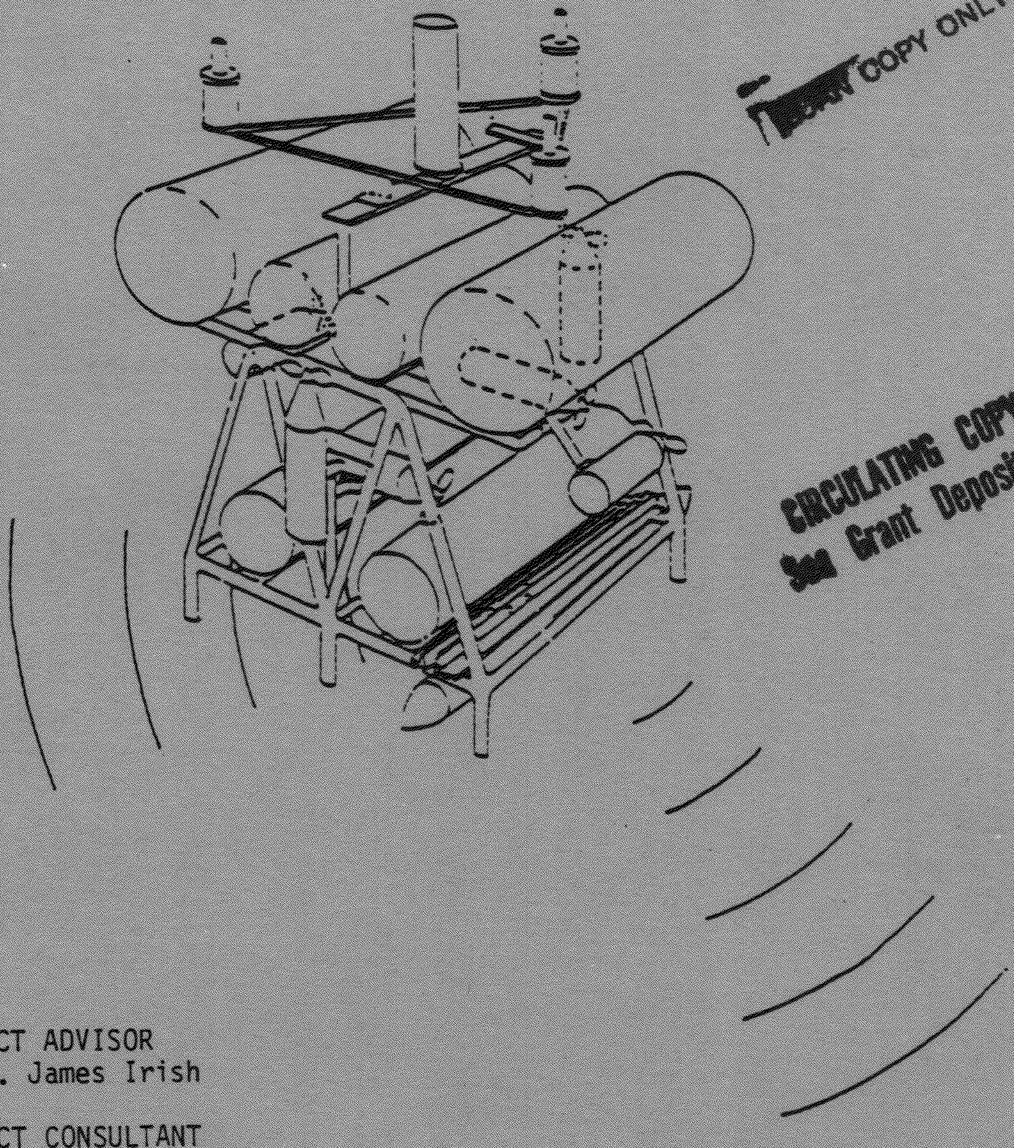
ARSUS

AUTONOMOUSLY RECORDED SIDE SCAN SONAR ON AN UNTETHERED SUBMERSIBLE



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1984-85 SEA GRANT OCEAN PROJECT

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SEA GRANT 1984 - 1985

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ACKNOWLEDGEMENT

Our group would like to thank Marty Klein and Klein Associates of Salem N.H., with special thanks to Terry Snider and James Glynn for their time and aid. We would also like to acknowledge Dick Blidberg, Jim Jalbert, Carl Beverly and Mike Shevenell of the Marine Systems Engineering Lab.

ABSTRACT

This paper will report on the development of a side scan sonar data storing system for use on the autonomous submersible EAVE. There will be a brief discussion on the uses for such a system and background on side scan sonar theory. The design of the system will be covered in detail from the mechanical and electrical standpoint. Special attention will be paid to test procedures and results, with a discussion on data interpretation. Future improvements will also be considered.

INTRODUCTION

This project's objective was to mate a side scan sonar unit donated by Klein Associates to the MSEL's unmanned, untethered vehicle. The design of this sonar data storing system eliminated the need for communication to the sea surface. An autonomous recording system enables the unit to gather information in areas otherwise inaccessible. Future goals of autonomous recording systems will be the eventual coupling of the sonar readings directly to the submersible's control computer.

The goals of the project were to design and build a working data storing system. Test the system with a graphical recorder in a towed configuration from the U.N.H. research vessel. Attach the system to the submersible vehicle and test in a self-contained free swimming configuration. The final goal was to obtain understandable data from the test on MSEL's submersible EAVE.

To complete the project goals requires several tasks. The most important task was to develop a side scan sonar data storing system. Next was to design a pressure case and packaging unit to house the electronics. Providing a sufficient power source for the electronics and the sonar fish was also necessary. Mounting of equipment on the submersible affected buoyancy and drag, therfore compensation was provided for added equipment.

BACKGROUND

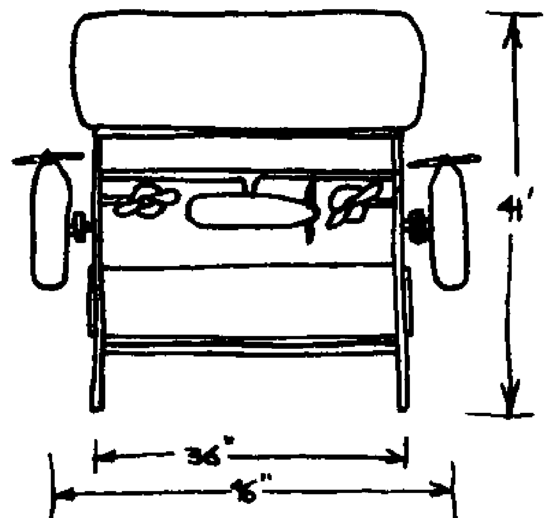
A side scan sonar system basically consists of three units. A transducer, which is often called the "fish", a tow cable to tow the fish which also doubles as a transmission line, and a dual channel recorder to record the side-scan signals.

The fish is a streamlined hydrodynamically balanced body about one meter long. It contains two sets of transducers that scan the ocean floor on either side. The dual channel recorder contains all the electronics to do the signal processing and the graphic mechanism to produce the side scan charts, often called a sonogragh.

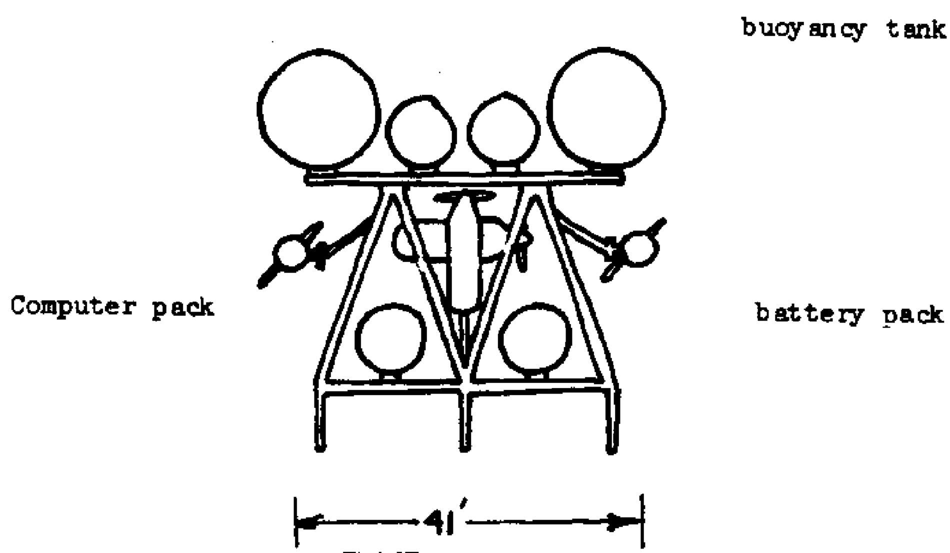
Side scan signals are produced by the transducers sending out short sonar pulses of 0.1ms duration, then waits for the return echos. The strength and time placement of these return echos are what make up the side scan signals. These are then amplified in the recorder and fed to the graphic mechanism in the form of variable currents.

