MULTIPLE MIRROR TELESCOPE OBSERVATORY

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MEMORANDUM TO: Distribution List

FROM: B.L. Ulich

RE: MMTO Technical Memorandum No. 82-2

DATE: February 25, 1982

Progress Report on Mount Pointing and Tracking

I. Absolute Pointing Accuracy

Analysis of the residuals of the mount pointing data fits indicates an RMS radial error of about one arc second. However, a plot of the number of residuals versus the radial error is enlightening, because it indicates that zero error has nearly zero probability. This implies that the errors are not random, but are dominated by systematic effects. In an effort to determine the accuracy of the stellar coordinates used to take pointing data, I have done some research on star catalogs and on precession, nutation, and aberration corrections. I found that the stars we have been using are mainly from the FK4 catalog, and have very well-known 1950 positions. Some have rather large proper motions because of their close proximity, but in general, this is not too serious an error. There is a problem, however, in the routines used at the MMT to precess the 1950 coordinates to current position. I compared about three dozen current positions calculated with the MMT mount control program, with the positions given by Apparent Places of Fundamental Stars - 1982, and found a mean radial error of 0.5 arc second, and a peak-to-peak error of 1.3 arc seconds. Although some of this error is undoubtedly erroneously absorbed into the mount pointing corrections, much of it is not, and contributes to the residual pointing errors.

I have obtained an algorithm for coordinate corrections which is supposed to be the best available (good to 0.05 arc second). In the next few months, we will convert this numerical algorithm to FORTH, and install it in the MMT mount control program. The result will be improved pointing and offsetting accuracy.

II. Mount Tracking Precision

In order to meet the desired goal of 0.1 arc second peak tracking error (over 10 minutes of time), improvements must be made in the mount control servos and in the absolute encoders on the MMT. The required RMS tracking error in each axis is about 0.03 arc second. Presently, the servo loop error is about 0.1 arc second. What limits the tracking smoothness of the MMT? There are two possible culprits: (1) encoder quantization and differential nonlinearity errors, and (2) mechanical friction variations (disturbances) in the drive system. In an effort to separate these two causes, I first measured the RMS tracking error as a function of the encoder resolution. Figure 1 is a plot of the RMS tracking error in each axis as a function of the size of the least-significant-bit read by the computer. At coarse resolutions, the error asymptotes to 0.4 bits, but at the highest encoder resolutions, the tracking errors considerably exceed this line. Is this because the encoder has errors comparable in magnitude to the quantization increment? Or have we simply reached the mechanical limit? A second test was conducted to decide this question. Figure 2 is a photograph of an oscilloscope display of the four least-significant encoder bits as a function of time, while the telescope was moving at a "constant" velocity of 20.6 arc seconds per second in elevation. The uppermost trace is the 24th bit, which varies in size (duration) by a factor of three on a time scale of only several milliseconds. Thus, unless the telescope can change velocity by a factor of three on a time scale of several milliseconds, the 24th bit must have differential nonlinearity errors at least as large as one-half of the 24th bit. I don't believe the telescope velocity can change that rapidly, and therefore, I believe these encoder errors are real. From Figure 1 I conclude that the 23rd and 24th encoder bits are not now contributing significant position information, and the telescope tracking is about the best possible for a perfect 22-bit system.

