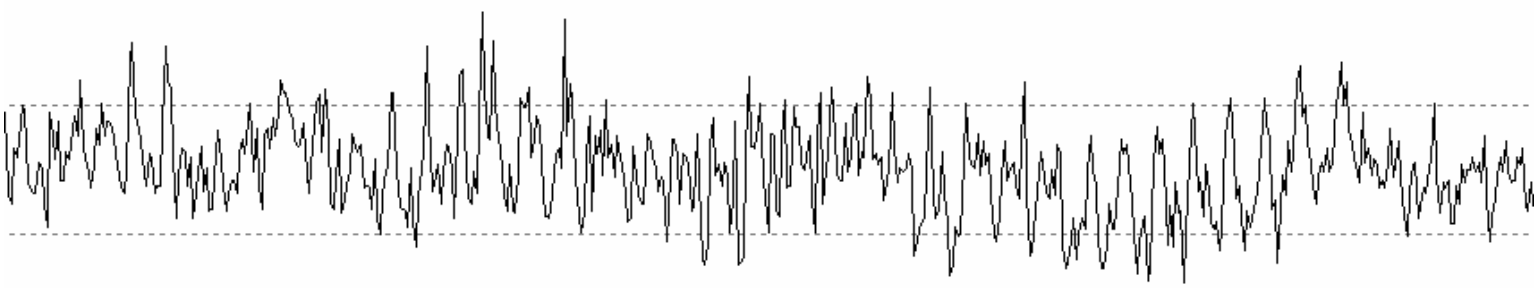


Wind Farm Noise and

Excess Amplitude Modulation

Listening Room Exercise

at the National Physical Laboratory

11th July 2012

Introductory notes

The objective of the exercise is to try to replicate listening to wind farm noise and in particular amplitude modulation in a home situation where the intent is rest and relaxation. It is intended that there is minimal conversation during the playback so as not to distort the purpose of the exercise and also to allow hearing to adjust to the quieter environment.

The initial period of no playback followed by background noise is to allow some acclimatisation of the hearing system. Some tracks are played to demonstrate the experience of longer periods of AM and others to identify character in the noise.

This document provides a schedule of the playback, a glossary of terms, some information on the prevalence of excess amplitude modulation (EAM) followed by a page for each period of playback. These pages show a graph of the noise trace, any relevant description or annotations and space for notes.

→ All graphs are related to BST (where appropriate)

→ Please note that the scale may vary between graphs.

Contents

Aerodynamic / Amplitude Modulation

Comments in the report by Salford University for the UK Government 2007:

"*The term AM indicates aerodynamic noise from wind turbines, but with a greater than normal degree of regular fluctuation at blade passing frequency, typically once per second. AM was considered to be a factor in four of the sites, and a possible factor in another eight. Regarding the four sites, analysis of meteorological data suggests that the conditions for AM would prevail between about 7% and 15% of the time*."

Some modulation of wind farm noise was foreseen by the authors of ETSU-R-97:

"*The noise levels recommended in this report take into account the character of noise described as blade swish… The modulation or rhythmic swish emitted by wind turbines has been considered to have characteristic that is irregular enough to attract attention…Blade swish is an amplitude modulation of noise in the frequency range which is associated with trailing edge noise… This rhythmic swish sound… is normally centred around the 800-1000Hz region of the frequency band… This modulation of blade noise may result in a variation of the overall A-weighted noise level by as much of 3dB(A) (peak to trough) when measured close to a wind turbine. As distance from the wind turbine / wind farm increases, this depth of modulation would be expected to decrease as atmospheric absorption attenuated the higher frequency energy radiated by the blade.*"

Discussion in the DTI report by HMP 2006:

"*The presence of high levels of amplitude modulation is not reported to occur for a significant majority of wind farms or wind turbines. However, some wind farms clearly result in modulation at night which is greater than that assumed within ETSU-R-97 Guidelines. The risk of aerodynamic modulation is believed to be greatest for sites where stable atmospheric conditions occur and tall wind turbines are proposed / operating or where high levels of wind shear exist at a site. In general, stable atmospheric conditions are more likely to occur at level sites which are to be found in the UK, i.e. eastern side of England for example. Site specific effects in hillier terrain, due to topographical effects, might also result in such modulation*."

Schedule of playback

Track	Duration Min/Sec	Location	Date	Start time	No. turbines / nearest turbine	Notes	Page no.
External measurements							
1	2:00	Site D (remote rural location)	2012	00:00:00	1km from the wind farm	Rural background noise outside with no turbines operating. Aims to provide perspective of external background noise levels. External equivalent of tracks 12 and 13.	7
2	2:00			00:12:00			8
3	4:40	Kessingland	10 June 2012	00:55:17	2 approx 550m away (housing is nearer than this)	This is a rural coastal location with excessive Amplitude Modulation outside.	9
4	2:00 × 2			00:27:17		Starts with a car passing on main road which partially but not totally masks the turbine noise. This provides contrast. Many characteristics are evident including the sudden drop in noise between peaks.	10
5	2:00 × 2			00:27:17		Same as track 4 but elevated by 13dB to provide comparison with how much noise ETSU-R-97 would allow before exceeding its lowest possible night time limit. Without separate control of AM this level of noise is then permitted.	11
6	3:00 × 2	Knabbs Ridge	8 March 2012	00:10:03	3 dominate, approx 550m away	This track is recorded at a mobile home site where many residents have sold up and moved out because of the wind farm. The track starts with a car on the road interspersed with turbine noise which dominates as the car fades away. Not all the turbines were audible or intrusive.	12
7	2:00 × 2	Site C (remote rural location)	2012	16:55:31	450m from 3 turbines	The measurements were made in an external amenity area location in a remote rural area. It is 450m from 3 turbines in a cross wind situation, not downwind (Site C – anonymous to meet complainant requirements). Dominating wind turbine noise at least 10dB(A) above the background.	13

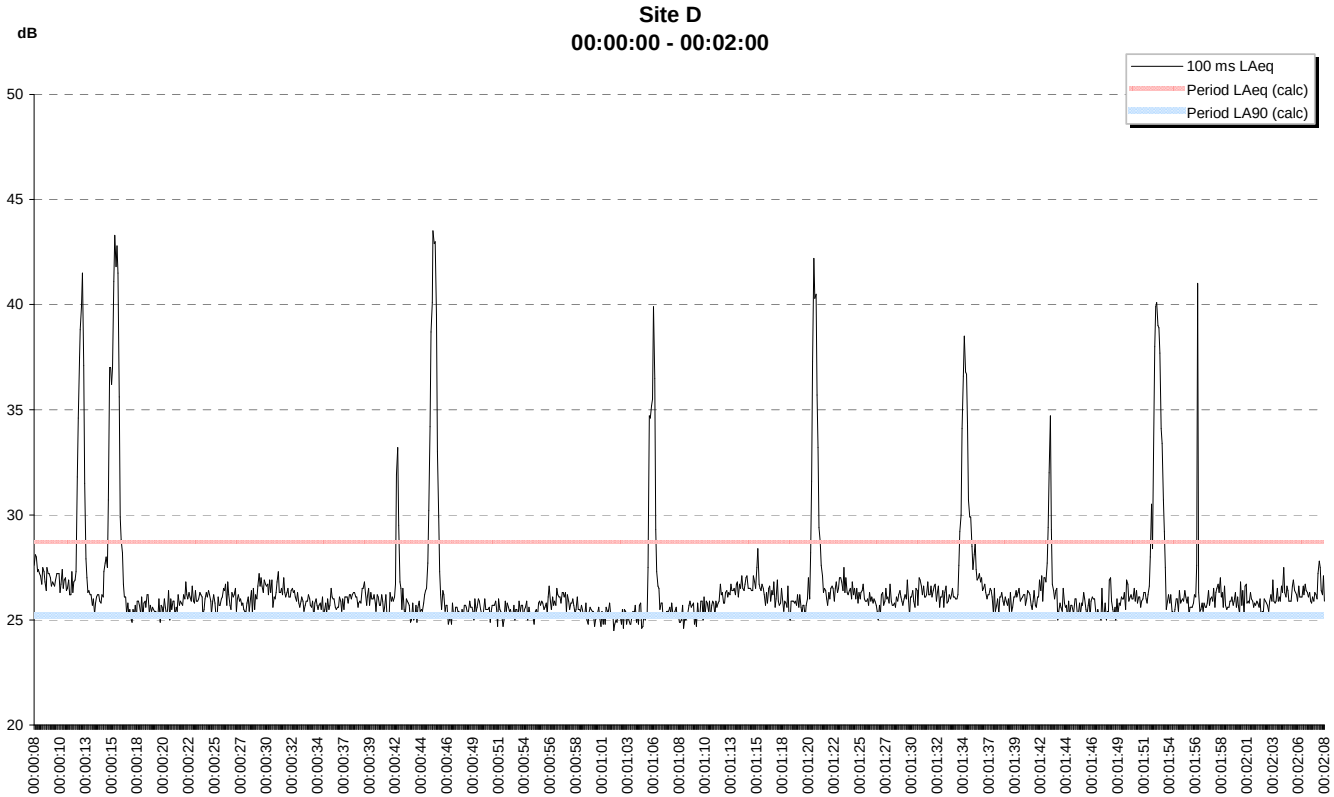
Track	Duration Min/Sec	Location	Date	Start time	No. turbines / nearest turbine	Notes	Page no.
8	1:00	Kessingland	28 June 2012	23:05:03	630 metres from 2 turbines	In this example the character of the EAM changes between one and two beats.	14
9	2:00			23:44:22		If you listen carefully you can hear some laughter nearby from a group of youths on a night out at this coastal resort.	15
10	1:30		29 June 2012	00:09:52		The graph gives five excerpts of EAM showing the range of different noise character throughout the night.	16
11	2.00	Site D (remote rural location)	2012	00:56:36	1km from the wind farm	Comparison with turbines off and on approximately 30 minutes apart. Character of sound scape significantly changed.	17
Internal measurements							
12	2:00	Site D (remote rural location)	2012	00:00:00	1km from the wind farm	Rural background noise inside with no turbines operating. Aims to provide perspective of internal background noise levels. Internal equivalent of tracks 1 and 2.	18
13	2:00			00:12:00			19
14	0:40	Kessingland	28 June 2012	23:33:04	Inside a car at 630 metres from the nearest of two turbines	This is to provide perspective and comparison with tracks 8-10 as it was recorded on the same night and so gives an indication of noise within dwellings.	20
15	1:00			23:36:04			21
16	2:30	Deeping St. Nicholas	5 July 2007	21:00:03	Inside a bedroom at Grays Farm Deeping St. Nicholas 1050m away from the wind farm.	The case can only be discussed in relation to those elements in the public domain as there was a settlement during proceedings in the High Court for nuisance. Track 16: AM can be heard but is not visible on the graph. Track 17: EAM is clearly visible and audible.	22
17	3:30		4 July 2008	22:02:56			23

Track	Duration Min/Sec	Location	Date	Start time	No. turbines / nearest turbine	Notes	Page no.
18	2:00 × 2	Site D	2012	02:52:04	Inside bedroom 1km from the wind farm	There is an intermittent drone or tone that also fluctuates in and out at times caused by the wind farm. Please try to imagine attempting to get to sleep with this. The drone / tone is no longer evident in track 12 below, one hour later.	24
19	2:00 × 2			03:52:03		The impact is continuing an hour later. The average levels are lower in sound energy and below the WHO Guideline levels for steady continuous noise that many acousticians apply as a limit of acceptability. Some low frequency thumping is evident.	25

Please note: the purpose of this exercise is to demonstrate the character of wind farm noise, AM and EAM at an approximate decibel level to that at which it was recorded. Although we have calibrated the recordings (measuring in accordance with BS7445:2003) to within approximately 1-2dB of the level recorded in the field there will be discrepancies between the two. For example, the decibel level heard by the listener will vary depending on their location in the room. There are also external noises being played internally which will be altered due to the different acoustics in an open and enclosed space. If you have any queries about the replication of the recorded noise for this exercise then please do not hesitate to ask.

