Submillimeter Array Technical Memorandum

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Notes on Azimuth Cable Wrap Alternatives

1. INTRODUCTION

The design of the SMA azimuth cable wrap is driven by the requirement to transport local oscillator reference signals in the 6 to 8 GHz frequency range to the rotating platforms with minimal phase perturbation. The reference frequencies are transmitted as modulated optical signals over single-mode fiber; the problem is to bring these fibers from a fixed point on the earth into the rotating antenna cabin while constraining the maximum change in the optical path length caused by thermal and mechanical stresses to 10 microns or less.

The initial design of the SMA azimuth cable wrap is based on the use of helical steel bands positioned at an nominal diameter of about 30 inches by a set of pivoted aluminum arms which freely rotate on a ten-inch central post. Power and signal cables, including optical fibers, are coiled around the outside of the steel bands and held in place by clamps or tie-wraps. At the bottom of the wrap assembly, the bands and the cables are clamped to a plate which is secured to the ground. Similarly, at the top of the assembly the bands and cables are attached to a plate which rotates with the antenna cabin. The relative angular motion between the top and bottom attachment points is absorbed into a continuous variation of the band diameter along the length of the helix in a rather complex fashion.

A demonstration model of the azimuth cable wrap, using only three turns of the helix rather than the full six turns required for 540° rotation, was assembled in early June. The first tests of phase stability as a function of mechanical rotation were performed on June 11, using four Sumitomo Temperature-Compensated Delay (TCD) fibers cabled into a semi-rigid, loose-tube configuration. Evaluation of two alternative fiber structures followed these preliminary measurements and, as expected, the fiber which exhibited the best temperature stability was most susceptible to mechanical perturbations. As a consequence of the observations and measurements made during the week of June 14, the field of potential candidate transmission lines was narrowed to two fiber structures; Sumitomo TCD cable and Siecor Loose-Tube (conventional) cable. Furthermore, this experience lead to a concept for a much simpler, high-performance cable-wrap structure, the "Torsion Wrap"; which is described in detail in section 2 below. Measured performance data for the torsion wrap, and for the original "Helical Wrap", is shown in Section 3.

2. TORSION WRAP DESIGN

2.1 Design Concept

Careful observation of the fiber path-length variations induced by the helical-wrap mechanisms clearly demonstrates that both the Sumitomo and the Siecor fibers are much less sensitive to pure torsional motion than to either bending or elongation. The torsion wrap design attempts to absorb the rotation of the platform entirely in twisting of the fiber. To this end, a vertical segment of fiber or fibers is clamped at each end and is allowed to rotate freely between the clamps. The fibers are aligned as precisely as possible along the axis of rotation, and the fiber clamping mechanisms are located on the vertical section of the fiber such that there no bends within the rotating fiber segment.

2.2 Proof of Concept Mock-Up

A demonstration model of the proposed azimuth wrap was set up in the laboratory as shown in the sketch of Figure 1. The "rotating platform" in the figure is the upper portion of the original wrap mock-up, specifically the top of the azimuth encoder case. This system forms a convenient and precisely controllable fixture for the demonstration torsion wrap. The two attachment panels are formed from L-shaped pieces of sheet aluminum and the fiber is secured to the flat vertical sides by means of duct tape. Note that two fibers, as a minimum, are required to implement the phase measurement setup described in Section 3 below.

Since it is necessary for the optical fibers to transit a relatively small cylindrical passage through the optical encoder, a modified version of the torsion wrap was also implemented to simulate this situation. The modified wrap adds a plastic tube just below the fixed attachment panel, 4 mm inside diameter and 180 mm long, to simulate the encoder axial sleeve. The tube is rigidly secured to the fixed attachment panel and the fiber rotates within the axial bore. The location of the tube and the attachment arrangement is shown in Figure 2.

3. MEASURED PHASE STABILITY PERFORMANCE

Sample data from measurements in both the initial helical cable wrap and the torsion wrap designs are shown in the following paragraphs. In all cases the data presented has been edited from much longer runs in order to emphasize a particular aspect of the test or to minimize extraneous perturbations caused by non-related activity on the distribution system. The data shown is, however, representative of the repeatable performance of the cable wrap under test.

Since the fiber transmission path must be returned to the stationary reference frame for measurement purposes, the total path includes two (or four in some cases) rotating segments. It is assumed for the purposes of this evaluation that the mechanical phase is approximately double (or quadruple, as appropriate) the one-way phase variation.

3.1 Test Instrumentation

The instrumentation for all measurements described in this section was designed to realistically simulate a complete, two-antenna reference distribution system. The fiber segment under test was inserted into one leg of the otherwise symmetric optical system, as shown in the simplified block diagram of Figure 3. The SMA Master Reference source, set to either 6.30 or 7.130 GHz, was used to modulate an Ortel 3530A laser transmitter. The modulated optical signal was split by an Aster power divider and routed directly to one optical diode receiver. The other output of the power divider is routed through the azimuth wrap mechanism and the fiber under test. Each optical receiver output is followed by an associated Reference Signal Generator: the phase record is produced by feeding the outputs of the Reference Signal Generator to the HP 8719C Vector Network Analyzer. The test data includes ambient temperature effects on both the fiber under test and the electrical/optical components; however, in most cases the time scales of the temperature and rotational perturbations are quite difference and it is relatively straightforward to distinguish the effects.

3.2 Helical Cable Wrap Data

Two types of fiber were tested in the helical wrap; Sumitomo TCD fiber in both its cabled form and as individual strands, and "conventional" Corning SMF fiber in Siecor Loose-Tube cable construction.

3.2.1 Figure 4 shows the rotational effects for Sumitomo cable wrapped around the outside of the helical bands for two rotation rates, 1.5 degrees per second and 0.75 degrees per second. Although the peak-to-peak amplitude is considerably greater than in other cases shown below, the repeatability from cycle to cycle is remarkable. The apparent lack of a rotational rate sensitivity, reported in other installations, should also be noted. The peak-to-peak phase variation, corrected for one-way propagation, is approximately 2 degrees at 6.36 GHz (corresponding to 260 μm of path length) or about 0.0075 degrees of phase (0.09 μm), on the average, per degree of rotation. Note for reference that the wavelength at the highest frequency of interest to the SMA, 900 GHz, is about 330 μm.

3.2.2 Figure 5 shows comparable data for Siecor Loose-Tube cable wrapped around the outside of the helical bands. The rotation rate is approximately 1.0 degree per second. Since approximately 200 meters of conventional fiber, go and return, is in use in this case, the temperature contributions are significant. The mechanical rotation was turned off about 145 minutes into the run to clarify the relative contributions of temperature and rotation. The corrected peak-to-peak phase variation is approximately 0.4 degrees (corresponding to 52 μm of path length), or about 0.0015 degrees of phase (0.18 μm) per degree of rotation.

3.2.3 Figure 6 is essentially identical to Figure 5 except that the total length of Siecor cable is reduced to about 20 meters; the stationary fiber which connects to the instrumentation is replaced by Sumitomo TCD fiber to reduce temperature effects. As can be seen from the figure, the rotational perturbations are very similar to those seen in Figure 5.

3.2.4 Figure 7 shows the phase variations for a variation of the Sumitomo fiber installation. Two strands of TCD fiber, uncabled, were laid along the edge of the helical steel bands within the cylindrical surface formed by the bands. The results were similar to those of Figure 4, except that the amplitude of the phase excursions was somewhat greater. The corrected peak-to-peak phase variation was about 4 degrees (520 μm of path length) or approximately 0.015 degrees of phase (1.8 μm) per degree of rotation on the average.

3.3 Torsion Cable Wrap Data

Again, two types of fiber were evaluated; uncabled Sumitomo TCD fiber and Siecor Loose-Tube cable. In the case of the Siecor cable, the outer jacket and strength member were stripped off in the rotating segment to expose the two protective tubes.

