Modeling of Common Mode Currents (CMC) on Electric Ship Hull Using Scattering Parameters*

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Abstract

- This behavioral (Physics-based)modeling is computationally efficient for modeling distributed currents and potentials throughout the ship's structure.

- S-parameter behavioral model of the ship's structure is calculated (by Agilent ADS/EMPRO FEM) to model parasitic paths to grounded equipment enclosures and cables sheaths.

- A time-domain common-mode conduction example to illustrate the work flow of converting physics-based models of elementary hull elements into a complete S-parameter behavioral model of an arbitrary hull structure with power cables running along it.

Common-Mode Current (CMC)

- A problem in power systems with motor drives and fast switching power converters
- Couples disruptive currents into equipment (i.e., conducted EMI)
- Parasitic paths from the energized portion of the power system can conduct common-mode current throughout :
  - Ship's hull, Bulkheads and decking
  - Equipment chassis, Protective armoring around power cables
- Behavioral modeling of the hull can improve the understanding and mitigation of CMC in ship systems.

Behavioral Modeling of CMC

A. Multi-Port Linear Modeling

This behavioral modeling is computationally efficient for use in modeling the many parasitic paths for broadband CMC and the heterogeneous nature of the complex structures the currents flow through.

B. S-Parameter Modeling

1– S-parameters are suitable for computing broadband voltages and currents at arbitrary numbers of ports on the ship's structure where equipment and cables are bonded to the structure.

2- S-parameter modeling is linear and so is, for the most part, the system being modeled.

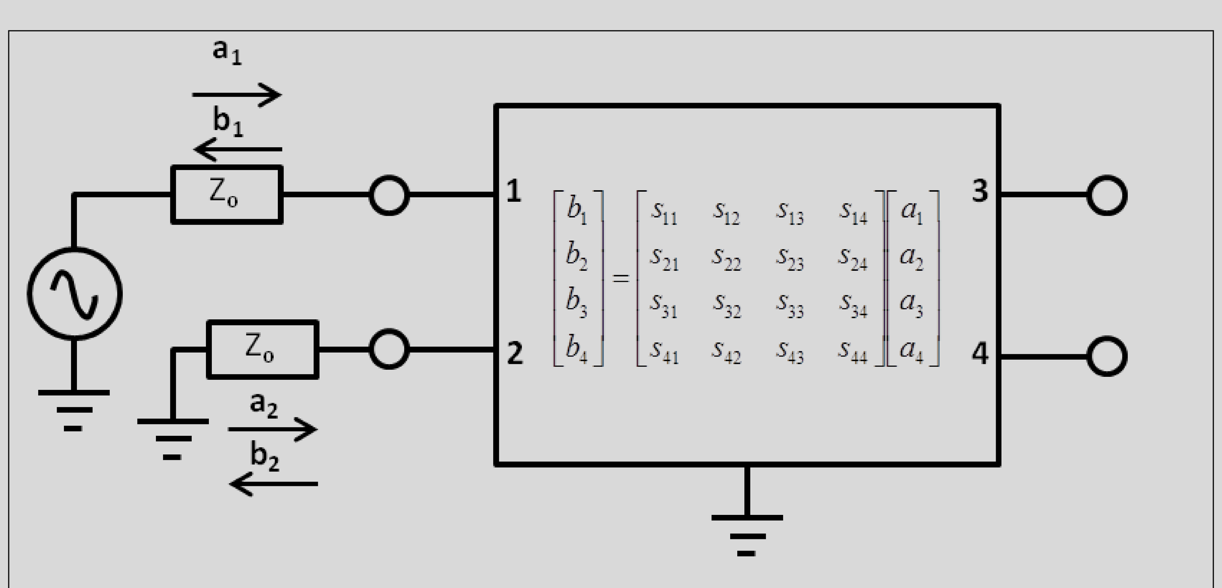

Fig. 1. Definition of a four-port S-parameter behavioral model where each port is referenced to a common "ground" terminal. Port one is connected to an active source, while port two is connected to a passive load. The definition of the reference potential, or ground terminal, is made at the physical modeling stage in the work flow.

