Numerical Evaluation of Seabed Influences on Underwater Electric Potential (UEP) Signatures and the Validation Framework

C. Broecheler(1), C. Thiel(1), F. Ludwar(2), J. Doose(2), A. Rennings(1), and D. Erni(1)

(1) General and Theoretical Electrical Engineering (ATE) University of Duisburg-Essen, D-47048 Duisburg, Germany

(2) Technical Center for Ships and Naval Weapons (WTD71), Deutsche Bundeswehr, D-24340 Eckernfoerde, Germany

E-Mail: claas.broecheler@uni-due.de Web: www.ate.uni-due.de

Abstract

Naval vessels are showing an underwater electric potential (UEP) signature generated by chemical potential differences of the ship's hull as well as by the corrosion protection systems. The UEP needs to be minimized to prevent the e.g. triggering of sea mines or other detections of the vessels. For such UEP signatures, the environment, in particular the electrical properties of the sea water and the seabed, is crucial for their amplitudes and shapes [1]. Additionally, beside the generated stationary electric fields, alternating current (AC) fields are present as well for example caused by the rotation of the ship's propeller [2]. Hence, a setup for the measurement of UEP signatures in the range of 0 Hz to 10 kHz is necessary together with a corresponding calibration system which is capable to compensate the environment influences of the measurement site.

For the calibration procedure it is essential to have a precisely known source. In order to design such a calibration source, a preliminary numerical evaluation is carried out with a simulation setup as sketched in Fig. 1 where on the one hand a submarine is placed in a free-water environment and on the other hand examined under measurement conditions including the seabed and the sensor array. As a simplification the ship's UEP signature is represented by a current dipole which is properly positioned and resized to mimic the real field distribution. Instead of discrete points corresponding to the positions of the sensors, the field is analyzed along a straight line emulating a crossing scenario. The software utilized for the numerical evaluation is the finite element method (FEM) based COMSOL Multiphysics simulator [3]. The applied permittivity and electrical conductivity of seawater are $\varepsilon_w = 81$ and $\sigma_w = 2.8$ S/m, respectively [4]. Above the sea level, air with $\varepsilon_l = 1$ and $\sigma_l = 0$ is used. The seabed consists of clay, sediments as well as shales and hence the electrical conductivity of this mixed composite material varies in the range of $\sigma_b = 0.1$ ... 0.0001 S/m [4]. Due to the penetration of seawater into the seabed layer the electrical conductivity is significantly increased. As a starting point for the numerical calculations an electrical conductivity of $\sigma_b = 0.73$ S/m is chosen. In order to achieve a dipole moment of 180 Am for the current dipole a length of 20 m and a current of 9 A is specified.

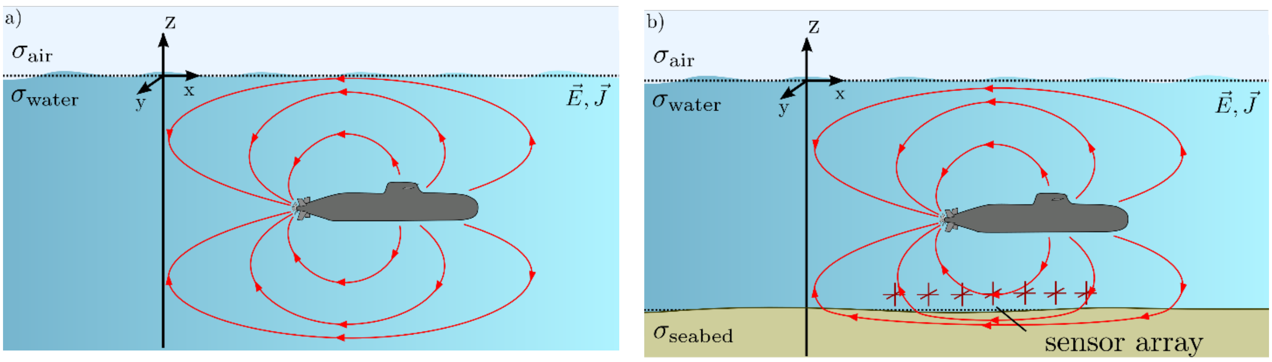


Fig. 1: Schematic of the simulation setup of a submarine in a free-water environment (a) and above a seabed of close proximity (b). The sensor array for measuring the UEP signature of the vessel is placed with a certain distance above the seabed. The field lines of the electrical field as well as the electric flux density are displayed as red colored lines.

