# PART ELEVEN

# SEISMIC DETECTION/LOCATION INSTRUMENTATION

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## PART ELEVEN

## SEISMIC DETECTION/LOCATION INSTRUMENTATION

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### I. INTRODUCTION

The instrumentation specification in the National Academy of Engineering (NAE) report of March, 1970, set forth some rather general guidelines that the seismic surface system should follow. The fact that there was no comparable equipment in existence at that time, and the need to produce a system from presently available equipment, was spelled out in that document.

The features that the system should include were listed, and included:

- Quick and simple deployment
- Portability
- Battery-powered operation
- All-weather operation
- Computational simplicity and speed
- High reliability and long shelf-life
- Dual service for location and communication
- Adaptability to widely varying seismic velocities, topography, and geologic structures
- Minimum maintenance
- Capability of continuous operation for extended periods, and
- Reasonable cost

Since that report, there has been a substantial amount of field work addressing the trapped miner detection and location problem carried out by Westinghouse Corporation under contract with the Bureau of Mines. Two complete surface systems have been designed, built, and field tested and substantial documentation has been produced on the mine environment and background noise using these systems. These systems, built from off-the-shelf equipment, have been designed with maximum flexibility in mind in order to explore what configuration a field unit should have.

This Part reviews the Westinghouse surface system, reviews the general system specifications in light of present experience, and describes in some detail a recommended system configuration that attempts to meet all the requirements of a truly fieldable system.

## II. WESTINGHOUSE SURFACE SYSTEM

Two complete surface systems were built by Westinghouse on contract† with the Bureau of Mines. Since the fabrication of these systems, a substantial amount of field experience has been gained with these units in actual test measurements at a number of working mines in the United States. Improvements and modifications have been made to the original system as field experience has dictated.

The present system is housed in a portable van that can be transported either by a companion 4 x 4 truck to which it is normally attached or via plane (e.g., a C-47). The instrumentation is self-contained except for primary power and telephone service. Geophones and cables for the array are stored inside compartments for easy accessibility. The power signal and telephone connections to the van are made via clearly marked terminal jacks. For field deployment, the system comes with a second truck to transport a portable 6" drill, spare fuel, and a primary power generator.

The van floor plan showing storage room and equipment layout is shown in Figure 1.* The instrumentation and computer system are centrally placed to balance the van for ease of loading and transport. Figure 2 shows the present equipment layout and jackfield location. The use of multiple jackfields, allows for maximum patching flexibility but does require the operator to be careful in setting up the patching arrangement. The use of commercial equipments throughout tends to provide more gain controls than may be required on a field system.

A block diagram of the complete system is shown in Figure 3. The system can be subdivided into four subsystems:

1. Seismic detection;
2. Signal conditioning;
3. Signal processing; and
4. Location processing.

† Contract H0101262 with Bureau of Mines.

* References to Figures, Tables, and Equations apply to those in this Part unless otherwise noted.

