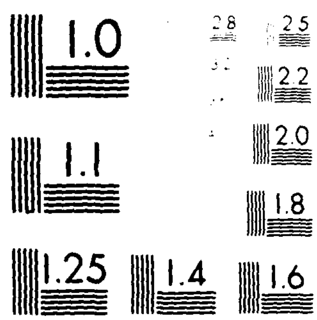
AD-A111 824 INSTITUTE OF OCEANOGRAPHIC SCIENCES BIRKENHEAD (ENGLAND) F/G 8/5
HIGH PRECISION TIDAL GRAVITY.(U)
MAY 81 T F BAKER, R J EDGE, G JEFFRIES AFOSR-80-0168
UNCLASSIFIED AFGL-TR-81-0339 NL

1 OF 1
AD A
111824

END
DATE
FILMED
04-82
DTIC



MICROCOPY RESOLUTION TEST CHART

(13)

AFGL-TR-81-0339

AD A111824

HIGH PRECISION TIDAL GRAVITY

T.F. Baker, R.J. Edge, G. Jeffries
Institute of Oceanographic Sciences (NERC)
Bidston Observatory
Birkenhead
Merseyside L43 7RA, U.K.

15 May 1981

Interim Scientific Report, 1 April 1980 - 31 March 1981

Approved for public release
distribution unlimited

Prepared for

INSTITUTE OF OCEANOGRAPHIC SCIENCES (N.E.R.C.)
Bidston Observatory, Birkenhead, Merseyside, U.K.

and

EUROPEAN OFFICE OF AEROSPACE RESEARCH AND DEVELOPMENT
London, England

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731

82 03 09 015

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. Report Number AFGL-TR-81-0339	2. Govt Accession No.	3. Recipient's Catalog Number
4. Title (and Subtitle) HIGH PRECISION TIDAL GRAVITY		5. Type of Report & Period Covered INTERIM SCIENTIFIC REPORT No. 1 1 April 1980 to 31 March 1981
		6. Performing Org. Report Number
7. Author(s) BAKER T.F., EDGE R.J. and JEFFRIES G.		8. Contract or Grant Number AFOSR 80-0168
9. Performing Organization Name and Address INSTITUTE OF OCEANOGRAPHIC SCIENCES NATURAL ENVIRONMENT RESEARCH COUNCIL BIDSTON OBSERVATORY, BIRKENHEAD L43 7RA,UK		10. Program Element, Project, Task Area & Work Unit Numbers Prog Elem: 61102F Proj/Task: 2309/G1 JON: 2309G1AZ
11. Controlling Office Name and Address Air Force Geophysics Laboratory/LWG Hanscom AFB, MA 01731 Monitor/James A. Hammond/LWG		12. Report Date 15 MAY 1981
		13. Number of Pages 26
14. Monitoring Agency Name and Address EOARD/LNG, Box 14 FPO New York 09510		15. Unclassified

16. & 17. Distribution Statement

Approved for public release; distribution unlimited.

18. Supplementary Notes

19. Key Words

EARTH TIDES, TIDAL GRAVIMETERS, OCEAN TIDE LOADING

20. Abstract

The progress made on the conversion to electrostatic feedback of the LaCoste tidal gravimeters ET10, ET13 and ET15 is reported. Tests on the absolute calibration of the gravimeters and the calibration/non linearity of the feedback system are described. A system has been designed and constructed for the continuous and reliable recording of high resolution tidal gravity data over a wide range. Some tests on this system are described.

FORM 1473

HIGH PRECISION TIDAL GRAVITY: Interim Scientific Report April 1980 - March 1981

INTRODUCTION

This scientific report describes the progress made during the first year of phase 1 of the research programme "High precision tidal gravity measurements". Full details of the programme may be found in the original proposal. A summary of the proposal appears below.

Phase 1 of the project is primarily concerned with instrumental modifications and improvements to the LaCoste-Romberg Earth Tide gravimeters ET10, ET13, and ET15. This is then followed by extensive testing and calibration under ideal laboratory conditions to determine how the instruments may be optimally operated when run under less than ideal field conditions in Phase 2. Phase 1 is scheduled to last for a period of 2 years during which time it is intended that

(1) All 3 gravimeters will be fully serviced, fitted with electrical levels and recalibrated by the manufacturer.

(2) All 3 gravimeters will be converted from mechanical feedback to electrostatic feedback by Dr. J.V. Larson, Maryland Instrumentation, U.S.A.

(3) In addition it is intended to

(a) improve the absolute calibration of the gravimeters

(b) examine and minimise any non-linearities in the system

(c) examine and quantify phase lags, and

(d) examine signal to noise ratios.

(4) During the Phase 1 period it is also necessary to design and construct sufficient ancilliary systems such that 3 complete gravimeter systems are built which are capable of operating continuously and which provide reliable, digitally recorded, high resolution signals over a large range.

(5) The final part of phase 1 consists of running one instrument at the Air Force Geophysics Laboratories (AFGL), Hanscom Field, to determine tidal gravity, and running two instruments simultaneously at Bidston for an extended period to check relative calibrations.

Phase 2, comprises of tidal gravity measurements at pairs of stations adjacent to ocean tide anti-amphidromes so that the differential tidal gravity signal can be used to focus on to the adjacent ocean area. Initial work will concentrate on a single ocean area. The M_2 and K_1 loading maps of Parke using his World ocean tide models show 14 anti-amphidromes for M_2 and 7 anti-amphidromes for K_1. The most suitable areas appear to be the north and west Indian Ocean (for both M_2 and K_1) or South Africa (for M_2). It is hoped to commence Phase 2 in early 1982.

GRAVIMETER CONVERSIONS

Both ET13 and ET15 were shipped from I.O.S. Bidston to LaCoste and Romberg at Austin, Texas where they were given a full service by the manufacturers, fitted with S.G, electro-levels and re-calibrated on the Texas shortrange gravity baseline. Following this work the instruments were forwarded to Dr. J.V. Larson* of Maryland Instrumentation U.S.A. for conversion from a system of mechanical feedback to one of electrostatic feedback and then returned to I.O.S. Bidston. On each occasion Dr. Larson followed the instruments to Bidston to assist in the commissioning of the new feedback systems. ET13 was finally commissioned during May 1980 and ET15 during September 1980. A block diagram showing the feedback system and the gravimeter system is shown in Fig 6a.

*Larson, J.V., 1968. A cross correlation study of the noise performance of electrostatically controlled LaCoste and Romberg gravimeters. Maryland University, Ph.D. thesis 138pp

ET10 is currently (April 1981) at LaCoste and Romberg where it is undergoing the same servicing, modifying and recalibrating as ET13 and ET15. It is expected that this instrument will shortly be sent to Dr. Larson and will be commissioned at AFGL Boston during the summer of 1981.