I also conducted (with the help of Warren Davison) a third test designed to determine the mechanical limit to tracking smoothness. We constructed an additional "angular" encoder by attaching a Linear Variable Differential Transformer (LVDT) to the edge of the telescope drive gear. Over a range of several arc minutes this resulted in an angular encoder with a resolution of about 0.004 arc second. I built an analog servo position loop to replace the mount computer, and we drove the telescope with a function generator. Figure 3 shows the tracking error and the actual position traces recorded on a chart recorder for the azimuth axis. At relatively slow constant rates the error was about 0.04 arc seconds peak-to-peak. Figure 4 is a similar plot for the elevation axis. Figure 5 is again a plot of the elevation tracking error for a sinusoidal position command. For both axes the worst-case sidereal tracking error was 0.065 arc second peak-to-peak or 0.020 arc second RMS, which apparently represents the true mechanical limit since the encoder resolution was only 0.004 arc second. The mechanical tracking limit predicted in the design stage is 0.05 arc second RMS in azimuth and 0.02 arc second RMS in elevation, which agrees fairly well with the measurements. The stick-slip oscillation amplitude was also predicted to be 0.06 arc second peak-to-peak in azimuth and 0.006 arc second in elevation. The measured stick-slip values are 0.05 arc second peak-to-peak in azimuth and 0.08 arc second in elevation. As shown in Figure 1, the mechanical tracking limit is about a factor of five better than the present performance and is sufficiently good to allow the desired tracking goal to be met. Thus we need "only" to improve our encoders (to 25 bit accuracy) in order to meet this goal. No mechanical modifications to the drive trains will be necessary. The only mechanical modification needed is to the elevation encoder coupling. Presently the encoder is coupled to the outer end of the east elevation stub axle. Friction in the elevation bearing supporting this axle causes torsional compliance between the OSS and the encoder of about 2 arc seconds peak-to-peak. This results in "hysteresis" in the optical pointing which can be minimized by "preconditioning" the mount. However, the absolute pointing accuracy and especially the offsetting accuracy of the MMT are compromised by this compliance since it is not entirely repeatable and therefore predictable. A simple solution exists, however, which will drastically reduce this problem and which can be implemented on the MMT in a straightforward manner. Since the elevation stub axle is a hollow tube we can replace the present encoder coupling with a longer one of slightly smaller diameter which will connect directly to the OSS. The torsional compliance will be reduced by a large factor (5-10) and the offsetting accuracy of the mount in elevation will be much improved. The only difficulty in implementing this modification seems to be the weight of the longer tube which may exceed the permissible encoder loading. "Exotic" materials such as carbon fiber laminates may be required to reduce the weight to an acceptable amount. Warren Davison is currently investigating this problem.

III. Improved Encoder Readout Electronics

My previous studies have shown that it is possible to improve both the accuracy and the precision of our present Inductosyn encoders by constructing a new set of readout electronics. The transducers are capable of greater resolution and accuracy than we are now achieving. Incidentally the U.S. Naval Observatory has a similar system on their transit circle in Washington, and they have independently confirmed these conclusions. The first step will be to construct a matched pair of preamplifiers with "identical" gain versus temperature characteristics. These preamps will be installed on the telescope in the near future in an attempt to reduce the periodic errors which currently result from mismatched gains for the sine and cosine outputs. The second step is to synchronously detect the outputs in new electronics. We have bench-tested four different circuits for doing this, and one of them appears capable of meeting our requirements. I have purchased a precision ratio transformer which will allow us to measure the nonlinearities of this detection circuit. Third, the signals must be digitized and fed into a computer for the angle calculation. We have also bench-tested a 17-bit analog-to-digital converter, and it appears to function well at the 16-bit level. We are not yet certain that the 17th bit can be made meaningful. I have also purchased a module which will directly convert the single-speed coarse resolver to a 12-bit binary angle. When it arrives I will test its accuracy and stability. In summary, the laboratory circuit development is proceeding subject to the delivery of parts and to the pressure to complete the Telescope Coalignment System.

