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Electromagnetic compatibility testing procedures of naval radars for installation on board military ships

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Abstract. The electromagnetic environment on board a military ship represents a delimited space in which there are disruptive sources and disturbance receptors. It is defined by the maximum disruptive levels in each point of the specified space. This electromagnetic environment is extremely complex because it is heavily dependent on: the density of the equipment on board, characteristics of installed equipment (frequency bands, power, modulation types, etc.), the design of the ship so that the electromagnetic field intensity within it is as small as possible. In order to install commercial radars on board military ships it is important to determine whether they can be installed in the Electromagnetic environment on board ships. An analysis of the standards of electromagnetic compatibility applied to them may determine whether commercial radars can be installed on board military ships.

1. Instroduction

The various missions of military ship as well as the continuous development of the technique and methods (principles) of the fighting, as well as the protection of the equipment on board ships, resulted in the increase in the number and complexity of the various electronic equipment, with various destinations, arranged on board ships. These equipments resulted in a continuous increase in the level of the electromagnetic field on board ships.

At the international level, increasing the safety of navigation is a continuing concern of the international maritime authorities, which, in the amendments to SOLAS, have specified that the radar remains the main sensor for safety of navigation. According to rule 19, annex 16 a SOLAS, on board the merchant ships must be installed, depending on the tonnage of the ship, radar equipment in the X (9GHz) and S (3GHz) bands.

For economic reasons, it is important to determine to what extent the commercial radars can be installed on board a military ship so that they are not sensitive to electromagnetic interference present in their installation environment and do not cause interference that degrades other equipment [16]. A first measure in risk assessment is the analysis of radar testing standards.

2. Electromagnetic compatibility test plan

An important requirement for measurements and electromagnetic compatibility tests is to ensure their reproducibility. In order to ensure the reproducibility of electromagnetic compatibility tests but also for comparing the obtained results, it is necessary that the procedures be carried out after the same test plan. Following the analysis of electromagnetic compatibility standards, I consider that the test plan must comprise the following points:

- introduction:
  - short description of the equipment under test (destination, compositing, technical-operational characteristics, place of installation and supply voltages);

- test procedures applicable to the equipment;
- changes in contracted test procedures (if approved);

- applicable documents:
  - military (standards, other documents regulating the acquisition activity of naval military equipment);
  - national or international standards, for procedures not covered by military standards and documents;
- test sites:
  - description of the spaces in which electromagnetic compatibility tests are conducted (size, ambient field level, radio frequency absorber material – shielded enclosure, facilities etc.);
  - the size and type of the grounding plan, the methods of grounding and shielding of the equipment under test to simulate the place of installation;
- test equipment used:
  - type and name of test equipment and calibration mode;
  - the characteristics of the coupling transformers and the bandpass filters;
  - type of antennae and their antenna factor;
  - current clamps and their transfer impedance;
  - line impedance stabilization network and their impedance;
  - software used;
  - bandwidths of the measurement receivers;
  - test signal parameters;
  - measurement tolerances;
- the equipment under test:
  - the modes and frequencies of operation for each individual test procedure;
  - adjustments to the equipment;
  - performance that is monitored;
  - enumeration of circuits, outputs or display devices required to be monitored during susceptibility testing;
  - criteria for determining susceptibility;
  - frequencies of local oscillators (frequencies of tact signals, etc.) that may exceed the limits imposed;
  - test procedures:
    - test setup;
    - the process of testing point by point;
    - limits imposed;
    - information and data required to be recorded during the testing procedure.

3. Comparative analysis of electromagnetic compatibility tests applicable to the testing of radar equipment for installation on board military ships

The electromagnetic compatibility testing of naval radars can be carried out according to the test procedures specified by the national standards if its exists. Where certain tests are not covered by these standards, international and military standards (IEC, STANAG, MIL-STD) may be used.

The electromagnetic compatibility testing matrix of electronic equipment is a tabular representation of the applicable test procedures, tests and standards. Based on the analysis of the test procedures provided by military standards and commercial standards, a matrix of electromagnetic compatibility testing of radars for installing on board ships may be established.

