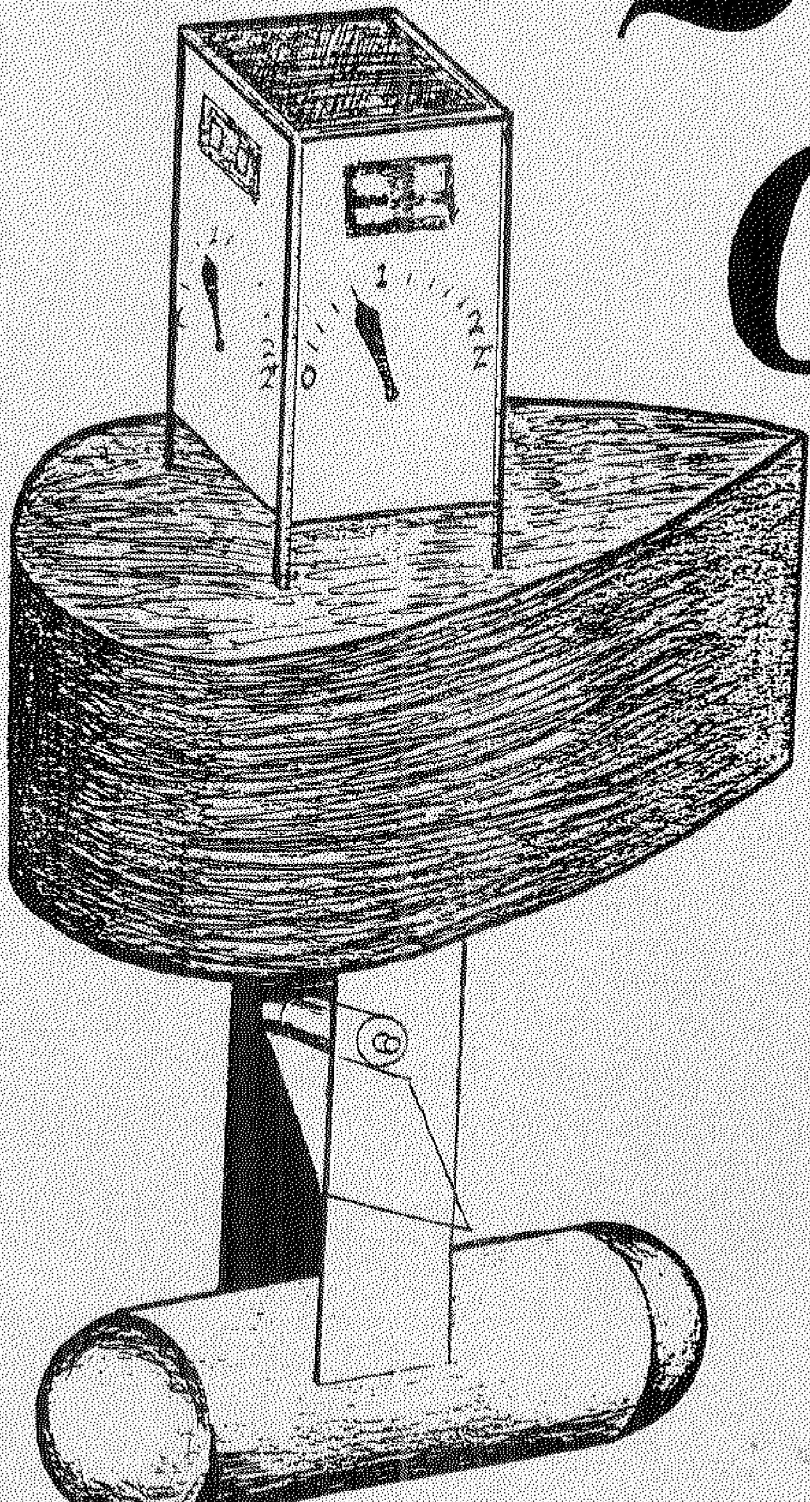
Surface Current Indicating Device



1986-87 UNH SEA GRANT OCEAN PROJECTS

S.C.I.D.

SURFACE CURRENT INDICATING PROJECT

ADVISOR: PROFESSOR FRANZ ANDERSON

PROJECT TEAM:

JAMES GREASON	ME	(GROUP LEADER)
KRISTIN BUCKLEY	ME	
CRAIG ENGELSEN	EE	
DAVID JOHNSON	ME	
JAMES O'TOOLE	ME	

TABLE OF CONTENTS

INTRODUCTION

Our design objective in this project is to design and fabricate a surface current meter accurate to two-tenths of a knot. It is to be a low cost, relatively maintenance-free unit with a display visible at fifty yards with the naked eye operating during both the day and night.

In this report, we will discuss the problems encountered and our strategy used in overcoming these problems. Initially, we attacked this surface current meter project as a group. Before any design work was done however, we decided to make a list of all the problems which would be encountered by placing an object into the ocean environment:

- Tidal Changes
- Temperature Changes
- Ease of Maintenance
- Marine Growth
- Weather
- Corrosion
- Theft
- Boat Damage
- Mechanical Fouling
- Power Supply

As the project progressed, each individual in the group took a particular area to concentrate on, these areas are listed as follows:

Buoy Frame and Mooring..................Kristen Buckley
Current Sensor..........................James O'Toole
Power Supply and Housing................David Johnson
Electronic Hardware.....................Craig Engelson
Display.................................James Greason

2.1
BUOY DESIGN

Requirements:

- Weigh less than 500 pound, easily manageable by the launching vessel (The RV Jere Chase)
- Stable in currents up to 2 knots
- Self orientation, always aligning itself in the direction of current flow
- Support structure for independent tilt system
- Made of strong, inexpensive, easily workable material

The purpose of this buoy is to support an independent tilting device, connected to the main buoy by a shaft and bearings, located under the water surface at a depth of two feet. The angle of tilt of this separate device will be directly related to the velocity of the surface current and independent of the angle of tilt of the main buoy.

The shape of the main buoy is a compromise between a streamlined structure and one that is easy to manufacture. The tear drop shape not only lessens drag forces on the buoy, but is also a self orienting feature. An extra fin is attached at the tail end of the tear drop to ensure proper orientation during times of slow current speed.

The main buoy is steel and is protected by several coats of a durable anti-rust primer and covered with marine antifoulant paint. This prevents barnacles and other marine life from growing on the buoy surface. The white color with an orange stripe at the waterline is the U. S. Coast Guard color for an information buoy.

Drag forces were approximated by modeling the system as two round cylinders, one cylinder representing the main buoy and the other cylinder representing the horizontal battery pack. The tear-drop shape has less drag than an upright circular cylinder so this approximation should be conservative. A detailed analysis to determine exact drag forces would require more time, money and resources than are available for our purpose. This simplified model of the drag forces should suffice.

Detailed calculations of the buoy's parameters and response can be found in Appendix A.

3.1 INTRODUCTION

The objective of the tilt meter is to measure surface currents from 0 to 2 knots while being suspended from the main buoy framework. The device must be inexpensive, rugged, and maintenance free for extended periods of time. When maintenance is required must be easily done.

The meter must also yield continuous output or at least output at regular intervals of time with these intervals being of short duration so as to be a useful navigation aid to boaters.

The buoy must be designed so as to stay within the boundaries of our budgetary constraints. The device must be a type of transducer that takes current energy and then converts it to some useful output. The device must also withstand the estuarine hazards of marine fouling, corrosion from salt water and water leakage.

Existing current meters usually measure current velocity with a rotor which spins at some rotational velocity when in a current. In group discussions it was agreed upon that these devices were subject to fouling from seaweed or kelp when left for long periods. It was felt that this fouling would eventually impair the proper function of the device so as to alter its output appreciably.

We set out to follow a novel approach to current measurement rather than the typical rotating element current meters; some simpler way to measure current with as little chance for mechanical failure as possible.

The nylon yarn inclinometer used on the submersible Trieste in the early 1960's serves as one example of simple current measurement. The nylon yarn was made slightly heavier than water so that it just sank. Hanging vertically when no current was present the yarn would incline due to the drag forces on it when current was present. The drawback of this method was that it had to be observed and therefore the accompanying apparatus (the Trieste) was very expensive.

Although this method is too simple for our purposes, it illustrates a possible way to measure currents using the basic concept behind it.

3.2 DESIGN DETAILS

While looking into ways to measure inclination we came into contact with tilt meters which usually incorporated potentiometers. By suspending a pendulum from a potentiometer, currents could be determined. The change in resistances would correspond to changes in current velocity. By measuring a current with a known current meter and noting a corresponding voltage output of the tilt meter, the meter could be calibrated. The problem here is offering adequate protection to the tilt mechanism. The following pages are concerned primarily with the container for the mechanism.

Our proposed solution to this problem was to mount the pot and pendulum in a cylinder and align it centrally on the horizontal and vertical axis within this cylinder. Attached to this cylinder would be a flat plate aligned centrally on the cylinder body and suspended vertically. The current drag would cause the plate to tilt and the cylinder to rotate (the cylinder and plate are to be supported along the cylinders' central axis). The shaft of the pot will have the pendulum attached to it. The pot would be connected directly to the cylinder and when the cylinder rotates the pot body does too. The pendulum, due to its inertia, remains in the vertical position and hence the pot shaft rotates. Figure 1. helps illustrate this concept.

Two 12 volt batteries will be used for a voltage source and will be used in conjunction with a bridge circuit. Voltage drops will be used to measure current velocities. The voltage output will be used to run a display system. Due to the non-linearity of drag force and the linearity of the pot system electronics must compensate for this. This is further explained in the electronics section.

Keeping in mind the nylon inclinometer it is desirable to have this cylinder and plate in a slightly heavier than neutral condition so it will hang vertically in still water but incline in a current path. This meter must be responsive to currents

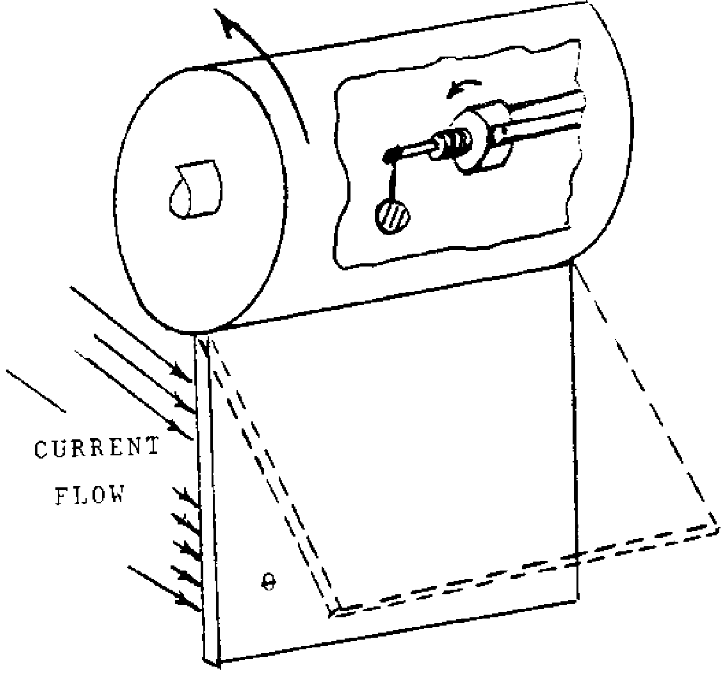


FIG. 1.

between .2kt. and 2kt. The device must tilt measurable in a .2kt current. Three broad material types were considered, those being steel, aluminum, and plastics.

The primary forces acting on the meter are the following: wieght (W), buoyancy force (FB), and drag force (FD). Starting with an approximate size meter consisting of a 7 in. outside diameter cylinder 1/8 in. thick and 12 in. long and a 12 x 12 x 1/4 in. plate, W was calculated for the different materials. FB and the various FD's were also calculated. The points of application of these forces were also calculated. FD poses a problem in that it varies with the angle of incline of the plate as does the normal component of velocity. Using the free body diagram in figure 2., using aluminum material properties, and summing moments about P a transcendental equation results. There are two equations in figure 2. because it has been shown[1] that the drag coefficient for a flat plate remains fairly constant up to tilt angles of 45 degrees.

[1] Dr. S.F. Hoerner, FLUID HYDRODYNAMIC DRAG, Hoerner Fluid Dynamics, pg 3-16

Assuming the velocity of the current is always normal to the plate and using a constant drag coeficient of 1.17 (for a flat plate) for angles below 45 degrees a material was selected which gave the best tilting range. Since water density changes negligably over the temperature ranges we expect to encounter a nominal density at 50 degrees was used. It is desired to have a range of tilt from 0 to 90 deg. or as close to that as possible for a current range between .2 and 2 knots. At this point in the design the sensitivity of the electronics was not known so the largest Δ deg./ Δ velocity was the goal so a large Δ voltage/ Δ velocity will result. Table 1 on the following page gives the results of the 3 different materials. Aluminum gives the best results and was therefore the material chosen.

The dimensions of the cylinder and plate were initially chosen as a general starting point and to aid in material selection. A size reduction of both plate and cylinder was advantageous because the buoyancy force was much larger than than the wieght and thus was extremely buoyant. A size reduction reduced this buoyancy force to a more acceptable level (the slightly heavier than neutral buoyancy condition). A cylinder 4 inches in diameter by 8 inches long and 1/4 inch thick was decided to be adequate to fit potentiometer, pendulum, and accompanying bridge circuit. The plate thickness was reduced to 1/8 in.

