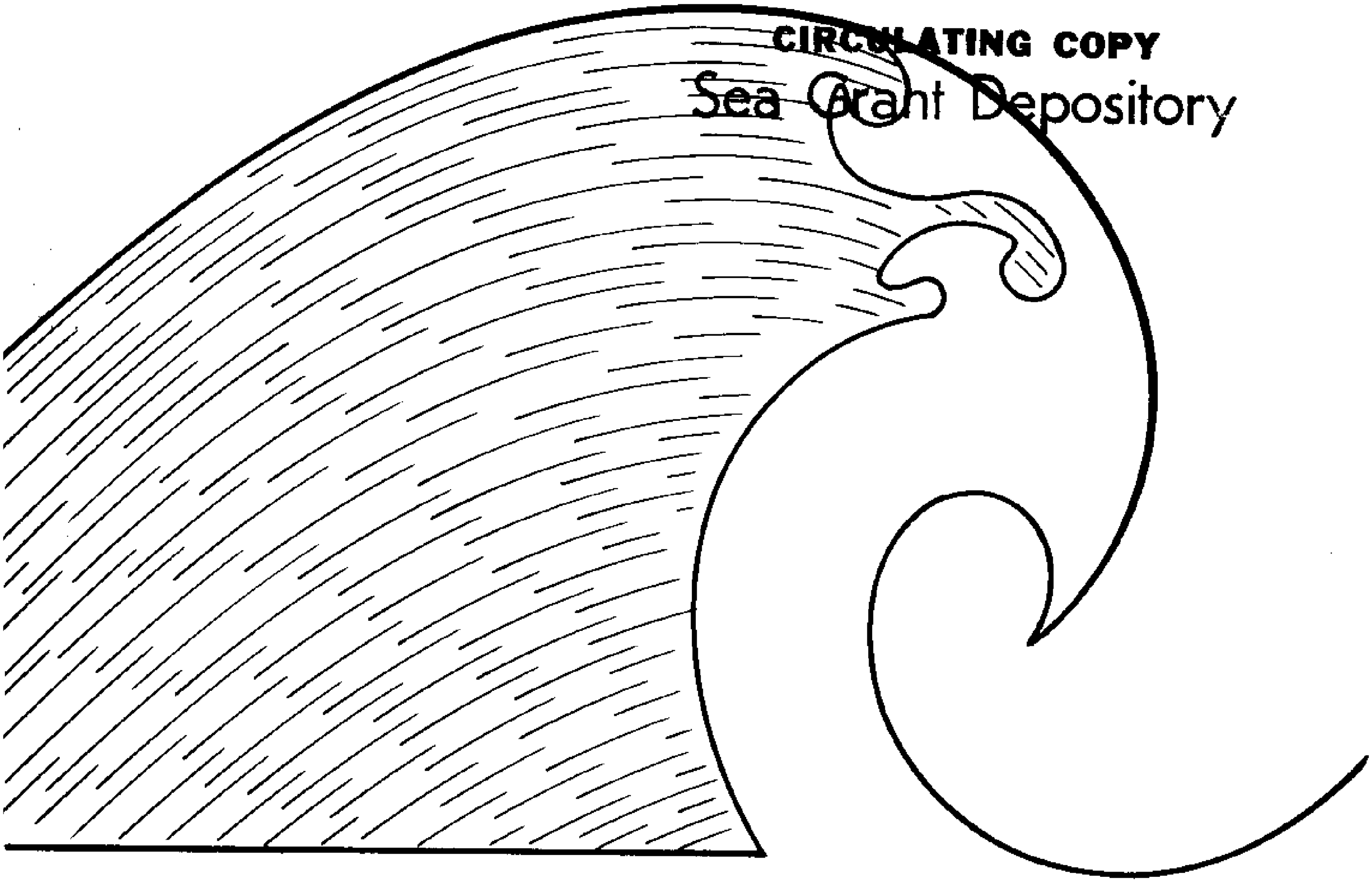

DEPARTMENT OF OCEAN ENGINEERING

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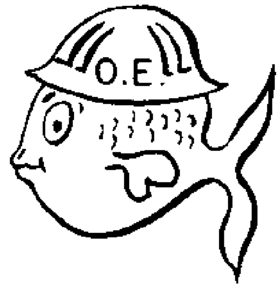
COLLEGE OF ENGINEERING UNIVERSITY OF RHODE ISLAND