In case of a submarine in close proximity above the seabed, due to the large differences in conductivity, a reflection of the electric fields takes place at the boundary between the seawater and the seabed. In Fig. 2a) the simulated stationary UEP signatures of the two cases given in Fig. 1 are displayed component-wise. It is clearly evident that the UEP signature has larger amplitudes in case of a nearby seabed. In order to investigate the influence of different conductivities of the seabed and the seawater a parameter sweep was carried out in the frequency range of interest.

The corresponding results are visualized in Fig. 2b) where the absolute value of the electric field is illustrated in a landscape plot. The changes in the seabed's electrical conductivity and the operating frequency result in different electrical field strengths, which tend to have a maximum value at virtually zero frequency and electrical conductivity, and decrease towards higher frequencies and conductivities. The significant variations of the field values show that it is necessary to exactly retrieve the local measurement conditions and to extract the electric conductivities of the individual layers involved in the measurement by using a calibrated measurement system.

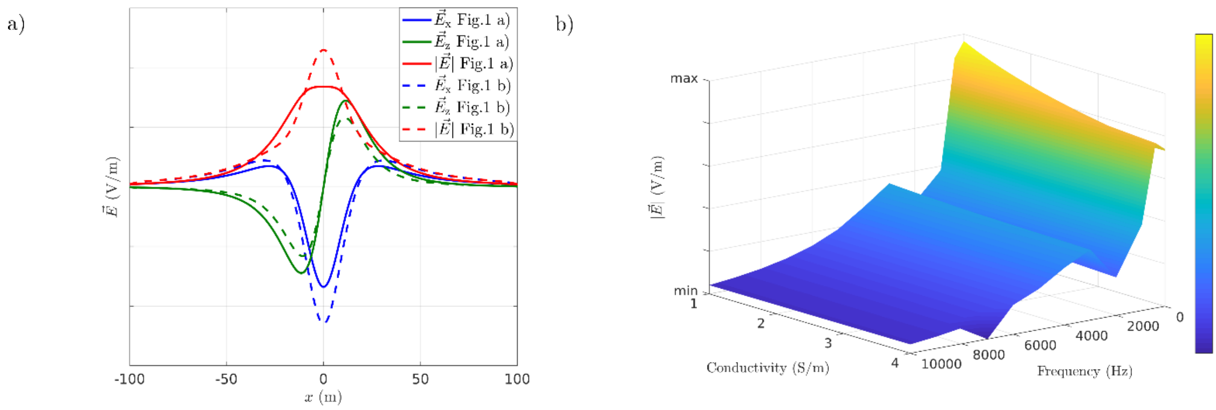


Fig.2: (a) Comparison of UEP signatures of a current dipole in free-water [cf. Fig. 1(a)], and in a 3-layer setup [cf. Fig. 1(b)] including the seabed and the sensor arrangement above; and (b) a landscape plot of the absolute value of the electrical field strength as a function of the operating frequency and the seabed's electrical conductivity.

In the following a 1:5 downscaled model for analyzing the 3-layer setup with a 20 cm long current dipole in a correspondingly tailored water basin will be considered for validation purposes. Based on our preliminary simulations following requirements are summarized for the measurement setup with corresponding calibration features: (i) Compact and transportable dipole/multipole excitation system for signature generation; (ii) excitation currents of up to 10 A for DC and AC signals with frequencies up to 10 kHz; (iii) current dipole/multipole arrangement that can be mounted at arbitrary orientations;

The design process of the downscaled measurement system (i.e. dipole system) already resulted in a first prototype of a reconfigurable dipole/multipole current source that will be later used for calibration purposes and to extract the electrical conductivity and associated structural information of the seabed. Similar reconfigurable current sources of larger extent will later be used for calibration of the sensor arrays in the marine signature measurement site in Aschau, Germany. The overall goal is to experimentally estimate the true free-water UEP signature of the naval vessel by de-embedding the measured signature from all its environmental influences, namely from the seabed.

References

[1] D. Schaefer, “Vorhersage und Umrechnung korrosionsbedingter UEP-Signaturen von Wasserfahrzeugen,” Ph.D. dissertation, University of Duisburg-Essen, Duisburg, Germany, 2015.

[2] D. Schaefer, J. Doose, A. Rennings, and D. Erni, "Numerical analysis of propeller-induced low-frequency modulations in underwater electric potential signatures of naval vessels in the context of corrosion protection systems," COMSOL Conference 2011, Oct. 26-28, Stuttgart, Germany, pp. 25, 2011.

