P
2 mif

Technical

Final Report
F-C3748

(NASA-CR-138830) TECHNIQUES DEVELOPMENT FOR WHALE MIGRATION TRACKING Final Report, Sep. - 30 Nov. 1973 (Franklin Inst. Research Labs., Philadelphia) 79 p HC $7.00 CSCL 06C G3/04

N74-28557

Unclas
15996

Report

TECHNIQUES DEVELOPMENT FOR WHALE MIGRATION TRACKING

September - 30 November 1973

by

R. M. Goodman, The Franklin Institute
K. S. Norris, Ph.D., University of California at Santa Cruz
and
R. J. Gibson, The Franklin Institute
R. Gentry, Ph.D., University of California at Santa Cruz
E. Dougherty, The Franklin Institute
L. Hobbs, University of California at Santa Cruz

Prepared for

National Aeronautics and Space Administration
Headquarters
Washington, D. C.

Contract No. NASW-2570

THE FRANKLIN INSTITUTE RESEARCH LABORATORIES
THE BENJAMIN FRANKLIN PARKWAY • PHILADELPHIA, PENNSYLVANIA 19103

ABSTRACT

Effort leading to the completion of development and fabrication of expansible whale harnesses and whale-carried instrument pods is described as are details of the gear.

Early preparative effort for a January-February 1974 field expedition is reported.

CREDITS

The work described in this report has resulted from the contributions of not only the authors, but their supporting staff: at FIRL--John Price and Earl Sonnie, at U.C.S.C.--T. Dohl.

PRECEDING PAGE BLANK NOT FILMED

CONTENTS

CONTENTS (cont)

FIGURES

FIGURES (cont)

TABLES

1. GOALS OF THE PROJECT

- CONTINUE TO EVOLVE WHALE CAPTURE, HANDLING TECHNIQUES AND HARNESS DESIGN.

  More specifically, in the present effort, to concentrate on the design of an expansible harness for application to the juvenile Gray whale and one able to carry a tracking transmitter plus the instrument package mentioned below.

- CONTINUE TO EVOLVE INSTRUMENTATION IN PLANNED PHASES, OF PERTINENCE TO AN ULTIMATE LONG-RANGE TRACKING EXPERIMENT.

  More specifically, in the present effort, to evolve a simplified instrument package, to acquire and record water pressure and temperature, when emplaced in a harness on a juvenile Gray whale.

We note that while each development phase represents successive improvements in our capabilities re technique and/or gear, every effort is made simultaneously to extract as much useful data regarding the subject and its environment as is possible. Thus, in the case at hand, we hope to record water pressure and temperature simultaneously each 5 seconds for periods of 3—5 days (72—120 hours). From such data we will improve our knowledge of temperature distribution in the lagoon where the subject is moving. We will also be able to learn much about the subject's behavior in these early weeks of its life: respiration rate, swimming activity, mean depth, etc.

2. WHALE HARNESS, LOCATION GEAR AND PERMITS INTRODUCTORY REMARKS

2.1 EXPANSIBLE HARNESS

After some negotiations with NASA/Ames, an engineer, Ronald Mancini, was located and given the task of designing our expansible harness. Time was too short to fabricate the thixotropic tube suggested earlier, and Mancini suggested a harness designed around springs. K. Norris and R. Gentry prepared a list of specifications, including range of thorax expansion on breathing, range of collapse on diving, time-rate of diving, greatest depth of dive, and other factors. Mancini translated these requirements into a spring system that would accommodate the girth changes associated with breathing, diving and growing, and submitted the design to a spring fabricator. R. Gentry and L. Hobbs designed a harness which would couple these springs with the back pack intended to carry the radio beacon. It was decided that two animals would be equipped with the expansible harness and tracked for periods of up to two weeks.

2.2 INSTRUMENT HARNESS

For the purpose of carrying the instrument pods we planned to modify the harness used in earlier tracks. These harnesses, which utilize stretch nylon rather than springs, are intended for use with the instrument pod being developed by the Franklin Institute. They were originally designed to stay on for three days only. R. Gentry and L. Hobbs made several changes in the harness that proved successful in the 1973 captures. These changes included (a) an expansible unit around the strength member of the harness, (b) changing the angle of the holes that attach the harness to the back pack, and (c) moving the lower batton 4 inches dorsad. The modified harness design was given to San Lorenzo Awning Company, who fabricated last year's harness, for production of a new test model.

2.3 TRACKING TRANSMITTER AND XENON FLASHER

Simultaneously, L. Hobbs contacted Ocean Applied Research, Inc. and discussed tracking transmitters which are superior to those used in the previous operation. A type was selected which has greater range, longer life, and smaller bulk than those used previously. Four of these units, broadcasting on special channels, were ordered from OAR.

L. Hobbs also investigated the possible uses of lights as secondary tracking aids. Xenon flashing units, similar to those used in aircraft, were decided upon and were ordered. It was decided to mount one light on each of the two new expansible harnesses, but to use only radios to track the instrument pods attached to the modified old type harness.

2.4 RELEASE MECHANISM

After investigating timed release mechanisms available on the market, it was decided to use magnesium bolts again this year due to their low cost and small size. Accordingly, Hobbs set up two test tanks in the laboratory with agitated, aerated sea water held at constant temperature. Into these tanks magnesium bolts of various thicknesses were immersed attached to clocks that indicated elapsed time since immersion. By the close of the report period, December 1, some preliminary results were available indicating the tank system is subject to some variation. Results are so random that sea tests may be necessary. More lab testing is planned to decide whether the latter course is required. A new variety of magnesium stock was ordered which should improve the precision of the bolts.

2.5 FIELD TRIP LOGISTICS

Letters were prepared to send to the cannery in Lopez Mateos regarding housing for the expedition members. No answer had been received by the close of the reporting date.

Tim Houshar, captain of the LOUSON which accomplished last year's captures, was contacted about contracting for this year's effort. He indicated he was available for charter, but that the charter price would have to be renegotiated. He conferred with his partner on the matter and then left town before a price could be established. By December 1, no agreement with Houshar had been made and other charter boats were being looked for.

The hoops used in capturing were redesigned after conferring with Frank Brocato, who constructed last year's hoops. It was decided to use stainless steel and to make larger hoops than used last year.

2.6 CINÉ PHOTOGRAPHY BEHAVIORAL STUDIES

Film documentation. Film coverage of the capture techniques was not adequate in the 1973 work and it was decided to make 16 mm films of the current work. Accordingly, a 16 mm Beaulier camera was borrowed for the trip, and film was purchased. Tom Dohl was assigned to do camera coverage.

2.7 PERMITS

By December 1, all permits had been applied for, but no permits had been received. See Figures 2-1 and 2-2.

2.8 SPECIAL CAPTURE GEAR

A special capture raft, designed to "dry-dock" whales at sea was obtained from a fabricator in Utah. The raft has been under construction for this purpose, but so far no decision has been made about its use in the 1974 capture effort. In view of the amount of work needed, this raft may not be used this year, but instead held until captures at sea are initiated.

August 14, 1973

Dr. Victor B. Scheffer
14-806 S. E. 54th Street
Bellevue, Washington 98006

Dear Vic:

I wish to make formal application for a permit to catch, instrument and release five (5) young gray whales in the vicinity of Boca Soledad, upper Magdalena Bay, Baja, California, during the calving season of 1974.

These animals will be captured by the methods outlined in the enclosed manuscripts, will be harnessed with either the harness described in the paper or a new one which will allow longer traverses and times on the animal. This latter harness will encorporate a device allowing for growth of the animal and will lead to a device allowing tracking for an entire migratory traverse by either satellite or aircraft monitoring. At this stage of our work, we expect to instrument and track our animals for a maximum of two weeks time in the first part of February 1974. A small instrument pack containing 2-4 data channels, and now under construction at Franklin Institute, Philadelphia, will be used. The ultimate pack, also being designed and built by them, will allow much additional data recovery.

Our attempt is to develop tracking methods which do not harm or disrupt the animals concerned and which will allow us to define precisely migration paths. Our first work fulfilled these expectations.

Sincerely,

Kenneth S. Norris
Professor of Natural History

Enclosure
(Draft of a paper)

Figure 2-1. Letter Requesting Whaling Permit from U.S. Authorities

October 31, 1973

Mr. George Rees
Mexico Department of State
Washington, D. C. 20521

Dear Mr. Rees:

In response to our telephone conversation of October 26, I have tried to compile the necessary details and data. If anywhere I have been negligent, I will be anxious to provide additional information.

1. General Purpose of our Research: It is our desire to acquire information about the population dynamics and migratory pathways of the great whales to insure intelligent management practices in the future. These parameters are largely undertermined for many species such as the humpback whale (Megaptera novaeangliae), the blue whale (Balaenoptera musculus) and the fin whale (Balaenoptera physalus). Initially, we will carry out short distance, surface tracks while testing harness design, data recovery systems and capture methods. Within the next few years we plan to apply the knowledge gained in these preliminary tests to long-term tracking and data acquisition, utilizing satellite telemetric capabilities.

2. Purpose of Immediate Research: In order to insure efficient and harmless harnessing and tracking procedures in oceanic capture of adult whales, we deem it necessary to test methods and materials in calm waters with small animals. To this end, we plan to capture four suckling gray whale calves (five, if there be need), fit them with harnesses, release them within minutes of restraint, and recover the harness after three, seven or fourteen days. We will be testing our data recovery system and a new harness design which will allow for the growth of a calf over a prolonged time period.

3. Method: We will use the same harnessing method successfully tested last January and described in the enclosed paper.

4. Region of Operation and Reason: Boca de Soledad will be the site of capture because it has a large number of whales, the water is navigable, and fewer calving whales will be disturbed in that area than in other calving grounds. It is outside the new whale reserve area of Laguna Ojo de Liebre.

Figure 2-2. Letter Requesting Whaling Permit from Mexican Authorities

5. Schedule: The support vessels will enter Mexican waters on January 15, 1974, and make landfall to clear customs in Ensenada. The scientific contingent will arrive by air on January 20. We would like permission to continue our work through the month of February until March 1, 1974.

6. Personnel: Robert Goodman and Robert Gibson of The Franklin Institute Research Laboratories; Kenneth S. Norris, Roger Gentry, Larry Hobbs, Thomas P. Dohl, Kenneth Balcomb of University of California, Santa Cruz: Paul Sebesta of NASA, Ames Space Center, Moffett Field, Calif.; Gerald Kooyman of Scripps Institution, La Jolla, California; Three Mexican observers (to be named); Tim Houshar, Master of the Louson plus three crewmen of the Louson; Dick Pierce, Master of the Scammon plus two crewmen of the Scammon; Dick Murray, Master of the Aikane plus two crewmen of the Aikane.

7. Financial Support: University of California, Santa Cruz, subcontract of The Franklin Institute Research Laboratories under contract with NASA (National Aeronautics and Space Agency).

8. Nationals other than U.S.: None.

9. Invitation for Mexican Participation: We will welcome representatives from the Mexican Government. Expenses on the work site for such personnel will be provided by this program. We cannot, however, cover travel costs to and from Lopez Mateos.

10. Support Vessels: The Louson will be used again--Tim Houshar, Master. For tracking support we will utilize one additional vessel. Unfortunately, at this time we are unable to specify which of the two vessels will be available. I will give you a description of both and inform you immediately upon decision of our choice. I am sure that you would know better than I whether both should be listed with the Mexican Government or list one arbitrarily now with the option to change that listing in the future.

    Scammon: 39 foot converted launch, C-4438, 15 ton, Cal. # CF 1000XS.

    Aikane: 43 foot Kettenburg sloop K-43 #7, 11 ton displacement, document # PYL 100; Official # 297 123; California # CF 0828 XS.

Thanks for your help and please call if additional information is needed (408) 429-2001. Would also appreciate your keeping us informed as this moves through the various channels to home base.

Sincerely,

Larry Hobbs

Figure 2-2. Letter Requesting Whaling Permit from Mexican Authorities (cont)

2.9 COMMENTS

Sufficient progress is being made so that the field portion of the effort will be ready by late January, as scheduled.

3. THE INSTRUMENT PACK

Insofar as possible, we have attempted to devise an instrument logic system which is expandable. This is to say, that as we move forward to more complex instrument packages (more sensors for more parameters and more control functions), the same basic logic will hold. Therefore, even though this first pack will be on the animal for only a relatively short time (3—5 days) we utilize a quartz clock as our basic timer.

Specific characteristics of the logic design are discussed below.

In the thirteen week period—the duration of the present contract—we evolved mechanical configurations for the pod (instrument package enclosure) and its baseplate, worked closely with our life science colleagues to ascertain its physiological acceptability, designed necessary molds, fabricated numerous pods and baseplates, tested them at depth equivalent, designed, fabricated and tested all circuitry, aged pertinent batteries after selection, modified the subminiature recorder design, ran several million tape-step cycles, evolved head/record-test procedures (a 40,960-word test program by computer) and almost completed all aspects of the instrument systems (2) for the 1974 field experiments.

3.1 ELECTRONIC GEAR

The function of the instrument pod is to collect and store data acquired while the unit is attached to the subject animal. In this first effort, the data consists of water pressure and temperature measurements made each 5 seconds. However, in future instrument pods, the data will include parameters such as axial velocity, pitch angle, magnetic heading, heart rate, body temperature(s), time and the like.

Since we had insights as to our future data requirements, the present pod design was evolved in an anticipatory manner. This is to say that the logical design was laid out in a format susceptible to easy expansion, that the design of basic circuits was such that, in the future, multiples could be used—and that overall, detailed consideration was given to designs requiring micropower for operation.

In view of the foregoing therefore, it is important to understand that the basic design of the present simple instrument pod represents in actuality , a fundamental approach entirely suitable for future—more sophisticated—packages.

3.1.1 Logic

The data acquisition system consists of a crystal-controlled oscillator, instrument amplifiers, a multiplexed analog-to-digital converter, a fault isolating network, and interface electronics for recording into and driving the magnetic tape recorder.

A block diagram of the system is shown in Figure 3-1.

Signals from the transducers are conditioned and then multiplexed to the 7-bit, analog-to-digital converter. The output of the converter is then processed onto the magnetic tape recorder. Along with transducer data a "label" is written on the tape. This label identifies the transducer data group (pressure/temperature) as one of 128 records with the group and the sequential record of the label repeats in time. This information will be useful in the later computer analysis.

The label is generated by incrementing a 7-bit counter immediately after recording associated transducer data. With the recording of each word on the tape (transducer datum or label) a "clock" pulse is recorded in the 8th-bit position. This pulse is incorporated to simplify computer retrieval of data from the tape.

The "fault isolation network" consists of an output display which monitors, in a simple way, critical nodes in the system. Visual monitoring of the display permits the viewer to be assured of proper operation

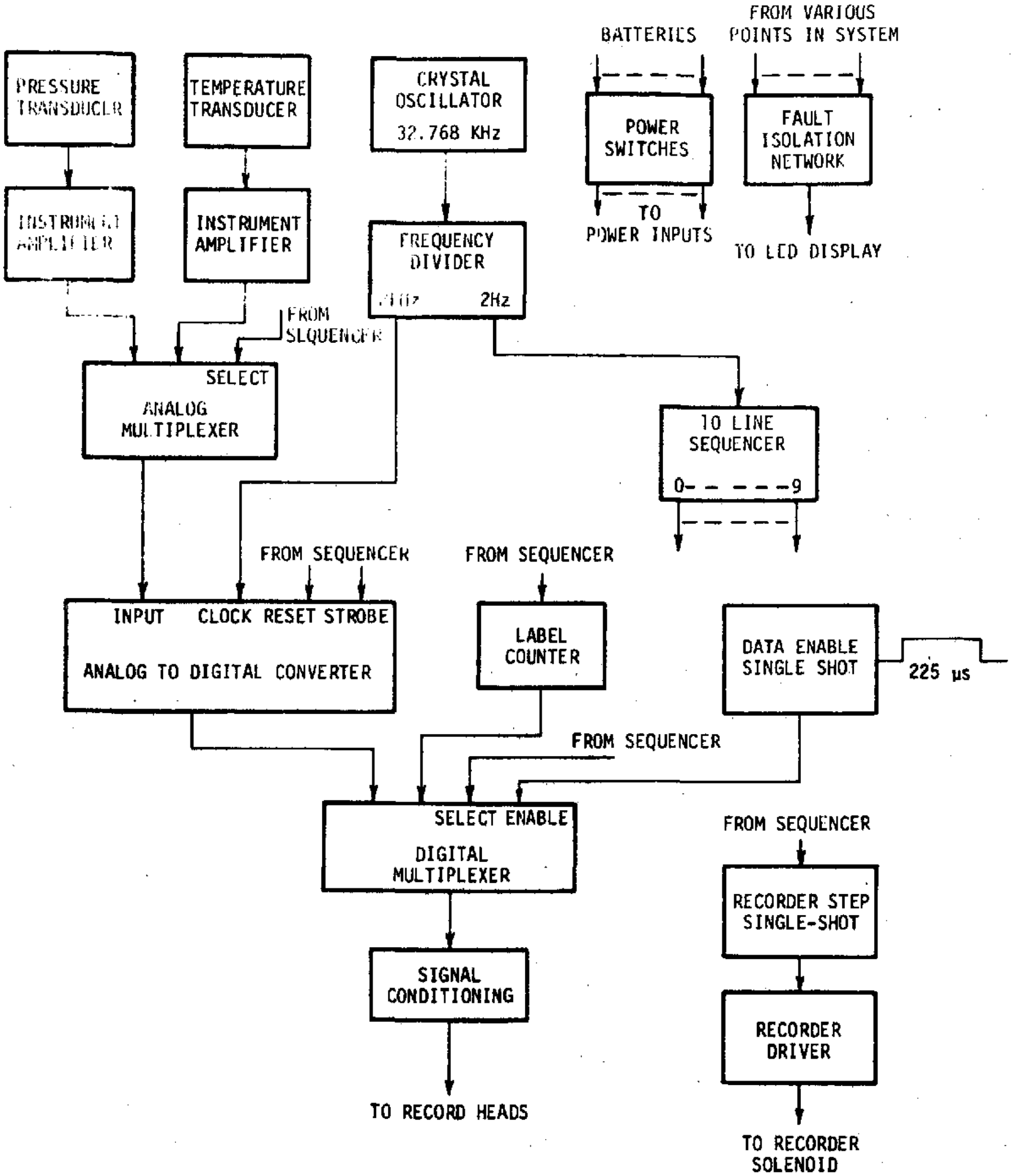


Figure 3-1. Micro-Power Data Acquisition System

of key circuits, or to trouble-shoot the key circuits in a systematic way—whichever the case may be.

Figure 3-2 is an Event Timing Diagram of the present system. The basic system design is arranged for convenient expansion as the number of transducers is increased. As shown in the Figure, only half of the available sequencer phases in the standard modules used are utilized. This means that by the simple addition of conditioning circuits and multiplexing channels, the present system can be expanded directly to five transducers. Further, by utilizing the higher clock rates inherent to the system (4 Hz, 8 Hz, 16 Hz, 32 Hz) and by expanding the sequence (one additional IC), the system can easily scan and record more than a dozen transduced signals within the present 5-second cycle. Since the overall system is presently operating far below its maximum frequency limit, we can easily move to the higher clock rates. For example, the A/D converter is now operating at 2 KHz, but is capable of operation at well in excess of 50 KHz. The comparator is presently resolving 10 m.v. while its capability is better than 100 μv. It is *theoretically* possible with the present A/D converter and the CMOS logic family, to scan, read and convert over 1000 transducers in a 5-second period.

In order to obtain data resolution greater than 7-bits, say to *m*-bits, an improved resistor network would be included at the converter and data words would be broken into bytes of 7 bits and recorded sequentially on the magnetic tape.

3.1.2 Circuitry

The basic building blocks for the system are MOS integrated circuits.

In Figure 3-3 we show the physical layout of the system and Figure 3-4 illustrates the electronics layout including component boards, power switches and IC's.