Putting side scan sonar on an autonomous vehicle has many useful applications. To obtain data where it could be dangerous to traverse or just unable to traverse. A minefield or under an icepack are a couple of the applications of side scan sonar on an autonomous vehicle. Other such applications are in the oil industry. To run along side a pipeline and inspect it, or to take surveys of a planned site .

EAVE: UNMANNED UNTETHERED SUBMERSIBLE



SIDE VIEW



FRONT VIEW

BACKGROUND ON EAVE

The EAVE vehicle is a submersible designed to develop unmanned, untethered technology. During testing of the sonar system EAVE ran without navigation, which usually directs her. The frame work, pressure tubes aand thrusters form a square configuration. EAVE is capable of performing many independant tasks, but for this projects was only required to run a straight course.

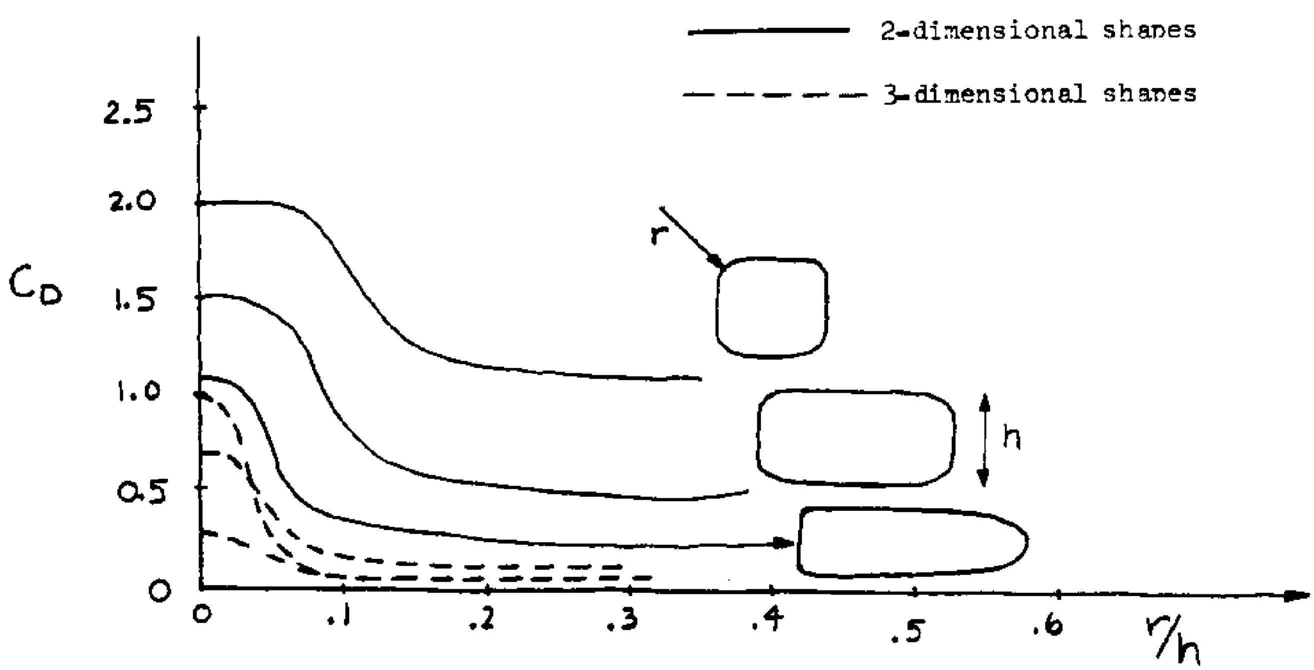
PRESSURE CASE

Due to the size of the pressure case necessary and the limited space on EAVE, the case was designed to replace one of the two buoyancy tanks. To make the case compatible with EAVE it was designed as similar to the buoyancy tanks as possible.

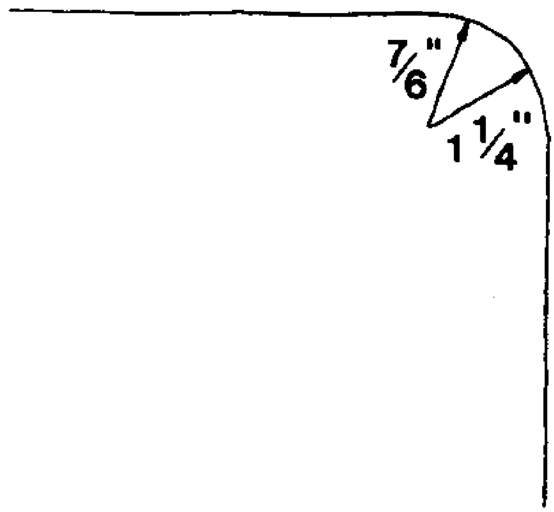
The existing floatation tube consists of a three piece welded construction with an outside diameter of 12.75 and a length of 40.75 inches. The cylinder and the torispherical end caps are made of 6061-T6 aluminum. 6061-T6 is an alloy with 1.0% magnesium and .6% silicon. The tensile strength range is from 20,000 to 42,000 psi. The qualities it possesses are good formability, weldability and corrosion resistance. The resistance to corrosion is the most important characteristic due to the constant exposure to water it must withstand. The pressure case is constructed from a cylinder and two end caps. All material is 6061-T6 aluminum.

The cylinder for the body of the pressure case is round aluminum pipe (schedule 40). The wall thickness is .4 inches, allowing for machining to a perfectly round inner diameter. The collapse depth of the aluminum cylinder is 1400 feet.

The two end caps iinitial design were torispherical caps, but eventually changed to flat end caps with rounded edges. Torispherical end caps were found to be very expensive to machine, yet reduce the drag an insignificant amount for this design application. Rounding off edges in blunt shapes is a less than perfect method of reducing drag. The critical radius ratio, which effects the change in flow pattern, is to some degree a function of Reynolds number. The ratio reduces slowly as the Reynolds number is increased. The suggested critical radius ratio is r/d=0.1. This is considered adequate for three dimenssional bodies. Calculations result in a critical radius for these end caps of 1.27 inches. The suggested rounding radius was approximated by combiening two radius to ensure gradual mating with the top and side of the end cap.



Influence of a Rounding Radius upon the Drag Coefficient



ROUNDING RADIUS FOR END CAPS

The two flat end caps are machined from 13 inch diameter, 1.5 inch thick 6061-T6 disks. Connecting the end caps to the cylinder is done by nelson clips. Four clips at each end was found to be more than sufficient. Using a collapse depth chart for flat end caps showed the collapse depth to be 800 feet. In comparision, the torispherical caps have a collapse depth of 1473 feet. This was found to be insignificant due to EAVE's overall operational depth.

The problem with any pressure case is maintaining a waterproof seal. Two O-rings, one at each end cap, provided this seal. The choice of O-ring is crucial to ensure a perfectly dry seal. Determination of the O-ring compound was first. The primary factor in choosing a compound is the fluid to be sealed. Temperature range and maximum pressure are secondary factors. The pressure case is designed for use in salt water. Using the table from the Parker O-ring handbook, the recommended compound was determined to be

N674-70. The polymer being nitrile. The three types of static O-rings are male and female seals and face type seals. Originally it was planned to use face type seals but on calculation of gland dimensions it was found to be difficult. No manufactured O-rings existed for the necessary specifications. Making an O-ring was considered, but disregarded for the higher quality and saftey of a manufactured one. The final O-ring design used a static male O-ring seal. Using the table for static seal glands in the handbook, a standard O-ring size appropriate for the case was choosen. The O-ring size is 2-278 and the gland dimensions were determined from the table.

The surface finish for O-rings was also important. Parker O-ring handbook suggests a surface roughness value not to exceed 32 microinches on the surfaces for sstatic seals. The specified roughness coefficient for the pressue case was 32 microinches. Equally important is the method used to produce the finish. Scratches and ridges that follow the direction of the groove, can be caused by turning the part on a lathe. If the surface is produced by turning the part on a lathe, very rough surfaces will still seal effectively. Some methods produce scratches that cut across the O-ring. These second type of scratches did create a problem leading to additional machining of the O-ring surfaces.

