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TECHNICAL REPORT NO. 68-11

FINAL REPORT

OPERATION OF THE TONTO FOREST SEISMOLOGICAL OBSERVATORY

Project VT/7702, 1 January through 31 December 1967

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GEOTECH

A TELEDYNE COMPANY

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OPERATION OF THE
TONTO FOREST SEISMOLOGICAL OBSERVATORY

Sponsored by
Advanced Research Projects Agency
Nuclear Test Detection Office
ARPA Order No. 624

GEOTECH
A TELEDYNE COMPANY
3401 Shiloh Road
Garland, Texas

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IDENTIFICATION

AFTAC Project No:	VELA T/7702
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ABSTRACT

This is a report of the work accomplished on Project VT/7702 from 1 January 1967 through 31 December 1967. Project VT/7702 includes the operation, evaluation, and improvement of the Tonto Forest Seismological Observatory (TFSO) located near Payson, Arizona. It also includes the installation and initial operation of a 37-element, short-period array and the installation of a 7-element, long-period array. Special research and test functions undertaken at TFSO, and research and development tasks performed by the Garland, Texas, staff using TFSO data are included.

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OPERATION OF THE
TONTO FOREST SEISMOLOGICAL OBSERVATORY

1. INTRODUCTION

1.1 AUTHORITY

The research described in this report was supported by the Advanced Research Projects Agency, Nuclear Test Detection Office, and was monitored by the Air Force Technical Applications Center (AFTAC) under Contract AF 33657-67-C-0091, dated 1 January 1967. The statement of work for Project VT/7702 is included as appendix 1 to this report.

1.2 HISTORY

The Tonto Forest Seismological Observatory (TFSO), located near Payson, Arizona, was constructed by the United States Corps of Engineers in 1963. TFSO was designed to record seismic events and to be used as a laboratory for testing, comparing, and evaluating advanced seismograph equipment and recording techniques. The instrumentation was assembled, installed, and operated until 30 April 1965 by United Electrodynamics (UED) - now Earth Sciences, A Teledyne Company - under Contract AF 33(657)-7747. In March 1964, the Long Range Seismic Measurements (LRSM) Program provided eight mobile seismic recording vans to extend the existing instrument arrays at TFSO. On 1 May 1965, Geotech assumed the responsibility for operating TFSO. The LRSM vans were phased out of the TFSO operation on 3 October 1965. During the 20-month period from 1 May 1965 through 31 December 1966, the operation of TFSO under Project VT/5055 was closely allied with the work performed at the Blue Mountains, Uinta Basin, and Wichita Mountains Seismological Observatories, under Projects VT/1124, VT/4054, and VT/5054. When reasonable, operating procedural changes, observatory instrumentation improvements, and special research investigations were accomplished simultaneously at all observatories. In other instances, improvements, modifications, and/or procedures that had been developed and proven at another observatory were incorporated into the TFSO operation.

1.3 WORK OF PROJECT VT/7702

The work of the past 12-months can be subdivided into five categories:

a. Continued operation of TFSO;

b. Design and installation of the 37-element, short-period array and the 7-element, long-period array;

c. Routine and special analysis of seismometric data;

d. Instrument tests and evaluation;

e. Research investigations.

2. SUMMARY

During the first 4 years of the operation of TFSO, the primary detection systems were a small-aperture, 31-element, short-period array; a crossed-linear, short-period array of vertical and 3-component seismographs; and a single, 3-component, long-period installation. During the period covered by Project VT/7702, the operation of the crossed-linear and the 31-element arrays was discontinued on a step-by-step basis. The gradual elimination of these detection systems was accomplished at the same time as the installation of a medium-aperture, 37-element, short-period array and the initiation of construction of a 7-element, 3-component, long-period array. Although considerable effort was directed toward accomplishing this rapid evolution of the instrumentation systems, routine analysis of the seismometric data, instrument tests and evaluation, and research investigations were accomplished without interruption.

Optimum operational characteristics and parameters of the interim standard systems were maintained through continual evaluation of the seismic data. Quality control checks were regularly made of both film and magnetic-tape seismograms selected on a random basis.

Data recorded at TFSO were routinely analyzed, the analysis checked, and a daily tabulation of arrival times of P phases and selected later phases of earthquake signals were transmitted to the Environmental Science Services Administration's Coast and Geodetic Survey (ESSA - C&GS). The results of the daily analysis were also transcribed onto magnetic tape and sent to the Seismic Data Laboratory (SDL) for use in the preparation of the seismological bulletin of the VELA-Uniform seismological observatories. The associated data were returned to Geotech, where the bulletin was published monthly.

Microseismic noise analyses were made daily at TFSO. Monthly probability of occurrence curves were prepared and distributed.

The design of the 37-element, short-period array was directed toward increasing the signal-to-noise ratio (S/N) of processed outputs in the frequency range 0.5 to 2.0 cps and providing the capability for velocity filtering of teleseismic signals. These criteria were found to be theoretically satisfied by a hexagonal array in which the distance between detectors is 5 kilometers and the overall diameter of the hexagon is 30 kilometers. Construction of access trails, sites, and cable trails was started during May 1967 and finished in September 1967. The installation of the instrumentation was completed on 15 November. Heavy rains in late November and 77 inches of snow in December kept the array from being fully operational by the end of the reporting period.

The construction of cable trails and vaults for the 7-element, long-period array was initiated during November. The December snow storm halted installation progress for the duration of the contract period.

To determine the operational characteristics of long-period seismometers in evacuated environments, a series of tests was conducted utilizing a sphere-housing for an ocean-bottom seismograph obtained on loan from Texas Instruments. The sphere provided an environment with a pressure of about one-thousandth of an atmosphere. It was hoped that the operation of a seismograph in such an environment would eliminate or greatly reduce the effects from several sources of potential noise. The tests indicated, however, that the ocean-bottom sphere does not represent a noticeable improvement over conventional methods used to reduce atmospheric effects.

To test the performance of a short-period seismograph employing a Geotech solid-state amplifier and a Model 6480 Johnson-Matheson seismometer with a high-impedance coil (which is the system used in the 37-element array), this system was installed adjacent to a standard short-period seismograph for comparison and evaluation. The results of these tests indicate that the solid-state system is superior to the short-period seismographs currently being operated at LASA or at the VELA-Uniform observatories.

Tests were performed on the Solion seismometer, which was developed by the Defense Research Laboratory of the University of Texas, to study the feasibility of using the instrument for field operation. Results indicated that the system can be operated at a magnification (at 20 seconds) of approximately 50,000 with a resulting system noise of about 3.7 millimeters. Normal power supply variations did not significantly increase the system noise level. Small variations in temperature on the order of 2 degrees Fahrenheit cause spiking. Normal changes in atmospheric pressure had no significant effect on the Solion, but the instrument proved to be quite sensitive to rapid temperature changes.

Three short-period array configurations, alternates to the adopted configuration, were evaluated on the basis of the characteristics of the wave-number response. Each of the three alternate configurations offered a reduced cost of installation and maintenance relative to the 37-element array, but none of the alternates demonstrated a wave-number response which was in our opinion sufficiently desirable to warrant its adoption.

A study of a system for the classification of teleseismic earthquake signals was conducted jointly under Projects VT/7702 and VT/6705. The system investigated in this study described a teleseismic signature by means of a seven-character, alphanumeric code based on the general shape of the signal envelope, the rate of buildup to the maximum amplitude, and other visual characteristics. Although the particular classification system investigated was adequate in the sense that the principal characteristics of the analog signal could be reproduced from the coded signal, it was too subjective in that a given signal could not be uniquely classified upon subjection to repeated and independent analysis.

A high-frequency seismograph was designed and fabricated under Project VT/7702. The system is designed for down-hole operation, and consists of eight geophones having natural frequencies of 8 cps. The purpose of the new system is to test the possibility of teleseismic energy existing in the frequency range 3-12 cps at a detectable signal-to-noise ratio. It will be field tested at TFSO in 1968.

3. OPERATION OF THE TONTO FOREST SEISMOLOGICAL OBSERVATORY

3.1 GENERAL

3.1.1 Security Inspection

Mr. M. R. Cray, industrial security chief, from Phoenix, Arizona, made a routine security inspection of the observatory during January 1967. New Standard Security Procedures for the station were approved. Routine security inspections were conducted during April and September 1967. The station vault was inspected and certified during the September inspection for classified document storage. During each of these visits, all items relating to station security were found to be in proper order.

3.1.2 Vandalism

Several instances of vandalism occurred during August 1967. A 300- to 400-foot section of cable was cut and removed from Z11 and the radio link. The cables to Z21 and the radio link were apparently used for target practice. The Phoenix office of the FBI was notified, and Mr. Henry Grady, special agent, visited TFSO on 26 September 1967 to investigate the case. During October, cable to Z9 was cut.

3.1.3 Quality Control

3.1.3.1 Quality Control of 16-millimeter Film Seismograms

Quality-control checks of randomly selected runs of 16-millimeter film from data trunks 1, 2, and 8 and the accompanying logs are made in Garland. Items that are routinely checked by the quality control analyst include:

a. Film boxes - neatness and completeness of box markings;

b. Develocorder logs - completeness, accuracy, and legibility of logs;

c. Film;

(1) Quality of the overall appearance of the record (for example, trace spacing and trace intensity);

(2) Quality of film processing;

d. Analysis - completeness, legibility, and accuracy of the analysis sheets.

Results of these evaluations are sent to the observatory for their review and comment.

Installation of the short-period and long-period arrays near the end of the contract period made constructive critiques difficult, with the result that the quality control checks were de-emphasized until installation is completed.

3.1.3.2 Quality Control of Magnetic-Tape Seismograms

Routine quality control checks of randomly selected magnetic-tape seismograms were made in Garland and at TFSO to assure that recordings met specified standards. Near the end of the contract period, quality control checks were made on one tape from each recorder each week. The following are among the items that were checked by the quality control group:

a. Tape and box labeling;

b. Accuracy, completeness, and neatness of logs;

c. Adequate documentation of logs by voice comments on tape, where applicable;

d. Seismograph polarity;

e. Level of calibration signals;

f. Relative phase shift between array seismographs;

g. Level of the microseismic background noise;

h. Level of the system noise;

i. PTA dc balance;

j. Oscillator alignment;

k. Quality of the recorded WWV signal, where applicable;

l. Time-pulse carrier;

m. Binary-coded, digital time marks.

The quality control checks led to improvement in such items as recorder noise, log completeness, and maintaining tape speed tolerances.

3.2 SEISMOGRAPH SYSTEMS OPERATED DURING PROJECT VT/7702

3.2.1 Termination of the Operation of the 31-Element, Short-Period Array

In December 1966, a 19-element array was formed by deleting selected elements from the original 31-element array. This array was operated until 22 April 1967, when eleven elements were deleted to form an 8-element array. The vault locations of the 19-element and the 8-element arrays are shown in figures 1 and 2, respectively. On 8 August 1967, operation of six elements of the 8-element array was discontinued, with Z60 and Z64 remaining.

3.2.2 Crossed-Linear Array

Near the end of Project VT/5055, the crossed-linear array consisting of 21 short-period vertical elements and 24 short-period horizontal elements was modified by discontinuing the operation of all crossed-linear array elements except those consisting of three-component systems and the element common to both legs. This resulted in 12 three-component seismographs spaced at intervals of about 2 kilometers. This configuration, also shown in figure 2, was operated throughout Project VT/7702.

3.2.3 Long-Period Seismographs

On 18 January 1967, the TFSO standard long-period response was changed to match that of the LRSM portable long-period systems. Two Model 8530-2 Harris galvanometers and a Model 6000 Lehrner-Griffith galvanometer were incorporated in the system to facilitate the change. The frequency response of the modified system is shown in figure 3. On 18 April 1967, the long-period seismograph was changed back to the standard responses (figure 4) and operated until 6 December 1967, when it was discontinued in order to install the new long-period systems.

3.2.4 Broad-Band Seismographs

On 19 April 1967, operation of the TFSO broad-band systems was suspended. This action was necessary to make available pier space on which to install the ocean bottom sphere for the long-period seismograph tests.

3.3 STANDARD SEISMOGRAPH OPERATING PARAMETERS

The operating parameters and tolerances for the TFSO standard seismographs are shown in table 1. Frequency response tests are made routinely, and parameters are checked and reset to maintain the specified tolerances.

Normalized response characteristics of TFSO standard seismographs are shown in figure 4. During portions of the contract period, the response of the TFSO long-period seismograph system was changed to conform to the response of the LRSM portable long-period seismograph systems.

In addition to these standard seismographs, two filtered summation seismographs were recorded. A UED filter with a high-cut frequency at 1.75 cps and a slope of 24 dB per octave and a low-cut frequency at 0.7 cps with a slope of 24 dB per octave is used to record the summation seismograms (ΣTF) on 16-millimeter

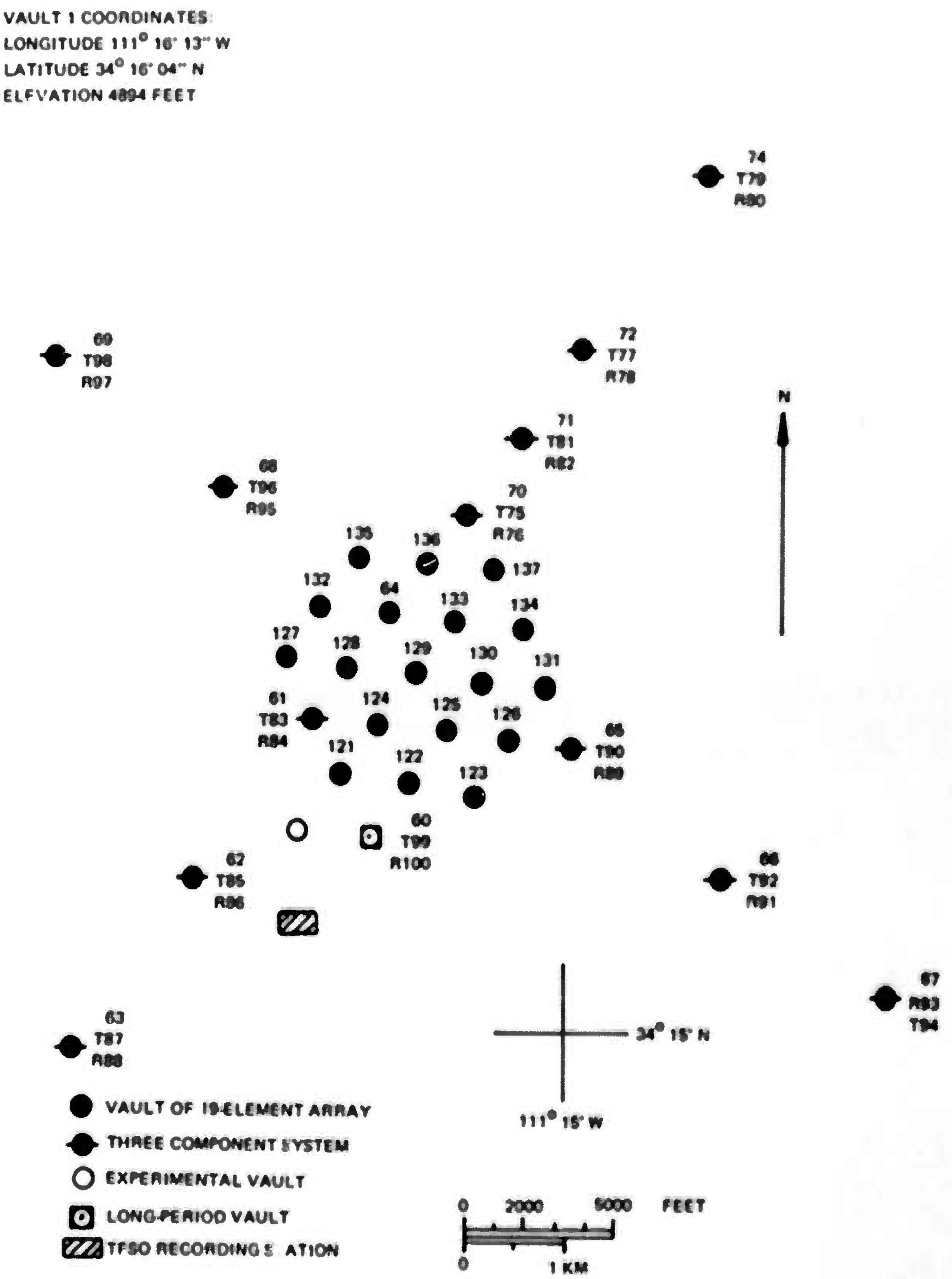

Figure 1. The 19-element, short-period array and other vault locations at TFSO, January - April 1967

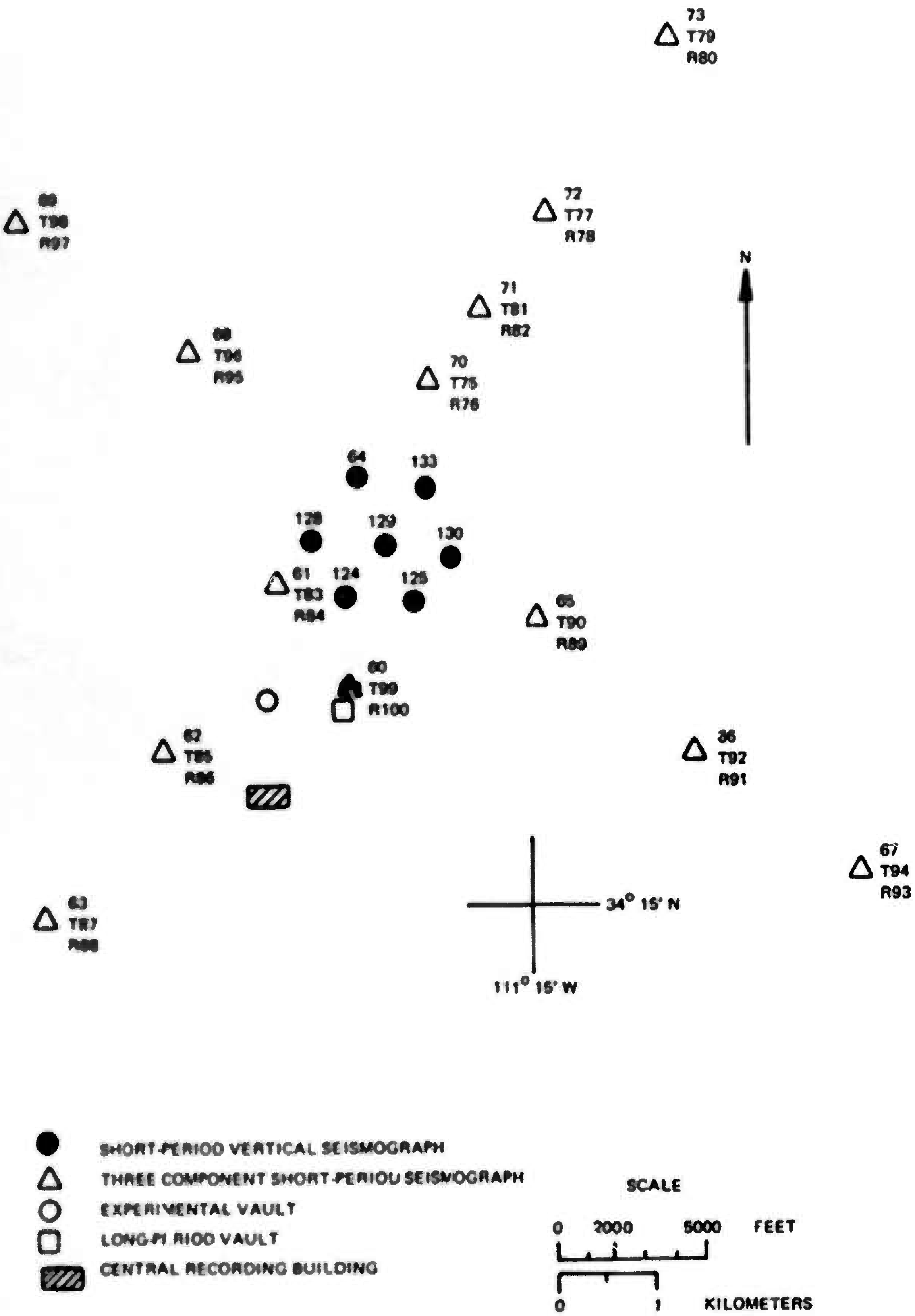

Figure 2. The 8-element, short-period array and other vault locations at TFSO, 30 June 1967

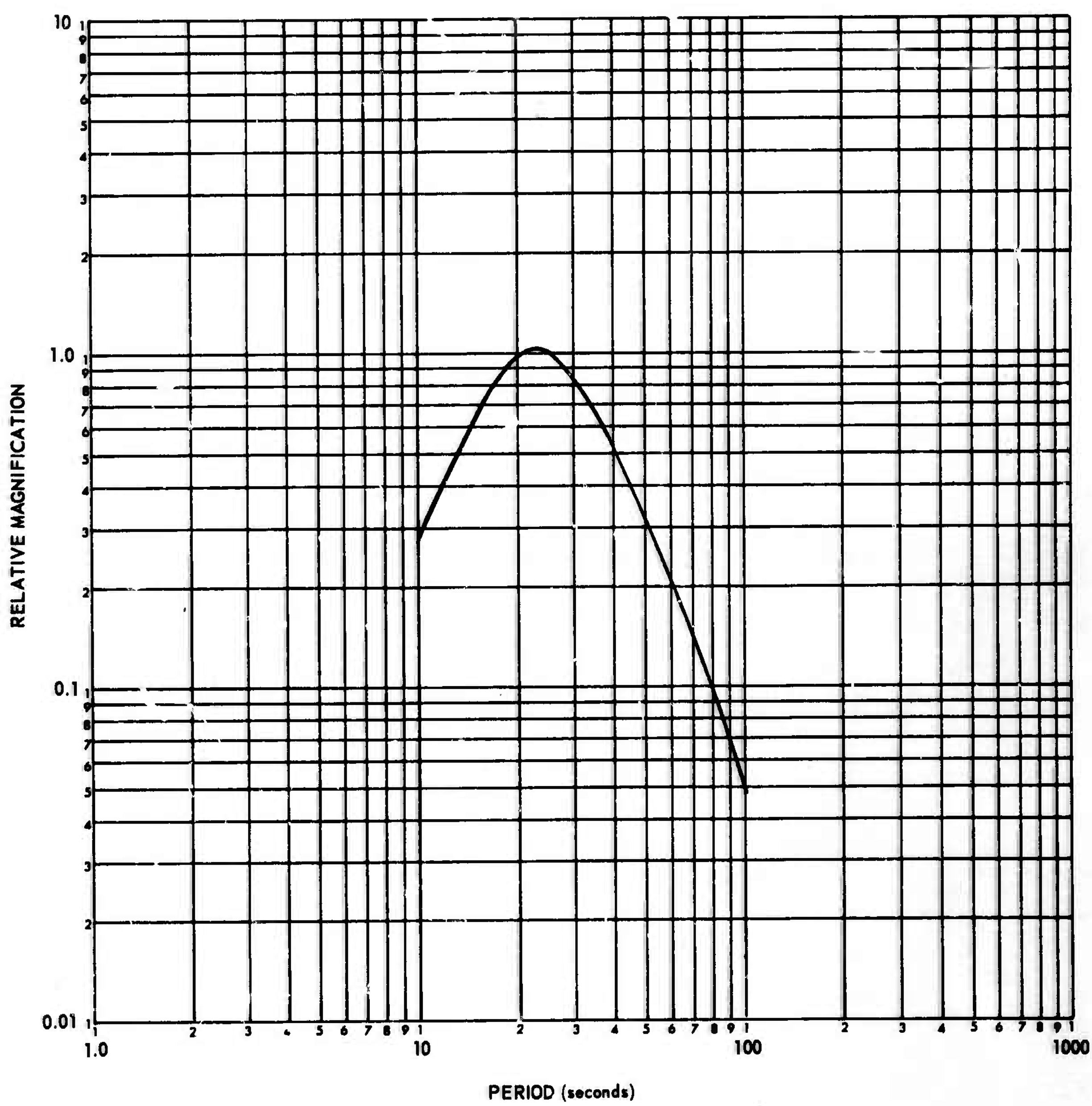

Figure 3. Typical amplitude response of the TFSO three-component, long-period system as modified on 18 January 1967

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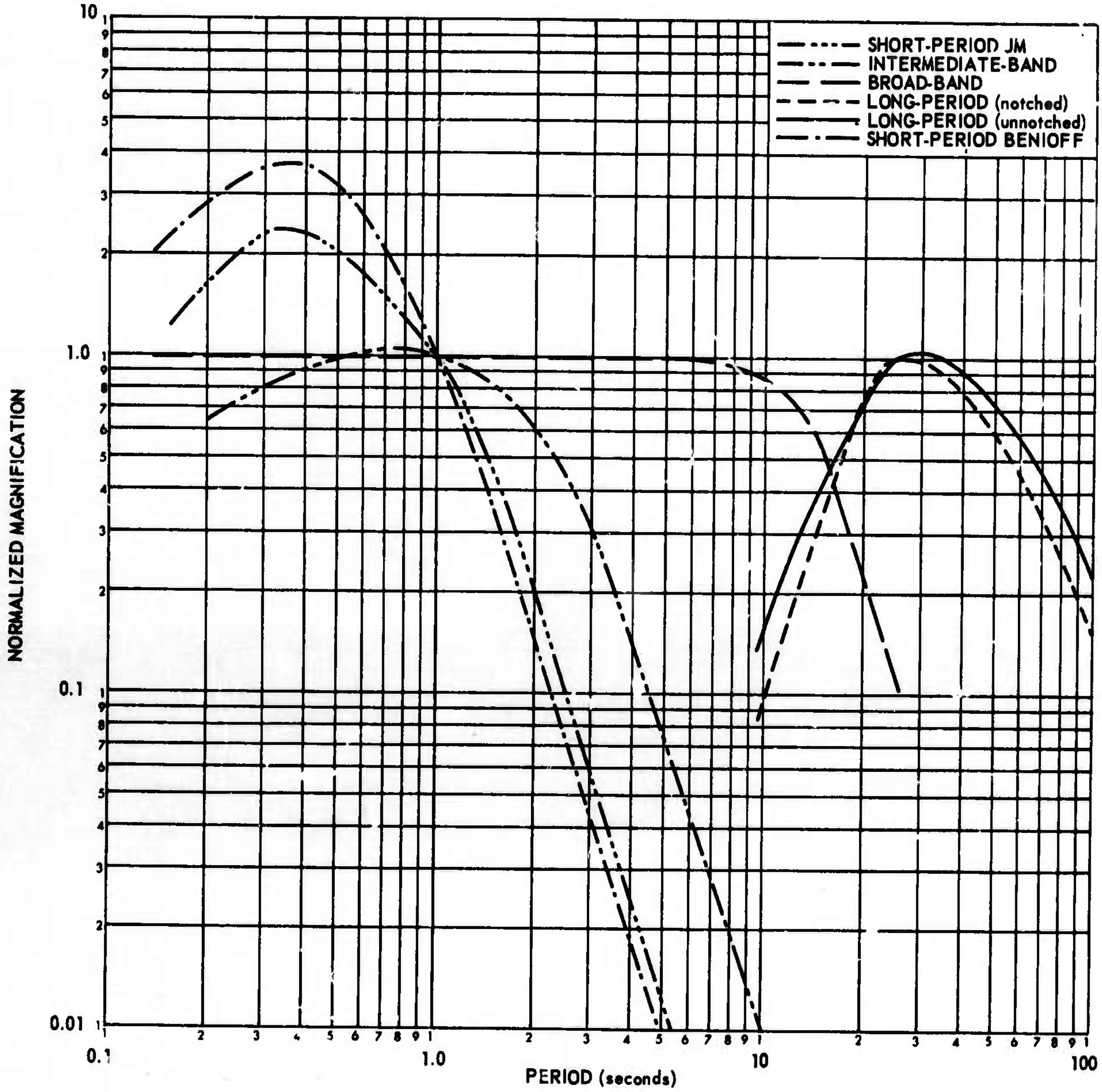


Figure 4. Normalized response characteristics of the standard seismographs at TFSO

Table 1. Operating parameters and tolerances of standard seismographs at TFSO

Seismograph				Operating parameters and tolerances				Filter settings		
System	Comp	Type	Model	Ts	λs	Tg	λg	δ^2	Bandpass at 3 dB cutoff (sec)	Cutoff rate at SP side (dB/oct)
SP	Z	Johnson-Matheson	6480	1.25 ±2%	0.54 ±5%	0.33 ±5%	0.65 ±5%	0.0117	0.1 - 100	12
SP	H	Johnson-Matheson	7515	1.25 ±2%	0.54 ±5%	0.33 ±5%	0.65 ±5%	0.0117	0.1 - 100	12
SP	Z	Benioff	1051	1.0 ±2%	1.0 ±5%	0.2 ±5%	1.0 ±5%	0.0104	0.1 - 100	12
SP	H	Benioff	1101	1.0 ±2%	1.0 ±5%	0.2 ±5%	1.0 ±5%	0.0104	0.1 - 100	12
SP	Z	UA Benioff	1051	1.0 ±2%	1.0 ±5%	0.75	1.0 ±5%	0.0245		
SP	H	UA Benioff	1101	1.0 ±2%	1.0 ±5%	0.75	1.0 ±5%	0.0245		
SP	H	Wood-Anderson	TS 220	0.8	0.78					
IB	Z	Melton	10012	2.25 ±5%	0.65 ±5%	0.64 ±5%	1.2 ±5%	0.0006	0.05 - 100	18
IB	H	Lehner-Griffith	SH-216	2.25 ±5%	0.65 ±5%	0.64 ±5%	1.2 ±5%	0.0004	0.05 - 100	18
BB	Z	Press-Ewing	SV-232	12.0 ±5%	0.425 ±10%	0.64 ±5%	9.0 ±10%	0.00027	0.05 - 100	18
BB	H	Press-Ewing	SH-242	12.0 ±5%	0.425 ±10%	0.64 ±5%	9.0 ±10%	0.00027	0.05 - 100	18
LP[a]	Z	Geotech	7505A	20.0 ±5%	0.74 ±10%	110.0 ±10%	0.83 ±10%	0.66	25 - 1000	12
									20 - 200[c]	12
LP[a]	H	Geotech	8700C	20.0 ±5%	0.74 ±10%	110.0 ±10%	0.83 ±10%	0.66	25 - 1000	12
									20 - 200[c]	12
LP[b]	Z	Geotech	7505A	20.0 ±5%	0.74 ±10%	110.0 ±10%	0.83 ±10%	-	25 - 1000	12
LP[b]	H	Geotech	8700C	20.0 ±5%	0.620 ±10%	30.0 ±10%	0.591 ±10%	-	25 - 1000	12
									20 - 1000[c]	12

KEY

SP Short period
IB Intermidiate band
BB Broad band
LP Long period
UA Unamplified (i.e., earth powered)

Ts Seismometer free period (sec)
Tg Galvanometer free period (sec)
λs Seismometer damping constant
λg Galvanometer damping constant
δ^2 Coupling coefficient

[a]Since March 1966, temporally deactivated on 18 January 1967
[b]Prior to March 1966, temporally deactivated on 18 January 1967
[c]With a 6-second notch filter

film (Data Trunks 1 and 7) and on magnetic tape (Data Trunks 2 and 5). A Krohn-Hite filter with the high-cut frequency set at 3.0 cps with a slope of 24 dB per octave and the low-cut frequency set at 1.0 cps with a slope of 24 dB per octave is also used to record the summation seismograms (ΣTFK) on 16-millimeter film (Data Trunk 1). On 28 April, the high-cut frequency of the Krohn-Hite filter was changed to 2.0 cps and was operated at this setting for the remainder of the contract.

3.4 DATA CHANNEL ASSIGNMENT CONTROL

Each data format recorded at TFSO was assigned a data group number. When the data assigned to a channel of any format were changed, a new data group number was assigned to the format. Data format change notices with the new channel assignments and data group numbers were submitted to the Project Officer and to frequent users of TFSO data when formats were changed.

3.5 ROUTINE OPERATION OF ASTRODATA DIGITAL DATA ACQUISITION SYSTEM

During August 1967, the Astrodata system was modified to increase the recording time of data recorded on each magnetic tape (see section 4.3.3.7). Prior to this date, the Astrodata system was operated routinely each month to supply digital data, principally, to the Seismic Data Laboratory. Table 2 lists the number of digital magnetic tapes used and the running time for each month.

Table 2. Tabulation of Astrodata tapes during period of routine recording in 1967

Month	Number of reels	Running time (hours)
January	10	21
February	7	16
March	4	6
April	11	15
May	14	23
June	12	unknown
July	4	unknown

3.6 EQUIPMENT MALFUNCTIONS

In the past, a Component Failure Card Report (Form TFSO-50) was completed for every component that failed. Component failure information received from the observatory was coded and punched onto standard 80-column IBM cards in Garland. Presently, the observatory personnel transfer the component failure information directly to the coding form (figure 5), which eliminates the use of the card report Form TFSO-50. Coded component failure data are received quarterly from the observatory and punched onto the IBM cards.

Program COMPFAIL, used to process the coded component failure data, accommodates up to 10 different types of subassemblies and 25 different components for each subassembly. Presorting of the cards by observatory, general function, and

OBSERVATORY COMPONENT FAILURES

	ASSEMBLY					SUB ASSEMBLY				COMPONENT				HOURS/10				C	
OBS	DATE	FUNCT	MODEL		SER	S/A	MODEL	P	SER	M	SYMBOL	MFG PART NO	MFG	REP	D		INOPER	P	#
1-3	4-8	9-12	13-20	21	22-24	25-28	29-36	37	38-41	42	43-53	54-63	64-68	69-71	72	73	74-78	79	80
												9							

Figure 5. Sample coding form for component failures

subassembly pertaining to a general function is required before the data can be processed. A sample of the output of COMPFAIL for data received from TFSO, for the reporting period 1 January 1967 to 31 December 1967 is given in table 3.

3.7 SHIPMENT OF DATA TO SDL

Six magnetic-tape units are used to record data for the AFTAC/VELA Seismological Center (VSC); these data are sent weekly to our Garland laboratory for quality control and selected studies. The data are shipped routinely to SDL from Garland about 15 days after the end of the month in which they were recorded.

Film records from ten Develocorders are shipped weekly to Garland, where they are continuously checked for quality. The film data are shipped to SDL about 45 days after the end of the month in which they were received. The film and magnetic-tape operation logs and calibration logs are copied and shipped with the seismograms.

3.8 ADVERSE WEATHER CONDITIONS

Electrical storms, rain, and snow hampered station operations during various periods of 1967.

Near the end of July and throughout August and September, lightning storms caused considerable equipment damage. Eighteen seismograph systems were damaged, several more than once, during this period. The standby generator was operated 87.4 hours due to the electrical storm activity.

Heavy rains near the end of November caused excessive line leakage in the cable used in the 37-element array. On 27 November, 21 elements of the 37-element array were either inoperative or extremely noisy due to the line leakage. Seventy sections of spiral-four cable were replaced.

Heavy snow started to fall on 13 December and continued through 20 December, for a total of 77 inches of snow. Temperatures fell to -5 degrees Fahrenheit. During this period, all field operations were halted. Twenty-seven elements of the 37-element array were either inoperative or extremely noisy due to cable breakage at junction boxes or to line leakage. Field operations were resumed on a limited basis on 28 December.

