

Frequency analysis

5.8.16. For the frequency analysis, a Fast Fourier Transform (FFT) of the signal was performed, averaged over a representative one minute period at a frequency resolution of 2 Hz. The resulting frequency spectrum for the ASHP operating under normal conditions is given in Figure 5-66, with that for the defrost cycle given in Figure 5-67.

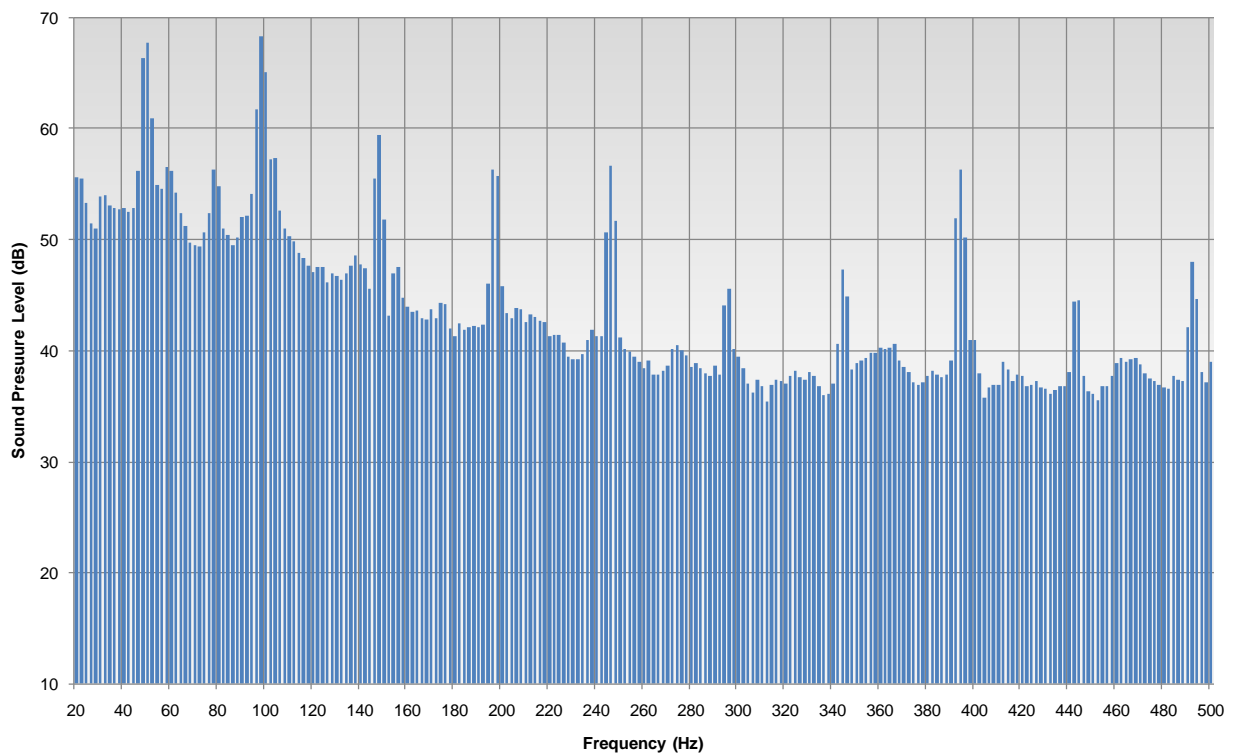


Figure 5-66. 475 West Berkshire (Site 2), Sound Pressure Level Frequency Spectrum (Normal Operation)

