Acoustic Performance Test of a SD Wind Energy SD6 Wind Turbine to IEC 61400-11:2012

A Report from NEL for:

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A report from NEL for:

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Date: February 2019

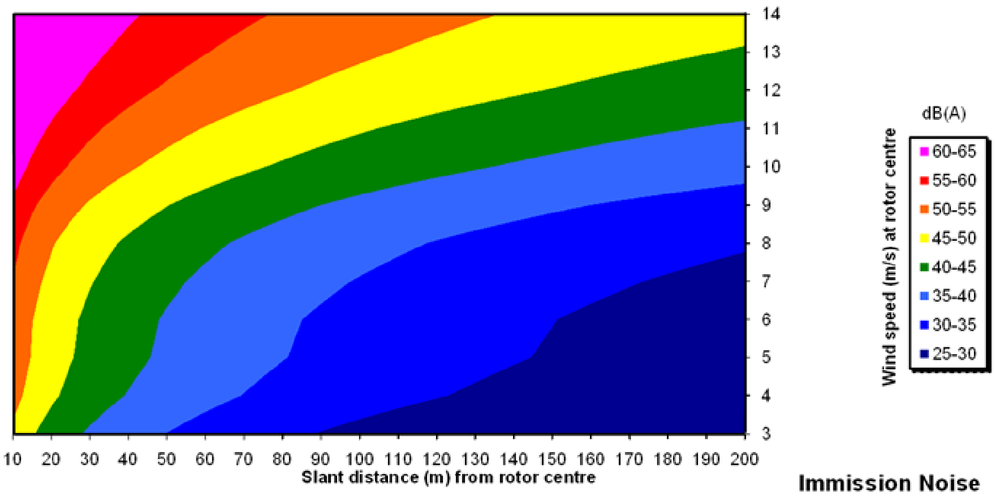
CONTENTS

SUMMARY

NEL (TUV SUD Limited) carried out a series of acoustic noise measurements on a SD Wind Energy SD6 wind turbine (formerly the Proven Energy P11) at Myres Hill on 14 April 2011, 09 May 2011 and 19 May 2011. A summary of the test results is shown in the immission noise map below.

ACOUSTIC NOISE LEVELS

Turbine Make:	SD Wind Energy	Model:	SD6									
IEC 61400-11:2012 NOISE EMISSION LEVELS												
Wind Speed (m/s) at Wind Turbine Hub Height	3	4	5	6	7	8	9	10	11	12	13	14
Apparent Sound Power Level, L_{WA}, dB(A) re 10^{-12}W	79.9	82.8	84.2	84.6	85.8	87.4	90.1	93.6	96.4	99.4	101.7	103.7
Combined Uncertainty, U_c, dB	0.93	0.63	0.58	0.66	0.68	0.65	0.70	0.75	0.80	0.68	0.74	0.93
Declared Sound Power Level, L_{Wd}, dB(A) re 10^{-12}W	81.4	83.8	85.2	85.7	86.9	88.4	91.2	94.8	97.8	100.5	102.9	105.2
IEC 61400-11:2012 TONALITY												
General Comment	0-20 kHz narrow-band analysis using Δf = 1.5625 Hz											
Wind Speed (m/s) at Wind Turbine Hub Height	3	4	5	6	7	8	9	10	11	12	13	14
Critical Band Centre Frequency (Hz)	-	8142	8142	8142	-	-	-	-	-	-	-	-
Tonal Audibility, ΔL_a	-	+2.1	+4.3	+2.4	-	-	-	-	-	-	-	-
ESTIMATED NOISE IMMISSION LEVELS (dB(A) at a distant observer location)												
Note: based on 'Apparent' Sound Power Level at Hub-height and 'Spherical' propagation.												



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1 INTRODUCTION

SD Wind Energy, a small wind turbine manufacturer based in Stewarton, Scotland, commissioned NEL to produce an IEC 61400-11:2012 acoustic test report for its SD6 small wind turbine. SD Wind Energy were previously Kingspan Environmental Ltd and originally Proven Energy Ltd. The SD6 model was previously the KW6 under Kingspan and originally the P11 under Proven.

An acoustic test was undertaken by NEL on the P11 in 2011 in support of Proven's application for MCS certification. The acoustic test was carried out in accordance with the applicable standards at the time, i.e.

- BWEA small wind turbine performance and safety standard dated 29 February 2008
- BS EN 61400-11: 2003 (incorporating Amendment No.1) Wind turbine generator systems – Part 11: Acoustic noise measurement techniques
- IEC TS 61400-14:2005 Wind turbine generator systems – Part 14: Declaration of apparent sound power level and tonality values
- ISO 1996-2: Acoustic – Description, Measurement and Assessment of Environmental Noise – Part 2: Determination of Environmental Noise Levels

With the release of the revised RenewableUK Small Wind Turbine Standard in January 2014, small wind turbine manufacturers with MCS certified products had until January 2019 to demonstrate compliance. One of the requirements to maintain MCS certification beyond January 2019 is an acoustic test in accordance with IEC 61400-11: 2012, the standard which superseded the standards which were applicable in 2011.

NEL's approach was to take the previously acquired test data from the P11, now the SD6, and re-analyse it in accordance with the more stringent requirements of IEC 61400-11: 2012.

Details of the test campaign and the results of the data analysis are presented in this report.

2 STANDARDS AND REFERENCE DOCUMENTS

The execution of the acoustic performance analysis of relevant data were undertaken in compliance with the following standards:

- IEC 61400-11: 2012 Wind turbine generator systems – Part 11: Acoustic noise measurement techniques (identical to BS EN 61400-11: 2013).
- IEC/TS 61400-14:2005 Wind Turbines – Part 14: Declaration of Apparent Sound Power Level and Tonality Values.
- ISO 17025:2005 General requirements for the competence of testing and calibration laboratories.

3 TEST WIND TURBINE CONFIGURATION

The SD6 wind turbine is a three-bladed downwind design turbine and is rated at 6 kWe at 11 m/s wind speed. The test turbine was installed at NEL's Myres Hill wind turbine test site on 14th January 2011. A summary of the test configuration is presented in Table 1. It should be noted that the test results are only applicable to the wind turbine configuration tested.

4 DESCRIPTION OF TEST SITE

The Myres Hill wind turbine test site is located in high moorland in the central belt of Scotland, within the Whitelee Forest area above Eaglesham, south of Glasgow. It is centred at Ordnance Survey grid reference NS 568 467, approximately 330 m above sea level.

There are a few small steel containers or portacabin style out-houses and other small outlying utility buildings within the confines of the test site, the closest of these lying approximately 60 m to the south and 20 m to the north of the turbine under test. The terrain slopes away steeply beyond the test site fence some 100 m to the west and 150 m to the north of the turbine while slopingdown more gradually southwards from the turbine beyond the test site fence 200 m south of the turbine under test. The slopes are all relatively gentle within the test site compound with areas of long grass, heather or otherwise low-lying shrubbery spread in all directions over the site grounds.

There were several wind turbines under test at the test site. During the acoustic testing reported here, it was ensured that all turbines remained in a parked condition. There are some large wind turbines and also forested areas within the Whitelee Wind Farm lying on neighbouring lands. These are well to the south and west outside the test site, with the closest being approximately 700 m away. The potential effect on the background readings and thereby the reported results is, however, deemed negligible following acoustic tests previously carried out when the entire Whitelee Wind Farm was put in a parked state for a few weeks.

There are a few transformers on the test site with mains hum detectable in the background readings. There is no evidence that this has underplayed tonalities.

5 DESCRIPTION OF MEASUREMENT EQUIPMENT

Table 2 lists the measurement instrumentation used. A photograph of the 2011 test arrangement is shown in Figure 1, while Figure 2 shows the system used for data re-analysis. The corresponding calibration certificates are provided in Appendix 1.

6 ACOUSTIC PERFORMANCE MEASUREMENTS

Audible noise measurements were undertaken at the Myres Hill test site on 14 April 2011, 09 May 2011 and 19 May 2011, covering a 10-second averaged wind speed range (normalised at Rotor Centre/Hub-height) of 3 to 15 m/s for a height above ground level of 9 m. The measurements were taken in accordance with Annex F of the IEC 61400-11: 2012 test standard.

During each measurement session, one-third octave spectra were measured concurrently with the overall continuous sound pressure levels. An audio recording of each session was also made on a Brüel & Kjær (B & K) 2250 noise analyser/SLM (Sound Level Meter). The audio signal was played back later via the B & K BZ-5503 Measurement Partner Suite software and input to a Quattro DP240 dynamic signal analyser which generated the fine frequency spectra to be used in the tonal assessment.

The instrumentation used in these measurements is listed in Table 2.

6.1 Measurement Procedure

A meteorological mast was used to cover south-westerly winds on the three test days. This mast had an anemometer mounted at 10 m above ground level, which corresponds closely with the hub height of the wind turbine and this was sited at nominally 12 m / 2.2 D from the turbine, on a bearing of 240° from the wind turbine.

The total testing period covering the measurements used in the analysis lasted from 12:30 until 13:34 on 14/04/2011, 12:00 until 13:04 on 09/05/2011 and 13:46 until 14:44 on 19/05/2011. During the total testing period the measured hub height wind speed ranged from just above cut-in at c. 3 m/s to c. 15 m/s.

The direction of the wind, air temperature and pressure were also monitored over this total testing period. On the 1st test day the air temperature was c. 8.5 °C within +/- 0.5 °C, while the atmospheric pressure was 976 mBar rounded to the nearest mBar. On the 2nd test day the air temperature was c. 13.5 °C within +/- 0.8 °C, while the atmospheric pressure was also 976 mBar rounded to the nearest mBar. On the 3rd test day the air temperature was c. 10.5 °C within +/- 0.6 °C, while the atmospheric pressure was 976 mBar rounded to the nearest mBar.

Noise measurements were made using a ½” diameter microphone located at the centre of a 1 m diameter ground-mounted (acoustically hard) board located 12 m downwind from the wind turbine. Noise, wind speed and direction data were captured in 10-second periods. The location of the ground mounted board and microphone was chosen to minimise influence of any out-houses, parked turbines, MET masts and ground vegetation in the immediate vicinity of the wind turbine upon reported test results. The conditions complied with free field behaviour for reflecting planes. Photographs showing the test arrangements are shown in Figure 1.

Simultaneous noise and wind speed measurements were made with the turbine running and then, as part of the same measurement session, with it parked and the control panel isolated.

Wind speeds were normalised to standard meteorological conditions as per Equation (F1) of IEC 61400-11:2012, where required.

Data were filtered to remove data points where either the noise board position was outside the valid sector (± 45° relative to the wind direction) or the anemometer mast position was not in the valid sector (± 90° upwind of the turbine). Filtering was also performed to discard data where there had been interference due to extraneous noise events, e.g. passing aircraft or bird noise during the background tests.

6.2 Apparent Sound Power Levels

There were 642 valid data sets, post-filtering, of which 448 samples had the wind turbine running and 194 samples had it switched off. Figure 3 shows data captured during the various measurement sessions, with the turbine running and with it parked again. A summary of the apparent sound power levels and associated uncertainty at wind speed bin centres at hub height are given in Table 3.

6.3 Noise Immission Levels

Estimated noise immission levels for different wind speeds and for selected slant distances from the rotor centre are presented in Figure 4. The sound pressure levels, dB(A), shown in the noise immission map are based on the Apparent Sound Power Levels referenced to the wind turbine hub height and are calculated assuming spherical propagation.

From the graph it can be seen that for a hub height wind speed of 9 m/s the sound pressure immission level at a slant distance of 160 m from the rotor centre is 35 dB(A). This distance reduces to 80 m for a wind speed of 5 m/s.

6.4 One-Third Octave Band Spectra

The A-weighted one-third octave band sound power spectra are shown in Figures 6 to 17 for each of the rotor wind speed bins. Note that the wind speed is referenced to the rotor centre height. Numbers shown in square brackets represent points where the background level is within 3 dB of the total noise level, i.e. with the turbine running.

The wind speed bin centre A-weighted one-third octave band sound pressure levels are presented in Table 4 with the corresponding uncertainty values. Wind speed is referenced to rotor centre height. The values marked with an asterisk represent the points in the spectrum where the difference between total noise and background noise is between 3 dB and 6 dB. Results shown in brackets indicate the difference is less than 3 dB and these values were not used in the calculation of the average.

In 2011, one-third octave spectra were analysed for the presence of tones and as such none were detected. Note: *Under the previous test standard, 3.2 Hz sampling was used, half the resolution called for in the present test standard. The present test standard looks at a broader 20 Hz to 20 kHz range, too, with previous test stand focussing on a range of 100 Hz - 10 kHz.*

6.5 Tonal Audibility

For each of the bins, 30 fine frequency spectra were available for the analysis, except for the 3 m/s bin where only a couple of valid measurements were available. For bins 13 – 15 m/s only forty or so valid measurements were available, spread over the higher integer wind speed bins, roughly averaging thirteen in each of these bins. Running results are only borderline 3 - 6 dB more over background readings in 13 - 15 m/s bins, meaning tones would be unlikely.

The search for tones was conducted in the frequency range 20 - 11,200 Hz. Narrowband spectra, with a resolution of 1.5625 Hz were generated from the Quattro DP240 dynamic signal analyser in 10-second periods using a Hanning window with an overlap of 50%.

Figures 18a to 28d show one representative fine frequency spectrum from each of the wind speed bins. Two graphs, a and b, are presented for each spectrum. The first, a, shows the whole spectrum with the frequency of highest tonality marked with a blue dotted vertical line. The two vertical blue lines show the limits of the associated critical band. Similarly the red vertical lines highlight the critical band with the next second highest tonality value and green lines mark the critical band containing the spectrum's peak. In some cases the spectrum peak and highest tonality coincide.

The second figure, b, shows the critical band in more detail. The spectral lines (points in the frequency domain) identified as possible tones are highlighted as red markers and the masking noise shown in green. Calculating the energy sum of all the points identified as tones gives the sound pressure level of the tone (Lpt) which is shown as a red dotted horizontal line on the graph. The black dotted horizontal line (Lpn, avg) represents the energy average of all the masking points and the dot-dash line represents the defined masking level (Lpn).

The tonality (ΔLtn) for each spectrum is determined by subtracting the masking level (Lpn) from the sound pressure level of the tone (Lpt). The final step is to calculate the tonal audibility (ΔLa) by subtracting the frequency dependent audibility criterion (La) specified in IEC61400-11:12 from the tonality.

The results of the analysis show a reportable tonal audibility at c. 8 kHz for the wind turbine in the range 4 - 6 m/s. Table 5 shows a summary of this reportable audibility.

There are no reportable audible tones for wind speeds above 6 m/s. In the range 4 to 6 m/s there are two tones with audibility greater than 0 dB. These are at c. 8 kHz with its highest audibility being +4.3 dB for 5 m/s wind speed and c. 6 kHz with its highest audibility being +2.1 dB but is always lower in audibility than for 8 kHz over 3 -14 m/s.

A tonal audibility calculation summary sheet for each of the wind speed bins is presented in Appendix 3 and includes a subordinate audible c. 6 kHz tone at 5 m/s.

7 DEVIATIONS

The sound recordings made in the original 2011 tests and subsequently re-analysed in line with the latest edition of IEC 61400-11: 2012 were zero-weighted, which was the requirement of the applicable standards at the time.

Nevertheless, a sensitivity analysis was carried out to find if there would be any increased uncertainty applying A weighting retrospectively to renewed fine frequency analysis of the original raw recorded sound levels. The finer frequency sampling interval of c 1.6 Hz was applied as opposed to the c. 3.2 Hz interval used previously.

The current standard samples over a wider frequency range, too. The SLM was capable of achieving this but again using the broader range combined with double resolution was not required. 0.3 dB under-read could arise for any frequencies close to adjacent one-third octave band borders. Being centred within a one-third octave band, c.8 kHz tones are reported without requiring any increased uncertainty to be added.

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TABLE 1 SUMMARY OF TEST WIND TURBINE CONFIGURATION

Turbine Characterisation (Section 10.2 IEC 61400-11:2012)	
WIND TURBINE DETAILS	
Manufacturer	SD Wind Energy
Model number	SD 6
Turbine ID / Serial number - [Head No.]	Drg. No. PR-06-WT-001 - [1546]
OPERATING DETAILS	
Vertical or horizontal axis wind turbine	Horizontal axis
Upwind or downwind rotor	Downwind rotor
Hub height	9 m
Horizontal distance from rotor centre to tower axis	1 m
Diameter of rotor – (from manufacturer's data)	5.5 m
Tower type (lattice or tube)	Hinged monopole tapered tower, CU twin nesting tube sections
Passive stall, active stall, or pitched controlled turbine	Passive pitch-to-stall (Coning)
Constant or variable speed	Variable speed
Power curve (if required for wind speed determination)	N/A
Rotational speed at integer standardised wind speed bins	N/A
Pitch angle at each integer standardised wind speed bins	N/A
Rated power output	6 kWe @ 11m/s
Turbine Control System	Passive pitch-to-stall system (plus Inverter*)
Control Software Version*	See note below Table 1
Vortex-generators, Stall-strips, Serrated-trailing-edges fitted	N/A – No such devices fitted
Blade Manufacturer	Green-Blade
Blade Type	Glass Thermoplastic Composite
Number of Blades	3
Gearbox and Generator Details	Direct-Drive c/w Rare-Earth Poles

* Inverter settings for 21st December 2010 Installation Datasheet, defined as Version 1.33 comprising 16 set-points, was advised by Proven Energy Limited (now SD Wind Energy) in an email to NEL dated 11th February 2011.

TABLE 2 INSTRUMENTATION USED IN ACOUSTIC TESTS

PARAMETER	INSTRUMENT	MANUFACTURER	TYPE	SERIAL NUMBER	CALIBRATION CERTIFICATE.REF.	CALIBRATION LABORATORY
Sound Level	Calibrator	Brüel & Kjær	4231	2651818	C1006721	Brüel & Kjær (UKAS 0174)
Sound Level	Microphone	Brüel & Kjær	4189	2643613	C1006722	Brüel & Kjær (UKAS 0174)
Sound Level	Handheld Analyser	Brüel & Kjær	2250	2653893	C1006722	Brüel & Kjær (UKAS 0174)
Sound Level	DP240A	Data Physics Corp.	D48-023 +A66-02	21717	Cert. No. 28450	Data Physics Corp.
Wind Speed	Anemometer	Gill Instruments	Windsonic	10150026	N20033/10	Littlebrook Calibration Services (UKAS 0436)
WindDirection	Anemometer	Gill Instruments	Windsonic	10150026	N/A	N/A
Wind Speed/ WindDirection	Datalogger	Campbell Scientific	CR1000	6345	N/A	N/A
Pressure	Barometric pressure transducer	Setra/ supplied via Campbell Scientific	CS100-278	4288966	N19273/10	Littlebrook Calibration Services (UKAS 0436)
Temperature	Temperature sensor	Vaisala/ supply via Campbell Scientific	HMP45AC	F1450158	N19272/10	Littlebrook Calibration Services (UKAS 0436)
Pressure/ Temperature	Datalogger	Campbell Scientific	CR1000	6280	N/A	N/A

TABLE 3 SUMMARY OF L_{WA} LEVELS AND ASSOCIATED UNCERTAINTY uL_{WA}, AT WIND SPEED BIN CENTRES

L_{WA} (dBA re 10^{-12} W) @ Rotor Centre Height, H

Parameter	Wind Bin Centre, k (m/s) at Rotor Centre Height												
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Run points (643 total)	31	111	58	42	55	88	45	54	55	66	26	11	1
Run V^{Bar}	3.17	4.01	4.89	6.02	7.01	8.01	8.90	10.01	11.04	11.96	12.94	13.90	15.05
Bkgd points (341 total)	24	82	41	40	19	14	13	17	38	29	12	8	4
$BgdV^{Bar}$	3.19	4.04	4.94	5.99	6.94	7.94	8.98	10.01	11.00	11.96	13.00	13.85	14.65
L_{WA} @ H	**79.9**	**82.8**	**84.2**	**84.6**	**85.8**	**87.4**	**90.1**	**93.6**	**96.4**	**99.4**	**101.7**	**103.7**	**-**
L_{WA} Status	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	-
uL_{WA} dB	**0.93**	**0.63**	**0.58**	**0.66**	**0.68**	**0.65**	**0.70**	**0.75**	**0.80**	**0.68**	**0.74**	**0.93**	**-**
$L_{WA,d}$ @ H	**81.4**	**83.8**	**85.2**	**85.7**	**86.9**	**88.4**	**91.2**	**94.8**	**97.8**	**100.5**	**102.9**	**105.2**	**-**

Note: Status:"OK"-Background noise is at least 6dB less than Turbine running,"*"-Background3to6dB lower thanTurbine,"DNR"-Background noise within 3dB of Turbine->DoNotReport levels.

L_{WA} (dBA re 10^{-12} W) @ 10m Height a.g.l.

Parameter	Wind Bin Centre, k (m/s) at 10 m Height												
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
V_H	2.9	3.9	4.9	5.9	6.9	7.8	8.8	9.8	10.8	11.8	12.7	13.7	14.7
L_{WA} @ 10m	**79.5**	**82.5**	**84.0**	**84.5**	**85.4**	**86.5**	**89.0**	**92.5**	**95.0**	**98.5**	**101.0**	**102.5**	-
uL_{WA} dB	**1.0**	**0.7**	**0.6**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.8**	**0.7**	**0.7**	**0.9**	-
$L_{WA,d}$ @ 10	**81.0**	**83.5**	**85.0**	**85.5**	**86.5**	**87.5**	**90.0**	**93.5**	**96.5**	**99.5**	**102.0**	**104.0**	-

Note: Simplified linear interpolation method used to calculate uL_{WA} and L_{WA} at 10 m height but in general accordance with the intent of IEC 61400-11:2012

TABLE 4

BIN CENTRE A-WEIGHTED 1/3 OCTAVE BAND SOUND PRESSURE LEVELS (AND UNCERTAINTY VALUES FOR ROTOR CENTRE HEIGHT WIND SPEEDS

Wind Bin centre, k (m/s)	Parameter	1/3rd Octave Band Centre Frequency																											dBA Total
		20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1kHz	1.25kHz	1.6kHz	2kHz	2.5kHz	3.15kHz	4kHz	5kHz	6.3kHz	8kHz	10kHz	
3	Total $L_{V,T}$	-0.6	4.1	10.3	15.0	22.9	23.4	26.2	28.1	28.8	30.3	32.1	32.9	32.9	33.7	35.7	37.4	41.0	42.7	43.2	42.6	43.3	42.4	39.3	34.3	30.8	29.5	26.6	20.1	51.6
	Bgnd $L_{V,B}$	-9.6	-5.3	1.1	3.4	20.5	12.9	13.0	17.5	15.5	18.0	18.7	19.2	18.2	15.7	17.1	16.9	16.3	15.4	13.8	11.2	8.8	8.8	10.8	14.8	13.9	16.0	13.6	7.0	29.7
	Corrected $L_{V,c}$	-1.2	3.6	9.8	14.7	[19.9]	23.1	26.1	27.7	28.7	30.1	31.9	32.7	32.8	33.7	35.7	37.4	41.1	42.7	43.3	42.6	43.3	42.5	39.3	34.3	30.7	29.3	26.5	19.9	51.5
	u_c	1.19	1.16	1.16	1.20	[2.03]	1.22	1.37	1.32	1.22	1.19	1.17	1.20	1.15	1.06	0.98	0.86	0.87	0.92	0.92	0.85	0.81	0.90	1.11	1.09	1.10	1.50	1.66	1.27	
4	Total $L_{V,T}$	0.7	5.2	11.0	15.0	22.3	22.7	25.4	27.7	29.6	31.9	34.1	35.1	35.7	37.1	39.1	40.4	43.7	46.0	47.5	47.4	47.1	45.5	42.8	38.4	34.0	37.3	34.8	23.2	55.3
	Bgnd $L_{V,B}$	-4.9	0.2	4.2	7.2	20.5	14.5	15.8	18.9	18.4	21.6	22.9	22.0	21.0	19.4	20.5	19.8	18.9	17.6	15.9	13.4	11.1	10.5	12.3	14.3	16.3	22.9	11.8	7.4	32.5
	Corrected $L_{V,c}$	-0.8*	3.6*	10.0	14.2	[19.3]	22.1	24.9	27.2	29.3	31.5	33.8	34.9	35.6	37.1	39.1	40.4	43.8	46.1	47.6	47.5	47.1	45.5	42.9	38.5	34.0	37.1	34.8	23.2	55.2
	u_c	0.93	1.00	0.82	0.77	[1.41]	0.75	0.71	0.73	0.68	0.70	0.69	0.67	0.66	0.64	0.64	0.63	0.62	0.62	0.63	0.64	0.63	0.62	0.62	0.63	0.64	0.77	0.78	0.69	
5	Total $L_{V,T}$	1.7	9.7	14.2	17.9	23.5	25.2	28.5	31.9	33.3	34.7	37.3	38.4	38.6	39.6	41.6	42.4	44.7	46.6	48.6	49.5	49.8	47.4	44.6	40.4	35.4	36.7	32.2	25.5	57.0
	Bgnd $L_{V,B}$	1.4	5.4	8.9	11.8	22.0	17.8	19.2	23.4	22.8	25.3	27.2	26.8	24.9	24.1	25.0	24.0	22.9	21.2	19.5	17.0	14.5	14.3	20.5	24.1	26.0	26.0	12.5	9.2	36.9
	Corrected $L_{V,c}$	[-1.4]	7.8*	12.8*	16.8	[20.5]	24.4	28.0	31.3	33.0	34.2	36.9	38.2	38.5	39.6	41.5	42.4	44.7	46.6	48.6	49.6	49.9	47.5	44.6	40.3	34.9	36.4	32.2	25.4	57.0
	u_c	[1.82]	1.25	0.96	0.86	[1.38]	0.74	0.70	0.77	0.69	0.68	0.67	0.65	0.61	0.59	0.58	0.57	0.56	0.55	0.56	0.58	0.58	0.57	0.57	0.57	0.69	0.69	0.63	0.62	
6	Total $L_{V,T}$	7.5	12.7	16.8	21.4	25.5	28.5	33.0	34.2	35.7	37.6	40.3	41.5	41.7	42.3	44.0	44.5	45.9	46.8	47.6	47.9	48.8	46.5	43.8	40.5	35.2	34.7	31.0	25.8	56.9
	Bgnd $L_{V,B}$	5.0	8.7	11.8	14.9	18.2	19.9	21.3	22.8	25.4	27.7	32.7	32.4	28.2	28.3	29.2	28.6	27.6	25.4	23.4	21.0	18.6	18.5	23.8	27.6	26.0	17.9	11.2	8.6	40.3
	Corrected $L_{V,c}$	[4.5]	10.5*	15.2*	20.3	24.7	27.9	32.7	33.9	35.3	37.2	39.6	40.9	41.5	42.2	43.9	44.5	45.9	46.8	47.7	47.9	48.9	46.6	43.8	40.3	34.7	34.7	31.0	25.8	56.9
	u_c	[1.88]	1.22	1.04	0.93	0.86	0.82	0.91	0.76	0.77	0.79	0.84	0.80	0.72	0.70	0.69	0.68	0.67	0.65	0.63	0.64	0.64	0.63	0.63	0.67	0.78	0.70	0.78	0.74	
7	Total $L_{V,T}$	11.6	14.2	19.5	23.4	27.0	30.2	33.3	38.2	39.1	39.1	42.5	43.6	43.7	44.6	46.2	46.9	48.4	49.0	49.2	48.4	48.8	46.3	43.9	40.9	36.1	35.1	31.6	27.4	58.3
	Bgnd $L_{V,B}$	4.8	8.6	11.6	15.2	18.5	20.5	31.0	31.2	25.8	28.4	34.3	34.4	29.5	29.1	30.3	29.8	29.1	26.8	24.8	22.5	20.1	18.4	19.1	20.0	18.7	15.5	12.1	9.8	41.8
	Corrected $L_{V,c}$	10.6	12.8*	18.7	22.8	26.4	29.8	[30.3]	37.3	38.9	38.8	41.9	43.1	43.6	44.5	46.1	46.9	48.4	49.0	49.3	48.4	48.8	46.4	43.9	40.9	36.1	35.1	31.6	27.3	58.2
	u_c	1.01	0.98	0.86	0.81	0.79	0.75	[2.53]	1.11	0.77	0.73	0.79	0.79	0.71	0.70	0.70	0.69	0.69	0.68	0.65	0.63	0.62	0.61	0.61	0.62	0.66	0.68	0.74	0.73	
8	Total $L_{V,T}$	14.0	15.4	21.2	25.0	28.3	31.4	34.7	37.1	39.2	40.3	43.4	45.0	45.3	46.1	47.7	48.5	50.0	50.7	50.6	49.3	48.9	46.6	44.3	41.6	37.7	36.5	33.1	29.2	59.5
	Bgnd $L_{V,B}$	9.6	11.2	12.9	15.7	18.9	21.1	26.6	29.9	27.2	29.3	35.0	34.0	29.9	29.6	30.8	30.5	29.9	27.9	26.1	24.1	22.3	21.0	22.1	21.9	20.2	19.1	15.7	13.0	42.1
	Corrected $L_{V,c}$	12.1*	13.4*	20.5	24.5	27.8	31.1	34.0	36.2	39.0	40.0	42.8	44.6	45.3	46.1	47.7	48.5	50.0	50.7	50.6	49.4	49.0	46.6	44.3	41.6	37.7	36.5	33.1	29.1	59.4
	u_c	1.25	1.22	0.78	0.72	0.72	0.71	0.80	0.90	0.68	0.69	0.75	0.70	0.67	0.66	0.66	0.66	0.65	0.65	0.63	0.62	0.61	0.61	0.61	0.62	0.65	0.66	0.70	0.70	
9	Total $L_{V,T}$	19.4	22.0	26.0	29.1	31.6	34.3	37.2	39.5	42.0	42.9	45.3	47.0	48.4	49.5	51.1	52.3	53.6	54.3	53.8	52.2	50.8	48.6	46.6	44.4	41.7	40.5	37.3	33.4	62.6
	Bgnd $L_{V,B}$	17.9	19.6	21.0	21.9	24.4	25.6	28.3	29.6	31.8	33.9	37.7	41.4	41.7	38.2	37.3	38.1	37.9	36.3	36.7	37.1	35.2	34.0	31.6	30.2	28.2	25.1	22.1	18.7	49.5
	Corrected $L_{V,c}$	[16.4]	[19]	24.4*	28.3	30.8	33.7	36.6	39.1	41.7	42.4	44.5	45.7*	47.4	49.2	51.0	52.2	53.6	54.3	53.7	52.1	50.7	48.5	46.5	44.3	41.6	40.4	37.3	33.3	62.3
	u_c	[2.98]	[2.99]	1.40	0.94	0.89	0.77	0.75	0.71	0.70	0.74	0.75	1.02	0.97	0.73	0.70	0.72	0.70	0.69	0.66	0.66	0.62	0.63	0.65	0.68	0.76	0.77	0.80	0.79	
10	Total $L_{V,T}$	22.4	26.3	28.9	32.3	34.1	36.7	39.6	42.2	44.6	45.3	47.5	49.3	51.7	53.1	54.8	56.4	57.6	58.2	57.2	55.5	53.4	51.7	50.5	48.8	46.8	45.6	42.5	38.3	66.1
	Bgnd $L_{V,B}$	21.3	24.3	26.3	27.1	28.0	29.8	31.0	31.9	33.5	35.2	37.4	40.5	42.9	43.4	39.6	39.8	40.3	38.6	38.7	38.6	37.1	35.6	33.9	32.4	29.8	27.2	24.1	20.6	51.3
	Corrected $L_{V,c}$	[19.5]	[23.3]	[25.9]	30.7*	32.9	35.8	39.1	41.8	44.3	44.9	47.1	48.7	51.1	52.7	54.7	56.3	57.5	58.2	57.2	55.5	53.4	51.7	50.4	48.7	46.8	45.5	42.5	38.3	66.0
	u_c	[2.1]	[2.24]	[2.08]	1.18	0.98	0.88	0.77	0.73	0.71	0.73	0.73	0.77	0.78	0.79	0.74	0.76	0.76	0.76	0.74	0.72	0.71	0.73	0.76	0.81	0.86	0.87	0.89	0.87	
11	Total $L_{V,T}$	25.5	29.0	31.5	35.3	36.4	39.0	41.8	44.2	46.6	47.3	49.6	51.5	54.3	56.0	58.0	59.7	60.8	61.3	60.3	58.6	56.6	55.3	54.5	53.1	51.4	50.0	46.9	42.5	69.3
	Bgnd $L_{V,B}$	24.2	27.0	29.0	30.5	31.4	32.2	33.1	33.8	35.2	36.7	38.4	41.0	44.7	45.9	41.6	41.5	42.3	40.7	40.6	40.5	39.8	37.9	36.1	34.9	32.1	29.5	26.7	23.1	53.3
	Corrected $L_{V,c}$	[22.6]	[26]	[28.5]	33.5*	34.7*	38.0	41.3	43.8	46.3	47.0	49.3	51.2	53.8	55.7	57.9	59.7	60.8	61.4	60.3	58.5	56.6	55.3	54.5	53.1	51.4	50.0	46.9	42.5	69.2
	u_c	[1.7]	[1.71]	[1.73]	1.19	1.10	0.91	0.81	0.76	0.75	0.76	0.77	0.79	0.82	0.84	0.79	0.80	0.79	0.78	0.77	0.77	0.79	0.82	0.88	0.91	0.94	0.93	0.95	0.93	
12	Total $L_{V,T}$	26.7	30.3	32.9	37.1	38.3	40.9	43.6	46.1	48.5	49.2	51.8	53.8	56.7	58.6	60.7	62.6	63.6	64.2	63.1	61.4	59.5	58.4	57.8	56.5	54.8	53.4	50.2	45.7	72.2
	Bgnd $L_{V,B}$	25.7	28.3	31.2	32.8	34.0	34.7	35.2	35.4	36.4	37.7	39.1	41.5	45.6	48.7	43.8	42.9	43.7	42.4	42.2	41.8	41.0	39.1	37.4	36.3	33.2	30.7	27.6	24.0	54.9
	Corrected $L_{V,c}$	[23.8]	[27.3]	[30]	35.2*	36.3*	39.7	43.0	45.8	48.2	49.0	51.6	53.6	56.4	58.2	60.7	62.6	63.6	64.2	63.1	61.4	59.5	58.4	57.8	56.5	54.8	53.4	50.2	45.7	72.1
	u_c	[1.61]	[1.6]	[1.66]	1.16	1.19	0.88	0.74	0.68	0.66	0.67	0.67	0.68	0.69	0.73	0.67	0.66	0.66	0.66	0.66	0.67	0.68	0.70	0.73	0.74	0.74	0.74	0.76	0.75	
13	Total $L_{V,T}$	28.4	32.1	35.0	38.5	39.7	42.4	45.1	47.5	49.9	50.7	53.3	55.5	58.3	60.2	62.4	64.2	65.1	65.7	64.6	63.0	61.2	60.2	59.7	58.5	56.8	55.3	52.2	47.6	73.8
	Bgnd $L_{V,B}$	26.7	29.2	31.8	32.6	34.2	35.2	35.6	35.7	37.4	37.9	39.5	41.9	45.5	49.9	44.2	43.4	44.4	43.0	42.8	42.4	42.1	39.9	38.5	37.6	33.8	31.2	28.1	24.4	55.6
	Corrected $L_{V,c}$	[25.4]	[29.1]	32.2*	37.2*	38.4*	41.6	44.6	47.3	49.7	50.5	53.2	55.3	58.1	59.8	62.4	64.2	65.1	65.7	64.6	63.0	61.2	60.2	59.8	58.5	56.8	55.4	52.2	47.6	73.7
	u_c	[1.94]	[1.99]	1.96	1.01	1.06	0.87	0.75	0.70	0.69	0.69	0.69	0.70	0.72	0.76	0.71	0.71	0.71	0.71	0.72	0.74	0.76	0.79	0.81	0.83	0.84	0.84	0.86	0.85	
14	Total $L_{V,T}$	29.4	33.0	37.0	39.5	41.7	44.2	46.9	49.1	51.3	52.4	55.2	57.6	60.7	62.5	64.8	66.5	67.3	67.9	67.0	65.6	64.1	63.4	63.1	62.0	60.3	58.8	55.6	50.9	76.3
	Bgnd $L_{V,B}$	28.2	31.9	34.1	35.6	36.4	36.9	37.3	37.3	38.5	39.3	40.7	43.1	46.1	49.4	45.4	44.1	45.0	43.6	43.6	42.8	42.9	40.9	39.9	38.3	35.2	33.0	30.1	26.4	56.2
	Corrected $L_{V,c}$	[26.4]	[30.1]	[34.1]	37.3*	40.3*	43.3	46.5	48.9	51.2	52.2	55.1	57.5	60.6	62.3	64.8	66.5	67.3	67.9	67.0	65.6	64.1	63.4	63.2	62.0	60.3	58.8	55.7	51.0	76.3
	u_c	[2.39]	[2.46]	[2.61]	1.62	1.41	1.05	0.95	0.84	0.81	0.85	0.81	0.79	0.85	0.86	0.86	0.85	0.85	0.86	0.88	0.96	1.00	1.09	1.16	1.19	1.20	1.20	1.23	1.20	
15	Total $L_{V,T}$																													
	Bgnd $L_{V,B}$	26.3	30.8	31.4	31.7	33.7	33.6	35.0	35.3	37.2	38.8	40.2	42.7	45.0	47.3	43.9	43.6	44.1	43.0	43.0	42.2	41.6	39.8	38.2	37.2	34.0	31.8	29.0	25.3	54.9
	Corrected $L_{V,c}$																													
	u_c																													

TABLE 5 TONAL AUDIBILITY RESULT FOR EACH WIND SPEED BIN

Wind Speed Bin at Rotor Centre (m/s)	Frequency (Hz)	Critical Bandwidth (Hz)	Tonality ΔL_k	Tonal Audibility $\Delta L_{a,k}$
3	No Relevant Tones at c. 2 or at c. 4 kHz			
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				

Wind Speed Bin at Rotor Centre (m/s)	Frequency (Hz)	Critical Bandwidth (Hz)	Tonality ΔL_k	Tonal Audibility $\Delta L_{a,k}$
3	c. 6080	No Relevant Tones at c. 6 kHz		
4	c. 6080			
5	c. 6080	1180	3.2	2.1
6	c. 6080	No Further Relevant Tones at c. 6 kHz		
7	c. 6080			
8	c. 6080			
9	c. 6080			
10	c. 6080			
11	c. 6080			
12	c. 6080			
13	c. 6080			

Wind Speed Bin at Rotor Centre (m/s)	Frequency (Hz)	Critical Bandwidth (Hz)	Tonality ΔL_k	Tonal Audibility $\Delta L_{a,k}$
3	c. 8100	No Relevant Tones at c. 8 kHz		
4	c. 8100	1750	3.3	2.1
5	c. 8100	1750	6.4	4.3
6	c. 8100	1750	3.8	2.4
7	c. 8100	No Further Relevant Tones at c. 8 kHz		
8	c. 8100			
9	c. 8100			
10	c. 8100			
11	c. 8100			
12	c. 8100			
13	c. 8100			

FIGURE 1 PHOTOGRAPH SHOWING ACOUSTIC TEST ARRANGEMENT

The Quattro Signal Analyser is connected to the Laptop via a USB lead. A special connector with BNC fittings at one end and a mini jack plug at the other links the output of the laptop (the headphones socket) to the input port of the Quattro (marked "IN 1"). As the recording is played back on the laptop it is directed through the signal analyser which generates a Fast Fourier Transform (FFT) of the signal.

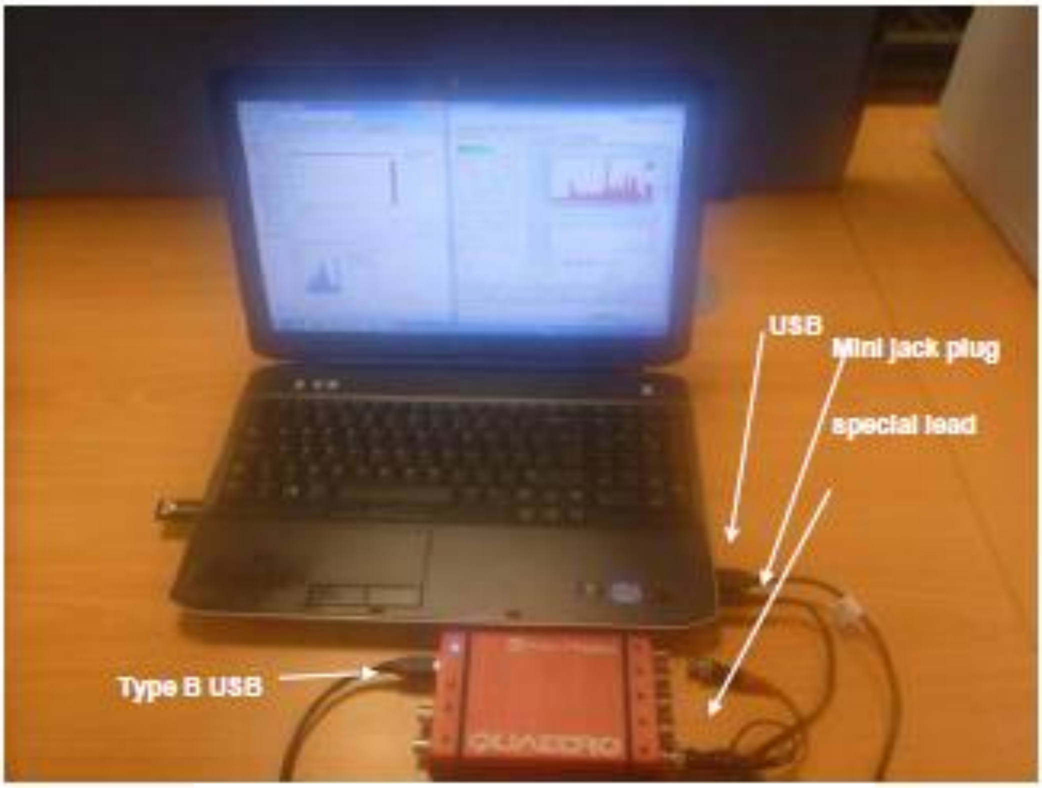
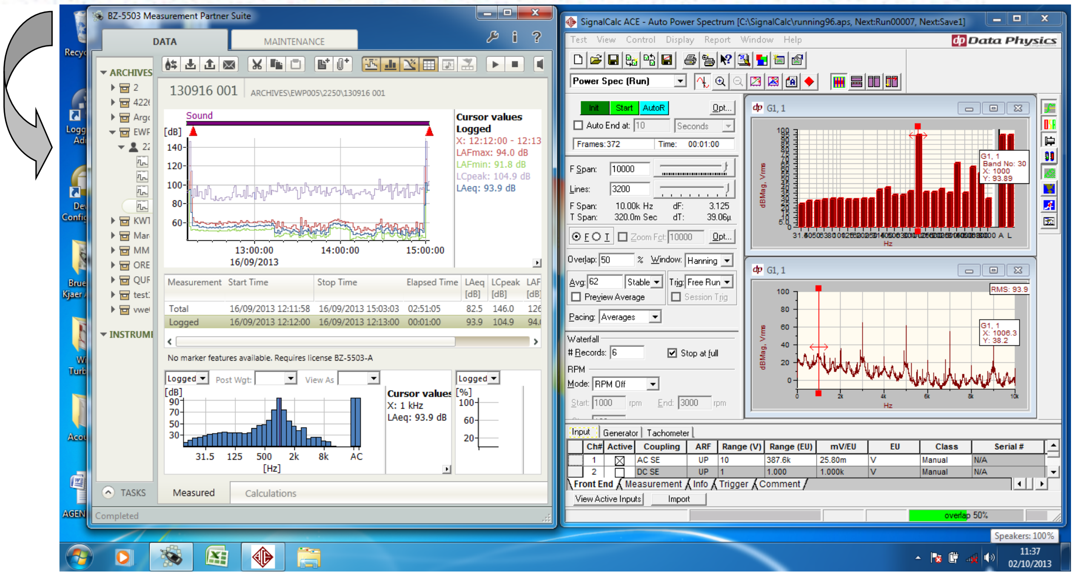


Figure 2 – Analysis System Configuration

B&K BZ-5503 software is used to playback the recorded signal and SignalCalc Ace software to interface with the Quattro. Both software packages have to be opened to generate the FFT data.

