VLA TEST MEMORANDUM NO. 156

VLA ANTENNA
TILT AND TEMPERATURE TESTS

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March 1991

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Introduction.

Tilt sensors were installed on VLA antennas 6 and 22 in November 1989 (reference 1), and temperature sensors were installed on antenna 6 in October 1990 (reference 2). This document is a status report of tests performed November 1990 through February 1991, using the tilt and temperature sensors to characterize performance of the VLA antennas, performance that may impact pointing.

During static tests, data were collected with the antennas stowed at different azimuth positions: the dish was moved to the zenith pointing position, the servos turned off, and the brakes set. During maintenance days, data were collected from sunrise to midafternoon. Over Thanksgiving and Christmas, and during the period Jan. 30 through Feb. 3, 1991, data were collected for 24 hours.

Two other tests were performed: one, to determine the performance of the tilt sensors while tracking a sidereal object; and two, to measure repeatability or hysteresis of tilt.

Static tilt and temperature tests.

The intent was to collect tilt and temperature data at 4 azimuth pointing angles, 90°, 180°, 270°, and 360° with the original insulation, and then to repeat the measurements with insulation added to the concrete piers and to the yoke face. Insulation was added to the east, west, and south faces of the concrete piers on January 2, and to the front yoke face on January 31 to mid-February.

The Command and Monitor System was used to sample all sensors every 80 seconds during the test period. As well, temperature and wind information was recorded every 320 seconds. Plots of all the data are too numerous to include in this document, but Figures 1 - 7 are included as examples. The remainder of the plots have been organized in a binder kept in the Electronics Lab, and all data, plotted or unplotted, are preserved on floppy disks.

The tilt data are read from sensor boxes, one mounted near the top of each yoke arm on antennas 6 and 22. Each box contains two single-axis tilt sensors mounted orthogonally to each other. One sensor measures tilt perpendicular to the elevation axle (x) and the other parallel (y). The sign of a given axis is reversed between yoke arms, so that a positive tilt on one yoke arm will register as a negative tilt on the opposite arm. With the dish at horizon pointing, a positive x tilt on the "encoder" arm indicates the antenna is tipping forward, pointing the dish lower. A tilt that raises the "waveguide" arm and lowers the encoder arm is a positive y tilt on the encoder arm. This sense was verified by moving the sensor and recording the effect with the Command and Monitor System.

Thirty-two temperature sensors measured the structure and pier temperatures: 7 sensors on the subreflector support legs, 2 on each yoke arm, 1 each on the front and back of the yoke base, 2 on each of the three tubes that lead from the piers to the azimuth gear "torque box" support, 2 on each of the 3 horizontal I-beams that rest on the piers, and 2 on each of the concrete piers (CN7). One sensor measured ambient temperature above the elevation axle.

Figures 1 and 2 show X and Y tilts for Antenna 6 when stowed at 90° geographical azimuth (270° encoder azimuth). Figures 3 and 4 show pier temperatures before and after the installation of R-4 Insulbead insulation on the south, east, and west faces. Figures 5 and 6 show yoke temperatures before and after the installation of the same insulation on the front and first 4' of the top front of the yoke base, but not the yoke arms, nor the back of the yoke base. Most of the yoke surfaces are already insulated; the new insulation was temporarily taped on top of the existing insulation. Figure 7 is an example of elevation encoder "drift" -- an apparent motion of the elevation axle with respect to the yoke arm that occurs with the antenna stationary and drives off.

Here is what the plots show:

1. Antenna 6 and 22 tilt north from a baseline established at dawn an average of 23 arcseconds. Averages for when the peaking occurred are misleading, since many of the tests ceased midafternoon. The latest recorded time for a peak was at 6 pm MST. The average time of day for the north tilting peak is probably around sundown. The averages were taken over 11 tests on each telescope.

2. Both antennas tilt west an average of 8 arcseconds from the dawn baseline in the morning and tilt west and average of 6 arcseconds in the afternoon. The peaks occur at 10:30 am MST and at 3:30 pm MST, respectively. The largest tilts that occurred in either east or west direction were 20 arcseconds.

3. The tilt sensor data show that the arms move with respect to each other. Since the tilt sensor on the "encoder" arm showed more reasonable results, the data from that sensor were established as "correct" without further verification. With this assumption, the "waveguide" arm of the yoke moves back from the dish and away from the center of the structure.

The waveguide yoke arm moves back an average of 11 arcseconds from the dawn baseline and an average of 39 arcseconds to the side, on the two antennas tested. The maximum peaks encountered during the test period were 40 and 90 arcseconds, respectively. The average time of day for the peaks to occur appears to be midafternoon.

4. The eight tests that were performed all night show that the tilt sensor axis parallel to the elevation axle, y, reaches the dawn baseline by 6:14 am MST on the average, and the perpendicular axis, x, by 11:10 pm MST on the average. The disparity between x and y is caused by the extra time necessary for the waveguide arm distortion discussed earlier to correct to its baseline position. The average and maximum tilt changes in arcseconds per tilt sensor for the period from 9 pm MST to dawn are shown in the chart below:

	Enc X	Enc Y	WG X	WG Y
average	6	10	7	12
maximum	15	18	15	28

These data show that the tilts introduced during the day by the sun take most of the night to fully "unwind."

5. The "encoder drift" data show that the elevation axle moves in the direction of descending elevation, peaking at an average of -21 arcseconds in the early afternoon. The shape of the drift curve repeats on every antenna at

a given azimuth position, and the amplitude is always about the same. The encoder returns to the dawn baseline by 11 pm MST on the average.

6. The additional insulation on the concrete piers reduced temperature differentials between north and south pier faces from a high of around 20°C to near 0.

7. The insulation added to the front yoke face alone reduced the temperature differentials between the front face and the yoke arms, but differentials between front and back and between back and yoke arms were still as high as 5°C. The consistently elevated temperature of the front yoke face is apparently real within 1°C, based on independent measurements with an electronic thermometer.

8. The differential temperatures in the tubes leading from the piers to the azimuth gear support are minimal with the insulation currently installed.

9. The differential temperatures between subreflector support legs and between horizontal I-beams are typically less than or equal to 1°C. There is a phase lag between an ambient temperature change and a structure change, more pronounced on the I-beams.

10. The ambient temperature sensor at the antenna followed the array temperature sensor reasonably, though the array sensor apparently has an integrator which smooths out some of the peaks measured with the sensor at the antenna.

11. The plots of the measured tilts in a given axis look much the same from test to test and for both antennas. The tilt curves and the encoder drift curves seem to indicate that the performance of antennas 6 and 22 as a result of solar heating is much the same and repeatable.