Memorandum Number 7M

A D. C. ELECTROMAGNETIC OCEAN CURRENT METER

BY
MARTIN R. LACKOFF

15 SEPTEMBER 1970



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A D.C. ELECTROMAGNETIC OCEAN CURRENT METER

by

Martin R. Lackoff

Prepared for

National Science Foundation

Under

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by

Department of Ocean Engineering

University of Rhode Island

15 September 1970

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ABSTRACT

This report is on the design of a D.C. electromagnetic ocean current meter. Included within are design considerations of a transducer with metal electrodes and permanent magnet field. Also included is a description of a high gain D.C. amplifier with high input impedance and low noise figure.

Difficulties in design and operation are pointed out and include polarization of electrodes, electrochemical potentials, and Hall effect.

Design of this device was undertaken in order to produce a self-contained current meter unit with no external A.C. power required. It was intended that the unit be inexpensive and further adapted to use as an instrument to determine a current velocity profile by lowering the unit slowly.

The project was dropped from BAY WATCH this summer as instrumentation development was determined better developed during winter months, subsequently, it is anticipated that the project will be resumed.

1.0 INTRODUCTION

The prime objective in developing a D.C. electromagnetic current meter was its relatively simple and inexpensive construction (after initial or prototype stage). Due to its theoretically infinite resolving ability, it was also anticipated that this instrument could be adapted to obtain current velocity profiles.

There are several minimum requirements that have to be met to construct this current meter. They are:

1. Permanent magnet (stationary) field.
2. High gain, high input impedance, low noise, D.C. amplifier.
3. Low frequency response only, with fast time constant.
4. Non-specialized electrodes.

As a result of the above requirements there are several pronounced problems that must be anticipated. Some of these difficulties are listed below:

1. Polarization of electrodes.
2. Electrochemical potentials.
3. Hall effect.
4. Low signal to noise ratio.

What will be said below, although no specific reference necessarily will be made, is aimed at solution of these difficulties through meeting the requirements mentioned before.

2.0 BACKGROUND THEORY

Before getting into the details of the system, some information on how the device works should be considered.

According to a law of electromagnetic induction, a time-varying magnetic field will set up an electric current in a closed conducting loop. Conversely, a moving conducting loop over a stationary magnetic field will produce a current in that loop. In either case, if the loop is not closed, a potential difference will exist between the two ends of the loop governed by the following vector equation:

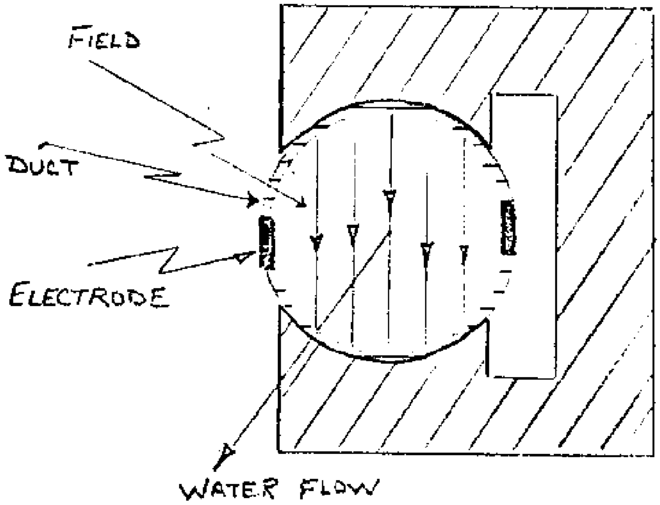
$$v = \oint (\vec{v} \times \vec{B}) \cdot d\vec{l} - \frac{\partial}{\partial t} \oint \vec{B} \cdot d\vec{s}$$

This equation represents Faraday's law of electromagnetic induction.

