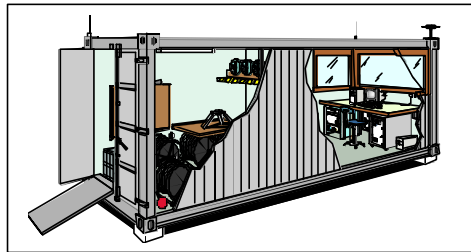


Management Of Multi-Influence Signatures In Littoral Waters

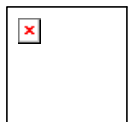
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Management Of Multi-Influence Signatures In Littoral Waters

1 Operation in Littoral Waters

The threats to the operation of a vessel close to the shore can be significantly different to those of deep-water operation. Apart from the obvious threat of operating in an environment where movement of the ship is restricted and which is cluttered with radar and sonar images, littoral water operation involves operation in waters that can change the various signatures of the ships by a substantial degree from that found in deep water. The signatures of a ship may be electro-magnetic or acoustic and interactions of these signatures with the seabed and other environmental factors such as changes in the conductivity and temperature of the water can change the threat from mines and other hostile agents. Thus in order to estimate the potential threat from mines in a littoral environment is necessary to fully account for the change of the signature due to the environment of the vessel.

In this document we shall describe the various influences and address the issue of how the various signatures of a vessel may be modified in littoral water operation. We show how they may be measured and modelled using a multi-influence range such as the arrays developed by Ultra Electronics. The multi-influence sensor array developed by Ultra Electronics is seen to be a highly transportable range that can be speedily deployed to measure and model ship signatures to a high degree of accuracy in a variety of environments in real time. The array provides the ability to set countermeasures to combat the threats to a vessel from mines, reduce the detection threat and also give the ability to assess the risk to a vessel when its environment changes.

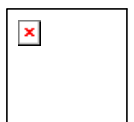
2 Signatures Of The Vessel

2.1 Introduction

The signature of a vessel can be broken down in two main groups: electro-magnetic and acoustic. The electro-magnetic signatures are due to the various electric and magnetic fields that may be present around the vessel due to its structure, engine and power supplies. The potential threat to a vessel because of its magnetic field, from mines for example, are well known and understood. A standard countermeasure employed to reduce this threat is the placement of degaussing (DG) coils on the vessel.

The acoustic signature will be due to any noise that the vessel may be emitting from it's engine, movement and propeller. Various sound reducing techniques are followed in the design of ships in order to reduce its acoustic signature. For example the structure of vessel is made of materials that do not vibrate when the vessel is underway.

As the magnetic and acoustic hygiene have improved other threats such as the electric and magnetic fields from the engine, power supplies and the cathodic protection system have become more important. In order to counter these signatures multi-influence sensor arrays have been developed in order to monitor and enable reduction of these threats.



Management Of Multi-Influence Signatures In Littoral Waters

2.2 Electro-Magnetic Signatures

When discussing electromagnetic signatures it is usual to break them down into DC and AC signatures. DC signatures do not change with time and thus are the same at any time when a measurement of them is performed. AC signatures depend on time and thus low frequency measurements will depend on the time the influence is measured, although at high frequency, the influence may appear static because of its rapid variation and only the time average can be measured.

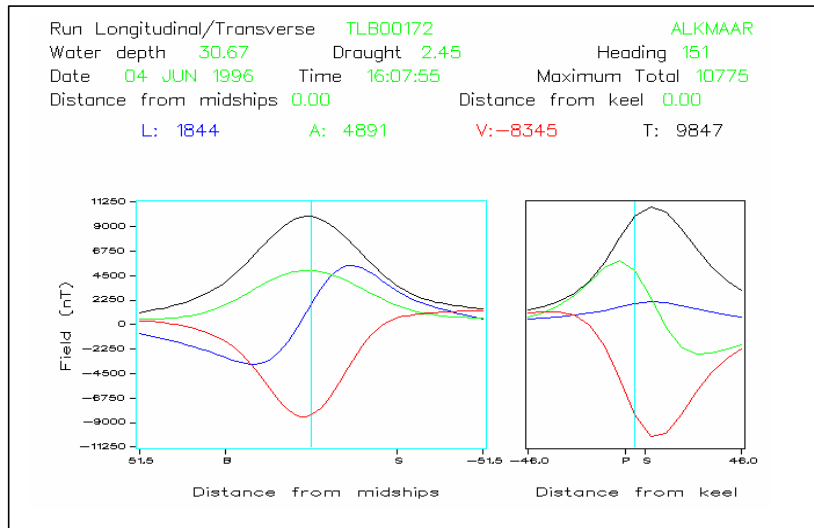
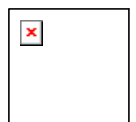


Fig. (1) The figure shows a typical ship's predicted DC magnetic signature when both permanent and induced magnetism and CRM have been included.

