SHIPBOARD HF ELECTROMAGNETIC FIELD MEASUREMENTS FOR EMC

Antonio Sarolic, Borivoj Modlic, and Kresimir Malaric

Faculty of Electrical Engineering and Computing, HR-10000 Zagreb, CROATIA
e-mail: antonio.sarolic@fer.hr

Abstract – *The distribution of shipboard HF electromagnetic field radiated from HF transmitter was needed for electromagnetic compatibility (EMC) and radiation hazard (RADHAZ) purposes. The electric and magnetic field were measured on the ship deck. Due to complex electromagnetic environment and measurement conditions, thorough pre-measurement analysis and planning was done. The fields on the deck were estimated analytically and calculated numerically. This analysis cleared the potential problems and enabled the right choice of measuring instruments. The fields were measured using narrowband equipment: loop and rod antenna connected to the test receiver. The measurement results were found to be similar to the values predicted by pre-measurement analysis.*

Keywords – shipboard electromagnetic field measurement.

1. INTRODUCTION

The big part of electromagnetic compatibility (EMC) problem is ensuring that electromagnetic interference (EMI) of an electrical device is within the appropriate limits. This kind of compliance is checked by measurements. The complexity of radiated EMI measurements (i.e. electromagnetic field measurements) is somewhat simplified by defining the measurement environment and procedures. That is why electromagnetic field measurements for EMC are done in the controlled environments: different types of shielded chambers, open area test sites (OATS), TEM/GTEM cells. Occasionally, radiated EMI must be measured in uncontrolled, or even hostile electromagnetic environment, such as onboard a ship. This situation demands detailed pre-measurement analysis and planning.

The shipboard electromagnetic environment is generally complicated by:

- many EM radiation sources onboard;
- adjacent EM radiation sources (neighboring ships, coast emitters);
- conductive objects of various shapes in the radiation zone, on and off the ship.

If disregarded, these conditions may deteriorate the quality of measurements.

2. PRE-MEASUREMENT ANALYSIS

Our measurement conditions were defined by the given ship. The ship was located in the port, about 100m far from other ships. The coast station was about 200m from the ship. The shipboard electromagnetic environment consisted of:

- 6m long vertical whip antenna as a HF radiation source, antenna located 16.5m from the stem, on the main cabin, antenna feed point 4.5m above the deck;
- other emitters and antennas on the ship topside;
- metallic (perfectly conductive) objects on the deck (cabins of different size and shape and other objects);
- metallic (perfectly conductive) ship hull;
- sea (ground plane).

The HF electromagnetic radiation source was a single side band (SSB) amplitude-modulated (AM) radio transmitter, working in the HF frequency band, with the peak envelope power of 100W. This analysis and measurements were done at the frequency of 5MHz.

A survey of other emitters showed a few communication transmitters and a navigational radar. All these sources were turned off during the measurements. Due to the existence of other EM radiation sources, especially off-ship, the measurements were to be done with selective, narrowband equipment.

A survey of objects on deck showed a good place for the measuring instrument (receiver) – between two conductive cabins where the lowest field value is expected.

The essential check before the electromagnetic field measurement is the near-field check. In the near-field zone (the zone nearest to the source), the field strength oscillates with the distance and the electric and magnetic field are not related, as opposed to the far field. That means that the electric and magnetic field have to be measured separately. Considering the line-antenna as a radiation source, we used a well known 2-3λ distance as the near-field boundary. At 5MHz, the whole ship deck of this 50m long ship was in the near field. Obviously, the electric and magnetic field had to be measured separately.

2.1 Analytical Estimation

The quickest way to the approximate field values is the analytical estimation. It is based on the equation:

$$S = \frac{P \cdot G \cdot F(\varphi, \vartheta)}{4\pi r^2} \quad , \qquad (1)$$

where S is the power density, P is the power radiated from the antenna, G is the antenna gain, F the field factor (gain reduction dependant on the direction, <1) and r is the distance from the antenna. With the far-field presumption, electric and magnetic field can be derived respectively by:

$$E = \sqrt{S \cdot 377\Omega} \quad \text{and} \quad H = \sqrt{\frac{S}{377\Omega}} \qquad (2)$$

For the sake of the order-of-magnitude estimation, we can presume:

- the far-field condition,
- electrically-short whip antenna with numerical gain of 3,
- F=1 (no gain reduction in the given direction),
- 10m distance from antenna.

