

ESD TR 67-221
ESTI FILE COPY

RECORD COPY
RETURN TO
SCIENTIFIC & TECHNICAL INFORMATION DIVISION
(ESTI), BUILDING 1211

ESD ACCESSION LIST

ESTI Call No. **AL 56694**

Copy No. of

ESD-TR-67-221



STUDY OF LASA DATA LINKS

Don R. Fink and Robert S. Dahlberg

March 1967

DIRECTORATE OF PLANNING AND TECHNOLOGY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford. Massachusetts

Distribution of this document is unlimited.

ESL-2

Sponsored by: Advanced Research Projects Agency. Washington, D.C.
ARPA Order No. 800

(Prepared under Contract No. AF 19(628)-6141 by PHILCO-FORD CORP.,
Communications and Electronics Division, Blue Bell, Pennsylvania

AD065 3223

LEGAL NOTICE

When U. S. Government drawings, specifications or other data are used for any purpose other than a definitely related government procurement operation, the government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

OTHER NOTICES

Do not return this copy. Retain or destroy.



STUDY OF LASA DATA LINKS

Don R. Fink and Robert S. Dahlberg

March 1967

DIRECTORATE OF PLANNING AND TECHNOLOGY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

Distribution of this document is unlimited.

Sponsored by: Advanced Research Projects Agency, Washington, D.C.
ARPA Order No. 800

(Prepared under Contract No. AF 19(628)-6141 by PHILCO-FORD CORP.,
Communications and Electronics Division, Blue Bell, Pennsylvania

FOREWORD

This research was supported by the Advanced Research Projects Agency. The Electronic Systems Division technical project officer for Contract AF 19(628) - 6141 is Major Cleve P. Malone (ESL-2). This report covers the period from 1 July 1966 to 1 November 1966.

Acknowledgement is made to Professor Otto Nuttli of St. Louis University, who served as consultant to Philco-Ford Corporation.

This technical report has been reviewed and is approved.

Paul W. Ridenour, Lt Col, USAF
Chief, LASA Office
Directorate of Planning and Technology
Electronic Systems Division

ABSTRACT

Investigation has been directed toward the utilization of data links for dissemination of seismic information from the Montana Large Aperture Seismic Array (LASA) to the scientific community. Methods and equipments are readily available for providing an essentially on-line seismic data link between Montana LASA and potential data users. Analog and/or digital data transmission appears feasible, and relative requirements and costs per data channel have been detailed. As a result of the study, which included a survey of the seismological community, it is recommended that a teletype station bulletin be made available to those desiring it. It is also recommended that consideration be given to providing a data transmission facility at the Montana LASA Data Center so that data can be transmitted directly to interested users. In addition, recommendation is made to investigate possible alternative approaches for mass storage of seismic data.

TABLE OF CONTENTS

	<u>Page</u>
SECTION I - INTRODUCTION	1
SECTION II - SURVEY OF DATA LINK SYSTEMS	3
A. SOURCES AND TYPES OF DATA	3
1. Raw Data	3
2. Processed Data	3
3. Seismological Bulletins	4
B. DATA REQUIREMENTS	4
C. STORAGE/RETRIEVAL SYSTEM CONCEPTS	5
1. Operational Concepts	5
2. Equipment Concepts	7
D. DATA TRANSMISSION	8
1. Communication Concepts	8
2. Transmission Methods	11
3. Equipments	15
4. Data Transmission Costs	22
E. DATA TRANSMISSION NETWORKS	28
1. Continental United States	28
2. Overseas	28
SECTION III - SEISMOLOGICAL COMMUNITY DATA REQUIREMENTS	33
A. DATA REQUIREMENTS SURVEY PROCEDURE	33
B. INTEREST IN LASA DATA	33
C. SURVEY RESULTS	34
SECTION IV - CONCLUSIONS AND RECOMMENDATIONS	37
A. TELETYPE STATION BULLETIN	37
B. DATA TRANSMISSION FACILITY	37
C. ADDITIONAL EFFORT	38
1. Transmission System Definition	38
2. Data Storage Study	39
APPENDIX I - FLOATING POINT TRANSMISSION	41
APPENDIX II - QUANTIZING NOISE	47
APPENDIX III - DATA PREPARATION FOR TRANSMISSION	53

LIST OF ILLUSTRATIONS

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1	Data Reduction Scheme for Fixed Storage	9
2	Data Link Configuration	12
3	Seismic Record	20
4	Seismic Record — Facsimile Transmission	21
5	WATS Calling Areas	26
6	Submarine Cable Network	30
7	Communications Satellite Stations	31
8	Floating Point Transmission Trade-Off Curves	42
9	Floating Point Code Sine Wave Transmission	44
10	Simplified Block Diagram of One Seismic Channel Selector	56
11	Multiplexer Block Diagram	57
12	Block Diagram of Receiving Interface Equipment	58

SECTION I

INTRODUCTION

This study has been directed toward the problems of data link dissemination of seismic information from the Montana Large Aperture Seismic Array (LASA) to the scientific community at large. With the implementation of LASA a wealth of potentially useful seismological data has become available. However, because of the vast quantities of data being generated at the LASA site, it is impractical to store all of this data for any considerable time.

Relatively rapid decisions are required as to what data to store even temporarily for distribution to the research community. The objective has been to evaluate means of making the product of this new data gathering system available to the investigator in a manner which would maximize information dissemination per dollar of investment.

The general scope of this study has been as follows:

- 1) Conduct a preliminary survey of methods and readily available equipments which could provide, at a reasonable cost, an essentially on-line seismic data link between Montana LASA and potential data users.
- 2) Conduct a survey of the seismological community to ascertain, within the framework of the data links determined in 1, their data requirements.
- 3) Translate the results of survey into the definition of potential data link systems which could be implemented in an efficient and economical manner.

SECTION II

SURVEY OF DATA LINK SYSTEMS

A. SOURCE AND TYPES OF DATA

The definition of a data link system requires identification and delineation of the mode of operation and specific user data requirements. Useful information for the seismological community can be actual raw or processed data for a specified interval of time, a report of an event, analytic information concerning an event or an analysis or history of events.

1. Raw Data

The raw seismic data at the Montana Lasa Data Center is in digital form as it is received from the subarrays. It is stored in digital form on magnetic tape; it is processed by an on-line computer program to detect events that merit further study. Each seismometer in the array yields 300 bits per second of raw data. The gross data rate from the 525 seismometers (not including the recently installed long-period instruments) is, therefore, 157,500 bits per second; this is a rate sufficient to fill over 140 tapes, each tape holding a hundred million bits, every 24 hours. It is therefore uneconomic and impractical to hold the raw data in storage on magnetic tape for more than a short time.

The 300 bits per second of data from each seismometer represents an analog voltage band-limited to 10 Hz and digitized to 14-bit precision at 20 samples per second. The 15th bit is a parity check bit. Digital to analog converters are available at the LASA Data Center for reconstructing the analog voltage from the bit stream. Seismic data can be made available in analog form for transmission to a potential user.

2. Processed Data

In addition to the raw data, several types of processed data may be available at the Data Center. Simple sums for each subarray, filtered data, delayed sums, correlation outputs, etc., are examples of processed data. Some of the processed results can be of sufficient interest to merit long-term storage.

The processed data may be assumed to be similar to the raw data (i.e. 300 bits per second — or 10 Hz analog) with the possible exception of non-filtered correlation outputs which contain a double frequency component and hence may extend to 20 Hz analog bandwidth.

3. Seismological Bulletins

Another type data developed at the LASA Data Center are periodic or special bulletins which announce the detection of events. The station bulletin, which has been distributed daily by teletype to a few recipients and weekly to a larger scientific group, includes such information as the following:

- (a) Date of Bulletin
- (b) Source data of event(s), such as time, latitude, longitude, level of confidence, magnitude range and geographic region.
- (c) Observed data for teleseismic compressional wave (P) arrival, such as arrival time, identification of the subarray for which arrival time is valid, estimate of zero to peak amplitude in millimicrons, estimate of dominant periods in seconds, estimate of direction of first motion, and estimate of the horizontal phase velocity.
- (d) Later phases information, such as arrival time, identification of subarray for which the arrival time is valid, and phase designation using standard seismic notation.
- (e) Weak or regional arrival information for events closer than 20 to 25 degrees from LASA and for arrivals that are barely detected, but cannot be analyzed for amplitude, period, etc. The information includes the arrival time, subarray designation, estimated class, and epicenter direction from LASA.

B. DATA REQUIREMENTS

There are a wide variety of seismological problems for which the Large Aperture Seismic Array could provide unique data. It is also apparent that individual data requirements for the seismological community can vary widely. There are numerous trade-off factors to be evaluated for efficient data distribution.

The information available at Montana LASA consists of raw signal data, certain processed signal data, the bulletin information, as previously mentioned. In many cases bulletin type information is the first step in helping the seismologist delineate specific events for which raw or processed data is then requested for further study.

These three types of information of use to potential subscribers of Montana LASA, or from any LASA Data Center equipped to furnish such information, may be categorized broadly into current data and history. Current seismic data is considered to be either concurrent or within a certain period of immediately preceding time. Historical data is considered to be that which is older and is stored in some manner.

The need for current and/or historical data by the investigator is an important criteria in determining an appropriate distribution system and in determining the constraints of a storage/retrieval/transmission system.

C. STORAGE/RETRIEVAL SYSTEM CONCEPTS

A fundamental problem at the Montana LASA is the extremely high raw data rate which makes storage of all data impracticable. Certain selected event data tapes will undoubtedly be saved and would be available to further study. Although it cannot be foreseen that an extensive information storage and retrieval system can be implemented at present for the LASA data, it is instructive to discuss the basic aspects of such systems in conjunction with the general features of data link systems.

1. Operational Concepts

Several concepts are feasible for a storage/retrieval/transmission system. One approach would be to avoid any unnecessary prior processing of records and assume that the available records on magnetic tapes are already indexed or "tagged" sufficiently for subscriber purposes. When specific records are requested by the subscribers, a record-by-record search of the collection would be made, found, and transmitted. This operating concept appears appropriate where the anticipated needs are general in nature and when rapid retrieval is not a necessity. A second operating concept is to analyze the re-organize the collection of records in anticipation of certain specific questions. When a question is asked, one would presumably have the pertinent records or their index entries already segregated from the rest of the collection, making retrieval and transmission rapid and routine. The second method is most useful if original records are not needed by subscribers, but answers to specific types of questions are desired. A third operating concept is to have a combination of the other two, or both concepts. Most retrieval systems employ a combination, since the user's needs cannot be fully anticipated. Some degree of prior organization of the basic records according to general areas of interest will eliminate large portions of the collection from consideration and thus make the search more efficient. The proper balance generally is known only after some experience and is governed by economic factors that frequently cannot be predicted precisely. Bulletin information could be sorted and indexed for various periods of time (days, months, years, etc.) according to characteristics such as the following:

- (a) Region or general location where significant events have occurred
- (b) Magnitude of seismic events
- (c) Frequency of significant events by region
- (d) Categorization of events; i. e. earthquakes, nuclear tests, explosions, etc.

(e) Periods of time.

However, for the Montana LASA installation, it is anticipated that the Data Center would function only to provide actual data, raw or processed, and concurrent bulletin information. Sorting and selection of historical and referenced data is presumed to be a function not within the immediate scope of Montana LASA.

The most significant assumptions to be made in connection with such a retrieval/transmission system are those pertaining to the indexing or "tagging" of the information on the magnetic tapes written onto by, and read from, the magnetic tape units on the digital processor equipments in the Data Center.

It could be assumed that significant event information resulting from off-line processing is tagged or indexed according to, or similar to, the following:

- (a) Date and time of event
- (b) Approximate epicenter (geographic location)
- (c) Focal depth
- (d) Magnitude
- (e) Distance from station
- (f) Nature of first motion
- (g) Time of onset of significant motion
- (h) Nature of significant phase
- (i) Dominant periods

The subjects of such indexing form the basis for periodic and special bulletins that are issued to interested agencies. It is visualized that most subscribers engaged in research will ask for seismic information identified only by time. It can also be assumed that basic raw data requested may or may not have been identified in a periodic or special bulletin which the subscriber received. If not so identified, it can be assumed that such data, if available, is available for only a relatively short period of time after the event.

It could be further anticipated that the data recorded onto magnetic tapes to form permanent records by the on-line processor equipments contain tags or information indexes which reveal the time or periods of time that the seismic observations were made, as well as identify the subarrays from which the information was taken, or that this information is at least on file.

2. Equipment Concepts

Two general configurations to providing appropriate retrieval/transmission capability are possible as follows: combined facilities and separate facilities.

a. Combined Facilities

Additional equipments to form a combined processing capability which would handle both the reception and processing of digital data from seismic sensors, and handle retrieval and transmission of information to subscribers are possible. Development of this concept would require that certain detailed information, such as signal processing methods, the availability of storage capacity and exact cataloging methods, be known. Many of these details are still in formative stages for LASA. A number of combined approaches are possible, however; the most simple and most complex are described below:

(1) The addition of manual-type facilities. These facilities would consist of recording equipment to store the processor equipment outputs on a no-interference basis, from the same processor outputs that serve the control console and/or the magnetic tape units. The records would be indexed so that an operator could readily recognize the indexing. A selection of the recordings so indexed would be made by the operator upon receipt of specific data requests and manually loaded into the communications data terminal equipments for transmission to the subscriber terminal equipments. The recording and manual selection of data and its transmission would thus be able to take place as a parallel operation to the regular processor using separate equipments so that no interference with the regular operation would take place. Bulletins would be continued as at present.

(2) The addition of processor(s) and associated facilities. The equipments would interface directly with the digital processor equipments to receive outputs, as they are generated. Such outputs would consist of automatically produced periodic and special bulletins, processed data from the off-line-computers, and raw data from the on-line processor. The information accumulated would be stored on a mass-storage medium, such as a magnetic drum, disc file, magnetic tapes, or a combination of these, as it is developed. The mass storage capability would need to equal or exceed the amount of data that would be accumulated in a specific period of time, such as 12 or 24 hours. As information was written-over on magnetic tape by the on-line processor, the system would also write-over the same information in mass storage. Thereby, the storage/retrieval system would keep in step with the on-line processor. In addition, the off-line processed information would also accumulate. This information would include automated periodic or special bulletins, if they are so produced, and any new data created from raw data. Providing periodic and special bulletins are produced automatically, the system could be equipped to automatically "dial" and transmit bulletins to a specified list of subscribers. The subscribers would have a capability to later query for additional information identified in the bulletins and have that information transmitted to them during the

same contact.

b. Separate Facilities

The provision of separate data processing facilities (separate from the on-line and off-line digital processor and associated equipments in the LASA Data Center) for retrieval of indexed seismic information from magnetic tapes and the transmission of selected seismic information to subscribers, upon request, is a feasible concept. These facilities would largely depend on the required information (that information referred to in bulletins, processed data, and raw data, as required) being in the Data Center tape library on groups of magnetic tapes written onto by, and removed from the tape transports of the present processor equipments. Numerous variations in equipments making-up the retrieval/transmission system and associated facilities are possible. However, the facilities at the LASA Data Center would generally consist of a data processor with core memory and operational programs, a control panel or console with an input/output keyboard/printer device, and a magnetic tape controller with tape transports, as a minimum. The transmission facilities would consist of various speed digital line termination buffers connected to comparable speed output lines from the system data processor.