DC Influences:

- **Permanent Magnetism.** Some vessels are constructed using magnetic materials such as iron and steel. These materials have, or can acquire, by being aligned in the Earth's magnetic field, a permanent magnetism. This, in the simple case, makes the ship look like a bar magnet and being such has an associated magnetic field that can be measured and which contributes to a vessel's magnetic signature.
- **Induced Magnetism.** A ship is always in a presence of an external magnetic field, the Earth's magnetic field. The Earth's magnetic field will induce a magnetic field in the vessel itself. This will lead to a contribution to the magnetic signature that depends on the heading of the vessel and its location on the surface of the Earth. Some vessels may be fitted with degaussing coils. Current carrying coils by their very nature generate magnetic fields; they also can, in the case of steel vessels, induce magnetic fields in the vessel itself thus contributing to the total signature. In this case the effect is beneficial since the degaussing coils if properly implemented and set up with the correct currents, will reduce the magnetic signature of a vessel.
- **DC Electric.** Hull corrosion and the cathodic protection system. These sources may be thought of as batteries and so will cause electrical currents to leak into the sea. The sea



Management Of Multi-Influence Signatures In Littoral Waters

being composed of salt water will conduct electricity, although by a factor of a million times less than copper. Thus there is a voltage in the sea and it is possible to measure this voltage and hence determine an electric signature of a vessel in the sea. This signature is also known as Static Electric, **SE**, or Underwater Electric Potential, **UEP**.

- **CRM** Corrosion related magnetic field. These fields are also due to the fact that there are electrical currents in the sea. As in degaussing coils (current carrying conductors which have a magnetic field associated with them) the corrosion currents in the sea will also have an associated magnetic field. Close to the vessel the CRM is measurable although generally it is a lot smaller than the permanent magnetic field. However for vessels constructed using non-magnetic materials, such as MCMVs, the CRM can be a large percentage of the ship's magnetic signature. Far from the vessel the CRM is more significant. The fall off with distances from the ship for the permanent magnetic fields is more rapid than that of the CRM. Thus far from the vessel the CRM field may be comparable to permanent magnetism regardless of the material used in the construction of the vessel.

AC Influences

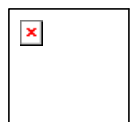
- **ELFE** Extra Low Frequency Electromagnetic. This can be caused by currents flowing between the hull and the propeller for example. As the propeller rotates the electrical resistance between the hull and the shaft will change with time over the period of rotation of the propeller. Since the resistance of the shaft is changing with time any electrical currents, and hence the electrical potential, will change with time. Other important sources of ELFE include power supply frequencies and their harmonics from the various electrical power systems and sub-system aboard the ship.
- **Power Supply Ripple**. It is possible that there are small voltage ripples in the power supplies that drive the cathodic protection system. This will lead to time dependent currents in the sea, which will give rise to a time dependent electrical signature.
- **AC Magnetic**. Turbines on the ship contain large rotating current carrying coils. These act as rotating magnetic dipoles, which will generate an AC magnetic signature. Furthermore because the sea is an electrical conductor then eddy currents may be induced in the sea by the magnetic dipoles; this is a consequence of Faraday's Law, which is the basis of operation of electrical motors, generators and transformers. These currents will be time dependent and so there is an associated AC electric field because of this.
- **AC CRM**. Power supply ripples will lead to time dependent currents in the sea. In a similar fashion to the DC CRM this will lead to an AC magnetic field due to AC currents flowing in the sea.

2.3 Acoustic Signatures

Acoustic waves or sound can propagate in the sea, 4-5 times faster than in air and without substantial loss. Thus any source of sound from a vessel may be detected in the air or sea surrounding it. Hydrophones are generally used to measure acoustic waves in the sea. These sensors can detect any acoustic waves between 1-100KHz generated in the sea by a vessel.