GRAVIMETER TESTS

Following the commissioning of ET13, a series of measurements and tests were carried out in order to improve the absolute calibration (μgals per fine screw counter unit), to determine accurately the calibration of the feedback system (millivolts per fine screw counter unit) and to determine accurately any phase lag or non linearity in the feedback systems. Tests were also carried out in order to maximise the signal to noise ratio.

(i) Absolute calibrations: Austin, Hannover and Bidston

Absolute calibrations of the gravimeters are conventionally made by repeatedly measuring counter screw differences between 2 locations between which the gravity difference is well known. Owing to the small range of the fine measuring screw on the tidal gravimeters (typically ~ 10 mgal) well calibrated baselines are uncommon. However the instruments are being calibrated at 3 sites; Austin, Texas,; Hannover, W. Germany; and Bidston, England. The Hannover baseline has been well established over a number of years and has been derived from a total number of about 1500 gravity differences using four different instruments (Torge and Kanngieser, 1979)*. This baseline is tied into the European absolute gravity line. The Austin baseline has been set up by the manufacturer and has been derived from a series of measurements made by LaCoste and Romberg Model G gravimeters some years ago. This baseline was specifically set up to

*Torge, W. and E. Kanngieser. 1979. Periodic calibration errors of LaCoste and Romberg model G and D gravimeters. Paper presented to the I.A.G. Intersection meeting "Global Gravity measurements", XVII. IUGG General Assembly, Canberra 2. - 15.12.79 (in press 1981) provide a manufacturer's calibration of the Earth Tide gravimeters. The Bidston baseline has only just been established and at present is only useful for checking relative calibrations, ET13 and ET15 have been calibrated at both Austin and Hannover and ET13 at Bidston. ET10 will shortly be calibrated at Austin by the manufacturer. It is worth noting that the Austin calibrations were carried out by zeroing the beam at each gravity station optically. At Hannover the electrostatic feedback system was used to sense the position of the beam and this helped in the repeatability of the measurements.

The results of the absolute calibrations carried out at Austin and Hannover for ET13 and ET15 are shown in Table 1. It is interesting to observe the close internal agreement, at the 0.1% level, of the Hannover calibration runs which were all carried out during December 1980 and the apparent change in the calibration line at Austin between 1974 and 1979 of 0.7%. Reasons for this change are being investigated with LaCoste and Romberg. Further calibrations at both Bidston and Hannover are planned. An example of a typical calibration run is shown in Figure 1.

Following the preliminary calibrations carried out to date it appears that the absolute calibration of the gravimeters may be determed to better than 0.1%.

(ii) Feedback calibrations/linearity tests

The linearity of the feedback system when coupled to the gravimeter is determined by a number of variables which may be adjusted within the feedback electronics. Final control is provided by the "plate offset" adjustment which enables a differential a.c. voltage to be applied to the capacitive plates. Tests carried out on ET13 have shown that it is possible to adjust the system such that it becomes essentially linear. Extended tests indicate that once set up, the system remains linear and is not susceptible to drift.

TABLE 1

Instrument	Calibration Run	Mean Screw Position	Site	Baseline mgal	Calibration (μgals/ctr unit)
ET15	1	43500	H	3.152	0.108502 ± 0.00010
ET15	2	43100	H	3.152	0.108463 ± 0.00007
ET15	3	45300	H	3.152	0.108511 ± 0.00006
ET15	4	74400	H	3.152	0.108712 ± 0.00009
ET15	5	Whole Screw	H	9.170	0.108560 ± 0.000015
ET15	6	Whole Screw	A(1980)	2.94	0.109200
ET15	7	Whole Screw	A(1971)	2.94	0.108447
ET13	8	52060	H	3.152	0.15474 ± 0.00013
ET13	9	49450	H	9.170	0.15449 ± 0.00006
ET13	10	Whole Screw	A(1979)	2.94	0.15498
ET13	11	Whole Screw	A(1974)	2.94	0.15398

H = HANNOVER

A = AUSTIN

The calibration of the electrostatic feedback system has been determined to better than 0.1% on ET13 by determining the voltage output for a given number of counter screw turns. A calibration in terms of μgals/volt may then be simply determined using the absolute calibration value. A typical calibration/non linearity run is shown in Figure 2. Table 2 shows a set of calibration runs carried out so far with ET13.

TABLE 2

Calibration Run	Calibration μgals/volt	Non linearity	Plate Offset volts (adjustment for non linearity)
1	64.50	+0.5%	-1.82
2	64.48	+0.6%	-1.70
3	64.42	+0.6%	-1.31
4	64.39	+0.2%	-3.50
5	64.42	-0.4%	-6.14
6	64.40	0.0%	-4.20

Mean 64.44 μgals/volt

Standard error 0.02 μgals/volt

It has thus been clearly demonstrated that the calibration may be easily determined to better than 0.1%. Figure 3 shows a graph of non-linearity against the "Plate offset" volts and indicates how the electrostatic feedback system may be finally adjusted to produce a linear output.

(iii) Phase lags

The phase lag of the system may be determined at any frequency from the response to a unit step function (i.e. an instantaneous change in counter screw units) (Torge and Wenzel 1979)*. The response of the system has been shown to be principally a function of a.c. gain, gravimeter displacement

*Torge, W. and H.G. Wenzel, 1979. Comparison of Earth tide observations with nine different gravimeters at Hannover. Proceedings of the 8th Int. Symp. on Earth Tides, Bonn. 632-640.

sensitivity and feedback voltage. Figure 4 shows typical responses to input step functions as a function of these variables for the gravimeter ET13. Further tests are being carried out to quantify these effects and to determine the optimum response of the system. This optimum response will be a compromise between minimising the phase lag whilst ensuring that the feedback system remains stable. Preliminary results indicate that the absolute phase lag on set up is likely to be $\sim 0.2^{\circ}$ and should be determinable to 0.02° for semi diurnal tidal frequencies. Under reasonable site conditions with minimal maintenance the phase lag should not vary by more than $\pm 0.01^{\circ}$. Some theoretical work on the system response and system stability is currently being carried out by W. Zürn of Schiltach Observatory, W.Germany (personal communication 1980).

(iv) Signal/noise tests

Various tests have been commenced which are aimed at maximising the signal/noise ratio on the gravimeter system. These include

(a) The response of the system, and in particular the noise introduced, by small changes in the tilt of the gravimeter during the course of an Earth Tide experiment. The electrolevels fitted to ET13 and ET15 by LaCoste-Romberg have been shown to be exceptionally stable and should allow the gravimeter to be set up level and to be maintained level to ± 3 secs arc during an experiment. This should help to improve the signal/noise ratio over previous experimental arrangements. Further work is needed in this area. An example of tilt induced noise already observed is a large increase ($\sim$100%) in the 8 min outer heater cycle noise to about 0.15μgal by operating the gravimeter 18 arc secs off level.

