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I.O.S.

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INSTITUTE OF OCEANOGRAPHIC SCIENCES

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1. INTRODUCTION

During the use of electronic instruments in the I.O.S. wave tank, several forms of electrical noise have appeared, sometimes interfering with instruments and causing errors or difficulties in measurement. D.C. gradients, 50 Hz supply frequency, radio frequency, and random noise from various sources have been found to be present in the water. Some measurements of these types of noise are described, and their origins and methods of reducing them are discussed.

2. THE TANK AND CARRIAGE

The wave tank at the Institute of Oceanographic Sciences, Wormley, is 50 metres long and 2 metres wide, and is filled to about 2 metres depth with fresh water with a chlorine additive to prevent the growth of algae. Its orientation is within a few degrees of a North/South line. At the North end there is a wave generator, and at the South end an energy-absorbing beach. A mobile carriage, equipped with an electro-hydraulic drive system, spans the width of the tank, running on steel rails on the side walls. 230 volt, 50 Hz single-phase power is supplied to the carriage by enclosed conductor rails and brush contacts along one wall.

As the earthing of equipment, and the possible presence of earth current loops, may be significant in dealing with electrical noise, the earthing and interconnections of the tank and carriage components are described here, and shown schematically in Fig. 1. The carriage chassis is connected by a brush contact to the earth conductor of the 230V supply along the tank wall, and the wiring to this system is connected at the South end of the tank. The steel rails on which the carriage runs are connected together at the North end by a heavy copper cable, but have no fixed connection to the supply earth. A further 5 metre length of cable is provided to enable them to be earthed if desired, but any such connection would be, in terms of conductor length, 50 to 100 metres distant from the earth connection to the carriage, depending on its position along the tank. Otherwise, the rails are only earthed in so far as they are connected to the carriage via the rolling contact of the wheels. The significance of this point will appear in the discussion of noise generated by the motion of the carriage.

3. TYPES OF NOISE AND METHODS OF MEASUREMENT

The tank is frequently used to test and calibrate current meters and other instruments. In particular, the Institute uses electromagnetic current meters for a variety of tasks, and it is mainly during the operation of these instruments in the tank that interference and noise have appeared, as an electromagnetic flow sensor will inevitably pick up any potentials present in the water, in addition to the signal induced by flow through its own magnetic field. However, the effects of interference on these or any other instruments are not discussed in detail here, nor has any precise mapping of the distribution of noise, or the mechanisms by which it reaches the tank, been attempted. The intention is rather to describe the forms and approximate magnitudes of noise which may be encountered. Qualitatively, they may be categorised as follows:-

D.C. gradients, probably caused by electrolytic action
50 Hz and related components
Radio-frequency noise
Noise generated by carriage movement

All of these forms of noise were first noticed during the operation of electromagnetic current meters, appearing as interfering signals at the electrodes. This suggested that a more methodical investigation of noise could be made, using a 'noise probe' consisting of a pair of electrodes a short distance apart, connected by sealed and screened leads to a differential amplifier (see Fig. 2). Common-mode A.C. measurements could also be made between a single electrode in the tank and an external reference level having some finite impedance to it, which in practice must mean the local main supply earth.

For differential A.C. measurements, the amplifier was similar to that normally used for a current meter input stage; i.e. an instrumentation amplifier having a voltage gain of 2000, with the inputs capacitively coupled to the probe electrodes and biased by 1 Megohm resistors to ground. In this mode, the amplifier bandwidth was about 3 kHz, with the low frequency response extending down to 2 Hz. For D.C. gradient and common-mode A.C. measurements, signal levels were up to 3 orders of magnitude higher, and the amplifier gain was reduced to 10. The D.C. measurements also required the probe to be directly coupled to the amplifier, and were found to be less affected by polarisation at the electrodes if a higher input resistance was used. This was achieved by using LM-II low bias current amplifiers in place of the OP-10, and removing the 1 Megohm bias resistors. Fig. 2 shows the probe, electrode detail and amplifier circuits.

