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DEVELOPMENT OF
AN ADVANCED OCEAN-BOTTOM SENSOR SYSTEM

ONR Contract N00014-77-C-0606

Final Technical Report

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Abstract

A low-cost, light-weight, long-life ocean-bottom sensor system has been developed. It incorporates three microprocessors, which control data acquisition, intermediate processing, and recording, all in digital form. The system has been used successfully in several seismic field experiments, which include detection of natural earthquakes, seismic refraction surveys and investigation of acoustic wave propagation.

I. Introduction

The University of Texas Institute for Geophysics (formerly Marine Science Institute, Galveston Geophysics Laboratory) has been involved in developing a low-cost, light-weight, long-life instrumentation system that operates on the ocean floor at any depth to detect and record seismic signals. The development of this ocean-bottom seismometer (OBS) system has been supported by several governmental agencies and industrial sponsors, including the Office of Naval Research (ONR), for which this report is being written. The most significant improvement to the OBS system during this ONR contract is the digital control, processing and recording of acquired data. Several field tests have also been conducted concurrently with the instrumental development, with objectives of distinct interest to the Navy.

This report first summarizes these various activities and accomplishments during the contract period. This is followed by a description of the developed OBS system. Finally, our current development effort since the termination of the contract support and some future plans are briefly described.

The almost entire activities reported here were performed by two of the principal investigators, Gary V. Latham and Paul L. Donoho, who are no longer with the Institute. All the credit for many innovative concepts and accomplishments described here belongs to these two dedicated scientists, while the present author is responsible for any inaccuracies in presenting their work.

II. Specific Tasks and Summary of Achievements

The contract covered nearly five and one-half years of effort. The initial task was to design a microprossesor-controlled OBS system and to build a breadboard model. As the development effort progressed, additional tasks were appended to the contract from time to time to complete the development, to construct OBS's for field use, and to conduct field experiments using these and other OBS's. This section briefly describes these various tasks in approximately chronological order. (The dates in parentheses indicate the periods of work performance as specified in the contract and its modifications.)

Task 1. Design, testing and construction of microprocessor-controlled OBS system (15 August 1977-31 October 1981)

This task proceeded successfully as various development tasks were completed as planned. The final product of the development will be described later in section III.

The successful development effort led to the use of the system in several field experiments. Among the first such experiments was the deployment of three digital OBS's on the outer continental shelf off Kodiak, Alaska in August 1978 for strong-motion earthquake observation. This was followed by additional deployments every year until 1981. Thirty-three deployments were made during this time on the Alaskan shelf and Bering Sea. This OBS system has been described by Steinmetz et al. (1981). Several other field experiments followed, including those described below.

Task 2. Measurement of ambient noise, effects of waves and currents, and low-frequency wave propagation on the Texas shelf and continental margin (15 October 1978-30 April 1981).

Several experiments were carried out on the Texas shelf on the following dates: August 11-12, 1979; January 7-9, 25-27 and 31, 1980. The primary objectives of these field experiments were to assess the ambient seismic noise level and to determine preferred detection sites for weak seismic signals. Various types of sensors were used for these experiments. Included were ocean-bottom seismometers and hydrophones attached to radiotelemetering bouys, conventional type (analog) OBS's, and a new digital OBS.

The observed levels of ambient noise on the Texas shelf at 10 Hz did not change appreciably from place to place for either geophones or hydrophones. However, a marked increase of ambient noise below 2 to 3 Hz was observed for hydrophone signals, especially in shallow water. For geophones, the increase of ambient noise at low frequencies was less pronounced. Consequently, 2 to 3 Hz was determined to be the lower practical limit for detection of weak seismic signals.

The predominant mode of propagation was found to be the water waves at nearly all distance ranges. Ground wave arrivals from air gun sources were significant only to about 10 km for shallow shelf regions and to about 20 km for deeper zones. (A later experiment, however, has shown this estimate to be too conservative. See section IV.) These results suggested to the investigators that an upper slope site was preferable to a shallow outer shelf site for detection of weak seismic signals. Details of these experiments and results have been presented in a progress report by Latham (1980).

Task 3. Continuous-wave and impulsive source propagation loss measurements on Bermuda pedestal (1 July 1979-30 April 1981)

In two field experiments that were carried out on 23-24 August, 1979 and on 27 November-3 December, 1979, conventional type (analog) ocean-bottom sensor units, each containing either a vertical-component geophone, a horizontal-component geophone or a hydrophone, were deployed, and signals from a Mark 6 10 Hz continuous wave (CW) source and from SUS charges were recorded at distances up to 30 nautical miles (56 km). Unfortunately, no useful data were acquired because either the instrumental gain was too high or the instrument was lost.

Task 4. Analysis of New Hebrides data (1 July 1979-1 February 1980)

Earthquake and seismic refraction data collected in 1976, 1977 and 1978 using conventional (analog) OBS's near the New Hebrides Islands were analyzed. These data were combined with those recorded at seismic stations on land to produce structural and tectonic models of the New Hebrides arc-trench system. The results of the analysis were included in papers by Ibrahim *et al.* (1980), Pontoise *et al.* (1980), Coudert et al. (1981), and Chen *et al.* (1982).

