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IRIS/USGS Plans for Upgrading The Global Seismograph Network

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PREFACE

This report has been prepared to provide information to organizations that may be asked to participate in a program to upgrade the global seismographic network. In most cases, the organizations that will be offered new instrumentation by the U.S. Geological Survey currently operate stations in the World-Wide Standardized Seismograph Network (WWSSN) or the Global Digital Seismograph Network (GDSN).

The deployment of the WWSSN in the 1960's and the subsequent equipping of some WWSSN stations with digital equipment and borehole seismometers during the 1970's has been a remarkably successful program that generated the high-quality data needed to fuel an unprecedented period of progress in earthquake and tectonic research. The success of the WWSSN can be attributed to the importance of the data, to the strong commitment by participating organizations to international scientific cooperation, to the dedication and skill of the station operators, and to the resourcefulness of the staff supporting the network. Benefits have been widespread. The community of scientists world-wide has benefitted from unrestricted access to a standardized base of calibrated data, and the participating stations have benefitted from the donation of modern observatory instruments that have been useful for local earthquake studies and for the training of scientists and engineers.

Now, an exciting opportunity has arisen to deploy a new generation of seismograph systems to replace the outdated equipment at many of the WWSSN and GDSN stations. The U.S. Geological Survey (USGS) is cooperating with the Incorporated Research Institutions for Seismology (IRIS) in a program to upgrade the global seismograph network. The equipment development phase is complete and ten of the new broadband seismograph systems have been installed. Deployment of the new equipment is continuing at a rate of about ten stations per year.

As this report will demonstrate, the IRIS broadband seismograph system combines the very latest data acquisition and computer technology to produce seismic data with unprecedented bandwidth and dynamic range. Moreover, the system has been designed so that the high-quality digital data are accessible for local display and analysis. The functional design of the new system, which uses off-the-shelf modules and a standard computer bus, will make it much easier than it has been in the past to modify and upgrade the data acquisition system as improvements in technology become available. With adequate support for the program, the new IRIS seismograph system need never become obsolete.

We want you to be aware of our plans and the possibility that you may be asked to participate in this program. The schedule for upgrading WWSSN and GDSN stations depends on the level of funding earmarked for the program by our National Science Foundation. We hope to deploy at least ten new GSN data systems each year. If you have any questions concerning this program, please contact the Albuquerque Seismological Laboratory, U.S. Geological Survey, Albuquerque, New Mexico 87115-5000, telephone 505-846-5646, facsimile 505-846-6973, email: *chief@asl.cr.usgs.gov.*

This report was revised in February 1992 in order to update information concerning the current program and instrumentation. The map in Figure 1 was revised in June 1993, April 1994, December 1994, and September 1996 to reflect updated siting information. In September 1996 a composite photo of standard and optional components of the IRIS-2 GSN system hardware was added as a separate page between Figures 9 and 10.

BACKGROUND

A major initiative is underway to modernize the global seismograph network by deploying a new generation of broadband seismograph systems and improving data collection and data management facilities. The deployment of the new Global Seismograph Network (GSN) is being led by the Incorporated Research Institutions for Seismology (IRIS), a private consortium of universities and research institutions sponsored and funded by the National Science Foundation (NSF). The goals and objectives of the IRIS program to upgrade the global seismograph network are documented in a report published in 1984, entitled *Science Plan for a New Global Seismographic Network*. As stated in the report, "the goal of a new generation global seismograph network is to produce broadband, wide dynamic range digital data from a global network of at least 100 stations and provide for the timely collection and distribution of these data to a wide variety of users". The authors of the *Science Plan* also used the term 'evolutionary' to characterize the new network, in the sense that it must be upgradable and supportable well into the 21st century.

Planning activities for the new network were organized and executed by an IRIS Standing Committee for the Global Seismographic Network (SCGSN), initially chaired by Professor Adam Dziewonski of Harvard University. The SCGSN, with representation by several member universities, the IRIS Staff, and the U.S. Geological Survey (USGS), developed design goals for the station instrumentation and a data collection center, detailed specifications for the IRIS system, and a siting plan for the network. The results of most of these planning activities are documented in reports. Current plans and organizational responsibilities have been summarized in a *Technical Plan for a New Global Seismographic Network* prepared jointly by IRIS and the USGS.

The GSN is generally understood to comprise all of those global networks that produce and freely exchange continuous high-resolution broadband data. Indeed, other global and regional networks were taken into account during development of an IRIS siting plan. Within the context of this document, however, the term GSN refers only to the IRIS contribution to the GSN.

The establishment of a new global network would be a much more difficult task were it not for the fact that the foundation for the new GSN already exists. The World-Wide Standardized Seismograph Network (WWSSN) and the Global Digital Seismograph Network (GDSN), both supported by the USGS, comprise operating stations and experienced personnel with a long record of excellent cooperation in data acquisition and exchange. In addition, there are maintenance and data collection facilities already in place. Therefore, it is not surprising that most of the new data systems will be used to upgrade stations in the existing networks. Member universities of IRIS will also be deploying new instrumentation, at both existing stations and at some new sites, principally new island sites in sparsely instrumented oceanic regions.

The map presented in Figure 1 shows the current proposed locations for the IRIS GSN stations. The siting plan for the IRIS GSN stations was developed by a Site Selection Subcommittee of the SCGSN, and the results were reported in 1986 as the *5-Year Siting Plan IRIS Contribution to the Global Digital Seismographic Network*. The most important of the criteria used was to obtain a uniform global distribution of stations. Other networks, or plans for other networks, that will freely exchange broadband data were taken into account to reduce duplication of effort. These include the China Digital Seismograph Network (CDSN), the Global Telemetered Seismograph Network (GTSN) being deployed by the USGS in the southern hemisphere, the French GEOSCOPE network, and the Canadian CANDIS network. Several modifications to the siting plan, principally additions, have been made since the original plan was developed. The additions include stations in the Soviet Union that have been installed as the result of an agreement between IRIS and the USSR Academy of Sciences. As indicated in Figure 1, two different types of instrumentation are being deployed in the GSN. The IRIS/USGS (IRIS-2) systems shown in the map are being deployed by the USGS, mostly at WWSSN and GDSN stations. The IRIS/IDA (IRIS-3) systems are being deployed by the University of California at San Diego (UCSD) to upgrade stations in the International Deployment of Accelerometer (IDA) network and at several new sites. The CDSN and GTSN stations shown in Figure 1 are not part of the IRIS network, but they will contribute equivalent data through the IRIS/USGS Data Collection Center. The GTSN systems are based on the IRIS-2 design. The CDSN, which was deployed in 1986 by the China State Seismological Bureau and the USGS, will be reequipped with IRIS-2 instrumentation in the next few years.

Substantial improvements are also being made in the data collection facilities used to review, compile, and distribute data from the GSN. This is an important part of the program because of the enormous increase in the amount of digital data that will be produced by the new network. An IRIS GSN station produces more than five times as much data each day (5 to 10 Mbytes) as a typical GDSN station. Data collected from the new network will be distributed through two data centers, one operated by the USGS National Earthquake Information Center (NEIC) in Golden, Colorado, which will distribute data on compact disks, and one operated by IRIS at the University of Washington in Seattle, Washington, which will distribute customized data sets on a variety of media and by electronic transmission. The data centers will also be exchanging data with other organizations that operate global or regional digital networks. As has been the case with the WWSSN and GDSN data, research scientists will have unrestricted access to the GSN data.

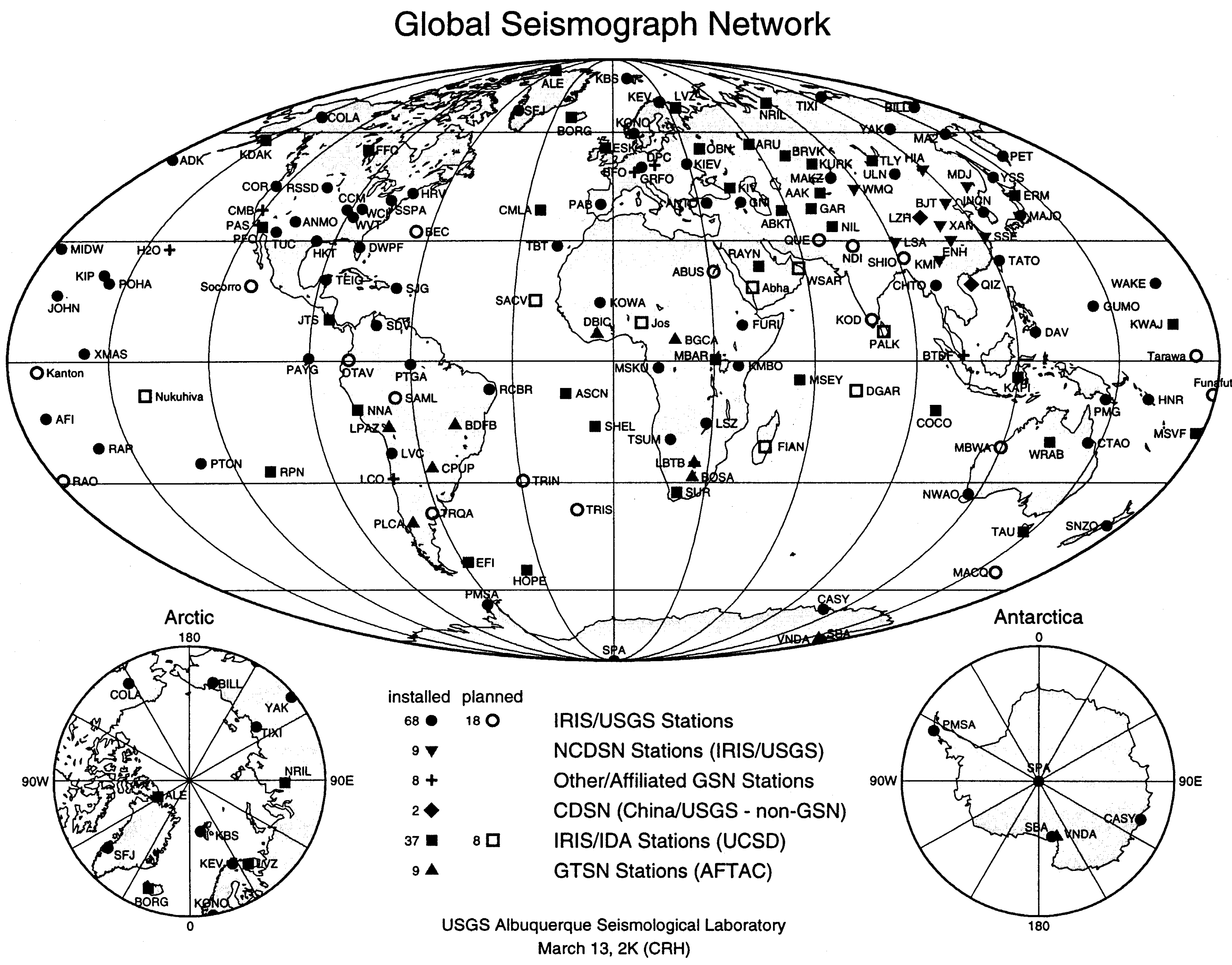


Figure 1. Map showing existing and proposed locations for IRIS systems. The USGS Albuquerque Seismological Laboratory is responsible for deployment of the IRIS/USGS systems; the University of California at San Diego (UCSD) is responsible for deployment of the IRIS/IDA systems. The GTSN network is funded by the U.S. Air Force and is not part of the IRIS program, but this network uses equipment similar to the IRIS/USGS equipment. The GTSN data are merged with other GSN data at the IRIS/USGS Data Collection Center in Albuquerque, New Mexico.

SYSTEM DESIGN

INTRODUCTION

The *Science Plan* described the GSN data requirements in terms of the most important system attributes -- resolution, bandwidth, and dynamic range. One of the early tasks of the SCGSN was to translate the general scientific goals for the GSN into design goals for the GSN data acquisition system. The result of this work was published in draft form as *The Design Goals for a New Global Seismographic Network* and distributed widely for comments and suggestions. The design goals were then used as the basis for preparing detailed specifications for the IRIS GSN data system. The development of the GSN system design goals and specifications was a deliberate process that drew upon a broad range of scientific and engineering expertise to insure that the latest applicable technology was used to create a digital broadband seismograph system that will produce much higher quality data than are now available and be supportable and upgradable well into the 21st century.

The key requirements for the new station instrumentation were listed in the design study as follows:

- Bandwidth sufficient to record the entire spectrum of teleseismic signals;
- Dynamic range sufficient to resolve ground noise and to record the largest teleseismic signals;
- Digital data acquisition and recording with real-time or near real-time data telemetry;
- Low noise instrumentation and environment;
- Linearity.

Several other design considerations were important in developing specifications. For example, it must be possible to tailor the GSN system configuration for particular locations. At some stations the sensor systems and recording systems are separated by a local telemetry link so that the sensors can be located away from sources of cultural noise. Analog and digital recording requirements also vary from station to station.

