GATES ACOUSTIC SERVICES

R/V KILO MOANA (AGOR 26)

ACOUSTIC TRIAL RESULTS

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EXECUTIVE SUMMARY

KILO MOANA's acoustic signature was higher than previous acoustical data following a shipyard period that included diesel engine work and the replacement of one EM 122 receive array module. The levels in the EM 122 sonar operational frequency of 12 kHz were also higher than historic data. A significant problem was noted during the most recent MAC sonar evaluations that precluded successful calibration of the EM 122 sonar array.

INTRODUCTION

GATES Acoustic Services was tasked by University of New Hampshire to investigate and quantify acoustic issues that are associated with operation of the R/V KILO MOANA. This was accomplished during ship operations off Oahu, Hawaii on August 9-12, 2015.

During the at-sea test on R/V KILO MOANA the goal was to determine ship acoustic characteristics and to assess potential impacts sonar performance from numerous acoustic sources. Particular care was to be paid to evaluating acoustic noise associated with diesel engine operations. Several objectives were accomplished for this testing and are listed below:

1. The noise levels at various reference hydrophone locations were measured.

2. The controlling sources of sonar background acoustic levels were determined.

3. Propeller cavitation characteristics were assessed.

4. EM 122 Sonar performance was investigated.

5. Machinery diagnostics were conducted on several key machinery systems.

BACKGROUND

The R/V KILO MOANA is a research vessel that is equipped with several Kongsberg multibeam sonars. The primary sonar is an EM 122 1 by 2 degree, 12 kHz system. The vessel also is configured with an EM 710 shallow water system as well as various other single beam acoustic systems.

INSTRUMENTATION

In order to successfully accomplish the desired objectives, it was necessary to install a special suite of acoustic and vibration sensors and monitoring equipment. Two accelerometers were installed, one near each propeller. The installed accelerometers were the Wilcoxon 752 model with a sensitivity of 100 mV/G. In addition, data was acquired from three permanently installed reference hydrophones (ITC model 6050). These hydrophones were located at each end of the EM 122 receive array and one in the EM 710 sonar fairing/gondola. The receive sensitivity of these sensors was -157 dB relative to 1 volt re 1 uPa. This data was then processed using a QUATTRO spectrum analyzer.

TEST CONDITIONS

The following test conditions were evaluated during the underway operations on KILO MOANA:

1. A speed series from 0 to 15 knots in 1 knot increments was conducted.

2. Selected machinery was cycled on and off for diagnostic evaluations.

3. A dead-in-the-water acoustic evaluation was also conducted as part of the diagnostic testing.

4. Several survey lines were run at different speeds/machinery conditions to evaluate EM 122 sonar performance in deep (4000 meters) water.

During the acoustic test conducted on KILO MOANA, data was collected in water depths over 1000 meters. Weather conditions varied approximately from a sea-state 1 to 2.

DATA RESULTS

Sonar Self Noise

As part of the acoustic test, data was acquired from the Built In Self Test (BIST) RX NOISE LEVEL routine of the EM 122 bathymetric sonar. The data was collected during all tested run conditions. An average of 20 samples was used to make the averages, which will be presented in this report. Figure 1 presents an overall average of all sonar elements at each speed in level versus speed format. The data contained in this figure starts out relatively high with levels over 50 dB and gradually rises as vessel speed increases. These levels are considered unacceptable and the majority of the at-sea test was spent attempting to determine the cause of this situation. Figure 2 compares this data with that obtained during several earlier acoustic tests. It is clear that data acquired in 2010 and 2012 is significantly quieter than any data obtained in 2015. The level increases were noted by University of Hawaii personnel during the April 2015 at-sea measurements. It was discovered that newly configured diesel engine mounts were improperly installed and that problem was corrected prior to additional measurements made in June 2015. The June and August data are similar and it was decided to immediately enter into diagnostic test conditions to troubleshoot the cause of this problem.

The initial diagnostics were focused on diesel engine noise. Figure 3 presents EM 122 RX NOISE LEVEL BIST data acquired during single engine operation while KILO MOANA was drifting with no propulsion. This figure reveals there are no level differences in sonar data associated with any particular engine line up. Since levels from the port engines (2 and 4) have historically produced significantly higher sonar levels due to their proximity to the sonar receive array, it was immediately suspected the cause of the EM 122 noise was not associated with diesel engine issues. Confirmation of this was obtained by shutting down all of the main diesel engines and powering the ship with the Emergency Diesel Generator (EDG). Figure 4 presents EDG data compared to a typical main engine and this comparison indicates the acoustic issue is still present. A final diagnostic test was conducted by taking KILO MOANA to a "Black Ship" condition, where all vessel machinery was secured and sonar data was acquired using UPS battery power. The Black Ship data is presented in Figure 5 and indicates the noise problem on KILO MOANA is not associated with any shipboard machinery system. This clearly points to the sonar itself as the cause and source of the high noise levels and dictated a different diagnostic path.

Figure 6 presents profiles from the EM 122 RX NOISE LEVEL BIST routine at all speeds tested. This figure indicates there is little speed dependence in sonar data and it also shows a very high noise spike contained in channel 11 of the sonar array. Figure 7 presents the current data with that collected in 2012 at a vessel speed of 0 knots. The large spike is not present in channel 11 of the 2012 data, but another spike is revealed at a different location. At this point, many sonar boards were swapped and different electronic conditions were evaluated. It was discovered the 2 spikes contained in this figure were actually the same channel on their respective boards and it is believed, with a high degree of confidence, the boards had previously been swapped and were actually the same problem. During the swapping of boards, data was acquired and it was discovered that when the board with the problem was not installed, significant changes occurred to all of the sonar data. Figure 8 presents EM 122 data collected with the "problem" preamplifier board removed. It is readily seen from this figure that, not only is the spike gone, but the acoustic levels from sonar hydrophones being processed through other preamplifier board were reduced and smoothed. Figure 9 demonstrates this conclusion more clearly by comparing the two data sets with the board installed and removed. Figure 10 confirms when the preamplifier board is installed in slot 2, the spike shifts to a different location, exactly in the same place as it was in 2012.

There were no spare preamplifier boards available on KILO MOANA, so in an attempt to provide a working solution, University of Hawaii personnel modified the board to effectively eliminate the one bad channel. (This is not a recommended procedure). Figure 11 presents data with the intentional dead channel and demonstrates the data is significantly better across the entire receive array. With this modification in place, a full speed test was conducted as quickly as possible to maximize remaining ship time and that data is presented in a speed versus level format in Figure 12. The data in this figure is significantly lower than that obtained at the beginning of the at-sea test as shown in Figure 13. Consistent 6 dB level improvements were realized for this test. A final comparison was made with the current configuration to historically good data and that comparison is presented in Figure 14 against 2010 and 2012 data. While the current data is not as good as the 2010 levels, it is as good or better than that measured in 2012.

An assessment of EM 122 operation was performed by Paul Johnson and Vicki Ferrini from the MAC committee to determine if the reduced noise levels improved operational sonar performance. It was quickly determined the data quality was still very poor and not considered acceptable for future science requirements. While their report will fully document the investigation and findings, it is appropriate to provide a quick snapshot of the diagnostics and results here. Figure 15 presents a screenshot of the Beam Intensity display from the EM 122 during mapping operations. This data was collected while KILO MOANA was drifting to eliminate all vessel noise associated with propulsion and motion. There are significant data drop outs noted in this data and these drop outs were determined to be associated with the reason the sonar was not working properly. Additional diagnostics were focused on these drop outs contained in the Beam Intensity display.

It was discussed on board the vessel, that at some point, the EM 122 receive array had been replaced and that some of the sonar hydrophone modules were wired 180 degrees out of phase. That situation had been corrected by Kongsberg personnel, by inserting a phase reversal wiring harness on the phase reversed modules. Since the most recent drydock had replaced one module, it was determined that a very detailed investigation of the modules should be conducted. It is possible to reconfigure the sonar from a 1 by 2 degree system to a 1 by 4 degree system. This configuration will only use 4 of the hydrophone modules, and allow for individual module assessment as long as the 4 modules used to operate the sonar were all in a row. Figure 16 presents a Beam Intensity screenshot with the EM 122 configured in a 1 by 4 degree mode, using modules 2, 3, 4 and 5. This configuration indicated the problem was eliminated. Figure 17 presents this data for modules 3, 4, 5 and 6. The problem returned for this configuration, but at a lower impact. Figure 18 presents data from modules 4, 5, 6 and 7. The problem was back with significant impacts. Figure 19 presents data from modules 5, 6, 7 and 8 with significant impacts indicated. What these tests revealed is that any time module 6 was included in the sonar configuration, it introduced artifacts that limited sonar performance. When module 6 was in the center of the 4-module cluster, the impact was significantly greater, due to beam-forming weighting issues.

Knowing module 6 was causing the problems, an additional test was conducted. The phase reversal cable was attached to module 6 and data was then reassessed with the system in a 1 by 4 degree mode for modules 5, 6, 7 and 8. The Beam Intensity screen shot of this configuration is presented in Figure 20. It is quite clear the problem was removed by reversing the phase of module 6. A final test was conducted by reconfiguring the sonar back to a 1 by 2 degree system with all 8 hydrophone modules, and adding a phase reversal modification to module 6. The Beam Intensity screen shot of this test is presented in Figure 21. The system was completely fixed in this configuration and there was much rejoicing! (A final note regarding module 6: The authors have heard that module 6 was actually not phase reversed, but that 5 of the original modules of KILO MOANA were out of phase. When the initial modification was performed to get the entire array in phase, it caused the entire array to be 180 degrees out of phase. When a "good" module was subsequently added to the array, it caused significant beam forming issues.).

During the acoustic test on KILO MOANA, data was also acquired from the internal RX NOISE LEVEL BIST routines of the EM 710 sonar. Due to time constraints, a very limited data set was obtained. Figure 22 presents a speed versus level of this data. As seen on the figure, the levels do not change with increasing vessel speed. Figure 23 presents a speed series format of the acoustic profile across the receive array for this sonar at the three tested speeds. With a few exceptions caused by typical electronic noise, the profile is relatively flat across the EM 710 receive array and no vessel noise impacts were noted. The acoustic levels of the EM 710 are completely controlled by the electronic noise floor of the system components. This is typical of this system and was expected from evaluations on other research vessels. Based on these measurements, it is expected the EM 710 sonar will realize full performance during all KILO MOANA operational conditions. Figures 24 and 25 compare current EM 710 data to that obtained in 2012 to document that no changes or degradations have occurred with this system.

Propeller Cavitation

Cavitation measurements were made on the propellers of KILO MOANA. The measurements were made using an accelerometer that was mounted on the hull plating located near each propeller. Cavitation performance was evaluated by monitoring the high frequency band levels of this sensor as speed was slowly increased in one-knot increments during straight-line course conditions. Cavitation was determined to incept between ship speeds of 90 and100 rpm. This is considered good for this ship and is very similar to results obtained on these propellers during acoustic testing at delivery and during 2010 testing. Figures 26 and 27 document propeller vibration levels for the port and starboard propellers, respectively. Figures 28 and 29 present this data in a speed versus level format for a frequency of 12 kHz.

Platform Noise Analysis

Acoustic measurements were made from the three permanent reference hydrophones installed on KILO MOANA. Data from these sensors was collected in baseline machinery conditions for ship speeds between dead-in-the-water to 15 knots in one-knot increments. Additional data was collected from these sensors at all machinery diagnostic test conditions.

Since the main thrust of this at-sea test was to investigate the cause of sonar performance issues, once it was determined that shipboard machinery was not the problem, very limited effort and data was collected for other machinery issues

Figures 30, 31 and 32 present data from the reference hydrophones for each diesel engine operating independently. Additionally, data from the Emergency Diesel Generator is included on these figures. The data from the EM 710 hydrophone is completely controlled by electrical noise and harmonics from air handler #4 and is not relevant for diesel engine comparisons. There are still some air handling contributions on the port and starboard hydrophone figures as well. These figures are included to document the quiet conditions observed when the EDG is the only significant machinery item operating.

Rattle

During the at-sea test a significant rattle was detected in the data of the EM 122 test hydrophones. This rattle was isolated to the sewage room and an inspection discovered the source to be associated with a chain that was put in place to ensure that a valve would not be inadvertently opened. When the chain was removed, an additional rattling noise was detected in the sewage piping valve that indicated the interior of the valve was loose. The specific valve was pointed out to the engineering department for future replacement. Rags were used to temporary eliminate this rattle, but it is suspected that this rattle will be detected in EM 122 sonar data and should be fixed in a more permanent fashion.

An additional metallic rattling was periodically detected in the data of test hydrophones. It was determined this rattling noise was present during the operation of the engine room air compressors. It was deemed to not impact sonar operations.

DIESEL ENGINE VIBRATION MEASUREMENTS

It was requested that vibration measurements be made on all main diesel engine sound isolation mounts. Data was acquired above and below each mount for all four engines. For each measurement, the above and below mount data was processed to yield the mount attenuation for each location. The data from these measurements will be presented in a separate report and provided directly to University of Hawaii.

SUMMARY

The majority of all at-sea time was dedicated to conducting diagnostic efforts associated with high levels of acoustic noise and poor performance of the EM 122 sonar. The high levels of noise observed in the data of EM 122 sonar hydrophones was determined to be associated with a bad preamplifier board. The poor performance of the EM 122 sonar was determined to be caused by the installation of a new module that was not in phase with the rest of the sonar array modules. Both of these issues were corrected and acoustic levels and sonar performance were acceptable at the conclusion of the at-sea test.

CONCLUSIONS

1. The EM 122 receive array had a bad preamplifier board that was causing the entire array to have higher noise levels and to exhibit non-uniform distribution of noise characteristics.
2. The EM 122 receive array module 6 was out of phase with the rest of the sonar receive array.

3. Propeller cavitation performance was good and consistent with previous results.
4. Following a modification to the bad preamplifier board, acoustic levels of the EM 122 sonar were considered acceptable and similar to levels measured in 2012.
5. Following a temporary phase shift of module 6 to correct the phase deficiency, sonar operations were good and will allow for good science data acquisition.
6. Noise from diesel engines was determined to not be the source of excessive sonar noise.
7. A sewage room rattle was detected and should be corrected when possible.

RECOMMENDATIONS

The following recommendations are provided:

1. Replace bad sonar preamplifier board.
2. Ensure all sonar modules are in phase with each other.
3. DOCUMENT all temporary fixes to the sonar so future operations issues are easier to diagnose.
4. Correct rattle in sewage room.
5. Install a permanent acoustic monitoring system to allow for shipboard personnel to listen to reference hydrophone data and to acquire and analyze this data during real time operations.