Almost all interconnections used are of the wire-wrap type. See Figure 3-5. Wire-wrapped interconnections are not ideal for purposes of subminiaturization. For present purposes however, the method was

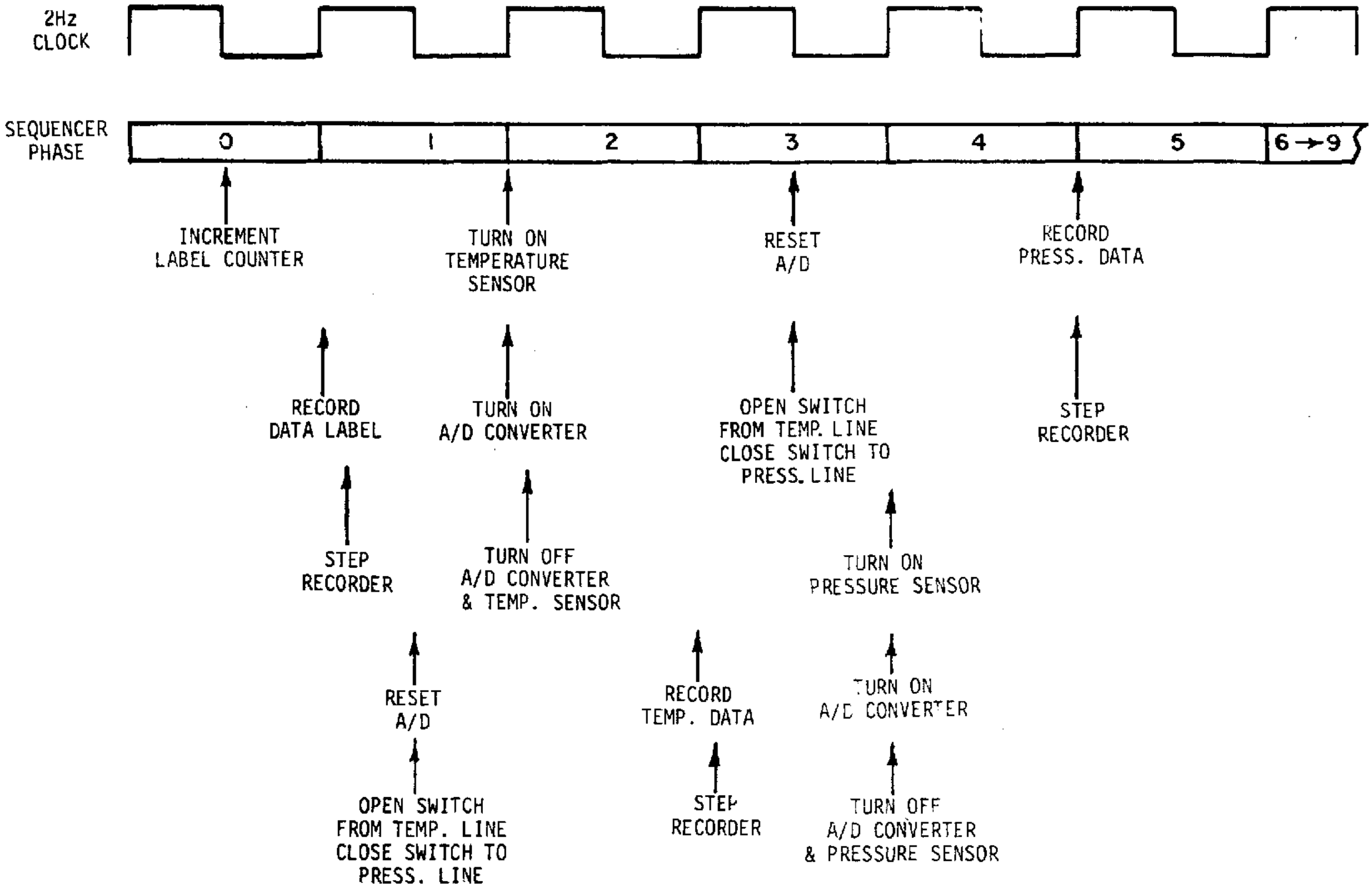


Figure 3-2. Event Timing Program

F-C3748

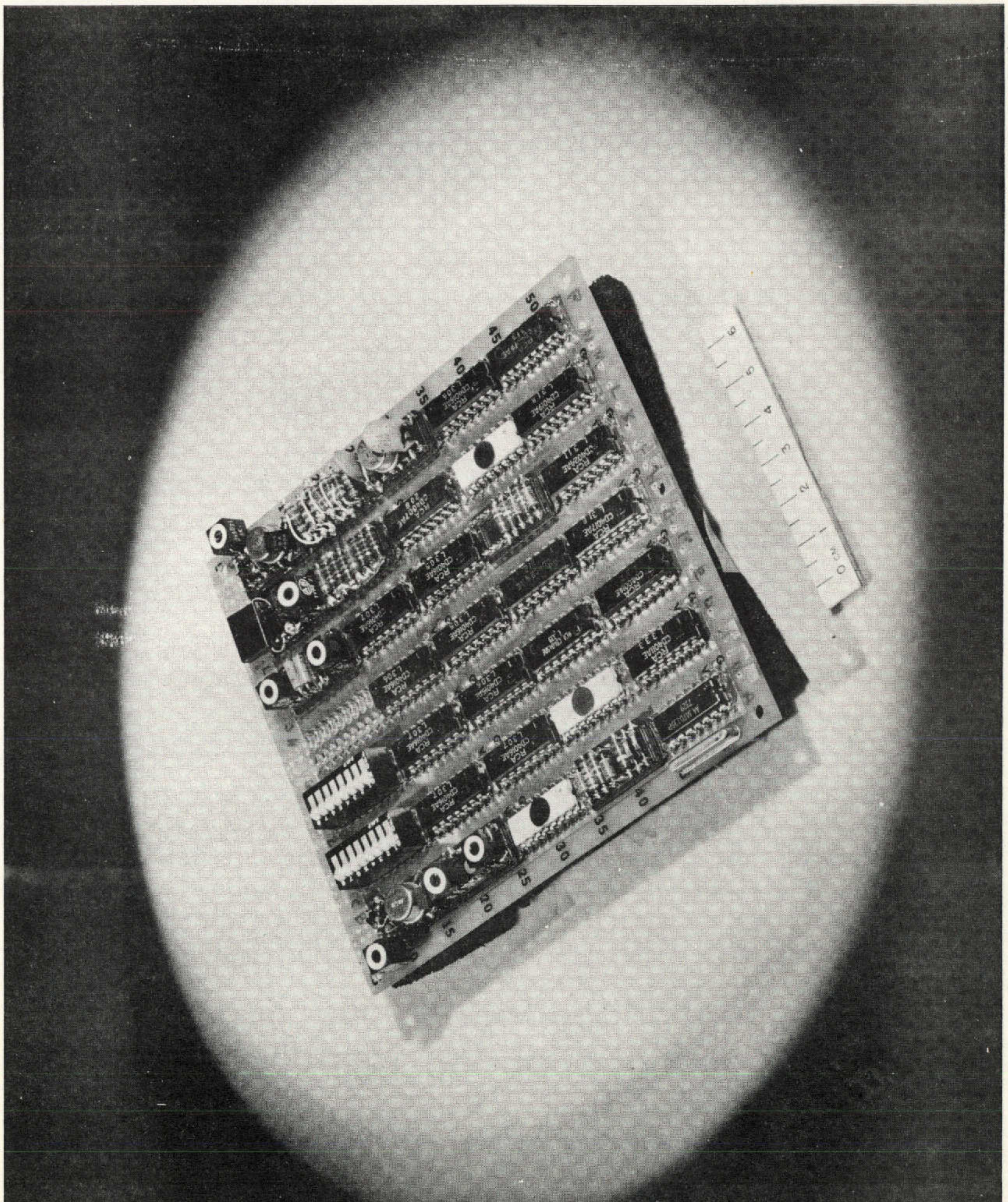


Figure 3-3. Electronic System Layout

FOLDOUT FRAME 1

FOLDOUT FRAME 2

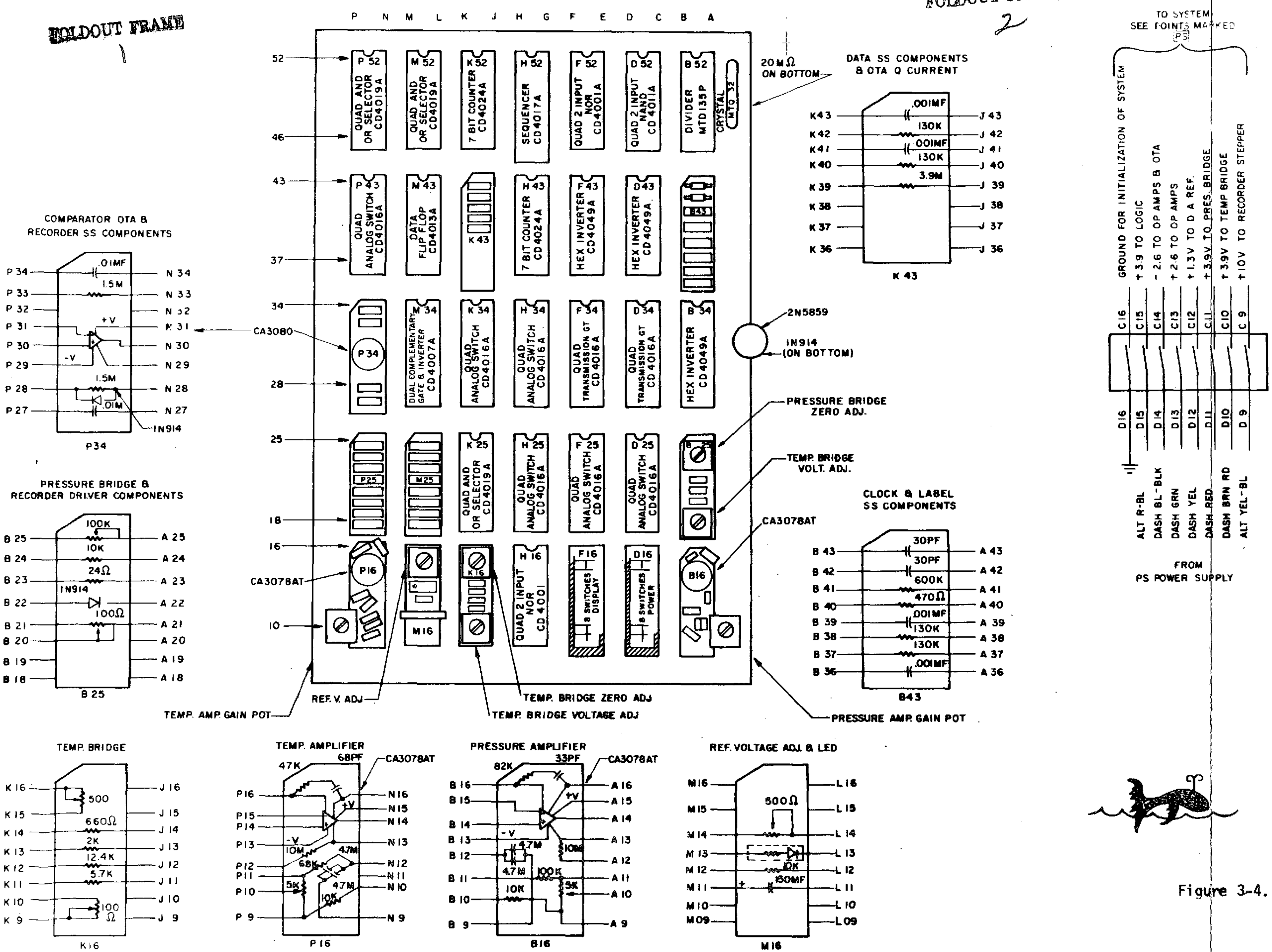


Figure 3-4. Identification of Layout

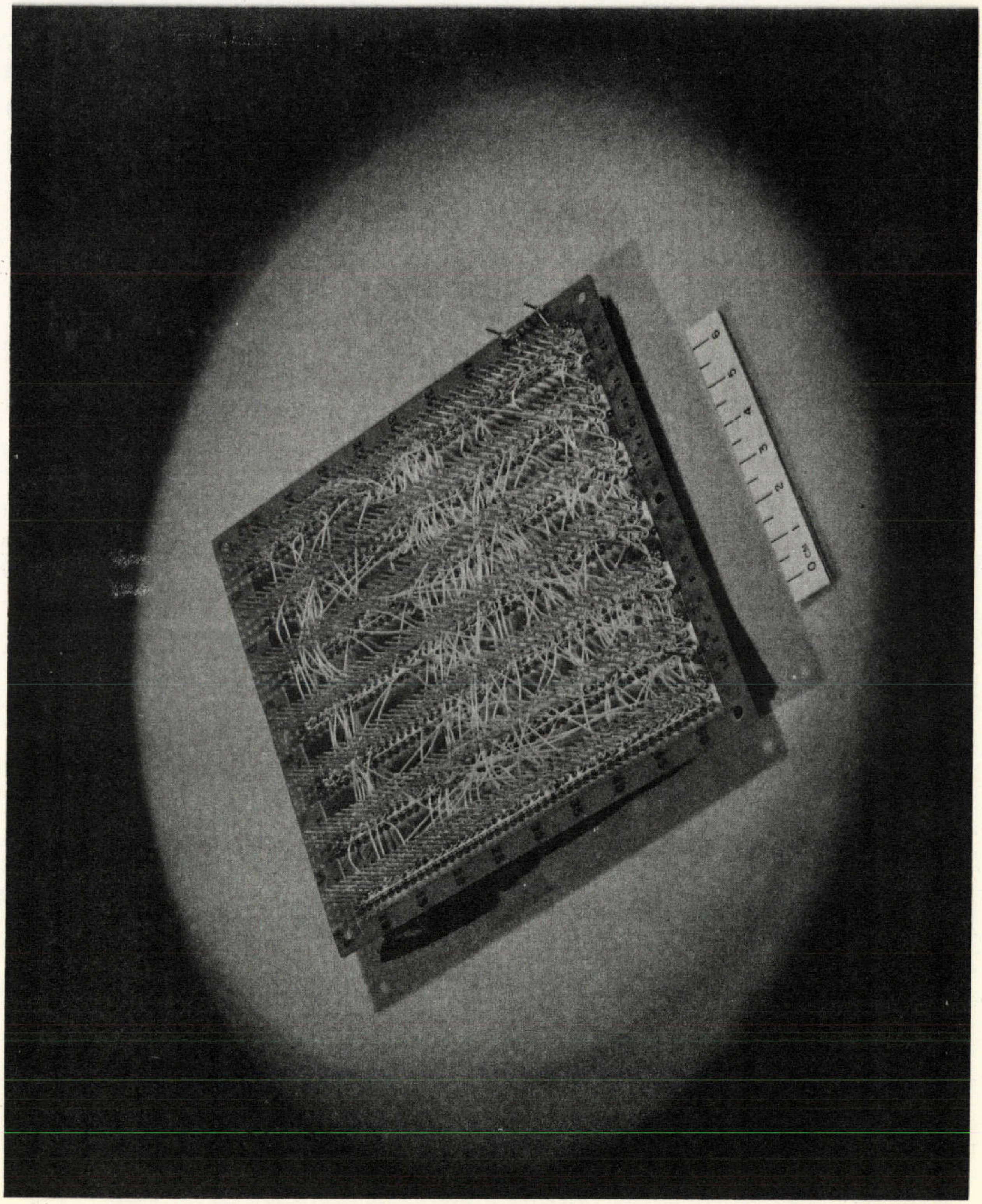


Figure 3-5. Wired Side of Electronic System

acceptable and proved to be the only reasonable approach because of severe constraints imposed by time and funding.

We note that the electronics as illustrated require a total volume—including space for interconnections—of about seven cubic inches (115 cc). This will reduce to about one-eighth cubic inch (2 cc) using present state-of-the-art, thick-film hybrid techniques. This latter technique will be essential for the more sophisticated instrumentation packages necessary in later phases of our work.

Schematics for the present system are shown in Figures 3-6A and 3-6B.

The functions of the digital portion of the system are to provide system timing, convert to binary form the analog signals generated by the temperature and pressure transducers, generate the data labels and to drive the incremental tape recorder.

The digital circuitry is composed intirely of CMOS-family IC's, chosen for their micropower operational level as well as their appropriateness to the logical task. They have a high noise immunity, good temperature characteristics and a wide range of operating voltage.

When the battery for the logic circuit is switched on, the 32 KHz crystal oscillator is counted down to two frequencies:

2 KHz for the A/D converter and 2 Hz for the system's basic clock.

The 2 Hz clock sequences a 1-to-10 line decoder (Module H52) and only the first five of the ten decode lines are used. When the sequencer "0"-line is high and the 2 Hz clock is high, the 7-bit label counter (Module K52) is incremented by one.

When the 2 Hz clock shifts from high to low, the sequencer is updated and the "0"-line moves from high to low while the "1"-line moves from low to high. The negative-going transition of the "0"-line triggers the data-label-enable-single shot. This single shot provides a 225 μs pulse to the 8 -AND-OR-SELECT gates (Modules P52 & M52) enabling the 7-bit count in the label counter plus the timing pulse to be presented to the recording heads as 150 m.v. pulses of 225 μs duration. The purpose of the data label is to record a known sequence onto the magnetic tape. This sequence will aid in computer retrieval and data reduction and the recording of known values among unknowns (temperature and pressure) provides verification of the recording system operation.

The trailing edge of the data label enable pulse triggers a 30 ms single shot (N34). This pulse drives the 2N5859 transistor which

FOLDOUT FRAME 1

FOLDOUT FRAME 2

F-C3748

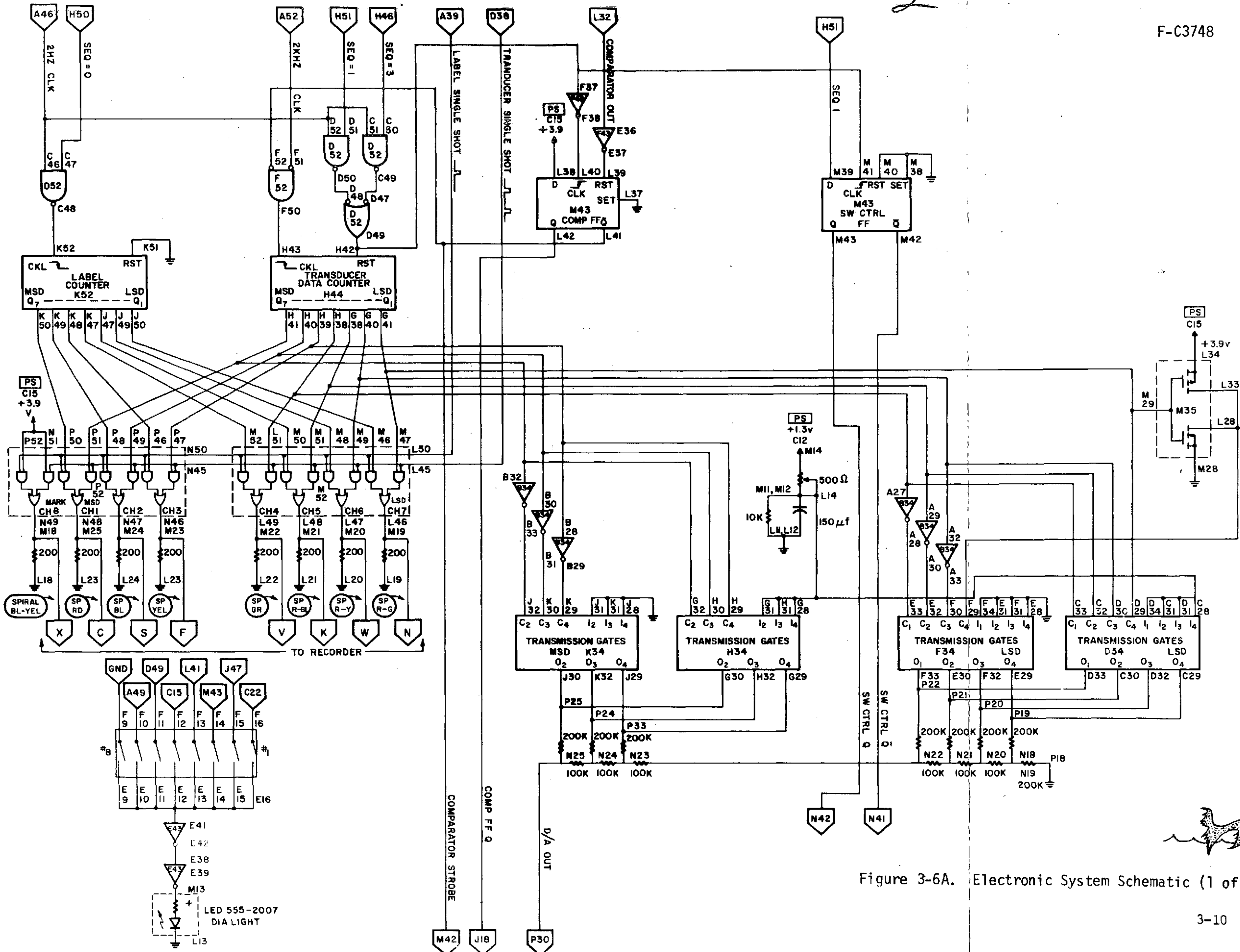


Figure 3-6A. Electronic System Schematic (1 of 2)

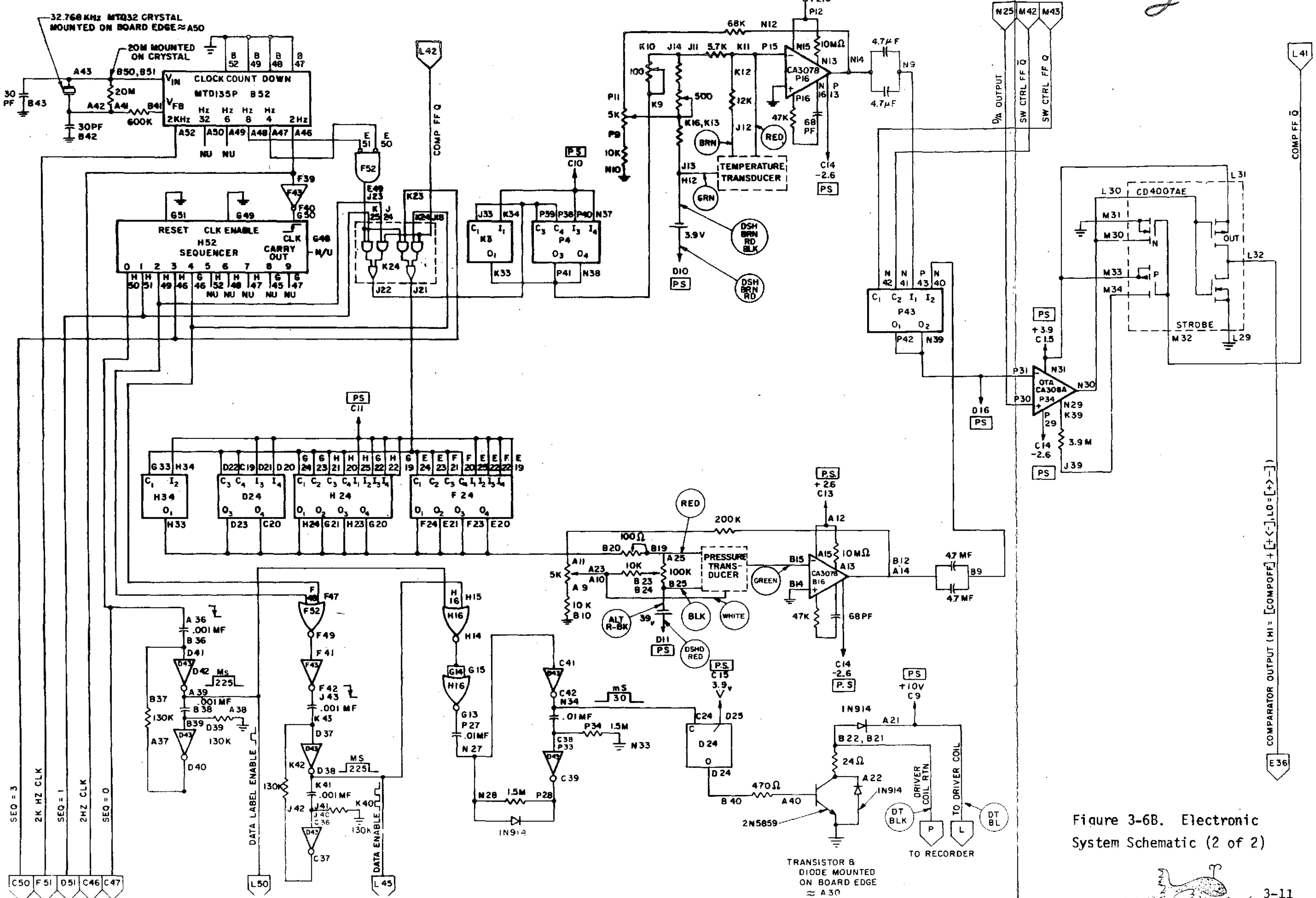


Figure 3-6B. Electronic System Schematic (2 of 2) provides the stepper pulse (20 ms) to the tape recorder driving motor.