Separate data processing facilities for an information storage retrieval/transmission system would permit certain reprocessing, such as sorting and reindexing of the information more specifically to meet possible requirements of subscribers. In theory, at least, the amount of significant event information data retained could decrease over a period of time. Raw data should be reduced faster than processed data, and analyzed data should be reduced to historical facts over a period of time. This data reduction could be made periodically, so that the amount of data on hand for a week should not equal seven days accumulation of data and the amount of data retained for a year would not equal the amount maintained for each of 12 consecutive months. The diagram, Figure 1, is illustrative of a possible reduction scheme given a fixed amount of storage.

D. DATA TRANSMISSION

1. Communications Concepts

A number of communication data link concepts are possible. Primary among the considerations are trade-off factors concerned with costs. One such aspect is whether there is a need for full-period on-line communications to subscribers or whether on-call/on-line communications will adequately serve the subscribers. In many instances, on-call communications are considered adequate and economical. When the projected costs of on-call, on-line digital data link communications equal or exceed the costs of full-period communications, full-period service is indicated. Each of the following concepts, or a combination of them, is feasible to serve potential subscribers.

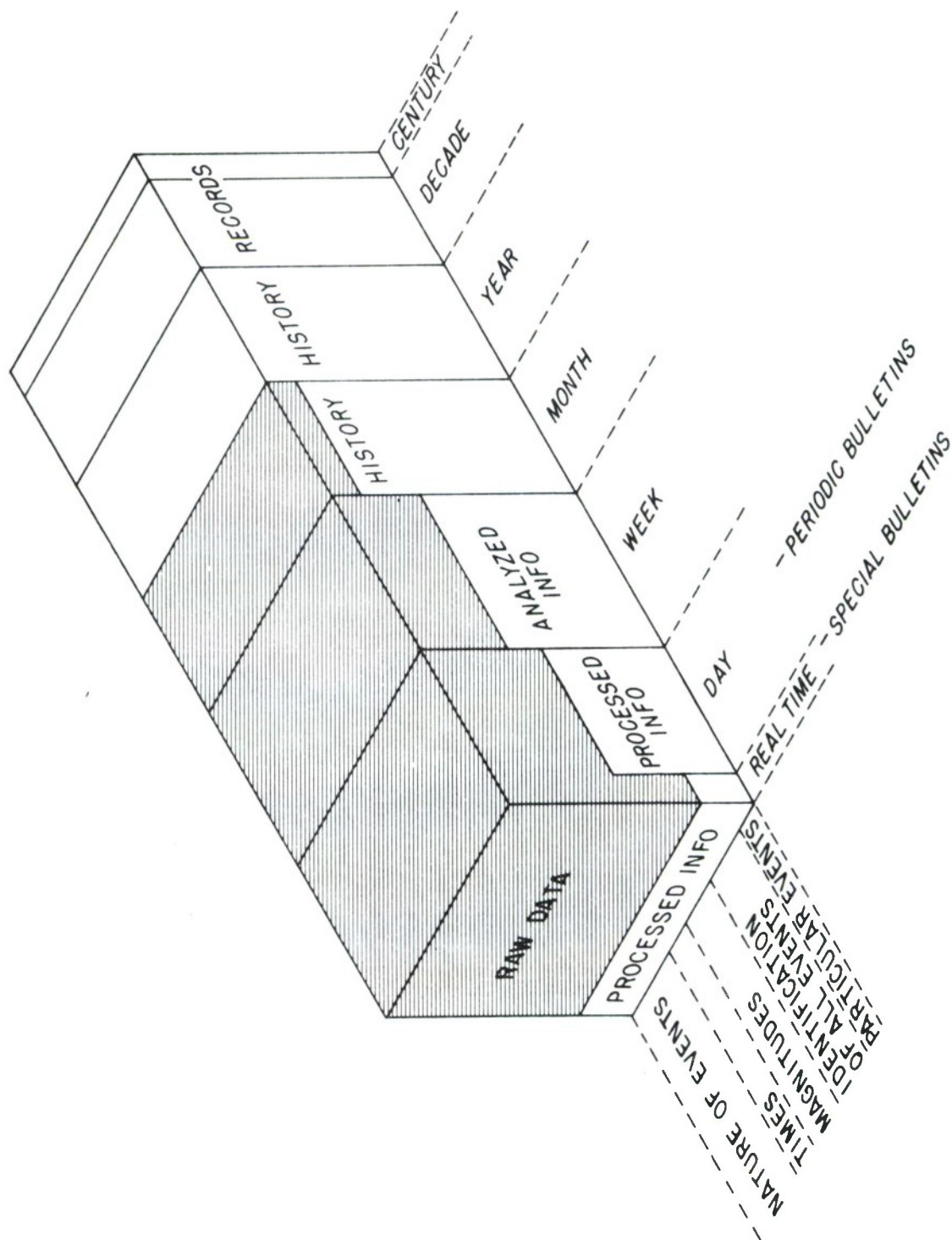


Figure 1. Date Reduction Scheme for Fixed Storage

a. Commercial telephone or TELEX lines switched manually to data operations between the LASA Data Center and subscriber equipments. Multiple full-period commercial telephone lines to the nearest "commercial carrier" switchboard or telephone switching center can be provided for a telephone operator at the LASA Data Center. These lines would be terminated on a terminal strip or display board which could provide a visual indication as well as an audible telephone-type ringing capability for each line. A headset and telephone instrument or teletype machine would be furnished, common to all compatible terminated lines. In response to announcements in periodic or special bulletins, subscribers could call the LASA Data Center telephone number via commercial communications long-distance or wide-area distant dialing service and be connected to the LASA Data Center over one of the terminated lines to the operator. The operator would verbally take the requests for seismic information and arrange for immediate transmission of the requested information, if readily available. If not immediately available, he would make arrangements to call back and arrange the transfer of the requested information. He could also arrange with the subscriber for switching the telephone line to the digital terminal equipment at the subscriber's end of the line and could also switch the Data Center end of the line to the data operation. The operation of a switch to "data" position would place a transmit line termination buffer and modem equipment, if necessary, which are connected to any retrieval/transmission equipments, on the line. He would then enter a command into the system to seek the required information from on-line magnetic tapes and/or mass magnetic storage and transmit the required information automatically to the connected subscriber equipments.

b. Commercial telephone or TELEX lines "dialed" automatically by the data processor and associated equipments. The data processor could contain subscribers' "numbers" in tables in its memory and trigger special interface equipment which automatically performs the equivalent of dialing by telephone or TELEX to make connection to the proper communication line and subscriber digital terminal equipments. The terminal equipment then automatically responds with its identification or indication of proper connection, thus initiating the start of data transmission to the subscriber terminal. The automatic dialing and connection features permit automatic and timely dissemination of bulletin information and is especially effective when bulletins are automatically prepared. The same special interface equipment would accept outside calls for specified information "advertised" as available in any special bulletins and initiate the transmission to subscribers' digital terminal equipments. This automatic arrangement of communications keeps costs based on line usage time at a minimum. This system requires multiple full-period commercial telephone or TELEX lines to the nearest commercial TELEX automatic switchboard or automatic telephone switching center. These lines would be terminated in both the automatic interface equipment and to terminal monitoring and operating equipment which permit operator intervention, if required.

c. Commercial TELEX line to a commercial communications message center, such as Western Union operates, for automatic filing of messages containing periodic and special bulletins to subscribers. The interconnection of commercial

telephone lines on an on-call basis between the LASA Data Center and subscribers requires dialing of the assigned telephone number on the terminal telephone instrument. The circuit, so connected, will then support verbal communications or audio signals. Unless the length of the interconnection is extremely short, the conversion of those circuits for use in digital data transmission requires interface equipments at both ends. The interface equipment consists of modem equipment for conversion of digital data to audio form at the transmitting end and re-conversion of the audio signals back to digital form for printing-type terminal equipments at the receiving end. The modem equipments available on the market may be single-channel-types in fixed or variable transmission speeds or multiple channel.

Various types of terminal equipments are available for digital circuits. Data can be handled in punched card form, magnetic tape form, perforated paper form and in printed form. Many equipments handle data in a combination of these forms. The most economical type of terminal which would be used by subscribers for seismic information is the standard teletypewriters produced by Teletype Corporation. This type of terminal is reasonable for rapid receipt of bulletin information. For rapid receipt of long periods of raw or processed signal data rather than event "information," a magnetic tape recorder or facsimile system would be indicated.

These equipments will be detailed later. For purposes of reference, Figure 2 presents the concepts involved in a data link system configuration which could serve for rapid dissemination of seismic information from LASA to potential subscribers.

2. Transmission Methods

Data transmission means are many and varied dependent upon user, speed, and form requirements. A distinction can be made between on-line and off-line operation and between analog and digital methods.

a. Off-Line and On-Line Operation

Off-line data transmission is characterized by a large and often variable delay between the generation of the data and its delivery to the recipient. A daily or weekly seismological bulletin transmitted by mail or teletype constitutes off-line data transmission. The events described in the bulletins may have occurred any-time within the past day or week before they are distributed. The shipment of chart recordings or magnetic tape reels is also an example of off-line data transmission. Off-line transmission is, in many cases, the most economical means of transmitting large amounts of data; it has an additional advantage that transmission-induced errors are nearly non-existent. If there is no compelling reason why actual data must be examined within hours or minutes of the time of arrival at the seismometer, normal mail service may well be the most satisfactory and economical means of dissemination.

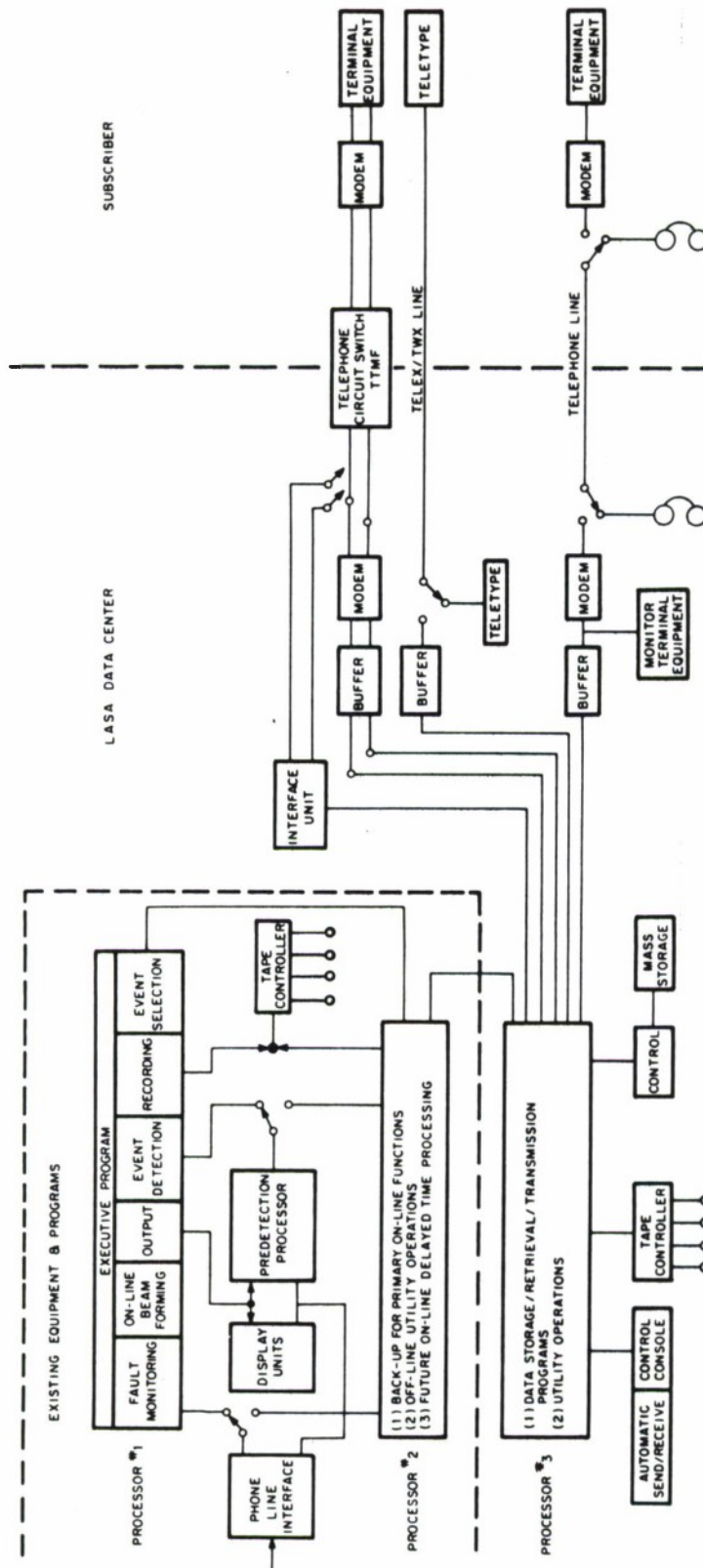


Figure 2. Data Link Configuration

In cases where it is desired to get data to the user as soon as it is generated, the data must be transmitted on-line. The data link transmission mode may be either analog or digital and should provide for one or more 300 bit per second digital channels or 10 Hz wide analog channels. In either case, control and timing information must also be provided. The requirements are substantially the same whether raw or processed data is sent.

b. Analog and Digital Methods

(1) Analog Transmission

Analog transmission may be approached in several ways: amplitude modulation, frequency modulation, phase modulation, pulse position modulation, etc. There are, however, only two in common use over telephone lines. These are frequency modulation (FM), utilizing an audio sub-carrier, and picture transmission.

In the FM method a variable frequency oscillator at the transmitting end has its frequency changed (modulated) in sympathy with the analog voltage to be transmitted, and the frequency varying audio tone is transmitted over a telephone circuit to a receiver. The receiver contains a frequency discriminator that changes the varying frequency of the audio tone back into a varying voltage. The voltage may then be recorded. It is noted that the seismic signal itself is not suitable for transmission directly over a telephone channel since the normal band of frequencies (say, 0.1 to 10 Hz) lies below the band of frequencies that the telephone channel can handle (300 to 3100 Hz).

Several traces of analog seismic data may be multiplexed together and transmitted over a single telephone voice channel by placing each channel on a distinct sub-carrier frequency. The several sub-carrier frequencies are then separated at the receiver with band-pass filters and demodulated, each by its own discriminator. At least ten seismic signals may be transmitted simultaneously by multiplexing them together in this way.

A second approach to the transmission of analog data is to take a seismic record, i.e., a hard copy seismogram of the trace or traces and transmit the record as a facsimile copy. This may be done with standard facsimile machines, or with slow-scan TV equipments. Slow scan TV operates like ordinary TV except that the rate of transmitting frames is slowed from 30 per second to, typically, one per minute. Hence the "video" information is narrowed to where it can be transmitted in the bandwidth afforded by a telephone channel. The reproduced picture on the receiver monitor may then be photographed for a permanent record.

(2) Digital Transmission

Digital transmission of data is becoming more prevalent as higher speed and greater precision requirements are imposed. The most common digital

transmission is teletype in which the characters to be transmitted are encoded into frequency shifted pulses of a sub-carrier, transmitted over the teletype channel, and then decoded to letters and numbers by the teletype receiver. Binary data may also be transmitted over a teletype channel. Compared to other digital circuitry, a teletype channel is relatively low speed; much higher data rates are handled by special modems. Use is made of frequency shifted sub-carriers, phase modulated sub-carriers and vestigial sideband modulated sub-carriers.

