GBT MEMO 151

FIBER OPTIC GAIN STABILITY

S. D. White

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Nature of the Problem

An important parameter for the GBT IF system is gain stability over time. Any change in gain over an integration time will effectively raise the minimum detectable signal criteria given by:

$$\frac{\Delta T}{T}=\frac{1}{\sqrt{\upsilon_{rf}\tau_{v}}}$$

where ΔT is the minimum detectable increase in system temperature
T is the system temperature
υ_{rf} is the RF bandwidth
τ_v is the post detection time constant

and adversely effects the performance during continuum observations.

Enforcing strict stability parameters for the IF system of υ_{rf} = 500 MHz and τ_v = 1 second gives an allowable gain change of 0.0002 dB.

Recent tests of the IF system on the 140 foot revealed unacceptable gain stabilities that were correlated with telescope movement. Several correctable problems contributed to the instabilities; however, further investigation indicated a fundamental instability with the fiber optics.

Fiber Optics Instability

Single-mode fiber actually supports two degenerate orthogonal modes: HE_x and EH_y. The phase velocities for the two modes are different, due to irregularities and imperfections, which produces a birefringence in the fiber. The birefringence of the fiber changes with external stresses due to movements, which causes the coupled power between the modes to change.

When a highly linearly-polarized light source such as the Distributed Feed Back (DFB) or Fabry-Perot laser launches an EM wave into the fiber, the birefrengence properties and external perturbations cause the linear polarization to evolve into an elliptical polarized state over a few meters of fiber. When the fiber is moved, the birefringence changes, thus changing the polarization state from one ellipse to another.

The demodulation of the intensity-modulated light is accomplished with a photodiode, which produces an electrical current proportional to the intensity of the light. Several different types of photodiodes are manufactured, each being optimum for a given wavelength, light sensitivity and bandwidth. For bandwidths greater than 1 GHz, gallium arsenide photodiodes are required. The two types available in gallium arsenide are the PIN photodiodes, or avalanche photodiodes (APD). The APD's bandwidth is limited to approximately 3 GHz; whereas, the bandwidth of the PIN photodiodes exceeds 10 GHz. Another type of photodetector worth mentioning is the metal-semiconductor-metal (MSM), which has bandwidths on the order of 60 GHz; however, the design of this device is inherently polarization sensitive.

In order to get the wide bandwidths from the PIN photodiodes, the capacitance of the devices has to be reduced to tenths of Pico-Farads. This is accomplished by reducing the size of the devices to about 3 square millimeters. To reduce back reflections and improve the return loss of the devices, designers angle the surface normal of the detector with respect to incoming beam of light. The manufacturers are protective of the methods for angling the incident beam. They probably use a thin-film mirror to divert the incoming beam, or angle the surface of the PIN diode with respect to the end of the fiber, or both. By making the angle of incidence different from normal, the orthogonal polarizations of the light are reflected differently, thus making the receiver sensitive to polarization changes. This phenomenon is well understood in thin-film physics and is how optical filters are designed. This phenomenon can be controlled in the manufacturing process by coating the mirror surface with gold or silver; however, manufacturers are not worried by polarization sensitivity to this level.

A paper by Bleyakov, et al., titled "PSSP: Polarization-sensitive Schottky photodiode," discusses intentionally designing photodiodes to be polarization sensitive. This is accomplished by creating a grating on the semi-conductor surface, which produces a surface EM wave. When the polarization is aligned with the grating vector, a greater current density occurs in the photodiode. With manufacturing processes being imperfect , PIN diodes may have similar surface gradients contributing to the polarization sensitivity of the photodiodes.

An HP photodiode, PDT0412-FC-A, was tested, which has no angled surfaces and has a flat polished FC connector as the interface between the SM fiber and the PIN photodiode. The photodiode was found to have similar polarization sensitivity as the best Ortel unit. With an angle-polished connector, the sensitivity increased to the level of the most polarization sensitive receiver. Therefore, the angled surface and some fundamental property of the diode both contribute to the polarization sensitivity.

Receiver Measurements

The polarization sensitivity is measured by changing the polarization in unjacketed fiber with a polarization controller. This device simply changes the birefringence of the fiber by inducing stresses from the twisting of the fiber. A 1 GHz sinewave is input to the fiber optic link, where the output is square-law detected and monitored by a chart recorder, as shown in Figure 1. The sensitivity of the chart recorder is about 0.001 dB. Table 1 gives the results of the measurements.

