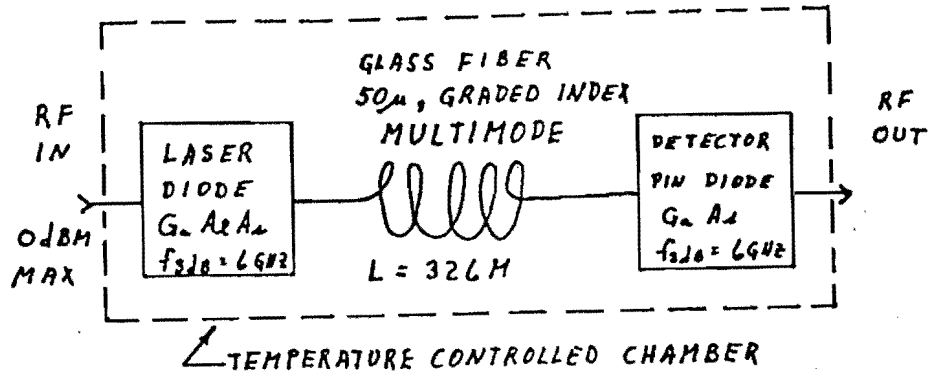


Fig. 1. Major FOL Components

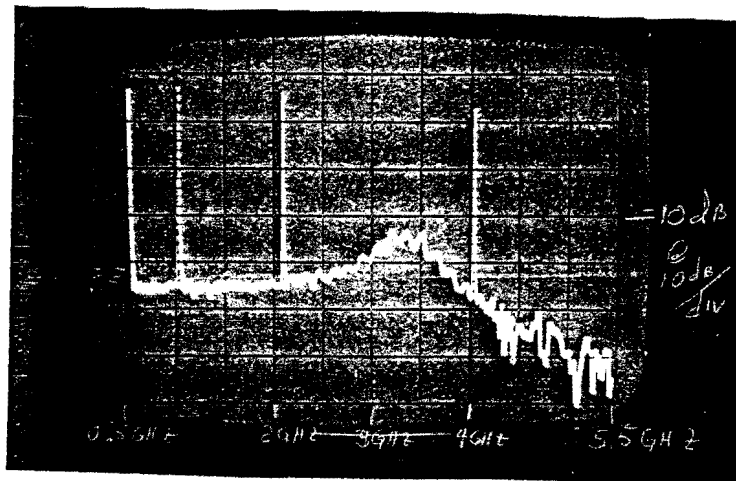


Fig. 2. FOL Frequency Response

Dynamic Range To measure dynamic range, the amplified output of the FOL (with no drive and input terminated) was recorded - Fig. 3 bottom trace.

A 1-2 GHz bandwidth noise signal with power equivalent to 0dBm was then connected to the input of the FOL and the output recorded, Fig. 3 top trace. The resulting minimum and maximum output levels thus established indicate notch depth values to be expected when using the FOL in a correlator notch filter, Fig. 4.

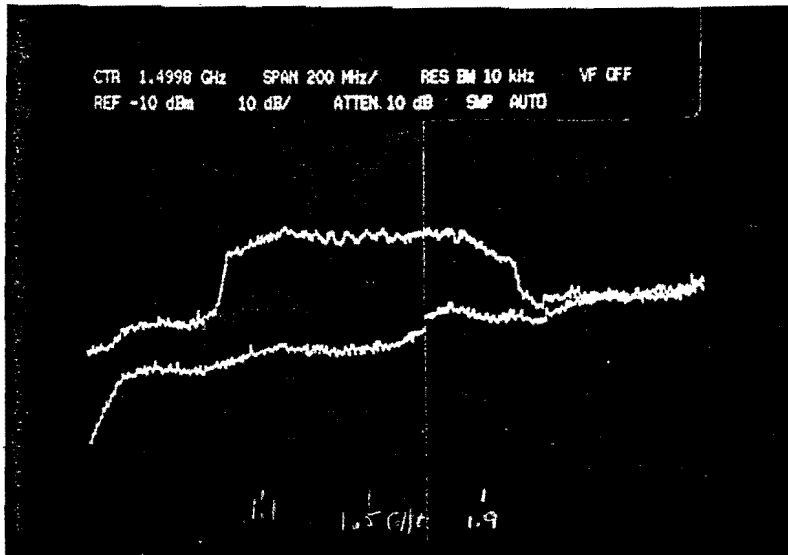


Fig. 3 FOL Dynamic range display. Here the bottom trace shows the output with no input and the top trace shows the output with 0dBm, 1-2 GHz noise input.