Modularity, the fullest possible use of off-the-shelf components, and a standard computer bus will make the system much easier to support and upgrade in the future. Ideally, the entire data system can be replaced over the years piece by piece as the need arises. The use of off-the-shelf, commercially available modules also reduces costly dependence on a single system manufacturer when design changes and modifications are needed in the future.

Reliability and maintainability are clearly important design considerations. A network data availability of at least 90% is the goal for the GSN. The reliability of a data acquisition system depends on many factors, including equipment design, local interest in the data, adequacy of spare parts at the station and at the maintenance center, turnaround repair time, training, power line stability, and environmental conditions. The methods used in this program to deal with factors affecting station reliability include the use of proven equipment, built-in diagnostics, operator training, robust backup power systems, and use of fiber optic cables where lightning and electronic interference is a problem.

Full access to the data produced by the GSN data system by the participating stations for local use is especially important. Because of its large bandwidth and dynamic range, the GSN system can replace most instruments now operated at seismological observatories. Signals emulating almost any conventional seismograph system can be derived from the broadband data channels by filtration. Not only will the GSN system produce data very useful for local analysis and research, it will serve as an excellent training facility for seismologists, engineers, and technicians.

The specifications for the GSN data system were part of a request for proposals issued by IRIS, and, after competitive evaluation of the responses, a contract was awarded to Gould, Inc. (now Martin Marietta Ocean Systems Operations, Glen Burnie, Maryland) for development of a GSN prototype data system (less seismometers). The prototype system was delivered to the USGS Albuquerque Seismological Laboratory in late 1988. Most of the important design features used in developing and configuring hardware and software for the GSN data system evolved from a very broadband (VBB) seismograph system conceived and developed at Harvard University by J. M. Steim (1986).

Following the testing and acceptance of the prototype system, ten production systems were delivered by Martin-Marietta and have since been deployed. The Martin-Marietta systems are designated as "Type M" IRIS-2 systems. Later versions of the IRIS-2 systems are being integrated and assembled at the Albuquerque Seismological Laboratory from separately purchased components. These are referred to as IRIS-2 "Type Q" systems (the Q in reference to the use of Quanterra, Inc. digitizers). IRIS-1 systems are essentially copies of the original Harvard system. Several have been deployed in the United States to demonstrate the VBB concept and will be converted to IRIS-2 systems in the future. After a contract was awarded for development of the IRIS-2 system, the IRIS staff decided to concurrently develop a lower cost data acquisition system based on a design for portable refraction equipment. The IRIS-3 (or IRIS/IDA) system, manufactured by Reftek, Inc., will be deployed by UCSD to upgrade IDA stations. The description of equipment in the remainder of this report applies to the IRIS-2 systems that will be deployed and supported by the USGS.

BANDWIDTH AND DYNAMIC RANGE

Perhaps the most fundamental design goal for the GSN system is to linearly record the entire signal spectrum from teleseismic events of any magnitude in a single continuously recorded broadband channel. To achieve this goal, the bandwidth must be sufficiently large to record both teleseismic body waves and the lowest frequency modes of free oscillations, and the dynamic range must extend from below background noise to the surface-wave amplitudes expected from the largest teleseismic events. Until recently, the required bandwidth could only be achieved by recording two or more signals from separate instruments, and the required amplitude range could only be achieved by using gain-ranged digital encoders or by recording in two or more gain levels. The combination of force-balance VBB sensor systems and high-resolution (24-bit) digital encoders makes it possible now to construct a truly broadband seismograph system without signal splitting to increase bandwidth or amplitude range.

The approximate recording range of the IRIS-2 VBB channel is illustrated in Figure 2 together with earthquake spectra recorded at a distance of 30° and background spectra from both high and low noise sites. Typical recording ranges for the WWSSN SP and LP seismographs are shown for comparison. The dynamic range of the IRIS-2 system is 138 dB compared to a dynamic range of about 40 dB for the WWSSN recorder. The difference cannot be fully appreciated when represented on a compressed logarithmic scale, but imagine a photographic recorder having a resolution of one millimeter and a center-to-edge dynamic range of 138 dB. The recorder drum would be nearly 16 kilometers wide, and the distance from the recorder drum to the galvanometer would be over 52 kilometers!

The advantage of using integer 24-bit digital encoders for broadband recording as opposed to automatic gain-ranged encoders or multi-level recording is evident from the data shown in Figure 2. At a quiet site, the difference between the noise minimum and the noise maximum is about 65 dB; at a noisy site, this difference is nearly 90 dB, and in the worst case of a microseismic storm at a quiet site, the difference can be over 100 dB. A 16-bit integer encoder used in multi-level recording has a zero-to-peak dynamic range of 90 dB and a 16-bit gain-ranged encoder with 14-bit resolution has a zero-to-peak dynamic range of only 78 dB. In both cases a significant loss of resolution occurs when background noise or the combination of noise and signal overdrives the most sensitive channel or resets the gain to a less sensitive setting. Gain-ranged encoders have an additional disadvantage of being basically non-linear devices that may introduce noise and distortion into the signal (Steim, 1986).

Despite the unprecedented bandwidth and dynamic range of the IRIS-2 VBB channels, the broadband records will not capture the entire signal spectrum that includes

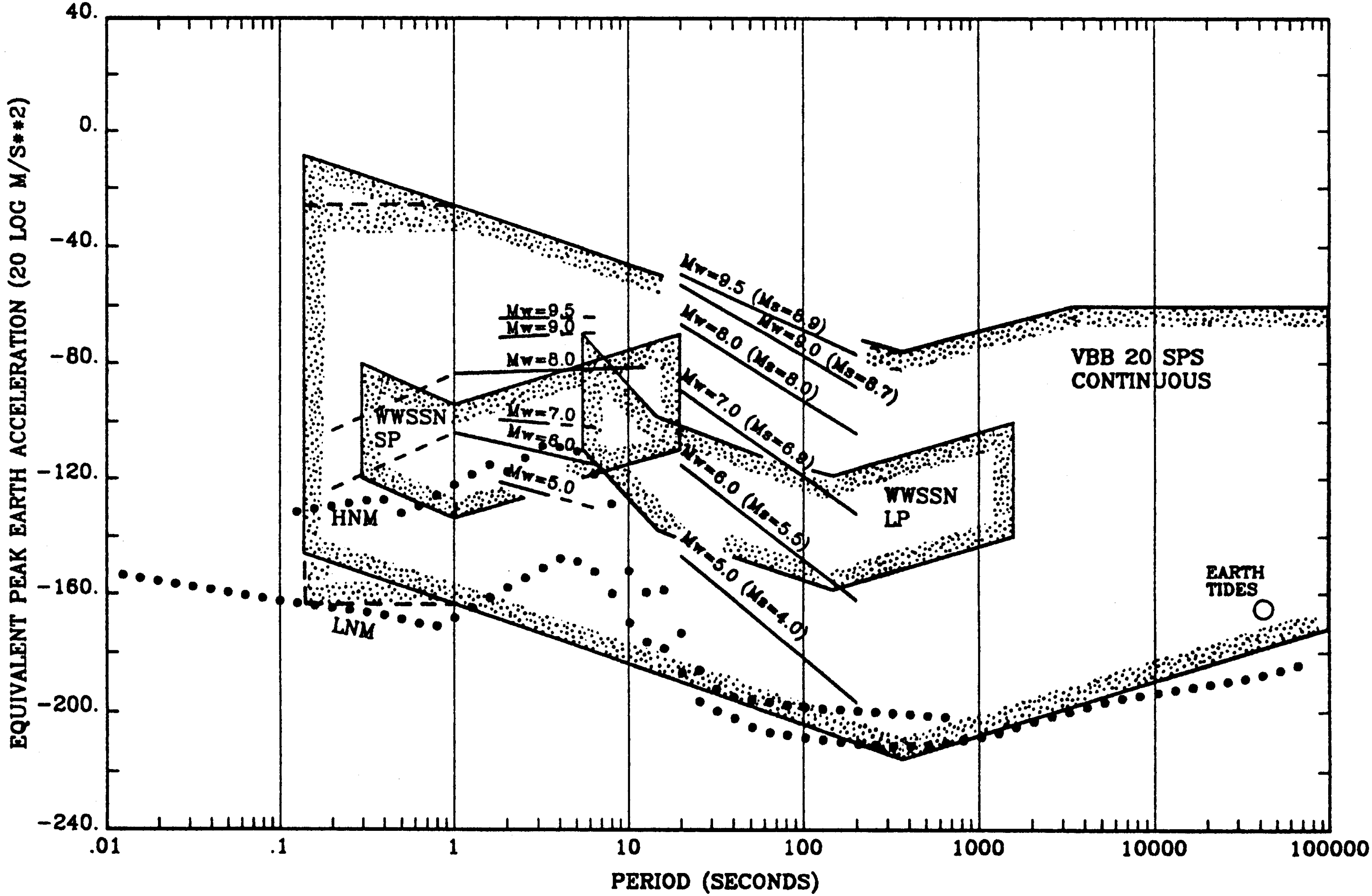


Figure 2.--Approximate recording range of the IRIS-2 VBB channel. The approximate recording ranges of the WWSSN SP and LP channels are shown for comparison. Earthquake spectra from sources at 30° were provided for the IRIS design study by H. Kanamori, California Institute of Technology. The dotted curves labeled HNM and LNM are *average* peak values of high and low Earth noise models computed from power spectral density over 1/3-octave bands. Very few sites have noise levels as low as the LNM curve in the short-period band. The dashed portion of the VBB operating range is an optional response available on the STS-1/VBB seismometers.

high-frequency signals (above 7 Hz) or strong ground motion. Therefore, an option has been provided to extend the recording range of the IRIS-2 system at stations where it is appropriate using very-short-period (VSP) and low-gain (LG) sensor systems. The VSP sensors extend the frequency range up to 25 Hz (Type M system) or 30 Hz (Type Q system), and the LG sensors extend the amplitude range up to 2 g of acceleration (see Figure 3). The VSP and LG signals are digitized at 100 samples per second using 16-bit encoders (Type M system) or at 80 samples per second using 24-bit encoders (Type Q system). They are recorded in a triggered mode.

Each IRIS-2 system also records long-period (LP), very-long-period (VLP), and ultra-long-period (ULP) signals. These signals do not contribute to the bandwidth as they are extracted from the VBB channels by filtration and decimation; however, they are useful for local analysis, and the generation of long-period data at the stations significantly reduces the processing time required of data users who are principally interested in longer period signals. LP, VLP, and ULP signals, derived from the VBB signals by weighted averaging (digital low-pass filtering) and decimation of data samples, have greater resolution than the VBB signals. The increased resolution, often called 'bit enhancement', is proportional to the square root of the decimation factor.

Amplitude response curves are shown in Figure 4 for the five types of standard and optional data channels recorded on an IRIS-2 system. Relative gain levels are shown, assuming the VSP is set at its highest sensitivity. Digital finite impulse response (FIR) filters are used to low pass the VBB, LP, and VLP signals.

AN OVERVIEW OF MAJOR SYSTEM FUNCTIONS

General

The most important function of an IRIS-2 system is to generate and record high-resolution broadband data. However, there are many other standard and optional features that make this seismograph system ideal for an observatory where a wide range of seismological and related data are recorded and analyzed. Yet, when configured in its most basic form, the IRIS-2 system will function with minimal operator intervention, or at an unattended site with data recovered by telemetry.