Standards for the testing of radiolocation equipment on board ships in accordance with IMO regulations are provided by the SOLAS'74 (International Convention for the Safety of Life at Sea, 1974) in Chapter 5 (Safety of Navigation), annex 9 (IMO performance standards for navigational equipment):

- IEC 60936-1 – Maritime navigation and radiocommunication equipment and systems - Radar - Part 1: shipborne radar - Performance requirements - Methods of testing and required test results.
- IEC 60945 – Maritime navigation and radiocommunication equipment and systems - General requirements - Methods of testing and required test results.

The commercial standard containing the procedures relating to the measurement of electromagnetic disturbances and the testing of susceptibility of equipment is IEC 61000, comprising 6 parts, each part having several sections. From IEC 61000 series, IEC 61000-6 refers to emission measurements and IEC 61000-4 to test equipment susceptibility.

IEC 61000-6-4 standards (Electromagnetic compatibility. Generic standards. Emission standard for industrial environments) is a general standard indicating the tests applied to equipment used in an industrial environment and does not include tests and methods of detailed measurement. As there are standards for family of products such as EN 55011 (Industrial, scientific and medical equipment. Radio-frequency disturbance characteristics. Limits and methods of measurement) and EN 55022 (Information Technology Equipment - Radio disturbance characteristics - Limits and methods of measurement), they will be used (contain precise measuring procedures).

The military standards for the test of electromagnetic compatibility of equipment for installing onboard ships are:

- MIL-STD-461G, Department of Defense Interface Standard: Requirements for the control of electromagnetic interference characteristics of subsystems and equipment;
- AECTP-500, Electromagnetic Environmental effects tests and verification.

Standard for testing electromagnetic compatibility of maritime equipment (radar) is IEC 60945. This standard provides for the following procedures:

- electromagnetic emission:
  - conducted emissions;
  - radiated emission from enclosure port;
- immunity to electromagnetic environment:
  - immunity to conducted radio frequency disturbance (is based on IEC 61000-4-6);
  - immunity to radiated radiofrequencies (IEC 61000-4-3);
  - immunity to fast transients on a.c. power, signal and control lines IEC 61000-4-4);
  - immunity to surges on a.c. power lines (IEC 61000-4-5);
  - immunity to power supply short-term variation (IEC 61000-4-11);
  - immunity to power supply failure (IEC 61000-4-11);
  - immunity to electrostatic discharge (IEC 61000-4-2).

3.1. Conducted emissions

This test measures the disturbances generated by the radar, which appear on its power supply port/power line and which can be conducted into ship's power supply, disturbances what may affect the other onboard equipment.

The tests are CE 101, CE 102 /MIL-STD-461G (military standard) and IEC 60945 (commercial standard).

Frequency ranges for the test are:

- CE 101: 30 Hz - 10 kHz;
- CE 102: 10 kHz – 10 MHz;
- IEC 60945: 10 kHz – 30 MHz.

In general, military standards provide that the lower limit of the frequency range in which the test procedure is carried out is the second harmonic of the frequency of the power supply of the equipment under test.

Testing is carried out in the frequency range 30 Hz – 10 kHz because the magnetic field of these conducted emissions, hard to shielded below 10 kHz, can disrupt the sensors of the hydroacoustic systems.

In order to ensure that new equipment to be installed on board ships will not affect the quality of the ship's power supply, a test in the frequency band 10 kHz – 1 MHz shall be performed.

High-frequency disturbances, exceeding 1 MHz, have the following characteristics:

- it can propagate by any type of coupling, galvanic isolation being unefficient;
- at high frequencies all conductors become antennas and electromagnetic disturbances are transmitted by radiation.

It can be said that the measurement of emissions in the 1 MHz-30 MHz band is a complement to the procedures for measuring radiated emissions.

The limits specified by the MIL-STD 461G standard, depending on the frequency bands, are:

- CE 101 test:
  - 30 Hz – 2,6 kHz: 95 dBμA (surface ships);
  - 2,6 kHz – 10 kHz: 95 dBμA - 76 dBμA (surface ships);
  - 60 Hz – 10 kHz: 120 dBμA - 76 dBμA (surface ships, 60 Hz, equipment and subsystems operating < 1 kVA);
  - 120 Hz – 1,92 kHz: 90 dBμA (surface ships, 60 Hz, equipment and subsystems operating $\geq$ 1 kVA);
  - 1,92 kHz – 10 kHz: 90 dBμA - 76 dBμA (surface ships, 60 Hz, equipment and subsystems operating $\geq$ 1 kVA);
- CE 102 test:
  - 10 kHz – 500 kHz: 95 dBμV - 60 dBμV;
  - 500 kHz – 1 MHz: 60 dBμV;

The limits specified by the IEC 60945 standard, depending on the frequency bands, are:

- 10 kHz – 150 kHz: 63 mV – 0,3 mV (96dBμV – 50 dBμV);
- 150 kHz – 350 kHz: 1 mV – 0,3 mV (60dBμV – 50 dBμV);
- 350 kHz – 30 MHz: 0,3 mV (50 dBμV).