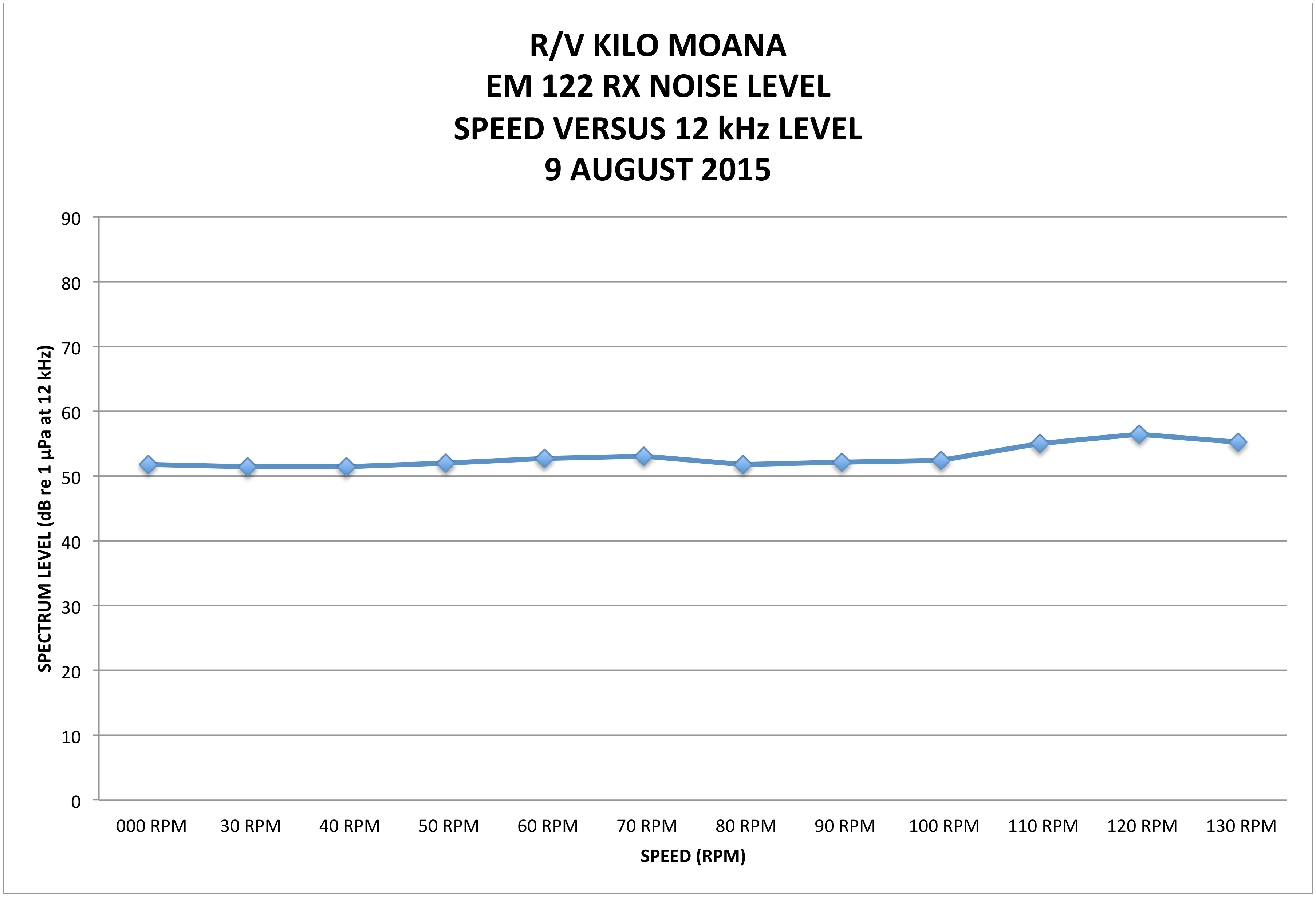

R/V KILO MOANA
EM 122 RX NOISE LEVEL
SPEED VERSUS 12 kHz LEVEL
9 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)
90
80
70
60
50
40
30
20
10
0
000 RPM
30 RPM
40 RPM
50 RPM
60 RPM
70 RPM
80 RPM
90 RPM
100 RPM
110 RPM
120 RPM
130 RPM
SPEED (RPM)

FIGURE 1

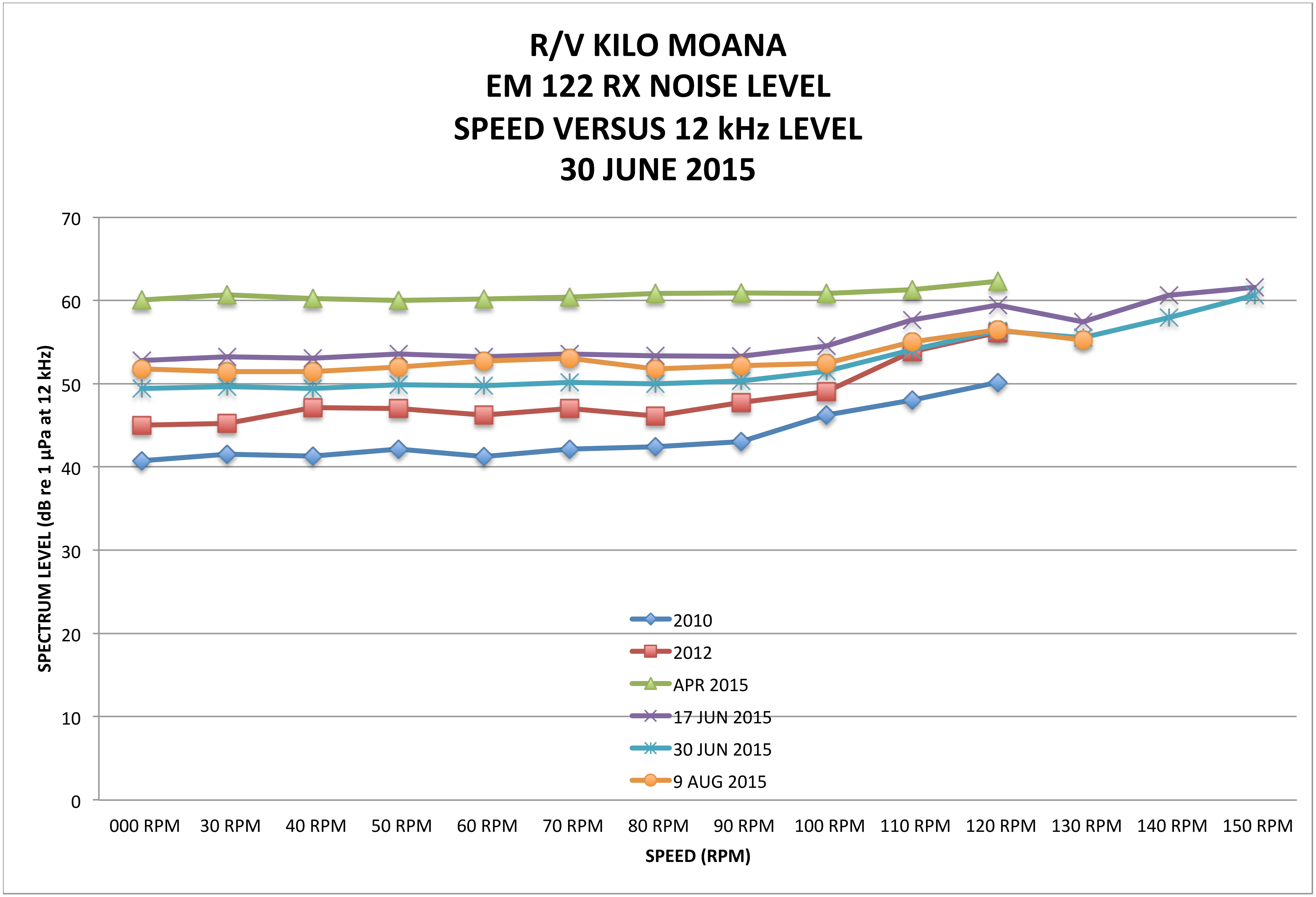

R/V KILO MOANA
EM 122 RX NOISE LEVEL
SPEED VERSUS 12 kHz LEVEL
30 JUNE 2015
SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)
70
60
50
40
30
20
10
0
2010
2012
APR 2015
17 JUN 2015
30 JUN 2015
9 AUG 2015
000 RPM
30 RPM
40 RPM
50 RPM
60 RPM
70 RPM
80 RPM
90 RPM
100 RPM
110 RPM
120 RPM
130 RPM
140 RPM
150 RPM
SPEED (RPM)

FIGURE 2

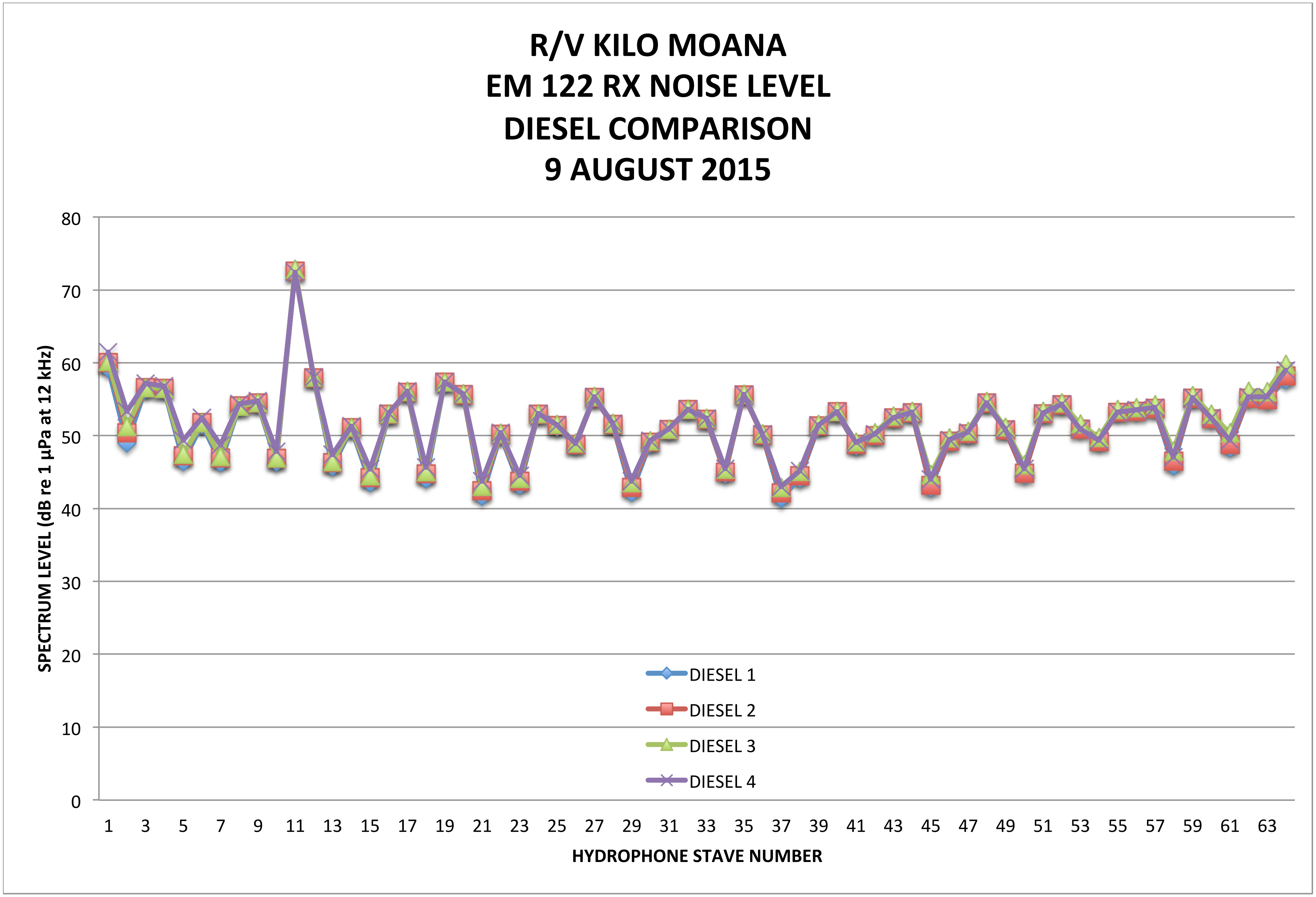

R/V KILO MOANA
EM 122 RX NOISE LEVEL
DIESEL COMPARISON
9 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)
80
70
60
50
40
30
20
10
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63
HYDROPHONE STAVE NUMBER
DIESEL 1
DIESEL 2
DIESEL 3
DIESEL 4

FIGURE 3

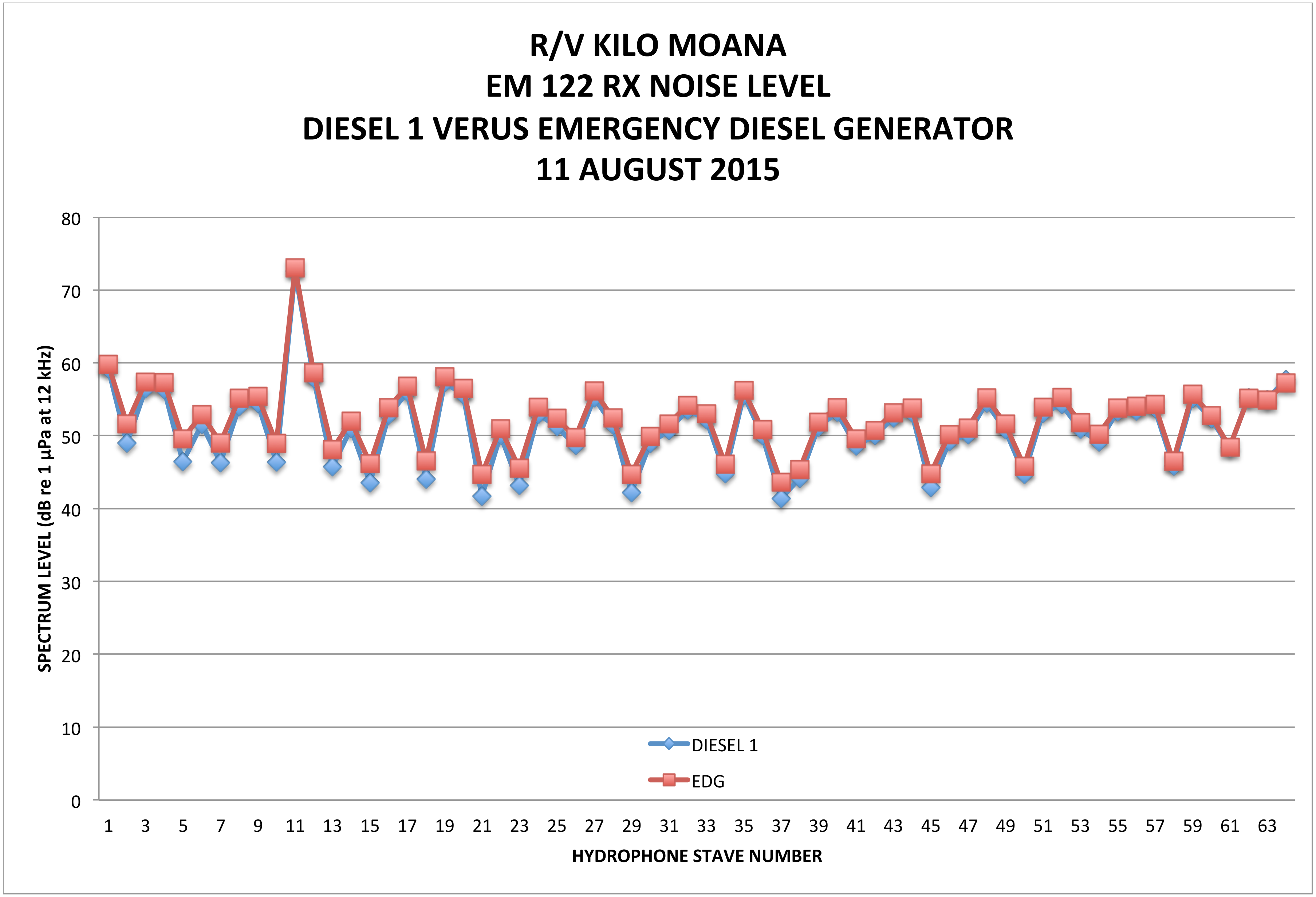

R/V KILO MOANA
EM 122 RX NOISE LEVEL
DIESEL 1 VERUS EMERGENCY DIESEL GENERATOR
11 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)
80
70
60
50
40
30
20
10
0
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
51
53
55
57
59
61
63
HYDROPHONE STAVE NUMBER
DIESEL 1
EDG

