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MONTANA LARGE APERTURE SEISMIC ARRAY

FINAL TECHNICAL REPORT, PROJECT VT 1708

CONTRACT F33657-71-C-0430

1 DECEMBER 1970 - 30 NOVEMBER 1971

22 December 1971

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ARPA ORDER NO. 1620

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Seismic Measurement Channel Performance						

MONTANA LARGE APERTURE SEISMIC ARRAY

FINAL TECHNICAL REPORT

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IDENTIFICATION

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Project Title: Montana Large Aperture Seismic Array

ARPA Order No.: 1620

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The technical activity associated with the operation, maintenance, and improvement of the Montana Large Aperture Seismic Array (LASA) during the period 1 December 1970 - 30 November 1971 is related in this report. The philosophy for array system performance measurement is discussed and performance statistics and measurements indicated for certain equipment. Some new surficial noise sources are identified. The number of failures is reported for each equipment type. Development of a new PDP-7 computer operating system with supporting programs for automatic maintenance and monitoring of selected array equipments is described. A narrative describing the array communications system and approaches studied to reduce operating costs is presented. Discussions and statistics relating to the operation and maintenance of the array and data center are included.

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ACRONYMS

AFSC	Air Force Systems Command
AFTAC	Air Force Technical Applications Center
ASPR	Armed Services Procurement Regulations
DCASD	Defense Contract Administration Services District
DSA	Defense Supply Agency
IRSPS	Integrated Seismic Research Signal Processing System
LAMA	Large Aperture Microbarograph Array
LASA	Large Aperture Seismic Array
LASAPS	LASA Processing Subsystem
LDC	LASA Data Center
LMC	LASA Maintenance Center
LP	Long-Period
MDC	Maintenance Display Console
MOPS	Multiple On-line Processing System
NOAA	National Oceanic Atmospheric Administration
PMEL	Precision Measurement and Equipment Laboratory
SAAC	Seismic Array Analysis Center
SDL	Seismic Data Laboratory
SEM	Subarray Electronics Module
SOU	Serial Output Unit
SP	Short-Period
VCO	Voltage Carrier Oscillator
VLR	Very Low Rate
VSC	VELA Seismological Center
WHV	Well Head Vault

SECTION I

INTRODUCTION

This report presents the accomplishments and administration of Contract Number F-33657-71-C-0430. This contract between the Philco-Ford Corporation and AFSC Aeronautical Systems Division is for continued operation, research, development of the Montana Large Aperture Seismic Array (LASA).

The LASA is part of the Vela Uniform Program which is sponsored by the Advanced Research Projects Agency of the Department of Defense. LASA is an experimental system consisting of many seismometers installed near Miles City, Montana, (Figure 1.1) used for the development of appropriate methods for the detection and identification of seismic events. Initially, the detection, location, and identification of seismic data were performed at the LASA Data Center (LDC) location at Billings, Montana. However, subsequent to implementation of the Integrated Seismic Research Signal Processing System (IRSPS), the array data is now transmitted to the Seismic Array Analysis Center (SAAC) in Alexandria, Va., for processing and analysis.

Following a brief history and description of the LASA, a summary of activities and accomplishments under Project V/T 1708 is presented in Section III. Array performance is discussed in Section IV. Section V describes the improvements and modifications made during this period. Maintenance activities are presented in Section VI. Assistance provided to other agencies is indicated in Section VII; documentation provided is shown in Section VIII.

1.1 History

The LASA, installed in Eastern Montana during 1964 and 1965, is used for experiments in advanced seismological detection and discrimination. The initial installation, composed of 21 subarrays geometrically placed at a diameter of 200 kilometers with 525 short-period and 63 long-period seismometers, has evolved into the present array with the original 21 subarrays reduced to 347 short-period seismometers and 51 long-period seismometers; 21 microbarographs and 8 weather stations have also been added.

Philco-Ford's participation in the Montana LASA began in 1964 by providing MIT Lincoln Laboratory with field engineering assistance. In June 1966, Philco-Ford assumed operational and maintenance responsibilities for MIT Lincoln Laboratory. On 1 May 1968, the project direction was transferred to the Electronics Systems Division, AFSC, with prime contracts to Philco-Ford through 30 November 1970.

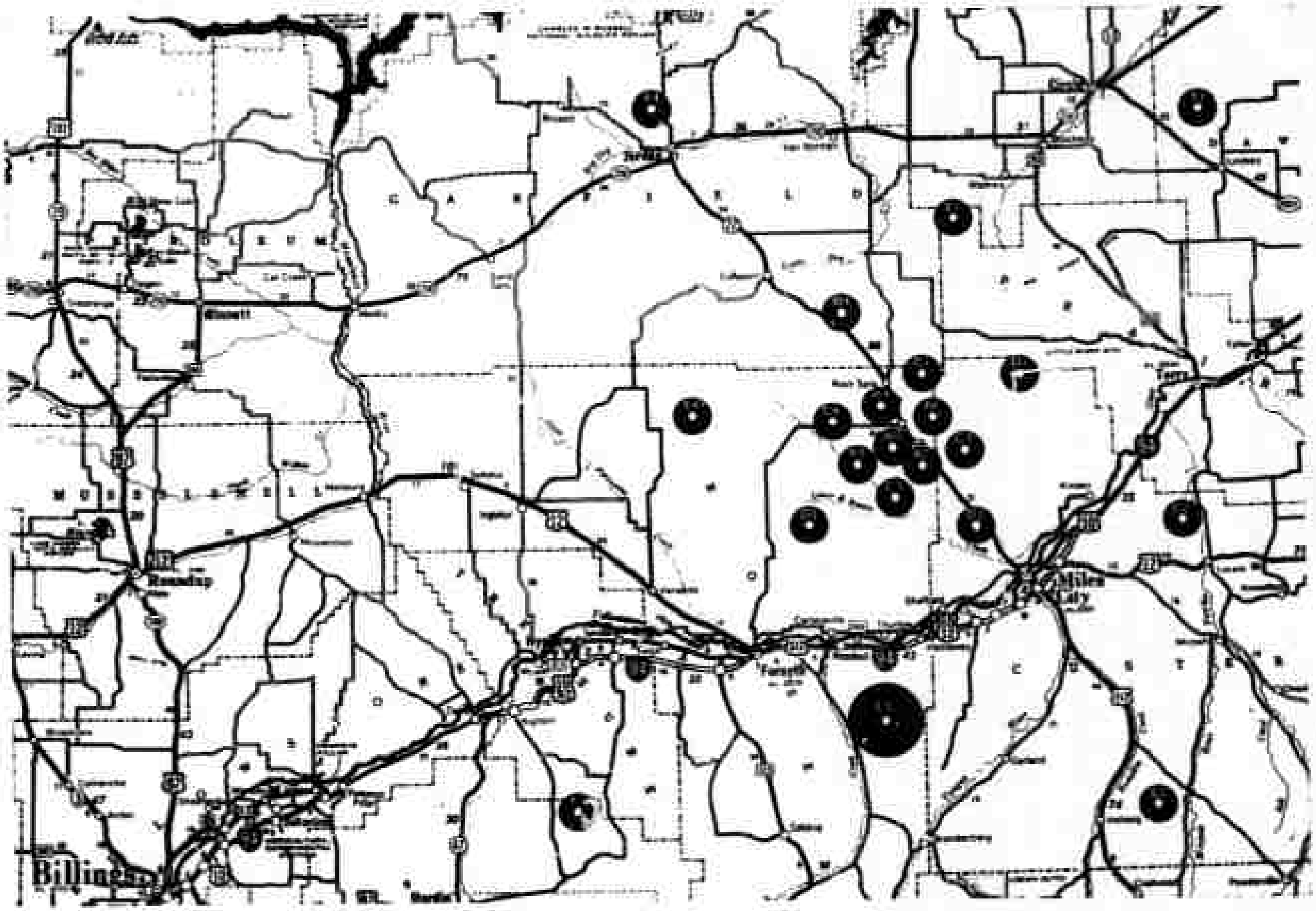


Figure 1.1 Montana LASA

Beginning 1 December 1970, technical direction of the Montana LASA was assigned to the Air Force Technical Applications Center (AFTAC). Under Project V/T 1708 Philco-Ford continues the work of previous Montana LASA projects. This work basically involves the continued operation and maintenance of the array and data center systems, logistics and administrative support, data provision, and hardware evaluation and installation.

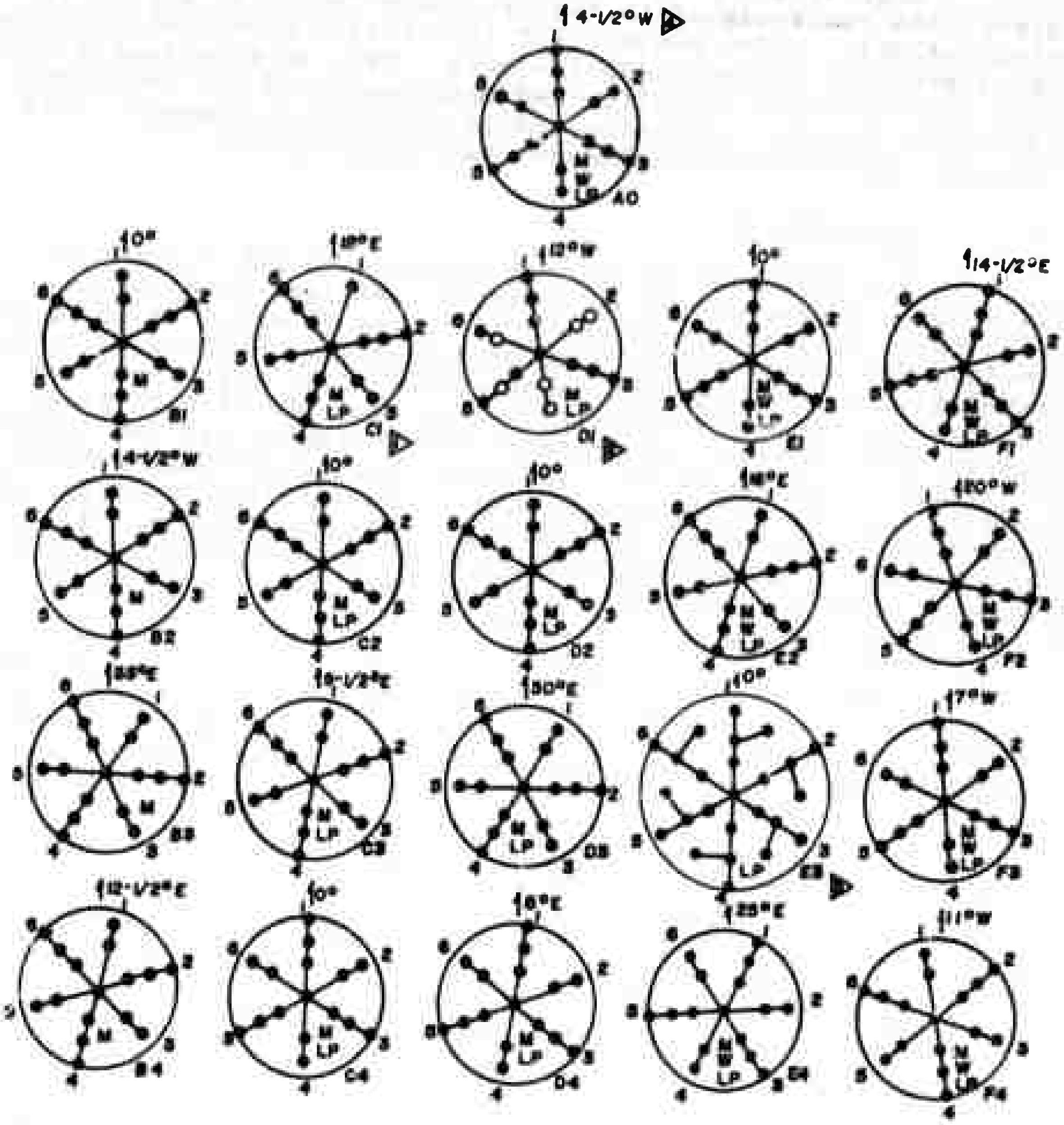
1.2 Description

The LASA with an overall diameter of 200 kilometers (124 miles) is composed of 21 subarrays arranged as shown in Figure 1.1. With the exception of subarray E3 which is 19 km in diameter, all subarrays are 7 km in diameter. Subarray E3 is configured with 25 short-period seismometers while all others now have 16. All subarrays originally were designed with 25 seismometers each, however, programmed sensor removal has now lowered this number to 16 except E3. The short-period seismometers are located along six radial cables which terminate in a central underground vault containing the Subarray Electronics Module (SEM). The subarrays also contain three-component long-period sensors, microbarograph sensors, and weather sensors. Figure 1.2 shows the present configuration of each subarray.

The LDC controls the array operation by sending a command signal to each SEM at a rate of twenty times each second to cause sampling of the subarray signals. This command signal is suitably delayed at the LDC prior to transmission so that data from all SEM's will arrive at the LDC within predetermined time intervals.

The SEM responds to LDC timing system control signals with signal sampling, conversion, and transmission of all data to the LDC. Flexibility exists within the array in that the SEM can accomodate as many as 30 signal inputs; currently, signals from short and long-period seismometers, weather sensing equipment, microbarograph sensors, and other measured parameters are telemetered. Signals from the 21 SEM's are transmitted to microwave junction points by open wire lines at a 19.2 kilobaud rate; from these points they are sent to the LDC by microwave radio facilities. At the LDC the data are recorded and reformatted for transmission over a 50 kilobaud channel to SAAC. The LDC also contains the array timing and maintenance monitoring equipment. By means of telemetry commands, signal sources at the subarray are controlled to provide equipment calibrations and verify equipment performance.

The different LASA seismographs operating parameters and tolerances are identified in Tables I and II. Figure 1.3 shows the five different seismograph responses available.



▷ **NOTES**

1. Sensors removed from leg I because of access difficulties.
2. O Denotes near surface sensors.
3. Expanded array, 18 Km diameter.
4. All degrees shown are orientations with respect to true north.
5. LP Denotes long period seismometers exist at center of array.
6. M Denotes microbarograph sensors exist at center of array.
7. W Denotes weather sensors exist at center of array.

Figure 1.2 LASA Subarray Configurations

TABLE I

LASA SEISMOGRAPH OPERATING PARAMETERS AND TOLERANCES

CHANNEL IDENT.	OPERATING PARAMETERS AND TOLERANCES				
	T_s	λ_s	(MP_s)	S_{chan}	Full Scale Within
SPZ	1.0	0.7±0.1		20±3mV/nm@1.0s	609-823nm@1.0s
SPIZ	"	"		"	"
SPTZ	1.15	0.7		"	"
SPTN	1.06	"		"	"
SPTE	1.03	"		"	"
SPAZ	1.0	0.7±0.1		636±95mV/μm@1.0s	19.2-25.9μm@1.0s
LPZ	20.0±5%	0.77	0±1.5mm	350±50mV/μm@25s	35.0-46.7μm@25s
LPH	"	"	"	"	"
LPAZ	"	"	"	11±1.7mV/μm@25s	1102-1505μm@25s
LPAH	"	"	"	"	"
LPWZ	"	"	"	55±8.3mV/μm@25s	221-300μm@25s
LPWH	"	"	"	"	"

LEGEND: T_s = Seismometer Free Period (Sec); λ_s = Seismometer Damping

(MP_s) = Seismometer Mass Position from Center

S_{chan} = Channel Sensitivity

TABLE II

LASA SEISMOGRAPH CHANNEL IDENTIFICATION

CHANNEL	MANUFACTURER/MODEL	SEISMIC AMPLIFIER MFGR/MODEL	FILTER MFGR/MODEL/TYPE
SPZ	GeoSpace/HS-10-1A	Texas Inst./RA-5	4 pole ½dB ripple Chebyshev low pass, f_c=5.0 hertz, @10 hertz, -30dB.
SPAZ	GeoSpace/HS-10-1A	Texas Inst./RA-5	
SPIZ	GeoSpace/HS-10-1B	Ithaco/6072-65	"
SPTZ	Teledyne/TD-201D	Texas Inst./RA-5	"
SPTN	Teledyne/TD-201D	Texas Inst./RA-5	"
SPTE	Teledyne/TD-201D	Texas Inst./RA-5	"
LPZ	Geotech/7505A	Texas Inst./Type II	Texas Inst./Type II/Response A. 24 dB/oct high-cut, centered at 65 sec.
LPH	Geotech/8700C	Texas Inst./Type II	
LPAZ	Geotech/7505A	Texas Inst./Type II	"
LPAH	Geotech/8700C	Texas Inst./Type II	"
LPWZ	Geotech/7507A	Texas Inst./Type II	Texas Inst./Type II/Response C. 12 dB/oct high-cut, centered at approx. 100 sec.
LPWH	Geotech/8700C	Texas Inst./Type II	

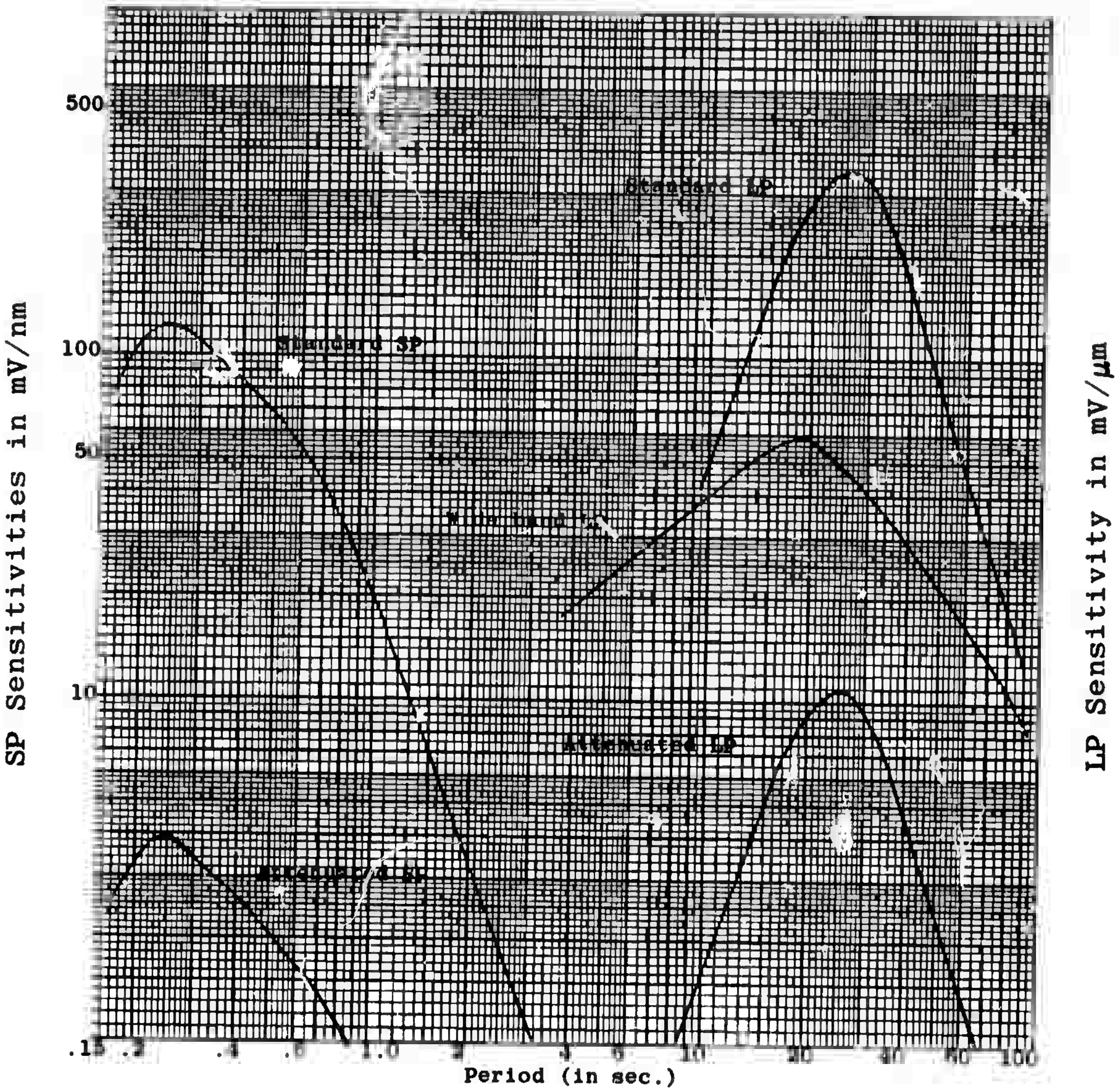


Figure 1.3 LASA Seismographs Response Curves

SECTION II

SUMMARY

The array operation, maintenance, and system improvement activities at the Montana LASA for this one-year contract period are described. The array operation support provided to SAAC via the LDC computers for both on-line data transmission (89.1%) and back-up recording (10.9%) is detailed. The array monitoring and remote calibrations performed are described.

The philosophy of performance measurement applied to the different array systems is discussed. A system definition in terms of input, output, and process parameters and their properties is the goal of this measurement effort. System parameters are identified and initial measurements to determine their expected values are described for selected equipment types; in particular, the HS-10-1/A seismometer natural frequencies and the RA-5 amplifier gain vs temperature characteristic. Some new surficial noise sources resulting from the start-up of coal mining in the southwest section of the array are identified. The number of failures for each equipment type is indicated; the RA-5 amplifier produced the largest number.

Development of a new PDP-7 computer operating system with supporting programs for automatic maintenance and monitoring of selected array equipments is described. These programs provide a ready means for quickly and accurately testing the array systems. Equipment modifications performed to improve the array operation are described.

Maintenance activity and accomplishments are presented. The 360 computer maintenance program and the SP sensor rehabilitation are noteworthy items. The assistance provided to other agencies, in particular SDL, the Weather Bureau, and Lincoln Laboratory is described.

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SECTION III

OPERATION

3.1 General

Array operation is performed to provide data continuously from the array sensing and data acquisition systems to the LDC, to provide data on-line from the LDC to the SAAC and to provide data recording in the event data transmission to SAAC is interrupted. Supporting array operation are the administrative functions of logistics (including property control and purchasing).

3.1.1 Safety

An intensive program encompassing and stressing safety is in effect at all levels in the operation and maintenance of the LASA Program. Safety officers at both the LDC and LMC monitor dedicated practices, detect potential safety hazards and inform all personnel regarding safe work habits. During the period a DSA representative conducted a safety inspection at both facilities with satisfactory results reported. Resulting from this active safety program, only one incident occurred in which a technician sustained a minor back sprain with no loss of time to the program. One vehicle mishap (paragraph 6.4.5) also occurred.

3.2 Logistics

The logistics provided to support the Montana LASA operation is divided into three areas of activity control, viz., purchasing, property and material. A summary of these activities for this contract is presented in the following paragraphs.

3.2.1 Purchasing

Purchase orders numbering 280 and amounting to $37,804.30 were released during this year in support of the maintenance and operation of the array. Additional fixed costs for facility leases, utilities, land leases, travel, data circuits, etc. amounted to approximately $308,000.00. An audit of the program purchasing system was performed in June by the Philco-Ford Corporation accounting department.

3.2.2 Property

An inventory of 352 line items of property with a value of $2,726,648.60 is maintained for use on this program. This reflects an increase of $328,899.00 resulting from the acquisition by the government of the data center's IBM/360 Model 44 computer system. All government-owned property is now included in the projects EDP record system.

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3.2.3 Material

An inventory of approximately 2,500 line items of material with a value of $267,368.00 is maintained for support of this program. The complete inventory of material was added to the EDP record system which reflects all material transactions on a monthly updated basis during this contract.

Henry Wopperer, Government Property Auditor from DCASD Seattle, conducted his annual property survey. His area of audit included: procurement, storage, utilization and records. Mr. Wopperer reported that Philco-Ford was operating in a satisfactory ASPR approved manner and noted no defects.

3.3 Data Center

The LASA Data Center (LDC) contains the equipment necessary to process the seismic array data either for transmission to SAAC or for recording locally. The equipment interconnections are shown in the signal flow diagram in Figure 3.1. In Figure 3.2 the present layout of the equipment is indicated. The diagrams reflect the configuration in effect on November 30, 1971, at the end of the contract period and shows some change from the configuration at the start of the period. A reduction in equipment was made which eliminated two LASAPS modes of operation previously available. Removal of peripheral equipment from the 360 computer system, viz., the 1443 line printer, the 2803 tape control unit, and three 2401 tape drives, eliminated the capability to: (1) transmit test data to SAAC on-line from tapes previously recorded to contain specified seismic activity from the array and (2) record array data processed and formatted by the 360 computer for direct use by the SAAC computers.

The activities in support of the LASAPS and other data center systems include: (1) IBM 360/44 computer operation on-line to SAAC, (2) PDP-7 computer operation to record array data in backup of the 360 computer and to perform array monitoring, automatic calibrations, and off-line processing of technical information, (3) maintenance display console operation for test and diagnosis of array equipment performance, (4) tape and film library operation for storage, handling, and shipment of array data recordings, and (5) develocorder operation for continuous recording of selected sensor channels for the Seismic Data Laboratory and array quality control testing and analysis.

3.3.1 SAAC/LDC Systems

Successful operation of the real time data link between the SAAC and the LDC so that the maximum amount of useful seismic data from the Montana array reaches the SAAC for analysis is one of the main goals of this project. Monitoring of the SAAC/LDC operation during this contract period produced the operational statistics in Table III. Table IV breaks down the statistics by month for the

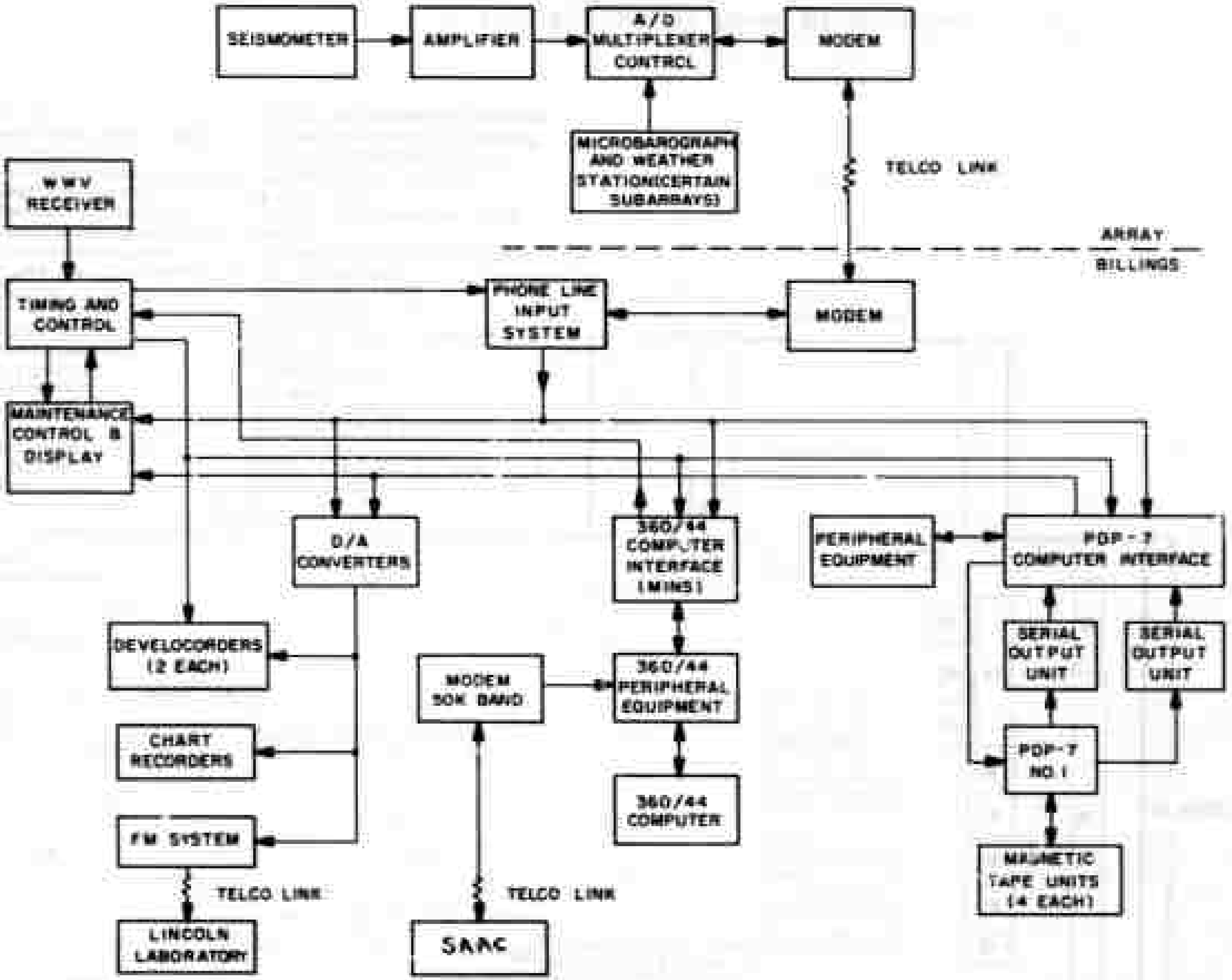
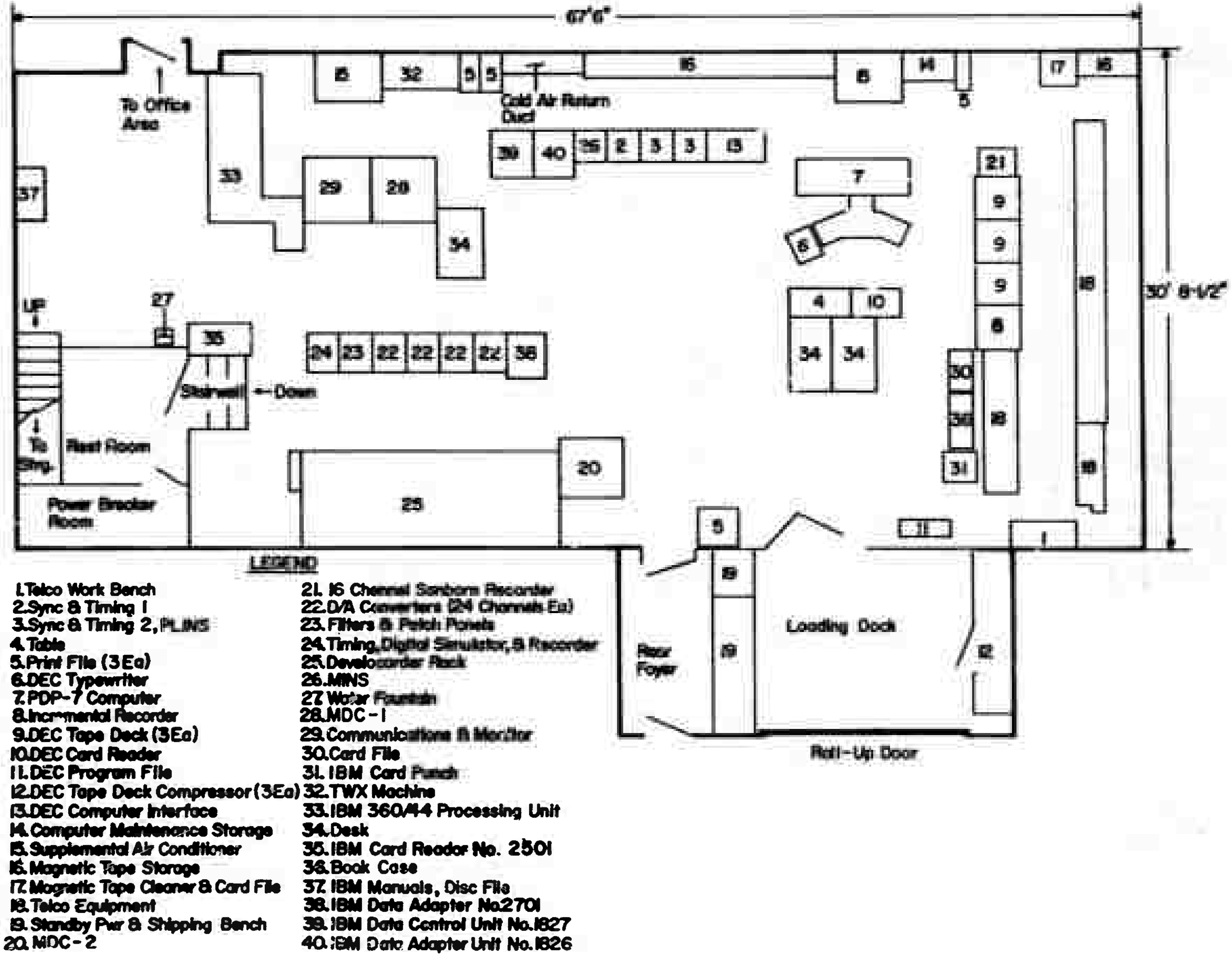


Figure 3.1 Montana LASA Signal Flow Diagram, 30 November 1971



1. Telco Work Bench
2. Sync & Timing 1
3. Sync & Timing 2, PLINS
4. Table
5. Print File (3 Ea)
6. DEC Typewriter
7. PDP-7 Computer
8. Incremental Recorder
9. DEC Tape Deck (3 Ea)
10. DEC Card Reader
11. DEC Program File
12. DEC Tape Deck Compressor (3 Ea)
13. DEC Computer Interface
14. Computer Maintenance Storage
15. Supplemental Air Conditioner
16. Magnetic Tape Storage
17. Magnetic Tape Cleaner & Card File
18. Telco Equipment
19. Standby Pwr & Shipping Bench
20. MDC - 2
21. 16 Channel Sanborn Recorder
22. D/A Converters (24 Channels Ea)
23. Filters & Patch Panels
24. Timing, Digital Simulator, & Recorder
25. Develocorder Rack
26. MINS
27. Water Fountain
28. MDC - 1
29. Communications & Monitor
30. Card File
31. IBM Card Punch
32. TWX Machine
33. IBM 360/44 Processing Unit
34. Desk
35. IBM Card Reader No. 2501
36. Book Case
37. IBM Manuals, Disc File
38. IBM Data Adapter No. 2701
39. IBM Data Control Unit No. 1827
40. IBM Data Adapter Unit No. 1826

3 2 LDC Equipment Room Floor Plan

TABLE III

SAAC/LDC SYSTEM OPERATING TIMES

OPERATION	ACCUMULATED TIME, HOURS				
	FIRST QUARTER	SECOND QUARTER	THIRD QUARTER	FOURTH QUARTER	TOTAL
SAAC & LDC 360 On-Line	1543.7	2040.3	2093.0	2132.7	7809.7
SAAC Off-Line, LDC 360 Running					
PDP-7 Recording	261.8	89.5	40.2	30.5	422.0
360 Idle	83.7	0.7	0.0	0.0	84.4
360 Recording	165.9	0.0	0.0	0.0	165.9
SAAC Up, LDC 360 Down PDP-7 Recording					
Scheduled Maintenance	48.3	15.8	12.6	12.7	89.4
Unscheduled Maintenance	36.0	9.7	44.0	2.3	92.0
SAAC Up, Other Equipment Down, PDP-7 Recording					
Scheduled	0.0	0.0	0.0	0.0	0.0
Unscheduled	20.6	52.0	18.2	5.8	96.6
TOTALS	2160.0	2208.0	2208.0	2184.0	8760.0

TABLE IV

SAAC/LDC SYSTEM OPERATING TIMES (SEPT. - NOV. 71)

OPERATION	SEPT.	OCT.	NOV.
SAAC & LDC 360 On-Line	698.1	734.1	700.5
SAAC Off-Line, LDC 360 Running			
PDP-7 Recording	14.1	7.0	9.4
360 Idle	0.0	0.0	0.0
SAAC Up, LDC 360 Down, PDP-7 Recording			
Scheduled	6.1	1.5	5.1
Unscheduled	1.0	1.3	0.0
SAAC Up, Other Equipment Down, PDP-7 Recording			
Scheduled	0.0	0.0	0.0
Unscheduled	0.7	0.1	5.0
Totals (in hours)	720.0	744.0	720.0

fourth quarter. Periods in which LASAPS data was not used in the IRSPS operation at SAAC totaled 950.3 hours or 10.9% of the period. Three operational modes which cause these outages are (1) the SAAC computers are not available for LASAPS data acquisition, (2) the LDC 360 Model 44 computer is not available for processing LASAPS data, and (3) the wideband communications channel between the LDC and SAAC is not in operation. These outage times are covered with digital recordings of the LASA data by the PDP-7 computer; however, no real time data is available at SAAC.

3.3.2 IBM/360 Model 44 Computer

The IBM/360 computer, the LASA data processor, operated on-line with IRSPS system at SAAC 89.1% of this contract period. This statistic was calculated using only the time periods in which the system was fully operational with SAAC and reflects the 15-day outage during January when SAAC equipment was being relocated. A summary of the System 360 computer utilization for the contract period is shown in Table V and a breakdown by month for the final quarterly period is given in Table VI. Based on the total on-line operating times, this machine was available for processing 96.8%. Since the reported down-time includes "shut-down - other equipment" which in all cases has resulted from either outages in the wideband data link connecting the computer to SAAC or to local power failures a more accurate availability percentage is 97.9%. Scheduled maintenance accounted for 49.3% of the total maintenance downtime.

3.3.3 DEC PDP-7 Computer

The role of the PDP-7 computer in the operation of the data center has changed greatly during this contract period. At the start of the period the PDP-7 was assigned the single function of recording array data in a high-rate format in the event the LASAPS system was not providing proper input to SAAC usually due to outages in either the 360 computer or the wideband data link. The development of added software to assist in the monitoring and maintenance testing of the array systems has evolved a new role for the PDP-7 computer. Figure 3.3 shows the operational capability now present in the PDP-7 computer system.