There are many sources of sound from a vessel primary source:

- The engine and power supplies and any mechanical/non-mechanical movement which generates sound.
- Movement of the ship through the sea will generate vortices in the sea.



Management Of Multi-Influence Signatures In Littoral Waters

- Rotation of the propeller through the water will also generate sound waves and may cause cavitation.

The vessel can also generate various mechanical, or pressure waves. These will travel at different speeds than acoustic waves and generally have frequencies between 0-1Hz. Pressure sensors are used to detect these waves in the sea and they can also be seen using geophones, seismic sensors on the seabed. Sources of pressure waves are:

- Motion of vessel, or its wake.
- Waves generated from the propeller or propulsor.

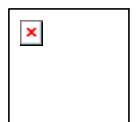
Acoustic waves can propagate in silt and rock which comprise the seabed. In these materials the waves are usually understood as seismic waves and these can be measured as disturbance in the particles that make up the seabed. There are two types of seismic waves; compression and shear waves. Compression waves occur where the disturbance of the particles in the seabed is in the direction of motion of the wave. Shear waves are associated with the disturbance of the particles in the seabed perpendicular to the direction of propagation of the wave.

3 Signatures In Littoral Waters

3.1 Electro-Magnetic Signatures

In littoral waters the electro-magnetic signature of a vessel will be changed with respect to deep waters. There are several factors and operation conditions that we must take into account.

- **Variation of sea depth.** The sea depth may vary quite dramatically with distance from the shore. The variation of the sea depth will change the signature of the ship. More importantly though, any mine placed on the seabed will see the ship signature at different depths and so in littoral water operation it is necessary to be able to predict the electro-magnetic signature at a variety of depths in order to assess the potential threat to a vessel.
- **Seabed.** In littoral waters the sea depth is comparable to the length of the ship, thus we must consider the nature of the seabed when predicting the signatures. The conducting properties of a seabed may be very different than the sea. A silt/sand layer may have a conductivity that is very similar to the sea because it is likely to be saturated with seawater. The underlying bedrock is likely to more like an insulator and has conductivity closer to air. In either case, the conductivity will change from that of seawater and this will change the amount of electrical current that flows in this region. Since the amount of electrical current that flows in the seabed can be substantially different from seawater, the electric signature of the ship in littoral waters will change compared with that in deep water. The seabed only effects the electromagnetic signatures that depend on the current that flows in the sea, i.e. the static electric, CRM, AC electric and magnetic fields. The permanent and induced DC magnetic will not change because these are independent of the electrical currents in the sea.
- **Seawater.** The seawater in littoral waters may have a different conductivity to that of deep water because the coastal region may be close to a river estuary. Fresh water flowing from such an estuary will mix with the sea water which will reduce the overall conductivity because fresh water contains only traces of ions and cations that allow



Management Of Multi-Influence Signatures In Littoral Waters

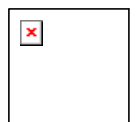
electrical conduction, i.e. there is little dissolved salt present. Tides will cause variation of the mixing of fresh water and hence the conductivity throughout the day. As in the seabed case, changing the conductivity of the sea water will change those electromagnetic signatures that depend on the currents flowing through the sea.

- **Temperature.** This is an indirect effect. The cathodic protection system, used to protect the ship against corrosion, works by applying a potential to the surface of the ship, which prevents the ship from corroding. The amount of current needed depends on the rate of corrosion. The corroding process is determined to a large extent by the amount of oxygen dissolved in the water. This is because the corrosion process needs oxygen in order to transform the iron for example to rust, i.e. iron oxide. The amount of oxygen dissolved in the water is very much dependent on temperature of the water, colder waters having more dissolved oxygen than warmer water. The temperature of coastal water is likely to be different from that of deep ocean waters, thus the amount of corrosion will be different. The electrical current needed to maintain the protection of the vessel will change and hence there will be a change in the electric and CRM signature of the vessel.
- **Water Speed.** The corrosion process is not only determined by the amount of oxygen present in the water but also by how the various reactants, again including oxygen, and the products, are transported to the surface of the hull. If the ship is moving the reactants will be replenished a lot quicker than if it were stationary and so the corrosion currents in the sea may change. A similar effect will occur if the ship is stationary and the water is moving. So the relative motion of the ship with the water will lead to changes in electric and CRM signature of the vessel.