(3) Comparison of Analog and Digital Methods

Comparing the relative merits of analog and digital transmission of the data, it is noted that analog transmission is characterized by a reduction in dynamic range as contrasted to the dynamic range of the digital data from which it is derived. LASA raw data has a dynamic range of over 72 db; this may be compared with the 60 db dynamic range of an exceptionally good analog transmission system having an accuracy of 0.1%. This is a reduction of at least 12 db.

Even within the relatively short distances of data transmission of the LASA array itself, digital transmission is used. Transmission in the analog mode is minimized by converting the analog information to digital form in the sub-array vault. Up to this point the exposure of the signal to environmental noise is minimized by burying the connecting cables and by amplifying the signal to a high level as close to the seismometer as possible. After conversion to digital form, the signal is rugged enough to complete its journey to the Data Center at Billings over open wire line and microwave circuits. By converting the seismic signal to digital form as close to its source as possible, the dynamic range of over 72 db in the data gathered is preserved through subsequent transmission to the Data Center. Analog transmission circuits are able to achieve such a large dynamic range only under exceptional circumstances.

On the other hand, the precision with which data may be transmitted is unlimited in the digital mode. As many data bits as necessary can be transmitted to specify amplitudes to one part in a hundred, one part in a thousand, ten thousand, or as required. The only limit is that imposed by the accuracy of the original data.

A second advantage of digital over analog transmission is that the digital signal is more rugged. It is more resistant to the random noise and distortion added by the transmission medium. This added noise and distortion increases with distance for both transmission modes. The longer the circuit the poorer the quality, since the circuit is subject to the addition of noise at many places; the greater the "exposure" the more noise is added to the signal. This noise steadily degrades the analog signal. With a digital signal, however, regeneration is possible. Ordinarily only two states - pulse or no pulse - are expected of a digital signal; hence, before the noise and distortion have become large enough to confuse a decision as to which state of the signal was intended, a regenerative repeater is inserted. The repeater makes a decision as to which state of the signal was intended and generates a new pulse, free of all noise and distortion, and sends

it on. By thus regenerating at intervals, the distance that a digital signal can be sent has no limit. For long distance data transmission (such as on a world-wide basis) this is a factor that weighs heavily in favor of the digital mode of transmission.

The complexity and cost of the terminal equipment for analog and digital systems is similar, although the digital systems may have a slight edge. There is a basic similarity between an FM analog telemeter and a Frequency Shift Keying (FSK) digital data set; but the FM analog system design must receive more emphasis on linearity than FSK and hence tends to be more complex and more costly. A facsimile or slow scan TV equipment is clearly more complex than any digital system.

3. Equipments

a. Digital

(1) Digital Data Sets

Digital data sets are available covering a wide range of requirements. The Western Electric 201A Data Set will handle up to 200 bits per second over the switched telephone network. The received data may be recorded on magnetic tape, in which case it is in a form for further processing by the recipient. Or it may be recorded for visual inspection by interposing a demultiplexer and digital to analog converter ahead of a recorder.

The Western Electric 201B Data Set is capable of digital data operation up to 2400 bits per second over specially treated (equalized) private line facilities. Provisions can be made for unattended operation, so that data can be received even during unattended hours.

For much higher data transmission rates (feasible generally only under computer control) Tel Pak Data Sets A, B, and C are available for transmission speeds of 40.8, 105, and 500 kilobits per second, respectively. These data sets require much more bandwidth than a voice channel provides and are transmitted in the slots otherwise allotted to groups, supergroups, etc.

(2) Teletype (TWX)

Rapid dissemination of seismological bulletins from the LASA Data Center to the seismological community appear most feasible by teletype. It can be anticipated that a daily bulletin may eventually be prepared by computer. At present, however, a bulletin may be prepared manually for TWX transmission. An operator in this case prepares a punched paper tape of the bulletin format.

(a) Semi-Automatic Operation

An operator inserts the punched tape in the teletype transmitter and dials a subscriber. The subscriber's machine in the automatic answering mode will acknowledge the call and respond with a "go-ahead," whereupon the transmitter will send the bulletin and the receiving machine will type it out. The call is automatically terminated at the end of the message; the operator then calls the next subscriber in turn. To conserve operator's time and to prevent mistakes, a card dialer could be used. With this device the effort in dialing the subscriber's number is reduced to the insertion of a punched card into the unit and pressing a button that gives the machine a "go-ahead."

(b) Automatic Operation

An alternate approach is to set up a second teletype machine for automatic transmission when called. The subscriber then would call the Billings Data Center at a time convenient to him and receive the bulletin automatically. An operator would prepare the bulletin on punched paper tape as before and load it into the teletype transmitter as a loop. This second teletype transmitter would be provided with its own line and telephone number. When the subscribers call in to that number, the bulletin would be transmitted to them.

(c) TWX Versus Data-Phone

Either of the above types of service may be provided either over the TWX network with a teletype machine alone, or over the switched voice network utilizing a teletype machine plus a Data-Phone. Reasons for preference of TTY-DATA PHONE to TWX include the following:

- . The possibility of voice coordination;
- . Possible use of Wide-Area Telephone Service (WATS) which may be cheaper for large message volumes;
- . Ease of adding automatic calling.

b. Analog

(1) FM Techniques

Standardized equipment for FM telemetering of analog data has been developed for airborne and space use and is available from a number of manufacturers. The IRIG standardized telemetering channels 1 through 8 have center frequencies that permit them to be carried over standard telephone circuits. These telemetering channels utilize frequency modulated sub-carriers and are suitable for relaying seismic data. The transmitter consists of a voltage controlled oscillator; the outputs of several oscillators may be added together and impressed on the telephone line. The receivers contain bandpass filters that separate the several sub-carriers and frequency discriminators that convert the FM signal

back to analog voltage. The characteristics of the first 8 IRIG channels are briefly summarized below:

PROPERTIES OF IRIG TELEMETERING CHANNELS

Channel Number	Center Frequency Hz	Data Bandwidth Hz
1	400	6.0
2	560	8.4
3	730	11.0
4	960	14.0
5	1300	20.0
6	1700	25.0
7	2300	35.0
8	3000	45.0

The standardized channels listed were devised to cope with a broad spectrum of analog ranging from slowly varying data to that with quite rapid variations. The seismic data of interest here does not cover a wide range of variation. It is filtered quite sharply above 5 Hz and has essentially no energy at 10 Hz. Thus, even the lowest channels on the IRIG series would transmit the data satisfactorily; however, the higher numbered channels have more data bandwidth than is needed. If the data bandwidth is reduced, the carrier frequencies may be placed closer together and more of them may be placed in the bandwidth available in a telephone channel.

The design of these FM telemetering channels is now so routine that applications to fit special circumstances are no particular problem. Sonex Inc., for example, offers a group of four channels with constant data bandwidths as follows:

SONEX INC. CONSTANT BANDWIDTH CHANNELS

Center Frequency	Deviation	Data Bandwidth
1200	200	50
1650	200	50
2100	200	50
2550	200	50

These appear to be suitable for the transmission of analog seismic data with the reservation that the highest frequency channel at 2550 Hz may not be usable on some circuits because of its proximity to 2600 Hz, a commonly used signalling frequency. This manufacturer offers the group of four VCO (voltage controlled oscillator) transmitters with power supply and rack mounting for about \$2300. The companion group of receivers also with power supply and rack mount is about \$2575.

Data Control Systems, Inc. has implemented a ten channel FM telemetering link with a constant per channel deviation of plus and minus 62.5 Hz and center frequencies for the sub-carriers of: 391, 625, 859, 1093, 1327, 1798, 2032, 2266, 2500, 2734 Hz. In addition to the channel frequencies listed a reference frequency is transmitted at 1562.5 Hz.

The Bell Telephone Company offers two types of single channel FM data sets either of which is more than adequate to transmit a channel of seismic data. Their Western Electroc Co. 602A Data Set transmits a 0 to 1000 Hz data bandwidth and has an input voltage range of 0 to 7 volts. The bipolar seismic data may be transmitted over this set by adding a DC offset at the transmitter in series with the analog voltage and by subtracting the same voltage at the receiver to restore the data to its bipolar form. Some recorders have a DC offset biasing arrangement built into the circuit that would conveniently nullify the offset put into the transmitter in order to transmit negative excursions of the seismic signal. Additional channels of seismic data might be multiplexed onto the 602A data set by adding FM sub-carriers above the baseband of 0 to 10 Hz occupied by the seismic signal. IRIG channels 1 through 3 (400 Hz to 730 Hz center frequencies) would be suitable for this purpose.

The Western Electric Co. 603A Data Set has a data bandwidth of 0 to 100 Hz and accepts input voltages up to plus and minus 2 volts. Hence, it is suitable for the transmission of one channel of analog seismic data. This is the data set that has received widespread publicity as a means of transmitting electrocardiograms from a patient to a remote interpretation center where a

heart specialist can make a diagnosis.

(2) Facsimile Transmission

At the LASA Data Center analog recordings of the seismic data are made for visual examination. A bank of Develocorders record the outputs of digital to analog converters on 16 mm film. As many as 16 traces may be recorded on each film. These recordings could be made available to the seismological community rapidly, and fairly economically, by facsimile data transmission. Facsimile machines exist that are capable of scanning the film directly; however, most facsimile machines are designed to transmit 8 1/2" x 11" documents. Some of these machines are capable of accepting documents 8 1/2" wide and any length. It would be possible, therefore, to photographically enlarge the Develocorder film to 8 1/2" or less in width into long rolls which feed into a facsimile machine for transmission as continuous copy.

The transmission speed attainable varies with the bandwidth of the transmission link. Over ordinary telephone lines, an 8 1/2" x 11" page may be transmitted in 3 minutes at a resolution of 85 lines per inch. This appears to be adequate. A schedule 4B or schedule 2 telephone line is required; thus, phase and amplitude equalization of a voice grade telephone line is needed. Commercial telephone companies furnish this equalizer.

At the speed of 3 minutes per 11 inches of record, the speed of recording and traces is about 1/7 of "real time." In other words, one minute of seismic data will take about 7 minutes to transmit as a facsimile record. The method is not suitable for real time transmission of everything that comes in, but would serve admirably to transmit selected events of special interest.

The feasibility of the method was briefly tested with good results. A section of 16 mm Develocorder film was enlarged about 15 times and transmitted over a Telautograph facsimile equipment. The original and the received copy are shown in Figures 3 and 4, respectively. The quality of the received copy is very nearly the same as that of the original.

It is significant that the ability of the facsimile machine to transmit copies of any graphic material means that both bulletins and actual data may be transmitted over the circuit.

Appropriate transmitting and receiving equipments sell for about \$2700 each, which compares favorably with other approaches, especially considering the flexibility of these systems.