3.3.1 Figure 8 shows the phase variations associated with two strands of Sumitomo TCD fiber. The phase perturbation signature is not nearly as repeatable as in the helical-wrap case and the usefulness of the "degrees of phase per degree of rotation" metric is questionable. However, the one-way peak-to-peak phase variation is very small, about 0.05 degrees at 7.067 GHz (corresponding to 6 μm of path length) worst case, including temperature effects. The mechanical rotation was turned off at about 100 minutes into the run: it is evident that the upward drift of the phase curve is unrelated to the mechanical rotation and that at least 25% of the observed variation is attributable to temperature and other noise mechanisms.

3.3.2 Figure 9 overlays the data from Figure 7, edge-mounted Sumitomo fiber in the helical configuration, and that of Figure 8 to provide a direct comparison of the two techniques.

3.3.3 Figure 10 shows the measured phase variations for two Siecor loose-tube fibers. Again, the rotation signature is not particularly visible and the total phase modulation is quite small. The mechanical rotation was turned off at 45 minutes, the effects of temperature can be clearly seen in the static segment of the data. The one-way peak-to-peak phase variation is about 0.1 degree at 7.067 GHz (12 μm of path length) worst case, including temperature effects, for 270 degrees of rotation.

3.3.4 Figure 11 portrays a somewhat more complex set of data than the earlier figures. The first 50 minutes is very similar to Figure 8 except that the two Sumitomo fibers are threaded through the 4.0 mm "encoder" sleeve. In the next 75 minutes, 350 to 425, the fibers were clamped at the bottom of the sleeve, eliminating interference effects within the sleeve but shortening the overall rotating segment from 1370 mm to 1190 mm. Note that the one-way peak-to-peak phase variation remained at about 0.025 degrees at 7.067 GHz (which is equivalent to 3 μm of path length) when the wrap was shortened, but the appearance of the phase signature changes in an unexpected fashion. At minute mark 425 the mechanical motion was stopped; the residual phase variation is correlated with the abrupt change in room ambient temperature. The peak-to-peak angular motion was increased to 350 degrees at 2 degrees per second for this data set.

3.3.5 Figure 12 shows the measured phase variations for a set-up almost identical to that which generated the first 50 minutes of Figure 11 except that the number of fibers is increased to four. That is, the signal is routed from the fixed point to the rotating platform, back to the fixed point, back to the rotating platform and finally back to the fixed point. As expected, the uncorrected peak-to-peak phase variation increased by roughly a factor of two relative to the comparable data segment in Figure 11; the one-way variation remained at approximately 0.025 degrees peak-to-peak.(3 μm path length). The peak-to-peak mechanical rotation angle was again set to 350 degrees.

3.3.6 Figure 13 demonstrates the effect of increasing the peak-to-peak rotation angle from 350 degrees to 400 degrees and eventually to 540 degrees. The number of fibers is four and the rotation rate is two degrees per second in all three cases. The one-way phase variation at 350 degrees was consistent with that seen in Figure 11, approximately 0.03 degrees peak-to-peak (3.5 μm path length) worst case. For the larger rotation angles, the peak-to-peak phase variation appears to increase more rapidly than would be expected from a simple linear dependence on rotation angle. At 400 degrees of total rotation the peak-to-peak modulation was roughly 0.04 degrees of phase (4.7 μm) and at 540 degrees rotation the peak-to-peak phase modulation was approximately 0.05 degrees (6 μm). There is a distinct asymmetry in the phase variation as a function of rotation angle which seems to depend on the maximum rotation angle in a rather unpredictable way.

4. CONCLUSIONS AND RECOMMENDATIONS

Any conclusions at this point must be considered to be highly preliminary, but nevertheless the torsion concept appears to be a very promising approach to the azimuth cable wrap problem. There are two particularly satisfying aspects to the torsion wrap: first, the mechanical structure is very simple and should be easily serviced in the field; and, second, the approach allows the use of temperature-compensated Sumitomo fiber throughout the distribution system. This second aspect is particularly important since the cable wrap well is not actively temperature controlled.

On negative side, the torsion wrap configuration has been shown to be very sensitive to axial alignment and to fiber tension. Bending of the fiber within the rotating segments appears to seriously degrade the performance. The phase stability is a non-linear, possibly square-law, function of the maximum angle of rotation and although 540 degrees can be accommodated with a 1300 mm wrap, stability is considerably improved if the maximum angle of rotation is reduced to 350 or 400 degrees.

There is a substantial amount of work to be done before it can be claimed that we understand or can totally predict the performance of the torsion wrap:

-- The durability of the fiber in the torsion mode is unknown. In particular, the aging characteristics of the Sumitomo temperature-compensation mechanism in both the static and torsioned environments is an open issue.

-- The effect of the length of the rotating segment on the overall performance has not been explored. All measurements shown above were made at fixed lengths in the order of 1100 to 1400 mm. The maximum rotation angle may also be a function of the wrap length, and this relationship must be determined before the mechanical design of the azimuth wrap is completed.

-- The asymmetric behavior of the phase modulation as a function of maximum rotation angle should be investigated in much greater detail.

-- The problems which arise from the size of the aperture in the encoder shaft and the requirement to pass three or four fibers through this limited space must be investigated further.

