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OCEAN ENGINEERING SUMMER LABORATORY

SUMMER 1973

Massachusetts Institute of Technology
and
Maine Maritime Academy
Prepared by students under the supervision of
Professor A. Douglas Carmichael - MIT
Professor David B. Wyman - MMA

Massachusetts Institute of Technology

Cambridge, Massachusetts 02139

Report No. MITSG 74-12
February 15, 1974

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ADMINISTRATIVE STATEMENT

A fundamental educational experience for undergraduate students of Ocean Engineering is the opportunity to design, build, and operate equipment in the ocean environment in an attempt to solve real world problems. This is the primary objective of the Summer Ocean Engineering Laboratory and is a joint effort by students and faculty of the Massachusetts Institute of Technology and the Maine Maritime Academy.

Ira Dyer, Director
M.I.T. Sea Grant Program

ACKNOWLEDGEMENTS

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The individuals who donated their time to the projects without compensation include:

Mr. Herman Kunz	Searle Consultants
Professor Dean Mayhew	Maine Maritime Academy
CAPT. Willard F. Searle, USN (Ret)	Searle Consultants

Miss Anita Harris kindly permitted the use of her dock and properties on Holbrook Island for some of the oceanographic experiments, for which we are very grateful.

It would be difficult to mention all the faculty, staff, and students at M.I.T. and the Maine Maritime Academy who have helped to make the 1973 Summer Laboratory a success. However, Glen Keller, who was the project leader for the radio ranging device, is grateful to Ralph Burgess at M.I.T. for his advice and guidance in the design of that project, and Brye Davis, who designed and built a current direction meter, would like to thank Skip Withrow, an undergraduate at M.I.T. for the help in the design of his electronic circuitry.

We are all grateful for the tolerance, understanding, and help of the administration, faculty, and staff of the Maine Maritime Academy during the month of July when the Summer Laboratory activity was at its peak.

LIST OF PARTICIPANTS

Massachusetts Institute of Technology	Maine Maritime Academy
Undergraduates:	
Gillian Carmichael	Kenneth Borneman
Craig Christensen	Patrick Dolland
N. Brye Davis	Mark Goughan
Tom Jacobs (part time)	Neal King
Stuart Jessup	Steven Lobley
Lawrence Kahn	William Orr
Glen Keller	John Sautter
Michael Kennedy	Roy Schepens
Carl Lacy	Michael Seavey
William Letendre	David Tothill
James Radochia	Jeff Wadman
Leonard Schneeman	Peter Wells
James Walton	
Graduates:	
Harry Kettel	
Yitshak Peery) part time	
Jan Willums) part time	
Walter Lincoln) part time	
Roger Wells (fall and spring terms)	
Faculty and Staff:	
A. Douglas Carmichael	David B. Wyman
Albert M. Bradley	Donald A. Small

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SUMMARY

The third Ocean Engineering Summer Laboratory has been successfully completed and is reported here. The descriptions of the various projects undertaken by the students are presented as chapters of this report. The projects are loosely grouped as oceanographic instrumentation experiments in the first twelve chapters and ocean engineering experiments in the final seven chapters of this report. It is difficult to single out any project as being more significant than any other, but it is worth noting that the "Constant Depth Tracking Buoy," described in Chapters 1 and 2, shows promise of being a useful oceanographic instrument for shallow water current measurements.

The survey of the wreck of the revolutionary warship "Defence" and the recovery of artifacts continues successfully, and is described in Chapter 18.

PROJECT SUMMARIES

No.	Title	Student Participants	Summary
1	The Prototype Constant Depth Tracking Float	Roger Wells Harry Kettel Yitshak Peery	A device has been designed, built, and tested which can be used to define streamlines in the ocean.
2	The Constant Depth Tracking Buoy, Mark II	Craig Christensen	An improved mechanical and control design of the Prototype Buoy was designed and built.
3	The Sonar Current Meter	William Letendre	A current meter using three hydrophones was designed and tested.

No.	Title	Student Participants	Summary
4	The Magnetohydrodynamic Current Meter	Leonard Schneeman	Two current meters based on MHD principles were built and tested.
5	The Underwater Current Direction Meter	N. Brye Davis	An instrument for measuring and recording the direction of ocean currents was designed and tested.
6	Recording Tide and Wave Height Gauges	James Radochia	A simple design of tide height gauge was developed using the electrical properties of the ocean. A wave height gauge using similar principles was also built.
7	A Pneumatic Tide Height Indicator	Roy Schepens	A pneumatic principle has been utilized to provide a portable tide height gauge.
8	A Mechanical Tide Height Indicator	Kenneth Borneman Patrick Dolland	A mechanical system for indicating tide height was built and tested.
9	A Seawater Temperature Survey of Holbrook Cove	Neal King David Tothill	Seawater temperatures were measured with a reversing thermometer and a thermistor at several depths.

No.	Title	Student Participants	Summary
10	A Radio Ranging Device	Glen Keller Carl Lacy James Walton	A sensitive method of determining range using radio transmitters and receivers has been developed.
11	A Gradiometer Magnetometer	Gillian Carmichael	A proton gradiometer magnetometer for detecting magnetic anomalies was designed and built.
12	A Power Tool for Divers	Lawrence Kahn	A power tool using seawater as the working fluid was used by divers for drilling metals.
13	An Experimental Ocean Mining System	Tom Jacobs Stuart Jessup Jan Willums	A model of a novel system for deep ocean mining was built and tested at the wreck of the Defence.
14	The Air Lift Dredge	William Parker John Sautter	An air lift system was built and used to excavate the cook stove area of the Defence.
15	Tidal Current Power Generator	Mark Goughan	A propeller-type tidal current generator was built and tested.
16	The Floating Breakwater	Jeff Wadman Peter Wells	A floating breakwater using inner tubes of truck tires was designed and tested.

No.	Title	Student Participants	Summary
17	A Lightweight Diving Ladder	Steven Lobley Michael Seavey	A diving ladder was constructed from PVC components.
18	Archaeological Work on the Defence		The survey and recovery of artifacts from the Defence was continued.
19	Small Boat Safety Study	William Hunt Michael Kennedy William Orr N. Brye Davis Lawrence Kahn	An investigation was carried out of the handling characteristics of a Jon Boat.

PREFACE

A fundamental educational experience for undergraduate students of Ocean Engineering is the opportunity to design, build, and operate equipment in the ocean environment in an attempt to solve real world problems. This is the primary objective of the Summer Ocean Engineering Laboratory.

The nineteen chapters of this report summarize the activities and accomplishments of the various experimental studies which were completed as part of the third Ocean Engineering Summer Laboratory. The chapters are the reports of the participants with the minimum of editorial changes and such modifications have only been made for the sake of uniformity. However, these reports do not convey the whole engineering experience. In particular, the joint activities are hardly mentioned. These joint activities are therefore described in this preface.

The 1973 Summer Laboratory was the third experience where students and faculty from M.I.T. and Maine Maritime Academy worked alongside each other to carry out engineering experiments in the ocean at Castine, Maine.

The M.I.T. students in many cases had planned and worked for the whole academic year on their projects. However, because of commitments and constraints during term time, much of the work was accomplished during the month of June, before traveling to Castine on July 1.

The students of the Maine Maritime Academy, on the other hand, spent the months of May and June on their summer cruise with no opportunity for serious work on their project. However, during the spring term the "PANTHALASS" was constructed to serve as an oceanographic and diving support boat. This boat, based on a lobster boat form, was very successful and proved to be invaluable for the longer trips such as to the wreck of the "Defence" and also the diving expeditions.

During the month of July at Castine the students not only carried out their own experiments but they were also expected to contribute to the joint projects, such as some of the larger experiments and the diving program. Two experiments required participation in addition to the students responsible for the experiment. The ocean mining experiment described in Chapter 13 of this report involved nearly every member of the group at one time or another. The device was large, cumbersome and not quite watertight. As a result of these shortcomings it had to be beached on more than one occasion: a task that required every available hand. The small boat safety study described in Chapter 19 of this report also collected a number of volunteers, advisors, and onlookers. The film making process for this experiment involved cameramen, small boat operators, safety personnel, and the director of the experiment.

THE DIVING PROGRAM

More than half the students participating in the Summer Laboratory were qualified scuba-divers. In order to improve their diving skill and also to indicate the role of diving in ocean engineering, the diving program was organized around the archaeological survey and salvage of the wreck of the revolutionary warship, the "Defence". The archaeological investigation is described in Chapter 18. The wreck was discovered by participants in the Summer Laboratory during the previous summer, 1972. The diving and salvage program was supervised by Captain Willard F. Searle, U.S.N. (Ret.), and Lcdr. Herman Kunz, U.S.N. (Ret.); whom once again contributed much to the Summer Laboratory. The safety officer for the diving program was Professor Edgar Biggie of the Maine Maritime Academy, and Professor Dean Mayhew of the Maine Maritime Academy again contributed to the historical and archaeological research for the wreck study.

The diving program was conducted on every day of the final three weeks of the project, that the weather permitted. Students who participated in the diving program could dive on one day in three, if they wished. The other days could be spent on their own project work or on other joint efforts.

The "Panthalass" was used on all the main diving expeditions. She was commanded on alternate days by Professors David Wyman and Donald Small of the Maine Maritime Academy.

OTHER ACTIVITIES

In addition to the experimental projects and the diving program, evening seminar meetings were held to discuss the experimental program; the meetings ended with one or more movies on ocean engineering and related topics, which were kindly organized by Captain Searle.

1. THE PROTOTYPE CONSTANT DEPTH TRACKING BUOY

1.1 INTRODUCTION

As part of the Ocean Engineering Department Summer Laboratory held during July 1972 in Castine, Maine, one of the projects undertaken was to measure the tidal currents in a small (approximately 1 mile across) body of water known as Holbrook Cove. This was felt to be of interest because of the presence of a mining corporation's operation near the southern edge of the cove. A northern entrance and a sandbar which was uncovered during half the tide cycle as well as a centrally located island made conjectures as to what might happen to an effluent difficult.

An experiment was designed to measure these currents using a drogue buoy. The buoy consisted of a large cross made of plywood approximately 2' x 4' held underwater by weights to a preselected depth and a small surface marker which was then tracked visually using shore based transit stations.

It was discovered that in all but extremely calm conditions the current due to wind drag on the water surface caused the buoy to drift with the wind and consequently all measurements were restricted to times when the wind was less than one or two knots. This period of calm usually occurred during the morning hours, before 9:00 a.m.

It became apparent that in order to measure currents in this manner i.e., using the Lagrangian method as opposed to Eulerian sensors which measure the flow of water past a fixed point - that some method which presented no surface penetration was necessary.

The justification for measuring currents in this manner is clear. Many applications of measured current data provide input to answer the question of where a pollutant will go when it is discharged into a river, coastal area, lake, estuary or harbor. A very good way to determine this is to follow a particle of water starting at different times during the basic current cycle. The other apparent use is to track ocean currents over large distances such as the Gulf Stream.

The two problems present requirements for quite different instruments. Although the basic principle - to track a buoy which is maintaining a constant depth or isopyknal - is the same, the approach to design is very different. The deep ocean instrument must operate in thousands of meters of water for weeks or months at a time while the river, harbor or estuary design must keep its depth at about ten feet for much shorter periods.

The swallow float developed by J. C. Swallow at the British National Institute of Oceanography in the mid-fifties tracks currents in the deep ocean. The method of depth keeping relies on the buoy being less compressible than water and therefore as the buoy goes deeper it reaches a point where the water becomes more dense than the buoy depending on the ballast which is carried and it remains at the depth of that isopyknal. Thus, the only power required is for the acoustic pinger which is used for tracking. While great improvements have been made recently the original experiments indicate that the intended depth could not be predicted with an accuracy better than 500 meters. Therefore a method of depth keeping within one or two feet of an intended depth must be developed for estuarine and other shallow water work. This is the problem which this development addresses.

1.2 DESIGN SPECIFICATION AND EVALUATION

The specific problem to be solved with this instrument is that of tracking the currents through Holbrook Cove in Castine, Maine. In a broader sense there exists a need for such an instrument in general current surveys conducted in coastal or estuarine areas.

The design working depth must be equal to the largest significant depth over which the buoy is expected to operate. In the Holbrook Cove area this is approximately twenty-five feet. In addition, it must be able to recover from the deepest hole within the cove if an unexpected vertical current should cause it to drift down into such a hole. This depth is approximately fifty feet.

Recovery of the buoy is another important consideration and it should include a "fail safe" system to allow recovery in case of power failure.

Sonar is used to track the buoy. Originally two frequencies were proposed to be used to fix the position. This required the buoy to be a receiving station as well as a transmitter. One shore station was both active and passive while the second was a passive testing station.

This system was abandoned in favor of another permitting use of one frequency which will allow the electronics in the buoy to be greatly simplified with a consequent increase in reliability. Another factor which prompted the changeover was the desire to use readily available and inexpensive government surplus transducers; these are piezoelectric barium titanate crystals.

The principle of operation of this system requires the measurement of the buoy position in absolute time. The buoy is an acoustic pinger which transmits a 10 ms tone burst at 8kHz once each second. Measurement of the time of the arrival of this tone burst at each of two listening stations at known locations fixes the position of the buoy. This system requires knowledge of when the tone leaves the buoy in order to measure its travel time.

Therefore a stable crystal oscillator is used in the buoy to accurately generate the one second time interval. The recording is made on a wet paper recorder which has a sweep rate also controlled by a crystal oscillator such that the tone leaving the buoy will occur at the same point in the sweep of the recorder. In practice the buoy is placed at a known distance from the listening hydrophones and the sweep of the recorder is adjusted until the plot of the received pulse occurs at a distance from the bottom of the paper which corresponds to the known distance.

1.3 THE DESIGN, MANUFACTURE AND INITIAL TESTING OF THE CONSTANT PRESSURE SYSTEM

In specifying materials for the construction of the pressure case of buoy, maximum consideration was given to the use of materials which were available in the Ocean Engineering Laboratory. There was available 4-inch polyvinyl chloride schedule 40 pipe. This is rated at a working pressure of 220 psi and has a wall thickness of approximately 0.3 inches which allowed convenient machining in a lathe in order to cut seats for seals. The inside diameter of over 3.5 inches allowed room for chassis construction with 6 volt heavy duty primary batteries mounted. These batteries provide 2.7 ampere-hour capacity and represent the largest readily available source of power and are the primary power source for the volume change mechanism within the buoy.

1.3.1 Volume Change Mechanism

Experiments were conducted to test the feasibility of using a moving piston to change the volume of the buoy approximately one cubic inch either side of neutral buoyancy. Assuming a drag coefficient of unity indicates sufficient buoyancy to provide a 1.7 in/sec vertical velocity.

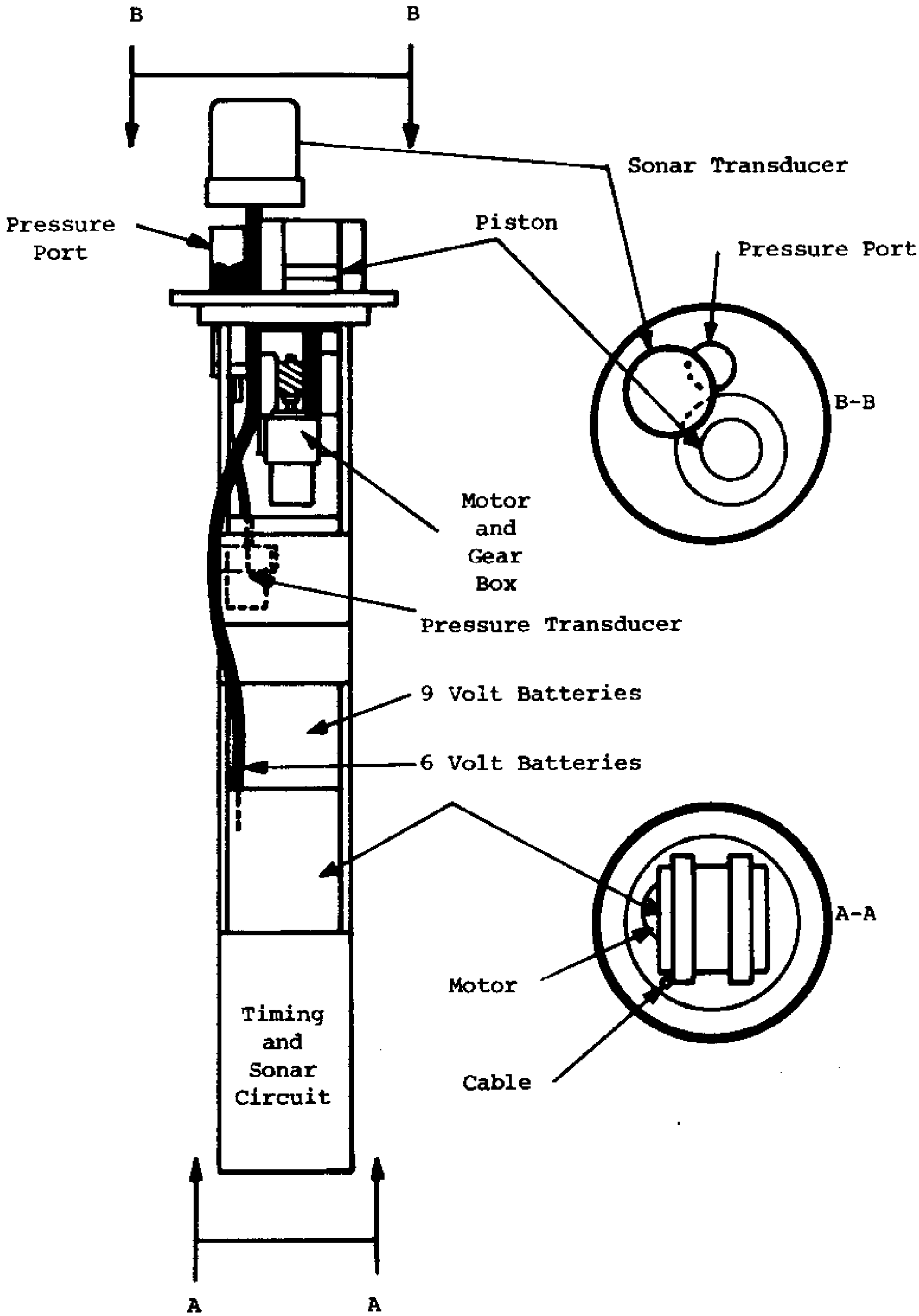


FIGURE 1.1 Layout of Buoy

Tests were made using an aluminum piston sealed with first two and then one O-ring seals running in a PVC cylinder. Results indicated that the breakaway friction associated with two O-ring seals was prohibitively high. Approximately ten pounds force was required to start the piston from rest. While the one-ring piston required about half that value.

The use of metal bellows was examined. This offered the possibility of obtaining the volume change with no dynamic seals and of canceling out the static pressure head with the spring constant of the bellows. Several companies which manufacture metal bellows were consulted. All such products were very expensive and thus a moving piston was selected for the prototype model. The arrangement was designed with the consideration of being able to convert from a piston to a bellows at a later date should the piston prove unsatisfactory, Figure 1.1. A metal bellows was used in the second tracking buoy described in section 2.

In order to move the piston a gear box consisting of a rack and pinion driven by a worm and wormwheel was designed and constructed. The worm and wormwheel were selected because power and movement cannot be transmitted from the wormwheel to the worm gear and the system thus provides its own locking in position when the motor stops.

The total reduction provides for one inch/sec rack speed with a motor speed of 6,500 RPM. The first motor ran at approximately that speed but another higher quality motor providing 85% efficiency and approximately 1,000 RPM output from a built-in gear head has been obtained. This motor provides near 50 pounds force at the piston if necessary.

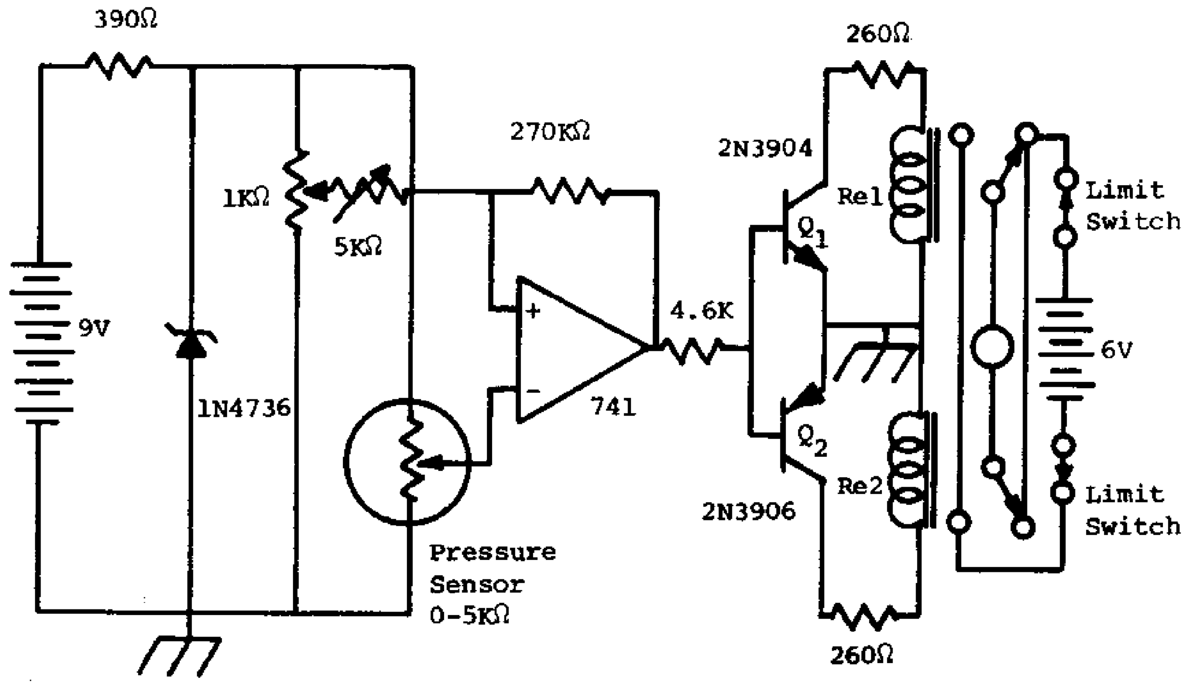


FIGURE 1.2 The Prototype Buoy Control Circuit

1.3.2 Pressure Sensing

A pressure sensing transistor (Pitran) was available in the Ocean Engineering Laboratory and a circuit was built to employ this device as the depth sensing unit.

The device was found to be very sensitive to temperature to the point where the device was unusable. A check with the manufacturer revealed that they considered this an unsuitable use for the device as no known way to compensate for large temperature changes over long periods of time exists. Thus a new device which varies a resistance linearly from 0-5000 ohms with 0-25 psig was purchased. This device has effectively no temperature dependence between -20 and +150°F is $\pm$ 0.5% of full scale value linear, 0.1% FSV repeatable and 0.5% FSV hysteresis. The 0.5% hysteresis corresponds to 3.375 inches in seawater and it is this which limits the band in which the buoy operates in practice. The control circuit is presented in Figure 1.2.

The remainder of the control circuit consists of an operational amplifier used in a Schmitt Trigger circuit which turns on either Q_1, Q_2 transistors which in turn operate relays Re_1 or Re_2. Control R_1 sets the depth at which the buoy is to operate, R_2 determines how far on either side of this dead band the piston operates. The output from the pressure sensing circuit is applied to the inverting (-) input of the op-amp. The relays turn on the motor to move the piston in the appropriate direction and microswitches, operated by an extension from the rackgear in the volume change mechanism, turn the relays off. The relays are wired so that when the microswitches turn them off they short circuit the motor winding thus stopping the motor quickly.

Power is supplied to the control circuit and the motor through one 6VDC battery and 2 9VDC batteries. The 6VDC battery provides power to run the electric motor only. The 9VDC plus and minus supply voltages provide current for the op-amp and associated circuitry, the relays, the pressure sensing circuit and ultimately the sonar system to be described later.

The 6VDC supply provides approximately 500 ma at 30 second intervals. With 2.7 ampere-hours available approximately 80 hours of operation should be possible.

The other batteries are arranged in a $\pm$ 9VDC configuration. They supply power to the control circuit, quartz timer and associated gating logic, pinger oscillator and pinger amplifier. The average current requirement for these is approximately 5 ma. With .38 ampere-hours available per battery in excess of 70 hours should be possible.

1.3.3 Pressure Case Design

The body of the pressure case was constructed of four-inch PVC schedule 40 pipe, 22 inches long. The end caps were cut from one inch slices of six inch aluminum round stock. The piston was made to have one square inch cross sectional area and was cut from 1½ inch aluminum round stock. The cylinder was made from 3 inch clear acrylic plastic which was available in the laboratory and press fitted to the end cap with an O-ring seal. O-ring seals were also used in both end caps and in three of the six joints associated with the pressure transducer. The other three joints used flared and ferrule type pressure fittings. A rubber diaphragm was fitted to the pressure port to prevent seawater from entering the transducer. Distilled water was in the space between the diaphragm and the pressure sensor.

1.3.4 Initial Testing of the System

The buoy was first tested with the pressure sensitive transistor. It was during this test that the temperature problems with this device were confirmed and the only positive result was that the pressure case, which employed four static and one dynamic O-ring seals, did not leak.

After the resistance pressure transducer was obtained a test was made in a lake on Cape Cod with encouraging results. A control circuit using two ($\pm$) 6 volt supplies was used and power transistors were used for switching instead of relays. The buoy was negatively buoyant and floatation in the form of a cork collar was necessary. Problems with the cork absorbing water were encountered. A new collar constructed of rigid polystyrene foam covered with fiberglass and epoxy was constructed and the tests were re-conducted in the M.I.T. pool. Problems were encountered with compressibility of the foam collar. The buoy would operate near the surface but if it were pushed down a few feet the floatation collar would compress more than the volume compensation could recover and the buoy went to the bottom. Problems with the motor mount were also encountered. At this point the transistor switches were replaced with relays, one six volt battery was eliminated, the buoy became positively buoyant and the floatation collar was abandoned. The motor mount problems were solved and tests were made in the M.I.T. pool with satisfactory results. The buoy kept approximately 7-8 feet depth for over an hour. At fifteen feet depth the motor was almost unable to push the piston against the pressure head. This problem was remedied by the new motor and gear head.

1.4 BUOY SONAR SYSTEM

The sonar pinging system within the buoy consists off an accurately calibrated quartz crystal time base and a local oscillator and amplifier circuit to provide the power to drive the transducer.

Preliminary investigations into the availability of suitable transducers for sonar applications indicated that such transducers fall into two distinct categories - very expensive or very inexpensive. The latter are available as U.S. government surplus from surplus stores. Several of these were obtained and it was decided to design the sonar system around these if possible. Impedance measurements indicated that the impedance of these transducers became resistive at 67 kHz and extensive testing showed that while there was satisfactory coupling with the water at this frequency drive levels above 10 mw resulted in no radiation. It was then discovered that significant amounts of power were radiated at much lower frequencies with a peak appearing near 8 kHz. The impedance of the transducer at this frequency is primarily capacitive so tests were performed in the M.I.T. pool resonating the transducer with a suitable inductor. Thirty millihenry coils were wound on high permeability toroidal cores for this purpose. This resulted in a circuit resonant at 8 kHz with a Q of 35 giving 350 volts across the transducer for a 10 volt peak to peak square wave drive voltage. Tests with a calibrated hydrophone showed 30-100 mw of power was radiated to the water. This should be power enough to transmit a signal for up to 4 km in the water assuming a 10 dB signal to noise ratio and ambient noise level of -54 dB re 1 microbar, 1 cycle band.

The next section to be built was the crystal time base. Crystals were obtained specially cut to have a frequency turnover temperature of 15°C and 25°C. The first for the buoy would allow for adjustment in the lab above the turnover temperature with use in the water near the same number of degrees below that temperature resulting the same frequency. With a stable 100 kHz

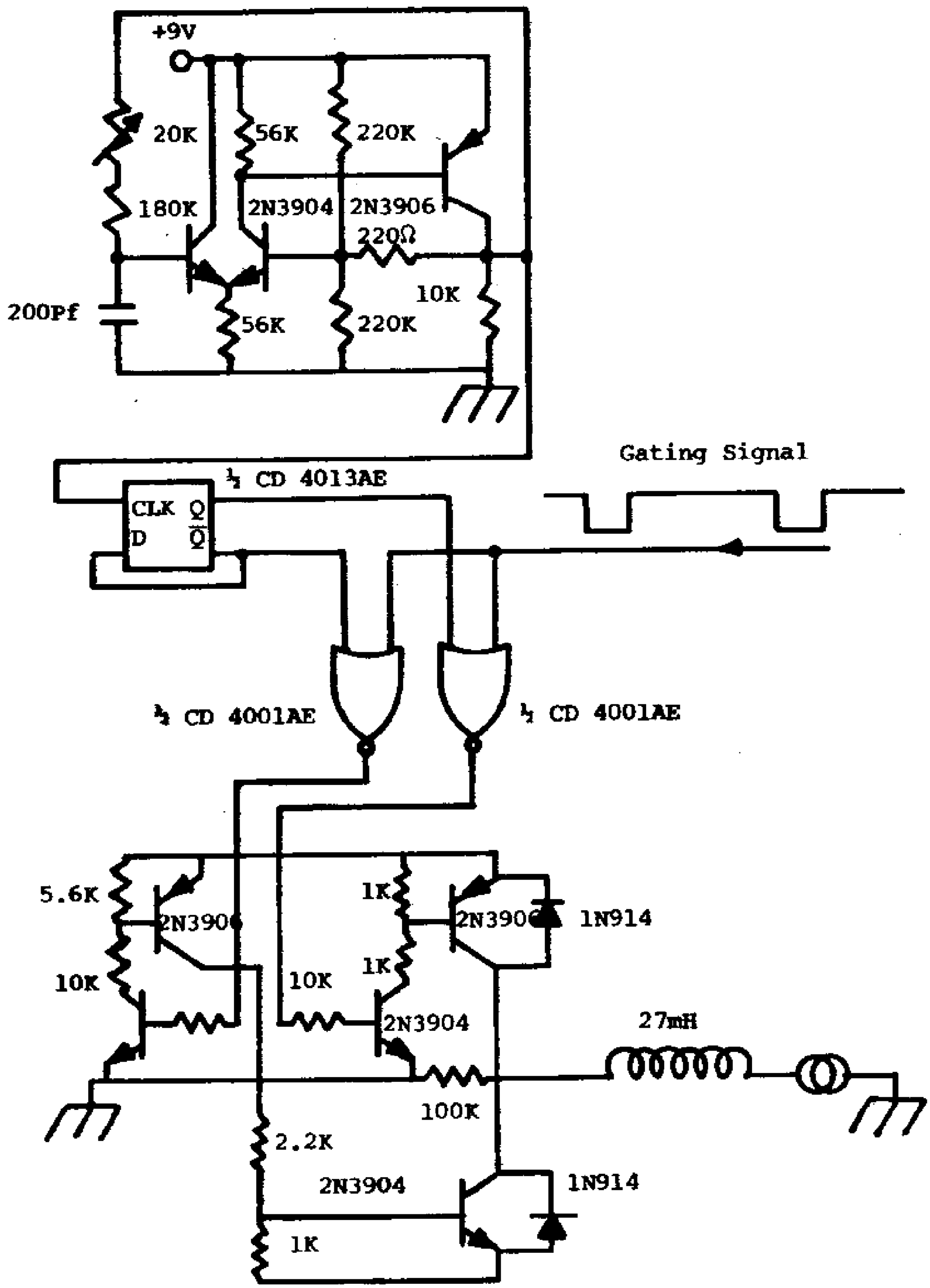


FIGURE 1.3 16kHz Oscillator and Pinging Amplifier Circuit

oscillator maximum use was made of C-MOS logic-integrated circuitry to successively divide the frequency by 100, 10 and 100 giving 1,000 Hz, 100 Hz and 1 Hz outputs from these stages. Use is then made of the 1 Hz and the 100 Hz signals to give a gating wave form.

A local oscillator which is tunable from 15 to 16 KHz was built. This frequency divided by two using a D-type flip flop each gives two 8 KHz signals 180 degrees out of phase with each other with 50% duty cycle Figure 1.3. This and the gating wave form are combined to give the signal to the pinger amplifier which in turn drives the transducer-inductor resonant circuit.

1.5 CURRENT MEASUREMENTS USING A CONSTANT DEPTH BUOY

To obtain useful data on current patterns with a constant depth buoy some sort of tracking system is necessary. This system should provide accurate buoy trajectories and should be able to locate the buoy for recovery. There are clearly many tracking methods available. A system using a sonar beacon on the buoy is described in this report. This system was constructed in the Spring and field tested at Castine during July, 1973. The tracking system and buoy worked quite well and the results of several drift measurements are given.

1.5.1 Tracking System

In order to track the constant depth buoy as it follows the local water flow, a sonar tracking system was developed consisting of a precision timed pinger in the buoy, two widely spaced receiving hydrophones and a receiver producing a graphic output. This system is shown in Figure 1.4. The buoy is located by measuring and recording the acoustic travel times for the ping to reach each hydrophone. As explained earlier a crystal oscillator in the buoy produces an accurate 100 kHz time-base frequency. Using C-MOS integrated

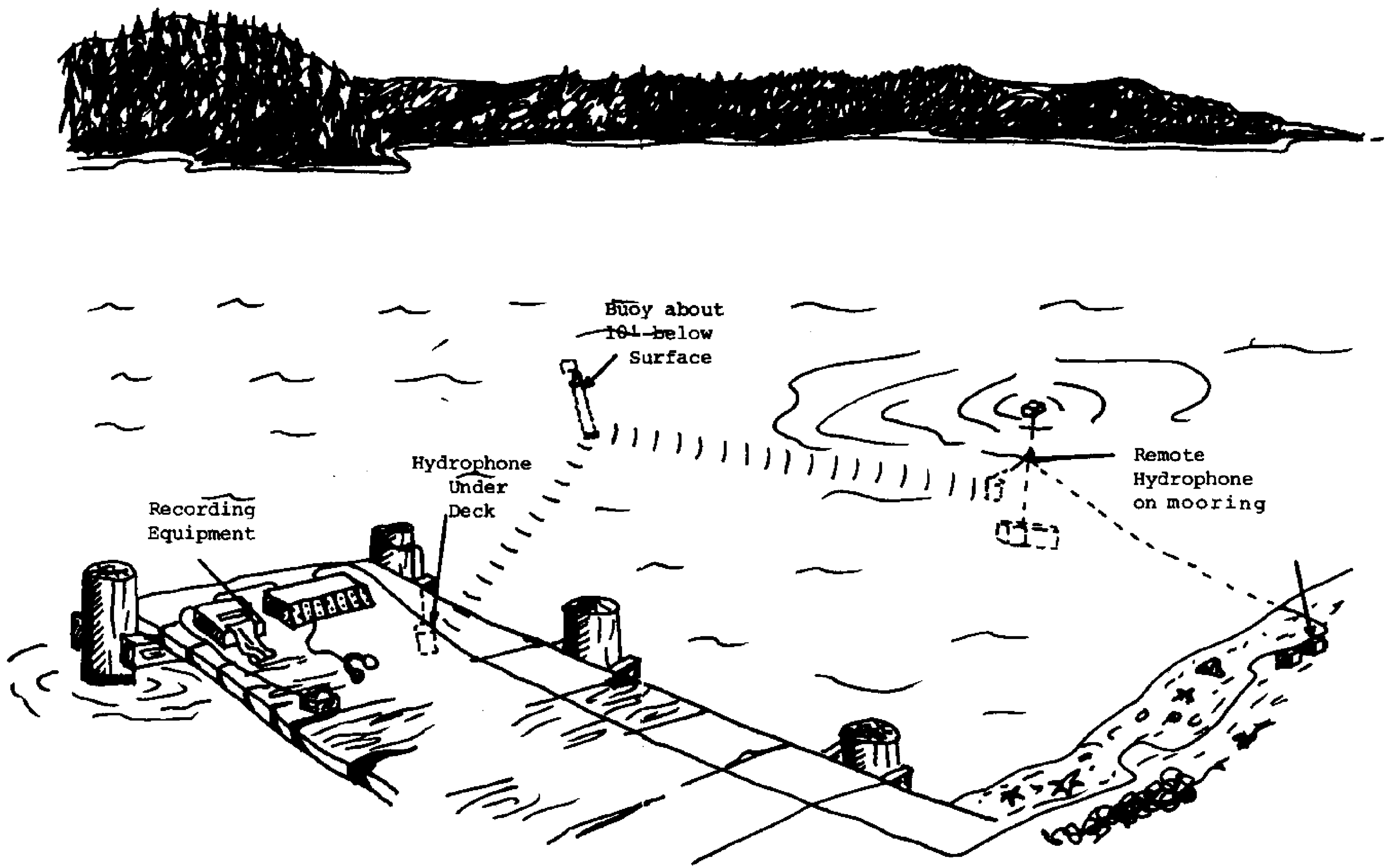


FIGURE 1.4 Experimental Arrangement at Holbrook Cove

circuits this 100 kHz is divided down in frequency to a 1 Hz signal which is used to initiate each ping. Due to the high stability of the crystal oscillator, the time when each ping is emitted is known. As indicated in Figure 1.4, this ping is received at the two hydrophones and their signals are recorded on the wet-paper graphic recorder. A block diagram of the receiver is given in Figure 1.5 and a sample of the graphic output is shown in Figure 1.6. As indicated in the diagram, the hydrophone signals are band-pass filtered, amplified, demodulated and added to produce the writing signal to the recorder. This recorder writes from left to right in the paper in lines or scans spaced about .012" apart. The writing rate is exactly one line per second as determined by a crystal clock in the receiver. The pings from the buoy therefore appear at the same point on subsequent lines, producing a dark vertical line. As the buoy moves closer to or further from the receiving hydrophone, this line deviates from the vertical indicating the sooner or later arrival of the acoustic pulse. The two crystal oscillators, one on the buoy, one in the receiver, are carefully adjusted to the same frequency at the beginning of each experiment. A cursor, generated in the receiver, which produces a pulse once a second, is adjusted to indicate the time at which the buoy actually pings. While the buoy is drifting, the spacing along the line between the cursor mark and the received pings indicates the travel time of the acoustic pulse from the buoy to the hydrophones. These two time intervals, one for each hydrophone, are then converted to actual ranges using the appropriate speed of sound value for the local conditions of water temperature and salinity. Once these two ranges are known, the position of the buoy can be plotted.

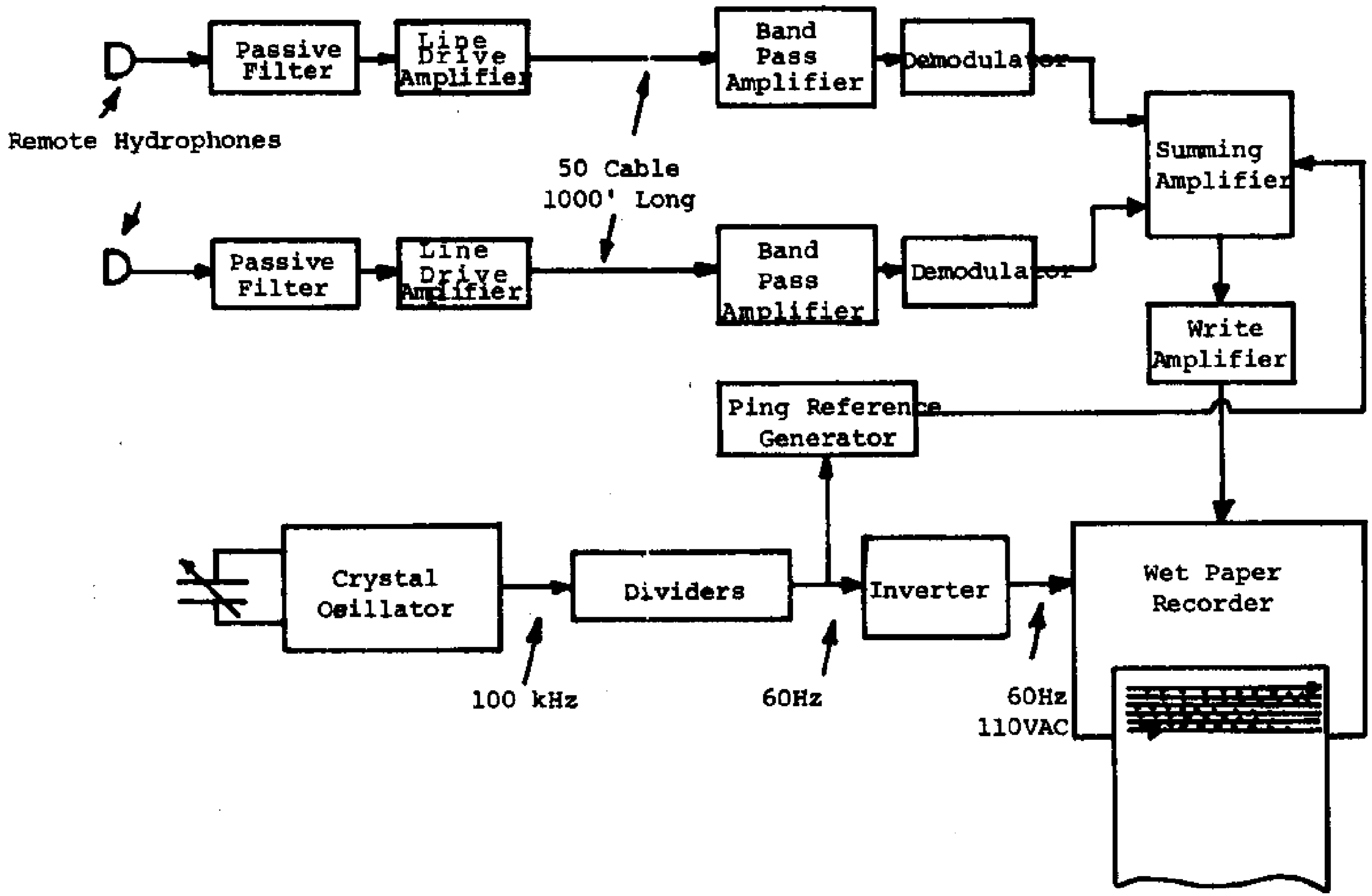


FIGURE 1.5 Block Diagram of the Hydrophone Receiver System

1.5.2 Sources of Error

Three major sources of error contribute to the uncertainty in the location of the buoy. The first is uncertainty in the exact sound speed in water. This is usually due to incomplete data on the temperature and salinity in the working area. The second source of error is drift in the two crystal oscillator frequencies. It is the nature of everything in the world to be temperature sensitive and quartz crystal resonators are no exception. The two oscillators can be adjusted to equal frequencies in the laboratory, however, when the buoy is in the water, its temperature drops by about 15°C. At the same time the receiver is sitting in the hot sun and its temperature rises by 10°C. In practice, the receiver oscillator must be readjusted in frequency to match the buoy oscillator with the buoy actually in the water near a hydrophone before the experiment can begin. This can reduce the error to tolerable limits, but cannot eliminate it entirely due to thermal stratification in the water and changing sun at the dock both of which will change the crystal frequencies. A solution would be to provide ovens for the crystals. This would consume much effort, money and battery power, shortening the useful life of the buoy. A more practical solution would be to temperature compensate the crystals with thermistors or capacitors. This does not require as much power as an oven but would probably take much more effort.

The third source of error is indeterminacy in the time of arrival of the acoustic pulse. There is a trade-off in the design of the tracking system between power consumption and range resolution. To achieve a good signal-to-noise ratio at the receiver, an acoustic pulse of a given bandwidth must have enough power to overcome the ambient noise in the same band. If the bandwidth of the pulse is decreased, there is less noise to overcome and less power can

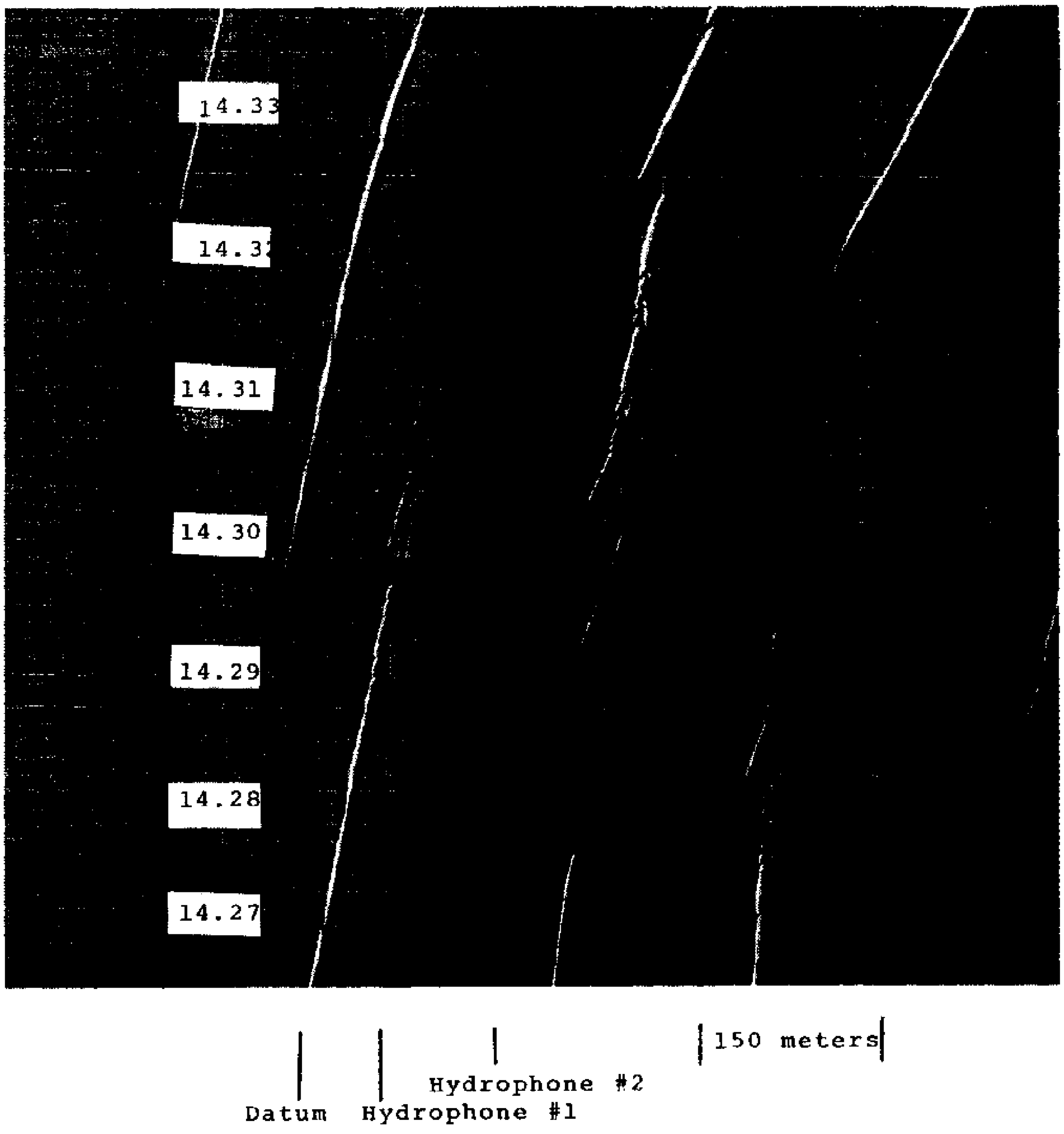


Figure 1.6 A Representative Wet-Paper Record for the Prototype Constant Depth Tracking Buoy

be used. The pulse length, however, must increase if the bandwidth decreases. This longer pulse length makes determination of the exact start time of the pulse less certain, contributing to the range error.

