Polarization State Measurement in the GBT Single-Mode Fiber Optic Cable

S. D. White

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As a consequence of the birefringence property in single-mode fibers, applied mechanical stresses perturb the polarization state of the guided light. This effect is easily demonstrated by flexing the fiber and measuring the polarization state. Gain instabilities arise in analog fiber optic links when photodiode detectors are sensitive to this state change. Photodiodes are constructed with fiber interfaces, having an angled surface that directs reflected light into the cladding. The angled surface, in conjunction with the air gap, causes the reflection coefficient to be different for orthogonal light polarizations incident upon the surface. A series of tests, characterizations, and solutions to this fundamental problem are documented in the GBT Memo series.[1] A solution was implemented in the GBT fiber IF links without the ability to quantify the polarization state changes in the fiber under telescope azimuth, elevation, and turret rotations. This memo documents a recent series of polarization measurements in a loop of fiber between the GBT Equipment and Receiver Rooms, with a polarimeter borrowed from the ALMA project. The GBT underwent rotations about each axis, as well as a turret rotation, and the Stokes parameters were recorded.

Test Data

Raw Polarimeter Data and Analysis Programs:

GBFILER\\DOC\DRAWINGS\ARCHIVE\GBELECTRONICS\35260\D074.

Telescope position data were logged independently from the polarimeter data, which has a slightly different time base. As a result, the data sets were merged in to an EXCEL spreadsheet, the time stamps aligned, and then exported for analysis into a *Mathematica* program. All these programs are in the archive and can also be used to examine the polarization states during the tests.

Test Equipment

An NRAO measurement system, loaned from the CDL photonics laboratory, measured the polarization in these tests. The system consists of a General Optics POD-001 polarimeter, and a *Labview* program for logging and displaying the data. The source for the experiment is an Ortel model 1772 1550 nm laser diode, spliced to a JDS Uniphase Mach-Zehnder Extended Frequency Range Analog Modulator. This is a spare modulator for the GBT IF system.

[1] GBT Memos: 151 and 163

Test Setup

Two spare SM fibers were connected with APC connectors at the IF rack, providing a round-trip measurement scheme. This was convenient, since the fibers' ends were in proximity both in the equipment room and on the receiver room turret. No access was required during the tests. The block diagram is shown in Figure 1.

Test Procedure

Three tests provided the baseline for the measurement. The first connected the output of the modulator directly to the polarimeter and data recorded for an hour. For the second baseline test, a 10-meter jumper connected the output of the modulator to the input of the polarimeter. The fiber was looped along the overhead tray down to the splice center. Frequent air conditioning cycles were a concern and the motivation for this test. For the third baseline test, data were taken with the telescope positioned at access with no movement. These tests were performed during a maintenance period, so the activities in the receiver room were not controlled. With the baseline stability established, the polarization state was recorded once a second as the telescope rotated 270 degrees in azimuth, with the elevation fixed at access, then back to the starting position. This test was repeated, keeping the azimuth fixed and rotating 85 degrees in elevation, then returning to the starting position. Finally, the turret was rotated 180 degrees, stopped, then returned to the initial setting, with the polarization recorded. The polarimeter output was sampled at 20-ms with a 700-KHz bandwidth. Only the samples at a one-second interval were logged.

Analysis

Fiber optic link gain depends upon the responsivity of the detector, the type of modulation (direct or indirect), and the input and output impedances.[2] The photodiode responsivity typically varies with light polarization. Therefore, the responsivity can be considered as composed of orthogonal components, with each responding independently to the average power of the associated polarization component of the incident light. This photodiode polarization sensitivity affects both external and direct modulation equations identically. Since RF gain is a function of the squared responsivity and is easily measured, the polarization sensitivity is parameterized as such. Typically, the difference in squared responsivity is on the order of a few percent, depending on the construction of the photodiode as shown in Table 1. The least sensitive detector, New Focus 1414, is constructed with a square fiber end but coupled to the photo sensitive semiconductor. As of ~2002, the manufacturer changed the interface to an angle polished fiber end with an air gap.