3.2 Acoustic Signatures

In littoral waters the acoustic signature of a vessel will be changed with respect to deep waters. There are several factors and operational conditions that we must take into account.

- **Variation of sea depth.** The variation of the sea depth will change the signature of the ship. One of the primary factors will be the reflection of acoustic waves off the seabed. As in the case of electromagnetic signatures, it is necessary to be able to predict the acoustic signature at a variety of depths in order to assess the potential threat to a vessel.
- **Seabed.** In littoral waters the seabed composition will become important when the propagation wavelength of the acoustic source is comparable to the depth of the sea. For these wavelengths we must consider the nature of the seabed when predicting the signatures. The propagation properties of a seabed may be very different than that of the sea: the velocity of propagation of acoustic waves is faster and also the amount of attenuation, will be different. Further more the seabed supports an additional type of acoustic wave, a shear wave. For these reasons the propagation of acoustic waves in littoral water will be a lot different because they will be interrelated to the propagation of the sound in the rocks. In order to get a good prediction of the acoustic signature it is necessary to take into account these factors at low frequencies.
- **The shore.** The presence of the shore and any other obstructions close to the vessel because of its operation in littoral waters will cause reflections of acoustic waves generated from the ship. These waves will interfere with one another leading to a modification of the ship signature.



4 Multi-Influence Sensor Array

In sections (2) and (3) the various signatures attributed to a vessel and how they are affected by littoral water operation were discussed. It is obvious that any operation in this environment requires a good understanding of how the signatures of vessels behave in order to assess potential threats and where possible modify the ship's signature so as to reduce these threats. To this end Ultra Electronics has developed, using its experience in ranging ships in several countries, the multi-influence, electro-magnetic and acoustic range.

4.1 Measurement System

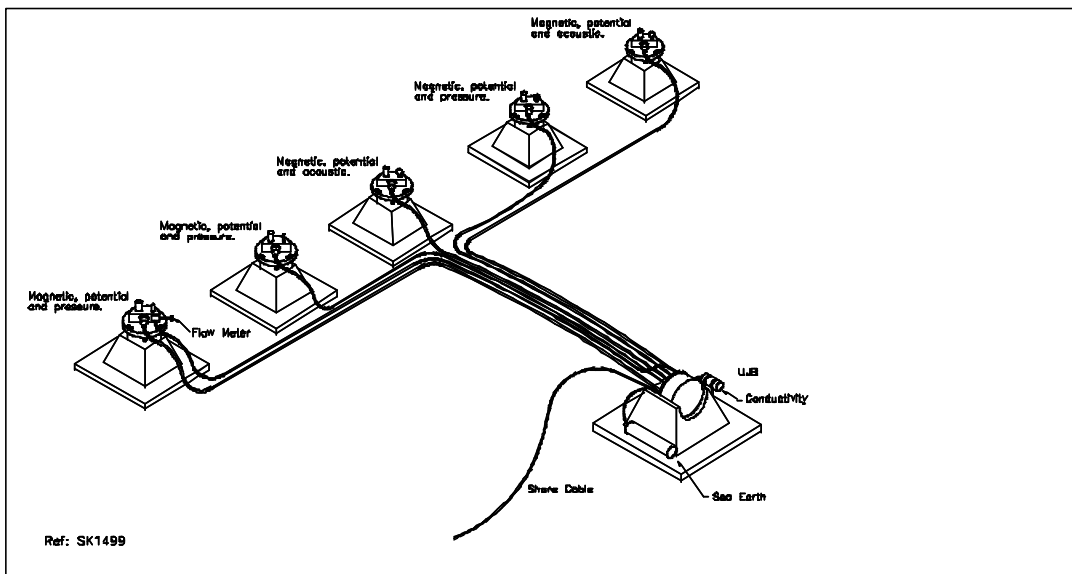
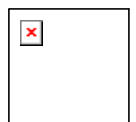


Fig. (2) The figure shows the multi-influence sensor array. The various sensors are coupled to an underwater junction box, which collects the data and transmits to the shore via a state of the art high-speed modem.

The multi-influence sensor array developed by Ultra Electronics provides a versatile signature range that can measure and predict a variety of ship signatures at any water depth, and at a multitude of sea states and seabed geometry. The multi-influence sensor array is an upgrade to the existing Transmag portable magnetic ranging system, which has been demonstrated as a reliable means of determining the magnetic state of a ship.

