Numerical Analysis of Propeller-induced Low-frequency Modulations in Underwater Electric Potential Signatures of Naval Vessels in the Context of Corrosion Protection Systems

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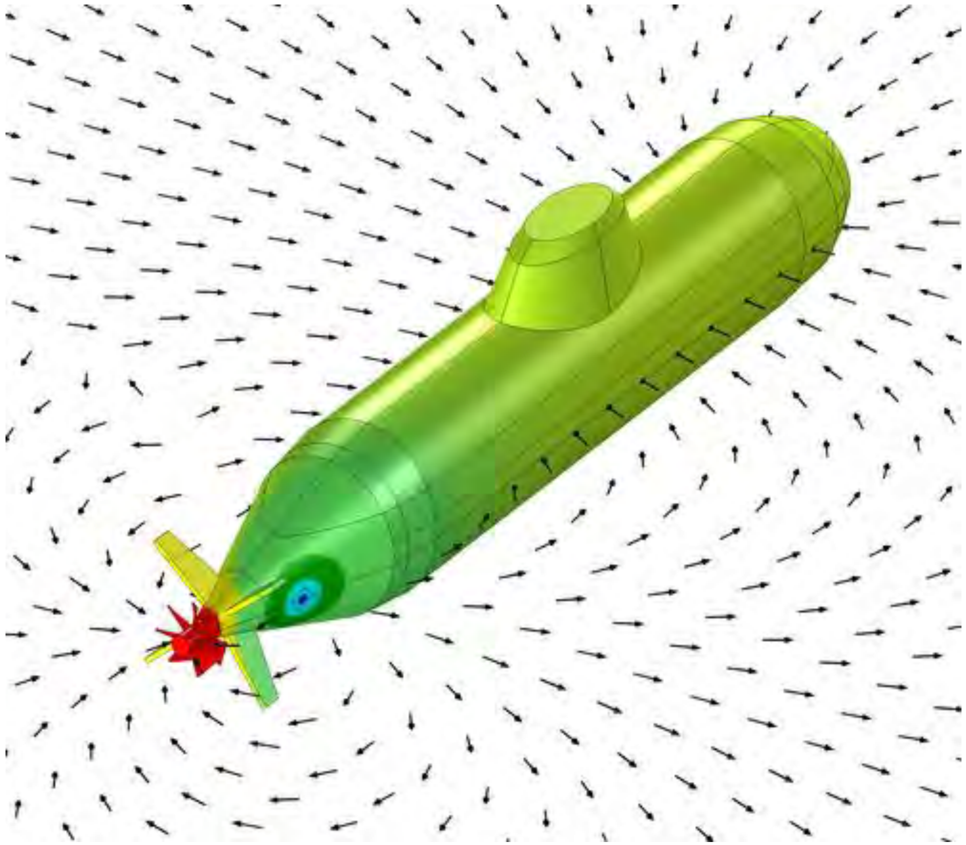

Outline

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- Conclusions and Outlook
- Literature

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Introduction (I)

Underwater signatures and “Mine warfare” (MIW)

- The term “signature” originally referred to acoustic measurements of a vessel's underwater sound pressure field [1, p.1ff].
- Different types of signatures:
  - Acoustic signature
  - Magnetic signature
  - Electric signature (UEP signature)
  - …
- Vessels (unintentionally) reveal their presence to their environment.
- Signatures exploited in “Mine warfare” (MIW) and “Anti-submarine warfare” (ASW).
- Naval influence mines buried in seabed can monitor signatures and actuate without direct contact.
- Acoustic and magnetic signatures well under control.
- Electric (UEP) signatures not so important until now, but probably in the future → **Focus of our research**

Diverse influence mines *(under CC-license; Author: Darkone@Wikipedia)*

Acoustic influence mine found in the Arabian Gulf

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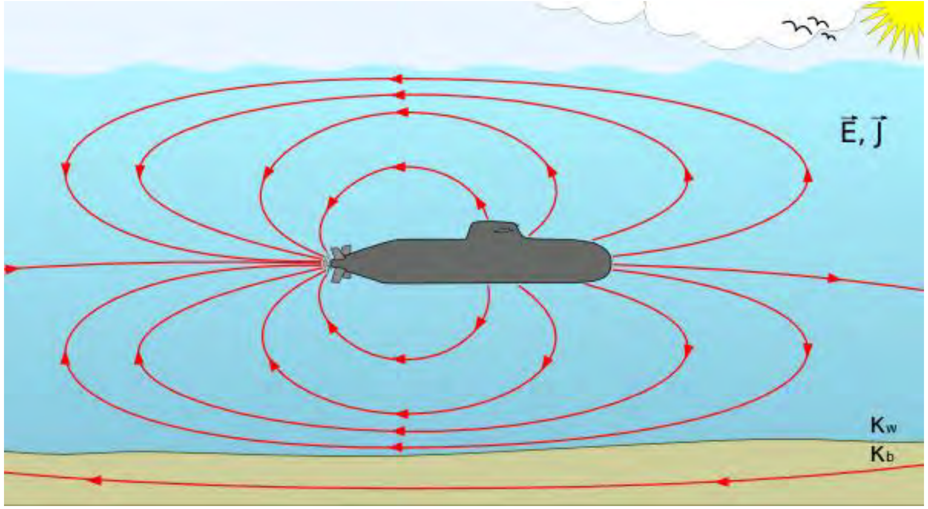
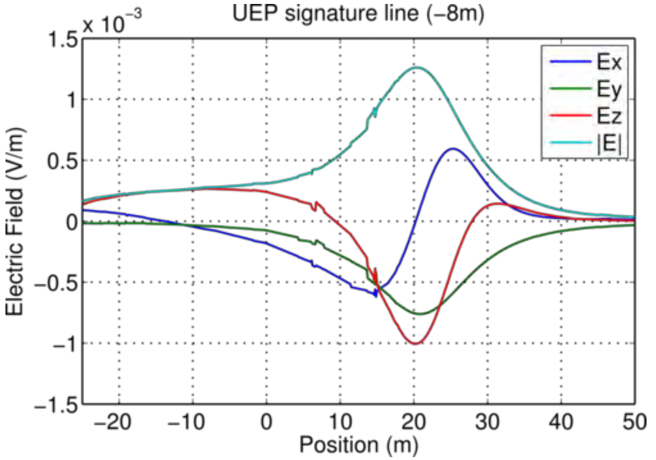
Introduction (II)

