



HF broadband antenna design for shipboard communications: Simulation and measurements



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ABSTRACT

The objective pursued in this work is to highlight the convenience of using electromagnetic simulation software as an alternative to the traditional scale model measurement when dealing with the design of HF antennas on real complex platforms.

The experience was developed during the building process of a real vessel. A low and a medium band antennas (fan-wire type) were designed ad-hoc for this project. The HF broadband antennas' study covered from the preliminary design stages to the final verification measurements completed onboard the ship. The experiment has demonstrated that more accurate results can be obtained when using an adequate electromagnetic simulation code, which, besides, brings important advantages in flexibility and usability. These advantages, inherent to the use of virtual models, hinge on the ability of the simulation tools to properly handle any modification of the vessel's structure that might arise during the platform construction.

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1. Introduction

Communications in the high frequency (HF) band are one of the main concerns in modern ships and vessels. Although the use of HF was expected to decay with the advent of satellite communications (SATCOMs) [1] providing enhanced data rates and usability, nowadays it is still of great relevance due to various reasons. Mainly, HF systems are long-range and very robust communication systems, independent of any relay mechanism (such as a satellite), which is of strategic importance in the naval environment. They may even become the only communication system available under some circumstances (very high latitude mobiles could be an example), with the consequent safety implications.

Typical naval HF antennas include single pole whips, twin pole whips, long wires and fans [2,3]. Whips (monopoles) are usually used in narrowband (NB) and they are the most common antennas

for shipboards. However, in the current context, the number of HF communication circuits required to satisfy the increasing operational requirements in modern naval units prevents the exclusive use of narrowband tuned whip antennas. Instead, HF broadband (BB) antennas such as the twin pole whips, long wires and fans need to be used in order to accommodate several communication circuits sharing the same antenna, thus reducing the number of antennas placed on the usually limited space available for this purpose on the deck. Typically, two or three BB antennas cover all the HF frequency range [1,3]. Several transceivers are connected throughout a diplexer (two ports) or triplexer (three ports) to the antennas by means of the proper combining and matching networks. Diplexers/triplexers are band-pass filters connecting the common port with the other ports ensuring high isolation between the latter. Signals of different frequency bands can coexist on the common port without interfering between them.

Otherwise, the aforementioned demand of operational requirements in modern ships and vessels implies the coexistence of a wide number of sensors and radiating systems in a very limited physical space. Therefore, electromagnetic interference (EMI) among the different systems becomes a major issue. In such a complex electromagnetic environment, a proper strategy to carry out a reliable electromagnetic compatibility (EMC) study becomes

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crucial. Thus, nowadays it is unquestionable that EMI/EMC considerations must be taken into account from the very early topside design stages. This dense electromagnetic environment forces the topside designer to address different interrelated aspects simultaneously. Namely, the optimization of antenna patterns, input impedances, coverage and blockage, issues concerning the hazard of electromagnetic radiation (EMR) to personnel (HERP) [4], ordnance (HERO) [5], and/or fuel (HERF) [4], or minimization of EMI, among others things.

The above exposition of the current context makes it clear that it is mandatory to find an alternative to the expensive and time-consuming build-and-test procedures used in the past. Scale brass models [6] and electromagnetic simulations can be useful ways to incorporate the electromagnetic constraints into the vessel design process already at the preliminary stages, improving the efficiency of the whole process in terms of time, cost and also in the final systems' performance. In this paper, we show the main advantages and drawbacks of both alternatives based on the results of a real experience, since from 2006 we had the extraordinary opportunity of participating in the electromagnetic design of a modern ship from the initial building stages to the final harbor acceptance trials (HAT) and sea acceptance trials (SAT). The conclusions of this paper are the outcome of the work developed during six years, from the preliminary design of the HF BB fan-type antennas to their implementation on the real platform and subsequent measurements. The work is focused on the study of the fan antennas because of their challenging design. The use of fan antennas is standardized for low HF ranges [1] and destined to cover a very large bandwidth. Additionally, their radiation patterns, and especially the input impedance, are strongly influenced by the elements of the superstructure whose size is comparable to the wavelength. Therefore, this study is a good example of how helpful the electromagnetic simulation tools used in this work can be in the optimization and characterization of the antennas' performance. The experiment allowed us to compare the capacities of the traditional scale model measurements versus the electromagnetic simulation when exploring the design of HF antennas for real complex platforms. Their accuracy was contrasted with measurements carried out onboard the real platform.

