GBT Memo No. 57

THE LASER RANGING SYSTEM FOR THE GBT

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1.0 Introduction

A method of implementing the active surface and the fine pointing for the GBT is outlined in GBT Memo No. 36. The method involves measuring distances between points on the structure and also from points fixed on the structure to points on the ground. Early work at NRAO and elsewhere suggested that laser ranging might satisfy the precision required, both for pointing and surface setting. For these tasks an accuracy of around 75 microns over a range of approximately 100 meters is required. Providing real-time data for pointing and surface corrections will probably require ranges to be measured between several (many) pairs of points at quite a rapid rate. No commercially available systems meet these accuracy requirements.

Accordingly, a prototype measuring device has been constructed and tested in Green Bank. The first objective of the tests was to demonstrate that the accuracy of such a device is not limited by atmospheric turbulence and that the required accuracy can be achieved. Initial results suggest that atmospheric effects will not limit the performance. A program of tests is now under way in Green Bank to measure the effects of the atmosphere over a period of several weeks. The prototype also shows that range data for one path can be taken and fed to a computer at a rate which could meet the needs of an active surface and pointing system.

2.0 Principle of Operation

The basic principle of operation of the instrument is shown in Figure 1. A light beam is amplitude modulated, transmitted over the path to be measured and reflected back to the instrument. The phase of the modulation envelope of the returned beam is measured with respect to a reference, the phase shift being proportional to the total distance the beam has travelled.

In Figure 1 the returned light beam will be shifted in phase by $2d/\lambda$. (λ is the wavelength of the modulating frequency.) If $\lambda < 2d$, then the phase will be shifted through more than one cycle and ambiguities in distance reading will arise.

The instrument described here uses a modulating frequency of 1.5 GHz, so ambiguities arise every 10 cm.

3.0 Atmospheric Effects

The two atmospheric effects to be considered in a laser ranging system are (1) the slowly changing value of the "bulk" refractive index and (2) the small scale rapid changes in refractive index or turbulence. (1) may be compensated for by measuring the air temperature, barometric pressure and humidity. To a first approximation changes in bulk refractive index will affect all paths similarly, but there may be differential effects over paths at different elevations.

The group refractive index of air (n_g) depends on

t = temperature in °C

p = pressure in mm H_g

e = partial pressure of water vapor in mm H_g)

and is given by

$$n_g = 1 + \frac{(n_{g0} - 1)}{1 + t/273} \times \frac{p}{100} - \frac{5.5e \times 10^{-8}}{1 + t/273}$$

where n_{g0} = refractive index at 0°C and 760 mm of mercury.

At 20°C $dn_g/dp = 3.678 \times 10^{-7}$.

At constant pressure and 20°C $dn_g/dt = 10^{-6}$; $dn_g/de = 0.5 \times 10^{-7}$ independent of temperature and pressure.

So, refractive index changes are dominated by temperature and pressure changes with temperature change having the greater effect.

At our initial range of 60 m the effect will be 60 microns per degree C.

The effect of (2), the turbulent effect, is potentially more serious and may prevent the method from working. GBT Memo 45 outlines the various results in the literature, none of which are directly applicable to our case.

4.0 The Instrument

A block diagram of the prototype instrument is shown in Figure 2. A 780 nm wavelength laser diode is amplitude modulated at 1.5 GHz, and its collimated beam is directed towards the distant corner reflector. The returned beam is focused onto a detector, amplified, and mixed with a local oscillator offset from the transmitter modulation by 1 kHz. The phase of this 1 kHz signal is compared with the phase of the 1 kHz reference signal and is a direct measure of the phase shift in the modulation envelope.

The phase shift between the 1 kHz reference waveform and the 1 kHz phase shifted signal is calculated by accumulating 20 MHz clock pulses in a register. The clock pulses are gated into the register during the interval between the start of the reference cycle and the start of the signal cycle. The accumulated clock pulses are then a measure of the phase difference between the two waveforms. A chosen number of cycles measured in such a way constitutes one measurement.

5.0 <u>The Test Set Up</u>

The set up of the test range is shown in Figure 3. The laser ranging unit is mounted on a machine tool stage that may be adjusted in the horizontal plane by about 9 inches. A digital readout on the stage permits the stage to be moved in accurately determined increments.

For the tests two methods of measuring the phase shifts were used: the digital system sending data to the AST 286 PC and a commercial phase meter, followed by a chart recorder.

Two stations for the retroreflector are available--one at 60 m and the other at 130 m. The light path is parallel to the (grass-covered) ground at an elevation of 75 cm.

6.0 <u>Initial Tests</u>

After set up at a range of 60 m and alignment the sensitivity of the instrument was checked by moving the ranging unit by 0.030 inch (762 microns) while monitoring the output of the phase meter on the chart recorder. The phase meter has a low pass filter on the output corresponding to an integration time of 1 second. The results are shown in Figure 4. The noise on the trace corresponds to an RMS deviation of 11 microns.

The computer system was also used to monitor a similar change in range with the result shown in Figure 5. A spread sheet program was then used to calculate the RMS of the last portion of the trace (30 seconds worth of data with one sample per second). The RMS value was 15 microns.

