Defence Research and Development Canada | Recherche et développement pour la défense Canada

Vessel detection using extremely low frequency magnetic signal

Marius Birsan, PhD

DRDC Atlantic

DRDC | RDDC

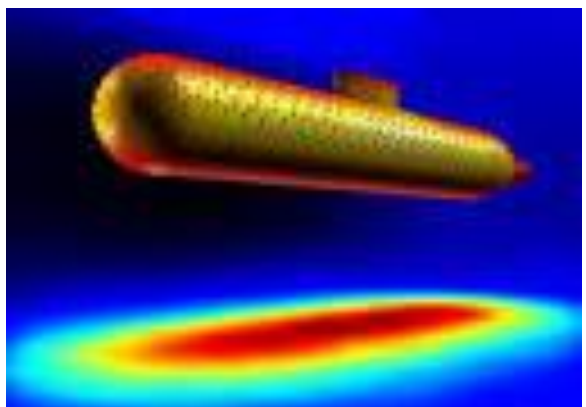
Canada

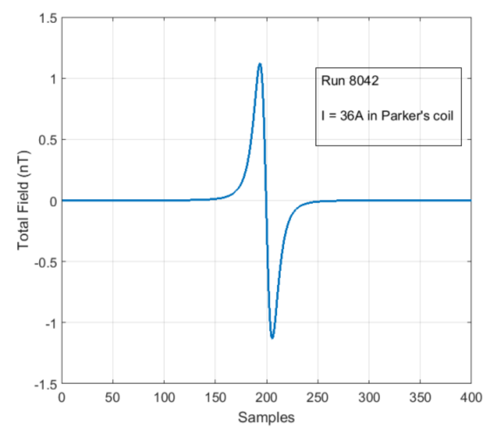
Classical Magnetic Anomaly Detection (MAD)

- Ferromagnetic materials distort the Earth's magnetic field.
- MAD exploits the vessel magnetic signature produced by ferromagnetic materials.
- Nowadays submarines are made of stainless steel and are very well magnetically maintained.
- Other signatures need to be exploited.

Classical Magnetic Anomaly Detection (MAD)