The average powers are determined from the measured Stokes parameters, and the responsivity can be assigned a value of one, with the difference in response parameterized without loss of generality. (Note the polarimeter uses the 45-degree shifted basis, $(\hat{a}, \hat{b})$, but all equations are in basis $(\hat{x}, \hat{y})$. The appropriate Stokes parameters were used in all calculations). All the calculations are with a 0.01

[2] Gain and Noise Figure in Analogue Fibre-Optic Links. CH Cox IEE Proceedings-J, Vol. 139, No. 4, August 1992

difference in the squared responsivity for comparison purposes. The results are normalized to an ideal gain, with photodiode responsivity set equal to the arithmetic mean. The source can be considered completely polarized, with an integral over the effective measurement time , $T = \frac{1}{50\ S/s}$, quantifying the gain changes.

To minimize any potential gain variations, the GBT analog fiber optic system design included the New Focus 1414 photodiode and implemented a feedback correction loop that further reduced the RF gain changes by 17 dB. Details are available in a *Review of Scientific Instruments* article. [3] As an estimate to the performance of the current IF system under telescope movement, the ordinate of Figures 5, 6 and 7 can be multiplied by the factor $\frac{0.0019}{0.01} * 0.020 = 0.0038$. This gives a maximum change of 3.8 10^{-6} for the complete elevation move, as an example.

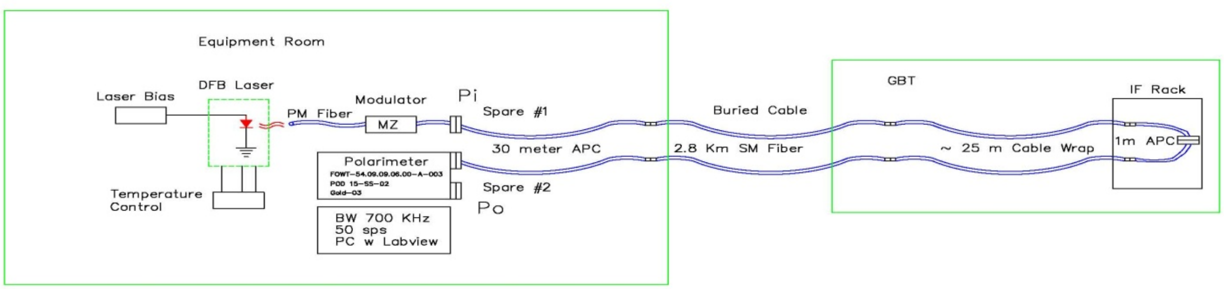

Figure 1. Polarimeter Test Diagram

[3] Implementation of a photonic automatic gain control system for correcting gain variations in the Green Bank Telescope fiber optic system, S. D. White, *Review of Scientific Instruments*, Vol. 71.

Manufacturer	Detector	Bandwidth [GHz]	Polarization Sensitivity $\frac{\Delta G_{rf}}{G_{rf}}$ $\pm\sigma$
Ortel 1990	2510A	3.0	0.0270 0.0038
Ortel 1992	2510A	3.0	0.0069 0.0016
Ortel	2515A	10.0	0.0430 0.0047
Ortel	2516A	20.0	0.0304 0.0005
Ortel	2518A	15.0	0.0123 0.0034
Lasertron	QDMH2	10.0	0.0151 0.0009
New Focus	1414	25.0	0.0019 0.0009
New Focus	1434	25.0	0.0042 0.0037
New Focus	1514	6.0	0.0080
HP	HPDT0412	3.0	0.057 0.0010

Table 1. Photodiode Polarization Sensitivity measurement.