The amplified noise signals were observed and measured on an oscilloscope. It was considered that no very high order of accuracy was required for this kind of survey; all figures given are considered accurate to within plus or minus 20 per cent, and all are for input signals, i.e. voltage at the electrodes. A.C. and random or transient noise values are given as peak-to-peak amplitudes, as the waveforms encountered are sometimes not easily quantified as r.m.s. values. At times when it was preferable to use a fully floating measurement system, avoiding any connection with the main supply or earth, both the amplifier and oscilloscope were powered by batteries.

4. D.C. GRADIENTS

The presence of D.C. potential gradients in the tank was suspected, prior to this survey, from certain features of current meter behaviour. In particular, when the orientation of an electromagnetic sensor was changed, the amplified electrode voltage would sometimes show a transient change related to the direction of rotation. No errors of measurement were identified as resulting from this source, but it was thought that an attempt should be made to confirm its principal features.

Voltage measurements by means of electrodes in a conductive fluid are notoriously subject to error from polarisation potentials developed at the electrodes themselves, unless non-polarising combinations of materials, such as silver/silver chloride electrodes in chloride solutions, are used. In the present case, using a pair of Monel electrodes and the high input resistance amplifier of Fig. 2c, polarising potentials of up to 120 millivolts were found. The electrodes being identical, there is no preferred polarity; reversals of polarity and changes of magnitude can occur from various causes: for example, electrode surface contamination, fluid flow or agitation, and external loading or an impressed potential from another source. Thus the only way of measuring a D.C. gradient in the fluid is to convert it to an A.C. signal with respect to the electrode pair, either by continuous rotation of the probe to give a sinusoidal variation of voltage, or by observing short-term changes of voltage consequent on, and consistently related to, changes of probe orientation. For the present purpose, the mechanical complexity of a continuously rotating probe was not considered justifiable, and the method of noting changes of voltage with incremental rotation was adopted.

A potential gradient in a body of liquid has a specific magnitude and direction at any location. It was possible therefore, by mounting the differential probe with its stem vertical and electrodes in a horizontal plane, to measure the gradient in this plane by rotations of the probe. For example, a small clockwise rotation, say through about 10 degrees, from a given starting orientation, might consistently produce a positive-going change of the amplified electrode voltage. If the probe was then rotated through 180 degrees, to interchange the positions of the electrodes, a similar 10 degree rotation, again clockwise, would produce a negative-going change.

By trial and error, a starting orientation could be found for which the 10 degree incremental rotation gave no definite change of voltage either way. This condition would of course occur when the electrodes were aligned with the direction of maximum gradient, and a further 180 degree rotation would then give a change, at the electrodes, of twice the difference between them when stationary.

Measurements were made in this way at intervals of 2 metres along the centre line of the tank, giving a profile of the D.C. gradient in the horizontal plane. This is shown in Fig. 3a, the gradient being given in millivolts for the electrode separation of 30 centimetres. If it is assumed that these local gradients are representative of the full 2 metre intervals at which they are made, and are scaled accordingly, then the resulting voltage level profile along the tank can be obtained by integration of the gradient profile. This is shown in Fig. 3b, and suggests a region of low level near the centre of the tank, with potential rising to about 170 millivolts higher at each end. An attempt was made to check this by removing the electrodes from the probe stem and extending the leads to allow measurements to be made between points up to 20 metres apart. The time taken to change electrode positions, and the greater delay in taking a reading following a change, certainly introduced larger errors from polarisation potentials, but measurements between the North end of the tank and a point 20 metres distant showed an overall gradient close to that of Fig. 3. The mean of six readings taken was about 180 millivolts, although individual values varied considerably, from 50 to 380 millivolts.

For all these measurements, the electrodes were immersed to a depth of 25 centimetres. Occasional measurements at about 1 metre depth at a few locations showed little change of gradient with depth, and no further measurements in the vertical plane were attempted.

The origin of these D.C. gradients remains a matter of conjecture, but in the absence of any obvious external source, it seems probable that they are caused by electrolytic action at metal surfaces in the tank, such as the steel frames of the observation windows. At the time when these measurements were made, quite heavy corrosion, and some leakage of water from the tank, was occurring at some of the frames, and Fig. 3 shows a sharp change of gradient at the South end, where there are windows on both sides of the tank.