A block diagram showing major system components is presented in Figure 5. Optional components marked as IRIS options will be provided at the discretion of IRIS and the USGS. Optional components marked as station options will be provided by the station, the presumption being that analog recorders currently operated at GDSN and WWSSN stations will be used for this purpose. In addition to the primary seismic data channels, the IRIS-2 systems can be equipped with optional auxiliary digital encoders that may be used to digitize signals from other sensors, such as meteorological instruments,

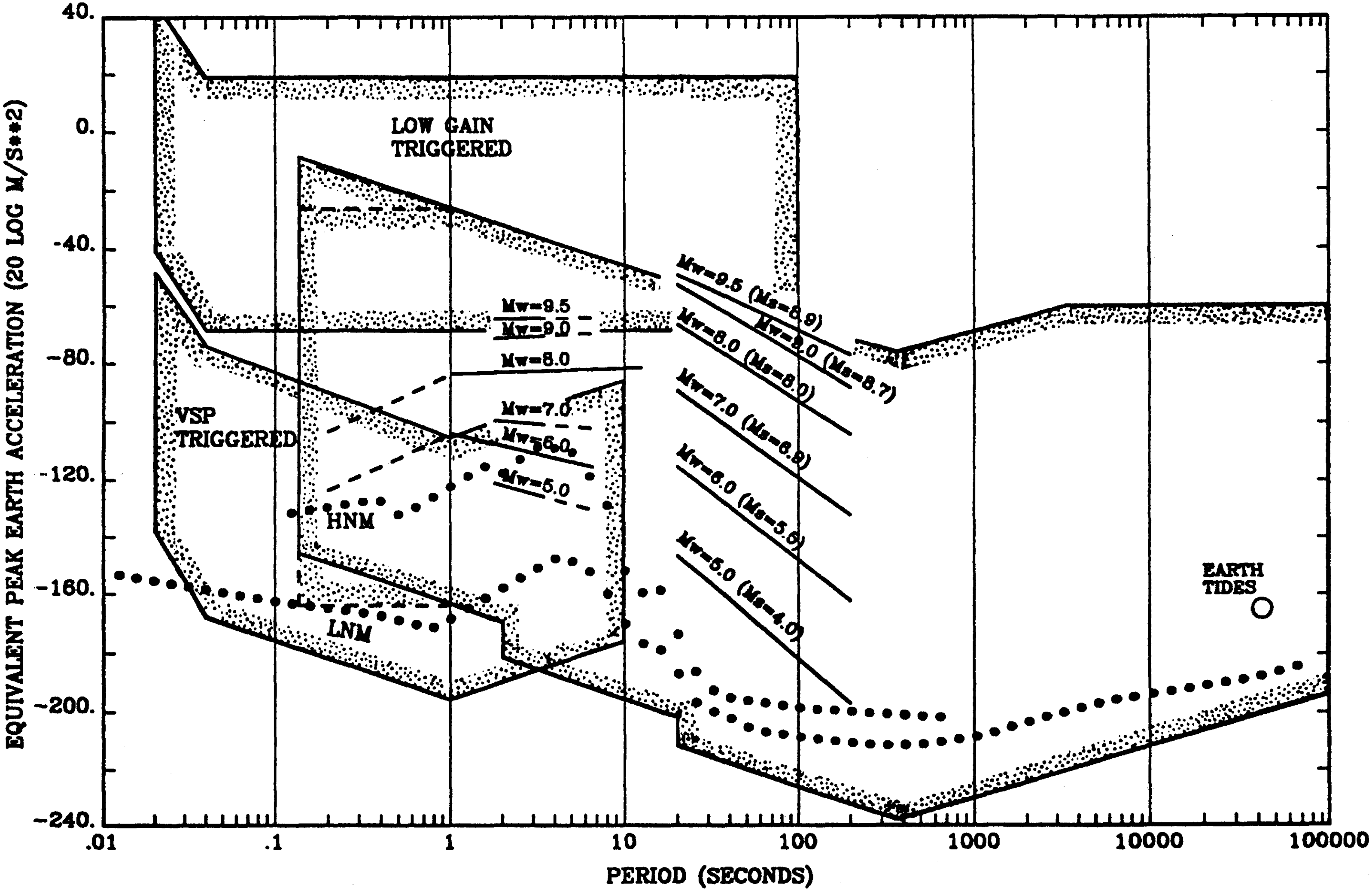


Figure 3.--Approximate recording range of the IRIS-2 system with the optional VSP and LG channels included. The VSP and LG channels are shown with 16-bit dynamic range, but the newer (Type Q) version of the IRIS-2 system uses 24-bit recording for these optional channels. The increased resolution shown at long periods is due to bit enhancement in the LP and VLP signals.

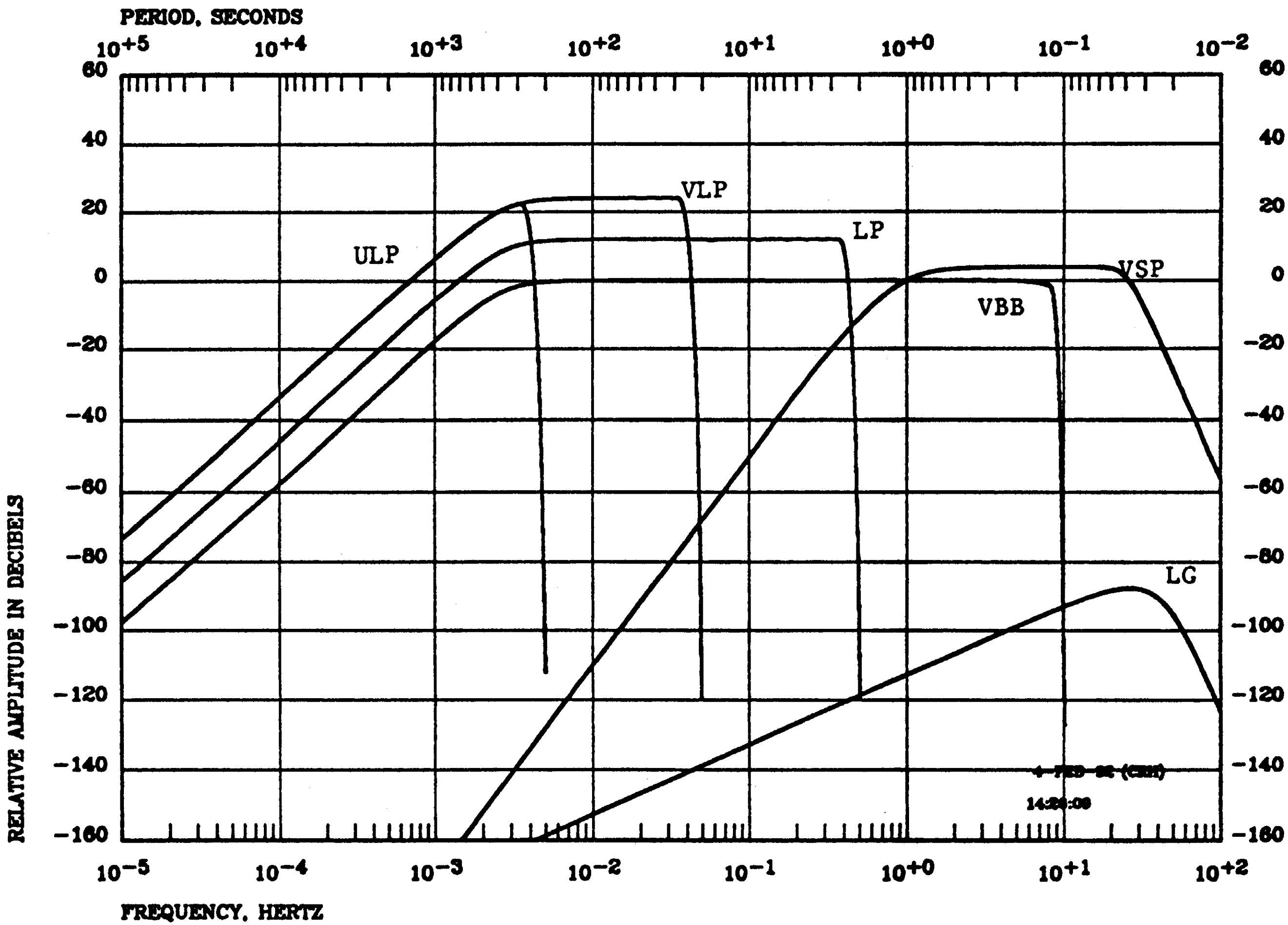


Figure 4.--Amplitude response curves for the six data channels recorded on the IRIS-2 system for an input of constant Earth velocity. The VSP and LG channels are optional. Digital FIR filters produce the very sharp cutoff just above the Nyquist period for the VBB, LP, VLP, and ULP channels. In the newer version of the IRIS-2 system, digital FIR filters are also used with the VSP and LG channels and the Nyquist period is at .025 sec rather than at .02 sec.

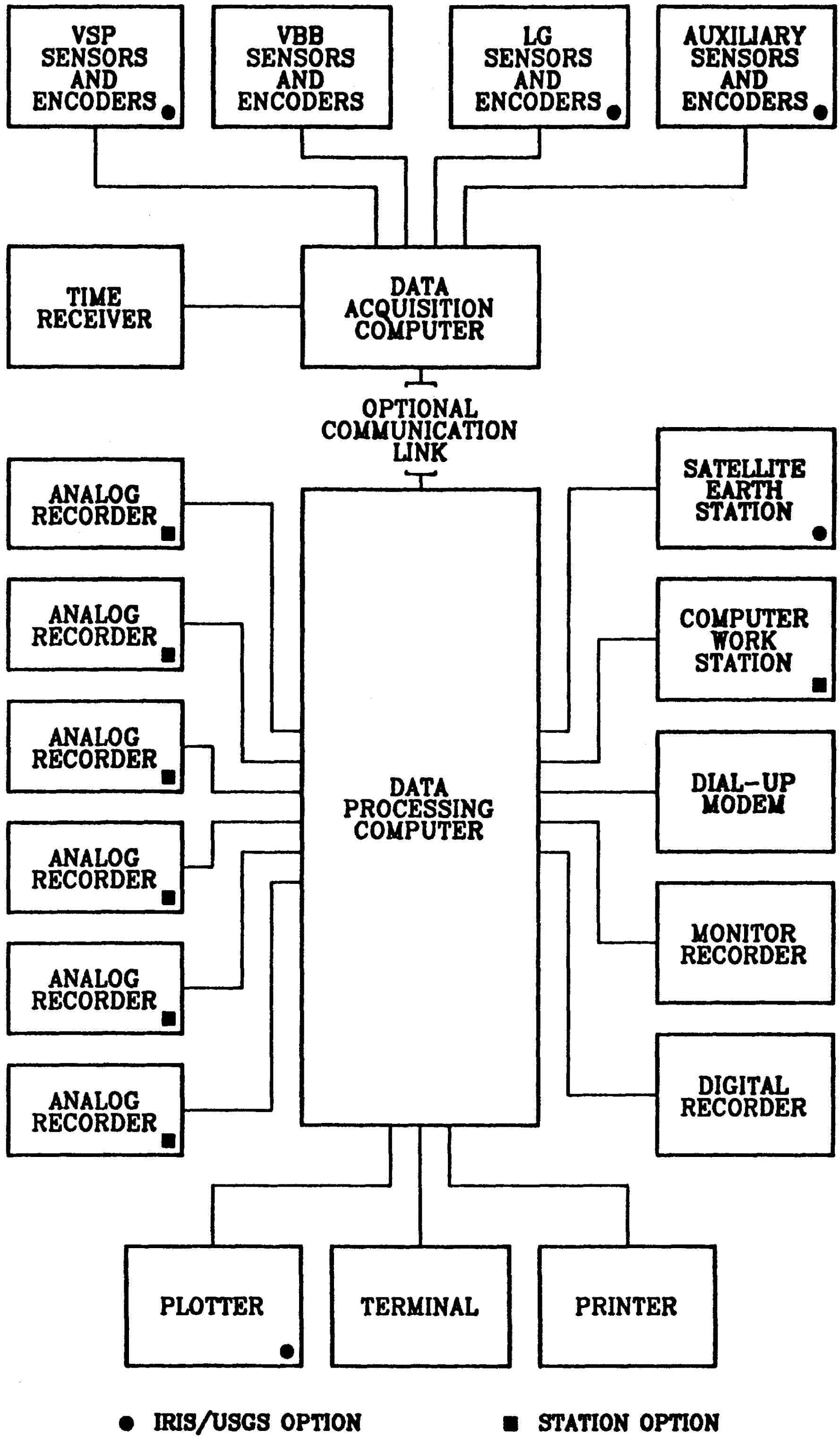


Figure 5.--Block diagram showing major components of the IRIS-2 system. The data acquisition and data processing functions are combined in a single computer when a communication link is not used.

microbarographs, tilt meters, or strain meters.

One of the features other than bandwidth or dynamic range that makes the IRIS-2 system unique is the accessibility of the data for display and analysis. There will be a choice of software filters at the stations that can be used to emulate signals from conventional seismographs for analog display. Standard filters include simulations of WWSSN SP, WWSSN LP, and Seismic Research Observatory (SRO) LP, with many others possible. In addition, station operators will have direct access to the high-resolution digital data for local processing. Current data stored in buffers may also be accessed remotely through a dial-up telephone connection, and an option has been provided for future satellite transmission of station data.

Separated and Compact Configurations

There are two configurations of the IRIS-2 system, a separated version and a compact version. In the separated version, the sensor systems, digital encoders, Omega or GPS time receiver, and data acquisition (DA) computer are all part of a remote data acquisition module that communicates with the data processing (DP) computer and recording module through a communication link. This permits the sensors to be installed at sites isolated from cultural noise. Many of the GDSN stations where GSN systems will be deployed currently operate in this fashion. The communication link can be wire or fiber optic cable, a dedicated telephone circuit, a radio frequency channel, or a satellite channel. The data are packetized and time tagged at the remote site, so there are no distance limitations because of circuit delays. The receiver/clock does not require adjustment, and a separate power supply with backup will be provided at the remote site, so routine maintenance visits will not be required. A voice-grade 2400-baud circuit will support telemetry of continuous VBB data and VSP or LG event data. A buffer memory in the remote module is used to store VBB, LP, VLP, and ULP continuous data, VSP and LG event data (if available), and VBB, LP, and VLP event data. The communication software detects transmission errors and retransmits buffered data packets if problems occur in the circuit. The random-access memory (RAM) buffer will store a minimum of 3,000 256-byte data packets depending on DA RAM size. This represents more than 10 minutes of continuous data storage if all channels are operational, and more than 2 hours of continuous data storage if the optional VSP and LG channels are not attached. Transmission errors caused by noise bursts and outages are typically of short duration, 10 minutes or less, but if a circuit outage persists and the buffer fills, packets of data will be systematically discarded based on a programmable priority to minimize total loss of data. For example, up to 24 hours of continuous LP and VLP data and VBB event data can be saved in the buffer for automatic retransmission when the circuit is reestablished.

