Low-Frequency Magnetic Field Limits for the Navy's HERO Program

By Charles C. Denham

HERO Threats Within U.S. Navy Operational Scenarios

Until recently, there has been only limited interest in the hazards posed by magnetic fields, because there were no known sources of magnetic field radiation at magnitudes perceived as HERO threats within U.S. Navy operational scenarios. The need for Hazards of Electromagnetic Radiation to Ordnance (HERO) magnetic field limits is due, in part, to the expectation of very high magnetic field levels from systems currently under development for use in the naval environment. Two new sources of high magnetic field levels that have raised concerns in the Navy are the Electromagnetic Aircraft Launch System (EMALS) and the Electromagnetic Railgun. These systems are currently in various stages of development but, when fielded, are expected to generate unprecedented magnetic field levels. Figure 1 depicts USS *Gerald R. Ford* (CVN 78) which, upon completion, will be the first aircraft carrier to have an EMALS system installed. It was desirable, therefore, to develop a magnetic field limit for system and platform developers when assessing HERO risks and remedial steps to reduce the radiated magnetic fields or otherwise protect the ordnance exposed to those fields.

The Emergence of New HERO Challenges

HERO is a fundamental safety issue throughout the Department of Defense (DoD) and, until recently, its focus was on the electric fields (E-fields) generated by communication and radar systems. The absence of equipment capable of producing "threat-level" magnetic fields precluded the need for HERO assessments or the establishment of magnetic field limits.[a] The Navy classifies its ordnance as either "HERO SAFE," "HERO SUSCEPTIBLE," or "HERO UNSAFE" ordnance, based on its degree of susceptibility to the defined DoD operational electromagnetic environment.[b] HERO SAFE ordnance requires no specific restrictions in the operational electromagnetic environment. The latter two, however, require restrictions and are subject to the generalized E-field strength limits for HERO SUSCEPTIBLE and HERO UNSAFE ORDNANCE prescribed in Figure 2. While these curves provide limits for the E-field below 2 MHz, the left-hand portion of the curve reflects little more than a 20 dB per decade of frequency roll-off from 2 MHz, the point where the empirical HERO test data ends. Thus, historically, little regard was paid to this low portion of the spectrum (and the limits represented in the curve) due to the lack of a specific threat or source at these frequencies.

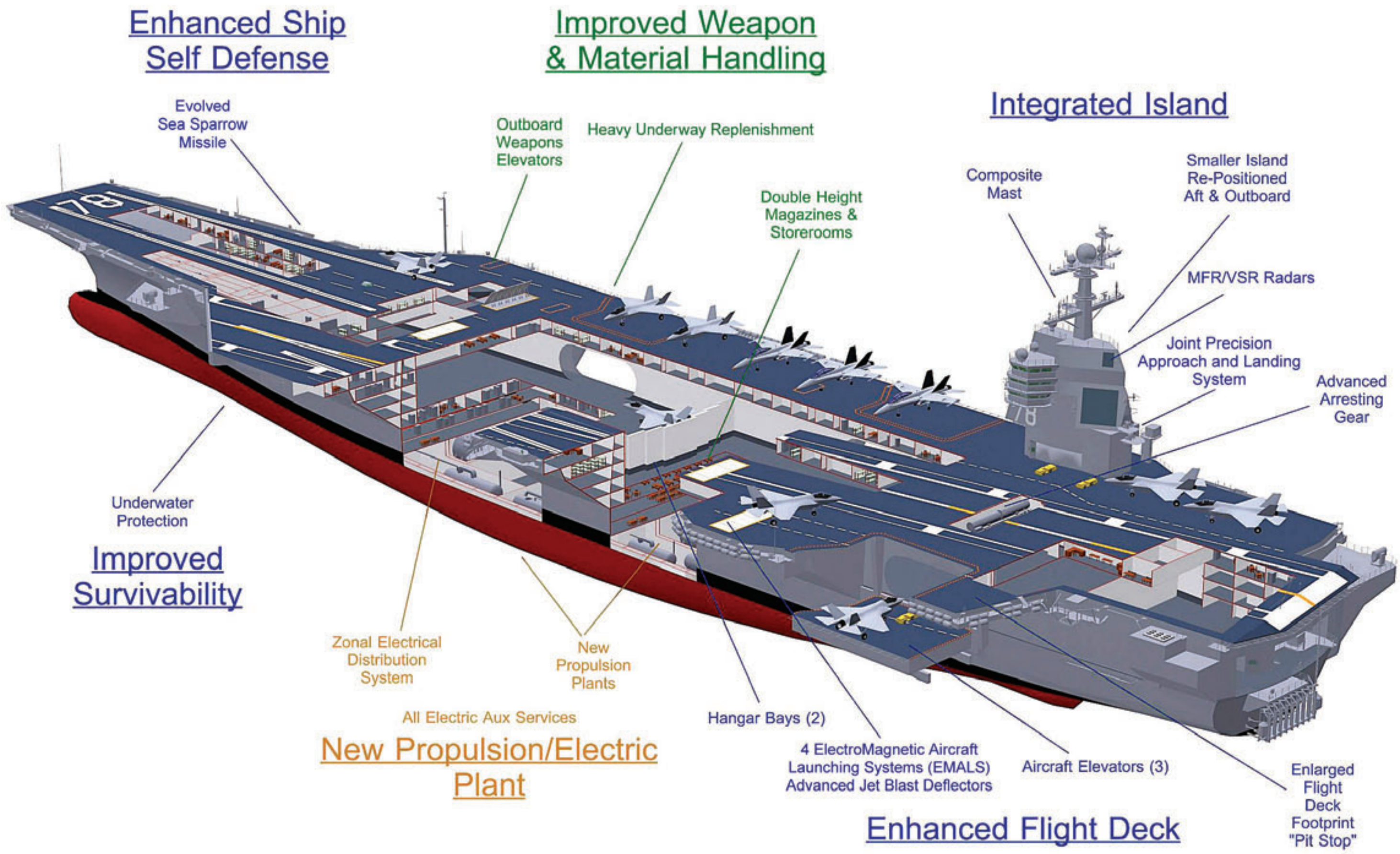


Figure 1. USS *Gerald R. Ford* (CVN 78)

As can be seen, the left-hand, theoretically based segment of the maximum allowable environment (MAE) decreases with frequency at a rate equivalent to the aforementioned 20 dB per decade. The flat region is based on empirical data from 30 years of HERO testing.

The more restrictive field limits apply to HERO UNSAFE ORDNANCE, the classification assigned to ordnance that has never been evaluated; it may be in a disassembled or test configuration, or is otherwise being subjected to unauthorized conditions or operations. In practice, HERO UNSAFE ORDNANCE is handled or stored in areas that are essentially free of radio frequency (RF) or "RF-free," that is, where the RF environment levels are less than HERO UNSAFE ORDNANCE levels. Typically, magazines and well-shielded spaces below decks satisfy this requirement, but HERO surveys are required to confirm that this is the case. Items not in this category, but which are susceptible and require modest RF environment restrictions, are classified HERO SUSCEPTIBLE ORDNANCE. Again, HERO surveys are necessary to confirm that the E-fields do not exceed SUSCEPTIBLE levels in areas where these items are stored or handled. It can be seen from Figure 2 that the E-field limits for HERO SUSCEPTIBLE ORDNANCE are relaxed approximately 12 dB from the HERO UNSAFE limits.

These traditional HERO terms, in addition to identifying a generic level of susceptibility in conjunction with the HERO curves, also have a very specific meaning to the sailor on a ship. As ordnance evolutions are executed, these terms allow the ship to plan for, and manage, the electromagnetic environment such that safety is maintained. Without knowing anything about specific susceptibilities for an ordnance item, the classification helps the sailor quickly identify whether or not specific steps are required to manage HERO, and what those required steps are. However, HERO guidance has historically been associated only with E-fields.