The multi-influence range is shown in figure (2). The multi-influence array consists of magnetic, electric potential, acoustic and pressure sensors fitted to non-conducting, nonmagnetic tripods to facilitate the measurement of the principle types of ship signatures. The array also comes complete with conductivity and temperature sensors so that the state of the water in which the range is deployed can be monitored. Tracking of the vessel across the range is normally achieved by directly interfacing the data collection computers with the GPS stations on the ship and the shore giving a position accurate to within a few centimetres.



Management Of Multi-Influence Signatures In Littoral Waters

Once the range computer has gathered data over a single ship run across the range, computer modelling is used to determine the various signatures of the vessel. Using 2 inter-cardinal runs we can determine the entire electromagnetic state of the vessel. This enables us to predict the signature of the vessel at any location, in any local environment, anywhere in the world.

4.2 Modelling The Signature

The data gathered from the multi-influence range is used by the range computers to determine the electro-magnetic and acoustic state of a vessel.

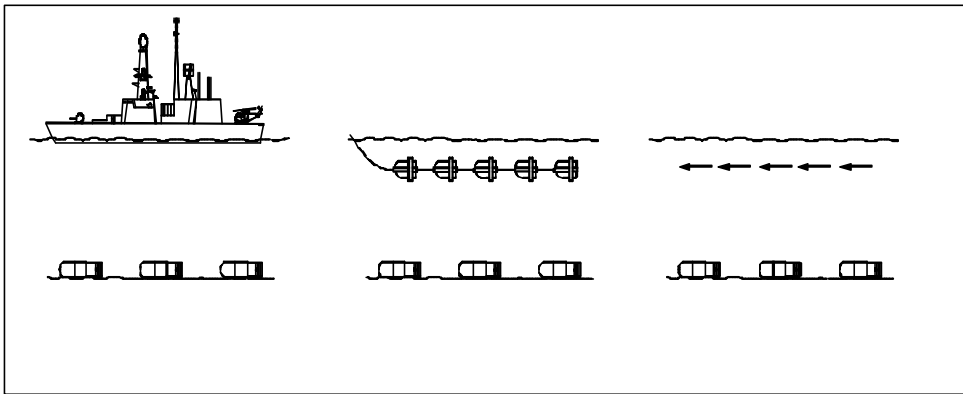
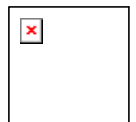


Fig. (3) The figure shows how a ship may be represented as a source of dipoles above the sensor array in a similar manner to a sweep. These dipoles are used to predict the ship signature at a variety of ship headings and spatial positions.

4.2.1 Electro-Magnetic Modelling

The electro-magnetic model of the vessel is achieved by a technique known as dipole modelling. This technique produces a model of the ship by representing the ship as a distribution of magnetic and electric dipoles, figure (3). DC dipoles are used to represent the static electric and magnetic signatures and AC dipoles are used to represent the time dependent electric and magnetic signatures.

Regardless of the exact physical form of the electric and magnetic dipoles, the basic idea is that these magnetic and electric dipoles can be thought of as being known sources of magnetic and electric fields. By changing the magnitude, orientation and number of dipoles used a representation of the ship's signature can be built up. Obviously the prescription by which this is done is quite sophisticated. The magnetic and electric fields measured at the sensors by the multi-influence array are related to their source, the ship, in a known way. The relations governing this are known as Maxwell's equations after the physicist who unified the understanding of electricity and magnetism in the 19th century. Using Maxwell's equations it is possible to calculate the nature of the source of the electric-magnetic signature from the measurements at the sensor. Since Maxwell's equations can describe the interaction of electric and magnetic field in any conceivable environment we can allow for the effects of the environment in which the vessel was measured. We can therefore account for the fact that the



Management Of Multi-Influence Signatures In Littoral Waters

ship might have been ranged in environment with fresh or shallow water with different types of seabed. The end result is that we can predict the signature of the ship not just on the range itself but in any conceivable environment and this may performed for any spatial position and ship heading.

4.2.2 Acoustic Modelling

Acoustic modelling is performed in a similar way to the electro-magnetic modelling. We represent the ship as distribution of monopole acoustic sources, or small sources of noise. Again by changing the distribution and magnitude of the acoustic sources it is possible to construct a picture of the acoustic signature of the vessel from the measurements made by the multi-influence array.