The calculation gives the electric field of 10V/m and magnetic field of $26 \cdot 10^{-3}$A/m.

2.2 Numerical Calculation

Numerical (computer) modeling of electromagnetic problems is an essential tool for shipboard electromagnetic environment analysis. The purpose of numerical calculation was to obtain more precise information on the field distribution, taking into account the real geometry (unlike the analytical estimation), searching for eventual extreme values.

The accuracy of the calculation depends mainly on the model quality. In this research, the electromagnetic problem of shipboard HF transmitter radiation on the ship deck was analyzed by Method of Moments using the Numerical Electromagnetics Code (NEC 2) computer program [10].

Five wiregrid models of different complexity were built for this problem. The models were built manually.

<u>Antenna</u> Antenna was modeled by a single wire with 20 segments.

<u>Deck objects</u> Deck objects were very close to prism-shaped. Each object was modeled by wiregrid parallelepiped. The deck was bordered by a fence with vertical steel rods modeled by wires.

<u>Ship hull</u> The ship deck was a flat area on which the deck objects were laid upon. It was also modeled by a wiregrid. It rose about 2m high from the sea, i.e. the hull was submerged into the sea. The hull sides were modeled by vertical wires.

<u>Sea</u> The sea was modeled by an infinite, perfectly conductive ground plane.

Wiregrid model complexity is measured in segments. We developed 5 models of different complexity:

1. Wiregrid model no. 1 was the antenna in the free space and consisted of 21 segments.
2. Wiregrid model no. 2 was the antenna in the free space, over a ground plane leveled with the ship deck (i.e. model no.1 + ground plane) and consisted also of 21 segments.
3. Wiregrid model no. 3 (Fig.1) was the antenna on the main cabin, over a ground plane leveled with the ship deck (i.e. model no.2 + main cabin) and consisted of 288 segments.

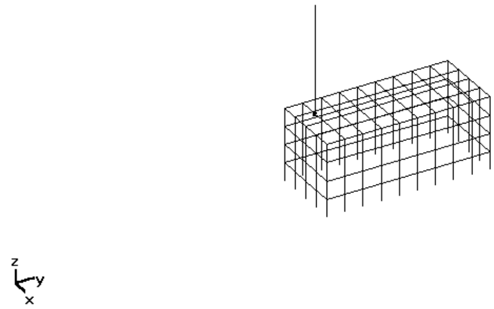

Fig.1 - Wiregrid model no. 3

4. Wiregrid model no. 4 (Fig.2) was the antenna on the main cabin, with all other cabins on the deck included, over a ground plane leveled with the ship deck (i.e. model no.3 + all other cabins) and consisted of 693 segments.

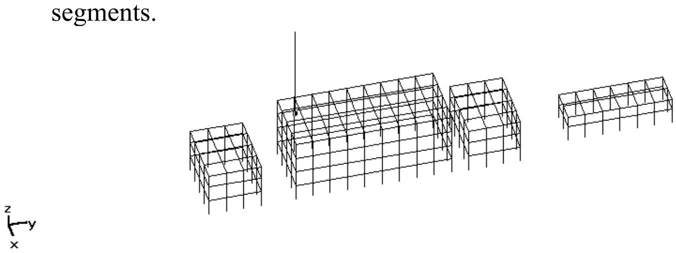

Fig.2 - Simplified wiregrid model no. 4

5. Wiregrid model no. 5 (Fig.3) was the antenna on the main cabin, with all other cabins and objects on the deck and the ship hull included, over a ground plane leveled with the sea surface (i.e. model no.4 + all other objects and more realistic ground plane) and consisted of 1374 segments.

