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Technical Memorandum

COAST AND GEODETIC SURVEY

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PRELIMINARY MEASUREMENTS WITH A LASER GEODIMETER

Rockville, Maryland
November 1966

U.S. DEPARTMENT OF COMMERCE John T. Connor, Secretary

ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

Robert M. White, Administrator

Coast and Geodetic Survey
James C. Tison, Director

Coast and Geodetic Survey Technical Memorandum 1

PRELIMINARY MEASUREMENT WITH A LASER GEODIMETER

S.E. Smathers, G.B. Lesley, and R. Tomlinson

and

H.S. Boyne

National Bureau of Standards

Rockville, Maryland
November 1966

CONTENTS

1. Introduction

2. General Approach

3. Geodimeter Modifications

3.1 LASER Light Source

3.2 KDP Cell Modulator

3.3 56 TVP Photomultiplier

3.4 Optical Coatings

4. Laboratory Tests and Evaluation

5. Geodetic Line Tests and Evaluation

6. Discussion and Conclusions

Appendix I

Appendix II

References

Acknowledgments

1. Introduction

Geodimeters utilizing noncoherent light sources for first-order measurements of distance are perfected to the point where the accuracy is limited only by the refractive index correction to the velocity of light (2-3 ppm) and the range is limited from approximately 15 to 20 miles at night in clear weather, and from 7 to 8 miles in average weather encountered by geodetic parties in the United States. In 1964 the Coast and Geodetic Survey initiated a "Precise Distance Measurement Program" for the purpose of improving range and accuracy of first order transcontinental traverse lines and for improving the index of refraction corrections. It is the purpose of this report to discuss improvement in range using a LASER light source.

Experiments in 1965 at the Coast and Geodetic Survey[1] with a LASER light source resulted in measurements up to 10 miles in moderate haze with power outputs of about 1 milliwatt/cm^2 with no loss of accuracy indicating a possible significant improvement in precision. These results provided the guide lines for permanent modification of a Model 4 Geodimeter which is described here.

Sufficient laboratory data and long line measurements are presented to show satisfactory performance of the modified system with no loss of accuracy and considerably increased range under adverse weather conditions.

Daylight tests and successful measurements of 10.2 miles with the standard Model 4 Geodimeter components indicate a range capability exceeding 15 miles in average (haze) weather conditions. Tests shown in Tables I and II indicate the stability and increased accuracy obtainable after optimized adjustment over a 1 mile tape base.

2. General Approach

Geodetic distance is measured by determining the time required for a light beam to make a round trip from the Geodimeter end of a line to a distant retrodirective reflector[2,3,4]. A refractive index correction is made to the velocity of light in vacuum to determine the ambient velocity along the path. The distance is the product of velocity and time. Time in these systems,[5,6] can be determined directly or indirectly as a phase difference and/or a ratio of the calibrated delay line reading and frequency. These are well known identities.

The standard Model 4D Geodimeter is equipped with a mercury vapor light source which is collimated into an optical shutter consisting of crossed polaroids, a Kerr cell, and a Cassegrainian collimator with a divergence of approximately 5 milliradians. The receiver optics consist of a similar Cassegrainian collector and a 1P21 photomultiplier with an S4 surface chosen for the green band of the high pressure mercury vapor lamp.

Experiments in 1965 with a 50 milliwatt LASER showed that the light loss in the Kerr cell can be as much as 90% and the response of the 1P21 photomultiplier at low light levels at 6328 Å is inadequate for this wavelength. Therefore, in order to use a LASER at 6328 Å with a Model 4 Geodimeter, it was necessary to redesign the transmitter and receiver including the Kerr cell and phototube.

3. Geodimeter Modifications

The principal changes to the Geodimeter are shown in figures 1, 2 and 3. The transmitter of the Geodimeter was removed to provide space for the LASER, KDP cell, and collimator which were mounted to permit easy access to the components. The receiver changes consist of addition of a 56TVP photomultiplier and coated receiver optics.

Since it was desired to make a relative comparison of the Kerr cell with the KDP cell and the 1P21 phototube with the 56TVP, the system was designed to permit interchanging of these components.

A small sighting telescope was mounted in the center of the Geodimeter with horizontal and vertical adjustment.

Alignment of the transmitter, receiving optics, and telescope was best accomplished by placing a white light source at the phototube aperture and collimating both the receiver and transmitter in a 6" reflecting telescope focused at infinity.

3.1 LASER Light Source

The LASER used was a 1 milliwatt/cm^2, cw, Helium-Neon gas LASER, 2.25 inches in diameter by 14.5 inches in length and an external DC power supply.[6] This LASER operates at 6328 Å and has an exit beam diameter of 2 mm. The divergence is diffraction limited at .1 milliradians. With supercleaning of the Brewster angle windows and end mirrors, powers up to 1.8 milliwatts were obtained. The LASER was mounted with the polarization in the vertical plane of the Geodimeter and was turned 180° by two coated mirrors.

3.2 KDP Cell Modulator

The KDP cell (Potassium dihydrogen phosphate) modulator[7] consisted of four crystal wafers mounted between two electrodes embedded in an oil filled cavity and followed by an external quarter wave plate. The exit and entrance diameters are 3 mm and light losses were found to be less than 1% at 6328 Å.

Alignment and adjustment is accomplished with a lock ring adapter with three degrees of freedom with respect to the optical axis.

This cell is designed to operate at about 90% efficiency at 1000 volts with a maximum voltage of approximately 1800 volts. Therefore, the power supply was modified to give 1000 volts peak-to-peak 60 cps and 50 volts of 30 megacycles on the KDP cell electrodes.

3.3 56 TVP Photomultiplier

The 56TVP photomultiplier[8] was selected for this application because it has an S20 surface giving 40% spectral response at 6328 Å. The gain is 10^8 at 2500 volts. This tube has 14 dynodes and internal focusing. The maximum frequency response is 200 MHz at a minimum light sensitivity of 85μ A lm. Transit time fluctuation at 2500 volts is of the order of 2 nanoseconds.

This tube was mounted across the front of the Geodimeter in a Conetic shielded case free to move with the receiver optics. The Geodimeter gray wedge was used to control the light level and a regulated power supply was provided to operate the tube at 2500 volts, thus giving maximum gain and minimum noise and transit time variations.

3.4 Optical Coatings

The collimator, flat mirrors of the transmitter, front lens and 45° cube in the receiver were coated for maximum transmission (99.9%) of 6328 Å LASER light. The back collecting mirror of the receiver was broad band coated for maximum reflection at this wavelength. This represents, conservatively, 20% more light. The entire receiving system was relatively insensitive to daylight as measured by the Geodimeter light dip indicator.

4. Laboratory Tests and Evaluation

Relative comparisons of the new modulator and photomultiplier were made with the LASER light source and the standard components to insure proper function, maintain sensitivity, and determine the relative noise contribution.

Anode signals without the delay line 30 megacycle signal, obtained on internal calibrate, (figure 4c) show a significantly improved KDP cell modulated signal as received by the 56TVP phototube. Figure 4a shows relative noise of the 1P21 phototube and insensitivity of this tube to 6328 Å. Figure 4b shows Kerr cell noise which is absent with a KDP cell.