5. **50 HZ AND RELATED COMPONENTS**

Noise at the 50 Hz supply frequency, and related harmonic frequencies, is always present to varying degrees, at levels high enough relative to the supply earth to be displayed on an oscilloscope without prior amplification. The signal at a single electrode in the tank typically appears as an irregular waveform of 20 to 40 millivolts, with higher frequency components in a constant phase relation to the 50 Hz component, and at large amplitudes, as would be expected if energy transmission into the tank is largely inductive or capacitive (see Fig. 4a). These higher frequencies are probably generated by equipment in which commutative or cyclic switching of the supply occurs, and sudden changes of the waveform, or transient peaks of higher amplitude, often occur as nearby equipment is switched on or off. The North end of the tank is only about 10 metres from the Institute's main workshop, welding shop, and assembly area, all of which contain equipment drawing fairly high currents from the supply. In general, noise levels decrease towards the South end of the tank, which is further away from these facilities.

Differential measurements with the probe and amplifier showed generally similar periodic and transient noise, with a level of the order of 10 microvolts at the electrodes (see Fig. 5a). In this mode, a clear phase reversal could be seen when the probe was rotated through 180 degrees.

A point worth notice in connection with instrumental work in the tank is that a large increase in this differential noise level can be caused by the introduction of an earth point into the water. If the noise field is represented three-dimensionally, with variations of noise level in the horizontal plane shown as variations in the height of a surface relative to an earth reference plane, then an introduced earth point can be seen as distorting the surface into a cusp, producing a local increase in gradient. This effect could be shown experimentally by dipping an earthed wire into the water and moving it around the probe. With the earth point at 1 metre from the probe stem, and in line with the electrodes, i.e. closer to one electrode than to the other, the differential noise increased from 10 to 100 microvolts. As the earth point was moved in a semi-circular path round the probe, the level decreased to a minimum at the half-way point, where the earth point was equidistant from the electrodes, then increased again, with reversed phase, as it completed the half-circle.

This effect probably accounts for an increase in noise sometimes seen at curent meter outputs when the sensor is mounted on a spar which is in contact with the carriage, and also extends below the water surface. As a general rule, this condition should be avoided, by mounting the spar in clamps or bushes made from an insulating material.

6. RADIO-FREQUENCY NOISE

Long and medium-wave broadcast RF interference has been observed in the tank in two cases. In one case, a few current meter input circuits using OP-10 operational amplifiers were found to be broadly tuned to common-mode input signals at about 200 kHz, and also to rectify them. In good signal propagation conditions, usually late in the afternoon, an electromagnetic flow sensor in the tank would give an AF output of about 20 millivolts from the input amplifier. This was strong enough to be audible on a small earphone, and was identified as the BBC Radio 4 transmission at 200 kHz. In the other case, a Doppler sonar current meter being tested in the tank was affected by RF signals close to its own working frequency of 1 MHz, which were picked up at the transducers in the water. No attempts have been made to carry out an overall survey of RF conditions in the tank.

7. NOISE GENERATED BY CARRIAGE MOVEMENT

The most troublesome interference with instruments in the tank comes from an increase of 50 Hz and random wide-band noise which occurs when the carriage is moving, and particular attention has been given to finding the cause of this, and possible ways of reducing it.

From the outset, the largely random nature of this noise suggested that it must be caused by intermittent or varying contacts somewhere in the carriage and rail system. The first suspected components were the contact brushes of the carriage power supply system, and the rotary wire brushes fitted to the carriage, which rotate in contact with the rails as the carriage moves, to keep the rail surfaces clean. After substituting a trailing cable for the normal power supply, and removing the wire brushes, it was concluded that although both contribute a little noise to the total, neither of them is the major cause. Finally, the cause was found to be intermittent or varying contact between the carriage itself and the rails, as it moves.

Resistance measurements between the carriage chassis, wheels, and rails, with the carriage at rest at various positions along the tank, gave values ranging from 2 ohms to 30 ohms. A very small change of position, or even someone moving about on the carriage, was often enough to cause a large change in these contact resistances. Thus it seems that in spite of the high contact pressures involved, the presence of a compressed layer of surface contaminants on the rails, and of lubricant in the wheel bearings, prevents constant low-resistance contacts being made at these points. The resulting condition is that while the carriage is properly earthed via its main supply earth, the rails are only intermittently or partially earthed via the rolling contact at the wheels. As mentioned in Section 2, the rails can be earthed by the optional connection shown in Fig. 1, but the distance of this earth point from that of the carriage results in an earth loop being formed, and no significant reduction of noise is found.

