



Report ITU-R M.2519-0
(11/2022)

**Protection of radio receivers
installed onboard vessels against
electromagnetic interference from
light emitting diode lighting systems
and other interfering sources**

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TABLE OF CONTENTS

	<i>Page</i>
Policy on Intellectual Property Right (IPR).....	ii
1 Introduction	4
2 Interference protection criteria for automatic identification system and VHF marine radios from interfering radiation sources	4
2.1 For the VHF marine radio receiver and the automatic identification system receiver	5
2.2 Conclusions.....	10
3 Interference protection criteria for marine global navigation satellite system receivers from interfering radiation sources	11
3.1 Adjustments for standard resolution bandwidth	12
3.2 Comparing these levels to current standards	12
4 Summary of results.....	13
4.1 Important precautions for avoiding interference when using light emitting diode lamps.....	13
4.2 Separate light emitting diode lamps from sensitive antennas.....	13
4.3 Use vertical separation wherever possible.....	14
4.4 Testing for interference following installation	14
Annex 1 Protection criteria for the VHF data exchange system.....	15
1 VHF data exchange system satellite system characteristics.....	15
2 VHF data exchange system satellite downlink budget.....	15
3 VHF data exchange system satellite downlink power flux-density and noise plus interference levels.....	16
4 Protection for the VHF data exchange system satellite downlink (refer to Recommendation ITU-R M.2092)	17
5 Relating VHF data exchange system interference protection to CISPR 25 Class 5 test levels.....	17

6	Protection for the automatic identification system	18
7	Conclusions	19
Annex 2	VHF and automatic identification system installation electromagnetic compatibility test results	20
Annex 3	Review of emission limits in the global navigation satellite service frequency bands	25

Scope

The purpose of this Report is to:

- Identify and describe the problem of electromagnetic interference (EMI) emanating from light emitting diode (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 to the problem and coordinate with appropriate standards groups.
- Develop installation guidelines for mariners to minimize degradation from EMI to sensitive radio communications and radio navigation equipment on their vessels.

Keywords

Electromagnetic interference (EMI), Light emitting diode (LED), Measurement bandwidth, Safety-related systems, Interfering sources

Abbreviations/Glossary

AIS	Automatic identification system
AV	Average
CISPR	Comité International Spécial des Perturbations Radioélectriques
EMI	Electromagnetic interference
GMDSS	Global maritime distress and safety system
GNSS	Global navigation satellite system
GPS	Global positioning system
IEC	International Electrotechnical Commission
LED	Light emitting diode
PER	Packet error rate
pfd	Power flux-density
PK	Peak
RBW	Resolution bandwidth, used in radiation measurements
RSSI	Received signal strength indication
SINAD	Signal-to-interference ratio including noise and distortion
VDES	VHF data exchange system

Related ITU-R Recommendations

- ITU-R F.699 Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to 86 GHz
- ITU-R F.1336 Reference radiation patterns of omnidirectional, sectoral and other antennas for the fixed and mobile service for use in sharing studies in the frequency range from 400 MHz to about 70 GHz
- ITU-R M.1371 Technical characteristics for an automatic identification system using time-division multiple access in the VHF maritime mobile band

- ITU-R M.1581 Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses
- ITU-R M.1902 Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) operating in the band 1 215-1 300 MHz
- ITU-R M.1903 Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) and receivers in the aeronautical radionavigation service 1 operating in the band 1 559-1 610 MHz
- ITU-R M.1905 Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) operating in the band 1 164-1 215 MHz
- ITU-R M.2092 Technical characteristics for a VHF data exchange system in the VHF maritime mobile band

1 Introduction

Maritime radiocommunication authorities have received many reports¹ of electromagnetic interference (EMI) emanating from light emitting diode (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 in close proximity to the AIS antenna and/or the VHF radio antenna. The latest bulletin² announces the final approval of a new maritime EMI standard RTCM 13700.0, 13 April 2022 which follows the analysis and test procedures recommended in this Report.

