U.S. Department of the Interior Geological Survey

Geophysical-Data Acquisition in Remote Environments

By Bruce P. Ambuter and Ray E. Davis

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ABSTRACT

Geophysical-data-acquisition systems must meet requirements of wide dynamic range, programmable modes of operation, large data storage capacity along with oftentimes opposing requirements of small size, low power consumption, and low cost. The U.S. Geological Survey (USGS) has devised a modular data-acquisition system that meets the above requirements for use in geophysical research programs. A major design goal was to devise a modular system that could be configured in several different operational modes and thus satisfy the requirements of many data-gathering experiments. For maximum flexibility, the specifications of the modular system were required to meet collective requirements of four geophysical-data-acquisition applications: an ocean-bottom instrument package for long-term seismic studies and short-term seismic-refraction work, a two-component surface buoy with FM telemetry and internal digital recording for refraction experiments, two- and four-component land systems for use in onshore seismic studies, and a real-time high-resolution data-acquisition system for marine geophysical studies. This paper describes the individual modules and then shows how the modules were configured in different applications.

INSTRUMENT MODULES

The system comprises three main modules: the data-acquisition module, the data-storage module, and the power-supply module. Module configuration is dependent only on the specific application and interfaces to other modules. For example, the data-storage module may contain a reel-to-reel recorder, a cartridge, or a cassette recorder as determined by the size and data-storage requirements. The power pack may consist of lithium, alkaline, or NiCad cells connected in varying packing arrangements as required by specific experiments. We start by describing the requirements for the data-acquisition module.

Data-Acquisition Module

The design of a low-power system represents a tradeoff of power consumption versus integrated circuit performance. Generally, low-power integrated circuits do not have as low an offset voltage or as high an input impedance or gain-bandwidth product as their higher power counterparts. Nevertheless, with the exception of the low-noise front end, all design tradeoffs were made in favor of low-power consumption. Extensive use of complementary metal oxide-semiconductor (CMOS), medium-scale-integration (MSI) circuitry, and low-power quad amplifiers, has kept system power consumption to less than 100 mW, enabling data-acquisition experiments to be carried out for as long as 3 months.

Appendix I lists the specifications of the data-acquisition module.

When this program was started, microprocessors were rejected due to excessive power consumption and the lack of peripheral support circuits. This situation has changed; 8-bit low-power CMOS microprocessors and associated support circuitry are currently available. At the same time, comparable strides in large-scale-integration (LSI) circuitry and (read only memory) ROM-centered design have made it possible to shrink component count of this system by 30 percent without compromising performance or flexibility. Any system redesign would have to seriously consider the incorporation of a microprocessor versus LSI or ROM-centered design.

A basic goal was to design a data-acquisition module that could be easily programmed, serviced, and updated. Accordingly, the data-acquisition module was divided into three relatively independent functional boards: the analog board, which contains the front-end preamps, the low-pass active filters, and event-detecter circuitry; the memory board, which contains the gain range amplifiers, the sample and hold, A-D converters, and buffer memories; and the control and format board, which contains the programming switches, system control logic, time of day logic, and tape storage module interface. Except for a few basic control and signal lines, each of these boards is functionally independent (fig. 1). All boards use a full ground plane to minimize digital noise and ground loop problems. The boards have been configured so as to permit complete access to all integrated circuits and test points without the use of extender cards. The analog and control format boards also flip down (fig. 2) for access to the wiring.

The system (fig. 1) may be functionally split into two main parts: the analog and digital circuitry. The analog circuitry comprises the low-noise amplifiers, low-pass filters, dynamic gain-range amplifiers with associated logic control, sample and holds, and the event detector. This circuitry conditions the incoming seismic information through amplification and filtering and determines whether an event has been observed.

The digital circuitry consists of the A-D converters, the semiconductor memories, timing, and the control and format unit. Its function is to sample the data from the output of the analog circuitry and to load these data into the semiconductor memory under the direction of the control and format unit. The event-detector line functions to turn on the storage recorder and thus record the output of the buffer memory.

In the two-channel configurations shown in figure 1, seismic signals from the two-component seismometer are first amplified by means of a low-noise integrated circuit amplifier, and are then passed through an 8-pole Butterworth low-pass active filter network. High-frequency cutoffs of 30 Hz, 60 Hz, and 120 Hz may be selected depending on sampling rate. The outputs from the low-pass filters are applied to the sample and hold circuits through the dynamic gain ranging amplifiers. One component (generally the vertical) of data output from the low-pass filter, goes to the event-detection circuitry (fig. 3) for use if the "event triggered" mode of operation has been selected.

One of the main applications of this system is the seismic triggered mode; thus, the system uses a decision algorithm which comprises long- and short-term averages. Current implementation of this algorithm is shown in figure 3. Signals from the event channel are fed directly to the short-term averager (STA) and through a digitally controlled switch to a long-term averager (LTA) (Ambuter and Solomon, 1974). Both averagers are identical in that they rectify and integrate the input signal, but with different integrator time constants, as determined by the resistor-capacitor time constant in each feedback loop. The LTA has a 5-minute time constant, much longer than the largest period of the seismic signals generally recorded. The LTA output is therefore representative of the average background level or noise. The STA has a time constant of 0.5 to 2 seconds and responds quickly to changes in signal level. The output of the LTA and a portion of the STA output are continuously monitored by the event comparator. The portion of the STA output that is fed to the event comparator determines the event threshold, i.e., the amount by which the STA output must exceed the LTA output in order to signify an event. Put simply, an event is detected when the STA output exceeds the threshold level.

The basic event detector is bounded in its operational dynamic range by the supply voltage on the high end and by amp offsets and resistor mismatches at the low end. In practice, this represents a range of about 40 db. To extend this range, a digitally controlled attenuator has been added which maintains the event detector in the middle of its operating range. The circuit works by continuously monitoring the LTA output, comparing it to a LTA reference and updating the attenuator setting using a multiplying digital-analog converter (MDAC) and associated counting circuitry. The digital attenuator operates over a 72-db range, thus allowing the event algorithm to function in environments where the background noise is unknown or is subject to wide variation.

The basic event detector references an event to the floating background set by the LTA. If the background noise is very small, detected events may be recorded that are of non-value in a given experiment and thus result in premature consumption of the data storage. This occurred in Yakutat Bay during the deployment of five U.S. Geological Survey Ocean Bottom Seismographs during July - August 1979. The addition of a second short-term averager, which bypasses the digital attenuator previously described, allows the setting of a minimum event threshold. Both the LTA vs STA event detector threshold and the minimum-event threshold must be exceeded in order for the data-storage module to be turned on. Thus, event detection is initiated by signals exceeding the minimum event threshold in very quiet environments, whereas in noisy environments, the LTA vs STA criterion is dominant. The switch at the input of the LTA is used to inhibit input to the LTA whenever an "event" decision has been made. This prevents high signal levels during a long event from erroneously influencing the detection algorithm and prematurely terminating data storage.

Gain Range Amplifier - A-D converter

A dynamic-floating-point amplifier (fig. 4) is used ahead of the A-D converter and consists of a multiplying digital analog converter (MDAC) and associated gain logic (Ambuter, 1979). Every 20 microseconds, the first four bits of a low-power analog-digital converter are interrogated. Whenever a conversion decode indicates greater than 50 percent of full scale, the system is reduced by 6 db.