Improvement with Polarization Maintaining Fiber

A special type of fiber, polarization maintaining (PM) fiber, was developed to keep the polarization state constant. This is accomplished by inducing controlled stresses in the fiber so that the orthogonal polarizations have a different but constant phase velocity. The isolation specification between polarizations is given as an "h" parameter per 1-meter length. There is a ratio of power in the orthogonal polarizations at the end of a fiber when linearly-polarized light is launched down one of the axes. In order to take advantage of polarization-maintaining properties of the fiber, the linear polarization from the laser diode must be aligned with the appropriate axis. The degradation due to movement and external stresses is not specified by the manufacturers; therefore, a 10-meter length of PM fiber manufactured by 3M was tested. Table 2 gives the h parameter specification from different manufacturers.

We were unable to insure that the polarization was linear and aligned properly in the test setup for the PM, because all transmitters were equipped with the SM pigtail. A 1-meter length of PZ fiber with a tunable connector was purchased, but this proved to be awkward and resulted in a low confidence level on the alignment. However, the elliptical polarization simulates the performance of the fiber as the isolation between orthogonal polarizations decreases, due to the approximately 300-meter length needed for the GBT.

The isolation specification for the 10-meter length of fiber is 33 dB. When the fiber is moved, the change in gain was measured to be 0.001 dB, which is a 20 dB improvement. However, when a photodiode with more polarization sensitivity was used, the gain changes remained the same. This indicated that the actual polarization change is too small to measure, and the gain changes were due to cladding-loss changes from bending. The PM fiber was subjected to bend radius changes, due to the length of the fiber and lab space available, which resulted from the fiber being coiled on the floor. This was atypical of the bend radius changes which can be expected from fiber installed on the telescope. The gain change due to the insertion loss from fiber movement should be less, depending upon the physical properties of the cable and the various bend radii on the telescope.

A slow drift in gain through the system was noted, with the ORTEL DFB as the transmitter. The slow drift in gain changed by the difference in polarization sensitivities for different photodiodes. This was a result of the polarization changes in the DFB laser's 1-meter SM pigtail which was exposed to the laboratory environment. With the Lasertron transmitter, which has a 2.8 pigtail coiled inside a metal box, the drift was greatly reduced. To take full advantage of the PM fiber, the laser transmitter must have a PM fiber pigtail with a connector properly aligned to the axis of the fiber.

The PM fiber was also tested for changes in gain over temperature. A comparison of the PM fiber and the SM fiber with a similar jacket is shown in Figure 2. The PM fiber is approximately a factor of phase-versus-temperature performance.

Increased relative-intensity noise in the Lasertron Fabry-Perot transmitter was observed when the transmitter was not optically isolated from the transmitter, especially during movement of the fiber. Also, instabilities in the output power of the laser were observed during the PM fiber tests, and during testing of the HP photodiode, which has only 20 dB return loss. Because the instabilities are due to reflections into the laser, an optical isolator eliminates the problem. Since PM fiber maintains the polarization, the reflections are more likely to enter the diode cavity with same polarization as the light in the cavity. Therefore, the laser transmitters must be isolated from the fiber.

Conclusions

The polarization state in standard single-mode fiber changes with even the slightest movement of the fiber. Because of angled surfaces and imperfections in the photodiode surfaces, the polarization changes are detected by the photodiode and manifested as unacceptable gain changes in the system. Improvement in gain stability and noise performance is possible by selecting a receiver with low polarization sensitivity, using polarization-maintaining fiber to reduce the polarization changes, and using a DFB laser transmitter with an optical isolator and a PM fiber pigtail.

There are two major concerns with the solution outlined above. Considerable cost is added to the system. The actual performance of a 300-meter length of PM fiber in a ruggadized cable, and subjected to the cable wraps on the telescope, is unknown. PM fiber is characterized by its ability to maintain the polarization through the fiber; however, the fibers ability to resist change in polarization when an elliptical state of polarization exists is an unspecified parameter. Laboratory tests with an elliptical SOP indicates at least 20 dB improvement in the most sensitive fiber optic link with a 10-meter length of PM fiber. The performance is expected to improve when linear polarization from the laser diode is aligned with the slow axis.

Further tests need to be conducted on longer lengths of fiber. Comparison tests between the Panda fiber and the 3M fiber should be conducted to justify twice the expense of the Panda fiber for the five-fold improvement in isolation. Both fibers should be tested on the 140 foot in actual observing runs in order to estimate the gain stability expected on the GBT. A laser diode with a PM fiber pigtail should also be tested with the fiber.