FIGURE 1

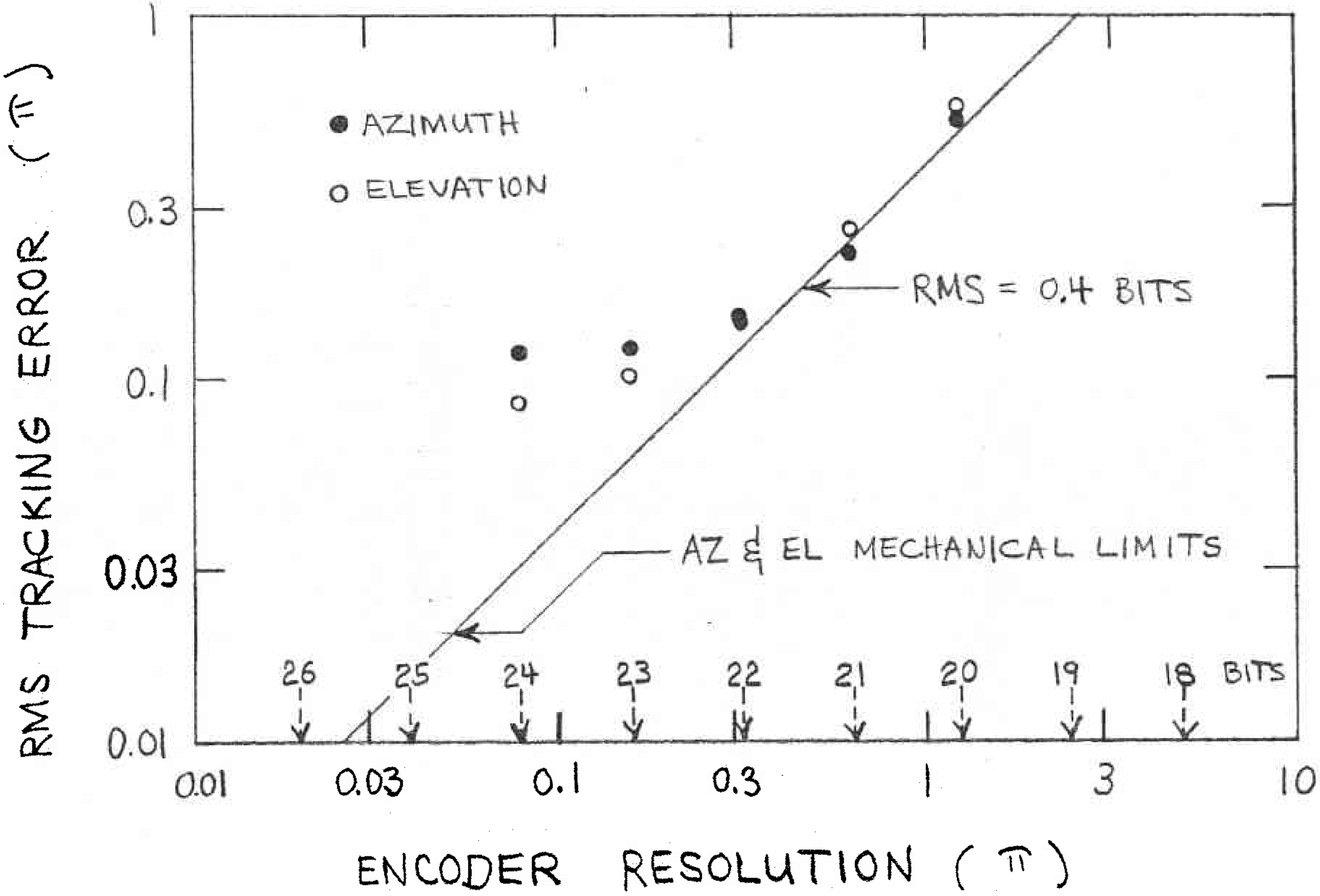

● AZIMUTH
○ ELEVATION
RMS = 0.4 BITS
AZ & EL MECHANICAL LIMITS
26
25
24
23
22
21
20
19
18 BITS
RMS TRACKING ERROR (π)
1
0.3
0.1
0.03
0.01
0.01
0.03
0.1
0.3
1
3
10
ENCODER RESOLUTION (π)

FIGURE 2

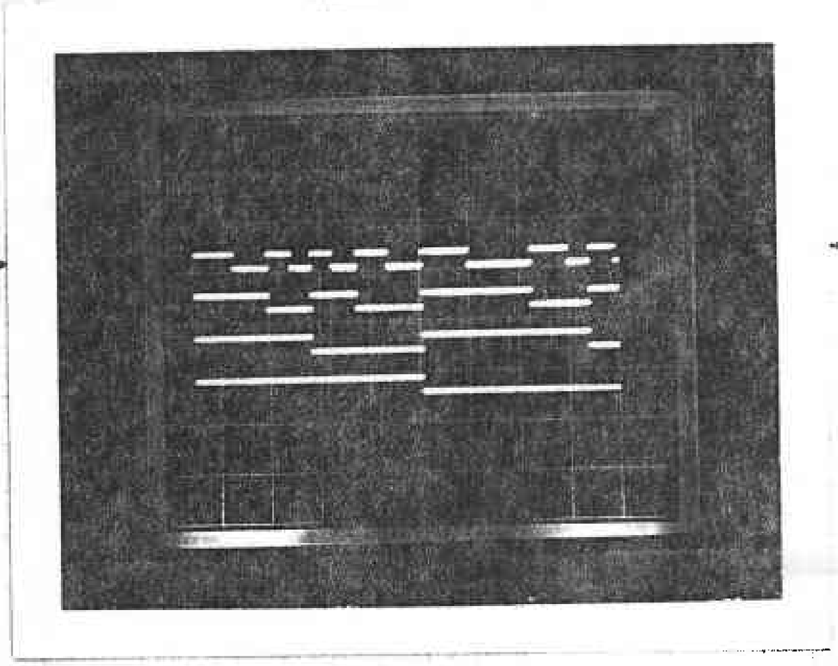
Note differential nonlinearity

ELEVATION

24th BIT
Rate = 20.6 $\frac{\text{arcsec}}{\text{sec}}$
$bvmax = 0
$avmax = 125
1 millisecond/cm