For the acoustic model the relation between the source and the measured signature are different because they obey different physical laws. In order to determine the acoustic model we must solve a mechanical wave equation. Again this contains all the necessary environmental factors so that we can allow for the site at which the ship is ranged and so predict the signature at any arbitrary spatial position and environment.

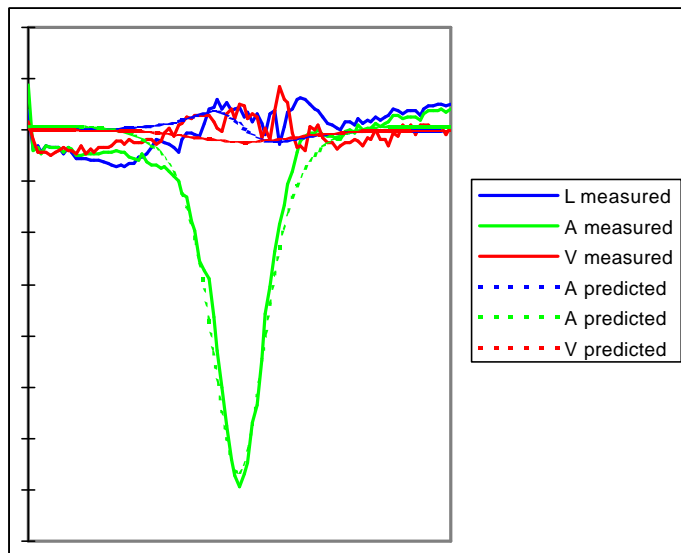
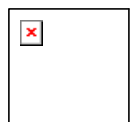


Fig. (4) The figure shows a typical ship's DC CRM signature. We see that the measured signature compares well with that computed using the modelling software.



5 Providing A Service

The multi-influence range provides a basis from which the signatures of vessel can be accurately predicted. This can be used in a variety of ways. For one it can be used to check the electro-magnetic and acoustic hygiene of a vessel before putting to sea. The multi-influence modelling software can, once the ship has been ranged, predict what the signature of a vessel is likely to look like in its operating environment such as littoral waters. Once this is done a risk assessment can be performed in order to see if the ship's target signature is essentially safe for operation in that particular environment.

The transportable multi-influence range can be taken into the theatre of operations for a final check of the vessel signature. It provides the facility of changing the setting of the degaussing coils if one or more are to fail in the field.

The range is easily transportable and quickly deployed. It generally takes two days using a three man team to deploy the range. The Transmag range, of which the multi-influence sensor range is an upgrade, has been deployed overseas in war during Operation Desert Storm in which foreign governments sent their minesweeping vessels to the range when deployed for active duties in MCM operations. The range has also been successfully deployed in the United States, Saudi Arabia, Australia, Norway, the Falklands, Gibraltar, Denmark and Portugal.

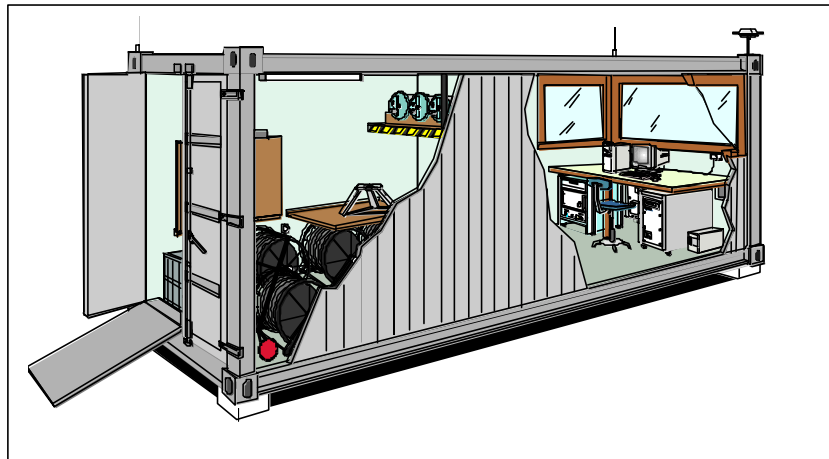
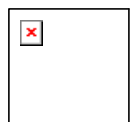


Fig. (5) The figure shows the multi-influence transportable range ISO container. The ISO container contains all the equipment necessary to measure and model a ship signature in the field enabling the system to be easily transported and quickly deployed.