While the 1-sequencer line is high, the 0-to-1 transition of the 2 Hz clock toggles the switch control flip-flop (Module M43) into the Q high state. This turns the temperature sensor analog switch line on (P43) and the pressure sensor line (N40) off. At the same time, the transducer data counter (7-bit counter, Module H43) is reset to zero.

When the 2-sequencer line goes high, a "1" is set into the comparator flip-flop (Module M43) and the power to the temperature transducer is switched on. The comparator flip-flop in the Q high state turns on the complementary transistor pair (of Module M34) which in turn, strobes the operational transconductance amplifier (OTA, Module P34). The comparator flip-flop enables the transducer data counter to increment at a 2 KHz rate; the binary counter in the transducer data counter is converted to an analog voltage by a combination of inverters, transmission gates and a resistor ladder network. Each bit of the counter is fed into an inverter providing a "true" and "not true" signal. The high "true" signals enable conduction of a reference voltage through a transmission gate; the high "not true" signals enable conduction of a ground path through a transmission gate. The transmission gates feed a R/2R resistor ladder forming an analog representation of the transducer data count.

The OTA compares the temperature transducer data, at its negative input, and the analog representation of the count in the transducer data counter. When the transducer data counter voltage is greater than the temperature sensor signal, the OTA resets the comparator flip-flop, thus effectively preventing the transducer counter to increment further and the power to the temperature transducer bridge is turned off. The transducer data counter now contains the digital representation of the water temperature.

On the negative transition of the 2-sequencer line, the 225 μs data enable single shot is enabled. This in turn, enables the data counter content to be recorded on the magnetic tape and the tape then incremented longitudinally. On the positive going transition of the 2 Hz clock during the 3-sequencer phase, the switch control flip-flop is toggled to the "0"-state. This opens the analog switch between the temperature sensor and the OTA. As a result, the switch between the pressure transducer and the OTA is closed. The pressure data is then counted and recorded in the same manner as the temperature data—the only difference being the phase of the sequencer.

After recording the pressure, the system rests through sequencer 5→9 phases and recycles its functions at sequence 0.

The pressure and temperature transducer networks consist of pressure and temperature-sensitive bridges, strobed bridge excitation circuits and a low power bridge amplifier. The linear integrated circuits used in the instrument amplifiers and the A/D converter are RCA CA3078 micropower op-amps and Type CA 3080 operational transconductance amplifiers. These were selected primarily for their low power consumption.

The pressue and temperature network designs are essentially identical and a basic circuit diagram is shown in Figure 3-7. The circuit contains three potentiometers—amplifier gain set (R.), zero balance set point, or more specifically, zero pressure and/or minimum temperature (R_2), and bridge excitation level set (R_3). As shown in the figure, the positive input of the op-amp is tied to ground thus holding the negative terminal at zero potential. When the analog gate is closed—and if the transducer causes an imbalance in its bridge, a positive voltage (V_1) is developed. V_1 is then amplified as shown by the following equation:

$$V_o = V_1 \left(1 + \frac{R_4 + R_{1F}}{R_7 + (R_1 - R_{1F})}\right)$$

where R_{1F} is the portion of R_1 in the feedback loop and (R_1 - R_{1F}) is the portion of R_1 out of the loop.

C_1 is part of a high-pass filter which rejects drift and passes the amplified, pulsed transducer voltages. The output voltage V_o is then presented to the OTA through the transmission gate multiplexer.

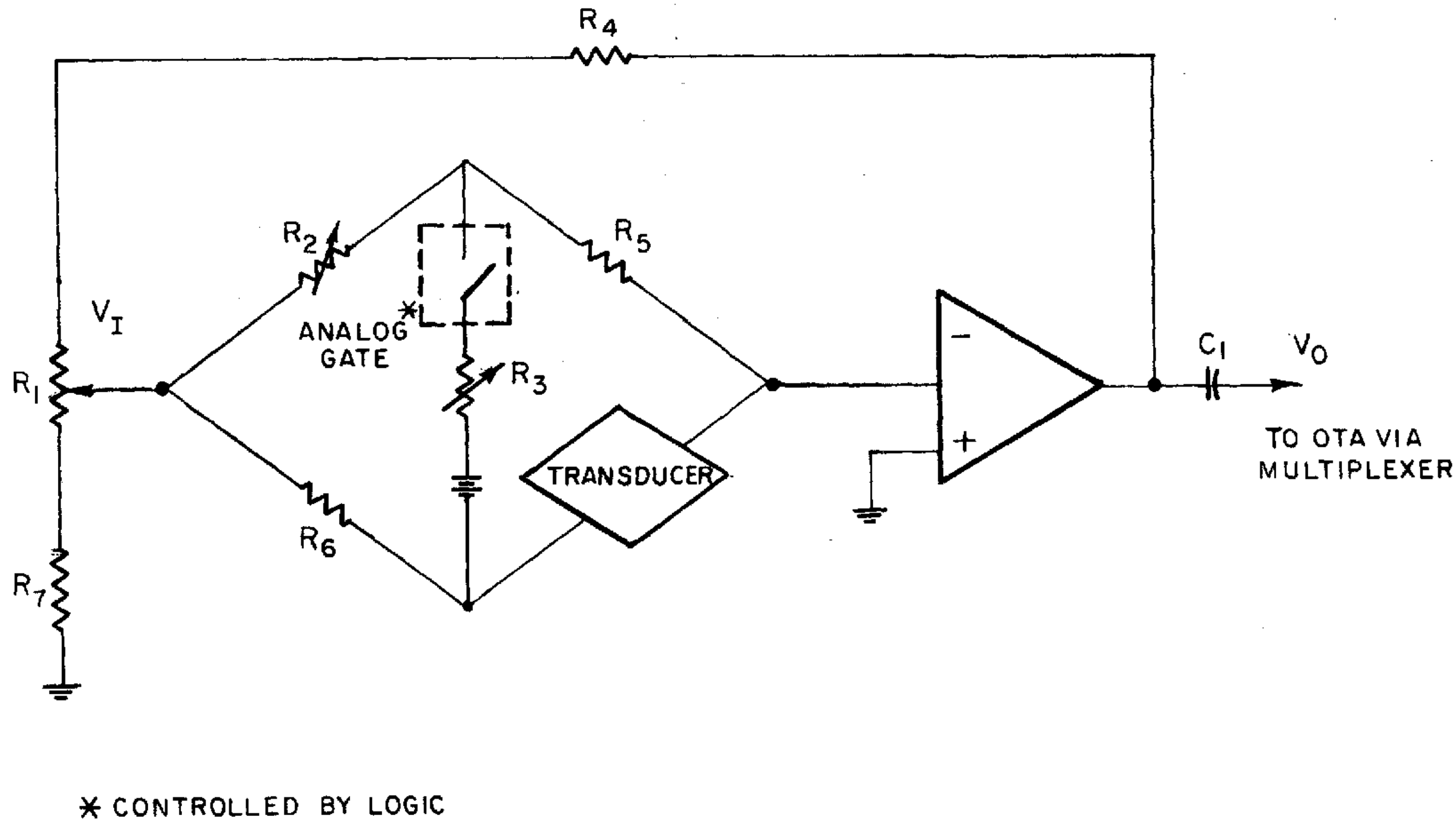
Figure 3-8 details the functions of the potentiometers in the pressure and temperature networks.

3.1.3 System Performance

Because of the logic used in design, system checking must be done in an orderly, systematic way.

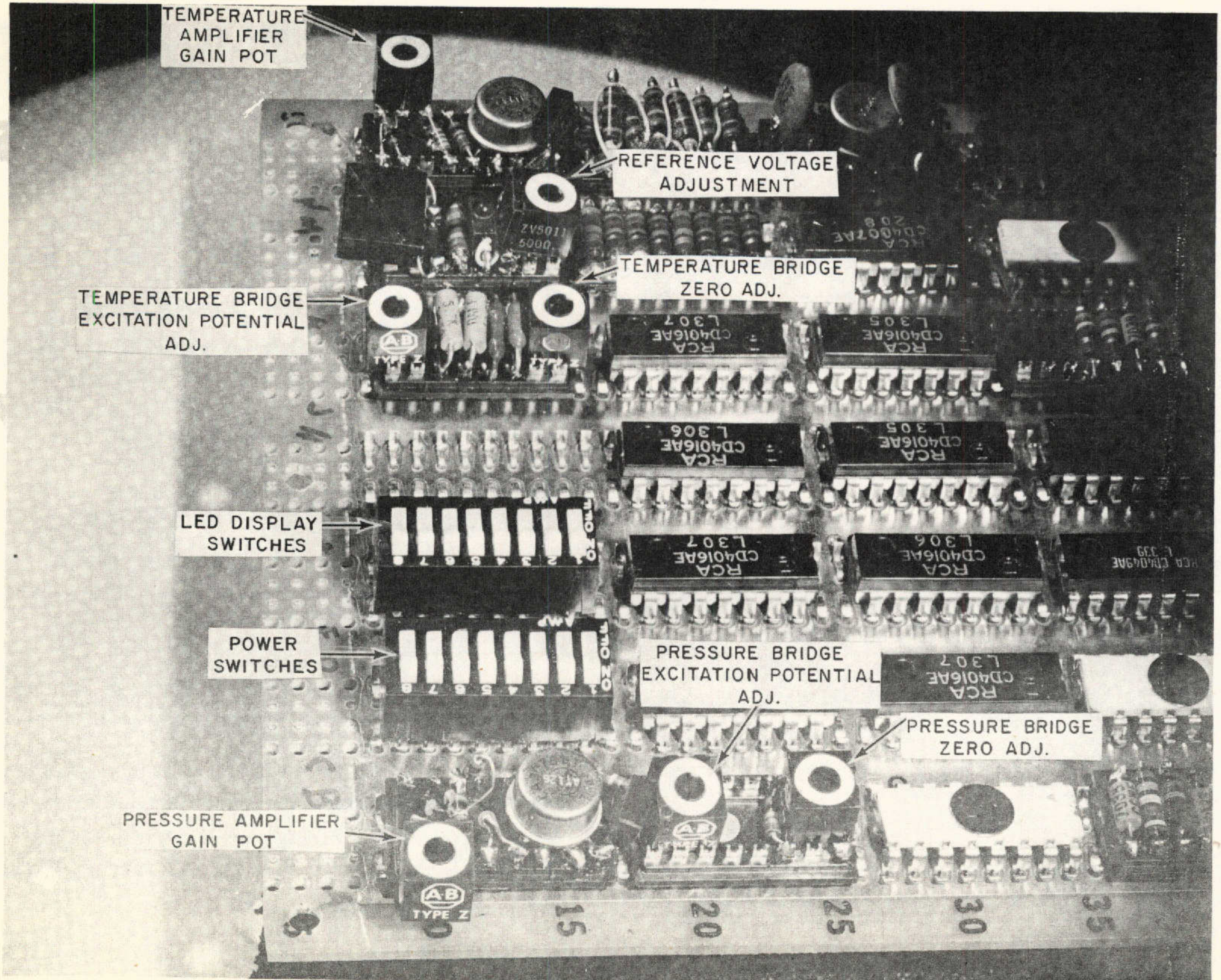
The system logic performance has checked out over the full range of possible battery voltages. This checkout was accomplished by comparing actual performance with the designed timing required as illustrated in Figures 3-9 and 3-10.

The digital-to-analog portions of the A/D converter were checked by observation of the 127-step ramp generated by disabling the comparator



F-C3748

Figure 3-7. Transducer Network, Basic Circuit



F-C3748

Figure 3-8. Controls for Circuits

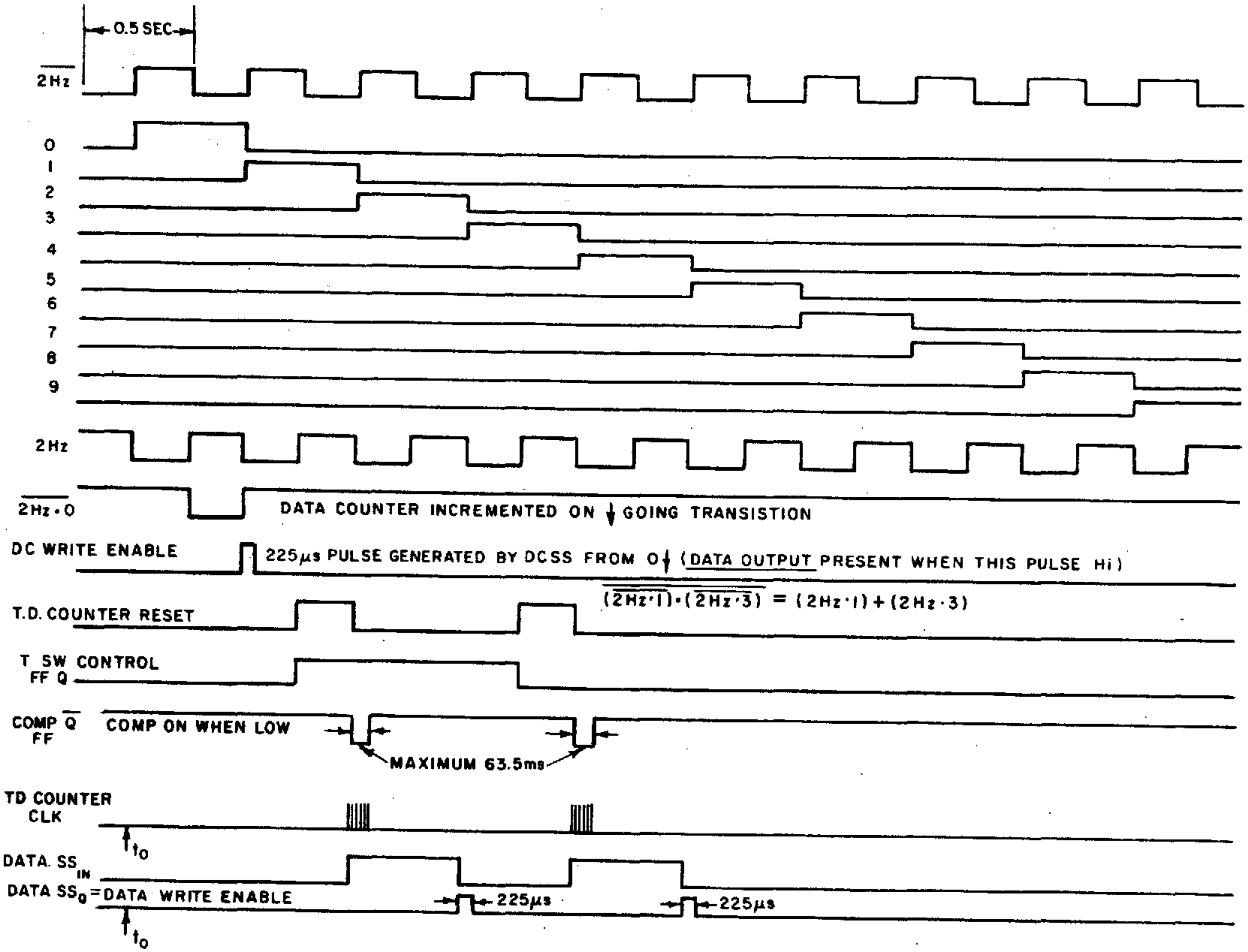
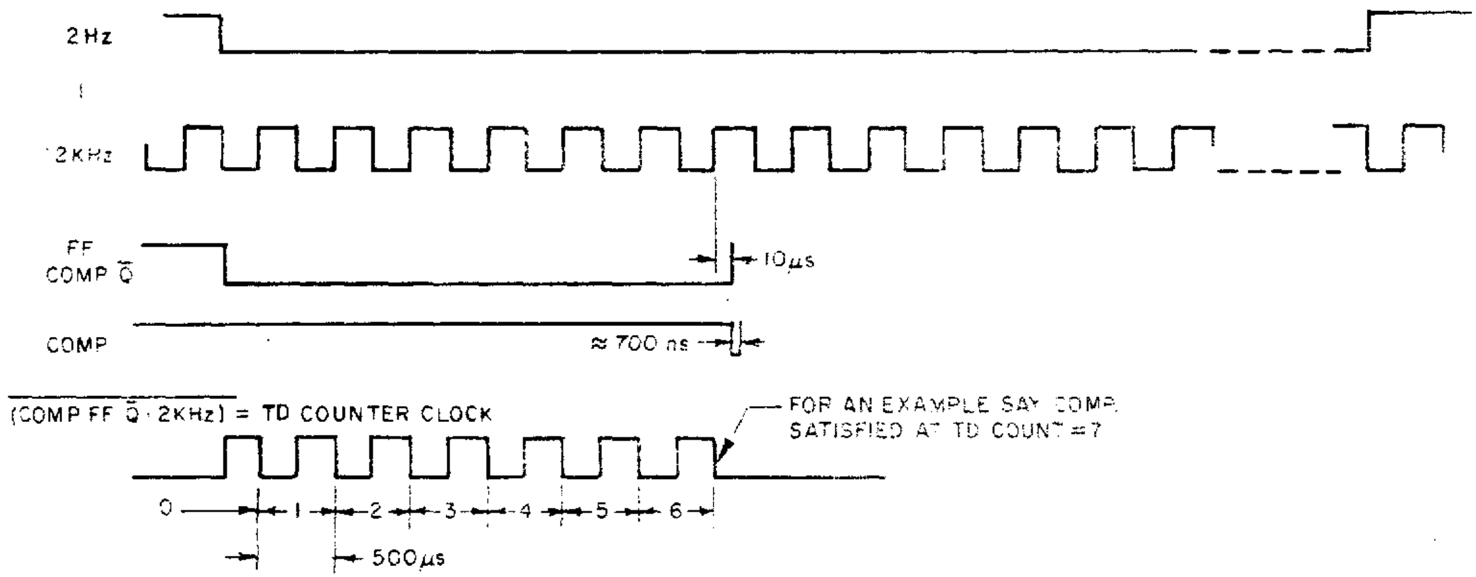


Figure 3-9. System Timing

F-C3748



F-C3748

Figure 3-10. Detail, Timing of Comparator Operation turn-off signal. The performance and linearity of the A/D converter was tested as follows:

For the 7-bit A/D converter with a 1.32 v reference, the last significant digit represents 0.010393 volts; test observations were made using a laboratory DVM to monitor A/D input. The input was generated by a variable power supply used to simulate voltages generated by the transducer network. The test setup is shown in Figure 3-11. Using a computer to simulate ideal conditions, it was made to calculate and list all possible values of A/D output (X) vs. voltage input (V). The results of this test for one of the units built is shown in Table 3-1A, -1B, and -1C.

The voltage in, V, was set between counter values, for example
if X = 3, for V = .031181
and X = 4, for V = .041574, the variable voltage source was adjusted to V≈.036 so the value would fall between the two thresholds. Note that the algorithm for the system is to record the count representing the voltage input *plus 1 count*; therefore, the correct results (and those actually obtained) show a reading of X + 1.

Bridge excitation voltages for the pressure and temperature transducers and the A/D converter reference voltage level were set using a laboratory DVM.

The bridge balance for pressure was accomplished simply by exposing the transducer to atmospheric pressure and adjusting the set-control for zero volts, as read with a DVM, at the output of the bridge amplifier. Balance for the temperature bridge was accomplished by placing the transducer in an ice-cooled bath set at the minimum design temperature of 12.8°C. The water bath was monitored against a calibrated, laboratory thermometer readable to ±.05°C. Again, as in the previous instance, the bridge was balanced by adjusting the set-control for zero volts,as read with a DVM, at the output of the bridge amplifier.

The gains of the bridge amplifiers were set by removing the bridge networks and injecting a known signal at the amplifier inputs. The output was monitored and the gain-set controls adjusted. Then with the bridge networks in the circuit, various bridge voltages and their amplified levels were monotored. The temperature data acquisition system was then checked from the sensor to the amplifier output by placing the sensor under known conditions and monitoring the system output at the correct phase of the system timing cycle. Temperature checks on one pod unit are shown in Tables 3-2A and -2B.