Mixing[5,9] of the returned light signal (figure 5) and the delay line 30 mc signal was accomplished at the anode of the 56TVP phototube with a series 300 K resister to filter the high frequency signal after addition of phase information. In figure 6 the phase output null detection signals reflect the total internal Geodimeter noise

which is inherent in readings of the null indicator. Noise at this point appears as a jitter in the null indicator and adds to the spread of the delay line readings. Comparison of 6a and 6b shows Kerr cell noise and 1P21 insensitivity to the LASER 6328 Å line. Figure 6c shows the 1P21 insensitivity without Kerr cell noise. A comparison of 6b and 6d show isolated Kerr cell noise. Adequate performance of the new components with the LASER light source is demonstrated by comparison of 6d and 6e.

5. Geodetic Line Tests and Evaluation

Comparable distance measurements were made with a standard model 4D Geodimeter and the LASER modified Geodimeter with and without the KDP cell and 56TVP phototube.

Optical collimation of the transmitter, receiver optics and a small centrally mounted sighting telescope were achieved using a 6" reflecting telescope focused at infinity.

The instrument was calibrated and the zero constant determined after each set of measurements in accordance with the Coast and Geodetic Survey's operational techniques.

Table I is a summary of measurements over the same path of approximately 10.2 miles from the Washington Science Center. These data show a maximum difference of 1.6 centimeters and are well within the specified requirement placed on first-order triangulation measurements. Appendix I gives the details of these measurements.

Table II presents comparable measurements of the LASER Geodimeter with the taped base line at Beltsville, Maryland. A series of four measurements were made using advanced and retarded phase increments to eliminate error of the delay line. The mean of these four measurements as compared with the taped base is 4 mm. Appendix II gives the details.

The delay line readings for these measurements while small in number indicate the order of magnitude of the precision improvement that can be expected with the addition of the LASER, KDP cell, and 56TVP phototube to the Geodimeter.

6. Discussion

The modifications which include the LASER source, KDP cell, and 56TVP phototube indicate an improved sensitivity by a factor of 2 over the conventional Geodimeter. However the improvement in range capability during adverse weather conditions and daylight measurements is far more significant. During the field testing of 10 miles it was noted that the LASER light source would measure through haze and marginal weather conditions with at least 50% more light return over the conventional Geodimeter. Experimental daylight tests over distances of 400 meters, 3 miles, and 10.2 miles showed sufficiently good sensitivity to the returned light signal to measure these distances. In addition the KDP cell shows considerable improvement in noise characteristics over the Kerr cell. The LASER light scintillated possibly due to thermal convection currents in the Kerr cell whereas the light through the KDP cell was uniform in intensity.

Test and evaluation of this improved system is presently being conducted under field operational conditions by the Geodesy Division of Coast and Geodetic Survey. These tests are being conducted along a segment of the transcontinental traverse line in Nebraska in order to evaluate the feasibility of measuring traverse lines 10 to 15 miles in length under marginal weather conditions.

REFERENCES

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5. Bjerhammar, Arne; Journal of Geophysical Research, Vol. 65, 412 (1960).
6. Perkin-Elmer Model 5200 Gas Laser.
7. Spectra Physics Model 320 KDP Cell.
8. Amperex Electronic Corporation 56TVP Photomultiplier.
9. Supplementary Paper 6 to Special Publication 39; Radio Aids to Maritime Navigation and Hydrography; Chapter V AGA Geodimeter; International Hydrographic Review, Monaco, June 1963.

ACKNOWLEDGMENTS

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TABLE I

SUMMARY

GEODIMETER OBSERVATIONS

State: Maryland
Station: Room 1022

Locality: Rockville
To Station: Tysons

Date	Geodimeter No.	Slope Distance (m)
3-7-66	246 (4-D)	16,445.695
		16,445.694
	Mean =	16,445.694
3-7-66	225 (Laser)	16,445.676
	(Kerr cell, 1P21 Phototube)	16,445.700
	Mean =	16,445.688
8-24-66	225 (Laser) (KDP cell, 56TVP Phototube)	16,445.678

TABLE II

SUMMARY

GEODIMETER OBSERVATIONS

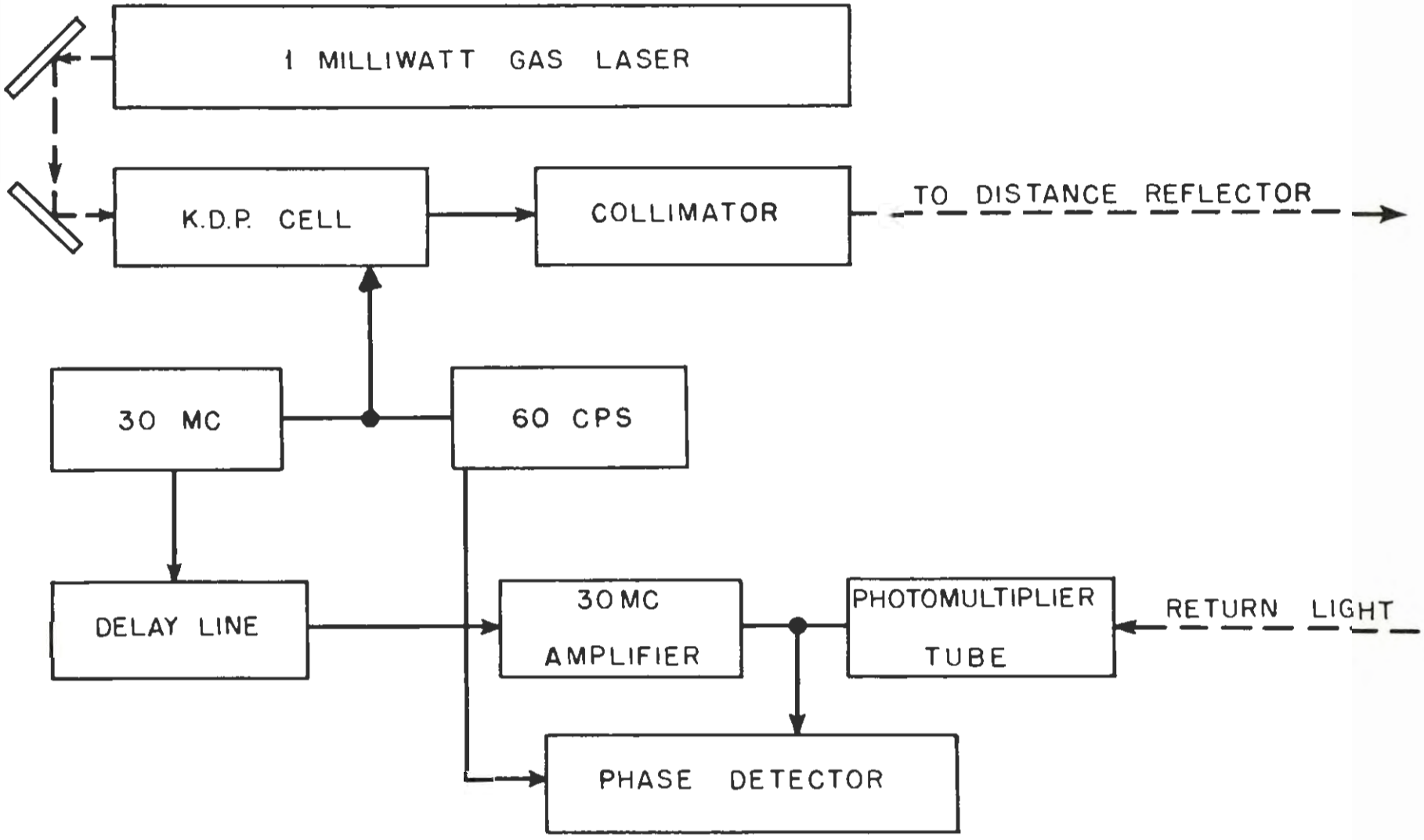
State: Maryland — Locality: Beltsville Date 9-30-66
Station: 150 meters — To Station: 1800 meters
Geodimeter No. 225 (Laser, KDP cell, 56TVP Phototube)