2 Interference protection criteria for automatic identification system and VHF marine radios from interfering radiation sources

Operational ‘Minimum sensitivity’ requirements for the AIS and for VHF marine radios are developed by ITU and International Electrotechnical Commission (IEC).

For the AIS, the minimum sensitivity is contained in Recommendation ITU-R M.1371 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%. Thresholds for protecting the VHF data exchange system (VDES), are derived in Annex 1, which indicates that the VDES threshold is approximately 1.3 dB stricter than for the AIS.

For the marine VHF radio, the ‘maximum useable sensitivity’ is contained in IEC 61097-3 edition 2 as “ $+6$ dB μ V 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 determined³ by:

¹ These reports were received in response to US Coast Guard Marine Safety Alert, Bulletins. Links to these bulletins are in the footnotes at the bottom of the next page Marine Safety Information Bulletin MSIB13-18 (see <https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/CG-5PC/INV/Alerts/1318.pdf?ver=2018-08-16-091109-630>).

² US Coast Guard Marine Safety Bulletin MSIB-03-22 <https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/MSIB/2022/USCG-MSIB-03-22-EMC-RTCM-13700.pdf?ver=bfEmAvRn18nyr0K-6SR9nA%3d%3d×tamp=1650662305308>

³ “Reference Data for Radio Engineers,” Fifth Edition, March 1970, Sections 21-11 to 21-12

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

Note that +6 dB μ V 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 μ V e.m.f. (the open-circuit output terminal of the 50-ohm signal source) and 1 μ V 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.

2.1 For the VHF marine radio receiver and the automatic identification system receiver

For the VHF marine radio receiver, the maximum interference plus noise ($I+N$) level, at the input of the receiver is ($-107 \text{ dBm} - 9.2 \text{ dB}$) = -116.2 dBm . Since thermal noise in the VHF marine radio receiver bandwidth of 16 kHz = $N = kTB = -131.96 \text{ dBm}$, and the maximum level of $I + N = -116.2 \text{ dBm}$, 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 ($-107 \text{ dBm} - 10 \text{ dB}$) = -117 dBm . Since thermal noise in the AIS receiver bandwidth of 18 kHz = $N = kTB = -131.4 \text{ dBm}$, and the maximum level of $I + N = -117 \text{ dBm}$, 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 . Thus, protection for the AIS will ensure protection for the VHF marine radio receiver.

2.1.1 Assessing the efficacy of the current electromagnetic interference 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 dB μ V/m = 16 μ V/m
- Separation distance for measurement: 3 m

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

- Maximum field-strength level (average): 15 dB μ V/m = 5.6 μ V/m
- Maximum field-strength level (quasi-peak): 22 dB μ V/m = 12.6 μ V/m
- Separation distance for measurement: 1 m

Note that the Comité International Spécial des Perturbations Radioélectriques (CISPR) measurement bandwidths for the VHF marine frequency band (156-162 MHz) is 120 kHz and the IEC 60945 measurement resolution bandwidth (RBW) 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, testing in a 20 kHz resolution bandwidth will more accurately assess the performance effects on both of these maritime VHF receivers. For example, it was found that changing from 120 kHz bandwidth to the IEC 60945 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 considered in § 2.1.3 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.