With the temperature sensor in an ice-cooled bath and monitored by a calibrated laboratory thermometer, readings of the data buffer were made at various temperatures.

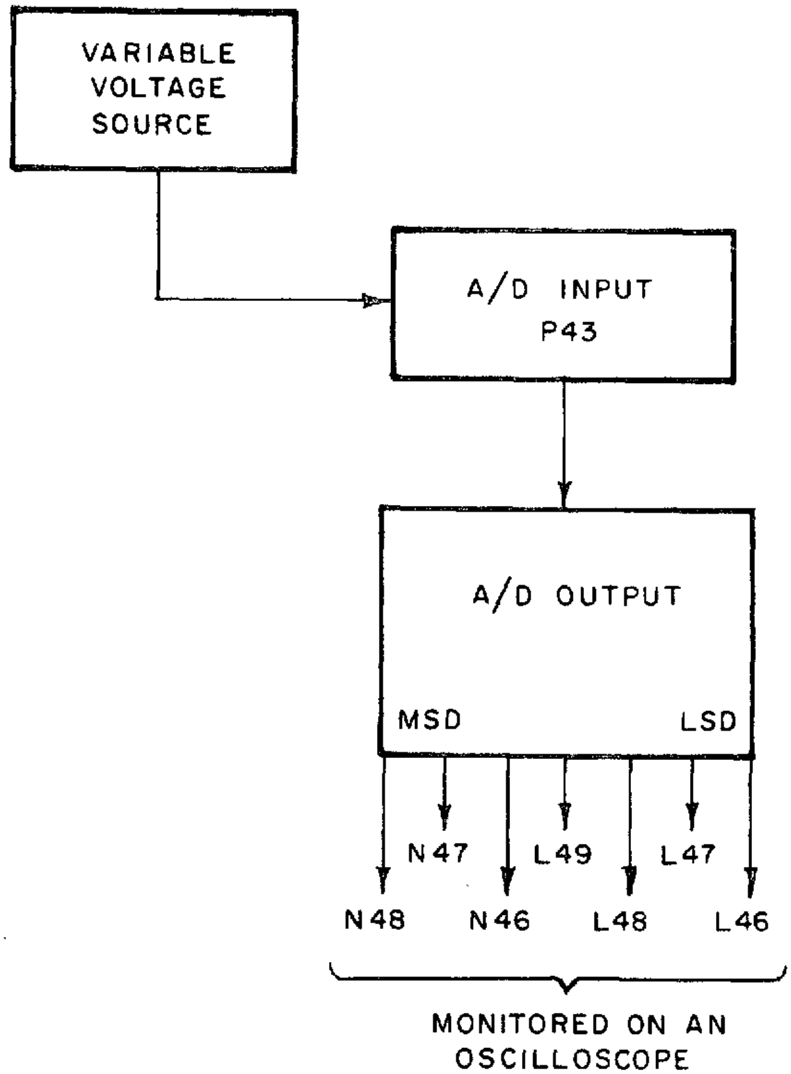


Figure 3-11. Test for A/D Converter

Table 3-1a. A/D Converter Test Data

VD COUNTER READOUT

V SET BETWEEN VALUES INDICATED

VT = 1.32 — VREF

V1 = .010393 = LSD

		COUNTER CONTENTS	DECIMAL
X = 0.0000,	V = .000000		
X = 1.0000,	V = .010393		
X = 2.0000,	V = .020787		
X = 3.0000,	V = .031181	0000101	5
X = 4.0000,	V = .041574		
X = 5.0000,	V = .051968		
X = 6.0000,	V = .062362		
X = 7.0000,	V = .072755		
X = 8.0000,	V = .083149		
X = 9.0000,	V = .093543	0001011	11
X = 10.0000,	V = .103937		
X = 11.0000,	V = .114331		
X = 12.0000,	V = .124724		
X = 13.0000,	V = .135118		
X = 14.0000,	V = .145512		
X = 15.0000,	V = .155905		
X = 16.0000,	V = .166299	0010010	18
X = 17.0000,	V = .176693		
X = 18.0000,	V = .187086		
X = 19.0000,	V = .197480		
X = 20.0000,	V = .207874		
X = 21.0000,	V = .218267		
X = 22.0000,	V = .228661		
X = 23.0000,	V = .239055		
X = 24.0000,	V = .249449		
X = 25.0000,	V = .259842	0011011	27
X = 26.0000,	V = .270236		
X = 27.0000,	V = .280630		
X = 28.0000,	V = .291023		
X = 29.0000,	V = .301417		
X = 30.0000,	V = .311811		
X = 31.0000,	V = .322204		
X = 32.0000,	V = .332598		
X = 33.0000,	V = .342992		
X = 34.0000,	V = .353385		
X = 35.0000,	V = .363779		
X = 36.0000,	V = .374173	0100101	37
X = 37.0000,	V = .384566		
X = 38.0000,	V = .394960		
X = 39.0000,	V = .405354		
X = 40.0000,	V = .415747		
X = 41.0000,	V = .426141		
X = 42.0000,	V = .436535		
X = 43.0000,	V = .446928	0101101	45
X = 44.0000,	V = .457322		
X = 45.0000,	V = .467716		
X = 46.0000,	V = .478109		
X = 47.0000,	V = .488503		
X = 48.0000,	V = .498897		
X = 49.0000,	V = .509290		
X = 50.0000,	V = .519684	0110100	52
X = 51.0000,	V = .530078		
X = 52.0000,	V = .540471		
X = 53.0000,	V = .550865		
X = 54.0000,	V = .561259		
X = 55.0000,	V = .571652		
X = 56.0000,	V = .582046		
X = 57.0000,	V = .592439		
X = 58.0000,	V = .602833		
X = 59.0000,	V = .613227		
X = 60.0000,	V = .623620		

Table 3-1b. A/C Converter Test Data

X = 61.0000,	V = .634014		
X = 62.0000,	V = .644408		
X = 63.0000,	V = .654801		
X = 64.0000,	V = .665195		
X = 65.0000,	V = .675588		
X = 66.0000,	V = .685982		
X = 67.0000,	V = .696376		
X = 68.0000,	V = .706769	1000110	70
X = 69.0000,	V = .717163		
X = 70.0000,	V = .727556		
X = 71.0000,	V = .737950		
X = 72.0000,	V = .748344		
X = 73.0000,	V = .758737		
X = 74.0000,	V = .769131		
X = 75.0000,	V = .779525		
X = 76.0000,	V = .789918		
X = 77.0000,	V = .800312	1001111	79
X = 78.0000,	V = .810705		
X = 79.0000,	V = .821099		
X = 80.0000,	V = .831493		
X = 81.0000,	V = .841886		
X = 82.0000,	V = .852280		
X = 83.0000,	V = .862674		
X = 84.0000,	V = .873067		
X = 85.0000,	V = .883461		
X = 86.0000,	V = .893854		
X = 87.0000,	V = .904248	1011001	89
X = 88.0000,	V = .914642		
X = 89.0000,	V = .925035		
X = 90.0000,	V = .935429		
X = 91.0000,	V = .945822		
X = 92.0000,	V = .956216		
X = 93.0000,	V = .966610		
X = 94.0000,	V = .977003		
X = 95.0000,	V = .987397		
X = 96.0000,	V = .997791		
X = 97.0000,	V = 1.00818		
X = 98.0000,	V = 1.01858	1100100	100
X = 99.0000,	V = 1.02897		
X = 100.000,	V = 1.03936		
X = 101.000,	V = 1.04976		
X = 102.000,	V = 1.06015		
X = 103.000,	V = 1.07055		
X = 104.000,	V = 1.08094		
X = 105.000,	V = 1.09133		
X = 106.000,	V = 1.10173		
X = 107.000,	V = 1.11212		
X = 108.000,	V = 1.12251		
X = 109.000,	V = 1.13291		
X = 110.000,	V = 1.14330		
X = 111.000,	V = 1.15369		
X = 112.000,	V = 1.16409		
X = 113.000,	V = 1.17448		

Table 3-1c. A/D Converter Test Data

```
X =  114.ØØØ,  V =  1.18486
X =  115.ØØØ,  V =  1.19527 ┐ 1110101        117
X =  116.ØØØ,  V =  1.2Ø566 ┘
X =  117.ØØØ,  V =  1.216Ø6
X =  118.ØØØ,  V =  1.22645
X =  119.ØØØ,  V =  1.23684
X =  12Ø.ØØØ,  V =  1.24724
X =  121.ØØØ,  V =  1.25763
X =  122.ØØØ,  V =  1.268Ø2 ┐ 1111011        123
X =  123.ØØØ,  V =  1.27842 ┘
X =  124.ØØØ,  V =  1.28881
X =  125.ØØØ,  V =  1.29921
X =  126.ØØØ,  V =  1.3Ø96Ø
X =  127.ØØØ,  V =  1.31999
←
```

Table 3-2a. Check of Sensor Through Amplifier

E_o AS READ ON DVM FOR TEMPERATURE OF WATER TC (MEASURED WITH FIRL STANDARD THERMOMETER)

```
 1.01)TC=11.9, T=1, 1, 180! TC=TC+.1, 2;
← 2.01)EB=9.3867*(((9/5)*TC)-32239)
← 2.02)EO=7.01*EB, TC: , EO, EB:
← 1.
TC =  12.0000, EO = -92.1214, EB = -13.1414
TC =  12.1000, EO = -80.2775, EB = -11.4519
TC =  12.2000, EO = -68.4336, EB = -9.76228
TC =  12.3000, EO = -56.5897, EB = -8.07271
TC =  12.4000, EO = -44.7455, EB = -6.38310
TC =  12.5000, EO = -32.9016, EB = -4.69353
TC =  12.6000, EO = -21.0577, EB = -3.00396
TC =  12.7000, EO = -9.21382, EB = -1.31438
TC =  12.8000, EO =  2.63008, EB =  .375190
TC =  12.9000, EO =  14.4742, EB =  2.06480
TC =  13.0000, EO =  26.3181, EB =  3.75437
TC =  13.1000, EO =  38.1620, EB =  5.44394
TC =  13.2000, EO =  50.0059, EB =  7.13352
TC =  13.3000, EO =  61.8498, EB =  8.82309
TC =  13.4000, EO =  73.6940, EB =  10.5127
TC =  13.5000, EO =  85.5379, EB =  12.2023
TC =  13.6000, EO =  97.3818, EB =  13.8918
TC =  13.7000, EO =  109.226, EB =  15.5814
TC =  13.8000, EO =  121.070, EB =  17.2710
TC =  13.9000, EO =  132.914, EB =  18.9606
TC =  14.0000, EO =  144.758, EB =  20.6502
TC =  14.1000, EO =  156.602, EB =  22.3397 ——160
TC =  14.2000, EO =  168.445, EB =  24.0293
TC =  14.3000, EO =  180.289, EB =  25.7189
TC =  14.4000, EO =  192.134, EB =  27.4085
TC =  14.5000, EO =  203.977, EB =  29.0981
TC =  14.6000, EO =  215.821, EB =  30.7876
TC =  14.7000, EO =  227.665, EB =  32.4772
TC =  14.8000, EO =  239.509, EB =  34.1668
TC =  14.9000, EO =  251.353, EB =  35.8564
TC =  15.0000, EO =  263.197, EB =  37.5468
TC =  15.0999, EO =  275.041, EB =  39.2355
TC =  15.1999, EO =  286.885, EB =  40.9251
TC =  15.2999, EO =  298.729, EB =  42.6147 ——300
TC =  15.3999, EO =  310.573, EB =  44.3043
TC =  15.4999, EO =  322.417, EB =  45.9939
TC =  15.5999, EO =  334.261, EB =  47.6834
TC =  15.6999, EO =  346.105, EB =  49.3730
TC =  15.7999, EO =  357.949, EB =  51.0626
TC =  15.8999, EO =  369.793, EB =  52.7522 ——373
TC =  15.9999, EO =  381.637, EB =  54.4418
TC =  16.0999, EO =  393.480, EB =  56.1313
TC =  16.1999, EO =  405.324, EB =  57.8209
TC =  16.2999, EO =  417.168, EB =  59.5105
TC =  16.3999, EO =  429.012, EB =  61.2001
TC =  16.4999, EO =  440.856, EB =  62.8896
TC =  16.5999, EO =  452.700, EB =  64.5792
TC =  16.6999, EO =  464.544, EB =  66.2688
TC =  16.7999, EO =  476.388, EB =  67.9584 ——483
TC =  16.8999, EO =  488.232, EB =  69.6480
TC =  16.9999, EO =  500.076, EB =  71.3375
```

Table 3-2b. Check of Sensor Through Amplifier

E_o AS READ ON DVM
TC (MEASURED WITH STANDARD THERMOMETER)

TC =	17.0999,	EO =	511.9[illegible],	EB =	73.0271	
TC =	17.1999,	EO =	5[illegible]3.7[illegible],	EB =	74.7167	
TC =	17.2999,	EO =	535.[illegible],	EB =	76.4062	
TC =	17.3999,	EO =	547.45[illegible],	EB =	78.0958	
TC =	17.4999,	EO =	559.296,	EB =	79.7854	
TC =	17.5999,	EO =	571.14[illegible],	EB =	81.4750	
TC =	17.6999,	EO =	582.984,	EB =	83.1646	
TC =	17.7999,	EO =	594.827,	EB =	84.8541	597
TC =	17.8999,	EO =	606.671,	EB =	86.5437	
TC =	17.9999,	EO =	618.516,	EB =	88.2333	
TC =	18.0999,	EO =	630.359,	EB =	89.9229	
TC =	18.1999,	EO =	642.203,	EB =	91.6125	
TC =	18.2999,	EO =	654.047,	EB =	93.3020	
TC =	18.3999,	EO =	665.891,	EB =	94.9916	
TC =	18.4999,	EO =	677.735,	EB =	96.6812	
TC =	18.5999,	EO =	689.579,	EB =	98.3708	688
TC =	18.6999,	EO =	701.423,	EB =	100.060	
TC =	18.7999,	EO =	713.267,	EB =	101.750	
TC =	18.8999,	EO =	725.111,	EB =	103.440	
TC =	18.9999,	EO =	736.955,	EB =	105.129	
TC =	19.0999,	EO =	748.799,	EB =	106.819	
TC =	19.1999,	EO =	760.643,	EB =	108.508	
TC =	19.2999,	EO =	772.486,	EB =	110.198	783
TC =	19.3999,	EO =	784.331,	EB =	111.887	
TC =	19.4999,	EO =	796.175,	EB =	113.577	
TC =	19.5999,	EO =	808.018,	EB =	115.267	
TC =	19.6999,	EO =	819.863,	EB =	116.956	
TC =	19.7999,	EO =	831.706,	EB =	118.646	
TC =	19.8999,	EO =	843.550,	EB =	120.335	845
TC =	19.9999,	EO =	855.394,	EB =	122.025	
TC =	20.0999,	EO =	867.238,	EB =	123.714	
TC =	20.1999,	EO =	879.082,	EB =	125.404	
TC =	20.2999,	EO =	890.926,	EB =	127.094	
TC =	20.3999,	EO =	902.770,	EB =	128.783	
TC =	20.4999,	EO =	914.614,	EB =	130.473	
TC =	20.5999,	EO =	926.458,	EB =	132.162	
TC =	20.6999,	EO =	938.302,	EB =	133.852	
TC =	20.7999,	EO =	950.146,	EB =	135.541	
TC =	20.8999,	EO =	961.990,	EB =	137.231	963
TC =	20.9999,	EO =	973.834,	EB =	138.921	
TC =	21.0999,	EO =	985.678,	EB =	140.610	
TC =	21.1999,	EO =	997.522,	EB =	142.300	
TC =	21.2999,	EO =	1009.37,	EB =	143.989	
TC =	21.3999,	EO =	1021.21,	EB =	145.679	1030
TC =	21.4998,	EO =	1033.05,	EB =	147.369	
TC =	21.5998,	EO =	1044.90,	EB =	149.058	
TC =	21.6998,	EO =	1056.74,	EB =	150.748	
TC =	21.7998,	EO =	1068.59,	EB =	152.437	
TC =	21.8998,	EO =	1080.43,	EB =	154.127	
TC =	21.9998,	EO =	1092.27,	EB =	155.817	
TC =	22.0998,	EO =	1104.12,	EB =	157.506	
TC =	22.1998,	EO =	1115.96,	EB =	159.196	
TC =	22.2998,	EO =	1127.80,	EB =	160.885	
TC =	22.3998,	EO =	1139.65,	EB =	162.575	
TC =	22.4998,	EO =	1151.49,	EB =	164.264	
TC =	22.5998,	EO =	1163.34,	EB =	165.954	1147
TC =	22.6998,	EO =	1175.18,	EB =	167.644	
TC =	22.7998,	EO =	1187.02,	EB =	169.333	
TC =	22.8998,	EO =	1198.87,	EB =	171.023	
TC =	22.9998,	EO =	1210.71,	EB =	172.712	

These experimental readings were compared with a computer simulation of an "ideal" system. The first column of the tables show water temperature in degrees Celsius. The second and third columns show expected bridge amplifier and bridge output (both in millivolts) respectively. The last column shows actual measurements with a laboratory DVM at the input to the A/D converter comparator. The temperature of the water bath was held as close to the computed values as possible.

Finally, each binary bit line of the output buffer (to the recording heads) was monitored and adjusted for a level of 150 mv (pulse) with a duration of 225 μs when loaded with the heads.

The stepper-motor (recorder) driving circuit was adjusted for a 6.6 v pulse at 20 ms with the motor on-line.

3.1.4 Electromagnetic Interference

Our only concerns with regard to RFI to our electronic system arose because of the possible close proximity of the porpoise tracking transmitter which broadcasts on the order of 500 mw of power in the 27 MHz band and the Xenon flasher which could conceivably radiate extremely high peak power over a very broad band—albeit for a very brief time.

Because the detailed nature of the interference to our circuits was unknown, as was the location within the circuit where it might occur we determined that the only feasible method for evaluation RFI was to place each unit at various anticipated distances from our unshielded system—and at various azimuthal positions with respect to the system—and then monitor critical system points for interference. These critical points were:

internal power lines
timing circuits
transducer circuits.

The porpoise transmitter produced no detectable RFI irrespective of distance from and relative geometric position to the system.

The Xenon flasher however (OAR Model XF-501-12), produced disruptive interference when placed 10 cm, or closer to our system. At 10 cm, extraneous pulses as large as 2.8 v appeared in the system. This RFI diminished rapidly as the flasher was moved farther from the system and at a radial distance of approximately 20 cm, no RFI was detectable.

3.1.5 Shielding

Because of the potential RFI from the Xenon flasher two steps were taken: first, the harness designers were asked to locate the flasher at least 20 cm (8") from the pod if possible and second, we decided to shield the pod.

Although our observations with the OAR, Model PI-208 Porpoise tracking transmitter showed no RFI, results, as discussed above, with the Xenon Flasher were seriously disturbing at close range. We decided therefore, to shield the pod with a conductive metal applied by spray. This decision is in effect, simply insurance since our colleagues working on the harness will locate the flasher as far from the instrument pod as is practicable.

The shielding material to be used is the Emerson and Cumings Type ES. It will be heavily coated on the pod and then overcoated with fiberglass resin. The surface coating on the pod will be bonded to the baseplate at a single point.

3.1.6 On Board Power Sources

The cells selected for use here are mercuric oxide. They were selected for two reasons: (1) ambient temperature will be in the 55—75°F range (2) insufficient time was available to us to evaluate thoroughly the new lithium fluoride cells which have become available. It is our preliminary opinion that the lithium cells will be used in all future packs.

Power was needed for the following circuits; milliampere-hour requirements are indicated for possible (likely) periods of use in the forthcoming field work for each circuit:

Application	Volt. Req'd.	(ma) Average Current Drain	ma-hours 3 Days	5 Days	7 Days
Logic Circuit	+(3.90-4.04)	0.05	3.6	6.	8.4
Pressure Bridge	+(3.90-4.04)	0.15	10.8	18.	25.2
Temperature Bridge	+(3.90-4.04)	0.029	2.1	3.5	4.9
Reference Voltage	+(1.33-1.35)	0.13	9.4	15.6	21.8
Op-Amps	+(2.60-2.70)	0.040	2.8	4.8	6.8
Op-Amps	-(2.60-2.70)	0.040	2.8	4.8	6.8
Recorder Drive	+(10.4-10.8)	0.86	62.	103.	144.

All batteries, except those for the recorder-stepper-drive were aged between 10—20% of their capacity for stabilization. We had originally hoped to bring them down to the mercury potential plateau which is very useful in the range of 1.300—1.330 volts/cell. This would have meant that our cells would have had the following voltage levels:

Logic circuit	3.90—3.99
Pressure bridge	3.90—3.99
Temperature bridge	3.90—3.99
Reference voltage	1.30—1.33
Op-Amps	2.60—2.66
Op-Amps	2.60—2.66
Recorder drive	10.40—10.64

However, an analysis indicated that little was to be gained in the present situation by running the cells down to the mercury level—other than reducing our safety factor perceptibly. The reasoning is as follows:

a. The logic circuit performance is not voltage dependent in the range of interest

b. The pressure and temperature bridges *are* voltage dependent, but we do not expect to experience a voltage shift in excess of 1% at the bridges if the run extends beyond 7 days, which is unlikely.

c. The same comment holds true for the reference cell as in 6. above.

