Submillimeter Array Technical Memorandum

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MODIFIED AZIMUTH CABLE WRAP

1. INTRODUCTION

Recent concerns about the orientation of the poured-concrete antenna pads on Mauna Kea have led to a reexamination of the limitations on antenna rotation imposed by the azimuth cable wrap; the single-mode fiber wrap in particular. It may be desirable to provide a total antenna rotation capability which is greater than the ±270 degrees currently envisioned. The current fiberoptic wrap design does not, in of itself, impose a physical constraint on the allowable rotation angle, within reasonable limits. However, performance considerations, especially phase and amplitude perturbations of the local oscillator signals, and reliability and longevity of the fiber and its jacket, must be taken into account in determining the maximum wrap angle. It should be emphasized that there is no particular significance to the present 270 degree limit, except that it is a formal requirement of the overall antenna specification and that our experience is very limited for excursions beyond 270 degrees.

The design of the SMA azimuth cable wrap is driven by the requirement to transport local oscillator reference signals in the 6 to 8GHz frequency range to the rotating platforms with minimal phase perturbation of the electrical path length. 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 20 microns or less.

Measurements of the fiber path-length variations induced by mechanical stress clearly demonstrates that optical fibers are much less sensitive to pure torsional motion than to either bending or elongation. The azimuth torsion wrap design exploits this characteristic by absorbing 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 positioned on the vertical section of the fiber such that there no bends within the rotating fiber segment.

2, OPTIONS FOR PAD ORIENTATION COMPENSATION

Two options are available to allow the cable wrap to operate with the existing, incorrectly orientated, antenna pads:

1. Allow the angular rotation of the fiber wrap to exceed 270 degrees as measured from the fiber neutral axis. No design changes are required to implement this approach, but for the reasons detailed in the following sections, there is the possibility of both performance and lifetime penalties.

2. Modify the existing design to allow the fiber neutral axis to be reset to accommodate the actual orientation of the antenna pad. The mechanical and electrical design is somewhat more complex than that of the existing concept, but an adjustment range of ±45 degrees is adequate to compensate for the existing pad orientation variations and maintain the total rotation angle to less than ±270 degrees for any observation schedule.

Note that the fiber neutral axis is defined as the baseline of the wrap rotation angle; the phase error increases symmetrically with rotation in either direction from the neutral axis. The neutral axis not visually obvious and must be determined by experiment for each wrap configuration.

3. DEVELOPMENT HISTORY

The present fiberoptic cablewrap design evolved in three distinct phases. The initial design of the SMA azimuth cable wrap was a conventional helical structure using steel bands positioned at an nominal diameter of about 30 inches by a set of articulated aluminum arms which freely rotated on a ten-inch central post. Power and signal cables, including optical fibers, were 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 were clamped to a plate which is secured to the ground. Similarly, at the top of the assembly the bands and cables were 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 using four Sumitomo Temperature-Compensated Delay (TCD) fibers cabled into a semi-rigid, loose-tube configuration. The results were unambiguous: The phase perturbations of the conventional helical structure was literally orders of magnitude too large for the SMA application.

However, a key observation was made during the testing of the helical wrap; there is a direct relationship between the axial tension applied to a fiber and the measured phase shift through the

Peak- to-Peak Wrap Rotation (In Degrees)	Peak- to-Peak Path-Length Error (In Microns)
350	5.9
400	12
540	24

In the closed loop case (tension servo enabled), the magnitude of the phase error is too small to extract a meaningful functional relationship, but the plot of phase error versus peak-peak rotation angle shown in Figure 3 (From SMA Technical Memorandum 73) is consistent with the quadratic hypothesis.

Several subtleties of the phase-error budget should be noted carefully. The first of these, and perhaps most important, is that there is currently no data for rotation angles greater than 540 degrees and little justification for assuming that the available data can be extrapolated to larger rotation angles. Secondly, simply redesigning the wrap to allow for a greater rotation does not degrade performance for smaller rotation angles: The error budget degrades only as the wrap is actually moved into the extended rotation range. Third, in interferometer mode, the total path-length error depends on how well the individual antenna azimuth wrap errors track each other. In the most optimistic case, the path-length error is highly reproducible and there is no net effect on the performance of the array.