Data acquisition and processing functions are combined and handled by a single

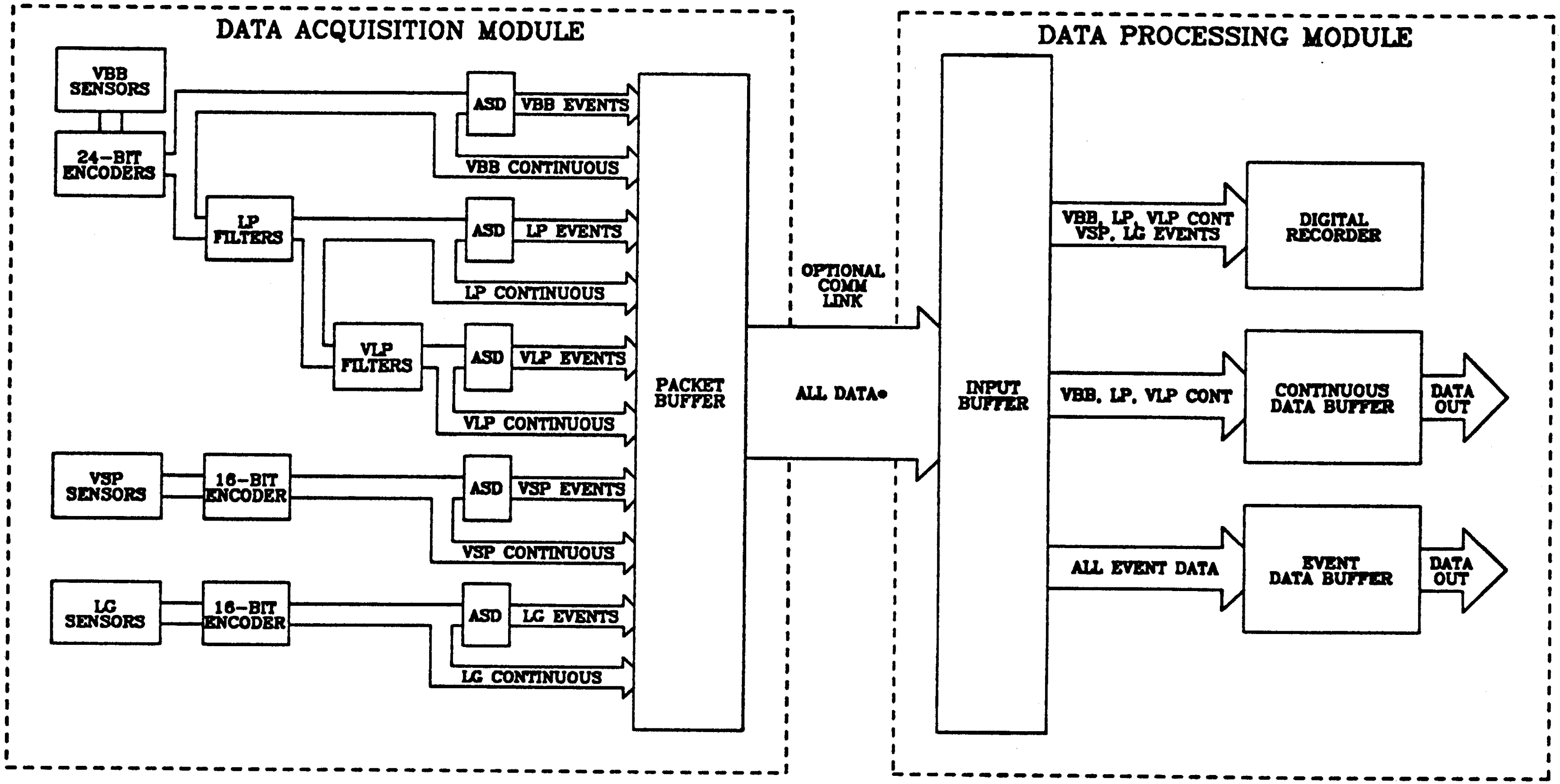
DA/DP microcomputer in the compact version of the IRIS-2 system. Apart from the communication link, the separated and compact versions of the IRIS-2 system have identical capabilities and functions.

Data Acquisition and Storage

A simplified schematic of internal digital data flow is shown in Figure 6. The VBB sensor signals are digitized at a high sampling rate, then filtered and decimated to 20 samples per second (sps) in the Type M system. In the Type Q system the VBB sensor signals are digitized at a high rate, then filtered and decimated to 80, 40, 20, and 1 sps. Data samples are four bytes in length, representing 32-bit integer words. In Type M systems, data taken from the VBB stream are filtered, then decimated to 1 sps to form the LP data stream. In Type Q systems, LP data are derived directly from the digitizer at 1 sps. Similarly, the VLP data stream, decimated to 0.1 sps, is derived from the LP data stream, and ULP data at 0.01 sps are derived from the VLP data. The linear-phase digital FIR filters provide very sharp low-pass corners to maximize bandwidth. Sampling rates are adjustable up to a maximum of 200 sps (Type M system) or 80 sps (Type Q system) for each of the optional VSP and LG sensors. Normally, each of the VSP and LG components will be sampled at a rate of 100 or 80 sps. VSP and LG samples are four bytes in length (Type Q system) or two bytes in length (Type M system) at the encoder but expanded to four bytes for processing.

An automatic signal detector may be operated on any or all of the continuous data streams to detect events. The detector, based on the algorithm described by Murdock and Hutt (1983) and Murdock and Halbert (1987), is used to extract segments of event data for storage and recording and to generate a listing of each detection that includes detection time, direction of first motion, maximum amplitude of first four cycles, and values indicating background level and quality of onset for each event. Normally, short-period event detection will be performed on the vertical-component VBB channel so that event lists are generated even at stations where VSP event data are not recorded. Listings of detections are stored and recorded with the data and automatically printed out on the station printer.

Prior to storage in buffers and recording, or transmission in the case of the separated version, all of the digital data streams are compressed using a Steim compression algorithm which forms first differences between successive four-byte samples. At most stations, the amplitude difference between successive samples for the VSP and VBB signals can be represented by one byte 99% of the time, providing an average compression ratio of about 3.72 to 1. LP, VLP, and ULP samples often require two bytes for representation, but the low sampling rates make efficient compression less important. A decompression algorithm provides perfect reconstructions of the original signals for



ASD -- AUTOMATIC SIGNAL DETECTOR   *OR A SELECTED SUBSET OF DATA, DEPENDING ON LINK BANDWIDTH

Figure 6.--Simplified schematic of IRIS-2 (Type M system) internal digital data flow. Tape cartridges are sent to the data collection. center. Data stored in the continuous and event buffers may be accessed by the operator through a direct connection to a host data access port or through the dial-up modem port. The Type Q systems use 24-bit encoders for the VSP and LG channels.

display and analysis.

The data processing module has a hard disk drive used primarily for on-line data storage. The disk has two circular buffers, one for continuous data and one for event data. Each component of data is stored in a separate file, and the relative sizes of the data files are adjustable via commands placed in the system configuration file. More than one day of VBB data, one week of LP data, and one month of VLP and ULP data will be stored in the continuous data buffer. Similarly, there will be at least a full day of event data stored in the event buffer. The primary purpose of the data buffers is to provide near real time access to the digital data.

Digital data are recorded on high-density (150-megabyte) tape cartridges. Each cartridge has sufficient capacity to store more than two weeks of VBB, LP, VLP, and ULP continuous data and VSP and LG event data. Automatic switchover occurs if the on-line cartridge fills with data or fails. Data are recorded in the Standard for Exchange of Earthquake Data (SEED) format. The SEED format, developed and described by Halbert and others (1987), has been adopted for use by the Federation of Digital Broadband Seismograph Networks (FDSN). All of the information needed for data analysis -- station coordinates, sampling, rates, calibration, and many other parameters -- is recorded at the station together with the data. The data format remains essentially unchanged from the time the data are initially recorded at the station through processing and distribution to the end user. This preserves data fidelity and reduces the processing load at data collection and management centers. State-of-health information, message text, event logs, and all operator commands and logs are recorded on the tape together with the data. It will not be necessary for any paper logs to accompany the tapes to the data collection center. Recorded data does not flow through the disk buffer memories. Data will continue to record on tape should the hard disk drive fail.

Analog Recording

A single-channel drum recorder is normally provided so that any of the active channels (VBB, LP, VLP, VSP, or LG) can be selected for recording by the operator. The drum recorder is used to record tests and sensitivity adjustments, to evaluate and refine signal detection parameters, and to provide a continuous analog record of any channel at the discretion of the operator.

Up to eight channels of analog signals may be produced by the data processing computer for local recording on conventional seismograph recorders provided by the station. The IRIS-2 data system will replace existing WWSSN and GDSN systems and the visual drum recorders currently used with the WWSSN and GDSN systems may be directly attached to the IRIS-2 system. The data processing computer generates software simulations of WWSSN SP and LP waveforms and of the SRO LP waveform, and any of these simulated signals may be selected for recording at the station. An optional laser printer may be provided in place of drum recorders for generating seismograms. Analog seismograms produced at the station will remain at the station.

Operator Control

The IRIS-2 system is equipped with a terminal and printer for operator control. The terminal may be used by the operator to initialize recording, check the time, and control the tape drives; view event detection, error, and status logs; set, change, or display event detection parameters; exchange message text via the real-time or dial-up ports; initiate a calibration; select channel and sensitivity for the monitor recorder; select software filters and magnifications for analog recording, examine the status of all active processes and view a continuously updated display showing a snapshot of all data channels, UTC time, space used on the active tape drive, text messages, status and error messages generated by internal diagnostics, and VBB seismometer mass position. However, the normal operation of the GSN system does not require operator intervention except to replace tapes at biweekly intervals and service any analog drum recorders that may be used at the station. It is also important to note that the IRIS-2 system will reinitialize and begin recording automatically should power fail and recover while the station is unattended.

The operator will also be able to display and plot digital waveform segments stored in the continuous and event buffers. Data can be displayed as unfiltered VBB, LP, VLP, ULP, VSP, and LG waveforms, or as simulated WWSSN SP or LP or SRO LP waveforms, and the full dynamic range of the signal is available for display. The segment of data selected by the operator is displayed on the monitor in Tektronix 4014 graphics mode. Cursors are used to pick time and amplitude, so that the operator can determine phase arrival times, amplitudes, and periods. A hard copy of the screen display may be dumped to the printer. An optional laser printer may also be attached to the system. It is used to produce high-quality custom plots of waveforms and may be used to produce 24-hour seismograms at stations that do not have analog recorders.

Data Access

One of the most important and innovative features of the IRIS-2 system is the availability of the digital data to the host organization and to other organizations that require near real-time data for analysis. There are three ports, in addition to the port used for the operator terminal, through which digital data can be accessed. One is designated for real-time telemetry, one is designated for a dial-up modem, and one is designated for a local work station. More ports can be added if needed.

Although it remains an important network design goal, the real-time telemetry of data from stations to the data collection center is not likely to be implemented from many stations in the very near future because of the high cost of equipment and circuits. However, system design includes the capability for attaching a satellite earth station in the future should real-time satellite telemetry become feasible.

Each system is equipped with a modem for use with a commercial telephone circuit. The dial-up circuit can be used to access buffered data and perform all of the functions available to the operator through the operator terminal. Access is limited by password. Stations may elect to provide either 'open' or 'limited' access to their system. Anyone may dial into an 'open' station to retrieve segments of data. The cost of the call is borne by the caller, and calls are limited to 30 minutes. Dialing into 'limited' access stations will be restricted to the data collection and network maintenance centers and to others at the discretion of the station. Examples of data obtained by dialing into the GSN station at the Albuquerque Seismological Laboratory are shown in Figures 7 and 8. The dial-up circuit also will be used to exchange messages between the station and network maintenance center and by the maintenance center to perform diagnostics and download software modifications.

Anyone wishing a demonstration of the dial-up functions of an IRIS-2 system is invited to dial into the operational IRIS-2 station at the Albuquerque Seismological Laboratory. The number is 505-846-0384. When asked for your user name, type in *VBB*, and when asked for your password, type in *data* (all responses may be in upper or lower case). Instructions are provided in the menu. Additional assistance can be obtained by calling 505-846-5646 and asking for the GSN system programmer.

