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Inverted Echo Sounder (IES) Instrument Report

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INSTRUMENT REPORT

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GSO TECHNICAL REPORT 84-4

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ABSTRACT

The Inverted Echo Sounder (IES) is an ocean-bottom moored instrument which accurately measures the time required for an acoustic pulse to travel from the sea floor to the ocean surface and back. The round-trip acoustic travel time varies in response to changes in the mean temperature profile of the water column above the instrument, as well as changes in water depth. The instrument is used as a sensitive indicator of changes in the main thermocline depth caused by synoptic-scale eddies or the shifting path of an ocean current. The IES is small (17"-diameter glass sphere) and self-contained, with its own acoustic release, relocation and recovery system. Its battery capacity and digital tape recorder (data capacity 10^7 bits) allow it to be deployed for up to 18 months. It can operate in water depths of up to 6700 m and requires only an anchor as mooring equipment. Microprocessor-based electronics allow programmable data formatting and sampling cycles. Additional data channels for pressure, temperature, and ambient noise are optional. The system has undergone extensive development and field testing, resulting in a reliable, cost-effective means to study temporal variability in large-scale features of the temperature field of the oceans.

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1. INTRODUCTION

In ocean waters, as temperature and salinity vary, the velocity of sound and, consequently, the acoustic travel time through the water column change. The inverted echo sounder (IES) is an ocean-bottom moored instrument which measures the time for an acoustic pulse to travel from the sea floor to the ocean surface and back.

The travel time, T, can be represented as $T = 2 \int_B^h dz/c$, where z is the vertical distance, h is the sea surface elevation, B is the bottom depth, and c is the sound velocity in seawater. Fluctuations in travel time are due to changes in sea surface elevation (h) and to variability of the above integral of the sound speed profile over the water column above the instrument. Rossby (1969) first showed conceptually that such a measurement can be used effectively to monitor changes in the depth of the main thermocline. Watts (1975), in discussing IES data from MODE I, showed that changes in dynamic height can be resolved with an accuracy of better than one dynamic centimeter. A unique capability of the instrument is that it can sense these quantities from the ocean bottom unattended; thus it can work in high current regions or other hostile environments.

The configuration of the inverted echo sounder (Bitterman, 1976) has been evolving since its initial development (Rossby, 1969). The first multi-instrument deployment was in MODE I (Watts and Rossby, 1977). An array of IESs was used to observe a ring interacting with the Gulf Stream (Watts and Olson, 1978). Recent deployments (1981-84) were under the Gulf Stream off North Carolina (e.g., Watts and Johns, 1982), equatorial Pacific (Watts and Wimbush, 1981, in EPOCS in 1980-81), and equatorial Atlantic (by Katz in SEQUAL in 1983-84). During the past year, development work has continued with complete redesign of analog and digital circuitry. The new analog echo detector is less noise-sensitive and cheaper to manufacture. The digital portion of the circuitry is now based on a low-power microprocessor which allows greater flexibility in programming system functions. The anchor release is a reliable and inexpensive electrochemical mechanism.

Optional additional measurements on this IES model are hydrostatic pressure and temperature at the sea floor and acoustic ambient noise level (Wenz, 1962; Evans et al., in press). Very accurate pressure measurements monitor barotropic variations in the water column; the temperature records are used primarily to correct for the small temperature sensitivity of the pressure sensor. The ambient noise measurements are used as an indicator of wind speed at the sea surface (Evans et al., in press).

Pressure and acoustic travel time measurements combined are used to determine an accurate total ocean surface height: The acoustic travel time has been shown to give an accurate measure of surface dynamic height, with a small additional variation due to barotropic water depth changes. Bottom pressure is sensitive primarily to barotropic variability, with a possible additional component due to imperfect baroclinic adjustment of the surface dynamic height. Hence, each measured parameter may be used to correct for second-order effects of the other and determine the combined barotropic and baroclinic variation of the sea surface height, as discussed in Watts and Wimbush (1981).

2. DESCRIPTION

A schematic diagram of a moored IES is given in Figure 1. A block diagram of the IES system is given in Figure 2. The IES operating characteristics are listed in Table 1.

Electronics System

A block diagram of the IES electronic components and detailed electronic schematics are given in the Appendix.

There are two large printed circuit boards, one round (12"-diameter; the processor board) and one square (12x12"; the transmit/record board), connected by a single 25-conductor cable. The large round board (Fig. 3) contains the microprocessor (CPU) with its related RAM, ROM and clock circuitry, a separate clock for time-keeping, timing control logic, and travel-time counter. The large square board (Fig. 4) contains the ON/OFF/RESET circuits, voltage regulators (+12 V and +6 V), output power amplifier, release relay and connectors to mount 2 echo detector cards, 6 Sea Link Systems series 200 release cards, 3 Sea Data model 610 recorder cards and tape transport, and optional space for auxilliary data channels (pressure, temperature and ambient noise - Sea Data XP-35, DC-37, and DC-35, respectively).

TABLE 1. IES OPERATING CHARACTERISTICS

PRESSURE CASE	17"-diameter glass sphere (Benthos)
OPERATING DEPTH	6700 m (maximum)
WEIGHT IN AIR	80 lbs plus 100-lb anchor
BUOYANCY IN WATER	20 lbs (with full load of batteries)
BATTERY	GTE Lithium +14 V @ 90 Ah
DATA STORAGE, CAPACITY	Sea Data model 610 cassette recorder, 10^7 bits
DEPLOYMENT TIME	18 months (maximum), consistent with data capacity and battery life
RECOVERY SYSTEM	Self-contained Sea Link series 200 decoder electronics and electrochemical ballast release mechanism
RELOCATION AND RECOVERY AIDS	10 kHz acoustic beacon (4-sec repetition rate), OAR radio and flasher, flag, backup release timer
OPTIONAL DATA CHANNELS	Bottom pressure, temperature, and acoustic ambient noise (see OPTIONAL SENSORS, below)

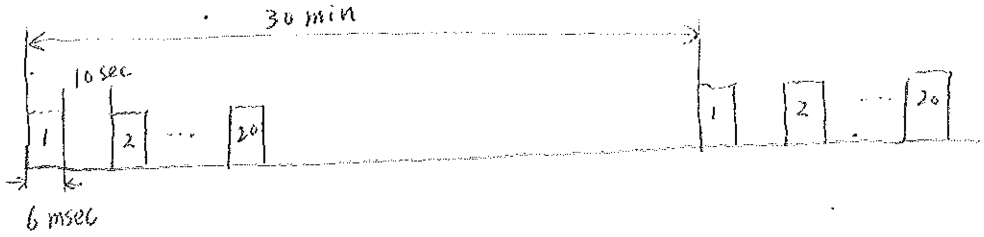


TABLE 1, CONTINUED

SAMPLING CHARACTERISTICS	All Programmable, typically:
Burst Rate	30 min between bursts
Burst Length [illegible]	20 pings/burst
Ping Rate	10 sec between pings
Ping Length	6 msec
Ping Frequency	10240 Hz
TRANSDUCER CHARACTERISTICS	Special ITC stacked piston
Transmit Bandwidth	9 to 11 kHz @ -3 dB power
Beam Width	80° (typical), 50° (optional)
Acoustic Power	197 (typical), 203 (maximum) dB re 1 uPa at 1 m
Electronic Power	250 Watts, pulsed
TIMING STABILITY	0.02 ppm/°C (typical) for 0-25°C 0.03 ppm/m (maximum) after first 3 months
TRAVEL TIME ACCURACY	0.049 msec resolution 0.5-1.5 msec standard deviation of single measurement 0.1-0.3 msec standard deviation of 20 measurements
OPTIONAL SENSORS	
Bottom Pressure	Paroscientific Digiquartz model 410K sensor (0-10,000 psi), powered and counted by Sea Data XP-35 electronics card with 0.28 ppm resolution
Temperature (of pressure sensor)	YSI thermistor and Sea Data DC-37 electronics card (0-25°C)
Acoustic ambient noise	@ 11 kHz in 2 kHz bandwidth using Sea Data DC-35 B or C WOTAN electronics card with 60 dB dynamic range

The two large boards are mounted on a PVC battery-holding frame capable of holding eight sticks of "D" or "DD" lithium cells. Typical battery capacity at 14 V DC is 90 Ah. A photo of the assembled electronics is in Figure 5.

The master oscillator runs at 4.19 MHz. After being divided by 2^{11}, the 2048 Hz is fed into two parallel phase-lock loop multipliers. The first multiplier (x10) generates two types of signals: 20.48 kHz to drive the travel time counter and 10.24 kHz for the acoustic pulses. The second multiplier (actually ÷8) drives the time-keeping clock, generates pulses at rates of 1 sec and multiples thereof (selectable by jumpers), and provides reference frequencies for auxilliary data channels and the CPU timer.

The sequence and timing of events which comprise an IES data scan are determined by the program stored in ROM. This program is chosen by the user and many variations are possible. To illustrate the functions of the circuits under program control, a typical data scan will be described. The sequence of events can be followed in the time line in Figure 6.

The ON/OFF/RESET circuits are activated by push-buttons on the square board or by light-sensitive diodes which may be activated by shining a flashlight through the glass sphere. When the reset circuit is activated, the CPU first checks to see if there is a terminal attached to its RS-232 I/O lines and, if so, will send a prompt to the terminal and continue polling the input line until it receives further instructions. The ROM contains a modified version of a Motorola monitor program written for the HMOS 6805 microprocessor. Memory locations and

CPU registers can be examined and changed, programs can be executed starting at any address and test programs can be loaded and run in RAM allowing the system to be used for program development as well as data acquisition.

If a terminal is not attached when the reset circuitry is activated, the CPU will begin executing the user's program stored in ROM.

After configuring its I/O lines and initializing its interval counters, the CPU will start our typical data scan. The acoustic pulse is transmitted and the travel time counter is started simultaneously. When the echo is detected by the echo detector, the contents of the counter are loaded into a parallel-to-serial shift register. The resulting 18-bit number is equal to the acoustic travel time. From the shift register the travel time is stored in RAM just prior to the next acoustic transmission. This sequence is repeated for each measurement until the burst of 20 pings is completed, whereupon the RAM buffer contains each of the individual travel times. The instrument then stops in a low-power STOP state until the next interrupt pulse is received from the time-keeper clock.

The program in ROM determines the number of travel time measurements performed during each burst. In our typical burst sampling program, a group or burst of travel time measurements is generated at a fixed rate of one measurement every 10 seconds with a total number of 20 measurements per burst. The number of measurements per burst is limited only by the size of the buffer memory (2K x 8 RAM).

Between measurements the CPU operates in a reduced-power WAIT state and between bursts it operates in a low-power STOP state. In the STOP state the CPU simply waits for the next interrupt pulse from the timekeeper clock. The operating state of the CPU does not affect the relocation and recovery functions as the circuits operate independently.

In our typical example, when the CPU receives the subsequent interrupt pulse, it first increments the 16-bit sequence number which is attached to every data record and then compares this number to the timed release number stored in ROM. If they are the same, the echo sounder will automatically be released from the bottom. (See the relocation and recovery section.) If the numbers are not the same, the CPU will return to the user's program and latch any optional data into a shift register and store it with the travel times in the temporary RAM buffer. The CPU then sends a record request pulse to the tape recorder system whose internal clock shifts all of the data record (sequence number, travel times, optional data) from RAM to magnetic tape. After recording a data record, the CPU will check if a terminal is attached and, if so, will display the data record on the CRT.