Underwater electric potential (UEP) signature

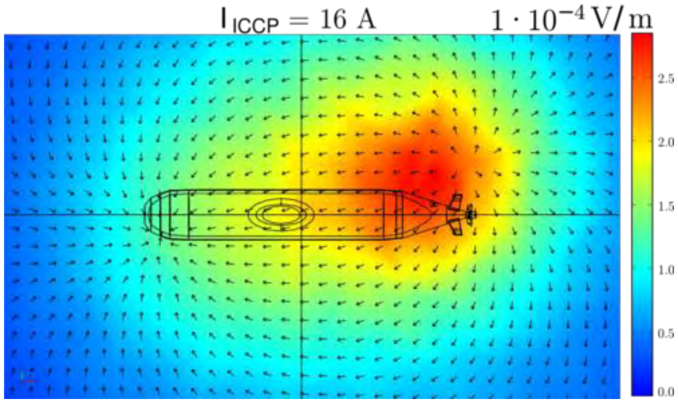
- Reasons for the electric currents in water:
  - Electrochemical reactions (Corrosion)
  - Corrosion protection systems
- Common representation for UEP signature:
  - “Signature line” (Axial trace)
  - “Signature plane” (Slice plot)



Sketch of typically electric current paths around a submarine.



Axial trace of the near-field (8m below the keel) UEP signature of a simplified submarine model, simulated with COMSOL.



Signature plane of the electric field in a depth of 20m (66ft) below the keel, simulated with COMSOL.

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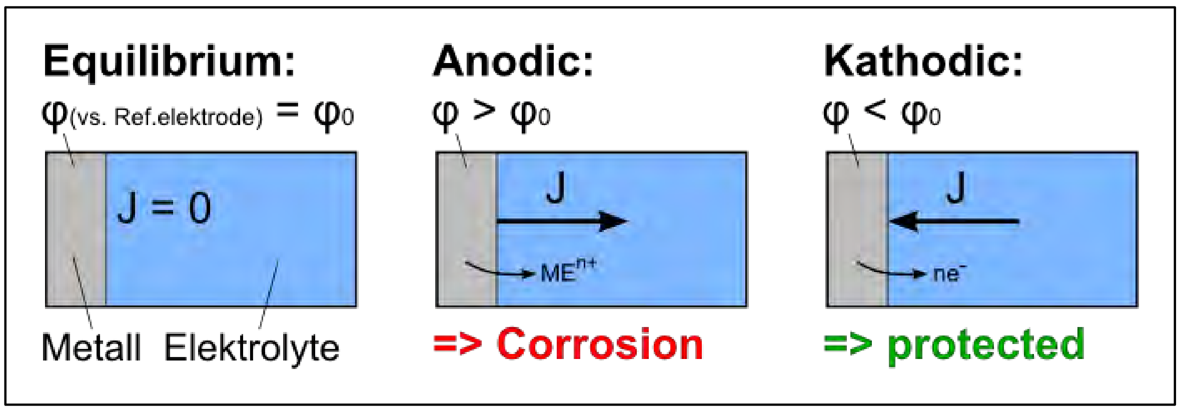
Introduction (III)

Corrosion protection (CP) for naval vessels

- Active corrosion protection systems:
  - Galvanic/sacrificial anodes
  - Impressed current cathodic protection (ICCP) systems
- Active CP often based on cathodic currents:



- Passive corrosion protection:
  - Isolating coatings
  - Protective paintings
  - Proper material combination
- **Question:** What is the ideal corrosion protection setup to minimize the UEP signature?