Modified Fiber Optic Gain Equations

$$G_p = \left(\gamma_x^2 \frac{1}{T}\int {E_x}^2 dT + \gamma_y^2 \frac{1}{T}\int {E_y}^2 dT\right) * \Gamma_m \quad (1)$$

$$G_{ideal} = \gamma^2 \left[\frac{1}{T}\int {E_x}^2 dT + \frac{1}{T}\int {E_y}^2 dT\right] * \Gamma_m \quad (2)$$

$$\Delta G = \frac{G_{ideal} - G_p}{G_{ideal}} \quad (3)$$

$$\frac{\gamma_x^2 + \gamma_y^2}{2} = \gamma^2 \quad (4)$$

$$\frac{{E_x}^2}{Z} = \frac{I - Q}{2} \quad (5)$$

$$\frac{{E_y}^2}{Z} = \frac{I + Q}{2} \quad (6)$$

Where, γ_x and γ_y are the respective photodiode responsivities, G_m represents the modulation and impedance factors, Z = 1 is the normalized impedance, I and Q are the Stokes parameters.

Polarimeter Measurement

Measurement	$\sigma^2_{E_x^2}$	$\sigma^2_{E_y^2}$	Samples
No Fiber	0.000008	0.000007	All
Loop Test: Access	0.000033	0.000027	1:2000
10m Fiber Test	0.0000056	0.0000064	3000:4000
Azimuth Move	0.000155	0.000155	All
Elevation Move	0.0024	0.0024	All

Table 2. Variance of E_x^2 and E_y^2

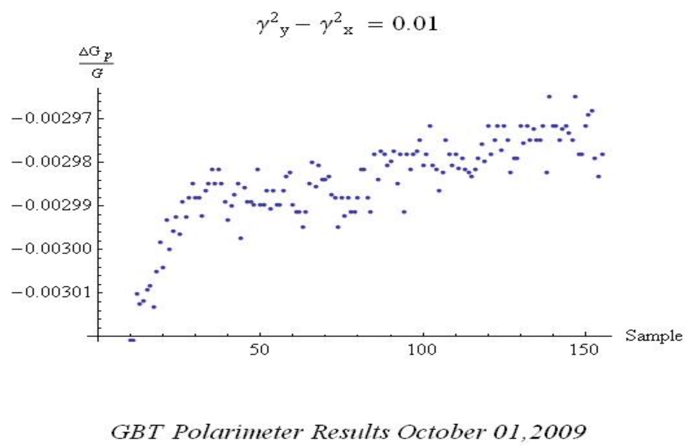

Figure 2. Laser/MZ directly to Polarimeter

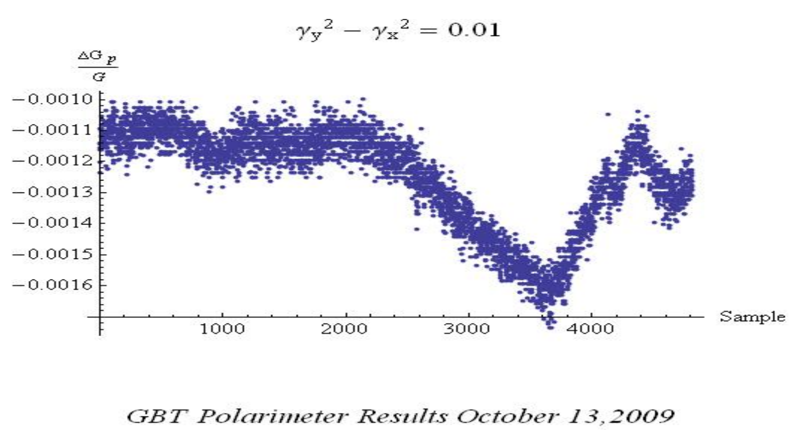

Figure 3. Round Trip (~5.8 km) GBT @ Access

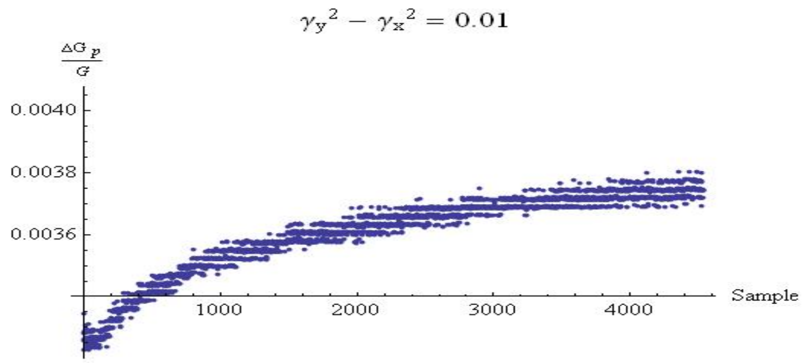

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Figure 4. Equipment Loop Test 10 meter fiber