3.9 ACQUISITION AND INSTALLATION OF MOBILE COMMUNICATIONS SYSTEMS

A communications system for use in the installation and operation of the short-period and long-period arrays at TFSO was ordered from Motorola Communications and Electronics, Inc., in February 1967. The system consists of two mobile transceivers, a base transceiver, a control console, and associated hardware. A Special Use Land Permit to install the base transceiver at Diamond Point was filed and approved by the U. S. Forest Service and U. S. Corps of Engineers. The installation of the tower and equipment building at Diamond Point was started in March and completed in April. The Motorola communications equipment was delivered during April. On 1 May, a Federal

Table 3. Sample output of COMPFAIL

STATION IFO

SPECIFIC FUNCTION	MODEL NO.	SUB. ASSEMBLY	TOTAL FAILURES	REPAIR TIME	TIME OP.	PREVENT.	CATAS.	COMPONENT	NO.
TN	(7460)		9	7.0	9.6	4	5		
								V2	1
								BEARING	1
								V1	1
								C104A	1
								C104B	1
								L103	1
								CR101	1
								CR102	1
								DS1	1
		PVR	1	.5	.5	0	1		
								FAN MTR	1
		DSC	24	2.4	2.6	0	24		
								DS1	24
		ISP	15	1.5	2.5	0	15		
								DS101	8
								DS102	5
								DS1	1
								DS	1
TN	(7460)	DISC	1	.1	.1	0	1		
								DS1	1
TN	(2009100)		11	2.4	4.0	0	11		
								DS17	2
								DS16	2
								D6	1
								DS23	1
								DS1	4
								DS18	1
		ISP	1	1.0	1.0	1	0		
								R2	1
DEV	(4000)		17	13.5	16.3	1	16		
								DS301	6
								ROLLER	2
								R302	2
								DS601	2
								S101	2
								R301	1
								SHAFT	1
								DS603	1
		DT	2	2.5	2.5	2	0		
								CV01	1
								RR02	1
DEV	(4000A)		6	5.8	5.8	0	6		
								DS301	3
								R304	1
								R303	1
								R306	1
DEV	(4000C)		2	2.5	2.5	0	2		
								R306	1
								R301	1

Communications Commission license for the TFSO mobile communications systems was received. Radio installation and check-out was accomplished by Motorola personnel on 4 and 5 May. The communications system has proven to be very satisfactory within a 30-mile radius of TFSO.

3.10 FACILITIES AND EQUIPMENT MAINTENANCE

3.10.1 Equipment Maintenance

3.10.1.1 Spiral-Four Cable Replacement

Table 4 summarizes the replacement of spiral-four cable.

Table 4. Spiral-four cable replacement in 1967

Month	Number of reels replaced	Reason for replacement
February	7	Line leakage due to rain and snow
April	2	Line leakage
August	7	Line leakage, lightning, vandalism
September	4	Electrical storm damage
October	2	Line leakage, vandalism
November	16	Line leakage due to heavy rains
December	70	Line leakage due to heavy rains

3.10.1.2 Phase-Shift Checks

Routine monthly phase-shift checks were performed on all Johnson-Matheson (JM) seismometers from January through August. During the period September through December 1967, when the construction of the short-period array was in progress, phase shift checks were not made on a routine basis.

3.10.1.3 Seismometer Motor-Constant Checks

The results of the semiannual seismometer motor-constant checks made during March 1967 are listed in table 5. Minor adjustments were required on five of the instruments. Annual checks of seismometer motor constants were started during September 1967 and were continued until the end of the year due to the installation of the short-period and long-period arrays. Results of these checks are listed in table 6.

3.10.1.4 Tape Speed Checks

Tape speeds were checked on the six tape transports during November and December. All recorders were within the ±0.5 percent tolerance.

Table 5. TFSO semiannual motor constant checks

System	Previous "G"	First "G"	Adjusted "G"	"G" used for calibration
Z60	0.2975	0.304		0.296
E99SP	0.2995	0.304		0.296
N100SP	0.2965	0.296		0.296
Z38BB	0.186	0.185		0.188
E39BB	0.186	0.176	0.189	0.188
N40BB	0.190	0.1815	0.1868	0.188
Z41IB	0.0212	0.02005		0.0206
E42IB	0.0474	0.0474		0.0474
N43IB	0.0482	0.0462		0.0474
Z44LP	0.030	0.030		0.030
E45LP	0.030	0.0312	0.030	0.030
N46LP	0.030	0.03135	0.0303	0.030
Z47BF	2.385	2.375		2.43
E48BF	2.31	2.355	2.303	2.26
N49BF	2.305	2.295		2.26
Z74	0.2985	0.3035		0.296
1A	2.10	2.155		2.12
1B	2.20	2.26		2.20
1C	2.18	2.20		2.20

Table 6. TFSO annual motor-constant checks

System	Previous "G"	Measured "G"	"G" used for calibration
Z60	0.304	0.298	0.296
E99SP	0.304	0.298	0.296
N100SP	0.2965	0.298	0.296
Z41IB	0.02005	0.0206	0.0206
E42IB	0.0474	0.0466	0.0474
N43IB	0.0462	0.0477	0.0474
Z1LP	NA*	0.0280	0.0280
E1LP	NA	0.0278	0.0280
N1LP	NA	0.0280	0.0280
Z47BF	2.375	2.38	2.43
E48BF	2.303	2.28	2.26
N49BF	2.295	2.26	2.26
1A	2.155	2.14	2.12
1B	2.26	2.19	2.20
1C	2.20	2.24	2.24
Z1	NA	0.297	0.296
Z2	NA	0.292	0.296
Z3	NA	0.299	0.296
Z4	NA	0.297	0.296
Z5	NA	0.299	0.296
Z6	NA	0.297	0.296
Z7	NA	0.297	0.296
Z8	NA	0.294	0.296
Z9	NA	0.293	0.296
Z10	NA	0.296	0.296
Z11	NA	0.298	0.296
Z12	NA	0.296	0.296
Z13	NA	0.300	0.296
Z14	NA	0.296	0.296
Z15	NA	0.297	0.296
Z16	NA	0.292	0.296
Z17	NA	0.291	0.296
Z18	NA	0.298	0.296
Z19	NA	0.291	0.296
Z20	NA	0.294	0.296
Z21	NA	0.300	0.296
Z22	NA	0.294	0.296
Z23	NA	0.296	0.296
Z24	NA	0.299	0.296
Z25	NA	0.296	0.296
Z26	NA	0.296	0.296
Z27	NA	0.293	0.296
Z28	NA	0.294	0.296
Z29	NA	0.297	0.296
Z30	NA	0.296	0.296
Z31	NA	0.294	0.296

*NA - Not applicable

Table 6. TFSO annual motor-constant checks, (Continued)

System	Previous "G"	Measured "G"	"G" used for calibration
Z32	NA	0.296	0.296
Z33	NA	0.297	0.296
Z34	NA	0.295	0.296
Z35	NA	0.295	0.296
Z36	NA	0.292	0.296
Z37	NA	0.297	0.296

3.10.1.5 Routine Calibration of Test Equipment

Routine calibration of test equipment was accomplished at TFSO during the reporting period by use of a 1-percent standard meter. This meter is sent to the Garland laboratory for a calibration check every 3 months. An equipment calibration log for each item of equipment is kept up to date by TFSO personnel.

3.10.2 Facilities Maintenance

The humidity in the central recording building is controlled by a series of humidifiers which are mounted directly in the building air ducts. Two of these units required replacement because of burned-out motors.

In July, lightning damage to station equipment facilities included a water circulating pump in the air conditioning system, two 440-volt circuit breaker units, and the station commercial power transformer. All units were repaired or replaced.

Heavy snow in December caused the well-house roof to sag and the walls to bow out, but the damage was repaired without difficulty. The control circuit from the water storage tank to the pump house was grounded by the snow. A manually operated system was implemented until repairs could be made.

4. CHANGES AND ADDITIONS TO THE TFSO INSTRUMENTATION SYSTEMS

4.1 DESIGN AND INSTALLATION OF THE 37-ELEMENT SHORT-PERIOD ARRAY

4.1.1 Array Design Parameters

4.1.1.1 Objectives of Array Design

The design of the 37-element array was directed toward accomplishing the following:

a. Increasing the signal-to-noise ratio (S/N) of processed outputs in the frequency range 0.5 to 2.0 cps;

b. Providing the capability for velocity filtering of teleseismic signals;

c. Maintaining a detection capability through simple summation of selected elements of the array that is as near as possible to that of the 31-element array.

4.1.1.2 Characteristics of the Noise Field

The power spectrum of the ambient noise at TFSO is significantly lower than the power spectra at other VELA-Uniform observatory sites (WMSO, UBSO, CPSO, BMSO), and is essentially independent of position over distances on the order of 10 kilometers.

There is a distinct difference in the spatial organization of the ambient noise at frequencies above approximately 2.0 cps and below approximately 1.0 cps. At frequencies above 2.0 cps, the field is generally incoherent over distances greater than about 0.6 kilometers. At frequencies below 1.0 cps the noise is well organized and is apparently propagating at mantle P-wave velocities. The frequency range between 1.0 and 2.0 cps appears to be a transition region between the coherent and incoherent fields. There does not appear to be any persistent low-velocity coherent noise at TFSO in the band of interest (0.5 to 2.0 cps).

4.1.1.3 Array Geometry

If an array is designed such that the noise in the frequency band of interest is reasonably incoherent between detectors (or if it is coherent but propagates at a different wave number than the desired signal), and if teleseismic signals are coherent across the array, beam steering of the outputs should provide an increase in S/N in the frequency range above 0.5 cps by suppressing the ambient noise field in this range. These conditions were theoretically satisfied at TFSO by a hexagonal array in which the distance between detectors is 5 kilometers and the overall diameter of the hexagon is 30 kilometers.

Theoretical studies have indicated that the steered output of the 37-element array can be expected to show an improvement in S/N over the summed output of the 31-element array of between 8 and 12 dB for frequencies less than 1.0 cps and of about 3 dB for frequencies greater than 1.5 cps.

4.1.2 Array Instrumentation Systems

4.1.2.1 Seismometers and Amplifiers

A Geotech Solid-State Amplifier, Model 25220-03 and a Model 6480 Johnson-Matheson seismometer with a special 2800-ohm impedance data coil were used in each short-period seismograph system. The data coil was changed to a higher impedance in order to obtain the optimum source impedance for the solid-state amplifier and still obtain the proper seismometer damping. The Geotech Model 25220-03 amplifier is a solid-state, frequency-modulated amplifier with a center frequency of 1550 cps and deviations of ±40 percent of the center frequency. An input of 24 to 28 volts dc is required for the amplifier.

Each seismometer is damped by the amplifier and a 1000-ohm variable resistance in series with the data coil. After conducting several frequency responses, it was found that with the 1000-ohm potentiometer a frequency response closely resembling the previous operational response could not be obtained. After running tests we found that the response could be obtained with a 50000-ohm potentiometer in parallel with the amplifier input. At the end of the reporting period all damping circuits were being changed to include 50000-ohm potentiometers in parallel with the amplifier input.

In addition to the damping circuit, a 24 dB attenuator with 12 dB steps was connected between the seismometer and amplifier. For normal operation the attenuators are set for 0 dB.

4.1.2.2 Data Transmission

The data signal, calibration current, and dc voltage are transmitted between the vault and the central recording building (CRB) by a single spiral-four cable. The dc voltage and the 1550 cps data signal are separated by Model 19275 isolation filters and are transmitted by one pair of the cable. The remaining pair is used for the calibration current. The isolation filters were modified as described in section 4.1.2.4 because of inadequate lightning protection.

Due to line loss of the 1550 cps data signal in the outer elements, 6-millihenry loading coils are installed at 2-mile intervals to reduce the line loss. Junction boxes are installed at 1-mile intervals on all data cables of the short-period array. The junction boxes were installed as an aid in trouble-shooting the data cables and to facilitate use of as much of the cable from the 31-element array as possible.

4.1.2.3 Data Conditioning

Data conditioning of the short-period array is accomplished in the Solid-State Amplifier, Model 25220, the FM Discriminator, Model 21894, and the Signal

Control Center, Model 22602. The three units amplify and filter the data signal to form the relative amplitude response shown in table 8.

Seismometer calibration is obtained by the electromagnetic calibration method. The calibration signal is generated at the CRB and transmitted to each field vault by spiral-four cable.

4.1.2.4 Lightning Protection

After the installation of the first 5 sites of the short-period array we found that the instruments were not adequately protected at the seismometer from current surges due to lightning. On several occasions, the Model 25220 amplifiers were damaged as the result of lightning activity. The damage was confined to the voltage regulator section of the amplifier and to the input stage of the preamplifier. To provide additional lightning protection for these circuits, two 1.0-millihenry coils were connected in series in the data lines and 0.02 microfarad capacitors were connected between each side of the data line and ground (see figure 6). This additional protection proved to be adequate for protecting the voltage regulator, but when severe lightning discharges occurred we found that the preamplifier was still not adequately protected. The path for the discharges resulting in damage to the preamplifiers was found to be the capacitance between the seismometer data coil and the seismometer case. To protect the preamplifier from the effects of discharges along this path, a 1.0-microfarad capacitor was added to the circuit between the negative side of the power line and ground. This addition is also shown in figure 6. Also, the AEI lightning protectors were moved from the junction box located adjacent to the vault to the module assembly located inside of the vault to reduce the resistance in the ground buss to the protectors.

Several lightning storms have been encountered since the lightning protection system was modified. Figures 7 and 8 show the effects of an electrical storm on the data traces protected by the modified lightning protection system. A small amount of lightning damage has occurred to the seismographs protected by this modified system.

4.1.2.5 Power

The dc voltage to power the solid-state amplifiers is obtained from several Lambda Power Supplies, Model 130FM, located at the CRB. The power is transmitted to each field vault by means of spiral-four cable. A power distribution unit is used to control the individual voltage to each site since several sites are supplied from one power supply.

During a rainy period in which some of the lines had a high resistance leakage, several of the 1500-ohm, 2-watt potentiometers were damaged because of excess current. To correct this problem, the 0.1-ampere fuse was changed to 0.06 ampere and the potentiometers were changed to 5-watt units. A detailed block diagram of power system is shown in figure 9.

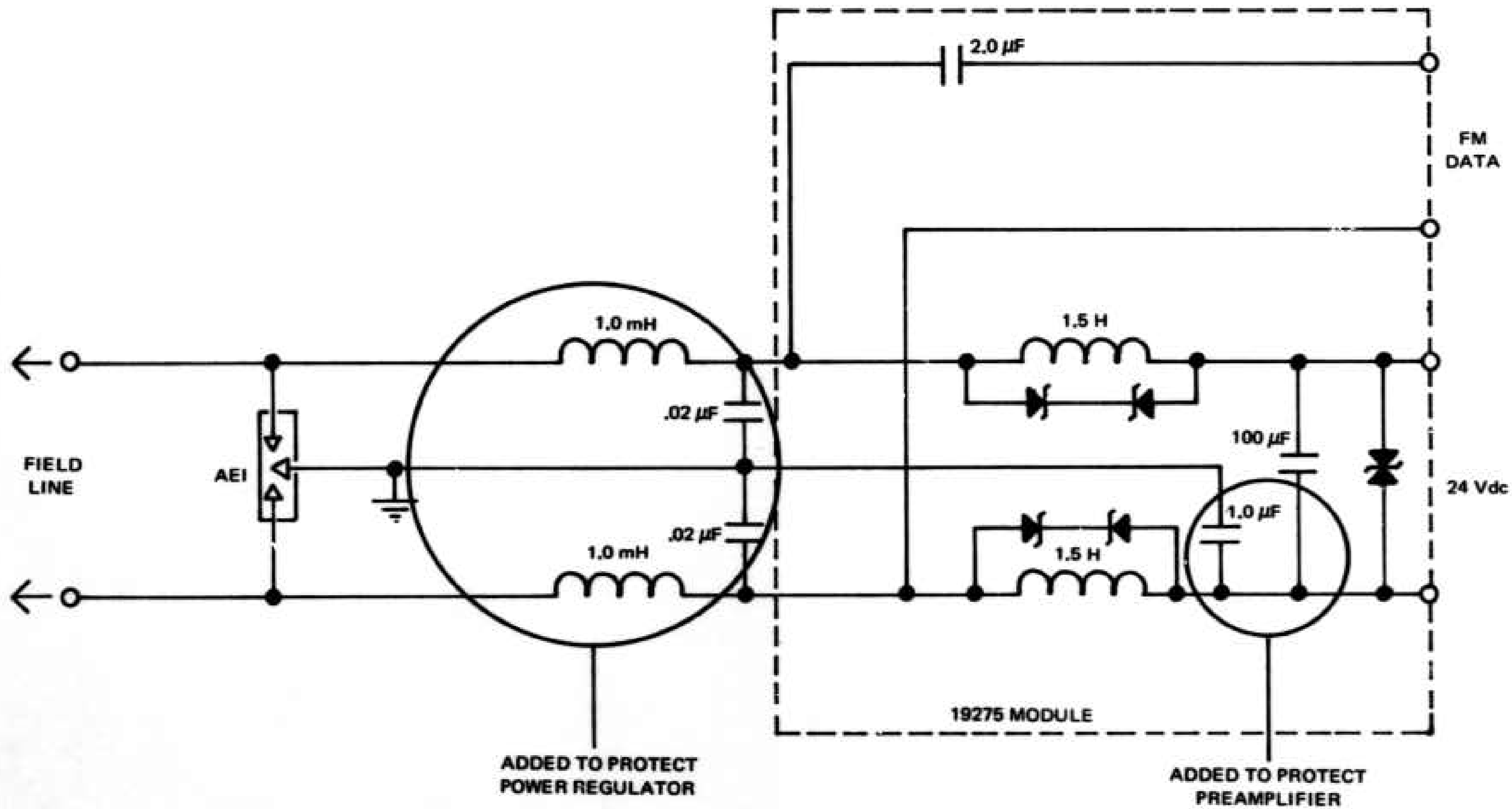
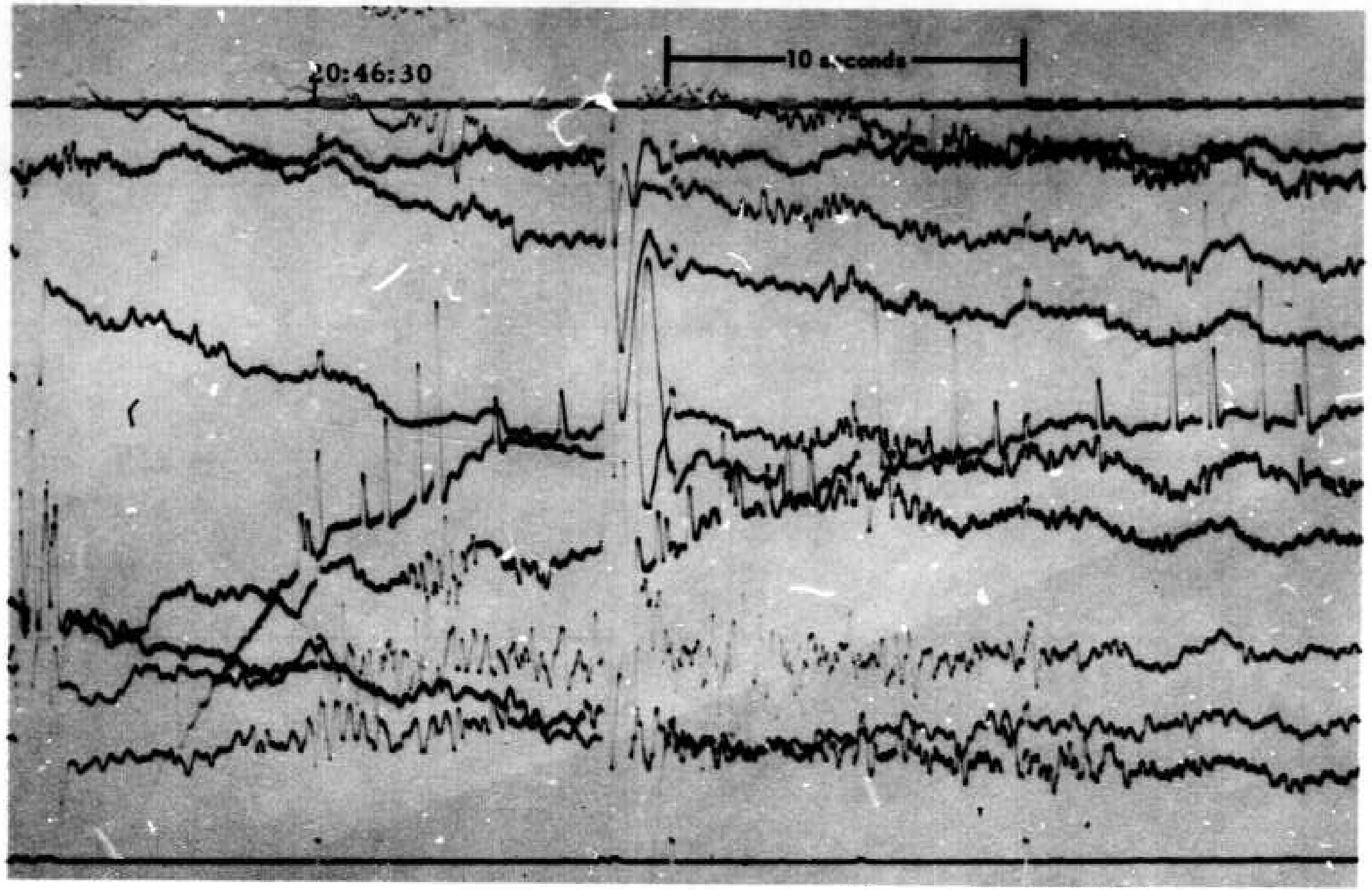


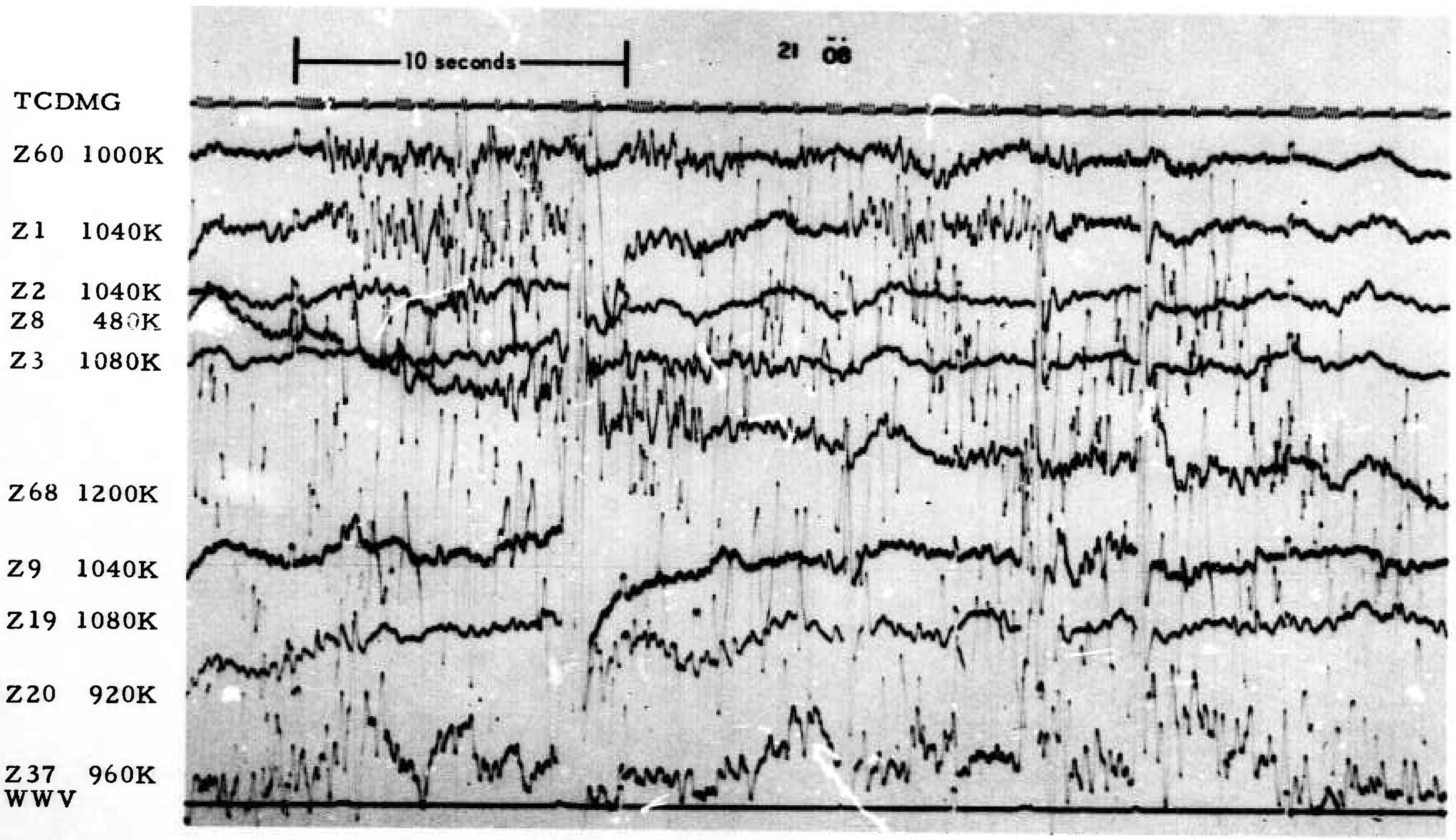
Figure 6. Portion of the lightning protection system installed at the seismometer vaults of the 37-element, short-period array at TFSO

TCDMG
Z60 1000K
Z1 1040K
Z2 1040K
Z3 1080K
Z8 480K
Z68 1200K
Z9 1040K
Z19 1080K
Z20 920K
Z37 960K
WWV



TFSO
13 Sept. 1967
RPN 256
DT SP EXP

Figure 7. Short-period seismogram illustrating the effects of lightning on the seismographs of the 37-element array protected by the modified lightning protection system



TFSO
13 Sept. 1967
RPN 256
DT SP EXP

Figure 8. Short-period seismogram illustrating the effects of lightning on the seismographs of the 37-element array protected by the modified lightning protection system

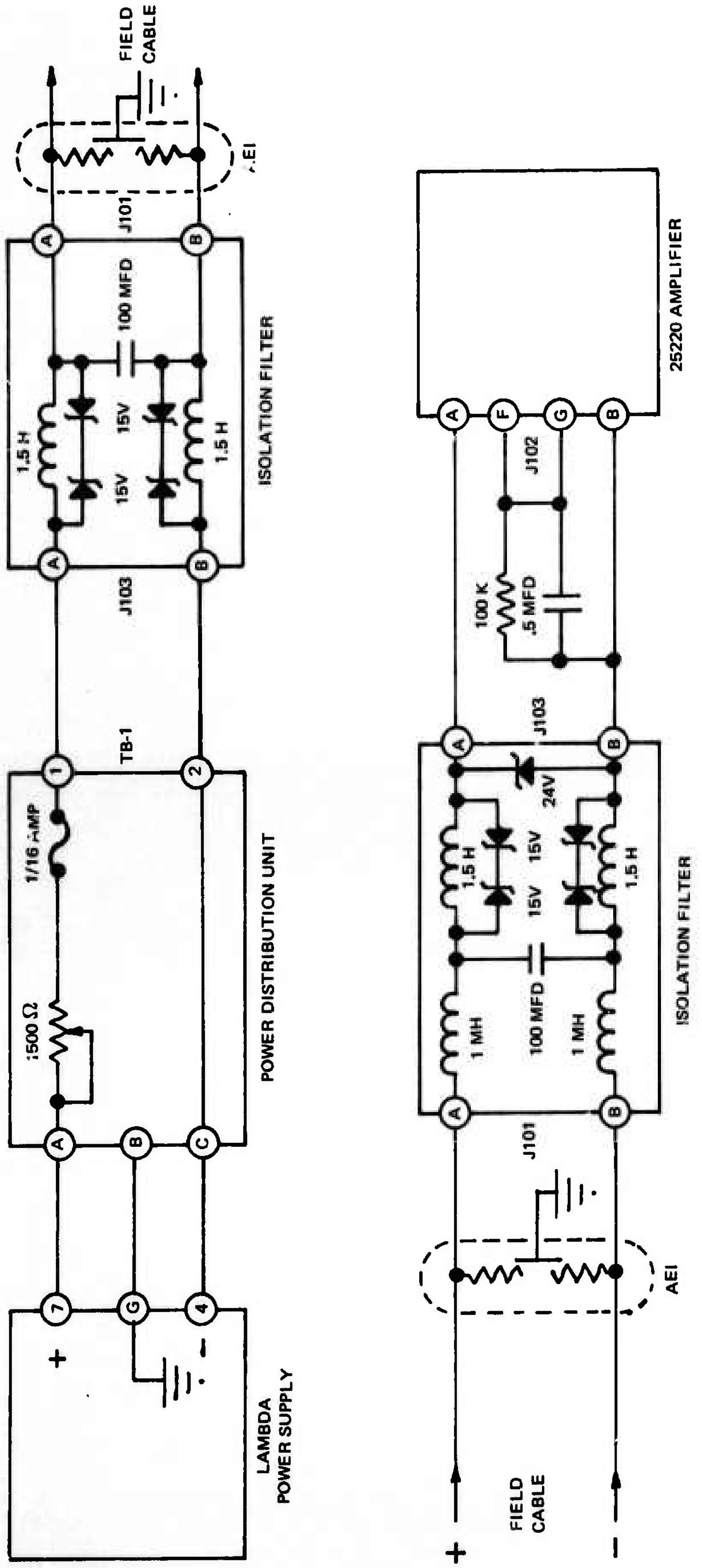


Figure 9. Block diagram of the power system for the short-period seismographs

4.1.3 Installation of Field Systems

4.1.3.1 Land Permits

The directive authorizing land procurement for the 37-element, short-period array was received by the Project Real Estate Office of the U. S. Army Corps of Engineers in Phoenix, Arizona, on 29 March 1967. A meeting was held on 3 April with representatives of the U. S. Forest Service, U. S. Army Corps of Engineers, and TFSO. It was decided that TFSO would furnish copies of maps showing plans for the 37-element array and that the Corps of Engineers would furnish an application for a Special Use Permit. The maps were supplied on 12 April. Verbal authorization to proceed with the construction was given by the Forest Service on 15 May, and a signed copy of amendment 4 to the TFSO Memorandum of Agreement, LA-1412, was received on 5 June.

4.1.3.2 Archeological Survey

Archeological inspection of the expanded array area was started on 14 June under the direction of Mr. Roger Kelley, Associate Professor of Archeology, Arizona Northern University. Inspection of the array was completed on 18 August, and clearance was given for excavation at all site and cable trails.

4.1.3.3 USAF Coordinate Survey of Array Locations

Approval was received from the Project Officer for the survey of the 37-element array by the 1381st Geodetic Survey Squadron. On 6 July, Mr. L. H. Schrag and Mr. R. S. Keenan of this unit visited TFSO to coordinate the survey with observatory personnel. The survey team arrived at TFSO on 15 August and remained until 14 November.

Table 7 shows the latitudes, longitudes, and altitudes above mean sea level, as preliminarily determined by the survey.

4.1.3.4 Construction of Cable Trails and Vaults

Magini Construction Company of Phoenix, Arizona, was awarded the site, access trail, and cable trail construction contract. Work began on 23 May on cable trails in the vicinity of Z9. Actual site preparation began on 5 July, and by 8 September all construction had been completed. Figure 10 shows the locations of the cable trails leading to each site. Figures 11 and 12 show the construction at a typical site.

Each vault site was excavated to competent rock to a minimum depth of 5 feet to allow the vault lid to be below the surface of the ground. Concrete was poured into the excavation to a level that would keep the lid of the vault within 2 to 3 feet of the surface when the vault was set into the concrete at a depth of 6 inches. Figure 13 shows a cross-section of a typical vault installation. After allowing the concrete to set properly, a 5-foot diameter culvert, 4 feet tall, was set around the vault to act as a retaining wall. Dirt was then used to fill in the area between the culvert and the sides of the excavation.

Table 7. Preliminary geographic positions and elevations of the Tonto Forest Seismological Observatory short-period array

I. SHORT PERIOD SENSORS

Site	Latitude (N)	Longitude (W)	Elevation Meters	Elevation Feet
**Z-1	34° 16' 42.330"	111° 18' 12.256"	1615.42	5299.94
*Z-2	34° 19' 14.119"	111° 19' 26.672"	1489.75	4887.62
*Z-3	34° 18' 42.576"	111° 16' 56.073"	1515.3	4971.47
*Z-4	34° 16' 13.891"	111° 14' 56.738"	1474.6	4837.79
*Z-5	34° 14' 10.222"	111° 17' 02.267"	1491.9	4894.82
*Z-6	34° 14' 55.697"	111° 20' 07.003"	1509.4	4952.1
*Z-7	34° 17' 09.183"	111° 21' 24.549"	1403.2	4603.74
*Z-8	34° 21' 42.290"	111° 20' 23.536"	1805.4	5923.216
*Z-9	34° 21' 10.002"	111° 17' 12.964"	1569.4	5148.92
*Z-10	34° 20' 52.209"	111° 14' 04.913"	1658.5	5441.31
**Z-11	34° 18' 04.865"	111° 12' 23.863"	1904.9	6244.96
**Z-12	34° 15' 49.507"	111° 11' 44.738"	1528.29	5014.07
*Z-13	34° 13' 48.402"	111° 13' 48.316"	1513.74	4966.34
*Z-14	34° 11' 41.443"	111° 16' 30.294"	1534.0	5032.64
*Z-15	34° 12' 08.076"	111° 19' 08.444"	1487.4	4879.91
*Z-16	34° 12' 32.081"	111° 22' 13.955"	1462.9	4799.67
*Z-17	34° 15' 03.954"	111° 23' 28.274"	1426.4	4679.89
*Z-18	34° 17' 40.876"	111° 24' 39.955"	1664.9	5462.34
*Z-19	34° 19' 39.854"	111° 22' 32.401"	1588.55	5211.76
*Z-20	34° 24' 09.131"	111° 21' 53.295"	1681.5	5516.65
*Z-21	34° 23' 37.574"	111° 18' 26.357"	1689.6	5543.27
*Z-22	34° 23' 28.832"	111° 15' 15.705"	1737.6	5700.70
*Z-23	34° 22' 49.935"	111° 12' 03.350"	1887.8	6193.48
*Z-24	34° 20' 19.749"	111° 10' 50.215"	1782.2	5847.13
*Z-25	34° 18' 00.133"	111° 09' 27.709"	1760.5	5775.96
**Z-26	34° 15' 26.079"	111° 08' 32.814"	1793.5	5884.23
*Z-27	34° 13' 17.260"	111° 10' 34.309"	1632.8	5356.86
*Z-28	34° 11' 06.032"	111° 12' 54.110"	1304.1	4278.48
*Z-29	34° 09' 15.999"	111° 14' 36.365"	1191.6	3909.49
**Z-30	34° 09' 38.040"	111° 17' 47.762"	1531.3	5023.82
*Z-31	34° 09' 53.404"	111° 21' 04.736"	1289.6	4231.03
*Z-32	34° 10' 27.080"	111° 24' 18.699"	1162.9	3815.44
*Z-33	34° 12' 57.216"	111° 25' 29.749"	1233.0	4045.33
*Z-34	34° 15' 27.436"	111° 26' 45.833"	1229.7	4034.33
*Z-35	34° 18' 01.630"	111° 27' 59.311"	1499.1	4918.33
*Z-36	34° 20' 02.520"	111° 25' 49.293"	1601.1	5253.08
*Z-37	34° 22' 04.959"	111° 23' 34.094"	1722.4	5651.06

*Geometric center (apex) of vault lid.
**Chiseled "X" mark in the center of the concrete base of the vault.