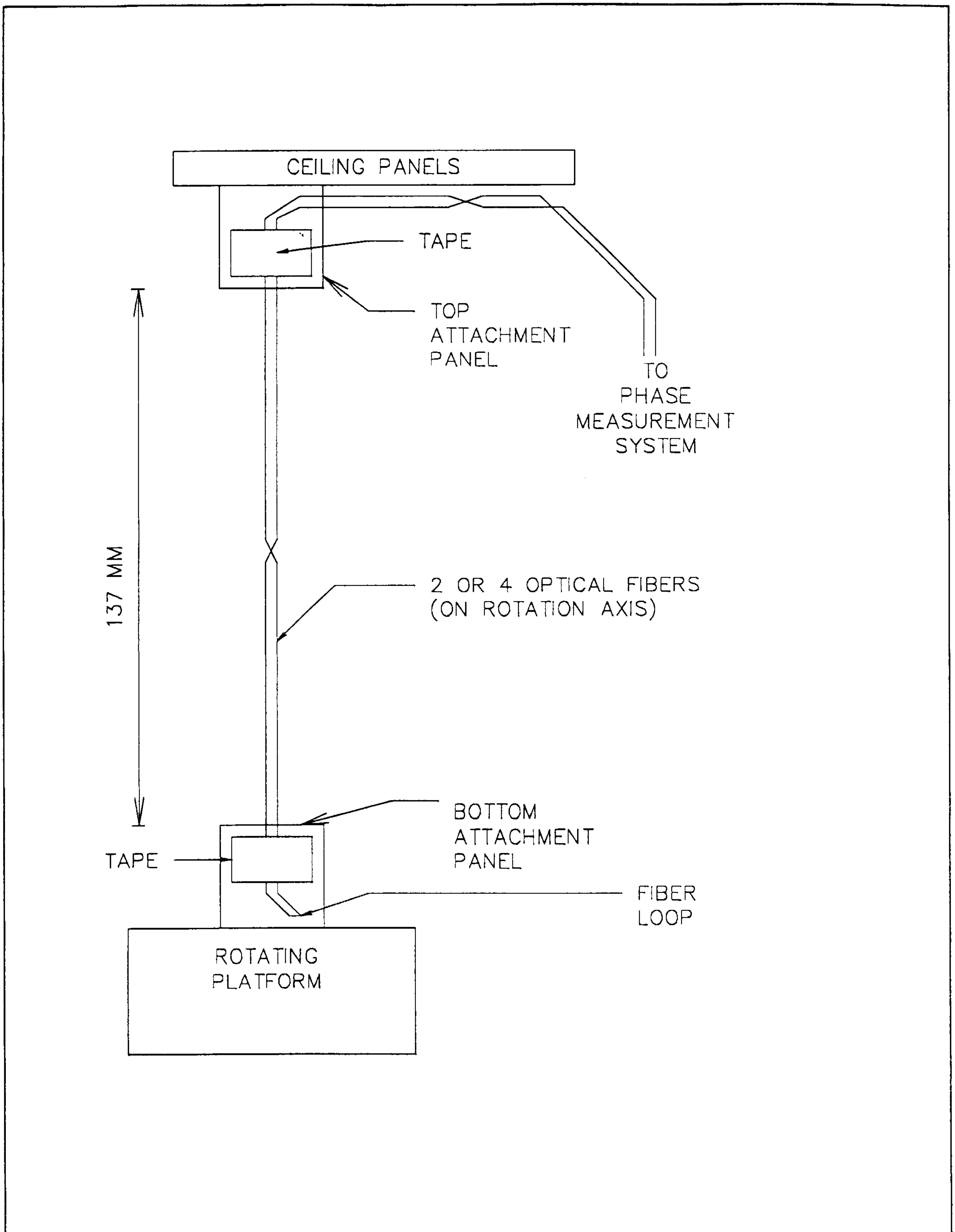

Figure 1 **AZIMUTH CABLE TORSION-WRAP MOCKUP**

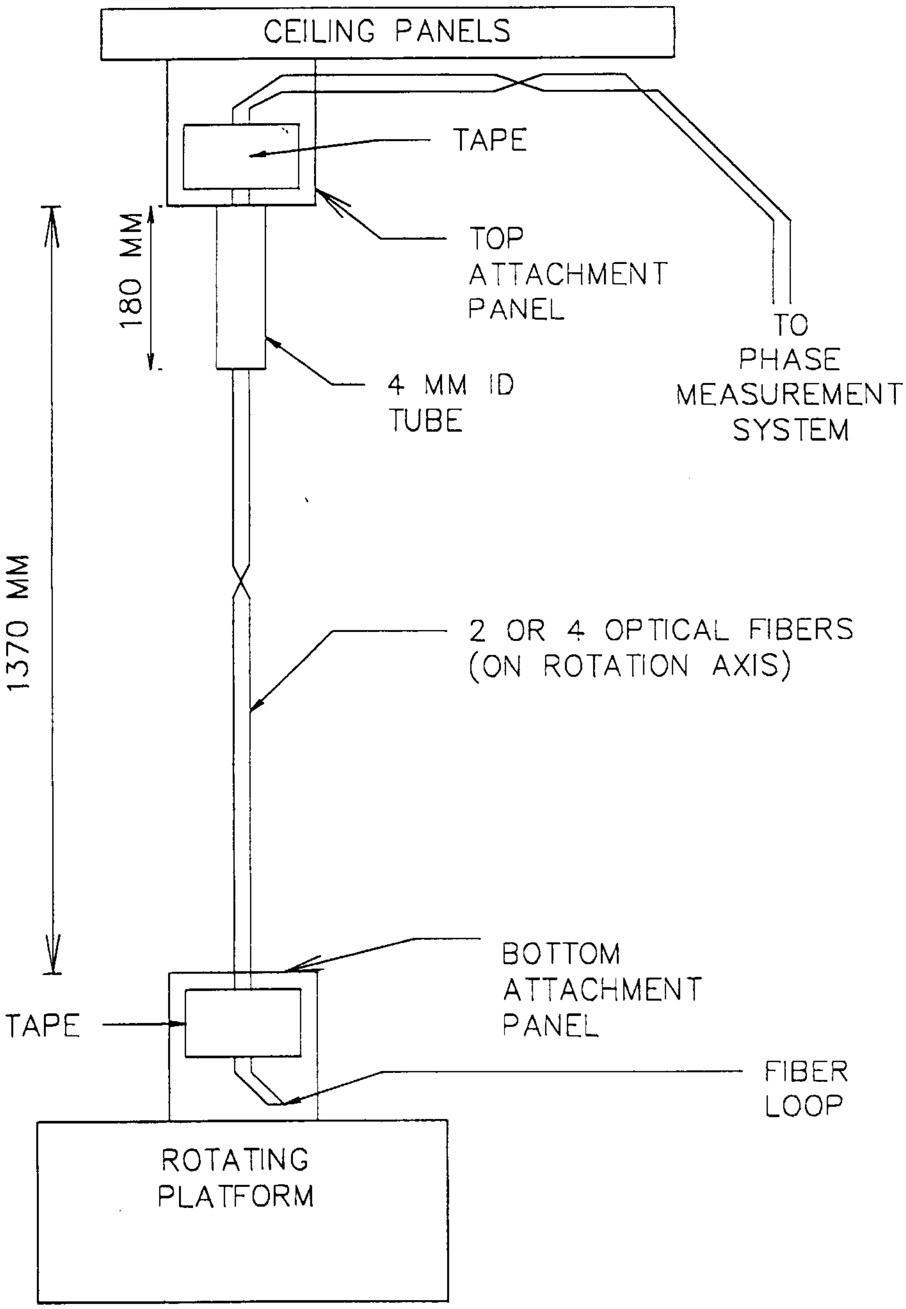

Figure 2 **MODIFIED AZIMUTH TORSION-WRAP MOCKUP**

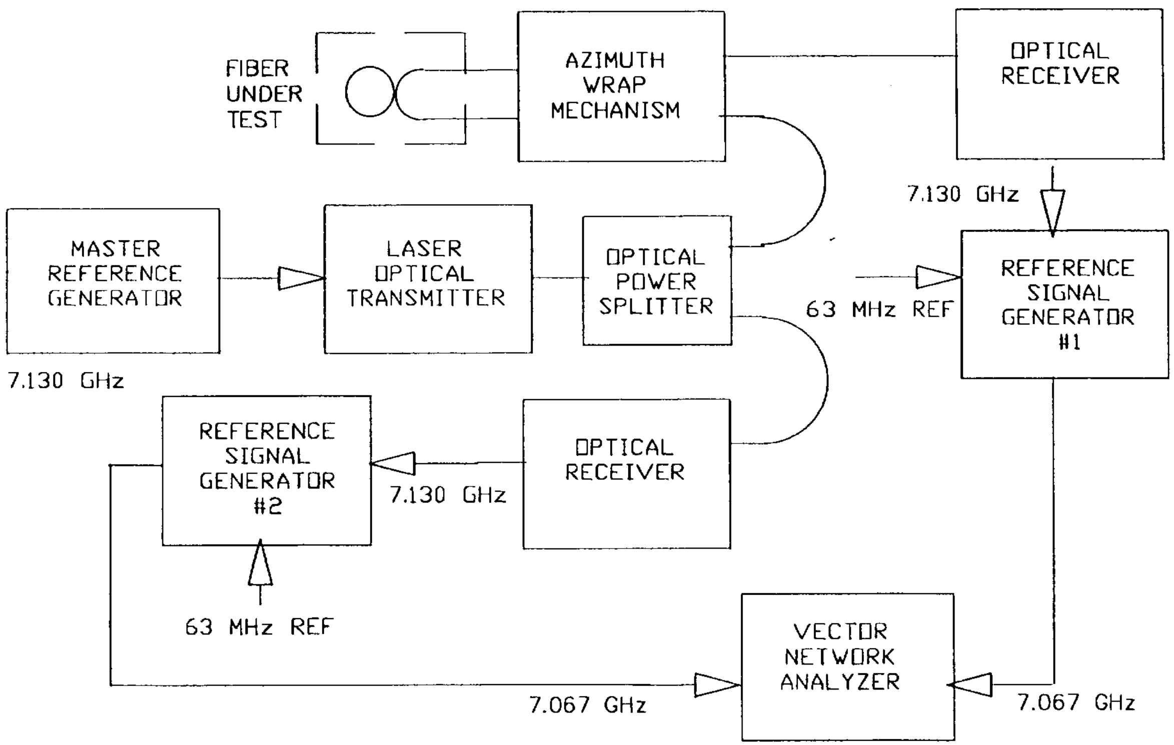

