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SOLID-STATE
VECTOR AVERAGING CURRENT METER

Sea Grant Ocean Projects 1986-1987

Project Members:
David Hermann ME
Mark Ouellette ME
Mark Pellegrini ME (Semester I Leader)
Rich Erlenbach EE (Semester II Leader)
Andrew Williams EE

Project Advisor:
Dr. James D. Irish

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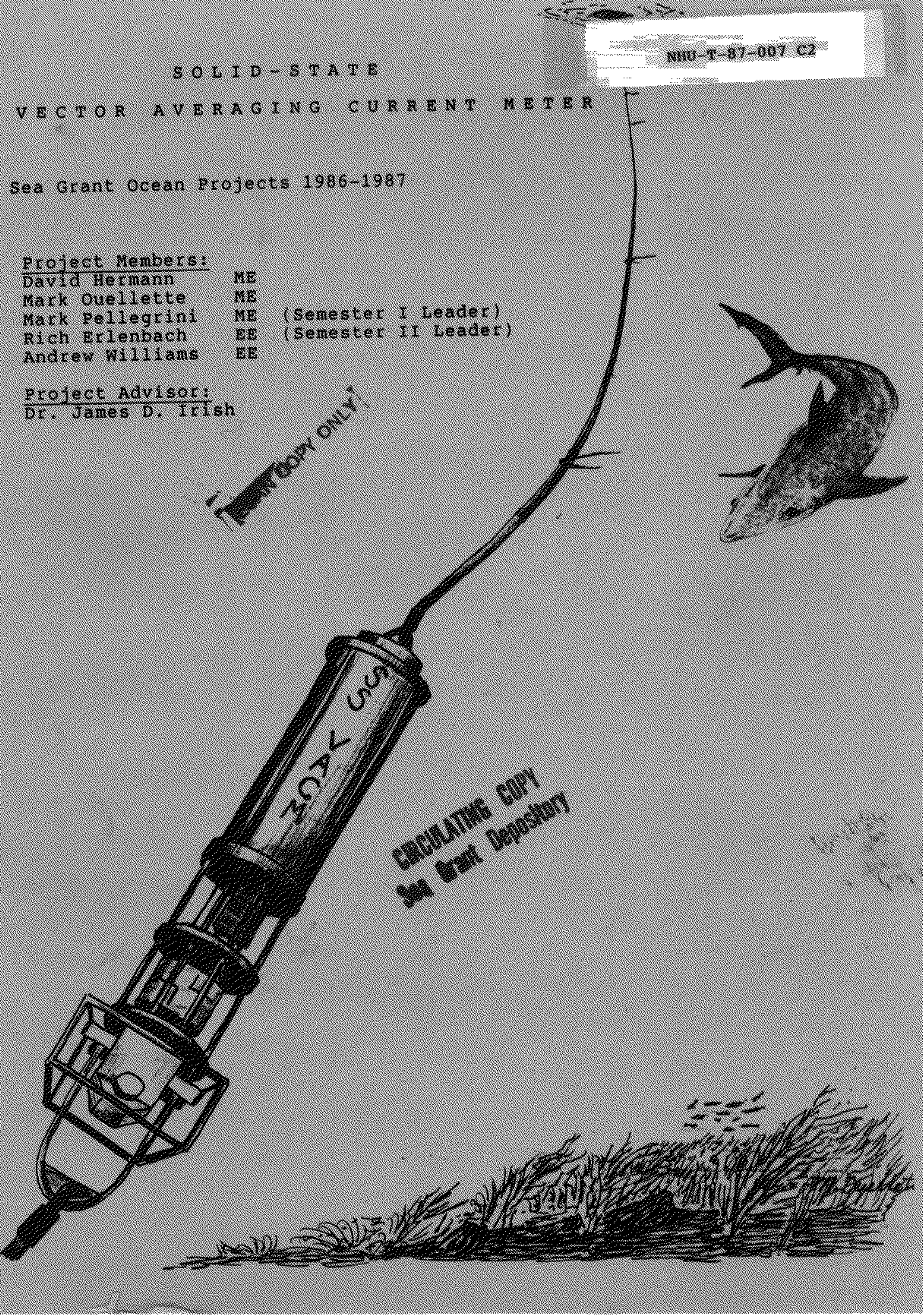

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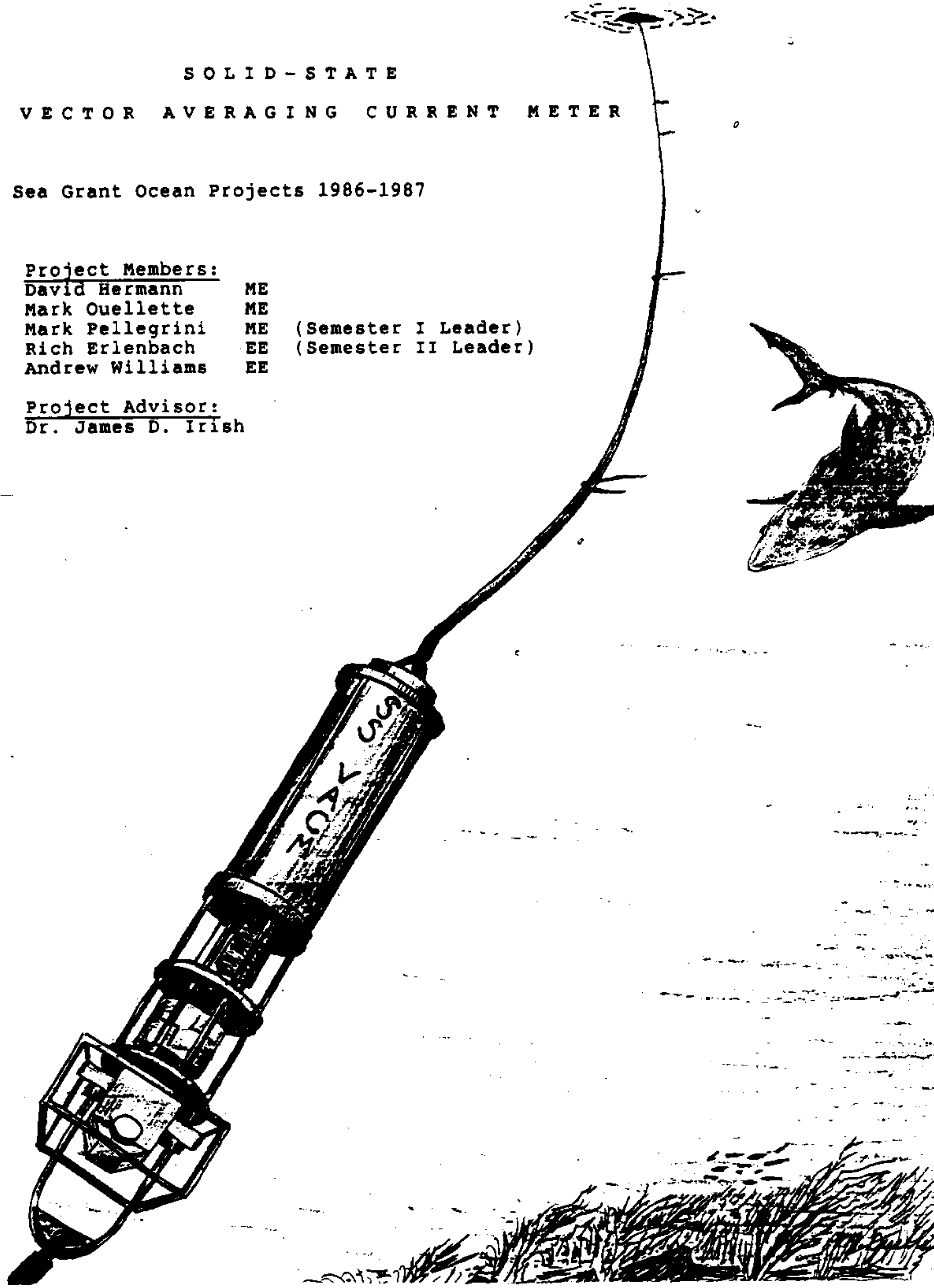

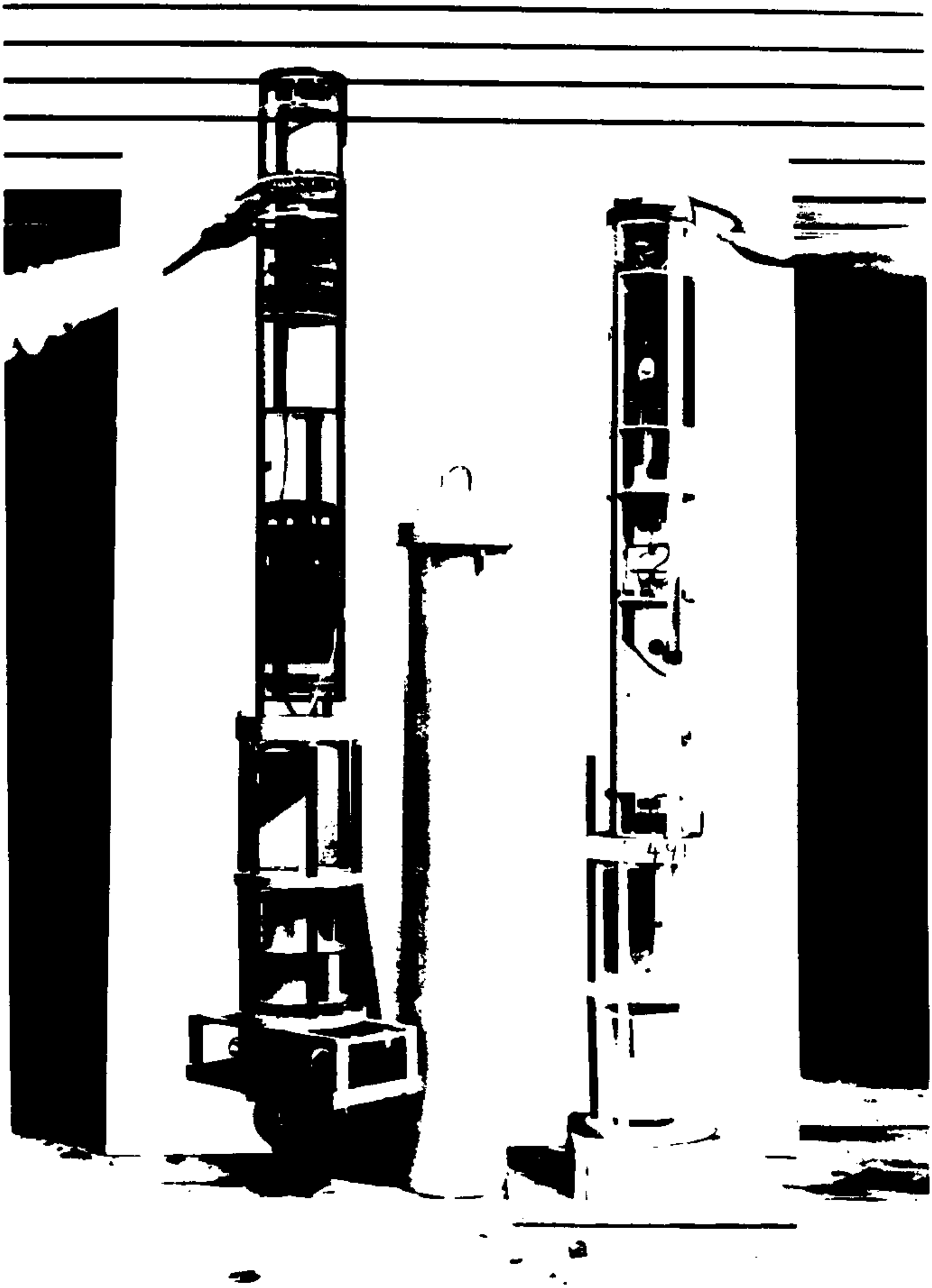

Prototype Deep Ocean Current Meter and Original EG&G 102 Current Meter

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ACKNOWLEDGMENTS

We wish to thank the following people for their support in this project: The people at the Physical Oceanographic Research Team, including Jerry Needell, Dave Ball, Jon Wood, Betsy Haley and especially our advisor Dr. Jim Irish. We appreciate the time and extra effort put into our project by Bob Blake in the Kingsbury machine shop. We are grateful for the advice of Jerry Dean at Woods Hole Oceanographic Institute. We also thank Ed Garcia of Sea Data Inc. and Marie Ecanto-Thomas and Doug Daprich of Sippican Inc. for their help.

ABSTRACT

SS-VACM: Solid State - Vector Averaging Current Meter

A prototype Solid State-Vector Averaging Current Meter (SS-VACM) was developed using the existing Savonius rotor, vane and pressure case of an EG&G Model 102 film recording current meter. The reliability and accuracy of the instrument was improved by replacing the film recording system with a microprocessor based recorder using solid state memory for data storage. Additional sensors measuring temperature, pressure and conductivity, and software control made the system more versatile and flexible to meet the expanding needs of oceanography. The prototype will have a functional span of at least one year and will be as reliable and accurate as the EGG&G VACM's which has been adopted by the ocean industry as a standard.

Along with the mechanical refurbishment, various electronic designs were evaluated for the recording system, rotor detection and the compass and vane follower. An important criteria was to develop the prototype at minimal cost so that a maximum number of old instruments can be converted for use in the World Ocean Circulation Experiment.

