The Choice of Sensor Type for Electric Field Measurement Applications

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Abstract

It is relatively straightforward to make electric field measurements in sea water by means of two electrical contact points made with the seawater, with connections to a measuring device or meter. The electric field value measured will be along the direction of the line between the two contacts. This paper will consider the various ways in which the sensing elements used in the measurement process can be optimised to suit a particular application.

Typically the electric fields of interest that are measured in the sea have a frequency range from quasi-DC up to a few kilohertz and amplitudes vary from millivolts per metre to picovolts per metre. These electric fields arise from many different sources including man-made sources (shipping activity, marine cathodic protection systems, offshore drilling rigs, oil pipeline, shore based power utilities, electromagnetic surveying) and natural sources (motion of the sea water in the earth's magnetic field, induced electric fields arising from changes in the geomagnetic field, ionospherically induced electric current flow, geological sources and marine life).

We will consider the particular requirements of vessel ranging, surveillance and geophysical survey with regard to sensor design including:

- the electrode spacing
- number of sensor axes
- the shape of the sensor housing
- choice of sensing element
- electrode design
- application of Boundary Element modelling

One example that will be analysed with regard to the various factors listed above will include a typical 1m diameter sphere electric field sensor with a noise level specification of order 1nV/m per root Hz.

Introduction

This paper focuses on how electric fields occur in sea water and how they can be measured. The design of a sensor can be optimised to meet the detection requirements of a particular application. A complete measurement system may be designed to enable timely data acquisition and data analysis to be performed in the given scenario.

An electric field is the voltage gradient along a defined direction in the given medium, usually expressed as volts per metre. In the sea, electric fields are caused by electric current flowing through the water, giving a voltage gradient as a result of the water resistivity. The electric fields measured in the sea have a frequency range from quasi-DC up to a few kilohertz and amplitudes vary from millivolts per metre to picovolts per metre.

Electric fields arise from many different sources which can classified into two main categories:-
a) Natural sources
b) Man made sources

Natural sources of electric field

Electric fields measured in seawater have components that vary with frequency and also with depth. Electric field levels are highest near the sea surface due to turbulent wave motion and also because signals from sources propagating into the sea are attenuated due to the conductivity of seawater. Figure 1 shows the measured electric field levels in open ocean. However many measurement sites, e.g. vessel ranges, are located in shallow water coastal areas and estuaries. Figure 2 shows the results for an estuarine site with local noise sources from shipping and ship yards in close proximity. It can be concluded that the sensor performance required for a particular application depends to a large extent on the level of background noise in the local environment where the sensor will be deployed. A summary of the common types of noise sources are detailed below.