Figure 3 **CABLE WRAP TEST INSTRUMENTATION - SIMPLIFIED BLOCK DIAGRAM**

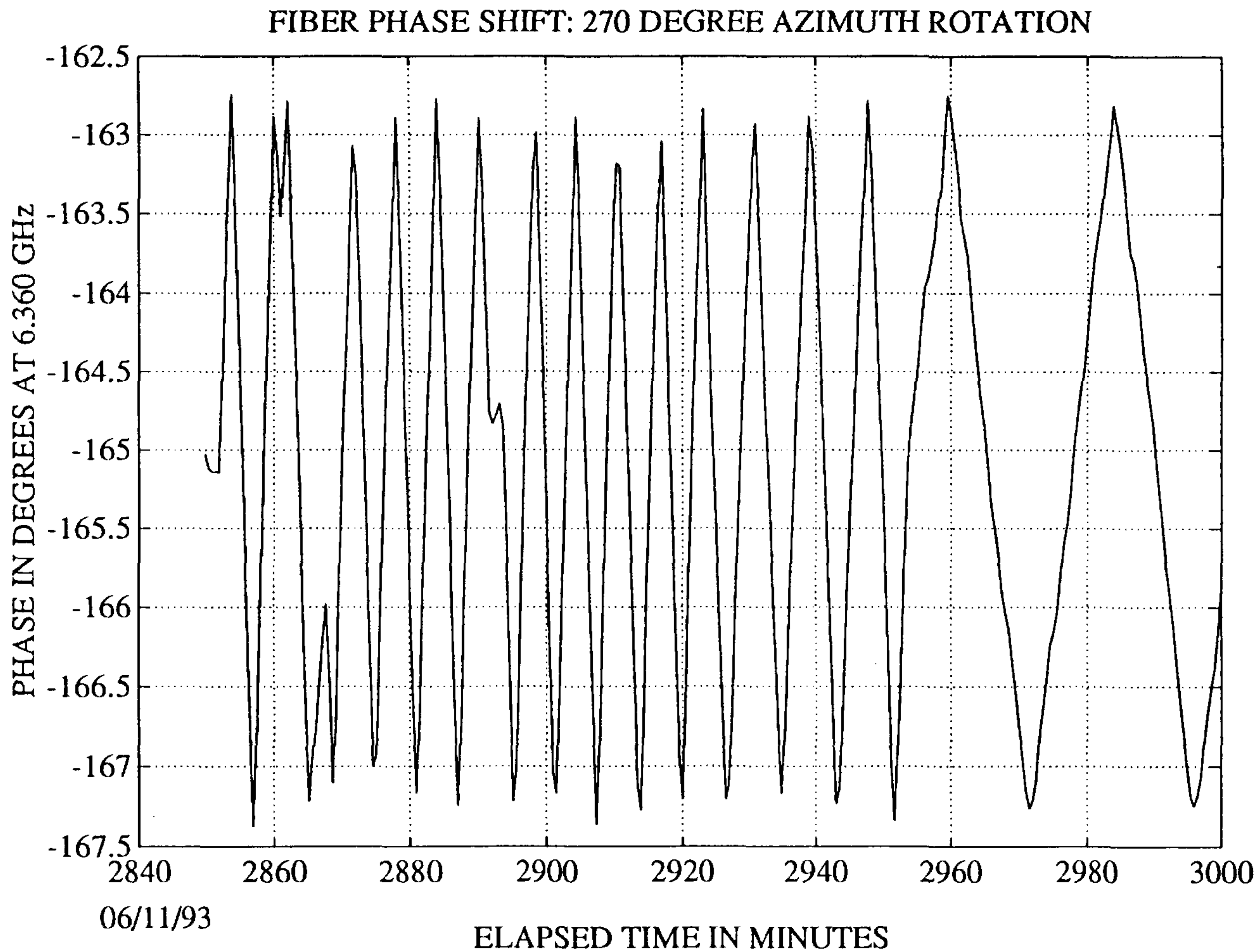

Figure 4 SUMITOMO CABLE (2 FIBERS) ON HELICAL WRAP - 270° ROTATION

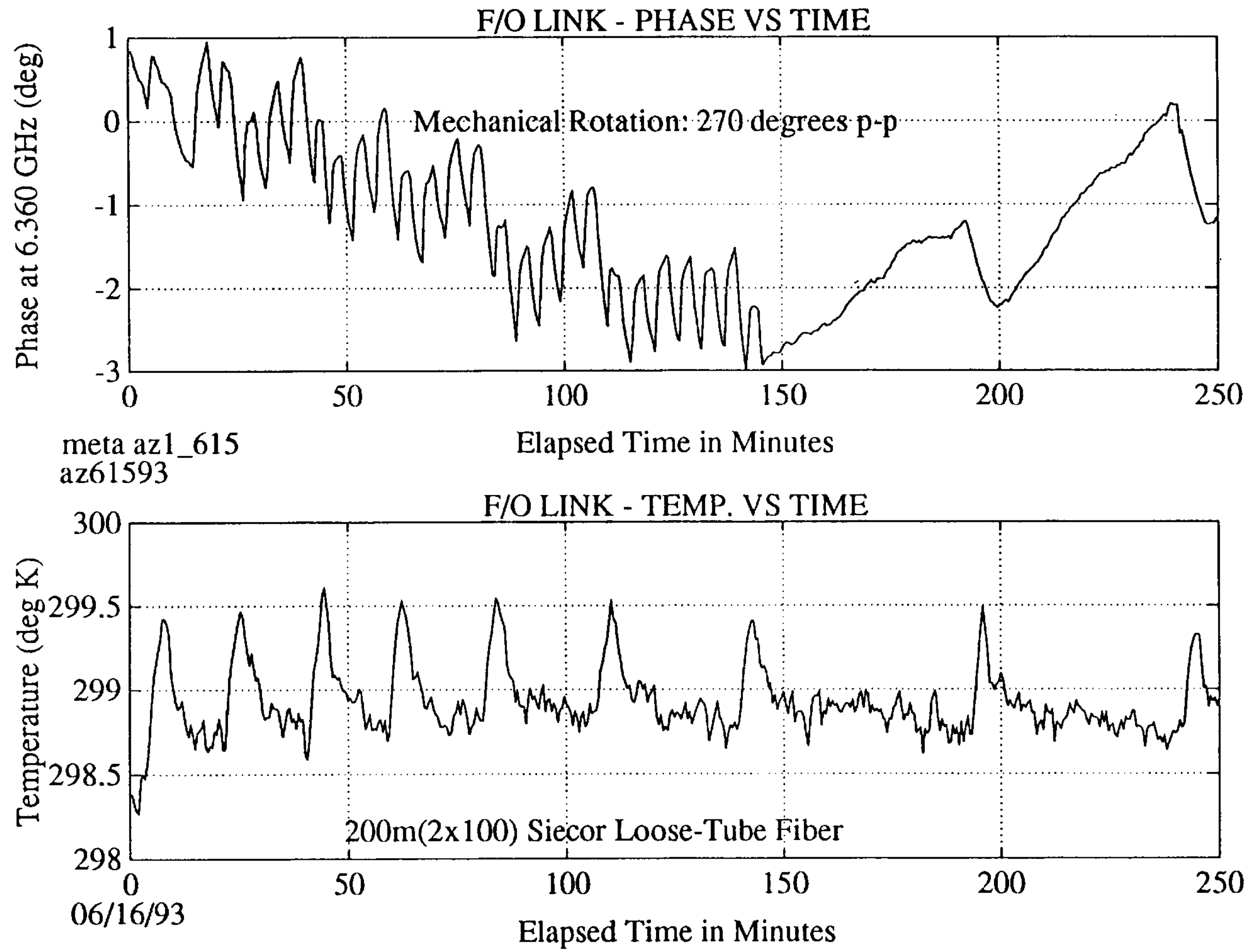

Figure 5 SIECOR LOOSE-TUBE CABLE (200 METERS) ON HELICAL WRAP: 270° ROTATION