A marked improvement was achieved by fitting an earth lead directly between the carriage chassis and the rails. This lead was a three metre length of thick flexible insulated wire, terminated with spring clips, allowing the carriage to be driven over a distance of about five metres without breaking the connection.

The wave-forms shown in Figs. 4 and 5 were recorded on a digital storage oscilloscope and played back at lower speed to a chart recorder. They show typical common-mode and differential noise levels in the water below the carriage when at rest and in motion, and the improvement effected by fitting the earth lead to the rails.

Figs. 5c, 5d and 5e are of particular interest, as they were recorded under the same conditions, but show different noise waveforms. 5c shows an increase in the 50 Hz component; 5d shows a change of level extending over 50 milliseconds or more, and 5e shows large amplitudes of pulse noise at frequencies up to several kilohertz. Taken together, therefore, these records show the random and wide-band nature of the noise generated by carriage movement. Figs. 4d and 5f show that the earth connection from carriage to rails reduces this noise to a level almost as low as when the carriage is at rest.

A permanent earth connection of this kind would of course have to allow carriage movement over the full length of the tank, and at any speed up to the maximum of about 3 metres per second. A trailing cable should be satisfactory in principle, but might be undesirable on grounds of safety or convenience. An alternative method might be a sliding brush contact on a conductor rail bonded at intervals to the support rail, provided that a constant low-resistance contact could be assured.

8. **CONCLUSIONS**

The measurements described here, together with effects noted during the testing of various current meters, confirm that a wide spectrum of electrical noise, from D.C. to radio frequencies, is present in the wave tank, and may interfere with instruments employing sensitive immersed transducers. However, the effects which have proved most troublesome in practice, those of interference from the 50 Hz main supply, and from the movement of the carriage, can be substantially reduced by specific methods of earthing and instrument mounting.

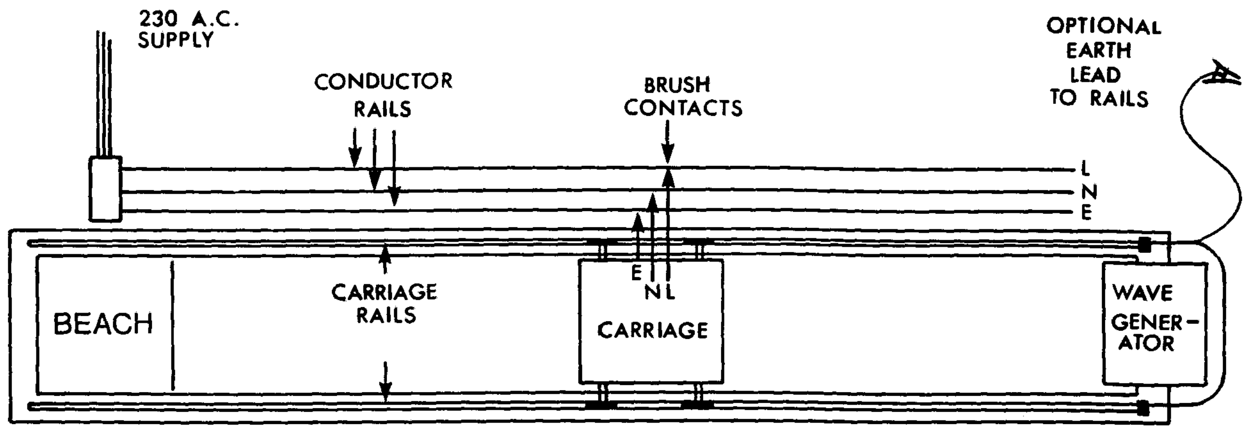
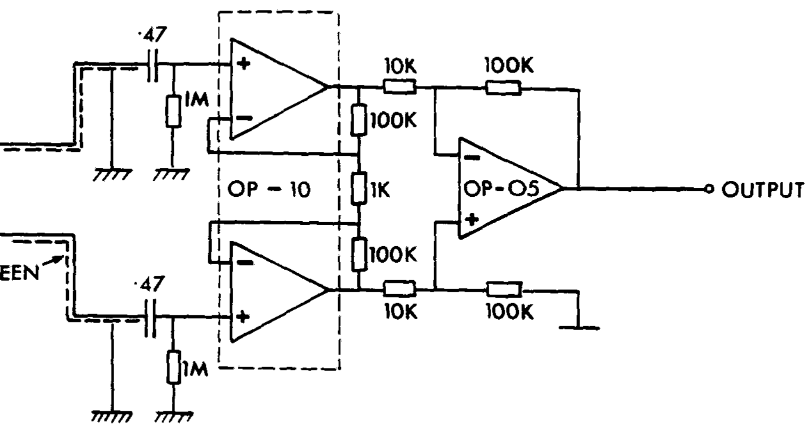