Civil standards are a viable alternative to testing the radar that can be installed on board military ships.

3.2 Radiated emissions – magnetic field

The test measures electromagnetic disturbances radiated by an equipment (excluding antenna) and associated cables which can potentially disturb other equipment on the ship, such as radio receivers. The tests are RE 101/MIL-STD-461G and IEC 60945.

The military standard covers the frequency range 30 Hz – 100 kHz (RE 101) and the civilian standard 150 kHz – 30 MHz. It is noted that military standards cover the 30 Hz – 9 kHz frequency range which is a very important for the electromagnetic environment on board ships because the emissions in this band are determined by the power supply installations (units) of electrical and electronic equipment.

The limits specified by the RE101/MIL-STD 461G standard, are:

- 30 Hz – 450 Hz: 160 dBpT – 114 dBpT;
- 450 Hz – 30 kHz: 114dBpT – 76 dBpT;
- 30 kHz – 100 kHz: 76 dBpT.

IEC 60945 standard does not specify magnetic field level limits.

3.3 Radiated emissions – electric field

The test measures electromagnetic disturbances radiated by an equipment (including antenna) and associated cables. This requirement does not apply to emitters on the fundamental frequency. The tests are RE 101/MIL-STD-461G and IEC 60945.The limits and the frequency range are (Table 1):

Table 1. Comparison of RE 102 and IEC 60945

Test	Frequency range	Limit levels
RE 102	10 kHz – 100 MHz	70 dBμV/m – 36 dBμV/m
	100 MHz – 18 GHz	36 dBμV/m – 82 dBμV/m
IEC 60945	150 kHz – 300 kHz	80 dBμV/m – 52 dBμV/m
	300 kHz – 30 MHz	52 dBμV/m – 34 dBμV/m
	30 MHz – 156 MHz	54 dBμV/m
	156 MHz – 165 MHz	24 dBμV/m (quasi-peak dector) 30 dBμV/m (peak detector)
	165 MHz – 2 GHz	54 dBμV/m

The equipment tested according to the IEC 609454 standard can be used on board ship in less stringent electromagnetic environments, due to the covered frequency ranges and levels.

3.4 Immunity to conducted emissions

This requirement is applicable for all interconnecting cables, including power cables. The applicable standards are MIL-STD-461E (CS 114) and IEC 60945.

Table 2. Comparison of CS 114 and IEC 60945

Parameter	CS 114	IEC 60945*
Frequency range	4 kHz – 200 MHz	150 kHz – 80 MHz
Test signal	10 kHz sinusoidal signal with 1kHz pulse modulation, 50% duty cycle.	Sinusoidal signal with 3V r.m.s amplitude, amplitude modulation at 400 Hz ± 10% to o depth of 80% ± 10%. 10 V r.m.s amplitude at spot frequencies: 2 MHz, 3 MHz, 4 MHz, 6,2 MHz, 8,2MHz, 12,6 MHz, 16,5 MHz, 18,8 MHz, 22 MHz and 25 MHz.
Apply to ..	a.c. and d.c. power ports, signal and control lines	
Limits	Figure 1	Figure 1

* The test shall be carried out as described in IEC 61000-4-6 with severity level 2.