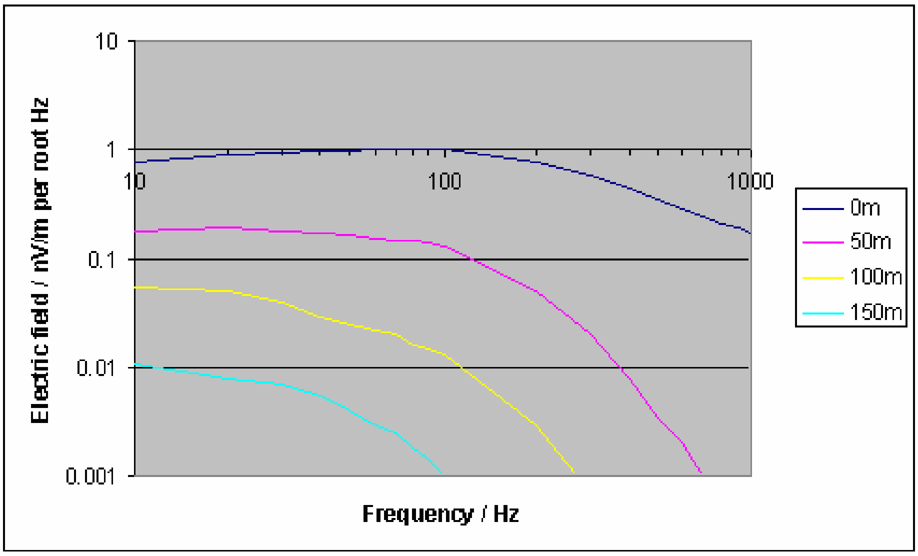
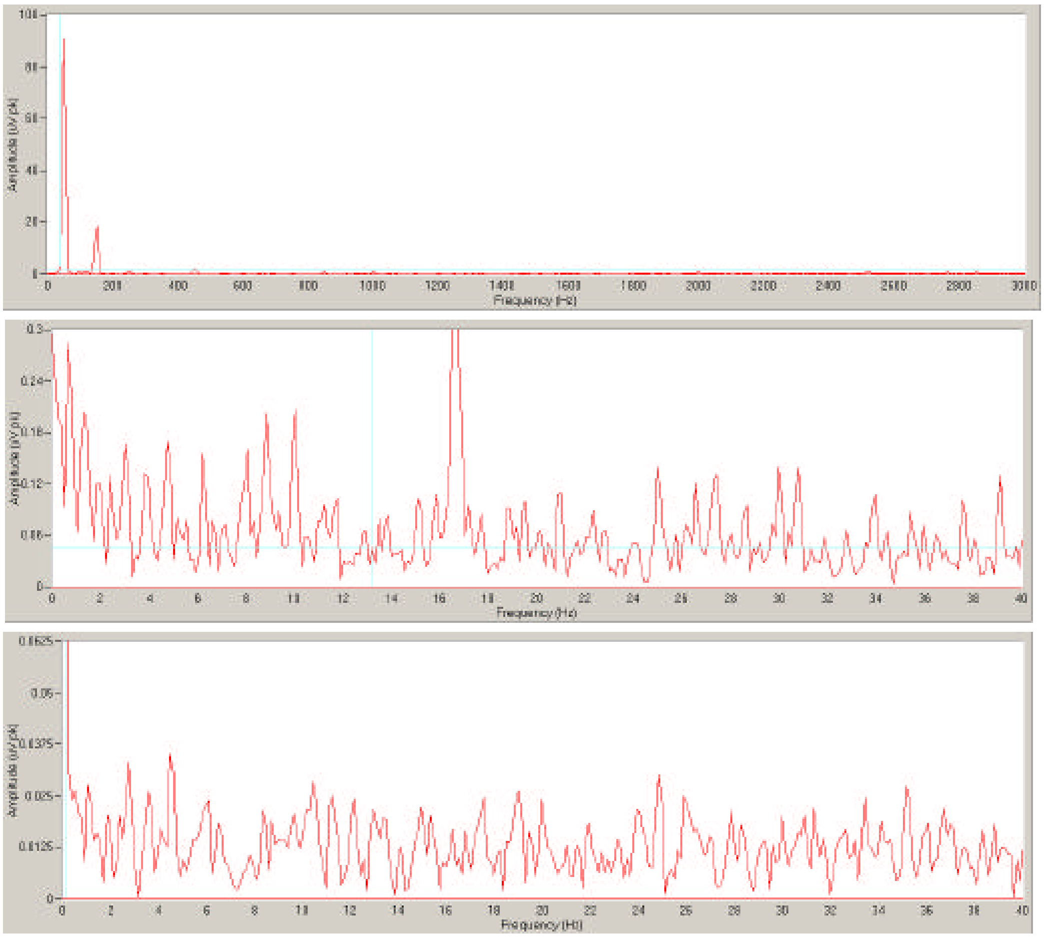


Figure 1 Dependence of background electric fields in open ocean on frequency and depth (after Cox and Chave)



a) b) c)

Figure 2 Measured spectra for an estuary area close to shipping channel a) 0-3000kHz potential spectrum with 50Hz and harmonics, b) 0-40Hz spectrum with shipping and site noise and c) 0-40Hz spectrum at quiet period

Electric fields induced by seawater motion

The electric fields induced by seawater motion, have been examined in great detail by a number of researchers [2]. The various types of water motion give rise to different amplitudes and frequencies of electric fields.

Surface water waves induce electric fields at frequencies corresponding to the wave frequencies. This gives a band of frequencies from around 0.08 Hertz to 0.5 Hertz. The largest amplitudes come from long ocean swells, with a period of approximately 0.1 Hertz. There is a peak at 0.2 Hertz, when measured on the sea bed, caused by non-linear interaction between opposing long ocean swell wave trains. Tidal flow gives rise to large amplitude horizontal electric fields on the continental shelf regions whenever tidal flow rates are large. The fields have a period of around 12 hours, and amplitudes may be as large as 100's of microvolts per metre, for regions with high tidal flow rates. The field amplitude is proportional to the vertical component of the Earth's magnetic field multiplied by the horizontal velocity of the water flow.