The IRIS-2 system can also be accessed by direct connection to a 19.2 Kbps serial port included specifically to support a local computer work station. It will also be possible to connect via an Ethernet port. A work station connected to the system in either of these ways has the same menu of functions available to it as the operator terminal. In addition, it has the capability to capture data files to disk or tape for off-line archiving and analysis. The work station need not be expensive to perform basic archiving, analysis, and graphics. For example, a personal computer (PC) with a 100 megabyte hard disk drive, Tektronix 4014 terminal emulator software, FORTRAN or C compiler, plotting software, and a laser printer can be purchased in the United States for less than $7,500. For an additional $600, a compact disk reader may be added to a PC-based system for reading the CD-ROMs distributed by the USGS. The CD-ROMs and software to read them are provided free of charge to GSN stations supported by the USGS. A compatible tape cartridge drive that can be connected to a PC is available for about $1,400. Software for copying the tape cartridges has been developed. Application programs developed specifically for PC-based seismological data processing, analysis, and graphics are becoming available. For example, the International Association of Seismology and Physics of the Earth's Interior (IASPEI)

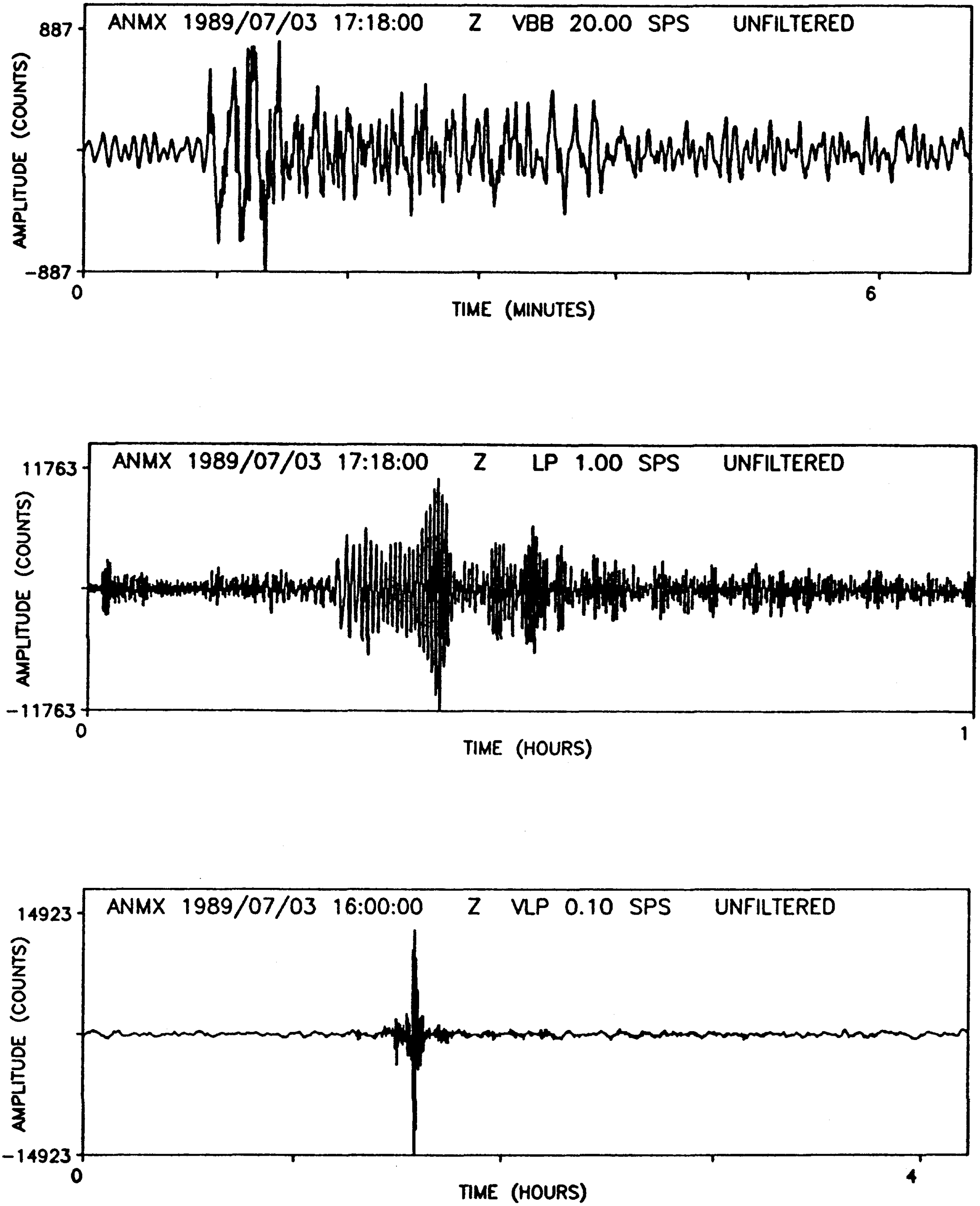


Figure 7.--Examples of unfiltered waveforms retrieved from an IRIS-1 system through a dial-up modem. Only the vertical components are shown. Signals are derived from a modified KS-36000 seismometer.

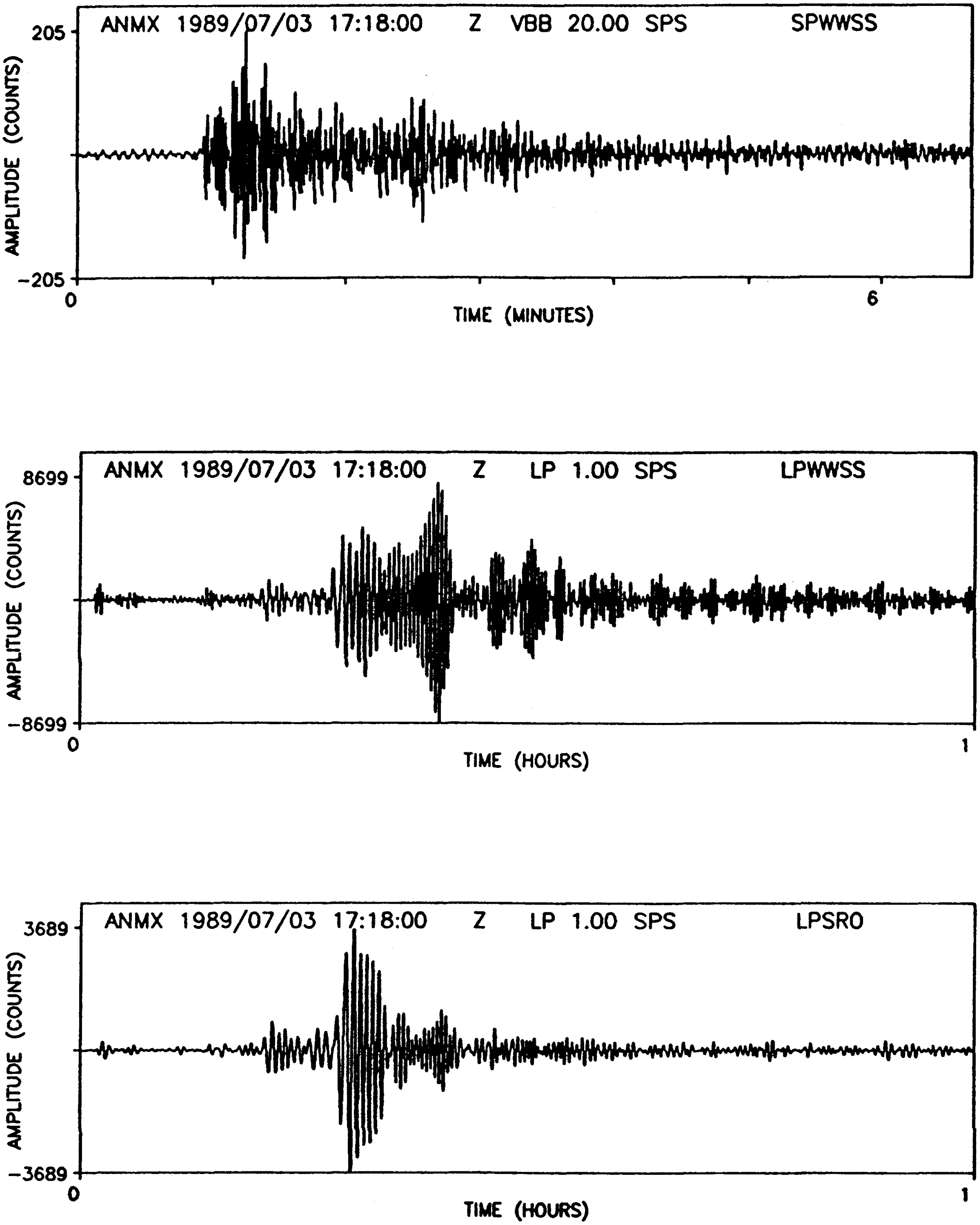


Figure 8.--Examples of waveforms retrieved from an IRIS-1 system while applying the WWSSN and SRO filters. Only the vertical components are shown. Signals are derived from a modified KS-36000 seismometer.

has formed a working group to promote the use of personal computers. Application software collected by the IASPEI working group is being distributed by the Seismological Society of America.

Calibration

In Type M systems, calibration signals applied to the VBB seismometers are generated within the 24-bit digital encoder unit and recorded on a fourth encoder channel that also serves as a spare. In the Type Q systems, the input calibration signal is substituted for one of the seismometer data channels during calibration only. In Type M systems, calibration input signals for the optional VSP and LG sensors are generated in the 16-bit encoder unit, and extra encoder channels are available for recording the calibration input signals. In Type Q systems, the VSP and LG calibration input signals are recorded by substitution for a sensor data channel. Step functions, random binary signals, and sine waves at several frequencies are available as calibration inputs. Since both the sensor input and output signals are measured and recorded, the determination of the transfer functions can be automated using techniques described by Wielandt (1986a, 1986b), in which the input signal convolved with a trial transfer function is matched to the sensor output signal using least-squares fitting. Quantization error, noise, instrument drift, and nonlinear behavior can also be identified using this method. Experience has shown that the transfer functions of force-balance sensors are very stable, and full-scale calibration is only needed during installation and when components become suspect or are replaced. However, step function calibration may be applied at tape change intervals so that system performance can be monitored. Sine-wave calibration may be used by operators to adjust and check analog recorder magnifications.

System Power

An uninterruptible power subsystem (UPS) is provided with each IRIS-2 system. The UPS will condition the local power and provide four hours of battery backup in the event of line power failure. The power required for system operation without analog recorders is about 400 watts. However, a 1,000-watt UPS is furnished with the system to provide the additional power needed to operate six analog recorders. An additional smaller UPS is provided with the separated version of the system to operate equipment at the remote site. The DP equipment is designed to operate from local power (110/220 VAC, 50/60 Hz) so that a failure in the power subsystem will not result in a complete system failure. The DA equipment operates from 24 VDC.

SYSTEM HARDWARE AND SOFTWARE

General

In developing the VBB concept at Harvard University, Steim combined the very latest sensor system technology with a powerful and versatile microcomputer-based data processing and recording system. The design anticipates modifications and improvements over the years, so customized hardware and software which make change difficult have been avoided. In fact, almost all of the hardware used in the system can be purchased off the shelf. Likewise, the operating system is commercially supported software, and the application software is written in a high level language. Several components and functions have already been added to the original Harvard design. These include the VSP and LG sensor systems, expanded analog recording capabilities, and the communication link used in the separated version of the system. Photographs of IRIS-2 system components are shown in Figures 9 and 10.

Sensor Systems

All of the IRIS-2 data systems are equipped with a triaxial set of VBB sensors. Currently, two types of VBB sensor systems are planned for use at the IRIS-2 stations with the choice depending on the site. STS-1/VBB seismometers manufactured by Streckeisen & Co. of Pfungen, Switzerland are being used at stations where seismometers are installed in vaults. The KS-36000 borehole seismometers will continue in use at SRO stations that convert to IRIS-2 equipment, but the seismometers are modified to produce a very broadband velocity output similar to the STS-1/VBB seismometer. There are other candidate vault and borehole seismometers that may be used in the future. The decision to use alternate VBB seismometers will be based on the results of performance tests and cost.

The decision to provide optional VSP sensors at IRIS stations will be based on the predicted usefulness of the VSP data, which is expected to be site dependent. The decision to provide optional LG sensors at GSN stations will be based on the probability of VBB saturation due to large regional and local events.

Digital Encoders - Type M System

Each Type M system is furnished with a four-channel high-resolution digitizer/calibrator unit (HRDCU) with 138 dB dynamic range and 24-bit resolution designed and manufactured by Martin Marietta, Inc. Each digitizer consists of an enhanced delta modulation encoder (EDME) and a FIR filter under control of an Intel 8751 microcontroller. VBB signals are sampled at a rate of 5120 sps, then filtered and decimated to produce 20 samples per second formatted into 24-bit words. Time marks

3 pages

NOT included

here

Page 21, 22, 23

received once per minute from the time receiver are used in the HRDCU to synchronize a sampling clock so that samples are synchronized to within one millisecond of universal time. During initialization or if synchronization should be lost, the DA computer automatically resynchronizes the sampling clock by incrementally adjusting the frequency of the HRDCU internal oscillator. The HRDCU has an additional function of generating the calibration signals applied to the VBB sensors. The analog signals used for calibration are generated by the microprocessor and processed through a 16-bit digital-to-analog converter (DAC) and a programmable attenuator. VBB sensors can be calibrated separately or simultaneously. Calibration signals are digitized for recording by the fourth encoder, which also serves as a spare channel.