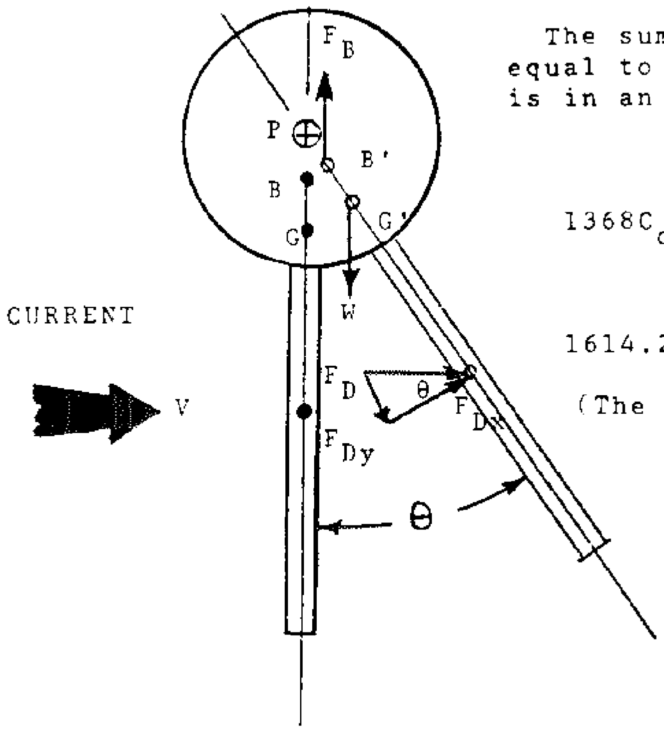


FIG. 2.

The sum of the moments about P are equal to zero assuming the tilt meter is in an essentially static condition.

for θ greater than 45:

$$1368C_dV\cos^3\theta - 21.3\sin\theta = 0$$

for θ less than 45:

$$1614.24V\cos^3\theta - 21.35\sin\theta = 0$$

(The material used in this case was Alum.)

	V(ft./sec.)	F_D(lb.)	θ (st) deg.	θ (Al) deg.	θ (Pl) deg.
(.2)	.34	.11	.75	3.10	52.9
(.4)	.68	.46	3.02	12.20	--
(.6)	1.01	1.02	6.67	25.60	--
(.8)	1.35	1.82	11.78	40.60	--
(1.0)	1.69	2.84	18.02	--	--
(1.2)	2.03	4.10	25.16	--	--

TABLE 1.

With these dimensions the weight of aluminum is 3.97 lb. and buoyancy force is 4.39 lb. The end caps and inards of the cylinder have not been added yet. Their weight should not be much greater than .5 lb. For this reason and the added attraction of fewer corrosive parts and easy machineability PVC material was used for the majority of the remaining parts of the tilt meter. In order to keep the potentiometer from tilting in the opposite direction of current a restrainer

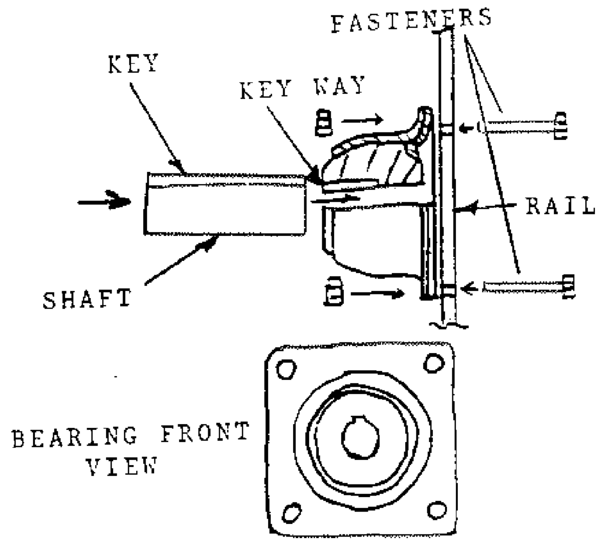


FIG. 3.

screw was mounted to the pot mounting plate. Two wood dowls support the pot mounting plate and also holds the bridge circuit. Wood was used due to its low electrical conductivity (which helps isolate the circuitry from errant currents in the buoy), its light weight and low cost.

The pendulum screws into a PVC attachment on the pot shaft and weight is supplied by washers held on by the head of the pendulum screw and secured by a nut.

Two rails run from a floating main buoy above the surface to about 2 feet below the surface. The tilt meter will be attached to these. A shaft and bearing system seemed most practical. Due to the steel buoy, aluminum tilt meter, and the sea water serving as an electrolyte the aluminum will corrode. For this reason it was desired to have the least conductive electrical path between the two so a non-metal was sought. A polymer, polyethelene terephthalate, was offered by ERTA inc. free of charge during inquiries into the companies products and since its properties seemed adequate (high resistivity, low water absorbtion, corrosion resistance) and it was already in rod form. The tensile strength of the material was 13,000 psi and the meter wieghed only about 5 lb. out of water with no supporting buoyancy so it was felt that the material was strong enough.

The next item to consider was the bearings. After much searching a bearing was selected that appeared to be suitably simple enough to meet the desired requirements. It is a pillow block and flange mounting with a ball type bearing made of ultra high molecular wieght polyethylene and a complex fluid libricant system. These bearings are designed with abrasive, corrosive, submerged or sanitary environments in mind with no need for lubrication. The flange mounting selected is illustrated in figure 3. The bearing material cannot be subjected to a pressure/velocity capacity of greater than 25,000 psi-fpm. Since our device will not be experiencing a continual rotational velocity and current will be changing rather slowly so rpm's will be practically zero, only swinging motion will be present. Using the parameters of the tilt meter n would have to be 287,500 rpm to exceed the operational limit. It is not so certain at this point how effective these self lubing bearing will be over the long term (life rating data could not be found), but

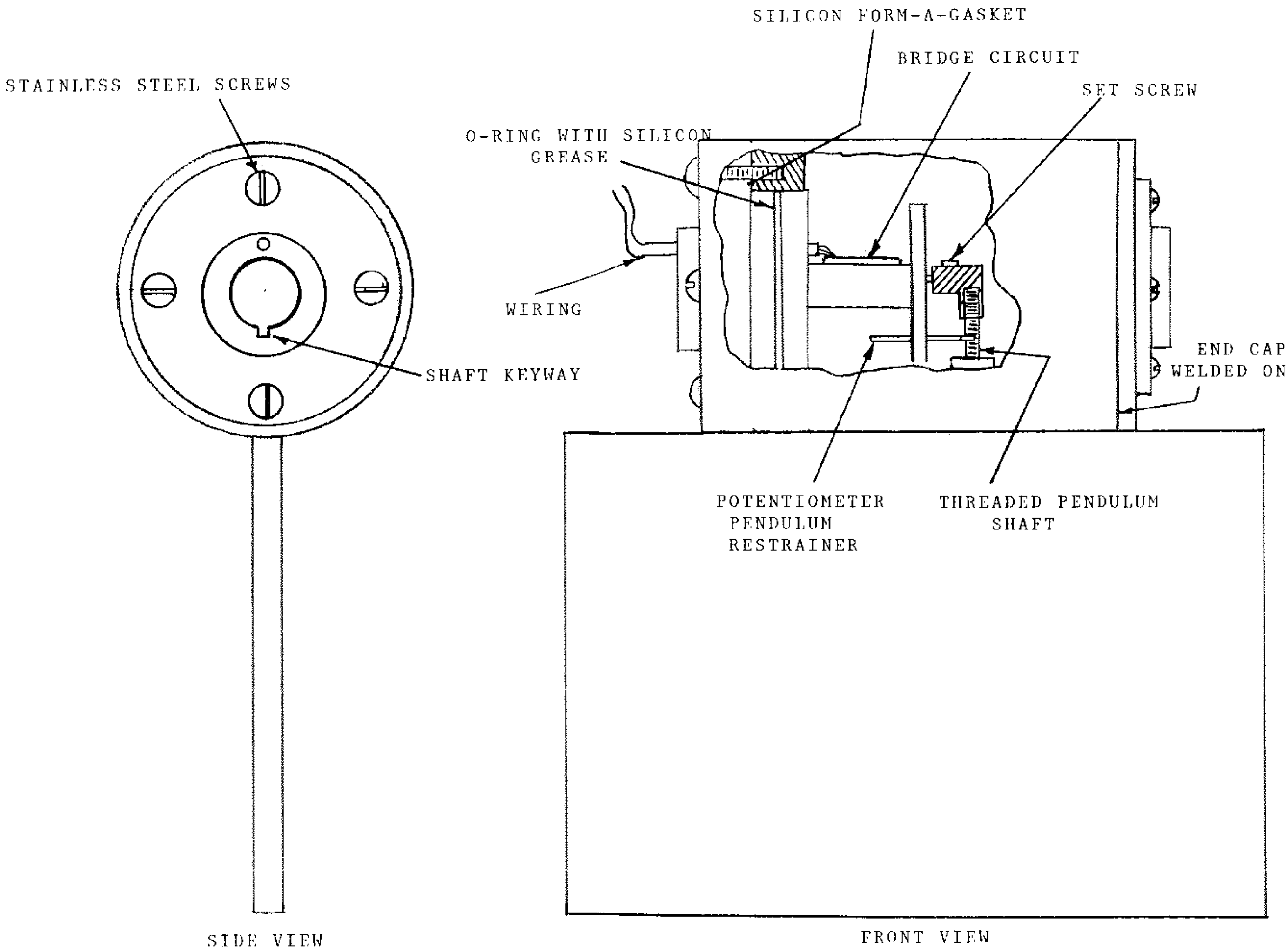

STAINLESS STEEL SCREWS
SHAFT KEYWAY
SIDE VIEW
SILICON FORM-A-GASKET
BRIDGE CIRCUIT
SET SCREW
O-RING WITH SILICON GREASE
WIRING
END CAP WELDED ON
POTENTIOMETER PENDULUM RESTRAINER
THREADED PENDULUM SHAFT
FRONT VIEW

FIG. 4.

the bearing do not corrode in sea water, they are self-lubing, and they only cost about $7.00 a piece when bought in quantity (20 or more). The arrangement of the shaft and bearings is shown in figure 3. There is an identical arrangement on the opposite end with the other end of the shaft fitting into a hole on the ends of the tilt meter cylinder. A keyway and key allow for the coupling of the low friction bearings and the tilt meter. The friction force of the bearings was found to be .19 lb.

3.3 WATER-TIGHT SEALING

In order to make the cylinder water tight, an o-ring was used in conjuction with silicon grease and silicon form-a-gasket. One end of the cylinder is removable and this is coupled with the bridge circuit and pot mounting plate for easy removal of the critical components. It is this end that is fitted with the o-ring. The other end of the cylinder is secured by a thin aluminum cap welded tight.

3.4 CORROSION AND FOULING

The steel buoy and aluminum tilt meter are not in direct electrical contact due to the high resistivity of the shafts and bearings. To insure additional corrosion resistance from an electrochemical standpoint a sacrificial zinc anode is used. Fouling and pitting of the aluminum is prevented by painting with a zinc chromate primer and an additional anti-fouling paint.

3.5 WIRE CONNECTION

The wiring for the meter is run through the PVC end cap and epoxied in place. This arrangement was tested underwater for 2 days and found to be leakproof. There is some question as to the long term durability of this arrangement but heavy duty wire connectors can be added to the meter if necessary.

3.6 CALIBRATION

In the event the device does not give a broad enough range of tilt several solutions exist. The meter can be reduced in wieght by using plastic fasteners instead of steel, thinner PVC parts, or using a different plate material. The reduction in wieght would make the meter more buoyant and responsive. A larger plate could be used to increase the drag force.

At this point in time the meter has not been calibrated. It is our objective to calibrate the meter in its deployment area using currents available off Jackson lab but finding the full range of currents we need is difficult. A towing tank would be ideal, such as the tank at M.I.T. Available funding will determine if it is an option.

3.7 SUMMARY

The tilt meter cost less than $100 to build although much of the work and some of the material were obtained free.

The tilt meter has been underwater 3 times, the longest being 2 days, and no leakage has occurred. How well the anti-fouling paint works over an extended period remains a question mark as does epoxy wire connection. The wire connection is no great problem if it fails and can be corrected.

Corrosion of the aluminum should not be great due to the zinc anode and the painting which should negate pitting.

The device does its job of putting out a useful output derived from current energy, it is easy to disassemble and put together. Until calibration it remains to be seen whether the tilting increments are adequate or if the device will have to modified.

4. ELECTRONICS

4.1 ABSTRACT

The function of the electronics is to convert the position of the independent tilt mechanism into a meaningful representation of current flow. In general, this is accomplished by convering the potentiometer voltage into a digital word, summing these words to get an average, interpreting the average and choosing the correct mode of display. This process is show in figure 1.