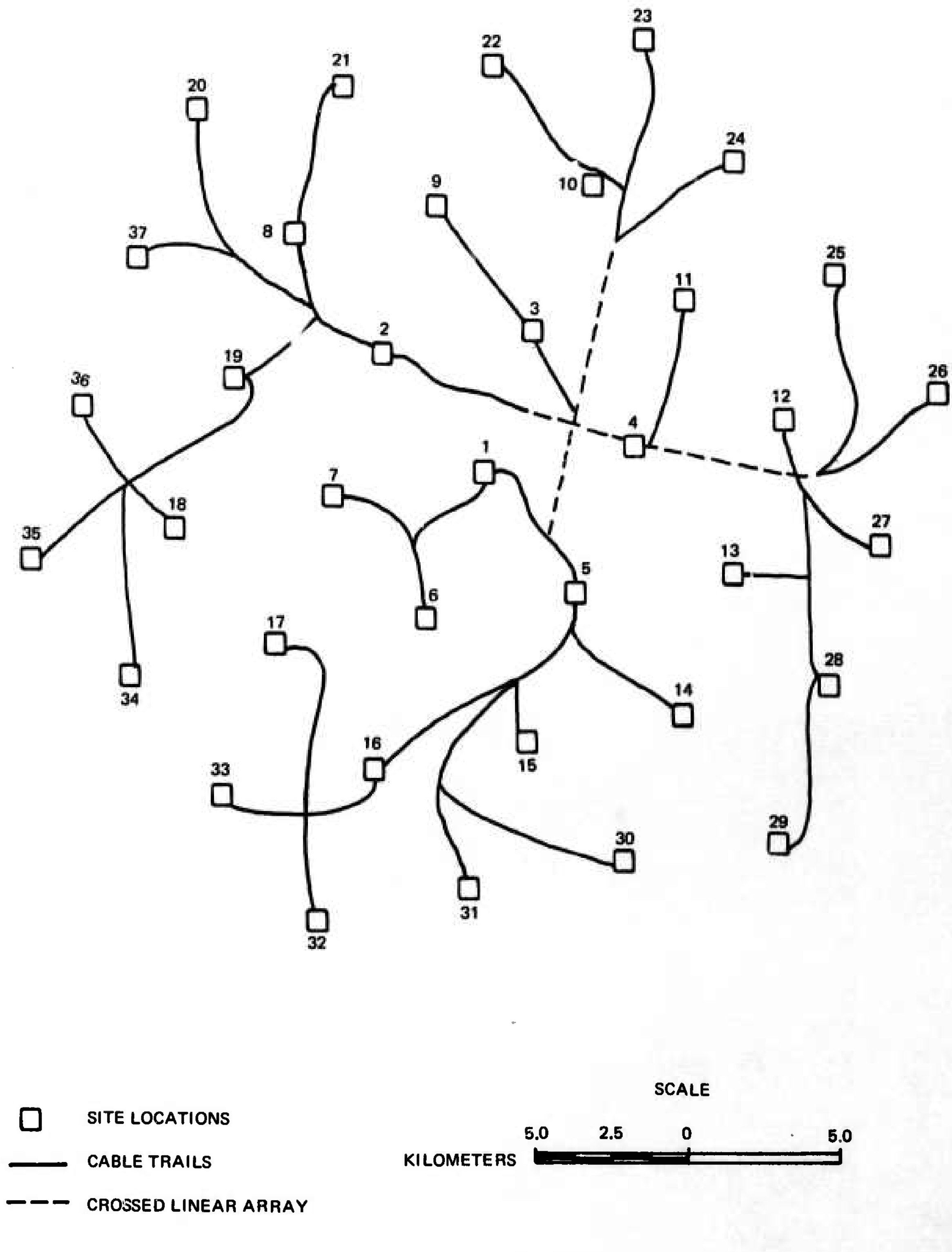


Figure 10. Locations of the sites and cable trails of the 37-element array at TFSO

Figure 11. Roadbed into site Z27 during construction

Figure 12. Site area of Z27 during construction

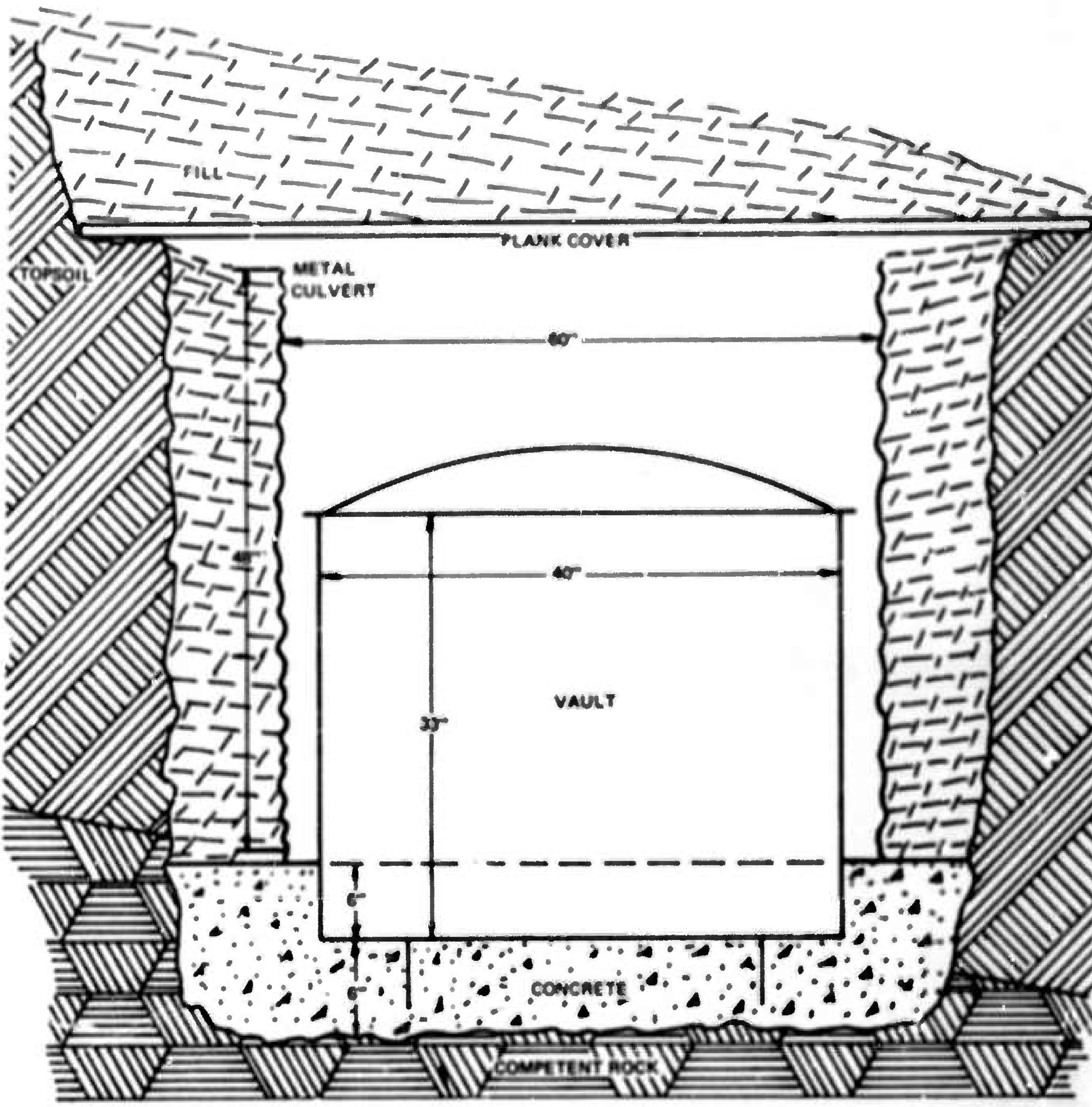


Figure 13. Cross-section of a typical vault installation in the short-period array at TFSO

An Epoxy paint was used to paint the bottom of the vault to a height of approximately 6 inches up the side. This was done to make a watertight seal and prevent ground water from seeping into the vault. The cable inlet was filled with Chico A05 after installing the cable to the vault. These steps along with a watertight lid prevent any moisture from entering the vaults. Many of these sealed systems have, in fact, operated with water over the top of the vault lid without any moisture entering the vault.

The amplifier and associated lightning protection are mounted on a panel which is welded to the side of the vault.

The seismometer feet are placed on glass coasters which are cemented to the bottom of the vault. This decreases the susceptibility of the instrument to lightning damage.

Upon completion of the installation and adjustment of the system parameters, the lid is bolted to the tank. Planking is placed over the vault and covered by a layer of dirt. The surface area around the vault is then leveled to reduce or eliminate the effects of wind noise on the records due to surface disturbances. Figure 14 shows a surface view of a typical short-period installation.

The construction work was stringently regulated by the Forest Service in regard to drainage, gradients, and brush and tree disposal. Upon completion of the work, the Forest Service prepared a report concerning necessary maintenance and rehabilitation work that in their opinion should be accomplished. This included reseeding of roads and sites. The manner in which this remedial work will be accomplished is pending.

4.1.3.5 Data Conditioning Equipment

Data conditioning is accomplished by the Signal Control Center. This unit shapes the response by the inclusion or omission of various resistors and capacitors mounted on a plug-in printed circuit board. The signal control center also has provision for controlling the level of the signal and can amplify the signal up to 128 times. Due to its low output impedance, variations in load will not affect the signal level on the various recorders.

4.1.3.6 Modification of the Astrodata Seismic Data Acquisition System

The Astrodata Seismic Data Acquisition System (ASDAS) was operated at intervals during the first half of 1967 for special test runs. It was modified during July and August to facilitate recording of the new 37-element and 21-element arrays.

Originally, the Astrodata system scanned 96 input channels at a rate of 20 scans per second. One hundred ten (110) scans constituted one record which represented a time interval of 5.5 seconds. Since each data sample is a 12-bit word, there were 126,720 bits of seismic data per record. At a density of 556 bits per inch, each tape ran for about 1 hour and 10 minutes. To increase this running time, it was decided to scan half as many channels (48) at a rate of 20 scans

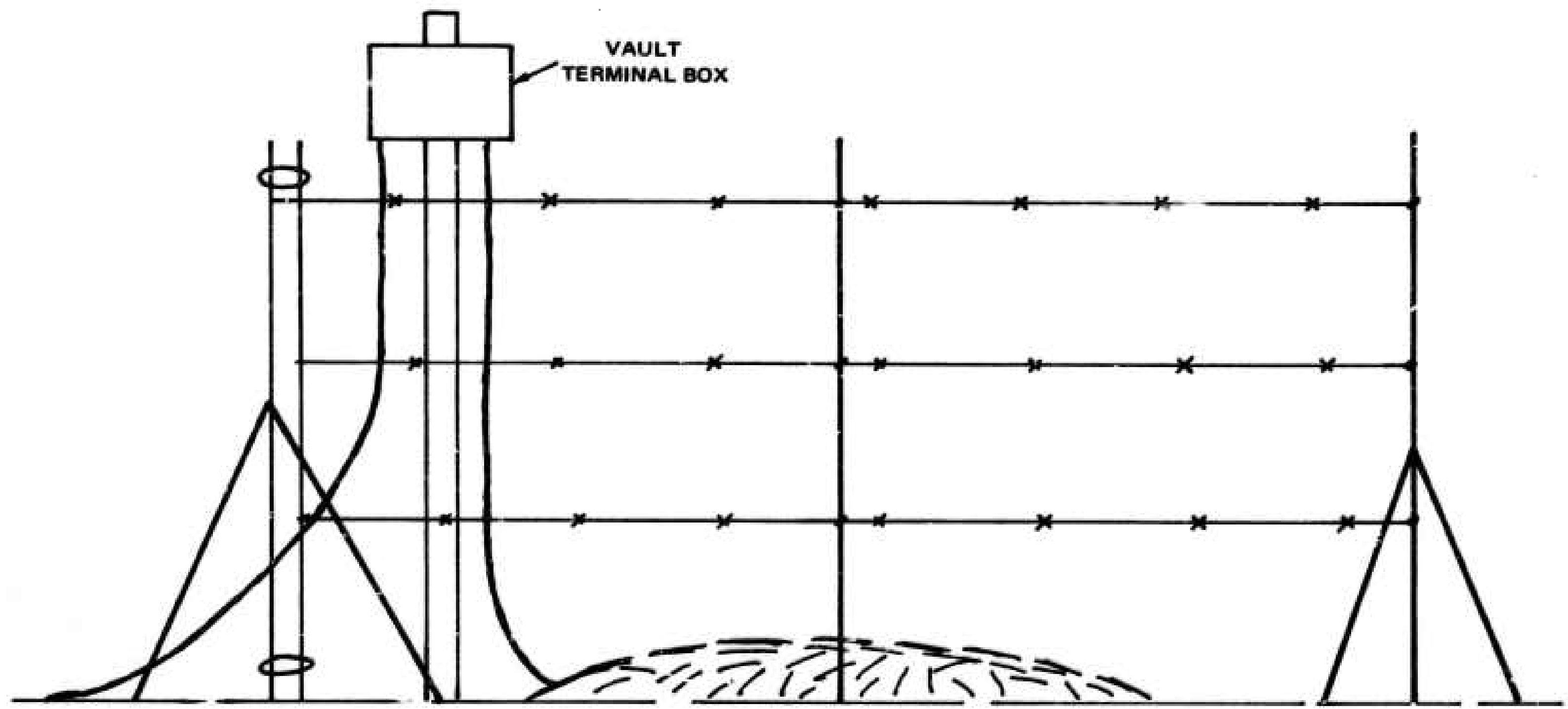


Figure 14. Surface view of a typical short-period vault installation at TFSO

per second but to retain the 126,720 bits per record. Each record, therefore, was modified to represent 11 seconds; the tape speed was halved and now each record represents about 2 hours and 15 minutes.

The approach used to accomplish this modification was to first slow the timing of the entire system by half. Since the initiation and sequencing of each of the internal operations of ASDAS is controlled by the timing counter, it was necessary to double the time interval between counter incrementations. Prior to the modification, a 1000 cps sine wave was used to activate the counter. Each peak of the sinusoid, occurring at 0.001-second intervals, caused the counter to be incremented. The time word was therefore updated at 1-millisecond intervals. Upon modification, a 500 cps sinusoid was used to activate the timing counter, and the time word was consequently updated at 2-millisecond intervals. In this way, the execution of the internal operations of the system were slowed by half with a minimum of hardware alteration. Another modification was necessary to terminate each scan after sampling 48 channels. There is a two-rank multiplexer system used to input data to the analog-to-digital converter (see figure 15). The first multiplexer selects an input channel and directs it to 1 of 3 amplifiers. Amplifier number one receives every third channel, beginning with channel 1, for example, channels 1, 4, 7, 10 and so forth; amplifier 2 receives every third channel beginning with channel 2; amplifier 3 receives the rest. The second multiplexer selects the proper amplifier. The purpose of the second multiplexer is to provide settling time for the amplifiers. The time required from the selection of a channel by the first-rank multiplexer to the storage of the digital sample in core is less than 60 microseconds, and the time required for a scan of all 96 channels is less than 6 milliseconds. A timing device, the scan intervalometer, is used to start the scans at the proper time. Before the modification, all 96 channels were sampled once within 6 milliseconds (see figure 16). For the next 44 milliseconds, no action was initiated by the multiplexer. This 50 millisecond cycle corresponded to 50 counts of the intervalometer, that is, 1 millisecond per count. As described, the intervalometer was modified such that there are now 2 milliseconds per count. After the modification, two 48-channel scans are accomplished within 50 counts of the intervalometer (or 100 milliseconds). The scan terms for channels 49 through 96 are connected so that the multiplexer turns on data channels 1 through 48 again to produce the desired second scan. It was found that the second scan must be started at a time slightly before the normal 50-millisecond interval to facilitate the detection of the end of a record, which is the end of the 220th scan. If equal intervals had been used, the criteria denoting the end of a record would not be satisfied since the end-of-record is produced when the core memory input and output addresses agree. Agreement would not occur with equal intervals because the output would overrun the input within 2-milliseconds of the time when the addresses should have come into agreement. By shifting the even numbered scans ahead 2 milliseconds, the proper relationships were obtained.

The tape transport must be started at exactly the correct time during the scan so that the unloading rate of the core memory will produce the proper timing at the end of 220 scans. This starting time is half way between the 16th and 17th count of the scan intervalometer. The starting time core input address was 966; however, with the scan of 96 channels broken in half and delayed, the new starting address of the unloading sequence is 870.

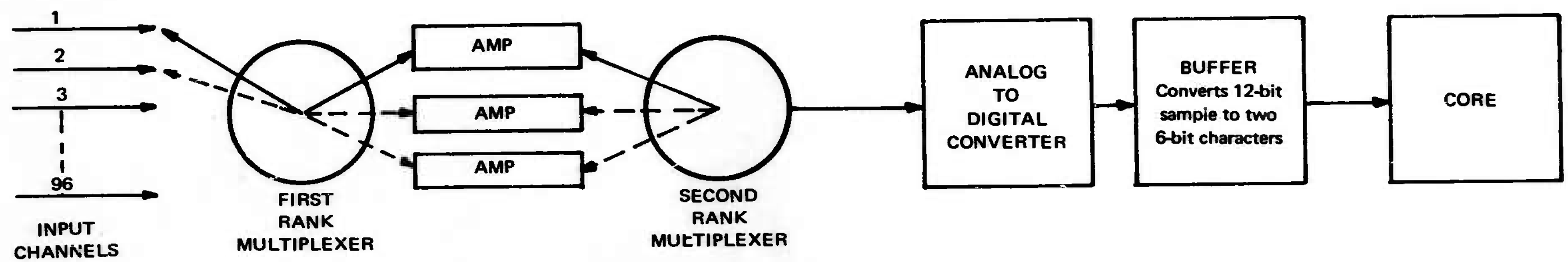


Figure 15. Schematic representation of the Astrodata two-rank multiplexer system

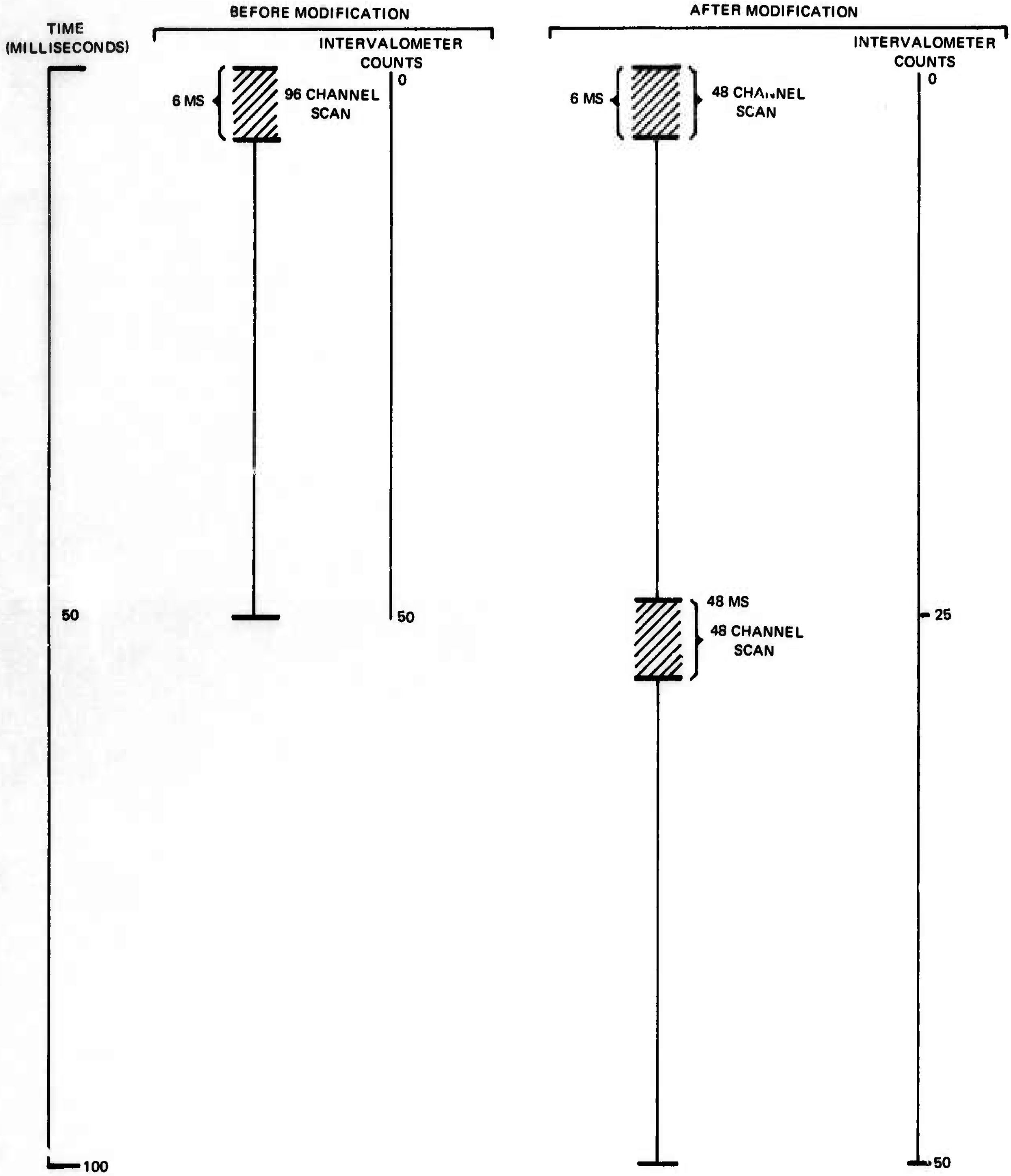


Figure 16. Schematic representation of the relationship of the Astrodata intervalometer and real time before and after modification

We found that the instructions to write the two characters denoting an end of file on tape were being given too close together. To correct the situation, a new term to delay the onset of the end-of-file was created. Also the time word was not being updated following the count lost during the clock sampling period. This was rectified by modifying the delay flip-flop used for this purpose.

Both tape transports were modified by halving the tape speed and changing the electronics for the new speed. The capstan drive pulleys were produced at the observatory. Both sets of heads were lapped at our Garland laboratory.

One serious problem which was finally resolved on 11 January 1968 involved the way in which characters are read into the core. Each sample was being transferred in reverse order. That is, the character with the least significant bits (LSB) was being transferred first, and the character with the most significant bits (MSB) was being transferred second. The first transfer was made during the time the core was being loaded with the time word, and that character therefore was lost. After the time word, the data were written as follows:

Channel Number	1	2	2	3	3	4	4	5	. . . .
Character Order	MSB	LSB	MSB	LSB	MSB	LSB	MSB	LSB	. . . . .
Computer Channels	1		2		3		4		

The manifestation of this problem on the output tape was extremely obscure. When the input to the ASDAS was a high-level calibration on all channels, the observed output on tape was a perfect calibration on all channels, since the shift of the lower order bits to a different channel caused an unnoticeable change. Seismic input to the system was always of a low level such that only the lower order 6 bits were activated. This type of input always produced an output on a different channel than the designated input channel and made the latter channel appear inoperative.

The problem was finally isolated with the help of Astrodata and was solved by inverting the analog to digital converter start conversion drive frequency. This had the effect of reversing the order of characters for each channel transferred to core.

Several unrelated problems occurred during the check-out of the newly modified ASDAS. In the analog to digital converter, the 6- and 10-volt regulators had several transistors damaged. In addition, parts in the decoding units were found to be bad due to the regulator malfunction.

During the modification, alignment of various components in the system was performed. This consisted primarily of complete alignment of the tape transport electronics and mechanical assembly and the complete alignment of the analog to digital converter.

Schematics showing the engineering changes required to achieve the modifications are on file at our Garland laboratory. The tape format of the Astrodata output tapes is presented in appendix 2.

4.1.4 Initial Operation of the 37-Element Array Seismographs

4.1.4.1 Preliminary Operating Parameters

The initial operating parameters of the new short-period solid-state systems were chosen such that the amplitude response would be very similar to the response of the short-period systems which utilize phototube amplifiers. Table 8 shows the normal frequency response and tolerances for each of the 37 short-period seismograph systems. The relative phase shift within the frequency band of interest between any two instruments will be maintained at less than 9 degrees. Other preliminary operational parameters are shown in table 9.

Table 8. Normalized frequency response and tolerances for the short-period seismographs at TFSO

Frequency	Normalized Value	Tolerance (%)
0.2	0.0118	10.0
0.4	0.0988	7.5
0.8	0.680	5.0
1.0	1.0	0
1.5	1.55	5.0
2.0	1.97	5.0
3.0	2.30	7.5
4.0	2.05	12.0
6.0	1.38	20.0

Table 9. Preliminary operational parameters for the 37-element, short-period array at TFSO

Seismometer free period (seconds)	1.25	
Set-up tolerance (percent)	±2.0	
Operate tolerance (percent)	±2.0	
Seismometer damping	0.54	
Set-up overshoot ratio	7.25-7.75	
Operate overshoot ratio	6.5-8.5	
Solid-state amplifier center frequency (cps)	1550	
Set-up tolerance (percent)	0.65	
Operate tolerance (percent)	0.97	
	Vert.	**Horz.**
Calibration motor constants (newtons/ampere)	0.296	0.296
Set-up tolerance (percent)	±2.0	±2.0
Operate tolerance (percent)	±3.0	±3.0
Effective mass (kgm)	18	18

4.1.4.2 Preliminary Calibration Schedule and Procedures

Each of the 37 short-period seismograph systems will be calibrated with a 1 cps sine wave daily. A calibration current of 0.06 milliamperes will be used to produce an equivalent ground motion of 25 millimicrons. The duration of the 1 cps calibration will be no less than 20 seconds.

Amplitude and phase responses as a function of frequency will be checked monthly.

4.1.4.3 Data Recording Formats

All 37 short-period seismographs will be recorded digitally by the Astrodata system. The tape format and channel assignments are shown in appendix 2.

The 37 seismographs are also recorded on film and magnetic tape. Table 10 shows the channel assignments for the 3 Develocorders on which the seismographs are recorded, and table 11 shows the channel assignments for the 4 tape recorders.

Table 10. Develocorder assignments for the 37-element, short-period array seismographs

Channel	Data Group 7240 Data Trunk 8	Data Group 7242 Data Trunk 5	Data Group 7251 Data Trunk 3
1	TCDMG	TCDMG	TCDMG
2	Z1	Z15	Z29
3	Z2	Z16	Z30
4	Z3	Z17	Z31
5	Z4	Z18	Z32
6	Z5	Z19	Z33
7	Z6	Z20	Z34
8	Z7	Z21	Z35
9	Z8	Z22	Z36
10	Z9	Z23	Z37
11	Z10	Z24	Microbarograph
12	Z11	Z25	Wind Indicator
13	Z12	Z26	Z67
14	Z13	Z27	Z69
15	Z14	Z28	Z73
16	WWV	WWV	WWV

Table 11. Tape recorder assignments for the 37-element, short-period array seismographs

Channel	Data Group 7239 Data Trunk 3	Data Group 7241 Data Trunk 6	Data Group 7244 Data Trunk 4	Data Group 7245 Data Trunk 5
1	TCDMG	TCDMG	TCDMG	TCDMG
2	Z1	Z13	Z25	Z69
3	Z2	Z14	Z26	Z68
4	Z3	Z15	Z27	Z65
5	Z4	Z16	Z28	Z66
6	Z5	Z17	Z29	Z67
7	Compensation	Compensation	Compensation	Compensation
8	Z6	Z18	Z30	Z73
9	Z7	Z19	Z31	Z72
10	Z8	Z20	Z32	Z61
11	Z9	Z21	Z33	Z62
12	Z10	Z22	Z34	Z63
13	Z11	Z23	Z35	ΣTF
14	Z12	Z24	Z36	Z37

4.1.4.4 Operating Problems

Installation of the cabling and instrumentation for the 37-element, short-period array was completed on 15 November 1967. Heavy rains in late November resulted in 21 inoperational systems. There is evidence that most of the trouble was due to bad cable. Approximately 60 percent of the cable replaced to date involved the old re-used cable from the linear array. In addition, newly purchased cable, which was checked to have between 10^6 and 5 x 10^6 ohms resistance to ground, appeared to be unsatisfactory for use in long lines. Approximately 70 reels of cable were replaced after the November storm. A study is currently underway to determine if bad cable is the only cause of the noisy systems, and if not, to isolate the other causes.

The short-period array was fully operational about 1 week during early December. Heavy snows in the Payson area resulted in inoperational systems through mid-January 1968. The heavy snowfall caused the following problems:

a. Cables were broken or pulled loose from junction boxes due to heavy ice buildup.

b. Cables were broken or shorted by falling trees and running water.

c. Some leakage occurred in marginal cables.

Electrolysis occurred at points where moisture could reach the data cables. This was observed at hock junctions, in junction boxes, and inside the vault in all terminals. This problem was created by the fact that the data circuit also carries dc power.

d. Not all vaults had been sealed water-tight prior to mid-December due to a continuing amplifier modification program, and some unsealed vaults were filled with water.

4.1.4.5 Predicted Response of Array as Constructed

The actual locations of the 37 short-period seismometers, listed in table 7, were used to calculate the true wave-number response of the array (see figure 17). Comparison of this response to the design response, shown in figure 18, shows that the beam-width of the two responses are equal. The secondary side lobes of the true array response are slightly distorted images of the side-lobes of the design response. In some cases, the side-lobes of the true response are about 3 dB higher than the corresponding side-lobes of the design response, but in general the levels are comparable.

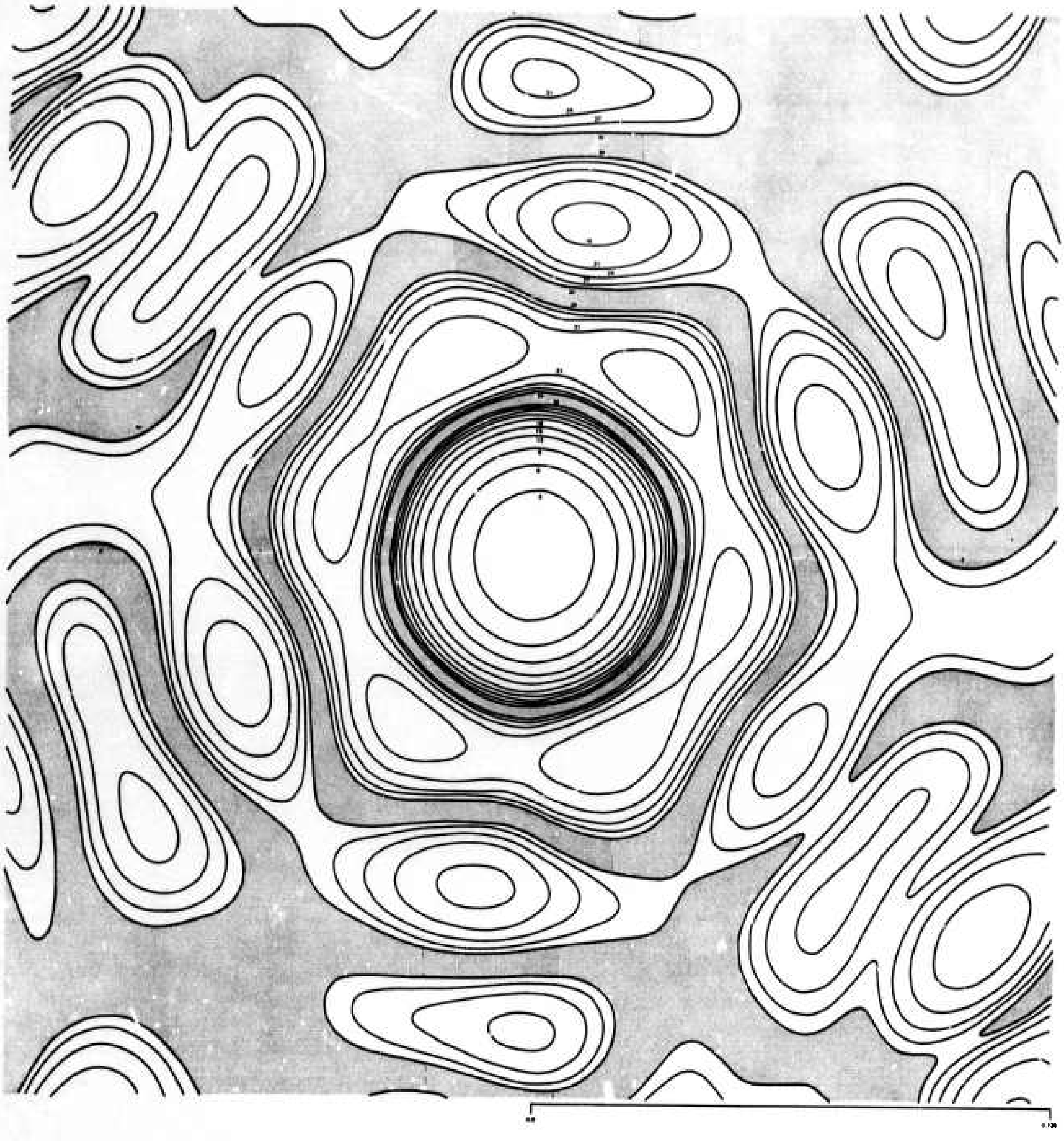


Figure 17. Wave number response of the 37-element, short-period array at TFSO

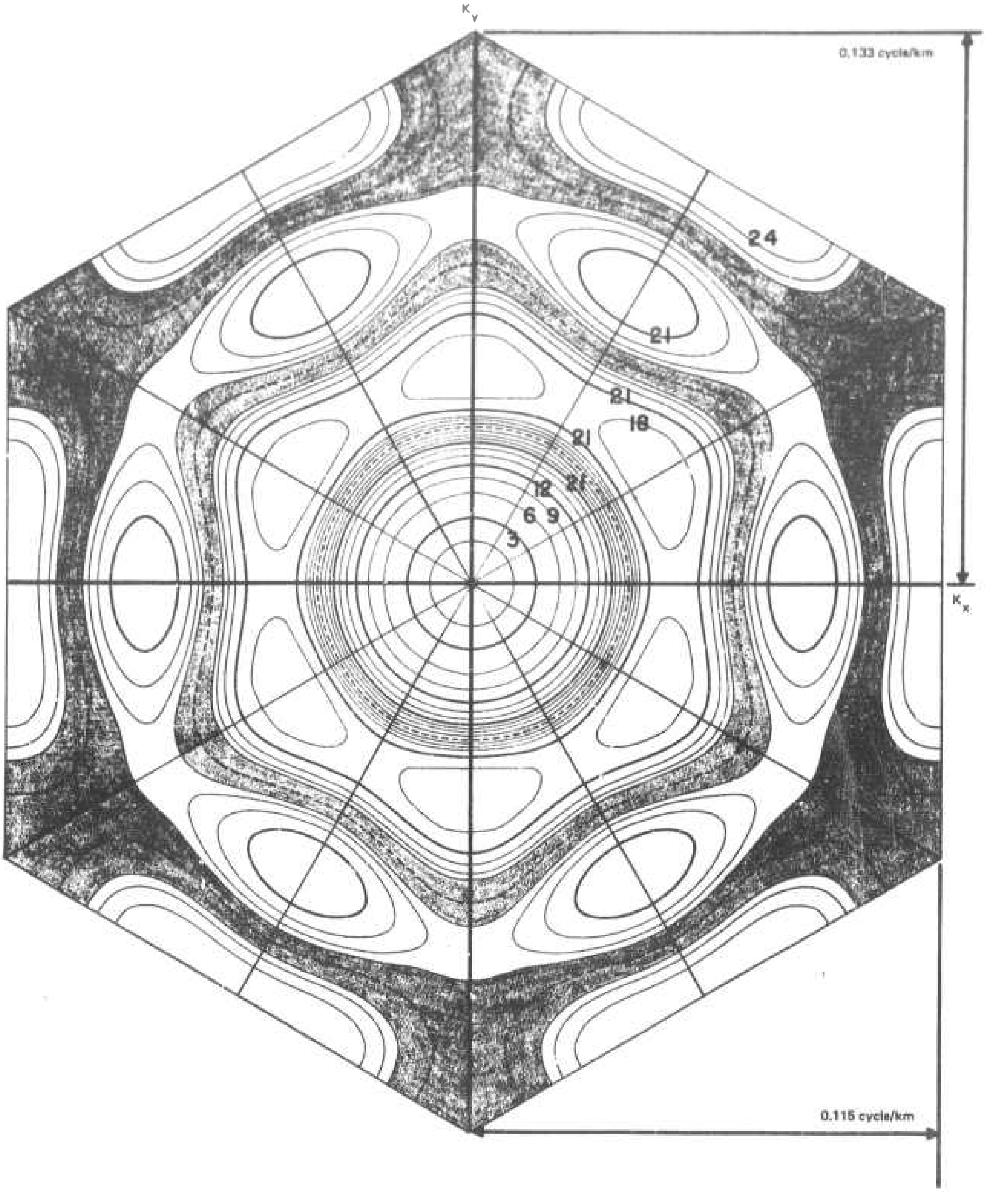


Figure 18. Predicted wave number response of the 37-element, short-period array at TFSO

4.1.5 On-Line Processing of the 37-Element Array

4.1.5.1 Mode of Initial Processing Planned

On-line beam-forming at TFSO will be initially accomplished by the Texas Instruments Multichannel Filter (MCF), which will be transferred from WMO to TFSO about 1 February 1968. The MCF has the capability of forming 8-10 output beams from 31 inputs. Although 10 output beams are insufficient to adequately cover the wave number spectrum, the MCF will provide a means by which the concept of on-line beam-forming can be evaluated.