FIGURE 4

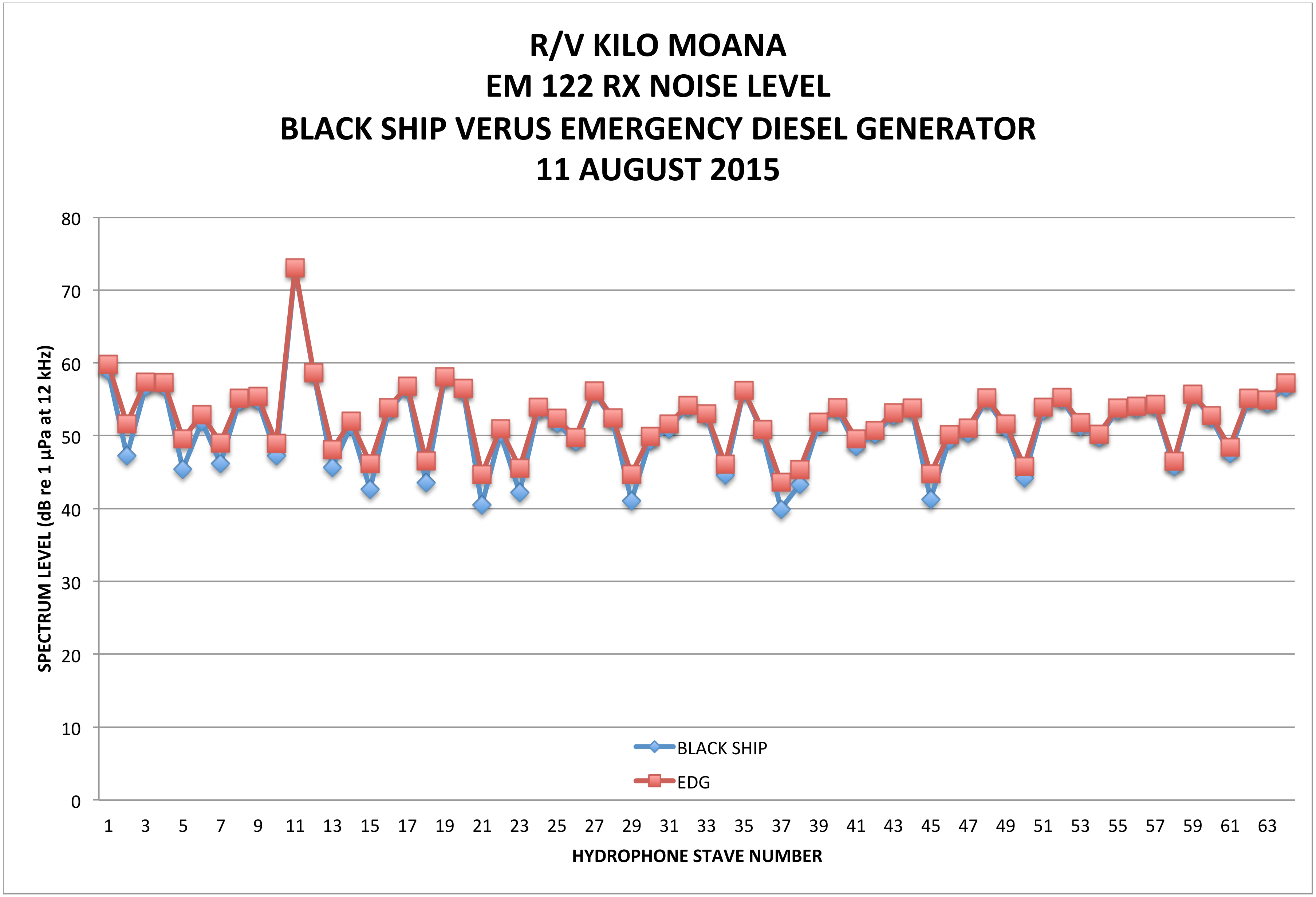

R/V KILO MOANA
EM 122 RX NOISE LEVEL
BLACK SHIP VERUS EMERGENCY DIESEL GENERATOR
11 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)
0
10
20
30
40
50
60
70
80
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
51
53
55
57
59
61
63
HYDROPHONE STAVE NUMBER
BLACK SHIP
EDG

FIGURE 5

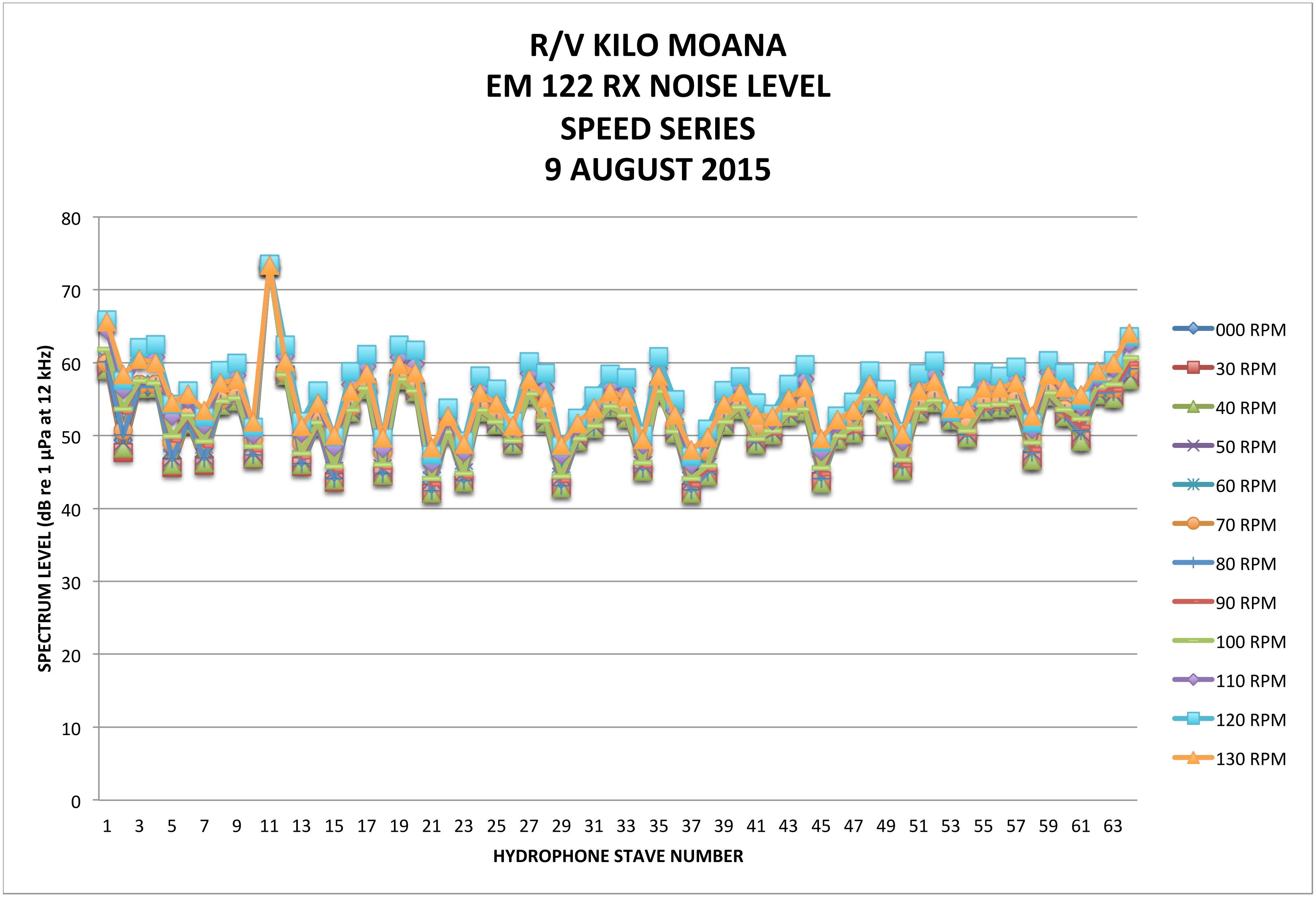

R/V KILO MOANA
EM 122 RX NOISE LEVEL
SPEED SERIES
9 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)
HYDROPHONE STAVE NUMBER
000 RPM
30 RPM
40 RPM
50 RPM
60 RPM
70 RPM
80 RPM
90 RPM
100 RPM
110 RPM
120 RPM
130 RPM

FIGURE 6

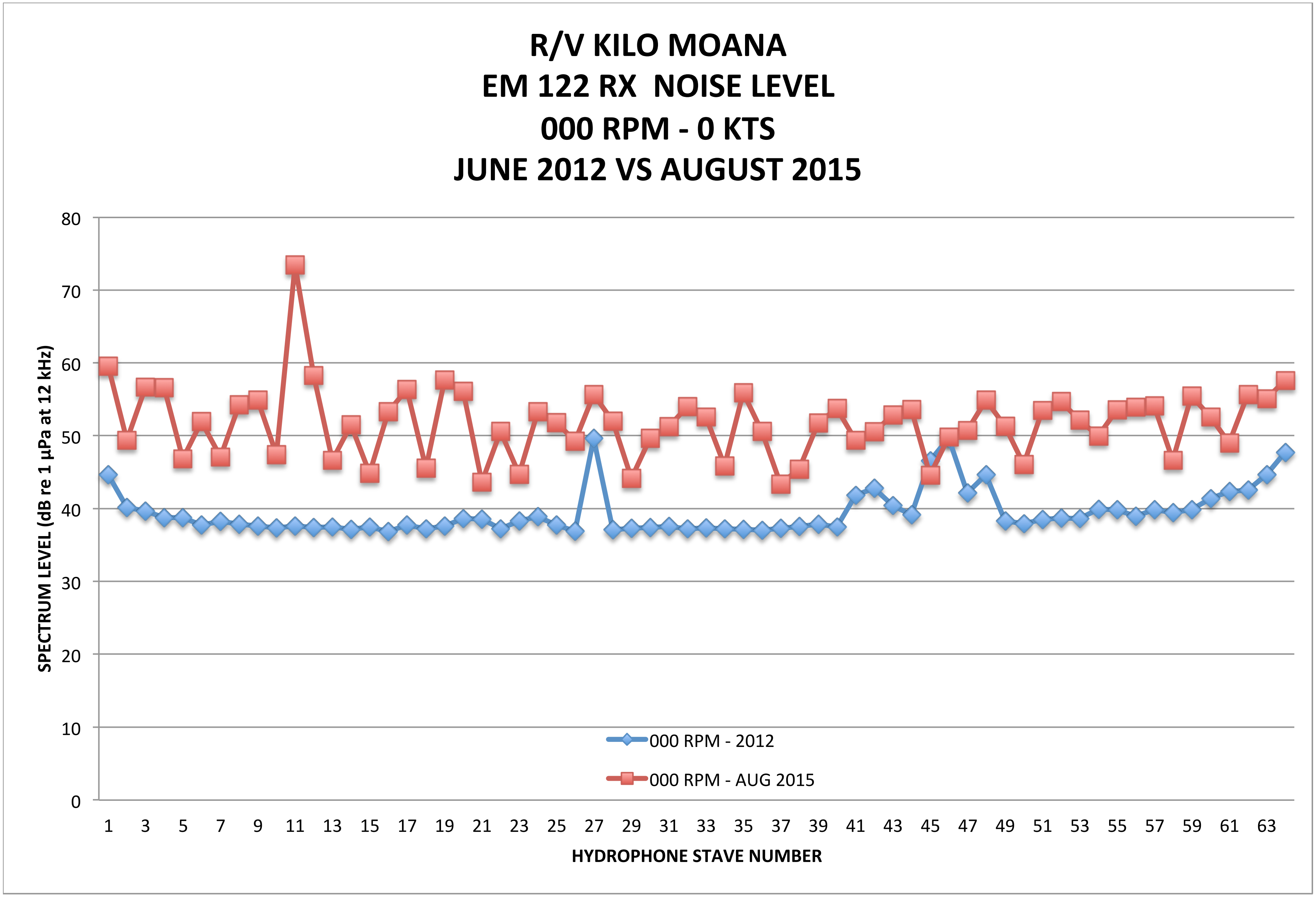

R/V KILO MOANA
EM 122 RX NOISE LEVEL
000 RPM - 0 KTS
JUNE 2012 VS AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)
HYDROPHONE STAVE NUMBER
000 RPM - 2012
000 RPM - AUG 2015
0
10
20
30
40
50
60
70
80
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
51
53
55
57
59
61
63

FIGURE 7

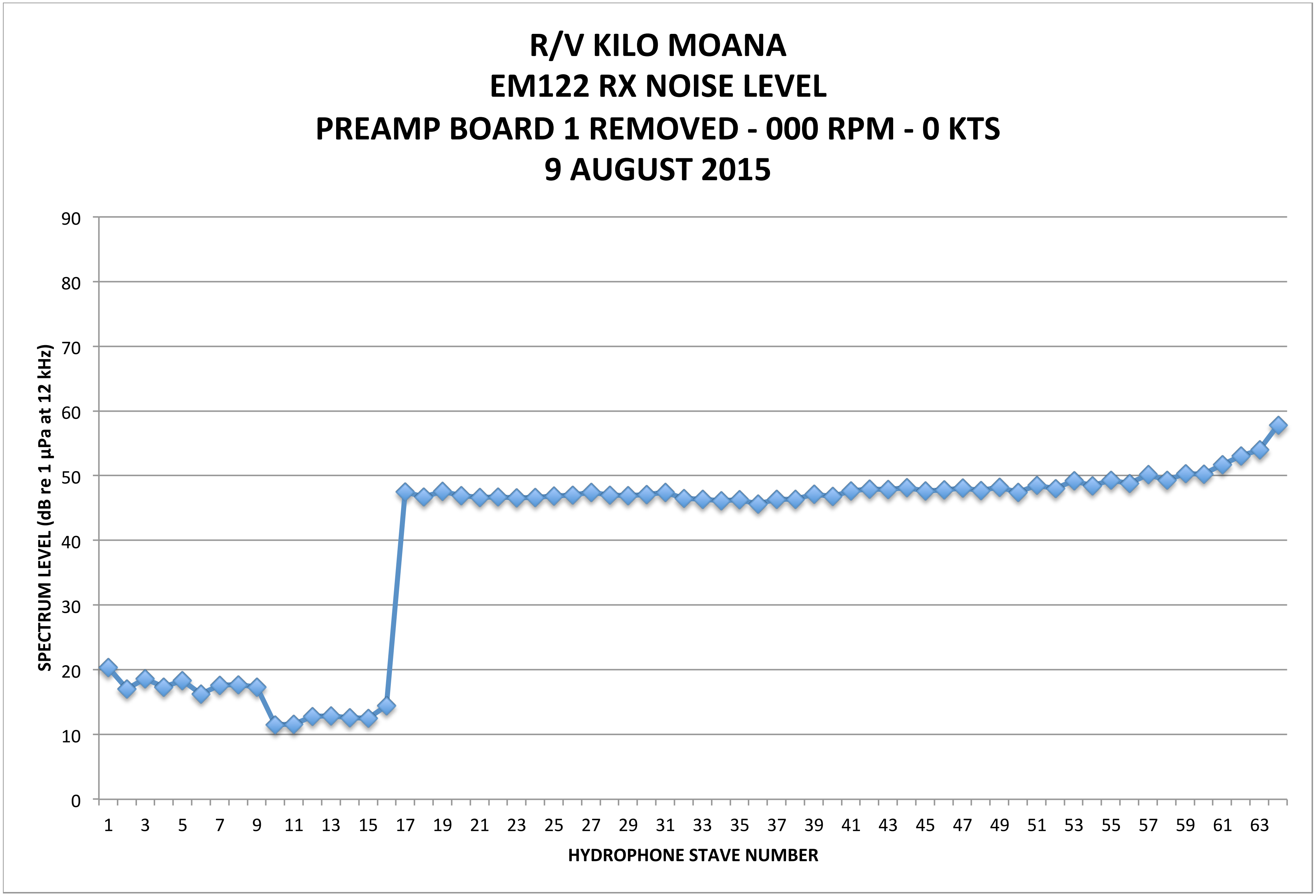

R/V KILO MOANA
EM122 RX NOISE LEVEL
PREAMP BOARD 1 REMOVED - 000 RPM - 0 KTS
9 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)
0
10
20
30
40
50
60
70
80
90
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
51
53
55
57
59
61
63
HYDROPHONE STAVE NUMBER