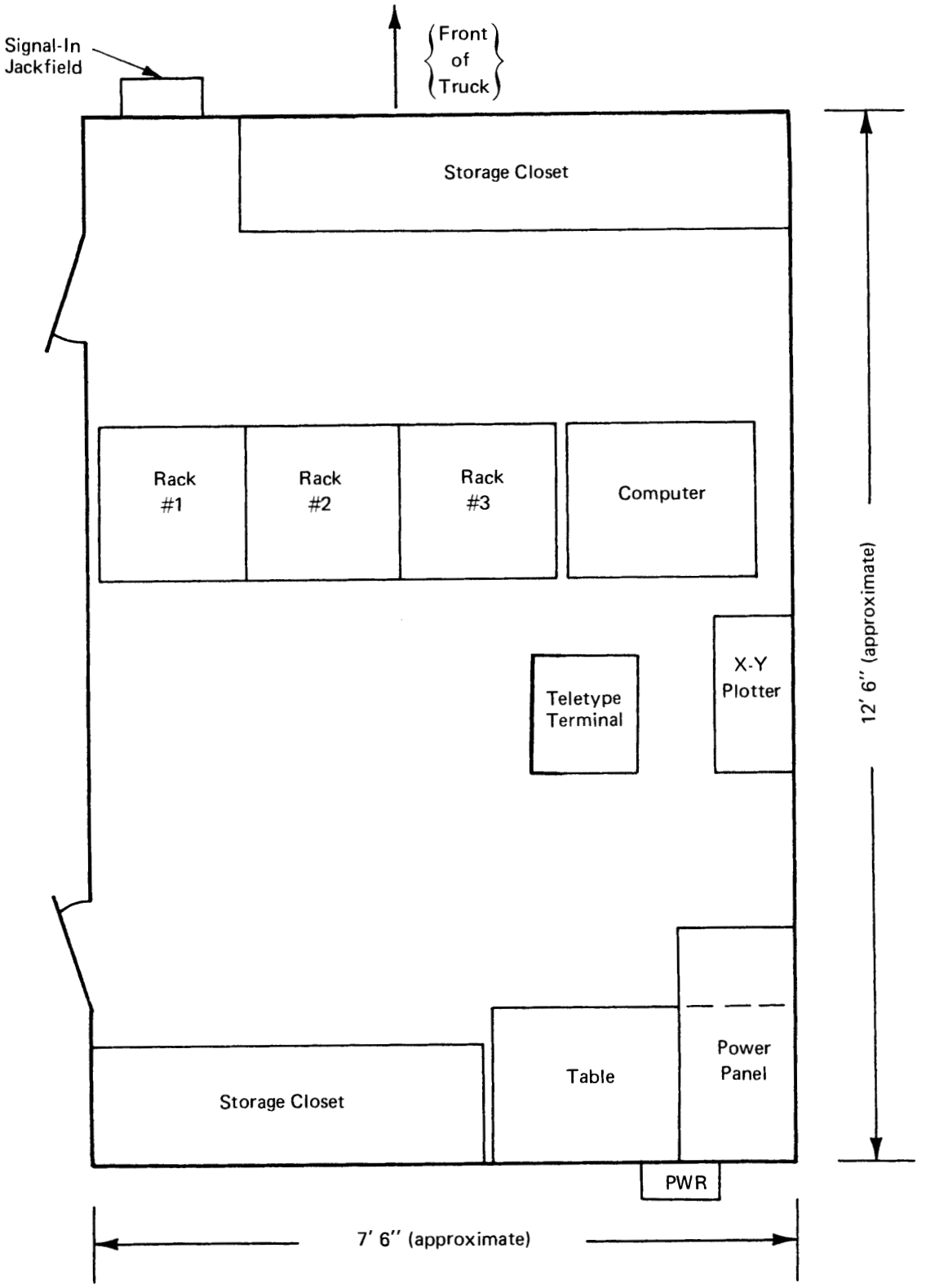


**FIGURE 1 PRESENT SEISMIC SYSTEM (Floor Plan)**