Decodes between 12.5 percent and 50 percent of full scale inhibit any gain changes. Decodes corresponding to less than 12.5 percent of full scale result in system gain being raised 6 db. System gain is updated at a 50-kHz rate. During sampling, all gain changes are inhibited and both the 4-bit gain code and 12-bit A-D converter value are output to the buffer memory.

The floating-point amplifier, by virtue of its operation, not only extends the overall dynamic range, but also maintains a high signal level to the A-D converter. Maximum A-D bit resolution is thus maintained over the range of the input signal. In addition, effects of the sample and hold voltage offset and digital noise are minimized, as both are small compared to the input A-D signal level.

The operation of the rest of the system is governed by the logic control and format unit:

The 12-bit A-D converter, upon command, samples the analog input and generates an equivalent digital code. The control and format unit then commands the A-D converter to load its 12-bit output words and the 4-bit gain code into the semiconductor memory. The memory, which consists of 1000-bit shift registers, has a capacity of 2000 16-bit words for each data channel. If the sample rate is 200 Hz, for instance, then the digital output would be delayed by 2000/200 or 10 seconds. During periods when the event detector is off, the buffer memory words are dropped off the end of the shift register. When an event is detected, the inputs to both long-term averagers are immediately inhibited, because the long-term averager is meant to reflect the average background noise, and, therefore, should not be allowed to respond to event signallevels. The STA, however, continues operation. Simultaneously, the tape recorder motor is turned on and, after a delay during which the tape motor comes up to speed, the buffer memory output is recorded. During the event, the system gain and timing marks are recorded on the control track. Recording continues until the threshold detector returns to its presignal "off" state for a period of 30 seconds.

Data Storage Module

Because no commercially available recorder could meet the size and power requirements, a reel-to-reel recorder was designed (Davis and Ambuter, 1979). The recorder shown in figure 5 has the capacity of 4×10^8 bits. At a sample rate of 125 Hz, two 132-db data channels plus time information may be recorded for a period of 15 hours, corresponding to a density of 2500 bpi. Specifications of the recorder module are listed in Appendix II.

Recorder Description

The storage module's main requirement is to transport the tape across the head while maintaining as fine as possible alignment from the tape supply reel to tape take-up reel. Use of NRZ (non-return-to-zero) format eliminates the need for tightly regulated speed control, which, in turn, allows a simple motor gearbox drive to be used. The use of a 1/4-inch-thick cast aluminum jig plate as the deck and subplate provides a stable and highly accurate platform for the guides, head, and bearing suppports for the reel spindles and capstan drive. The capstan shaft is fixed in a 12-oz flywheel to reduce shaft-speed variations; it meters the tape when a urethane pinch-roller is engaged. A single stock motor/gearhead combination drives the capstan through two extruded-urethane belts for additional isolation, and the motor itself is uncoupled from the deck by means of resilient mounts. The motor belt also drives the take-up reel through a fluid clutch so that a uniform tape tension is maintained as the reel fills. A similar undriven clutch dampens feed-reel oscillations and provides the necessary tape tension across the head.

Other notable features include the use of special bearings to reduce vibration transmission from rotating parts, and the three piece fixed guide of polished stainless steel that permits a precision alignment at minimum expense. The 7-track Applied Magnetics Head is optically mounted to insure minimum skew and tracking errors. The motor draws only 250 milliwatts and requires two wires; the head requires another fourteen.

These wires are fed through a single connector to link the storage module to the data-acquisition package. It is important in geophysical application to minimize tape recorder noise particularly in instruments where the sensors are placed in the same package as the recorder. In the USGS Ocean Bottom Instrument Package (OBIP), the recorder module is mechanically decoupled from the instrument by means of rubber isolation mounts used as frame supports. Present recorder noise corresponds to less than 30 millimicrons displacement at 10 Hz as detected by the geophone sensors used in the USGS OBIP. To reduce tape noise in the future, the motor-gearbox will be replaced by a direct-drive tach-driven motor.

Recording format

In order to be consistent with the design goals of simple operation and maximum flexibility, no directly mounted electronics are associated with the recorder. Wiring is limited to two power leads for the motor and seven pairs of signal leads corresponding to the seven tracks on the digital head.

The principal application of this recorder in the digital mode has been in the USGS OBIP. In this application, digital data are written onto the tape through a seven-track head, using NRZ format to minimize recorder and playback electronics. The USGS OBIP has two data channels, which are sampled at either a 125-Hz or 250-Hz rate. Each data sample consists of 16 bits, 12 bits from the main A-D conversion and 4 bits from the gain ranging, for a useful dynamic range of 132 db. During recording, these 16 bits are split into two 8-bit data tracks.

Each sample word is divided into eight phases, which generate eight bits, and the sync track is used to denote each phase. Data are stored on the tape coincident with the negative transition of the sync track. During playback, the data are read midway through the 1 or 0 state coincident with the positive transition of the sync track as shown in figure 6. Because data are read only when the sync track goes high, and because all tracks are in the same relative position within the constraints of dynamic skew (the angular wandering of the tape as it passes over the head), variation in wow and flutter have little effect. An end-of-word track is used to denote the eighth phase and thus the start of the next sample. Reproduction of the recorded data requires integration of the sync track, an end-of-word track, and one or more data tracks. As the bit density is increased for a constant tape speed, the bit length becomes proportionally shorter. When the dynamic skew causes a tape offset of greater than half the bit length, errors in data reproduction result, so the upper limit for bit density and storage capacity is set by the acceptable error rate. Because the skew-induced error is not simply the error on a per-track basis but is determined by simultaneous alignment of three or more tracks, a quantitative bit error rate is most difficult to obtain. It is probably more meaningful to report that the USGS OBIP at a recording density of 2,500 bpi, has an error rate due to dropouts and tape skew of between one part in 10^5 and one part in 10^6 bits.

No 1/2-mil tape is manufactured exclusively for digital use, and thus tape must be selected carefully. Tape dropouts, which also contribute to the bit error rate, are generally not as detrimental to audio-instrumentation applications as they are to digital applications. Manufacturers, therefore, do not specify dropout rates for audio tape. For our purposes, 3M990 tape has provided the most uniform output and fewer dropouts than other audio tapes tried.

Power Supply Module

Obviously, all remote applications require some sort of battery-supplied power for routine operation. Depending on the experiment's duration and packaging considerations, three different packs have been used. For maximum long-term seismic studies where space is a problem, as in our Ocean Bottom Seismograph, lithium cells have been used. These are non-rechargeable and a 2-month deployment can consume $400 in lithium cells. For experiments of shorter duration or where space is not so critical, NiCad or lead-acid Gel cells have been used. These batteries are rechargeable, and thus, battery cost per experiment can be substantially reduced.

Oscillator

Timing accuracy is extremely important in land-based or ocean-bottom earthquake-detection arrays. Seismic-epicenter location requires a maximum timing uncertainty of 100 milliseconds between deployed instruments; 10 milliseconds would be optimal. Because the instruments used in these remote applications are linked only by the oscillator in each unit, the oscillator stability is of paramount importance and warrants a detailed discussion.

Oscillator accuracy is dependent on two factors:

A) Frequency offset: due to errors in initial frequency setting, temperature fluctuations, etc.

B) Aging: The daily oscillator drift rate which is assumed to be constant.