FIGURE 8

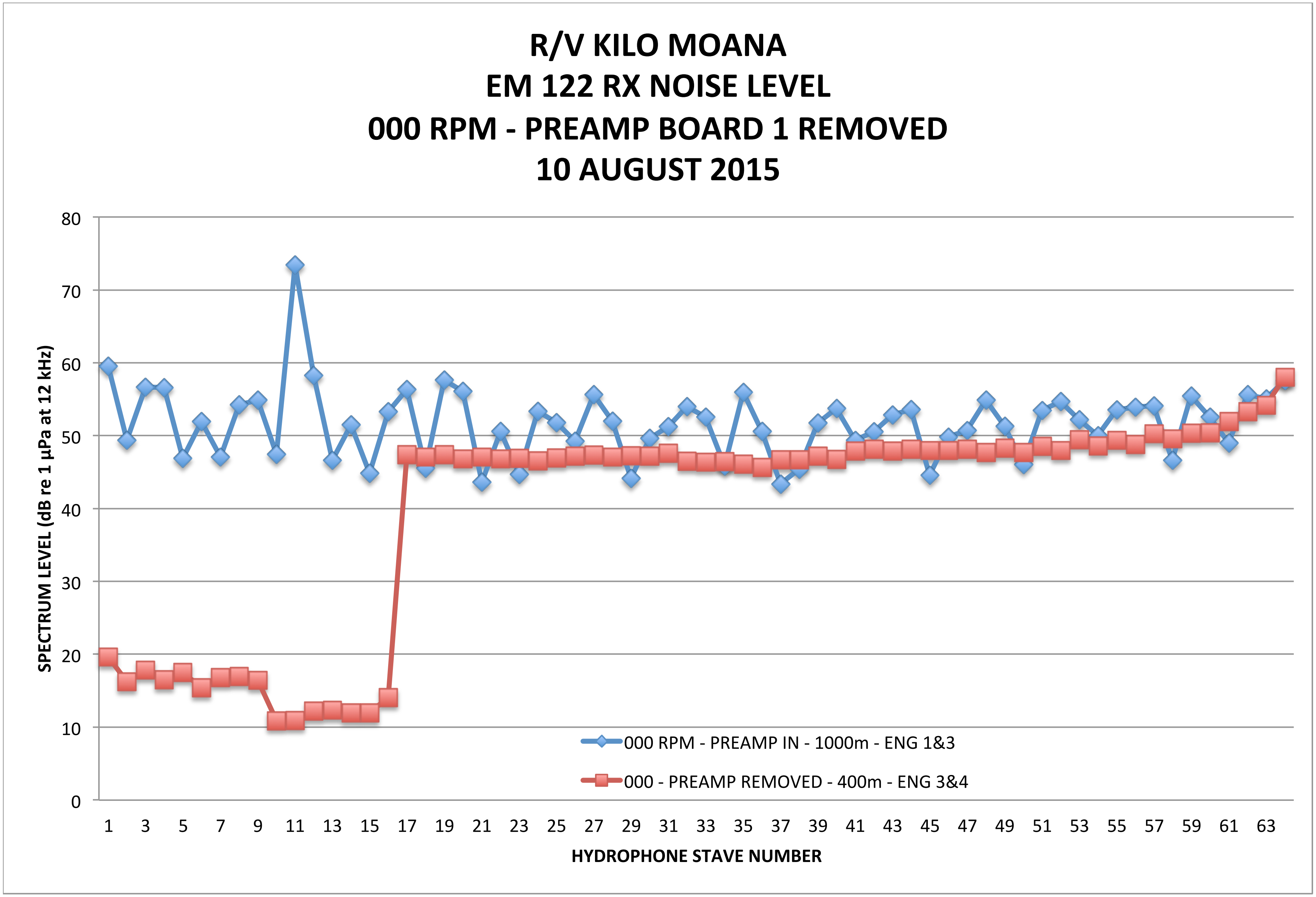

R/V KILO MOANA
EM 122 RX NOISE LEVEL
000 RPM - PREAMP BOARD 1 REMOVED
10 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)
80
70
60
50
40
30
20
10
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63
HYDROPHONE STAVE NUMBER
000 RPM - PREAMP IN - 1000m - ENG 1&3
000 - PREAMP REMOVED - 400m - ENG 3&4

FIGURE 9

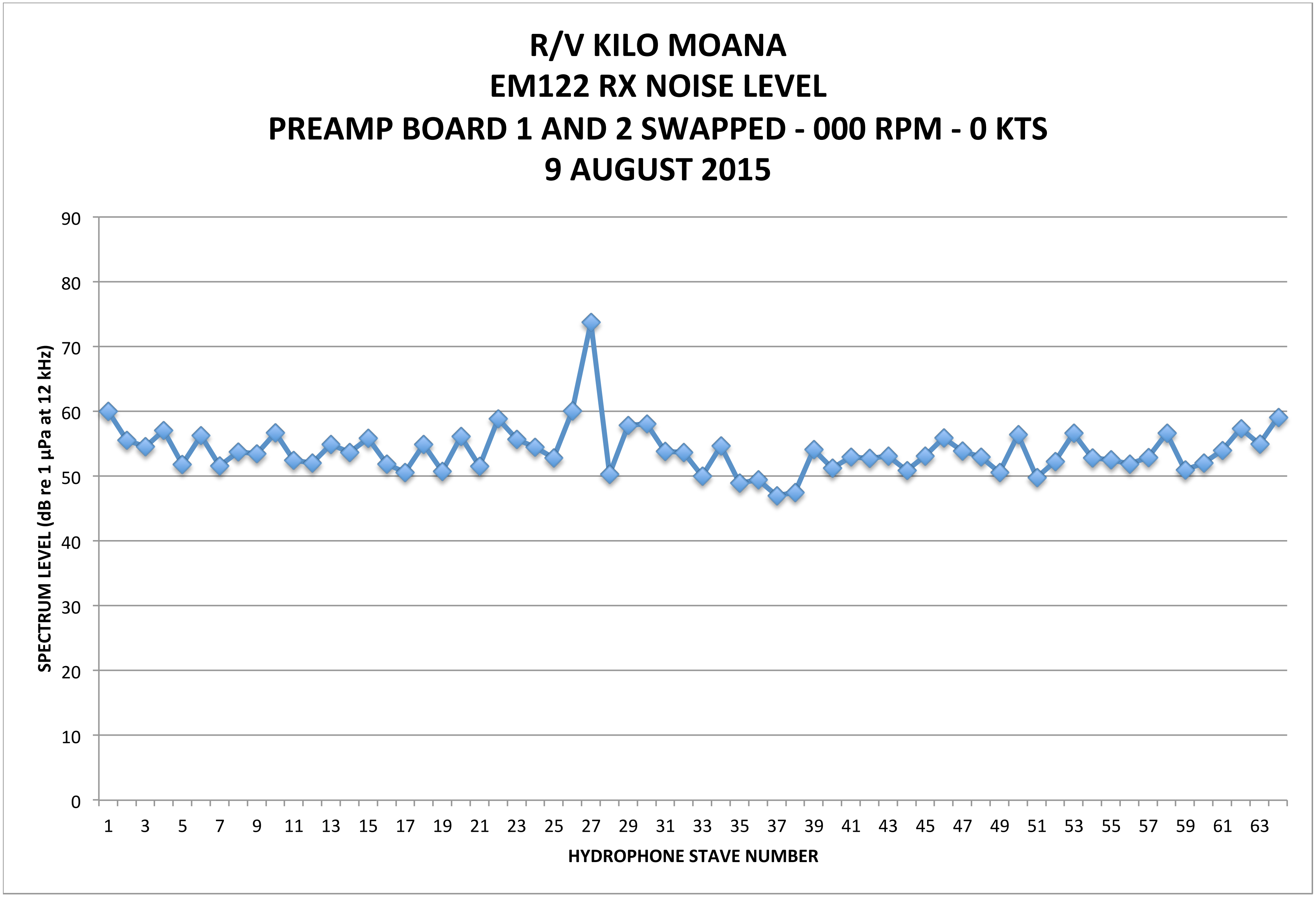

R/V KILO MOANA
EM122 RX NOISE LEVEL
PREAMP BOARD 1 AND 2 SWAPPED - 000 RPM - 0 KTS
9 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)
90
80
70
60
50
40
30
20
10
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63
HYDROPHONE STAVE NUMBER

FIGURE 10

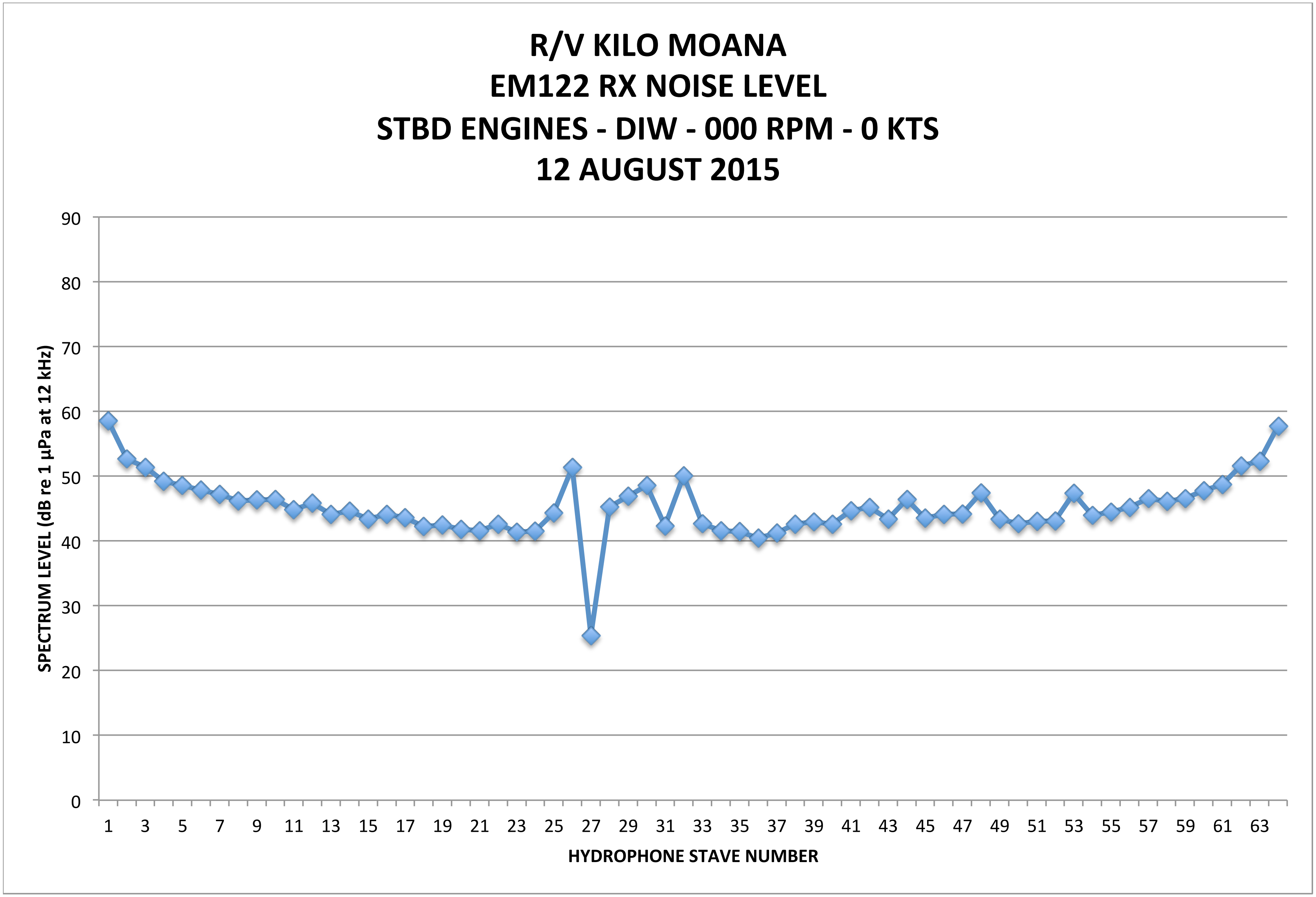

R/V KILO MOANA
EM122 RX NOISE LEVEL
STBD ENGINES - DIW - 000 RPM - 0 KTS
12 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)
90
80
70
60
50
40
30
20
10
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63
HYDROPHONE STAVE NUMBER

FIGURE 11

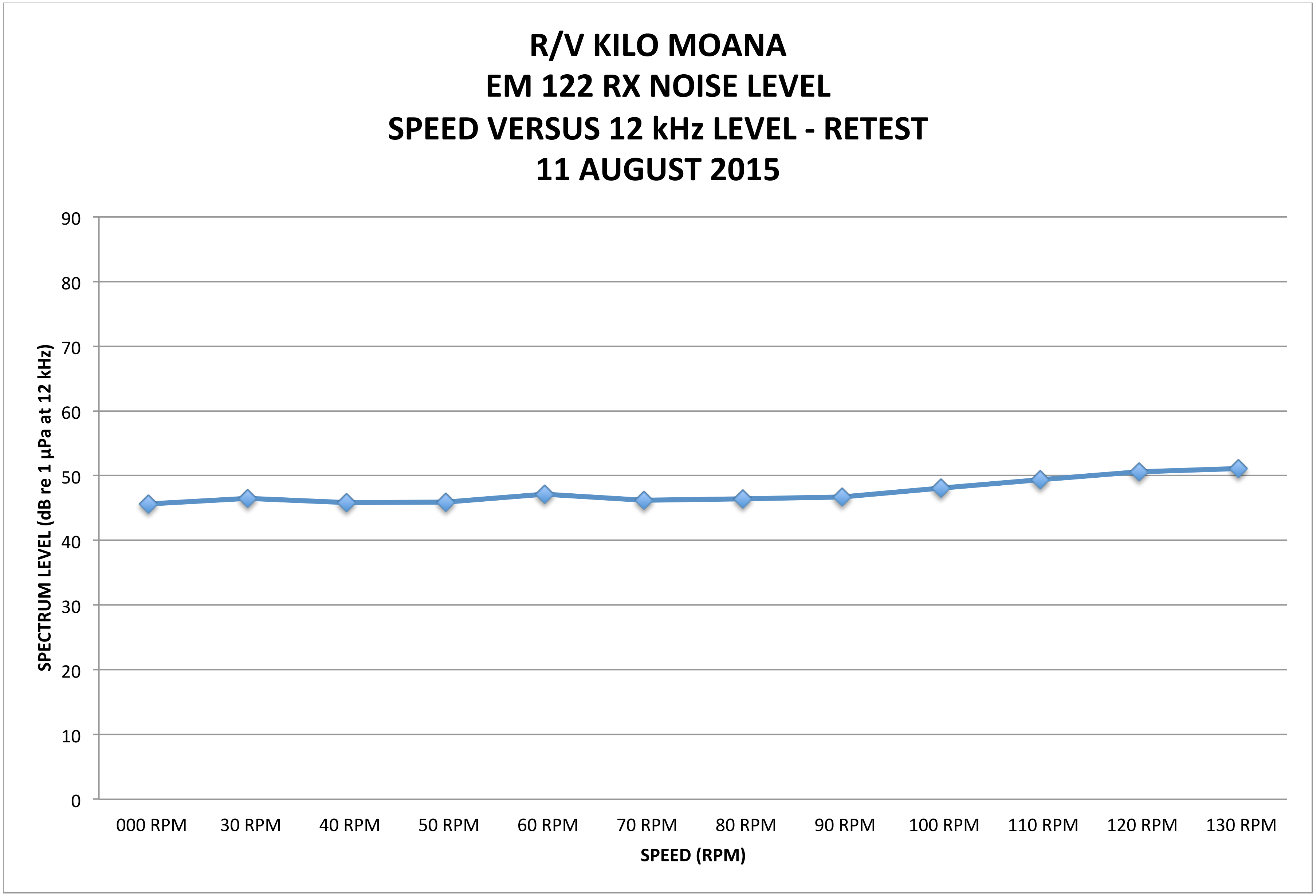
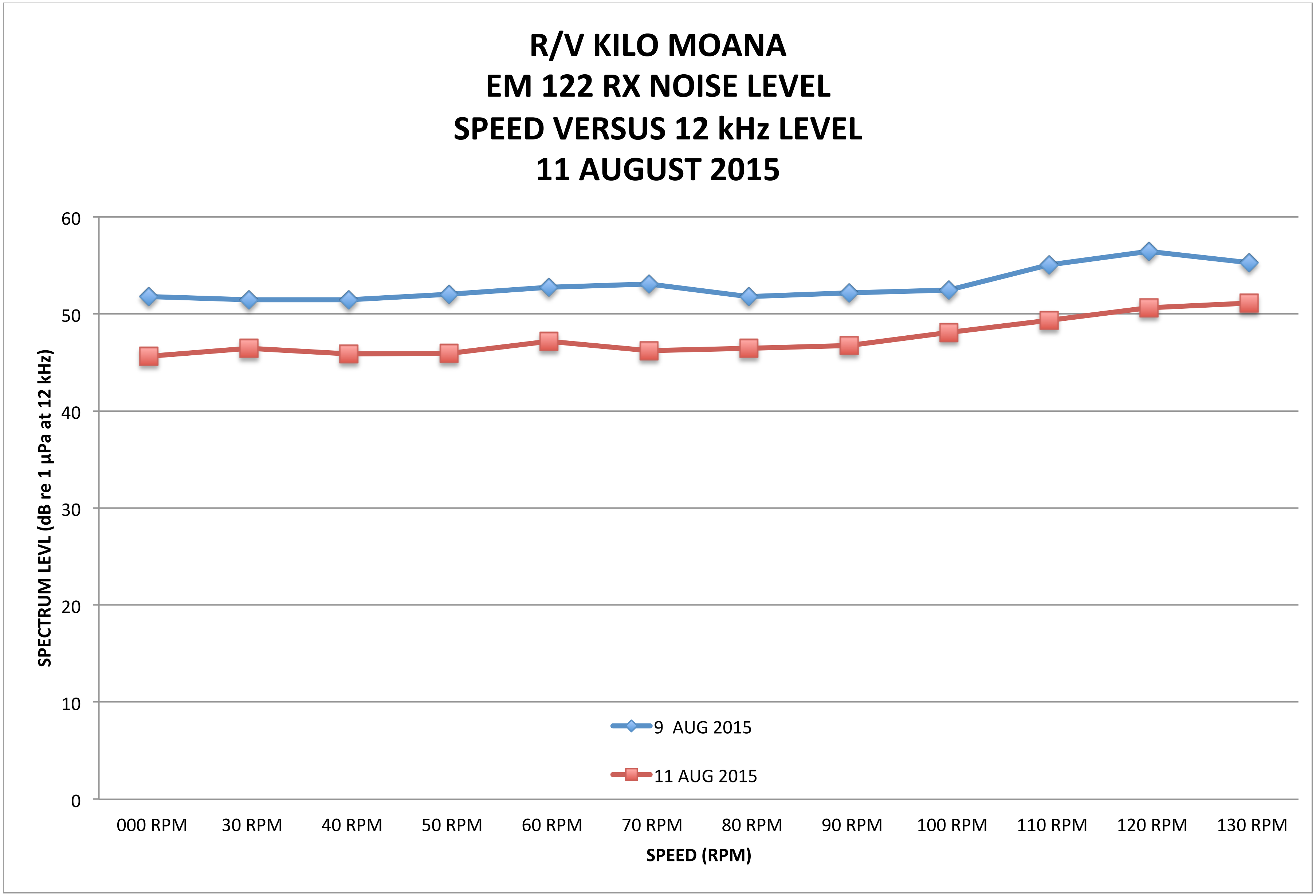