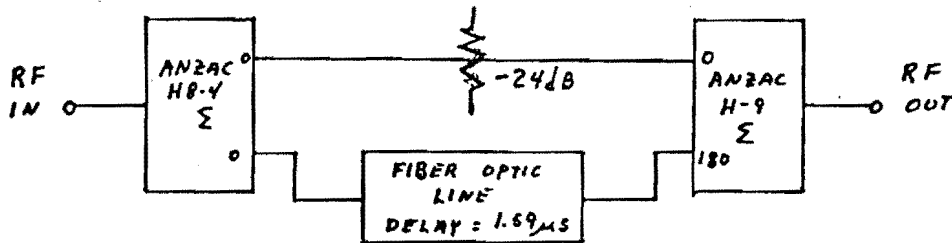


Fig. 4. Correlator Notch Filter Configuration

Notch Depth To determine individual narrow band notch depth performance of a correlator filter utilizing the FOL as the long delay element, the configuration in Fig. 4 was assembled. This system was swept over the frequency range of 1 to 2 GHz and results shown in Fig. 5.

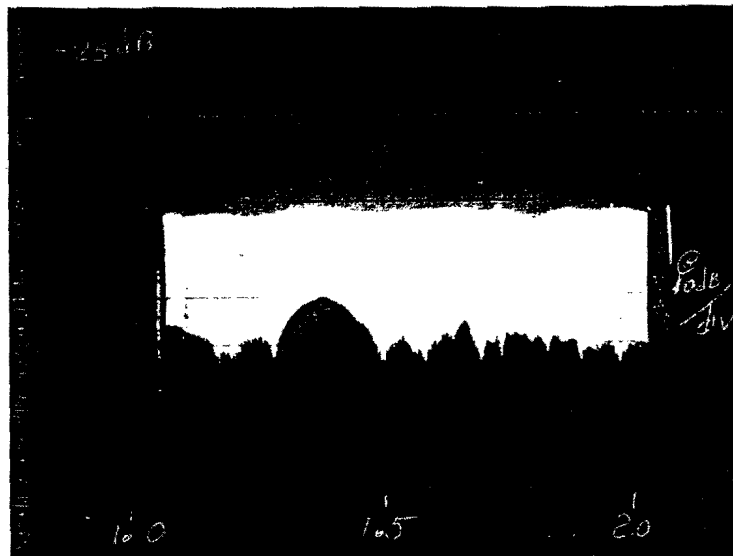


Fig. 5. Correlator Filter Notch Depths (1-2 GHz) with FOL used as long delay element

Dispersion The effective electrical length of the FOL as a function of frequency was measured using the FOL as the long delay line in a correlator notch filter as shown above in Fig. 4. The notch minima, determined by the effective differences between the long line and short line, were measured over the 1-2 GHz frequency range. The frequencies corresponding to notch minima were found by measuring the response at seven evenly spaced frequencies that spanned the notch minima, and fitting the data to an analytic function that calculated the frequencies equivalent to notch minima. In this manner, notch minima frequencies were determined with an accuracy of  $\leq \pm 1$  ppm. Notch frequency dispersion was calculated from Eq. 1 and shown in Fig. 6.