A linearity check was then made by moving the stage in intervals of 0.5 inch. The results are shown in Figure 6. A linear regression yielded $R^2 = 0.9999$ and $\sigma = 0.101$ mm for the residual. There is no sign of cyclical errors resulting from transmitter leakage or multiple reflections.

7.0 Tests Over Several Days

The computer system has been set up to take data continuously. A typical result for 4 hours is shown in Figure 7. The RMS of this entire data set is 90 microns and result mainly from the slowly changing temperature. Figure 8 shows a portion of a data set of 100 points at one second per point. The RMS of this data is 26 microns.

During the initial set up the chart recorder was used to measure the noise on the range reading. Below are some of the results:

Date	Conditions	RMS
July 17	Early morning fog.	25 microns
July 18	Hot and cloudy.	14 microns
July 19	Sunny--p.m.	11 microns
July 19	Evening--light rain.	15 microns
July 20	5 a.m.--heavy fog.	8 microns

The 20th July early morning result was particularly interesting. The fog was heavy enough that the monument on which the corner cube is mounted was only just visible. The amplitude of the returned signal was reduced by around a factor of 3 but was very steady. The noise on the range reading was small--around 8 microns RMS.

8.0 Tests at 130 Meters Range

The measurements from fixed points on the ground to points on the structure will involve range measurements of up to 130 m. A larger corner cube (2.5 inches in diameter) will be used for these measurements. Preliminary measurements at 130 m have been made and RMS deviations between 15 microns and 45 microns were measured. The signal to noise is more than adequate.

9.0 Conclusions and Future Work

We plan some more measurements and tests at both 60 meters and 130 meters. We will experiment with white painted panels on the ground and whatever other simple tests come to mind.

In the light of these initial results it seems extremely unlikely that the method will fail due to atmospheric effects.

A possible next step would be to install a pointing system using a "production" version of the laser ranger on the 140-ft. This would provide both hardware and experience for the 100 m installation.

A more complete report together with test results will be issued in a few months.

10.0 Acknowledgments

Dwayne Schiebel in Green Bank who designed the digital circuits and wrote the software; Andy Dowd in Tucson who designed the high speed digital dividers; Richard Bradley in Charlottesville who designed and built the laser modulator; Dick Thompson in Charlottesville for the 1.5 GHz phase-lock circuitry; Tom Dunbrack in Green Bank for excellent construction work; and Ginger Parker for reducing the data.