4.2 Mechanical Abrasion and Fatigue

As will be described in more detail in Section 5 below, the optical fibers are firmly clamped at two points, one of which rotates with the antenna cabin and one which is fixed to the base of the antenna. The clamping forces are applied directly to a thin plastic jacket which overlies the temperature-compensating coating. In laboratory life testing, this jacketing material has been observed to eventually wear out, exposing the temperature-compensation layer. The abrasion mechanism does not appear to effect the performance of the fiber, but eventually the clamp begins to slip and the tension servo is unable to compensate. The fiber has survived continuous rotation over a 540 degree rotation angle at 1.5 degrees per second for more than three months, which translates to at least a year of field service. However, we have no experience with rotation angles greater than 540 degrees and again there is no justification to extrapolate the available lifetime data to rotation angles other than 540 degrees.

Abrasion lifetime is purely a mechanical design issue. It is probable that a clamp can be designed to more evenly distribute the torsional forces over the surface of the fiber, minimizing these concerns. Also, as in the case of the phase-error budget, designing the wrap for a greater rotation angle does not lead to a shorter fiber lifetime, in of itself. Fatigue, and consequent failure of the glass fiber, is a more fundamental issue. The conventional wisdom is that “glass is not subject to fatigue” but experimental evidence to support or dispute this

contention, particularly in the torsion mode in which the azimuth wrap fibers are stressed is unavailable. As a practical matter, no fatigue failures have been observed during lifetime testing at SAO, but this may simply be due to the earlier onset of abrasion effects in the fiber jacket.

5. AZIMUTH WRAP MECHANICAL DESIGN

5.1 Current Design Concept

Figure 3 illustrates the major elements of the azimuth tension servo wrap. The upper portion of the mechanism, which includes the tension servo components, is secured to the alidade and rotates with the antenna structure. The bundle of three Sumitomo Temperature Compensated Delay (TCD) fibers is clamped into a v-groove adapter which is rigidly mounted to the actuator arm of a Minibeam MB-5 load cell. The Minibeam load cell is ideally suited for this application; since the internal strain gauge simples measures the deflection of a 6-mm thick aluminum block, there are no moving parts and very little displacement of the actuator is required. The load cell, in turn, in rigidly mounted to the platform of a three-axis Newport M-462 optical stage and the cell moves with the platform. The vertical motion of the platform is controlled by Newport motorized micrometer with an integral incremental optical encoder. The strain gauge and optical encoder outputs are fed to a PMAC motion controller, which is programmed to maintain a constant tension as the antenna tracking motion twists and untwists the fiber bundle.

The fiber bundle passes vertically through a 4-mm clearance hole in the center of the azimuth encoder body to the bottom of the well formed by the azimuth bearing support, The lower end of the fiber bundle is terminated at the fixed clamp, about two meters below the upper clamp, which is rigidly attached to the antenna support base. The fibers are precisely aligned along the axis of rotation and the upper and lower clamps are positioned such that there no bending forces imposed on the rotating fiber segment. Not shown in the figure is a hollow tube, backfilled with a hydrophobic gel, which serves to dampen vibrations of the taut fibers.

The rotating fibers, as they emerge from the fixed lower clamp, are fusion spliced to an extension cable which terminates in a junction box near the antenna base handhold. Three Diamond E-2000 adapters are accessible on the front surface of the junction box for the connectorized jumper fibers which feed the antenna pad junction box.

5.2 Proposed Upgrade to the Azimuth Wrap

The modified tension-servo azimuth wrap is shown schematically in Figure 4. The upper mechanism and tension servo, which are located in and rotate with the antenna cabin, are identical to the corresponding parts of the existing design. The lower mechanism, within and fixed to the base of the antenna, is modified to provide an additional degree of freedom: The

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lower fiber clamp can be rotated by approximately ±45° around its vertical axis with respect to the nominal neutral axis. This rotation capability, in turn, allows the antenna fiducial point to be repositioned anywhere within this ±45° range to compensate for misorientation of the pad.

The lower clamp is secured to a bearing which is rigidly secured to the antenna base. The stepper motor is coupled to the lower clamp through a simple gear train which allows the motor to rotate the clamp over the ±45° range in increments of approximately 1.4". The stepper motor actuator is directly controlled by the antenna computer; an internal optical encoder provides angular position feedback to the computer. The fiber bundle is affected in only one detail by the addition of the rotatable 'clamp; the exit point of the bundle moves over a comparable angular range, requiring a service loop in the extension cable to the antenna base junction box. The service loop is constrained to move in a controlled, repeatable manner as the lower clamp is rotated, preferably in a single plane.