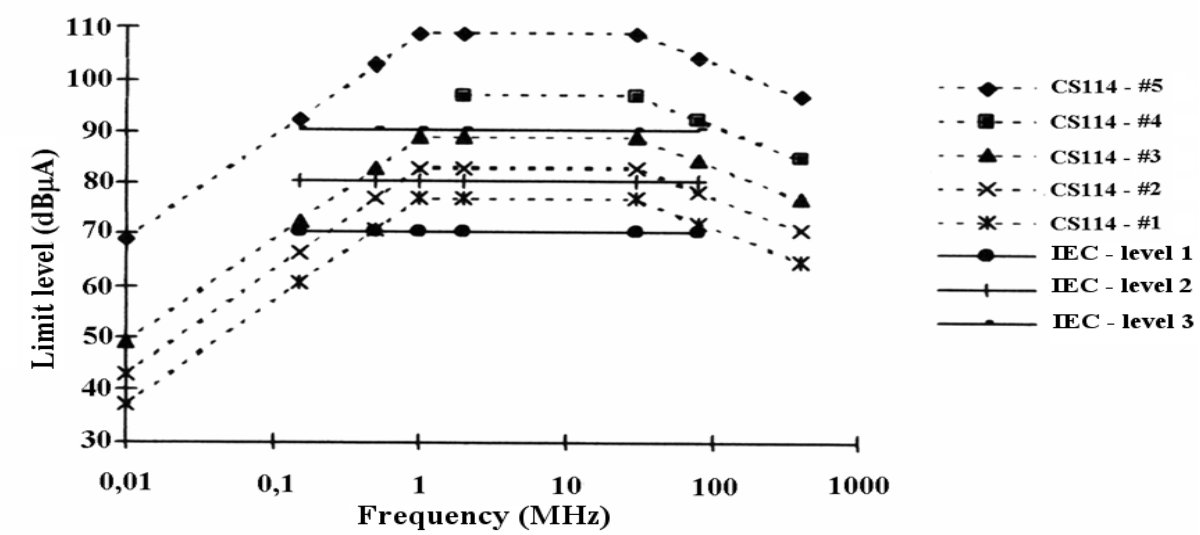

Figure 1. Limits for conducted radiofrequency disturbance

Analyzing limit levels, the frequency ranges in which the test is carried out and the parameters of the test signal can be concluded that the equipment tested according to commercial standard can be used on board the ship in areas similar to industrial environments.

3.5 Immunity to fast transients – BURST and to surges on a.c. power lines

a) Immunity to fast transients – BURST

This test procedure is used to verify the ability of the equipment under test (EUT) to withstand impulse signals coupled onto EUT associated cabling and it is one of the most relevant electromagnetic compatibility tests.

The applicable standards are MIL-STD-461E (CS 115) and IEC 60945.

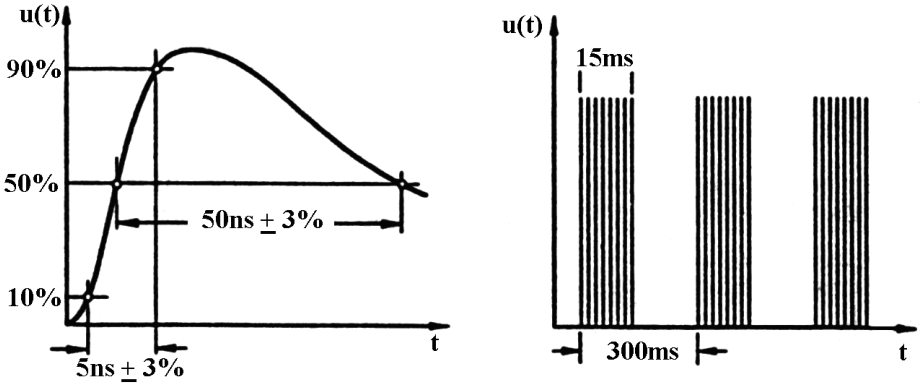

Figure 2. Singular impulse and BURST - IEC 61000-4-4 [9]

Table 3. Comparison of CS 115 and IEC 60945

Parameters	CS 115	IEC 60945*
- pulse rise time	< 2 ns	5 ns (value between 10% and 90%)
- pulse width	≥ 30 ns	50 ns (50% value)
- pulse amplitude	5A	2 kV differential on a.c. power lines

		1 kV common mode on signal and control lines
- pulse repetition rate	30 Hz	5 kHz (1kV), 2,5 kHz (2 kV)
Application	specified in the requirement	15 ms burst every 300 ms
Duration		3 min to 5 min for each of positive and negative polarity pulses

* The test shall be carried out as described in IEC 61000-4-4 with severity level 3.

It is noted that the equipment tested according to IEC 60945 (IEC 61000-4-4) may be installed on board the ship without any new tests being required because its requirements are higher than the MIL-STD-461E military standard.

b) Immunity to surges on a.c. power lines

In order to meet this requirement, commercial radars are tested in accordance with the IEC 60945 standard which provides that the test shall be carried out as described in IEC 6000-4-5 at test severity level 2. In accordance with Annex A of IEC 61000-4-5, the selection of the test levels should be based on the installation conditions.