Frequency offset produces an error that is linear with respect to time, i.e., if the offset error were 100 milliseconds a day, at the end of a week, the offset error would be 7 times 100, or 700 milliseconds. Crystal aging produces a continuous change in oscillator frequency and thus, an accelerating time error. If the crystal aging rate is constant, the error will be proportional to the square of the elapsed time. For example, if the constant aging rate were such that at the end of the first day, a 1-millisecond time error were observed, at the end of 2 days, an error of 4 milliseconds would be observed, and at the end of 3 days, a 9-millisecond error would be observed. Thus, during a long time period, time errors due to crystal aging will dominate. A nomograph of time errors due to crystal aging and offset is shown in figure 7.

To achieve an accuracy of 10 milliseconds during a 2-month experiment period requires an oscillator aging rate of ± 5 parts per 10^{11} not counting offset contributions due to temperature and battery-voltage fluctuations. Thus, in a 1-month deployment, the time error due to aging alone would be 390 milliseconds. The only way to meet a 10-millisecond time stability during a 2-month period is to use an oven-controlled oscillator that has an aging rate of ± 5 parts in 10^{11}. Crystal aging rate is markedly reduced in oven-controlled oscillators and, in addition, crystals with similar oscillators age in the same direction. This means a correction for aging can be applied which improves the time accuracy by an order of magnitude. Oven-controlled oscillators, however, consume much power and thus impose a limit on battery capacity and experiment duration. Temperature-compensated oscillators (TCXO) have been used because of their low power consumption, but they have a higher aging rate of $\pm$ 1 part in 10^{8}. The USGS's present shallow-water Ocean Bottom Instrument Package can power a TCXO for 2-1/2 months and a ± 5 parts in 10^{11} oven-controlled oscillator for 3 weeks. The choice of oscillator amounts to a calculated tradeoff among required accuracy, battery capacity, and experiment duration.

APPLICATIONS AND SPECIAL PACKAGING

The principal application of the modular data-acquisition system described has been in the U.S. Geological Survey's OBIP (fig. 8). Packaging specifications are shown in Appendix III. The USGS OBIP was designed to be used in the event-recording mode for long-term seismicity studies as long as 60 days and in programmable window mode for refraction experiments of 2 days duration. In designing the OBIP package, much concern was given to the problem of simplifying instrument operation and handling, particularly in multiple deployment applications. Accordingly, the OBIP was designed to be lightweight, and features one-bolt instrument access and one-bolt instrument removal.

The present USGS OBIP is housed in a 19.0-inch I.D. (20.3 inch O.D.) aluminum sphere which is rated to a 1-km operational depth. An acoustic recall system is used rather than a time-release system because the latter requires the recovery vessel to be in a specified place at a specified time regardless of weather conditions, which might hinder or prevent recovery. In contrast, release by acoustic recall system is commanded by recovery personnel. Recovery aids include a radio beacon and flasher, which are mounted on top of the grab ring. A hydrophone also is mounted on the grab ring and is used as an additional sensor for refraction experiments. A purge valve for checking the sphere closure integrity and for backfilling with nitrogen is provided. The deployed package is 28 in. high and has a negative buoyancy of 75 lbs. An initial 200-lb upward displacement is provided by an elastomeric spring upon bottom release, and positive buoyancy of 30 lbs then carries the package to the surface.

The anchor consists of a concrete "flower pot" with a three-pronged tripod attachment. In soft sediments, the OBIP floats on the pot base with the tripod prongs increasing lateral resistance. In gravel or hard sediments, positive, stable, coupling is provided by the tripod spikes. The anchor geometry insures a strong righting moment for stable freefall and also protects the OBIP from impact and soil contamination that could prevent proper release operation. Package design significantly effects free-field particle motion of the sediments and influences phase amplitude response of an instrument such as the USGS OBIP. Improved coupling response on soft bottoms can be achieved by reducing the bearing stress of the instrument system and approaching neutral density. A soft-bottom anchor might compromise hard-bottom stability, at least in theory, and would be highly subject to currents and biological artifact.

The present anchor reflects a compromise between optimal hard-soft anchor design, because most OBIP deployments have been in shallow waters, where hard and uneven bottom conditions are often encountered and require tripod stability. Overall emphasis has been placed on minimizing overall OBIP mass and reduction of cross-sectional moments in the water column, thus improving coupling response for all conditions.

Instruments are accessed by removal of the equatorial clamp. The internal hardware (fig. 9) consists of the sensor package, release mechanism, tape recorder, battery pack, and data-acquisition module. The release is a lighter, modified version of the highly reliable AMF re-cockable weight dropper. Lithium batteries have been used for event recording applications, and NiCad batteries have been used for refraction studies.

During the past 3 years, more than 70 deployments have been made. Though not all these deployments were designed to yield useful geophysical data, all produced useful design data, and instrument malfunctions were minimal. Figure 10 shows typical seismic records obtained from Yakutat Bay in Alaska during July and August 1980.

ON-SHORE APPLICATION

The logistics are much simpler for land-based applications than for ocean-bottom applications; no pressure housing is needed, and space considerations are less stringent. To date, 1-Hz geophones have generally been used instead of the smaller 3.5-Hz geophones. Figure 11 shows the two-component land stations used by the U.S. Geological Survey during an Alaskan field operation. The case is a hermetically sealed fiberglass design costing about $200. As space was not critical, cheap rechargeable land-acid batteries were used to provide 30 days' operation before recharging was required.

The basic three-board data-acquisition module is a two-channel recording system. Expansion to four channels is accomplished by adding a second analog board and a second memory board and by changing the control board from two-channel format to four-channel format. This five-board system is placed into a five-card rack holder, and the same recorder is used, with tape speed being doubled to accommodate the increased data rate.

The third major application of this system was derived from the playback system. As described above, the data-acquisition system has had to meet requirements of low power consumption and small size, and accordingly, a digital tape recorder was devised in-house. The nonstandard generated field tapes are converted into a format that can be read and processed by a computer system. Figure 12 shows a diagram of the system designed to perform this task. Data from the tape-storage module are output through a parallel interface board to the Cromemco microprocessor board, where they are reformatted and written to buffered Kennedy transports.

The system consists of a Cromemco microprocessor, dual buffered Kennedy tape transports, CRT (cathode ray tube), keyboard, dual floppy disc, and the data storage module. In transcribing a tape, all parameters are entered via the keyboard so that every tape is fully annotated. The data-acquisition tape recorder is turned on, and the incoming data are reformatted and written to the Kennedy transports in 1- or 2-second blocks according to the recorded sample rate. Because the source data were written by the data-acquisition module, input to the Cromemco can also come directly from the acquisition electronics. Thus the system is a real-time two-channel data-acquisition system. The sample rate of this system may be increased to 1/2 ms, which makes it useful for high-resolution geophysical applications. Expansion to multichannel applications may be accomplished by simply adding more two-channel data-acquisition cards.

CONCLUSIONS AND FUTURE PLANS

The present plans call for continued usage of the modular data-acquisition system. Long-term seismic deployments are planned in both shallow water and on land during 1981. In addition, the system will be configured to function as a two-channel 1/2-ms sampling system for high-resolution geophysical applications.

Although initially designed for geophysical applications, the system is basically a programmable two- or four-channel data-acquisition system that can accept input from a variety of sensors, such as strain gauges or thermocouples, and should find usefulness in several nongeophysical applications.

During the spring of 1981, an intensive appraisal of acquired data will be performed, and the system design will be updated. Incorporation of a microprocessor is anticipated inasmuch as power consumption and performance have markedly improved during the last 3 years. Addition of the microprocessor should greatly enhance system flexibility and application.