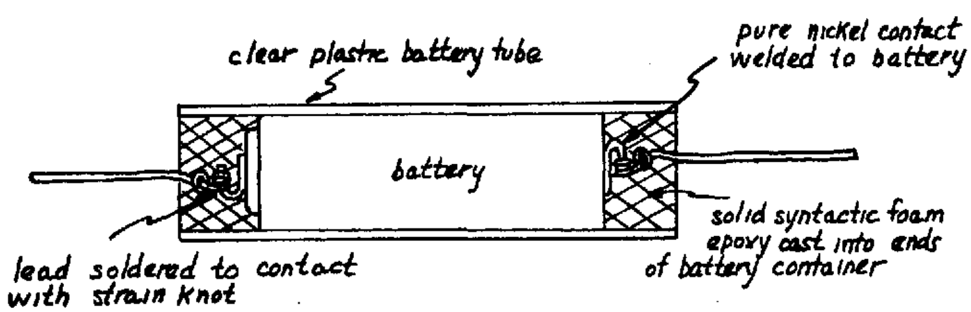
d. The operational amplifiers will be insensitive to cell voltage change so long as (+) and (-) voltages move together.

e. The recorder drive will not be sensitive to voltage change.

Resulting available battery capacities and computed safety factors are as follows:

Application	Available ma - hrs.	Safety Factors 3-Day Run	5-Day Run	7-Day Run
Pressure Bridge	250	23X	14X	10X
Temperature Bridge	250	119X	71X	51X
Reference Voltage	189	20X	12X	9X
Op Amp (+)	188	67X	39X	28X
Op Amp (-)	188	67X	39X	28X
Recorder Drive	960	15X	9X	6X
Logic Circuits	260	72X	43X	31X

All cells and batteries have been packaged ruggedly so as to minimize chances of intermittent contact. Each unit is essentially similarly packaged as follows:



Total battery pack weight is 186 grams.

Battery color coding system is as follows:

Function	Polarity	Code
Pressure Bridge	(+)	Dashed Red
Pressure Bridge	(-)	Alt. Red-Black
Temperature Bridge	(+)	Dashed Brown-Red
Temperature Bridge	(-)	Alt. Brown-Red-Black
Op-Amp (+ Supply)	(+)	Dashed Green
Op-Amp (+ Supply)	(-)	Alt. Green-Black
Op-Amp (- Supply)	(+)	Dashed Blue
Op-Amp (- Supply)	(-)	Alt. Blue-Black
Reference Cell	(+)	Dashed Yellow
Reference Cell	(-)	Alt. Yellow-Black
Logic Circuits	(+)	Alt. Red-Blue
Logic Circuits	(-)	Alt. Red-Blue-Black
Recorder Stepper	(+)	Alt. Yellow-Blue
Recorder Stepper	(-)	Alt. Yellow-Blue-Black

3.1.7 Operational Start-Up and Testing in the Field

3.1.7.1 Start-Up

The application of power to the instrument system is controlled by a dual in-line switch module (D16) accessible when the pod baseplate is removed.

The sequence of operation is as follows:

a. Switch 1 is turned ON; this action removes any charge on the bridge amplifier capacitors.

b. Switches 2 through 8 are then turned ON in serial sequence. These provide power to:

Logic
Op-Amps
D/A Reference
Pressure Bridge
Temperature Bridge
and the recorder-stepper drive circuit.

c. Switch 1 is then turned OFF, permitting the transducer signals to be processed.

3.1.7.2 Testing

The fault isolation network consists of a dual in-line package of eight SPST switches, two inverters and a light-emitting-diode (LED) as shown in Figure 3-13.

The purpose of the system is to permit a system check in the field *without the use of ancillary equipment.* The operator simply presses any one of the eight switches at a time and observes the LED. In the field, the LED is covered with a red filter to permit its viewing even in sunlight.

Figure 3-14 illustrates the status of the LED indicator versus the operation of any one of the test switches.

In the case where system malfunction is suspected or observed, the test system can be used to aid in fault isolation. In this regard, Table 3-3 illustrates the establishment of a fault and possible corrective action to be taken.

In any case, only one switch at a time may be in the ON position This precludes the injection of improper signals to the circuits. When the fault isolation network is not in use, switch #8 is placed in the ON position to cut out the LED and prevent unnecessary power drain.

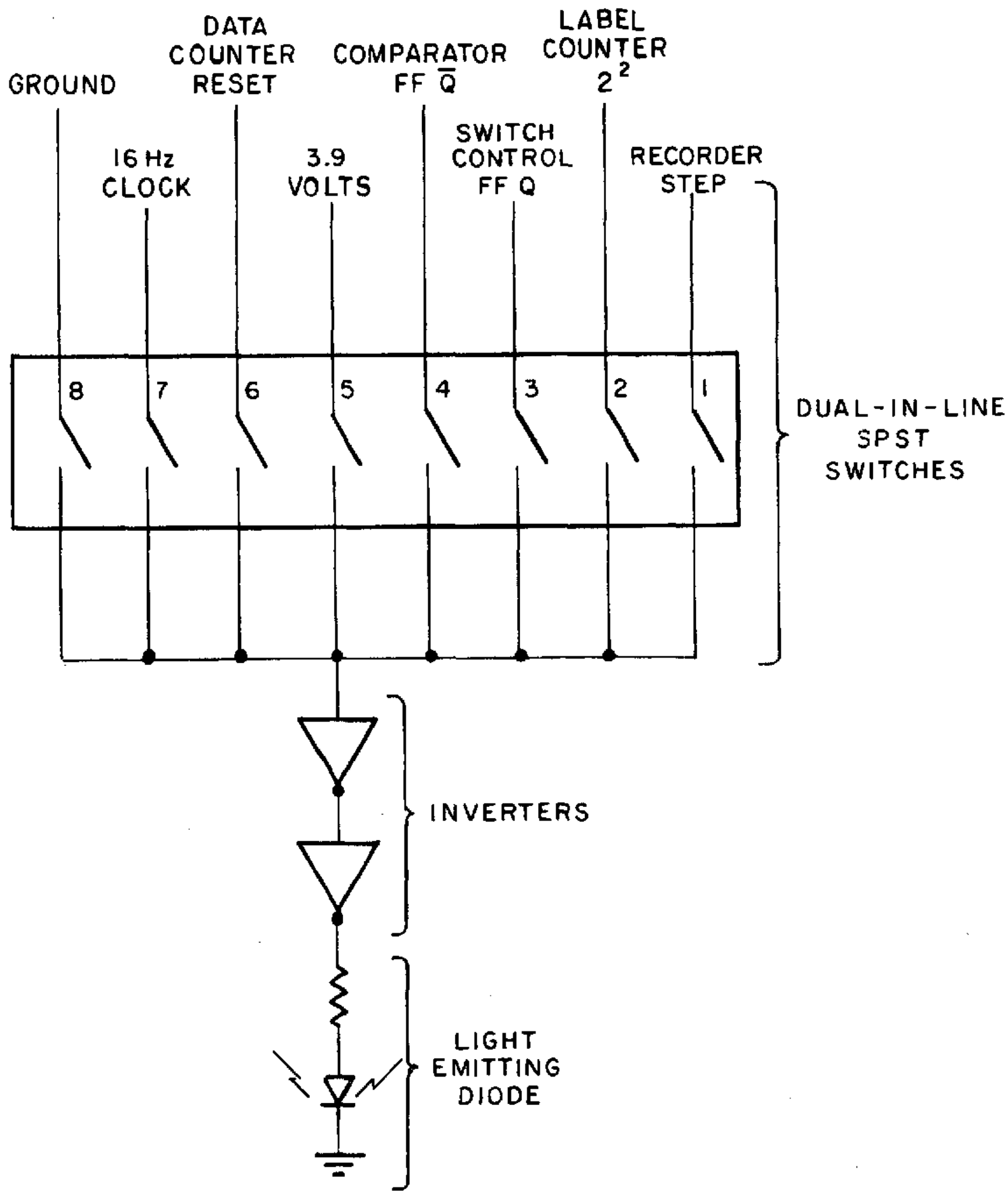


Figure 3-13. Fault Isolation Network

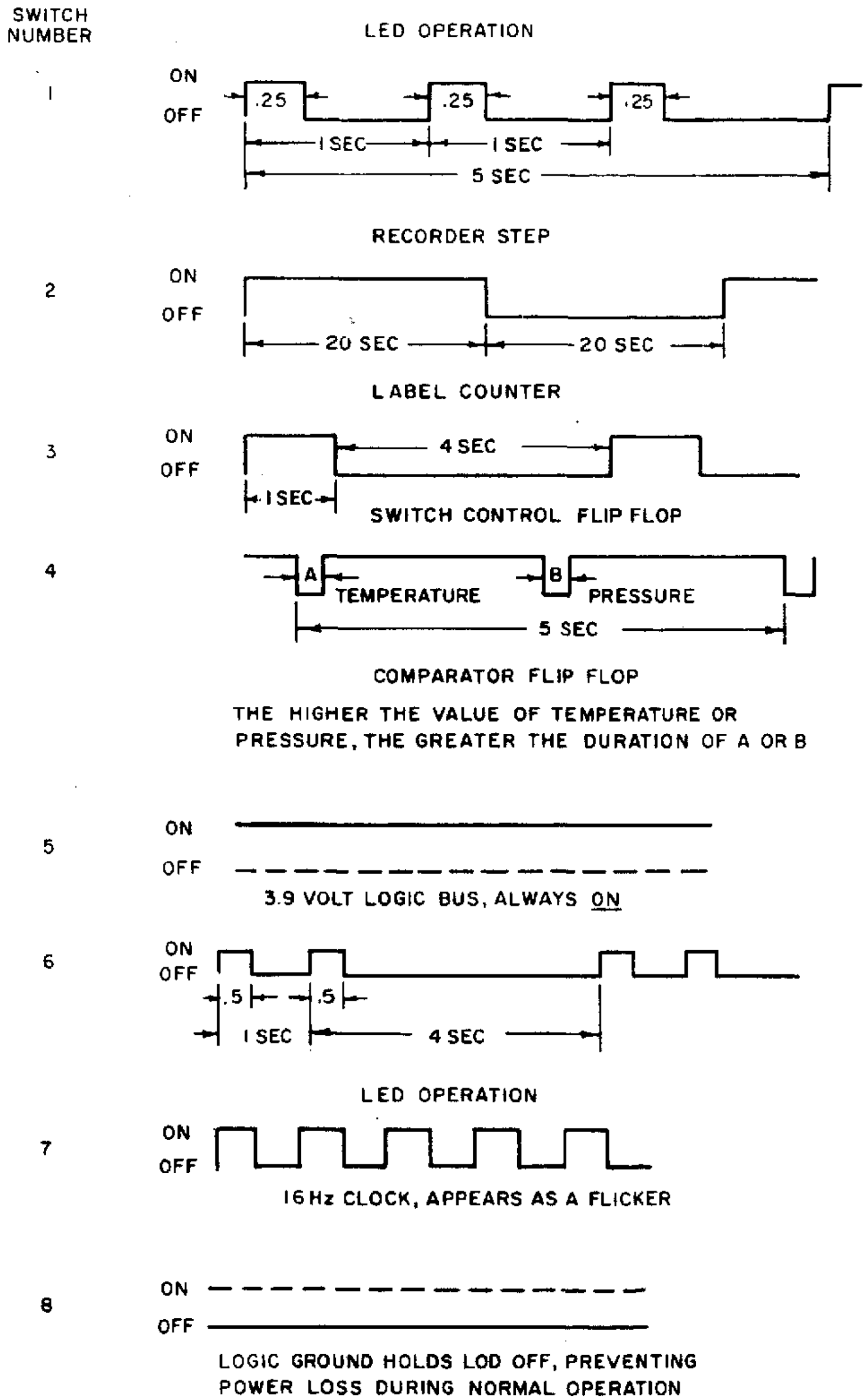


Figure 3-14. LED Status

Table 3-3. Recommended Action in the Event of Malfunction, as Indicated by LED

General:

- Check proper operation of power switches.
- Insure that only *one* LED switch is on at any one time.
- Check for loose wires, loose components, foreign materials, etc.

Handling:

- Before touching circuits, touch a finger and hold to ground. Ground is the metal plane on the component side of the board.

LED Switch No.	Problem	Solution (in order of implementation)
1	Only 2 pulses.	1. Replace D43 (CD4049A) 2. Check component board B43 for component connections.
1	Only 1 pulse.	1. Replace D43 (CD4049A). 2. Check leads on component board K43.
1	No pulses.	1. Replace D24 (CD4016A). 2. Replace H52 (CD4017A).
1	Pulses present, but recorder not stepping.	1. Check transistor 2N5859 position. 2. Check cable to recorder, lines P, L.
2	Switch position 1 OK, but 2 not proper.	1. Replace K52 (CD4024A). 2. Check under conditions for LED Switch 6.
3	Switch position 1 OK, but 3 not proper.	1. Replace M43 (CD4013A). 2. Replace D52 (CD4011A).
4	If under no pressure, both "OFF" pulses can be seen.	1. Turn power switch #1 on for approx. 5 sec., and then off.
4	If first "OFF" pulse not working properly. (This is temperature section.)	1. Check wiring from temperature sensor. 2. Check component boards P16 and K16. 3. Check wiring from batteries (±2.6V).

Table 3-3. Recommended Action in the Event of Malfunction, as Indicated by LED (cont)

LED Switch No.	Problem	Solution (in order of implementation)
4	If second "OFF" pulse not working properly. (This is pressure section.)	1. Check wiring from pressure sensor. 2. Check component boards B16 and B25. 3. Check wiring from batteries (±2.6V).
4	If neither "OFF" pulse operating.	1. Check wiring on P34. 2. Check wiring on P25. 3. Check wiring on M15. 4. Check wiring from batteries (+3.9 Logic, ±2.6V).
5	If not "ON".	1. Check power switch #2. 2. Check wiring from battery +3.9 (Alt R-BL to D15), 3.9V return (Alt R-BL-BLK) to ground.
6	If only one pulse present.	1. Replace D52 (CD4011A).
6	If none present.	1. Replace H52 (CD4017A).
7	If not functioning.	1. Turn power switch #2 off and on (repeating once or twice if still not operating). 2. Touch top two capacitors (A43, A42) on board A43. 3. Check wires to crystal. 4. Replace A52 (MTD D135P).

3.2 TRANSDUCERS - GENERAL CONSIDERATIONS

The lagoons or bays to the north and south of the Boca de Soledad vary in width from about one-half mile to perhaps three miles. In the central deepest positions, the depth may reach fifty feet, but in general runs thirty-five to forty feet or less; the temperature of the water varies around 65°F within a few degrees. The tidal currents in and out of the Boca may reach speeds of five to six knots bringing in slightly cooler ocean water of 62 to 63°F. Shallow, isolated back waters may reach higher temperatures of a few degrees due to heating by the sun.

In the design of the pressure and temperature ranges to be recorded in this experiment these natural ranges were taken into consideration. The temperature range was chosen to be 65° $\pm$10°F, i.e. 55° to 75°F. This provided an ample safety margin without losing sensitivity since the limitation by the digital format was 1 part in 128. This provided 0.1563°F per bit least count which was on the order of the sensitivity and accuracy of the thermistor, bridge and amplifier networks. A pressure range of 50 psi was chosen which is equivalent to approximately 113 feet depth in sea water. A compromise between several factors had to be made such as fixed ranges of transducers and safe overload. The choice of this range (0 - 50 psi; 0 - 113 feet) yielded a least count of approximately one-half foot with an accuracy of about one foot. This was considered satisfactory for these feasibility experiments.

A mother, juvenile pair surfaces to breathe in patterns with wide variance. Approximate ranges could be chosen as 2 to 5 seconds at surface and 30 to 120 seconds submerged. A continuous record of depth pattern would be ideal, but because of the nature of the recording system and the long records involved (3 to 10 days), a sampling scheme had to be selected. The sampling interval chosen was 5 seconds. Samples of the temperature and pressure were each obtained instantaneously at 5-second intervals stored and recorded on tape. For a cycle of breath-to-breath of 30 seconds, this would give 6 samples or points on the diving profile and for longer cycles more data points. It was felt that this number was sufficient to reconstruct fairly smooth diving profiles and readily fitted the various limitations of supply power, tape length and data reduction. Any profiles which we may be able to obtain from these experiments will enable us to verify that this was a good sampling rate or help us choose an alternative.

3.2.1 Pressure Sensor

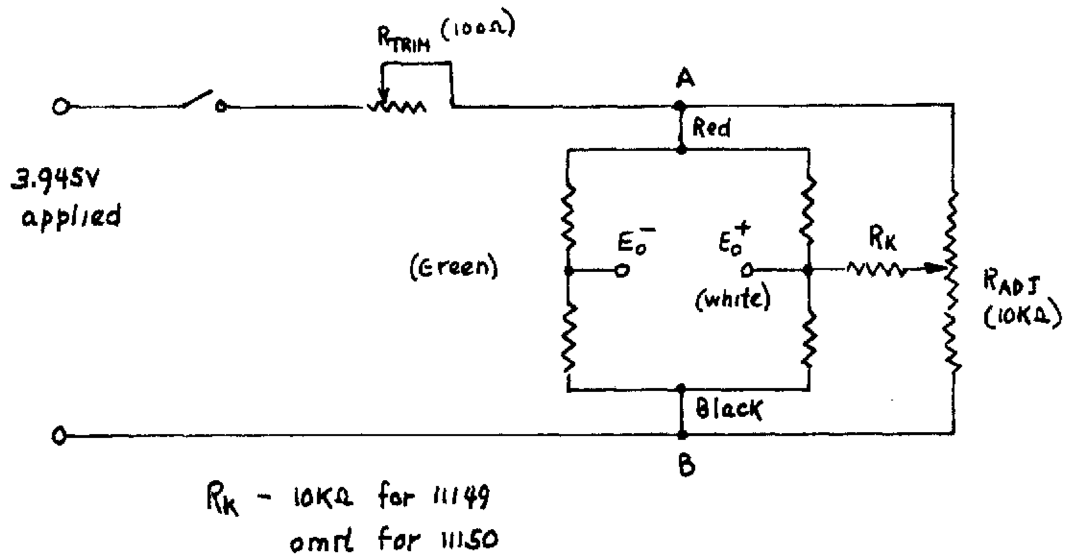
Many transducers are available to measure pressure and hence depth. Primary criteria in the selection were small size and weight, high output, stability, reproducibility and low power consumption. Another important factor was immediate availability because of the limited time for circuitry development and construction. A miniature semi-conductor strain gage unit was chosen. This was a Sensotec Model No. SAH-6G(W). The unit had a welded diaphram, was only 0.250 in. diameter and had an impedance of approximately 500 ohms. It was calibrated for zero output at atmospheric pressure (14.7 psi) and had a range of 0 - 50 psi linear and was usable to reach 60 psi with about 2% error above 50 psi. An overload of approximately 100% can be applied without damage to the transducer. The strain gages had external compensation for temperature in the leads and was compensated for a temperature range of 60°F to 160°F. For a standard input voltage of 5.0 volts, the output was about 2.50 millivolts/psi. Two units were obtained and separately calibrated using air pressure in a suitable jig. A mercury manometer for low pressure range and a bourdon tube pressure gage was used for the standard pressure measurements. Calibration curves were obtained from which the mean slopes were derived as given below.

unit no.	-	mv/psi @ 4.00 volts applied
11149	-	2.03 $\pm$.01
11150	-	1.93 $\pm$.01

The output was proportional to the applied voltage and the final circuits were adjusted to 2.852 volts for unit no. 11149 and 3.00 volts for unit no. 11150.

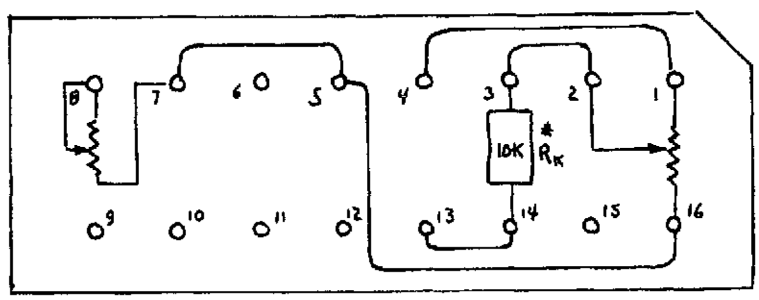
unit no.		mv/psi @ 2.852 volts for 11149 and 3.00 volts for 11150
11149	-	1.45 ±.01
11150	-	1.45 ±.01

The balancing and zeroing circuits for the transducers are shown below.



R_{TRIM}, adjusted to give 3.00 volts at points A-B for no. 11150 and 2.852 volts for no. 11149. R_{adj}, adjusted to give 0.000 volts out at $E_o^{\pm}$ at atmospheric pressure.

The circuit was constructed on a 16-pin blank DIP socket board as shown below.



*omit for no. 11150

Board for no. 11149 marked with Blue dot.
Board for no. 11150 marked with Red dot.

Pin connections:

Pin 4 to V_B^- and Black bridge lead

Pin 5 to Red bridge lead

Pin 6 to E^- and Green bridge lead

Pin 8 to V_B^+

Pin 13 to E^+ and White bridge lead.

All other pins N.C.

Adj voltages pins 4-5.

No. 11149 to 2.852 volts.

No. 11150 to 3.000 volts.

R_T and R_A Allen Bradley

Type Z 1/4 in. cube pots.

At a calibration of 1.45 $\pm$.01 mv/psi we have:

Full scale (50 psi) output = 50 X 1.45 = 72.50 mv.

If 72.50 mv is recorded we obtain:

$$\text{psi} = \frac{72.50}{1.45 \pm .01} = 49.658 \text{ to } 50.347 \text{ psi}$$

which is equivalent to a depth of:

$$\begin{aligned}\text{Depth (feet)} &= 2.253\ (49.658 \text{ to } 50.347)\\ &= 111.89 \text{ to } 113.45 \text{ feet}\end{aligned}$$

which is better than $\pm$1% of the measured depth.