Stations equipped with optional VSP and LG sensor systems are furnished with a 6-channel model RD-6 digitizer/calibrator developed and manufactured by Nanometrics, Inc., Kanata, Ontario, Canada. The RD-6, referred to in system specifications as the low resolution digitizer/calibrator unit (LRDCU), has a dynamic range of 90 dB and 16-bit resolution and is microprocessor controlled. Sampling rates are selectable up to a maximum aggregate rate of 600 samples per second from all attached sensors. Calibration signals generated within the microprocessor are applied to the sensors through a 16-bit DAC and are digitized for recording by a separate encoder.

Up to 12 additional digitizer channels are provided when needed for encoding auxiliary sensor signals. The auxiliary digitizer units (AUXDU) are also Nanometrics RD-6 digitizers, with the sampling rate set to 1 sample per second.

Digital Encoders - Type Q System

Each Type Q system is furnished with a 3- to 12-channel (in 3-channel increments) high-resolution digitizer with an optional low-distortion calibrator designed and manufactured by Quanterra, Inc. The digitizers have 142 dB dynamic range and format the data into 32-bit words. Each 3-channel digitizer group has an analog front end that is electrically isolated from every other 3-channel group and a digital processor that performs FIR filtering and decimation and, optionally, event detection. Seismometer signals are sampled at a rate of 5120 sps, then filtered and decimated to produce 80, 40, 20, and 1 sps data streams. Time marks received once per minute from the time receiver are used in the digitizer to synchronize a sampling clock so that samples are synchronized to within one millisecond (rms) of universal time. If time marks are lost, or if the quality of the time from the receiver is degraded, the sampling clock is automatically set to run at the rate determined to be the "best" rate over the entire operating history of the system since its last initialization.

Each 3-channel digitizer group may be equipped with an optional high-accuracy calibrator that generates calibration signals to be applied to the seismometers attached to that group. The analog calibration signals have a linearity of 96 dB and programmable attenuation levels. The three seismometers on the 3-channel digitizer group may be calibrated separately or together. Calibration signals are digitized for recording so that a complete analysis of seismometer transfer functions may be performed.

In stations equipped with optional VSP or LG sensor systems, the optional sensors may be connected either to a 3-channel high-resolution digitizer group or to a 16-bit RD-6 digitizer/calibrator (described above in the previous section as the LRDCU). Auxiliary 8-channel, 8-bit digitizers will be furnished with some Type Q systems for digitizing state-of-health information.

Time Receiver

The first type of time receiver, used in the Type M systems, is the Kinemetrics OM-DC clock synchronized to the very-low-frequency signals transmitted by the Omega navigational system. The receiver automatically seeks and locks onto one of the eight Omega transmitters distributed globally; it is self synchronizing and does not require operator adjustment after initialization. Other types of time receivers include the Kinemetrics GOES satellite receiver and the Quanterra GPS-1 receiver supplied with most Type Q systems. In all cases, time marks generated by the time receiver are used to synchronize sampling with universal time and to generate the time-of-year used to time-tag the data packets. In addition, the GPS receiver may be used to determine receiver location.

Data Acquisition Computer - Type M System

Two microcomputers are used in the separated version of the IRIS-2 system, one in the compact version. In the separated version the DA computer hardware consists of a Motorola 68020 16-MHz CPU with 64 Kbyte of read-only memory (ROM) on the CPU card, 2 Mbyte of random-access memory (RAM) and 1/2 Mbyte of ROM supplied on an external card, all configured around a standard VME bus. The VME bus supports 32-bit wide address and data transfers at 40 Mb/sec and provides expansion capabilities in keeping with basic system design philosophy. Additional hardware modules include an 8-port serial interface. These ports are used for RS 232/422 connections to the time receiver, the HRDCU, the LRDCU, the AUXDU, the STS-VBB control box, and through the communication link to the DP computer.

Data Acquisition Computer - Type Q System

In the separated version of the Type Q systems, the DA computer hardware will consist of one of the three options below.

- Standard Version: Motorola 68030 CPU running at 16.7 MHz, boot ROM, and 4 MBytes of RAM.

- Low-Power Version: Oettle & Reichler CMOS 68000 CPU running at 16 MHz, boot ROM, and 4 MBytes of RAM.

- High Performance Version: Motorola 68030 CPU running at 25 MHz, boot ROM, and up to 32 MBytes of RAM.

Most systems will be furnished with the standard version. The low-power versions will be used in cases where power consumption at the seismometer site is of critical concern. The high performance version will be used in cases where a large amount of data buffering is required at the seismometer site.

Data Processing Computer - Type M and Type Q Systems

The DP computer consists of a Motorola 68030 25-MHz CPU with boot ROM and a minimum of 4 MBytes of RAM, configured around a VME bus. Other hardware includes an 8-port serial interface, parallel port, Ethernet port, optional digital-to-analog converters, SCSI interface, and an integrated peripheral plug-in module containing two 150-MByte cartridge tape drives and an 80 MByte (minimum) hard disk drive. Data are recorded on one tape drive at a time, with the alternate drive serving as a backup should the first one fail or fill up. The tape drives are also used for loading system software and diagnostics. The hard disk is used for buffering data for use by the station or dial-up users for several days after acquisition. Serial ports are used to communicate with the operator terminal, printer, dial-up modem, real-time transmission equipment, and the DA computer.

In the compact version of the IRIS-2 system, the data acquisition and data processing functions are combined into a single processor (either the "Standard Version" or the "High-Performance Version" described above). The compact version is built by adding tape and disk drives to the Type Q DA computer.

Software

The operating system is purchased from Microware, Inc., Des Moines, Iowa. Microware's OS-9 operating system is UNIX-like software written expressly for the 68000-series microcomputer with time-critical sections coded in assembly language. OS-9 provides an interrupt-driven, multi-tasking programming environment and a high level language interface for application programs. It does not require a disk for operation; programs may be stored in ROM, making OS-9 suitable for operation in remote installations. The operating system software provides all of the device drivers and manages the files, interrupts, and system tasks. Compilers and debuggers are available for several high level programming languages.

The IRIS-2 Type M application software provided by Martin Marietta evolved from software originally developed by J.M. Steim for the Harvard VBB system. It currently consists of over 50,000 lines of code written in an extended version of Pascal. Major programs are written for buffer management, data acquisition and processing (automatic signal detection, filtering, compression, decompression, formatting, etc.), operator monitoring and control, data access protocol management, analog recording, and other processes. Configuration files are used to store literally hundreds of system operating parameters that are subject to change, such as types of hardware used, data flow, data buffer and file sizes, detection parameters, and station information. Much of the versatility of the IRIS-2 system derives from the fact that it can be so easily reconfigured. Moreover, the software is written in a high level language so that it can be easily modified and extended to accommodate changes in the future to take advantage of improvements in technology.

Digital Recorders

Digital data are recorded on unformatted high-density (150 Mbyte) tape cartridges using Archive Model 2150L tape drives. There are two tape drives, each controlled by a separate controller. Switchover occurs automatically if a tape cartridge fills with data or if either the drive or controller fails. In the event that the system fails and recovers from an extended power outage, the software prevents overwriting of recorded data. Digital audio tape (DAT) drives may be used in the system in place of the Archive drives.

Analog Recorders

A Helicorder, manufactured by Teledyne-Geotech of Garland, Texas, is normally provided with each system to serve as a monitor recorder. Optional analog recorders are likely to be either Helicorders (at SRO stations) or WWSSN drum recorders that have been modified for thermal pen recording. Other types of analog recorders having approximately equivalent input impedances and sensitivities may also be used with the system. The optional digital plotter may also be used to produce analog seismograms (see below).

Operator Terminal and Printer

The operator terminal is a Graphon 235 terminal manufactured by Graphon Corporation, Campbell, California. The terminal is operated in VT220 mode for text display and in Tektronix 4014 mode for graphics. A dot matrix printer is supplied with the system to provide hard copies of information displayed on the terminal.

Digital Plotter

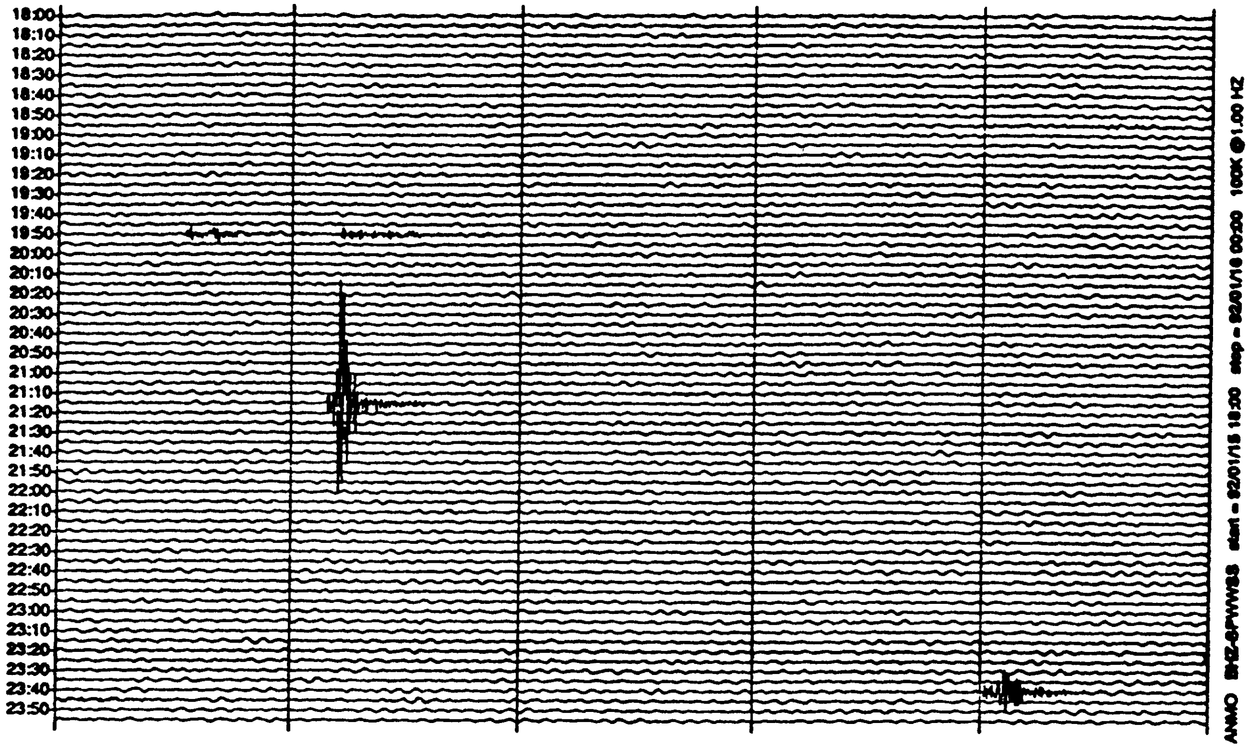
Current plans are to provide a laser printer as the optional IRIS-2 system plotter. Application software is being developed for high-resolution plotting of signals extracted from the system disk. Software is available now to produce a suite of seismograms. VBB and LP signals are filtered to emulate the WWSSN SP and SRO LP responses that are plotted on 8-1/2" by 14" paper. Six hour segments of SP signals are plotted at a standard 60 millimeters per minute and 12-hour segments of LP signals are plotted at the standard 15 millimeters per minute, providing rectilinear plotting with a resolution at least equal to the resolution on standard size seismograms. Reductions of the laser printer generated seismograms are shown in Figure 11.

Lightning Protection

All data lines in the IRIS-2 system are protected using Zener diodes, and DC power lines are protected with a combination of Zener diodes and gas arresters. The use of fiber optic cable for long signal lines will further reduce susceptibility to lightning-induced failures.

Mechanical Configuration

The station DA/DP or DP computer and standard recording equipment, including the monitor recorder, are mounted in a single cabinet. The terminal, printer, and optional plotter are placed on tables. The digitizers are mounted in small sealed enclosures that will be installed in the vault near the seismometers. A small sealed enclosure is used for mounting the DA computer at remote sites. The AC UPS with batteries requires about one square meter of floor space. Normally, the UPS will be located in a separate, well-ventilated room or shed. At SRO stations, the DA/DP or DP computer and standard recording equipment will be mounted in the racks that currently contain the SRO computer and tape drives.