The tilt measurements imply that antenna 6 and 22 tilt north, and to a lesser extent west and east, during the day, taking at least half the night to "unwind." The relationship between the "daytime" tilts and pointing is unknown. P. Napier points out that similar tests on the VLBA antenna showed surprisingly small pointing error for the amount of tilt measured with the antenna standing still. He theorizes that temperature differentials of the antenna in use are less than with the antenna stationary, because the structure in motion is heated more uniformally. To pursue the use of tilt sensors further, the relationship between measured tilts and pointing needs to be established. Also, tilts need to be measured with the antenna in operation, but the tracking tests explained later on explain why this is difficult.

The average displacement of the waveguide yoke arm with respect to the encoder yoke arm is 40.5 arcseconds. Coincidentally, the tilt that would be introduced in the waveguide yoke arm by the expansion of one-half of the elevation axle over a 20°C temperature rise is 44 arcseconds. The elevation bearing on the encoder arm is a floating bearing so that the thermal axle expansion should pass through the arm instead of distorting it. But the waveguide arm has a fixed bearing, and supports for the vertex room welded to the axle may prevent the expansion from the waveguide half of the axle from passing through the floating bearing. R. Stidstone points out, however, that these supports are not fastened to the vertex room floor. A third sensor on the yoke base or other independent means is necessary to verify the tilt measurements. In any case, the relationship between the motion of the waveguide arm and pointing is unknown.

Any motion of the structure that turns the elevation axle will show up as a drift on the elevation position encoder, since the servos were off for the tests. During normal operation, the elevation drive would servo the axle to force the encoder to a commanded value. Because of this, the drift may not be of much importance, though understanding the mechanism may lead to a useful understanding of thermally-introduced distortion in the structure.

Temperature differentials in the yoke are the most likely source of the diurnal tilt motions. Based on R. Newell's estimates in VLA Test Memo 129 and summarized in Reference 3, the 5°C temperature differentials measured in the yoke during the test period will introduce 25 arcseconds of tilt deviation. Additional insulation of the yoke base, barriers between upper and lower pedestal rooms, and air circulation in the yoke are fertile test possibilities.

Insulation of the concrete piers, though reducing temperature differentials between north and south faces to near 0, had little effect on the daytime tilts. Added insulation to the yoke front showed that the existing insulation is not insulating all that well, but the test was inadequate to remove large temperature differentials.

Tilt sensor performance while tracking.

To test the performance of the tilt sensors while tracking the antenna, a fictitious sidereal object was selected at about 30° declination and -2 hours hour angle. At this position in the sky, azimuth velocity is fairly constant and as slow as the elevation velocity. The recording data tap chart recorder was set to record two tilt axes at the waveguide sampling rate (19.2 Hz), and the LSB for both absolute position encoders. Figure 8 shows the result. Large spikes of 10's of arcseconds in amplitude, caused by an as yet unidentified torque disturbance, are followed by a ringing oscillation at 2.2 Hz, the locked-rotor resonant frequency of the drives according to the E-Systems servo drive manual. The wind was less than 10 mph for the duration of the tests, and thus unlikely to be the source of the torque disturbances. A measurement of the other tilt axes on antenna 6 and on antenna 22 revealed similar performance.

To develop credibility for the data recording tap tests, we manually tracked the antenna in azimuth only, by dialing in a rate with the control panel at the antenna. In this configuration, the motor tachometer feedback is summed with a manual rate command instead of a velocity command from the position loop. The response of the servo drive system to external torque disturbances for the manual operation should, therefore, be the same as under computer control.

An oscilloscope connected to tilt sensor monitor test points in the vertex room showed the following signals:

1. 100 mv p-p of 48 MHz, all channels, including the temperature sensors, apparently a system noise.
2. 55 Hz in the following amplitudes:

Ex	100 mv p-p
Ey	80 mv p-p
Wx	120 mv p-p
Wy	50 mv p-p

The 55 Hz is thought to originate in the sensor since it was not observed on the temperature sensing channels located in the same boxes as the tilt sensors.

3. 2.22 Hz in tilt y and 2.3 Hz in tilt x with an amplitude a function of torque disturbance to the telescope.

4. There was also 25 mv of 60 Hz noted on just the temperature channels. The scale of the tilt test monitor points is 100 arcseconds per 1 volt.

The 2.2 - 2.3 Hz oscillation on the tilt sensor outputs could be introduced with the slightest movement in the vertex room. The oscillations "rang" as they did on the strip chart at the control building. Although Schaevitz gives the natural frequency of the tilt sensor to be 2.5 Hz, the units are heavily damped so that the response to an impulse is specified to settle out in 0.4 seconds. Bench tests on the Schaevitz sensors show no tendency to resonate at the natural frequency.

While tracking at approximately 1.3 arcminutes per second in azimuth, the tilt sensor oscillations were about 30 arcseconds peak-to-peak in tilt x and 5 arcseconds p-p in y. When the tracking rate was increased to 3.3 arcminutes per second, tilt x settled down to 10 arcseconds p-p while y stayed the same. Accelerating to a new tracking velocity caused huge "spikes" which continued to ring at 2.2 Hz for many cycles. The test at the antenna did not include a measurement of the unexplained peaks seen on the chart recorder.

Lissajous (x-y) plots displayed on the oscilloscope showed that Ey and Wy are 180° out-of-phase at the 2.2 Hz frequency with very little phase error, indicating excellent correlation of y axis tilt measurements. Ex and Wx are in-phase while tracking and 180° out-of-phase when stationary, but the Lissajous plot is an ellipse indicating there is phase error and so, some correlation error in x across the yoke, presumably introduced by compliance in the yoke arms.

The tests of the tilt sensors while tracking may indicate that the servo drive system for the antenna is underdamped. If the motor tachometers are "seeing" the antenna motion, it may be possible to stiffen the drive response by decreasing the phase margin or increasing the gain of the servo system.

The large 2.2 Hz spikes on the tilt data, and the relatively slow sampling rate of the Command and Monitor system alias the ModComp tilt data. Even to measure slow tilts introduced by day time heating, the data will have to be averaged in hardware or software for successful use while tracking.

The tests also show that the ModComp Command and Monitor System is an ineffective tool to measure dynamic performance of the tilt sensors. Although the position loop at each antenna is updated at 10 Hz, there is not the bandwidth in the system to read more than two tilt sensors at a time that fast. K. Sowinski claims the maximum practical rate for applying pointing corrections as a function of tilt is once every 10 seconds. The tilt sensor may be an effective tool in measuring tracking performance of each antenna, but without a way to feed the information back into the servo system, the data cannot be used to correct pointing errors introduced by torque disturbances.

Hysteresis test.

Some past data seem to show a hysteresis in tilt on Antenna 6, primarily in tilt y; that is, the tilt measurement did not repeat when the antenna was moved in axis in one direction and then moved back over the same arc in the opposite direction. For this test, I moved the antenna from 180° encoder azimuth to 540° and back to 180°, first in 90° swings and then in 180° swings.