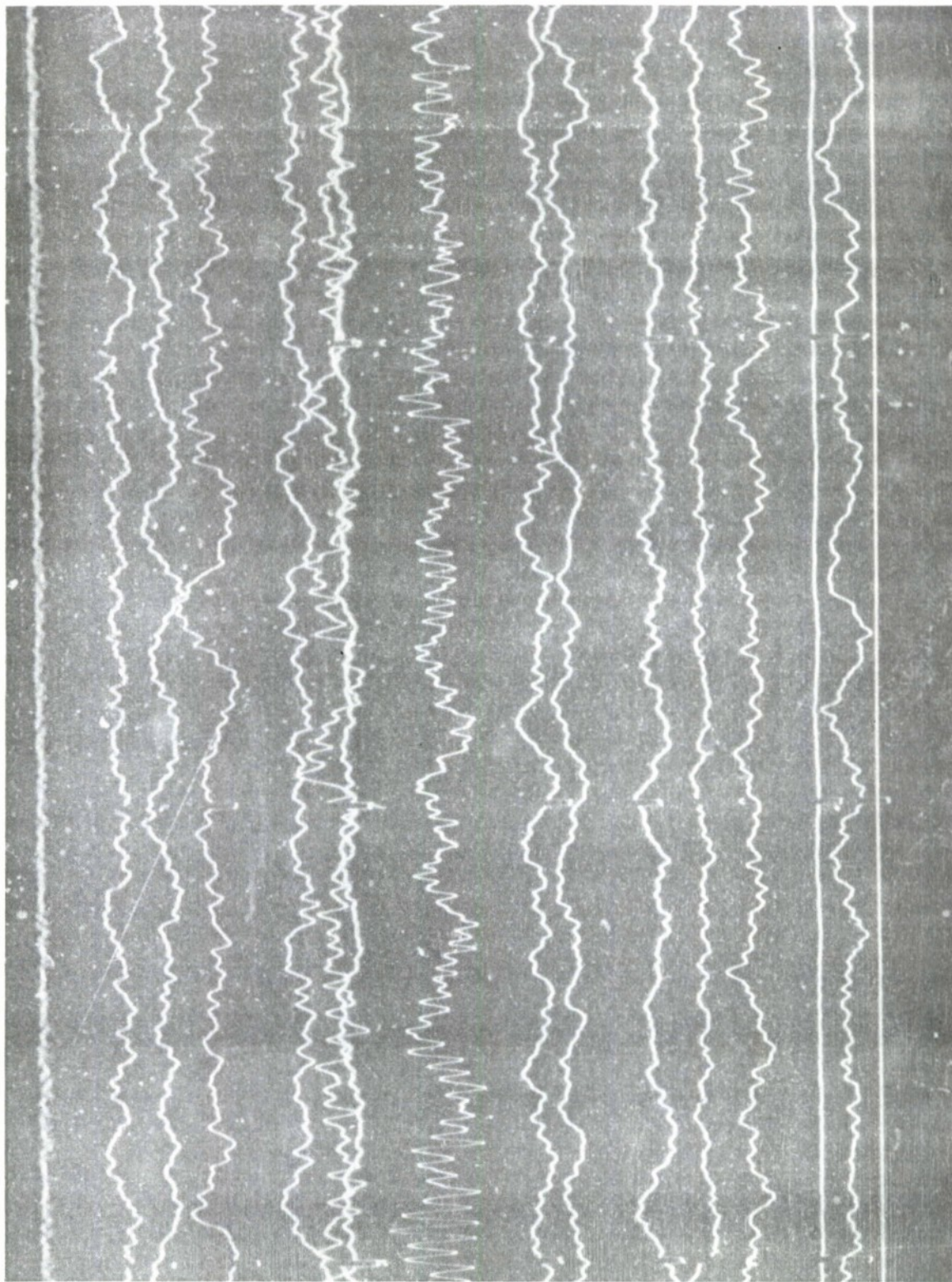


Figure 3. Seismic Record

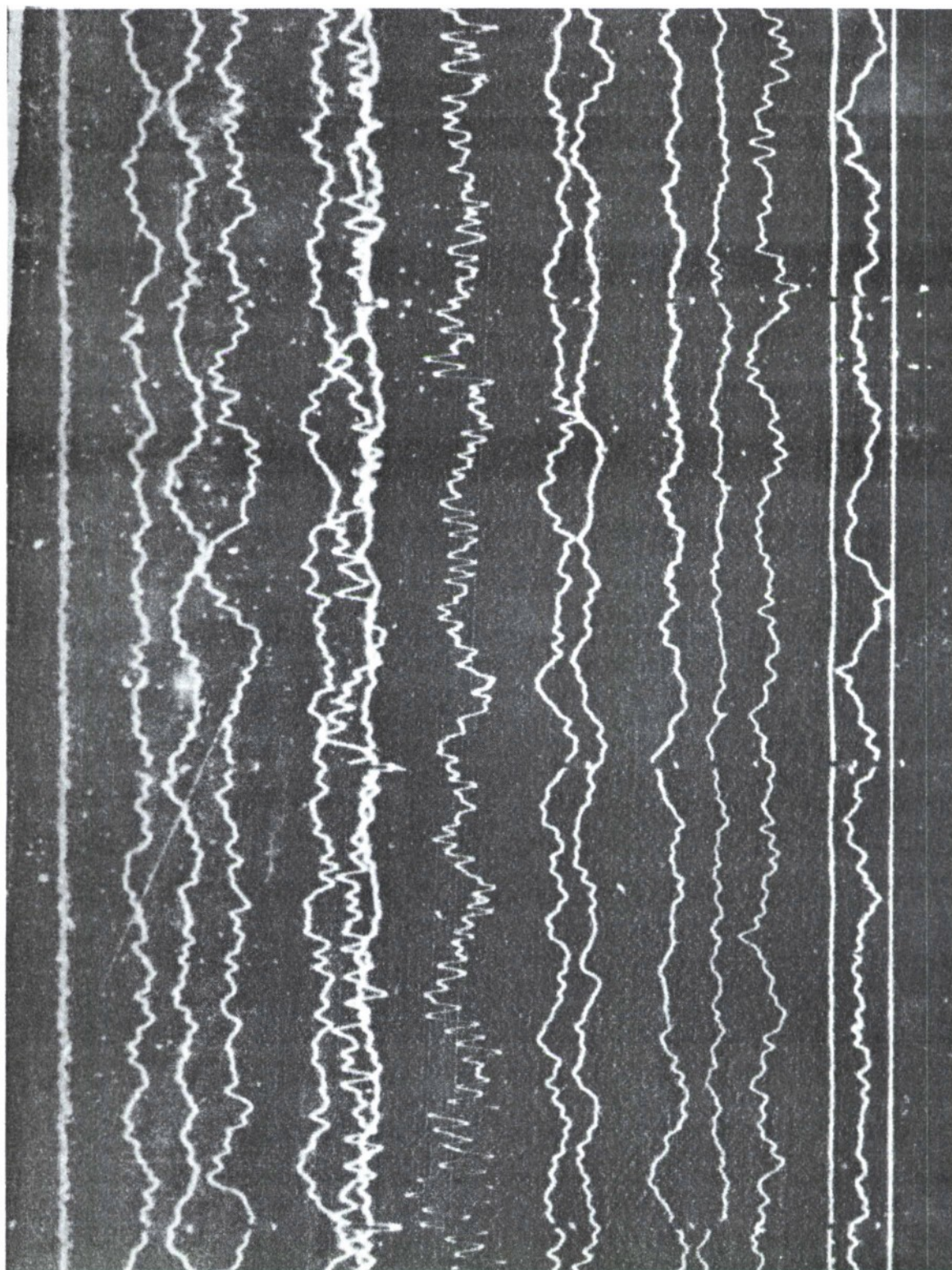


Figure 4. Seismogram Record — Facsimile Transmission

4. Data Transmission Costs

The costs of transmitting LASA seismic data has been estimated for both analog and digital modes for two representative paths: Billings, Montana to Los Angeles and Billings to New York City. The figures may be taken as an index to the costs that might be incurred.

Two distinct expense categories are involved: (a) a fixed installation charge and monthly rental (and/or amortization) for terminal equipment and local lines to the telephone exchange; (b) a variable cost that depends on the distance and activity. For limited usage (up to above 15 or 20 hours per month) Direct Distance Dialing (DDD) is the most economical. If more nearly continuous on-line data reception is required Wide Area Telephone Service (WATS) may result in reduced per-hour cost.

Multiplexing terminal equipment to supplement telephone company rental apparatus would be needed if more than one data stream (10 Hz analog or 300 bits/second digital) were to be handled. Rough investment cost estimates for this equipment have been made. It is to be noted that, in addition to terminal equipments, buffering to the transmission terminals is required, particularly for digital transmission. Cost estimates are possible only after detailed system definition.

For a data transmission system it will generally be advisable to install a local line direct from the premises to the local telephone central office not involved with PBX or key-plan circuitry so that optimum service can be achieved with the data set. The rental of the local line and the data set plus the amortization of such auxiliary equipment as may be required, make up the fixed charges against the data transmission system.

In addition to the fixed charges, there will be a variable charge for the long distance connection time actually used. Regular long distance rates apply, and the connection can be dialed when it is needed. For a few hours of usage per month, DDD is found to be economical. If heavy circuit usage is envisaged, advantage may be taken of the Wide Area Telephone Service. In this scheme, the country is divided into Zones, based on distance from the calling point. The customer may call anywhere up to a specified distance Zone at a fixed charge for the first 15 hours of usage. Usage over 15 hours is billed at a flat rate per hour, or fraction. Unlimited usage up to and within this distance Zone is available for a flat monthly charge. This class of service may result in a lower per hour cost for activity in excess of 15 to 20 hours per month of actual data transmission time.

The highest class and most expensive telephone service is the leased line or dedicated circuit set up independently of the switched network and providing a continuous connection between two fixed points. The charges for this service are on an airline miles per month schedule between central offices plus charges for the local lines at each end.

Several data transmission and receiving system arrangements ranging from a single analog channel to several digital channels with estimated costs for each are detailed in the following sections. Additional costs other than those presented are involved in providing necessary buffers. The complexity and hence cost of such hardware is dependent on the exact nature of data transmitted and could range up to \$25,000 for high digital transmission capacity. Essentially no buffering is required for analog transmission because of the nature and availability of the data terminals at the LASA site.

a. Fixed Charges

<u>Single Analog Channel Cost</u>	<u>Monthly Rental</u>	<u>Installation</u>
602A Data Set	\$50.00	\$50.00
Local Line - MB	13.00	18.00
	<u>\$63.00</u>	<u>\$68.00</u>

4 Analog Channel Cost

Sonex Receivers (Investment)	\$2575	
Sonex Transmitters (Investment)	2295	
	<u>\$4870</u>	
Local Lines - MB	\$25.00	\$20.00

Ten Analog Channel Cost

Transmitting Terminal (Investment)	\$5910	
Receiving Terminal (Investment)	14,370	
	<u>\$20,280</u>	
Local Line - MB	\$25.00	\$20.00

Six Channel Digital Cost

Capability 2000 bits per second or 6 data streams plus timing.

Investment Estimated for Data Multiplexer and Demultiplexer	\$5000	
201A Data Set	\$140	\$200
Channel Termination	25	
Local Lines	25	20
4C Data Channel Conditioning	112	
	<u>\$302</u>	<u>\$220</u>

<u>Teletype</u>	<u>Monthly Rental</u>	<u>Installation</u>
TWX Service		
Model 33 ASR	\$ 60.00	\$50.00
Model 35 ASR	115.00	50.00
DATA-PHONE Service		
Model 33 ASR	\$50.00	\$25.00
101 C Data Set	30.00	25.00
MB Line (varies with State)	<u>6.50</u>	<u>9.00</u>
TOTAL	\$86.50	\$59.00
Model 35 ASR	\$115.00	\$25.00
101 C Data Set	30.00	25.00
MB Line	<u>6.50</u>	<u>9.00</u>
TOTAL	\$151.50	\$59.00
Miscellaneous Optional Teletype Equipment		
Card dialer with TTY	\$2.00	\$15.00
Card dialer with Data Phone	3.00	15.00
Remote Transmitter Control		
33 ASR START & STOP	4.00	15.00
Typing Reperforator 35 ASR	7.50	10.00

Note: The Model 35 ASR machine has more features such as vertical and horizontal tabulating capabilities that do not seem necessary for the transmission of the seismic bulletins. The speeds are the same for the two models and both have Automatic Send Receive capability.

Digital Data Channel

A private line connection conditioned as a schedule 4C data channel is able to utilize a 201B Data Set at 2400 bits/second which will yield 7 multiplexed data streams plus 300 bits/second for timing and control.

	<u>Monthly Rental</u>	<u>Installation</u>
201B Data Set	\$140	\$200
Channel Termination	25	
Local Channel	25	20
4C Data Channel Conditioning	<u>112</u>	
	\$302	\$220

b. Variable Charges

In addition to the installation costs and monthly rentals, there are toll charges which depend on distance and activity, but not on the type of terminal equipment. The toll charges are the same whether the data is handled in digital or analog form, or whether a teletype machine with Data Phone is employed.

Teletype costs on the TWX network are different. The TWX network has its own switching centers and call numbers distinct from the regular telephone network and the toll charges accumulate by the minute starting from the first minute in contrast to the three minute minimum of the telephone network. Otherwise the toll charges are similar for the same total activity.

Representative toll charges are listed below for two distances as a function of activity. Such charges are more a function of activity than of distance.

Direct Distance Dialing (DDD)

Billings - Los Angeles: First 3 min \$1.50 plus \$0.40/min

Billings - New York City: First 3 min \$1.80 plus \$0.45/min

<u>Activity</u>	<u>Los Angeles*</u>	<u>New York City</u>
1 hr/mo	\$24.30	\$ 27.45
5 hr/mo	121.50	137.25
10 hr/mo	243.00	274.50
15 hr/mo	364.50	411.75
20 hr/mo	486.00	549.00

*Based on a one hour connection per call

Wide Area Telephone Service (WATS)

	<u>Full Time</u>	<u>First 15 Hours</u>	<u>Each Additional Hour</u>
To Los Angeles	\$1500/mo	\$430/mo	\$25.00
To New York City	\$2050/mo	\$540/mo	\$30.50

WATS map centered on Billings is shown in Figure 5 and the WATS rate tabulation by corresponding zones is as follows:

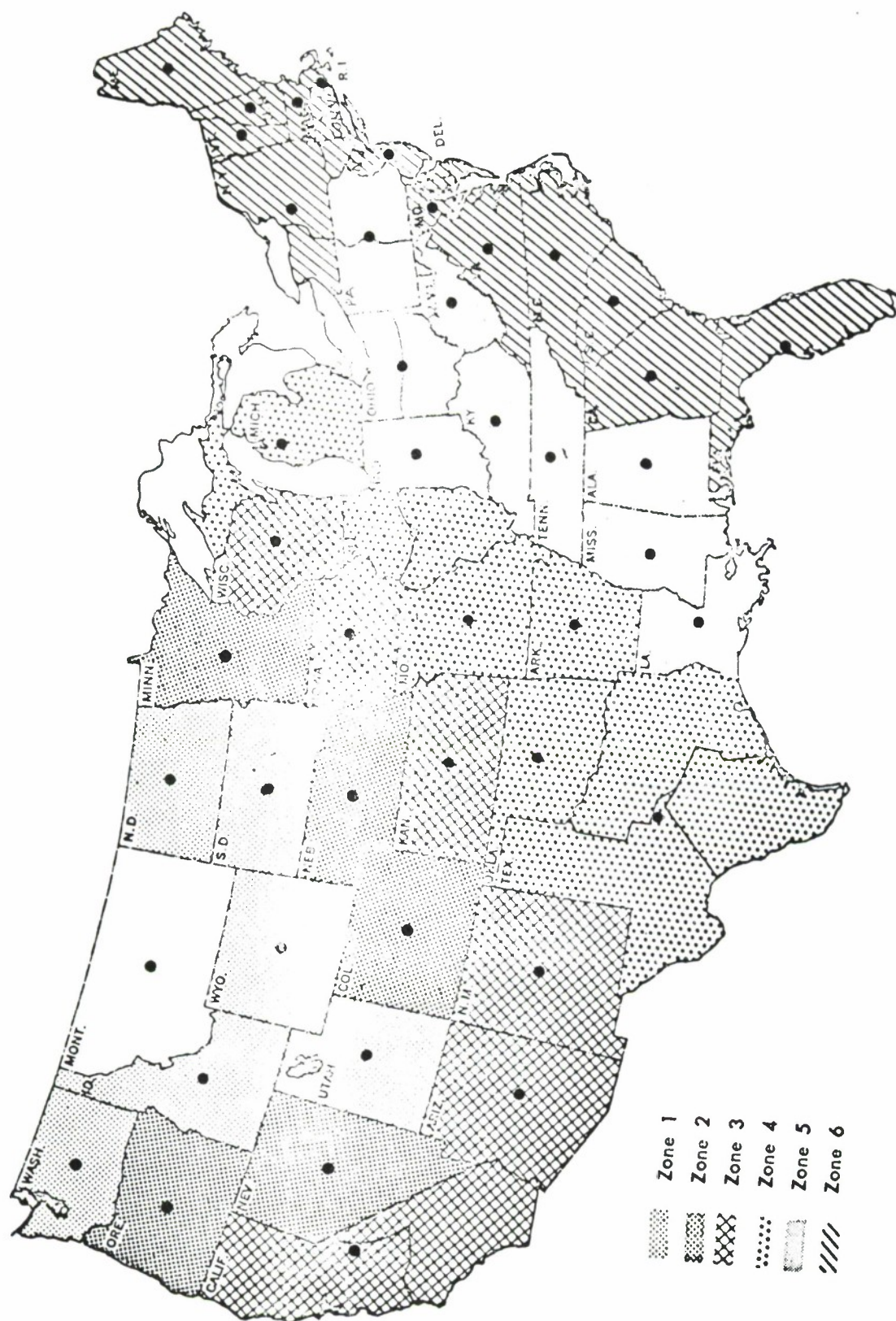


Figure 5. WATS Calling Areas

	<u>Flat Rate Service</u>	<u>Measured Service</u> <u>1st 15 Hrs.</u>	<u>Ea. Addl. Hr.</u> <u>or fraction</u>
Zone 1	\$1100	\$370	\$21.00
Zone 2	1300	400	23.00
Zone 3	1500	430	25.00
Zone 4	1750	475	27.50
Zone 5	1900	510	29.00
Zone 6	2050	540	30.50

Zone 1 - Wyo., Ida., N.D., S.D., Wash., Utah
 Zone 2 - Ore., Colo., Neb., Nev., Minn.
 Zone 3 - Kan., Calif., Iowa, N.M., Ariz., Wisc.
 Zone 4 - Okla., Mo., Ill., Mich., Tex., Ark.
 Zone 5 - Ind., Ky., Ohio, Tenn., Miss., La., Ala., W.V., Pa.
 Zone 6 - N.Y., Va., Ga., D.C., Md., N.C., S.C., Vt., Del., N.J., N.H.,
 Conn., Mass., R.I., Me., Fla.

Private Line Digital Data Channel

IXC Interexchange Mileage (Air Line)			
First 250 miles	@ \$2.02/mi mo	=	\$ 505.00
Second 250 miles	@ \$1.717/mi mo	=	429.25
All over 500 miles	@ \$1.616/mi mo	=	2424.00
(based on 2000 mi circuit)			\$3358.25

c. Comparative Cost Summary

The following table summarizes costs for various combinations for comparison. It is to be noted that the costs reflect the total data link expense; including both transmission and reception terminals, but not including costs for transmission buffering required for digital transmission or costs for recorders at the receiving end.