I. INTRODUCTION

Background:

The measurement of ocean currents has been traditionally made with rotors and propellers used to sense current velocity, and a vane and compass to sense its direction. The Vector Averaging Current Meter (VACM) is the present oceanographic standard, and uses a Savonius rotor and vane to measure the speed and direction and then convert "instantaneous" readings to two vector components of velocity and average them over a sample interval. The design is dated and does not take advantage of the power of microprocessors available today.

The Physical Oceanographic Research Team (PORT) at UNH does not have any standard oceanographic current meters, and would benefit from having some for use in upcoming work in Brazil during the next five years. They recently were given 24 old EG&G Model 102 film recording current meters by EG&G, but they have outdated film recording systems utilizing cumbersome and unreliable light pipes and a camera. However, the Savonius rotor (identical to that used on the VACM), vane and pressure casings are in good condition and can still be used to accurately measure ocean current and velocity.

Project Objectives:

This five member ocean project team constructed a prototype current meter using the existing EG&G Savonius rotor, vane and pressure case, and replaced the film recording system with a microprocessor based recording system using solid state memory for data storage. Our intention in using the microprocessor was to:

a) Make accurate measurements of speed and direction by vector averaging the currents, which is necessary because the average of two vector components is different than the average of speed and direction.

b) Store the data in solid-state memory; perform analysis and computations with the data; and provide quick access to the data.

c) Record and integrate the data from additional sensors such as temperature, pressure, and conductivity.

d) Software control of the sampling which provides the ability to make easy changes in the sampling program making the system user friendly and more flexible. Thus the software can change the sampling program to take advantage of unusual occurrences in the ocean.

e) Improve the reliability of the instrument by using solid state electronics. To house the new microprocessor and solid state data storage units we redesigned the framework inside the pressure case. The new framework is specially designed to compactly contain the batteries, compass and vane follower as well as the microprocessing equipment.

We made the current meter more versatile by adding additional sensors such as conductivity, pressure, and temperature sensors. This will enable the instrument to collect more useful information about the ocean water being sampled than just the current velocity and direction. We mounted the sensors and brought the wires into the pressure case, and PORT took care of the recording these parameters.

System Description:

As stated previously, the final goal of this project was to develop a relatively low cost prototype vector averaging current meter using solid state technology. The prototype is to have a functional span of at least one year and should be as reliable as other presently used methods and recording ocean currents.

This two semester project was based on a task list which is broken down into the following areas:

1) MECHANICAL - Refurbishment of the existing meter and the design of any necessary new parts. The removal and salvage of parts was followed by a cleaning and inspection of the pressure housing. Rotor and vane bearings were checked and found to be in poor condition so new bearings were researched and ordered.

A new circuit card rack design was necessary to accommodate the new solid state electronics in addition to the mounting of additional sensors, compass, and cables.

A new system of bringing the external sensor wires into the pressure housing was needed, since the additional sensors and external computer link require more leads to communicate with the microprocessor than the original design had available. To do this a new type of penetrator system was designed to connect the external and internal elements despite the space limitations of our current meter.

2) ELECTRONICS - Five major goals were associated with this task.

A) The recording system was to be replaced. The original system records information from the rotor, vane, and compass by coding it into tiny light pulses and lines of light, which are transmitted via light pipes, photographed by a camera, and stored on film. The film is advanced through the camera by a stepping motor at each sample interval. The control electronics accepts timing pulses from the sequence timer and initiates sampling commands to the various sensors.

Our replacement recording system consists of a microcomputer to control the sampling and perform the vector averaging, an accurate electronic clock, solid state EPROM (erasable-program-only-memory) memory chips for data storage and the necessary interfacing of the sensors with the microcomputer and processing.

B) Replace the compass assembly. The old compass assembly consists of balanced magnets surrounded by an oil dampening fluid, all encased in a plastic housing. A shaft which rotates with the magnets is connected to a Gray binary coded disk to provide the information of the meter orientation by light pipes. The information is compared with the position of the vane follower assembly which is also determined by a Gray coded disc to obtain a vector average of the current direction.

The compass was replaced with a flux gate sensor for improved accuracy and stability. Two flux gate sensor units (donated by Sippican) was used, one to measure meter orientation and one to measure vane position. We assembled the control circuits for the flux gate compass to translate their information to the microprocessor.

C) Provide software to control the basic sampling program, provide servicing for the clock and rotor interrupts and to perform the desired data processing.

D) Provide battery power contained in the pressure case for the sensor and microprocessor requirements for a minimum deployment of one year. Alkaline or lithium batteries will be used as required.

E) Add sensor for temperature, pressure, and conductivity. The sensors we used are already owned by the Physical Oceanographic Research Team. The use of these sensors will increase the value of the current speed and direction data collected by the current meter, since the temperature, pressure, and conductivity of the same water will be measured.

II. DESIGN SOLUTIONS

A. Hardware

In order to obtain the vector average of the ocean currents, accurate measurements of speed and direction are necessary. The original EG&G model 102 system records information from the rotor, vane and compass by coding it into light pulses which are transmitted via light pipes, photographed by a camera, and stored on film. Since the existing rotor and vane were to be used along with a new microprocessor based recording system, a new design was required for these sensor interfaces. The primary goal of obtaining data from these sensors with greater accuracy and reliability at minimal cost led to the use of the fluxgate compass to sense current direction and the Hall Effect device to sense current speed.

Sensing Current Direction Using The Fluxgate Compass:

Originally our intention was to salvage the existing oil dampened magnetic compass and vane follower assemblies used to sense the current meter case orientation and vane position relative to the case but investigation into their accuracy and reliability revealed that they did not appear to be worth converting. These compasses use a 7-bit Gray coded disk to provide the information of the meter orientation and vane position by light pipes. This 7-bit resolution results in a 2.81 degree resolution (360/128) on each sensor. In order to match the accuracy of the VACM's used throughout the industry today, we needed to have a resolution of 8 bits or 1.4 degrees. Also, the compass and vane follower would have to be converted to a digital readout from the existing lightpipes which have demonstrated in the past to be highly unreliable. In our opinion, the apparent benefits of the fluxgate compass outweighed the slight increase in cost required to convert the old current meters.

A major advantage of the fluxgate compass is its simplicity. It is rugged, has no moving parts and occupies less space. Also, it has improved sensitivity, stability and is easily adaptable to automatic data processing allowing a resolution of 8-bits. Two fluxgate compass units will be used, one to measure meter orientation and one to measure vane position.

The fluxgate compass used (donated by Sippican Inc.) is shown in FIG. 1. It consists of a toroidal ferromagnetic core of high permeability enclosed in a plastic housing which is wound with 2 sets of windings. The primary or driver winding is wound around the cross section of the core and two mutually perpendicular secondary or pickup windings are wound around the entire core. The primary winding is driven by a 7.85khz, 5 volt squarewave represented by Ei in FIG. 2. The core has a sharp transition between the linear and saturation regions of its characteristic curve so that the primary current saturates the core twice each cycle. When a magnetic material is saturated its permeability to

FLUX GATE COMPASS

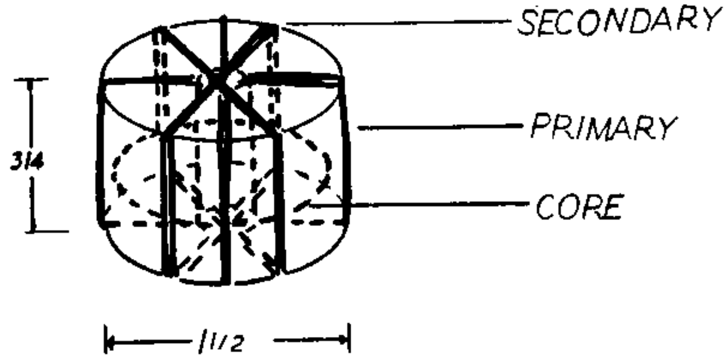


Figure 1a - Fluxgate Compass

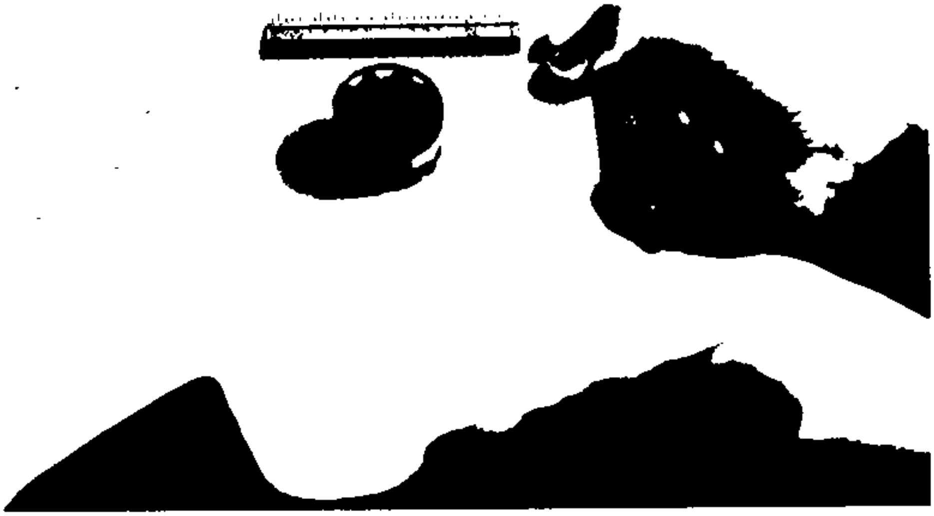
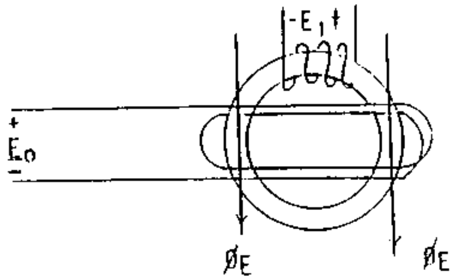
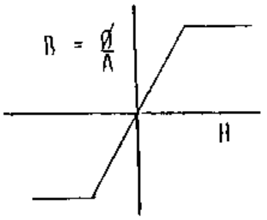


Figure 1b - Fluxgate Compass Mounted on Circuit Card



- CORE: HIGH PERMEABILITY
  LOW HYSTERESIS
  SHARP SATURATION



- $E_0 = N \frac{D\phi}{Dt}$
- FOR $E1 = 0 \Longrightarrow \phi = \phi_E$

  FOR $E_1 = MAX \Longrightarrow \phi = +\phi_S - \phi_S = 0$

  $\therefore \Delta\phi = \phi_E$

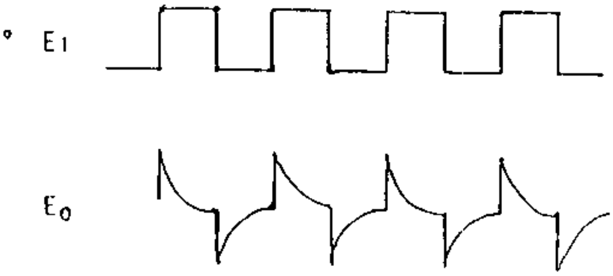


Figure 2 - Fluxgate Theory

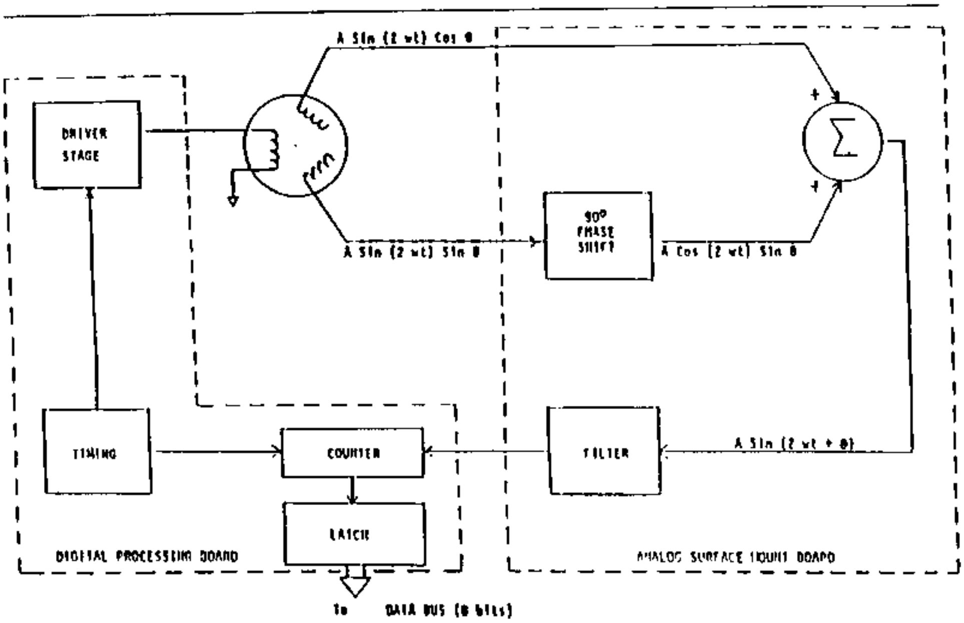


Figure 3 - Block Diagram of Phase Modulated Circuit Approach

further magnetization decreases. As the core is saturated and thus the permeability reduced when the current has its peak positive as well as negative value, then the variation of the core permeability will have twice the frequency of the magnetizing or driving current. Since the core is driven into saturation, the changing core magnetization induces a voltage which is a nonlinear function of the source waveform. The second harmonic voltage appearing across the fluxgate is selected by means of a high Q filter with a centerband at twice the driving frequency or 15.7Khz. Each of the two secondary windings which are placed 90 degrees apart has an ac output with an amplitude proportional to the cosine of the angle between the winding and the horizontal surface component of the earth's magnetic field. Thus, if one winding is pointing north, it will have a maximum output and the other winding will have a minimum output. The two ac outputs are combined by shifting the phase of one output by 90 degrees and then passing both signals through a summing circuit. The summed output is an ac signal of twice the driving frequency and constant amplitude, but varying in phase with respect to the driving signal depending on the sensors orientation in the earth's field. One disadvantage of the fluxgate compass is that its operation is based on the fact that the field lines of the earth's magnetic field are essentially parallel to the earth's surface at some place in the vicinity of the equator. Therefore, the field has no vertical component. In regions close to the earth,s magnetic poles however, the earth's magnetic field has both a horizontal and a vertical component, with the horizontal component getting smaller as the earth's poles are approached. If the direction needed to be measured is in regions near the magnetic poles, another form of compass measurement would have to be used.