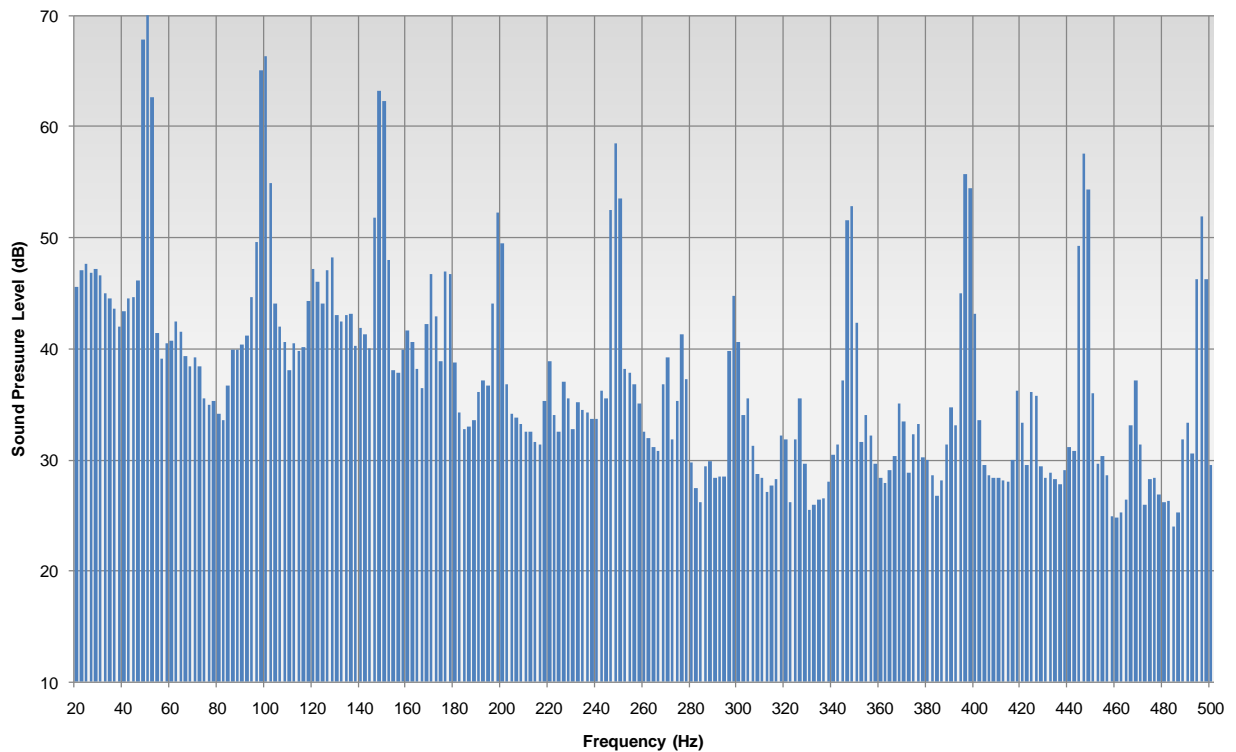
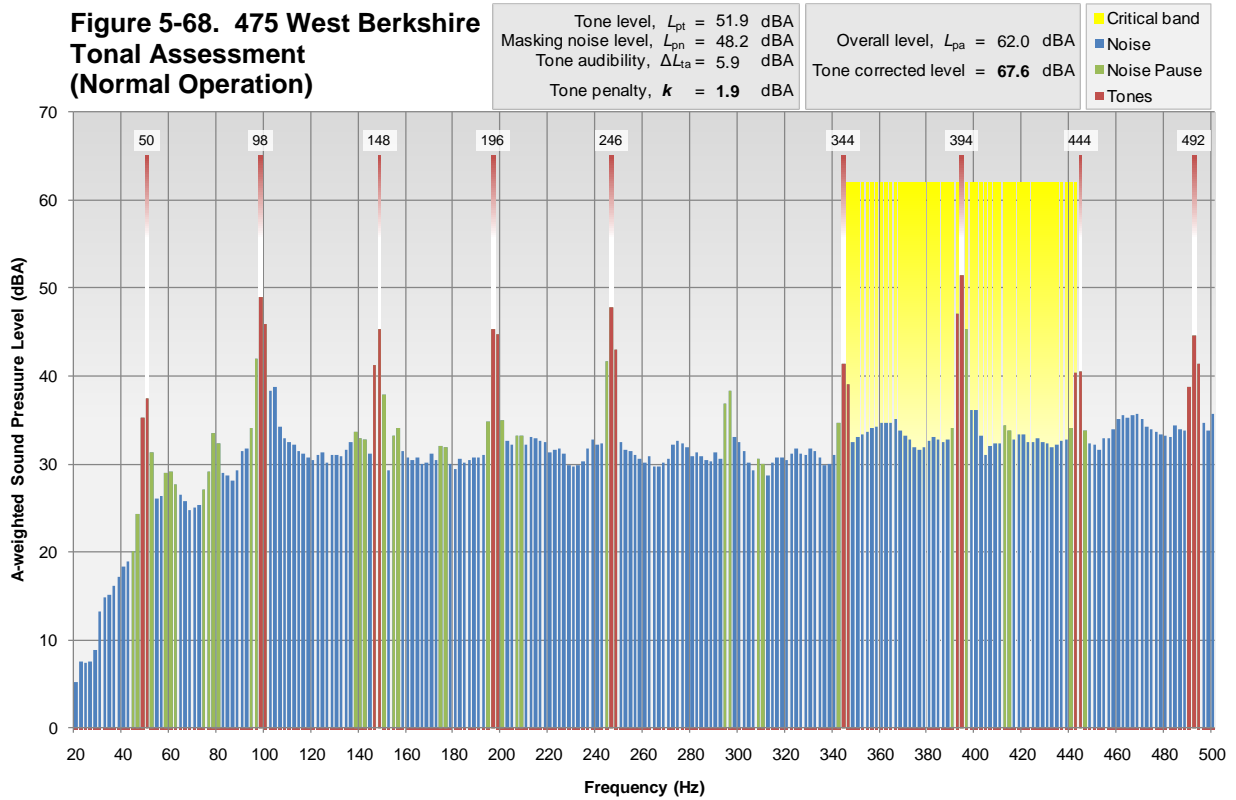