$$\Delta = \frac{f_n - nf_o}{nf_o} \quad (1)$$

where

$f_o$  = the fundamental notch frequency

$n$  = harmonic number

$f_n$  = frequency at harmonic number

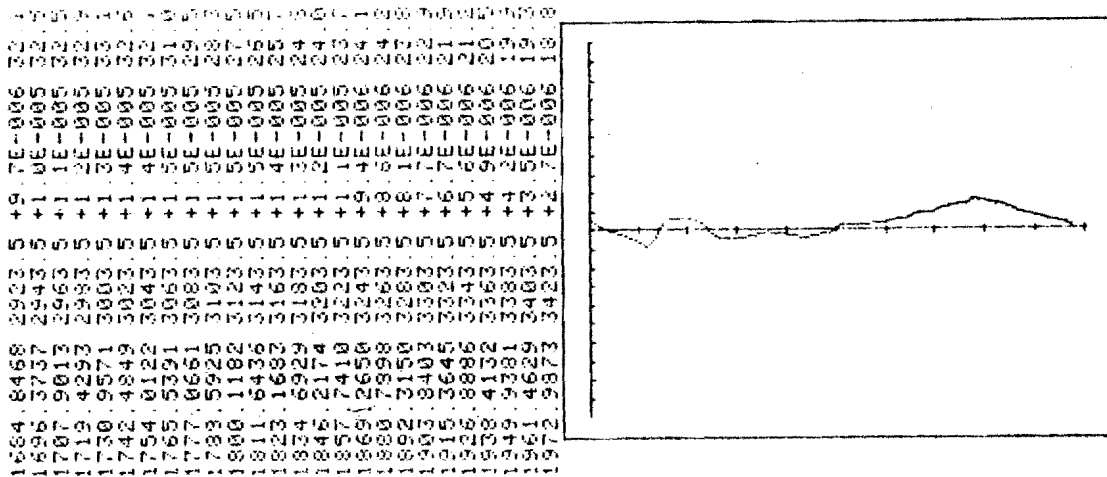
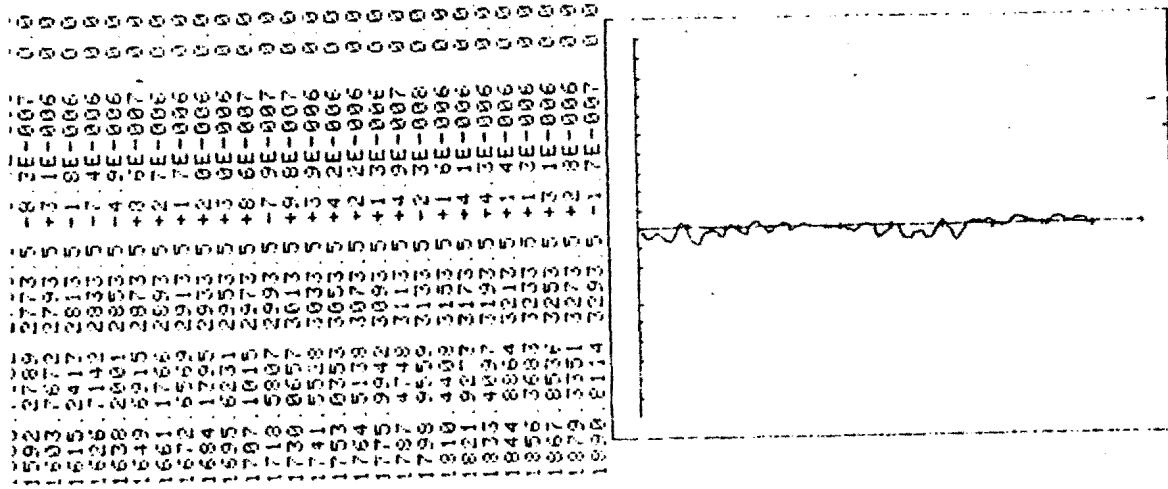


Fig. 6. Effective Length Change of FOL, 1-2 GHz

A second method used to measure dispersion was to measure  $0^\circ$  phase crossings in the correlator system. To do so, the output combiner was removed and the two output signals fed directly to the network analyzer. As before an analytic fitting program was used to determine zero crossings. However, the seven measured frequencies now spanned the  $0^\circ$  phase crossing frequency. Dispersion values improved, Fig. 7 possibly due to the removal of one error producing element, namely, the output combiner.



PMS DELTA=3.3E-006

Fig. 7. Effective Length Variation of FOL using 0° Phase Crossings to Determine Measured Frequency Points

Third Order Intermodulation Products The FOL was driven by two frequencies  $F_1 = 1.0$  GHz,  $F_2 = 1.4$  GHz at various equal power levels. The third order term  $F_3 = 1.8$  GHz ( $2F_2 - F_1$ ) was measured and is plotted Fig. 8.