2. Scale models vs. EM simulations

In the past decades, scale brass model measurement has been the most extended methodology to assist in the onboard antennas design and in the selection of their optimal placement. The capacity of the computers available at that time was still far away from the massive computational resources required for the EM simulation of this kind of problems. For this reason, since the eighties different countries like the United States of America (USA) [6], the Netherlands [7], India [8], Germany [9], or China [10] have evaluated different sorts of naval platforms with scale models.

The scale model of a ship is a detailed brass model linearly downscaled from the original dimensions of the vessel. The scaling factor is determined by the manageable size of the model and the frequency capabilities of the measuring equipment. Also the frequency must be suitably scaled in order to maintain the size of the brass model in terms of the wavelength [3]. The place where the measurements of the model are carried out must complain restrictive characteristics of isolation and absorption at the proper frequency band, such as an anechoic or semi-anechoic chamber.

Despite the widespread use of scale brass models during the design process, there are undeniable disadvantages [7]. One of them arises from the fact that they are handmade, using bend or twisted metal plates that have been welded together. A single model on the scale of 1/50 takes about four months to be finished,

and it has a very high economic cost. Another of the drawbacks is that the ideal design of the vessel is used to create the scale model but, unfortunately, this initial design experiments a lot of modifications during its construction process. Any change entails modifying or rebuilding the scale model, which inevitably leads to a slow and expensive process. Hence, certain changes are oftentimes omitted such that the final installed versions of the antennas and other topside elements significantly differ from those used to create the scale model.

As previously mentioned, EM numerical simulations involve dense and complex shipboard environments, becoming extremely demanding in terms of computational resources (both memory and CPU time). In recent years, there have been increasing endeavors to achieve rigorous solutions for extremely large electrodynamic problems. The development of fast and efficient algorithms has gone hand-in-hand with the constant breakthroughs in computer science and technology. Modern high performance computing (HPC) systems provide the scientific community with unprecedented computational resources (meaning large amounts of memory and parallel processors). In this context, parallelized implementations of the fast multipole method (FMM) [11] and its multilevel version, the multilevel fast multipole algorithm (MLFMA) [12,13] have been extensively applied to expedite the iterative resolution of the large and dense matrix systems resulting from the application of the integral-equation formulations and the method of moments (MoM) [14], showing their ability to solve large problems that were unattainable in the past decades [15,16].

Thus, in this new scenario the EM simulation has become a necessary complement or even an essential alternative to scale models. Nowadays, it is possible to simulate a real complex electromagnetic environment involving the whole set of radar, communication, and electronic warfare systems placed in the topside of a modern ship. This allows the integrated topside design (ITD) engineer to handle important electromagnetic issues (EMC, EMI, EMR) in the early stages, prior to the physical placement of the systems onboard. Moreover, the assessment of the influence of any design modification using simulations on a virtual model instead of the scale model results in evident cost and time savings.

3. Experiment setup

3.1. The ship

The vessel we have used in this experiment is a platform of the Spanish Navy with over 240 m in length. It is a landing helicopter dock (LHD) class vessel, a new model of warship smaller than an aircraft carrier that can also work as a transport and landing ship. Nowadays many countries are building such a class of ships: USA (WASP class [17]), Australia (CANBERRA CLASS), France (MISTRAL CLASS [18]), and other countries (Japan, China [19] and Algeria [20]).

Fig. 1 shows the model discretized with the proper format to carry out the simulations. It is based on the CAD drawing of the vessel provided by Navantia, which is the company responsible for the construction of the platform. The position of the low and medium BB fan antennas under study is indicated in this figure. It can be appreciated that all the transmitting antennas (blue¹ wires in Fig. 1) were considered in the model employed for the numerical simulations.

¹ For interpretation of color in Fig. 1, the reader is referred to the web version of this article.

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