Modeling Approach

An example consists of a hull plate in contact with seawater supporting an isolated DC power system consisting of two power cables connecting a medium voltage source to a load. The hull plate is 3 m x 3 m . The cable has an armored sheath that is "grounded" for safety by risers that bond the sheath to the hull plate at eight locations on the plate. CMC's are induced by a step change in the source voltage of 5 kV.

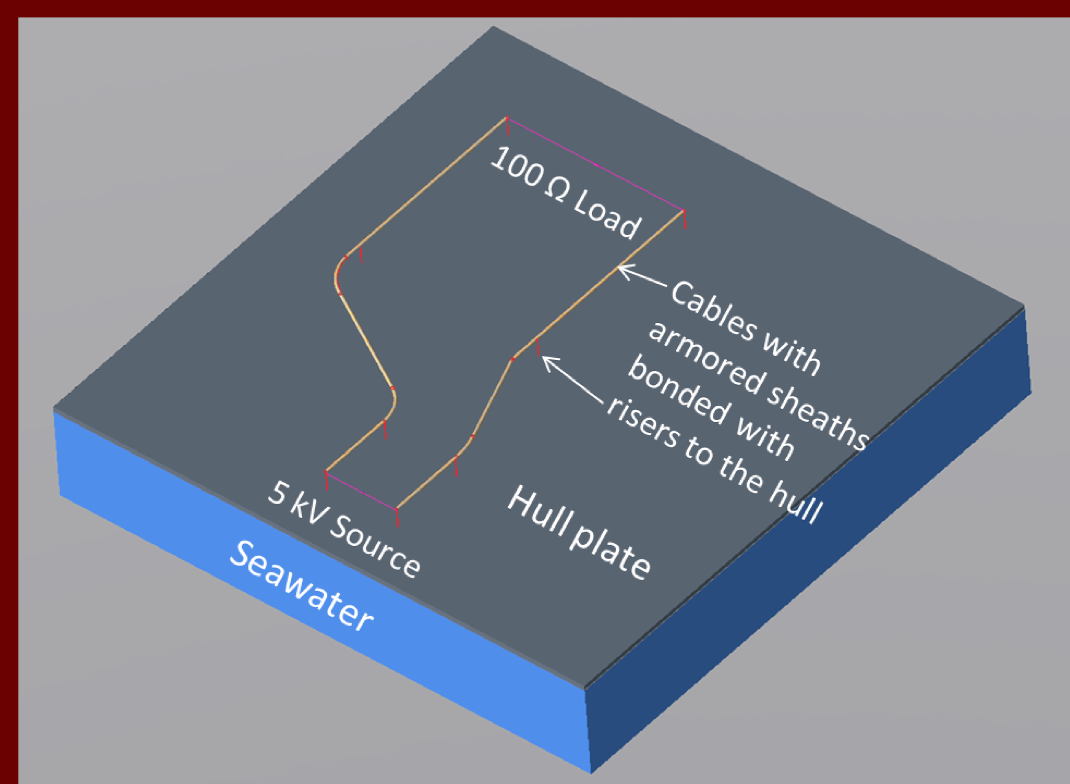

Fig. 2. Hull and power system layout for the CMC modeling example.

A. Physics-Based Models of the Sub-elements

Agilent EMPro is the software tool in which CAD models of the sub-elements are drawn. EMPro automatically meshes these physical models and solves the S-parameter extraction problem using the finite -element method (FEM).