REFERENCES CITED

Ambuter, P.B., and Soloman, S.C., 1974, An event recording system for monitoring small earthquakes: Bulletin of Seismological Society of America, August 1974.

Ambuter, B.P., 1979, Low cost low power binary gain range amplifier operates over wide dynamic range: Electronics Design, February 1, 1979.

Davis, R.E., and Ambuter, B.P., 1981, An oceanographic data recorder: Society of Exploration Geophysicists, v. 46, p. 203-208.

APPENDIX I
DATA-ACQUISITION MODULE SPECIFICATIONS

Electrical specifications:

Data channels	2/4
Time channels	1
Dynamic range	
Main converter	72 db
Gain ranging	48 db
TOTAL gain	120 db
Gain range rate	150,000 db/sec
Sample rate	125,250 Hz
Filters	
Type	Butterworth
Frequency	30,60 selectable
Roll off	48 db/oct
Event detector	
Type	MOS swift registers
Size	1,000 words
Delay	8 sec/1,000 Hz

Functional specifications:

Event recording	
Criteria	Long term vs short term
LTA time constant	10 minutes
STA time constant	.5 seconds
Threshold	6-20 db variable
Operational range	90 db
Programmed window	
Turn-on delay	1-80 hr (1-hr increments)
Continuous run	0-8 hr
Window spacing	15 min, 30 min
Window duration	5 min
Power requirements	
Voltages required	±6, ± 12
Power drain	100 mw

APPENDIX II

DATA-STORAGE-MODULE SPECIFICATIONS

All recorder parts are of aluminum, with the exception of stainless steel shafts and guides, and a brass flywheel. Bearings are of instrument quality, ball type, that are self-lubricated. Aluminum parts are machine finished with alodine protection. Tape guides are polished and buffed to mirror quality (00 RMS surface variation). Basic machining tolerances were ± 0.001 inch.

Mechanical specifications:

type	Reel-to-reel
length	12 inches
width	5-1/2 inches
height	3-1/2 inches
weight	7 lbs
tape	Scotch 871 and 990, 1/2 mil, 1/4 in. wide
reels	5-in. diameter, standard audio
tape capacity	1800 ft
tape take-up	fluid clutch
tape tensioning	fluid clutch
tape metering	capstan/pinch roller
tape	1/2-2 1/2 ips, digital
guides	fixed, polished stainless steel
drive	15 VDC motor/gearhead 5.1 digital
transmission	extruded urethane belts
bearings	instrument quality, self-lubricated, ball type
seals	"O"-ring, Parker "U"-seals
clutch fluid	Dow Corning silicone fluid (200cs), analog, Mobil 1 synthetic automotive (700cs.) digital
pinch roller	urethane, 5/8-inch diameter

Electrical specifications:

data capacity	$4 \cdot 10^8$ bits
density	2.5×10^3 bits per inch per track
wow and flutter	± 9% digital
dynamic range	128db digital (per format)
frequency range	digital, 0-60 Hz at 125 Hz sample rate, 0-125 Hz at 250 Hz

APPENDIX III

PACKAGING SPECIFICATIONS

Ocean Bottom Instrument Package

Housing specifications	
material	Aluminum sphere
inside diameter	19.3 inches
outside diameter	20 inches
collapse pressure	3000 psi
working pressure	1500 psi (1 km)
Package dimensions	
deployed height	28"
deployed weight	200 lbs
recovered weight	95 lbs
Ballast (anchor - unrecoverable)	
type	cast concrete
cost	$50
weight	100 lbs
Recovery aids	
flasher	
acoustic transponder	
Sensors	
type	geophones
frequency	4.5 Hz

Land Station Package

Housing specifications	
material	fiberglass
dimensions (L-W-H)	24" x 12" x 12"
cost	$200
weight with batteries	40 lbs
Sensors	
type	geophones
frequency	1 Hz