Geodimeter slope distance=	1649.998
	1650.008
	1650.015
	1650.009
Mean =	1650.008m

Mean Geodimeter slope distance	=	1650.008
Sea level correction	=	- 0.013
Slope correction	=	- 0.008
Geodimeter Geodetic distance	=	1649.987 meters

Geodimeter distance	=	1649.987
Tape distance	=	1649.983
Difference	=	0.004 = 1/412,500

BLOCK DIAGRAM OF MODIFIED LASER GEODIMETER



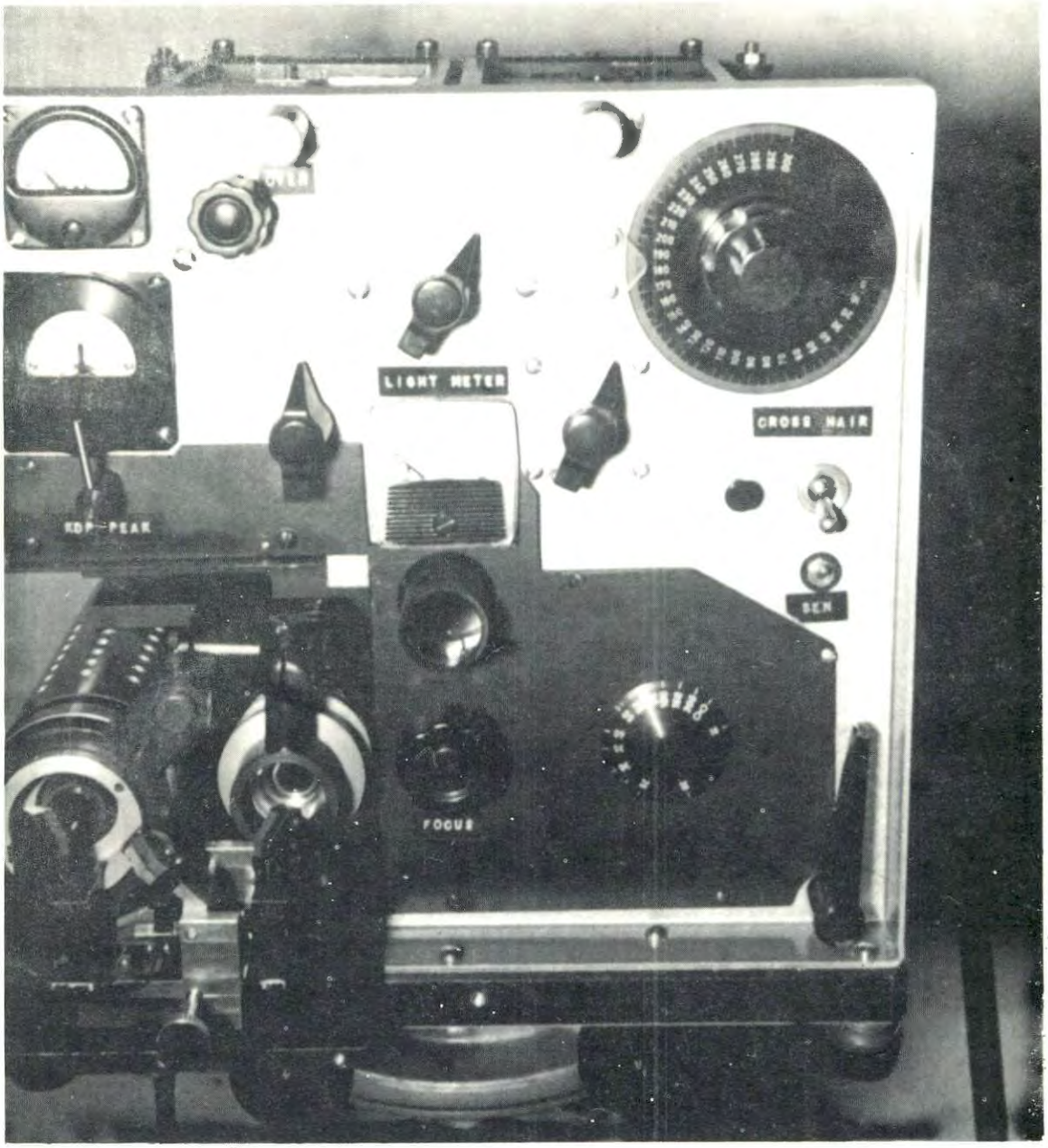


Figure 2

Control panel and optics showing beam path from LASER (left) into KDP cell (right).

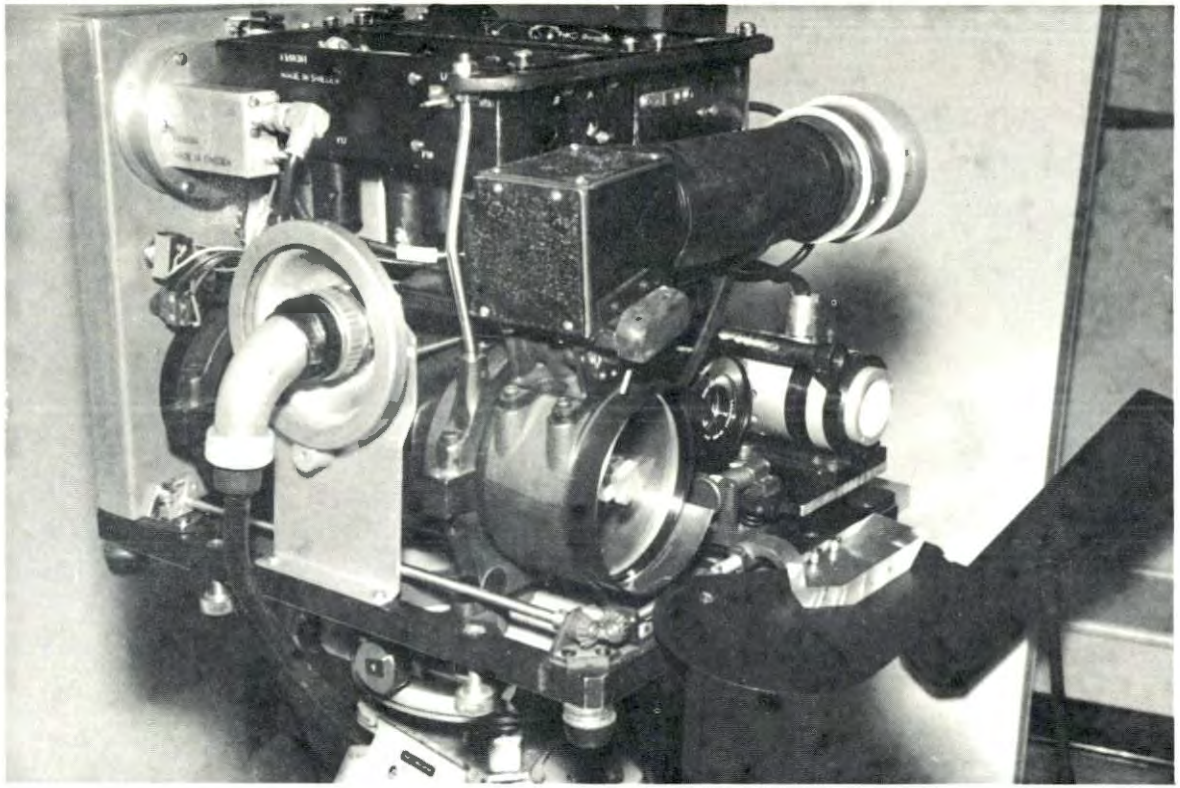


Figure 3

Collimator and 56 TVP phototube.