We should now expect that moving seawater, being a conductor, should be that part of a moving circuit such that measuring a potential difference perpendicularly across the direction of flow is possible, provided that a magnetic field is present. If that field is geomagnetic, we have the device first conceived by Faraday in 1832 and used by von Arx in 1950 called a geomagnetic electrokinetograph (GKE). If we reduce the measurement cross section from the mouth of a bay, required by the GKE, to a small ducted tube, and use a self-contained permanent magnet for a field, we have a useful induction meter. Further mathematical details or proof is not of interest here, as they greatly surpass the scope of this paper. It is incidentally mentioned that the ideas considered above are some of the fundamental laws of the field of magnetohydrodynamics.

3.0 TRANSDUCER DESIGN

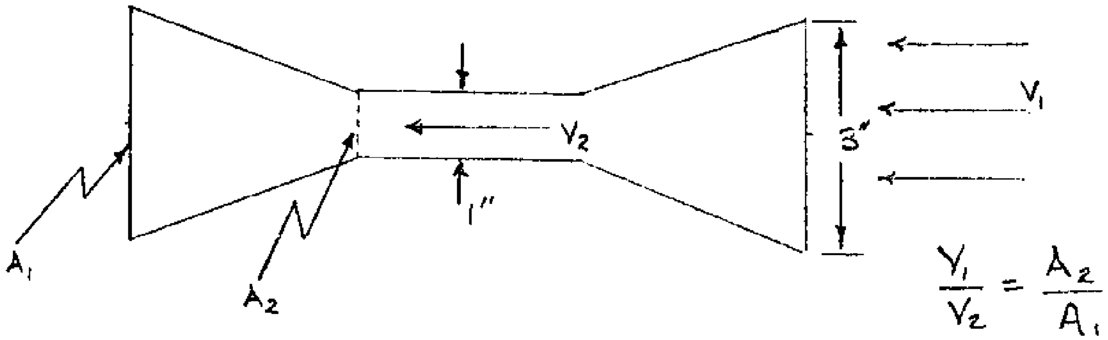
The transducer consists of a tube with two electrodes mounted inside. Orthagonal to these electrodes are the two pole pieces of a permanent magnet. The transducer may be schematically represented at the top of the following page. The reason for orthogonality lies in maximization of the vector cross products, which is more obvious in the derivation.[5]



It has been found in general that special electrodes made of calomel or silver/silver chloride were necessary in order to prevent electrochemical polarization. It has been anticipated by this author that if extremely small amounts of current is drawn via a metalic conducting path (the amplifier circuit), that special electrodes are not necessary, and that any reasonably corrosion resistant metal such as Cu, Pt, or Ti should be suitable. This point will be discussed in more detail when the requirements of the D.C. amplifier are considered.

The cross section where this induced voltage is picked off is a circular, one inch inner diameter tube. A quick calculation assuming water velocity of 10 cm/sec., and 1000 gauss magnetic field gives a voltage of about 2.5 millivolts. A higher velocity flow would yield a larger voltage reading. However, if the difference in water velocity was only 1 cm/sec then the change in voltage would be .25 millivolts--(not a very substantial change for purposes of signal detection). It would then be desirable to force the velocity within the detection tube to be faster than the outside flow for a water velocity increase of 1 cm/sec--a change of 9 cm/sec would suffice.

This can be done by constructing a Venturi type of detection tube where the opening to the transducer would be 3 inches in diameter tapered down to the 1 inch detection tube, and then taper back up to the three inch diameter as shown below.



The velocity in the small tube varies as the inverse of the ratio of cross sectional areas, large (3" diameter) to small (1" diameter). This should make the unit very sensitive to changes in velocity of the surrounding medium.