Task 5. OBS experiment in the vicinity of DSDP site 395A (1 March 1981-31 August 1981)

Four digital OBS's configured for refraction survey were deployed near DSDP site 395A on the mid-Atlantic ridge near Kane fracture zone on March 29, 1981 from USNS Lynch. This was the first time the digital seismic refraction OBS system developed under this contract was used for a field experiment. The purpose of the experiment was to compare the noise and refraction seismic data as recorded by a down-hole seismometer with those from OBS's.

Each OBS unit contained a 10 Hz, 3-component geophone set. All deployment sites were within 6 km of the DSDP hole at depths approximately 4.5 km. Explosive charges were fired from USNS Lynch at various distances for recording both by the OBS's and by the borehole seismometer package. All four OBS's were then recovered. Several instrumental malfunctions prevented three of the OBS's from recording any usable data. However, the fourth OBS, at 760 m from the hole, successfully recorded seismic data on the vertical component. The acquired data have been transferred to a standard SEG-Y format tape, and copies have been sent to Scripps and NORDA for analysis.

Task 6. NAVOCEANO Mediterranean Sea Field tests (1 April 1981-31 December 1982)

Two seismic refraction lines were shot in the Mediterranean Sea between Sicily and northern Africa on 6 and 9 November, 1981, as a part of a

U.S. Navy test program USNS Wilkes Survey 3306-81. The objectives of the experiment were (1) to determine the sub-bottom structure and sound velocity profile and (2) to compare the signal-to-noise ratio, frequency content and relative energy levels of the water-borne and solid-earth propagations.

On the 48 km long first line, three OBS's were deployed at depths ranging from 910 m to 1300 m, and Mark 61 SUS charges (1.8 lbs or 0.82 kg of TNT at 800 ft or 244 m depth) were fired at about 0.9 km intervals along the line. On the 78 km long second line, four OBS's were deployed at depths ranging from 305 to 465 m, and Mark 82 SUS charges (1.8 lbs or 0.82 kg of TNT at 300 ft or 91 m depth) were fired at about 1.7 km intervals along the line. Each OBS contained a 10 Hz, 3-component geophone set, and the data were sampled at 7.344 ms intervals. The intrumental pass band was 10 to 31 Hz.

The rate of signal attenuation with distance was found to be proportional to somewhat less than the negative second power of distance for water waves in shallow water, slightly more than the negative second power of distance for water waves in deep water and the negative third to fifth power of distance for body waves through solid earth. As expected, the water waves were much more pronounced than body waves at all distances; the latter were detectable only up to about 20 km from the shallower sources (Mark 82 SUS), while the former were detectable along the entire length of the lines. Body waves from the deeper sources (Mark 61 SUS), which produce high frequency signals, were not detectable at any distance above the background noise in the instrumental pass band. There was no significant dependence of attenuation on frequency either for the water wave or for the body waves within this frequency band.

Because of the large frequency mismatch between the signal sources and the sensing instrument, detection of usable body waves for determination of sub-bottom structure was quite limited. Only two layers with compressional-wave velocities of 2.5 km/s and 3.8 km/s were identified beneath the 78 km line. Details of this experiment and analysis results are given in a technical report by O'Brien and Chatterjee (1983), which accompanies this final report.

III. Description of the Developed Senor System

The description of the ocean-bottom sensor system presented in this section is based on what we now have after six years of development, testing and continual modifications. The development is nearly complete in certain respects; i.e., the system functions quite well for some applications, such as for seismic refraction studies. However, for other applications, such as earthquake observations, further development efforts are needed.

Figure 1 depicts the overall functional blocks of the sensor system. The system accepts input signals from up to three sensors. Normally, a three-component geophone or geophones and/or a hydrophone in any combination is used for sensors, but any other signal sources may be accepted.

Each of the sensor signals is amplified through a preamplifier and a binary-gain-ranging amplifier, multiplexed with signals from other channels and digitized in the data acquisition module. The gain ranging permits a wide dynamic range of over 96 dB. The multiplexing and the digitization are program-controlled from the system controller module; thus one, two or three channels of data may be sampled at any desired sampling rate.

The system is controlled by three microprocessors. One in the clock control module updates the real-time clock with appropriate software-controlled clock-drift compensations and controls timing of various system functions. For example, it activates the system controller for data acquisition and the release mechanism for recovery at preprogramed times.

The second microprocessor controls the overall system function. This includes acquisition and transfer of data from the digital-to-analog converter to the memory, and then to the control of the tape controller. It may also handle detection and identification of seismic events through a software-controlled logic.

The third microprossor controls transfer of data from the memory to the digital tape recorder. It also controls appropriate formating of the data and various functions of the tape recorder.

All three microprocessors function more or less independently with proper handshaking among them for functional synchronization. They are individually programmed, thus permitting wide flexibility in the mode of data acquisition.

The system accommodates up to 96 K bytes of temporary data storage memory, enough to store 48,000 12-bit data words, each with sign, exponent and component identification.