Terminal Equipment Costs

	One Channel Analog	Four Channel Analog	Ten Channel Analog	Six Channel Digital	Teletype
Investment	—	4870	20280	5000	—
Installation	68	20	20	220	59
Monthly Rental	63	25	25	302	86.50

Activity Charges Based on Billings - New York City

<u>DDD</u>		<u>WATS</u>	
5 hours/mo	\$137.25	40 hours/mo	\$ 762.50
20 hours/mo	549.00	Full Time	2050.00
40 hours/mo	1098.00		

E. DATA TRANSMISSION NETWORKS

Analog or digital data suitably modulated on audio sub-carriers may be transmitted almost everywhere over various transmission media. Among these media are land lines, buried cable, microwave, tropospheric forward scatter, HF radio, and submarine cables.

1. Continental United States

Users in the continental United States are particularly fortunate because they have access to an extensive switched telephone network. Data channels can be set up between any two points at reasonable cost. Telephone companies will furnish the data modems needed for either analog or digital data on a rental basis.

The United States is laced together with broadband microwave systems, aerial cable systems, and buried co-axial cable systems that carry thousands of voice circuits multiplexed together. The capacity of the data circuits that may be set up over this network is not confined to the capacity of one voice channel, but may utilize the bandwidth of a half-group, group, or super group, or indeed the bandwidth required for a television picture.

2. Overseas

An extension of data link services to overseas users is more complex and involves a more detailed examination of available transmission facilities.

Outside of the continental United States there is a comparable network of telephone facilities. Even today, however, submarine cables nearly girdle the globe and satellites are in orbit and undergoing tests; these will vastly increase the channels of communication. Submarine cables are limited in bandwidth. In most cables the voice channels are allotted 3 kHz spacing instead of the 4 kHz spacing common in other carrier systems. The maximum data transmission rates will therefore be reduced. On the other hand, the submarine cable is highly reliable and tends to be less noisy than other circuits. Recent emplacement of cables has proceeded at such a rapid rate that spare circuit capacity remains available.

There are, at present, six submarine cables that link North America with Europe, two that reach the North Coast of South America, one to Alaska, two that cross the Pacific and link New Zealand, Australia, the Philippines and Southeast Asia to each other and to Canada and the United States. Projected cables will loop down both sides of South America, down both sides of Africa, and a global cable system is projected to reach from the U.S. around the tip of Africa and across the Indian Ocean to Australia to complete the circuit. Numerous coastwise loops are planned to tie Asia and many island groups into the network. The map, Figure 6, portrays the present and projected global submarine cable network.

Satellites will eventually make commercial communication services available for use by ground stations in most of the areas of the world. Progress in the planning for and construction of foreign earth stations has been highly encouraging. Earth stations are operating at Goonhilly Downs, England; Pleumeur-Bodou, France; Raising, West Germany; Fucino, Italy; Takahagi, Japan; and Mill Village, Nova Scotia. Stations are under construction in Spain, by the United Kingdom on Ascension Island, by Spain on the Grand Canary Island, and by Australia at Carnarvon. Still other stations are being planned in Thailand, the Philippines, India, Hong Kong, a second in Australia and a second antenna at Takahagi, Japan. At least three stations are being considered in Africa and four in Latin America.

Comsat (Communications Satellite Corp.) is constructing earth stations in Brewster Flat, Washington, and Paumotu, Oahu, Hawaii, in addition to its station at Andover, Maine. It is also planned to build stations in the Southeast and Southwest regions of the U.S. and in the Virgin Islands. The map, Figure 7, illustrates the anticipated coverage of the Pacific and Atlantic communication satellites. By the end of 1968, as many as 30 earth stations may be in operation around the world to work with the global satellite system planned for that time. Comsat recently awarded a contract, for construction of six satellites for the 1968 system, each with a capacity of at least 1200 two-way telephone circuits or four television channels. Also Comsat is developing specifications for a high-capacity multi-purpose satellite, capable of perhaps 6,000 to 20,000 two-way telephone circuits, 12 to 20 television channels or perhaps a dozen circuits for aeronautical communications between aircraft and ground stations.

World-wide high speed data transmission systems have already been implemented for NASA mission support. The Apollo and Gemini man-in-space programs have been able to centralize control at Houston, Texas due to the availability of rapid data exchange on a worldwide basis. The prospects are bright for a tremendous increase in global data exchange capability.

In addition armed services have implemented extensive worldwide communications systems using combinations of all the available media. These systems are generally available only for military-connected activities.

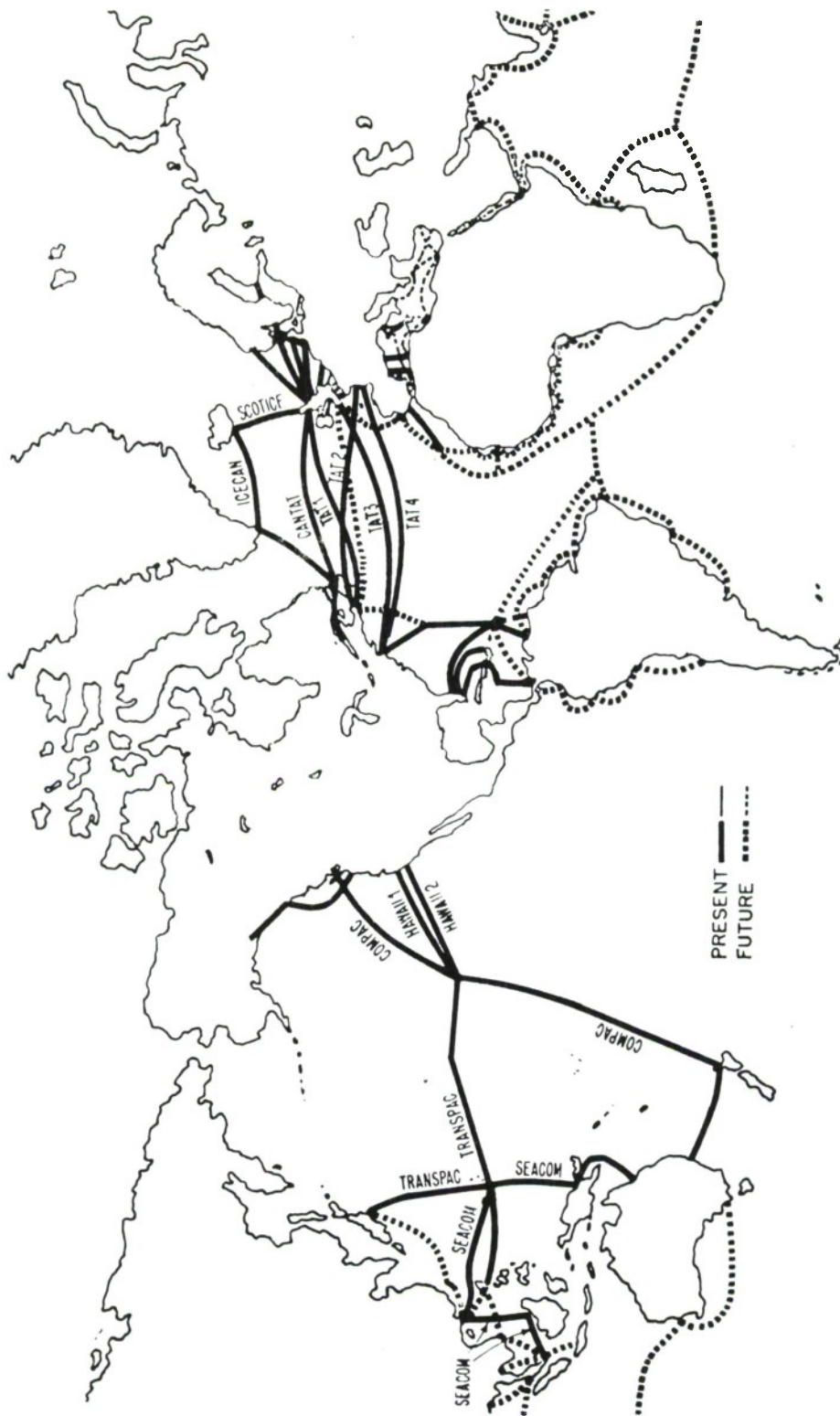


Figure 6. Submarine Cable Network

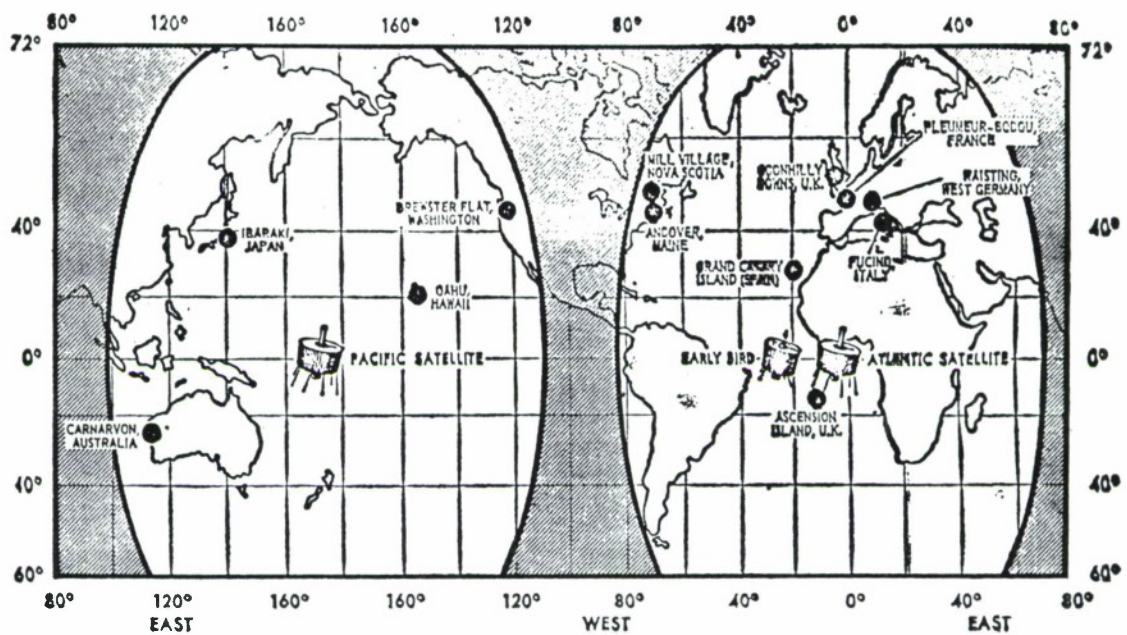


Figure 7. Communications Satellite Stations

SECTION III

SEISMOLOGICAL COMMUNITY DATA REQUIREMENTS

A. DATA REQUIREMENTS SURVEY PROCEDURE

In order to define system constraints for possible data communications between Montana LASA and the seismological community, a sampling of researchers was conducted. The survey was generally restricted to seismologists in the university community who are active in research. No attempt was made to obtain the opinions of all seismologists. Rather, samplings were taken with conscious effort to include a spectrum of investigators ranging from those heavily involved in digital processing to those making relatively infrequent use of primarily analog data. Discussions with the seismologists took place at the western meeting of the American Geophysical Union at Los Angeles during September, 1966 and at the eastern section meeting of the Seismological Society of America at Ottawa, Canada in October, 1966.

The discussion topics were concerned with the general problem of data storage at the Montana site, the practical problems of storage of the digital tapes, the consequent necessity for seismologists to make some decision as to what data should be saved, the problems of getting data to them from Montana, and the possibility of a direct data link. Information was elicited as to their interest in LASA data (including bulletins sent weekly and daily by telctype), their needs for, and interest in, receiving LASA data in analog or digital form, quantities of data visualized, and a possible minimum period of time needed to obtain information about an event before deciding whether the LASA data of that event is of sufficient interest to make storage or transmission of it desirable. The general approach in conducting this survey was to maintain an informal, discussion-type style, specifically avoiding a questionnaire-type approach.

B. INTEREST IN LASA DATA

At the present time it is apparent that many seismologists do not feel any close association with the Montana large aperture array. They are, however, aware of its unique capabilities; many have given some thought to the type of research problems they desire to investigate when LASA data are available to them. A representative sample of the type of studies that might be anticipated includes:

(a) $dT/d\Delta$ of P and PKP waves - Apparent surface velocities of the P and PKP waves, as measured across the LASA, provide a sensitive means of determining the velocity structure in the mantle and core because they are better able to determine the existence of regions of rapid or discontinuous velocity changes than the conventional travel-time and surface wave dispersion methods. Other existing arrays are inadequate for such studies because their small dimensions do not permit the needed accuracy in apparent velocity determinations, i.e., 0.01 km/sec.

PKP studies would use data for earthquakes at distances of 110° to 130° (Tonga and Kermadec Trench, New Guinea, Celebes, and Himalayas), and thus provide information on the velocity structure of the outer core and the transition region from the outer to the inner core.

(b) Regional studies of velocity variation - There are a number of seismically active regions (Alaska, Queen Charlotte Islands, California-Nevada, Lower California, Central America, Caribbean, Buffin Bay) which are about 2000 to 4000 kilometers from LASA and which cover the azimuth range of 30° to 320° . Thus, LASA is ideally located to provide information about regional velocity changes in the upper mantle, as can be obtained from surface wave dispersion and body wave $dT/d\Delta$ studies.

(c) Signal enhancement - LASA, with its large number of detectors and relatively uniform surface geology, is especially well-suited for the enhancement of seismic signals that are indistinguishable at conventional stations because of their relatively small amplitude compared to that of other waves arriving by other paths at about the same time. Examples include second and later P wave arrivals when the travel-time wave is multi-branched, and PKJKP (if it exists).

(d) Regional seismicity studies - LASA can contribute to seismicity studies of seismically active regions that are geographically remote, and thus have insufficient nearby stations to record the smaller magnitude earthquakes. LASA has this capability because it can detect and locate earthquakes of less magnitude than a conventional seismograph station by signal to noise improvement.

The above examples do not represent an exhaustive list, but show some of the unique characteristics of LASA for providing seismological data that are needed for a better knowledge of the structure of the earth's interior, and that research seismologists have a strong interest in using such data. It should be noted that the research problems which the seismologists propose to study often would require the data from all 525 short period instruments, as well as the data from the long period three-component sets at the 21 stations; otherwise the full potentialities of LASA cannot be realized.

C. SURVEY RESULTS

Although a large variety of opinions were expressed in discussion with seismologists, the results of the survey may be summarized as follows:

(a) There is no all-inclusive solution to satisfy all seismologists except to save actual event data at some depository. Most seismologists want the data to be stored at some centralized location where it will be accessible to all, rather than having responsibility for storing it themselves. The suggestion was made that a university-cooperative data center be established.

(b) There is a strong feeling that many of the most important problems will be generated in the future, so that the "average" seismologist would like to see all LASA data stored indefinitely. He generally cannot project research problems that would require the use of these data more than one year in the future. He strongly believes that new problems of research will be generated as seismologists begin to use LASA data, and these problems and the kind of data which they require cannot be anticipated; the minimum acceptable storage time for LASA data is on the order of 1 a year on this basis.

(c) Most of the seismologists queried would be willing to prepare a list of preselected events (based on magnitude, geographical location, etc.) for at least temporary storage for further review.

(d) Many of those queried would be satisfied with a weekly bulletin of LASA events; a few would anticipate the desirability of a teletype system.

(e) An on-line access is desired by a few users. In general, at least several analog traces would be desired for monitoring. The potential users do not want continuous on-line data transmission, but would rather use the monitor to decide when to make a request for data. This requires a built-in time delay for the interval between scanning the monitor and getting the digital transmission; the general view is that this delay should be at least two days. However, if they have the analog trace there is no real necessity to have the digital data on-line; it could just as well come by mail.