In the present experiment, pulses 10 ms long were used, giving a bandwidth of 100 Hz. To achieve optimum signal to noise ratios, the receiver used filters of the same bandwidth, 100 Hz. The rise time of such a filter is on the order of the pulse length, 10 ms, giving a worst case range uncertainty of around 15 meters. In our ocean experiments, however, we found the power of the signal from the buoy was more than adequate and had very good signal to noise ratios at the receiver. This permitted a more careful determination of the start of each pulse and our actual errors are probably more like 2 ms, or about 3 meters.

An additional source of innaccuracy arises from uncertainty in the exact location of the receiving hydrophones. This is entirely a surveying problem and not inherent in the system.

1.5.3 System Field Tests

The buoy and tracking system were tested as time permitted. The range of the tracking system was first checked by towing the buoy behind a rowboat off Castine. It was discovered that passing outboard motorboats generated enough noise to swamp the signal. The situation was improved by increasing the band-pass filter's out of band rejection by adding a second filter stage. This second filter was placed right after the hydrophone and helped to prevent overloading of the subsequent amplifier stages. This filter is entirely passive and is shown in Figure 1.5.

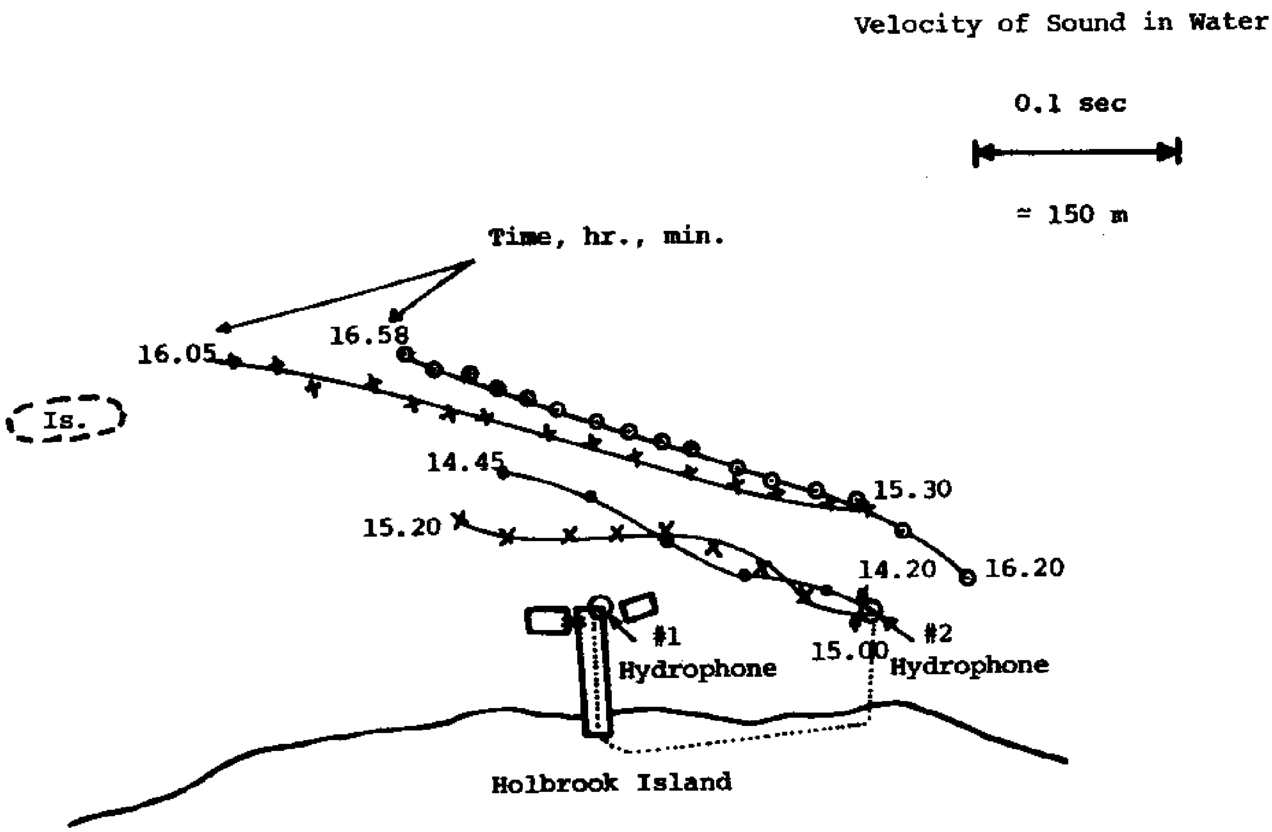


FIGURE 1.7 Buoy Trajectories in Holbrook Cove, 7-24-73

The maximum range at which the system was tested was about one kilometer. The signal was adequate at this distance and hence stronger than necessary for our drift tests which involved ranges of about 300 mm.

The current tracking tests were conducted in Holbrook Cove with the equipment set up as shown in Figure 1.7. Tests were conducted on several days while the bugs were removed from the system. Four buoy trajectories were recorded on the rising tide of the final day of tests. These trajectories are also shown on Figure 1.7 with the positions calculated at approximately 2½ minute intervals. The buoy was turned on and placed in the water while the rest of the equipment was being set up. This gave the crystal oscillator time to stabilize before the experiment began. After the receiver was running, the buoy was placed next to hydrophone #1 to measure the zero time reference point. The buoy was then taken to hydrophone #2 to measure the acoustic time travel from hydrophone #2 to #1 and to recheck the zero reference. For the first drifts, the buoy was attached to a nearby boat for safety. The boat followed the buoy keeping the string slack at all times and it exerted only a mimimal drag. The drifts were terminated when the buoy got too far from the baseline to permit accurate tracking. After the drift period, the buoy was not removed from the water (therefore preventing a temperature change) but was towed immediately to one of the hydrophones to check the zero point. There was always some drift and a linear interpolation was used between the two calibration points to obtain a better time reference. The observed time base drift rates were on the order of one millisecond per minute giving a range change of about 1.5 meters per minute. After interpolating, this was reduced by a factor of between ten and twenty, giving a range error of about three meters during the twenty minute drifts.

1.5.4 Conclusions

The constant depth buoy employing a sonar tracking system as described herein is clearly an excellent method of following water motions accurately. The entire system is portable making measurements in remote areas (such as Holbrook Cove) possible. The experiments conducted in Castine, however, indicated two important areas of system improvement. First, the accuracy of the time-base oscillator must be improved as discussed above. Perhaps the best solution would be to buy a commercial temperature compensated crystal oscillator. The second improvement would be to increase the percent volume change in the buoy's variable buoyancy system and to use a linear control system to reduce depth hunting. Such an improvement is discussed in the following section.

2. THE CONSTANT DEPTH TRACKING BUOY, MARK II

2.1 INTRODUCTION

The goals of this project were to design and build an improved constant depth tracking buoy. The improvements sought were as follows:

1. To maintain a given ocean depth to 100 ft. below the surface with smaller depth oscillations.
2. To have a volume change of 3.5% of its total volume.
3. To produce this overall volume change in thirty seconds or less.

The prototype "Constant Depth", or more accurately, "Constant Pressure" buoy described in the previous section was a unit designed to maintain a specified underwater depth by sensing pressure, and if need be, changing its volume, and hence its buoyancy in order to compensate for deviations. If the buoy's volume increases it rises, and for a volume decrease it sinks. The uses for such a device are numerous, some examples being to follow current flows or to measure ocean gradients of such properties as temperature, sunlight, and salinity.

2.2 INITIAL DESIGN IDEAS

Initially, the design of the central mechanism for volume change consisted of a motor coupled directly to a screw. As the screw turned in its stationary vertical postion a long hexagonal nut (e.g. five inches long) would ride up and down the screw. The resultant thrust motion would be translated into a piston that slid in and out of a bored cylinder, and had an O-ring for a seal between the cylinder-piston-seawater interface.

After careful analysis and consideration, these initial ideas were rejected because of their weaknesses or limitations.

The piston was replaced by a bellows. This was felt to improve the performance because of the elimination of sliding seals and because friction of the piston was eliminated.

The crude bolt and nut mechanism (max. Of 30 percent efficiency) was replaced with a linear actuator's lead screw with its great efficiency (over 65 percent?) and precision alignment. This greater efficiency is obtained because it has a special acme thread (commonly used in metal working lathes) and uses ball bearing balls which roll between the nut threads and the bolt threads.

2.3 THE BUOY COMPONENTS

2.3.1 The Housing

The most difficult piece to machine and weld was the stainless steel housing. The unit was initially found in a scrapyard and purchased for $14. The housing itself was taken from this liquid heating unit, from which the top dome was removed, the three inside pipes were drilled out, and the top plate turned off. The three resultant holes in the bottom were then arc-welded closed with three stainless steel plugs.

2.3.2 The Bellows

The stainless steel bellows were selected from a number of available bellows. The one chosen in particular is normally used in a vacuum system but met specifications for the pressure at a seawater depth of 100 ft. (3 atm.).

2.3.3 The Ball Bearing Screw

This was removed from a linear actuator with a 4" stroke and a capability of 1,000 lbs static load.

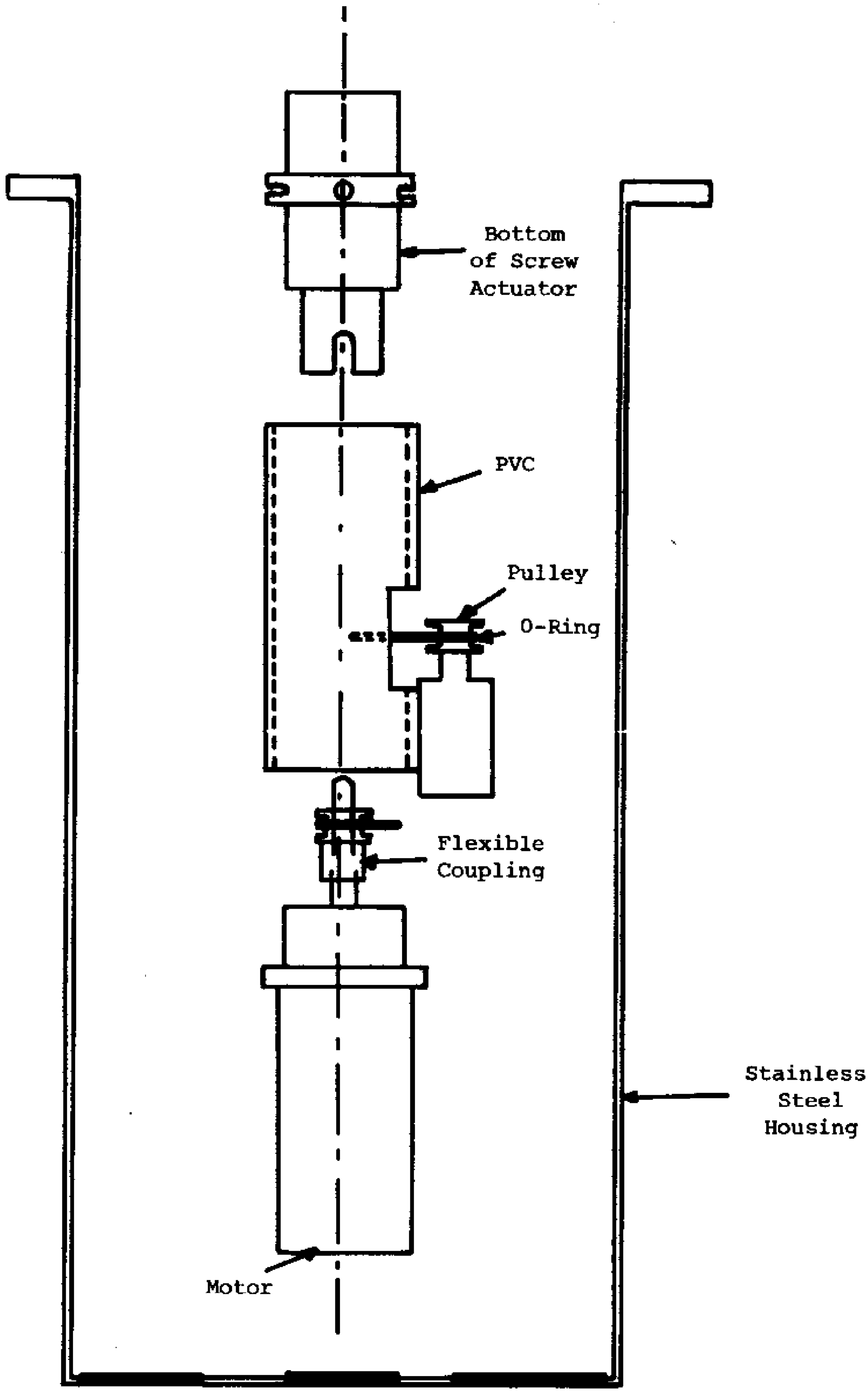


FIGURE 2.1 Exploded View of the Mechanical Components of the Mark II Tracking Buoy

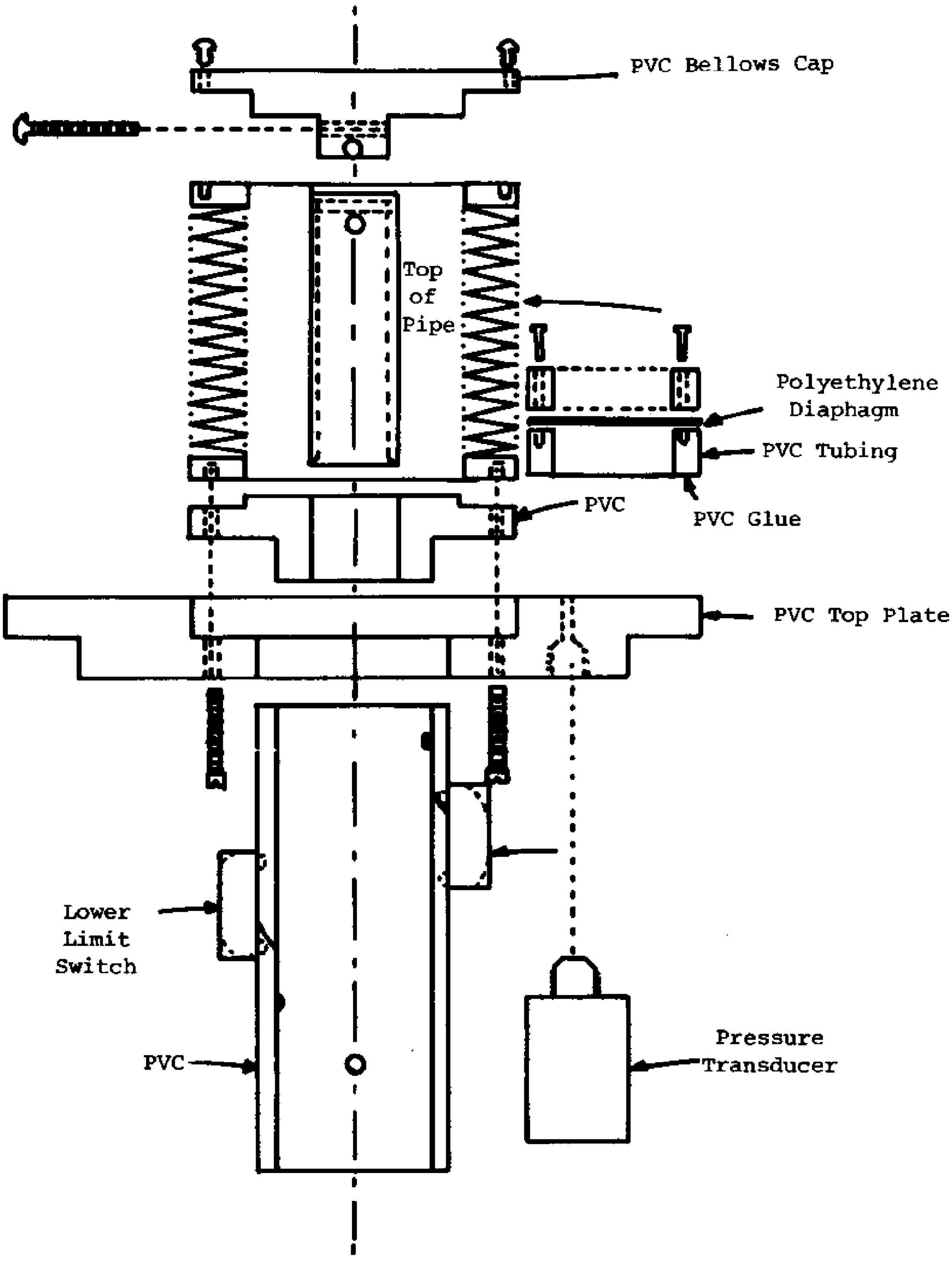


FIGURE 2.1 Continued, a.

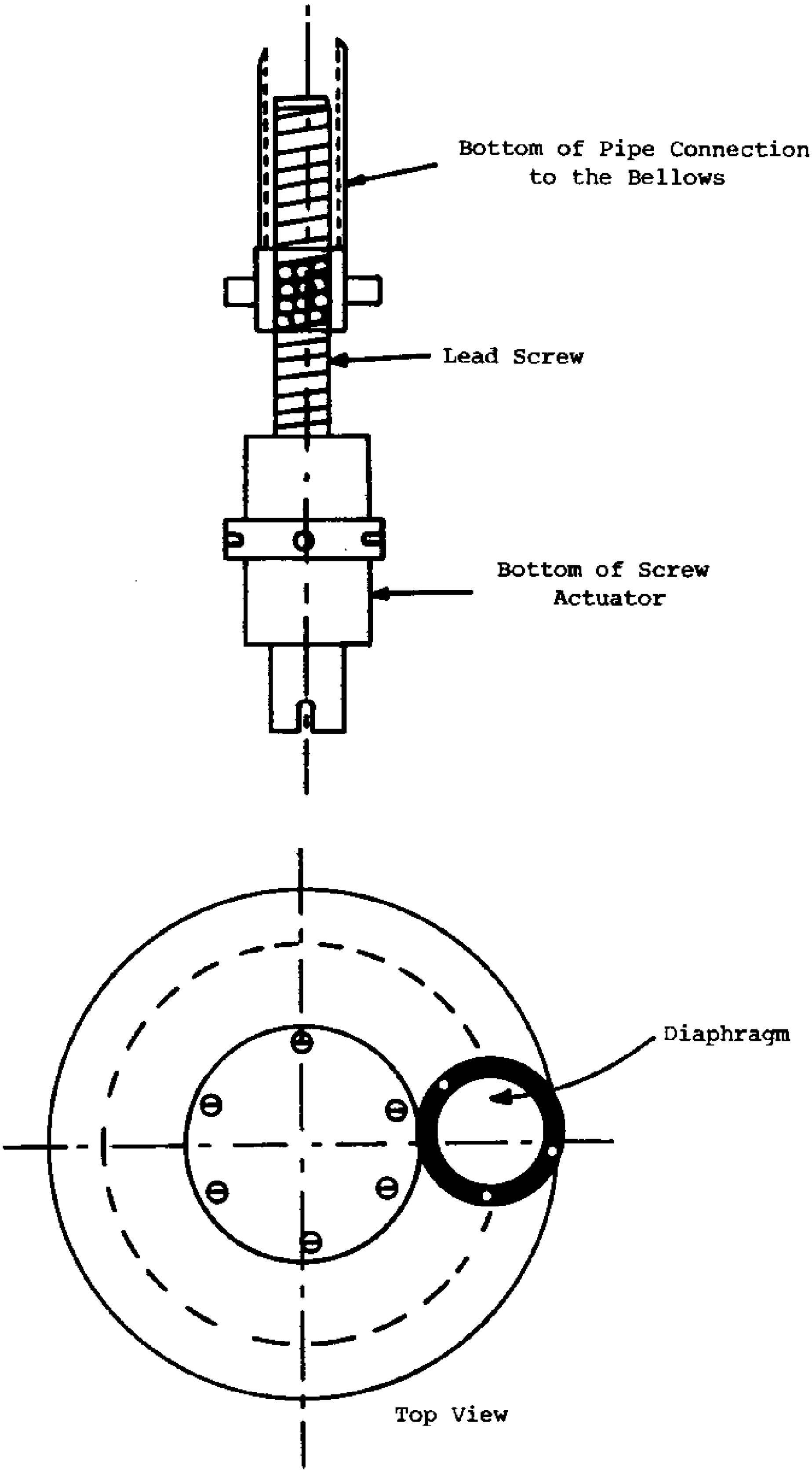


FIGURE 2.1 Continued, b.

2.3.4 The Motor

A suitable motor was extracted from an aircraft linear actuator. It was a permanent magnet type motor rated at 24-27 volts d.c. but would operate as low as 4 volts. Apparently this motor had its own slip mechanism to prevent over heating or damage when the shaft was stalled externally. Tests were conducted with the motor and linear actuator and gear box which demonstrated that the system would operate at depths down to 100 ft. with a 12 V battery supply.

2.3.5 Batteries

Lightweight Ni-Cad type batteries were obtained. A typical 6 volt cell pack had dimensions of 2" x 3" x 6", weighed 2 lbs, and put out 4 amp-hrs. In the actual test run, 6 V primary cells were used from weight considerations.

2.3.6 Pressure Transducer

The same type of transducer was used in the prototype tracking buoy. A potentiometer connected to a diaphragm provides a linear resistance variation with applied pressure.

2.4 BUOY MANUFACTURE

2.4.1 Mechanical Equipment

The greatest (and most persistent) problem was that of weight. The housing had a displacement of approximately 632 in^3, or the equivalent of 23 pounds of seawater. It became apparent that the weight of all the internal works plus the 12 pound housing would undoubtedly sink. Unfortunately, placing a flotation collar around the buoy would fail because of the great compressibility of most light materials under moderate pressures. Possibly a copper pipe could have been welded into a donut, but this did not appear to be feasible.

The first attack on this problem was made in using a lathe to turn two pounds of stainless steel off the flange on the housing. This took a long time because only cobalt-steel cutting tools were available, and when stainless steel work hardens it is harder than the cutting tool. Tungsten steel cutting tools should have been used instead to do a proper job. Eventually the housing was reduced from 12 pounds to 9 lbs. 10 ozs.

The next approach was towards lightening the linear actuator. This 10 pound unit had to be stripped to its essentials. The 2½ pound motor was replaced, and both the lead screw's protective sheath and the thrust cylinder attached to the lead screw were taken off.

Eventually attempts to reduce the weight got no further, the unit was still too heavy at five pounds. This led to the single alternative of directly coupling the motor to the lead screw and throwing aside the heavy duty (designed for 1,000 lb gear loads) gear box. This was very satisfactory although the depth capability of the buoy was reduced. The final arrangement is shown in Figures 2.1 and 2.2

2.4.2 <u>Electrical and Electronic</u>

There were no problems in the electronics. The circuit has three control variables. They are:

1. Depth - the previously mentioned "specified depth".
2. Dead band - the deviation setting for determining how far off the specified depth the buoy would go before reacting. Variable from a few inches to a few feet.
3. Gain - the force that the buoy would exert towards getting back to the specified depth for a specified depth error. This could cause either "overshoot" or a gradual approach.

BLANK

The circuit is shown in Figure 2.2. It differs from the prototype system because it has a position potentiometer to reduce hunting.

2.5 THE TEST PROGRAM

After complete assembly of both the mechanical and electrical sections of the buoy, a temporary power supply made of dry cells was used. A preliminary test of letting the buoy to the bottom of Penobscot Bay and checking showed no leakage to a depth of 25 feet.

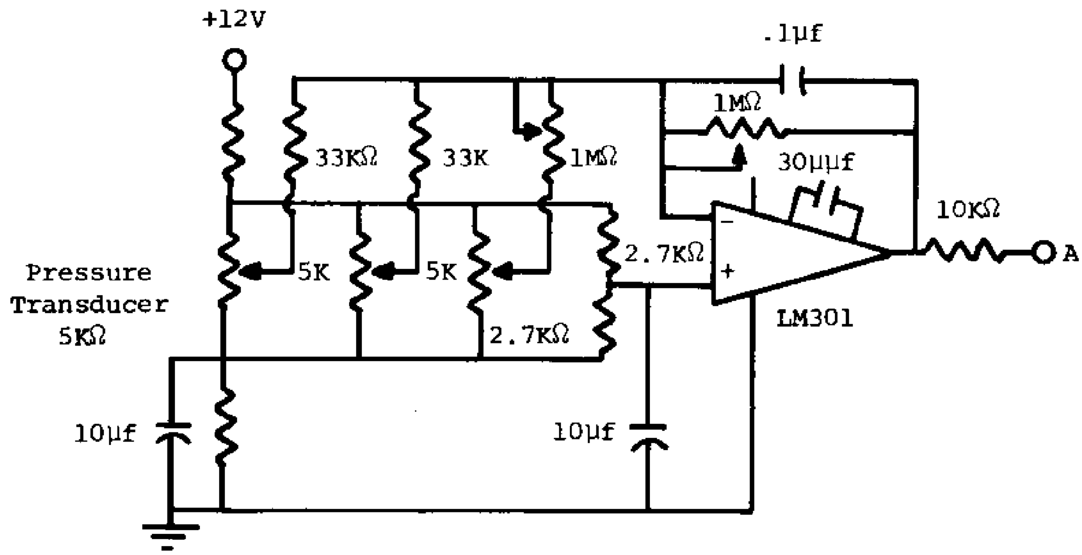
There were two tests on the final day of the summer laboratory in Castine. In the first the buoy oscillated between the surface and barely out of view, or approximately eleven feet. On the second test, after adjusting for lower gain, it oscillated between two and six feet of depth.

2.6 FURTHER POSSIBLE IMPROVEMENTS

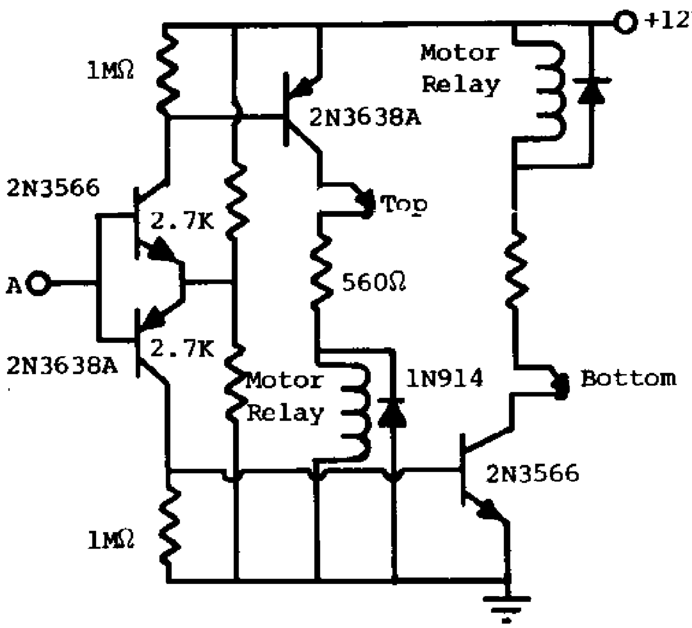
A further innovation would be a gas valve. If the housing were pressurized to the depth to be worked at, the expended energy employed to move the bellows would be minimal. Time did not permit the installation of a bicycle type elbow valve to do this.

2.7 CONCLUSIONS

The mechanical design and buoyancy control of the prototype constant depth tracking buoy has been improved in the Mark II design. It should be possible to utilize the modified buoy in a wide range of shallow water studies.

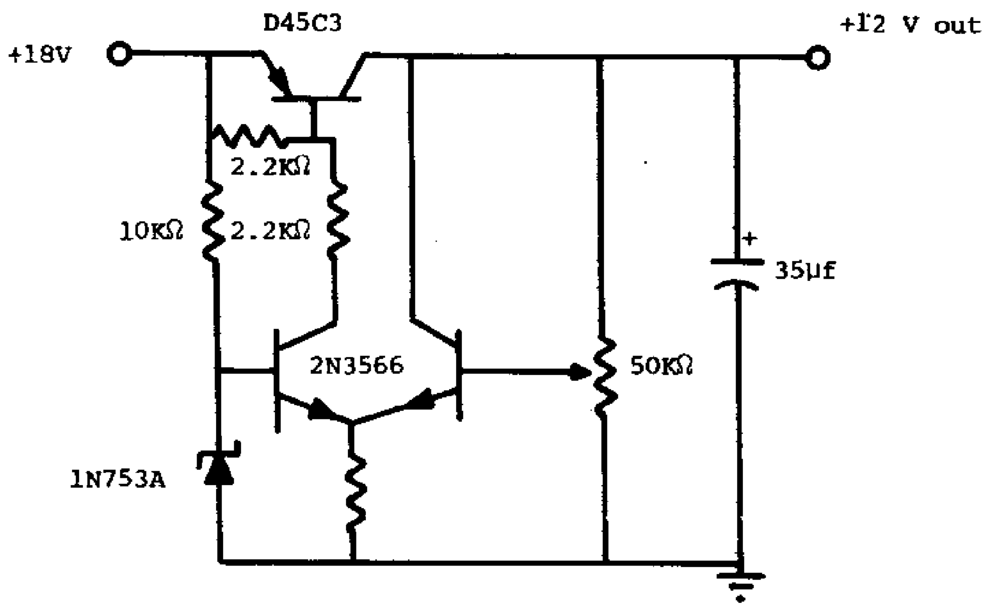


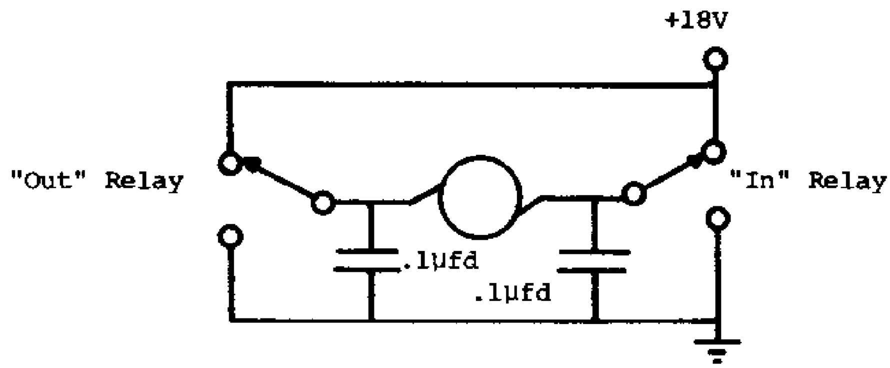
a. Control



b. Hysteresis

FIGURE 2.2 The Mark II Buoy Control Circuits





c. Voltage Regulator

FIGURE 2.2 Control Circuits (contd.)

3. THE SONAR CURRENT METER

There is a need for a simple, accurate, and reliable current meter for the determination of ocean, estuary and river currents. In previous summer laboratory investigations propeller type, and Karman vortex type current meters have been designed. Although these instruments were reasonably successful they both suffered from inaccurate current indication when the water velocity was very low. In an effort to remedy these deficiencies further current meters were studied.

A sonar current meter was designed and built which, in principle, could be very accurate at low velocity and, at the same time, it should be reliable because it has no moving parts.

3.1 DESIGN PRINCIPLES

Consider two sonar transducers placed at the opposite ends of an accustic path of length ℓ (as shown on Figure 3.1). At time t = 0 each transducer is excited with a pulse. The sonar pulse generated by transducer #1 travels to the right to transducer #2 and an identical pulse travels from #2 to #1. Each pulse will be received at the opposite end of the acoustic path at $t = \ell/c$, where c is the speed of sound in the medium separating the transducers.

Now suppose the same experiment is performed in a medium which moves with velocity v in the x direction. Now the pulse traveling from #1 to #2 travels with velocity $c_1 = c + v$. The other pulse travels at $c_2 = c - v$. The first pulse arrives at $t_1 = \ell/c_1$, and the second at $t_2 = \ell/c_2$. The time difference is approximately, for $c >> v$, $t_d = t_2 - t_1 \underset{c >> v}{\simeq} \frac{2\ell v}{c^2}$. It is this time difference which will be used as a measure of fluid velocity; the ocean currents in particular.

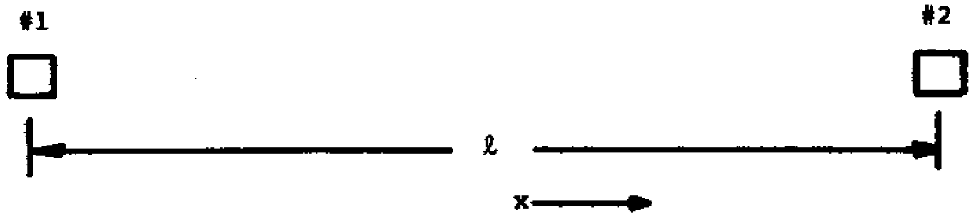


FIGURE 3.1 The Principle of the Sonar Current Meter

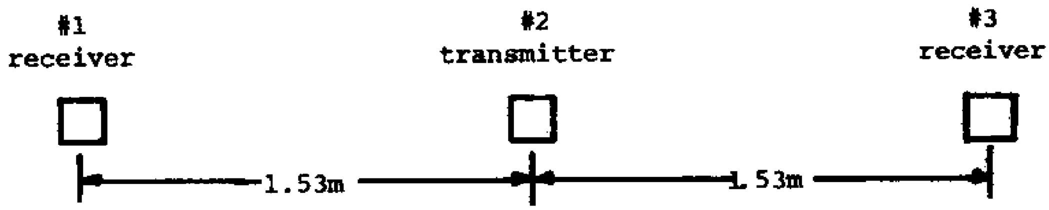


FIGURE 3.2 The Arrangement of the Transducers for the Sonar Current Meter

3.2 SYSTEM DESIGN

The system used has three transducers rather than two (as shown in Figure 3.2). A steady state sine wave at 7 kHz is fed to the transmitting transducer. This signal is received by two receiving transducers, amplified, and the two amplified signals compared in phase (Figure 3.3), as a phase shift and a time delay are equivalent.

To produce the 7 kHz tone fed to the transmitting crystal a basic op-amp multivibrator is used, Figure 3.4. This produces a square wave at 7 kHz. This is put through a transistor power gain stage, and this square wave is fed to a resonant circuit composed of a 34mh inductance and the transducer crystal itself. Since the impedence of the crystal is highly capacative, this resonant circuit has a very high Q, and at the transmitting frequency the gain of this resonator is about 25. So when a 10 volt square wave is applied to the resonator, a 250 volt sine wave appears across the crystal. This provides a way of applying sufficient drive voltage to the transducer without using high voltage power supplies and semiconductors.

The preamplifier, used to boost the signal received by the receiving transducers is a very straight-forward circuit. The imput stage is an IC operational amplifier, set to a gain of 250. A National Semiconductor LM301 was chosen for this stage because of its wide bandwidth and ease of compensation. The second stage is a level comparator, which converts the amplified sine wave produced by the first stage to a square wave suitable for driving TTL logic.

This square wave is fed to a phase comparator. The circuit detects the phase difference between the outputs of the two preamp channels. The basis for the comparator is an exclusive OR gate, a logic device which registers a 1 output whenever its inputs are not the same. An asynchronous memory was added

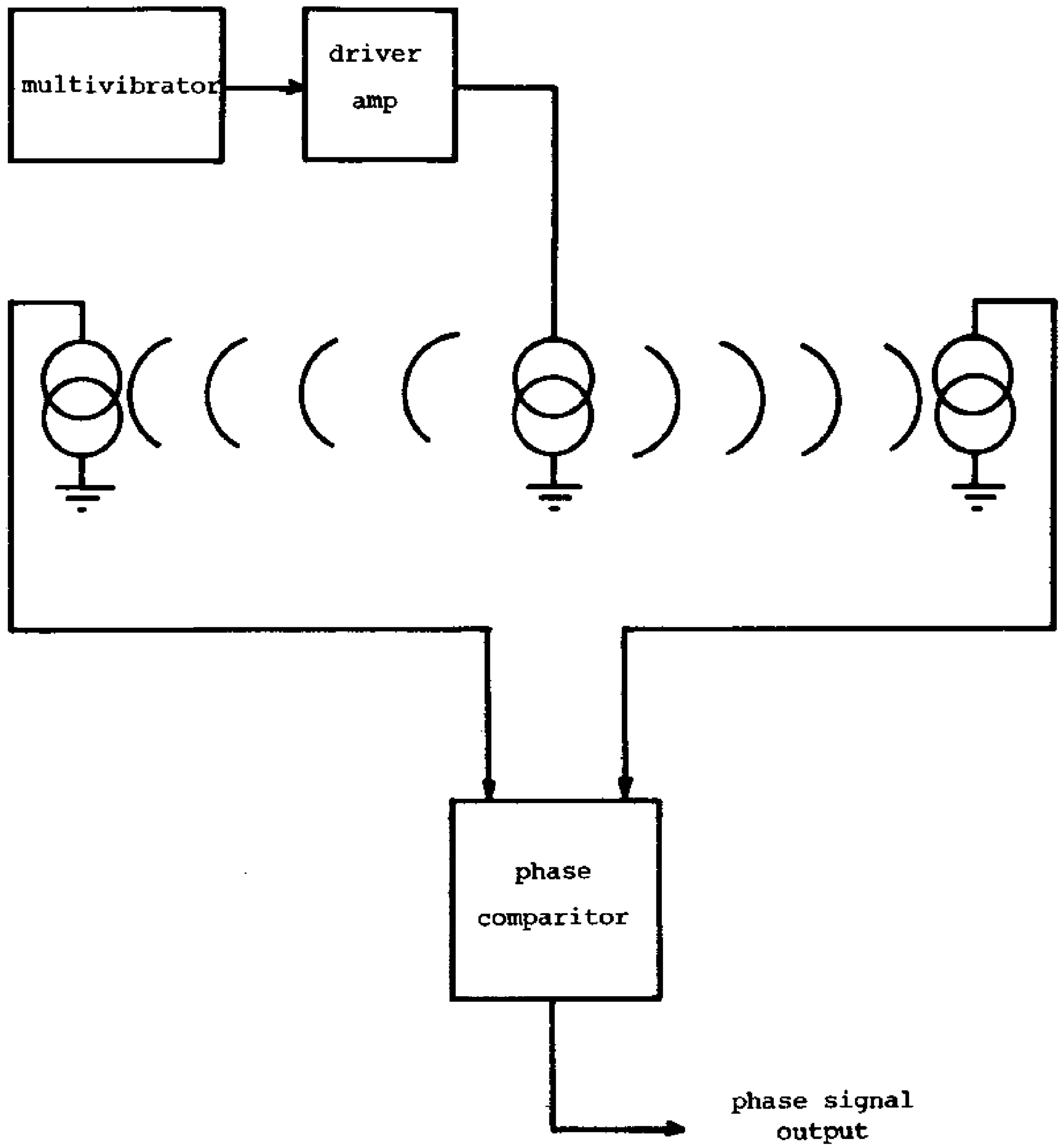


FIGURE 3.3 The Sonar Current Meter System

to this to differentiate between the cases of #1 goes high (or low) first, or #3 goes high (or low) first. The output of the logic part of the phase comparator is two pulse trains on two wires. On line A, a 1 is outputted when the inputs differ, but #1 went high or low first. On line B, a 1 is outputted when the inputs differ but #3 changed first. These pulse trains are then low pass filtered into two DC levels, which are subtracted by a differential amplifier to produce an output voltage proportional to the phase difference.

3.3 EXPECTED PERFORMANCE

The instrument should produce a voltage proportional to fluid velocity, with a proportionality constant of 30 volts/(m/sec). This should remain linear down to about 1 cm/sec, the limitation being imposed by the resolution of the phase comparator.

3.4 RESULTS

When the device was placed in the water at Castine, the only output observed was a rapid fluctuation in output voltage. It was impossible to determine any current velocity, for the noise at the output was too high.

The problem with this system is that the velocity of the sound carrying medium is only one possible cause of phase shift. Top and bottom reflections at oblique angles will also effect phase, as will any difference in the speed of sound between transducers #1 and #2, and between #2 and #3. Wave action and bottom terrain, not necessarily the same on each "leg" of this device, influence top and bottom reflections. The speed of sound in seawater is a sensitive function of depth, salinity, and temperature, all of which can very over short distances. A solution to this problem was not found at Castine.

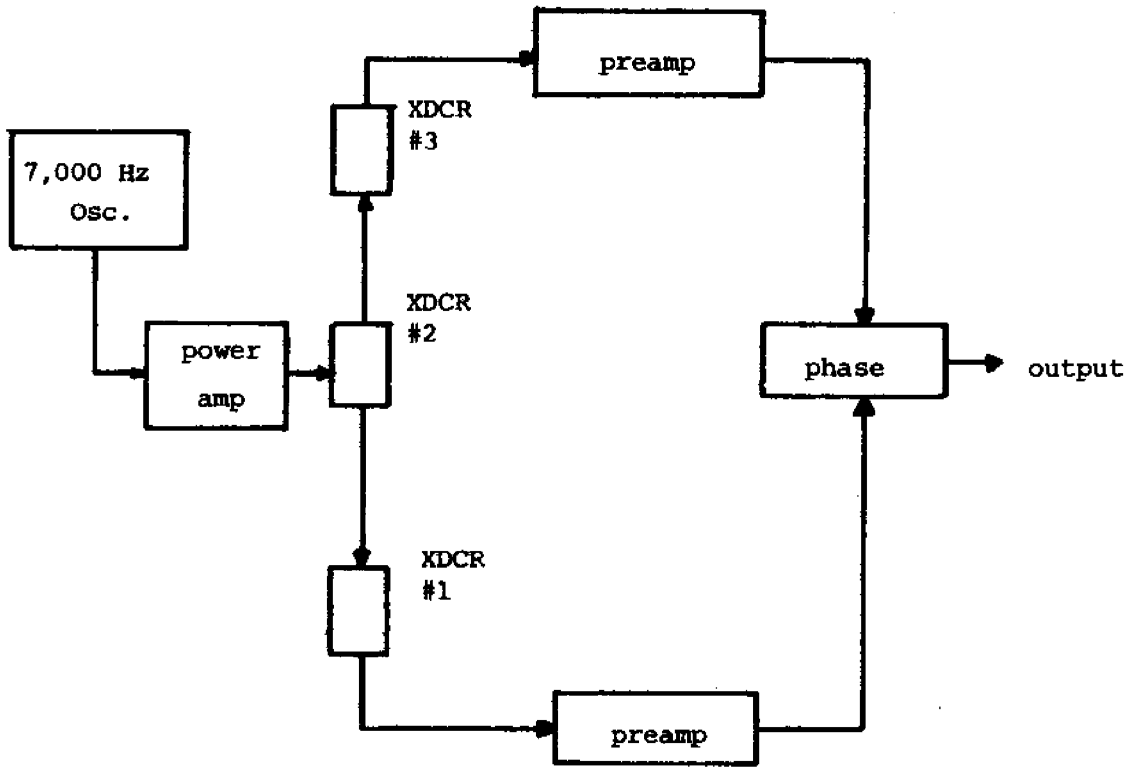


FIGURE 3.4 System Block Diagram

3.5 RECOMMENDATIONS

Most of these random phase variations can be suppressed or eliminated by using only two transducers rather than three. If each transducer is used both as a transmitter and receiver, then both pulses will traverse the same paths, and variations in the speed and sound, reflection paths, and so on will tend to cancel out.

However, to use both crystals as loudspeaker and microphone, one must turn the transmitter on, turn it off as the sound waves reach the opposing ends of the acoustic path, turn on the receiver, turn off the receiver as the sound waves propagate away, and so on. Unfortunately, the very high Q of the transmitting circuit used makes this difficult. A solution is to redesign the transmitting amplifier using a high voltage battery and high break-down transistors.

4. A STUDY OF MAGNETOHYDRODYNAMIC CURRENT METERS

A second type of current meter was investigated as part of the quest for an accurate method of measuring water currents. In principle an accurate and reliable current meter can be developed with no moving parts using magnetohydrodynamic effects.

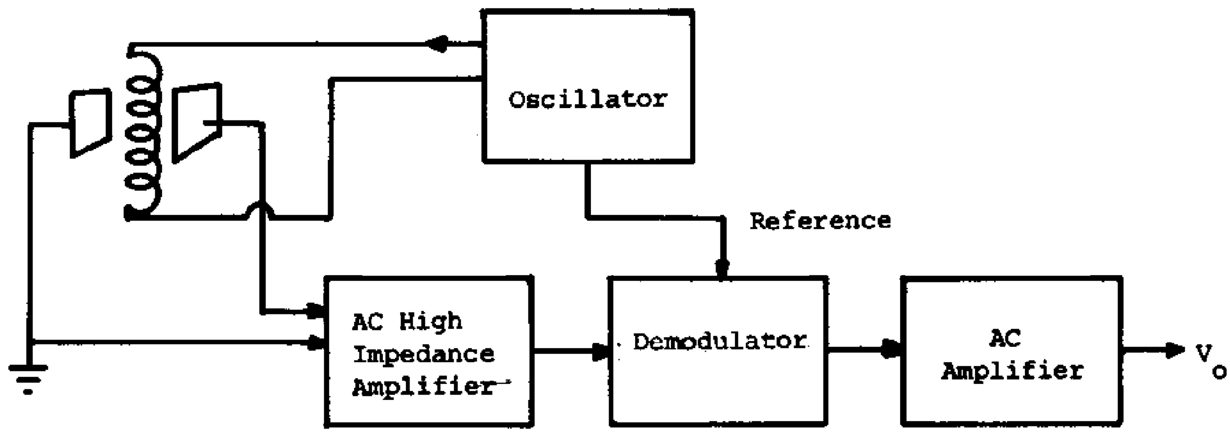
4.1 THEORETICAL PRINCIPLES

The theoretical principle behind the magnetohydrodynamic water current velocity meter is that a velocity of charged particles, flowing perpendicular to a magnetic field, creates an electric potential in the third perpendicular axis, and a consequent voltage across two electrodes placed on that axis.