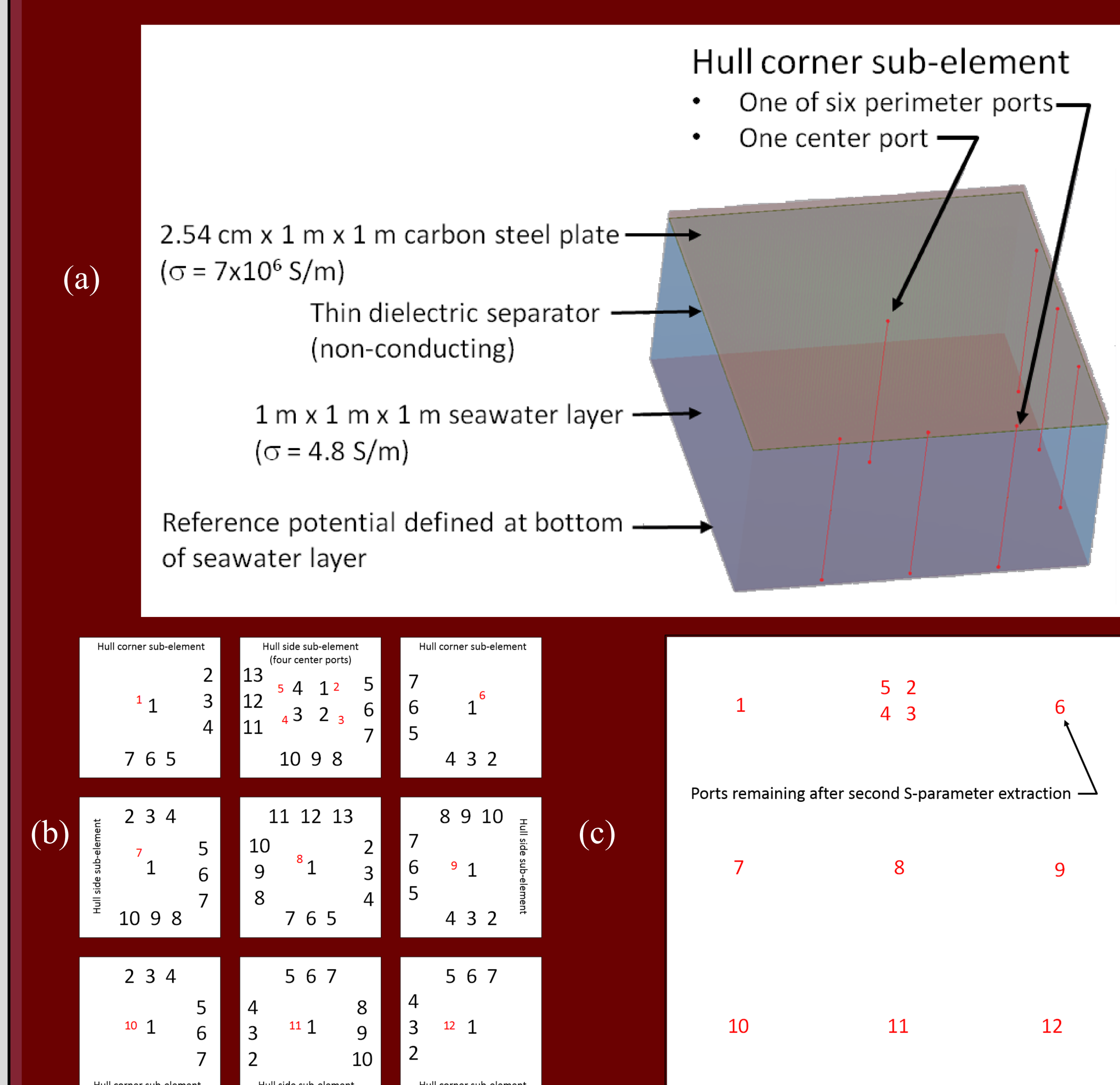

Fig. 3. Illustration of work flow leading to a behavioral model of the hull section shown in Fig. 2. (a) Physical model of a standard corner element. (b) Arrangement of S-parameter behavioral models of all sub-elements. (c) Final 12-port S-parameter model of hull section shown in Fig. 2.