A summary of the PDP-7 computer utilization statistics for the contract period is shown in Table VII and Table VIII shows the monthly utilization during the fourth quarter. The back-up operating mode of high-rate recording (Ref. 1) was required on 435 occasions covering an accumulated time period of 659.7 hours. During this operation 5,003 magnetic tapes were recorded by the computer on 219 of the 365 days of the contract. Low-rate recordings totaling 3782.2 hours were made; however, only those tapes with special interest events were saved for further processing. Very-low-rate (VLR) recordings of microbarograph array data on the incremental recorder were made covering 2660.1 hours of the contract.

TABLE V

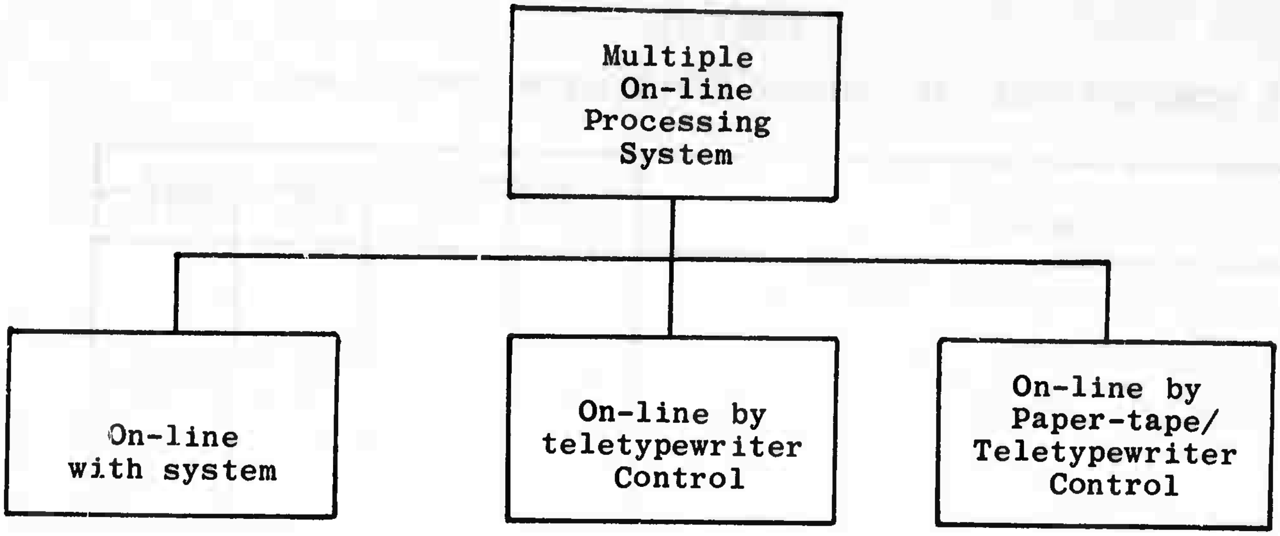
SYSTEM/360 MODEL 44 COMPUTER UTILIZATION

OPERATION	ACCUMULATED TIME, HOURS				
	FIRST QUARTER	SECOND QUARTER	THIRD QUARTER	FOURTH QUARTER	TOTAL
On-Line Processing Including:					
Fully Operational with SAAC	1543.7	2040.3	2093.0	2132.7	7809.7
Running at LASA Only	261.8	89.5	38.6	30.5	420.4
Recording at LASA Only	165.9	0.0	0.0	0.0	165.9
Off-Line Processing Including:					
Transmitting Non-Real Time Data	23.6	0.0	0.0	0.0	23.6
Program Development	8.5	0.0	0.0	0.0	8.5
Diagnostic Programs	4.3	0.0	0.0	0.0	4.3
Training	0.0	0.3	1.9	0.4	2.6
Down-Time Operation Including:					
Scheduled Maintenance	16.2	15.8	10.7	12.3	55.0
Corrective Maintenance	15.8	2.6	21.5	2.3	42.2
Shut Down - 360 Equipment	1.2	2.4	21.4	0.0	25.0
Shut Down - Other Equipment	20.6	52.0	18.1	4.8	95.5
Program Halt or Loop	3.7	1.1	1.5	1.0	7.3
Idle Time	83.9	0.5	0.0	0.0	84.4
System Initialization	10.8	3.5	1.3	0.0	15.6
TOTAL	2160.0	2208.0	2208.0	2184.0	8760.0

TABLE VI

SYSTEM/360 MODEL 44 COMPUTER UTILIZATION (SEPT. - NOV. 71)

OPERATION	ACCUMULATED TIME, HOURS			
	SEPT.	OCT.	NOV.	TOTAL
On-line processing including:				
System initialization	0.0	0.0	0.0	0.0
Fully operational with SAAC	698.1	734.1	700.5	2132.7
Running at LASA only	14.1	7.0	9.4	30.5
Down-time operating including:				
Scheduled maintenance	6.1	1.1	5.1	12.3
Corrective maintenance	1.0	1.3	0.0	2.3
Training	0.0	0.4	0.0	0.4
Shut down - 360 equipment	0.0	0.0	0.0	0.0
Shut down - other equipment	0.1	0.1	4.6	4.8
Program halt or loop	0.6	0.0	0.4	1.0
Idle time	0.0	0.0	0.0	0.0
Totals	720.0	744.0	720.0	2184.0



1. Weather
2. Event detection which includes beam forming

1. Hi-rate Record
2. Lo-rate Record
3. VLR Record
4. Weather
5. Display selected data through SOU.
6. Monitor-provides array status, site deletions/ replacements
7. Programming changes and/or changing contents of selected core locations.

1. TESP
2. TELP
3. MASPOS
4. FREECK
5. DC OFF
6. BATCK
7. DEVCAL
8. Card List
9. Tape List
10. Data-Playback

Figure 3.3 PDP-7 Computer Operational Capabilities

TABLE VII

PDP-7 COMPUTER UTILIZATION

OPERATION	ACCUMULATED TIME, HOURS				
	FIRST QUARTER	SECOND QUARTER	THIRD QUARTER	FOURTH QUARTER	TOTAL
On-Line System Program Operation Including:					
Monitor & Weather	36.3	34.3	353.8	52.8	477.2
VLR (Microbarograph Recording)	657.7	703.9	290.1	531.2	2200.9
High Rate Recording Only	64.2	37.3	61.9	6.6	170.0
Low Rate Recording Only	20.5	12.1	479.7	33.4	545.7
VLR & High Rate	206.8	124.5	49.9	43.8	425.0
VLR & Low Rate	586.8	854.5	546.5	1184.5	3171.8
VLR & High Rate & Low Rate	12.5	19.7	4.2	7.8	44.2
High Rate & Low Rate	13.6	0.0	6.5	0.4	20.5
Off-Line Program Operation Including:					
Tape Duplication & Verification	11.1	16.4	13.9	30.9	72.3
Data Analysis	178.6	94.5	1.9	9.5	284.5
Utility Operation	48.2	27.5	21.6	32.4	129.7
Program Development	245.4	220.5	225.5	186.3	877.7
Diagnostic Programs & Testing	26.4	39.2	59.4	26.9	151.9
Training	0.6	0.7	0.6	0.8	2.7
Down Time Operation Including:					
Scheduled Maintenance	0.0	0.4	1.2	0.9	2.5
Unscheduled Maintenance	8.4	3.0	62.7	14.6	88.7
Shut Down - PDP-7 Inoperative	2.7	1.6	8.0	1.9	14.2
Shut Down - Other Equipment	2.1	3.7	6.5	0.9	13.2
Program Halts	7.0	9.2	10.1	8.8	35.1
Idle	13.1	5.5	4.0	9.7	32.3
TOTALS	2160.0	2208.0	2208.0	2184.1	8760.1

TABLE VIII

PDP-7 COMPUTER UTILIZATION (SEPT. - NOV. 71)

OPERATION	ACCUMULATED TIME, HOURS			
	SEPT.	OCT.	NOV.	TOTAL
On-line program operation including:				
Monitor & Weather Processing only	28.2	8.0	16.6	52.8
VLR Recording only	153.2	194.6	183.3	531.2
High Rate Recording only	2.1	1.9	2.6	6.6
Low Rate Recording only	18.4	8.1	6.9	33.4
VLR & High Rate Recording	15.5	7.4	20.9	43.8
VLR & Low Rate Recording	373.4	403.7	407.4	1184.5
VLR, High & Low Rate Recording	5.1	2.3	0.4	7.8
High & Low Rate Recording	0.0	0.4	0.0	0.4
Off-line program operation including:				
Tape Duplication & Verification	9.2	11.5	10.2	30.9
Data Analysis	9.2	0.0	0.3	9.5
Utility Operation	4.8	12.3	15.3	32.4
Program Development	63.3	82.8	40.2	186.3
Diagnostic Programs & Testing	14.3	0.0	12.6	26.9
Training	0.8	0.0	0.0	0.8
System Initialization	0.0	2.6	0.2	2.8
Down-time operation including:				
Scheduled Maintenance	0.0	0.9	0.0	0.9
Corrective Maintenance	12.0	2.6	0.0	14.6
Shut down PDP-7 Inoperative	1.0	0.0	0.9	1.9
Shut down - Other Equipment	0.3	0.0	0.6	0.9
Program Halts	3.8	3.7	1.3	8.8
Idle	5.3	1.2	0.3	6.8
Totals	720.0	744.0	720.0	2184.0

Program development accounted for 877.7 hours of the PDP-7 computer use. This time is utilized during periods in which high rate recording is not required. Section 5.2 describes some of the program development work accomplished.

3.3.4 Analog System

3.3.4.1 Develocorder

Two Geotech Model 4000 Develocorders are operated at the data center. One is used to support data analysis work at SDL (see paragraph 7.1) and the other to support array maintenance by providing a means to display various sensor outputs during different intervals of time. The SDL Develocorder is operated 24 hours a day and each film is scanned in the film viewer to determine the quality of the film record and provide a log of occurances which affect the quality and usability of the film record. A total of 158 films were recorded for SDL during this contract.

3.3.4.2 FM Link

The Analog System provides outputs of ten selected sensors for telemetering to MIT Lincoln Laboratories. The FM equipment, manufactured by Data Control Systems is composed of a transmitter with constant bandwidth (±62.5 Hz) VCO's for multiplexing the signals onto one leased telephone circuit. Operation of this system is verified by periodic monitoring of the signals into the system and through telephone contact with Lincoln Laboratory personnel.

3.3.5 Tape/Film Library

The data center's library is used to store the PDP-7 computer magnetic tape recordings, the 360 computer disc recordings, and the Develocorder film recordings prior to distribution and for reuse or reference. The library use statistics for this contract are:

5003	PDP-7 high-rate format tapes retained for recycling
4	PDP-7 high-rate format tapes distributed to SDL
3	PDP-7 high-rate format tapes distributed to SAAC
1	PDP-7 high-rate format tape retained for reference
278	PDP-7 very-low rate format tapes distributed to SDL
8	PDP-7 low-rate format tapes retained for reference
31	360 tapes distributed to SAAC
158	Develocorder films of SDL format distributed to SDL
3980	Develocorder films of LDC formats distributed to SDL

3.4 Array

Array operations functions performed include (1) monitoring of all array systems to detect equipment and data degradation, (2) testing of all array systems to measure equipment performance characteristics, (3) interfacing with telephone company personnel to determine communications equipment performance, and (4) processing of array maintenance and operation data to obtain statistics and information for efficient array management. These tasks are performed utilizing the PDP-7 computer, the maintenance display console, and the Develocorders. The overall system quality control efforts are applied through these activities.

3.4.1 Monitoring

Full time monitoring of the array systems is accomplished at the LDC using the built-in data monitors. There are three such monitors available. One is the MDC alarm monitor panel which provides instantly both a visual and audible indication at the occurrence of either a data link failure between the LDC and a subarray or an alarm signal of subarray power and vault failures transmitted on telemetry word 31. The PDP-7 monitor program outputs each telemetry word 31 data change from any subarray and also prints out the duration of subarray data interruptions. The 360 computer's on-line system program provides at periodic intervals a variety of messages generated to indicate significant events, to report error conditions, or to respond to operator requests.

Operation and maintenance of the array equipment requires that the data be interrupted at various periods, during which time normal or reliable data may not be available to the LASA data user. The reasons established for data interruptions are: maintenance, either being performed or initiated; subarray equipment failure in which no maintenance has been initiated; telephone company(s) performing tests on the communication circuits; telephone company(s) communication link not functioning; power outage at the subarray; or special data center testing. In the event any of these situations occur, a notation is made in the data interruption log relating to the data affected and the time period. For the case of short-period and long-period interruptions, SAAC is alerted via the System 360 typewriter. The total duration of data interruption recorded for each subarray during this twelve month contract period is reported in Table IX. A monthly breakdown of the data interruptions for the fourth quarterly period is shown in Table X.

The PDP-7 monitor program is illustrated by presenting one operational case of an extended data interruption. The situation occurred at subarray F1 on 10 September 1971 (day 253) when a small twister knocked down at least five telephone poles. The print-out in Figure 3.4, sheet 1, shows at 0148:30.5 subarray F1 lost data. The LDC operator, alerted by the computer alarm bell, deleted the subarray from the system by typing "DEL,F1.". Sufficient print-out is shown to indicate evidence of a disturbance in the array, viz., the storm. At times 0150:35.1 to 0150:41.2 twelve subarrays show loss of AC power which was restored almost immediately according to the print-out at time 0151:02.4. The line at 253-0151:18.1 indicates the subarrays used in the event detector program; normally the eight sites in the E and F rings. Here site F1 is automatically replaced by D1 and site E1 deleted earlier has been replaced by C1.

TABLE IX

SUBARRAY DATA INTERRUPTION OUTAGES

December 1970 - November 1971

	TOTAL TIME DURATION OF DATA INTERRUPTIONS (h:m)						
DATA	AO	B1	B2	B3	B4	C1	C2
SP	28:15	29:17	13:26	19:20	20:13	24:15	21:12
LP	23:29	-	-	-	-	20:43	16:48
μbaro	23:29	24:53	9:02	14:56	15:49	19:41	20:01
Meter	23:03	-	-	-	-	-	-
Telco	74:43	16:31	49:20	15:39	25:29	17:07	54:57
DATA	C3	C4	D1	D2	D3	D4	E1
SP	27:14	25:50	29:23	33:22	251:51	22:43	18:42
LP	77:56	10:31	24:56	56:15	247:37	19:19	36:52
μbaro	22:50	10:31	24:56	28:58	247:37	19:19	33:10
Meter	-	-	-	-	-	-	33:10
Telco	24:11	14:38	47:27	9:30	63:51	48:25	63:48
DATA	E2	E3	E4	F1	F2	F3	F4
SP	22:10	12:09	47:01	72:43	19:11	41:46	37:34
LP	17:44	6:51	42:37	67:55	14:47	37:32	36:52
μbaro	17:44	-	42:37	67:55	14:47	37:32	33:10
Meter	15:14	-	42:37	67:55	14:47	53:45	33:10
Telco	30:55	35:59	46:08	55:50	41:37	28:27	63:48

TABLE X

SUBARRAY DATA INTERRUPTION OUTAGES (SEPT. - NOV. 71)

		TOTAL TIME DURATION OF DATA INTERRUPTIONS (h:m)			
SUB ARRAY	DATA	SEPT.	OCT.	NOV.	TOTALS
AO	SP		3:32	:12	3:44
	LP		3:32	:12	3:44
	μbaro		3:32	:12	3:44
	Meteor		3:32	:12	3:44
	Telco	1:37	3:53	:07	5:37
B1	SP		:37	2:06	2:43
	μbaro		:37	2:06	2:43
	Telco	1:35	1:17		2:52
B2	SP	:08	4:21		4:29
	μbaro	:08	4:21		4:29
	Telco	:41	:59		1:40
B3	SP		:13		:13
	μbaro		:13		:13
	Telco	1:09	:51		2:00
B4	SP	1:04	1:10	:53	3:07
	μbaro	1:04	1:10	:53	3:07
	Telco	1:24			1:24
C1	SP	:04	1:33		1:37
	LP	:04	1:33		1:37
	μbaro	:04	1:33		1:37
	Telco	1:18	1:14		2:32
C2	SP		:33	8:25	8:58
	LP		:33	8:25	8:58
	μbaro		:33	8:25	8:58
	Telco	3:05	1:57	:09	5:11
C3	SP	:36	9:34		10:10
	LP	5:56	9:34		15:30
	μbaro	:36	9:34		10:10
	Telco		:41		:41

TABLE X

SUBARRAY DATA INTERRUPTION OUTAGES (CONTINUED)

		TOTAL TIME DURATION OF DATA INTERRUPTIONS (h:m)			
SUB ARRAY	DATA	SEPT.	OCT.	NOV.	TOTALS
C4	SP		:54		:54
	LP		:54		:54
	µbaro		:54		:54
	Telco	1:09			1:09
D1	SP	:14	:05	5:07	5:26
	LP	:14	:05	5:07	5:26
	µbaro	:14	:05	5:07	5:26
	Telco	9:21	1:33		10:54
D2	SP	7:34		6:09	13:43
	LP	7:34		6:09	13:43
	µbaro	7:34		6:09	13:43
	Telco	2:28			2:28
D3	SP	1:02	2:13		3:15
	LP	1:02	2:13		3:15
	µbaro	1:02	2:13		3:15
	Telco		:41		:41
D4	SP	2:20		3:27	5:47
	LP	2:20		3:27	5:47
	µbaro	2:20		3:27	5:47
	Telco	2:47	6:50		9:37
E1	SP			1:17	1:17
	LP			1:17	1:17
	µbaro			1:17	1:17
	Meteor			1:17	1:17
	Telco	2:38	4:48	1:00	8:26
E2	SP		4:22	:55	5:17
	LP		4:22	:55	5:17
	µbaro		4:22	:55	5:17
	Meteor		4:22	:55	5:17
	Telco	3:36			3:36

TABLE X

SUBARRAY DATA INTERRUPTION OUTAGES (CONCLUDED)

		TOTAL TIME DURATION OF DATA INTERRUPTIONS (h:m)			
SUB ARRAY	DATA	SEPT.	OCT.	NOV.	TOTALS
E3	SP	1:20	:41	:22	2:23
	LP	1:20	:41	:22	2:23
	Telco	4:24		13:34	17:58
E4	SP	7:27			7:27
	LP	7:27			7:27
	µbaro	7:27			7:27
	Meteor	7:27			7:27
	Telco	:19	1:12		1:31
F1	SP	:18	2:03	3:23	4:44
	LP	:18	2:03	2:23	4:44
	µbaro	:18	2:03	2:23	4:44
	Meteor	:18	2:03	2:23	4:44
	Telco	12:47	4:24		17:11
F2	SP		1:49	1:41	3:30
	LP		1:49	1:41	3:30
	µbaro		1:49	1:41	3:30
	Meteor		1:49	1:41	3:30
	Telco	:26		:56	1:22
F3	SP	4:06	1:24	:16	5:46
	LP	4:06	1:24	:16	5:46
	µbaro	4:06	1:24	:16	5:46
	Meteor	4:06	1:24	:16	5:46
	Telco	:56	:45	2:57	4:38
F4	SP		:33	3:16	3:49
	LP		:33	3:16	3:49
	µbaro		:33	3:16	3:49
	Meteor		:33	3:16	3:49
	Telco	1:42	1:06	:27	3:15

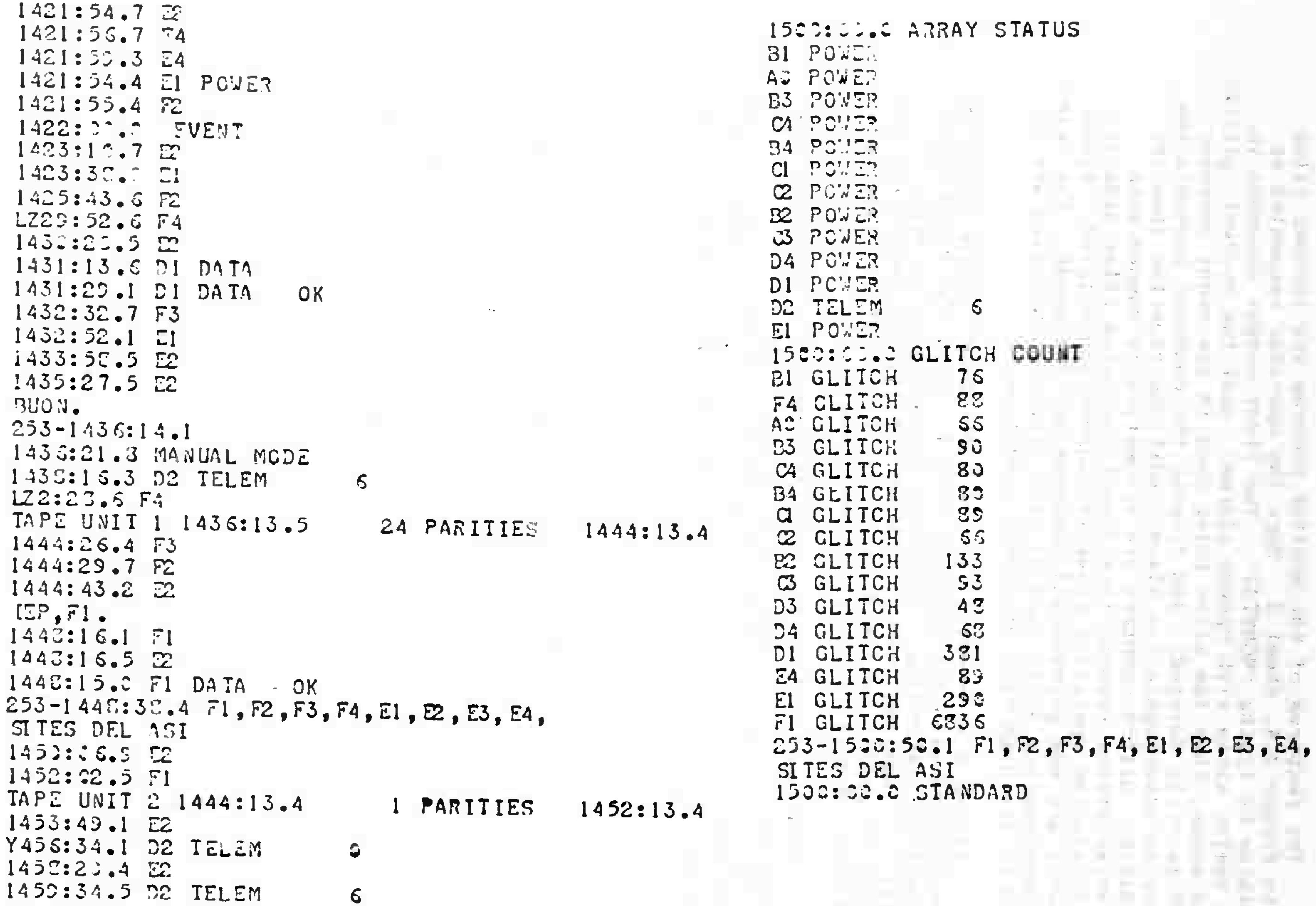
```
0148:00.2 D4 POWER
253-0148:23.3 F1,F2,F3,F4,C1,E2,E3,E4,
SITES DEL E1,
0148:30.5 F1 DATA
DEL,F1.
0150:35.1 F4 LOSTAC
0150:35.2 D1 LOSTAC
0150:35.2 C4 LOSTAC
0150:35.2 B4 LOSTAC
0150:35.2 C1 LOSTAC
0150:35.2 D4 POWER  OK
0150:35.3 A0 LOSTAC
0150:35.3 B3 LOSTAC
0150:35.3 C2 LOSTAC
0150:35.3 B2 LOSTAC
0150:35.3 C3 LOSTAC
0150:35.3 D1 POWER  OK
0150:39.2 D1
0150:40.2 D4 LOSTAC
0150:41.2 D1 LOSTAC
253-0151:18.1 D1,F2,F3,F4,C1,E2,E3,E4,
SITE  DEL E1,F1,
0151:02.5 D1
0151:02.4 B1 LOSTAC OK
0151:02.4 F4 LOSTAC OK
0151:02.4 A0 LOSTAC OK
0151:02.4 B3 LOSTAC OK
0151:02.4 C4 LOSTAC OK
0151:02.4 B4 LOSTAC OK
0151:02.4 C1 LOSTAC OK
0151:02.4 C2 LOSTAC OK
0151:02.4 B2 LOSTAC OK
0151:02.4 C3 LOSTAC OK
0151:02.4 D4 LOSTAC OK
0151:02.4 D4 POWER
0151:02.4 D1 LOSTAC OK
0151:02.4 D1 POWER
0151:23.5 D1
0152:23.2 F2
0154:19.4 F4
0154:23.4 E4
0154:40.5 F2
X157:44.2 D1
0158:15.7 E4
```

Figure 3.4 PDP-7 Monitor Program Sample Printout (Sheet 1)

```
MONSTAT.
1410:10.2 ARRAY STATUS
B1 POWER
A0 POWER
B3 POWER
C4 POWER
B4 POWER
C1 POWER
C2 POWER
B2 POWER
C3 POWER
D4 POWER
D1 POWER
E1 POWER
1410:10.2 GLITCH COUNT
B1 GLITCH    76
F4 GLITCH    88
A0 GLITCH    66
B3 GLITCH    90
C4 GLITCH    80
B4 GLITCH    80
C1 GLITCH    89
C2 GLITCH    66
B2 GLITCH    77
C3 GLITCH    93
D3 GLITCH    48
D4 GLITCH    68
D1 GLITCH    66
E4 GLITCH    89
E1 GLITCH   175
253-1410:57.1 D1,F2,F3,F4,E1,E2,E3,E4,
SITES DEL F1,
1410:10.3 STANDARD
1410:10.7 B1 TELEM     53
1410:10.7 B1 EQUBAT
1410:10.7 A0 TELEM     53
1410:10.7 A0 EQUBAT
1410:10.7 B3 TELEM     53
1410:10.7 B3 EQUBAT
```

```
1410:10.7 C4 TELEM     53
1410:10.7 C4 EQUBAT
1410:10.7 B4 TELEM     53
1410:10.7 B4 EQUBAT
1410:10.7 C1 TELEM     53
1410:10.7 C1 EQUBAT
1410:10.7 C2 TELEM     53
1410:10.7 C2 EQUBAT
1410:10.7 B2 TELEM     53
1410:10.7 B2 EQUBAT
1410:10.7 C3 TELEM     53
1410:10.7 C3 EQUBAT
1410:10.7 D4 TELEM     53
1410:10.7 D4 EQUBAT
1410:10.7 D1 TELEM     53
1410:10.7 D1 EQUBAT
1410:10.7 E1 TELEM     53
1410:10.7 E1 EQUBAT
1410:17.2 D1 TELEM      0
1410:17.2 A0 TELEM      0
1410:17.2 D3 TELEM      0
1410:17.2 C4 TELEM      0
1410:17.2 B4 TELEM      0
1410:17.2 C1 TELEM      0
1410:17.2 C2 TELEM      0
1410:17.2 B2 TELEM      0
1410:17.2 C3 TELEM      0
1410:17.2 D4 TELEM      0
1410:17.2 D1 TELEM      0
1410:17.2 E1 TELEM      0
1413:58.0 F3
1416:46.0 E1
1419:17.0 E1
1419:53.0 E4
1421:03.8 F4
1421:27.4 E1
1421:29.0 E1 POWER  OK
1421:46.0 E1 POWER
1421:51.2 E1 POWER  OK
```

Figure 3.4 PDP-7 Monitor Program Sample Printout (Sheet 2)



```
1421:54.7 E2
1421:56.7 F4
1421:59.3 E4
1421:54.4 E1 POWER
1421:55.4 F2
1422:00.0  EVENT
1423:19.7 E2
1423:30.0 E1
1425:43.6 F2
LZ29:52.6 F4
1430:20.5 E2
1431:13.6 D1 DATA
1431:29.1 D1 DATA    OK
1432:32.7 F3
1432:52.1 E1
1433:58.5 E2
1435:27.5 E2
BUON.
253-1436:14.1
1436:21.3 MANUAL MODE
1438:16.3 D2 TELEM       6
LZ2:23.6 F4
TAPE UNIT 1 1436:13.5     24 PARITIES   1444:13.4
1444:26.4 F3
1444:29.7 F2
1444:43.2 E2
[EP,F1.
1448:16.1 F1
1448:16.5 E2
1448:15.0 F1 DATA    OK
253-1448:38.4 F1,F2,F3,F4,E1,E2,E3,E4,
SITES DEL ASI
1450:06.9 E2
1452:02.5 F1
TAPE UNIT 2 1444:13.4      1 PARITIES   1452:13.4
1453:49.1 E2
Y456:34.1 D2 TELEM       6
1458:20.4 E2
1459:34.5 D2 TELEM       6
```

```
1500:00.0 ARRAY STATUS
B1 POWER
A3 POWER
B3 POWER
C4 POWER
B4 POWER
C1 POWER
C2 POWER
B2 POWER
C3 POWER
D4 POWER
D1 POWER
D2 TELEM       6
E1 POWER
1500:00.0 GLITCH COUNT
B1 GLITCH    76
F4 GLITCH    88
A3 GLITCH    66
B3 GLITCH    90
C4 GLITCH    80
B4 GLITCH    89
C1 GLITCH    89
C2 GLITCH    66
B2 GLITCH   133
C3 GLITCH    93
D3 GLITCH    43
D4 GLITCH    68
D1 GLITCH   381
E4 GLITCH    89
E1 GLITCH   298
F1 GLITCH  6836
253-1500:50.1 F1,F2,F3,F4,E1,E2,E3,E4,
SITES DEL ASI
1500:00.0 STANDARD
```

Figure 3.4 PDP-7 Monitor Program Sample Printout (Sheet 3)

The features of the monitor program are further illustrated in Figure 3.4, sheet 2. Here the operator requested an array status by typing "MONSTAT". The first output sequence indicates twelve sites with "power alarms", next the current "glitch" count is shown, then the sites being used in the event detector (site Fl is still deleted), and finally the computer controls the telemetry to interrogate the alarm conditions reported from the twelve sites. Glitch counters are automatically dumped with hourly array status report; this report generated after approximately 10 minutes operation shows the number accumulated. Since zero counts are not printed all subarray are not shown. The telemetry interrogation shows that at each site the batteries are in equalize or the high-rate of charge condition.

Figure 3.4, sheet 3, begins with "BUON" which indicates the typed instruction the operator used to start the PDP-7 high-rate, "back-up" recording. The later lines beginning with "TAPEUNIT..." show the time periods of the digital recordings and the number of parity errors detected by the computer during the eight-minute interval recorded on each tape.

Finally at 1448:15.0 with the message "Fl DATA OK" the data from subarray Fl became available again and the operator replaced the site. The subarray then resumed operation in the event detector and the "all sites in or ASI" was reported. The hourly array status report completes the print-out. The computer printout illustrated in Figure 3.4 is typical of the array monitoring operation.

3.4.2 Calibrations

The equipment groups connected to the data center via the telemetered communications channels have known responses for each of a set of telemetry command controls whereby the condition of the various equipment may be determined remotely. The telemetry commands now in use are indicated in Table XI. Calibration of a complete seismograph channel is provided by TC-06 for the short-period system and TC-20 for the long-period system. Normal channel responses to these sinusoidal calibrations are shown in Table XII, where A (volts) is the analog value, A (digital) is the digital value in decimal, and Y is the corresponding equivalent earth motion.

When the measured responses exceed the tolerances established for a particular channel, an equipment failure is reported. The report, the Defective Signal Channel Status Report, is distributed each week to authorized agencies. Figure 3.5 shows a sample of the daily report prepared for internal use by the maintenance and engineering sections. Table XIII indicates the incidence of defective channels detected during the twelve month period for the four types of array channels and two equipment groupings; Table XIV shows the trouble detections for the fourth quarterly period only.

TABLE XI

TELEMETRY COMMAND RESPONSE

TC COMMAND	WORDS 1-25	WORDS 26-28	WORD 29	WORD 30	FUNCTION
1	Fixed Word	Fixed Word	Fixed Word	Fixed Word	Fixed Word to Output
2	+3 Volts	+3 Volts	No Affect	+3 Volts	+3 Volts to MUX
3	0 Volts	0 Volts	0 Volts	0 Volts	GND to MUX
4	+6 Volts	No Affect	+6 Volts	+3 Volts	+6 Volts to Input Drawer
5	0 Volts	No Affect	0 Volts	0 Volts	GND to Input Drawer
6	8 V p-p 1 Hz	No Affect	8 V p-p 1 Hz	10 V p-p 1 Hz	20 V p-p 1 Hz to SP Seismometer
7	10 V p-p 1 Hz	10 V p-p 1 Hz	10 V p-p 1 Hz	10 V p-p 1 Hz	10 V p-p 1 Hz to MUX
8	12 V p-p 1 Hz	No Affect	12 V p-p 1 Hz	10 V p-p 1 Hz	10 V p-p 1 Hz to BAL/ UNBAL Amplifier
14	No Affect	No Affect	No Affect	10 V p-p 1 Hz	10 V p-p 1 Hz to Word 30
15	10 V p-p 1 Hz	No Affect	10 V p-p 1 Hz	10 V p-p 1 Hz	20 V p-p 1 Hz to SP Amplifier
17	Fixed Word	Fixed Word	Fixed Word	Fixed Word	Fixed Word Complement to Output
19					Free Period
20	No Affect	8 V p-p .04 Hz	No Affect	10 V p-p .04 Hz	.04 Hz to LP Seismometer
22	No Affect	8 V p-p .04 Hz	No Affect	10 V p-p .04 Hz	.04 Hz to LP Amplifier

TABLE XI

TELEMETRY COMMAND RESPONSE (CONTINUED)

TC COMMAND	WORDS 1-25	WORDS 26-28	WORD 29	WORD 30	FUNCTION
24	No Affect	No Affect	No Affect	No Affect	Reset Seismometer Power Supply
25	"	"	"	"	Standby Power Equalize
26	Test Pattern	Test Pattern	Test Pattern	Test Pattern	Test Pattern to Modem
27	No Affect	O V	No Affect	No Affect	GND to Input LP Channels
28	"	-6 Vdc	"	+3 Vdc	6 Vdc to Input Channels
29	"	10 V p-p .04 Hz	"	10 V p-p .04 Hz	.04 Hz to Input Drawer
31	"	No Affect	"	+5 Vdc	Mass Position Monitor Vertical
32	"	"	"	+5 Vdc	Mass Position Monitor NS
33	"	"	"	+5 Vdc	Mass Position Monitor EW
45	"	"	"	No Affect	+LP Motor Control
46	"	"	"	"	-LP Motor Control
47	"	"	"	"	Control LP Mass Position Vertical
48	"	"	"	"	Control LP Mass Position NS
49	"	"	"	"	Control LP Mass Position EW

TABLE XI

TELEMETRY COMMAND RESPONSE (CONCLUDED)

TC COMMAND	WORDS 1-25	WORDS 26-28	WORD 29	WORD 30	FUNCTION
50	No Affect	No Affect	No Affect	No Affect	Control LP Free Period Vertical
51	"	"	"	"	Control LP Free Period NS
52	"	"	"	"	Control LP Free Period EW
53	"	"	"	"	Check Power Alarms
54	"	"	"	"	Check Vault Alarms
55	"	"	"	"	Check Spare Alarms
56	"	"	"	+3.3 V	Measure I
57	"	"	"	+3.3 V	Measure II
58	"	"	"	+3.3 V	Measure III
59	"	"	"	+3.3 V	Measure IV
60	"	"	"	+1.5 V	Measure V, Temperature B
61	"	"	"	+1.5 V	Measure VI, Temperature A
62	"	"	"	≈+6 Vdc	Measure VII, Line Voltage
63	"	"	"	≈+6 Vdc	Measure VIII, Battery

TABLE XII

LASA SEISMOGRAPH CALIBRATION RESPONSE TOLERANCES

CHANNEL IDENT.	TC	Peak-to-Peak Sinusoidal Amplitudes								
		A_{nom} Volts	A_{max} Volts	A_{min} Volts	A_{nom} Digital	A_{max} Digital	A_{min} Digital	Y_{nom}	Y_{max}	Y_{min}
SPZ	06^1	7.91	9.09	6.72	9257	10638	7864	395nm	455nm	336nm
SPAZ	06^1	.25	.289	.214	293	407	236	395nm	455nm	336nm
SPIZ	06^1	7.91	9.09	6.72	9257	10638	7864	395nm	455nm	336nm
SPTZ	06^1	7.91	9.09	6.72	9257	10638	7864	395nm	455nm	336nm
SPTN	06^1	7.91	9.09	6.72	9257	10638	7864	395nm	455nm	336nm
SPTE	06^1	7.91	9.09	6.72	9257	10638	7864	395nm	455nm	336nm
LPZ	20^2	6.98	7.98	5.99	8168	9339	7010	20.0μm	22.8μm	17.1μm
LPH	20^2	6.98	7.98	5.99	8168	9339	7010	20.0μm	22.8μm	17.1μm
LPAZ	20^3	2.77	3.19	2.34	3242	3733	2738	252μm	290μm	213μm
LPAH	20^3	2.77	3.19	2.34	3242	3733	2738	252μm	290μm	213μm
LPWZ	20^2	1.10	1.26	0.93	1287	1475	1088	20.0μm	22.9μm	16.9μm
LPWH	20^2	1.10	1.26	0.93	1287	1475	1088	20.0μm	22.9μm	16.9μm

Note 1. Amplitude measurements corrected for response to 400nm, 1s calibration signal.
2. Amplitude measurements corrected for response to 20μm, 25s calibration signal.
3. Amplitude measurements corrected for response to 222μm, 25s calibration signal.