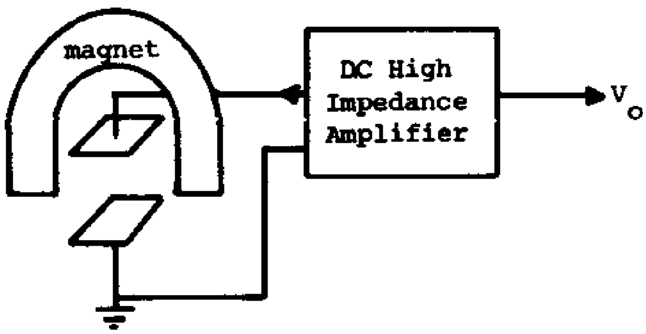
To establish some idea of the output voltage of such a device a highly idealized calculation was made. With the assumption that the magnetic field strength is one kilogauss, the distance between the plates is two centimeters, and the water velocity (salt water) is one meter per second, the calculated output voltage is two millivolts. The circuitry involved was designed with that approximation in mind.

4.2 INITIAL EXPERIMENTS

The first experiment was performed with the similar conditions as assumed in the calculation except that brine was used instead of seawater and higher velocities than one meter per second were used. The plates utilized were brass and the signal was amplified by an operational amplifier with an FET high input impedance buffer stage, Figure 4.1a. The results of this operational were highly successful, in that approximately linear reproducable results were attained. At the same time it was determined that the amplifier was much too temperature sensitive for our purposes.



b. AC Instrument



a. DC Instrument

FIGURE 4.1 Magnetohydrodynamic Current Meters

A second amplifier was built which was less sensitive to ambient temperature. Preliminary experiments using a brine of density close to seawater indicated that there was a potential layer build-up on the electrode plates resulting in spurious potential differences. There appeared to be two possible solutions to this problem:

a. using inert electrodes

b. using an AC magnetic field.

Both of these systems were designed and built to be tested at Castine.

4.3 THE DC MAGNETOHYDRODYNAMIC CURRENT METER

The DC device was built with first carbon, then brass electrodes. A 900 gauss permanent horse shoe magnet was placed over a PVC tube containing the electrodes. The flat electrodes were placed in the circular pipe which obstructed the smooth flow in the pipe. To improve the flow in the pipe two plastic ramps were placed upstream and downstream of the plates. The amplifier was placed in a watertight PVC tube with end caps.

The tests with carbon electrodes were not successful probably due to the small size of the carbon rods and perhaps also due to turbulence. The carbon electrodes were replaced by brass electrodes. The earlier laboratory experiments were confirmed in the ocean. The device only operated to the extent that the direction of the water through the instrument could be detected.

4.4 THE AC MAGNETOHYDRODYNAMIC CURRENT METER

The AC device had carbon electrodes about 1½ inches square placed 1½ inches apart. The electromagnet had an inductance of 104 millihenries. The coil was driven by a Wein Bridge oscillator to produce an alternating magnetic field, Figure 4.1b. The signal was amplified and demodulated again.

The device was tested in the ocean at Castine but the magnetic coil shorted out before any decisive results could be determined. The results before the misfortune were encouraging.

4.5 CONCLUSIONS

DC devices using the MHD principle do not appear to be successful in seawater. Potentials other than those due to the MHD principle are large enough to limit the accuracy of the DC current meter.

The AC device should be capable of avoiding the spurious DC potentials and could provide a suitable current meter.

5. THE DEVELOPMENT OF AN UNDERWATER CURRENT DIRECTION METER

5.1 INTRODUCTION

Many current meters in use today are complex and expensive. This is very limiting to someone wishing to make a current study without vast amounts of financial support. Simpler units which record in analog form require much time to analyze the data as it must all be reduced by hand. These limitations led to the following question:

> Can an underwater current direction meter of simpler and less expensive design than existing devices be developed, while retaining the same or improved accuracy, utilizing a system to have all the recorded data automatically processed and converted to a form for direct input into a computer?

5.2 DESIGN EVOLUTION

The project began on paper as a slow evolution of a simple mechanical, remote reading, wind vane. Problems and design needs soon became apparent. No cables or mechanical rotors should extend outside the pressure housing. It should be totally self contained with no surface tethers or support systems. Also it would not be practical to moor it if a diver was needed to orient the device once underwater. It must be self orienting or have its own reference point.

The later of these was most important in determining the design. It brought about the idea of a compass used as a reference point, about which the housing turns. The difference between the two can be used to determine the current direction. Next, if the device was to have no surface link, it must record the current direction and the recording device must be inside the pressure housing. This led to the choice of film as the recording medium. It would be cheaper than chart recording and is capable of recording numerous kinds of data in several ways. Further its compactness adds to its versatility.

The current meter began to develop around a compass and a camera. The first thought was a compass card on a bearing. The card was a binary code disc. On one side of the disc was a row of photo cells along the disc's radius. On the opposite side, a row of lights. They would sense the binary digit which corresponds to the position of the code disc (or compass card). Because of the complexity of this, fluid damping of the compass for more stable operation would not be practical. So a clamping system to hold the card horizontal during coding would be needed. For recording this, a remote light display of the code would be placed in the field of a camera. For reading the data, all that would be necessary would be a line of photocells which the movie could be projected on. They would sense the information frame per frame and be fed directly to an automatic paper tape punch. At the time, no particular thought was given to the mooring system that would direct the meter into the current flow.

Work started on building this idea and it soon became evident that it was not as simple as hoped for. A suggestion of photographing the code disc directly rather than a remote display was made. An extension of this idea led to merely photographing a compass without any coding. This would enable a damped compass to be used which would be less sensitive to deviations from the vertical. The whole system would be much simpler. The drawback was that the recorded information would have to be coded later at the time of data reading. This was not considered a sacrifice as it tends to keep the underwater part of the system simple and puts the complex part on dry land. Also if a number of units were to be used, only one coder would be necessary rather than duplicating it in every unit. The idea was beginning to take a good shape.

A small battery powered Super-8, cartridge movie camera was purchased. It needed to be very simple, fixed focus, no electric eye, and yet it needed one

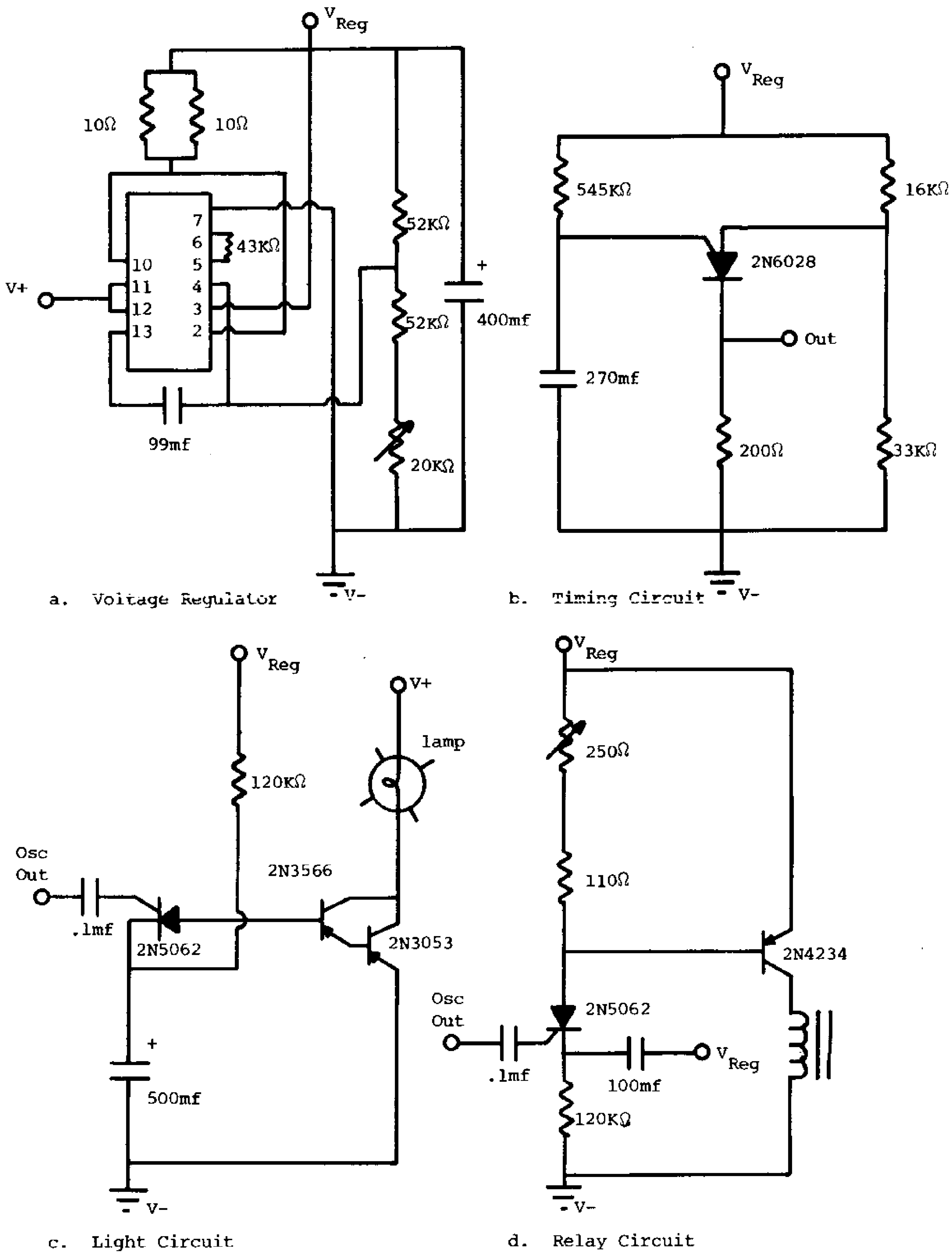


FIGURE 5.1 The Circuits for the Current Direction Meter

more sophisticated feature; to be capable of electrically triggered single frames. Not all of these features were to be found on a cheap camera. Modification was necessary. A Konica camera seemed best, as it could be readily disassembled to be worked on. A spring which gave extra tension to the shutter button was removed, along with the shutter release button. A 24 volt relay was mounted on the camera face with a plunger extending into the camera to push the release pedal. The contacts were removed from the relay. By short pulsing of the relay, a single frame could be made consistantly. The camera is designed so that once a frame is initiated, it continues until it has completed one full frame.

Next a quick acting compass with good damping and a contrasting colored needle was needed for the system. A Boy Scout Silva compass filled the qualifications. It also worked accurately at positions far from level, a definite plus for undersea operation.

With a compass and a camera, a timing circuit to control the data recording was needed. The unit should run for a week unattended. That would be more useful than one needing daily attention. The limiting factor in how much data could be recorded was the number of frames on one roll of film. Thus, a period of 3 minutes between pictures was chosen to maximize the data and still retain a weeks working period per roll of film. The circuit used (Figure 5.1) was designed and tested by several weeks of continuous operation to check the timing period and battery life. The battery life should exceed a months continuous running. The period was determined to be 3 minutes $\pm$ several seconds. Not accurate enough to be the time base of the data so a watch with a date on it would be added to the field of view for checking specific times. The circuit would then serve the purpose and its relative simplicity blends in with the basic simplicity of the whole device.

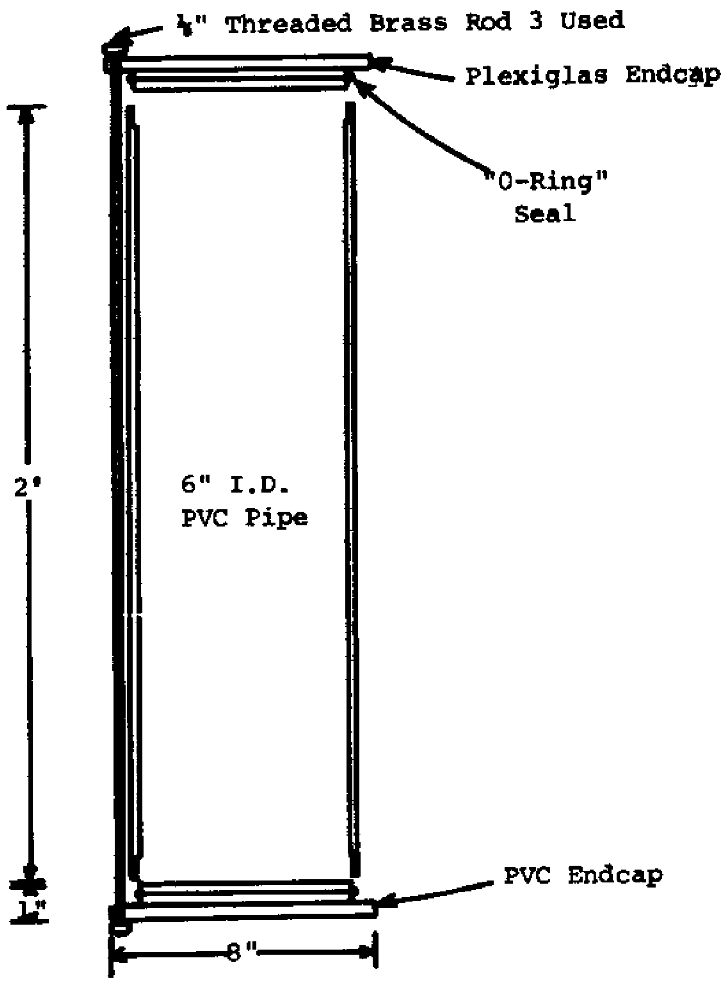
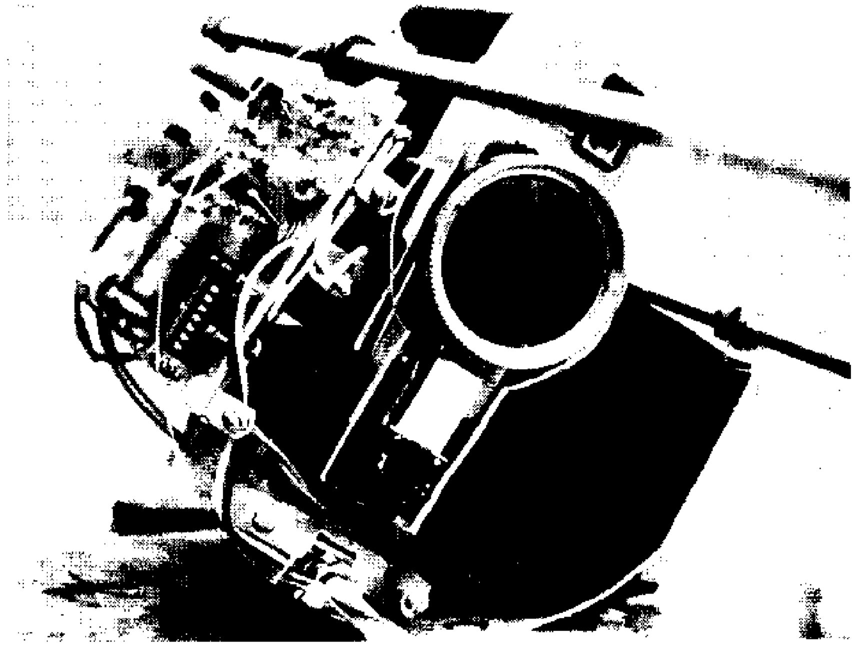


FIGURE 5.2 Current Meter Waterproof Housing

The internal parts still lacked one key ingredient, the means of photographing a compass and watch in a field only 3 x 5 inches with a fixed focus camera. A system of close-up lenses was needed. Determination of the needed lens was made simple by use of a thru-the-lens Super-8 camera with a zoom which included the focal length of the Konica Camera. The zoom was set for the focal length of the Konica and the focus set for 6 feet (the distance the Konica is fixed at). Then closeup lenses were placed in front of the lens and the subject viewed. The camera was moved in and out until in focus on the subject. Then the field of view was checked to see if it included the whole compass and watch. When the proper field was found, that was the close-up lens to use. The distance from the close-up to the subject would also be the distance for the other camera. A +3 close-up lens was found to be proper for the job and one was acquired in the closest size to the camera filter diameter. Two adapter rings were required to reduce from the lens size to the filter size. Next, with the distance from subject to lens, 11 5/8 inches, it was possible to determine the waterproof housing size needed to contain this package.

The housing had to be non-magnetic and non-corrosive in seawater, so PVC pipe of 6 inch diameter was chosen using "O-ring" sealed plastic endcaps. The length chosen was 2 feet so that several extra inches, would be left for future additions or changes. The endcaps were machined, one from 1" PVC and one from 1" plexiglas. The clear end would enable internal observation of the sealed unit during testing of watertightness and operation. Brass tie rods were used externally to hold the endcaps in place, Figure 5.2.

The internal parts were assembled on a frame made of three threaded brass rods and 3/16" plexiglas platforms; the compass and watch at the bottom



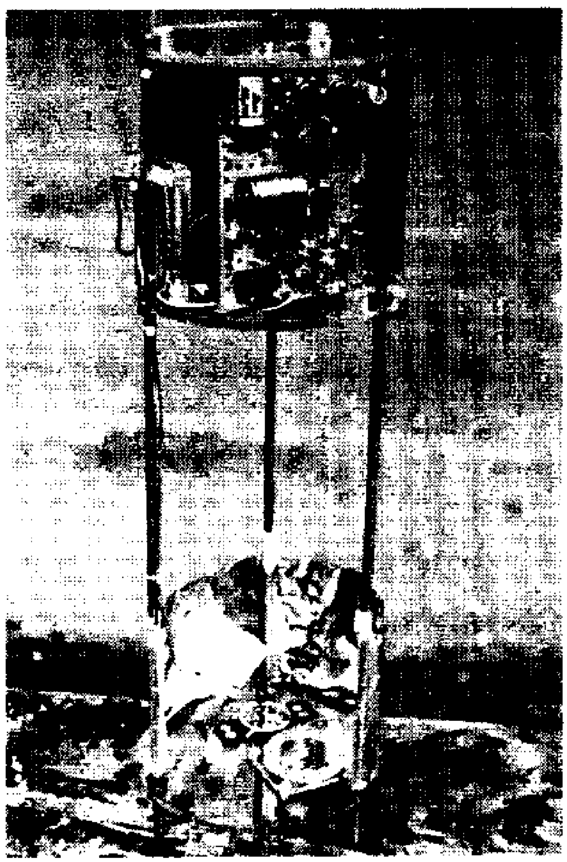


FIGURE 5.3 The Internal Components of the Current Direction Meter

and the camera, electronics and battery at the top (clear of water in case of partial flooding), Figure 5.3. The 11 5/8 inch distance between compass and camera lens also eliminates magnetic deviation due to the iron parts in the system. The watch gives a 1-2 degree error. This error may later be removed by relocation of the watch or by its removal.

The internal assembly slides into the housing with a snug fit and will rotate to any desired position relative to the housing. It is then held in place by friction at either end by a ¼" piece of armaflex insulation when the endcaps are secured in place.

5.3 INITIAL TESTING

The assembled housing was lowered to a depth of twenty feet and found to be water tight.

The camera was loaded with Tri-X film ASA 200 and allowed to run for 5 hours photographing a watch. Then the film was hand processed to check the results quickly. It was developed for 5 minutes in Dektol developer 1:1 solution. The result was a negative but it was sufficient for examination. Several frames were enlarged and printed on photographic paper. The image was clear and properly exposed, thus the small light source would suffice. One problem was noted. Rather than a single frame each 3 minutes, 3 frames were being exposed.

The 3 frame problem was determined to be a mechanical problem of the relay. It would not react strongly enough at the pulse length required for a single frame, to fire the camera. This problem can be remedied by a change of relays or by a change in circuitry for finer control. Data could still be recorded adequately and this problem was set aside for later revision.

At this point, all systems were functioning and only a directional mooring system remained to be developed. This turned out to be the largest problem on the project.

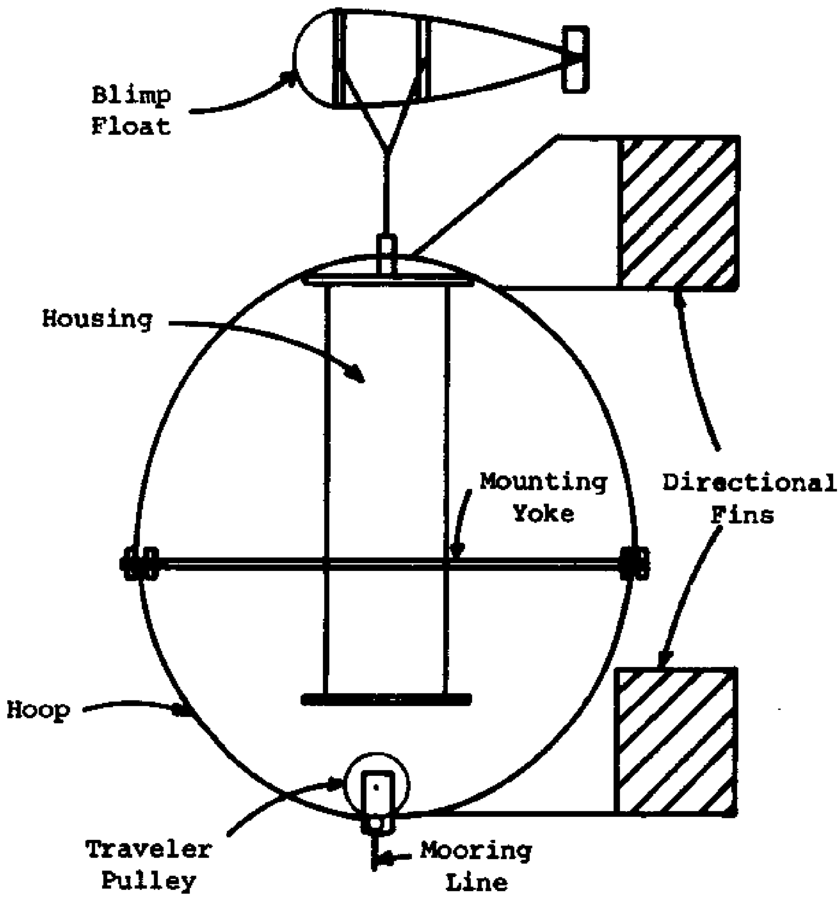


FIGURE 5.4 U.C.D.M. with Blimp

5.4 OCEAN TESTS

The first consideration of the mooring was a system to keep the housing vertical at all times for proper compass operation. The method decided on, instead of a gimbals, was a hoop with a pulley running on it, Figure 5.4. The more the current pushes the mooring line off center, the farther off center the pulley pulls. The housing is positive bouyant and ballasted at the bottom so that it tends to float vertically. The bouyancy of the housing keeps the mooring line taught. It was expected that the hoop would align itself in the current flow without additional fins but this proved unsatisfactory when tested.

A way of suspending the housing in the hoop was devised so that the hoop could be removed for loading the device into the housing. The hoop was made from copper and the mounting for it of PVC and plexiglas, for non-magnetic, non-corrosive operation. Various fin designs were then tested to check their characteristics. This was done by placing a mooring in a spot with a regular current flow. The device could be pulled down by means of a pulley on the mooring and observed from the surface as it reacted to the current. The greatest problem observed was a slow random oscillation, not in direction, rather in the mooring line. The oscillations made no directional error greater than $\pm$ 15 degrees but was still significant. This was on a mooring line of about 17 feet. When that length was reduced the oscillations were not as great. The movements seemed to be due to the cylindrical shape of the housing (vortex shedding) which would create turbulent water behind it and alternately pull from side to side.

A solution to this difficulty was sought. As the problem seemed related to the housing shape the first consideration was to change its shape or turn it horizontal for better flow through the water. This was set aside as too involved for the time available. One thought for improving the existing unit was a fairing over the hoop to change the shape of the housing. When tested it proved not the solution. It acted like a sail in the water because of a slight asymmetry. The oscillations were enlarged rather than reduced. The best configuration of fins was a pair of fins located above and below the cylindrical housing in the relatively clear (unturbulent) water. This configuration tended to maintain its alignment even as it wandered on the mooring line. The fins were of equal area and symmetrical placement above and below. The hoop and pulley worked well in all tests; keeping the unit almost perfectly vertical.

While the unit was still not as stable as eventually desired, it was decided that due to the irregularities in the water flow at the test mooring (due to surrounding pilings and dock floats) that an open water test should be made of the whole unit. It could then be seen how irregular the data would be as a result of these oscillations, or if they would tend to average out.

The internal unit was checked once again, loaded with film, watch wound and set, and then loaded into the housing. Then the unit was moored in Holbrook Cove on 7/16/73, Figure 5.5. The mooring method shown was used so that the float for locating it and retrieving it would not interfere with the units operation. It was put in at 3:25 p.m. and removed the following day at 4:48 p.m., 25 hrs. and 23 mins. later. Immediately after placement a dive was made to observe the system and check that lines were not fouled. Another dive just before removal was made. All was clear and operating well in both cases.

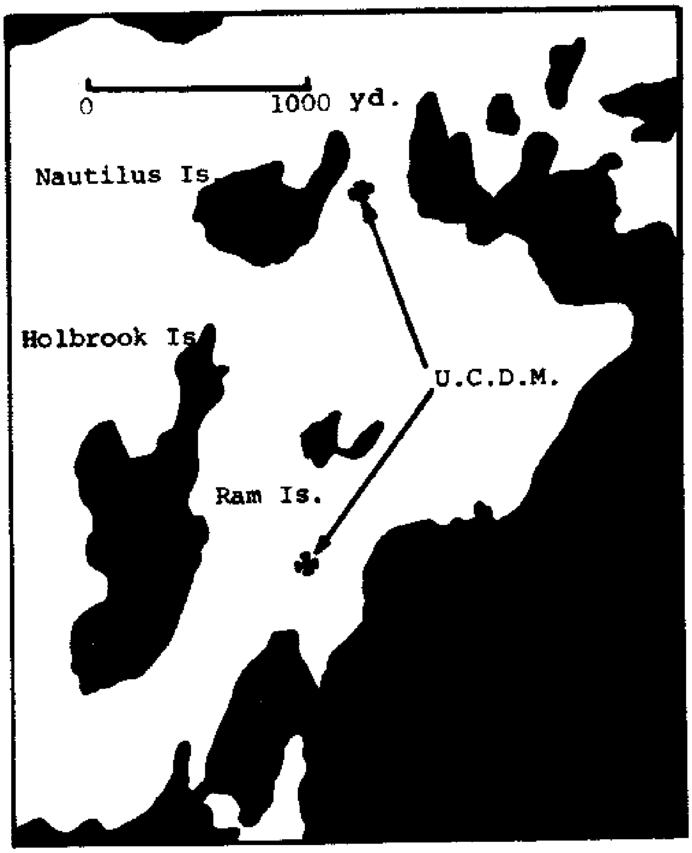
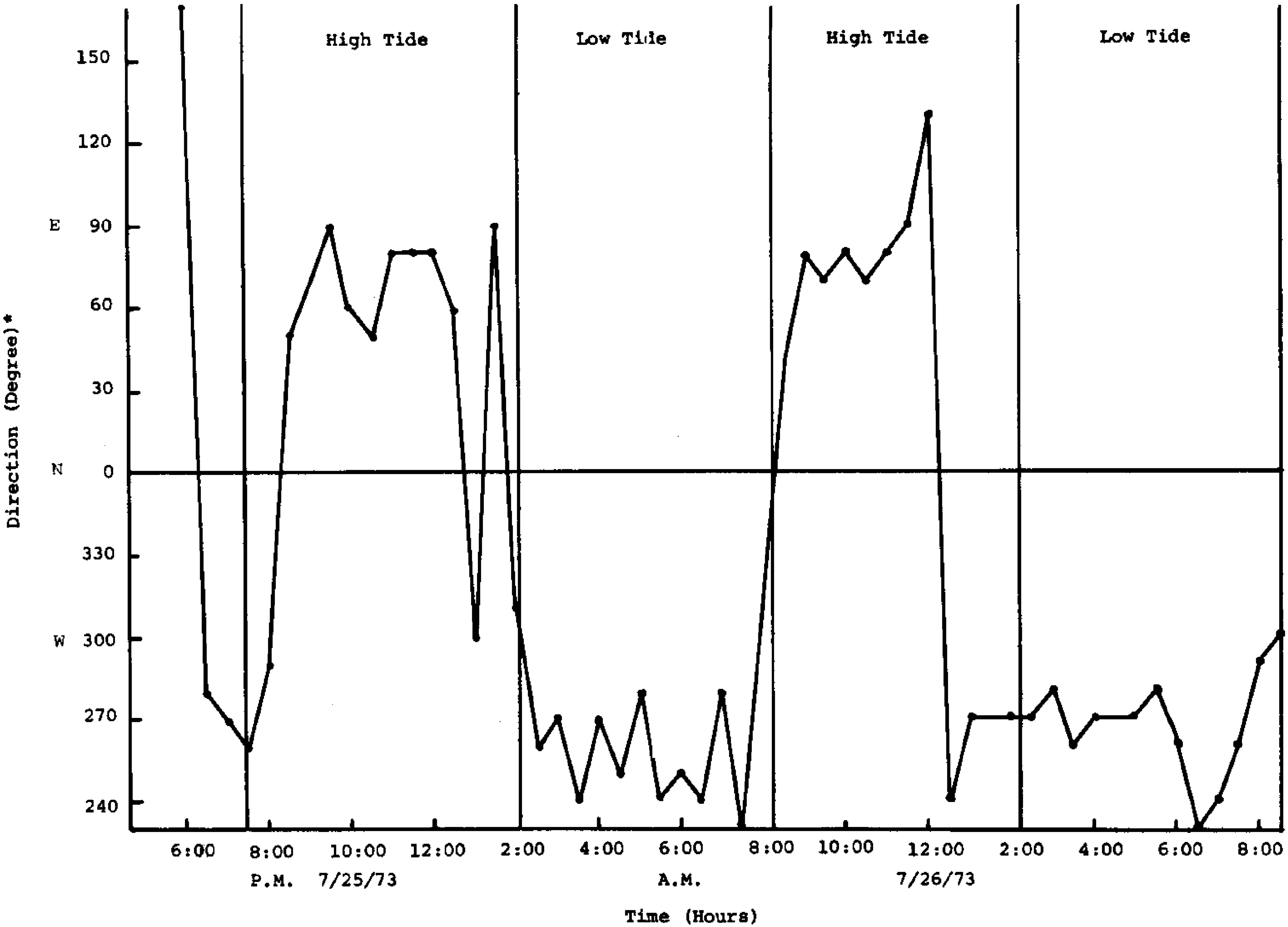


FIGURE 5.5 The Positions of the Test Moorings for the Current Direction Meter in Holbrook Cove

The unit was then rinsed in fresh water and opened. The container was dry and the camera and light still functioning on a 3 min. cycle. The film used was Tri-X ASA 200 and was processed by hand for immediate observation of the data. A print of a frame of the movie was made to analyze. The results were clear, well exposed and tended to show the tidal trend, reversing when the tide did so and going slack or random when the water went below the sandbar and the current flow ceased. There were still 3 frames at each 3 minute period, but it remained consistant. The movie, when projected showed current change with respect to time. The results were definitely positive and useable. They indicated that the system as a whole, functioned well and it was reasonable to go ahead with further work toward stabilizing the mooring.

The system decided upon was to add more bouyancy to the system to reduce the frequence of the oscillations. It would be similar to adding mass to a system with a constant force on it. Consideration then had to be given to how the bouyancy could be added. A subsurface float above the housing, on a close tether was considered, but the shape of the float needed to be thought about. If an irregular float were used it could make the oscillations more severe. It was necessary to have a float with minimal drag in the water. The shape decided upon by virtue of its low drag to length ratio was a blimp, much like the WW.II barrage balloon. The length was 3 times the diameter in a teardrop shape, Figure 5.4. The same virtue that made it good for barrage balloons, would also provide what was needed in the mooring system. The blimp when pushed off center becomes an airfoil and produces lift which acts to right the tether to its upright position. The blimp also tends to point into the current flow. It is necessary to bridal the blimp and tether to it at a point

FIGURE 5.6 Current Direction vs. Time



*Note: An East Currrent Flows from the East.

close to the center of bouyancy so that the blimp is perpendicular to the mooring line when in the stationary upright position. Thus, it must be level. It must have a 4 point harness so that when off-center it does not wobble or oscillate. A float in this shape was turned from fine grained styrafoam and fins were cut out of ¼" plywood and glued into the tail of the blimp. Two harnesses of wire were attached, one ahead and one behind the center of bouyancy. Then 4 wires were run to a point below the center of buoyancy from the center of the blimp on the two harnesses. This was then pulled down a foot below the surface at the test mooring and observed. At first it wandered and was unstable because it was not level in the stationary state. Several adjustments in the length of the harness lines to level the blimp brought it to a stable state and it remained aimed into this current without wandering for a 10 minute test period. This was the desired result. It never appeared to pull off center and the mooring line remained vertical.

Now what remained was to tether the float to the U.C.D.M. (Underwater Current Direction Meter) and run another open water test for a comparison of stability. No test at the test mooring site with the blimp and U.C.D.M. was made due to lack of time. The unit was moored in Holbrook Cove and left for 26 hours and 45 minutes. It was placed in a new location in about the same depth as the first test, Figure 5.5. It used High Speed Ektachrome film ASA 160 rather than Tri-X, to be processed by Kodak. The blimp was tethered 6" above the housing by a wire tied to the harness. In this test, no observation dives were possible as the unit was retrieved after dark. No fouling or tangles were present when it was removed and it seemed to be working stablely.

Data conclusions from the processed film indicate regular tide changes at around 6 and ½ hour intervals, Figure 5.6. A period of between ½ and 1½ hours of unstable readings were found around the time of tide change or slack tide. During the steady change, the readings remained within a range of 20 degrees or a 5½% accuracy. Some discrepencies in the data may have been caused by boats and the shallow mooring. The data is readily read while in a projector or editor with an accuracy of ± 3 degrees direction. The current direction shifted between almost due West and East. The new results with the blimp float appeared more stable than the first test. This suggests that improved operation can be achieved and that this new shape (a blimp) is on the right track toward stabilization.

5.6 CONCLUSIONS

The project proved successful in enough of the proposed objectives to warrent further time and work to improve and complete the total system. A simpler and less expensive working device was built and successfully tested. Data was recorded and is useable for tracing current trends. There are still many areas to further the development of this Underwater Current Direction Meter.

While the system works, it did not reach all the goals hoped for. The stability and inturn, accuracy are not satisfactory. This will hopefully be achieved by building the system into a better shaped housing. Perhaps enclosing it in a blimp shaped fairing like the mooring float used. Accuracy might also improve with more continuous recording of data (at shorter intervals). Either a more accurate timing circuit or an accurate reset of this one would improve correlation between data and time. This will be necessary when automatic decoding is achieved. The mechanical problem of the camera relay should be easily fixed by replacement of the relay with a faster acting more powerful one which would enable consistant single frame exposure.

Further completion of the proposed system would involve constructing a shaft encoder for automatic analysis of the filmed data (this part of the project was suspended due to time). Using the data from the tests of the U.C.D.M. a decoder could be built and tested for future use of the U.C.D.M.

The proposed coder would use a rotary scanning light sensor which would have the compass image projected on it. It would sense the position of the compass needle and stop when aligned with it. On the other end of the shaft would be a digital code disc which would generate a binary number to correspond to that position. That signal would then be fed into a paper tape punch and recorded. Then the film is cycled to the next frame; the scanning begins, then the recording and so on. This will all occur rapidly, hopefully at the projectors normal speed. A system such as this will ease greatly the use of the current meter, by eliminating tedious hand viewing and decoding of data.

6. SIMPLE RECORDING TIDE AND WAVE HEIGHT GAUGES

The measurement and recording of tide height and wave height can be achieved by a variety of devices. Purely mechanical devices using floats and strip charts can be used, and pneumatic systems, as described in a later section of this report, have been utilized. A very simple electrical system is described here where the device in the water is extremely inexpensive although the recording apparatus remains similar to other arrangements and is the most expensive part of the system.

The purpose then of this project is to design a simple and inexpensive tide guage and wave guage that will function properly. In addition, the devices should be able to operate continuously over a reasonable length of time with a minimum of maintenance required.

6.1 THE DESIGN AND CONSTRUCTION OF AN ELECTRICAL RESISTANCE TIDE GAUGE

The principle upon which this gauge is based is that salt water is a conductor of electricity. Keeping this in mind, a string of resistors is soldered together at regular intervals (2.4 inches). Using a circuit which produces a constant current as the power source, as shown in Figure 6.1, a current runs through all the resistors that are out of the water. The salt water effectively short circuits those resistors that are submerged. Since the current is constant, the voltage is directly proportional to the resistance, or the number of resistors that are out of the water. A commercial recorder then measures and records the voltage over a period of time. From these conditions, it can be seen that the value of the resistorsused in the string is critical. They must be large enough to make the resistance of the salt water negligable, but they must be small enough to permit the current to pass through them.

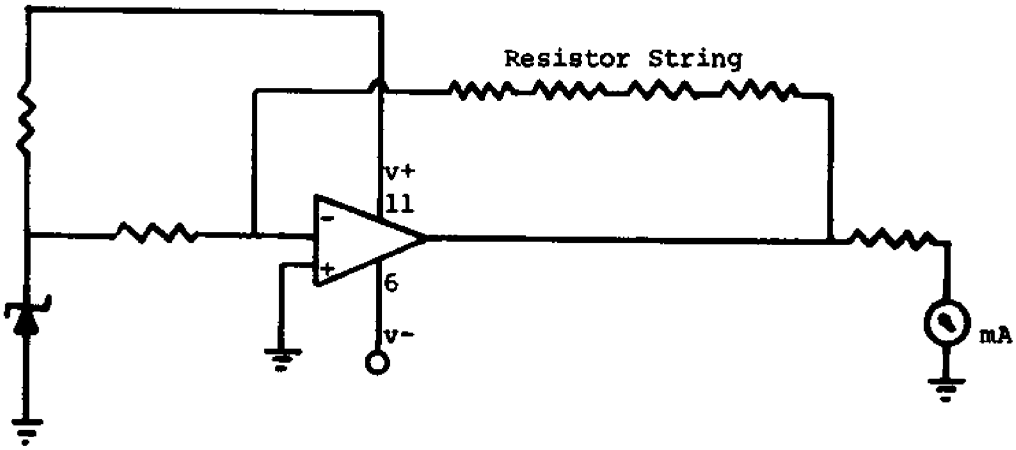


FIGURE 6.1 The Constant Current Circuit

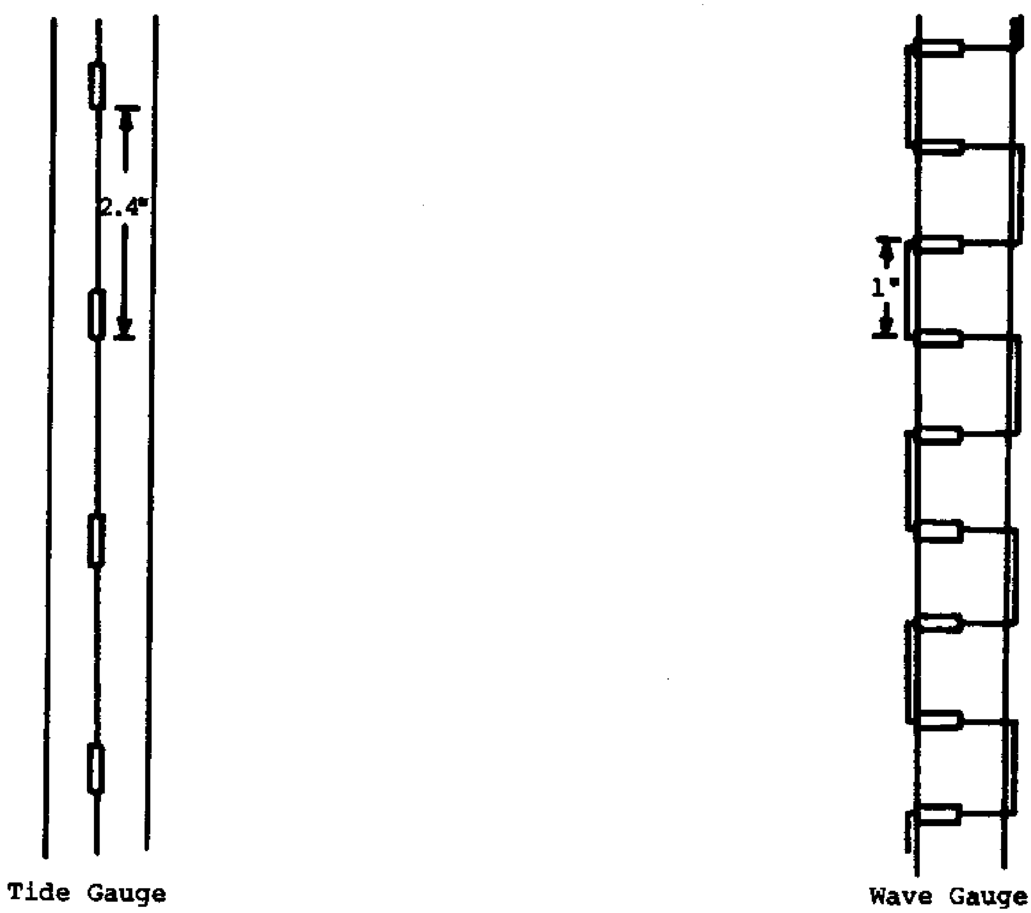
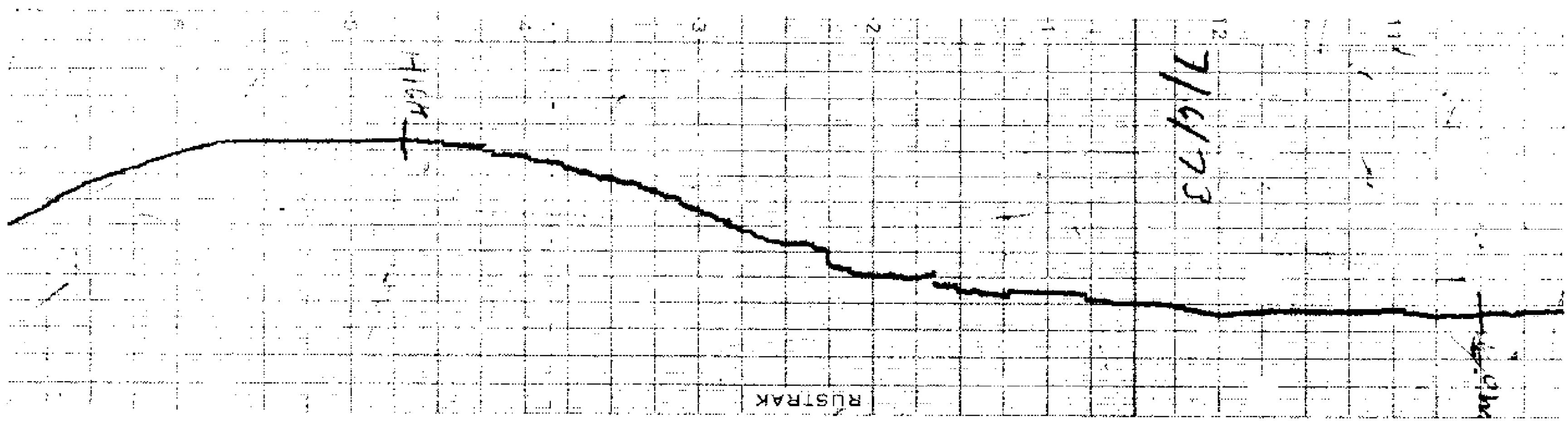


FIGURE 6.2 The Resistor Arrangement in the Tide and Wave Gauges

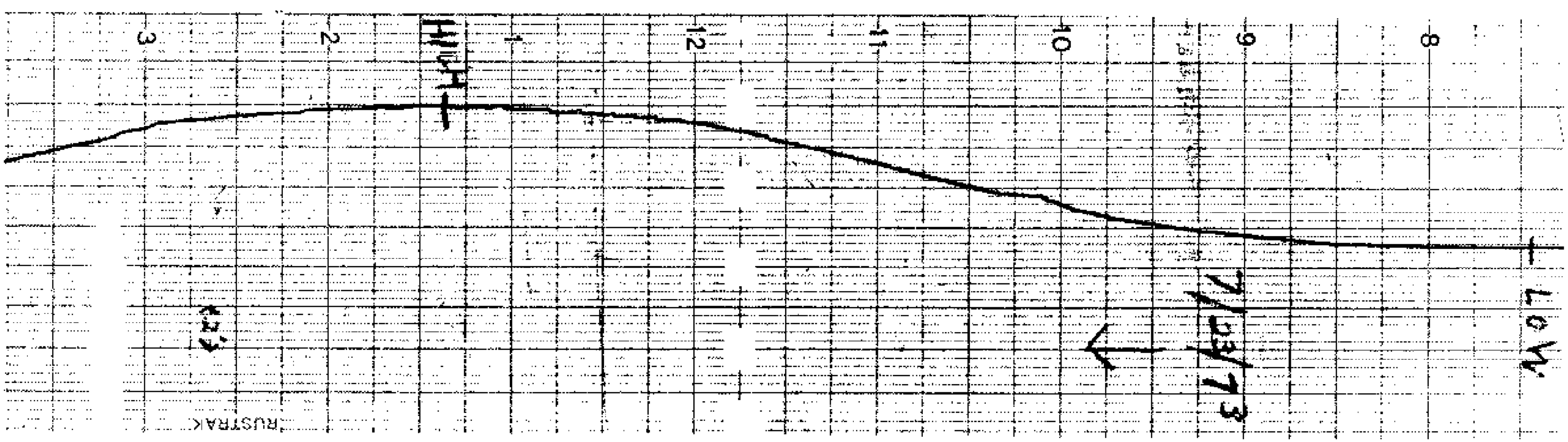
The string of resistors is entirely enclosed by PVC pipe to damp out any local disturbances on the water surface, as shown in Figure 6.2. Water may enter the tube through small holes hear the bottom of the pipe. For convenience in transporting the tide gauge, the tube is divided into three lengths of pipe, each five feet long, and each containing five feet of resistors. Each string of resistors is held in place by being soldered at each end to a thick piece of uninsulated buss wire. When they are brought to the desired site, the pipes can just be screwed into couplers joining the lengths. Connections between the end resistors of two separate pipes is made by joining the pieces of insulated wire running out of the side of the pipes on each end.