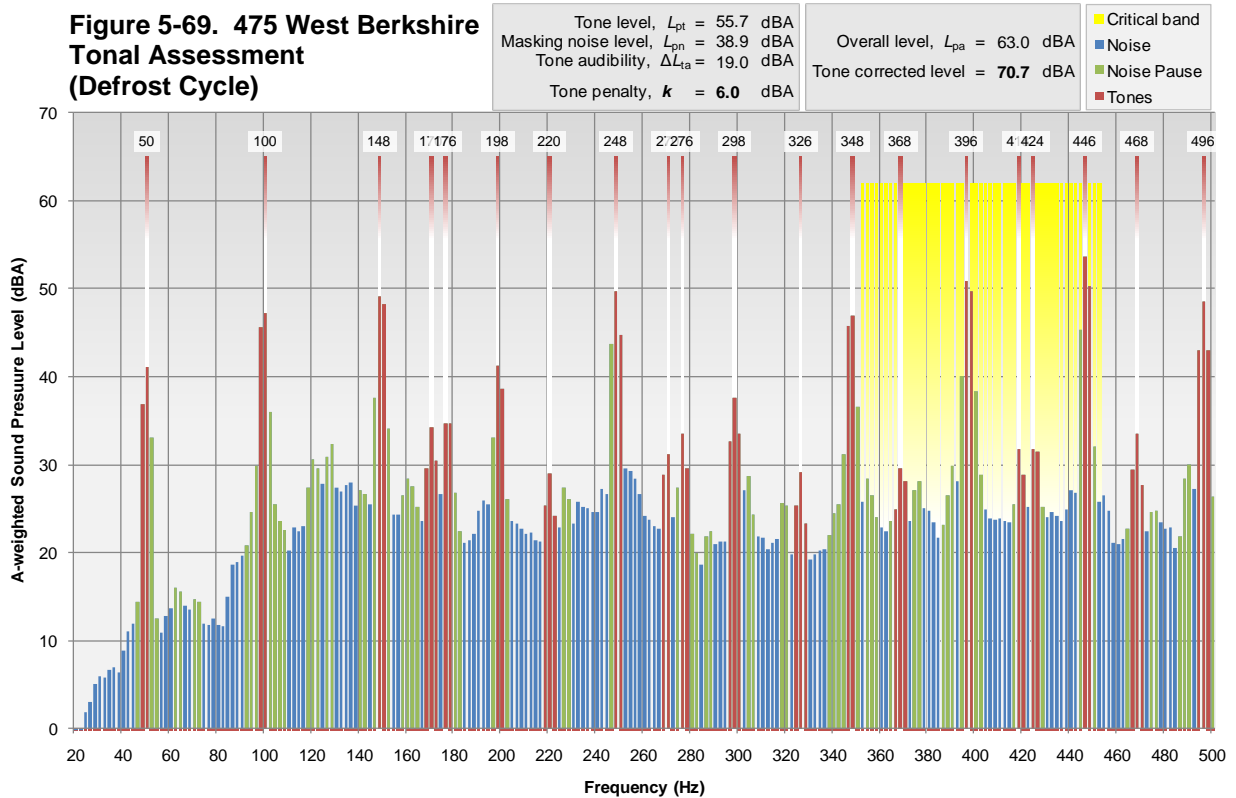
Figure 5-67. 475 West Berkshire (Site 2), Sound Pressure Level Frequency Spectrum (Defrost cycle)

- 5.8.17. Tonal analysis of the frequency spectra shown in Figure 5-66 and Figure 5-67 has been undertaken in accordance with the Joint Nordic Method (v2). The resulting tonal assessments are presented in Figure 5-67 and Figure 5-68, showing that the tones identified within the spectrum would lead to a **2 dB tonal penalty** for normal operation and a **6 dB tonal penalty** for the defrost cycle.

**Figure 5-68. 475 West Berkshire
Tonal Assessment
(Normal Operation)**



**Figure 5-69. 475 West Berkshire
Tonal Assessment
(Defrost Cycle)**



Sound Power Level calculations

5.8.18. Figure 5-8 presents a statistical analysis plot of the percentage of time that a specific sound power level would be recorded, when the ASHP is under operation.