B.Steps for Constructing the Behavioral Model

- Partition the ship's structure into finite elements.
- Calculate elementary S-parameter models. (EMPRO)
- Convert physics-based models of elementary pieces of the ship into a complete multi-port S-parameter behavioral model. (ADS)
- Connect components (power cables, fixed loads and sources) to the multi-port model. (ADS)
- Solve with a standard circuit-based solver for voltages and currents as functions of time or frequency at any of the ports. (ADS or SIMULINK)

Modeling Results

A.Constructing the Complete Behavioral Simulation

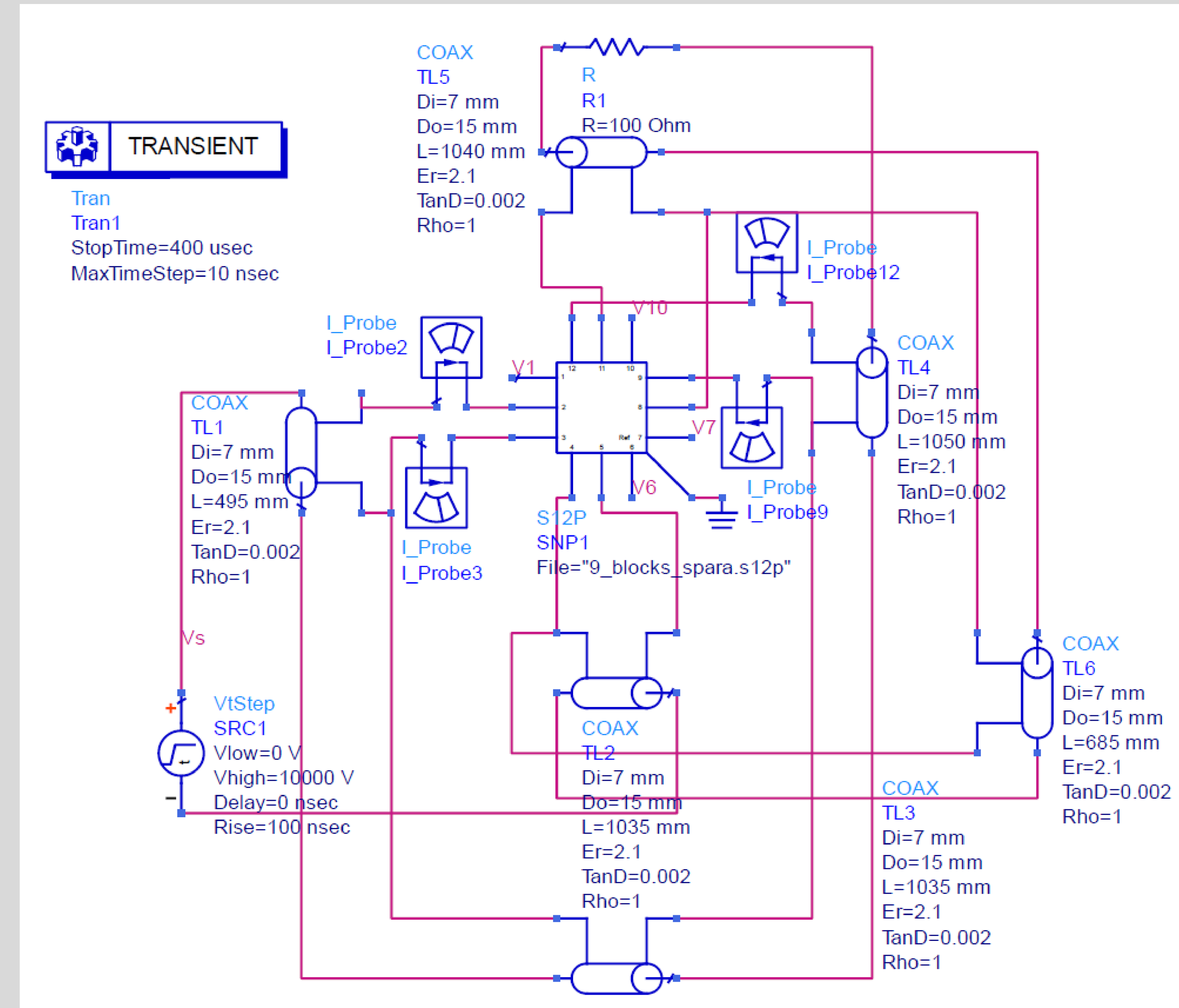

Fig. 4. Transient simulation using the behavioral model of the hull and power system example.

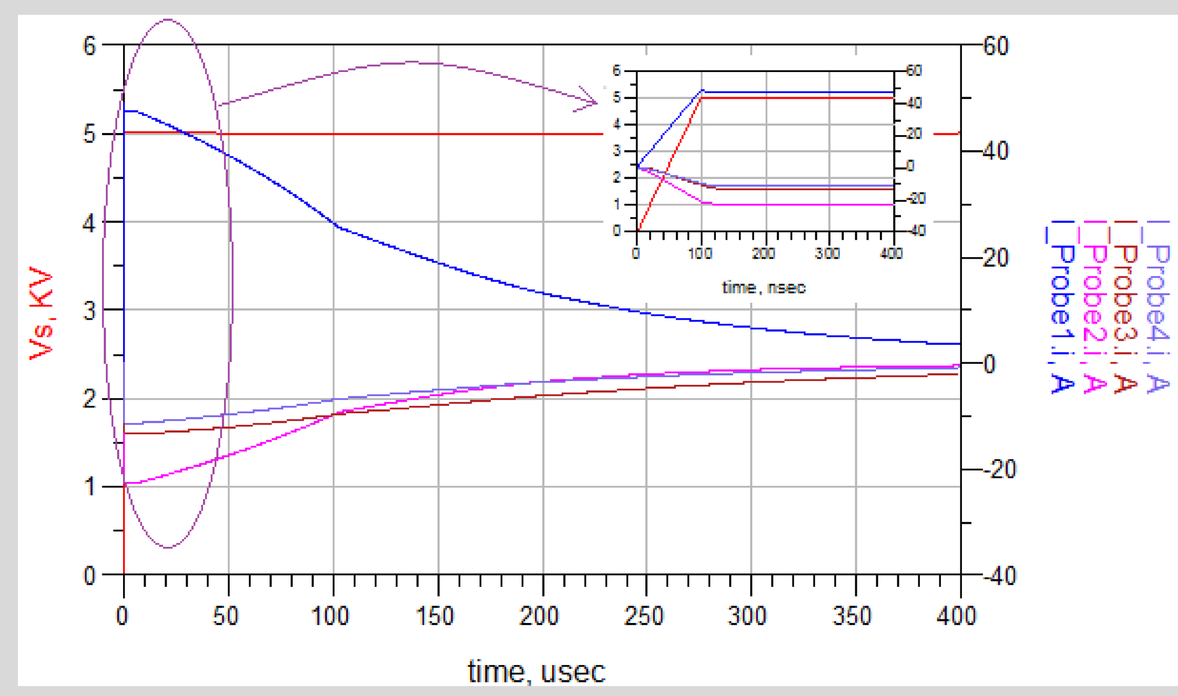

Fig. 5. Port currents (plotted on right vertical axis in A) that were computed by the behavioral model for the stepped source voltage Vs (plotted on left vertical axis in kV). The key to port currents: I_Probe1 = port 2, I_Probe2 = port 3, I_Probe3 = port 9, and I_Probe4 = port 12. The insert plots the initial values of the same currents zoomed in to a time scale of 0-400 ns.