FIG. 3 shows a block diagram of this phase modulated circuit approach. Two separate circuits were used, one digital and one analog. The digital circuit controls the necessary timing and provides the compass drive signal to the primary windings of the fluxgate. The timing circuit also resets an 8-bit digital counter on the rising edge of the driver signal. The second harmonic of the voltages induced across the two secondary windings is sent to the analog circuit where it is filtered out of each winding. One side is then phase shifted 90 degrees so that the two signals can be trignometrically summed together. The resulting signal has twice the frequency of the driving signal but with a phase delay proportional to the fluxgates position relative to its reference position or true north. The signal is then sent to a filter network where it is shaped into a squarewave and sent back to the digital circuit. The rising edge of the phase shifted signal stops the counter so that the count is proportional to the phase difference between the driver signal and the signal coming out of the filter. Since the two signals can have a phase difference of up to 360 degrees and the counter can sequence through a total of 256 counts, this results in a measurable resolution of 1.4 degrees. The count value can then be latched to the data bus where this information can be processed along with the rotor and vane follower data in order to obtain the vector average of the ocean current velocity.

Appendix A-1 gives a description of the actual circuit design which originated at the Sippican Corporation in Marion MA. and was modified for our project.

Sensing Current Speed Using A Hall-Effect Device:

The Hall effect device is an electromagnetic component that was used in replace of a reed switch. The advantage of using this type of device is that it contains no moving parts and therefore is not susceptible to mechanical failure.

The purpose of the Hall-effect device is to detect a rotor revolution. A rotor revolution acts as a trigger to the vector averaging routine in the software. Everytime the rotor makes a revolution a magnet attached to the top of the rotor signals the Hall-effect sensor through its magnetic field. This signal creates a voltage that is sent to the speed board.

In our application of this device we wired a source-type Hall-effect device to the latch board through a transistor that was added to hold the open output signal low. A diagram of this setup is shown in FIG 4. The Hall-effect sensor circuit is an inexpensive way to improve the rotor detection device on a current meter.

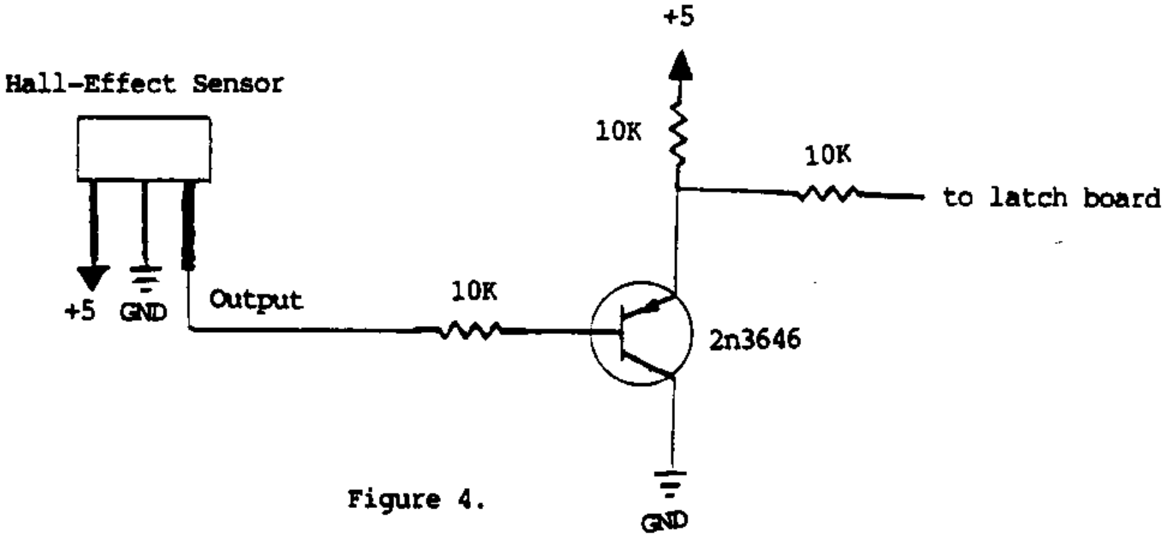


Figure 4.

Microprocessor:

In choosing the hardware that we needed to do the project the PORT group had one objective for us to meet. This was to make sure that the system we bought could be easily adapted to meet not only the needs of the VACM, but also be used for temperature, pressure and conductivity measurements as well as data transmission. The microprocessor chosen for this project must have the capability of serving as a smart datalogger that could also meet changing needs of an oceanographer.

With this goal in mind we researched the hardware and software that a number of companies. A specific need of our the VACM was that the hardware needed to be able to handle synchronous external timer interrupts and asynchronous rotor interrupts. Two companies, Sea Data Inc. of Newton, MA and On-Set in RI, both built systems that could meet these needs. After doing an analysis of the hardware that both companies offered we decided to buy the hardware that Sea Data designed for the reasons of adaptability, expandability, cost, and support. This analysis can be found in Appendix A-2.

Along with the microprocessor, hardware to record temperature, pressure, and conductivity as well as a clock and EPROM memory boards were also purchased.

Latch Board:

In order to interface that flux gate compass board with the microprocessor a circuit had to be designed that would control the data flow when a rotor interrupted was detected. Within this data board are some critical timing areas that are used to decided what data is on the data bus. A picture of the board is also shown in the Appendix A-3. Also added to the latch card was a 4MHz clock used to drive the flux gate compass boards.

B. Software

The software provided by Sea Data was altered to that timer interrupts could be triggered by an external clock board. The external clock board is used instead of the internal SB-12 clock for purposes of precision. The clock board is connected to the microprocessor so that interrupts would be produced at certain time intervals depending on how often data should be recorded. While the processor is waiting for a clock interrupt it is in a "SLEEP" mode. The "SLEEP" mode is used to save power when no processing is being done, but at the same time the processor is not completely without power since data still needs to be saved. When the microprocessor is "AWAKE" it draws 27mA as opposed to about 0 mA when the processor is in "SLEEP" mode. Once a clock interrupt is generated the processor "WAKES UP", goes through a forced interrupt, takes the data stored in RAM memory and writes it to EPROM memory. RAM memory is then cleared and the processor goes back to sleep. The only alterations that needed to be made to this software was to force a rotor interrupt, add this data to the stored data stream, and then clear the vane and compass data.

This software needed to be altered to handle a second external interrupt created by the Hall-effect device. This interrupt is generated everytime the rotor makes a revolution and will be discussed further later.

The software that Sea Data provided was already designed to to record pressure, temperature, and conductivity. Also included was a basic operating system for the 8085 microprocessor and some basic commands that would allow the user to monitor what the microprocessor was doing. The development of this software for the SS-VACM consisted of taking software already written and alter it so that it would be able to receive a rotor interrupt, do a vector average, store the data and go back to "SLEEP".

The software written to process a rotor interrupts is listed in Appendix A-2. Since the hardware relies on the software for timing purposes a basic description of the software will now be given so that the reader may better understand how this system is tied together.

When the hardware is turned on, the system boots up, and clock interrupts are generated by the clock board. As stated before the interval between these interrupts can be controlled by the user. For testing purposes this time interval was set at four seconds.

When the Hall-effect device senses that the rotor has made a complete revolution a rotor interrupt is generated and sent to the data latch board. This signal will wake up the SB-12 with a rotor interrupt and also latch the compass data into the data bus. When the SB-12 receives this interrupt it goes into a routine which will process the data. A flow chart of this routine is shown in figure 7 .

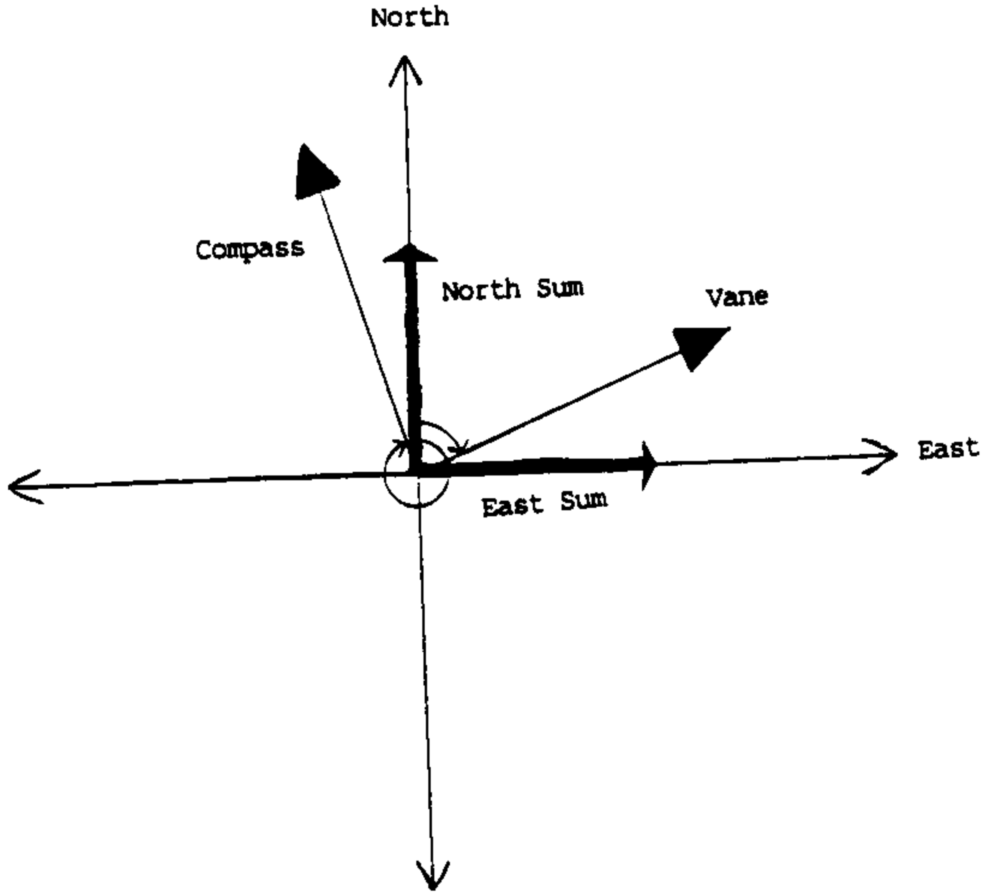
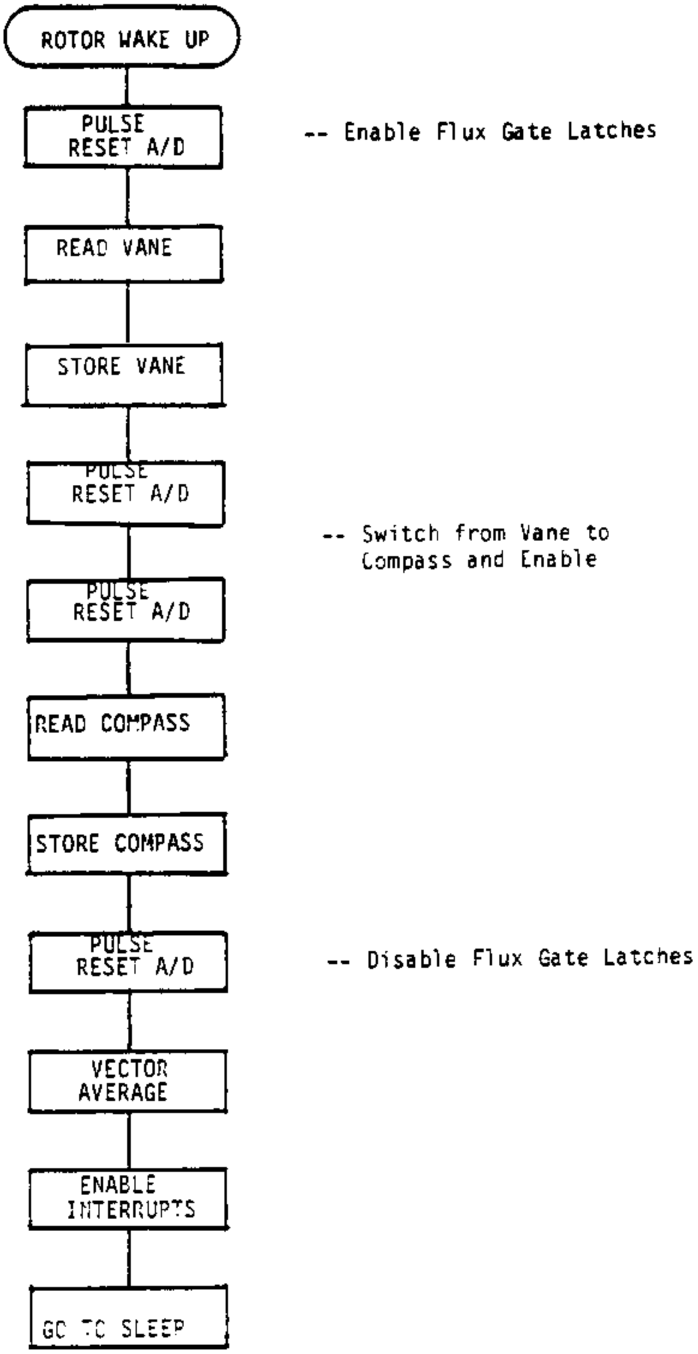


Figure 6



-- Enable Flux Gate Latches

-- Switch from Vane to
Compass and Enable

-- Disable Flux Gate Latches

Figure 7. Flowchart of Rotor Interrupt Routine.