To help prevent corrosion, the lead from the bottom resistor is not connected directly to the wire leading to the top. Instead, uninsulated wire is coiled around the pipe about an inch or two below the lead of the bottom resistor. When the negative end of the circuit is connected to this end, this serves as the sacrificial anode.

The circuit board, the recorder, and the two six volt lantern batteries are all enclosed by a removable watertight plexiglas case mounted on a one inch thick block of PVC, upon which two mounting brackets are fastened. This case protects the delicate instruments from the surrounding environment, and insures that they will function well during all kinds of weather. Connected to the PVC block and surrounding the plexiglas case are three strips of brass which are held together by means of a hinge at one junction and a lock at the other one. This arrangement increases the security of the device.



a. Before Modification



b. After Modification

FIGURE 6.3 The Tide Gauge Records

6.2 THE DESIGN AND CONSTRUCTION OF A WAVE HEIGHT GAUGE

Using these same principles, a wave gauge was designed and built in Maine during the summer. Figure 6.2 illustrates the similarities and differences between the tide and wave gauges by showing a small portion of each device. The basic difference is in the fact that the tide gauge resistors are shorted by the seawater inside the tube which protects them from the waves while the resistors of the wave height gauge are shorted outside the tube. This results in a different method of construction with the resistors inserted in holes in the PVC tube. All the holes where the resistors were inserted as well as the two ends were sealed with epoxy. This made the PVC pipe watertight, insuring that an out-of-phase signal would not be recorded from the inside of the tube. Except for the differences just mentioned, the wave gauge was operated in the exact same way as the tide gauge.

6.3 TEST RESULTS AND INSTRUMENT DEVELOPMENT

Initial testing of the tide gauge revealed that two variable resistors needed to be adjusted, which was expected. The results obtained during this time were somewhat similar to a sine wave, but it was a little erratic. Figure 6.3a shows an example of this. At a certain point on the chart, a step always occurred on the record as indicated on the figure. Thinking it might be a faulty resistor, the tide gauge was taken out of the water and the string which was believed to have a bad resistor contained in it was taken out and tested but every one was still perfect. As mentioned previously, each five foot length of resistors was held together by an uninsulated piece of buss wire which, along with the soldered outside connection of the insulated wire, went outside the tube and was directly exposed to the sea (see Figure 6.4). Such an obvious oversight resulted in the tide gauge becoming a sort of wave gauge around the

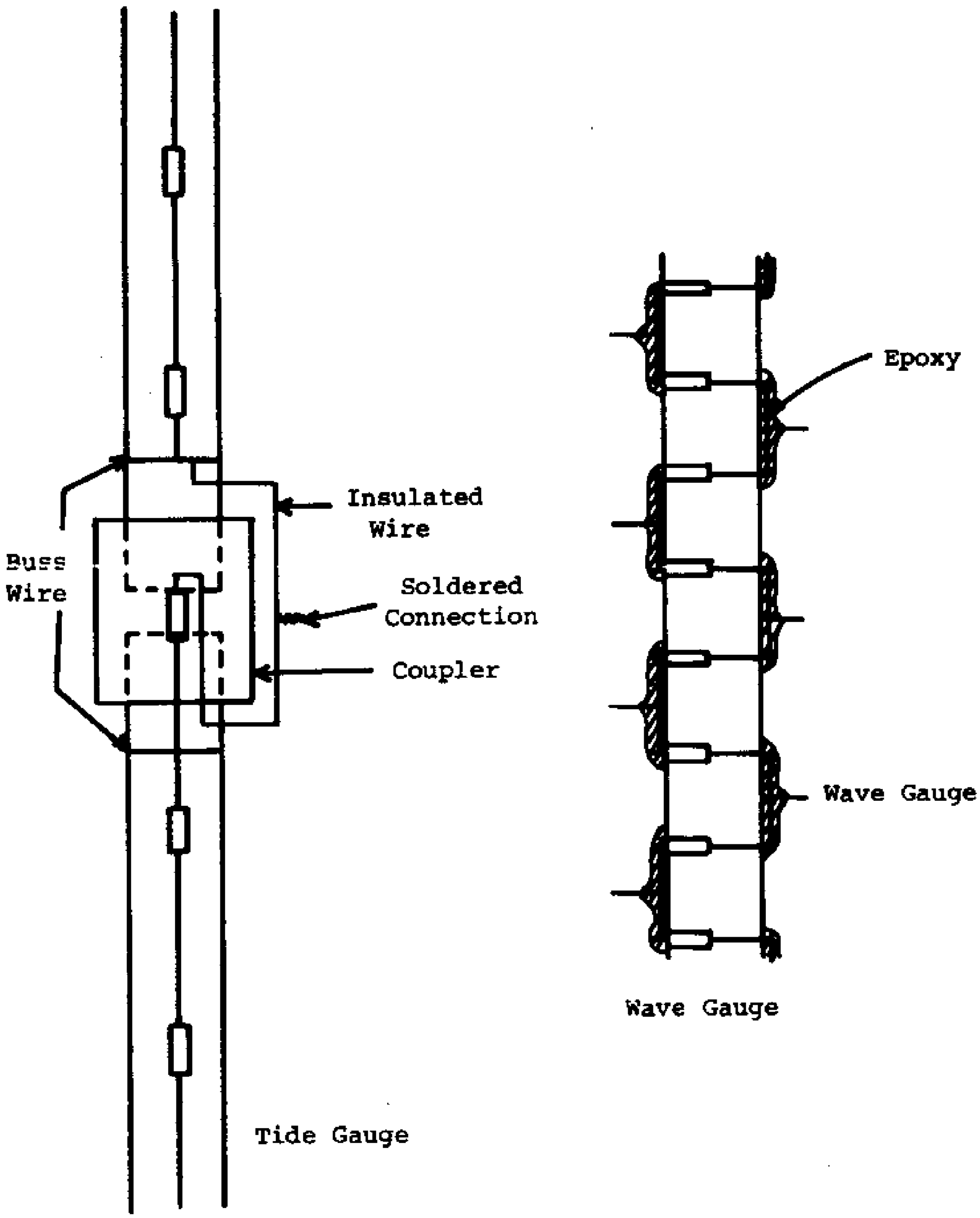


FIGURE 6.4 Details of the Joints in the Tide and Wave Gauge

junctions of the tubes at the five and ten foot marks and accounted for the steps and the erratic appearance of the tide records.

After this error was quickly corrected by sealing the buss wire and the soldered connection with epoxy, the tide gauge was put back in the water. Figure 6.3b shows the kind of results that were then obtained from it after it was returned to the water. It was obviously operating successfully.

Before testing was even begun on the wave gauge, it was realized that it would not work without a modification. As the waves hit the wave gauge, the resistors would be shorted out, but they would remain wet for a short period of time. This would, in effect, continue to short the resistors even though the wave crests would have already passed. Figure 6.4 shows the change made: a piece of wire was added to the middle of each resistor wire while everything except the tips of the added wires was sealed in epoxy. It was then ready to be tested.

Due to time limitations, only one test could be performed on the wave gauge, and this was on a fairly calm day. In spite of this, the results were very encouraging, and further development of this idea is recommended.

Useful data was obtained from the tide gauge during its last week of operation. At this time, it gathered information in the Holbrook Cove area of Penobscot Bay, which is near Castine. Hourly readings of the tide in Castine itself were taken and recorded. By combining these data, phase shifts and tidal height differences can be obtained between Castine and Holbrook Cove. Figure 6.5 shows a comparison of the graphs of each.

It can be seen from this graph that there is both a tide height difference and a slight phase shift between the tides in Holbrook Cove and

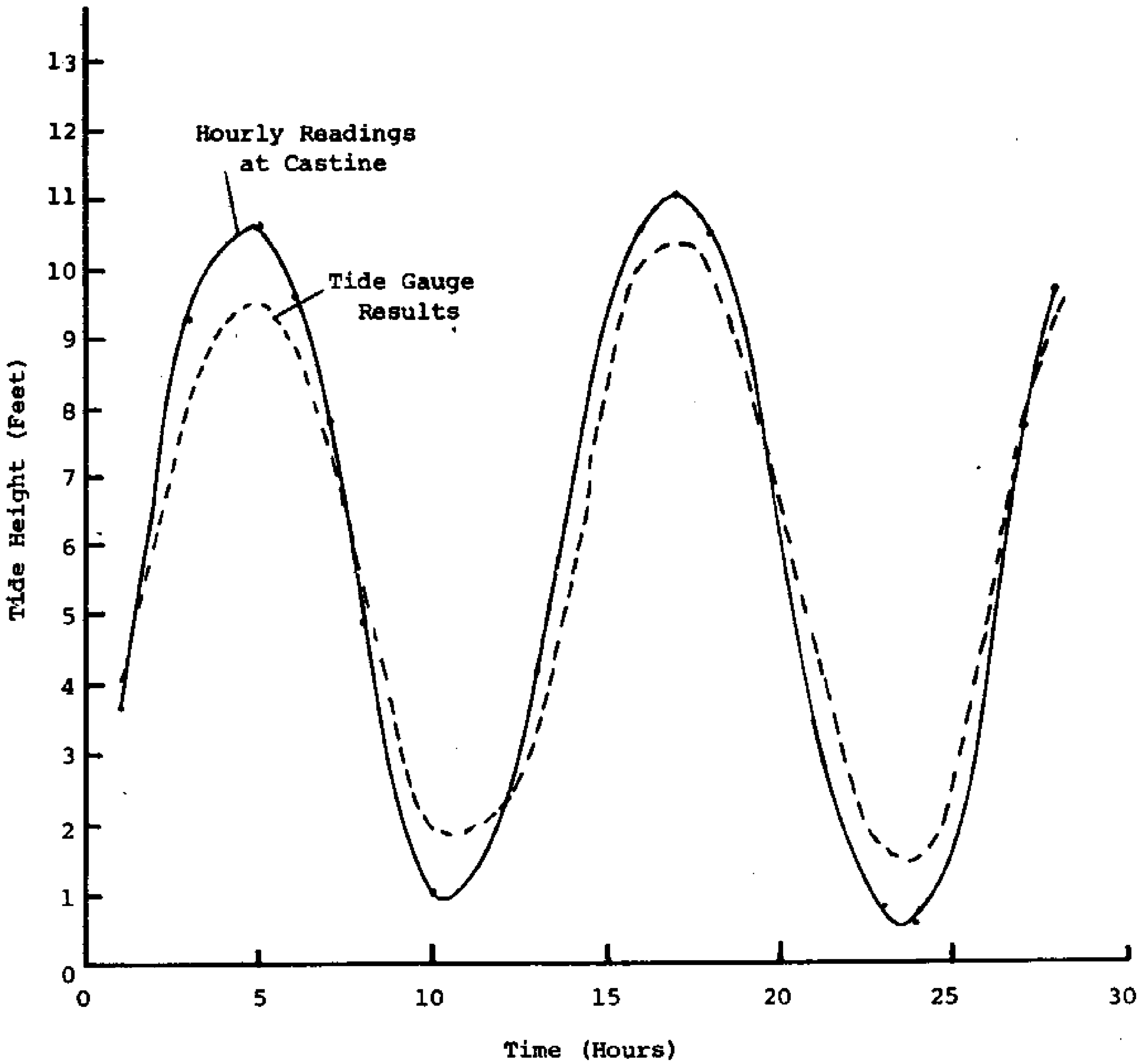


FIGURE 6.5 Comparison of Measured Results at Castine with Gauge Measurements at Holbrook Cove

Castine. This is due to the fact that water must forced into and out of Holbrook Cove. Because of this resistance, the high tides are about a foot lower and the low tides are about a foot higher. The slight phase shift is also a result of this.

One problem with the recorder, however, was encountered in using the data. The recorder was powered by a six-volt lantern battery, but this battery did not always put out exactly six volts. This resulted in the chart paper moving either more or less than one inch per hour, which was the intended speed. When a new battery was installed, the chart would move faster than normal, but after a day or two, it would move slower. Assuming that speed change due to voltage drop versus time is approximately linear for small drops in voltage over a period of two or three days, the gain or loss of time by the recorder per hour can be predicted using a simple analysis. Of course, this can be done only if two points are known, and two points were known. After 27.75 hours of operation, the recorder had gained 35 minutes; after 74.5 hours, the recorder had lost 175 minutes. In the following correction procedure Δt is the time gained or lost by the recorder in minutes per hour of operation and T is the elapsed time:

$$\int_0^{74.5} \Delta t \, dt = -175 \text{ min.} \qquad \int_0^{27.75} \Delta t \, dt = 35 \text{ min.}$$

$$\int_0^{74.5} (mt + b) \, dt = -175 \qquad \int_0^{27.75} (mt + b) \, dt = 35$$

By calculating the two integrals, and then by solving the two simultaneous equations, m is found to be -0.155 and b equals 3.44. The equation of the line is thus $\Delta t = -0.155T + 3.44$. From this equation, the time gained or lost by the recorder can be determined at any time.

Since voltage drop is almost certainly not linear, a better approximation would result from obtaining many more points than the two just mentioned. This would result in higher order equations which would be more accurate. For the purpose of this project, however, the linear approximation is a reasonably close one.

6.4 CONCLUSIONS AND RECOMMENDATIONS

The tide gauge was successful after modification and it operated for about one month with no signs of corrosion. The wave gauge was inadequately tested but appeared to be satisfactory.

It might be mentioned that the tide gauge gave erratic results during electrical storms so that results taken in such a storm must be ignored.

While the tide gauge was successful in its operation, there are some aspects of it that can be improved upon. The basic design of the resistor string should be changed to be similar to the design of the wave gauge. The string could then be put into a larger diameter tube to be used. There are several advantages to this design. If a resistor is thought to be bad, it would be very simple to test it. There would be no danger of the salt water leaving any water behind as it goes down to slightly short the resistors above the water line. The final reason is that it is easier to assemble.

An addition to the electrical circuit to regulate the voltage would be beneficial for both the tide and wave gauge. With a regulated voltage for the recorder, the problems of it running fast or slow would be eliminated.

Although no adverse results were noticed because of it, the plexiglas case should be enclosed by a screen to help shade the sun and thus prevent the greenhouse effect from taking place. Excessive heat could disturb the batteries, the circuit, and the recorder. A cover would insure that none of these things would ever happen.

A change in the motor of the recorder used for the wave gauge would be in order. The two RPM motor used made a mark on the chart record every two or three seconds. Waves do not, however, take too much longer than this to rise and fall. A much faster motor would be needed in order to see the waves clearly. In this way, entire waves, not just parts of waves, would be recorded.

7. A PNEUMATIC TIDE HEIGHT INDICATOR

A compact, portable tide-height indicator would provide a useful instrument for estuary studies. The gauge could be placed at any convenient spot and would not rely on careful vertical positioning and support, as many tide gauges require.

7.1 THE DESIGN PRINCIPLES

The tide height indicator consists of an air tank supplying air to a pressure regulator which maintains constant discharge pressure, as shown in Figure 7.1. The air then passes through a needle valve which is used to adjust the sensitivity of the apparatus. From the needle valve the air then flows to a fixed underwater nozzle; the air pressure between the valve and the nozzle is measured using a mercury manometer or other pressure gauge.

The flow rate through the system depends on the depth of the nozzle. The pressure drop across the valve, in turn, depends on the flow rate. Since the pressure upstream of the valve is constant, the pressure downstream is a function of the depth (pressure) outside the nozzle.

7.2 THE CONSTRUCTION, OPERATION AND CALIBRATION OF THE TIDE GAUGE

The tide height indicator was assembled as shown in Figure 7.1 except that a pressure gauge was initially used instead of a mercury manometer. The lines downstream of the needle valve were 1/8 inch rubber tubing and the nozzle was constructed in brass with a 1/64 inch diameter outlet.

Several tests were conducted to determine appropriate settings of the needle valve. The pressure gauge was replaced by the manometer because of the lack of sensitivity. Figure 7.2 provides a calibration of the device when the pressure regulator was set at 10 lbf/in^2 with 200 lbf/in^2 air in the tank. It

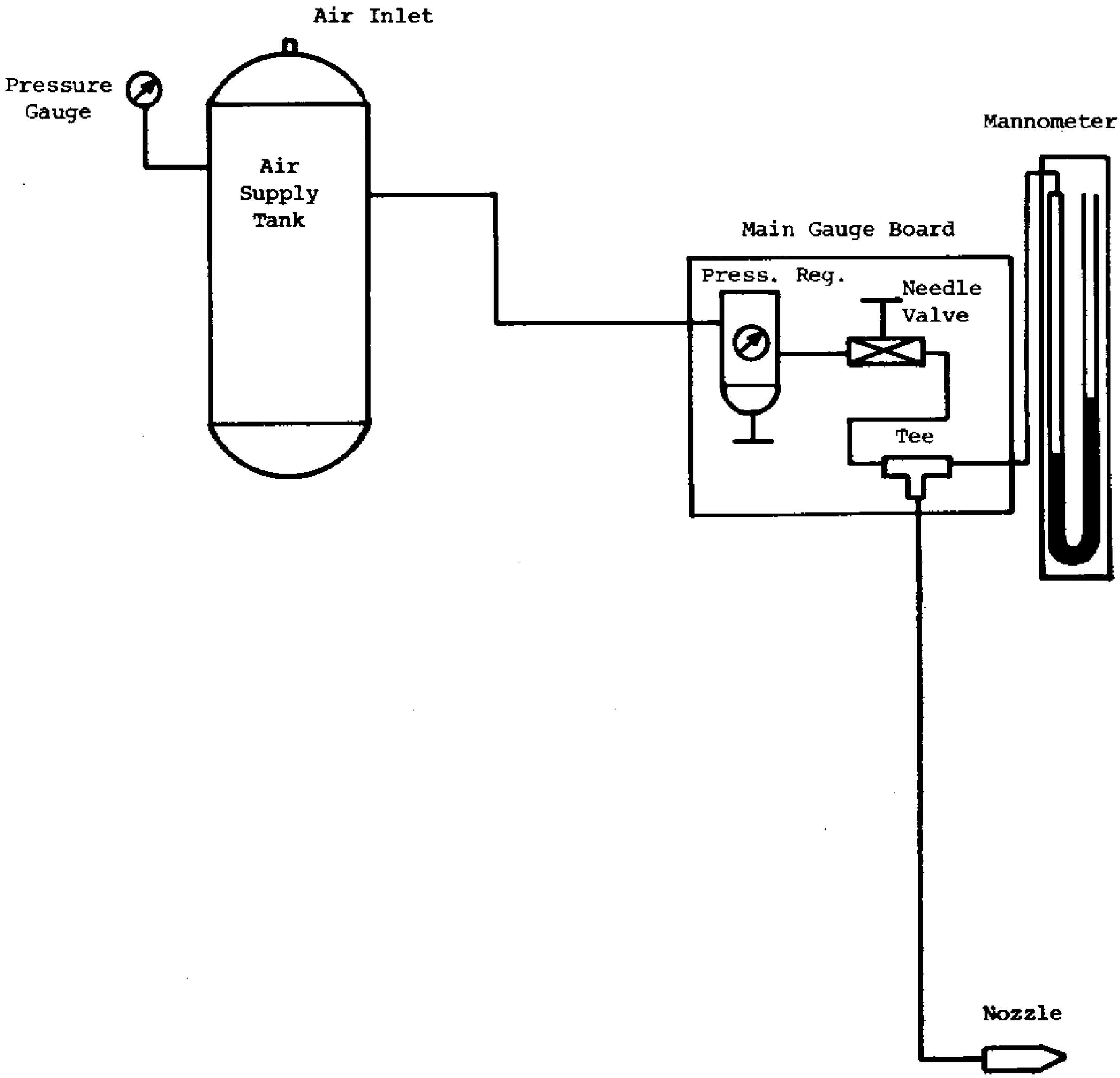


FIGURE 7.1 The Arrangement of the Pneumatic Tide Height Indicator

can be seen that there is an approximately linear relationship between the manometer pressure and the water depth.

7.3 CONCLUSIONS AND RECOMMENDATIONS

An pneumatic tide height indicator has been designed and built which can be placed very easily in any suitable spot where tide height is required to be measured. It was found that a mercury manometer was necessary to obtain suitable results. The calibration of the instrument indicated that there was an approximately linear relationship between the tide height and the manometer reading.

A recording tide height indicator could be provided by replacing the manometer with a pressure transducer and recording system.

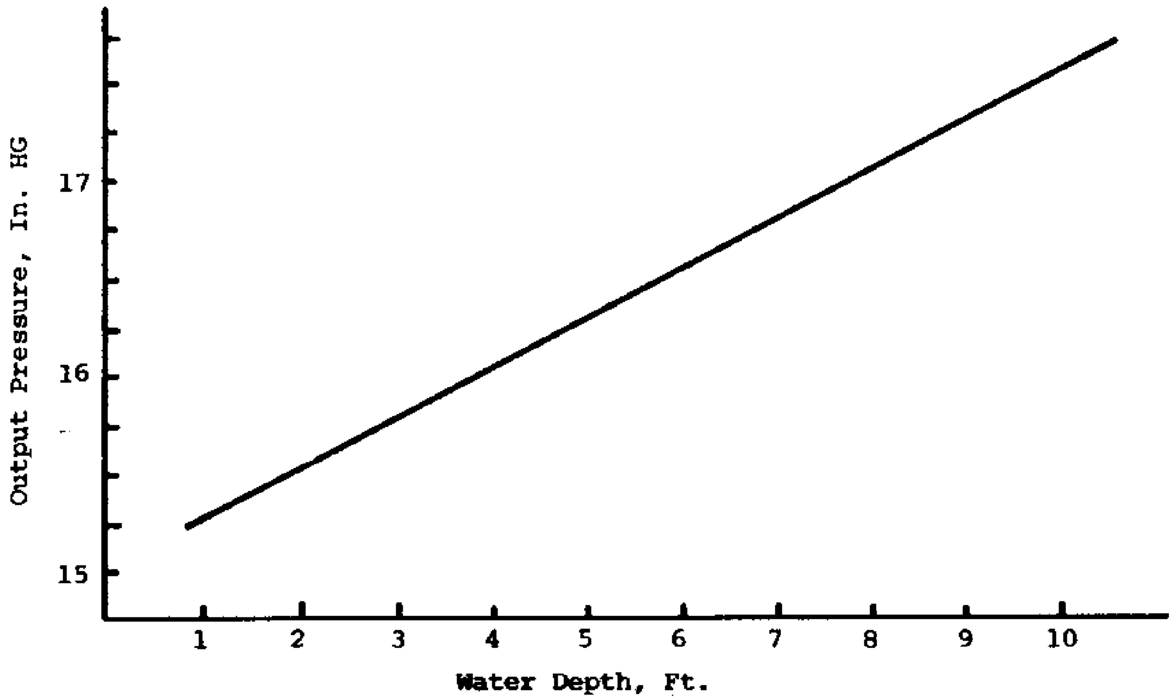


FIGURE 7.2 A Representative Calibration Curve
for the Pneumatic Tide Height Indicator

8. A MECHANICAL TIDE HEIGHT INDICATOR

A simple mechanical tide height sensor was required for placement on a tower to be erected at the northerly entrance to Holbrook Cove. The tide height indicator should have a relatively long response time so that it would show seches and tidal height changes but would not be influenced by wave action. Because of the remote location of the proposed tide indicator the gauge should be easily read, perferably from a distance.

8.1 DESIGN ARRANGEMENT

A diagram of the device is shown on Figure 8.1. A "styrofoam" float of 3 inch diameter and 20 inches long is placed inside a 4 inch diameter PVC pipe. The pipe has a cap at the bottom with a 3/32 inch hole so that the float will not respond to surface waves. A cap is also placed at the top of the pipe with a hole in it large enough to permit the passage of the ½ inch dowel rod which is attached to the top of the float. Funnels are attached to both sides of the top cap to permit the movement of the dowel rod and the dowel joints without catching. There is a pointer at the top of the dowel rod to indicate the tide height on a fixed vertical scale which has one foot markings.

8.2 EXPERIMENTAL RESULTS

The tide height indicator was installed at the dock in Castine during the last week of the Summer Laboratory. The major problem encountered after installation was the "leaning" of the rod at high tide. This problem was solved by providing a track for the pointer to run up. The large buoyancy of the float eliminated any sticking of the indicator. The tide height indicator was installed for testing in a sheltered position where wave action was minimal, so that a true test of the instrument was not made.

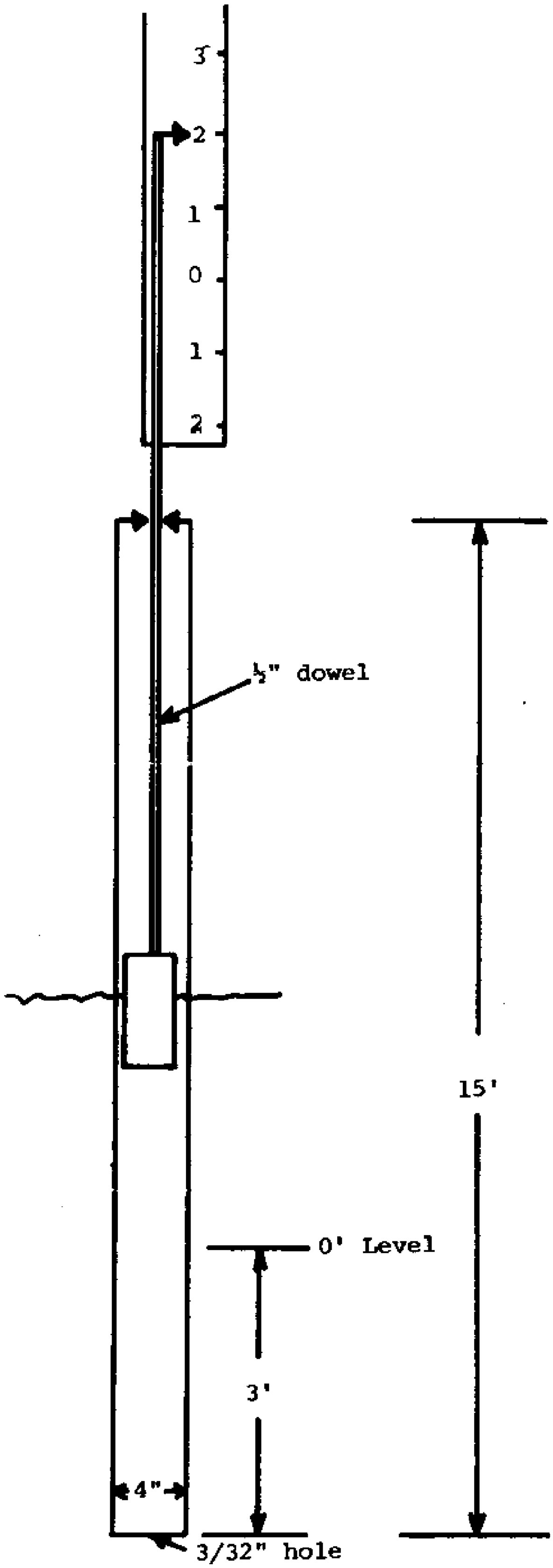


FIGURE 8.1 A Mechanical Tide Height Indicator

8.3 CONCLUSIONS AND RECOMMENDATIONS

A simple reliable tide height indicator has been built and tested. However, the disadvantage of requiring visual readings to obtain data is a strong one.

The main improvements to the design would be to provide better joints in the dowel rod to reduce the risk of catching.

9. A SEAWATER TEMPERATURE SURVEY OF HOLBROOK COVE

The measurement of seawater temperature in Holbrook Cove at a range of depths and as a function of time was considered to be a useful addition to the accumulated knowledge of that cove. The purpose was to gather the bathymetric temperature data at several locations during the month of July.

9.1 PROCEDURE

Using a chart of Holbrook Cove, stations were chosen which would give data for the entire Cove area. Buoys were placed at these stations to moor a small boat while the temperature measurements were taken, as shown in Figure 9.1. Four temperature readings were taken at each station, the surface, three meters, six meters, and the bottom. The temperature measurements were taken with a reversing thermometer during the early part of the month. The use of a single reversing thermometer required lowering, raising, and reading the instrument four times at each location. In addition, time was spent at each depth for the thermometer to reach the local temperature. Later in the month a thermistor was obtained which enabled the temperature survey to be made with the instrument lowered and raised just once. The instrument measurements were recorded by a meter in the boat. The temperature measurements using the two types of instruments were first compared to show that the results were similar before the thermistor method was finally accepted as the more efficient method for obtaining the results.

The temperature readings were taken at each location twice during the day, at high tide and at low tide.

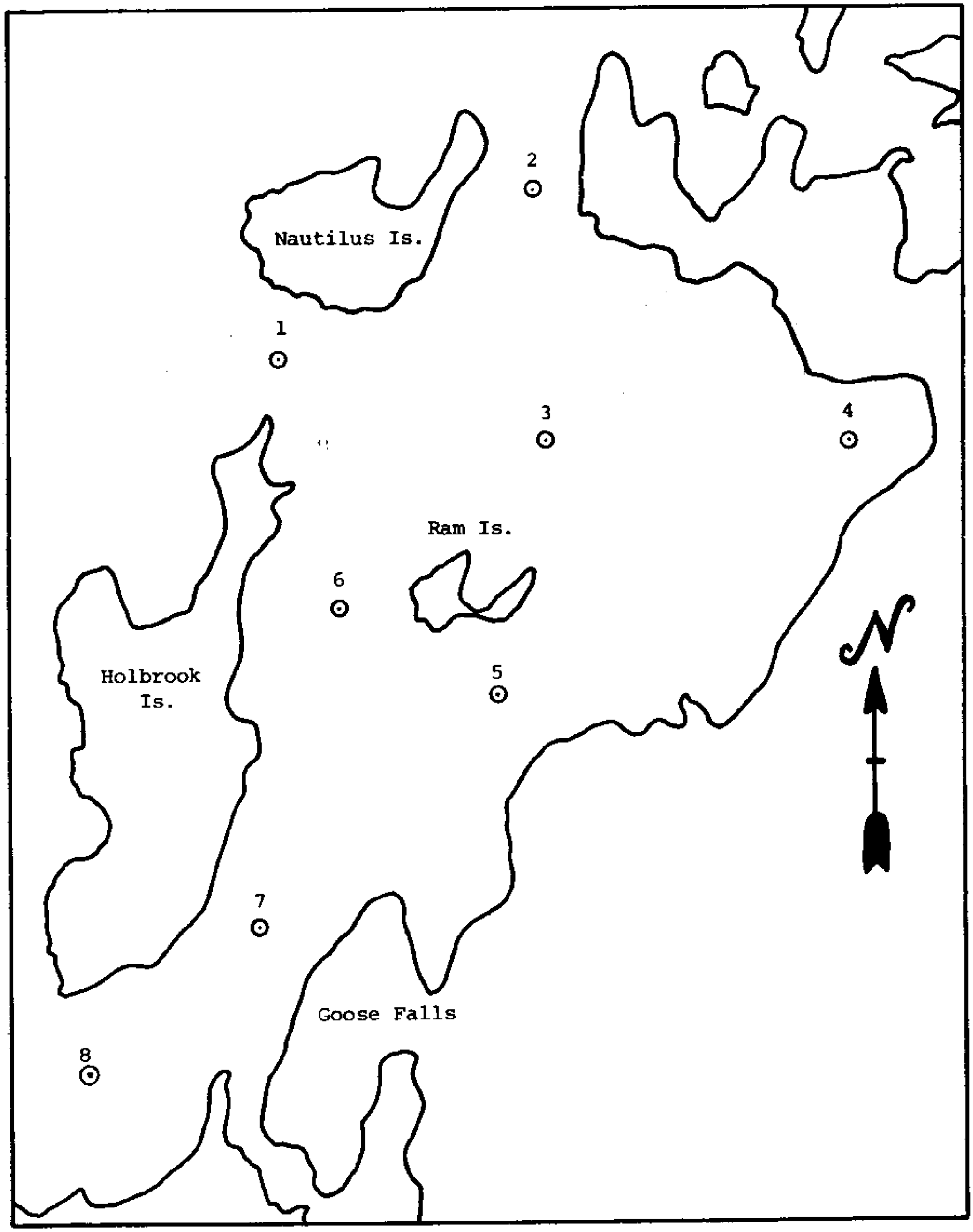


FIGURE 9.1 The Locations of the Temperature
Measuring Stations in Holbrook Cove

9.2 TEMPERATURE SURVEY RESULTS

The measured temperature for the eight stations are tabulated in Table 9.1. The results for stations 1 and 8 are shown graphically on Figure 9.2. The results show the comparative stability of the deeper water where the maximum temperature variation was only about $1^{o}C$ during the period of the study. On sunny warm days, on the other hand, the surface water temperature was $4-6^{o}C$ warmer than on overcast days. Also playing a part in the surface temperature variation was the rainfall in the region. This appeared to raise the temperature of the surface water.

9.3 CONCLUSIONS AND RECOMMENDATIONS

The bathymetric measurement of temperature using reversing thermometers was time consuming. The measurements using a thermistor were easier to carry out and equally as accurate, perhaps more accurate. The results may be interpreted in terms of the heating of the sun, the effect of rainfall, and the tidal flow. However, the task is beyond the scope of this preliminary study.

The thermistor method could be used, to determine the water temperature variation at smaller depth intervals in order to determine the thermocline in the cove.

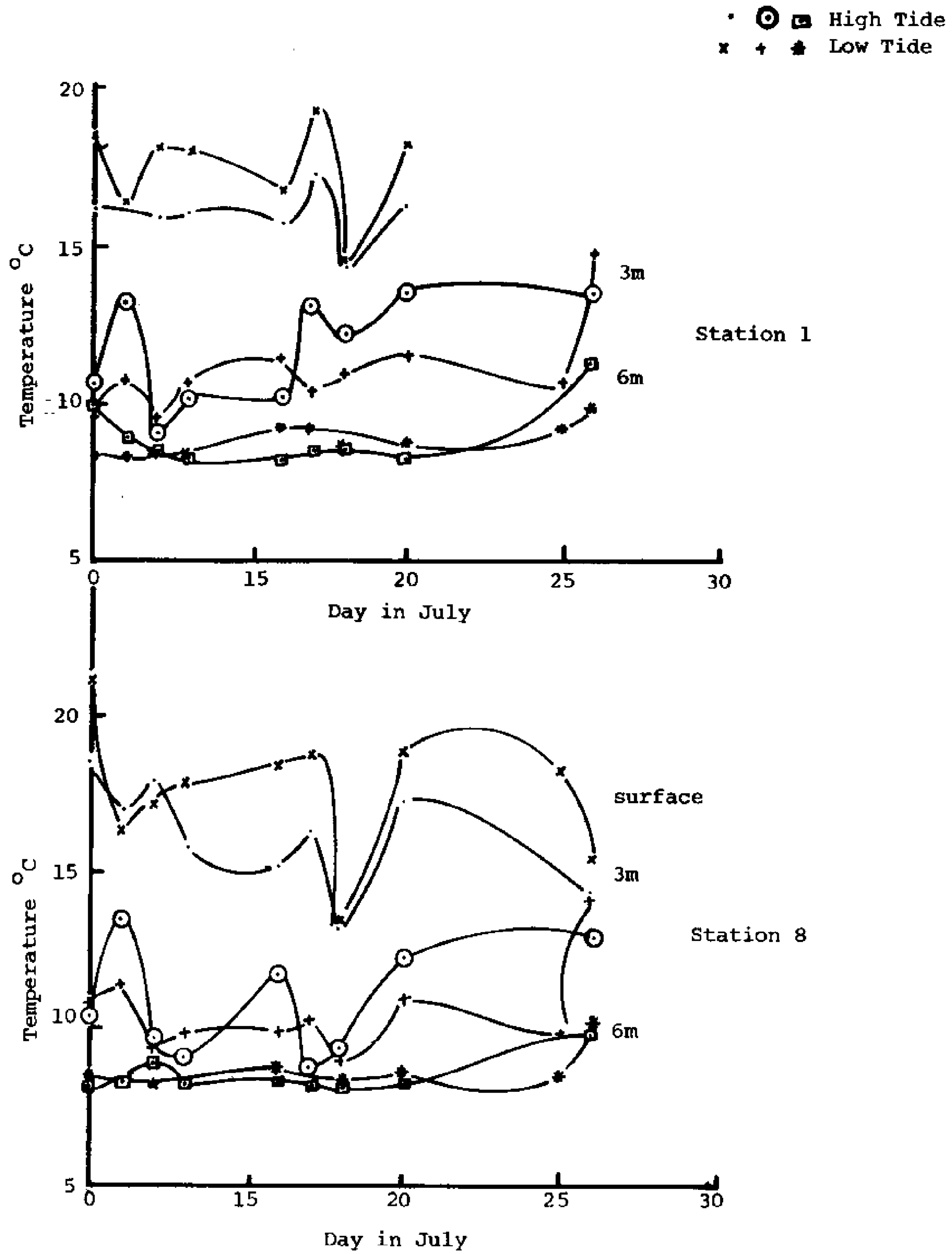


FIGURE 9.2 The Temperature Distributions at Several Depths at Stations 1 and 8 in Holbrook Cove

TABLE 9.1 Temperature at Surface, °C

Station No.	Tide	Day of Temperature Sample 10	11	12	13	16	17	18	20	25	26
1	HIGH	16.2	16.2	16.0	16.0	15.6	17.2	14.3	16.4		
	LOW	18.6	16.4	18.1	18.0	16.8	19.4	14.6	18.3	14.0	15.4
2	HIGH	19.2	18.8	17.0	15.8	14.9	18.0	14.9	17.6		15.3
	LOW	22.2	19.0	18.2	17.8	17.9	16.4	15.6	18.6	17.2	16.1
3	HIGH	19.4	17.8	17.2	17.0	15.3	17.8	15.1	18.1		15.1
	LOW	22.0	18.4	19.2	19.1	18.8	18.0	16.6	19.4	17.2	15.4
4	HIGH	19.8	19.0	17.2	19.0	16.7	18.0	15.0	17.5		14.8
	LOW	24.2	19.0	19.4	18.8	19.9	19.0	16.1	19.0	18.9	16.1
5	HIGH	22.1	18.7	17.2	17.4	15.3	17.2	14.6	18.0		14.6
	LOW	19.7	17.8	19.1	18.6	19.1	19.8	15.5	19.2	17.8	15.2
6	HIGH	20.4	17.0	16.8	16.8	15.1	18.0	15.1	17.3		14.8
	LOW	20.2	17.6	19.1	18.7	17.1	19.8	16.4	17.6	17.2	15.0
7	HIGH	21.1	18.0	17.2	16.8	15.8	16.2	13.4	18.0		14.5
	LOW	22.8	16.9	19.8	19.1	19.6	19.8	13.8	18.4	18.3	15.1
8	HIGH	18.8	17.0	18.0	15.8	15.1	16.4	13.2	17.3		14.3
	LOW	21.4	16.6	17.2	17.9	18.6	18.8	13.4	18.8	18.3	15.4

TABLE 9.1, contd. C^{o} Temperature at 3 Meters Depth

Station No.	Tide	Day of Temperature Sample 10	11	12	13	16	17	18	20	25	26
1	HIGH	10.8	13.2	9.0	10.2	10.2	13.0	12.3	13.5		13.6
	LOW	9.6	10.9	9.5	10.5	11.6	10.2	10.9	11.6	10.7	14.8
2	HIGH	9.7	14.0	9.8	10.0	13.8	12.0	12.1	13.1		14.1
	LOW	9.6	11.9	10.2	10.4	10.1	11.0	10.4	11.2	10.2	12.7
3	HIGH	9.8	14.3	9.8	11.4	12.2	12.2	12.2	13.5		13.6
	LOW	9.8	12.5	9.9	11.4	10.6	9.8	10.6	11.8	10.2	11.9
4	HIGH	9.4	12.2	10.4	10.0	11.0	11.8	11.8	12.4		12.6
	LOW	9.8	13.2	10.2	10.7	12.1	9.8	10.9	13.2	10.2	12.1
5	HIGH	10.6	14.0	9.2	10.4	12.1	11.0	11.6	12.4		13.3
	LOW	9.8	14.1	10.5	10.9	11.3	9.8	10.8	11.6	9.8	14.4
6	HIGH	9.2	12.8	9.2	9.8	11.0	11.2	11.6	12.0		12.6
	LOW	11.0	14.7	11.0	10.1	10.6	10.4	11.1	13.2	11.1	12.6
7	HIGH	10.2	13.0	9.8	10.2	11.9	9.8	12.4	12.7		12.4
	LOW	10.0	14.1	11.0	11.0	10.1	9.8	12.1	12.2	10.2	12.0
8	HIGH	10.6	13.7	918	9.2	11.8	8.8	9.4	12.4		12.8
	LOW	10.8	11.4	9.4	9.9	9.9	10.2	9.0	11.0	9.8	14.2

TABLE 9.1, contd. C^{o} Temperature at 6 Meters Depth

Station No.	Tide	Day of Temperature Sample 10	11	12	13	16	17	18	20	25	26
1	HIGH	9.9	8.9	8.6	8.2	8.1	8.4	8.5	8.2		11.4
	LOW	8.5	8.4	8.6	8.4	9.4	9.4	8.6	8.8	9.2	9.9
2	HIGH	8.5	8.6	8.8	8.1	8.4	8.4	8.5	12.8		11.7
	LOW	8.6	8.6	8.6	8.6	8.5	8.4	8.7	8.7	8.7	9.3
3	HIGH	8.5	8.4	9.4	8.4	8.6	12.1	8.3	8.6		10.0
	LOW	8.4	8.2	8.2	8.4	8.2	8.6	8.6	8.8	8.8	9.1
4	HIGH	8.3	9.1	8.8	8.4	8.8	8.8	8.4	8.6		9.6
	LOW	8.6	8.3	8.3	8.5	8.7	8.4	8.6	8.5	8.7	10.9
5	HIGH	8.2	8.8	9.2	8.6	8.8	9.0	8.5	8.5		10.1
	LOW	8.4	9.1	8.1	8.3	8.6	8.6	8.7	8.5	8.6	9.2
6	HIGH	8.3	8.9	8.4	8.4	8.4	8.8	8.6	8.5		9.4
	LOW	8.5	8.5	8.6	8.6	10.0	8.8	8.7	8.7	10.2	11.2
7	HIGH	8.4	8.7	8.4	8.6	8.7	8.8	8.6	9.0		10.6
	LOW	8.6	8.5	8.2	8.3	8.4	8.8	8.7	8.7	8.6	9.2
8	HIGH	8.1	8.3	9.0	8.2	8.4	8.2	8.2	8.3		9.8
	LOW	8.4	8.2	8.2	8.2	8.8	8.8	8.3	8.4	8.6	10.2

TABLE 9.1 contd. C^{o} Temperature at the Bottom

Station No.	Tide	Depth*	Day of Temperature Sample									
			10	11	12	13	16	17	18	20	25	26
1	HIGH	14.5	8.4	8.3	8.2	8.0	8.0	8.4	8.2	7.8		8.9
	LOW	13.0	8.0	8.0	8.3	8.2	8.2	8.2	8.2	8.4	8.6	9.2
2	HIGH	11.5	8.0	8.0	8.8	8.0	8.2	8.2	8.2	8.2		8.9
	LOW	9.5	8.0	7.9	8.1	8.3	8.2	8.2	8.2	8.4	8.3	8.7
3	HIGH	9.5	7.9	8.0	8.2	8.0	8.2	8.2	8.3	8.1		8.9
	LOW	6.5	8.8	8.1	8.2	8.3	8.2	8.4	8.3	8.3	8.4	9.1
4	HIGH	8.5	8.1	9.1	8.8	8.2	8.5	8.6	8.4	8.2		9.3
	LOW	5.5	8.6	8.3	8.2	8.5	8.7	8.4	8.6	8.6	8.7	10.9
5	HIGH	12.0	8.1	8.4	8.4	8.2	8.6	8.4	8.3	8.2		9.1
	LOW	8.5	8.2	8.2	8.1	8.2	8.3	9.0	8.3	8.3	8.3	8.8
6	HIGH	7.5	8.3	8.9	8.4	8.4	8.3	8.6	8.6	8.2		9.3
	LOW	4.5	8.5	8.5	8.6	8.6	10.0	8.8	8.7	8.9	10.2	11.2
7	HIGH	13.5	7.9	8.2	8.2	8.0	8.3	8.4	8.2	8.2		9.2
	LOW	9.0	8.4	8.0	8.2	8.2	8.2	8.4	8.4	8.4	8.6	8.8
8	HIGH	8.5	7.9	8.4	9.0	8.0	8.3	8.2	8.2	9.1		9.0
	LOW	6.5	8.5	8.0	8.2	8.2	8.6	8.6	8.2	8.4	8.6	

*Note: Bottom depth given in meters in an approximate depth based on the ave. depths encountered on stations.

10. A RADIO RANGING DEVICE (PROJECT ODYSSEUS)

Project Odysseus was begun after the first summer lab in 1971 when the usefullness of a highly accurate short range navigation system for the placement of instruments and the refinding of bottom objects was seen. The first year, 1972, was spent searching for the best system and trying to get it going. This year much research and development work was done and continued through the school year. Toward the end of the second term the rebuilding of Project Odysseus began. It was clear by this time that the entire radio navigation system could not be completed, so a part of the system, a radio ranging device, was built. With suitable multiplexing and another shore station this could be converted to a radio navigation system.

10.1 SYSTEM OPERATION DESCRIPTION

Project Odysseus measures distance by comparing the phase of the signal transmitted from the boat station with the phase of the signal returning from the shore station as indicated in Figure 10.1. A signal is sent from the boat station and is received by the shore station. It is divided by two in frequency and then retransmitted. This signal, 1672 kHz, is received by the boat station and doubled in frequency. Both the original signal and the returning signal are heterodyned to an audio tone for easy phase comparison. The phase comparator output is a repeating sawtooth with a ramp proportional to distance, each sawtooth wave representing 45 meters of movement.