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Figures 9 and 10 were made by plotting the measurements made while moving clockwise (CW) on top of measurements made while moving counterclockwise (CCW). No significant hysteresis is evident. It may be that what appears to be hysteresis in past measurements is the result of real tilts introduced by temperature changes between the time tilt was measured in one direction and when tilt was measured at the same location going in the opposite direction.

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Figures:

1. X Tilts of Antenna 6 while stowed at 90° azimuth.

2. Y Tilts of Antenna 6 while stowed at 90° azimuth.

3. Pier temperatures before insulation.

4. Pier temperatures after insulation.

5. Yoke temperatures before added insulation.

6. Yoke temperatures after added insulation.

7. Elevation encoder drift.

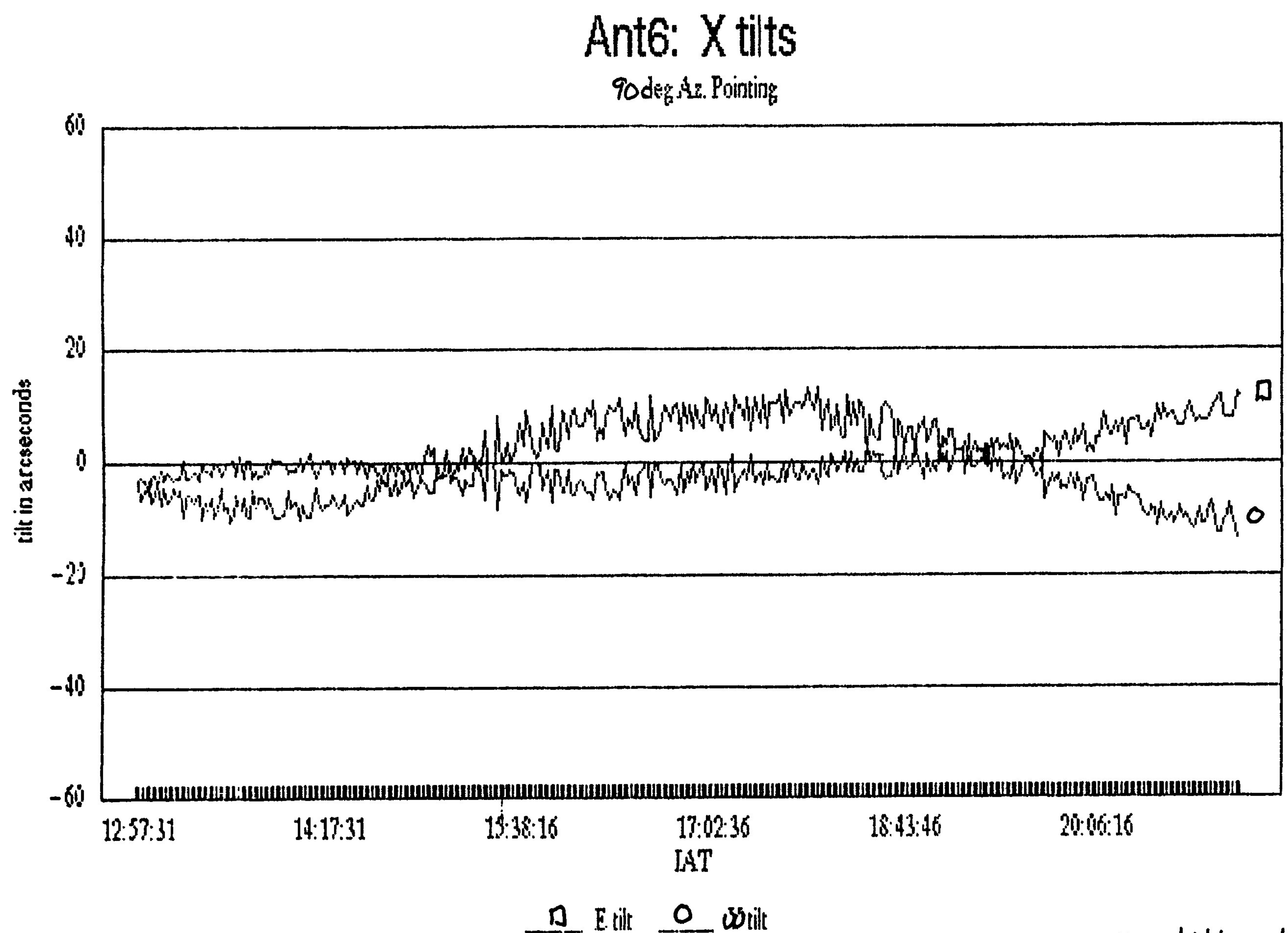
8. Tilts sampled at 19.2 Hz while tracking.

9. X Tilts on Antenna 6 while slewing the antenna.

10. Y Tilts on Antenna 6 while slewing the antenna.

References:

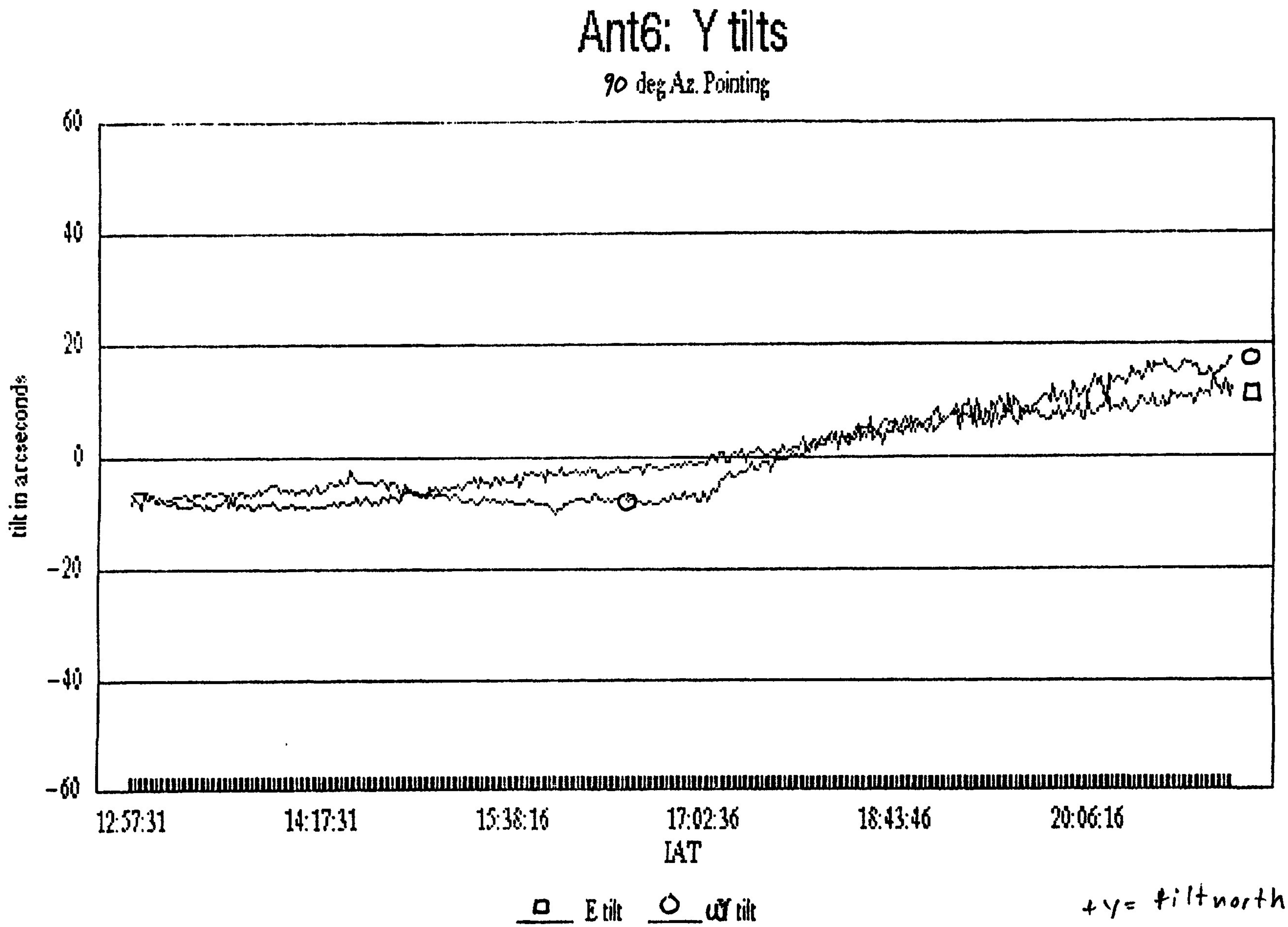
1. VLA Technical Report No. 65, VLA Antenna Tiltmeters, C. Janes and A. Sittler, January 1990.
2. VLA Technical Report No. 66, VLA Antenna Temperature Sensor Array, C. Janes and A. Sittler, March 1991.
3. A Review of VLA Pointing, D. Morris, February 1991.