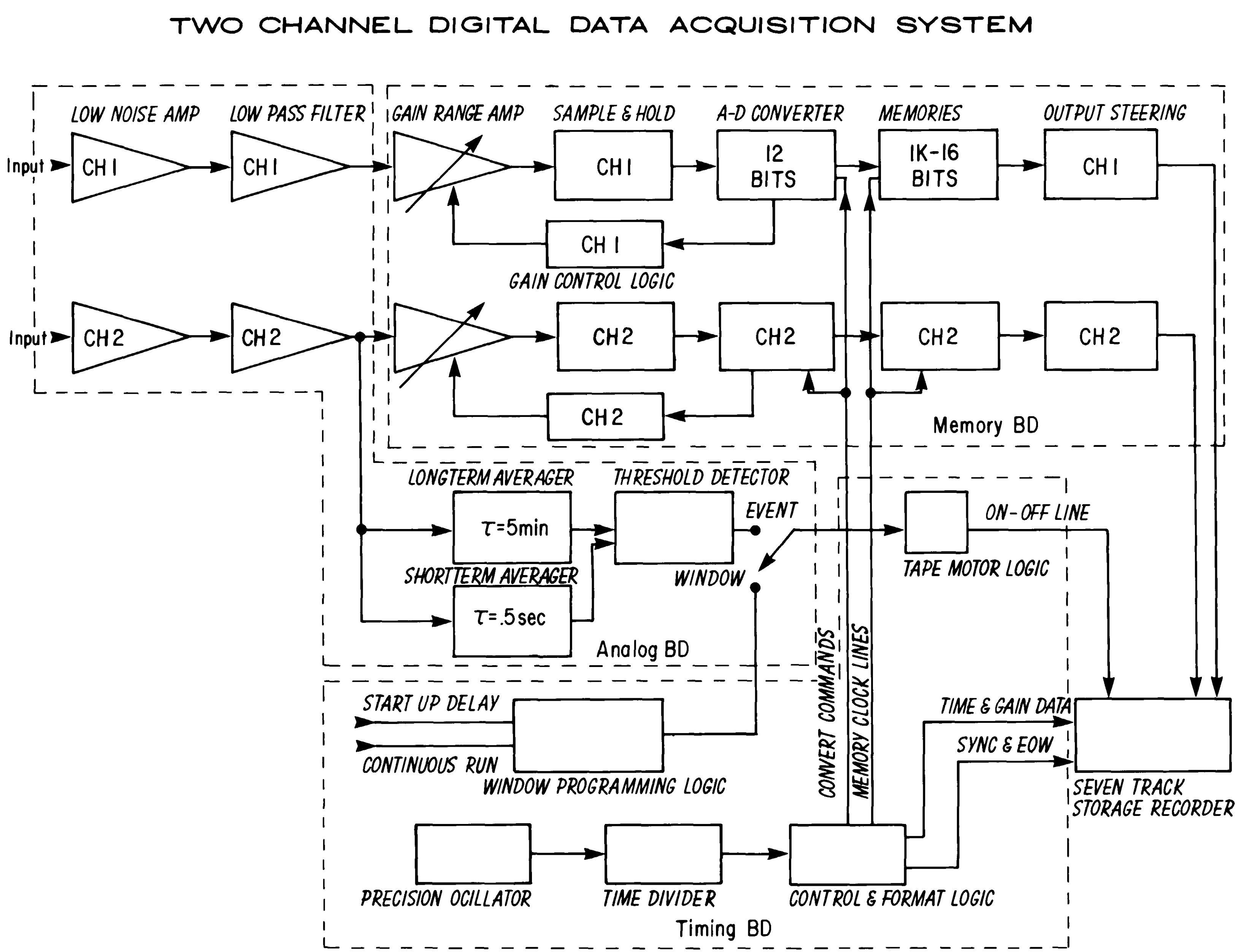

Figure 1. Block diagram of two-channel digital-data-acquisition system

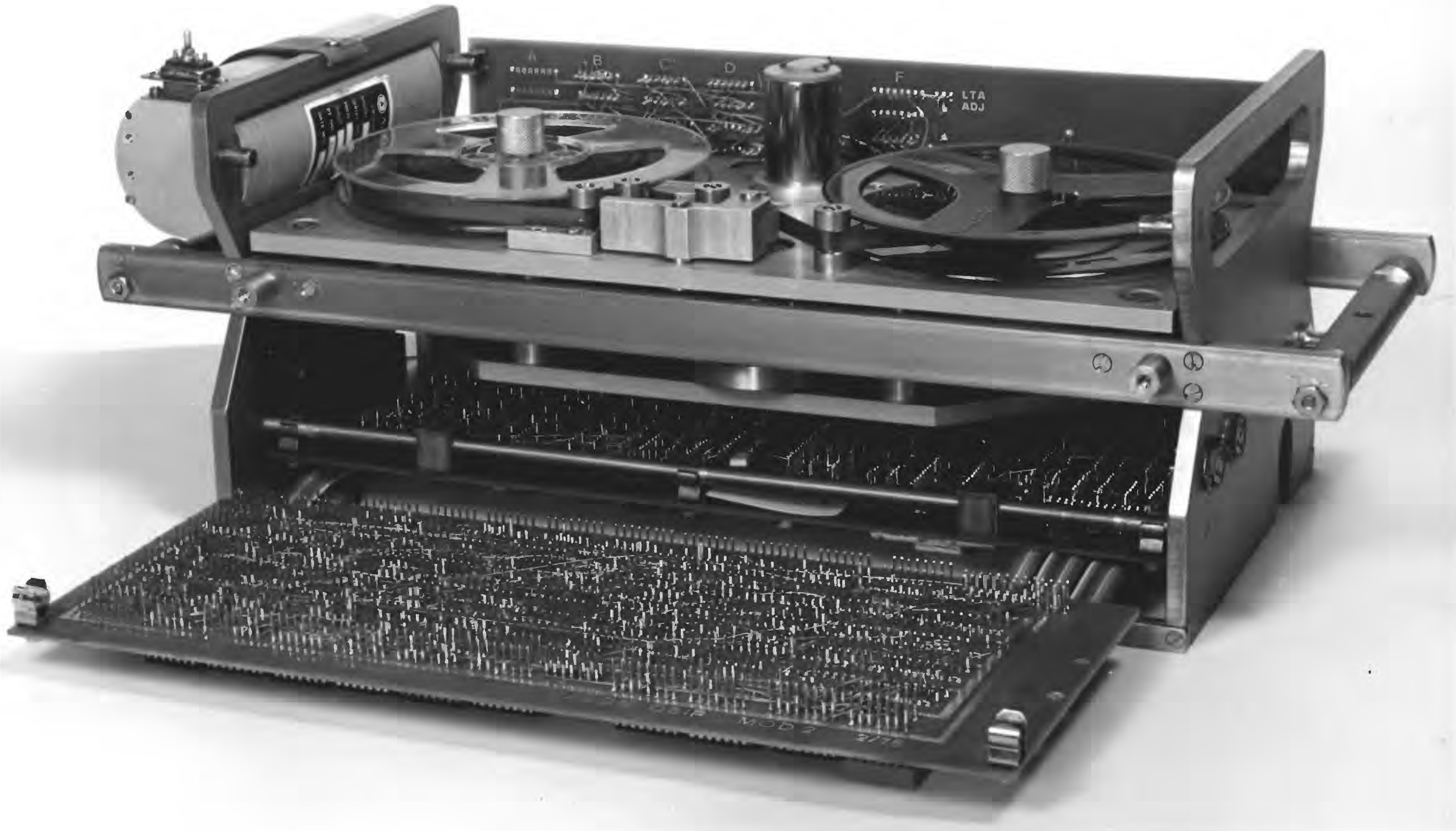

Figure 2. Photograph of the data-acquisition module illustrating accessibility