Internal waves and turbulence also generate electric fields. The dimensions of turbulent water flow, in water depths less than 200 metres, is limited vertically, but horizontally may extend for hundreds of metres. Internal waves and turbulence are caused by tidal mixing and convection currents. The electric fields generated may amount to several tens of microvolts per metre. Long-period gravity waves have wavelengths up to 20 kilometres, and periods up to 100 seconds. These will give rise to electric fields with a lowest frequency of 10 milliHertz.

Electric fields induced by changes in the magnetosphere

The Earth's magnetic field has both a static component and time varying component. The varying part can induce electric current flow in the earth and the sea, so giving a varying electric field. Plasma from the sun confines the Earth's magnetic field within a region called the magnetosphere. Solar activity causes alterations in the magnetosphere which give rise to time-varying magnetic fields. Magnetic storms have very large amplitude changes, up to 5000 nT, lasting for several hours. There are also short-period variations, or pulsations, with a wide frequency range. The different types of variation are listed in reference 1. The induced electric field variations can be of the order of tens of microvolts per metre with the induced field depends on the change in magnetic field and the effective impedance of the medium at the relevant frequency.

Electric fields induced by ionospheric currents

Lightning discharges in the troposphere are the major source of electric field noise from 5 Hertz up to 1 kilohertz. The cavity formed between the earth and the ionosphere has a number of resonant frequencies which enhance certain frequency components of the energy from lightning strikes. These resonances are called the Schumann resonances, and have frequencies of 7.8, 14.3 and 21 Hertz, for the strongest components. The resonant peaks have a broad spectrum, and the centre frequencies vary from daytime to night-time. The magnitudes of the electric field levels vary depending on the intensity of lightning activity at the time. Fields can be as high as a few nanovolts per metre.

Geophysical sources of electric fields

Conducting ore-bodies under the seabed can generate electric fields. The self-potential method for metal ore prospecting has been used for many years, and is based on the detection of the electric field produced by electrochemical reactions at the surface of ore-bodies. These can give static electric fields of tens of microvolts per metre, although not much is known about the time-varying nature of these sources. Note that active marine sources are now used in similar way.

In regions of the world which are seismically-active, electric fields are generated in the earth during the build-up to earthquake activity. The mechanism which causes this phenomenon is not yet fully understood, but the occurrence of such signals is well-documented. The signals are emitted in the frequency range from DC to many kilohertz, and amplitudes on land are as large as 500 microvolts per metre. The gradual variation of electric field (GVEF) is the largest signal, and has a time period of up to 30 days. More rapid variations of up to 50 microvolts per metre have time periods of up to tens of minutes. There are emissions in the ULF, ELF and VLF frequency bands are believed occurring a few hours prior to the onset of earthquakes.

Electric fields from marine life

Electric fields from marine life are expected to be low and localised compared to all the other sources of electric field noise in the sea. Most types of fish emit small electric fields and there are some fish (e.g. electric rays) which use electric fields to stun their prey.

Man-made electric fields in the sea

The electric currents flowing between the different metals may be direct currents, or may be modulated in some way, either through intermittent connections, or through turbulent flow altering the electrochemical processes.

The largest signals arise from cathodic protection systems, whereby current is forced to flow from sacrificial or impressed current anodes, into the wetted surface of a submerged metal vessel. Currents vary from a few amperes, in the case of a patrol vessel, to a thousand amperes, in the case of a large oil tanker. Permanent oil installations have even larger cathodic protection currents, up to 10,000 amperes in some cases. Anodes may be attached to the platform, or may be remotely-sited on the seabed. The currents may be from sacrificial anodes, or impressed current anodes, which will then give rise to signals with power frequencies and harmonics.

Submarine pipelines provide a very long signal source, sometimes hundreds of kilometres long, with anodes every hundred metres or so. Long distance electric currents flow between regions of different pipe coating quality and condition. Oil-producing areas will be crossed by a network of submarine pipelines, linking different platforms together. When platforms are electrically-connected to pipelines, which they often are, any changes in the potential of one platform can cause changes in pipe potentials for tens of kilometres. The very low impedances between the platforms, pipelines and the sea, give rise to large electric fields over very long distances.