10.2 CIRCUIT DESCRIPTION

10.2.1 Oscillators

One of the oscillators used was taken from last year's equipment, with an emitter follower buffer stage added, Figure 10.2. The second oscillator

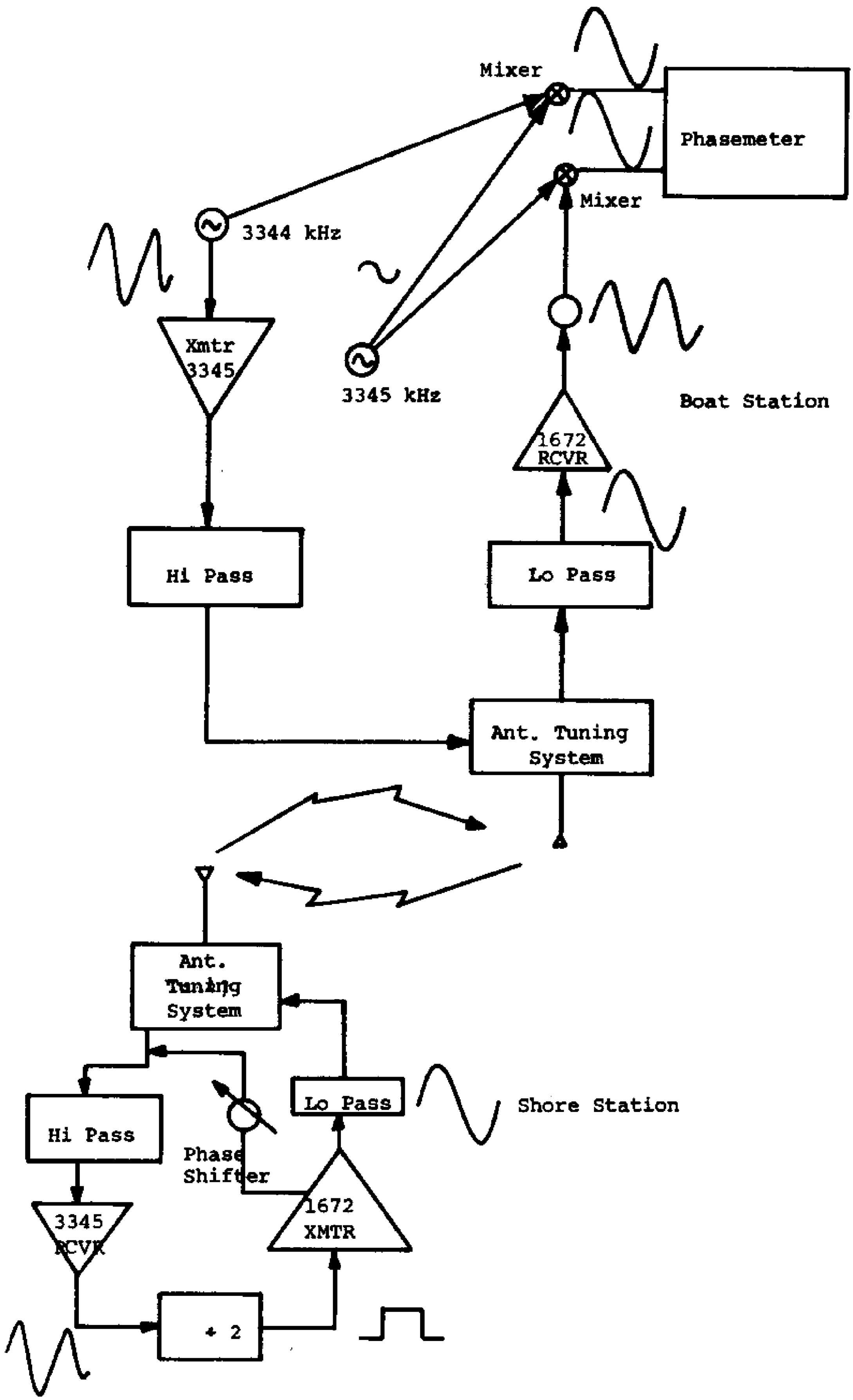


FIGURE 10.1 The Radio Ranging System

was built with a frequency doubling circuit in it, as no 3345 kHz crystals were available. It is a standard output circuit, with a buffer on each of the two outputs.

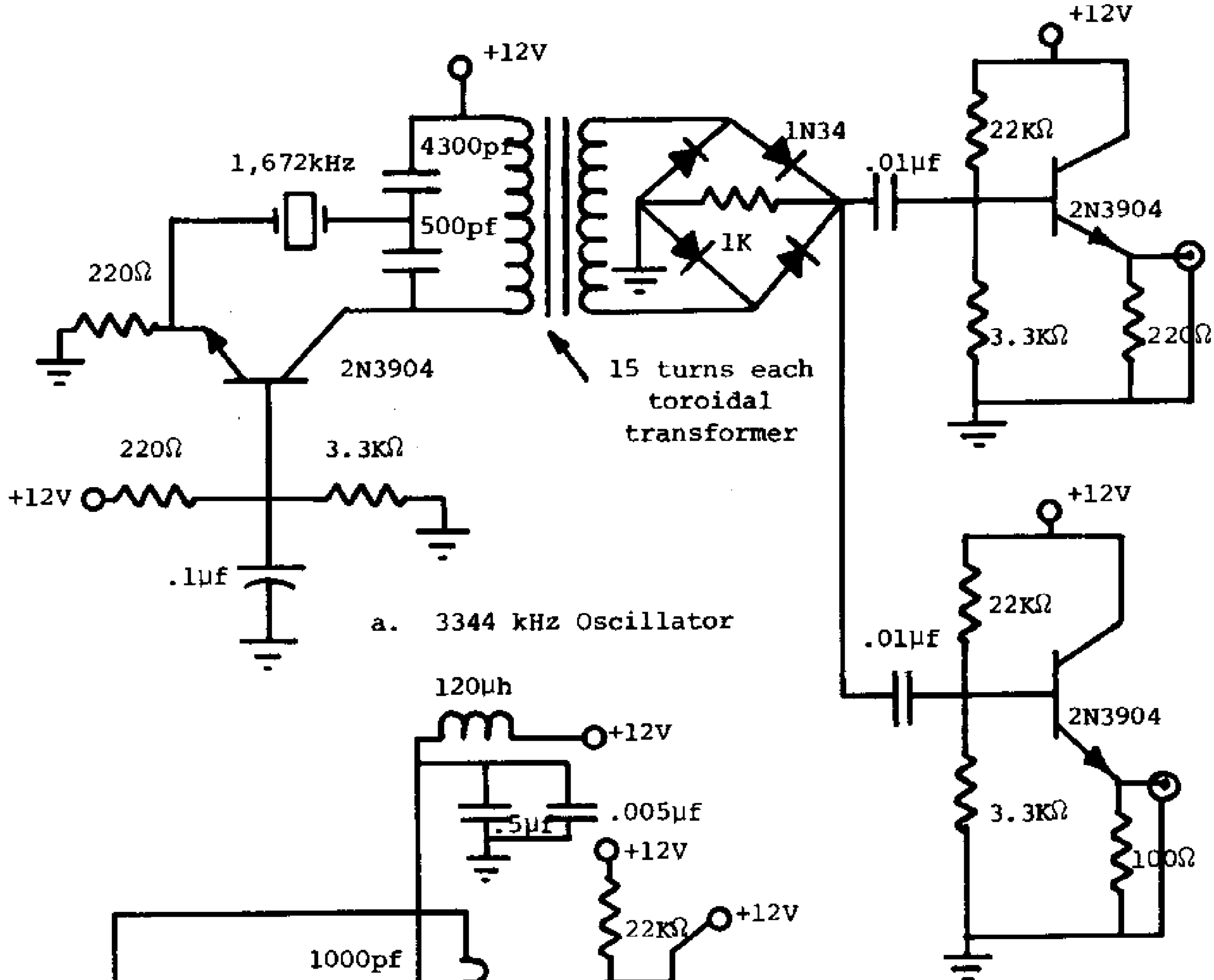
10.2.2 Transmitters

The transmitters are standard class C rf tuned amplifiers as shown in Figure 10.3. They were consistent and stable in operation, but the T-section output networks did not work as designed. With much adjusting of components, moving far from design values, about half of the original value of 5 watts output was obtained. This problem is still unexplained.

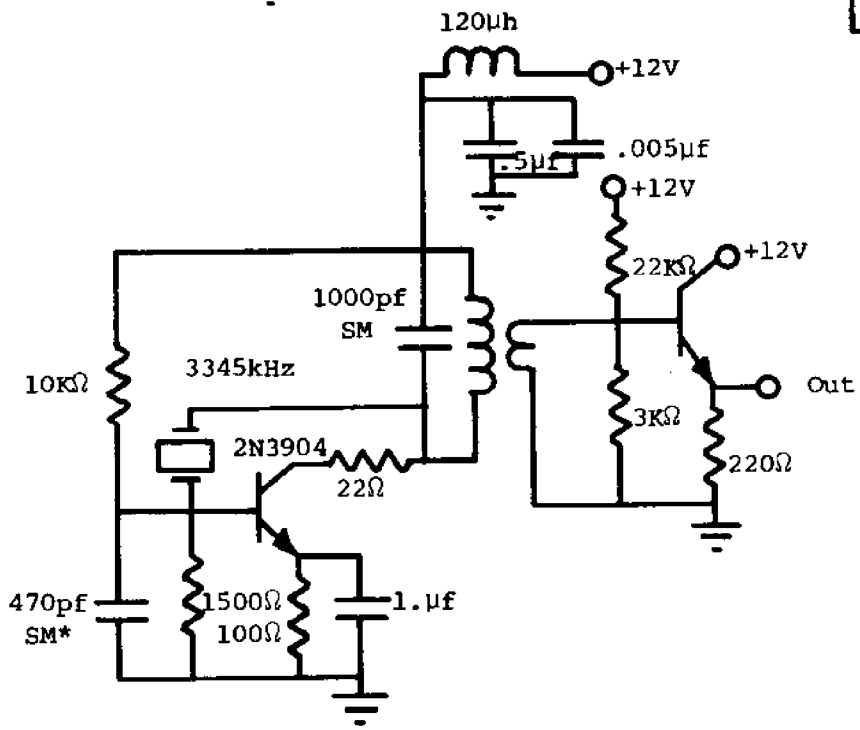
10.2.3 Filtering and Shielding

When transmitting and receiving at the same time on the same antenna, on harmonically related frequencies, extreme care must be taken to filter out unwanted signals. The first filtering is in the power supply, Figure 10.4a. There is power supply filtering in each box, as well as a separate box for isolating each module from the others. Each module or group of modules is built in a separate brass box with radio frequency interference shielding in the lid. TNC connectors and double shielded cable were used when available to reduce pickup from interconnections. In addition to this, electrical filters were needed to reduce harmonic and subharmonic transmitter output, and to prevent overloading of the receiver input by the transmitter signal.

The basic building block of the first filters used was a diplexer, designed to be series resonant at one frequency and parallel resonant at the other, Figure 10.5. The problem with these was that it was difficult to adjust for both pass of one frequency and reject of the other at the same time. These were replaced at the transmitter output by a many section T filter (hi or low



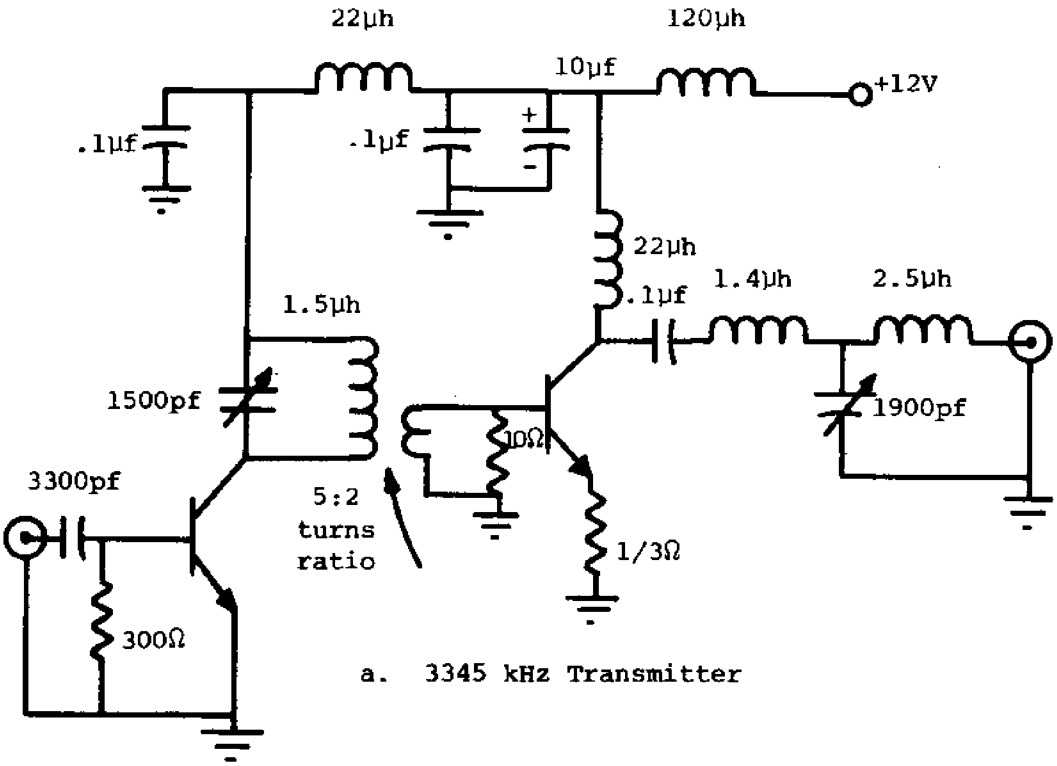
a. 3344 kHz Oscillator



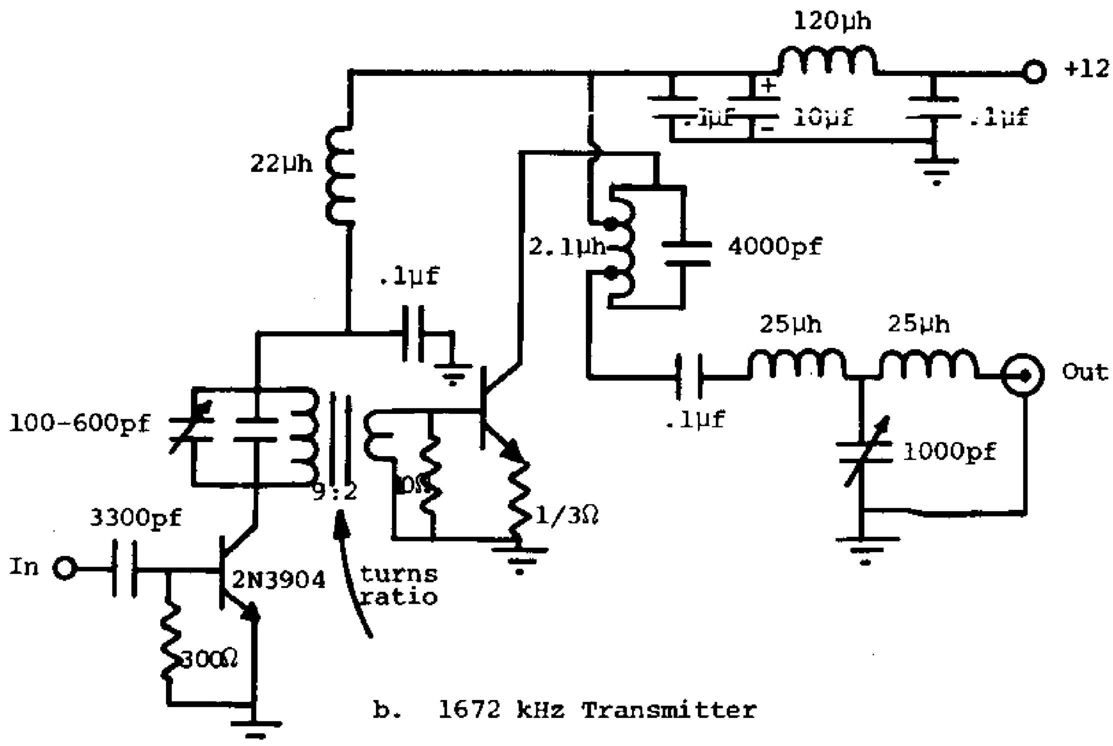
*SM - Silver Mica

b. 3345 kHz Oscillator

FIGURE 10.2 3345 kHz and 3344 kHz Oscillators

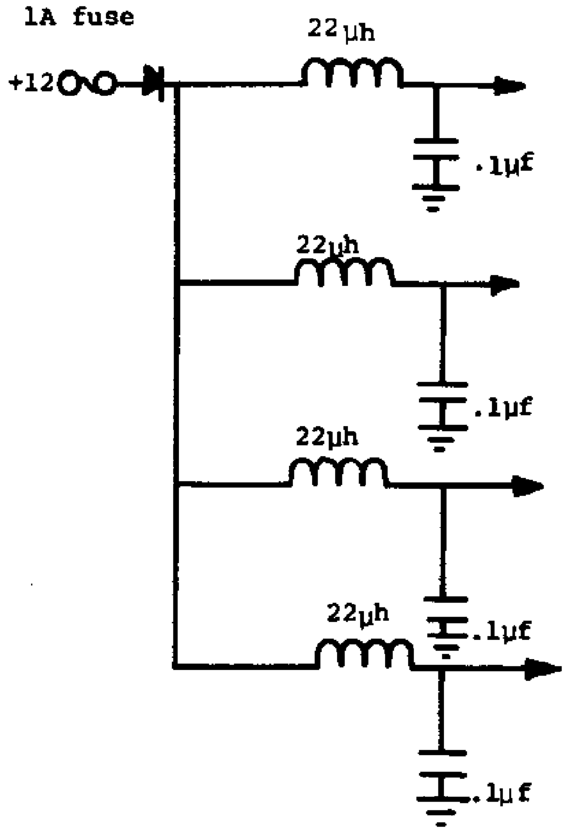


a. 3345 kHz Transmitter

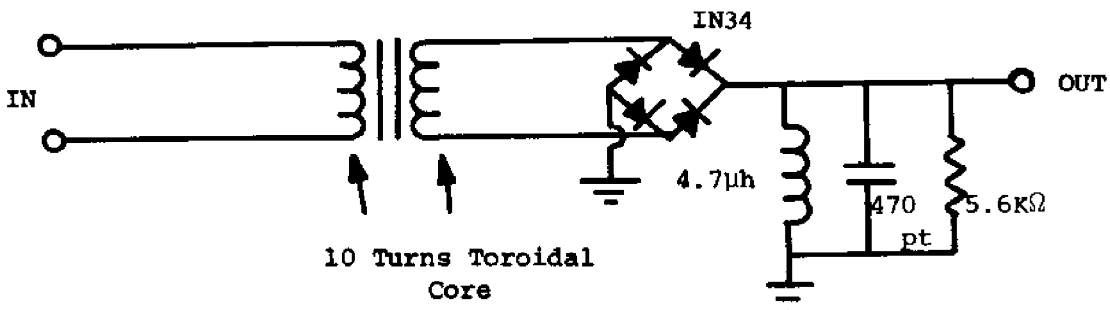


b. 1672 kHz Transmitter

FIGURE 10.3 The 1672 kHz and 3345 kHz Transmitters

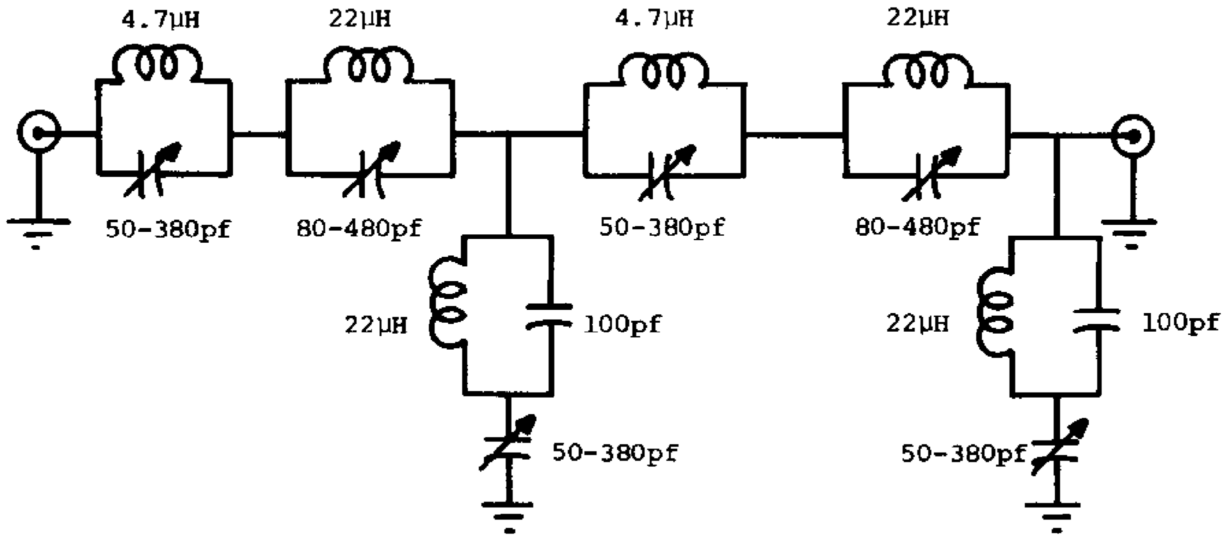


a. Power Filtering

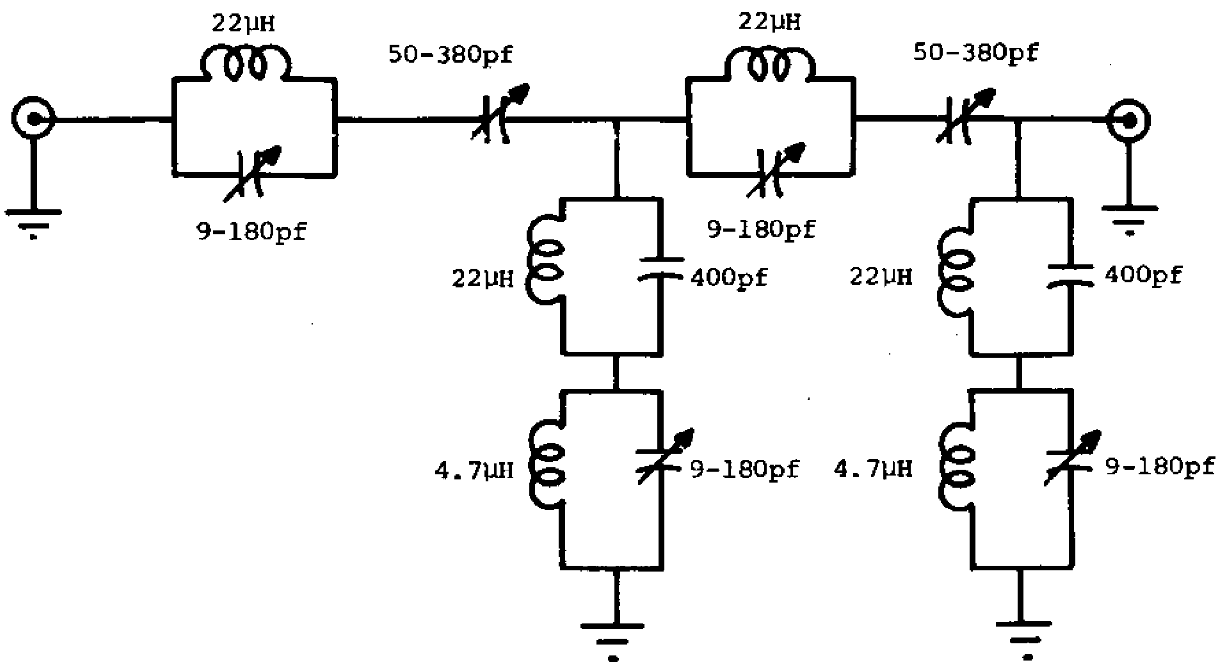


b. X2 Multiplier, 1672 kHz to 3344 kHz

FIGURE 10.4 Power Supply Filter and the Time 2 Multiplier

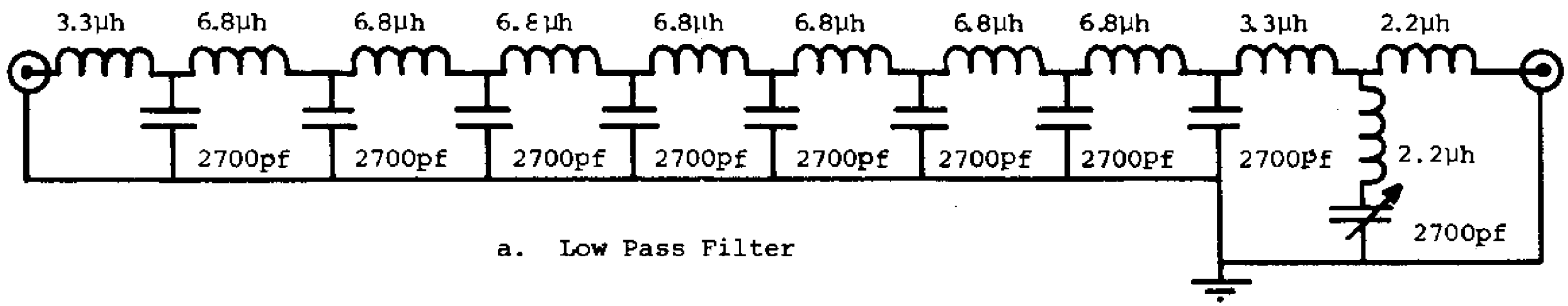


a. Hi Pass



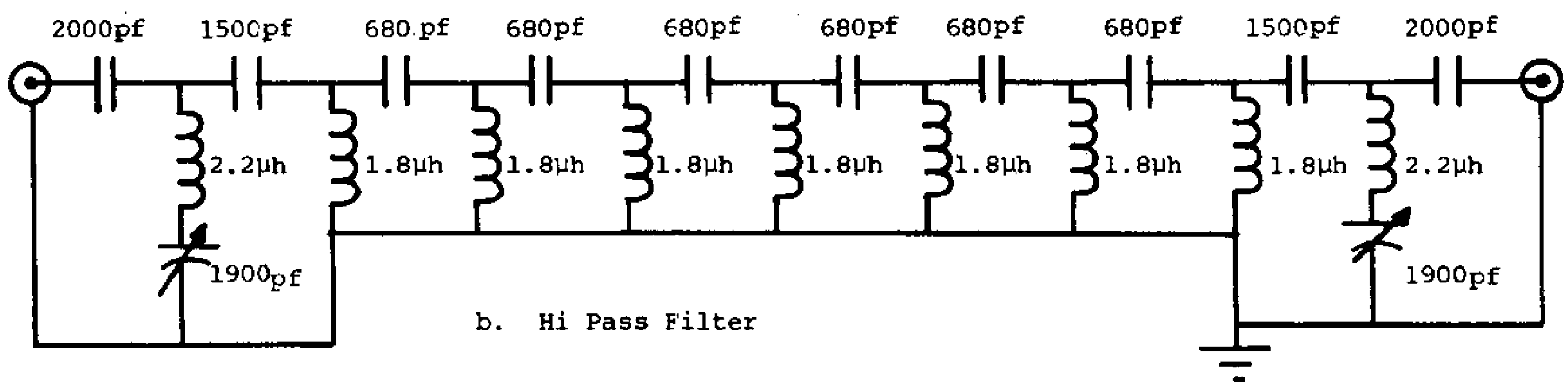
b. Low Pass

FIGURE 10.5 Receiver Filters



a. Low Pass Filter

FIGURE 10.6 Transmitter Filters



b. Hi Pass Filter

pass) as appropriate, with M derived sections at each end to give a "notch" at the frequency to be attenuated, Figure 10.6. The M derived section at the output of the 1672 kHz transmitter was removed because the combined system worked much better that way. Better filters could be made with a long T section chain with higher loaded Q and maybe an M-derived section at the end.

An additional device related to filtering is the phase shifter. This provided an output of harmonic energy which could be adjusted in phase and amplitude from the transmitter to cancel out any second harmonic, 3345 kHz, getting to the receiver, Figure 10.7. It turned out not to be necessary, however.

10.2.4 Antenna Tuning and Antennas

The design problem was to make a short, reasonably efficient antenna system that would be resonant at both frequencies of operation, Figure 10.8. This network was used because of smaller size inductors than a similar network with elements in parallel, The brass boxes that the system was built in are designed for a Q of approximately 500 for the coils. The taps for each frequency were chosen so the antenna system would look like 50 ohms at that frequency. Performance of this system was quite satisfactory, although the values of the inductors were low and the capacitor high when adjusted for correct operation.

10.2.5 Receiver

The receivers are simple tuned amplifiers, designed using y-parameter calculation for the active devices involved (2N5459, MC1550), Figure 10.9. Gain of the 3345 kHz receiver was somewhat higher and bandwidth less than design values called for. The inductors used were of higher Q than assumed in design so this is understandable. The 1672 kHz receiver was completed in Castine, so measurement of these was not possible. It performed satisfactorily, however.

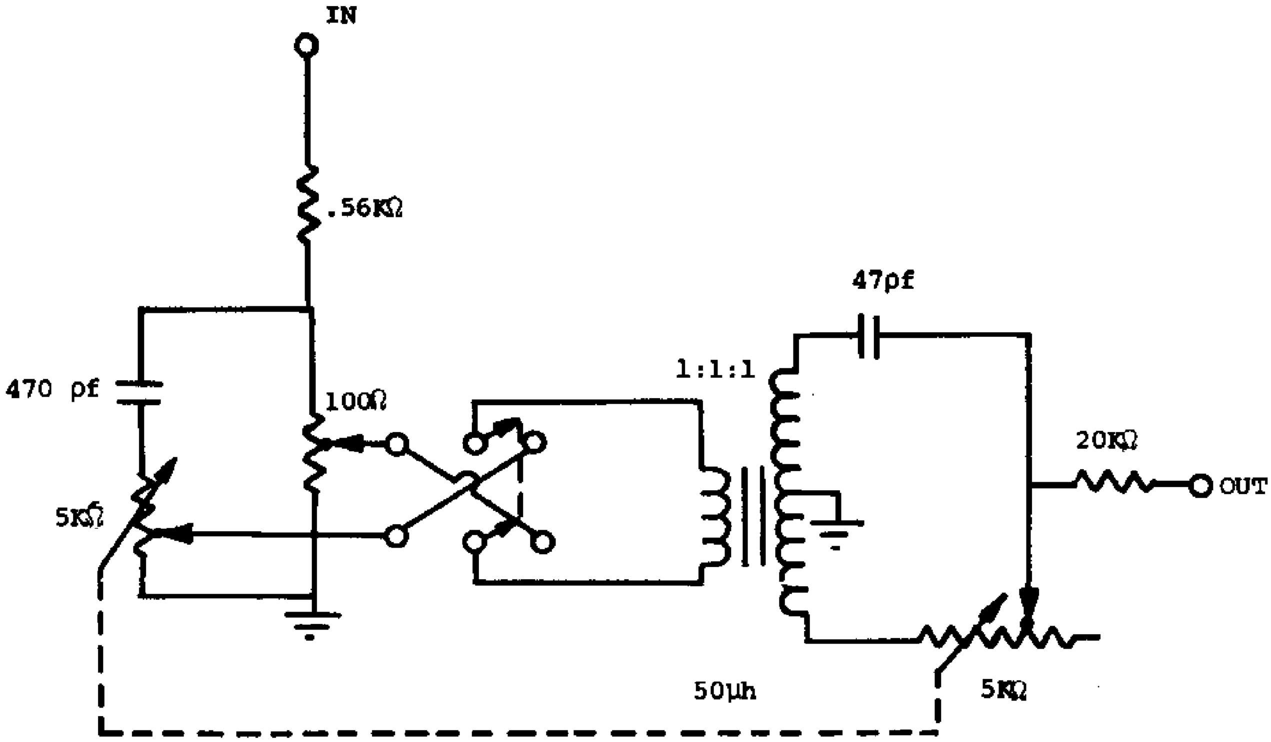
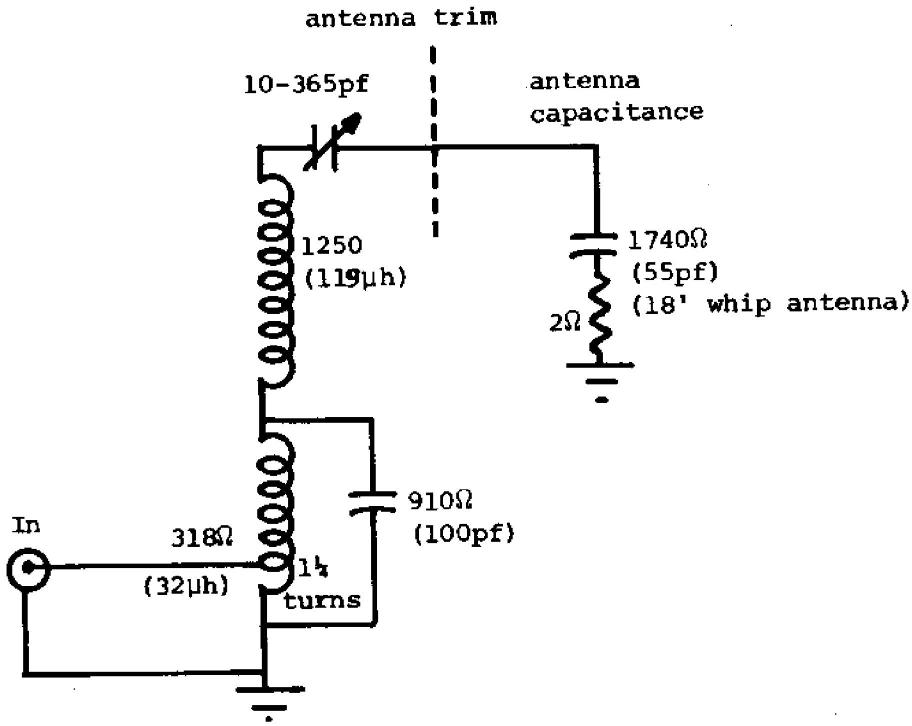
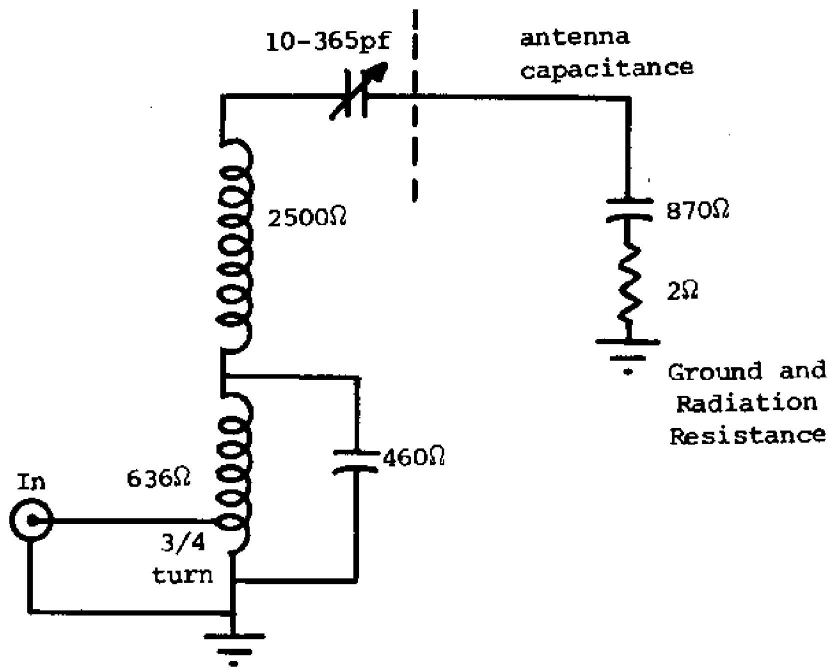


FIGURE 10.7 The Phase Shifter



a. 1672 kHz



b. 3345 kHz

FIGURE 10.8 Antenna Tuning

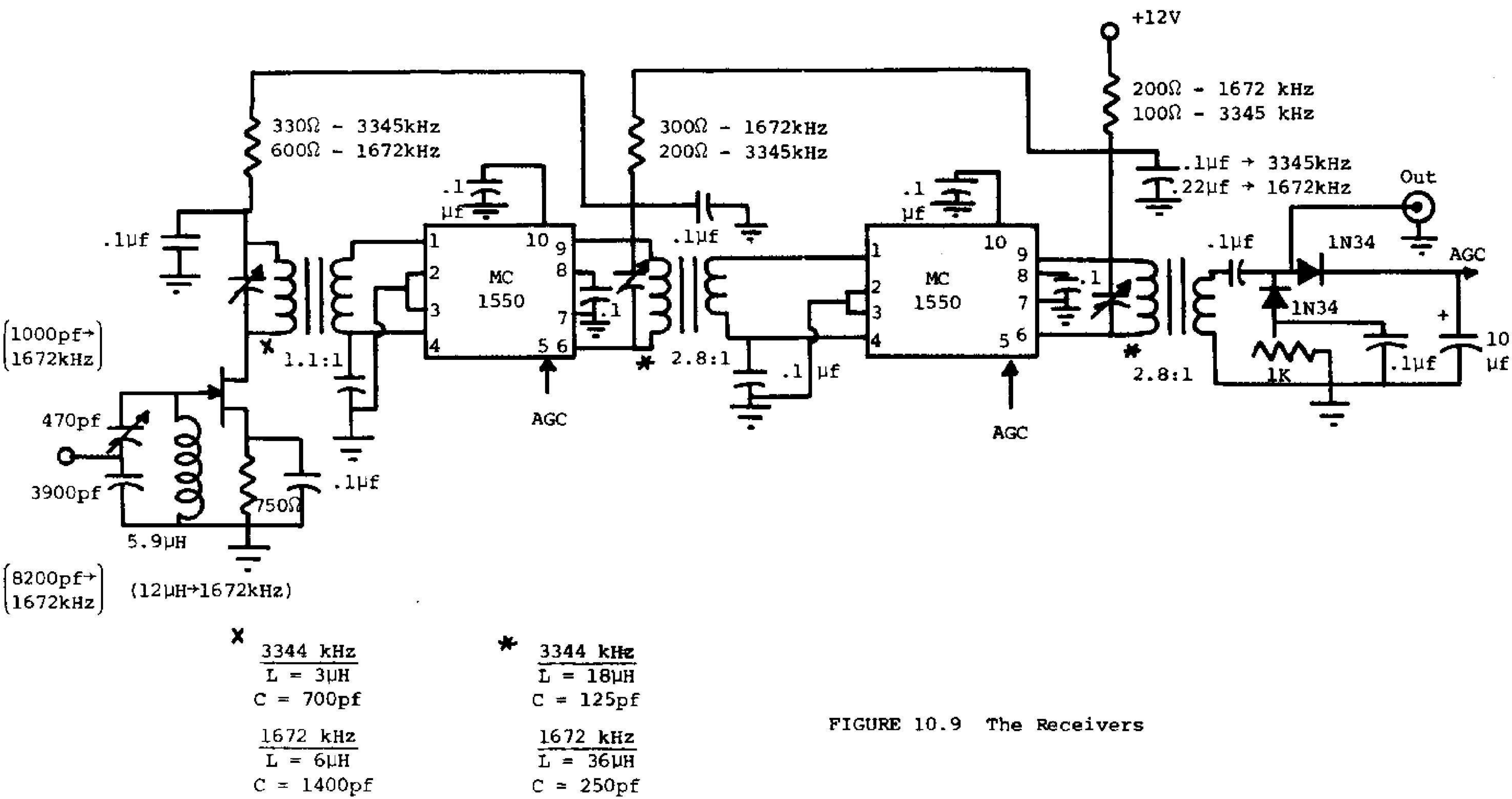


FIGURE 10.9 The Receivers

10.2.6 ÷2 and x2 Circuits

The divide-by-two circuit is a limiting circuit running into the clock input of a J-K flip-flop, which halves the frequency, Figure 10.10. An emitter follower output is used to keep the transmitter from loading the flip-flop. The transistor was used in inverted mode to clean up a spurious oscillation.

The times two circuit is a full wave diode bridge, filtered at the output to leave only the wanted doubled frequency, Figure 10.4b.

10.2.7 Mixers

This circuit is built around a four quadrant multiplier integrated circuit, Figure 10.11. It was built in last year's summer lab and worked satisfactorily this year.

10.2.8 Phasemeter

This circuit's output is a voltage proportional to the phase difference between the two imput signals, Figure 10.12. Each monostable is triggered at the 0 crossing of it's input signal, and thus the flip-flop is set on the 0 crossing of one signal, then reset ($Q = 0$) on the 0 crossing of the other signal. The flip-flop output is integrated to get a DC level which may be watched on any reasonably high impedance ($\geq$ 100k) voltage measuring device. The meter works satisfactorily, but the input circuit to the monostables can be improved considerably.

10.3 RESULTS

The building was completed with the boat and shore stations installed in boxes as shown in Figure 10.13 and 10.14 and operational tests began in the third week of July. Although the system is sensitive to movement of less than a meter, static tests indicated the equivalent of 5 meters of drift which appears to be caused by changing temperature, approximately half a meter per degree Centigrade. Keeping the stations out of the direct sunlight will decrease this problem. Distance checks indicated a useful range on the order of 1 kilometer. However, noise caused by a rapidly moving motorboat will overwhelm the signal.

In Figure 10.15 the system was set up and a strip recorder was used to record the expected drift in the output with both stations at a fixed distance. One test for operation was to shake an antenna; this resulted in a damped sinusoidal output. Over a period of two hours the drift was .4 volts, corresponding to about 5 meters.

The first test for range is shown in Figure 10.16. The boat station was in a fixed location and the shore station was moved about in a boat. The record is reasonably clean except where the boat noise caused considerable interference, Figure 10.16. The range appeared to be 30 wavelengths or 1,400 meters.

An RC filter with a time constant of one half second was added to the output of the phase meter to smooth it and another range test was run, Figure 10.17. The output was much smoother than the previous test and would give more accurate measurements. However, in this test an anomaly began occuring when the phase shifted from 360 degrees to 0 degrees. Later tests showed this to be caused by the phasemeter circuit.

Another drift test was run, of which a five hour segment is in Figure 10.18. There appeared to be an initial drift due to the stations reaching air temperature. Then there was very little drift for 3 hours except for one large unexplained jump.