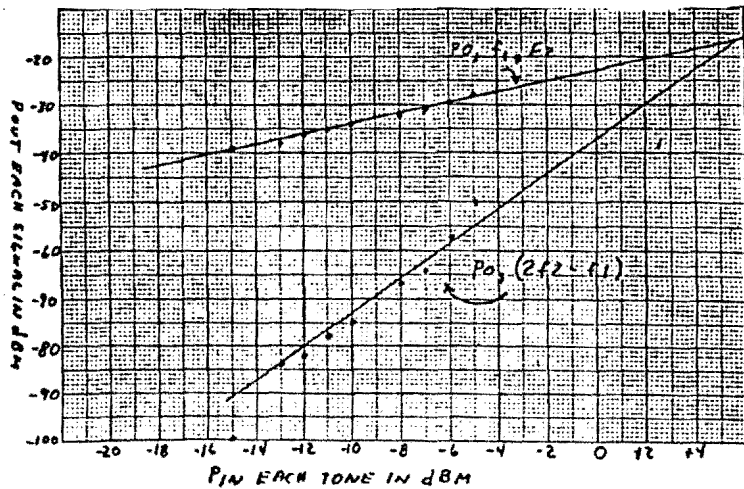


Fig. 8. Third Order Products at Output of FOL

Thermal Dependence The FOL time delay sensitivity to internal as well as external temperature variations was measured in the three following situations.

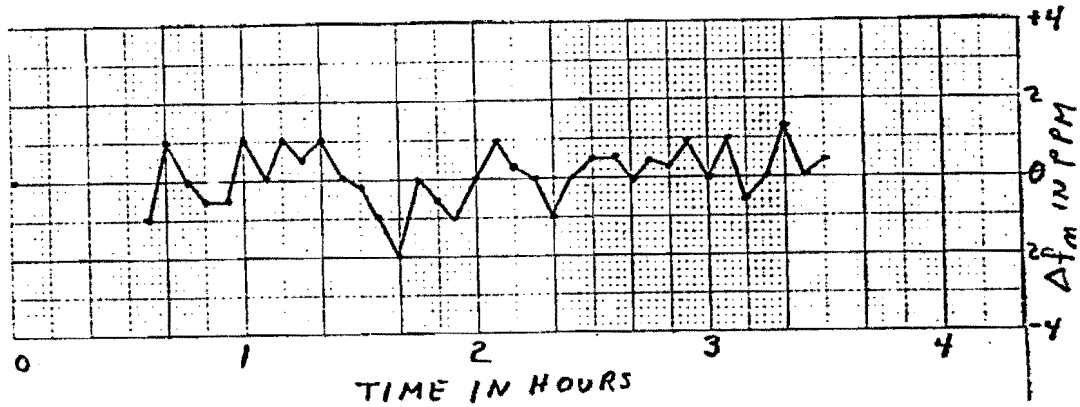


Fig. 9. FOL time delay variation with FOL operating on a table top in a room ambient air temperature of  $\sim 72^\circ\text{F}$ . The FOL temperature regulator was set to maintain the FOL chamber at  $65^\circ\text{F}$ .

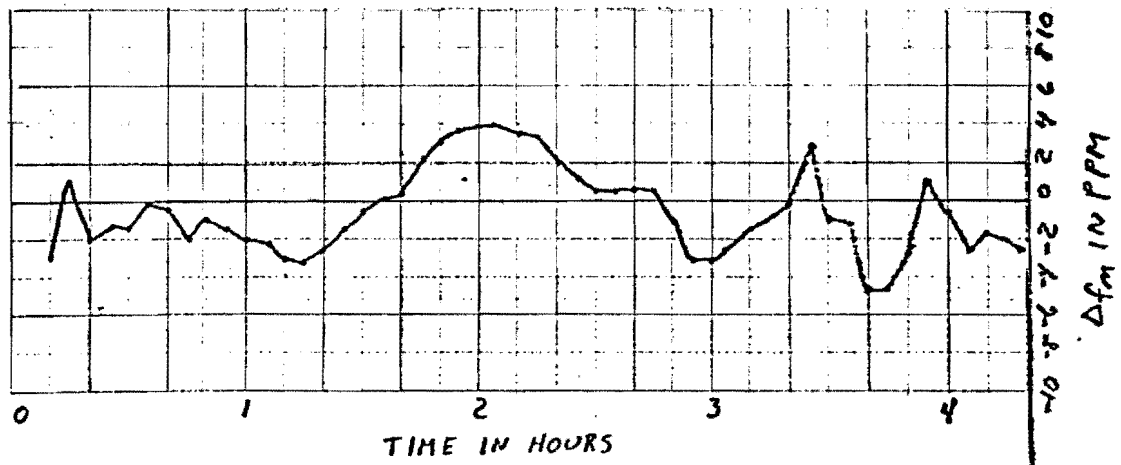


Fig. 10 FOL time delay variation with FOL housed in a  $4' \times 4' \times 4'$  chamber with  $75^\circ \pm 5^\circ$  air being vigorously circulated within the chamber.



