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Subject: EMI Effects of LED lighting systems on ships

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**24 June 2020**
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**United States of America**

# WORKING DOCUMENT TOWARD A PRELIMINARY DRAFT NEW REPORT ITU-R M.[LED-EMI]

## EMI Preventive Requirements for the Protection of VHF GMDSS, AIS and GNSS Systems from Unintended Radiation from LED Lighting Systems On-Board Marine Vessels

## 1 Introduction

The United States hereby submits this important information and proposes that ITU-R Working Party 5B consider using this information as the basis of a working document toward a preliminary draft new ITU-R Report: "EMI preventive conditions for the protection of VHF GMDSS and AIS systems from unintended radiation from LED lighting systems on-board marine vessels."

## 2 Description of the problem

In the United States, the US Coast Guard (USCG) and the Federal Communications Commission (FCC) have received reports[1] of electromagnetic interference (EMI) emanating from LED lighting systems on marine vessels. These reports have been primarily focused on EMI to the automatic identification system (AIS) and to VHF marine radios, both of which operate in the 156-162 MHz band and are essential to maritime safety related applications. It was found that most LED lighting systems on marine vessels cause significant desensitization of the receivers of both the AIS and the VHF marine radios, especially when the LED lamps are located in close proximity to the AIS antenna and/or the VHF radio antenna.

[1] These reports were received in response to USCG Marine Safety Alert, Bulletin 13-18 (see https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/CG-5PC/INV/Alerts/1318.pdf?ver=2018-08-16-091109-630).

## 3 Purpose of this document

The purpose of this document is to:

- Identify and describe the problem EMI emanating from LED lighting systems on marine vessels.
- Assess the problem in terms of the potential performance degradation of safety related shipborne radiocommunications and radio-navigation equipment that are mandatory carriage requirements under SOLAS IV and SOLAS V (Chapters 4 and 5 of the safety of life at sea (SOLAS)) convention administered by the international maritime organization (IMO).
- Quantify the intensity of this problem in technical terms.
- Assess the insufficiency of current EMI standards to address this problem.
- Develop new technical guidance relevant to the problem and coordinate with relevant standards groups.
- Develop installation guidelines for mariners to minimize degradation from EMI to sensitive radio communications and radio navigation equipment on their vessels.

## 4 Proposal

The United States proposes that ITU-R Working Party 5B consider this document in the development of “Working document toward preliminary draft new Report ITU-R M.[LED-EMI]: EMI preventive conditions for the protection of VHF GMDSS and AIS systems from unintended radiation from LED lighting systems on-board marine vessel.”

WORKING DOCUMENT TOWARD A PRELIMINARY DRAFT NEW REPORT ITU-R M.[LED-EMI]

# EMI Preventive Requirements for the Protection of VHF GMDSS, AIS and GNSS Systems from Unintended Radiation from LED Lighting Systems On-Board Marine Vessels

## 1 Scope

The purpose of this report is to:

- Identify and describe the problem of electromagnetic interference (EMI) emanating from LED lighting systems on marine vessels and the effects of EMI on maritime safety-related systems.
- Quantify the intensity of this problem in technical terms.
- Assess the insufficiency of current EMI standards to address this problem.
- Develop new technical guidance relevant problem and coordinate with relevant standards groups.
- Develop installation guidelines for mariners to minimize degradation from EMI to sensitive radio communications and radio navigation equipment on their vessels.

## 2 Introduction

Maritime radiocommunication authorities have received many reports[2] of electromagnetic interference (EMI) emanating from LED lighting systems on marine vessels. These reports have been primarily focused on interference to the automatic identification system (AIS) and to VHF marine radios, both of which operate in the 156-162 MHz band and are essential to safety of navigation and safety of life. It was found that most LED lighting systems on marine vessels cause significant desensitization of the receivers of both the AIS and the VHF marine radios, especially when the LED lamps are located close proximity to the AIS antenna and/or the VHF radio antenna.

## 3 Interference protection criteria for AIS and VHF marine radios from unintended radiation sources

Operational "Minimum sensitivity" requirements for the AIS and for VHF marine radios are developed by ITU and IEC.

For the AIS, the minimum sensitivity is contained in Recommendation ITU-R M.1371-5 as -107 dBm for a maximum packet error rate (PER) of 20%, which occurs at approximately carrier-to-interference plus noise ratio = 10 dB (C/(N+I)) = 10 dB, based on the specified co-channel rejection ratio, which is 10 dB for a PER of 20%.