(f) There appear to be relatively few universities that are sufficiently involved in digital techniques to have a major requirement at this time for on-line LASA data in digital form. Even for those users who would want to use digital data, a more satisfactory arrangement appears to be to have some analog data along with bulletin information to permit decisions within a few days as to what data would be wanted in detail and in what form. These analog signals on-line, together with back-up facilities for request of digital or analog tapes to be sent by mail, would appear to be most suitable. There would then be no need for on-line transmission of many channels of digital data.

(g) It is premature to attempt to evaluate such things as precision, data rates, extensive terminal equipments, etc., since few individual users or possible subscribers have, at present, given detailed thought to extensive use of LASA data.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

A. TELETYPE STATION BULLETIN

In order to satisfy the expressed needs of part of the seismological community, it is recommended that a teletype station bulletin be made generally available.

A seismological station bulletin is the standard medium for exchange of basic information concerning seismic events as detected at individual seismograph stations. It serves not only to alert interested investigators to detailed aspects received by other stations, but also as a reference source for selecting individual seismic records for research and further analysis.

Such a station bulletin is now being generated daily at the Montana Large Aperture Seismic Array and is distributed by mail to interested investigators. A few recipients get the bulletin by teletype.

Since there are some seismological centers with an expressed interest in teletype bulletins, it is recommended that arrangements be made to supply the bulletin in this way to those who desire it. The mechanics and cost of providing such service have been discussed. In order to relieve the LASA Data Center of the additional burden of dialing and transmitting a bulletin to possibly many additional users, it appears most reasonable to provide for an additional TWX machine with a separate number at the Data Center which would automatically answer and transmit from a punched paper tape loop, the bulletins for the preceding day, or 24-hour interval, for example.

Initial equipment installation costs to provide such service would be about \$75. The monthly equipment and line-service cost would be less than \$75, each subscriber would have to have his own TWX machine at a similar expense; the subscriber would bear the actual time charges incurred in dialing the Montana site and receiving the bulletin on his machine.

This would provide, then, at minimal additional expenditure the TWX station bulletin on a daily basis to interested members of the scientific community, at their option.

B. DATA TRANSMISSION FACILITY

Although there appears to be a very limited body of researchers who, at present, want an on-line link to Montana LASA data, it is recommended that consideration be given to providing the capability to transmit such data from the Billings site.

The initial expenditure for equipment necessary to provide a data transmission facility is relatively low. It is felt that, if the on-line access were available, more seismological researchers would be inclined to use it than have expressed such a desire during the study. This may be especially true as seismologists become more impressed with the fact that it is not possible under the present mode of operation to maintain an extensive library of LASA seismometer data for future research purposes. It appears reasonable to assume that there is a sufficiently large group of potential users to warrant serious consideration of the transmission facility.

It does not seem feasible to provide such on-line access simultaneously from a large number of seismic sensors. It is envisioned that the general utility of the on-line link would be for general monitoring purposes as well as specific investigations utilizing selected seismometers. A data link could be particularly useful in providing a relatively rapid means for individual investigators to decide whether particular data is of sufficient interest to merit additional study and hence, form the basis for decisions as to whether to request additional magnetic tape data within the time it remains available in temporary storage at the LASA Data Center.

Costs of various data link systems have already been presented in an earlier section. The equipment investment for providing a data transmission facility at the LASA Data Center is on the order of \$2500 for terminal equipment for four channels of analog or six channels of digital data to be available to any number of potential subscribers. Installation costs are negligible; monthly equipment rentals are about \$25 for analog and \$300 for digital. Expenditures would, of course, be proportionately greater for more channels. Additional costs are involved in terminal buffering equipment. These costs cannot be definitized without a more detailed system analysis.

Essentially no buffering equipment is required for the LASA system for analog transmission. But for digital transmission, these equipments are not commercially available on an off-the-shelf basis; hence, design and assembly for any specific installation is required. It is roughly estimated that such equipment could require expenditures on the order of \$25,000. Thus, for an estimated expenditure on the order of \$2500 for the analog or \$25,000 for the digital, a data transmission facility could be provided at the Montana site.

C. ADDITIONAL EFFORT

1. Transmission System Definition

The system and cost estimates given are based on taking the data with bit rates, precision, etc. as they appear at terminals in the LASA Data Center. A complete system definition is recommended prior to undertaking any specific transmission facility installation. The major requirement is analysis, definition, and specifications of the buffering equipment required between the terminal equipment and the LASA output for digital data handling.

Some preliminary thoughts have been given to these matters. For example, if the seismic data disseminated from the LASA Data Center is to be used for analog displays, and not for elaborate computational routines as practiced at the LDC itself, 14 bit samples are excessively precise. Ten bits, which yield 0.1% accuracy are ample; this is already beyond the resolving power of ordinary small-scale recordings. Furthermore, little is to be gained by having a parity bit. Reducing the precision of the samples and omitting the parity bit would reduce the data rate per seismic channel and, consequently, increase the number of channels that may be transmitted within the data rate limitation of one voice channel. Having a larger number of reduced precision channels would appear to be a more favorable employment of the available data rate. The trade-offs for a maximum Data Set capacity of 2000 bits per second are summarized below:

Number of Seismic Channels	Number of Bits per Sample	Accuracy Per Cent	Remarks
6	15	0.00625	includes parity
7	14	0.00625	sync marginal
8	12	0.025	
9	10	0.1	
10	9	0.2	
12	8	0.4	
13	7	0.8	
14	7	0.8	sync marginal
16	6	1.6	
19	5	3.2	

(The notation "sync marginal" means that only 40 bits per second are available to transmit the time-of-day and framing information. This is adequate but framing will be slower than if a longer sync pattern is available.)

Some of the additional technical details that must be considered in defining an adequate transmission facility are discussed in appendices to this report. Details are presented in Appendix I of floating point transmission, which provides a means of preserving dynamic range while simultaneously reducing the number of bits to be transmitted. In Appendix II, quantizing noise is examined which determines the quality of the resulting recording when reducing the number of bits. Specific consideration of the preparation of data for transmission is given in Appendix III.

2. Data Storage Study

The key problem precipitating the present study is the tremendous quantity of data which is assembled on a continuous basis at Montana LASA. It does not appear feasible to maintain any extensive facility for long-term storage of this data for possible later study by the seismological community. Since technological

advances in techniques for storage of large amounts of data are being made, it is recommended that the data storage problem be investigated with the hope that a solution may be reached for maintaining more of the output of the Large Aperture Seismic Array.

APPENDIX I

FLOATING POINT TRANSMISSION

Dropping bits from the data samples provides a ready means of reducing the data rate so that a larger number of channels may be transmitted over a bandwidth limited transmission facility. However, the dynamic range of the data that can be transmitted is curtailed. The dynamic range is defined as the ratio of full scale to the least step. In a 7 bit code, for example, the step size is $1/128$ of the maximum peak to peak amplitude. In the 14 bit code of the LASA data, the step size is only $1/16,384$ of the peak to peak full scale range. The dynamic range of the 14 bit code is $2^7 = 128$ times the dynamic range of the 7 bit code.

A floating point arithmetical code offers the possibility of preserving the dynamic range of the data while at the same time reducing the number of bits that must be transmitted. In floating point encoding, the amplitude to be transmitted is expressed as a magnitude multiplied by a power of 2. The exponent of 2 and the magnitude are transmitted as two groups of bits in the data word. As an example, consider a 14 bit code, the 14 bits can express any magnitude from 1 to 16,383 units. In floating point form we can express numbers covering the range from 1 to 16,256 by a 7 bit magnitude multiplied by 2 to an exponent between 0 and 7. The exponent expressed as a binary number requires 3 bits. The total group required is 10 bits in place of the original 14. The price of this reduction is a loss of precision in the large amplitudes; but this is where the loss is not as important. Any amplitude up to 127 is expressed as $2^0 = 1$ times the magnitude. From 128 up to 254 the amplitude is expressed as $2^1 = 2$ times a number between 1 and 127. In other words, the step size has gone up from 1 to 2. In the next range the multiplier is $2^2 = 4$ and the step size has doubled again. At the top end the step size has increased to $128 = 2^7$. The encoding system is quasilogarithmic. The step size over the entire dynamic range tends to be a constant percentage of the sample amplitude instead of being a constant percentage of full scale. The resolution is nearly constant regardless of the sample amplitude. The percentage accuracy in terms of the sample amplitude tends to be fixed. This is often a highly desirable situation.

Various trade-offs can be made between the number of bits assigned to the exponent, the magnitude and the total required. Some of these are tabulated below for the sign plus 13 bit coding of the LASA seismic data:

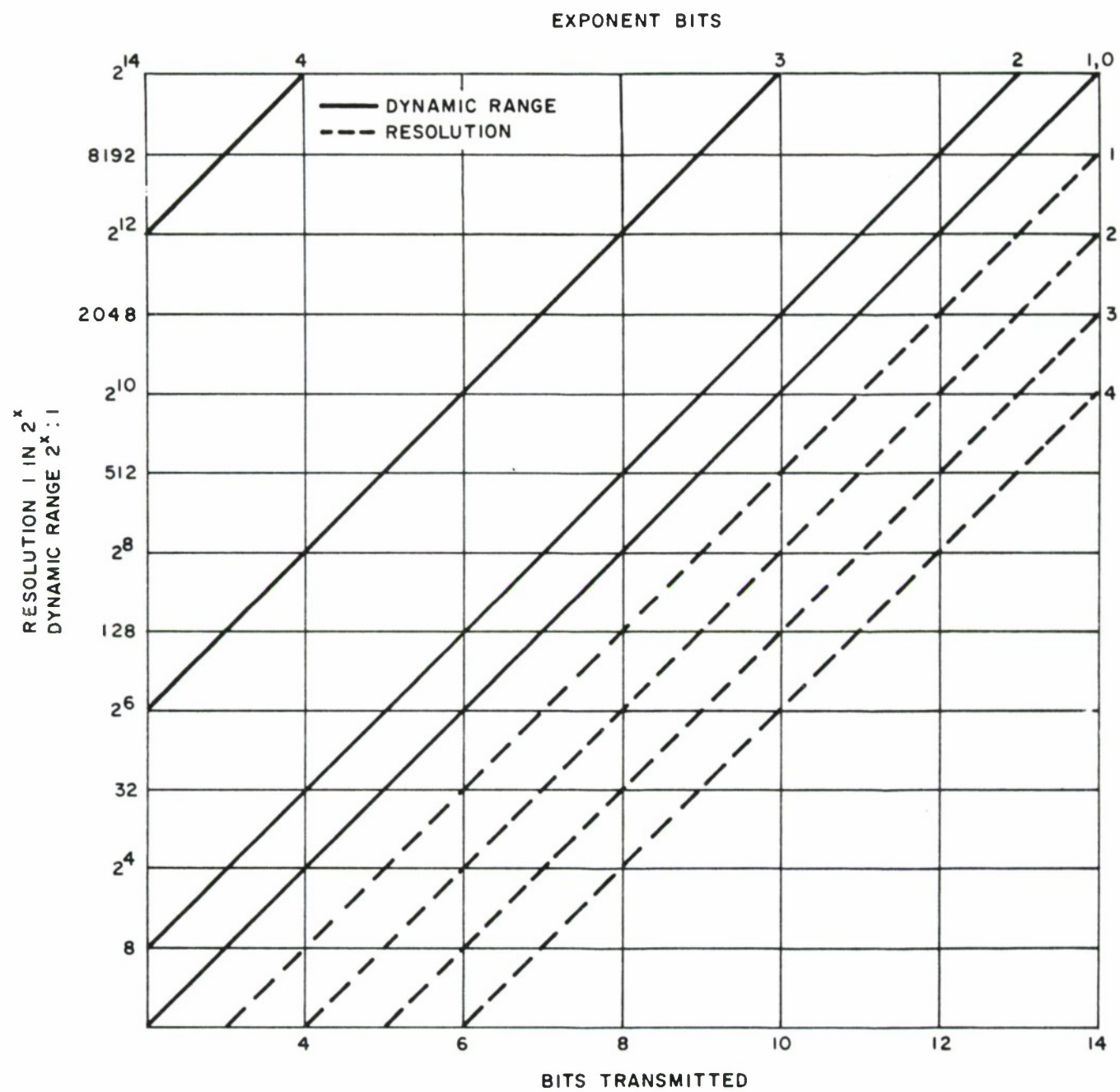


Figure 8. Floating Point Transmission Trade-Off Curves

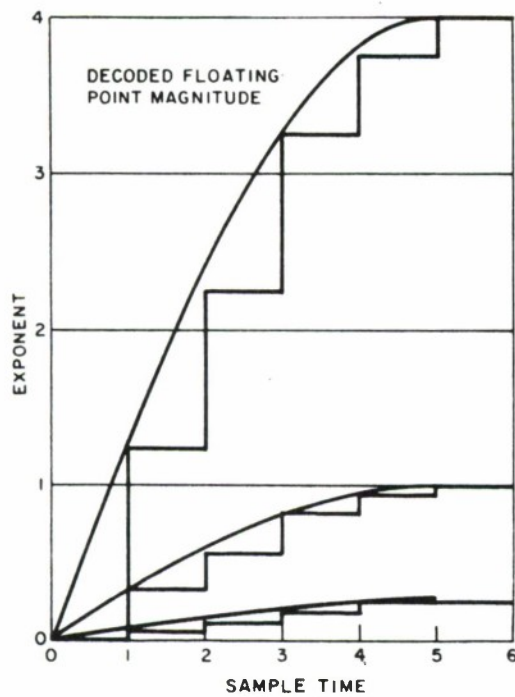
Exponent Bits	Magnitude Bits	Total Bits	Resolution	Dynamic Numerical	Range db
0	13	14	1:16,383	16,383:1	84
2	10	13	1:2,046	16,368:1	84
	9	12	1:1023	8,176:1	78
	8	11	1:511	4,080:1	72
	7	10	1:255	2,032:1	66
	6	9	1:127	1,008:1	60
	5	8	1:63	496:1	54
3	9	13	1:1023	> 16,383:1	
	8	12	1:511	> 16,383:1	
	7	11	1:255	> 16,383:1	
	6	10	1:127	16,383:1	84
	5	9	1:63	7,936:1	78
	4	8	1:31	3,840:1	72

The trade-offs are shown in Figure 8. Dynamic range (solid lines) and the resolution (dashed lines) are shown as a function of the number of bits transmitted with the number of bits assigned to the exponent as a parameter. The case of zero exponent bits is the straight binary code. For this case, the dynamic range and resolution curves coincide. The ordinate should be interpreted as one part in 2^x for resolution and $2^x:1$ for dynamic range. For example, if 9 bits are transmitted, and two of these are assigned to the exponent the dynamic range is 2^{10} or 1024:1 and the resolution is 1 in 128 (2^7) or somewhat better than 1% accuracy.

It is interesting to note that for 1 or 2 bits in the exponent, resolution is lost more rapidly than dynamic range is gained. For 3 or more digits in the exponent, the factor by which the dynamic range is increased is greater than the factor by which the resolution is decreased. With 3 bits in the exponent, and 10 total bits transmitted, the entire dynamic range of the original data, 2^{14} , can be covered with a resolution of 1 in 27.