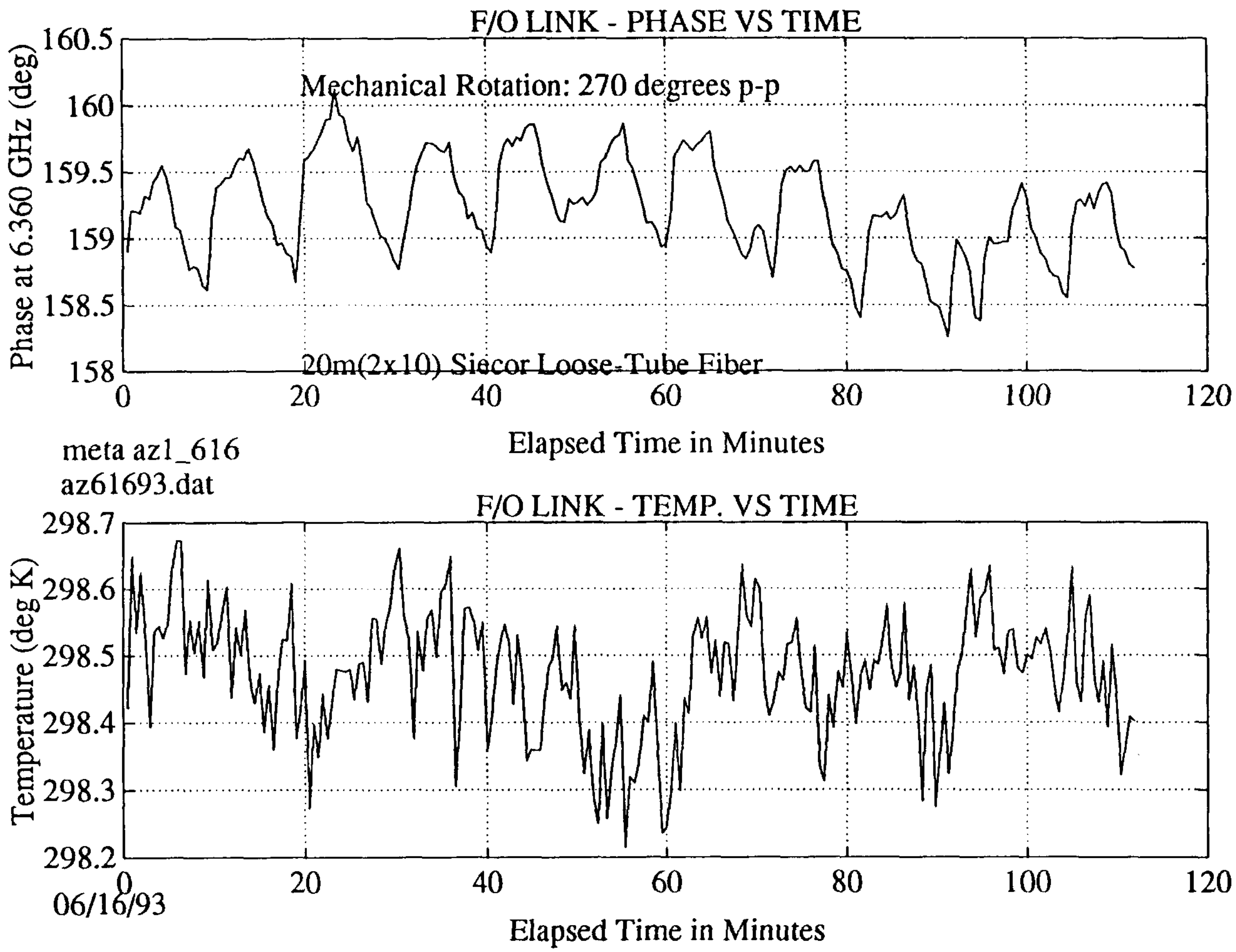

Figure 6 **SIECOR LOOSE-TUBE CABLE (20 METERS) ON HELICAL WRAP: 270° ROTATION**

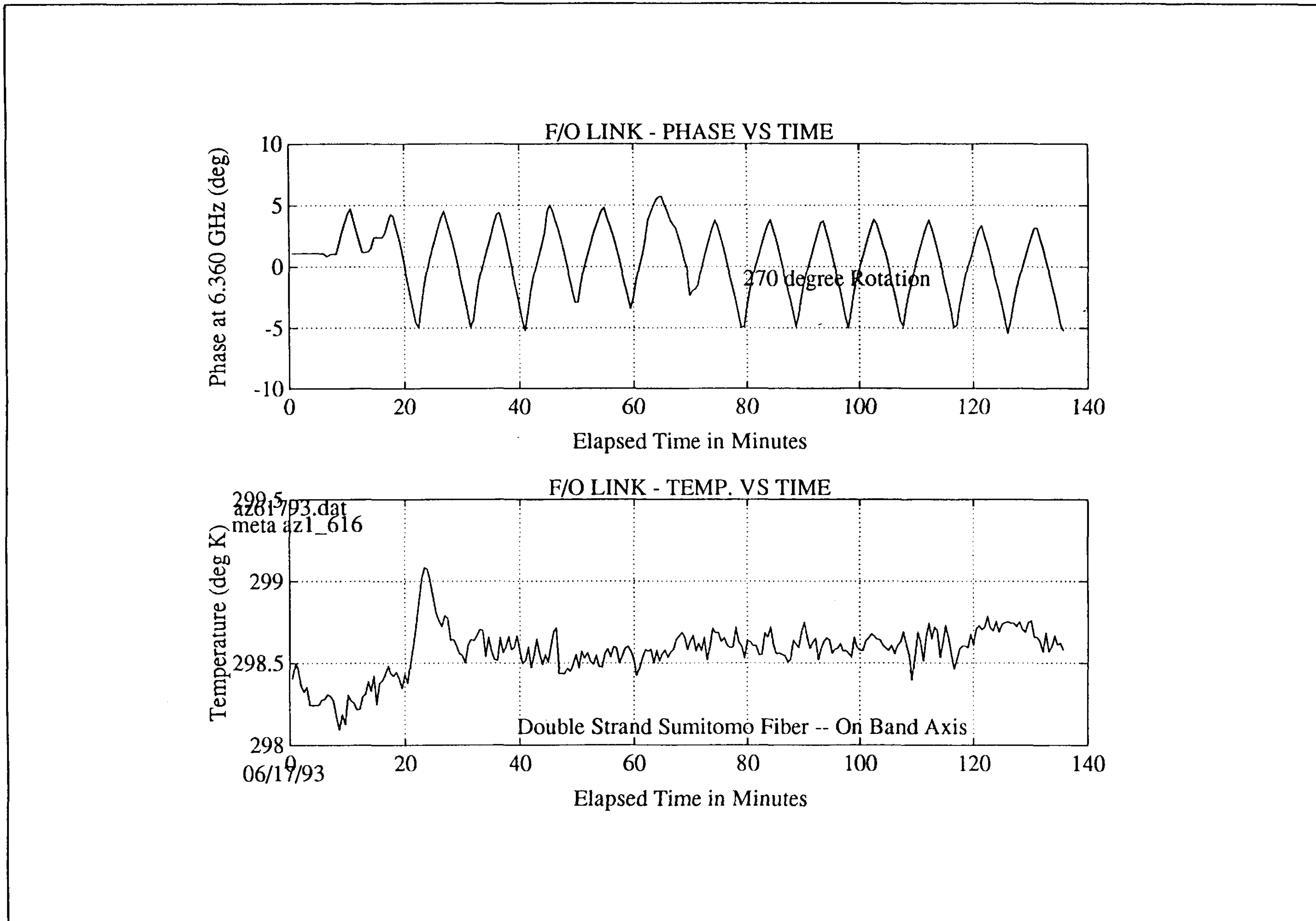

Figure 7 **SUMITOMO FIBER (2 FIBERS) ON HELICAL BAND AXIS: 270 DEGREE ROTATION**