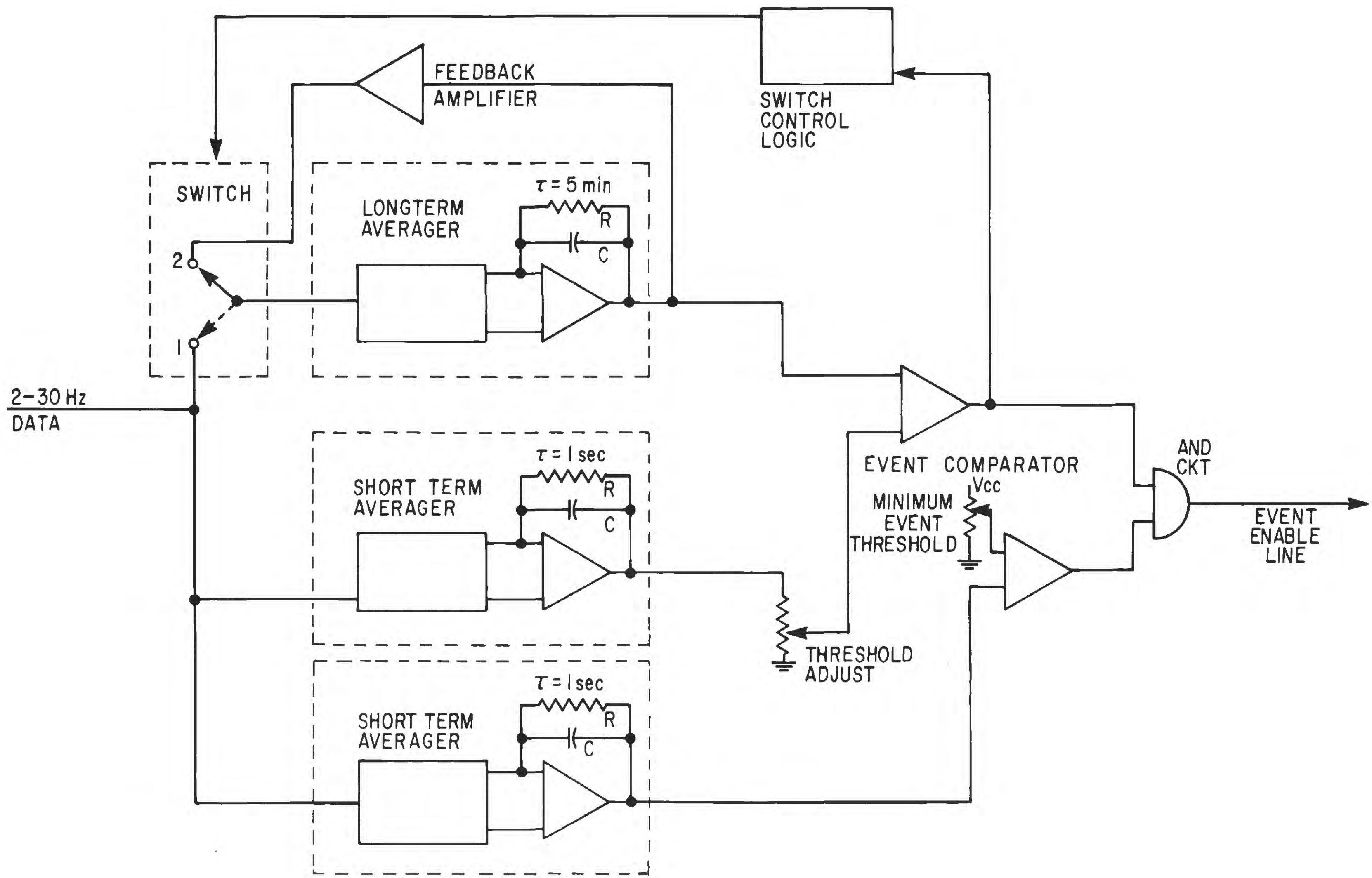

Figure 3. Block diagram of event-detector circuitry

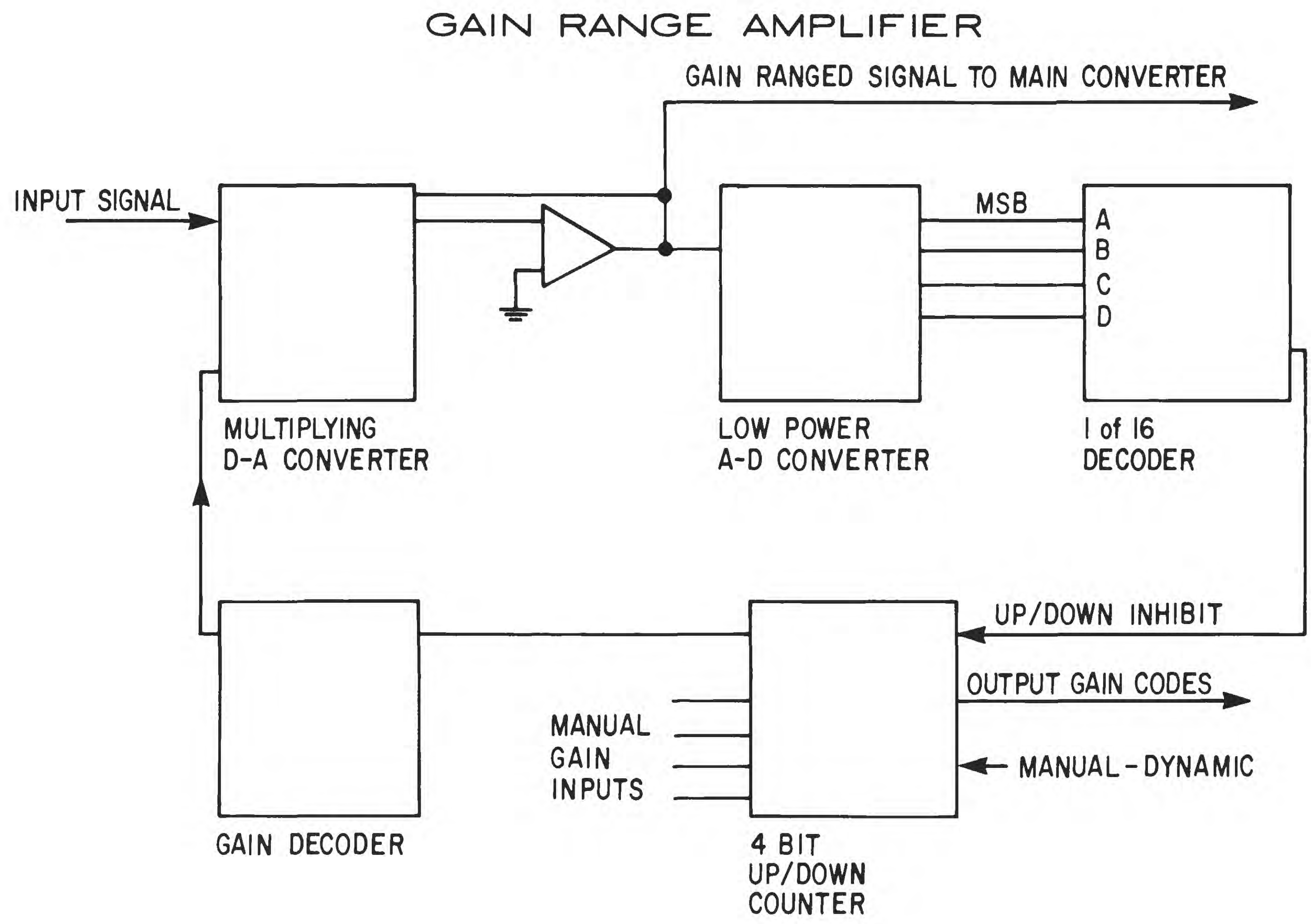

Figure 4. Block diagram of gain range amplifier

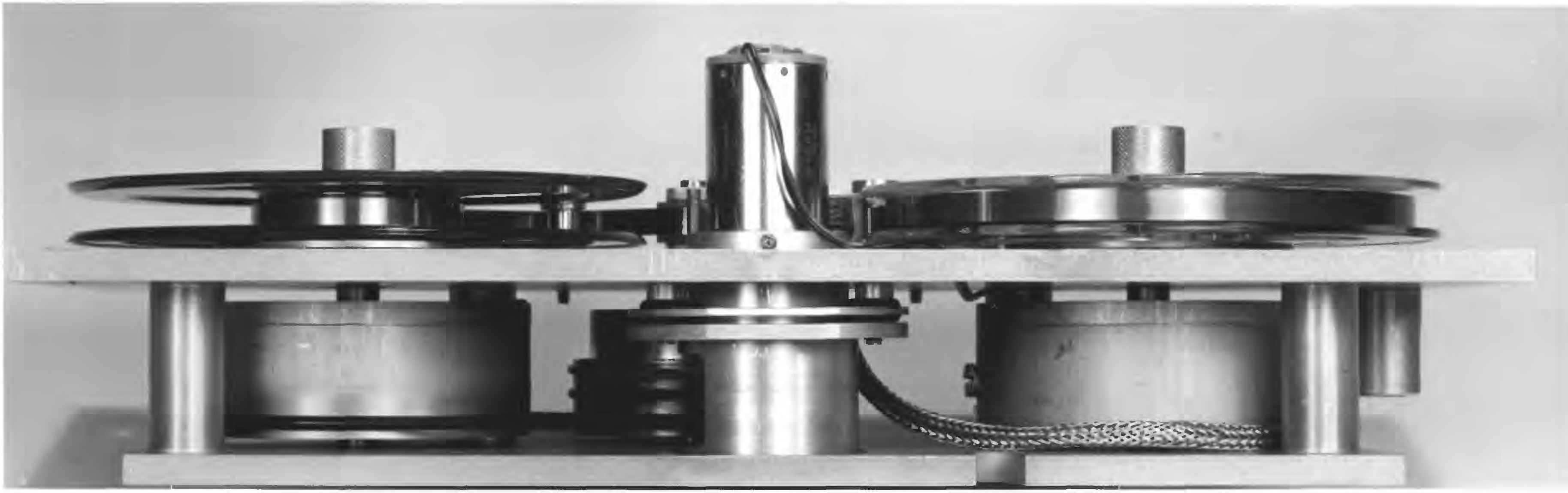