[2] These reports were received in response to USCG Marine Safety Alert, Bulletin 13-18 (see https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/CG-5PC/INV/Alerts/1318.pdf?ver=2018-08-16-091109-630).

For the marine VHF radio, the “maximum useable sensitivity” is contained in IEC 61097-3 as “+6 dBµV e.m.f. for a SINAD, psophometrically weighted, of 20 dB”, which occurs at approximately C/(N+I) = 10.8 dB, based on an “FM improvement factor” ($FM_i$) of 9.2 dB, which is determined[3] by:

$$FM_i = (S/N)_o/(C/(N+I)) = 3(\Delta F/f_m)^2 = 3(5/3)^2 = 8.33, \text{ logarithmically, } 10 \log_{10} 8.33 = 9.2 \text{ dB}$$

Note that +6 dBµV e.m.f. is equivalent to -107 dBm in a 50-ohm system, since e.m.f. is technically defined as the open-circuit voltage of the energy source. Also note that this level is the same as 2 µV e.m.f. (the open-circuit output terminal of the 50-ohm signal source) and 1 µV at the 50-ohm input terminal of the victim equipment. Therefore, the sensitivity and interference protection criteria for both the AIS and the marine VHF radio are within 0.8 dB:

### 3.1 For the VHF marine radio receiver and the AIS receiver

For the VHF marine radio receiver, the maximum interference plus noise (I+N) level, at the input of the receiver is (-107 dBm - 9.2 dB) = -116.2 dBm. Since thermal noise in the VHF marine radio receiver bandwidth of 16 kHz = N = kTB = -131.96 dBm, and the maximum level of I+N = -116.2 dBm, the maximum level of interference (I) can be calculated from the linear power terms and converted back to logarithmic terms. Consequentially, the maximum level of interference (I) at the VHF marine radio receiver input is -116.32 dBm.

And for the AIS receiver, the maximum interference plus noise (I+N) level, at the input of the receiver is (-107 dBm – 10 dB) = -117 dBm. Since thermal noise in the AIS receiver bandwidth of 18 kHz = N = kTB = -131.4 dBm, and the maximum level of I+N = -117 dBm, the maximum level of interference (I) can be calculated from the linear power terms and converted back to logarithmic terms. Consequentially, the maximum level of interference (I) at the AIS receiver input is -117.16 dBm.

#### 3.1.1 Assessing the efficacy of the current EMI standards for this application

The current EMI standards specify a maximum field strength level measured at a separation distance.

**Example 1: IEC 60945 specification (per 9 kHz bandwidth):**

– Maximum field strength level (quasi-peak): 24 dBµV/m = 16 µV/m

– Separation distance for measurement: 3 meters

**Example 2: CISPR 25 Class 5 specification (per 120 kHz bandwidth):**

– Maximum field strength level (average): 15 dBµV/m = 5.6 µV/m

– Maximum field strength level (quasi-peak): 22 dBµV/m = 12.6 µV/m

– Separation distance for measurement: 1 meter

Note that the CISPR measurement bandwidths for the VHF marine band (156-162 MHz) is 120 kHz and the IEC 60945 measurement bandwidth for this band is 9 kHz. Considering that the VHF marine radio receiver bandwidth is 16 kHz, and the AIS receiver bandwidth is 18 kHz, the CISPR levels should be adjusted for bandwidth by 10 log (120/16) = 8.75 dB for the victim VHF marine radio receiver and by 10 log (120/18) = 8.24 dB for the victim AIS receiver to determine their derogatory effects on victim receivers. When changing from 120 kHz bandwidth to the IEC 60945

[3] “Reference Data for Radio Engineers,” Fifth Edition, March 1970, Section 21-11 to 21-12.

specified 9 kHz bandwidth, “the test level of the marine VHF band will decrease 16-20 dB for most signals” [4]. This measurement bandwidth factor is taken into account in Section 3.1.3.1 below.

### 3.1.2 Information needed for this application

- Separation distances between victim antennas and unintentional interference sources, e.g., for LED navigation lights:

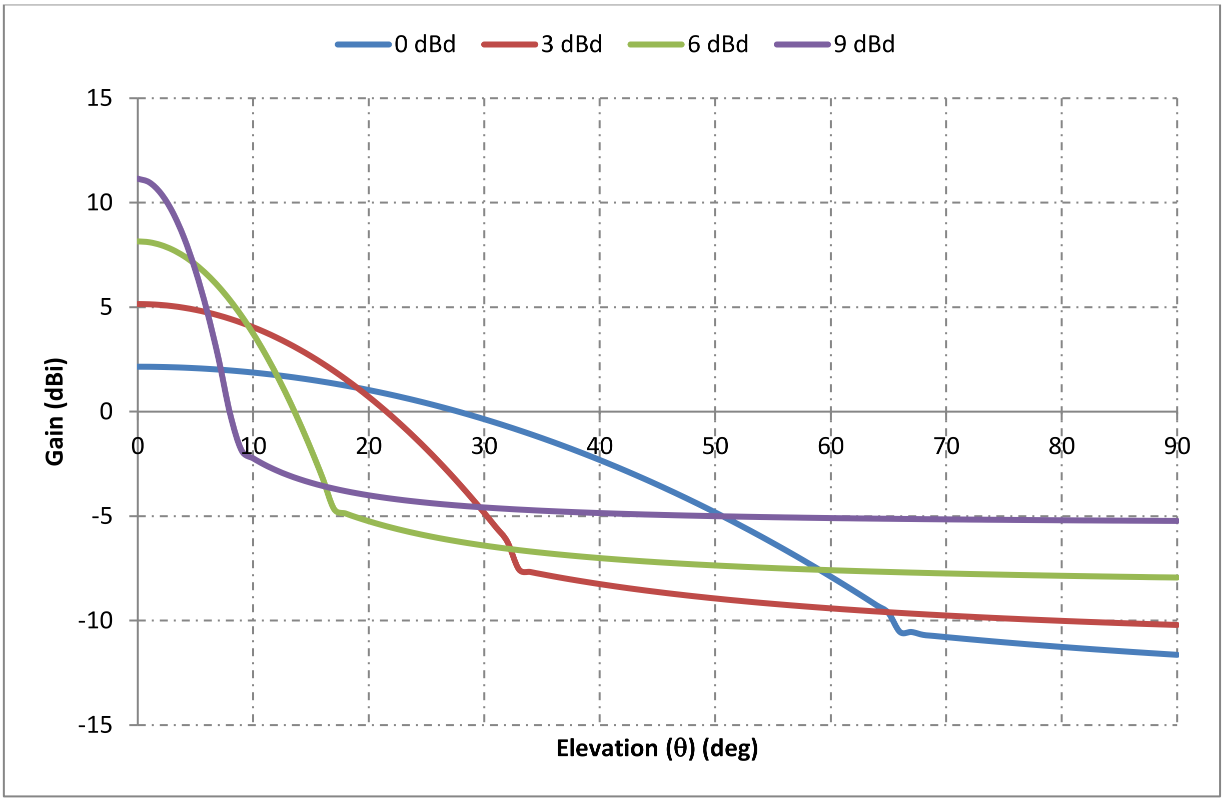
NOTE: The separation distance, for this analysis, is the distance between the interfering device and the center of radiation of the victim antenna. The antenna gain for this analysis may also be adjusted (see graph in Figure 1) to account for the angular offset to the antenna radiation pattern relative to the reference elevation angle of zero degrees ($0^0$).

Worst case = 1 meter; edge of antenna near-field, minimum separation. In rare cases = 0.5 meter; in the antenna near-field, should be avoided if possible. Characteristics of the victim equipment antennas are shown in Figure 1 below:

[4] H. Jin, W. Yang, F. Yu and Z. Wang, "A novel EBG structure with spiral line bridges for radiation suppression in marine VHF band," in IEEE Electromagnetic Compatibility Magazine, vol. 8, no. 4, pp. 56-61, 4th Quarter 2019

FIGURE 1

**Characteristics for vertical whip antennas based on Recommendation ITU-R F.1336**[5]




NOTE: Antenna gain is defined as the gain at $0^0$ elevation angle.

- For the AIS, the typical antenna is a 4-foot whip; gain= +2 dBi = 0 dBd
- For the VHF radio, the typical antenna is an 8-foot whip; gain = +6 dBi = 3 dBd

### 3.1.3 Necessary adjustments to current standards to fit this application

Adjustments to field strength level

- Adjustment for distance separation: $20\log_{10}$ D, in meters
- Adjustment for marine VHF radio is based on receiver sensitivity and antenna characteristics (gain, radiation pattern and angular offset of the position of the interfering source relative to the antenna)
- Adjustment for AIS is based on receiver sensitivity and antenna characteristics (gain, radiation pattern and angular offset of the position of the interfering source relative to the antenna)
- Adjustment based upon the sweep measurement bandwidth compared to the bandwidth of the victim receiver, based upon the type of detector used to measure interference (e.g., average, quasi-peak and peak) and the type of interference encountered.