R/V KILO MOANA
EM 122 RX NOISE LEVEL
SPEED VERSUS 12 kHz LEVEL - RETEST
11 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)
90
80
70
60
50
40
30
20
10
0
000 RPM
30 RPM
40 RPM
50 RPM
60 RPM
70 RPM
80 RPM
90 RPM
100 RPM
110 RPM
120 RPM
130 RPM
SPEED (RPM)

FIGURE 12



R/V KILO MOANA
EM 122 RX NOISE LEVEL
SPEED VERSUS 12 kHz LEVEL
11 AUGUST 2015
60
50
40
30
20
10
0
SPECTRUM LEVL (dB re 1 µPa at 12 kHz)
9 AUG 2015
11 AUG 2015
000 RPM
30 RPM
40 RPM
50 RPM
60 RPM
70 RPM
80 RPM
90 RPM
100 RPM
110 RPM
120 RPM
130 RPM
SPEED (RPM)

FIGURE 13

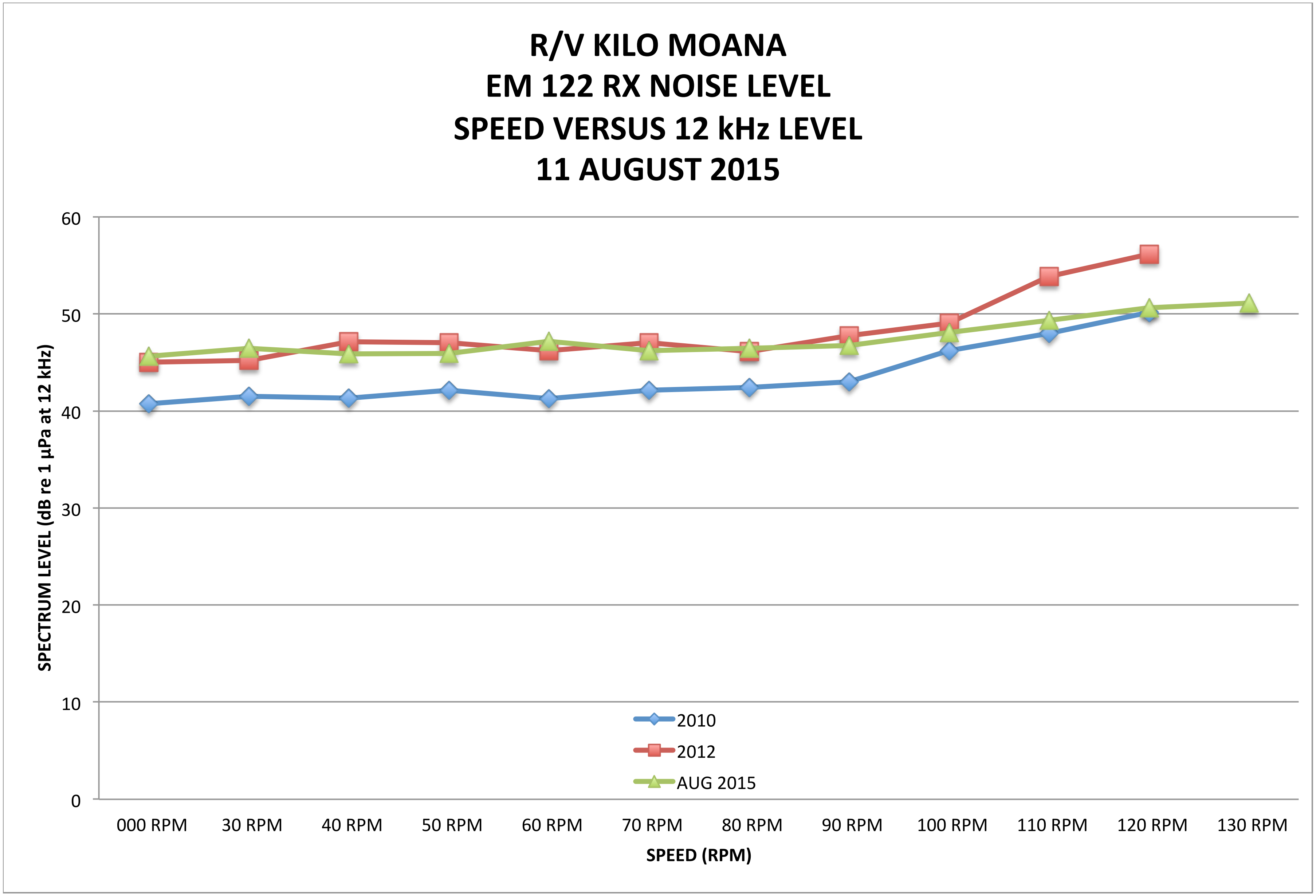

R/V KILO MOANA
EM 122 RX NOISE LEVEL
SPEED VERSUS 12 kHz LEVEL
11 AUGUST 2015
60
50
40
30
20
10
0
SPECTRUM LEVEL (dB re 1 µPa at 12 kHz)
2010
2012
AUG 2015
000 RPM
30 RPM
40 RPM
50 RPM
60 RPM
70 RPM
80 RPM
90 RPM
100 RPM
110 RPM
120 RPM
130 RPM
SPEED (RPM)