The first step in the software is to send a pulse to the latch board in order to set in the vane data. This is done by toggling the RESET A/D line of the SB-12. Once this data is read and stored the RESET A/D line is pulsed twice with a small pause to let the line settle. The compass data is now read and stored and the RESET A/D is toggled once more to bring the rotor enable down. Now that the data for the vector averaging has been saved the latch board can be disabled and the vector averaging can take place. A description of this process has already been given. Interrupts are now enabled and the processor goes back to sleep.

As it can be seen here the software and hardware are heavily dependent on each other. The design of each part had to take into account the limitations of the other.

Vector Averaging

A vector averaging current meter is a current meter that measures currents be taking the average of the direction over a period of time. An example of how this is more accurate than taking the instantaneous direction at the end of a time period is shown below.

time	compass	vane	North	East
1	10	170	-1	0
2	10	260	0	-1

Old Method:

$\text{Speed} = \frac{\text{\# interrupt}}{\text{time}}$

Direction = 270°

Vector Average = 325°

Example #1.

Figure illustrating the old and new methods of VACM.

In this example each time period represents a rotor interrupt. It can be seen that a substantial error can be introduced after just taking two samples.

In this VACM the two components of direction are found be reading the vane and the compass. The vane measures the direction of the rotor and the compass is used to figure out the orientation of the current meter relative to north. Once this data has been read in the two components are:

$$\text{North} = \cos(\text{Compass} + \text{Vane})$$
$$\text{East} = \sin(\text{Compass} + \text{Vane})$$

These two components are then summed over the period between timer interrupts. A sample of how this is done is shown in figure 6.

C. Mechanical

Since one of our goals was to build the current meter at minimal cost, we wanted to make use of as many parts from the EG&G 102 current meter as possible. Most importantly, we wanted to use the savonius rotor and the vane from the old current meter, as these are standard parts of modern VACM current meters and have been used and tested so that their performance is well documented. The pressure case and endcaps of the old current meter were in good condition, so there was no need to replace them. The support rods and plates that made up the rotor and vane assembly and mooring connection could also be used again, however new hollow "dummy" rods were needed for the penetrator cable.

Some new parts were also needed to meet the requirements of our new current meter and to utilize new advances in technology to improve it. The old bulkhead penetrators were only capable of handling two wires. Since we needed twelve leads running from the outside of the pressure case to the inside, we needed new penetrators. The performance of the rotor and vane were improved by replacing the old bearings with technologically advanced new bearings, which improved the accuracy and response of the rotor and vane. The mooring line connection U-bolt was replaced by a larger one in order to allow room for the pressure, temperature meter which held the camera, compasses, batteries and electronics needed to be replaced by a card rack which could hold all the required circuit boards and provide additional battery space.

The pressure, temperature and conductivity sensors were additional features of our current meter. These sensors needed a mounting and protective assembly which was not part of the old current meter.

Corrosion:

To effectively discuss the mechanical aspects of the SS-VACM one must first understand the corrosion problem of metals in sea water(Dean,1987). Seawater is an electrolyte, a solution capable of conducting electricity. In the presence of an electrolyte, corrosion is electrochemical in nature and involves the flow of electrons and current. For corrosion to occur an anode and a cathode must be present to form a cell and current must be allowed to flow.

The anode is the area where corrosion occurs whereas the cathode is the area where little or no corrosion occurs. Electrons flow from the anode to the cathode. Current flows in the opposite direction. Two dissimilar metals are not required because anodes and cathodes can localize on a single metal strip. The metal of the anode is oxided and releases electrons as shown in the following equation:

$$\text{oxidation:} \quad M \rightarrow M^{N+} + Ne^{-} \qquad \text{eqn.1}$$

The electrons travel to the cathode where hydrogen ions are reduced to hydrogen gas:

$$\text{reduction:} \quad 2H^{+} + 2e^{-} \rightarrow H_2(g). \qquad \text{eqn.2}$$
$$O_2 + 2H_2O + 4e^{-} \rightarrow 4(OH)^{-}$$

Current flows from the anode to the cathode through seawater and back to the anode through the metal making a complete circuit as show below.

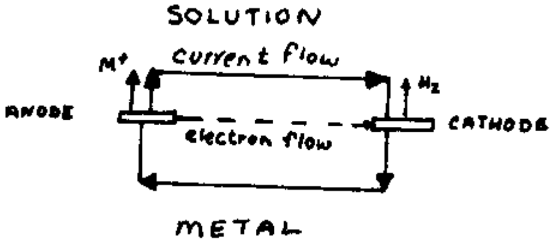


Fig.8 Schematic Diagram of the Electrochemical Corrosion Process.

Corrosion occurs at the surface of the anode as the metal is converted to its ionic form (M^{N+}) at oxidation. The ionic metal reacts with the oxygen in the water to form an oxide layer on the metal. In rust, the iron oxide layer is weak and flakes off, constantly exposing new iron metal. This type of corrosion is continuous. However, some forms of corrosion are not as destructive An aluminum oxide layer is hard and protects the metal below from further oxidation. In a severely corrosive environment such as sea water, the protective layer becomes pitted and causes further oxidation. Shown is an illustration of the various oxide layer described(Dickerson,1979).

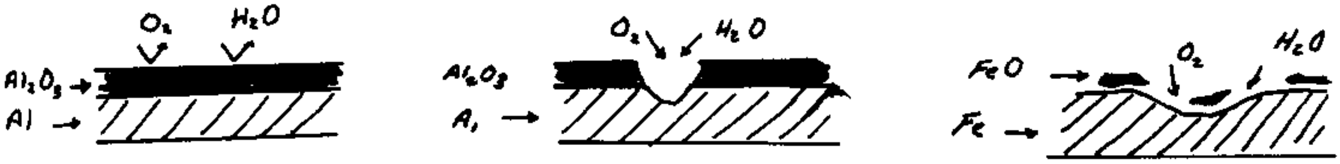


Fig.9 (a)finite oxide layer (b)Pitted oxide layer (c)continuous oxide layer

Anodization is the chemical acceleration of the formation of the oxide layer. Aluminum alloy components of the SS-VACM were anodized by submersion in an acid bath. Any components that were removed from the SS-VACM for machining were re-anodized. Several layers of anti-corrosive marine paint were applied to further protect the metal.

The identity of the anode and cathode is determined by its reduction potential(Hunt,1967), which is a measure of the ability of metal to be reduced. The metal with the greater reduction potential will be the cathode and the other will be the anode. With this in mind a metal will act as a anode or cathode depending on the other metals present. To avoid corrosion, a metal with a lower potential can be used sacrificially; it will act as the anode and corrode before the desired metal. This is referred to as a sacrificial metal. Zinc blocks are used on the SS-VACM to protect the aluminum structure and stainless steel(316) instruments(for electropotential values see appendix). Aluminum Alloy(7075-76) is the desired structure material because it provides high strength, machineability, but can have corrosive problems because of its zinc content.. Another method of reducing corrosion is the use of plastics. This has been accepted in bearings and in sensor mounts.

There are many factor that contribute to the rate of corrosion of metals in seawater. By controlling as many of these as possible we significantly reduced the corrosion rate of the SS-VACM components. This was a major priority in designing the SS-VACM especially considering its long time employment and delicate sensors.

Cardrack:

In the initial stage of redesigning the old EG+G current meters we disassembled one of the meters and evaluated the design. Among the aspects of the meter that had to be changed was the instrumentation rack within the pressure casing. The old meter used a camera and two relatively large compasses. The camera and accompanying light pipe apparatus was the main part of the meter to be changed. Specifically, replace this old technology with solid state microprocessing technology. This entails providing a rack for the microprocessing boards. Our team decided to replace the existing compasses with fluxgate magnetometers which require further special consideration. Another aspect was to provide room and connivance for a control panel.

After defining these changes, certain requirements needed to be developed in order to come up with a final design. The space set aside for the card rack was a major consideration. Because the meter will continue to be developed through the summer of 1987 and beyond, room for adaptation had to be provided. For this reason, space for the card rack had to be maximized. The fluxgate compasses had a bearing on the design because their position relative to the other instrumentation is important. The vane follower fluxgate compass needed to be as close to the vane as possible(ei. mounted on the bottom end plate). The fluxgate measuring the instruments orientation needed to be away from the vane follower and both of the fluxgates required two card spaces. Also affecting the design of the card rack was which company we would obtain our hardware from. Sea Data boards were shaped and made to fit into a card rack design that has become very common in oceanography. We chose to go with this design because it is stable and easy to adjust.

As a final design the forty and a half inches of available space was divided as follows:

Card Rack - 22 1/2 inches
Battery - 16 inches
Control Panel - 2 inches

The pressure casing is 6 inches is diameter, an oceanographic standard. See

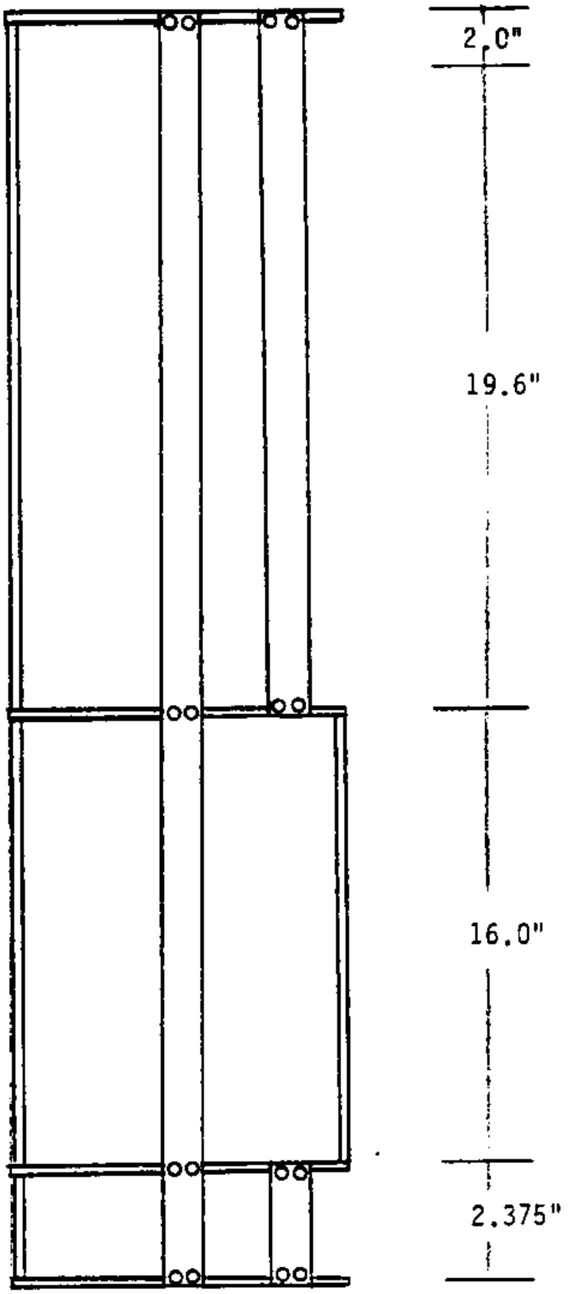


Figure Ten: Side View of Card Rack

CARD RACK

(side view)

Figure Eleven: Top View of Card Rack and Control Panel figures 10 and 11 accompanying this section for layout and top view.

The material used to construct the card rack was aluminum 6061-t6. Three different types of this material was needed;
1/4 x 1 inch bar stock for the main frame support, 1/16 x 1/2 x 1 inch angle stock for the mounts of the pin connectors for the cards, and 1/4 inch plate from which the separating plates were machined. See machine drawings for required fasteners.

The company from which the aluminum was ordered was Northstar Steel. The company from which the fasteners were ordered was All-Stainless Inc. Both companies had reasonable prices and all the material we needed for this card rack design.

Power Requirements For A One Year Deployment:

Two types of batteries were considered for powering our system; Alkaline and Lithium. They have the following characteristics:

	supply	length	diameter
Lithium	3.5v at 25amp-hr	5 inches	1.31inches
Alkaline	1.5v at 5 amp-hr	2.5inches	1.31inches

Because one lithium delivers more power than two alkalines and takes up the same space, lithium batteries were chosen to be the most practical despite the fact they are more expensive.