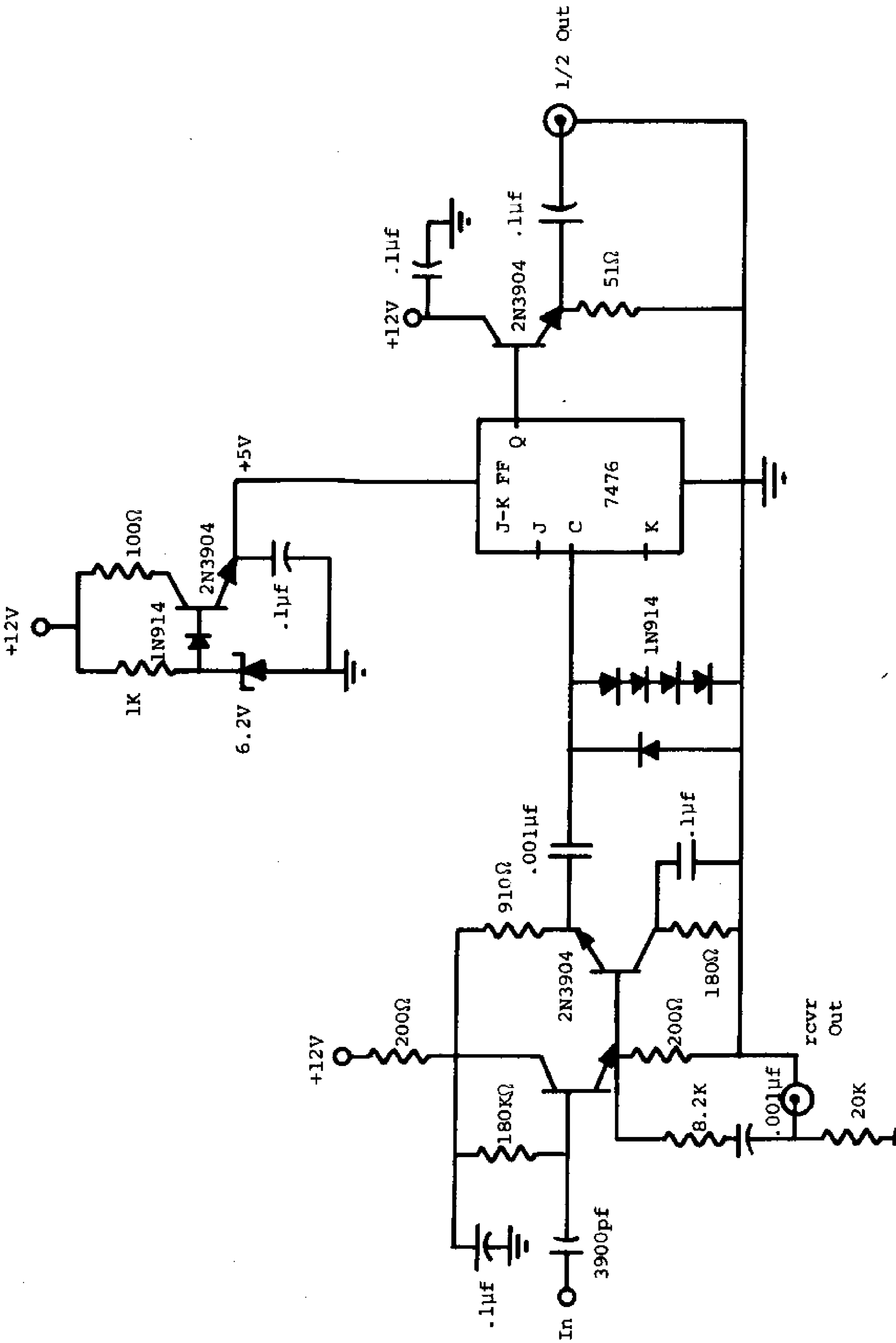


FIGURE 10.10 The Divide by Two Circuit

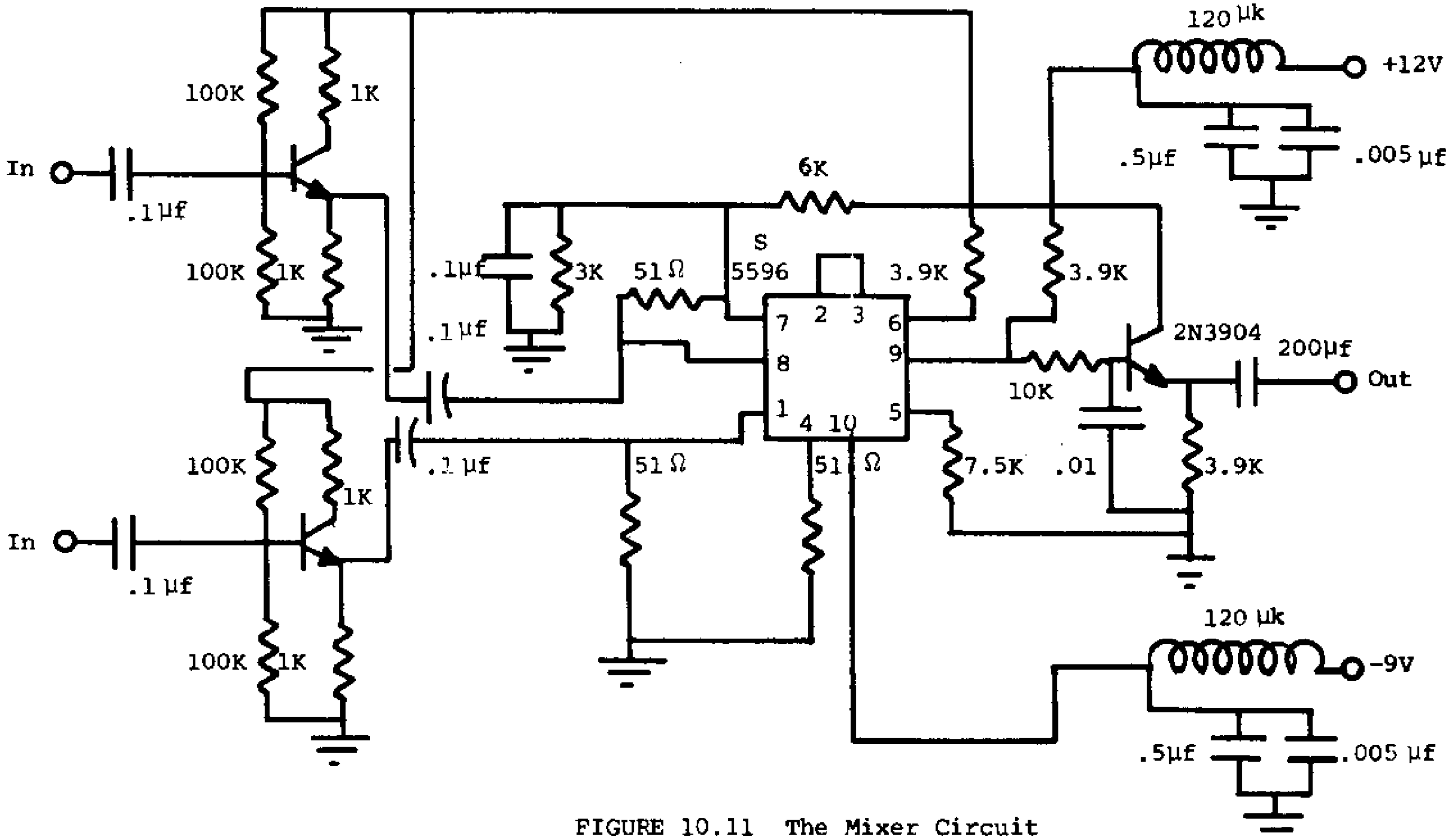


FIGURE 10.11 The Mixer Circuit

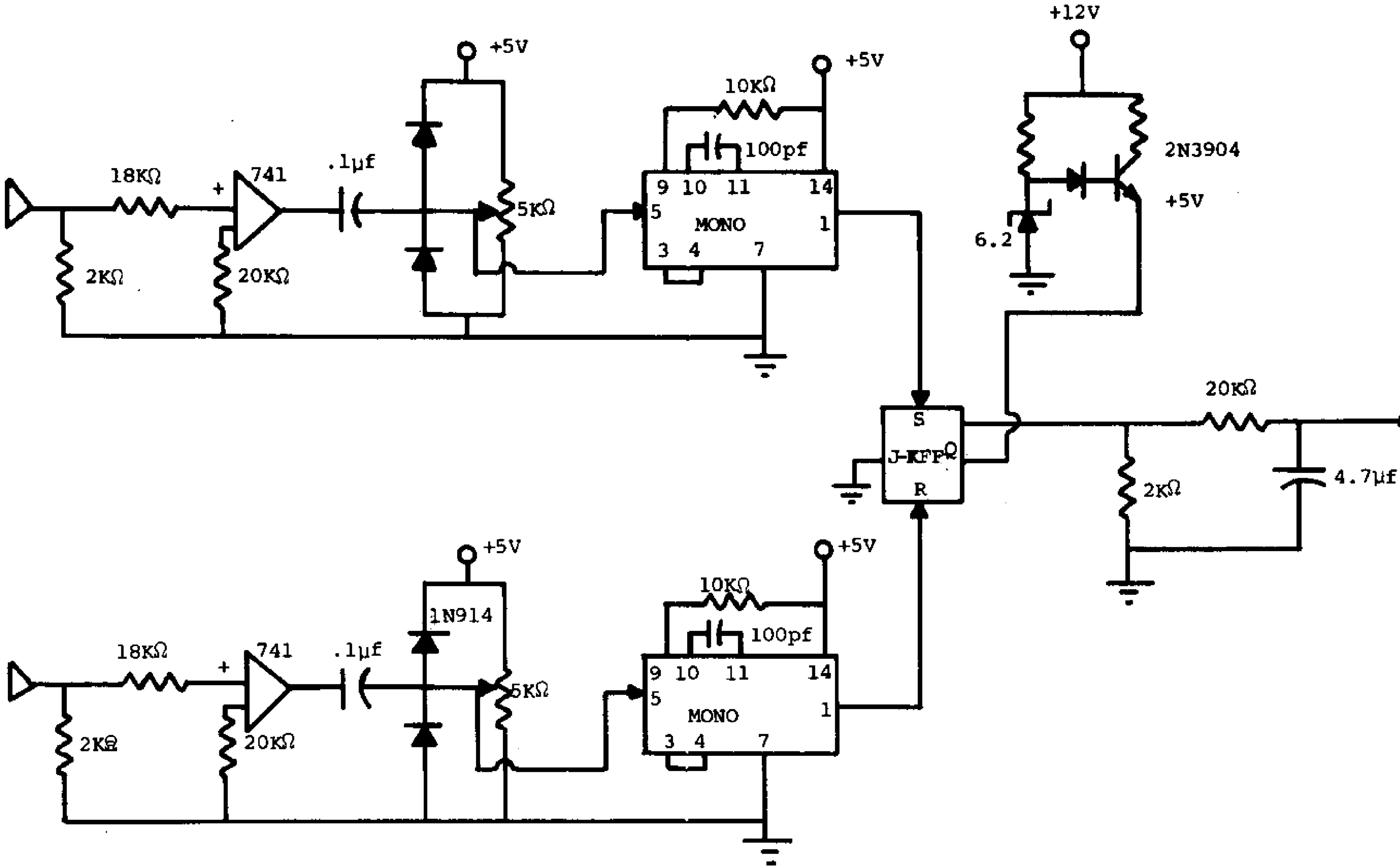
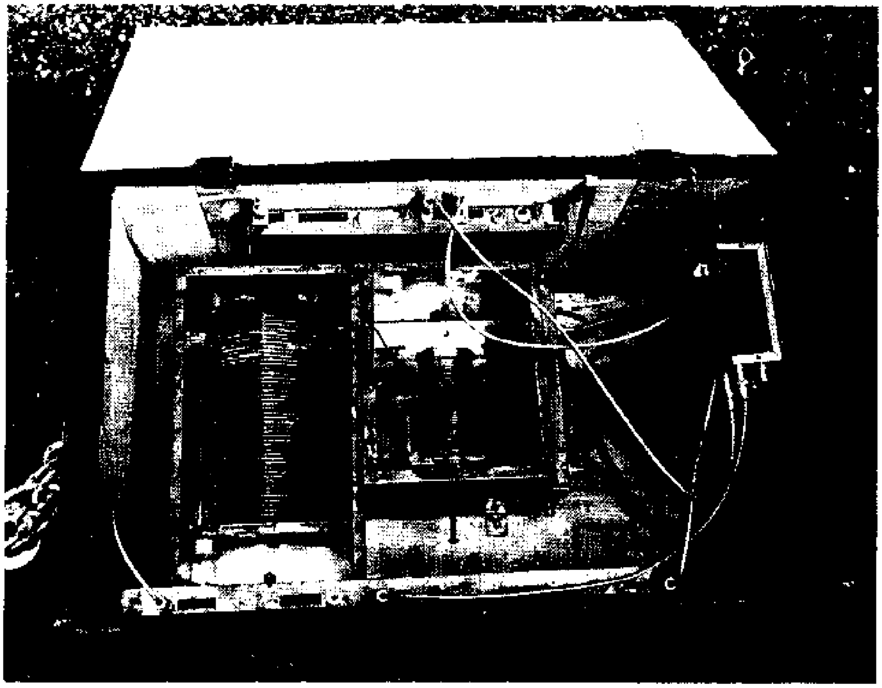


FIGURE 10.12 The Phase Comparator



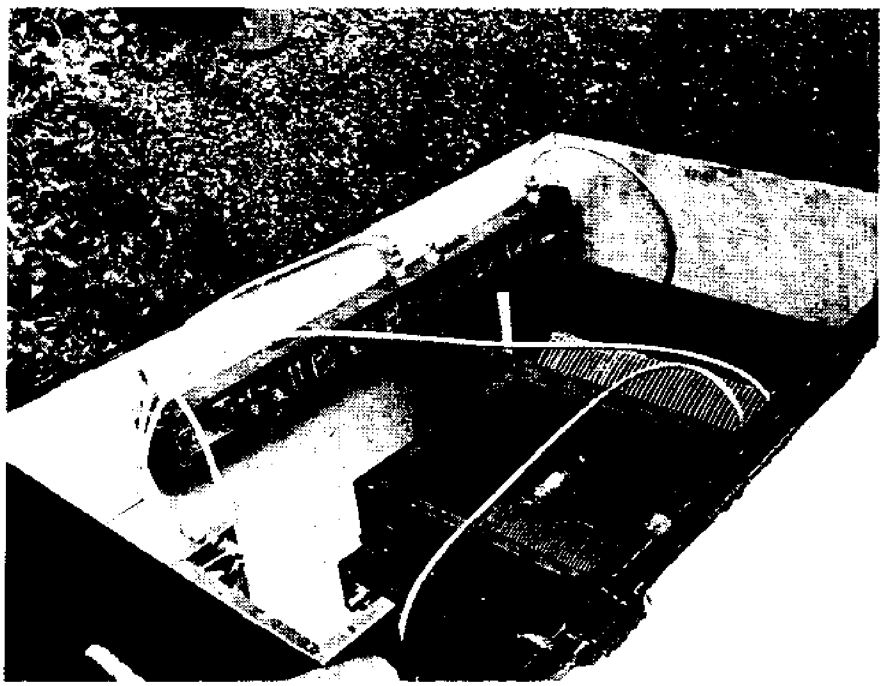


FIGURE 10.13 The Shore Station (Covers Removed only for Photographs)

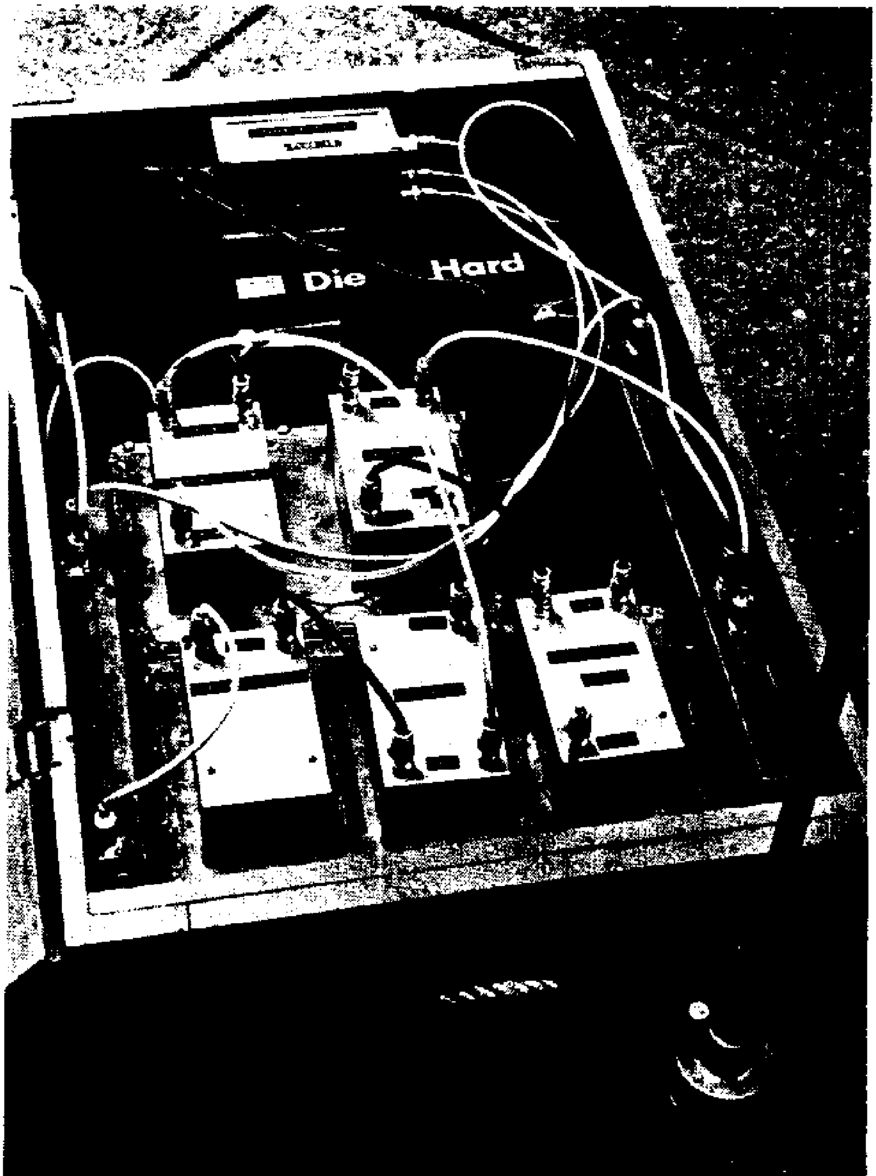


FIGURE 10.14 The Boat Station

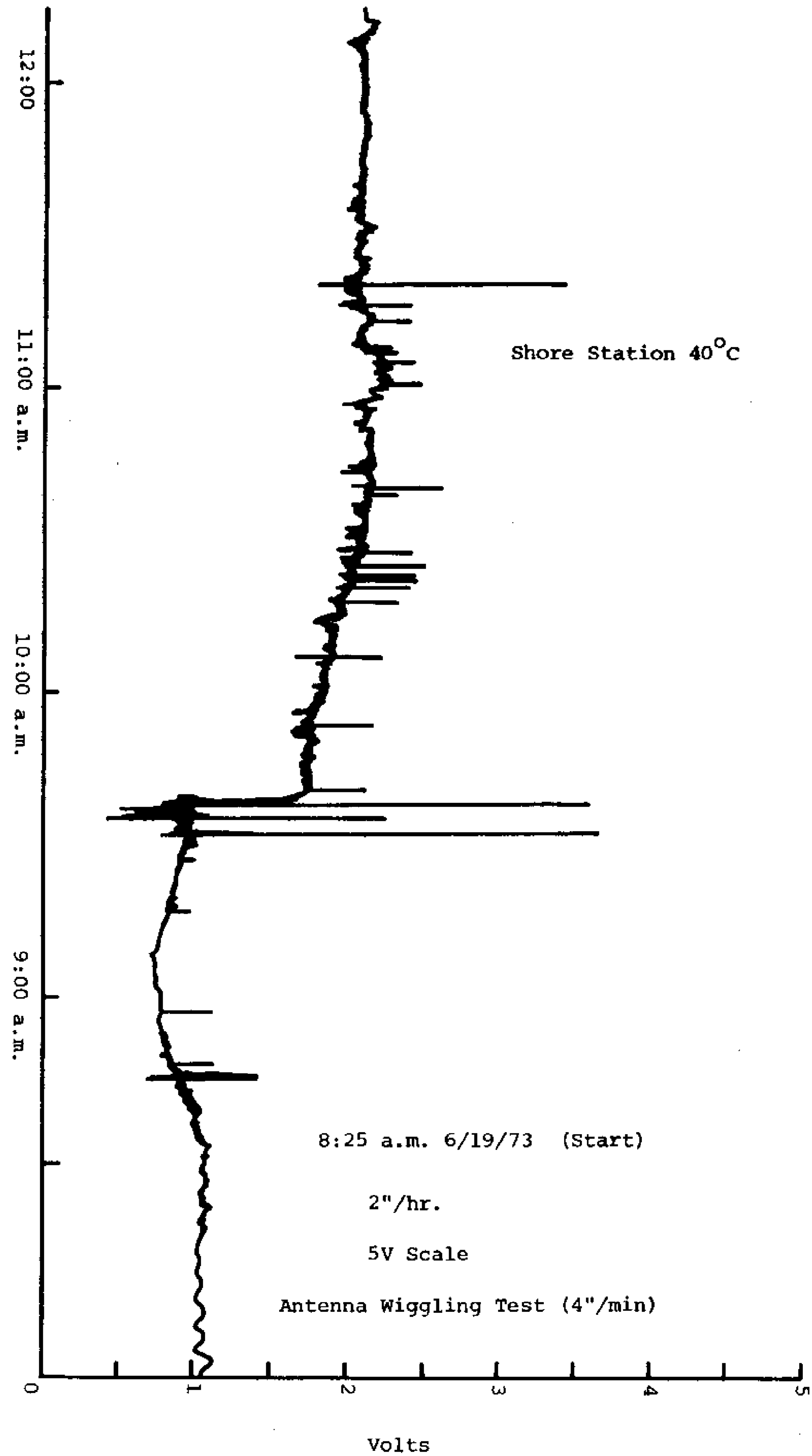


FIGURE 10.15 The Initial Tests with the Boat and Shore Stations Stationary

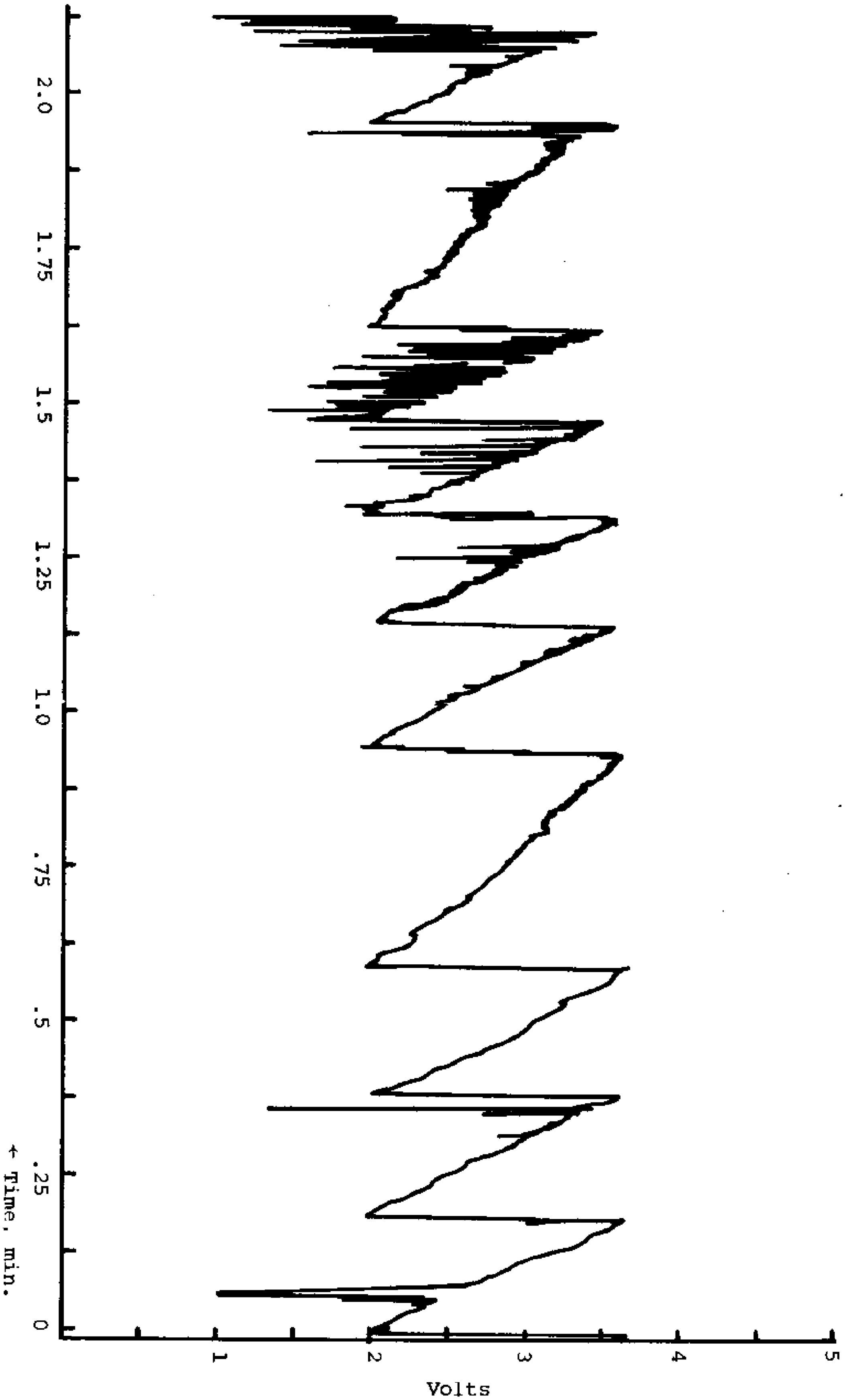


FIGURE 10.16 The First Range Tests for the System

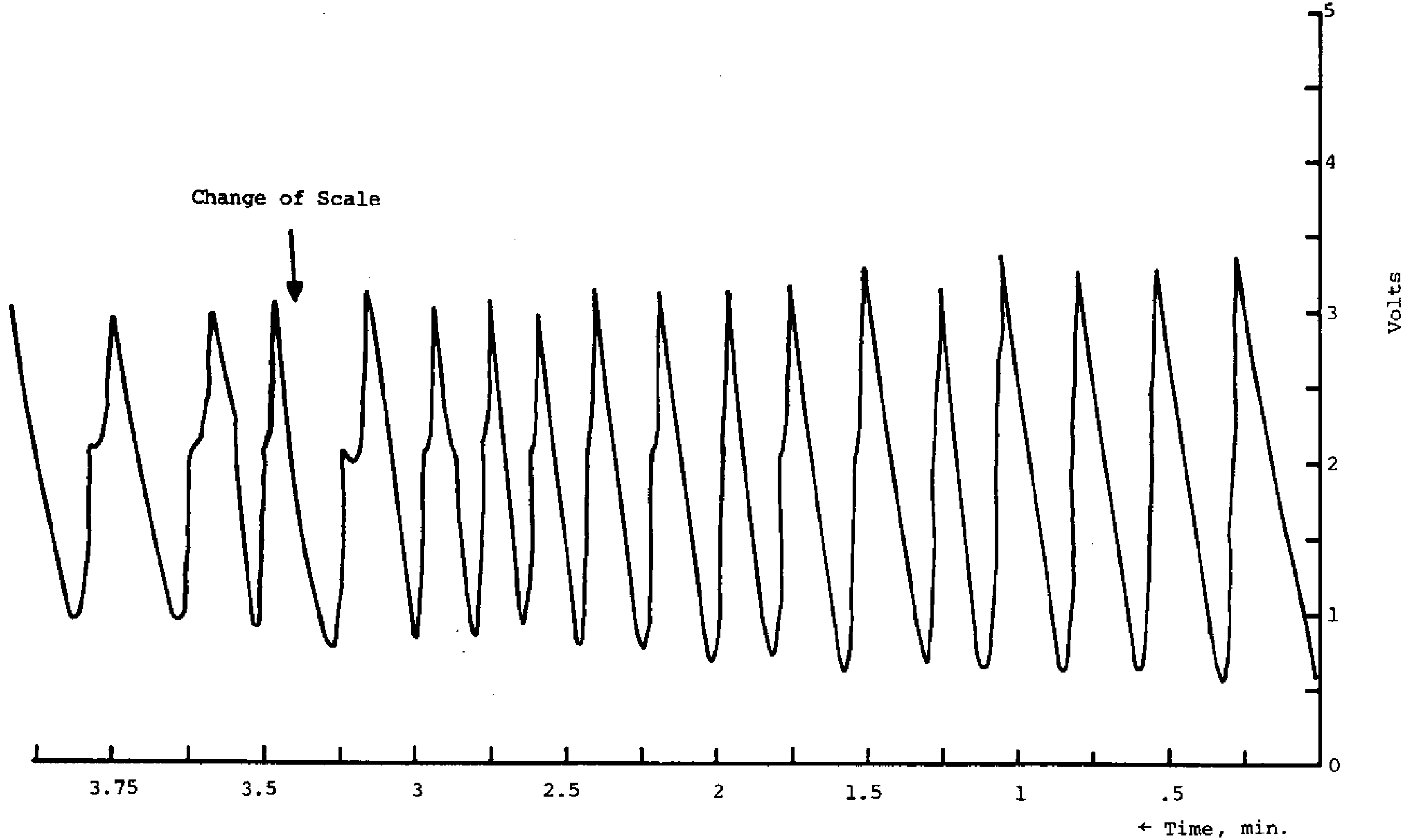


FIGURE 10.17 The Range Tests with the RC Filter

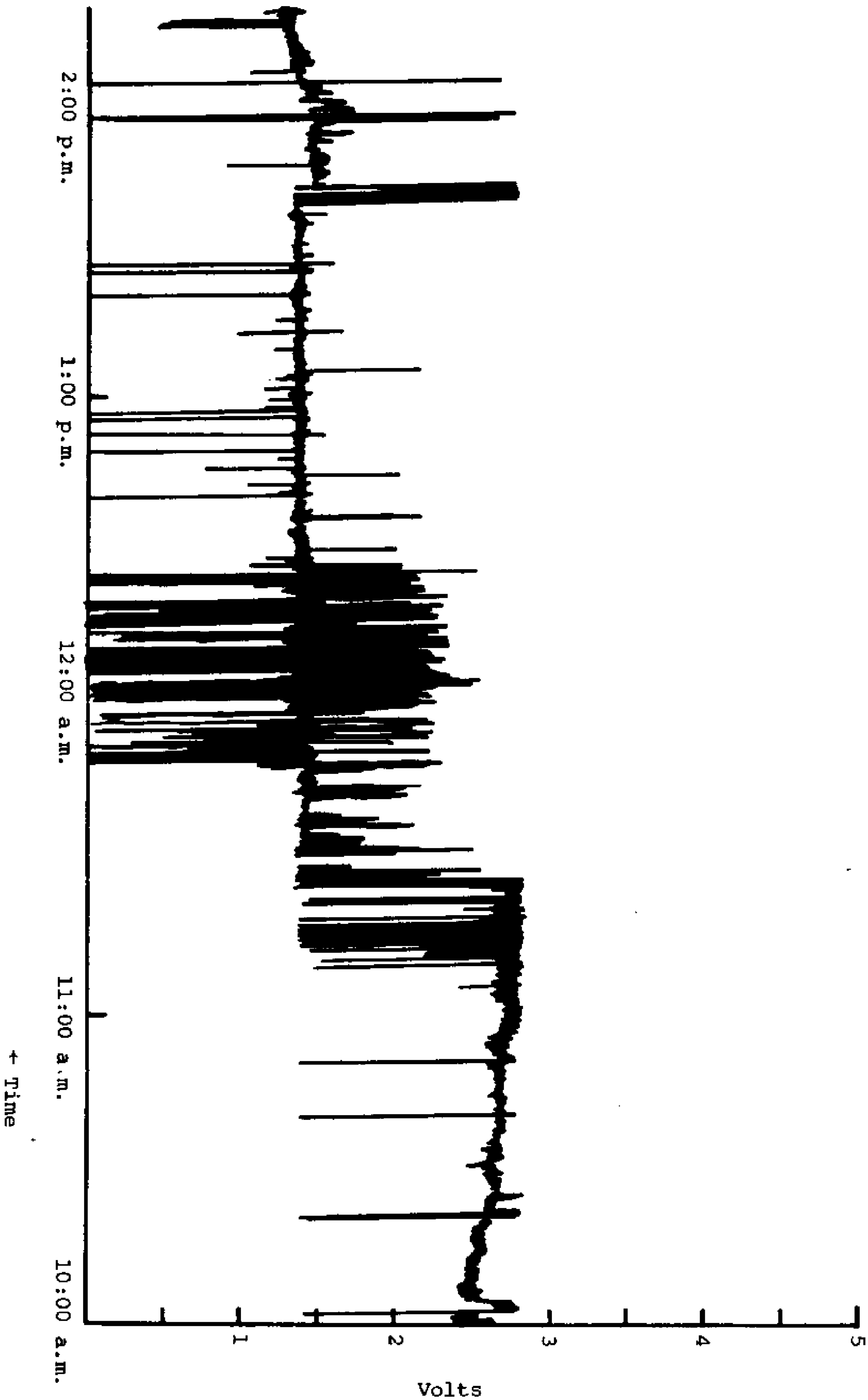


FIGURE 10.18 Final Drift Test

10.4 CONCLUSIONS AND RECOMMENDATIONS

Project Odysseus was considered to be a qualified success. The range of a boat could be determined with acceptable accuracy up to about one mile.

To improve the system more powerful transmitters and simpler and better attenuators would help. The phasemeter is another weak link in the system, as it is rather sensitive to noise. Temperature sensitivity can be isolated and reduced.

11. A GRADIOMETER MAGNETOMETER

The gradiometer magnetometer was chosen as a practical instrument for surveying the wreck of the "Defence" because it is capable of detecting iron underwater with remarkable sensivity. It would be useful for pinpointing cannons, cannon balls, iron spikes and other implements which might be buried in the mud around the wreck. Unlike most metal detectors, the gradiometer does not depend on the electrical properties of the metal. It is completely separate from the seawater, therefore, the water has no effect upon the performance of the device. The gradiometer is non-directional and measures only the magnitude of the magnetic gradient.

The aim of the project was to develop an inexpensive, underwater, gradiometer magnetometer for archaeological use. It is based on a design of a magnetometer by Waters and Francis (ref. 11.1) in 1958 and a gradiometer by Aitken and Tite (ref. 11.2) in 1962.

This gradiometer magnetometer was designed using modern electronic techniques to be portable and take static readings of the magnetic gradient between two sensors.

Iron objects, or anything with iron impurities, will create a magnetic gradient between the object and the earth's magnetic field. The gradiometer sensors are at the ends of a five foot staff which is held vertically so that the upper sensor is influenced only by the earth's magnetic field and is used as a reference from which to detect magnetic anomalies, near the lower sensor.

11.1 THE PRINCIPLE OF THE PROTON MAGNETOMETER

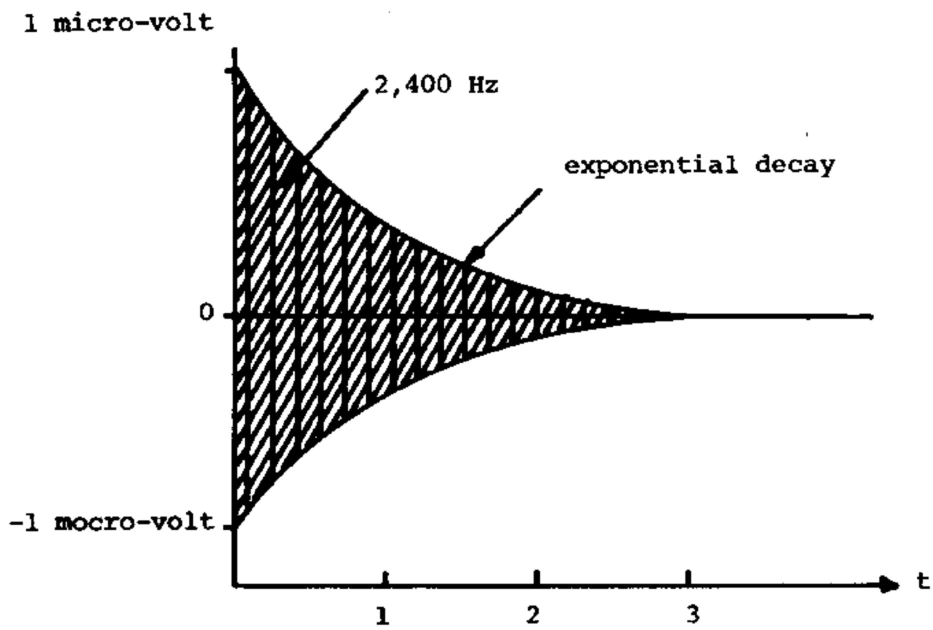
This gradiometer magnetometer makes use of proton spin resonance to measure magnetic fields. If a strong magnetic field is passed through a source of protons (water), many of the protons line up in the direction of the field. If the field is removed quickly enough the protons will precess around any available magnetic field. The protons act like damped oscillators and have an angular frequency which is directly proportional to the intensity of the magnetic field.

0.6 amperes of "polarizing" current is passed through the coils in the sensors, for three seconds, to create a strong magnetic field. When the current is turned off the proton precession produces an alternating voltage, in the coils, of about one micro volt peak-to-peak. If the two sensors are in equal magnetic fields, the procession frequency, of about 2,400 Hz, dies away with an exponential decay after about three seconds as illustrated in Figure 11.1a.

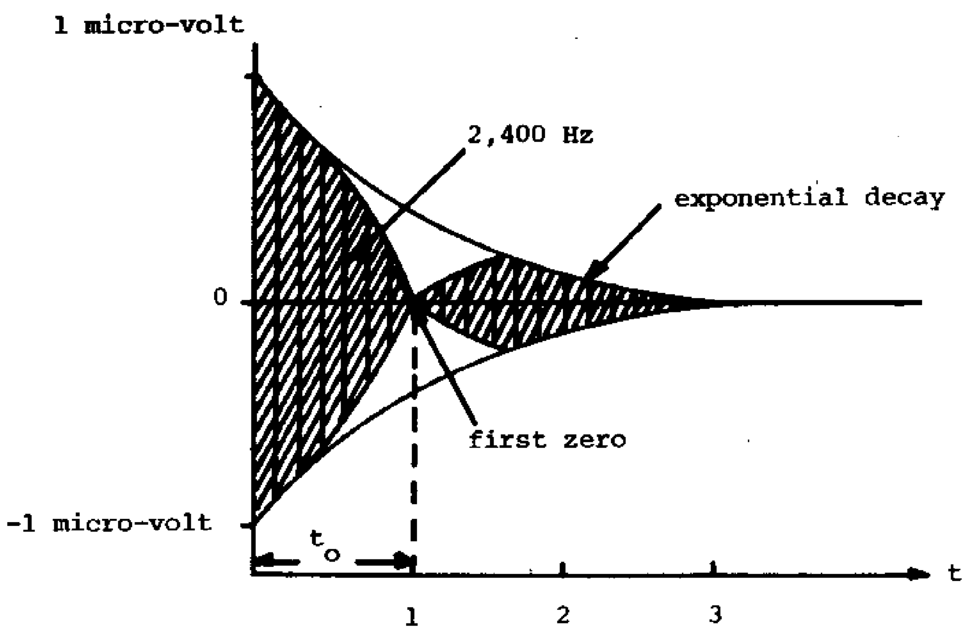
If the sensors are in slightly different magnetic fields, the two frequencies detected in the sensing coils mix together and form "beats" as indicated in Figure 11.1b.

The time between beats is inversely proportional to the magnetic gradient. The time from the polarizing current cut off to the first "zero" is exactly half of the time between beats, because the coils are subject to the same sharpness of break in polarizing current and the two procession signals begin in phase, from ref. 11.2.

$$\Delta F = \frac{11,7413 \times 10^{-5}}{t_o} \text{ gauss}$$



a. Signal in a Uniform Magnetic Field



b. Signal in the Presence of a Magnetic Anomaly

FIGURE 11.1 The Expected Signals from the Magnetometer

ΔF is the magnetic gradient. t_o is the time measured from the break in polarizing current to the first zero.

11.2 THE DESIGN OF THE MAGNETOMETER

Each sensor consists of a plastic bottle filled with water, wrapped around by a thousand turn coil of 22 gauge copper wire. The two coils were mounted in series, at the ends of a PVC pipe as shown in Figure 11.2. A five ampere-hour, twelve-volt motor-cycle battery was used to provide the three second 0.6 ampere polarizing current to the coils.

The polarizing current was switched on and off by a relay with two thirty-six volt zener diodes to clamp the negative spikes of voltage during turn-off and to prevent too much sparking across the relay contacts. The zener diodes also insured that the current turn-off was sufficiently fast to allow proton precession to occur.

The amplifiers were turned on eighteen milli-seconds after the break in polarizing current to protect the amplifier from the large transient and to allow the ringing in the coil to be damped by a 2.2k ohm resistor.

The preamplifier was built to have the lowest noise level possible for the available components and had a gain of 800. The preamplifier was tuned to a frequency of 2,330 Hz and had a Q of about 25. The noise level was about 0.5 micro volts peak-to-peak. The preamplifier was connected to a head phone amplifier with a gain of 10 and finially to a set of headphones. Although additional amplifiers, rectifiers and digital counters were also built experiments were carried out using only the headset because it was possible to distinguish more with the earphones than rectifiers and level detectors amid electrical noise.

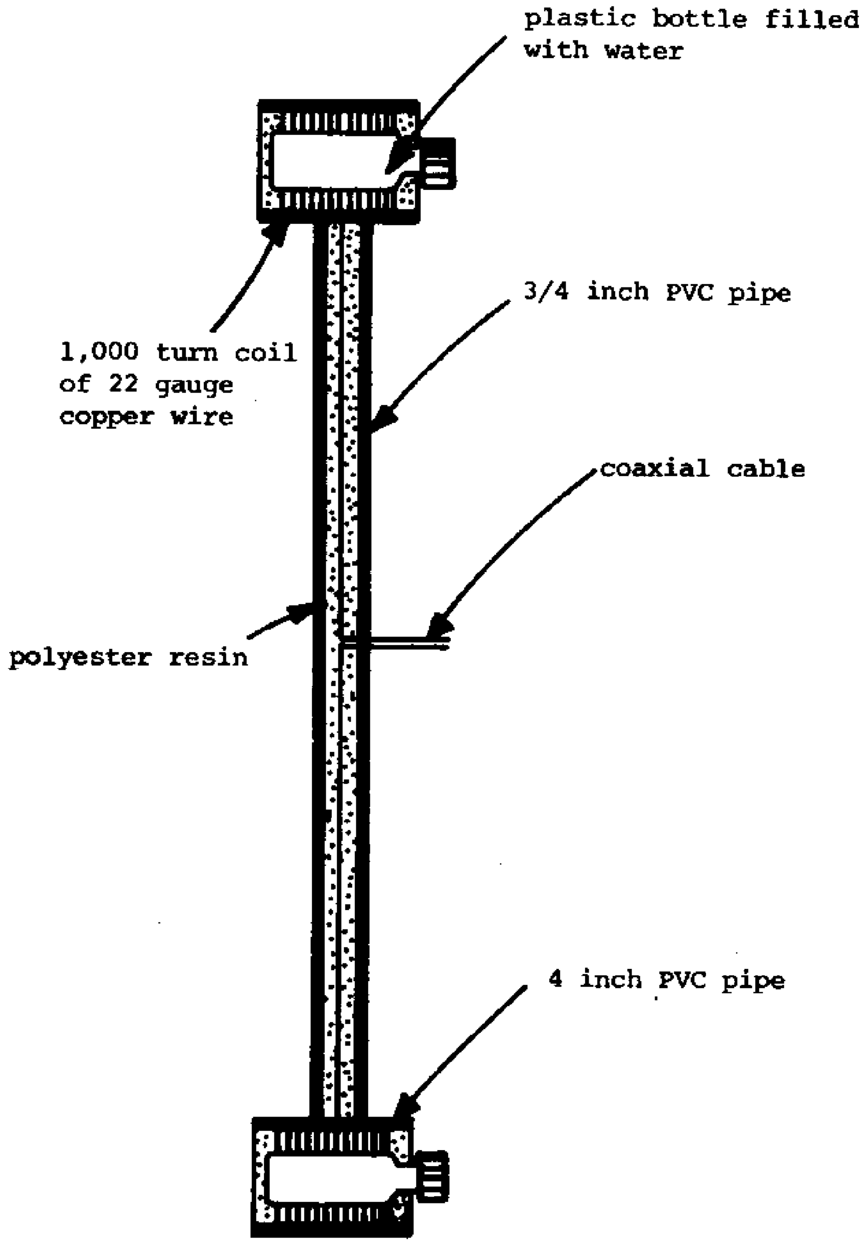


FIGURE 11.2 The Sensor of the Magnetometer

11.3 RESULTS

Due to the extreme sensitivity of the amplifiers it was impossible to operate the gradiometer in the laboratory because of sixty cycle hum and its harmonics.

The most successful experiments were carried out upon a rock, in the middle of a cove far away from interference.

The precession signal was audible through the head phones but not as clear as expected. The frequency was higher than the amplifier had been designed for but as the preamplifier was a broad band pass filter this would not have greatly affected the signal.

When the gradiometer magnetometer was brought near to a piece of iron, beats could be heard which would become faster the closer the gradiometer was operated to the iron. Directly above the iron no precession signal could be heard which was exactly what would be expected because iron will "kill" the precession signal. A hand drill was detected by the beats at a distance of about two yards.

11.4 CONCLUSIONS

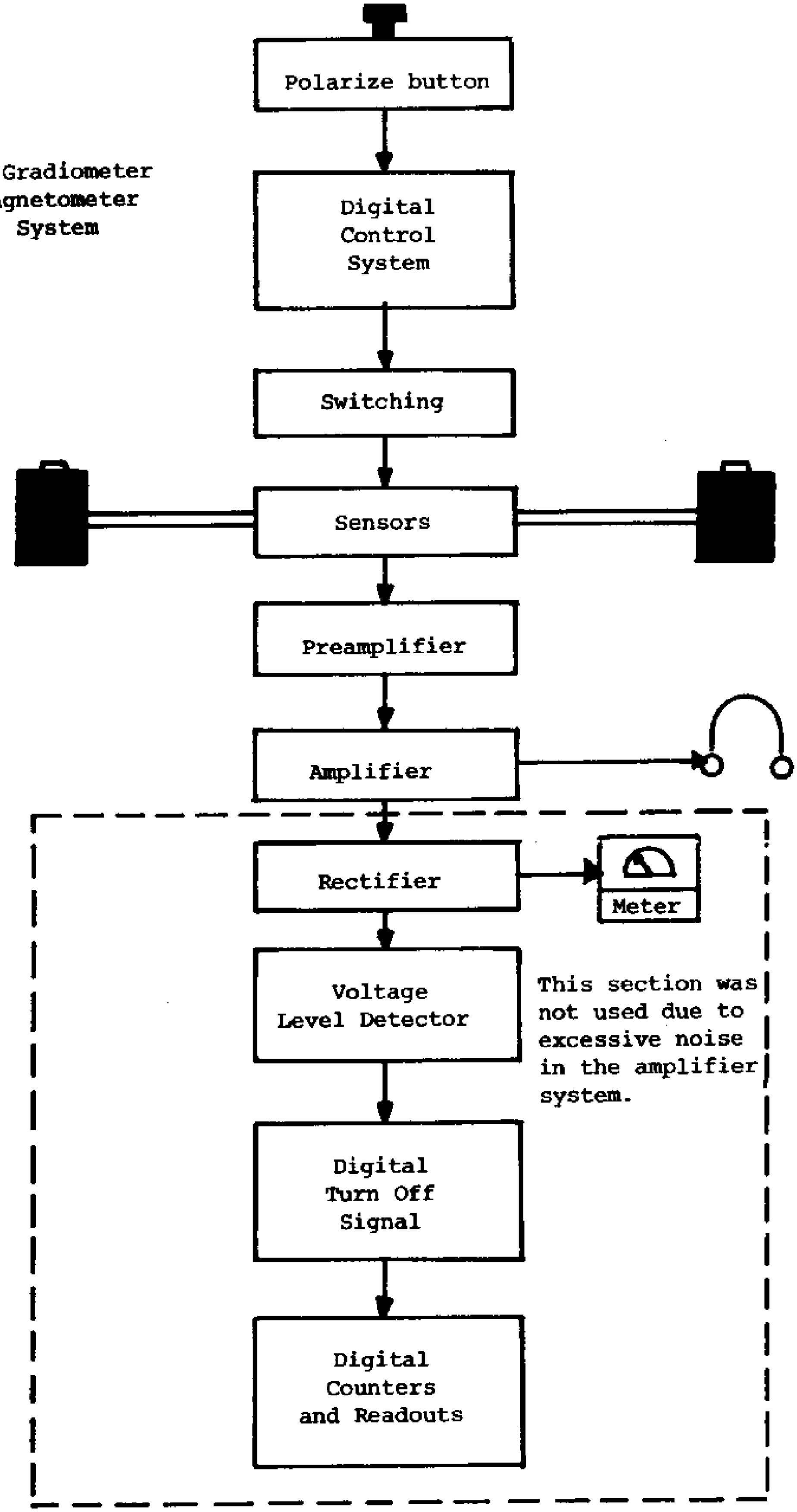
A proton magnetometer gradiometer has been built which has the capability for detecting iron objects. Some improvements in both the sensor and the electronic arrangements are necessary to make it a useful and reliable instrument.

11.5 REFERENCES

11.1 G. S. Waters and P. D. Francis, "A Nuclear Magnetometer", Journal of Scientific Instruements, Vol. 35, 1958.

11.2 M. J. Aitken and M. S. Tite, "A Gradient Magnetometer, Using Proton Free-Precession", Journal of Scientific Instruments, Vol. 39, 1962.

FIGURE 11.3 The Gradiometer Magnetometer System



12. A POWER TOOL FOR DIVERS

The power unit for the power tool, a seawater turbine, was designed and built two years ago, ref. 12.1, with the expectation that it would be incorporated in an underwater power tool. The next year was spent in designing and fabricating a hydraulic control device, which turned out to be a large piston to control the flow leaving the turbine. A trigger control for the tool was designed, and finally the tubing and main supply hose was added. Full pressure tests were run at M.I.T. using water directly from the City water supply, and the drill showed enough power to drill through aluminum and thin steel plate. The purpose of the development described here was to provide a protective casing for the tool and to evaluate the system in the ocean.