Track 01 **Site D - External background noise level**

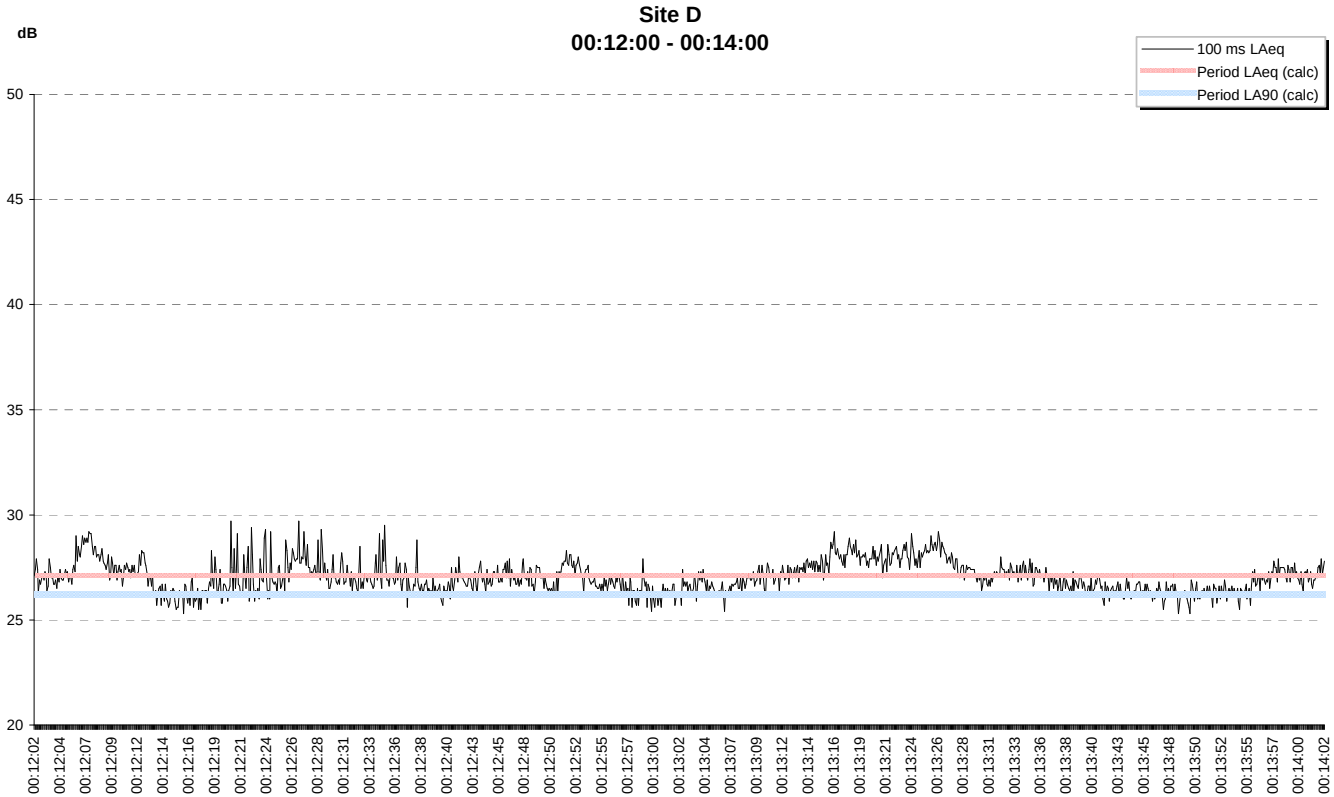
NOTES



Rural background noise level outside approximately 1km from a wind farm with no turbines operating. It provides a perspective of typical internal background noise levels in rural areas. The peaks are caused by animal noise. This extract corresponds to track 12 and is its external equivalent.

Track 02 **Site D - External background noise level**

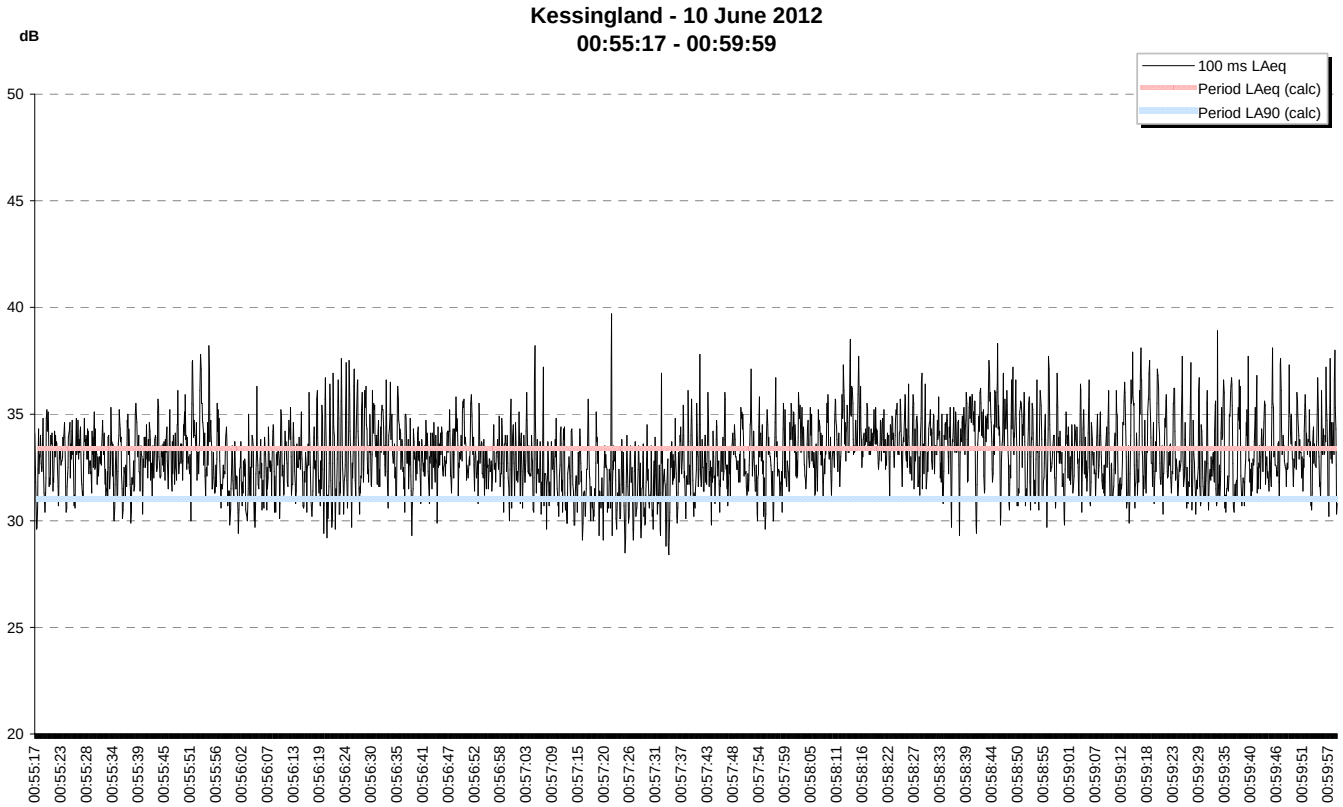
NOTES



Rural background noise level outside with no turbines operating. This extract corresponds to track 13 and is its external equivalent.

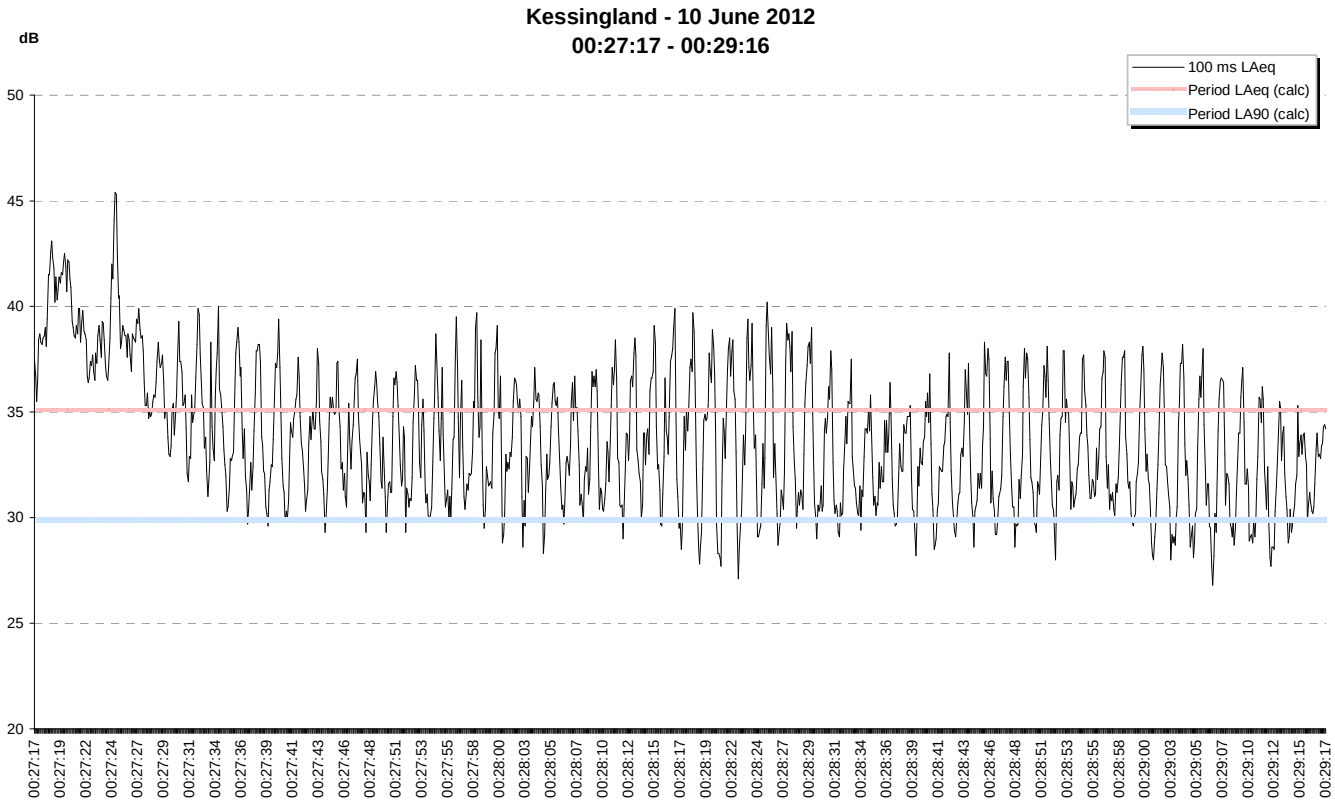
Track 03 **Kessingland - External Amplitude Modulation**

NOTES



This is a rural location with excess amplitude modulation outside. It gives noise at levels which are 5dB below the minimum daytime ETSU-R-97 limit and 13dB below the night time limit allowed by the guidance. This period includes a period where there are double beat peaks due to separate peaks from both the turbines.

Track 04 Kessingland - External Amplitude Modulation



This track provides contrast. It starts with a car passing on a main road which partially but not totally masks the turbine noise. The peak to trough variations recorded were previously considered impossible by industry experts. Furthermore, the peak to trough variations were considered to reduce over distance. This clip provides significant contrast with what is a quiet environment absent the wind farm noise. Many characteristics are evident including the sudden drop in noise between peaks.