The playback software window is shown on the left and the signal analyser, (FFT) window, on the right. In this particular example, the FFT software has been set up to analyse one-minute of noise data in ten-second chunks. The actual noise signal is from an actual test on a turbine and shows the calibration check (94 dB and 1 kHz) carried out at the beginning of campaign.



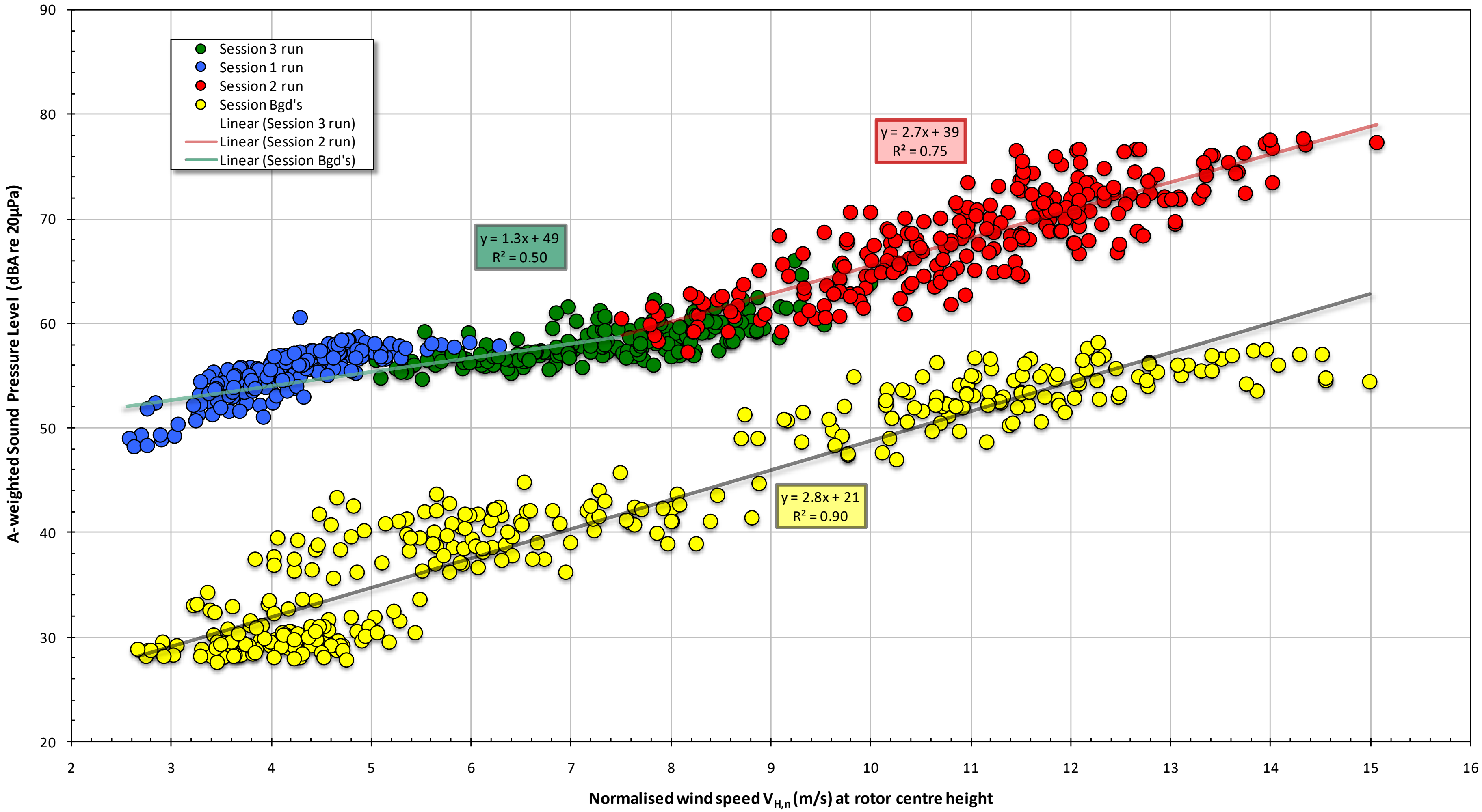
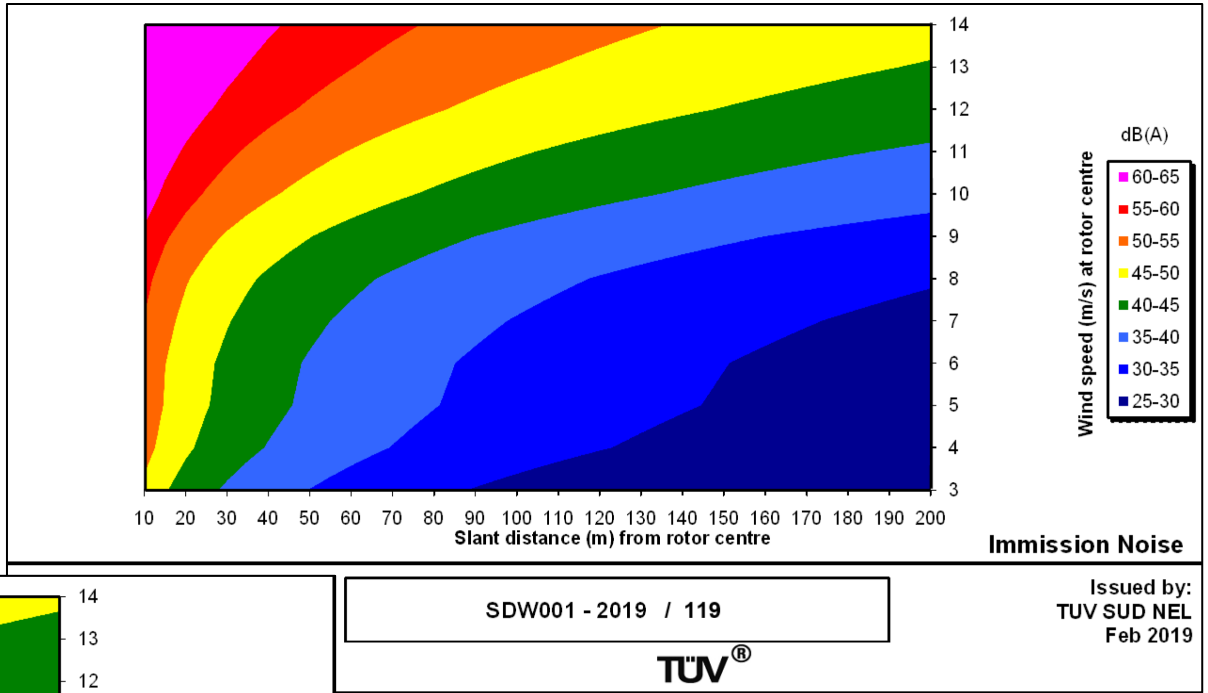


FIGURE 3 AUDIBLE NOISE (AS MEASURED AT THE GROUND BOARD) AS A FUNCTION OF WIND SPEED AT 9 M ABOVE GROUND LEVEL (Rotor Centre Height/ Hub Height)

FIGURE 4 IMMISSION NOISE MAP

(Based on Wind Speeds at Rotor Centre Ht.)



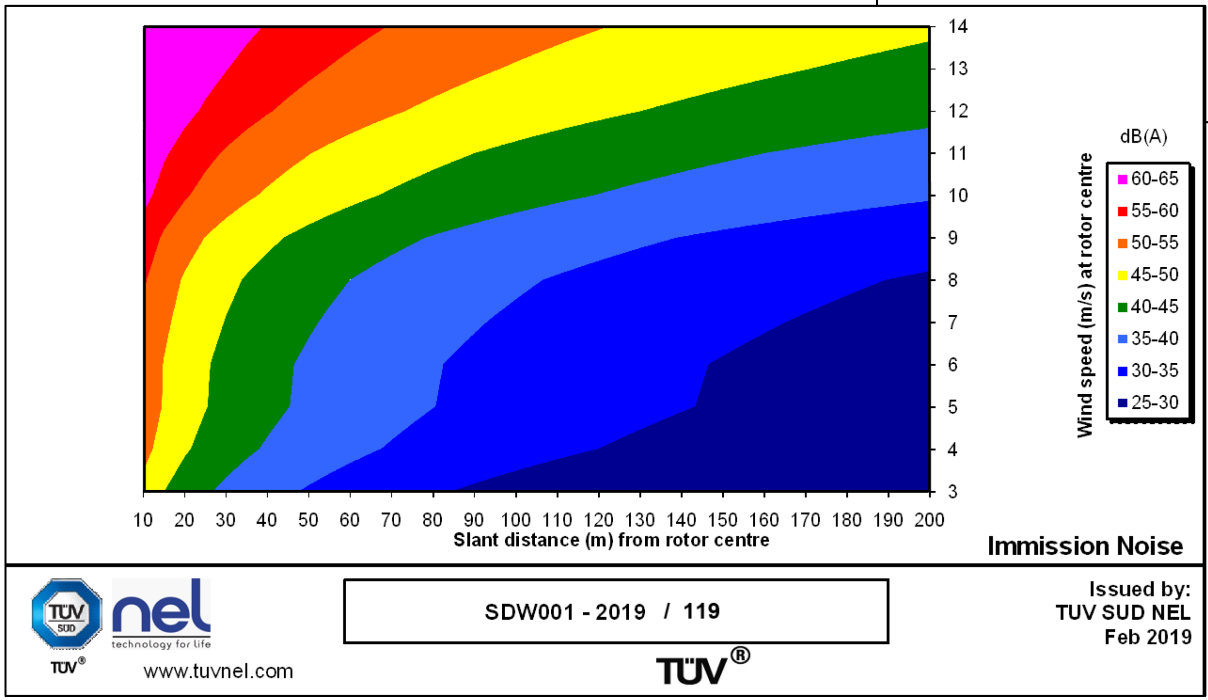
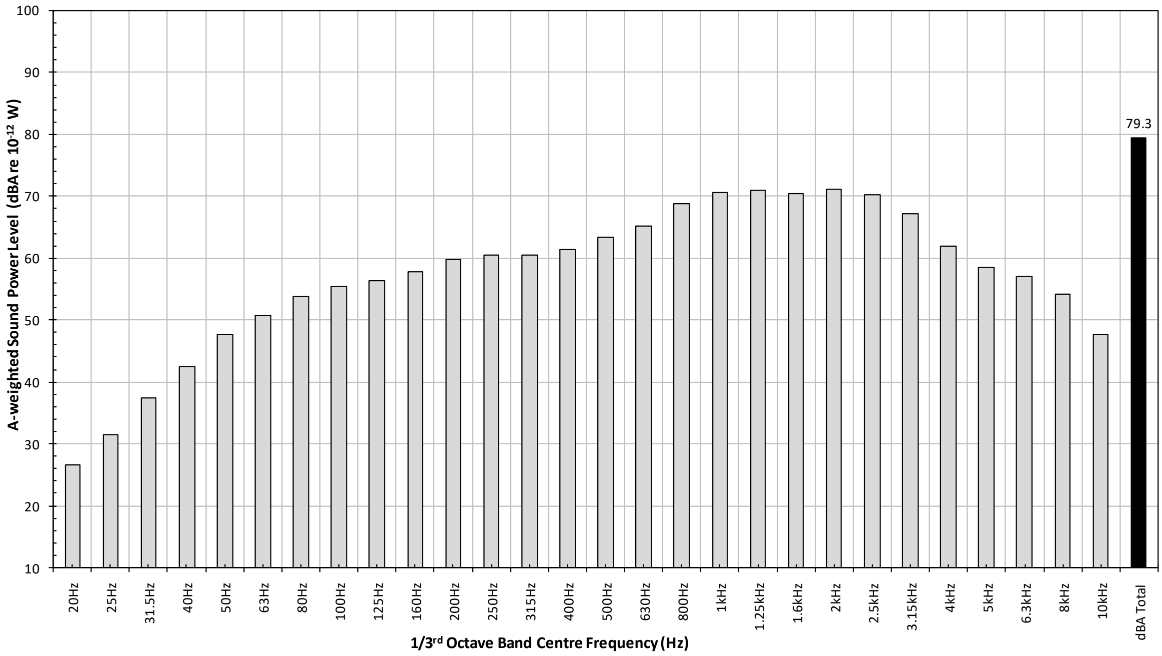


FIGURE 5 IMMISSION NOISE MAP

(Based on Reference Wind Speeds @ 10 m Ht. a.g.l.)

A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 3. m/s at Rotor Centre Height

1/3rd Octave Band Centre Frequency																												
20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1kHz	1.25kHz	1.6kHz	2kHz	2.5kHz	3.15kHz	4kHz	5kHz	6.3kHz	8kHz	10kHz	dBA Total
26.6	31.4	37.5	42.5	[47.7]	50.8	53.8	55.4	56.4	57.8	59.7	60.5	60.5	61.4	63.4	65.1	68.8	70.5	71	70.4	71.1	70.2	67.1	62	58.5	57.1	54.2	47.7	79.3



A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 3. m/s at Rotor Centre Height

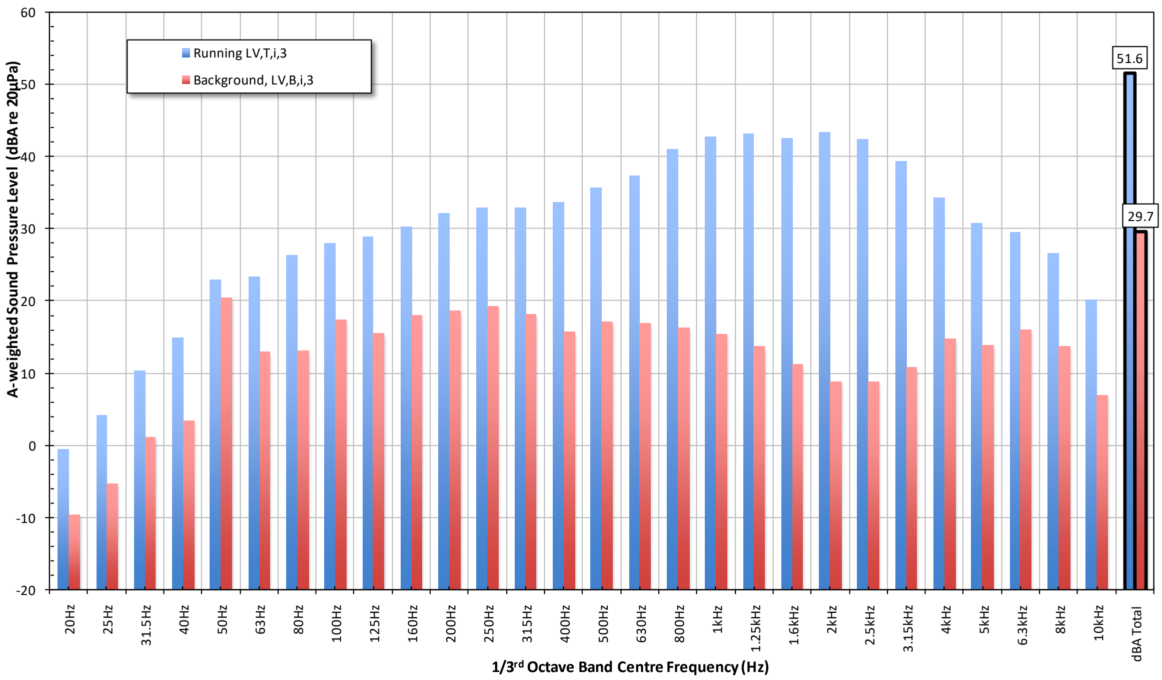
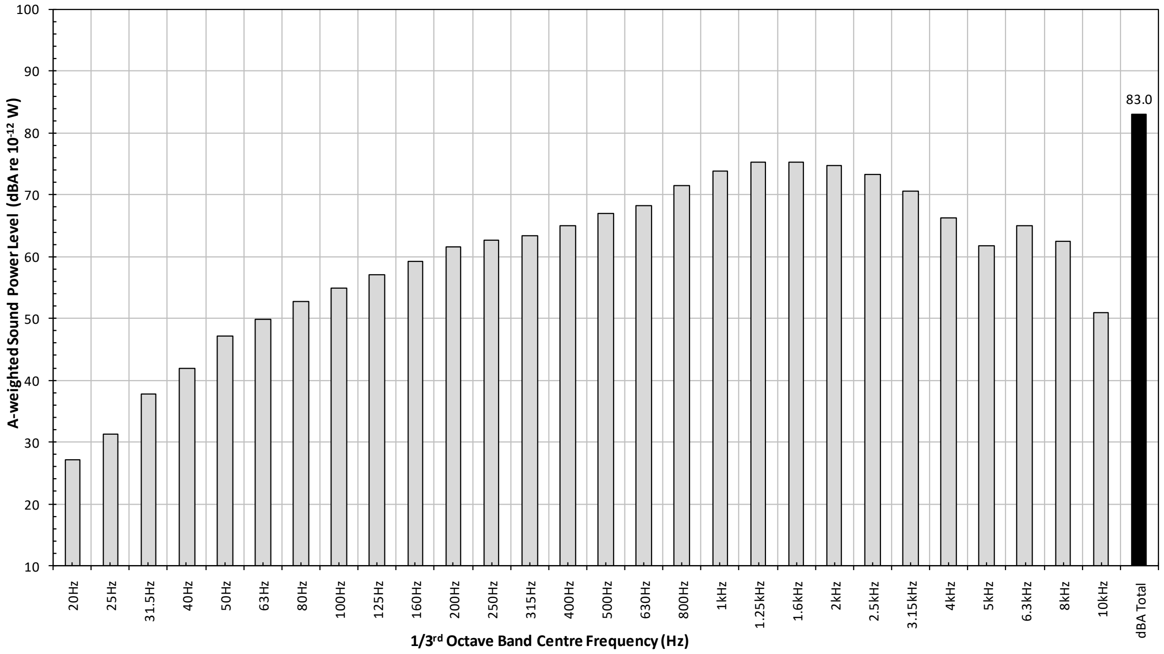


FIGURE 6 A-WEIGHTED 1/3 OCTAVE BAND SOUND POWER LEVELS (& SPL) FOR 3 m/s WIND SPEED BIN AT ROTOR CENTRE HEIGHT

A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 4. m/s at Rotor Centre Height

1/3rd Octave Band Centre Frequency																												
20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1kHz	1.25kHz	1.6kHz	2kHz	2.5kHz	3.15kHz	4kHz	5kHz	6.3kHz	8kHz	10kHz	dBA Total
27.1	31.3	37.8	41.9	[47.1]	49.8	52.7	54.9	57.1	59.2	61.5	62.7	63.3	64.9	66.9	68.2	71.5	73.8	75.3	75.2	74.8	73.3	70.6	66.2	61.8	64.9	62.5	50.9	83.0



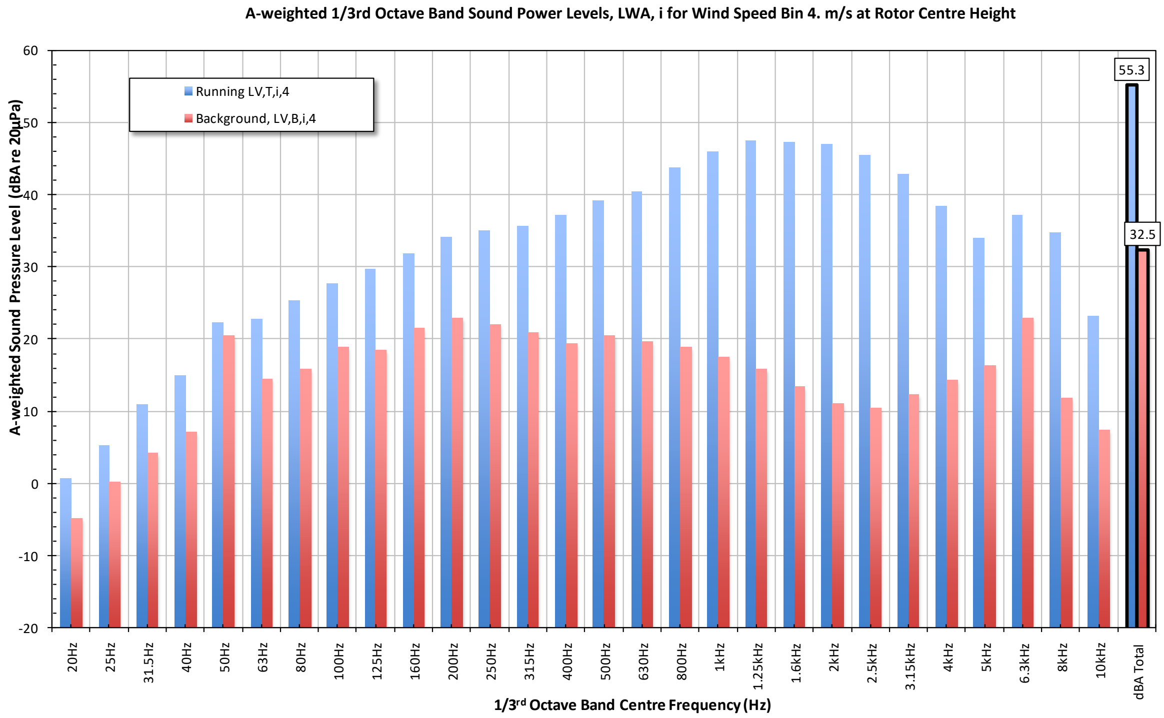
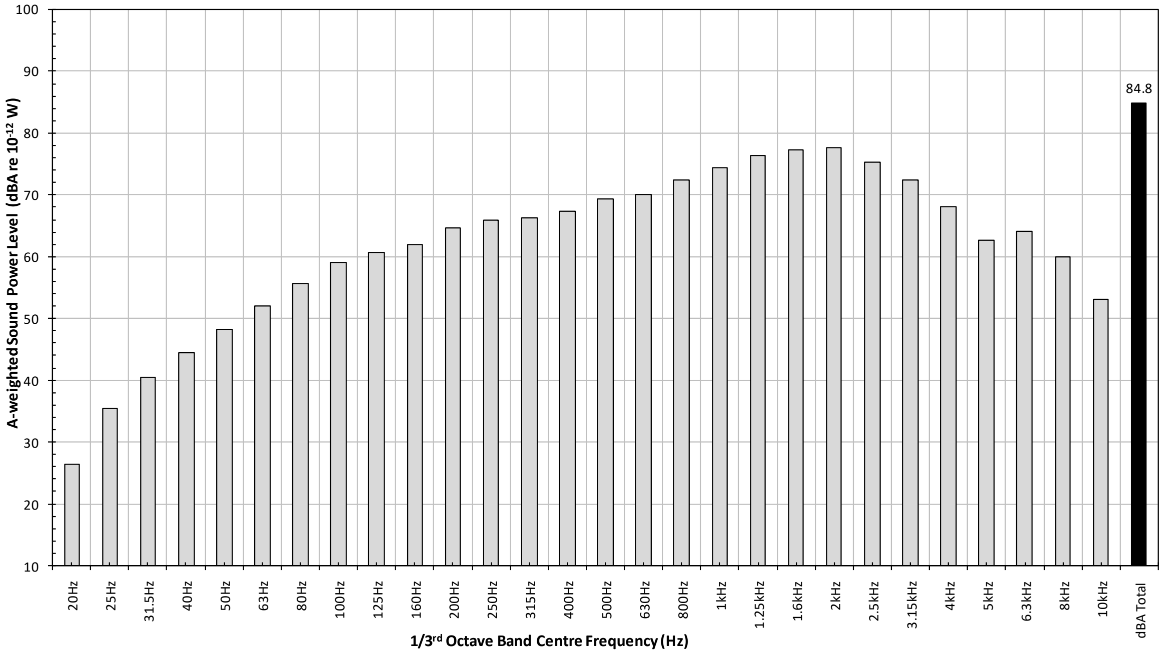


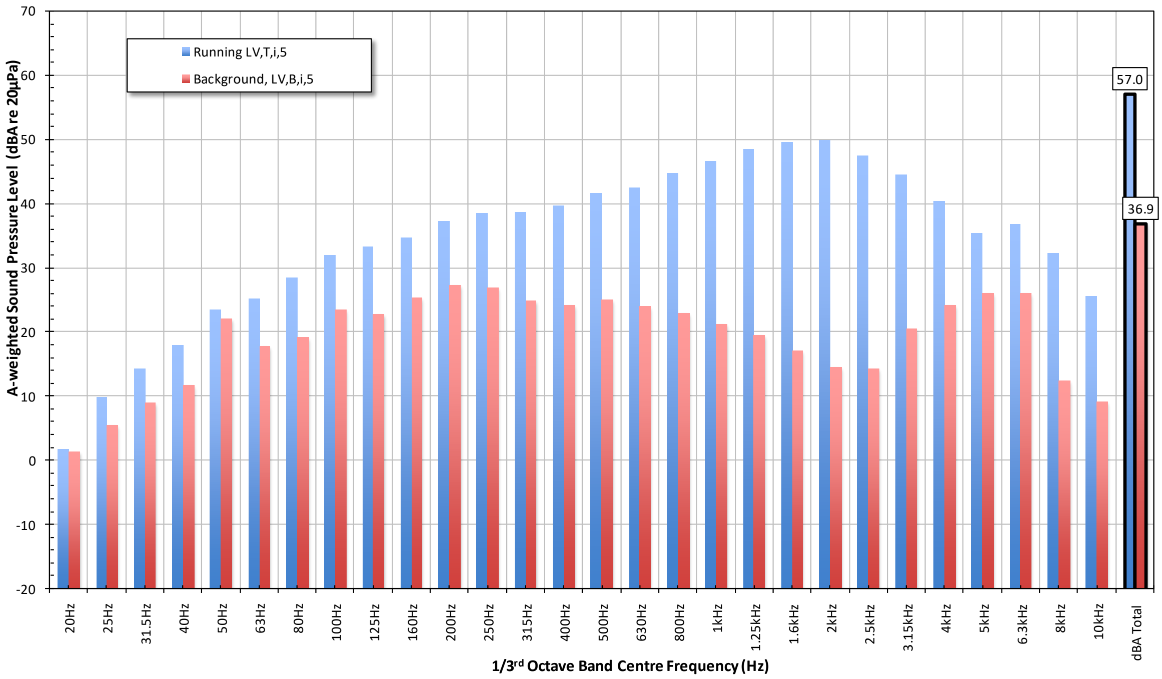
FIGURE 7 A-WEIGHTED 1/3 OCTAVE BAND SOUND POWER LEVELS (& SPL) FOR 4 m/s WIND SPEED BIN AT ROTOR CENTRE HEIGHT

A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 5. m/s at Rotor Centre Height

1/3rd Octave Band Centre Frequency																												
20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1kHz	1.25kHz	1.6kHz	2kHz	2.5kHz	3.15kHz	4kHz	5kHz	6.3kHz	8kHz	10kHz	dBA Total
[26.5]	35.5	40.5	44.5	[48.2]	52.1	55.7	59	60.7	61.9	64.7	65.9	66.2	67.3	69.3	70.1	72.4	74.4	76.4	77.3	77.6	75.2	72.3	68.1	62.6	64.1	59.9	53.1	84.8



A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 4. m/s at Rotor Centre Height

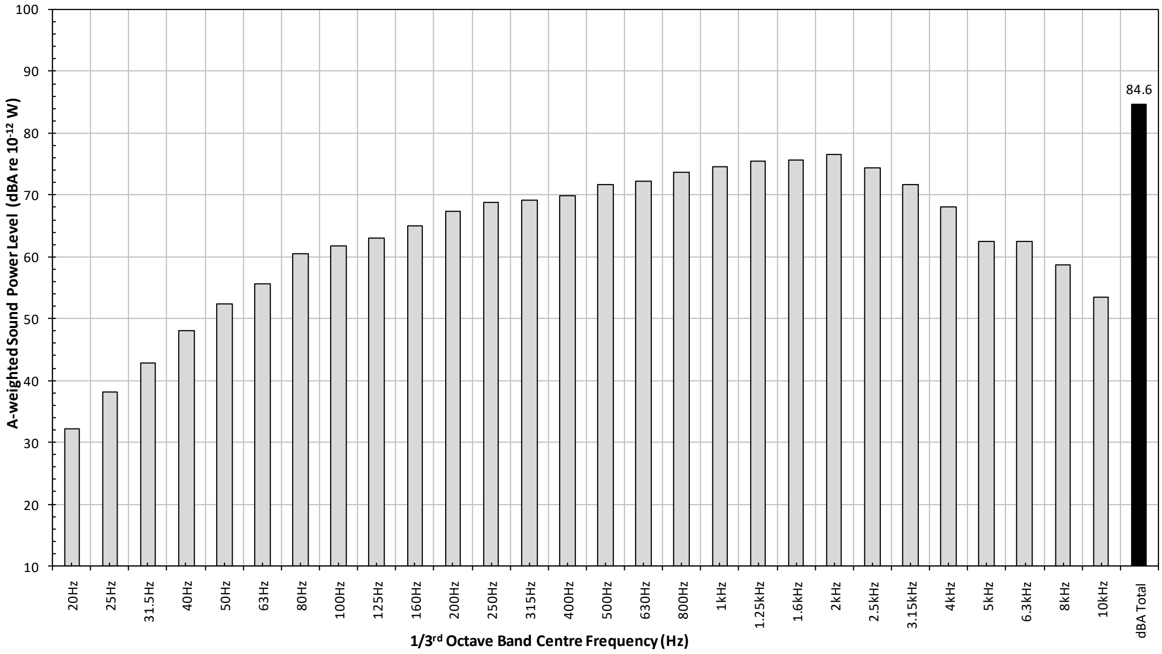


Normalised A-weighted 1/3rd Octave Band Spectra at Wind Bin 6. m/s

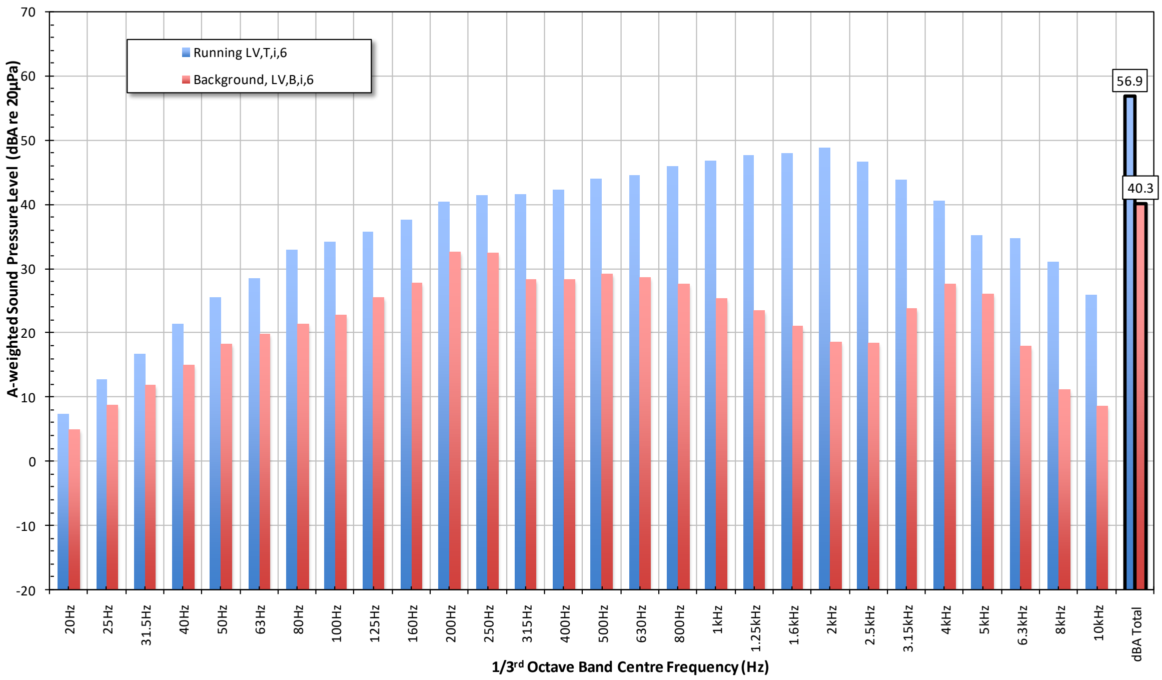
FIGURE 8 A-WEIGHTED 1/3 OCTAVE BAND SOUND POWER LEVELS (& SPL) FOR 5 m/s WIND SPEED BIN AT ROTOR CENTRE HEIGHT

A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 6. m/s at Rotor Centre Height

1/3rd Octave Band Centre Frequency																												
20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1kHz	1.25kHz	1.6kHz	2kHz	2.5kHz	3.15kHz	4kHz	5kHz	6.3kHz	8kHz	10kHz	dBA Total
[32.2]	38.2	42.9	48	52.4	55.6	60.4	61.7	63	65	67.3	68.7	69.2	69.9	71.6	72.2	73.6	74.5	75.4	75.7	76.6	74.3	71.6	68.1	62.4	62.4	58.7	53.5	84.6



A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 6. m/s at Rotor Centre Height

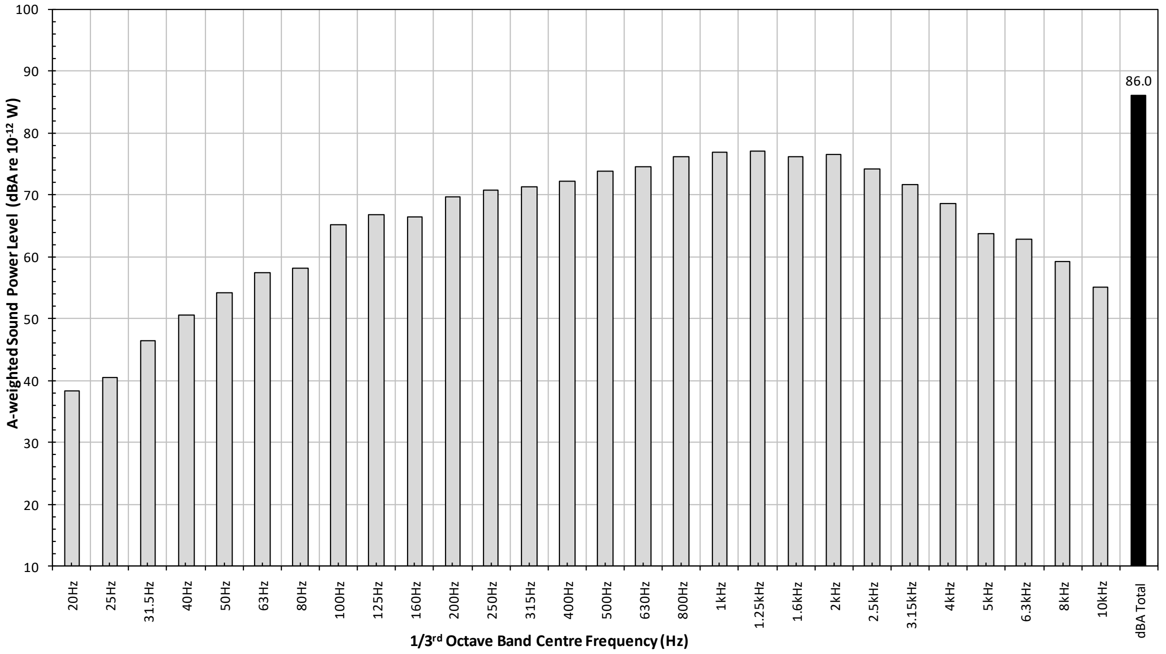


Normalised A-weighted 1/3rd Octave Band Spectra at Wind Bin 6. m/s

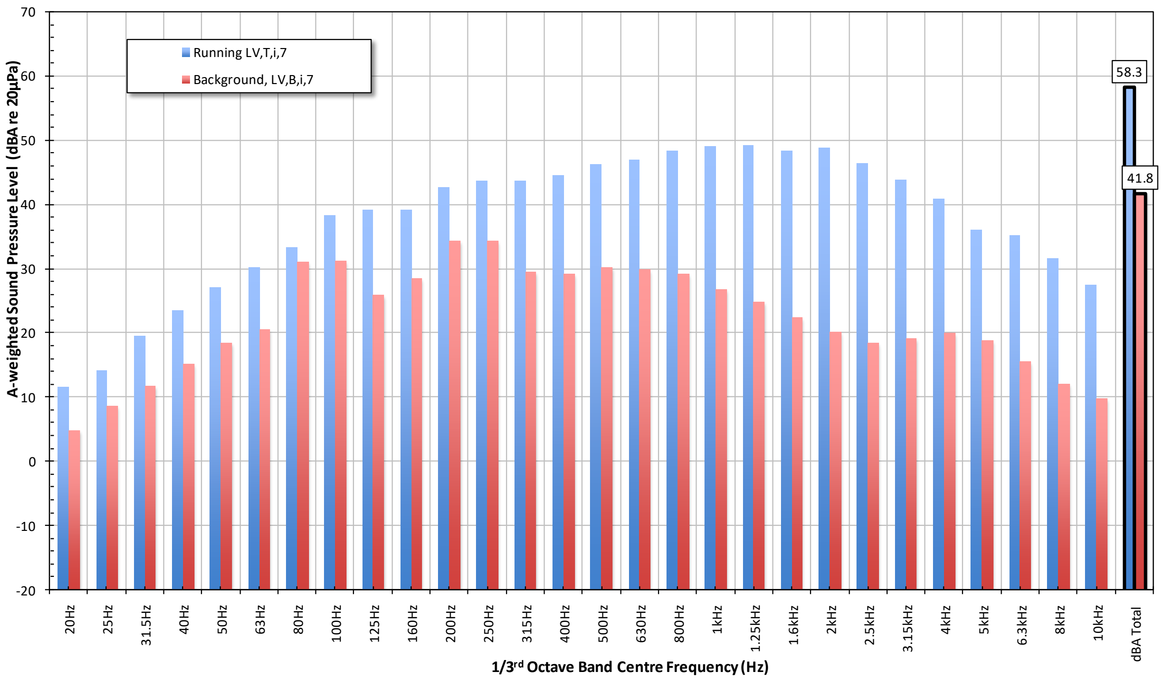
FIGURE 9 A-WEIGHTED 1/3 OCTAVE BAND SOUND POWER LEVELS (& SPL) FOR 6 m/s WIND SPEED BIN AT ROTOR CENTRE HEIGHT

A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 7. m/s at Rotor Centre Height

1/3rd Octave Band Centre Frequency																												
20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1kHz	1.25kHz	1.6kHz	2kHz	2.5kHz	3.15kHz	4kHz	5kHz	6.3kHz	8kHz	10kHz	dBA Total
38.4	40.5	46.5	50.5	54.1	57.5	[58.1]	65.1	66.7	66.5	69.6	70.8	71.3	72.2	73.8	74.6	76.1	76.8	77	76.2	76.6	74.1	71.7	68.6	63.8	62.8	59.3	55.1	86.0



A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 7. m/s at Rotor Centre Height