If a terminal is not attached, the CPU will enter its low-power STOP state and await the next 15-minute interrupt pulse. This next pulse will cause the CPU to increment the sequence number, compare it to the timed release and start another travel time data scan. This cycle will continue until the IES is reset or recovered. Notice that, in this example, the sequence number is not the number of data records but the number of elapsed 15-minute periods, and hence uniquely specifies the time.

Housing

The electronics and batteries are contained in a 17"-diameter (outer diameter) glass sphere (from Benthos, Inc.). The sphere has a wall thickness of 9/16 inch, a weight in air of 39 lbs, and a buoyancy in seawater of 56 lbs (sphere only).

The glass sphere is housed in a polypropylene "hard hat" with the pinger and its protective cage (which is also its lifting bale) bolted to one end. The electrochemical release block is bolted to the other end (see Fig. 1). When deployed, the pinger is pointed vertically up toward the sea surface; when released from the bottom, the IES turns over and the pinger is pointed down. When the instrument reaches the surface, the OAR flasher and radio, which were on the bottom of the IES for deployment, will then be out of the water and the pinger will remain in the water. A polypropylene rope is tied around the rim of the hard hat to facilitate retrieval.

Weights

An 80- to 100-lb anchor is attached by a 1-m length of 5/16-inch-diameter nylon line. This tetherline must be short (about 20 cm longer than the radio antenna) so that any swinging motions caused by varying bottom currents do not cause the instrument to vary significantly in depth. Also, the anchor must be rigid enough that varying drag does not cause bobbing.

Relocation and Recovery System

An acoustic beacon system has been incorporated as the primary relocation aid. A modified (lengthened) AMF Sea Link transpond pulse is projected from a hydrophone on the ship. This pulse initiates a continuous series of 10 kHz pulses from the IES of an 8-sec (selectable) repetition rate. The relocation pulse rate is an exact integral number of seconds (8) so they are received at the same spot on the chart of a line scan recorder at a 2-sec sweep rate. The ship can be maneuvered to minimize the distance from the instrument, to a position directly above the moored IES. The relocation beacon is shut off at the first pulse of a data scan but, if need be, can be reinitiated after the data scan is complete, by another signal from the Sea Link shipboard deck set.

When the ship has been positioned close to the IES, the appropriate release code is sent via the Sea Link deck set. When the release code is accepted by the IES and current is detected in the electrochemical ballast-release system, the release-sensor relocation pinger (which produces a 10-kHz pulse train with a 4-sec rate) is initiated and within 16-20 minutes the IES will release its ballast anchor and rise to the surface. The IES can be tracked to the surface using the line scan recorder and, if need be, the ship can be maneuvered to remain close while the IES rises.

Because the IES is small, once it is on the sea surface an OAR (Ocean Applied Research) radio beacon and strobe flasher, as well as a flag, are used as backup and nighttime recovery aids.

A backup release timer has also been built into the IES. It is programmed in ROM prior to launch and will activate the electrochemical release in case the instrument is unable to receive or detect the acoustic release command. This timer is usually set to activate several months after the expected recovery cruise.

Data Sample

Figure 7 is a data sample from an IES, with no processing. It is a strip chart record, obtained by direct digital-to-analog conversion of the cassette data, and shows all the measured acoustic travel times. The instrument was deployed in 3,500 m of water near the north edge of the Gulf Stream off Cape Hatteras, North Carolina in November 1983.

The straight lines in the top half of Figure 7 are plots of the sequence number (bits 0-8), which rolls over every 64 hours. In the lower half of Figure 7, the semidiurnal tides show up clearly as low-amplitude, high-frequency signals and exhibit a beat frequency of about 15 days, corresponding to spring and neap tides. The large, low-frequency excursion corresponds to changes in the thermocline depth due to Gulf Stream meandering. The approximate conversion factor is a change of 1 msec = 20 m change in the depth of the $15^{\circ}C$ isotherm and is incorporated into the scale on the right.

3. COSTS

The major components of each instrument and their costs are listed in Table 2.

TABLE 2. COSTS OF MAJOR IES COMPONENTS

TAPE RECORDER AND CONTROL	$ 1,800
AMF RELEASE RECEIVER	2,300
GLASS SPHERE AND PENETRATORS, HARD HAT	800
ELECTRONICS FRAME	300
ANCHOR RELEASE	100
TRANSDUCER	1,000
ELECTRONICS	800
MISCELLANEOUS FITTINGS	300
OAR RADIO AND FLASHER	1,100
TOTAL	$ 8,500
COST PER DEPLOYMENT (CONSUMABLES)	500
	$ 9,000

With the exception of the electronics, nearly all the major cost items have been purchased from outside vendors. Thus the total instrument cost is fixed rather firmly.

4. SUMMARY

Extensive field testing has shown that the concepts behind the inverted echo sounder are technically feasible, and has yielded interesting data. The latest design incorporates changes (in checkout and deployment procedures) which make the IES appealing for general use by the oceanographic community; also, the improved operating characteristics (echo detector, deployment lifetime) should make the IES more attractive scientifically. Experience has standardized deployment and recovery logistics, making the system easy to handle at sea. Extension of deployment life to 18 months and flexibility in burst sampling should prove very useful for studying ocean features with low-frequency variability.

ACKNOWLEDGMENTS

Recent IES developments reported here were made under grants from NSF (OCE 82-01222) and NOAA/ERL (NA 79 RAD 00022).

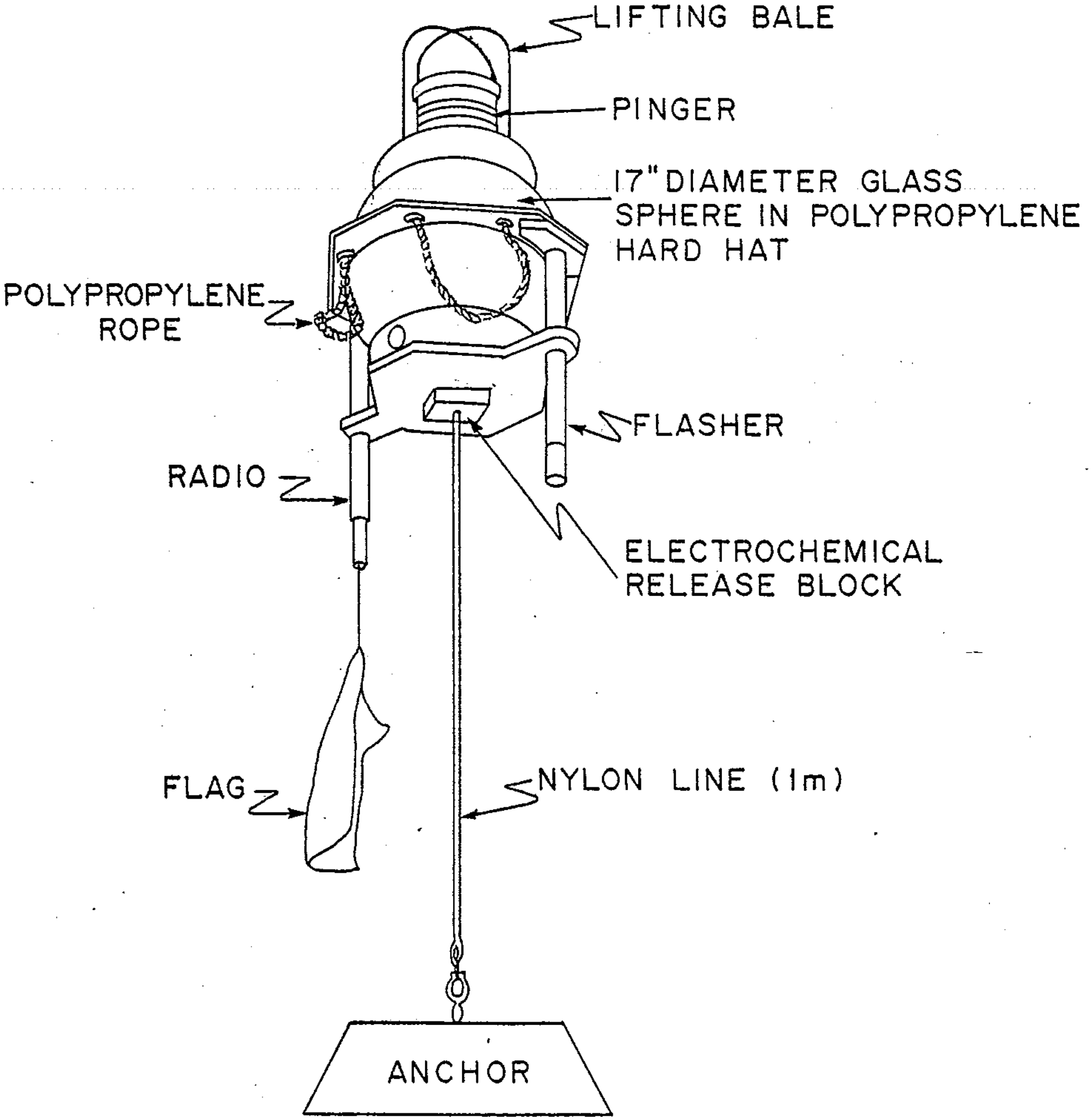


Fig. 1 Diagram of Moored IES.