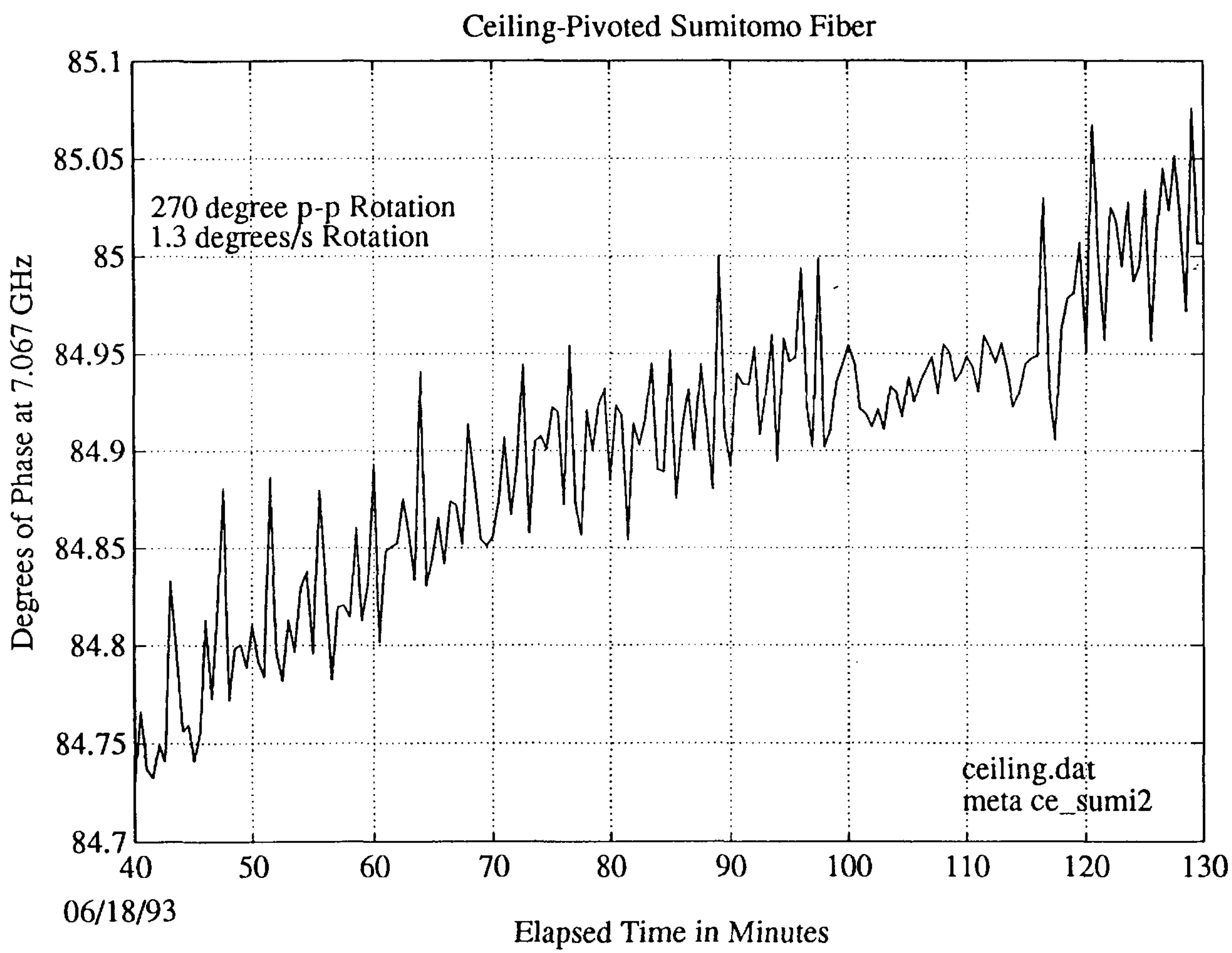

Figure 8 **SUMITOMO FIBER (2 FIBERS) IN TORSION WRAP: 270 DEGREE ROTATION**

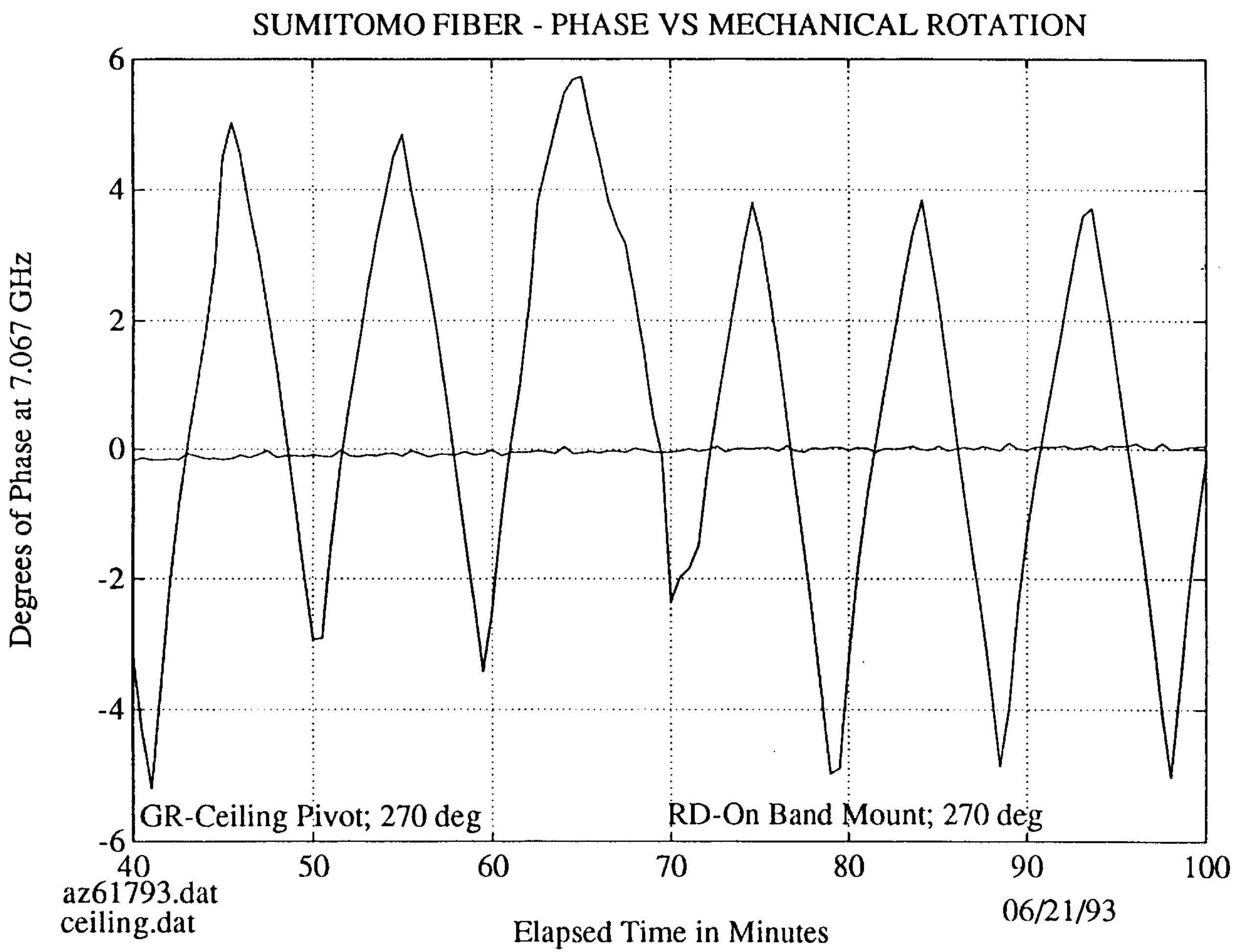

Figure 9 **SUMITOMO FIBER: COMPARISON OF HELICAL AND TORSION CABLE WRAPS**