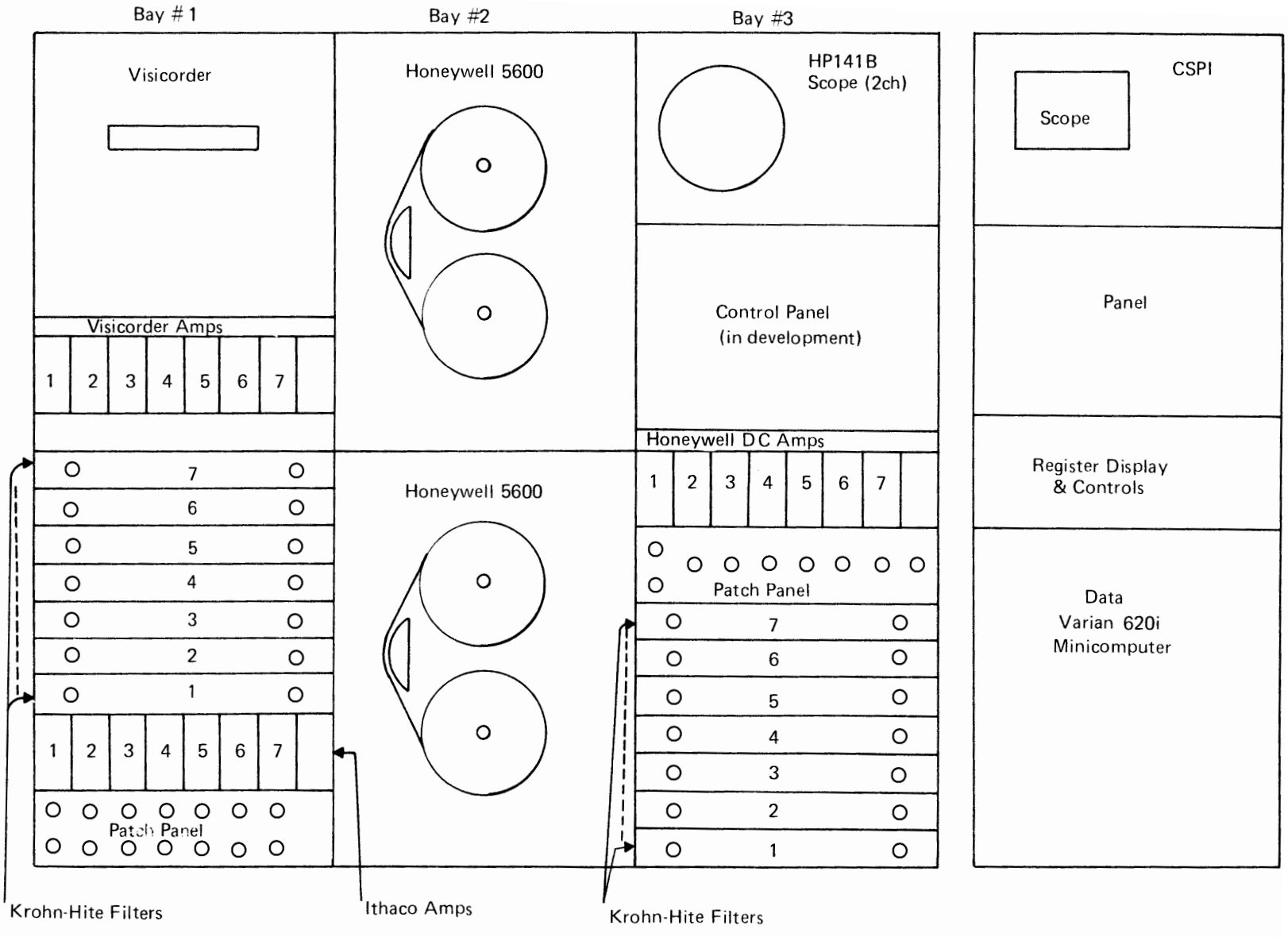


FIGURE 2 EQUIPMENT LAYOUT (PRESENT SYSTEM)