Inasmuch as the EMALS is expected to produce low-frequency magnetic fields at magnitudes that exceed existing shipboard radiation sources (e.g., communications, radar, degaussing systems), the Navy's HERO Program has been prompted to develop new HERO limits to ensure safe ordnance operations in the presence of high magnetic fields. The effect of these unprecedented magnetic field levels, both above and below decks, is a concern

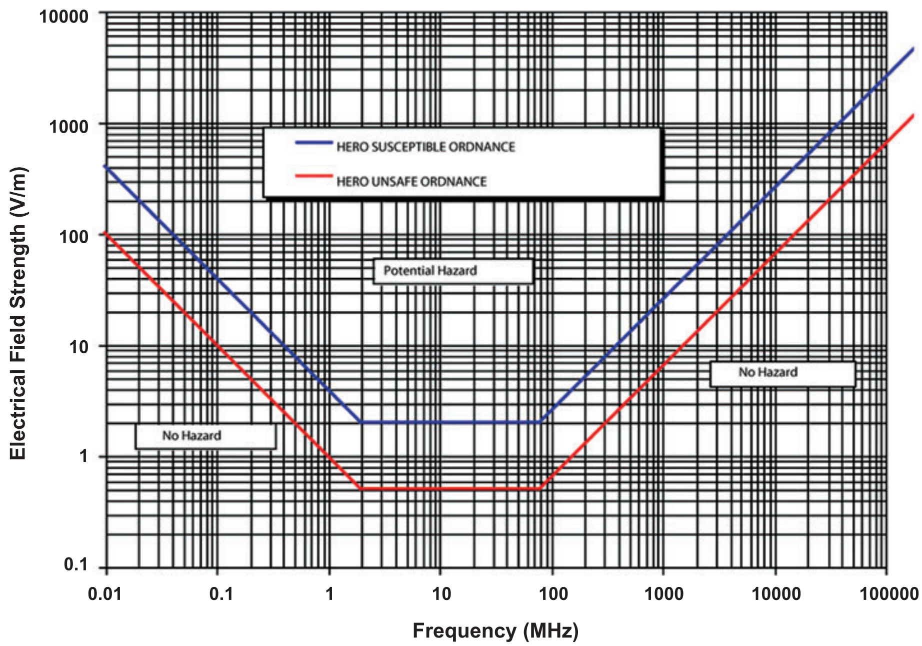


Figure 2. E-Field Limits for HERO SUSCEPTIBLE and HERO UNSAFE Ordnance

from the standpoint of potential electromagnetic interference (EMI) to electronic equipment and radiation hazards (RADHAZ); the latter concern most notably to personnel and ordnance. To develop new HERO limits, it was proposed that magnetic field limits be established in similar fashion for HERO UNSAFE ORDNANCE, as was done for the E-fields. And while this effort is still in its infancy, the development of these limits begins with a prediction of the response of HERO UNSAFE ORDNANCE to magnetic fields.

Development of Magnetic Field Limits

The approach taken to develop the magnetic field limit for HERO UNSAFE ORDNANCE mimicked the approach used to develop the E-field limits. Most importantly, this included conservative assumptions about the electroexplosive device (EED) sensitivity and the use of "worst-case" coupling models to calculate the voltage induced into the EED from an incident magnetic field. The EED sensitivity parameters used were the same as those used to derive the E-field limits. For E-fields, a λ/2 dipole antenna was used to model the EED firing circuit; for the case of magnetic fields, a 4.6-m^2 loop antenna was used. Here, a number of assumptions were made, including: the loop is always oriented for maximum pickup; no shielding exists from circuit leads; firing leads are not close to the ground plane; the magnetic field is homogeneous across the entire loop plane loop.

Once these important parameters were defined, the magnetic field limit was determined for each of two distinct frequency regions. The first region, for frequencies from 1 Hz to 2 MHz, was modeled by an electrically small loop. A loop area of 4.6 m^2 was chosen for two reasons: it is a practical representation of maximum firing-circuit loop areas, and this value "harmonizes" the electric and magnetic field limits. The loop area was held constant for all frequencies over which the model was used. The model was derived from Faraday's Law and was used to calculate the magnetic field limit based on the 4.6-m^2 loop area and electrical characteristics of a sensitive EED. For the second region, at frequencies between 2 and 30 MHz, there was no accepted model, so for a simplified approach, a constant value for the magnetic field was chosen to derive a magnetic field limit "equivalent" to the HERO UNSAFE ORDNANCE E-field limit. This amounts to deriving a magnetic field limit based on the 377-Ω far-field free space impedance relationship between electric and magnetic fields.

The resulting two-segment curve is depicted in Figure 3. The limit extends only to 30 MHz because it was determined that neither the EMALS nor Railgun will produce significant magnetic field levels above that frequency. It is also expected that E-fields become the predominant concern above 30 MHz. Figure 3 illustrates the proposed magnetic field limit from 1 Hz to 30 MHz, in units of magnetic field intensity, H(A/m). This simplistically derived graph constitutes the most severe limit and is generally applicable to all ordnance.

Future Efforts for Low-Frequency Magnetic Field HERO Guidance

To date, the Navy's HERO Program has developed the "proposed" worst-case, low-frequency magnetic field limit depicted in Figure 3. Still, there is much work to be done. In the near future, the Naval Surface Warfare Center (NSWC) Dahlgren plans to conduct validation testing to measure

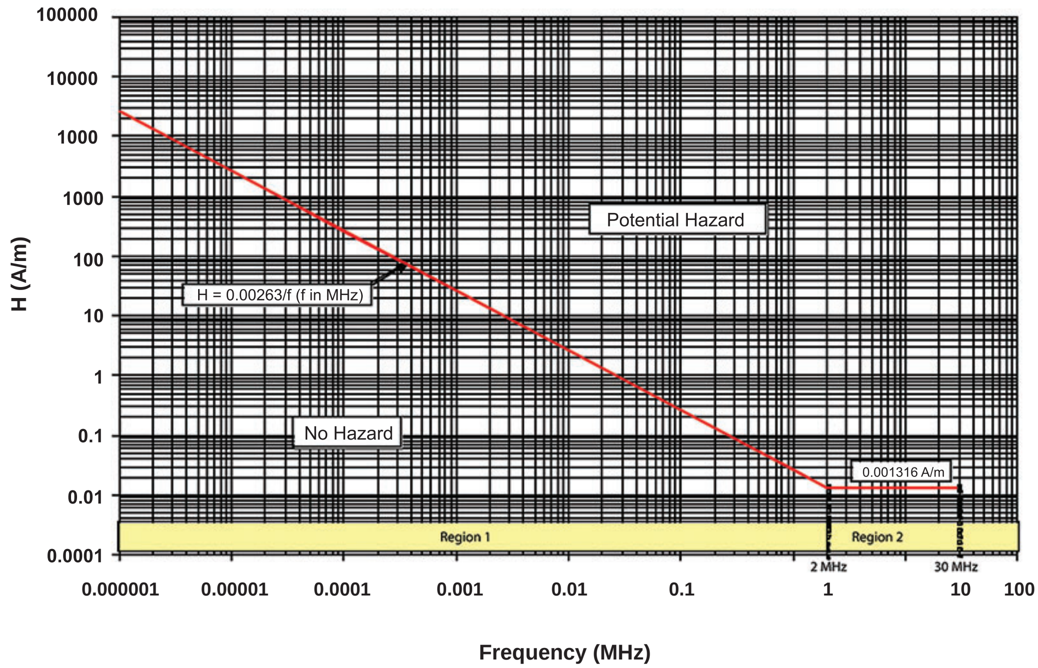


Figure 3. Proposed HERO Magnetic Field Limit (A/m)

various EED responses to various loop areas/geometries to compare measured responses to the predicted responses that form the basis of the derived field limits in Figure 3. As a result, this very conservative limit may be relaxed to a more practical level to minimize the HERO requirements during the design criteria for systems radiating low-frequency magnetic fields, as well as to reduce the level of HERO management necessary in the operational environment. Also, as was the case for the E-field limits, empirical magnetic field test data will result in the development of relaxed limits for ordnance classified as "SUSCEPTIBLE" and a new magnetic field limit curve to address HERO SUSCEPTIBLE ORDNANCE.