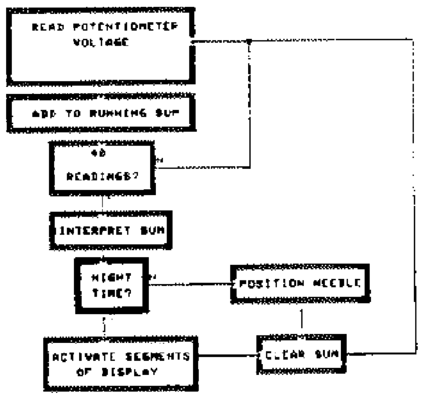


FIGURE 1: SYSTEM FLOWCHART

4.2 INTRODUCTION

The overall system can be broken into the following catagories:

- sensor design
- sampling and averaging process
- timing requirements
- calibration technique
- day display
- night display
- voltage reguation

Since there are several catagories, a modular, top-down organization was taken in the designing, building, and testing of the electronics. The design goals are as follows: to design, build, and test a system that converts potentiometer position into an understandable display. The display should update itself every four to five minutes but be readable every minute for approximately two seconds. The system should conserve power where ever possible. Figure 2 is the block representation of the electonics package.

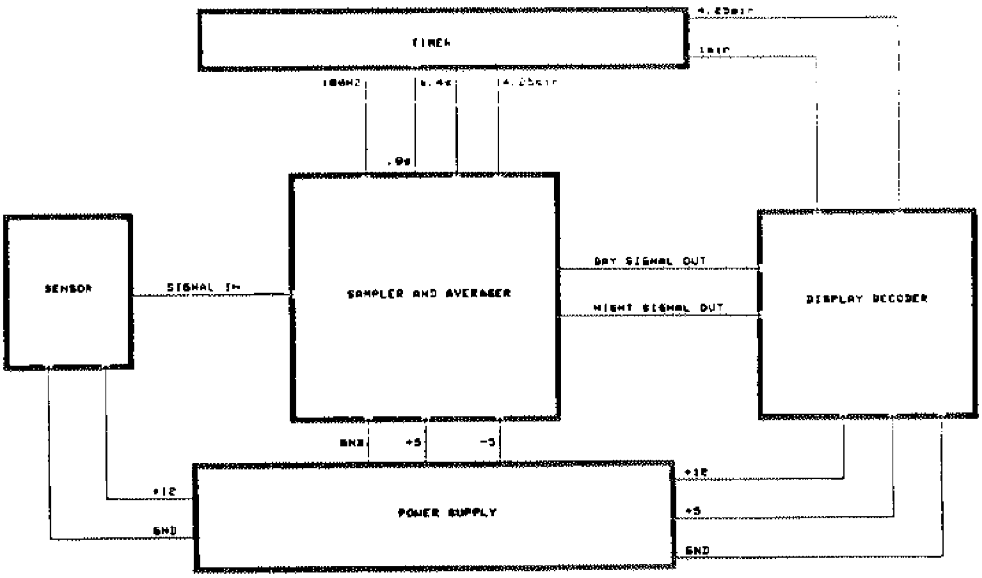


FIGURE 2 : SYSTEM OVERVIEW

4.3 SENSOR

The sensor is within the housing of the tilt mechanism. It consist of a potentiometer arranged in a double divider configuration as shown in figure 3.

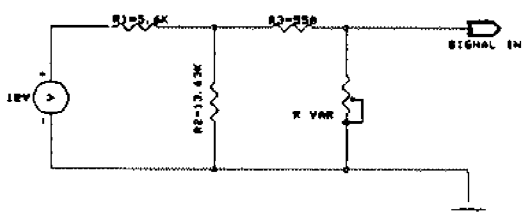


FIGURE 3: SENSOR CIRCUIT

When there is no current, Rvar and the output signal will be at their maximum values. On the other hand, when Rvar is small the output will be small. This corresponds to a ninety degree rotation in the tilt mechanism (maximum current). Table 1 contains the upper and lower limits for the sensing device.

Table 1: output sensor signal values

Rvar	signal out (volts)	current (knots)
3.3k	3.60	0
165	0.30	maximum tilt

4.4 SAMPLING AND AVERAGING

Initially, the display was going to be instantaneous. A reading would be taken and the result displayed. This was not a practical design because there is a high probability for displaying a false reading. Hence, the output from the sensor will be sampled once every six seconds (approximatly) over a 4.25 minute span by an Analog to Digital Converter (A/D). The digital output will be summed to produce an average value. The circuit diagram for this process is shown in figure 4.

The AD7581 is an 8 bit successive approximation A/D converter. Since only one analog input is used the other seven input lines are tied to ground and the channel selection is set so that only channel "0" will appear at the output.

Conversion of single channel requires 80 input clock periods and a complete scan through all channels requires 640 input clock periods. With the 555 timer producing a 100Hz signal, channel "0" will be sampled every 6.4 seconds.

Once a conversion of any channel is complete "stat" will go low for a short time. "Stat" changes eight times faster then channel "0" is being sampled. Therefore a octal divider (14022B) is used to signal that the conversion is done and it clocks the hex flip-flops (14174B) so that the conversion and sum will be stored until the next conversion is complete.

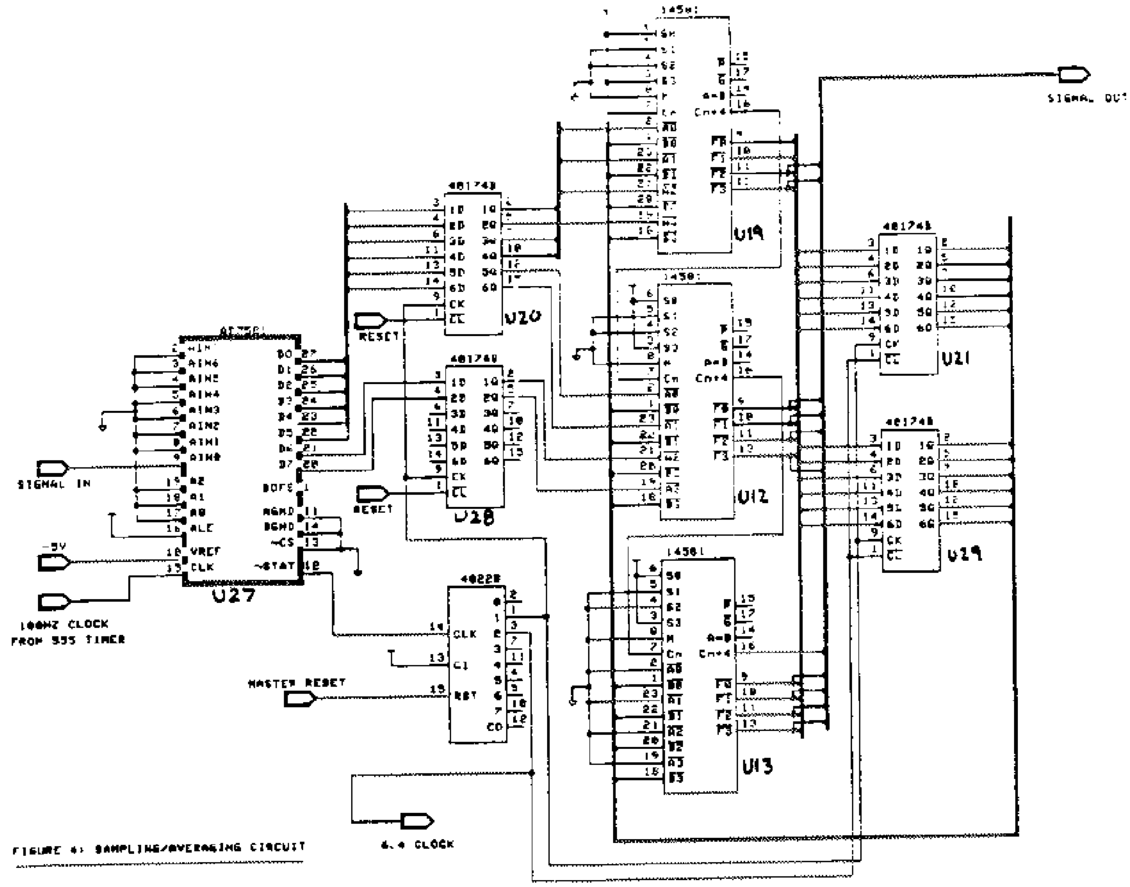


FIGURE 4: SAMPLING/AVERAGING CIRCUIT

The digital words produced by the A/D and stored by the flip-flops must be summed. This is done by three, 4 bit, arithmetic logic units (ALU) cascaded to produce a 12 bit ALU. The ALU is permanently in the add mode and the result of the addition is fed back around to the ALU inputs in order to produce a running sum of the sampled current.

With Vref equal to -5volts the A/D can convert an input range of 0 to 5 volts. Therefore the resolution of the system is 0.0195volts/bit, (5volts/256bits). In other words, if the analog input changes by 0.0195volts or more, a different digital word will be produced by the A/D.

The analog input is limited to 3.6volts. This results in the largest digital word of 185bits, (3.6/.0195). The EPROM can accept a number as large as 8192bits,(2**13). Therefore a 3.6volt signal could be sampled and summed 44 times,(8192/185) before an overflow occurred.

This means that 44 samples are the most the system should try to average. To be safe the system is designed to sample 40 input signals (one every 6.4seconds). After 4.25 minutes the system will reset and start over. By sampling and averaging the system as a whole will be much more accurate than if an instantanious display were used.

4.5 TIMER

In order for the system just discussed to operate correctly a signal that activates every 4.25 minutes must be generated. Furthermore, as mentioned earlier, the night display must go on every minute. The timing circuit shown in figure 5 will meet these needs.

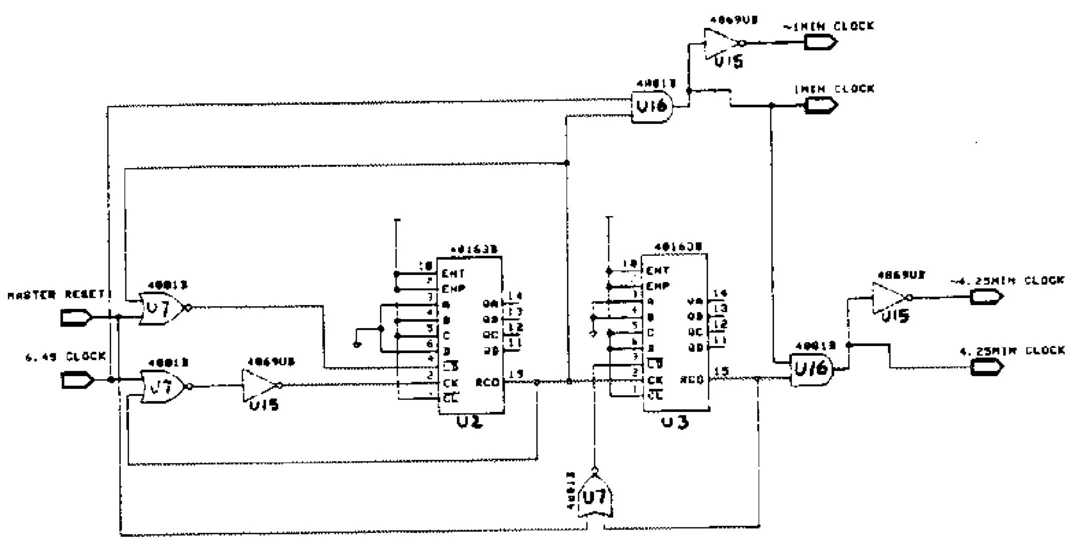


FIGURE 5: TIMER CIRCUIT

Recall that the octal divider produces a 6.4 second output. Stage one of the timing circuit is set to count ten times before the ripple carry out is set. Since the activating signal is the octal divider output, stage one produces a 64 second (one minute) timer. Similarly, stage two is set to count four times before the ripple carry out is activated. With the one minute clock controlling the count time of stage two a 4.25 minute,(4*64sec), clock has been created. Figure 6 shows the output wave forms and the effect "ANDING" the input clock with the carry out of each stage has on the overall output clock signals.

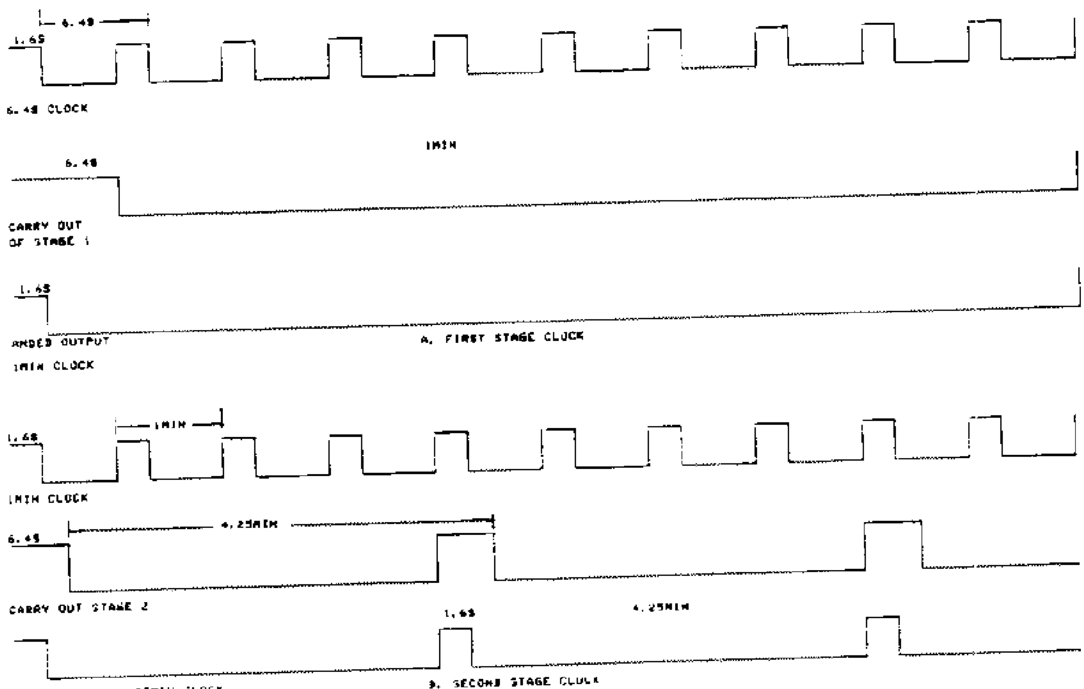


FIGURE 6: CLOCK TIMING DIAGRAMS

4.6 CALIBRATION

The 2732A Eprom is a very important component in the design of the electronics and is shown in figure 7. The Eprom performs the function of calibrating the digital sum produced by the ALU.