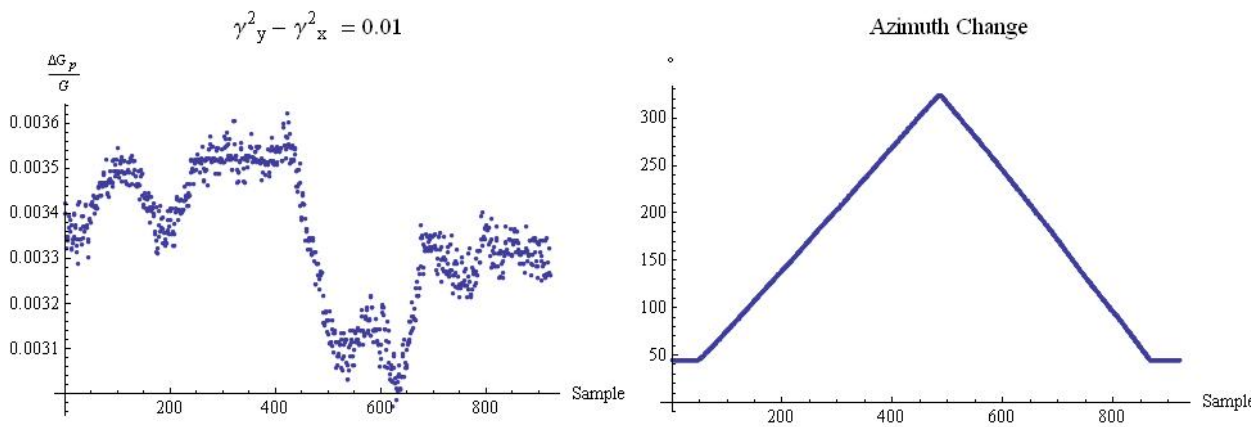

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Figure 5. Azimuth Move

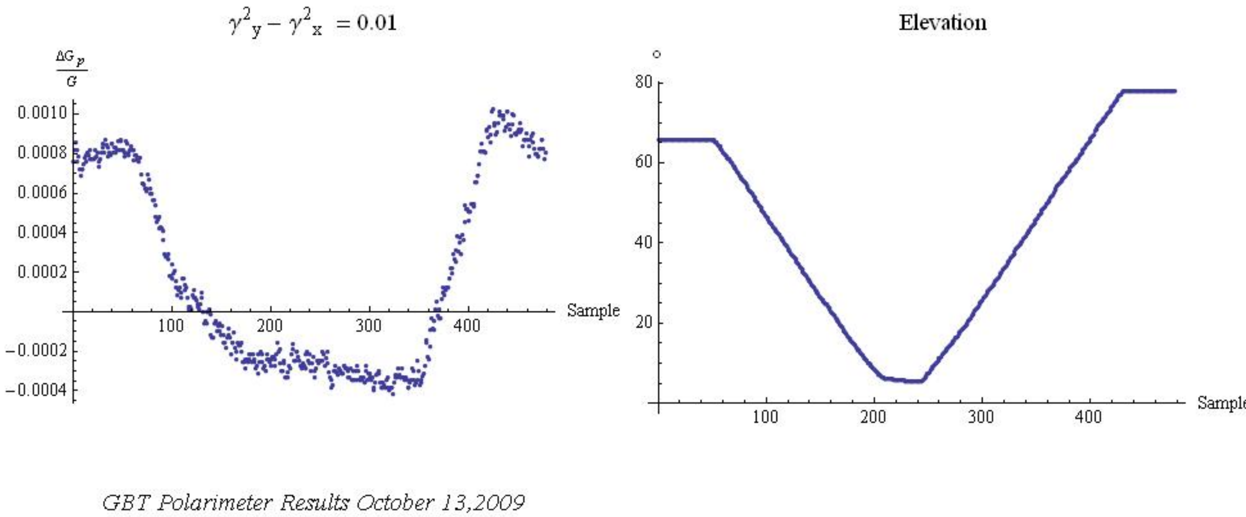

Figure 6. Elevation move

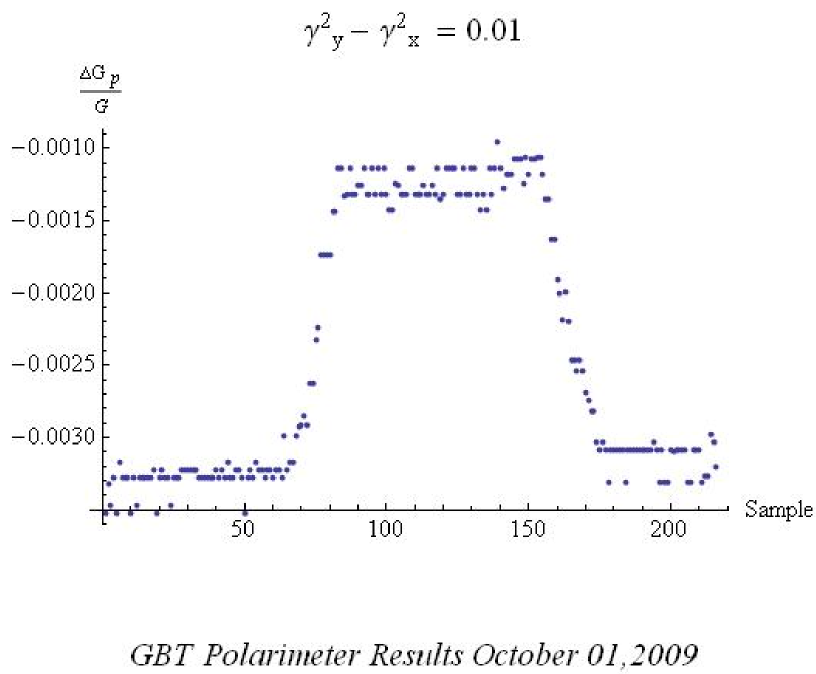

Figure 7. 180 Degree Turret Rotation and Return.

Conclusion:

From the baseline tests, Figures 2-4, the polarization state at the external modulator output is seen to drift. Most likely, this is from temperature cycling in the equipment room affecting the laser diode and external modulator. Fortunately, the drifts occur at rates long compared to the telescope slew rates. Also, the gain changes in Figure 3, with the telescope in access, are the same order of magnitude as the movement tests but over longer time scales. Activity on the telescope, temperature changes of the structure, or receiver room temperature changes could have been the cause.

As seen in Figures 5 and 6, the azimuth movements have less effect, and the gain changes are not as correlated with telescope movement as the elevation results. In this analysis, the maximum gain change occurs when a linear polarization state undergoes an orthogonal change polarization state. As evident in the elevation tests, the gain changes are an order of magnitude less than the maximum 1 percent. Examination of the polarization state reveals only slight changes under telescope movement.

From these results, inferences in cause and effect are difficult to understand. The elevation wrap is large in diameter and should impose less stress on the fibers. By comparison, the turret cable wrap has relatively small bend radiuses, and turret rotations create comparatively large gain perturbations as evident in Figure 7. More tests eliminating the fiber connectors and reducing the loops of fiber in the splice tray may reduce the variance in the measurements. A smaller interval between logged samples may also be informative.

Acknowledgements

Bill Shillue and Jason Castro, of the CDL, loaned the polarimeter and provided valuable information on the specifics of the measurement system. Roger Norrod collaborated on the experiment methodology, aided in clarifying the presentation of the data, and edited the memo.