Preliminary circuit diagrams of the data acquision module, the clock module, the system controller module, the tape controller module and the memory module are shown in Figures 2 through 6.

The release of the system from the ocean bottom for surface recovery is controlled by three independent subsystems: programmed release controlled by the clock module, preset release initiated by a backup clock and surface-ship commanded release through an acoustic transponder. These redundant subsystems assure successful release of the instrument system even when two of the three fail to function.

The entire electronics subsystems, the acoustic transponder, a strobe light and geophones, if used, are contained in a glass sphere of 43 cm (17 inch) diameter, which fits snugly into a molded plastic cap. The sphere, its contents, the plastic cap, a hydrophone, if used, two radio beacons and two orange flags to aid recovery constitute the recovery capsule, the part that is released from the ocean floor after data collection, and recovered. A strobe light inside the sphere also aids in recovery of the capsule.

On deployment, the recovery capsule is attached firmly to a steel frame footing by three stiff elastic straps as seen in Figure 7. The frame has many spikes which penetrate the ocean bottom sediments to improve acoustic coupling to the ocean floor for seismic measurements.

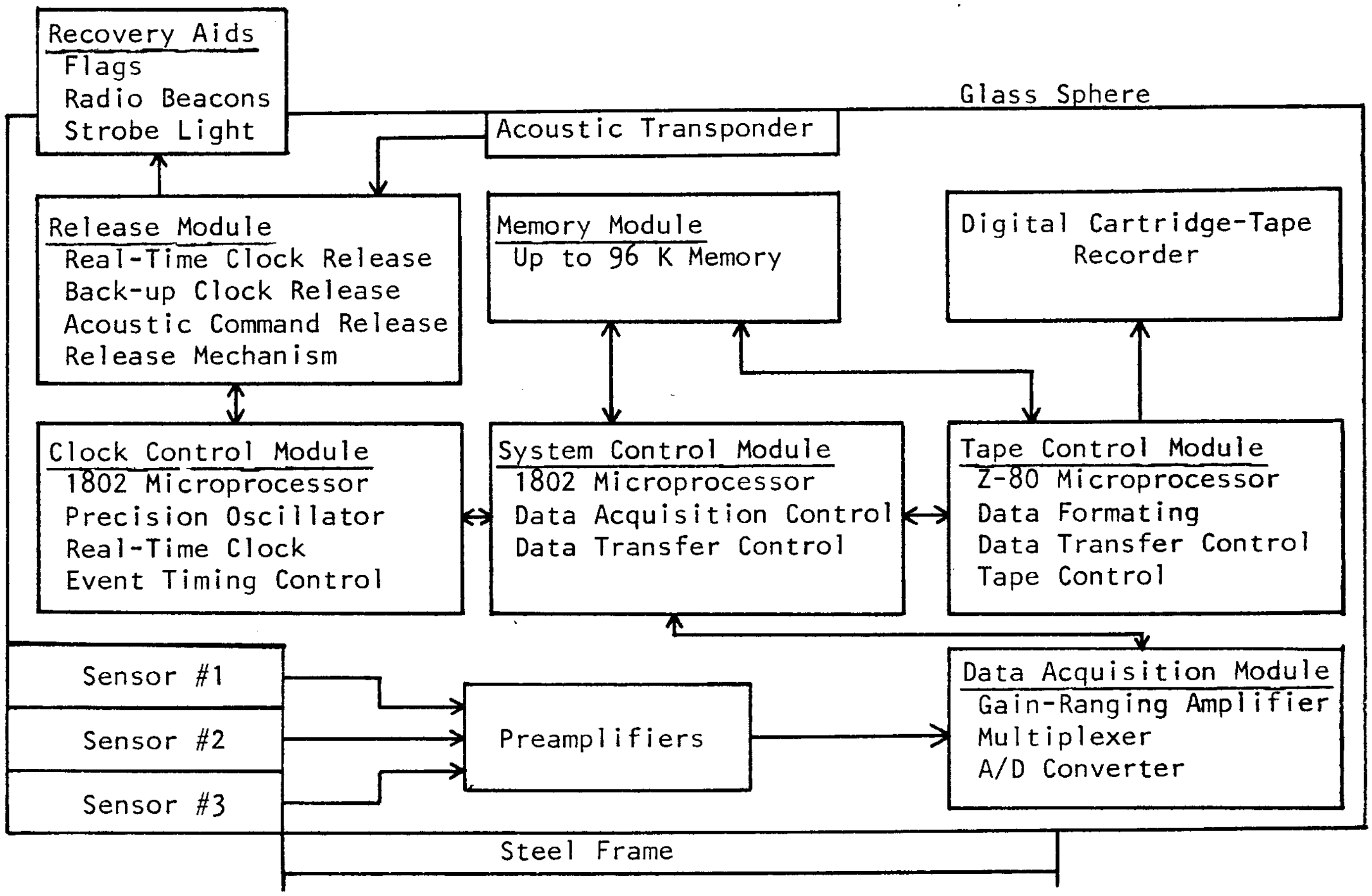