FIGURE 14

R/V KILO MOANA
EM 122 BEAM INTENSITY

REPRESENTATIVE EXAMPLE OF DATA DROPOUTS

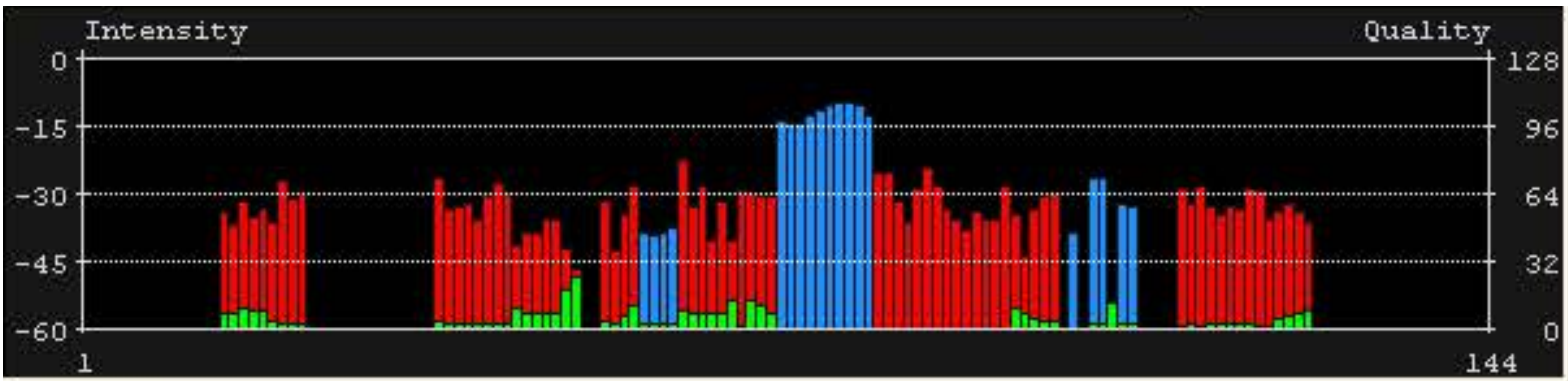


FIGURE 15

R/V KILO MOANA
EM 122 BEAM INTENSITY

EM 122 IN 1X4 DEGREE MODE USING MODULES 2, 3, 4 AND 5

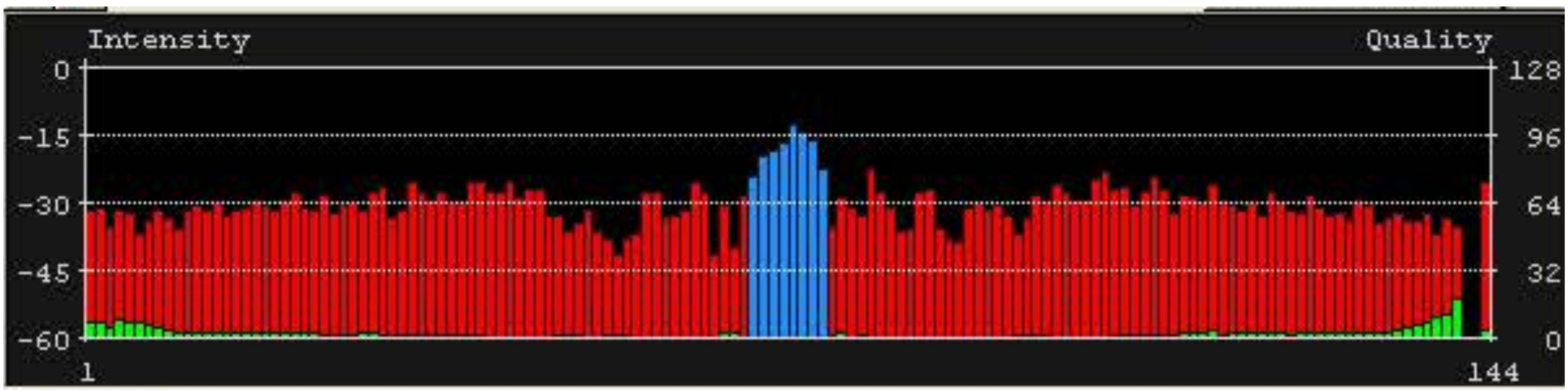


FIGURE 16

R/V KILO MOANA
EM 122 BEAM INTENSITY

EM 122 IN 1X4 DEGREE MODE USING MODULES 3, 4, 5 AND 6

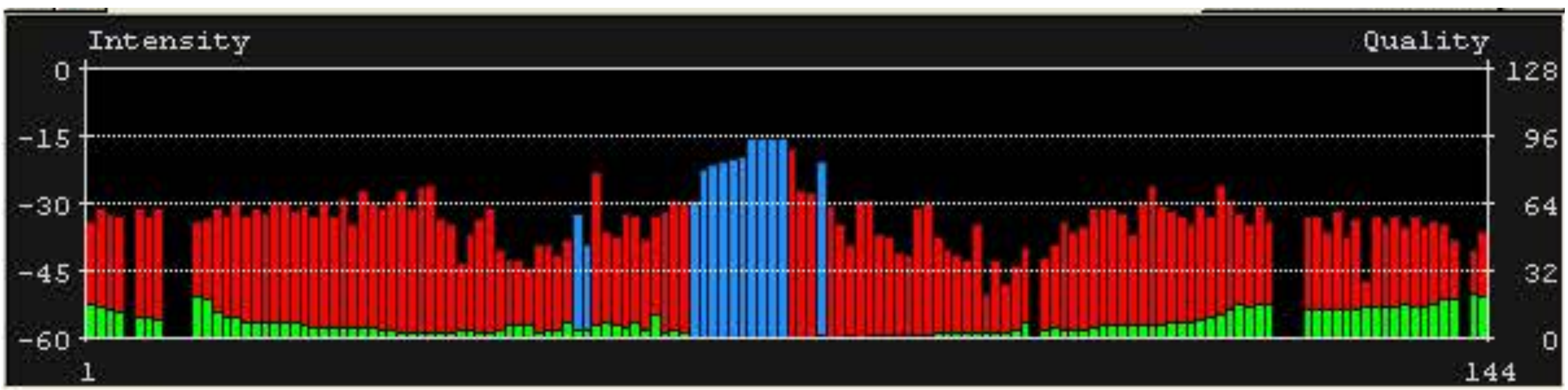


FIGURE 17

R/V KILO MOANA
EM 122 BEAM INTENSITY

EM 122 IN 1X4 DEGREE MODE USING MODULES 4, 5, 6 AND 7

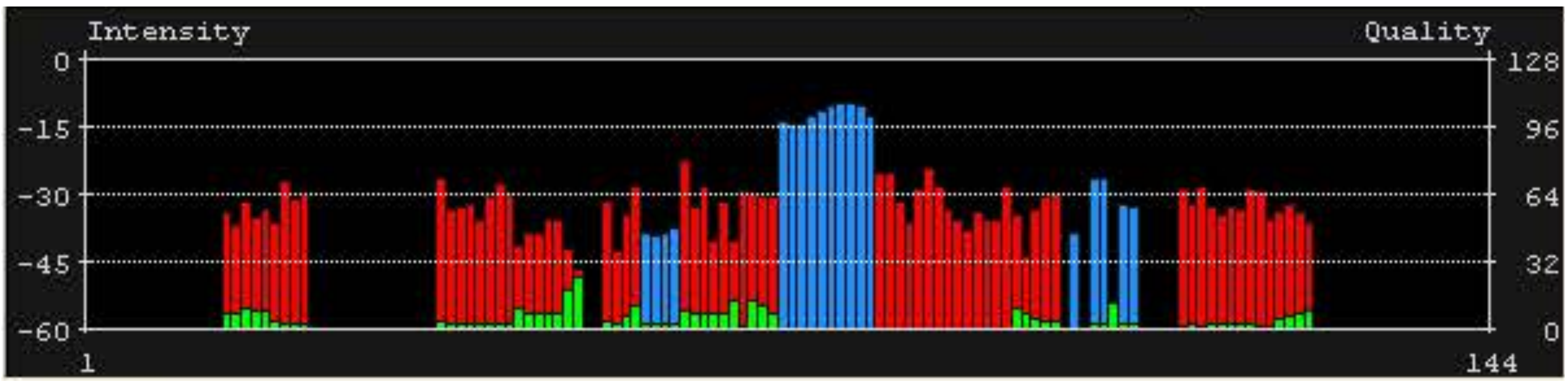


FIGURE 18

R/V KILO MOANA
EM 122 BEAM INTENSITY

EM 122 IN 1X4 DEGREE MODE USING MODULES 5, 6, 7 AND 8

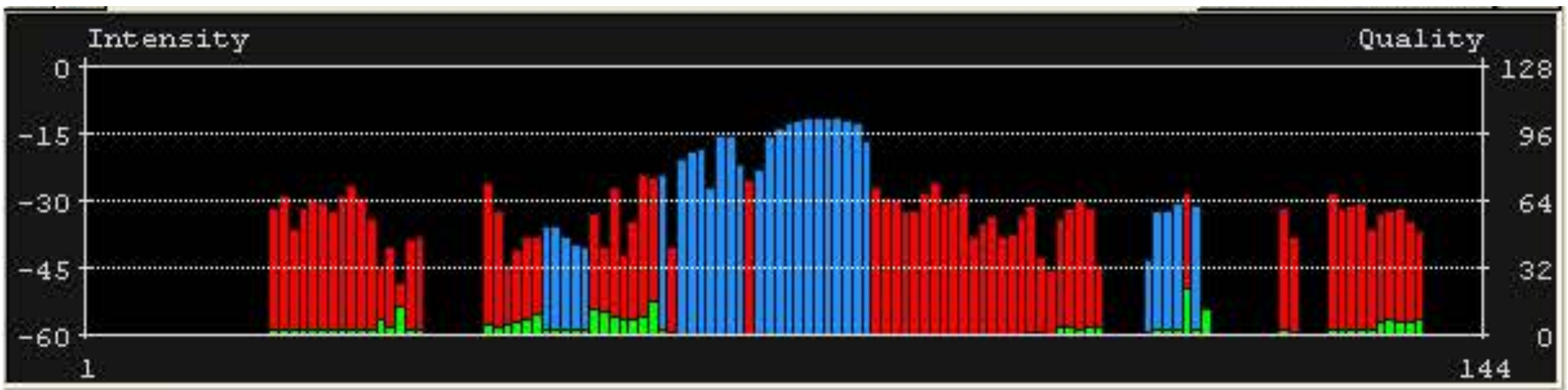


FIGURE 19

R/V KILO MOANA
EM 122 BEAM INTENSITY

EM 122 IN 1X4 DEGREE MODE USING MODULES 5, 6, 7 AND 8 WITH MODULE 6 CORRECTED

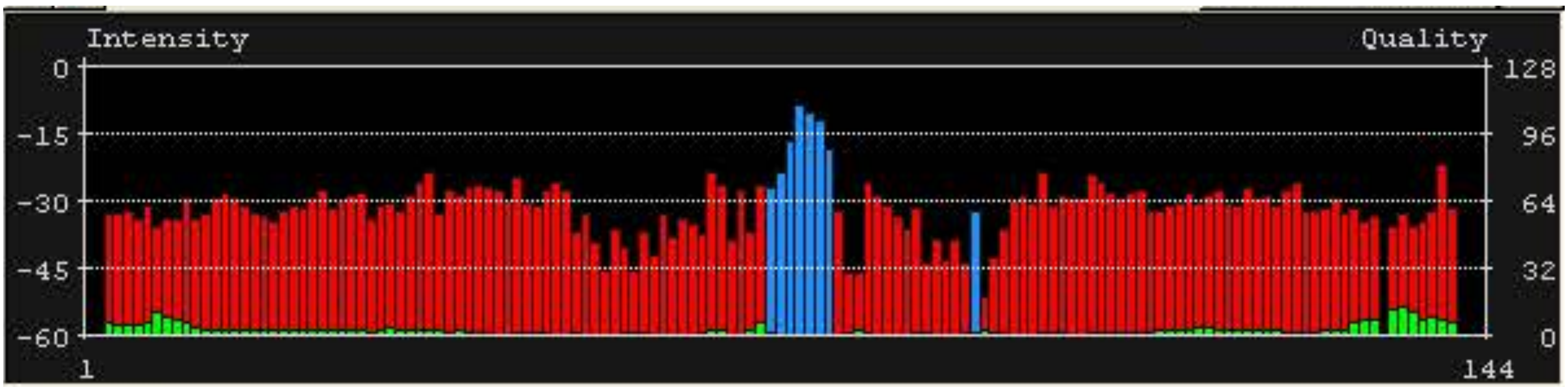


FIGURE 20

R/V KILO MOANA
EM 122 BEAM INTENSITY

EM 122 IN 1X2 DEGREE MODE WITH MODULE 6 CORRECTED

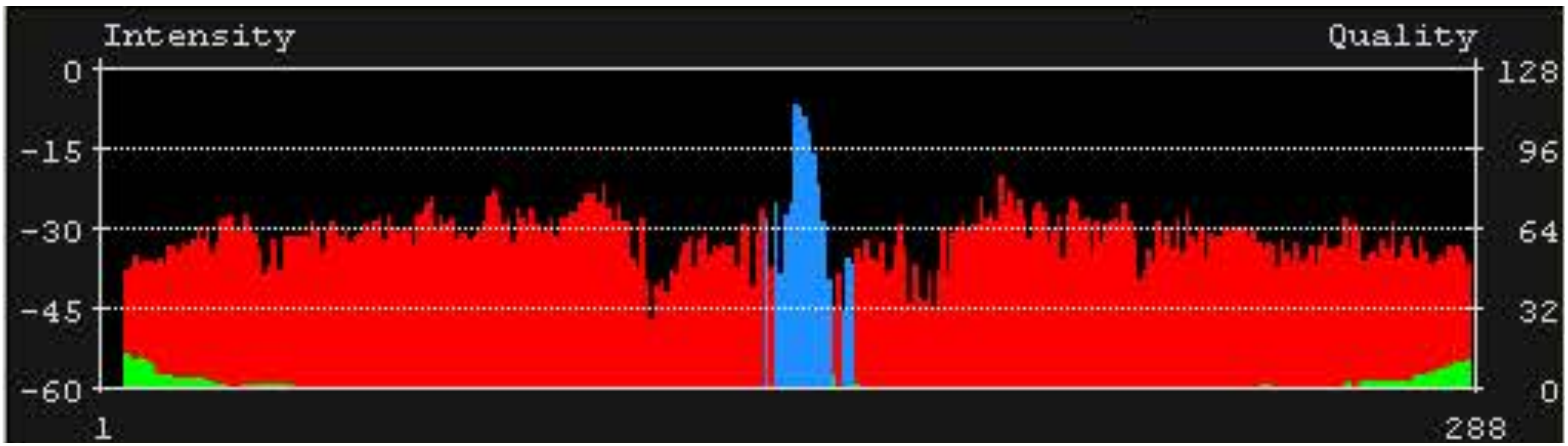


FIGURE 21

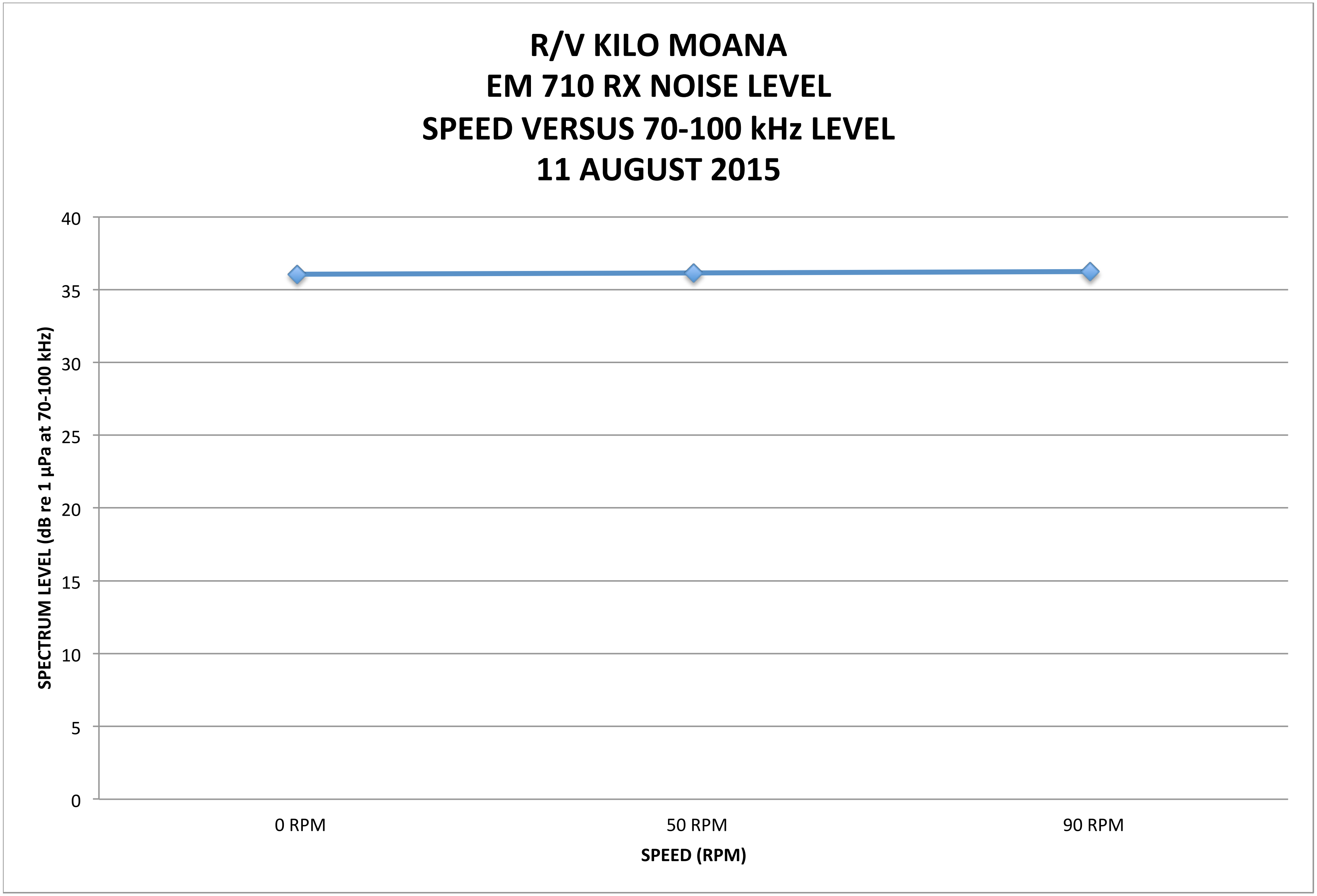

R/V KILO MOANA
EM 710 RX NOISE LEVEL
SPEED VERSUS 70-100 kHz LEVEL
11 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 70-100 kHz)
40
35
30
25
20
15
10
5
0
0 RPM
50 RPM
90 RPM
SPEED (RPM)

FIGURE 22

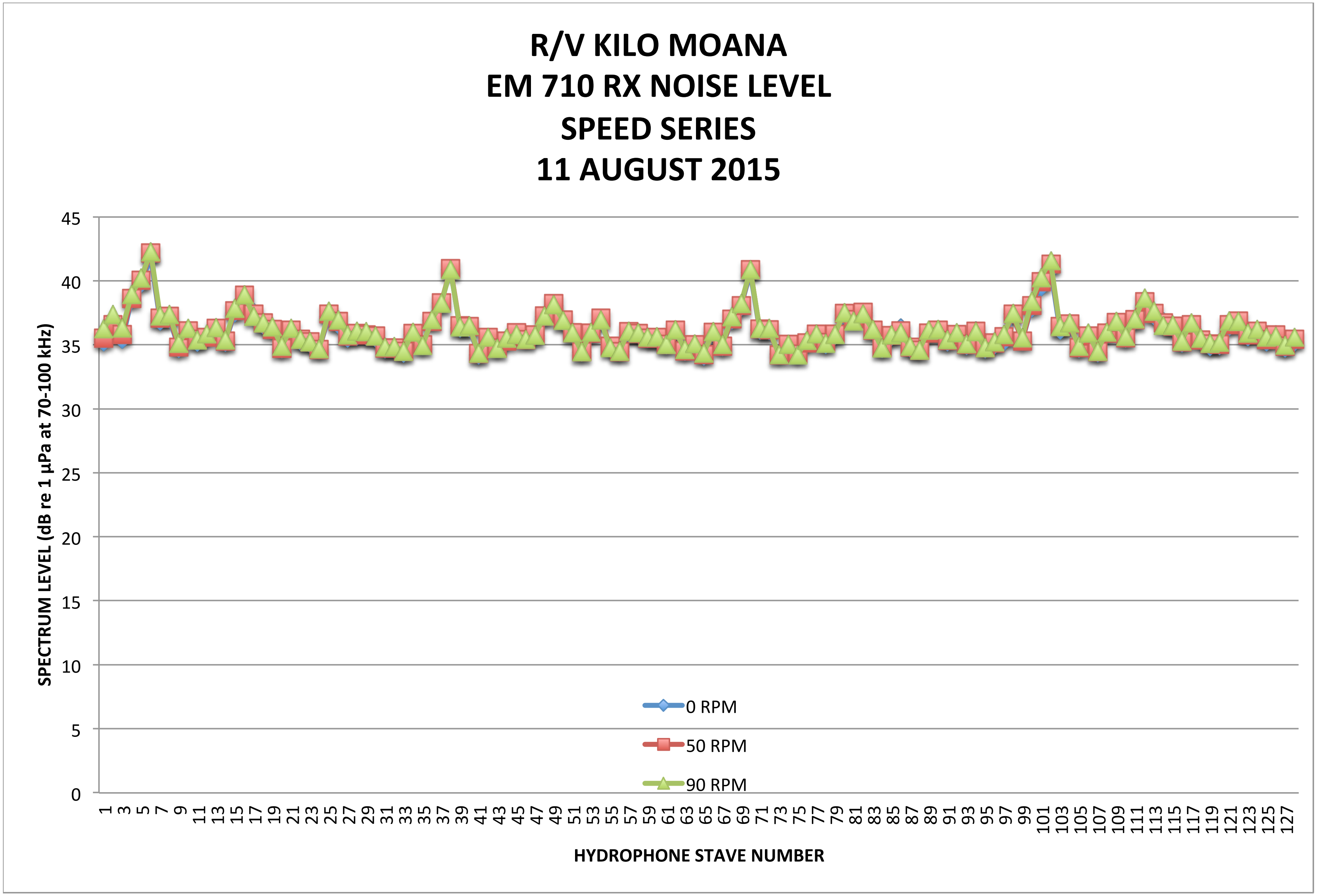

R/V KILO MOANA
EM 710 RX NOISE LEVEL
SPEED SERIES
11 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 70-100 kHz)
HYDROPHONE STAVE NUMBER
0 RPM
50 RPM
90 RPM

FIGURE 23

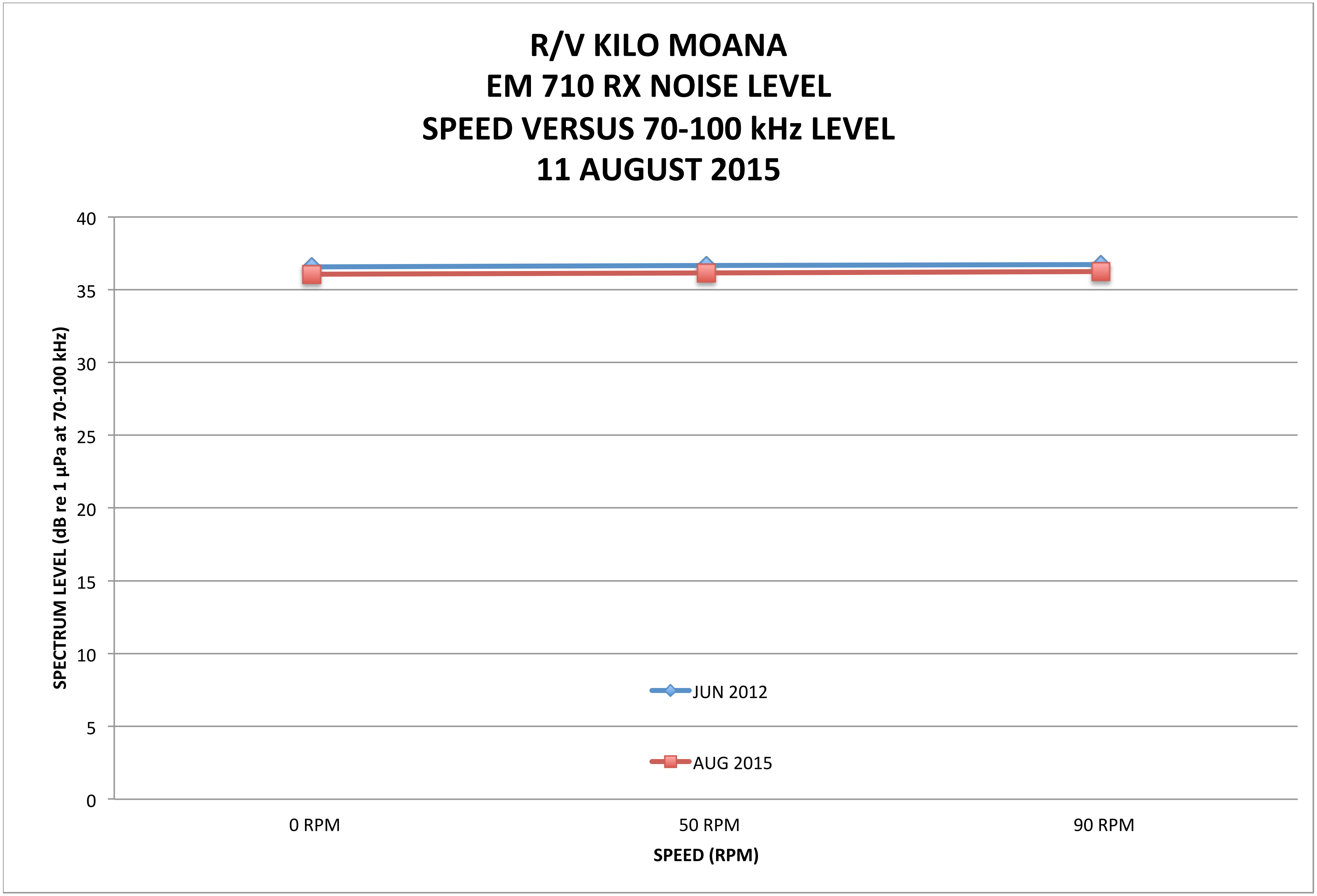

R/V KILO MOANA
EM 710 RX NOISE LEVEL
SPEED VERSUS 70-100 kHz LEVEL
11 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 70-100 kHz)
40
35
30
25
20
15
10
5
0
JUN 2012
AUG 2015
0 RPM
50 RPM
90 RPM
SPEED (RPM)