[3] Software COMSOL Multihphysics v5.4. [Online]. Available: https://www.comsol.com (accessed on March. 26, 2019).

[4] G. Schlögel, “Modellierung und Lokalisierung kleinräumiger Einlagerungen (Kriegsrelikte) im Untergrund mit Geo-radar,” Diploma thesis, Angewandte Geowissenschaften u. Geophysik, Montanuniversität Leoben, Austria, 2007.

IEEE Workshop / Sensorica 2019
June 6-7 , 2019
Ruhr West University of Applied Siences
Mülheim a. d. Ruhr, Germany

Numercial Evaluation of Sea bed Influences on Underwater Electric Potential (UEP) Signatures and the Validation Framework

Claas Bröcheler*, C. Thiel*, F. Ludwar**, J. Doose**, A. Rennings*, and Daniel Erni*

* General and Theoretical Electrical Engineering (ATE), Faculty of Engineering
University of Duisburg-Essen, D-47057 Duisburg, and CENIDE – Center for Nanointegration
Duisburg-Essen, D-47048 Duisburg, Germany

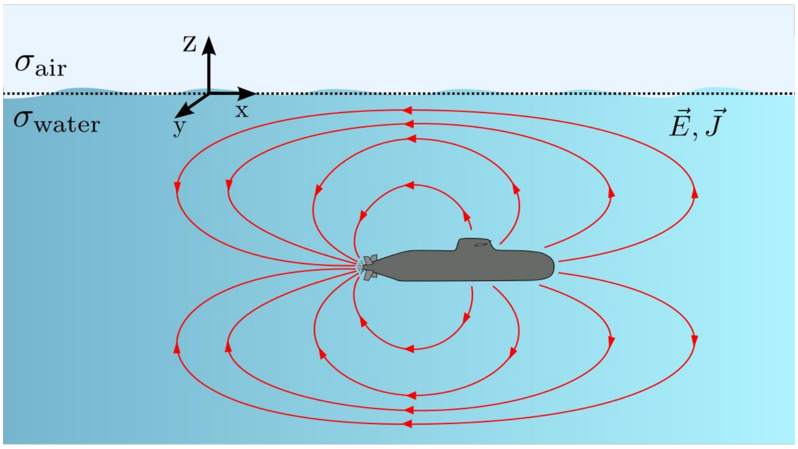
** Technical Center for Ships and Naval Weapons (WTD71), Bundeswehr,
D-24340 Eckerfoerde, Germany

Table of contents

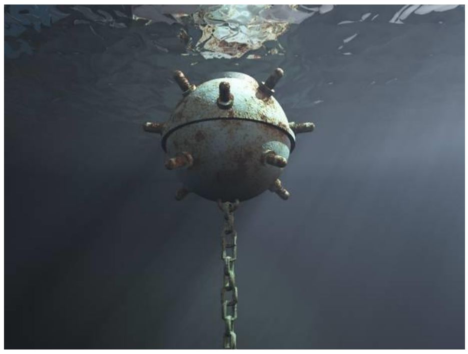
Introduction and motivation

Naval detection systems are becoming more and more intelligent

- Need for improved protection systems
- Underwater electric potential (UEP) signature of a naval vessel is the key for detection since it is detectable by sea mines.



Old anchor mine with contact fuse



Source: http://artist-3d.com/free_3d_models/dnm/model_disp.php?uid=4630&count=count

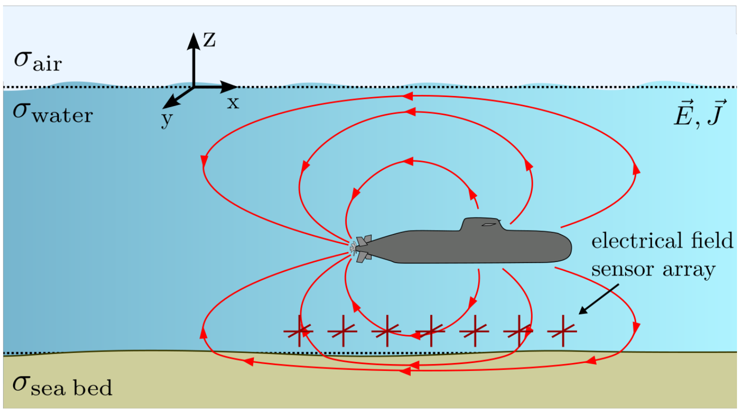
Introduction and motivation

Problems for the measurement station:

- UEP signature is measured by an array of sensors positioned very close to the sea bed
- Influence of the water surface as well as the sea bed are present by measuring the ships UEP signature

Aim:

- Separation of the sea bed influence and free-water UEP signature by proper de-embedding to predict the vessels UEP signature in other environments



Solution:

- Set up a measurement system for sea bed logging
- Measure the sea bed conductivity
- Use the data for de-embedding the UEP signature

Origin of the UEP signature

Naval vessels are equipped with corrosion protection system

- Ship’s hull protection through current impressing with anodes above the ship’s hull
- Current controlling system protect the naval vessel against corrosion
- Protection system causes AC and DC shares
- The current flow via the ship's propeller generates also a small alternating current (<10Hz)

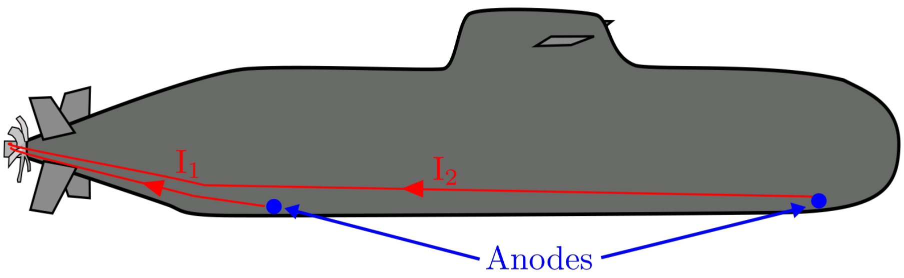


Figure: Schematical function of an Impressed Current Cathodic Protection *(ICCP)* system of a submarine

UEP signature detection

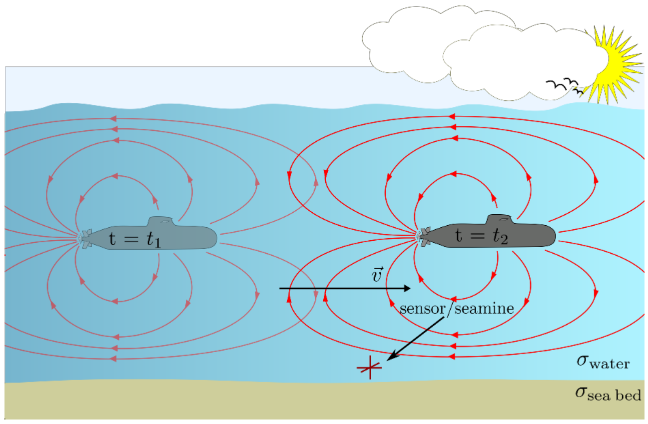
Recording of a UEP signature (left-bottom figure):

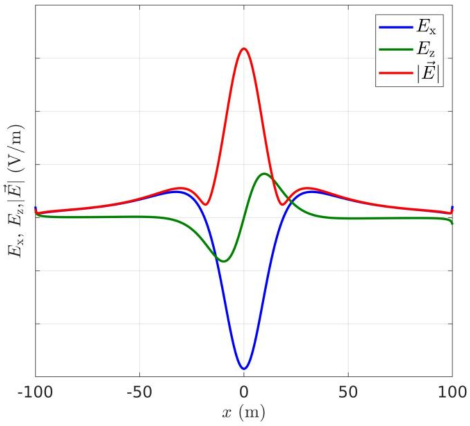
- Presence of the naval vessel in the sensor detection range for certain time interval

Simulation of a UEP signature (right-bottom figure):

- Stationary object with a sensor array below it

***Please note**:* The simulated signature is issued in the opposite direction and must be inverted for comparisons.





Wavelength in electrical conductive media

The wavelength in media with a electric conductivity is defined as:

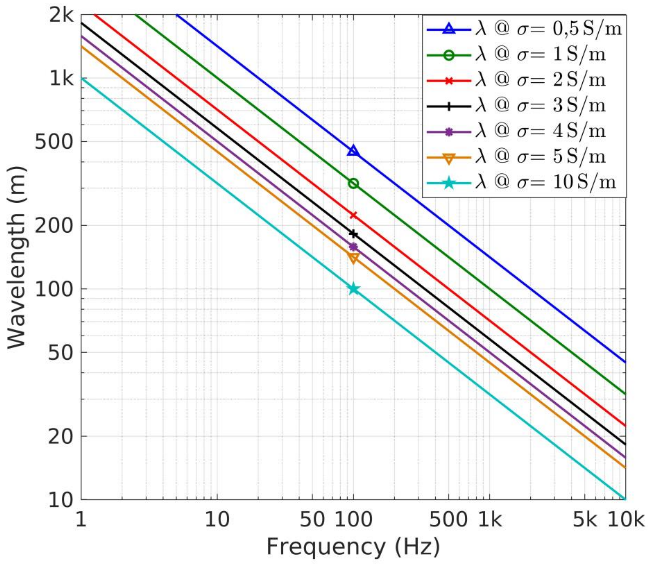
$$\lambda\left(f, \varepsilon_r, \sigma\right) = \frac{c_0}{f\left(\sqrt{\frac{\mu_r \varepsilon_r}{2}\left(\sqrt{1+\left(\frac{\sigma}{2\pi f \varepsilon_0 \varepsilon_r}\right)^2}+1\right)}\right)}$$ [1]

Significant:

- small wavelengths elute to sea water conductivities

Conclusion:

- Wavelength propagation also in a low frequency range
- Wave phenomena takes place for UEP signatures



[1] O. Georg, *Elektromagnetische Wellen.* Springer-Verlag GmbH, Jan, 1997.

Damping in electrical conductive media

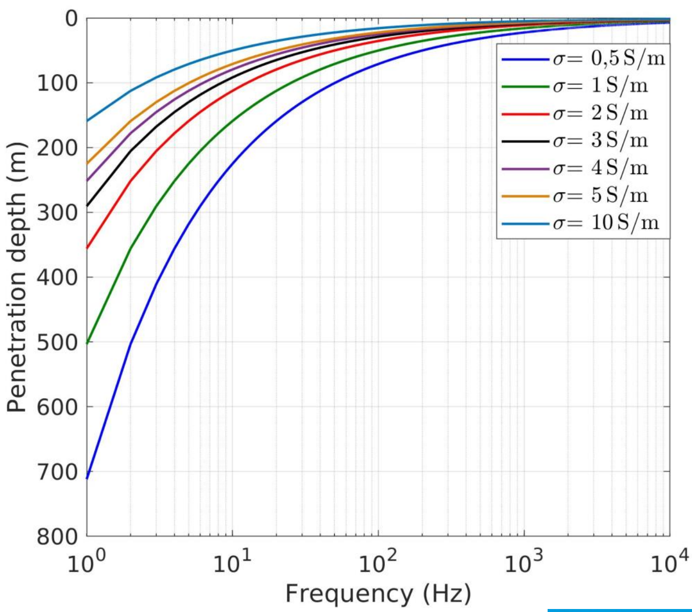
- Wave propagation in small distances is possible due to the wavelength reduction
- The wave is damped by the damping constant (α)
- The damping constant is extracted from the complex propagation constant $\underline{\gamma}$:

$$\underline{\gamma} = \alpha + \mathrm{j}\beta = \sqrt{\mathrm{j}\omega\mu(\sigma + \mathrm{j}\omega\varepsilon)}$$ [1]

where α is defined as:

$$\alpha = \omega\sqrt{\frac{\mu\varepsilon}{2}\left(\sqrt{1+\left(\frac{\sigma}{\omega\varepsilon}\right)^2}-1\right)}$$ [1]

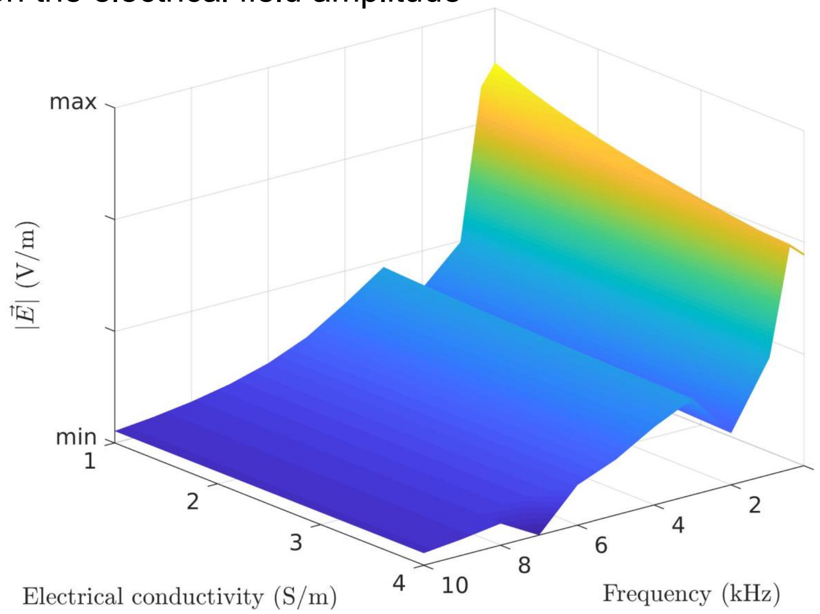
The resulting penetration depths δ is calculated by the reciprocal value $\frac{1}{\alpha}$