Figure 5. Photograph showing side view of recorder

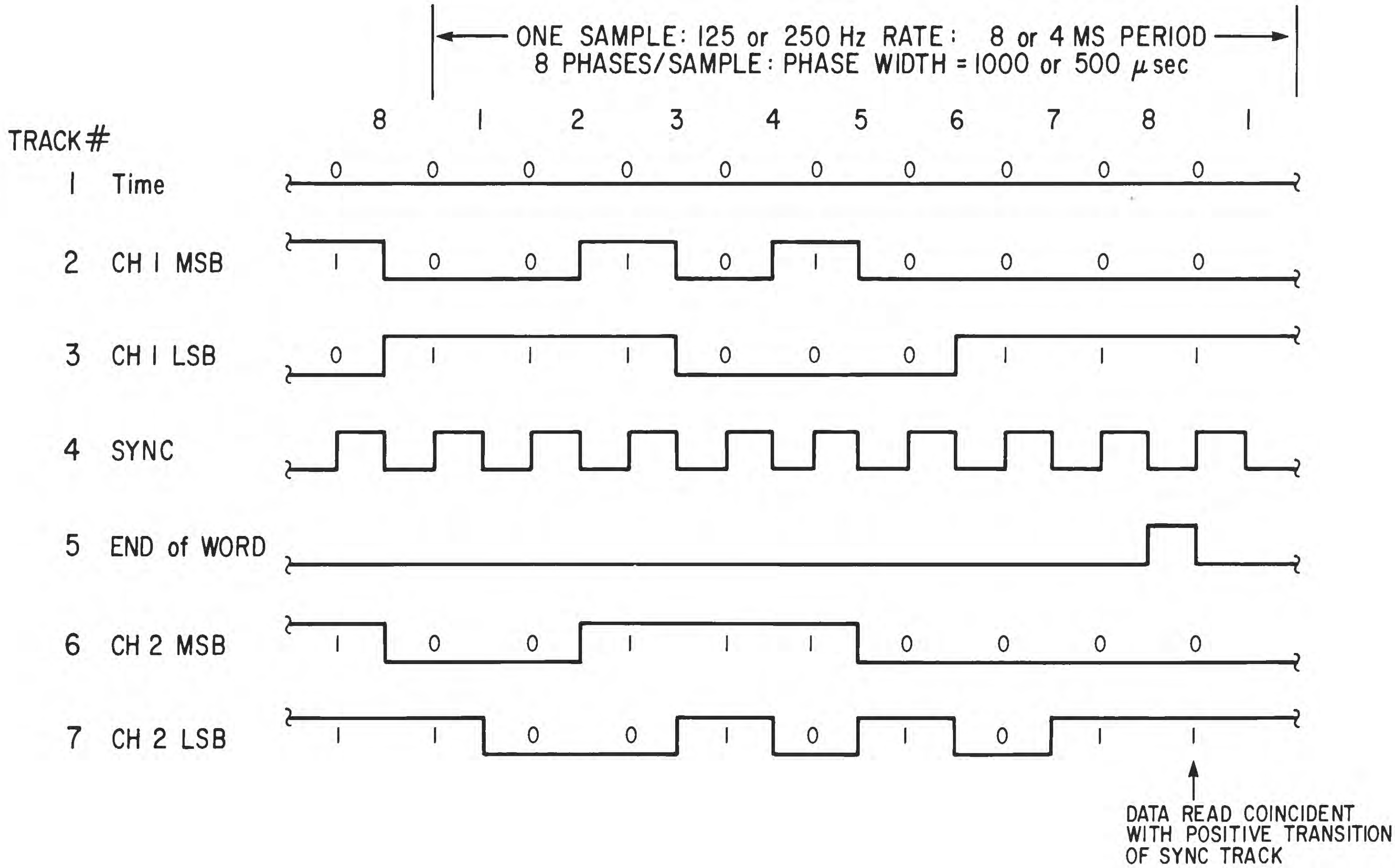

Figure 6. USGS tape recorder data format

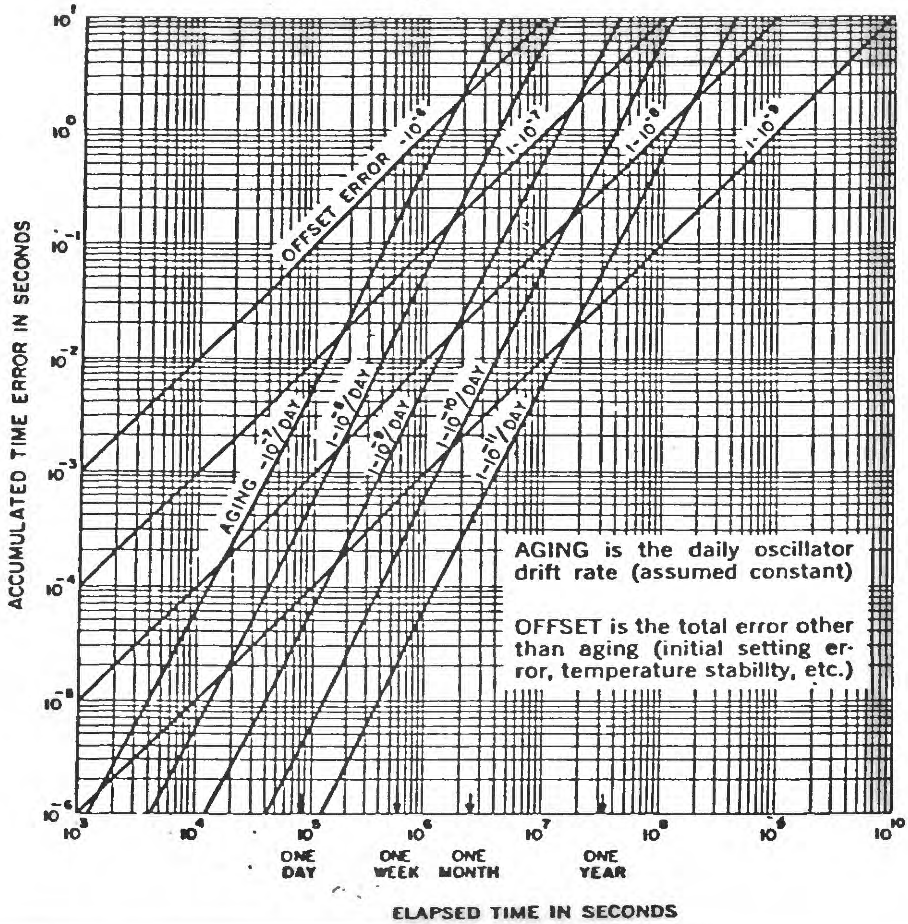

Figure 7. Graph showing accumulated time errors due to crystal frequency offset and aging