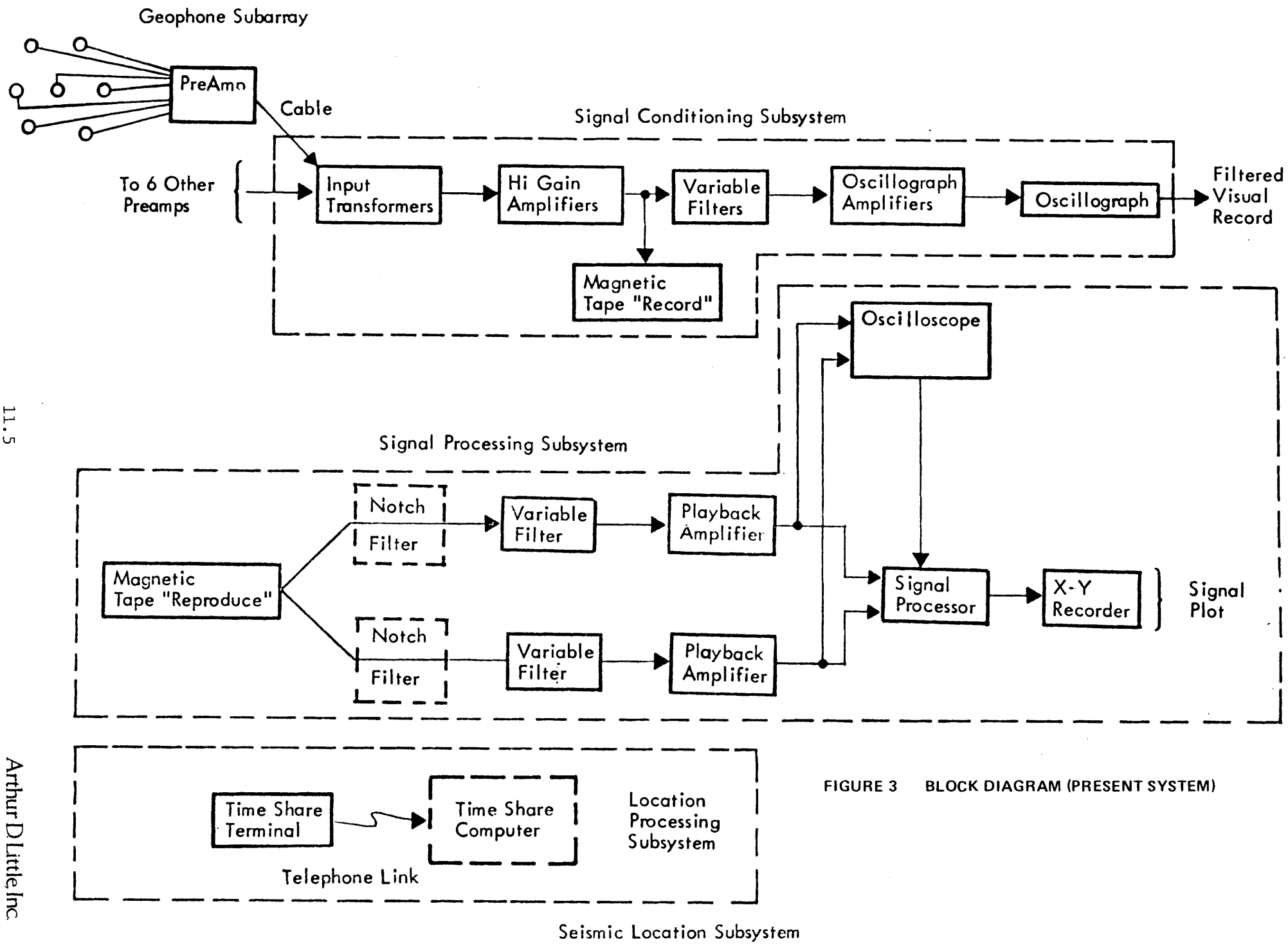


FIGURE 3 BLOCK DIAGRAM (PRESENT SYSTEM)

A. Seismic Detection Subsystem

The seismic detection subsystem consists of the array geophones, associated cabling, and array preamplifiers. The present array configuration is seven array elements each with seven geophones connected in parallel, then connected to a preamplifier. Each preamplifier has a fixed gain of 69db. The output of each preamp is an unbalanced to balanced transformer feeding the signal cable to a connector on the van. The balanced cable system is intended to minimize noise pickup in the system due to external noise fields.

B. Signal Conditioning Subsystem

The input of the signal conditioning subsystem is a balanced to unbalanced transformer matching the array cable to the input high gain amplifiers. Present amplifiers are ITHACO models with an adjustable gain range of -10 to +90db. Nominal gain settings for this amplifier is in the 10 to 50db range producing a signal output of approximately 0.5 volts peak-to-peak (p-p).

In normal field operations this signal is recorded on a seven track Honeywell 5600 tape recorder and/or can be displayed in real-time on a seven track Visicorder.

C. Signal Processing Subsystem

The signal processing subsystem is designed to play out stored data for visual display and/or processing. Processing of the data can be achieved by either varying the filter bandwidth with the Krohn-Hite filter bank, or by processing the signal in the CSPI data processing system for gain enhancement. The CSPI system using the Varian Data 620 i computer can perform fast Fourier transforms on incoming signals or noise, and play out power density spectra on the x-y plotter. On repetitive seismic signals, the computer is programmed to do signal stacking giving a gain enhancement and signal-to-noise improvement over background noise. In the signal stacking mode the oscilloscope trigger circuit is used to detect the signal arrival on one channel and trigger the sampling gate of the computer for the other channels. Two channels at a time are treated in this way. Each channel can be displayed on the x-y recorder for comparative analysis of first arrival times.

D. Location Processing Subsystem

The present location processing subsystem as shown in Figure 3 is not located on-site with the other system. The crew chief now uses the telephone to send

first arrival time data, estimated on-site by viewing all seven channels on the play out of the x-y recorder or the Visicorder. A resident location program called MINER is used in a remote time-share computer to compute the estimated signal source location based on array arrival time data.

## III. SYSTEM MODIFICATION

The Westinghouse system described above has provided a substantial insight into the system and fieldability problems that are encountered in deploying such a unit and making practical field measurements. Some major modifications were incorporated into the Westinghouse system as deficiencies in system performance were identified. The preamplifiers and the high gain amplifiers were replaced along with the tape recorder.

Present modifications now in process call for an increase in memory capacity of the CSPI processing system. The present capacity of 8,000 16-bit binary words will be expanded to 20,000. This will reduce signal processing time substantially and reduce corrective maintenance time. The number of input channels to the computer will be increased from two to eight to reduce the analysis time.

In the signal detection subsystem, current plans call for a change in the present parallel geophone arrangement to a series connection and a new transformer in the preamp to match the new geophone connection. This will improve the sensitivity of the subarray.

A high speed paper tape reader will be used with the computer expanded memory to increase the operating efficiency. Additional amplifiers and filters will be added to interface the tape recorder to the computer.

In summation, the above modifications are designed to expand processing capacity, reduce processing time, and improve system sensitivity.

## IV. SYSTEM SPECIFICATIONS

The specifications listed above in Section I, as spelled out in the NAE report, are still a valid set of specifications. However, in view of the experience gained in the interim period, a more detailed set can now be made covering the seismic surface instrumentation.

Quick and simple deployment can be specified in relation to deployment by any common means of transport. This is related to the availability of the transportation, and requires a somewhat different packaging concept than used up to now. It relates to portability; where the packages could be hand loaded onto a

commercial or private airplane, or on a pick-up truck for over-the-road deployment.