Welding activities during the construction of offshore oil installations, can give large electric fields as a result of ground-loop currents between the welding barge and the installation being constructed. Land based sources of electric field noise include AC power transmission lines and substations, electric traction systems, light railways, dockside cranes, jetty cathodic protection systems and arc welding at coastal installations.

In recent years active marine sources have grown in popularity for oil prospecting purposes and are used in conjunction with traditional seismic methods to confirm the conducting nature of apparent reservoirs. Currents are of thousands of amperes magnitudes are used to transmit continuous, pulsed or transient signals which are detected with long baseline electric field sensors hundreds of metres away [3].

Shipping

All forms of seagoing vessel will emit electric fields as a result of bi-metallic couples existing between the different metals used in their construction. On an unprotected vessel the two main items that cause corrosion are the steel hull and the bronze propeller. The hull can be protected from corrosion by painting. However the paint layer will not remain intact for very long due to scrapes, defects and other problems and corrosion will tend to penetrate under the paint.

In order to protect the hull of a ship with damaged paintwork from rusting, a cathodic protection system can be used. There are 2 main types: sacrificial anode systems and Impressed Current Cathodic Protection (ICCP) systems. In both systems the principle is the same: an electrical potential and current must be maintained between the artificial anode and the hull such that the hull becomes the cathode and the vessel does not corrode. In general sacrificial anode systems are used on smaller vessels and ICCP on large vessels but this is not a fixed rule. Unfortunately, to be sure of effective and uniform protection, the sacrificial anodes and standard ICCP systems produce a greater current than the original corrosion so that the electric signature size increased. ICCP systems can be designed to minimise signatures threat as well as the primary requirement to protect from corrosion [3].

The underwater electromagnetic signature of a vessel is commonly considered as comprising 4 components: two DC terms, the Static Electric and Static Magnetic, and two AC terms, the Alternating Electric (AE) and the Alternating Magnetic (AM). The AE and AM are together known as Extra Low Frequency Electromagnetic (ELFE). The so called Static components arise from the constant field that move with the ship past the sensor and effectively can be considered to have frequencies up to 0.1Hz at a measurement device. The alternating signatures arise from sources that are intrinsically time-dependent. Frequencies of interest are generally below 1Hz to 3kHz.

The ship's ELFE signature depends on the equipment fitted or in use on the ship at any time, the ship's speed and the electric conditions of the environment. The presence of a ship will cause a change in the measured alternating electric and magnetic fields in the vicinity. This effect is known as the ELFE signature of the ship. An alternating field is one which varies with time with or without a regular periodicity.

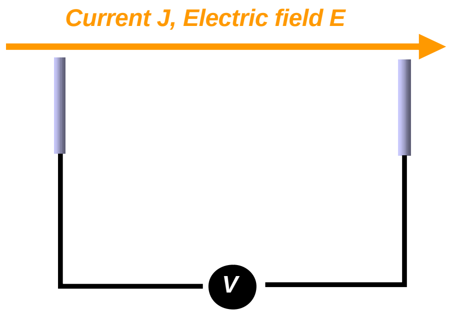
Some causes of that ELFE effect include:
(1) The modulation of the static electric signature by the shaft rate frequency due to variable resistance between the hull and the propeller.
(2) The modulation of the static electric signature by the blade rate frequency.
(3) Onboard electrical power generating systems, motors and power cables electromagnetically radiating at power frequencies and their harmonics.
The relative importance of these and other causes will vary with the type of ship and the countermeasures fitted. For example a ship fitted with shaft grounding will have a reduced shaft rate frequency signature.

The Electrical Environment

The size of the static electric signature depends on several parameters in addition to the size of the source, the three most important being the sea water conductivity, the seabed conductivity and the depth of the water. These parameters are important because they affect the current path. For example the presence of a non-conducting seabed restricts where the current can flow. Note that the deeper the seabed is below the vessel the less effect it will have on the vessel’s signature, but for ranging purposes the effect of the seabed will be significant. This can mean that the vertical electric field component is very small.