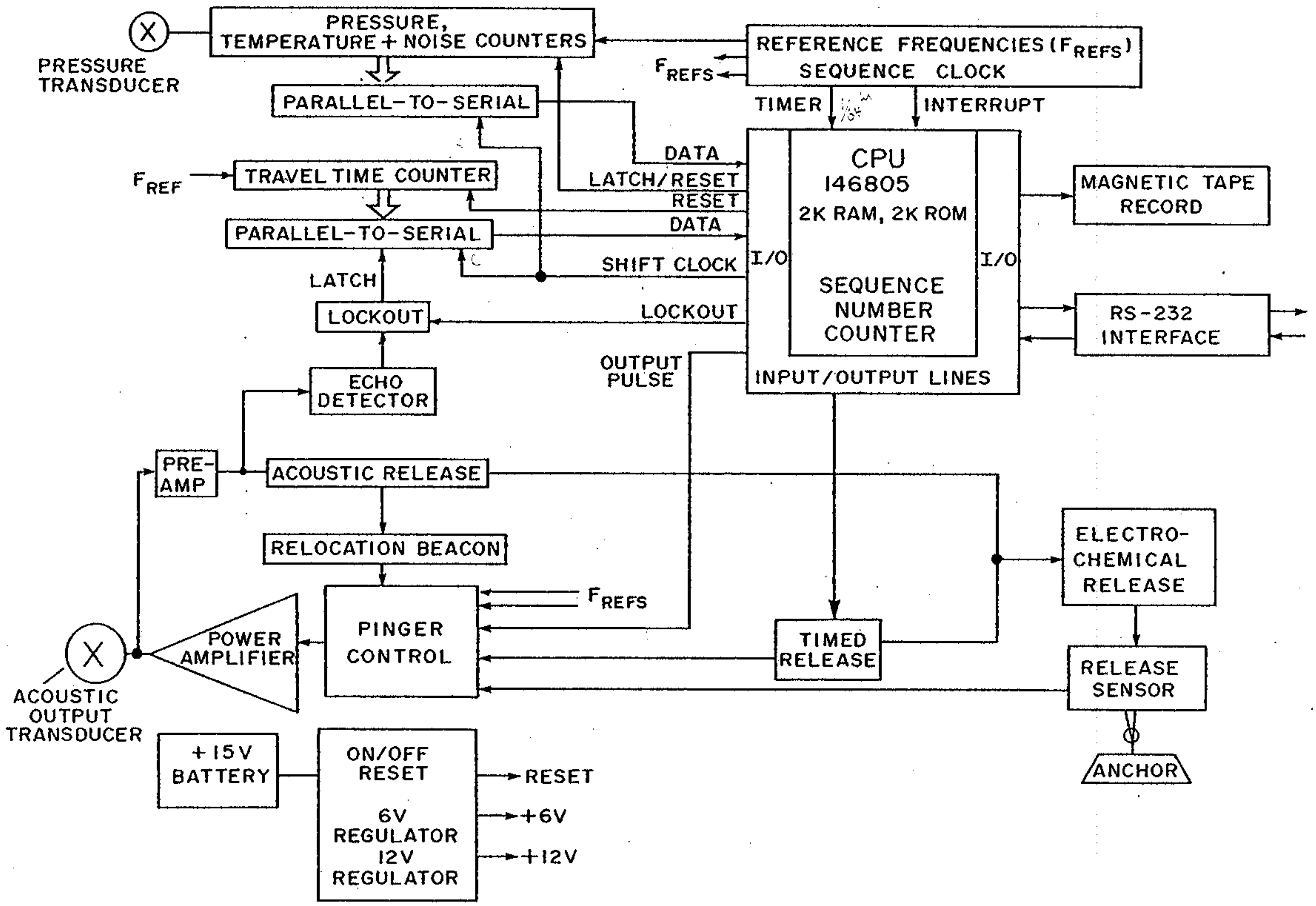


Fig. 2 BLOCK DIAGRAM OF INVERTED ECHO SOUNDER

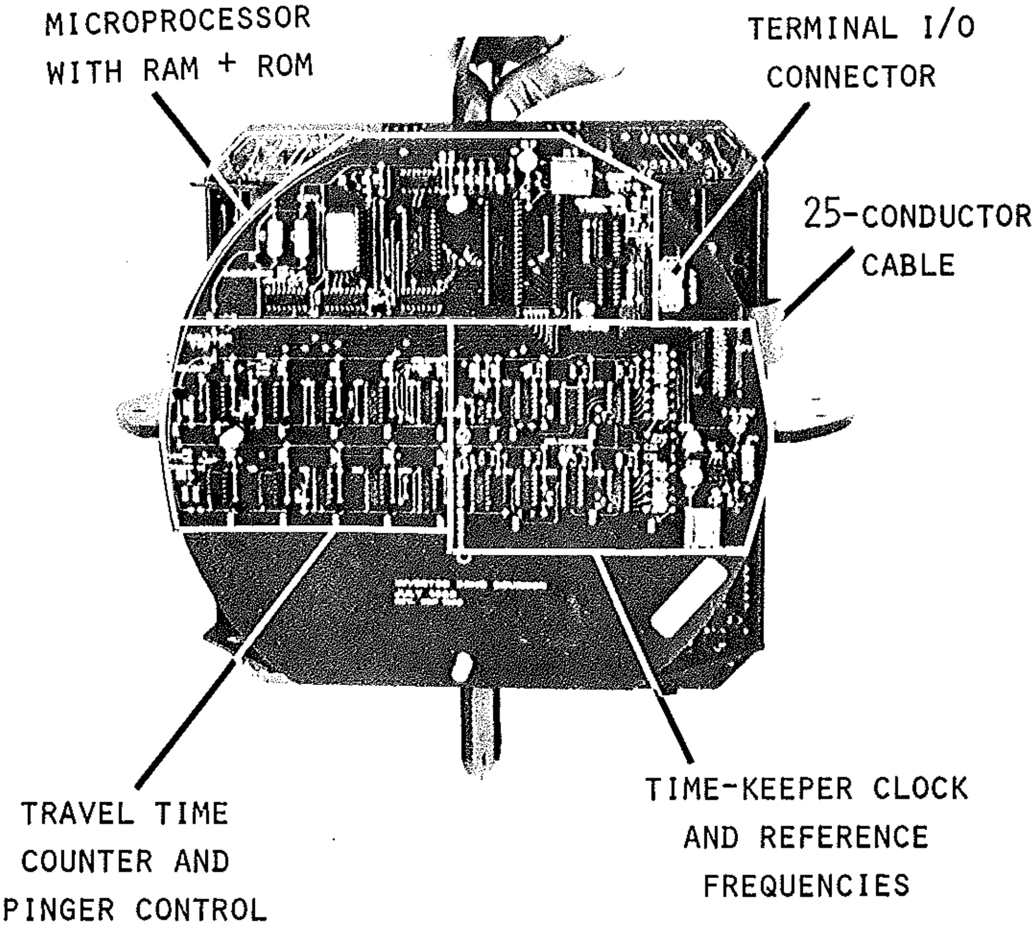


FIG. 3. PHOTO OF PROCESSOR BOARD

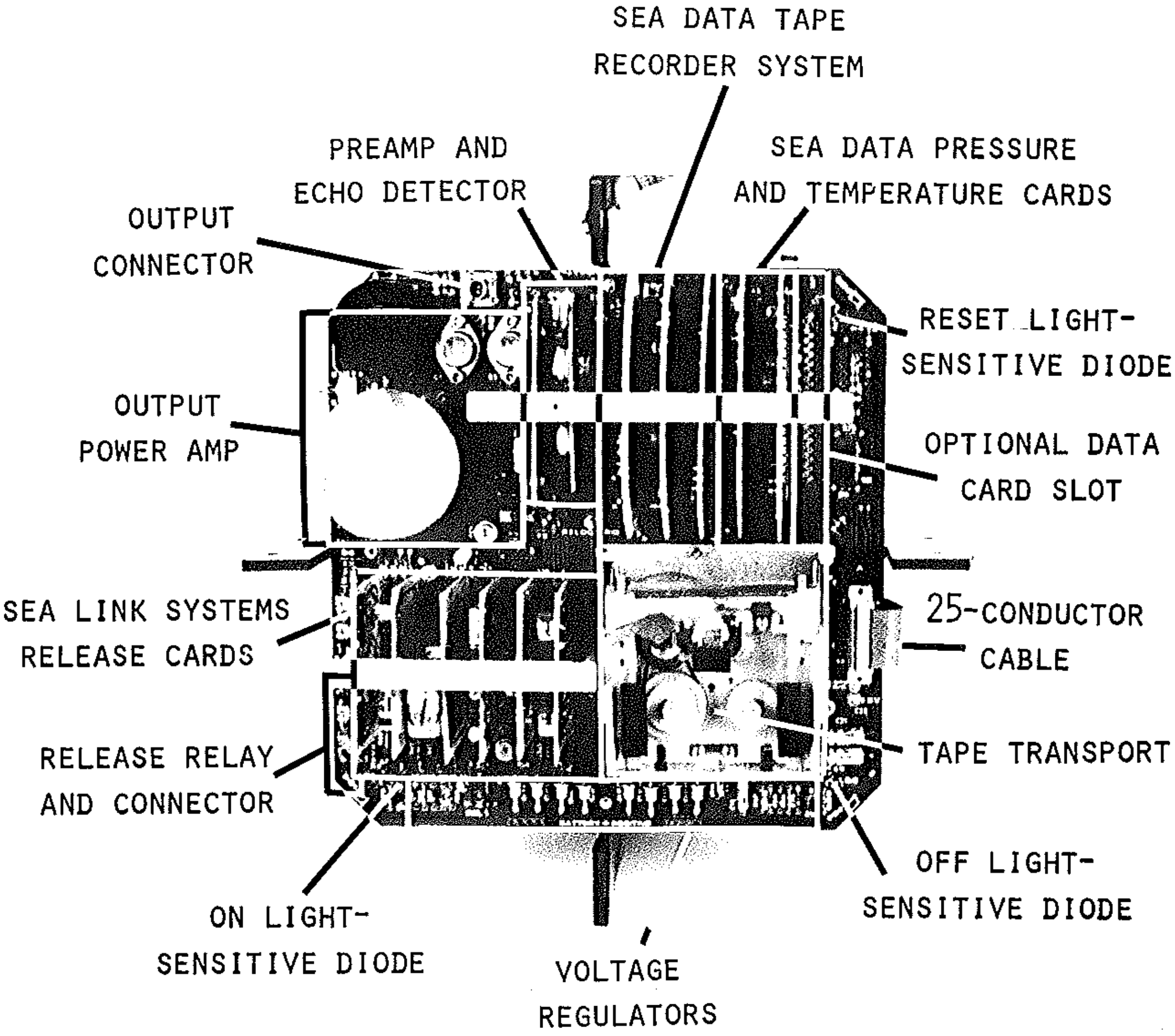


FIG. 4. PHOTO OF TRANSMIT/RECORD BOARD

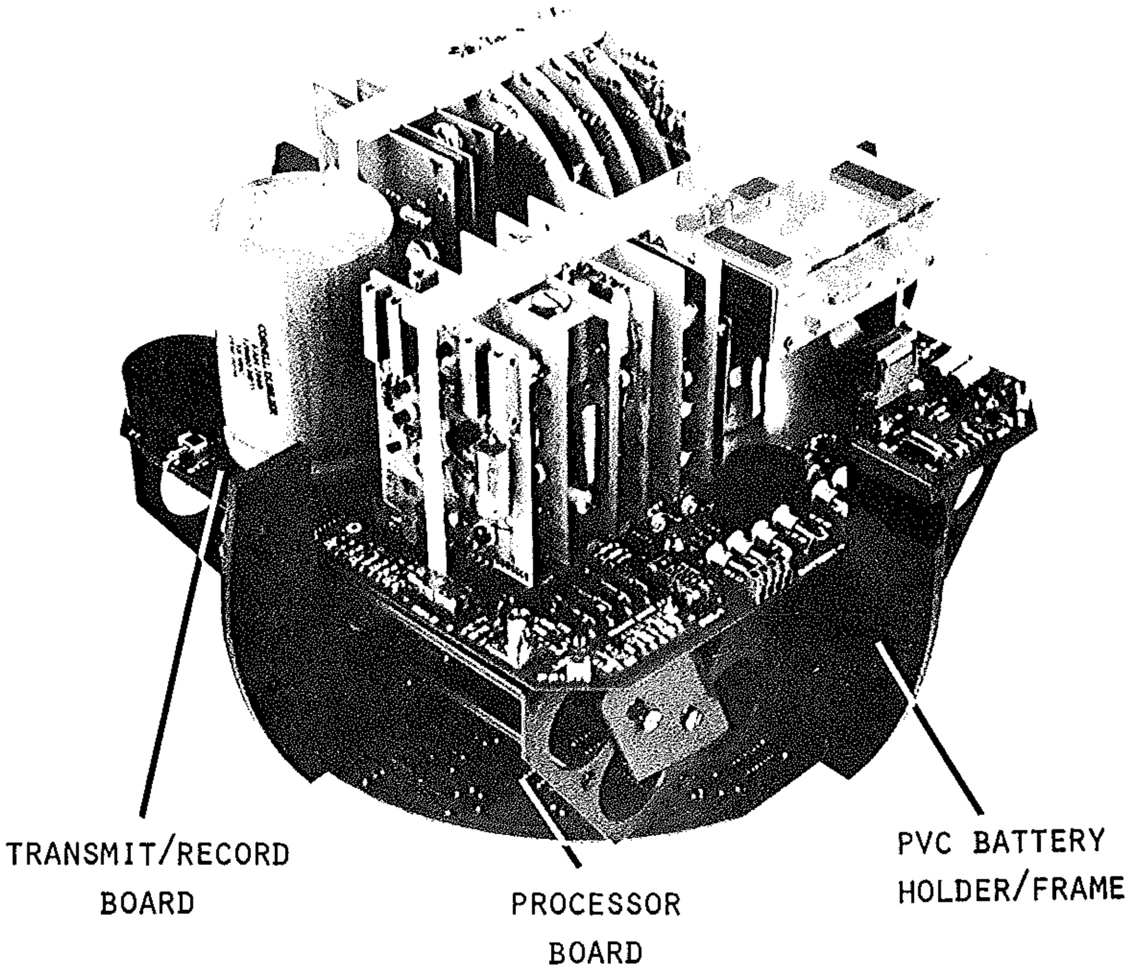
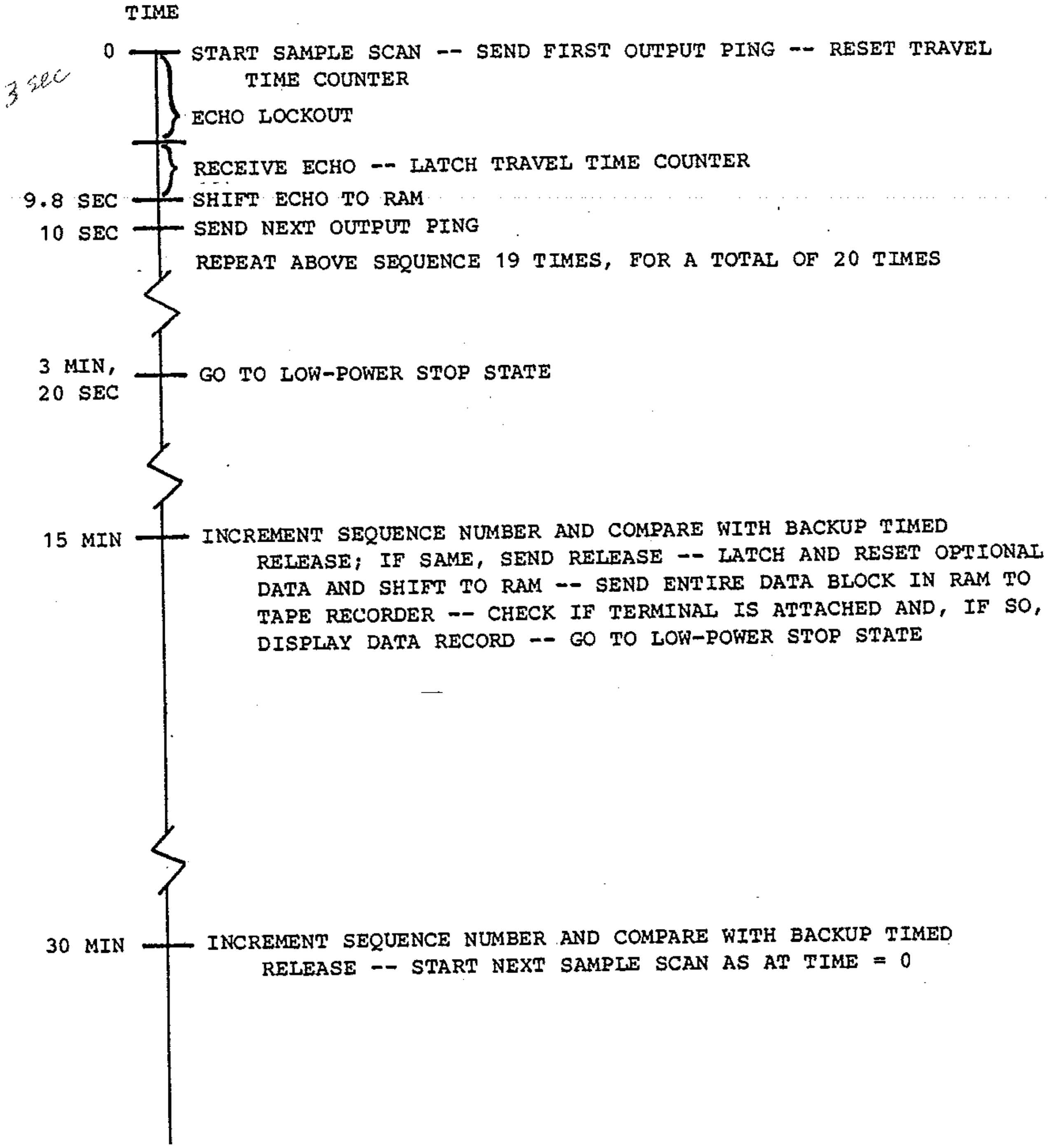


FIG. 5. PHOTO OF ASSEMBLED ELECTRONICS



0 START SAMPLE SCAN -- SEND FIRST OUTPUT PING -- RESET TRAVEL TIME COUNTER

ECHO LOCKOUT

RECEIVE ECHO -- LATCH TRAVEL TIME COUNTER

9.8 SEC SHIFT ECHO TO RAM

10 SEC SEND NEXT OUTPUT PING

REPEAT ABOVE SEQUENCE 19 TIMES, FOR A TOTAL OF 20 TIMES

3 MIN, 20 SEC GO TO LOW-POWER STOP STATE

15 MIN INCREMENT SEQUENCE NUMBER AND COMPARE WITH BACKUP TIMED RELEASE; IF SAME, SEND RELEASE -- LATCH AND RESET OPTIONAL DATA AND SHIFT TO RAM -- SEND ENTIRE DATA BLOCK IN RAM TO TAPE RECORDER -- CHECK IF TERMINAL IS ATTACHED AND, IF SO, DISPLAY DATA RECORD -- GO TO LOW-POWER STOP STATE