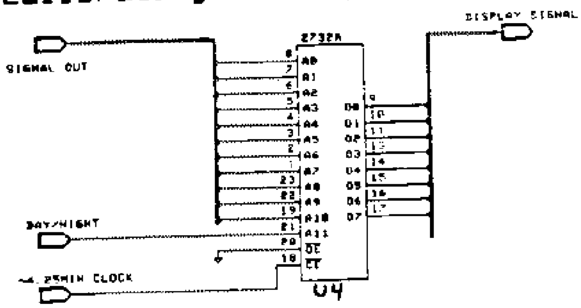


FIGURE 7: CALIBRATING CIRCUIT

The running sum is fed into the address lines of the Eprom. The two lowest bits of the sum are eliminated because there are only twelve address lines available. This divides the sum by four with a maximum error of three(decimal). Address line eleven is controlled by the day/night sensor. Therefore the Eprom can contain the data needed by the day and night display.

The Eprom will only be enabled once the running sum is complete. This is accomplished by using the negative 4.25 minute clock signal as the chip enable signal. When the chip is disabled it consumes one third as much power.

The tilt mechanism is not a linear device and hence the digital words produced are also nonlinear. By knowing the range of digital words that corespond to each 0.2 increment in current the system can be calibrated.

4.7 DAY TIME DISPLAY

The display for day time hours will be a large needle type readout similiar to an analog meter. The position of the display will be controlled by a stepping motor (see figure 8).

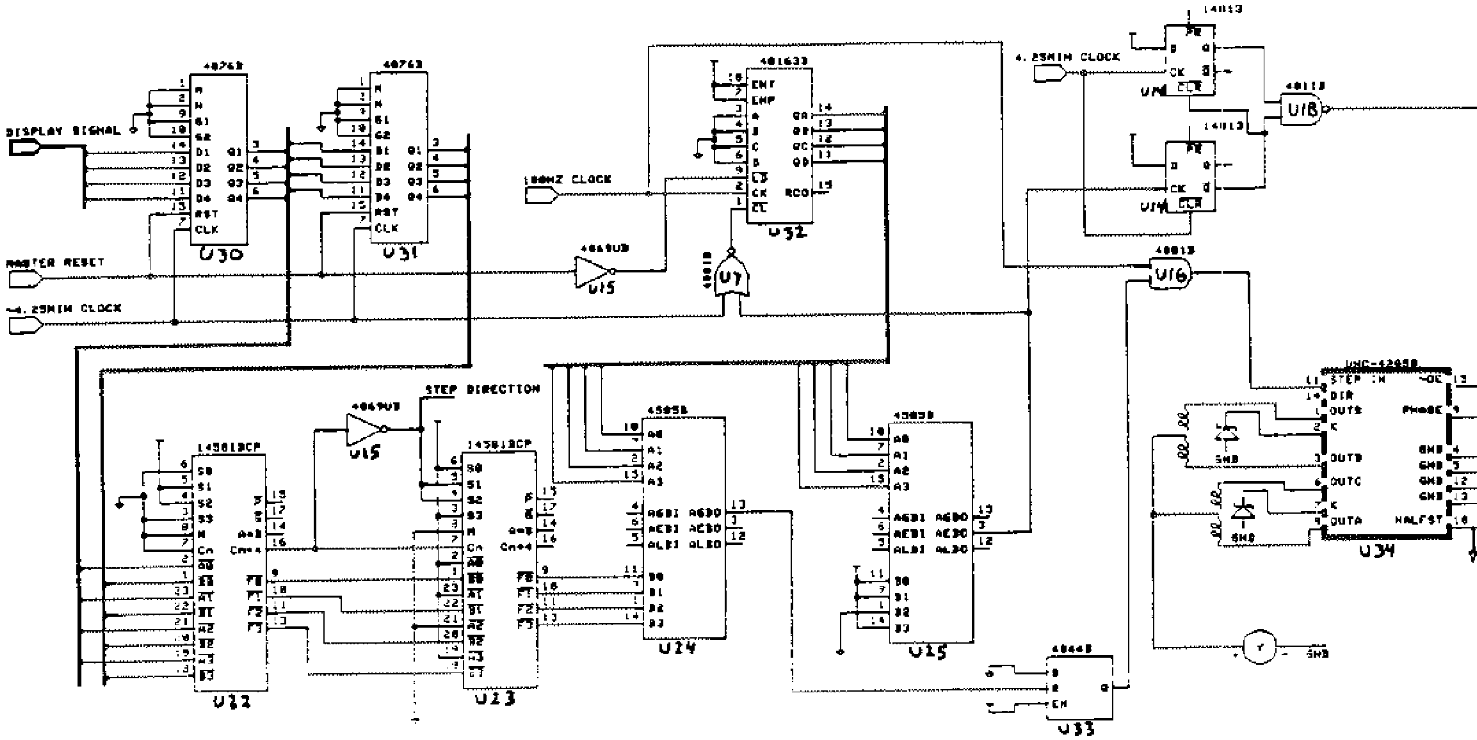


FIGURE 9: DAY TIME DISPLAY

The process by which the needle moves is as follows; The maximum number of steps the motor would ever have to take is eleven steps. Thus U25 is set to activate once the count reaches eleven,and at that time it resets the counter. U25 decides how many pulses there will be in one period. U24 decides how many of the eleven pulses to eliminate or pause out.

As long as the count is less than the needed number of pauses, the driver chip (UCN-4205B) will not receive any clock pulses and the motor will not step. However, once the count is greater then the number of pauses the RS flip-flop is set and the driver chip will receive pulses until A=B of U25, at which time the system shuts off until new data is available.

The pause comparator needs to know how many of the eleven pulses to cancel out. The number of pauses is produced by subtracting the present location from the desired location. If the result is positive then it is subtracted from the offset to produce the correct number of pauses. If the result of U22 is negative then the result is added to the offset and the direction of the motor changed.

4.8 NIGHT DISPLAY

For night time display, two large 7 segment displays will show the correct water velocity. The circuit for this is fairly straight forward, however special design consideration was taken because the individual segments are electroluminescent (EL)lamps which need to have 115volts ac to light up. Figure 9 shows the circuit used to control the night display.

The night display process is as follows. The Eprom produces an eight bit word which feeds into two seven segment decoders. These decoders decide which segments should be activated and latch the data when the clock goes high.

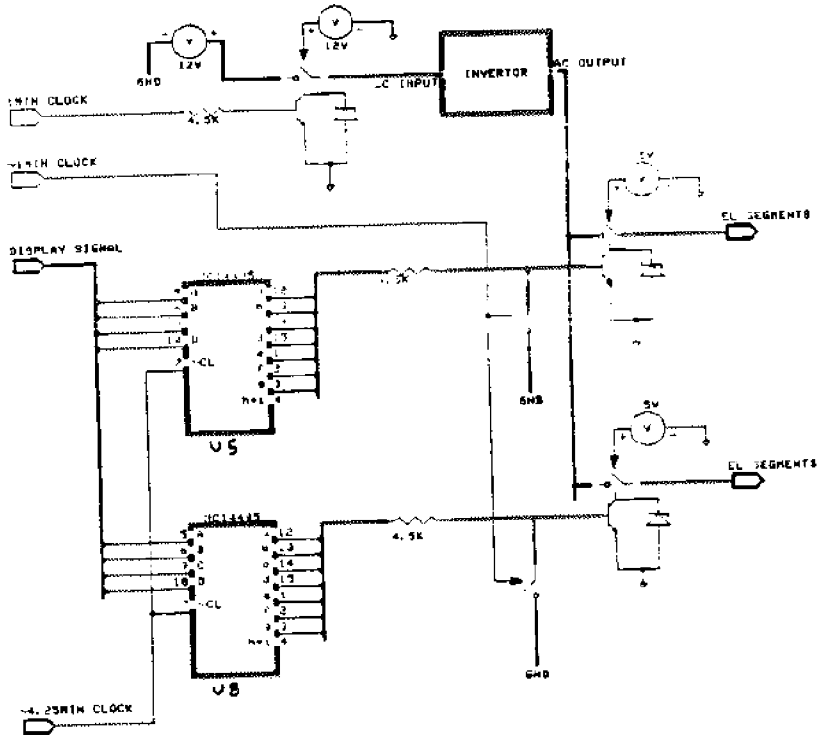


FIGURE 9: NIGHT TIME DISPLAY

The EL lamps receive a 115ac voltage from the inverters.

Thus the outputs of the seven segment decoders must activate a switch capable of allowing the voltage to pass through. This is done with transistors and relays. If the decoder output is low the transistor is in the cutoff region and no current will flow through the collector so the relay will be open and the EL segment off. However, if the signal is high the transistor is in the saturation mode and the voltage across the relay is approximately five volts. The relay is closed and the EL lamp is on. By shorting the decoders output with the negative one minute clock the display will flash on for 1.6 seconds every minute. This saves power and meets the display design goals.

4.9 DAY/NIGHT SENSOR

The day/night sensor operates in the same fashion as the signals for the EL lamps (see figure 10). When light hits the photocell current will flow and the transistors will be turned on and activate the relay. This results in a logical one for an output. However, if an insufficient amount of light strikes the photocell then the transistors will be off and the relay will produce a logical zero signal. The sensitivity of the circuit to the amount of sun needed is controlled by the 10k resistor.

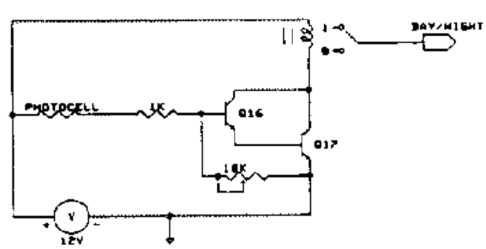


FIGURE 10: DAY/NIGHT CIRCUIT

4.10 POWER

The system is powered by two twelve volt marine batteries in parallel. Since multiple voltages are required, voltage regulators and convertors are used. The digital chips and relays have separate regulators in order to prevent noise. Voltage regulation is done in two stages. Twelve volt regulators are connected to the batteries and then the five volt regulators are connected to the twelve volt regulators. This reduces the amount of power the five volt regulators must dissipate.

4.11 RESET

A master reset is provided and must be activated once power is supplied to the system. This reset will guarantee that the moter takes the correct number of steps by clearing all the flip-flops, registers, and counters in the circuit.

4.12 BOARD LAYOUT

The electronics package is contained on two circuit boards. Individual modules are grouped together. And the relays have been separated from the logic in order to reduce noise. Figures 11 and 12 show the board layouts.