+x = tilt east

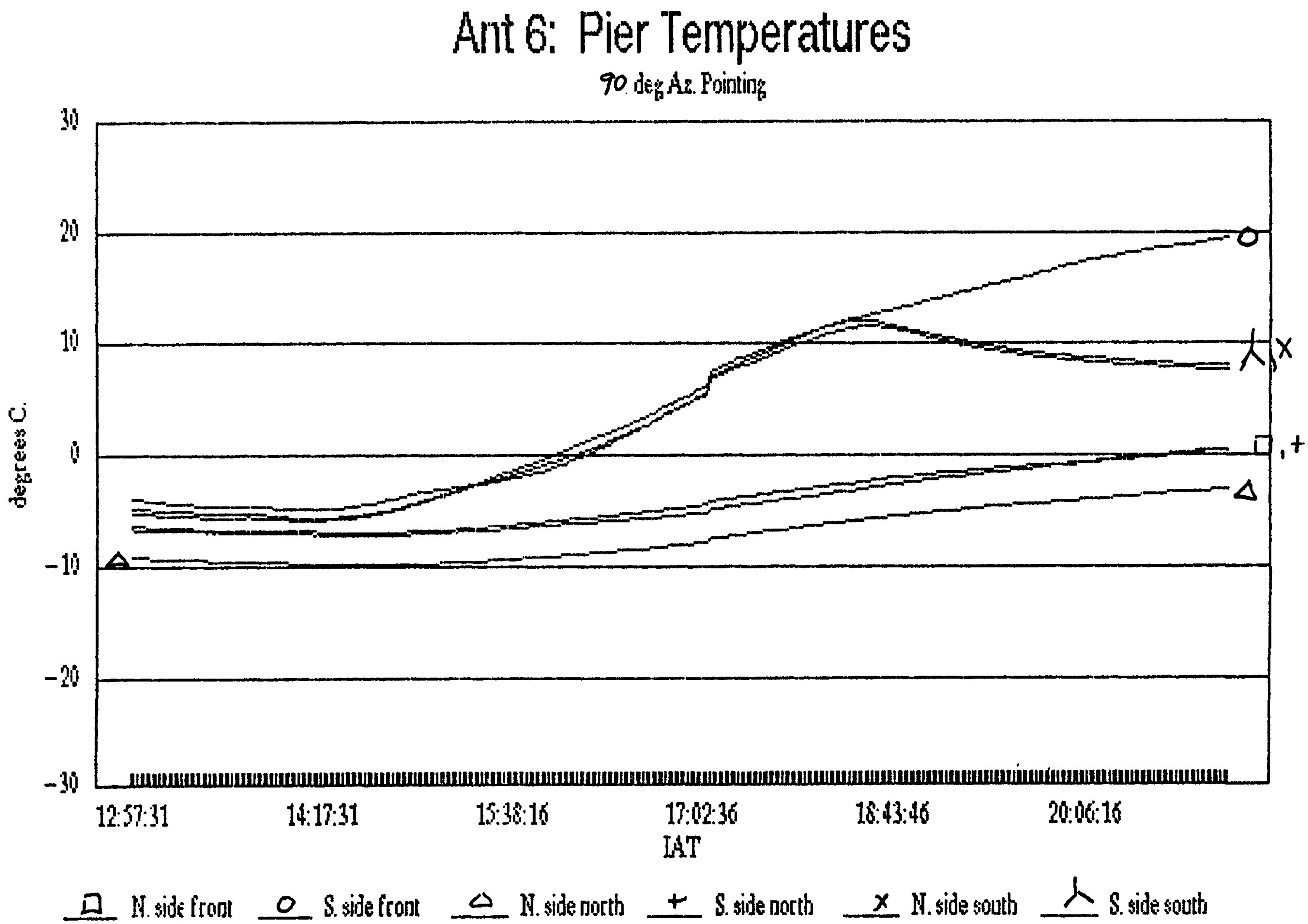
Data taken Dec. 4, 1990
CCJ, Dec 5, 1990