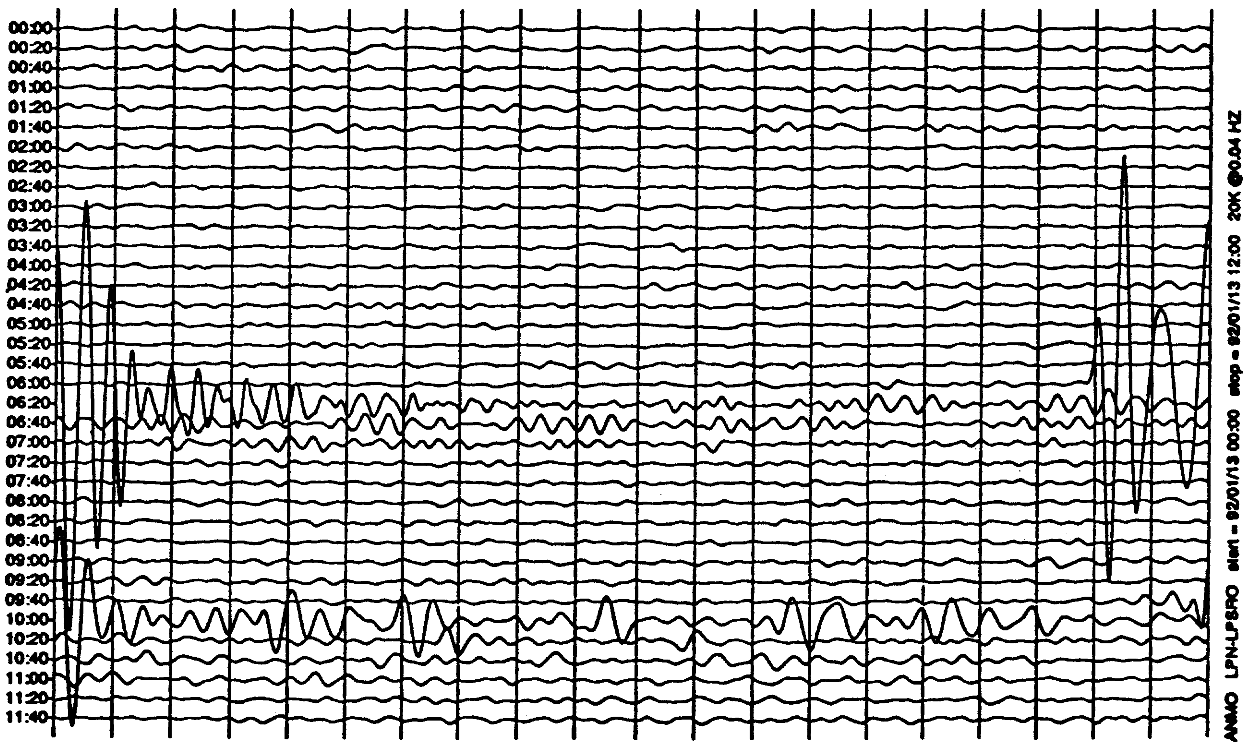


Figure 11.--Reductions of seismograms generated on the optional digital plotter. Originals are plotted on 8-1/2" by 14" paper. The seismogram on the top is 6 hours of data derived from the VBB channel emulating the WWSSN SP response; the bottom seismogram is 12 hours of data derived from the LP channel emulating the SRO LP response.

NETWORK DEPLOYMENT

STATION AGREEMENTS

The first important step in the deployment of the GSN will be to contact organizations that will be asked to participate in the program for the purpose of establishing the necessary approvals to upgrade existing stations or install new stations. Formal or informal agreements between the USGS and the host organization form the basis of cooperation in the deployment, operation, and support of station equipment. Such agreements have been in effect between the USGS and the WWSSN and GDSN stations through many years of successful cooperation. Typically, the agreements for GSN stations will define organizational responsibilities as follows:

USGS Responsibilities

- Assist with site preparation
- Delivery of equipment to the station
- Installation of equipment
- Training of station personnel
- Provision of operating supplies and replacement parts
- Equipment repair and technical assistance
- On-site maintenance when required
- Prompt return of original data to station if requested
- Provide GSN event data on CD-ROMs

Host Responsibilities

- Site preparation
- Assist with importation of equipment
- Furnish vault and space for recording equipment
- Furnish power to operate equipment
- Furnish local data telemetry link if required
- Furnish dial-up telephone circuit to station
- Assist with installation of equipment
- Operate and service equipment
- Notify maintenance center of any problems
- Mail data promptly to the data collection center

SITE PREPARATION

Each station will be visited prior to the installation of the IRIS-2 system, and a detailed site plan will be developed in cooperation with the host organization. Important considerations are the vault type, the system configuration (separated or compact), type of local telemetry, if used, analog recording requirements, and commercial power specifications. The site plan will include layouts showing the location of the sensor systems, recording equipment, power equipment, and the power and signal cables. It will detail any special requirements for extra length cables, new conduit, air conditioning, building modifications, and so forth. Most stations that will receive IRIS-2 systems already have adequate vault and recording facilities. The IRIS-2 system will require less vault space, less space for recording equipment, and less power than most equipment that it will replace, so major site preparation work is not anticipated.

However, many older stations that were once located at quiet, isolated sites have become noisy because of urban encroachment or other factors. Moving the entire station may be too difficult, costly, or impractical, but it may be feasible to relocate the seismometers to a remote site and use a telemetry link between the DA and DP modules. The minimum requirement for this link is that it be a reliable dedicated duplex 2400-baud circuit. A line-of-sight radio link is a very good solution where feasible because it is reliable and there usually are no recurring costs of operation. However, dedicated voice-grade telephone circuits usually provide the most flexibility in choosing a site. In either case, the USGS can assist with site testing and development of plans. A decision to relocate must be made carefully because there may be a tradeoff between improvements in short-period noise, which depends largely on the proximity of cultural noise sources and surface geology, and the possibility of increasing long-period noise, which depends to a large extent on the depth and condition of the vault.

INSTALLATION

The time required to install an IRIS-2 system is expected to be three or four weeks depending upon the system configuration and the type of sensor systems to be used at the site. The first week is typically used to complete minor site preparation work, install and test the sensor systems, and assemble the data recording equipment, the second week to perform the component and system tests and complete the installation report, and the third week to monitor system performance and train station personnel.

Because of the importance of information concerning the station, a special Installation Report form will be used specifically for GSN stations. Following formats used during deployment of the WWSSN, GDSN, and CDSN networks, the report will contain a brief history of the station, a detailed description of the vault and other facilities, coordinates of the sensor systems, notes on local geology and topography, a description of nearby cultural and natural sources of seismic noise, a list of equipment and sensitivity constants, calibration and test instructions in cookbook form, and test results.

TRAINING

The training of station operators is a very important part of the deployment plan. The IRIS-2 system will function on a day-to-day basis with very little operator intervention. At the same time much greater interaction between the operator and system is provided when needed to reconfigure operating parameters, monitor system operation, perform calibration and diagnostics, and to access and process the data for local use, all of which are implemented using menu-driven programs developed to serve as an interface between the operator and the system.

An important part of the training will take place at the station when the system is installed. All phases of system operation and maintenance will be covered using a structured training program developed specifically for use at the station after the equipment is installed, tested, and placed in operation.

The USGS hopes to provide IRIS-2 familiarization training for station operators at the Albuquerque Seismological Laboratory (ASL) prior to installation, as it has in the past for SRO and ASRO station operators. Familiarization with the system hardware and software makes the station training much more effective, and the time spent at the ASL greatly enhances communication and cooperation between station operators and network support personnel. Familiarization training at Albuquerque is not a definite part of the program plan at this time; it depends on the availability of funds.

The requirement for training will continue after the new instrumentation has been deployed because of operator turnover and modifications to the equipment. Initial training at the stations will be followed up by the distribution of training courses, special instructions, and diagnostics on software tapes that can be loaded and accessed through the operator terminal.

NETWORK OPERATIONS

INTRODUCTION

Like its predecessors, the WWSSN and GDSN, the new GSN will be a global infrastructure comprising the network stations operated by the host organizations, a data collection center, a network maintenance center, and data management centers, as illustrated in Figure 12. The basic product of the network is a data volume compiled by the data collection center from station data for a specific interval of time. These are provided to data management centers which often reorganize the network volumes into libraries and data files that are more convenient for data users to access. Some data centers, including the IRIS and USGS data centers, serve the general community of data users, while others may serve a select group of data users.

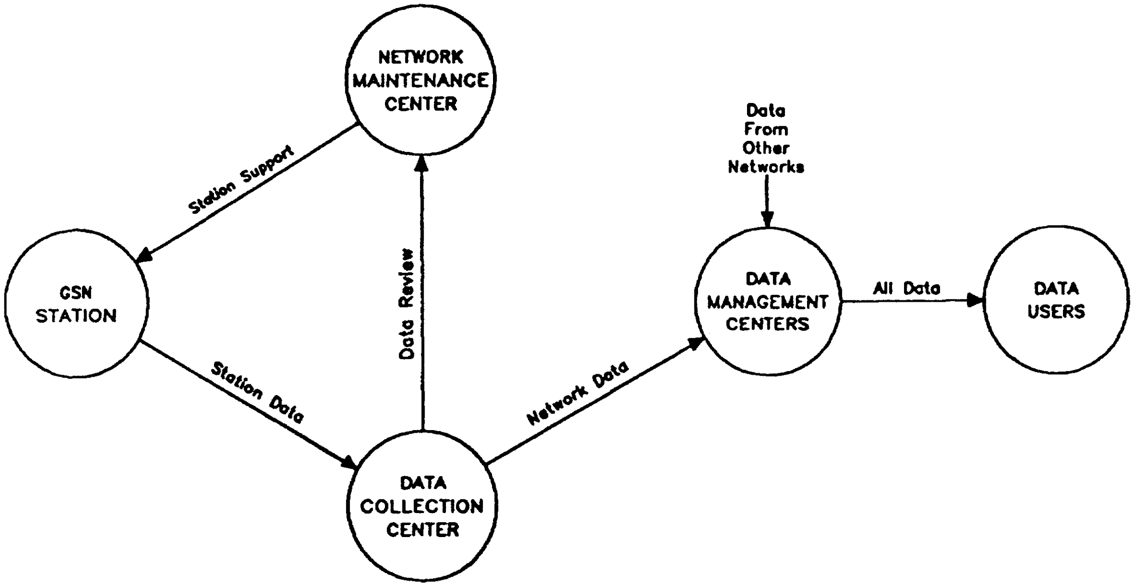


Figure 12.--Elements of a global seismograph network. The diagram does not show all of the important interactions between the network components.

Each station, the data collection center, and the network maintenance center are tightly coupled in the sense that they interact on an almost daily basis. These are the three elements of the network that have operational roles in producing the network data volumes. Data recorded at each station are sent to the data collection center where they are reviewed, reformatted, and merged with other station data in a mass store facility. Support for the operation is provided by the network maintenance center which furnishes supplies, parts, and training and responds to problems reported by the station or the data collection center. The operation of the new network will be modeled on past operations of the WWSSN and GDSN networks. Most of the organizations that will be involved in the new network are thoroughly familiar with procedures used in the past for the interchange of data and support. Nevertheless, a review of network operations will be useful because the new generation of instrumentation provides some opportunities to improve procedures both at the stations and at the supporting centers, which are located at the Albuquerque Seismological Laboratory.

STATION OPERATION

As stated earlier, the IRIS-2 system has been designed to function with minimal operator support. On a daily basis, the operator will change paper on any analog drum recorders being operated at the station and check the terminal and printer for messages. Status messages will be printed every eight hours. They contain quick scan low-level diagnostics, such as the average values and standard deviations of background noise on the data channels. Any error messages generated by the system are written to the terminal and printer as are any incoming messages sent to the station via the dial-up line. The printout will also contain a list of all event detections and a log giving the name and organization of anyone who has logged into the system via the dial-up port. Tape cartridges will be changed at two-week intervals; then the cartridge with recorded data will be mailed to the data collection center using current mailing procedures. Periodically, the operator will clean the heads in the cartridge drives and check the electrolyte levels in the UPS batteries if unsealed batteries are used. These are the only preventive maintenance procedures required.

The routine procedures described above are sufficient to keep the system operating normally on a day-to-day basis. However, the operator has access to much more status information and system control as well as the data using menu-driven programs available at the terminal. The operator can examine active processes running on the system, send dial-up messages, review and edit detection parameters, list all of the segments of data stored in the buffers, list an activity log showing all of the information and messages that have been on the screen, activate calibration, and select channels of data to be recorded on the monitor recorder. He or she can display on the screen for analysis any segment of data stored in the continuous or event buffers and make hard copies of the waveform on the printer or optional plotter. The operator can also select segments of data from the main temporary buffers for storage in an archive buffer for later display and analysis. The processes available to the operator for control, diagnostics, and data display are almost certain to be expanded in the future as refinements are made to the application software.

The role of station operator becomes especially important when problems develop in the system, and of course these events are inevitable. There are many self checks in the system that produce error messages to assist the operator in isolating defective boards and modules, and these procedures will be expanded and refined as operational experience with the system is accumulated. Much of the operator training will address trouble shooting and diagnostics. The ability of the station operator to correct a problem at the station usually depends mostly on the availability of replacement parts. If a replacement unit is available at the station, downtime is minimized; if not, the operator must request a replacement from the network maintenance center. The level of replacement parts initially assigned to the station represents an important tradeoff between deployment costs and network reliability. A high level of station spares to include major components clearly reduces the amount of data loss during a failure, but it is also very expensive. In the case of the GSN, cost is likely to be the decisive factor. Some experience with component failures in the IRIS-2 systems is needed before a final list of station spares can be developed.

Good communication between the station operator and the network maintenance center is essential so that assistance can be provided when needed. Communication channels have been established over the years with most of the stations, and efforts will be made by the USGS to improve these channels where improvement is needed.