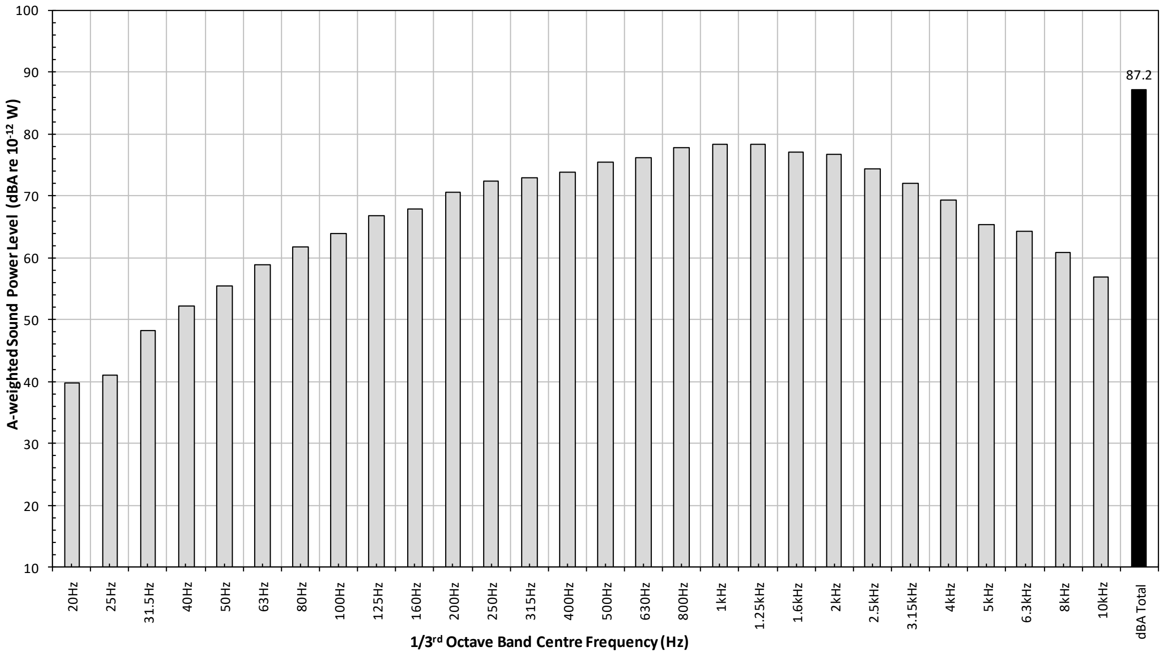


Normalised A-weighted 1/3rd Octave Band Spectra at Wind Bin 7. m/s

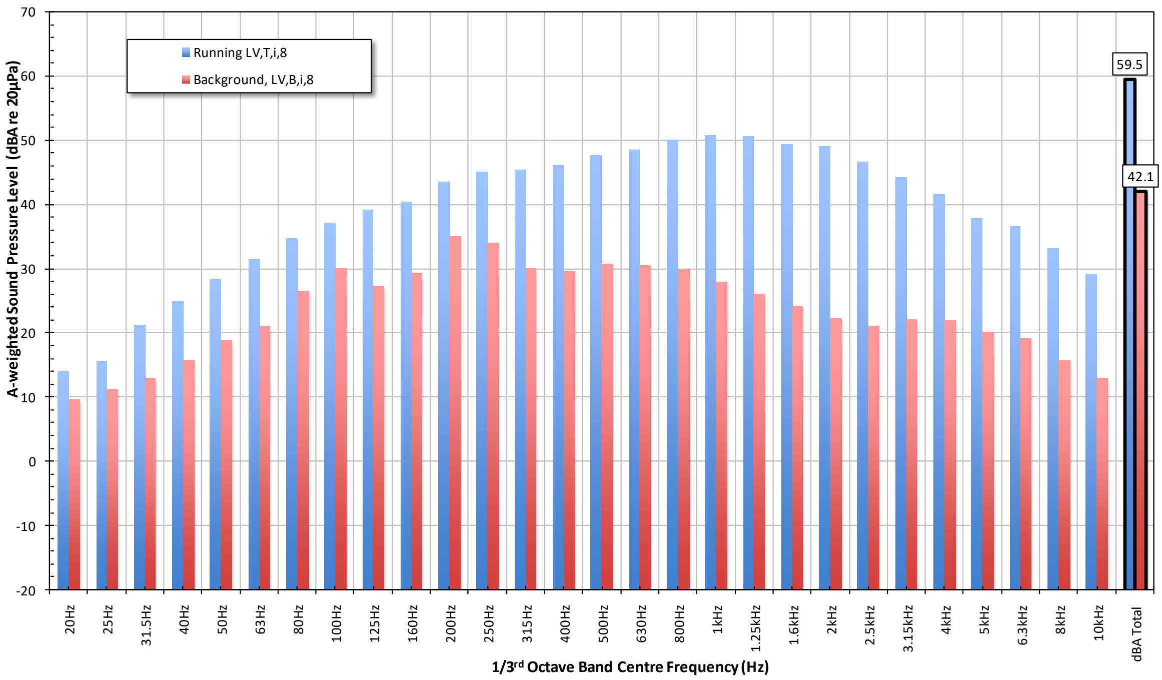
FIGURE 10 A-WEIGHTED 1/3 OCTAVE BAND SOUND POWER LEVELS (& SPL) FOR 7 m/s WIND SPEED BIN AT ROTOR CENTRE HEIGHT

A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 8. m/s at Rotor Centre Height

1/3rd Octave Band Centre Frequency																												
20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1kHz	1.25kHz	1.6kHz	2kHz	2.5kHz	3.15kHz	4kHz	5kHz	6.3kHz	8kHz	10kHz	dBA Total
39.8	41.1	48.2	52.2	55.5	58.8	61.7	63.9	66.7	67.8	70.5	72.4	73	73.8	75.4	76.2	77.7	78.4	78.4	77.1	76.7	74.3	72	69.3	65.4	64.2	60.8	56.8	87.2



A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 8. m/s at Rotor Centre Height

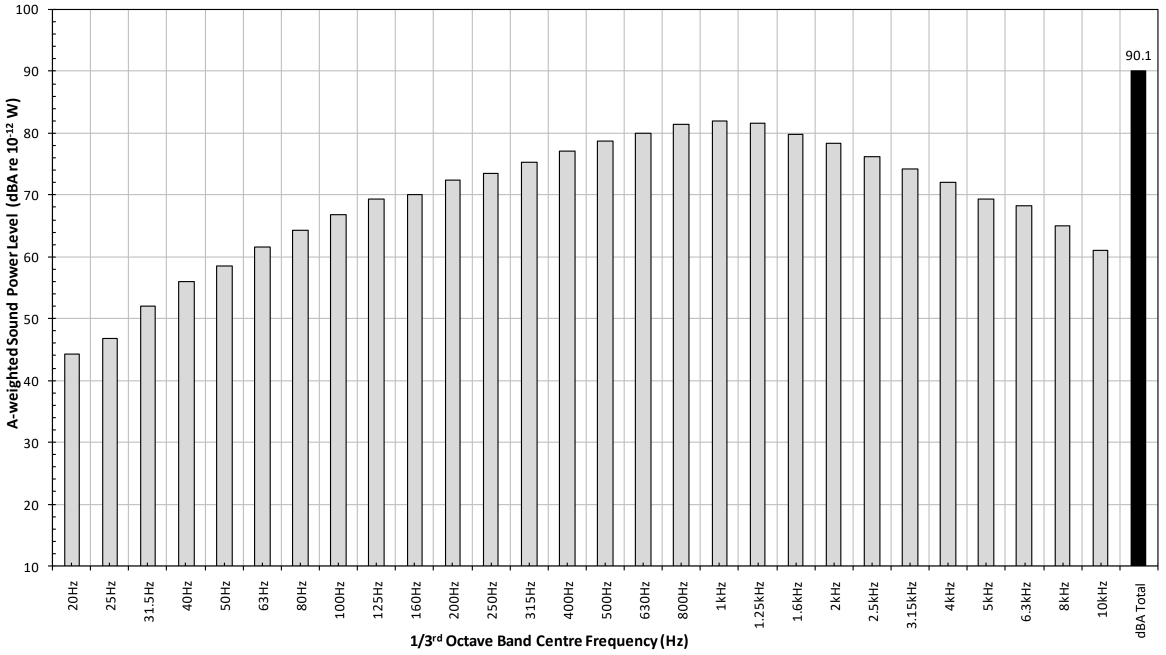


Normalised A-weighted 1/3rd Octave Band Spectra at Wind Bin 8. m/s

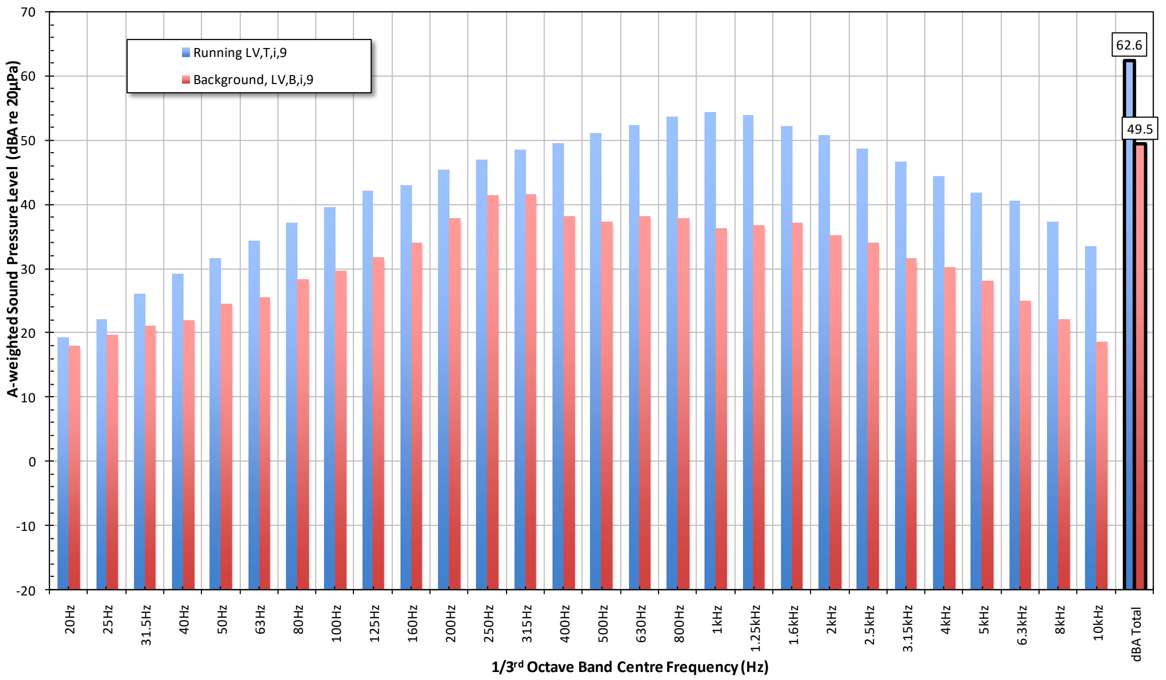
FIGURE 11 A-WEIGHTED 1/3 OCTAVE BAND SOUND POWER LEVELS (& SPL) FOR 8 m/s WIND SPEED BIN AT ROTOR CENTRE HEIGHT

A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 9. m/s at Rotor Centre Height

1/3rd Octave Band Centre Frequency																												
20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1kHz	1.25kHz	1.6kHz	2kHz	2.5kHz	3.15kHz	4kHz	5kHz	6.3kHz	8kHz	10kHz	dBA Total
[44.2]	[46.8]	52.1	56	58.5	61.5	64.3	66.8	69.4	70.1	72.3	73.4	75.2	77	78.7	79.9	81.3	82	81.5	79.8	78.4	76.2	74.2	72	69.3	68.2	65	61.1	90.1



A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 9. m/s at Rotor Centre Height

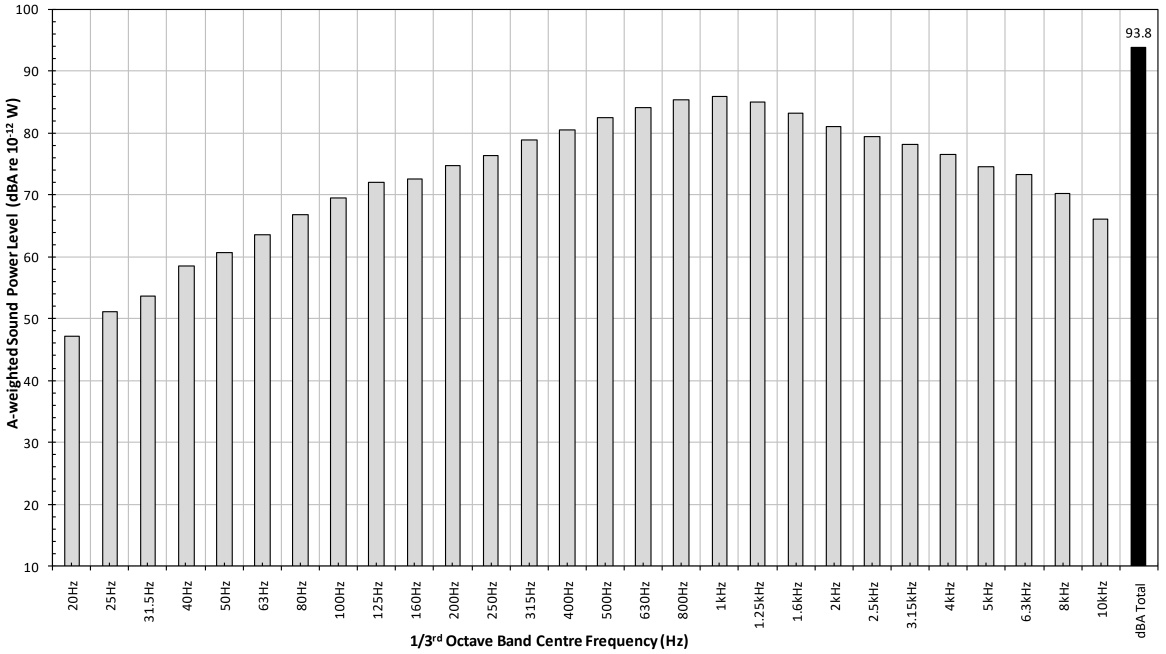


Normalised A-weighted 1/3rd Octave Band Spectra at Wind Bin 9. m/s

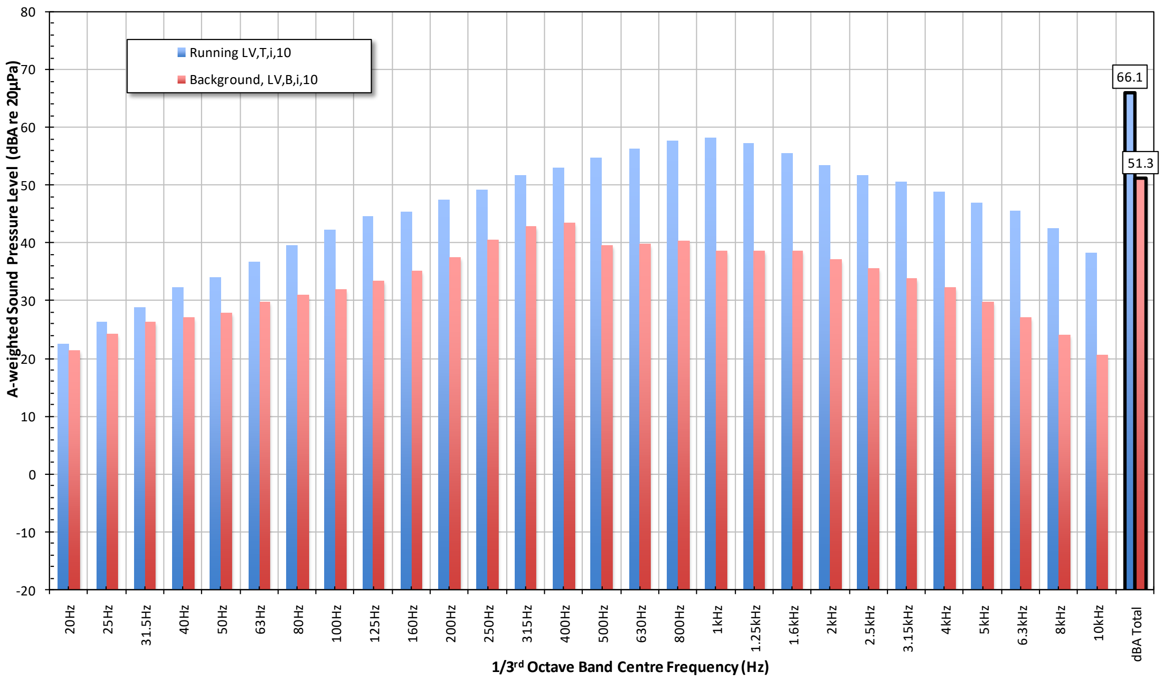
FIGURE 12 A-WEIGHTED 1/3 OCTAVE BAND SOUND POWER LEVELS (& SPL) FOR 9 m/s WIND SPEED BIN AT ROTOR CENTRE HEIGHT

A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 10. m/s at Rotor Centre Height

1/3rd Octave Band Centre Frequency																											
20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1kHz	1.25kHz	1.6kHz	2kHz	2.5kHz	3.15kHz	4kHz	5kHz	6.3kHz	8kHz	10kHz	dBA Total
[47.2]	[51.1]	[53.7]	58.5	60.6	63.6	66.8	69.5	72	72.6	74.8	76.4	78.9	80.4	82.4	84.1	85.3	85.9	85	83.2	81.1	79.4	78.1	76.5	74.5	73.3	70.2	66	93.8



A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 10. m/s at Rotor Centre Height

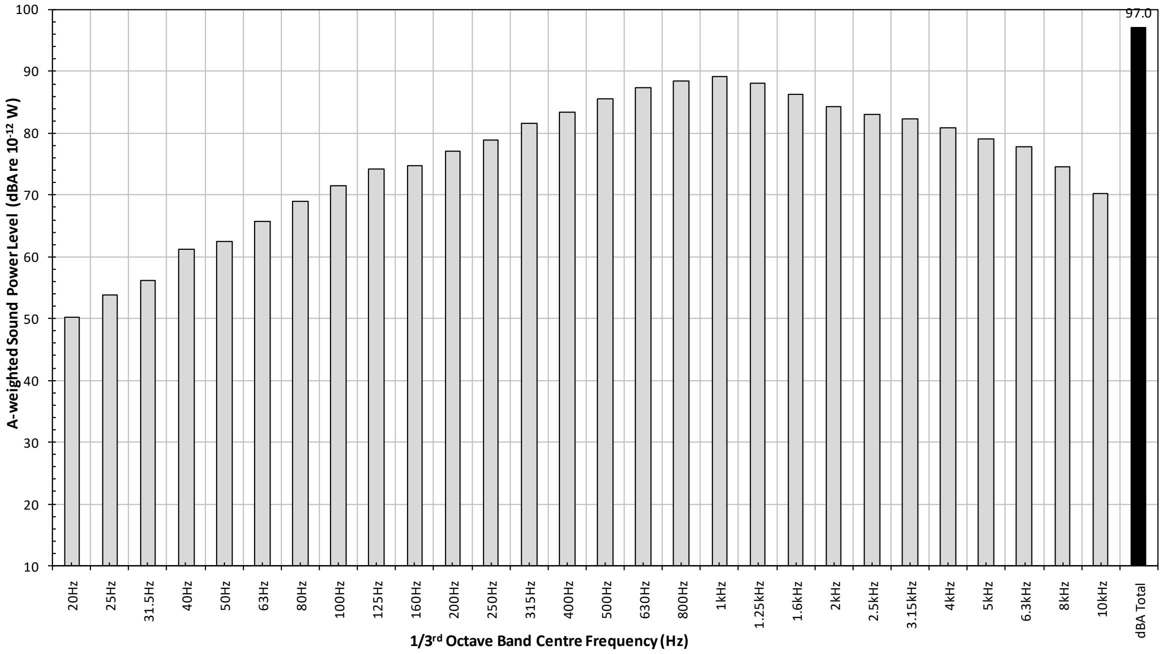


Normalised A-weighted 1/3rd Octave Band Spectra at Wind Bin 10. m/s

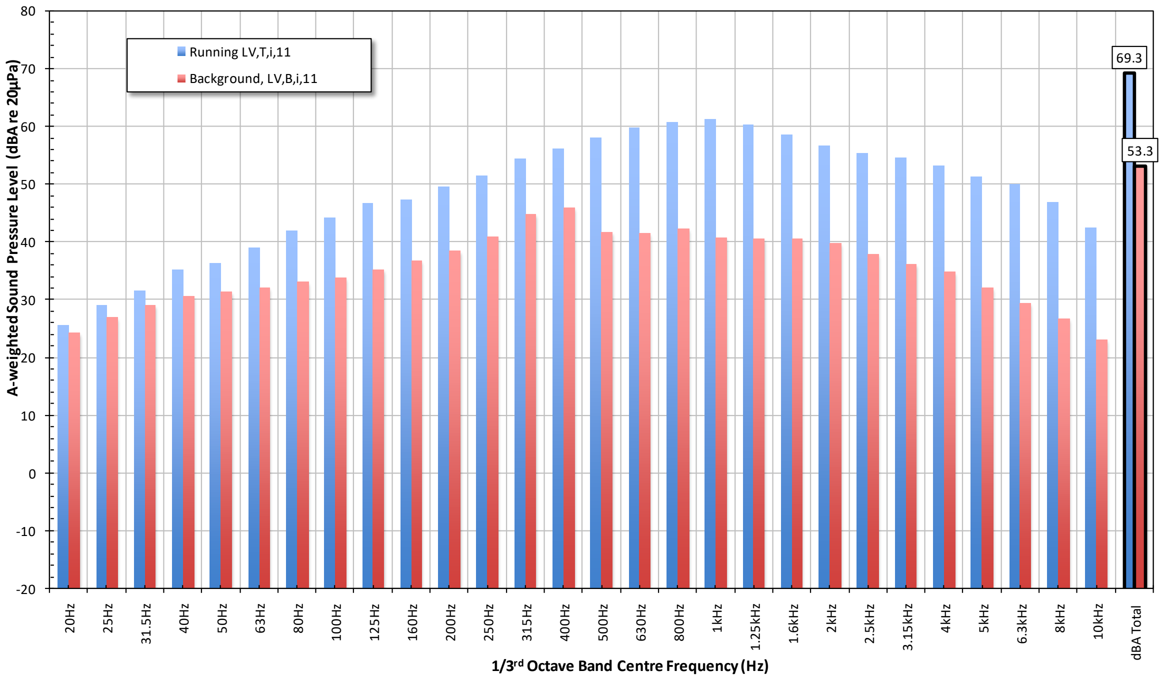
FIGURE 13 A-WEIGHTED 1/3 OCTAVE BAND SOUND POWER LEVELS (& SPL) FOR 10 m/s WIND SPEED BIN AT ROTOR CENTRE HEIGHT

A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 11. m/s at Rotor Centre Height

1/3rd Octave Band Centre Frequency																											
20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1kHz	1.25kHz	1.6kHz	2kHz	2.5kHz	3.15kHz	4kHz	5kHz	6.3kHz	8kHz	10kHz	dBA Total
[50.3]	[53.8]	[56.2]	61.2	62.5	65.7	69	71.5	74.1	74.7	77.1	78.9	81.6	83.4	85.6	87.4	88.5	89.1	88	86.3	84.3	83	82.2	80.9	79.1	77.8	74.6	70.2	97.0



A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 11. m/s at Rotor Centre Height

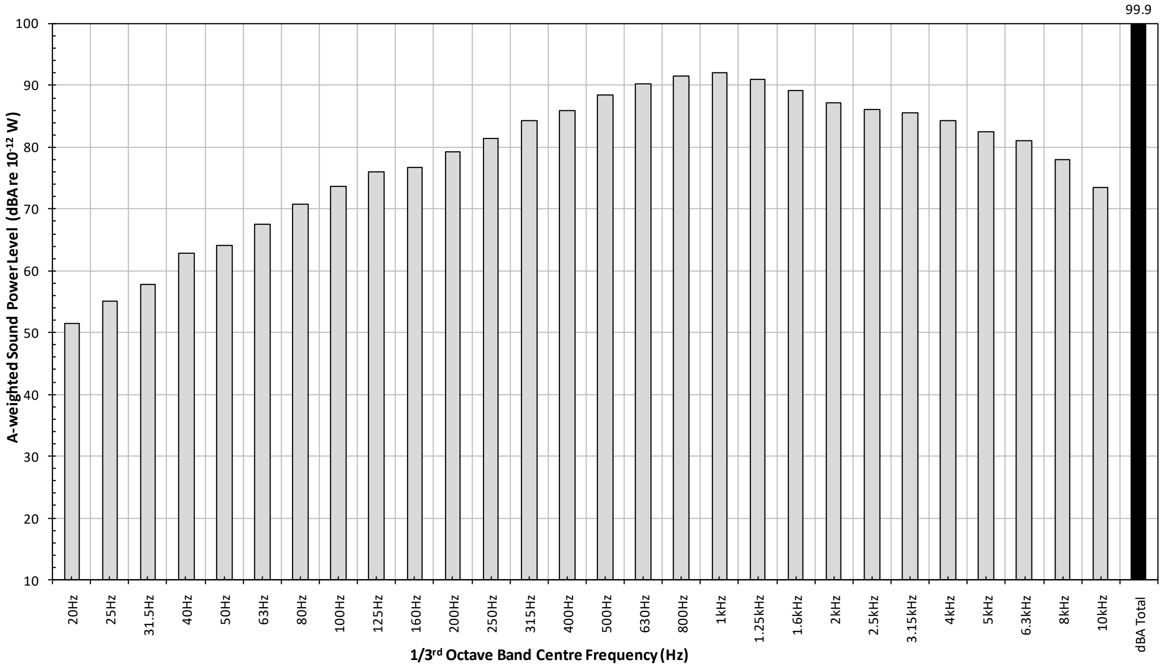


Normalised A-weighted 1/3rd Octave Band Spectra at Wind Bin 11. m/s

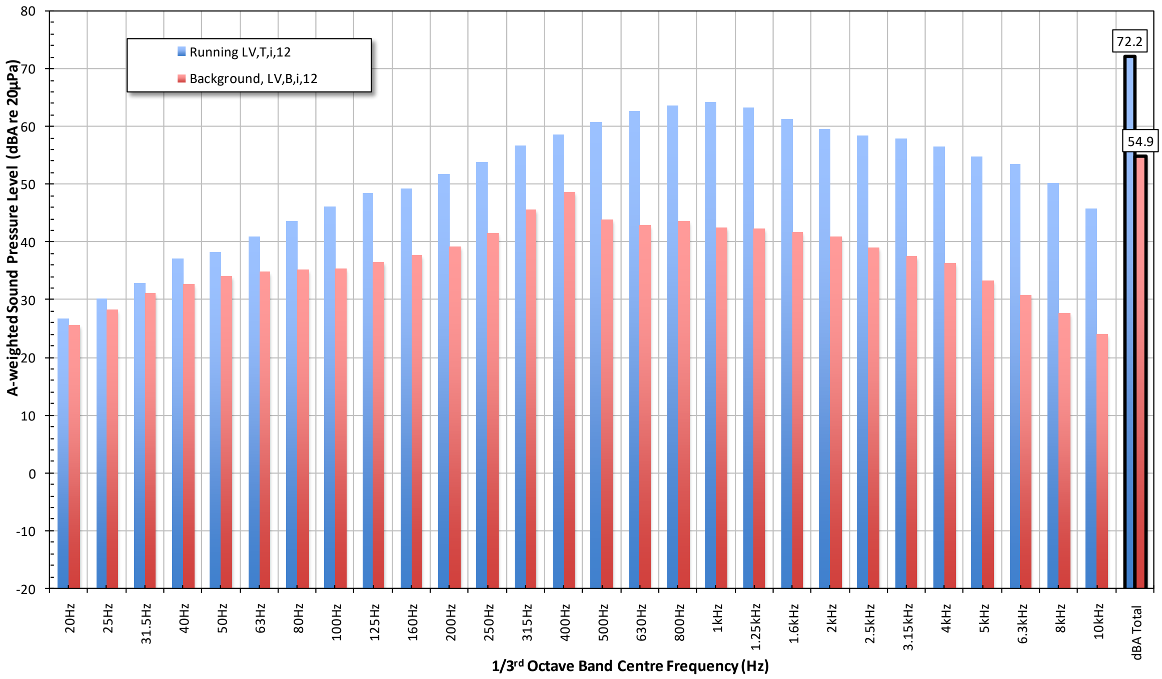
FIGURE 14 A-WEIGHTED 1/3 OCTAVE BAND SOUND POWER LEVELS (& SPL) FOR 11 m/s WIND SPEED BIN AT ROTOR CENTRE HEIGHT

A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 12. m/s at Rotor Centre Height

1/3rd Octave Band Centre Frequency																											
20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1kHz	1.25kHz	1.6kHz	2kHz	2.5kHz	3.15kHz	4kHz	5kHz	6.3kHz	8kHz	10kHz	dBA Total
[51.5]	[55.1]	[57.7]	62.9	64	67.5	70.7	73.6	76	76.7	79.3	81.4	84.2	85.9	88.4	90.3	91.4	92	90.9	89.1	87.2	86.1	85.5	84.2	82.5	81.1	78	73.4	99.9



A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 12. m/s at Rotor Centre Height

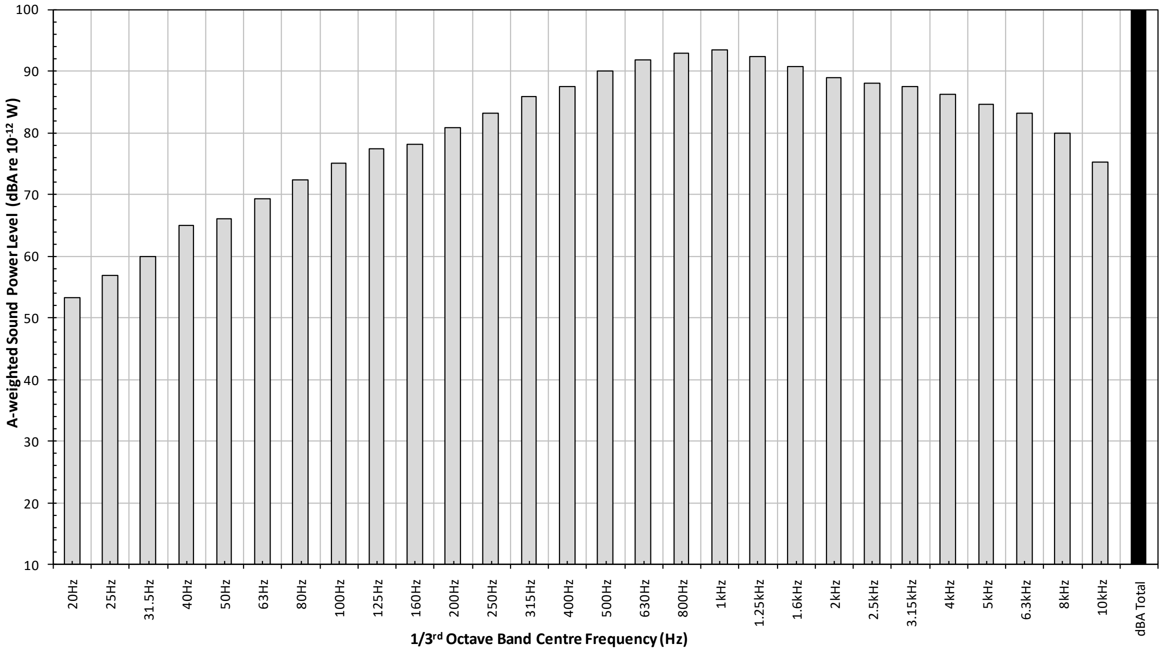


Bin Centre A-weighted 1/3rd Octave Band Sound Pressure Levels and uncertainty values for Rotor Centre Height Wind Speeds

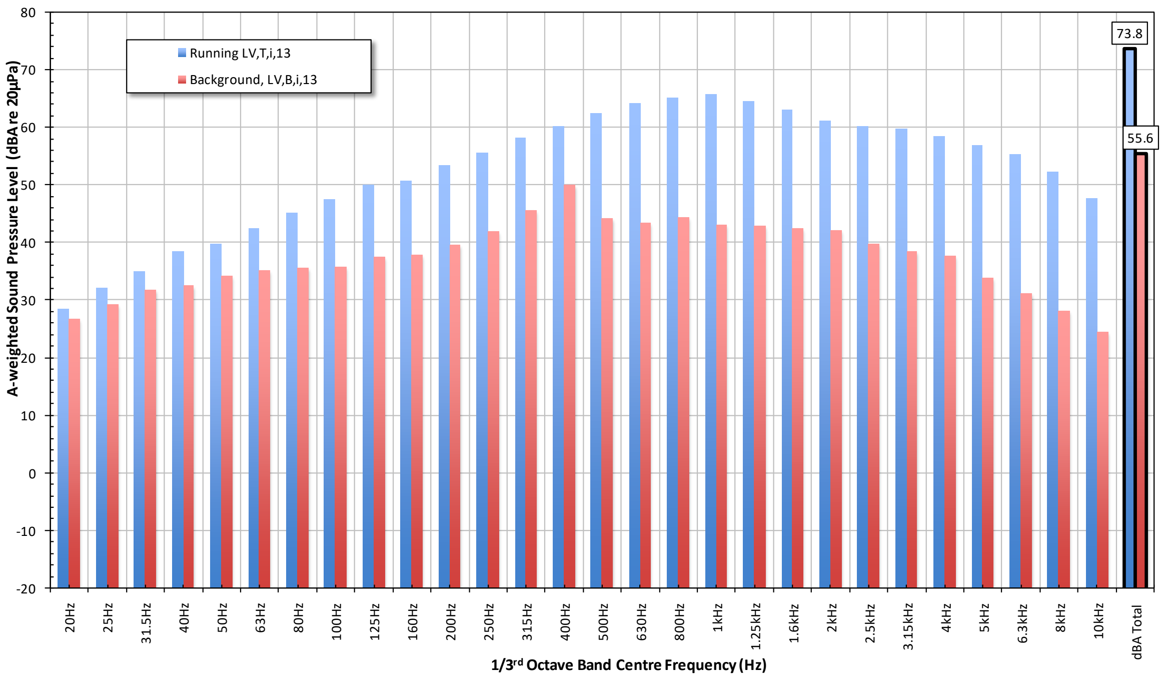
FIGURE 15 A-WEIGHTED 1/3 OCTAVE BAND SOUND POWER LEVELS (& SPL) FOR 12 m/s WIND SPEED BIN AT ROTOR CENTRE HEIGHT

A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 13. m/s at Rotor Centre Height

1/3rd Octave Band Centre Frequency																												
20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1kHz	1.25kHz	1.6kHz	2kHz	2.5kHz	3.15kHz	4kHz	5kHz	6.3kHz	8kHz	10kHz	dBA Total
[53.2]	[56.9]	59.9	65	66.1	69.3	72.4	75	77.5	78.2	80.9	83.1	85.8	87.5	90.1	91.9	92.9	93.4	92.4	90.7	88.9	88	87.5	86.2	84.6	83.1	80	75.3	101.5



A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 13. m/s at Rotor Centre Height

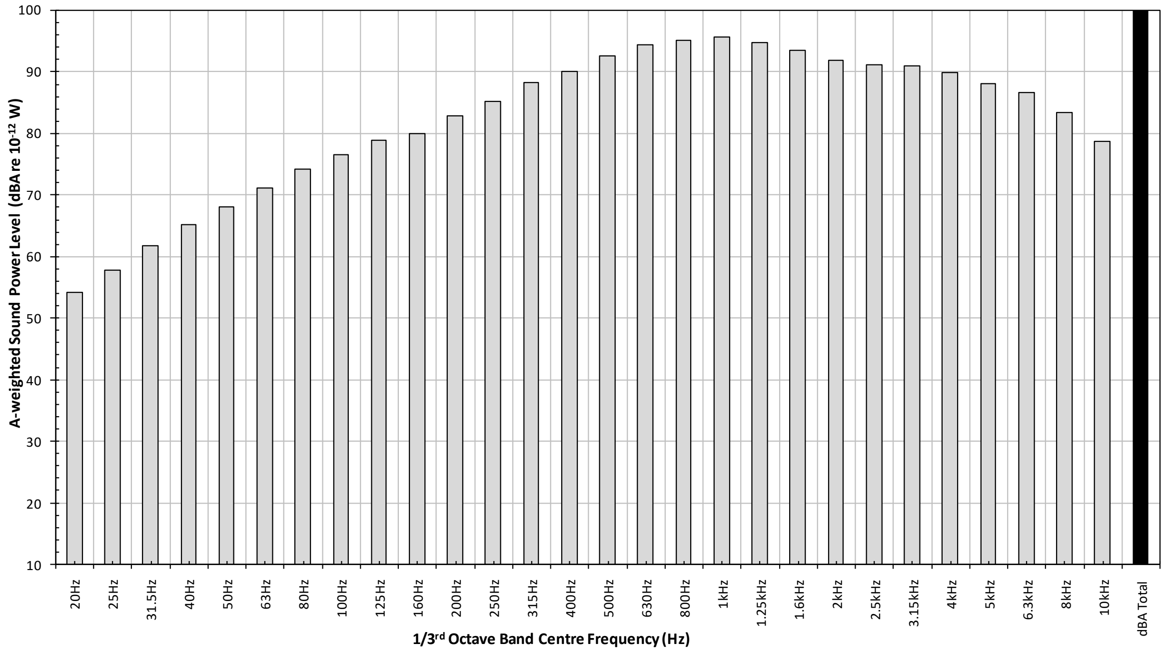


Normalised A-weighted 1/3rd Octave Band Spectra at Wind Bin 13. m/s

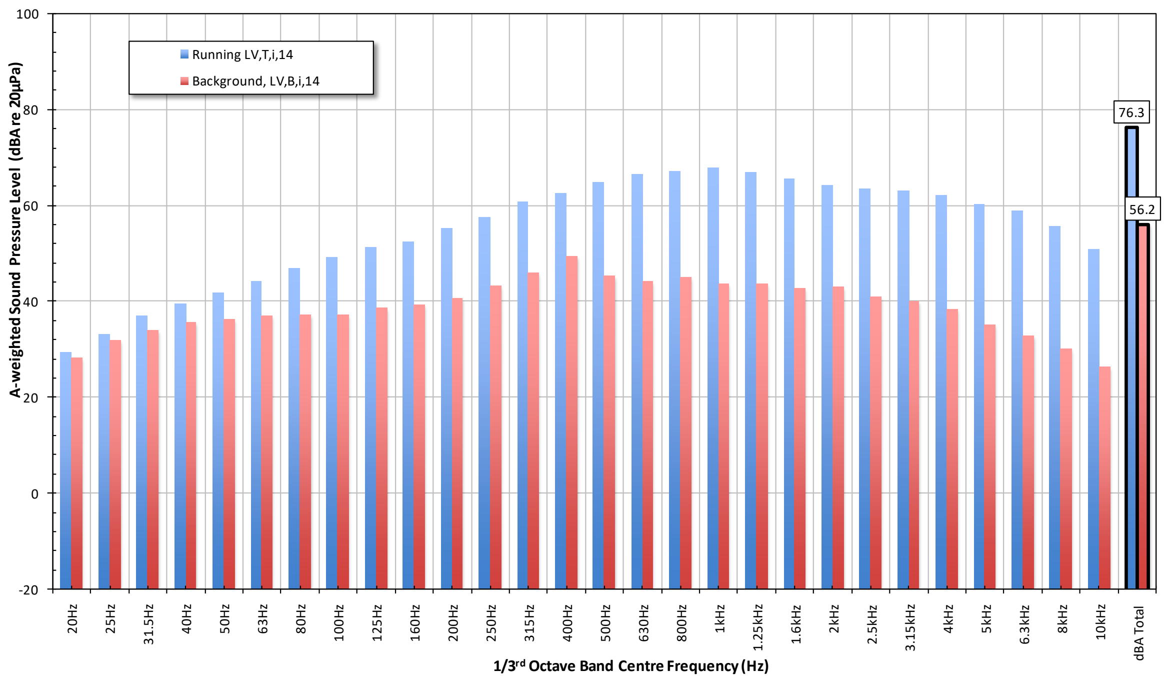
FIGURE 16 A-WEIGHTED 1/3 OCTAVE BAND SOUND POWER LEVELS (& SPL) FOR 13 m/s WIND SPEED BIN AT ROTOR CENTRE HEIGHT

A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 14. m/s at Rotor Centre Height

1/3rd Octave Band Centre Frequency																												
20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1kHz	1.25kHz	1.6kHz	2kHz	2.5kHz	3.15kHz	4kHz	5kHz	6.3kHz	8kHz	10kHz	dBA Total
[54.2]	[57.8]	[61.8]	65.1	68	71.1	74.2	76.6	78.9	79.9	82.8	85.2	88.3	90	92.6	94.3	95	95.7	94.7	93.4	91.8	91.2	90.9	89.8	88.1	86.6	83.4	78.7	104.1



A-weighted 1/3rd Octave Band Sound Power Levels, LWA, i for Wind Speed Bin 14. m/s at Rotor Centre Height



Normalised A-weighted 1/3rd Octave Band Spectra at Wind Bin 14. m/s

FIGURE 17 A-WEIGHTED 1/3 OCTAVE BAND SOUND POWER LEVELS (& SPL) FOR 14 m/s WIND SPEED BIN AT ROTOR CENTRE HEIGHT

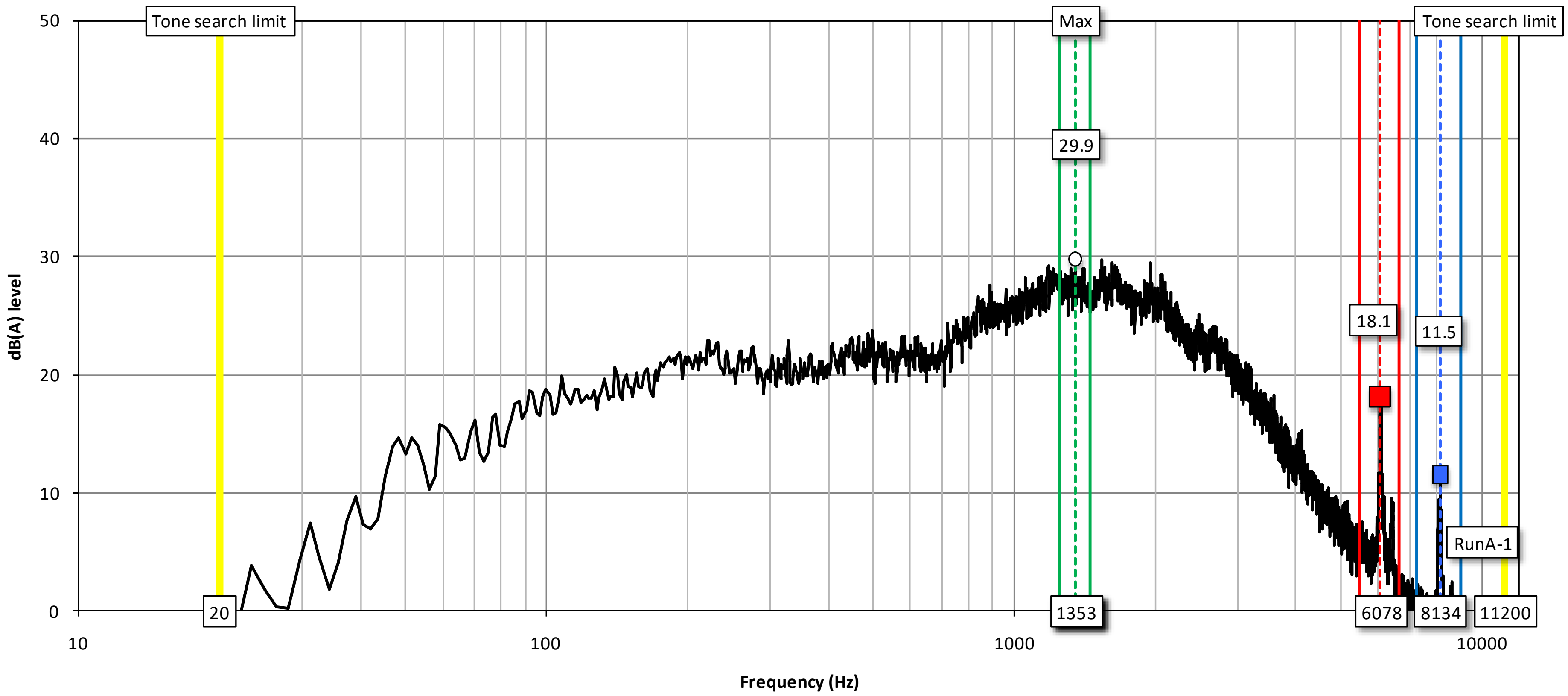


FIGURE 18a TONAL ASSESSMENT USING THE IEC 61400-11:2012 METHOD FOR THE 4 m/s HUB-HEIGHT WIND SPEED BIN

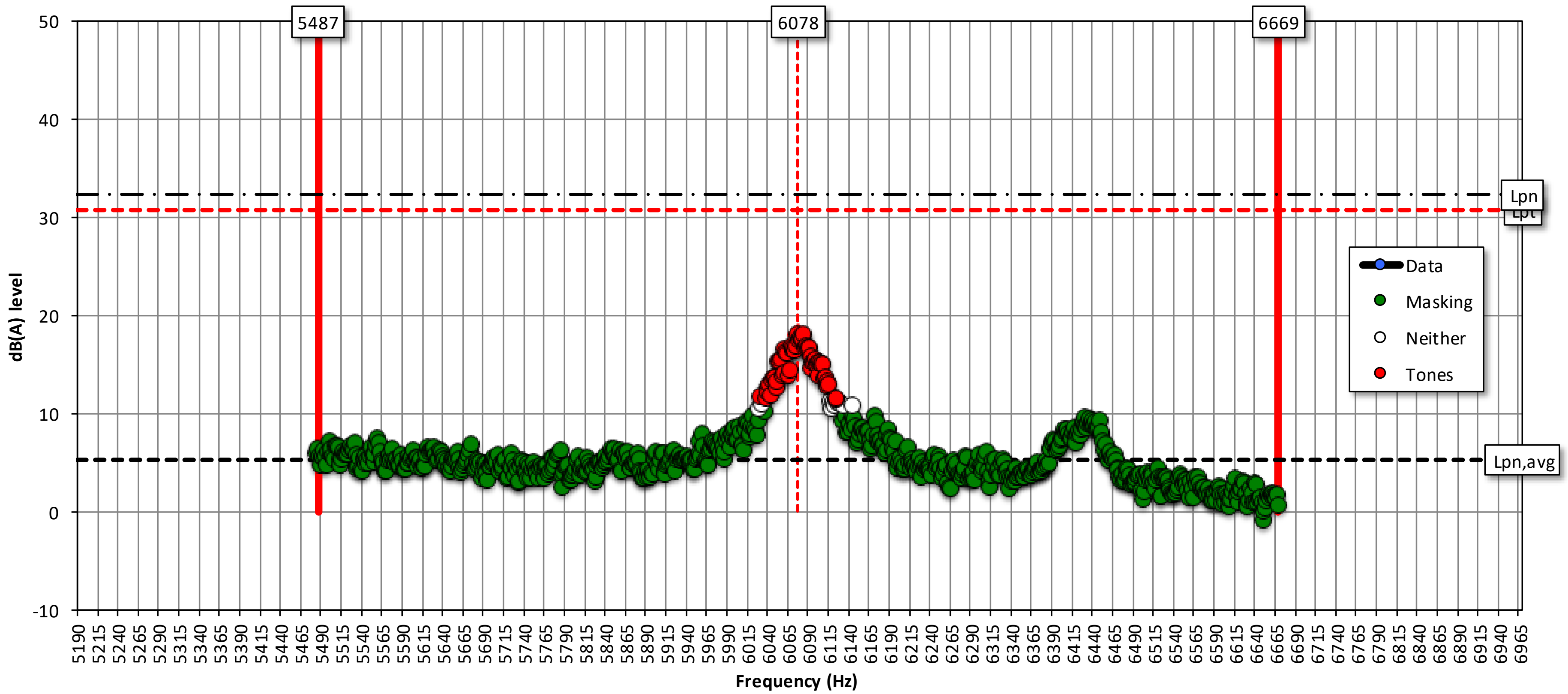


FIGURE 18b CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 4 m/s WIND SPEED BIN