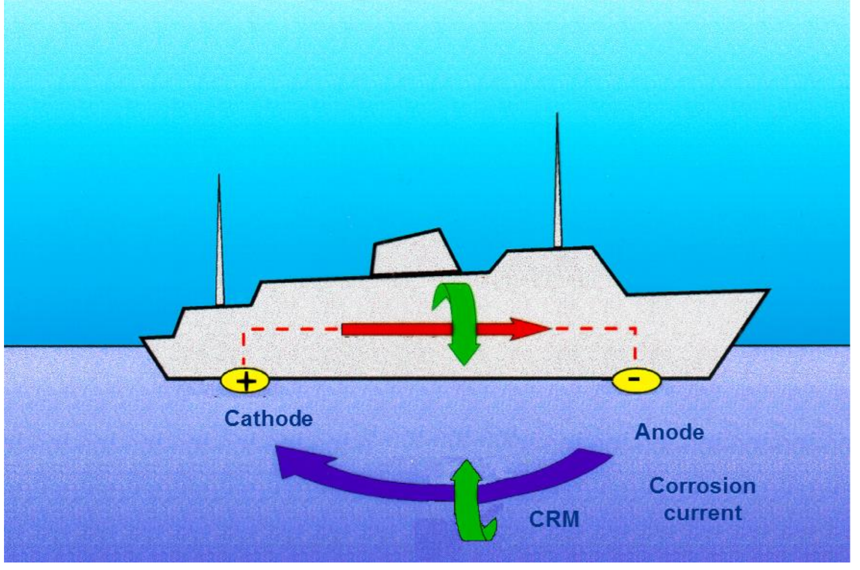
Scalar (optically pumped) magnetometer



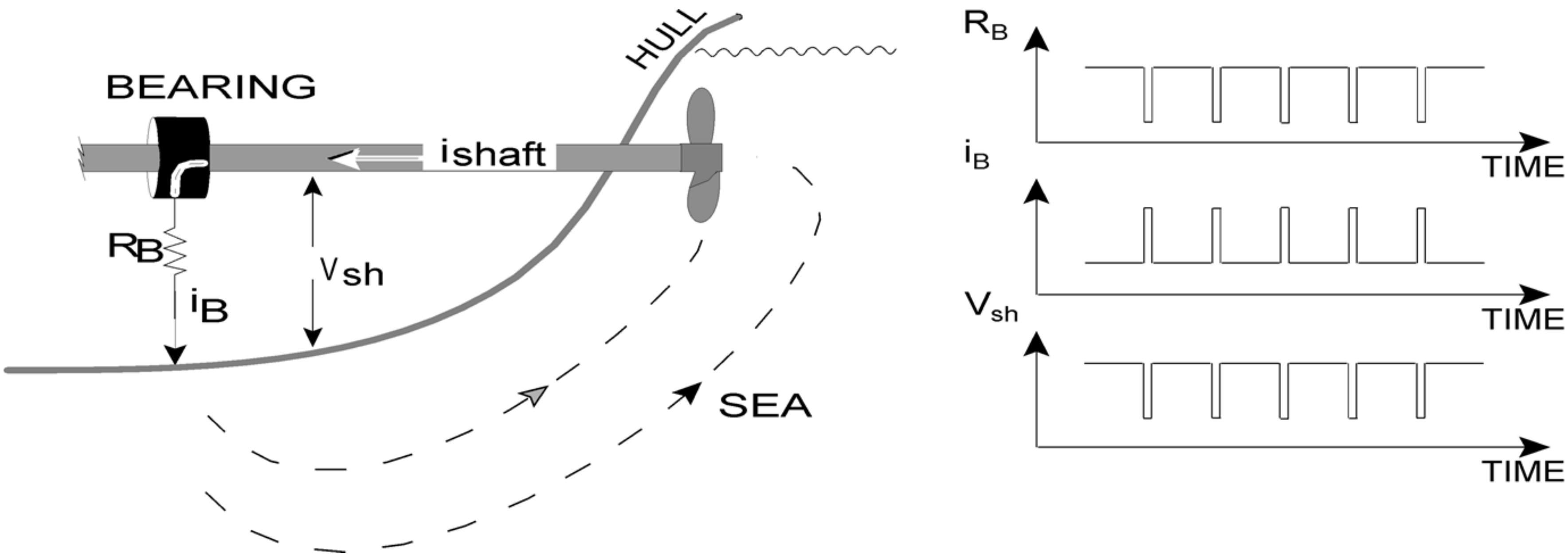


New signature: Electric currents from corrosion

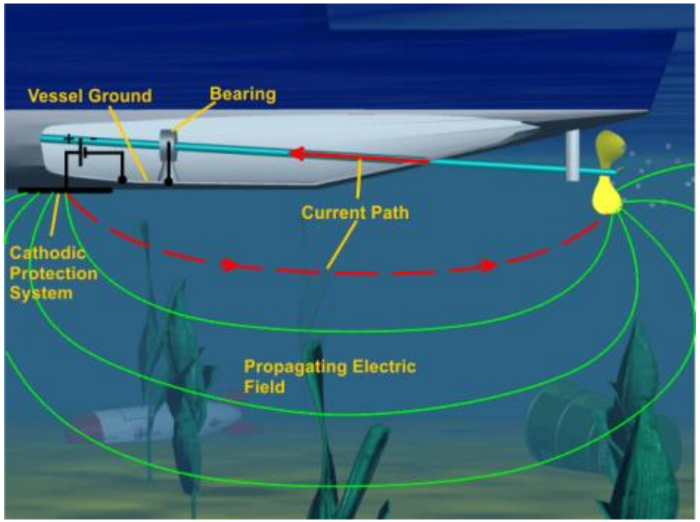
- Dissimilar materials corrode in seawater.
- Electric current is part of the process.
- A signature impossible to eliminate!