Once the model and the subsequent HERO limits have been established and validated, the limits will be published in NAVSEA OP 3565.[1] This data will also be incorporated into existing HERO standards to address HERO certification testing. Finally, the Navy's HERO Program will need to address rise-time limits for transient sources, as this may prove important when systems are encountered that exceed the magnetic field limits in Figure 3, but may not impact slower-responding EEDs, thus mitigating the HERO concern. This will allow the Navy HERO Program to address ongoing concerns at the Strategic Weapons Facility, Pacific and the Strategic Weapons Facility, Atlantic with regard to weapons-handling cranes that generate transient fields. Similarly, other examples of equipment producing severe broadband EMRs with large spectral components below 100 kHz, with a potential to create a HERO threat, are arc welders, power contactors, and weapons-handling vehicles. All of these programmatic efforts—from the defining of the magnetic field limits and addressing the transient nature of the fields to validating the models through the characterization of the actual fields and determining the sensitivity of various EEDs—will allow the Navy to adequately address HERO in the future as new systems are introduced that generate low-frequency magnetic fields of a transient nature aboard ship.

Acknowledgment

Mr. John Bean, EG&G Technical Services, contributed to this article.

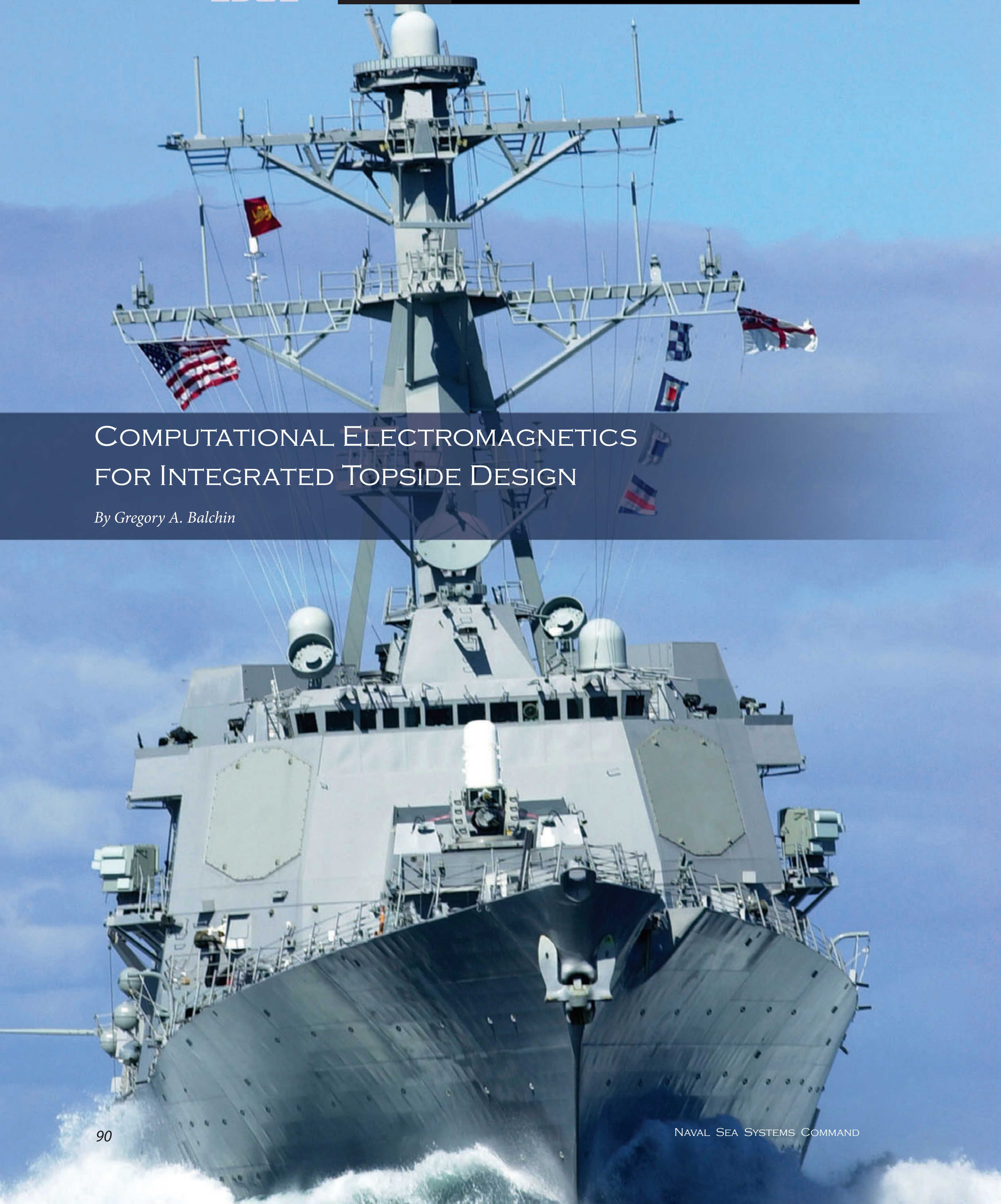
Endnotes

a. E-Field limits for HERO are identified in Figures 2-1 and 2-2 of NAVSEA OP 3565/NAVAIR 16-1-529, Volume 2, Sixteenth Revision, for HERO SUSCEPTIBLE and HERO UNSAFE ORDNANCE, respectively.

b. E-Field HERO certification requirements are provided in Table 3A of MIL-STD-464A, *Department of Defense Interface Standard, Electromagnetic Environmental Effects Requirements for Systems*, 19 December 2002.

Reference

1. NAVSEA OP 3565/NAVAIR 16-1-529, Volume 2, Sixteenth Revision.



Computational Electromagnetics for Integrated Topside Design

By Gregory A. Balchin

The Topside Design Challenge

Integrated topside design (ITD) is the part of the ship design process that deals with the placement, interaction, safety, and effects of weapons systems, sensors, antennas, and other equipment placed topside of the ship. ITD is a complex and challenging process. Many systems must function properly for the ship and its crew to perform their operations safely and effectively. Figure 1 shows a picture of USS *Anzio* (CG 68), which illustrates the numerous systems, including weapons systems, radars, and antennas that are topside of the ship, and includes antennas on the masts and yardarms. The ITD process must be applied to both in-service ships as well as new construction ships.

In-service ships are challenging because these ships have limited topside real estate for new systems and may already have existing performance issues with the systems already installed topside of the ship. For example, there may be issues with electromagnetic interference (EMI) among several of the topside systems. The ITD engineer for an in-service ship must find an innovative way to place new systems on the ship—given the limited space and weight restraints—and still remain within budget. This must be accomplished without impacting the efficacy of the ship's performance.[1]

ITD for new construction ships ensures that the systems planned for installation will be integrated properly in order to maximize system performance. This process continues throughout ship acquisition, beginning with concept design and continuing through the ship's life cycle. With a systems-engineering approach to ITD, new construction ships will have reduced postproduction rework, which can have a major impact on ship schedule and cost. The ITD engineer must also consider possible future issues for new construction ships so that mitigation plans can be developed.[2]

Areas of concern for the topside engineer include: pointing and firing cutout zones; missile and gun blast effects; structural test firing; antenna coverage and blockage; target detection range; EMI; electromagnetic compatibility (EMC); hazard of electromagnetic radiation to personnel (HERP);

Figure 1. USS *Anzio* (CG 68) Showing the Various Topside Systems That Impact Integrated Topside Design

hazard of electromagnetic radiation to ordnance (HERO); hazard of electromagnetic radiation to fuel (HERF); and their appropriate radiation hazard (RADHAZ) cutout zones.[3]

In the past, topside design involved developing separate topside systems that were placed on the ship to optimize their performance. However, this build-and-test procedure proved too costly due to the EMI problems and subsequent in-service rework required to correct or mitigate these problems. EMI can be a major issue for systems placed topside. Interference from one system can cause the detection of false targets in another system. Blockage and radio frequency (RF) “blind spots” can also occur, which could make the ship and crew vulnerable to hostile weapons. Postproduction testing and mitigation of these issues is costly and time-consuming while keeping the ship out of service.

Today, a more cost-effective approach involves using computational electromagnetics (CEM) to model and simulate the various radar and communications antennas that are placed topside. This allows the ITD engineer to determine, prior to physical placement of a system, if there will be issues concerning EMI, blockage among different systems, or if there are possible hazards with the placement of a system. If issues are discovered, the ITD engineer can consider different placement options and mitigation procedures before installation of the system.

What is Computational Electromagnetics?

Electrodynamics is the branch of physics that deals with electric and magnetic fields, their sources, and their interactions with matter. Classical electrodynamics is completely specified by Maxwell’s equations. CEM is the branch of electrodynamics that uses various numerical techniques to solve Maxwell’s equations. The field of CEM has improved tremendously in the last decade due to advances in computer technology and the development of fast, efficient algorithms for numerical solutions of differential and integral equations (IEs).