Figure 8. Photograph showing exterior view of Ocean Bottom Instrument Package

Figure 9. Photograph showing interior view of Ocean Bottom Instrument Package

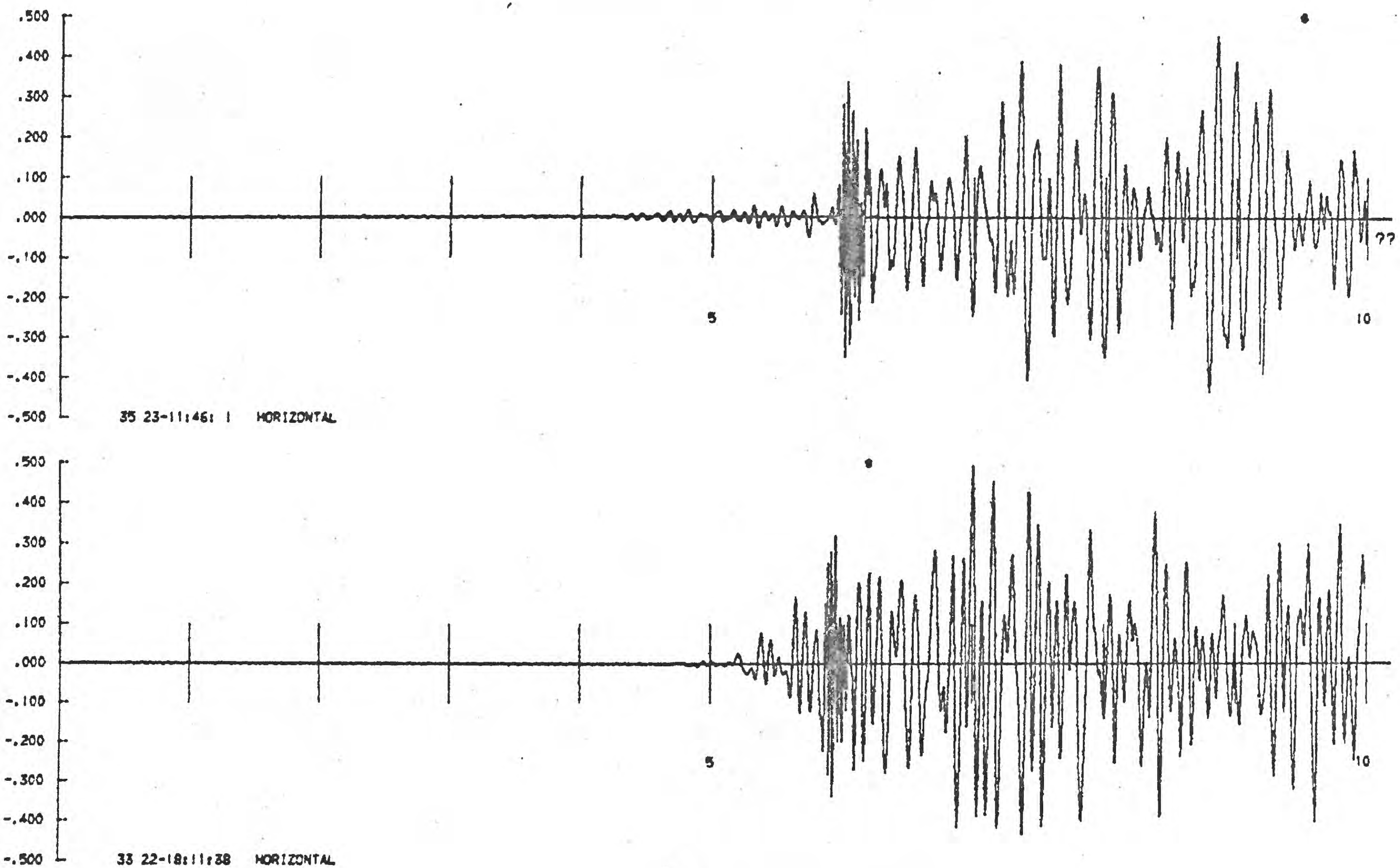

Figure 10. Seismic records from Yakutat Bay, Alaska, August 1980

Figure 11. Photograph showing interior view of land station

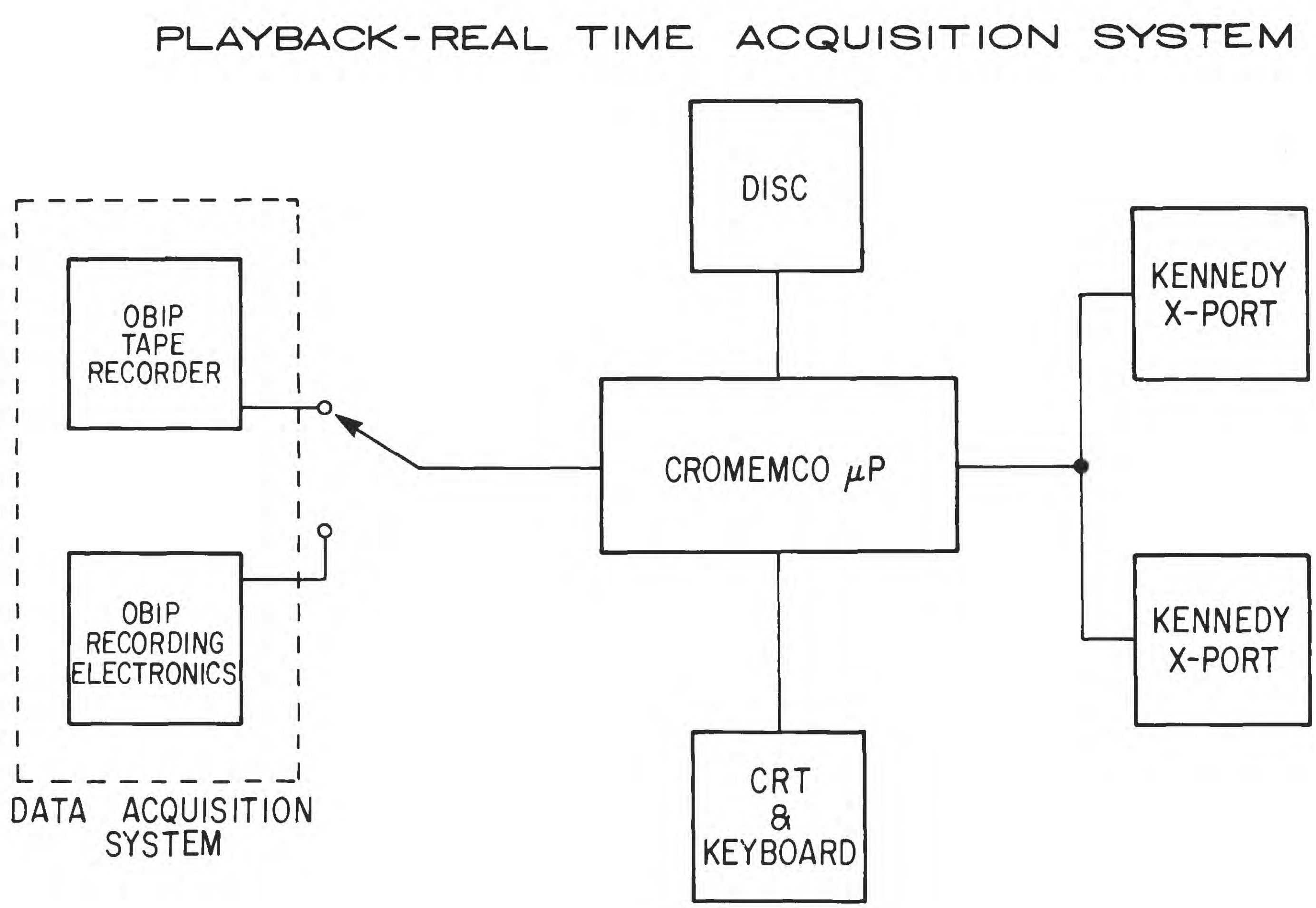

Figure 12. Block diagram of digital playback system.