(a)

(b)

(c)

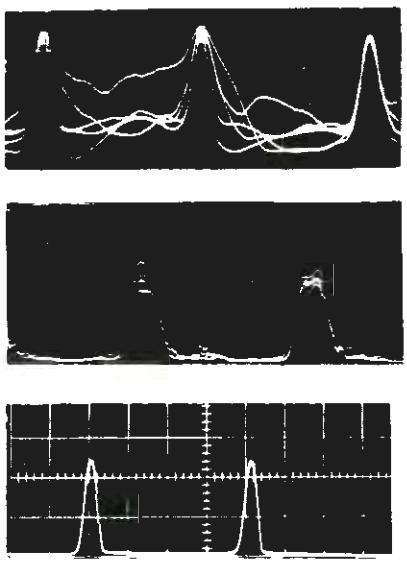


Figure 4 ANODE NOISE

Anode voltage on internal calibrate with LASER light source and without the calibrated 30 mega cycle delay line signal. 2 milliseconds/cm; 1 volt/cm.

(a) 1P21 photomultiplier KDP cell modulator showing noise and a low spectral response for 6328 Angstroms.

(b) 56 TVP photomultiplier, and Kerr cell modulator showing Kerr Cell noise due to thermal convection of nitrobenzene.

(c) 56 TVP photomultiplier and KDP cell.

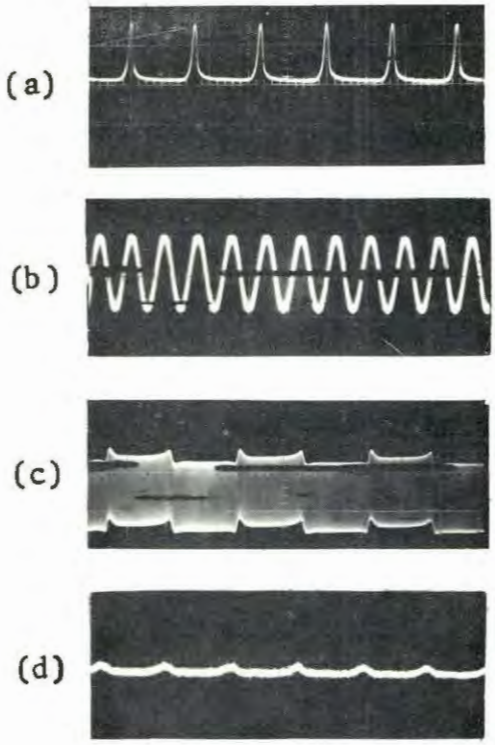


Figure 5 ANODE DELAY LINE MODULATION LASER, KDP CELL, AND 56 TVP PHOTOTUBE

(a) Anode signal output without delay line 30 mega cycle modulation. 5 milliseconds/cm; 1 volt/cm.

(b) Calibrated delay line signal (30 mega cycles; 15 volts PP).

(c) Modulated anode voltage, phase of delay line unbalanced (amplitude modulation of low frequency carrier).

(d) Modulated anode voltage after high frequency filtering, phase delay balanced. (Phase detector bias).

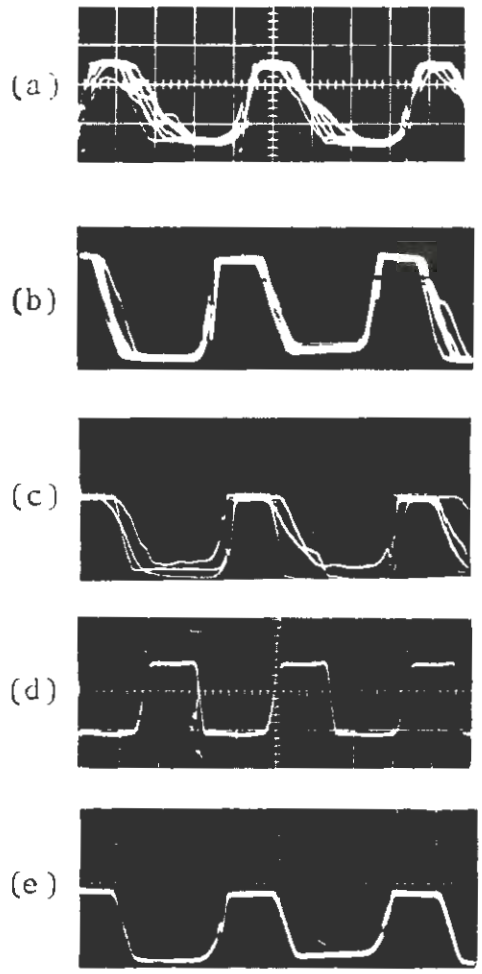


Figure 6 NULL INDICATOR SIGNAL

(a) LASER, Kerr Cell, 1P21 Phototube

(b) LASER, Kerr Cell, 56 TVP Phototube

(c) LASER, KDP Cell, 1P21 Phototube

(d) LASER, KDP Cell, 56 TVP Phototube

(e) Mercury Vapor Lamp, Kerr Cell 1P21 Phototube
2 ms/cm; 1 Volt/CM.

A P P E N D I X I

Atmospheric corr'n = 4.7
Color corr'n = - 0.9
Correction = + 3.8
P.P.M.

FORM C&GS-328 (11-62)
F1=29,970,057
F2=30,044,992
F3=31,468,597

U.S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

GEODIMETER MODEL 4 OBSERVATIONS

State Maryland Locality Rockville, WSC Date 3-7-66
Station Room 1022 To Station Tysons (10.2 mi.) Geod. No. 246 (4-D)
Chief of Party J. O. Phillips Observer G. B. Lesley
Proj. No. Ht. of Geod. 1.50 M. Ht. of Reflex 1.55 M.

	G	M	G	M
Time	1955			
Temp.	-0.2°C	-3.6°C	-00.4°C	-4.4°C
Press.	1100.ft	974.ft	1100.ft	972 ft
Rel. Hu.				