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MONTANA LASA DEFECTIVE SIGNAL CHANNEL STATUS

WEEK BEGINNING     DAY 17    MONTH 10    YEAR 71

SITE  SEN    SYS    S     M     T     W     T     F     S       REMARKS

B1    1373   SP           H     *
C1    2466   SP     H     *     H
C2    0862   SP     C     C     C
C2    1253   SP           L     *
C2    1544   SP           L     *
C2    18SCA  NR                 O
D1    0110   SP     H     *     H
D1    2185   SP                 H
D1    2456   SP           L     *
D2    1253   SP     H     *     H
D2    1544   SP     L     L     *
D2    18SCA  NR                 O
F1    0110   SP     H     H     H
F2    1143   SP     H     H     Y                                   SITE OUT
F3    1774   SP     H     H     H
F4    0451   SP     L     *     L

[illegible] - DISTORTION
C - LOW & DISTORTED
D - DEAD
L - LOW
H - HIGH
O - OFFSET
Y - SEE REMARKS
* - OKAY
```

Figure 3.5 Sample Daily Defective Signal Channel Status Report

TABLE XIII

INCIDENCE OF DEFECTIVE SUBARRAY CHANNELS

December 1970 - November 1971

SUBARRAY	CHANNELS			
	SP	LP	μBARO	METEOR
AO	11	0 (35)	2	0
B1	17	-	0	-
B2	4	-	1	-
B3	9	-	3	-
B4	12	-	2	-
C1	7	0 (27)	1	-
C2	17	1 (45)	4	-
C3	1	0 (48)	1	-
C4	4	0 (22)	3	-
D1	11	0 (52)	0	-
D2	10	2 (43)	4	-
D3	3	1 (33)	0	-
D4	13	0 (54)	2	-
E1	5	1 (60)	0	0
E2	10	0 (37)	0	2
E3	20	1 (36)	-	-
E4	10	0 (43)	0	0
F1	6	1 (40)	1	0
F2	4	0 (47)	2	0
F3	4	1 (29)	0	1
F4	9	2 (36)	0	1
TOTALS	187	10 (687)	26	4

TABLE XIV

INCIDENCE OF DEFECTIVE SUBARRAY CHANNELS

September - November 1971

	CHANNELS			
SUBARRAY	SP	LP	μBARO	METEOR
AO	6	0 (13)	0	0
B1	6	-	0	0
B2	3	-	1	-
B3	4	-	0	-
B4	3	-	0	-
C1	5	0 (10)	1	-
C2	11	0 (11)	1	-
C3	0	1 (17)	1	-
C4	3	0 (2)	1	-
D1	7	0 (19)	0	-
D2	7	0 (12)	2	-
D3	2	0 (7)	0	-
D4	5	0 (15)	1	-
E1	4	1 (20)	0	0
E2	5	0 (13)	0	0
E3	9	1 (14)	-	-
E4	7	0 (10)	0	0
F1	2	1 (10)	0	0
F2	2	0 (18)	0	0
F3	2	1 (8)	0	1
F4	4	1 (12)	0	0
TOTALS	97	6 (211)	8	1

With the addition of array calibration using the PDP-7 computer and the Multiple On-line Processing System (MOPS) on-line monitor feature the precise times in which calibrations occur become more readily available. A report of these times for the final quarter of the contract is shown in Table XV for the SP sensors along with the equivalent earth motion of the 1-hertz calibration signals as determined from SEM channel 30 measurements during the calibration time. SEM channel 30 monitors the output of the calibration oscillator used to develop the signal applied to the seismometer. Table XVI shows the LP sensor calibration times and input signal amplitudes for the last fourteen weeks of the contract.

Remote calibration of the long-period seismometer positioning is now performed routinely by the PDP-7 computer. The computer controls the telemetry commands to each subarray allowing both measurement and adjustment of each LP seismometer. Patch programs MASPOS and FREECK (see paragraph 5.2) provide the computer control. The capability of controlling the seismometer positioning by telemetry from the LDC which was added in conjunction with the auxiliary control and conditioning box installation (Ref. 2) has proven to be very useful in the efficient operation of this system. Each seismometer mass is recentered when it measures greater than ±1.4 mm from center position. The natural frequencies are adjusted when measured in excess of 20 ± 1 sec/cycle.

During this contract 687 remote adjustments were necessary during the 52 weekly tests to maintain the seismometers within these established tolerances. For the 51 seismometers mass positions were adjusted 538 times and 149 natural frequency corrections made. The weekly statistics show an average of 10.3 and 2.9 adjustments were required for correcting these two parameters, respectively. All out-of-tolerance measurements were satisfactorily readjusted from the LDC.

The LP seismometer mass positioning by PDP-7 computer control is described in detail to illustrate the remote adjustments more clearly. As shown in Figure 3.6 the mass position measurements for the LP array's 51 seismometers are made by the operator typing "MASPOS". The computer output which follows shows the mass positions given in divisions on a chart recorder scale previously employed for this measurement; one chart division corresponds to 0.28 mm of mass displacement from its center position. The report from subarray E1 word 27 (the north-south horizontal) shows "----" which indicates the mass position is at or near one of the stops. Fifteen other sensors indicate mass positions outside the ± 5.0 divisions or ± 1.4 mm tolerance.

To correct these conditions the operator types "CORRECTMP." as shown in Figure 3.7 . Corrections are performed as required in three sequences of A0 through F4 starting, first, with the vertical seismometers, followed by the north-south horizontals and finally

TABLE XV

SP ARRAY SINUSOIDAL CALIBRATIONS (SEPT. - NOV. 71)

SUBARRAY	Short-Period Array Sinusoidal Calibration Signal Start Times and Amplitudes										SUBARRAY
	Day 249 6 Sept 71		Day 256 13 Sept 71		Day 263 20 Sept 71		Day 270 27 Sept 71		Day 277 4 Oct 71		
	Start Time (GMT)	P-P Ampl. nm	Start Time (GMT)	P-P Ampl. nm	Start Time (GMT)	P-P Ampl. nm	Start Time (GMT)	P-P Ampl. nm	Start Time (GMT)	P-P Ampl. nm	
AO	1724:51	414	2001:12	416	1537:29	423	2127:45	420	1607:27	425	AO
B1	1725:21	403	2001:42	400	1537:59	405	2128:15	404	1601:57	400	B1
B2	1725:51	448	2002:12	448	1538:29	454	2128:45	441	1602:27	434	B2
B3	1726:21	403	2002:42	400	1538:59	406	2129:15	404	1602:57	408	B3
B4	1726:51	414	2003:12	411	1539:29	411	2129:45	411	1603:27	411	B4
C1	1727:21	403	2003:42	398	1539:59	400	2130:15	400	1603:57	400	C1
C2	1727:51	392	2004:12	394	1540:29	397	2130:45	397	1604:27	398	C2
C3	1728:21	403	2004:42	403	1540:59	403	2131:15	403	1604:57	397	C3
C4	1728:51	403	2005:12	397	1541:29	397	2131:45	397	1605:27	394	C4
D1	1729:21	414	2005:42	408	1541:59	408	2132:15	407	1605:57	404	D1
D2	1729:51	426	2006:12	426	1542:29	425	2132:45	396	1606:27	394	D2
D3	1730:21	403	2006:42	405	1542:59	402	2133:15	403	1606:57	401	D3
D4	1730:51	381	2007:12	381	1543:29	388	2133:45	388	1607:27	386	D4
E1	1731:21	403	2007:42	402	1543:59	403	2134:15	404	1607:57	404	E1
E2	1731:51	426	2008:12	418	1544:29	420	2134:45	420	1608:27	420	E2
E3	1732:21	414	2008:42	412	1544:59	408	2135:15	411	1608:57	410	E3
E4	1732:51	414	2009:12	408	1545:29	412	2135:45	411	1609:27	412	E4
F1	1733:21	403	2009:42	395	1545:59	400	2136:15	400	1609:57	400	F1
F2	1733:51	403	2010:12	404	1546:29	407	2136:45	408	-	-	F2
F3	1734:21	403	1811:43	404	1546:59	406	2137:15	406	1610:57	408	F3
F4	-	-	1812:13	420	1547:29	418	2137:45	418	1611:27	418	F4

TABLE XV

SP ARRAY SINUSOIDAL CALIBRATIONS (SEPT. - NOV. 71) CONTINUED

SUBARRAY	Short-Period Array Sinusoidal Calibration Signal Start Times and Amplitudes												SUBARRAY
		Day 284 11 Oct 71		Day 291 18 Oct 71		Day 299 26 Oct 71		Day 305 1 Nov 71		Day 312 8 Nov 71			
		Start Time (GMT)	P-P Ampl. nm	Start Time (GMT)	P-P Ampl. nm	Start Time (GMT)	P-P Ampl. nm	Start Time (GMT)	P-P Ampl. nm	Start Time (GMT)	P-P Ampl. nm		
AO		1537:42	426	1421:47	427	1501:00	431	1536:11	432	1536:34	434		AO
B1		1538:12	408	1422:17	411	1501:30	411	1536:41	416	1537:04	418		B1
B2		1538:42	456	1422:47	408	1502:00	410	1537:11	412	1537:34	413		B2
B3		1539:12	407	1423:17	411	1502:30	411	1537:41	415	1538:04	416		B3
B4		1539:42	411	1423:47	411	1503:00	410	1538:11	402	1538:34	401		B4
C1		1540:12	411	1424:17	400	1503:30	400	1538:41	398	1539:04	400		C1
C2		1540:42	398	1424:47	401	1504:00	401	1539:11	403	1539:34	405		C2
C3		1541:12	405	1425:17	404	1504:30	404	1539:41	404	1540:04	404		C3
C4		1541:42	395	1425:47	383	1505:00	397	1540:11	395	1540:34	297		C4
D1		1542:12	407	1426:17	407	1505:30	406	1540:41	406	1541:04	407		D1
D2		1542:42	395	1426:47	395	1506:00	394	1541:11	393	1541:34	393		D2
D3		1543:12	402	1427:17	400	1506:30	398	1541:41	395	1542:04	392		D3
D4		1543:42	393	1427:47	396	1507:00	397	1542:11	402	1542:34	405		D4
E1		1544:12	408	1428:17	396	1507:30	408	1542:41	406	1543:04	407		E1
E2		1544:42	420	1428:47	421	1508:00	421	1543:11	422	1543:34	422		E2
E3		1545:12	407	1429:17	408	1508:30	407	1543:41	405	1544:04	406		E3
E4		1545:42	412	1429:47	413	1509:00	413	1544:11	414	1544:34	416		E4
F1		1546:12	401	1430:17	400	1509:30	401	1544:41	403	1545:04	405		F1
F2		-	-	1430:47	408	1510:00	408	1545:11	408	1545:34	408		F2
F3		1547:12	410	1431:17	411	1510:30	411	1545:41	413	1546:04	414		F3
F4		1547:42	418	1431:47	418	1511:00	405	1546:11	418	1546:34	417		F4

TABLE XV

SP ARRAY SINUSOIDAL CALIBRATIONS (SEPT. - NOV. 71) CONCLUDED

SUBARRAY	Short-Period Array Sinusoidal Calibration Signal Start Times and Amplitudes						SUBARRAY
	Day 319 15 Nov 71		Day 326 22 Nov 71		Day 333 29 Nov 71		
	Start Time (GMT)	P-P Ampl. nm	Start Time (GMT)	P-P Ampl. nm	Start Time (GMT)	P-P Ampl. nm	
AO	1525:32	433	1604:16	434	1602:57	435	AO
B1	1526:02	416	1604:46	406	1603:27	406	B1
B2	1526:32	411	1605:16	410	1603:57	412	B2
B3	1527:02	414	1605:46	416	1604:27	416	B3
B4	1527:32	408	1606:16	407	1604:57	395	B4
C1	1528:02	400	1606:46	400	1605:27	400	C1
C2	1528:32	404	1607:16	402	1605:57	406	C2
C3	1529:02	405	1607:46	403	1606:27	403	C3
C4	1529:32	397	1608:16	397	1606:57	395	C4
D1	1530:02	410	1608:46	407	1607:27	408	D1
D2	1530:32	393	1609:16	393	1607:57	392	D2
D3	1531:02	396	1609:46	395	1608:27	394	D3
D4	1531:32	403	1610:16	404	1608:57	405	D4
E1	1532:02	412	1610:46	402	1609:27	410	E1
E2	1532:32	422	1611:16	422	1609:57	422	E2
E3	1533:02	406	1611:46	404	1610:27	405	E3
E4	1533:32	415	1612:16	415	1610:57	416	E4
F1	1534:02	404	1612:46	404	1611:27	401	F1
F2	1534:32	408	1613:16	408	1611:57	410	F2
F3	1535:02	414	1613:46	414	1612:27	414	F3
F4	1535:32	417	1614:16	415	1612:57	417	F4

TABLE XVI

LP ARRAY SINUSOIDAL CALIBRATIONS (SEPT. - NOV. 71)

SUBARRAY	Long-Period Array Sinusoidal Calibration Signal Times and Input Amplitude									SUBARRAY
	Day 249: 6 Sept. 71			Day 256: 13 Sept. 71			Day 263: 20 Sept. 71			
	Start Time (GMT)	Stop Time (GMT)	Input Ampl. μm P-P	Start Time (GMT)	Stop Time (GMT)	Input Ampl. μm P-P	Start Time (GMT)	Stop Time (GMT)	Input Ampl. μm P-P	
AO	1739:10	1742:10	20.3	1819:29	1822:29	20.5	1729:46	1732:46	20.5	AO
C1	"	"	20.6	"	"	20.5	"	"	20.4	C1
C2	1747:10	1750:10	268	1827:29	1830:29	267	1737:46	1740:46	267	C2
C3	"	"	20.4	"	"	20.4	"	"	20.3	C3
C4	1755:10	1758:10	20.4	1835:29	1838:29	20.4	1745:46	1748:46	21.1	C4
D1	"	"	20.4	"	"	20.6	"	"	20.5	D1
D2	1803:10	1806:10	20.7	1843:29	1846:29	20.6	1753:47	1756:47	20.6	D2
D3	"	"	21.2	"	"	20.9	"	"	21.0	D3
D4	1811:10	1814:10	21.1	1851:29	1854:29	21.0	1801:47	1804:47	21.0	D4
E1	"	"	20.3	"	"	20.3	"	"	20.2	E1
E2	1819:11	1822:11	20.0	1859:30	1902:30	20.6	1809:47	1812:47	20.0	E2
E3	"	"	20.5	"	"	20.6	"	"	20.4	E3
E4	1827:11	1830:11	20.7	1907:30	1910:30	20.3	1817:47	1820:47	20.6	E4
F1	"	"	20.4	"	"	20.4	"	"	20.4	F1
F2	1835:11	1838:11	21.1	1915:30	1918:30	21.1	1825:47	1828:47	21.1	F2
F3	"	"	20.4	"	"	20.4	"	"	19.9	F3
F4	-	-	-	1923:30	1926:30	19.7	1833:47	1836:47	20.1	F4

TABLE XVI

LP ARRAY SINUSOIDAL CALIBRATIONS (SFPT. - NOV. 71) CONTINUED

SUBARRAY	Long-Period Array Sinusoidal Calibration Signal Times and Input Amplitude									SUBARRAY
	Day 270: 27 Sept. 71			Day 277: 4 Oct. 71			Day 284: 11 Oct. 71			
	Start Time (GMT)	Stop Time (GMT)	Input Ampl. μm P-P	Start Time (GMT)	Stop Time (GMT)	Input Ampl. μm P-P	Start Time (GMT)	Stop Time (GMT)	Input Ampl. μm P-P	
AO	1825:07	1828:07	20.6	1901:19	1904:19	20.4	1625:10	1628:10	20.6	AO
C1	"	"	20.2	"	"	20.5	"	"	20.9	C1
C2	1833:07	1836:07	262	1909:19	1912:19	265	1633:10	1636:10	262	C2
C3	"	"	20.3	"	"	20.3	"	"	20.3	C3
C4	1841:07	1844:07	20.6	1917:20	1920:20	21.3	1641:10	1644:10	20.4	C4
D1	"	"	20.7	"	"	20.4	"	"	20.7	D1
D2	1849:07	1852:07	20.7	1925:20	1928:20	20.6	1649:11	1652:11	20.7	D2
D3	"	"	21.2	"	"	20.9	"	"	20.7	D3
D4	1857:07	1900:07	21.0	1933:20	1936:20	21.0	1657:11	1700:11	21.0	D4
E1	"	"	20.2	"	"	20.1	"	"	20.1	E1
E2	1905:07	1908:07	20.3	1941:20	1944:20	20.5	1705:11	1708:11	19.9	E2
E3	"	"	20.0	"	"	20.8	"	"	20.6	E3
E4	1913:07	1916:08	20.5	1949:20	1952:20	19.8	1713:11	1716:11	20.1	E4
F1	"	"	20.4	"	"	20.4	"	"	20.4	F1
F2	1921:08	1924:08	21.2	-	-	-	-	-	-	F2
F3	"	"	20.5	1957:20	2000:20	19.8	1721:11	1724:11	20.5	F3
F4	1929:08	1932:08	19.8	2005.20	2008:20	19.8	1729:11	1732:11	20.0	F4

TABLE XVI

LP ARRAY SINUSOIDAL CALIBRATIONS (SEPT. - NOV. 71) CONTINUED

SUBARRAY	Long-Period Array Sinusoidal Calibration Signal Times and Input Amplitude									SUBARRAY
	Day 291: 18 Oct. 71			Day 299: 26 Oct. 71			Day 305: 1 Nov. 71			
	Start Time (GMT)	Stop Time (GMT)	Input Ampl. μm P-P	Start Time (GMT)	Stop Time (GMT)	Input Ampl. μm P-P	Start Time (GMT)	Stop Time (GMT)	Input Ampl. μm P-P	
AO	2142:25	2145:25	20.7	1711:12	1714:12	20.3	1638:57	1641:57	20.3	AO
C1	"	"	21.2	"	"	20.4	"	"	20.2	C1
C2	2150:25	2153:25	264	1719:12	1722:12	270	1646:58	1649:58	266	C2
C3	"	"	20.3	"	"	20.3	"	"	20.3	C3
C4	2158:25	2201:25	20.8	1727:13	1730:13	21.3	1654:58	1657:58	21.1	C4
D1	"	"	20.3	"	"	20.9	"	"	20.3	D1
D2	2206:25	2209:25	20.7	1735:13	1738:13	20.6	1702:58	1705:58	20.7	D2
D3	"	"	21.2	"	"	21.3	"	"	21.2	D3
D4	2214:25	2217:25	21.1	1743:13	1746:13	21.0	1710:58	1713:58	21.0	D4
E1	"	"	20.1	"	"	19.3	"	"	20.0	E1
E2	2222:25	2225:25	20.2	1751:13	1754:13	20.9	1718:58	1721:58	19.9	E2
E3	"	"	20.9	"	"	20.6	"	"	20.1	E3
E4	2230:26	2233:26	19.7	1759:13	1802:13	20.2	1726:58	1729:58	20.2	E4
F1	-	-	-	"	"	20.4	"	"	20.4	F1
F2	2238:26	2241:26	21.0	1807:13	1810:13	21.1	1734:58	1737:58	21.1	F2
F3	"	"	20.3	"	"	20.3	"	"	20.5	F3
F4	2246:26	2249:26	19.7	1815:13	1818:13	20.1	1742:59	1745:59	20.3	F4

TABLE XVI

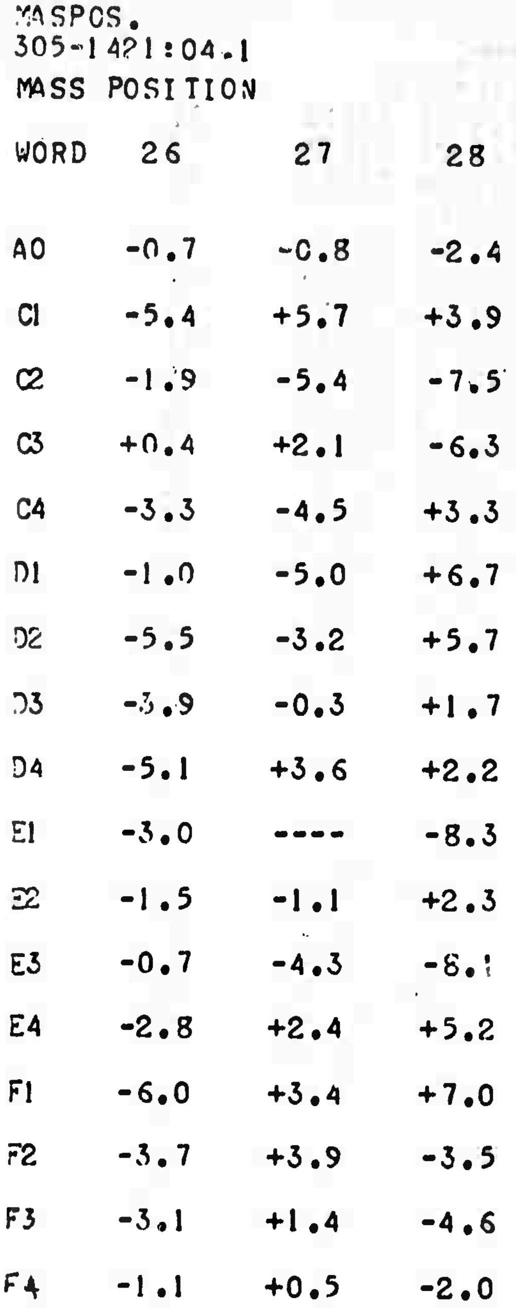
LP ARRAY SINUSOIDAL CALIBRATIONS (SEPT. - NOV. 71) CONTINUED

SUBARRAY	Long-Period Array Sinusoidal Calibration Signal Times and Input Amplitude						SUBARRAY
	Day 312: 8 Nov. 71			Day 319: 15 Nov. 71			
	Start Time (GMT)	Stop Time (GMT)	Input Ampl. µm P-P	Start Time (GMT)	Stop Time (GMT)	Input Ampl. µm P-P	
AO	1709:27	1712:27	20.4	1602:22	1609:22	20.5	AO
C1	"	"	20.0	"	"	20.3	C1
C2	1717:27	1720:27	267	1614:22	1617:22	269	C2
C3	"	"	20.3	"	"	20.2	C3
C4	1725:27	1728:27	20.8	1622:22	1625:22	20.5	C4
D1	"	"	20.3	"	"	20.3	D1
D2	1733:27	1736:27	20.7	1630:22	1633:22	20.7	D2
D3	"	"	20.5	"	"	20.5	D3
D4	1741:28	1744:28	21.0	1638:22	1641:22	21.0	D4
E1	"	"	20.0	"	"	20.0	E1
E2	1749:28	1752:28	20.5	1646:22	1649:22	20.6	E2
E3	"	"	20.6	"	"	20.0	E3
E4	1757:28	1800:28	20.3	1654:22	1657:22	19.9	E4
F1	"	"	20.4	"	"	20.4	F1
F2	1805:28	1808:28	21.1	1702:23	1705:23	21.1	F2
F3	"	"	20.2	"	"	20.4	F3
F4	1813:28	1916:28	20.1	1710:23	1713:23	19.7	F4

TABLE XVI

LP ARRAY SINUSOIDAL CALIBRATIONS (SEPT. - NOV. 71) CONCLUDED

SUBARRAY	Long-Period Array Sinusoidal Calibration Signal Times and Input Amplitude						SUBARRAY
	Day 326: 22 Nov. 71			Day 333: 29 Nov. 71			
	Start Time (GMT)	Stop Time (GMT)	Input Ampl. μm P-P	Start Time (GMT)	Stop Time (GMT)	Input Ampl. μm P-P	
AO	1618:17	1621:17	20.5	1623:04	1626:04	20.3	AO
C1	"	"	20.0	"	"	21.1	C1
C2	1626:17	1629:17	263	1631:04	1634:04	267	C2
C3	"	"	20.3	"	"	20.2	C3
C4	1634:17	1637:17	21.1	1639:04	1642:04	20.5	C4
D1	"	"	20.4	"	"	20.9	D1
D2	1642:17	1645:17	20.7	1647:04	1650:04	20.7	D2
D3	"	"	21.2	"	"	20.9	D3
D4	1650:18	1653:18	21.0	1655:04	1658:04	21.0	D4
E1	"	"	20.0	"	"	20.0	E1
E2	1658:18	1701:18	20.8	1703:04	1706:04	20.5	E2
E3	"	"	20.4	"	"	20.6	E3
E4	1706:18	1709:18	20.1	1711:04	1714:05	20.3	E4
F1	"	"	20.5	"	"	20.4	F1
F2	1714:18	1717:18	21.0	1719:05	1722:05	21.1	F2
F3	"	"	19.9	"	"	20.4	F3
F4	1722:18	1725:18	19.6	1727:05	1730:05	19.4	F4



```
MASPOS.
305-1421:04.1
MASS POSITION

WORD   26      27      28

A0     -0.7    -0.8    -2.4

C1     -5.4    +5.7    +3.9

C2     -1.9    -5.4    -7.5

C3     +0.4    +2.1    -6.3

C4     -3.3    -4.5    +3.3

D1     -1.0    -5.0    +6.7

D2     -5.5    -3.2    +5.7

D3     -3.9    -0.3    +1.7

D4     -5.1    +3.6    +2.2

E1     -3.0    ----    -8.3

E2     -1.5    -1.1    +2.3

E3     -0.7    -4.3    -8.1

E4     -2.8    +2.4    +5.2

F1     -6.0    +3.4    +7.0

F2     -3.7    +3.9    -3.5

F3     -3.1    +1.4    -4.6

F4     -1.1    +0.5    -2.0
```

Figure 3.6 Example of LP Seismometer Mass Positions Prior to Remote Adjustment