30 MIN INCREMENT SEQUENCE NUMBER AND COMPARE WITH BACKUP TIMED RELEASE -- START NEXT SAMPLE SCAN AS AT TIME = 0

Fig. 6 Time Line of a Typical IES Cycle

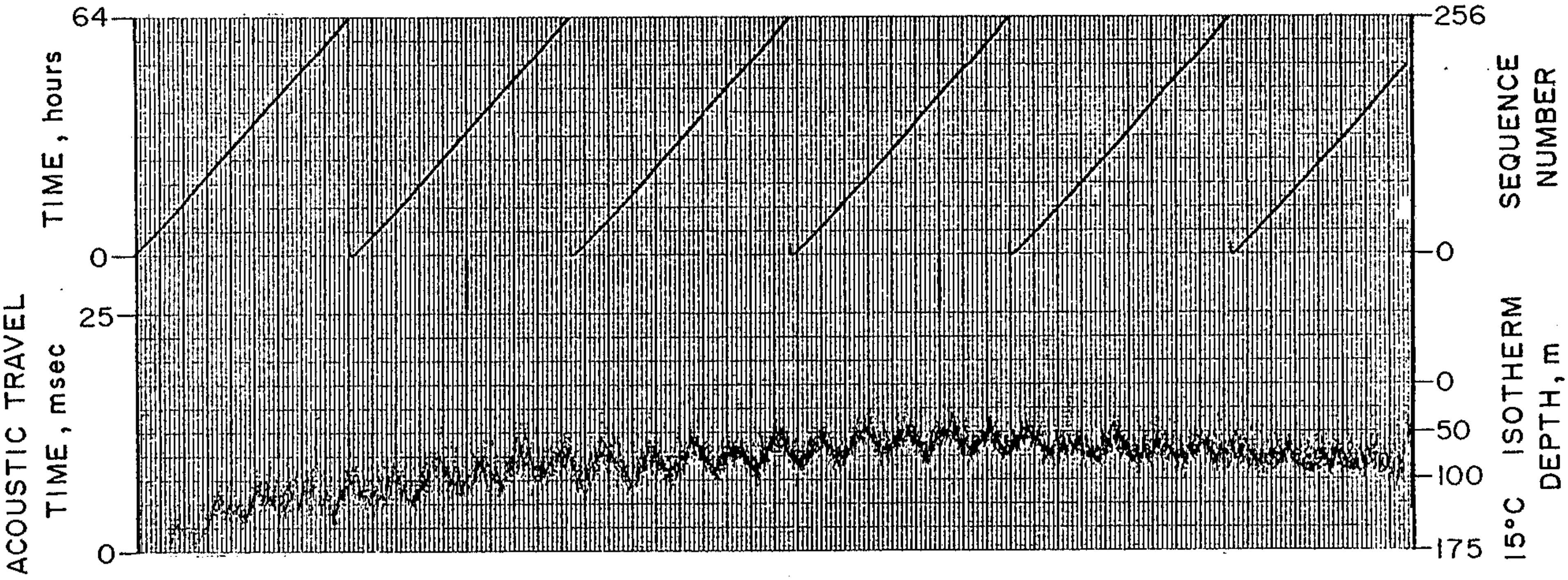


Fig. 7. IES Data Sample – Strip Chart Record

APPENDIX - IES ELECTRONICS BLOCK DIAGRAM AND SCHEMATICS

LIST OF APPENDIX FIGURES

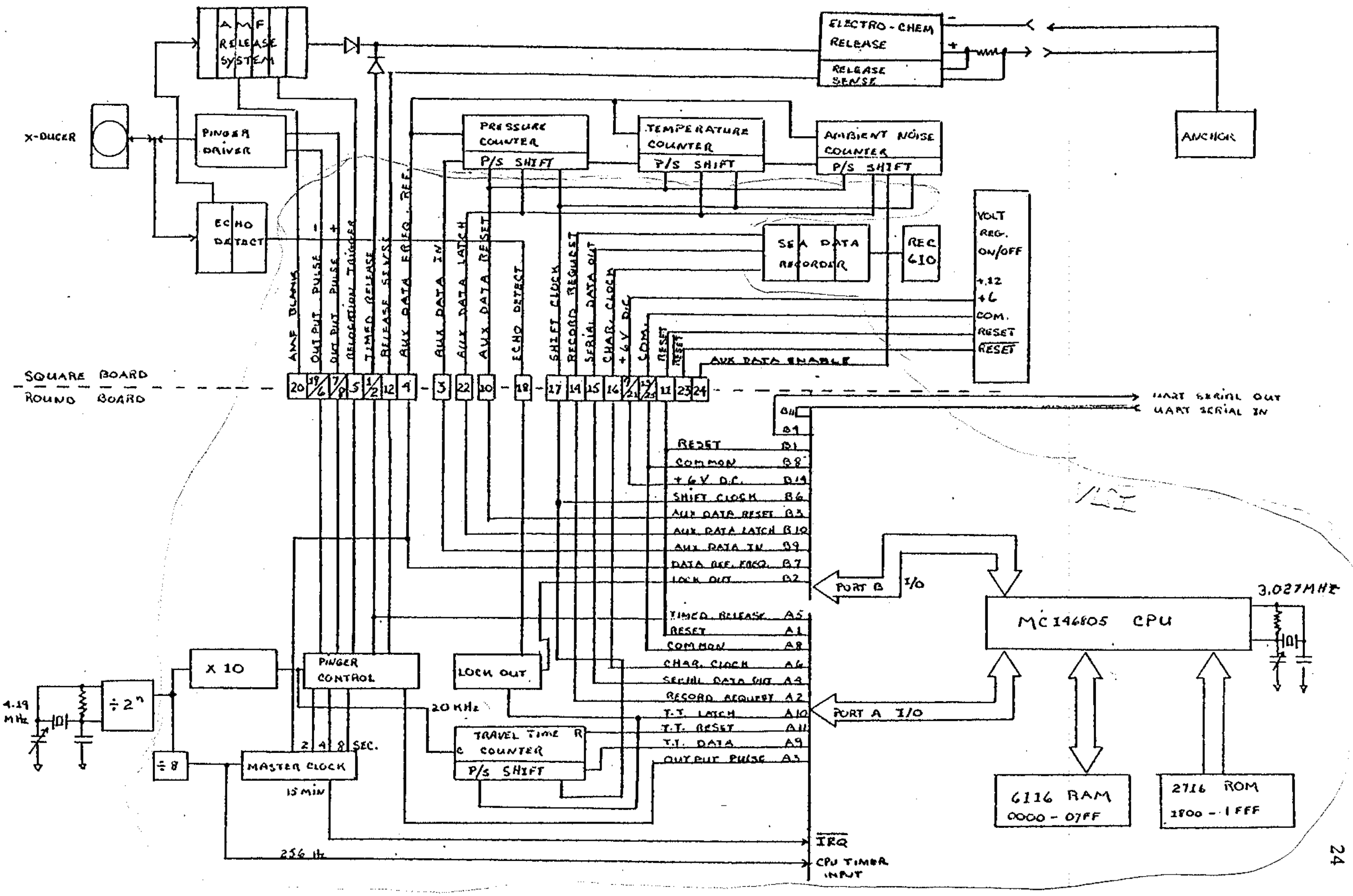


Fig. A-1. IES Electronics Block Diagram