BULKHEAD CONNECTORS

The bulkhead connectors were chosen before the final electrical configuration had been determined. With this in mind the number of connectors and their type was chosen to allow the most flexiblity to adapting to the final configuration

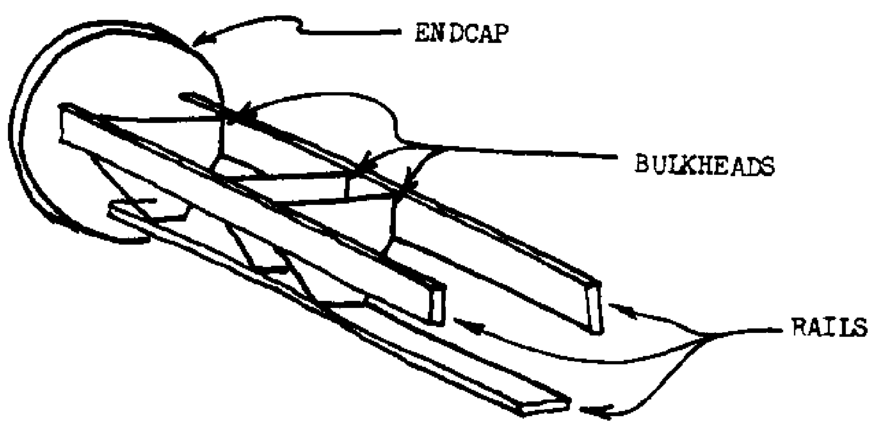
A total of four connectors were installed. They were; A Envirocon VSK-3-BCL 3-pin female connector compatible with connections to EAVE's 24 volt battery pack, An Envirocon VSG-4-BCL 4-pin female connector compitable with connections to EAVE's combination 16 and 9 volt battery pack, A KLEIN 4-pin/8-conductor female connector compatible with connections to the KLEIN towfish, and A KLEIN 12-pin female connector also compatible with connections to the KLEIN towfish. All four connectors were rated to depths many times greater then those in which EAVE can operate. In the final configuration only two of the connectors were used; the Envirocon 3-pin connector to supply 24 volts to the electronics and the KLEIN 4-pin for communications between the sonar electronics in the tube and the towfish.

INTERNAL ELECTRONICS CAGE

The design of the electronics cage had to ensure that the electrical componets were safe from physical damage, the controls and connections of the individual components were easily accessable, and the system as a whole was easily accessable.

In order to make the design of the cage easier, a cardboard model of the inside of the pressure tube was made. The electrical components were then assembled and positioned in various ways inside the model until the optimal configuration was found. Detailed drawings were then made and the actual design layed out for machining.

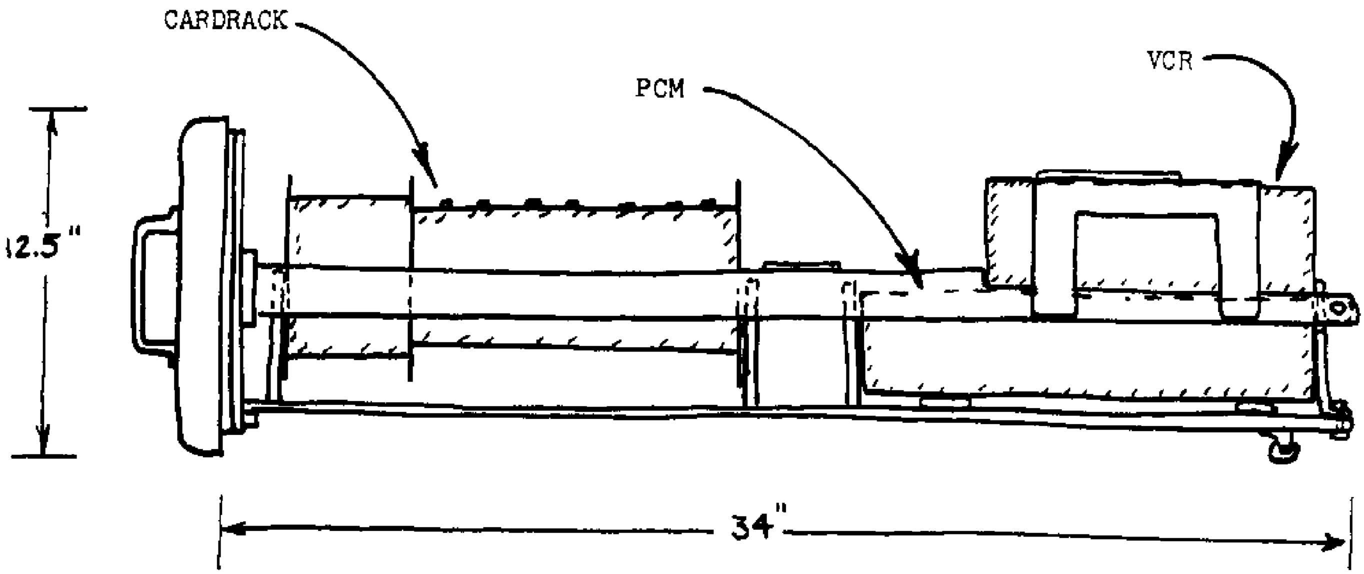
The design was based on three main rails anchored into the end cap of pressure case and running the length of tube. Two rails acted as walls and the third as a floor. The rails were regularly connected to each other by bulkheads. The cage then acted as a cradle and the components were layed into it.



BASIC STRUCTURE OF ELECTRONICS CAGE

The units to be fitted into the cage were; the PCMF-1 digital formater 8.5"*12.5"*3.0", the panasonic VCR 9.5"*9.5"*3.75", and the cardrack/transformer 7.6" dia * 16". The inside diameter of the tube was 12.25" and its length 35.0". These dimensions did not allow for the units to be placed end to end so the VCR was placed on top of the PCMF-1. The cardrack/transformer was placed nearest the end cap so that connections between it and the bulkhead connectors would be short. The VCR and PCMF-1 were placed at the opposite end from the cardrack/transformer so that their controls could be easily accessable by removal of the opposite endcap.

All pieces of the rack were constructed from aluminum scrap giving the cage a weight of approximately 4lb. A wheel was placed on the bottom of the cage at the end furthest from the end cap to make sliding of the assembly into the pressure tube easier.



ELECTRONICS CAGE, SIDE VIEW

PRESSURE TEST

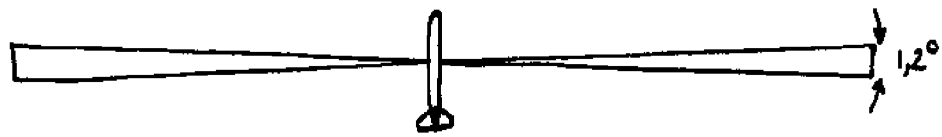
With the help of Paul Lavioe and the New England Hyperbaric Chamber, the pressure case was tested before housing the electronics. The case was placed inside the decompression chamber with one end submerged in water. Holding the pressure at two atmosheres absolute for fifteen minutes, the pressure case remained dry. Then the second end was submerged in water and tested at the same depth. Agaiin the result was no leaking.

ATTACHMENT OF THE SONAR

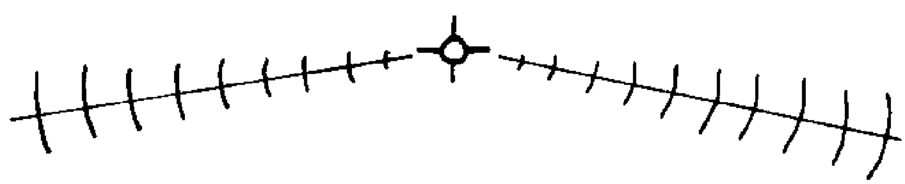
The attachment of the soar to EAVE had to have a minimal effect on the performance of the vehicle and at the same time allow for the accurate collection of data.

For good performance the sonar's transducers must travel in as straight a line as possible and maintain a constant depression of 10 deg. from the horizontal axis.

TOWFISH



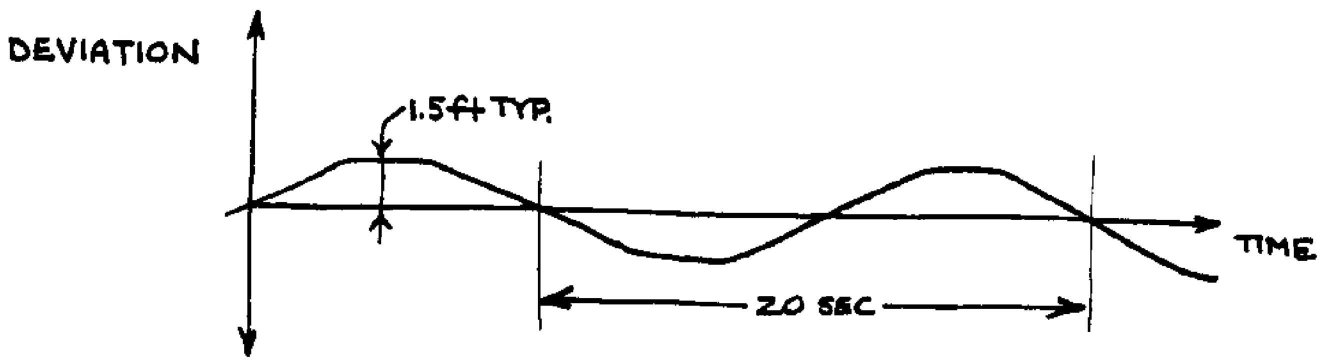
TOP VIEW



FRONT VIEW

EAVE has a maximum speed of approximately 1.5 knots. It's control system can direct the vehicle in a relatively straight path but only buy periodically making coarse corrections.

EAVE'S HORIZONTAL DEVIATION FROM COMMANDED PATH WITH TIME



The possibilities considered were to leave eave on its controler and tow the towfish under it and try to isolate the movement one from the other.