The following table describes the power requirements for each component of our system.

microprocessor memory (RAM) clock temp. cond. counters pres.	10.5v at 27mamp power up 3 mamp power down (duty cycle)
sensors temp.,cond. pres.	 10.5v-14v at 7.5mamp each continuous 10.5v at 1.5mamp continuous
fluxgate compasses	10.5v at 60mamp duty cycle

The duty cycle is dependent on the speed of the current. Therefore to get an accurate estimate of the power requirement one must compute what percent of one cycle the microprocessor and fluxgate compasses are powered up. To do this a current speed, one that this meter is likely to see, must be assumed. A current speed of 2 knots will be used in this analysis.

Each Savonius Rotor revolution has 2 sample cycles. During a sample cycle and upon power up the microprocessor is up for 75msec and the fluxgate compasses for 65msec. The Savonius Rotor has a calibration of 37.5cm per revolution.

Computation of percent power up of duty cycle:

52 cm/sec=1knot
104cm/sec=2knots
This implies that there will be approximately
6 sample cycles per sec in a 2knot current.
(104cm/sec)/(37.5cm/revolution)=2.77revolution/sec
(2.77revolution/sec)x(2cycles/revolution)=~ 6cycles/sec
The percentage of one cycle that power is
required for components on duty cycle is:
(75msec/cycle)x(6cycle/sec)=45%

The total power needed for components on duty cycle when powered up is approximately 87mamp. Therefore, an equivalent continuous current drain is 45% of 87mamp or 39.15mamp.

The following table depicts the power requirements in amp-hr and the equivalent in lithium batteries.

	Power Requirements	Battery Equivalent
microprocessor memory clock temp., cond., and pres. counters fluxgate compasses	342.9amp-hr	14 packs of 3 lithium cells each
sensors temp. cond. pres.	122.6amp-hr	5 packs of 3 lithium cells each

The total battery requirement is 57 cells. The batteries would be packed together to fit in the card rack such that there would be 12 cells per layer of lithium batteries. 5 such layers would therefore be required. 5 layers of lithium batteries would take up 25 inches of card rack space. The current layout of the card rack doesn't provide for this much battery space. However, if additional meters were to be produced the space for cards can be reduced enough to fit both the required batteries and hard ware. It is, therefore, feasible to deploy our meter for one year.

Penetrators:

Adding the new features that were desired to upgrade our current meter meant that more leads from the external sensors to the electronics inside the pressure case were needed. The minimum number of leads required by the new Hull effect device, RS232 link, conductivity, temperature and pressure sensors was twelve; the original EG&G required only two leads for the magnetic rotor switch. The problem in this case was how to bring these leads from the sensors and link outside the pressure case to the microprocessing electronics inside the pressure case without allowing any seawater to violate the pressure case, seawater that would ruin the electronics and consequently destroy the instruments data collecting ability.

The original leads pierced the bottom endcap of the current meter using two single pin bulkhead penetrators. This method worked well, however, to accommodate the additional leads a larger bulkhead penetrators would would be required, if standard model bulkhead penetrators were to be used. This larger penetrator would interfere with the motion of the vane and prevent it from turning freely.

One possible solution was to change the size of the vane, or lower the vanes position so that it could pass freely by the larger bulkhead penetrators. This solution turned out to be unacceptable for two reasons: 1) the vane needed to be close to the vane-follower (flux gate compass element) mounted on the inside of the endplate, and 2) we did not want to change the design of the vane or rotor, as response of the rotor and vane have been studied in their present configuration and are well known.

The problem then became a decision of whether to mount the penetrators on some other part of the pressure case than the bottom endcap, or to develop some specialized bulkhead penetrator system that was able to accommodate twelve leads and still fit between the bottom endplate and the vane.

The sides of the pressure case were considered and determined not be good places to mount the penetrators. Once the penetrators were installed in this position, it would be difficult to access the internal instrumentation, and difficult to test the circuit boards with the current meter assembled. Also, in order to seal properly the connectors need a flat surface, and experience has shown that it is very difficult to machine the pressure case sides so that a penetrator mounted there will have a good seal. Another argument against mounting penetrators on the side of the pressure case was that it is undesirable to have things protruding out from the sides of the pressure case which would get in the way during deployment and recovery of the instrument and possibly be damaged.

The top endcap was another alternative place to mount the bulkhead penetrators, however this would mean cable would have to be run up the sides of the instrument and checking the instrument prior to deployment would be more involved.

Clearly, the most desirable place to bring in the leads was the bottom endplate, where the original penetrators were. The original penetrators were countersunk into the endcap so as to fit under the vane. The required standard sized penetrators would be almost as long as the endcap thickness, and wide enough so that countersinking them to that depth would significantly weaken the endplate.

During our trip to Woods Hole Oceanographic Institute, Jerry Dean told us the solution WHOI had come up with was a penetrator custom made for them by Brantner and Associates, a California firm. We contacted Brantner, and arranged to have them make two similar penetrators for us, each which would contain six leads. (see figure 12) These penetrators were small enough to fit on the bottom endcap without interfering with vane motion. They only need to be countersunk .25 inches, so did not weaken the endcap significantly. We were able to convince them to give us a discount in purchasing these two penetrators, even though we needed such a small quantity, because we were

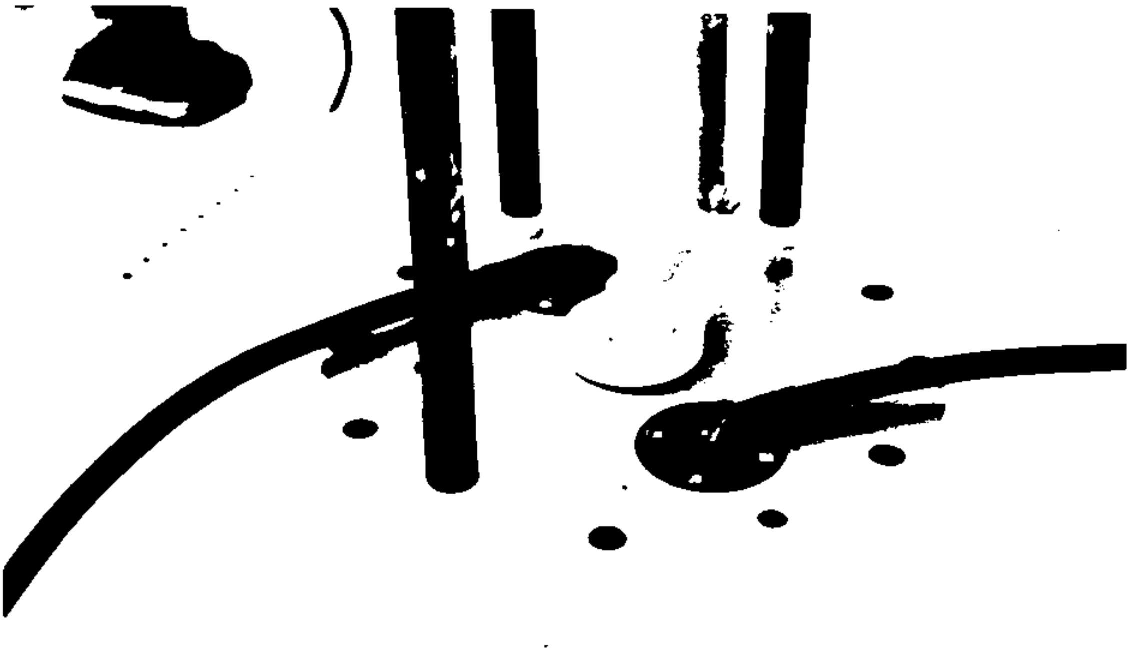


Figure Twelve: Brantner custom made penetrator mounted in endcap.

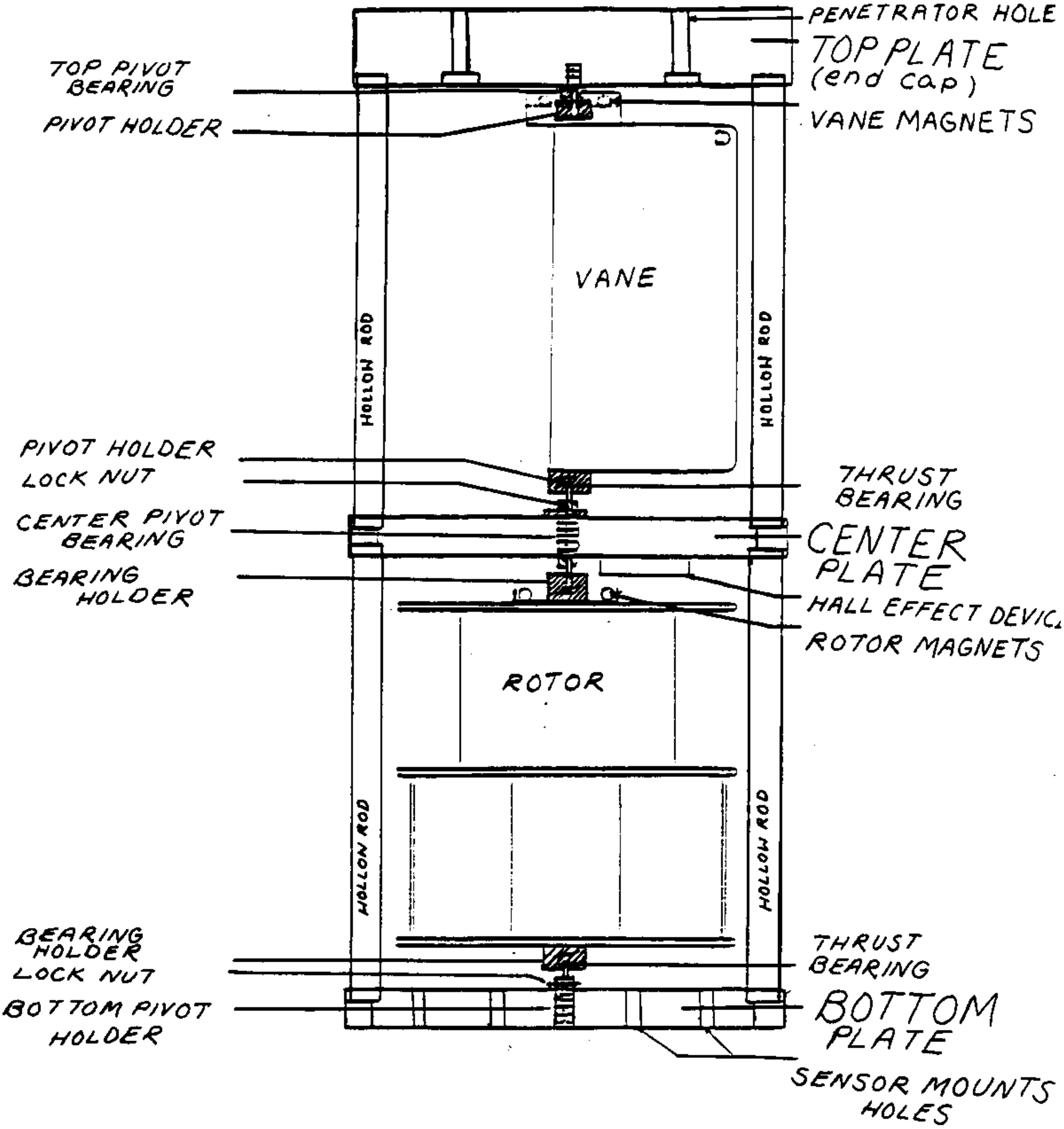


fig. 13 ROTOR/VANE ASSEMBLY

working on a student project.

The penetrator is made with an aluminum base with six 24 gauge leads piercing it, and topped by a waterproof resin bubble. The penetrator installed in an endcap is good to pressures of 10,000 psi without leaking.

Bearings:

The SS-VACM uses the vane direction sensor and Savonious rotor speed sensor of the EG&G model. These sensors have maintained their high performance and reliability and are presently used in the standard VACM and Geodyne Type 850 current meters. The vane and rotor is set on pivots in bearings as shown in fig 14.

A new bearing design was adopted to the SS-VACM to improve reliability and performance over the existing bearings in the EG&G model. With the old bearings, carbonate deposists formed in the bearings. These deposits inhibited and even prevented the response of sensors mounted on the bearings(Dexter,1975). The new design minimizes the formation of deposits and is used in the standard VACM.

The principle factors in the formation of the carbonate deposits (siderite, aragonate and calcity) are:

1) electrical path between zinc anode and the bearing.
2) electrical isolation of stainless steel from aluminum.
3) composition of the radial bearing.

The EG&G bearing materials are stainless steel and sintered tungsten carbide (fig 16). Both the aluminum alloy and zinc anode are electrochemically active with respect to stainless steel and tungsten carbide in seawater (see appendix). The bearing becomes the cathode. In the corrosion process the electrochemical reaction at the cathodic area is:

reduction: $O_2 + H_2O + 4e^- \rightarrow 4OH^-$ eqn 2

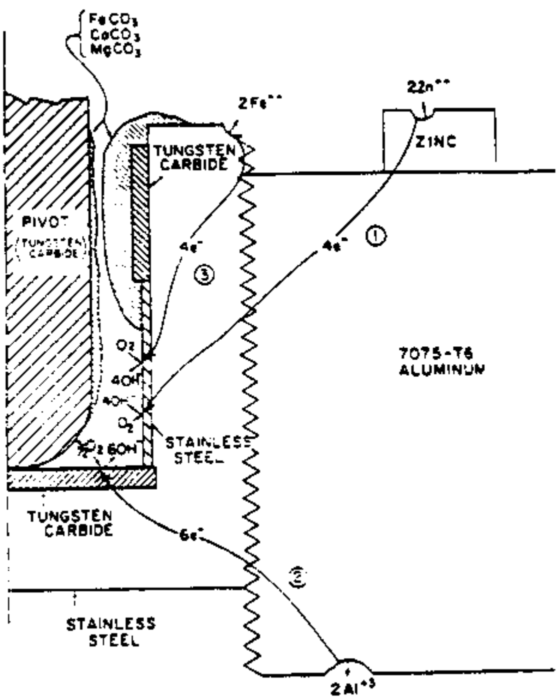


fig 14. Schematic diagram of the three electrochemical cells capable of raising the pH inside the bearing: (1) zinc (2) aluminum (3) iron.