FIGURE 24

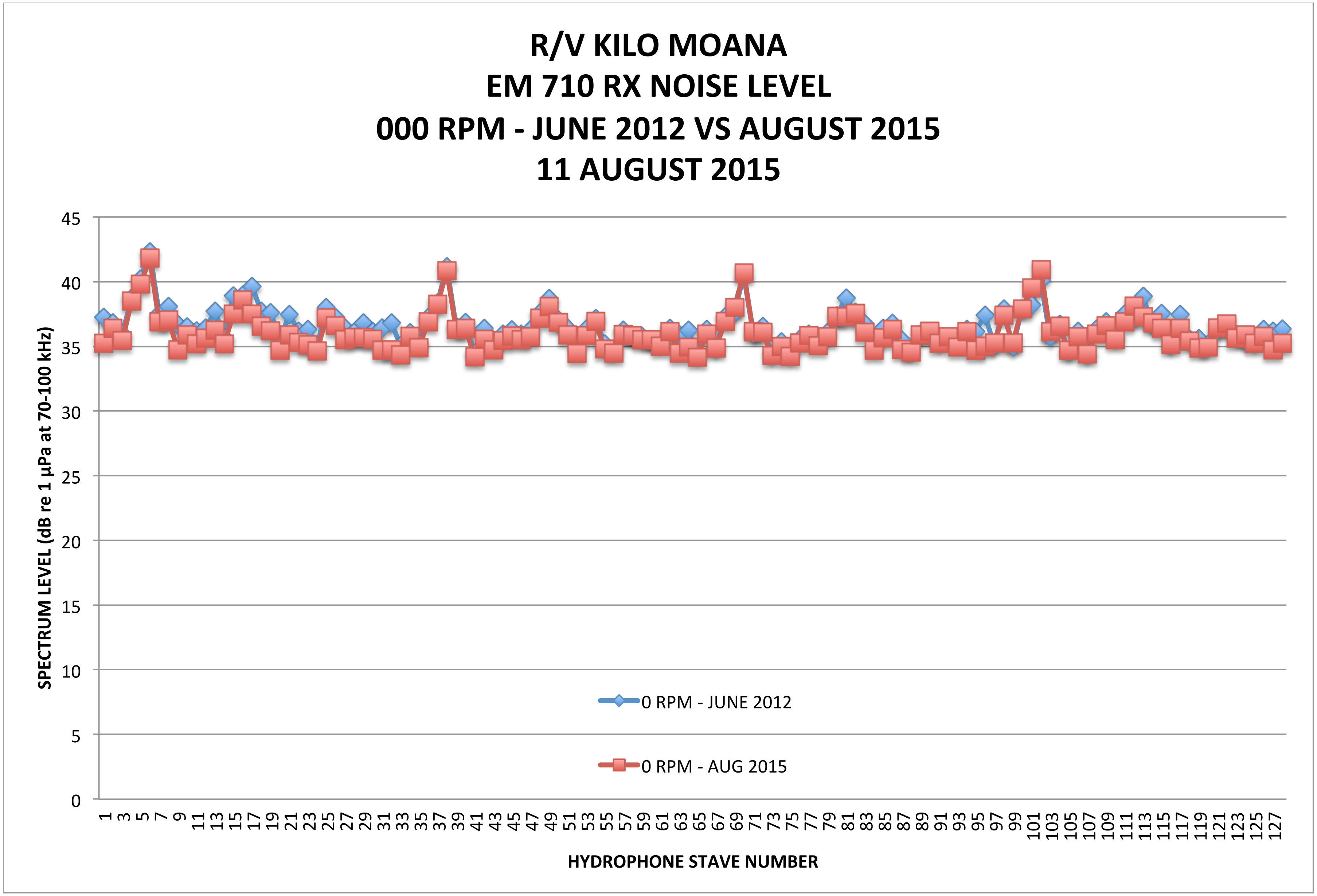

R/V KILO MOANA
EM 710 RX NOISE LEVEL
000 RPM - JUNE 2012 VS AUGUST 2015
11 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa at 70-100 kHz)
HYDROPHONE STAVE NUMBER
0 RPM - JUNE 2012
0 RPM - AUG 2015

FIGURE 25

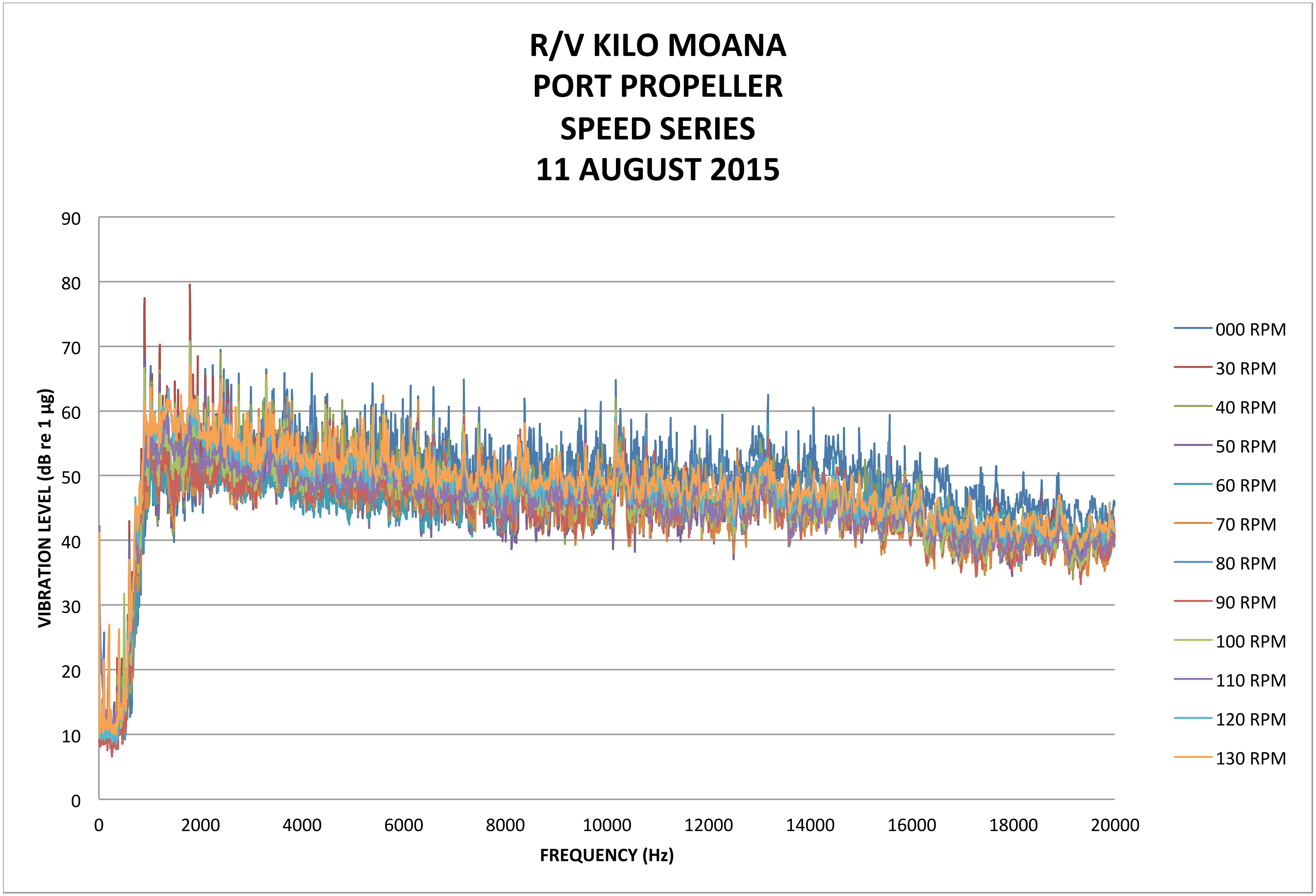

R/V KILO MOANA
PORT PROPELLER
SPEED SERIES
11 AUGUST 2015
VIBRATION LEVEL (dB re 1 µg)
90
80
70
60
50
40
30
20
10
0
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
FREQUENCY (Hz)
000 RPM
30 RPM
40 RPM
50 RPM
60 RPM
70 RPM
80 RPM
90 RPM
100 RPM
110 RPM
120 RPM
130 RPM

FIGURE 26

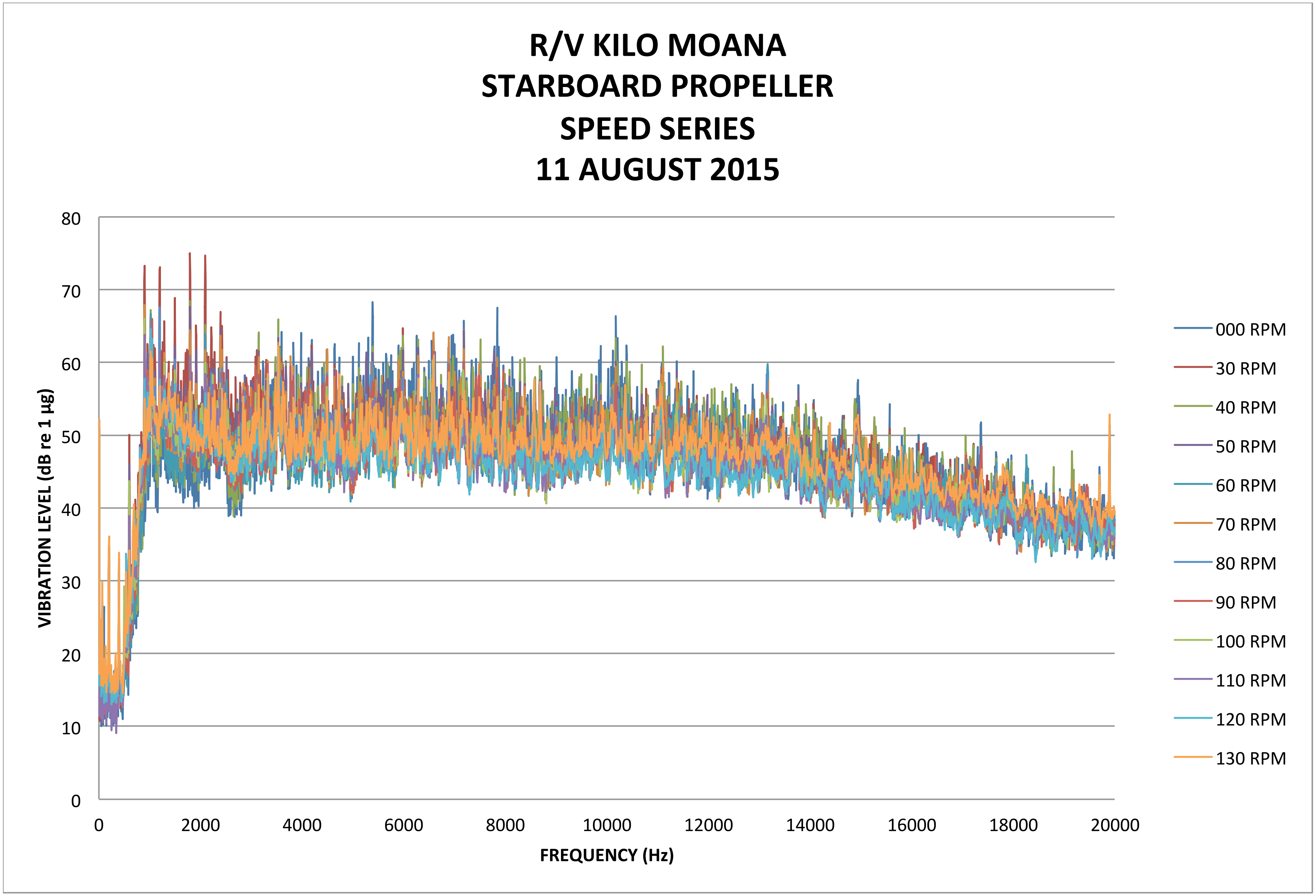

R/V KILO MOANA
STARBOARD PROPELLER
SPEED SERIES
11 AUGUST 2015
VIBRATION LEVEL (dB re 1 µg)
FREQUENCY (Hz)
0
10
20
30
40
50
60
70
80
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
000 RPM
30 RPM
40 RPM
50 RPM
60 RPM
70 RPM
80 RPM
90 RPM
100 RPM
110 RPM
120 RPM
130 RPM

FIGURE 27

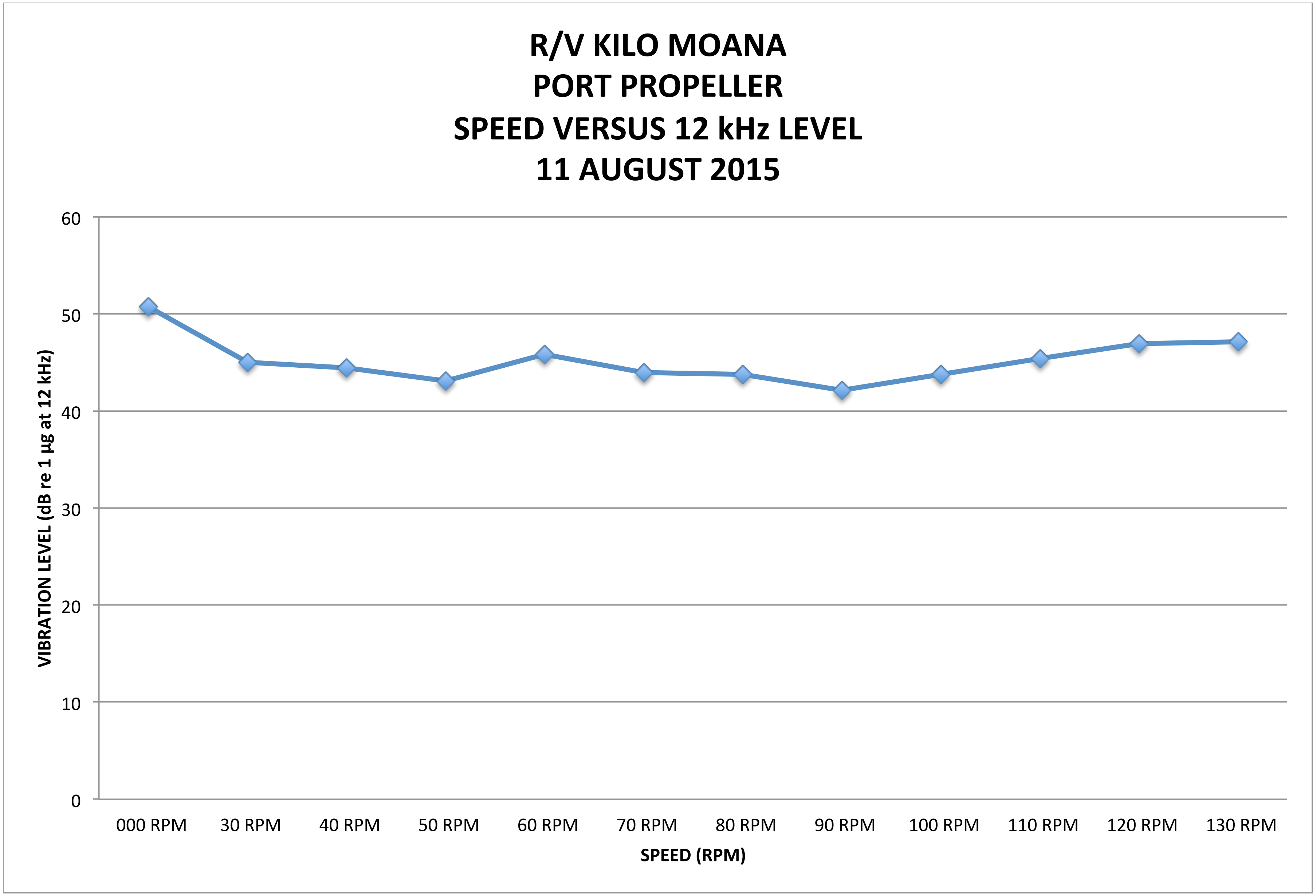

R/V KILO MOANA
PORT PROPELLER
SPEED VERSUS 12 kHz LEVEL
11 AUGUST 2015
VIBRATION LEVEL (dB re 1 µg at 12 kHz)
60
50
40
30
20
10
0
000 RPM
30 RPM
40 RPM
50 RPM
60 RPM
70 RPM
80 RPM
90 RPM
100 RPM
110 RPM
120 RPM
130 RPM
SPEED (RPM)