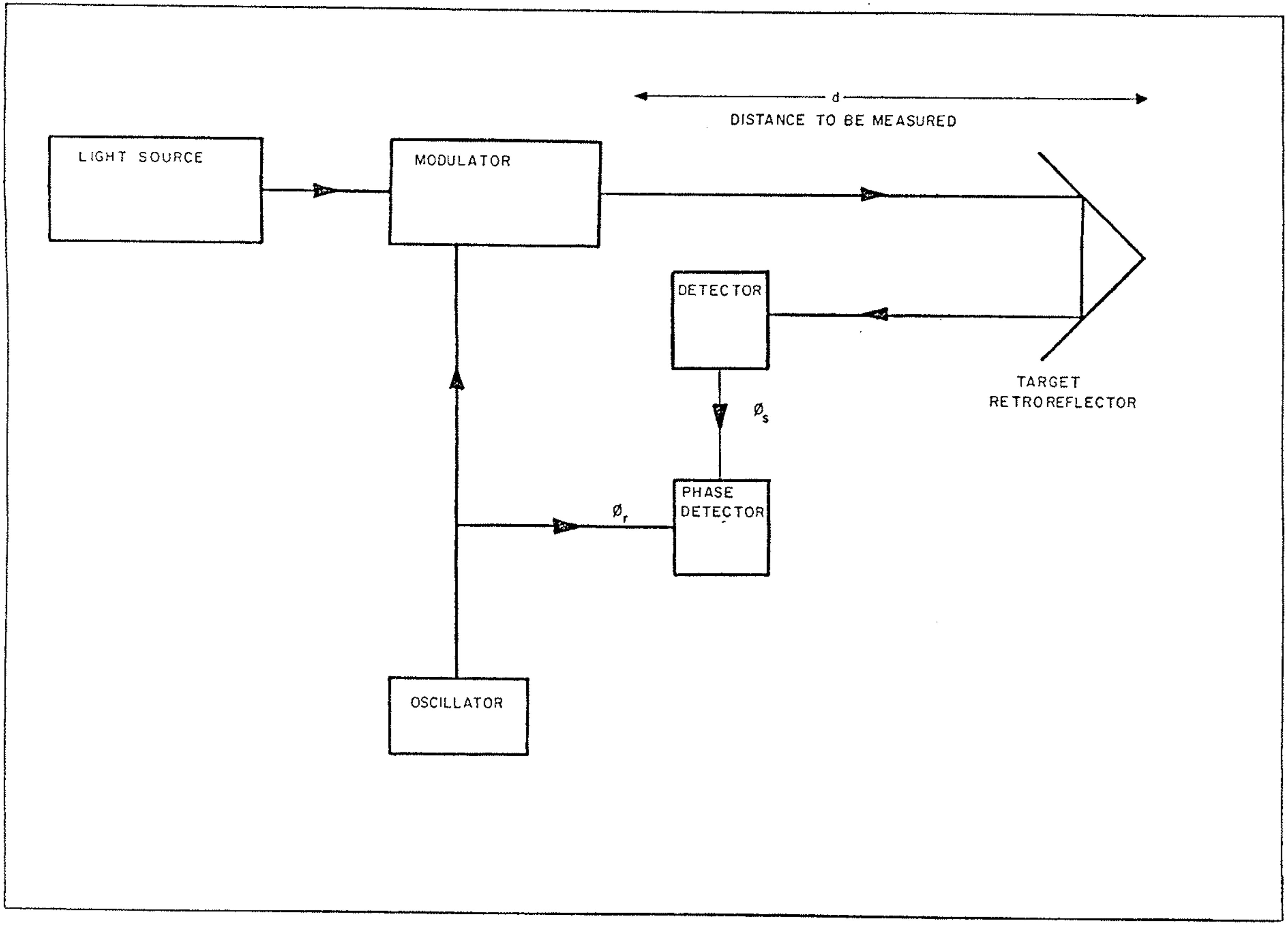


Figure 1

Simplified Block Diagram

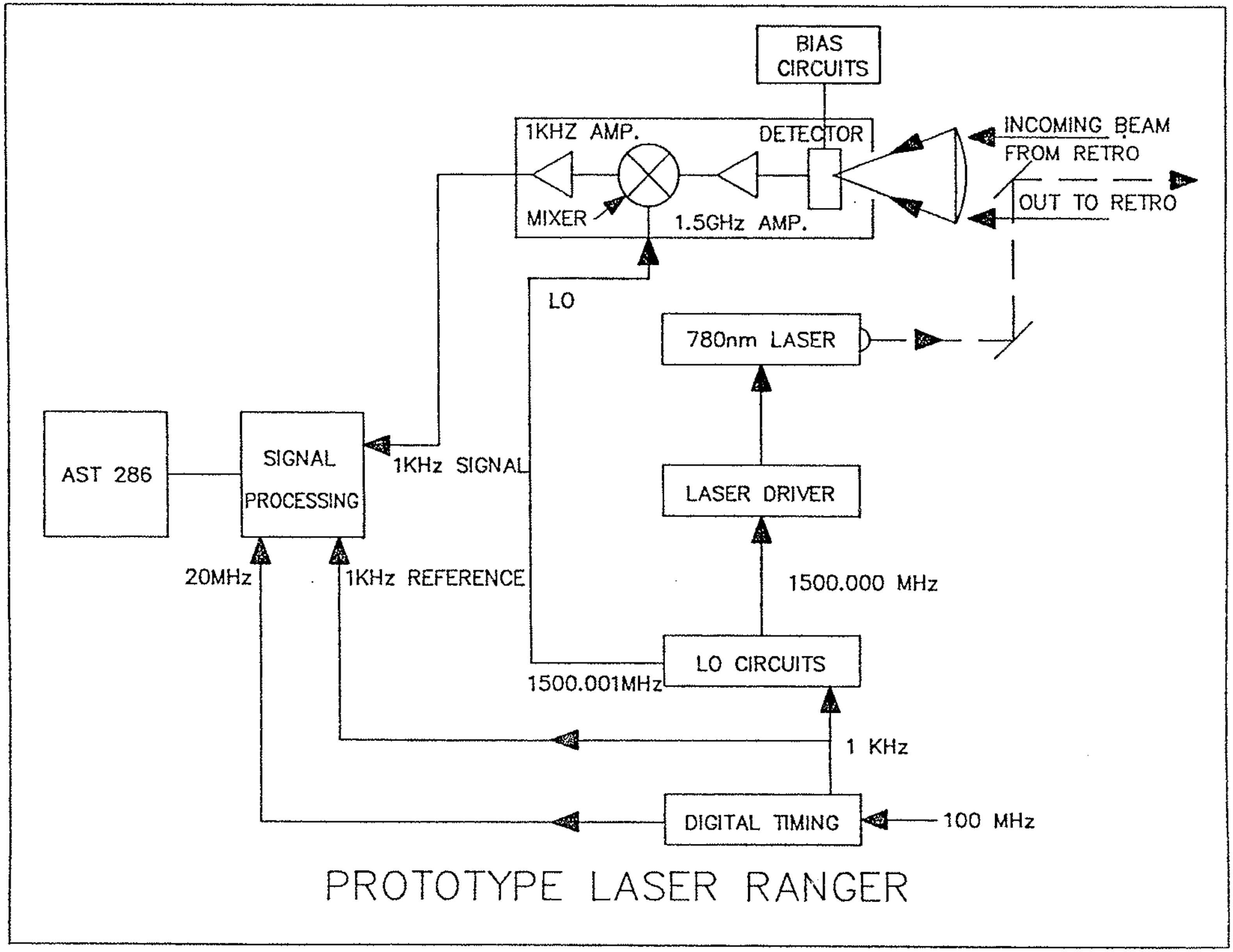

BIAS CIRCUITS
1KHZ AMP.
DETECTOR
INCOMING BEAM FROM RETRO
OUT TO RETRO
MIXER
1.5GHz AMP.
LO
780nm LASER
AST 286
SIGNAL PROCESSING
1KHz SIGNAL
LASER DRIVER
20MHz
1KHz REFERENCE
1500.000 MHz
LO CIRCUITS
1500.001MHz
1 KHz
DIGITAL TIMING
100 MHz
PROTOTYPE LASER RANGER

