Acquisition Directorate
Research & Development Center

Report No. CG-D-01-22

Testing for EMC/RFI Emissions of LED Navigation Lights and Susceptibility Levels for Marine Radionavigation Receivers

Rapid Evaluation and Analysis of Current Technologies (REACT) Report

August 2021

Homeland Security

N O T I C E

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Technical Report Documentation Page

1. Report No.	2. Government Accession Number	3. Recipient's Catalog No.
CG-D-01-22		
4. Title and Subtitle Testing for EMC/RFI Emissions of LED Navigation Lights and Susceptibility Levels for Marine Radionavigation Receivers Rapid Evaluation and Analysis of Current Technologies (REACT) Report		5. Report Date August 2021 6. Performing Organization Code Project No. 999119
7. Author(s) Mark D. Wiggins, Joseph D. Hersey		8. Performing Report No. RDC UDI # 1914
9. Performing Organization Name and Address . Coast Guard Research and Development Center 1 Chelsea Street New London, CT 06320		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Organization Name and Address COMMANDANT (CG-672) US COAST GUARD STOP 7710 2703 MARTIN LUTHER KING JR AVE SE WASHINGTON, DC 20593		13. Type of Report & Period Covered Final 14. Sponsoring Agency Code Commandant (CG-672) US Coast Guard Stop 7710 Washington, DC 20593
15. Supplementary Notes The RDC's technical point of contact is Mr. Mark Wiggins at (860) 271-2620 or by email at Mark.D.Wiggins@uscg.mil.		

16. Abstract (MAXIMUM 200 WORDS)

USCG Safety Alert 13-18 warns of light-emitting-diodes (LEDs) interfering with shipboard Very High Frequency (VHF) and Automatic Information System (AIS) signals despite adhering to existing lighting standards which generally either exempt or are not otherwise intended for specific maritime applications. This report documents the results of preliminary electromagnetic interference (EMI) testing on a set of commercially available LEDs. The results confirm that certain LED designs installed in close proximity to communications equipment can generate significant levels of EMI and recommends additional testing and analysis to generate a new standard for shipboard LEDs.

17. Key Words	18. Distribution Statement		
LED, EMI, EMC, RFI, Interference, RTCM	Distribution Statement A: Approved for public release; distribution is unlimited.		
19. Security Class (This Report)	20. Security Class (This Page)	21. No of Pages	22. Price
UNCLAS//Public	UNCLAS//Public	30	

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EXECUTIVE SUMMARY

In 2018, the U.S. Coast Guard (USCG) Spectrum Management and Telecommunications Policy Division (CG-672) and USCG Navigation Center (CG-NAVCEN) became aware of severe interference experienced by shipboard Very High Frequency (VHF) radios and Automatic Information System (AIS) equipment from light-emitting-diode-(LED) equipped navigation, deck, and flood lights. The problem was exacerbated if it became necessary to install lighting less than one meter from VHF antennas.

Current LED maritime electromagnetic interference (EMI) standards are too lenient and are not sufficient to protect maritime safety communication and navigation systems from interference. Due to the importance of uninterrupted VHF and AIS services for maritime safety, a new standard is necessary. To create an adequate standard, new electromagnetic compatibility (EMC) tests are needed on a variety of shipboard above-deck navigation and other LED lighting to verify calculated EMI levels and guide the development of a new standard for maritime navigation LED assemblies.

The USCG Research and Development Center (RDC) contracted IMANNA Labs in Rockledge, FL to perform testing and analysis. This included measuring reactive near-field effects on shipboard whip antennas; determining the relationship of various measurement results (peak, average, and quasi-peak detection) to VHF and AIS equipment performance; establishing specification limits for various measurement types; and determining the relationship between measured, radiated, and conducted emission results.

The effort confirmed that LED lights can be a source of interference for marine-radio and navigation equipment. Results support the need for industry to develop a standard which states the allowable level of radiated and conducted emissions for LED light sources used on marine vessels to ensure that LED lights do not inadvertently impede mariners' safety at sea.

Since the tests were limited in scope with regard to sample size, follow-on tests should include specific LEDs installed on USCG assets. Testing should focus on navigation lights rated for at least three nautical miles with a one-meter antenna separation distance. Testing should also investigate the installation issues and environmental conditions that could exacerbate the Radio Frequency Interference (RFI) effects on marine traditional VHS and advanced VHF Data Exchange System (VDES) AIS receivers. This should include field inspections of vessels reporting radio frequency or electromagnetic interference problems to identify installation issues such as shielding, bonding, grounding, and location factors that would not be quantified through additional laboratory testing.

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LIST OF ACRONYMS

AIS	Automatic Identification System
AV	Average
CISPR	Comité International Spécial des Peturbations Radioélectriques (in English, the International Special Committee on Radio Interference)
CE	Conducted Emissions
CFR	Code of Federal Regulations
CG	Coast Guard
CG-672	Spectrum Management and Telecommunications Policy Division
dB	Decibel
EMI	Electromagnetic Interference
EMC	Electromagnetic Compatibility
ft	Foot
FCC	Federal Communications Commission
GMDSS	Global Maritime Distress and Safety System
GNSS	Global Navigation and Safety Service
GPS	Global Positioning System
IEC	International Electrotechnical Commission
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union-Radio Telecommunications
IMO	International Maritime Organization
LED	Light Emitting Diode
LISN	Line Impedance Stabilization Network
m	Meter
MRCC	Maritime Rescue Coordination Centre
MHz	Megahertz
MLB	Motor Life Boat
NAVCEN	Navigation Center
PER	Packet Error Rate
QP	Quasi-Peak
R&D	Research and Development
RDC	Research and Development Center
REACT	Rapid Evaluation and Analysis of Current Technologies
RBW	Resolution Bandwidths
RE	Radiated Emissions
RF	Radio Frequency
RFI	Radio Frequency Interference
RTCA	Radio Technical Commission for Aeronautics
RTCM	Radio Technical Committee for Maritime Services
SC	Special Committee
SME	Subject Matter Expert
SOLAS	Safety of Life at Sea

LIST OF ACRONYMS (Continued)

SINAD	Signal-to-Noise and Distortion Ratio
TDMA	Time-Division Multiple Access
USCG	United States Coast Guard
VHF	Very High Frequency
VDES	VHF Data Exchange System

1 BACKGROUND – THE LED EMC SHIPBOARD SAFETY PROBLEM

In 2018, the U.S. Coast Guard (USCG) Spectrum Management and Telecommunications Policy Division (CG-672) and USCG Navigation Center (CG-NAVCEN) became aware of severe interference experienced by shipboard Very High Frequency (VHF) radios and Automatic Information System (AIS) equipment from light-emitting-diode (LED) equipped navigation, deck, and flood lights. France's maritime operators and industry experts also reported that LED interference had affected ship safety (Reference 1) and that lights compliant with the maritime Electromagnetic Compatibility (EMC) standard International Electrotechnical Commission (IEC 60945) and the international EMC lighting standard Comité International Spécial des Peturbations Radioélectriques (CISPR; English: International Special Committee on Radio Interference) 15 also caused significant interference. As a result, the US Coast Guard subsequently published Safety Alert 13-18 describing the interference created by LED navigation lights. Responses to the Safety Alert indicated the problem was widespread in the US Coast Guard fleet.

Interference from LEDs mainly manifests as lost received calls over VHF and lost AIS targets. LED interference also prevents the reception of VHF Data Exchange System (VDES) satellite downlink communications. VDES is an upgraded version of AIS, which is expected to be widely used for maritime application such as navigation, security, and ship route management. The problem is exacerbated by the necessity of installing lighting near shipboard VHF antennas where 1 meter or less separation between the antenna and LED is typical.

CG-672 requested support from the Radio Technical Commission for Maritime Services (RTCM) to quantify and resolve this issue. In 2019, RTCM established Special Committee 137 *Electromagnetic Compatibility Requirements for LED Devices and other Unintentional Emitters Located Near Shipboard Antennas* (RTCM SC-137) to address LED interference. RTCM SC-137 recognized that current maritime Electromagnetic Interference (EMI) standards for LEDs were not sufficient to protect maritime safety communications and navigation systems from interference (see Section 1.1).