```
CORRECTMP.
305-1424:43.6
1424:43.4 C1  TELEM       31
1425:18.6 C1  TELEM        0
1425:18.7 D2  TELEM       31
1425:55.9 E3
1425:53.9 D2  TELEM        0
1425:53.9 D4  TELEM       31
1426:11.6 D4  TELEM        0
1426:11.7 F1  TELEM       31
1426:47.0 F1  TELEM        0
1426:47.0 C1  TELEM       32
1427:22.3 C1  TELEM        0
1427:22.3 C2  TELEM       32
1428:33.3 C2  TELEM        0
1428:33.3 D1  TELEM       32
1429:08.5 D1  TELEM        0
1429:08.5 E1  TELEM       48
1429:12.0 E1  TELEM       32
1429:27.0 E1  TELEM       48
1429:30.4 E1  TELEM       32
1429:36.3 E1
1430:57.0 E1  TELEM        0
1430:57.0 C2  TELEM       33
1432:25.7 C2  TELEM        0
1432:25.7 C3  TELEM       33
1434:29.7 C3  TELEM        0
1434:29.8 D1  TELEM       33
1434:47.7 D1  TELEM        0
1434:47.7 D2  TELEM       33
1435:23.1 D2  TELEM        0
1435:23.1 E1  TELEM       33
1435:58.8 E1  TELEM        0
1435:58.9 E3  TELEM       33
1437:28.1 E3  TELEM        0
1437:28.1 E4  TELEM       33
1438:03.4 E4  TELEM        0
1438:03.4 F1  TELEM       33
```

Figure 3.7 Example of PDP-7 Monitor Program Print-Out During LP Seismometer Mass Position Remote Adjustment.

the east-west horizontals. The amount of correction applied depends upon the length of time, T, in seconds in which the telemetry is sent to a particular subarray. This time is determined from: T = 0.125 N, where N is the number of divisions the mass is displaced from center. The program will make an adjustment until the mass positions measure ± 2 divisions or ± 0.56 mm from center. Since the monitor program which prepares the print-out shown in Figure 3.7 does not output telemetry changes with a duration less than 3.5 seconds, the mass positioning control telemetry is not indicated except for the E1 seismometer whose mass was at the stop. Two attempts were necessary at times 1429:08.5 and 1429:27.0 to return this mass to within tolerance. The program will attempt to adjust a seismometer up to seven times if necessary before sequencing to the next subarray. The telemetry necessary for mass position measurements, viz, TC-31, -32, and -33, following the adjustments are printed out since these commands are inserted for more than 3.5 seconds.

Finally in Figure 3.8 is shown the report which is printed automatically following the mass position adjustment. Note that the E1 north-south horizontal seismometer mass was repositioned to + 1.7 divisions or + 0.48 mm from center.

3.4.3 Communications

An important part of the array operation is the interface between the array and data center provided by the communications systems. (These systems are described in some detail in Appendix B.) The operations emphasis is placed on determining data interruptions due to telephone circuit outages. Reporting of this communications operation has improved by the establishing of weekly meetings with telephone company viz., Mountain Bell and Mid Rivers, personnel to review all outages. All outages reported by data center personnel are assigned a ticket number to aid in accounting for and identifying of the outages. Table XVII has been prepared to show the extended LASA data interruptions resulting from both communication and power outages.

Two major causes of extended communication circuit outage have been inverter failures at the Angela microwave station and "high-low" frequency filter failures. To prevent the inverter failures, the Mid-Rivers Telephone Cooperative has installed an automatic switch for connecting to raw AC in the event of a failure in their battery system. Previous to June 1971, when the switch was installed a manual connection was necessary. Since then, no failures of this type have occurred.

The "high-low" frequency filter, which separates the voice and subarray data signals, is installed on the end pole of the open wire line to the subarray CTH. Although protected by gas discharge tubes, this filter appears to be failing due to nearby lightning strikes. These filters have been used in the array since 1965 without the noticable failure rate that occurred this year. For this

MASS POSITION

WORD	26	27	28
A0	-0.7	-0.8	-2.4
C1	-0.7	+1.6	+3.9
C2	-1.9	-1.5	-1.7
C3	+0.4	+2.1	-3.0
C4	-3.3	-4.5	+3.3
D1	-1.0	-1.3	+1.9
D2	-0.6	-3.2	+1.2
D3	-3.9	-0.3	+1.7
D4	-1.0	+3.6	+2.2
E1	-3.0	+1.7	-1.9
E2	-1.5	-1.1	+2.3
E3	-0.7	-4.3	-1.2
E4	-2.8	+2.4	+1.1
F1	-0.5	+3.4	+1.3
F2	-3.7	+3.9	-3.5
F3	-3.1	+1.4	-4.6
F4	-1.1	+0.5	-2.0

Figure 3.8 Example of LP Seismometer Mass Positions After Remote Adjustment.

TABLE XVII

EXTENDED ARRAY DATA INTERRUPTIONS DUE TO COMMUNICATIONS AND POWER SYSTEMS OUTAGES

December 1970 - November 1971

1971 DATE	DURATION	SITE/CIRCUIT	REASON FOR OUTAGE
14 Feb.	15:01	F3 (2702)	Flood washed down pole line
21 Feb.	15:17	C2 (2709)	Hi-lo frequency noise on Mtn. Bell line
21 Feb.	13:35	B2 (2701)	No transmit entrance link at Forsyth central office
24 Apr.	3:25	Angela MW Sites	Angela MW inverter failure
21 May	3:50	Angela MW Sites	Angela MW inverter failure
30 May	:39	All sites except E3,F1,F3	Open wire line between Miles City and Hathaway affected radio link
9 June	14:05	D3 (2712)	Hi-lo frequency filter damaged by lightning
12 June	25:07	E2 (2720)	Open wire line, repair delayed due to bad weather
15 June	1:21	Angela MW Sites	Angela MW inverter failure
17 June	15:45	F3 (2702)	Hi-lo frequency filter inoperative
19 June	13:00	E4 (2717)	Hi-lo frequency filter inoperative

TABLE XVII

EXTENDED ARRAY DATA INTERRUPTIONS DUE TO COMMUNICATIONS AND POWER SYSTEMS OUTAGES (CONCLUDED)

December 1970 - November 1971

1971 DATE	DURATION	SITE/CIRCUIT	REASON FOR OUTAGE
19 June	12:50	AO (2704)	Hi-lo frequency filter inoperative
24 June	15:25	F4 (2703)	Hi-lo frequency filter inoperative
3 July	20:48	D3 (2712)	Lightning knocked down two Telco poles
30 July	11:15	F1 (2719)	Farm equipment knocked down line
9 Aug.	14:40	AO (2704)	Amplifier in TELCO MODEM
16 Aug.	17:36	AO (2704)	Amplifier in TELCO MODEM
10 Sept	12:47	F1 (2719)	Storm knocked down five poles
2 Oct.	318:31	F2 (2721)	Snow storm brought down 150 power poles
19 Oct.	11:34	F2 (2721)	No commercial power
26 Nov.	11:37	E3 (2716)	Open wire, Range TELCO equipment

reason, Mid Rivers has installed a new type of filter. The success of the new filters will not be known until after the spring lightning season next year.

The distribution of the 557 communications circuit outages reported during this contract year are shown in Figure 3.9 where the length of outages is classified into ten different intervals. Almost half, or 43.8%, of the outages last from ten minutes to one hour; this time interval usually covers the brief storm periods which pass through the array causing "wire slap" on the open lines. Approximately 20% exceeded the two hour outage time which results in a rebate in the circuit cost and usually requires a field trip by TELCO personnel and only 2.9% of the outages were in excess of ten hours. Not shown in the distribution are the numerous outages which last for only a few seconds and consequently "come clear" before any action can be taken.

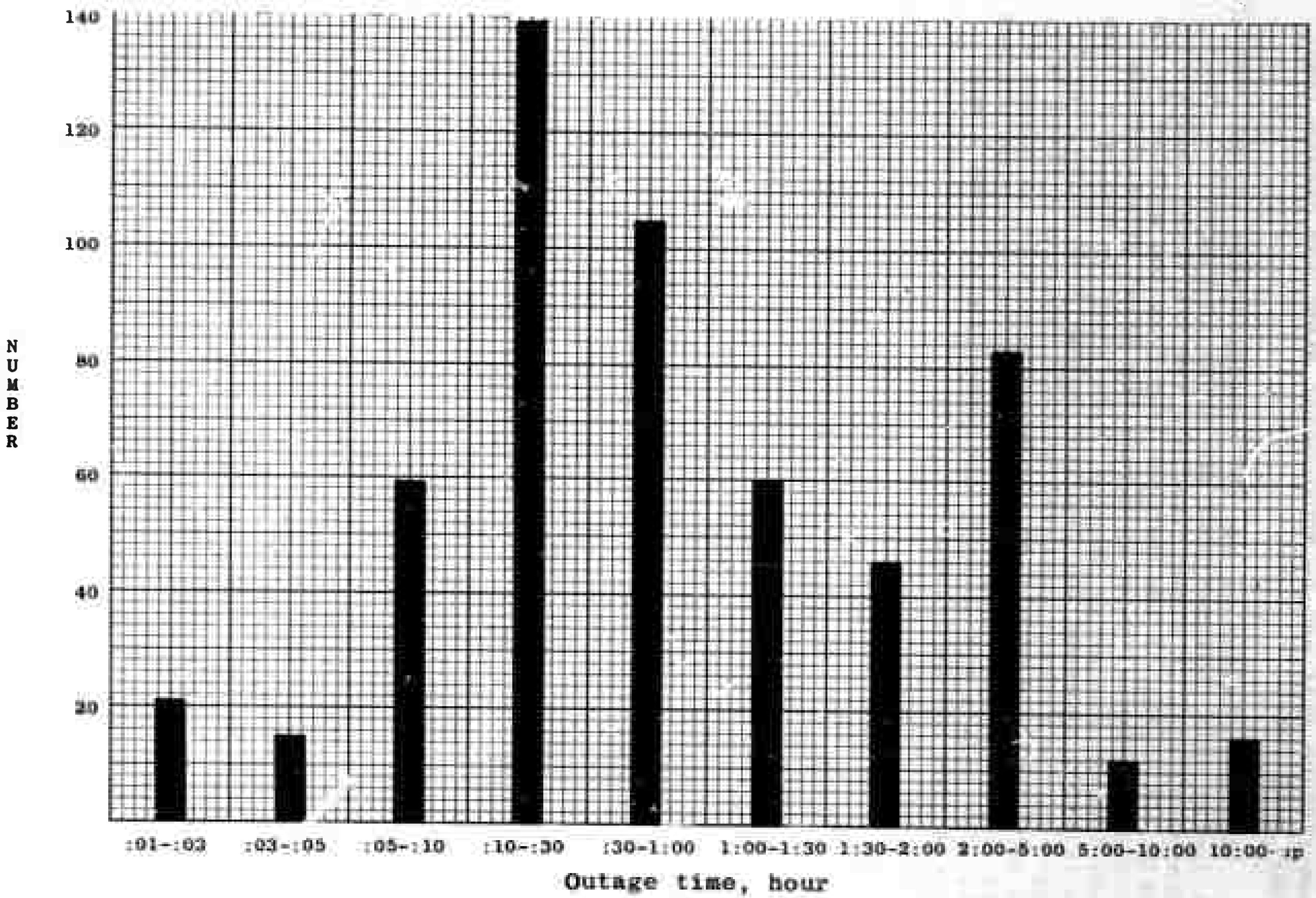


Figure 3.9 Distribution of Communication Circuit Outages

SECTION IV

ARRAY PERFORMANCE

4.1 Philosophy

Array performance measurement is the process of quantitatively describing the operating characteristics of a LASA sensing and instrumentation system; five systems are identified, viz. SP seismograph, LP seismograph, ESYS microbarograph, LTV-6 microbarograph, and meteorological sensing. The steps in this measurement process are:

(1) Data Acquisition. In this step the raw data about the systems performance is obtained. The systems have been instrumented so that access to necessary information can be obtained simultaneously with minimum disturbance of the system's operation. Instrumentation provided includes the remote telemetry controls and calibration signals. Use of these results in some interruption of seismic data; however, since the beginning of array operation, interruptions have been made for maintenance purposes. Further, the use of the computer in obtaining performance data has reduced the length of these seismic data interruptions. In addition, data acquisition is augmented by on-site field tests and LMC equipment tests. Array performance data acquisition simply uses this data collected.

(2) Measurement. For this step the data to be collected is defined. An analysis is made to determine when data is to be recorded and precisely, as possible, what information the data represents. Control and/or understanding of the system environment is necessary to realize significance of the collected data.

(3) Measures. The quantitative interpretation made from the collected data are the measures of performance. Some measures are defined as a result of interest in a specific problem area, e.g. RA-5 amplifier stability, others from theoretical considerations. Statistical analysis of the measurements also produce information useful in further system development.

(4) Performance Criteria. Performance criteria are established for the measures to provide operational significance. Relating the array performance criteria to the desired operational requirements provides the basis for the array system improvement activities in progress at the Montana LASA facilities.

4.2 Systems

One measure of the overall performance of each of the systems is the array data availability. This performance measure is based on the periods the array systems were on-line and is determined by combining the total subarray data interruption times of Table IX with the total sensor outage times reported on the Defective Signal Channel Status Reports. Disregarding the slight errors caused by outages overlapping into both the subarray and sensor times, the percentage data availabilities for this contract period are given in Table XVIII. Telephone circuit and power outages which affect all subarray systems are not included in the percentages shown in the table. For the contract period the listed data availabilities were further reduced by 0.45% for telco outages and 0.18% for power outages. It should be noted that this power outage percentage results from one extended outage at subarray F2 (see Table XVII) and did not affect the entire array.

The performance measured for each of the array systems is reported in the following paragraphs.

4.2.1 SP Seismograph

The LASA SP array is composed of 345 SP seismometer locations. These locations have been standardized with a few exceptions. The standard LASA SP seismograph system consists of (1) an HS-10-1/A seismometer installed in either 200 ft. steel cased holes along the subarray radial legs or 500 ft. steel case holes at the subarray central, (2) an RA-5 low noise parametric amplifier installed in a well head vault (WHV) for amplifying the damped seismometer output, (3) PE-23 cable buried over distances varying up to 3.5 km (except at one subarray where the distances vary up to 10 km) for transmission of the signals to the central terminal housing (CTH), (4) a near unity-gain amplifier, which converts the high-level signal from a balanced to an unbalanced, single-ended signal for ease in handling during further processing, (5) a low-pass filter, which is flat to 5 hertz and then cuts off at a rate providing 30 db attenuated at 10 hertz, performs filtering for prevention of signal aliasing during later sampling at a 20 samples/sec rate, (6) a multiplexer merges all the SP seismograph signals from a particular subarray into one data stream, and (7) an analog-to-digital converter and a buffer storage shift register prepare the digital data for transmission from the subarray CTH to the LDC.

Two additional seismograph signals are available, viz. an analog summation of selected SP seismometers within a subarray and an attenuated signal from the center hole of each subarray except E3. (At subarray D2 the attenuated signal is generated at hole location 26 instead of 10.) The exceptions to the standard sensor are indicated in the array Status Report (Appendix C) and described here briefly. At subarray D1 six of the seismometers are in uncased holes, one in a plastic-cased hole and six in near-surface installations at a depth of 10 feet. And at subarray D2, the 500 ft. center hole contains a tri-axial seismometer, two locations (holes 23 and 62) contain an improved sensor package (Ref. 3) composed of an HS-10-1/B seismometer and Ithaco amplifier in a stainless steel case, and one location (hole 46) has an experimental sensor consisting of an HS-10-1/A seismometer and an RA-5 amplifier in a common case. Also, the WHV electronics differ at subarrays B1, F3, and E3.

TABLE XVIII

ARRAY SYSTEMS DATA AVAILABILITIES

SYSTEM	DATA AVAILABILITIES IN PERCENTAGE				CONTRACT AVERAGE
	1ST QUARTER	2ND QUARTER	3RD QUARTER	4TH QUARTER	
SP	95.5	96.7	97.4	97.0	96.65
LP	98.4	99.3	98.4	98.1	98.55
μbaro	97.9	97.9	95.5	98.2	97.38
MET	99.5	99.3	98.3	99.8	99.23

The performance monitoring of the 345 individual short-period seismographs during this twelve month period has indicated an average channel sensitivity of 20.36 mV/nm at 1s with a standard deviation of 1.69. A summary of the test results obtained each week of the final quarterly period together with the averages from the three preceeding quarters is shown in Table XIX. The mean and standard deviation of the channel calibration output and the sensitivities as determined from the 1.0 hertz sinusoidal equivalent earth motion input are shown, together with minimum and maximum channel sensitivities of the indicated total number of sensors, for each period. When a channel output is very low during a calibration test indicating a severely malfunctioning channel, it is not used in the calculation of the mean; hence the total number of sensors is somewhat less than 345.

An improvement in the SP channel performance permitted an approximate 40% tightening of the tolerance limits on 1 September. The mid-scale sensitivity at one second periods is now maintained at 20 ± 3 mV/nm.

Plotted in Figure 4.1 are the percentages of SP array sensors within the 20 ± 3 mV/nm sensitivity tolerance throughout the 20 month period 30 March 1970 through 31 November 1971. The cyclic variation displayed is related to the seasonal temperature changes and the RA-5 amplifier rehabilitation efforts began during this period. The best sensor gain stability occurs during stable temperature periods. This measure of channel performance is based on the relation

$$S = \frac{4\pi^2 MA}{G_C i T^2} \qquad (4\text{-}1)$$

where S is the channel sensitivity, V/m,
M is the seismometer moving mass in Kg,
A is the signal amplitude of the channel output in V,
G_C is the motor constant of the seismometers calibration coil in N/A,
i is the amplitude of the calibration coil current in A
T is the period of the calibration signal in s

The sensitivity determination is based on a measurement of A, i, t; the values for G_C and M are assumed to be at their nominal values, viz. 0.0326 N/A and 0.833 Kg respectively. (The confidence associated with this assumption is discussed somewhat in paragraph 4.3.1) The improved sensitivity resulted directly from an improved sinusoidal signal amplitude response, A, which is now allowed to vary between 6.72 and 9.09 volts p-p instead of 6.4 to 11.0 volts p-p during telemetry calibrations.

The measurement of the SP channel frequency responses continued throughout the contract period; response data were collected from 65 sensors at four subarrays during the fourth quarterly period. Shown in Figure 4.2 are the plots of the mean, the minimum, and the maximum responses of the sensors of the entire SP array

TABLE XIX

SP ARRAY PERFORMANCE TESTING SENSITIVITY STATISTICS

DATE	NO. SENSORS	SENS. MEAN mV/nm	SENS. σ mV/nm	SENS. MAX. mV/nm	SENS. MIN. mV/nm	SENS. DEV. mV/nm
9/6	329	20.22	1.41	24.75	13.94	10.81
9/13	346	19.79	1.48	24.05	16.12	7.93
9/20	343	20.59	1.38	24.83	14.81	10.42
9/27	347	20.39	1.27	23.62	17.32	6.30
10/4	332	20.64	1.42	23.73	16.64	7.09
10/11	331	20.55	1.30	24.62	16.92	7.70
10/18	346	20.61	1.30	23.86	16.51	7.35
10/25	347	20.66	1.35	23.75	16.25	7.50
11/1	345	20.61	1.43	23.61	16.32	11.61
11/8	347	20.56	1.35	23.67	16.73	6.94
11/15	346	20.63	1.35	23.95	16.97	6.98
11/22	345	20.54	1.27	23.07	16.92	6.15
11/29	342	20.47	1.40	24.72	13.37	11.35
AVERAGE	342.0	20.48	1.362	24.02	16.03	8.32
3RD QTR. AVERAGE	343.6	19.86	1.498	24.9	14.1	10.8
2ND QTR. AVERAGE	345.2	20.7	1.82	26.9	9.9	17.0
1ST QTR. AVERAGE	344.7	20.3	2.11	30.3	10.9	19.4
CONTRACT AVERAGE	343.9	20.36	1.694	26.5	12.7	13.8

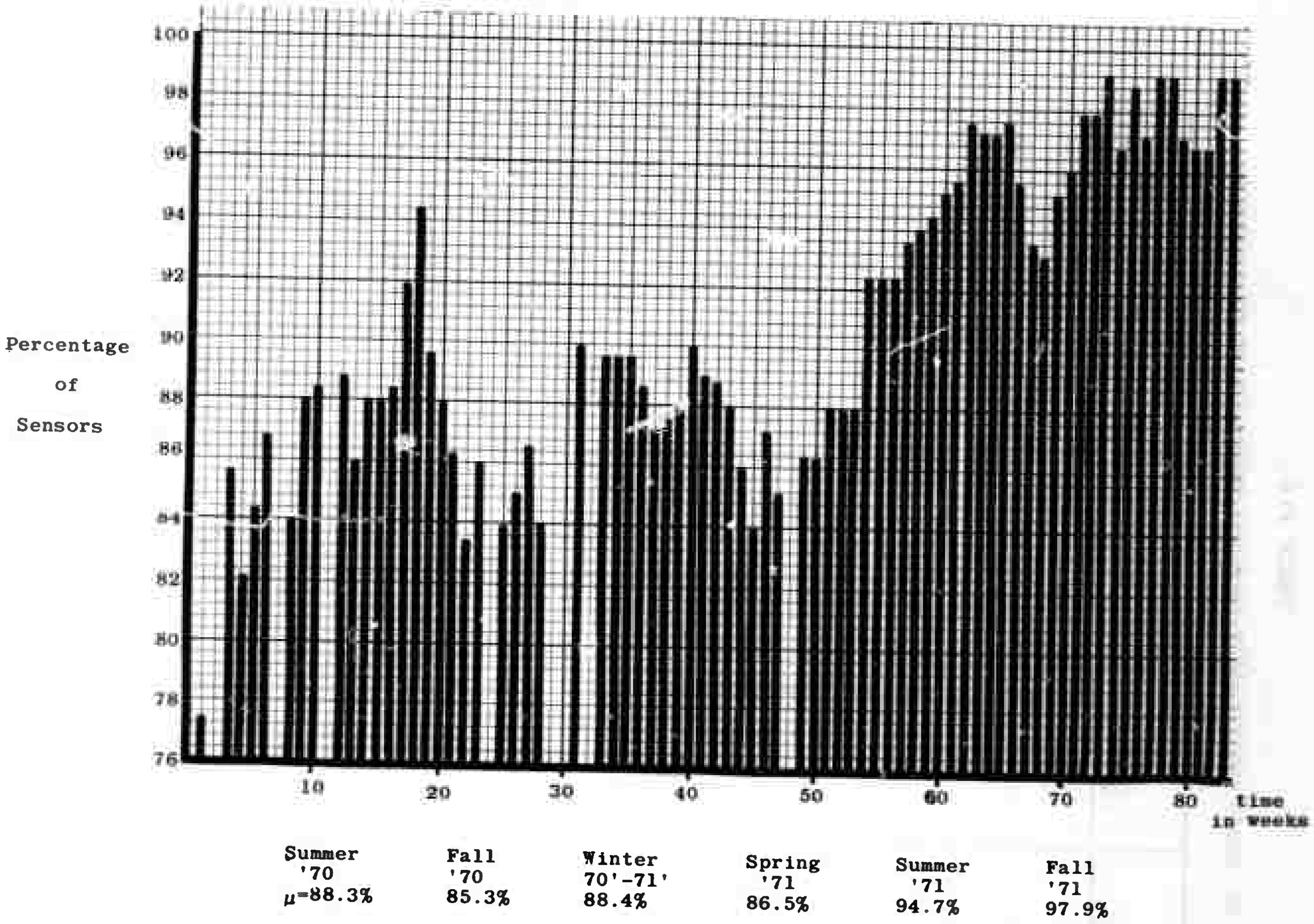


Figure 4.1 Percentage Distribution of SP Sensors in ±15% Sensitivity Tolerance

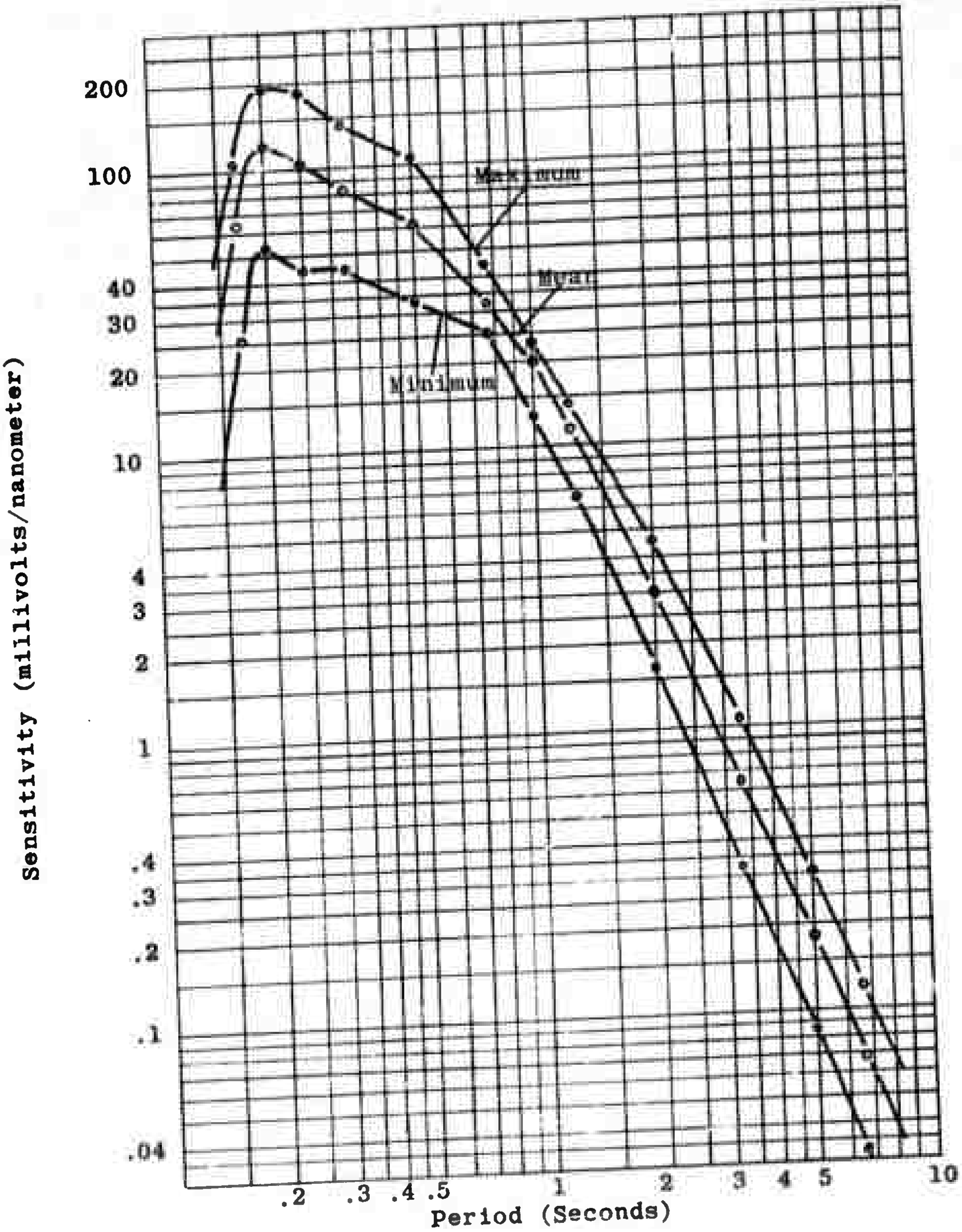


Figure 4.2 LASA SP Sensor Period vs Sensitivity Response Curves

measured during the period May 1970 through October 1971. These curves were calculated using equation (4.1). Values of A, i, T were measured and while G_C and M assumed nominal values. Individual plots have been made to display the frequency response of each SP seismograph channel and to assist maintenance quality control in determining channel malfunctions (see Table XXXVII).

4.2.2 LP Seismograph

The LASA LP array is composed of 17 sets of LP seismometers installed at the central site of each LASA subarray except those in the B-ring. Each set senses the vertical, north-south and east-west components of earth motion. The sensors at fifteen sites are adjusted for a nominal system sensitivity of 350 mV/μm at 25s. At subarray C2, where the channels have been modified to preclude saturation from strong amplitude ground motion, the system sensitivity is adjusted for approximately 11 mV/μm at 25s. The standard amplifier channel filters for the LP seismographs at subarray C1 have been replaced with broadband filters, 12 db/octave high-cut, resulting in a system sensitivity of 55 mV/μm at 25s. The response curves for all the LP seismographs are shown in Figure 1.3.

The performance monitoring of the 45 standard LASA LP long-period sensors during this one year contract period has indicated an average channel sensitivity of 356.1 mV/μm at 25s with a standard deviation of 18.8. For the fourth quarter these two statistics were 351.2 and 18.0 mV/μm respectively. A summary of the test results obtained each week of the final quarter of the contract is shown in Table XX. This table shows the mean and standard deviations of the channel sensitivities calculated from the 25s, 20μm p-p sinusoidal equivalent earth motion inputs. The range of the sensitivity deviations over the 45 standard LP seismographs in the array is shown as well as the maximum and minimum values. For comparison the averages for the quarter are shown with the average for each parameter from the preceeding periods and the total contract period.

The tolerance on the amplitude stability of the LP seismograph channels was tightened at the beginning of the fourth quarter. This change is reflected in the improvement in the channel sensitivity specification from an allowable range of 260 to 430 mV/μm to a range of 300 to 400 mV/μm at a period of 25 seconds.

Plotted in Figure 4.3 are statistics which show the percentage of the 45 standard LP array sensors within the 350 ± 50 mV/μm sensitivity tolerance throughout the twelve month period starting 8 December 1970 through 29 November 1971.

4.2.3 Microbarograph Array

The Large Aperture Microbarograph Array (LAMA) complements the Montana LASA by the placement of microbarograph signal acquisition equipment at all subarrays except E3. Comprised of two

TABLE XX

LP ARRAY PERFORMANCE TESTING SENSITIVITY STATISTICS

DATE	NO. SENSORS	SENS. MEAN mV/μm	SENS. σ mV/μm	SENS. MAX. mV/μm	SENS. MIN. mV/μm	SENS. DEV. mV/μm
9/6	42	338.9	15.1	371	308	63
9/13	45	338.5	15.8	379	308	71
9/20	45	343.8	16.4	387	312	75
9/27	45	343.8	18.6	403	311	92
10/4	42	349.3	18.1	393	309	84
10/11	42	348.7	18.6	394	317	77
10/18	41	348.9	19.8	396	278	118
10/25	45	355.4	15.7	393	322	71
11/1	45	358.1	17.9	404	314	90
11/8	45	359.0	21.0	410	289	121
11/15	45	359.3	19.7	404	295	109
11/22	45	360.1	20.8	421	331	90
11/29	45	362.3	17.0	410	335	75
AVERAGE	44.0	351.2	18.0	397	310	87
3RD QTR. AVERAGE	44.5	341.6	18.5	387	304	81
2ND QTR. AVERAGE	44.9	364.3	17.3	408	325	82
1ST QTR. AVERAGE	45.0	368.5	22.0	420	306	114
CONTRACT AVERAGE	44.6	356.1	18.8	403	312	90

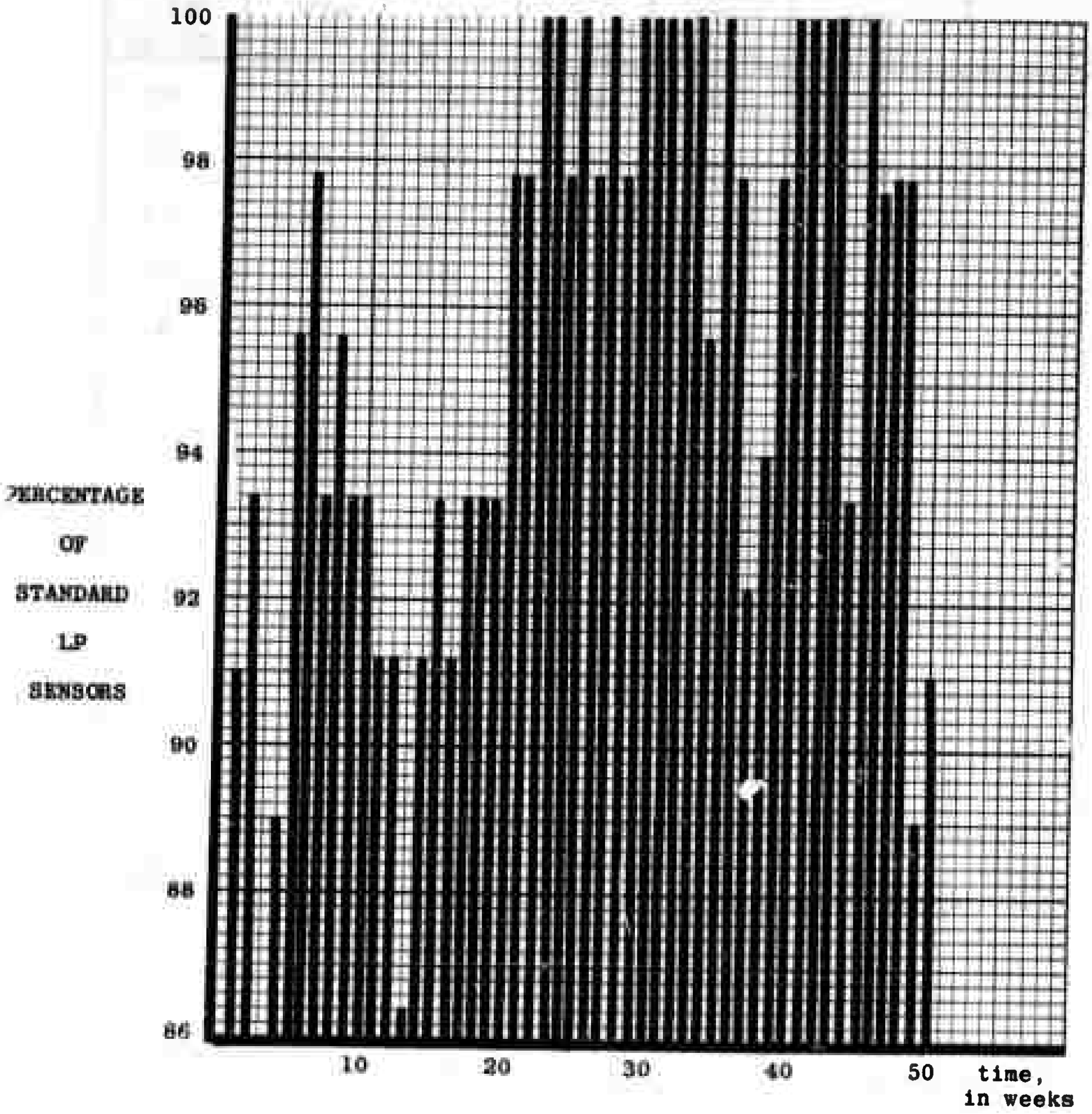


Figure 4.3

Percentage Distribution of LP Sensors within ±50mv/μm Sensitivity Tolerance different types of sensors installed at the locations shown in Figure 4.4, the array provides signal detection over the range of frequency responses plotted in Figure 4.5. The microbarographs with responses labeled C are from the NOAA Geoacoustics Laboratory and installed at the B,C, and D ring subarrays and AO. They operate on a capacitor microphone principle whereby the deflected diaphragm results in a capacitance change in the frequency determing circuit of an oscillator, thus producing a frequency modulated signal whose deviation is a measure of the pressure deflecting the diaphragm. When passed through an FM discriminator this deviation is converted to a DC voltage and is available as a balanced output. The LTV-6 microbarographs with responses shown as A on Figure 4.5 are installed at the E and F rings and AO subarrays and operate on a capacitor microphone principle whereby the deflected diaphragm results in a capacitance bridge circuit unbalance. The resulting carrier signal is demodulated, amplified and made available as a balanced direct output. The one LTV-6 microbarograph with response B in Figure 4.5 is installed at subarray AO.

The microbarograph array channel calibrations for each of the 22 microbarographs in the array are shown in Table XXI. The LTV-6 or "L" system calibrations were performed at the LMC. The instrument sensitivities which are adjustable were accurately set and checked at the LMC on the date shown and then installed in the subarray CTH. The responses are fixed; the lower response is determined by the LTV-6 acoustical network and the upper response by a 3-pole Chebyshev, presampling filter. The responses are measured using a step-function calibration technique.

Each week telemetry calibrations (TC-41) from the LDC check the amplitude response from the microbarograph's electronics section as a partial verification of the shop calibrations. This command uses a step function that simulates a 100 μbar signal in the microbarograph which has a sensitivity of 56 mV/μbar. The calibration responses are plotted over the year to determine output stability. Figure 4.6 shows the response of the LTV-6 microbarograph installed at subarray E2. The overall drift in sensitivity was 9 mV/μbar. No failures or adjustments were made to this instrument during the contract period. The poorest stability was reported from subarray AO which had a deviation in sensitivity of 28 mV/μbar due to a failure in the LTV-6 and the calibration card. All eight systems showed a tendancy to drift lower in warm weather. At this time it is not known if this is caused by calibration circuit or the microbarograph.

The ESYS or "E" system calibrations were performed with a portable sinusoidal pressure calibrator. The sinusoidal calibration signals were recorded at the LDC. The time period of the sinusoidal calibration in GMT is shown. Immediately prior to this calibration the sensor acoustical input was plugged and system noise recorded for approximately 10 minutes. The sensitivities are not adjustable and vary from system to system depending upon the characteristic differences in the acoustic networks, diaphragms, and discriminators. The responses are fixed; the lower response is determined

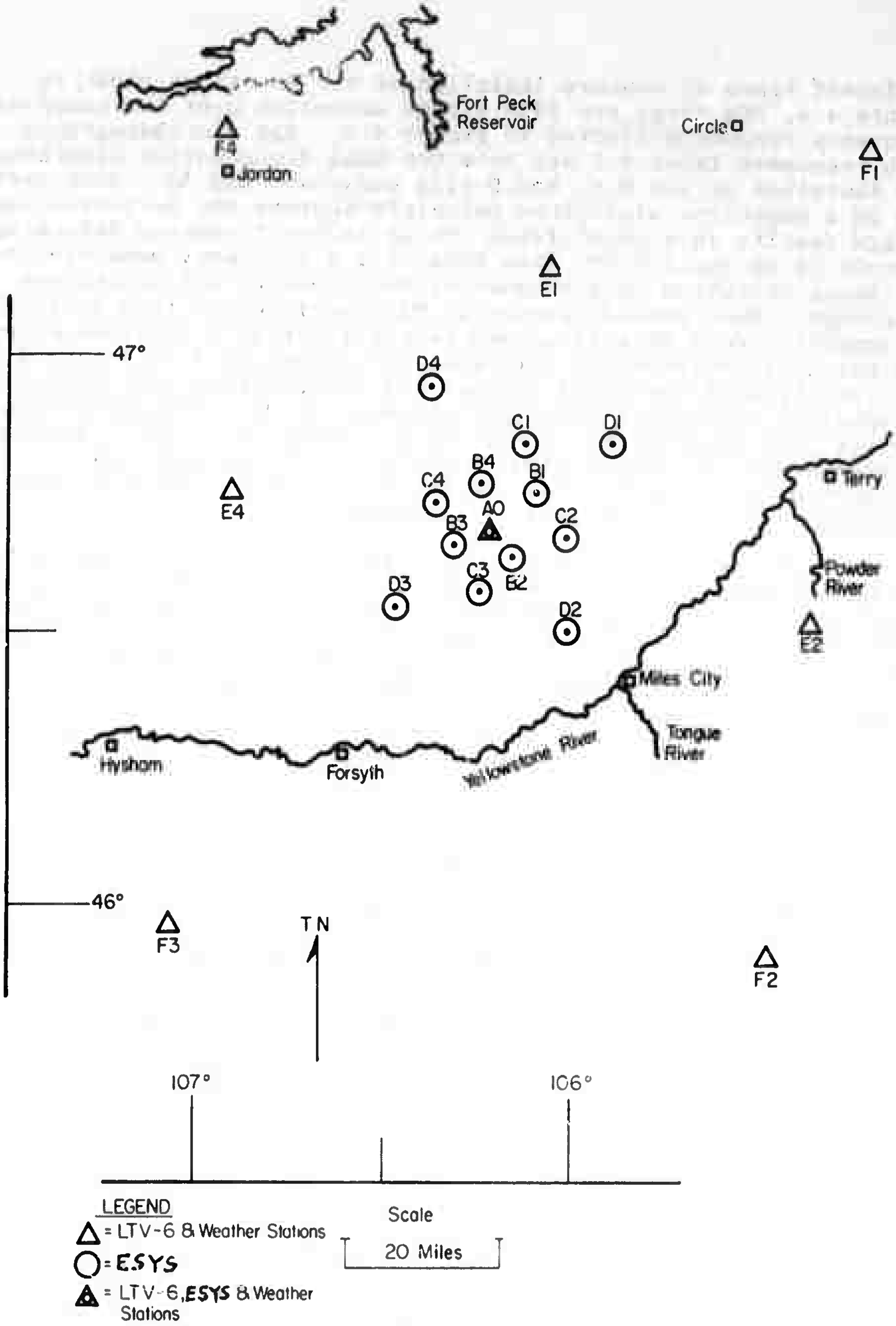


Figure 4.4 LAMA Geometry and Sensor Locations

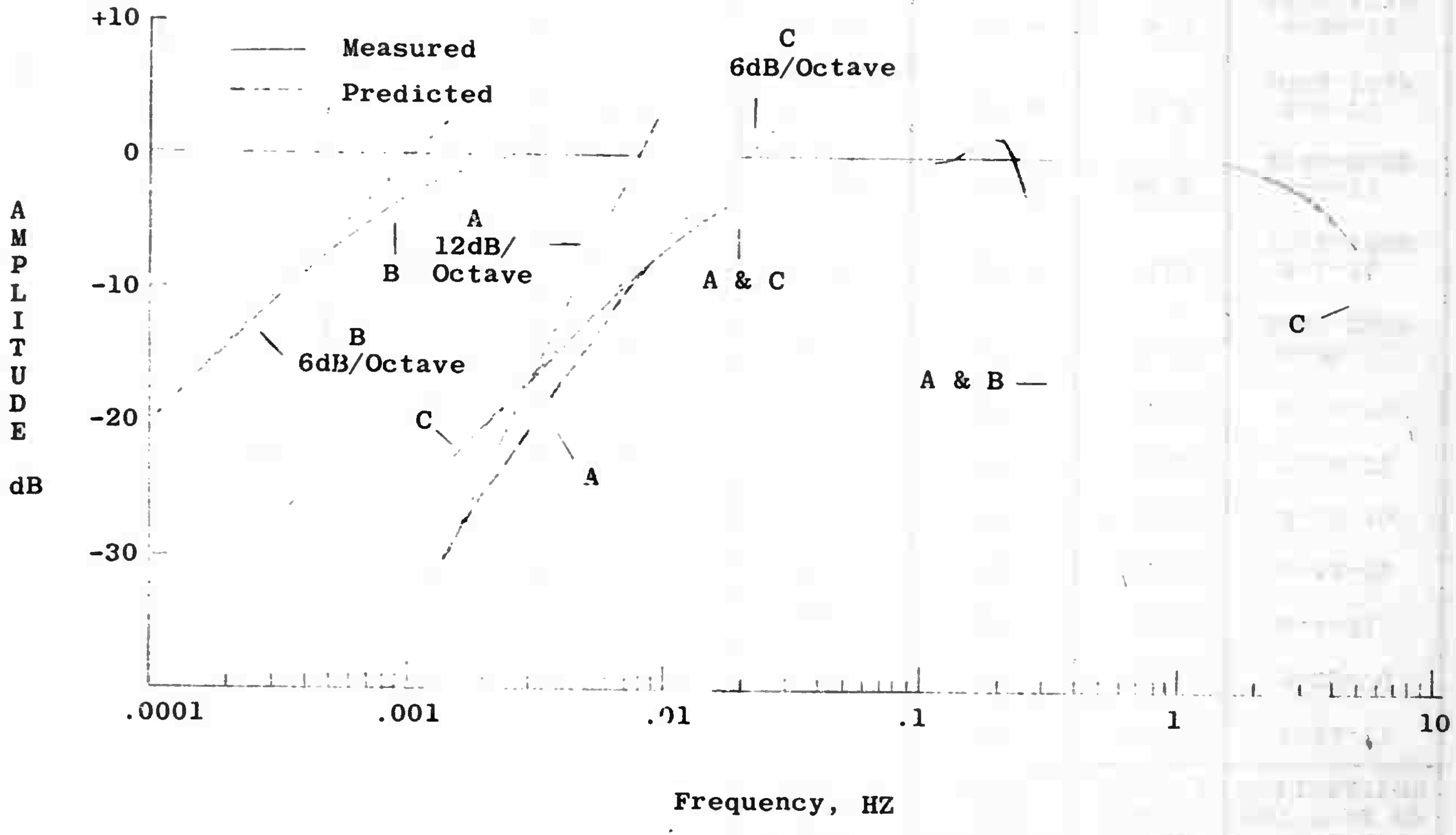


Figure 4.5 Microbarograph Frequency Response A,B, and C.

TABLE XXI

MICROBAROGRAPH ARRAY CALIBRATIONS

SITE	SYSTEM NUMBER	RESPONSE CODE	CHANNEL SENSITIVITY μv/μbar	CHANNEL FULL SCALE (μbar) p-p	UPPER RESPONSE TIME (SEC)	LOWER RESPONSE TIME (SEC)	SYSTEM NOISE LEVEL (mv) p-p	DATE AND GMT TIME OF CALIBRATION
F3	L-109	A250	56	250	4.3	67	<1.0	3-24-71
F4	L-111	A250	56	250	4.3	67	<1.0	9-29-70
AO	L-103	A250	56	250	4.3	67	<1.0	6-4-71
E4	L-101	A250	56	250	4.3	67	<1.0	4-12-71
E1	L-107	A250	56	250	4.3	67	<1.0	12-23-70
F1	L-106	A250	56	250	4.3	67	<1.0	7-12-71
E2	L-104	A250	56	250	4.3	67	<1.0	8-15-70
F2	L-105	A250	56	250	4.3	67	<1.0	4-20-71 2026-2039
B1	E-5	C125	84.7	166.3	0.29	47.6	118	4-1-71 1713-1728
AO	E-11	C125	108.9	128.6	0.29	47.6	30.6	4-2-71 2038-2052
C4	E-8	C125	124.2	112.6	0.29	47.6	17.5	4-5-71 1632-1642
B4	E-12	C125	113.4	123.3	0.29	47.6	8.8	4-29-71 1716-1739

TABLE XXI

MICROBAROGRAPH ARRAY CALIBRATIONS (CONCLUDED)

SITE	SYSTEM NUMBER	RESPONSE CODE	CHANNEL SENSITIVITY mv/μbar	CHANNEL FULL SCALE (μbar) p-p	UPPER RESPONSE TIME (SEC)	LOWER RESPONSE TIME (SEC)	SYSTEM NOISE LEVEL (mv) p-p	DATE AND GMT TIME OF CALIBRATION
C1	E-4	C125	122.5	114.3	0.29	47.6	43.8	4-26-71 1730-1742
C2	E-3	C125	140.0	100.0	0.29	47.6	26.3	4-1-71 1712-1735
B2	E-10	C125	109.0	128.2	0.29	47.6	3.5	4-22-71
C3	E-9	C125	67.3	208	0.29	47.6	12.3	4-23-71 1838-1900
D3	E-13	C125	85.7	164.5	0.29	47.6	3.5	4-15-71 1829-1849
D4	E-7	C125	73.4	190.7	0.29	47.6	280	4-1-71 1818-1840
D1	E-2	C125	124.2	112.6	0.29	49.6	30.6	4-1-71 1731-1750
D2	E-1	C125	68.0	205.8	0.29	47.6	6.1	4-2-71
AO	L-110	B1667	8.4	1667	4.3	1000	<1.0	5-15-68 2026-2044
B3	E-6	C125	84.0	166.6	0.29	47.6	8.8	4-23-71

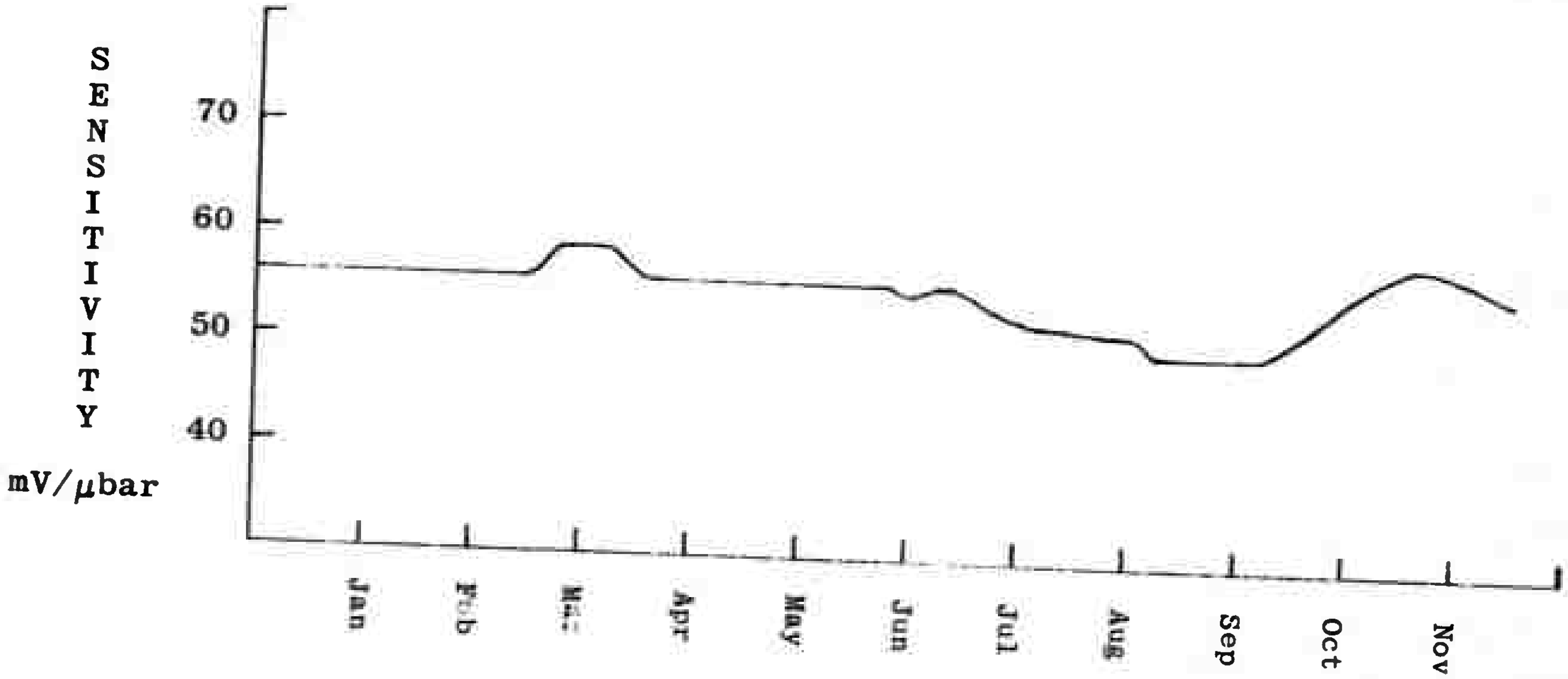


Figure 4.6 Subarray E2 LTV-6 Calibration Response

by the acoustical network and discriminator and the upper response by the standard LASA short-period, 5 second, presampling filter.

The most significant effect on the performance of the ESYS microbarograph is the instability of the output causing a channel dc offset from zero. Maintenance on the equipment is performed routinely in conjunction with other systems maintenance when the dc offsets exceed 2.0 volts. The extent of this is reflected by the number of dc offsets made, viz 13.

4.2.4 Meteorological Instrumentation

The Montana LAMA was augmented at the time of installation with several meteorological measurement systems or weather stations at the subarray locations shown in Figure 4.4. Each weather station measures wind direction, wind speed and temperature and consists of an anemometer and wind vane combined in one unit and a thermistor sensor with associated bridge circuitry. The instrumentation protected against lightning strikes is interconnected to the subarray SEM for data transmission to the LDC. In addition to the eight weather stations a tipping bucket rain gauge is installed at subarray F3 and a barometric pressure sensor at subarray AO. The data from the systems are also telemetered to the LDC. Operation of these systems is verified by the hourly weather report generated by the PDP-7 automatically during MOPS program operation (see paragraph 5.2). Calibration is performed on site using a portable test set which replaces the weather station sensors and provides selected fixed inputs covering the range of each circuit. A total of 8 such calibrations were performed during this past year.

4.3 Equipment

4.3.1 SP Seismometer, HS-10-1/A

The standard LASA seismograph utilizes the GeoSpace HS-10-1/A seismometer. This seismometer is a spring-mass device providing a velocity dependent output from a coil and magnetic transducer. A built-in calibrator consisting of a coil and magnetic circuit whereby a current through the coil produces a force which is transmitted to the seismic mass is included as a part of the seismometer.

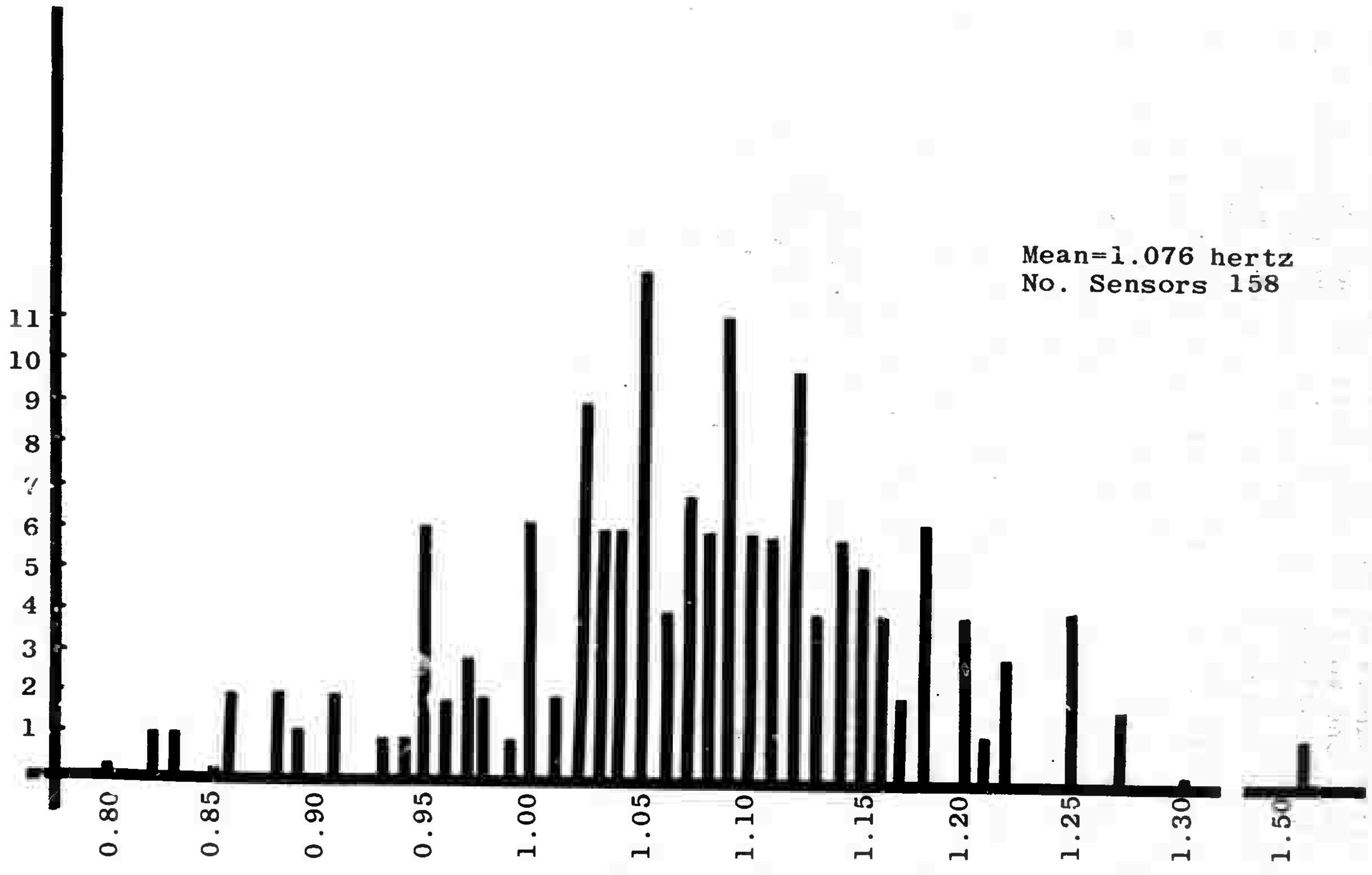
During this contract a program of natural frequency measurements was undertaken in conjunction with the array preventive maintenance. Measurements at the sensor WHV location using the phase-resonant or Lissajous pattern method is necessary because the high internal damping of the seismometer does not permit a free period impulse response that could be performed remotely. The natural frequency data collected during the fourth quarter at four subarrays are tabulated in Table XXII where the measured value can be compared with the frequency measured following the initial installation. These measurements combined with others collected from this program form the frequency distribution shown in Figure 4.7.

