The Impact of Corrosion and Cathodic Protection Systems on the Electromagnetic Signature of Naval Vessels

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Abstract

Operations in the littoral naval environment pose a variety of threats to vessels. The corrosion related signatures can have a significant impact on both the electric and magnetic signatures of a vessel and this fact has prompted the replacement of degaussing ranges with multi-influence ranges. Multi-influence ranges measure and analyse signatures including static magnetic, static electric, alternating magnetic, alternating electric, pressure and acoustic signatures.

The parameters of the electric environment surrounding the vessel (i.e. seawater and seabed conductivities) can have a significant impact on a vessel's electromagnetic signature. Using range analysis software such as that in Transmag*Plus* the signature of a vessel can be predicted from the range measurements to any possible environment. However in some cases the environment may not be well known. In such cases a forward area range is invaluable in determining a vessel's signature in the field of operations.

This paper will be illustrated using simulations of typical vessel signatures.

Electric Fields in the Sea

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. These electric fields arise from many different sources including:-

Man made sources include:

- Shipping activity
- Marine cathodic protection systems (ships, offshore drilling rigs, oil pipelines)
- Shore based power utilities

Natural sources include:

- Motion of the sea water in the earth's magnetic field (Waves and tides)
- Induced electric fields arising from changes in the geomagnetic field (Pulsations)
- Ionospheric-induced electric current flow (Lightning, Schumann resonances)
- Geological sources (Conducting ore bodies, earthquake precursors)
- Marine life

Electromagnetic Signature Components

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. All the signature components contribute to the mine and detection threat.

Sources relating to electric current sources and alternating sources, whose propagation is affected by the conducting seawater environment, will be discussed below. In this document we shall not consider in detail the static magnetic components arising from ferromagnetic sources or the degaussing systems used to compensate for these sources. The degaussing of ferromagnetic signature components have been covered in earlier papers (Davidson et al (1)). The summation of both the static magnetic components, the Corrosion Related Magnetic (CRM) signature which arises from electrical currents and the ferromagnetic signature arising from steel components comprising the vessel however can provide interesting insights into the behaviour of the measurable gross magnetic signature in sea and in air.

What causes Static Electric signatures?

Static electric field signatures will arise from the corrosion of the metals from which the vessel is constructed. Corrosion occurs between metallic components made from dissimilar metals: this occurs because the metals create bi-metallic couples due to their different electrochemical. The rate of corrosion depends on the oxygen concentration, temperature and salinity. As part of the corrosion process currents flow in the sea. The resistivity of the sea means, that as the current flows through the sea, a voltage drop arises. It is these voltage drops that can be measured electric field sensors.

The size of the static electric signature depends on several parameters, 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. Using Transmag software the electric and also CRM signatures can be predicted for any known electrical environment.

Protection from Corrosion

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 (Figure 1). 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 or ICCP systems produce a greater current than the original corrosion so that the SE and CRM signatures are increased.

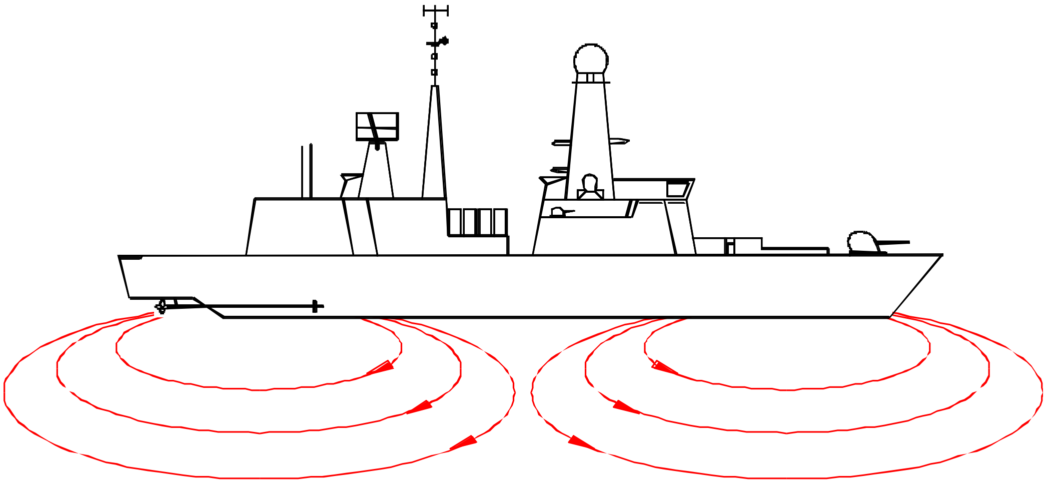

Figure 1 Simplified diagram of current flow around a ship with cathodic protection