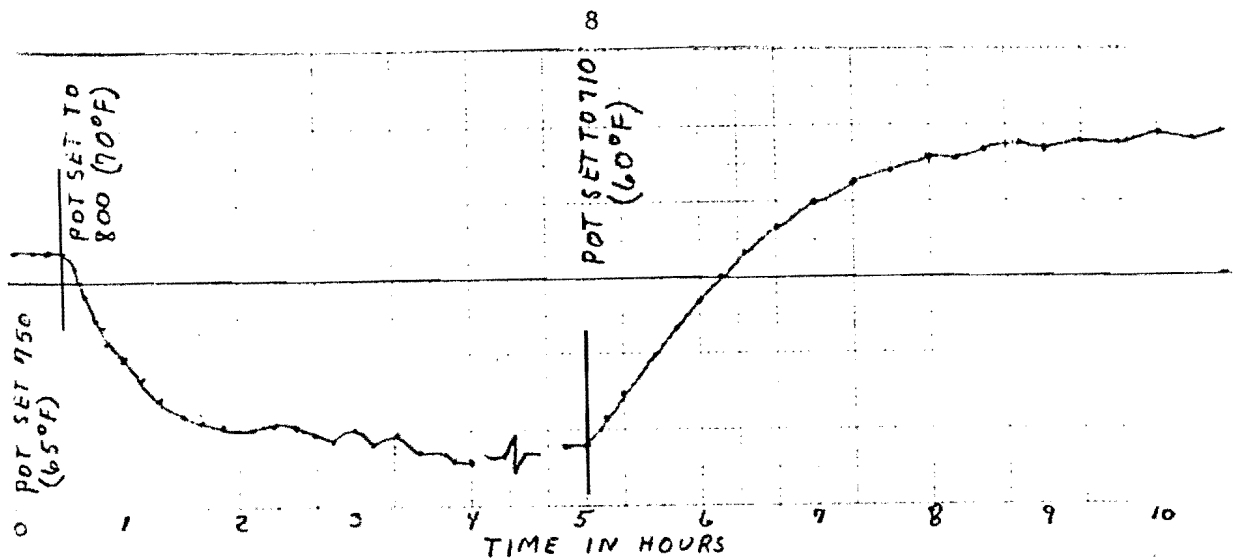


Fig. 11. This data shows the FOL's effective length sensitivity to regulated temperature values and the time needed to reach stability at newly selected FOL temperatures.