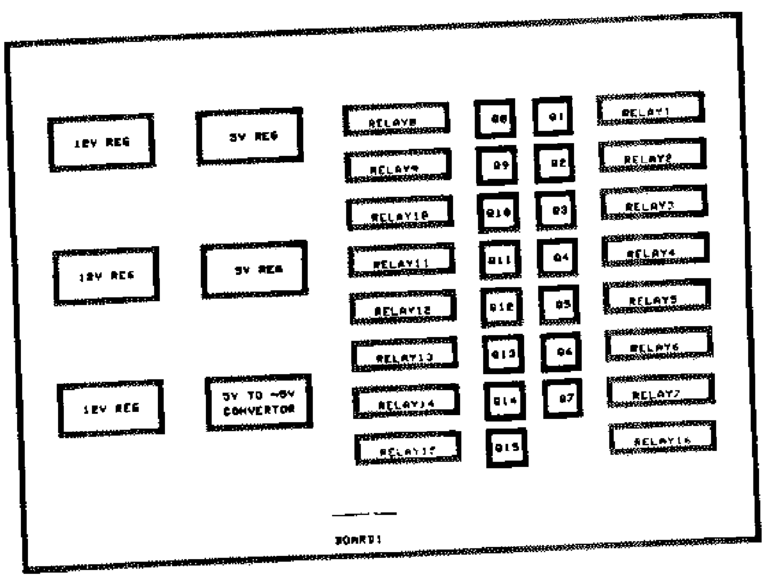


FIGURE 11: BOARD1 LAYOUT TOP VIEW

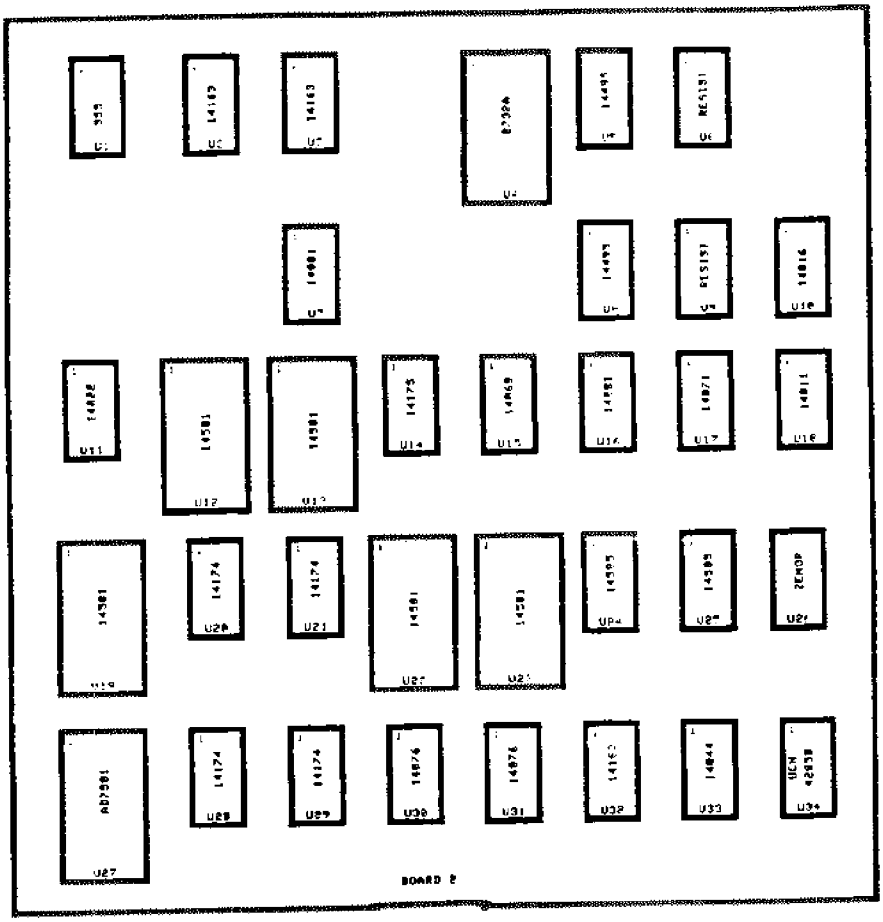


FIGURE 12: BOARD 2 TOP VIEW

4.13 SUMMARY

In designing this circuit a modular approach was taken. The entire goal was broken down into specific tasks and a circuit was designed to accomplish the task.

This circuit will sample the potentiometers voltage, average fourty samples then update either the analog display or the segment display. It shuts off parts of the circuit that are not needed in order to conserve power and thus extend the life of the system as a whole.

5.1

POWER SUPPLY

The power supply for the system will be housed in a battery pack three feet under the ocean surface. The pack is made of schedule 40 PVC tubing with an outside and inside diameter of 16" and 14.94" respectively. Caps for each end will be made of the same material with the front cap permanantly sealed while the rear cap will have removable stainless steel screws, allowing access to the batteries inside.

There will be two Diehard Incredicell Marine Batteries inside the pack. They each operate under a maximum load of 100 Amp hours or slightly less than 200 Amp hours when attached in parallel. The batteries will rest on a PVC tray housed in aluminum brackets inside the tubing (see figure 5-1). The batteries will be connected to the display by wiring running through a hole in the top of the pack and up against the buoy frame. The pack itself will be mounted onto the frame by six bolts. A small catalizer will be placed in the tube to convert any hydrogen gas emitting from the batteries to water. Care must be taken to seal the caps, wiring, hose, and bolts with silicone to prevent leaking. Each cap has another rounded fiberglass cap attached in order to make the pack more hydrodynamic and therefore less prone to drag from ocean currents. This will increase stability to the buoy as a whole.

The design of the buoy is such that once the battery life is depleted, the buoy can be lifted out of the water by the winch on the R/V Jere Chase. The screws on the rear cap can then be easily removed by hand. The batteries can then be removed from

BATTERY PACK

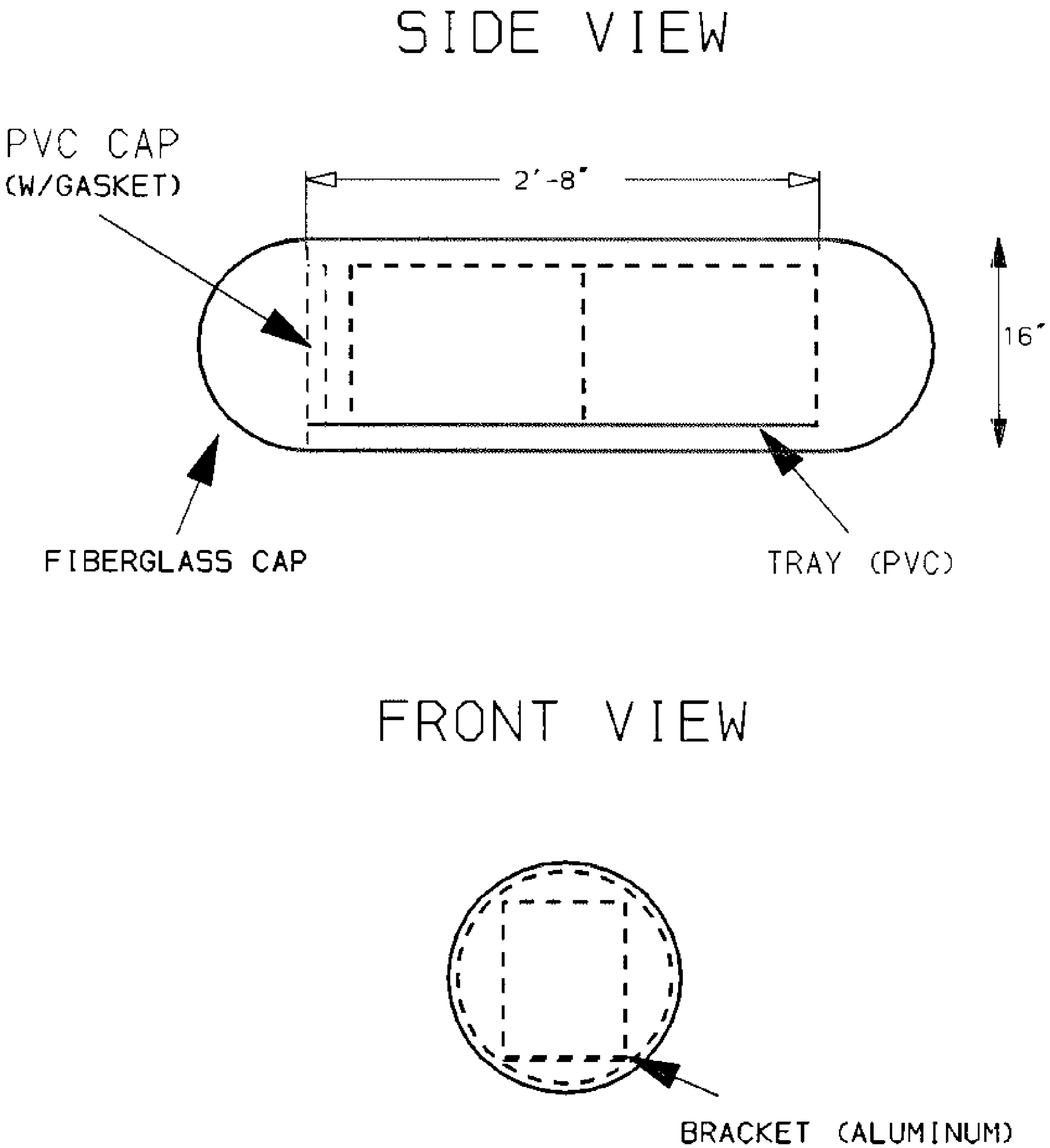


FIGURE 5.1

the compartment on the PVC tray which slides on the brackets. A crewman will then loosen the two wingnuts on the first battery and unhook the wiring to the display. Without the sliding tray for easy access, the crewman retrieving the batteries would have a difficult time trying to reach his arms into this confined area to unhook the wiring, therefore increasing the risk of electrocution. It is also very awkward trying to reach into the pack to remove each of the 61lb batteries. Once removed, new batteries will be set into the tray, rewired and slid back into the pack. After the cap is closed, the buoy is ready for redeployment. The addition of the tray allows easy access and speed in replenishing the power supply. The depleted batteries would then be recharged using any standard AC to DC battery charger for later use. With the amount of power in the batteries and the drain from the equipment, we will get a 235 day operating life out of the batteries (see Appendix 5A).

The actual operating life of the buoy can be extended by the addition of solar panels to the buoy. Solarex's model SX-10 was found to be the best. One SX-10 placed parallel to the ocean surface would recharge the batteries indefinately under normal operating conditions (see Appendix 5B & 5D). The problem with attaching the panel to the buoy is twofold: first, the inherent cost of the panel ($200 + the cost of extra electronics such as a voltage regulator), made the panel unfeasible because of our very limited operating budget. Later, when our budget was increased, the addition 25lbs added to the top of the already-designed buoy would have drastically reduced stability. A large pack of lithium batteries would have extended the operating life for more than 1 year, however the lithium pack is very expensive ($1000) and cannot be recharged.

There are also some improvements that can be incorporated into any future production of this current meter. First, because of a last-minute design change in the size of the main section of the buoy, the lightweight PVC tubing became too buoyant and required an addition 85lbs of ballast. Any future pack could be made out of heavier aluminum which is also stronger and therefore more durable in the ocean environment. Excellent corrosion resistance could be produced by using standard anti-fouling paint on the pack. This heavier pack, while retaining the same interior size of the PVC pack, would eliminate the need for any ballast (see Appendix 5C).

Also, the removal of the rear cap is somewhat time consuming as there are eight screws to remove. The original design called for a thicker cap (3/4" instead of 1/2"), which would have allowed for the use of Nielson Clips which seal very well and are very easily unlatched, making the removal of the cap much quicker. However, the manufacturer modified the cap design and shipped a thinner cap with an outside thickness of only 1/4".

6. THE DISPLAY SYSTEM

The display system, which shall be fastened to the top of the buoy, must be designed to fulfill the following requirements:

Display Requirements:

1) Legible at 50 yards with the naked eye
2) Legible both night and day
3) Must be seen at night at least once every minute
4) Must be easily understood
5) Must meet color requirements for an information buoy
6) Use a minimum amount of power (1 amp)
7) Display a range of current from 0 to 2 knots
8) Display a current in increments of 1/5 of a knot

Some of the ideas which were thought up to meet the requirements only to be rejected were as follows: a sound system, a coded blinking light, a LCD system and a background lit system.

The sound system as well as the coded light system were rejected because they would not be easily understood.

The LCD system would be hard to see in the day and would require more power during the evening for back lighting.

The background lit number system would require at least a 4 amp halogen bulb. This system was very hard to read in day light so it was disguarded.

Finnaly a system which would meet all of the requirements was designed. This proposed system is very unique. It consists of two separate systems, one for the daytime and one for the nighttime.

The daytime system is a mechanical system and consists of the following: a stepping motor, 1-(2"OD gear), 4-(1"OD bevel gears), 4-(8" * 3/8" shafts) and 4-large arrows (8" long). see figures 6-(1 & 2) for details.

The system works as follows:

The 2" gear is rigidly attached to the stepping motor. The stepping motor will step 7.5 for every pulse. This will turn the 2" gear 7.5 which will turn the four 1" bevel gears 15 all at the same time. The 8" shafts are attached to the bevel gears and each shaft extends out through a wall of the box. An arrow is rigidly connected to the end of each shaft opposite to that of the bevel gear. Thus one step of the motor will result in a 15 change in the arrows position. A 180 sweep will result from 12 steps of the motor which is exactly the same number of increments required to display. (0, .2, .4,...2, 2+) The arrow will point at (2" * 3") numbers which can be seen at a distance of 50 yards.

This system is unique because power is drawn from the batteries only when a change in current is detected.

As the evening approaches this mechanical system will power down and a digital system will power up. A day/night switch will be responsible for this action.