FIGURE 28

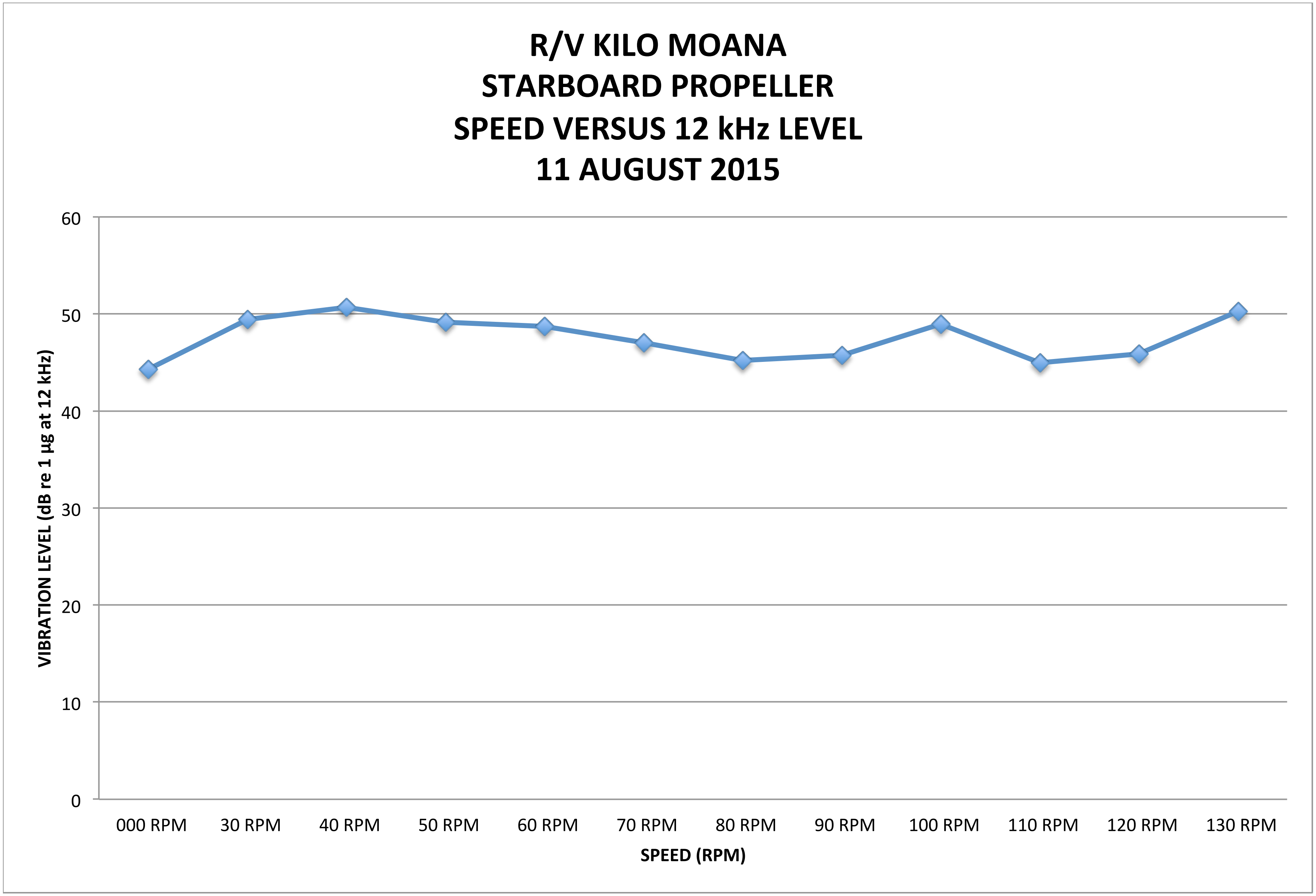

R/V KILO MOANA
STARBOARD PROPELLER
SPEED VERSUS 12 kHz LEVEL
11 AUGUST 2015
VIBRATION LEVEL (dB re 1 µg at 12 kHz)
0
10
20
30
40
50
60
000 RPM
30 RPM
40 RPM
50 RPM
60 RPM
70 RPM
80 RPM
90 RPM
100 RPM
110 RPM
120 RPM
130 RPM
SPEED (RPM)

FIGURE 29

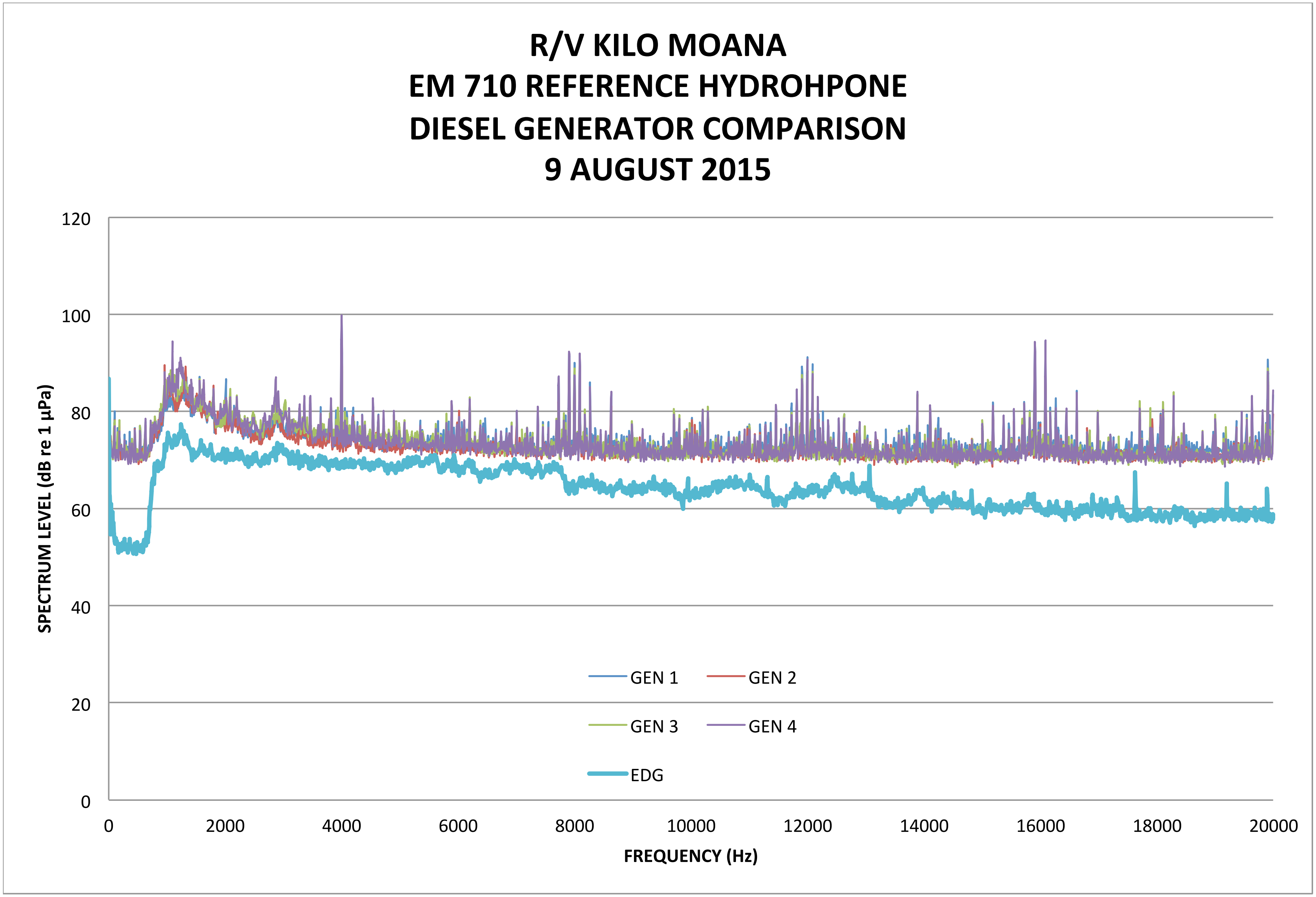

R/V KILO MOANA
EM 710 REFERENCE HYDROHPONE
DIESEL GENERATOR COMPARISON
9 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa)
120
100
80
60
40
20
0
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
FREQUENCY (Hz)
GEN 1
GEN 2
GEN 3
GEN 4
EDG

FIGURE 30

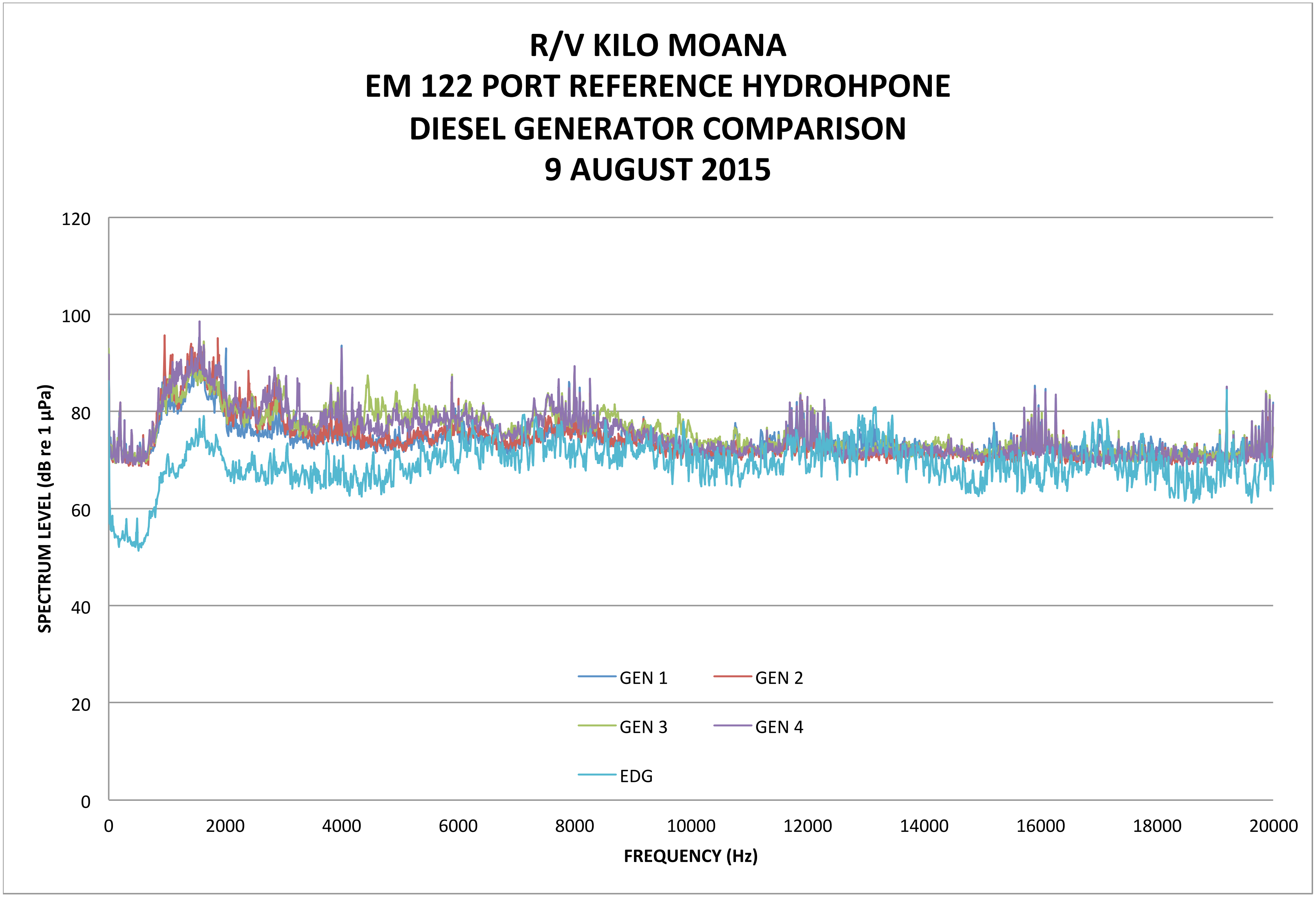

R/V KILO MOANA
EM 122 PORT REFERENCE HYDROHPONE
DIESEL GENERATOR COMPARISON
9 AUGUST 2015
120
100
80
60
40
20
0
SPECTRUM LEVEL (dB re 1 µPa)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
FREQUENCY (Hz)
GEN 1
GEN 2
GEN 3
GEN 4
EDG

FIGURE 31

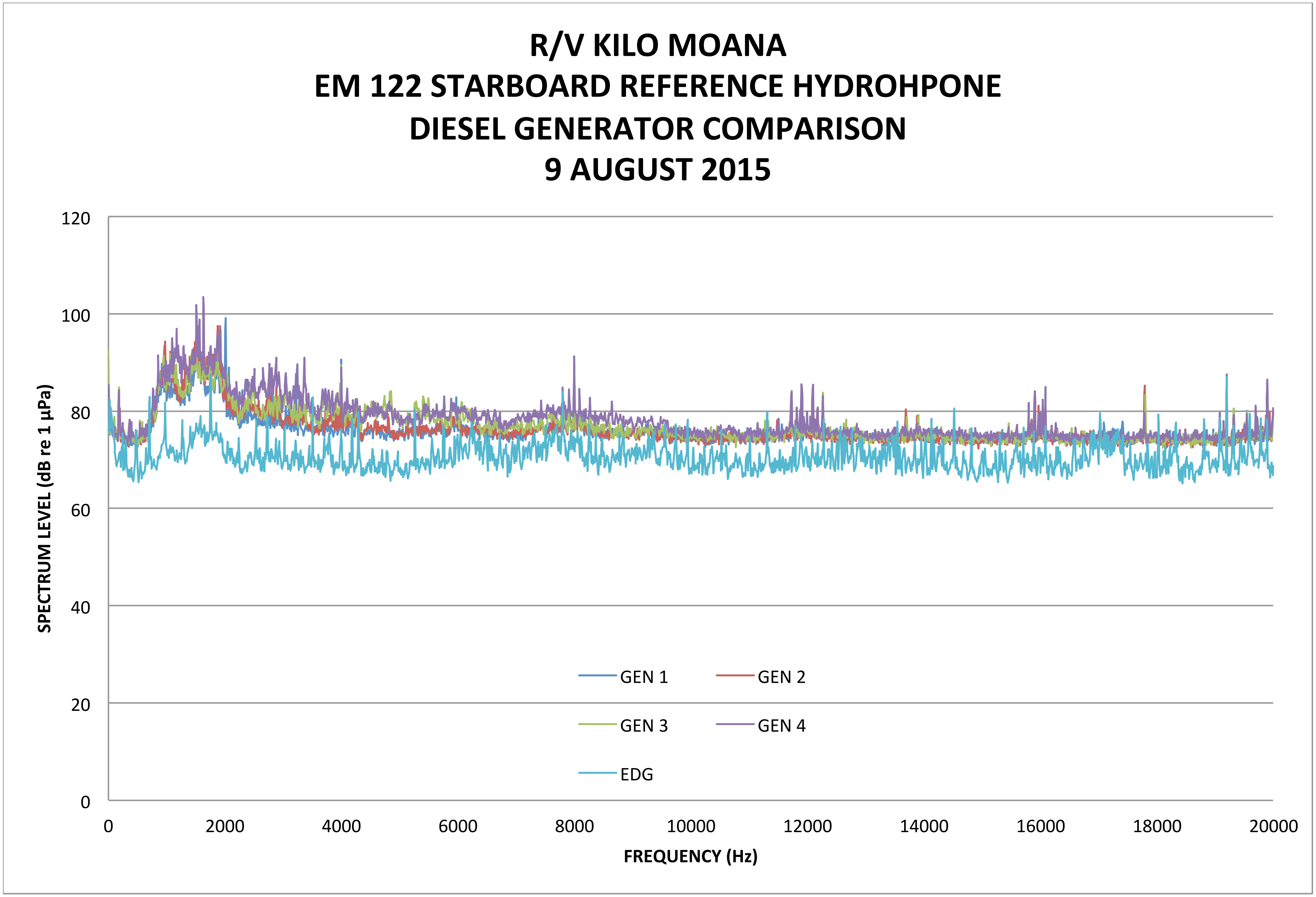

R/V KILO MOANA
EM 122 STARBOARD REFERENCE HYDROHPONE
DIESEL GENERATOR COMPARISON
9 AUGUST 2015
SPECTRUM LEVEL (dB re 1 µPa)
120
100
80
60
40
20
0
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
FREQUENCY (Hz)
GEN 1
GEN 2
GEN 3
GEN 4
EDG

FIGURE 32