Maxwell’s equations can be formulated either as a set of partial differential equations (PDEs) or as a set of IEs. The techniques used in CEM exploit both formulations of Maxwell’s equations and can be divided into three broad categories: full-wave methods, asymptotic methods, and hybrid methods.

Figure 2[a] shows a chart of some of the various techniques used in CEM. This chart is not exhaustive. There are many numerical techniques available to the CEM engineer.

Full-wave methods involve numerical techniques that solve Maxwell’s equations rigorously and are, therefore, the most accurate of the computational categories. Asymptotic methods employ a high-frequency approximation to Maxwell’s equations. These methods provide good accuracy when used in the high-frequency region for which they are intended. Hybrid methods combine various computational techniques from full-wave methods and asymptotic methods.

Full-wave methods employ either frequency-domain (FD) techniques or time-domain (TD) techniques. Both FD and TD techniques can be formulated as a set of PDEs or as a set of IEs. Often there is a range of frequencies that are of interest for a system being modeled. TD techniques are appropriate because the system can be illuminated with a TD impulse across a wide range of frequencies. FD information is then obtained with the use of a Fourier transform. FD techniques are used to model the system at a specific frequency. These codes tend to run faster than the TD codes, and they are very good at modeling antennas at resonance.[4] In the FD, codes that are used extensively include finite element methods (FEMs), finite difference methods (FDMs), method of moments (MoMs), and fast multipole methods (FMMs). In the TD, frequently used codes include finite difference time domain (FDTD), transmission line matrix (TLM) methods, and integral equation time-domain (IETD) methods.

Asymptotic methods are used when the physical size of the object under consideration is very large compared to the wavelength of the electromagnetic energy illuminating the object. By very large, we mean an object size on the order of tens to hundreds of times the wavelength of the electromagnetic energy. Asymptotic methods are usually divided into field methods and current methods. Many of us are familiar with ray tracing optics from our introductory physics or engineering courses. The rays trace the paths of the planar wave fronts of the electromagnetic waves that impinge on a mirror or lens. Ray tracing optics falls under geometrical optics (GO), which is a field method. In order to accurately predict the fields interacting with an object, we must also include the geometrical theory of diffraction (GTD) and its extension, the uniform theory of diffraction (UTD).

GO does not involve the calculation of currents induced on an object due to the electromagnetic fields interacting with the object. Other asymptotic methods include the calculation of the induced current on a conducting object illuminated by an electromagnetic field. The induced current is then

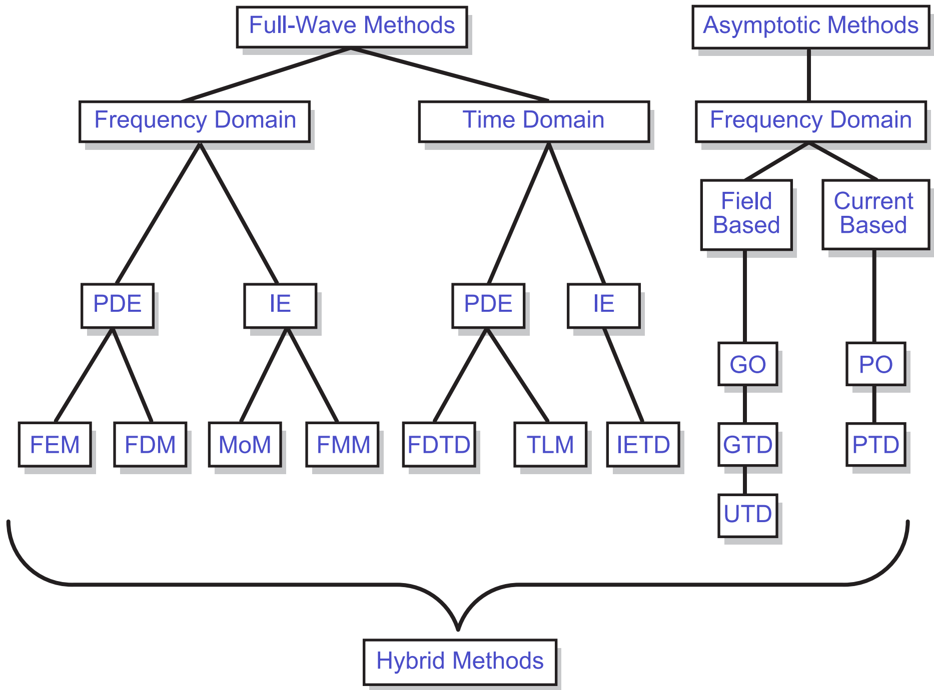


Figure 2. Various Computational Methods Used in Computational Electromagnetics

used to predict the radiated fields. Physical optics (PO) is an example of a current-based asymptotic method. PO must also be extended with the physical theory of diffraction (PTD) in order to accurately predict the fields interacting with an object.

The applicability of full-wave methods and asymptotic methods is shown in Figure 3.[5] In Figure 3, the size of the object is given in wavelengths. Full-wave methods are appropriate when the size of the object is on the order of the wavelength of the electromagnetic energy. Full-wave methods can be used with objects on the order of hundreds of wavelengths in length if the computer can handle the mesh constraints to minimize numerical dispersion and impacts to precision. For very large objects, the wavelength is short in comparison to the size of the object, and asymptotic methods are appropriate for that region.

Hybrid methods combine numerical techniques from full-wave methods and asymptotic methods. There are several commercial codes available that employ hybrid methods. A great deal

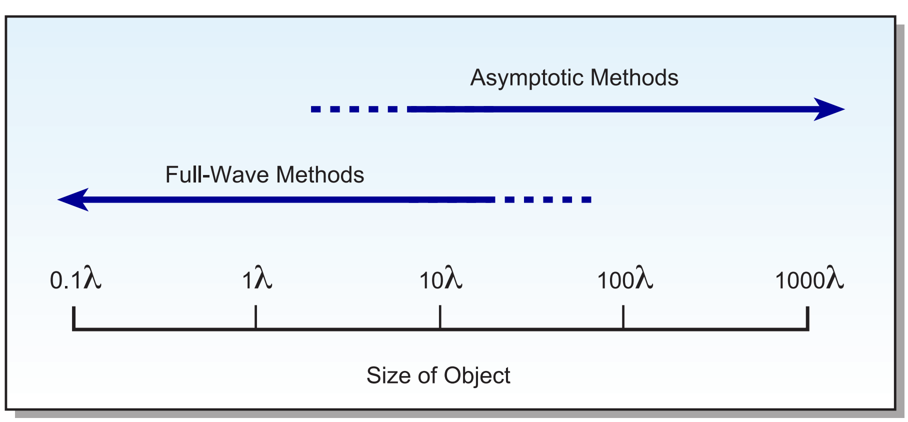


Figure 3. Range of Applicability of Methods Used in CEM

of research is currently being done in hybrid methods for Navy shipboard use because current computers still cannot handle the entire ship topside at many of the frequencies of interest. For example, in a hybrid method, a full-wave algorithm will be used to model an antenna; then the results of this model will be "handed-off" to an asymptotic algorithm to model the scattering between the antenna and other systems and shipboard structures.

The methods discussed are numerical; however, CEM also employs analytical techniques where appropriate. There are some problems in which a quasi-static approximation can be made, and the fields can be solved from Maxwell's equations analytically.

The CEM Modeling and Simulation Process

The CEM process begins with the identification of possible issues (such as a proposed system placement) on an in-service ship or new construction ship. The approach is shown in Figure 4.