Fig. 1. Schematic diagram of ocean bottom sensor system

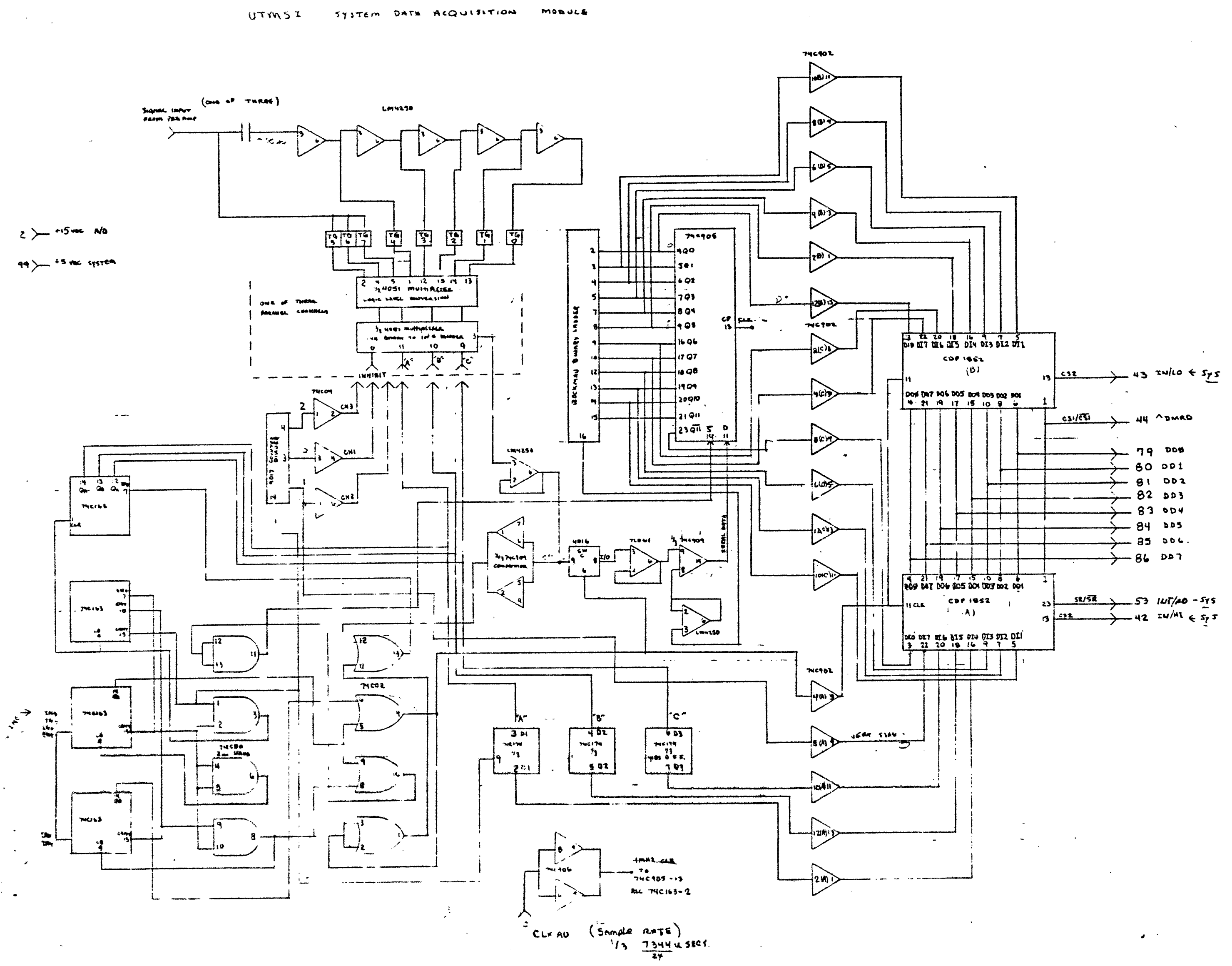

Fig. 2. Data acquisition module

UTMSI SMOBS CLOCK

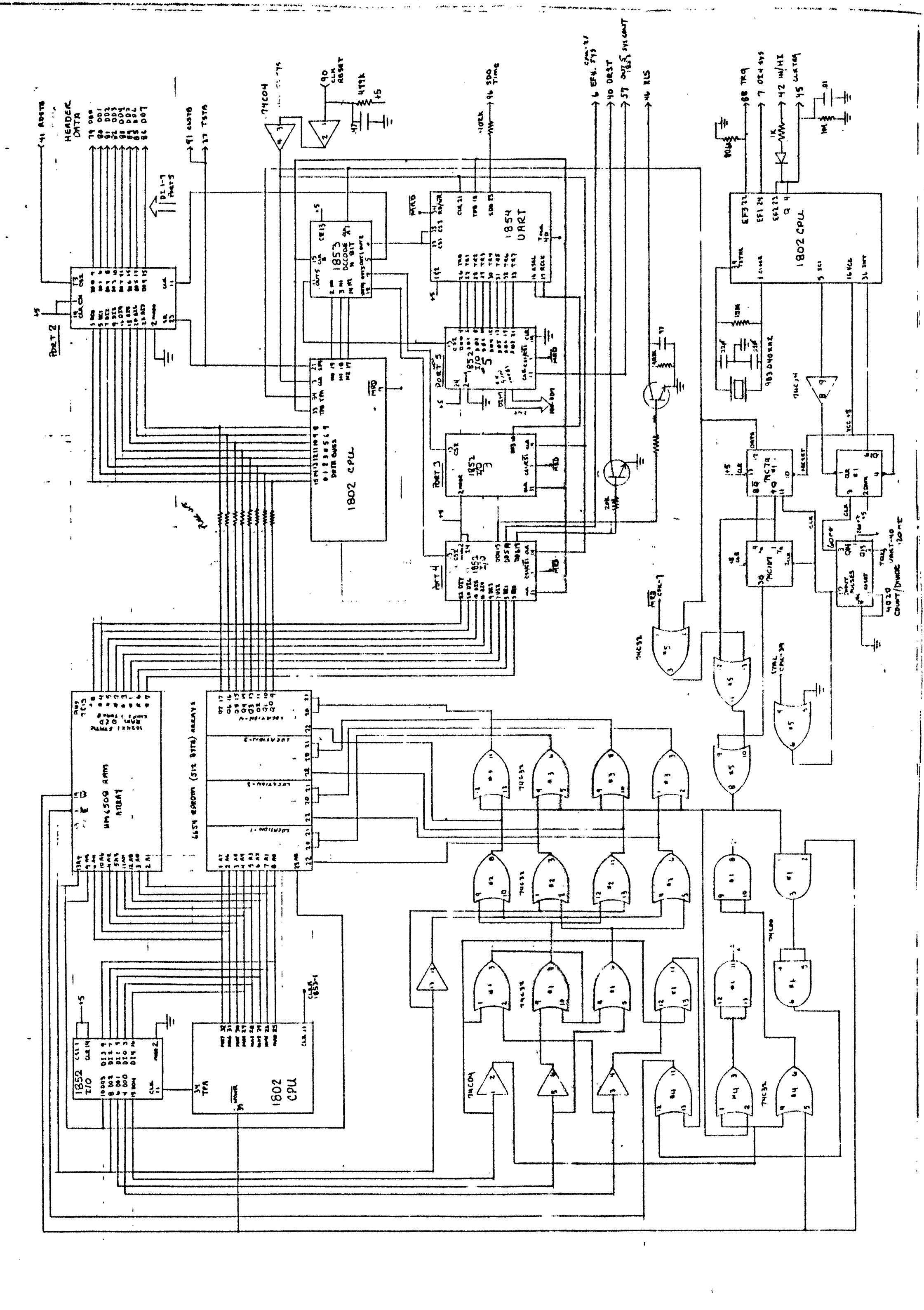

Fig. 3. Clock module

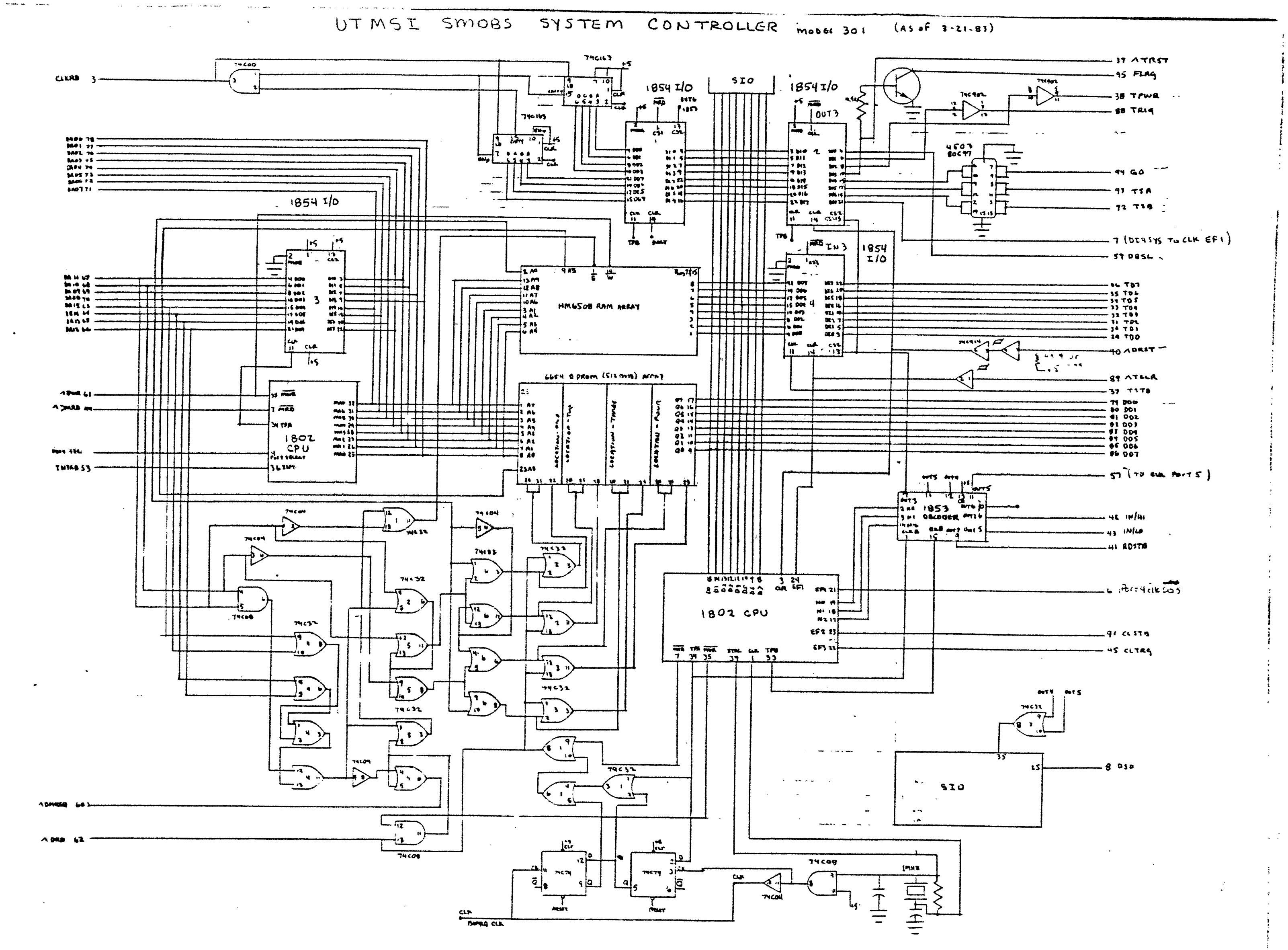

Fig. 4. System controller module

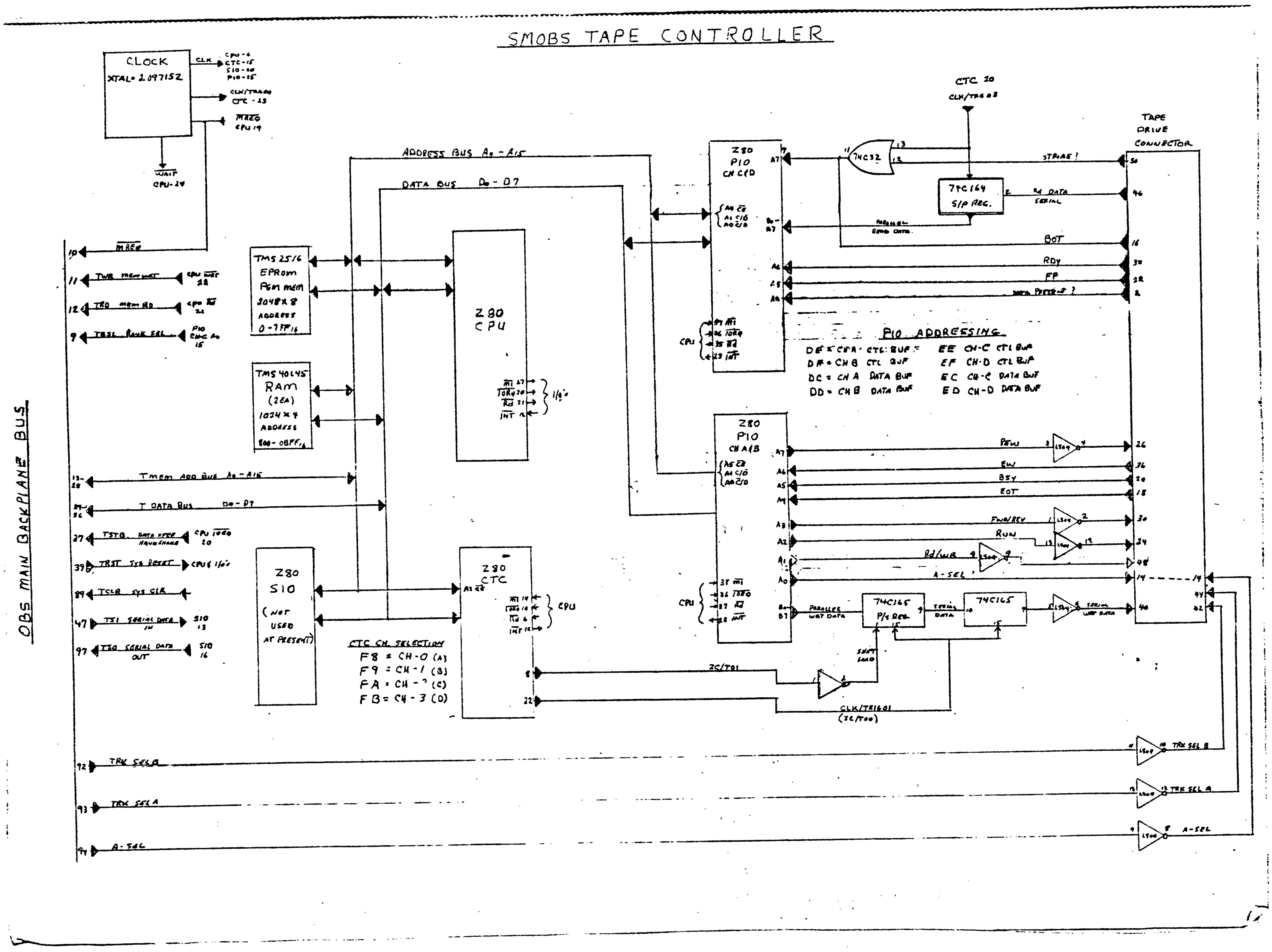

Fig. 5. Tape controller module

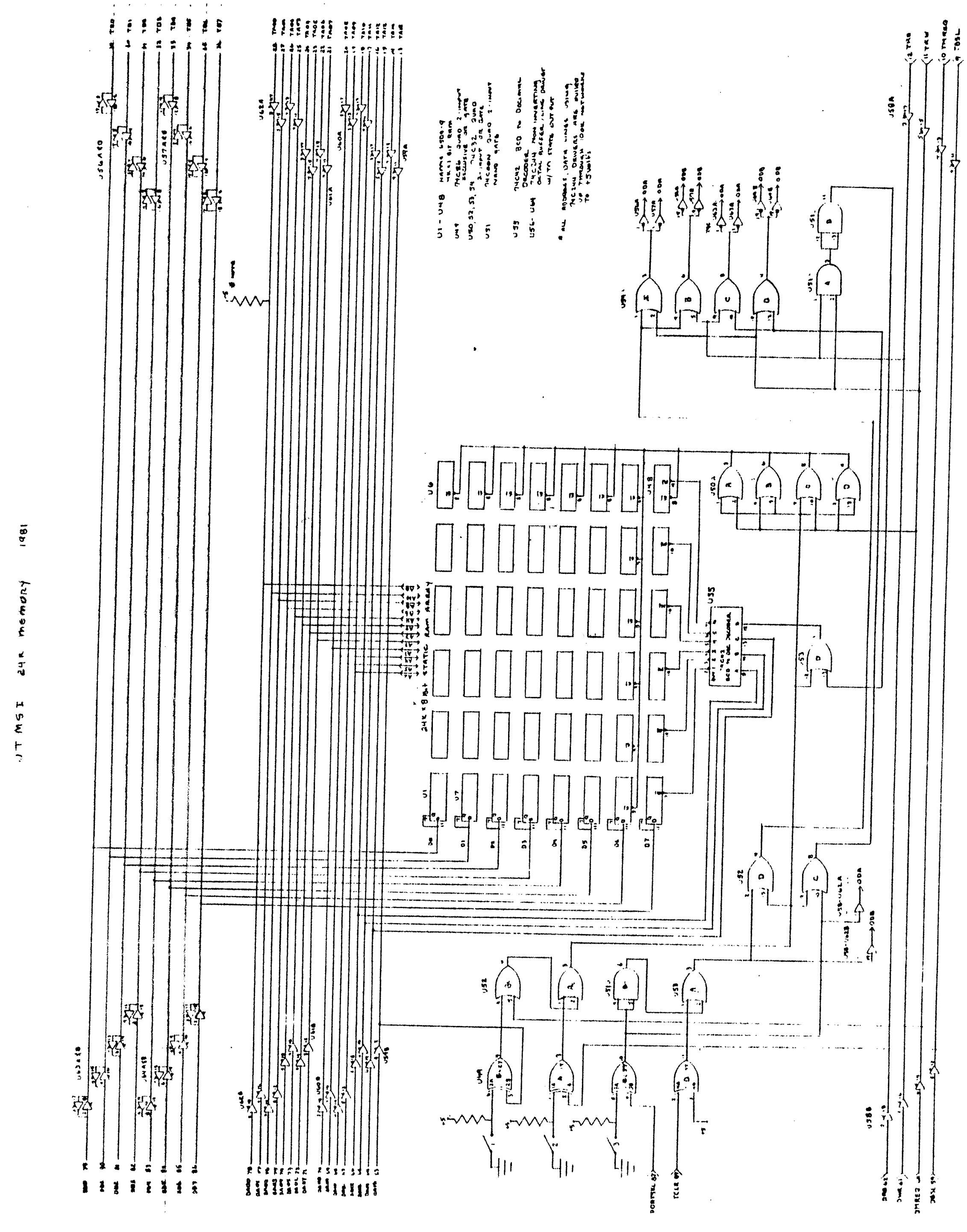

Fig. 6. Memory module

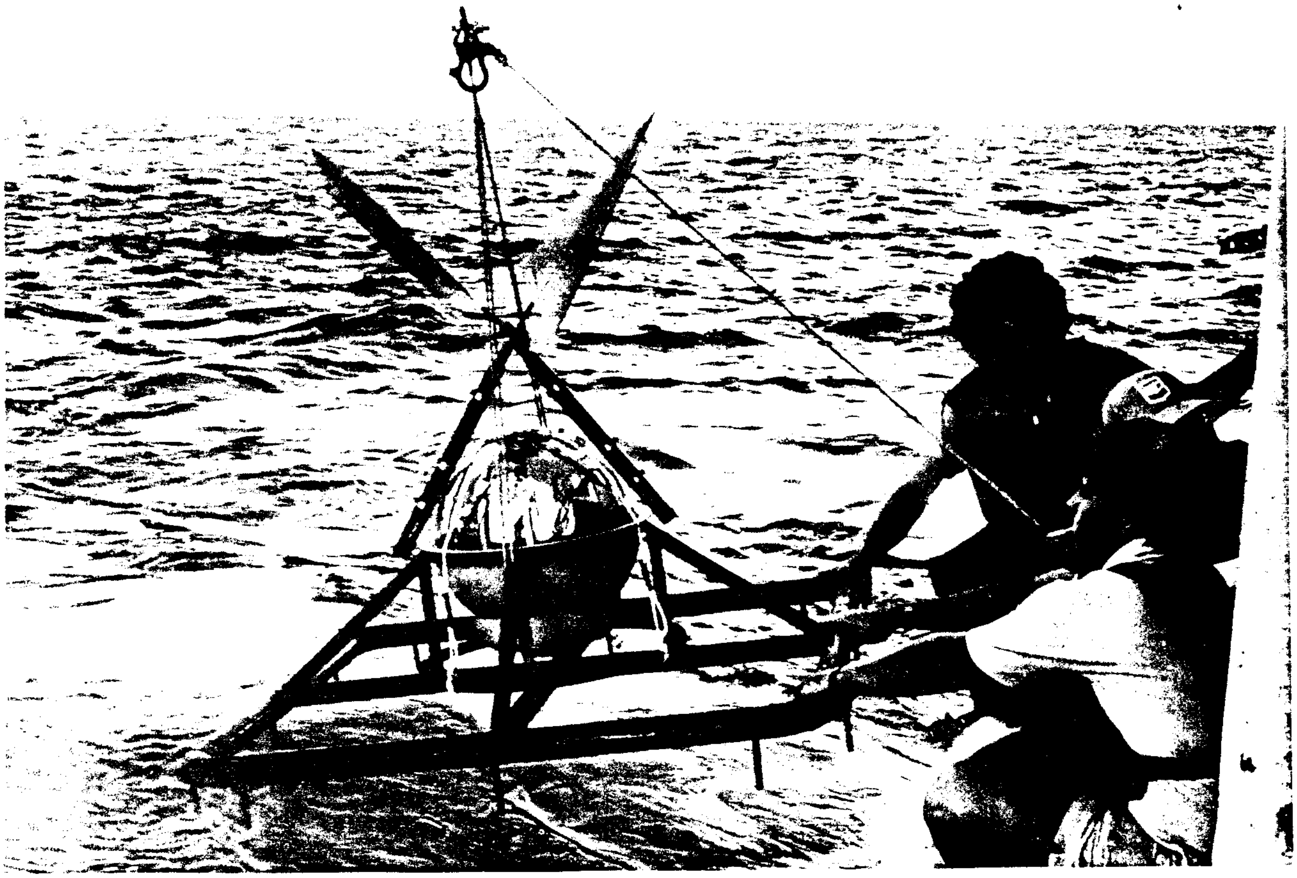

Fig. 7. Ocean bottom seismometer being deployed from R/V Fred H. Moore

IV. Continuing Development Efforts

The OBS development effort at the University of Texas Institute for Geophysics is continuing. After the expiration of this ONR contract, we