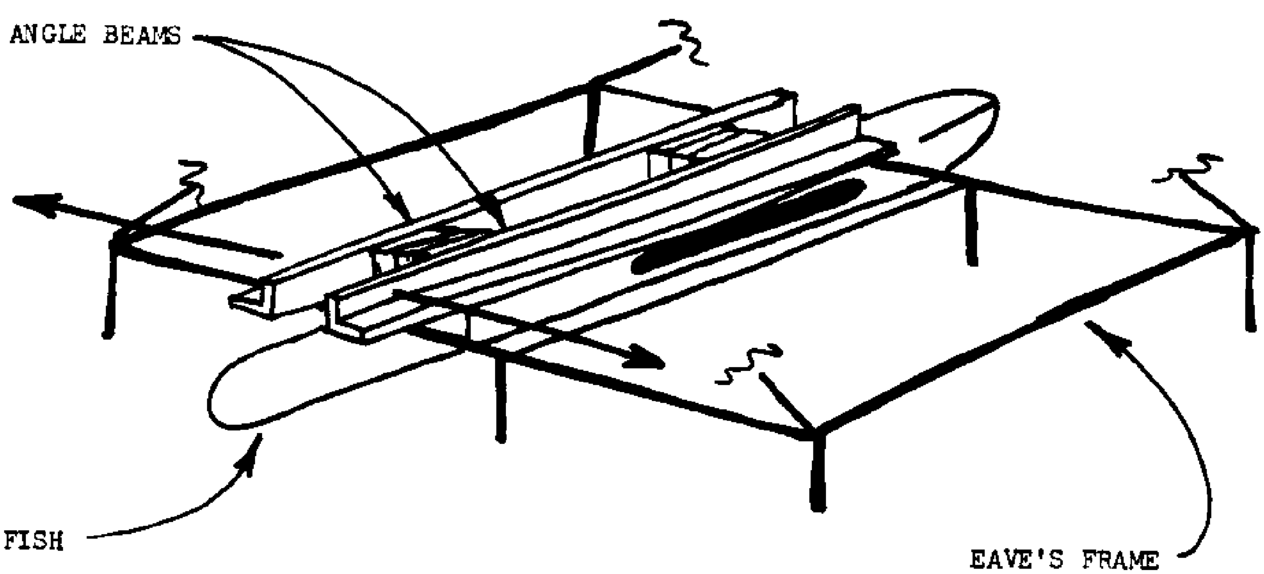
The other option was to rigidly attach the sonar to EAVE and to take EAVE off its guidance system for a period of time.

The first option of towing the towfish was discarded because isolating the movement of the two bodies would involve considerable effort and resources and it was decided to instead settle for a smooth but probably curvature path and concentrate as a team on developing an accurate electronic storage rather then getting a sonar package to move in a straight line.

Once the decision had been made to mount the sonar rigidly to EAVE it was next decided to leave it in its towfish configuration. this would simplify the job and would increase the future utility of the sonar to other users.

Another consideration was to mount the fish in such a way that its transducers were free from obstruction. It was also important to make the design flexible because at the time of its conception the final. final bouyancy and trim calculations had not been made leaveing its exact final location undetermined. To have the transducers clear, the towfish should be mounted as low as possible and yet still inside EAVE's tubular framework to protect it from physical abuse.

The final design called for the towfish to be hung from the bottom horizontal framework of EAVE but above its 6"legs". The hanger was based on two aluminum angles running from the forward horizontal piece to the rear horizontal piece. It's exact location from side to side would be determined by buoyancy and trim considerations. To move the towfish forward enough to have the transducers clear of the rear legs the fish's nose weights were removed



POSITION OF TOWFISH ON EAVE

BUOYANCY CALCULATIONS

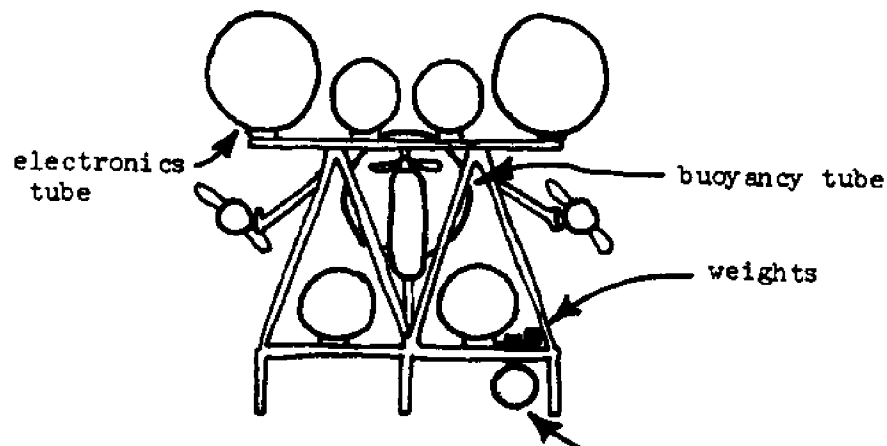
The physical adaptations to EAVE had to be made in such a way as to leave the vehicle with a slight positive buoyancy on it's center axis. EAVE's horizontal thrusters would not be used and were removed to increase buoyancy along with a dead weight and one of the vehicles original buoyancy tanks that would be replaced by the electronics pressure tube. The ARSUS project would be adding to the vehicle an electronics pressure tube, a towfish and necessary buoyancy and weight.

ALTERATIONS TO EAVE'S BUOYANCY

REMOVE:	1 BUOYANCY TANK..................	103 lb
	1 DEAD WEIGHT....................	-50 lb
	2 HORIZONTAL THRUSTERS...........	-24 lb
		29 lb
ADD:	1 ELECTRONICS TUBE...............	40 lb
	1 TOWFISH........................	-30 lb
	1 BUOYANCY TANK..................	60 lb
	VARIOUS WEIGHTS..................	42 lb
		30 lb

For simplicity it was decided to balance EAVE on the horizontal with the addition of weight and the add whatever buoyancy was necessary on the centerline. Calculations along these lines were carried out and it was determined that the towfish would be placed 17" from the axis on the opposite side that the pressure tube would be added. It was also determined that an additional 42lb would have to be added at approximately at the same distance from the axis as the fish. With these additions it would be necessary to add 57lb buoouyancy about the centerline.

PHYSICAL ALTERATIONS TO EAVE



EAVE
FRONT VIEW

The weight near the fish was added by modifiing the mounting rail to have three bolts pointing upward for one of the angle pieces so that weights could be placed on them. A 60lb buoyancy tank was found at the MSEL lab attached to the vehical underneith its computer tubes. Final bouyancy alterations were made in the field with additions of small weights.

ELECTRONICS

The design of the electronics system involved the following considerations. The accurate storage of side scan signals to be kept within a given budget, a reasonable packaging volume, and a set time limit. The side scan signals comprise of three independent signals, a trigger, left channel and right channel. The left and right channels are at a voltage level of 0-5Vdc with a bandwidth of DC to 10KHZ. The trigger is a square wave with one sweep defined as 500 cycles. The first 16 cycles at 5V pk-pk and the remainder at half this amplitude.

A choice had to be made as to use a digital system or an analog system. the various digital systems investigated were to use microprocessor control and store it onto RAM, a 3M Data Cartridge drive system, or a Seadata digital drive system. The analog systems considered were a cassette tape or a VCR tape.

All the digital systems were either too expensive, the 3M drive was in the range of 3000 dollars and the Seadata was around 4000 dollars, or not feasible with the amount of volume. the amount of RAM required to store the amount of data from one run would of been phenomenal. Another drawback of using a digital system in this project is the time requirement. All the systems required the design of a digital interface. To be able to design, build, and debug one with the available equipment would be too time consuming. In the future a digital system will be the best way to go to extend the applications of autonomously recorded side scan sonar. For in a digital format it can be tied in with the vehicles CPU and navigation system. It would also allow the data to be analyzed by a computer sometime after the data was taken.

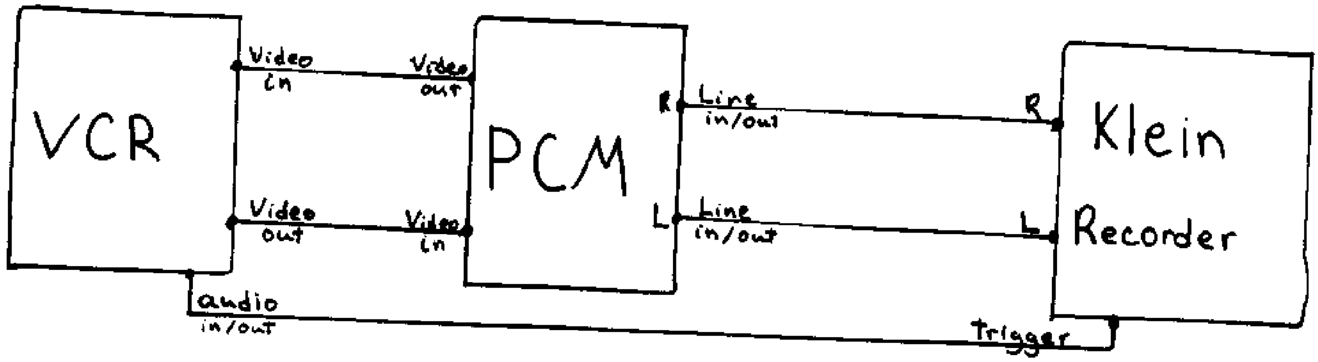
After determining that a digital system was unfeasable the analog systems were evaluated. A cassette tape would not work because of the amount of wow and flutter in a portable cassette deck. This would distort the side scan signals too much for accurate reproduction. The VCR appeared to be the best system to use. A portable VCR had a cost within the project budget, and it has a two hour running time which is more than enough time for a good run. The VCR is stable enough so that the signals going into it will not be too distorted when reproduced.