The classification of environments according to IEC 61000-4-5:

- *class 0*: well-protected electrical environment, often within a special room;
- *class 1*: partly protected electrical environment;
- *class 2*: electrical environment where the cables are well-separated, even at short runs;
- *class 3*: electrical environment where cables run in parallel;
- *class 4*: electrical environment where the interconnections run as outdoor cables along with power cables, and cables are used for both electronic and electric circuits;
- *class 5*: electrical environment for electronic equipment connected to communication cables and overhead power lines in a non-densely populated area;
- class x: special conditions specified in the product specification

Table 4. IEC 60945 - Characteristics of test signal

Parameter	IEC 60945*
- pulse rise time	1,2 μs (value between 10% and 90%)
- pulse width	50 μs (50% value)
- pulse amplitude	1 kV line/earth 0,5 kV line/line
- pulse repetition rate	1 pulse / min
Application	continuous
Duration	5 min for each of positive and negative polarity pulses

The requirements of the IEC 61000-4-5 standard with the changes provided by IEC 60945 correspond to the classes of the electromagnetic environment on board ships. Equipment tested according to these standards may be installed on board ships in the environmental class 2 (electrical environment where the cables are well separated, even at short runs).

3.6 Immunity to conducted damped sinusoid

This requirement is applicable for all interconnecting cables, including power cables, and individual high side power leads to ensure the protection of equipment against external electromagnetic disturbances that can cause transients in the form of damped sinusoids (switching transients and lighting). The tests are CS 116/MIL-STD-461G (military standard) and IEC 61000-4-12 (commercial standard).

Table 5. Comparison of CS 116 and IEC 61000-4-12

Parameter	CS 116		IEC 61000-4-12	
Frequency range	10 kHz – 100 MHz		1 kHz; 1 MHz	
Test signal	damped sinusoid: 0,01; 0,1; 1; 10; 30; 100MHz; damping factor 15±5		Damped sinusoid, 75-ns rise time, 400 Hz repetition rate, burst duration > 2 ns	
Application	Signal leads and power leads (common mode coupling)		Signal and power leads (common and differential mode coupling)	
Limits	Frequency (MHz)	Peak current (A)	Frequency (MHz)	Peak current (A)
	0,01 – 0,1	0,1 - 1	0,1	10 for level 3 (2 kV)
	0,1 – 1	1 - 10	1	10 for level 3 (2 kV)
	1 – 30	10		
	30 – 100	10 – 3		

The MIL-STD-461E standard (CS 116) is used because testing is done for a large number of frequencies. According to IEC 60945 testing is carried out for frequencies of 0.1 MHz and 1 MHz and the current limits are similar to the military standard.

3.7 Immunity to power supply short-term variation

This test simulates power supply variations due to large changes in load. In order to meet this requirement, commercial radars are tested in accordance with the IEC 60945 standard which provides that the test shall be carried out as described in IEC 6000-4-11, with the next observations:

- voltage and frequency variation are 1/min:
- voltage and frequency variation rise:
  - voltage: nominal voltage + (20 ± 1)%, duration 1,5s ± 0,2s;
  - frequency: nominal frequency + (10 ± 0,5)%, duration 5s ± 0,5s;
- voltage and frequency variation decay:
  - voltage: nominal voltage - (20 ± 1)%, duration 1,5s ± 0,2s;
  - frequency: nominal frequency - (10 ± 0,5)%, duration 5s ± 0,5s;
- voltage and frequency variation rise and decay times are 0,2s ± 0,1s (from 10% to 90%).

3.8 Immunity to radiated electromagnetic fields

The IEC 60945 standard provides for testing of the immunity of equipment installed on board the ship only for radiated electric field.

MIL-STD-461G (RS 101) and IEC 61000-4-8 standards provide immunity tests for magnetic field, requirement being applicable for equipment and subsystem enclosures, including electrical cable interfaces in frequency range:

- 30 Hz – 100 kHz, RS 101;
- 50 or 60 Hz, IEC 61000-4-8.

The requirement is not applicable for electromagnetic coupling via antennas.