To create an adequate standard, RTCM determined new EMC tests were needed on a variety of shipboard above-deck navigation and other LED lighting to verify calculated EMI levels and address a variety of other issues (Reference 3). RTCM SC-137 subsequently asked CG-672 for assistance in sponsoring EMC tests. In 2020, CG-672 requested that the U.S. Coast Guard Research and Development Center (RDC) lead testing efforts. RDC initiated a Rapid Evaluation and Analysis of Current Technologies (REACT). The purpose of the REACT was to quantify the EMI with the goal of providing sufficient information to guide the development of a new standard for maritime navigation LED assemblies.

1.1 Existing Standards

RTCM SC-137 surveyed existing relevant EMC standards and found them deficient in addressing the problem of LED interference:

- IEC 60945 *Maritime navigation and radio communication equipment and systems—General requirements—Methods of testing and required results* (Reference 4). This is the most relevant EMC standard for ships with provisions for protecting maritime VHF systems from EMI. That protection, however, assumes unintentional emitters can be separated by at least 15m from VHF antennas. This

15m constraint is based upon the Safety of Life at Sea (SOLAS) Convention Regulation 5/17, which only requires equipment installed on the bridge of a ship be EMC certified. IEC 60945 assumes VHF antennas are typically separated from the bridge by 15m, which is an impractical constraint on the majority of shipboard navigation and other LED lighting systems.

- Federal Communications Commission (FCC) 47 Code of Federal Regulations (CFR) Part 15 *Radio Frequency Devices* (Reference 5). Part 15 emission limits are based on the victim receiver antennas being adequately separated from potential interferers. The emission limits are inadequate to address the LED problem on ships. Furthermore, devices installed on ships are exempt from Part 15 emission limits.
- Radio Technical Commission for Aeronautics (RTCA) DO-160 *Environmental Conditions and Test Procedures for Airborne Equipment, Section 21 – Emission of Radio Frequency Energy* (Reference 6). DO-160 does not provide EMI protection to the maritime VHF band. The International Telecommunication Union defines the VHF maritime mobile radio band in the frequency range between 156 and 174 MHz. Protection to the aeronautical VHF band was also found inadequate to address the LED problem on board ships.
- MIL-STD-461F *Military Standard: Electromagnetic Interference Characteristics Requirements for Equipment* (Reference 7). Acceptable EMI levels for ship topside were last updated in 2007 and are inadequate to address LED VHF interference on board ships. During the IEEE & SIPI Conference in 2020, participants in the Military EMC panel indicated that the MIL-STD-461F creators advised that it was never intended to address problems caused by LEDs and that users of the standard were expected to adjust the MIL STD (Reference 7) requirements as necessary.
- CISPR 15 *Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment*. Emission limits are similar to those of FCC 47 CFR Part 15 and were found to be inadequate to address the LED problem on ships.
- IEC Generic and CISPR Product EMC standards. Standards such as IEC 61000 series, CISPR 12, CISPR 14, and CISPR 22, like FCC part 15 and CISPR 15, were never intended to protect on-board VHF receivers and were found inadequate to address the LED interference on ships.
- CISPR 25 *Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of on-board receivers* (Reference 9). This standard is intended to protect on-board receivers and is adequate, or nearly adequate, in addressing the LED interference problem on ships. However, CISPR 25 specifically excludes any application to ships >15m length. Despite these inadequacies, RTCM SC-137 has begun using CISPR 25 as a resource in developing its own standard.

Due to EMI safety risks and insufficient existing standards, RTCM SC-137 agreed that a new standard to protect marine safety communications and radio navigation systems from LED interference was necessary. To meet the goal of creating this necessary standard, RTCM requested EMC tests on a variety of shipboard above-deck navigation and other LED lighting to resolve a variety of issues (Reference 3).

1.2 Testing Lab Requirements and Lab Selection

The testing requirements included the following:

- Measurement of reactive near field effects on shipboard whip antennas.
- Comparison of various measurement results (peak, average and quasi-peak detection) with VHF and AIS equipment performance.

- Establishment of specification limits for average and quasi-peak detection.
- Comparison between measured radiated (energy escaping the equipment) and conducted (energy escaping the power cables) emission results.

Active participation in SC-137 was also needed to address and interpret unpredicted electromagnetic results of the demonstration testing.

The RDC contracted IMANNA Laboratory, Inc. in Rockledge, FL to perform testing to resolve the numerous technical questions and uncertainties necessary for RTCM SC-137 to develop a voluntary consensus maritime electromagnetic compatibility standard. IMANNA Labs was the only USCG accepted laboratory for equipment (Reference 10) and a member of RTCM SC-137.

2 TESTING OF MARITIME LED LIGHTS

2.1 Test Objectives

The goal of the demonstration test was to provide data to assess the problem with Radio Frequency Interference (RFI)/EMC between LED navigation lights and the VHF and/or AIS receivers on board marine vessels. The ultimate objective was to provide the foundational information for the standard requirements that future LED navigation lights would need to meet in order to eliminate any EMI to radio and navigation equipment installed on marine vessels. Testing would verify anecdotal evidence of LED EMI, determine the focus of further testing if interference was confirmed, and lay the foundation for modern LED EMI standards. It was not intended to be an exhaustive test in scope or effort. CG-627 would use the test results to begin to develop and augment existing standards that do not currently account for LED EMI in Coast Guard applications.

The purpose of the test was to:

- Confirm the LED EMC problem is real, resolvable, and affects both VHF less than 20 dB Signal-to-Noise and Distortion Ratio (SINAD) and AIS less than or equal to 20% Packet Error Rate (PER).
- Measure the effects of radiation emission from LEDs within the reactive near-field of both 4-foot (ft) and 8-ft antennas and deviation from traditional predicted emission curves.
- Compare average, quasi-peak, and peak measurement values of various LED emissions at a fixed distance.
- Compare radiated emission limits against International Maritime Organization (IMO)/IEC performance requirements for shipborne AIS and VHF.
- Better understand the relationship of EMC measurement bandwidth to AIS and VHF performance requirements.
- Gauge the urgency in addressing radiated emission from LEDs in the Global Positioning System (GPS) and Global Maritime Distress and Safety System (GMDSS) satellite bands (L-band).

2.2 Test Plan

The test plan was modeled after the document *Plan for a demonstration test of LEDs, VHF voice radio and AIS performed in a controlled environment* which was extracted from RTCM Paper 2019-SC137-0007

(Reference 3). Additionally, the SC-137 committee provided input to the test plan. The final test plan for this effort is shown in Table 1 below:

Table 1. Testing methodology and task descriptions.

Task No.	Task Description	Expected Output
1	Inspect actual test article and document details of findings.	• Product definitions and photographs of each article to be tested and documented. • Make, model, and serial number of each LED assembly provided to be tested and whether it is advertised as complying with IEC 60945 or other EMC standard will be recorded.
2	Verify the operational instructions for each article.	• The installation of each article for test will be verified to make sure the test set-up does not contribute to any RF emissions. • The installation and operation instructions received for each item will be retained and followed to ensure conducted emissions are performed consistent with those instructions.
3	Verify the ambient RF within the test chamber.	• Document the ambient RF levels inside the test chamber especially in the frequency range of interest and at each bandwidth for this project. • The chamber ambient conditions will be recorded for each bandwidth and frequency range for each test.
4	Measure and document the radiated and conducted RF emissions of each test article in the frequency range of interest.	• The RF emissions for each test article will be measured and recorded for Peak, Average, and Quasi-Peak measurement modes for each of three measurement bandwidths at VHF (9 kHz, 20 kHz, and 120 KHz). • Conducted emission tests will only include the CISPR-mandated measurement bandwidth of 120 kHz. L-band radiated emission tests will be performed at a bandwidth of 1 MHz in addition to the ICE 60945-specified bandwidth included in the RTCM test plan. • A Line Impedance Stabilization Network (LISN) will be in the system during the data collection process.
5	Determine the threshold level of interference for VHF radios and AIS receivers through RF susceptibility fields produced in the frequency of interest.	• The RF field emitted from each LED as received by a VHF Radio (8' Whip) or AIS receiver (4' Whip) in the test chamber will be varied through attenuators and combined with the specified evidence of interference as shown in 2019-SC137-0007 Rev5 Figure 2. • The interference level (if present) will be documented and recorded for each receiving device tested for this effort. • The dB attenuation relative to the measured interference field strength at 1 meter for each LED will be recorded at each setback distance for each Whip antenna.