Figure 2

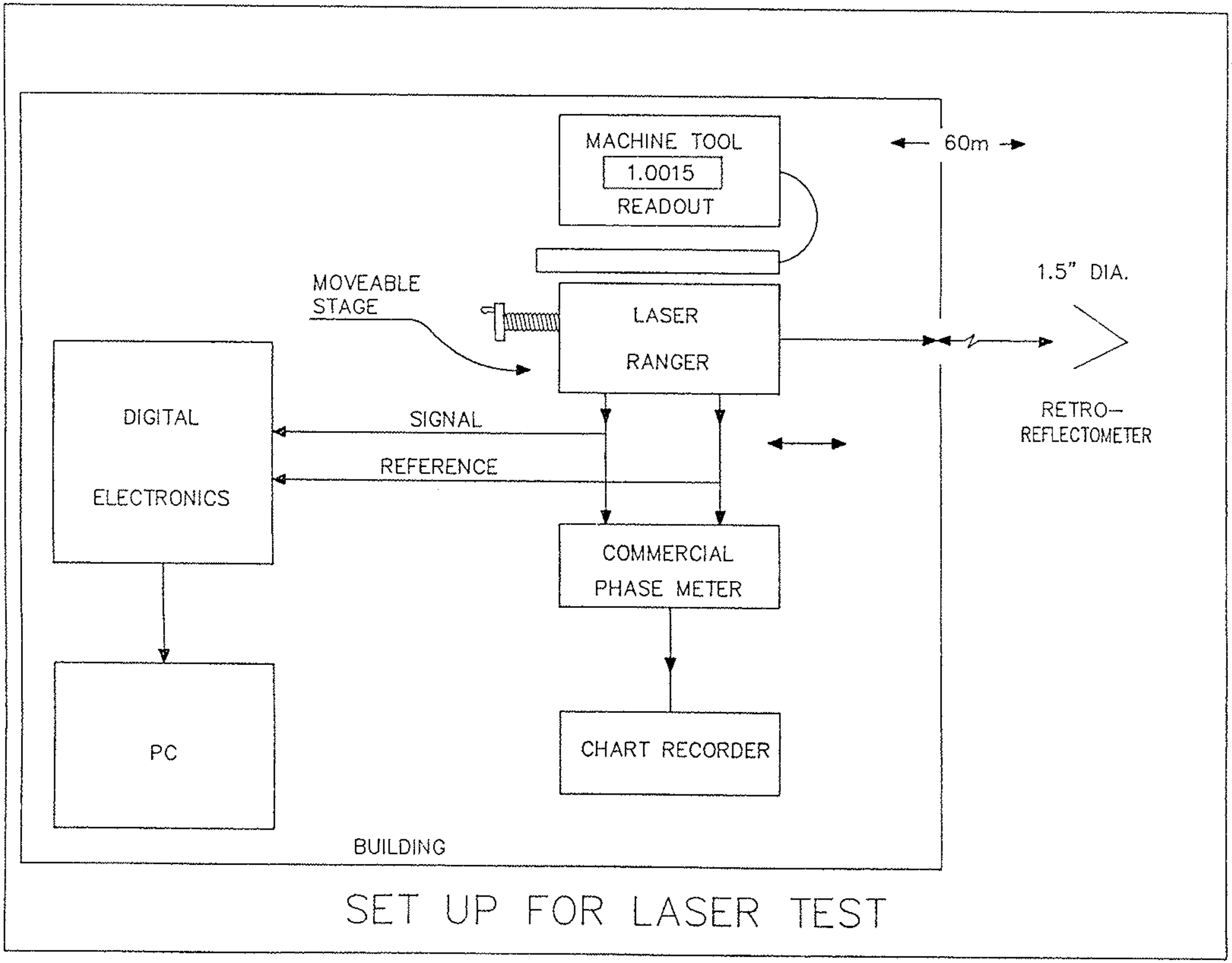

MACHINE TOOL
1.0015
READOUT
60m
1.5" DIA.
MOVEABLE
STAGE
LASER
RANGER
RETRO–
REFLECTOMETER
DIGITAL
ELECTRONICS
SIGNAL
REFERENCE
COMMERCIAL
PHASE METER
PC
CHART RECORDER
BUILDING
SET UP FOR LASER TEST