TABLE XXII

SP SEISMOMETER NATURAL FREQUENCY MEASUREMENTS

SEPTEMBER - NOVEMBER 1971

SENSOR SUBARRAY	CURRENT f_n HERTZ	1965 f_n HERTZ	f_n HERTZ
C2			
0110	1.20	1.20	0.00
0982	1.08	1.10	-0.02
1253	0.95	0.88	+0.07
1544	1.27	1.17	+0.17
1784	1.00	0.97	+0.03
D1			
0110	1.00	1.15	-0.15
1945	1.08	1.05	+0.03
2185	1.16	1.29	-0.13
D2			
2055	1.15	0.96	+0.19
2175	1.06	1.02	+0.04
2466	1.25	1.04	+0.21
F3			
0341	1.14	1.20	-0.06
1383	1.22	1.01	+0.21
1774	1.11	1.20	-0.09
1945	1.05	1.20	-0.15



Mean=1.076 hertz
No. Sensors 158

Seismometer Natural Frequency (hertz)

Figure 4.7 SP Seismometer Natural Frequency Distribution, 1970-71

This natural frequency (f_n) distribution of 158 seismometers indicates that approximately 59% are operating within the established tolerance of ± 10% and 18% are within the ± 3% manufacturer's specification. Considering these measurements to be a good representative sample of the 342 HS-10-1/A seismometers installed in the array, one would estimate that 140 are now outside the ± 10% limit and 280 outside the ± 3% limit. The difference in natural frequency (Δf_n) between the series of measurements and those made five years prior during the installation is indicated in the comparison made in Table XXIII. Improvement between the two sets of data was noted in 41% of the measurements, eight percent showed no change, and 51% drifted further from the 1.0 hertz nominal value. Of those seismometers with an improvement 83% showed a decrease in natural frequency and of the ones which deteriorated 93% showed an increase in natural frequency; ten sensors indicated the same natural frequency to the nearest hundredth of a cycle.

Measurements at the near-surface SP seismometers installed at subarray D1 were made in attempt to determine the affect of temperature change upon the natural frequency of these sensors. The measured natural frequencies for the six sensors at each of the three different temperatures are shown in Table XXIV. No conclusions concerning the temperature affect on the seismometer natural frequencies has been reached. These data and a related set of data collected from ten seismometers at the LMC are inconsistent and of insufficient sample size to establish the relationship between the two parameters. Design of an experiment which would include collection of more data points over the temperature range is suggested as a follow-up action in the study of this type sensor installation.

The motor constant, G_c, of the seismometer's electromagnetic calibrator is defined as the magnitude of force produced per unit current and is specified at 0.0326 N/A. Since the records do not indicate G_c values for the seismometers installed in the SP array, an estimate has been made based on G_c measurements of the HS-10-1/A seismometers removed for shipment to the Norway array in 1968. The motor constants of 77 seismometers were measured using the one-gram, weight-lift test in which the output produced by the motion of the mass in response to the removal of the one gram weight from the center of gravity of the inertial mass system is compared with the output from a 301 mA current pulse applied to the calibration coil. The motor constant is calculated from

$$G_c = \frac{X_i \; Mg}{X_w \; i} \qquad (4\text{-}2)$$

where M is the effective mass of the lifted test weight in grams,
g is the acceleration due to gravity,
i is the amplitude of the current applied in amperes,
X_i is the output due to the applied current, and
X_w is the output due to the weight removal.

TABLE XXIII

SP SEISMOMETER NATURAL FREQUENCY STATISTICS

FREQUENCY LIMIT IN HERTZ	NUMBER WITH f_n WITHIN FREQUENCY LIMIT	PERCENTAGE OF TOTAL	NUMBER WITH Δf_n WITHIN FREQUENCY LIMIT	PERCENTAGE OF TOTAL
±0.00	6	3.8	10	6.3
±0.01	9	5.7	21	13.3
±0.02	20	12.7	43	27.2
±0.03	29	18.4	57	36.1
±0.04	37	23.4	71	44.9
±0.05	55	34.8	77	48.7
±0.06	60	38.0	85	53.8
±0.07	68	43.0	97	61.4
±0.08	74	46.8	108	68.4
±0.09	87	55.1	116	73.4
±0.10	93	58.9	128	79.9
±0.11	100	63.3	131	82.9
±0.12	112	70.9	133	84.2
±0.13	116	73.4	136	86.1
±0.14	124	78.5	136	86.1
±0.15	129	81.6	141	89.2
±0.16	133	84.2	141	89.2
±0.17	136	86.1	142	89.9
±0.18	143	90.5	142	89.9
±0.19	143	90.5	143	90.5
±0.20	147	93.0	144	91.1
±0.25	155	98.1	148	93.7
±0.25	158	100.0	158	100.0

TABLE XXIV

SUBARRAY D1 NATURAL FREQUENCY MEASUREMENTS

TEMP IN °C	NATURAL FREQUENCY IN HZ.					
	D1 SITE 0852	D1 SITE 0972	D1 SITE 1654	D1 SITE 1774	D1 SITE 2065	D1 SITE 2456
-5.3°	1.00	1.04	1.05	1.17	1.30	.995
+1.9°	1.10	1.30	1.19	1.20	0	1.06
+32.8°	1.06	1.21	1.15	1.15	1.25	1.01
Δ MAX	.10	.26	.14	.03	.05	.065

Table XXV shows the variation in G_C values obtained for the 77 seismometers and the estimated variation in this parameter across the array.

4.3.2 SP Seismic Amplifier, RA-5

The Texas Instruments Model RA-5 low frequency parametric amplifier provides signal amplificiation of the HS-10-1/A SP seismometer output. Previous analysis of the SP seismograph channel stability (Ref. 4) has shown the RA-5 amplifier to be the major source of gain instability. The gain of a properly operating amplifier remains fairly constant over the range of 45° to 70° F and drops by approximately 1.3 dB at both WHV temperature extremes of 20° and 100° F (Ref. 5). This gain vs temperature characteristic of the RA-5 has now been verified by measurements on 90 amplifiers at the LMC.

Since it appears that the mean sensitivity of the array appears to follow this amplifier characteristic, the SP array amplifiers are either being adjusted or replaced with reconditioned and tested RA-5's for operation within the gain vs temperature characteristic. Approximately 50% of the array has received this maintenance action. Shown in Figure 4.8 are plots of the mean sensitivity of the array and the temperature measured at subarray AO. This figure shows that as the temperature increased from January to April the mean sensitivity also increased and from April to June when the temperature was between 45° and 70° F the sensitivity remained relatively constant. With the further increase in temperature, peaking in August, the sensitivity decreased. Then as the temperature dropped, the sensitivity started to increase until it reached the 40° to 70° F region. At the end of the contract with the temperatures still dropping the sensitivities are now starting to decline. As more amplifiers are either replaced or adjusted and as the performance is observed during future temperature changes, the certainty of this variation will become more evident.

The RA-5 tests and repairs at the LMC have produced much data for analyzing the amplifiers performance. Two areas of testing discussed here are the amplifier's maximum gain and maximum output before limiting. One of the series of tests performed is the measurement of gain with the gain control at the maximum position. With a 0.8 mV p-p sinusoidal signal input the output across a 10,000 ohm load is measured. The distribution of maximum gains for 78 amplifiers showed the following gain statistics: mean, 14,200; standard deviation, 1849; maximum, 19500; minimum, 10,125; and a significant mode, 21 of the 78, 15,000. The circuitry of the IF amplifier section requires the four 2N929 transistors (Q1-Q4) to be well matched for high amplification. This requirement explains the large spread in maximum gain, i.e., 8,375, measured from these 78 amplifiers.

The maximum output before limiting is another RA-5 parameter measured at the LMC. The input sinusoidal signal level

TABLE XXV

SP SEISMOMETER MOTOR CONSTANT MEASUREMENTS

MOTOR CONSTANT LIMIT	PERCENTAGE OF SAMPLE WITHIN LIMIT	NUMBER IN ARRAY ESTIMATED WITHIN LIMIT
.0326 N/A	48.1	165
.0326 N/A ±1%	53.3	182
.0326 N/A ±3%	72.7	249
.0326 N/A ±5%	80.5	275
.0326 N/A ±7%	84.4	289
.0326 N/A ±9%	96.1	329
.0326 N/A ±10%	100.0	342

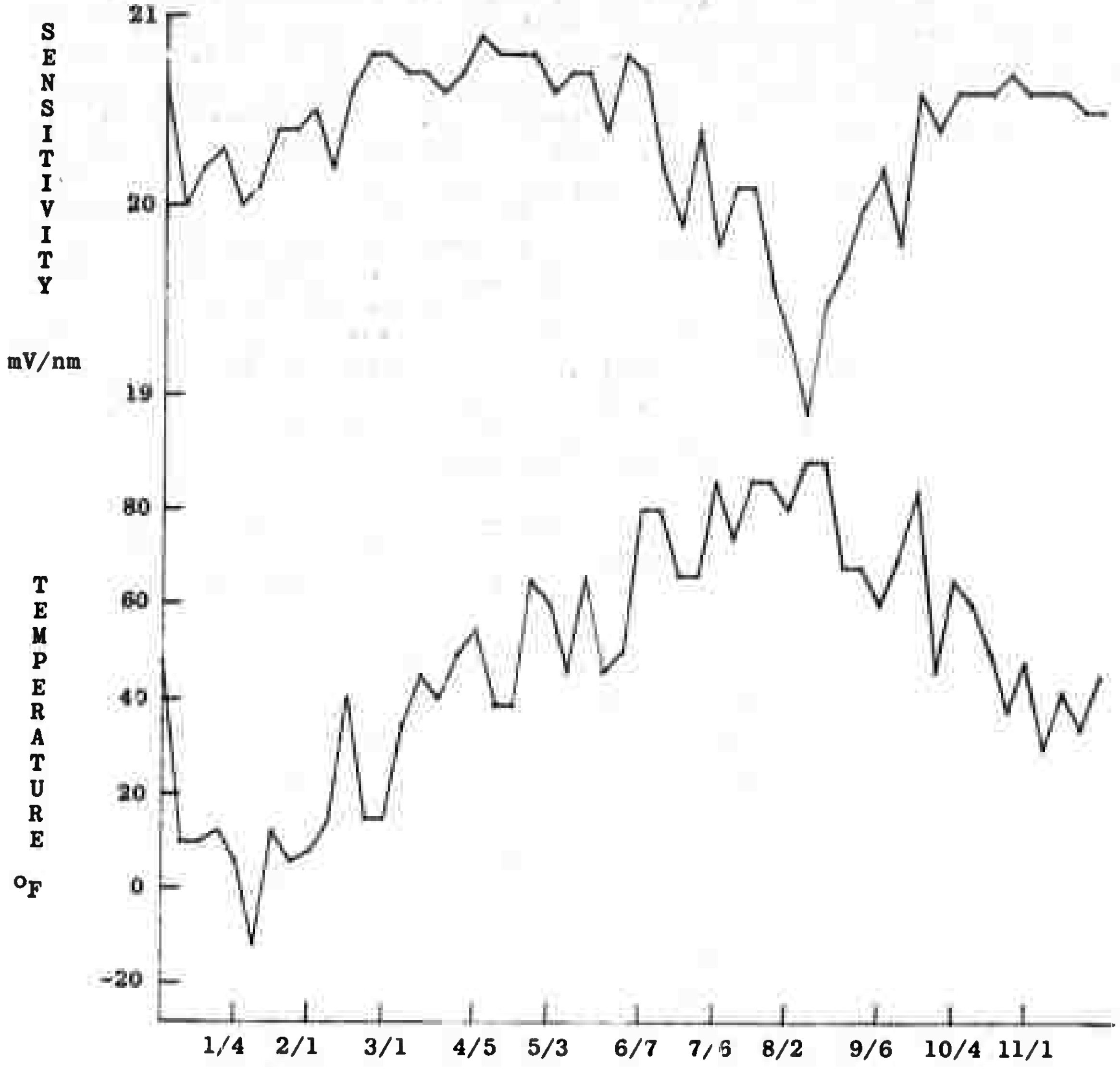


Figure 4.8

SP Array Mean Channel Sensitivity and Temperature Comparison is increased until the signal output across a 10,000 ohm load begins to limit. This output level must measure 11.6 volts p-p or the amplifier is rejected. Amplifiers are repaired and retested with all parameter measurements before installation into the array. The measured value of the maximum output before limiting has been recorded for 20 amplifiers and showed a mean of 12.49 volts and a maximum of 14.0 volts.

4.3.3 LP Seismometers

The seismometers installed at each of the seventeen LP sites which include a Geotech Model 7505B vertical motion sensor and two Geotech Model 8700D horizontal motion sensors have been in operation now since October 1967. The performance of these instruments during this contract period has been very good. Two seismometer tank failures are reported in Table XXXII. These failures, with the relay which switches the external damping resistance in and out for the remote free period measurement, represent the only two occasions in which the long-period seismometer tanks were opened during this contract. Since the installation of the long-period system cabling and free period modification (P-76), which increased the range of free-period adjustment by a factor of three, opening the seismometer tank to manually recenter the adjusting device has not been necessary. Likewise, the relocation of the vault junction box components into the tank by this modification has successfully eliminated all problems resulting from the high humidity in the LP vault.

The extent of the remote seismometer positioning performed from the LDC to readjust mass positions and free periods is shown by the distribution of adjustments plotted in Figures 4.9 and 4.10 for the two parameters.

4.3.4 LP Seismic Amplifier, Type II

The Texas Instruments Type II Multichannel Parametric Amplifier provides signal amplifications for the long-period seismometer output. Each amplifier has three channels, one for each of the three long-period seismometers installed at the subarray. Each amplifier channel includes a parametric amplifier, two filters, and two line drivers. The parametric amplifier provides preamplification to increase the signal amplitudes to a level suitable for further conditioning; a gain range from 100 to 250 is available. Each preamplifier drives two active filters connected in parallel. The system frequency response is determined by these filters and the seismometer. The three different filters available are: A, the 25-sec peak response; B, the 45-sec peak response, and; C, a wider band response. Two different response filters are installed in each amplifier, viz. A and B except at C2 where the responses are C & B. The line drivers amplify the output of each filter by a factor of approximately 184. The B responses are not telemetered from the subarray.

The gain stability of the array's Type II amplifiers has been measured throughout the one-year period of this contract. The

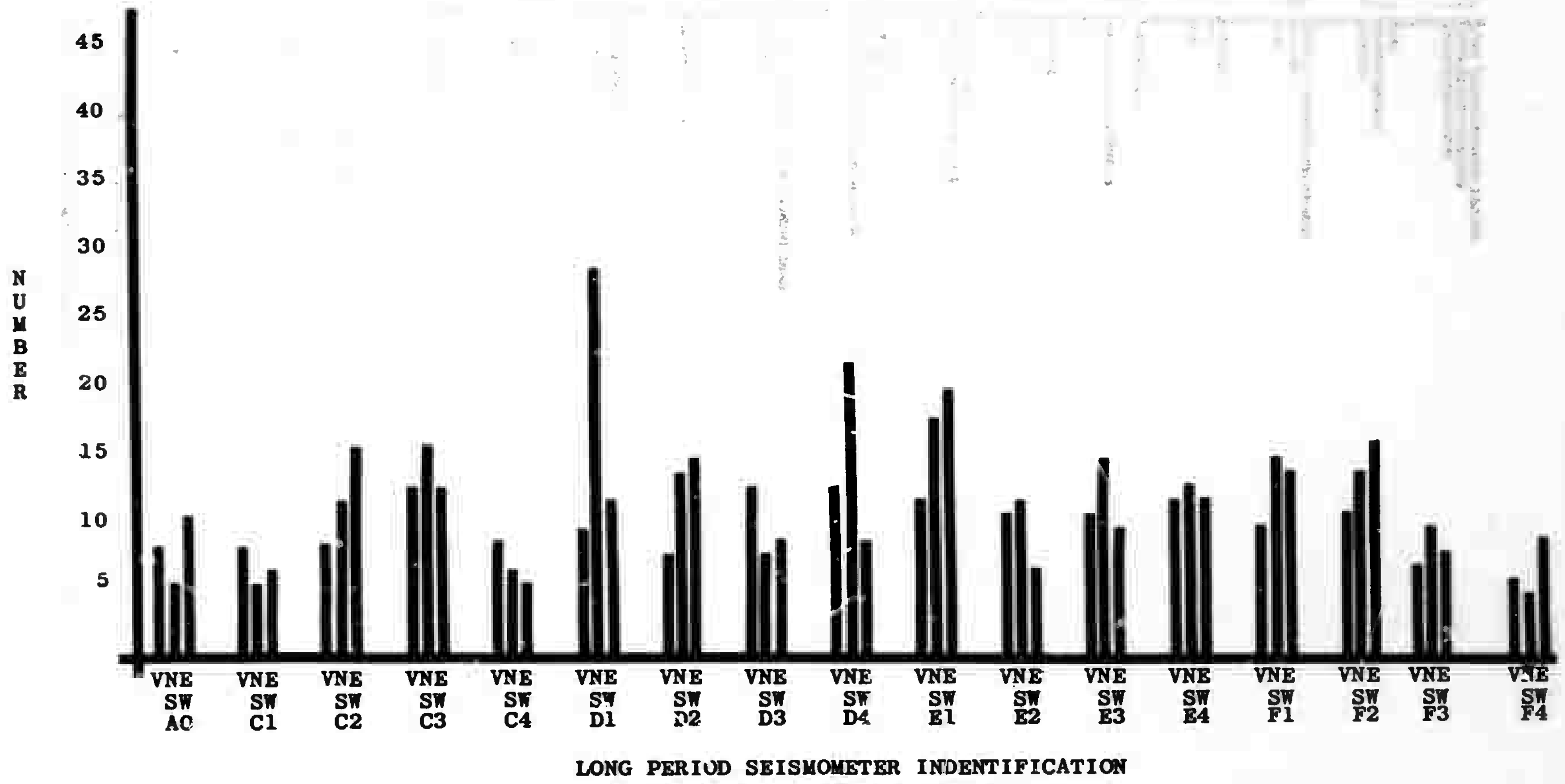


Figure 4.9 Distribution of LP Seismometer Mass Position Adjustments (Dec 70 - Nov 71)

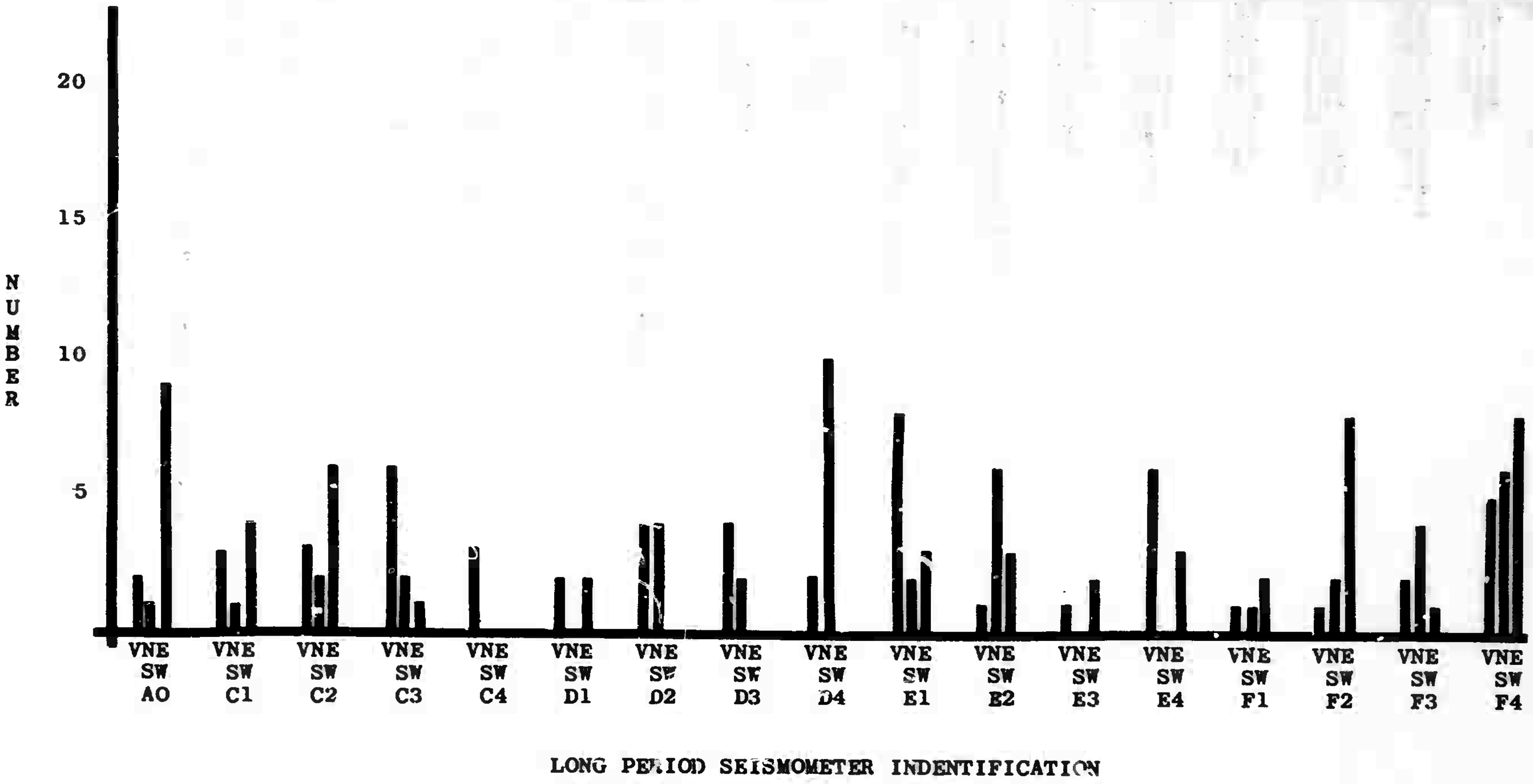


Figure 4.10 Distribution of LP Seismometer Free Period Adjustments (Dec 70 - Nov 71)

measurements are made remotely at the LDC during the weekly array checkout and channel calibrations. Reference 6 details how the amplifier gains shown in Table XXVI were determined from the telemetry responses. Of the five failures reported in Table XXXII, only two required amplifier removal from the subarray and LMC repair.

4.3.5 SEM LP Amplifier

The SEM LP amplifier is composed of two amplifier circuits a balance-to-unbalance amplifier and a gain control amplifier. The balanced-to-unbalanced amplifier consists of an operational amplifier connected as a differential input amplifier to the two input lines from one channel output of the LP Type II seismic amplifier. This circuit provides a nominal gain of 0.232 so that the output from the LP system amplifier is attenuated and the system sensitivity is converted from 1500 mV/μm to 350 mV/μm at 25s. This output is fed to the gain control circuit whose amplifier gain is adjustable from approximately 0.8 to 1.3.

The gain of the SEM LP amplifier is measured remotely by telemetry during the weekly testing of the LP system. The operating gain range of the 45 amplifiers used for the LP standard channels is from .87 to 1.38. The amplitude stability of these amplifiers is indicated by the gain variations statistics. These are: 76% of measurements showed no gain change, 90.6% within ± 0.01, 94.1% within ± 0.02, 96.4% within ± 0.03, 97.8% within ± 0.04, 99.2% within ± 0.05, and 100% within ± 0.08.

4.3.6 SEM LP Calibration Oscillator

The LP calibration oscillator develops a sinusoidal 25 second period signal from a free running multivibrator circuit adjusted to a 25 second period. The multivibrator output is applied to a series of four FET operational amplifier circuits which comprise a 4 pole RC filter for filtering the higher order harmonics leaving the 25 second sinusoidal signal. This is amplified to provide a nominal 20 V p-p balanced signal.

With the development of program TELP improved measurement of the amplitude of this signal became available. Since the signal is applied to the long-period seismometers for an electromagnetic calibration, the signal amplitude from the oscillator determines the equivalent earth motion of the calibration signal. Using the relation

$$Y = \frac{G_C\, i}{4\pi^2 fm} \qquad (4\text{-}3)$$

where Y is the equivalent earth motion of the calibration input in meters

G_C is the seismometer calibrator motor constant in newtons/ampere

i is the amplitude of the current into the calibration coil in amperes,

TABLE XXVI

LP TYPE II AMPLIFIER GAIN STATISTICS - DEC 70 THRU NOV 71

TYPE II AMPLIFIER CHANNEL	MEAN GAIN x10^3	GAIN STD. DEV x10^3	MAX. GAIN x10^3	MIN. GAIN x10^3	MAX. ΔGAIN x10^3
AO-V	15.72	.858	17.38	13.94	3.44
AO-N/S	12.16	.559	13.24	11.05	2.19
AO-E/W	12.56	.637	13.57	11.18	2.39
C3-V	13.04	.674	14.49	11.27	3.22
C3-N/S	13.48	.497	14.52	12.59	1.93
C3-E/W	12.56	.556	14.27	11.54	2.73
C4-V	12.63	.549	13.76	11.41	2.35
C4-N/S	11.67	.538	12.67	10.51	2.16
C4-E/W	11.57	.404	12.34	10.57	1.77
D1-V	9.41	.461	10.34	7.75	2.59
D1-N/S	8.81	.443	9.65	8.19	1.46
D1-E/W	8.68	.501	9.46	6.77	2.69
D2-V	13.34	.625	14.63	12.21	2.42
D2-N/S	12.38	.659	13.77	11.56	2.21
D2-E/W	9.28	.633	10.73	6.77	3.96
D3-V	15.39	.690	16.67	13.95	2.72
D3-N/S	14.71	.796	15.90	12.19	3.71
D3-E/W	14.29	.887	15.30	12.17	3.13
D4-V	13.37	.661	14.68	12.03	2.65
D4-N/S	11.58	.418	12.53	10.62	1.91
D4-E/W	11.54	.654	14.70	10.51	4.19
E1-V	11.61	.822	16.10	10.66	5.44

TABLE XXVI

LP TYPE II AMPLIFIER GAIN STATISTICS - DEC 70 THRU NOV 71 (CONCLUDED)

TYPE II AMPLIFIER CHANNEL	MEAN GAIN x10^3	GAIN STD. DEV x10^3	MAX. GAIN x10^3	MIN. GAIN x10^3	MAX ΔGAIN x10^3
E1-N/S	10.76	.449	11.62	9.89	1.73
E1-E/W	14.48	.612	15.95	13.17	2.78
E2-V	13.43	.488	14.52	12.19	2.33
E2-N/S	11.54	.313	12.13	10.87	1.26
E2-E/W	12.10	.532	13.20	11.07	2.13
E3-V	11.86	.528	12.98	10.83	2.15
E3-N/S	11.43	.391	12.40	10.70	1.70
E3-E/W	11.93	.422	12.68	10.90	1.78
E4-V	12.72	.657	14.27	11.01	3.26
E4-N/S	12.35	.448	13.13	11.29	1.84
E4-E/W	11.93	.581	14.67	11.01	3.66
F1-V	13.23	.884	14.33	10.81	3.52
F1-N/S	12.17	.425	13.11	11.43	1.68
F1-E/W	15.09	.954	18.71	13.77	4.94
F2-V	15.43	.828	16.71	12.00	4.71
F2-N/S	10.79	.461	11.42	9.63	1.79
F2-E/W	12.54	.408	13.45	11.67	1.78
F3-V	11.32	.421	12.38	10.47	1.91
F3-N/S	11.13	.373	12.04	10.42	1.62
F3-E/W	13.07	.683	14.12	9.87	4.25
F4-V	11.98	.656	14.92	10.79	4.13
F4-N/S	10.52	.367	11.34	9.63	1.71
F4-E/W	12.94	.598	14.49	11.80	2.69

f is the frequency of the calibration signal in hertz,
m is the seismometer moving mass in kilograms,

and inserting the LASA LP system parameters,

$$Y = 1.995\times10^{-6}\ A \quad \text{for all LP sites except C2} \tag{4-4}$$

and

$$Y = 2.515\times10^{-5}\ A \quad \text{for site C2} \tag{4-5}$$

A is the peak-to-peak signal amplitude measured on telemetry word 30 during the calibration. Site C2 is calibrated at a higher level of input current to provide an increased output on the attenuated output seismometers at this site.

One measurement of performance of the oscillator is the amplitude stability. Shown in Table XXVII are output means for each of the 17 calibration outputs together with the maximum deviations measured for each over the 23-week period commencing June 28 to November 30, 1971.

4.3.7 SEM SP Calibration Oscillator

The SP calibration oscillator consists of a 1.0 hertz sinusoidal oscillator and an oscillator driver, each on separate printed circuit boards. The Wein bridge oscillator produces two separately adjustable, 10 V p-p, 1 hertz signals. These in-phase signals are applied to the oscillator driver which inverts one signal 180°; the difference signal output is a 20 V p-p, 1 hertz signal.

The 1 hertz signal is used during five of the telemetry commands listed in Table XI. One command, TC-06, is used for electromagnetic calibration of the SP seismograph channels. The nominal 20 V p-p signal applied to the seismometer calibration circuit produces 400 μA p-p of current into the seismometer calibration coil which results in an equivalent earth motion of 396 nm p-p at 1.0s.

Program TESP measures the amplitude of the oscillator output to use in correcting each SP seismograph's output to this 396 nm p-p at 1.0s equivalent earth motion input. In August the TESP program was revised to print out the oscillator's output amplitude and frequency. The output amplitude statistics collected to date for evaluation of this oscillator are shown in Table XXVIII. Two oscillator failures occurred, one requiring card replacement and another adjustment of the output amplitude. The frequency is not adjustable except by component replacement. Table XXIX shows the frequency stability of the oscillator over the final 15 weeks of the contract.

TABLE XXVII

LP SEISMOGRAPH CALIBRATION OSCILLATORS AMPLITUDE OUTPUT STATISTICS

SUBARRAY	OUTPUT AMPLITUDE IN μm p-p			MAXIMUM DEVIATION %
	MEAN	MAXIMUM	MINIMUM	
AO	20.49	20.74	20.26	2.34
C1	20.60	21.48	19.96	7.38
C2	266.68	273.61	262.29	4.24
C3	20.31	20.39	20.19	0.98
C4	20.83	21.74	20.38	6.53
D1	20.53	20.93	20.29	3.12
D2	20.76	21.11	20.60	2.46
D3	21.00	21.32	20.46	4.10
D4	21.01	21.08	20.93	0.71
E1	20.29	21.32	19.28	10.05
E2	20.32	20.86	19.90	4.72
E3	20.52	20.93	19.97	4.68
E4	20.16	20.59	19.65	4.66
F1	20.41	20.46	20.34	0.59
F2	21.08	21.17	21.00	0.81
F3	21.19	20.50	19.83	3.16
F4	19.86	20.24	19.39	4.28

TABLE XXVIII

SP SEISMOGRAPH CALIBRATION OSCILLATORS AMPLITUDE OUTPUT STATISTICS

SUBARRAY	OUTPUT AMPLITUDE IN nm p-p MEAN	MAXIMUM	MINIMUM	MAXIMUM DEVIATION %
AO	428.60	438.8	413.2	5.97
B1	409.60	421.6	400.0	5.27
B2	414.40	416.4	413.2	0.77
B3	411.96	420.0	400.8	4.66
B4	413.72	416.8	411.2	1.35
C1	402.76	403.2	402.0	0.30
C2	402.76	409.2	396.0	3.27
C3	407.08	408.4	406.0	0.59
C4	400.12	403.2	398.4	1.20
D1	411.16	412.8	410.4	0.58
D2	389.48	399.6	394.8	1.23
D3	403.64	408.8	397.2	2.87
D4	395.76	408.4	378.8	7.49
E1	408.48	415.2	392.4	5.59
E2	423.76	426.0	420.8	1.23
E3	411.84	416.0	408.0	1.94
E4	415.64	420.0	411.2	2.12
F1	403.32	408.4	397.6	2.68
F2	411.40	412.4	410.0	0.58
F3	412.00	418.0	402.4	3.79
F4	421.08	423.6	408.4	3.61

TABLE XXIX

SP SEISMOGRAPH CALIBRATION OSCILLATORS OUTPUT FREQUENCY STATISTICS

SUBARRAY	MEDIAN PERIOD AT SECONDS/CYCLE	READINGS AT MEDIAN PERIOD	DEVIATIONS OF ±.002 CYCLES/SEC. FROM THE MEDIAN	DEVIATIONS OF ±.004 CYCLES SEC. FROM THE MEDIAN
AO	1.004	15	0	0
B1	1.000	8	7	0
B2	0.996	9	6	0
B3	1.000	9	6	0
B4	1.000	12	3	0
C1	0.996	14	1	0
C2	1.004	14	1	0
C3	1.000	9	6	0
C4	1.000	12	3	0
D1	1.000	11	4	0
D2	0.998	12	3	0
D3	1.004	13	2	0
D4	0.996	13	2	0
E1	1.000	12	3	0
E2	0.996	11	4	0
E3	1.000	7	8	0
E4	1.002	12	3	0
F1	1.000	9	6	0
F2	0.998	13	2	0
F3	0.998	9	5	1
F4	0.996	11	4	0
TOTALS		235	79	1

PERCENTAGE OF DEVIATION FROM MEDIAN INTERVAL	PERCENTAGE OF TIME OSCILLATOR IS IN INTERVAL
0%-0.2%	74.6%
0.2%-0.4%	25.1%
0.4%-0.6%	0.3%

4.4 Surficial Noise Studies

Investigation of surficial noise sources has occurred for two reasons. One, the scanning of Develocorder film recorded for SDL revealed a seemingly high incidence of local events and two, the oil drilling activity in the area of the array had previously attracted interest by certain LASA data users. Comments from these investigations are summaried in the following paragraphs.

The high-level, high-frequency noise recorded on the Develocorder film from sensors E3-82 and E3-86 was the initial reason for investigating noise sources in southwestern section of the array. Two related areas providing present and potentially interferring surficial noise have been identified. These are the increase in train traffic over the railroads near subarray E3 and the blasting activities of the two coal mining companies starting strip mining operations in the vicinity. In particular, a noise effect lasting up to 30 minutes and resulting from loaded coal trains crossing just north of the E3 sensors has been identified; approximately 10 to 12 trains daily pass over the tracks located five miles from these two sensors.

The two coal mining companies operating from Colstrip, Montana, are blasting daily at a rate of 2 to 8 times. These blast vary in size from large overburden shots and medium coal shots. An increase in this activity is anticipated for the future.

The drilling activity for oil exploration was limited to seven new locations. These, labeled 40 through 46, have been added to the chart shown in Figure 4.11, which shows the approximate locations of all drilling sites since 1 June 1969. The exact locations and depths are listed in Table XXX.

4.5 Failure Report

The array system and equipment failures which occurred this contract are discussed in this section. All the failures are classified according to the type of failure and include these five classifications:

(1) System failure -	A failure resulting in zero or no system output which prevents the system or equipment assembly from performing its primary function and identified as a Type 1 failure.
(2) Mode failure -	A failure resulting in a zero or no system output only during one of several different modes of operation; a Type 2 failure.

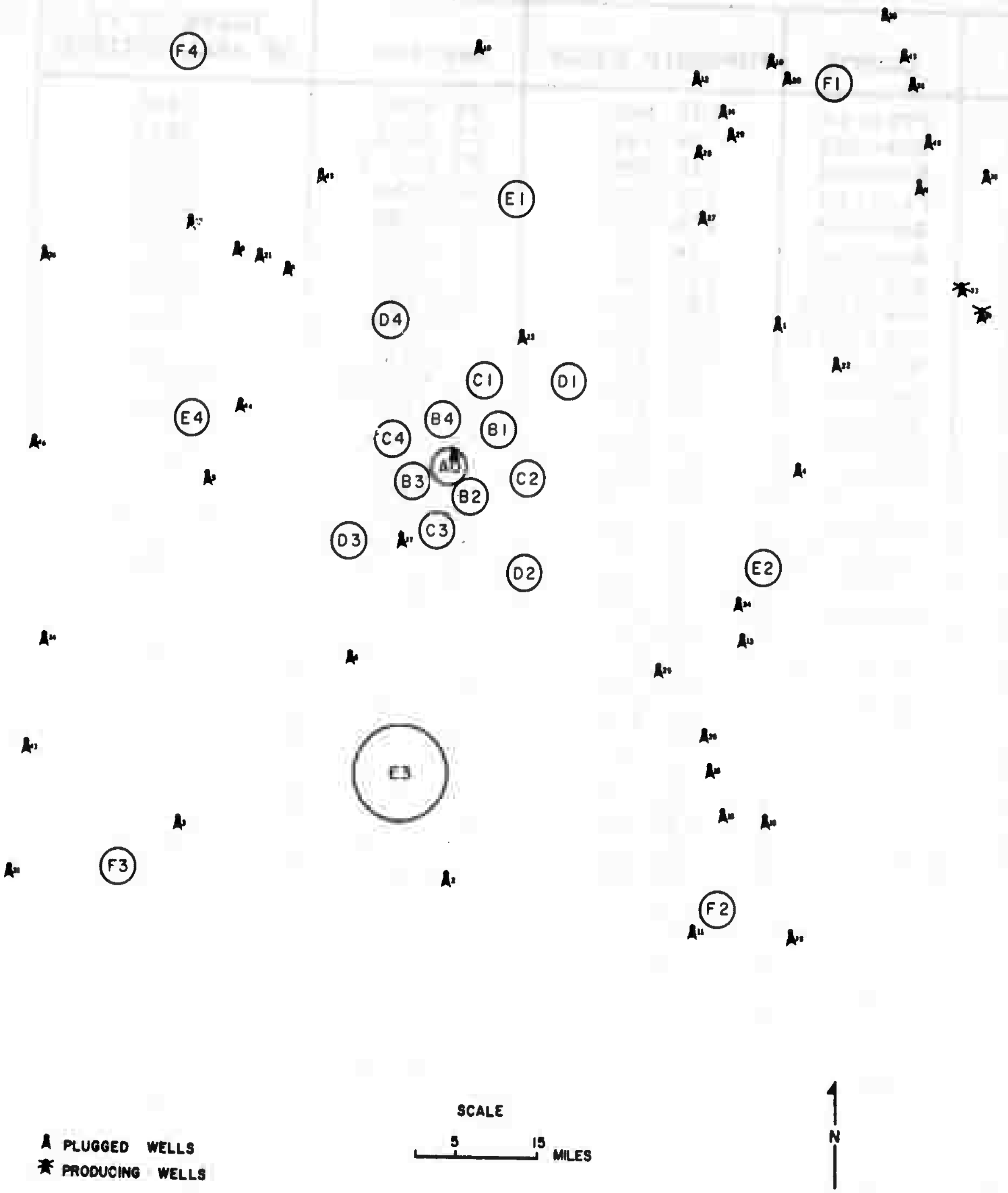


Figure 4.11

LASA Complex Status Chart For Oil Drilling Activity

TABLE XXX

OIL DRILLING LOCATIONS

1 June 1969 - 30 November 1971

LOC. NO.	COUNTY	TOWNSHIP/RANGE	SECTION	DEPTH IN FT. OF WELL DRILLED
1	Prairie	14N 50E	24 SESE	5100
2	Rosebud	3N 44E	35 NENE	5914
3	Rosebud	4N 39E	25 Lot 1	5470
4	Prairie	11N 51E	23 NENW	5454
5	Rosebud	11N 39E	31 NENW	2450
6	Rosebud	7N 42E	16 SENW	5304
7	Rosebud	11N 44E	8 SESE	5178
8	Garfield	15N 40E	21 SESE	5709
9	Garfield	15N 39E	9 NENW	5938
10	McCone	19N 44E	7 NWNE	5700
11	Custer	2N 50E	31 NWSWSW	Unknown
12	McCone	19N 48E	23 SESE	5200
13	Custer	7N 50E	1 NWNW	5700
14	McCone	18N 49E	9 SWSW	5000
15	Custer	4N 51E	27 NENE	5306
16	Custer	5N 50E	29 NWNW	Unknown
17	Garfield	16N 38E	28 NENW	5319
18	Custer	4N 50E	23 NWSW	5455
19	Dawson	19N 50E	9 SWSW	5336
20	Dawson	19N 50E	23 SWSW	5000
21	Garfield	15N 39E	13 NWNW	5622
22	Dawson	14N 52E	17 SWNW	5200
23	Prairie	14N 45E	33 NESE	5730
24	Custer	8N 50E	11 SESE	5575
25	Custer	7N 49E	19 SESW	5561
26	Custer	6N 50E	31 SWSW	5350
27	Prairie	16N 49E	17 SESE	5680
28	McCone	17N 48E	1 SWSW	5685
29	McCone	18N 49E	27 SWSW	5620
30	Dawson	20N 52E	11 SESE	5100
31	Treasure	3N 35E	32 SENE	6600
32	Dawson	19N 53E	28 SENW	11070
33	Dawson	15N 54E	36 SWNW	9072
34	Treasure	7N 35E	12 SENW	7177
35	Dawson	17N 54E	25 SESE	10600
36	Garfield	15N 35E	17 SWNE	5505
37	Rosebud	9N 43E	5 NWNW	4666
38	Custer	1N 52E	6 NENE	5196
39	Dawson	14N 55E	17 SESE	8900
40	Dawson	18N 53E	35 NWSW	10700
41	Dawson	17N 53E	34 NWSW	7190
42	Treasure	5N 35E	15 NWSW	6764
43	Dawson	19N 53E	5 SW	11200
44	Rosebud	12N 39E	14 SESW	3806
45	Garfield	17N 40E	26 NESE	8708
46	Rosebud	11N 35E	9 SENW	4600

(3) Limited failure - A failure resulting in a system output which is outside the allowable tolerance limits but permits degraded performance; a Type 3 failure.

(4) Latent failure - A failure which changes a system output either by an amount less than the allowable tolerance or from the nominal output when no tolerance limits have been established; a Type 4 failure.

(5) Temporary failure - A failure produced by an operating or environmental stress which results in no permanent physical damage; a Type 5 failure.

Table XXXI indicates the number of failures detected and corrected in each of the twelve array systems. In decreasing order, the three systems with largest number of failures were the SP sensor, the SEM, the PDP-7 computer.

The number of SP sensor system failures is influenced by the testing methods employed to detect improper sensor operation. At the beginning of the fourth quarterly period, the SP channel gain stability tolerance was improved (para. 4.2.1) and the daily testing of all the SP seismograph channels began. The number and duration of the defective SP channels detected during that time is shown in Figure 4.12. There were two failures in effect at the start of the period. At the end of the contract 20 failures were uncorrected and not included in the distribution. As evidenced, the majority of failures are single day occurrences; thus, the previous procedure of testing at weekly intervals probably did not detect many of these short duration failures. A distribution of this type will be continued so that the performance of the SP array in terms of the number and duration of channel failures can be readily determined.

The distribution of the equipment failures within each system is shown in Table XXXII. The WHV amplifier panel caused the largest number of failures; 94% of the 212 failures reported for the SP system. A breakdown of these amplifier failures show only 16 which failed completely, 59 would not operate within the prescribed gain or signal quality tolerances without adjustment or replacement, 86 showed evidence of instability and/or operation away from the channel nominal levels and were adjusted or replaced during the SP rehabilitation preventive maintenance program, and 38 amplifiers displayed intermittant operation when their performance improved without maintenance assistance.

The major portion of the SEM failures were reported in the input and control drawers. Three input drawer component failures were corrected and 57 adjustments were made during preventive maintenance to reduce the high dc offsets measured on the channels.

TABLE XXXI

LASA SYSTEM FAILURE DETECTIONS AND CORRECTIONS

DECEMBER 1970 - NOVEMBER 1971

	STARTING BACKLOG	DETECTED	CORRECTED	ENDING BACKLOG
SP SENSOR	8	219	212	15
LP SENSOR	0	15	15	0
LTV-6 MICROBAROGRAPH	1	10	11	0
ESYS MICROBAROGRAPH	2	15	17	0
METEOROLOGICAL SYSTEM	0	3	3	0
SEM	1	103	104	0
POWER SYSTEM	2	16	18	0
360 COMPUTER	0	17	17	0
PDP-7 COMPUTER	0	142	136	6
LDC DIGITAL	0	7	7	0
LDC ANALOG	0	52	51	1
LDC TEST AND SUPPORT	0	83	83	0
TOTALS	14	682	674	22

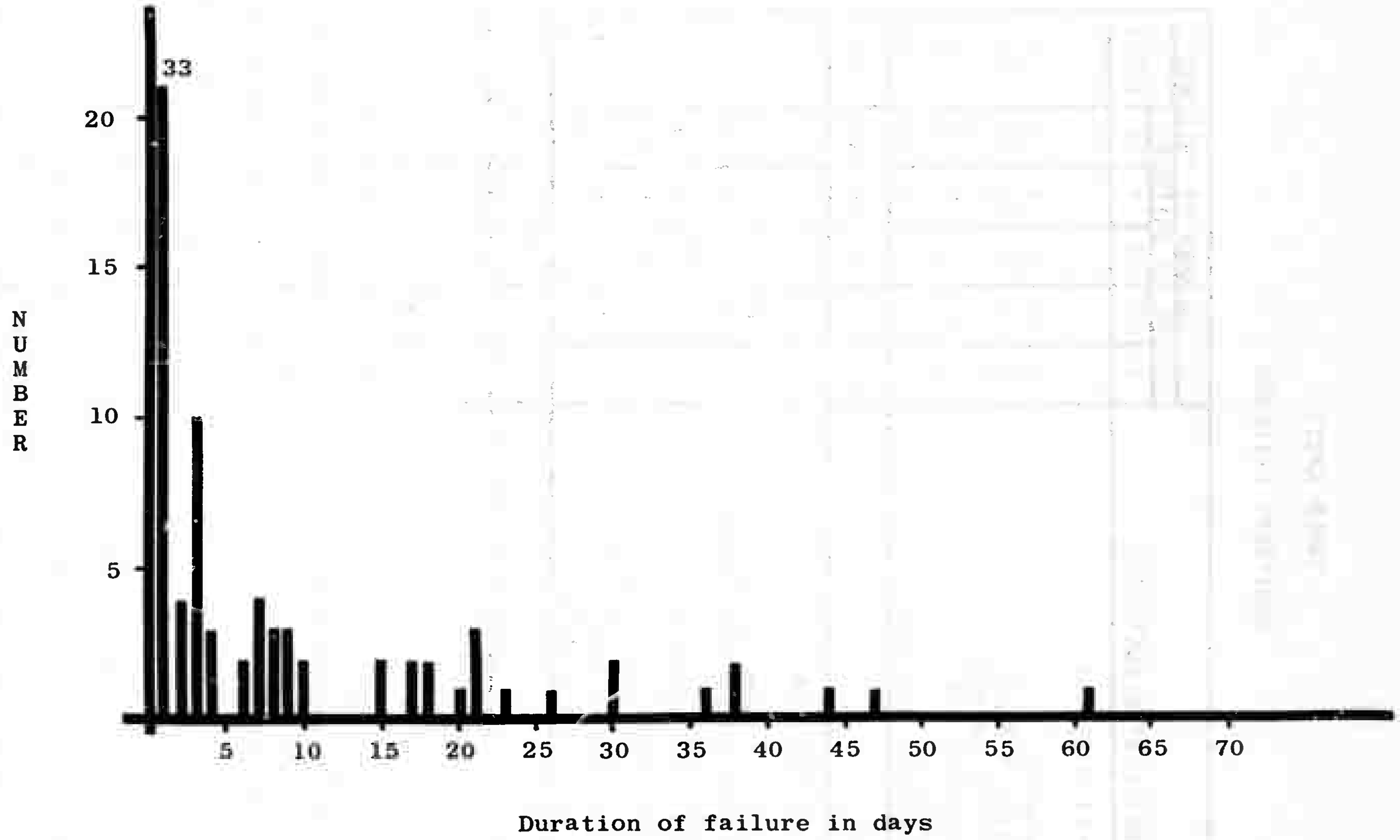


Figure 4.12 Distribution of the Number and Duration of the Defective SP Seismographs between 5 Sept. and 30 Nov. 71

TABLE XXXII

EQUIPMENT FAILURES

ARRAY SYSTEM/EQUIPMENT	NUMBER OF FAILURES					
	TYPE OF FAILURE					TOTAL
	1	2	3	4	5	
Short-Period System						
Seismometer	1	0	1	4	0	6
WHV Panel W/RA-5	16	0	59	86	38	199
RA-5 Power Supply	0	0	0	0	0	0
WHV Junction Box	1	0	0	0	0	1
WHV/Cables	3	0	1	0	0	4
CTH Junction Box (SP)	0	0	2	0	0	2
Total	21	0	63	90	38	212
Long-Period System						
Vertical Seismometer/Tank	0	0	0	0	1	1
Horizontal Seismometer/Tank	1	0	0	0	0	1
LP Vault/Cabling	0	0	0	0	0	0
LP Junction Assembly	4	0	0	0	2	6
Motor Assembly	0	0	0	0	0	0
Seismic Amplifier, Type 2	0	0	4	0	1	5
Amplifier Power Supply	0	0	1	0	1	2
CTH Junction Box (LP)	0	0	0	0	0	0
Total	5	0	5	0	5	15
LTV-6 Microbarograph						
Microbarograph	1	0	4	2	0	7
Power Supply	0	0	0	0	0	0
Cabinet/Cabling	0	0	0	0	0	0
Pipe Array	0	0	4	0	0	4
Total	1	0	8	2	0	11
ESYS Microbarograph						
Acoustical Can/Cabling	1	0	0	0	0	1
Capsule	0	0	0	0	0	0
Oscillator	0	0	0	0	0	0
Discriminator/Power Supply/Cables	3	0	13	0	0	16
Pipe Array	0	0	0	0	0	0
Total	4	0	13	0	0	17

TABLE XXXII

EQUIPMENT FAILURES (CONTINUED)

ARRAY SYSTEM/EQUIPMENT	NUMBER OF FAILURES					
	TYPE OF FAILURE					TOTAL
	1	2	3	4	5	
Meteorological System						