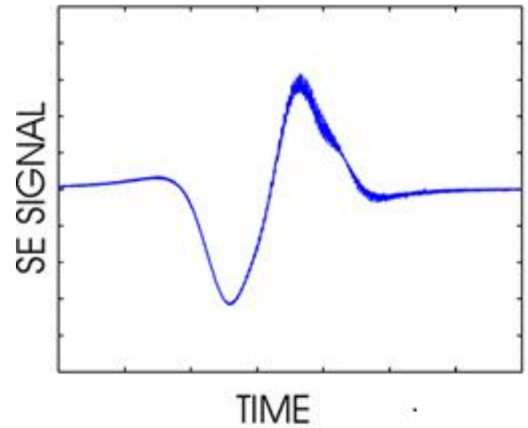


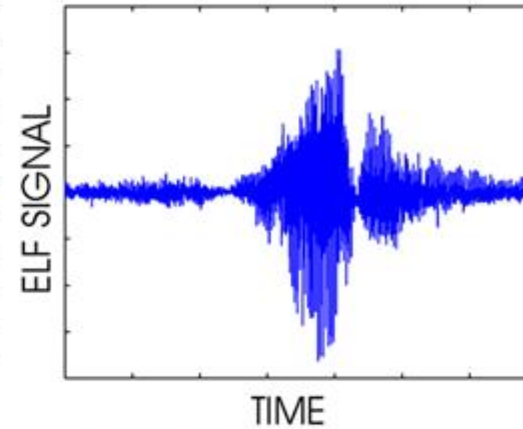
Alternating electromagnetic field

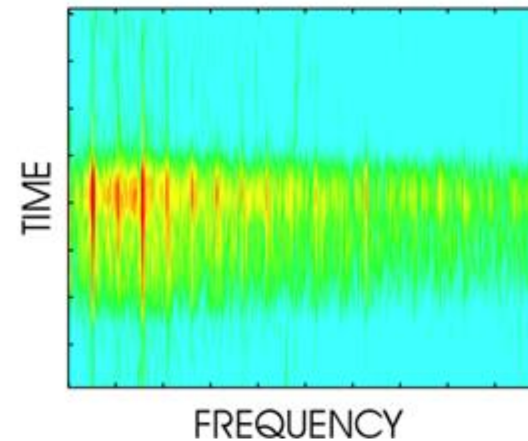


New signature: Magnetic field from corrosion currents









- Vessels are protected against corrosion.
- Corrosion protection increases this signature.
- AC field is lowered by shaft grounding.
- Shaft rate is clearly visible.

Vessel detection using ELF magnetic signal

- AC signal is not contaminated with geomagnetic noise.
- Magnetic ELF ~ $1/R^2$, longer distance of detection.
- Uses the same scalar MAD magnetometer(s).
- Magnetometer floor noise is low (~ 0.1 pT/√Hz).
- Detection range mainly limited by the environment noise:

  400m for 1 pT/√Hz to 1200m for 0.1 pT/√Hz.

This work addresses the problem of single channel noise reduction to improve the magnetic ELF detection.

DRDC trials: towed electric source, AC-DC signals

Example: Torpedo and Ship Ranging Vessel as target

First stage noise reduction: model based

- Additive noise is produced by the local **permanent** ($c_{1\text{-}3}$), **induced** ($c_{4\text{-}9}$), and **eddy current** ($c_{10\text{-}18}$) magnetic vectors.
- These effects are modeled with 18 terms (classical):