Figure 3

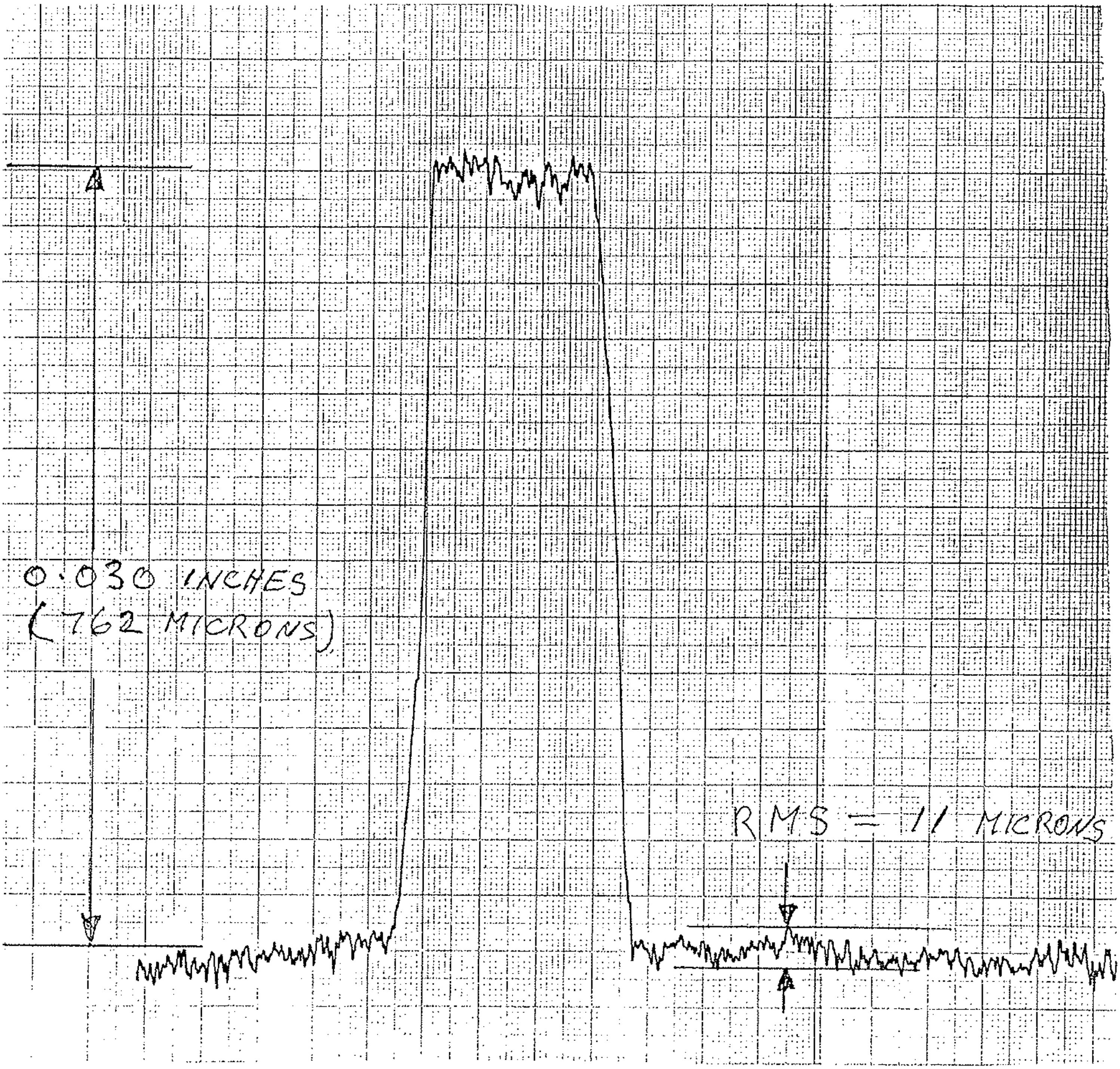


Figure 4

Output of Phase Meter for a 760 Micron Movement

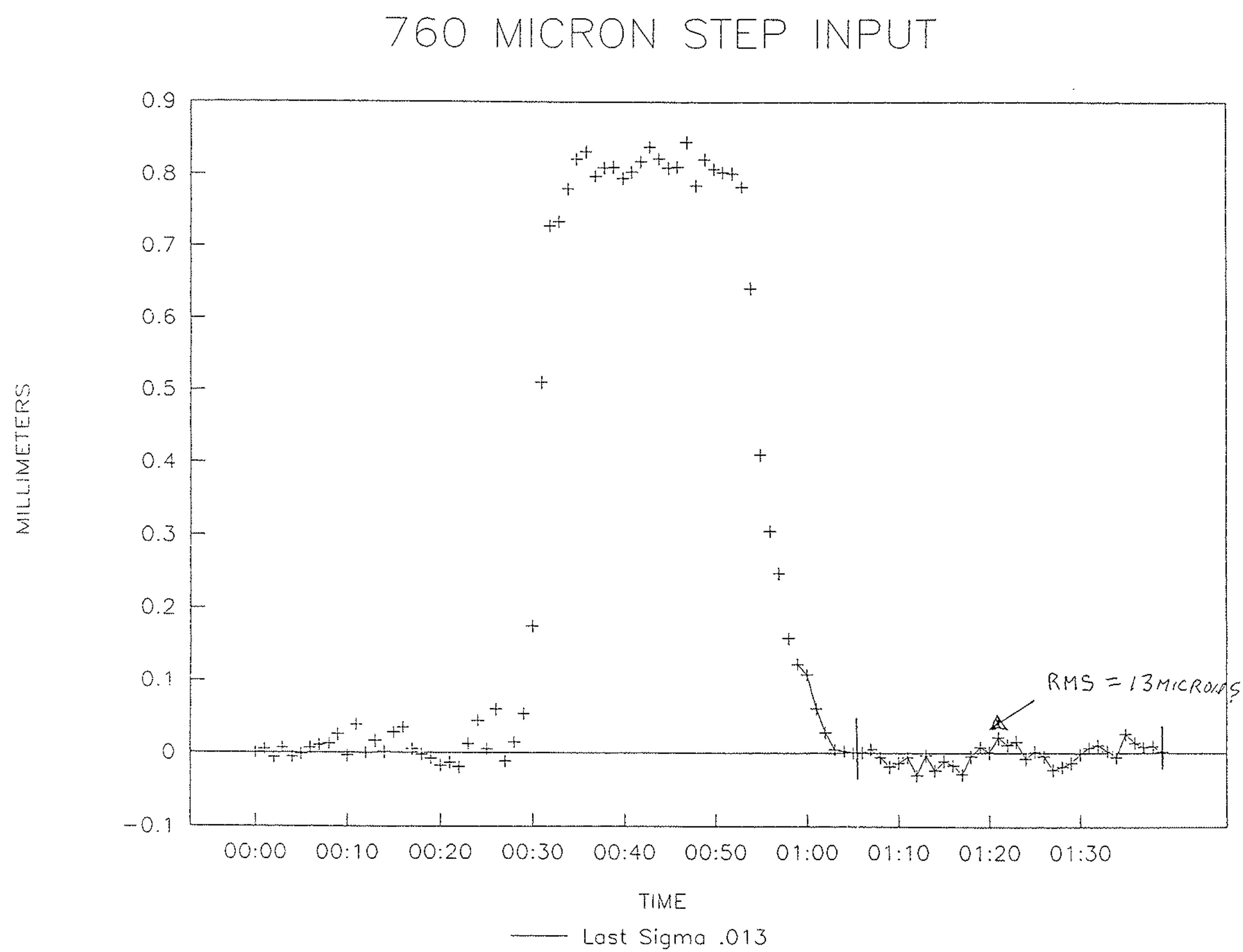

760 MICRON STEP INPUT
MILLIMETERS
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
00:00
00:10
00:20
00:30
00:40
00:50
01:00
01:10
01:20
01:30
TIME
Last Sigma .013
RMS = 13 MICRONS