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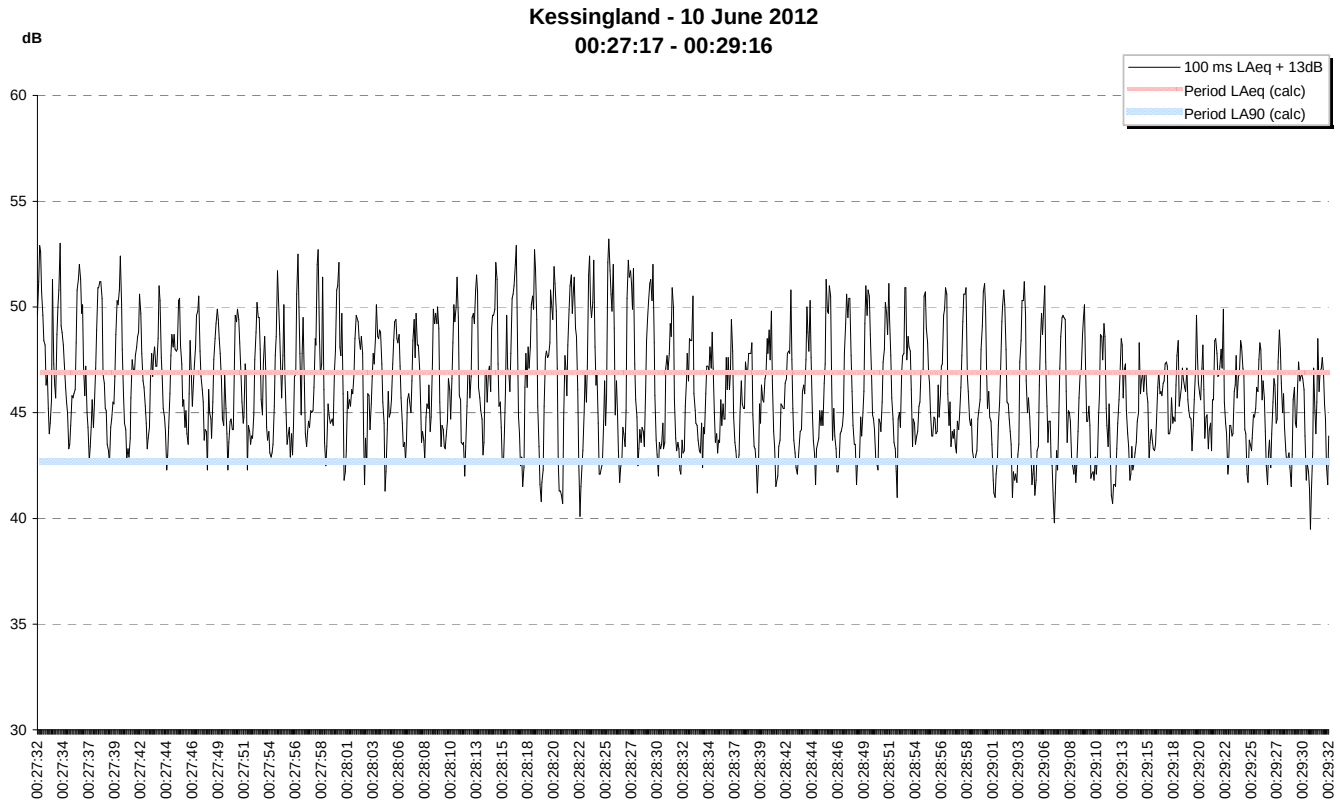
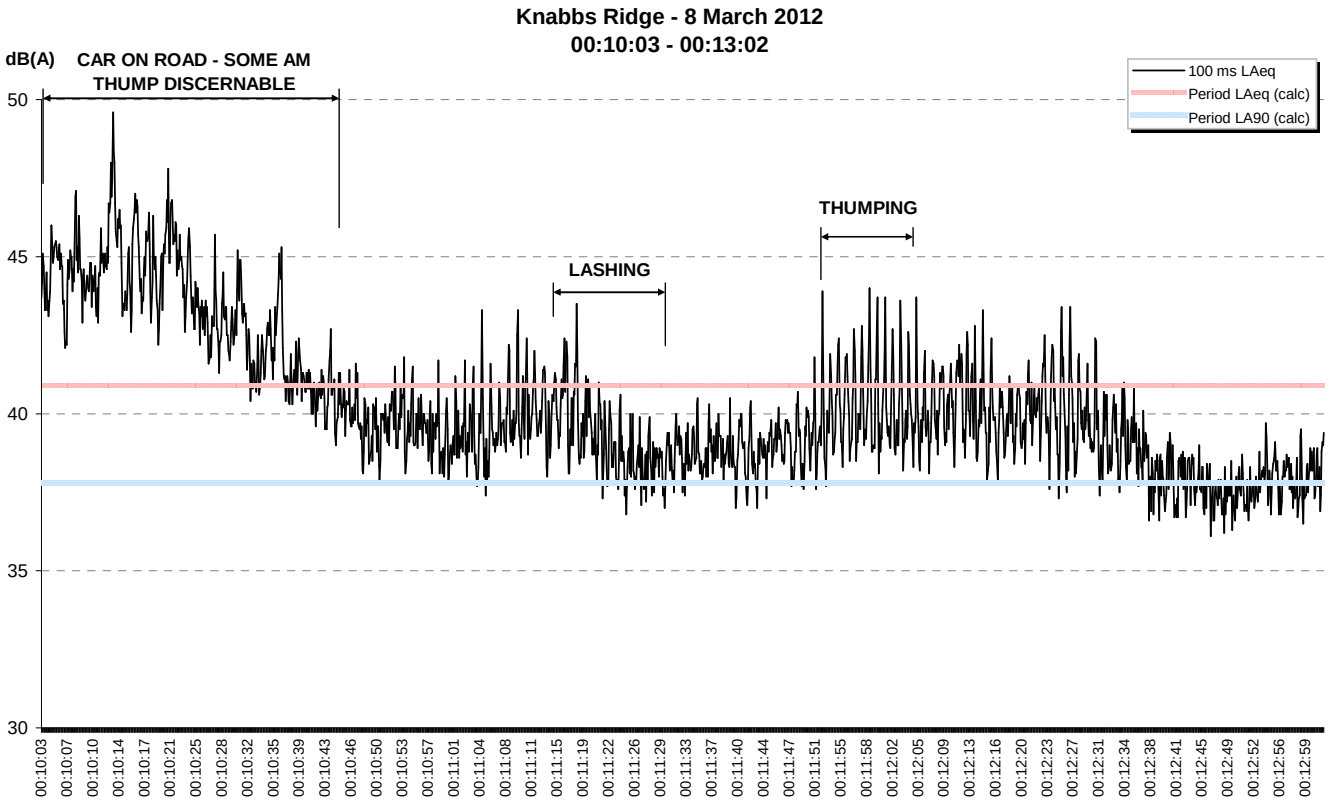
Track 05 **Kessingland - External Amplitude Modulation +13dB**

NOTES



The wind turbine noise is elevated to provide comparison with how much noise ETSU-R-97 would allow before exceeding the lowest possible night time limit (43dB LA90). Without separate control of amplitude modulation this level of noise is then permitted under the current guidance. It is at the ETSU-R-97 limit of what would still be allowed under the guidance. Whilst the peaks go above the ETSU-R-97 limit the LA90 (blue line) value does not and ETSU-R-97 is based on this index.

Track 06 Knabbs Ridge - External Amplitude Modulation



This track was recorded outside dwellings approximately 550m from the turbines. The impact is mainly from two turbines. It starts with a car on the road interspersed with wind turbine noise. The car fades away and the wind turbine noise then dominates. The track includes some periods of rumbling / roar, thumping, lashing and also more typical wind turbine noise. Not all turbines were audible or visible. Measurements were made at a mobile home site where many residents have sold up and moved out because of the wind farm.

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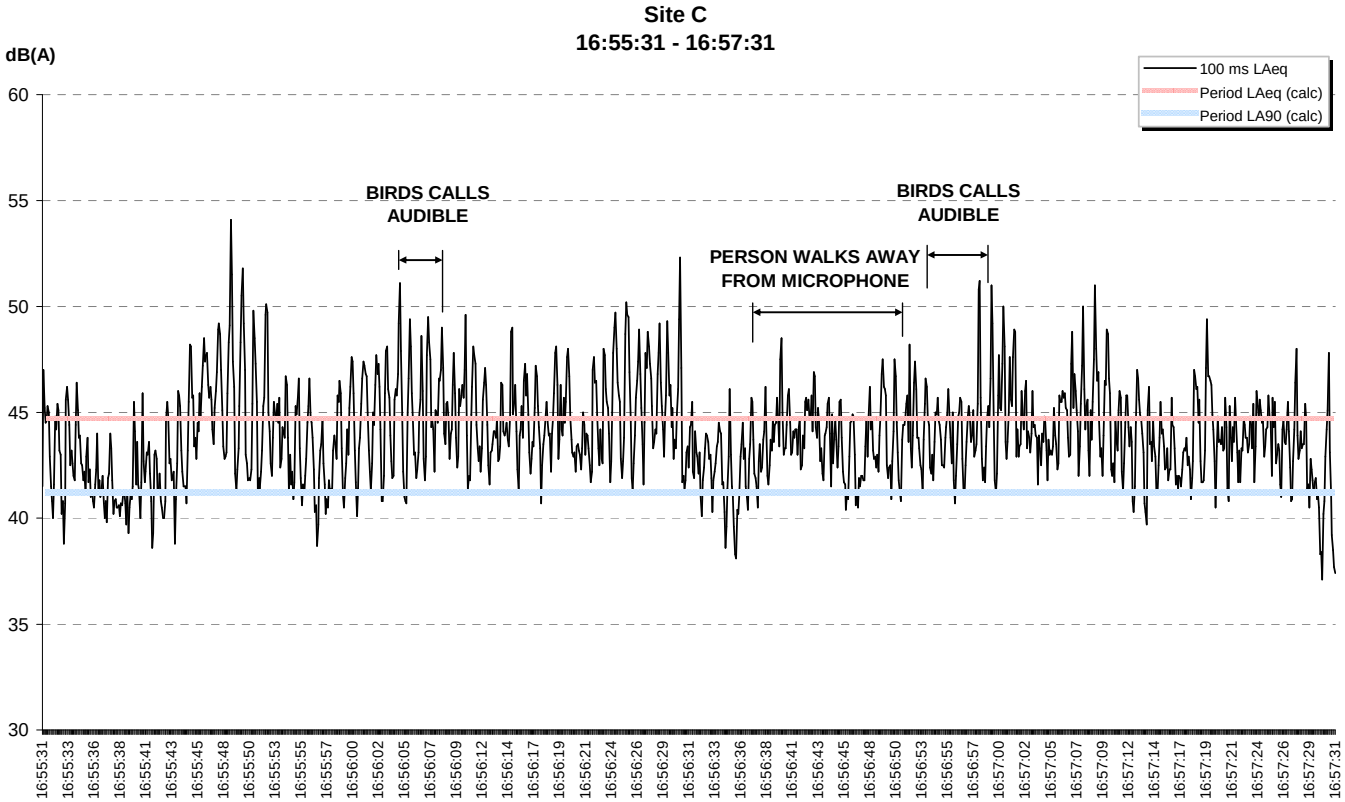
Track 07 Site C - External Amplitude Modulation



This site remains anonymous due to potential litigation. The measurements were made in an external amenity area location in a remote rural area. It is 450m from 3 turbines in a cross wind situation (as opposed to downwind). The wind turbine noise is dominating and at least 10dB above the background noise level. The track does not do justice to the intrusion experienced. When actually heard, the changing direction of the noise added substantially to its impact. This cannot be captured in a simple microphone. 40 seconds in (16:56:05) you can hear birds in adjacent trees for comparison and also someone moving about (16:56:43) and at other times (near the microphone). They finally walk away at 1 minute 15 seconds. More birds are evident at 16:56:42 but the turbines dominate.