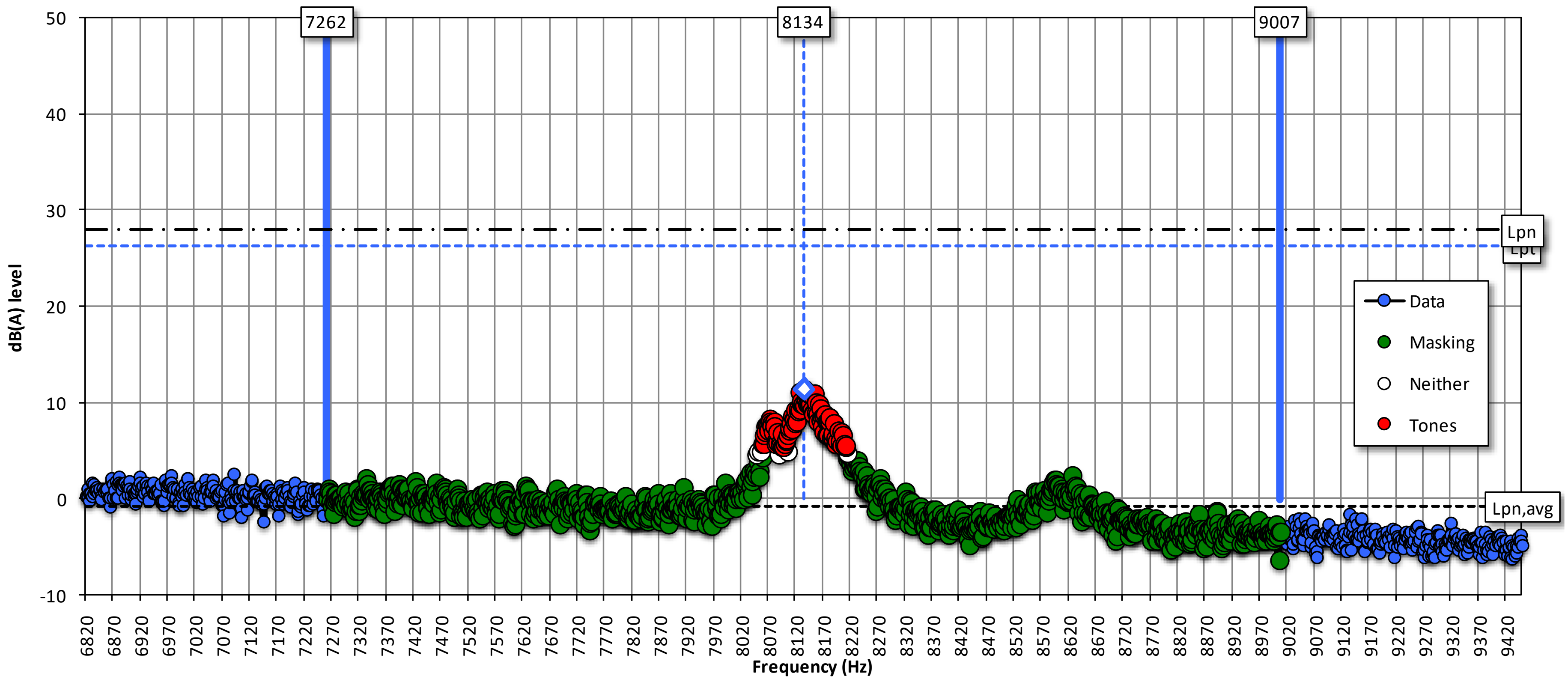


FIGURE 18c CRITICAL BAND WITH 2nd HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 4 m/s WIND SPEED BIN
(Tonality +3.3 dB)

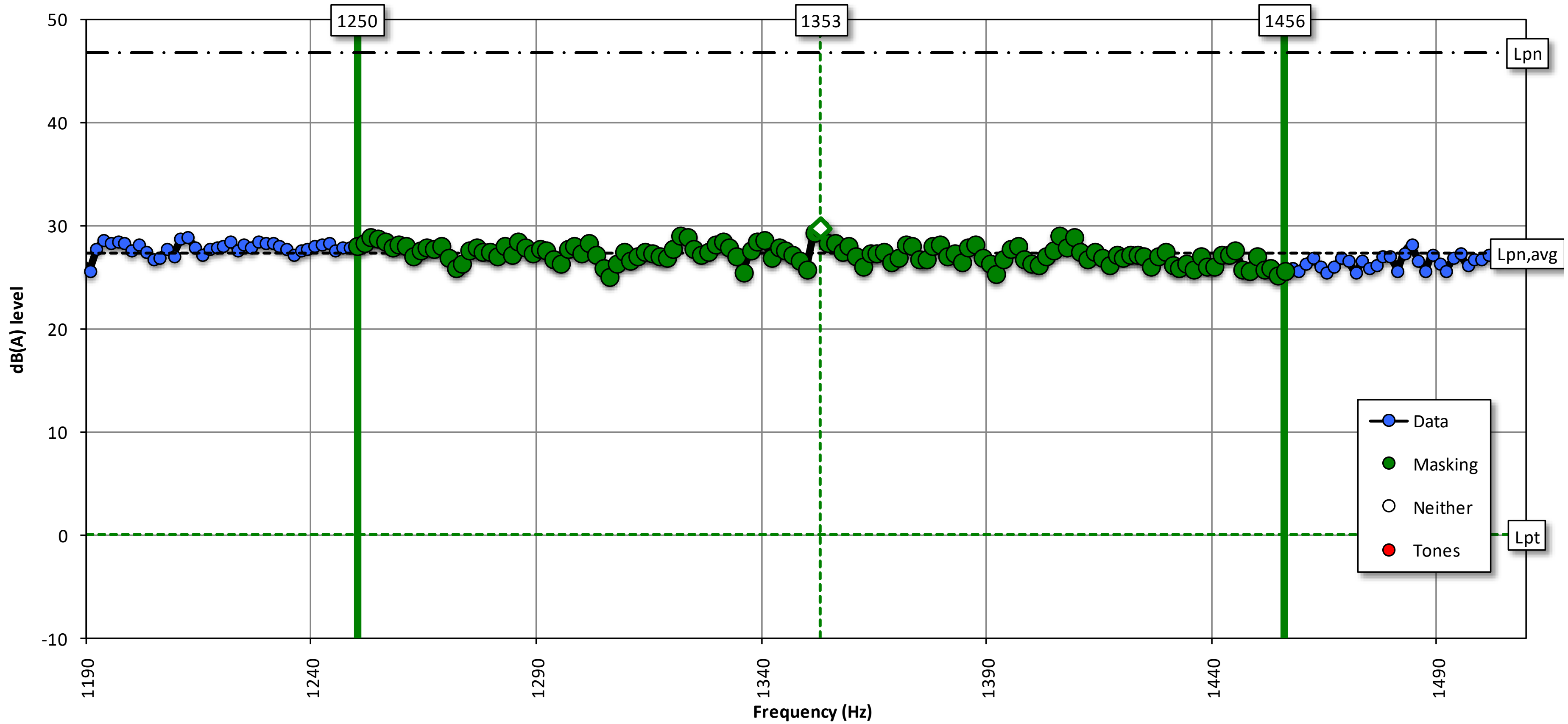
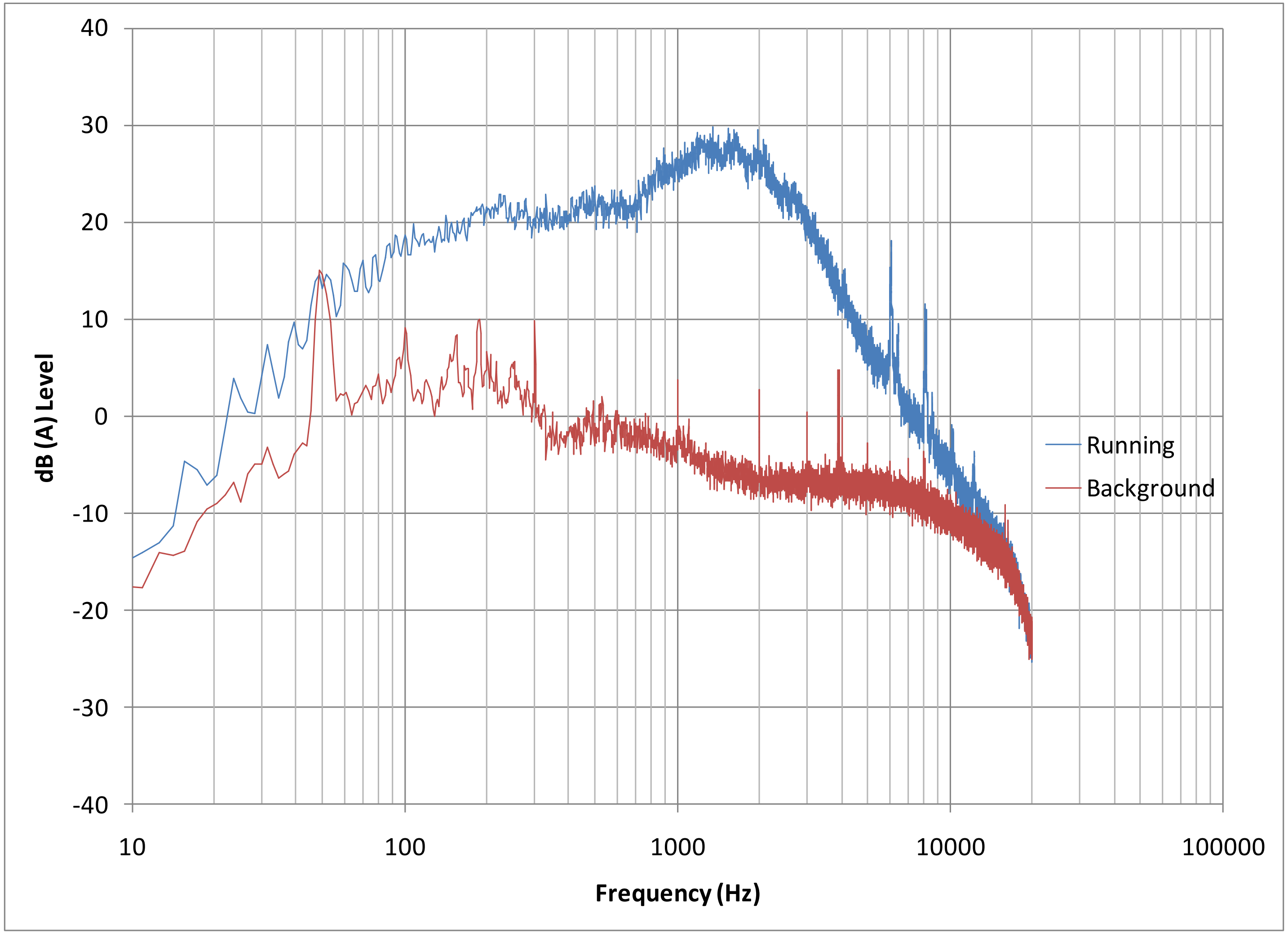


FIGURE 18d CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 4 m/s WIND SPEED BIN (Spectrum Maximum and Highest Tonality are equivalent in this case)



N.B.

Some 50 Hz content found in the background does not affect tonalities & any tonal audibility.

There are some high frequency tones at 6 & 8 kHz and are most likely higher harmonics of a fundamental tone at c.2 kHz.

c.2 kHz and the 1st harmonic of this at c.4 kHz appears highly masked within adjacent critical frequency bands.

With wind speeds above 6 m/s the higher 2nd & 3rd harmonics then also become masked too, in increasing broadband noise.

Only the tonalities with > 0 dB 'audibility' are to be reported.

Figure 18e An example of fine frequency spectrum of SPLs recorded in 4 m/s wind speeds

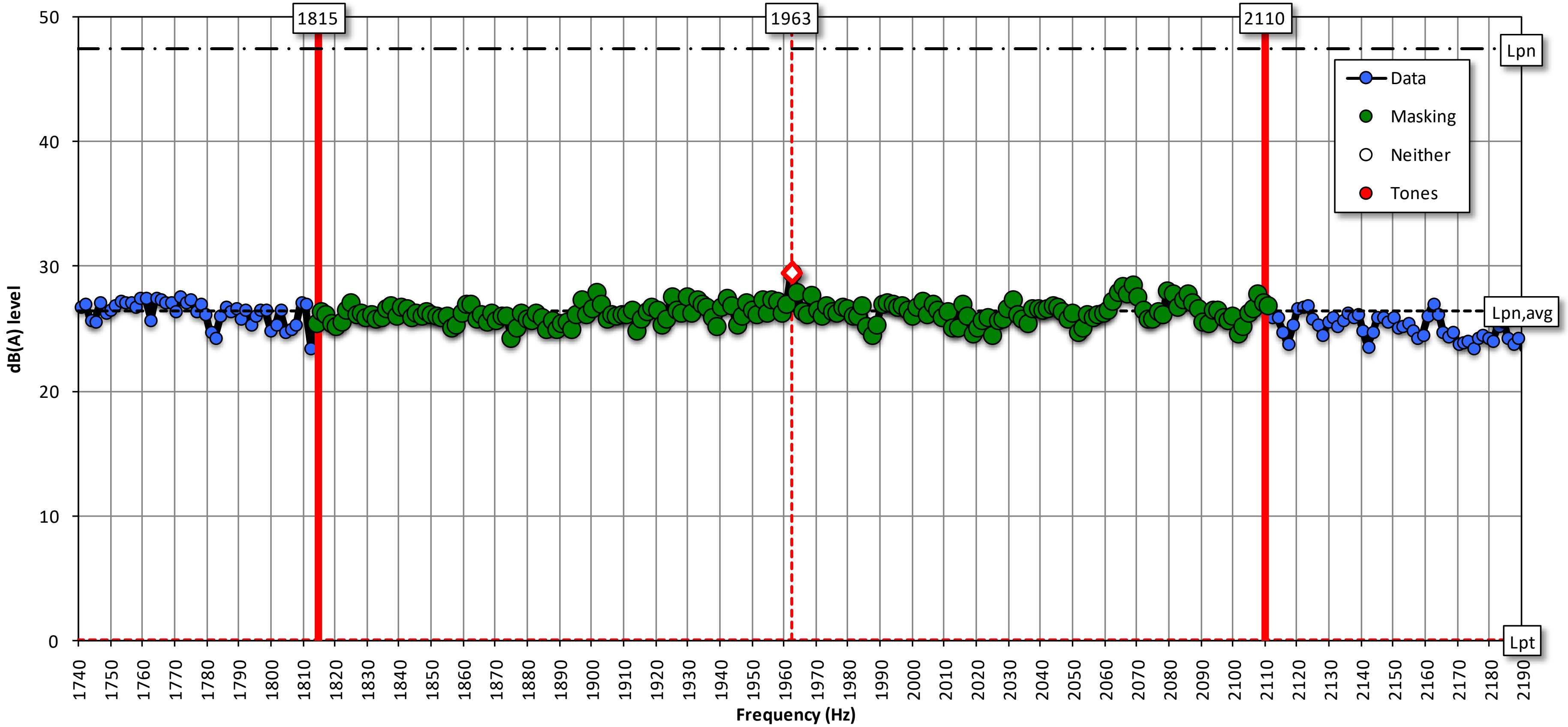


FIGURE 18f CRITICAL BAND WITH LOWEST 2 KHz BASED TONALITY SHOWING TONE & MASKING NOISE AT 4 m/s WIND SPEED

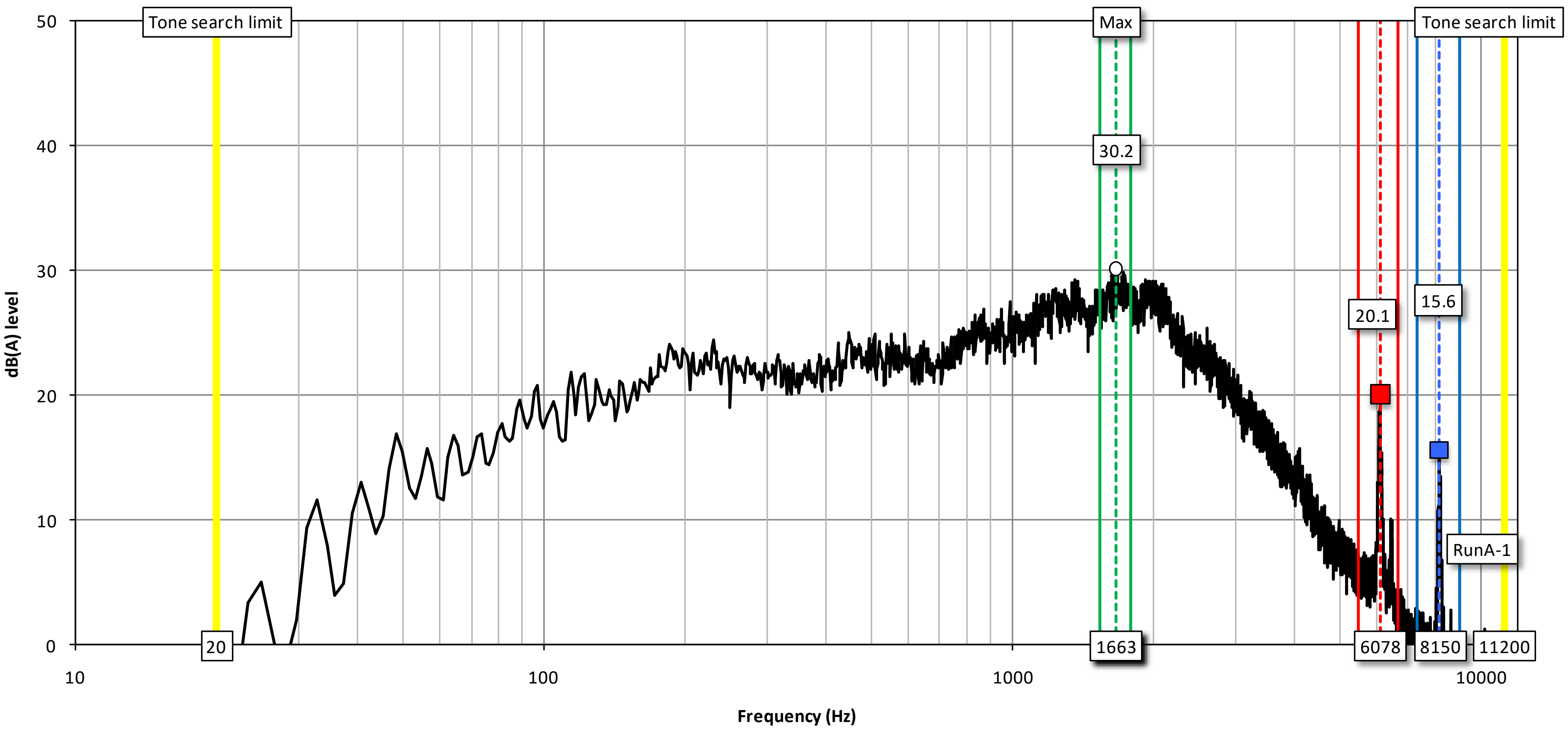


FIGURE 19a TONAL ASSESSMENT USING THE IEC 61400-11:2012 METHOD FOR THE 5 m/s HUB-HEIGHT WIND SPEED BIN

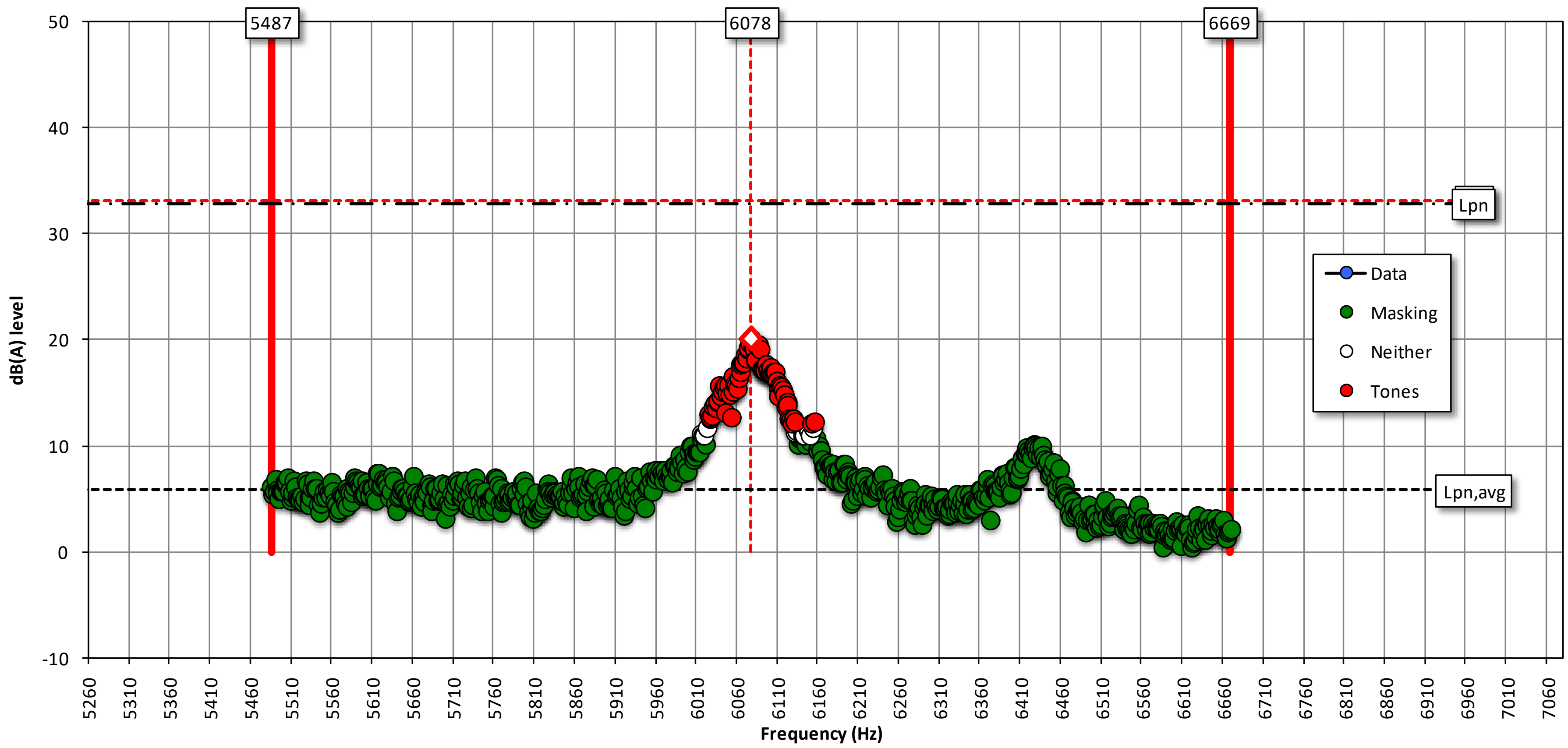


FIGURE 19b CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 5 m/s WIND SPEED BIN
(Tonality +3.2 dB)

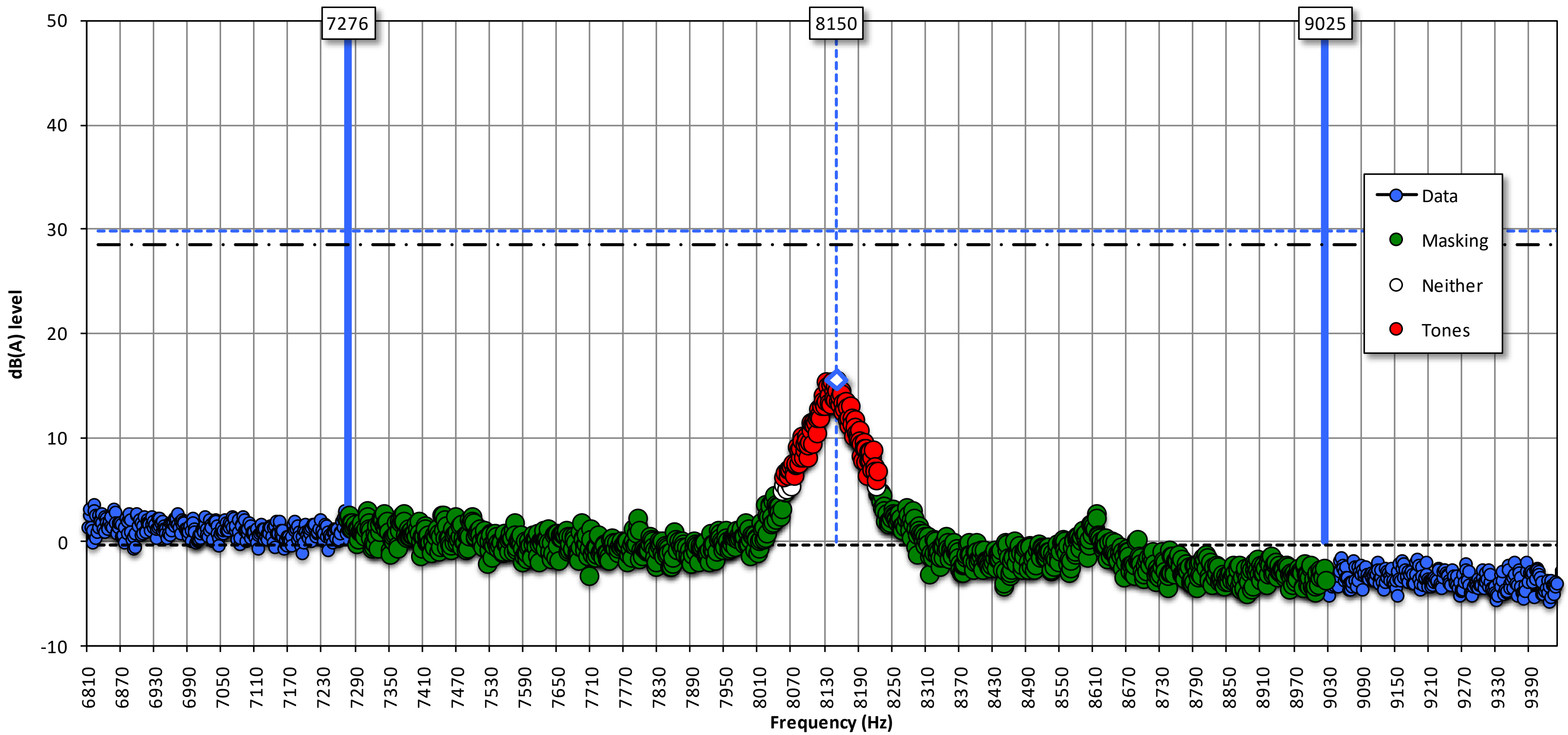


FIGURE 19c CRITICAL BAND WITH 2nd HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 5 m/s WIND SPEED BIN (Tonality +6.4 dB)

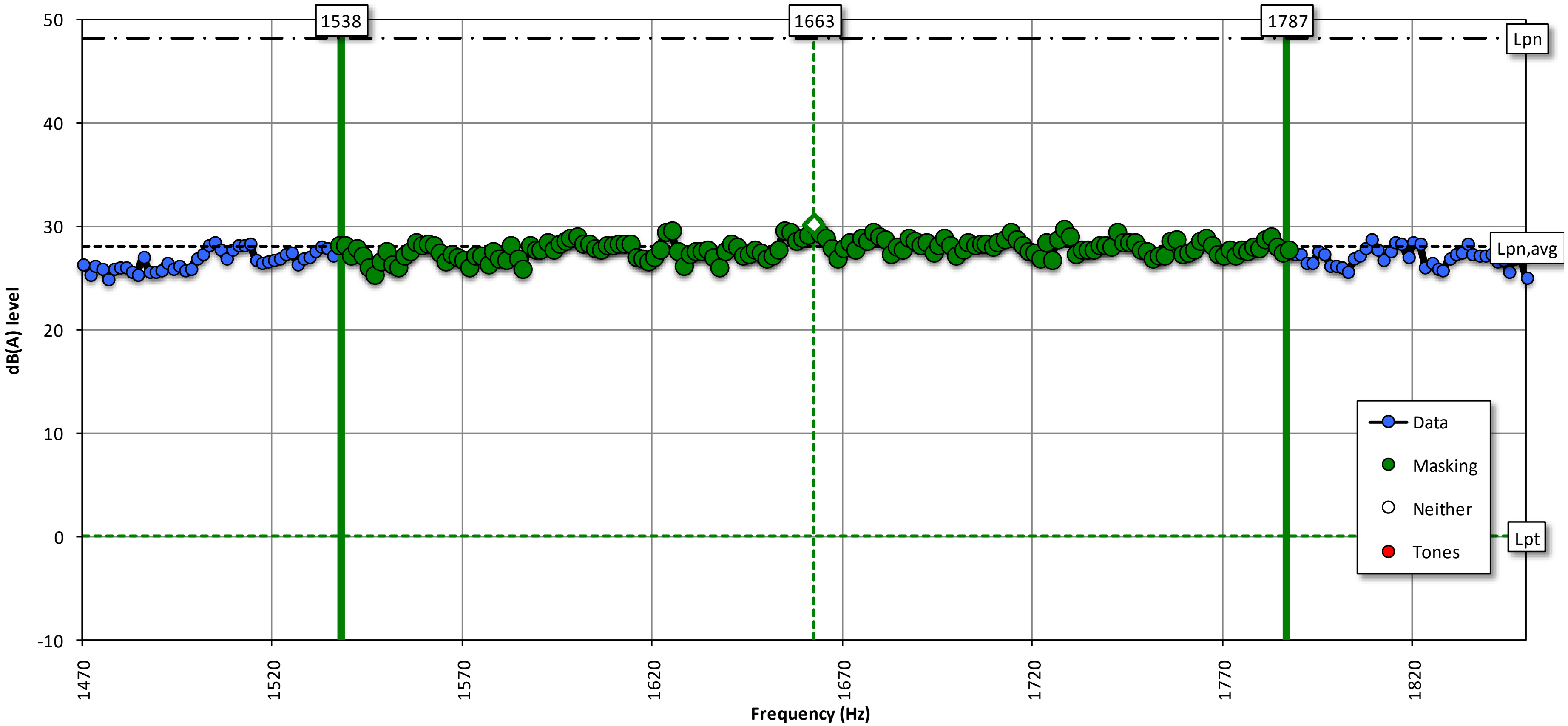


FIGURE 19d CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 5m/s WIND SPEED BIN (Spectrum Maximum and Highest Tonality are equivalent in this case)

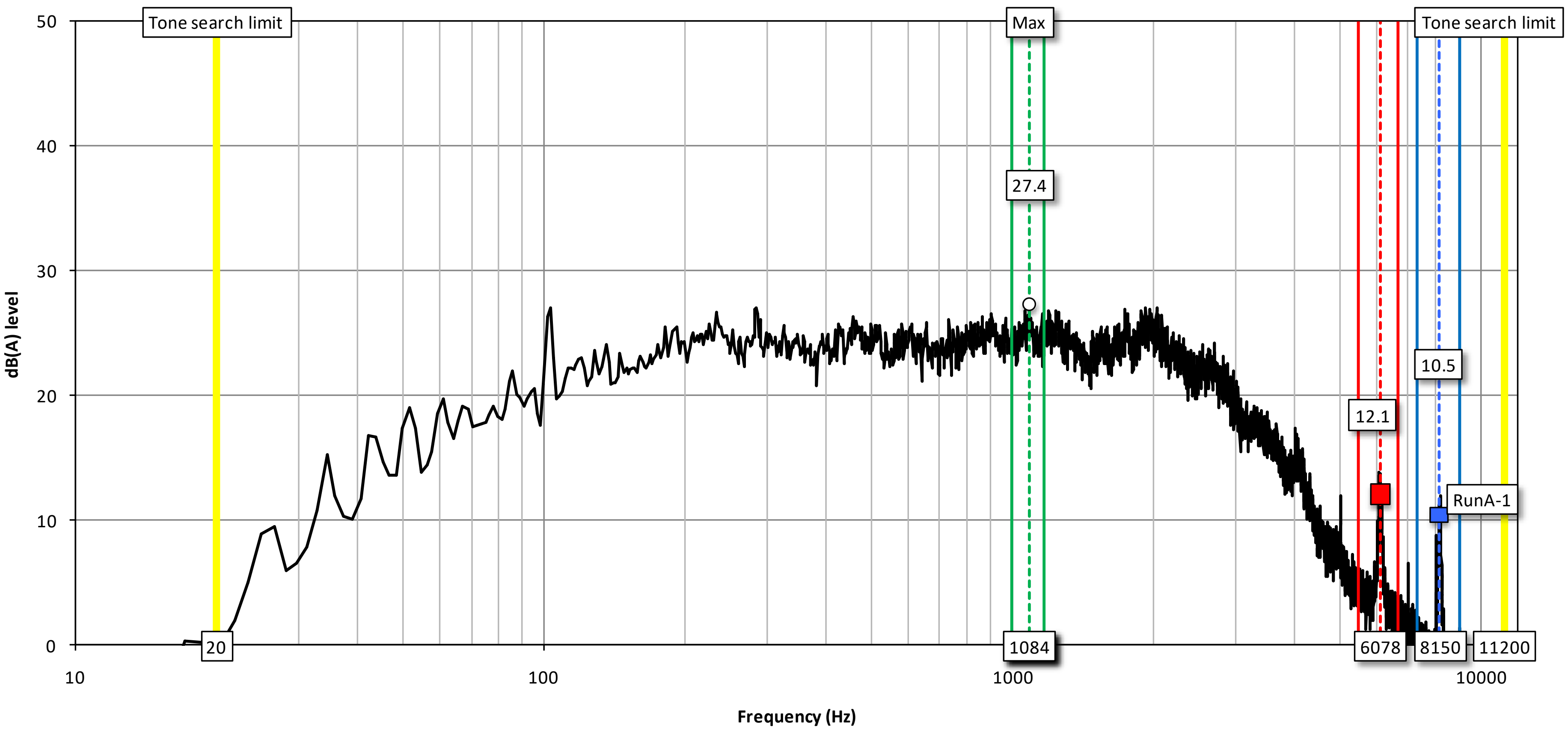


FIGURE 20a TONAL ASSESSMENT USING THE IEC 61400-11:2012 METHOD FOR THE 6 m/s HUB-HEIGHT WIND SPEED BIN

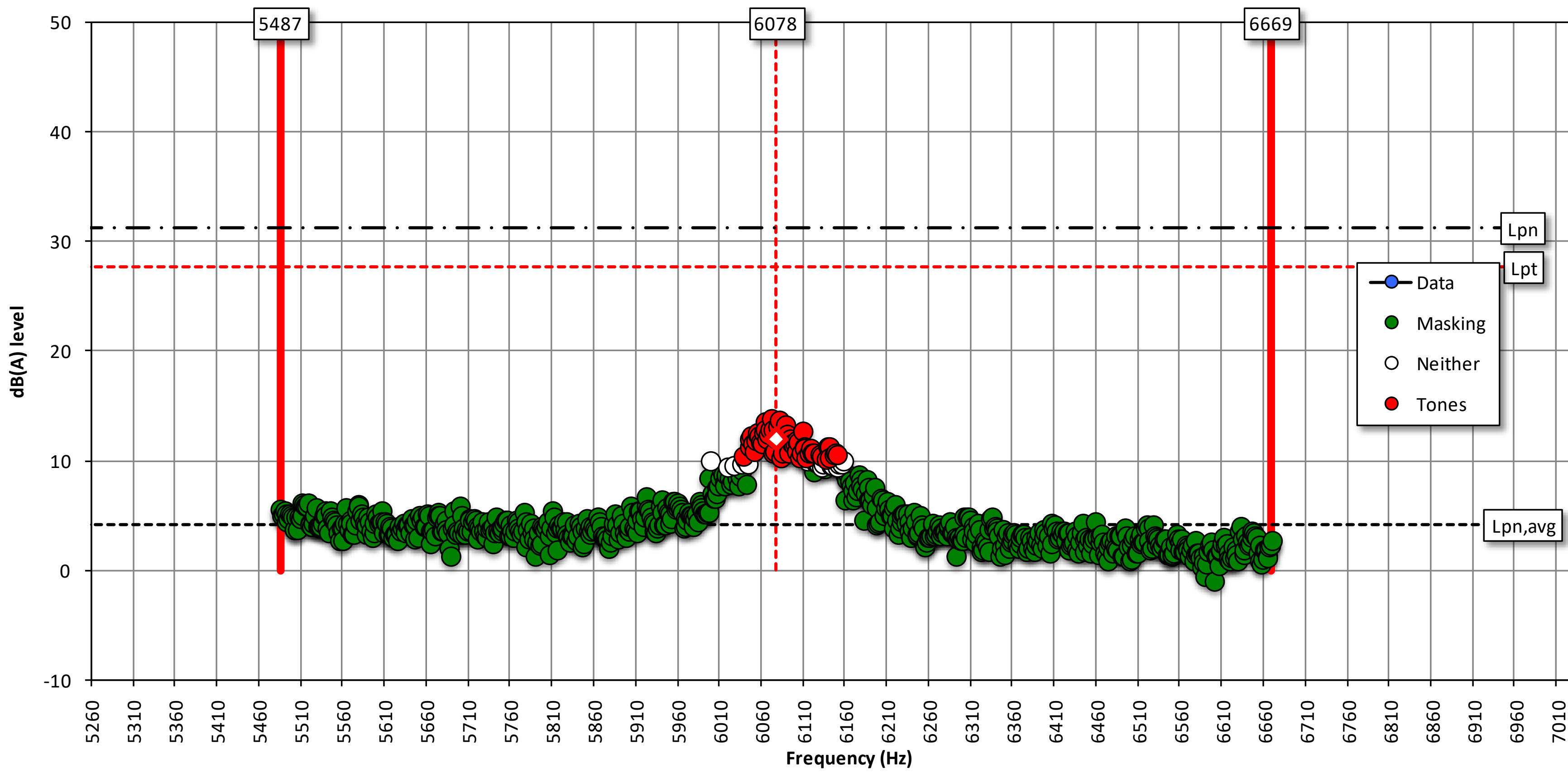


FIGURE 20b CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 6 m/s WIND SPEED BIN