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[5] Based on equations for average sidelobe levels for omnidirectional antennas in Recommendation ITU-R F.1336-5, *recommends 2.2.* These patterns are for use in the far field, beyond the reactive near field.

Adjustment for reactive near field effect in partially illuminating a 2.5 m shipboard VHF marine radio antenna, for example, from an unintentional emitter separated by as little as 1m or even 0.3 meters. The reactive near field for such an antenna begins at 1.5 m separation.

### 3.1.3.1 Field strength determination examples for the AIS and the VHF marine radio

**First example, for the AIS:**

Maximum interference signal level at the AIS RF input terminal = -117.16 dBm

The conversion of maximum interference power level to maximum interference field strength level is as follows:

NOTE: Units are assumed to be rms values (average values, not quasi-peak values).

**Method 1: (standard method)**

$E_{dB\mu V/m} = AF_{dB/m} + V_{dB\mu V}$

$AF_{50\Omega} = 20 \log_{10} f_{MHz} – 10 \log_{10} G – 29.7707$, where

G = 1.64 for the 0 dBd AIS antenna

$AF_{50\Omega} = 44.19 – 2.15 – 29.7707 = 12.27$ dB/m

$V_{dB\mu V}$ (for -117.16 dBm) = -10.17 dBµV

$E_{dB\mu V/m} = AF_{dB/m} + V_{dB\mu V} = 12.27 – 10.17 =$ +2.1 dBµV/m

**Method 2: (according to: Wikipedia, Antenna Factor),**

$AF_{50\Omega} = 9.73/(\lambda\sqrt{G}) = 4.10$/m = 12.26 dB/m

And

AF = E/V

Thus

$AF_{dB/m} = E_{dBV/m} – V_{dBV} = E_{dB\mu V/m} - V_{dB\mu V}$

$E_{dB\mu V/m} = AF_{dB/m} + V_{dB\mu V} = 12.26 + (-10.17) =$ +2.1 dBµV/m

**Result:** The results of Method 1 and Method 2 are identical.

Based on these results, the maximum interference field strength measured in a 120 kHz bandwidth with a separation of 1 meter, for the victim AIS receiver with a 0 dBd antenna and an 18 kHz receiver bandwidth, to provide C/(N+I) ≥ 10 dB, would be:

$E_{dBV/m}$ = +2.1 dBµV/m + 10 $\log_{10}$ (120/18) - 0 dB = +2.1 + 8.2 = **+10.3 dBµV/m (avg.)**

**Second example for the VHF marine radio (adjusted from the first example AIS):**

The maximum interference field strength measured in a 120 kHz bandwidth with a separation of 1 meter, for the victim VHF marine radio receiver with a +3 dBd antenna and a 16 kHz receiver bandwidth, to provide C/(N+I) ≥ 9.2 dB, would be:

$E_{dBV/m}$ = +2.1 + (10 - 9.2 = 0.8) + (10 log (120/16) = 8.75) - 3 = **+8.65 dBµV/m (avg.)**

**Comparing this to current standards:**

– CISPR 25 Class 5 (120 kHz bandwidth and 1 meter):

- ° Maximum field strength level (average): +15 dBµV/m
- ° Maximum field strength level (quazi-peak): +22 dBµV/m
- ° Maximum field strength level (peak): +35 dBµ

– IEC 60945 (9 kHz bandwidth and 3 meters):

- ° Maximum field strength level (quasi-peak): +24 dBµV/m

## 4 Interference protection criteria for marine GNSS receivers from unintended radiation sources

The interference protection criteria for GNSS (e.g., GPS) receivers should be based on Recommendation ITU-R M.1903-1 *Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) and receivers in the aeronautical radionavigation service operating in the band 1 559-1 610 MHz*

Acquisition mode threshold power density level of aggregate wideband interference at the passive antenna output: **-142 dB W/MHz = -112 dBm/MHz**

Tracking mode threshold power density level of aggregate wideband interference at the passive antenna output: **-136 dB W/MHz = -106 dBm/MHz**

Antenna gain: **6 dBi**

RF filter 3 dB bandwidth: **32 MHz**

Pre-correlation filter 3 dB bandwidth: **2 MHz**

Noise temperature: **645ºK**

$AF_{50\Omega} = 20 \log_{10} f_{MHz} - 10 \log_{10} G_{numeric} - 29.7707$ dB/m, $G_{numeric} = 3.981$ for 6 dBi

$= 63.945 - 6 - 29.7707 = 28.175$ dB/m at 1 575 MHz

$P_{dBm} = V_{dB\,uV} - 107$

$E_{dB\,\mu V/m} = AF_{50\Omega} + V_{dB\,\mu V} = AF_{50\Omega} + P_{dBm} + 107 = P_{dBm} + 107 + 28.175 = P_{dBm} + 135.175$