The digital system is constructed by forming EL-Lamps into a seven segment digital display. These lamps are approximately 2.75" long, 0.75" wide and 0.04" thick. Eight numbers were constructed using 56 EL-Lamps. Two numbers are placed on each

TOP VIEW

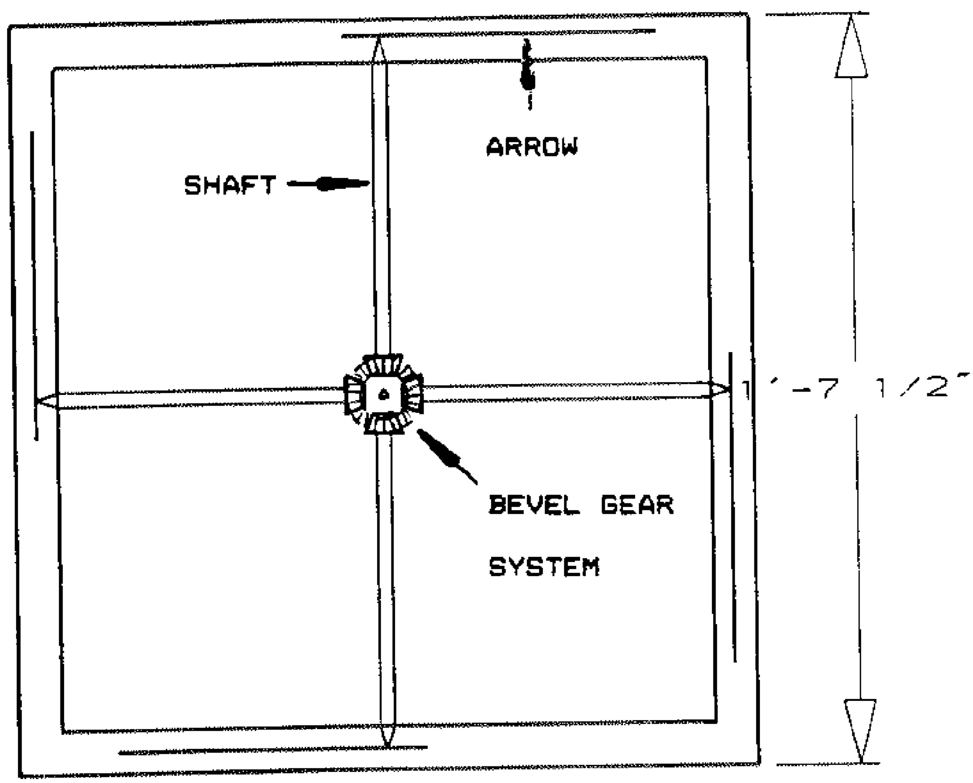


FIG 6-1

FRONT VIEW

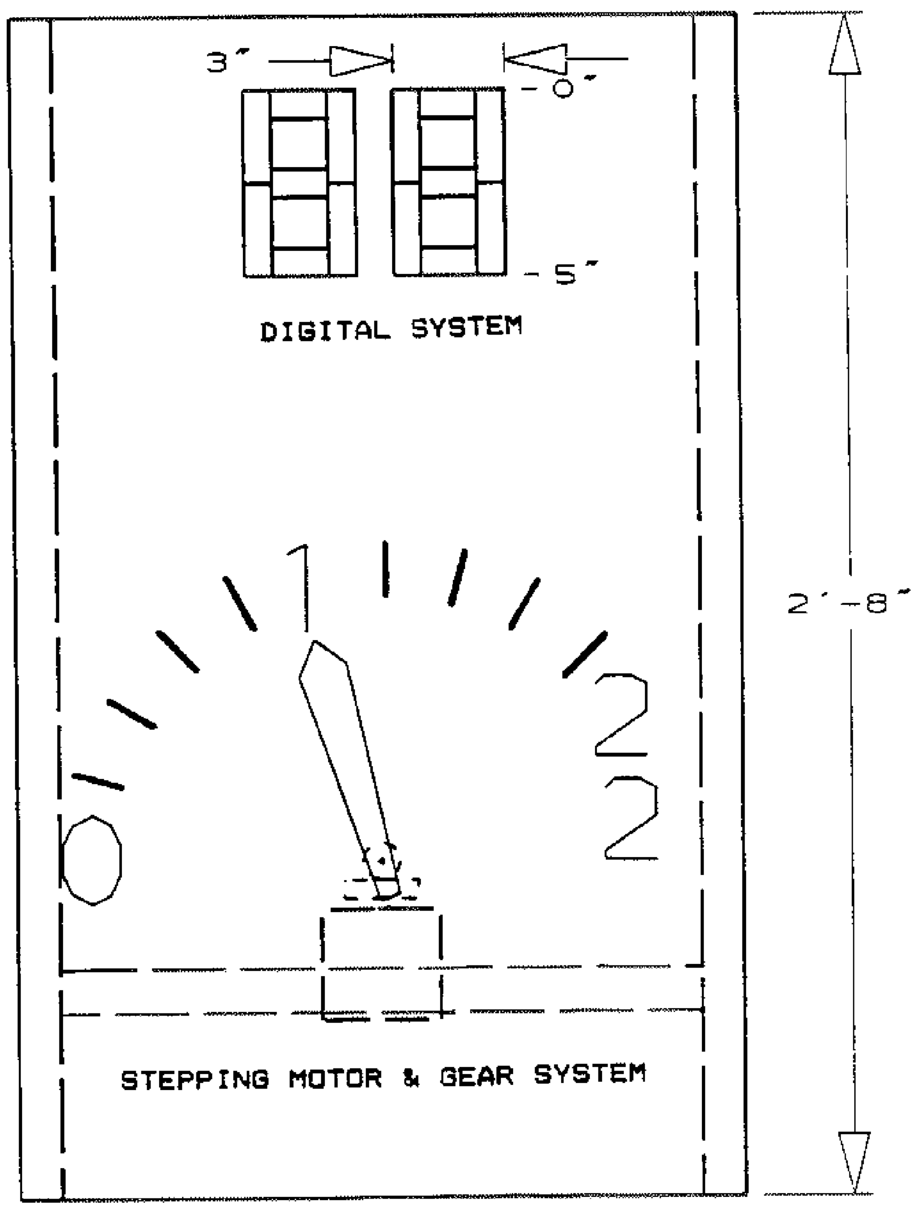


FIG 6-2

side of the display. The numbers are 5" tall and 3" wide. The EL-Lamps are excellent for night time visibility and readability because of the thousands of light emitting phosphor particles covering the surface of any lamp. They are especially good in fog (up to 170 times better than incandescent lights) and a better sense of distance.

This system will flash the current for about 2 seconds every minute during the evening. The power consumption is based on the number of square inches that are lit up. The lamps run off AC current so a DC to AC inverter is used to power the system. Four inverters are used for the display, one for each side. Each inverter draws 0.245 amps when lighting 40 square inches. Since each side of the display has 29 square inches of lamp, the lamps will simply shine brighter (approximately 18 F/L). Thus the entire system will draw only 1 amp. when activated. See appendix 6-f

The display box as seen in figure 6-(1, 2 & 3) is constructed from Acrylite GP Acrylic Sheet. The dimensions of the box are 17.5" * 17.5" * 32" * 1/8". This box contains both the mechanical system as well as the digital system. It will be painted white which is required by the coast guard for an information buoy. This box will also house all of the electronics for the entire buoy system.

To protect the arrow and EL-Lamps, which are located on the outside of the box, from the elements the entire box was placed inside a slightly larger box made from the same material. The protective shell has the following dimensions: 19.5" * 19.5"

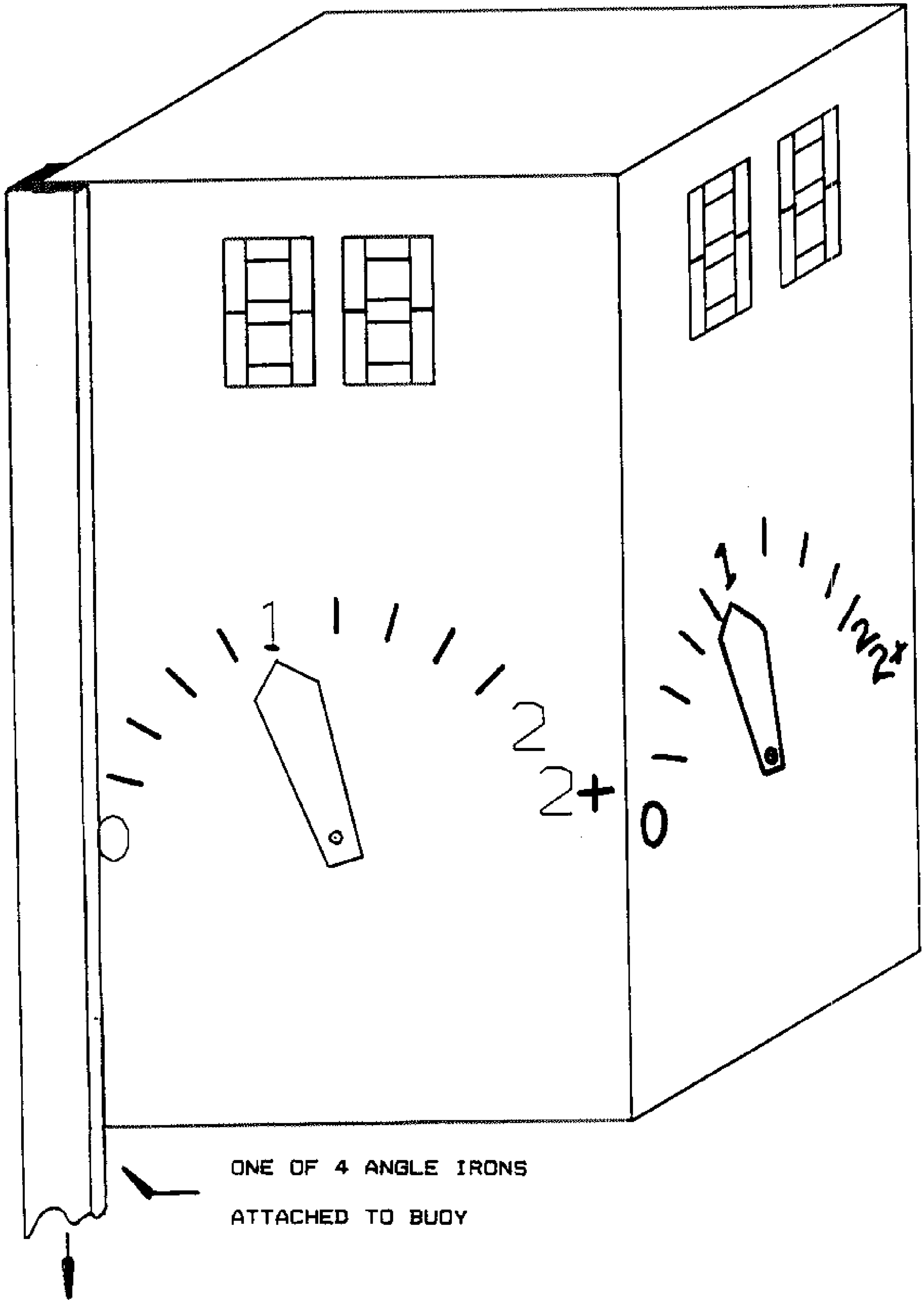


FIG 6-3 DISPLAY SYSTEM

* 32" * 1/8". The power from the batteries as well as the information from the current sensor will be plugged into the connectors located on the bottom of the protective shell.

The protective shell is attached to the buoy by sliding it down along the four angle irons which are welded vertically to the buoy. To remove the display one simply unplugs it and slides it out.

For a future project I believe that the relative size of the system could be reduced. This would result in a smaller surface area which in turn would reduce the coefficient of wind drag, (sail affect) produced by the display.

In theory this system should work. If the electronics send the correct information to the display there should be no problems.

APPENDIX A

MAIN BUOY PARAMETERS AND CALCULATIONS

TABLE OF CONSTANTS

constants	units	value	name
density sea water	slugs/ft*3	1.98	dw
gravity	ft/sec*2	32.17	g
density steel	slugs/in*3	0.28	Ps
pi	...	3.14	Pi

DRAG COEFFICIENTS (at two knots)

constants	units	value	Reynolds#
CYLINDERS:			
horizontal(L/D=2) (tangential flow)	---	0.85	6E+05
vertical(finite) (normal flow)	---	0.20	4E+05
long, slender, rough (normal flow)	---	1.50	2E+05

PLATE PORTION

item	units	value	name
plate width	in	0.25	pw
plate height	in	8.00	ph
plate length	in	36.00	pl
plate weight	lbs	20.42	p1
plate weight	lbs	20.42	p2

TOP PORTION

item	units	value	name
area of tear	in*2	951.22	At
top weight	lbs	235.85	tp
length of top	in	24.00	Lt
volume top	ft*3	13.21	Vt
top diameter	in	30.25	Td

BOTTOM PORTION

item	units	value	name
cylinder length	in	32.00	cyl.l
cylinder radius	in	8.00	cyl.r
cylinder weight	lbs	18.00	cyl.w
cylinder volume	ft*3	3.72	cyl.v
battery weight	lbs	122.00	bat.w
buoyant capacity	lbs	228.99	cyl.b
buoyant force	lbs	88.99	c.b.f.

TOTAL WEIGHT AND BOUYANCY

item	units	value	name
top weight	lbs	235.85	tp
top buoyancy	lbs	841.52	bc
buoyancy remaining	lbs	605.67	tbr
weight of plates	lbs	40.84	2*pw
buoyancy of plates	lbs	5.31	b.o.p.
plate water weight	lbs	35.53	pww
bottom weight	lbs	228.99	bt
bottom bouyancy	lbs	228.99	cyl.b
water weight	lbs	0.00	bww
control box	lbs	5.00	cb
display weight	lbs	25.00	dy
mooring line	lbs	60.00	ml
line bouyancy	lbs	7.80	mlb
water weight	lbs	52.20	mlww

total weight	lbs	595.68
buoyant capacity	lbs	1083.62
static reserve buoyancy	lbs	487.94

DRAG FORCES(NO CURRENT)

speed of current	knots	2.00	vel
buoy drag(top)	lbs	11.28	t.drag
buoy drag(bottom)	lbs	13.39	b.drag
mooring drag	lbs	63.45	m.drag
total drag	lbs	74.74	drag
static buoyant force	lbs	595.68	Bs
total buoyant force	lbs	670.41	Tb
draft	in	12.22	Dr
buoyant capacity	lbs	1083.62	bc
reserve buoyancy	lbs	413.20	rb

DRAG FORCES(2 KNOT CURRENT)

speed of current	knots	2.00	vel
buoy drag(top)	lbs	11.28	t.drag
buoy drag(bottom)	lbs	13.39	b.drag
mooring drag	lbs	63.45	m.drag
total drag	lbs	74.74	drag
static buoyant force	lbs	595.68	Bs
total buoyant force	lbs	670.41	Tb
draft	in	12.22	Dr
buoyant capacity	lbs	1083.62	bc
reserve buoyancy	lbs	413.20	rb

The area of the tear is found by adding together the area of the semicircle (section #1), the trapezoidal approximations (section #2 through section #6), and the triangular approximation (section #7) to obtain a total area.