References

[1] Belyakov, L.V., et al., 1992 Polarization Analysis and Measurement, ed. D. H. Goldstein, R.A. Chipman (Belingham: SPIE), p. 407.

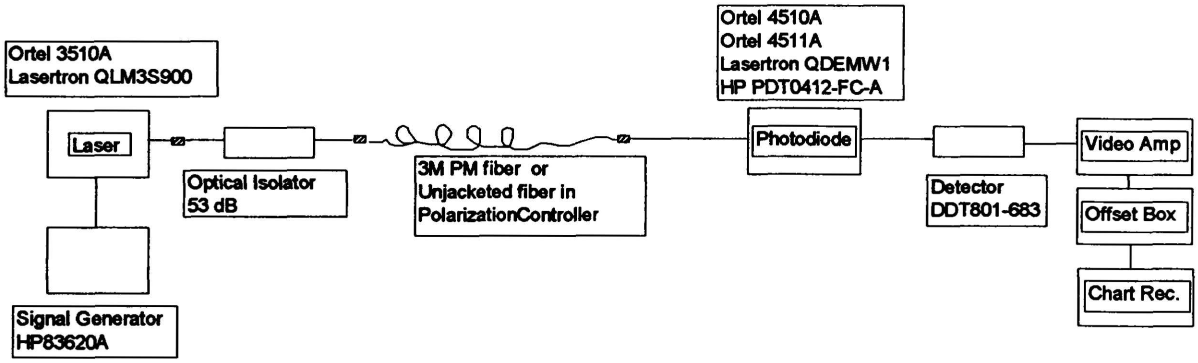

Figure 1. Fiber Test Intrumentation

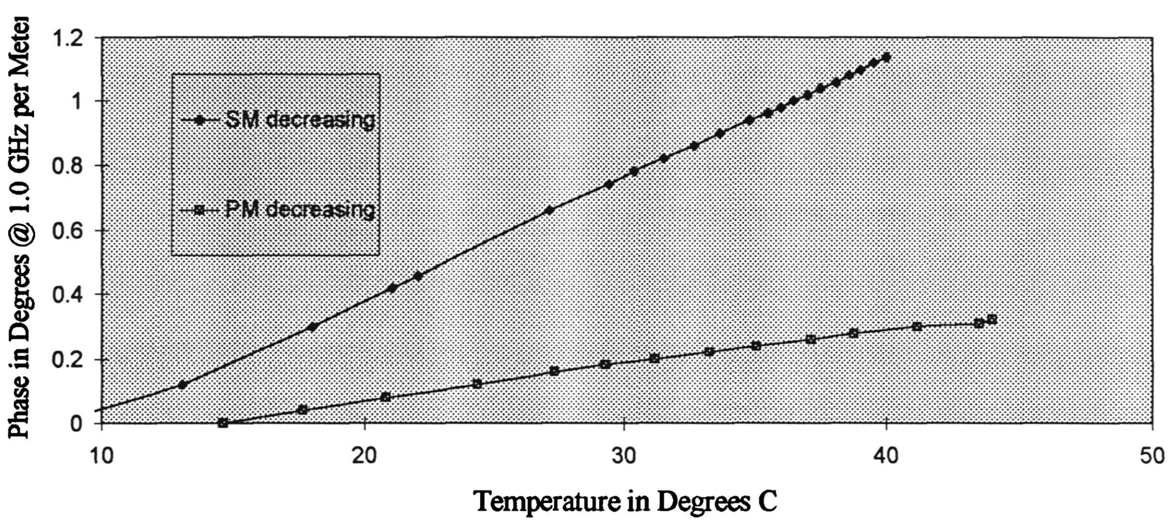

Figure 2. Comparison of Phase versus Temperature

Table 1 PIN Photodiode Sensitivity Measurement			
Manufacturer	Detector	Connector	Sensitivity [dB]
Ortel	4510A	APC	0.012 +/- 0.005
Ortel	4511A	APC	0.100 +/- 0.01
Lasertron	QDEMW1	APC	0.100 +/- 0.01
HP	HPDT0412	FC	0.020 +/- 0.02
HP	HPDT0412	APC	0.210 +/- 0.01

Table 2 PM fiber Isolation Parameters			
Manufacturer	Type	h parameter	Isolation [dB] @ 300 m
Fujikura/Corning	Panda	1.00E-05	-25.23
Fujikura/Corning	elliptical	1.40E-04	-13.77
3M	FS-PM-6621	5.00E-05	-18.24