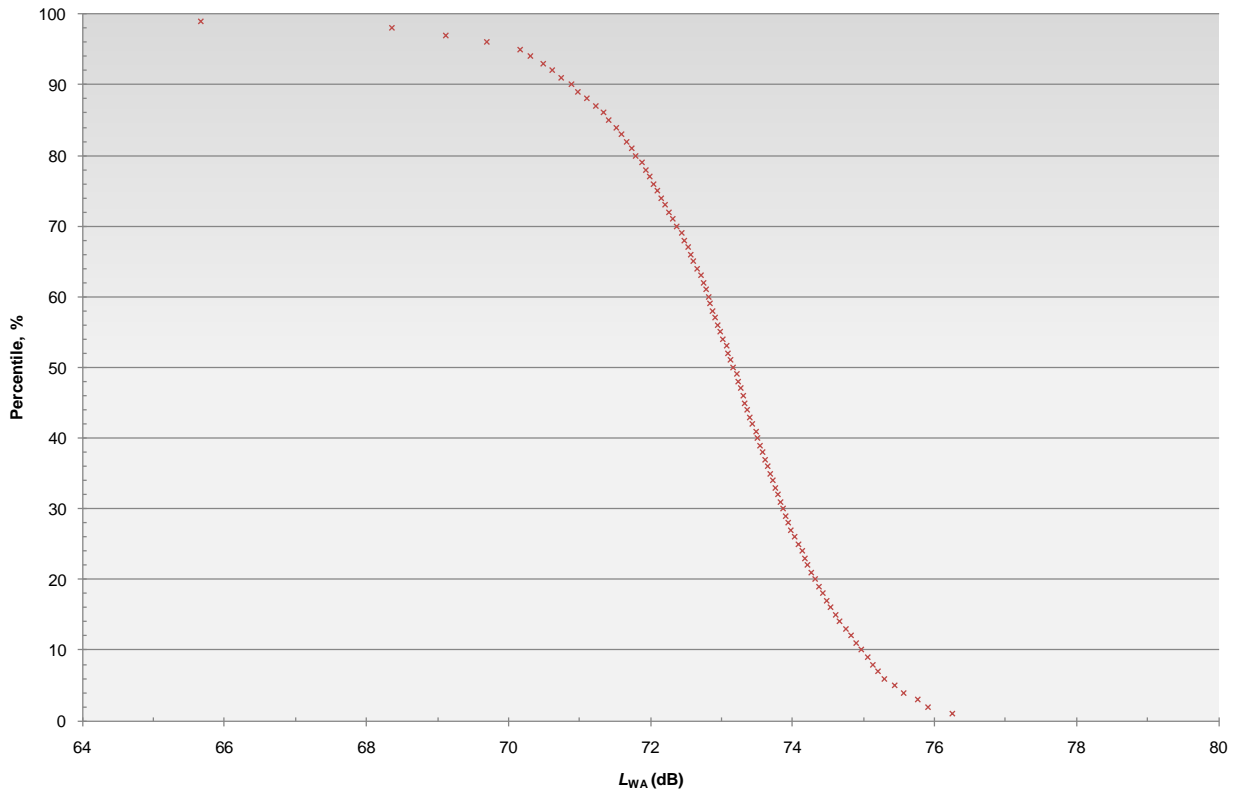


Figure 5-70. 475 West Berkshire (Site 2), Sound Power Level Statistical Analysis

5.8.19. The chart indicates that noise from the ASHP during operation will have a 90% certainty of being within around 3 dB of L_{WA} **73 dB**.

5.8.20. Use of Equation 1 leads to an estimation that noise levels from the unit operating normally would drop to L_{Aeq} 42 dB at a distance separation of approximately **20 m**. If a tonal penalty were to be included, then this distance would rise to around **25 m**. This assumes that the ASHP is located in the common mounting scenario as detailed in Section 3.42, which is not necessarily representative of the actual measured condition.

Vibration

5.8.21. An FFT analysis of the vibration levels recorded for normal operation of the ASHP is shown in Figure 5-71. The overall weighted peak vibration level at the wall surface was 0.007 ms^{-2} , below the average perception threshold for whole-body vibration.