NOTES

Track 08 **Kessingland - External Amplitude Modulation**

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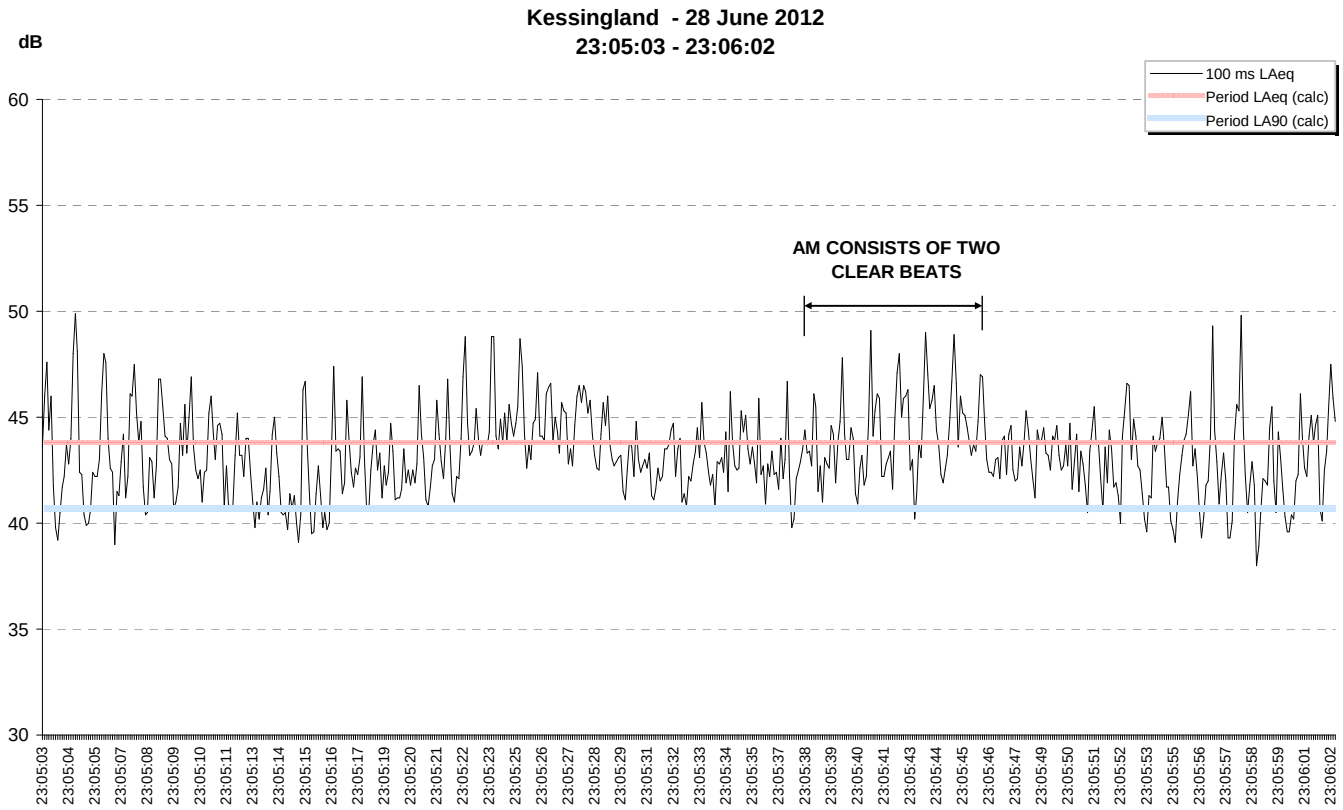
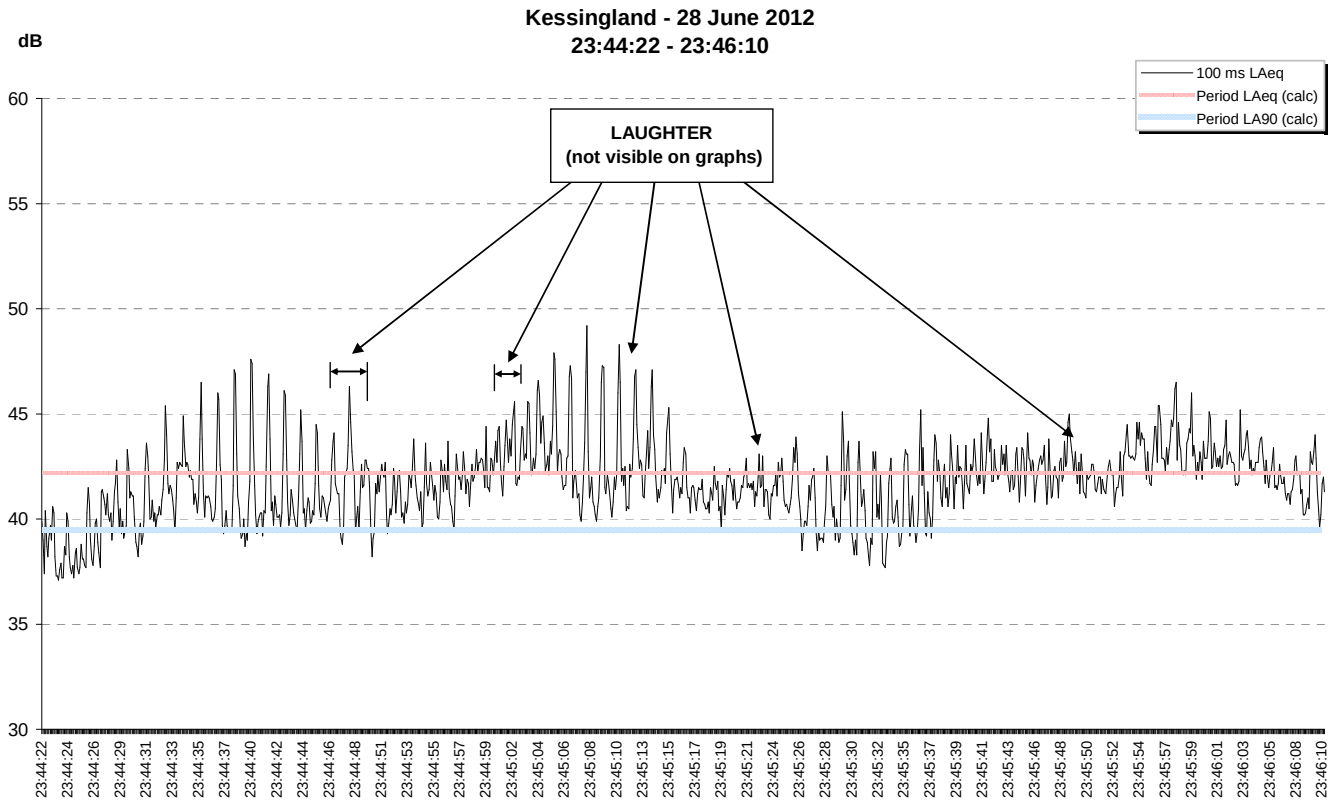


In contrast to tracks 3-5 also taken at Kessingland this period gives a good example of amplitude modulation where two distinct beats are heard as part of the peak rather than one. This demonstrates the different character that turbine noise can manifest.

Track 09 **Kessingland - External Amplitude Modulation**

NOTES



If you listen carefully you can hear some laughter from a group of youths on a night out in this coastal resort but the AM wholly dominates the noise environment and causes the peaks.

Track 10 **Kessingland - External Amplitude Modulation**

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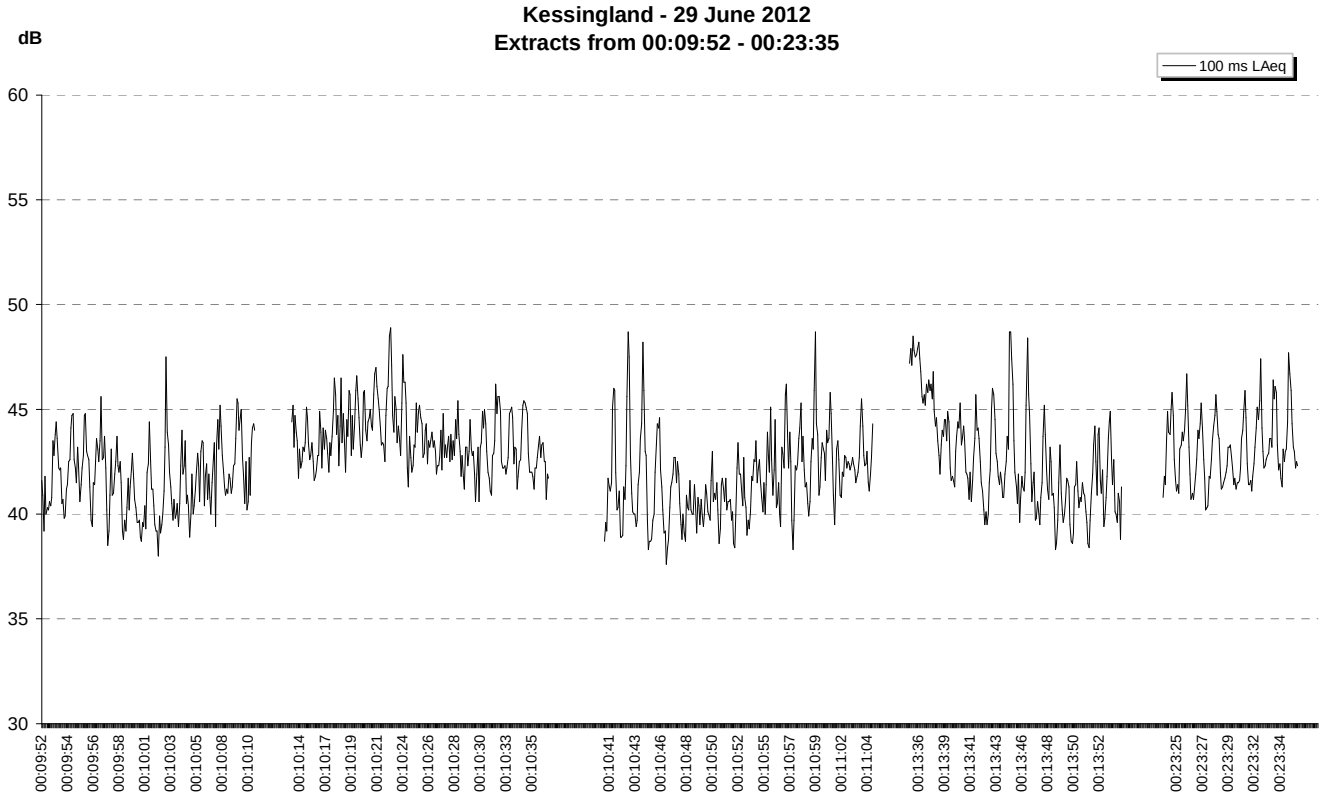
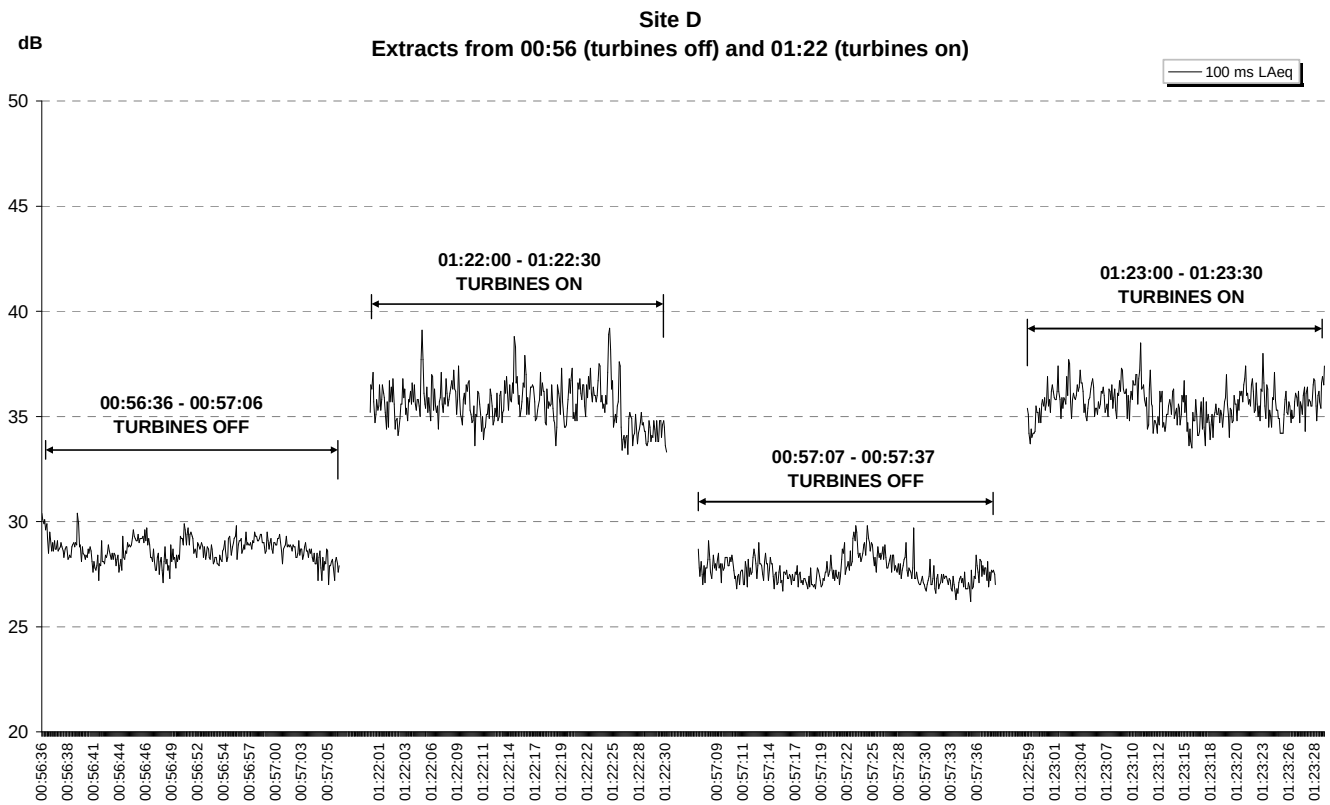


These shorter extracts demonstrate the different character of the noise. This is largely dependent on the frequency content of the amplitude modulation but there is also some contrast between single beats and double beats per peak.