(b) In addition to tilt induced noise there are also direct temperature effects on the gravimeter and these may be minimised by altering the heater cycling times to suit the local environment. Further tests in this area are still needed but the effect of temperature cycling may be seen in Figure 8.

(c) It is also intended that air pressure fluctuations will be examined in the future.

SYSTEM CONSTRUCTION AND TESTS

In addition to the servicing, conversion and gravimeter tests described above much effort during the year has gone into the design and construction of the support instrumentation and interfacing to the gravimeters. This support instrumentation is essential if the gravimeters are to be operated continuously, withhigh resolution data recorded over a wide range in less than ideal environmental conditions. Each system comprises

(i) "Mains independent" power supplies
(ii) 2 Range steppers
(iii) 2 active low pass tidal filters
(iv) Digital data acquisition system
(v) Analogue data collection
(vi) Earthquake hammer
(vii) Quartz clocks

(i) "Mains independent" power supplies are essential to ensure that the gravimeter and data acquisition system operate continuously during periods of mains power failure. The system requires 75 watts and a system of back up power supply incorporating 2 lead acid 12 volt cells and a Telecor Power supply has been built. Since February this system has been incorporated into the ET13 system for tests before use on ET10 at AFGL.

(ii) Range steppers have been introduced to ensure that a digitisation resolution of 0.012 μgal is maintained over an operating range of 700μgals. A number of these CS.10 range steppers have been purchased from DELTA I Devices Ltd. and two of them adapted and incorporated into the ET13 system for tests. These two range steppers have each been preliminarily calibrated to better than 0.1% in amplitude and have negligible phase lag at tidal frequencies.

(iii) Two active low pass 3rd order Bessel tidal filters have been designed, constructed and incorporated into the ET13 system for tests. The filter characteristics are shown in Figure 5 and both filters have been preliminarily calibrated to 0.1% in amplitude and 0.02^{o} in phase at tidal frequencies. It has been necessary to introduce these filters to filter out energy in the microseismic frequency band ($\sim$0.1 to 0.2 Hz) and to avoid any aliasing when sampling at one minute intervals.

(iv) Digital data acquisition system

A Rapco, 10 channel, reel to reel, digital data logger is currently used to record the data derived from the gravimeter system. The 10 data channels are sampled simultaneously at 1 minute intervals and recorded in addition to timing information and an identity label. Each data channel comprises 2^{11} bits and this may be extended by a factor $\sim$28 by using the C.S.10 range steppers - see (ii) above. One Rapco logger has been set up on the ET13 gravimeter system and has been calibrated to better than 0.1% in amplitude. There is negligible phase lag.

(v) Analogue data collection

In the event of the failure of the digital data acquisition system an analogue "back up" of the prime data channels is recorded on a Philips dual pen chart recorder. This system should allow any data gaps to be filled in without loss of range or resolution. In addition it also produces a quick check to any observer that the system is operating normally and if any adjustments are necessary to the gravimeter (for example: if the fine counter screw requires adjustment to compensate for gravimeter drift). Extensive tests have been carried out on several of these recorders to improve their reliability over long periods of continuous recording. The analogue recorder does not operate in the event of a mains power failure.

(vi) Earthquake hammer

Owing to the fact that the electrostatic restoring forces on the gravimeter beam are small it has been necessary to construct a small electronic circuit controlling a "hammer" which will prevent the beam from going unstable and sticking to either of the "stops" within the gravimeter during large teleseismic Earthquake events. Experience has shown this may occur a few times per year. When the seismic level reaches a certain amplitude this circuit drives a motor carrying a small mass eccentrically mounted on the side of the gravimeter and a vibration is imparted to the gravimeter. This usually provides sufficient energy to prevent sticking and to allow the electrostatic feedback to operate normally, following the end of the Earthquake. Tests have been carried out but it is difficult to test this system comprehensively.

(vii) Quartz clocks

There are two independent quartz clocks incorporated into the system. They are both accurate to 3 secs per month. One controls the time put on to the Rapco digital data and the other places a ½ sec pulse on the hour on the analogue data chart. Both clocks have undergone tests during the year on the ET13 gravimeter system.

Figure 6b shows schematically how all these various pieces of support instrumentation are incorporated into the gravimeter system while figure 6a shows in more detail the gravimeter and electrostatic feedback system itself.

DATA ACQUISITION

Figure 7 shows in some detail the means by which the raw signal outputs from the elctrostatic feedback system (direct tide, buffered tide, free modes) are processed by the filters and the range steppers before being recorded on the Rapco data logger and the Philips analogue chart recorder. Table 3 shows the data which have been chosen for recording during the AFGL experiment and gives an idea of the range and resolution capability of the gravimeter system. Figure 8 shows some sample analogue record achieved by the system. The 8-9 minute periodicity at the 0.1 to 0.2 μgal level is caused by the outer heater cycling of the gravimeters. When the gravimeter is optimally set up this cycling may be considerably reduced and with 1 minute sampling before digital filtering should not cause any problems with either noise or aliasing in the tidal bands. Figure 9 shows the data format of the 10 channel Rapco data logger with timing information and some preliminary data channels in operation. Many tests have been carried out to ensure the reliability of this system during an extended tidal gravity experiment.

CONCLUSIONS

During the first year of phase 1 of this project much has been achieved with the instrumentation: 2 gravimeters have been successfully converted to electrostatic feedback following servicing and recalibration, a set of support instrumentation has been designed, constructed and tested and two further sets are under construction for the future. Much has been learned during the year about the behaviour of the gravimeter when operated with electrostatic feedback and their fundamental absolute calibrations have been considerably improved. It is still expected that these instruments will be capable of measuring diurnal and semidiurnal Earth tides to the necessary precision of 0.1%, with an uncertainty in phase of less than 0.1° although further laboratory tests and calibration runs

TABLE 3

DATA TO BE RECORDED DURING THE A.F.G.L. EXPERIMENT

(a) RAPCO CHANNEL ALLOCATIONS

Channel	Data	Range	Resolution
1 2	Range stepped Direct Tide	$\pm 350\mu$gal	0.0125μgal
3 4	Filtered, range stepped Direct Tide	$\pm 350\mu$gal	0.0125μgal
5	Filtered, Buffered Tide	$\pm 500\mu$gal	0.5μgal
6	Buffered Tide	$\pm 500\mu$gal	0.5μgal
7	Direct Tide	$\pm 1000\mu$gal	1.0μgal
8	Cross level(S.G.electro-level 1)	± 30 arc secs	30 msecs arc
9	Long level(S.G. electro-level 2)	± 30 arc secs	30 msecs arc
10	Free modes	$\pm 10\mu$gal	0.01μgal

(b) PHILIPS ANALOGUE DATA

Channel	Data	Range	Resolution
1	Filtered Range stepped Direct Tide	$\pm 350\mu$gal	0.05μgal *
2	Direct Tide	$\pm 1000\mu$gal	1.5μgal *

NOTES

*Dependent on accuracy of manual digitisation and quality of paper chart

1. Prime data channels 3,4,10
2. Secondary data channels 1,2
3. Ancilliary data channels 5 to 9

are still required.