Table 1. Testing methodology and task descriptions (Cont'd).

Task No.	Task Description	Expected Output
6	Verify whether the RF levels produced by the test articles affect the VHS quality of operation.	• Using the emissions and susceptibility information obtained in Tasks 4 and 5, the interference potential of each LED light assembly will be documented by placing the LED assembly at varying distances from the receivers to determine separation distance criticality for each of the LED light assemblies tested under this effort. • The Reduction in VHF receiver maximum useable sensitivity at separation of VHF antenna at 1/3, 2/3, 1, 2, and 3 meters will be recorded along with effects on the squelch control for the VHF receivers. The dB attenuation relative to the measured interference field strength at 1 meter for each LED will be recorded at each setback distance for the 8' Whip antenna. The data will be recorded and compared to the data documented in the RTCM test Plan for 20 dB SINAD.
7	Verify whether the RF levels produced by the test articles affect the AIS quality of operation.	• Using the emissions and susceptibility information obtained in Tasks 4 and 5, the interference potential of each LED light assembly will be documented by placing the LED assembly at varying distances from the receivers to determine separations distance criticality for each of the LED light assemblies tested under this effort. • Reduction in AIS receiver sensitivity at separation of AIS antenna (4' Whip) of 1/3, 2/3, 1, 2, and 3 meters will be recorded. • The data recorded will be compared to the 20% Packet error rate performance standard documented in the test plan.
8	Determine VHF Squelch at 1 meter	• The VHF quality of operation at 1 meter antenna separation distance will be determined by performing the squelch test described in §3.2.4 of RTCM 2019-SC137-0007 Rev 5. • The frequency of the measurement is the frequency determined in step 6 above. • The same measurement for squelch will be performed on a commercial handheld VHS radio. • The attenuator setting difference between the results of the test in step 6 and the squelch test in the step will be recorded.

2.3 Radiated Emissions Testing

The radiated emissions, or emissions of the LED itself, was measured according to the IEC 60945 *Maritime navigation and radio communication equipment and systems—General requirements—Methods of testing and required results* (Reference 4) with one notable exception: radiated emission tests at VHF and L-band were performed at 1 meter rather than 3 meters due to the close proximity of unintentional emitters to VHF antennas observed on maritime vessels. This better represented the USCG and general maritime use of these systems.

2.3.1 Initial Testing Setup

The initial test equipment setup and data collection presets were applied in accordance with the IEC 60945, which calls for an antenna calibration at 3 meters. Calibration of the antenna from an accredited lab is done with a separation distance of 3 meters. To adjust the test setup so that measurements could be taken at 1m separation to align better with USCG installations, the documented calibration information was entered into the spectrum analyzer, which then automatically applied default corrections for separation distance. See Figure 1 for the depiction of the initial test layout.

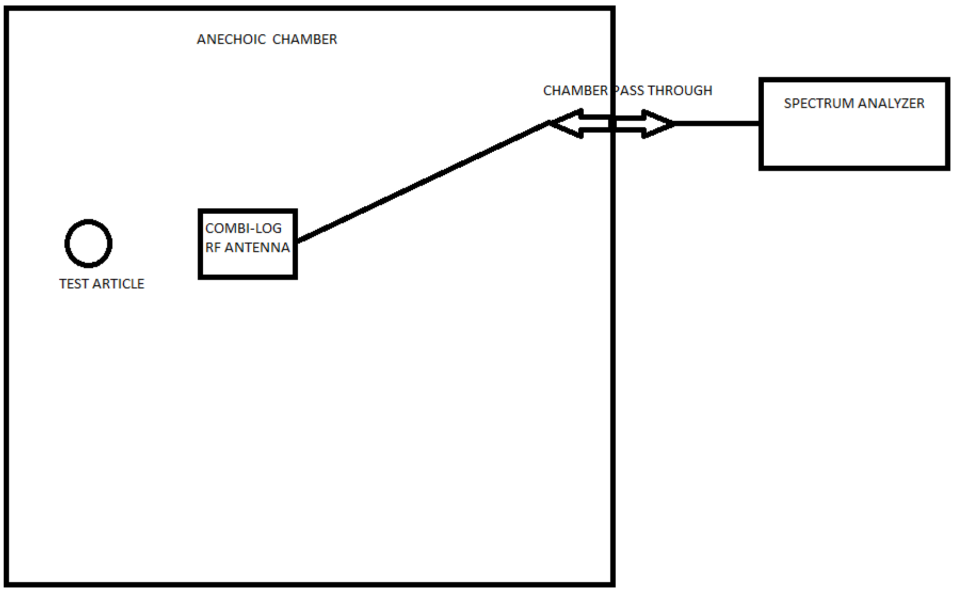

Figure 1. Equipment setup diagram for initial test.

2.3.2 Issues Identified with Initial Setup

Following the collection of data using the initial setup and distance correction factors preprogramed into the spectrum analyzer, IMANNA discovered that the recorded data were incorrect. The error led to inaccurate measurements for distance correction. Also, the spectrum analyzer used to perform IEC 60945 tests on navigation lights was pre-programmed with factory defaults to highlight pass/fail for specific IEC 60945 tests at 3m distance and 9 kHz Resolution Bandwidth (RBW) for VHF. The majority of the planned tests did not use these default parameters, therefore the pre-programmed pass/fail indicators were not valid. This further illustrates that there is not a specific standard for LED EMI, and therefore test equipment have inadequate pre-programmed standard testing parameters for LED EMI testing.

Additionally, the ambient noise floor seen on the spectrum analyzer was elevated significantly. After identification of this issue, a 20-22db preamp was installed in the signal line immediately prior to the spectrum analyzer to reduce the noise floor in the display. The refined setup is shown in Figure 2. The preamplifier used was an older model HP 8447E that had been the lab standard used to reduce the noise floor display for radiated emissions. The preamp also needed to be calibrated and corrected to 1m separation to match the antenna test configuration.

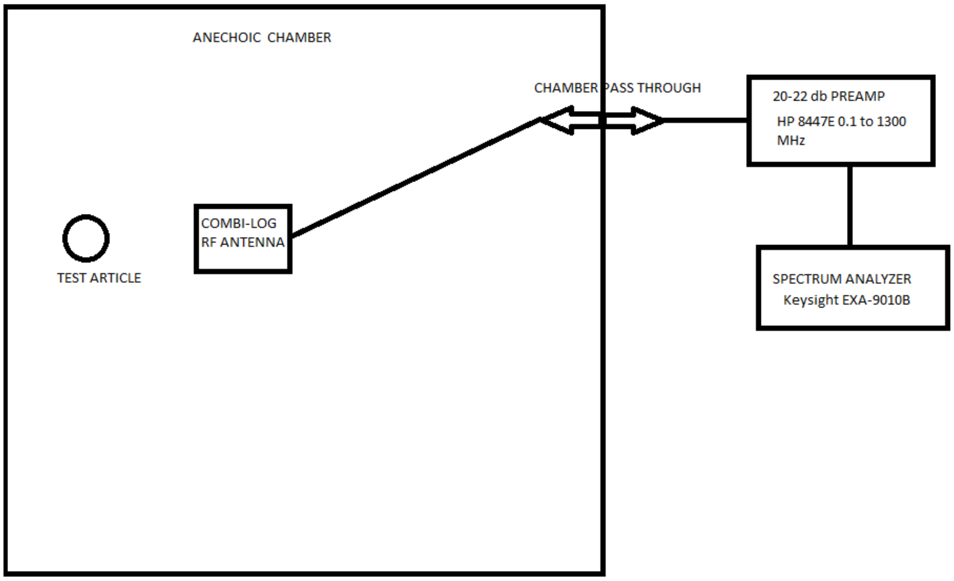

Figure 2. Equipment setup diagram for refined setup with preamplifier.