Track 11 **Site D - Extracts with turbines off and on**

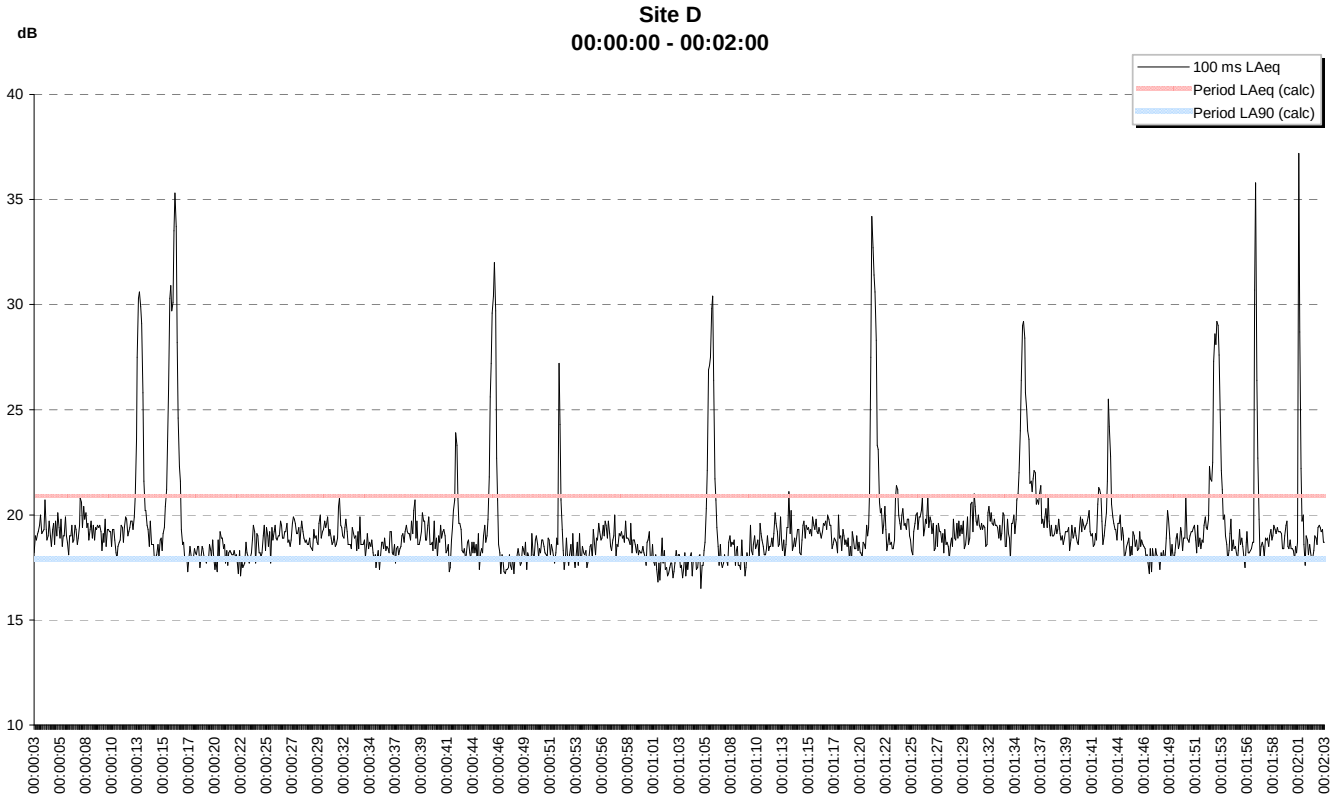
NOTES



The measurements were made in an external amenity area location in a remote rural area approximately 1km from the wind farm. The graph compares a period when the turbines are not operating with a period just under half an hour later when the turbines are operating. There is approximately a 7dB increase in background noise level and the character of the sound scape if significantly altered.

Track 12 **Site D - Internal background noise level**

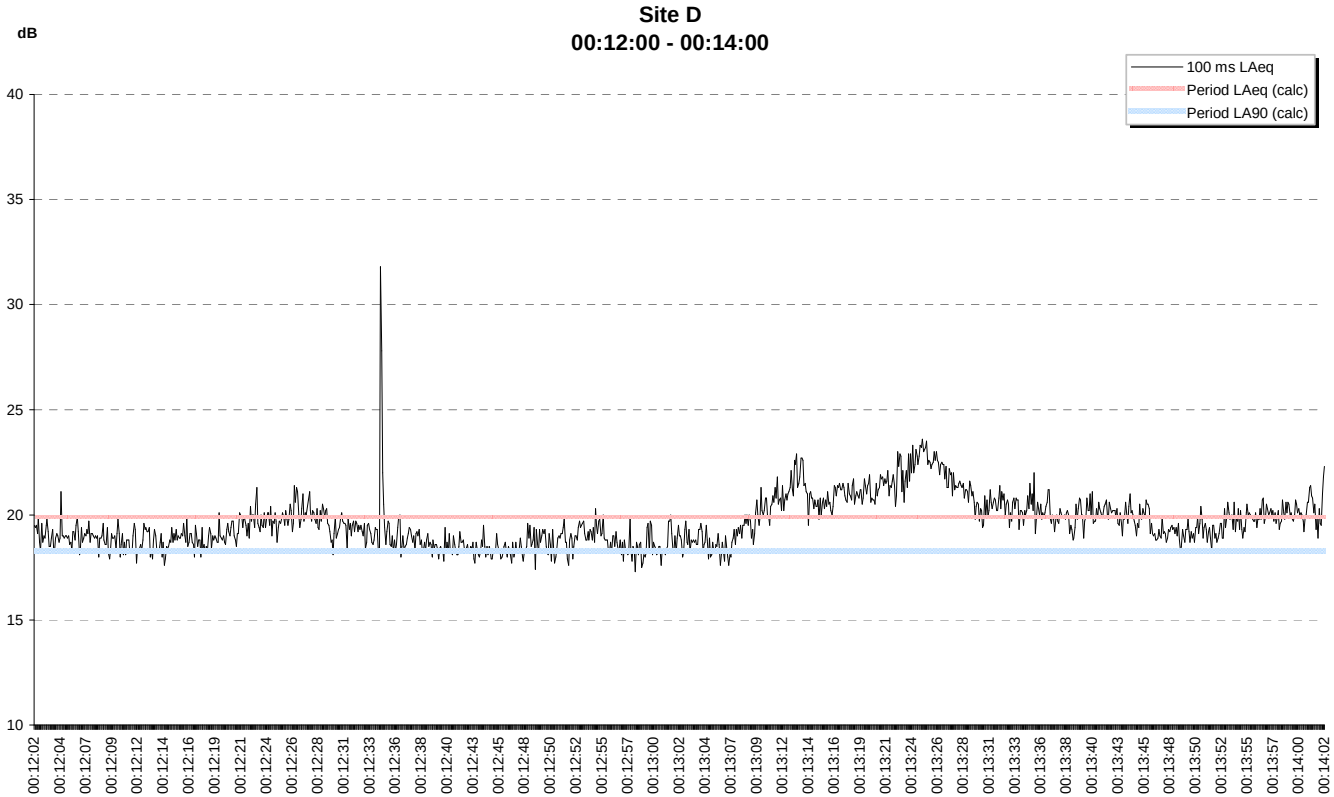
NOTES



This is the background noise level within a rural dwelling approximately 1km from a wind farm. It provides a perspective of typical internal background noise levels in rural areas. The peaks are caused by animal noise. This extract corresponds to track 1 and is its internal equivalent.

Track 13 **Site D - Internal background noise level**

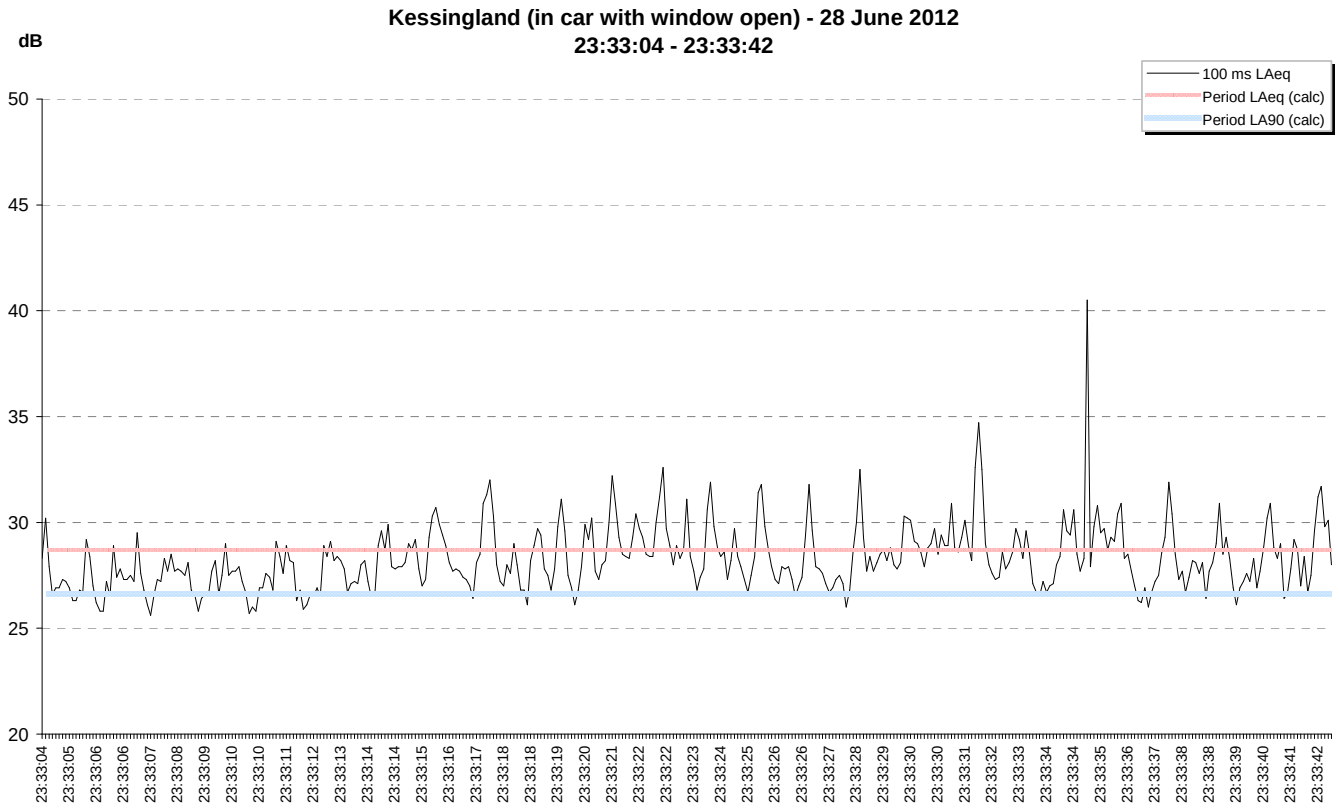
NOTES



This is the background noise level within a rural dwelling approximately 1km from a wind farm. It provides a perspective of typical internal background noise levels in rural areas. This extract corresponds to track 2 and is its internal equivalent.