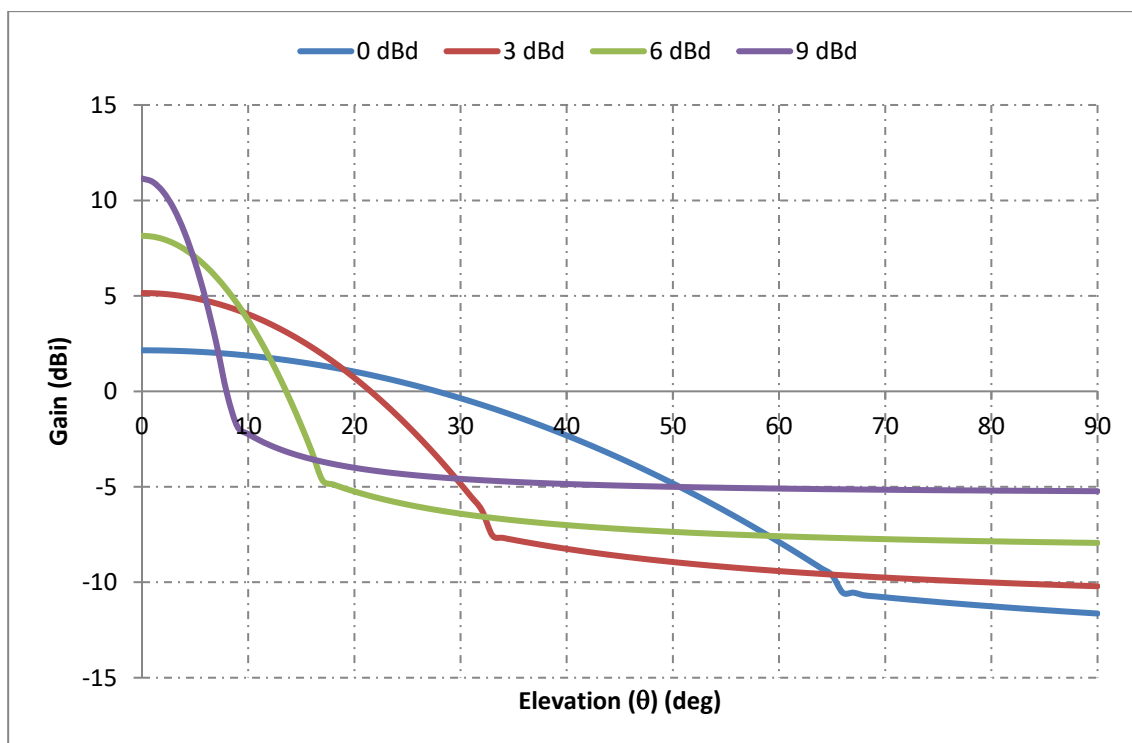
2.1.2 Information needed for this application

- 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 centre of radiation of the victim antenna. The antenna gain for this analysis may also be adjusted (see graph in Fig. 1) to account for the angular offset to the antenna radiation pattern relative to the reference elevation angle of zero degrees (0°).

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

FIGURE 1
Characteristics for vertical whip antennas based on Recommendation ITU-R F.1336⁵



NOTE: Antenna gain is defined as the gain at 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.

2.1.3 Necessary adjustments to current standards to fit this application

Adjustments to field-strength level:

- Adjustment for distance separation: $20\log_{10} D$, in metres
- 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)

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 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).
- Consideration of the measurement resolution 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, as noted in §§ 2.1.3.2 and 2.1.3.5.
- 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 1 m or even 0.3 m, as noted in Annex 2. The reactive near field for such an antenna begins at 1.5 m separation.

2.1.3.1 Field-strength determination examples for the automatic identification system

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)

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

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

$$G = 1.64 \text{ for the } 0 \text{ dBd AIS antenna}$$

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

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

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

Method 2 (according to: Wikipedia, Antenna Factor)

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

and

$$AF = E/V$$

Thus

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

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

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

2.1.3.2 Adjustments for standard resolution bandwidth

Ideally, if the spectral distributions of all interference sources could be assumed to be Gaussian, a test standard with an RBW of B_1 could be adjusted to a victim receiver with effective receiver bandwidth B_2 , by adjusting the test levels according to $L_1/L_2 = 10 \log (B_1/B_2)$ as shown below. Units are assumed to be average values (not peak or quasi-peak values). However, it has been found that this test bandwidth adjustment does not accurately represent the interference scenario in the VHF maritime environment, as previously noted in § 2.1.1, and as further evidenced by the test results reported in § 2.1.3.5.