CRM Signatures

In addition to creating electric field signatures, the current flowing in the hull and the sea also creates a magnetic field. The current tends to flow in a longitudinal direction along the vessel e.g. from the anodes located along the length towards the stern and propeller. In contrast to the electric field, the CRM field generated is at right angles to the current. Therefore a longitudinal current will produce a large athwartships component directly beneath the ship.

In general for steel vessels the CRM signature is small in the near field, but it can become the dominant magnetic component in the far field due to it's slower rate of decay (Figure 2). For vessels made of GRP, wood or low magnetic steel the CRM component can become significant. By measuring magnetic and electric fields at the same sensor location the measured magnetic signature can be separated into its ferromagnetic and CRM components. The magnitude of the CRM signature is affected by the electrical environment.

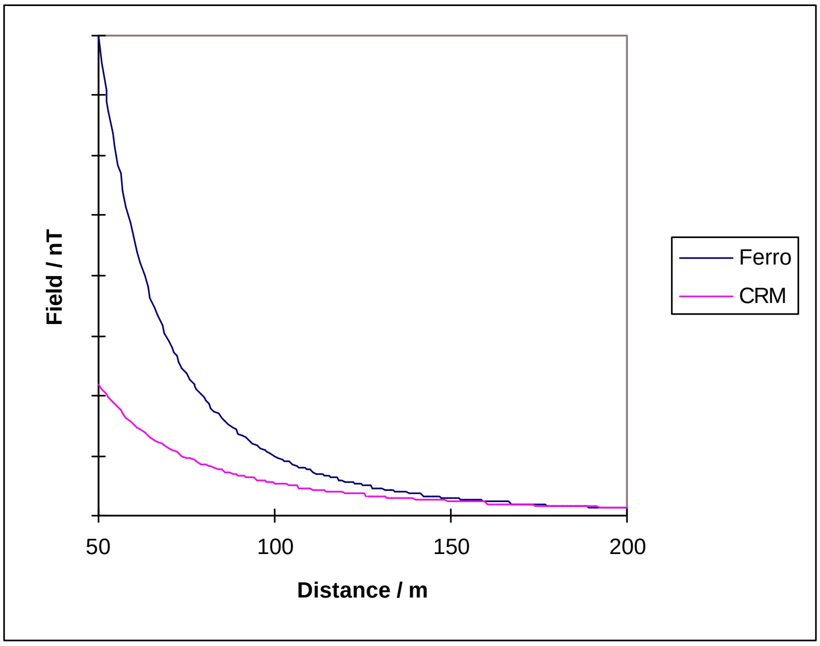

Figure 2 A plot of ferromagnetic and CRM signature magnitude versus distance

The ELFE Signature

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. 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 alternating electric sources onboard the vessel can produce both magnetic and electric effects. Similarly alternating magnetic sources of the ELFE signature may also produce electric effects. On board power systems act as alternating magnetic sources which generate both alternating magnetic and electric fields.

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.

Shaft Rate

The proportion of the static electrolytic currents flowing from the hull or cathodic protection anodes to the propeller returns to the anodes by travelling up the propeller shaft and through the hull (Figure 3). As the shaft rotates, the variable contact resistance between the shaft and its bearings modifies the current. The current is modulated at the shaft rate frequency producing alternating electromagnetic signatures at this frequency and its harmonics.

Shaft grounding ideally eliminates shaft rate frequencies by electrically shunting the variable bearing resistance and effectively shorting the shaft to the hull. Passive shaft grounding utilises a slip ring fitted to the shaft and brushes to provide a low resistance path. Active shaft grounding (ASG) uses the same system but uses electronic feedback to supply a counter current in order to maintain a low shaft to hull alternating voltage.