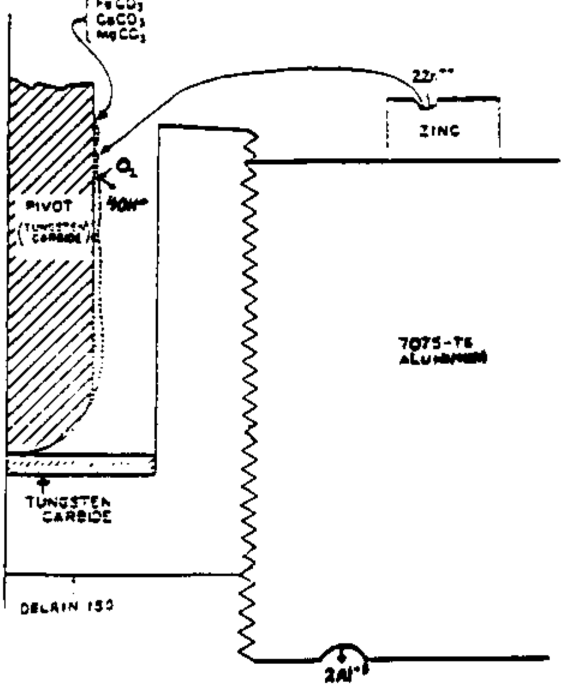


fig 15. Schematic diagram of minimized electrochemical cell process with Delrin 150 and absence of radial bearing.

The electron in this reaction are from (shown in fig 14) 3 sources:

1) corrosion of zinc anode $Zn \rightarrow Zn^{2+} + 2e^-$
2) corrosion pits of Al. alloy $Al \rightarrow Al^{3+} + 3e^-$
3) corrosion of stainless steel $Fe \rightarrow Fe^{2+} + 2e^-$

The OH^- ions produced by the reaction in eqn(2) are injected into the small amount of water trapped in the bearing crevice. As a result the pH is increased. If the pH in the crevice is raised sufficiently carbonate deposits will precipitate according to the following reactions:

$$2OH^- + Ca(HCO_3)_2(\text{soluble}) \rightarrow CaCO_3(\text{insoluble}) + CO_3^{2-} + 2H_2O$$

If the seawater in the crevice was completely stagnant then only a limited amount of OH^- would form. However, the vane usually changes direction allowing more O_2 to enter which produces more OH^- ions. This results in a continuous deposit forming process.

The major contributor of the electrons is the zinc anode because of its low reduction potential with respect to stainless steel. By restricting the current density, fewer OH^- ion would exist. This would reduce the carbonate deposits significantly. The new design restricts this flow by replacing the stainless steel bearings with Delrin 150 (fig 15), a non-conductive material. The new pivots and thrust bearings are made from Kennemetal K801 tungsten carbide. The Kennemetal K801 resists embrittlement in seawater and maintains high strength. The combination of Delrin 150 in seawater and Kennemetal K801 is presently being used in the standard VACM after experiencing the problem of carbonate deposits in earlier models.

The new design allows easy assembly and compensation for biological factors. Clearances for the rotating sensors must be permitted in case of fouling. After all parts have been treated for corrosion and antifouling, the cage should be assembled except for the bottom plate. The hollow rods are in position to protect the leads from extending from the penetrators. The aluminum rods should be torqued to 120 in.lbs. Bearings and pivots should be cleaned (see FIG. 13).

1. Install upper vane bearings without spacers.
2. Place vane in position and insert the center pivot bearing into the lower vane pivot holder.
3. Place vane into position and secure bottom cage plate. Insert bottom pivot holder into bottom bearing holder.
4. Adjust center bearing for .030" clearance between hall effect rotor device and high spot on the magnets.
5. Estimate washer(s) need for upper vane bearing to provide .030" play in vane once center pivot bearing is adjusted for rotor clearance.
6. Remove rotor, vane and all bearings and lubricate cage plate threads.
7. With washers in place, assemble vane with center pivot bearing positioned.
8. Insert rotor checking clearance again. Check play in vane again. Secure center pivot bearing with lock nut.
9. Insert bottom pivot holder until .030" play exist in rotor.

Sensor Mounts, Cage and Mooring:

Temperature, conductivity, and pressure sensors are the standard oceanographic water sampling sensors that enable the oceanographer to determine the salinity, density, and depth of a water sample. An important improvement of our prototype current meter is the addition of these conductivity, temperature, and pressure sensors which increases the usefulness of the current meter data by providing more information about the properties of the water being sampled. It is crucial that the sensors be located as near as possible to the rotor and vane so that they will be sampling the same water, and that the temperature and conductivity sensors be next to each other. It is also important that the sensors be protected from damage especially during deployment and recovery of the instrument.

The first criteria of design for any sensor mount and protection system was that it did not interfere with the continuous mooring connection of the instrument, or provided some way to maintain this connection. Our design called for removing the original stainless steel U-bolt to make space for the sensor mounts. We replaced the original U-bolt with a larger six inch stainless steel one that fit over the sensor mounts. (see figure 18) A two inch wide stainless steel plate was welded to the top of the U-bolt, with a hole drilled into it to mount a mooring line shackle and prevent the mooring adjustment.

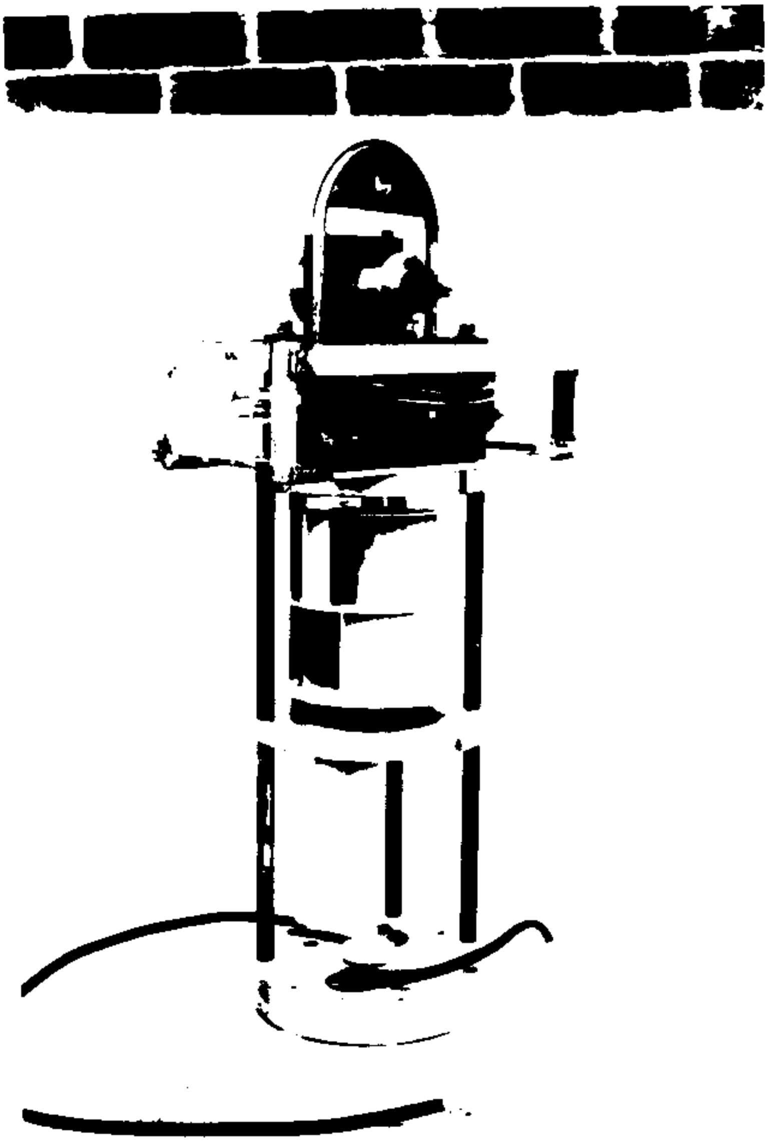


Figure Sixteen: Sensor Mounts, Cage, and Mooring Connection line from slipping on the U-bolt and banging into the sensors.

The second criteria was that the sensors be mounted securely as near as possible to the rotor and vane, with unrestricted flow of sample water to all sensors. The sensors should be subject to minimal mooring shock. The conductivity sensor needed to be mounted horizontally to facilitate flushing of the sensor. The mounting scheme needed to be flexible, so that any combination of the three sensors could mounted at one time. For instance, often the temperature and conductivity sensors would be mounted together without the pressure sensor. In addition, it was desirable to mount the sensors so that the current meter itself afforded them maximum protection. With our design the sensors were mounted underneath the bottom plate using clamps made of one inch thick polyvinylchloride. The conductivity and temperature sensors were mounted side by side horizontally onto the bottom plate. (see figure 18) The pressure sensor was mounted horizontally on top of the conductivity and temperature sensor mounts, perpendicular to the other two sensors. This design meant that the pressure sensor, which would not always be used, could be removed or installed without removing the other two sensors. This design also provided the sensors with protection from the bottom plate and the U-bolt, which was mounted over the sensors.

The sensors that the mounting clamps were designed for were the Seabird SBE-3 and SBE-4 temperature and conductivity sensors, and the Paroscientific 8270 pressure sensor. These are the sensors used by the Physical Oceanographic Research Team, so the sensors, documentation and calibration data were already available.

The third criteria was that the sensors be adequately protected by some sort of cage assembly. This cage should protect the sensors with efficiency; be built with a minimum amount of materials and not be too big, cumbersome, heavy, or interfere with criteria one and two. Our design for a cage was simply a box made out of aluminum strips 1" by 1/4". It fastened between the sensor mounts and bottom plate. The cage was 4" X 14.5" X 7", so that it completely encompassed the conductivity and temperature sensors. Our design scheme enabled the pressure sensor to be protected by the bottom plate and by the U-bolt, so the cage did not need to be built around it. The aluminum material was light, and also readily available.

The fourth criteria was that the mooring/sensor mount/cage system should allow for easy access to the sensors for replacement, and should be easily removed itself if not necessary to use it. Our design offered the choice of not mounting the pressure sensor if one was not needed, or easily attaching one. Since the cage was not necessary if there were no sensors, the cage and sensor mounts were attached in the same way and could be taken off at the same time. The option of using the original U-bolt is still available if no sensors are mounted.

This sensor mounting scheme enables the conductivity, temperature, and pressure sensors to be attached to the current sensor so they sample accurately, are protected, and do not interfere with the mooring connection of the instrument. With these sensors the current meter becomes a more versatile oceanographic instrument, capable of supplying more details about the sampled water.

The vane and rotor pivoted smoothy on the new bearings. Adjustments for clearences were easily met. However, caution is needed when appling Delrin bearings. Threads may strip if more than thirty pounds inch torque is applied. Overall, this is a highly recommended design, which allows easy

III. TEST RESULTS

Electronics:

The new Hall effect rotor sensor was successfully implemented in our project. Lab tests revealed that the Hall effect device proved to be more reliable and less expensive, but it required a constant power drain of 10mW whereas the old reedswitch assembly consumed no power. This would decrease the allowable deployment time of the current meter by approximately three weeks based on a full battery capacity of 486 amp-hours. The major advantage of the Hall effect device is that there are no moving parts which would eventually wear out thereby allowing the device to operate virtually forever. This results in a slightly faster response than the reed switch since the magnetic field is sensed instantaneously as opposed to the finite time interval it takes for the reed switch to actuate. The Hall effect devices reliability, response time and low cost convince us that it is the best solution to sensing current speed with a Savonius rotor.

One hardware problem prohibited the successful completion of the project in time to perform test analysis on the vector averaging circuits. At this point we have not been able to measure the fluxgate position in relation to a magnetic field. The digital circuit was separately tested with known data and operated as designed. Extensive testing indicates that a problem lies in the phase detection of the analog circuit. Each stage of the circuit was individually isolated and tested with a signal generator and expected operation was observed with the exception of the MF10 dual switched capacitor filter. With a known signal applied to the input of the MF10 filter stage, the output was a sinewave at approximately 14.6 Khz or 1 Khz less than its designed centerband frequency. At frequencies slightly above or below the 15.63 Khz desired frequency, the output was severely distorted. Component values and the MF10 transfer function were rechecked but no errors were found. The MF10 filter chip was replaced with another to check for the possibility of a defective chip but this did not prove to be the source of the problem. At this point it was decided to completely bypass the MF10 filter and connect the output of bandpass filter U1 directly to the phase shift network U4. Less distortion was observed at the output of the phase shift network but a phase difference between this signal and the compass drive was still not detected. Sippican Inc., an engineering firm located in Marion MA. had donated the fluxgate sensors used in our project and had suggested much of the design techniques used in the control circuit. They are currently working with us on this problem and we expect to have it resolved in the near future.