4.1.5.2 Recommended Processing Techniques

To fully realize the potential on-line detection capability of the 37-element array, it will probably be necessary to form and display between 25 and 50 beams. This could best be accomplished by a small general purpose processor controlled by a stored program. A special purpose processor, such as an expanded version of the MCF, could form 25 or more beams, but because the purpose of the TFSO array is to develop and test techniques for the operation of medium-aperture arrays, we consider only general purpose processors to be satisfactory for the TFSO application. We recommend that a small, general purpose processor be procured for TFSO for semi-continuous, on-line beam-forming operation. The operation of this processor could be interrupted for use in on-line evaluation of other processes for which encouraging results are obtained in off-line tests, and for evaluation of the feasibility of automating some of the routine operational tasks.

If a general purpose processor becomes available we would initially propose to form 30 beams "tuned" to velocities and azimuths adequate to achieve global coverage with minimum attenuation for 1 cps teleseismic P-wave signals from hypocenters located at least 25 degrees from TFSO. The initial beams would be tuned as follows:

a. Twelve beams tuned to 12.5 kilometers/second in azimuthal increments of 30 degrees;

b. Twelve beams tuned to 19.2 kilometers/second in azimuthal increments of 30 degrees;

c. Six beams tuned to 47.6 kilometers/second in azimuthal increments of 60 degrees.

The above deployment in wave number space of the 30 beams would ensure that any off-beam signal will be recorded on one of the beams with a maximum attenuation of 6 dB relative to its arrival at a wave number to which a beam is exactly tuned.

The effectiveness of these beams would be evaluated, and based on this evaluation, it might be desirable to test the effectiveness of more beams (up to 50) and/or beams steered to different velocities.

4.2 DESIGN AND INSTALLATION OF A 7-ELEMENT LONG-PERIOD ARRAY

4.2.1 Long-Period Noise Analysis

Six three-component, long-period seismographs recorded data in the TFSO vicinity between 2 February and 7 April 1967. The array, shown in figure 19, consisted of five portable, long-period seismographs and the TFSO long-period seismographs. The TFSO seismographs were modified to match the response of the portable systems.

Four samples of long-period noise recorded on a vertical seismograph at each station were selected and digitized. The autopower spectra and coherence functions were computed for each of the noise samples. Phase velocities for selected frequencies were computed from the phase angles of the crosspower spectra, using standard tripartite methods. The following conclusions were made regarding the power spectra, phase velocities, and coherence functions:

a. The noise power is concentrated in two frequency bands, 0.04 to 0.082 cps and 0.11 to 0.165 cps.

b. The autopower spectra may be space stationary but relative variations in spectral level cause some doubt.

c. The autopower spectra are not time stationary.

d. The experimental phase velocities showed some scatter, but were in basic agreement with a theoretical dispersion curve determined for the TFSO area.

e. The coherence functions are neither time nor space stationary.

f. The noise in the frequency band 0.04 to 0.082 cps shows high coherence for small station separations and tends to decrease with increasing distance between stations.

g. The peak coherence usually occurs near the same frequency as the spectral peak in the frequency band 0.04 to 0.082 cps.

Complete details on the installation and operation of the array and the analysis of the data have been published in Technical Report (TR) 67-54, Analysis of TFSO Long-Period Noise Survey Data Conducted under Project VT/7702.

4.2.2 Array Design Parameters

The 7-element, long-period array, shown in figure 20, was designed so that a simple summation would improve the S/N for body wave signals. Because of the space stationarity of long-period body waves over large distances and their high apparent velocity, little signal degradation is expected from a simple sum. Thus, predicted improvements in S/N are based primarily on noise reduction obtainable if the noise satisfies the assumed characteristics.

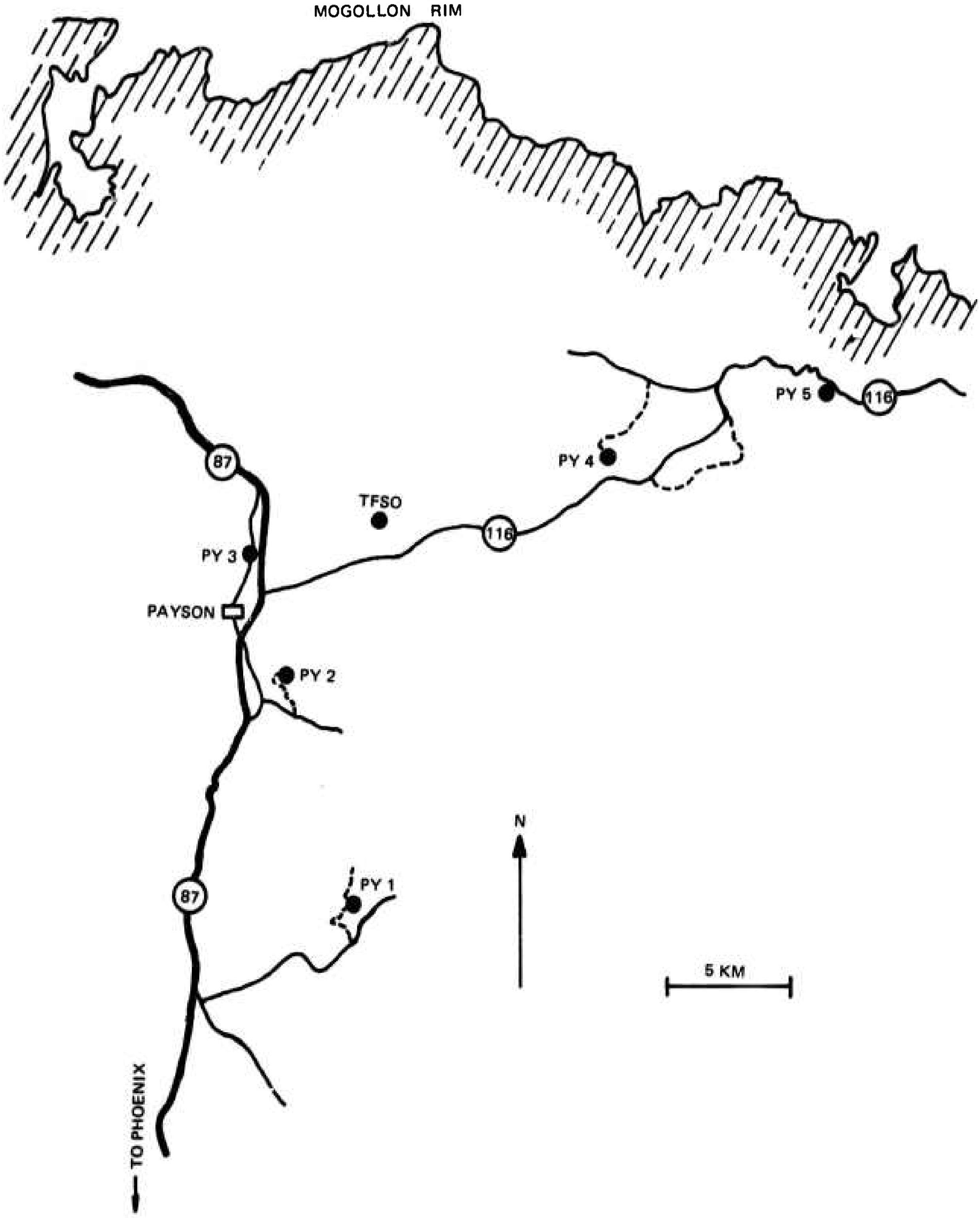


Figure 19. General orientation and spacing of the LRSM portable stations relative to TFSO and Payson, Arizona

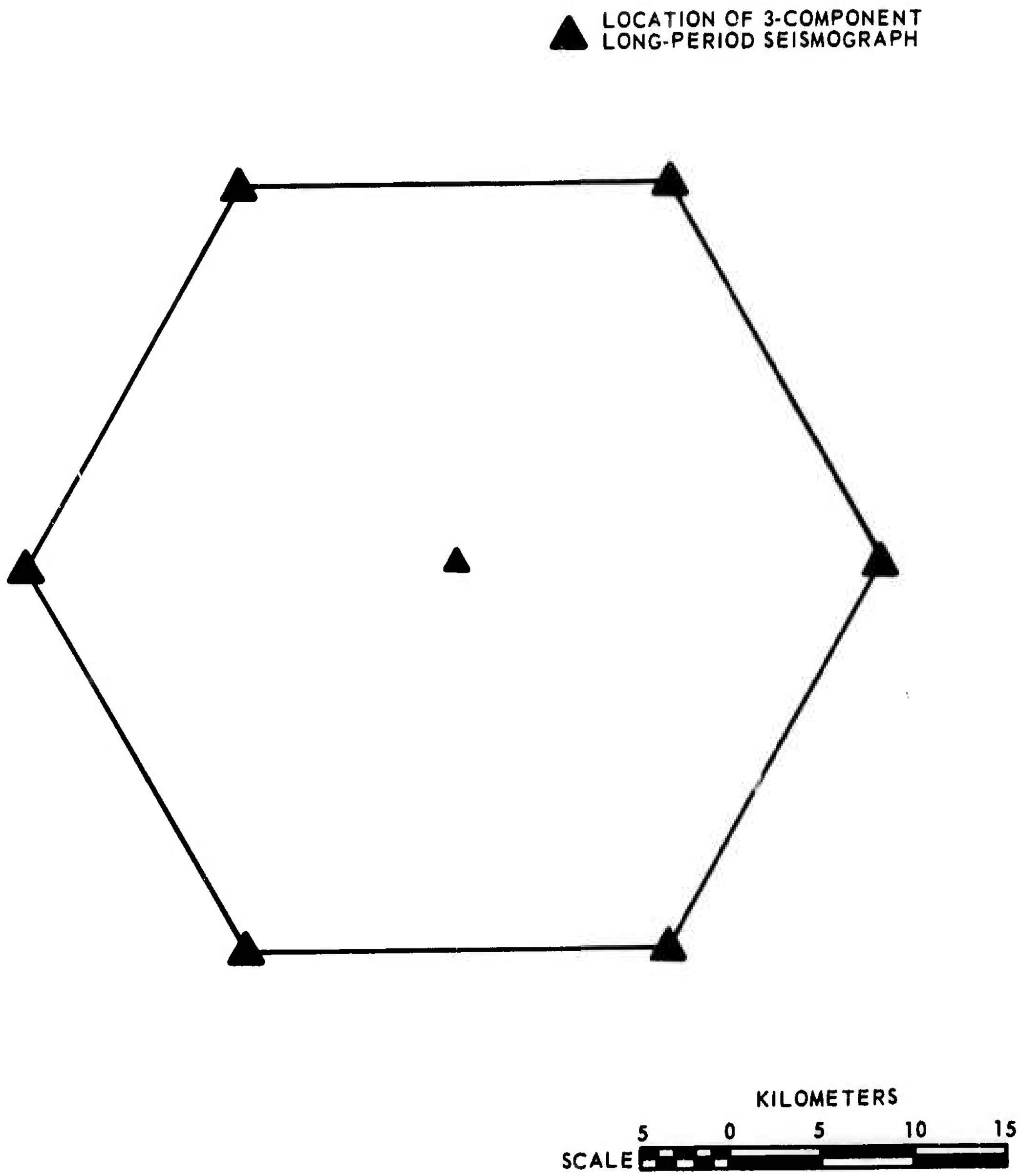


Figure 20. Configuration of recommended TFSO long-period array

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The simple summation of the recommended 7-element, long-period array should provide a minimum improvement in body wave S/N of about 9 dB over the period band 12 to 20 seconds, relative to a single detector.

Surface wave S/N improvement is difficult to estimate due to the dispersive nature of surface waves. Improvement by summation should be in the range 3 to 10 dB. It is probable that beam steering could offer greater improvement.

4.2.3 Array Instrumentation Systems

4.2.3.1 Seismometers and Amplifiers

The long-period array will consist of seven sites with one Vertical Advanced Long-Period Seismometer, Geotech Model 7505A, and two Horizontal Advanced Long-Period Seismometers, Geotech Model 8700C, at each site. Two modifications were performed to improve the operation of the instruments. A second remote leveling foot was added to each seismometer so that the free period could be adjusted from a remote location. Controls for the free period and mass position adjust are located at each site. An extension of the free-period foot was required to provide adequate clearance between the motor cover and the data output terminal posts.

The two data coils were connected in series to obtain the optimum source impedance for the solid-state amplifier so that with the proper seismometer damping we could obtain the best signal-to-noise ratio.

The amplifier being used in the long-period array is the Geotech Solid-State Amplifier, Model 28470. This amplifier replaces the Model 5240A galvanometer-type amplifier that was previously used in the long-period systems at TFSO. The Model 28470 amplifier has the following advantages over the galvanometer-type amplifier: (1) The solid-state amplifier is smaller; (2) no adjustments are necessary when installing the amplifier; (3) there is a low power requirement; (4) there is a capability of multiplexing the three data outputs to be transmitted over one data line; and (5) it is expected to provide a more stable and reliable system.

The data output from the amplifiers is a frequency-modulated carrier with a bandwidth of ±15 percent of the center frequency. The amplifier center frequencies are 560 cps for the east-west horizontal seismographs, 960 cps for the north-south horizontal seismographs, and 1700 cps for the vertical seismographs.

4.2.3.2 Data Transmission

The data for the long-period array will be transmitted by three different methods. Spiral-four cable will be used to transmit data from sites 1, 6, and 7. A Motorola microwave system is to be used to transmit data from site 5. Data from sites 2 and 3 will be transmitted by telephone company facilities, using a panhandle carrier over open-wire facilities. Data from site 4 will be transmitted by telephone company microwave circuits except for a short length of cable at each end.

Data at each site will be multiplexed with a summing amplifier which is also used as a line driver to increase the signal level before it is transmitted over the data lines. This amplifier has an adjustable gain so that the signal level can be reduced when operating into the telephone company circuits.

4.2.3.3 Data Conditioning

Data conditioning of the long-period system will be accomplished by the solid-state Telemetry Amplifier, Geotech Model 28470, the FM Discriminator, Geotech Model XD410, and the Signal Control Center, Geotech Model 22602. The three units will amplify and filter the data signal to form the relative amplitude response shown in table 14.

Seismometer calibration will be achieved by the electromagnetic calibration method. The calibration signal will be generated at the CRB and converted to a frequency modulated signal. The signal will then be transmitted to the vault over spiral-four cable, telephone company facilities, or microwave facilities, depending on the particular site location. The calibration signal will then be discriminated and converted to a sinusoidal signal. The calibration system will be adjusted so that the current through the seismometer coil is equal to the amount of current fed into the system at the CRB.

4.2.3.4 Lightning Protection

Based upon experience for the short-period array, the long-period array lightning protection will be similar to the short-period protection.

4.2.3.5 Power

At the sites where 110 volts ac commercial power is available (sites 1, 2, 3, and 4), a Lambda Power Supply, Model LH127, will supply 24 volts dc to the vault equipment. The power supply is mounted on the power company pole, and dc power will be transmitted to the vault over spiral-four cable. The length of cable required for each site varies up to a maximum of 2 miles at site LP4.

Thermoelectric generators, General Instrument type U2P, will provide 24 volts dc power to sites 6 and 7.

Site LP5 will be powered by a 9.0 kilowatt Witte generator operated on diesel fuel. The requirement for 110 volts ac power was necessitated by the decision to use the Motorola tube-type microwave equipment to transmit the data to TFSO. A Lambda power supply will supply the required 24 volts dc for the vault equipment.

4.2.4 <u>Installation of Field Systems</u>

4.2.4.1 Land Permits

The Phoenix real estate office of the United States Corps of Engineers received the Air Force request for use permits for the long-period sites on 28 August. A meeting was held between personnel of the Corps of Engineers and TFSO personnel shortly thereafter. On 6 September, all maps, specifications, and updated information for the long-period array were forwarded to the Corps of Engineers, so that an application for a Special Use Permit could be submitted to the Forest Service. The Corps of Engineers sent the application to the Forest Service on 6 October. Verbal approval to proceed with sites LP2, LP3, LP5, LP6, and LP7 was received from the Forest Service on 2 November. Approval to proceed with site LP4 was received on 5 November.

4.2.4.2 Archeological Survey

Site LP5 was inspected and approved for construction by Mr. Roger Kelley of Arizona Northern University during September. Messrs. P. J. Pilles, Jr., and W. Barrera, Jr., archeologists from the Museum of Northern Arizona, inspected and approved sites LP2, LP3, LP4, LP6, and LP7 during November.

4.2.4.3 Survey of Long-Period Sites

The 1381st Geodetic Survey Squadron determined the geographic positions and elevations of the long-period array sites. Table 12 lists the preliminary results.

Table 12. Preliminary geographic positions and elevations of the long-period array sites

Site	Latitude (N)	Longitude (W)	Elevation Meters	Elevation Feet
LP1	34° 16' 03.760"	111° 16' 12.972"	*	
LP2	34° 23' 28.832"	111° 15' 15.705"	*	
LP3	34° 19' 23.249"	111° 01' 01.673"	1852.9	6079.06
LP4	33° 06' 18.813"	110° 58' 04.318"	1651.8	5419.28
LP5	33° 58' 51.966"	111° 10' 00.916"	1634.9	5363.83
LP6	34° 03' 11.521"	111° 24' 08.340"	1151.2	3776.90
LP7	34° 15' 27.436"	111° 26' 45.833"	*	

*Not available in the preliminary report

4.2.4.4 Construction of Cable Trails and Vaults

The construction of the vault sites and the cable trails for the 7-element, long-period array was initiated during November 1967. Snow storms during December halted progress for the duration of the contract period. Table 13 summarizes the construction status at the end of December.

Table 13. Status of the long-period array on 31 December 1967

Site designation	Site Status	Communication type	Communication status
LP1	Previously constructed	Cable	Cable trail complete
LP2	Constructed	Telephone line	50 percent complete
LP3	Constructed	Telephone line	Completed
LP4	50 percent complete	Telephone line	50 percent complete
LP5	Not started	Microwave	10 percent complete
LP6	Not started	Cable	75 percent complete
LP7	Constructed	Cable	Cable trail complete

4.2.4.5 Installation of Field Equipment

The installation of field equipment varies at the different long-period sites due to the differences in vaults.

At LP1, the previously constructed walk-in long-period vault is being used. A standard Emcor "half-rack" is used to mount a panel containing the amplifier-multiplexer, lightning protection, and other peripheral equipment. At LP4, the 3-component system is installed in a single tank vault, which is 6 feet in diameter and 20 feet deep.

At the other locations, each of the 3-components are housed in separate vaults. A Hoffman box which houses lightning protection, calibration distribution, and mass position monitoring circuits is installed in the vicinity of the vaults. The amplifier and junction assembly are mounted on a panel which is welded to the inside of the vault.

Metal tanks are set in concrete to provide good coupling to competent, near-surface rock, and a multiconductor cable completes the circuits between the Hoffman box and the vault through a flexible plastic conduit.

When the installation is complete the system parameters will be adjusted, and the vault will be filled with an insulating material to reduce the effects of convection currents. The vault lid will be sealed, the vault will be covered with several feet of sawdust, and the area will be leveled. Figure 21 shows a plan view of a typical long-period installation.

4.2.5 Planned Operation of the Long-Period Array

4.2.5.1 Planned Operating Parameters

The planned frequency response and tolerances for each of the seven 3-component long-period seismograph systems is shown in table 14. Other planned operating parameters are shown in table 15. The relative phase shift, within the frequency band of interest, between any two seismograph systems will be initially maintained at less than 20 degrees. It is expected that operational characteristics of the systems will allow a closer tolerance to be adopted.

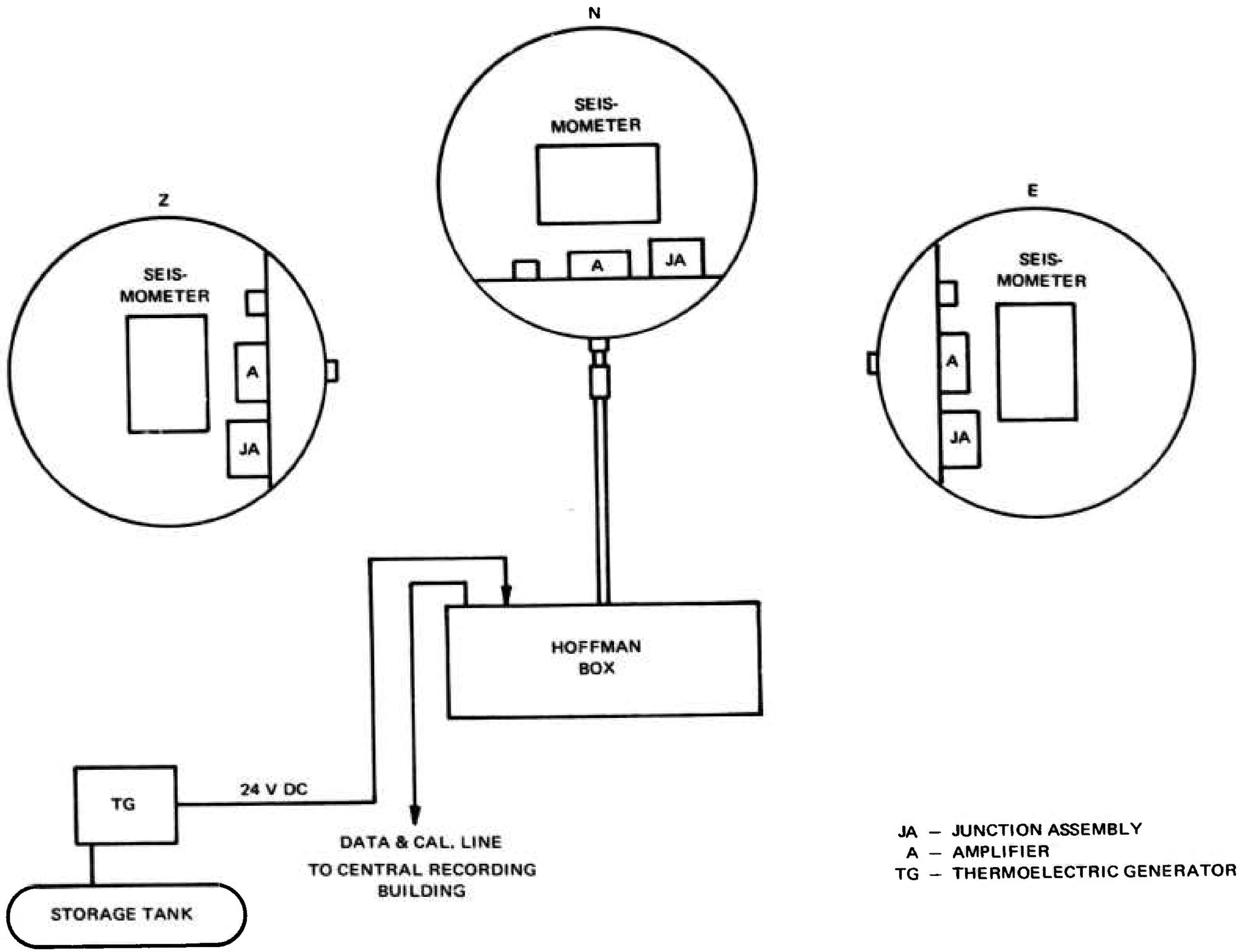


Figure 21. Plan view of a typical long-period installation

Table 14. Normalized frequency response and tolerances for the long-period seismographs at TFSO

Frequency	Normalized Value	Tolerance (%)
0.01	0.135	20
0.0125	0.278	20
0.0167	0.485	15
0.02	0.644	15
0.025	0.874	10
0.033	1.03	5
0.04	1.00	0
0.05	0.825	5
0.0667	0.470	10
0.100	0.110	20

Table 15. Planned operational parameters for the 7-element, long-period array at TFSO

Seismometer free period (seconds)	20.0	
Set-up tolerance (percent)	±2.0	
Operate tolerance (percent)	±5.0	
Seismometer damping	0.77	
Solid-state amplifier center frequency cps	560,960, and 1700	
Set-up tolerance (percent)	0.1	
Operate tolerance (percent)	0.8	
	Vert.	Hor.
Calibration motor constants (newtons/ampere)	0.028	0.028
Set-up tolerance (percent)	±2.0	±2.0
Operate tolerance (percent)	±3.0	±3.0
Effective mass (kilogram)	10.5	10.5

4.2.5.2 Planned Calibration Schedule and Procedures

Each of the 21 long-period seismograph systems will be calibrated daily, with a 0.04 cps sine wave. A calibration current of 0.024 milliamperes will be used to produce an equivalent ground motion of 1000 millimicrons. The duration of the 0.04 cps calibration will be no less than 3 minutes.

Amplitude and phase response as a function of frequency will be checked monthly.

Motor constants of the seismometers will be checked semi-annually.

4.2.5.3 Recommended Provisions for Digital Recording

The modification of the Astrodata system reduced the number of available input channels to 48. Since 37 of these channels will be used to record the outputs of the short-period seismographs, and 1 channel will be used for timing, only 10 channels will be available to record the outputs of the 21 long-period seismographs. To enable all the long-period outputs to be recorded by the Astrodata system, we recommend that the system be further modified to include a multiplexer subcycle generator which will facilitate the recording of 40 or more channels of long-period data, each sampled once each second. The effect of this recommended modification would be to take advantage of the slower sampling rate required for long-period data so that each 50-millisecond scan would not need to sample every long-period input. That is, successive scans would sample different long-period inputs, and a given digital output channel would provide data from more than one long-period input.

4.2.5.4 Predicted Response of Array as Constructed

The wave-number response of the 7-element, long-period array is shown in figure 22. Due to the fact that the interior element is offset from the center, as shown in appendix 3, the response along northwest-southeast wave-number vectors is down only about 15 dB. This makes the response inferior to the wave-number response of the recommended array, shown in figure 23. In comparing the two responses, the theoretical response should be rotated about 8 degrees counterclockwise.

4.2.6 Recommended On-Line Processing of Long-Period Array Data

If a suitable processor is made available, we propose to steer the vertical components of the long-period array to a velocity of 3.4 kilometers/second and 5 azimuths for Rayleigh wave enhancement. For Love wave enhancement, we will steer the horizontal components of the array to a velocity of 3.5 kilometers/second and 5 azimuths. For each steered azimuth we will rotate by coordinate transformation the orientations of the horizontal components so that they will be radial and transverse to the steered azimuth.

5. ROUTINE ANALYSIS

5.1 INTRODUCTION

Seismometric data were recorded at TFSO continuously throughout this reporting period. The recorded data were routinely analyzed, the analyses checked,and a daily tabulation of arrival times of P phases and selected later phases of earthquake signals transmitted to the Environmental Science Services Administration's Coast and Geodetic Survey (ESSA-C&GS). Analysis data were finalized at SDL where they were associated, when possible, with known earthquakes using the Automated Bulletin Process (ABP). Automated Bulletin Process association is based on hypocentral information furnished by ESSA-C&GS. Using these data, a monthly earthquake bulletin was prepared and published at our Garland laboratory.

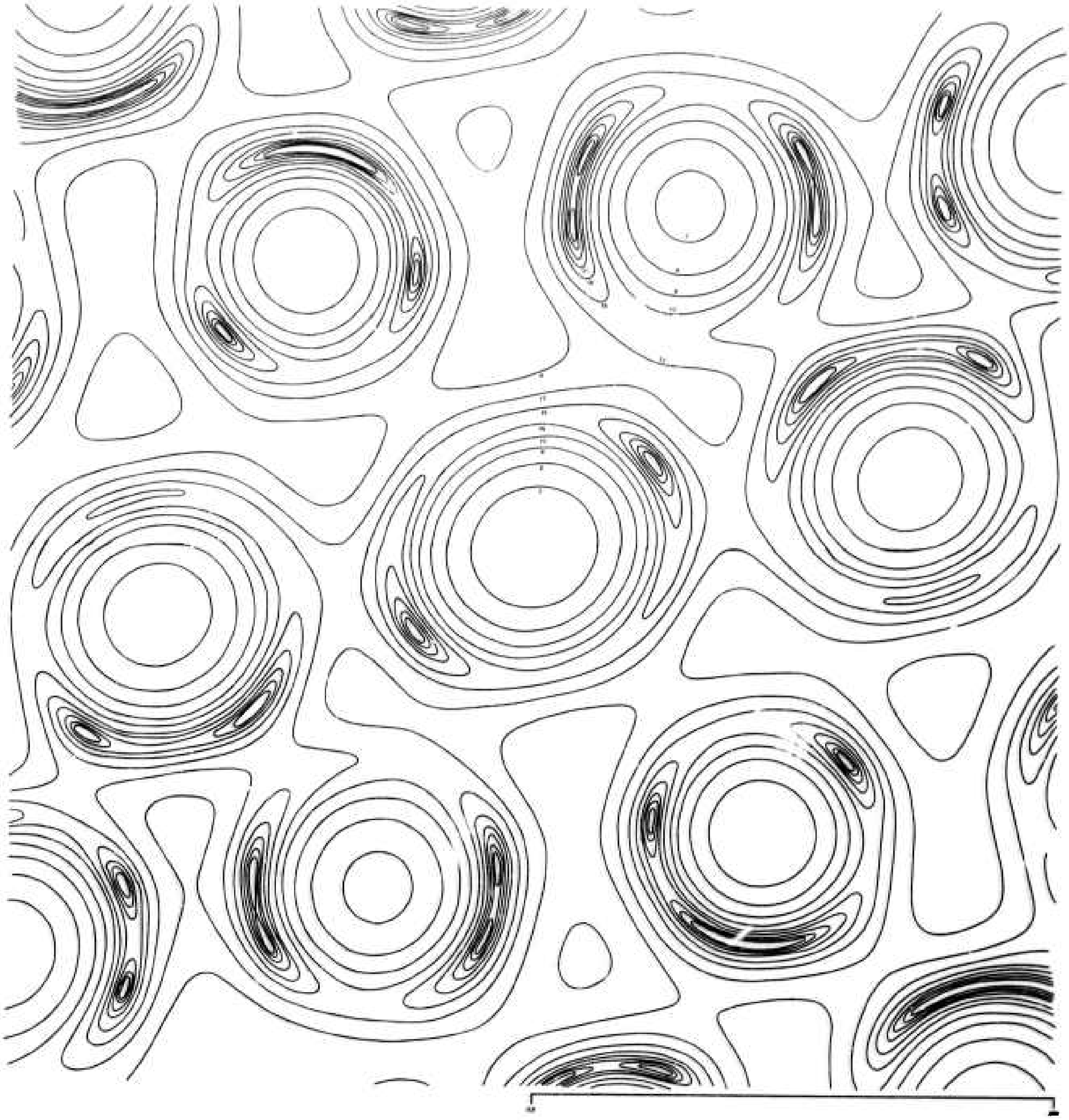


Figure 22. Wave number response of the 7-element, long-period array at TFSO

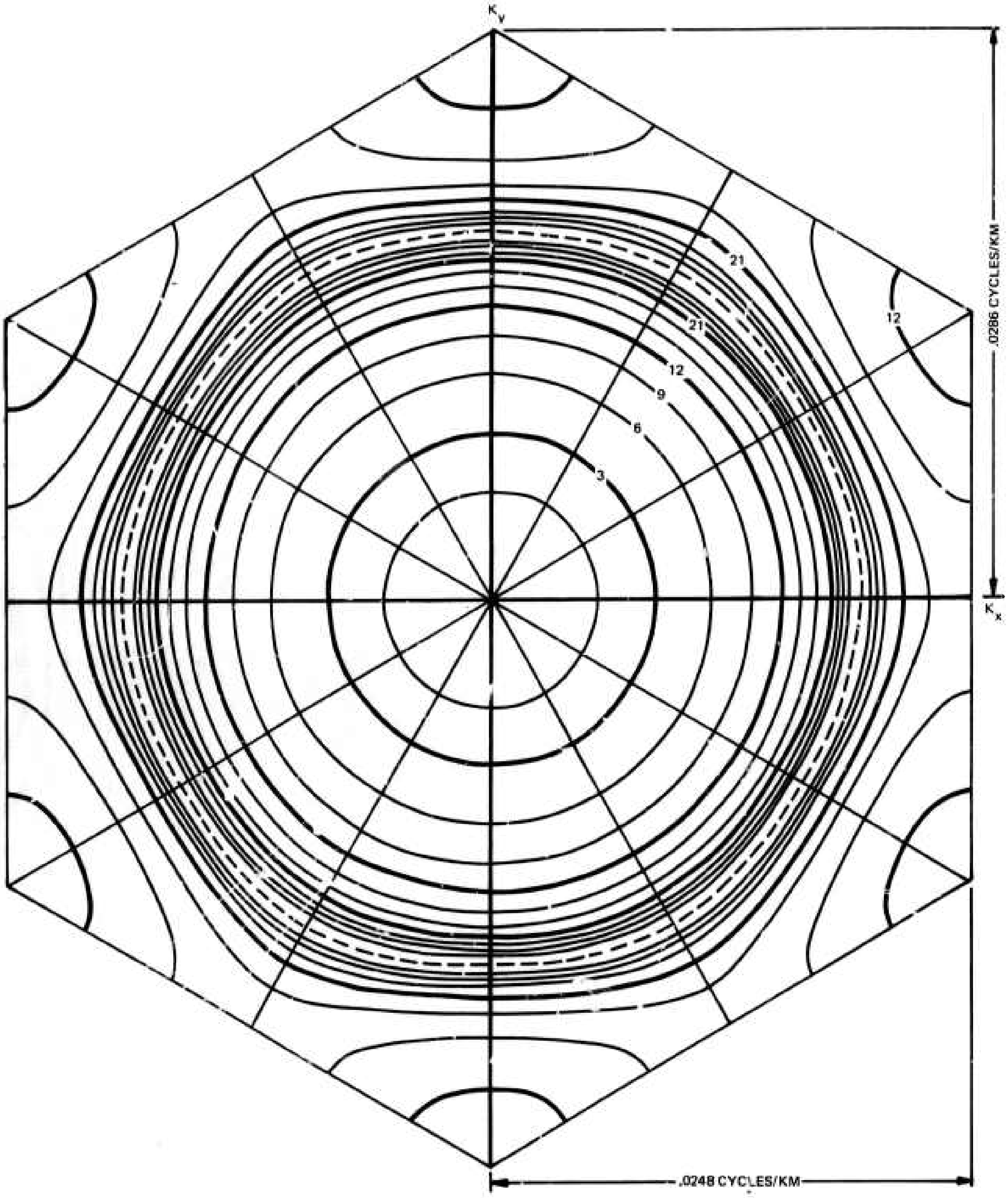


Figure 23. Predicted wave number response of the long-period array at TFSO

Sixteen-millimeter film seismograms and associated preliminary analysis data were routinely selected on a random basis by our Garland laboratory personnel for review by a quality-control analyst. Recorded data were also used to evaluate routine and special seismograph systems operated at TFSO and to obtain data for research studies.