Once it was determined to use a VCR, the next step was to decide how to put the data on the VCR. At first it was thought that the signals could be multiplexed directly onto the VCR. After some lab tests it was determined that the VCR required the proper video sync pulses to get data on and off the VCR tape.

There were two possibilities for providing these sync pulses. The MM5320 TV camera sync generator, and the Sony Digital Audio Processor PCM-F1. After being informed that the Sony PCM-F1 had been used successfully in similar applications in a lab at Woodshole, MA. it was decided to go with the Sony instead of the sync chip for two reasons. It was an already proven working system, and an off the shelf item that could be bought immediatly without havng to order it. From this point, all that was left to do was to test and work out the little bugs within the system.

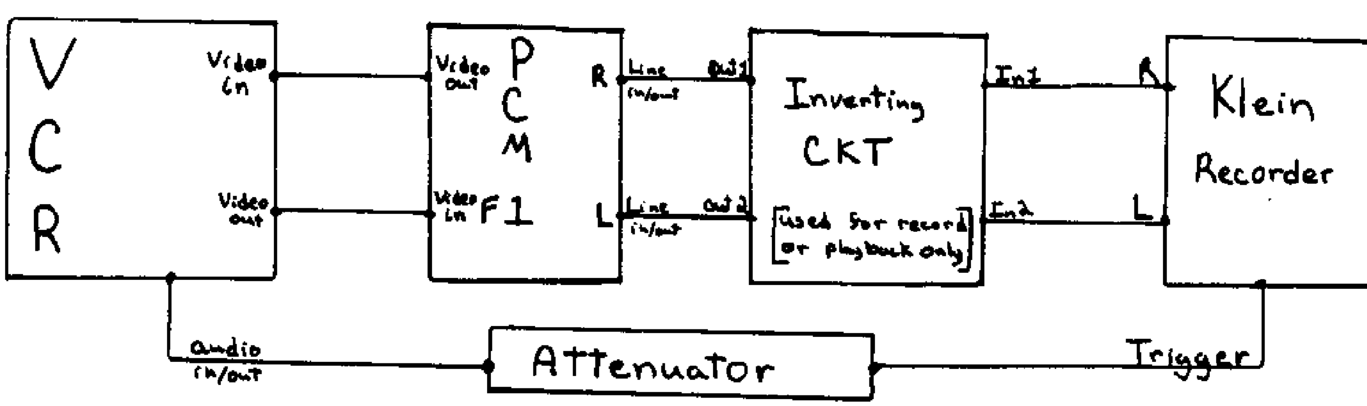
The PCM took two channels and put it on the video input to the VCR; the VCR also had an audio input. With this configuration the left and right side scan signals went into the pcm then onto the VCR video input. The trigger was fed directly into the audio input.

At our first test all connections were made direct without any extra circuitry added.



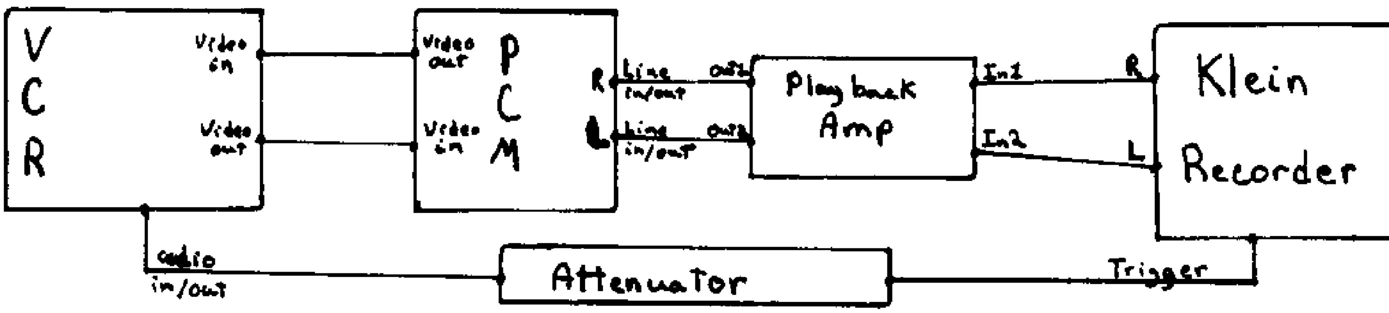
FIRST TEST SET UP

Using side scan signals that were already recorded on a reel to reel recorder provided by Klien we tested the PCM and the VCR. From this, several problems occured during playback. The right and left side scan signals were inverted and the trigger was greatly distorted. The trigger distortion was caused by overdriving the VCR audio input. To correct this, an attenuater was inserted in front of the VCR during the recording process. To correct the right and left side scan signals an inverter was inserted between the PCM and the Klien recorder during playback or record. The other problem that was encountered was that the PCM did not pass the DC component. It was not imperative to fix this immediatly for even without the dc component, good reproduction of the side scan data is obtainable.



SECOND TEST SET UP

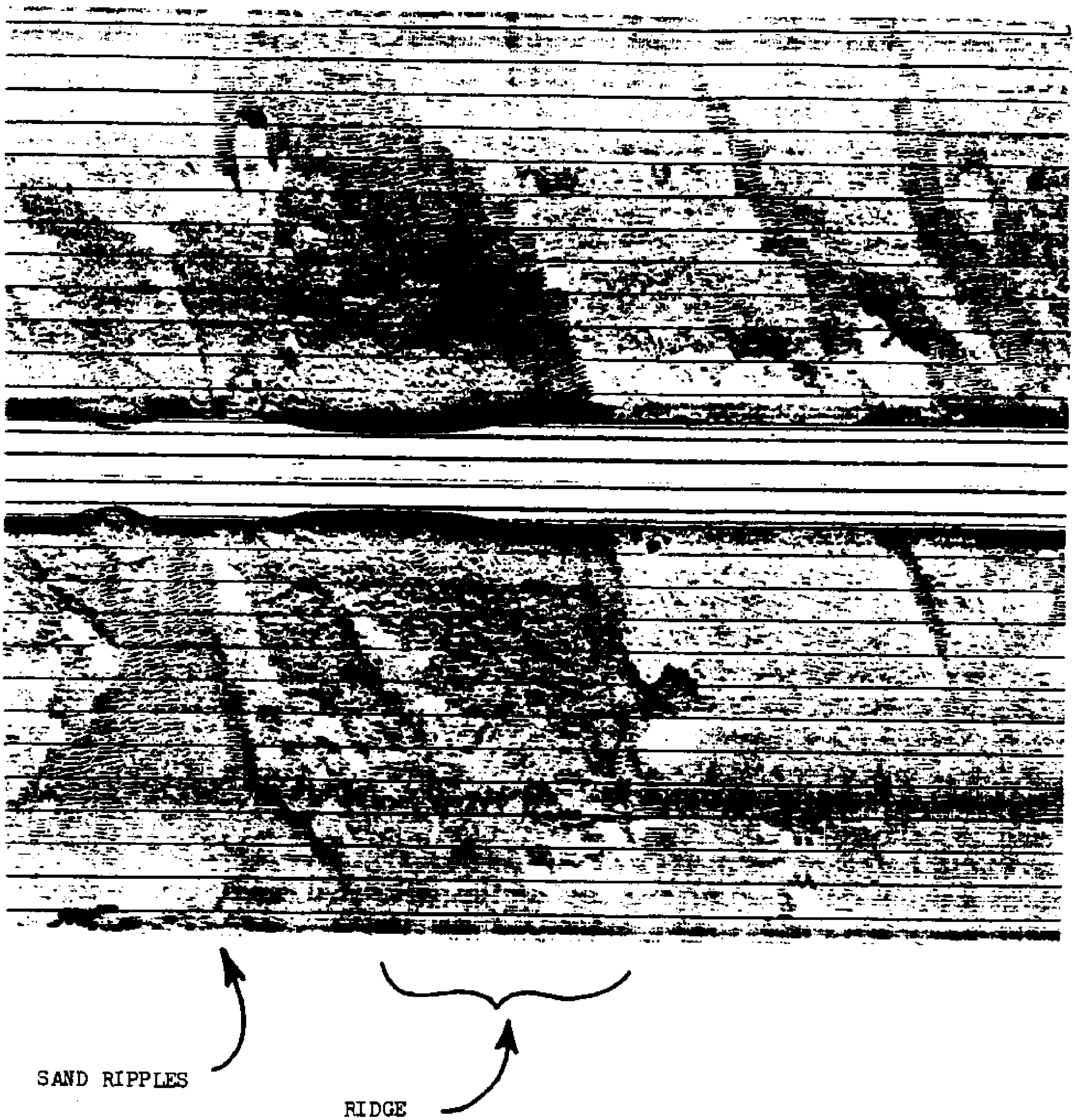
Our next testing came on the UNH boat Jere Chase. This allowed us to record real time side scan data as what will occur eventually on EAVE. From our first test on the Jere Chase, it was found that the side scan signals were weak coming into the Klien recorder and needed to be amplified. To do this, an amplifier was incorporated in the inverters and now this added circuitry had to be used during the playback process.