Geod. Ecc. 0.000
Geod. Const. + 0.188
Reflex No. AGA Type Const. - 0.027
Reflex. Ecc. 0.000
Atmospheric Correction + 0.062

Means Tm= -02.2°C Pm=758.5mm Hm= 01 Sum of Constants + 0.223

Dial readings	Frequency 1		Frequency 2		Frequency 3	
Phase	C	R	R	C	C	R
1	+ 39.0	+ 86.0	+ 201.0	- 263.5	+ 41.0	- 82.0
2	37.0	84.5	201.5	264.5	41.0	84.0
3	38.5	88.0	201.0	263.0	41.5	84.0
4	37.5	85.0	197.5	263.0	42.0	89.0
Sum of 2 and 3	37.75	86.25	201.25	263.75	41.25	84.0
Sum of 1 and 4	38.25	85.5	199.25	263.25	41.5	85.5
Total sum						
Means	+ 038.0	+ 085.9	+200.2	- 263.5	+ 041.4	- 84.8
Means in meters	.395	.911	2.048	2.880	.330	.626

L= R-C Note (1) U1 2.500 U2 2.494 U3 2.381

L = Note (2) U1 2.500 U2 2.494 U3 2.381

2U2 4.988 2U3 4.762

L1= .516 L2= 1.662 L3= 2.677

Note (3) -L1 .516 -L1 .516

A= 1.146 B= 2.161

Ax400 = 458. Bx20 =

Bx21 = 45.4

Ax400 minus Bx21 = E = 400 (nearest hundreds) - Bx21 = F = 45 (nearest 5 multiple)

D´ = E + F D´= 445. m

n = 8

	D1		D2		D3		
D´ =	445.	D´ =	445.	D´ =	445.	Mean D1, D2, D3 =	445.534
+L1	.516	+L2	1.662	+L3	2.677	+n x 2000	16,000.
D1 =	445.516		446.662		447.677	D =	16,445.534
		-K2	1.110	-K3	2.143	Sum Corr'ns	+ 0.223
		D2 =	445.552	D3 =	445.534	D (slope) =	16,445.757

Note (1). If R − C is negative, add U1, U2, or U3 before subtracting.
Note (2). If sign of R is negative, add U1, U2, or U3. 0.999 996 226 x 16,445.757=16,445.695 meters
Note (3). If L2 or L3 is less than L1, add 2U2 or 2U3 before subtracting.
Means in meters is obtained from latest calibration table for the particular instrument being used.

USCOMM-DC 8232-P62

K.D.P. Cell, 56 T.V.P.
Phototube, Laser

Atmosphere corr'n = + 30.1
Color corr'n = + 3.5
Correction = + 33.6

FORM C&GS-328 (11-62)

F1=1.000005138
F2=1.000006224
F3=1.000002764

P.P.M.
F1=29,969,805
F2=30,044,692
F3=31,468,375

U.S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

GEODIMETER MODEL 4 OBSERVATIONS

State Maryland Locality Rockville, WSC Date 8-24-66
Station Room 1022 To Station Tysons (10.2 mi.) Geod. No. 225 (Laser)
Chief of Party J. O. Phillips Observer R. W. Tomlinson
Proj. No. 221104000 Ht. of Geod. 1.50 M. Ht. of Reflex 1.53 M.

	G	M	G	M
Time	2035	2035		
Temp.	17.8°C	21.0°C		
Press.	1260.ft	1310.ft		
Rel. Hu.				

Geod. Ecc. 0.000
Geod. Const. 0.259
Reflex No. AGA Type Const. - 0.027
Reflex. Ecc. 0.075
Atmospheric Correction 0.553

Means Tm= +19.4°C Pm= 751.5mm Hm= -4 Sum of Constants 0.860

Dial readings	Frequency 1		Frequency 2		Frequency 3	
Phase	C	R	R	C	C	R
1	- 59.0	- 26.0	- 117.0	- 46.0	- 148.0	+ 125.0
2	59.0	26.0	118.0	46.0	148.0	123.0
3	58.0	28.0	118.0	39.0	147.0	125.0
4	58.0	28.0	120.0	39.0	146.0	126.0
Sum of 2 and 3	58.5	27.0	118.0	42.5	147.5	124.0
Sum of 1 and 4	58.5	27.0	118.5	42.5	147.0	125.5
Total sum						
Means	58.5	27.0	118.2	42.5	147.2	124.8
Means in meters	0.466	0.203	1.144	0.329	1.204	0.747
L= R-C Note (1)		U1 2.500	U2 2.494			U3 2.381
L =						
Note (2)		U1 2.500	U2 2.494			U3 2.381
			2U2 4.988			2U3 4.762
	L1= 4.737		L2= 5.803		L3= 6.686	

Note (3) -L1 4.737 -L1 4.737
A= 1.066 B= 1.949
Ax400 = 426. Bx20 =
Bx21 = 40.9

Ax400 minus Bx21 = E = 400 (nearest hundreds) - Bx21 = F = 40 (nearest 5 multiple)

D´ = E + F D´= 440. m

n = 8

D1	D2	D3		
D´ = 440.	D´ = 440.	D´ = 440.	Mean D1, D2, D3 =	444.741
+L1 4.737	+L2 5.803	+L3 6.686	+n x 2000	16,000.000
D1 = 444.737	445.803	446.686	D =	16,444.741
	-K2 1.097	-K3 1.905	Sum Corr'ns	0.860
	D2 = 444.706	D3 = 444.781	D (slope) =	16,445.601

Note (1). If R − C is negative, add U1, U2, or U3 before subtracting.
Note (2). If sign of R is negative, add U1, U2, or U3. 1.000004709 x 16,445.601 = 16,445.678m
Note (3). If L2 or L3 is less than L1, add 2U2 or 2U3 before subtracting.
Means in meters is obtained from latest calibration table for the particular instrument being used.

USCOMM-DC 8232-P62

Laser, Kerr cell,
IP21 Phototube

Atmospheric Corr'n = 6.7
Color corr'n = 3.5
Correction = + 10.2 P.P.M.

FORM C&GS-328 (11-62)

U.S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

F1=29,969,986
F2=30,044,926
F3=31,468,504

GEODIMETER MODEL 4 OBSERVATIONS

State Maryland Locality Rockville, WSC Date 3-7-66
Station Room 1022 To Station Tysons (10.2 mi.) Geod. No. 225
Chief of Party J. O. Phillips Observer S. E. Smathers
Proj. No. Ht. of Geod. 1.50 M. Ht. of Reflex 1.50 M.

	G	M	G	M
Time	1825			
Temp.	+01.8°C	-02.5°C	+00.6°C	-2.5°C
Press.	1140.ft	974.ft	1140.ft	974.ft
Rel. Hu.				