Electric field measurement

It is relatively straight forward to make electric field measurements in sea water by means of two electrical contact points made with the seawater, with connections to a measuring device or meter. The electric field value measured will be along the direction of the line between the two contacts.



The actual voltage measured will depend on the separation distance between the points. The simple expression for the electric field, expressed in volts per metre, is given by this voltage divided by the separation distance.

The contact points, or electrodes as they are called, are designed in such a way that they produce a minimal voltage when the sensor is placed in zero field, and this contact voltage has a very small variation, or self-noise. The voltage measured by a two-electrode sensor depends on the electrode spacing. In theory, the greater the separation, the greater the sensitivity. The shape of the housing can give amplification of the electric field.

Sensors can be configured as single-, two- or three-axis units. Single- or two-axis sensors are most often used for detection purposes where the presence of more axes would cause deployment problems or where the limitations of environment or source signal would mean that the signature magnitude in third axis would not be significant. Three-axis sensors are most commonly used in range deployments where an accurate knowledge of all three electric signature components is important

Choice of Sensing Element

There are two main types of electrode that can be used to measure electric fields in seawater.

1. Inert e.g. carbon, titanium, gold, lead, silver.
2. Chloride forming e.g. silver, cadmium, lead.

Materials which are inert in seawater in general are characterised as polarisable and have potentials which vary widely depending on the surface condition of the electrode and the current drawn from it. They are not suitable for low noise sensors. Carbon fibre based technologies are subject to capacitative effects at low frequencies and as such are not well suited to low noise measurements at frequencies close to DC.

The second type of materials form chlorides in seawater. They are non-polarisable and as such have relatively constant potentials when small changes in current occur. Many of the chloride type electrodes are poisonous and not suitable in range applications. Ag/AgCl however is robust and has excellent long term stability. It has been used for cathodic protection monitoring for over 40 years and for almost 20 years in military applications.

All sensor types are subject to gradual marine fouling. In general such growth is minimised by the presence of a cap which shields the electrode whilst still allowing sensor functioning. Ag/AgCl electrodes exhibit an additional protective effect due to the presence of silver ions which act as a biocide to reduce marine growth. Trials have shown negligible marine growth in over 500 days of submersion in the sea.

Ultra utilises specially developed silver / silver chloride electrodes which have self-noise levels below the nanovolt region, with offset voltages of the order of a few microvolts. The electrodes have been developed to have a low contact resistance with the seawater even at DC. This ensures very low noise levels at frequencies well below 1 Hz. The specially developed housing for the electrodes allows these properties to be retained, even after prolonged immersion in the sea. The electrodes are encapsulated, and contained in their own electrolyte. Contact with the seawater is via a porous barrier, which excludes gross ingress of contaminants. It also removes the problem of flow noise, which otherwise arises when an electrolyte flows past an electrode sensing surface. The reliability of the sensors has been shown to be very good over many years of operation in these various installations. The actual construction of the electrode elements is very strong and resistant to shock and vibration. This gives them a very high reliability, in contrast to some other electrode types.

The Sensor Electrode Noise Voltage

If we measure the voltage difference signal using a low noise amplifier and spectrum analyser across two electrodes in a shielded container of salt water, we will find a frequency dependent noise voltage, generated by the electrode pair, if the amplifier noise is low enough.

At frequencies above a few Hertz, the noise spectrum is flat, and results from the Boltzmann noise of the electrode pair impedance. Below 1 Hertz, there are two sources of noise; one is a result of competing electrochemical processes on the electrode surfaces; the other is the long term difference in temperature and salt concentration between the two electrodes.

Electric Field Sensor Electronics

The signals from each electrode pair are passed to pre-amplifiers, which have been specially developed to match the ultra-low-noise performance of the electrodes. The low frequency or 1/f noise has been minimised, as well as the higher frequency noise. The low offset voltage of the electrode pairs allows DC coupling in the preamplifiers.

For applications that require very high gain sensors, for example ELFE requirements, high pass filtering follows the pre-amplifier stage, together with a band-limiting filter to limit the upper frequency response.

After the signal conditioning, the output signals are available to be transmitted to the recording device. The method of transmission used is a differential analogue voltage drive. The drive circuitry is optimised for low noise and high linearity.