Coupled with the portability is the ability of hand carrying the units over otherwise inaccessible terrain. This requires portable cases with handles and weighing no more than 70 pounds per case.

Battery powered operation is a must in some instances, if the terrain or emergency conditions prevent the use of commercial power.

Experience by the Westinghouse team shows that snow and temperatures around zero require operational units to perform over a wide range of temperature and environment conditions. All units must be weather-tight and not temperature sensitive to expected conditions.

There is a real need for processing speed once the system has been deployed. Processing times of received data should be measured in minutes rather than hours.

Reliability goes with good design. Data acquired should be accurate and reproducible. System operation and checkout should be almost automatic. All systems should be easily checked and calibrated on deployment and periodically recalibrated during the work.

The system should be deployable in various configurations depending on the need for detection and/or location.

The system must be adaptable to the condition expected. For example, there may be occasions when power is not available or telephone communication non-existent. The system configuration must be tailored to operate under almost any condition.

Minimum maintenance and reliable operation is a must if the system is on stand-by at all times. Small portable units incorporating solid state design where possible should meet this criterion. Continuous operation for extended periods of time is feasible with small rechargeable battery operated units.

The concept of small portable units could reduce overall program costs, since specialized equipment may not be necessary.

## V. SUGGESTED SYSTEM CONFIGURATION

The need for a truly portable hand carried system has been established in many cases during the extensive field work*in the past two years. Contrasted with this is the requirement of computer equipment to perform signal processing to enhance signal-to-noise in high noise environments. Thus, the suggested system described in this section will attempt to meet these conflicting requirements in addition to all the others stated above.

Our approach to the system configuration is to recognize the fact that there are a wide span of field requirements that must be met. These range from the need for possible simple detection processes in remote quiet areas to a complex detection/location problem in high noise environments with relatively easy accessibility. In one case, a simple hand carried system with hard copy play out may be all that is necessary, where in the latter case a full system with a sophisticated computer system may be required. We have, therefore, taken a modular approach, with each subsystem capable of add-on to meet the existing requirements.

In each of the portable package designs described below, we have considered only equipment that is now available. Little or no major R&D work is required to produce the field package described below, only good equipment layout and packaging design are required. Figure 4 shows the overall block diagram of the suggested seismic detection subsystem. A description of this subsystem and the signal process- and location subsystem will be covered in the following sections.

### A. Seismic Detection Subsystem

The seismic detection subsystem consists of the array element geophones, the associated cables, and a hand carried array control unit.

We recommend geophones that can be placed in boreholes, or on the surface if hard rock overburden is encountered. The phones could be of the marine-type, since they are more sensitive than the ones now used. Tests conducted with the Westinghouse system indicated a 6-8 db discrimination to local noise sources with a geophone buried one foot in the ground. The phones should be completely sealed against water since they will frequently be in water.

A hand auger can be used to make the boreholes for easy implantation. A much better coupling could be established to the surrounding earth if dirt were tamped back over the phones, or if some form of integral bellows arrangement could be used to expand the phone casing to the borehole walls.

Integral with each geophone should be a preamp with 70 db of gain, and a calibration coil that induces a known motion to the phone sensing elements.

* Westinghouse Contracts H0101262 and H0210062 with Bureau of Mines.