Following the addition of the 20-22db preamp and the re-programing of the spectrum analyzer software for distance correction, additional data were recorded for the lights. This data indicated a high noise floor in the test chamber. Separate measurements, however, revealed that the true noise in the chamber was not being accurately represented.

2.3.3 **Final Test Configuration**

Following the identification of the noise floor errors, a new 20db preamp was used to replace the HP 8447E preamp in the test setup. The 20db preamp also needed to be calibrated and corrected for 1m separation, as did the additional antennas used in later tests. All combined, the calibrations and corrections for the antennas and preamps resulted in significant delays from initial schedule estimates. The final test setup for the VHF band is shown in Figure 3, and the final L-Band test set-up is shown in Figure 4. The final set-up allowed for identification of the light signal at an extremely low level and comparison to an extremely low noise floor.

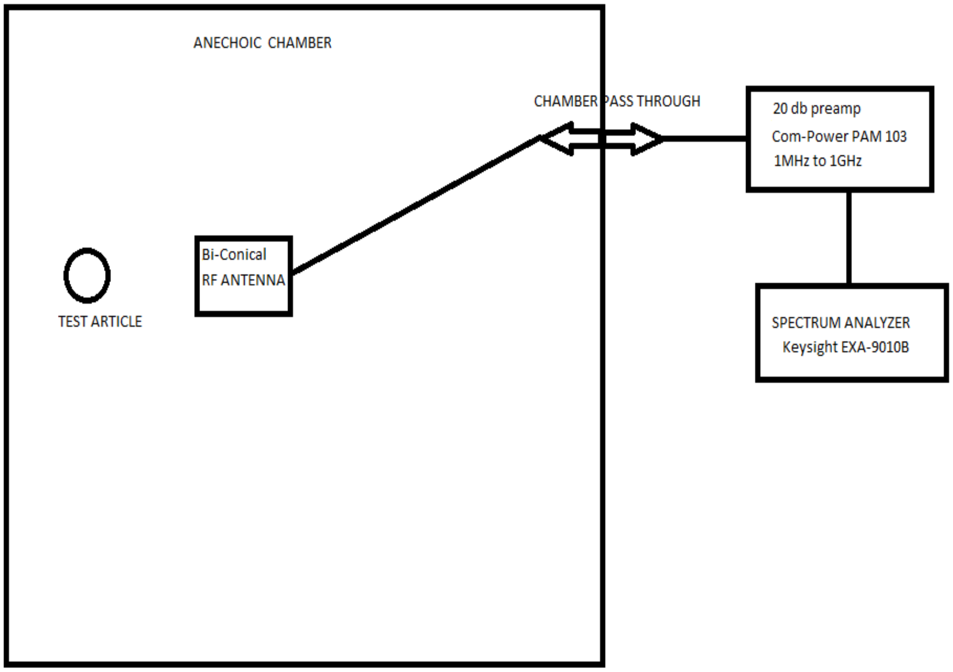

Figure 3. Final equipment setup diagram for VHF band.

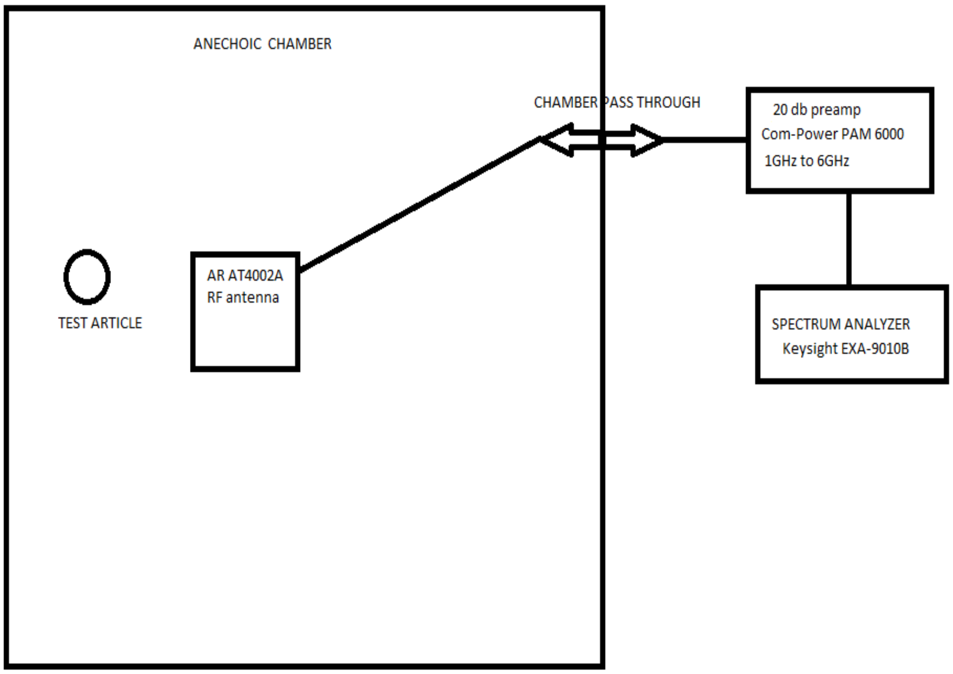

Figure 4. Final equipment setup diagram for L-Band.

Figure 5 is an example of one of the testing chamber set-ups. In this case, an LED is being tested for Radiated Emissions using a biconical antenna for VHF bands. Figure 4 shows the setup for the L-Band radiated emissions testing.

Figure 5. Radiated emissions test setup inside the chamber at IMANNA Labs.

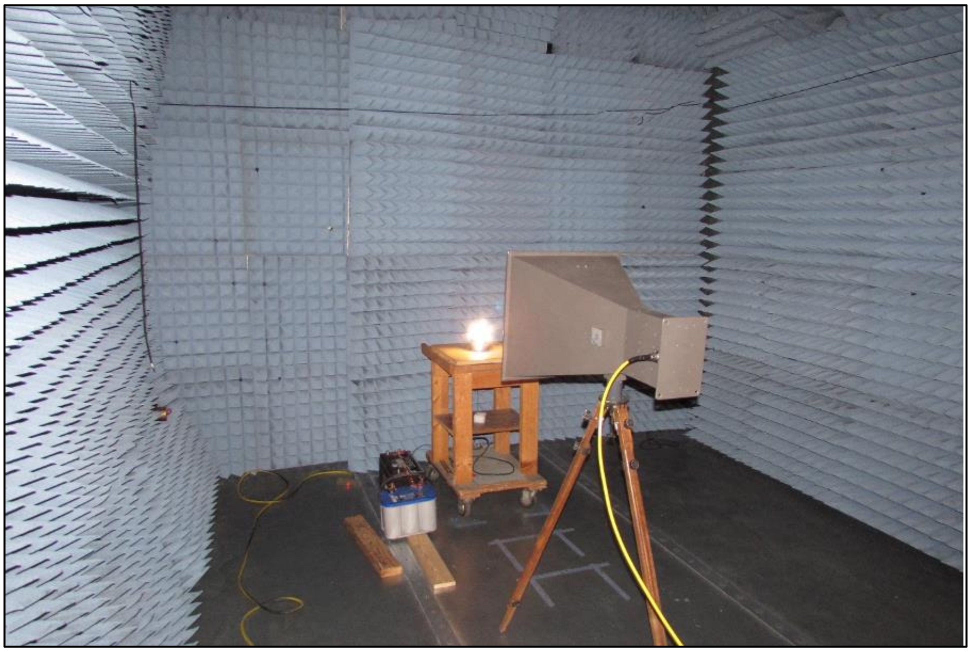

Figure 6. Radiated emissions test setup for L-Band data collection.