The Electric Field Sensor Sensitivity, Gain and Noise

The electrode pair noise is reduced in proportion to the sensor gain. The gain produced by a two-electrode sensor is determined by:

- the electrode spacing

- the shape of the sensor housing

Electrode Spacing

The voltage measured by a two-electrode sensor depends on the electrode spacing. In theory, the greater the separation, the greater the sensitivity and this property can be useful for detection devices. For geophysical surveys sensor baselines can also be up to ten metres long. However for ranging purposes in order to accurately measure a vessel signature the maximum useful baseline is 1m or less. This is because the gradient of the electric field itself may vary over short distances in the near field; the longer the baseline the less accurately the measured electric field value represents the true electric field at a point beneath a ship. Hence for ranging applications which measure ship signatures in tens of metres of water the length of the baseline and hence the sensitivity of the sensor is limited. It may be concluded that any sensitivity improvement for ranging applications must be derived from factors other than increased electrode spacing. In practice, the size of a sensor also determines how easy it is to deploy, and for three-axis sensors especially, large separations are impractical.

Sensor Housing

The sensor electrode bodies, as well as the complete sensor housings, are manufactured from tough engineering plastic materials. This is necessary so that the housing does not generate electric fields itself, as would be the case if metal construction were used.

The shape of the housing can give amplification of the electric field. For example, a sphere gives a gain of 1.5. The signal gain produced is called the shape gain. Thus the sphere can be useful, as it reduces the electrode separation required for a given sensitivity and noise specification. The distortion of the electric fields, existing in the sea, by virtue of the insertion of the sensor, is taken into account in the signal conditioning. The improvement in sensitivity arising from the sensor shape is calculated for each axis.

Use of Boundary Element Modelling For Electrode and Sensor Design

In order to effectively design electric sensors it is important to be able to accurately determine the electrode resistance in seawater. There are numerous factors that determine the resistance of the electrode. Two of the more important factors are the geometry of the electrode and any material that may surround it. In this section we shall describe how the resistance of an electric sensor in seawater is affected by the choice of surrounding material and casing. We shall consider an electric sensor developed around a cylindrical electrode. We shall describe how the sensor can be modelled using boundary element modelling.

The impedance of a pair of electrodes is very complex, but it has a major bearing on the performance of the pair as an electric field sensor. The resistance R_S represents the spreading resistances of the two electrodes, in the electrolyte paths from the electrode surfaces out to infinity in the electrolyte. These are a function of the electrode element shape, the housing restrictions, porous plugs etc., and the impedance is effectively ohmic. The value of R_S may typically be in the range of 1 to 25 ohms, depending on the electrode size and shape. The resistances R_{ct} represent the charge transfer impedances across the electrode / electrolyte interfaces. These arise from the electrochemical actions at the element surfaces and characterise the ease with which charge can leave or enter the element surface. The value of R_{ct} may be in the range of 0.1 to 5 ohms, depending on the electrode size and shape. The capacitances C_{dl} are the double-layer capacitances formed by the Helmholtz double-layers at the electrode / electrolyte interfaces.

For cylindrical electrode we can find the approximate resistance using the resistance for a cylinder in free space, Dwight formulae. The resistance of an electrode in seawater of resistance *rho* is given by,

$$R = \frac{r}{2pL}\left(\ln\frac{2L}{a} - 1\right) \qquad (1)$$

where L and a are the length and radius of the electrode respectively. For an electrode with dimensions of L=40mm and a =7.5mm we obtain R=1.36O in seawater of conductivity of 4S/m.

We would normally fix an electrode to a base of non-conducting material and this will affect the resistance of the electrode. It is difficult to obtain an analytical expression for the effect of incorporating the base and we must employ numerical techniques. One such method that is suitable for calculating the potential and current distribution of arbitrary geometry's is the boundary element, BE, method. In the design of a complete electric sensor it is usual to surround the electrode by a porous material and a casing, this is expected to have a considerable impact on the resistance of the electrode. The BE mesh of an electrode surrounded by a porous material and casing is shown in Figure 3. The potential distribution is shown in Figure 3.