FINAL TEST SET UP

The amplifiers were given a gain of ten. The second test on the Jere Chase tested the complete system obtaining real time data along with the recorded data. Everything worked excellent with remarkably accurate results. The third and final test on the Jere Chase before attaching it on EAVE was to run the system inside the pressure tube with the PCM and the VCR running on batteries. The system worked and we got data. All that was left was to get it running on EAVE.

Side scan sonar data collected by the ARSUS electronics from the R.V. Jere Chase near the Isles of Shoals.



POWER

There are several units and devices that require power: the Sony PCM F-1, VCR, playback amplifiers, Klien electronics, and the fish. All the power must come from EAVE, with the exception that batteries can be used with the Sony PCM F1 and the VCR

EAVE operates on 24Vdc, so Klien Associates designed thier electronics boards which also power the fish, to EAVE's 24 volts. Klien's boards had plus and minus 15Vdc connections which were utilized to power the playback amplifiers.

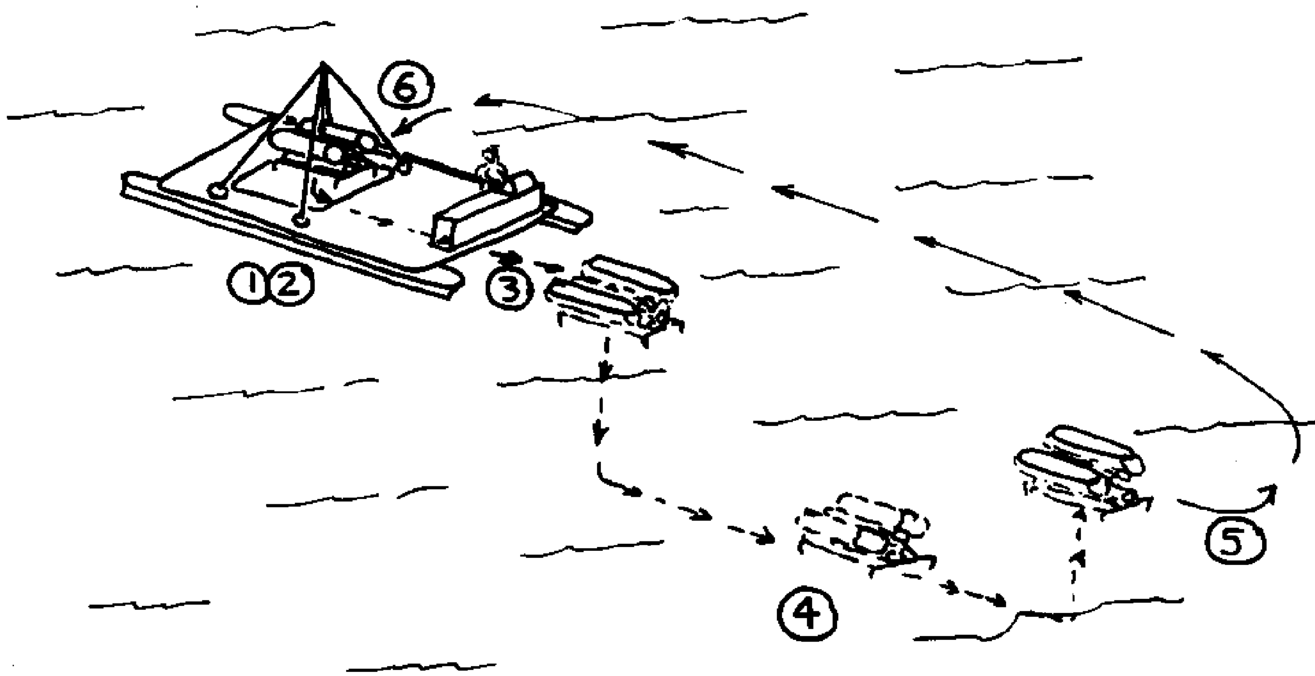
There were two options in powering the PCM and the VCR. The PCM had an adapter that allowed the unit to operate on 12 volts dc negative ground. This could of been adapted to run off EAVE's power, but for a couple of reasons it was decided to run it off its own battery. The PCM had a very high power consumption, 17 watts. It was of concern if EAVE could power the fish, EAVE itself, and the PCM and have an acceptable running time. The other factor was space. The accessory 12 volt adapter was of significant size and might have been difficult to package. The decision finally came when we were unable to get the part in time to test it on EAVE. It would have been preferable to operate the PCM off EAVE for the running time of the PCM on batteries is only one hour. The VCR battery pack allowed for over two hours of operation which is sufficient since a tape ohly lasts for two hours. This allowed our entire system to run for one hour.

FINAL TESTING

The final testing on EAVE took place april 24 and 30 1985 with successful results on the second day. The purpose of thetests were to prove that the ARSUS system could allow an autonomous vehicle to collect side scan sonar inforation and store it for later analysis.

The test consisted of;

1. programming the vehicle to (at a predetermined time) turn on its vertical thrusters and maintain a certain depth, then turn on its forword thrusters and leave them on for a instructed amount of time,
2. turning the ARSUS electronics onto the record mode,
3. lowering the vehicle into the water and pushing it away from the barge,
4. the vehicle obtaining a depth and moving in a run,
5. the vehicals thrusters shutting down, the vehicle floating to the surface and being towed back to the barge
6. ARSUS tube being opened ,the electronics turned to play back and the information about the bottom the vehicle travelled over played back over a paper printer.



TEST SEQUENCE FOR THE ARSUS PROJECT

During the first unsuccessful day of testing the vehicle was successfully programmed to make test runs but examination of the ARSUS recordings revealed a hardware malfunction of the system which prevented useful data from being optained. Closer examination revealed that the VCR had broken and that the slightest physical blow would prevent it from recording information. After attempts to fix the VCR failed funding was obtained and a new one was purchased. Modifications were made to the electronics cage to fit in the new VCR and all other connections and equipment were checked to prepare for a second day of testing.

On the second day of testing 6 runs were attempted; three in the morning and three in the afternoon. On two of the runs information was successfully taken. Two runs were unsuccessful due to batteries to the ARSUS project running out. One run had to be aborted when the vehicle strayed to close to the anchor lines to the barge and one run was unsuccessful because the connection between the electronics tube and towfish was broken when a connecting cable came loose.

In each of the successful tests information about the bottom over which the vehicle had travelled was stored but the quality of the records could be inproved.

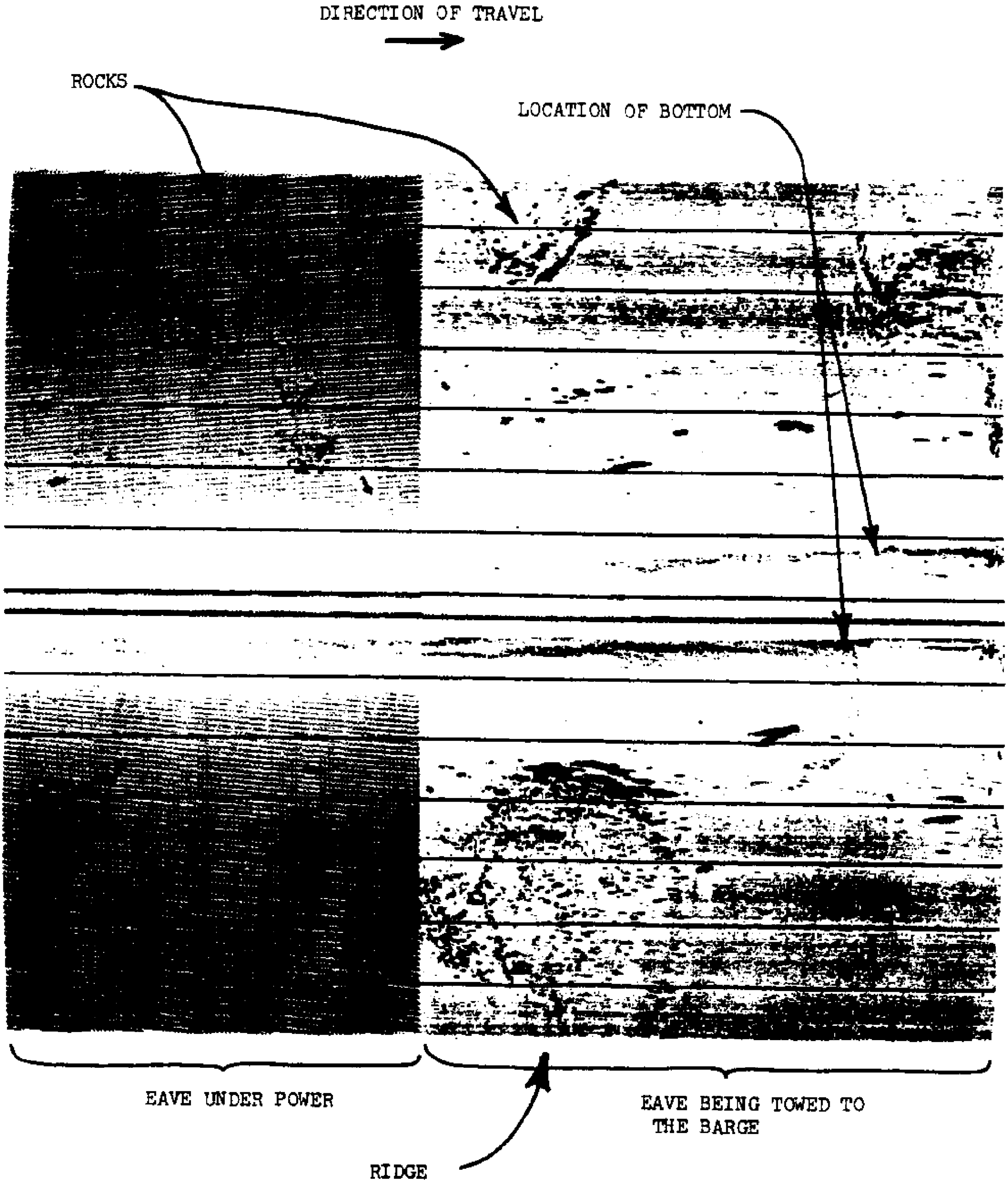
Rocks and ridges can be seen and the depth of water under the vehicle can be determined all along its run in the ARSUS sonar records.