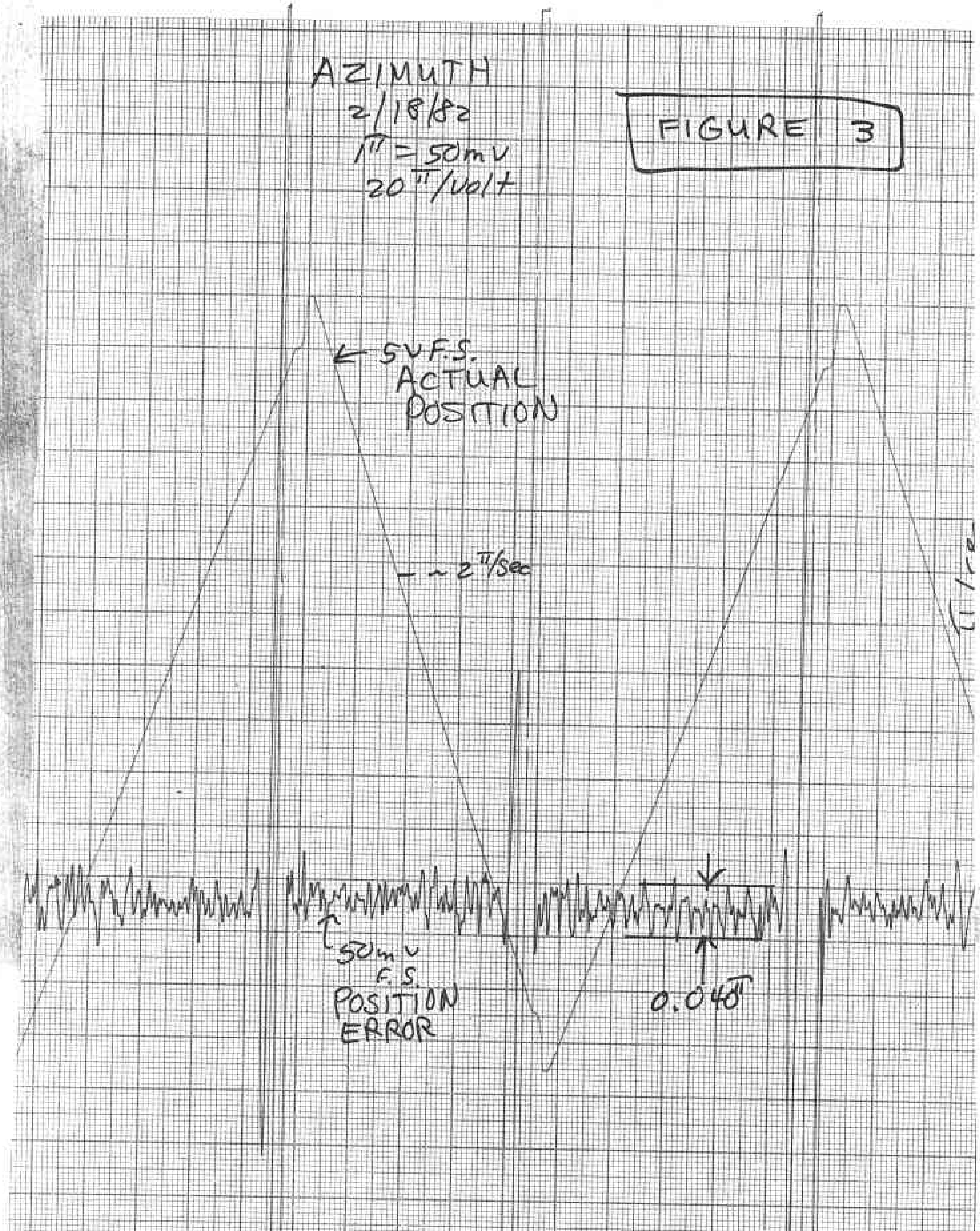
BIT
24
23
22
21

1 msec



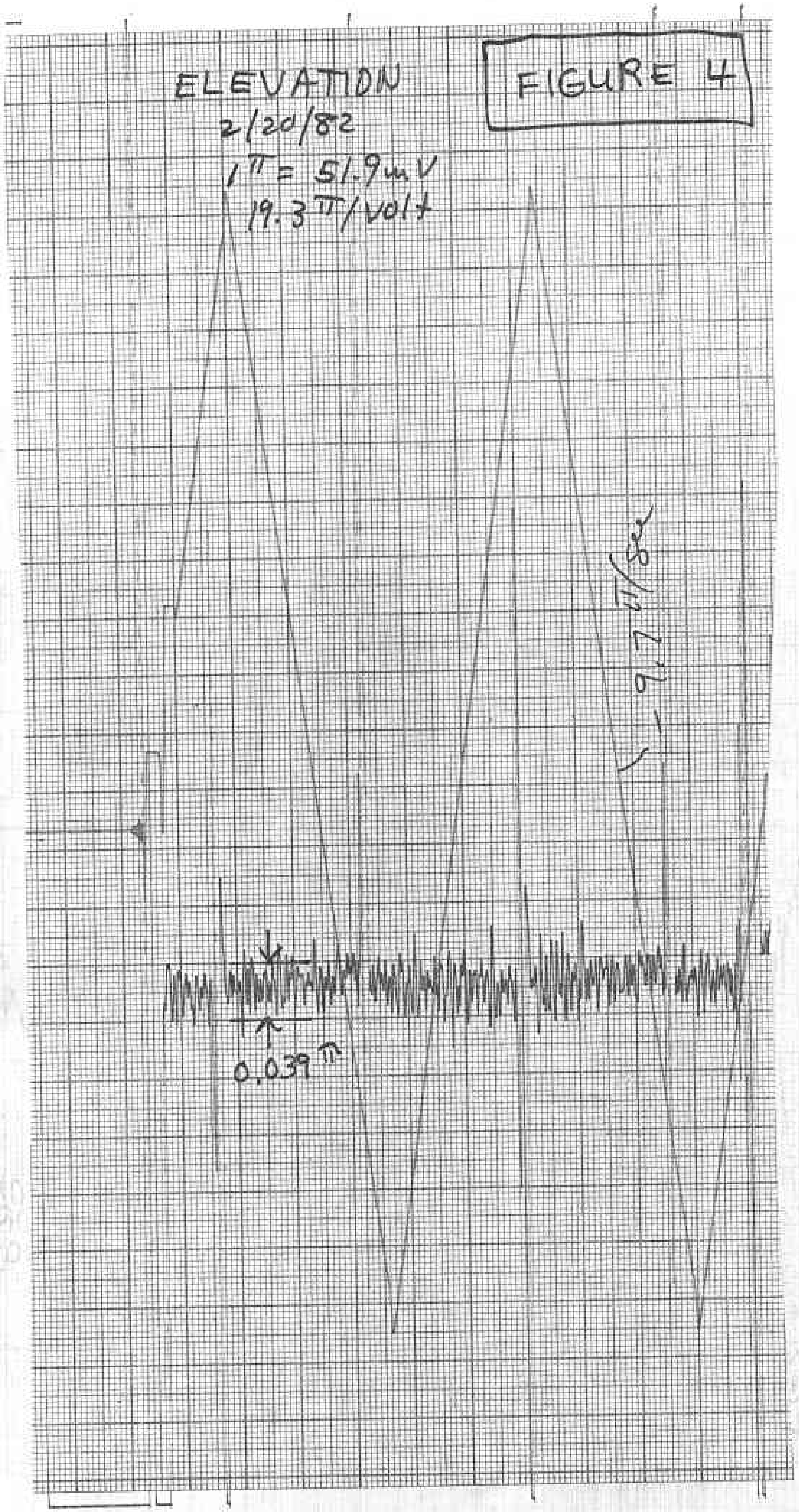
At high speeds the EL behaved the same as AZ, that is, all the bits became equal in duration. The EL speed was constant within 1% Peak-TO-Peak.