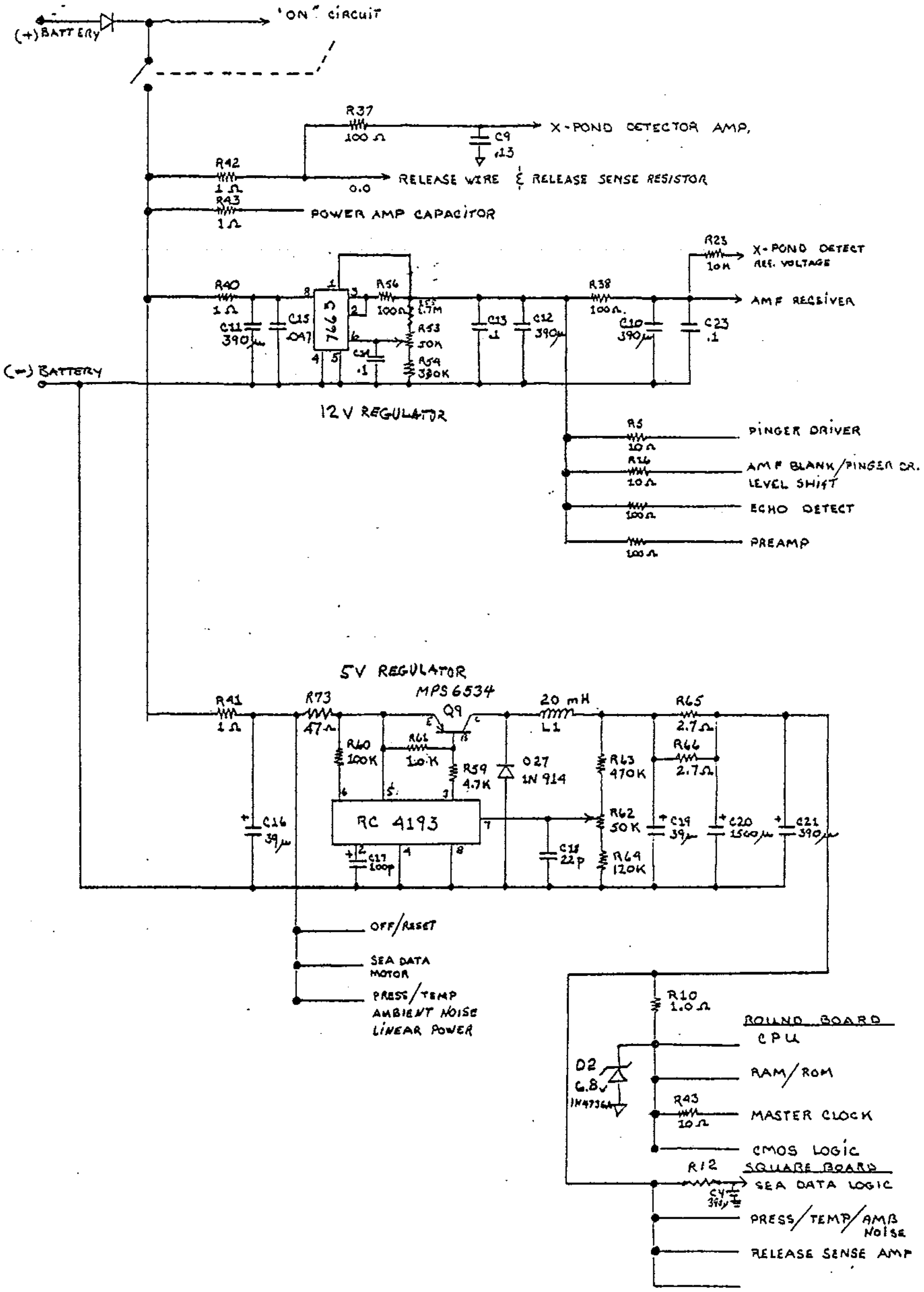


Fig. A-2. Power Tree and Voltage Regulators

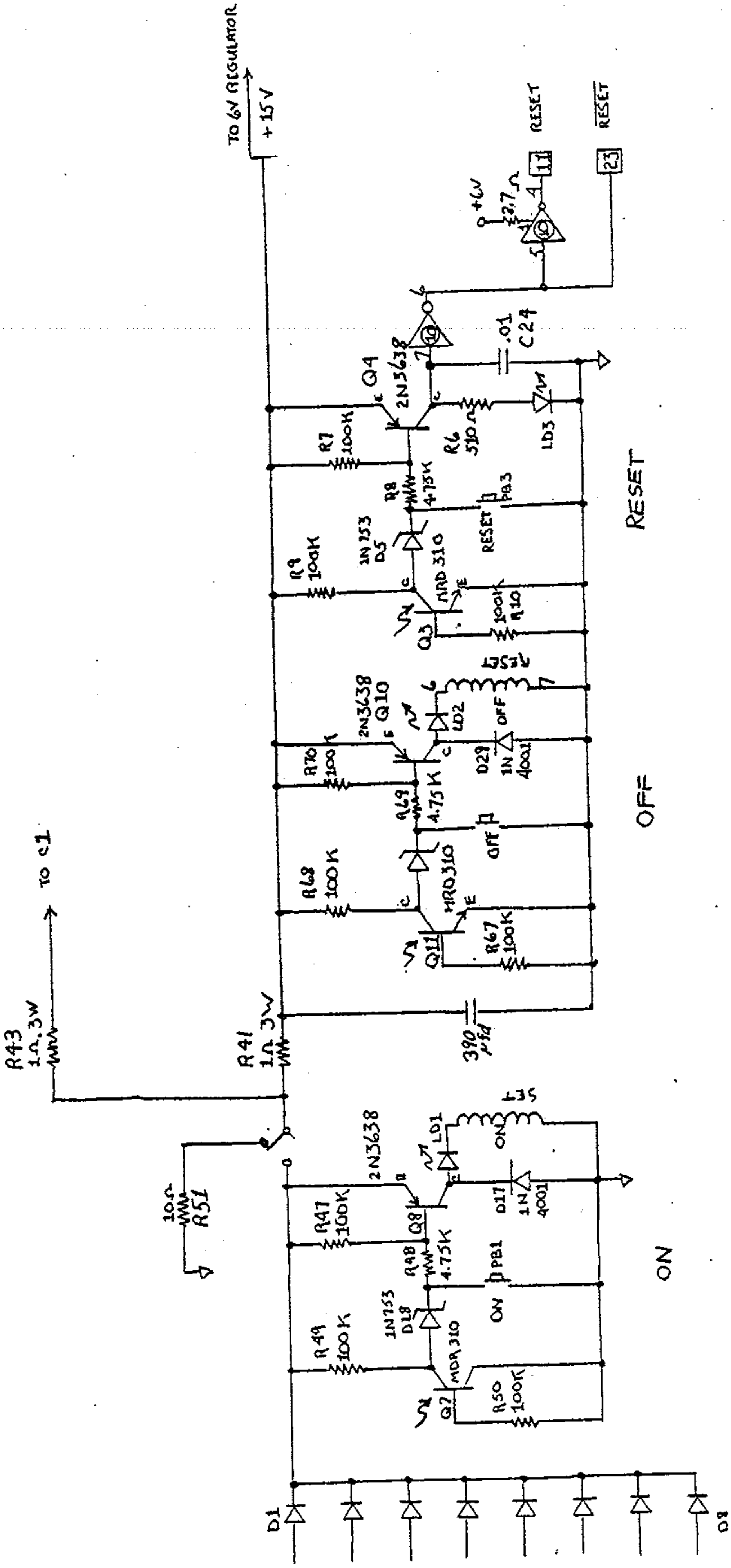


Fig. A-3. Transmit/Record Board - ON/OFF/RESET

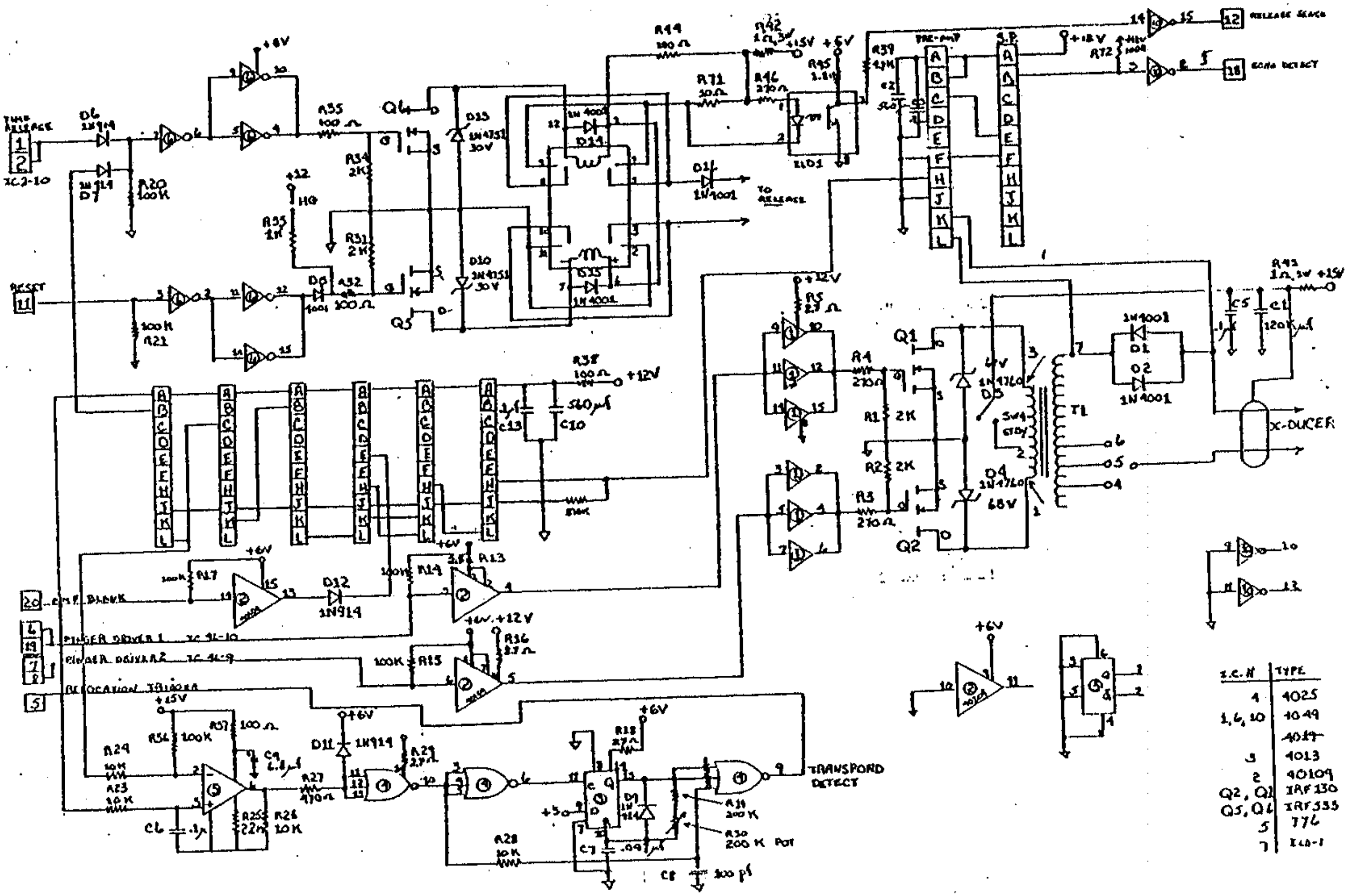


Fig. A-4. Transmit/Record Board - Output Driver and Release

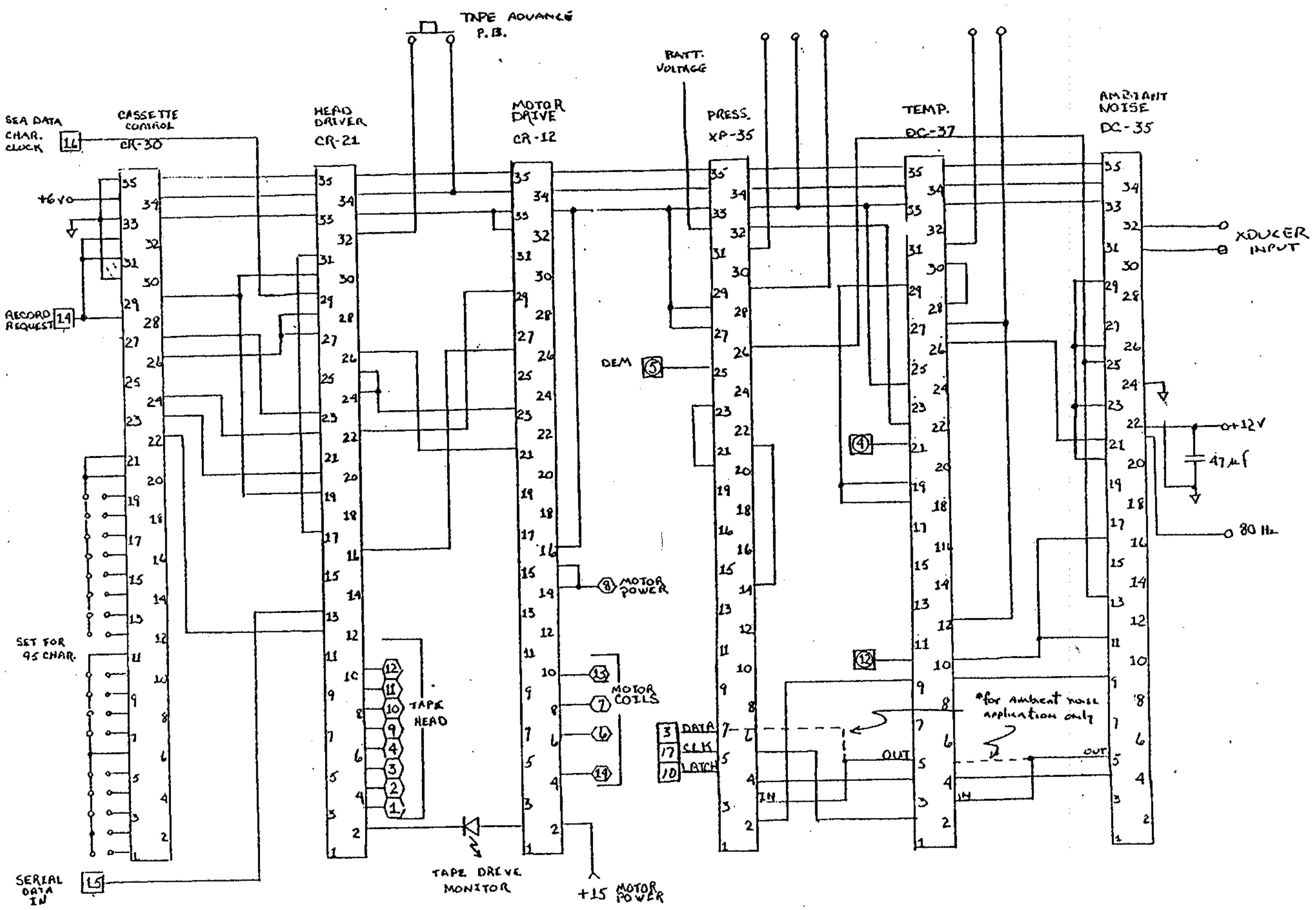


Fig. A-5. Transmit/Record Board - Recorder, Pressure, Temperature, and Ambient Noise Backplane