For recording purposes, the resolution need not be very great, because the resolution given is in terms of the sample amplitude. For an amplitude between the full peak to peak pen excursion and half that amount, the amplitude sample is specified to 1 part in 128 or better than 1%. If the sample amplitude is between one-half and one-quarter of the chart range, the amplitude is specified to 1 part in 128 of half the full-scale amplitude or 1 part in 256 of the full-scale. Similarly, amplitudes less than one-fourth-full scale are given in terms of parts in 512 of full-scale. The graininess of the presentation will only be apparent at very large amplitudes.

A sample of the sine wave assumed transmitted using a floating point code with a resolution of a sign bit plus 4 magnitude bits is calculated below and plotted in Figure 9.



FIRST QUARTER CYCLE
OF SINE WAVE OF VARIOUS
AMPLITUDES RECONSTRUCTED
FROM FLOATING POINT CODING
AT 5 BIT RESOLUTION

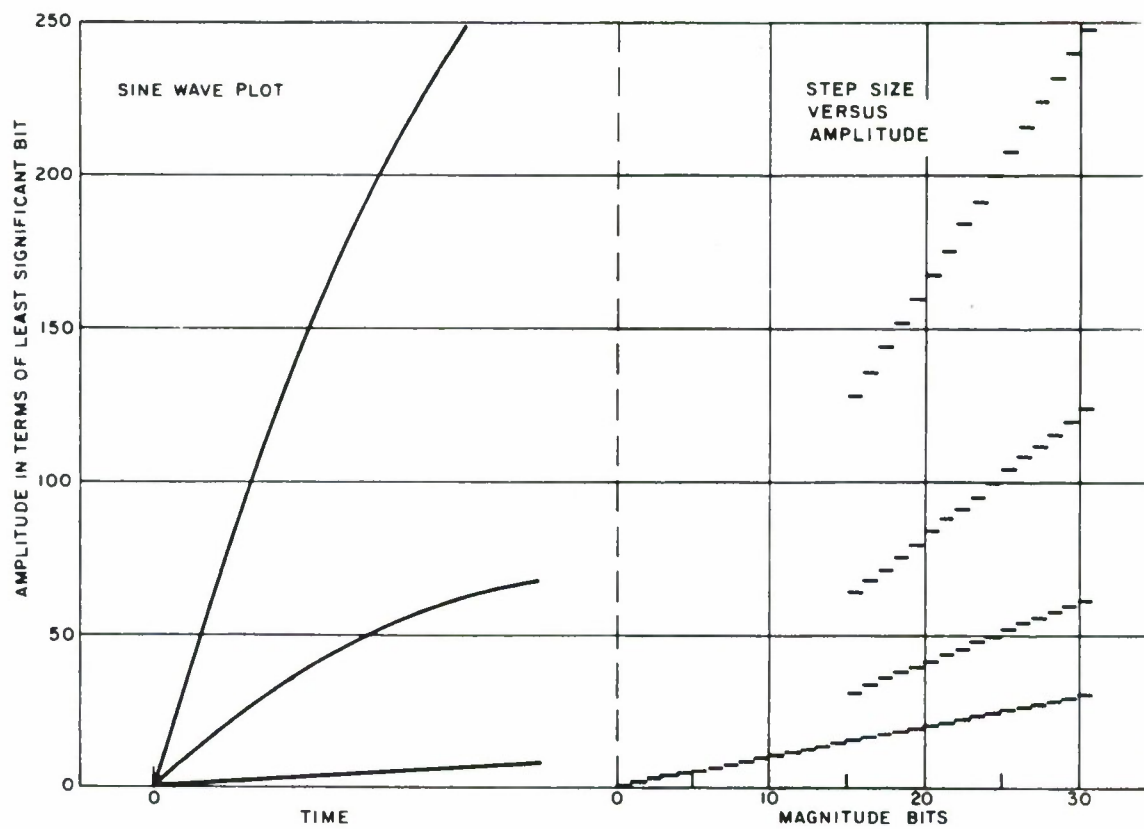


Figure 9. Floating Point Code Sine Wave Transmission

Signal 1 CPS at 4 units amplitude

Resolution sign + 4 bits (1:32)

<u>wt</u>	<u>Sample</u>	<u>4 sin wt</u>	<u>Exponent</u>	<u>Magnitude</u>	<u>Product</u>
0	0	0	0	0	0
18°	1	1.24	2	0.625	1.25
36°	2	2.35	4	.5875	2.25
54°	3	3.24	4	.81	3.25
72°	4	3.81	4	.9525	3.75
90°	5	4	8	.5	4.00

AT 1 UNIT AMPLITUDE

0	0	0	0	0
1	.308	1	.3125	0.3125
2	.5875	1	.5625	0.5625
3	.81	1	.8125	0.8125
4	.953	1	.9375	0.9375
5	1.0	2	.5	1

AT 1/4 UNIT AMPLITUDE

0	0	1/4	0	0
1	.077	1/2	.154	.0625
2	.147	1	.125	.125
3	.205	1	.1875	.1875
4	.238	1	.25	.25
5	.25	1	.25	.25

The decrease in step size for small amplitudes is graphically demonstrated in the plot. The stepped curve used to emphasize that the graininess in the graph will be smoothed by a low pass filter in actual practice. The rather coarse illustration would be satisfactory in many cases and certainly one additional magnitude bit would be sufficient for all but the most exacting applications.

The curve also suggests that little is to be gained by having more than 2 exponent bits. With two exponent bits, the multiplier takes on the values 1, 2, 4 and 8, hence the smallest peak amplitude that is reproduced with the full resolution range of the magnitude bits is 1/8 of the largest amplitude that can be handled. Or, to put it another way, the smallest step with sign plus 4 magnitude bits is 1/8 x 32 or 1/256th of the maximum peak to peak range. For a chart recording

confined to a 2 in. wide chart, the smallest step will be 0.008" which is about at the limit of visibility. It can be concluded that a coding with 7 total transmitted bits might be adequate.

To transmit a 7 bit code made up as 2 exponent bits, a sign bit and four magnitude bits requires:

- (1) Conversion of two's complement coding to binary.
- (2) Conversion of binary to floating point form.
- (3) Conversion of received floating point form to binary.
- (4) Conversion of binary to two's complement for decoder.

Considering that the transmission of an 8 bit code (cost one more bit) as the unaltered seismic code will yield the same dynamic range (see graph) and improved resolution, one questions whether saving one bit is worth the trouble. The increase in the number of channels that may be transmitted over a 2000 band circuit must be evaluated. The table below summarizes the number of channels that may be transmitted over a 2000 band binary channel as a function of the number of bits per sample. An allowance has been made to include synchronizing information and a time read out once per frame.

Code Bits per Channel Sample	Number of Channels Possible
15	6
14	7
13	7
12	8
11	9 2-second frame*
10	9
9	11 2-second frame
8	12
7	14
6	16
5	19
4	24

* One-second frames unless otherwise noted.

The payoff for reducing the number of bits per channel sample from 8 to 7 is seen from the table to be the ability to send 14 channels of seismic data over one voice channel in place of only 12.

APPENDIX II

QUANTIZING NOISE

The limiting dynamic range in any transmission system is the dynamic range of the original data itself. This limit for LASA is set by the dynamic range of the well head amplifier. It is assumed that the seismometer voltage due to the irreducible ground unrest at the seismometer location is greater than the thermal noise voltages introduced by the well head amplifier.

The published characteristics of the amplifier give:

$$\begin{aligned}\text{Voltage Gain} &= 10^4 \\ \text{Maximum Output} &= 14\text{V peak to peak} \\ \text{Noisc} &= \text{less than } 0.05 \text{ microvolts rms referred to input.}\end{aligned}$$

The maximum signal for a sine waveform reduced to rms and referred to the input is:

$$\begin{aligned}E_{\text{max}} &= 14 \times 10^{-4} / 2 \sqrt{2} \text{ volts} \\ &= 493 \text{ microvolts}\end{aligned}$$

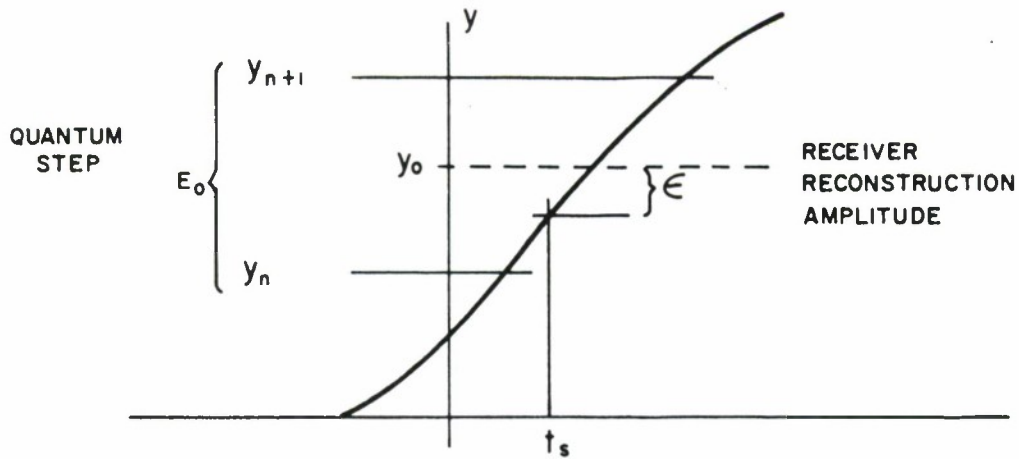
Hence the dynamic range of the amplifier is:

$$493/0.05 = 9860 \text{ or } 80 \text{ db}$$

expressed as rms signal to rms noise.

The conversion of a continuous analog signal to the discontinuous (discrete) levels of a digital encoding is a source of distortion. It may be regarded as an added noise component called quantizing noise. This noise in the encoded rendition of the signal arises because the digital signal cannot specify the amplitude of the analog signal "exactly" but only to the nearest quantum step. It is desirable to use a sufficient number of steps (and hence small enough steps) so that the contribution of the quantizing noise to the total noise is small.

One may calculate the encoder-decoder quantizing noise, or rms error. Consider a portion of a sampled analog signal and the action of the encoder and decoder on that signal as diagrammed in the figure below:



The signal, at the sampling time, t_s , may lie anywhere between two encoder decision levels y_n and y_{n+1} separated by a quantum step, E_o . The receiver reconstructs the sample amplitude as y_o , the average of y_n and y_{n+1} . The error in the reconstructed amplitude is:

$$\epsilon = y - y_o.$$

The error varies from $-E_o/2$ to $+E_o/2$ and averages zero, provided that all signal amplitudes, y , are equally likely. This condition is usually satisfied in practice as the quantum step is usually small.

The average squared error is:

$$\begin{aligned} \overline{\epsilon^2} &= \frac{1}{E_o} \int_{y_n}^{y_{n+1}} (y - y_o)^2 dy \\ &= \frac{1}{E_o} \left[\frac{(y - y_o)^3}{3} \right]_{y_n}^{y_{n+1}} \\ &= \frac{1}{3 E_o} \left[(y_{n+1} - y_o)^3 - (y_n - y_o)^3 \right] \end{aligned}$$

Substitute

$$\begin{aligned} E_o/2 &= (y_{n+1} - y_o) \text{ and} \\ -E_o/2 &= (y_n - y_o) \end{aligned}$$

and we obtain:

$$\begin{aligned} \overline{\epsilon^2} &= (1/3 E_o) (E_o^3/8 - (-E_o^3/8)) \\ &= E_o^2/12 \end{aligned}$$

Whence the root mean square quantizing noise is:

$$\sqrt{\epsilon^2} = E_o/2 \sqrt{3} = N_q$$

To see what this means in terms of signal distortion, this must be related to the signal amplitude. A linear encoder of n bits will have $2^n - 1$ quantum steps each of size, E_o . The peak to peak signal amplitude that will just exercise the full range of the encoder will be $E_o (2^n - 1)$. This is equal to $2\sqrt{2} S$ where S is the rms signal amplitude. The signal to quantizing noise power ratio is therefore:

$$\begin{aligned} S^2/N_q^2 &= \frac{E_o^2 (2^n - 1)^2 / 8}{E_o^2 / 12} \\ &= (3/2) (2^n - 1)^2 \\ &\approx (3/2) 2^{2n} \end{aligned}$$

The approximation holds since 2^n is very much greater than 1. The signal to noise ratio may be expressed in db by the following formula.

$$S^2/N_q^2 = 6N + 1.75 \text{ db}$$

This formula permits a quick estimate of the signal to quantizing noise ratio as a function of the number of bits in the code and leads to the following tabulation:

SIGNAL TO QUANTIZING NOISE

<u>Number of Code Bits</u>	<u>S^2/N^2 db</u>
3	20
4	26
5	32
6	38
7	44
8	50
9	56
10	62
11	68
12	74
13	80
14	88

The quantizing noise decreases 6 db for each bit added to the code. The values in the table have been rounded upward to the next higher integral number of decibels. This is justifiable, in practice, since the formula gives somewhat

pessimistic values. It may be shown that the quantizing noise has a relatively flat frequency spectrum and that the formula derived includes all of the noise contributions up to one-half of the sampling frequency. Since in practice the sampling frequency is chosen higher than twice the highest frequency in the data and the reconstruction is correspondingly low pass filtered, the quantizing noise is somewhat less than indicated above. As an example, a 3100 Hz voice channel PCM encoded at an 8 kHz rate, leads to a constant of 3 db in the above formula instead of 1.75 db. The seismic data under consideration drops off sharply above 5 Hz while the sampling rate is 20 Hz, hence even more reduction in quantizing noise should be realized than in the voice channel case.

It may be seen that the quantizing noise due to the 14 bit encoder is at least 8 db below the dynamic range of the signal into the encoder; hence, little impairment of the seismic signal results from the encoding step. The analog to digital conversion that takes place at the subarray does not degrade the data.

If the seismic data is transmitted by reducing the number of bits, the quality of the resulting recording will be determined by the quantizing noise. An extensive table follows showing code combinations possible and their capabilities for various numbers of transmitted bits per sample. We can reduce the possibilities down to a more manageable set by the following arguments.

If we are to have more than 7 channels of seismic data, the number of transmitted bits in the code must be 12 or less. With 12 total bits the 3 + 9 coding decreases the resolution (increases the quantizing noise) with no real gain in dynamic range over the 2 + 10 coding which at 78 db dynamic range covers the entire range of the seismic signal.

A 10 total bit code offers no advantage over 11 since the number of channels available is not increased.

For 7 or fewer bits in the coding quantizing noise is coming up and dynamic range is going down, hence unless there is some reason why a very large number of low quality channels offers some unforeseen benefit, we can terminate the table at 8 bits.

All the codings with 4 bits in the exponent may be eliminated. These codes offer 16 different multipliers for the magnitude and these range from 2^0 to 2^{15} . The potential dynamic range of this coding is so much larger than the dynamic range of the data, that the potential of the coding is wasted. Resolution suffers for no real gain.

Transmitted Bits	Available Channels	Exponent Bits	Magnitude Bits (includ- ing) sign	RMS Quantizing Noise db	Dynamic Range db
14	7	0	14	-88	84
13	7	0	13	-80	78
12	8	0	12	-74	72
		2	10	-62	78
		3	9	-56	➤84
11	9	0	11	-68	66
		2	9	-56	72
		3	8	-50	➤84
10	9	0	10	-62	60
		2	8	-50	66
		3	7	-44	84
		4	6	-38	➤84
9	11	0	9	-56	54
		2	7	-44	60
		3	6	-38	78
		4	5	-32	➤84
8	12	0	8	-50	48
		2	6	-38	54
		3	5	-32	72
		4	4	-26	➤84
7	14	0	7	-44	42
		2	5	-32	48
		3	4	-26	66
		4	3	-20	➤84
6	16	0	6	-38	36
		2	4	-26	42
		3	3	-20	60
		4	2	-14	➤84
5	19	0	5	-32	30
		2	3	-20	36
		3	2	-14	54
		4	1	- 8	➤84
4	24	0	4	-26	24
		2	2	-14	30
		3	1	- 8	48
		4	0	0	84

The reduced table after striking out the entries discussed is presented below. It is in this reduced table that we must seek a practical compromise.