Aerovane, Wind Direction	1	0	1	0	0	2
Aerovane, Wind Speed	0	0	0	0	0	0
Pole Assembly	0	0	0	0	0	0
Pole Junction Box/Cabling	0	0	0	0	0	0
Temperature Probe	0	0	0	0	1	1
Electrobarometer/Baffle	0	0	0	0	0	0
Rain Gauge	0	0	0	0	0	0
Rain Gauge Electronics Panel	0	0	0	0	0	0
Total	1	0	1	0	1	3
Subarray Electronics Modules						
Input Drawer #1	0	0	27	0	1	28
Input Drawer #2	3	0	30	3	0	36
Multiplexer/ADC	1	0	7	1	1	10
Output Drawer	2	0	4	0	2	8
PDC Drawer	3	0	17	0	0	20
ACC Cabinet	0	0	2	0	0	2
SEM Cabinet/Cabling	0	0	0	0	0	0
Alarms	0	0	0	0	0	0
Total	9	0	87	4	4	104
Power System						
Control Drawer	6	0	0	0	0	6
Inverter	8	0	0	0	0	8
Charger	1	0	1	0	0	2
Battery	0	0	0	0	0	0
SOLA Transformer	0	0	0	0	0	0
Rack/Cabling	0	0	1	0	0	1
Isolation Transformer	0	0	0	0	0	0
Breaker Panel	0	0	0	0	0	0
Vault/Wiring/Breakers/Outlets	1	0	0	0	0	1
Total	16	0	2	0	0	18

TABLE XXXII

EQUIPMENT FAILURES (CONTINUED)

ARRAY SYSTEM/EQUIPMENT	NUMBER OF FAILURES					
	TYPE OF FAILURE					TOTAL
	1	2	3	4	5	
360 System						
CPU 2044	4	0	1	0	0	6
Disc Drive 2315	0	0	0	0	0	0
Typewriter 1052	3	0	2	1	3	9
Card Reader 2501	0	0	0	0	0	0
Data Control 1826	0	0	0	0	0	0
Data Adapter 1827	0	0	1	0	0	1
Data Adapter 2701	0	0	0	0	1	1
Total	8	0	4	1	4	17
PDP-7 System						
Computer	2	0	4	1	4	11
Teletypewriter KSR-35	7	0	5	0	0	12
Card Reader	10	0	1	0	2	13
SOU	1	0	0	0	0	1
Interface	0	0	0	0	0	0
Tape Unit #19	8	0	12	0	7	27
Tape Unit #32	12	0	17	0	3	32
Tape Unit #33	10	0	17	0	0	27
Incremental Recorder	5	0	3	0	5	13
Total	55	0	59	1	21	136
Digital System						
Timing System #1	2	0	3	0	0	5
Timing System #2	0	0	1	0	0	1
Digital Data Simulator	0	0	0	0	0	0
Power System	0	0	0	0	0	0
PLINS	0	0	1	0	0	1
MINS	0	0	0	0	0	0
Total	2	0	5	0	0	7

TABLE XXXII

EQUIPMENT FAILURES (CONCLUDED)

ARRAY SYSTEM/EQUIPMENT	NUMBER OF FAILURES					
	TYPE OF FAILURE					
	1	2	3	4	5	TOTAL
Analog System						
D/A Patch Panel Cabinet	0	0	1	0	0	1
D/A Converter #1	1	0	2	0	0	3
D/A Converter #2	1	0	0	0	0	1
D/A Converter #3	0	0	0	0	0	0
D/A Converter #4	0	0	2	0	0	2
FM System	0	0	2	0	0	2
16 Channel Chart Recorder	0	0	8	1	2	11
WHV Receiver	2	0	0	2	0	4
Analog Calibration System	0	0	0	0	0	0
Analog Timing System	0	0	3	0	0	3
SP Develocorder	4	1	3	2	1	11
LP Develocorder	4	0	8	1	0	13
Total	12	1	29	6	3	51
LDC Test and Support System						
MDC-1	3	4	39	0	1	47
MDC-2	0	0	27	1	1	29
Clocks	0	0	0	0	0	0
Film Viewer	0	0	1	0	0	1
Film Duplicator	0	0	0	0	0	0
Copier	0	0	0	0	0	0
Emergency Lights	1	0	0	0	0	1
Compressor, Blower	2	0	0	0	0	2
Digital Clocks	0	0	1	0	0	1
Air Conditioners	2	0	0	0	0	2
Humidifier	0	0	0	0	0	0
Tape Cleaner	0	0	0	0	0	0
Electrostatic Filters	0	0	0	0	0	0
Total	8	4	68	1	2	83

Three control drawers circuit failures combined with 17 telemetry malfunctions to produce 20 failures.

In the PDP-7 computer system, the teletypewriter and the magnetic tape units accounted for 98 of the 136 reported failures. The majority of these were of a mechanical nature and due primarily to the wear resulting from continued system usage during the past seven years. Mechanical wear of the 16-channel chart recorder and the two Develocorders resulted in 35 failures in the Analog System. In the LDC Test and Support System the replacement of the chart recorder bias batteries continues to produce the largest number of failures; the comsumption rate is normal as expected.

SECTION V

IMPROVEMENTS AND MODIFICATIONS

5.1 General

Important to the operation of the Montana LASA is the continuing incorporation of improvements and modifications into the various equipments. These improvements permit increased efficiency in the utilization, operation and maintenance of the seismic observatory's systems. The improvements reported for this contract are cateogorized into these three areas, PDP-7 programming, array equipment and data center equipment. Improvements in the PDP-7 programming result in more efficient operation and increase the data collection capability of the array performance measurement activity. Modifications to the array and data center equipment are made to reduce the need for maintenance (i.e. improve reliability), to improve data quality, or to extend the operating capability.

5.2 PDP-7 Programming

The most significant accomplishment associated with Project VT1708 has been in the area of PDP-7 programming. Development of an efficient on-line system that provides operation flexibility, utilizes the full capability of previously developed programs, and performs automatic monitoring, control, and measurement of the array's telemetry signals and responses has been the goal of the programming activity of this contract. The system prepared, called MOPS for Multiple On-line Processing System, was developed from the previous system, TRIREC, (Ref. 9), which in turn was built from BIREC, the original PDP-7 system program designed for LASA signal processing. The capabilities of these three systems are compared in Table XXXIII.

MOPS contains all the features of TRIREC, adds the event detection and beamforming programs of BIREC, and allows for the input of a variety of patch programs for the automatic handling and processing of the LASA telemetry response signals, as well as, the display on peripheral chart recorders of selected seismograph signals. The MOPS program routines with their respective memory size and core locations are shown in Table XXXIV.

The seven programs developed for "patching" into the on-line system by paper tape to overlay portions of the PDP-7 memory during MOPS operation are: TESP, TELP, DCOFF, MASPOS, FREECK, BATCK, and DEVCAL. Each of these programs are described in Appendix A. All of these programs can operate without interference with other MOPS functions such as the high rate back-up recording of array data. Some of the programs have undergone several revisions with new versions written to improve the program operation and to increase the quality and quantity of the data output. The flexibility of these overlay programs to revision is an important advantage

TABLE XXXIII

PDP-7 COMPUTER PROGRAM DEVELOPMENT

ON-LINE OPERATION

BI-REC	TRI-REC	CURRENT OPERATING SYSTEM
High Rate Recording	*High Rate Recording	*High Rate Recording
Low Rate Recording		*Low Rate Recording
*VLR Recording	*VLR Recording	*VLR Recording
Event Detection		*Event Detection
Beam Forming		Beam Forming
Site Deletions		*Site Deletions
	*Monitor	*Monitor
	Weather Bureau	Weather Bureau
		*Display-Select Data
	*Programming Changes	*Programming Changes
	*Card List O	Card List O
	*Tape List V	Tape List V
	*Send TC-06 E	TESP E
	TELP R	TELP R
	L	DEVCAL L
	A	DCOFF A
	BATCK Y	BATCK Y
	Computer Use Log S	FREECK S
	List Log	MASPOS
		Plot Data
	Punch	

*May be turned on and off while system is running

TABLE XXXIV

MOPS PROGRAM ROUTINES

CORE LOCATIONS (OCTAL)	ROUTINE NAME	FUNCTION
00100-14336	IODABUF	Input-output data buffers
14337-17777	PATCH	Used for patch overlay
CONTROL SECTION (C)		
20000-20130	C CON BUF	Control pointers and flags
20131-20556	C TYPOUT	Typewriter and paper tape output routine
20557-21136	C TYP	Typewriter input
21137-21303	C TYPBUF	Addresses of all typewriter and paper tape messages to be outputted
21304-21350	C WTLOOP	Wait loop for interrupt servicing
21351-21432	C REINIT	Re-initialization of tape commands and buffers after a function of MOPS has been completed
21433-22105	C INTANS	Interrupt answering routine for processing all input-output devices
22106-22516	C OEFRPR	Odd-even frame sequencer
22517-23114	C INKY	Build and write incremental records (VLR)
23115-23374	C HIRATE	Hi rate tape control functions
23375-23635	C LORATE	Lo rate tape control functions
23636-23717	C TPCONT	Magnetic tape control indicators
23720-24313	C BEDEL	Delay values for beamforming
24314-24514		Literals for LONS section

TABLE XXXIV

MOPS PROGRAM ROUTINES (CONCLUDED)

CORE LOCATIONS (OCTAL)	ROUTINE NAME	FUNCTION
PROCESSING SECTION (P)		
24515-24565	P PROCON	Odd-even sequencing for beams and event detector
24566-25033	P LRREBD	Building of low rate record
205034-24206	P SOUOUT	Digital to analog conversion routine for outputting beams
25207-25540	P BMFORM	Building of 5 array beams and 4 E3 beams
25541-27061	P EVTDET	Event detector routine
27062-27754	P EVDEBU	Event detector buffers
27755-30227		Literals for LOPPS section
MONITOR SECTION (M)		
30230-31057	M WEABLD	Weather processing and transmission to weather bureau
31060-31131	M HIRTTR	Array seismometer status (trailer)
31132-33651	M MONTEL	Monitor of subarray and communication lines and generation of telemetry via computer for array analysis
33652-34765	M MONBUF	Buffers for monitor
34766-35233		Literals for MOPS section
36000-36473	M INTPAT	System initialization and after system is started available for patch overlay
35300-37777	PATCH	Used for patch overlay

and provides a wide range of array system measurement possibilities using the PDP-7 computer. These programs written in machine language can become powerful tools in assisting not only in the performance measurement of the different systems but in the overall operation and maintenance of the Montana array. As the library of programs grows, this will become more evident.

5.3 Array Equipment

Three modifications to the array equipment were implemented during this contract. These were (1) improved LP seismometer remote free period measurement, (2) ESYS microbarograph equipment relocation, and (3) SEM calibration channel test jack installation. The installation schedule by subarray for these modifications is provided in reference 10.

5.3.1 LP Seismometer Remote Free-Period Measurement

To improve the repeatability of the remote free-period measurements on the LP seismometers, a modification (P-80) was installed in each SEM Control Drawer to increase the amplitude of the current pulse applied to seismometer calibration coil during telemetry command TC-19. When this command is initiated the external damping resistance is removed from the damping coil circuit and a dc pulse is applied to the calibration coil to start mass motion. At least five cycles of mass oscillation are averaged to obtain an accurate measurement of the seismometer free period.

Prior to this modification, the seismometer output amplitude from the mass oscillations resulting from a 6 Vdc pulse was too low with respect to the channel noise level to obtain repeatable readings with the desired precision. The signal output decayed down to the noise level too quickly; the resultant distorted output caused inconsistancy in the measurements. Increasing the amplitude of the dc pulse to 10.8 V has resulted in an improvement in weekly measurements which are made on each seismometer.

5.3.2 ESYS Microbarograph Relocation

To eliminate a source of failure in the ESYS microbarograph which had resulted from the temporary nature of the original installation, the system's discriminator/power supply has been relocated to an aluminum shelf installed on the CTH walls at the thirteen innermost subarrays. This unit had experienced several failures when installed on top of the battery rack due to moisture seeping into the vault onto the cables above and dripping into the unenclosed assemblies. Although the vault leakage problem is being corrected (see paragraph 6.4), this change (modification, P-81) will preclude any further moisture damage, and provide easier access and less interruption of the microbarograph system operation during battery servicing.

5.3.3 SEM Calibration Channel Measurements

To improve the accuracy of the SEM calibration data collected at the LDC which are referenced to signals on word 30, a co-axial test jack for monitoring the calibration channel output at the CTH has been added to all SEM control drawers. Utilizing telemetry control, channel 30 can be used to measure such functions as ac power, vault temperatures, battery voltage, and the output from the 1 hertz and .04 hertz oscillators. Prior to adding the test jack, measurement of these outputs for calibration purposes required removal of the drawer cover to gain access to the test points. Since this disturbed the temperature balance of the circuits, measurement errors occurred. Now, during routine maintenance visits to the CTH, accurate channel calibration measurements can be made conveniently.

5.4 Data Center Equipment

Two modifications were designed and installed in the data center equipment during this contract. These were to the PDP-7 magnetic tape units for improved reliability and performance of the broken tape lamp assembly and to the 16-channel analog chart recorder for additional control of the PDP-7 computer serial data output. The details of these modifications are provided in the following paragraphs.

5.4.1 Broken Tape Lamp Assembly Modification

A high failure rate of the broken tape lamp assemblies has been experienced in the 570 tape units used with the PDP-7. The broken tape photo sensing cells are activated by a corresponding broken tape lamp assembly during two logical functions. They occur when and if a tape breaks during recording or during the rewinding of tapes when the end of rewind occurs. It has been found that the amount of light emitted by the lamps is barely adequate to excite the sensors. Dust on the lamp or ageing of its filaments has required frequent cleaning, adjusting, and replacements of the assembly.

To correct the problem the broken tape lamp wiring has been removed from the series string which included the end-of-tape, the load point, and the broken tape lamps. A lamp of the same type was located in the tape deck and wired in series with the end-of-tape and load point lamps to maintain them at their normal operating voltage. The broken tape lamp was wired in series with another lamp of the same type. The voltage now applied to the broken tape lamp is 3 volts compared to the original 2 volts. The lamp, type 328, is rated at 6 volts. After three months of operation there have been no failures or intermittant problems. This change has been made in all three tape unit .

5.4.2 PDP-7 Control of MDC-2 Chart Recorder

During certain processing the PDP-7 controls the start/stop circuit of the 16-channel chart recorder to provide a hard copy of selected analog data. To provide this control to the 8-channel chart recorder in MDC-2, which is more accurate and versatile, a double pole, double throw switch has been mounted on the 16 channel chart recorder. With the appropriate wiring this switch permits the circuit that receives the start-stop signal from the SOU and provides operating current to a relay, to be switched to either the 16 channel or 8 channel chart recorder start relay.

SECTION VI

MAINTENANCE

6.1 General

Maintenance activity is required for all of the array's twelve systems. These systems include: the SP sensors, the SEMs, and the power systems installed at all 21 subarrays; the LP sensors at all except the four B-ring subarrays; the LTV-6 microbarographs and the meteorological systems at the eight subarrays A0, E1, E2, E4, F1-F4; the ESYS microbarographs at the thirteen innermost subarrays; and the 360 computer, the PDP-7 computer, the digital, the analog, and the test and support systems at the data center. The types of activity include failure correction, preventive maintenance, equipment modification, and special tests and equipment calibrations. The number and type of system failures corrected are shown in paragraph 4.5.

The extent of the maintenance activity is shown in Tables XXXV and XXXVI where the number of all equipment (LASA) and facility (utility) work orders are tabulated for the contract and fourth quarterly periods, respectively. The 1,873 work orders completed represent 2,281 individual maintenance actions performed by the maintenance technicians. Work orders are used to document all array and data center equipment maintenance. Although they do not indicate the actual time or complexity required of the task, the work orders do indicate the type of work performed and the size of the work load. All repair actions are traceable to a particular trouble or failure by using the same number on all three work order types, viz., the part A for system work, part B for system assemblies, and part C for assembly components. In the case of preventive maintenance or other non-failure related maintenance, the part A work order is used. Utility work orders are prepared for all maintenance on such facilities as array trails, cable trenches, vaults, fences and vehicles. During this contract period 87.5% of the 592 scheduled preventive maintenance routines were completed.

6.2 Data Center

The goals of the LDC maintenance efforts have been to develop the IBM 360 computer maintenance program, to maintain all online systems fully operational 24 hrs/day, and to complete all the scheduled preventive maintenance.

Development of the 360 system maintenance has progressed successfully so that all preventive maintenance routines and diagnostic programs are now effectively handled by LDC personnel. Corrective actions were satisfactorily applied to all major system malfunctions; these are listed as:

(1) The 1052 typewriter, which had a history of intermittent troubles until repaired during this contract,

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TABLE XXXV

WORK ORDER SUMMARY

WORK ORDER TYPE	BACK LOG START OF CTR	INITIATED	COMPLETED	BACK LOG END OF CTR
System - A	18	1061	1052	27
Subassembly - B	22	186	168	40
Component - C	154	160	187	127
Total	194	1407	1407	194
Utility:				
Cable trench & trail inspection	7	26	33	0
Cable trench backfill	0	10	9	1
WHV sites landscaped	20	176	196	0
Marker posts &/or WHV covers replaced	0	47	47	0
CTH maintenance	14	69	76	7
Vehicle maintenance and inspection	2	38	37	3
Fence inspections	5	57	58	4
Trail repairs	1	11	10	2
Total	49	434	466	17
WORK ORDER TOTALS	243	1841	1873	211

TABLE XXXVI

WORK ORDER SUMMARY

SEPTEMBER - NOVEMBER 1971

WORK ORDER TYPE	BACK LOG START OF QTR	INITIATED	COMPLETED	BACK LOG END OF QTR
System - A	50	269	292	27
Subassembly - B	30	40	30	40
Component - C	10	122	5	127
Total	90	431	327	194
Utility:				
Cable trench & trail inspection	0	10	10	0
Cable trench backfill	5	0	4	1
WHV sites landscaped	0	6	6	0
Marker posts &/or WHV covers replaced	3	17	20	0
CTH maintenance	1	25	19	7
Vehicle maintenance and inspection	4	17	18	3
Fence inspections	12	11	19	4
Trail repairs	4	2	4	2
Total	29	88	100	17
WORK ORDER TOTALS	119	519	427	211

received frequent attention. Initial maintenance on this unit involved replacement of the pinion gear and the carriage return spring, alignment of the main shaft, and adjustment of the print and cycle contacts, the cam brake pad and the escapement linkage. The later repairs, a jammed space bar and a noisy shift clutch were adjusted.

(2) In the CPU 2044 a continuously high SDR bit 10 was corrected by card replacement in location A-A3J4.

(3) The 1827 Data Adapter caused high parity errors in subarray C4 data until an unsoldered wire was found on the card in location 1B-A1-K7.

(4) The system would not power up until the SCR diode failures in the temperature controller for one of the memory core stacks were replaced.

(5) A CPU 6 volt power supply failure resulted from a factory defective component. A mechanical open circuit in one of two high wattage resistors, which are used to provide a current path through parallel transistor regulators, caused overheating in the other resistor from carrying the full load current.

Additionally, several instances of 360 system failures have resulted from local power outages. No equipment damage has resulted, but the system required resetting of power breakers and a complete recycling.

Program malfunctions resulted in PDP-7 computer corrective maintenance. Maintenance performed included retiming of the main and extended arithmetic element timing chains, retuning of the memory, relocation of several sense amplifier logic cards, replacement of the logic card used to generate the "slow cycle" timing required for all multiply and divide operations, and replacement of the memory buffer logic cards for bits 0-5.

Several problems occurred with the incremental recorder. One was based on an improper hardware connection of the input-output transfer (I/OT) instructions to coincide with the program instructions used with the MOPS program. To improve a high parity error rate, three logic cards were replaced and the recording head alignment corrected by shimming the head mount.

Problems occurred (and are continuing to occur) in the PDP-7 teletypewriters and magnetic tape units, the chart recorders, the Develocorders, the compressor blower, the air conditioners, and in the humidifiers and blower motors due to the mechanical aging of these equipments. During this contract, both Develocorders were overhauled and refurbished. The compressor room blower motor was replaced and the humidifier and two air conditioners were repaired.

Numberous repairs were necessary on the PDP-7 magnetic tape units; the vacuum motors in all three have deteriorated and are awaiting replacement. One problem, air leaks through cracks in the rubber pressure hoses, has been corrected by the use of a different type reinforced hose. Several of the capstan assemblies have clogged air holes and are awaiting replacement; two internal and two external air compressors have been overhauled. Many air couplers and transducers have been either repaired or replaced. The tape drive hub and unit door assemblies were overhauled on two tape units. One servo motor has been replaced and others show evidence of wear. This wear-out due to the ageing of mechanical components should be anticipated to continue.

The 8 channel chart recorders in MDC-1 and 2 required bias battery replacement on 66 occasions. These units are functional 24 hours a day and this consumption is considered reasonable. As used on the zero suppression amplifiers, these batteries have a life expectancy of 1,200 hours, there being 16 of them installed.

6.3 Maintenance Center

Effort at the LMC was directed toward the timely repair of array systems failures, completion of the preventive maintenance schedule, rehabilitation of WHV seismic amplifiers, and shop level repairs of all the defective assemblies removed from the array. Travel by LMC personnel in support of these efforts resulted in 414 field trips covering 66,164 miles throughout the array's roads and trails and eight trips to the USAF PMEL at Great Falls, Montana to pick-up and deliver test equipment for repair and calibration.

The scheduled preventive maintenance program includes all items that are not checked by telemetry or by diagnostic programs. Although the schedule is based on requirements, such considerations as weather, work load, and man-hours available affect the number of preventive maintenance procedures completed each month. Further, all the three programmed modifications described in Section V were completed by LMC personnel.

Rehabilitation of the WHV seismic amplifiers, i.e. the RA-5 is considered as phase one of the SP array sensor maintenance programs. To date all subarrays have been serviced with amplifier rehabilitation at least once and they will continue to be scheduled for this type attention into the ensuing contract period. As the success of the program becomes more evident, the phase one activity will require less and less effort from the LMC personnel. In addition to the amplifier maintenance, phase two will commence in 1972 with the replacement of out-of-tolerance seismometers.

A total of 196 work orders were completed during this contract in support of the SP sensor maintenance program. Accomplished at the WHV, these included either adjustments on or replacement of the WHV panel, which contains the RA-5 amplifier and other sensor channel circuitry.

Replacements resulted in the reconditioning of 60 amplifiers and panels at the LMC. The RA-5 amplifier failures observed were mainly output instability and low gain. The prime cause detected for the instability problem was the malfunctioning of feedback network involving both the feedback and signal bridges. In most cases, correction was effected by replacement of the bias batteries (B1, B2, and B3) and trimmer capacitors (C1 and C2). The most frequent cause of amplifier low gain has been the failure of one or more of transistors (Q1-Q4) in the IF amplifier. In the WHV panel circuitry, the seismometer output equalization resistors have been the prime source of channel failure. These 40,000 ohm variable resistors are the slider type and failures are due to corrosion and mechanical opens at the point of contact of the slider with the wire wound resistor body. Since the resistor adjusts the level of low voltage seismometer output and controls the balance of the differential input signal into the RA-5, this control is being replaced by a 50,000 ohm dual adjustment potentiometer.

One SP seismometer replacement at location D1-83, is of interest. This seismometer responded well to the electromagnetic calibration signal; however, the outputs from actual seismic events were very low. Disassembly of the seismometer revealed water in the inner case. A total of fifteen HS-10-1/A seismometers with cable assemblies were refurbished at the LMC. These units were cleaned, repaired, adjusted for proper natural frequency, potted, and pressure tested. The distribution of failures was: water leakage, 7; balance spring, 5; improper natural frequency, 2, and; open data coil, 1.

Sensor cabling repairs were required on three occasions. Subarray E1 leg 6 cables were cut by a county road crew and a rancher cut the leg 1 cables at F2. In both cases a new section of cable was spliced in and retrenched. Damage to the C2 microbarograph cable by a rodent required splicing.

Channel dc offsets are now being measured by the PDP-7 computer DCOFF program. Adjustments and repairs of these out-of-tolerance conditions form a part of a continuing maintenance quality control effort; all reported offsets have been corrected. Channel offset, which can occur in both the SEM input and the multiplexer/ADC assemblies, usually is caused by the balance-to-unbalance amplifiers in the input drawers. During this period 21 input drawers and three multiplexers were either adjusted or repaired to place all channels within the ± 5 millivolt operational limits.

Nineteen SEM control drawer failures occurred. Of these, 17 were instances of loss of the analog calibration and measure capability provided by the Control Drawer and were caused by shorted SQ-10a operational amplifiers. This op amp has a history of failure during the hot summer months. When the environmental temperature of the amplifier is high, but still within amplifier specifications, there is a tendancy for the internal bypass capacitors across the B+ inputs to short to ground causing the power supplies to load down. The same problem does not occur with an SQ-5 type operational amplifier used in the same drawer. Tests were conducted at LMC where the SQ-5 and SQ-10a were found to be interchangeable. One SQ-5 was heated to 65°C for two days and its operation remained stable, thus in the future the SQ-5 will be used as a replacement for the SQ-10a.

The status of the short period channels at the end of the contract is shown in Table XXXVII. This information will be used for scheduling maintenance for the next contract period.

Calibration response refers to the continuing plot of weekly calibration data of the channels. This plot indicates the stability of the RA-5 amplifiers. An amplifier is considered unsatisfactory if it will not maintain the 20 ± 3 mV/nm sensitivity tolerance.

During the phase one sensor preventive maintenance schedule SP rehabilitation, the natural frequency of the seismometer is measured and the damping ratio adjusted. If the damping ratio is beyond adjustment, the seismometer is replaced. If the natural frequency is not within the 1 Hz ± 10% tolerance the seismometer is considered unsatisfactory and will be scheduled for rehabilitation. Since the natural frequencies of all the seismometers in the array have not been measured, the number reported in the table is not yet complete.

Additionally, during the phase one effort the period vs sensitivity is measured for each channel (except attenuated channels) and a plot prepared as in Figure 4.2. If there is a major departure from the nominal, the channel is considered unsatisfactory and will be scheduled for further investigation. The response curve can be affected by the seismometer, amplifier, or SEM channel.