12.1 DESCRIPTION OF THE POWER TOOL

The tool consists of three main parts, as shown in Figure 12.1:

1. The power converter, a water turbine,
2. The controls,
3. The protective casing.

12.1.1 The Turbine

The seawater turbine is of the Francis type and has a runner, fabricated in "monel 401" which is approximately 2½ inches in diameter. The seawater is directed and accelerated onto the runner by means of a plexiglas scroll. The turbine runner is supported on its shaft in a monel casing by polyethylene journal bearings. The end of the shaft has a #2 Morse taper chuck to accept drill bits etc.. The thrust applied to the power tool is taken by a hydrostatic thrust bearing using the pressure of the seawater entering the turbine. The measured performance of the unit gave 0.7 horsepower at 4,000 rpm using 50 gallons per minute at 45 lbf/in^2.

12.1.2 The Tool Controls

The tool is controlled by a throttle in the turbine exit. The throttle is in the form of a specially shaped plexiglas piston which covers or uncovers holes in the side of the turbine exit pipe. The piston throttle is operated using water pressure from the turbine inlet which first passes through a small brass spool valve arrangement placed on the handle of the power tool. The end of the spool valve is the "trigger" of the power tool. When the trigger is depressed by the diver the pressure on one end of the piston throttle is vented to the ocean and the piston moves to uncover the ports to start the turbine. When the diver releases the trigger, high pressure water is applied to the end of the piston throttle to cover the ports and stop the turbine. When the power tool was first operated it was observed that there was sticky operation of the piston throttle due to water leaking past the piston. The leakage was completely prevented by installing an O-ring on the piston throttle. The friction was raised by the O-ring but this was more than compensated for by increased pressure acting on the piston resulting from the reduced leakage. The piping to and from the trigger used ¼ inch braided Tygon tubing having a working pressure in excess of 55 lbf/in^2.

12.1.3 The Protective Outer Casing

The outer casing was designed to protect the plexiglass components from damage and also to provide some buoyancy. The casing was constructed of two pieces of hard foamed-plastic material which were shaped to the power tool as a snug fit. The plastic material was covered with several layers of fiberglas to provide strength, and fitted with ski-buckles to clamp the halves together.

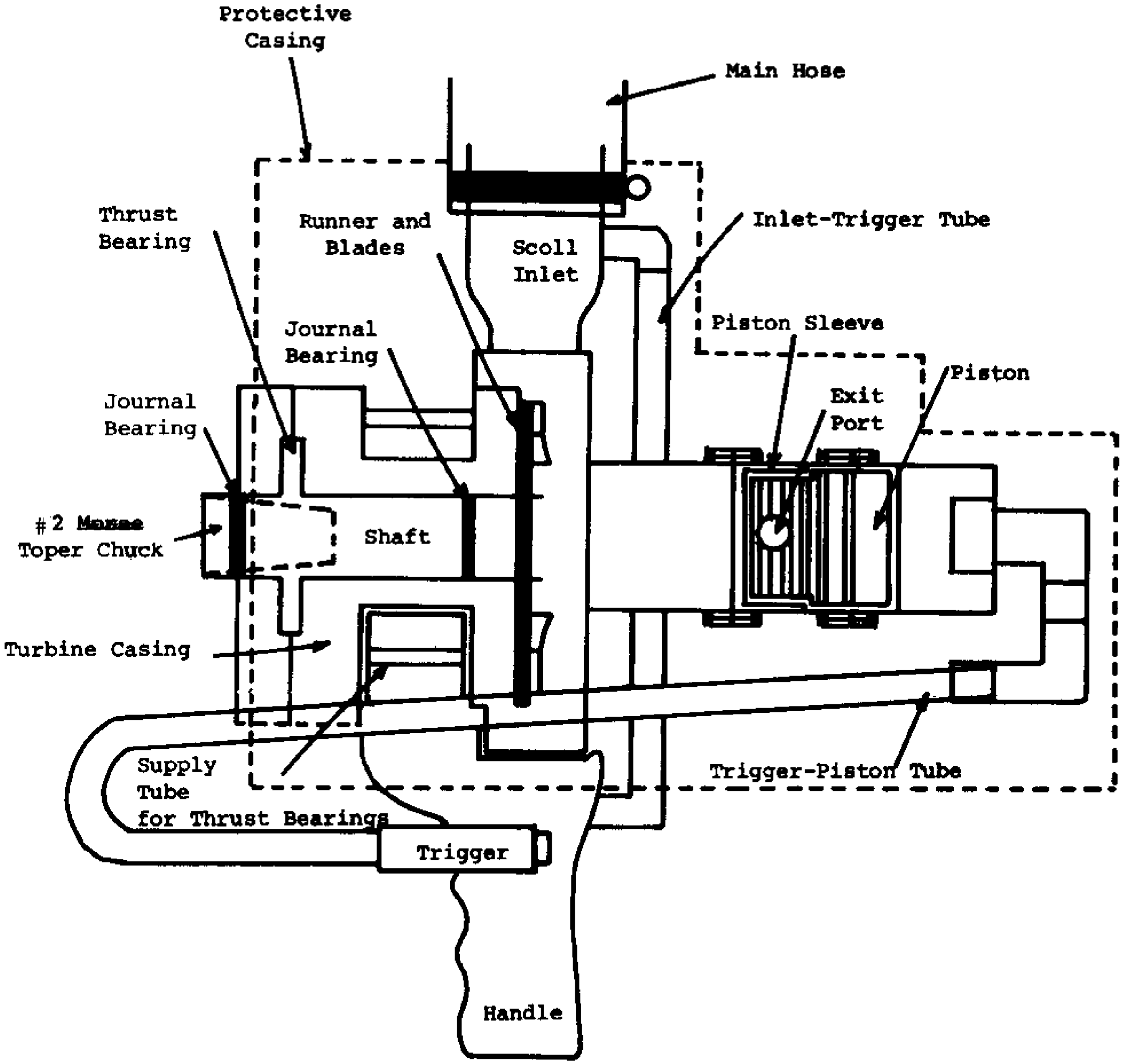


FIGURE 12.1 A Diagrammatic View of the Diver Power Tool

12.2 THE PUMPING SYSTEM

The seawater was provided by a centrifugal pump driven by a 7 horsepower gasoline engine. The engine was capable of supplying 70 gallons/min at 55 lbf/in^2. The water was supplied to the power tool by means of 25 ft. lengths of fire hose. A special attachment was made to connect the fire hose to the scroll of the power tool. Provision was made at the pump outlet pipe to divert the water from the pump when the power tool was not operating.

12.3 TEST RESULTS

The drill performed and handled well, and under test operating conditions at the Castine dock, was able to drill holes up to ½" diameter in ½" steel plate in one or two minutes. It was difficult to start holes without using a centerpunch, but once started, drilling was fairly easy. At a wreck in approximately 35 ft. of water, divers attempted to drill into a brass steering wheel shaft. They managed to drill several ½" holes about 3/4" deep, but progress was difficult beyond that. The method of diver support was to tie a loop of rope to two points on the steering wheel shaft, and the rope was passed behind the diver so he could lean against it.

It took a relatively long time to set up prior to drilling, so that the drilling itself only took place for about 5 to 10 minutes for each team. Currents on the bottom made it difficult to keep the bit aligned in the hole, this was one reason the holes were not very deep. One feature of the drill discovered was that when the drill bit stalled, there was very little torque placed on the diver. This was due to the swirling path of the water upon exit from the turbine blades, and the symmetry of the four exit holes.

The drill was somewhat cumbersome underwater with the large casing and the full 75 ft. of hose attached, and it was difficult to apply a large amount of forward pressure while drilling. However, this is a problem common to all underwater tools, and not just a characteristic of this drill.

The attempt to drill granite (Nautilus Rock) was a failure. Tests on granite samples at the dock yielded a hole about ¼" deep, after which no progress could be made. Attempts were made with an electric drill and a drill press, with the same result. This showed that the fault did not lie in the drill itself, but rather in the bit, even though carbide-tipped bits were used. The standard procedure for drilling granite is with an impact star drill, not a rotary type drill, and the only possible solution would be to use a harder bit, such as diamond tipped.

The only major problem that developed was that the pressure on the bit while drilling would sometimes force the shaft back slightly through the thrust bearing so that the turbine would rub against the scroll, causing a loss of power. The shaft could be moved back in place while using a drift to remove the drill bit.

An inspection of the journal bearings after approximately 12 hours of drilling showed no appreciable wearing, to .002". All other parts of the drill were intact, except for a slight amount of rust on some areas.

12.4 RECOMMENDATIONS

The problem of the shaft slipping back and forth can probably be solved by inserting a "snap ring" immediately ahead of the thrust disk on the shaft. The "snap ring" would have to be fabricated from monel to prevent corrosion. The protective outer casing could be reduced in size, and possibly clamped together instead of using ski buckles which tended to unbuckle fairly easily. The trigger is difficult to depress for long periods of time, this could be eased by reducing the diameter of the plunger, thus reducing the force, or by mounting a large thumb rest on the plunger to have a larger area to push against. It is unlikely that granite can be drilled in a rotary fashion without using diamond-tipped bits.

REFERENCES

12.1 T. G. Curtis, "A Hydraulic Power Tool for Divers", M.I.T. Ocean Engineering Report No. 71-18.

13. AN EXPERIMENTAL OCEAN MINING SYSTEM, DUMP 1

Over the past years the interest in manganese nodule mining as a new supply for various minerals in high demand has been rising in the U.S., Europe and Japan. The size of a typical manganese nodule found in some regions of the Pacific Ocean is shown in Figure 13.1. Several systems to recover these deposits have been suggested, ranging from continuous bucket line system and underwater robots to hydraulic systems. Only three systems have so far been tested on a larger scale: the Japanese bucket system, the airlift system by Deep Sea Venture, and the Hughes-Global Marine submerged vessel system.

The major problem inherent with most of the proposed systems arises from the requirement that the system has to operate reliably under a wide range of adverse weather conditions, and with equipment at depths greater than 15,000 feet, corresponding to an environmental pressure of approximately 7,000 lb/in^2. From an engineering analysis point of view a hydraulic system with surface mounted power generation seems to suggest an appropriate solution. A new hydraulic system, based on a European patent, was examined using theoretical and experimental techniques.

13.1 THE DESIGN PRINCIPLES

The working principle can be summarized as follows: a pressure differential is created by lowering the level inside an open vessel to a level T_{eff} below the surface, as illustrated in Figure 13.2. The pressure difference will induce an upwards water flow in the pipe attached to the bottom of the vessel, thereby creating a suction effect at the lower end of the pipe. The water level can be maintained and controlled by pumping the water out from

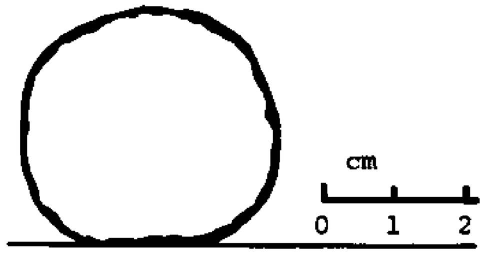


FIGURE 13.1 Manganese Nodule

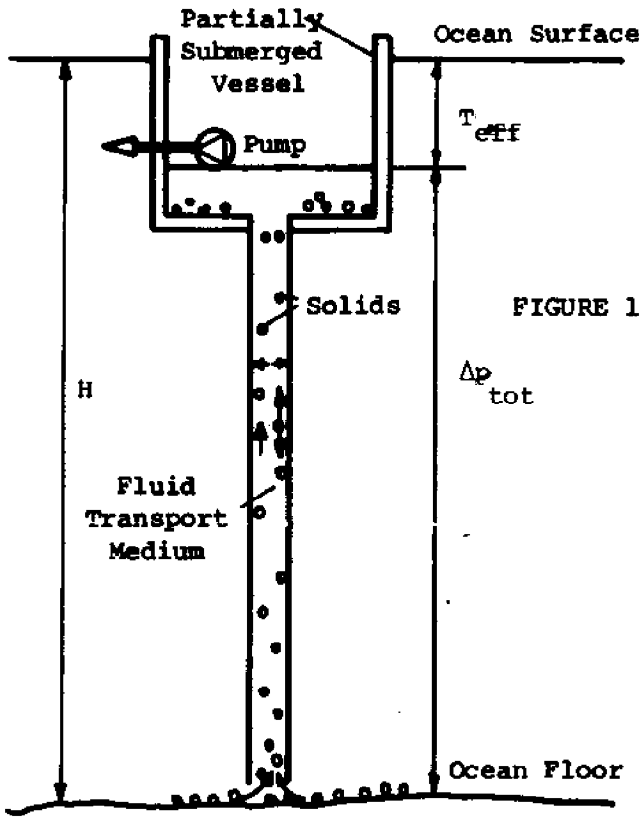


FIGURE 13.2 Schematic Diagram of the Hydraulic Conveying System

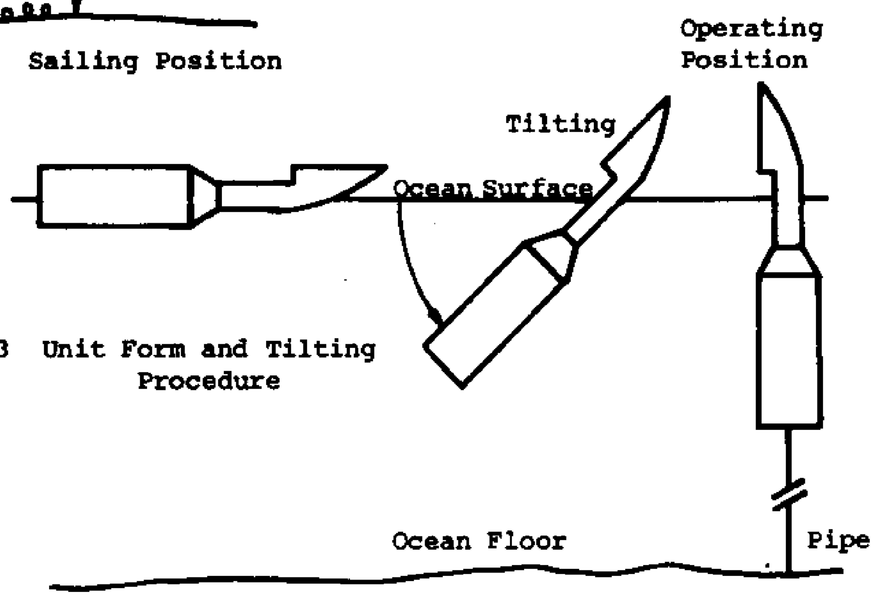


FIGURE 13.3 Unit Form and Tilting Procedure

the lower part of the vessel after separating the water stream and the solid particles. Only a high concentration of mined material has then to be transported by conventional means the remaining short distance to the surface.

By designing the surface vessel as sketched in Figure 13.3, a stable platform can be obtained. With such a system, the following important requirements can be satisfied:

1. All equipment with moving parts, such as pumps, generators etc. which require periodic maintenance and continuous control is easily accessible inside the vessel under atmospheric pressure.
2. The surface unit is extremely weather stable. The FLIP-like shape has proven to be a stable platform for scientific research in the ocean.
3. The construction costs should be below the costs encountered with other systems under construction, and the operating cost would be comparably low due to high automation and stability and dependability of the surface unit.

The analysis of the technique feasibility was carried out in three stages:

1. Development of a computer program enabling the optimization of the system and the prediction of measurements on the model tank test and the ocean test.
2. Model tank testing, scale 1 : 500
3. Ocean testing, scale 1 : 50

13.2 COMPUTER PROGRAM

A computer program was written to calculate flow rates in the pipe as a function of various pressure heads, pipe length, pipe diameter and solid particle concentration. It was found that with a pressure head of 4-6 feet and a low concentration of 1-3% solid particles in the water, a reasonable flow rate could be obtained for the ocean test model. Similar computer runs were made for the tank test.

13.3 SMALL MODEL TANK TEST

Small models of various diameter were designed and constructed in plexiglas, which allowed the process both within the pipe and the vessel to be observed. Various grades of sand were sucked up from 4 feet water depth and the computer data was verified. Various phenomena, like circular flow pattern in the lower part of the tube and turbulence creating design details were observed and filmed for further studies.

13.4 OCEAN TEST

A model for ocean testing, 8 feet high and 4 feet square, with a pressure head range of 4 to 6 feet was designed and built at M.I.T. and transported to the Maine Maritime Academy in Castine, where the Revolutionary Wreck "Defence" was being excavated.

The model system was built around an 8 foot high, 4 foot square plywood box, stiffened with 2 by 4 inch members. The box was constructed of five prefabricated sections that could be bolted together to form the box shape. This provided the greatest ease in transporting the system to Maine. The box was painted with epoxy paint, the seams between the sections were caulked, and then fiberglassed. But the box still required baling twice

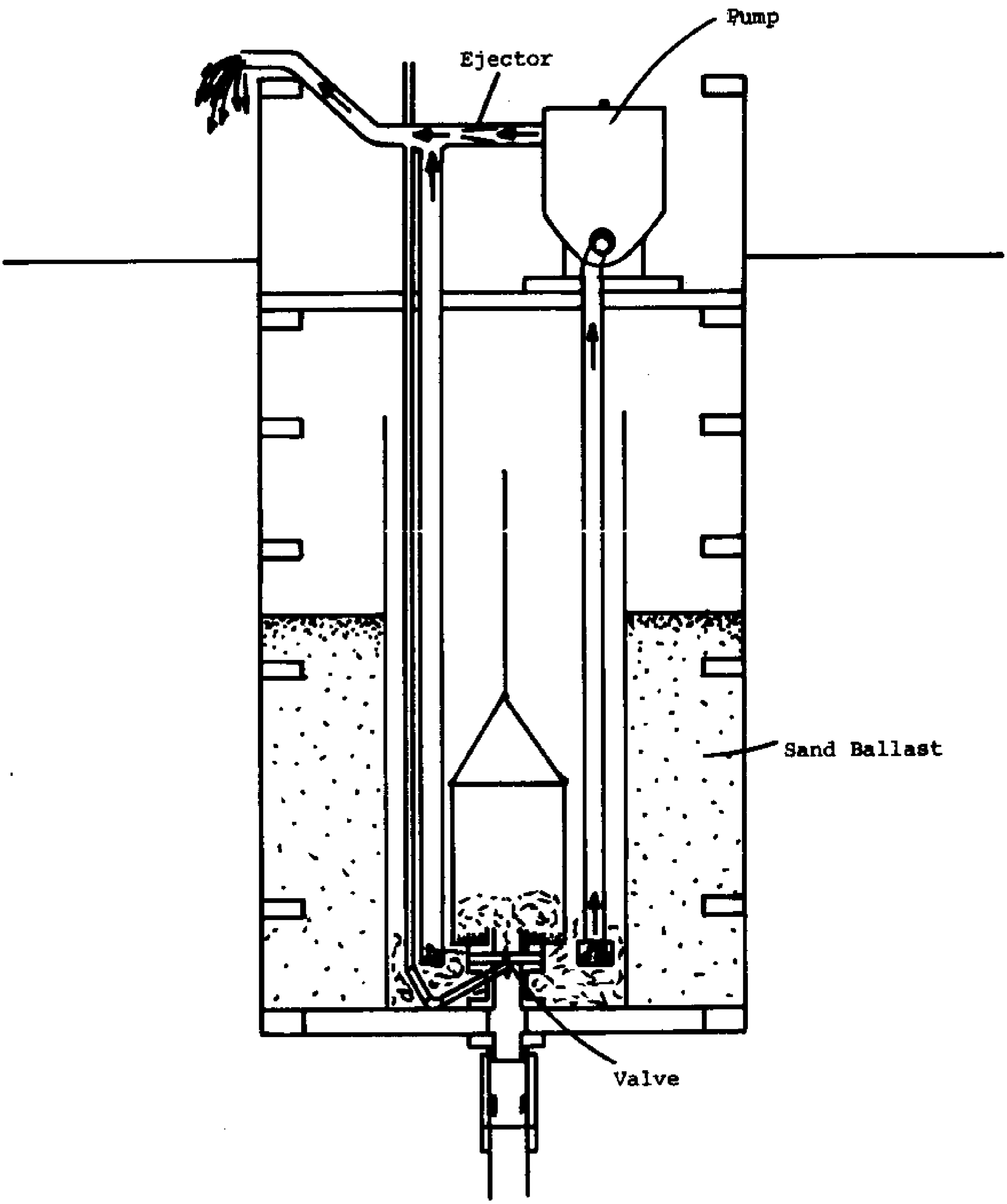


FIGURE 13.4 The Large Model of the Mining Device

a day to keep it afloat because external plywood rather than marine plywood was used.

Through the bottom of the box, a set of 4 inch pipe flanges sandwiched a standard 55 gal. drum, with a welded extension inside the bottom of the box, as shown in Figure 13.4. Inside the bottom of the drum, a 4 inch butterfly valve was bolted against the inside flange.

4 inch PVC pipe was attached to the outside bottom flange with a length of flexible marine exhaust hose. (The exhaust hose proved not to be flexible enough). 45 degree PVC elbows, and various lengths of 4 inch pipe were used to change the length and position of the suction end. The suction end consisted of a clear plexiglas section for observation purposes, and a diver operated shut-off valve.

A 2 inch centrifugal pump driven by a 7 hp gas engine was the basis for the pumping mechanism. Water was pumped from either the inside of the barrel, or from the surface water outside the box, into a nozzle that reduced the diameter of the water flow to ½ inch. The nozzle jetted the water into a brass T, creating an ejector suction up the 2 inch pipe from the bottom of the box. Pumping from the barrel to the ejector proved more efficient than pumping surface water to the ejector.

The pump was eventually mounted inside the box, reducing the length of pipes and providing a completely independent system.

Sand was shoveled into the area between the box, and the barrel as ballast. About 3 feet of sand provided enough ballast (2-3 tons) to create a 4-6 foot head. Water could be pumped on top of sand to provide more head, with a sacrifice of stability. With the proper amount of sand the center of mass would be below the center of bouyancy, creating a stable platform.

In the actual testing with a 6 foot head, and a 15 foot 4 inch pipe, a sufficient suction was produced to lift ½ to 1 cubic feet of sand per minute. Ideally the system worked well, but many design problems existed.

Because of the large mass of the box structure, its maneuverability was very limited. It was very difficult to hold the structure over a site in a current, or move the box along in the water. Because the box was so difficult to move, the pipe system was not flexible enough for the diver to operate. Also there was no method of immediately varying the length of the pipe to account for the changing tide height.

The collecting nozzle also created problems. With a straight collector pipe, large objects, sea urchins and mussel shells would enter and eventually clog the pipe at the valve. A large mesh screen was placed at the end of the collector. This successfully prevented large objects from entering the pipe but then objects would attach to the screen, held on by suction, and eventually clog the pipe.

The flow rate in the pipe was limited by the flow rate of water out of the box. The pumping system operated at 50-80 gal/min. and at best could not keep up with the incoming flow.

The biggest problem with the system was its size and bulk. 2-3 tons of sand ballast had to be shoveled in and out of the box for operation. With only one foot of sand in the box towing was very difficult, resulting in 1-2 knot tow speeds.

13.5 CONCLUSIONS

From the model test it would appear that the computer analysis of the flow rate was fairly accurate. The analysis could probably be successfully adapted to a large scale system.

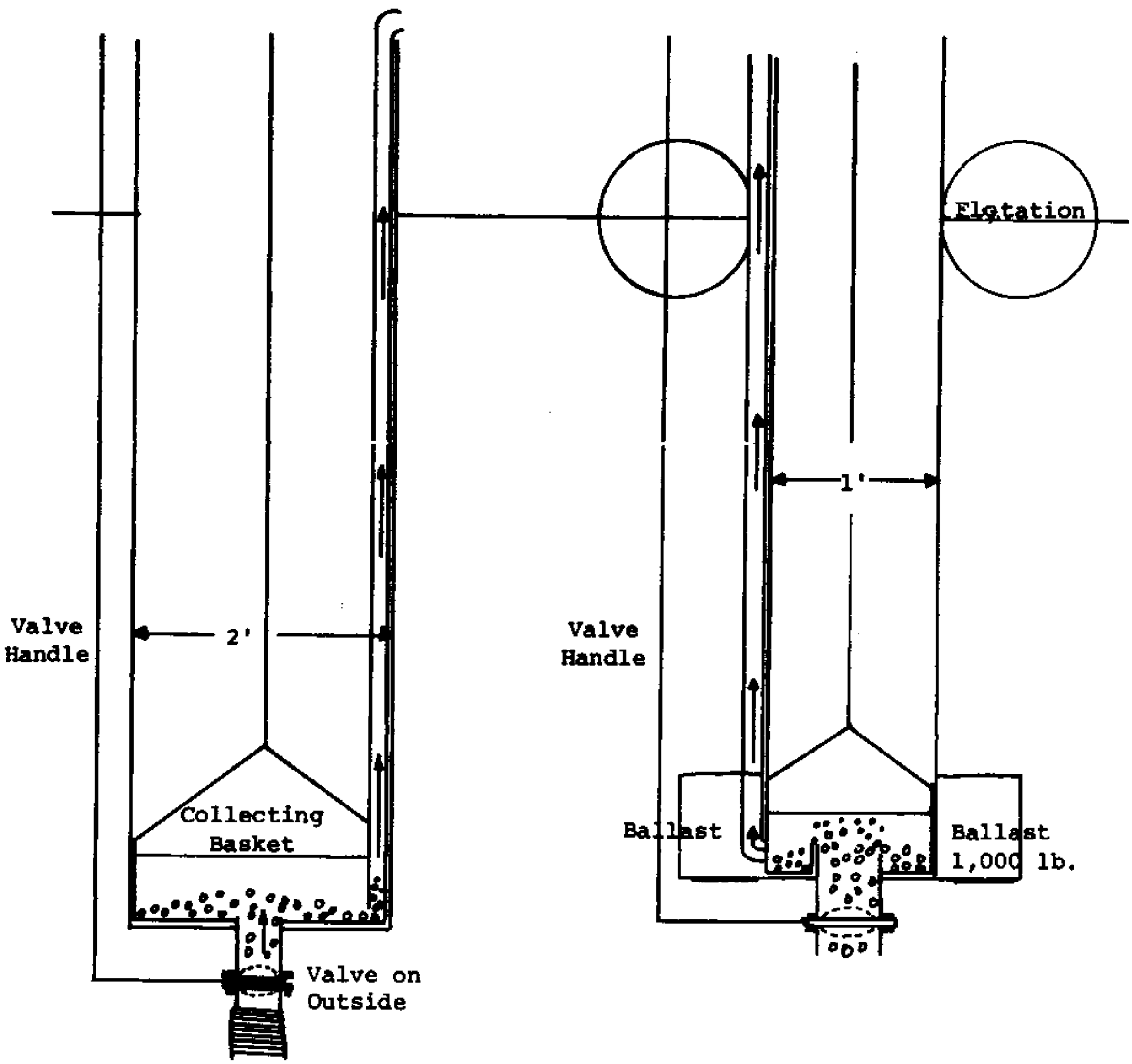


FIGURE 13.5 Suggested Modifications to the Model System

The most critical consideration rests with the feasibility of the general design of the system. The displacement of the device must be minimized to reduce the amount of ballast needed, and reduce the drag in towing and maneuvering. It is questionable whether a large scale system, with perhaps a 150 foot head, could maneuver across the deep ocean bottom. The mere bulk of a large scale system would greatly complicate the operational control, and the transportation to and from the site. Again, only if the displacement and the bulk of the system can be reduced, will the system be able to compete with the alternate systems.

13.6 RECOMMENDATIONS

The size of the system model could be greatly reduced, and still maintain a sufficient pressure head. This would increase maneuverability and decrease ballast. Figure 13.5 shows examples of a more compact system.

The pumping system should also be reconsidered. It is questionable if an ejector system is needed, since large objects seldom enter the system. Also, a low pressure, high capacity pump may prove more efficient in removing larger quantities of water. However, the available pump was also utilized in the diver power tool studies described previously.

14. THE AIR LIFT DREDGE

A simple rugged dredge was required to assist in the archaeological investigation of the wreck of the "Defence". An attempt was made in 1972 to utilize an air lift dredge. The purpose of the development described here was to make a more reliable and self contained system.

14.1 THE AIR LIFT DESIGN

In an air lift system the compressed air is taken to a position near the bottom of a dredge pipe. The air bubbling into the pipe rises because of the buoyancy forces and the flow of bubbles up the pipe induces the water to flow. The water flow in the dredge pipe carries along mud and low density small objects to the surface.

In the present design of air lift system, two 10 ft. lengths of 4 inch PVC pipe provided the dredge pipe. Two feet above the bottom of the pipe the air hose was attached together with a quick throw shut-off valve. A steel sleeve was put on the PVC around the air line to help to strengthen the PVC in that region.

The air supply to the air lift dredge was provided by an available (but heavy) air compressor driven with a belt drive by a small 2½ horsepower gasoline engine. The engine and compressor were mounted together on a wooden base plate. The compressor was hinged so that it could be raised to slacken the belt drive for starting purposes.

A screen raft was used to filter the effluent from the dredge pipe.

14.2 DEVELOPMENT AND RESULTS

The ease of handling and operating the dredge was improved by the addition of a one foot length of flexible hose (normally used as a dryer exhaust hose) at the end of the dredge pipe.

When using the dredge the first six inches of mud was sucked up easily. However, as it moved deeper the mud became more compacted and scooping it into the dredge pipe by hand was the easiest method. The dredge occasionally became clogged with shells, but by manipulating the quick-throw valve, first off and then on, it was easily cleared. Also be moving the flexible hose like an accordion, the dredge would also clear easily.

14.3 CONCLUSIONS AND RECOMMENDATIONS

The air lift project was successful and ideally suited for shallow water dredging. On the "Defence", the area around the brick stove was cleared of silt and may small items were recovered.

Some improvement to the system can be made. A tender is needed at the surface to sort through the mud dredged up. To make his job easier more flotation and a seat should be placed on the screen raft. Other minor modifications could be made to the compressor and the dredge pipe itself.

15. TIDAL CURRENT POWERED ELECTRICAL GENERATOR

The underwater power generator was an attempt to capture energy from the water currents caused by the action of the tide. A small scale model was to be built and tested during the four-week period of July. The idea was to have such an underwater power generator without the problem of marine traffic, ice in the winter, and while producing electricity it would remain pollution free. The objective was to accomplish these goals with a small scale model to see how feasible it would be to build on a larger scale. From the information gathered the previous year and parts that were already bought, and underwater power generator on a small scale was designed.

15.1 DESIGN DETAILS

The general layout is shown in Figure 15.1. Construction of the model started with the building of a wooden box, open at the bottom, 10" x 18" x 22". The idea of the open bottom was to let the air pressure on the inside be equal to that of the water pressure on the outside. This would lessen the chance of any leaks. The extra air needed for the box to stay full of air as it was lowered in the water came from the diver's mouthpiece.

Within this box a combination of belts and pulleys was set up in order to increase the rpm needed to turn the generator. Two ten-inch pulleys and two two-inch pulleys were used. The generator which would produce the current was that of a bicycle generator.

After placement of the parts, the box was then fiberglassed to make it watertight. Fins were added for the stability of the device in both the horizontal and vertical positions.

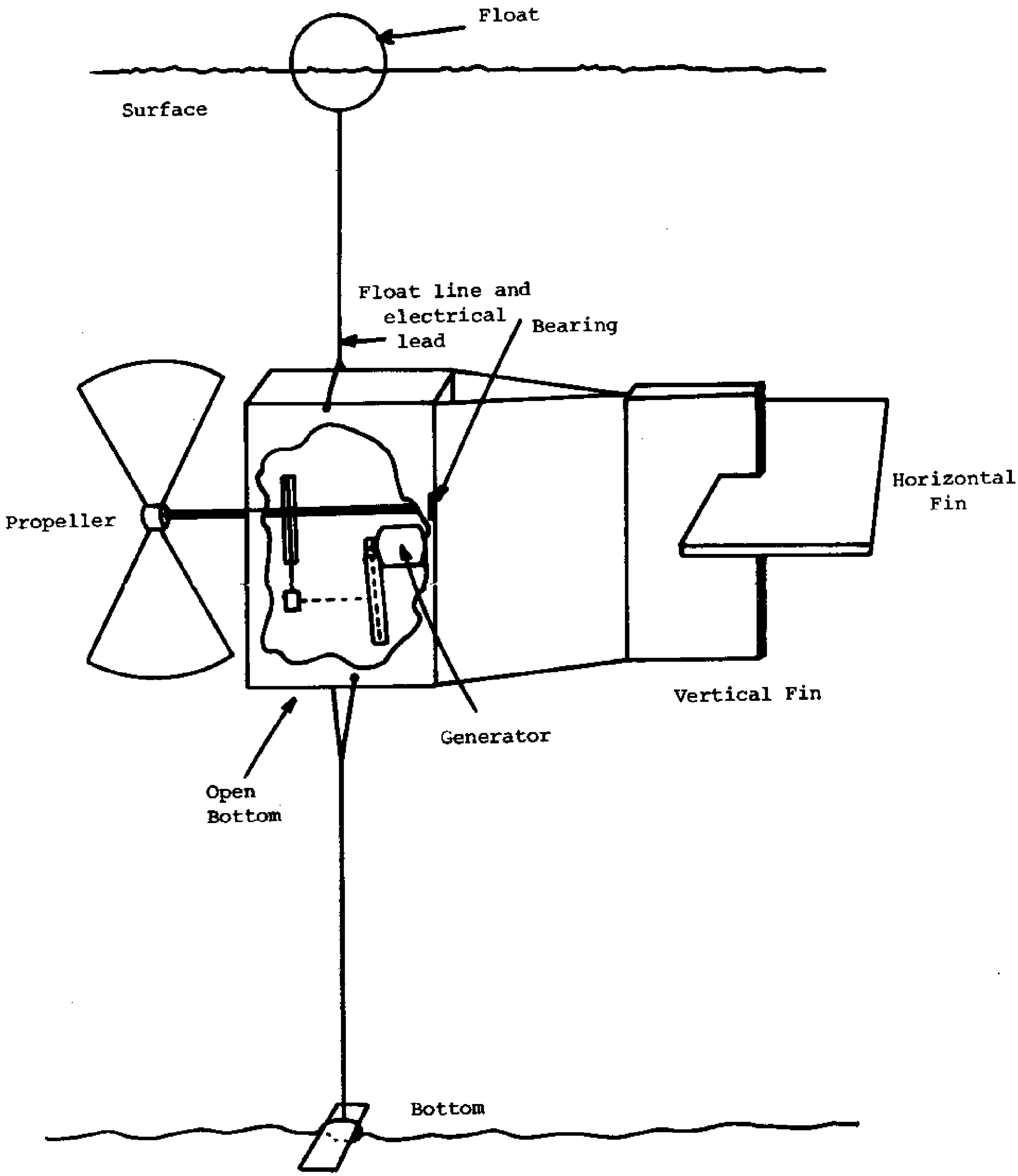


FIGURE 15.1 Tidal Current Powered Generator

Different mooring means were examined and some were tried. The one used was to find an object already on the bottom and use that to tie a line to. This was not a satisfactory solution as on return to the mooring site the model was missing. It was found about half a mile up the channel. The mooring line had worked loose and the model had floated away until it was snagged by a large rock. The model tidal current generator was seriously damaged.

15.2 CONCLUSIONS AND RECOMMENDATIONS

The model tidal current generator was capable of generating electrical current in the narrows of the Baggaduce River, although the magnitude of the power generation was not determined. The drag on the housing was obviously high and the method of mooring was inadequate in such circumstance.

Several changes are recommended for future designs of a tidal current powered generator. A smaller housing is suggested so that the drag is reduced. Smaller pulleys and bearings should be used because the loads and power generated is small. The most important change proposed is to the mooring arrangement. A sound mooring line is required to hold the device in the rapid currents.

16. THE FLOATING BREAKWATER

The floating breakwater arrangement was suggested by Dr. Buckminster Fuller who assisted in the design and the funding of this project. Such a breakwater would be useful to Dr. Fuller at Little Spruce Head Island to provide a suitable small boat landing area; it was also a useful project in its own right. A floating breakwater would have certain advantages; it would be deployed in the summer when it is needed, furthermore it would cause very little environmental change in the area compared with a permanent rock breakwater. The task then, was to design, build,and test a floating breakwater.

16.1 DESIGN ARRANGEMENT

Preliminary studies were made in the spring of a model in a wave tank. It was observed that a wave of twice the height of the exposed breakwater could be dissipated down to a wave height less than half of the exposed breakwater.

A larger scale model was built for testing at a cove on Hospital Island, near Castine. The floating breakwater was built of truck inner-tubes with a thin polyethylene jacket surrounding the inner-tubes, as shown in Figure 16.1.

The inner tubes were partially filled with water, then air was pumped in, to provide buoyancy. Each tube was independently attached to a three-line bridle which ran along the inside of the tubes. The three lines were taken up at each end and attached securely to the end of the mooring lines.

The polyethylene jacket was made in the form of a tube 40 feet long and the ends of the jacket were gathered. The structure was moored at each end by 300 ft. of nylon line, fifty ft. of chain, and a seventy five pound

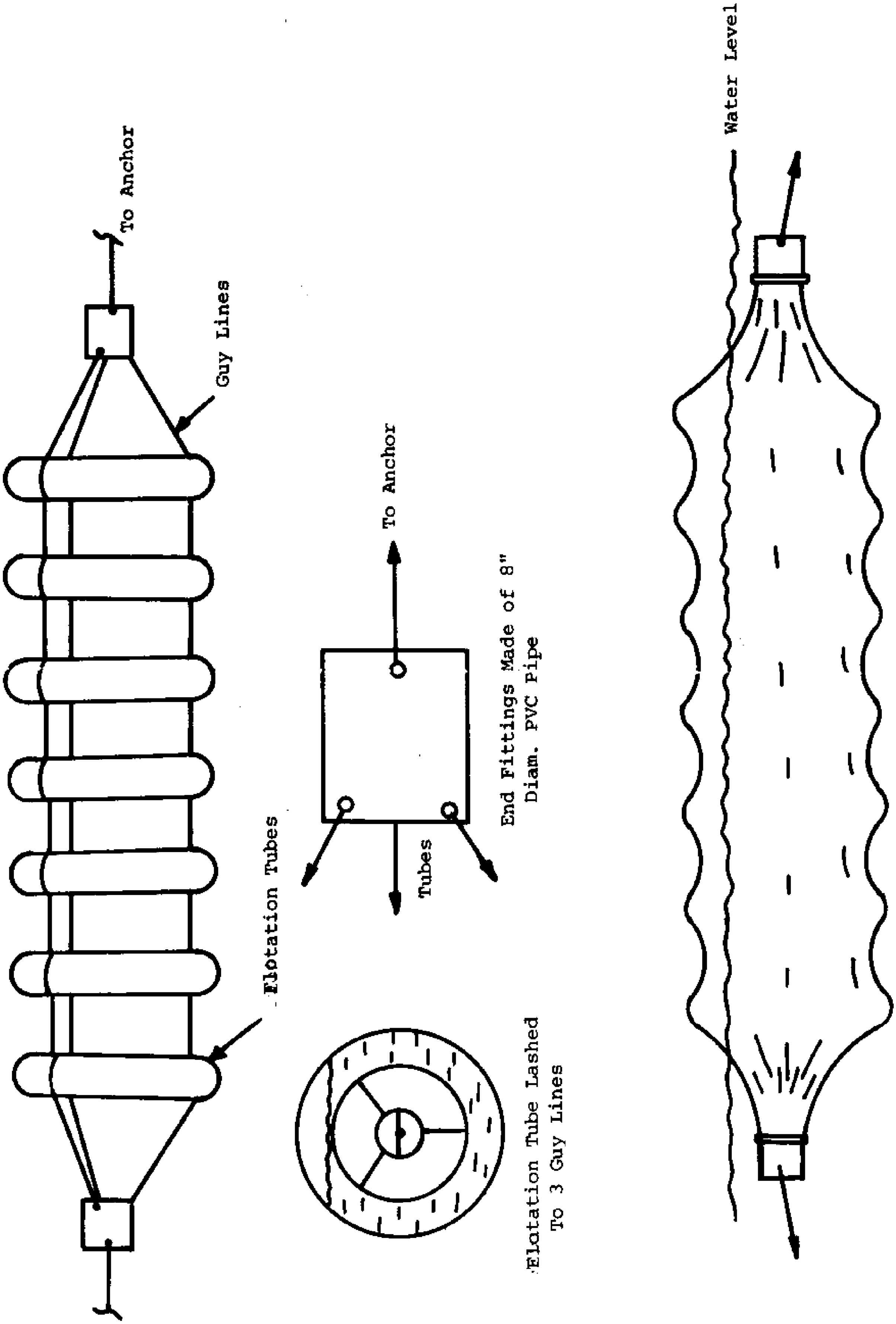


FIGURE 16.1 The General Layout of the Floating Breakwater

mushroom anchor. The anchors were spread as far apart as possible, stretching the breakwater like an accordion.

16.2 TEST RESULTS

The breakwater was moored off a cove on Hospital Island. During the period that the breakwater was moored, as one might expect, no waves of any significance were observed. Waves were created artificially by running boats past the breakwater at different angles to provide various wave incidences. It was observed that only slight wave formation ever occurred behind the breakwater. The lightweight plastic jacket was ripped after very little use.

16.3 CONCLUSIONS AND RECOMMENDATIONS

The tests showed that the principle of the floating breakwater can be used to break waves of about half its height. Sufficient information was obtained to build a full sized floating breakwater for placement at Little Spruce Head Island.

The main problem with the breakwater was the integrity of the covering. This should be made from a more substantial material such as sailcloth, treated canvas, or heavy duty reinforced plastic.

17. THE LIGHTWEIGHT DIVING LADDER

An important accessory for a boat used for scuba diving is the diving ladder. The ladder should be easy to climb, maintenance free, durable, lightweight, and should not extend into the water when the boat is underway. In order to fulfill these requirements construction of both aluminum and PVC were considered. Due to the lack of welding facilities for aluminum, PVC was decided upon.

17.1 DESIGN OF THE LADDER

A convenient size of pipe had to be selected which could easily be grasped and would have sufficient surface area to act as a step. It was decided that 1¼ inch PVC pipe would suffice. Since PVC is not an accepted structural material data on limiting bending stresses is not available. A bending experiment was conducted with a twenty one inch piece of schedule 80 pipe (the length of a ladder tread). It was found to have acceptable strength with a load of 300 lb.

Originally the ladder was to have a folding joint to allow the ladder to be folded at its midsection, to clear the water. However, it was not possible to design a joint of acceptable strength. The best design solution was to make the ladder continuous and to remove the ladder from the stern when it was not in use. It was the intention to mount a wooden platform on the stern of the boat just above the waterline. This would also support the ladder and give it the proper angle of inclination. The final design of the ladder is illustrated in Figure 17.1. It can be seen that it was constructed in PVC pipe, joints and tee joints.

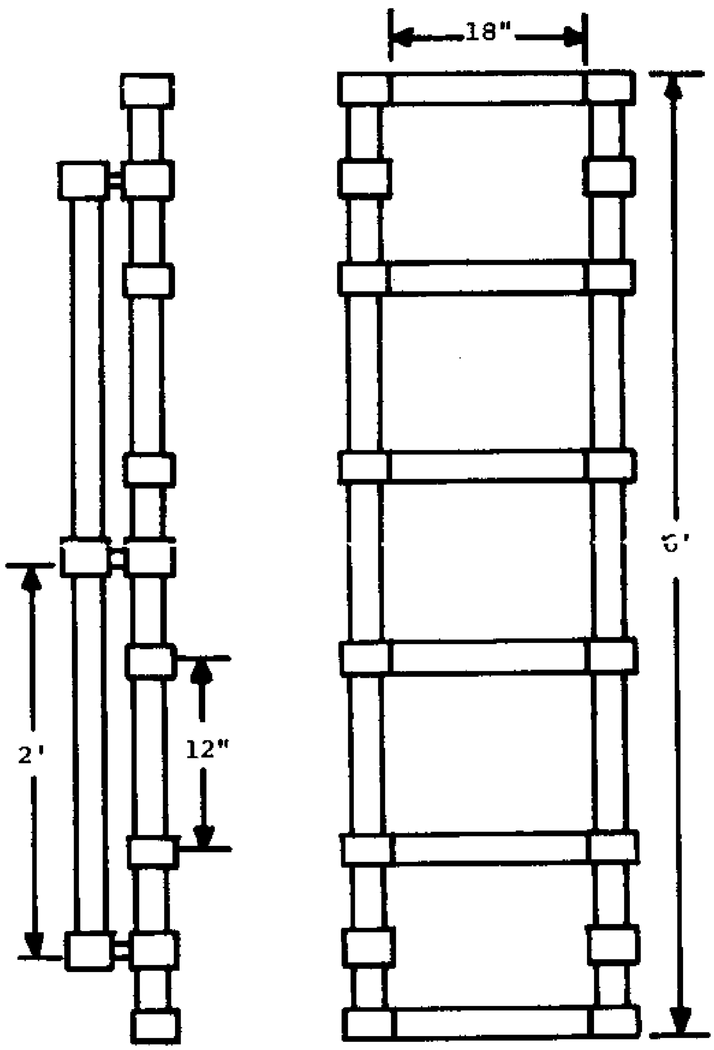


FIGURE 17.1 The PVC Diving Ladder

17.2 TEST RESULTS

The PVC ladder was built and together with a mock up of the diving platform it was tested at the dock. A diver in full dress attempted to climb up the ladder but the joints that were in tension failed. It was also concluded that the pipes as well as the joints were close to failure. The PVC piping utilized was just not strong enough for the job.

17.3 CONCLUSIONS

A lightweight ladder is still a requirement and further thought should be given to alternate design solutions.

18. UNDERWATER ARCHAEOLOGICAL WORK ON THE WRECK OF THE DEFENCE

The privateer Defence was burned and sunk in Stockton Springs Harbor about 1779 during the American Assault on Castine. The wreck was located and some artifacts recovered by the Summer Laboratory during July of 1972. The 1973 Ocean Engineering Summer Laboratory recovered additional artifacts and excavated a small area near the brick cook stove. Work started on the wreck during the second week in July. Work began by divers visually surveying the wreck site. Large objects such as cannons, the cook stove, spars, side frames, planking, and others were buoyed for easy return to the objects and so a layout map of the wreck site could be prepared. The completed map of the wreck site is shown in Figure 18.1.