Fig. 1 Schematic of I.O.S. Tank, Showing Carriage Power Supply and Earthing.
(not to scale)



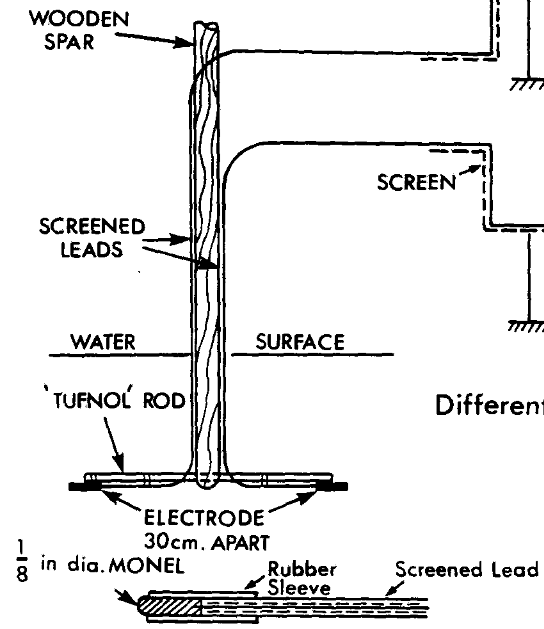


Fig. 2a
Differential Noise Probe and Amplifier

Fig. 2b
Electrode Detail

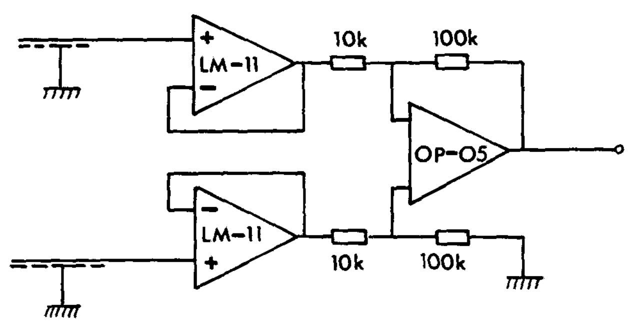


Fig. 2c.
Amplifier for Common – Mode and D.C. Measurements.