Track 14 **Kessingland - Internal Amplitude Modulation**

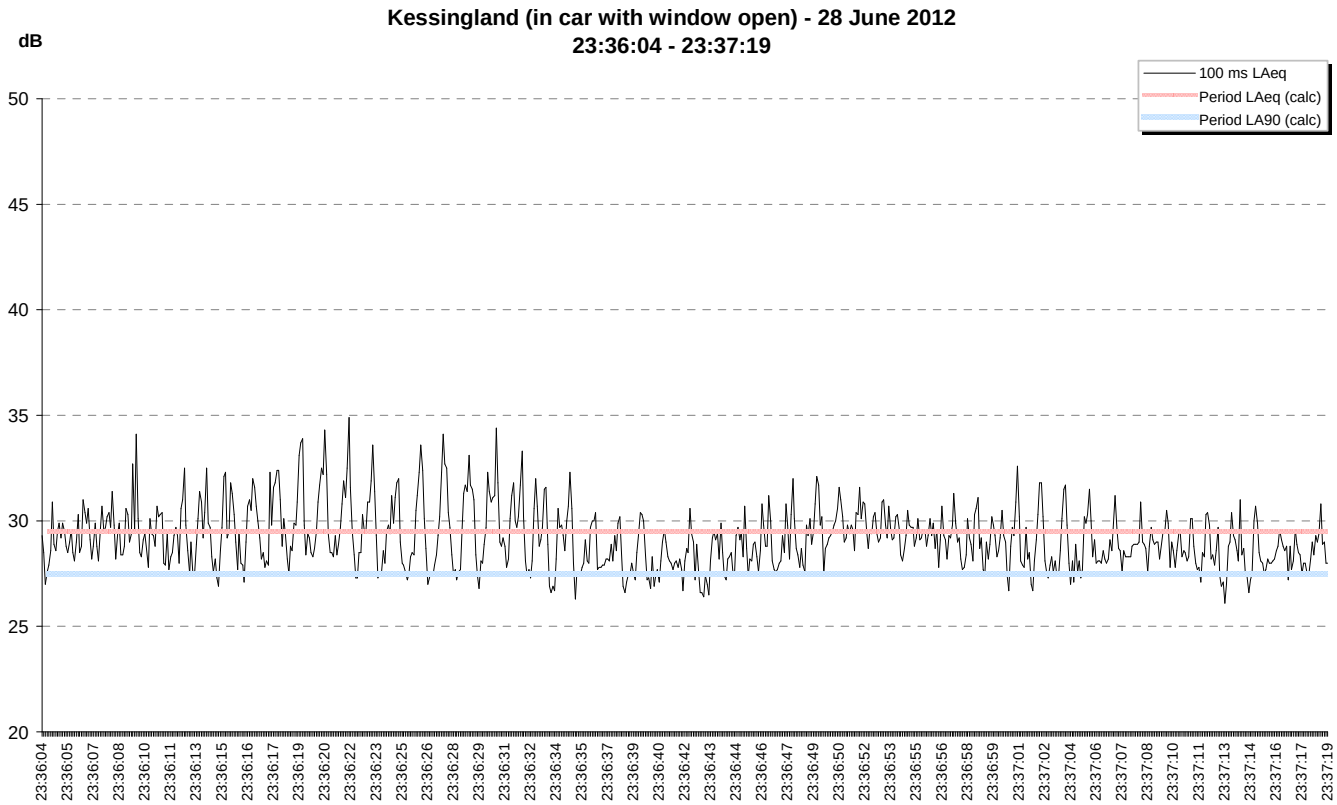
NOTES



Inside a car at 630m from two turbines This is to provide perspective and comparison with tracks 8-10 as it was recorded on the same night and so gives an indication of noise within dwellings. The window was open.

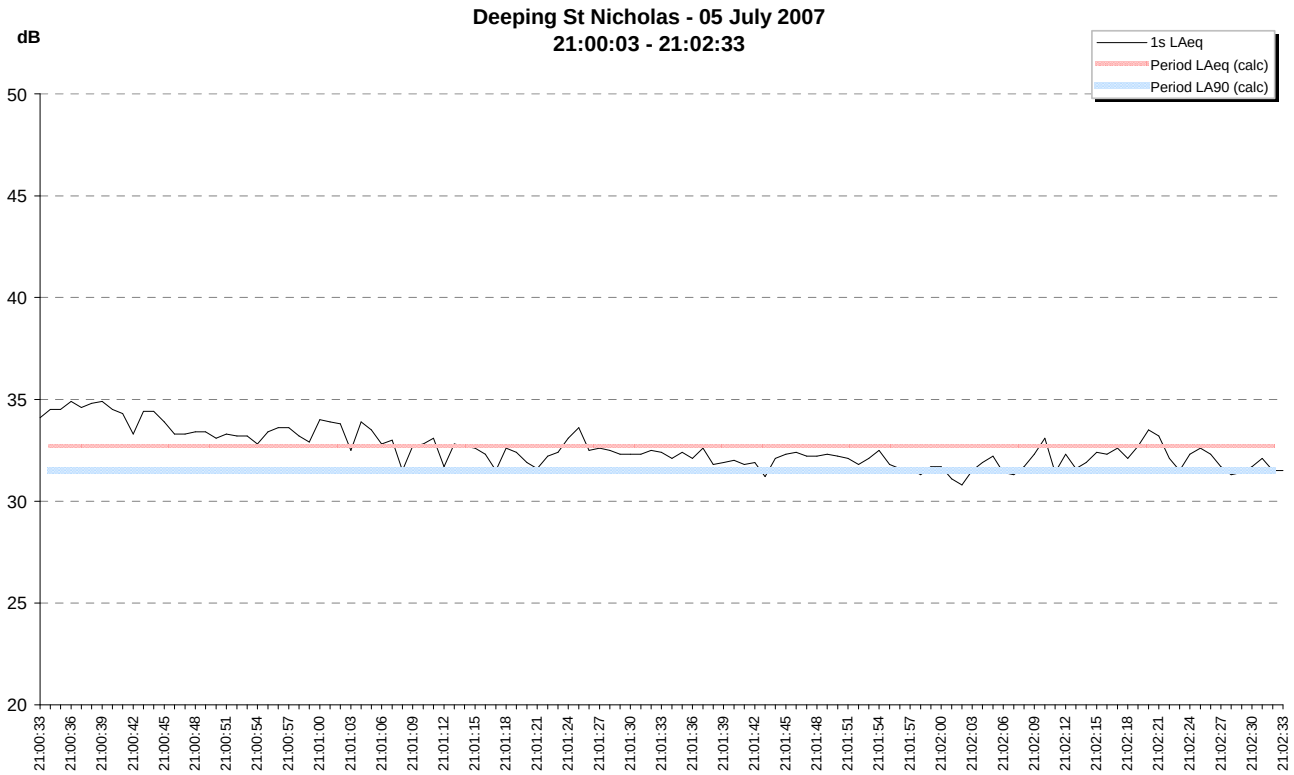
Track 15 **Kessingland - Internal Amplitude Modulation**

NOTES



Inside a car at 630m from two turbines This is to provide perspective and comparison with tracks 8-10 as it was recorded on the same night and so gives an indication of noise within dwellings. The window was open.

Track 16 Deeping St Nicholas - Internal Amplitude Modulation

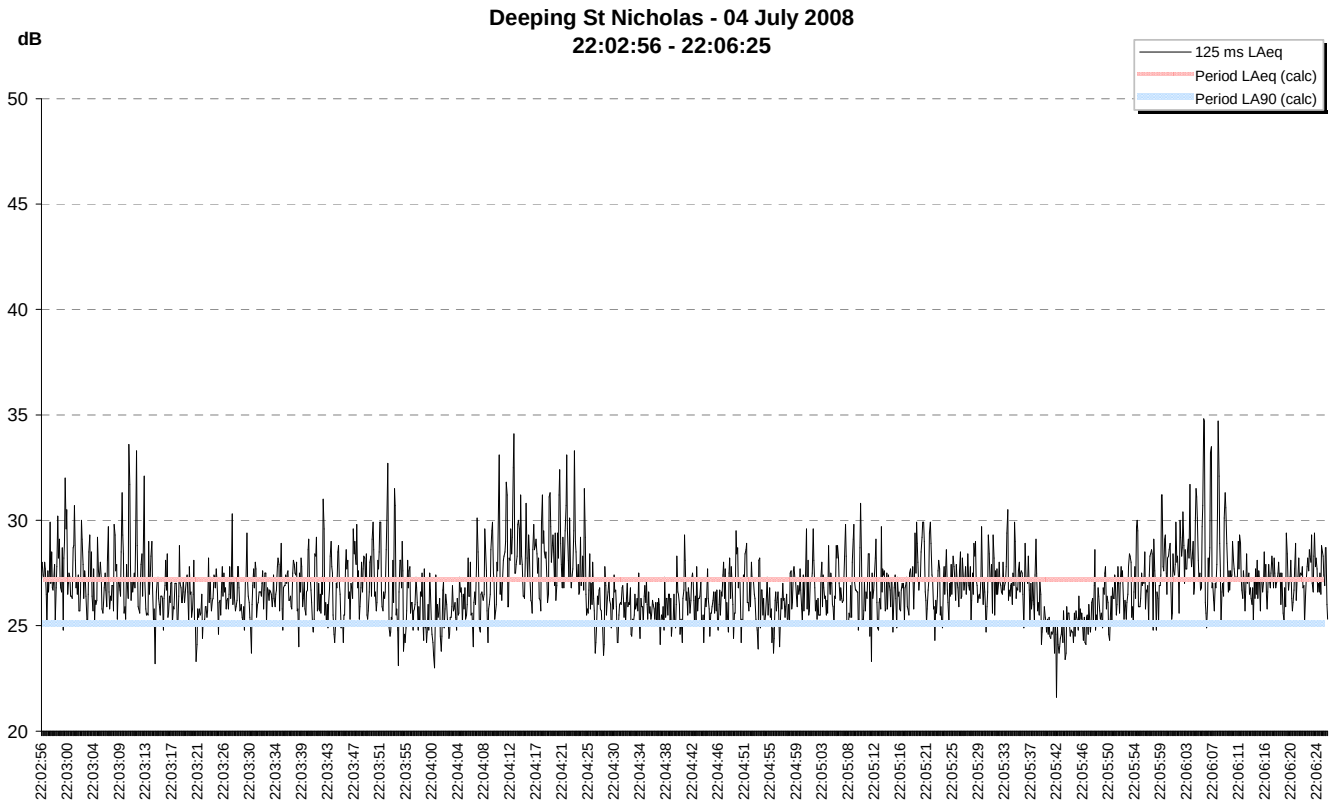


In this extract amplitude modulation is audible but not discernible on the graph. This was one of the earlier amplitude modulation measurements MAS undertook to see the effect of sample time. It shows the importance of using the correct sampling rate for the type of noise that is being measured. The sound level meter in this example is averaging the noise level every second; however, to gain a true representation of the nature of amplitude modulation a sampling rate of 1/8th (125ms) or 1/10th (100ms) of a second is needed. **Note:** this case can only be discussed in relation to those elements in the public domain as there was a settlement during proceedings in the High Court for noise nuisance.