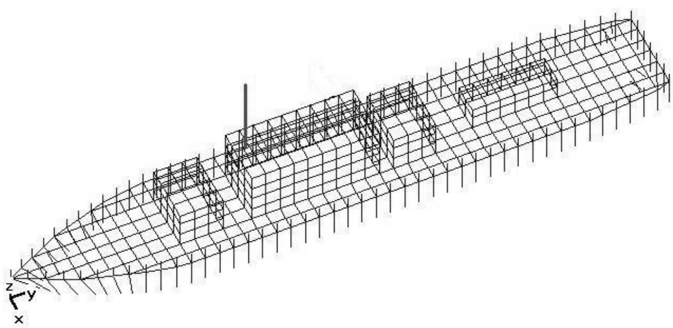

Fig.3 - Simplified wiregrid model no. 5

Using NEC2 program, we calculated only the vertical component of the electric field (E_z) at every point of the 1m×1m rectangular grid covering the accessible parts of the ship deck, 1m high above the deck. These results were used for graphical representation of the electric field distribution and the anticipation of the measured distribution.

3. MEASUREMENT INSTRUMENTATION AND PROCEDURE

Measurement was done with the selective narrow-band equipment:

- active rod antenna R&S HFH 2-Z6 for electric field;
- active loop antenna R&S HFH 2-Z2 for magnetic field;
- EMI test receiver R&S ESMI.

The test receiver was also the power source for the active antennas. It was also used as a spectrum analyzer for the spectrum observation during the measurement. The antennas were connected to the receiver via low-loss coaxial cables laid on the deck. All other objects, including humans, were excluded from the measurement environment.

The accessible parts of the deck were covered by the grid of points - 36 points in all, each point 1m high above the deck (Fig.4). The number of points was limited by the duration of entire measurement and practical access on the deck.

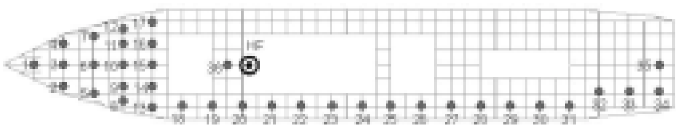

Fig.4 - Measurement points on the ship deck

The distance between two adjacent points was not greater than 2m. The points were numerated and marked on the deck. The vertical component of electric field (E_z) and the azimuthal component of the magnetic field (H_φ) were measured at the each point.

During the measurement, the radio operator took care of the appropriate source antenna tuning, to obtain the maximum radiated power. Also, the radio operator turned the emitter on only for the time of measurement at each point, because of the port emission restriction. At each point, the measuring antenna was set up, the people and the receiver were dislocated, the radio transmitter was turned on and then the measurements were made. The results were immediately printed out on a printer for each point.

4. RESULTS

The measurement results are shown in Table I. The calculated wave impedance value (E_z/H_ϕ) should yield 377Ω (free-space impedance) for the far-field conditions and good-quality measurements. Impedance values close to 377Ω, as well as the field values close to the far-field analytical estimation, show that the deck is located in the so-called radiating part of the near-field zone.

Figures 5 and 6 show the electric field distribution on the ship deck. Figure 5 is obtained from numerical calculation with model no.5. Fig.6 was obtained by interpolation of the measurement results. The obvious difference is the field outside the deck borders. The electric field outside the deck borders is shown as 0V/m in Fig.6 because it could not have been measured. Calculated values at that points are shown in Fig.5.

Table I – Measurement results

	E_z	H_ϕ	E_z/H_ϕ
Point no.	V/m	A/m	Ω
1	10,691	1,53E-02	701
2	6,974	1,59E-02	440
3	9,258	1,74E-02	532
4	6,479	1,59E-02	408
5	6,792	1,78E-02	382
6	5,991	1,85E-02	324
7	7,015	1,78E-02	394
8	6,871	1,90E-02	361
9	11,429	1,95E-02	585
10	6,295	2,11E-02	298
11	6,831	2,17E-02	316
12	11,194	1,87E-02	598
13	6,653	2,36E-02	282
14	9,705	2,35E-02	413
15	6,060	2,80E-02	217
16	9,451	2,49E-02	380
17	7,244	2,07E-02	350
18	11,285	2,42E-02	467
19	7,630	3,29E-02	232
20	10,127	2,00E-02	506
21	5,998	1,42E-02	422
22	6,019	2,11E-02	285
23	3,467	1,55E-02	223
24	2,894	1,60E-02	181
25	3,350	1,64E-02	205
26	4,320	2,47E-02	175
27	4,529	1,75E-02	259
28	4,207	8,81E-03	478
29	3,408	7,86E-03	434
30	4,853	1,67E-02	290
31	1,726	1,75E-02	99
32	0,501	6,17E-03	81
33	0,620	1,04E-02	60
34	6,012	1,15E-02	524
35	4,004	1,11E-02	361
36	10,206	2,71E-02	377