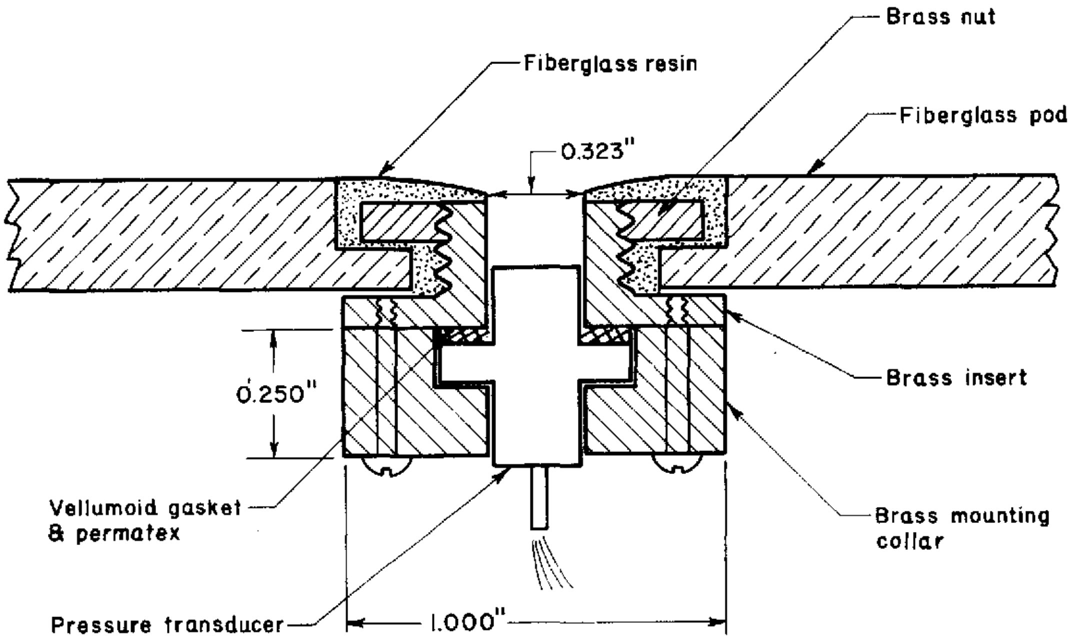
The pressure transducer was mounted at the rear of the fiberglass pod to prevent erroneous pressures due to flow head. A brass mounting sleeve was designed and machined to fit the pressure transducer. This mounting was made an integral part of the fiberglass housing (see Figures 3-15 and 3-16). A 1-in. diameter seat was counter-bored into the fiberglass from the outside surface. The insert was put into place and fastened with a thin brass nut. The assembly was then cemented into place with the same resin used in the construction of the pod. The transducer could be mounted and removed from the inside of the pod by means of the collar and three holding screws. Sealing of the transducer was accomplished by means of a 1/32 in. vellumoid gasket and Permatex #2 sealing compound. This proved to be a highly effective seal.

3.2.2 Temperature Sensor

The temperature range selected was 55° to 75°F, a range of 20°F which was considered more than sufficient for the expected temperature variation and with a least count of 1/128 of full scale or 0.16°F compatible with the expected circuit accuracy and linearity. A Yellow Springs Inst. Co. Thermolinear Thermistor Network YSI part No. 44204 was chosen as the temperature sensing element. This is a composite device consisting of two precise thermistors in one bead and a pair of resistors providing an output voltage linear with temperature. The specifications are given below for the approximately 1/10" diameter head.

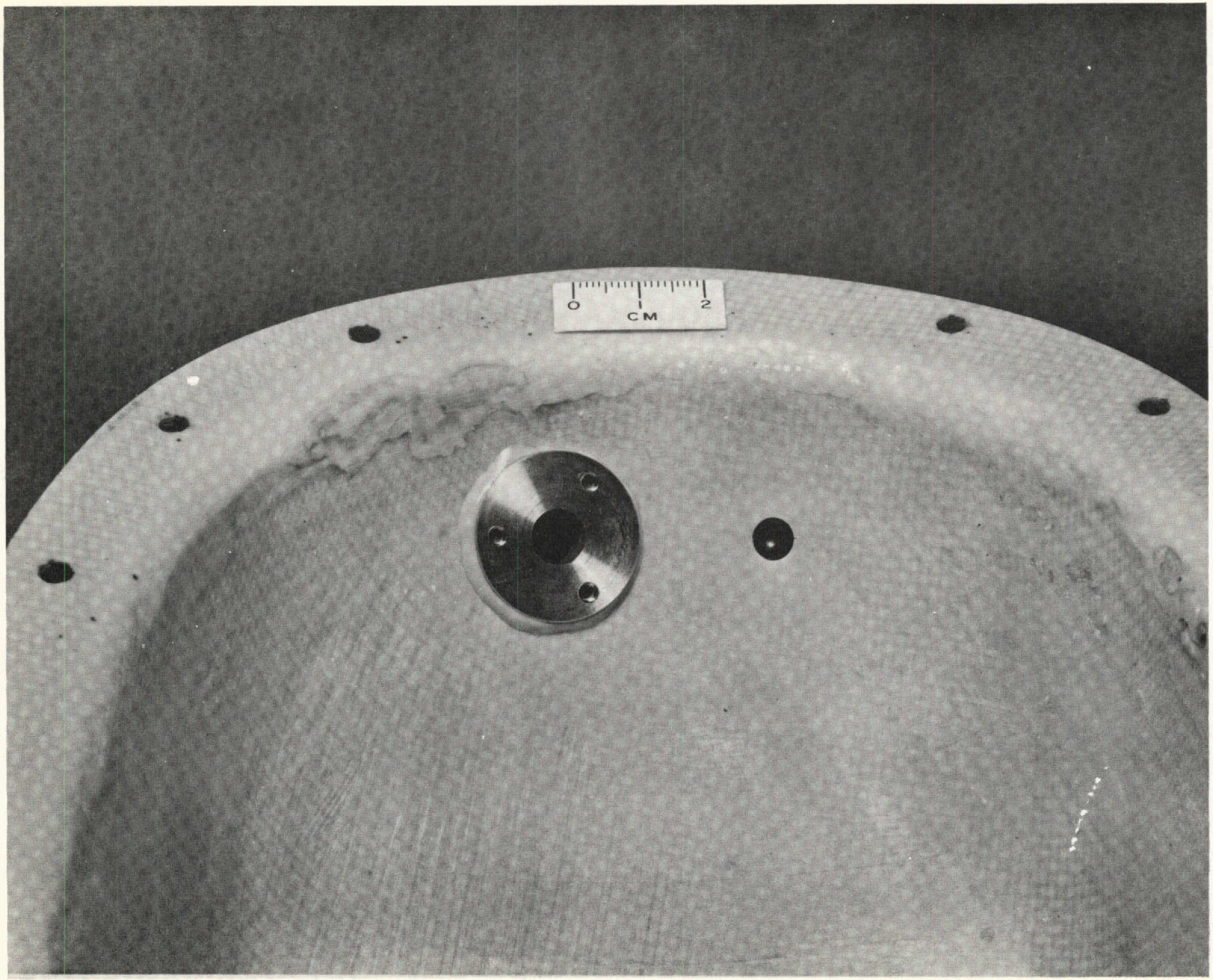
Absolute accuracy and inter-changeability, ±0.27°F
Linearity deviation, ±0.06°F
Max E_{in}, volts, 4.0 volts
Sensitivity, 3.129×10^{-3} E_{in}/°F
Time constant, 63% in 1 sec. in stirred oil

The circuit developed for use with this network is shown below.



F-C3748

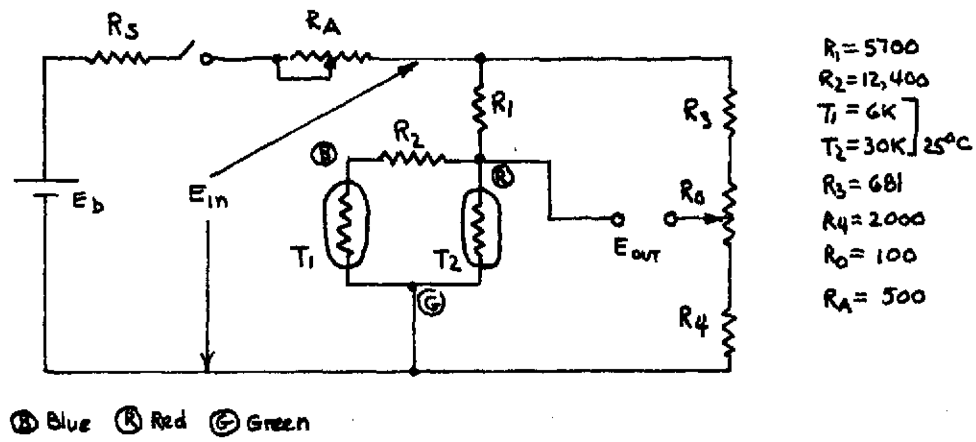
Figure 3-15. Pressure Sensor Mounting Detail



F-C3748

Figure 3-16. Pressure Sensor Mount-Fitting in Pod

The circuit developed for use with this network is shown below.

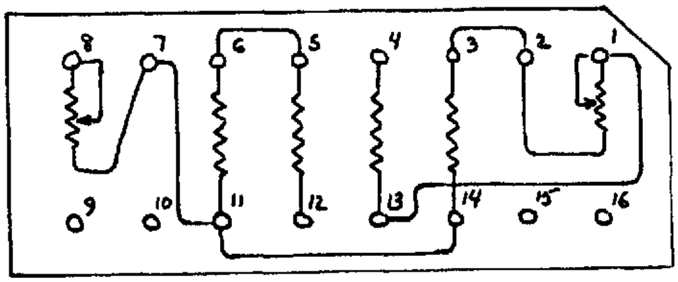


The equation for calculating the output voltage is:

$$E_{OUT} = (-.003129\ E_{in})\ T + 0.9077\ E_{in}$$

The offset voltage is removed by the bleeder chain R_3 and R_4. These resistors are selected to provide zero bridge output at 55°F. They must be selected to be as high in resistance as possible to reduce battery drain, but as low as possible to reduce detector loading. The values chosen were in a broad acceptable range. R_o is used as a zero adjustment of the bridge at 55°F. R_A is used to adjust the applied voltage E_{in} to permit exact calibration. The battery voltage E_b was chosen as 3.945 (3 Hz cells) large enough to overcome the voltage drop in R_s, the COSMOS switch resistance and the voltage drop in R_A. The bridge is calibrated for exactly 3.00 volts E_{in}. With these conditions the bridge output is 187.7 mv for 75°F with 0.0 mv at 55°F or 9.39 mv/°F. The COSMOS switch is pulsed at approximately a 2.5% duty cycle. Under these conditions, the power requirements of the thermistor bridge is about 0.12 milliwatts average or a battery drain of about .03 milliamps average.

The circuit components were mounted on a DIP blank socket board as shown below.



Pin connections:

Pin 1 E_{OUT} +

Pin 4 V_B - and green thermistor lead

Pin 5 Red thermistor lead

Pin 6 E_{OUT} -

Pin 8 V_B +

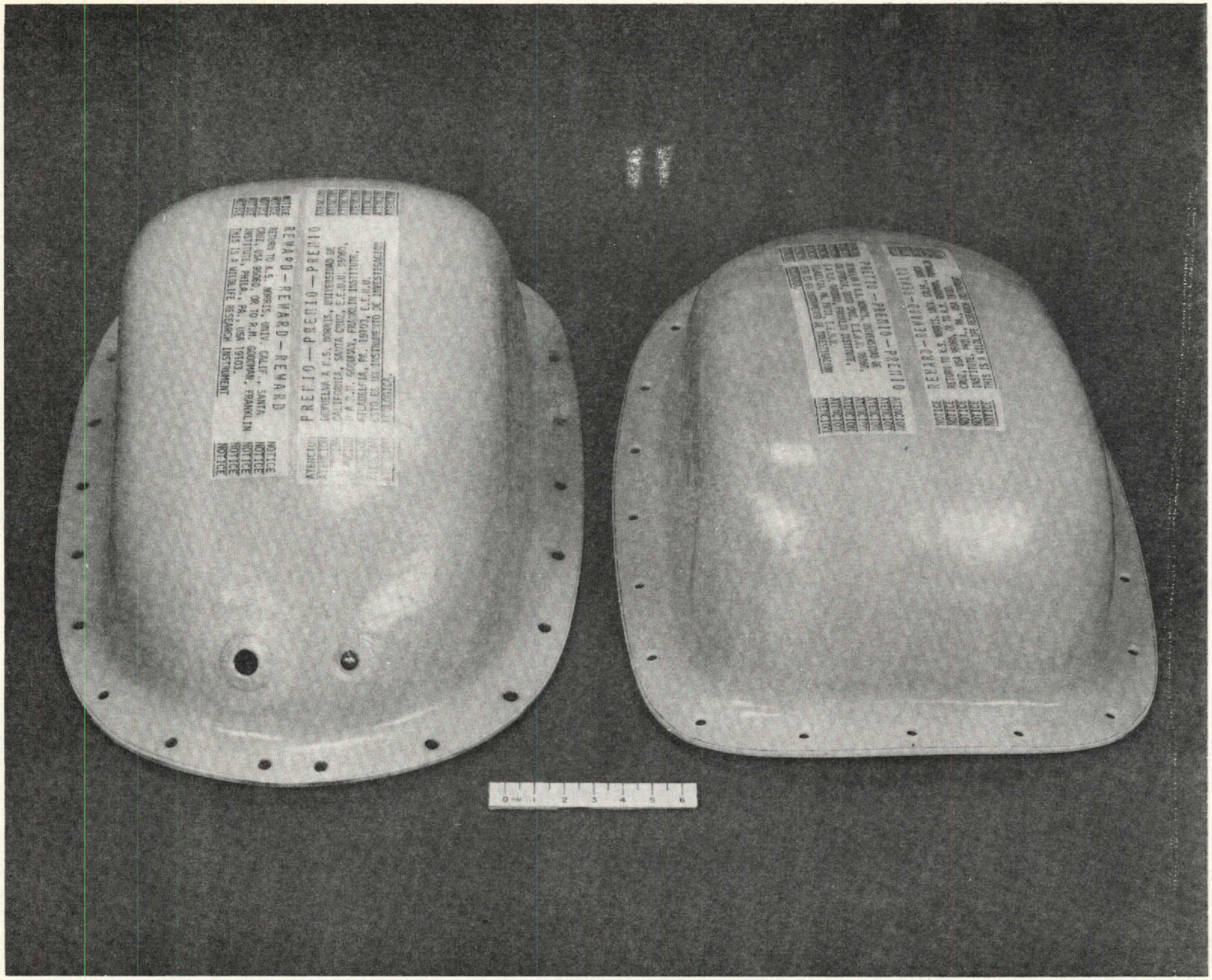
Pin 12 Brown thermistor lead

All other pins N.C.

R_A & R_0 1/4 in. cube Allen-Bradley pots.

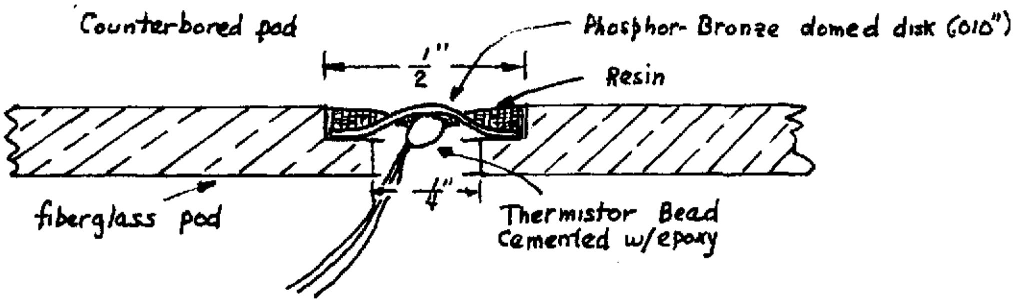
Thermistors and circuit boards are completely inter-changeable.

The thermistor was mounted in the rear of the protective fiberglass cover (see Figure 3-17). It was cemented in place with one drop of Epo-tek epoxy resin no. 201 to the inside of a small domed phosphor bronze disk inserted into the fiberglass body. (See diagram below.) This disk can also be seen in Figure 3-16.



F-C3748

Figure 3-17. External View of Sensor Fittings



The design of this thermistor mount had to minimize the amount of material, miximize the strength and be thin enough to have high thermal conductivity from the water to the thermistor. The present design is a successful compromise between these conflicting requirements.

Measurements of the response time, in a stirred water bath, of the mounted thermistor were made and yielded a time constant of less than five seconds.

Calibration of the thermistors used (#100 and #101) in the final bridge circuits showed an accuracy and deviation from linearity of better than 0.1°F throughout the 20° temperature range.

3.3 DATA RECORDER

The micropower, subminiature, high data-density recorder used in our present work is a further developed version of the unit begun under NASA Contract No. NAS2-6860. The device has a capacity of 64 meters (210 feet) of 1/4 mil tape. The maximum data capacity is 2.52 X 10^6, 8-bit words or 20.16 X 10^6 bits.

3.3.1 Mechanical Design

A major effort was undertaken to improve the tape transport system function in both the "record" and playback operational modes. Additional work was invested in redesigning the drive and detent pawls and their adjustment mechanisms.

A baseplate was designed and fabricated as well as a machined aluminum container for the unit. Tape snubbers were found to be essential and and were also designed and fabricated. Simple jigs were made for loading tape reels while simultaneously polarizing the tape in preparation for reverse-polarization recording.

Tape Drive

Analysis and bench studies indicated clearly that compound angles were required at two of the four tape transport pulleys if we were to obtain adequate transport at the incremental stepping speeds (record mode) and during playback speeds of about 5 cm/sec. we found further that all rotating pulleys had to be crowned to assure proper pulley tracking of the tape. In the process of carrying out this development about 3,000,000 increments were stepped.

Critical tolerances between transport pulleys, between-head tape guide and the drive capstan were established and frozen. These were evaluated during a 500,000-step observation period.

Figure 3-18 shows the base of the recorder, the dive pawl on the left and the cam-adjustable detent pawl at the upper right.

Figure 3-19 illustrates the topside of the unit. The two compound angled pulleys are in the foreground. The tape snubbers can be seen at the heads.

Figure 3-20 illustrates the unit within its aluminum enclosure.

The total weight of the unit, fully loaded, is about 110 grams. More than 5×10^6 operations of the unit have produced no signs of wear in any of the drive mechanism components.

3.3.2 Electrical Design and Special Test Gear

The drive motor used in the recorder is the electromagnetic element from a subminiature Couch relay. Approximately 6 volts is applied for 20×10^{-3} seconds to operate the motor and move the tape. On the bench, this drive signal is produced by a special test circuit pulsing at 2 hertz.

A playback drive rig was arranged from a surplus tape unit drive. The subminiature unit is designed so that it will lock, precisely into position, on the playback drive. In this condition, the recorder is plugged into a high-gain amplifier system for interfacing with the PACER 100 computer. The amplifier has a designed input threshold of 60 µv and produces an output of 5 volts (low Z) when a pulse is persent (see Figure 3-21).

Preliminary playback runs showed serious variability in output levels and led to the redesign of our pre-polarization jigs and the addition of pressure snubbers for the tape. These changes produced the desired improvements and stable playback (min. of 200 µv, p-p) was obtained on all channels.