Galvanic zinc anodes *(under CC-license; Author: Hgrobe@Wikipedia)*


Galvanic anodes placed on a ships hull

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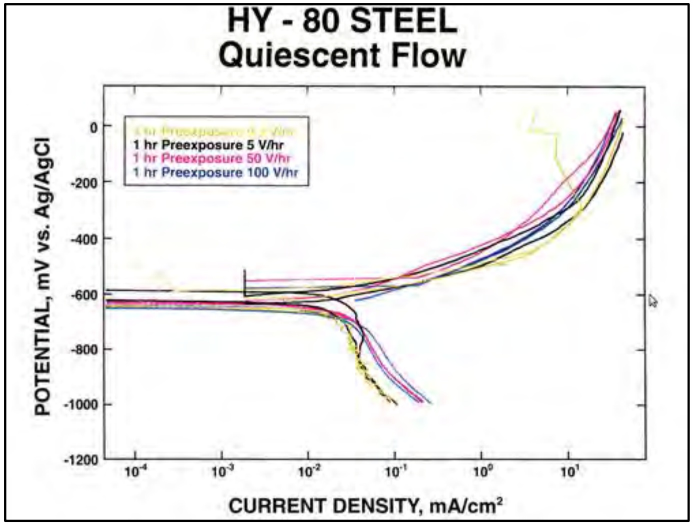
COMSOL Multiphysics simulations

Governing equations

- Poisson equation (AC/DC Module – Electric Currents): $\Delta(\sigma \cdot V) = 0$
- Electric field and current density: $\vec{E} = -\nabla V$ $\vec{J} = \sigma \cdot \vec{E}$

Electrode kinetics considering measured polarization curves

- Neumann boundary condition ("Inward current density"):
  $\vec{n} \cdot \vec{J} = J_i(V)$
- $J_i(V)$ represents a nonlinear polarization curve.
- Simulated in COMSOL by using a piecewise interpolated function.



Polarization diagram measured my Hack [3].

Simulating via "LiveLink for Matlab"

- Capability to...
  - ...perform complex parameter sweeps.
  - ...implement customized optimization procedures.
- In-house developed toolbox to receive entity-ids by referring to the name-tag.

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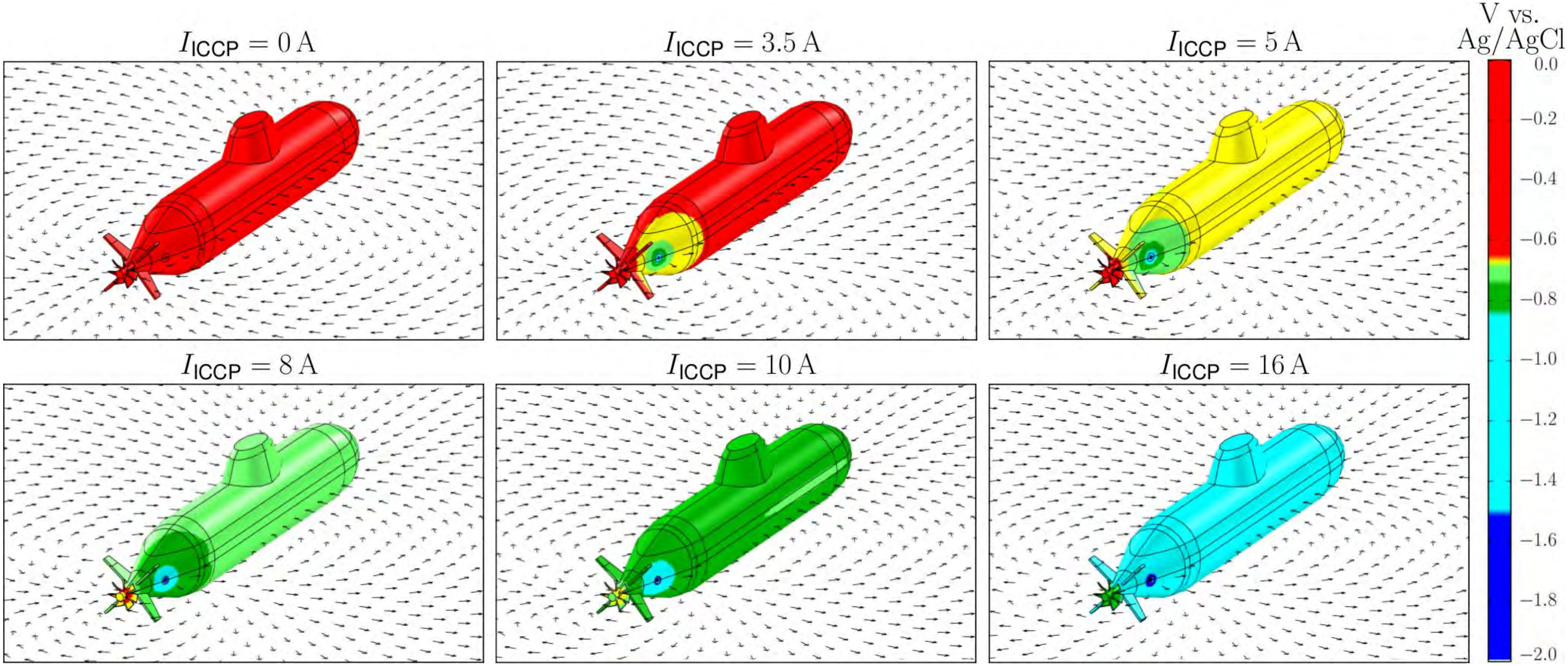
Research results (I)

Potential distributions on the vessel's hull



Potential distribution on the hull of a simplified submarine model, for different currents impressed by the ICCP system. The colorbar is based on the German naval directive “VG 81259” [2].

- Good protection at $I_{ICCP} \approx$ 8-10A for this submarine model.