FIGURE 1



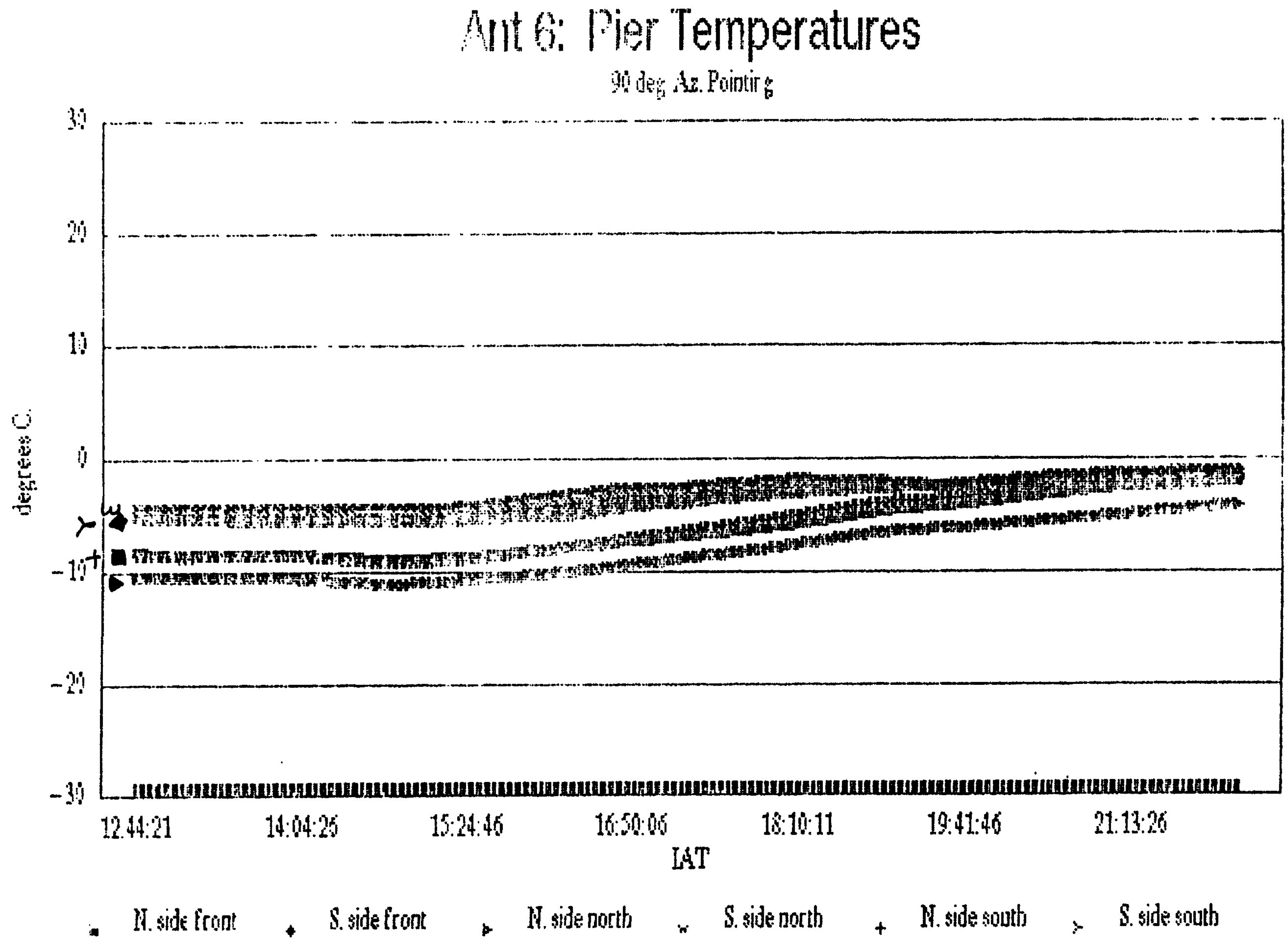
Data taken Dec. 4, 1990
CCJ, Dec 5, 1990

FIGURE 2



Data taken Dec. 4, 1990
CCJ, Dec. 5, 1990

FIGURE 3 (BEFORE INSULATION)

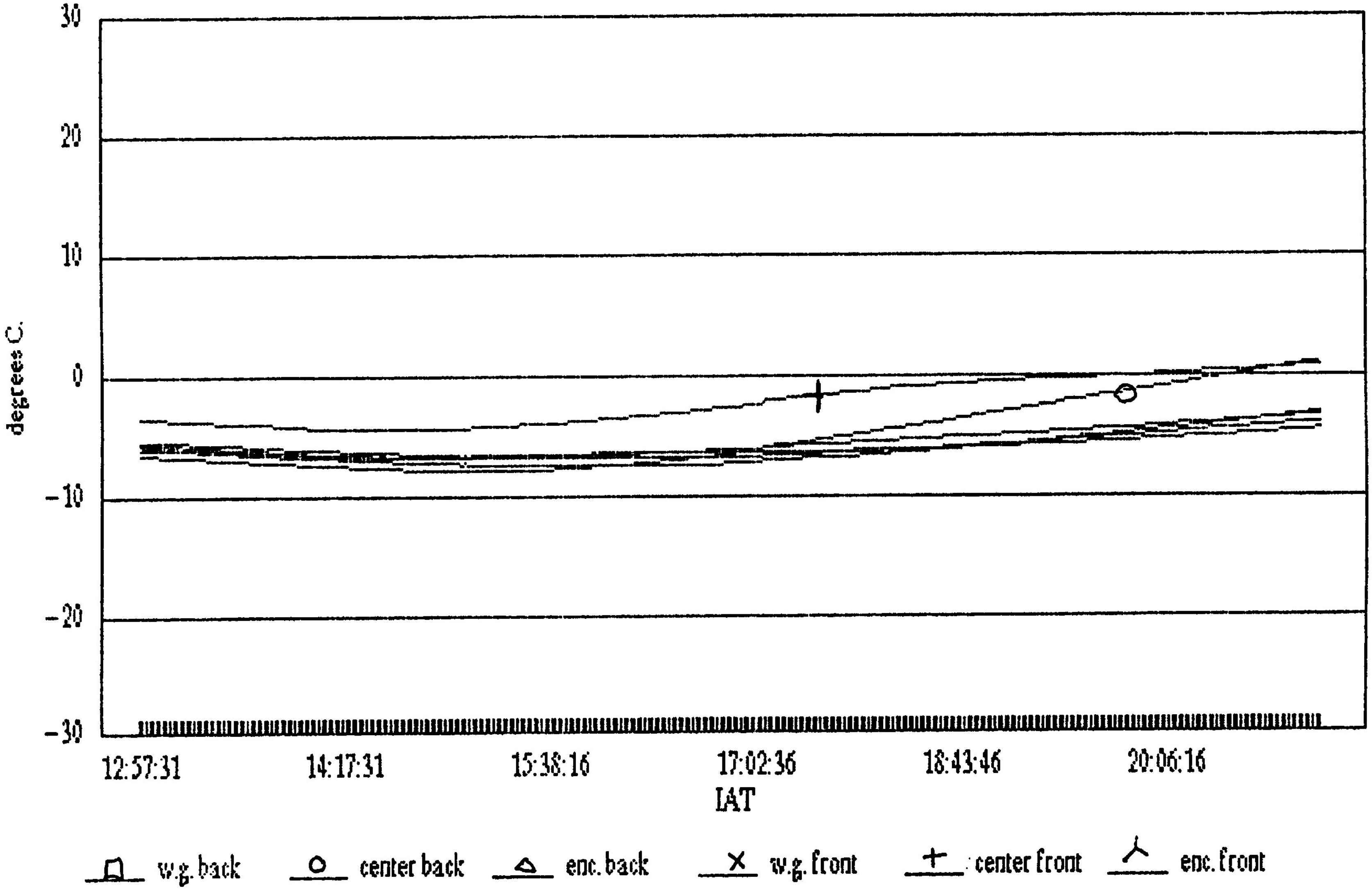


Data taken Jan. 23, 1991
CCJ, Jan. 24, 1991

FIGURE 4. (AFTER INSULATION)