2.4 Conducted Emissions Testing

The conducted emissions (CE), which are unintended emissions from power or data cables of an object under test, are not fully quantified by IEC 60945 standard (Reference 4), which addresses only conducted emissions at or below 30 MHz. The standard does not address the conducted emissions measurement in the Maritime VHF Spectrum, therefore, the contribution of conducted emissions related to interference with VHF radios and AIS has been unknown. Furthermore, IEC 60945's test setup is imprecise concerning power cable layout when performing radiated emission testing. Cable layout can affect the results of radiated emission testing if the conducted emission levels are high. RTCM SC-137 is deliberating on the required use of shielded power cables when installing LED lights. CISPR 25 does apply conductive emission procedures and limits to the VHF maritime band which could be applied to ships, and could be considered by RTCM SC-137 for use in the proposed new standard.

The *DO-160 Section 21* (Reference 6) specifies measurement of conducted emissions up to 152 MHz, which is lower than the frequency range of interest for VHF radio. The test methods, however, are in line with the goal of the conducted emissions for the LED Navigation lights. Measuring the conducted emissions for the 156 to 165 MHz range would necessitate a different Line Impedance Stabilization Network (LISN) and project scope change. The conducted emissions for the LED light program is outside the scope of the DO-160 Section 21 standard. For this effort, CE tests were performed using a current probe in the 156-165 MHz band.

2.5 Radio Interference Testing

Once the LED emissions were quantified, each light was also assessed for RF interference with common VHF antennas used by the USCG for voice communications. Figure 7 is an example of the testing chamber for VHF Radio Testing. In this case, an LED assembly was tested for EMI with 4-ft (left panel) and 8-ft (right panel) VHF whip antennas. The VHF radio tests followed the VHF receiver maximum useable sensitivity in accordance with Reference 11.

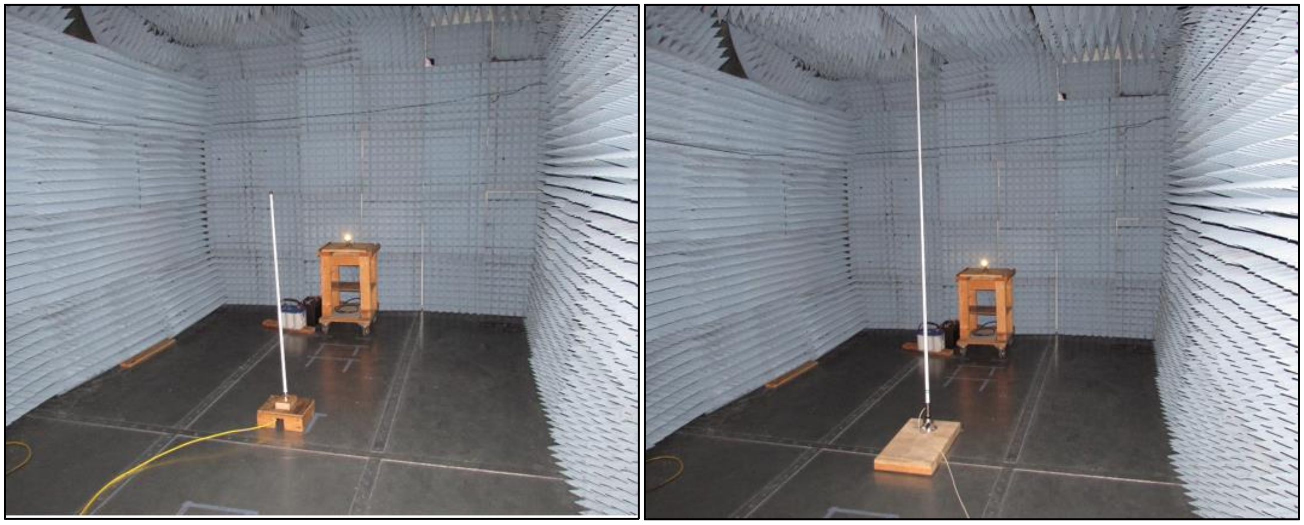

Figure 7. VHF radio frequency interference test setup inside the chamber at IMANNA Labs.

2.5.1 SINAD Checks

The signal-to-noise ratio (SNR) level for 20 dB SINAD was measured using a Marconi Instruments radio communications test set 2955B to determine the level of emissions that would affect radio performance in operations. The sensitivity of the test equipment required an additional Faraday cage and additional RF shielding of all of the cables. The only pieces of equipment that were not in the additional Faraday cage were the variable attenuators used to vary the signal incoming to the test set.

2.5.2 Squelch Tests

The squelch was set at mid-point with the LED lights off. The IMANNA technician verified that the squelch setting was above the ambient noise floor. Each of the LED lights were turned on and the technician verified that the noise floor did not rise above the initial setting of the VHF radio.

For the squelch tests, the Furuno FM8900S radio and the VHF radios listed below were tested.

a) Standard Horizon HX40.
b) Standard Horizon Submersible HX 380.
c) Standard Horizon GPS HX890.

2.6 AIS Testing

The AIS test consisted of an AIS Time-Division Multiple Access (TDMA) receiver sensitivity test in accordance with IEC 61993-2 para. 15.2, using the test signal defined by para. 10.4 with the LED electrically deactivated.

The AIS Packet Error Rate (PER) tests were performed on each of the LED lights in accordance with IEC 61993-2, paragraph 15.2. The level needed to pass the PER test was recorded and compared to the level with no LED light activated in the EMC chamber.

2.7 LED Assembly Selection

The selected LED navigation lights represent a broad coverage of manufacturers and light designs for an appropriate investigation. They were chosen as representative samples of LED assemblies used in the maritime environment which were available immediately to support the REACT effort. Supporting documentation listing the RDC-supplied test articles, including manufacturer, model number, and description is available for internal CG use upon request: RDC-Info@uscg.mil.

3 RESULTS

3.1 Summary of Radiated Emissions Results

Given the limitations on time and resources for this REACT, raw data was not collected or analyzed. Instead, screen captures were taken from the Keysight Spectrum Analyzer. Conclusions were drawn from the observed sweeps which identified the extent of the EMI issue with the LED assemblies under test. This method produced 21 individual documents, each over 60 pages long, one for each LED assembly and in total over 1,200 pages of tests results. This report summarizes the key findings of the study. Internal CG users can request the full IMANNA test results report by sending an email referencing UDI 1914 to RDC-Info@uscg.mil.

Table 2 provides a summary of the radiated emissions test results for each light for average (AV) and quasi-peak (QP) detectors. The 20 kHz results best represented RE levels that were likely to affect VHF and AIS signals. The 9 kHz results best aligned with common practice for RE testing per CISPR standards for easier comparison with other data sets. The twelve LED lights highlighted in dark green showed no appreciable emissions and would likely receive passing grades under any proposed new RTCM standard. CISPR 25's radiated emissions limit is 15 dB µV/m average. Should RTCM adopt the same standard, the two lights shown in light green (numbers 1 and 8) that showed some level of radiated emissions would likely pass emissions testing. Conversely, shades of yellow, orange, and red (light numbers 2, 3, 4, 5, 6, 7, and 10) exceeded the CISPR standard and would likely fail to meet new RTCM standards. The masthead light shown in red (number 5) had the highest radiated emissions and created significant EMI in the VHF band.

Table 2. Summary of VHF radiated emission results for lights tested at 1m.