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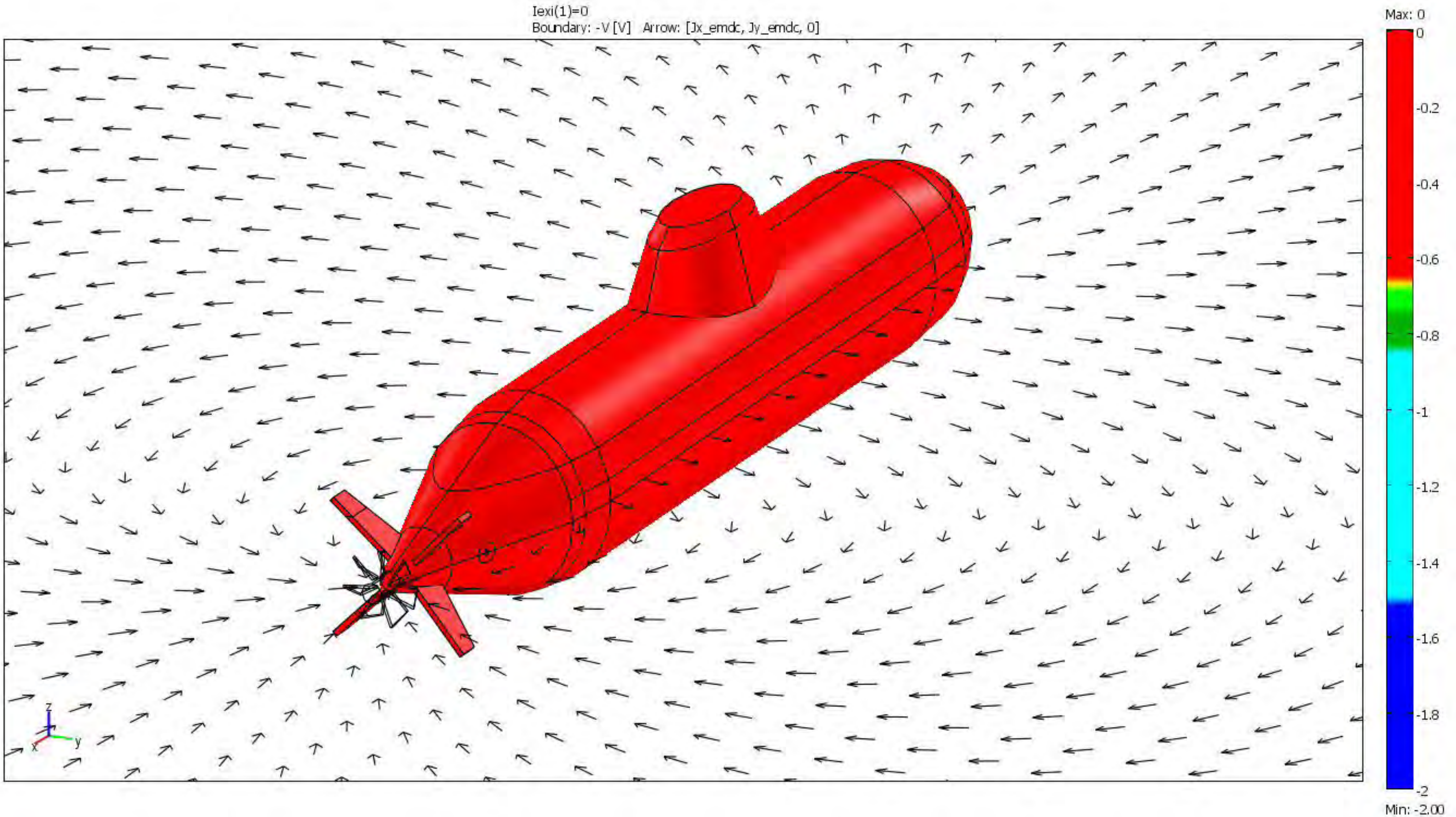
Research results (II)