It is hoped to commence the simultaneous experiment of Earth tide recording at Bidston later this year and to commence the tidal gravity measurement at AFGL Boston during the summer.

REFERENCES

1. Baker, T.F., 1980. Tidal Gravity in Britain: tidal loading and the spatial distribution of the marine tide, Geophys. J.R. Astr. Soc. 62, 249-267.
2. Larson, J.V., 1968. A cross correlation study of the noise performance of electrostatically controlled LaCoste and Romberg gravimeters. Maryland University. Ph.D. thesis 138pp.
3. Weber, J. and J.V. Larson, 1966. Operation of LaCoste and Romberg Gravimeter at sensitivity approaching the thermal fluctuation limits. J. Geophys. Res. 71, 6006-6009.
4. Torge, W. and E. Kanngieser, 1979. Periodic calibration errors of LaCoste and Romberg model G and D gravimeters. Paper presented to the I.A.G. Intersection meeting "Global Gravity measurements", XVII. IUGG General Assembly, Canberra 2.-15.12.79. (in press 1981).
5. Torge, W. and H.G. Wenzel, 1979. Comparison of Earth tide observation with nine different gravimeters at Hannover. Proceedings of the 8th Int. Symp. on Earth Tides, Bonn. 632-640.

A TYPICAL CALIBRATION OF THE E.T.13 GRAVIMETER

FINE SCREW OVER A BASELINE ~ 3·6 mgal AT BIDSTON

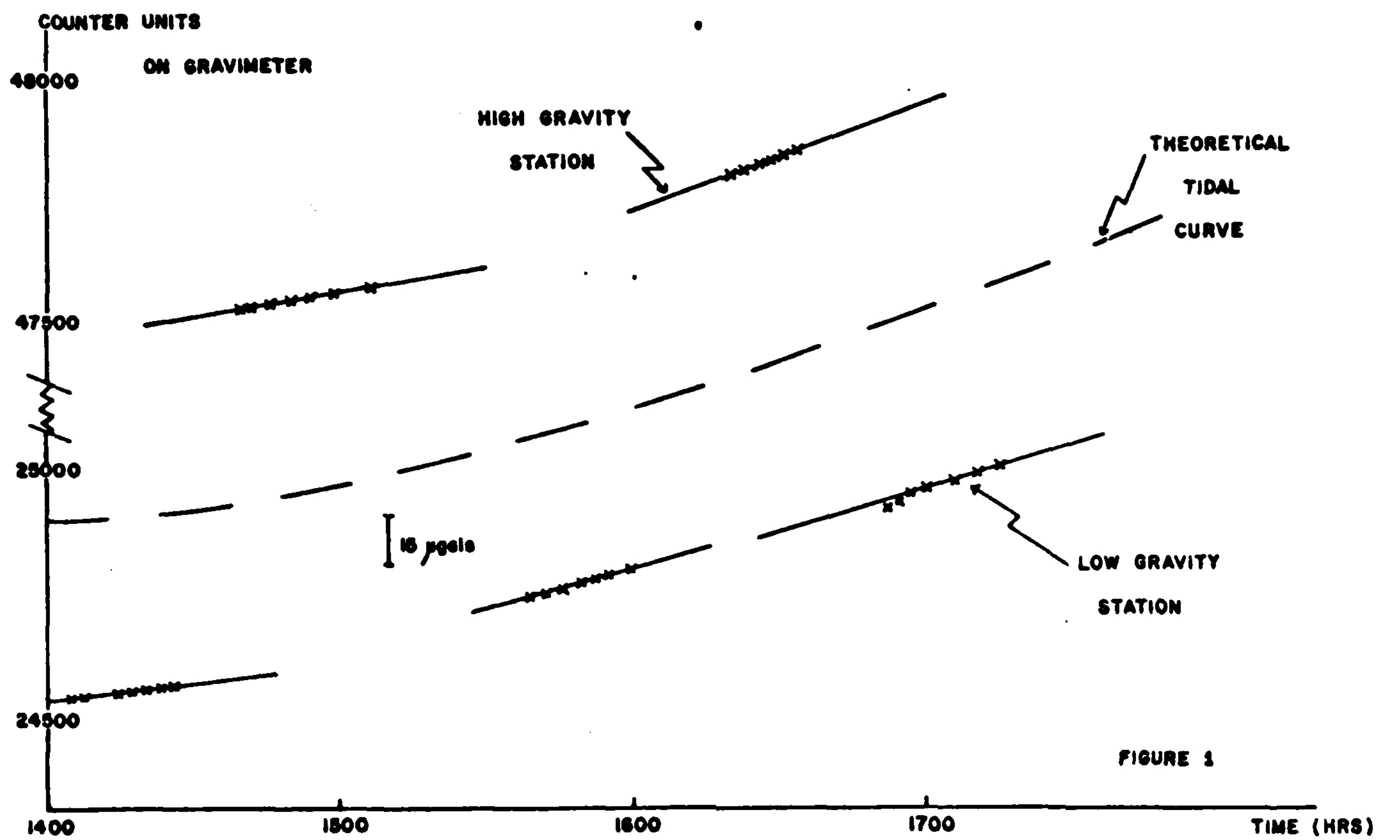


FIGURE 1

A TYPICAL "NON-OPTIMISED" CALIBRATION OF THE ELECTROSTATIC FEEDBACK SYSTEM ON E.T. 13

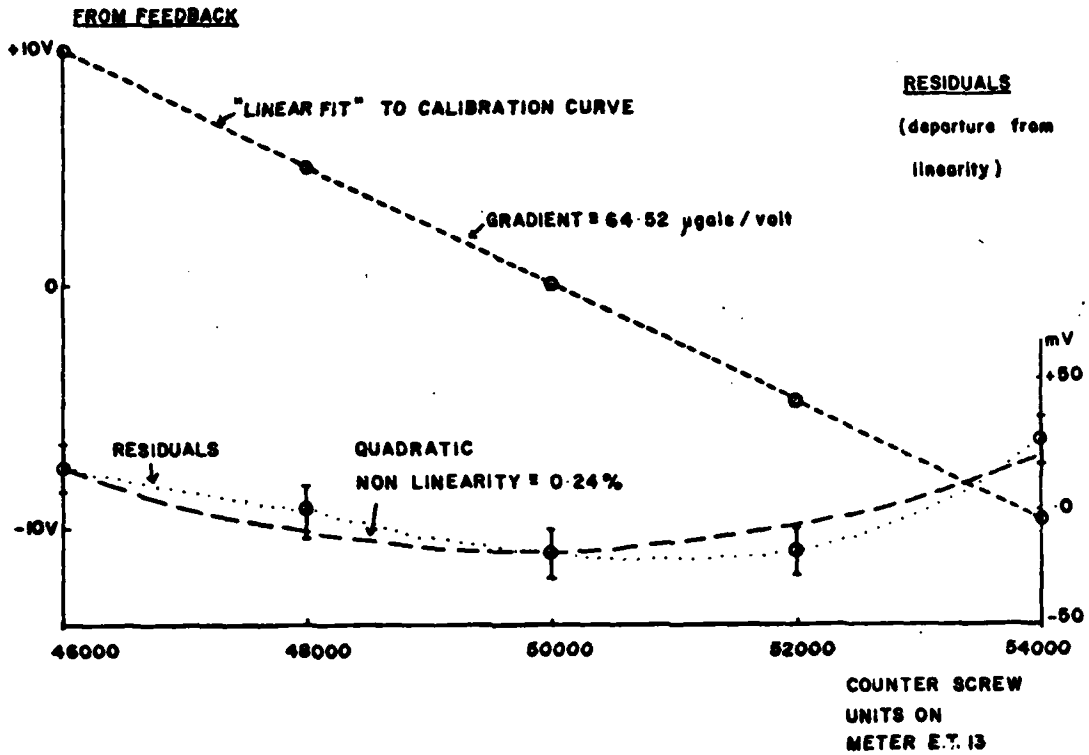


FIGURE 2

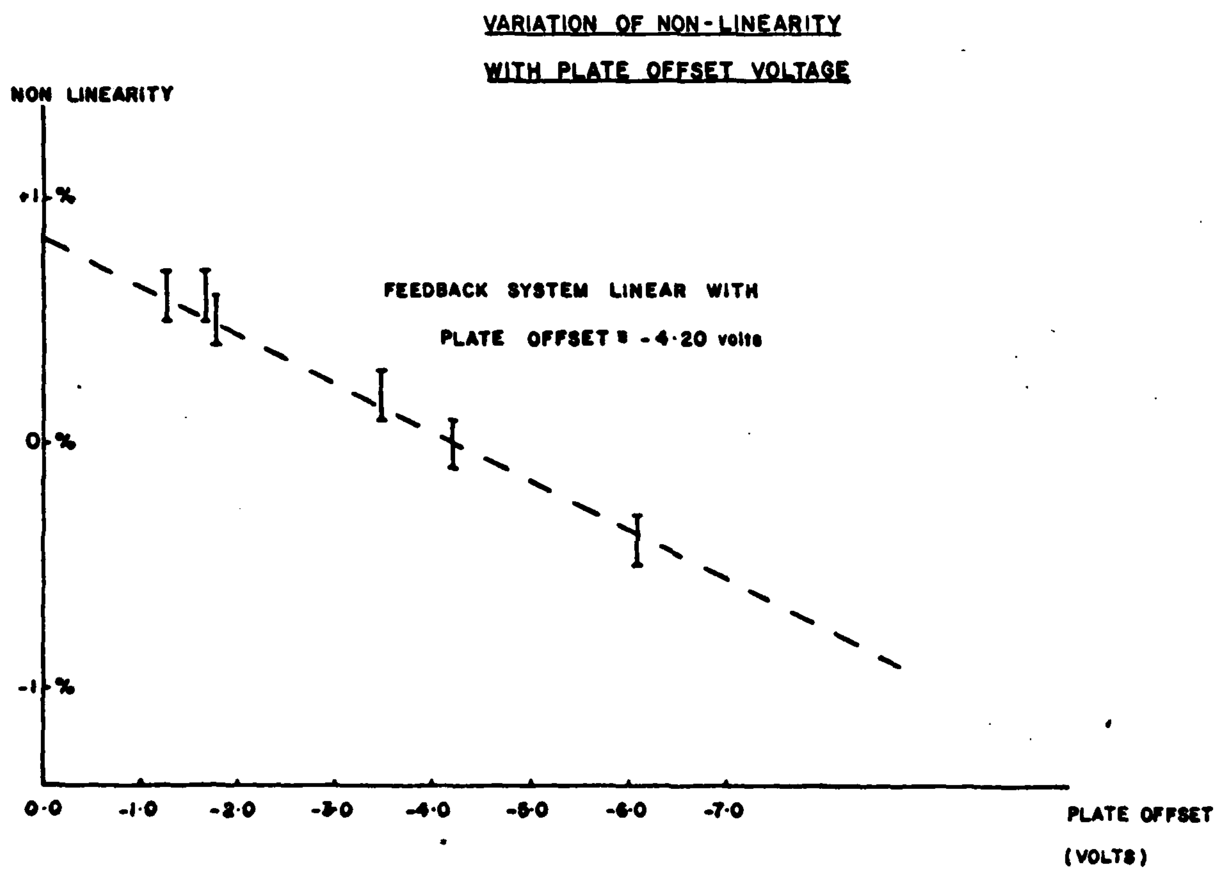
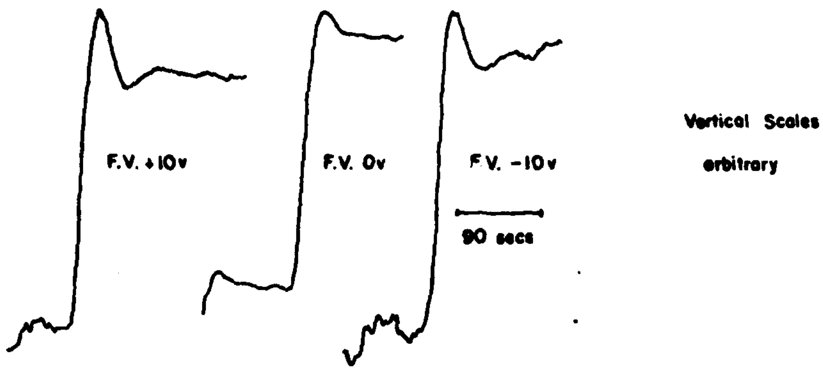

VARIATION OF NON-LINEARITY
WITH PLATE OFFSET VOLTAGE
NON LINEARITY
+1 %
0 %
-1 %
FEEDBACK SYSTEM LINEAR WITH
PLATE OFFSET = -4·20 volts
0·0
-1·0
-2·0
-3·0
-4·0
-5·0
-6·0
-7·0
PLATE OFFSET
(VOLTS)