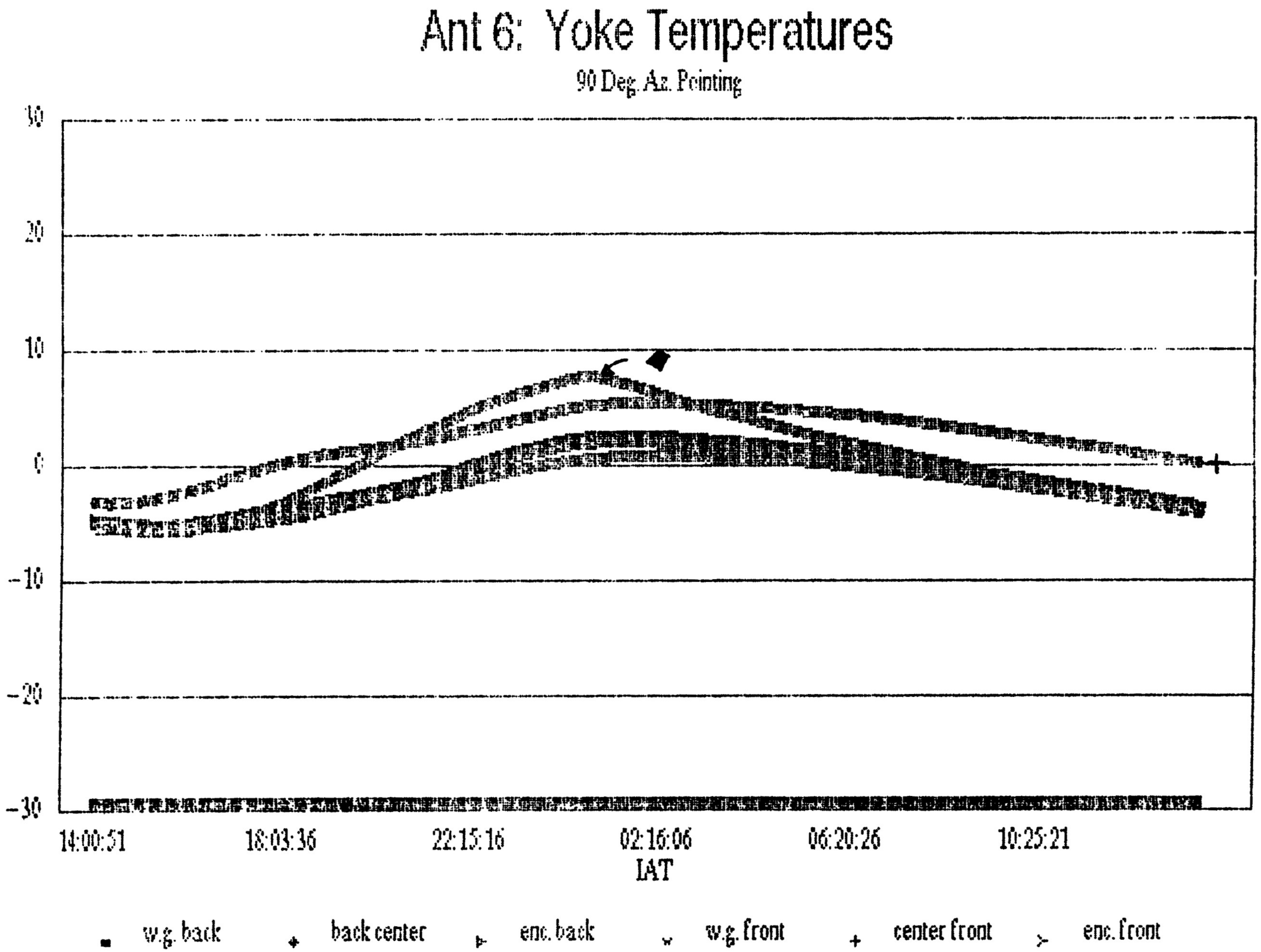
Ant 6: Yoke Temperatures

90 deg Az. Pointing



Data taken Dec. 4, 1990
CCJ, Dec. 5, 1990

FIGURE 5 (BEFORE ADDED INSULATION)