Mechanical:

A wet test of the pressure case with the new Brantner penetrators in the endcaps was conducted in the water tank of the PORT/MSEL high bay in the New Science Building at the University of New Hampshire. The pressure case was lowered into the tank with the winch and left in the tank for about one hour.

Although the current meter will be operated in the deep ocean, it is the shallow water where O-ring seals like those of the endcap and penetrators of the current meter are most susceptible to leak. O-rings are designed so that they seal better when subjected to high pressures, such as deep water. It is therefore the low pressure leaks in shallow water that are more likely to allow water into the pressure case where it could damage the internal electronics.

Parts of the single-pin penetrators from the original current meter were left in the endplate to plug the holes that they were in. The endcap O-ring seals were polished to insure that they were clean and smooth. Silicon grease was applied to all O-rings to facilitate even sealing.

After about one hour the pressure case was removed from the tank and examined under the supervision of Jim Irish, the resident expert in O-rings. The insides of the pressure case were completely dry, the O-ring seal wet test was a success.

IV. CONCLUSION

Electronics:

As mentioned in the test results, the Hall effect device proved to be a successful method of sensing rotor speed. The advantages of reliability and low cost outweighed the disadvantage of its moderately low power consumption. Whenever rotor or propeller speeds are to be measured, the Hall effect device is an accurate, reliable and cost effective way to sense these parameters.

The use of the fluxgate compass to sense the orientation of the meter and vane follower position was an option we chose for several reasons. First, we wanted our prototype to have the accuracy of 8-bit resolution or 1.4 degrees at the lowest possible cost. Second, the current meter needed to be more reliable than the existing light pipes used with the old compass and vane follower assemblies. At this point we believe that the fluxgate compass could still be the best solution to meet these requirements but a final conclusion cannot be made until we have thoroughly tested an operating circuit.

As with most design criteria, there are tradeoffs and this proved to be true with the fluxgate sensor. If our control circuit proves to be successful, then it is estimated that the cost of converting other current meters would be approximately $100 for each circuit. The cost of converting the existing compass and vane follower assemblies using the light pipes would be approximately $50 per circuit but resolution would be only 7-bits. This does not necessarily mean that the accuracy of measurement would be less since it has not been determined what the actual sensitivity of our fluxgate compass is. If the digital circuit has 8-bit resolution but the compass is only sensitive to 2.8 degrees at best, then the accuracy would be no better than the existing system. An alternate solution might be to use a fiberoptic system using an array of phototransistors with an 8-bit Gray coded compass assembly. This would improve reliability and ensure a resolution of 1.4 degrees but the cost would be approximately $1000 per circuit.

The hardware purchased has provided our group and other members of PORT with the versatility that had been desired. The software has been altered to measure things like FSK signals and TP&C signals. The software that accompanied the hardware was easy to use and easy to alter for a number of specific applications.

Mechanical:

The Brantner custom made bulkhead penetrators proved to be a success.

They provided a way to communicate electronically between all the sensors and link outside of the pressure case and the microprocessing and data storage units inside the pressure case without allowing seawater to infiltrate the pressure case. Particular to the problem with this current meter, they were able to penetrate the pressure case at a convenient location on the current meter without interfering with the workings of the vane. They are rugged, have a low profile (so have a smaller risk of being knocked or damaged) and are good to a water pressure of 10,000 psi. The cost of $220.00 each was expensive for one pair, but if fourty-eight penetrators were ordered to upgrade all the EG&G 102 current meters in the possession of PORT, the price for each penetrator would be significantly less.

The sensor mounting and protecting scheme and the bottom mooring line connection accomplished their functions effectively. The sensor mounts enabled the sensors to be mounted near the rotor and vane, so they were sampling the same water. The conductivity sensor was mounted horizontally to facilitate flushing. The sensor mounting scheme was flexible so that various combinations of the pressure, conductivity and temperature sensors were possible. The sensors were easy to attach and remove.

The sensors were adequately protected by taking advantage of the protection offered by the endplate and U-bolt as well as the shielding cage that was built around the two sensors that protruded from the endplate.

The mooring line connection was maintained by replacing the original U-bolt with a larger one that fit around the sensors. The larger U-bolt had a bridle at the top to hold the mooring line in place and prevent it from damaging the sensors.

An improvement to this system would be to build the protective cage out of round stock material as opposed to flat stock so the cage would have less effect on the flow of water past the sensors. The cage would also less likely be effected by currents in the water that might change the orientation of the current meter. Another improvement would be to mount the pressure sensor in a way that would not require a metal bolt to be threaded into the PVC sensor mount, as it is in this design. With this design the PVC threads have the potential of being stripped, which would risk losing the pressure sensor.

There are machine drawings in existence for exact dimensions of the card rack. Since PORT has requested the machine shop in Kingsbury Hall to produce similar card racks there was no problem with the final product. This is true with the exception that the aluminum angle stock used for this rack proved to be too thick. 1/8" X 1/2" X 1" was used, 1/16" X 1/2" X 1" angle stock would eliminate some machining and make the installation of the pin connectors much easier.

APPENDIX A-1: OPERATION OF FLUXGATE CONTROL CIRCUITS

The phase modulated circuit approach was used for the fluxgate control circuits in the compass and vane follower assemblies, and consists of two separate circuits, one digital and one analog. The digital circuit is used to develop the compass drive signal at the required frequency and to control the timing needed to gate the compass and vane follower inforation to the data bus. The analog ciruit senses the desired signal which is induced across the two secondary windings of the fluxgate, provides the necessary filtering and sends the resulting signal back to the digital circuit to be compared with the phase of the driver signal to determine the position of the compass or vane follower.

The digital processing circuit of FIG. A-1a which utilizes high speed CMOS technology, is composed of three "D"-flip flops, three nand gates, two eight bit counters, an eight bit latch register and two power mosfet transitors. The circuit is driven by a 4Mhz clock which is divided down to 2Mhz by the "D" flip flop U5 and sent to an eight bit counter U6. Three outputs of U6 are used to obtain 15.6Khz, 7.81Khz, and 500Khz signals. The 7.81Khz output is sent to the two power mosfet transitors which are configured as a complimentary CMOS inverter to provide the 7.81Khz square wave compass drive signal through the DC isolation capacitor C10. The 15.6Khz output is used to reset the eight bit counter U2 to begin a count sequence.

The second harmonic voltage appearing across the fluxgate is selected and enters the analog circuit of FIG. A-1b as the sine and cosine of the compass return signals. Capacitor C3 is used to shift the compass return sine signal 90 degrees so that it can be summed with the compass return cosine signal to produce a constant amplitude phase shifted signal at a frequency of 15.6Khz which is twice the frequency of the driver signal. The phase delay is proportional to the position relative to its reference position. The resulting signal is sent to the bandpass filter stage U1 which has a center frequency of 15.6Khz. The signal is then sent to U3 which is a monolithic dual switch capacitor filter configured to perform as two bandpass filters with a center frequency slightly below 15.6Khz in the first stage and a center frequency slightly above 15.6Khz in the second stage to help compensate for variations in temperature. The external clock frequency of 500Khz is provided from the eight bit counter U6 in the digital circuit. The signal is then passed through the phase shift network U4 where potentiometer R26 is used to adjust the phase of the signal so that the compass may be calibrated to its reference position of magnetic north. The filter stage of U4 is used to provide further rolloff at the 15.6Khz frequency where it is then sent to the comparator circuit U2 which is used to send the squarewave compass out signal back to the digital circuit.

The compass out signal returns to the digital circuit as the clock input at the "D" flip flop U1. The signal is divided down to 7.81Khz, the same frequency as the drive signal. This signal stops the eight bit counter U2 which was triggered to start counting by the compass drive signal. The count value will be proportional to the phase difference between the two signals with a complete 360 degree phase shift corresponding to a full sequence of 256 counts. This results in a resolution of 360/256 or 1.4 degrees per count. The signal out of U1 is also used to enable the eight bit latch register U3 so that a read compass signal from the microprocessor can latch this count value to the data bus for vector average processing the counter U2 is reset through U4 and "D" flip flop U1 to begin a mew count. FIG. A-2 shows one of the two assembled control circuits for the fluxgate sensor.