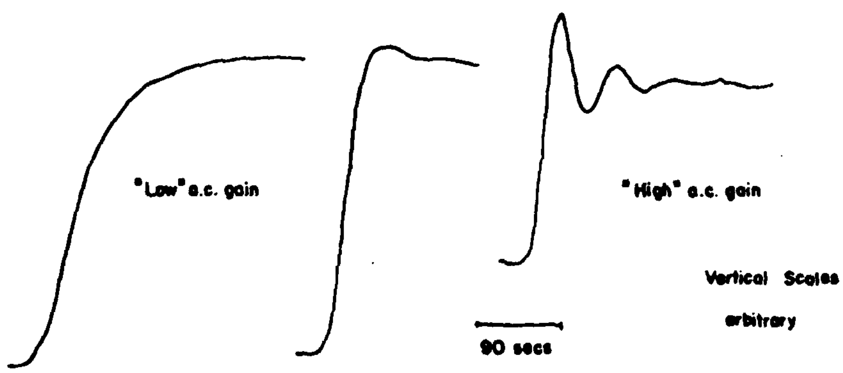
FIGURE 3

SOME TYPICAL STEP RESPONSES FROM THE FEEDBACK SYSTEM

RESPONSE = f (DISPLACEMENT SENSITIVITY, A.C. GAIN, FEEDBACK VOLTAGE)



(a) RESPONSE as a function of Feedback Volts (AC GAIN & DISPLACEMENT SENSITIVITY CONSTANT)



(b) RESPONSE as a function of a.c. gain (DISPLACEMENT SENSITIVITY, FEEDBACK VOLTAGE CONSTANT)

(c) The response as a function of Displacement Sensitivity is almost identical to (b)