$P_{dBm\,(acquisition)} = -112$ dBm/MHz + 10 log (2) = -109 dBm

$E_{dB\,\mu V/m\,(acquisition)} = -109$ dBm + 135.175 = 26.2 dB µV/m

$E_{dB\,\mu V/m\,(120\,kHz)} = 26.2$ dB µV/m + 10 log (0.12/2) = 26.2 – 12.2 = **14 dBµV/m**

$E_{dB\,\mu V/m\,(9\,kHz)} = 26.2$ dB µV/m + 10 log (0.009/2) = 26.2 – 23.5 = **2.7 dB µV/m**

**Comparing this to current standards:**

– IEC 60945 (120 kHz, quazi-peak, 3 meters): 54 dB µV/m

- ° Adjustment for 3 meters to 1 meter: 20 log (3/1) = – 9.54 dB
- ° Adjustment for quazi-peak to average: + 10 dB
- ° Adjusted value: + 54 + 10 – 9.54 = 54.5 dBµV/m
- ° Difference to this calculation: 54.5 – 14 = 40.5 dB

– CISPR 25 Class 5 (9 kHz, 1 meter, average): 10 dBµV/m

- ° Difference to this calculation: 10 – 2.7 = 7.3 dB

## 5 Summary of Results

If these lighting systems are installed on marine vessels that installers use the following guidelines to avoid unintended interference to safety related marine radio communications (both HF and VHF) and radio-navigation systems (both AIS and GPS).

### 5.1 Important Precautions for avoiding interference when using LED lamps

If LED lamps are used, insure they are proven to meet CISPR 25 Class 5 radiated emissions limits in the marine radio communications and radio-navigation frequency bands, measured at 1 meter from the LED lamps:

- HF Marine Band (RR Appendix **17**) 2-30 MHz: 20 dB(μV/m) average
- VHF Marine Band (RR Appendix **18**) 156-162 MHz: 15 dB(μV/m) average
- GNSS L1 Marine Band (1 559-1 610 MHz): 10 dB(μV/m) average

### 5.2 Separate LED lamps from sensitive antennas

To mitigate EMI from LED lamps, separate the LED lamps as far as possible from VHF marine band antennas, with a minimum distance of 1 meter wherever possible.

### 5.3 Use vertical separation wherever possible

If possible, separate the LED lamps from the sensitive antennas in the vertical direction, either over or under each other, in order to minimize the coupling between them. Refer to the antenna patterns on Figure 1 for +/- 90 degrees elevation angle.

### 5.4 Testing for interference following installation[6]

**Test the VHF marine radio for interference**

To simply test for the presence of EMI, switch off all lighting that could be a source of EMI. Tune the radio to a weak continually broadcasting station. Turn on the LED light(s) one at a time, and then all on. If the broadcast signal vanishes after a lamp is energized, it is generating RF interference.

As an alternative to tuning to a weak continually broadcasting channel, with all the lights off, tune the VHF radio to some quiet channel. Adjust the VHF radio's squelch control until the radio outputs audio noise. Re-adjust the squelch until the audio noise is quiet, only slightly above the noise threshold. If, after energizing the lights, the radio now outputs audio noise, then the LED light(s) have raised the noise floor.

The advantage of the weak continuously broadcasting radio test is that it is simple and quick, and can be performed on radios having adaptive or coherent squelch. The advantage of the squelch test is that it is a more accurate test and can more readily detect lower levels of interference. Note that neither of these tests will ensure that all unintentional interference is reliability detected. A spectrum analyser is the most positive instrument for detecting such interference.

**Test the AIS for interference**

If the AIS antenna is closer to an LED lamp than the VHF marine radio antenna, disconnect the AIS antenna from the AIS and connect it to the marine VHF radio and rerun the test in 4.4 above to

[6] These tests are included in the US Federal Communications Commission Ship Inspection Checklists available at https://www.fcc.gov/eb-ship-inspection-checklists and are also planned for inclusion in the next edition of NMEA 0400 Installation Standard.

verify that the AIS antenna is not degraded.  If that is impractical, performing these tests using a VHF handheld in the vicinity of an AIS antenna is a reasonable substitute.

**Test the GNSS for interference**

Turn off the LED lamps and note the indicated GNSS S/N values on the various satellites. Turn on the LED lamps, wait ten minutes and then observe whether the GNSS S/N values on the satellites have degraded significantly.

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