NOTES

Track 17 **Deeping St Nicholas - Internal Amplitude Modulation**

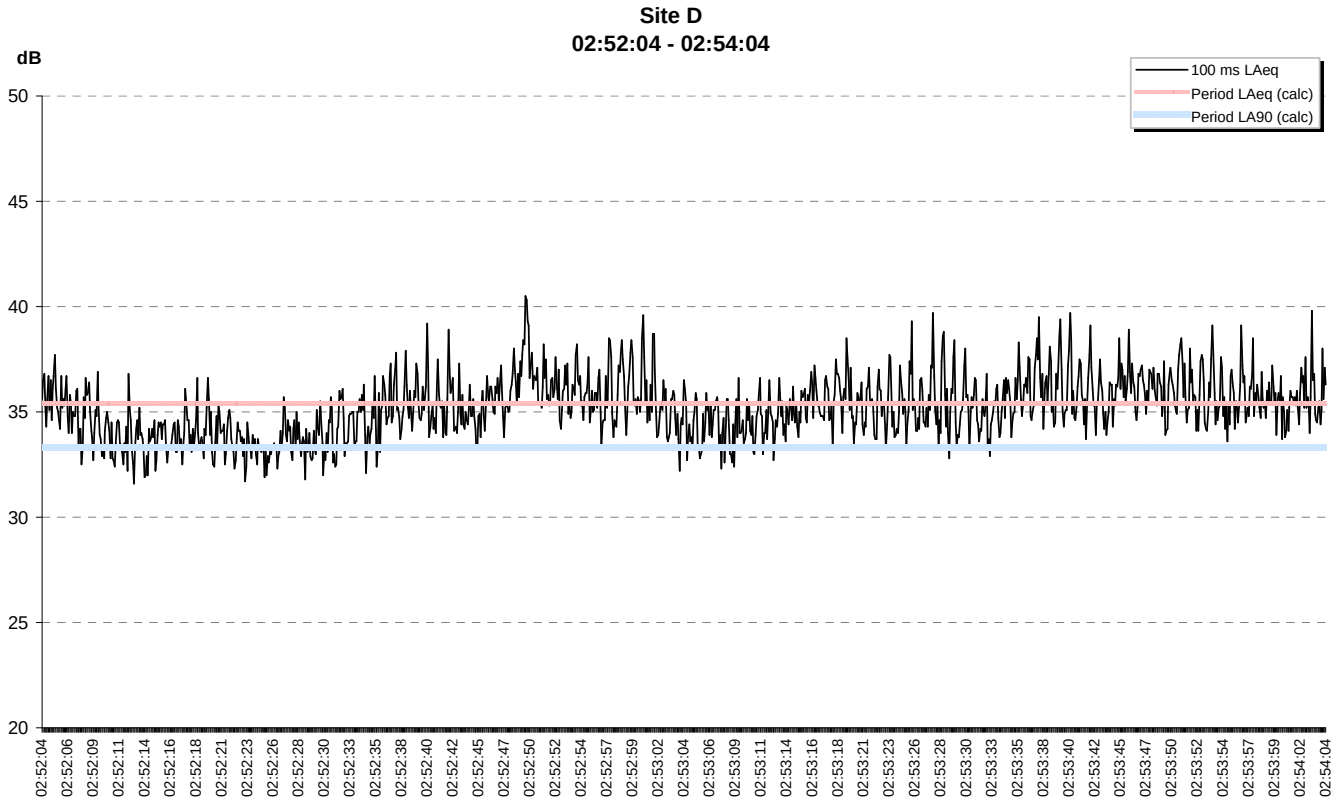
NOTES



As above, amplitude modulation was measured inside a bedroom at Grays Farm, Deeping St Nicholas 1050m away from the wind farm but can now be seen as averaging is 1/8th second. The peaks of amplitude modulation fade in and out throughout the period.

Note: this case can only be discussed in relation to those elements in the public domain as there was a settlement during proceedings in the High Court for noise nuisance.

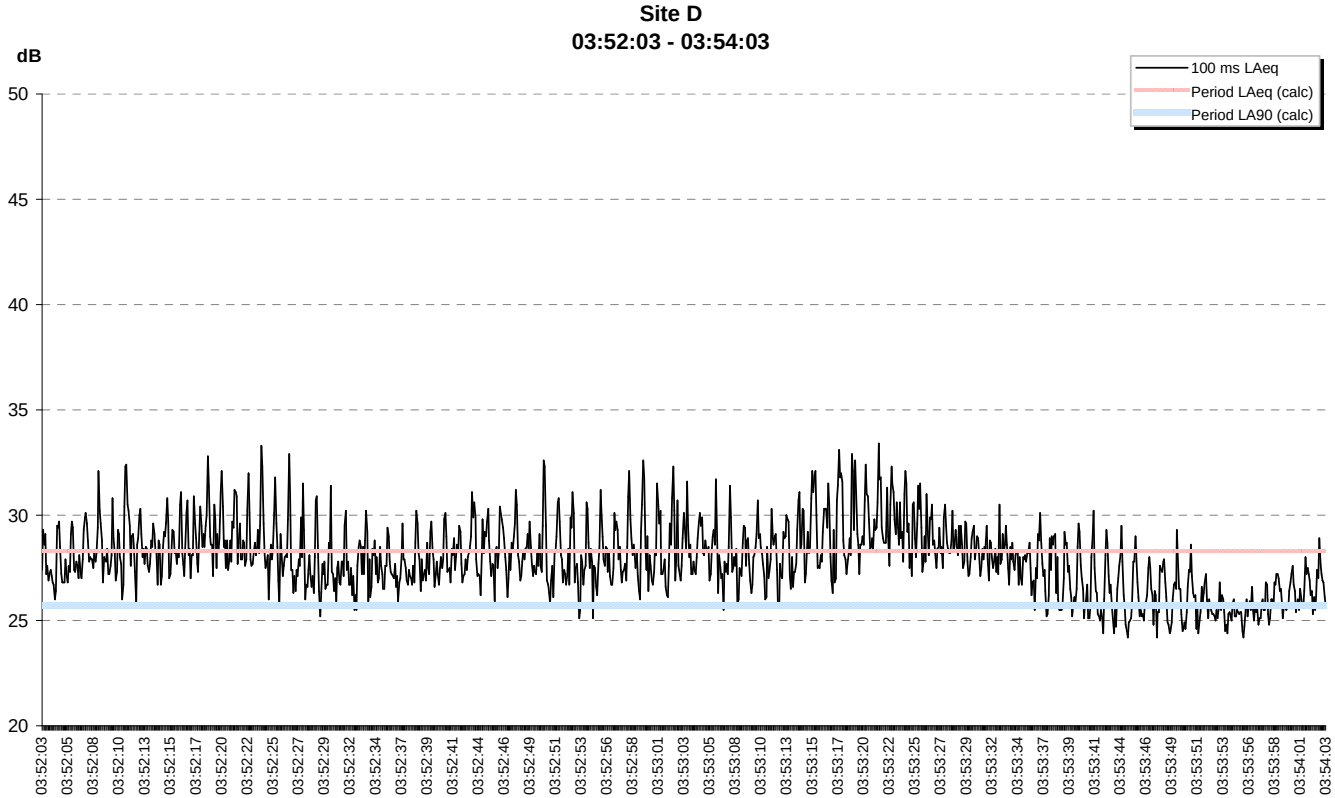
Track 18 **Site D - Internal Amplitude Modulation**



This measurement is taken 1km from the wind farm inside a bedroom with window open. There is an intermittent drone or tone that also fluctuates in and out at times which is caused by the wind farm. It does not happen all of the time and is not occurring long enough to attract a decibel penalty using the procedure stated in ETSU-R-97; however, it is still noticeable and arguably still disturbing. Please try to imagine sleeping with this. The drone / tone is no longer evidence in track 19 below an hour later.

NOTES

Track 19 **Site D - Internal Amplitude Modulation** **NOTES**



This measurement is taken 1km from the wind farm inside a bedroom, the same as that in track 18 above. The impact is still continuing an hour later. The average levels are lower in sound energy and below the WHO Guideline levels for steady continuous noise that many acousticians apply as a limit of acceptability. Some low frequency thumping is evident (200-315Hz).

Glossary of terms

Aerodynamic noise*	Noise emitted by a wind turbine due to the passage of air over the blades.
'A' Weighting	This is a function which attempts to simulate the characteristics of human hearing. See also dB(A) below.
Background Noise*	The ambient noise level already present within the environment in the absence of wind farm operation.
Blade Passing Frequency*	The frequency at which blades pass over the tower i.e. three times rotational speed for a three bladed machine.
Blade Swish*	The modulation of broadband noise at blade passing frequency.
Decibel (dB(A))	A logarithmic unit in which sound is measured. dB(A) relates to decibels measured on a sound level meter weighted by a scale which is designed to reflect the weighting placed on noise by the human ear. A noise meter incorporates a frequency weighting device to create this differentiation. The dB(A) scale is now widely accepted. Measurements in dB(A) broadly agree with people's assessment of loudness for broadband noise. A change of 3dB(A) is the minimum perceptible under normal conditions, and a change of 10dB(A) corresponds roughly to halving or doubling the loudness of a sound.
Excess Amplitude Modulation (EAM)	This is the term that has commonly been used to express amplitude modulation noise from wind turbines / wind farms that was not foreseen or discussed in ETSU-R-97, i.e. modulation noise greater than 3dB(A) (peak to trough) and below the frequency range of 800-1000Hz. It is also a level identified as causing significant impact and not just that not included in ETSU-R-97 limits.
Frequency	This is the number of air vibrations or pressure fluctuations per second. The unit is the hertz (Hz). See also pitch.
Hertz (Hz)*	The unit of frequency measurement representing cycles per second.
L_{A90}	The A weighted noise level exceeded for 90% of the specified measurement period. It is a statistical measurement and now generally it is used to define background noise level. Thus if it was measured for 1 minute it would equate to the quietest 6 seconds. In one hour it would be the quietest 10% of time or 6 minutes. Thus if a machine ran continuously without a reduction in noise for 54 minutes and then stopped it would represent the quiet 6 minutes but if it ran for 55 minutes it would represent the quietest period of machine noise.

L_{Aeq}	The A weighted equivalent continuous sound level - the sound level of a notionally steady sound having the same energy as a fluctuating sound over a specified measurement period. L_{Aeq} is used to describe many types of noise and can be measured directly with an integrating sound level meter. It is obtained by continuously integrating ('adding up the energy of') a fluctuating sound signal and dividing by the elapsed time, to give the true mathematical average of any time varying signal. An L_{Aeq} reading must always be related to a time period, it should not be read as an instantaneous value of sound pressure.
Masking*	The process by which threshold of audibility of one sound is raised by the presence of another (masking) sound.
Modulation*	Periodic variation in phase, frequency or amplitude but most commonly in amplitude when associated with wind turbine noise.
Pitch	Frequency is an objective measure whereas the term pitch is subjective, and although mainly dependent on frequency is also affected by intensity.
Tones / Tonal Noise*	Noise containing a discrete frequency component most often of mechanical origin.
Wind Shear*	A description of the increase in wind speed with height above ground level.

*** definitions taken from ETSU-R-97**

Reports:

→ ETSU-R-97 (1997) The assessment and rating of noise from wind farms.

→ DTI (2006) The measurement of low frequency noise at three UK wind farms. Issued by the DTI in July 2006.