Adjustments based on Gaussian interference spectrum:

For a 9 kHz resolution bandwidth, per IEC 60945

$$P_{dBm} = -117.16 + 10 \log (9/18) = -120.16 \text{ dBm}$$

$$P_{dBm} = V_{dB\mu V} - 107$$

$$V_{dB\mu V} \text{ (for } -120.16 \text{ dBm)} = -120.16 + 107 = -13.16 \text{ dB}\mu\text{V}$$

$$E_{dB\mu V/m} = 12.27 + (-13.16) = \mathbf{-0.89 \text{ dB}\mu\text{V/m}}$$

For a 20 kHz resolution bandwidth, for VHF maritime 25 kHz channels⁶

$$P_{dBm} = -117.16 + 10 \log (20/18) = -116.70 \text{ dBm}$$

$$P_{dBm} = V_{dB\mu V} - 107$$

$$V_{dB\mu V} \text{ (for } -116.70 \text{ dBm)} = -116.70 + 107 = -9.70 \text{ dB}\mu\text{V}$$

$$E_{dB\mu V/m} = 12.27 + (-9.70) = \mathbf{+2.57 \text{ dB}\mu\text{V/m}}$$

For a 120 kHz resolution bandwidth, per CISPR 25 Class 5

$$P_{dBm} = -117.16 + 10 \log (120/18) = -108.92 \text{ dBm}$$

$$P_{dBm} = V_{dB\mu V} - 107$$

$$V_{dB\mu V} \text{ (for } -108.92 \text{ dBm)} = -108.92 + 107 = -1.92 \text{ dB}\mu\text{V}$$

$$E_{dB\mu V/m} = 12.27 + (-1.92) = \mathbf{+10.35 \text{ dB}\mu\text{V/m}}$$

2.1.3.3 Comparing these levels to current standards

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

- Maximum field-strength level (average): +15 dB μ V/m

The minor difference (15 dB μ V/m – 10.35 dB μ V/m = 4.65 dB) between the CISPR 25 Class 5 level and the level calculated for the AIS may be attributed to the higher gain (physical size) of the typical marine antenna compared to the typical automotive antenna addressed by CISPR 25 Class 5.

- Maximum field-strength level (quasi-peak): +22 dB μ V/m
- Maximum field-strength level (peak): +35 dB μ V/m

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

- Maximum field-strength level (quasi-peak): +24 dB μ V/m

2.1.3.4 Measurements in a typical electromagnetic interference laboratory test chamber

For the 9 kHz resolution bandwidth, the ambient noise floor (kTB) is:

$$P_{dBm} \text{ (kTB for 9 kHz resolution bandwidth)} = -134.43 \text{ dBm}$$

For the test chamber:

The noise figure of the measurement system is 3.0 dB.

The antenna factor of the test antenna is 14.7 dB/m.

Therefore:

$$P_{dBm} = (\text{kTB} + \text{NF}) = -134.43 + 3 = -131.43 \text{ dBm}$$

$$V_{dB\mu V} \text{ (for } -131.43 \text{ dBm)} = -131.43 + 107 = -24.43 \text{ dB}\mu\text{V}$$

⁶ RR Appendix 18.