[1] O. Georg, *Elektromagnetische Wellen.* Springer-Verlag GmbH, Jan, 1997.

Electric field amplitude in a changing environment

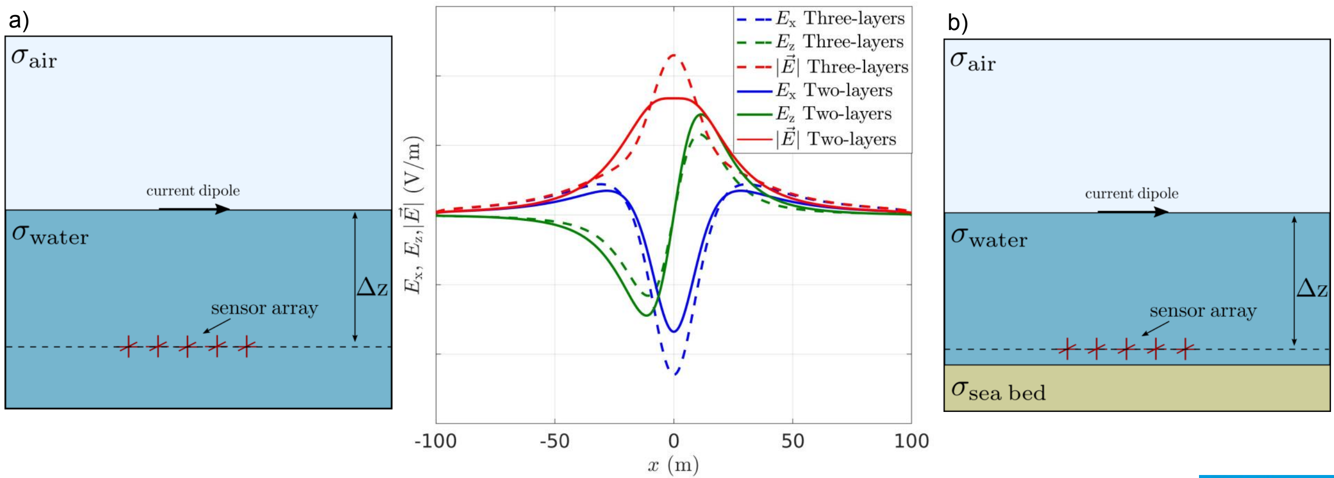
- Variation of the electric field amplitude of the UEP signature from a three-layered model
- Changing of the sea water conductivity and the frequency has a significant influence on the electrical field amplitude