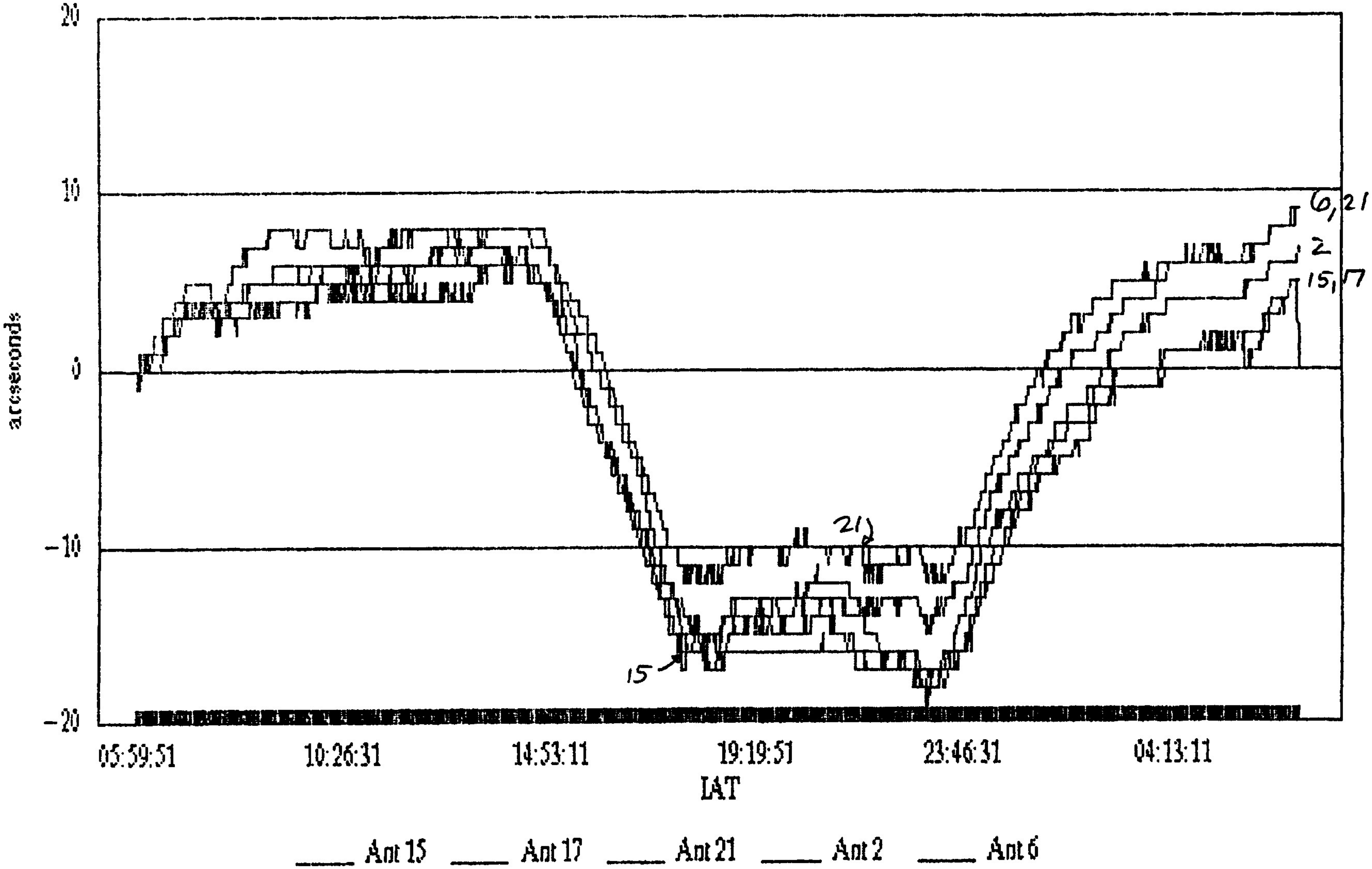


CCJ, Feb. 6, 1991

FIGURE 6 (AFTER ADDED INSULATION)

El Encoder Drift

North Arm



Data taken Thanksgiving shutdown, 1990
CCJ, Nov 29, 1990

FIGURE 7

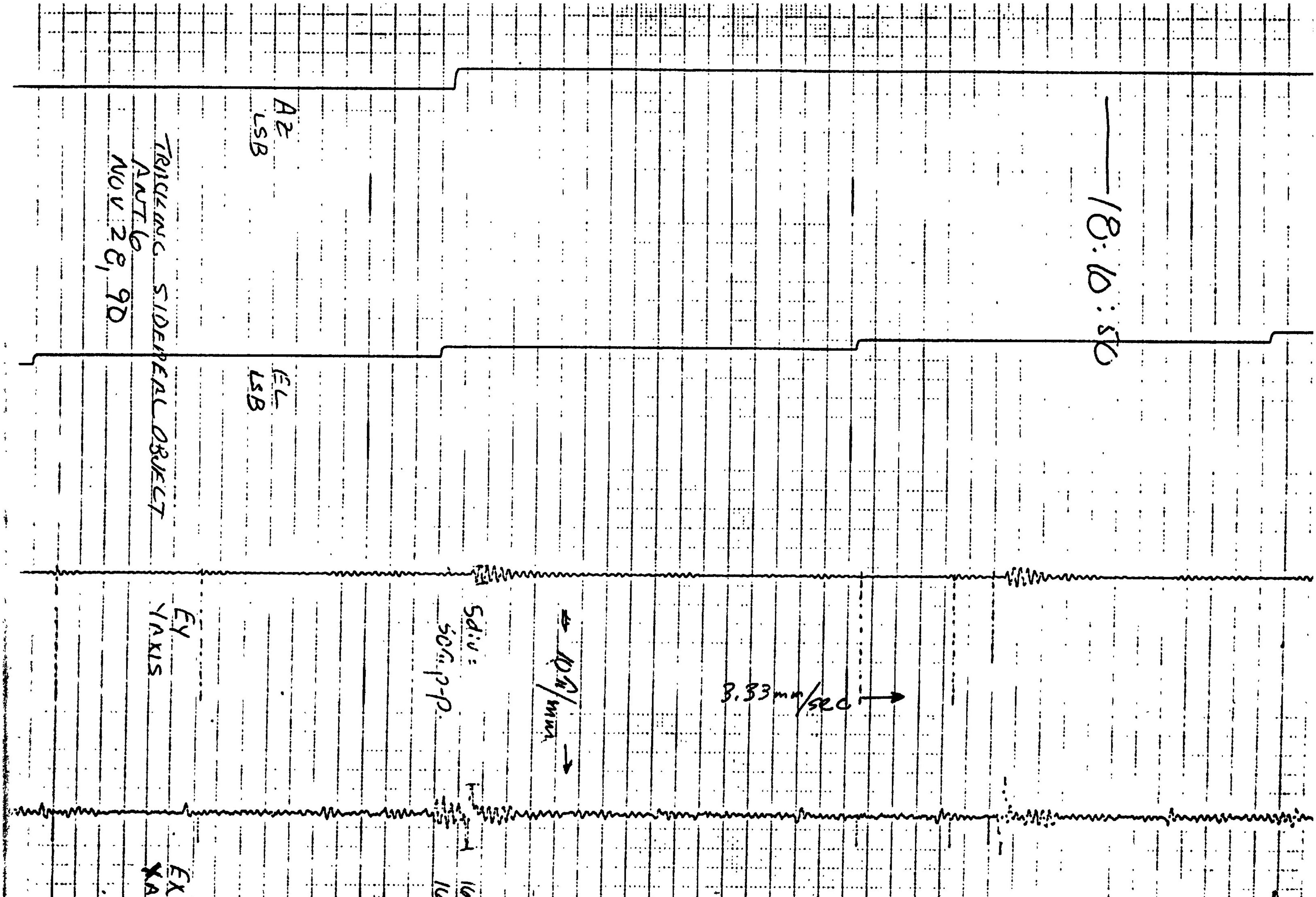
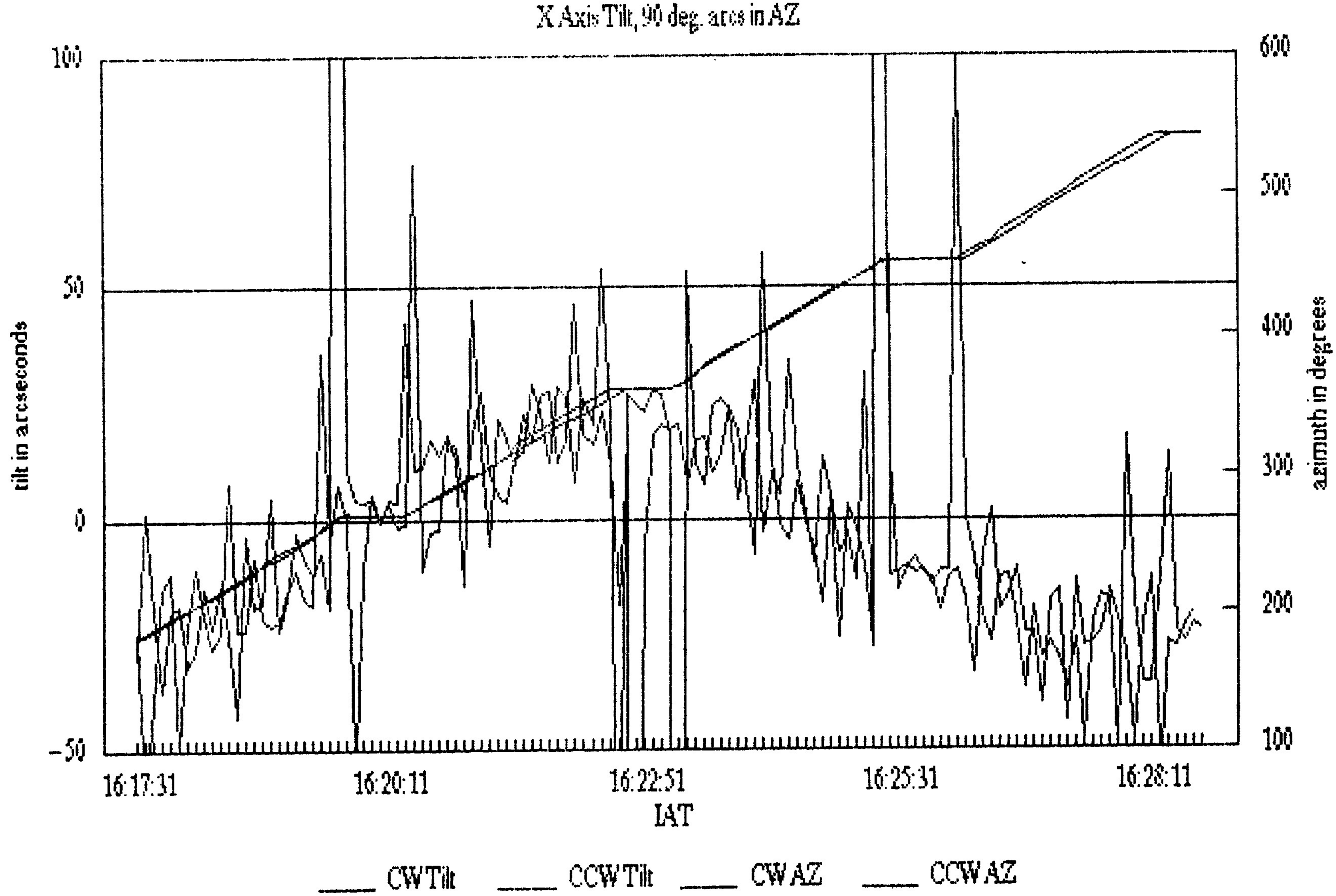