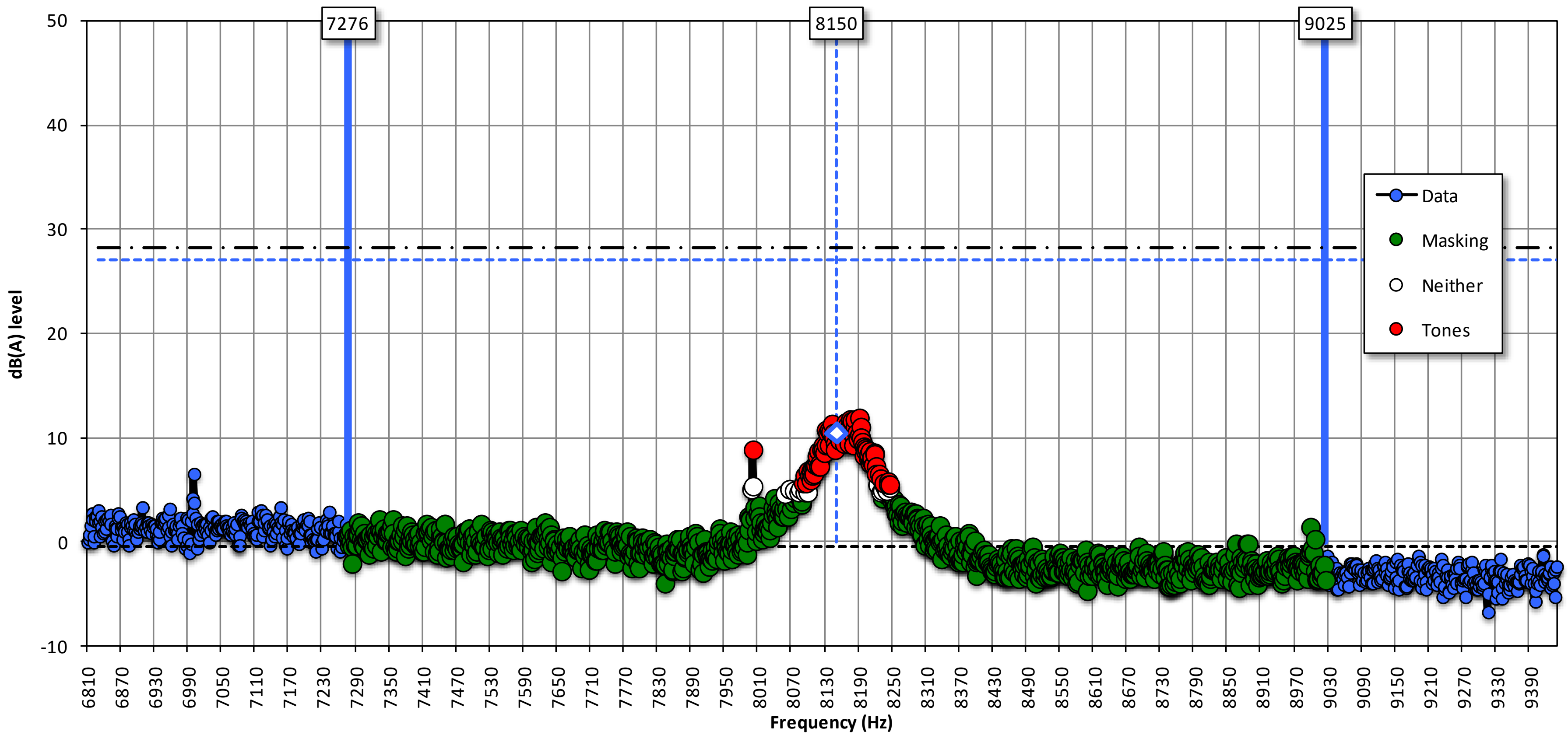


FIGURE 20c CRITICAL BAND WITH 2nd HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 6 m/s WIND SPEED BIN (Tonality +3.8 dB)

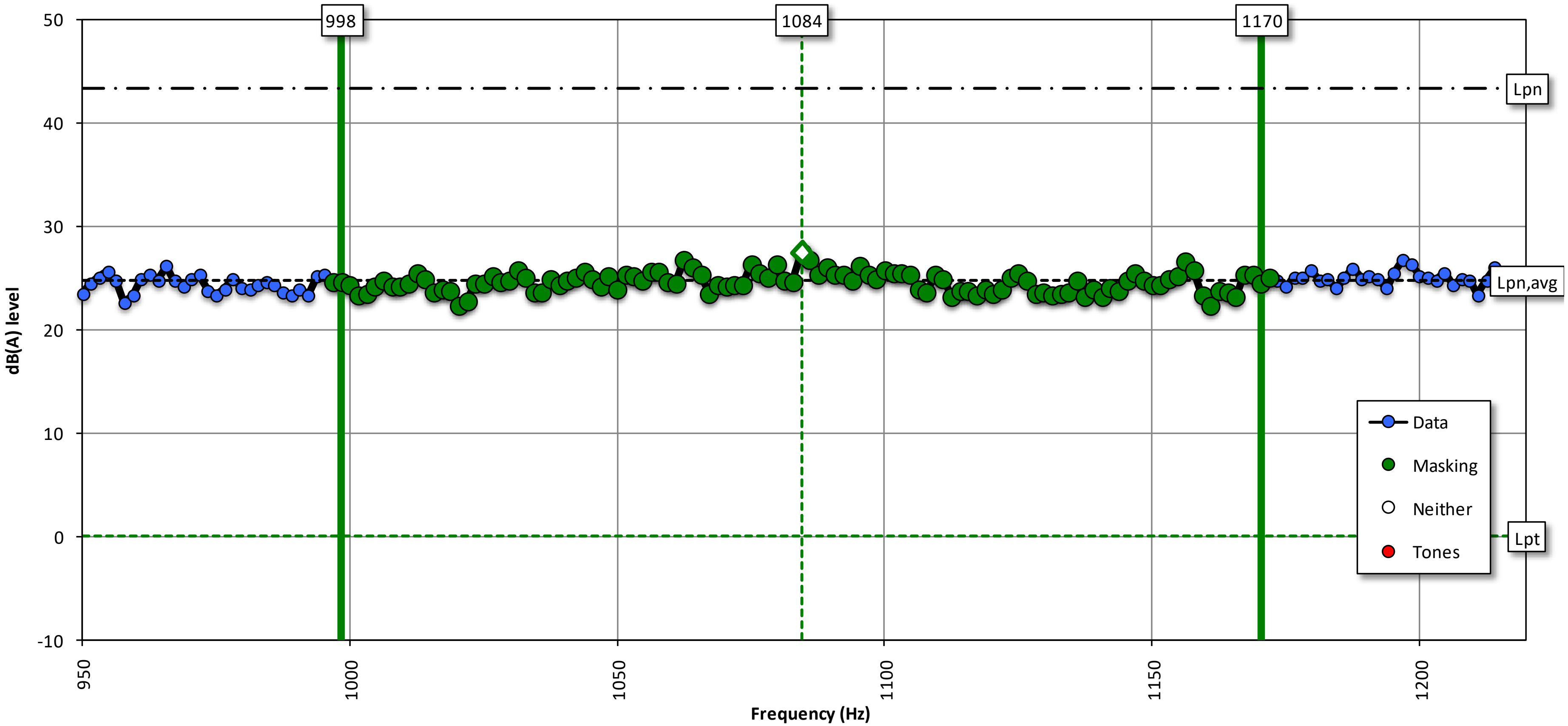


FIGURE 20d CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 6m/s WIND SPEED BIN (Spectrum Maximum and Highest Tonality are equivalent in this case)

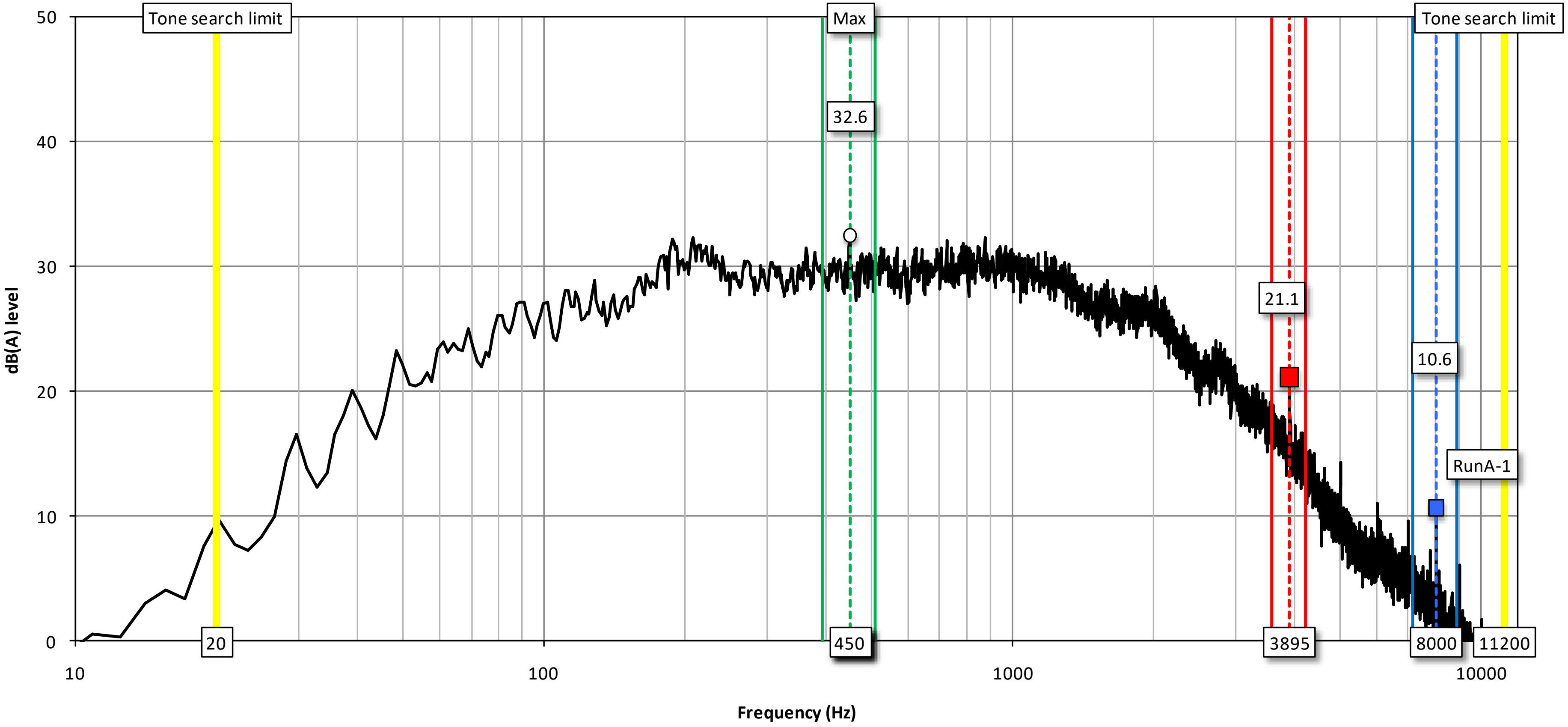


FIGURE 21a TONAL ASSESSMENT USING THE IEC 61400-11:2012 METHOD FOR THE 7 m/s HUB-HEIGHT WIND SPEED BIN

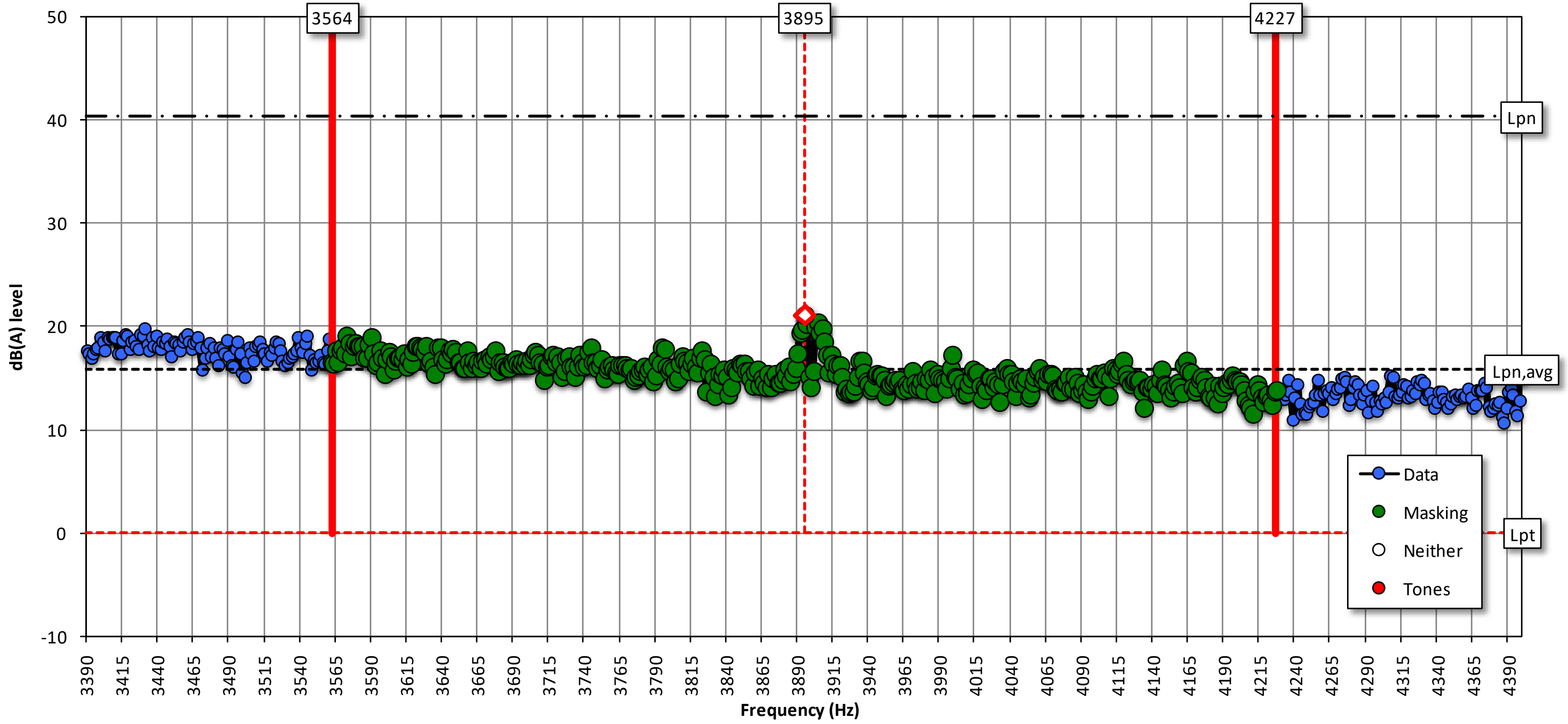


FIGURE 21b CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 7 m/s WIND SPEED BIN

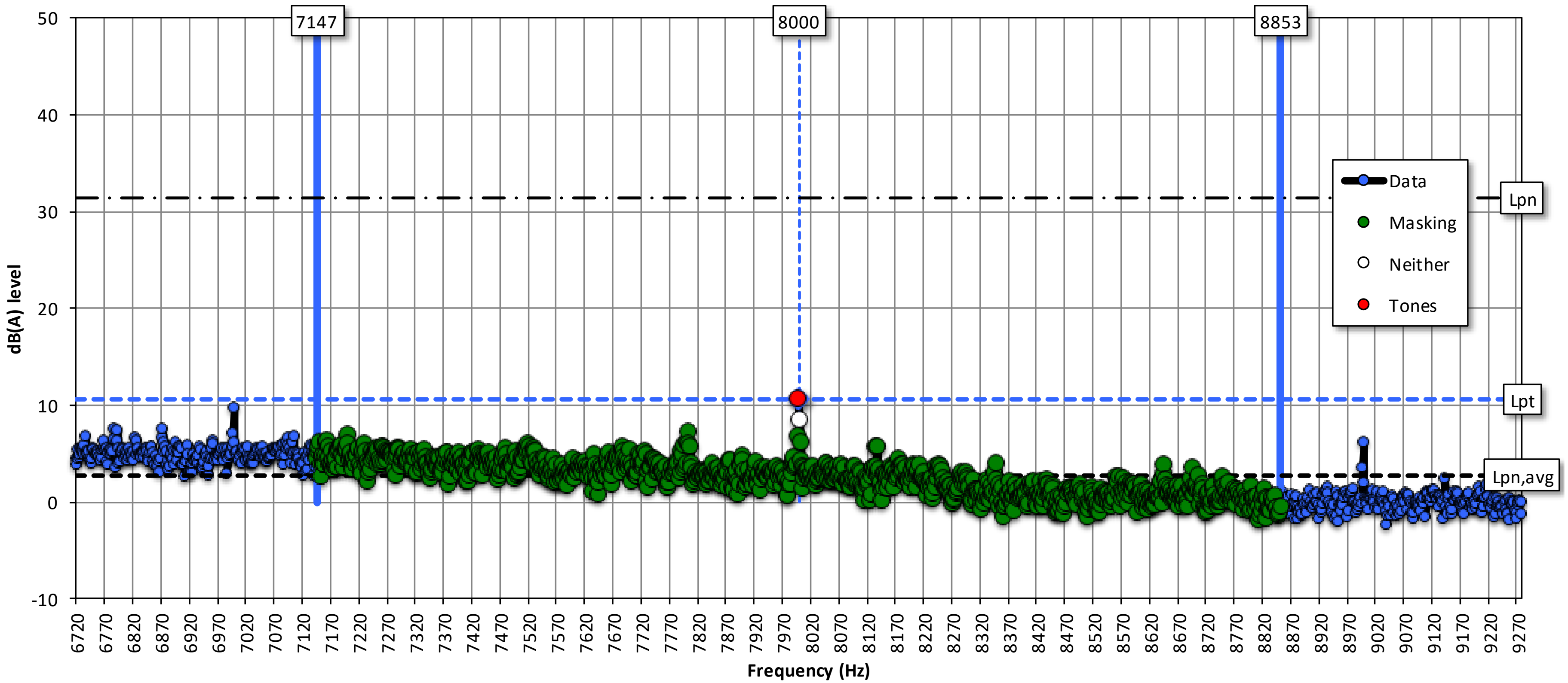


FIGURE 21c CRITICAL BAND WITH 2nd HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 7 m/s WIND SPEED BIN

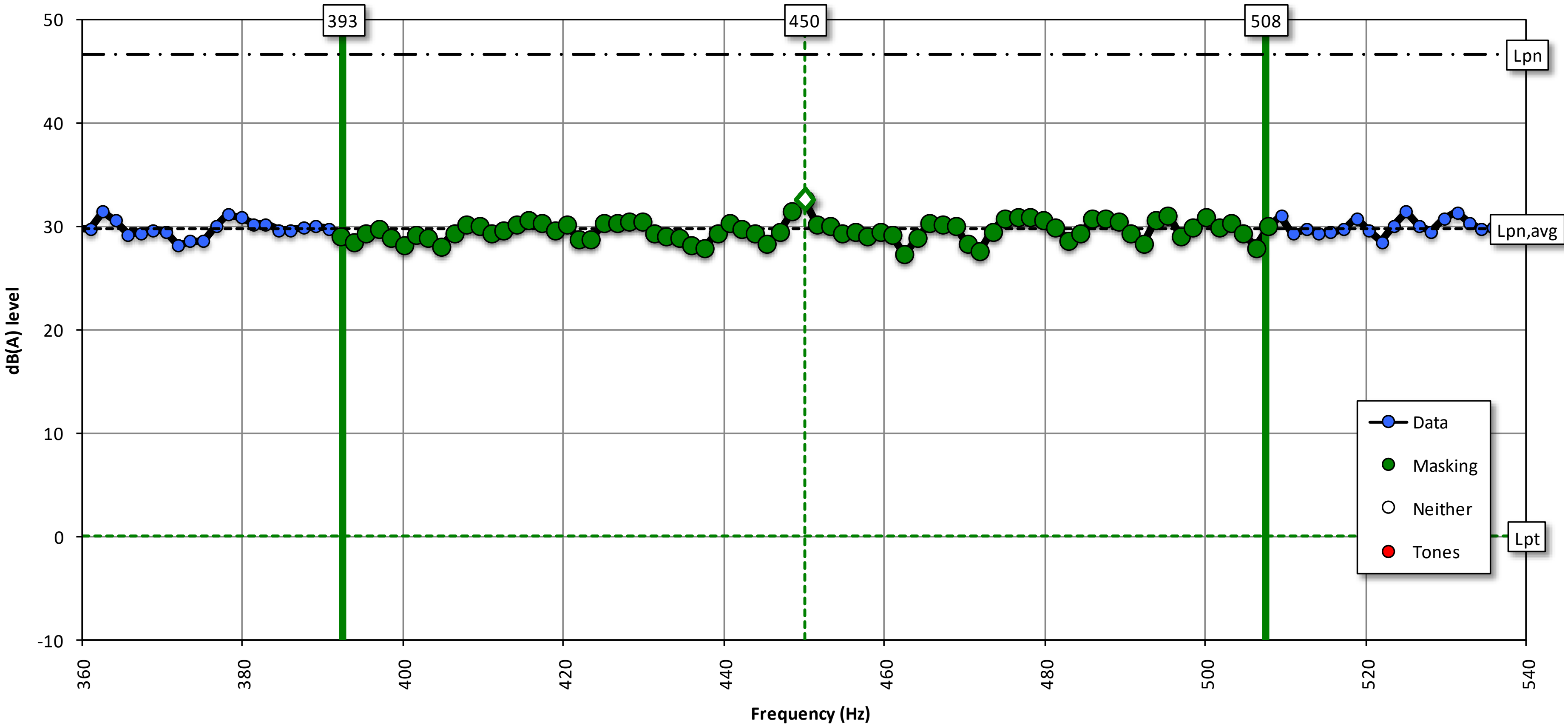


FIGURE 21d CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 7m/s WIND SPEED BIN (Spectrum Maximum and Highest Tonality are equivalent in this case)

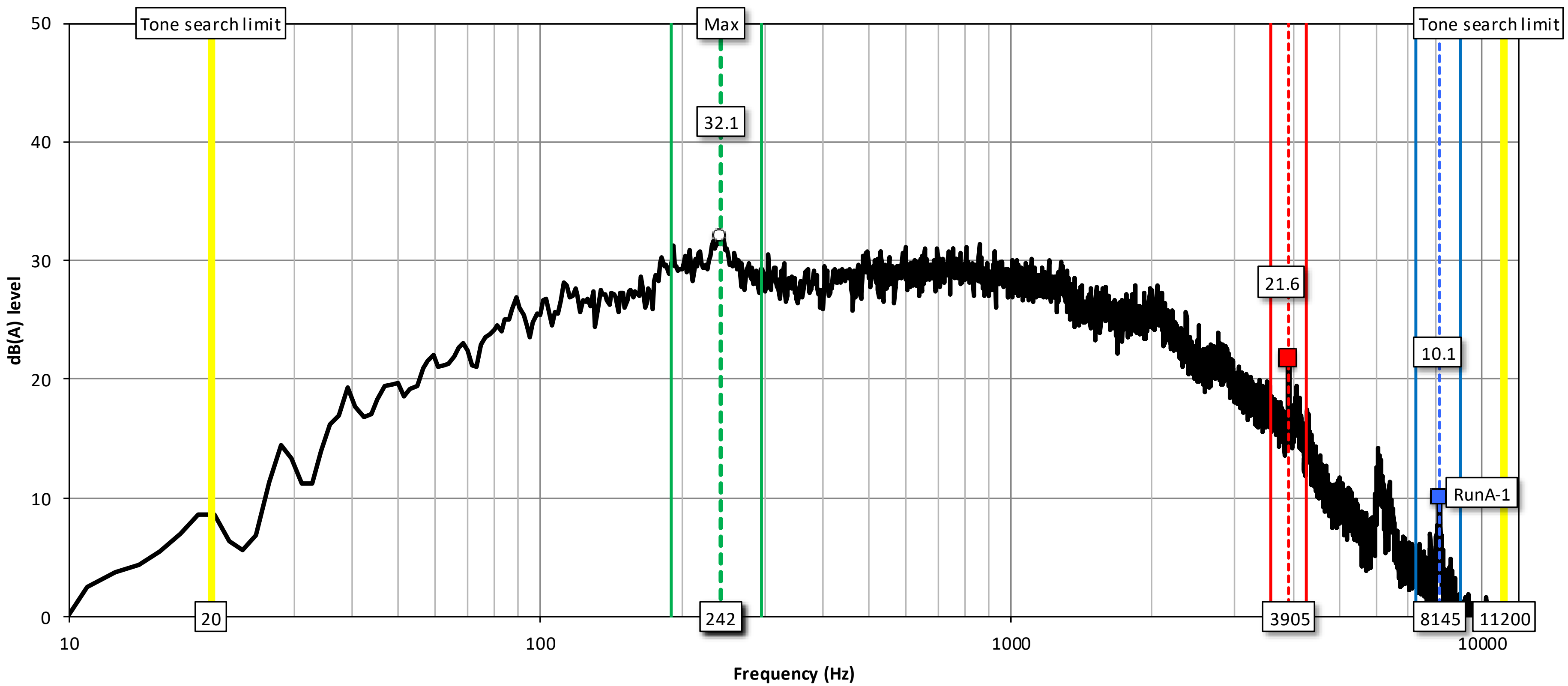


FIGURE 22a TONAL ASSESSMENT USING THE IEC 61400-11:2012 METHOD FOR THE 8 m/s HUB-HEIGHT WIND SPEED BIN

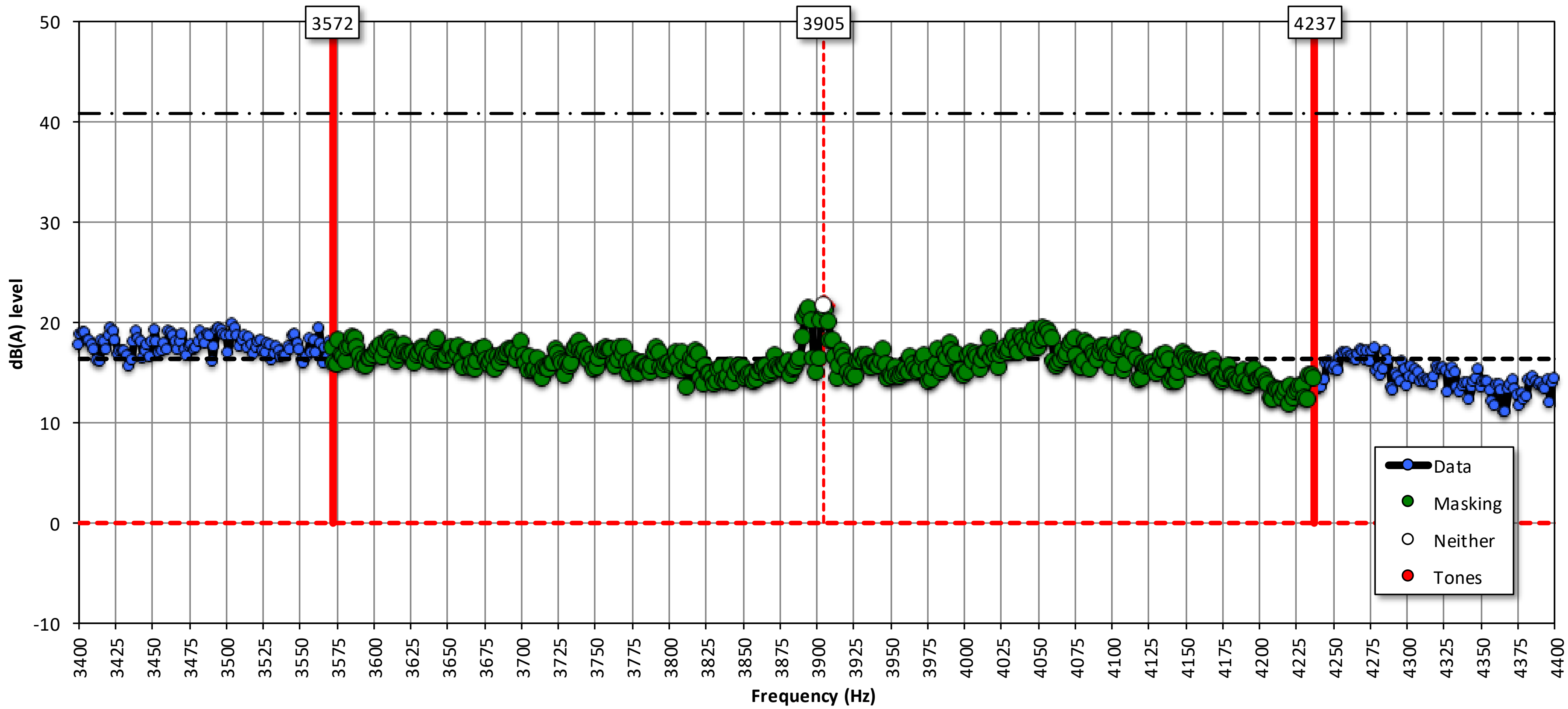


FIGURE 22b CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 8 m/s WIND SPEED BIN

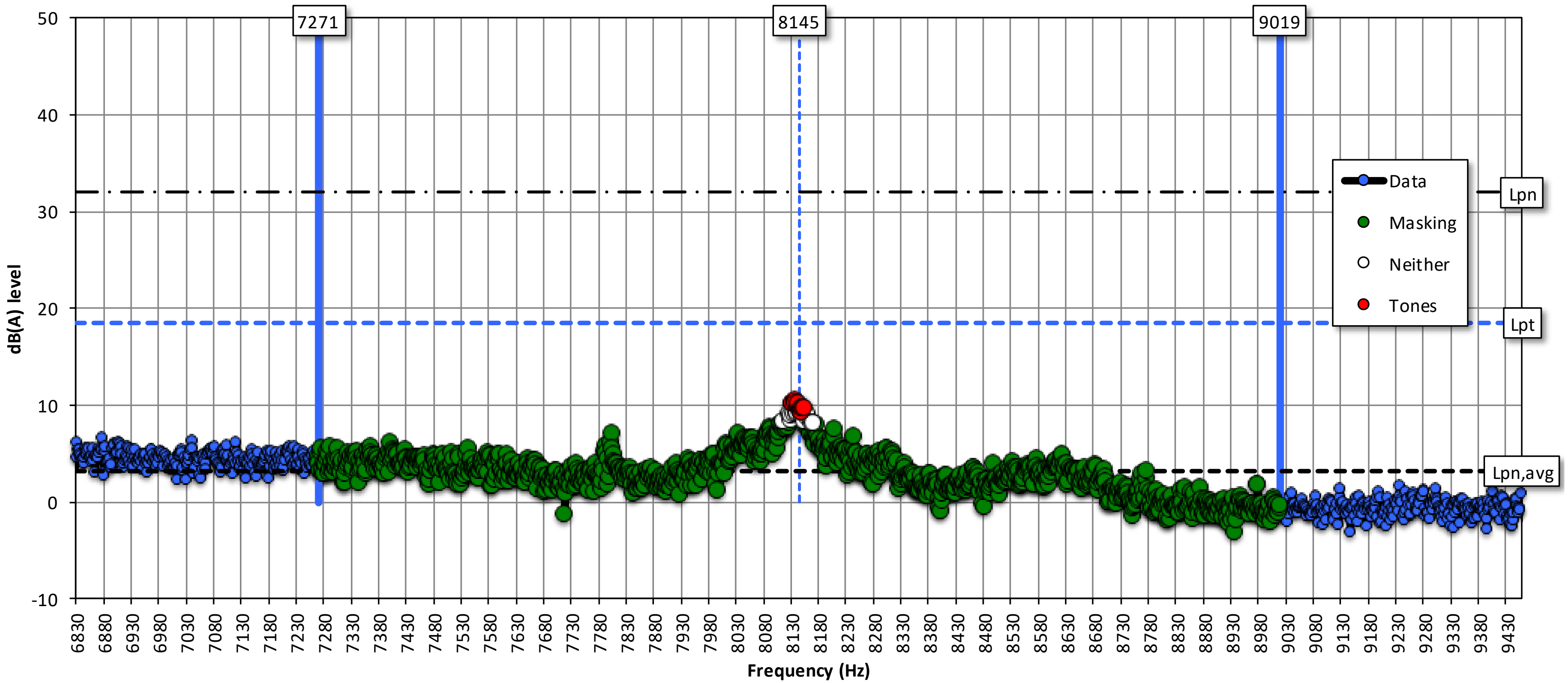


FIGURE 22c CRITICAL BAND WITH 2nd HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 8 m/s WIND SPEED BIN

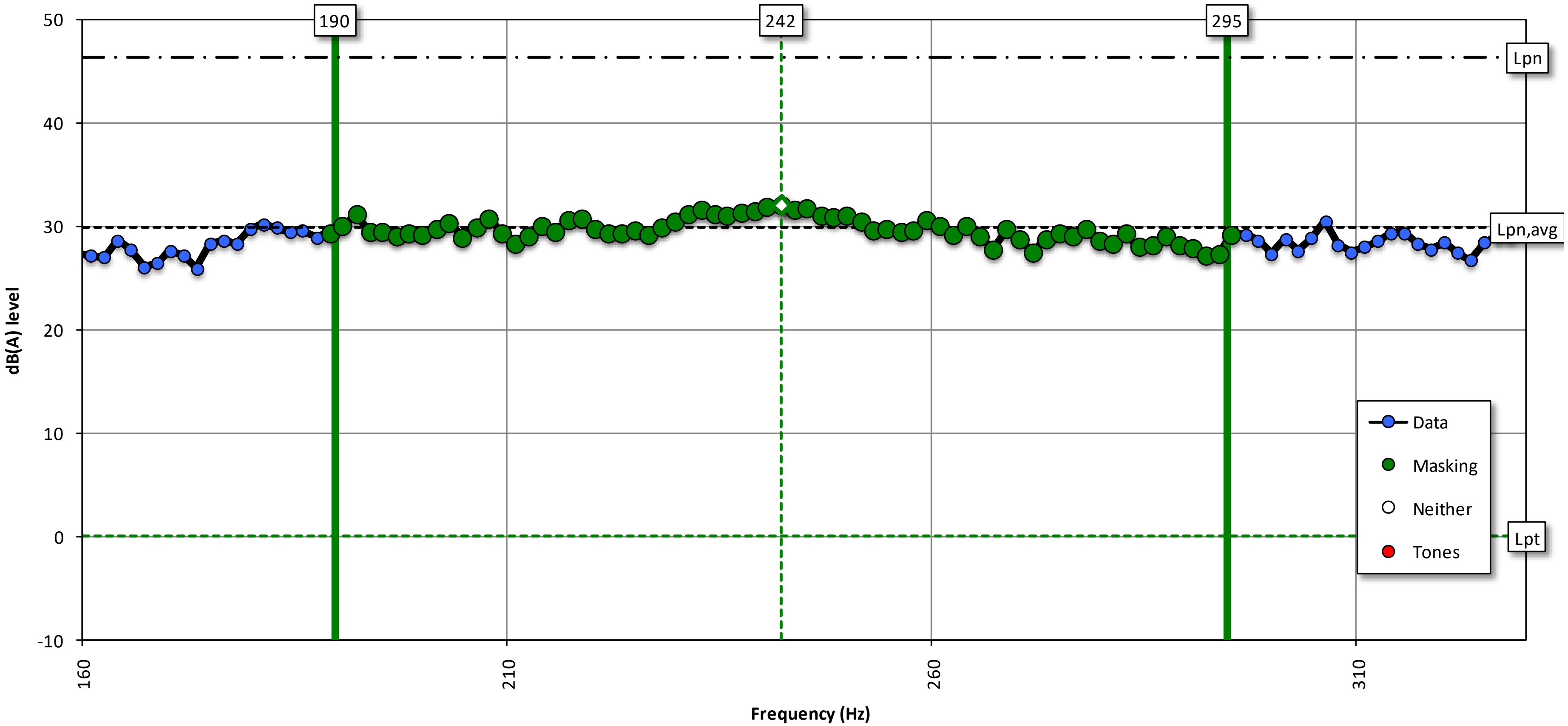


FIGURE 22d CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 8m/s WIND SPEED BIN (Spectrum Maximum and Highest Tonality are equivalent in this case)

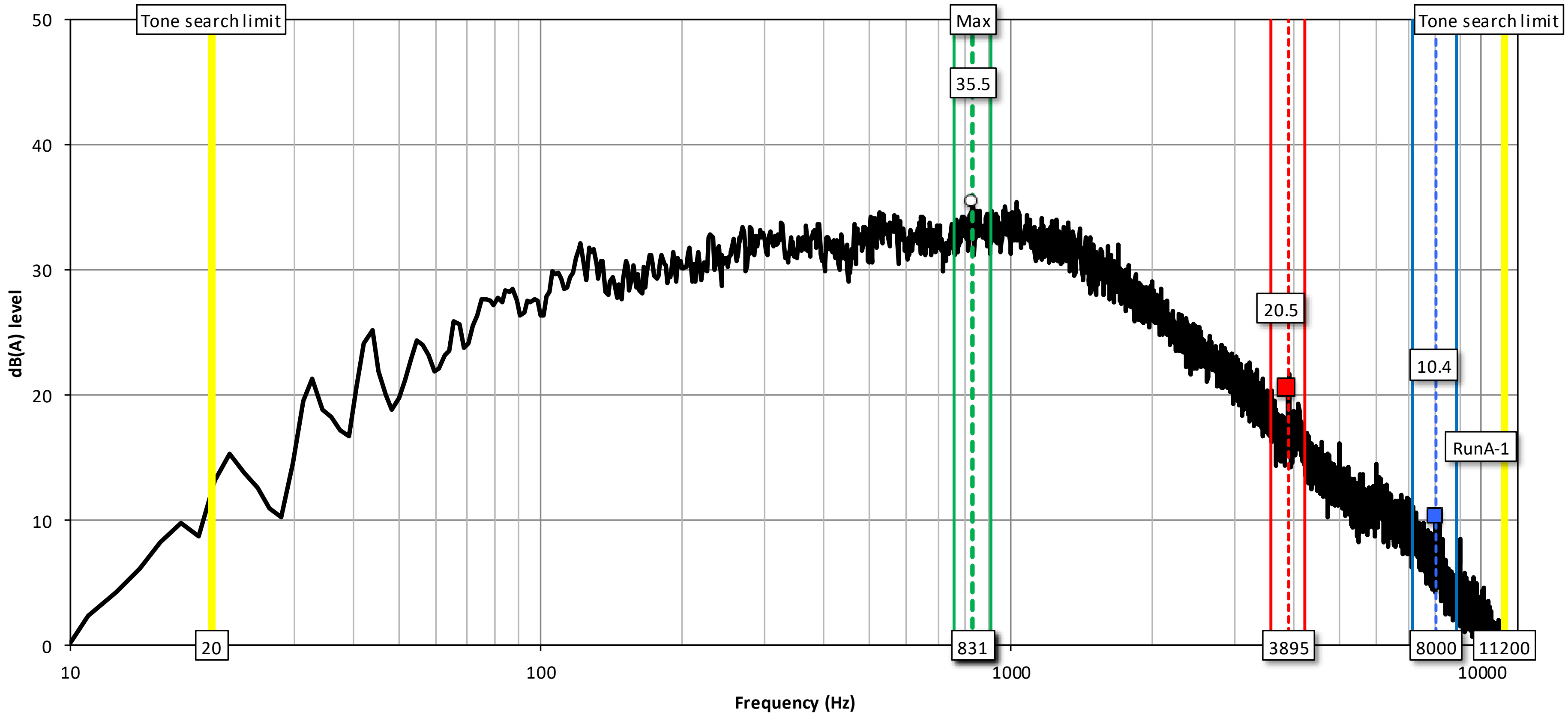


FIGURE 23a TONAL ASSESSMENT USING THE IEC 61400-11:2012 METHOD FOR THE 9 m/s HUB-HEIGHT WIND SPEED BIN

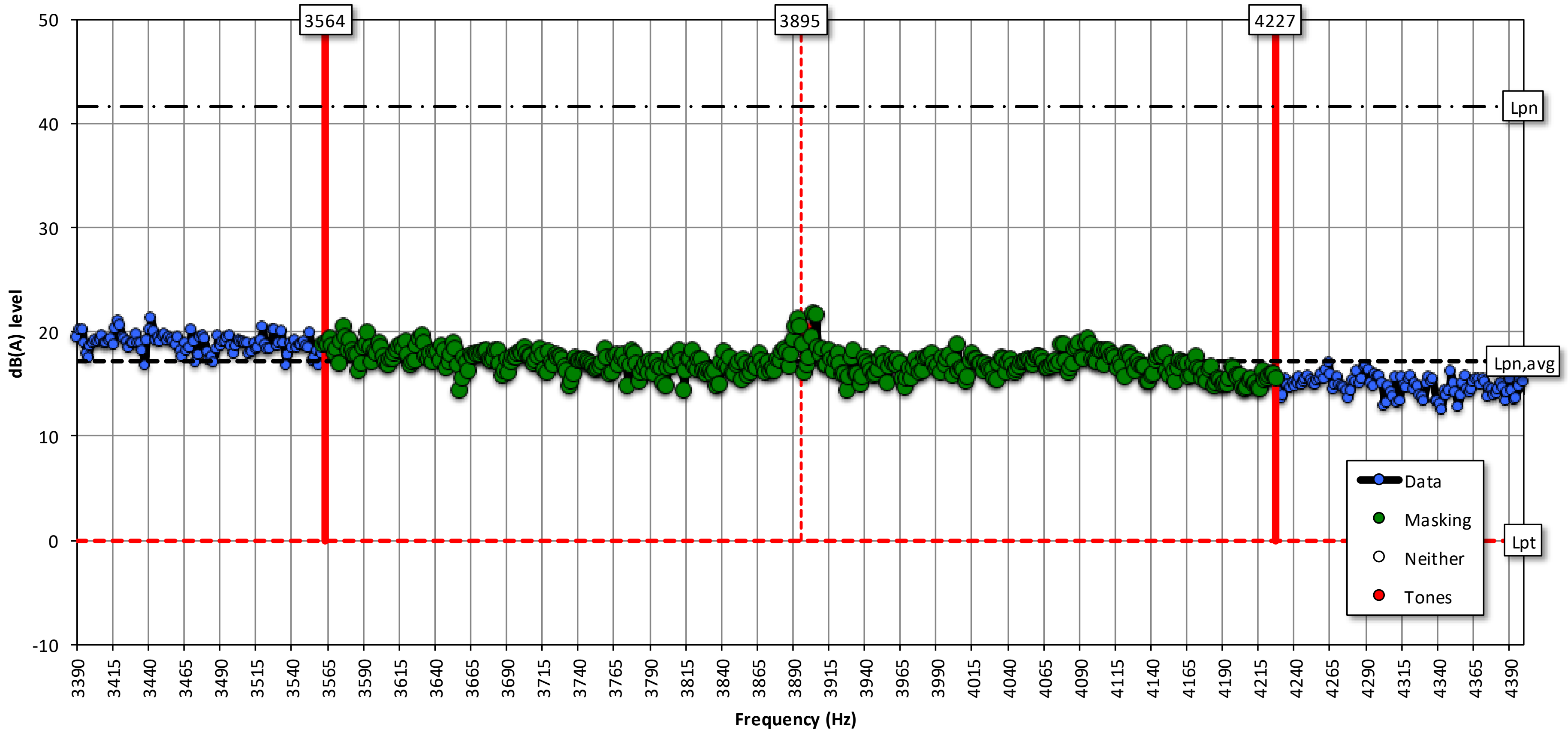


FIGURE 23b CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 9 m/s WIND SPEED BIN