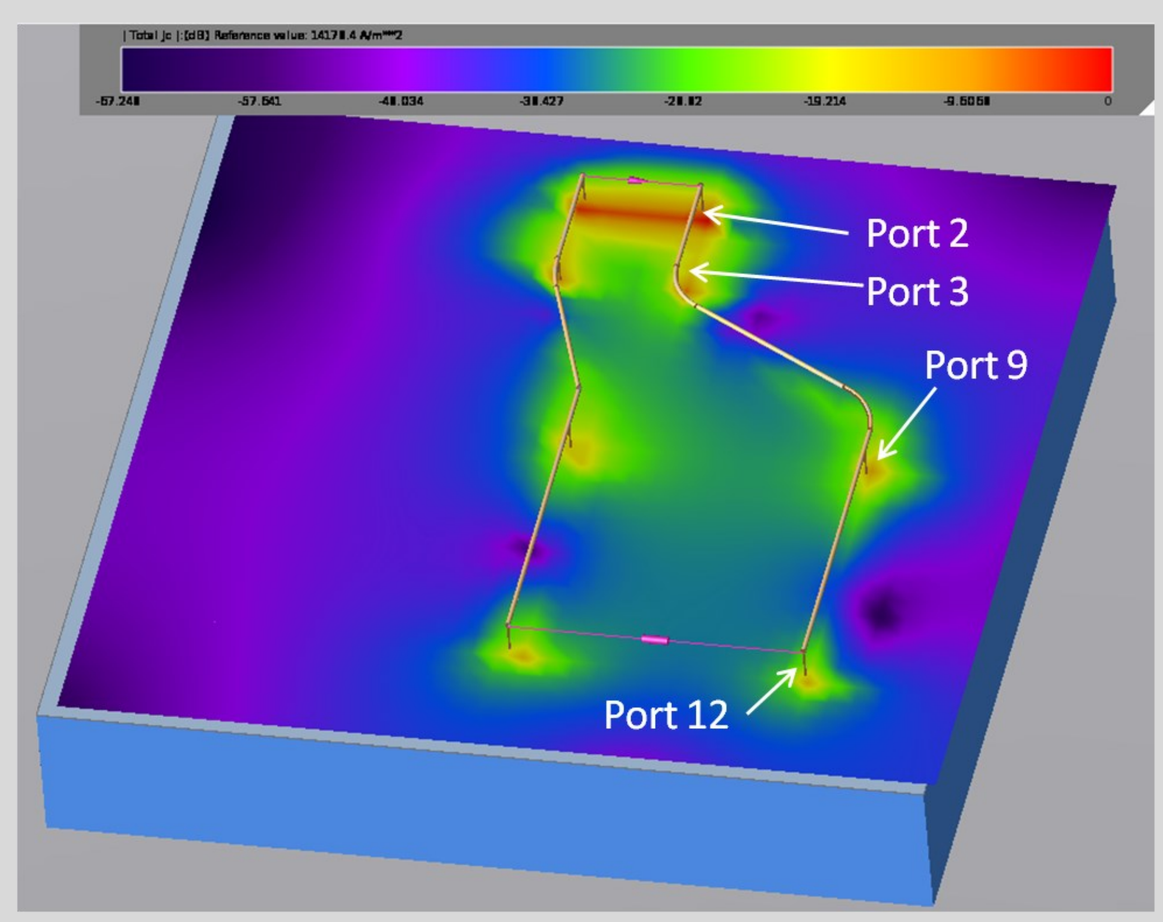

Fig. 6. Magnitudes of the surface currents at one instant of time (100 µs) computed for the complete system shown in Fig. 2 by EMPro using finite element analysis. The color scale is in dB (reference 14.17 kA/m^2).

Conclusions

- Methods for creating a linear behavioral model to understand paths for common-mode currents in conventional and electric ships is addressed.
- Utilizing RF modeling tools, a work flow was demonstrated that creates computationally efficient behavioral models without sacrificing traceability to physics-based simulation.

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