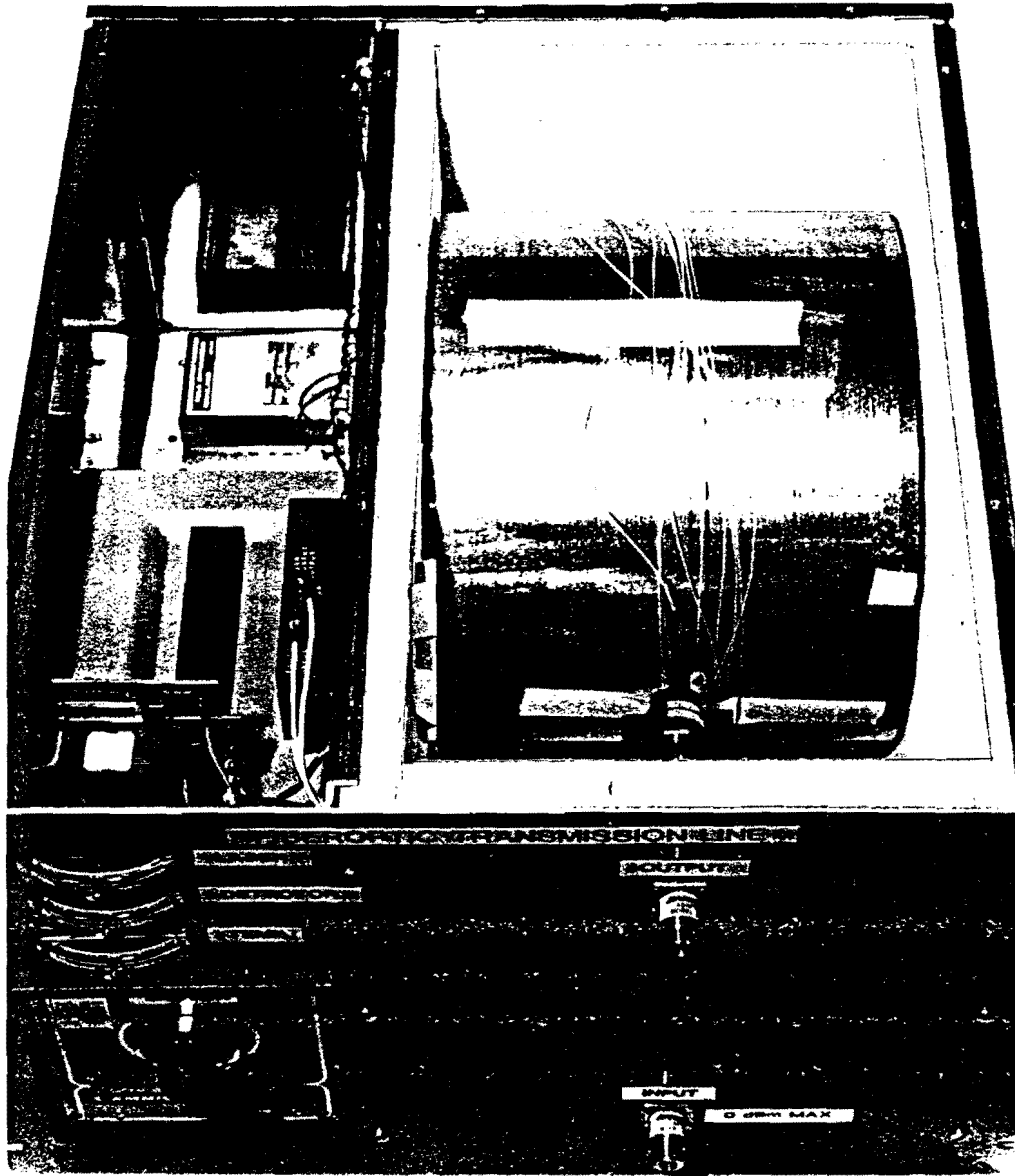
### Conclusion

The FOL described above had an upper  $f_{3dB}$  frequency response of 4.5 GHz which was measured using 0dBm input signal. The laser diode manufacturer suggests 0dBm as a safe maximum operating input level with levels over +2 dBm possibly causing diode damage. The input-to-output FOL rf gain measured  $-25 \text{ dB} \pm 1 \text{ dB}$  (1-2 GHz) and  $-25 \text{ dB} \pm 10 \text{ dB}$  (2-4 GHz). Notch depths achieved using the FOL as the long delay in a correlator notch filter averaged 25 dB. This filter was assembled primarily to measure the FOL dispersion. Judicious selection of combiners, attenuators, etc. would probably yield greater average notch depths.

Laboratory table top operating stability (Fig. 9) measured  $< \pm 1 \text{ ppm}$  over three hours. With  $75^\circ\text{F} \pm 5^\circ\text{F}$  air vigorously blown around the FOL (Fig. 10), stability measured  $< \pm 4 \text{ ppm}$ . By varying the FOL temperature  $\pm 5^\circ\text{F}$  and measuring the effective time delay change, the FOL was found to have  $+14.7 \text{ ppm}/^\circ\text{C}$  delay versus temperature dependence. This suggests using the FOL temperature as a means of fine delay adjustment.

Components currently available to improve the FOL include a 15 GHz anti-reflection coated PIN photodetector diode. Use of this diode in the FOL suggests a 10 dB increase of the dynamic range (by lowering the system noise floor) and an increase of the systems upper frequency response.

Components proposed to be made available commercially within this next year include a 10 GHz laser diode pigtailed with 5 micron glass fiber suggesting a system frequency response increase to  $\approx$  8 GHz.



Fiber Optic Transmission Line