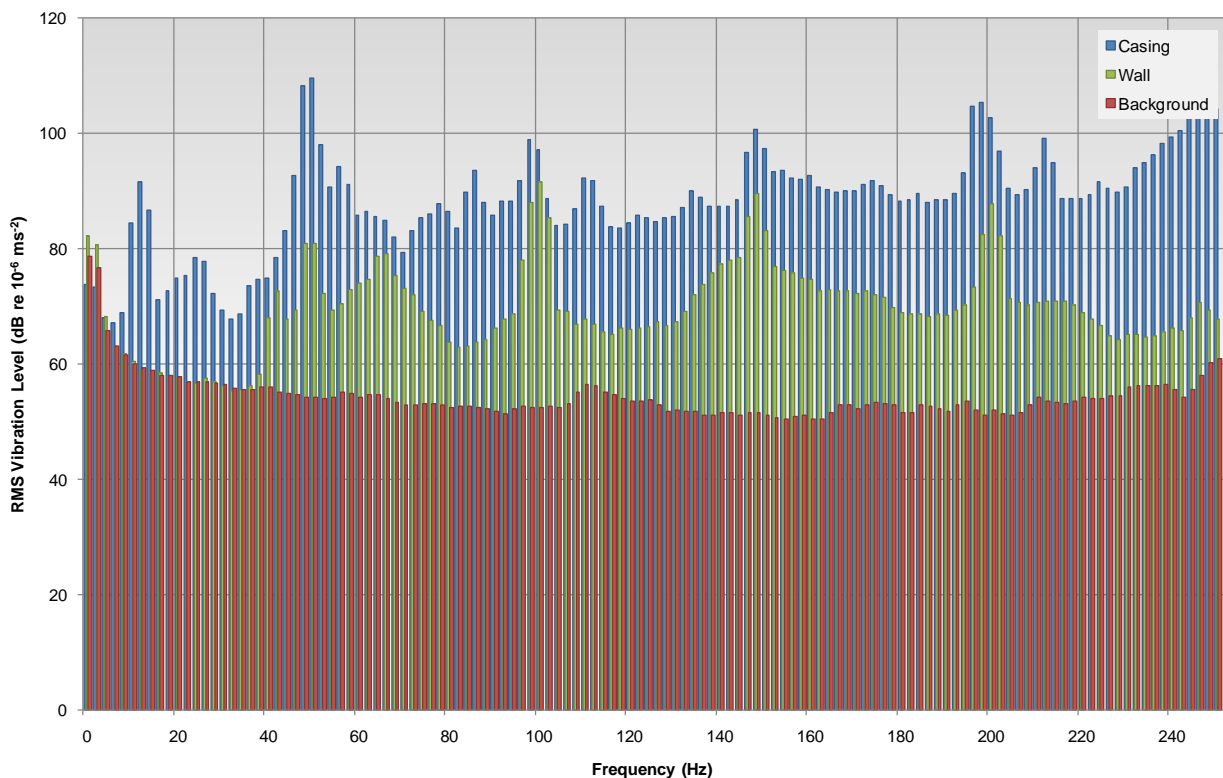


Figure 5-71. 475 West Berkshire (Site 2), Vibration Levels

Discussion

5.8.22. The manufacturer has indicated that the speed rating of the fan is nominally 770 rpm, and the compressor speed is 2850 rpm. With four fan blades, the passing frequency would correspond to around 51 Hz, with upper harmonics around 102 and 153 Hz. The compressor speed corresponds with a rotation frequency of around 48 Hz, upper harmonics are clearly visible in the defrost cycle frequency spectrum.

- 5.8.23. From analysis of the spectra, it is apparent that the natural frequencies of the fan during normal operation are not readily distinguishable over those produced by the compressor. It is likely that the natural frequencies of the fan and compressor are occurring so closely that constructive and destructive interference is occurring.
- 5.8.24. During normal operation, the compressor contributes a greater amount of noise than the fan, as well as the majority of tonal content.
- 5.8.25. The vibration data shows that whilst there is in general good attenuation between the ASHP casing and the wall structure, at certain frequencies there is still an amount of transmission that could cause structure-borne noise. It should be noted however, that due to difficulties in effectively mounting the accelerometer to the wall surface directly, it had been mounted to a lightweight timber conduit, which may show exaggerated vibration levels through surface excitation from airborne ASHP noise.
- 5.8.26. A rattle was audible, particularly with the compressor operation, it is therefore possible that some component around the compressor assembly may need tightening or fixing.