Potential distributions on the vessel's hull



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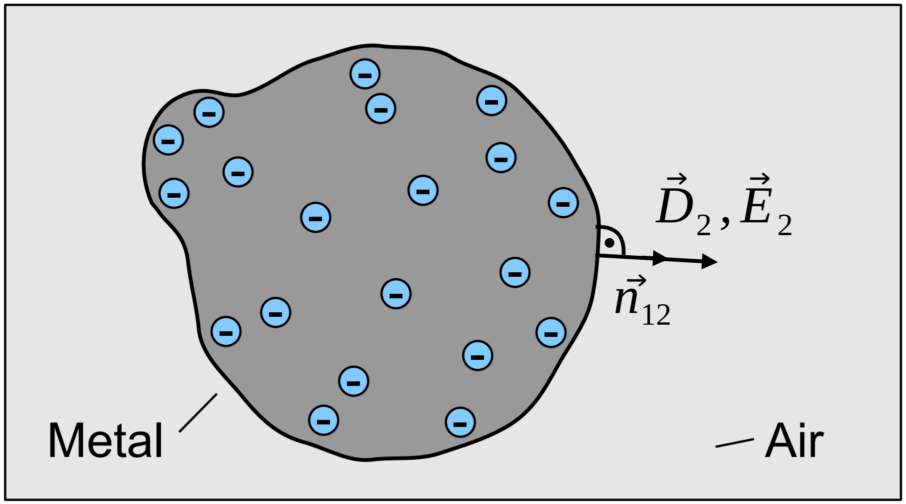
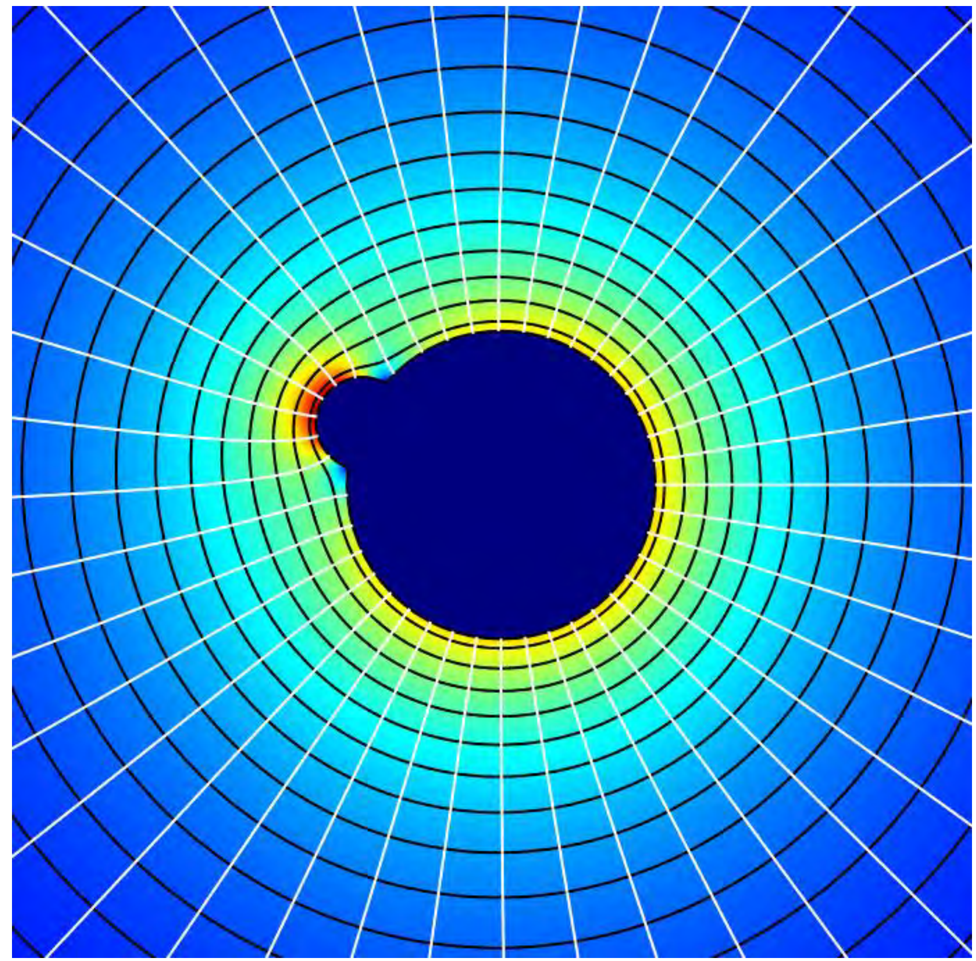
Research results (III)

Singular field peaks at sharp angles and edges



- Charges repel each other and move to the surface of the conductor.
- More charge on surface areas with small curvature (e.g. on buckles/angles/edges).
- Relation between $\vec{D}$ and σ [4, S.102]:

$$\vec{n}_{12} \cdot (\vec{D}_2 - \vec{D}_1) = \sigma \quad \Rightarrow \quad |\vec{D}_2| = \sigma$$



Field- and equipotential lines for an electrically charged "potato" simulated with COMSOL.