No.	Generic Description	20 kHz RBW AV	9 kHz RBW QP
1	Masthead light, 6nm, EN14744	7 dB µV/m	4 dB µV/m
2	Masthead light, 3nm, EN14744	20 dB µV/m	15 dB µV/m
3	Sidelight, 3 nm, EN60945 (added)	25 dB µV/m	21 dB µV/m
4	Sidelight, 3 nm. EN60945 (added)	25 dB µV/m	22 dB µV/m
5	Masthead light, 6nm, UL1104	41 dB µV/m	37 dB µV/m
6	Deck light, 1389 lumens	22 dB µV/m	19 dB µV/m
7	Masthead light, 3nm, ABYC A-16	32 dB µV/m	31 dB µV/m
8	Sidelight, 3nm, EN14744	8 dB µV/m	6 dB µV/m
9	Tricolor light, 2nm, ABYC A-16	ambient	ambient
10	Masthead light, 5nm, EN14744	25 dB µV/m	20 dB µV/m
11	Masthead light, 2nm, ABYC A-16	ambient	ambient
12	Floodlight, 550 lumens	ambient	ambient
13	LED replacement bulb (non-OEM) in 2nm sidelight	ambient	ambient
14	LED replacement bulb (non-OEM) in 2nm sidelight	ambient	ambient
15	LED replacement bulb (non-OEM) in 2nm sidelight	ambient	ambient
16	Masthead light, 2nm, ABYC A-16	ambient	ambient
17	Sidelight, 2nm, A-16	ambient	ambient
18	Masthead light, 2nm, ABYC A-16	ambient	ambient
19	Masthead light, 2nm, Unknown	ambient	ambient
20	Sidelight, 2nm, ISO 19009	ambient	ambient
21	Masthead light, 2nm, ABYC A-16	ambient	Ambient

3.2 Effect of Resolution Bandwidth on VHF Emission Measurements

One of the greatest challenges RTCM SC-137 had was in establishing a VHF radiated emission limit based upon IMO and IEC's VHF radio and AIS performance standard while using CISPR's recognized measurement resolution bandwidths (RBWs) of either 9 kHz or 120 kHz. The RBW defines the bandwidth of the intermediate frequency filter in a heterodyne receiver, and it controls the frequency resolution of the resulting spectrum. The smaller the RBW, the higher the spectral resolution, which means more peaks of frequencies are shown and distinguishable. If the resolution bandwidth is too broad, two frequencies can easily be combined into one and it can be difficult to tell them apart. (Reference 13*)*. The necessary bandwidths for VHF and AIS, upon which equipment performance standards are based, are 16 kHz and 18 kHz respectively.

RTCM SC-137 initially assumed RF noise across bandwidths would follow a Gaussian curve, allowing RF noise effects to be predicted at different bandwidths by using 10 log of the bandwidth ratio. 20 log of the bandwidth ratio was later proposed as better reflecting the type of RF noise commonly experienced. LED EMC tests addressing this matter were performed using three measurement RBWs: the two CISPR-standard bandwidths 9 kHz and 120 kHz, and 20 kHz reflecting the necessary bandwidths for VHF and AIS.

Figure 8 summarizes results for the 9 LEDs with observable EMI, along with comparisons for both 10 log and 20 log assumptions. The results were unexpected; while the average of the 20 to 9 kHz measurements (blue bars in Figure 8) better correlated with a 20 log model and the average of the 20 to 120 kHz measurements (orange bars) better correlated with the 10 log model, therefore neither logarithmic method could be reliably applied.

In addition, noise received with a 120 kHz RBW better correlated with that received with a 20 kHz RBW than did 9 kHz. The 9 kHz RBW measurement appeared to miss much of the noise the VHF radio and AIS were seeing. Therefore, a 120 kHz RBW may be a better choice than 9 kHz as the measurement bandwidth used in RTCM SC-137's standard (Reference 14).

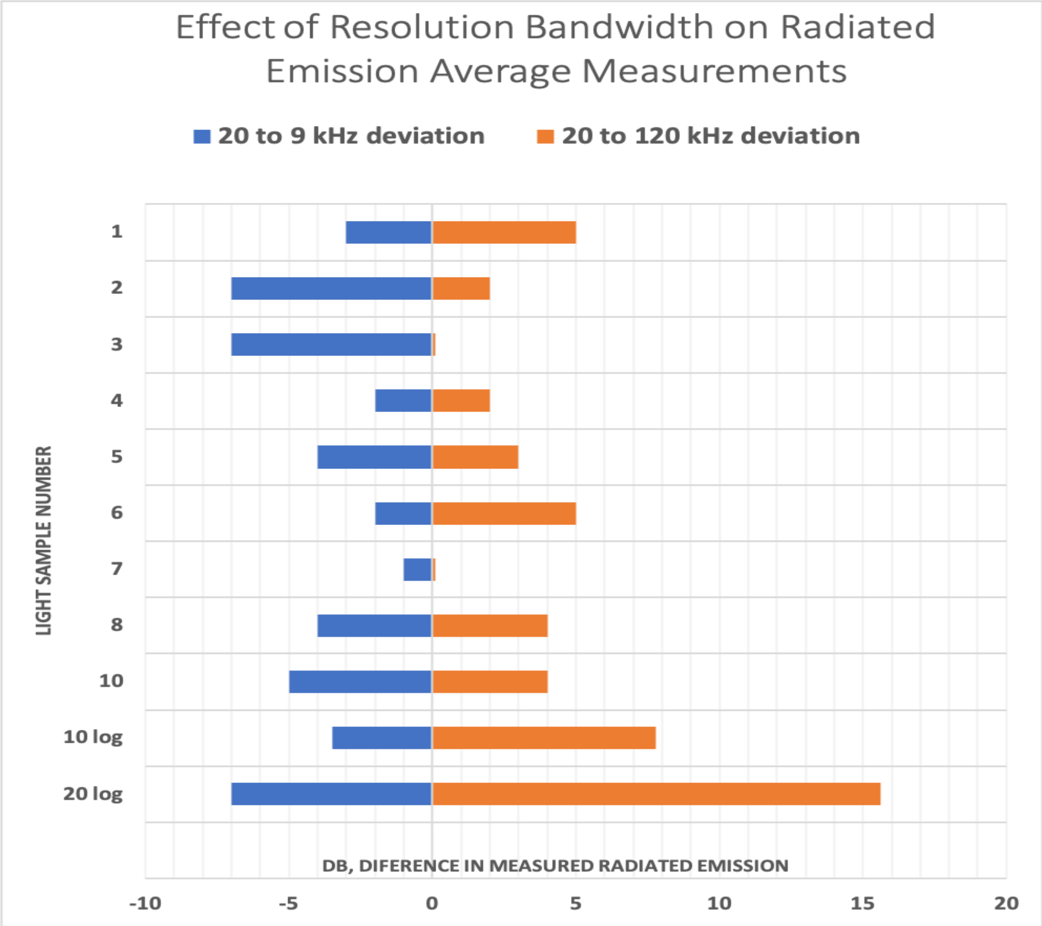

Figure 8. Effect of resolution bandwidth on radiated emission average measurements.

3.3 Effect of VHF Conducted Emission on Radiated Emission Results

CE test results are compared with radiated emissions (RE) results in Figure 9 below. Only the LEDs with observable emissions are shown. The CE results are represented in orange with the scale on the right, and the RE results are shown in blue with the scale on the left. The CISPR 25 Class 5 CE limit of -16 dB µA is shown as a horizontal orange line. CISPR 25's RE limit is 15 dB µV/m.

Conducted emissions and radiated emissions results did not always correlate. This was especially true for light sample number 8, an IEC 60945-compliant 3nm sidelight. Its radiated emission was within CISPR 25's limit, yet exceeded its conducted emission limit by about 11 dB. Light number 7 showed a different CE issue. Both radiated and conducted emissions exceeded CISPR limits. More importantly, it was found that AIS and VHF installation tests were affected by the cable layout of the LED assembly. This would likely result in significantly different CE depending on the test setup and EMI depending on how the light is installed on a vessel. These results show the need to include VHF conducted emission testing in the RTCM SC-137 standard.