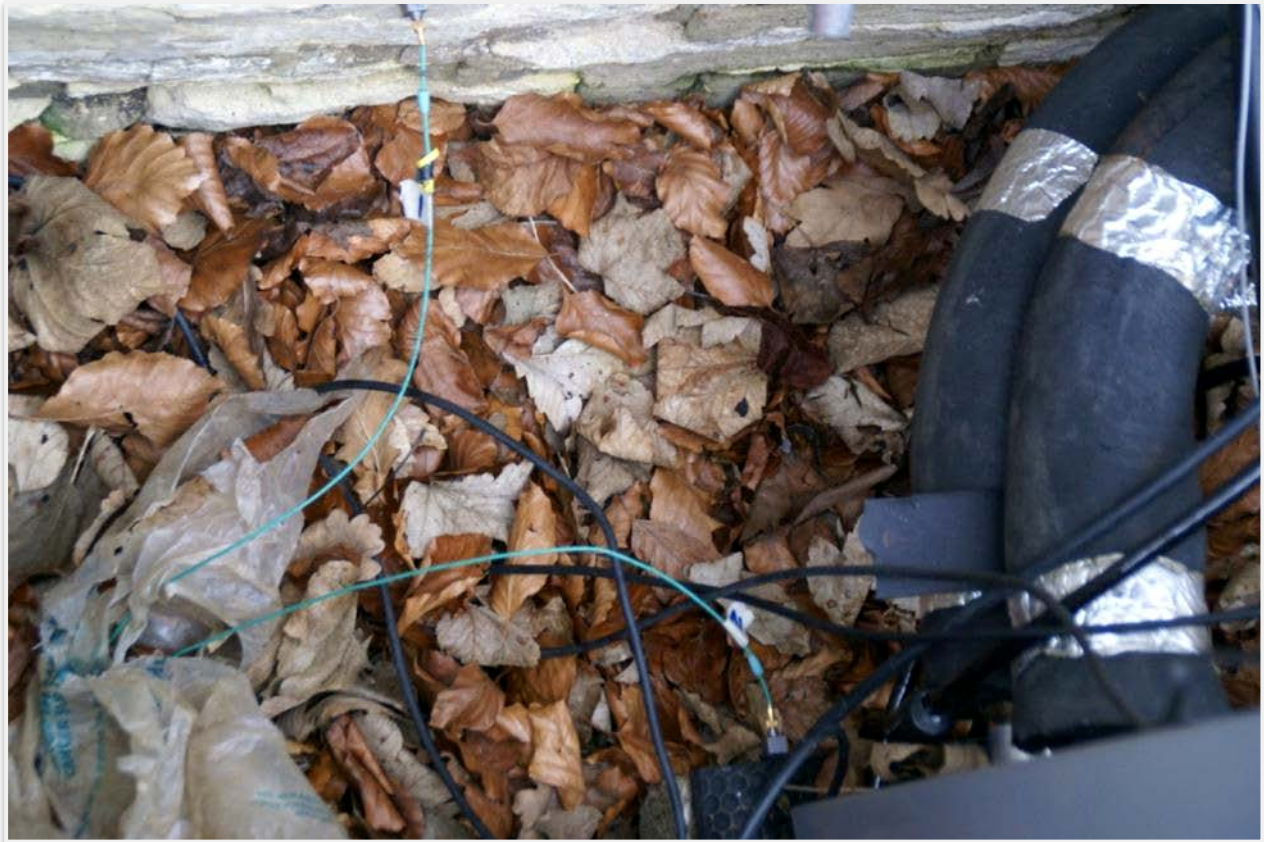
5.9 **478 Cotswold (Courtyard)**

Site description

- 5.9.1. The property is located at a farm in a rural location. The ASHP is located within a courtyard, enclosed by stone built single story accommodation. The unit is mounted onto concrete paving slab footings.
- 5.9.2. Subjectively the unit appeared to be operating normally with no audible rattle, resonance or fault.

Equipment set up

- 5.9.3. The 9 Channel PULSE system was used at this site.
- 5.9.4. The unit was mounted above a mixed ground surface of gravel and paving slabs. A stone wall had been built around the ASHP unit as a visual barrier. This interfered with proper placement of microphones, which were placed in a position deemed to be most representative of the ASHP noise emissions.
- 5.9.5. Accelerometers were fixed to the ASHP footings and to the wall surface immediately behind the unit as shown in Picture 5-22. The accelerometers were fixed to the surfaces using cyanoacrylate cement.



Picture 5-22. 478 Cotswold (Courtyard), Accelerometer Positions

5.9.6. The microphones were mounted on tripods as shown in Picture 5-23. All microphones were positioned 1 m from the ASHP casing, with the exception of the microphone to the left, which had a separation of 60 cm.



Picture 5-23. 478 Cotswold (Courtyard), ASHP and Microphone Arrangement

Measurement Results

- 5.9.7. Figure 5-72 presents the $L_{Aeq(1min)}$ measured noise levels at the microphone 1m in front of the unit set against time, along with the per-minute logged ASHP power consumption. Equipment failure prevented recording between 1/2/11 and 4/2/11.