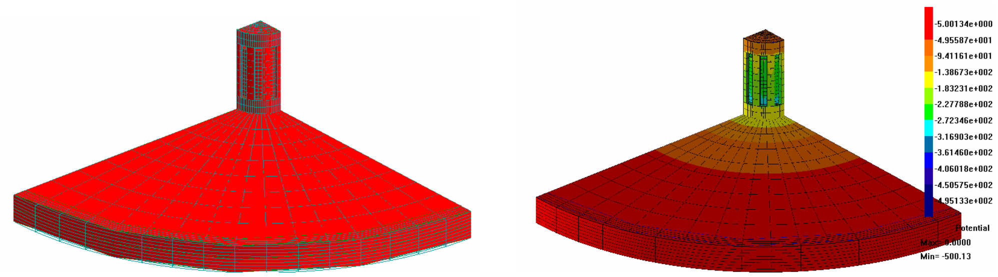


Figure 3 a) The BE mesh of the electrode encased in porous material casing b) The BE mesh of the electrode encased in porous material casing with -500mV applied

The resistance of the electrode depends on how porous the material surrounding it is. We can model this by assuming the porous surround has a lower conductivity than the seawater, this is given in Table 1. Typical electrodes have resistances of approximately 4 Ohms.

Conductivity S/m	R (Ohms)
4	2.5
2	3.1
1	4.2
0.1	11.3

Table 1 Dependence of electrode resistivity on the effective conductivity of the encapsulation material

From Table 1 we see that when the conductivity is 4S/m, the same as the surrounding seawater, the effect is as if the porous material is not there. However the casing is still contributing to a 25% increase in resistance to when the electrode was just supported on a base on non-conducting material. Table 1 shows that there is a dramatic increase in electrode resistance with the incorporation of the porous material that has a low effective conductivity, this is because it is shielding the electrode from the seawater.

Low Noise Electrode Design

If we measure the voltage difference signal using a low noise amplifier and spectrum analyser across two electrodes in a shielded container of salt water, we will find a frequency dependent noise voltage, generated by the electrode pair, if the amplifier noise is low enough.

At frequencies above a few Hertz, the noise spectrum is flat, and results from the Boltzmann noise of the electrode pair impedance. Below 1 Hertz, there are two sources of noise; one is a result of competing electrochemical processes on the electrode surfaces; the other is the long term difference in temperature and salt concentration between the two electrodes.

The signals from each electrode pair are passed to pre-amplifiers, which have been specially developed to match the ultra-low-noise performance of the electrodes. In order to make use of the high performance sensor elements that Ultra has developed it is necessary to design a suitably high performance amplifier. In order to do this the following parameters need to be considered: The input noise spectrum should ideally be flat from DC to the upper frequency response limit. In practice most circuits exhibit 1/f noise below the 1/f break frequency, typically a few Hz. The lowest amplifier noise is obtained by using a linear matched transistor front end. Chopper stabilised amplifiers can be also be utilised but typically have higher overall noise even if the 1/f portion is flatter.

Since the source impedance of the sensors is low the input impedance of the amplifier need not be particularly high thus reducing the effective input noise, and since the sensors are none polarisable the small current drawn from them (<1nA) does not effect the offset voltage. Since in a DC coupled amplifier the input offset is amplified by the gain of the amplifier the input offset voltage needs to be as small as possible.

Amplifier common-mode rejection ratio

The sensors once deployed in the sea will be subjected to relatively high levels of common mode signals and is by their very nature connected to Earth it is important that a high common mode rejection ratio is achieved. This is typically greater than 120dB.

To achieve the very high performance parameters that are required all components have been carefully selected for their low noise performance. The current paths within the first stage of the amplifier have been carefully matched and the PCB layout designed to minimise thermal and thermo electric effects. For applications that require very high gain sensors, for example ELFE requirements, high pass filtering follows the pre-amplifier stage, together with a band-limiting filter to limit the upper frequency response. After the signal conditioning, the output signals are available to be transmitted to the recording device. The method of transmission used is a differential analogue voltage drive. The drive circuitry is optimised for low noise and high linearity.

Typical Noise Plot

The following noise plot was obtained with a sensor deployed within the test facility. The gain applied when making the measurement was 2000; therefore the vertical axis scaling is equivalent an input voltage from the sensor pair and amplifier of 0.1 nV per root Hz per division. The tests performed shows an input noise floor of 0.5 nV per root Hz (Figure 4). Such low noise electrodes can be used in a variety of configurations and applications (Table 2) to provide a high performance electric field capability.

