Frequency Dependent UEP Signatures of Naval Vessels Modeled By a Current Dipole

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Abstract

The underwater electric potential (UEP) signature of naval vessels poses a severe threat as it is detectable by advanced sea mines. The signature depends also on the environment, mainly the water-seabed interface, leading in summary to the total UEP signature. The seabed has a significant influence as it consists of several sediment layers with different electrical characteristics where the latter are approximated by a stack of homogeneous layers with corresponding electrical conductivities. To de-embed the free-water UEP-signature of a naval vessel the seabed layers need to be properly analyzed. With increasing frequency there are also significant changes to the UEP-signature as the electrical conductivity in the water as well as in the seabed system has a lowering effect on the wavelength, which is further perturbed by the conductive layer morphology. Hence, propagating effects of the UEP signature comes into play because the underkeel clearance may become comparable to the wavelength. A similar reasoning applies to the experimental retrieval of the UEP-signature, given the fact that the field sensors are usually located on the seabed maintaining a certain (small) distance to the proper water-seabed interface.
For the classification of the effects mentioned above comprehensive computational electromagnetics analyses have been carried out in the frequency-domain using COMSOL Multiphysics® to simulate the deviation of the free water UEP-signature by the presence of the seabed. For this purpose a simulation Box with 3 layers has been utilized and a sensor line for the UEP-signature was created at 0.5 meters above the seabed layer. The excitation consists of a current dipole (with dipole moment = 180 Am) and the resulting frequency-dependent UEP signature for the setup is evaluated along the sensor line for operation frequencies in the range of 0,1Hz up to 10kHz. Initially we relied on a quasi-static analysis using the AC/DC module with its Electric Current (EC) interface. For a later comparison with the full-wave simulation we define a port excitation (with equivalent current values) instead of the dipole moment, allowing for the observation of the port impedance. The EC interface yields a virtually frequency-independent UEP signature with a real-valued port impedance. To accurately access the weak dispersive behavior stemming from wave propagation effects within the assigned small frequency range we thus changed to the full-wave RF module with its Electromagnetic Waves (EMW) interface, which is better suited to provide the full picture especially at higher frequencies. Hence, the same setup now yields UEP signatures with e.g. about 60% larger maximal field strengths

even at 1kHz compared to the quasi static (EC) analysis where the port impedance is now complemented by a frequency-dependent imaginary part. The latter accounts for the fact that the wavelength in the (conducting) seawater reduces to 18m at 10kHz while becoming comparable to the underkeel clearance of 23m. In conclusion, the proper de-embedding of the free-water UEP signature from sensor data gets very challenging as it has to account for wave effects in the conducting seawater even at very low frequencies, which is only tractable within a full-wave analysis.

Figures used in the abstract

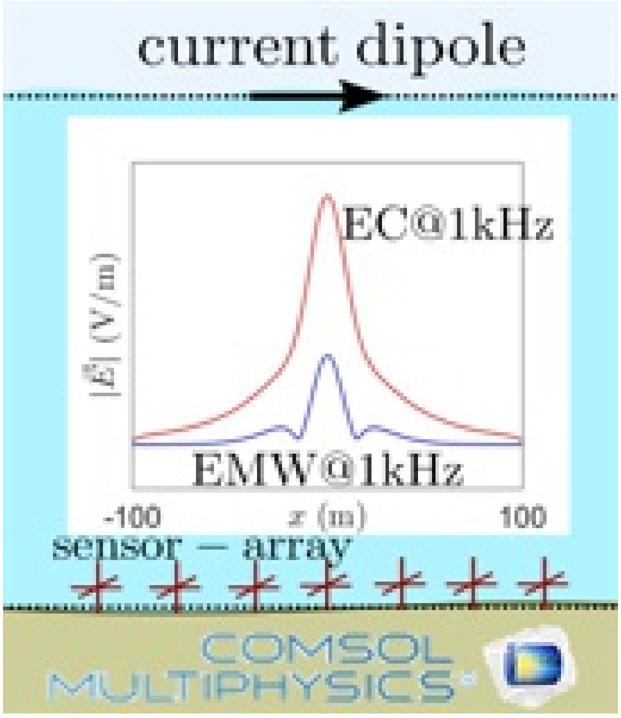

Figure 1: Simulated UEP Signature of a Current Dipole at a frequency of 1 kHz using Electric Currents (EC)- and Electromagnetic Waves (EMW) physics interfaces.