FIGURE 4

LOW PASS FILTER CHARACTERISTICS

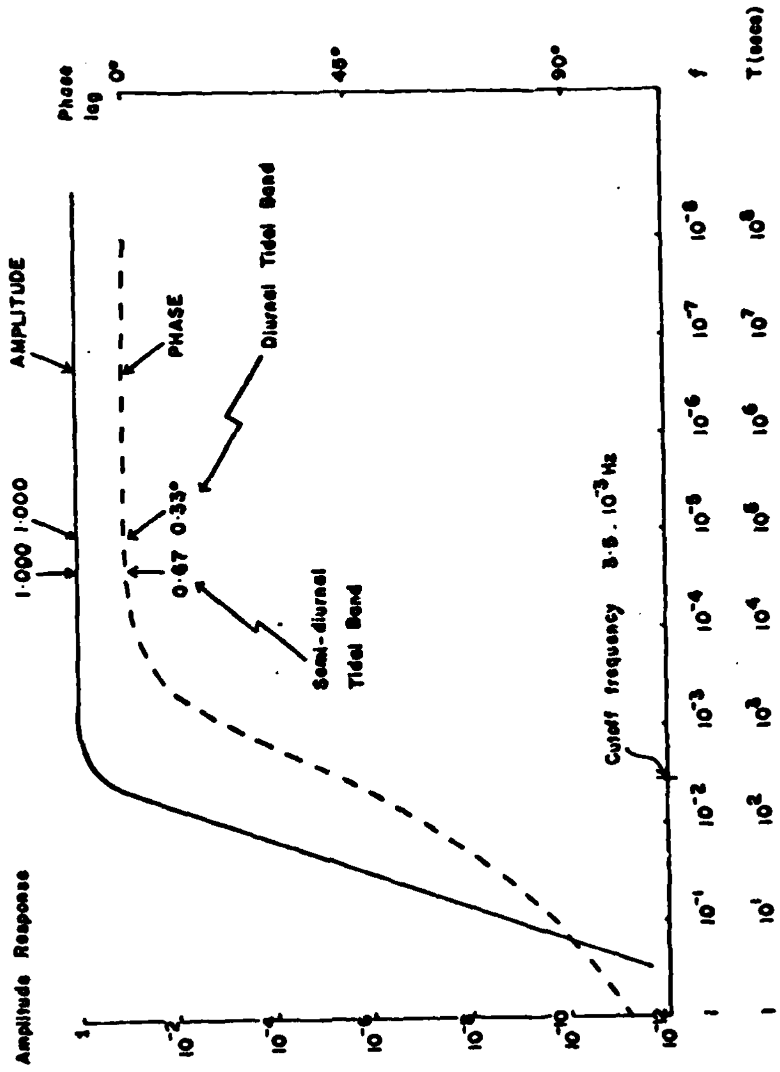


FIGURE 5

BLOCK DIAGRAM OF ELECTROSTATIC FEEDBACK GRAVIMETER

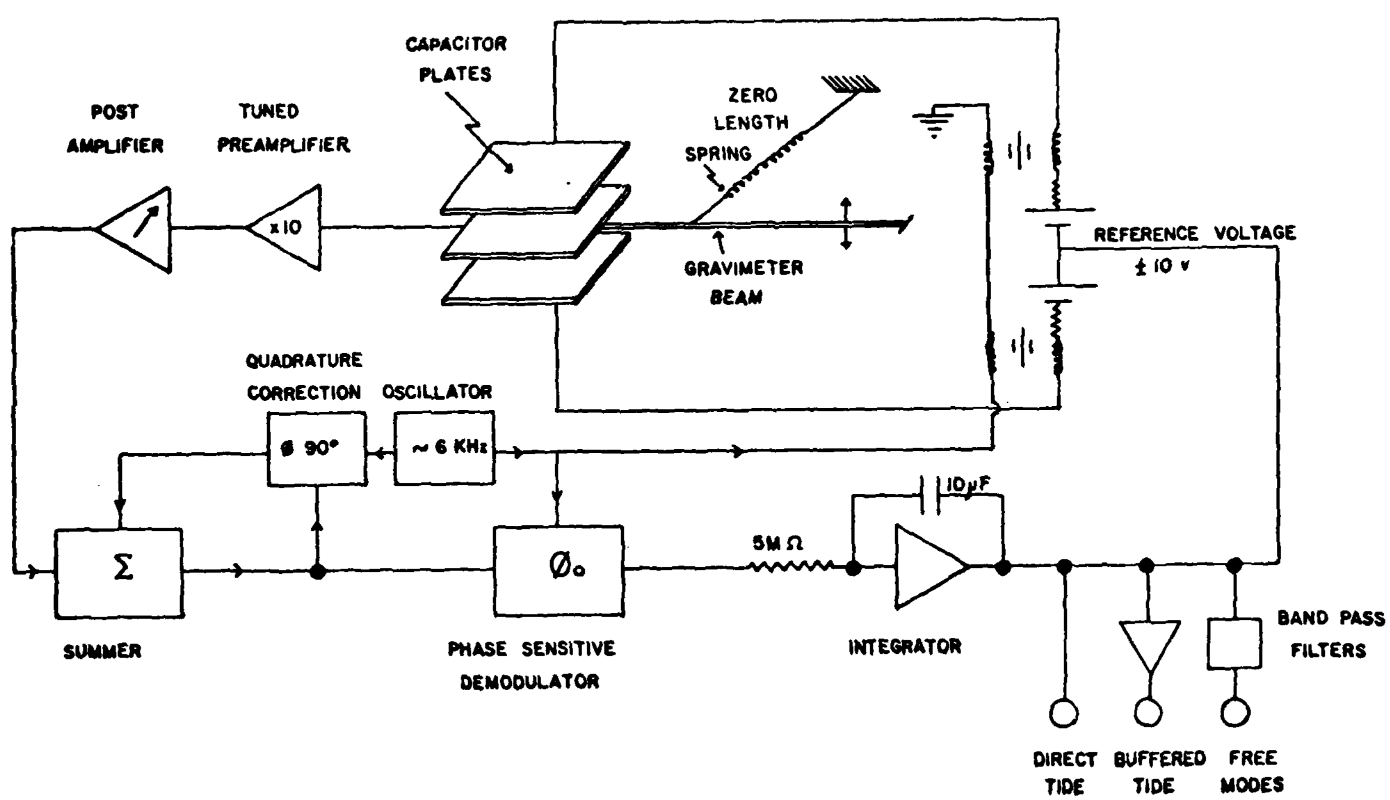


FIGURE 6a

BLOCK DIAGRAM OF ELECTROSTATIC FEEDBACK GRAVIMETER

AND ASSOCIATED ELECTRONICS - (Prepared for Boston Experiment)