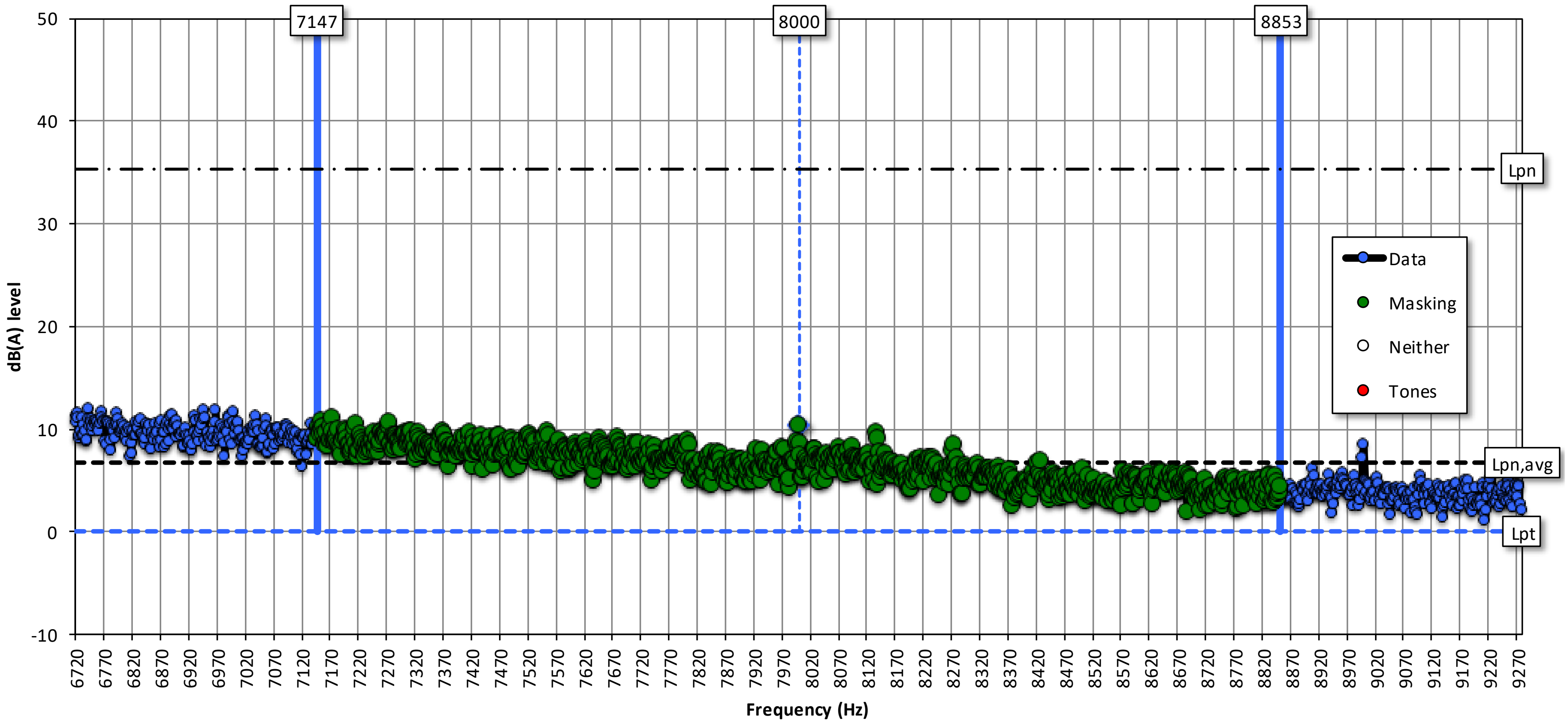


FIGURE 23c CRITICAL BAND WITH 2nd HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 9 m/s WIND SPEED BIN

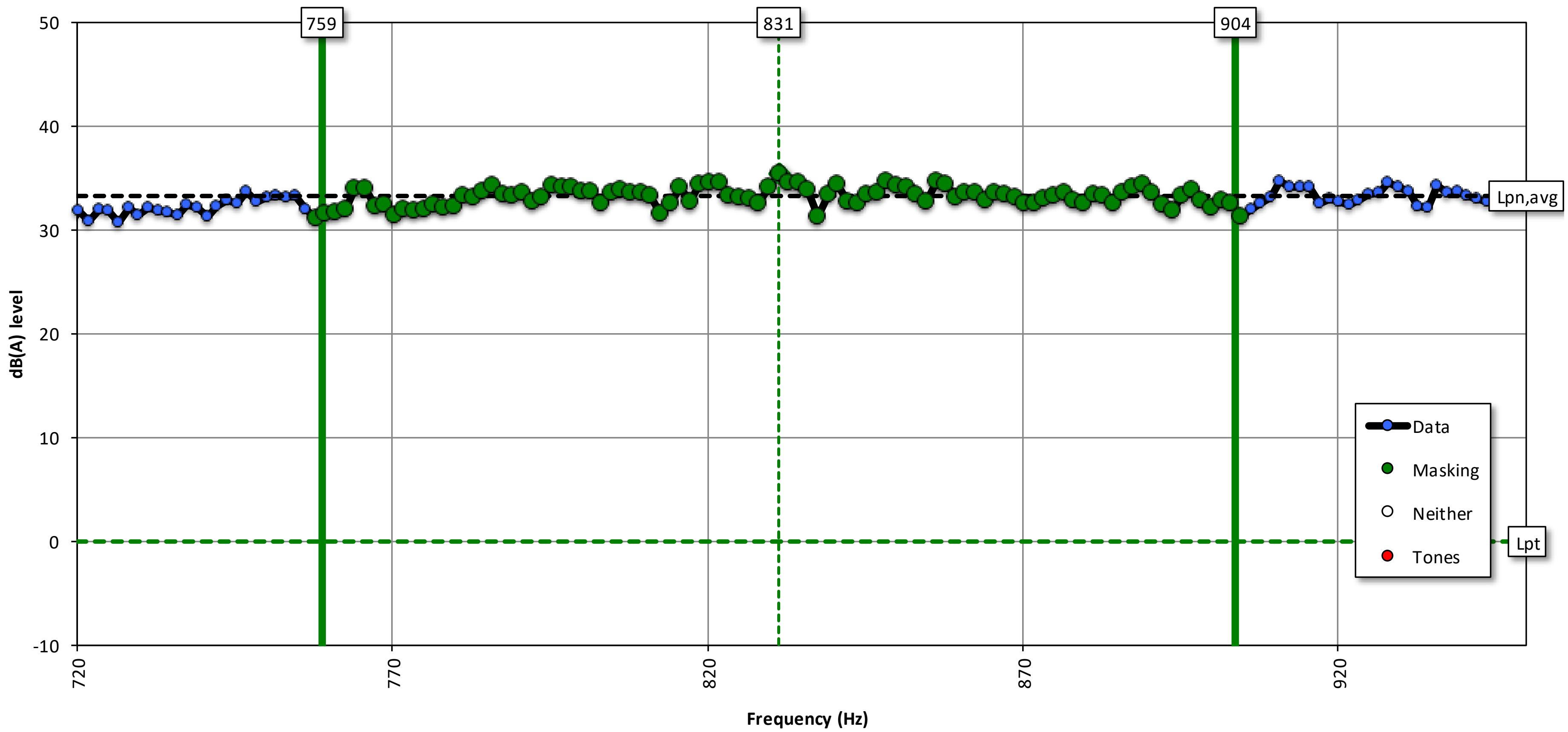


FIGURE 23d CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 9m/s WIND SPEED BIN (Spectrum Maximum and Highest Tonality are equivalent in this case)

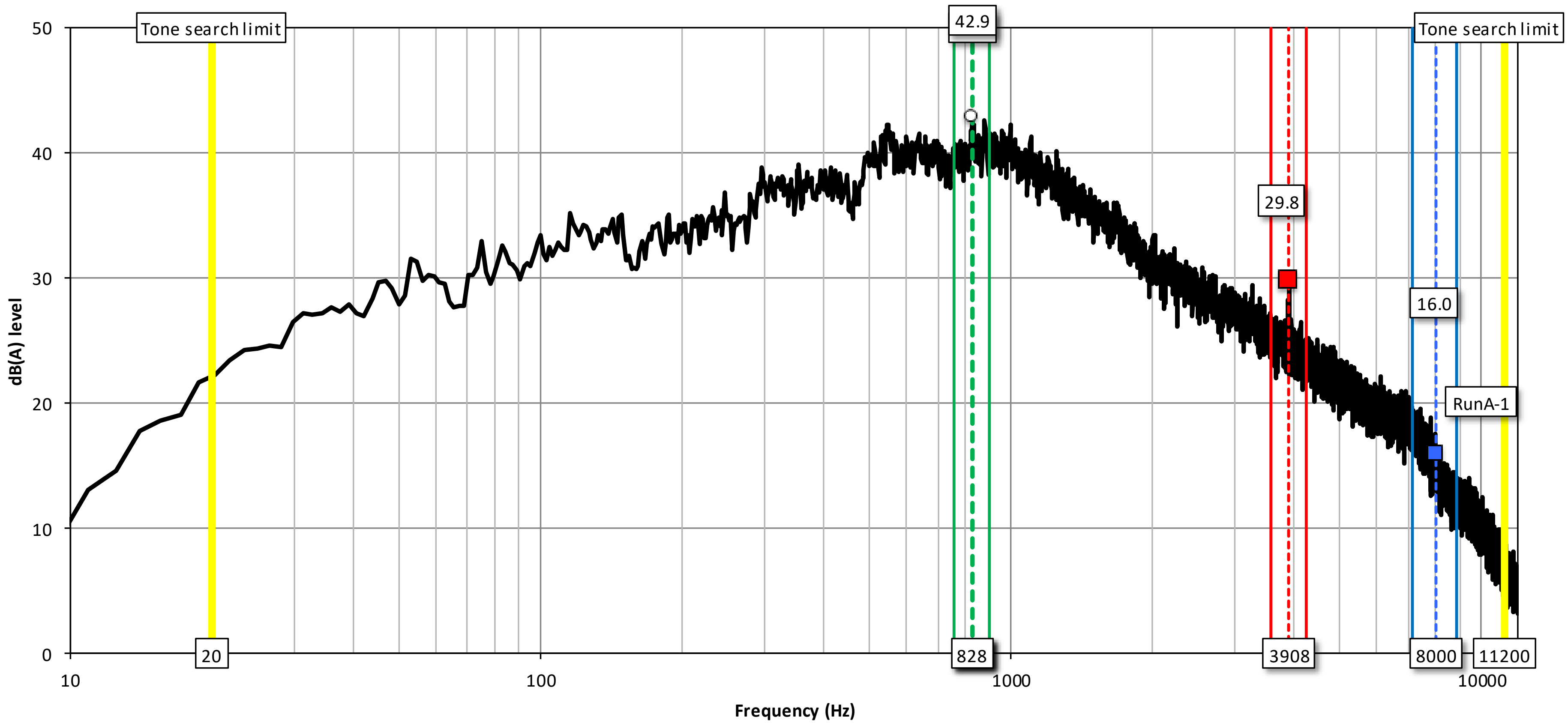


FIGURE 24a TONAL ASSESSMENT USING THE IEC 61400-11:2012 METHOD FOR THE 10 m/s HUB-HEIGHT WIND SPEED BIN

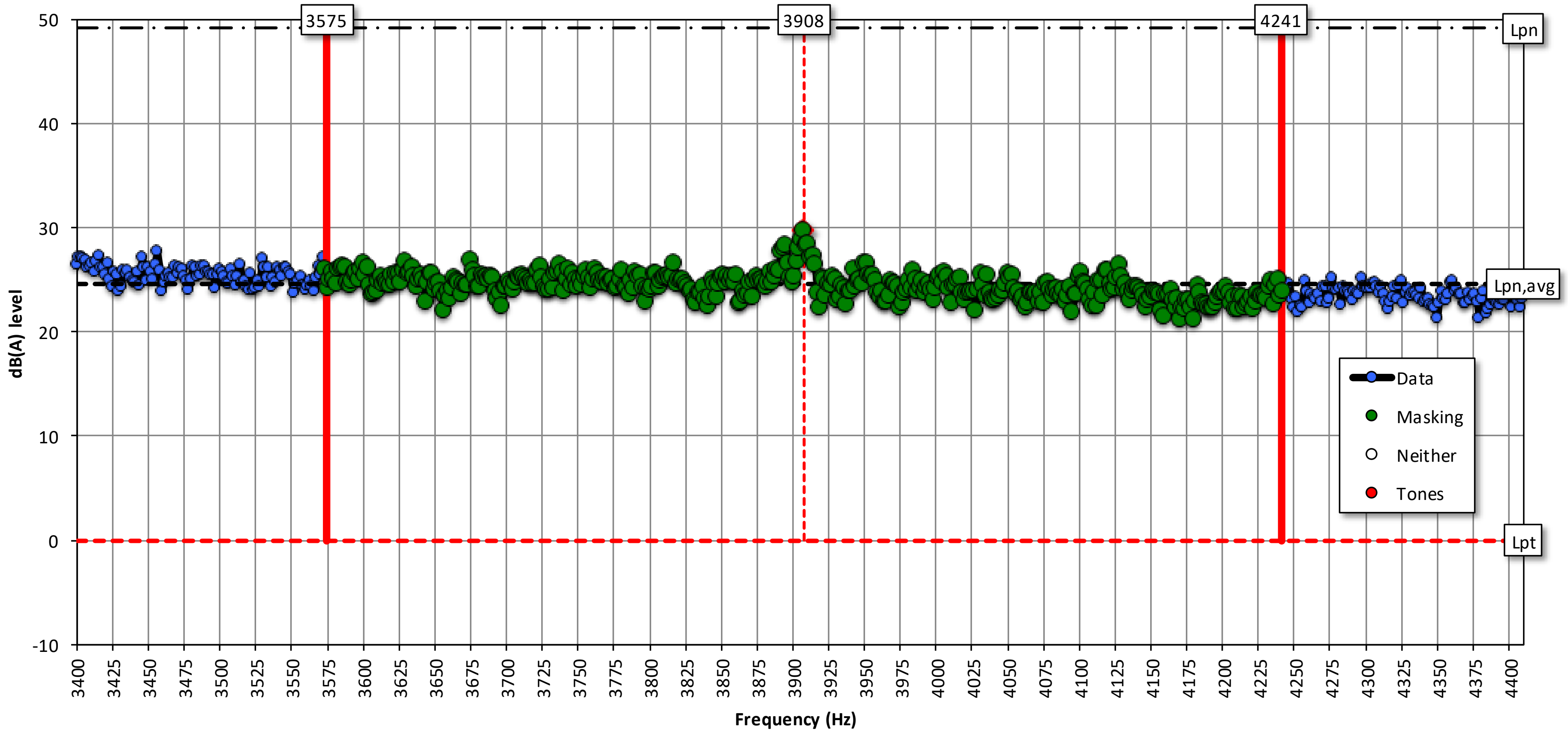


FIGURE 24b CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 10 m/s WIND SPEED BIN

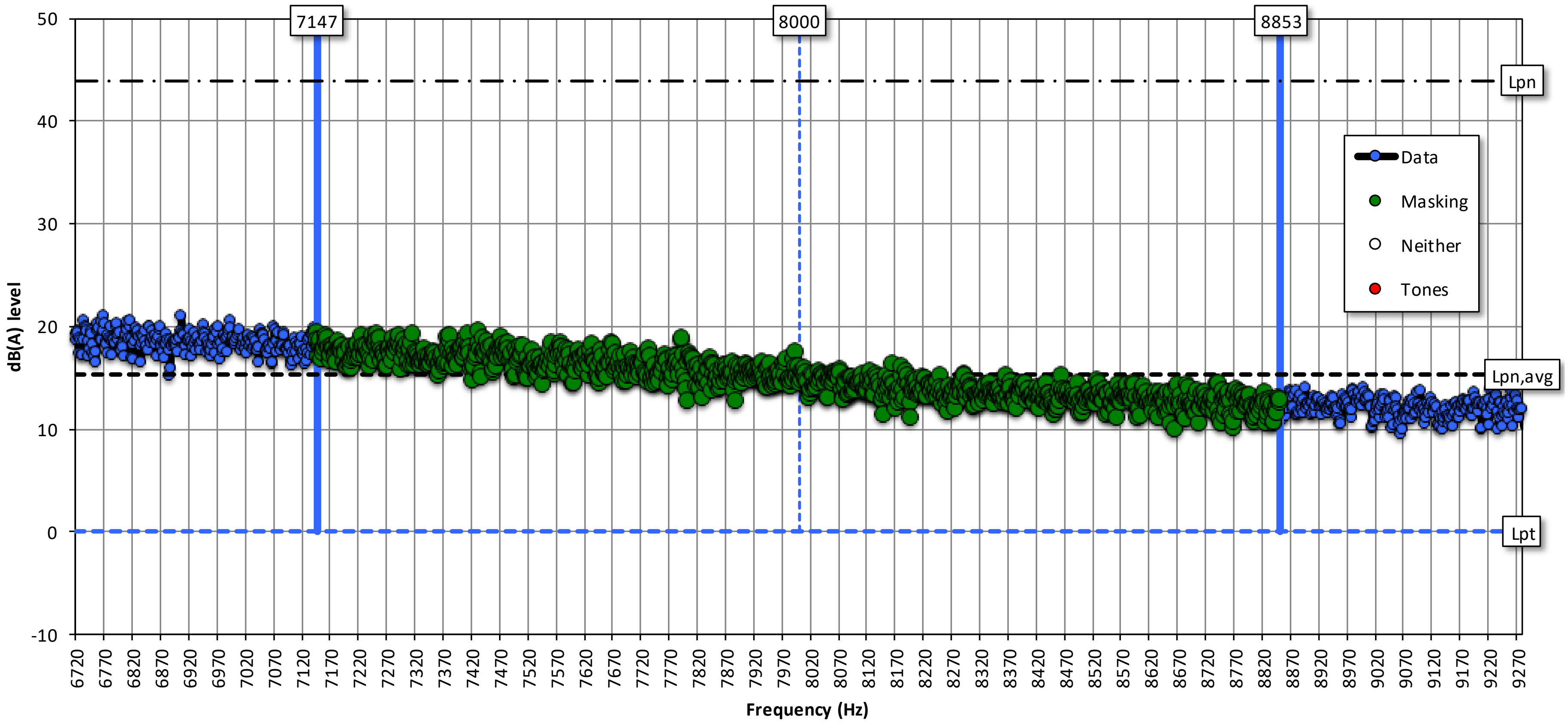


FIGURE 24c CRITICAL BAND WITH 2nd HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 10 m/s WIND SPEED BIN

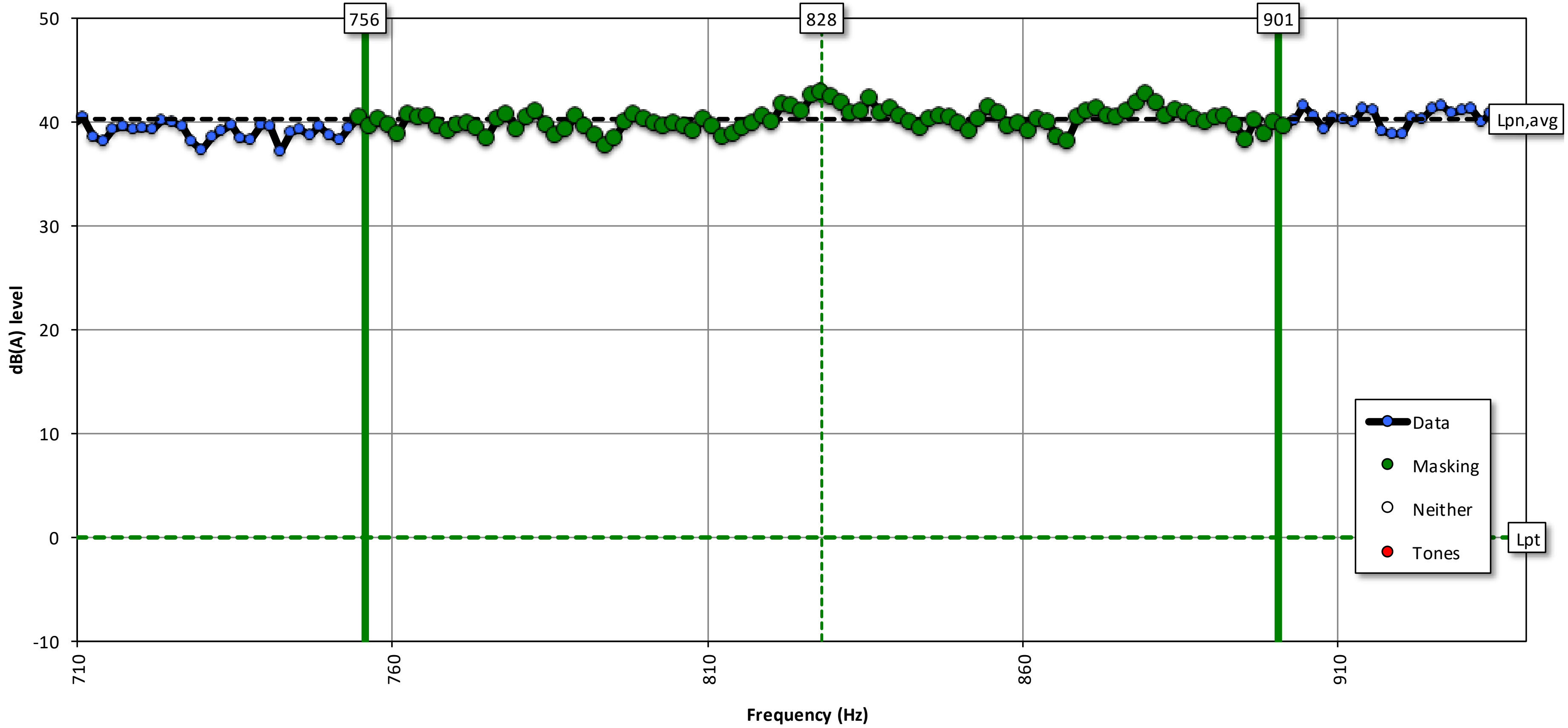


FIGURE 24d CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 10m/s WIND SPEED BIN (Spectrum Maximum and Highest Tonality are equivalent in this case)

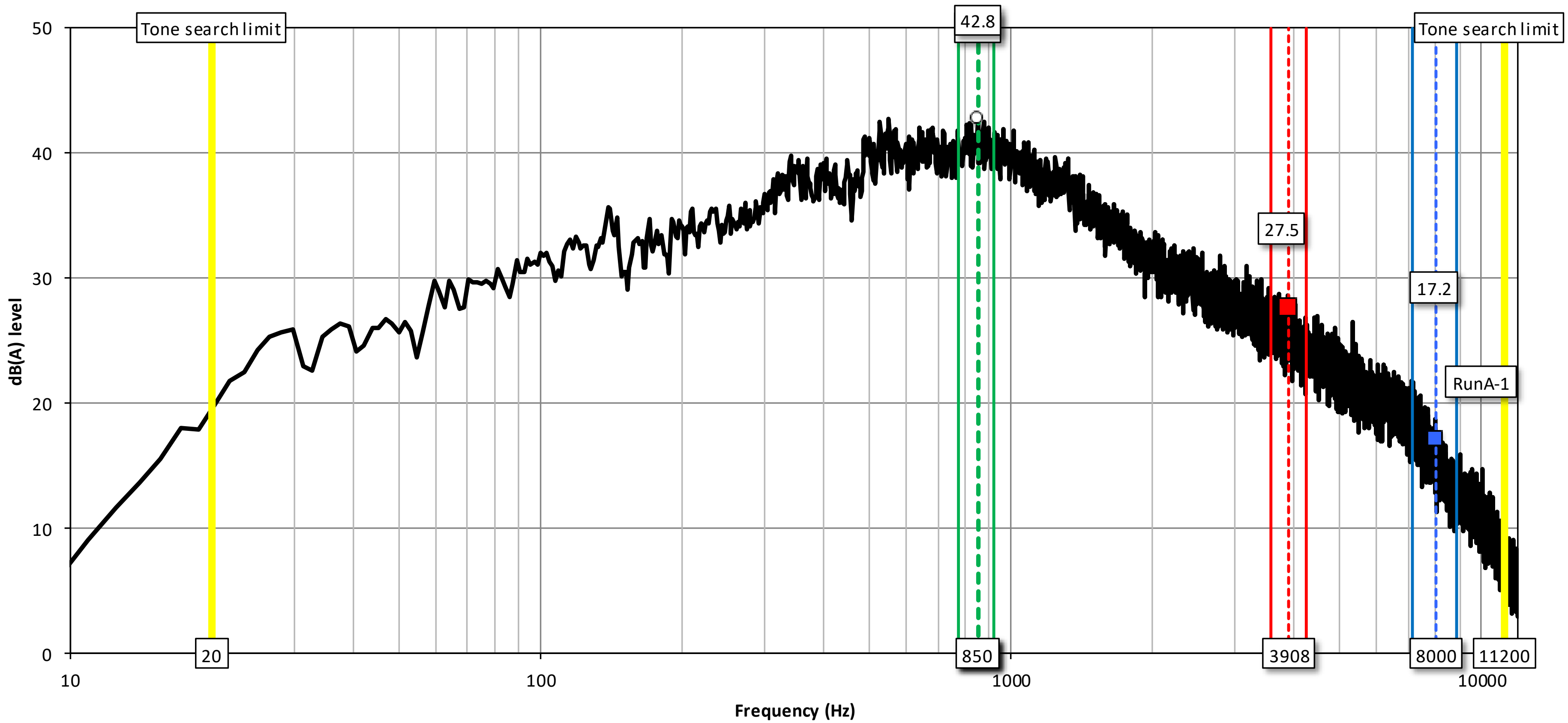


FIGURE 25a TONAL ASSESSMENT USING THE IEC 61400-11:2012 METHOD FOR THE 11 m/s HUB-HEIGHT WIND SPEED BIN

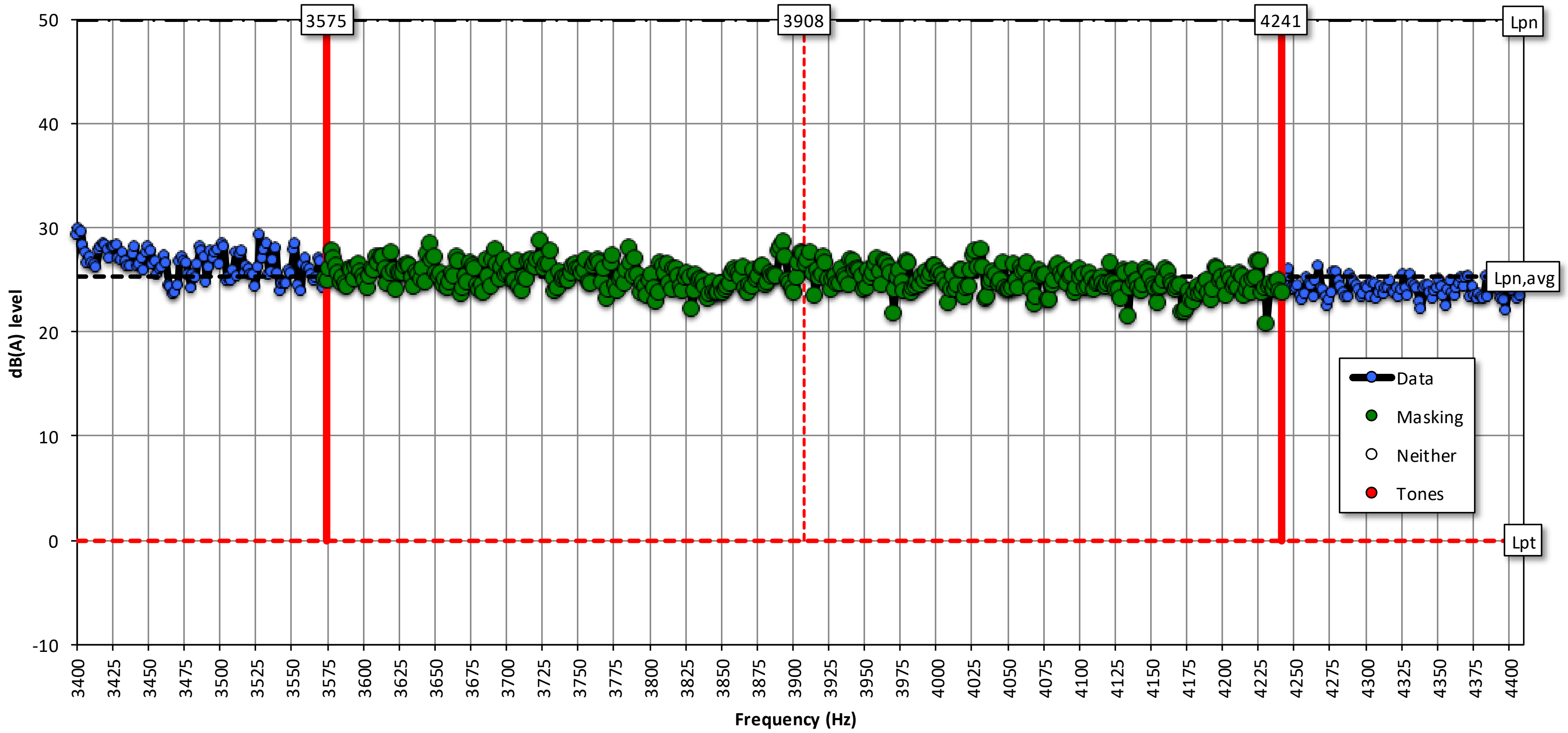


FIGURE 25b CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 11 m/s WIND SPEED BIN

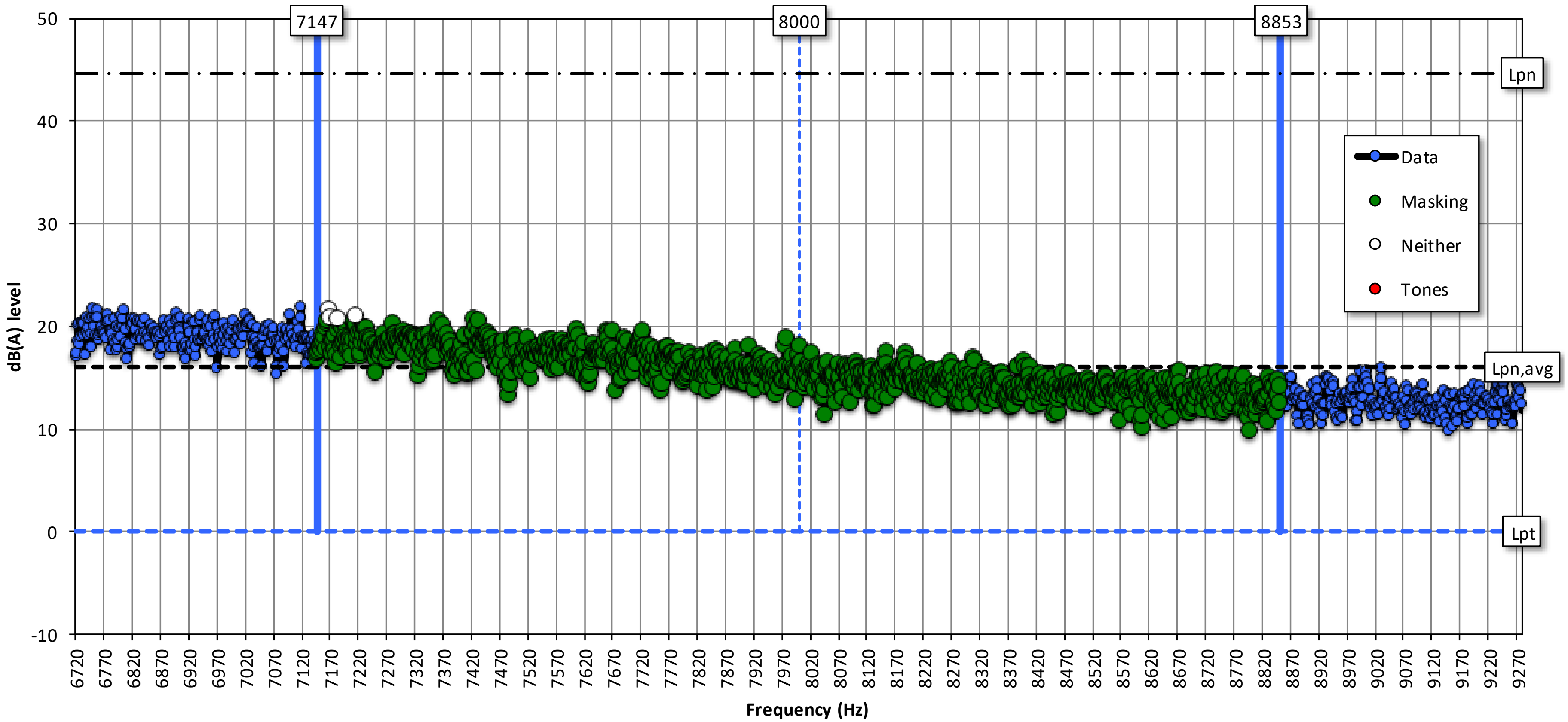


FIGURE 25c CRITICAL BAND WITH 2nd HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 11 m/s WIND SPEED BIN

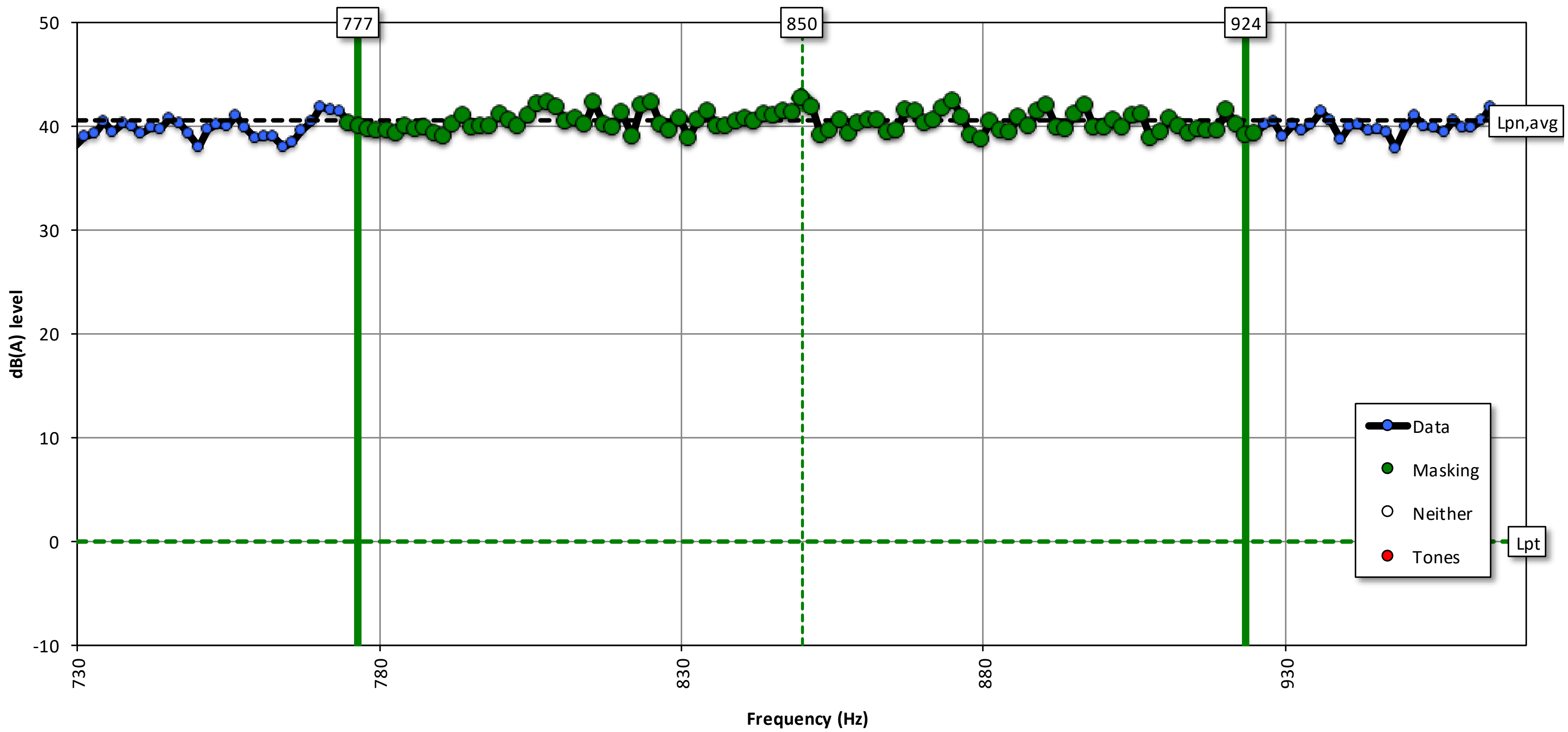


FIGURE 25d CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 11m/s WIND SPEED BIN (Spectrum Maximum and Highest Tonality are equivalent in this case)

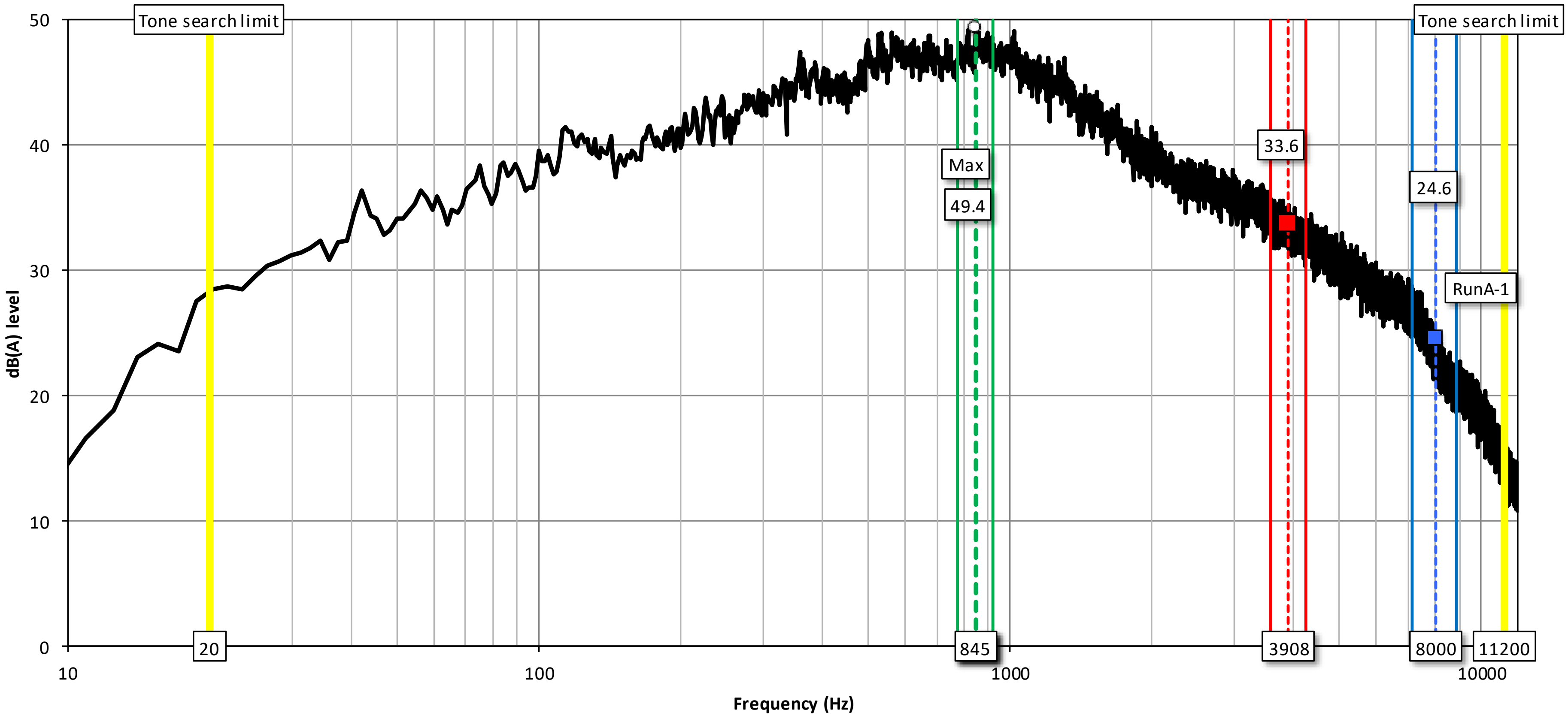


FIGURE 26a TONAL ASSESSMENT USING THE IEC 61400-11:2012 METHOD FOR THE 12 m/s HUB-HEIGHT WIND SPEED BIN

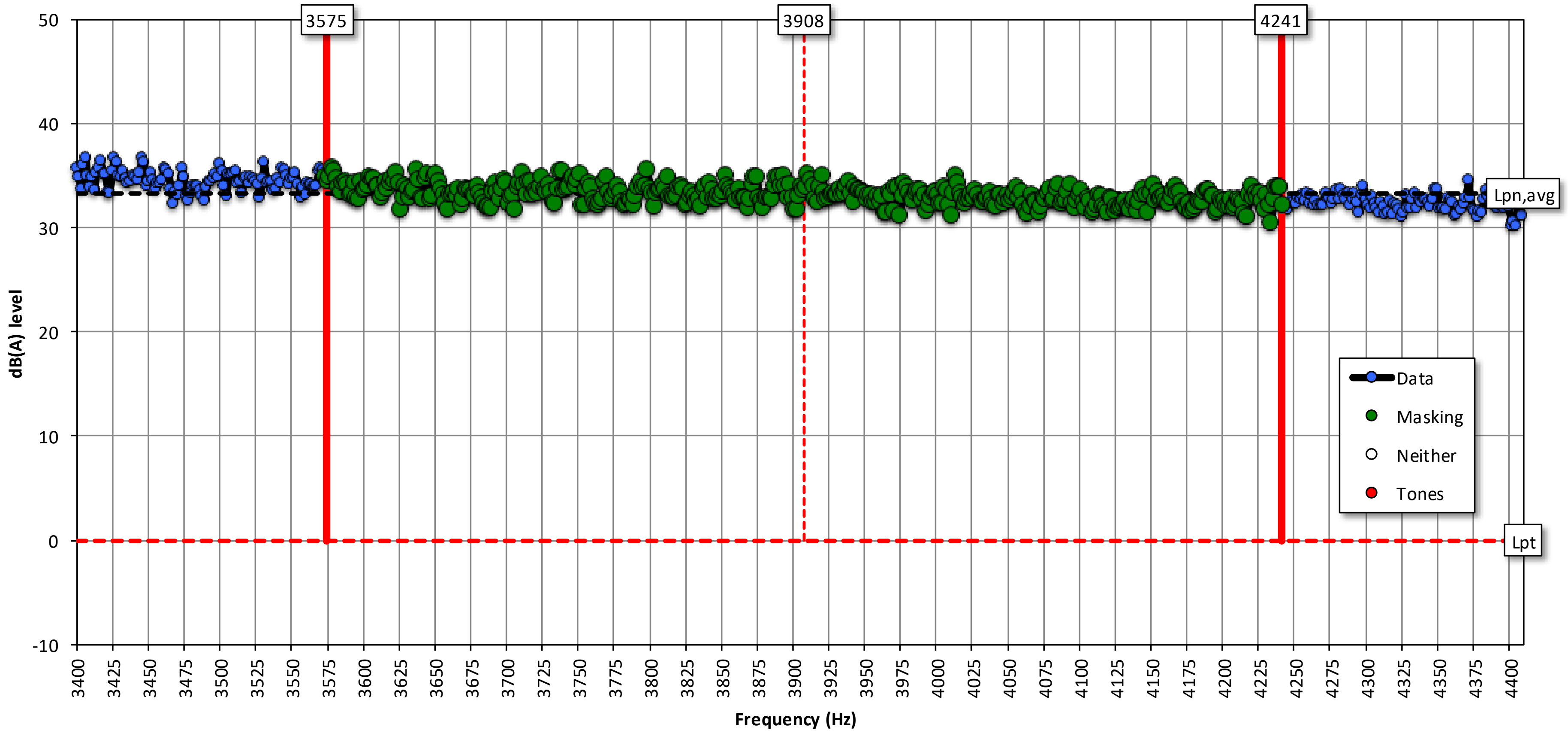


FIGURE 26b CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 12 m/s WIND SPEED BIN