To help identify issues, computer-aided design (CAD) drawings of the ship are first developed. These drawings must be checked against the actual ship if it is an in-service ship to ensure the accuracy of the drawings. The drawings are updated, as required, to accurately reflect the ship. The first step in analyzing any possible issues is to apply well understood empirical methods and lessons learned to determine if the issues can be resolved using

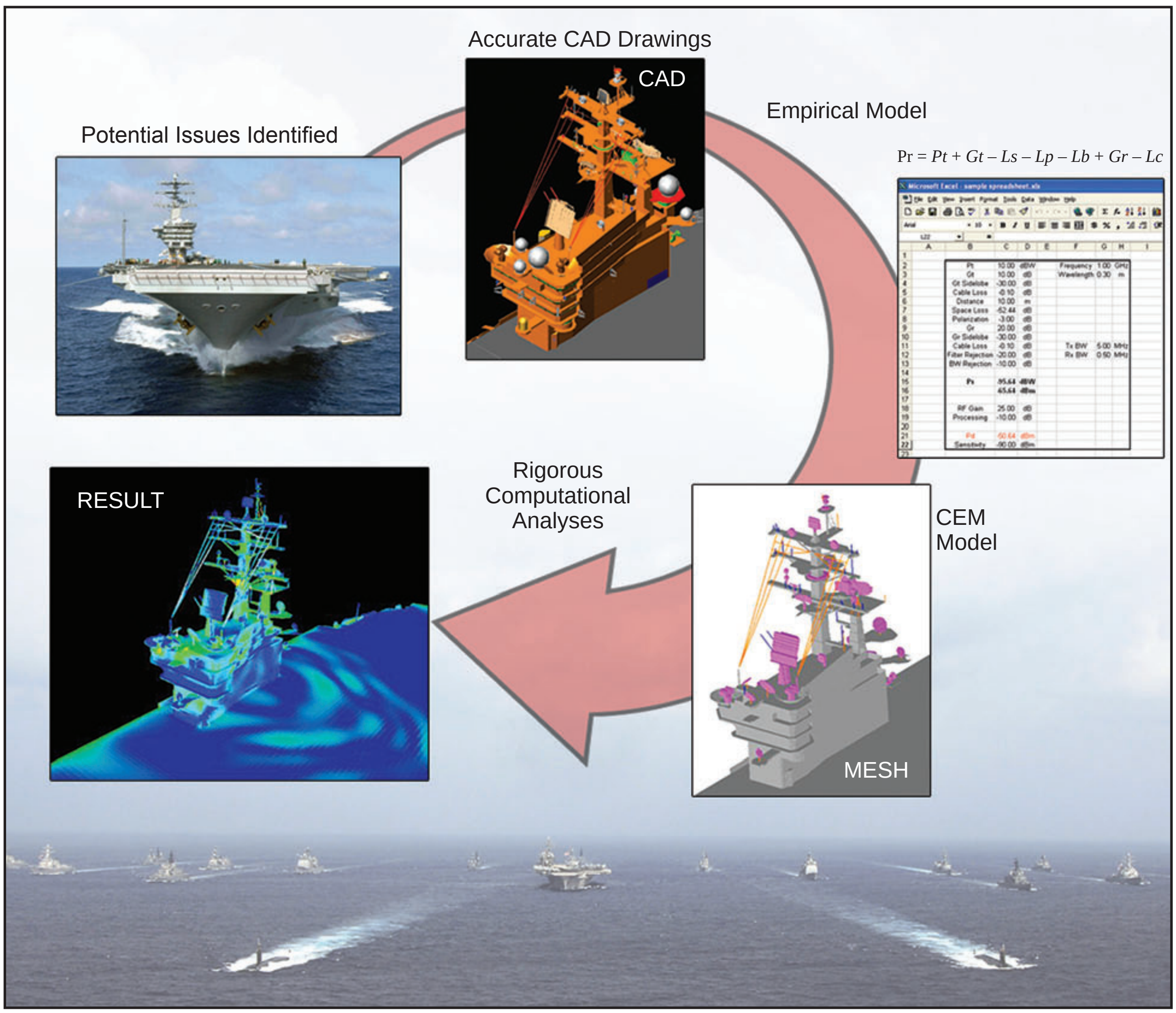


Figure 4. CEM Modeling and Simulation Process

methods from past mitigation efforts, or if further detailed modeling and analyses are required. If more analysis is required, the next step involves applying a more computationally rigorous analysis tool that provides a "quick look" at the possible issues. With each of these steps, the more difficult issues that pose the most risk to the ship are identified, and it is these high-risk issues that are subjected to the full rigor of computational analysis using state-of-the-art CEM codes and algorithms.

If more rigorous computational analysis is required, the next step is to create a model of the ship that can be incorporated into the computational electromagnetic codes. The amount of detail retained in this model depends on the frequencies of interest, the algorithm being used to solve Maxwell's equations, and the number of mesh points required to provide an accurate solution to the problem. Other issues that impact this model include the amount of computer memory storage required and the computer run time required for convergence of the solution. Once a model has been developed, the simulation is allowed to run to achieve a result. The result often requires postprocessing to interpret the result for the topside engineer to use in making decisions concerning the placement of equipment on the ship. Depending on the issues to be solved, this CEM modeling and simulation process can take several days to several months before an appropriate result is obtained.

The Navy Ship Challenge for CEM

Systems currently installed on Navy ships range in frequency from the high-frequency band to the extremely high-frequency band. This range encompasses frequencies from below 3 MHz to approximately 50 GHz. As an example of the Navy ship challenge for CEM, consider the LPD 17, which has an overall length of approximately 200 m. The length of the LPD 17 in terms of wavelength is shown for various frequencies in Table 1.

Comparing the LPD 17 length in wavelength given in Table 1 with the ranges in Figure 3, we see that the computational electromagnetic techniques required for a typical Navy ship encompass the full range of numerical methods. At the lower frequency range, full-wave methods would be used for a particular problem. At the higher frequencies, an asymptotic method would be used.

To perform a computational electromagnetic simulation involving LPD 17, an appropriate electromagnetic model of the ship must be constructed. An example of this model is shown in Figure 5a. Next, this model must be meshed to generate cells on which the electric and magnetic fields and currents are calculated. A meshed model of the LPD 17 is shown in Figure 5b. The number of cells depends on the size of the object and the frequency of interest. For accuracy, the cell size should be $\lambda/10$ or smaller in each dimension for use with full-wave methods. The number of mesh points or unknowns for the LPD 17 is also shown in Table 1.

The number of unknowns has an impact on both the computer memory storage required for the simulation, as well as the computer run time required to arrive at a solution. For example, if a MoM algorithm is chosen for the full-wave solution, and there are N unknowns, the computer storage required is on the order of N^2, and the time required is on the order of N^3. As a comparison, a model using an FDTD algorithm will have M unknowns with $M > N$, but the computer storage requirements are less for the FDTD algorithm (on the order of M) than for the MoM algorithm, and the time required for the FDTD algorithm (on the order of $M^{1.67}$) is less than the time required for the MoM algorithm.

There are computer storage and time requirement trade-offs in computational electromagnetic modeling that must be taken into account. The selection of an appropriate algorithm will depend on the frequency, physical size, and computer/scheduling resources available to solve the problem.

Table 1. LPD 17 Length in Wavelengths and Mesh Points

Frequency	LPD 17 Length	Mesh Points/Unknowns
3 MHz	2 λ	50
30 MHz	20 λ	5000
300 MHz	200 λ	500,000
3 GHz	2,000 λ	50,000,000
30 GHz	20,000 λ	5,000,000,000

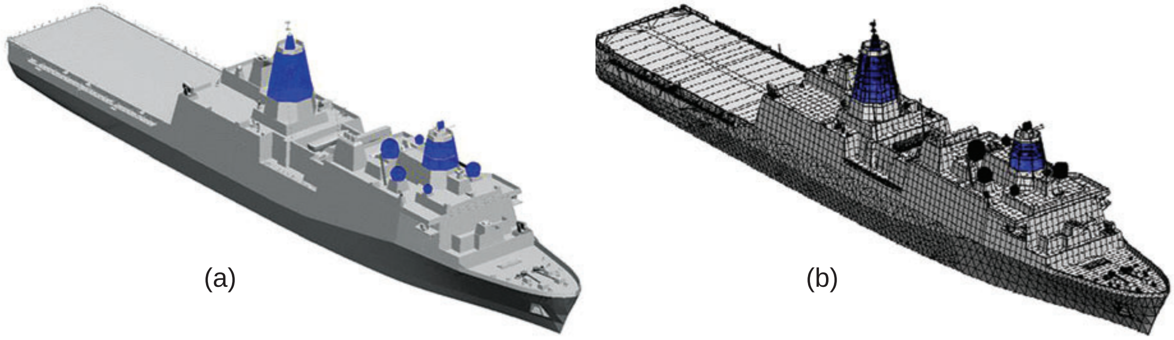


Figure 5. (a) Model of the LPD 17; (b) Mesh of the LPD 17

The CEM Group at the Naval Surface Warfare Center (NSWC) Dahlgren

The CEM group at NSWC Dahlgren consists of five CEM analysts and two CAD experts. The CEM group has a suite of 15 desktop computers and a cluster with 13 nodes dedicated to computational analysis and CAD development. The CEM group uses both government-developed codes and commercial codes to encompass all of the numerical algorithms required to cover the range of numerical methods needed to perform CEM analysis on a Navy ship. These codes include, for example, TLM algorithms, MoM algorithms, finite element analysis algorithms, and ray tracing and casting algorithms, as well as diffraction analysis algorithms. As part of its services, it provides CEM analysis on blockage, field patterns, coupling and EMI between systems, and field strengths for RADHAZ issues.