It should be emphasized that the rotation operation occurs only once, at each repositioning of an antenna onto a pad. The service loop is not stressed during routine antenna tracking. Nevertheless, the service loop must be carefully designed and installed to minimize kinking and bend instability. The uncontrolled relaxation of a cable bend during an observation could cause a major phase perturbation. It should also be noted that the interior of the antenna base is relatively inaccessible and routine installation and maintenance, for either the present or the upgraded version of the cable wrap, may be somewhat awkward.

Each antenna is aware of the pad on which it is situated; this information is required for tracking and collision avoidance purposes, and is available to the cable wrap rotation mechanism. If the pad orientation (or orientation error) is stored in the array controller database, the antenna computer will automatically set the neutral axis so as to minimize total antenna rotation. No operator intervention is required, either at initialization or during the progress of the observation.

5.3 Cost Estimates for the Upgraded Azimuth Wrap

The following estimates represent the additional costs to upgrade the existing azimuth wrap concept. The estimates do not include the nonrecurring and recurring costs of the baseline azimuth wrap.

Estimated Incremental Nonrecurring Costs

Mechanical Engineer:	1 Man Week
Mechanical Designer:	4 Man Weeks
Electrical Engineer:	3 Man Weeks

Drafting and Documentation:	2 Man Weeks
Programmer	1 Man Week
Miscellaneous Parts and Services	$3500

Approximate Incremental Nonrecurring Costs: $17,000

Estimated Incremental Recurring Costs (Per Antenna)

Mechanical Technician	1 Man Week
Mechanical Parts	$1800
Electrical/Electronic Parts	$1200