Figure 5

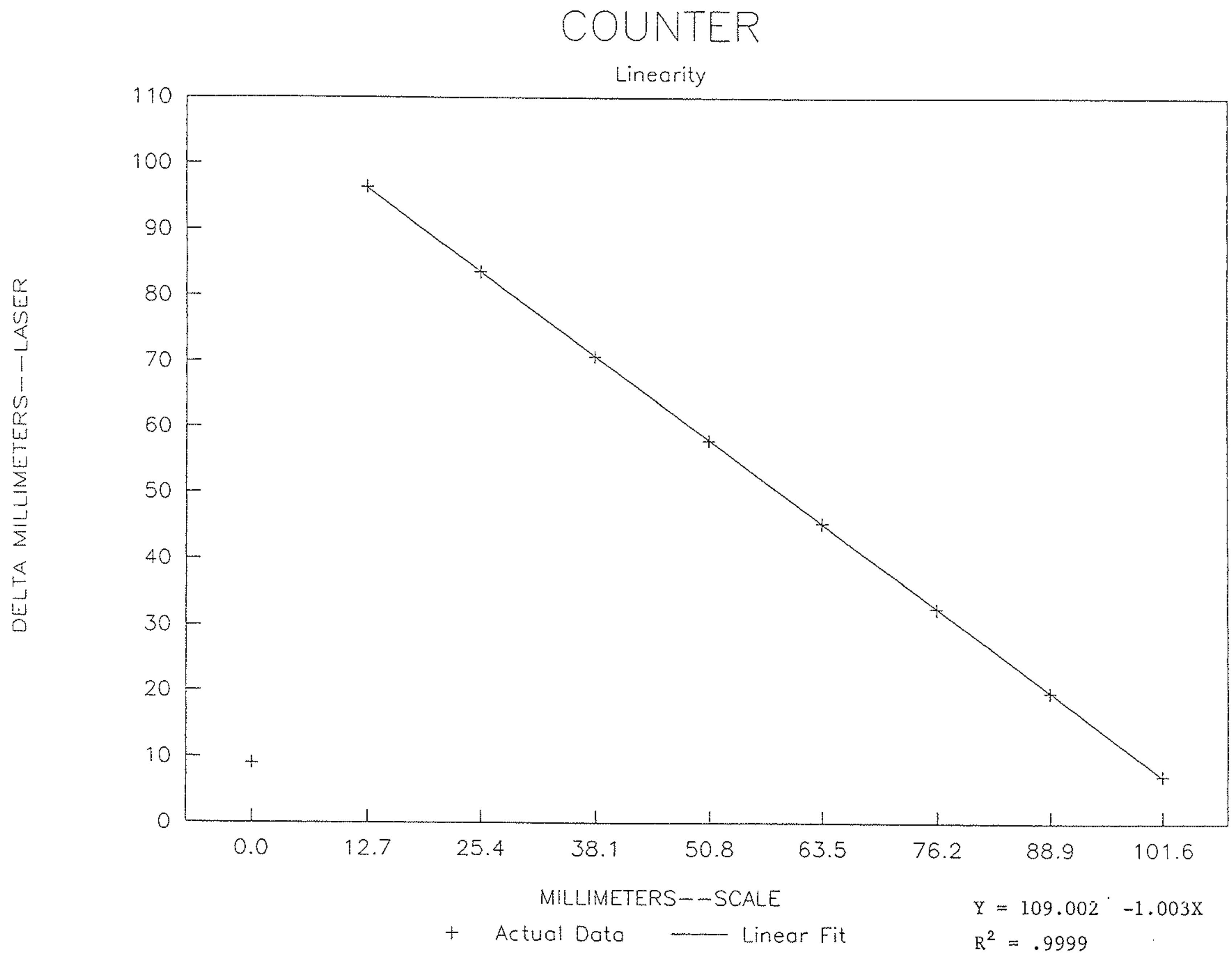
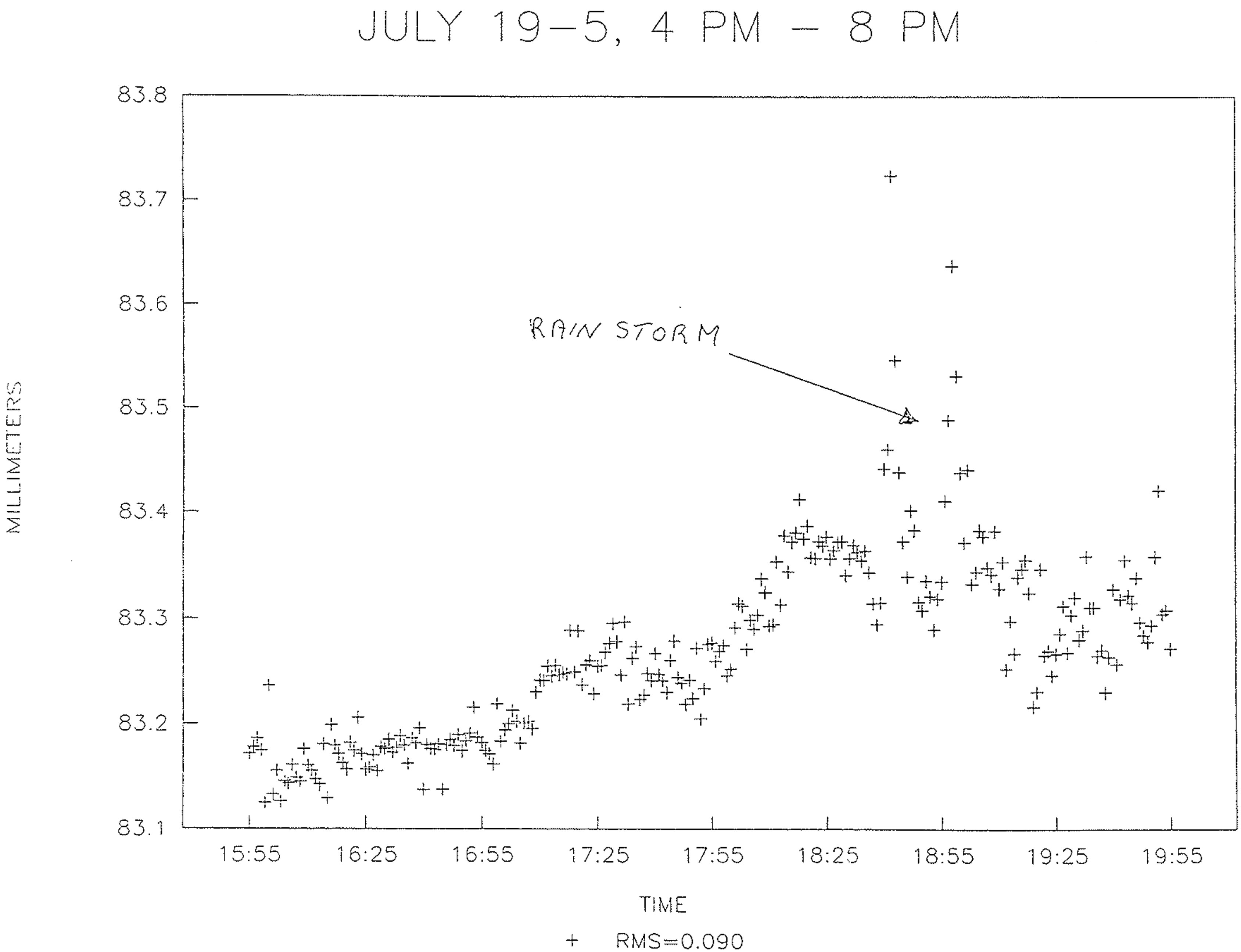