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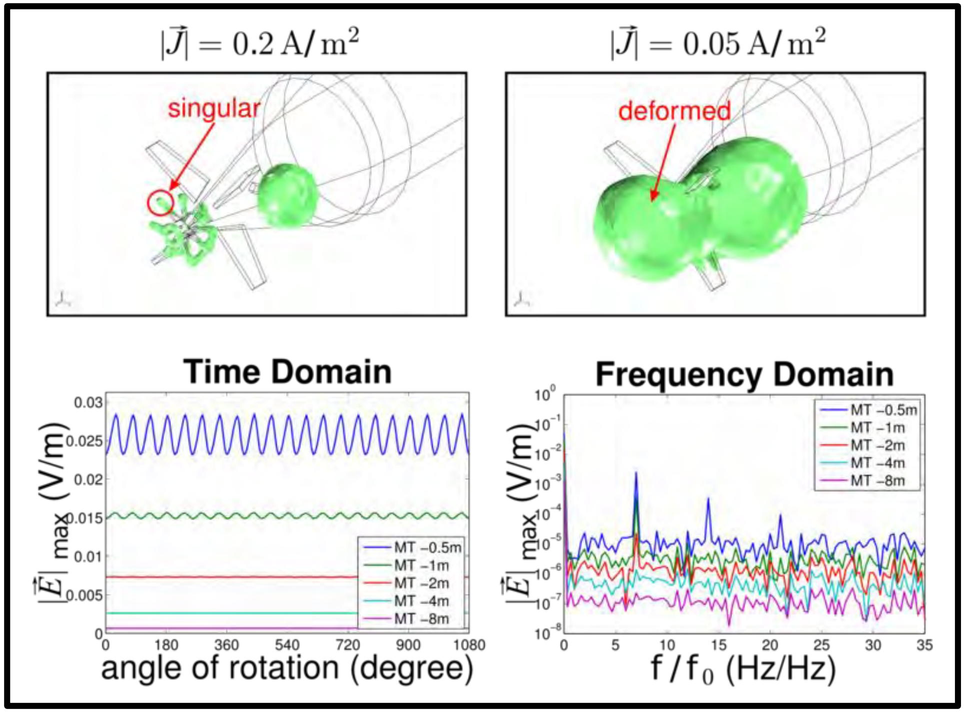
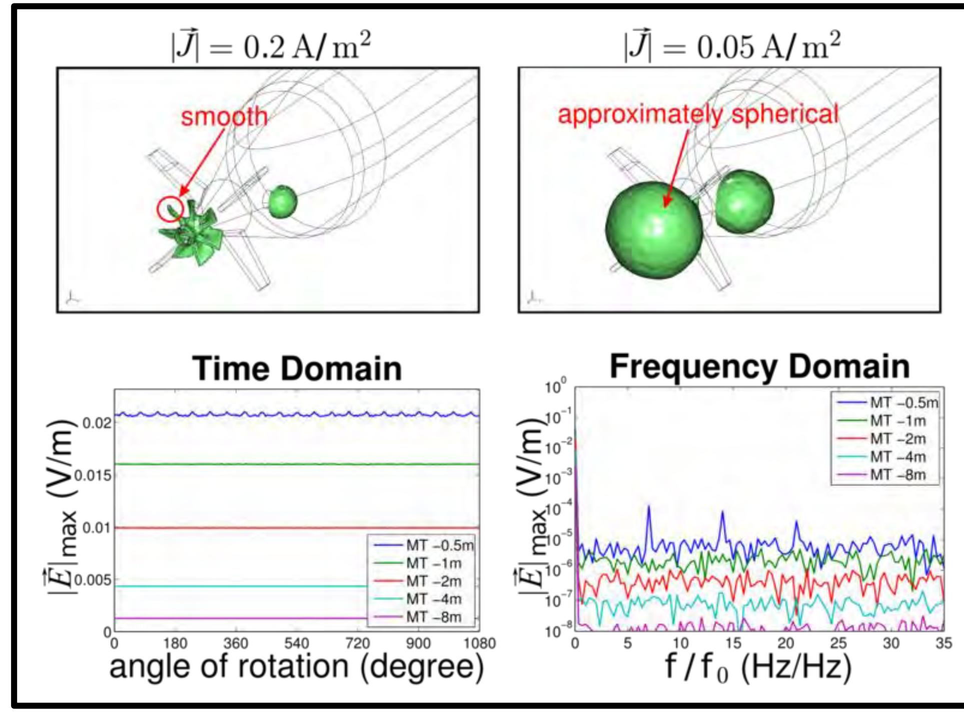
Research results (IV)

"Smoothing effect" of the polarization resistance



Simulated near-field modulation with **Dirichlet** boundary conditions.