NETWORK MAINTENANCE

Introduction

GSN stations will be supported by a Network Maintenance Center (NMC) that was established at the Albuquerque Seismological Laboratory during deployment of the WWSSN. Although the technology has changed dramatically since then, the organizational concepts and basic functions of the NMC have changed very little. One of the serious problems of network support has always been the difficulty of obtaining adequate funding. While the deployment of new instrumentation is usually undertaken with much enthusiasm and support, funding agencies find it very difficult to sustain their contributions to the operational network over a long period of time. Thus, a very important strategy for network support is to insure that the instrumentation is reliable and supportable to begin with and that the support facilities and inventories are well equipped and well stocked. It also helps to have well-trained station operators and support personnel at the outset.

Network Maintenance Center Functions

The goal of the NMC is to maintain the highest possible level of network data availability by providing close support to the stations. The first important task is to provide the stations with the supplies and replacement parts needed for day-to-day operation. This is not a trivial effort considering the complex shipping arrangements necessary to support stations in over 50 countries and islands, each with its special customs regulations. However, these procedures have been established and refined over a period of years.

Equipment repair is one of the most important functions of the maintenance center. Some defective equipment must be returned to the manufacturer for repair, but most can be repaired in the ASL electronics shop, saving considerable time and expense and reducing the number of spare components required to support the network. The electronics shop has one of each type of supported system installed to serve as a test bed for diagnosing problems and checking repaired boards and modules. Both Type M and Type Q GSN systems are designated at ASL for this purpose.

The NMC maintains the station files. These include installation reports, maintenance reports, calibration test records, correspondence and messages, shipping documents, export licenses, and any other documents related to individual station operation. The NMC also maintains the manuals, source codes, drawings, schematics, and other documentation describing the data acquisition systems, maintains detailed records of system modifications on a station-by-station basis, and maintains statistics on component failures.

The NMC is responsible for the training of station operators and support personnel. Although most structured training takes place before and during deployment of the instrumentation, there is a continuing need for training as modifications are made to the system and as a result of operator turnover. In the case of the IRIS-2 systems, there are attractive possibilities for distributing instructions and training on tape.

The NMC provides engineering support for the network. The first modifications of a new data acquisition system inevitably precede the first installation, and they are a recurring practice thereafter. System performance must be closely and continuously monitored to identify software bugs and hardware design problems. Feedback from the station operators is especially important during the initial operation of new instrumentation. Hardware and software modifications must be carefully tested and evaluated before they are implemented on a network-wide basis.

The NMC provides field engineers for on-site station maintenance when visits are needed to install modifications, update training, and assist when failures cannot be corrected by the operator. Massive failures caused by lightning strikes and malfunctions in borehole seismometers are examples of problems that often require expert assistance. Unfortunately, field support is expensive and is usually the first maintenance function to be affected when the operating budget is reduced or eroded by inflation.

Effective communication is needed between the NMC and the supported stations. Telephone, telex, and facsimile are the most common methods of communication at present. Where dial-up circuits can be established, the NMC will be able to communicate directly with the IRIS-2 system to exchange messages with the operator.

With the deployment of the IRIS-2 data acquisition systems, the interaction between the stations and the Albuquerque Seismological Laboratory are likely to become more frequent and broader in scope than they have been in the past. The potential for this new VBB seismograph system to provide high-resolution digital data in support of local analysis and research is certain to generate special interest in the data retrieval and processing functions of the IRIS-2 system. Because there is excess computer capacity at the station, many of these features can be expanded and refined in the future. For example, custom amplitude responses may be digitally simulated for study of local and regional events, and programs can be developed to aid in the preparation of earthquake reports. There are likely to be many such suggestions from the station operators after they have become familiar with the IRIS-2 system. Local use of the data and data processing features will be encouraged and supported because it is important that the capabilities of this versatile new seismograph system be exploited to the fullest at the stations as well as by the research community at large.

DATA COLLECTION

Introduction

The basic functions of a seismological data collection center were instituted with the establishment of the WWSSN. Seismograms were collected from the stations, reviewed for correct labeling, calibration, and quality, then microfilmed, archived, and organized for efficient retrieval, and finally copies were distributed to data users on request. After copying, the original seismograms were returned to the stations, and the stations were advised of any problems noted during data review. These procedures are still operational. The functions changed little with the advent of digital recording in the early 1970's. Since then the volume of digital data and complexity of operations have both increased substantially, but the only important functional change has been that the data collection center now does not normally distribute data directly to the data user. Data management centers have evolved to merge data from several networks and to organize the data to provide more efficient access by the end user.

The Albuquerque Seismological Laboratory has operated a digital data collection center (DCC) since the earliest deployment of digital systems and will continue as the principal data collection center for the GSN. The need to revamp and expand the DCC was dictated by the extraordinary increase in data volume that is expected over the next several years. In 1989, when this report was first drafted, the ASL DCC processed approximately 30 Mbytes of data each day, collected principally from the GDSN and CDSN networks. In late 1996 the amount of digital data processed each day had increased to 1,000 megabytes. Each new GSN station increases the data load by another 5 to 20 Mbytes, so the volume of data processed at the DCC is expected to approach 1,500 Mbytes within a few years. New concepts, new hardware and software, and greatly increased automation were needed to keep pace with the increasing data flow. Since the capacity to process network data had to be in place before the network was deployed, the expansion of the data collection center at ASL was given a high priority. IRIS began purchasing hardware for the new DCC several years ago, and concurrently application software was developed at ASL. As a result, the new, expanded DCC is already in operation.

Data Collection Center Functions

The principal role of the DCC is to review data collected from the network stations and merge them into a collated data volume that can be easily copied and distributed. The data volumes must be in a standardized format and contain all of the station and data parameters needed by an analyst to fully characterize the recorded signals. The process involves several tasks.

All of the incoming data arrive at the ASL DCC on tape reels or high-density cartridges, usually within 30 to 40 days of the recording date. The data tapes, which currently are written in several different formats, are read and loaded into a disk staging area. During this process the data records are checked for continuity, correct format, correct timing, correct record lengths, hard read errors, and correct header information. State-of-health and other parametric values are monitored. Except for time errors, all corrections and salvaging operations are performed automatically as the data are loaded into disk. After the data records are in the disk, a time edit list is produced that tabulates any time errors and provides a summary of the data record quantities. Timing errors are the most common form of errors in the GDSN data, usually caused by transients that affect the clock, operator error in setting time, or gaps in the data. Corrections can be made to repair time errors using either an automatic editor or a manual screen-oriented editor.

After any corrections needed have been made to the subsidiary information on the record headers, the data quality is evaluated. A series of waveform plots are made automatically, including 24-hour seismograms plotted on a reduced scale, and calibration signals are automatically plotted and checked for stability. The original seismic data are not modified in any way. However, comments are placed in the data logs on the network volume to alert data users to data or calibration anomalies. Data qualification procedures are being improved and refined with further automation. The comparison of recorded and synthetic earthquake signals is planned, as this is an effective means of revealing polarity reversals and gross timing errors, which have been surprisingly difficult to detect in the past. Data from the new GSN stations are expected to have much higher quality than data from the GDSN because of the automated time correction and the quality control procedures that are available to the operator at the station.

After review and editing, both the original station data and corrected versions of the station data are archived on an optical mass storage device. Problems and defects found during initial review and edit or during quality control are reported promptly to the network maintenance center so that steps can be taken to correct them.

After the data from all available stations have been processed, the data are demultiplexed and repacked into a network volume using SEED format, then written to an optical disk for permanent storage. Currently, network volumes containing several days of data are read from the optical disks and written on 6250 bpi tapes or high-density cartridges for distribution to data centers. High speed digital links may be used in the future for transferring data from the DCC to the data centers. The DCC also serves as a communication interface between the network and the data centers and data users. The data users are the final evaluators of network performance, and their feedback is essential to maintaining data quality.

Data Collection System

A flexible, expandable design was needed for the IRIS/USGS data collection system so that capacity, investment, and technology can be tailored to current requirements, making it less costly and less susceptible to rapid technological obsolescence. Reliability is an essential attribute because the flow of data into the DCC is relentless. A prolonged failure can mean weeks or months of catching up. Expandability and reliability are both enhanced by splitting the computational load between several high-performance processors. Operated in a cluster, the processors appear to the user as a single large computer, but a failure in one will not seriously impair system operations. Much of the desired automation is achieved through the development of software that reduces the need for operator intervention as the data are processed. A most important step is to reduce tape handling to a minimum, and the optical mass store is the key piece of equipment needed for this purpose.

In its pre-1995 configuration, the ASL data collection system consisted of eight Digital Equipment Corporation (DEC) Microvax II's, two Vaxstation 3100's, and one Vaxstation 2000. With Ethernet as a high speed communications system, and with DEC cluster software which allowed any peripheral to be used with any processor, the Microvaxes appeared to the user as one large processor. Each processor had access to the cluster disk farm which had a nine Gbyte capacity. There were also four tri-density tape drives, two 3M tape cartridge drives for reading CDSN tapes, three Archive Q-150 cartridge drives for reading GSN tapes, and two Exabyte drives for data distribution. The mass store, a Sony "jukebox" style optical double-density disk drive, served both as an archive and as an on-line storage system for a minimum of six months of network data. The Microvax 2000 workstation functioned primarily as a network analysis system for data quality evaluation and served as an auxiliary processor if needed. A Sun Sparc LPC functioned as an electronic mail terminal and a programmer's workbench. The DCC had an Ethernet link to NEIS and was directly on the NSF Internet and NASA SPAN networks.

Clustered VAX/VMS was used as the operating system, and all application software had been written in C language. The Sun system provided a UNIX environment that could be used to modify application software for UNIX-based systems. A backup power system has been in operation at ASL for several years. It provides 10-15 minutes of uninterrupted battery power for computers when line power fails, sufficient to allow an orderly shutdown during working hours.

A major upgrade to the DCC hardware occurred during 1995 and 1996. DEC/VAX equipment was completely replaced with Sun workstations and all new production software was implemented in the UNIX environment. A 120 Gigabyte RAID (Redundant Array of Inexpensive Disks) SCSI disk system was installed, providing a much larger working space along with fault tolerant operation. In addition, a Metrum VHS tape based mass storage system was installed alongside the existing optical jukebox, providing an additional 980 Gigabytes of on-line data storage (as well as an unlimited on-the-shelf storage space in the form of VHS tapes). The upgrade to new computer, storage equipment, and software has made it possible for the ASL DCC to keep up with the rapidly expanding daily data volumes from the new GSN stations.

Other buildings at ASL are connected to the DCC system on an Ethernet link through fiber optic cables. An additional function of the DCC is to provide general-purpose computer support to the laboratory.

The IRIS/USGS data collection system has a very flexible design that can be scaled up or down to perform data collection, review, assembly, and storage in support of local, regional, or global networks. It is intended that the data collection system design, both hardware and software, be made available to any organization that requires a computer facility to perform these tasks. Documentation describing the IRIS/USGS data collection system has not been completed, but information can be obtained from the DCC system manager at the Albuquerque Seismological Laboratory.

DATA MANAGEMENT

The success of this program depends ultimately upon the widespread use of the data for earthquake studies and fundamental research in seismology and tectonics. The deployment of the new GSN would be incomplete without the data management facilities needed to insure that the data are easily accessible to research scientists. The major role of a data management center (DMC) is to compile and distribute usable data sets extracted from the large and rapidly expanding archive of global data. There are two data management centers designated to process and distribute GSN data, one operated by the USGS National Earthquake Information Center (NEIC) in Golden, Colorado, and one established by IRIS at the University of Washington in Seattle, Washington. Both receive GSN data from the ASL DCC shortly after initial quality control processing at the DCC, as well as data from other networks.

The USGS NEIC will routinely archive and distribute GSN, CDSN, GTSN, and other FDSN event data. The NEIC has been archiving and distributing event data from the global networks for many years. Most data users are primarily interested in event data, a small enough subset to be distributed in total at low cost. Distribution of event data from the NEIC was made initially using magnetic tape; later, CD-ROM technology was adopted for this purpose. A CD-ROM will hold as much data as 25 1600-bpi tapes and has the additional advantage of using a reading device that is low in cost and compatible with personal computers. The CD-ROMs contain triggered SP and BB data and segments of continuous BB and VBB data associated with earthquakes of magnitude 4.9 and larger and segments of LP data for all events of magnitude 5.5 or larger. Continuous VLP data are included for the entire time span of the CD-ROM.

The IRIS DMC will archive all continuous and triggered GSN data, as well as data from other networks (CDSN, GTSN, FDSN) and data collected from the Program for Array Studies of the Continental Lithosphere (PASSCAL) experiments. The IRIS DMC will operate a data base management system for retrieval of parameter and waveform data in an integrated form from random-access storage in response to customized data requests. The data will be distributed to users on a variety of high-density media or by electronic transfer.

Data management procedures will evolve just as the GSN system is expected to evolve. Both the IRIS and USGS DMCs promote the use of the GSN data and will take advantage of any new technology that will lower the cost and improve the timeliness of data distribution.

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