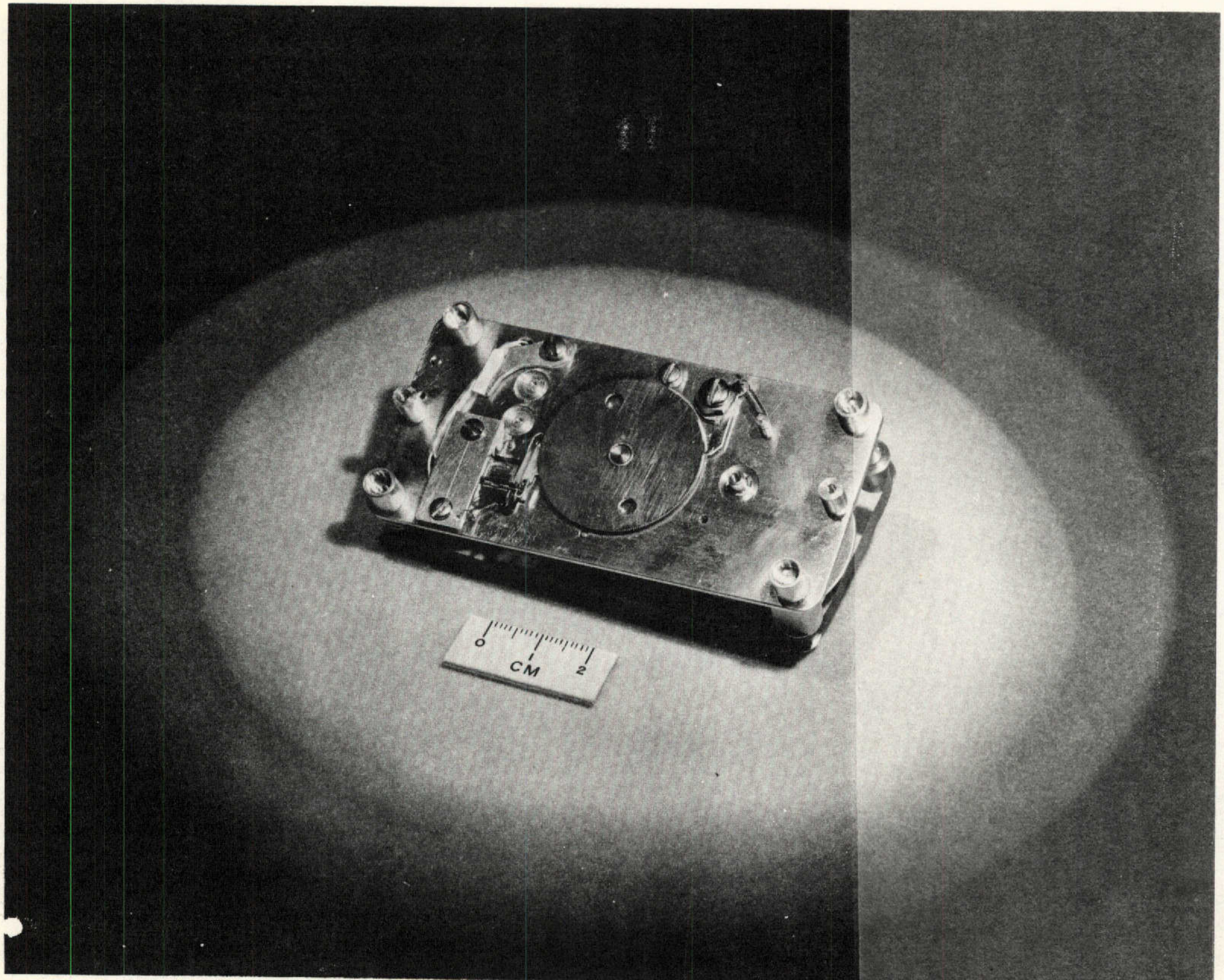
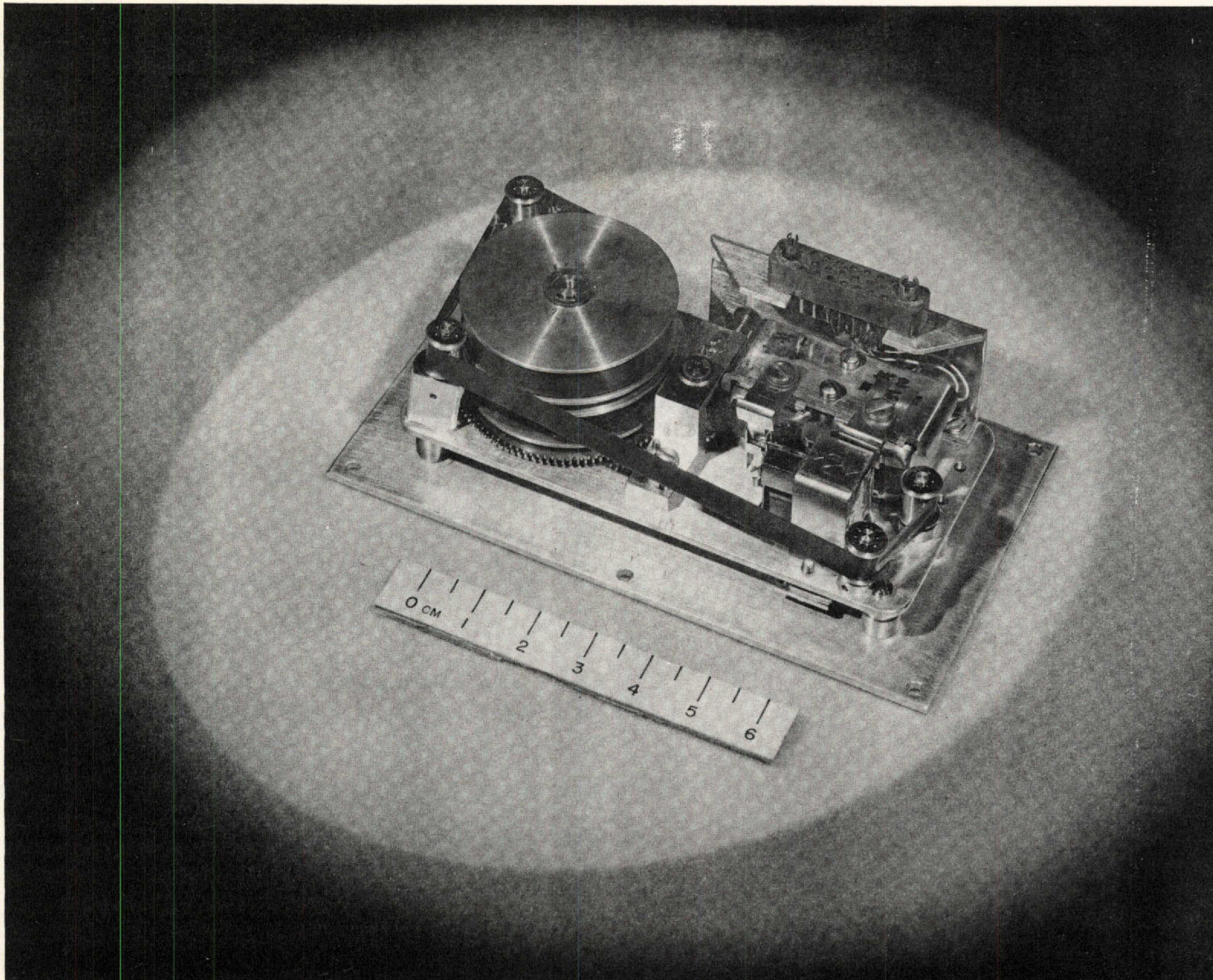


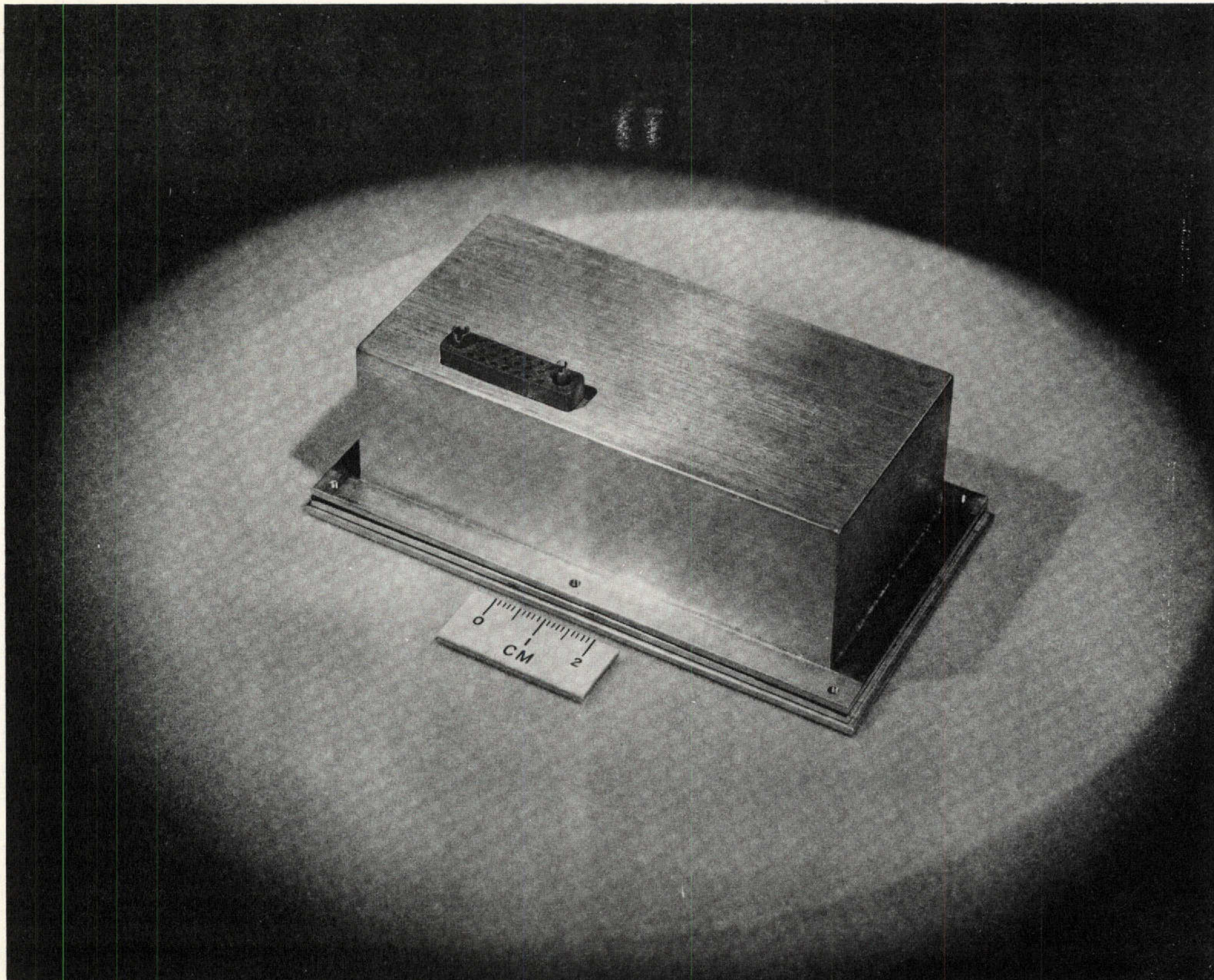
Figure 3-18. Recorder - Bottom View

F-C3748



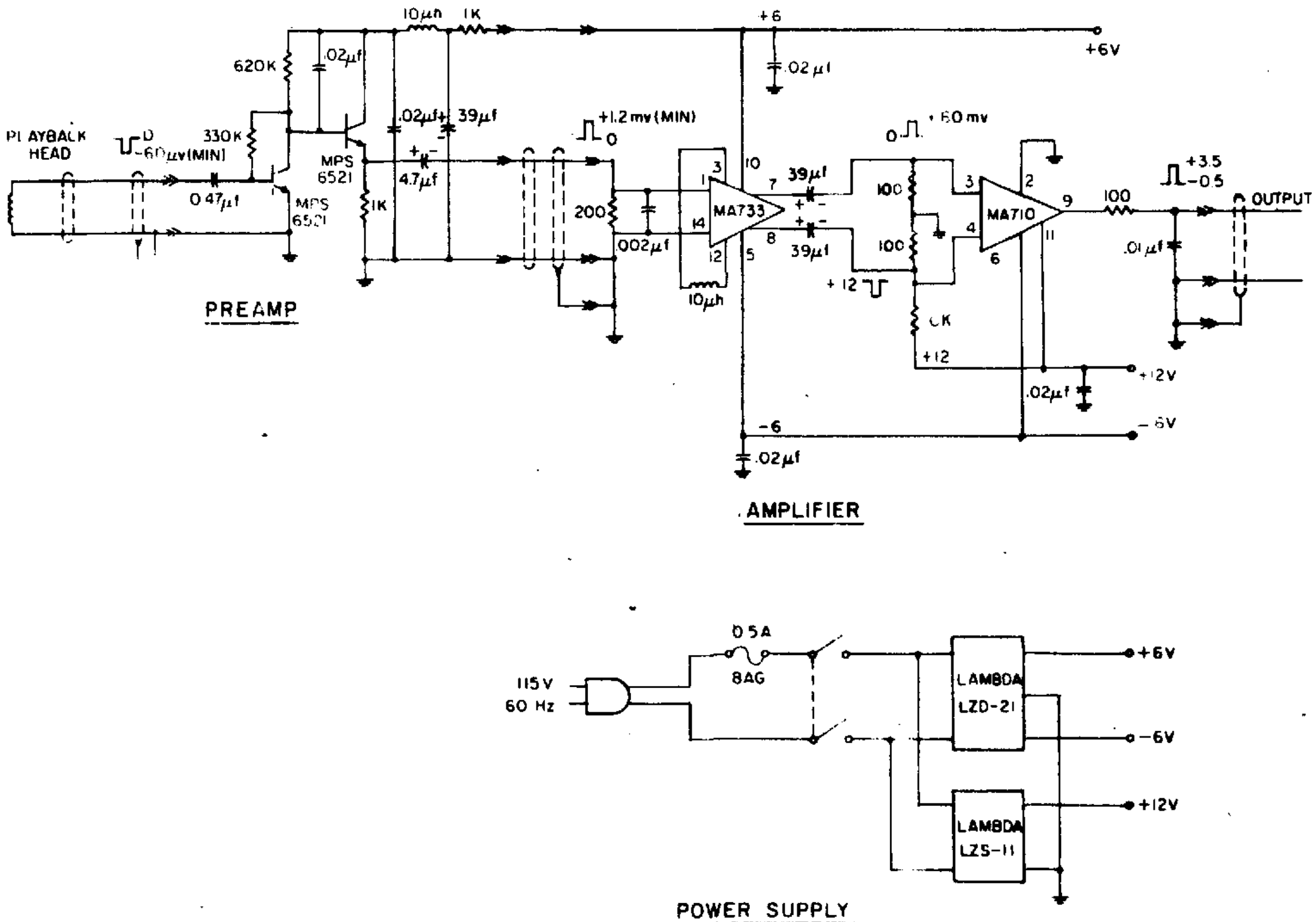
F-C3748

Figure 3-19. Recorder - Top View



F-C3748

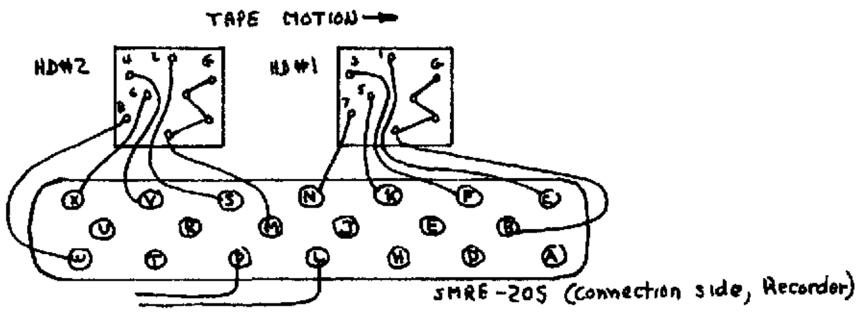
Figure 3-20. Recorder in Enclosure



F-C3748

Figure 3-21. Playback Amplifier

Wiring from the tape heads and electromagnetic drive motor feeds a single, multipin connector mounted on the recorder. These wires are soldered to the connector and are friction-connected to the heads using berrylium copper, gold-plated, spring connectors supplied by the head manufacturer. Wiring is indicated in Figure 3-22 below.



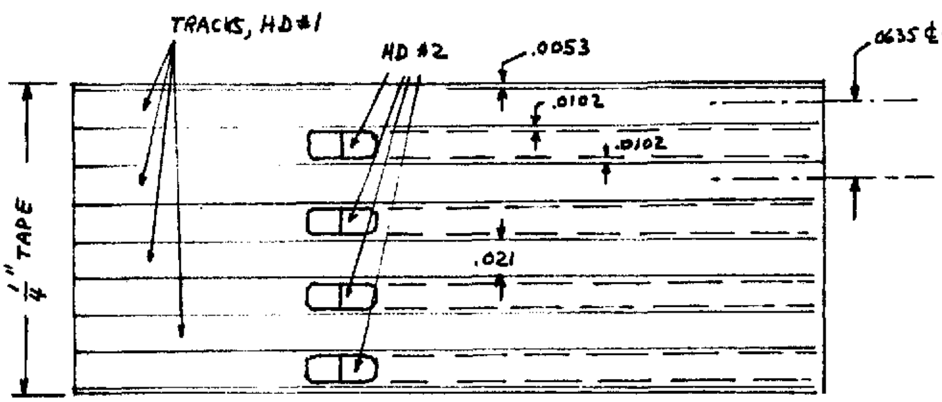
Pin	Function
A	(NC)
B	Ground
C	Channel - 1
D	(NC)
E	(NC)
F	Channel - 3
H	(NC)
J	(NC)
K	Channel - 5
L	Motor
M	Ground
N	Channel - 7
P	Motor
R	(NC)
S	Channel - 2
T	(NC)
U	(NC)
V	Channel - 4
W	Channel - 6
X	Channel - 8

Figure 3-22. Tape Recorder Wiring

3.3.3 Test Procedures

Testing of the tape recorder can best be done using a computer. In laying out a procedure, it is necessary to evaluate both correct playback of data encoded *and* the absence or presence of cross-talk between tape tracks. Such cross-talk is possible if the mechanical relationships between heads are not properly set to permit optimum interlacing of two groups of four tracks each.

Optimal interlacing is shown in the sketch below.



TAPE HEAD INTERLACING

Simple test patterns were evolved to check all tracks and to slow up cross-talk if it existed. These patterns appear below as Figure 3-23.

	Channel or Track							
Word Number	1	2	3	4	5	6	7	8
1	0	1	0	1	0	1	0	1
2	1	0	1	0	1	0	1	1
3	0	1	1	0	1	1	0	1
4	1	1	0	1	1	0	1	1
5	1	0	1	1	0	1	1	1

Figure 3-23. Recorder Test Patterns

The test pattern (word) circuits were designed to record 8192 prints of each word and then to step to the next word. Thus, a total of 40,960 words will be recorded for each complete evaluation pattern. Each channel is repeatedly checked and bits are simultaneously written on all adjacent channels to check for cross talk.

3.4 MECHANICAL DESIGN

A crude sketch was made of an instrument pod which was then studied by the life scientists of the team. They modified the general configuration to what appeared to them acceptable for mounting on a juvenile gray whale. In this manner, a start was made on the instrument pod design.

3.4.1 The Instrument Pod

Based on our estimates of component, recorder and battery volume--coupled with the crude outlines of a pod acceptable to the life scientist members of the team, a fiberglass unit has been designed. The development of that unit is illustrated in Figure 3-24.

From that development drawing, we constructed a male mold on which to form the pod. See Figure 3-25 showing the mold. The mold was made of pine sections, each cut to approximate shape (from the development drawings) and then glued together and smoothed.

The mold was mounted on a baseboard with a 19 in. (48.3 cm) radius (taken from the UCSC whale model) and then covered with a thin layer of paraffin. A fiberglass pod was then built up on the mold by sequencing a layer of resin, followed by fiberglass cloth soaked with resin, followed by a layer of resin, etc. Initially, the pods were made up of three such cloth rovings. Upon completion of cure, the pods were removed from the mold, trimmed, drilled for bolt-holes to the baseplate and drilled for transducer apertures and mounts.

After pressure tests in water (See Section 3.4.4) the pods were remade using five rovings of fiberglass cloth.

Finished pods are shown in Figure 3-26.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