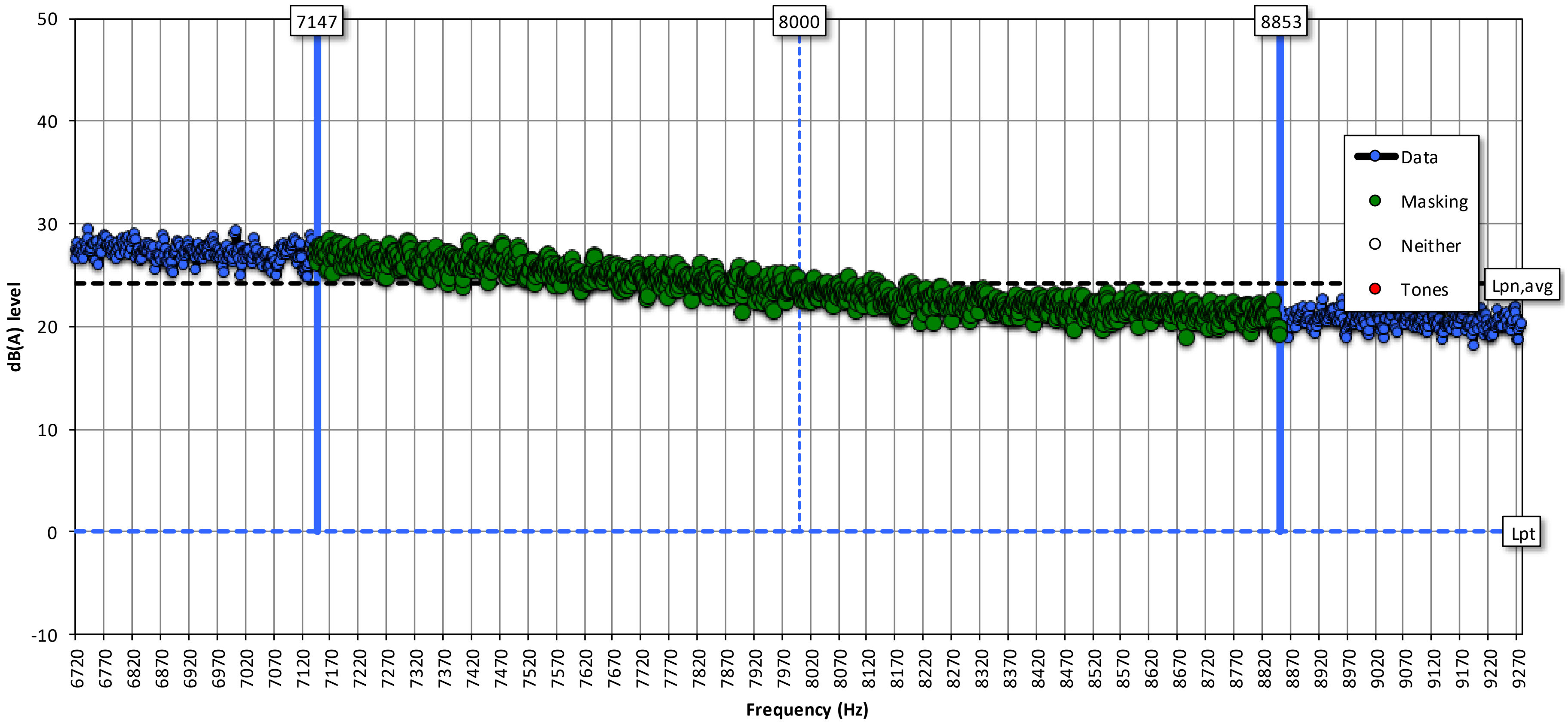


FIGURE 26c CRITICAL BAND WITH 2nd HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 12 m/s WIND SPEED BIN

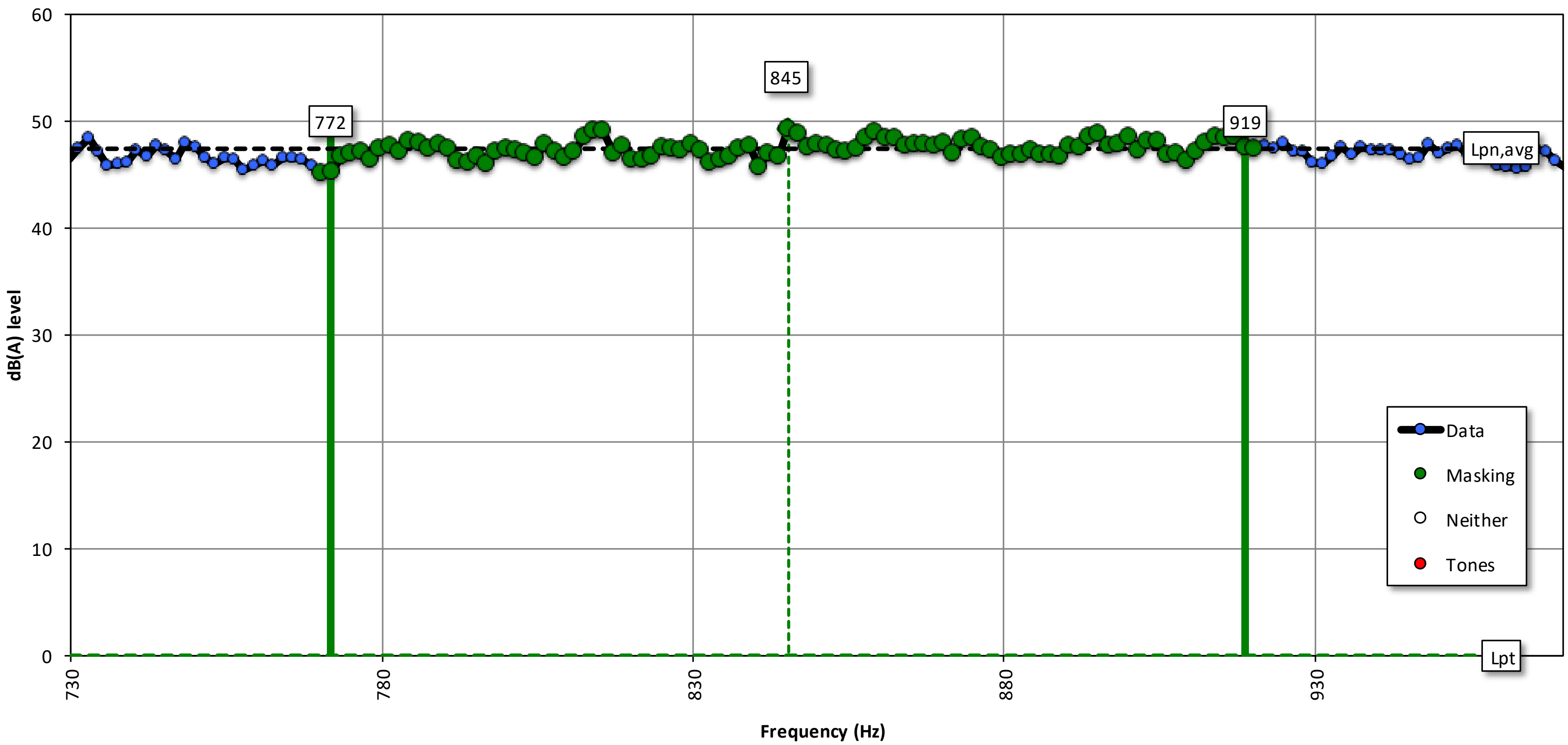


FIGURE 26d CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 12m/s WIND SPEED BIN (Spectrum Maximum and Highest Tonality are equivalent in this case)

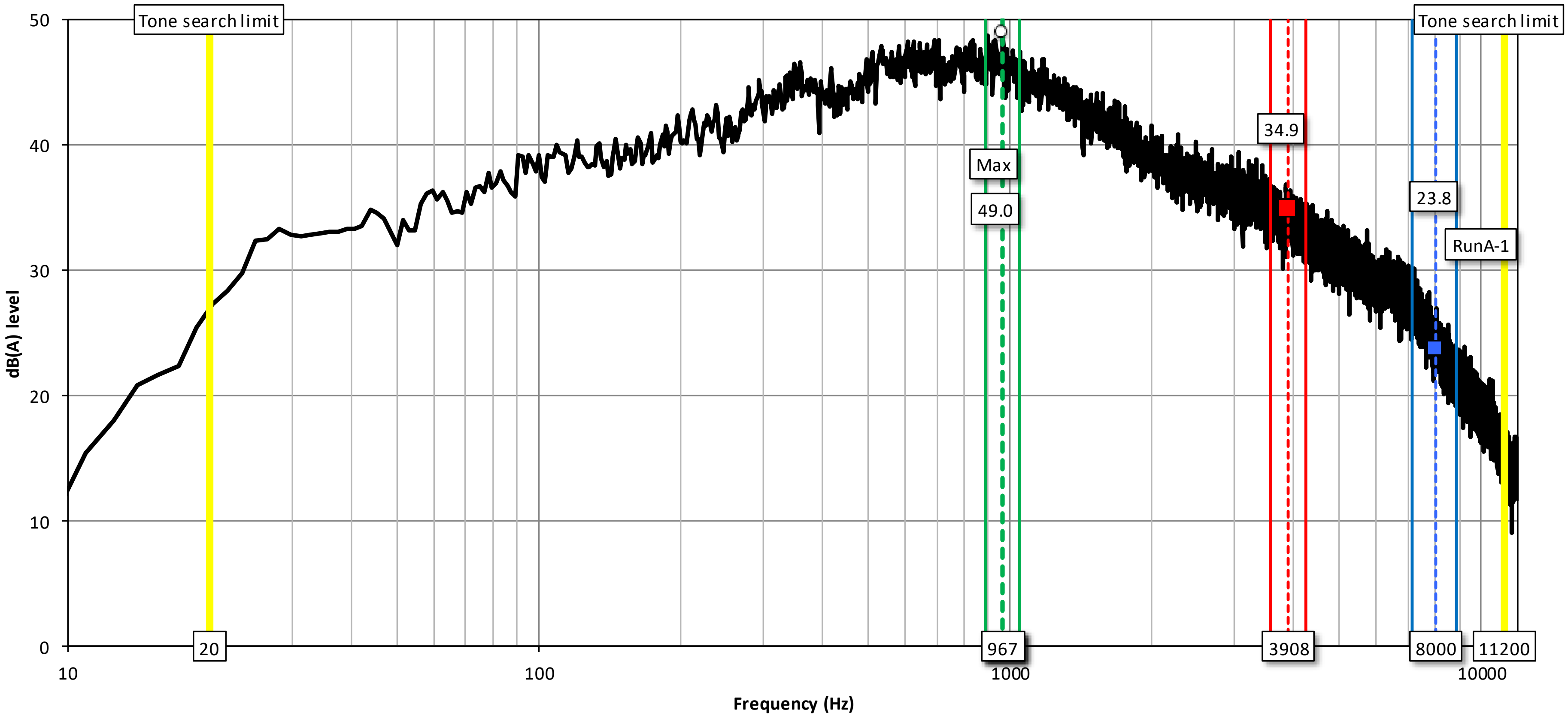


FIGURE 27a TONAL ASSESSMENT USING THE IEC 61400-11:2012 METHOD FOR THE 13 m/s HUB-HEIGHT WIND SPEED BIN

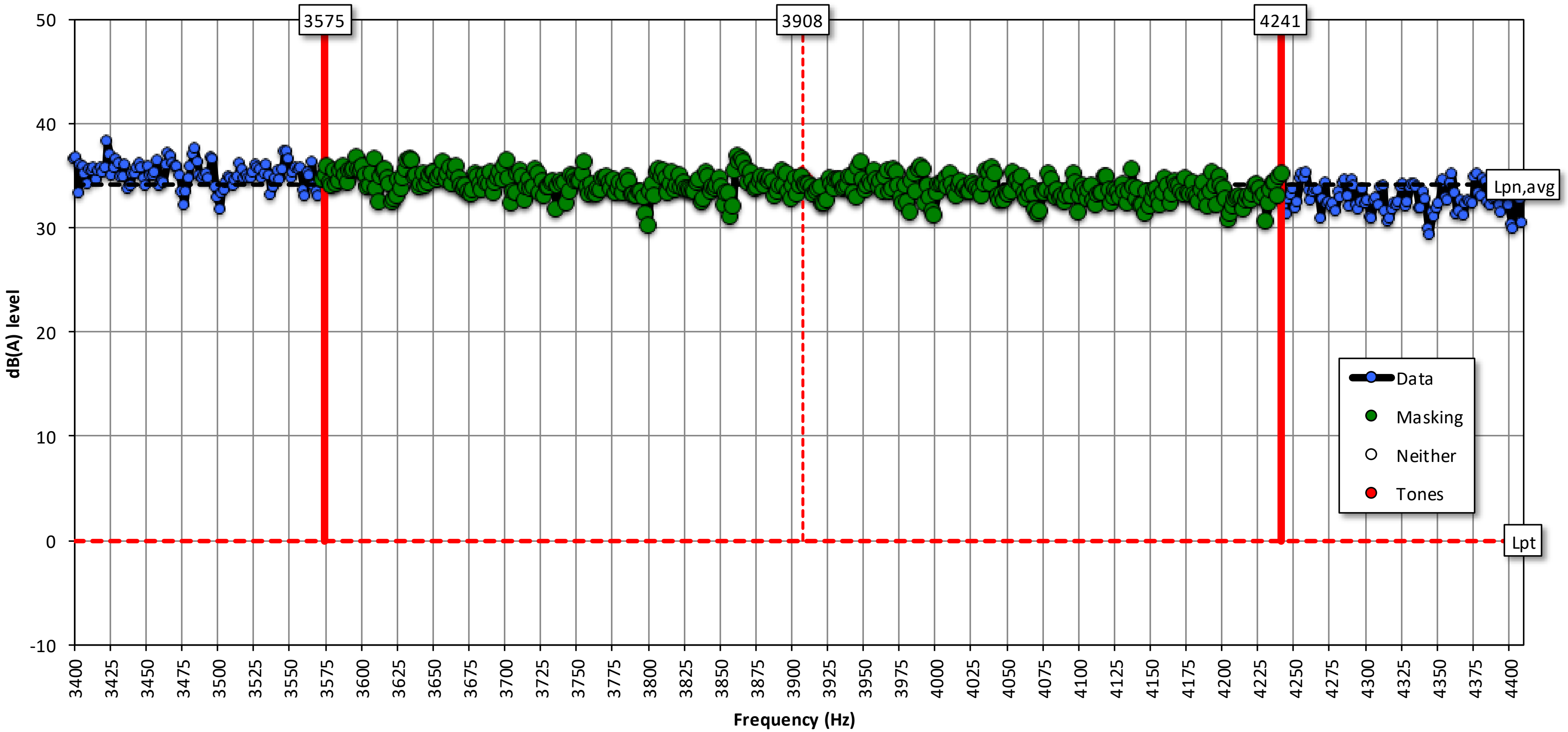


FIGURE 27b CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 13 m/s WIND SPEED BIN

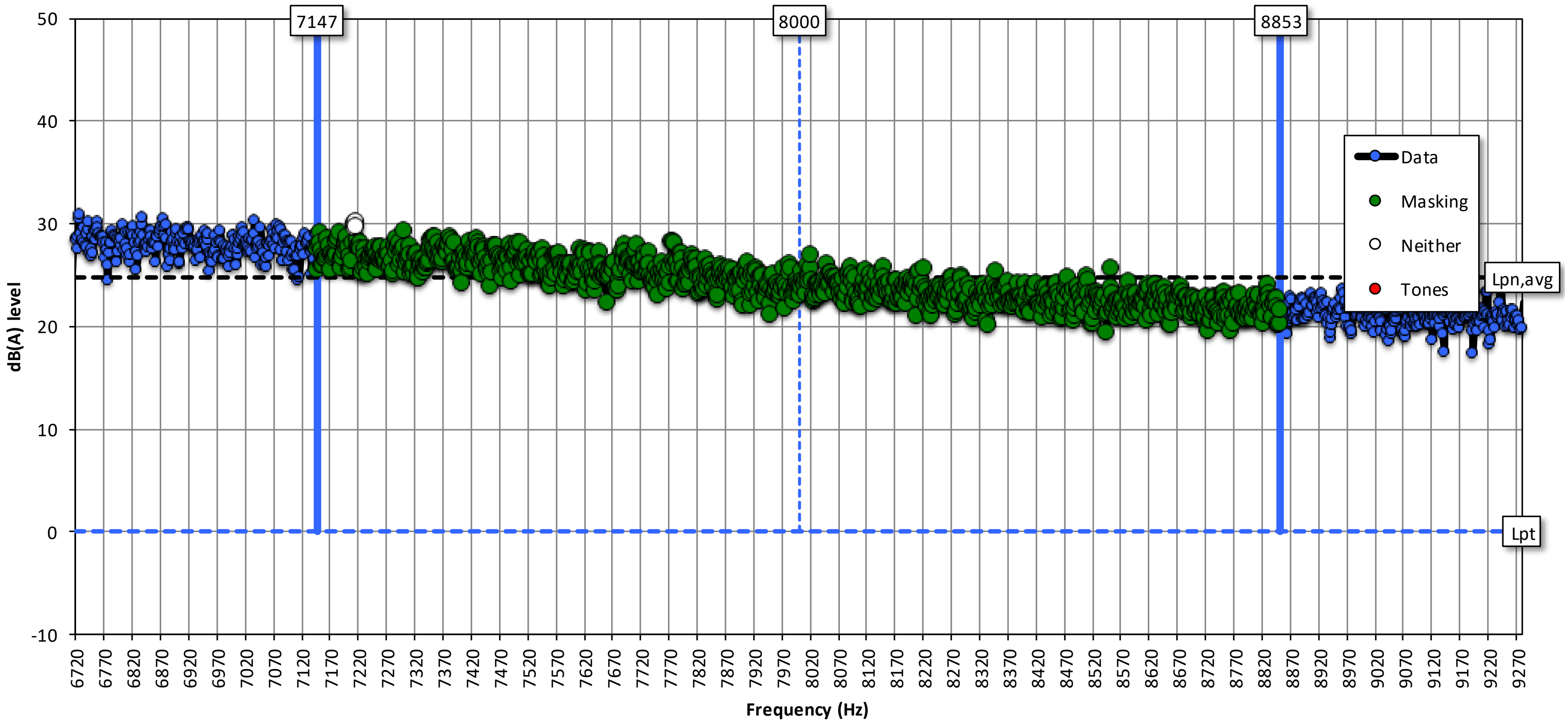


FIGURE 27c CRITICAL BAND WITH 2nd HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 13 m/s WIND SPEED BIN

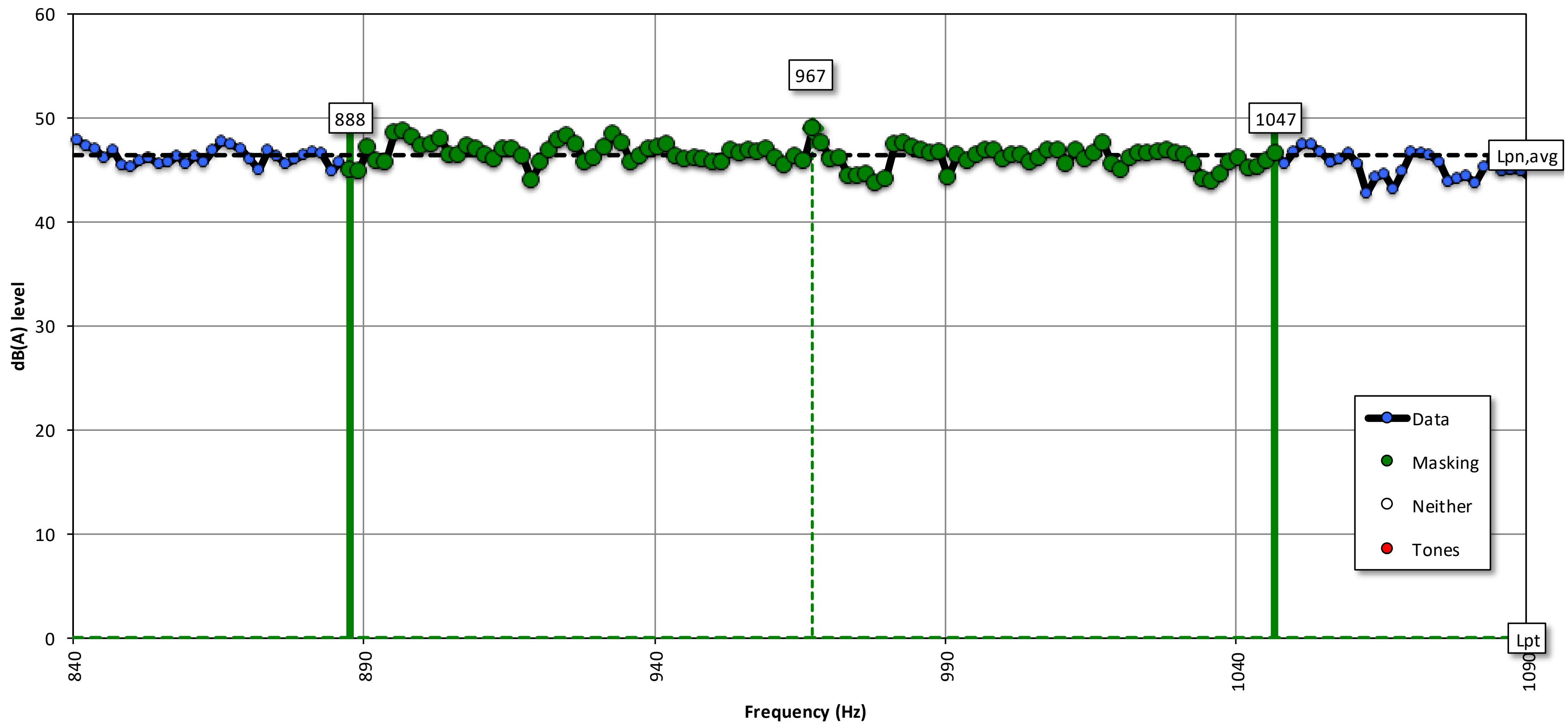


FIGURE 27d CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 13m/s WIND SPEED BIN (Spectrum Maximum and Highest Tonality are equivalent in this case)

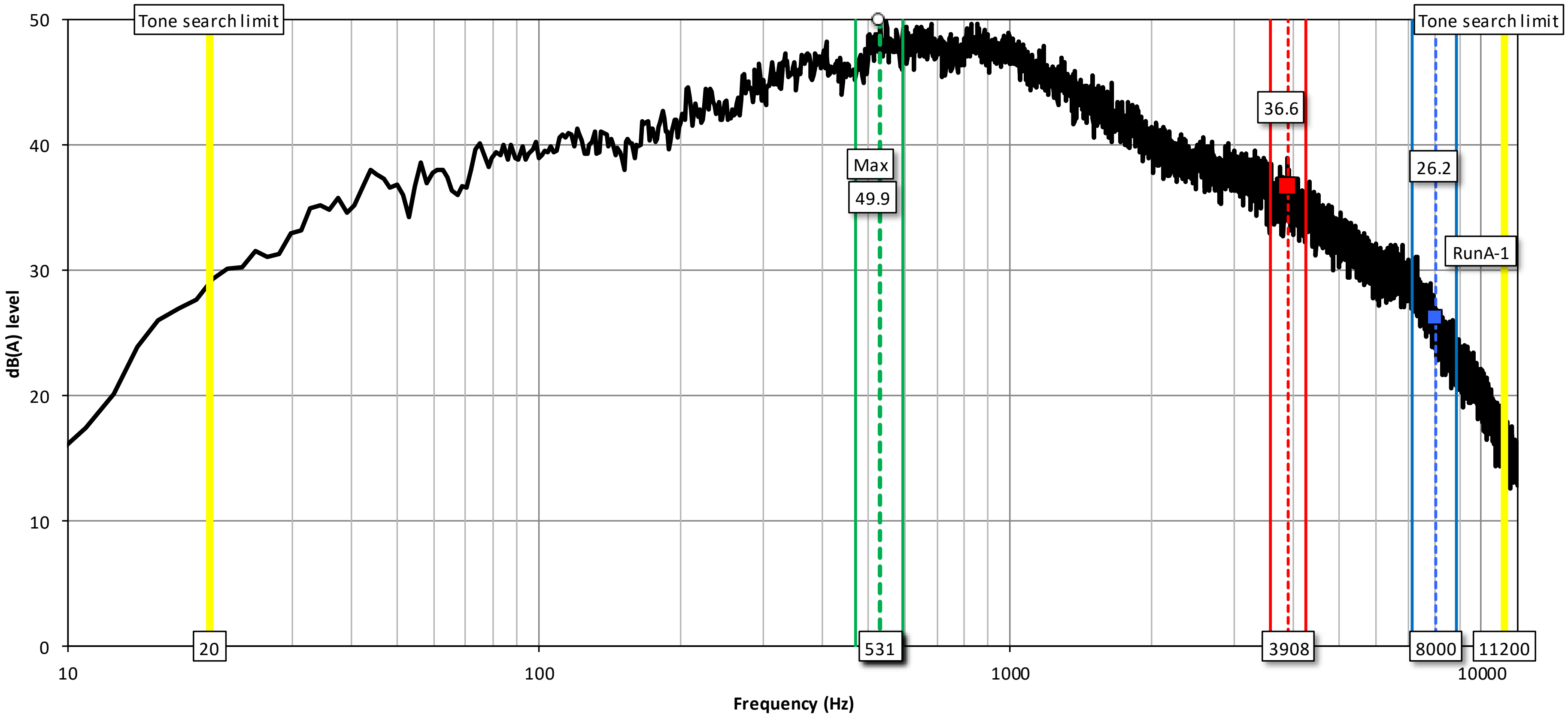


FIGURE 28a TONAL ASSESSMENT USING THE IEC 61400-11:2012 METHOD FOR THE 14 m/s HUB-HEIGHT WIND SPEED BIN

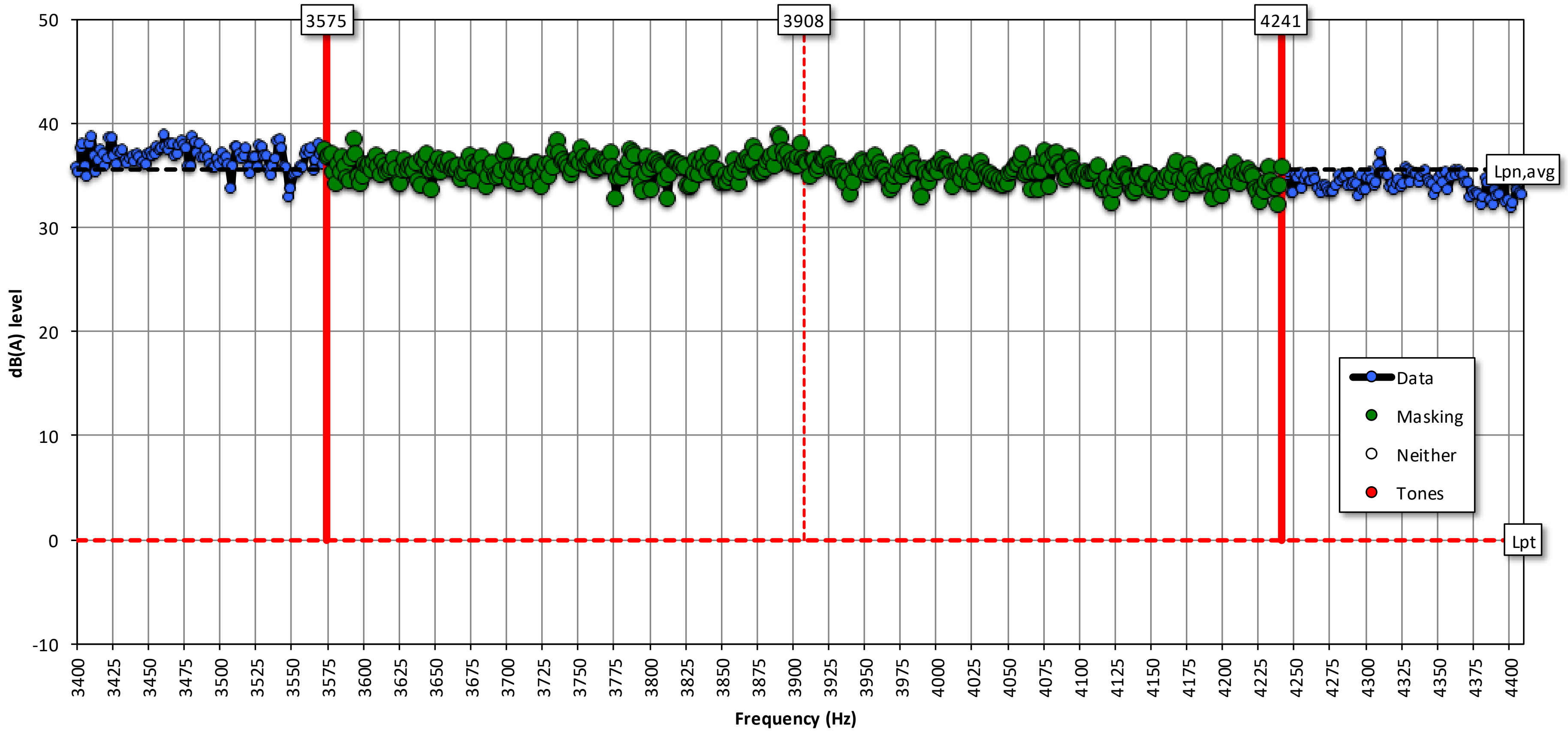


FIGURE 28b CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 14 m/s WIND SPEED BIN

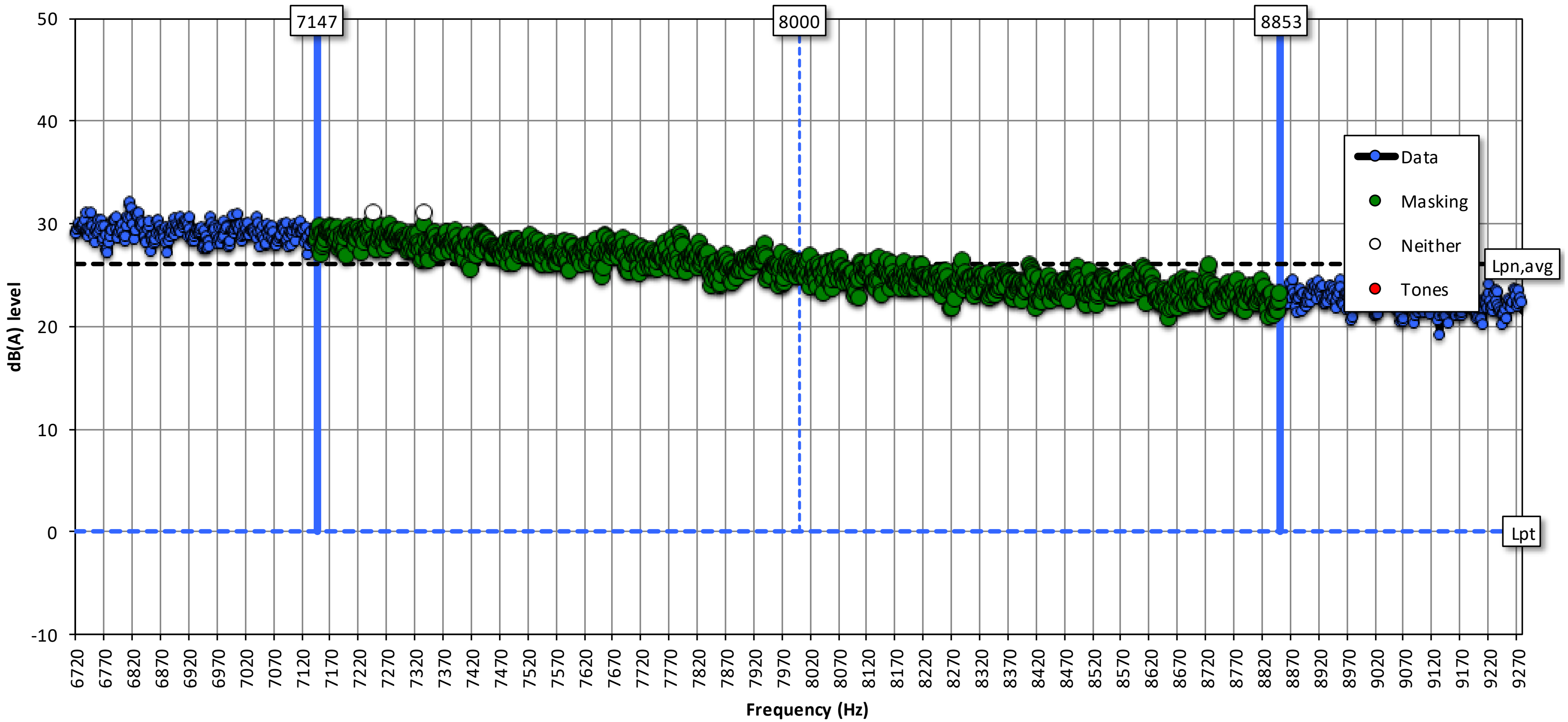


FIGURE 28c CRITICAL BAND WITH 2nd HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 14 m/s WIND SPEED BIN

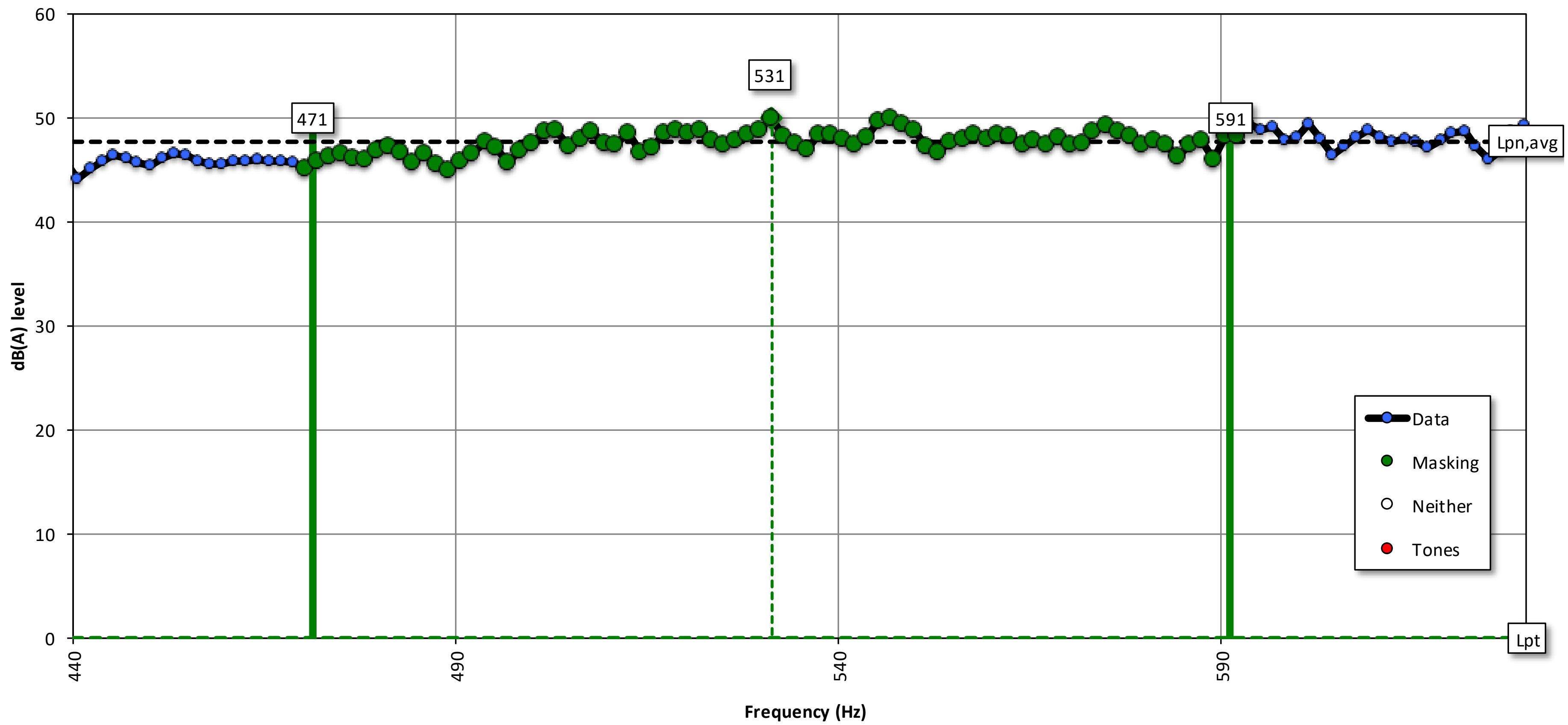


FIGURE 28d CRITICAL BAND WITH HIGHEST TONALITY SHOWING TONES AND MASKING NOISE FOR 14 m/s WIND SPEED BIN (Spectrum Maximum and Highest Tonality are equivalent in this case)

[END OF MAIN BODY OF REPORT / TEXT EXCLUDING (31 PAGES OF) APPENDICES FOLLOWING]

APPENDIX 1

CALIBRATION CERTIFICATES

CERTIFICATE OF CALIBRATION

Date of issue: 3 August 2010   Certificate Number: C1006721

UKAS CALIBRATION
0174

Page 1 of 2 pages

Brüel & Kjær
The Calibration Laboratory
Skodsborgvej 307, DK-2850 Nærum, Denmark
E-Mail: ukservice@bksv.com

Approved signatory
Henrik Nyholt

Customer:	TUV NEL Ltd Scottish Enterprise Technology Park East Kilbride G75 0QF Glasgow United Kingdom	**Manufacturer:**	Brüel & Kjær
		Description:	Sound Level Calibrator
		Type:	4231
		Serial No:	2651818
Inventory ID:	-	**Date of receipt:**	30 July 2010
Customer Ref:	Service Contract	**Calibration Date:**	2 August 2010

The calibration was performed to laboratory procedure TWI-104-DK.

Sound pressure level in the coupler of this calibrator was measured with a calibrated, laboratory grade condenser microphone specified in the certificate. In the case of 1/2 inch microphone, the 1/2 inch adaptor supplied with the calibrator was used. Choice of 1 or 1/2 inch microphone is specified in the customers order.

Sound pressure level measured was compared with sound pressure level generated in the coupler of a working standard pistonphone calibrated by the National Physical Laboratory using the same microphone and at the same ambient conditions.

Appropriate corrections for atmospheric pressure during calibration and for measurement system frequency and level response were taken into account.
Sound pressure level results given in the certificate are the mean of 5 measurements.
Calibration results apply at ambient conditions during the process of calibration, which are given in the certificate.

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k = 2$, providing a level of confidence of approximately 95%.
The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CUBK4231A10

CERTIFICATE OF CALIBRATION

UKAS Accredited Calibration Laboratory No. 0174

Certificate Number
C1006721

1. ACOUSTIC MEASUREMENTS

Coupler Configuration	Microphone Type (without grid)	Output Level, dB re 20 µPa at ambient test conditions	+20 dB Level Step in dB	Frequency Hz *	Total Harmonic Distortion % *
1/2"	4180	94.00	20.01	1000	0.4
1"	-	-	-	-	-
Measurement Uncertainty	-	0.15	0.04	0.1	0.3

* Frequency and Distortion measurements are not covered by the UKAS accreditation.

Ambient conditions during calibration were:

Atmospheric Pressure:	100.96 kPa
Temperature:	23.1 °C
Relative Humidity:	52 %

Note:

Manufacturers manual should be consulted when the calibrator is used with free field microphones which are normally supplied with sound level meters.

This instrument was calibrated by: Lene Petersen

END

CERTIFICATE OF CALIBRATION

Date of Issue: 02 August 2010 Certificate Number: C1006722

UKAS CALIBRATION 0174

Brüel & Kjær S&V A/S

Skodsborgvej 307, DK-2850 Nærum, Denmark
Tel: +45 45 800 500 Fax: +45 45 801 405
Email: ukservice@bksv.com

Approved Signatory

Lars Mårtensson

CALIBRATION OF:

Sound Level Meter	2250	No: 2653893
Microphone:	4189	No: 2643613
Associated Calibrator:	Brüel & Kjær 4231	No: 2651818
Calibrator Certificate	C1006721	Level: 94.00 dB SPL
Inventory ID:		
Date of receipt:	30 July 2010	
Date of calibration:	02 August 2010	

CUSTOMER:

TUV NEL Ltd
Scottish Enterprise Tech Park
East Kilbride
G75 0QF Glasgow
United Kingdom

Customer Ref.: Service Contract

CALIBRATION CONDITIONS:

Preconditioning: 12 hours at 23 °C

Environment conditions:

Air temperature:	23.4 °C
Air pressure:	101.0 kPa
Relative Humidity:	54.0 %RH

SPECIFICATIONS:

The Sound Level Meter was calibrated according to the procedure given in BS7580: Part 1: 1997.

PROCEDURE:

The measurements have been performed with the assistance of Brüel & Kjær Sound Level Meter Calibration System B&K 3630 with application software type 7763 and test collection 2250-4189

RESULTS:

Unless otherwise stated herein, the reported uncertainty is based upon a standard uncertainty multiplied by a coverage factor $k = 2$, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements. The uncertainties refer to the measured values only with no account being taken of the ability of the device under test to maintain its calibration.