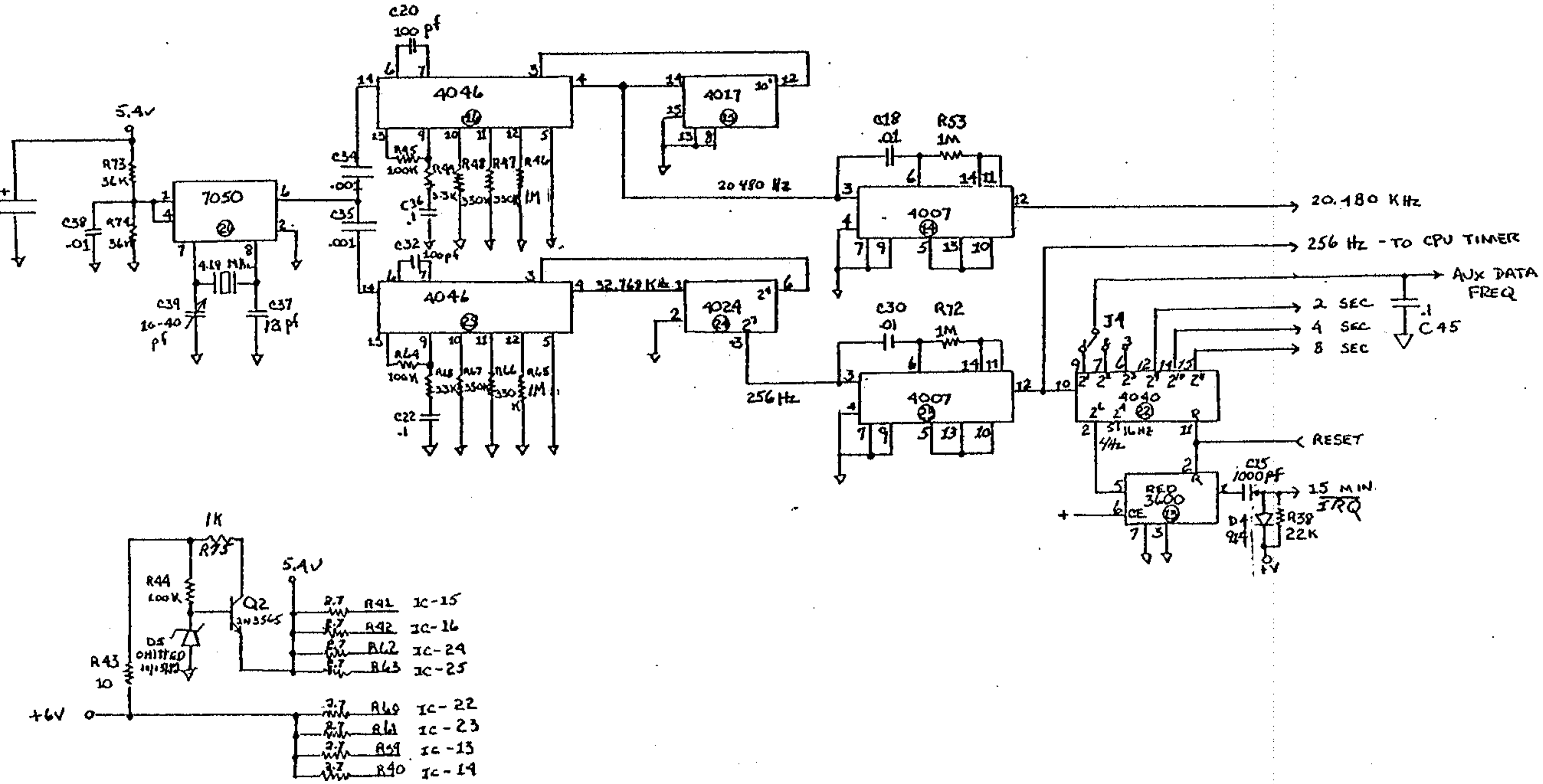


Fig. A-6. Processor Board - Master Clock

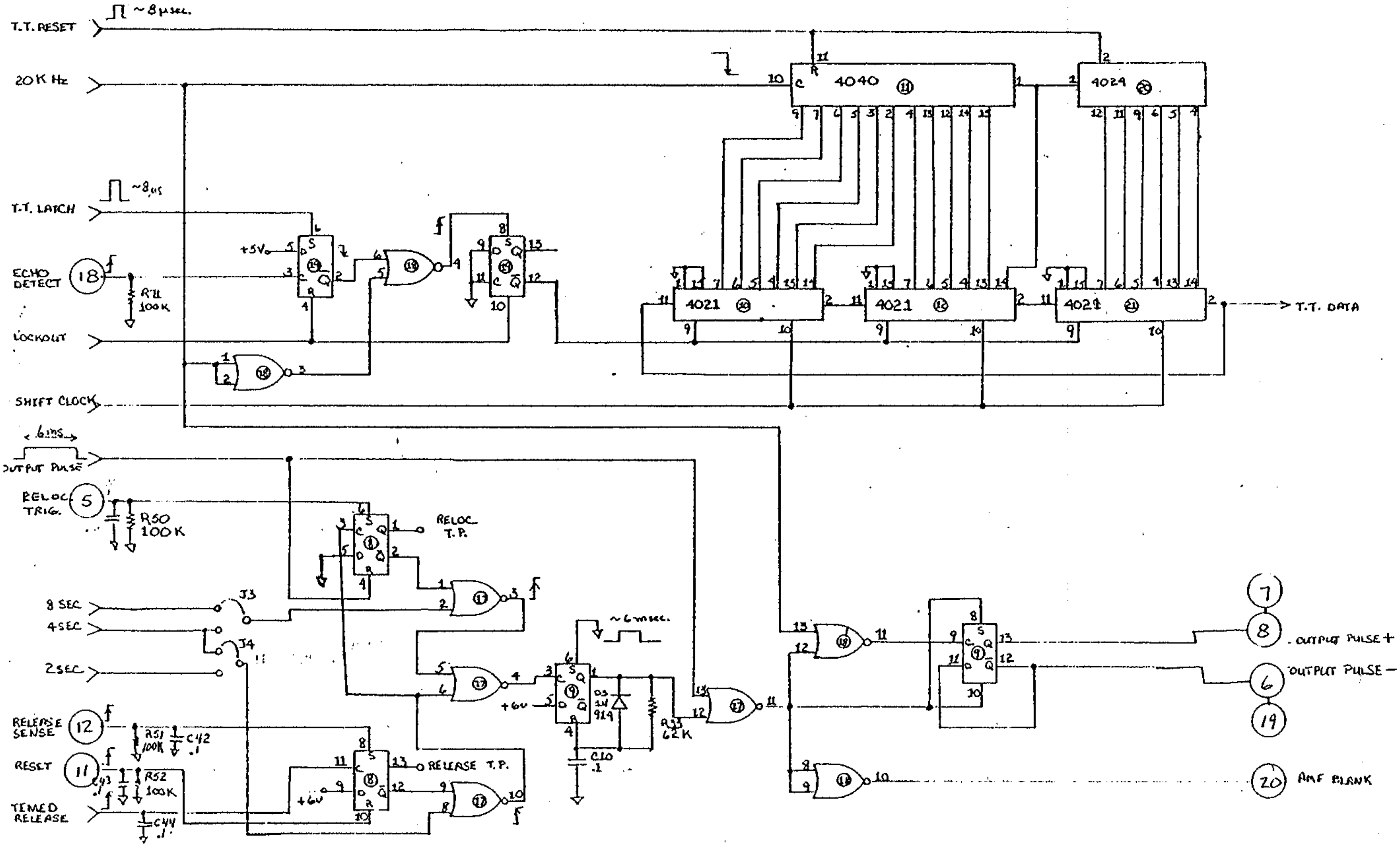
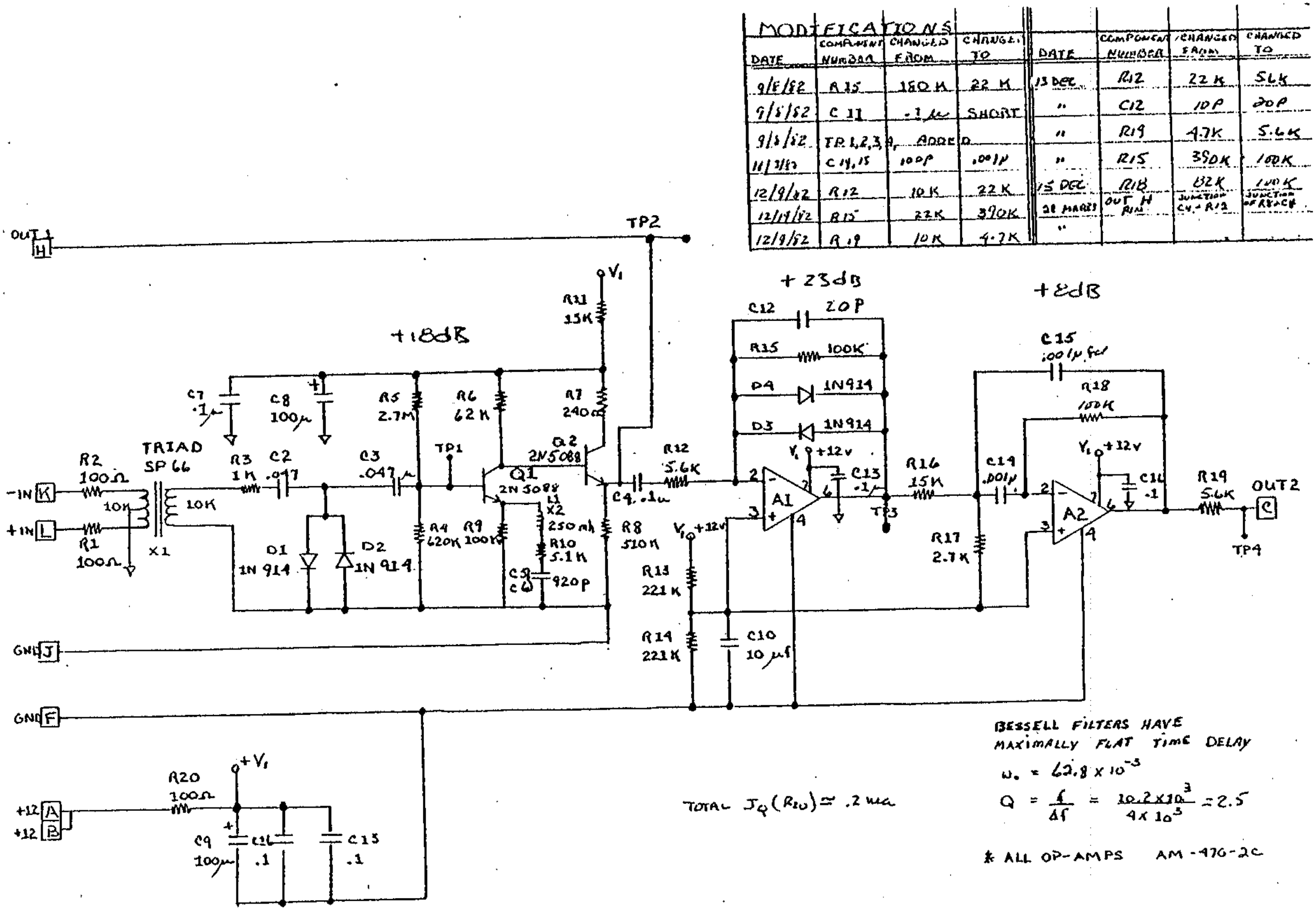


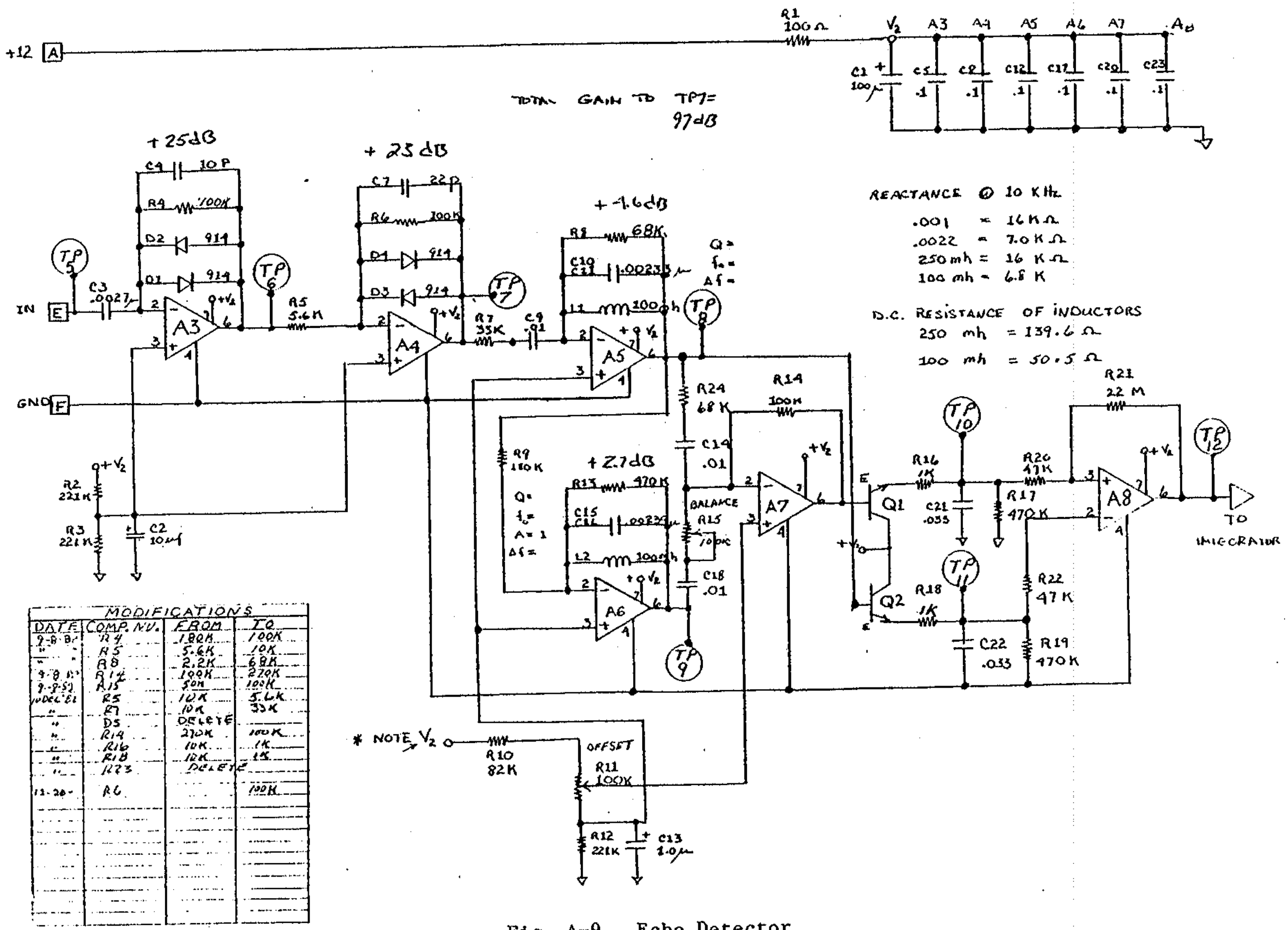
Fig. A-7. Processor Board - Travel Time Counter with Lockout