Approximate Incremental Recurring Costs: $4,000 per antenna

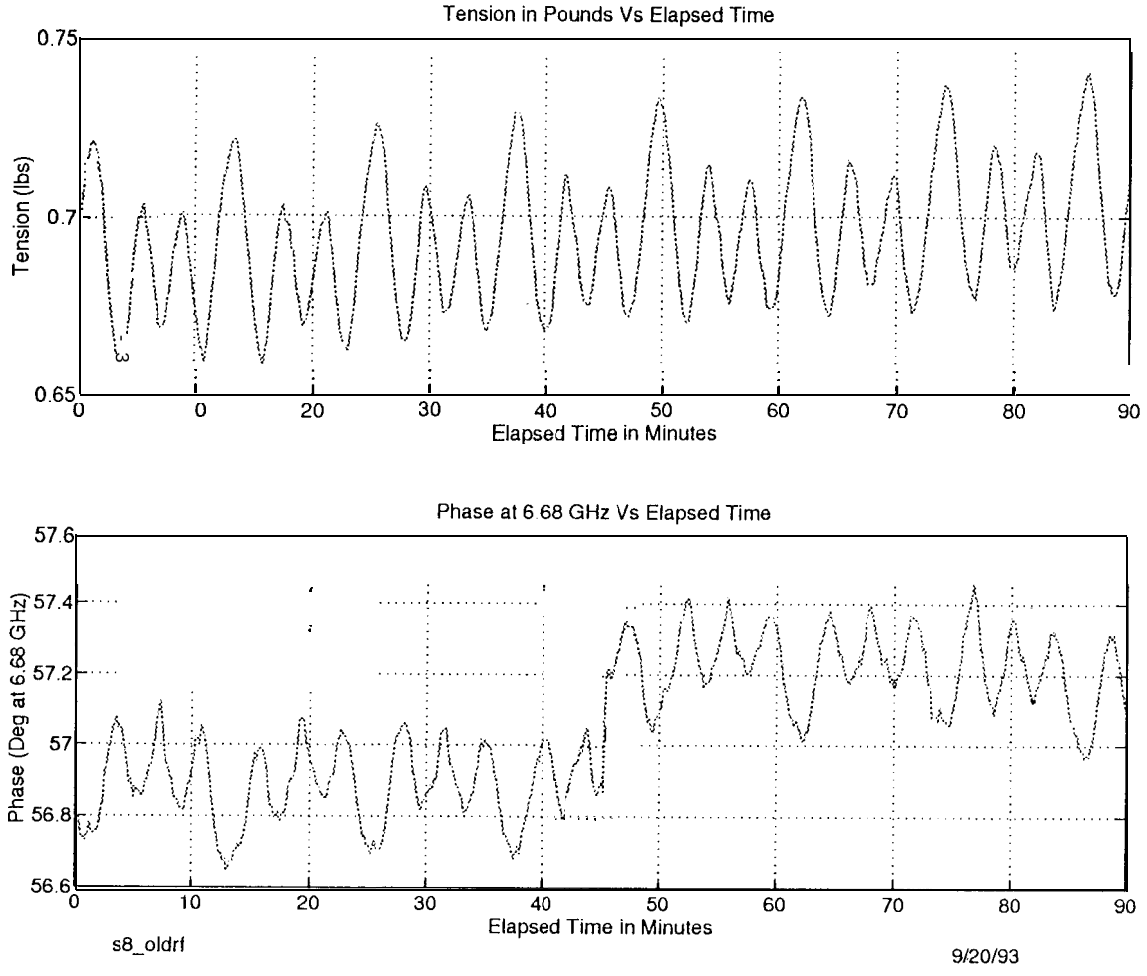

Figure 1 FIBER TENSION AND PHASE ERROR VS ELAPSED TIME