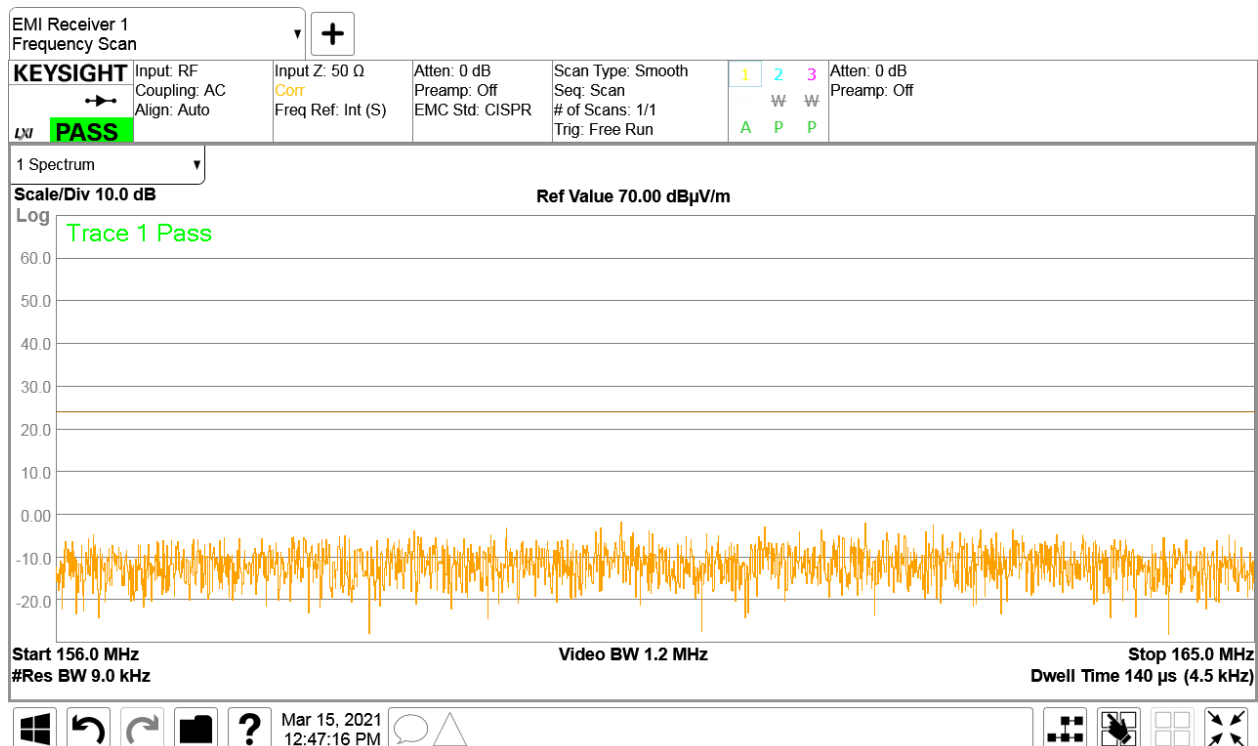
$$E_{dB\mu V/m} = 14.7 + (-24.43 \text{ dB}\mu V) = -9.73 \text{ dB}\mu V/m$$

Thus, the ambient level of the chamber, $-9.73 \text{ dB}\mu V/m$, is 8.84 dB below the test level, $-0.89 \text{ dB}\mu V/m$, which meets the 6 dB CISPR minimum requirement.

Test results from the test chamber (ambient level, average level measurement) shown in Fig. 2 are consistent with the calculated value ($-9.73 \text{ dB}\mu V/m$) shown above. Thus, it is practical to measure the levels required to protect the AIS in a typical EMI test laboratory, e.g. footnote 6.

FIGURE 2

Measurement of the ambient noise level (9 kHz resolution bandwidth, fast Fourier transform, average level) of the electromagnetic interference test chamber⁷



2.1.3.5 Results from testing numerous maritime light emitting diodes navigation lights in the electromagnetic interference laboratory test chamber

Annex 2 provides measured effects of radiation from the “active” sample LED lights on the installed victim receivers, VHF marine radio, and AIS, at various installed separation distances from 0.33 m to 3 m.

Figure 3 provides a summary of test results from testing radiation from numerous samples of marine LED lights in the EMI laboratory test chamber referred to in footnote 6. The samples were tested in the resolution bandwidths of 9 kHz, 20 kHz, and 120 kHz noted in § 2.1.3.2 above, using average, peak, and quasi-peak detectors. Only the results from the “active”⁸ samples are recorded here because the others did not radiate above the ambient noise level of Fig. 2.

Figure 4 provides a comparison of measured radiation levels as a function of resolution bandwidth. Figure 4 shows the deviations for the test samples and two additional scaling factors ($10 \log B_1/B_2$ and $20 \log B_1/B_2$) for comparison.

⁷ Sponsored by the United States Coast Guard at IMANNA Laboratory, Inc. www.imanna.com

⁸ ‘Active’ means that a switch-mode power supply is used to drive the LED light.