Frictional effects have not yet been considered, but it is anticipated that these effects will prove to be a limiting factor in the venturi tube design

4.0 D.C. AMPLIFIER DESIGN CONSIDERATIONS

The D.C. amplifier must have a high input impedance so that an extremely small amount of current will be allowed to be drawn through the electrodes. As mentioned previously, any current drawn through the electrodes will enhance the undesirable process of electrochemical polarization. MOSFET's are available which provide input impedances of typically 10^{11} to 10^{12} ohms. Thus an input stage utilizing these FET's for impedance matching would be desirable.

The input stage would be a complimentary pair of FET's (one P channel and one N channel) arranged as a ground reference differential amplifier. The source coupling potentiometer is tapped to ground. Thus we would be able to balance the differential pair, hopefully to null out fixed value electrochemical potentials. Figure 1 shows the input stage of the amplifier. It is noted that at this point in the circuit we wish to have as low a noise level as possible. Hence, FET's with low noise characteristics should be used.

When measuring a D.C. voltage between the drains of the FET's of the input stage, it will always be above or below ground (depending on polarity) with the signal voltage superimposed on it. This is due to the biasing of those transistors. Since we wish only to detect and amplify the signal, it is necessary to remove the bias voltage. The bias voltage may be eliminated from detection by means of a level shifter. This essentially shifts the detected signal to a level where the bias voltage is at ground potential and the superimposed signal can deviate from ground. One for each FET is needed.

It is noted here that until level shifting is accomplished, the detected voltages are not differentially amplified. One configuration permits differential amplifier saturation to occur thereby losing the signal by clipping.

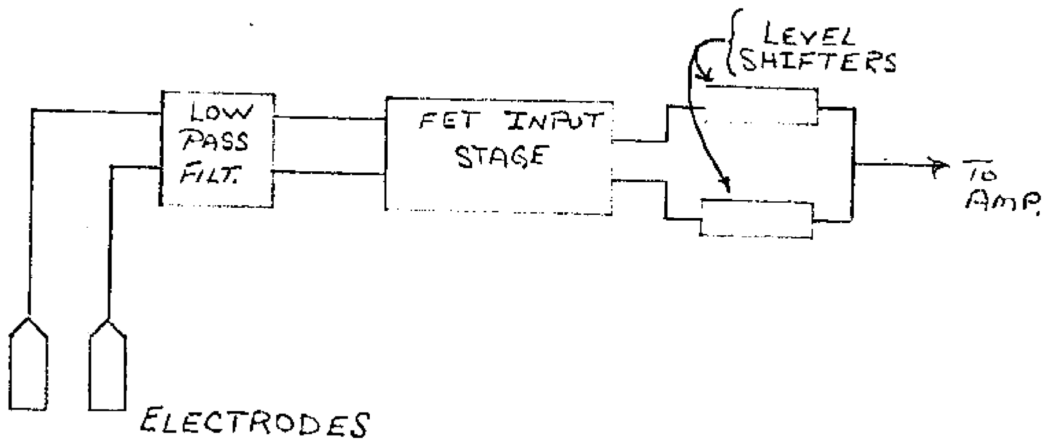


Figure 1: Block Diagram of the Input Circuit

Alternately input inversion at the differential amplifier input would force an output of zero to always be present.

The output of the differential amplifier is then passed through an operational amplifier for signal voltage gain. A 1000-times amplifier is considered, but any value of amplication can be used to obtain a desired output level. Any standard operational amplifier can be used. However, one with a low noise figure would be most desirable.

The entire amplifier package must have low frequency response, preferably below 5 Hertz. This will not only limit the wideband thermal (assumed "white") noise, but would reduce fluctuations of velocity due to orbital water particle motion due to waves. It is important that the roll-off characteristics of the filter be as steep as possible, for example, as much as 20 db down at 6 Hertz, if this requirement is possible. Probably an active filter would be able to supply this sharp roll-off. The filtration would probably best be designed into the feedback of the operational amplifier. In fact if the active filter can be designed with enough gain it may replace the operational amplifier. However, the most practical design may be to place it just in front of the operational amplifier filtering the signal before amplification, and probably supplying several db of extra gain.