5.2 ANALYSIS PROCEDURES

5.2.1 Preliminary Analysis

Film seismograms were analyzed during each 24-hour period. Preliminary analysis was conducted on an "on-line" basis and the analysis data were recorded on worksheets compatible to both observatory use and direct transcription of data to IBM cards. Data recorded during preliminary analysis consist of:

a. Phase arrival time;

b. Period and peak amplitude of each phase arrival;

c. Preliminary phase identification when possible;

d. Classification of events by general type (for example, local, near regional);

e. Estimated station-to-epicenter distance and/or azimuth (when possible);

f. Seismograph system and component.

5.2.2 Checking and Finalization of Preliminary Analysis

The seismograms were reviewed by a second analyst who checked the arrival time, period, and amplitude data recorded on the worksheets, and reviewed portions of the seismogram classified as "possible signal" by the preliminary analyst. Data from the analysis sheets were used for compilation of information for ESSA-C&GS, the monthly earthquake bulletin, and for various statistical analyses.

Before the analysis sheets are sent to our Garland laboratory, events are assigned sequence numbers for ABP control.

5.2.3 Daily Reporting to the ESSA-C&GS

Throughout the reporting period, the arrival time, signal period, signal amplitude, and estimates of epicentral locations (when estimates were possible) of events recorded at TFSO were reported daily to the ESSA-C&GS in Washington, D. C. Daily messages, sent by TWX, are relayed to Washington, D. C., by the General Services Administration in Phoenix on week days, and are sent directly to Washington, D. C.., on weekends and holidays. Data are used by the C&GS in their hypocenter location program.

Table 16 shows the number of events of each type reported, the number of hypocenters reported by the C&GS, and the percentage of those events located by the C&GS having P or P' detected.

Table 17 shows the number of earthquakes having P or P' detected by TFSO and the number reported by C&GS for four distance ranges. Table 18 shows the number of earthquakes having any phase detected by TFSO and the number reported by C&GS for four distance ranges.

5.3 PUBLICATION OF THE VELA-UNIFORM EARTHQUAKE BULLETIN

5.3.1 Transmittal of Raw Data to SDL

Data from TFSO were keypunched into IBM cards directly from the analysis sheets. The cards were checked for proper sequencing, anomalous data values, and incomplete data using a CDC 3100 computer program. Necessary corrections were made, and the data were transcribed onto digital magnetic tape and shipped to SDL for processing by the ABP.

5.3.2 Final Bulletin Preparation

After the raw analysis data were processed by the ABP at SDL, the associated data were returned to our Garland laboratory for final processing. After the ABP output is checked for anomalous data, the updating program makes the necessary corrections; automatically calculates ground displacement values and magnitudes that may be missing from the ABP output; and associates Love and Rayleigh wave arrivals with the proper hypocenters (Love and Rayleigh arrival associations made during the preliminary analysis are accepted by the ABP). Subsequently, a third program controls the proparation of the offset masters by the ABP.

5.4 ROUTINE ANALYSIS OF NOISE DATA

Microseismic noise analysis was routinely accomplished at the observatory. Nine samples of noise in the period range between 0.4 and 1.4 seconds are measured from the film seismogram each day. The data are processed, and monthly probability of occurrence curves are prepared for both X10 trace amplitude measurements and ground displacement for an individual seismogram, the summation seismogram, and the filtered summation seismogram. These data are routinely sent to the Project Officer.

Table 16. Locals (L), near regionals (N), regionals (R), and teleseisms (T) reported to the C&GS by TFSO from 1 October 1966 through 30 September 1967

Month	L	N	R	T	Per[a]	C&GS located
October 1966	10	325	20	1371	74.6	387
November	9	179	22	1229	79.2	365
December	2	140	8	1220	71.3	320
January 1967	12	149	10	1510	74.6	494
February	25	139	7	902	72.5	301
March	40	141	17	1422	72.5	411
April	15	142	24	1252	66.7	427
May	32	188	44	1078	65.1	413
June	38	124	16	1038	59.3	444
July	9	152	21	1200	64.6	439
August	19	128	16	903	64.6	395
September	16	236	12	902	60.9	411
October	7	127	12	913	b	b
November	14	135	16	987	b	b
December	8	228	15	746	b	b

[a] Percentage of those events located by C&GS having P or P' detected

[b] This information not available at time of publication

Table 17. Earthquakes having P or P' detected by TFSO, and earthquakes reported by C&GS between 1 October 1966 and 30 September 1967

Month	16.0-20.0			20.1-90.0			90.1-104.0			104.1-180.0		
	Loc[a]	Det[b]	Per[c]	Loc	Det	Per	Loc	Det	Per	Loc	Det	Per
October 1966	3	3	100.0	207	194	93.7	71	40	56.3	64	33	51.6
November	3	3	100.0	227	204	89.9	59	32	54.2	45	17	37.8
December	4	4	100.0	196	162	82.7	70	40	57.1	45	21	46.7
January 1967	5	5	100.0	191	166	86.9	191	136	71.2	71	38	53.5
February	1	1	100.0	161	139	86.3	59	28	47.5	54	35	64.8
March	0	0	0	244	216	88.5	62	33	53.2	88	37	42.0
April	6	6	100.0	203	175	86.2	108	43	39.8	84	44	52.4
May	1	1	100.0	222	182	82.0	100	43	43.0	60	22	36.7
June	9	8	88.9	226	171	75.7	118	45	38.1	77	35	45.5
July	1	1	100.0	243	194	79.8	95	41	43.2	73	38	52.1
August	2	2	100.0	210	172	81.9	92	30	32.6	70	38	54.3
September	0	0	0	194	158	81.4	106	44	41.5	77	29	37.7

[a]Number of epicenters in this distance range from TFSO located by C&GS
[b]Number detected by TFSO
[c]Percent detected by TFSO

Table 18. Earthquakes having any phase detected by TFSO, and earthquakes reported by C&GS between 1 October 1966 and 30 September 1967

Month	16.0-20.0			20.1-90.0			90.1-104.0			104.1-180.0		
	Loc[a]	Det[b]	Per[c]	Loc	Det	Per	Loc	Det	Per	Loc	Det	Per
October 1966	3	3	100.0	207	196	94.7	71	43	60.6	64	41	64.1
November	3	3	100.0	227	206	90.7	59	36	61.0	45	21	46.7
December	4	4	100.0	196	169	86.2	70	45	64.3	45	26	57.8
January 1967	5	5	100.0	191	168	88.0	191	145	75.9	71	46	64.8
February	1	1	100.0	161	141	87.6	59	35	59.3	54	37	68.5
March	0	0	0	244	217	88.9	62	39	62.9	88	49	55.7
April	6	6	100.0	203	177	87.2	108	55	50.9	84	54	64.3
May	1	1	100.0	222	187	84.2	100	50	50.0	60	32	53.3
June	9	9	100.0	226	178	78.8	118	58	49.2	77	42	54.5
July	1	1	100.0	243	202	83.1	95	48	50.5	73	48	65.8
August	2	2	100.0	210	179	85.2	92	39	42.4	70	44	62.9
September	0	0	0	194	164	84.5	106	60	56.6	77	42	54.5

[a]Number of epicenters in this distance range from TFSO located by C&GS
[b]Number detected by TFSO
[c]Percent detected by TFSO

6. INSTRUMENT TESTS AND EVALUATION

6.1 TESTS OF THE PERFORMANCE OF LONG-PERIOD SEISMOMETERS IN AN EVACUATED SPHERICAL CHAMBER

To determine the operational characteristics of long-period seismometers in evacuated environments, we obtained a spherical chamber used to house the Texas Instruments (TI) ocean bottom seismograph on a loan basis.

We postulated that an environment evacuated to a pressure of about one-thousandth of an atmosphere would eliminate or greatly reduce the effects from several potential sources of nonseismic noise. The effects caused by pressure changes (for example, mass bouyancy forces and piston-type forces exerted on the boom assembly) and those caused by air convection currents acting on the seismometer case were expected to be substantially reduced. Because the heat conduction through the air is greatly reduced, the temperature of the instruments was expected to be considerably more stable than that of similar instruments operated in conventional environments, allowing quieter operation of the seismographs.

We anticipated that the attenuation of the noise produced by these mechanisms would allow a more detailed study of any remaining nonseismic noise, afford a better opportunity to isolate specific sources of this noise, and to study the effects of controlled noise generators (for example, differential heating of the seismometer and earth tilt).

The spherical housing and a vacuum system were sent to TFSO during early April, and a mobile hoist was modified to handle the sphere within the long-period vault and pier room. During May, the sphere was assembled on the pier, a horizontal long-period seismometer was checked out and installed inside the sphere, oriented east-west, and the sphere was sealed and evacuated (see figure 24). Shortly thereafter, lightning damaged a portion of the remote, mass-positioning equipment, necessitating opening of the sphere to repair the damage. The sphere was again sealed and evacuated to approximately 0.001 atmosphere.

The seismograms produced by the seismometer in the sphere were designated E57LP and were recorded on the experimental long-period Develocorder adjacent to the E52LP seismograms which were produced by the standard east-west long-period horizontal seismometer installed on the same pier. Figure 25 shows the orientation of the instruments in the vault. All of the seismograms made with the vault sealed showed a marked similarity between E57LP and E52LP (see figures 26 through 29). A detailed examination of all data recorded on 16 and 17 June revealed no difference in the seismograms, except for minor variations expected because of slight differences in the operating magnification and in the seismograph frequency and phase responses. A test on 18 July with the marine door opened and the convection shield off of the standard seismometer showed considerable noise on both systems.

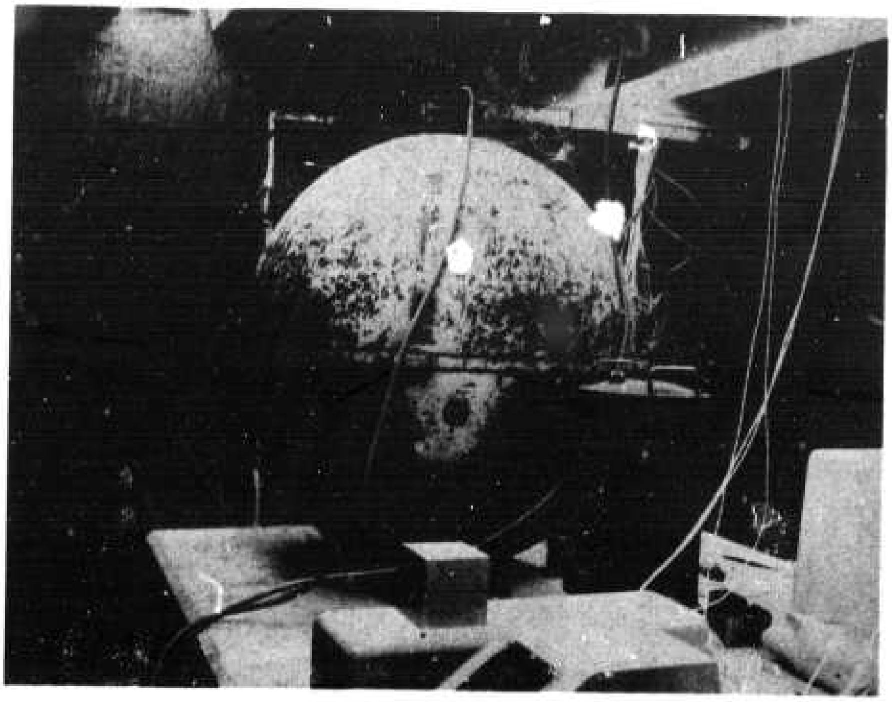


Figure 24. Ocean bottom sphere in place on the long-period pier at TFSO. The sphere has been sealed and evacuated

To evaluate the effects of air turbulence around the sphere, a fan was placed inside the room with the door closed. Noise was observed on the sphere system as expected. Differential heating of the vault area produced by a lamp placed against the sphere caused the seismometer mass to drift to the stop. In this test, the sphere was significantly affected by the temperature gradients either due to expansion of the sphere itself or due to the effects of convection currents.

Tests using the heating elements built into the seismometer lids indicated that heat has no visible effect on either of the systems. Both of the systems were shielded from the effects of air convection; the standard system by convection shields and the test systems by the near-vacuum in the sphere.

The tests indicated that use of the ocean bottom sphere does not effect a noticeable improvement over the conventional methods used to reduce the effects of atmospheric pressure. They showed also that the sphere is susceptible to convection currents, although this would not be the case if it were buried directly in the ground.

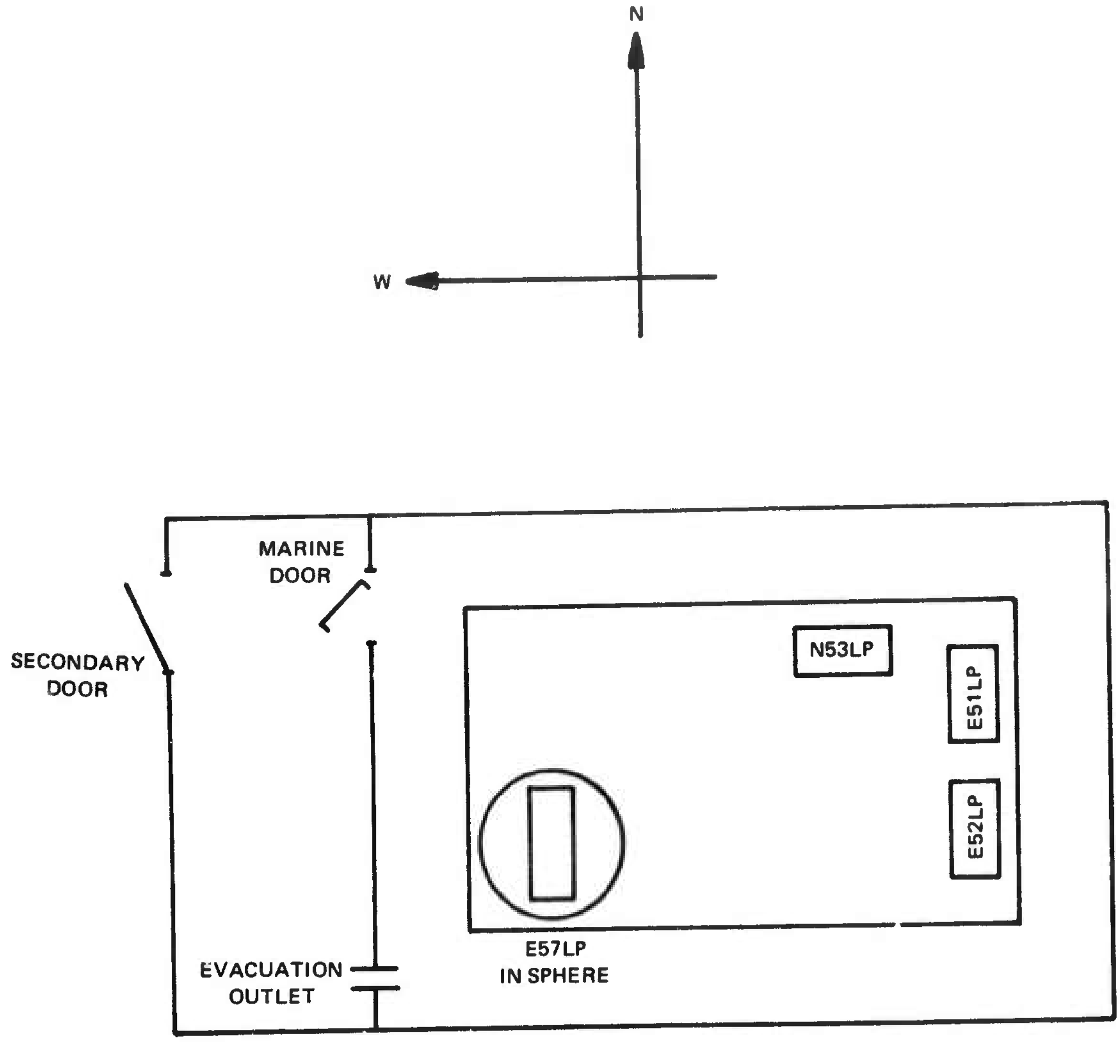
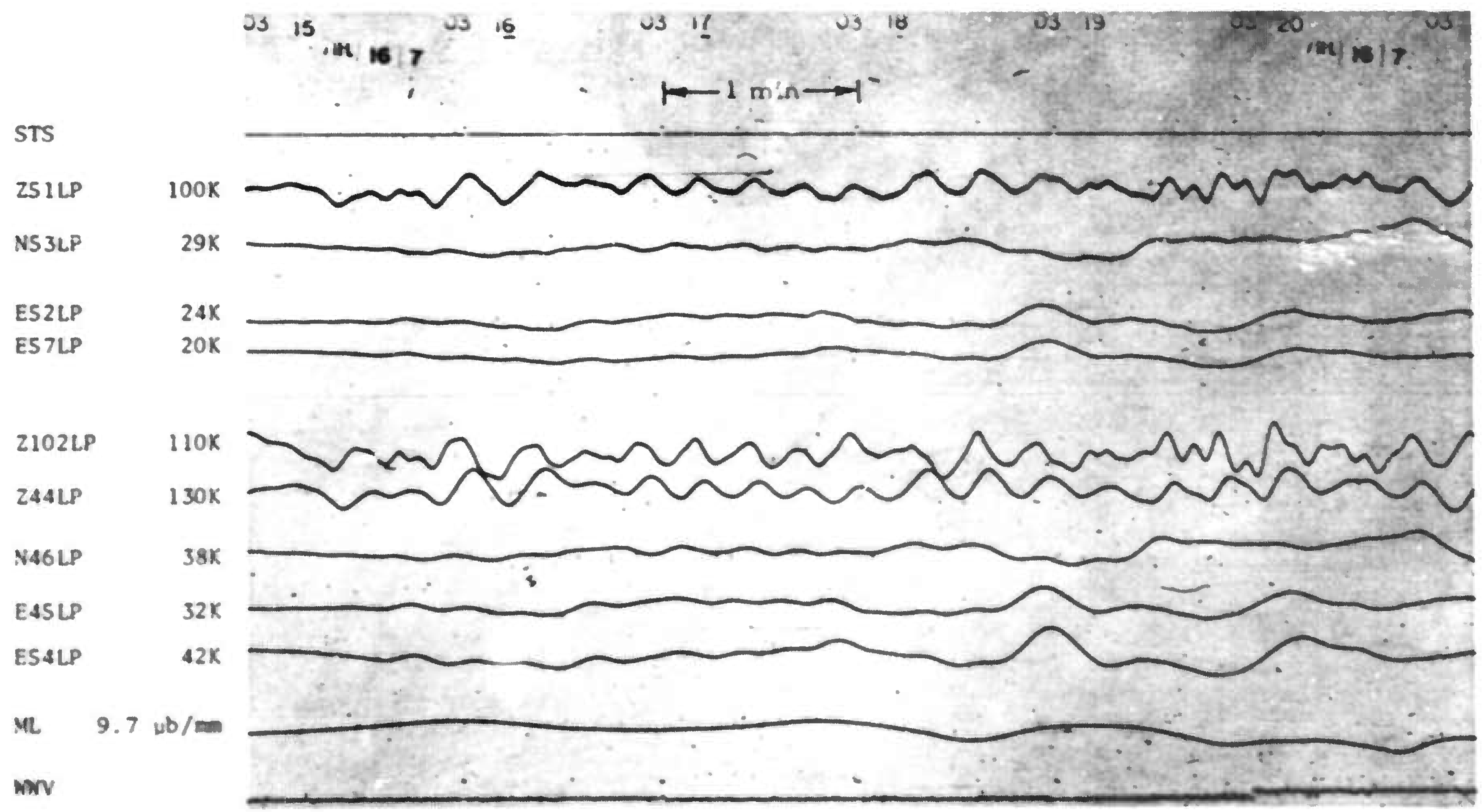
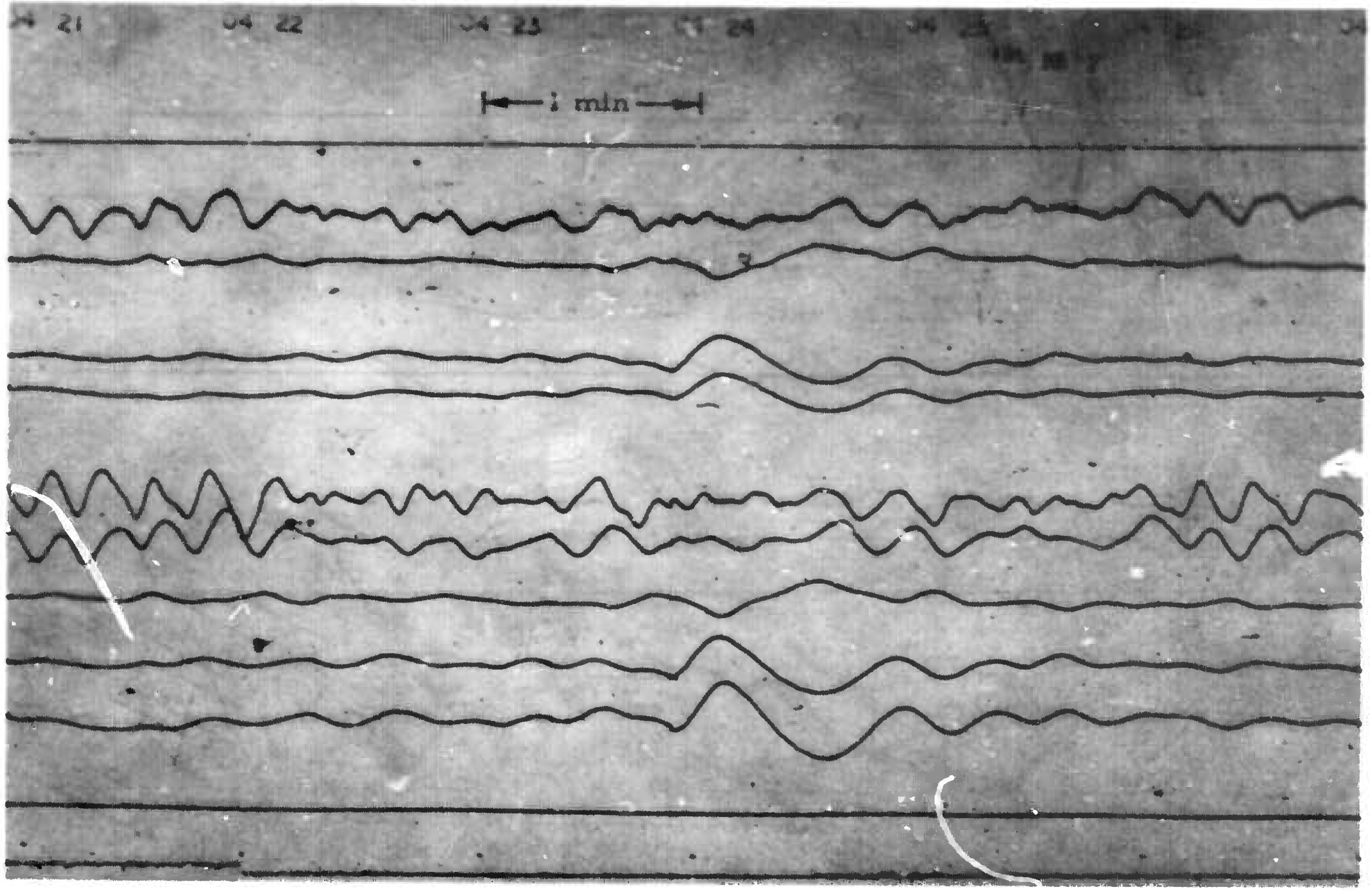


Figure 25. Orientation of the long-period seismographs during the tests on the ocean bottom sphere



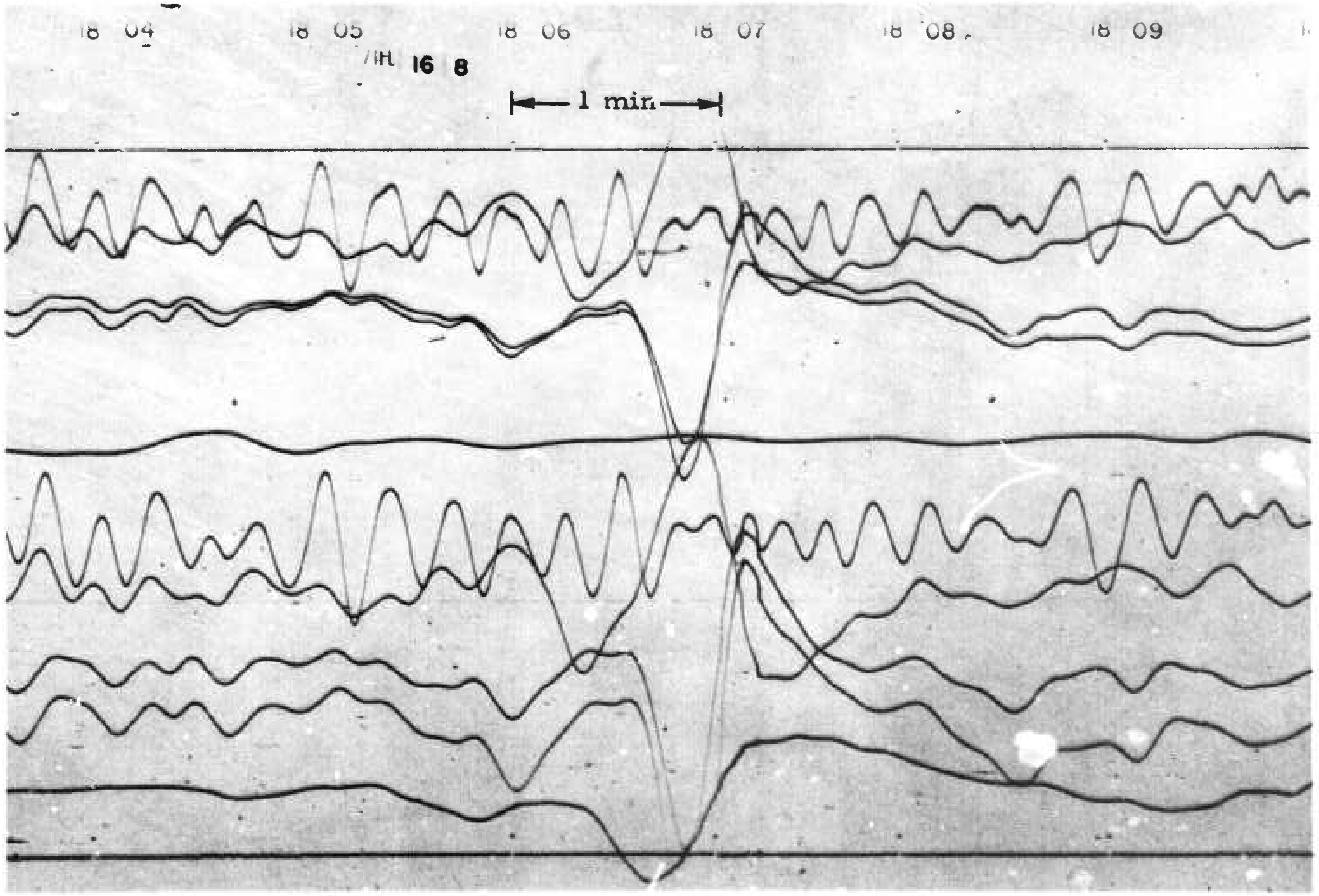
TFSO
16 June 1967
Run 167
DT LP Exp

Figure 26. Experimental, long-period seismogram illustrating the similarity in the response of the test seismographs (E52LP and E45LP) and the corresponding control seismographs (E57LP and E54LP) during an atmospherically calm period; the door to the long-period pier room was sealed



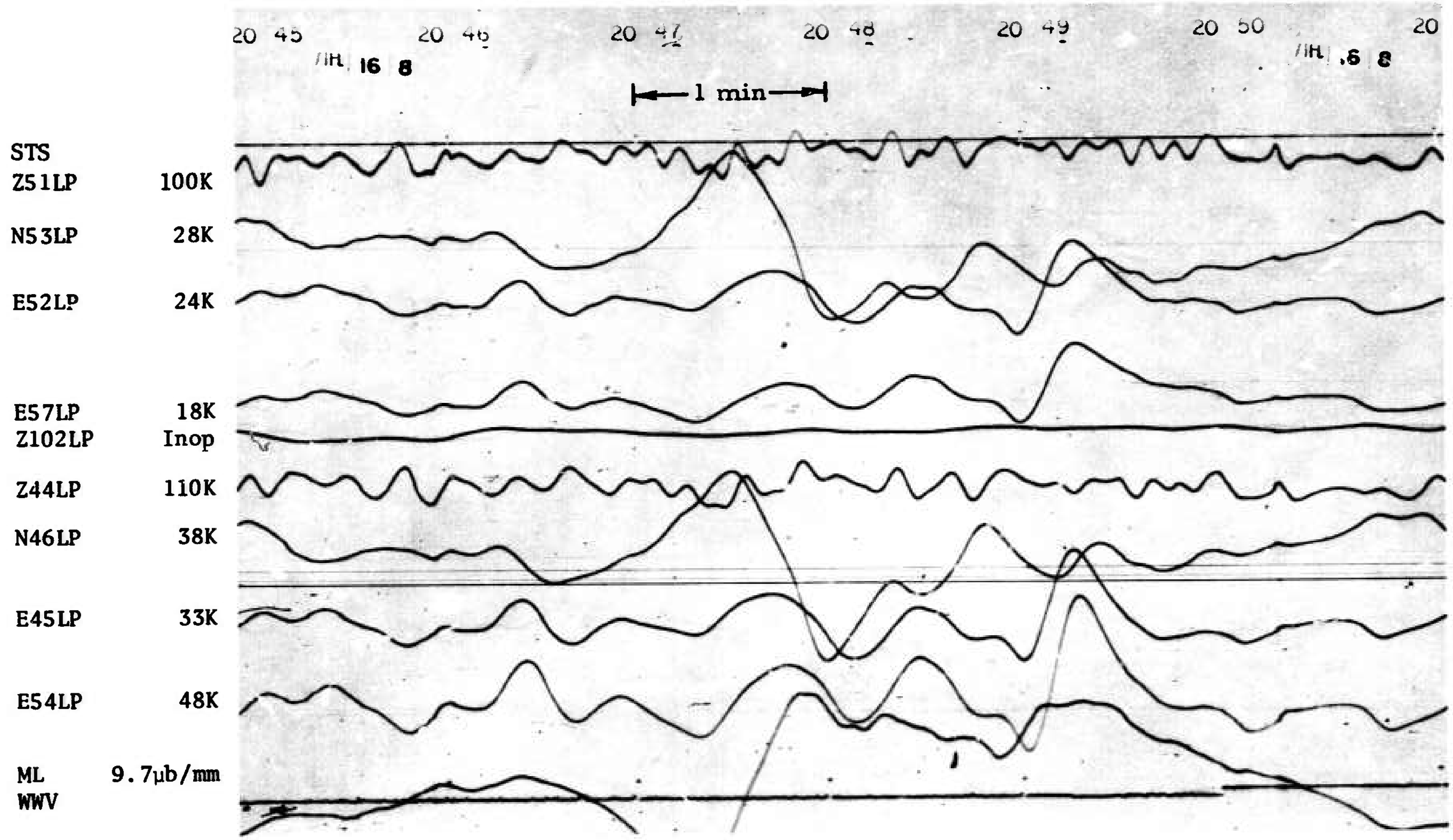
TFSO
16 June 1967
Run 167
DT LP Exp

Figure 27. Experimental, long-period seismogram illustrating the similarity in the response of the test seismographs (E52LP and E45LP) and the corresponding control seismographs (E57LP and E54LP) during an atmospherically calm period; the door to the long-period pier room was sealed



TFSO
17 June 1967
RPN 168
DT LP Exp

Figure 28. Experimental, long-period seismogram illustrating the similarity in the response of the test seismographs (E52LP and E45LP) and the corresponding control seismographs (E57LP and E54LP) with wind gusting to about 36 miles per hour



TFSO
17 June 1967
RPN 168
DT LP Exp

Figure 29. Experimental, long-period seismogram illustrating the similarity in the response of the test seismographs (E52LP and E45LP) and the corresponding control seismographs (E57LP and E54LP) with wind gusting to about 20 miles per hour

6.2 EVALUATION OF A SHORT-PERIOD SEISMOGRAPH WITH A SOLID-STATE AMPLIFIER

In April 1967, a short-period seismograph employing a Geotech Solid-State Amplifier, Model 25220-03, and a Model 6480 JM seismometer with a special high-impedance coil were installed at TFSO, adjacent to a standard short-period seismograph, for evaluation.

This system was similar to the short-period, solid-state seismograph tested at TFSO in December 1966 (see TR 67-13) except that this system uses wide-band FM data transmission. A block diagram of the system is shown in figure 30.

Frequency responses of the short-period, solid-state seismograph (Z55SS) and the standard TFSO control seismograph (Z74) are shown in figure 31. Visual analysis of the film seismograms indicates that the performance of the two systems is essentially identical (see figures 32 and 33).

Digital samples of seismic background and system noise from the Z55SS and Z74 seismographs were recorded on the Astrodata digital data acquisition system. The digital magnetic tapes were processed on the CDC 3100 computer in Garland to calculate the power spectral estimates presented in figures 34 and 35. In each figure, curve A corresponds to the seismic background during an interval of low seismic activity and curve B corresponds to the system electronic noise with the seismometer replaced by a resistor with a resistance equal to that of the seismometer data coil. All curves were corrected for system frequency response.

These figures indicate that the level of the system noise of the Z55SS seismograph is approximately 6 dB below that of the Z74 seismograph and also at least 22 dB below the level of the seismic background throughout the frequency range 0.2 to 4.0 cps.

The results of these tests coupled with the results of tests reported in TR 67-13 show that the seismograph employing the JM seismometer and the Model 25220-03 amplifier is superior to the short-period seismographs currently being operated at LASA or at the VELA-Uniform observatories.

6.3 EVALUATION OF A LONG-PERIOD SEISMOGRAPH WITH A SOLID-STATE AMPLIFIER

Tests of the Model 28450-02 long-period, solid-state amplifier were started in June 1967. Throughout much of the testing, difficulties were encountered with faulty components in the preamplifier portion. These problems were solved, and field tests, to date, have shown the noise level of the amplifier to be equivalent to between 5 and 10 millimicrons within the frequency band of interest. This is not as good as the noise level obtained during the laboratory tests conducted in Garland (between 3 and 5 millimicrons). However, the noise level of the solid-state amplifier obtained in the field is comparable to the noise level of the Model 5240A PTA as normally operated in the field. Figure 36 is a representative, experimental seismogram, made using the Model 28450-02 amplifier. The amplitude response and block diagram of this seismograph are shown in figures 37 and 38.