F-C3748

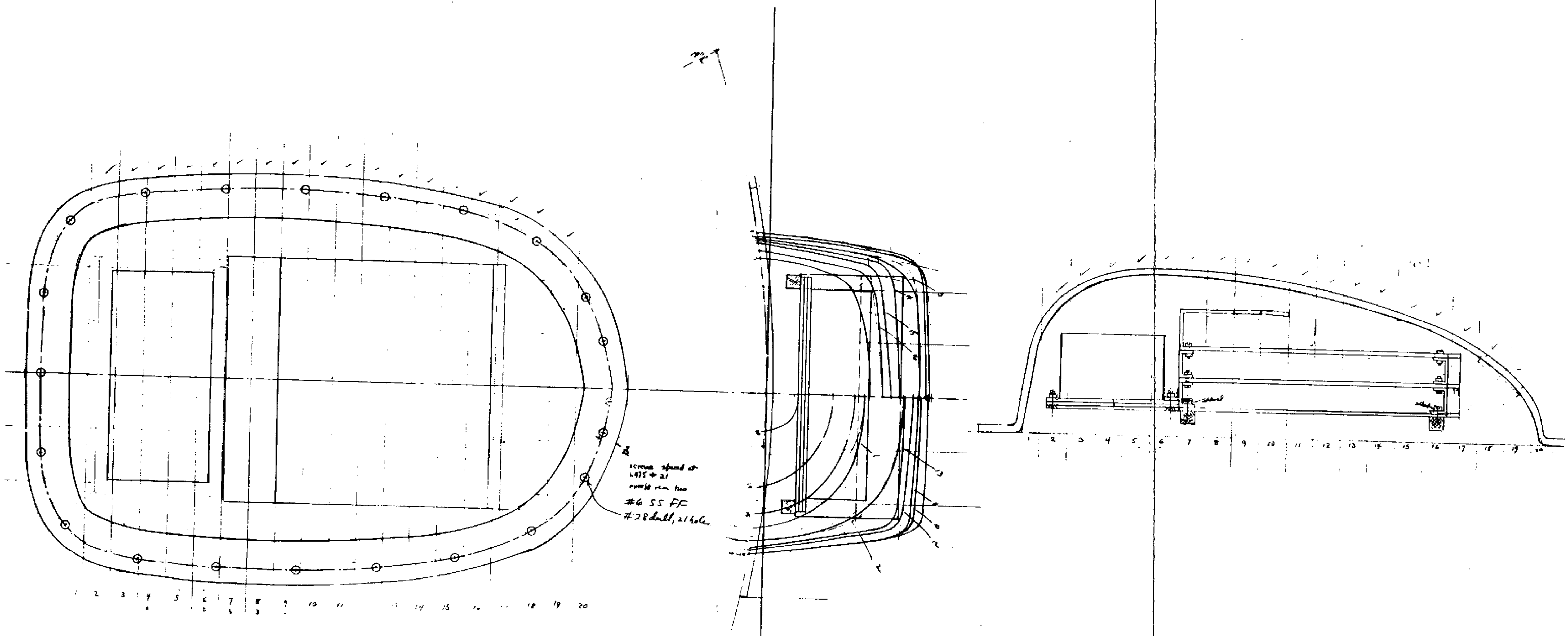


Figure 3-24. Pod Development

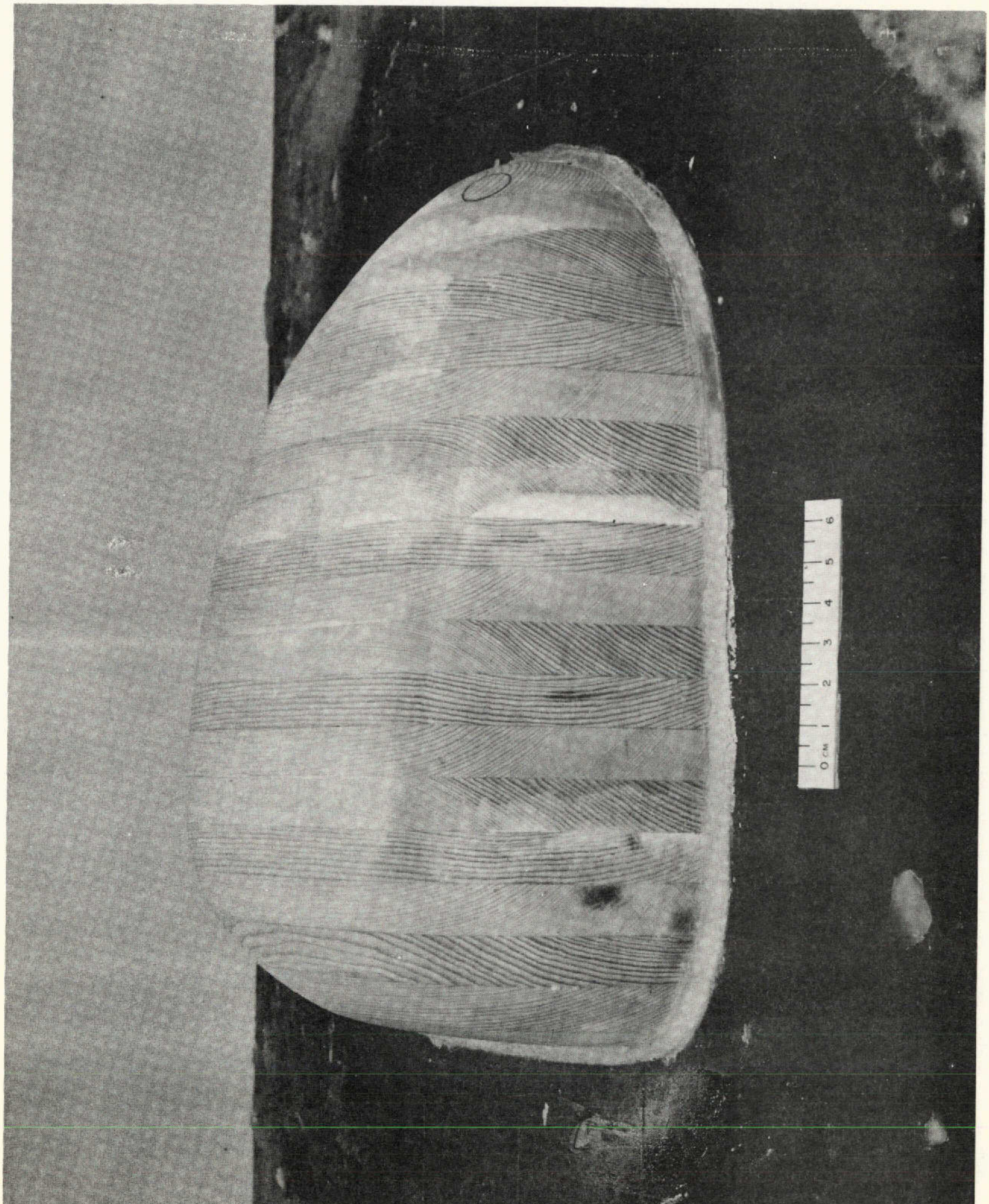


Figure 3-25. Mold for Fiberglass Pod

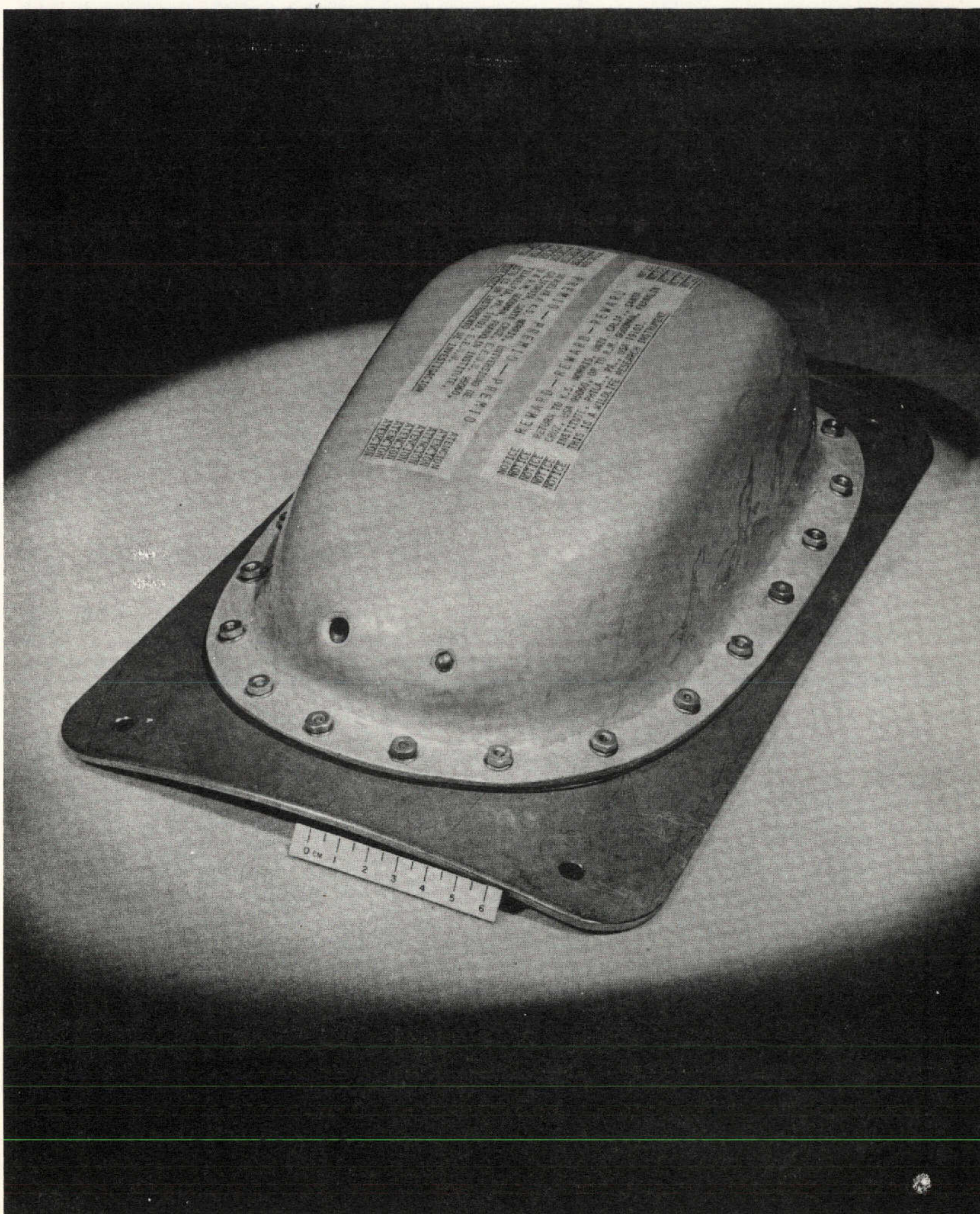


Figure 3-26. Finished Pod

3.4.2 Internal Instrument Support

In order to further strengthen the pod itself, by use of internal support material and to provide a "floating", shock-proof support for the instrument package a polyurethane syntactic foam was used.

An exact mockup of the instrument package was fabricated, coated with a release agent, and suspended in its precise position within the pod. Then Emerson and Cuming polyurethane foam, type Eccofoam VIP was poured in place. After a 72-hour cure cycle the instrument mockup was removed and the pod appeared as shown in Figure 3-27.

This foam has a density of about 37 $lbs/ft.^3$. It has a closed cell structure, low moisture absorbance and is flexible and compressible.

3.4.3 The Baseplate

The first baseplate used in the design was fabricated from .097 in. half-hard aluminum. Physical dimensions were checked with personnel working on the harness to which it was to be attached. Through close liaison these dimensions were "frozen" satisfactorily.

Double gaskets of .015 in. Vellumoid were fabricated for placement between the baseplate and the pod. At sealing, each gasket surface was to be covered with Permatex No. 2, a non-hardening, pliable sealant--soluble only in alcohol.

Subsequent to our first set of pressure tests, the baseplate was modified to 0.125 in. type 304 stainless steel.

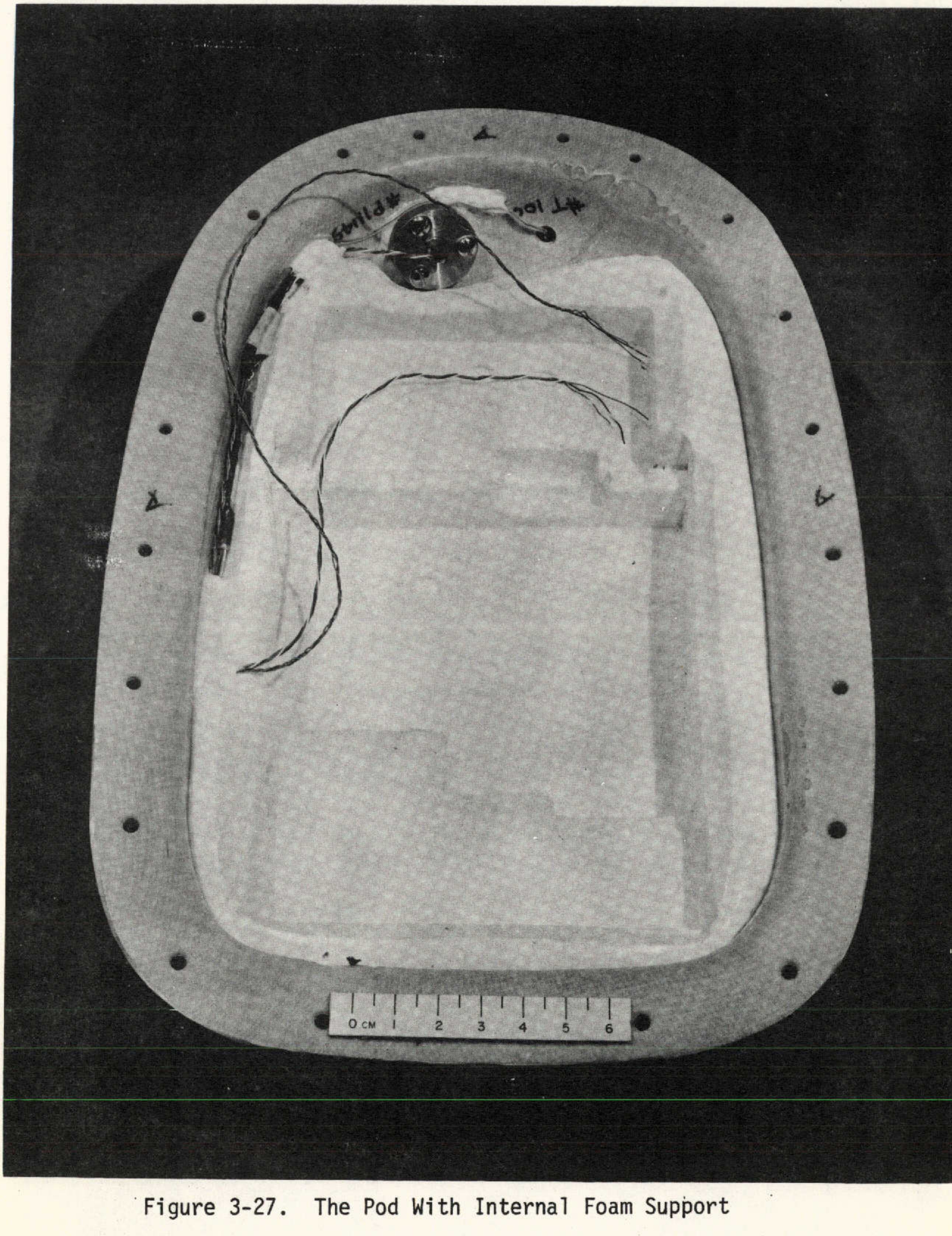


Figure 3-27. The Pod With Internal Foam Support

3.4.4 Pressure Evaluation Tests

Arrangements were made at FIRL to place our pods, suitably sealed to their baseplates (.097 in. aluminum) in water tanks which were then placed in a pressure vessel. Each pod was loaded with a cobalt chloride moisture sensor.

The pressure transmitted to the pods were increased from atmospheric (0 - psig) to 50 psig--equivalent to about 100 feet of water. This pressure was almost 300% than anticipated in the lagoon. Pressure was held for about an hour and then brought back to normal over a 20-minute period.

On opening the chamber, it was seen that the pod seal was breached as caused by the buckling of the aluminum baseplate. Figures 3-28 and 3-29 show the damage sustained by the complete mechanical system and by the pod itself, respectively.

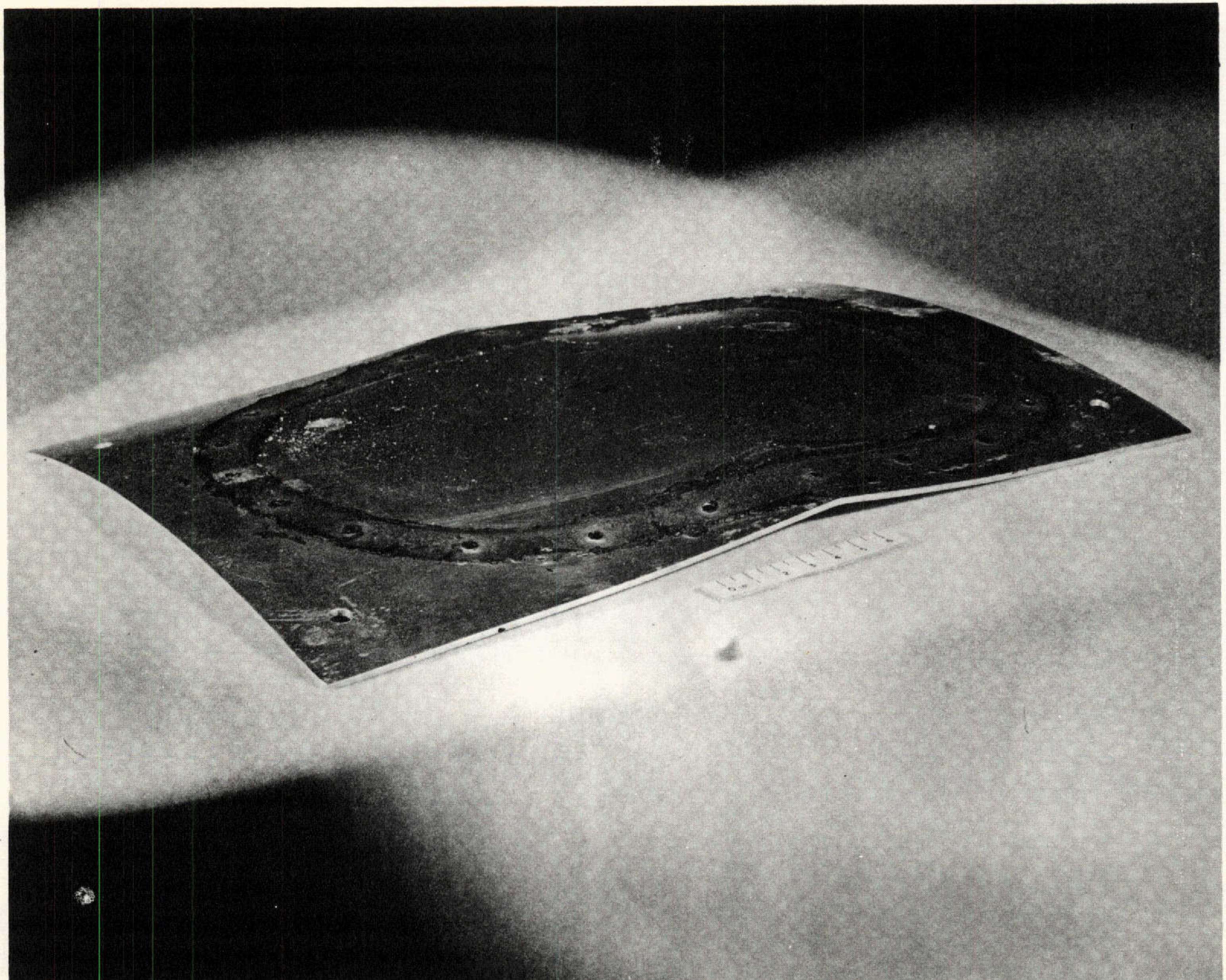
It was recognized that the pressure/depth conditions to which we had subjected the pod was far in excess of what was anticipated; we decided to do three things:

a. Beef up the pod itself from 3 to 5 rovings as a way to acquire far greater strength at a low cost in weight.

b. Go to .125 in. stainless for the baseplate--a material which would be useful in subsequent longer term studies anyway.

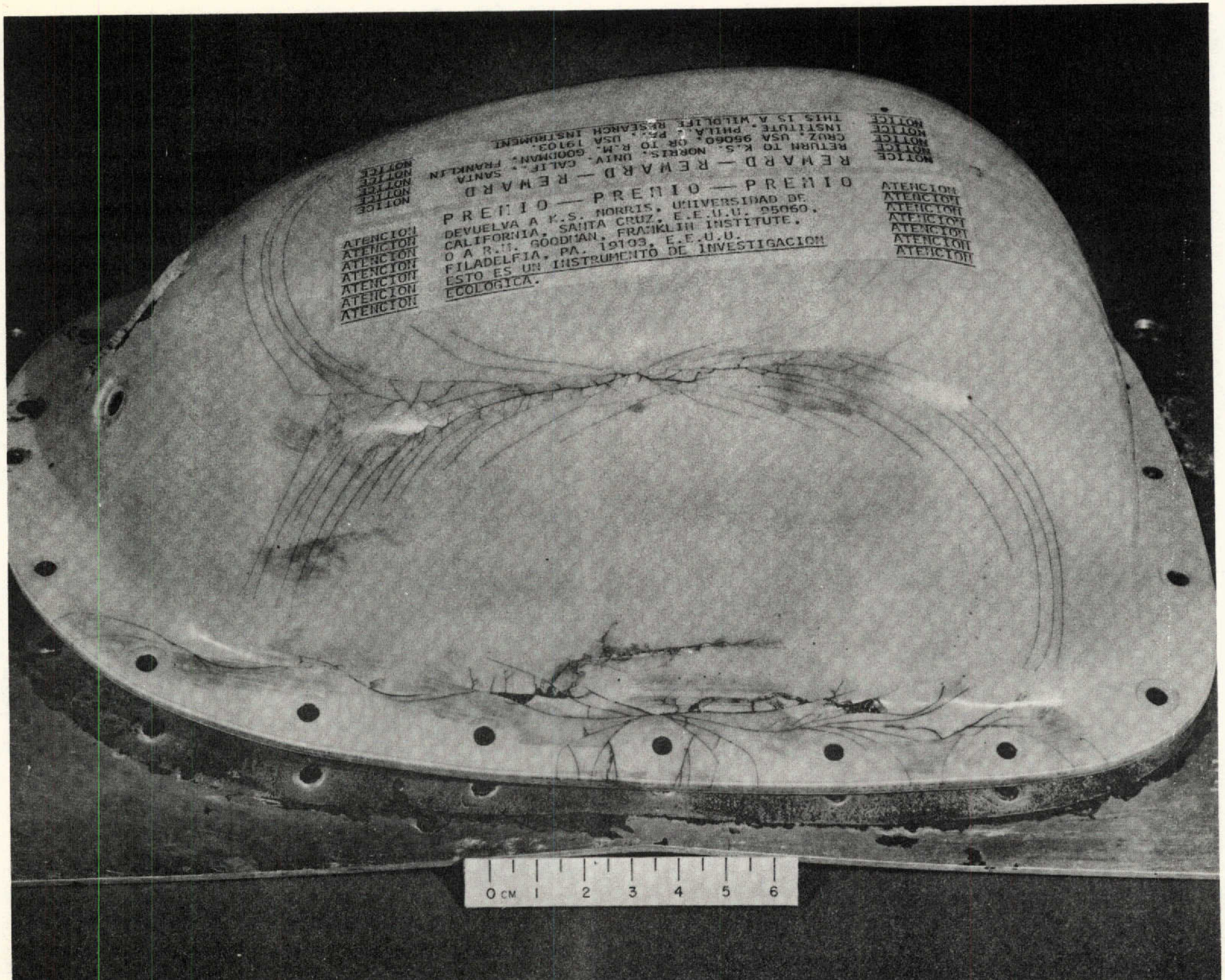
c. With new pods an baseplates rerun pressure tests at the equivalent of 72 feet of water--or twice (200%) the anticipated depth.

This was done and the tests were totally successful.



F-C3748

Figure 3-28. Buckled Baseplate (Aluminum)



F-C3748

Figure 3-29. Pod Damage Caused by Baseplate

3.4.5 Instrumentation Weights

Stainless steel baseplate		1792 g
Pod with foam and transducers		891 g
*Instrument package		746 g
	Total	3429 g

In sum, the total package with a weight of 3,429 grams proved to have a buoyancy of (-)1 kg. This negative buoyancy datum was transmitted to the men working on the harness and flotation gear for inclusion in their considerations.

*The instrument package *includes* all circuitry and controls as well as 185 g of mercuric oxide batteries.

4. CONCLUSIONS

Liaison between our two centers of effort, FIRL and UCSC, has been excellent.

There appears to be no question but that the gear will be completed in time for the expedition to start late next month.