As an alternative to the above described amplifier another configuration was evaluated. It was what will be termed here as a "one-sided amplification." The signal from only one electrode was amplified, while the other was used as the return part of the circuit. Hence, the amplifier was floating. It is the opinion of this writer that this system would not be feasible here due to the low signal-to-noise ratio, as all extraneous potentials (thermal, chemical, etc.) are also amplified with no hope of balancing them out. Thus the differential approach is recommended.

Another addition to be considered for the above D.C. system amplifier is synchronous chopping (input and output). A.C. signals are easier to amplify without many of the previously cited problems. Also, A.C. coupling may be used, which will possibly eliminate the need for level shifting. Details of this must still be investigated to determine its feasibility. A block diagram of the amplifier section is given in Figure 2.

5.0 PROBLEM SUMMARY

The problems of this system lead to almost a paradoxical amplifier. The amplifier calls for high gain and high input impedance yet low noise and good stability. It must be able to amplify D.C. signals in a large noise field. Also it should filter out essentially all frequencies superimposed on the D.C. signal above 5 Hertz. This may seem to call for a very sophisticated system, and indeed this will undoubtedly prove to be the case. Fortunately, some sophistication is built into integrated circuit components, and with proper adaptation of these circuits the problem of obtaining good D.C. amplification at low cost is not insurmountable.

6.0 OTHER CONSIDERATIONS

These considerations are essentially self-explanitory and merely listed below:

1. Streamline housing for transducer to reduce hydrodynamic drag and hence, erroneous readings.
2. Calibration of transducer in a flume.

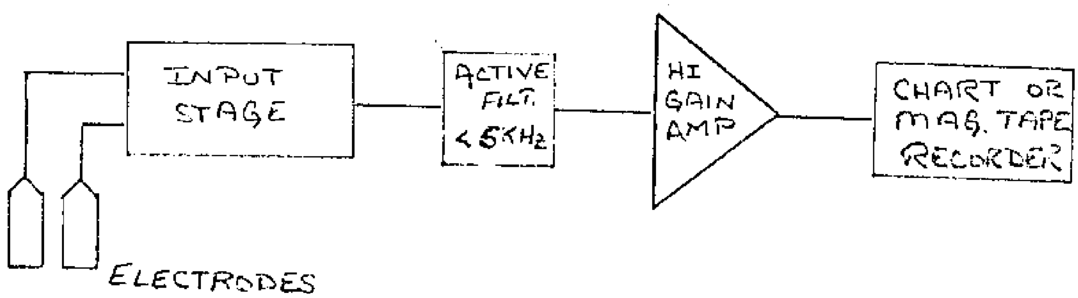


Figure 2: Block Diagram of the Amplifier Section

7.0 PROGRESS TO DATE

This project was suspended in late July 1970 as it was determined that to the overall BAY WATCH summer program, it was more important to be taking data. It was determined that such an instrument would be useful to the BAY WATCH program but that its development, as well as that of other instruments should be undertaken during the winter months when field data is more difficult to take. It is expected that this project will be resumed during the 1970-1971 winter.

BIBLIOGRAPHY

1. Feder, W., and E. B. Bay: "The D.C. Electromagnetic Flowmeter and its Application to Blood Flow Measurement in Unopened Bessels", Trans. Jour. Radio Engrs., ME-6 240, 1959.

2. Horrer, Paul L.: "Methods and Devices for Measuring Currents", Estuaries, AAAS, 1967.

3. Johnson, J. W. and R. L. Wiegel: Investigation of Current Measurement in Estuaries and Coastal Waters, State Water Pollution Board, Sacremento, California, Pub. #19, 1958.

4. Lamb, H.: Hydrodynamics, Macmillan & Co., London, 1932.

5. Longuet-Higgins, M. S., Stern, M. E., and H. Stommel: "The Electrical Field Induced by Ocean Currents and Waves with Applications to Towed Electrodes", Pap. Phys. Ocean & Metero., WHOI, 1954.

6. Shercliffe, J. A.: Electromagnetic Flow Measurement, Cambridge University Press, 1962.