MODIFICATIONS

DATE	COMPONENT NUMBER	CHANGED FROM	CHANGED TO	DATE	COMPONENT NUMBER	CHANGED FROM	CHANGED TO
9/8/82	R15	180K	22K	13 DEC	R12	22K	5.6K
9/8/82	C11	.1µ	SHORT	"	C12	10P	20P
9/8/82	TP 1,2,3,4,	ADDED		"	R19	4.7K	5.6K
11/3/82	C14,15	100P	.001µ	"	R15	390K	100K
12/9/82	R12	10K	22K	15 DEC	R18	82K	100K
12/14/82	R15	22K	390K	28 MAR83	OUT H PIN	JUNCTION C4 + R12	JUNCTION OF R8&C4
12/9/82	R19	10K	4.7K	"			

Fig. A-8. Pre-amp Card



MODIFICATIONS

DATE	COMP. NO.	FROM	TO
9-8-81	R4	180K	100K
" "	R5	5.6K	10K
" "	R8	2.2K	68K
9-8-81	R14	100K	270K
9-9-81	R15	50K	100K
MODEL E1	R5	10K	5.6K
"	R7	10K	33K
"	D5	DELETE	
"	R14	270K	100K
"	R16	10K	1K
"	R18	10K	1K
"	R23	DELETE	
12-20-	R6		100K

Fig. A-9. Echo Detector

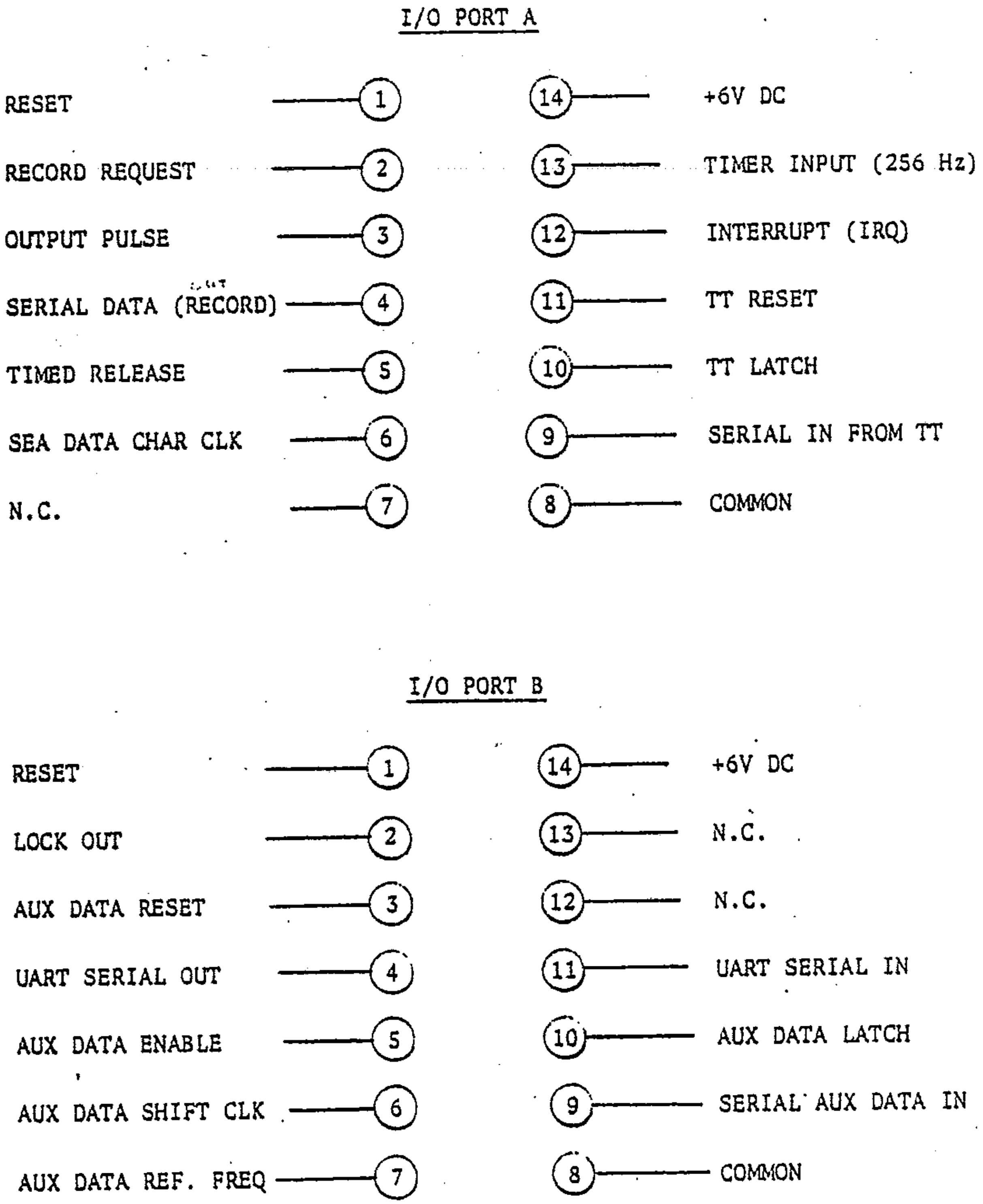


Fig. A-10. I/O Ports A and B

CONNECTOR A ASSIGNMENTS

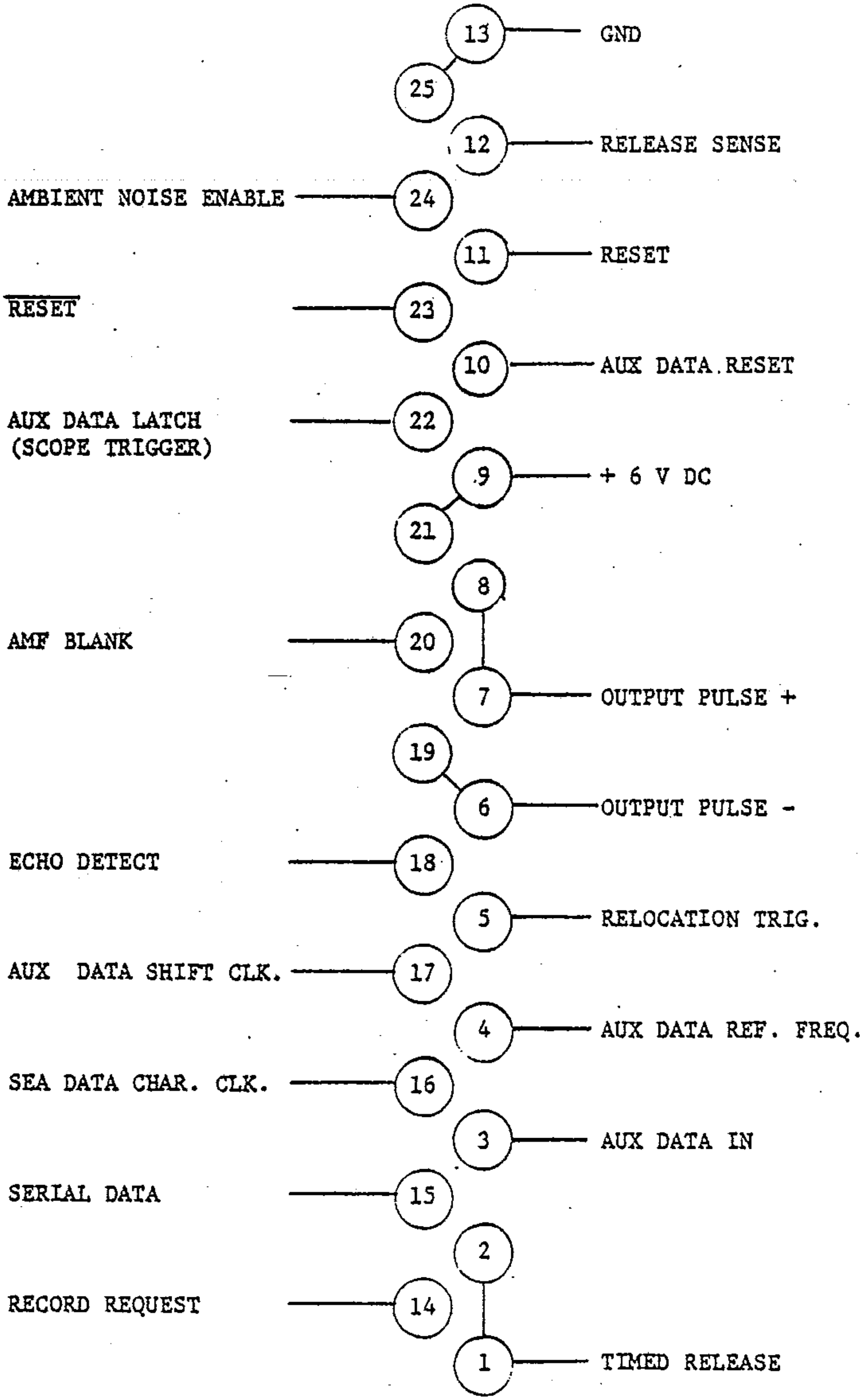


Fig. A-11. Connector A Assignments

BIBLIOGRAPHY

Bitterman, D.S.,Jr., 1976. Inverted Echo Sounder Instrument Report. WHOI Technical Report (Unpublished Manuscript).

Evans, D.L., D.R. Watts, D. Halpern and S. Bourassa, in press. Oceanic Winds Measured from the Seafloor. J. Geophys. Res.

Rossby, H.T., 1969. On monitoring depth variations of the main thermocline acoustically. J. Geophys. Res. 74: 5542-5546.

Watts, D.R., 1975. Inverted Echo Sounder, Hydrographic and Moored Temperature Array Intercomparisons. Instrument Description and Intercomparison Report of the Mode I Intercomparison Group, December 1974, pp. 65-68 and 149-163 (Unpublished Manuscript).

Watts, D.R. and W.E. Johns, 1982. Gulf Stream Meanders: Observations on Propagation and Growth. J. Geophys. Res. 87 (No. C12): 9467-9476.

Watts, D.R. and D.B. Olson, 1978. Gulf Stream-Ring Coalescence with the Gulf Stream off Cape Hatteras. Science 202: 971-972.

Watts, D.R. and H.T. Rossby, 1977. Measuring Dynamic Heights with Inverted Echo Sounders: Results from MODE. J. Physical Oceanogr. 7: 345-358.

Watts, D.R. and M. Wimbush, 1981. Sea surface height and thermocline depth variations measured from the sea floor. Paper presented at the International Symposium on Acoustic Remote Sensing of the Atmosphere and Oceans, Univ. of Calgary, Calgary, Alberta, June 22-25.

Wenz, G.M., 1962. Acoustic Ambient Noise in the Ocean Spectra and Sources. J. Acoustical Soc. America 34 (12): 1936-1956.