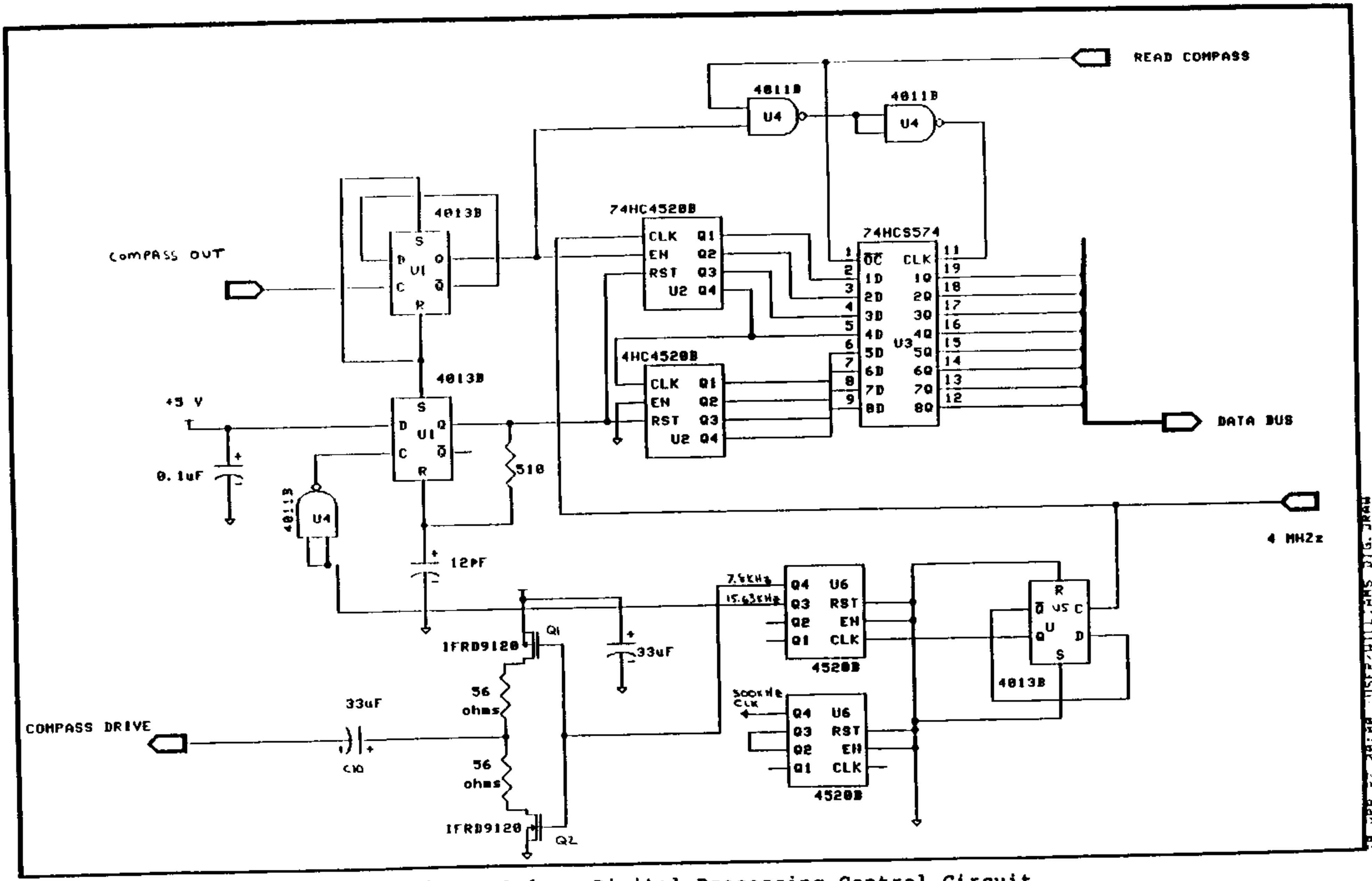


Figure A-1a - Digital Processing Control Circuit

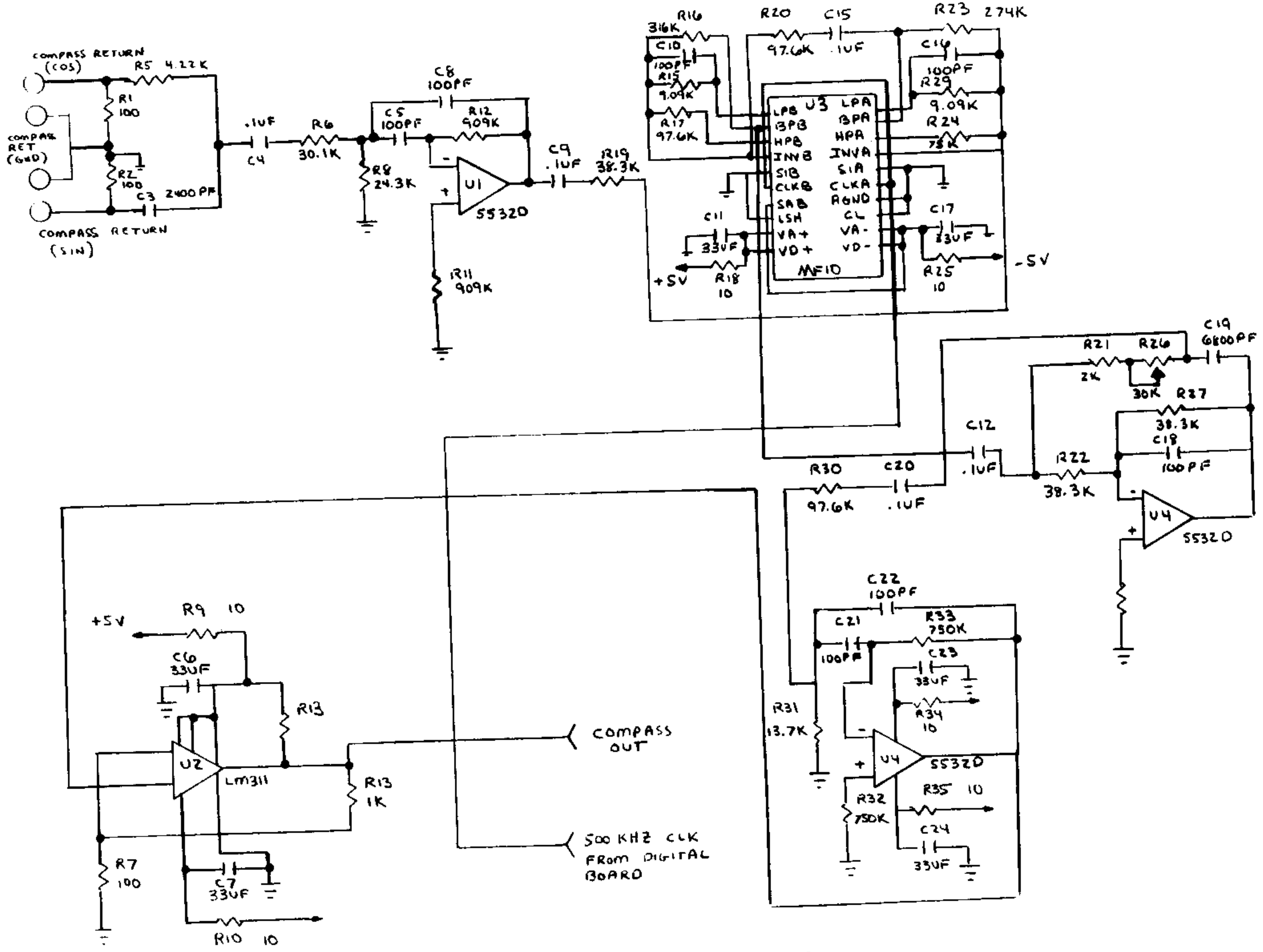


Figure A-1b - Analog Circuit

Figure A-2: Assembled Fluxgate Control Circuit

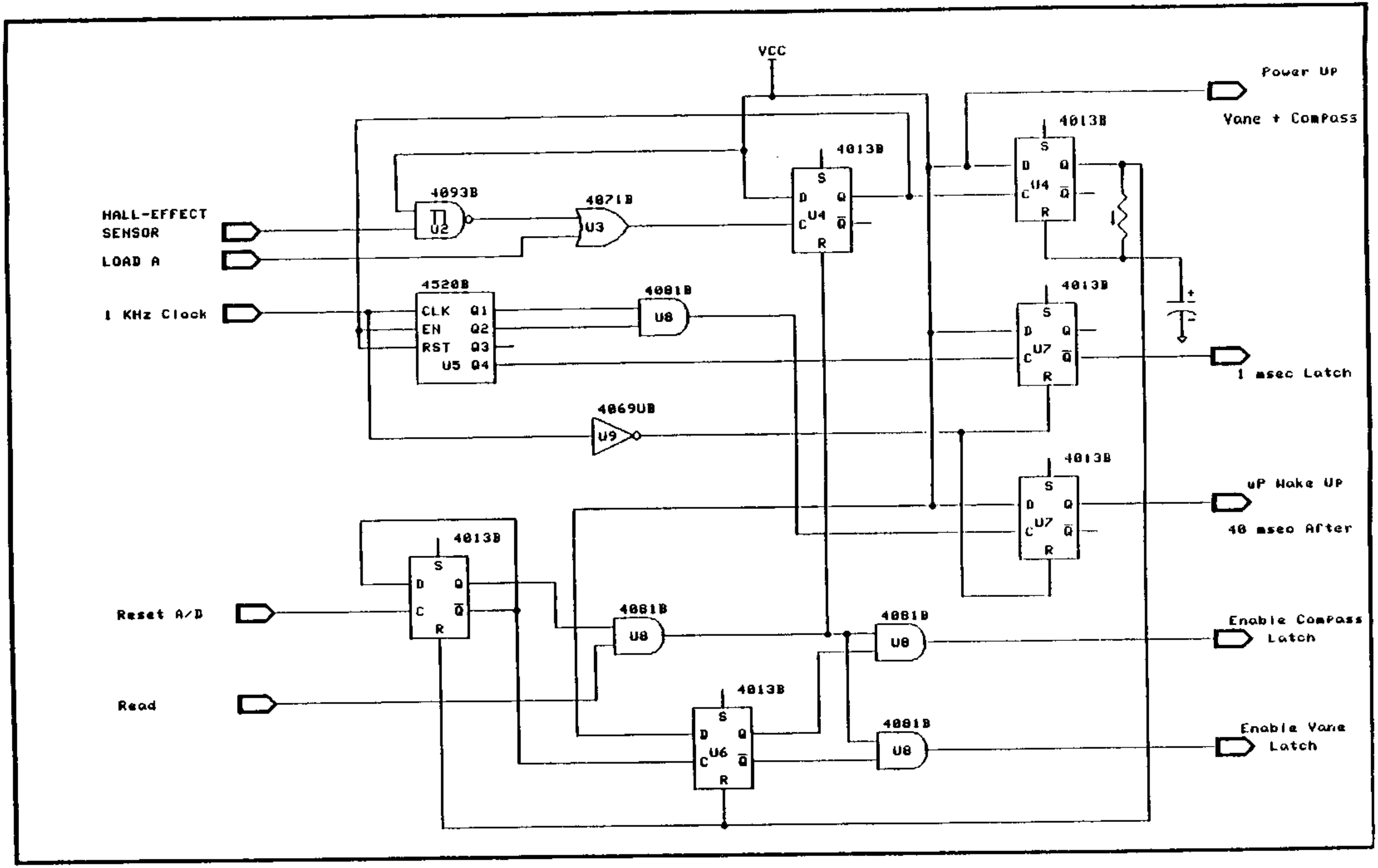


Figure B-1 - Digital Data Latch Board

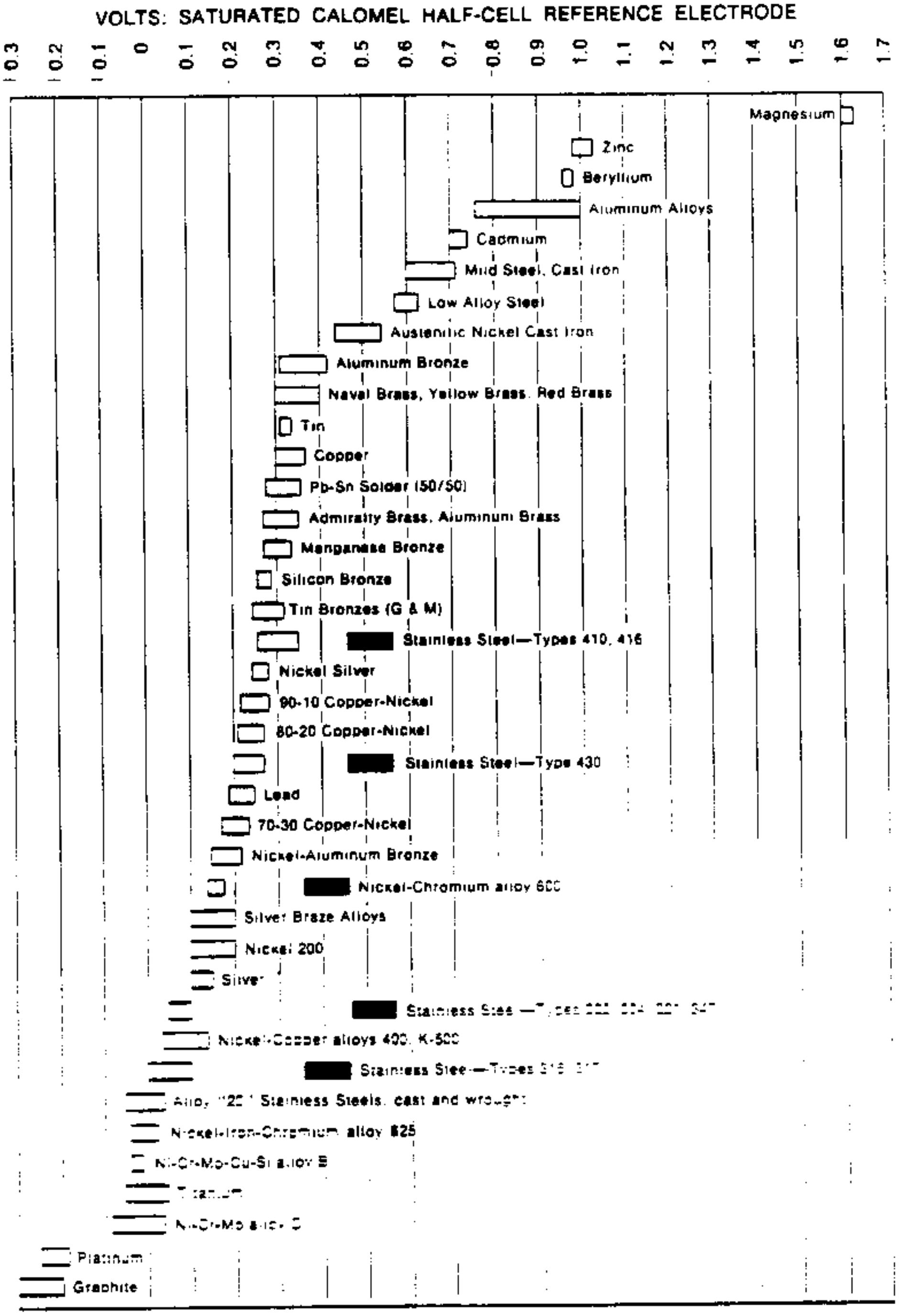
```
; This module handles the ROTOR interrupt via RST7.5
;
        %INCLUDE "\sd605\605mac.mac"
        %INCLUDE "\sd605\stdmac.mac"
        %INCLUDE "\sd605\stdmath.mac"
        %INCLUDE "\sd605\stdstor.mac"
        %INCLUDE "\sd605\xcute.map"
;
;
__RotEnb        %macro
        in      .PIO.PC         ; get current port setting
        xri     _RotEnb         ; toggle rotor enable bit
        out     .PIO.PC         ; put it out on port
        xri     _RotEnb         ; toggle rotor enable bit
        out     .PIO.PC         ; put it out on port
        %endm
;
;
        EXTERN .CmRec,.CmRotor,.CmCompass,.CmVane,.CmEast,.CmNorth
        EXTERN .StrFlag,.CmByt,.TmpEast,.TmpNorth,.ForceRot

        PUBLIC  DoRotor
DoRotor:
        mvi      a,00010000b  ;set up to clear 7.5 flag
        __SetIntrMask
;
        __PrtTst        .PIO.PC,_StrEnb         ;see if SSR enabled
        sta     .StrFlag
        jz      NotEnb
        in      .PIO.PC
        ani     low (NOT _StrEnb)               ;disable SSR
        out     .PIO.PC
NotEnb: __RotEnb                                ;pulse Rotor enable - up
        __RdStrByt                              ;read byte - same as SSR
        sta      .CmCompass                     ;first is compass
        __RotEnb                                ;pulse rotor enable - down
        push    h                               ;let line settle
        pop     h
        __RotEnb                                ;pulse Rotor enable - up
        __RdStrByt                              ;read byte - same as SSR
        sta      .CmVane                        ;second is Vane
        __RotEnb                                ;pulse rotor enable - down
;
        lda  .ForceRot                          ;see if this was forced
        ora  a
        jnz  WasForce                           ; yes skip vec. avg.
        call VecAvg                             ;do vector average
;
;
        lhld     .CmRotor       ;get rotor count
        inx     h               ;increment
        shld    .CmRotor         ;store it
        __load  .CmEast,.TmpEast,3
        __load  .CmNorth,.TmpNorth,3
;
WasForce:
        lda     .StrFlag        ;see if SSR needs to be reenabled
        ora     a               ;if non zero then flag was set
        jz      CmDone
        __PrtSet        .PIO.PC,_StrEnb
CmDone: lxi     h,.Cmbyt
        mvi     m,10            ;set size to 10 bytes
        xra     a               ; clear a
        sta     .ForceRot       ; clear force rotor flag
        ret
VecAvg:
```

Figure B-2 - Rotor Interrupt Routine

```
;        lxi     h,table
;        mov     a,m
;        sta     .CmCompass
;        inx     h
;        mov     a,m
;        sta     .CmVane
        __load .TmpEast,.CmCompass,1
        __load .TmpNorth,.CmVane,1
        ret
table:  db  01,02,03,04,05
        END
```

CORROSION - POTENTIALS IN FLOWING SEA WATER (8 TO 13 FT./SEC.) TEMP RANGE 50° - 80°F



Alloys are listed in the order of the potential they exhibit in flowing sea water. Certain alloys indicated by the symbol: ■ in low-velocity or poorly aerated water, and at shielded areas, may become active and exhibit a potential near −0.5 volts

Appendix C.

REFERENCES

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