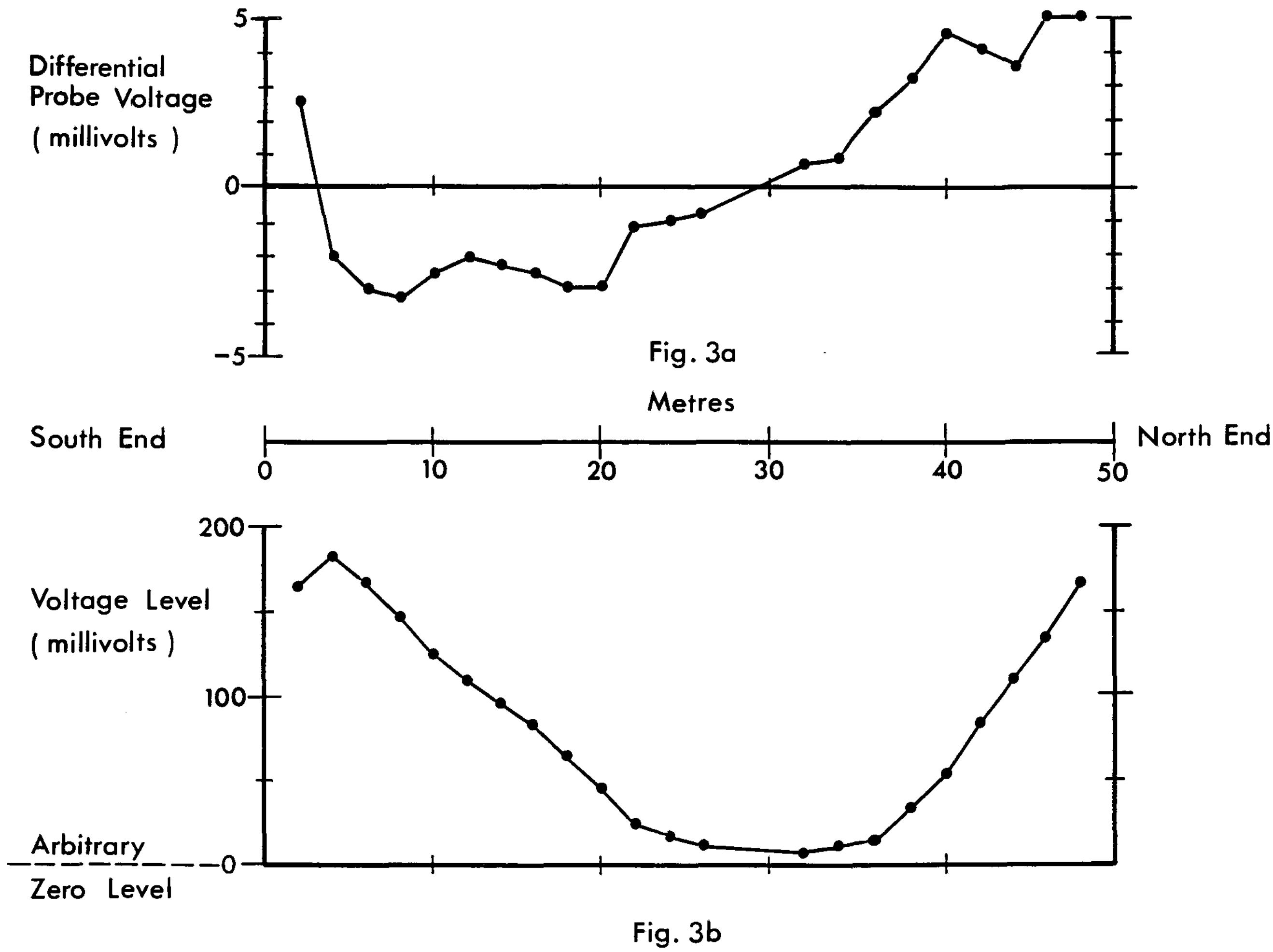


Fig. 3 D.C. Voltage Gradient and Voltage Level along the I.O.S. wave tank.