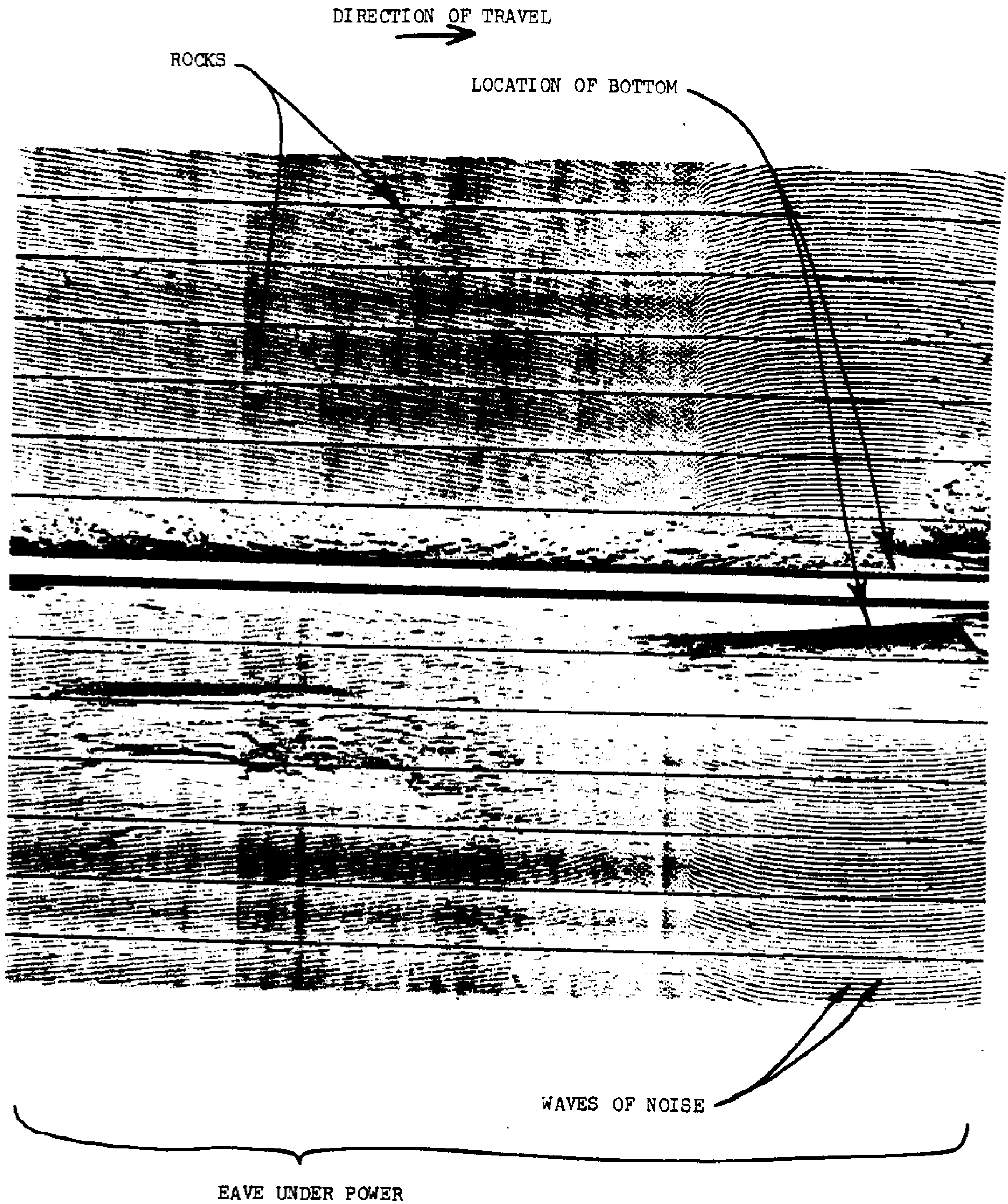
examination of the records revealed that two factors greatly decreased the quality of the sonar records; fluctuations in current available to the sonar electronics, and the closeness that the vehicle travelled to the bottom during parts of its runs.

The fuctuations in current avalible to the electronics occured because they were supplied power from the same battery packs as the vehicles motors. The running of the motors then caused waves of noise to be imposed on the sonar records. This interference can be clearly identified when records taken during a run are compared to those taken when the vehicle was being towed to its starting position or back to the barge. The mutual coupling is also suspected of causing the automatic tuner of the sonar to shut down during the test run. This would happen because the tuning circuit is very sensitive to fluctuations in its current source. The addition of a filter between EAVE's battery packs and the electronics would have increased the quality of the records significantly.

during the test runs it was evident from the data that EAVE had travelledn 5' off the bottom the majority of the time. Running the sonar close to the bottom restricts the range that it can "see" on either side of it. Another effect of running close to the bottom is that the closeness of the initial returns and their intensity causes information about the bottom close to the sonar to become distorted. Because EAVE only ran at -3' at the deepest only testing in a deeper part of the lake would have helped the depth problem.

Sample of side scan sonar printouts made form data collected by the submersible EAVE during the final testing of the ARSUS project.




DIRECTION OF TRAVEL
ROCKS
LOCATION OF BOTTOM
WAVES OF NOISE
EAVE UNDER POWER

TEST PROCEDURE FOR ARSUS

I) For Run On EAVE

A) Recording

1) make all proper connections to PCM and VCR
2) proper settings on PCM and VCR
   a) VCR
      1. PLAY/REC. BUTTON SET TO RECORD
   b) PCM
      1. MUTING OFF
      2. COPY OFF
      3. SET RECORDING LEVELS TO 2 ON BOTH RIGHT AND LEFT CHANNELS
3) Power VCR
4) Put in VCR tape
5) Put assembly in tube
6) Hit play button on VCR to start recording
7) Power PCM
8) Seal tube

B) Playback

1) Open tube
2) Pull out rack
3) Power down PCM
4) Stop VCR
5) Rewind tape
6) Make proper connections from trig, right, and left outputs labelled "VCR" into klien recorder
7) Power up PCM
8) Play VCR tape

c) Dry test notes

outputs labelled Real Time, "R.T.", can be connected directly to Klien recorder for real time data while VCR is recording. These connectors can also be used as inputs for recording data that is on another tape recording.

MECHANICAL IMPROVEMENTS

The following mechanical improvements would make the system more functional

The substitution of locking nelson clips for the unlocking kind currently used to secure the endcaps onto the pressure tube would make the electrical equipment safer.

The addition of a wheel at the front end of the electronics cage would make it easeir to put in and out of the pressure tube.

Painting the pressure tube white instead of yellow would keep its contents cooler if it were left out on a deck in the sun.

Anodizing the aluminum pressure tube would make it last longer if used in salt water and make the surface less easy to scratch.

ELECTRICAL IMPROVEMENTS

Although the electrical and power system used worked and was able to reproduce the side scan data. There are many improvements which could be done. The entire power system should be redone. The noise put out by EAVE's motors caused a lot of noise in the form of waves to show up in the final test results. To eliminate this, the power going to the Klien electronics needs to be isolated with various filters from EAVE's power. The PCM should be powered by an external source because the battery is only good for a one hour run and then has to be recharged. Replacing the battery will also save weight. For this same reason the VCR could also be run from an external power source.