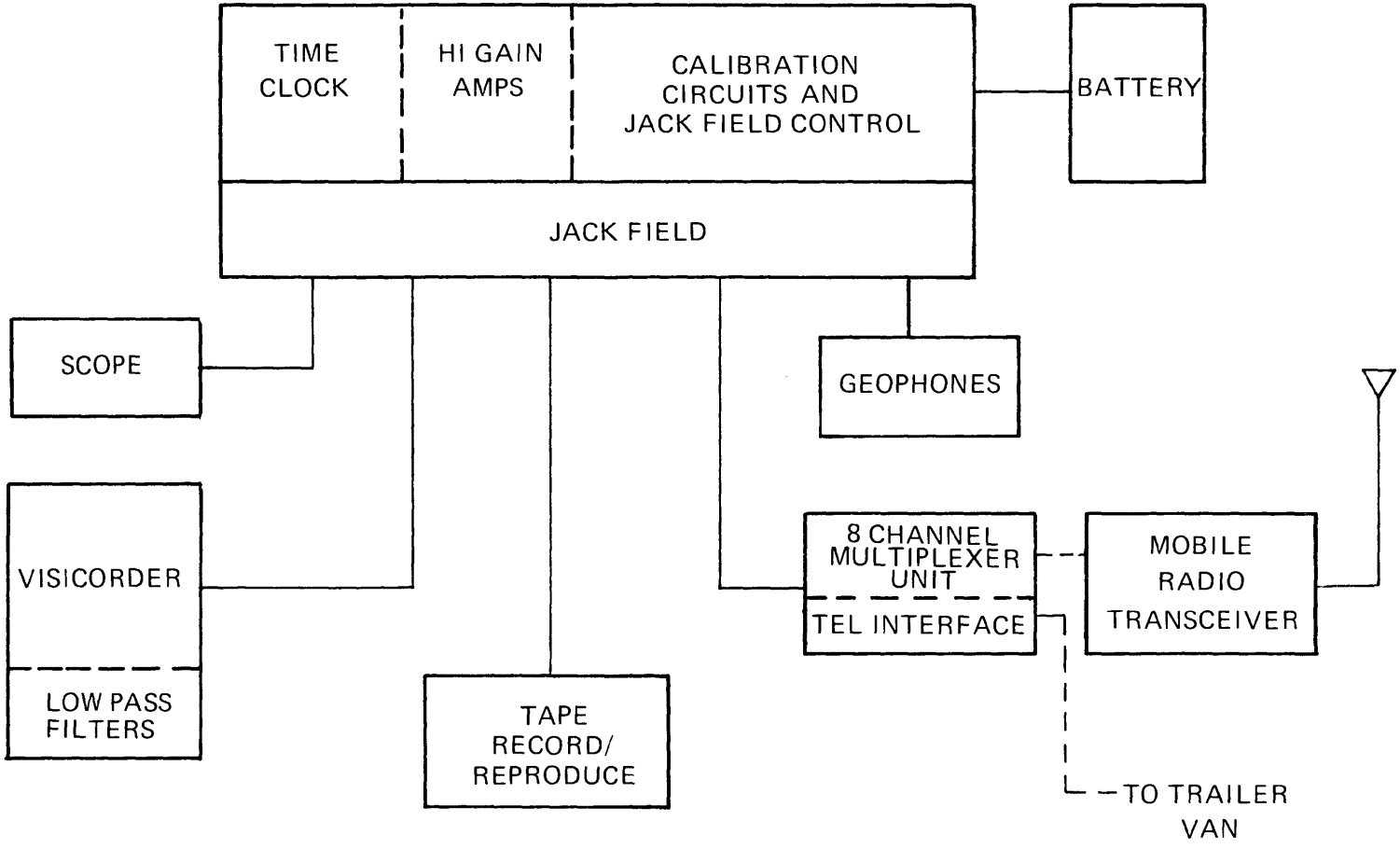


FIGURE 4 SUGGESTED SEISMIC DETECTION SUBSYSTEM

The calibration circuit is necessary to establish the proper operation of each phone in the array, and to reference the relative delay in the system between channels. Should a delay exist, for example, in the tape recorder subsystem as was the case in the Westinghouse system, the delay can be recognized and measured. First-motion picks on seismic signal records could then be adjusted to allow for instrumentation delays.

Should multiple geophones be used for each element array, we recommend they be wired in series for the output signal to achieve greater sensitivity than the present arrangement, and that each calibration coil be connected individually to ensure the proper operation of every phone in the array.

In configuring this system, we considered the use of digital vs. analog geophones. The use of digital geophones has many advantages in field applications. Digital systems are more immune to noise interference than analog systems, and once in digital format, waveforms can be processed in a more convenient manner. An additional advantage is the ability to obtain a greater dynamic range of up to 90 db by utilizing digital formats, geophones, and recorders. The maximum dynamic range of current analog systems is approximately 45 db.

The use of the system for miner detection would require only the array and a portable scope and Visicoder system. Since the signals on the scope and the Visicoder are analog, we see no reason to complicate the front end of the system with A/D and D/A circuits. The need for a large dynamic range in the system has not been demonstrated in the Westinghouse field work. Therefore, with a proper gain setting, a 40 db dynamic range seems adequate for all expected conditions. Considering all the advantages of both systems, we have concluded that for this application, the use of the analog format in the array system is preferable to digital.

The cable connecting each geophone to the control unit should be a three twisted pair cable with a separate external shield. A balanced transformer should be used at the geophone output interface and the control unit input circuit interface. The ground return can be the geophone housing connected to the external cable shield and the control unit case. The third pair of wires are used to power the geophone preamp from the control unit battery supply.

The array control unit should be a hand carried aluminum watertight case approximately 2 x 3 x 1 feet and weighing under 75 pounds. Key elements in this unit are:

a. system time clock,

b. main amplifier and gain adjust unit,

c. control status panel, and

d. battery unit.

There is no stringent accuracy requirement on the system time clock, since the relative signal arrival times are the important information required. The time clock, therefore, should be capable of coding the local time by minutes in a format suitable for placing on the voice channel of the tape recorder. This time code can be used for computer tape search during the processing of data. In addition, to minutes time codes, pulses of 5, 10, and 50 ms should be available on the tape. These pulses will be used to accurately measure arrival times of signals, and gate the computer accurately during the processing phase.