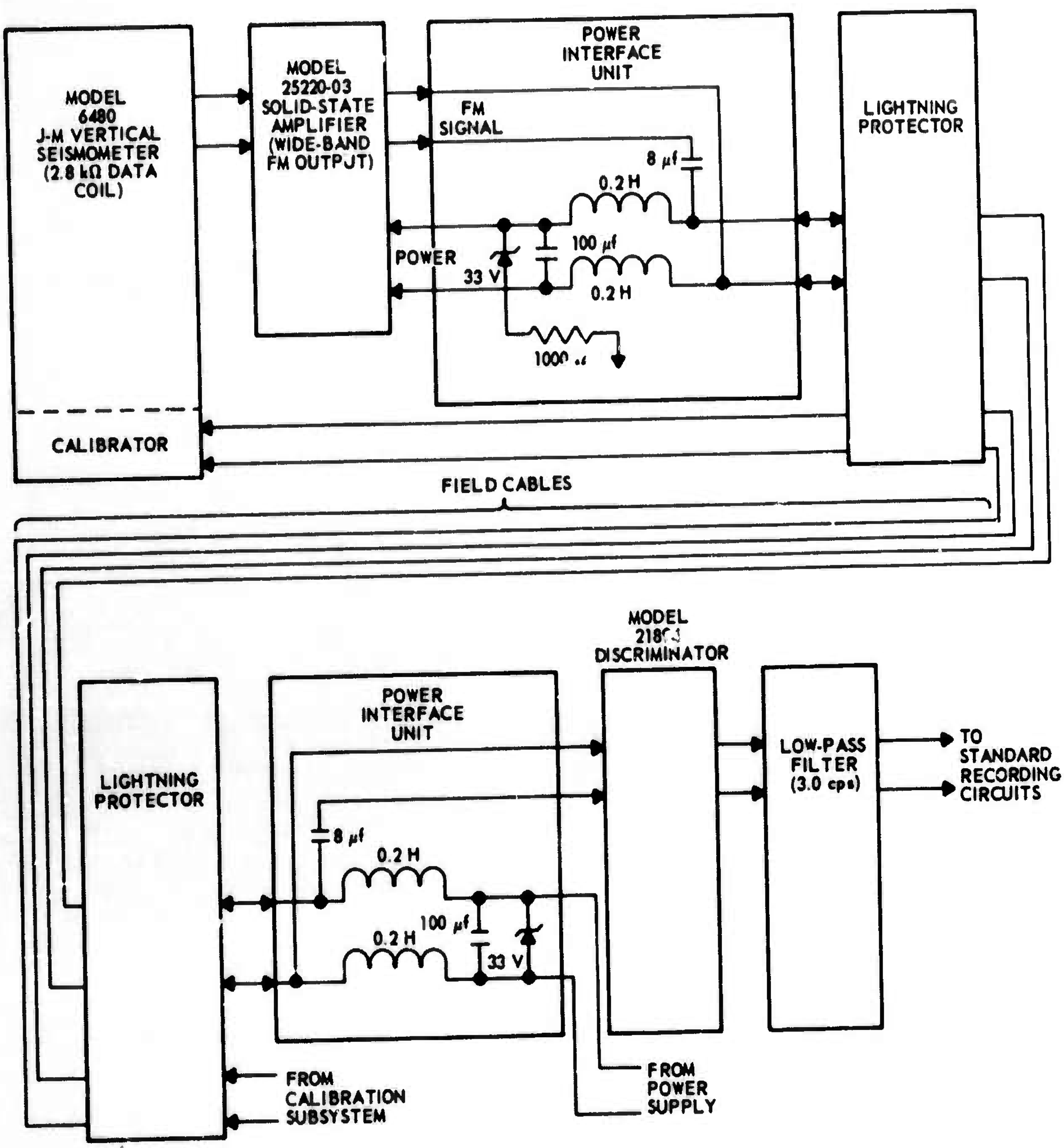


Figure 30. Simplified block diagram of the short-period system with a solid-state amplifier (Z55SS) tested at TFSO

G 2920

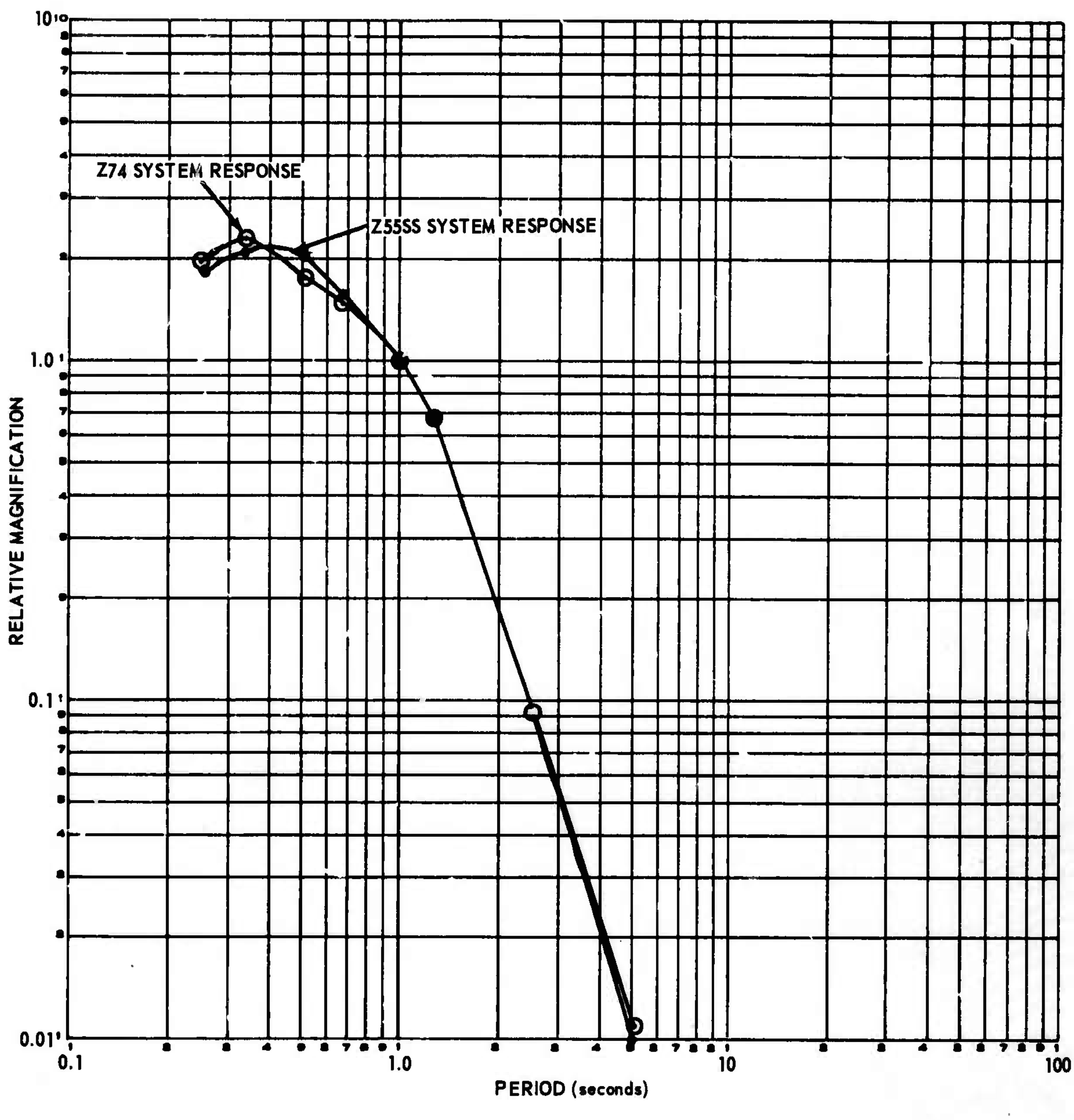
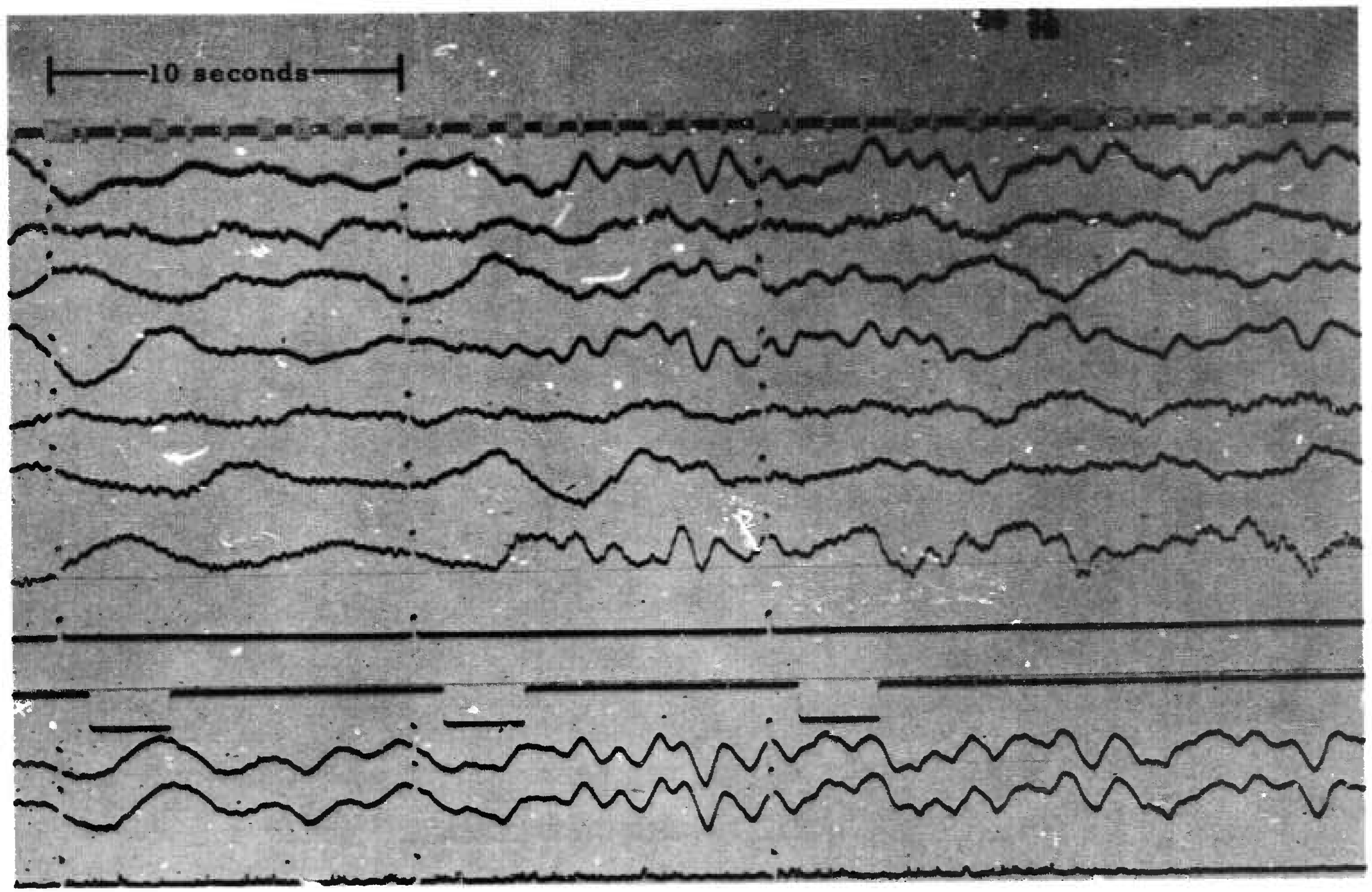


Figure 31. Amplitude responses for the Z55SS seismograph using a solid-state amplifier, and the Z74 seismogram using a phototube amplifier

G 2921



TFSO
26 May 1967
Run 146
Data Group 7215

Figure 32. Short-period seismogram illustrating the similarity in the response of the Z55SS and the Z74 seismographs to an arrival from a teleseismic event (epicenter unknown)

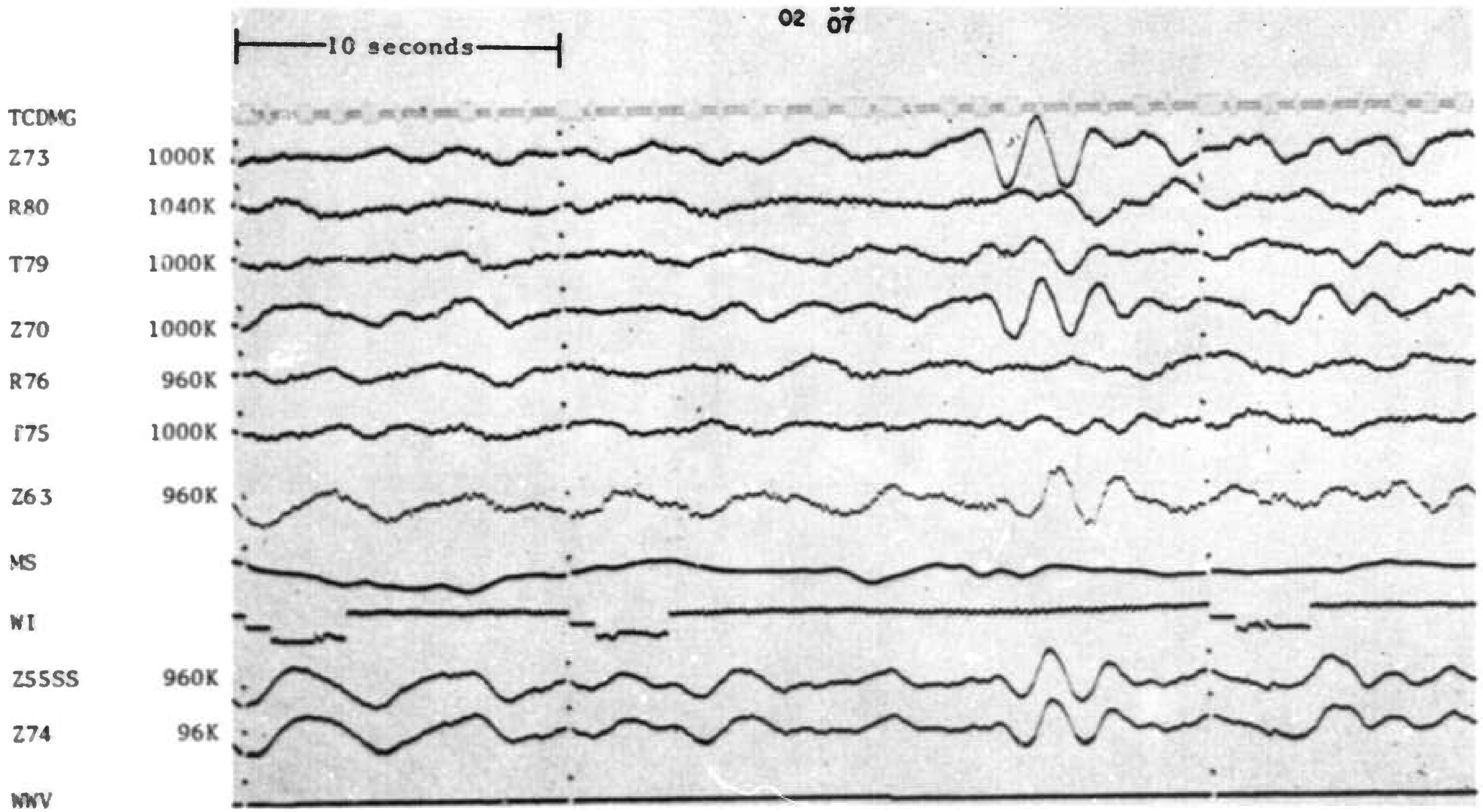


Figure 33. Short-period seismogram illustrating the similarity in the response of the Z65SS and the Z74 seismographs to an arrival from a teleseismic event (epicenter unknown)

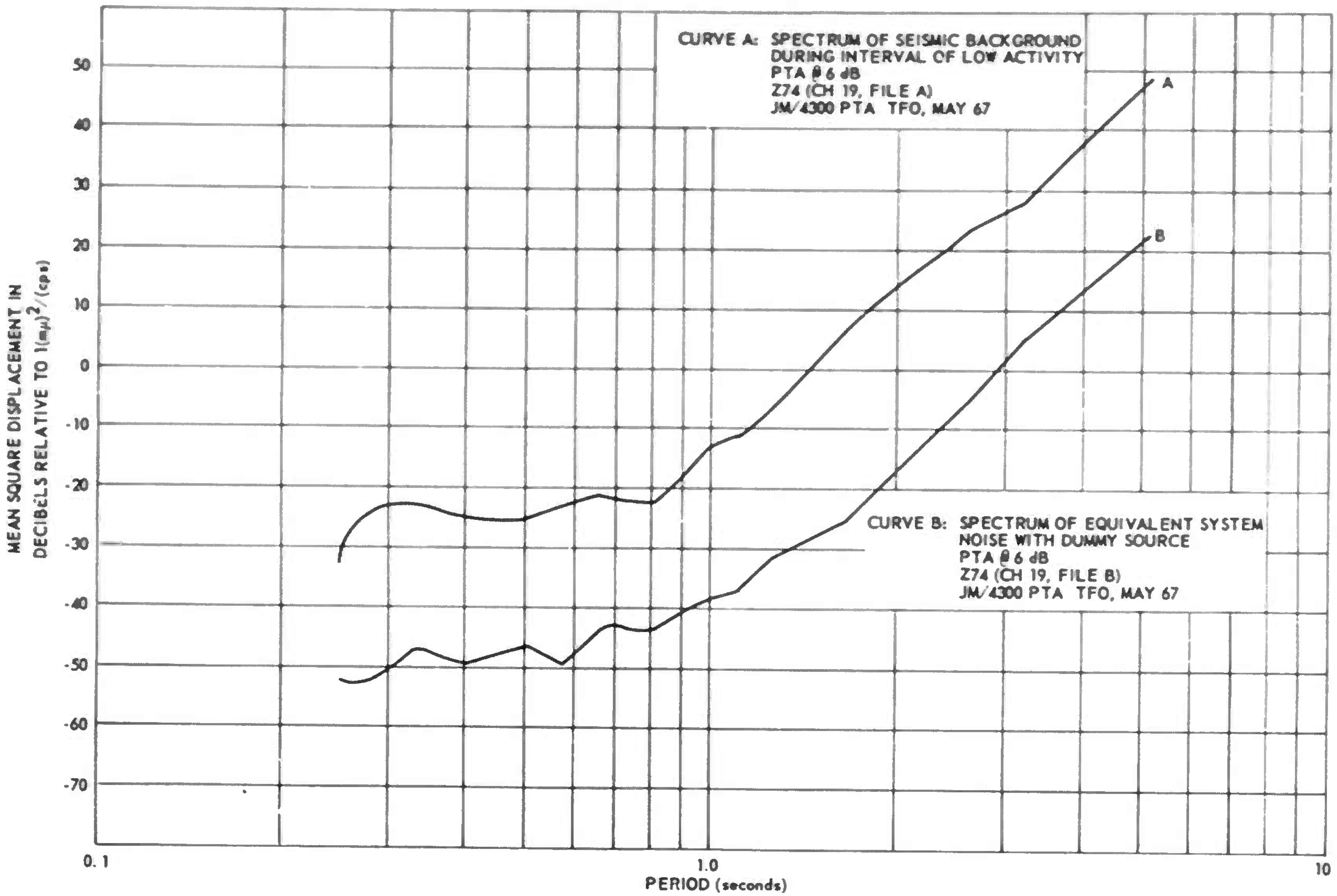


Figure 34. Spectral relations of low-level seismic background and system noise of the Z74 seismograph

G 2922

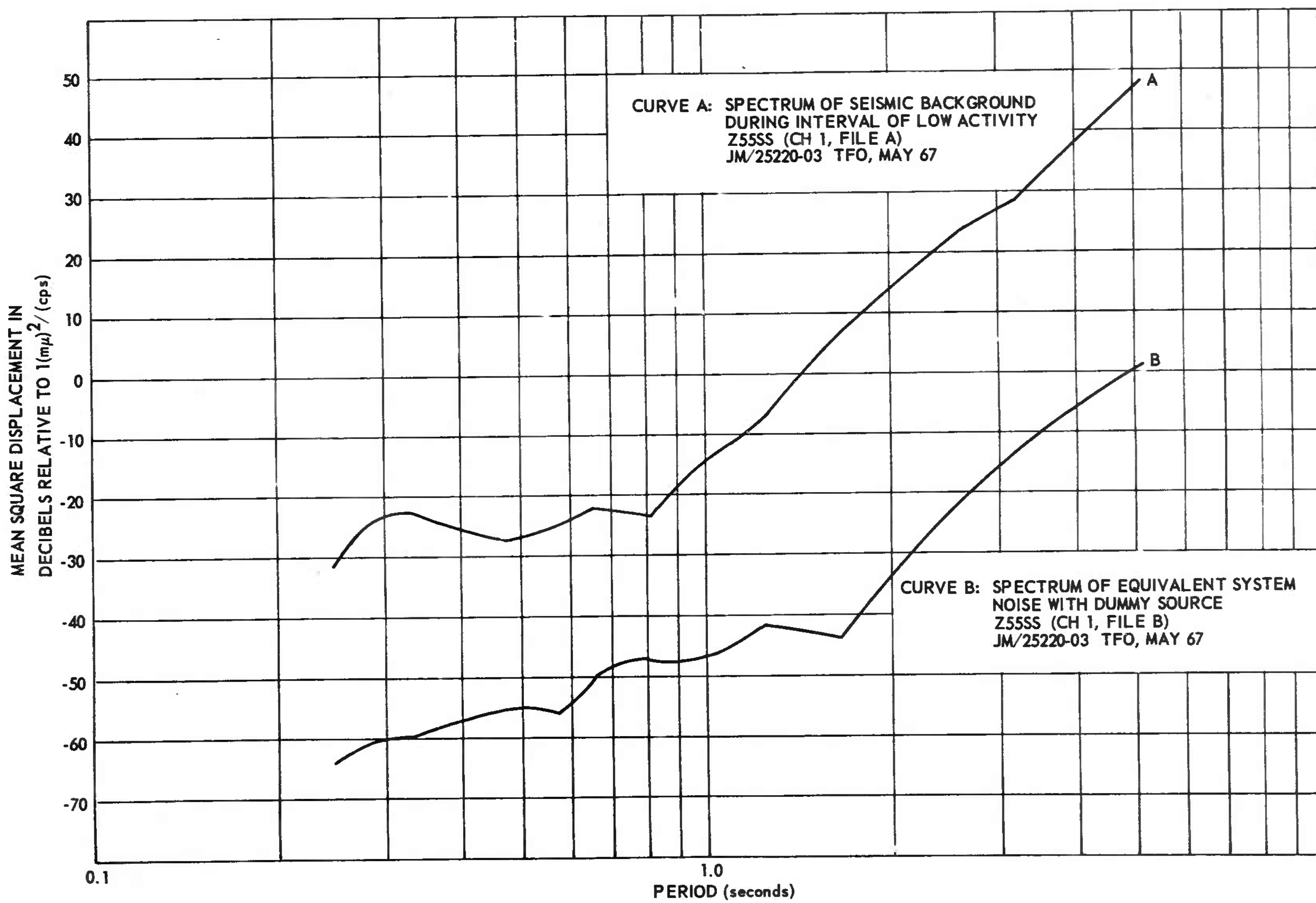


Figure 35. Spectral relations of low-level seismic background and system noise of the Z55SS seismograph

G 2923

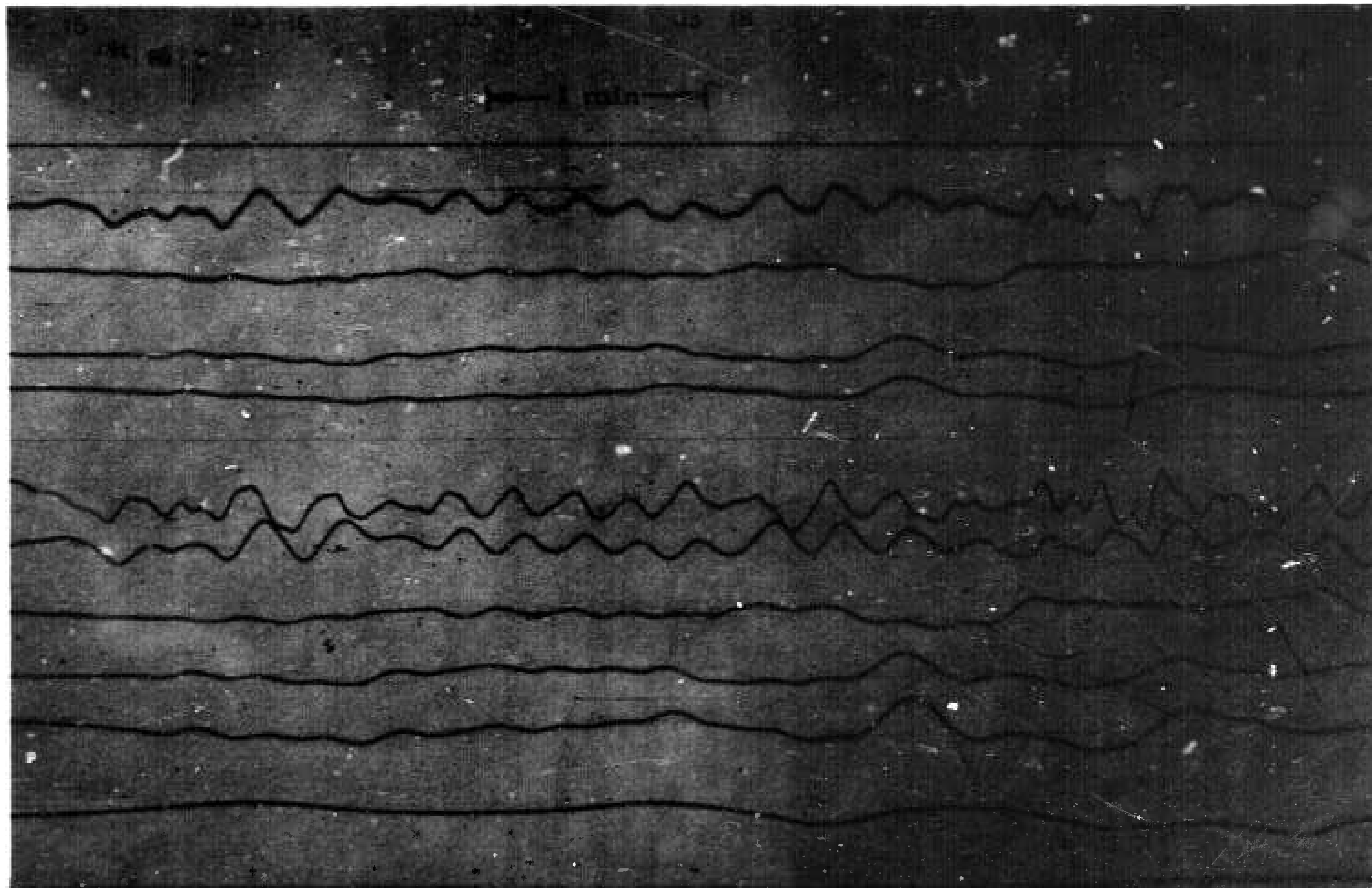


Figure 36. Experimental seismogram showing the noise level of a dummy-loaded, long-period seismograph using the Model 28450-02 long-period, solid-state amplifier (Z102LP) and operated at an equivalent magnification of 100K at 0.04 cps

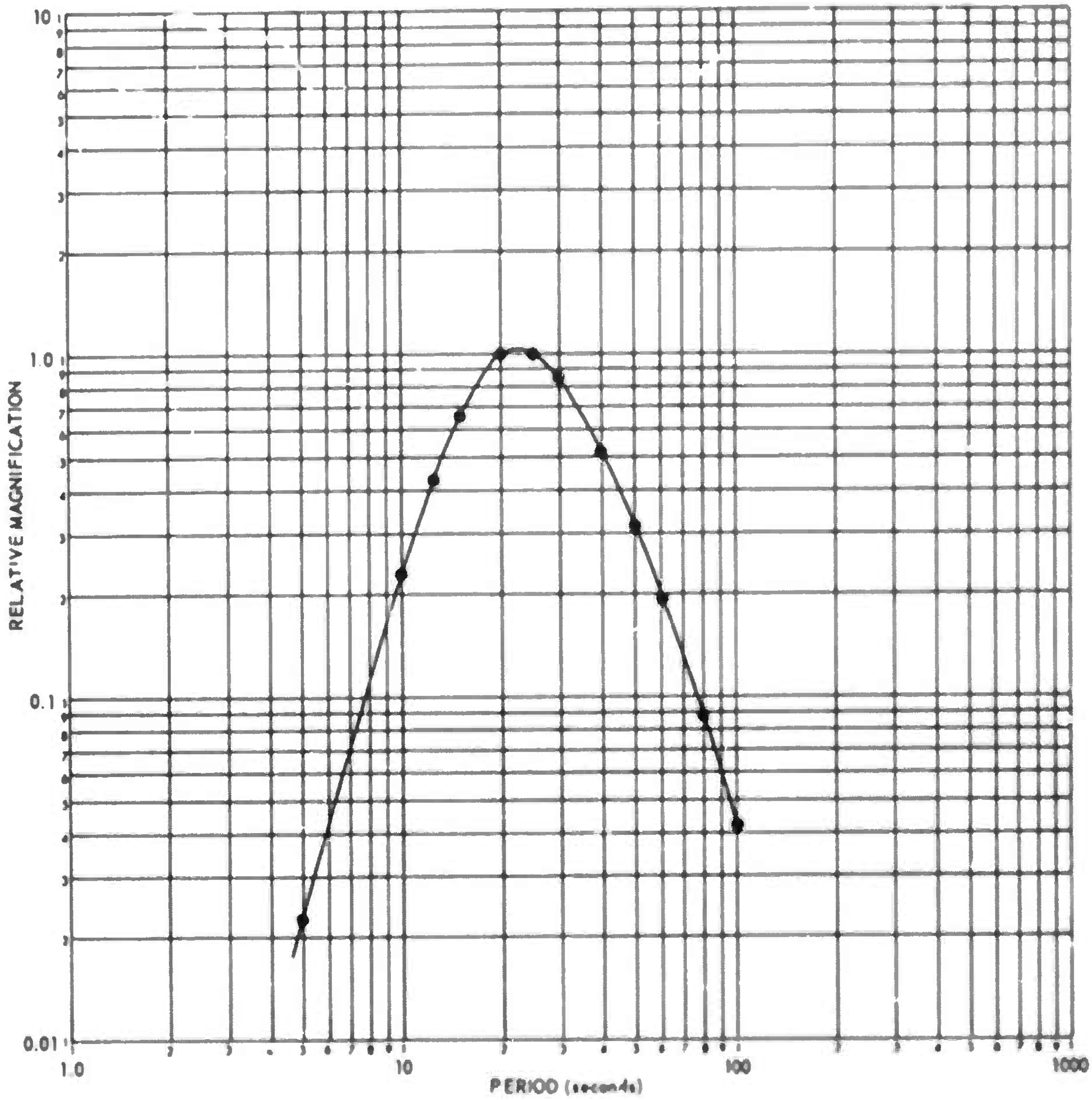


Figure 37. Amplitude response of the long-period seismograph utilizing the Model 28450-02 amplifier

G 2925

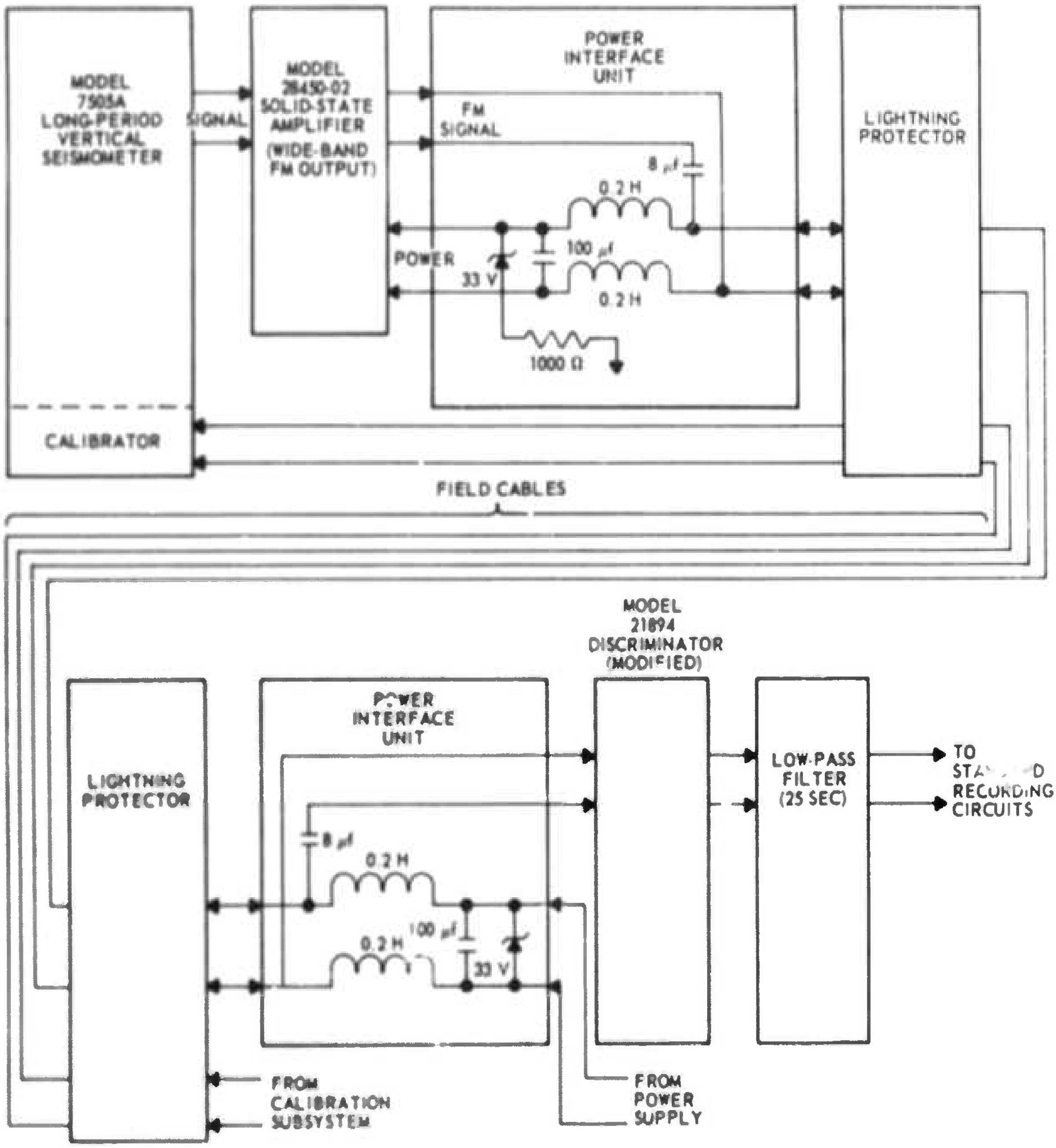


Figure 38. Simplified block diagram of the long-period system with a solid-state amplifier (Z102LP) tested at TFSO

6.4 TESTS OF JOHNSON-MATHESON SEISMOMETERS WITH HIGH-IMPEDANCE COILS

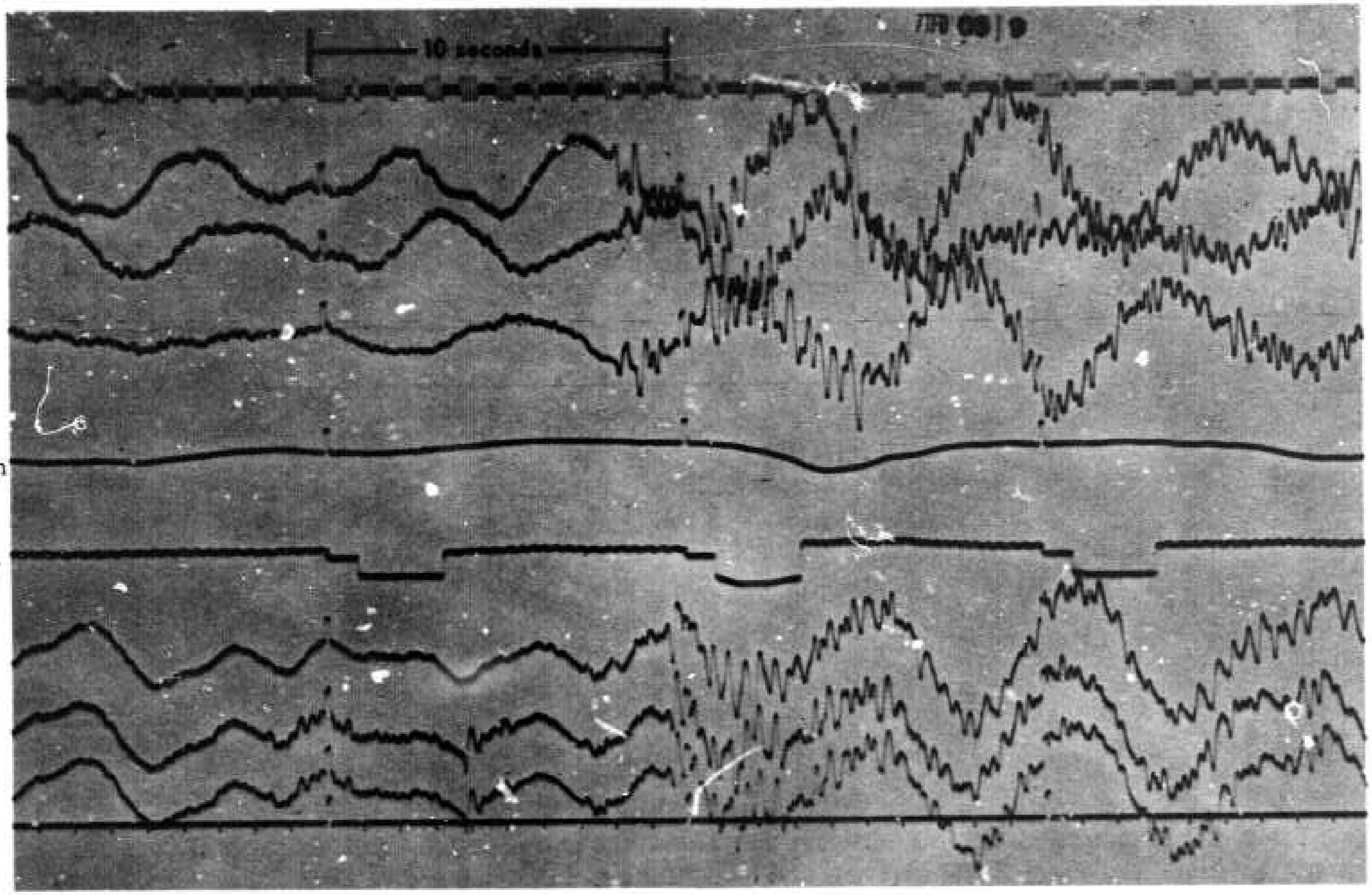
The use of solid-state amplifiers in the seismographs of the 37-element, short-period array required that each seismometer be equipped with a high-impedance coil. To eliminate the expense and delay of shipping the seismometers to the Garland plant for installation of standard high-impedance coils, TFSO personnel designed special high-impedance coils which could be installed at the observatory. To compare the performances of the special and the standard coils, a seismograph utilizing a Johnson-Matheson (JM) seismometer with a special high-impedance coil and a Model 25220 solid-state amplifier (Z103X) was operated during February 1967 on a pier in the underground experimental vault. A seismograph utilizing a JM seismometer with a standard high-impedance coil and a Model 25220 solid-state amplifier (Z102X) was installed on the same pier. Careful visual analysis of the seismograms indicated that the electronic noise of the two systems was essentially the same. Figures 39 and 40 show seismograms produced by the two systems.