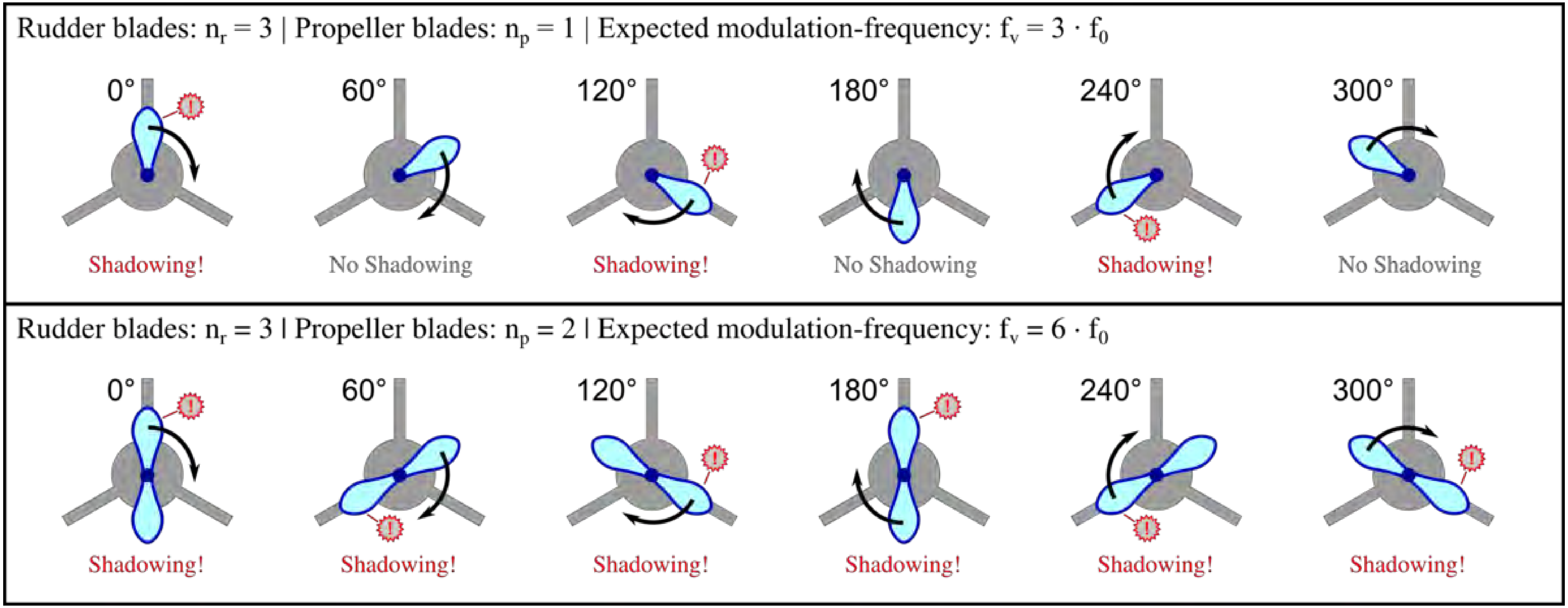


Boundary conditions based on **non-linear polarization curves**.

- Dirichlet: Singular field-peaks occur on sharp edges like the tips of the propeller blades.
- Rotating propeller modulates the electric near-field (rotating deformed equi-surfaces).
- Polarization resistance reduces the modulation (spherical equi-surfaces)

Research results (V)

Vernier-/Nonius effect



Theoretically example to illustrate the Vernier-/Nonius effect. The figure shows an astern view on a simplified submarine model.

- Propeller blades get covered behind rudder blades during the rotation of the propeller.
- **Question:** Does the total ICCP current become modulated?
- Frequencies corresponding to Vernier-/Nonius **not observable** in simulation.

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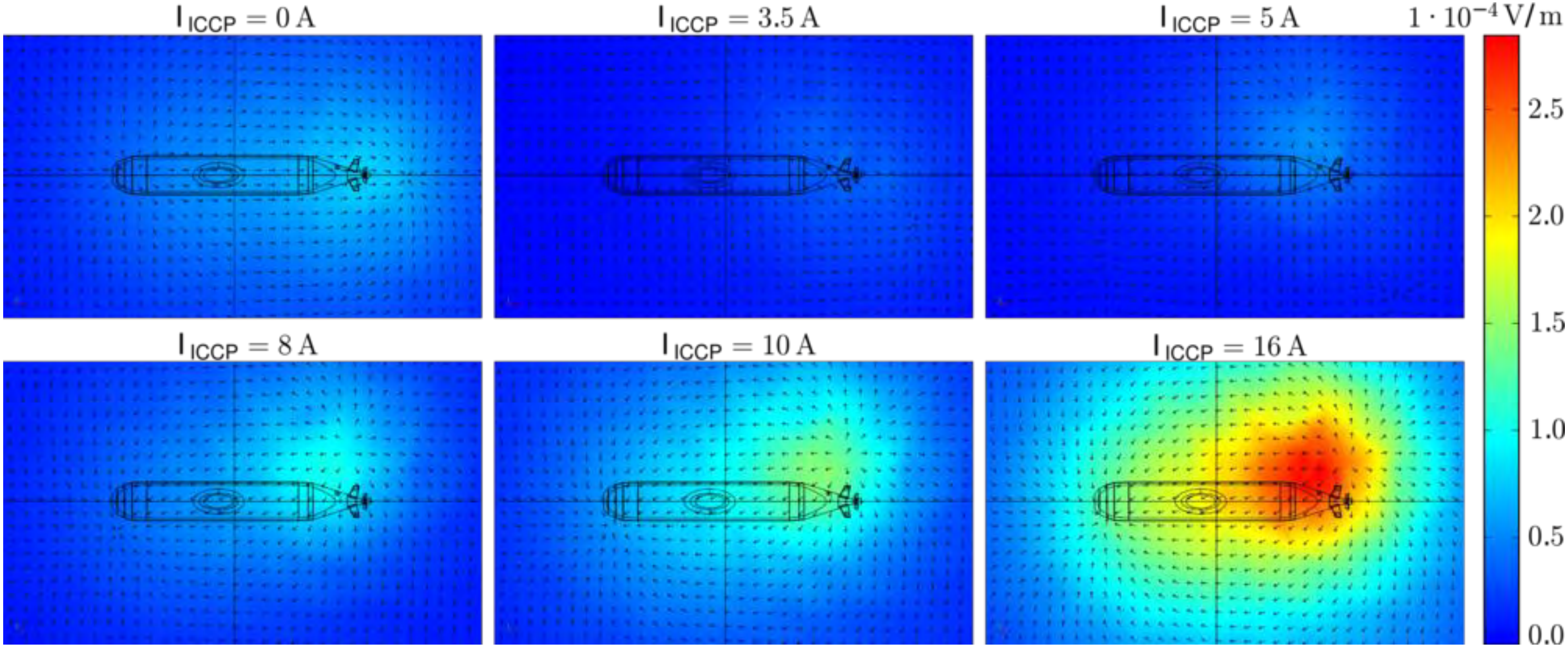
Research results (VI)

Optimal ICCP current for “silent running” (stealth mode)



Signature planes of the electric field in a depth of 20m (66ft) below the keel, for different currents impressed by the ICCP system.

- Optimized ICCP currents can in fact reduce the UEP signature (**3.5A**).
- Switched off ICCP system does not necessarily produce the smallest UEP signature (**0A**).
- Overprotection can increase the UEP signature critically (**16A**).