Other improvements to be made to make the system more convenient is to package the playback amplifiers in its own casing. this would allow data to be played back without bringing the entire assembly to the playback site. An external switch or a timer to turn on the PCM , and start the VCR recording would be useful It would save power, and make it easier handling because it would require one less opening and closing of the tube. To improve the electronics the schematic of the PCM could be studied to try and alter some of the circuitry to pass the dc component of the side scan sinals.

CONCLUSION

The ARSUS project demonstrates through repeated tests the feasibility of autonomously recorded sonar systems. The final test results contained understandable side scan sonar data. Futher efforts towords developing similar systems can expect excellent results.

ELECTRICAL EQUIPMENT SUMMARY

PANASONIC PV-5800 PORTABLE VCR

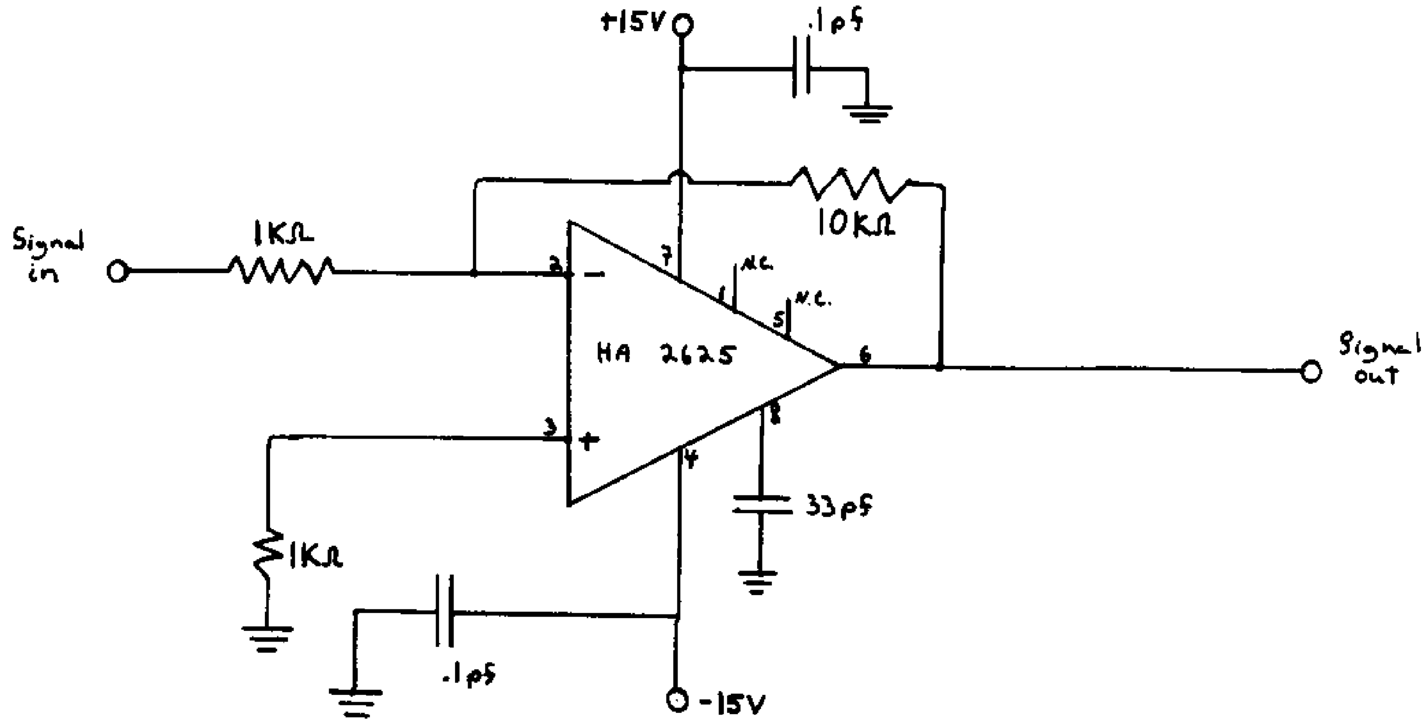
SONY DIGITAL AUDIO PROCESSOR PCM-F1

PLAYBACK AMPLIFIERS

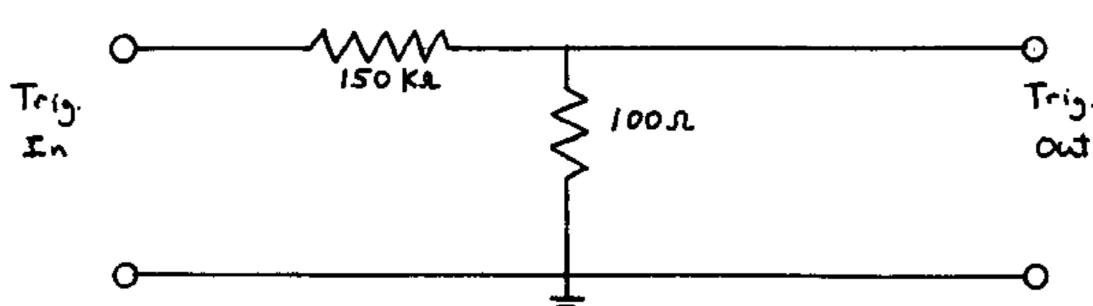
ATTENUATER

KLIEN ELECTRONICS

PLAYBACK AMPLIFIER



ATTENUATOR



CONNECTION DIAGRAM

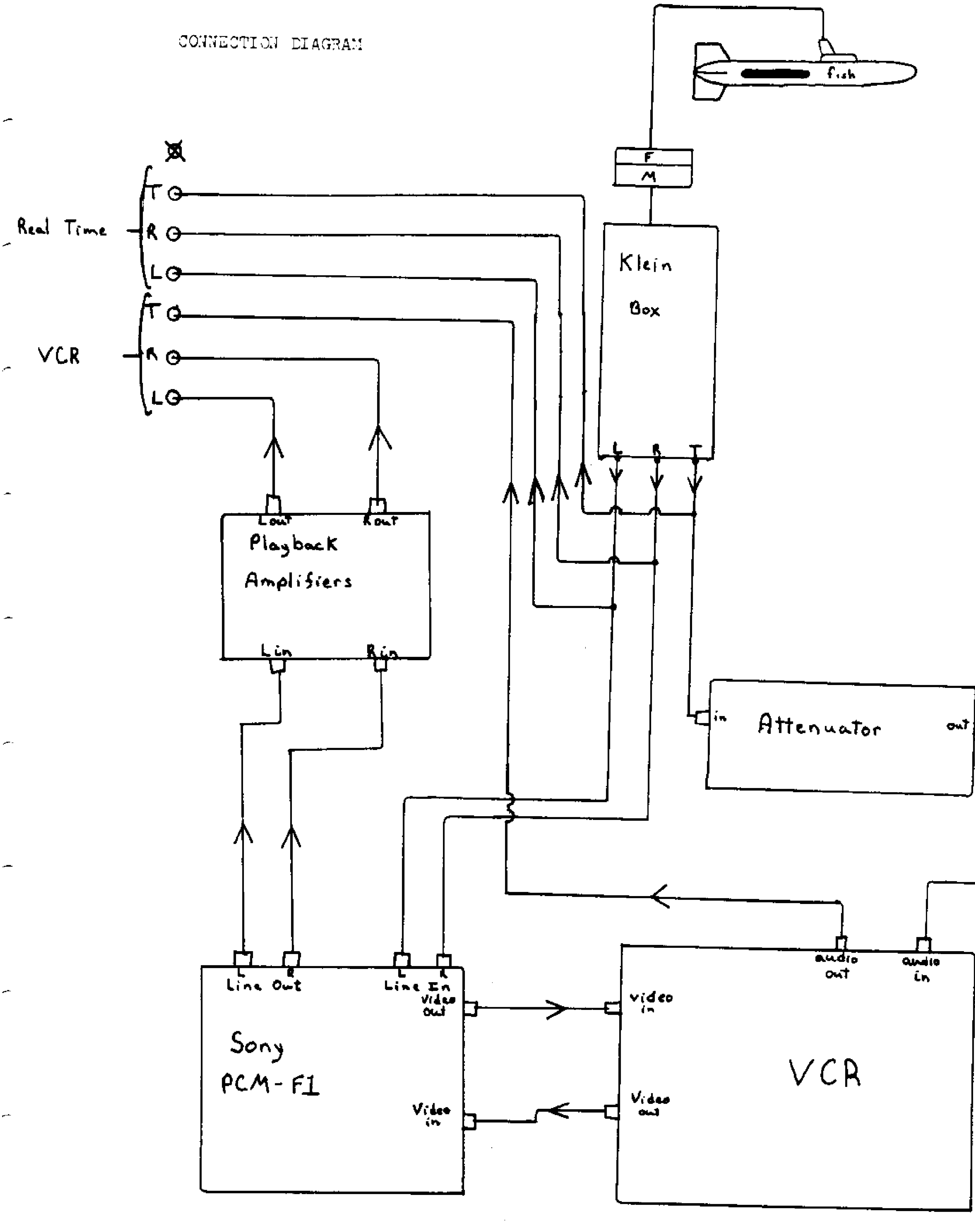


DIAGRAM OF POWER SYSTEM