FIGURE 3



AZIMUTH
2/18/82
1" = 50mV
20"/volt
← 5V F.S. ACTUAL POSITION
← ~2"/sec
50mV F.S. POSITION ERROR
0.040"
Time

FIGURE 4

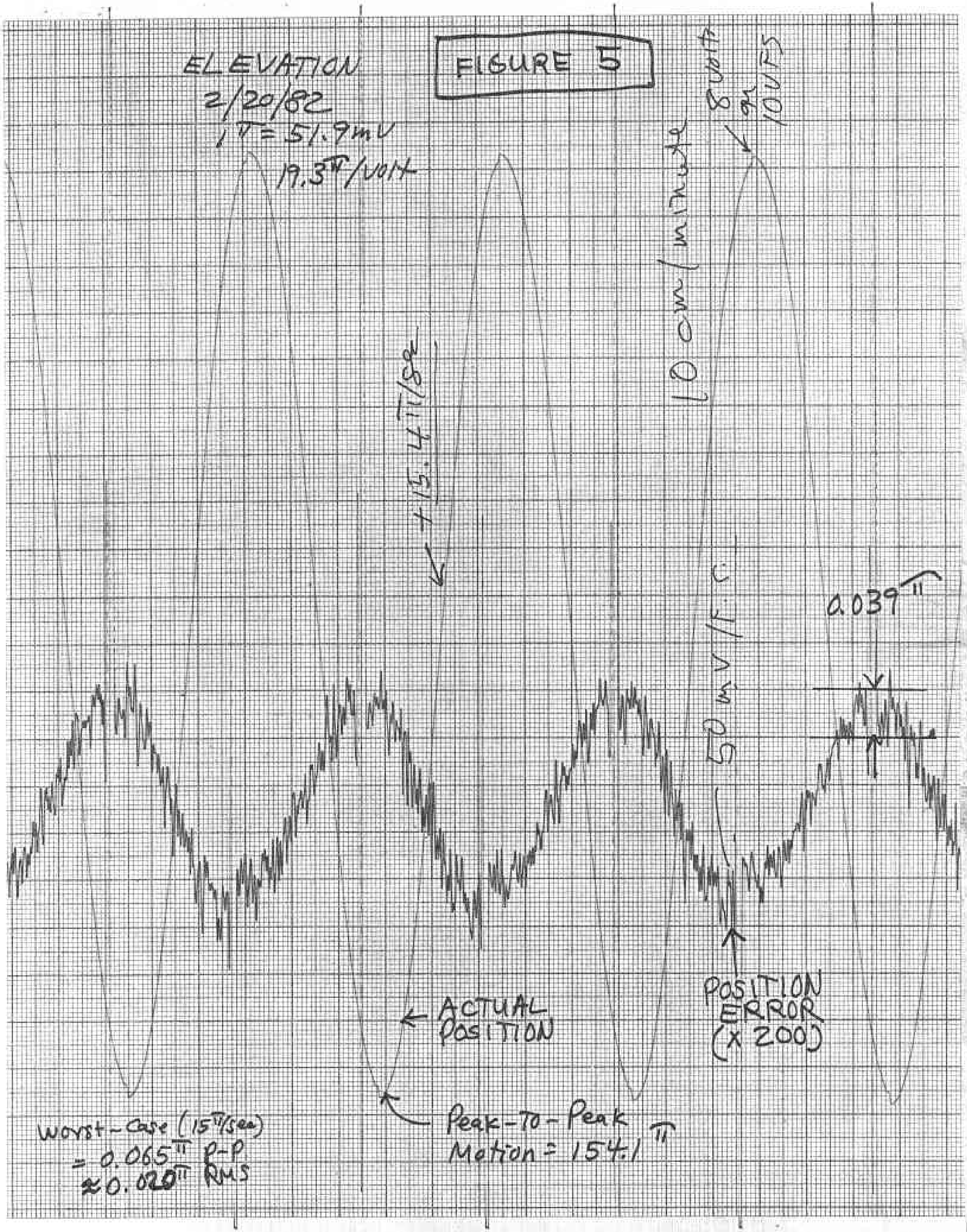


ELEVATION
2/20/82
1" = 51.9 mV
19.3"/volt

0.039"

9.7"/sec

FIGURE 5


ELEVATION
2/20/82
1″ = 51.9mV
19.3″/volt
+15.4″/sec
10 cm/minute
8 volt on 10 VFS
50 mV/F.S.
0.039″
ACTUAL POSITION
POSITION ERROR (x 200)
Peak-To-Peak Motion = 154.1″
Worst-Case (15″/sec)
= 0.065″ P-P
≈ 0.020″ RMS