Often, the CEM group is asked to provide a quick analysis of possible blockage of one antenna due to another antenna or the shipboard structure. Figure 6 shows a model of an aircraft carrier island with various systems installed. The ITD

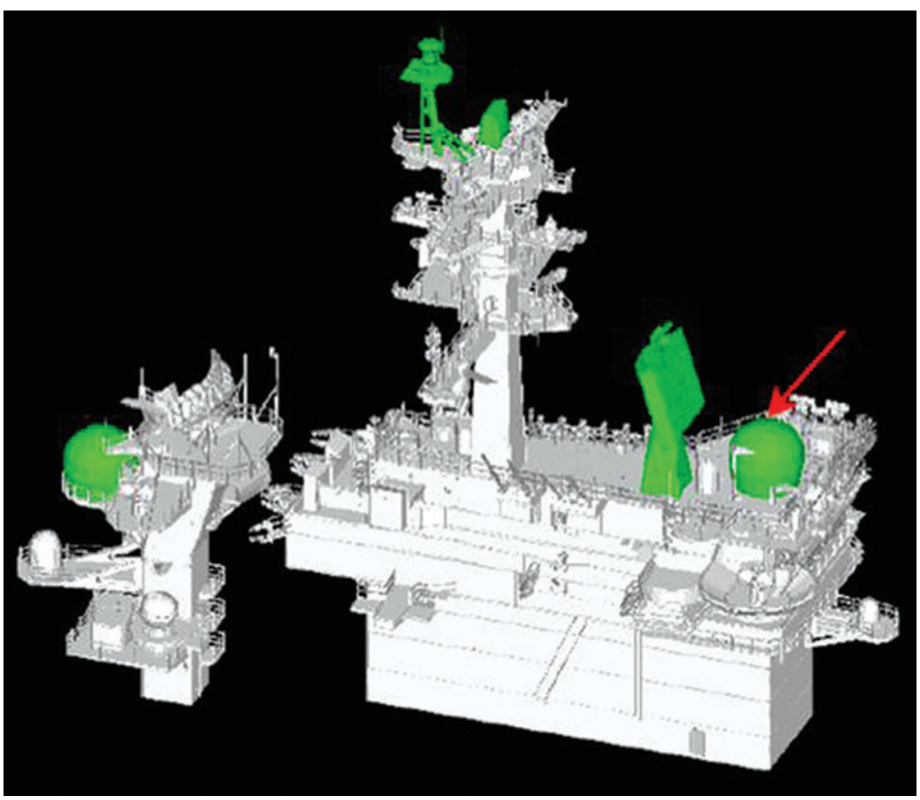


Figure 6. CEM Model for Blockage Analysis (Arrow Points to the Antenna Under Test)

engineer will want to know how blockage from other systems and structures affects what the antenna under test "sees." The CEM group performs blockage analyses using a ray casting algorithm to determine the blockage. This is shown in Figure 7.

The blockage analysis model (BAM) optical coverage plot provides a "quick-look" line-of-sight view from the perspective of the antenna under test. This plot covers the full 360° in azimuth and below zero (horizon) to 90° (zenith) in elevation. This type of analysis is quick and provides the ITD engineer and program manager with a good estimate of the blockage of the antenna under test. The ITD engineer and program manager can see any coverage issues that the system under test may have at the chosen location.

Based on the requirements of the ITD engineer and program manager, more refined and detailed analyses may be carried out, which gives a more accurate picture of the blockage and the impact of the blockage to the RF patterns of the antenna under test. This requires the use of more rigorous computational techniques. As an example, the CEM group was asked to model the currents induced on a carrier due to a high-altitude electromagnetic pulse (HEMP). The unclassified HEMP waveform covers a wide frequency range. Therefore, a time-based code is used because the frequency response of the ship can be analyzed through a Fourier transform of the time response, providing a wide range of frequencies. The full-wave software used to perform this analysis employed a TLM algorithm. A plane wave was used to simulate the HEMP impinging on the ship.

Because of the computer storage requirements based on the number of mesh points, the entire carrier could be modeled only up to 30 MHz. However, the carrier island, because of its smaller size compared to the ship, could be modeled up to 100 MHz. Figure 8 shows the model of the carrier island and part of the deck.

The resultant current on the island at one instant in time due to the HEMP is shown in Figure 9. The HEMP is traveling from port to starboard in the figure. The induced currents due to reflected RF energy from the island can be seen in the deck of the carrier.

The CEM group also provides CAD services for ITD. This involves performing ship checks to develop models of ships and antennas. These CAD models are used for future installations of systems and CEM analyses. The CAD services include providing the ITD engineer with alternate views of

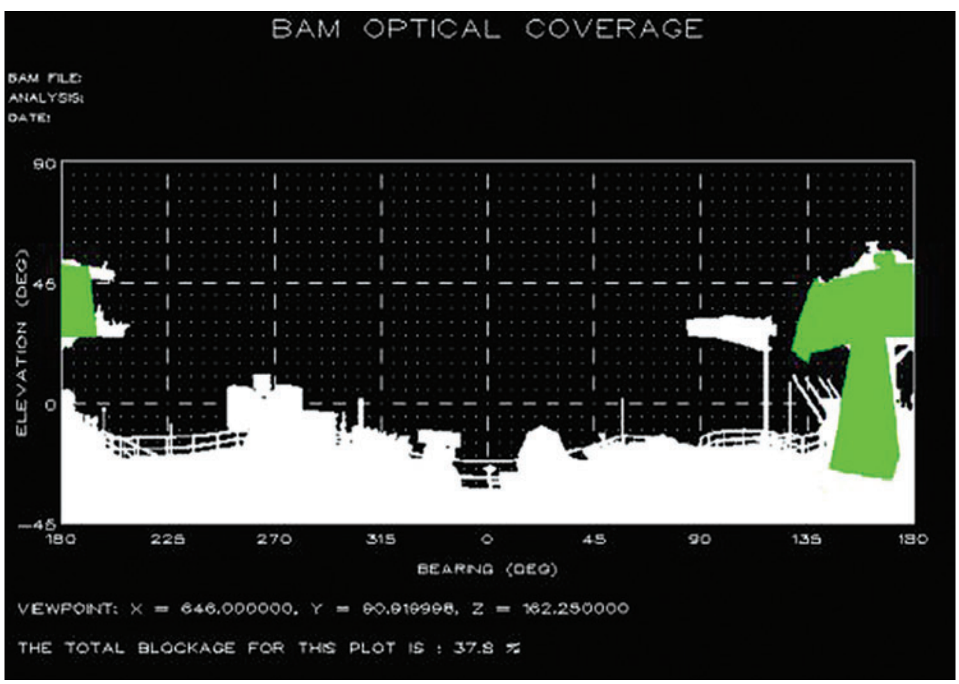


Figure 7. Blockage Analysis Model (BAM) for the Antenna Under Test in Figure 6

Figure 8. Model of an Aircraft Carrier Island and Deck

system location prior to physical placement and 2-D drawings, as requested by the ITD engineer, as well as the CAD basis for most of the numerical modeling. Other CAD services include serving as a repository of ship drawings in order to maintain and update the drawings as required.

Future CAD services will provide 3-D photo-realistic renderings of ships and ship systems, as well as animations to provide the program manager and engineer with "fly-bys" and "walk-throughs" of the ship.