Blade Rate

This effect is similar to that of the shaft rate: the current is modulated at the shaft rate multiplied by the number of blades producing alternating electromagnetic signatures at this frequency and its harmonics.

Stray Fields

Onboard electrical power generating systems, motors and power cables electromagnetically radiate at the onboard power frequencies and their harmonics. *Alternating fields generated within a vessel* which has a conducting hull will be attenuated as they pass through the hull. Thus attenuation will be apparent for steel hulled vessels but not for GRP vessels. Stray field signatures can be reduced by the use of shielding, avoiding current loops where possible and pairing outward and return cable paths. With careful design the impact on signature magnitude can be minimised.

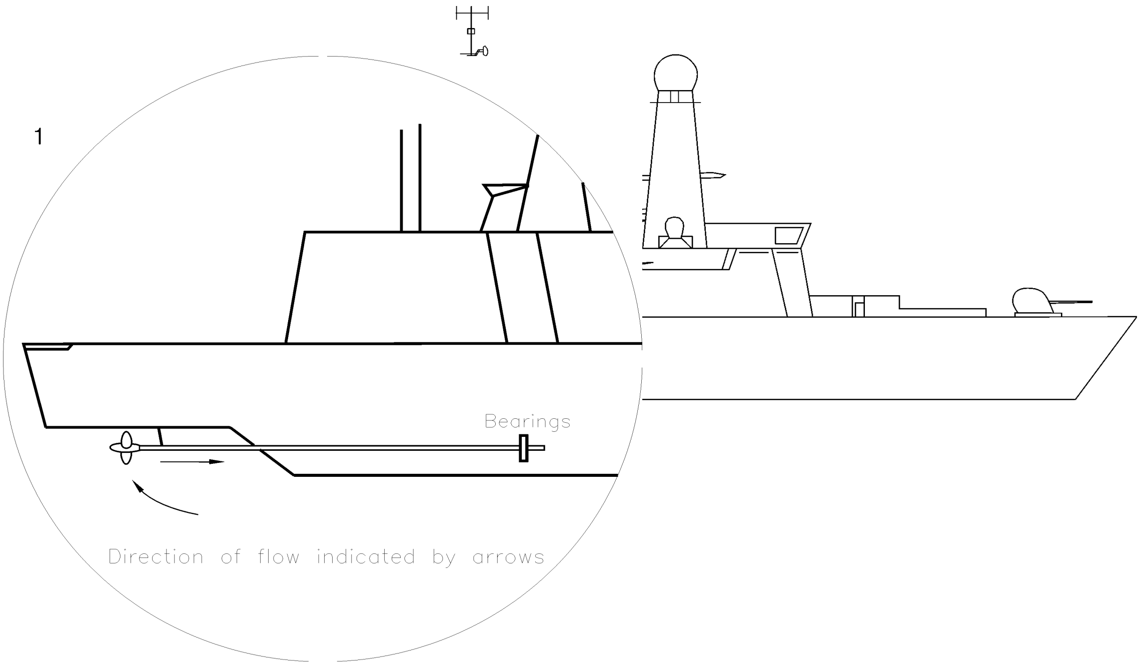

Figure 3 The origin of shaft rate signature frequencies

Electric Field Measurement

Standard Method
An electric field in the sea can be measured 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.

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 or research deployments where an accurate knowledge of all three electric signature components is important.

An Alternative Method of Electric Influence Measurement
Ultra's Transmag *Plus* ranges use a patented method of voltage potential measurements to determine a ships electric field. In order to provide measurements of the potential (voltage) in

the sea, single electrodes are added to the standard magnetic sensor housings to provide a mutli-influence range. This is a novel method of electric influence measurement. Formerly the static electric field signature has been measured directly using an electric field sensor; for this application a typical sensor requires two electrodes separated by 20cm to 1m in each of the three electric field axes (though some reduction in number can be made by clever placement of electrodes). The single electrode sensor therefore has the advantage of being much smaller and cheaper. In addition, because a simple voltage measurement is made using a single electrode, no sensor alignment is required in contrast to electric field sensor deployment. The magnetic sensor is of course easily aligned using the Earth's magnetic field.

How can potential measurements be used to determine the electric field?