We have reviewed the use of portable tape recorders, and believe that either a portable seven (7) or fourteen (14) track analog system is feasible. Good systems are available that use an FM format and meet all IRIG specifications. These units are more than accurate enough to meet the system requirements. The expected portable package should be no more than 24" x 16" x 12" in dimensions, and weigh approximately 80 lbs.

The main amplifier circuit should be a stable high gain amplifier with a gain adjust over the range of 0 to +90 db. These amplifiers should have two modes of operation; one mode a straight gain where the gain of the system is set by the amplifier control setting. This is used in calibration procedures. A second mode should be an AGC mode where once the system gain has been set for standard output levels, the system can maintain a standard output level of 1.5 volts peak-to-peak under varying input signal levels. AGC can be used effectively since arrival times are of importance and not absolute signal levels.

The control status panel consists of the calibration circuitry, switch control, and output signal switches to display individual channels for oscilloscope viewing, or all channels for magnetic tape recording. Output BNC and/or multipin connectors will be used to connect to companion units such as the portable oscilloscope and magnetic tape recording systems shown in block diagram form in Figure 4.

The hard copy play out unit shown in Figure 4 can be a portable unit equivalent to a Visicoder unit capable of reproducing all seven channels plus the timing track. This will allow first cut estimation of arrival times on each channel, and with the control status panel and array unit, constitute a complete austere field system. Integral with the Visicoder unit would be a switchable low pass filter unit for each channel. Suggested cutoff frequencies are 200 Hz and 500 Hz. A filter roll off of 24 db per octave is recommended.

A key field unit in this system is the 8 channel MUX* and a telephone interface unit shown in Figure 4. This unit is designed to interface directly with the array control unit and works with the standard level output on each channel.

Each channel consists of an input buffer stage coupled to a VCO with a center frequency assigned to allow seven signal channels plus a time channel to be sent over a standard telephone line. The output of each VCO is then combined and buffered to a common output circuit designed to reflect to the telephone system an off-hook telephone set. A standard telephone set is also incorporated in this unit to permit communication between the field crew and/or the data processing center. Should telephone lines be available, the array subsystem, array control unit, oscilloscope, and the 8 channel MUX unit could constitute the entire field system. Data processing could then be performed at any point in the United States (Boulder, Pittsburgh, etc.).

The interface to the telephone line can be a short patch or may be in some cases up to several miles of 20 gauge cable. This cable may in many cases interface on a hard wire basis with the trailer van described later.

An alternative to the telephone hard wire connection could be another hand carried package housing a mobile radio transceiver. This could provide radio transmission of the data to some more accessible location at which point the data could be interfaced with the telephone network or to the trailer van.

B. Seismic Signal Processing and Location Subsystem

The trailer van subsystem is configured as shown in Figure 5. Major components are the minicomputer and associated A/D converter and disk pack, variable filter banks such as the Krohn-Hite, an x-y plotter such as a Calcomp, Visicorder or equivalent for hard copy play out, and a monitoring unit with a memory type oscilloscope.

In addition to the equipment above, an eight channel discriminatory bank and a mobile radio transceiver would be required to interface with the field units. Telephone equipment with signaling capability would be required should the communication link be hard wired.

A more powerful minicomputer, in the PDP-11, class and associated disk pack has the following advantages over the present system:

1. It appears likely that computer programs already in existence for signal processing, and system organization and control may be available to the Bureau of Mines.
2. The disk pack arrangement with digital format is more efficient in interfacing a computer in the signal processing mode. Access time is significantly less, programs are available on data search, and