COUNTER
Linearity
110
100
90
80
70
60
50
40
30
20
10
0
DELTA MILLIMETERS--LASER
0.0
12.7
25.4
38.1
50.8
63.5
76.2
88.9
101.6
MILLIMETERS--SCALE
+ Actual Data
Linear Fit
Y = 109.002 -1.003X
R2 = .9999

Figure 6



JULY 19-5, 4 PM - 8 PM
MILLIMETERS
83.8
83.7
83.6
83.5
83.4
83.3
83.2
83.1
RAIN STORM
15:55
16:25
16:55
17:25
17:55
18:25
18:55
19:25
19:55
TIME
+ RMS=0.090

Figure 7

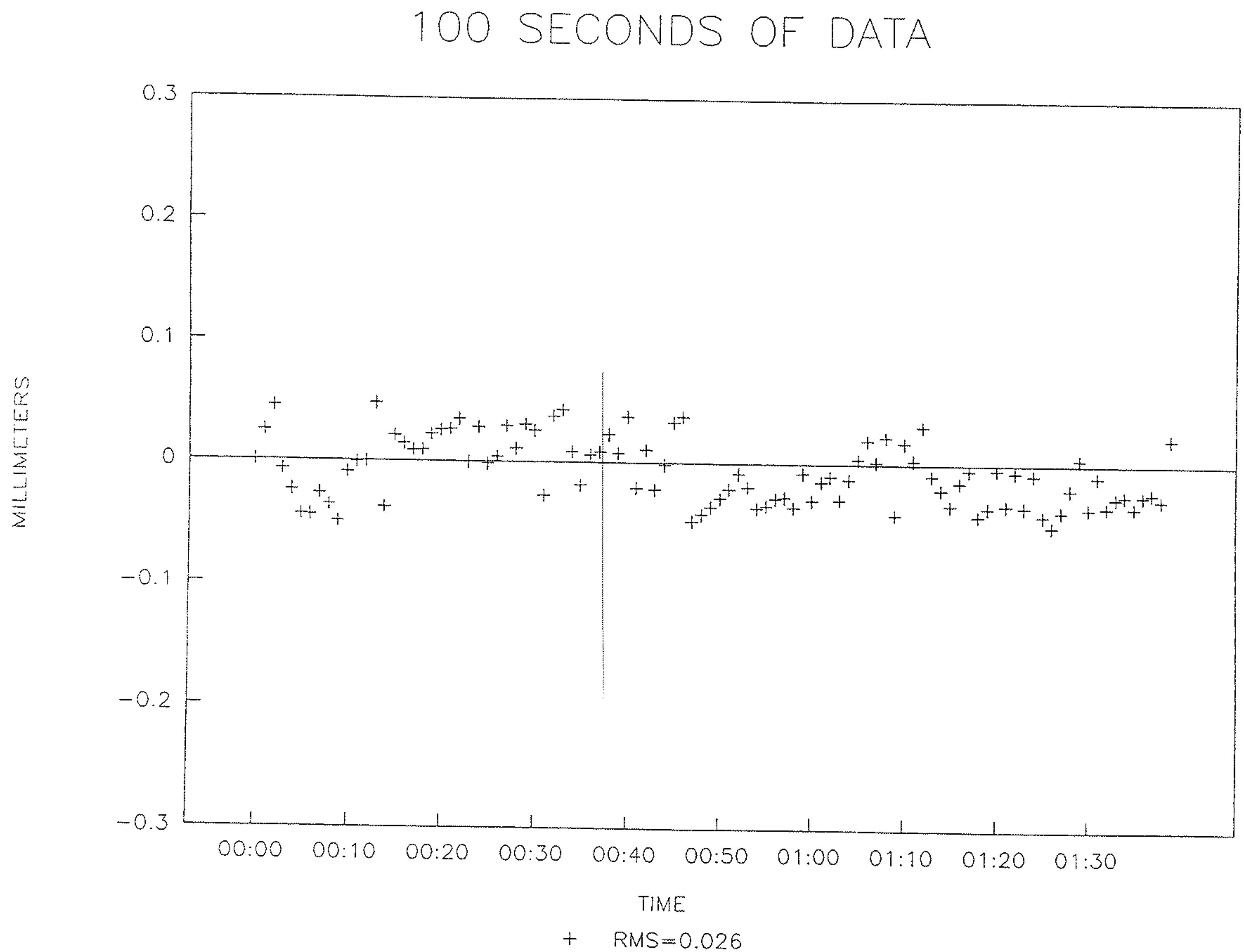

100 SECONDS OF DATA
MILLIMETERS
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
00:00
00:10
00:20
00:30
00:40
00:50
01:00
01:10
01:20
01:30
TIME
+ RMS=0.026

Figure 8