A typical working day at the wreck site began with an 0800 departure in the "Panthalass", the new Maine Maritime Academy Ocean Engineering and Oceanography boat, for the 45-minute trip across Penobscot Bay to the wreck site. Typically these were 10 to 18 people aboard with about half to two-thirds diving each day. At the site the "Panthalass" would be anchored over the wreck and diving operation begun. Diving safety was maintained with strict safety procedures as outlined in Appendix 18.1. The wreck is situated in about 20 ft. of water in a cove off Penobscot Bay. The area is protected and except for poor underwater visibility (2-3 ft.) is a good location for diving. Each day various survey and recovery tasks were undertaken. At the end of the working day on the wreck, the "Panthalass" would return to Castine where the divers refilled scuba tanks and made plans and preparations for the next day's operation.

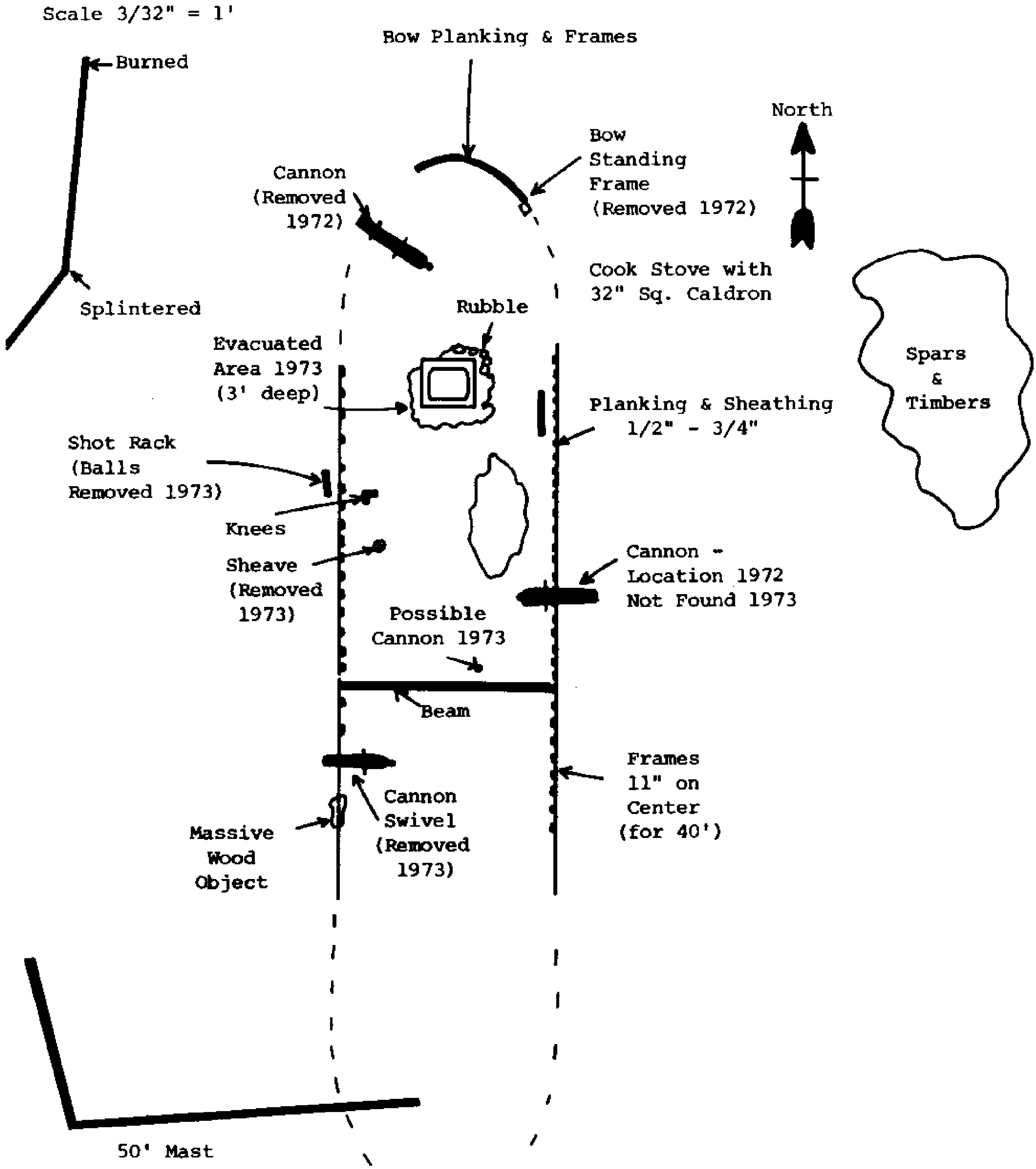


FIGURE 18.1 The Layout of the Wreck of the Defence

The following is a log of the highlights of the activities of the work on the wreck:

Tuesday, 10 July 1973 --- Diver check out and practice dives on schooner wreck "Alice B" off Isleboro. A buoy placed on the wreck last year was still in place. Lumps of coal from the schooner's cargo were recovered.

Wednesday, 11 July 1973 --- Continued diver check out and practice dives on schooner wreck off Isleboro.

Thursday, 12 July 1973 --- Started work on wreck of Defence in Stockton Springs Harbor. To prevent scavengers from working the wreck site no buoys were left on the wreck site last year. The day was spent trying to locate the wreck with side-looking sonar and diver surveys. By the end of the day the wreck had not been located.

Friday, 13 July 1973 --- Returned to Stockton Springs Harbor and continued searching for wreck which was located after about an hour of searching. A cannon, the cook stove, and various timber parts were located and buoyed for ready identification. A preliminary map of the wreck site was started.

Sunday, 15 July 1973 --- "Panthalass" was anchored over the wreck site and surveys by divers of the wreck site were begun. Side frames and planking were located, frames were measured to be 11 inch on center. Various measurements of the vessel were made as shown on the map of the wreck site.

Monday, 16 July 1973 --- Departure from Castine was delayed due to fog. At the wreck site the cannon proposed for raising was investigated and was found to have a good deal of understructure which if raised carefully might come up with the cannon. A lead scupper, various pieces of wood, and approximately 34 bricks from the cook stove were recovered. (A detailed listing of all artifacts brought up from the wreck is included as Appendix 18.2.)

Tuesday, 17 July 1974 --- The cannon to be raised was investigated further. It appears to be a 6-pound cannon with a unique swivel mount. In addition, a large oval shaped tub about 3 ft. in diameter was found built into the cook stove (this was not raised). Parts of a small wooden bucket (oak), a stone grinding wheel, and a 12½ by 7 inch copper pot lid were recovered. In addition,

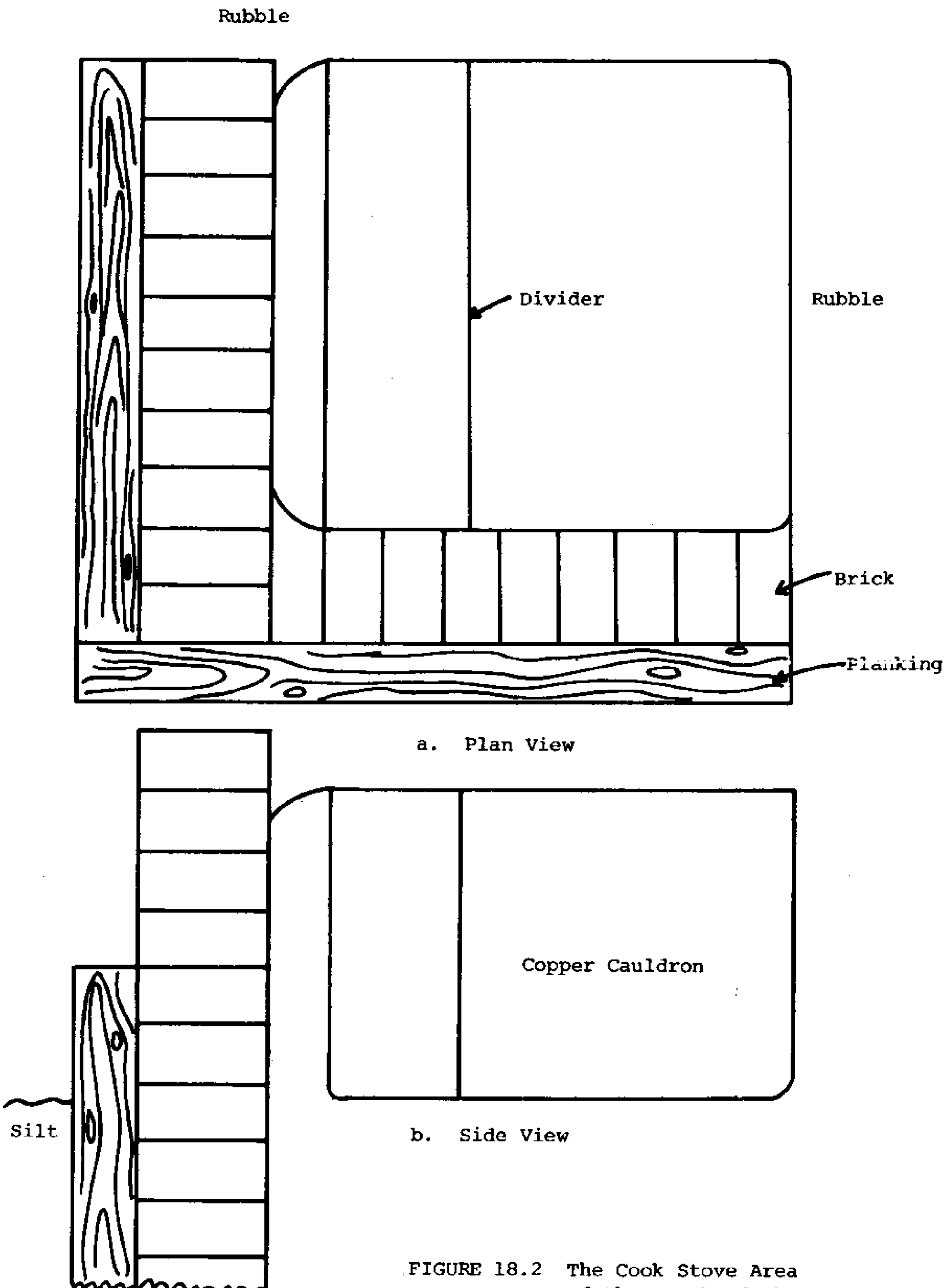


FIGURE 18.2 The Cook Stove Area of the Wreck of the Defence

an approximately 6 ft. long wooden cannon ball rack with cannon balls intact was located on the bottom but was not raised.

Wednesday, 18 July 1973 --- Departed Castine with 3 ft. diameter by 4 ft. long heavy-duty inflated rubber fender and slings for raising the cannon. At the site the slings were rigged on the cannon and secured to the fender at low tide. The buoyancy of the fender using the rising tide was used to raise the cannon out of the mud. While waiting for the cannon to break loose from the bottom, the caldron in the stove was investigated further and found to be of copper or brass, 32 inches square, with rounded corners. A shot rack was brought to the surface and cannon balls removed. The cannon finally broke loose from the bottom and was secured to the vessel and towed to Castine. The cannon was cleaned and put in a chemical bath to cure.

Thursday, 19 July 1973 --- More detailed investigation of cook stove, see sketch of cook stove Figure 18.2. An athwartships deck beam was found intact about 20 ft. aft of the cook stove. There appears to be the end of a cannon protruding from the mud at about the centerline near the deck beam.

Friday, 20 July 1973 --- Dense fog, no work on wreck.

Saturday, 21 July 1973 --- Tested diver power tool by drilling brass shaft on schooner wreck off Islesboro. No work on the Defence.

Monday, 23 July 1973 --- Departed Castine at 10:00 a.m. with four-inch Air Lift aboard and Towing Deep Underwater Mining Pump (DUMP) at three knots to wreck site. Upon arrival at wreck site DUMP was ballasted with sand and later anchored over wreck site. Underwater picture taken of wreck while DUMP was ballasted. Air Lift not put into operation due to lack of time.

Tuesday, 24 July 1973 --- Air Lift in operation excavating area near cook stove. Pottery pitcher recovered along with various small pieces of wood, pottery, twine, and pitch. DUMP put into operation later excavating around cook stove.

Wednesday, 25 July 1973 --- Took underwater photographs prior to start of dredging which clouds water with silt. Air Lift put into operation to continue excavation around cook stove.

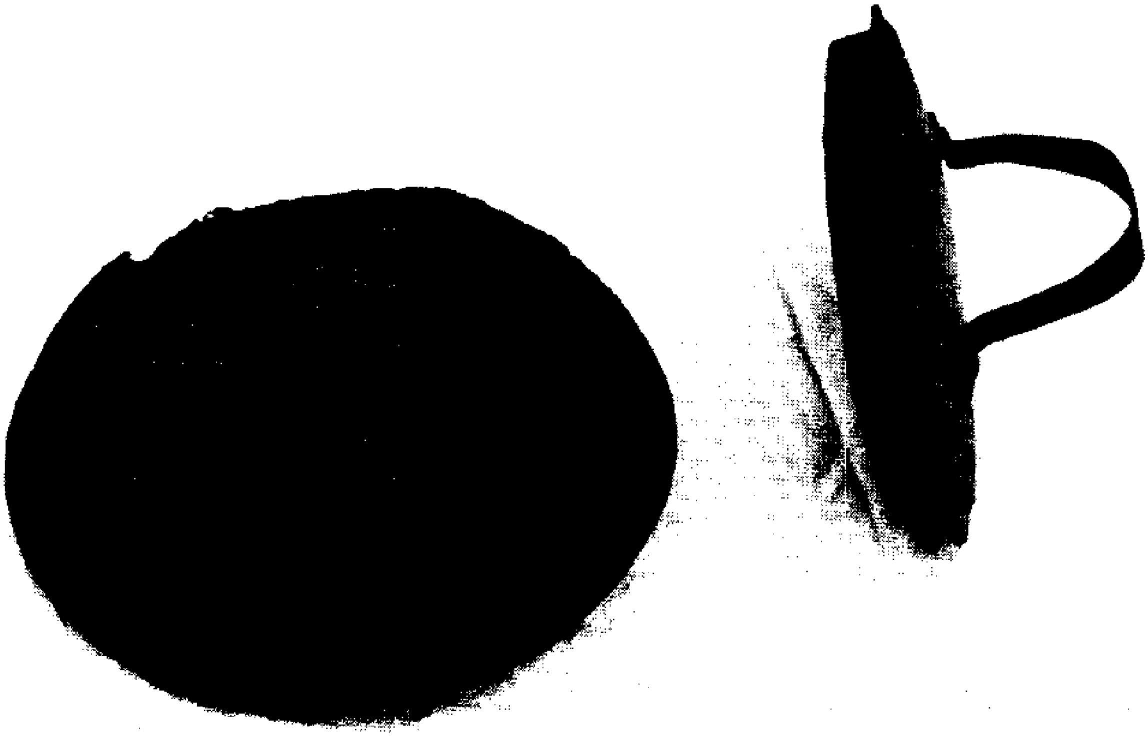
Various artifacts recovered including beef bones, pottery pieces, axe handle, lead sheet, barrel staves, and a barrel bottom, see Figure 18.3.

Thursday, 26 July 1973 --- Continued work with Air Lift around cook stove; various artifacts recovered including pieces of dead eyes, barrel staves, a shoe, and a small wooden button. This was the last working day at the wreck site so buoys were removed and all equipment returned to Castine including DUMP which was towed across the Bay to Castine.

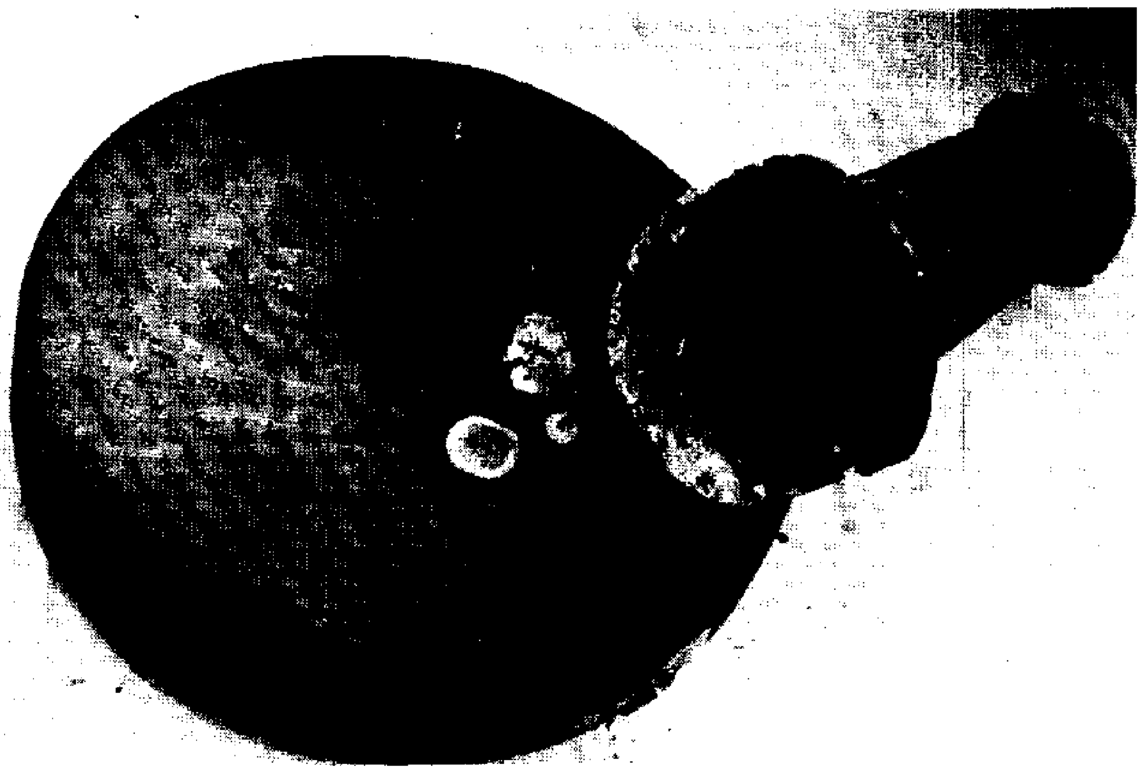
18.1 CONCLUSIONS

The surveying, random diver recovery of objects on the bottom, and excavation of a small area around the cook stove produced a large number of artifacts (list of artifacts included as Appendix 18.2). The wreck site is considered a valuable historic find by the Maine State Museum officials. It is planned that work on the wreck site will be continued as part of next summer's Ocean Engineering Summer Laboratory.

The students involved gained valuable experience from this Ocean Engineering project, underwater searching, surveying, and recovery operations. The specialized equipment (Air Lift and DUMP) were student designed and built, and operated well. On the whole the project was well executed and provided a good educational experience with a real purpose. The project also recovered and preserved valuable historical artifacts from an American Revolutionary War privateer.

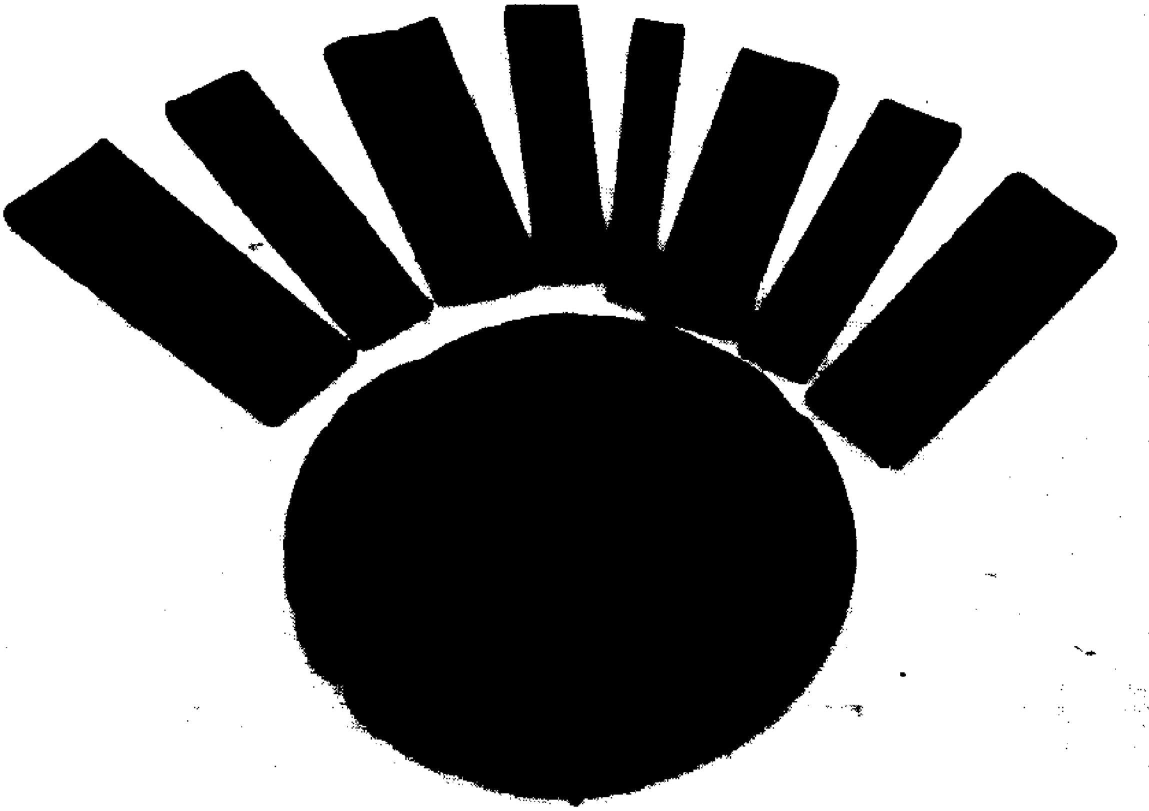


a. Pot Lids

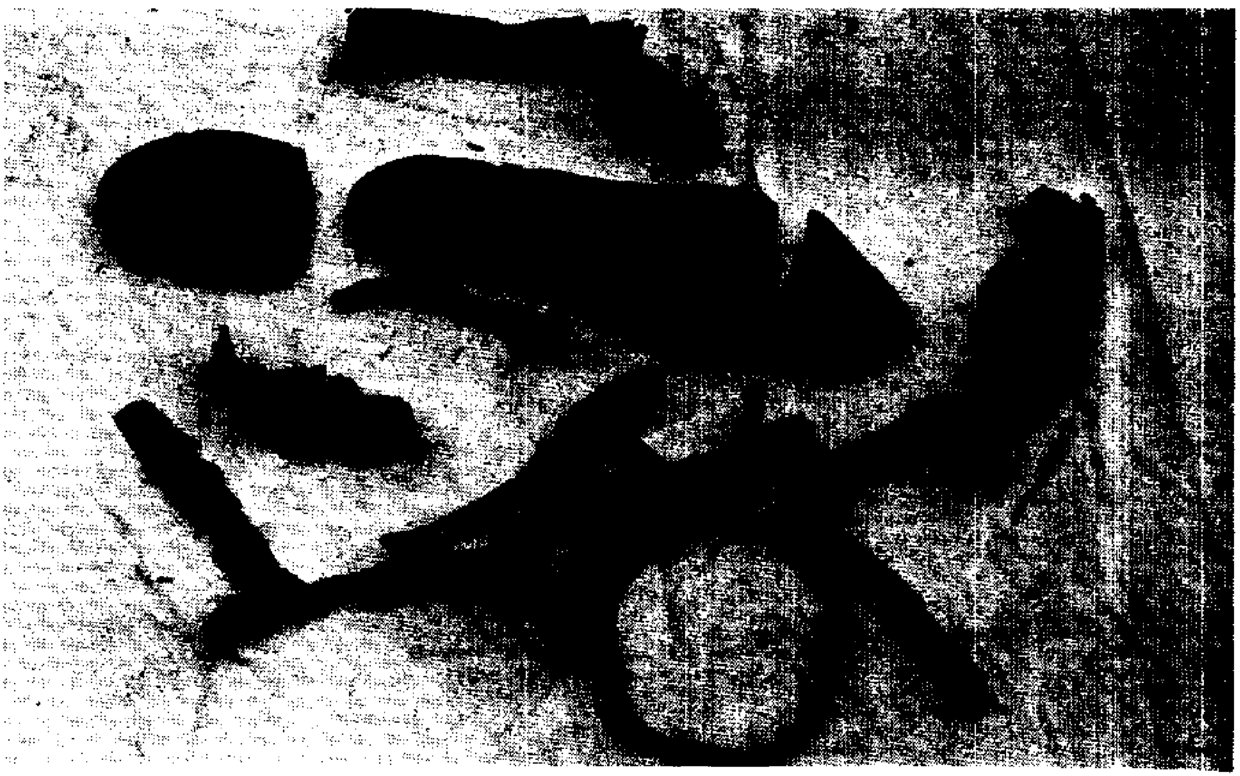


b. Scupper and Grindstone

FIGURE 18.3 Some Artifacts Recovered from the Defence



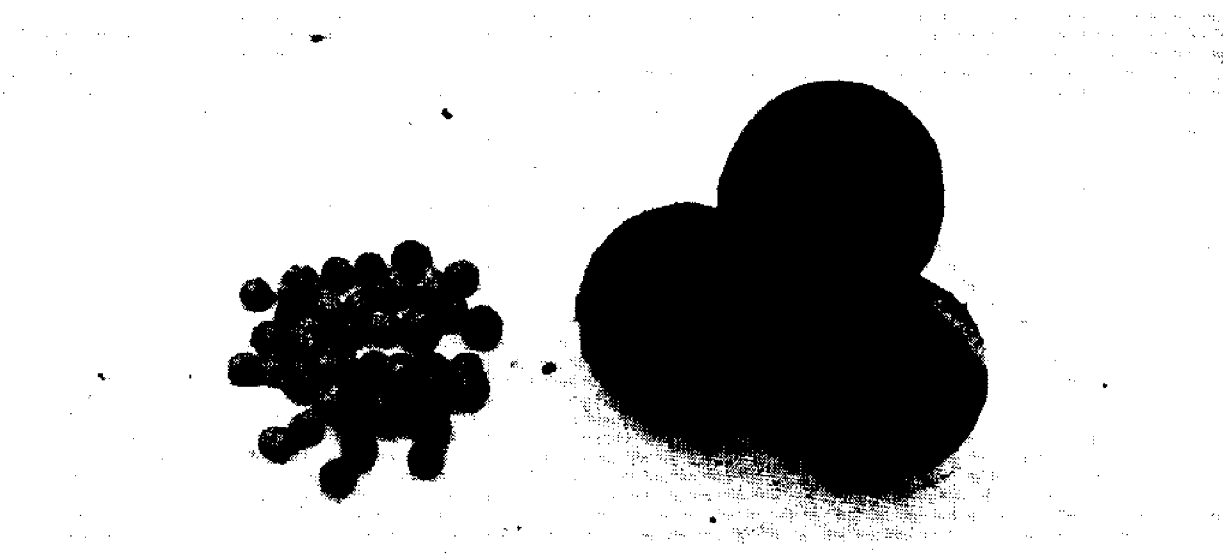
c. A Wooden Bucket



d. A shoe

FIGURE 18.3 (contd.) Some Artifacts Recovered from the Defence

e. Rack of Cannon Balls



f. Shot and Chain Shot

FIGURE 18.3 (contd.) Some Artifacts Recovered from the Defence

APPENDIX 18.1

SCUBA DIVING STANDARD OPERATING PROCEDURES

The purpose of this instruction is to establish responsibilities and standard operating procedures for SCUBA diving operations conducted in conjunction with the 1973 MIT-MMA Summer Laboratory at Castine, Maine.

Diver Quals

Only divers certified by formal SCUBA courses such as NAUI, YMCA, or U.S. Navy Diving School will dive in this program.

Diver Instructions

1. No recompression diving will be conducted.

2. A safety diver will be fully rigged and standing by whenever divers are in the water.

3. All divers will wear the inflatable flotation vest.

4. Divers will maintain visual contact with their assigned buddy. As soon as visual contact is lost, a diver will surface.

5. Depth limit is 45 ft. for newly qualified divers until further open water checkout by the diving officer.

6. All divers shall report to the Diving Officer before entering the water and notify him of any dives conducted within the last 12 hours.

Operating Procedures

1. The Diving Officer shall:

    a. Give the diver briefing.

    b. Maintaim station in the dive launch.

    c. Assign buddy teams.

    d. Designate safety diver.

    e. Make equipment check of divers prior to their entering the water.

f. Maintain the diving log and repetitive dive sheets.

g. Direct chase boat activities.

h. Ensure diving flag is visible.

i. The diving officer may delegate temporary responsibility to the assistant diving officer when he is actually diving.

The Diving Officer shall have the final determination with regard to diving conditions and diver capabilities for a given dive.

2. The safety diver shall be prepared to render aid at the discretion of the diving officer to any disabled diver. He shall be rigged prior to any diver entering the water.

3. Diving ops. will normally be conducted from the PANTHALASS and the M.I.T. Research Vessel. They may maintain contact with each other on VHF radio channel 9. A chase boat shall accompany the dive boat and shall be manned at all times.

4. Conduct a radio check with the nearest Coast Guard facility on VHF channel 16 before beginning diving ops.

5. The MMA Medical Officer (Dr. Russell) shall be informed when open water dives are planned, and suitable communication procedures established in the event of emergency.

6. All dive gear shall be off-loaded as soon as the boat returns to port. Gear shall be washed in fresh water and stored in a designated place. Tanks shall be filled as soon as possible by personnel qualified on the air compressor.

Emergency Procedures

In any emergency the Camden Marine Operator may be utilized to conduct telephone calls from the boats. In case of air embolism or decompression sickness the nearest recompression facility is at Portsmouth Naval Shipyard. Emergency medical evacuation is made by helicopter; the following steps are to be followed:

1. Call Coast Guard on VHF channel 16 and request emergency medical evacuation. Identify yourself as M.I.T.-Maine Maritime Diving Group. Give victim status and location.

2. If the return trip by boat to Castine will involve some time call MMA via Camden Marine Operator.

3. Personnel at MMA will call the Duty Officer at Portsmouth, 207-439-1000, Ext. 1900. Tell him that victim is on the way for recompression.

4. Administer first aid in accordance with App. A of the U.S. Navy Diving Manual until arrival of a medical doctor qualified in diving medicine. Air embolism and decompression sickness treatment is in section 1.6.2-1.6.3 of USNDM.

APPENDIX 18.2

ARTIFACTS RECOVERED FROM "WRECK OF DEFENCE", 1973

5 assorted shot fragments in poor condition

1 board 28" x 17"

1-6 lb. shot rack 76" long

5 oak barrel staves 28" long

1-14" oak barrel stave

18-6 3/4" powder bucket staves (oak) 2 numbered

1-9½" diameter powder bucket bottom

2 partial deadeyes oak

5 bully beef bones

1 partial barrel bottom

1 wooden pot handle

1-6" octagonal trunnel

1-3¼" oak sheave pin

2-5" sheaves

1-6½" sheave

1-5" sheave (not grooved for line)

1-3" sheave

1 stand grape shot (complete)

1 oval copper pot top

1 round copper pot top

1-13½" diameter grindstone

2 pieces lead (strip)

38 assorted lead bullets

2-9½" iron spikes

1-9" iron spike

1 axe handle

2 lead scuppers

3-6 lb. solid shot

1 grape shot in matrix

4-6 lb. chain shot

approx. 200 bricks from cook stove

1 bronze ingot (possibly an erratic)

1 broken ceramic pot

1 broken red ware bowl bottom and 4 pieces (glued together)

1 fragment biege eggshell ware

1-6 lb. pivot cannon carriage

1-9½" length zinc scupper line

assorted fragments of rope and light line some from cannon training tackle

7-6 lb. solid shot in poor condition

1 large hunk sailmaker's twine

1 shoe (disassembled)

1 bag trinidad pitch

1 bayonet (in matrix)

1-3" piece ribbed clay pipe

1-10 3/4" rough pine piece (scupper?)

1 box assorted bits of unidentifiable wood

1 large heavy "dumbell" with embedded piece of two-by-four

2 empty stands grape shot (shows detail) 1 shot with quilting

1 piece trunneled deck planking

19. A SMALL BOAT SAFETY STUDY

The U.S. Coast Guard suggested and funded a small research project to investigate the stability and handling of the type of small aluminum boat termed the Jon boat and to examine possible modifications to improve its characteristics. Most of the theoretical work, including a computer analysis of static stability, was conducted at M.I.T. before and after the summer laboratory experience. However, during the month of July stability and handling experiments were conducted in the waters close to Castine with a 14 ft. Jon boat furnished by the U.S. Coast Guard.

According to U.S. Coast Guard statistics the Jon boat accounts for many of the fatalities and injuries in pleasure boating. The project described here is part of the effort sponsored by the U.S. Coast Guard to improve small boat safety.

19.1 DESCRIPTION OF THE JON BOAT

The Jon boat has a simple geometry which lends itself to easy and inexpensive fabrication. It is manufactured in aluminum, it has a trapizoidal cross section and is fitted with seats under which flotation material is permanently fixed. A 14' Jon boat capable of carrying two adults and powered by a 10 horsepower outboard motor was used in the stability and handling experiments. The geometry and dimensions of this Jon boat are shown in Figure 19.1.

19.2 TESTING OF THE ORIGINAL JON BOAT

The Jon boat was tested both statically and dynamically. The static tests were conducted to determine the circumstances which might lead to the

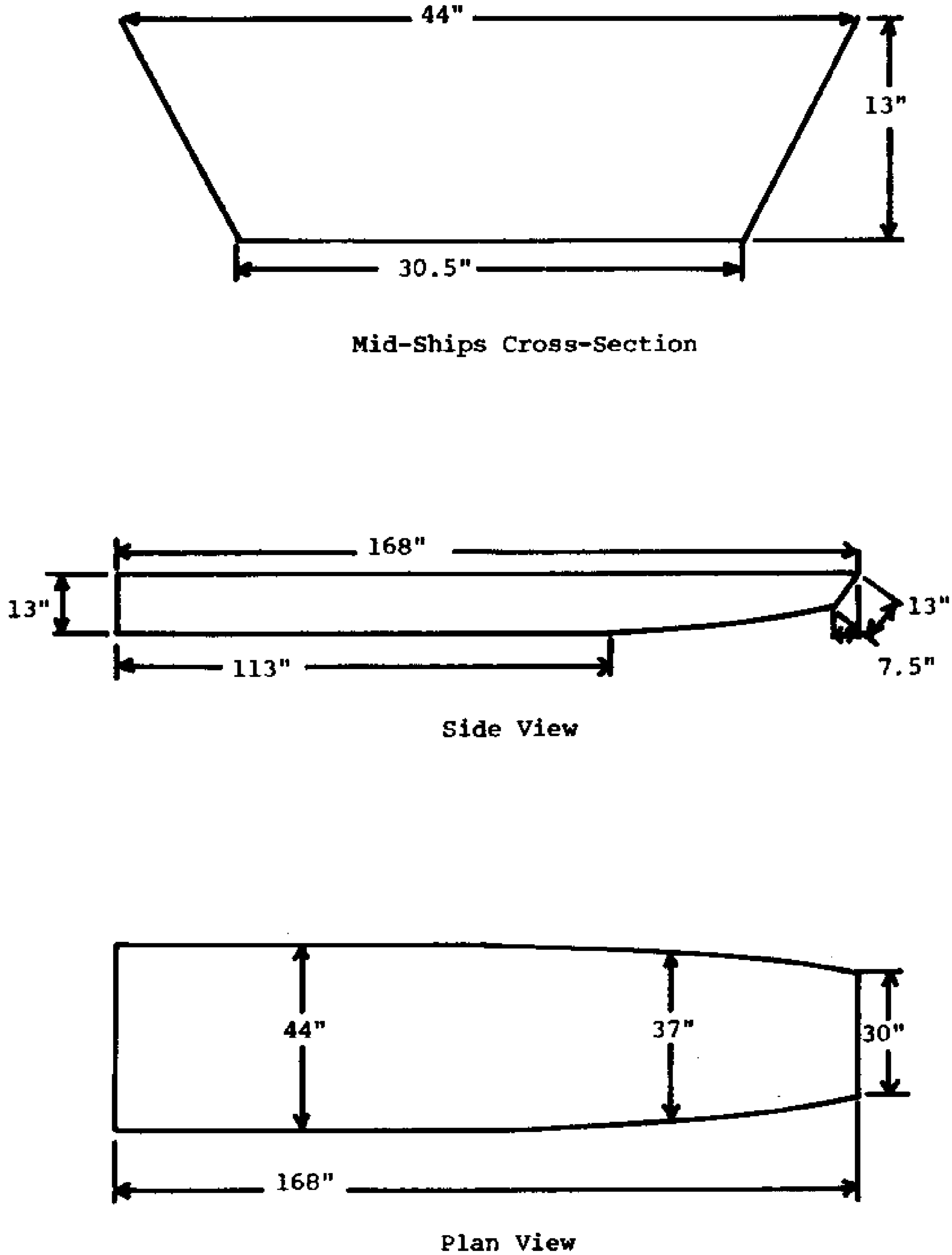


FIGURE 19.1 The 14' Jon Boat

boat capsizing, shipping water, or tipping the occupants out. The dynamic tests were conducted to determine the powering characteristics of the boat. The experiments were filmed for later assessment.

19.2.1 The Static Tests

The static tests were carried out with a weight attached to the transom to simulate the mass and center of gravity of the outboard. It was not proposed to "dunk" the motor should the boat capsize.

With the boat tethered to the dock, but not constrained, a single occupant and then two occupants were asked to simulate the actions of rather clumsy boatmen.

The tests showed that the Jon boat was extremely tender and easy to roll. In addition, one person standing at the stern could make it ship water. The operators felt that the Jon boat was highly unstable and came close to capsizing during the static tests.

19.2.2 The Dynamic Tests

The dynamic tests were conducted on a special course used by the industry and the Coast Guard, as shown in Figure 19.2. The test course requires the boat to be operated at full throttle and made to go first on a straight course between two lines of buoy markers, then to turn and pass around a marker buoy, and finally to return to the original course. Safety procedures for this experiment required the boat driver to wear a crash helmet and the motor to be fitted with a dead-man's throttle. Although the boat driver was proficient, he was unable to complete the course at full throttle. Tests were also conducted on the test course with a passenger in the boat seated in various positions. All the tests were timed to provide a basis for comparison with the modified Jon boat described next.

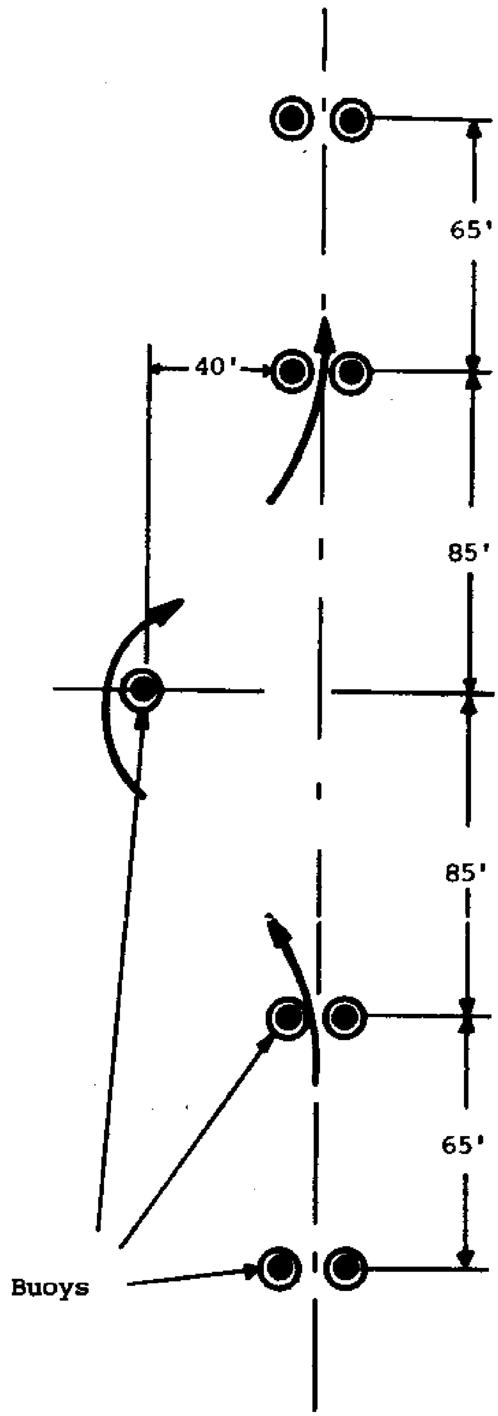


FIGURE 19.2 Test Course for the Jon Boat

19.3 THE JON BOAT MODIFICATIONS

The main purpose of the modifications considered was to improve the static stability characteristics. It was not easy to devise a modification which would improve stability and at the same time maintain the Jon boat's inexpensive and shallow draft capabilities. Finally a modification was developed which could be attached easily to the Jon boat and would improve the static stability. The modification was in the form of bilge keels which effectively increased the beam of the boat.

The bilge keels were constructed of 1/4" exterior plywood, and temporarily fastened to the hull with epoxy fiberglas as shown in Figure 19.3. The bilge keel was fitted flush with the transom at the after end, and ran 9' along the chine towards the bow. Bulkheads were placed in the bilge keel at intervals to stiffen the structure. Styrofoam was placed between the bulkheads for flotation purposes. A watertight bulkhead was placed at the stern of each bilge keel, and pieces of styrofoam were faired at the front end to cut down water resistance.

The modification resulted in an increased righting moment, compared with the original Jon boat, resulting in reduced the angle of heel when the occupants were off-center.

19.3.1 The Static Tests

There was a noticeable difference in static stability when the modification was fitted. One man could now walk along the side of the boat without trouble and when standing in the stern of the craft there was nearly half a foot of freeboard. The boat was then put through the same series of static tests, with first one and then two occupants.

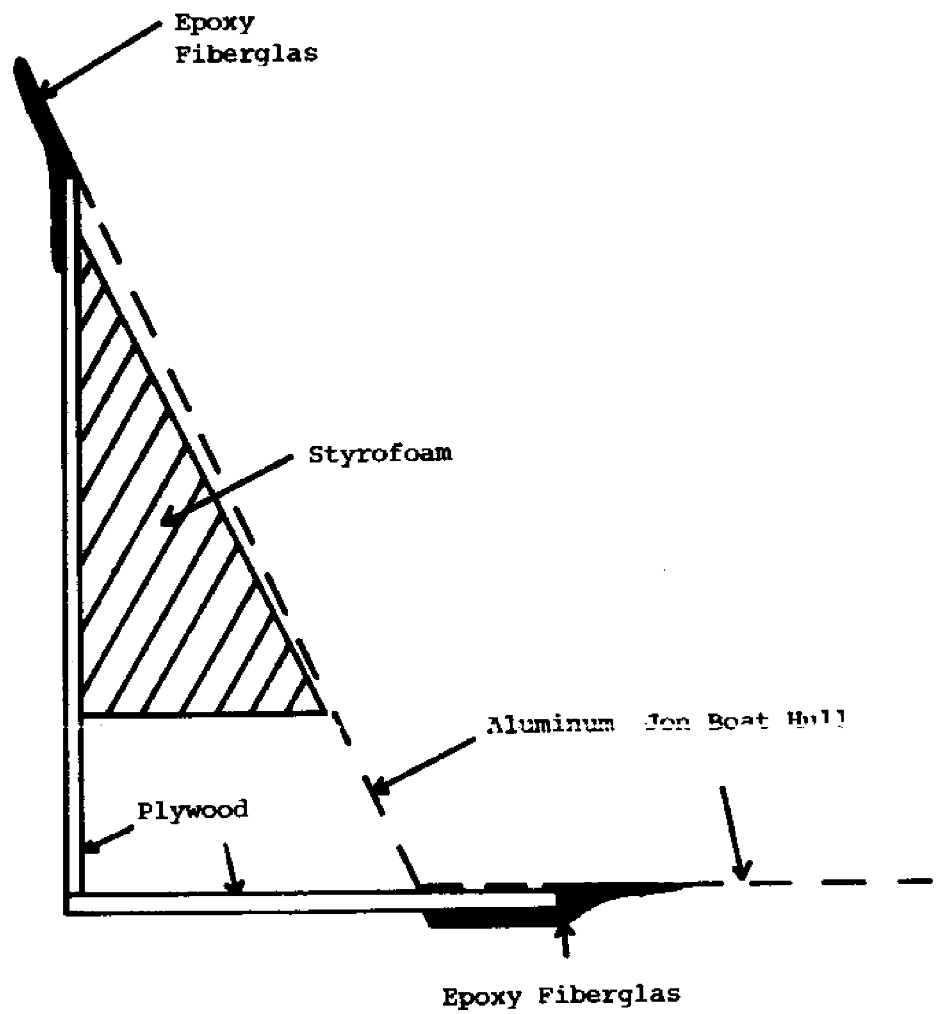


FIGURE 19.3 Bilge Keel Modification to the Jon Boat

At this point the boat was removed from the water and ¼" holes were drilled in the bilge keels at intervals of one foot along the bottom and smaller holes were drilled 2 inches up the side of the bilge keel to allow air to escape. The purpose of this modification was to increase still further righting moment, although, in retrospect, the change was not important.

The static tests were again conducted with somewhat less satisfactory results. Since the bulkheads inside the bilge were not watertight the water in the bilge keels moved fore and aft as the occupants of the boat shifted. The transverse stability, however, was not greatly changed

19.3.2 The Dynamic Tests

The dynamic tests were now repeated with mixed results. The craft now slid badly around sharp turns, as in the manner of a hydroplane. The timing of the runs had also increased approximately 2-3 seconds in all cases. In many cases the course could not be completed due to the poor handling qualities.

The test driver, however, expressed a noticeable difference in the overall stability of the craft. Disregarding his loss of control of the boat, he felt much less of a tendency for the boat to catch water in a turn and felt much safer from capsizing. The boat did roll over to about 30° around one turn, throwing the passengers from the craft, however, this was attributed to the fact that the engine had locked on its mounting and the driver could not control the slide. Luckily, proper safety measures had been taken; the driver was wearing a crash helmet and a cut-out switch connected between the driver's arm and the engine. Both passengers were picked up safely and the tests were continued.

19.4 CONCLUSIONS

A 14 ft. Jon boat has been tested at Castine and, as expected, it had rather unstable characteristics. A modification to the original boat was designed and tested and found to improve the static stability characteristics but it also detracted, to some extent, from the high speed handling qualities.

It was felt that the overall characteristics of the Jon boat were safer after the modification had been completed. No tests were carried out in waves so that a complete seaworthiness study has not been made.