Test level:

- 800 A/m for RS 101;
- 1, 3, 30, 100, 300 A/m for IEC 61000-4-8.

The applicable tests for immunity to radiated electromagnetic fields – electric field are MIL-STD-461E (RS 103) and IEC 60945 (IEC 61000-4-3). For IEC 60945 the test shall be carried out as described in IEC 61000-4-3, at severity level 3 with the next observations:

- frequency range: 80 MHz – 2 GHz;
- strength of modulated electric field: 10V/m;
- amplitude modulation at 400Hz ± 10% to a depth of 80% ± 10%;

- swept of frequency range:
  - $1{,}5 \cdot 10^{-3}$ decades/s for the frequency range 80 MHz – 1 GHz;
  - $0{,}5 \cdot 10^{-3}$ decades/s for the frequency range 1 GHz – 2 GHz.

The comparative data corresponding to these tests are presented in table 6.

Table 6. Comparison of RS 103 and IEC 60945

Parameters	RS 103	IEC 60945
Frequency range	2 MHz – 18 GHz 18 GHz – 40 GHz – optional	80 MHz – 2 GHz
Test signal	1 kHz pulse modulation, 50% duty cycle	amplitude modulation at 400Hz ± 10% to a depth of 80% ± 10%
Limits	Table 7	Table 7

Table 7. RS 103 - Limit levels

	Electric field level (V/m)			
	Above and below deck	Below deck		
Frequency	All ships	Ships (metallic)	Ships (non-metallic)	Submarine
2 MHz - 30 MHz	200	10	50	5
30 MHz - 1 GHz	200	10	10	10
1 GHz - 18 GHz	200	10	10	10
18 GHz - 40 GHz	200	10	10	10

(i)

Table 8. IEC 61000-4-3 – Test levels

Level	Electric field level (V/m)
1	1
2	3
3	10
x	Special

The following classes of electromagnetic environment are considered as general guidelines for the selection of the corresponding levels:

- *class 1*: low-level electromagnetic radiation environment.
- *class 2*: moderate electromagnetic radiation environment. A typical commercial environment.
- *class 3*: severe electromagnetic radiation environment. A typical industrial environment.
- *class 4*: Portable transceivers are in use within less than 1 m of the equipment. Other sources of significant interference may be within 1 m of the equipment.
- *class x*: x is an open level which might be negotiated and specified in the product standard or equipment specification.

IEC 61000-4-3 standard has limited frequency range, 80 MHz – 2 GHz, but the level 3 of the test (severe electromagnetic radiation environment - a typical industrial environment) can be a test alternative.

3.9 Immunity to electrostatic discharge

The test procedure presents a controlled method to evaluate the susceptibility of electrical and electronic subsystems to human body electrostatic discharge.

The applicable tests/standards are: CS 118/MIL-STD-461G, NCS 12/AECTP-500 and IEC 60945 (the test shall be carried out as described in IEC 61000-4-2 at severity level 3).

The test level as described in IEC 60945 is 6 kV contact discharge and 8 kV air discharge (20 discharges per second – 10 discharges positive and negative with intervals of at least 1 s between discharges on each side and 0,1m from the EUT). For testing EUT shall be used contact discharge, but air discharge shall be used where contact discharges cannot be applied.

The test level as described in MIL-STD-461G is presented in the table 9 (5 positive discharges and 5 negative discharges to each EUT test point). Air discharge is only required where contact discharge cannot be applied.

Table 9. Comparison of MIL-STD and IEC – Test levels

Level	Test voltage (kV) / Method (Contact, Air)		
	MIL-STD-461G	AECPT 500	IEC 61000-4-2
1	± 2 (A)	± 2 (C/A)	± 2 (C/A)
2	± 4 (A)	± 4 (C/A)	± 4 (C/A)
3	± 8 (C/A)	± 6 (C) / ± 8 (A)	**± 6 (C) / ± 8 (A)**
4	± 15 (A)	± 8 (C) / ± 15 (A)	± 8 (C) / ± 15 (A)

It is noted that the equipment tested according to IEC 60945 standard (IEC 61000-4-2) can be installed on board the ship without any new tests required.