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No. 0174

Certificate Number:

C1006722

Summary

Preliminary Inspection (5.3)	**Passed**
Setting up (5.4)	**Passed**
General (5.5.1)	**Passed**
Self-generated noise (5.5.2)	**Passed**
Linearity, reference range SPL (5.5.3)	**Passed**
Linearity, reference range Leq (5.5.3)	**Passed**
Frequency weighting A (5.5.4)	**Passed**
Frequency weighting C (5.5.4)	**Passed**
Frequency weighting Lin (5.5.4)	**Passed**
Time weighting Fast (5.5.5)	**Passed**
Time weighting Slow (5.5.5)	**Passed**
Peak response (5.5.6)	**Passed**
R.M.S. accuracy (5.5.7)	**Passed**
Time weighting I (5.5.8)	**Passed**
Time averaging (5.5.9)	**Passed**
Pulse range and sound exposure level (5.5.10 and 5.5.11)	**Passed**
Overload indication, Non-integrating (5.5.12)	**Passed**
Overload indication, Integrating (5.5.12)	**Passed**
Acoustic calibration at 1000 Hz (5.6.1)	**Passed**
Acoustic test at 125 and 8000 Hz (5.6.2)	**Passed**
Response to sound calibrator (5.6.3)	**Passed**

STATEMENT OF RESULT:
- THE SOUND LEVEL METER CONFORMS TO BS7580: PART1:1997 VERIFYING CONFORMANCE TO BS EN 60651:1994, BS EN 60804:1994 AND BS3539:1986.

Instruments used in the verification procedure were traceable to national standards. The method of acoustic calibration employed a standard sound pressure calibrator. The test results were corrected for the difference between the free field and pressure response of the microphone supplied. The uncertainty of the standard calibrator is not included in the applied tolerances. The instrument was calibrated without a windscreen, consult manufacturer's manual if using a windscreen. The upper limit of the primary indicator range is 10dB less than the corresponding indicator range. The sound level meter was manufactured in accordance with BSEN60651:1994 Type 1, and BSEN60804:1994 or BSEN60804:2001 Type 1 if an integrating meter, and has been pattern evaluated and approved by a European National Institute of Metrology.

Calibration has been performed with original microphone grid.

The uncertainties quoted for the measurement shown are based on an estimated confidence probability of not less than 95% using a coverage factor k>=2.

CERTIFICATE OF CALIBRATION

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Certificate Number:

C1006722

Note:

Measurements close to or at the upper limit of a measuring range may produce an overload indication.
Similarly measurements close to or at the lower limit of a measuring range may produce an underrange indication.
This is not to be interpreted as an error of the Sound Level Meter, but an indication that the signal has reached the limit of the measuring range.

Instruments

Category:	Type:	Manufacturer:	Serial No.:	Last Calibration date:	Traceable to:
Generator	Pulse Generator	Brüel & Kjær	2558896	02 August 2010	DANAK 307
AmplifierDivider	3111 Output Module	Brüel & Kjær	2481841	02 August 2010	DANAK 307
Voltmeter	DMM34970A	Agilent	MY44013679	05 October 2009	DANAK 22
Calibrator	4226	Brüel & Kjær	2560144	13 April 2010	DANAK 307
Adaptor	WA0302B, 15 pF	Brüel & Kjær	2557070	26 September 2008	DANAK 22

The uncertainties quoted for the measurement shown are based on an estimated confidence probability of not less than 95 % using a coverage factor k>=2.

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No. 0174

Certificate Number:

C1006722

Preliminary Inspection (5.3)

Inspection and control of instruments submitted for calibration and verification of instruments power supply by service engineer initials: LP.

Setting up (5.4)

Test and adjust sound level meter using the supplied calibrator.

Certificate Value of the associated calibrator	94.00	dB SPL
Coupler Free-field Correction	-0.15	dB
SPL before adjustment	93.80	dB SPL
SPL after adjustment	93.81	dB SPL

General (5.5.1)

Electrical tests have been performed with the microphone replaced by a capacitive adaptor.

Self-generated noise (5.5.2)

The self-generated noise has been measured using a shortcircuit on the input of the capacitive adaptor.
If 'underrange' indicated, the level was below the minimum measureable value.

	Measured [dB SPL]
Noise FW A	13.2
Noise FW C	14.2
Noise FW Lin	19.8

The uncertainties quoted for the measurement shown are based on an estimated confidence probability of not less than 95% using a coverage factor k=2.

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Certificate Number:

C1006722

Linearity, reference range SPL (5.5.3)

The Linearity of the Sound Level Meter has been tested relative to the reference sound pressure level as indicated on the reference range using a continuous sinusoidal signal Frequency of 4000 Hz. The lowest test level is determined by the noise as measured in 5.5.2.

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
94 dB Ref.	94.0	94.0	-0.2	0.2	0.0	0.12
30 dB. Rel. Ref.	30.0	30.1	-0.7	0.7	0.1	0.30
31 dB. Rel. Ref.	31.0	31.1	-0.7	0.7	0.1	0.30
32 dB. Rel. Ref.	32.0	32.1	-0.7	0.7	0.1	0.30
33 dB. Rel. Ref.	33.0	33.0	-0.7	0.7	0.0	0.30
34 dB. Rel. Ref.	34.0	34.0	-0.7	0.7	0.0	0.30
39 dB. Rel. Ref.	39.0	39.0	-0.7	0.7	0.0	0.30
44 dB. Rel. Ref.	44.0	44.0	-0.7	0.7	0.0	0.30
49 dB. Rel. Ref.	49.0	49.0	-0.7	0.7	0.0	0.30
54 dB. Rel. Ref.	54.0	54.0	-0.7	0.7	0.0	0.30
59 dB. Rel. Ref.	59.0	59.0	-0.7	0.7	0.0	0.30
64 dB. Rel. Ref.	64.0	64.0	-0.7	0.7	0.0	0.30
69 dB. Rel. Ref.	69.0	69.0	-0.7	0.7	0.0	0.30
74 dB. Rel. Ref.	74.0	74.0	-0.7	0.7	0.0	0.30
79 dB. Rel. Ref.	79.0	79.0	-0.7	0.7	0.0	0.30
84 dB. Rel. Ref.	84.0	84.0	-0.7	0.7	0.0	0.30
89 dB. Rel. Ref.	89.0	89.0	-0.7	0.7	0.0	0.30
99 dB. Rel. Ref.	99.0	99.0	-0.7	0.7	0.0	0.30
104 dB. Rel. Ref.	104.0	104.0	-0.7	0.7	0.0	0.30
109 dB. Rel. Ref.	109.0	109.0	-0.7	0.7	0.0	0.30
114 dB. Rel. Ref.	114.0	114.0	-0.7	0.7	0.0	0.30
119 dB. Rel. Ref.	119.0	119.0	-0.7	0.7	0.0	0.30
124 dB. Rel. Ref.	124.0	124.0	-0.7	0.7	0.0	0.30
129 dB. Rel. Ref.	129.0	129.0	-0.7	0.7	0.0	0.30
134 dB. Rel. Ref.	134.0	134.0	-1.0	1.0	0.0	0.30
135 dB. Rel. Ref.	135.0	135.0	-1.0	1.0	0.0	0.30
136 dB. Rel. Ref.	136.0	136.0	-1.0	1.0	0.0	0.30
137 dB. Rel. Ref.	137.0	137.0	-1.0	1.0	0.0	0.30
138 dB. Rel. Ref.	138.0	138.0	-1.0	1.0	0.0	0.30
139 dB. Rel. Ref.	139.0	139.0	-1.0	1.0	0.0	0.30
140 dB. Rel. Ref.	140.0	140.0	-1.0	1.0	0.0	0.30

The uncertainties quoted for the measurement shown are based on an estimated confidence probability of not less than 95% using a coverage factor k>=2.

Linearity, reference range Leq (5.5.3)

	Expected [dB Leq]	Measured [dB Leq]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
94 dB Ref.	94.0	94.0	-0.2	0.2	0.0	0.12
30 dB. Rel. Ref.	30.0	30.1	-0.7	0.7	0.1	0.30
31 dB. Rel. Ref.	31.0	31.1	-0.7	0.7	0.1	0.30
32 dB. Rel. Ref.	32.0	32.0	-0.7	0.7	0.0	0.30
33 dB. Rel. Ref.	33.0	33.0	-0.7	0.7	0.0	0.30
34 dB. Rel. Ref.	34.0	34.0	-0.7	0.7	0.0	0.30
39 dB. Rel. Ref.	39.0	39.0	-0.7	0.7	0.0	0.30
44 dB. Rel. Ref.	44.0	44.0	-0.7	0.7	0.0	0.30
49 dB. Rel. Ref.	49.0	49.0	-0.7	0.7	0.0	0.30
54 dB. Rel. Ref.	54.0	54.0	-0.7	0.7	0.0	0.30
59 dB. Rel. Ref.	59.0	59.0	-0.7	0.7	0.0	0.30
64 dB. Rel. Ref.	64.0	64.0	-0.7	0.7	0.0	0.30
69 dB. Rel. Ref.	69.0	69.0	-0.7	0.7	0.0	0.30
74 dB. Rel. Ref.	74.0	74.0	-0.7	0.7	0.0	0.30
79 dB. Rel. Ref.	79.0	79.0	-0.7	0.7	0.0	0.30
84 dB. Rel. Ref.	84.0	84.0	-0.7	0.7	0.0	0.30
89 dB. Rel. Ref.	89.0	89.0	-0.7	0.7	0.0	0.30
99 dB. Rel. Ref.	99.0	99.0	-0.7	0.7	0.0	0.30
104 dB. Rel. Ref.	104.0	104.0	-0.7	0.7	0.0	0.30
109 dB. Rel. Ref.	109.0	109.0	-0.7	0.7	0.0	0.30
114 dB. Rel. Ref.	114.0	114.0	-0.7	0.7	0.0	0.30
119 dB. Rel. Ref.	119.0	119.0	-0.7	0.7	0.0	0.30
124 dB. Rel. Ref.	124.0	124.0	-0.7	0.7	0.0	0.30
129 dB. Rel. Ref.	129.0	129.0	-0.7	0.7	0.0	0.30
134 dB. Rel. Ref.	134.0	134.0	-0.7	0.7	0.0	0.30
135 dB. Rel. Ref.	135.0	135.0	-0.7	0.7	0.0	0.30
136 dB. Rel. Ref.	136.0	136.0	-0.7	0.7	0.0	0.30
137 dB. Rel. Ref.	137.0	137.0	-0.7	0.7	0.0	0.30
138 dB. Rel. Ref.	138.0	138.0	-0.7	0.7	0.0	0.30
139 dB. Rel. Ref.	139.0	139.0	-0.7	0.7	0.0	0.30
140 dB. Rel. Ref.	140.0	140.0	-0.7	0.7	0.0	0.30

The uncertainties quoted for the measurement shown are based on an estimated confidence probability of not less than 95 % using a coverage factor k>=2.

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No. 0174

Certificate Number:

C1006722

Frequency weighting A (5.5.4)

The frequency weighting has been tested at octave intervals from 31.5 Hz to 12.5kHz relative to 1000 Hz at the specified reference level. The measured values have been corrected for the effect of body influence.

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
1000Hz Ref.	94.0	94.0	-0.2	0.2	-0.1	0.12
31.623Hz	54.5	54.6	-1.5	1.5	0.0	0.20
63.096Hz	67.7	67.8	-1.5	1.5	0.2	0.20
125.89Hz	77.8	77.9	-1.0	1.0	0.2	0.20
251.19Hz	85.3	85.4	-1.0	1.0	0.2	0.20
501.19Hz	90.7	90.8	-1.0	1.0	0.3	0.20
1995.3Hz	95.1	95.2	-1.0	1.0	0.1	0.20
3981.1Hz	94.9	95.0	-1.0	1.0	0.2	0.20
7943.3Hz	92.8	92.9	-3.0	1.5	0.3	0.20
12589Hz	89.6	89.2	-6.0	3.0	0.3	0.20

Frequency weighting C (5.5.4)

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
1000Hz Ref.	94.0	94.0	-0.2	0.2	-0.1	0.12
31.623Hz	90.9	91.0	-1.5	1.5	-0.0	0.20
63.096Hz	93.1	93.2	-1.5	1.5	0.2	0.20
125.89Hz	93.7	93.8	-1.0	1.0	0.2	0.20
251.19Hz	93.9	94.0	-1.0	1.0	0.2	0.20
501.19Hz	93.9	94.0	-1.0	1.0	0.3	0.20
1995.3Hz	93.7	93.8	-1.0	1.0	0.1	0.20
3981.1Hz	93.1	93.2	-1.0	1.0	0.2	0.20
7943.3Hz	90.9	91.0	-3.0	1.5	0.3	0.20
12589Hz	87.7	87.3	-6.0	3.0	0.3	0.20

The uncertainties quoted for the measurement shown are based on an estimated confidence probability of not less than 95% using a coverage factor k=2.

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No. 0174

Certificate Number: C1006722

Frequency weighting Lin (5.5.4)

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
1000Hz Ref.	94.0	94.0	-0.2	0.2	-0.1	0.12
31.623Hz	93.9	94.0	-1.5	1.5	-0.0	0.20
63.096Hz	93.9	94.0	-1.5	1.5	0.2	0.20
125.89Hz	93.9	94.0	-1.0	1.0	0.2	0.20
251.19Hz	93.9	94.0	-1.0	1.0	0.2	0.20
501.19Hz	93.9	94.0	-1.0	1.0	0.3	0.20
1995.3Hz	93.9	94.0	-1.0	1.0	0.1	0.20
3981.1Hz	93.9	94.0	-1.0	1.0	0.2	0.20
7943.3Hz	93.9	94.0	-3.0	1.5	0.3	0.20
12589Hz	93.9	93.6	-6.0	3.0	0.4	0.20

Time weighting Fast (5.5.5)

Time weighting was tested by comparing the response of a single sinusoidal Burst with the response of a continuous sinusoidal signal at a level 4 dB below the upper limit of the primary indicator range. The test frequency is 2000 Hz.

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
Ref. 126 dB	126.0	126.0	-0.2	0.2	0.0	0.20
Burst Meas. 126 dB	125.0	125.0	-1.0	1.0	0.0	0.20

Time weighting Slow (5.5.5)

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
Ref. 126 dB	126.0	126.0	-0.2	0.2	0.0	0.20
Burst Meas. 126 dB	121.9	122.0	-1.0	1.0	0.1	0.20

The uncertainties quoted for the measurement shown are based on an estimated confidence probability of not less than 95% using a coverage factor k>=2.

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No. 0174

Certificate Number:

C1006722

Peak response (5.5.6)

The onset time of the peak detector has been tested by comparing the response to a 100 µs rectangular pulse with the response to a 10 ms reference pulse of the same amplitude and polarity.

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
10 ms. Pos Ref.	129.0	129.0	-0.2	0.2	0.0	0.20
100 µs, Pos	129.0	127.5	-2.0	0.0	-1.5	0.20
10 ms. Neg Ref.	129.0	129.0	-0.2	0.2	0.0	0.20
100 µs, Neg	129.0	127.5	-2.0	0.0	-1.5	0.20

R.M.S. accuracy (5.5.7)

The r.m.s. accuracy has been tested on the reference range for a crest factor of 3 by comparing the response to a sequence of tone bursts with that for a continuous sinusoidal signal of 2000Hz at a level at 2 dB below the upper limit of the primary indicator range.

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
Ref. 128 dB	128.0	128.0	-0.2	0.2	0.0	0.20
Burst Meas. 128 dB	128.0	128.3	-0.5	0.5	0.3	0.20

Time weighting I (5.5.8)

Time weighting Impulse has been tested by comparing the response of a single sinusoidal Burst with a duration of 5 ms, and a repetitive Burst with the duration of 5 ms and a repetition frequency of 100 Hz , with the response of a continuous sinusoidal signal at a level at the upper limit of the primary indicator range. The test frequency is 2000 Hz.

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
Ref. 130 dB	130.0	130.0	-0.2	0.2	0.0	0.20
Sing. Burst Meas. 130 dB	121.2	121.1	-2.0	2.0	-0.1	0.20
Cont. Burst Meas. 130 dB	127.3	127.2	-1.0	1.0	-0.1	0.20

The uncertainties quoted for the measurement shown are based on an estimated confidence probability of not less than 95% using a coverage factor k=2.

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No. 0174

Certificate Number:

C1006722

Time averaging (5.5.9)

The time averaging has been tested on the reference range by comparing the response to a continuous sinusoidal signal of 4000 Hz, with that for a sequence of tone bursts having the same equivalent level.

	Expected [dB Leq]	Measured [dB Leq]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
Ref. Cont.	110.0	110.0	-0.2	0.2	0.0	0.20
Leq 1/1000	110.0	109.9	-1.0	1.0	-0.1	0.20
Ref. Cont.	100.0	100.0	-0.3	0.3	0.0	0.20
Leq 1/10000	100.0	99.9	-1.0	1.0	-0.1	0.20

Pulse range and sound exposure level (5.5.10 and 5.5.11)

The Pulse range has been tested by comparing the response to a single sinusoidal burst with the theoretical value of the equivalent continuous level of the test signal. The Sound Exposure Level where available has been determined using the same test signals.

	Expected [dB Leq]	Measured [dB Leq]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
Ref. Cont., 78	78.0	78.0	-0.2	0.2	0.0	0.20
Leq 10mS, 78	48.0	48.0	-1.7	1.7	0.0	0.20
SEL 10mS, 78	58.0	58.0	-1.7	1.7	0.0	0.20
Ref. Cont., 135	135.0	135.0	-0.2	0.2	0.0	0.20
Leq 10mS, 135	105.0	105.0	-1.7	1.7	0.0	0.20
SEL 10mS, 135	115.0	115.0	-1.7	1.7	0.0	0.20

Overload indication, Non-integrating (5.5.12)

Non-integrating mode. The overload indicator has been tested using a sequence of tone bursts as specified in BS7580 clause 5.5.7. The level of the tone bursts was increased until an overload indication occurred. The level was then reduced by 1dB so that no indication occurred. The level was further reduced by 3dB and the meter indication recorded.

	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
Non-integrating	131.7	131.7	-0.4	0.4	0.0	0.10

Overload indication, Integrating (5.5.12)

Integrating Mode. The overload indicator has been tested using single sinusoidal bursts with duration of 1 ms at a frequency of 4000 Hz. The level of the burst was increased until the meter just indicated a permanent overload. The signal was then reduced by 1dB. With a continuous signal of the same amplitude applied the meter indication was recorded.

	Continuous Level [dB Leq]	Expected [dB SPL]	Measured [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
Integrating	141.5	101.5	101.4	-2.2	2.2	-0.1	0.10

The uncertainties quoted for the measurement shown are based on an estimated confidence probability of not less than 95% using a coverage factor k>=2.

CERTIFICATE OF CALIBRATION

UKAS ACCREDITED CALIBRATION LABORATORY No. 0174

Certificate Number:

C1006722

Acoustic calibration at 1000 Hz (5.6.1)

The complete instrument has been calibrated at reference conditions, 1000 Hz at 94 dB. A correction in accordance with manufacturers data was made for the difference between the free field and pressure response of the microphone supplied to determine the adjustment level. If a correction for the effect of body influence is required so that the meter reads correctly, this has also been included in the determination.

	Coupler Pressure Lc [dB SPL]	Mic. Correction C4226 [dB]	Body Influence bi [dB]	Adjustment Level [dB SPL]
Ref. Conditions	93.91	0.10	-0.07	93.8

Acoustic test at 125 and 8000 Hz (5.6.2)

The complete instrument has been tested using continuous acoustical signals of 125 Hz and 8000 Hz relative to the reference reading at 1000Hz. Corrections in accordance with manufacturers data were made for the difference between the free field and pressure response of the microphone supplied to determine the expected reading. Manufacturers data for body influence has been used in calculating the corrected measured readings representing use within free field conditions.

	Coupler Pressure Lc [dB SPL]	Mic. Correction C4226 [dB]	Body Influence bi [dB]	Measured [dB SPL]	Corrected Measured [dB SPL]	Free Field Level [dB SPL]	Response (Rel Ref) [dB]	Expected [dB SPL]	Accept - Limit [dB]	Accept + Limit [dB]	Deviation [dB]	Uncertainty [dB]
1000Hz Ref.	93.91	0.10	-0.07	93.9	93.91	93.9	0.0	0.0	-0.2	0.2	0.0	0.20
125.89Hz	93.97	0.00	0.00	78.0	77.89	77.9	-16.1	-16.1	-1.0	1.0	0.1	0.20
7943.3Hz	93.49	2.80	-0.08	89.7	90.15	92.9	-1.1	-1.1	-3.0	1.5	0.1	0.40

Response to sound calibrator (5.6.3)

The response to the associated Sound Calibrator has been recorded.

	Measured [dB SPL]	Uncertainty [dB]	Coverage Factor [k]
Ref.	94.0	0.20	2.13

------------------------------ **End** ------------------------------

The uncertainties quoted for the measurement shown are based on an estimated confidence probability of not less than 95% using a coverage factor k>=2.

Certificate of Calibration

Issued by University of Salford (Acoustics Calibration Laboratory)
UKAS ACCREDITED CALIBRATION LABORATORY NO. 0801

UKAS CALIBRATION 0801

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APPROVED SIGNATORIES
Claire Lomax [ ] Andy Moorhouse [ ] G. Phillips
Gary Phillips [x] Danny McCaul [ ]

University of Salford MANCHESTER

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The University of Salford, Salford, Greater Manchester, M5 4WT, UK
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Certificate Number: 02965/1 Date of Issue: 5 December 2016

CALIBRATION OF A SOUND CALIBRATOR

FOR:	TUV SUD Scottish Enterprise Tech Park East Kilbride G75 0QF
FOR THE ATTENTION OF:	Patrick Jones
DESCRIPTION:	Calibrator with housing for one-inch microphones and adaptor type UC 0210 for half-inch microphones.
MANUFACTURER:	Bruel & Kjaer
TYPE:	4231
SERIAL NUMBER:	2651818
DATE OF CALIBRATION:	02/12/2016
TEST PROCEDURE:	CTP06 (Laboratory Manual)

Test Engineer (initial): CL Name: Claire Lomax

Calibrations marked 'Not UKAS Accredited' in this certificate have been included for completeness.

This certificate is issued in accordance with the laboratory accreditation requirements of the United Kingdom Accreditation Service. It provides traceability of measurement to the SI system of units and/or to the units of measurement realised at the National Physical Laboratory or other recognised national metrology institutes. This certificate may not be reproduced other than in full except with the prior written approval of the issuing laboratory.

Certificate of Calibration

Issued by University of Salford (Acoustics Calibration Laboratory)
UKAS ACCREDITED CALIBRATION LABORATORY NO. 0801

Certificate Number: 02965/1 Date of Issue: 5 December 2016

MEASUREMENTS

The sound pressure level generated by the calibrator was measured using a calibrated, WS2P condenser microphone as specified in the certificate. The calibration was carried out with the calibrator in the half-inch configuration.

Five determinations of the sound pressure level, frequency and total distortion were made.

The results have been corrected to the reference pressure of 101.325 kPa using manufacturer's data.

RESULTS

Coupler configuration:	Half-inch
Microphone type:	GRAS 40AG
Output level (dB re 20μPa):	94.01 dB ± 0.10 dB
Frequency (Hz):	999.98 Hz ± 0.12 Hz
Total Harmonic Distortion (%):	0.40 % ± 0.15 % (Not UKAS Accredited)

Average environmental conditions at the time of measurement and maximum deviation from the stated average:

Pressure:	102.215 kPa ± 0.018 kPa
Temperature:	22.5 °C ± 0.4 °C
Relative humidity:	41.1 % ± 2.0 %

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a coverage probability of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

All measurement results are retained at the acoustic calibration laboratory for at least four years.

Data Physics Corporation

Certificate of Calibration
for System No. 21717 SignalCalc Quattro – 4C1S
Date: November 19th, 2012

Customer:

Data Physics UK / NEL (TUV SUD Ltd)
South Road, Hailsham
East Sussex BN27 3JJ
United Kingdom

Data Physics Corporation certifies that System No. 21717 of the following hardware components:

Model:	Serial No:
DP240D	D48-023
DP240A	A66-023

Has been calibrated complying with MIL-STD-45662A/ANSI/NCSL Z 540-1-1994. The calibration instrument was a Hewlett Packard digital multimeter model 34401A, Serial No.US36062207 with Testwave LLC calibration certificate No. 12N0319.

The recommended calibration interval is 6 months. Based on this interval, the calibration due date is May 19th, 2013.

Calibrated by: [signature]

Certified by: [signature]

1741 Technology Drive • Suite 260 • San Jose, CA 95110
TEL: 408.437.0100 • FAX: 408.437.0509 • www.dataphysics.com

Data Physics (UK) LIMITED

Data Physics (UK) Ltd
South Road, Hailsham, East Sussex, BN27 3JJ
www.dataphysics.com sales@dataphysics.com
TEL: 01323 846464 FAX: 01323 847550

TUV SUD NEL Ltd
James Young Building
East Kilbride
Glasgow
G75 0QF

01 February 2016

Data Physics (UK) Ltd. certifies that the system number 21717 consisting of the following hardware components:

Location	Model	Serial Number	Inputs	Outputs
1	DP240	12A66023	4	1

Has been verified to be in current calibration and then re-calibrated complying with MIL-STD-45662A/ANSI/NCSL Z 540-1-1994. The calibration instrument was an Agilent DVM model 34401A serial number MY45018142 with UKAS calibration certificate number 28450 dated 19th May 2015.

Date of calibration 1 February 2016

The recommended calibration interval is 12 months

Calibrated by ________________________________ **G Murphy**

CERTIFICATE OF CALIBRATION

ISSUED BY: Littlebrook Calibration Services Ltd

ilac-MRA

UKAS CALIBRATION 0436

DATE OF ISSUE: **12 November 2010** CERTIFICATE NUMBER: **N20033/10**

5 Optima Park
Thomas Road (Off Thames Road)
Crayford
Kent, DA1 4QX
Telephone (01322) 556111 Facsimile (01322) 520400

PAGE 1 OF 2 PAGES

APPROVED SIGNATORY

CUSTOMER DETAILS **LCS REF: LCS9751/10/1**

Company	: **TUV NEL Ltd**
Address	: James Young Building Scottish Enterprise Technology Park East Kilbride Glasgow, G75 0QU
Order number	: 10005013

UNIT CALIBRATED

Manufacturer	: Gill Instruments & Campbell Scientific Ltd
Model	: Windsonic Anemometer with CR1000 and CFM100 Data Logger
Range	: 0 to 60 m/s
Serial numbers	: Anemometer: 10150026 Enclosure: BW-427162 Logger: E5204 and 6345
Instrument Condition	: Operational
Date unit received	: 09/11/2010
Date calibrated	: 12/11/2010

LABORATORY CONDITIONS : Temperature 23°C ± 2°C

CALIBRATION PROCEDURES : PROC0025

The uncertainties reported relate only to the measured values and do not imply any long-term performance for the instrument.

UKAS Calibration for Air Velocity.

Calibration limited from 2 m/s to 16 m/s.

Approved Signatory (Print): A M Sidgwick

CERTIFICATE OF CALIBRATION

Littlebrook Calibration Services Ltd

UKAS ACCREDITED CALIBRATION LABORATORY NO. 0436

CERTIFICATE NUMBER
N20033/10

CALIBRATION METHOD

The Campbell Scientific system and Windsonic anemometer was submitted to The Littlebrook Calibration Laboratory for calibration. For the purposes of the calibration the conditions and procedure listed below applies.

1] Prior to calibration the anemometer was energised for a minimum period of 1 hour.

2] The instrument was placed 120mm from the end of a wind tunnel with the head aligned perpendicularly to the direction of flow.

3] The instrument was calibrated with the unit orientated vertically.

4] The instrument output was recorded by a PC using 'LoggerNet 3.4.1.16 ' software.

5] The Unit Under Test (UUT) reading is the average of a minimum of three measurements.

6] Standard Velocity measurements have been corrected to air density (ρ) of 1.1996 kg/m^3 from the condition at time of calibration.

7] The instrument indicated a Barometric Pressure of 993.90 mbar

AIR VELOCITY CALIBRATION

Calibrated range: 2 to 16 m/s
Atmospheric pressure: 0.9945 bar absolute
Temperature: 21.6 °C
Humidity: 36 % rh

STANDARD VELOCITY m/s	UUT READING m/s	UUT ERROR m/s
2.02	1.64	-0.38
4.05	3.54	-0.51
5.05	4.51	-0.54
7.99	7.16	-0.83
11.99	10.69	-1.30
16.06	14.47	-1.59

UNCERTAINTY OF VELOCITY MEASUREMENT: ±(1.7 % + 0.05 m/s)

END OF CERTIFICATE.

"The reported expanded uncertainty is based on a standard uncertainty multiplied by coverage factor *k*=2 providing a confidence level of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements."

CERTIFICATE OF CALIBRATION

ISSUED BY: Littlebrook Calibration Services Ltd

ilac-MRA

UKAS CALIBRATION 0436

DATE OF ISSUE: **01 June 2010** CERTIFICATE NUMBER: **N19273/10**

5 Optima Park
Thomas Road (Off Thames Road)
Crayford
Kent, DA1 4QX
Telephone (01322) 556111 Facsimile (01322) 520400

PAGE 1 OF 2 PAGES

APPROVED SIGNATORY

CUSTOMER DETAILS **LCS REF: LCS9397/10/6**

Company	: **TUV NEL Ltd**
Address	: James Young Building Scottish Enterprise Technology Park East Kilbride Glasgow, G75 0QF
Order number	: 10004300

Acceptable Paul Jones

UNIT CALIBRATED

Manufacturer	: Campbell Scientific Ltd
Model	: Setra 278 Pressure module CR1000 and CFM100 Data Logger
Range	: 600 to 1100 mbar absolute
Instrument condition	: Operational
Serial numbers	: Module: 4288966 Logger: 6280
Date unit received	: 25/05/2010
Date calibrated	: 01/06/2010

LABORATORY CONDITIONS : Temperature 20.1°C ± 1.5°C

CALIBRATION PROCEDURE : PROC0023

The uncertainties reported relate only to the measured values and do not imply any long-term performance for the instrument.

UKAS Calibration For Pressure.

Approved Signatory (Print): M A Bauer

CERTIFICATE OF CALIBRATION

Littlebrook Calibration Services Ltd

UKAS ACCREDITED CALIBRATION LABORATORY NO. 0436

CERTIFICATE NUMBER
N19273/10

CALIBRATION PROCEDURE

The Campbell Scientific system was submitted to The Littlebrook Calibration Laboratory for calibration. For the purposes of the calibration the conditions and procedure listed below applies.

1] Prior to calibration the instrument powered up for a minimum period of 1 hour. It was leak tested and exercised until the outputs at 10% and full range pressure were repeatable.

2] The pressure medium used for the calibration was nitrogen.

3] The instrument reference level was taken to be the bottom of the pressure connection port.

4] The instrument was mounted vertically with the pressure connection port pointing downwards.

5] The SI unit of pressure is the Pascal (Pa), the conversion from used on this certificate is;
1.0 mbar = 100.000000 Pa

6] The output from the instrument under test (UUT) were connected to the datalogger. The datalogger in turn was connected to a pc, where Campbell Scientific LoggerNet 3.4.1 software was used to interpret the outputs.

CALIBRATED PRESSURE RANGE: 600 to 1100 mbar absolute.

STANDARD INPUT mbara	UUT RISING READING mbara	UUT RISING ERROR %	UUT FALLING READING mbara	UUT FALLING ERROR %
605.00	605.10	0.017	605.10	0.017
650.00	650.08	0.012	650.08	0.012
700.00	700.29	0.041	700.29	0.041
750.00	750.30	0.040	750.30	0.040
800.00	800.31	0.039	800.31	0.039
850.00	850.26	0.031	850.25	0.029
900.00	900.20	0.022	900.20	0.022
950.00	950.15	0.016	950.14	0.015
1000.00	1000.15	0.015	1000.15	0.015
1050.00	1050.23	0.022	1050.23	0.022
1100.00	1100.51	0.046	1100.51	0.046

UNCERTAINTY OF MEASUREMENT: ± 0.21 mbar absolute.

END OF CERTIFICATE.

"The reported expanded uncertainty is based on a standard uncertainty multiplied by coverage factor k=2 providing a confidence level of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements."

CERTIFICATE OF CALIBRATION

ISSUED BY: Littlebrook Calibration Services Ltd

ilac-MRA UKAS CALIBRATION 0436

DATE OF ISSUE: 02 June 2010 CERTIFICATE NUMBER: N19272/10

5 Optima Park
Thomas Road (Off Thames Road)
Crayford
Kent, DA1 4QX
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APPROVED SIGNATORY

CUSTOMER DETAILS

LCS REF: LCS9397/10/5

Company	: **TUV NEL Ltd**
Address	: James Young Building Scottish Enterprise Technology Park East Kilbride Glasgow, G75 0QU
Order number	: 10004300

UNIT CALIBRATED

Manufacturer	: Vaisala & Campbell Scientific Ltd
Model	: HMP45AC Temperature/Humidity Probe, CCSL001990 extension cable CR1000 and CFM100 Data Logger
Ranges	: -39.2 to 60 °C 0.8 to 100 % rh
Instrument Condition	: Operational
Serial numbers	: Enclosure: BW-427163 Probe: F1450158 Logger: E5221 and 6280
Date unit received	: 25/05/2010
Date calibrated	: 26/05/2010 to 02/06/2010

LABORATORY CONDITIONS : Temperature 23°C ± 2°C
: Relative Humidity 50 % ± 25 % rh

CALIBRATION PROCEDURES : PROC0027 (Temperature) & PROC0028 (Humidity)

The uncertainties reported relate only to the measured values and do not imply any long-term performance for the instrument.

UKAS Calibration for Air Temperature & Humidity.
Calibration limited from 0 to 40°C and from 35 to 80 % rh.

Approved Signatory (Print): M A Bauer

CERTIFICATE OF CALIBRATION

Littlebrook Calibration Services Ltd

UKAS ACCREDITED CALIBRATION LABORATORY NO. 0436

CERTIFICATE NUMBER
N19272/10

CALIBRATION METHOD

The Campbell Scientific temperature/humidity system was submitted to The Littlebrook Calibration Laboratory for calibration. For the purposes of the calibration the conditions and procedure listed below applies.

1] The probe with extension cable was calibrated in air using a characterised environmental chamber and calibrated platinum resistance thermometers. The instruments were allowed to stabilise in the environmental chamber for at least an hour at each temperature before measurements were performed.

2] The Unit Under Test (UUT) reading is the average of a minimum of three measurements.

3] The probe was calibrated for accuracy only and was not checked for conformity with any standard or specification.

4] The instrument reading was recorded by a PC using 'LoggerNet 3.4.1.16 ' software.

TEMPERATURE CALIBRATION.

STANDARD TEMPERATURE °C	UUT READING °C	UUT ERROR °C
* -20.10	-19.79	0.31
0.45	0.76	0.31
19.94	20.03	0.09
41.08	40.90	-0.18

UNCERTAINTY OF MEASUREMENT: ± 0.50 °C.

Note: The calibration marked * in this certificate are not UKAS accredited, but has been included for completeness.

HUMIDITY CALIBRATION.

STANDARD HUMIDITY % RH	UUT READING % RH	UUT ERROR % RH
34.88	33.23	-1.65
49.95	49.18	-0.77
80.08	78.61	-1.47

UNCERTAINTY OF MEASUREMENT: ±(0.9 % of reading + 1.60 % rh).

END OF CERTIFICATE.

"The reported expanded uncertainty is based on a standard uncertainty multiplied by coverage factor k=2 providing a confidence level of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements."

[END OF APPENDIX1]

APPENDIX 2

DESCRIPTION OF TYBE 'B' UNCERTAINTIES

Type B uncertainties

For these measurements all the type B measurement uncertainty components as specified in IEC 61400-11:2012 are given in Table 6. For all of the Type B uncertainties mentioned here, a rectangular distribution of possible values is assumed for simplicity with a range described as "±a". The standard deviation for such a distribution is:

$$U = \frac{a}{\sqrt{3}}$$

Table 6 - Type B measurement uncertainty components

Parameter	Value
Calibration, U_{B1}	0.2 dB
Instrument, U_{B2}	0.1 dB
Ground Board, U_{B3}	0.3 dB
Wind screen insertion loss, U_{B4}	N/A – primary screen with no secondary windscreen
Distance and direction of microphone, U_{B5}	0.1 dB
Air absorption (impedence), U_{B6}	0.2 dB
Weather, U_{B7}	0.5 dB
Wind speed (measured), U_{B8}	0.2 m/s
Wind speed (derived), U_{B9}	N/A for small wind turbines tested according to testing option as per Annex F of IEC 61400-11:2012 standard
Wind speed from power curve, U_{B9}	N/A for small wind turbines tested according to testing option as per Annex F of IEC 61400-11:2012 standard

Before calculating the sound power level uncertainty the average wind speed and uncertainty per bin needs to be considered. Specifications are given in IEC 61400-11:2012
The values per bin shall be averaged arithmetically as:

$$\overline{V}_k = \frac{1}{N} \cdot \sum_{j=1}^{N} V_{j,k}$$

where

N is the number of measurements in wind speed bin k;
$V_{j,k}$ is the average value of wind speed at measurement period j in wind speed bin k.

The Type A uncertainty of the average wind speed per bin k is calculated as:

$$s_{V,k} = \sqrt{\frac{\sum_{j=1}^{N} \left(V_{j,k} - \overline{V}_k\right)^2}{N \cdot (N-1)}}$$

where

$V_{j,k}$ is the average value of wind speed at measurement period j;
$\overline{V}_k$ is the average wind speed in wind speed k.

The Type B uncertainty on the wind speed for each measurement period j, u_{Vj} is calculated as:

$$u_{Vj} = \sqrt{\sum_{q=1}^{q} u_{Vj,q}^2}$$

where

$u_{Vj,q}$ is the Type B uncertainty from source q on the average wind speed for each measurement

Information about the sources are given in Table 6.

The Type B uncertainty on average wind speed in bin k, $u_{V,k}$ is calculated as:

$$u_{V,k} = \sqrt{\frac{1}{N} \cdot \sum_{j=1}^{N} u_{Vj}^2}$$

The combined uncertainty $u_{com,V,k}$ can be expressed as:

$$u_{com,V,k} = \sqrt{s^2_{V,k} + u^2_{V,k}}$$

<u>Uncertainty of average sound spectra</u>

For each 1/3-octave band i the average sound pressure level is averaged energetically as:

$$\overline{L}_{i,k} = 10 \cdot \log\left[\frac{1}{N} \cdot \sum_{j=1}^{N} 10^{\left(\frac{L_{i,j,k}}{10}\right)}\right]$$

where

N is the number of measurements in wind speed bin k;
$L_{i,j,k}$ is the und pressure level of 1/3-octave band I measurement period j, in wind speed bin k.

The Type A standard uncertainty of the average wind speed per bin k is calculated as:

$$s_{Li,k} = \sqrt{\frac{\sum_{j=1}^{N}\left(L_{i,j,k} - \overline{L}_{i,k}\right)^2}{N \cdot (N-1)}}$$

Where

$\overline{L}_{ik}$ is the average sound pressure spectrum in wind speed bin k

The Type B uncertainty on the energy averaged sound pressure level of 1/3-octave band i, for each measurement period j is calculated as:

$$u_{Lij} = \sqrt{\sum_{q=1}^{7} u_{Lij,q}^{2}}$$

where

$u_{Lij,q}$ is the Type B uncertainty from source q on the average sound pressure level of 1/3-octave band for each measurement period j.

The Type B uncertainty on the average sound pressure level of 1/3-octave band I in wind speed bin k is calculated as:

$$u_{Li,k} = \sqrt{[\frac{1}{N} \cdot \sum_{j=1}^{N} u^{2}_{Lij,k}]} = u_{Lij,k}$$

The combined uncertainty can be expressed as:

$$u_{com,L_i,k} = \sqrt{s^{2}_{Li,k} + u^{2}_{Li,k}}$$

Uncertainty of noise levels at bin centres

The sound pressure level for both total noise and background noise at bin centre has to be calculated. This has to be done at each 1/3- octave band i and at every bin centre of wind speeds. Using linear interpolation the estimated sound pressure level at wind speed v is given as:

$$L_{v}(t) = (1-t) \cdot \overline{L}_{k} + t \cdot \overline{L}_{k+1}$$

where

$\overline{v}_{k} \leq v < \overline{v}_{k+1}$

The t value at a certain wind speed v is given as:

$$t = \frac{(v - \overline{v}_{k})}{(\overline{v}_{k+1} - \overline{v}_{k})}$$

To fulfil an entire statistical evaluation according to IEC 61400-11:2012 a corresponding covariance is calculated as:

$$cov_{LV,i,k} = \frac{1}{N-1} \cdot \sum_{j=1}^{N} (v_{j,k} - \overline{v}_{k}) \cdot (L_{i,j,k} - \overline{L}_{i,k})$$

The corresponding covariance is used to calculate the uncertainty on the sound pressure level at bin centre wind speed v using:

$$U_{C,L,v}(t) = \sqrt{U_L^2(t) - \frac{\mathrm{cov}_{LV}^2(t)}{U_v^2(t)}}$$

where

$$U_L^2(t) = (1-t)^2 \cdot U_{C,L,k}^2 + t^2 \cdot U_{C,L,k+1}^2$$

$$\mathrm{cov}_{LV}(t) = (1-t)^2 \cdot \frac{\mathrm{cov}_{LV,k}}{N_k} + t^2 \cdot \frac{\mathrm{cov}_{LV,k+1}}{N_{k+1}}$$

$$U_v^2(t) = (1-t)^2 \cdot U_{C,v,k}^2 + t^2 \cdot U_{C,v,k+1}^2$$

and

N_k is the number of measurements in wind speed bin k

[END OF APPENDIX 2]

APPENDIX 3

TONALITY AUDIBILITY SUMMARY FOR EACH INTEGER WIND SPEED BIN

BS EN 61400-11:2013 - Tonal Audibility Calculation Summary - For Windspeed Bins 4.0 through 13.0 m/s

Speed, k (m/s)	Running, 4 - 9 m/s bin							
Spectrum, j	CB Centre	Lpn,avg	Lpt	Lpn	DLtn	DLa	Report?	DLa Energy
1_4 m/s	8134	-0.8	26.2	28.0	-1.7	3.3	AUD	2.1
2_5 m/s	8150	-0.3	29.8	28.4	1.3	6.4	AUD	4.3
3_6 m/s	8150	-0.5	27.0	28.2	-1.2	3.8	AUD	2.4
4_7 m/s	8000	2.8	11	31	-21	-16	NO	0
5_8 m/s	8145	3.4	18	32	-14	-9	NO	0
6_9 m/s	8000	9.8	None	38	-29	-24	NO	N/A
1_4 m/s	-	-	-	-	-	-	-	N/A
2_5 m/s	6078	5.3	30.8	32.3	-1.6	3.2	AUD	2.1
3_6 m/s	-	-	-	-	-	-	-	N/A
4_7 m/s	-	-	-	-	-	-	-	N/A
5_8 m/s	-	-	-	-	-	-	-	N/A
6_9 m/s	-	-	-	-	-	-	-	N/A

[END OF APPENDIX 3]

[END OF ALL APPENDICES]

[END OF REPORT]