A seismic event that occurred on 14 September 1971 was recorded and played back on all channels. The event was used to determine proper earth motion recorded (polarity) and signal amplitude of the event. At that time all channels were of the proper polarity and no major amplitude variances were noted.

6.4 Facilities Support

6.4.1 Program Supporting Structures

The comprehensive provision and maintenance of two building structures, 1) LASA Maintenance Center (LMC) at Miles City, Montana and 2) LASA Data Center (LDC) at Billings, Montana was continued on a lease basis during the period of this contract. Each building with circa 6,000 sq. ft. floor space adequately accomodated all hardware, vehicles, personnel, and administrative and logistical functions.

6.4.2 Surficial Land Maintenance

Periodic inspections of surficial land conditions were made during this contract period. This work is performed to insure access

TABLE XXXVII

SP CHANNEL STATUS, 30 NOV. 71

SUBARRAY	CALIBRATION RESPONSE		NATURAL FREQUENCY		SENSITIVITY RESPONSE		SEISMIC EVENT POLARITY		SEISMIC EVENT AMPLITUDE	
	SAT.	UNSAT.	SAT.	UNSAT.	SAT.	UNSAT.	SAT.	UNSAT.	SAT.	UNSAT.
AO	14	3	9	7	13	3	17	0	17	0
B1	13	4	11	5	15	1	17	0	17	0
B2	14	3	12	4	14	2	17	0	17	0
B3	14	3	14	2	7	9	17	0	17	0
B4	16	1	11	5	10	6	17	0	17	0
C1	12	4	12	3	13	2	16	0	16	0
C2	14	3	12	4	12	4	17	0	17	0
C3	16	1	12	4	12	4	17	0	17	0
C4	12	5	14	2	13	3	17	0	17	0
D1	15	2	13	3	12	4	17	0	17	0
D2	20	1	19	1	19	1	21	0	21	0
D3	13	4	14	2	12	4	17	0	17	0
D4	17	0	16	0	11	5	17	0	17	0
E1	16	1	12	4	15	1	17	0	17	0
E2	11	6	14	2	13	3	17	0	17	0
E3	22	3	25	0	23	2	25	0	25	0
E4	14	3	13	3	14	2	17	0	17	0
F1	15	2	15	1	14	2	17	0	17	0
F2	11	5	11	4	9	6	16	0	16	0
F3	13	4	13	3	14	2	17	0	17	0
F4	16	1	11	5	11	5	17	0	17	0
TOTAL	308	59	283	64	276	71	367	0	367	0

to sensor sites in this rural area where the use of dirt trails is predominate and accordingly must be maintained. This region includes much rugged terrain where erosion is a frequent problem, thus regular inspections insure that other conditions such as exposed cables and sensor surface landscaping is properly taken care of. This effort includes establishing and maintaining rapport with landowners which is in the best interest of the program to insure that surficial land conditions and exposed equipment are maintained without complaint. See Table XXXV for a summary of workorders which reflect the accomplishments of the land maintenance effort.

6.4.3 LASA Lease Agreements

Ninety-three (93) lease agreements were again renewed during this contract period. In general, the terms of these agreements include the use of an area 150 ft. x 150 ft. at each sensor and at each subarray central, cable right-of-way, access to these sites, the right to place and use seismic and related equipment at each site, the responsibility for maintaining surficial landowner property effected by the program such as sensor site landscaping, trails, fences and gates and the responsibility to maintain safeguards against injury or damage to landowner property and livestock.

To maintain effective liaison with landowners there were two hundred and six (206) rancher visits within the array area during this contract period. One landowner claim was handled during this period. This resulted from the death of a baby calf which entered a subarray site and died of starvation when it could not get out of the enclosed area.

6.4.4 CTH Vault Maintenance

There is evidence that several Central Terminal Housing (CTH) vaults have sustained cracked wall damage from prior winter frost conditions allowing water leakage into them. During the spring of 1971, 5 CTH vaults were treated with heavy surface applications of bentonite, a chemical with sealing properties. At the close of this contract, no recurrence of leakage has been noted and it is expected that the use of this chemical will be realized as an adequate remedial measure for sealing these breaks in the vault walls.

6.4.5 Vehicles

A fleet of five four-wheel drive Ford F-100 trucks with power winches, radio telephones, spare fuel tanks and other emergency equipment was maintained at all times for the various array maintenance functions. With these vehicles all of the necessary program field related travel requirements were met. Vehicular activity during this contract period consisted of 75,000 miles safely driven in the conduct of LASA maintenance under varying conditions of roads and weather. Only one accident occurred during this reporting period when a bull emerged upon a state highway causing an unavoidable colision. Minor vehicle damage was sustained with no injury to personnel.

SECTION VII

ASSISTANCE PROVIDED TO OTHER AGENCIES

7.1 Seismic Data Laboratory

Develocorder film recording of the data from a selected number of SP sensors for the Seismic Data Laboratory (SDL) began this quarter. Weekly shipments totaling 158 films were sent to SDL together with the operating logs and calibration data. Each film covers a period of approximately twenty-four hours; film change is made at about 2200 GMT. The format of the film recordings are as follows:

Develocorder Channel	Signal Input
1	Vela time code
2	Site F4 sensor 10
3	Site F1 sensor 10
4	Site F3 sensor 10
5	Site F2 sensor 10
6	Site AO sensor 10
7	Site E3 sensor 10
8	Site E3 sensor 82
9	Site E3 sensor 84
10	Site E3 sensor 86
11	WWV time code

The block diagram of the system employed is shown in reference 11. The data center analog system converts the digital signals from the array to analog for recording on the Develocorder. Calibration of the complete seismograph channel from the seismometer through to the Develocorder is performed using the PDP-7 computer program DEVCAL (see Appendix A.7) once for each film, usually at the start of the film.

Assistance to SDL is also provided by the recording and shipment of microbarograph array and related digital data recorded by the PDP-7 computer's incremental recorder. This recording system and the record format are described in detail in reference 11.

7.2 Weather Bureau

Hourly weather information obtained from sampling the outputs of the array's twenty-six temperature, wind direction and speed, barometric pressure and rainfall sensors were transmitted via TWX from the data center's PDP-7 computer to the Billings weather bureau office until September 20, 1971. Now, at the request of the local meteorologist, reports are made by telephone. The details of the weather sensors and instrumentation (Ref. 7) and the TWX format (Ref. 8) have previously been reported.

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7.3 MIT Lincoln Laboratory

Changes are made to the channel assignments on the ten channel FM link between the data center and MIT as they are requested by Lincoln Laboratory. The present channel assignments are:

FM Channel	Signal Input
1	Subarray F1 short-period sensor 10, word 01
2	Subarray F2 short-period sensor 10, word 01
3	Subarray F3 short-period sensor 10, word 01
4	Subarray F4 short-period sensor 10, word 01
5	Subarray F4 long-period vertical, word 26
6	Subarray E1 short-period sensor 10, word 01
7	Subarray E2 short-period sensor 10, word 01
8	Subarray E3 short-period sensor 10, word 01
9	Subarray AO short-period sensor 10, word 01
10	Subarray F4 short-period attenuated sensor 10, word 22

The system provides continuous on-line data transmission to MIT for array analysis.

7.4 Visitors

Visitors to the Montana LASA during the fourth quarter were:

(1) G. Douglas, J. Buckley, G. Windschell, D. Aichele, and L. Allsup of Mountain Bell, 1 September 1971 to observe system operation.

(2) L. Littlepage, Mountain Bell, September 3, 1971 to coordinate communication outage reporting procedures.

(3) G. Sykes, Philco-Ford, C&TS Division, 15 September 1971 to audit local accounting procedures.

(4) L. Sargent, MIT Lincoln Laboratory, 24 September 1971 to install and align FM link equipment.

(5) J. Alston, Contracts Compliance Specialist, DCASD, Seattle, 27 October 1971 to review Philco-Ford's Billings office EEO compliance and Affirmative Action Program.

SECTION VIII

DOCUMENTATION PROVIDED UNDER VT1708

8.1 Technical Reports

As required by the CDRL, eight monthly reports, each entitled "Operation and Maintenance of the LASA, Monthly Progress Report" were distributed for each month in which a quarterly technical report was not required. Three quarterly technical reports plus this final report which includes the fourth quarterly period were published and distributed. These reports included:

(1) Montana LASA First Quarterly Technical Report, Project VT1708, T/R2039-71-01 (AD882818) 12 Mar. 71.

(2) Montana LASA Second Quarterly Technical Report, Project VT1708, T/R2039-71-07 (AD885649) 15 June 71.

(3) Montana LASA Third Quarterly Technical Report, Project VT1708, T/R2039-71-10, 15 Sept. 71.

Other technical reports and letters submitted to the project office are identified in the above three quarterly reports.

8.2 Operations Data

Operations data distributed from the LDC included:

52 weekly issues of the Defective Signal Channel Status Report,
52 weekly issues of the LASA Data Interruption Logs,
1 issue of the Array Status Report,
2 issues of the Array Modification Status Report,
23 weekly issues of Develocorder operations logs.

8.3 Alternate Management Summary Reports

Twelve Alternate Management Summary Reports (AMSR) were distributed; one for each month of the contract period.

APPENDIX A

PDP-7 OVERLAY PROGRAM DESCRIPTIONS

A.1	TESP
A.2	TELP
A.3	MASPOS
A.4	FREECK
A.5	DCOFF
A.6	BATCK
A.7	DEVCAL

APPENDIX A

PDP-7 OVERLAY PROGRAM DESCRIPTION

A.1 TESP

Program TESP provides an on-line program for automatic measurement of the SP seismograph sinusoidal calibrations. By proper telemetry control and measurement, the PDP-7 computer performs the following tasks during the running of TESP.

(1) Determines the peak-to-peak amplitude of the sinusoidal calibration inputs to the short period seismometers.

(2) Calculates peak-to-peak amplitudes using the values from step (1) and the measured level of the calibration input signals to standardize the input level so that improper channel responses may be determined readily.

(3) Calculates the channel sensitivity for each of the SP seismographs using the responses measured in step (1).

(4) Compares the positive and negative portions of each cycle of the calibration responses to determine distortion and offset of the seismograph output.

(5) Calculates the sensitivity mean and standard deviation for all the SP seismographs operating within a specified range.

Since the telemetry is sequentially applied to each subarray for 30 seconds, the total run time for the program to complete the array is 10.5 minutes. The program outputs are (1) a paper tape formatted to contain the results of all previously indicated calculations, and (2) a playout of all signals through the computer's Serial Output Unit. The paper tape is processed on an off-line printer to provide hardcopy printouts for maintenance, quality control and array performance evaluation purposes. The playouts permit a visual inspection of the calibration responses to observe signal quality and noise level. (Since the seismometer cannot be decoupled from the earth motion during the electromagnetic calibration, the test is invalid if the seismic noise level is high.) In addition to the described measurements, the program run daily provides a good status check on all the array systems (except the LP seismographs) from a single, short data interruption.

TESP, on paper tape, is loaded during PDP-7 MOPS operation. The computer controls the sending of telemetry TC06 sequentially through the array; the sequence is A0, B1, B2, ..., F4.

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Of the 30 seconds or 30 cycles of calibration response from the sinusoidal signal into the seismometer, the computer uses 25 cycles to determine the average peak-to-peak signal amplitude. The relationship used in this determination is

$$A_{ch} = \frac{\sum_{i=1}^{50} (X_i)_{ch}}{\sum_{i=1}^{50} (X_i)_{30}} \times C \qquad \text{(A-1)}$$

where A_{ch} is the peak-to-peak amplitude,

$(X_i)_{ch}$ is the bit value of the i^{th} peak of 25 cycles of the sinusoidal signal for a normal SP channel,

$(X_i)_{30}$ is the bit value of the i^{th} peak of the 25 cycles of the sinusoidal signal for the reference word 30,

C is the nominal value of channel 30 response to the calibration signal. The units of C determine the units of A_{ch}, e.g. 35.71 for chart divisions and 10.0 for volts.

The channel sensitivity is calculated from

$$S = \frac{708}{1000} A_{ch} \qquad \text{(A-2)}$$

for all SP seismographs except the attenuated channels on data word 22. The attenuated channel sensitivities are calculated using

$$S = \frac{354}{10000} \times A_{22} \qquad \text{(A-3)}$$

where S is the channel sensitivity at 1 hertz in mV/nm,

A_{ch} is the SP channel amplitude response during TC06 calibration in div. p-p,

A_{22} is the attenuated channel amplitude response during TC06 in div. p-p.

The ratio of the positive half-cycle samples to negative half-cycle sample values are calculated to provide a simple check on the signal distortion and offset present in each seismograph response. The final calculation determines the sensitivity mean and standard deviation for the array of SP seismographs. These provide an easy measure of the array's performance on a daily basis over an extended period.

A.2 TELP

Program TELP provides an on-line program for automatic measurement of the LP seismograph sinusoidal calibrations. By proper control of the LASA telemetry, the PDP-7 computer performs the following operations:

(1) Measures the peak-to-peak amplitude of the responses from separate sinusoidal calibration inputs to the long-period seismometers, the seismic amplifier, and the SEM signal - conditioning amplifier.

(2) Calculates peak-to-peak amplitude values from these calibration signal measurements based on a standardized input level to permit ease in determining improper channel responses.

(3) Calculates the channel sensitivity for each of the 51 seismographs using the amplitude responses measured in (1) above.

(4) Calculates the mean and standard deviation of channel sensitivity for the array's 45 standard LP channels.

(5) Calculates the gain of each seismic amplifier and of each signal conditioning amplifier.

(6) Calculates the equivalent peak-to-peak earth motion of the sinusoidal signal into each seismometer.

A hard copy printout is produced for identifying the times the LP array was interrupted for calibration and for study of the systems performance. The run time for this program totals 72 minutes.

The program is loaded into the computer by paper tape during MOPS operation. The computer sends telemetry for controlling the calibration signal input into the LP seismograph channels at three different points according to the sequence listed below:

A0 & C1	TC20 input to seismometer	3 minutes
A0 & C1	TC22 input seismic amplifier	3 minutes
A0 & C1	TC29 input to signal conditioner	2 minutes
C2 & C3	TC20 input to seismometer	3 minutes
.		
.		
.		
F2 & F3	TC29 input to signal conditioner	2 minutes
F4	TC20 input to seismometer	3 minutes
F4	TC22 input to seismic amplifier	3 minutes
F4	TC29 input to signal conditioner	2 minutes

The signals are played out through the Serial Output Unit to display the calibration responses for visual inspection of data quality.

Using 2000 samples or four cycles of the 25 - second sinusoidal response, the peak-to-peak amplitude is determined from

$$A = \frac{\sum_{i=1}^{2000} x_i}{4167} \qquad \text{(A-4)}$$

where A is the average peak-to-peak value of the sinusoid to the nearest hundredth of a chart division, ·0.28 volt/division,

x_i is the decimal word value of the i the sample of the sinusoid response from an LP seismograph.

The LP system parameters indicated in (3), (4), (5), and (6) above are calculated and punched out on paper tape for off-line listing. The calculation of channel sensitivity uses this relation

$$S = 502240 \times \left[\frac{A_{ch}}{A_{30}}\right]_{TC20} \qquad \text{(A-5)}$$

for all subarrays except C2. For the three seismographs at C2, the channel sensitivity is calculated from

$$S = 394300 \times \left[\frac{A_{ch}}{A_{30}}\right]_{TC20} \qquad \text{(A-6)}$$

where S is the sensitivity in mV/μm

$$\left[\frac{A_{ch}}{A_{30}}\right]_{TC20}$$

is the ratio of the amplitudes of the TC20 calibration responses for the seismograph channel to the reference or word 30 channel.

The calculation of seismic amplifier gain uses

$$G = 21460 \times \left[\frac{A_{TC22}}{A_{TC29}}\right]_{ch} \times \left[\frac{A_{TC-29}}{A_{TC-22}}\right]_{30} \qquad \text{(A-7)}$$

where G is the gain

$\left[\frac{A_{TC22}}{A_{TC29}}\right]_{ch}$

is the ratio of the amplitude response during TC22 to the amplitude response during TC29 for each amplifier channel.

For the signal conditioning amplifier the gain is determined from

$$G = \left[\frac{A_{ch}}{A_{30}}\right]_{TC29} \qquad \text{(A-8)}$$

where $\left[\frac{A_{ch}}{A_{30}}\right]_{TC29}$

is the ratio of the amplitude response of the amplifier channel to the amplitude response of the reference channel during TC29 calibrations.

The equivalent earth motion of the calibration input is calculated from

$$Y = \frac{5544}{10000} \times (A_{30})_{TC20} \qquad \text{(A-9)}$$

for all seismographs except at subarray C2. At C2 the equivalent input is determined from

$$Y = \frac{6987}{1000} \times (A_{30})_{TC20} \qquad \text{(A-10)}$$

where Y is the peak-to-peak equivalent earth motion in μm

$(A_{30})_{TC20}$

is the amplitude of the signal on the reference channel during TC20 calibrations

The sensitivity mean and standard deviation statistics of the test are determined for the LP array using the sensitivities of all LP seismograph except the six with special responses at subarrays C1 and C2.

A.3 MASPOS

Program MASPOS provides an on-line program for automatic mass position measurement of the 51 LASA LP seismometers. By proper control of the LASA telemetry, the PDP-7 computer measures the mass position of each seismometer and, at operator request, recenters the mass positions. The hard copy printout from this program provides a record of system operation. This program is normally run once each week and has a maximum running time of 15 minutes.

The program is loaded into the computer by paper tape during MOPS operation. Following initialization, the mass positions of the seismometers are measured. First, telemetry TC-31 is sent to all sites to measure the output from the mass positions monitor circuits of the vertical seismometers. The computer selects a sample value of word 30 from each subarray and calculates the mass positions using the relation

$$\text{Mass Position} = \frac{(\text{Word 30 value}) \times 50}{3278} \qquad \text{(A-11)}$$

The constants in this relation convert the vertical mass position monitor outputs to mass position measurements in chart divisions. One mm mass position away from center produces an output on word 30 of one volt or 3.571 chart divisions. The computer stores these 17 vertical seismometer mass positions and proceeds to measure the horizontal seismometer mass positions. The procedure is the same except for the telemetry; the north-south horizontals require TC-32 and the east-west horizontals, TC-33. All 51 values are then printed out.

The operator reviews the printout to determine if any masses need to be recentered. Mass positions are maintained within ± 1.4 mm or ± 5.0 chart divisions of center. The program is continued by the operator request to correct the out-of-tolerance mass positions. The computer performs readjustments of the seismometer masses as necessary sequencing the subarrays from A0 through F4 first for the verticals, then the north-south horizontals and finally the east-west horizontals. For each adjustment required the program determines which direction the mass needs to be moved, initiates either telemetry TC-45 for positive mass motion control or TC-46 for negative motion control, then following a one second pause inserts the mass adjustment telemetry (TC-47 for vertical seismometers, TC-48 for north-south horizontal and TC-49 for east-west horizontal.) for an appropriate time period to complete the necessary readjustment. The length of time (T) in seconds is determined from the number of divisions (N) in which the mass is displaced from center according to the relation, T = 0.125N. Following each readjustment the computer checks the mass position to determine if the mass is within ± 2 divisions or ± 0.56 mm from center. If not, the computer will attempt adjustment up to six additional times. Then if unsuccessful, the program moves to the next seismometer requiring correction. Figures 3.6 and 3.8 show examples of the printouts obtained from this program.

A.4 FREECK

Program FREECK provides an on-line program for automatic free period measurement of the 51 LASA LP seismometers. By proper control of the LASA telemetry, the PDP-7 computer measures the average free-period of each seismometer, provides a playout from the computer's serial output unit (SOU) for signal display, and a hard copy printout for a record of system operation. This program is normally run once each week and has a maximum running time of 25 minutes.

The program is loaded into the computer by paper tape during MOPS operation. Following initialization, four sites are selected at a time viz., A0, C1-C4, D1-D4, E1-E4, and F1-F4, for five telemetry control sequences by the computer. When the telemetry command is sent, a two minute wait loop is started to allow time for the external damping resistance to be removed and the mass to be positioned away from center. The mass is then released and the first zero crossing of the output signal is detected. This zero-crossing time is stored and a counter set to indicate ten more zero crossings. The time of the tenth crossing is compared with the initial time to determine the total elapsed time of the five cycles or ten crossings. Dividing this elapsed time by five gives the average free period. The calculation is printed out to the nearest tenth of a second together with the start and stop times in which the telemetry was applied.

A.5 DCOFF

Program DCOFF provides an on-line program for automatic measurement of the dc offset voltages on all short-period channels at either the SEM input or SEM multiplexer drawers. The LDC operator determines the site or sites to be tested and the computer controls the telemetry. Since each of the two telemetry commands used in the dc offset measurement are inserted for only one second, the actual data interruption time is minimal. This program is normally run once each month for each subarray and requires a maximum of five minutes to completely check all the array's channels. The hard copy printout is provided to the maintenance supervisor for appropriate corrective actions if required.

The program is loaded into the computer by paper tape during MOPS operation. Following initialization, the LDC operator selects which site or sites to be tested and which telemetry either TC-03 or TC-05 or both are desired. Telemetry TC-03 applies zero volts at the input of the multiplexer channels for a test of the SEM multiplexer and A/D converter while TC-05 applies zero volts at the input of the SEM input circuits for a test of the entire SEM analog-conditioning circuitry. The computer then controls the sending of the telemetry command to the selected subarray. A sample data response word from each SP data channel is brought into the computer where multiplication by 0.4273 occurs to convert the positive or negative digital word value to millivolts of offset.

A.6 BATCK

Program BATCK provides an on-line program for an automatic battery voltage measurement of the 21 subarray power systems. The PDP-7 computer controls the telemetry to the subarrays to effect the measurement and prepares a hard-copy printout for a record of system operation. Normally run once each week, this program has a maximum run time of approximately one minute.

The program is loaded into the computer by paper tape during MOPS operation. Following initialization, the computer sends telemetry TC-63 to all subarrays simultaneously. At the subarray the SEM control drawer multiplexer connects the battery voltage sensor which converts the 0-40 volt battery voltage range to a 0-7 volt range to SEM channel 30. The computer reads the digital values (N) transmitted from each subarray on word 30 and calculates the battery voltage (B) from

$$B = \frac{1000N}{4096} . \qquad \text{(A-12)}$$

The printout shows the power system measurements to the nearest hundredth of a volt.

A.7 DEVCAL

Program DEVCAL provides an on-line program for calibration of a selected SP seismograph channels which operate with a Develocorder. This program is run daily and requires approximately 30 seconds of run time.

Following an interchange of a signal cable in the analog system, the program is loaded into the computer by paper tape during MOPS operation. The operator selects the subarrays to be used in the calibration. The computer then sends telemetry TC-06 to these sites sequentially three at a time for five seconds each. The seismograph channel responses are brought into the computer, divided by ten, and played out through the Serial Output Unit to the Analog System for input to the Develocorder.

Since the dynamic range of this film recorder is less than the digital channels, saturation occurs on the Develocorder channels during normal TC-06 SP sinusoidal calibrations. DEVCAL overcomes this by providing a lower level signal into the Develocorder and also permits a calibration which includes the seismometer as well as the Develocorder.

APPENDIX B

ARRAY COMMUNICATIONS COST REDUCTION STUDY

APPENDIX B

ARRAY COMMUNICATIONS COST REDUCTION STUDY

A study of methods to reduce the operating costs of the array communications systems has been made. This study has investigated three different approaches to cost reduction, viz., (1) eliminating subarray data circuits by eliminating subarrays from the array, (2) replacing the existing wideband data circuits with narrowband circuits after reducing the data rate requirements of the circuits, and (3) reducing the number of wideband data circuits required by merging two subarray data bit streams into one data circuit. Before discussing considerations of each of these approaches, a brief description of the array communications and the associated costs is presented.

B.1 Review of Array Communications

The communication systems which provide the interface between the array's sensing instruments and the data center's processing equipment are reviewed in this section by a description of the telephone company facilities used and their related costs.

B.1.1 System Description

Array communications systems provide full-duplex communications between each subarray and the data center for both voice and data. Also, a wideband communications link is provided between the Miles City maintenance center and the Billings data center. Data transmission is over both open wire lines and microwave links. The communications system routing is shown in Figure B-1. This figure shows the segments which are open wire and which are microwave.

Each subarray has a single pair of open wire lines which connect a common carrier junction with a wideband microwave system. Fifteen subarrays connect with the Lenkurt Type 76A microwave terminal near the center of the LASA at Angela. Four sites connect with Type 76A system at Angela junction, west of Miles City, from the Miles City main office. These 19 sites are on the same radio system to the Forsyth microwave junction where they are joined by two more from the Forsyth main. From Forsyth to the Billings microwave junction these 21 data channels are on the Lenkurt 76A radio system. One subarray, F1, which connects at the West Glendive junction is handled by a TD2 system to the Billings junction. Between the Billings junction and Billings main, the 22 data channels are divided between two TD2 systems. Each subarray utilizes a one-half group bandwidth.