have developed a new software package that allows recording of seismic signals from closely spaced air-gun shots. In a latest series of experiments conducted in a shallow mid-shelf region of the Gulf of Mexico, high quality seismic refraction data were recorded from air-gun sources at distances beyond 60 km. This is a significant improvement over the earlier results mentioned in section II. This effort is continuing with plans to shoot several more refraction lines in deeper waters.

The sensor system that utilizes a triggering mechanism, designed mainly for detecting and recording earthquake signals, is currently less reliable than the seismic refraction unit. One of our ongoing efforts is to find the cause of some malfunctions and to improve the reliability.

There remain several fundamental problems associated with ocean-bottom sensor systems. For seismic measurements, good coupling of the measurement system to the ocean floor is important for faithfully recording the seismic signal. Results to date in attempts by many investigators to achieve good coupling have been quite unsatisfactory, especially for horizontal ground motion. We have recently obtained a prototype gimbal-mounted 4.5 Hz, 3-component geophone, which we plan to use in experiments especially to examine this problem.

Acknowledgements

Many people besides the principal investigators of the project were involved from time to time in the development and testing effort. Participants in scientific activities (listed in approximate chronological order) include H. James Dorman, Abou-Bakr K. Ibrahim, Jeff Carye, Allen T. Chen, Alan E. Morris,Jeff Lawton, William P. O'Brien, Jr., Toru Ouchi, Joseph O. Ebeniro, Peter Glover and Subir K. Chatterjee. Archie C. Roberts and Kenneth H. Griffiths provided engineering support. Robert Cheney, Ronald Pugh, Stephen Payne, Oommen M. Eapen, Phillip H. Roper, George W. Pearcy, Michael E. Butterfield, Paul M. McPherson and Stirling Gilfillan provided technical support. Cliff Frohlich reviewed a draft of this report; his constructive comments were also appreciated.

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