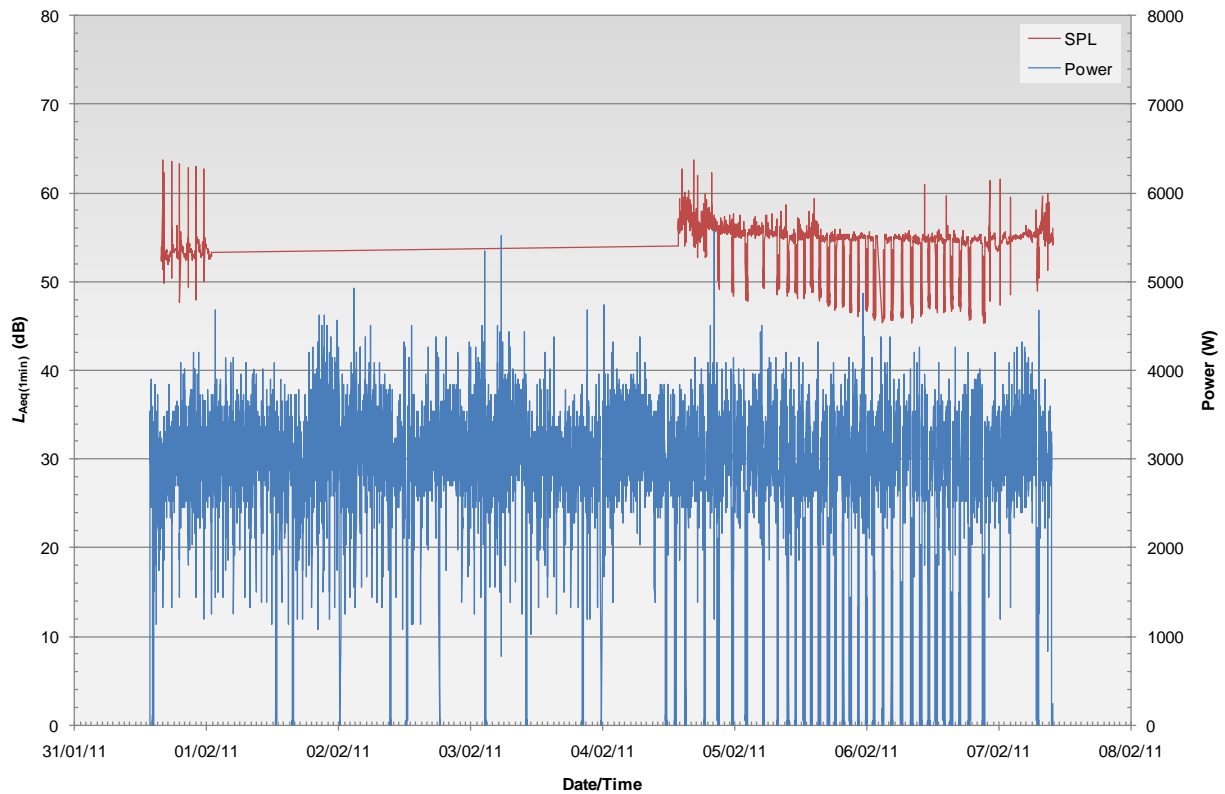


Figure 5-72. 478 Cotswold (Courtyard), SPL and Power Consumption vs Time

- 5.9.8. The chart highlights that the ASHP is cycling on and off, at a cycle interval determined by the power demands of the system. Throughout the measurement period, the ASHP was operational for approximately 85% of the time.
- 5.9.9. The data shows an increase in measured noise level during periods when the ASHP is operating.

Measurement Analysis

- 5.9.10. Figure 5-73 presents a scatter diagram showing the noise levels against the power consumption, for the periods when the ASHP was operating. The chart shows no apparent link between power and noise level.

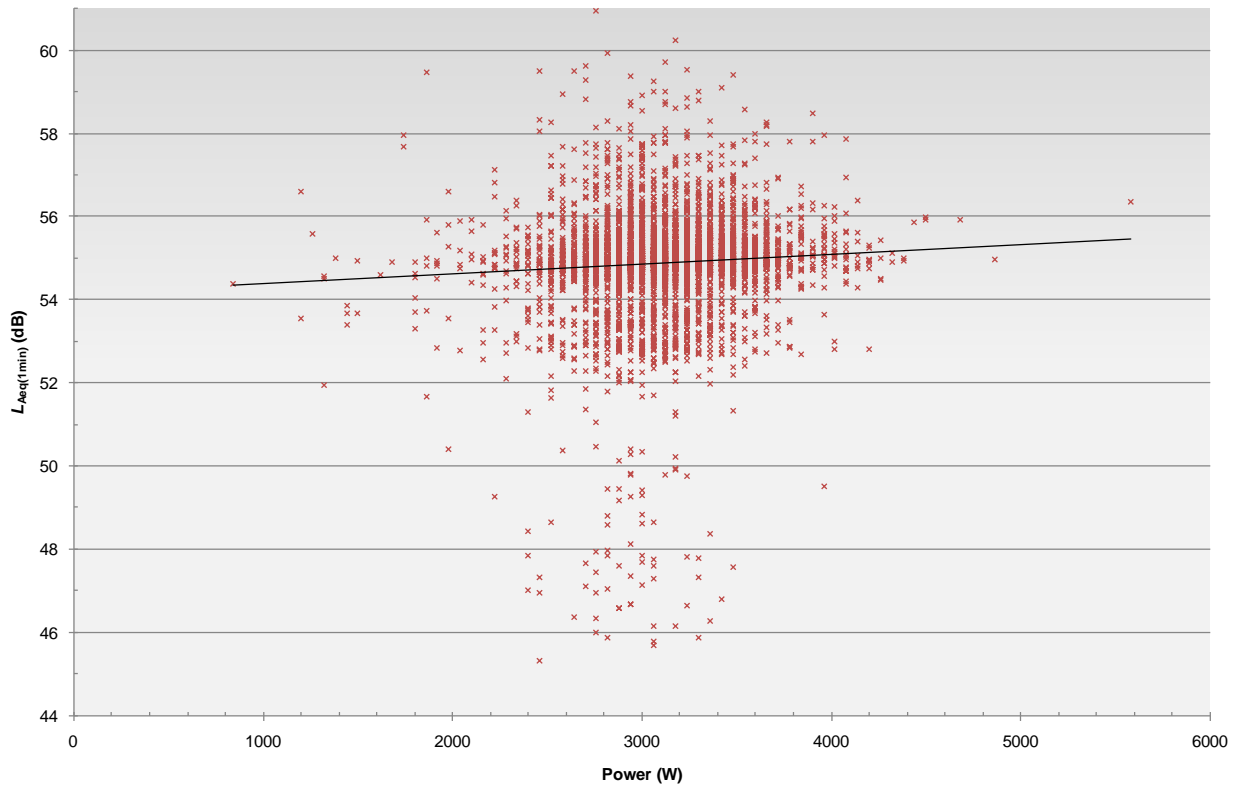


Figure 5-73. 478 Cotswold (Courtyard), SPL vs Power Consumption

5.9.11. Figure 5-74 presents a statistical analysis plot of the percentage of time that a specific noise level would be recorded, when the ASHP is under operation. From this confidence intervals can be presented for the typical noise levels.