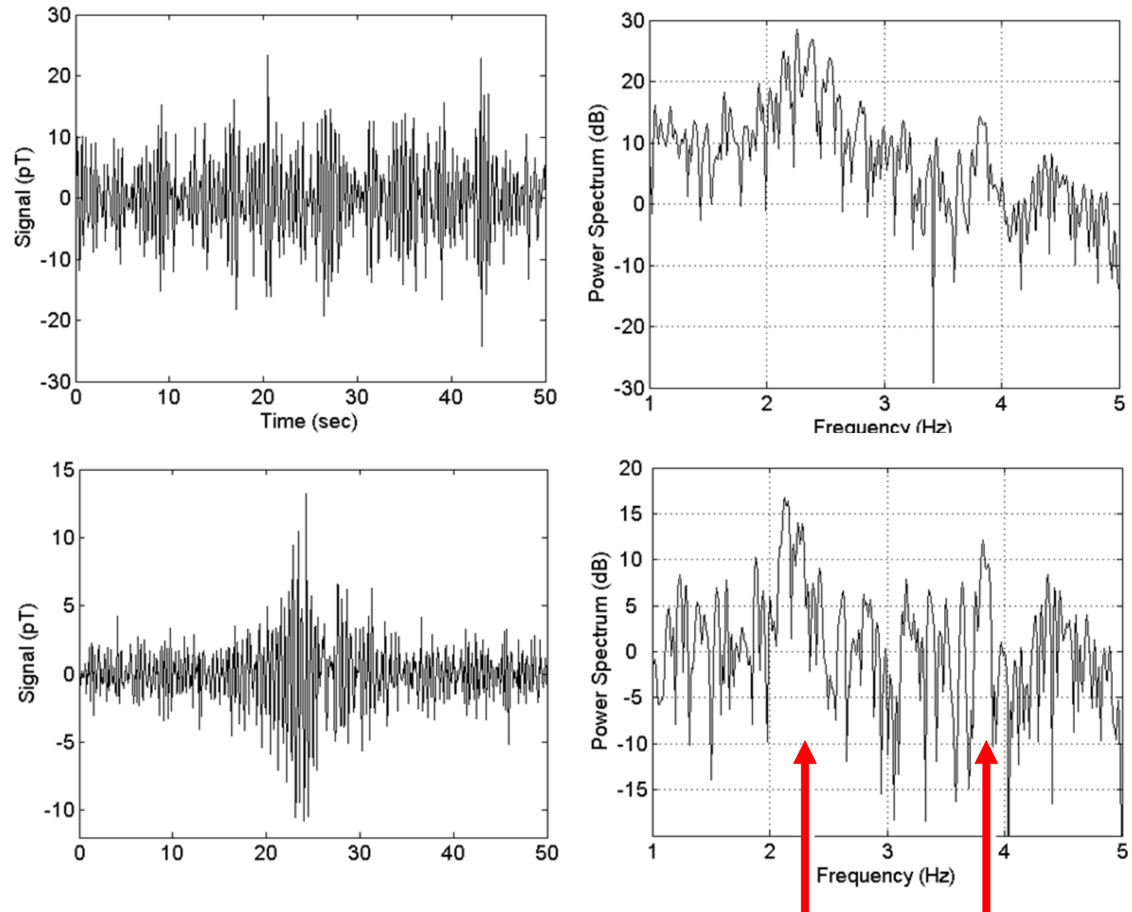
$$
\begin{aligned}
T &= c_1 \cos X + c_2 \cos Y + c_3 \cos Z + \\
&+ H_e\{c_4 \cos^2 X + c_5 \cos X \cos Y + c_6 \cos X \cos Z + c_7 \cos^2 Y + c_8 \cos Y \cos Z + c_9 \cos^2 Z + \\
&+ c_{10} \cos X (\cos X)' + c_{11} \cos X (\cos Y)' + c_{12} \cos X (\cos Z)' + c_{13} \cos Y (\cos X)' + \\
&+ c_{14} \cos Y (\cos Y)' + c_{15} \cos Y (\cos Z)' + c_{16} \cos Z (\cos X)' + c_{17} \cos Z (\cos Y)' + c_{18} \cos Z (\cos Z)'\}
\end{aligned}
$$

(cosX, cosY, cosZ) = directional cosines of the Earth’s field and airplane’s axes.

First stage noise reduction: 18 terms model

Raw data

18 terms noise reduction



Second stage: spectral noise reduction

- Noisy signal = the signal, s(t), plus additive noise, n(t):

$$v(t) = s(t) + n(t)$$

- The noise reduction process consists in the application to each short-time frequency spectrum, $V(m,\omega_k)$, of a spectral gain, $G(m,\omega_k)$:

$$G(m,\omega_k) = f\,[SNR_{prio}(m,\omega_k), SNR_{post}(m,\omega_k)]$$

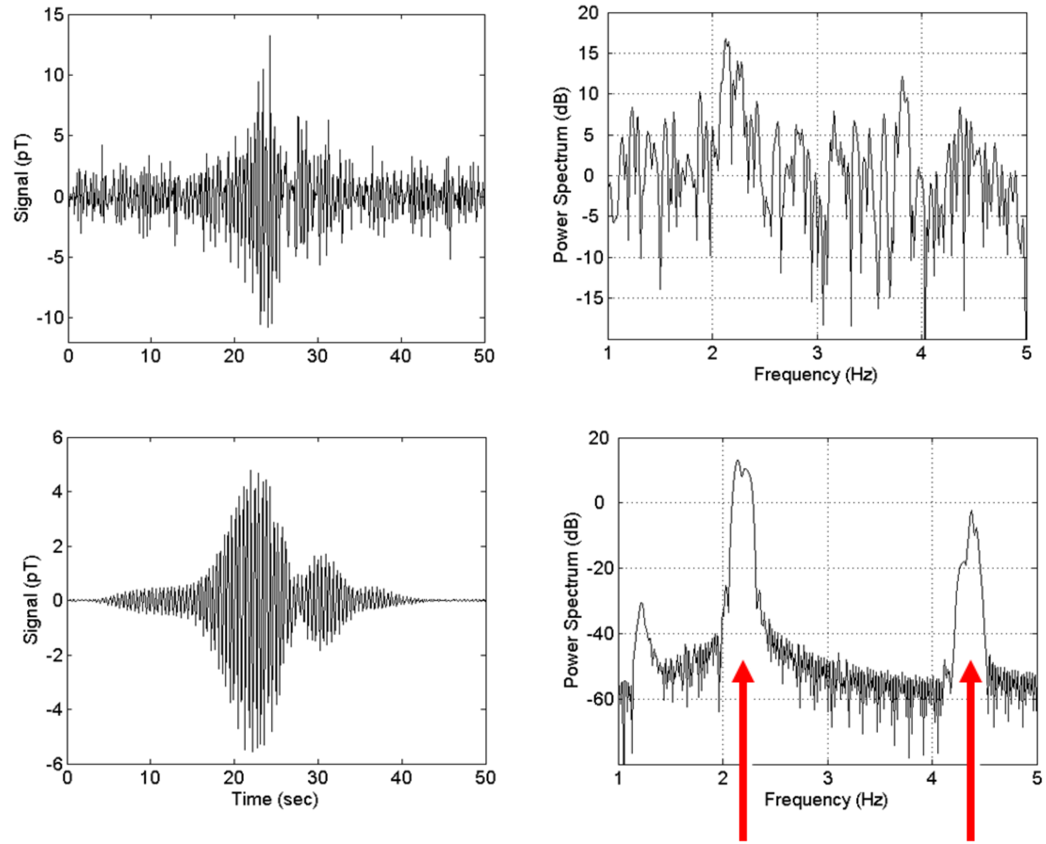
$$SNR_{post}(m,\omega_k) = \frac{|V(m,\omega_k)|^2}{E\{|N(m,\omega_k)|^2\}}; \quad SNR_{prio}(m,\omega_k) = \frac{E\{|S(m,\omega_k)|^2\}}{E\{|N(m,\omega_k)|^2\}}$$