Although the main service of the CEM group is to help the ITD engineer solve issues with EMI for topside systems, the CEM group also provides computational electromagnetic modeling and simulation services to other organizations and services, such as the Office of Naval Research (ONR), the Marine Corps, and the Coast Guard.

Future CEM work at Dahlgren will involve analysis of large phased-array apertures to include element-to-element coupling, coplanar coupling, and array edge effects. Members of the CEM group interact closely with the Naval Research Laboratory (NRL) and several professional CEM organizations to keep abreast of the latest code and algorithm developments.

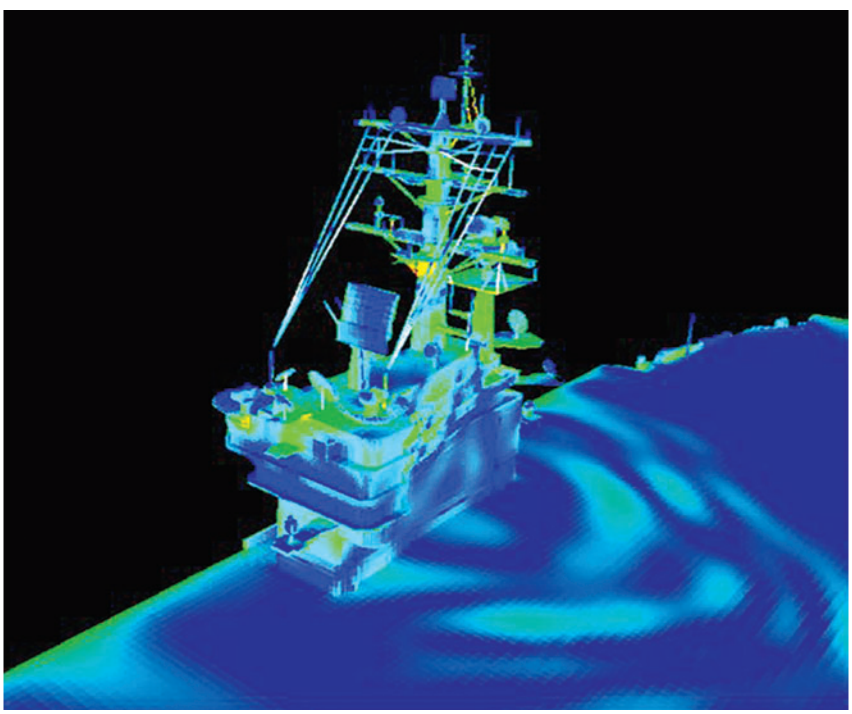


Figure 9. Induced Currents on an Aircraft Carrier Island and Deck

Endnote

a. This figure is based on a similar figure on p. 428 of Reference 5.

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USN Integrated Topside Design

By Mark Silva

Electromagnetic environmental effects (E3) and spectrum issues impact virtually every Navy acquisition program, as well as all fleet and shore activities. Naval Surface Warfare Center (NSWC) Dahlgren's E3 Ship Integration Branch, which includes the Integrated Topside Design (ITD), Total Ship Electromagnetic Environmental Effects (TSE3), and Computational Electromagnetics groups provides up-front engineering for both new construction ships and new system installations aboard in-service ships. The ability of fleet and shore commands to successfully perform their missions without degradation due to electromagnetic interference (EMI) is a direct result of the team's efforts.

ITD is the up-front, systems-engineering-centric design process that manages the coordination of all surface ship systems and components exposed to the external environment into a functioning unit to meet all mission requirements. ITD delivers total, ship-driven, responsive, objective, and in-depth scientific and engineering solutions to ensure fleet mission success in the operational electromagnetic environment. The ITD team incorporates all topside structures, associated equipment, and cooperating elements as a total ship topside system, ensuring operability, interoperability, and survivability, while reducing installation problems and unintended impacts to ship operations and safety.

As a key contributor to the Electromagnetic Mission Assurance Center (EMAC), located at Dahlgren, the ITD team directs ship design to maximize system performance for new ships and ship alterations. The team employs the systems engineering process during the acquisition or improvement of a platform, system, or associated equipment to provide an optimized system of systems that seeks to ensure that electromagnetic compatibility (EMC) is achieved. In this capacity, the team's technical engineering products and services enhance the fleet's readiness posture.

As the Navy's engineering agent (EA) for ITD and TSE3, technical warrant holders (TWH) SEA 05D3 and SEA 05W43, respectively, the ITD team conducts analyses of shipboard topside designs, candidate equipment, and system locations to determine optimal placement of equipment and structures. These analyses support new ship design and construction, scheduled ship overhaul or upgrade periods, rapid deployment capabilities (RDC), and new system integration to meet evolving mission needs. Work efforts include all surface classes (see Figures 1 and 2): carriers, combatants, amphibious warfare ships, and ships. Future design work includes programs such as:

- Littoral Combat Ship (LCS)
- Cruiser (CG(X))

- Aircraft Carrier (CVN 21)
- Destroyer (DDG 1000)
- Amphibious Assault Ship (LHA 6 & LHA 7)
- Joint High Speed Vessel (JHSV)
- U.S. Coast Guard's Deepwater Program, including:
  - National Security Cutter (NSC)
  - Offshore Patrol Cutter (OPC)
  - Fast Response Cutter (FRC)

Topside Design Process

The goal of the topside designer is to maximize overall ship performance in meeting mission requirements. Teams of naval architects, marine engineers (mechanical and electrical), combat system engineers, physicists, computer modelers and ship integrators work in concert to accomplish this goal. Members of this team incorporate various stakeholders to include:

- Naval Sea Systems Command (NAVSEA)
- Space and Warfare Systems Command (SPAWAR)
- Naval Air Systems Command (NAVAIR)
- Program executive offices (PEOs)
- U.S. Marine Corps
- Ship program managers
- Ship design managers
- Planning yard
- Radar Cross Section (SEA 05T)
- Shock and Vibration (SEA 05P)

Priority is given to locating primary, secondary, and tertiary mission-related elements, followed by:

- Ship-defense
- Communications
- Navigation
- Deck operating envelopes
- Other competing weapons or sensors
- Underway replenishment
- Mast
- Other systems

Ship constraints include:

- Superstructure
- Propulsion intake and uptake stacks
- Cranes and boats
- Flight deck operating envelopes