Over the open wire lines, data transmission leaving the subarray is in the band 28 to 44 kHz, using A.M. vistigial sideband

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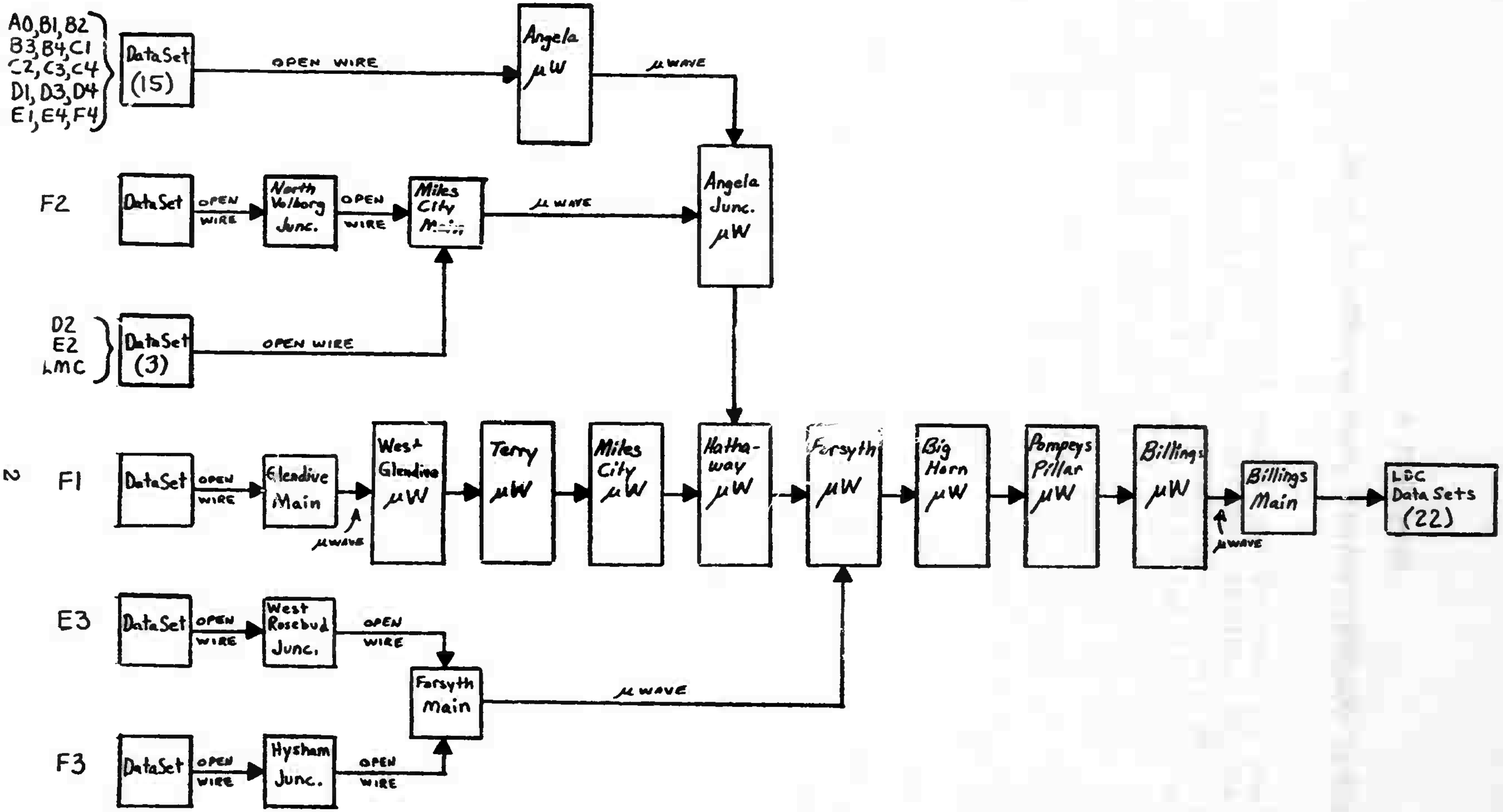

Figure B-1 LASA Data Communications Routing modulation techniques which permit the 19.2 kHz modulation rate in the 16 kHz of bandwidth. Incoming to the subarray, the band 5 to 18 kHz is used for data. The two-way voice circuit is handled in the band below 4 kHz.

The microwave radio links are modulated by a carrier multiplex system. The three-step modulation plan employs a scheme of half-group, group, and super-group frequencies. Each subarray is assigned to a half-group channel which is equivalent to six telephone voice channels of 4 kc each. A single-sideband, suppressed carrier output from each channel results from the modulation process and the frequency selective filters. The two channels or half groups occupy an output frequency range of 60 to 108 kc. Each of these groups modulates one of five group carriers. The outputs of the five single-sideband, suppressed carrier group modems combine in increments of 48 kc to form a basic super-group with a frequency range of 312 to 552 kc. The basic super-group information is used to modulate one of nine super-group carriers. There are ten super-groups allocated; however, since super-group 2 is transmitted directly at the basic super-group frequency, only nine super-group carriers are required. The ten super-groups combine into a baseband of 60 to 2540 kc. This baseband then is applied to the microwave radio system.

B.1.2 System Costs

The array communications as related to the present cost structure are diagrammed in Figure B-2. The equipment and line rental costs vary among the different subarrays. The subarray communications equipment charges differ with each of the four telephone operating companies. At fifteen subarrays, viz. A0, B1-B4, C1-C4, D1, D3, D4, E1, E4, and F4; the charge is $528 month/site. This rental charge includes the Angela microwave facility and no intersystem charges are made. At subarrays E3 and F2 the site equipment charge is $394.08 month/site with an interexchange charge of $196 month/site; the subarray F3 charge is $520 plus $196 for interexchange cost. A charge of $150 month/site is made for the equipment at subarrays D2, E2, and LMC and a Bell System exchange cost of $234 month/site; there are no open line charges for these sites.

Line charges are shown together with the monthly rentals of all the communications in Table B.1. For 14 of the 15 subarrays which input the Angela microwave station the charges are calculated at $12.19 month/mile; the line distance is the sum of the open wire line length and 15.85 miles of microwave to the meet point with the Bell System microwave. For subarray F4, the other subarray feeding into Angela, the line distance is the sum of 6.9 miles from the site to Jordan exchange, 47.0 miles on to the Rock Springs exchange, 11.0 miles on to the Angela microwave, and 15.85 to the microwave meet point. For subarrays E3 and F2 the line charges are $16.08 month/mile and for subarray F3, $18.00 month/mile. Subarray F1, at $12.19 month/mile, has a line distance of 13.0 miles from the site to Lindsay exchange and from Lindsay

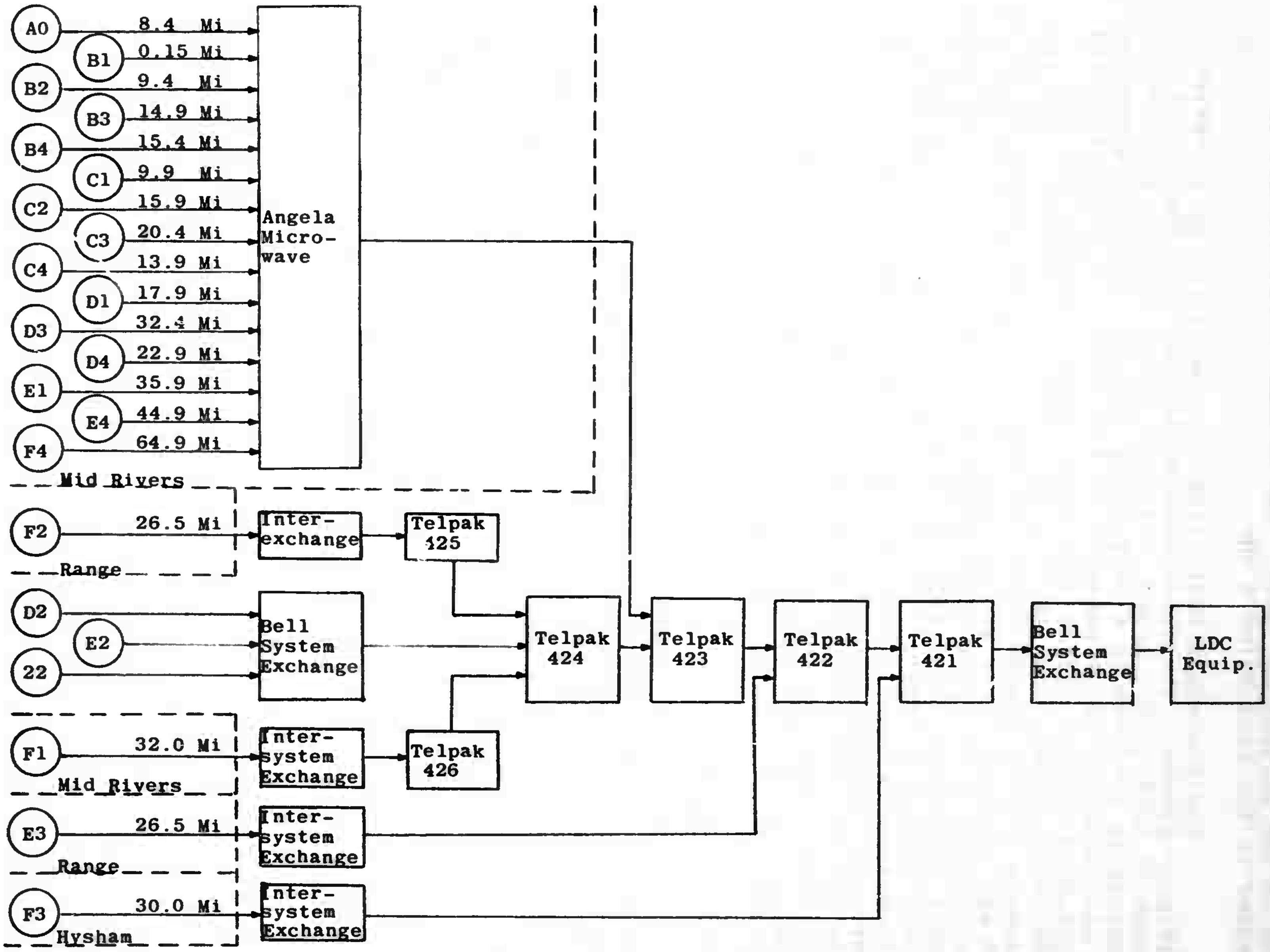

Figure B-2 Array Communications Structured According to Cost Elements

TABLE B.1

MONTHLY RENTALS FOR LASA DATA COMMUNICATIONS

SITE	TELEPHONE COMPANY	SITE EQUIPMENT	LINES	INTEREXCHANGE FACILITIES	BELL SYSTEM EXCHANGE FACILITIES	TELPAK	BILLINGS EXCHANGE FACILITIES	DATA CENTER EQUIPMENT	TOTALS
AO	Mid Rivers	528.00	295.61	-	-	287.52	99.00	135.00	1,345.13
B1	" "	528.00	195.04	-	-	287.52	99.00	135.00	1,244.56
B2	" "	528.00	307.80	-	-	287.52	99.00	135.00	1,357.32
B3	" "	528.00	374.84	-	-	287.52	99.00	135.00	1,424.36
B4	" "	528.00	380.94	-	-	287.52	99.00	135.00	1,430.46
C1	" "	528.00	313.89	-	-	287.52	99.00	135.00	1,363.71
C2	" "	528.00	387.03	-	-	287.52	99.00	135.00	1,436.55
C3	" "	528.00	441.89	-	-	287.52	99.00	135.00	1,491.41
C4	" "	528.00	362.65	-	-	287.52	99.00	135.00	1,412.17
D1	" "	528.00	411.41	-	-	287.52	99.00	135.00	1,460.93
D2	Mountain Bell	150.00	-	-	234.00	352.52	99.00	135.00	970.52
D3	Mid Rivers	528.00	588.17	-	-	287.52	99.00	135.00	1,637.69
D4	" "	528.00	472.36	-	-	287.52	99.00	135.00	1,521.88
E1	" "	528.00	630.83	-	-	287.52	99.00	135.00	1,680.35
E2	Mountain Bell	150.00	-	-	234.00	352.52	99.00	135.00	970.52
E3	Range	394.08	426.44	196.00	-	222.30	99.00	135.00	1,472.82
E4	Mid Rivers	528.00	740.54	-	-	287.52	99.00	135.00	1,790.06
F1	" "	528.00	390.08	196.00	-	1,402.52	99.00	135.00	2,750.60
F2	Range	394.08	426.44	196.00	-	577.52	99.00	135.00	1,828.04
F3	Hysham	520.00	540.00	196.00	-	147.30	99.00	135.00	1,637.30
F4	Mid Rivers	528.00	984.34	-	-	287.52	99.00	135.00	2,033.86
22	Mountain Bell	200.00	-	-	234.00	352.52	99.00	135.00	1,020.52
	TOTALS	10,256.16	8,670.30	784.00	702.00	7,720.00	2,178.00	2,970.00	33,280.46

to West Glendive junction to 19.0 miles. Line charges are not directly billed for the subarrays D2, E3, and the LMC.

The monthly charges for the six separate TELPAKS in use to handle the LASA circuits are shown below:

Telpak	421D	for	72	miles	at	$45	month/mile	costs	$2340
"	422D	"	34	"	"	"	" "	"	1575
"	423D	"	29	"	"	"	" "	"	1305
"	424C	"	13	"	"	25	" "	"	325
"	425C	"	15	"	"	15	" "	"	225
"	426A	"	70	"	"	15	" "	"	1050
									$6820

The equipment charges at the Billings array terminal include $99 month/subarray for Bell System Exchange facilities and $135 month/subarray for the data center data communications equipment.

B.2 Approaches to Cost Reduction

Three approaches to reducing the array communications costs have been studied; these are discussed in this section.

B.2.1 Communication Channel Elimination by Removal of Subarrays

The first method of communications cost reduction considered was subarray elimination. The cost savings cannot be determined directly from Table B.1 since the TELPAK costs are based on channel groupings rather than by channel. Therefore, the cost savings from each alternative subarray elimination must be determined separately.

Using the assumption that array symmetry should be maintained, cost savings from the subarray eliminations by ring have been calculated. Table B.2 shows the cost breakdown for the elimination of the four subarrays in the B, C, D, E, and F rings individually. Savings greater than the simple sum are realized when the elimination includes two or more array rings. This additional savings results from reduced TELPAK charges. The affect on the TELPAK arrangement by various subarrays elimination schemes is shown in Table B.3 where the required number of equivalent telephone channels is indicated together with the letter designation of the TELPAK necessary. In addition to the array data communications, the channel requirements include two channels for foreign exchange telephones, 252-0742 at the LMC and 232-1531 at the LDC. The non-linear rate of cost reduction on the TELPAK is indicated by the elimination of site 22 at the LMC in two of the alternatives where additional savings of 2% and 8.5% result depending upon the alternative selected, viz, B and C rings or B, C, and F-rings.

TABLE B.2

COST OF ALTERNATIVE SUBARRAY ELIMINATION SCHEMES

Cost Item	Present System	Elimination B-ring	Elimination C-ring	Elimination D-ring	Elimination E-ring	Elimination F-ring
Site equipment rent	10,256.16	8,144.16	8,144.16	8,522.16	8,656.08	8,286.08
Open-wire charges	8,670.30	7,411.68	7,164.84	7,198.36	6,872.49	6,329.44
Interexchange charges	784.00	784.00	784.00	784.00	588.00	196.00
Local exchange charges	702.00	702.00	702.00	468.00	468.00	702.00
TELPAK costs	7,720.00	7,720.00	7,720.00	7,720.00	7,720.00	6,380.00
Billings exchg. charges	2,178.00	1,782.00	1,782.00	1,782.00	1,782.00	1,782.00
Data Ctr. equip. rent	2,970.00	2,430.00	2,430.00	2,430.00	2,430.00	2,430.00
Total Monthly Cost	33,280.46	28,973.84	28,727.00	28,904.52	28,516.57	26,105.52
Monthly savings	-	4,306.62	4,553.46	4,375.94	4,763.89	7,174.94
Percentage savings	-	13	14	13	14.5	21.6

TABLE B.2

COST OF ALTERNATIVE SUBARRAY ELIMINATION SCHEMES

(CONCLUDED)

Cost Item	Elimination B-&C-rings	Elimination B-,C-,&D-rings	Elimination B-,C-,&F-rings	Elimination B-&C-rings & Site 22 (LMC)	Elimination B-,C-,&F-rings & Site 22 (LMC)
Site equipment rent	6,032.16	4,298.16	4,062.08	5,832.16	3,862.08
open-wire charges	5,906.22	4,434.28	3,566.14	5,906.22	3,566.14
Interexchange charges	784.00	784.00	196.00	784.00	196.00
Local exchange charges	702.00	468.00	702.00	468.00	468.00
TELPAK costs	7,720.00	7,140.00	5,800.00	7,720.00	3,660.00
Billings, exchg. charges	1,386.00	990.00	990.00	1,287.00	891.00
Data Ctr. equip. rent	1,890.00	1,350.00	1,350.00	1,755.00	1,215.00
Total Monthly Cost	24,420.38	19,464.44	16,666.22	23,752.38	13,858.22
Monthly savings	8,860.08	13,816.02	16,614.24	9,528.08	19,422.24
Percentage savings	26.6	41.5	50.0	28.6	58.5

TABLE B.3

AFFECT OF SUBARRAY ELIMINATIONS ON THE BELL SYSTEM TELPAK ARRANGEMENTS

TELPAK IDENT.	No. of channels and TELPAK required for elimination of indicated subarrays										
	None	B-ring	C-ring	D-ring	E-ring	F-ring	B-&C-rings	B-,C-&D-rings	B-,C-,& F-rings	B-,C-rings & Site 22 (LMC)	B-,C-,F-rings & Site 22 (LMC)
421	134-D	110-D	110-D	110-D	110-D	110-D	86-D	62-D	62-D	80-D	56-C
422	128-D	104-D	104-D	104-D	104-D	110-D	80-D	62-D	62-D	74-D	56-C
423	122-D	98-D	98-D	98-D	104-D	104-D	74-D	50-C	65-C	68-D	50-C
424	32-C	32-C	32-C	26-C	26-C	20-B	32-C	28-C	20-B	26-C	14-B
425	6-A	6-A	6-A	6-A	6-A	0-	6-A	6-A	Not Reg'd	6-A	Not Reg'd
426	6-A	6-A	6-A	6-A	6-A	0-	6-A	6-A	Not Reg'd	6-A	Not Reg'd

In considering the elimination of entire subarrays from the array by removing the telephone equipment, the effort has been to show only communications cost savings. The follow-up activities pertaining to the government's property control requirements, the proper protection or storage of the subarray electronics equipment, and the upkeep of the subarray facility have not been discussed. Each of these activities require special considerations based on the subarrays affected, the season the eliminations might be effected, and the duration, whether permanent or temporary.

B.2.2 Communications Channel Bandwidth Reduction

The next approach taken was to investigate methods of lowering the present data rate from 19.2 kilobits/sec to a data rate compatible with communications channels with less bandwidth and, hopefully, less cost.

Consideration of a lower data rate communications system is made possible by the changing of three communications parameters of the present system. These are:

(1) reducing the number of signal channels between the subarray and the data center from 32 to 16,

(2) reducing the signal sampling rate for each channel from 20 to 10 samples/second, and

(3) eliminating the data redundancy feature whereby bit 1 is transmitted in two bits as 10 and bit 0 as 01.

A review of the present communications system bit rate calculation shows that if these changes could be implemented a reduction in the data rate from 19,200 to 2,400 bits/second would be achieved.

For the minimum impact on the LASA data acquisition and processing hardware, the suggested new communication system would operate very similar to the present system but at reduced clock rates. This is possible because the digital word structure from the subarray is the same in both systems.

To accomodate this alternative communications system certain modification to the present LASA hardware are necessary. At the subarray, modifications to the SEM for the following purposes are required:

(1) change sampling rate of SEM multiplexer,

(2) change cut-off frequency of presampling filter at the SEM input,

(3) change the rate of the data signal at the SEM output,

(4) change the number of signal inputs to the SEM.

At the data center the modifications required are centered around the system timing. Considerable rework is necessary to convert from 19,200 to 2,400 bit/sec for the system clock.

The MODEM is the key to the proper implementation of this communications system change. Because of the open wire segments of the present system, modem selection is limited to one which can operate full duplex with two wires. Other requirements are external timing, a built-in diagnostic capability, and a means of data equalization. Several sources of modems including the Bell System have been contacted without success in locating a suitable unit.

First, the Bell System has no modem which will operate full-duplex at 2400 B/S over two wires. Their recommendation for this data rate is the 201B modem. However, this is a four-wire modem; it provides full duplex operation and offers phone (voice) capability as an alternate with the data and not simultaneously. Reviewing the four wire problem, Mid-Rivers Telephone Coop has indicated an unwillingness to install additional wire lines throughout their system; instead they plan to use only buried cable. The Mid-Rivers 1968 estimate to replace the two wires with a four wire system was: $658,156.75 for the buried, four wire cable; $25,000 for additionals; and $62,174 for the 201B data sets. The estimates from the Range and Hysham Cooperative would be additional to this.

Further comments regarding the Bell System communications include:

(1) There will be very little savings gained by lowering TELPAK costs. TELPAK savings are derived from the use of a large amount of bandwidth or channels. Conversely, to save costs by reducing the number of channels requires a very large reduction in bandwidth.

(2) The modem charges by the telephone company for a lower rate, less sophisticated modem would probably increase from the cost of the present 303A10 modem. This results from the low cost (relative to other 19.2 Kbaud systems) of the present system. Our rates are based upon the initial LASA tariffs and have not been increased. Correspondingly, the LASA modems have not been modified to the present Bell System standards for the 303A10; costs to modify only the 22 units at LDC is estimated at $16,000.

(3) An overall estimate made in 1968 to modify and change the present communications system throughout the array, including the four-wire buried cable, is in the cost range of $700,000 to $800.000.

B.2.3 Combining Subarray Data Links into Fewer Communications Channels

Study of methods to merge the subarray to data center communications links so that some of the 22 channels now in use might be eliminated was the final approach taken.

The geographical arrangement must be considered in this approach since interconnecting of the subarrays is necessary. The distances between the subarrays become a major factor. The minimum and maximum distances between the array rings and between subarrays within a ring are listed below:

A to B ring:	8.2 to 13.3 km
Between B ring:	11.8 to 14.2 km
B to C ring:	9.7 to 13.4 km
Between C ring:	20.6 to 23.1 km
C to D ring:	17.9 to 23.1 km
Between D ring:	36.4 to 44.3 km
D to E ring:	350.0 to 54.2 km
Between E ring:	79.4 to 89.5 km
E to F ring:	61.1 to 96.4 km
Between F ring:	124.1 to 164.2 km

Inspection of the list above indicates that if interconnecting costs are to be limited to a reasonable value, only subarrays in the B and C ring and AO should be considered. The possible two site combinations are AO/B4, B1/C2, B2/C3, B3/C4 for a total of four subarrays eliminated. If the present TELCO open wire lines passing between the subarrays be utilized, then additional site merges such as, AO/B2, B1/D1, C1/E1, C3/D3, C4/E4, and D4/F4 might be considered.

Implementing this approach requires (1) installation of communications links, viz., modems and cabling, between the subarray pairs, (2) modification of the subarray and data center processing equipment with data recognition circuits to control the input and output data of each of the two subarrays, and (3) reformatting the 19.2 Kbaud data frame to accomodate the subarray pair. The combination of two subarrays has been considered assuming a required configuration at each site of 9 SP sensor channels, 3 LP sensors, and 1 microbarograph. These 13 channels combined with the synchronization, telemetry response, and reference channels for each subarray require 16 channels. Since the present link has 32 channels, two subarrays could be handled. If additional subarray interconnections could be arranged, then some of the data reductions indicated in paragraph B.2.2, e.g. reduction of sampling rate and elimination of data redundancy might also be incorporated to accomodate the other subarrays onto the one 19.2 Kbaud link.

B.3 Comparison of Cost Reduction Approaches

The considerations for selecting one of the three communications cost reduction alternatives are summarized by the factors presented below. A decision on any approach would be based on the reactions of the VELA program to these factors. If the consideration is based entirely on achieving the minimum cost, including operating and implementing the alternative selection, then the first approach, whereby subarrays are eliminated from the array provides the best solution.

Factors for considering each of the three alternatives are as follows:

Alternative 1: Channel elimination by removal of subarrays

1. Reduces the number and affects the distribution of subarrays.
2. Reduces the number of both SP and LP sensors.
3. Reduces the communication monthly operating cost.
4. Requires minor PDP-7 programming changes.
5. Provides telemetry channels at the remaining subarrays for future sensor expansion.
6. Retains the existing LASA system proven designs.
7. Requires minor programming changes for LDC and SAAC 360 computers.

Alternative 2: Channel bandwidth reduction

1. Reduces the number of SP sensors.
2. Reduces the data sampling rate for each sensor channel.
3. Eliminates the bit redundancy in the subarray data output.
4. Eliminates the simultaneous voice and data communications between the subarray and data center.
5. Requires PDP-7 programming changes.
6. Requires extensive redesign of LASA systems, e.g., SEM, Timing System, PLINS.
7. Requires installation of new TELCO modems.
8. Provides no telemetry channels for future sensor expansions.

9. Requires extended interruption of the LASA operation to install and test the new system design.
10. Requires programming changes for LDC and SAAC 360 computers.

Alternative 3: Combining subarray data links into fewer communications channels

1. Requires the acquisition of land leased for cable right-a-way.
2. Requires interconnecting cabling between selected subarrays.
3. Requires installation of additional TELCO modems.
4. Eliminates the simultaneous voice and data communications between the subarray and data center.
5. Requires PDP-7 programming changes.
6. Provides no telemetry channels for future sensor expansions.
7. Requires extended interruption of the LASA operation to install and test the new system design.
8. Requires redesign work on LASA system, e.g., SEM, Timing Systems, PLINS.
9. Requires programming changes for LDC and SAAC 360 computers.

APPENDIX C

MONTANA LASA ARRAY STATUS REPORT

This appendix shows the Montana Array Status Report reflecting the instrumentation configuration of each array data channel as of the end of the contract period.

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MONTANA LASA ARRAY STATUS

REPORTING DATE 1 MAY 1971 PREVIOUS REPORT 30 NOV 1970

ISSUE AS-64

PHILCO-FORD CORPORATION

WD/SENS

SUBARRAY

	A0	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	F1	F2	F3	F4	REMARKS
01/10	SQ	SA	SQ	SQ	SQ	SQ	SQ	SQ	SQ	SQ	SS	SQ	SQ	SQ	SQ	SK	SQ	SQ	SQ	SA	SQ	
02/SCA	T										*			T	T	*	T	T	T	T	T	
02/21	*	*	*	*	*	*	*	*	*	*	ST	*	*	*	*	SC	*	*	*	*	*	
03/SCA	*								*	*	*		*	*		*	*	*	*	*		
03/31	*	*	*	*	*	*	*	*	*	*	SU	*	*	*	*	*	*	*	*	*	*	
03/41	SP	*	*	*	*	*	*	*	SP	SL	*	*	SP	SP	*	SC	SP	SP	SP	SB	*	
04/SCA	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
04/51	*	SH	SP	SP	SP	*	SP	SP	*	*	SP	SP	*	*	SP	*	*	*	*	*	SP	
04/61	SP	*	*	*	*	*	*	*	SP	SP	*	*	SP	SP	*	SC	SP	SP	SP	SB	*	
05/71	*	SH	SP	SP	SP	SP	SP	SP	*	*	SP	SP	*	*	SP	SC	*	*	*	*	SP	
05/81	SP	*	*	*	*	*	*	*	SP	SL	*	*	SP	SP	*	*	SP	SP	SP	SB	*	
06/SCA	WD													WD	WD	*	WD	WD	WD	WD	WD	
06/32	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	SC	*	*	*	*	*	
07/SCA	MX	*	*	*	*	*	*	*			*	*			*	*					*	
07/42	*	SH	SP	SP	SP	SP	SP	SP	*	*	SP	SP	*	*	SP	*	*	*	*	*	SP	
07/52	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	SC	*	*	*	*	*	
08/52	SP	*	*	*	*	*	*	*	SP	SY	*	*	SP	SP	*	*	SP	SP	SP	SB	*	
08/62	*	SB	SP	SP	SP	SP	SP	SP	*	*	SF	SP	*	*	SP	SC	*	*	*	*	SP	
09/72	SP	*	*	*	*	*	*	*	SP	SY	*	*	SP	SP	*	*	SP	SP	SP	SB	*	
09/82	*	SH	SP	SP	SP	SP	SP	SP	*	*	SP	SP	*	*	SP	SC	*	*	*	*	SP	
10/SCA	WS										*			WS	WS	*	WS	WS	WS	WS	WS	
10/23	*	*	*	*	*	*	*	*	*	*	SF	*	*	*	*	SC	*	*	*	*	*	
11/SCA	*								*	*	*		*	*		*	*	*	*	*		
11/26	*	*	*	*	*	*	*	*	*	*	SN	*	*	*	*	*	*	*	*	*	*	
11/43	SP	*	*	*	*	*	*	*	SP	SL	*	*	SP	SP	*	SC	SP	SP	SP	SH	*	
12/53	*	SH	SP	SP	SP	SP	SP	SP	*	*	SP	SP	*	*	SP	*	*	*	*	*	SP	
12/63	SP	*	*	*	*	*	*	*	SP	SL	*	*	SP	SP	*	SC	SP	SP	SP	SB	*	
13/73	*	SH	SP	SP	SP	SP	SP	SP	*	*	SP	SP	*	*	SP	SC	*	*	*	*	SP	
13/83	SP	*	*	*	*	*	*	*	SP	SH	*	*	SP	SP	*	*	SP	SP	SP	SH	*	
14/SCA	M													M	M	*	M	M	M	M	M	
14/34	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	SC	*	*	*	*	*	
15/SCA	H	*	*	*	*	*	*	*			*	*			*	*					*	
15/44	*	SH	SP	SP	SP	SP	SP	SP	*	*	SP	SP	*	*	SP	*	*	*	*	*	SP	
15/54	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	SC	*	*	*	*	*	
16/54	SP	*	*	*	*	*	*	*	SP	SY	*	*	SP	SP	*	*	SP	SP	SP	SB	*	
16/64	*	SB	SP	SP	SP	SP	SP	SP	*	*	SP	SP	*	*	SP	SC	*	*	*	*	SP	
17/74	SP	*	*	*	*	*	*	*	SP	SY	*	*	SP	SP	*	*	SP	SP	SP	SH	*	
17/84	*	SH	SP	SP	SP	SP	SP	SP	*	*	SP	SP	*	*	SP	SC	*	*	*	*	SP	
18/SCA	MF	MF	MF	MF	MF	MF	MF	MF	MF	MF	MF	MF	MF			*						

WD/SENS	A0	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	F1	F2	F3	F4	REMARKS
21/75	*	SR	SP	SP	SP	SP	SP	SP	*	*	SP	SP	*	*	SR	SC	*	*	*	*	SP	
21/85	SP	*	*	*	*	*	*	*	SP	SP	*	*	SP	SP	*	*	SP	SP	SP	SB	*	
22/10	SV	SR	SV	SV	SV	SV	SV	SV	SV	SV	*	SV	SV	SV	SV	*	SV	SV	SV	SR	SV	
22/26	*	*	*	*	*	*	*	*	*	*	SM	*	*	*	*	*	*	*	*	*	*	
22/36	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	SC	*	*	*	*	*	
23/SCA	*	*	*	*	*	*	*	*			*	*			*	*				P	*	
23/46	*	SH	SP	SP	SP	SP	SP	SP	*	*	SE	SP	*	*	SP	*	*	*	*	*	SP	
23/56	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	SC	*	*	*	*	*	
24/56	SP	*	*	*	*	*	*	*	SP	SY	*	*	SP	SP	*	*	SP	SP	SP	SB	*	
24/66	*	SB	SP	SP	SP	SP	SP	SP	*	*	SP	SP	*	*	SP	SC	*	*	*	*	SP	
25/76	SP	*	*	*	*	*	*	*	SP	SL	*	*	SP	SP	*	*	SP	SP	SX	SB	*	
25/86	*	SH	SP	SP	SP	SP	SP	SP	*	*	SP	SP	*	*	SP	SC	*	*	*	*	SP	
26/LP11	LP					LT	LW	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	LP	
27/LP12	LR					LU	LX	LR	LR	LP	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	
28/LP13	LS					LV	LY	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	
29/SUM	ZZ	YY	YY	YY	YY	XX	YY	YY	ZZ	WW	YY	YY	ZZ	ZZ	YY	VV	ZZ	ZZ	ZZ	ZZ	YY	

CODING LEGEND

B	BAROMETER CHANNEL CONSISTING OF ELECTROBAROMETER, MODEL I503, AND ANALOG SIGNAL CONDITIONING TYPE ASC-7
M	MICROBAROGRAPH CHANNEL CONSISTING OF MODEL LTV-6, POWER SUPPLY, ANALOG SIGNAL CONDITIONING TYPE ASC-3, PIPE ARRAY, AND RESPONSE A250. SHORT PERIOD SENSOR EQUIPMENT REMOVED
MF	MICROBAROGRAPH CHANNEL CONSISTING OF ESSA MBARO, POWER SUPPLY, ANALOG SIGNAL CONDITIONING TYPE ASC-I, RESPONSE CI25 AND PIPE ARRAY INSTALLED. SHORT PERIOD SENSOR EQUIPMENT REMOVED
MX	CODE M EXCEPT HAS RESPONSE BI667 AND NO PIPE ARRAY
P	PRECIPITATION ACCUMULATION CHANNEL CONSISTING OF A TIPPING BUCKET RAIN GAUGE AND PULSE-COUNTER TO ANALOG CIRCUITRY
T	TEMPERATURE CHANNEL COMPRISED OF TYPE 44203 THERMISTOR TEMPERATURE SENSOR, TEMPERATURE BRIDGE AND ANALOG SIGNAL CONDITIONING TYPE ASC-4. SHORT PERIOD SENSOR EQUIPMENT REMOVED
SA	CODE SP EXCEPT THAT HOLE IS 500 FEET DEEP, 7 IN. O.D. AND DWG 520 WHV PANEL REPLACED WITH DWG 525 WHV PANEL.
SB	CODE SP EXCEPT DWG 520 WHV PANEL REPLACED WITH DWG 521 WHV PANEL
SC	CODE SP EXCEPT DWG 520 WHV PANEL REPLACED WITH DWG 522 WHV SYSTEM
SE	CODE SP WITH HS-10-IA AND RA-5 COMBINED AND INSTALLED DOWNHOLE AND DWG 520 WHV PANEL REPLACED WITH DWG 523 PANEL
SF	CODE SP WITH HS-10-IA AND RA-5 REPLACED WITH HS-10-IB/ITHACO AMP COMBINATION DOWNHOLE, DWG 526 WHV PANEL AND ANALOG SIGNAL CONDITIONING TYPE ASC-IA IN SEM
SH	CODE SP EXCEPT STEEL CASING REPLACED WITH PLASTIC CASING
SK	CODE SQ EXCEPT DWG 520 WHV PANEL REPLACED WITH DWG 522 WHV SYSTEM
SL	CODE SP EXCEPT SEISMOMETER IN UNCASED HOLE
SM	CODE SP EXCEPT SENSOR OUTPUT IS 30 DB ATTENUATED. SHORT PERIOD SENSOR EQUIPMENT IS IN PLACE
SN	CODE SM EXCEPT SENSOR OUTPUT IS UNATTENUATED. RA-5 AMPLIFIER INSTALLED IN HOLE 26
SP	STANDARD SHORT PERIOD CHANNEL CONSISTING OF 1. STEEL CASED HOLES, 200 FEET DEEP, 5 I/2 IN. O.D. 2. SEISMOMETER, GEOSPACE VERTICAL, TYPE HS-10-1A 3. WELL HEAD VAULT, STEEL DRUM 4. TEXAS INSTRUMENT AMPLIFIER, PARAMETRIC, TYPE RA-5 5. DWG 520 WHV PANEL 6. ANALOG SIGNAL CONDITIONING, TYPE ASC-1
SQ	CODE SP EXCEPT THAT HOLE IS 500 FEET DEEP, 7 IN. O.D. AND DWG 520 WHV PANEL REPLACED WITH DWG 524 WHV PANEL

SR	CODE SA EXCEPT THAT SIGNALS OBTAINED THROUGH A SECOND RA-5 WITH A 30 DB ATTENUATOR. SHORT PERIOD SENSOR EQUIPMENT REMOVED
SS	CODE SP EXCEPT HS-10-1A REPLACED WITH TELEDYNE TD-202, TRIAXIAL, VERTICAL, AND DWG 520 WHV PANEL REPLACED WITH EXPERIMENTAL PANEL CONTAINING THREE RA-5 AMPS LOCATED IN HOLE 10
ST	CODE SS EXCEPT NORTH-SOUTH COMPONENT OF TRIAX SEIS. RA-5 INSTALLED IN HOLE 10
SU	CODE SS EXCEPT EAST-WEST COMPONENT OF TRIAX SEIS. RA-5 INSTALLED IN HOLE 10
SV	CODE SQ EXCEPT THAT SIGNALS OBTAINED THROUGH A SECOND RA-5 WITH A 30 DB ATTENUATOR. SHORT PERIOD SENSOR EQUIPMENT REMOVED
SW	CODE SP EXCEPT SEISMOMETER DEAD AND STUCK IN UNCASED HOLE
SX	CODE SP EXCEPT SEISMOMETER DEAD AND STUCK IN CASED HOLE
SY	CODE SP EXCEPT THAT HOLE IS 10 FEET DEEP
LP	STANDARD LONG PERIOD CHANNEL CONSISTING OF 1. SEISMOMETER TANK, TEXAS TANK MODEL 23232A 2. LP SEISMOMETER, MODEL 7505B, VERTICAL 3. SEISMOMETER DAMPING ASSEMBLY, MODEL 14415-02 4. LP SEISMIC AMPLIFIER, TYPE II WITH 24 DB/OCTAVE HIGH OUTPUT FILTER 5. ANALOG SIGNAL CONDITIONING, TYPE ASC-2
LR	CODE LP EXCEPT MODEL 7505B REPLACED WITH MODEL 8700D, NORTH-SOUTH
LS	CODE LP EXCEPT MODEL 7505B REPLACED WITH MODEL 8700D, EAST-WEST
LT	CODE LP EXCEPT 24 DB/OCTAVE FILTER CHANGED TO 12 DB/OCTAVE
LU	CODE LR EXCEPT 24 DB/OCTAVE FILTER CHANGED TO 12 DB/OCTAVE
LV	CODE LS EXCEPT 24 DB/OCTAVE FILTER CHANGED TO 12 DB/OCTAVE
LW	CODE LP EXCEPT 30 DB ATTENUATOR INSTALLED
LX	CODE LR EXCEPT 30 DB ATTENUATOR INSTALLED
LY	CODE LS EXCEPT 30 DB ATTENUATOR INSTALLED
WD	WIND DIRECTION CHANNEL CONSISTING OF MODEL 120 WINDVANE, MODEL 9072 POTENTIOMETER ASSEMBLY AND ANALOG SIGNAL CONDITIONING TYPE ASC-6. SHORT PERIOD SENSOR EQUIPMENT REMOVED
WS	WIND SPEED CHANNEL CONSISTING OF MODEL 120 WINDVANE, AND ANALOG SIGNAL CONDITIONING TYPE ASC-5. SHORT PERIOD SENSOR EQUIPMENT REMOVED
VV	SPECIAL ANALOG SUM WORD CONSISTING OF OUTPUT FROM HOLES 10, 21, 32, 23, 34, 25, 36
WW	SPECIAL ANALOG SUM WORD CONSISTING OF OUTPUT FROM HOLES 41, 61, 81, 43, 63, 83, 45, 85
XX	SPECIAL ANALOG SUM WORD CONSISTING OF OUTPUT FROM HOLES 71, 42, 62, 82, 53, 73, 44, 84, 55, 75, 46, 86
YY	ANALOG SUM WORD FOR SHORT LEG SUBARRAY CONSISTING OF OUTPUTS FROM HOLES 51, 71, 42, 82, 53, 73, 44, 84, 55, 75, 46 AND 86
ZZ	ANALOG SUM WORD FOR LONG LEG SUBARRAY CONSISTING OF OUTPUTS FROM HOLES 41, 81, 52, 72, 43, 83, 54, 74, 45, 85, 56 AND 76
SCA	DENOTES SUBARRAY CENTRAL AREA - INSIDE PERIMETER FENCE
BLANK	CURRENTLY NOT IN USE
*	NOT APPLICABLE
$$	CHANGE FROM PREVIOUS REPORT

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6. Philco-Ford Corp., *Montana LASA Second Quarterly Technical Report*, AD885649, Billings, Mont., 15 June 71, pp 47-53.

7. Philco-Ford Corp., *Montana LASA Third Quarterly Technical Report*, AD850373, Billings, Mont., Feb. 69, Sect. II.

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9. Philco-Ford Corp., *Montana LASA Final Report*, AD881614, December 70, pp 27-30.

10. Philco-Ford Corp., *Montana LASA Array Modification Status Report*, MS-51.

11. Philco-Ford Corp., *Montana LASA Third Quarterly Report*, T/R 2039-71-10, Billings, Mont., 15 September 71, p 56.