PRACTICAL CODINGS

Transmitted Bits	Available Channels	Exponent Bits	Magnitude Bits	RMS Quantizing Noise db	Dynamic Range db
12	8	0	12	-74	72
		2	10	-62	78
11	9	0	11	-68	66
		2	9	-56	72
		3	8	-50	84
9	11	0	9	-56	54
		2	7	-44	60
		3	6	-38	78
8	12	0	8	-50	48
		2	6	-38	54
		3	5	-32	72

If rms quantizing noise 32 db below the rms signal is tolerable, eight bits in a 3 + 5 coding is the obvious choice, as it preserves very nearly the entire dynamic range of the original data. If a 38 db signal to noise ratio is deemed necessary, then the 78 db dynamic range of the 3 + 6 coding seems to outweigh the reduction in the number of channels from 12 to 11.

At a signal to quantizing noise demand of 44 db, we have one choice: 9 bits in a 2 + 7 coding and a dynamic range of 60 db which is still good. Any increase over 44 db will cost two channels or a further reduction in dynamic range to 54 db (500:1).

If we are content with 8 channels, superb performance in both noise and dynamic range are offered by the binary coding. The slight gain of the 2 + 10 coding in dynamic range is probably not worth the extra complication. The increase in quantizing noise from - 74 to - 62 is not significant.

APPENDIX III

DATA PREPARATION FOR TRANSMISSION

To consider how parts of the flood of seismic data coming to the LDC or stored on magnetic tape might be selected and converted in speed and format for transmission over a Dataphone link requires some assumptions as to exactly how many seismic channels are to be made available and how they are distributed over the LASA array. Several operations must be performed:

- (1) The seismic word must be selected from the high speed format in which it exists - either on the PLINS output line or on magnetic tape.
- (2) A speed changing buffer must assemble the words to be transmitted, and read them out to the Dataphone.
- (3) Framing information must be added to the data stream to enable the receiver to unscramble the seismic channels.
- (4) The time frame relevant to the data must be identified.

Looking first at the problem of selecting raw data from the PLINS output, we note that the PLINS output consists of 21 serial data streams at 9600 bits per second. Each serial stream contains 25 seismometer outputs and the subarray sum plus other information.

Assume, to make the discussion concrete, that the seismologist will want not more than 6 channels of seismic information, and that he will want (most likely) a channel from each of 6 different subarrays. The selector unit then must be programmable to select the desired seismic word from any specified data stream and store the data words in a buffer. The operation required is very similar to what the digital-to-analog converter console now does. The console can select by programmable switch settings any seismic word from a PLINS data stream and store it for conversion to analog form. The selection unit for the data link must do the same thing with the added feature that it must have access to all 21 PLINS output lines. The timing signals for the selection operation are supplied by the PLINS.

Provision should be made to put the seismic data words dipped out of the fast flowing data stream into an agreed upon order for transmission. No more than six words which then have been predicted, can come from no more than six different subarrays for any one setup. Ordering the data then might be done by having 6 only numbered input jacks for the 6 active PLINS lines and plugging in the lines in the order desired for transmission.

The data are now held in a buffer ready for transmission. Framing information may be added and the information read-out to the Data Set. The output data rate is much slower than the input serial-stream data rate, and the rate will depend on the number of channels being transmitted. Hence auxiliary timing signals must be generated. These may conveniently be obtained by counting down the clock signal from the PLINS.

One more operation needed at the transmitter is to add bits that will frame the data and give the time epoch to which the data are referred. A commonly used and easily implemented framing scheme consists of adding to each frame a signal bit that alternately is given the values 1 and 0. This sequence is quite unlikely in most data. The receiver counts frames modulo 2 and compares the locally generated "data frame" bit with the incoming "data frame" bit. If they agree, the receiver is in frame. Should the receiver get out of frame, the error rate in the comparison will rise abruptly toward an expected value of 50%. This is easily recognized and may be used to initiate a slipping of the receiver with respect to the transmitter until the framing bit is found. Occasional errors in the frame bit comparison are ignored, so that random errors in transmission do not cause the receiver to lose frame.

Frames occur at the sampling rate of 20 per second. Once per second should be ample for a time readout. The TOD (time-of-day) generator at the LASA site is synchronized with the time signals from WWV and generates a time code, day-of-year, hour, minute, and second in binary coded decimal (BCD) format. The nine decimal digits are expressed in binary form with 36 bits. If two bits per data frame are assigned to transmitting the time, there will be 40 bits per "time frame" available for transmitting the time. Thus, besides the 36 bits for the time code which is being updated each seconds tick, there are four bits that may be assigned a fixed coding to mark the start of the time frame. Actually, at start-up, the time will be known in advance at the receiver to the nearest ten minutes even with a poorly synchronized local clock. The time register may be preset in the receiver and a longer code sequence made available for rapid timing framing of the receiver.

The addition of 20 "data frame" bits and 40 "time frame" bits to the data stream increases the required transmission rate by 60 bits per second over that required for the transmission of the data. For various assumed numbers of seismic data channels to be transmitted, the data rates required may be tabulated as below:

DATA RATES REQUIRED

Number of Channels	Bits per Second
1	360
2	660
3	960
4	1260
5	1560
6	1860

All these are within the range of a Dataphone operating over telephone voice channels.

If historical data (stored on magnetic tape) is to be transmitted, the same sequence of operations already outlined will be necessary plus providing a tape reader to read the data and the associated time from the tape. This is a computer operation that could be programmed.

A possible arrangement for the interface equipment between the PLINS and a Dataphone output to the telephone line is suggested in a simplified block diagram, Figure 10. The data on one of the PLINS output lines is shifted through a shift register under the control of clock pulses from the PLINS unit. Simultaneously, a counter, set to select the data word desired, recognizes when the data word has entered the shift register and gates it out in parallel form into a buffer register. From the buffer register, the word is transferred to a read out register, and read out to the multiplexer under the control of a program unit that generates read out and transfer pulses. The multiplexer is indicated in Figure 11. The six data channels to be made available, plus the time code from the TOD generator and synchronizing pulses are gated out to the Dataphone modem under the control of the programmer. The programmer utilizes clock timing from the PLINS unit to generate the various control signals required; and the output data to the line is thus transmitted synchronously with the data input from the LASA array.

The subscriber will need interface equipment to accept the digital data stream from the Data Set, demultiplex the seismic channels, convert to analog form for recording, extract and display the time, and furnish time marks for the analog record. Figure 12 is a block diagram of a possible arrangement. For simplicity, it is assumed that time marks at ten second intervals might be put on the record and a manual entry of the time made on the record. A complete print out of the time at suitable intervals could be arranged, as well as special time marks for the minute and hour.

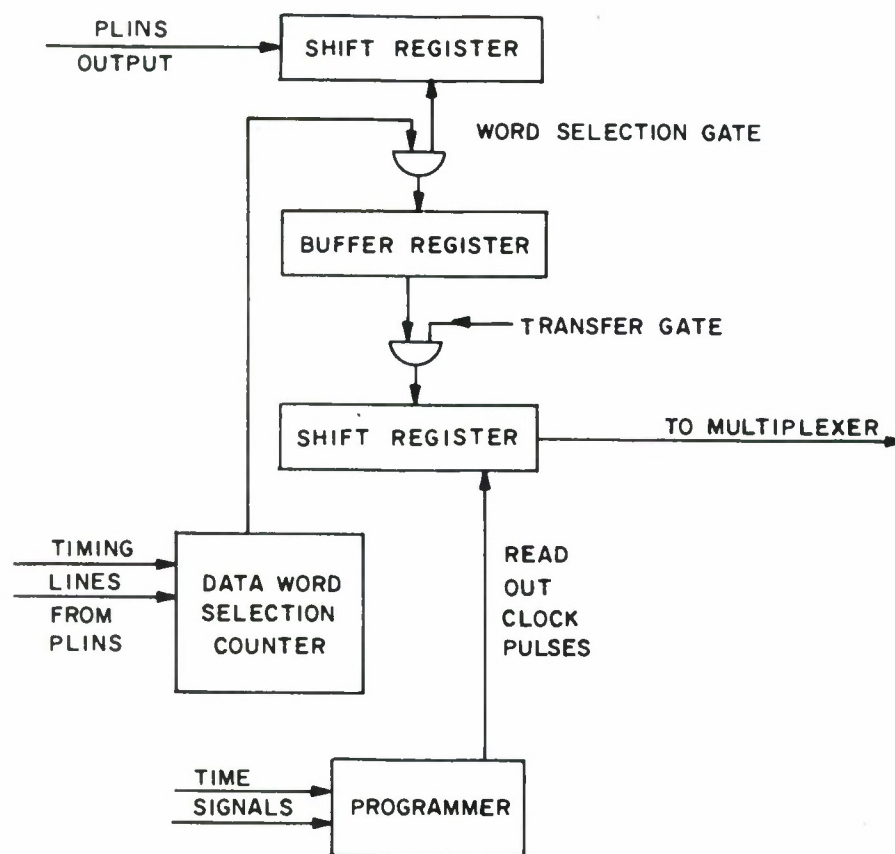


Figure 10. Simplified Block Diagram of One Seismic Channel Selector

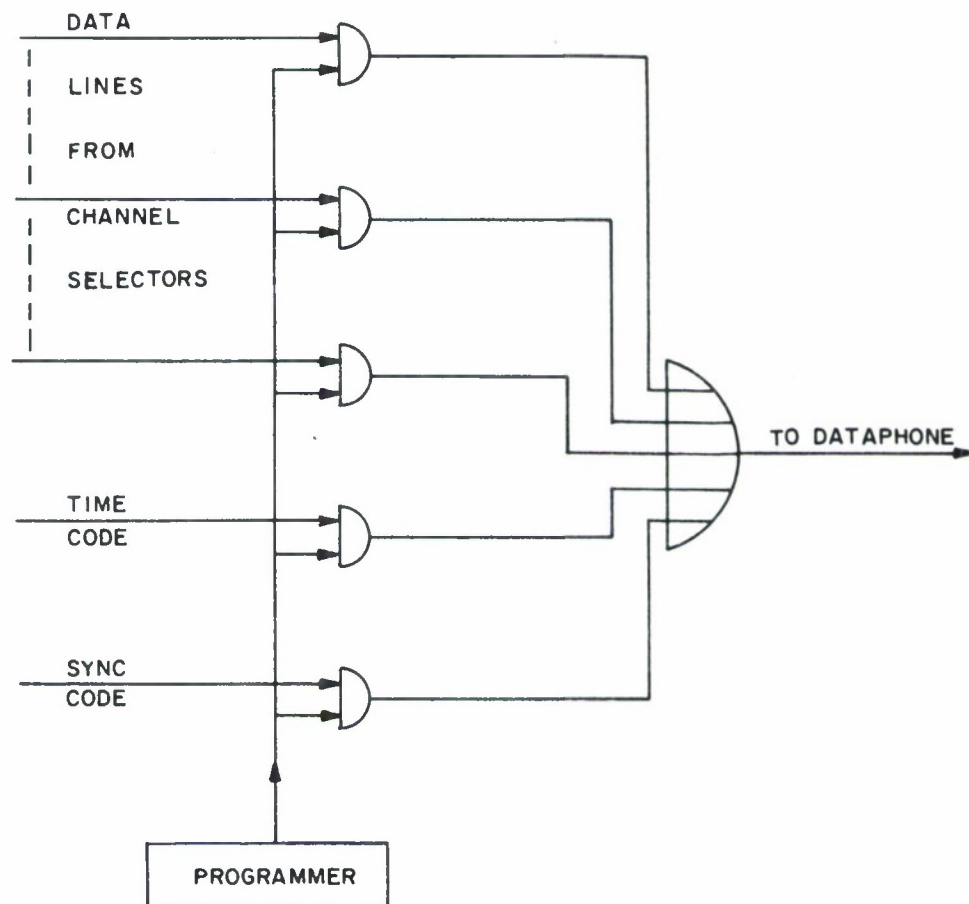


Figure 11. Multiplexer Block Diagram

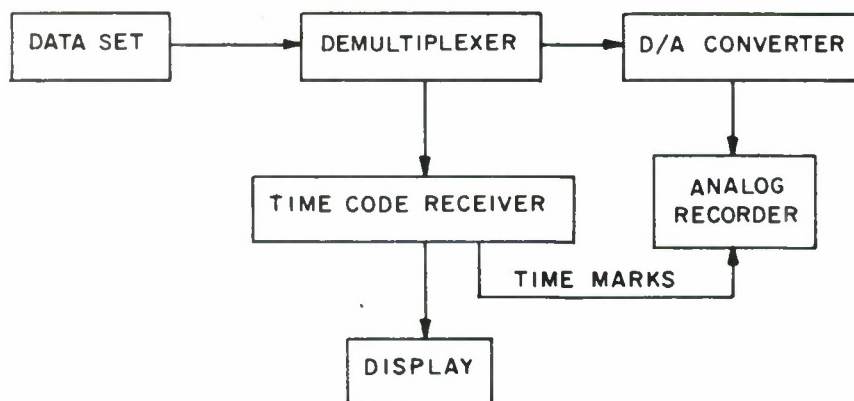


Figure 12. Block Diagram of Receiving Interface Equipment

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
DATA LINK SYSTEMS DATA TRANSMISSION METHODS SEISMIC DATA SEISMIC ARRAY COMMUNICATIONS INFORMATION STORAGE AND RETRIEVAL SEISMOLOGICAL STATIONS						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (paying for) the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) PHILCO-FORD CORPORATION Communications and Electronics Division Blue Bell, Pennsylvania 19422		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
		2b. GROUP N/A	
3 REPORT TITLE STUDY OF LASA DATA LINKS			
4 DESCRIPTIVE NOTES (Type of report and inclusive dates) N/A			
5 AUTHOR(S) (Last name, first name, initial) FINK, DON R. DAHLBERG, ROBERT S.			
6 REPORT DATE March 1967		7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO. AF 19(628)-6141		9a. ORIGINATOR'S REPORT NUMBER(S) ESD-TR-67-221	
b. PROJECT NO.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) N/A	
c.			
d.			
10. AVAILABILITY/LIMITATION NOTICES Distribution of this document is unlimited.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Electronic Systems Division L. G. Hanscom Field Bedford, Massachusetts 01730	
13 ABSTRACT Investigation has been directed toward the utilization of data links for dissemination of seismic information from the Montana Large Aperture Seismic Array (LASA) to the scientific community. Methods and equipments are readily available for providing an essentially on-line seismic data link between Montana LASA and potential data users. Analog and/or digital data transmission appears feasible, and relative requirements and costs per data channel have been detailed. As a result of the study, which included a survey of the seismological community, it is recommended that a teletype station bulletin be made available to those desiring it. It is also recommended that consideration be given to providing a data transmission facility at the Montana LASA Data Center so that data can be transmitted directly to interested users. In addition, recommendation is made to investigate possible alternative approaches for mass storage of seismic data.			