4. Conclusions

The electromagnetic compatibility of electronic (electrical) equipments on board a military ship consists in coordinating the disruptive levels that exist or potentially may occur on board, with the levels of immunity of these equipments. In order to achieve this, it is necessary to measure the levels of conducted emission and radiated emissions of on board equipment as accurately as possible and to determine the level of susceptibility to conducted emissions and radiated emissions of such equipment. Another condition that is required to achieve electromagnetic compatibility is to ensure the reproducibility of the testing procedures. Ensuring the reproducibility of the test procedures ensures that any measures to be taken aboard the ship to ensure compatibility of the equipment will not cause unforeseen situations.

By analysing the content and how to apply the tests, I believe that each test procedure must comprise:

1. Name;
2. Scope of application;
3. Limits imposed;
4. Purpose of the procedure;
5. Test equipment (main characteristics of test equipment);
6. Preparation of the test procedure:
   - 6.1 Organizing the test;
   - 6.2 Calibration of the test apparatus;
   - 6.3 EUT test Assembly;
7. Test procedure (punctual conduct of the test procedure);
8. Presentation of the data.

Another disadvantage of this type of standards relates to the overall approach of several types of equipment within the same standard which does not allow the highlighting of performance (technical parameters and operational characteristics) necessary to consider testing the electromagnetic compatibility of equipment. So it is also necessary to elaborate in the military the standards for different types of equipment (standards for product families or products standards).

In the electromagnetic immunity tests of radar equipment, is necessary to analyze and verification of the technical parameters of the radar to achieve electromagnetic compatibility of it on board the ship, for different regimes and adjustments (Minimum and maximum values) of these parameters, in order to determine the cases of the most unfavourable electromagnetic compatibility.

The choice of the technical parameters of the radar equipment, required to be tested in the procedures for testing immunity to electromagnetic disturbance, must be done following a detailed analysis of the influence of the parameter on Operational characteristics and electromagnetic compatibility of the equipment.

It is necessary to test the equipment at higher variations in signal parameters, power supply to determine an extended compatibility margin. For example, the MIL-STD-2036A (General requirements for electronic equipment specification) provides that electronic and electrical equipment on board ships operate at electrical voltage variations from + 35% to – 20%.

Conclusions on the comparative analysis of electromagnetic compatibility tests applicable to the testing of radar equipment for installation on board military ships:

1. *Conducted emissions*: The IEC 60945 standard represents a viable alternative for MIL-STD-461G standard.
2. *Radiated emissions – magnetic field*: applicable is the MIL-STD-461E standard, the commercial standard IEC 60945 does not provide limit values.
3. *Radiated emissions – electric field*: equipment tested according to IEC 609454 can be used on board the ship in less stringent electromagnetic environments, due to the frequency range covered and the levels.
4. *Immunity to conducted emissions*: analyzing limit levels, the frequency ranges in which the test is carried out and the parameters of the test signal can be concluded that the equipment tested according to IEC 60945 can be used on board the ship in areas similar to industrial environments.
5. *Immunity to fast transients – BURST*: the equipment tested according to IEC 60945 (IEC 61000-4-4) may be installed on board the ship without any new tests being required because its requirements are higher than the MIL-STD-461E military standard.
6. *Immunity to surges on a.c. power lines*: the requirements of the IEC 61000-4-5 standard with the changes provided by IEC 60945 correspond to the classes of the electromagnetic environment on board ships. Equipment tested according to these standards may be installed on board ships in the environmental class 2 (electrical environment where the cables are well separated, even at short runs).
7. *Immunity to conducted damped sinusoid*: the MIL-STD-461E standard (CS 116) is used because testing is done for a large number of frequencies. According to IEC 60945 testing is carried out for frequencies of 0.1 MHz and 1 MHz and the current limits are similar to the military standard.
8. *Immunity to power supply short-term variation*: the test procedure shall be carried out in accordance with the IEC 61000-4-11 commercial standard, but with the amendments stipulated by the IEC 60945 standard.
9. *Immunity to radiated radiofrequency – electric field***:** the test procedure shall be carried out in accordance with the IEC 61000-4-3 commercial standard, but with the amendments stipulated by the IEC 60945 standard. The commercial standard IEC 60945, compared to MIL-STD-461G, has limited frequency range, 80 MHz – 2 GHz, but the level 3 of the test can be a test alternative.
10. *Immunity to electrostatic discharge:* equipment tested according to IEC 60945 standard (IEC 61000-4-2) can be installed on board the ship without any new tests required because its requirements are much higher than the MIL-STD-883 military standard.

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