AREA OF TEAR

Portion	x	2y	Area(in*2)
section #1	---	30.25	359.34
section #2	0.00	30.25	147.50
section #3	5.00	28.75	137.50
section #4	10.00	26.25	121.88
section #5	15.00	22.50	96.88
section #6	20.00	16.25	64.38
section #7	25.00	9.50	23.75

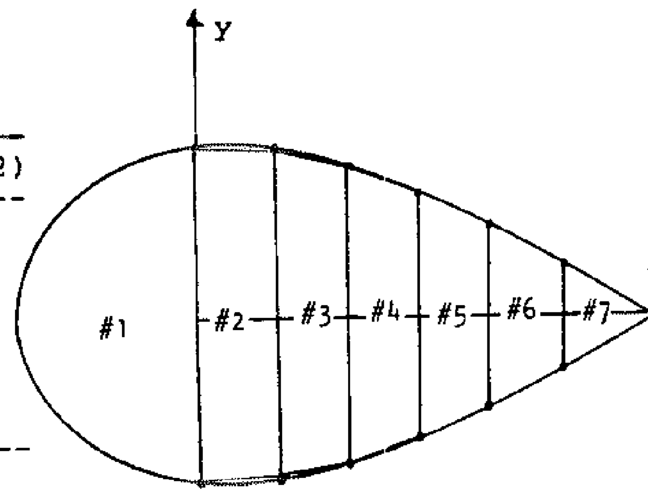


FIGURE A.1

Area of the tear(At)= 951.22 sq.in.

Volume of the tear = 13.21 cu.ft.

The perimeter of the tear, which is required for calculation of weight of the top, is determined using some straight line approximations for the curved tail end of the tear. Segment #1 is simply the perimeter of a semicircle, while segments #2 through #7 are simply straight line approximations.

Perimeter of Tear

Portion	Length
Segment #1	47.52
Segment #2	5.06
Segment #3	5.15
Segment #4	5.34
Segment #5	5.90
Segment #6	6.03
Segment #7	10.74
Segment #2'	5.06
Segment #3'	5.15
Segment #4'	5.34
Segment #5'	5.90
Segment #6'	6.03
Segment #7'	10.74

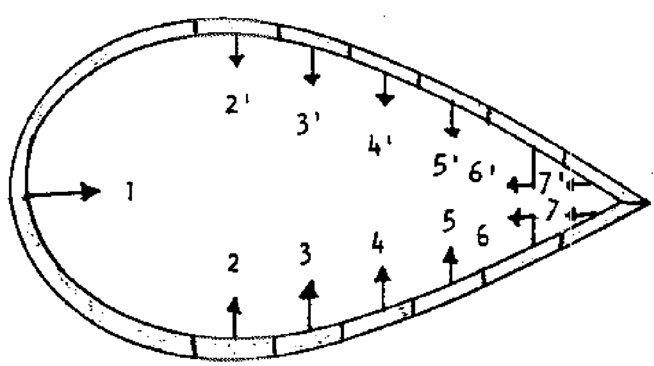


FIGURE A.2

Perimeter= 123.94 in.

Weight of Top

Portion	Length	width	thickness	volume	weight
* top tear	45.00	30.25	0.13	118.90	33.72
**middle	123.94	24.00	0.13	371.83	105.45
* bttm tear	45.00	30.25	0.13	118.90	33.72
support #1	45.00	24.00	0.13	135.00	38.29
support #2	29.00	24.00	0.13	87.00	24.67

Total weight of top= 235.85 lbs

* Volume = Area of tear
**Length = perimeter of tear

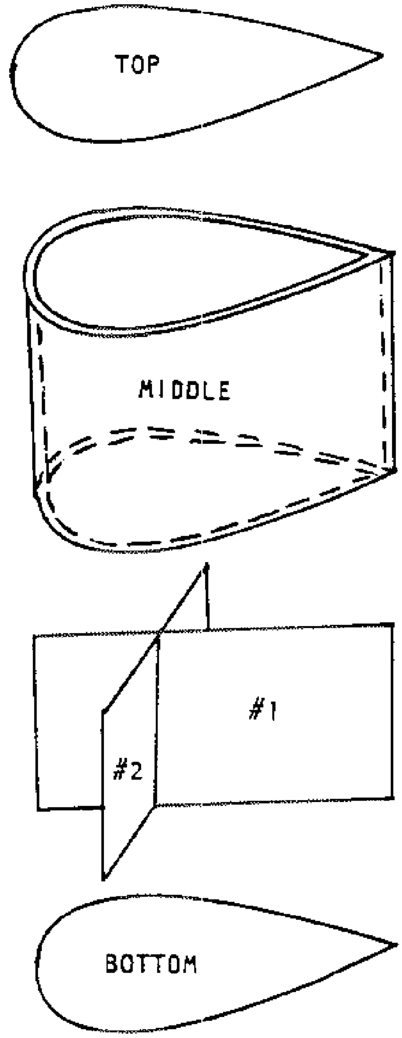


FIGURE A.3

The center of buoyancy is solely a function of volume. The centroid of displaced water is the center of buoyancy. It is not affected by the weight or density of a submerged object. Only the outer dimensions are needed for the center of buoyancy calculations.

Center of Buoyancy
(Top portion only)

segment	volume	x	V*X
part#1	8624.26	-6.42	-55361.28
part#2	3540.00	2.48	8775.00
part#3	3300.00	7.46	24625.00
part#4	2925.00	12.44	36375.00
part#5	2325.00	17.37	40375.00
part#6	1545.00	22.28	34425.00
part#7	570.00	26.67	15200.00

sum V = 22829.26 sum V*x =104413.72

center of buoyancy = 4.57 inches

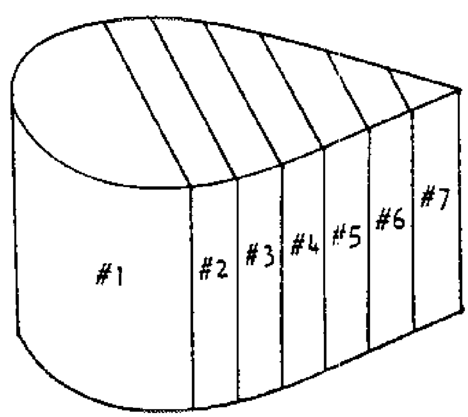


FIGURE A.4

Centroid of Top Only

Table I

segment	length	x	x*L
A	47.52	-9.63	-457.53
B	2.53	2.50	6.32
B'	2.53	2.50	6.32
C	2.58	7.50	19.33
C'	2.58	7.50	19.33
D	2.67	12.50	33.38
D'	2.67	12.50	33.38
E	2.95	17.50	51.59
E'	2.95	17.50	51.59
F	3.02	22.50	67.87
F'	3.02	22.50	67.87
G	5.37	27.50	147.61
G'	5.37	27.50	147.61
sum L =	85.73 inches	sum x*L=	194.65 sq.in

partial centroid = 2.27 inches

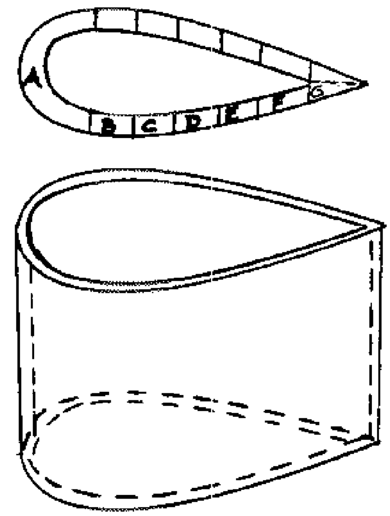


FIGURE A.5

Table II

segment	area	x	A*x
part #1t	359.34	-6.42	-2306.72
part #2t	147.50	2.48	365.63
part #3t	137.50	7.46	1026.04
part #4t	121.88	12.44	1515.63
part #5t	96.88	17.37	1682.29
part #6t	64.38	22.28	1434.38
part #7t	23.75	26.67	633.33
part #1b	359.34	-6.42	-2306.72
part #2b	147.50	2.48	365.63
part #3b	137.50	7.46	1026.04
part #4b	121.88	12.44	1515.63
part #5b	96.88	17.37	1682.29
part #6b	64.38	22.28	1434.38
part #7b	23.75	26.67	633.33
support#1	1080.00	7.38	7965.00
support#2	696.00	5.00	3480.00
sum A =	3678.44 sq.in.	sum A*x=	20146.14 cu.in.

partial centroid = 5.48 inches

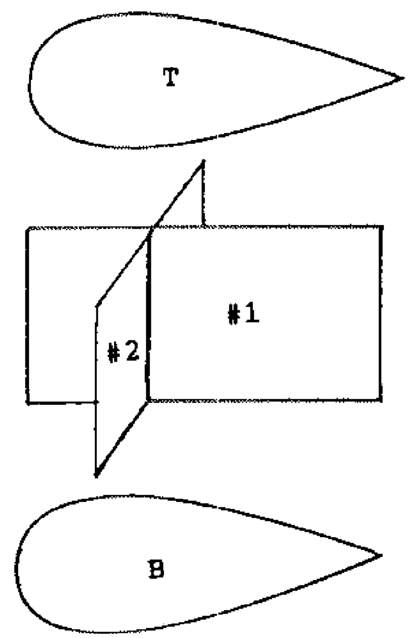


FIGURE A.6

The center of mass is determined by using centroids, but unlike the center of buoyancy, the center of mass is not the centroid of the total volume, but rather the centroid of the individual volumes of steel. This is only true because the steel is of constant density. Table (I) and (II) calculate centroids of various parts, then table (III) combines these to find one final centroid. This is the center of mass of the top portion.

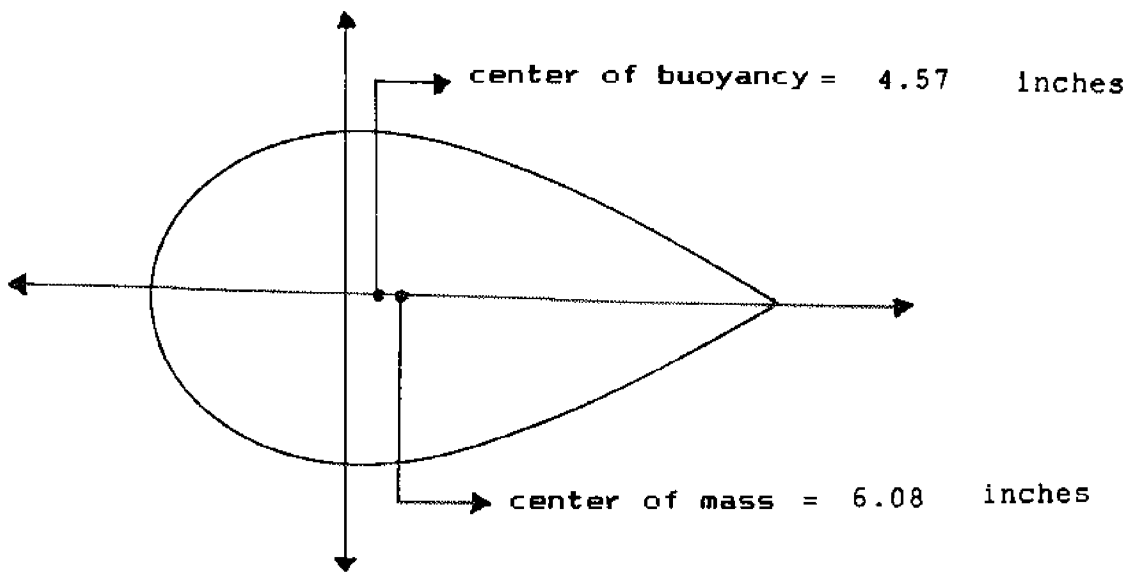


FIGURE A.7

Table III

segment	volume	x	V*x
table I	371.83	6.83	2540.51
table II	459.80	5.48	2518.27
sum V =	831.64 cu.in.	sum V*X=	5058.78 in*4

Total Centroid (of the Top) = 6.08 inches

To minimize tilt, the mooring line location is chosen to be at the first moment of area about the submerged region of the buoy normal to the current flow (at static conditions). As the current increases, the area above the pivot point will increase causing the buoy to tilt but the drag on the bottom of the buoy will help to counter the drag on the top, and tilt is minimized. (Remember tilt of the buoy does not effect the independent tilting device which measures current speed).