A simple analogy of contour lines on a map can be considered where the contour lines are used to represent points of the same height (Figure 4). If the heights of different points on a hill are known then the direction of slope and it's steepness can be identified (Lorrain et al (2)). In our case the heights at given points correspond to the potential measurements and the direction and steepness of the slope correspond to the direction and magnitude of the electric field. Either the potential or electric field signature can be measured in order to determine a model of the electric state of the vessel.

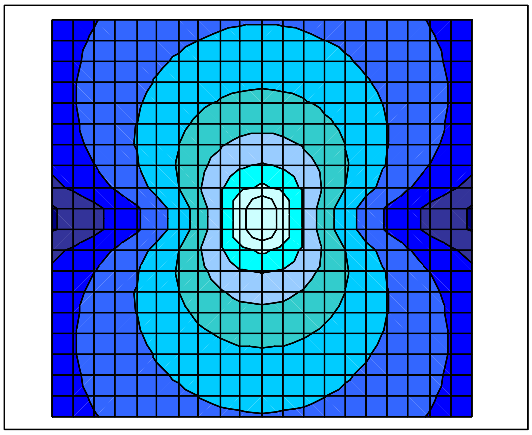

Figure 4 Potential contour lines around an electric source

A height or potential must be measured relative to an arbitrary level. An equally valid method is to measure the difference in heights or potential between two locations. For example the Transmag measurement system contains 5 electrodes and the differences are taken between pairs of electrodes. e.g. between pairs of neighbouring sensors 1 and 2, 2 and 3, 3 and 4, 4 and 5 and finally 5 and 1.

The potential signature is subject to a modelling process such that the more intuitive electric field can be displayed. The CRM signature and in air Magnetic Anomaly Detection (MAD) signature may also be calculated. The modelling process has been discussed in earlier papers (Webb et al (3)).

The Effect of CRM on Global Magnetic Signatures

The DG-off ferromagnetic signature of a vessel comprises components from the vessel's permanent and induced magnetisations. The induced component is dependent on the magnitude of the Earth's magnetic field and on the vessel's heading with respect to this magnetic field.

The DG-on vessel signature clearly additionally includes the effect of the degaussing coils used to compensate for the vessel's permanent and induced signature components. The DG coils will have been designed to minimise the vessel's signature to within the required target levels in given regions within the limits of cost, power and other aspects. Thus dependent on the DG system's design parameters the vessel's signature will vary across the globe.

The vessel's CRM is dependent largely on the electrical environment in which the vessel is located although other factors such as vessel speed relative to the seawater may affect the rate of corrosion. The corrosion currents will in general flow along the longitudinal axis of the boat creating an athwartships static magnetic field as discussed earlier in this paper. Thus the CRM is largely independent of heading.

The interaction of the CRM and ferromagnetic signature components with the DG system can be predicted by the Transmag software. Figure 1 illustrates an example of a typical gross magnetic signature of a vessel worldwide. The vessel's DG system has been set up to compensate for the vessel's signature in European waters only. It can be seen in Figure 5 that as the vessel approaches the equator the signal level increases and that there are some southern regions for which the signature increases still further to approximately six times the value in the European area.

The Transmag system allows DG coil setting to be optimised globally and for local regions worldwide, therefore allowing the signature to be minimised at any chosen location or locations.