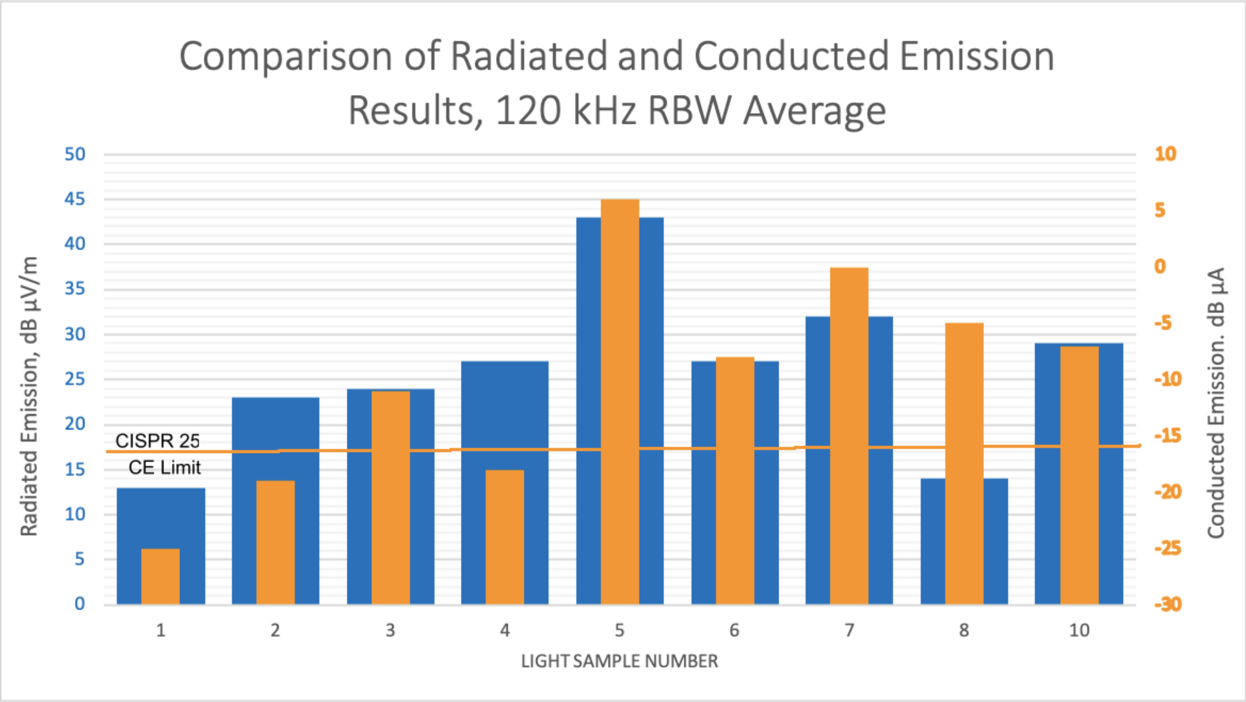

Figure 9. Comparison of radiated and conducted emission results – 120kHz RBW average.

3.4 Comparing RBW effect on Average, Peak and Quasi-Peak detectors

One of the purposes of the LED EMC tests was to compare results using the three different CISPR-recognized emission detectors: average (AV), peak (PK), and quasi-peak (QP). Average detectors are understood to be a more accurate means for measuring broadband emissions, while peak or quasi-peak detectors are understood to more accurately measure narrowband emissions. CISPR 25 specifies a 20 dB increase of peak radiated emission limits over average radiated emission limits, and 7 dB for quasi-peak over average limits.

The chart in Figure 10 summarizes VHF radiated emission test results from the nine sample LEDs found to emit interference. Measurements were taken using average and peak detectors at three resolution bandwidths (RBWs): 9 kHz, 20 kHz and 120 kHz. Quasi-peak measurements were added at 9 kHz RBW.

In general, differences between average, quasi-peak and peak results were smaller than expected. In light sample numbers 1 and 6, quasi-peak was one dB less than average, and for light sample number 3, peak was one dB less than quasi-peak. The greatest difference between average and peak measured was seven dB from light sample number 3.

For the lights tested, quasi-peak measurements were normally within a dB of average measurements, meaning there appeared to be no special advantage in using a peak detector. This is significant because quasi-peak tests take considerably longer then peak or average test runs. If these lights had been tested using CISPR 25 limits, the average limit alone would have been sufficient (Reference 17). By CISPR standards, many lights would fail the average limit but pass a peak limit. Therefore, future testing should be focused on average radiated emission limits to take a conservative stance on EMI issues.

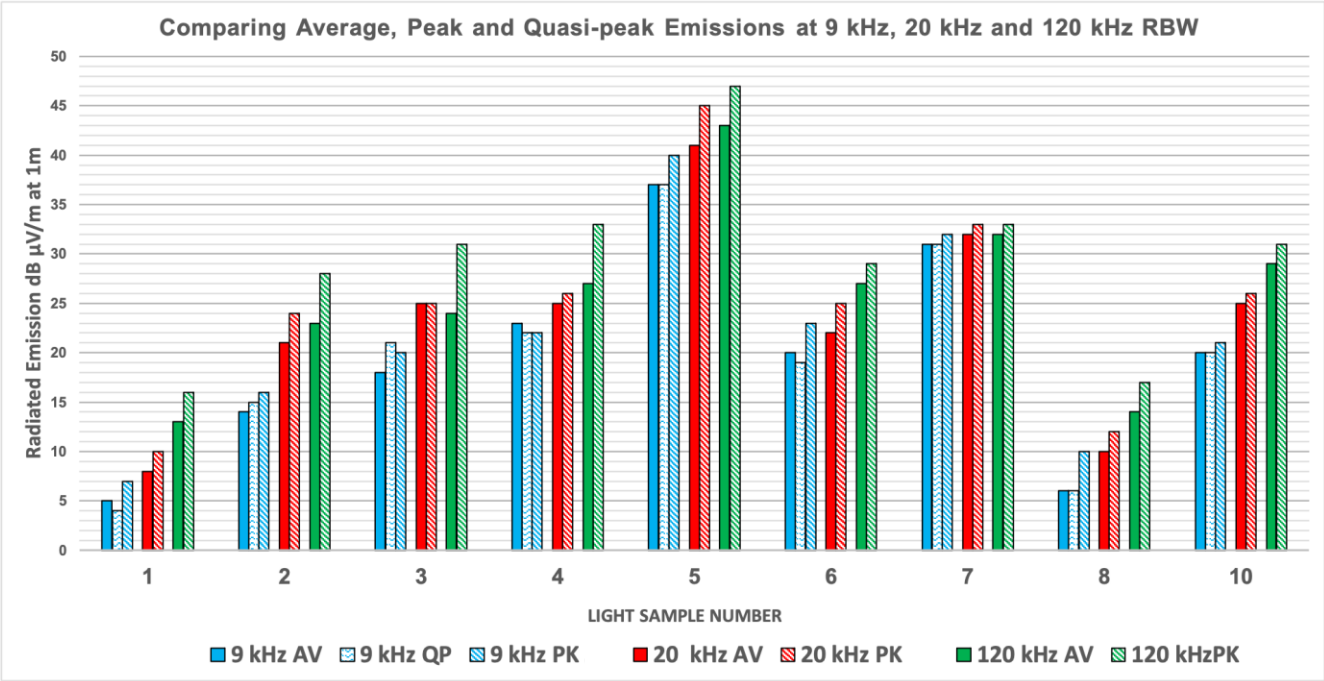

Figure 10. Comparing average, peak and quasi-peak emissions at 9 kHz, 20 kHz, and 120 kHz RBW.

3.5 VHF and AIS Installation EMC Test Results

VHF and AIS installation tests were undertaken with two purposes:

- To validate predicted interference protection criteria (i.e., what level of interfering field strength actually degrades the performance of installed VHF radio and AIS systems).
- To measure the effect of an interfering source when placed at various distances within the reactive near-field of a victim antenna.

To accomplish these objectives, the radiated emissions from the light test samples were measured at 1m distance at the operating frequencies of both VHF radio (156.75 MHz) and AIS (161.975 and 161.025 MHz) using an average detector and a resolution bandwidth of both 20 kHz (representative of VHF/AIS frequencies but not an existing RBW standard) and 120 kHz (CISPR standard and proposed RTCM protocol). Receiver sensitivity was measured for the following: a VHF radio using a 4-ft whip, a VHF radio using an 8-ft whip, and an AIS using a 4-ft whip. Receiver sensitivity was measured in accordance with the relevant IEC receiver test standard. Each LED test sample was activated at distances of 3m, 2m, 1m, 2/3 m and 1/3 m from the receiver whip antenna.