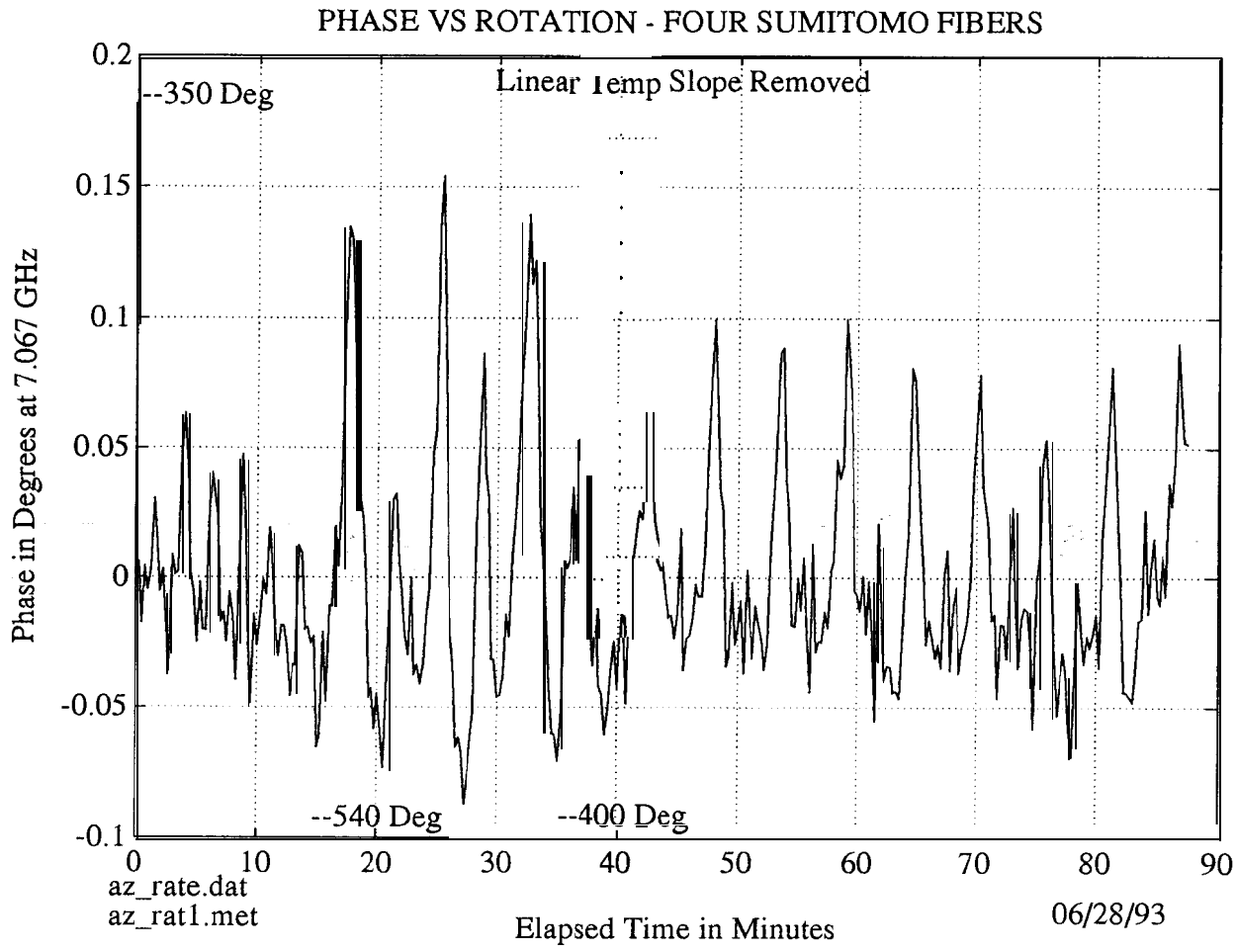

FIGURE 2 **SUMITOMO FIBER IN TORSION WRAP: 270, 400, 540 DEGREE ROTATION ANGLE**