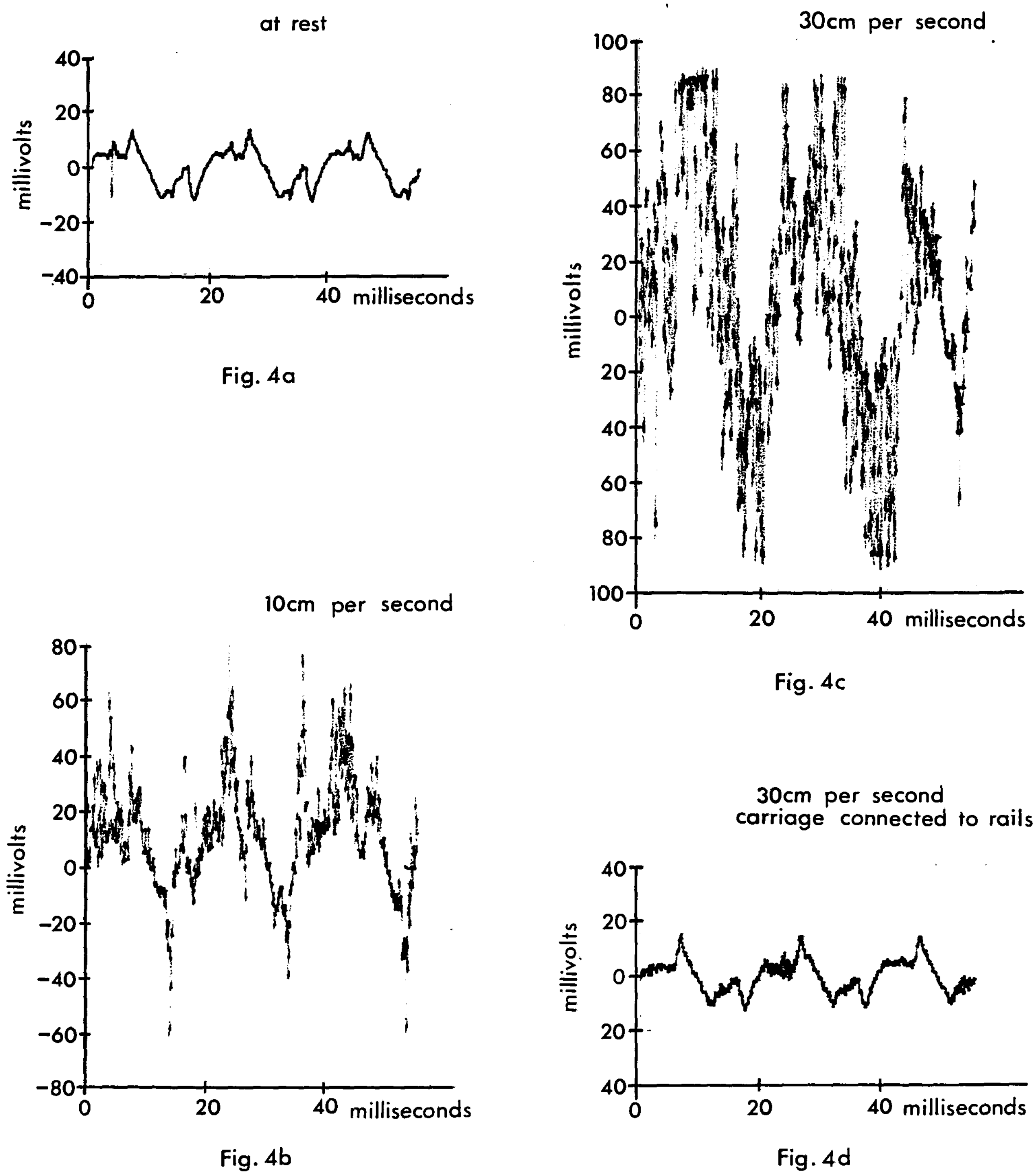


Fig. 4 COMMON-MODE NOISE IN THE TANK, BELOW THE CARRIAGE.

4a Carriage at rest.

4b Carriage moving at 10cm per second.

4c Carriage moving at 30cm. per second.

4d Carriage moving at 30cm per second; rails earthed to carriage.