Table 3 shows that for VHF, interference increased as a noisy LED was placed closer to a 4-ft whip antenna, even as close as a 1/3 m from the antenna. In light sample number five for example, interference from that light increased by 2 dB when the light was moved from one meter to 2/3 m from the antenna, and then increased another 3 dB when moved from 2/3 m to 1/3 m from the antenna. The same was not true for an 8-foot antenna. Maximum susceptibility appeared to occur 1m from the antenna. Interference from light sample number 5 actually decreased by 5 dB when the light was moved within 2/3 m of the antenna, and decreased further by another 4 dB when moved to within 1/3 m of the antenna.

Table 3. VHF radio installation SINAD test (4-ft and 8-ft whip antennas).

Light Sample Number	3 Meter Antenna Setback		2 Meter Antenna Setback		1 Meter Antenna Setback		2/3 Meter Antenna Setback		1/3 Meter Antenna Setback	
	Power in dBm over Ambient Conditions									
	4' WHIP	8' WHIP	4' WHIP	8' WHIP	4' WHIP	8' WHIP	4' WHIP	8' WHIP	4' WHIP	8' WHIP
1	2	0	1	0	0	0	0	0	1	0
2	2	1	2	2	4	2	5	3	8	3
3	6.5	2	7	3	10	5	11	6	12	6
4	7	4	3	1	3	3	7	2	11	2
5	36.5	25.5	32.5	38.5	43.5	39.5	45.5	34.5	48.5	30.5
6	9	5	6	1	7	1	12	2	16	2
7	9.5	8.5	8.5	7.5	8.5	7.5	10.5	8.5	10.5	8.5
8	2	2	2	1	3	1	3	4	4	4
10	7	10	6	1	4	10	11	13	19	14

Table **4** shows that AIS interference followed similar trends to VHF test results using the 4-ft whip, in that measured effects were greater on average at closer setback distances. However, the trend was somewhat inconsistent. For light sample number six, the observed interference actually decreased as the distance decreased from 3m to 2/3 m, but then increased significantly from 2/3 m to 1/3 m.

Table 4. AIS radio installation test (4-ft whip antenna).

Light Sample Number	3 Meter Antenna Setback	2 Meter Antenna Setback	1 Meter Antenna Setback	2/3 Meter Antenna Setback	1/3 Meter Antenna Setback
	Power in dBm over Ambient Conditions				
1	4	2	2	3	3
2	3	3	5	4	5
3	2	1	2	4	4
4	1	0	2	3	3
5	17	18	23	23	21
6	4	2	1	1	5
7	4	3	3	4	4
8	1	2	2	2	2
10	2	2	5	6	10

Although test limitations resulted in data anomalies making it difficult to come to a precise conclusion, testing did appear to confirm the predicted radiated emission limit of 2 dB µV/m average at 20 kHz RBW, necessary to protect a VHF radio and AIS, as calculated in RTCM Documents 2020-SC137-0026 and 2021-SC137-0062 (Reference 19). It also shows that based upon the lights tested, a radiated emission limit of about 10 dB µV/m average at 120 kHz RBW should provide equivalent protection.

A review of emission limits necessary to protect the VHF Data Exchange System (VDES) satellite downlink described in RTCM Document 201-SC137-0062 (Reference 19) needs to also be reviewed before final recommendations are made.

3.6 GPS and GMDSS Radiated Emissions

Given the documented effects of unintended emissions in the VHF band affecting safety of life at sea, there was growing concern that the same LEDs would be affecting GPS and GDMSS systems as well. The LEDs under test were also assessed for interference in the L-band. None of the lights were found to have radiated emissions in the L-band.

4 CONCLUSIONS

Testing verified that some LED lights used in the marine environment can initiate reduced performance of safety equipment on marine vessels. The testing represents the first major step in quantifying the EMI issues and informing new RTCM standards for maritime LED assemblies.

In the VHF bands of interest, of the 21 lights tested:

- Six showed significant interference.
- Three showed marginal interference.
- Twelve showed no detectable emissions.

Eight of the nine LEDs with observed EMI would most likely fail any proposed new emission limits. The remaining assembly might also fail as a result of specific limits added to protect VDES. None of the lights tested showed measurable emissions in the L-band, indicating that GPS systems are not likely to be affected by use of LED assemblies even in close proximity to GPS receivers.

The tests were also instrumental in helping to determine:

- Necessary limits to protect VHF radios and AIS from interference,
- Appropriate resolution bandwidth for data collection,
- Detector types required for EMI testing, and
- The importance of including conducted emission tests in LED EMI assessments.

This effort confirmed that some LED lights are a source of interference for marine-radio and navigation equipment. The 21 LED assemblies were chosen with no intention to mimic or model any specific government or commercial ship or boat. Commercial popularity and immediate availability was a major factor in the procurement of the LEDs. Follow-up efforts should focus on LED assemblies that are currently installed in the USCG Fleet or at Small Boat Stations as well as any ships or boats that are currently in the design phase or scheduled mid-life maintenance overhauls. Results support the need within the industry to develop a standard which states the allowable level of radiated and conducted emissions for LED light sources used on marine vessels to ensure that LED lights do not inadvertently impede mariners' safety at sea.

5 RECOMMENDATIONS

This test was very limited in scope with regard to the sample size of the LEDs tested. In light of a recent test of LED assemblies installed on a USCG 47' Motor Life Boat (MLB), a concerted effort to test LEDs that are currently installed on USCG assets should be conducted. The test on one small boat demonstrated that navigation LEDs are in fact a source of RFI to crucial navigation equipment currently installed (Reference 18).

The following is a list of additional recommendations for future testing:

- Include a larger selection of LED lights, especially those navigation lights rated 3nm and above.
- Focus on test data at a 1m antenna separation.
- Study installation issues such as location, shielding, bonding, and grounding that could raise the levels of conducted interference beyond the levels measured for the LED light in the EMC chamber.
- Perform field inspections to assess the installation issues and environmental conditions that could exacerbate RFI/EMI effects on marine VHF and AIS receivers.
- Test and certify all LED lights intended for installation on marine vessels against proposed EMC emission standards from RTCM SC-137.
- Conduct an extensive review of emission limits necessary to protect the VHF Data Exchange System (VDES) satellite downlink described in Reference 19.

6 REFERENCES

1. "Ship Hermes I, in Granville. Problem in traffic separation scheme, the MRCC did not manage to contact the ship, very poor AIS reception", ITU-R 5B/498 May 2018 (France)

2. USCG Marine Safety Alert 13-18, August 15, 2018. Potential interference of VHF-FM Radio and AIS Reception. https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/CG-5PC/INV/Alerts/1318.pdf?ver=2018-08-16-091109-630

3. RTCM Document 2019-SC137-0007 Demonstration Test Plan.

4. IEC 60945 Maritime navigation and radio communication equipment and systems—General requirements—Methods of testing and required test results

5. FCC 47 CFR Part 15

6. RTCA DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

7. MIL-STD-461F

8. CISPR 15 Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment.

9. CISPR 25 Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of on-board receivers.

10. USCG Acceptable Laboratory database, https://cgmix.uscg.mil/EQLabs/EQLabsSearch.aspx

11. IEC 62238 para. 9.3.

12. IEC 61993-2 Maritime navigation and radiocommunication equipment and systems – Automatic identification systems (AIS) – Part 2: Class A shipborne equipment of the automatic identification system (AIS) – Operational and performance requirements, methods of test and required test results

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14. RTCM Document 2021-SC137-0066 9 June 2021

15. RTCM Document 2021-SC137-0067 9 June 2021

16. RTCM Document 2021-SC137-0064 9 June 2021

17. RTCM Document 2021-SC137-0061 Rev.1 9 June 2021

18. 47 MLB Service Life Extension Program (SLEP) Electromagnetic Interference (EMI) Survey Report 19May21 C5ISC-ESD-RFCB

19. RTCM Document 2021-SC137-0062 9 June 2021