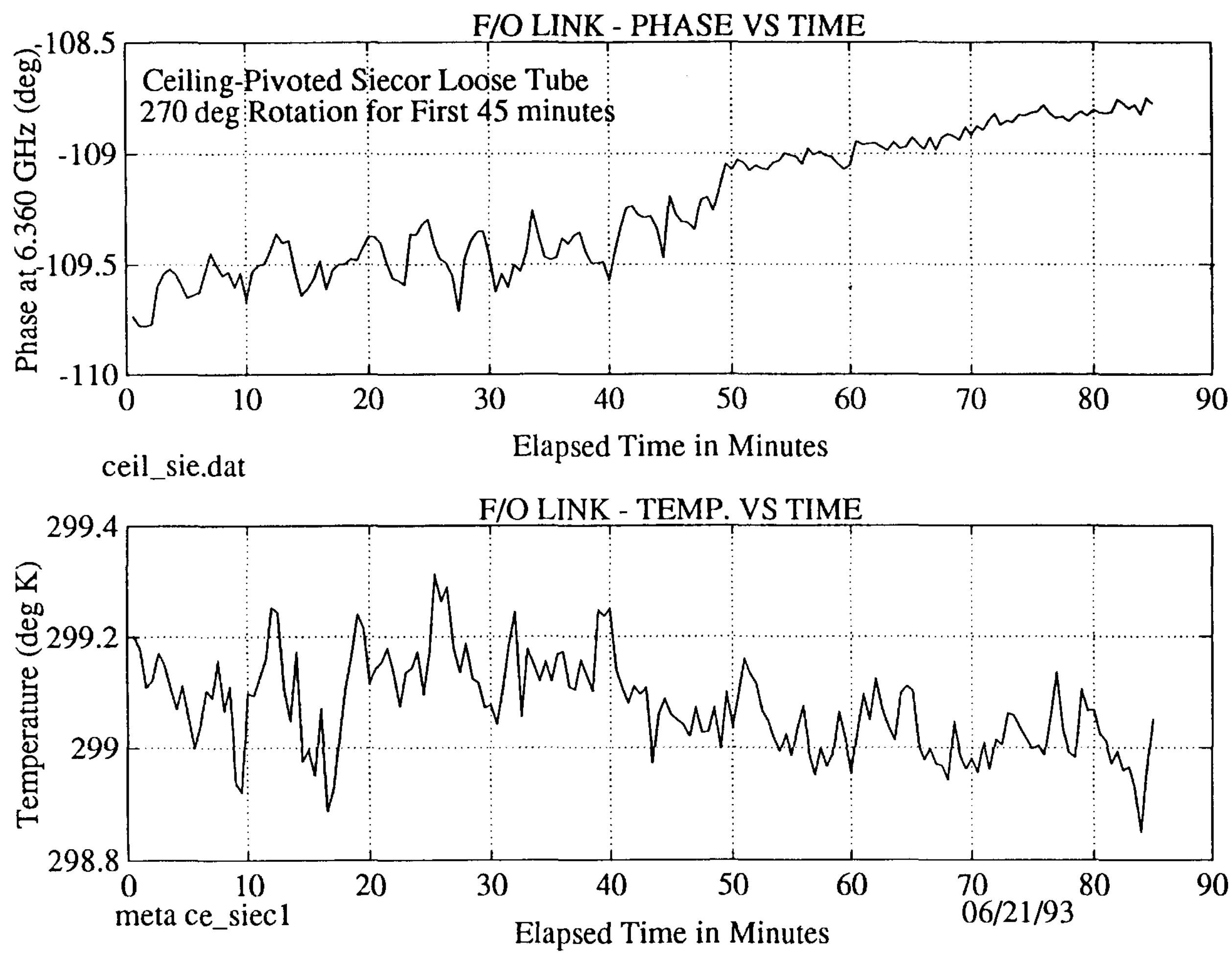

Figure 10 **SIECOR LOOSE-TUBE (2 FIBERS) IN TORSION WRAP: 270 DEGREE ROTATION**

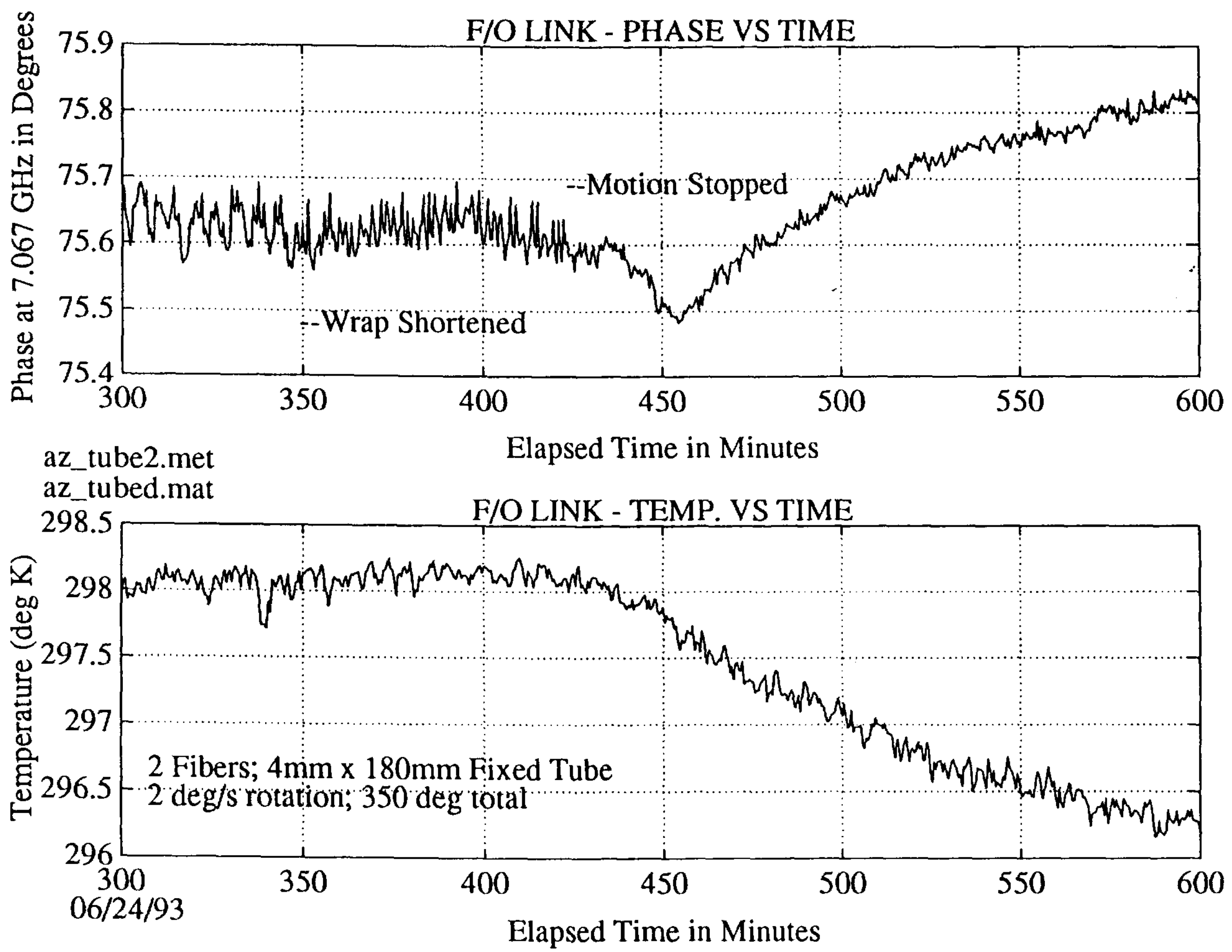

Figure 11 **SUMITOMO FIBER (2 FIBERS): TORSION WRAP WITH ATTACHED 4 mm SLEEVE**