Figure 1. USCGC *Bertholf* (WMSL 750): Newest Surface Combatant to Join the USCG

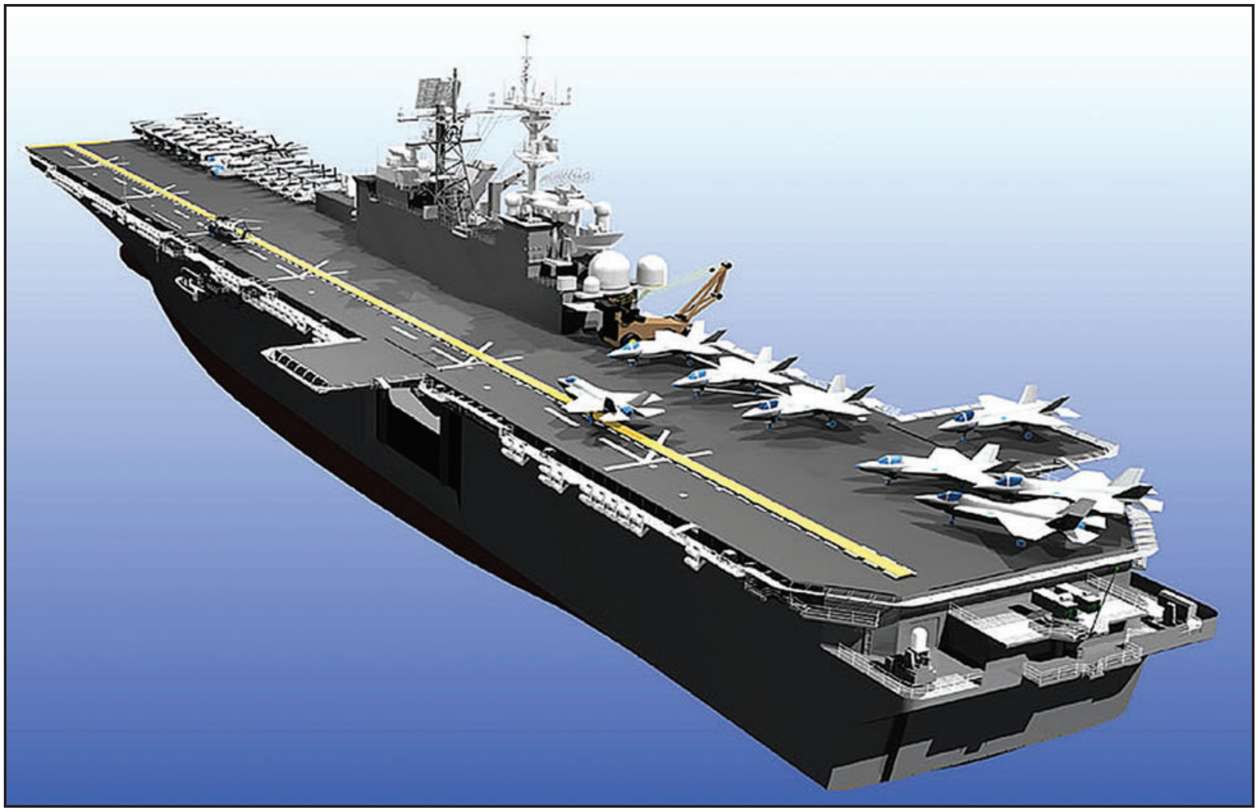

Figure 2. LHA 6 Conceptual Design to Support Joint Services Air Operations

- Other competing weapons or sensors
- Underway replenishment
- Mast height
- Panama Canal width restrictions

After placing the topside elements, the team assesses the individual performance of each system and the performance of the entire ship (see Figure 3). The team typically executes several design iterations to arrive at an optimized ship design.

Integrated Topside Design

In addition to enhancing sensor and weapons coverage and performance, new ship designs increasingly require an ITD to achieve the performance necessary to reduce ship vulnerability. In the past, equipment design was done independently of the topside design. The systems undergoing integration were mostly stand-alone systems, and a repeatable, standardized integration process was lacking or usually occurred late in the acquisition process. Near the end of the last century, the Navy recognized that such an approach was no longer adequate because newer, more powerful systems were coming to the fleet, and future performance requirements were increasingly more challenging (see Figure 4).

Consequently, the EMAC topside design team is increasingly involved with new equipment acquisition programs to ensure that crucial ship integration design aspects are addressed. New programs such as the Commercial Broadband Satellite Program (CBSP), the Mk 38 Mod 2 Machine Gun System, and the Enhanced Manpack Ultrahigh Frequency (UHF) Terminal (EMUT) are being matured utilizing a concurrent engineering approach that has involved all the technology stakeholders early on to provide quality solutions that, in turn, enhance the sailors' and Marines' capabilities to engage enemies, assure victory, and return safely to home port.

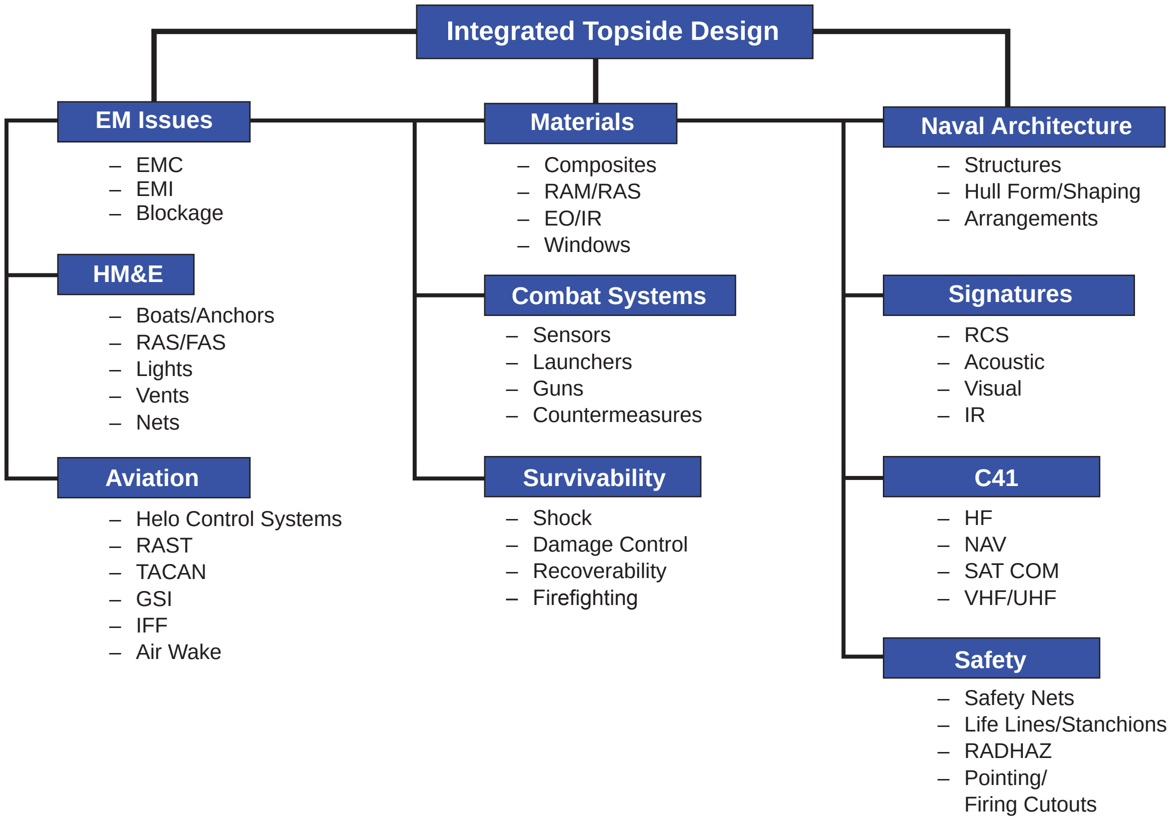

Figure 3. Topside Design Incorporates Multiple Disciplines

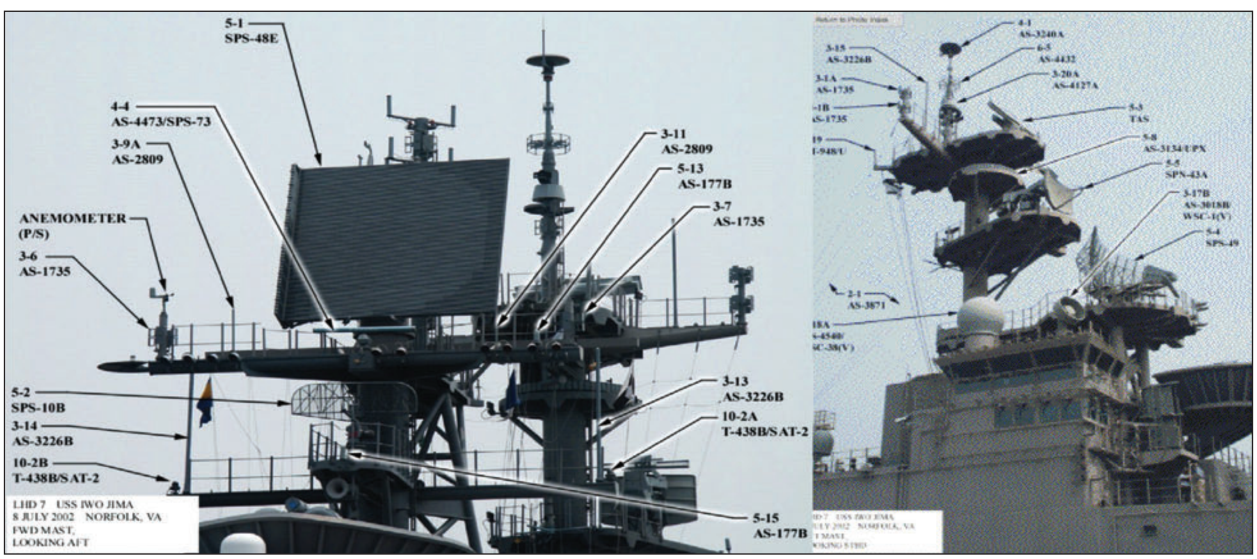

Figure 4. Numerous antennas competing for limited space and coverage result in a complex electromagnetic environment (EME), presenting a challenge for effective topside integration and maintaining the topside baseline.