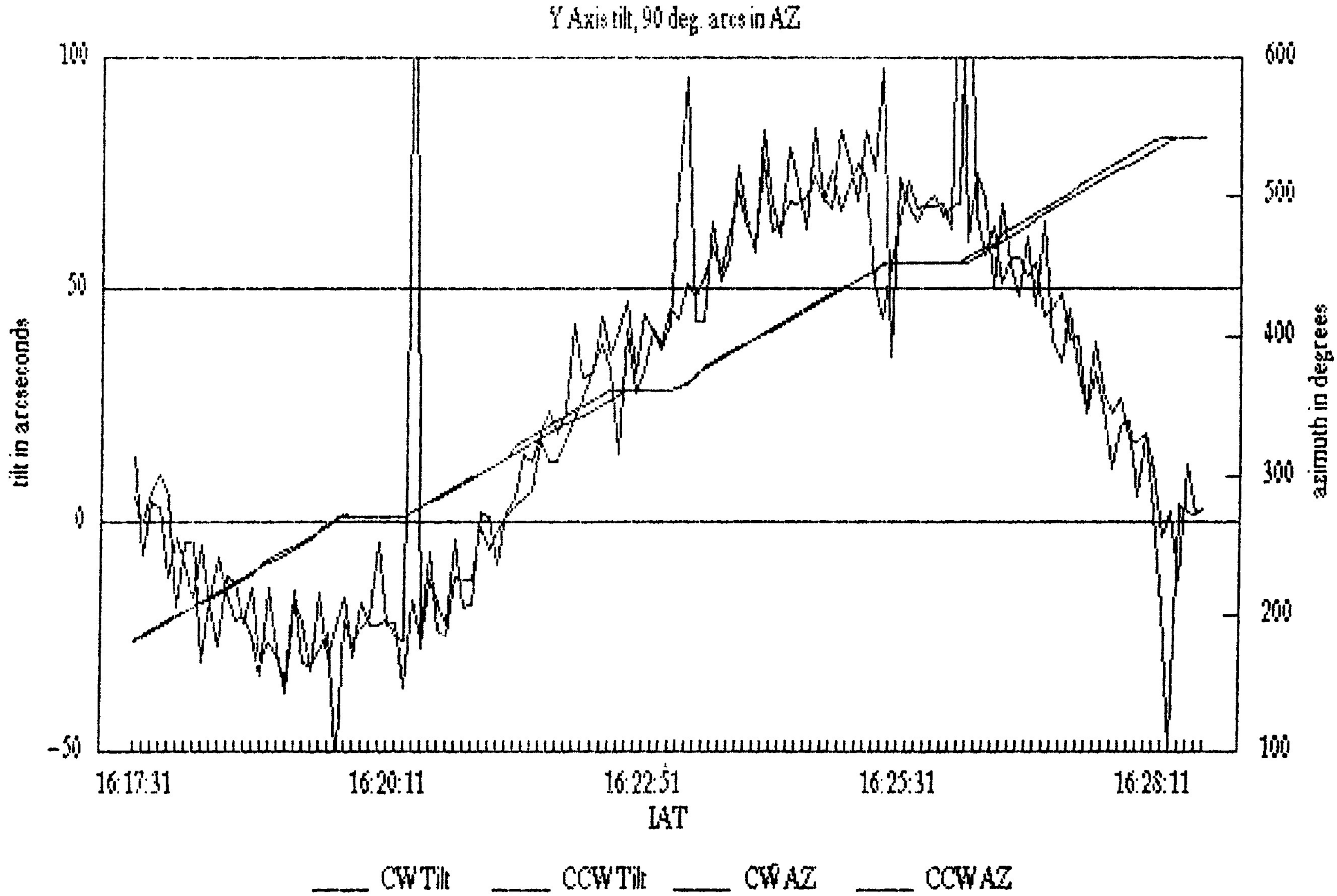
FIG. 8
TILTS SAMPLED AT 19.2 HZ
WHILE TRACKING [redacted]

Ant 6: Tilt Test



Data taken Nov. 28, 1990
CCI, Dec. 4, 1990

Ant 6: Tilt Test



Data taken Nov. 28, 1990
CCJ, Dec. 4, 1990