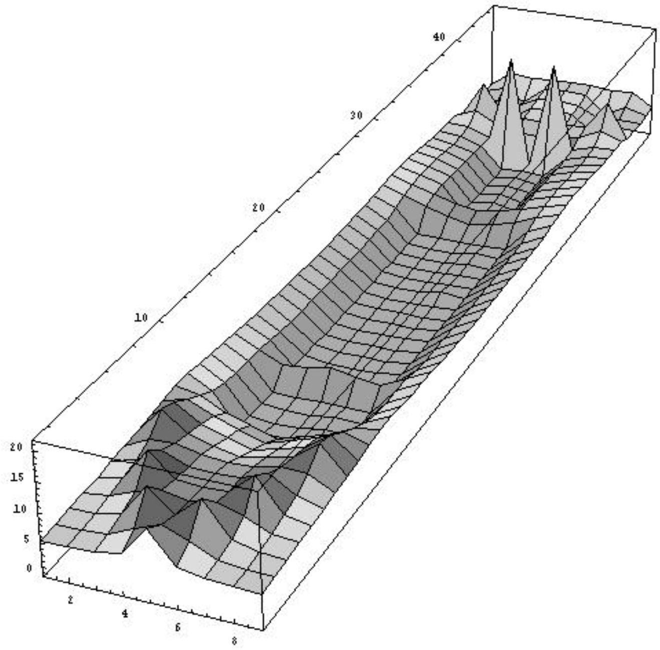

Fig.5 - Electric field distribution on the deck calculated with model no.5, in V/m

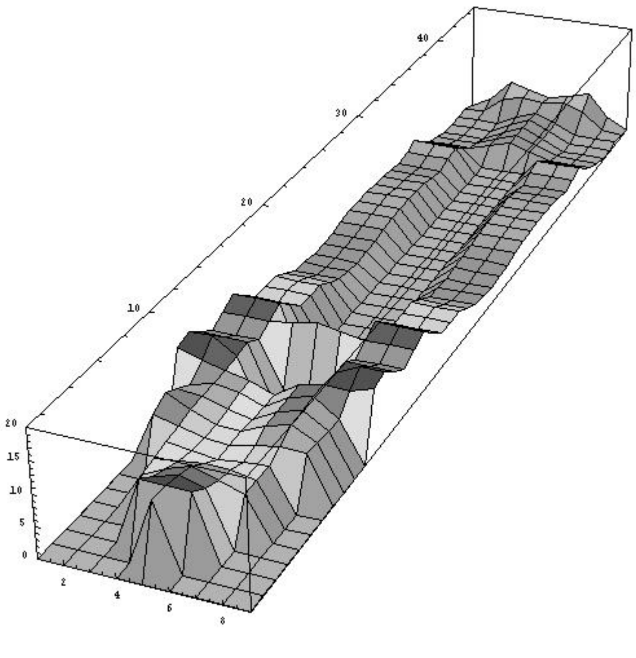

Fig.6 - Measured electric field distribution on the deck, in V/m

Regarding the area of the deck, there is a great similarity in these two figures, especially considering the rise and fall trends. Qualitatively, the calculation follows nicely to the measured results. Quantitative errors were calculated as follows:

$$\text{Average error [V/m]} = \frac{1}{N}\sum_{1}^{N}\left(E_{calculated} - E_{measured}\right) \quad (3)$$

$$\text{Average error [dB]} = \frac{1}{N}\sum_{1}^{N} 20\log\left(\frac{E_{calculated}}{E_{measured}}\right) \quad (4)$$

and are shown in Table II.

Table II - Comparison of calculated and measured results

Model no.	Average error in V/m	Maximum error in V/m	Average error in dB	Maximum error in dB
1	6.3	53.5	5.3	18.9
2	8.8	65.5	6.3	20.7
3	**2.0**	**6.5**	**3.7**	**20.0**
4	2.2	7.8	4.1	13.7
5	2.4	6.7	4.2	21.5

The models no. 3, 4 and 5 showed very good accuracy. Although they gave very similar results as far as accuracy was concerned, surprisingly, model no.3 was the most accurate one.