Geod. Ecc. 0.000
Geod. Const. + 0.205
Reflex No. AGA Type Const. - 0.027
Reflex. Ecc. 0.000
Atmospheric Correction + 0.168

Means Tm= -00.6°C Pm= 757.8mm Hm= 01 Sum of Constants + 0.346

Dial readings	Frequency 1		Frequency 2		Frequency 3	
Phase	C	R	R	C	C	R
1	+ 36.0	+ 70.0	+ 195.0	- 271.0	+ 37.0	- 41.5 42.0
2	36.0	62.0	187.0	273.0	36.0	47.0 54.0
3	40.0	61.0	192.0	267.0	38.0	58.0 48.0
4	39.0	54.0	181.0	269.0	35.5	73.0 66.0
Sum of 2 and 3	38.0	61.5	189.5	270.0	37.0	52.5 51.0
Sum of 1 and 4	37.5	62.0	188.0	270.0	36.25	57.25 54.0
Total sum						
Means	+037.8	+061.8	+188.8	-270.0	+036.6	-54.9 -52.5
Means in meters	.429	.748	1.947	2.985	.333	.483
L= R-C Note (1)		U1 2.500	U2 2.494			U3 2.381
L =						
Note (2)		U1 2.500	U2 2.494			U3 2.381
			2U2 4.988			2U3 4.762
	L1=	.319	L2=	1.456	L3=	2.531
Note (3)			-L1	.319	-L1	.319
			A=	1.137	B=	2.212
			Ax400 =	454.	Bx20 =	
					Bx21 =	46.4

Ax400 minus Bx21 = E = 400 (nearest hundreds) - Bx21 = F = 45 (nearest 5 multiple)

D´ = E + F D´ = 445 m

n = 8

	D1		D2		D3		
D´ =	445.	D´ =	445.	D´ =	445.	Mean D1, D2, D3 =	445.351
+L1	.319	+L2	1.456	+L3	2.531	+n x 2000	16,000.
D1 =	445.319		446.456		447.531	D =	16,445.351
		-K2	1.110	-K3	2.143	Sum Corr'ns	+ 0.346
		D2 =	445.346	D3 =	445.388	D (slope) =	16,445.697

Note (1). If R − C is negative, add U1, U2, or U3 before subtracting.
Note (2). If sign of R is negative, add U1, U2, or U3. 0.999 998 733 x 16,445.697=16,445.676 meters
Note (3). If L2 or L3 is less than L1, add 2U2 or 2U3 before subtracting.
Means in meters is obtained from latest calibration table for the particular instrument being used.

USCOMM-DC 8232-P62

Laser, Kerr cell,
IP21 Phototube

Atmospheric corr'n = 5.9
Color corr'n = 3.5
Correction = + 9.4
P.P.M.

FORM C&GS-328
(11-62)

U.S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

GEODIMETER MODEL 4 OBSERVATIONS

State Maryland Locality Rockville, WSC Date 3-7-66
Station Room 1022 To Station Tysons (10.2 mi.) Geod. No. 225
Chief of Party J. O. Phillips Observer H. S. Boyne
Proj. No. _____ Ht. of Geod. 1.50 M. Ht. of Reflex 1.50 M.

	G	M	G	M
Time	1950		1900	
Temp.	+00.5°C	-2.5°C	+00.5°C	-3.1°C
Press.	1120.ft	974.ft	1120.ft	974.ft
Rel. Hu.				

Geod. Ecc. 0.000
Geod. Const. + 0.205
Reflex No. _____ Const. - 0.027
Reflex. Ecc. 0.000
Atmospheric Correction + 0.155

Means Tm= -01.2°C Pm= 758.1 Hm= 01 Sum of Constants + 0.333

Dial readings	Frequency 1		Frequency 2		Frequency 3	
Phase	C	R	R	C	C	R
1	+ 38.5	+ 82.0	+ 201.0	+ 42.0	+ 38.0	- 32.0
2	37.0	71.0	199.0	40.5	35.5	44.0
3	38.0	60.0	190.0	42.5	38.5	62.0
4	36.0	52.5	183.0	40.0	36.0	72.0
Sum of 2 and 3	37.5	65.5	194.5	41.5	37.0	53.0
Sum of 1 and 4	37.25	67.25	192.0	41.0	37.0	52.0
Total sum						
Means	+037.4	+066.4	+ 193.2	+041.2	+037.0	- 52.5
Means in meters	.424	.808	2.002	.487	.336	.472

L= R-C Note (1) U1 2.500 U2 2.494 U3 2.381

L = Note (2) U1 2.500 U2 2.494 U3 2.381

2U2 4.988 2U3 4.762

L1= .384 L2= 1.515 L3= 2.517

Note (3) -L1 .384 -L1 .384

A= 1.131 B= 2.133

Ax400 = 452. Bx20 =

Bx21 = 44.8

Ax400 minus Bx21 = E = 400 (nearest hundreds) - Bx21 = F = 45 (nearest 5 multiple)

D´ = E + F D´ = 445. m

n = 8

	D1	D2	D3		
D´ =	445.	445.	445.	Mean D1, D2, D3 =	445.388
+L1	.384	+L2 1.515	+L3 2.517	+n x 2000	16,000.
D1 =	445.384	446.515	447.517	D =	16,445.388
		-K2 1.110	-K3 2.143	Sum Corr'ns	+ 0.333
		D2 = 445.405	D3 = 445.374	D (slope) =	16,445.721

Note (1). If R − C is negative, add U1, U2, or U3 before subtracting.
Note (2). If sign of R is negative, add U1, U2, or U3. 0.999 998 733 x 16,445.721 = 16,445.700
Note (3). If L2 or L3 is less than L1, add 2U2 or 2U3 before subtracting.
Means in meters is obtained from latest calibration table for the particular instrument being used.

USCOMM-DC 8232-P62

Atmospheric corr'n = 4.5
Color Corr'n = - 0.9
Correction = + 3.6
P.P.M.

FORM C&GS-328 (11-62)

U.S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

GEODIMETER MODEL 4 OBSERVATIONS

State Maryland Locality Rockville, WSC Date 3-7-66
Station Room 1022 To Station Tysons (10.2 mi.) Geod. No. 246 (4-D)
Chief of Party J. O. Phillips Observer J. H. Shirley
Proj. No. Ht. of Geod. 1.50 M. Ht. of Reflex 1.55 M.

	G	M	G	M
Time				
Temp.	-0.4°C	-4.4	-0.4	-4.4
Press.	1100.ft	972.ft	1100.ft	972.ft
Rel. Hu.				

Geod. Ecc. 0.000
Geod. Const. + 0.188
Reflex No. AGA Type Const. - 0.027
Reflex. Ecc. 0.000
Atmospheric Correction + 0.059

Means Tm= -02.4°C Pm= 758.5mm Hm= 01 Sum of Constants + 0.220

Dial readings	Frequency 1		Frequency 2		Frequency 3	
	C	R	R	C	C	R
Phase 1	+ 34.5	+ 87.0	+ 198.0	- 260.0	+ 41.0	- 80.5
2	35.0	84.0	199.5	262.0	41.0	82.0
3	35.0	85.5	199.5	264.5	41.5	83.0
4	35.0	82.5	195.5	262.0	41.0	86.5
Sum of 2 and 3	35.0	84.75	199.5	263.25	41.25	82.5
Sum of 1 and 4	34.75	84.75	196.75	261.0	41.0	83.5
Total sum						
Means	+034.9	+084.8	+198.1	- 262.1	+041.1	-083.0
Means in meters	.356	.901	2.020	2.864	.328	.614

L= R-C Note (1) U1 2.500 U2 2.494 U3 2.381

L = Note (2) U1 2.500 U2 2.494 U3 2.381

2U2 4.988 2U3 4.762

L1= .545 L2= 1.650 L3= 2.667

Note (3) -L1 .545 -L1 .545

A= 1.105 B= 2.122

Ax400 = 442. Bx20 =

Bx21 = 44.5

Ax400 minus Bx21 = E = 400 (nearest hundreds) - Bx21 = F = 45 (nearest 5 multiple)

D´ = E + F D´= 445. m

n = 8

D1	D2	D3	
D´ = 445.	D´ = 445.	D´ = 445.	Mean D1, D2, D3 = 445.536
+L1 .545	+L2 1.650	+L3 2.667	+n x 2000 16,000.
D1 = 445.545	446.650	447.667	D = 16,445.536
	-K2 1.110	-K3 2.143	Sum Corr'ns + 0.220
	D2 = 445.540	D3 = 445.524	D (slope) = 16,445.756

Note (1). If R − C is negative, add U1, U2, or U3 before subtracting.
Note (2). If sign of R is negative, add U1, U2, or U3.
Note (3). If L2 or L3 is less than L1, add 2U2 or 2U3 before subtracting.
Means in meters is obtained from latest calibration table for the particular instrument being used.