$$\hat{S}(m-1,\omega_k) = G(m-1,\omega_k)\,V(m-1,\omega_k)$$

Second stage: spectral noise reduction

18 term noise reduction

Windowed spectral reduction



Target information

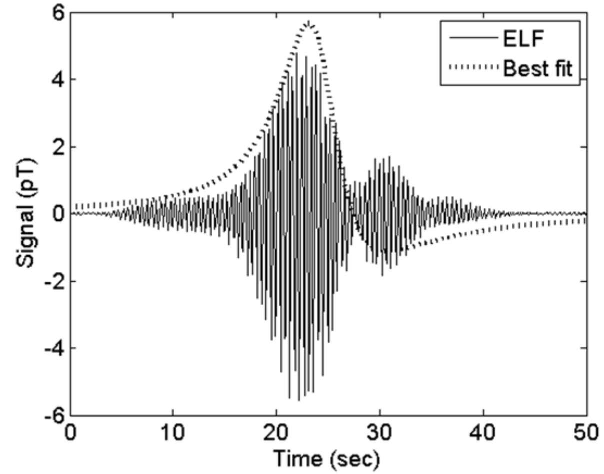
ELF inversion: Heading = -18°

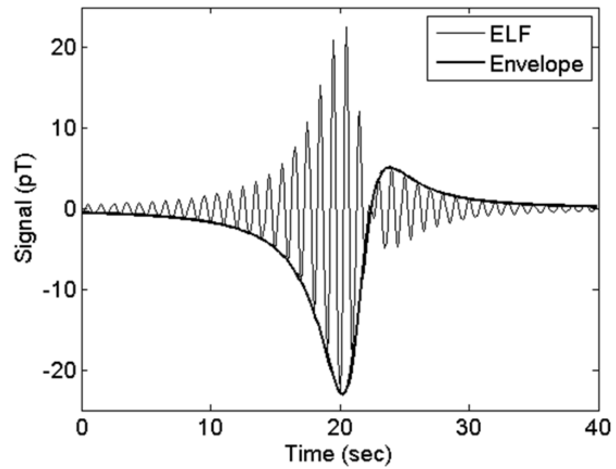
Altitude (x_{CPA}) = 90m

Slant distance = 106m (inversion)

Hor. Offset = ± 55m

ELF modeling: 10A-m, 2Hz





DRDC | RDDC

Conclusions

- The MAD system can detect a vessel from its magnetic ELF radiation.
- A noise reduction technique, adapted from acoustics, was applied in addition to the classical 18 term model method.
- The reduction of the background noise was substantial, so that the ELF radiation offers a long range means of detection.

DRDC | RDDC

SCIENCE, TECHNOLOGY AND KNOWLEDGE
FOR CANADA'S DEFENCE AND SECURITY

SCIENCE, TECHNOLOGIE ET SAVOIR
POUR LA DÉFENSE ET LA SÉCURITÉ DU CANADA