*MUX = Multiplexer

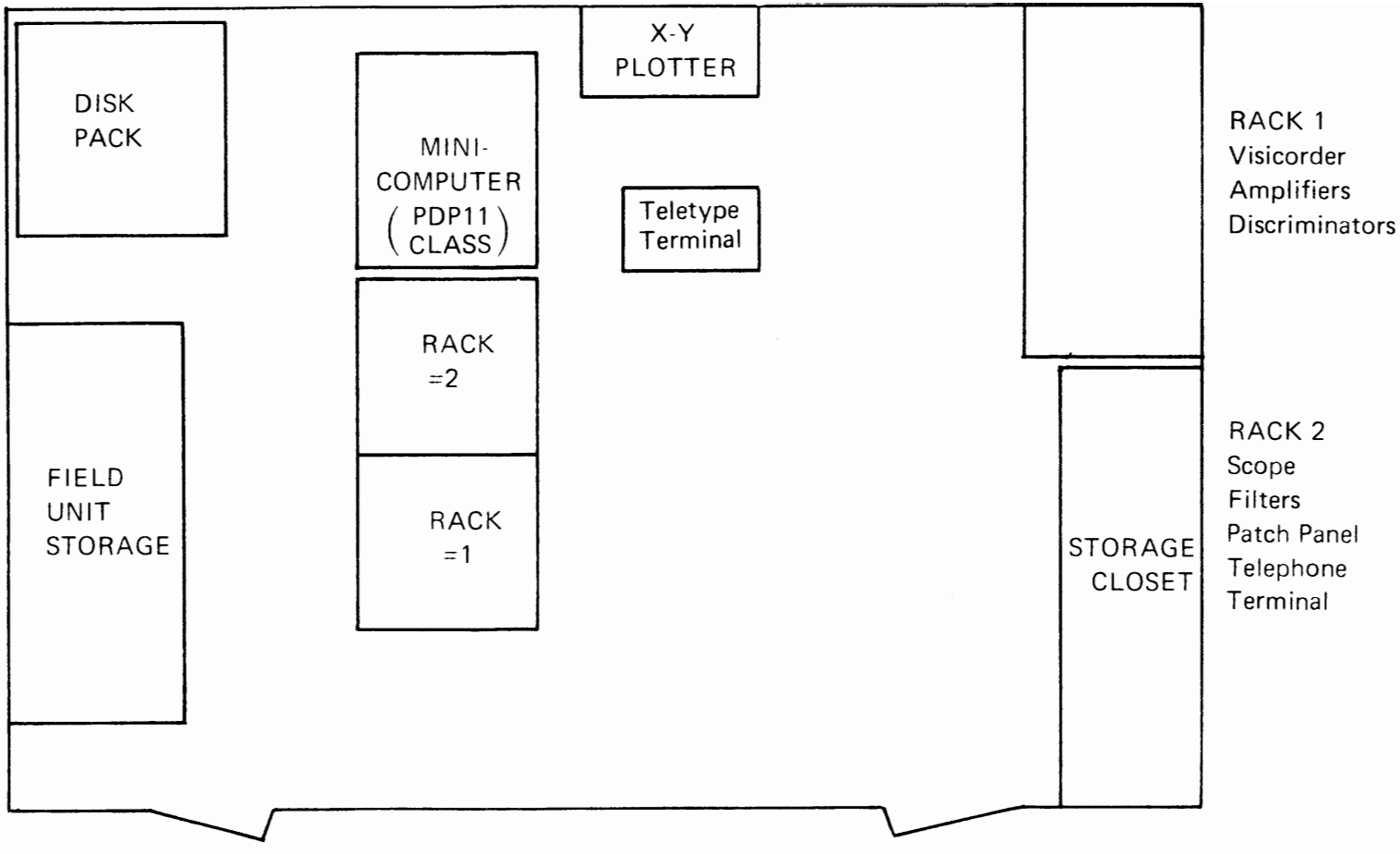


FIGURE 5 SUGGESTED TRAILER VAN SIGNAL PROCESSING AND LOCATION SUBSYSTEM

reproduction costs are also competitive.

3. Location programs such as "MINER" could be incorporated in this system thus eliminating the need for an additional time-share facility.

## VI. DEPLOYMENT

The suggested configuration described above solves the critical requirements of portability, rapid deployment, and cost. It is flexible in configuration to satisfy a wide range of needs and is of comparatively low cost for initial purchase and maintenance.

We visualize a possible deployment of this system in phases: on notification of a disaster, the initial deployment would be of the array subsystem, the array control unit, and the scope. These three units are sufficient to perform the initial function of miner detection. They can be hand carried on a commercial airliner or even in a passenger car. They are reasonable in cost so that a number of these could be placed in strategic locations throughout the United States. We expect that such a subsystem could be deployed and begin the miner detection process in several hours. Several variations in this scenario can be made. If telephone lines are known to be available and working, it is conceivable that as a fourth unit only the 8 channel MUX need be deployed and real-time data collection and processing could be performed at Pittsburgh, for example. On the other hand, a full blown system may be more convenient on-site, in which case the trailer van and additional subsystem units could be deployed as soon as possible. The important characteristic of the portable system described in this section is the ability to begin the detection process in a minimum of time, and to deploy the larger and more cumbersome comprehensive location system later when it is needed. In many cases, the van may not even be necessary.

In summary, the suggested system represents a truly portable self-contained system that is self-calibrated, tested, and usable under a wide variety of conditions. It is modular in growth to match every type of disaster condition, and is reasonable in cost. All system units and circuits described are off-the-shelf items that can be integrated and packaged to satisfy the above-described system requirements.