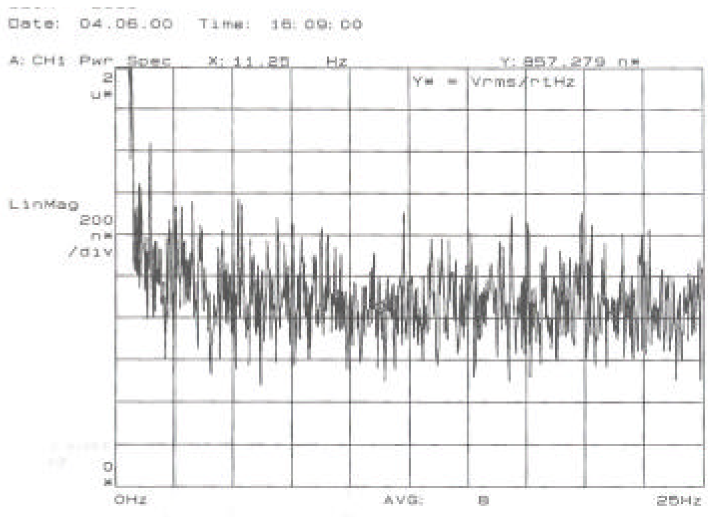


Figure 4 Sensor Noise Versus Frequency (Gain 2000)

Conclusions

We have shown that sensor design is highly dependent on the application for which is required as may be expected. It is important to determine the local site noise in order to determine the sensor baseline length, number of axes and electrode noise that may be necessary to meet the requirement. For three–axis electric field measurements it has been shown that a 1m sphere is not a necessary requirement to meet a standard noise specification of 1nV/m, but also that meeting a 1nV/m sensor resolution may not be necessary for some typical measurement sites. A lowering of specification by a factor of 2 or 3 can dramatically reduce the sensor diameter allowing lighter and more easily deployable sensors.

References

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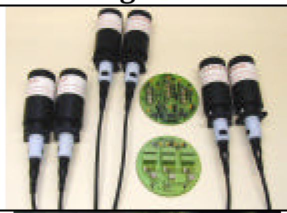
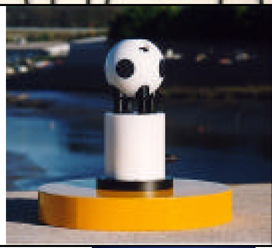
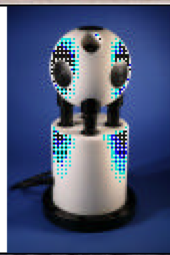
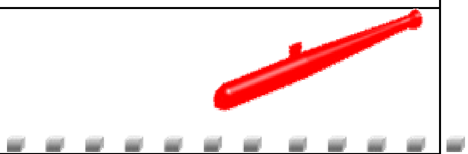
Table 2 Sensor applications

For different applications sensors with different noise levels, dynamic ranges, frequency responses and supply voltages can easily be created using the above design parameters (see Table 2).

Application	Requirements	Typical design solution	Physical design
Geophysical, electromagnetic surveying	Long baseline Low noise	Flexible configuration of low noise electrodes, 0.05nV/m/root Hz for 10m baseline	
Earthquake detection Range arrays (static and ELFE)	Low noise, short baseline. Ranges 0-3kHz bandwidth.	3-axis compact, low noise, 2.5nV/m/root Hz for 0.25m baseline. Ranges 3-8 sensors	
Range arrays (static and ELFE)	Low noise, short baseline. 0-3kHz bandwidth. 0-3kHz bandwidth.	3-axis compact, low noise, <1nV/m/root Hz for 0.50m baseline. Ranges comprising 3-8 sensors	
Redeployable range array (static and ELFE)	Light weight, small size. Multi-influence sensor. Quick stabilisation. 0-3kHz bandwidth.	Single electrode and modelling to predict 3-axis field. Electrodes stored in correct conductivity electrolyte. Range comprising 3-8 sensors	
Static electric range array only	Standard noise level, DC	Commercial electrodes	
Barrier array	Low noise	Small dimensions, optional tracking capability	
Mine / Exercise mine	Low noise, short baseline	Short baseline 3-axis sensor, 2.5nV/m