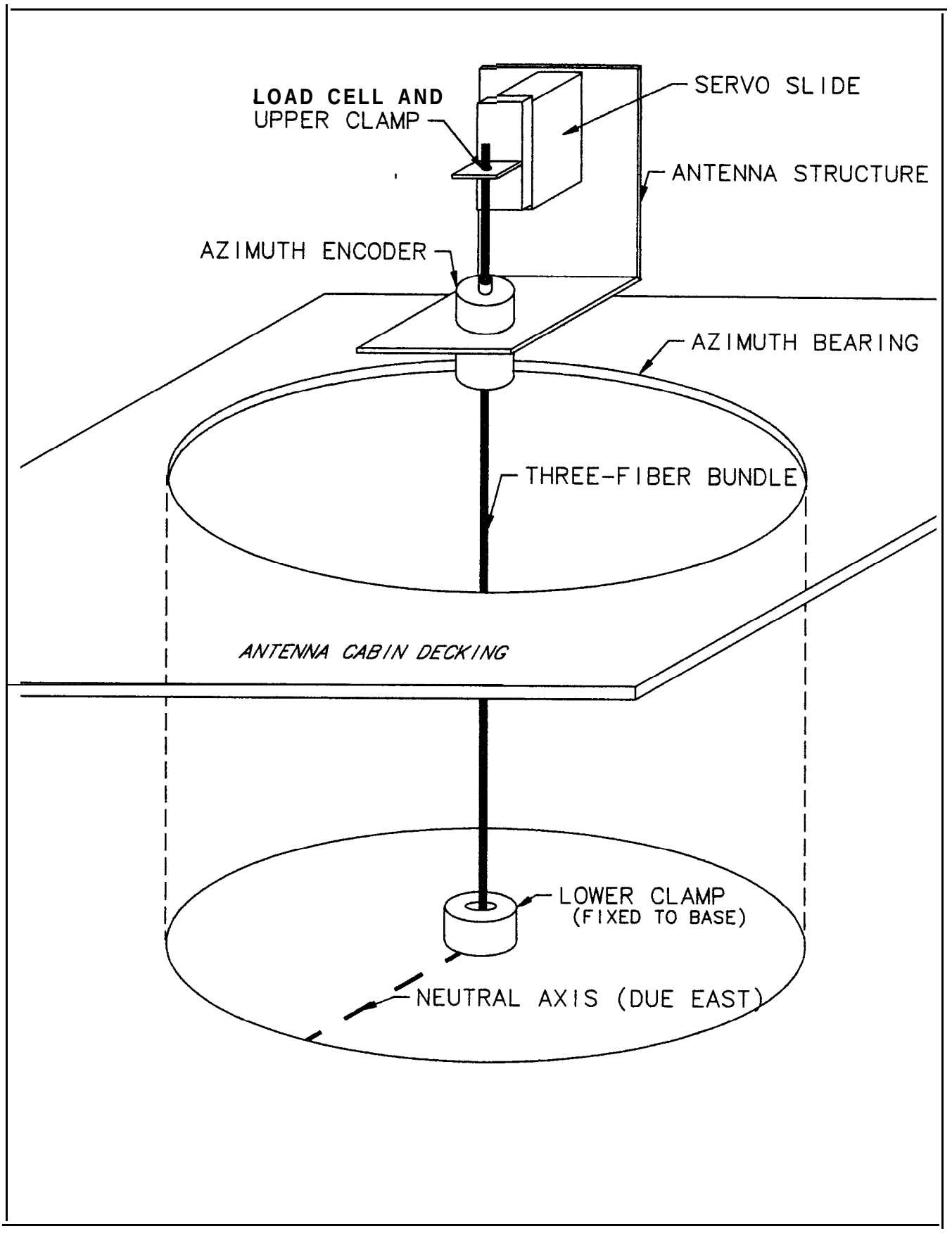

FIGURE 3
TENSION SERVO AZIMUTH WRAP

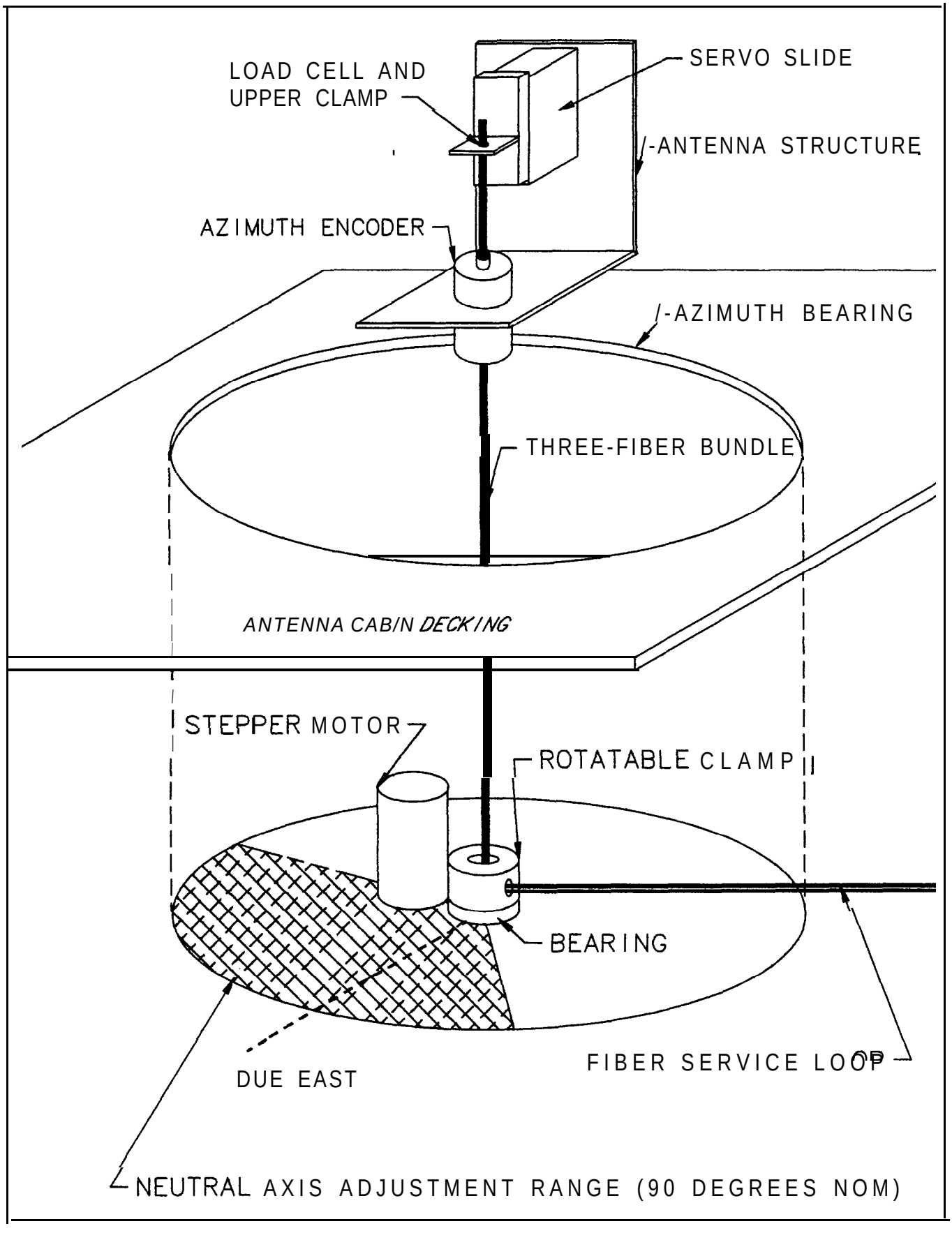

FIGURE 4
UPGRADED TENSION SERVO AZIMUTH WRAP