6.5 EVALUATION OF THE SOLION SEISMOMETER

The Solion seismometer was built by the Defense Research Laboratory (DRL) of the University of Texas. The term Solion is a contraction of SOLution ION device. There are several types, but the one of interest here is called the polarized cathode type. A solution of iodine and iodide ions is contained by diaphrams within a plastic housing. The ions being formed at the cathodes normally migrate to the anodes at a slow rate due to a bias applied between each set of electrodes. Movement of the diaphrams because of a pressure differential across the Solion transducer causes the charge transport process to increase between one set of electrodes and to decrease between the other set. The two anodes are connected together, and a voltage proportional to pressure is obtained between the two cathodes. The differential arrangement of the electrodes is such that changes in applied bias voltage tend to be cancelled at the Solion differential output. The addition of a liquid mass (mercury) outside one of the diaphrams to apply pressure completes the basic ingredients for a seismometer. It is necessary to house the Solion seismometer in a sealed case to provide a quiet pressure reservoir for the exposed diaphram of the Solion transducer.

Two Solion seismometers were evaluated under Project VT/7702 to determine their suitability for field operation. The seismometers tested were found to be easily portable, easy to install, to have a reasonable stabilizing time, and to have the advantage of producing both long- and short-period seismograms from the same instrument. Their biggest disadvantages appeared to be sensitivity to rapid changes in temperature and susceptibility of the wiring to mercury contamination.

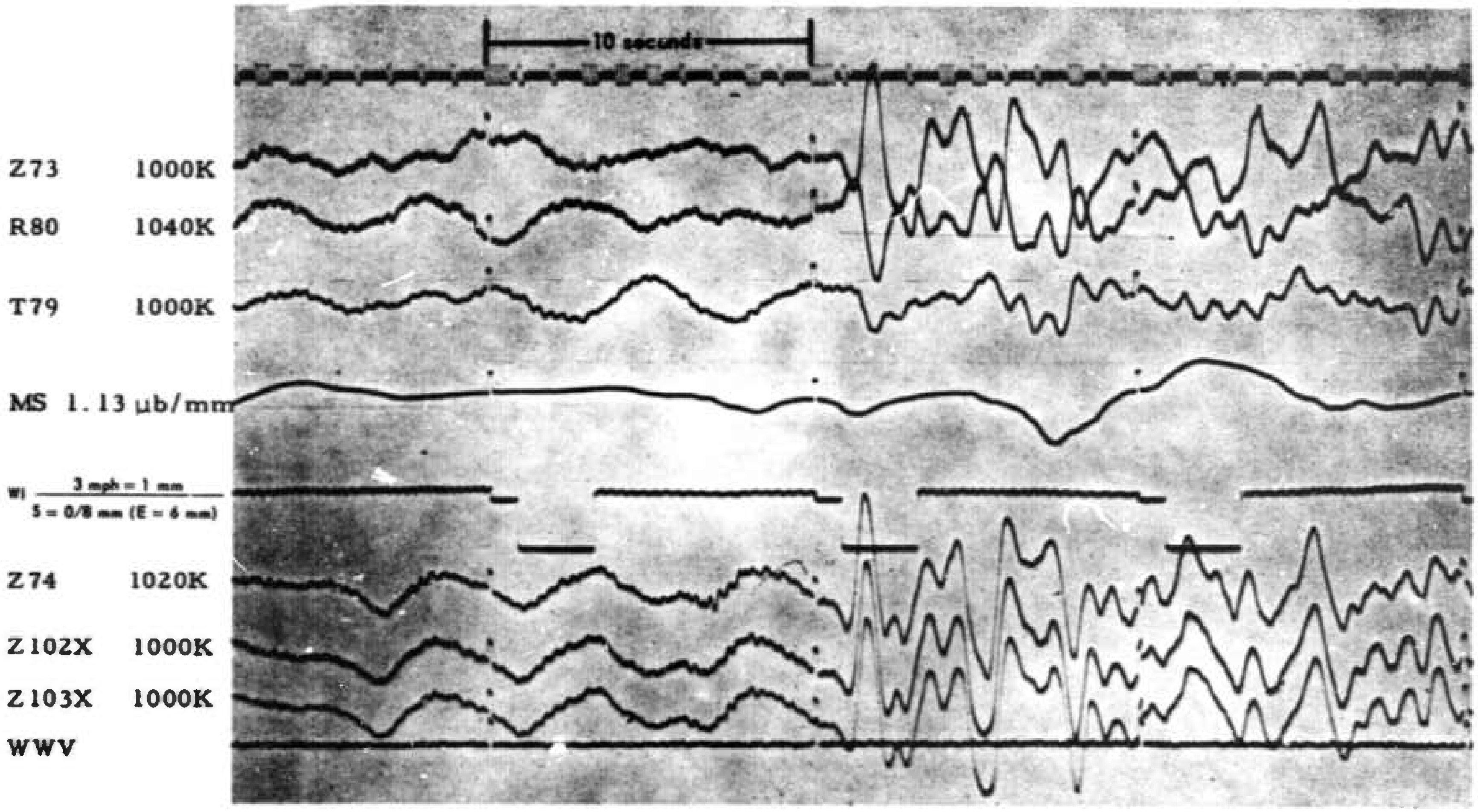
Temperature change produced several undesirable effects that are related to the rate of change of the seismometer temperature. The differential output voltage of the Solion transducer apparently varies as the derivative of the temperature of the seismometer producing drift in the long-period output that is proportional approximately to the second derivative of the seismometer temperature (due to a single stage of capacitive coupling between the input



TFSO
Data Group 7207
Run 039
8 February 67

Figure 39. Short-period seismogram comparing the response of Z102X and Z103X to a near-regional event

G 2648



TFSO
Data Group 7207
Run 039
8 February 67

Figure 40. Short-period seismogram comparing the response of Z102X and Z103X to a teleseismic event with epicenter near Qaxaca, Mexico; Δ = 23.3 degrees; azimuth = SSE; origin = 193914.2, m = 4.7 (C&GS) G 2649

of the amplifier and the long-period output). As the differential output voltage of the Solion departs from a low value, its gain increases, with more change in gain occurring for the short-period output than for the long-period output. In addition, if the temperature of the seismometer is decreasing, noise in the form of regular oscillations of about a 1-minute period appears in the long-period output. The threshold temperature change below which these effects would not be observed is estimated to be approximately two degrees Fahrenheit per hour increasing, or one-half degree per hour decreasing temperature at the seismometer.

Excess mercury in the case caused the connector joints to fail due to the amalgamation of the mercury with the solder.

The system noise of the Solion was found to be between 0.14 and 0.36 millimicron equivalent ground motion at 1 cps, and between 95 and 120 millimicrons equivalent ground motion at 0.05 cps.

7. RESEARCH INVESTIGATIONS

7.1 STUDIES OF ALTERNATE CONFIGURATIONS FOR THE EXPANDED SHORT-PERIOD ARRAY

At the request of the Project Officer, three alternate array configurations were evaluated on the basis of the characteristics of the wave number response of the arrays. Particular attention was given to the main-beam width and the level of the first side lobes.

The justification for the study of the three alternate configurations was that each geometry offered a potential reduction in cost of installation and maintenance relative to the estimated cost of the 37-element array.

The geometry of each of the three arrays consisted of the main features of the 37-element array, with modifications to 1 or 2 rings. The following is a description of each array:

Array A - consists of 37 elements; four hexagons concentric about a center element.

Array B - consists of 37 elements; two concentric hexagons plus seven elements scattered inside the inner hexagon; five of the seven elements correspond to cross-linear array locations.

Array C - consists of 35 elements; two concentric hexagons plus five elements scattered inside the inner hexagon; the five elements correspond to cross-linear array locations.

Figure 41 shows the configuration of each of the three arrays.

The $\vec{k}$-plane response of array A is considerably inferior to the $\vec{k}$-plane response of the 37-element array. The main-beam width of array A varies considerably with azimuth, but even along the best azimuths it is almost twice the main-beam width of the 37-element array. The first quadrant of the $\vec{k}$-plane response for array A is shown in figure 42. The other quadrants are identical due to the array symmetry.

The $\vec{k}$-plane responses for arrays B and C indicate that these two arrays are essentially equally effective; both are inferior to the $\vec{k}$-plane response for the 37-element array. For some azimuths, the main-beam width of arrays B and C compare favorably with the main-beam width of the 37-element array. However, for a majority of azimuths, the main-beam of arrays B and C does not reach the 30 dB attenuation level, which is used to measure beam width. In general, the lowest attenuation level on the main beam is about 18-21 dB. Figures 43 and 44 show the first and second quadrants of the $\vec{k}$-plane responses for arrays B and C, respectively. The third and fourth quadrants are identical to the first and second quadrants.

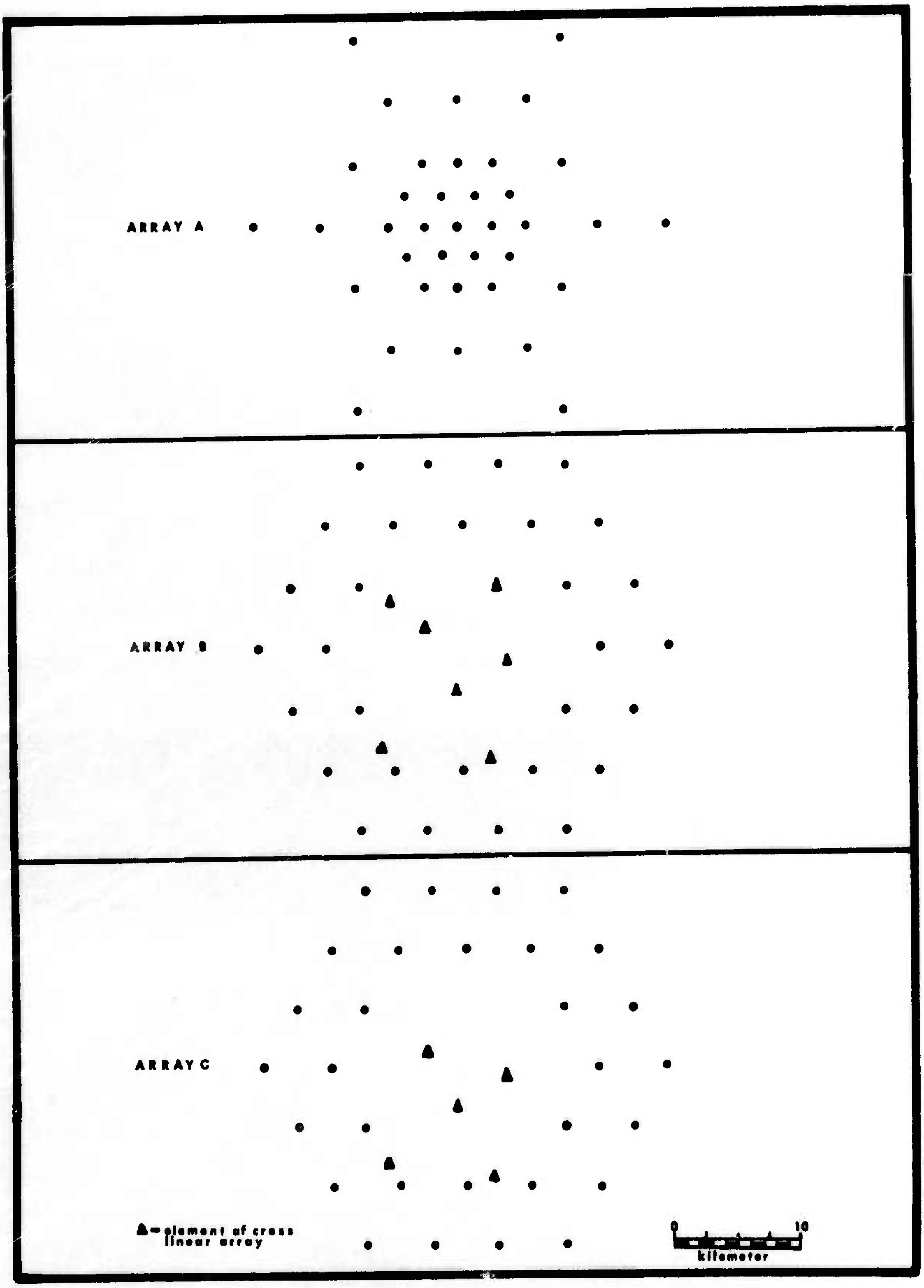


Figure 41. Alternate configurations considered for the short period array

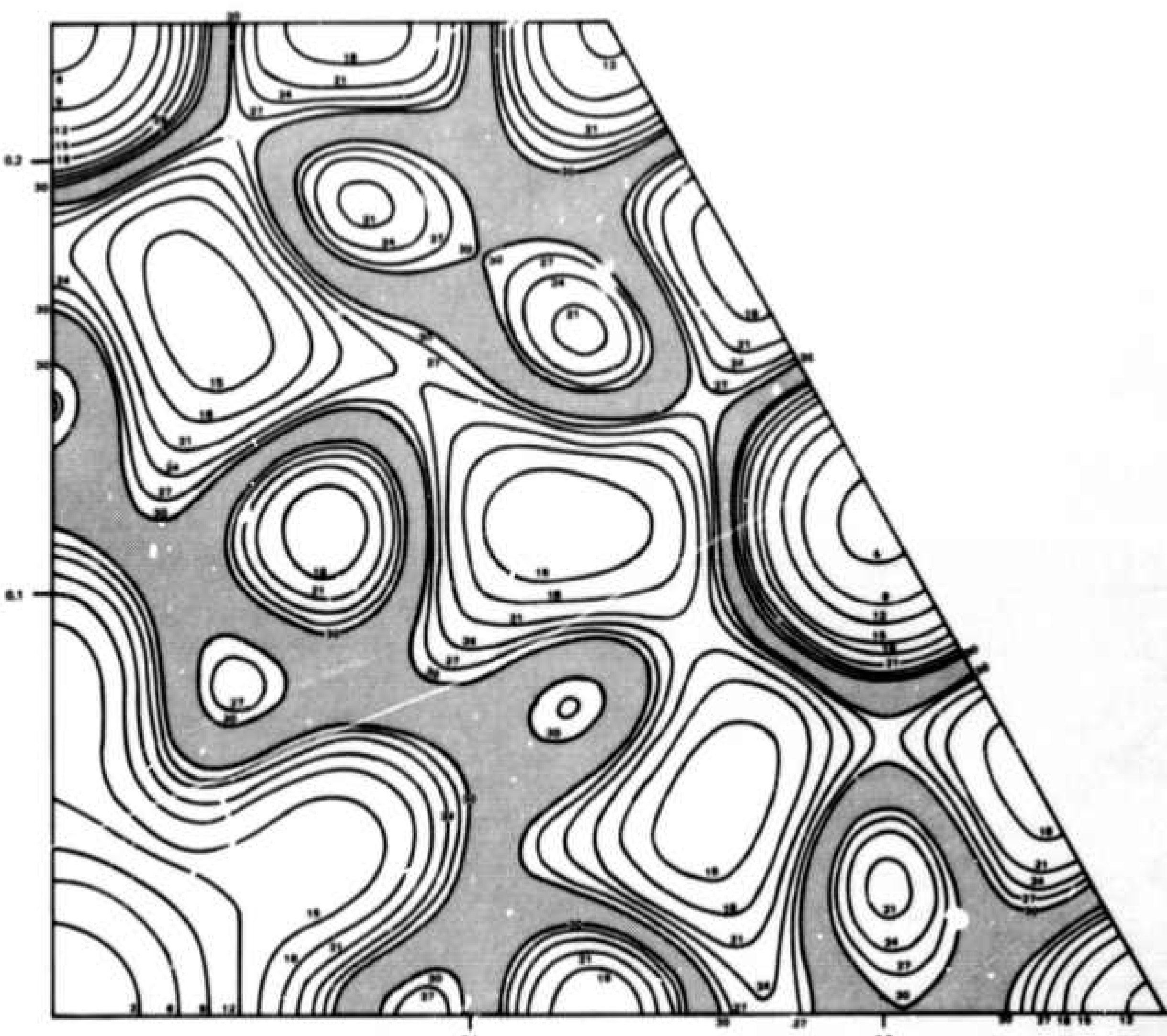


Figure 42. First quadrant of the wave number response of alternate array A

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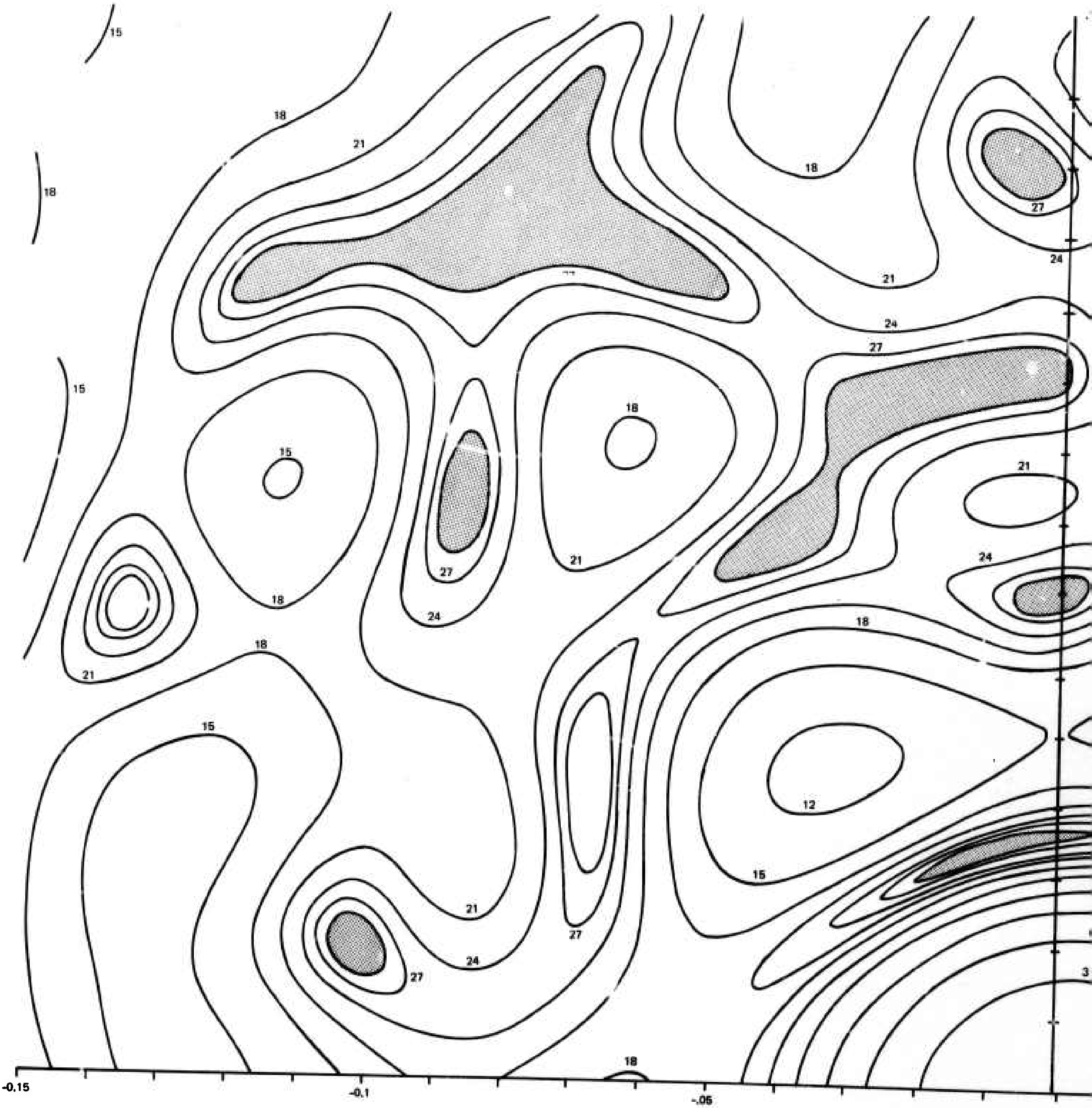


A

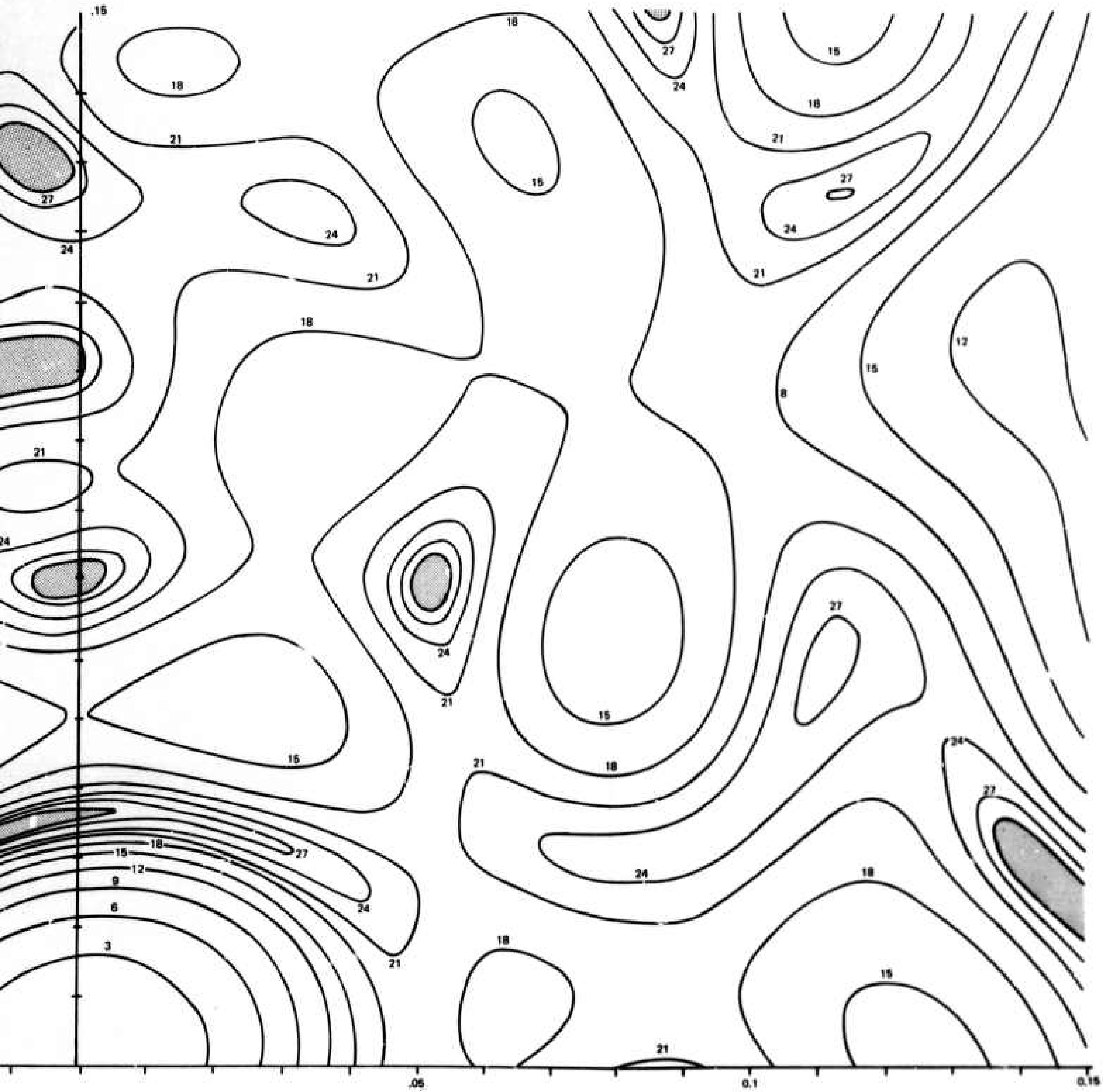
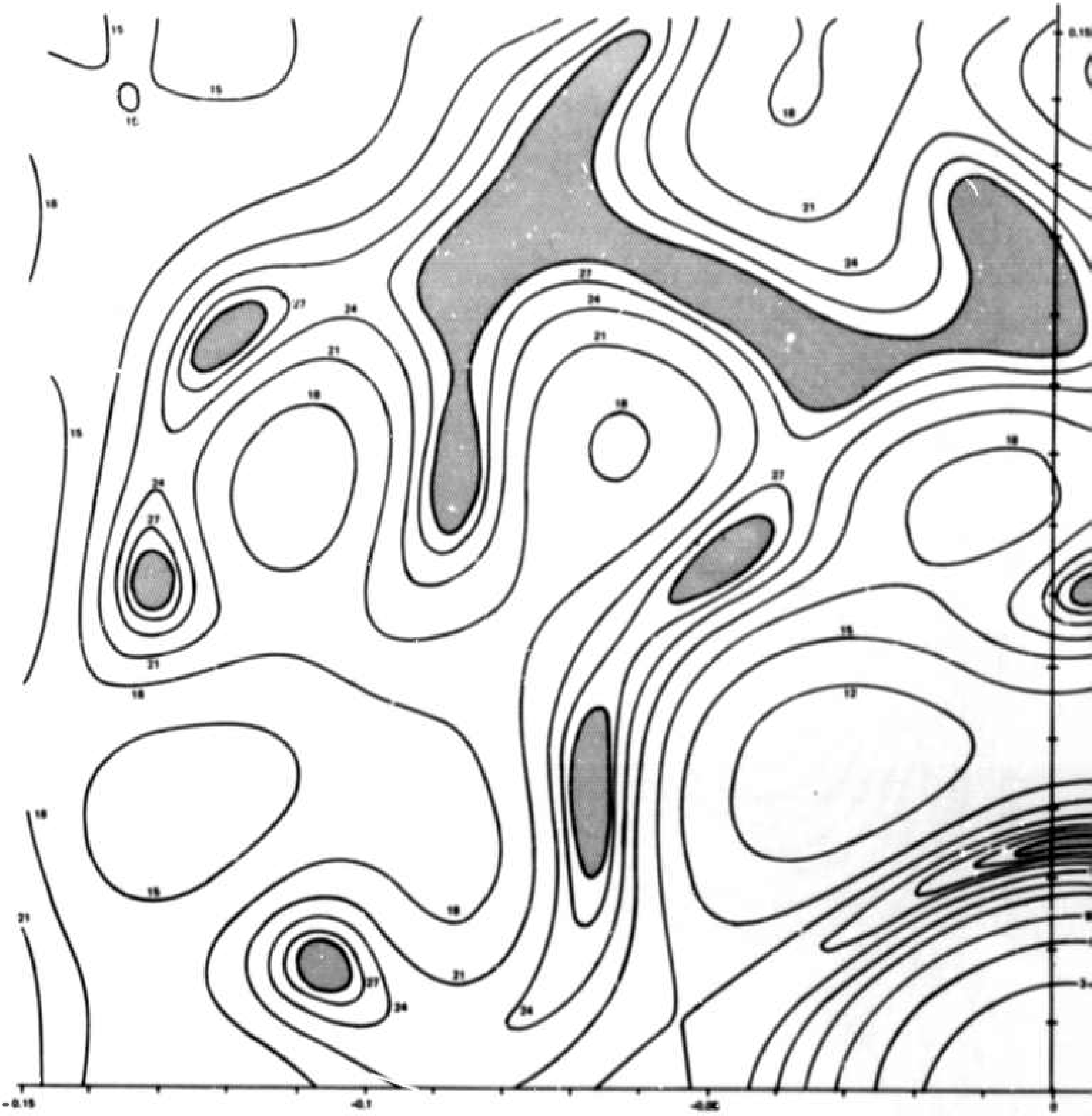


Figure 43. First and second quadrant of the wave number response of alternate array B

B



A

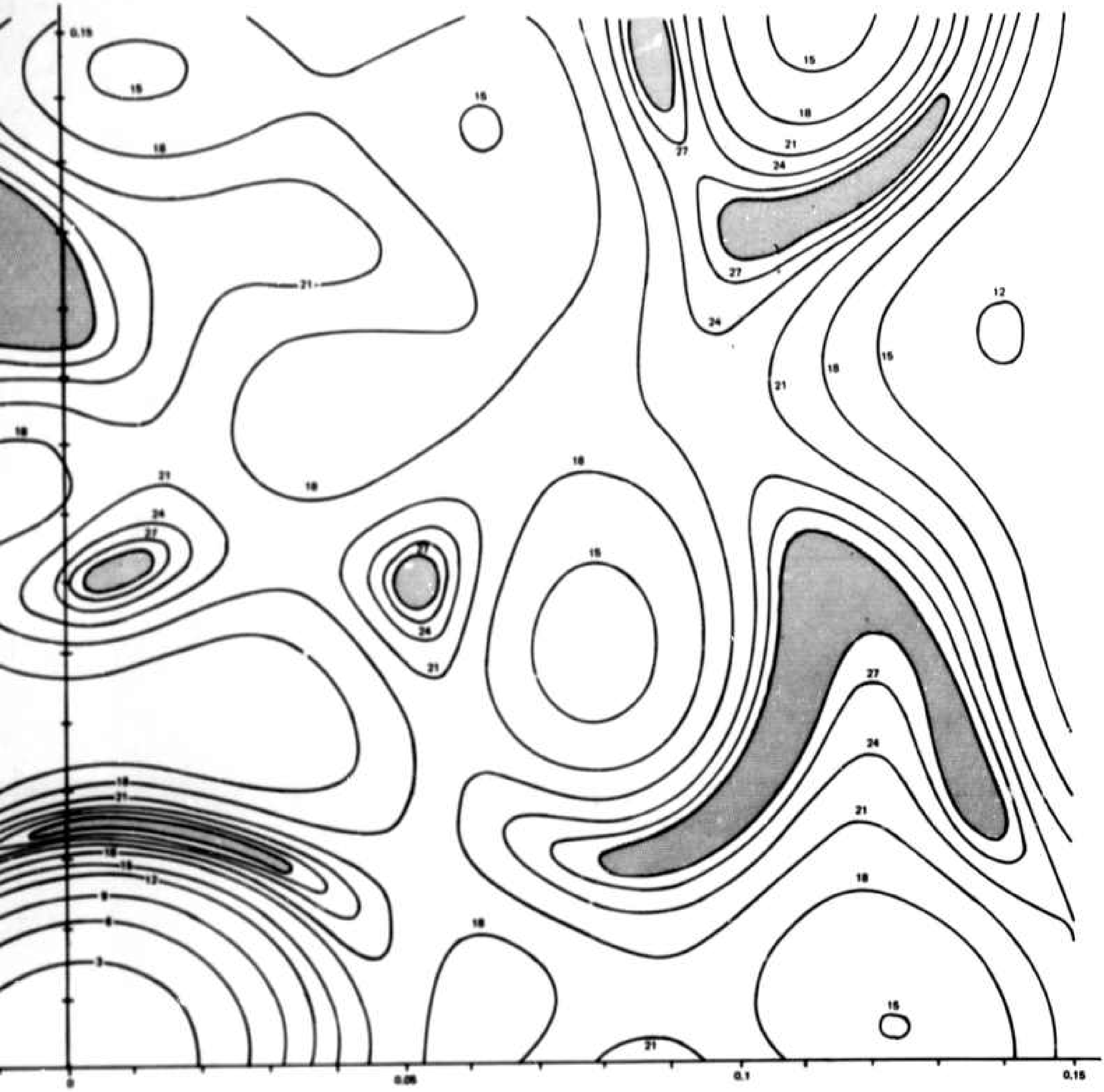


Figure 44. First and second quadrant of the wave number response of alternate array C

7.2 SIGNAL CLASSIFICATION STUDY

A study of a system for the classification of teleseismic earthquake signals was conducted jointly under Contracts AF 33(657)-67-C-0091 and AF 33(657)-16563. The study was made in response to a need for a concise expression of the physical appearance of seismograms. In addition, a classification system based on the visual appearance of the signal could provide a means of focal mechanism discrimination.

The classification system investigated in this study describes a teleseismic signature by means of a seven-character, alphanumeric code. The seven characters of classification in order of decreasing generality are as follows:

1. Four possible categories pertaining to the general shape of the signal envelope;

2. Ten possible categories concerned with the time lapse between the signal start and maximum;

3. Ten possible categories pertaining to the time lapse between the signal start and a secondary pulse;

4. Ten possible categories pertaining to the rate of buildup to the maximum amplitude;

5. Ten possible categories pertaining to the rate of buildup to a secondary pulse;

6. Eighteen possible categories pertaining to the rate of decay after the first principle pulse of the signal;

7. Six possible categories based on the amplitude of the maximum pulse relative to that of a secondary pulse.

One hundred and fifty-three earthquakes were selected which had epicenters at teleseismic distances from UBSO, TFSO, and WMSO, and whose magnitudes exceeded 5.0. The epicenter and magnitude data were taken from C&GS earthquake data reports of June through August 1966.

The recorded signals at each of the observatories were inspected, and those which had sufficient S/N to exhibit some definite signal character were classified by mutual agreement among a panel of Garland-based analysts. This resulted in a total of 247 signature classifications. These data were designated the "reference" set and the classification codes were punched onto IBM cards. The signatures from the various films were reproduced photographically and reassembled on one composite 16-millimeter film, ordered by date of origin. Copies of this classification study film were sent to UBSO and TFSO along with instructions for use of the system. Four TFSO and three UBSO analysts classified the signatures independently according to their understanding of the instructions. These classifications were recorded on standard computer data forms and were sent to the Garland facility where they were punched onto computer cards. The classifications of each of the seven categories for each of the seven analysts were compared with the reference classifications for all signals. Since the

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analysts did not necessarily use the same data trace (system) to classify a signal as did the reference, it was possible to make the comparison for the case of random trace selection by the analyst relative to the reference and for the case where both the analysts and the reference classified the signal from the same trace. To determine if experience in using the system improves the analyst's ability to classify a given signal correctly, the classifications made by two analysts who were experienced in using the system were compared to the reference. The results are summarized in table 19. The maximum percentage agreement with the reference upon a classification is obtained when the analysts are experienced in using the system, and when they use the same trace as that used during the reference classification. These conditions would be the normal ones if the system were used on a routine basis.