Location of mooring line

segment	area(in*2)	y (in)	area * y
A)top	316.35	-5.23	-1654.21
B)plates	18.00	24.96	449.24
C)bottom	200.96	44.00	8842.24
D)supports	3.75	7.50	28.13
sum A =	539.06	sum A*y =	7665.40

hinge = 14.22 inches

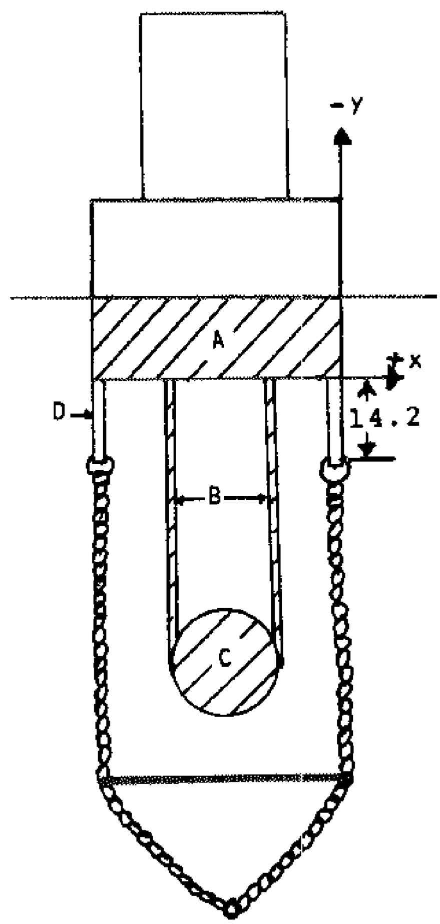


FIGURE A.8

(Vertical)
Center of Gravity

segment	weight	y (in)	w*y
display	25.00	-43.00	-1075.00
c-box	5.00	-43.00	-215.00
top	235.85	-12.00	-2830.23
plate	20.42	18.00	367.55
plate	20.42	18.00	367.55
bottom	0.00	36.00	0.00
mooring	60.00	14.22	853.19
	sum w = 366.69 lbs		sum w*y = -2531.95 lbs*in

center of gravity = 3.55 inches

center of buoyancy = -5.23 inches

distance between the center of gravity & center of buoyancy = 8.78 inches (gb)

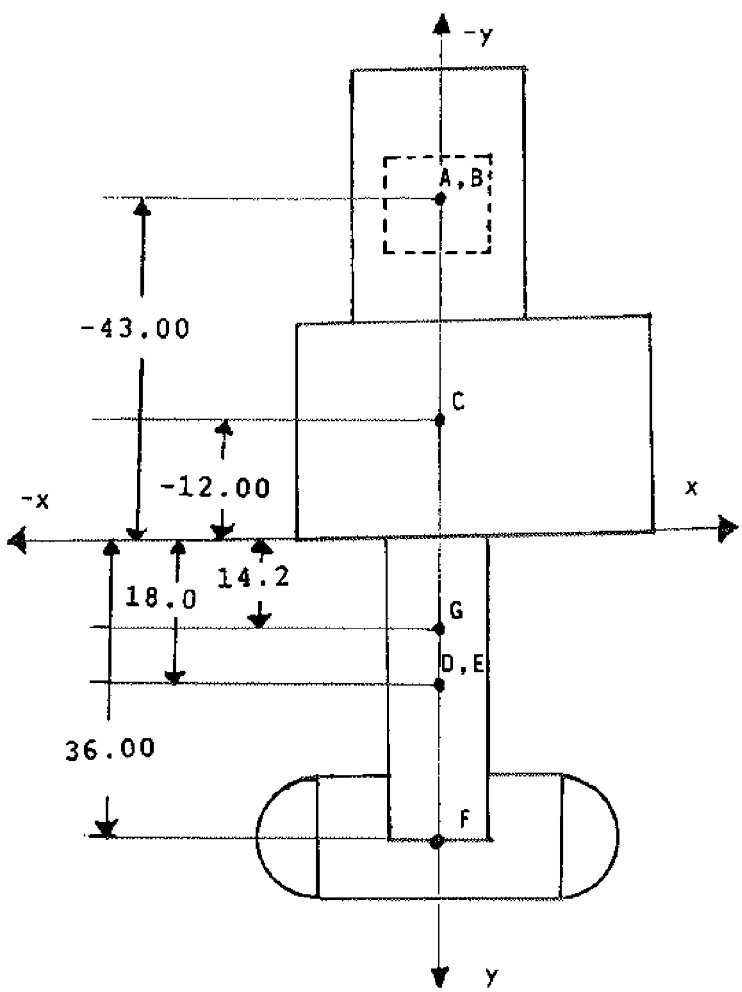


FIGURE A.9

Metacentric height is useful for determining the stability of a floating body. It is a critical factor when partially submerged objects, a boat for example, have a center of gravity above the center of buoyancy. This buoy however has a center of bouyancy above the center of gravity and is therefore relatively stable. By maximizing metacentric height stability is maximized.

metacentric height (gm)

gm = gb + bm

bm = I / V

It	=	22500.00
Isc	=	20540.98
I	=	43040.98
a	=	15.13
b	=	30.00
h	=	30.00
bm	=	4.33
V	=	9947.82
gb	=	8.78
gm	=	13.11 inches

Righting Moment

M = W gm (theta)

angle (degrees)	moment (ft-lbs)
0	M = 0.00
3	M = 20.41
6	M = 40.82
9	M = 61.23
12	M = 81.64
15	M = 102.05
20	M = 136.07
25	M = 170.09
30	M = 204.11
35	M = 238.13
40	M = 272.14
45	M = 306.16
60	M = 408.22
90	M = 612.33

The righting moment gives some indication of the bucy's stability. Tipped to various degrees, the above table shows corresponding righting moments acting to set the bouy back to its upright position in static conditions.

APPENDIX 5A

OPERATING LIFE OF POWER SUPPLY

Daytime:
Display uses .5A, cycle of 2secs/1min = .2 Amp hours/day (assuming 12 hours of daylight)

Night:
Display uses 1A cycle of 2secs/1min = .4 Amp hours/day

Electronics: .25A constantly = .25 Amp hours/day

Total Draw: .2+.4+.25=.85 Amp hours/day

200 Amp hours/(.85Amp hours/day) = 235 days of operating life

APPENDIX 5B

ADDITION OF SOLAREX SX-10 SOLAR PANEL

Drawing daily average of 1 Amp (1.25A at Night, .75A during day)

Duty cycle 2secs/1min = .0333 (.0333)(1A)= .0333 Amp draw

Assume: 4 Amps

Assume 66% efficiency in batteries: .04/.66 = .061 Amps charging

Assume: minimum of 8 hours sunlight at 40% light energy.

From chart: SX-10 .26A for 1/3 day (8 hours)= .0866 Amps

.0866(# of panels)=.061 Therefore, 1 Solarex SX-10 solar panel will be sufficient mounted on the top of the buoy parallel to the ocean surface.

APPENDIX 5C

ALTERNATE ALUMINUM BATTERY PACK

Need 217 lbs total ballast in pack, less 122lbs of batteries leaves 95 lbs. Also need same length and inside diameter.

Tube Weight=(density)(pi)[(Ro*Ro-Ri*Ri)](length)

=(.0975)(3.14)[7.97*7.97-7.47*7.47)](32)=75.7 lbs

Cap Weight=2(density)(Ro*Ro)(pi)(thickness)

=2(.0975)(7.97*7.97)(3.14)(.5)= 19.46 lbs

Total Weight = 75.7 + 19.46 =95.16lbs

Note: Density of aluminum is .0975 lbs/in*in*in

All dimensions in inches

Electrical Characteristics

	SX-10	SX-20
Nominal Battery Voltage (Vnom)	12.0V	12.0V
Peak Power (Pp)	9W	18W
Voltage at Peak Power (Vpp)	17.3V	17.3V
Current at Peak Power (Ipp)	0.52A	1.04A
Short Circuit Current (Isc)	0.6A	1.2A
Open Circuit Voltage (Voc)	22.0V	22.0V

NOTES

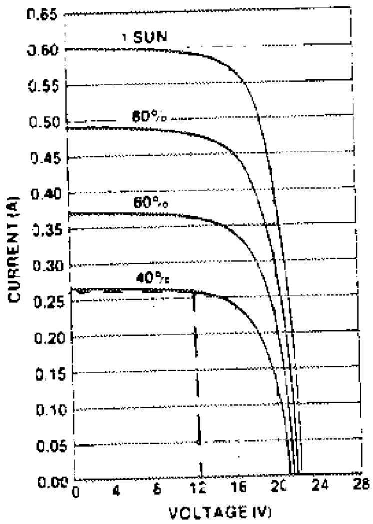
1. Modules are measured under full sun illumination ($1kW/m^2$) at 25°C ± 3°C cell temperature. Minimum performance is 5% less than peak. The ruling specification is peak watts. For a more detailed explanation, see our *Electrical Performance Measurements* bulletin.

2. Electrical characteristics vary with temperature.

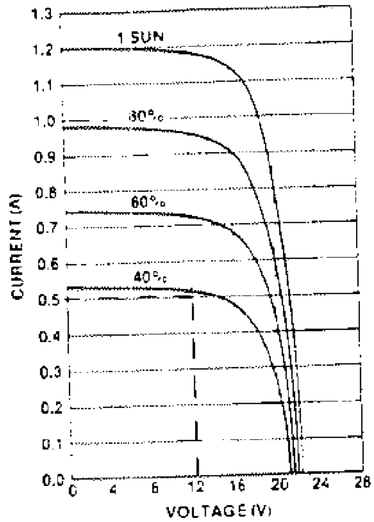
Voltage (Voc)	increases by / decreases by	2.4mV/°C/cell	below / above	25°C
Current (Isc)	increases by / decreases by	$25\mu A/°C/cm^2$	above / below	25°C
Power (peak)	increases by / decreases by	0.4%/°C	below / above	25°C

3. These modules can also be wired for 6 volt applications. Electrical characteristics are available from Solarex upon request.

SX-10 Performance at Various Light Intensities, T = 25°C



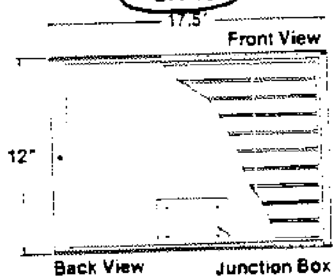
SX-20 Performance at Various Light Intensities, T = 25°C



NOTE: These curves are representative of the performance of typical modules at the terminals without any additional equipment such as diodes, cabling, etc. These curves are intended for reference only. Additional technical data is available from Solarex upon request.

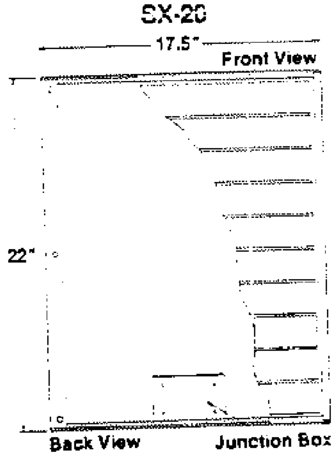
Mechanical Specifications

SX-10



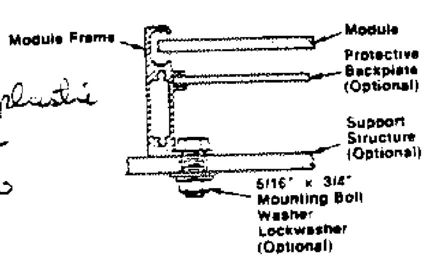
17.5" x 12" x 2.1"
(44.5cm x 30.5cm x 5.4cm)
5.6 lbs. (2.5 kg)

SX-20



17.5" x 22" x 2.1"
(44.5cm x 55.9cm x 5.4cm)
9.4 lbs. (4.3 kg)

Cross Section of Module



now use a plastic back panel

mount @ 45°

Reliability and Environmental Specifications

These modules are subjected to intense quality control during manufacture and rigorous testing before shipment. They meet or exceed the following tests with no performance degradation:

- Repetitive cycling between −40°C and 100°C.
- Prolonged exposure to 90-95% humidity at 70°C.
- Wind loading of over 160 m.p.h.

All SX Series modules are covered by the standard Solarex five year limited warranty.

Options and Accessories

Mounting Hardware - Pole or flat surface mounting hardware is available.

Diodes and Regulators - Blocking diode is available to prevent reverse current flow from module to the battery during darkness. Voltage regulator circuit with heat sink is also available to prevent overcharge of the battery.

Backplates - Anodized aluminum backplate is available to protect the module in harsh environments.

Wiring — Six volt option is available for low voltage applications.

For further information, contact the Solarex Sales Department.

BIBLIOGRAPHY:

1. Baumiester & Marks, Standard Handbook for Mechanical Engineers 7th Ed., McGraw Hill, 1967

2. Beateaux, H.O., Buoy Engineering, Wiley, New York, 1976

3. Gerhart, P. M., and R. J. Gross, Fundamentals of Fluid Mechanics, Addison-Wesley Publishing Co., Ma., 1985.

4. Hibbler, R. C., Engineering Mechanics Dynamics, (third ed.) Macmillan Publishing Co., Inc., New York, 1983.

5. Hibbler, R. C., Engineering Mechanics Statics, (third ed.) Macmillan Publishing Co., Inc., New York, 1983.

6. Gerard Neumann, Principles of Physical Oceanography, Prentice-Hall Inc., Englewood, N.J., 1966

7. L.L. Shreir, Corrosion 2- Corrosion Control, Newnes-Butterworths, London

8. Thomson, W. T., Theory of Vibration with Applications, (second ed.) Prentice-Hall, Inc., New Jersey, 1981.

9. Van Vlack, Materials for Engineering, 4th edition, Addison-Wesley Publishing Co., Ma., 1980