0.999 996 226 x 16,445.756=16,445.694 meters

USCOMM-DC 8232-P62

A P P E N D I X II

K.D.P. Cell, 56 T.V.P. Phototube, Laser

Atmosphere corr'n = + 31.4
Color corr'n = + 3.5
Correction = + 34.9 P.P.M.

Weather: Bright sunlight, light s.w. wing

FORM C&GS-328 (11-62)
F1=0.999999632
F2=0.999999700
F3=0.999999745

GEODIMETER MODEL 4 OBSERVATIONS

U.S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY
F1=29,969,970
F2=30,044,888
F3=31,468,470

State Maryland Locality Beltsville Date 9-30-66
Station 150 m To Station 1800 m Geod. No. 225 (Laser)
Chief of Party J. O. Phillips Observer G. B. Lesley
Proj. No. 221104000 Ht. of Geod. 0.25 M. Ht. of Reflex 2.31 M.

	G	M	G	M
Time	1048		1058	
Temp.	20.8°C	20.3	20.9°C	20.5
Press.	1280.ft	1290	1275.ft	1285
Rel. Hu.	58%			

Geod. Ecc. or tilt 0.000
Geod. Const. + 0.256
Reflex No. 7 Prism AGA Type Const. - 0.027
Reflex. Ecc. - 0.400
Atmospheric Correction + 0.058

Means Tm= +20.6°C Pm= 751.5mm Hm= -5 Sum of Constants - 0.113

Dial readings	Frequency 1		Frequency 2		Frequency 3	
Phase	C	R	R	C	C	R
1	+ 47.0	+ 56.5	- 222.0	- 270.0	+ 96.5	- 106.5
2	47.5	55.0	224.0	269.5	95.5	105.5
3	48.0	54.5	223.5	268.0	95.0	104.0
4	47.5	55.0	223.5	270.0	96.0	104.5
Sum of 2 and 3	47.75	54.75	223.75	268.75	95.25	104.75
Sum of 1 and 4	47.5	55.25	222.75	270.0	96.25	105.5
Total sum						
Means	+047.6	+055.0	- 223.2	- 269.4	+095.8	- 105.1
Means in meters	.633	.742	2378	3.140	.920	1.036

L= R-C Note (1) U1 2.500 U2 2.494 U3 2.381

L =
Note (2) U1 2.500 U2 2.494 U3 2.381
2U2 4.988 2U3 4.762

L1= .109 L2= 4.226 L3= 2.497

Note (3) -L1 .109 -L1 .109
A= 4.117 B= 2.388
Ax400 = 1647. Bx20 =
Bx21 = 50.1

Ax400 minus Bx21 = E = 1600 (nearest hundreds) - Bx21 = F = 50 (nearest 5 multiple)

D´ = E + F D´= 1650. m

n = 0

	D1	D2	D3	
D´ =	1650.	1650.	1650.	Mean D1, D2, D3 = 1650.112
+L1	.109	+L2 4.226	+L3 2.497	+n x 2000
D1 =	1650.109	1654.226	1652.497	D = 1650.112
		-K2 4.114	-K3 2.381	Sum Corr'ns - 0.113
		D2 = 1650.112	D3 = 1650.116	D (slope) = 1649.999

Note (1). If R − C is negative, add U1, U2, or U3 before subtracting.
Note (2). If sign of R is negative, add U1, U2, or U3. 0.999999692 x 1649.999 = 1649.998 m
Note (3). If L2 or L3 is less than L1, add 2U2 or 2U3 before subtracting.
Means in meters is obtained from latest calibration table for the particular instrument being used.

USCOMM-DC 8232-P62

K.D.P. Cell, 56 T.V.P. Phototube, Laser

Atmosphere corr'n = 31.5
Color corr'n = + 3.5
Correction = 35.0 P.P.M.

Weather: Bright sunlight, light s.w. wing

FORM C&GS-328 (11-62)

U.S. DEPARTMENT OF COMMERCE COAST AND GEODETIC SURVEY

GEODIMETER MODEL 4 OBSERVATIONS

State Maryland Locality Beltsville Date 9-30-66

Station 150 m To Station 1800 m Geod. No. 225 (Laser)

Chief of Party J. O. Phillips Observer G. B. Lesley

Proj. No. 221104000 Ht. of Geod. 0.25 M. Ht. of Reflex 2.31 M.

	G	M	G	M
Time	1058		1106	
Temp.	20.9°C	20.5	21.0	20.3
Press.	1275.ft	1285	1290.ft	1300.
Rel. Hu.	58%			

Geod. Ecc. or tilt	0.000
Geod. Const.	+ 0.256
Reflex No. 7 Prism AGA Type Const.	- 0.027
Reflex. Ecc.	- 0.400
Atmospheric Correction	+ 0.058
Sum of Constants	- 0.113

Means Tm= +20.7°C Pm= 751.5mm Hm= -5

Dial readings	Frequency 1		Frequency 2		Frequency 3	
Phase	C	R	R	C	C	R
1	- 272.0	- 279.0	- 225.5	- 271.0	+ 98.0	- 107.0
2	272.5	280.0	224.5	271.5	99.0	108.0
3	269.5	279.5	225.5	268.5	97.5	107.0
4	270.0	280.0	224.5	270.0	97.5	106.5
Sum of 2 and 3	271.0	279.75	225.0	270.0	98.25	107.5
Sum of 1 and 4	271.0	279.50	225.0	270.5	97.75	106.75
Total sum						
Means	- 271.0	- 279.6	- 225.0	- 270.2	+ 098.0	- 107.1
Means in meters	3.160	3.284	2.405	3.153	.946	1.062

L= R-C Note (1) U1 2.500 U2 2.494 U3 2.381

L =

Note (2) U1 2.500 U2 2.494 U3 2.381

2U2 4.988 2U3 4.762

L1= .124 L2= 4.240 L3= 2.497

Note (3) -L1 .124 -L1 .124

A= 4.116 B= 2.373

Ax400 = 1646 Bx20 =

Bx21 = 49.8

Ax400 minus Bx21 = E = 1600 (nearest hundreds) - Bx21 = F = 50 (nearest 5 multiple)

D´ = E + F D´= 1650 m

n = 0

D1	D2	D3	
D´ = 1650.	D´ = 1650.	D´ = 1650.	Mean D1, D2, D3 = 1650.122
+L1 .124	+L2 4.240	+L3 2.497	+n x 2000
D1 = 1650.124	1654.240	1652.497	D = 1650.122
	-K2 4.114	-K3 2.381	Sum Corr'ns - .133
	D2 = 1650.126	D3 = 1650.116	D (slope) = 1650.009

Note (1). If R − C is negative, add U1, U2, or U3 before subtracting.
Note (2). If sign of R is negative, add U1, U2, or U3. 0.999999692 x 1650.009 = 1650.008 m
Note (3). If L2 or L3 is less than L1, add 2U2 or 2U3 before subtracting.
Means in meters is obtained from latest calibration table for the particular instrument being used.