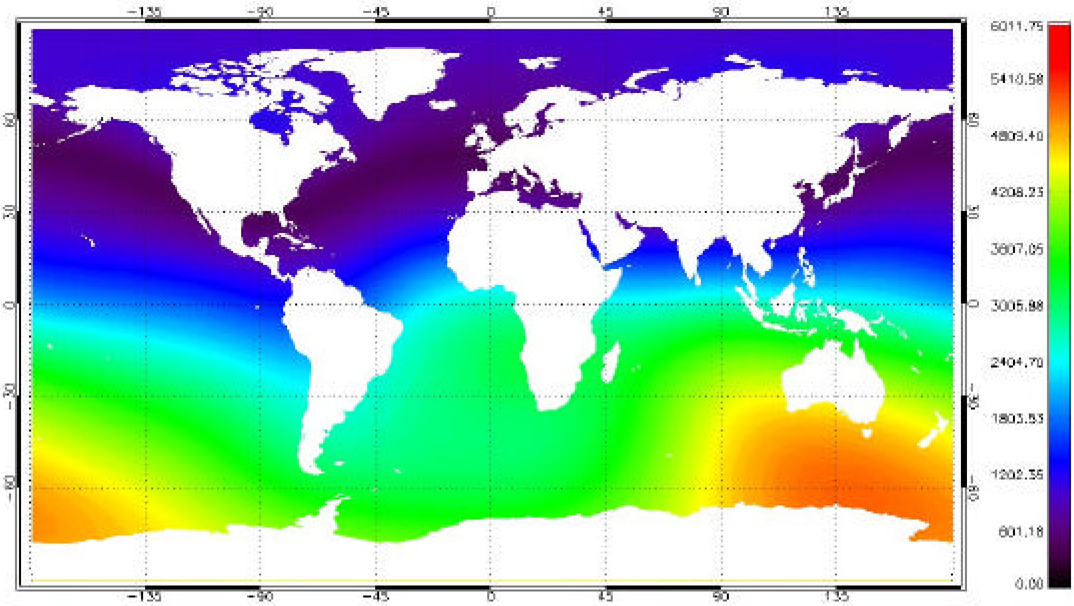

Figure 5 A sample plot of DG-on worldwide signature level

The Transmag system also allows the user to determine the heading on which the best or worst vessel signature occurs. Figure 6 shows a typical plot. The arrows point in the direction of the worst heading for the example vessel worldwide.

Both the map types illustrated in Figures 5 and 6 can be used to show signature variations in smaller local regions.

Conclusions

The electric and CRM signatures of a vessel which arise from the corrosion of or ICCP system fitted to a vessel contribute to the detection and mine threat of a vessel by means of sensors using electric sensing methods.

In addition the interaction of the ferromagnetic and the CRM signatures can produce unforeseen effects in the measured gross magnetic signature. It has been shown that these effects can be analysed by the Transmag system to calculate the threat to the vessel worldwide and display the results in a readily understood visual format that can be used by both ranging officers and mission planning teams.

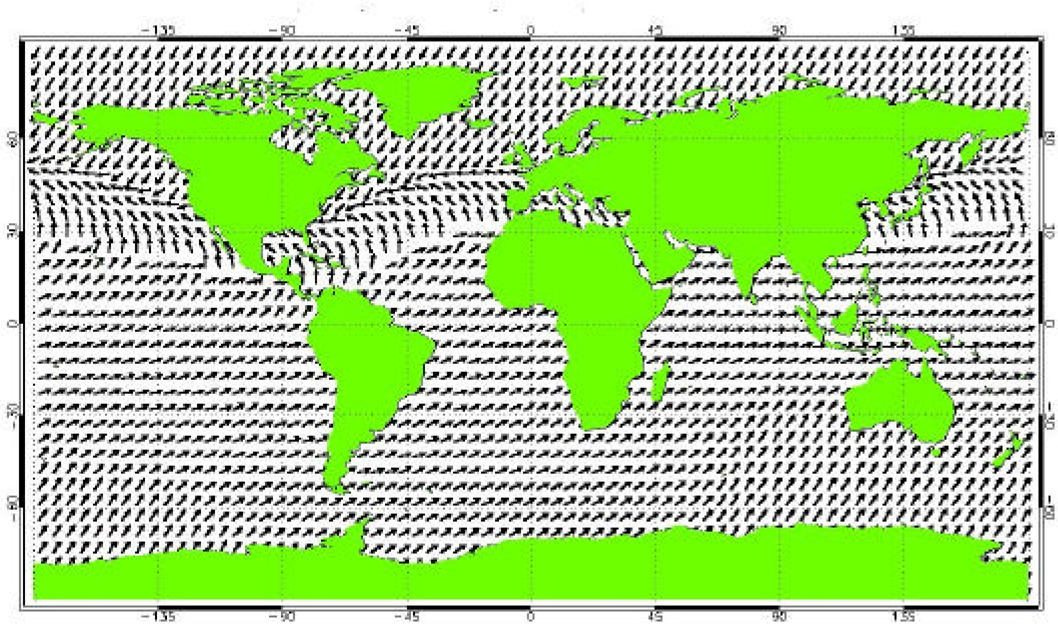

Figure 6 A sample worldwide map of the heading on which the worst signature level occurs

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