Investigation of the environmental setup

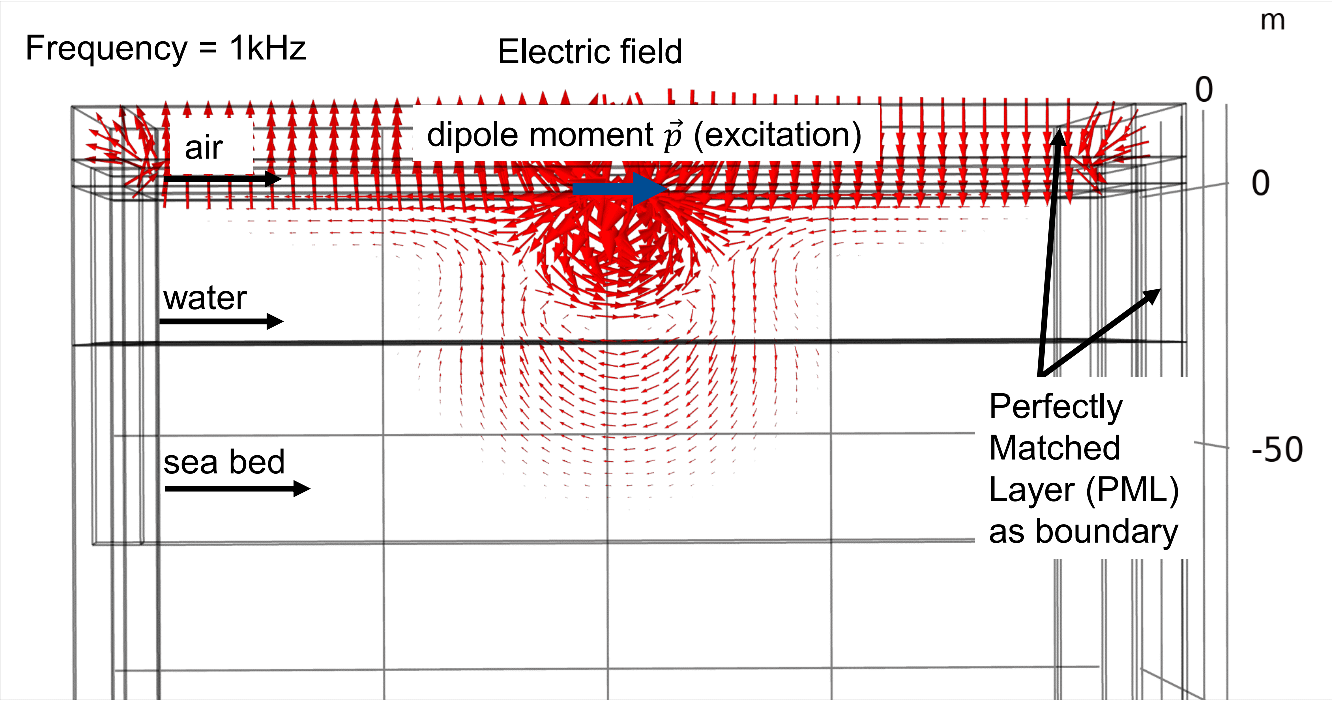
A numerical model is set up with the FEM based simulation software COMSOL and its electric currents(ec) physics to simulate the influences from the sea bed and the air on the UEP signature

- Effects of parameters such as electric conductivity of the layer or the frequency can be investigated
- Study the effect of the sea bed through comparison of Two- and Three-layered models to visualize the influences