Table 19 shows percentage agreements with the reference for each of the seven character positions that constitute the complete signal classification. With the considerations of analyst's experience and constancy of the trace used, good agreement is observed for most of the character positions; however, the percentage of agreement on the complete classification (all seven characters) is the product of the seven probabilities (assuming character independence) and is only about 40 percent.

Although the seven-character, alphanumeric system is adequate in the sense that the principal characteristics of the analog signal can be reproduced from the coded signal, it is too subjective in that a given signal cannot be uniquely classified upon subjection to repeated and independent analysis. The principal factor which introduces subjectivity into the system is that characters 1 through 6 are critically dependent upon the analyst's selection of the signal arrival-time. A slight shift in the start time (0.1 second) can cause a given signal to fall into a different category.

We recommend that the seven-character, alphanumeric system be revised so that characters conveying the information now encoded by characters 1-6 would not be dependent upon the signal start. This change could be accomplished by keying on the signal maximum instead of the signal start. This modified classification system should be free of errors associated with picking the signal start time and should, as a result, permit unique classification of a signal under repeated, independent analysis. We also recommend that the modified system be evaluated to determine the degree to which the analog signal can be reproduced from the coded representation of the signal. The reproduction of the analog signal should be accomplished by machine processing to remove bias in the reproduction of the signals and also to evaluate possible routine reproduction of analog signals from codes received at a seismological, data reduction center.

If the modified system proves to be sufficiently objective and capable of retaining the principal visual characteristics of a signal, we recommend that a number of signals of known but different source mechanism be classified and that these signals and the corresponding codes be examined to see if a particular type of source mechanism tends to produce signatures which are similarly classified.

Table 19. Percent of agreement of analysts' classifications with the reference classifications

Source of reference classification	Source of analysts' classification	CHARACTER 1	2	3	4	5	6	7	Comments
Classifications made using various traces (systems)	Classifications made using the trace which, in the analyst's opinion, showed the signal character best	85.7	83.4	67.4	89.6	60.1	54.3	73.9	The analysts (7) were inexperienced in the use of classification system.
Same	Classifications made using the same trace as the reference	89.9	89.7	78.3	88.1	71.5	64.0	82.2	The analysts (7) were inexperienced in the use of classification system.
Same	Classifications made using the same trace as the reference	93.8	90.7	83.3	93.8	85.2	80.4	87.8	The analysts (2) were experienced in applying the system.

7.3 DESIGN AND FABRICATION OF A HIGH-FREQUENCY SEISMOGRAPH

The high-frequency seismometer is composed of a special case designed to accommodate eight modified Model GS-13V geophones for down-hole operation. The geophones were modified by Engineering Products Company of Tulsa, Oklahoma, the manufacturer, so that each geophone would have a 0.453 kilogram mass, a 2860-ohm data coil, and a natural frequency of 8 cps. In addition, a calibration coil was added to each geophone by Geotech. A calibration motor constant of 0.114 newtons per ampere was determined by comparing a series of weight lift pulses to a series of direct current pulses. This value was verified by shake-table tests. A damping ratio of 0.33 is obtained by mounting 5100-ohm resistors across each geophone data coil.

The seismometer case consists of inner and outer portions which are joined together at the bottom and top. The seismometer package weighs 250 pounds with the holelock attached, and is approximately 100-inches long. A 7-pin header is used to connect the data and calibration circuits to the armored cable which carries the data to the amplifier. The seismometer is locked in place, in the hole, by the use of a mechanical holelock, Geotech Model 22350A. Figure 45 shows the complete seismometer package.

The output of the seismometer will be amplified by an Ithaco Amplifier, Model 6052-17. This unit has a gain of 10^3 over the frequency band of interest. The system is then fed through two Philbrick P-65 amplifiers with filtering designed to shape the response to the desired band-pass of approximately 3 to 12.5 cps. The gain of these units is controlled by changing the resistance in the feedback circuit.

We plan to field test this unit in one of the existing shallow holes at TFSO.

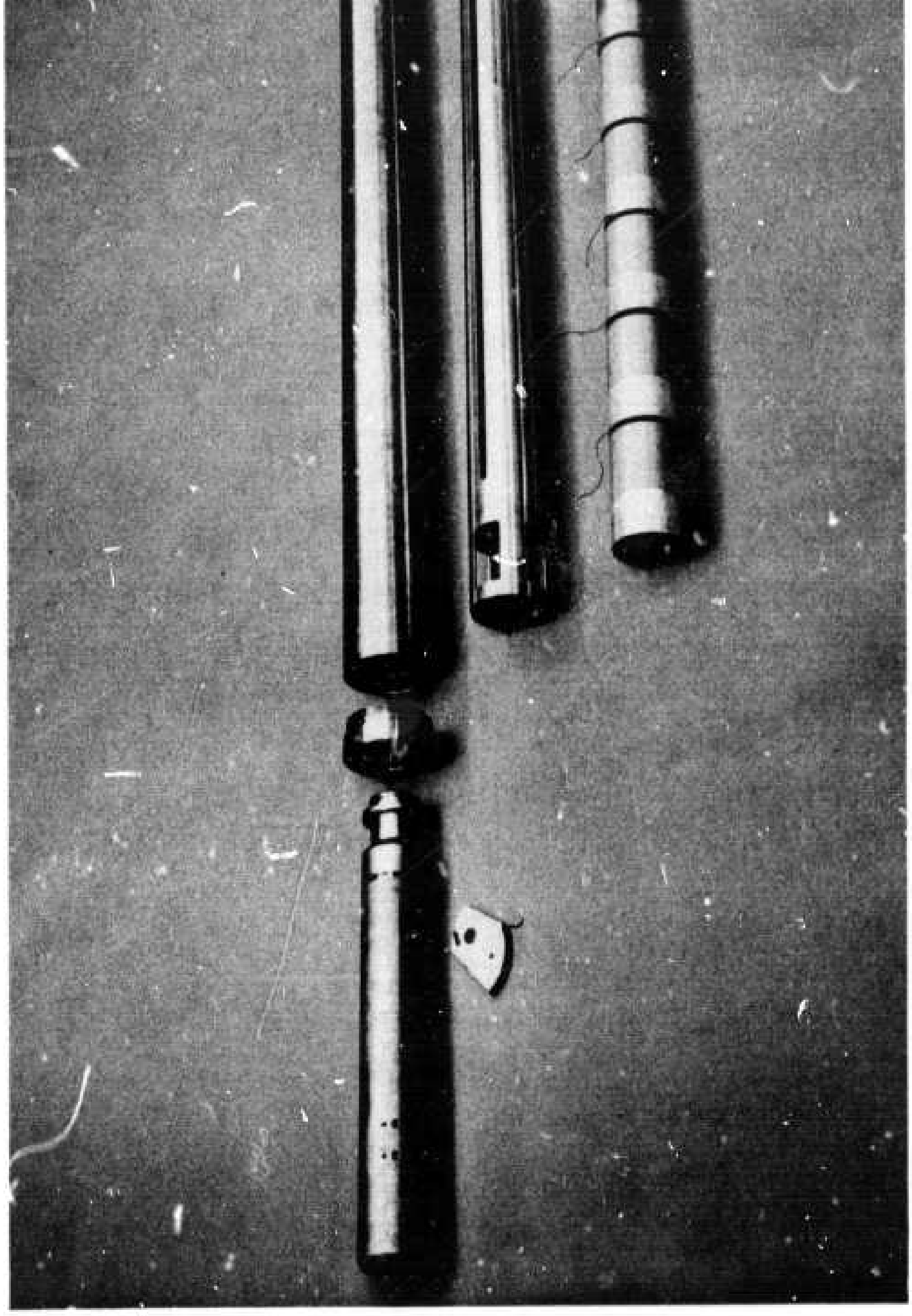


Figure 45. Components of the high frequency seismograph

8. ASSISTANCE PROVIDED TO OTHER GROUPS

8.1 CALIFORNIA INSTITUTE OF TECHNOLOGY (CAL TECH)

All 16-millimeter film containing data from the seismographs listed in table 20 was sent to Cal Tech during the first 10-months of the contract period. Recording of these data was terminated on 30 October 1967 at the request of Cal Tech.

Table 20. Seismograph systems recorded for Cal Tech

Channel	System
1	TCDMG
2	Z69
3	Z67
4	Z73
5	Z63
6	Z64
7	Z47BF
8	N49BF
9	E48BF
10	Z41IB
11	N43IB
12	E42IB
13	Z44LP
14	N46LP
15	E45LP
16	WWV

Key

TCDMG - Time Code Data Management Generator
Z - Vertical Johnson-Matheson (JM) short-period (SP)
N - North-south JM SP horizontal seismometer
E - East-west JM SP horizontal seismometer
BF - Benioff SP seismometer
LP - Geotech long-period seismometer
IB - Intermediate-band seismometer
WWV - Timing

8.2 MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT)

Telemetry of seven seismograph channels to Lincoln Labs, MIT, was accomplished throughout the reporting period. MIT was notified when the seismographs were attenuated for special tests.

8.3 ASTROGEOLOGICAL DEPARTMENT OF THE USGS

Throughout the report period TFSO furnished data to Dr. Harold Krivoy of the Astrogeological Center of the U. S. Geological Survey (USGS) concerning local earthquake activity. At the request of the Menlo Park office of the USGS, we sent all available back issues of the five-station earthquake bulletin (April 1963 through November 1966) to Dr. Krivoy on 25 May. Dr. Krivoy received copies of the daily station message routinely, and prints of events of special interest were sent to him on request.

8.4 NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

Assistance was provided to the personnel recording field data during the NASA-sponsored sonic boom tests at TFSO. Three of 8 scheduled missions were flown on 16 February, and 4 were flown on 21 February. Standard JM seismometers were replaced with JM seismometers equipped with high-impedance coils at six short-period locations. Solid-state amplifiers were installed in the vaults to amplify the signals from these transducers. Data from the modified systems were recorded on a station Develocorder at five times the normal film speed and on a station magnetic-tape recorder which operated with a tape speed of 0.6 inches per second. We also supplied station time (BCD) for the Philco Corporation (NASA) acoustic team.

8.5 OTHER GROUPS

Effective 8 April 1967, copies of the TFSO daily TWX message to the C&GS were mailed to the LRSM Group in Garland, Texas. Also, from 1 through 23 May 1967, information consisting of basic measurements taken from large teleseismic events was reported by telephone.

Beginning in December 1967, copies of the daily TWX message were routinely sent to Roy Hartenberger, SDL, and to the Project Officer.

In October, a request was received from the Military Electronics Division of Motorola Inc. to use the TFSO parking lot for vehicle storage at night and to use some of the vault access roads. Permission was granted by the station manager. Motorola was in the area to field test some new military communications equipment.

8.6 VISITORS

8.6.1 Visits by Project Managers

Mr. B. B. Leichliter, Geotech Program Manager, and Mr. M. E. Robinson, Program Engineer, visited TFSO during May 1967. The status of current work was reviewed and future work of Project VT/7702 was planned, especially the expansion of the short-period array.

Dr. Frank Pilotte, VSC; Mr. J. M. Whalen, Geotech Geophysical Operations Department Manager; and Mr. B. B. Leichliter, Geotech Project VT/7702 Program Manager, visited TFSO on 26 and 27 July 1967.

Dr. Frank Pilotte, VSC, and Mr. Don Clements, ARPA, visited TFSO on 13 September 1967.

Captain Frederick Munzlinger, VSC Project Officer, and Mr. B. B. Leichliter, Geotech Program Manager, visited TFSO from 25 through 27 September 1967. During each of these visits the status of current work was reviewed, and future work of Project VT/7702 was planned.

Captain Frederick Munzlinger, Project Officer, George Gerlach, Geotech, Roy Hartenberger, SDL, and Dean Rabenstein, SDL, were visitors at TFSO from 4 through 7 December.

8.6.2 Teledyne Visitors

Mr. George Walker, head buyer for Geotech, visited the station during April 1967 to interview contractors interested in submitting bids for site preparation and road construction for the 37-element, short-period array, and to receive bids.

Mr. O. D. Starkey visited TFSO during May 1967 to install and check the solid-state, long-period amplifier which was being evaluated.

Mr. Martin Robinson, Program Engineer, visited the station from 15 through 22 August for the purpose of testing new lightning protection circuitry for the 37-element array.

Mr. Arnold Sisson, Program Engineer, visited the station from 5 through 8 September for the purpose of general orientation, and from 10 through 16 December to assist in the installation of the long-period array.

Messrs. G. S. Gerlach, B. B. Leichliter, and J. M. Whalen, Geotech, visited the VELA Seismological Center, Washington, D. C., on 20 and 21 November for a technical review of the TFSO proposal (VT/8702).

Joe Herrage, Geotech, was at TFSO from 4 to 16 December 1967 to assist in the installation of the long-period array.

8.6.3 Visits by School Groups

Arizona State University students and instructors visited TFSO on 14, 21, and 28 April 1967. Approximately 210 visitors were given tours of the observatory and brief lectures on seismology. In July, another group of students and instructors from Arizona State University visited TFSO. Approximately 65 vistors were given tours of the observatory. Three other Arizona State groups visited on 13 and 20 October and 3 November.

8.6.4 Sonic Boom Program

Mr. G. S. Gerlach, Geotech, and Mr. H. R. Henderson, NASA, Langley Research Center, visited TFSO on 24 and 25 January. The purpose of the visit was to organize the preliminary groundwork for the sonic boom study made on 16 and 21 February 1967.

8.6.5 Others

Mr. L. H. Schrag and Mr. R. S. Keenan, 1381st Geodetic Survey Squadron, USAF, Warren AFB, Cheyenne, Wyoming, were visitors at TFSO on 6 and 7 July 1967. The purpose of the visit was to coordinate the new short- and long-period array surveys with TFSO personnel. Personnel from the 1381st Geodetic Survey Squadron were at TFSO from 15 August to 14 November 1967.

Twelve Naval Intelligence Officers from Phoenix, Arizona, visited the station on 8 July 1967. A tour was arranged and brief discussions held on instrumentation, engineering, and seismology.

Dr. E. B. Danson, Mr. Alexander Lindsey, and Mr. Roger Kelley, archeologists from the Museum of Northern Arizona, visited the station on 18 August. The TFSO array projects were discussed from an archeological viewpoint, and plans were made concerning future work.

Mr. T. C. Varghese, Atomic Energy Commission, Bombay, India, was a visitor at TFSO on 21 and 22 September. Mr. Varghese was given a tour of the observatory and facilities, and various aspects of observatory preparation and array installation techniques were discussed.

Messrs. P. J. Pilles, Jr., and W. Barrera, Jr., archeologists from the Museum of Northern Arizona, were at TFSO on 6 November through 8 November. They approved sites LP2, LP3, LP4, LP6, and LP7 for soil disturbance.

Messrs. R. E. Courtney, J. Cockrane, L. Jackson, and P. C. Smith of the U. S. Forest Service, visited TFSO on 22 November.

Dr. R. F. Roy, Cal Tech, was a visitor on 6 December 1967. He requested and received permission to drill a 3-inch by 1000-foot hole for heat flow measurements.

9. REPORTS AND DOCUMENTS PUBLISHED UNDER PROJECT VT/7702

The following technical reports were published:

a. Technical Report No. 67-25, Operation of the Tonto Forest Seismological Observatory, Quarterly Report No. 1, Project VT/7702, 1 January through 31 March 1967.

b. Technical Report No. 67-42, Operation of the Tonto Forest Seismological Observatory, Quarterly Report No. 2, Project VT/7702, 1 April through 30 June 1967.

c. Technical Report No. 67-73, Operation of the Tonto Forest Seismological Observatory, Quarterly Report No. 3, Project VT/7702, 1 July through 30 September 1967.

d. Technical Report No. 67-54, Analysis of TFSO Long-Period Noise Survey Data Conducted Under Project VT/7702, 6 November 1967.

The following letter reports were submitted to the Project Officer:

a. "Alternate Array Configurations for TFSO," dated 26 December 1967;

b. "P-Wave Magnitude Calculations for the Five-Station Earthquake Bulletin," dated 8 November 1967;

c. "Tests of the Model 28450-02 Long-Period Solid-State Amplifier," dated 20 October 1967;

d. "Evaluation of the Analog Devices Model 301 Amplifier," dated 29 September 1967;

e. "Arrival-Time Accuracy, Detectability, and Accuracy of First Motion Resolution for Signal 9 of the Detection Capability Study," dated 1 May 1967;

f. "Instrumentation and Configuration of Expanded Short-Period Array at TFSO," dated 6 March 1967.

APPENDIX 1 to TECHNICAL REPORT NO. 68-11

STATEMENT OF WORK TO BE DONE

STATEMENT OF WORK TO BE DONE
(AFTAC Project Authorization No. VELA T/7702/S/ASD) (32)

Tasks:

a. Operation:

(1) Continue operation of the Tonto Forest Seismological Observatory (TFSO), normally recording data continuously.

(2) Evaluate the seismic data to determine optimum operational characteristics and make changes in the operating parameters as may be required to provide the most effective observatory possible. Addition and modification of instrumentation are within the scope of work. However, such instrument modifications and additions, data evaluation, and major parameter changes are subject to the prior approval of the AFTAC project officer.

(3) Conduct routine daily analysis of seismic data at the observatory and transmit daily seismic reports to the Environmental Science Services Administration, Coast and Geodetic Survey, Wash DC using the established report format and detailed instructions.

(4) Record the results of daily analysis on magnetic tape in a format compatible with the automated bulletin program used by the Seismic Data Laboratory (SDL) in their preparation of the seismological bulletin of the VELA-UNIFORM seismological observatories. The format should be established by coordination with SDL through the AFTAC project officer. The schedule of routine shipments of these prepared magnetic tapes to SDL will be established by the AFTAC project officer.

(5) Establish quality control procedures and conduct quality control, as necessary, to assure the recording of high quality data on both magnetic tape and film. Past experience indicates that a quality control review of one magnetic tape per magnetic tape recorder at the observatory during each week is satisfactory unless quality control tolerances have been exceeded and the necessity of additional quality control arises. Quality control of magnetic tape should include, but need not necessarily be limited to, the following items:

(a) Completeness and accuracy of operation logs.

(b) Accuracy of observatory measurements of system noise and equivalent ground motion.

(c) Quality and completeness of voice comments.

(d) Examination of all calibrations to assure that clipping does not occur.

(e) Determination of relative phase shift on all array seismographs.

(f) Measurement of DC unbalance.

(g) Presence and accuracy of tape calibration and alignment.

(h) Check of uncompensated noise on each channel.

(i) Check of uncompensated signal-to-noise of channel 7.

(j) Check of general strength and quality of timing data derived from National Bureau of Standards Station WWV.

(k) Check of time pulse modulated 60 cps on channel 14 for adequate signal level and for presence of time pulses.

(l) Check of synchronization of digital time encoder with WWV.

(6) Provide observatory facilities, accompanying technical assistance by observatory personnel, and seismological data to requesting organizations and individuals after approval by the AFTAC project officer.

(7) Maintain, repair, protect, and preserve the facilities of TFSO in good physical condition in accordance with sound industrial practice.

b. Instrument Evaluation: On approval by the AFTAC project officer, evaluate the performance characteristics of experimental or off-the-shelf equipment offering potential improvement in the performance of observatory seismograph systems. Operation and test of such instrumentation under field conditions should normally be preceded by laboratory test and evaluation.

c. Special Investigations:

(1) Conduct research investigations as approved or requested by the AFTAC project officer to obtain fundamental information which will lead to improvements in the detection capability of TFSO. These programs should take advantage of geological, meteorological, and seismological conditions of the observatory. The following special studies should be accomplished:

(a) Design and install an array of approximately 37 short-period vertical seismographs. This array should be about 30 kilometers in diameter. The equipment and detector sites of existing arrays should be used to the extent possible in the design of the extended array.

(b) Design and install a 7 to 10 element array of long-period seismographs. This array should be approximately 30 kilometers in diameter.

(c) Evaluate the beam-steering capabilities of both arrays.

(2) Research might pursue investigations in, but is not necessarily limited to, the following areas of interest: microseismic noise, signal characteristics, data presentation, detection threshold, and array design (surface and shallow borehole).

(3) Prior to commencing any research investigation, AFTAC approval of the proposed investigation and of a comprehensive program outline of the intended research must be obtained.

APPENDIX 2 to TECHNICAL REPORT NO. 68-11

ASTRODATA SEISMIC DATA ACQUISITION SYSTEM TAPE FORMAT

ASTRODATA SEISMIC DATA ACQUISITION SYSTEM TAPE FORMAT

The TFSO digital recordings are written on seven-track IBM compatible magnetic tape.

1. DEFINITIONS

1.1 DATA WORD

A 36-bit word containing three samples of data from three different seismographs. Sources (seismometers) are identified as channel "i" where i is the detector identity and $1 \leq i \leq 48$.

1.2 TIME WORD

A 36-bit word which contains clock samples in milliseconds and the time the clock was reset to zero from 0000Z.

1.3 SCAN

Equal to 16 data words, i.e., one data sample from each of 48 seismographs.

SCAN = (16 data words) (3 samples per data word) = 48 samples. The real time required for a scan is approximately 50 milliseconds. The scans alternate starting time to synchronize the input with the output. The scans are started at intervals of 48 and 52 milliseconds in the following sequence:

0, 48, 100, 148, 200, 248, 300, 348, 400, etc.

1.4 DATA RECORD

Consists of one Time Word and 220 Scans. All the data for all channels for a 11-second sample period (220 data samples from each seismometer). Data Record = (220 scans) (16 data words per scan) + (1 time word) = 3,521 thirty-six bit words.

1.5 HEADER RECORD

An auxiliary record containing only 36 bits. It is the first record of each tape. (If there is more than one file, it is the first record of each file.) The data on this record includes the date, format designation, and the Astrodata amplifier gain settings.

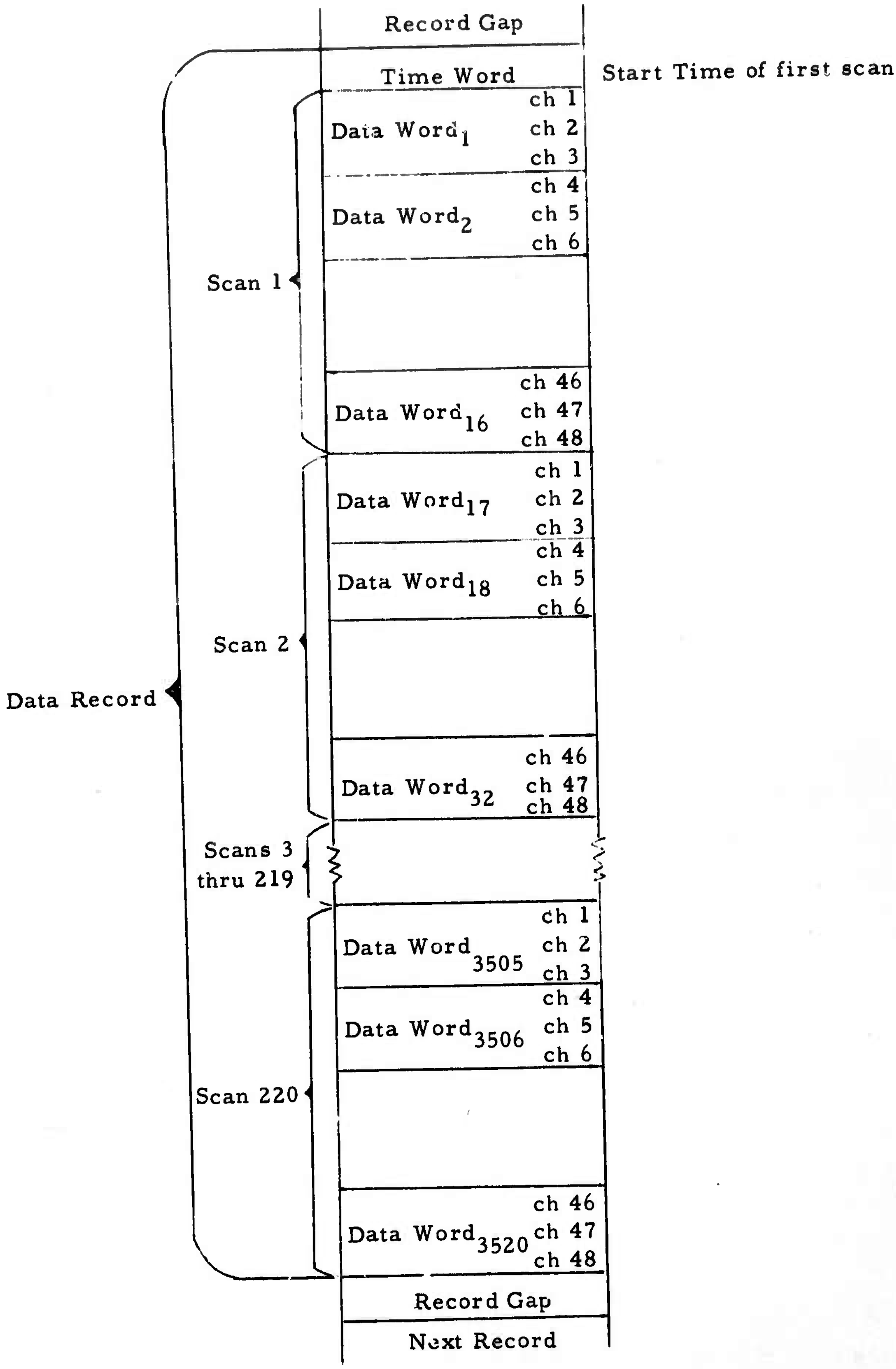
2. FORMATS

2.1 OVERALL FORMAT

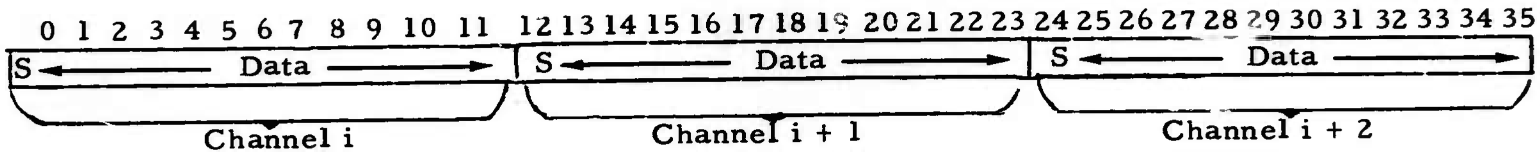
Header Record	Record Gap	Data Record	Record Gap	Data Record	Record Gap	EØF

A tape can record approximately 2 hours and 20 minutes of data with each data record being 11 seconds of data.

2.2 FORMAT OF EACH DATA RECORD

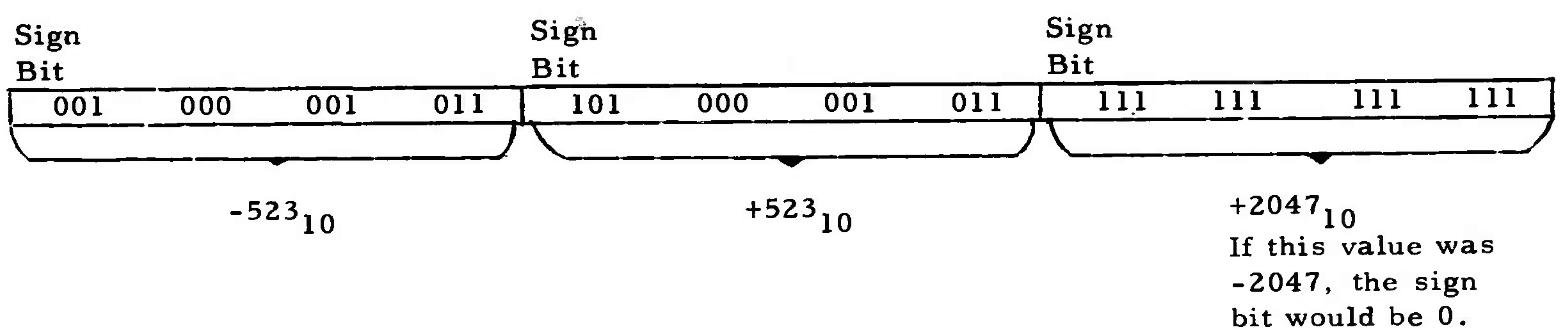


2.3 FORMAT OF ONE DATA WORD CONTAINING THREE DATA SAMPLES FROM THREE DIFFERENT CHANNELS



Each sample is represented by 12 bits with the highest order bit indicating the sign and the remaining 11 bits being the data value. Positive and negative values are represented the same with the only difference being the sign bit. If the sign bit is one, the value is positive; if zero, the value is negative.

2.3.1 Example of how Actual Samples would be Represented



2.4 FORMAT OF HEADER RECORDER:

0 1 2 3 4 5	6 7 8 9 10 11 12 13 14	15 16 17 18 19 20	21 22 23 24 25 26	27 28 29 30 31 32 33 34 35
0 0 0 0 0 0	0 0 0 0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0 0 0 0
Format	Astrodata 884 Amplifier gain settings	Spares	Year	Day of Year

2.5 FORMAT OF TIME WORD:

0	1 2 3 4 5 6 7 8 9	10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35
0	0 0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
Spare	A	B

A - Number of five minute intervals past 0000Z when the clock was reset to zero.

B - Number of ms from the time in A to the first data sample of the record. The value of the low order bit is 2^1 instead of the standard 2^0. Therefore, the bit value of B is 2^{26}, 2^{25}, 2^{24} ... 2^3, 2^2, 2^1.

The decoded time word gives the time of the start of the first scan of each record.

APPENDIX

CHANNEL ASSIGNMENT

Channel	Seismometer Assignment	Channel	Seismometer Assignment
1	Z1	25	Z25
2	Z2	26	Z26
3	Z3	27	Z27
4	Z4	28	Z28
5	Z5	29	Z29
6	Z6	30	Z30
7	Z7	31	Z31
8	Z8	32	Z32
9	Z9	33	Z33
10	Z10	34	Z34
11	Z11	35	Z35
12	Z12	36	Z36
13	Z13	37	Z37
14	Z14	38	Z60
15	Z15	39	N100SP
16	Z16	40	E99SP
17	Z17	41	Z44LP
18	Z18	42	N46LP
19	Z19	43	E45LP
20	Z20	44	Z51LP
21	Z21	45	N53LP
22	Z22	46	E52LP
23	Z23	47	WWV
24	Z24	48	*STS

NOTE

When LP array is installed, channels 38 through 44 will record 7 long-period vertical instrument while channel 45 through 47 will record 3 long-period horizontal instrument. Other channel assignments will remain the same.

*Station Timing System

APPENDIX 3 to TECHNICAL REPORT NO. 68-11

VAULT POSITIONS OF THE 37-ELEMENT, SHORT-PERIOD ARRAY AND THE 7-ELEMENT, LONG-PERIOD ARRAY

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The following illustration (figure 1) shows the vault positions of the 37-element, short-period array and the 7-element, long-period array. Also shown are the central recording building, the experimental vault, and the crossed-linear array.

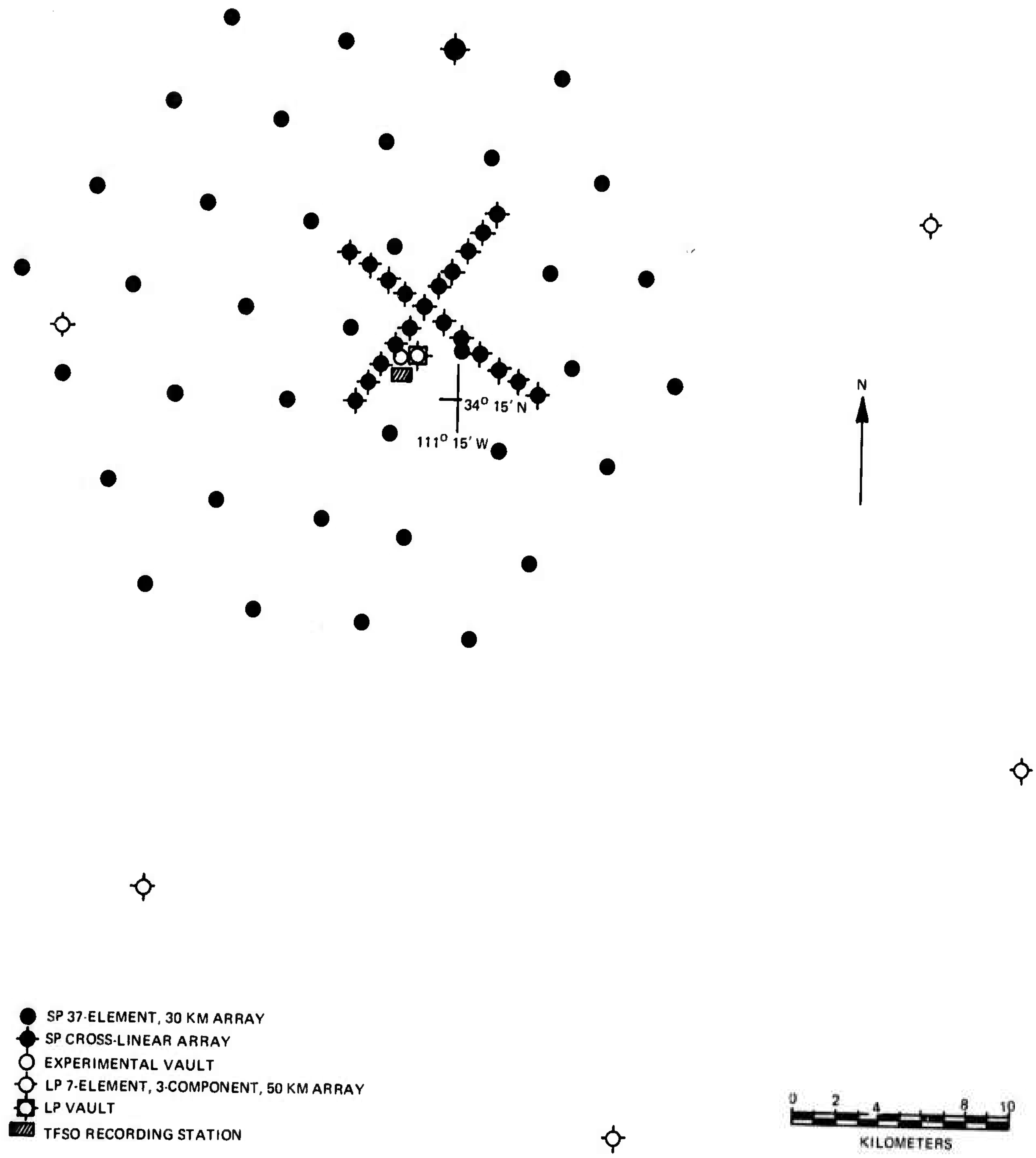

Figure 1. Vault locations in the 37-element, short-period array, the 7-element, long-period array, and the crossed-linear array at TFSO

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13. ABSTRACT

This is a report of the work accomplished on Project VT/7702 from 1 January 1967 through 31 December 1967. Project VT/7702 includes the operation, evaluation, and improvement of the Tonto Forest Seismological Observatory (TFSO) located near Payson, Arizona. It also includes the installation and initial operation of a 37-element, short-period array and the installation of a 7-element, long-period array. Special research and test functions undertaken at TFSO, and research and development tasks performed by the Garland, Texas, staff using TFSO data are included.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Seismograph operating parameters						
Short-period array installation						
Long-period array installation						
Long-period noise analysis						
Solid-state amplifier tests						