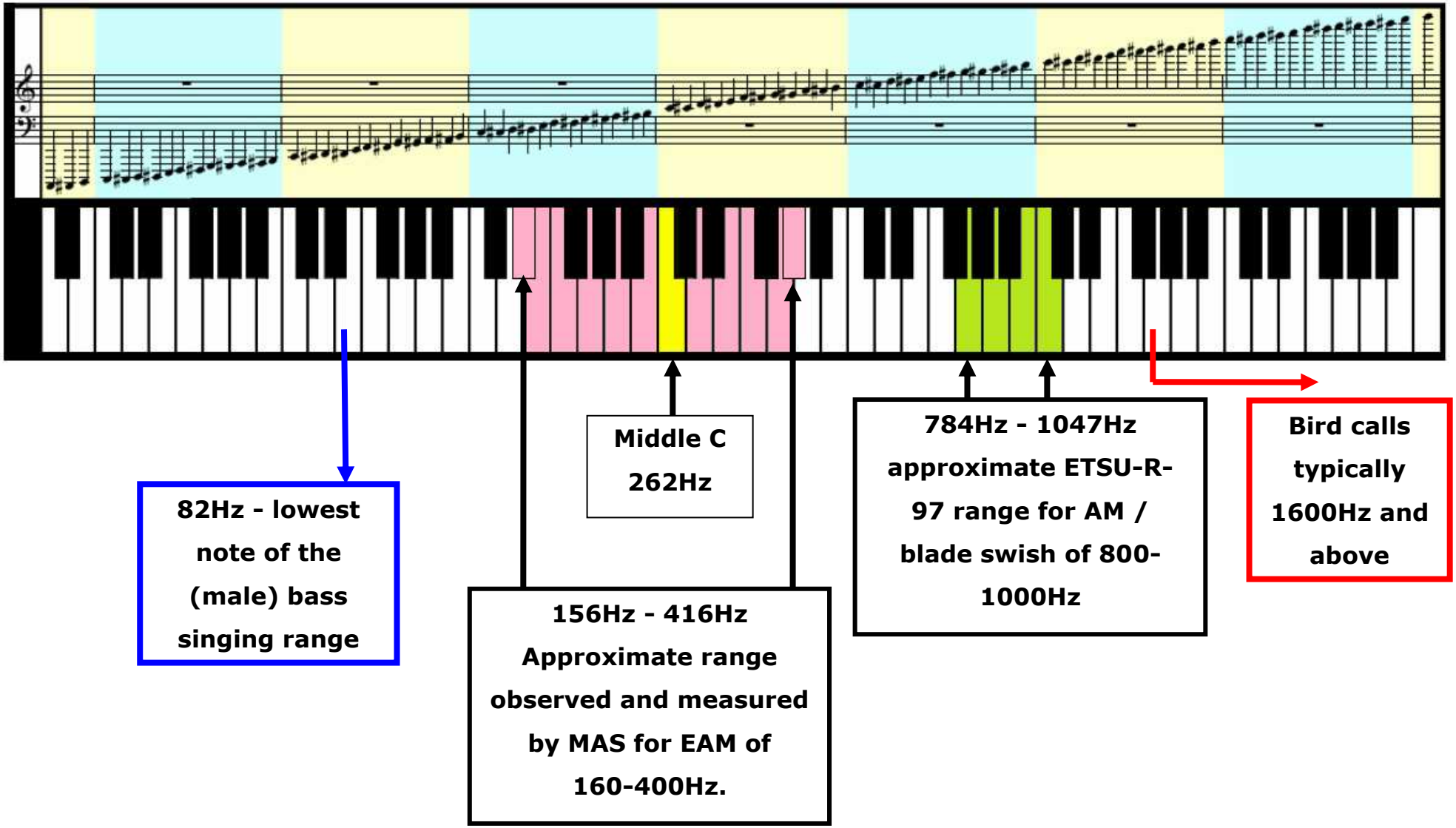
→ University of Salford for BERR (2007) Research into Aerodynamic Modulation of Wind Turbine Noise.

Prevalence of AM / EAM - the wind farms / turbine developments below have all been noted as generating AM / EAM noise

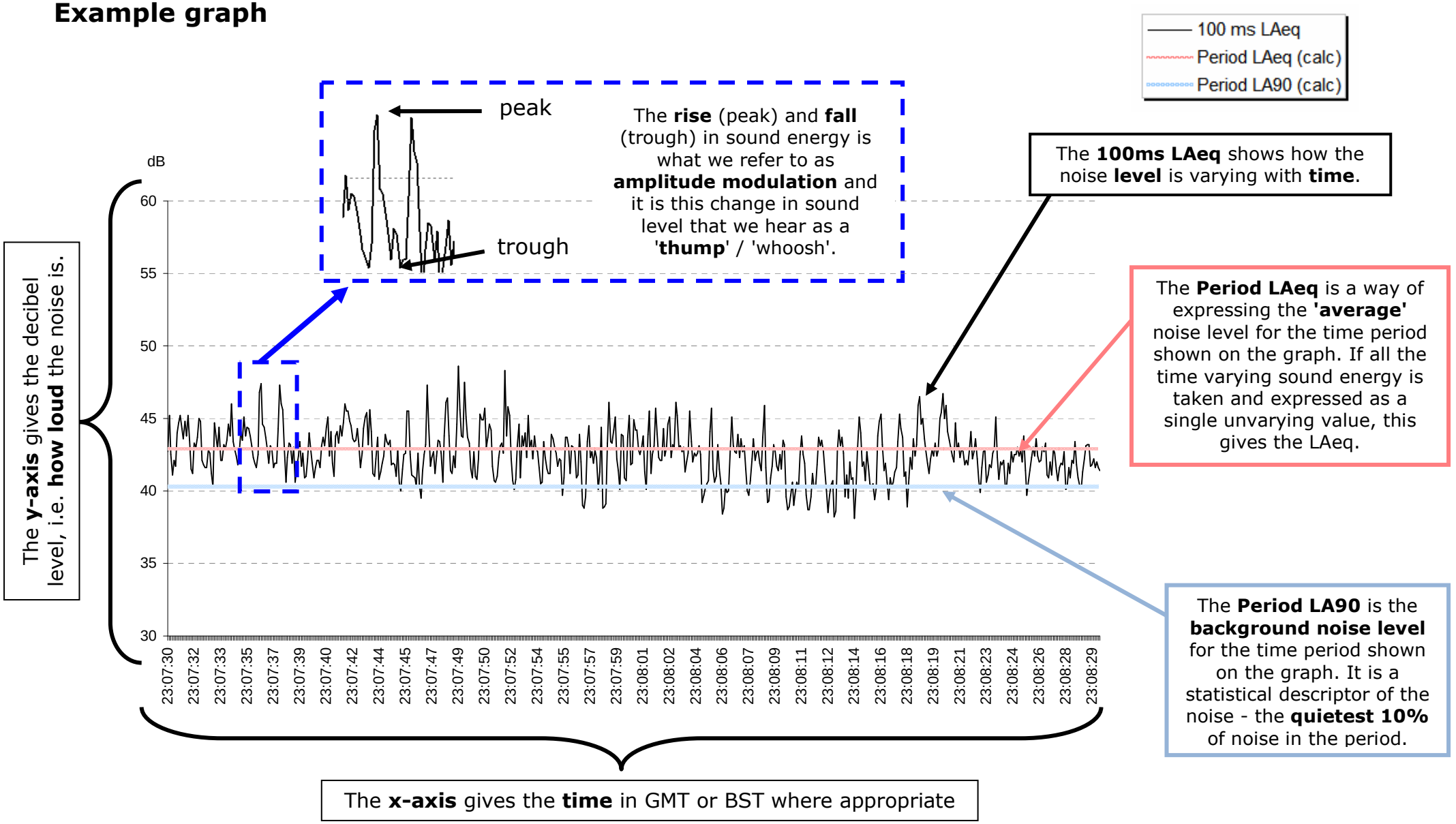
Wind Farm	Location	Turbine model	MW per turbine	No. of turbines	MW total	Hub Height (m)	Reference
Askham	Cumbria	V47	660kW	7	4.62	40	Salford - clear case added
Bears Down	Cornwall	Bonus	600kW	16	9.6	30	Salford - clear case added
Bicker Fen	Lincolnshire	Repower MM82	2MW	13	26	59	Statement from complainant - clear case
Black Law, Forth	South Lanarkshire	Siemens	2.3MW	42	97	82	MAS have no direct evidence
Blaen Bowi	Carmarthenshire	Nordex	1.3MW	3	3.9	46	Salford - clear case but not added
Blaengwen (statkraft)							Multiple complaints
Carland Corss	Cornwall	Vesta WD34	400kw	15	6	30	In ETSU-R-97 and Salford
Causeymire	Highland	Bonus	2.3MW	21	48.3	60	In Salford but not added by Salford
Coal Clough	Lancashire	Vestas WD34	400kw	24	9.6	30	In ETSU-R-97 missed in Salford
Cold Northcott	Cornwall	WEG MS3-300	300kw	22	6.3	25	In ETSU-R-97 - in Salford but not added
Coldham	Cambridgeshire	Vestas V.80	1.75MW	8	14	60	Statements from complainant
Conisholme		Bonus	2.3MW	21	48.3		MAS have no direct evidence
Cruach Mhor	Argyll & Bute	Vestas V52	850kw	35	29.75	45	Salford - but not added
Crystal Rig	Scottish Borders	Siemens 2.3	2.3MW	51 + 9	117.3 + 20.7	60 + 80	MAS have no direct evidence
Darracott	Devon	Gamesa G5	850kW	3	2.55	50	Complaints by residents of AM
Deeping St Nicholas	Lincolnshire	Repower MM82	2MW	8	16	59	In Salford and added, MAS confirmed
Delabole	Cornwall	Enercon E70	2.3MW	4	9.2	99 (tip)	Direct complaints and advice of acoustician
Forestmoor, Bradworthy	Devon	Vestas 1.0	1MW	3	2.7	48	MAS have no direct evidence
Fullabrook	Devon	Vestas V90	3MW	22	66	65	Complaints by many residents of AM, post Salford
Gedney Marsh (Red House)	Lincolnshire	Repower MM82	2MW	6	12	59	MAS have no direct evidence
Glens of Foundland	Aberdeenshire	Bonus	1.3MW	20	26	46	In Salford but not added
Hadyard Hill	South Ayrshire	bonus 2.3	2.5MW	52	130	60-70	In Salford, possible case, but no direct evidence
Hafoty Ucha	Gwynedd	V52	850kW	1	0.85	39-44	In Salford, questionable case, but no direct evidence
Harlock Hill	Cumbria	Wind World	500kW	5	2.5	35	MAS have no direct evidence
High Volts	County Durham	NM80/2750	2750kW	3	7.85	60	MAS have no direct evidence
Kessingland	Suffolk	Repower MM92	2.05MW	2	4.1	80	MAS measured, post Salford
Knabs Ridge	North Yorkshire	Repower MM70	2MW	8	16	58	Complaints and MAS measured - post Salford
Llyn Alaw	Anglesey	Bonus	600kW	34	20.4	31	In Salford and WAS added
Lynch Knoll	Gloucestershire	Enercon E40	500kW	1	0.5	42	In Salford but not added
Mablethorpe	Lincolnshire	Enercon E40	600kW	2	1.2	65	MAS have no direct evidence
Michelin Tyre Factory	Dundee City	Enercon E70	2MW	2	4	85	In Salford but not added
Mynydd Clogau	Powys	Vestas	850kW	17	14.45	34	In Salford, possible case, but no direct evidence
North Pickenham	Norfolk	Vestas V90	1.8MW	8	14.4	80	MAS measured - residents not complaining officially
Penrhyddlan & Llidiatywaun						45	MAS have no direct evidence, but noise problems noted in ETSU-R-97
Red Tile / Warboys	Cambridgeshire	Repower MM82	2MW	12	24	59	MAS measured and complaints - missed by Salford
Rhyd y Groes	Ceredigion	Bonus B300	300kW	24	7.2	31	MAS have no direct evidence, but noise problems noted in ETSU-R-97
Royd Moor	South Yorkshire	Bonus 500	500kW	13	6.5	35	In Salford but not added, MAS heard
Site C							MAS measured, complaints from residents, post Salford cannot disclose
St Breock	Cornwall	Bonus	450kW	11	4.95	35	MAS have no direct evidence
Swaffham	Norfolk	Enercon E82	1.8MW	1	1.8	67	Complaints and MAS measured, missed by Salford
Tir Mostyn & Foel Goch	Denbighshire	Gamesa	850kW	25	21.25	49	In Salford but not added
Trysglwyn	Gwynedd	Bonus	400kW	14	5.6	25	In Salford but not added
Wharrels Hill, Bothel	Cumbria	Nordex N60	1.3MW	8	10.4	76	Complaints by residents of AM, post Salford

Frequency comparator

(sourced from http://www.music.vt.edu/musicdictionary/appendix/pitch/pitch.html)



Example graph



Acknowledgements

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For more information please see below.

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