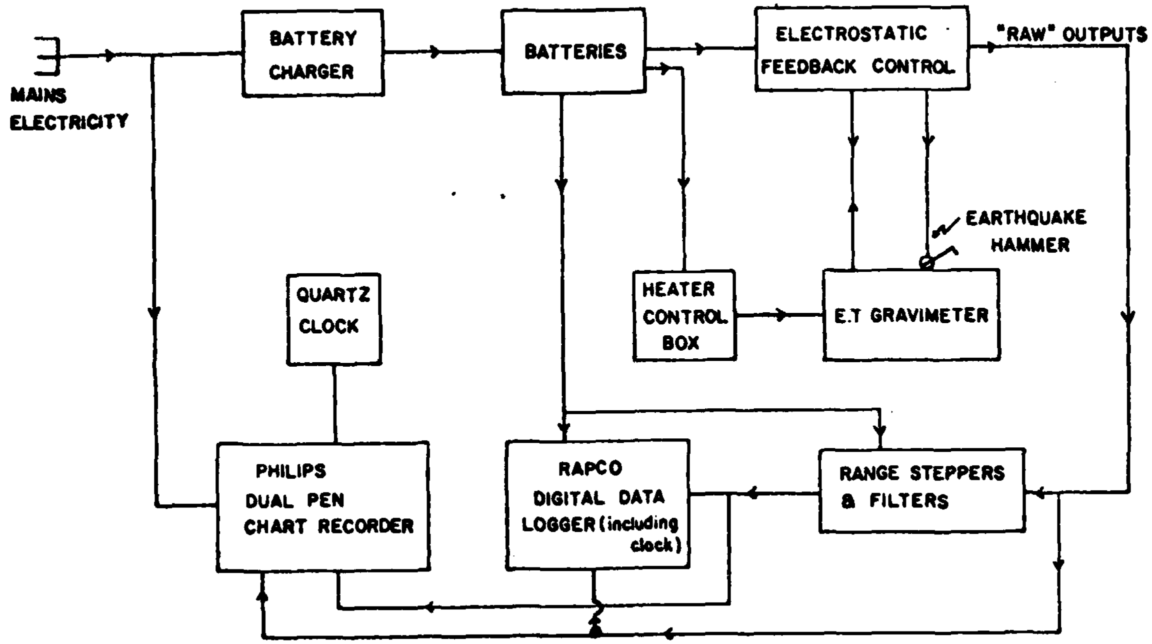


FIGURE 6b

BLOCK DIAGRAM OF SIGNAL PROCESSING AND DATA ACQUISITION

SYSTEM PREPARED FOR BOSTON EXPERIMENT

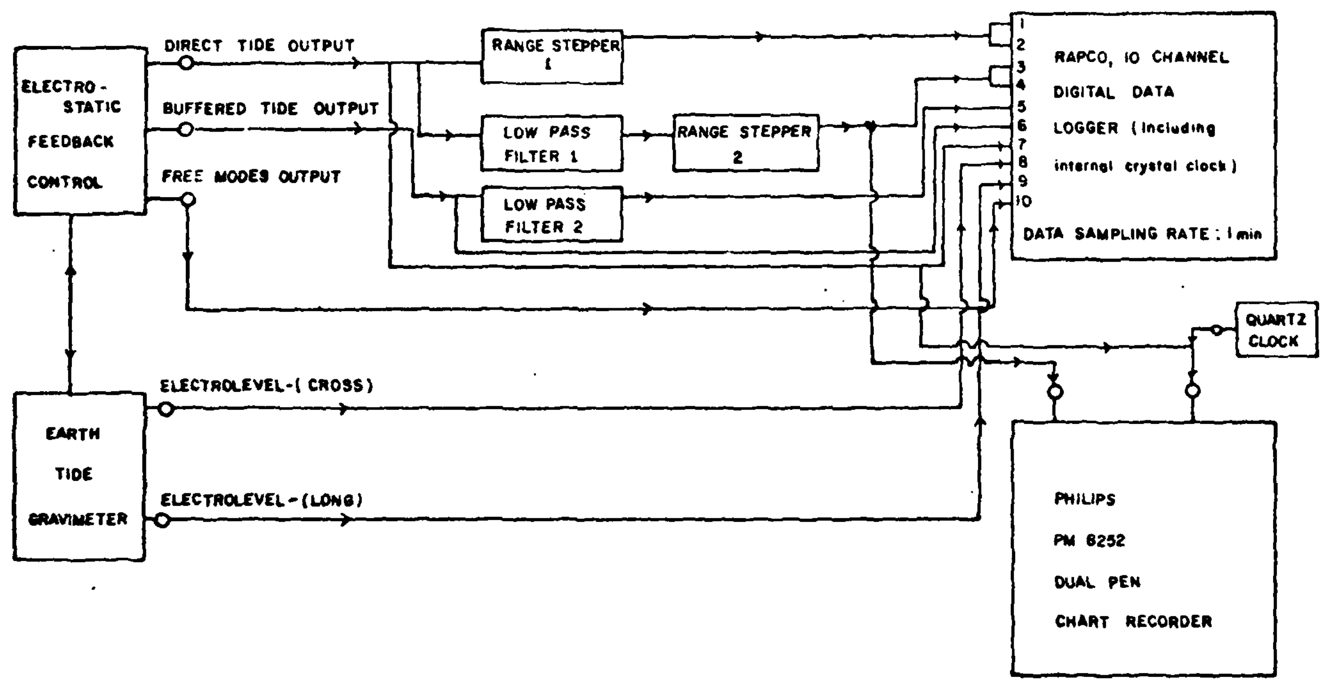


FIGURE 7

SAMPLE ANALOGUE RECORD FROM E.T. 13

USING ELECTROSTATIC FEEDBACK

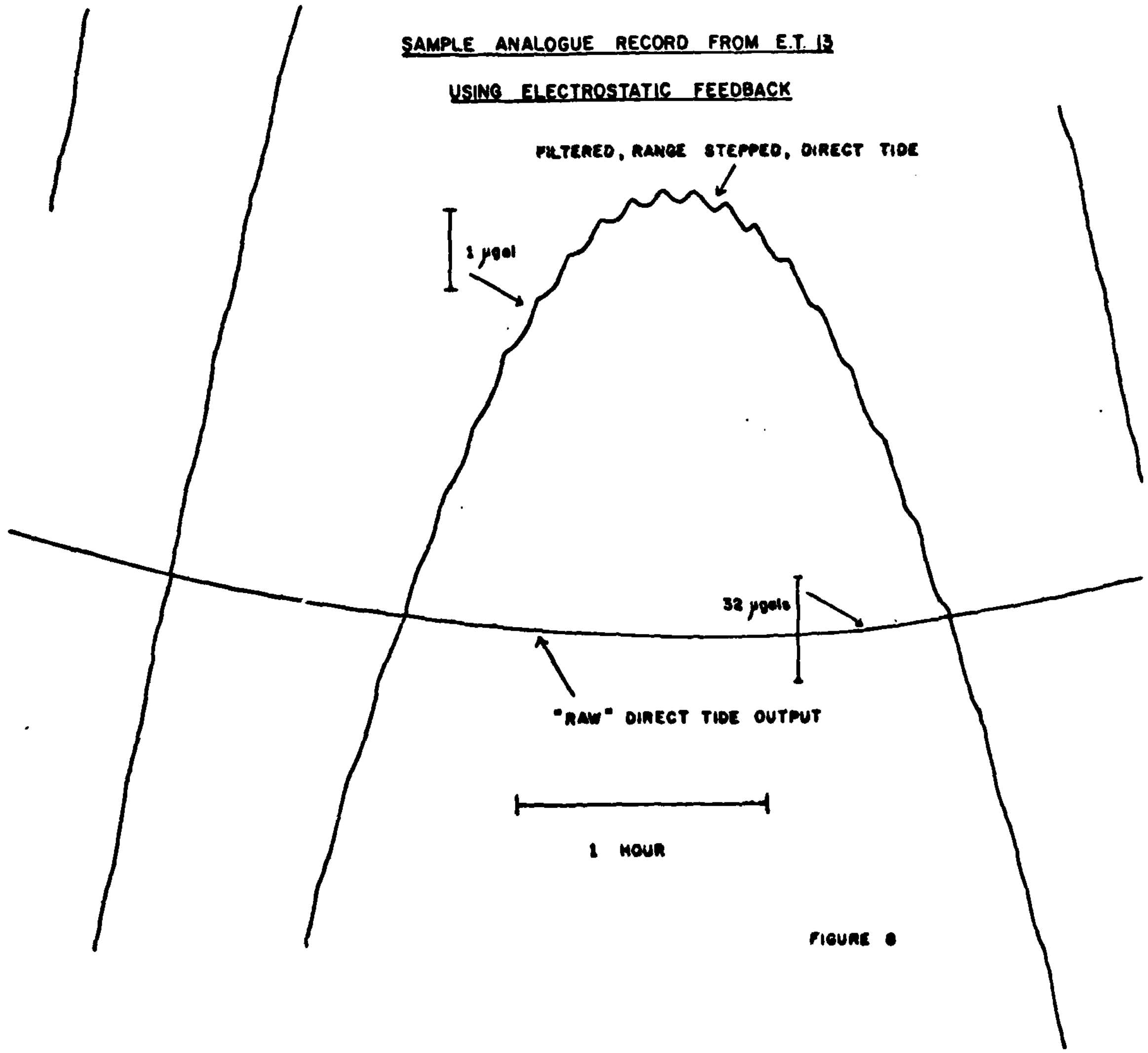


FIGURE 8

DATA FORMAT OF RAPCO DIGITAL DATA LOGGER WITH SOME PRELIMINARY DATA CHANNELS SHOWN

Range Stepped Direct Tide — Filtered, Range stepped, Direct Tide — NOT OPERATIONAL — Direct Tide — Free Modes

```
80+326+19+39+19+1111-529-533-445-451+059+999-999-005-093+051++
80+326+19+40+19+1111-419-426-373-371+067+739-999-005-094+067++
80+326+19+41+19+1111-138-141-299-291+073+965-999-006-098+077++
80+326+19+42+19+1111-298-305-207-205+056-394-999-006-095+038++
80+326+19+43+19+1111-239-239-122-117+056-525-999-006-097+021++
80+326+19+44+19+1111-022-029-034-034+054+999-999-006-097+021++
80+326+19+45+19+1111+030+023+039+047+056+999-999-007-101+015++
80+326+19+46+19+1111+174+167+125+125+056+999-999-007-101+029++
80+326+19+47+19+1111+029+037+195+193+057+045-999-006-101+076++
80+326+19+48+19+1111+255+257+278+270+056-339-999-007-102+071++
80+326+19+49+19+1111+291+295+361+357+055-999-999-007-103+058++
80+326+19+50+19+1111+449+451+444+450+054-031-999-007-106+015++
80+326+19+51+19+1111+485+490+537+534+043-999-999-007-106+009++
80+326+19+52+19+1111+717+723+617+619+058+999-999-009-109+003++
80+326+19+53+19+1111+557+550+698+699+054-729-999-009-106+057++
80+326+19+54+19+1111+637+633+777+775+075-999-999-009-107+059++
80+326+19+55+19+1111[+747[+785+841+849+072-253-999-009-110+102++
80+326+19+56+19+1111[-825[-827[+932[+930+054-999-999-009-111+071++
80+326+19+57+19+1111-689-593[-734[-733-042+999-999-009-113+045++
80+326+19+58+19+1111-553-553-657-650+055+999-999-010-115+031++
80+326+19+59+19+1111-641-637-569-577+055-999-999-009-114+046++
80+326+20+00+19+1111-533-537-487-492+053-873-999-010-115+046++
80+326+20+01+19+1111-505-505-414-423+077-173-999-010-115+085++
80+326+20+02+19+1111-447-445-349-341+076+235-999-010-117+098++
80+326+20+03+19+1111-242-239-267-262+054+999-999-011-121+094++
80+326+20+04+19+1111-203-197-179-181+071+405-999-010-119+075++
80+326+20+05+19+1111-121-126-085-089+053+755-999-011-119+038++
80+326+20+06+19+1111-201-205-001-005+054-137-999-011-119+033++
```

RANGE STEPS

YEAR DAY HR MIN SEC TAPE IDENTITY

FIGURE 9

FILMED

4-8