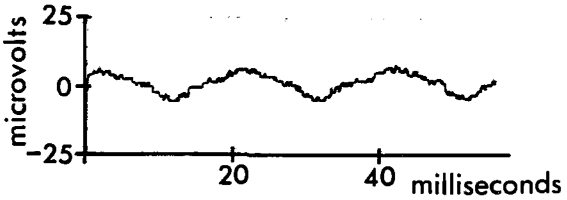


Fig. 5a

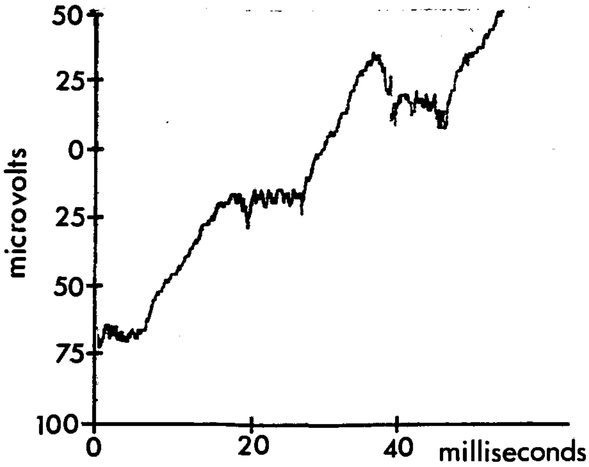


Fig. 5d

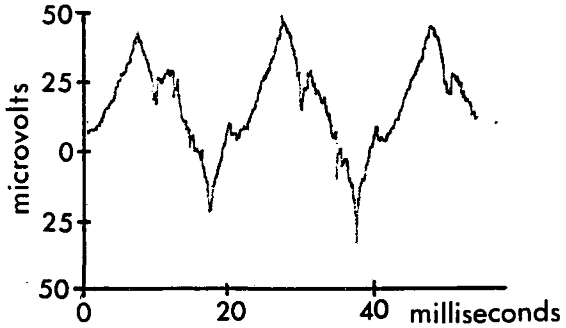


Fig. 5b

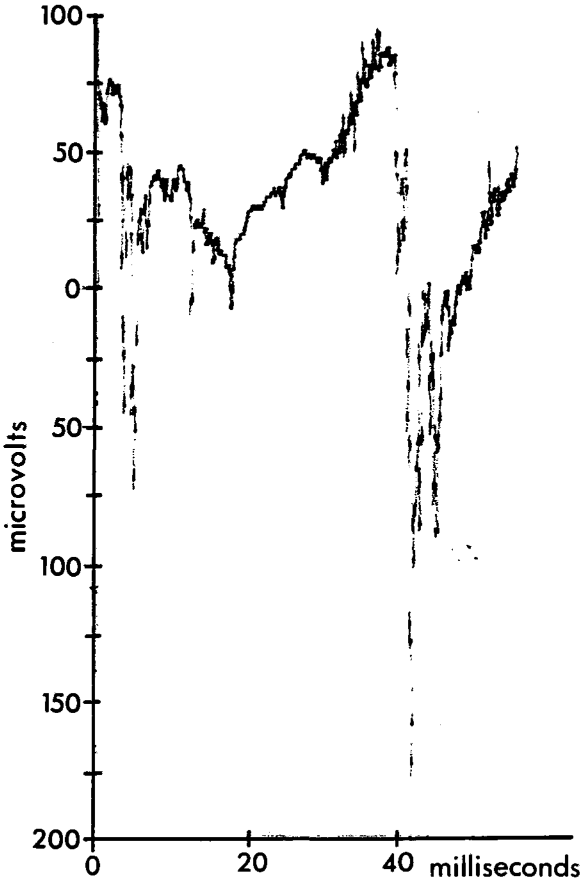


Fig. 5e

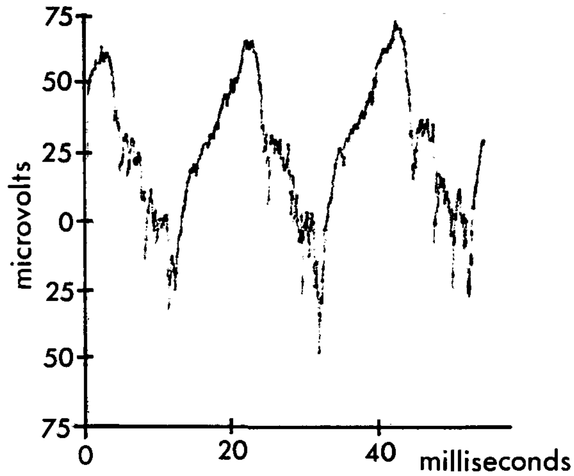


Fig. 5c

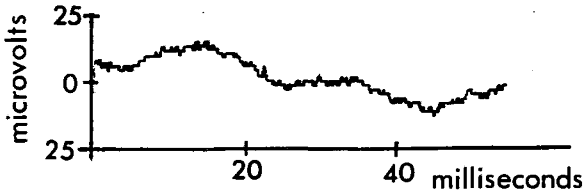


Fig. 5f

Fig. 5 DIFFERENTIAL NOISE IN THE TANK, BELOW THE CARRIAGE. ELECTRODES 30cm APART.

5a Carriage at rest.
5b Carriage moving at 10cm. per second.
5c,5d and 5e. Carriage moving at 30cm per second
5f Carriage moving at 30cm per second: rails earthed to carriage.