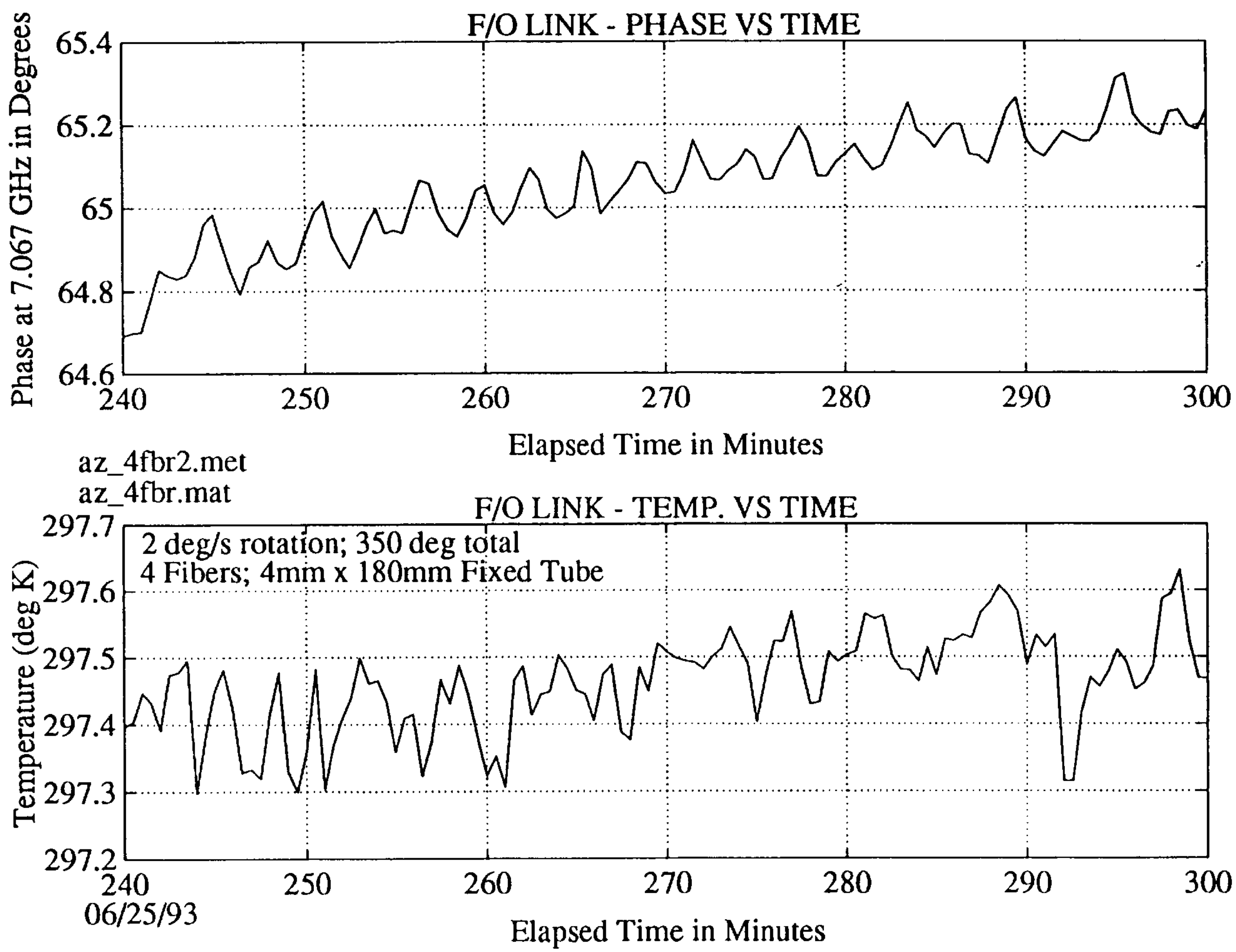

Figure 12 **SUMITOMO FIBER (4 FIBERS): TORSION WRAP WITH ATTACHED 4 mm SLEEVE**

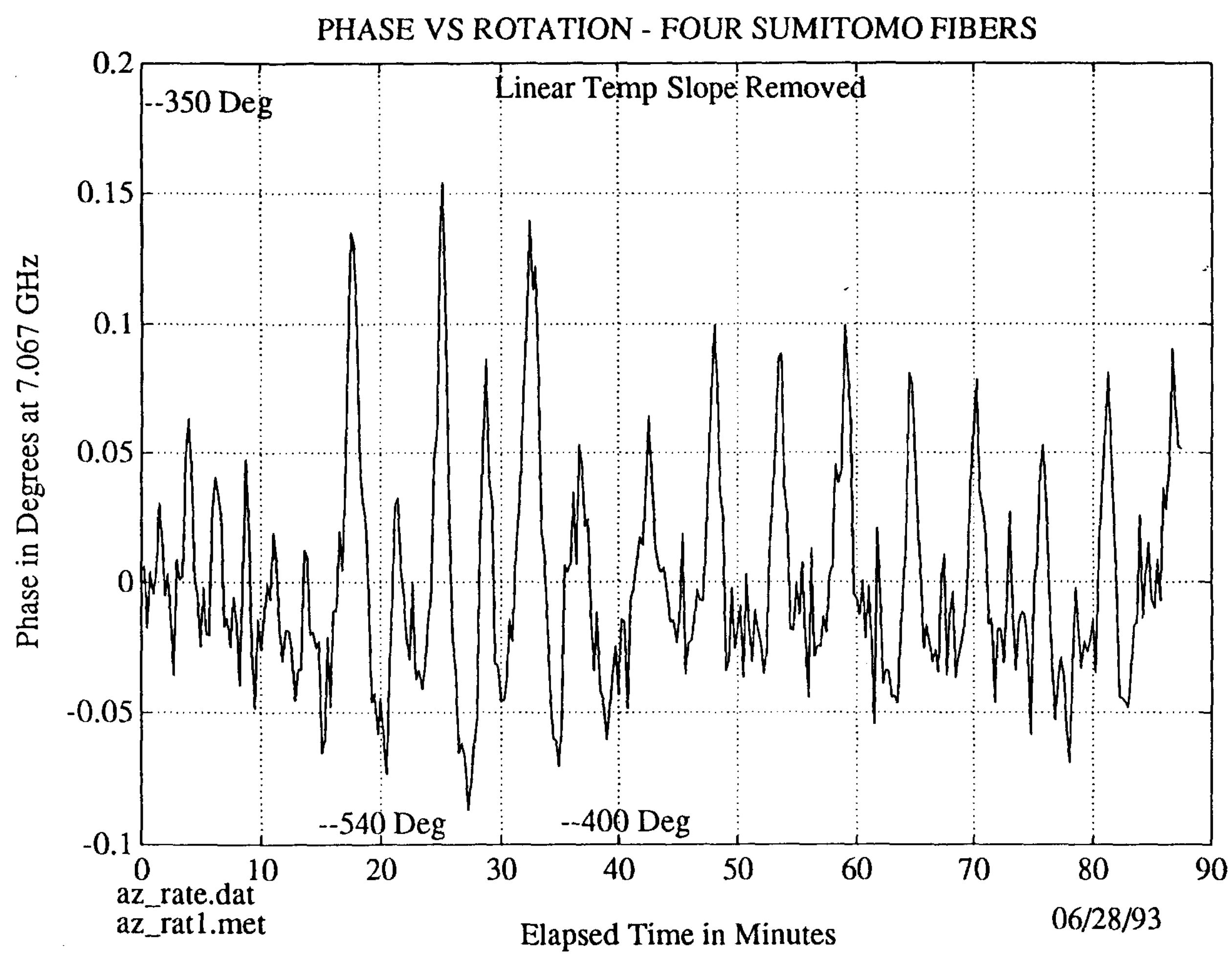

Figure 13 **SUMITOMO FIBER IN TORSION WRAP: 270, 400, 540 DEGREE ROTATION ANGLE**