Management Of Multi-Influence Signatures In Littoral Waters

5.1 Examples Of A Typical Ranging and Signature Assessment

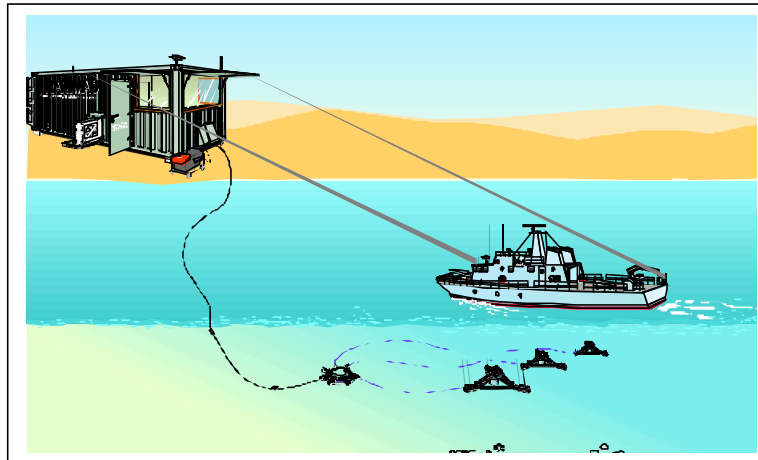
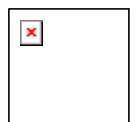


Fig. (6) The figure shows a typical ranging using the transportable multi-influence range.

- i. The customer ranges a vessel that has recently undergone a minor refit. Two runs are made across the multi-influence sensor range. The data is gathered and used to predict the various ship signatures. The DC magnetic signature is used to determine new settings for the DG coils. The predicted acoustic signature is compared with the expected class average. It is determined that the acoustic signature conforms to the expected norm. The electric field signature is examined and it is seen that it is not within the target for the vessel. Closer examination reveals that the problem area appears to be at the stern of the vessel. The CRM signature also shows a similar problem. After a radio conversation with the crew it turns out that the potential setting for the cathodic protection system was not correctly set for that zone. The correction is made and an additional two runs are made. The data gathered is used to recompute the signature, since the electro-magnetic state of the ship has changed. It is seen that both the magnetic and electric signatures now conform to their target levels.
- ii. Operation of a vessel is necessary in coastal waters where the water is fairly shallow and environmental composition unknown. The vessel is to be used in a suspected mined area. The multi-influence modelling software is used to predict the signatures in the region of operation given the potential variation in the seabed composition. This is then used to assess the likely risk to the vessel. The vessel sails to its place of operation, a 2000 mile journey. The multi-influence range is quickly deployed to check the vessel's signature. It is seen that after two reciprocal runs that the contribution of the magnetic signature due to ferromagnetism is within target level. However data obtained from the electric and CRM signature suggests that there is problem since they do not match the signature of the vessel after it left port given that environmental factors have been allowed for. It



Management Of Multi-Influence Signatures In Littoral Waters

is seen that after closer inspection that damage to the paint has occurred along the hull of the ship, giving rise to corrosion. The damage is repaired. The ship is re-ranged and the ship's signature is within target levels.

6 Conclusion

In this document the various signatures that are encountered have been examined and the effect of a littoral water environment discussed. We have demonstrated how the multi-influence sensor array developed by Ultra Electronics as an upgrade to the Transmag system can be used to measure and model ship's signatures and have described how it may be used in littoral water operations. It has been shown that this array is easily transportable and quickly deployable. The multi-influence range is an extremely effective method of signature management and can be used as basis of any risk assessments due to signature related threats.

7 References

- [1] G.J. Webb, S.S. Tut, S.J. Davidson and A.J. Wilkinson, Multi-Influence electromagnetic and Acoustic Ranging, UDT Conference Proceedings, UDT Pacific 98, Sydney, Australia.
- [2] S.J. Davidson, T.D. Cassel, G.J. Webb A.M. Cross, Transmag-a transportable degaussing range, UDT Conference Proceedings, UDT 94, London, UK.
- [3] G.J. Webb and S.J. Davidson, Why Bother With Signature Reduction, UDT Conference Proceedings, UDT Pacific 98, Sydney, Australia.

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