Maximum errors are caused by complex geometry near the stern, not shown in this paper. Few measurement points at that part of the deck (out of 36 points in all) deteriorate overall accuracy of the models. Considering that no model is absolutely accurate, these results must be taken into account with caution. Measurement neither confirmed nor denied the extreme calculated values because there were no measurement points at the extremes, but still there are great errors in their vicinity.

Fig.6 cannot show greater values than measured at the specific points (extreme values) because the figure is obtained by interpolation of measured values.

5. CONCLUSION

The tool of great importance in the EMC measurements is numerical calculation of electromagnetic field using computer. The precision of this calculation depends on the model used.

We concluded that the models no. 1 and 2, which did not take into account any objects on the ship deck or the deck itself, were not good models of the real situation. The errors were too big and the reason was obvious – the deck objects were too important to neglect. If we had wanted to calculate far fields in the line of horizon, model no. 2 would have perhaps served the purpose.

Model no. 3 was the first in line to give acceptably accurate results, taking into account the main object on the deck.

Models no. 3, 4 and 5 gave very similar accuracy, with model no. 3 being surprisingly the most accurate one. The best accuracy of the simpler model could be explained by:

- modeling inaccuracy of more complex models;
- measurement uncertainty.

Since model no. 3 was acceptably accurate (3.7dB average error), complexity of models no. 4 and 5 should have added to the fine accuracy. But the ship was still more complex than these two models and, to improve accuracy under 3dB, the model itself should have been geometrically absolutely accurate, which was not the case here. Considering the measurement uncertainty of field measurement in uncontrolled environment, these models were totally acceptable.

The idea of this work was to reduce the measurement time by thorough pre-measurement surveys and analysis. The instruments, procedure and measurement points were chosen according to the analysis results. Electromagnetic field measurements are generally complex and time-consuming procedure. In the complex electromagnetic environment, the measurement can be further delayed by unexpected situations. The right choice of instrumentation and procedure becomes increasingly important when measuring in such a hostile environment as a ship. In a physically limited space and in a limited measurement time, no mistakes or delays are welcome.

ACKNOWLEDGMENT

The authors wish to thank "Rohde & Schwarz" for the kind support of this research with their measuring equipment.

REFERENCES

[1] A. Sarolic, B. Modlic, and D. Poljak, "Measurement Validation of Ship Wiregrid Models of Different Complexity", in *2001 IEEE EMC Symposium Proceedings*, in press.

[2] K. Malaric, A. Sarolic, V. Roje, J. Bartolic, and B. Modlic, "Measured distribution of electric field in GTEM cell", in *2001 IEEE EMC Symposium Proceedings*, in press.

[3] A. Sarolic, *Electromagnetic Compatibility of Shipboard RF Equipment,* FER, Zagreb, 2000.

[4] P. Pavic, A. Sarolic, and B. Modlic, "Harmful Electromagnetic Fields on Ships – Standards and Worst Case Estimation", in *Electronics in Marine 40th International Symposium Proceedings*, ELMAR, Zadar, 1998, pp. 75-79.

[5] B. Modlic, A. Sarolic, and V. Roje, "GSM base stations impact on environmental electromagnetic pollution", *Electronics in Marine 42nd International Symposium Proceedings*, ELMAR, Zadar, 2000. pp. 22-27.

[6] *IEEE C95.3-1991: IEEE Recommended Practice fot the Measurement of Potentially Hazardous Electromagnetic Fields – RF and Microwave*, Institute of Electrical and Electronics Engineers (IEEE), New York, 1991.

[7] *Handbook of Electromagnetic Compatibility*, ed. Perez, J., Academic Press, San Diego, 1995.

[8] Law, P.E., *Shipboard Antennas*, Artech House, Boston, 1986.

[9] Law, P.E., *Shipboard Electromagnetics*, Artech House, Boston, 1987.

[10] G.J. Burke and A.J. Poggio, *Numerical Electromagnetics code (NEC) – Method of Moments,* Lawrence Livermore Laboratory, Livermore, 1981.