USCOMM-DC 8232-P62

K.D.P. Cell, 56 T.V.P. Phototube, Laser

Atmosphere corr'n = + 31.6
Color corr'n = + 3.5
Correction = + 35.1 P.P.M.

Weather: Bright sunlight, light s.w. wing

FORM C&GS-328 (11-62)

U.S. DEPARTMENT OF COMMERCE COAST AND GEODETIC SURVEY

GEODIMETER MODEL 4 OBSERVATIONS

State Maryland Locality Beltsville Date 9-30-66

Station 150 m To Station 1800 m Geod. No. 225 (Laser)

Chief of Party J. O. Phillips Observer G. B. Lesley

Proj. No. 221104000 Ht. of Geod. 0.25 M. Ht. of Reflex 2.31 M.

	G	M	G	M
Time	1106		1114	
Temp.	21.0°C	20.3	21.5°C	20.6
Press.	1290.ft	1300.	1280.ft	1290.
Rel. Hu.	58%			

Geod. Ecc. or tilt 0.000
Geod. Const. + 0.256
Reflex No. 7 Prism AGA Type Const. - 0.027
Reflex. Ecc. - 0.800
Atmospheric Correction + 0.058

Means Tm= +20.8°C Pm= 751.4mm Hm= -5 Sum of Constants - 0.513

Dial readings	Frequency 1		Frequency 2		Frequency 3	
Phase	C	R	R	C	C	R
1	+ 51.0	+ 98.5	+ 29.0	+ 50.0	+ 101.5	- 141.0
2	50.0	98.0	29.5	50.5	102.0	143.0
3	52.0	97.0	30.0	51.0	100.5	140.5
4	50.0	96.0	29.0	50.5	101.5	141.0
Sum of 2 and 3	51.0	97.5	29.75	50.75	101.25	141.75
Sum of 1 and 4	50.5	97.25	29.0	50.25	101.5	141.0
Total sum						
Means	+ 050.8	+ 097.4	+ 029.4	+ 050.5	+ 101.4	- 141.4
Means in meters	.682	1.206	.350	.687	.988	1.508

L= R-C Note (1) U1 2.500 U2 2.494 U3 2.381

L =

Note (2) U1 2.500 U2 2.494 U3 2.381

2U2 4.988 2U3 4.762

L1= .524 L2= 4.651 L3= 2.901

Note (3) -L1 .524 -L1 .524

A= 4.127 B= 2.377

Ax400 = 1651. Bx20 =

Bx21 = 49.9

Ax400 minus Bx21 = E = 1600 (nearest hundreds) - Bx21 = F = 50 (nearest 5 multiple)

D´ = E + F D´= 1650 m

n = 0

D1	D2	D3	
D´ = 1650.	D´ = 1650.	D´ = 1650.	Mean D1, D2, D3 = 1650.527
+L1 .524	+L2 4.651	+L3 2.901	+n x 2000
D1 = 1650.524	1654.651	1652.901	D = 1650.527
	-K2 4.114	-K3 2.381	Sum Corr'ns - .513
	D2 = 1650.537	D3 = 1650.520	D (slope) = 1650.016

Note (1). If R − C is negative, add U1, U2, or U3 before subtracting.
Note (2). If sign of R is negative, add U1, U2, or U3. 0.999999692 x 1650.016 = 1650.015 m
Note (3). If L2 or L3 is less than L1, add 2U2 or 2U3 before subtracting.
Means in meters is obtained from latest calibration table for the particular instrument being used.

USCOMM-DC 8232-P62

K.D.P. Cell, 56 T.V.P.
Phototube, Laser

Atmosphere corr'n = + 32.0
Color corr'n = 3.5
Correction = + 35.5 P.P.M.

Weather: Bright sunlight, light s.w. wing

FORM C&GS-328 (11-62)

U.S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

GEODIMETER MODEL 4 OBSERVATIONS

State Maryland Locality Beltsville Date 9-30-66
Station 150 m To Station 1800 m Geod. No. 225 (Laser)
Chief of Party J. O. Phillips Observer G. B. Lesley
Proj. No. 221104000 Ht. of Geod. 0.25 M. Ht. of Reflex 2.31 M.

	G	M	G	M
Time	1114		1121	
Temp.	21.5°C	20.6	21.7°C	21.3
Press.	1280.ft	1290	1270.ft	1280
Rel. Hu.	58%			

Geod. Ecc. or tilt 0.000
Geod. Const. + 0.256
Reflex No. 7 Prism AGA Type Const. - 0.027
Reflex. Ecc. + 0.800
Atmospheric Correction + 0.059

Means Tm= +21.3°C Pm= 751.6mm Hm= -5 Sum of Constants + 1.088

Dial readings	Frequency 1		Frequency 2		Frequency 3	
Phase	C	R	R	C	C	R
1	- 274.0	- 206.5	- 100.0	+ 51.5	+ 102.0	+ 205.0
2	273.5	206.5	101.0	51.0	103.0	205.5
3	273.0	206.0	99.0	52.5	102.5	206.0
4	273.0	207.0	100.0	51.0	102.0	205.0
Sum of 2 and 3	273.25	206.25	100.0	51.75	102.75	205.75
Sum of 1 and 4	273.5	206.75	100.0	51.25	102.0	205.0
Total sum						
Means	- 273.4	- 206.5	- 100.0	+ 51.5	+ 102.4	+ 205.4
Means in meters	3.194	2.120	1.230	.701	1.001	2.284
L= R-C Note (1)		U1 2.500	U2 2.494			U3 2.381
L =						
Note (2)		U1 2.500	U2 2.494			U3 2.381
			2U2 4.988			2U3 4.762
	L1= 3.926		L2= 8.011		L3= 6.045	

Note (3) -L1 3.926 -L1 3.926
A= 4.085 B= 2.119
Ax400 = 1634. Bx20 =
Bx21 = 44.5

Ax400 minus Bx21 = E = 1600 (nearest hundreds) - Bx21 = F = 45. (nearest 5 multiple)

D′ = E + F D′ = 1645. m

n = 0

D1	D2	D3	
D′ = 1645.	D′ = 1645.	D′ = 1645.	Mean D1, D2, D3 = 1648.912
+L1 3.926	+L2 8.011	+L3 6.045	+n x 2000
D1 = 1648.926	1653.011	1651.045	D = 1648.912
	-K2 4.102	-K3 2.143	Sum Corr'ns +1.088
	D2 = 1648.909	D3 = 1648.902	D (slope) = 1650.010

Note (1). If R − C is negative, add U1, U2, or U3 before subtracting.
Note (2). If sign of R is negative, add U1, U2, or U3. 0.999999692 x 1650.010 = 1650.009 m
Note (3). If L2 or L3 is less than L1, add 2U2 or 2U3 before subtracting.
Means in meters is obtained from latest calibration table for the particular instrument being used.

USCOMM-DC 8232-P62