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Conclusions and Outlook

Conclusions

- COMSOL simulations provide us with a reliable basis for understanding the principally coherences in the application of UEP signatures.
- Polarization resistance “smoothens” singular field-peaks.
- Frequencies corresponding to Vernier-/Nonius effect not observable.
- Optimized ICCP currents can reduce UEP signature, but overprotection can increase the UEP signature critically.

Outlook

- Simulations of the electric currents flowing back through the electron conductor (Using the COMSOL “Batteries & Fuel Cells Module”).
- Simulations of the corrosion related magnetic field.
- Qualitative changes in the UEP signature of scaled models.

Literature

[1] J. J. Holmes, “Exploitation of a Ship’s Magnetic Field Signature”, Morgan & Claypool Publishers, (2006).

[2] BWB, VG 81259 Teil 1-3, "Kathodischer Korrosionsschutz von Schiffen – Außenschutz durch Fremdstrom", Beuth, (1994).

[3] H. P. Hack, "Atlas of Polarization Diagrams for Naval Materials in Seawater", Carderock Division Naval Surface Warfare Center (1995).

[4] Erni, D. : *Theoretische Elektrotechnik 1+2* (2010).

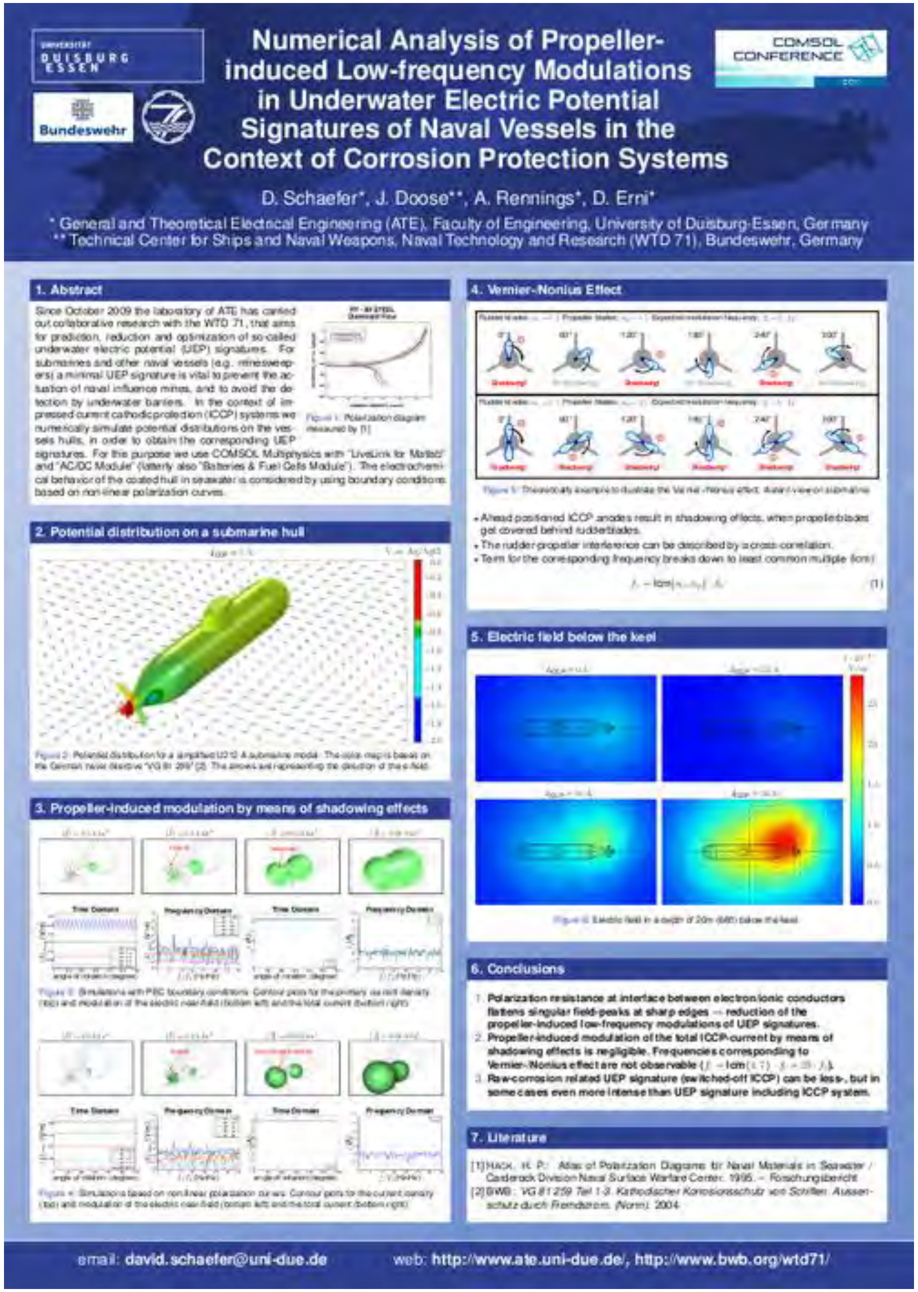
[5] http://wikipedia.org/

Thank you for your attention!

Questions?

Meet me at my poster →

When? 17:30 – 19:30
Where? Bürgersaal-Foyer



(also you can find my paper in the conference proceedings)