Investigation of the environmental setup

Animation of the wavepropagation of a current dipole in a three-layer structure

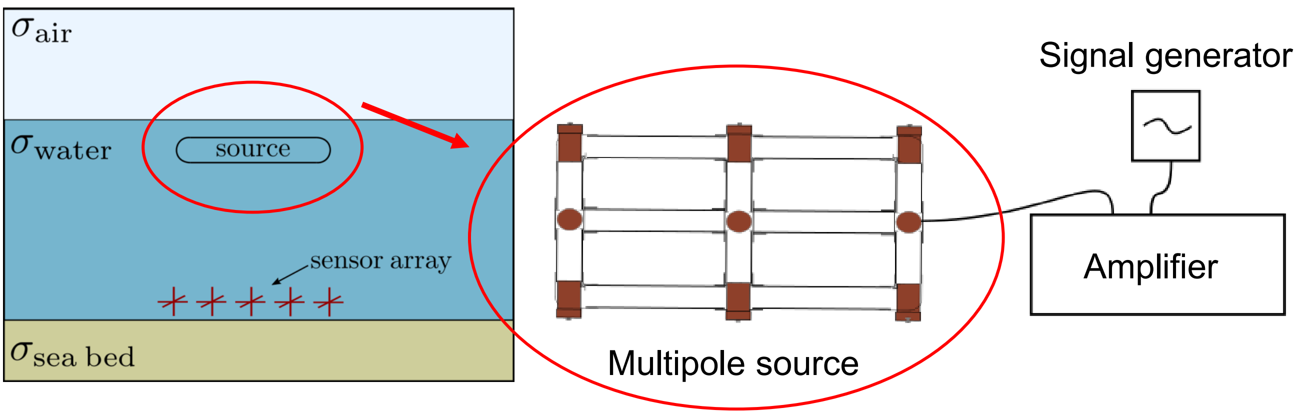


The measurement system

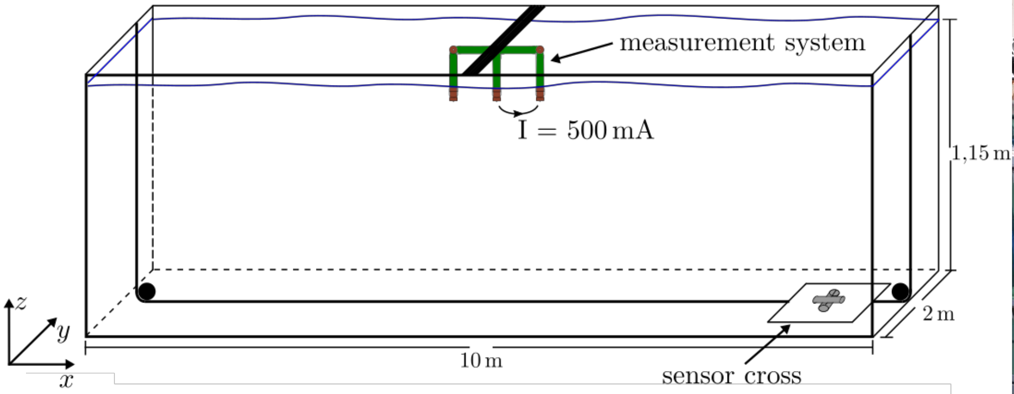
To determine the sea bed conductivity the following measurement system is designed

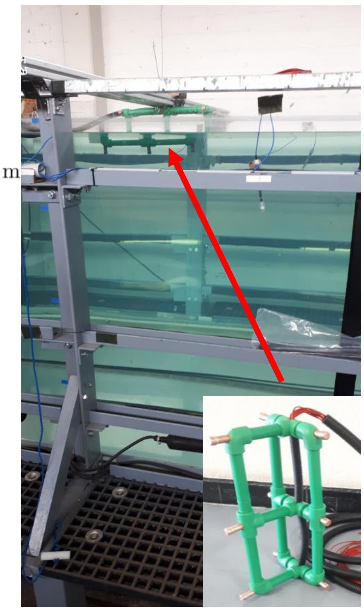
- Each electrode can be controlled individually for different dipole orientations
- Using at the place for the naval vessel measurements to impress signals which return the sea bed conductivity

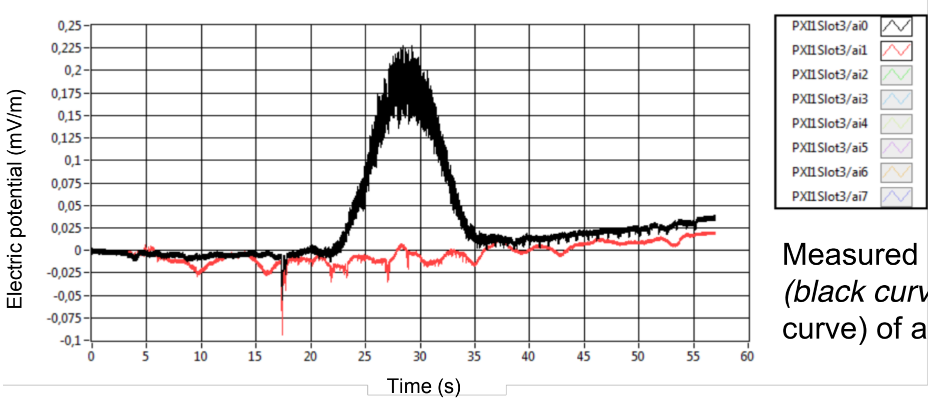
The source is placed over the sensor array and generates a current flow inside the water and the sea bed



First measurements with a multipole source







Measured UEP signature of the *x-(black curve) and y-component* (red curve) of a dipole excitation (f = 1kHz)

Conclusions / outlook

Conclusions:

- The environment, in particular the sea bed, influences the measured UEP signature of the naval vessel, which should be taken into account.
- Having the measured UEP signature, the environmental influences should be separated from the free-water UEP signature to predict the vessels signature in other unknown environments
- Account for environmental influences such as the sea bed, a COMSOL model with the AC/DC-module is set up.
- The sea bed parameter should determined. Through setting up a multipole measurement system.

Outlook

- The COMSOL model will be validated, using designed measurement system.
- The validated model will serve as basis for further models and the improvement of the sea bed conductivity to be measured.

Thanks for your attention!

For more details: www.ate.uni-due.de