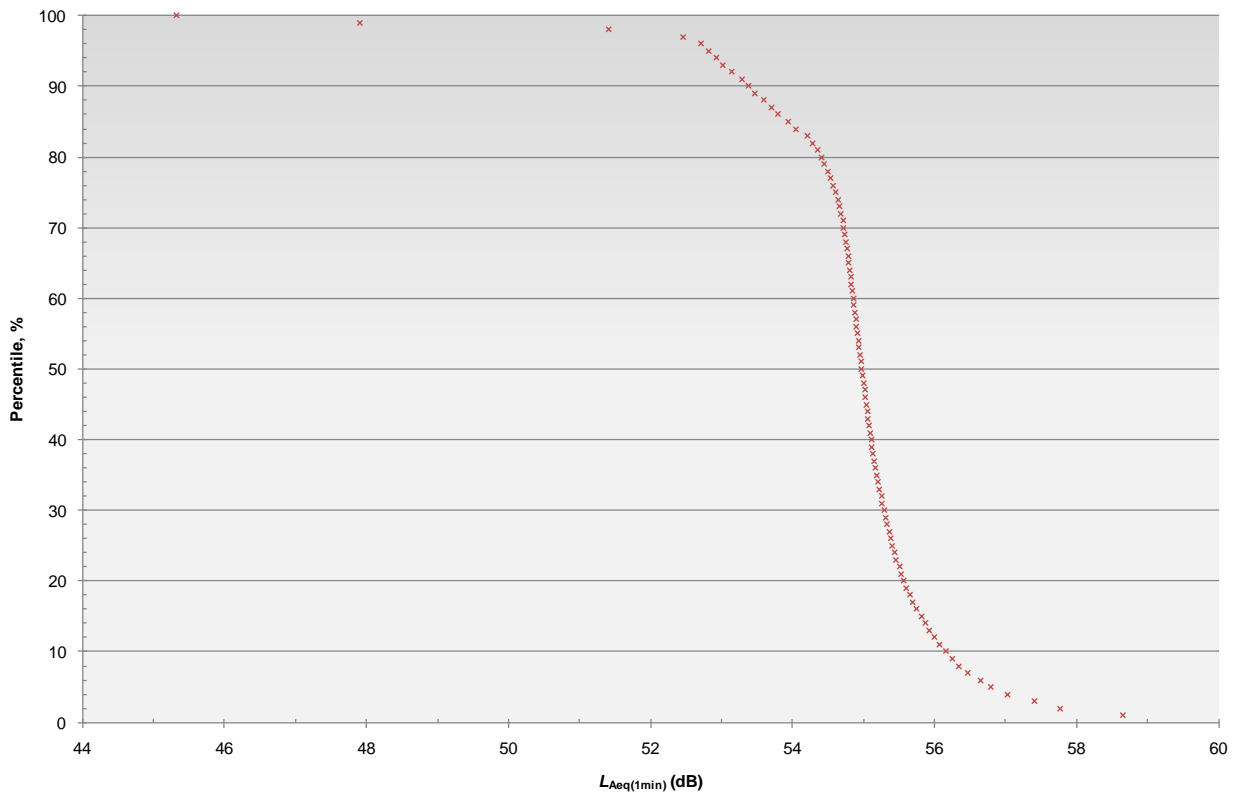


Figure 5-74. 478 Cotswold (Courtyard), SPL Statistical Analysis

- 5.9.12. The chart indicates that noise from the ASHP during operation will have a 90% certainty of being within around 3 dB of $L_{Aeq(1min)}$ **55 dB**. The corresponding total ASHP noise dose over the whole assessment period is calculated as $L_{Aeq(1week)}$ 54 dB.

Defrost Cycle

- 5.9.13. Analysis of the measurements failed to identify defrost cycles with any certainty. Whilst certain short periods of operation were revealed within the measurement data, the analysis has shown the noise to be very similar to that of a 'normal' operating condition. It is therefore likely that either no defrost cycles occurred during the measurements or that the sound characteristic during the defrost cycle is similar to that during normal operation.

Directivity

5.9.14. Table 5-9 shows the directivity in noise emissions from the unit by comparing the noise levels at the different microphones, for a typical period of ASHP operation.

| Table 5-9: Directivity Analysis of the ASHP Noise Emissions $L_{Aeq(1min)}$ dB 478 Cotswold (Courtyard), normal operation | | | | |
|---|--------------|-------------|--------------|--------------|
| Microphone Location | Front | Left | Right | Above |
| Typical Microphone Level | 52 | 52 | 52 | 55 |
| Change from front microphone | -3 | -3 | -3 | - |

5.9.15. It is seen that the ASHP exhibits some directivity, such that noise is greatest in line with the fan.

Frequency analysis

5.9.16. For the frequency analysis, a Fast Fourier Transform (FFT) of the signal was performed, averaged over a representative one minute period at a frequency resolution of 2 Hz. The resulting frequency spectrum for the ASHP operating under normal conditions is given in Figure 5-75.

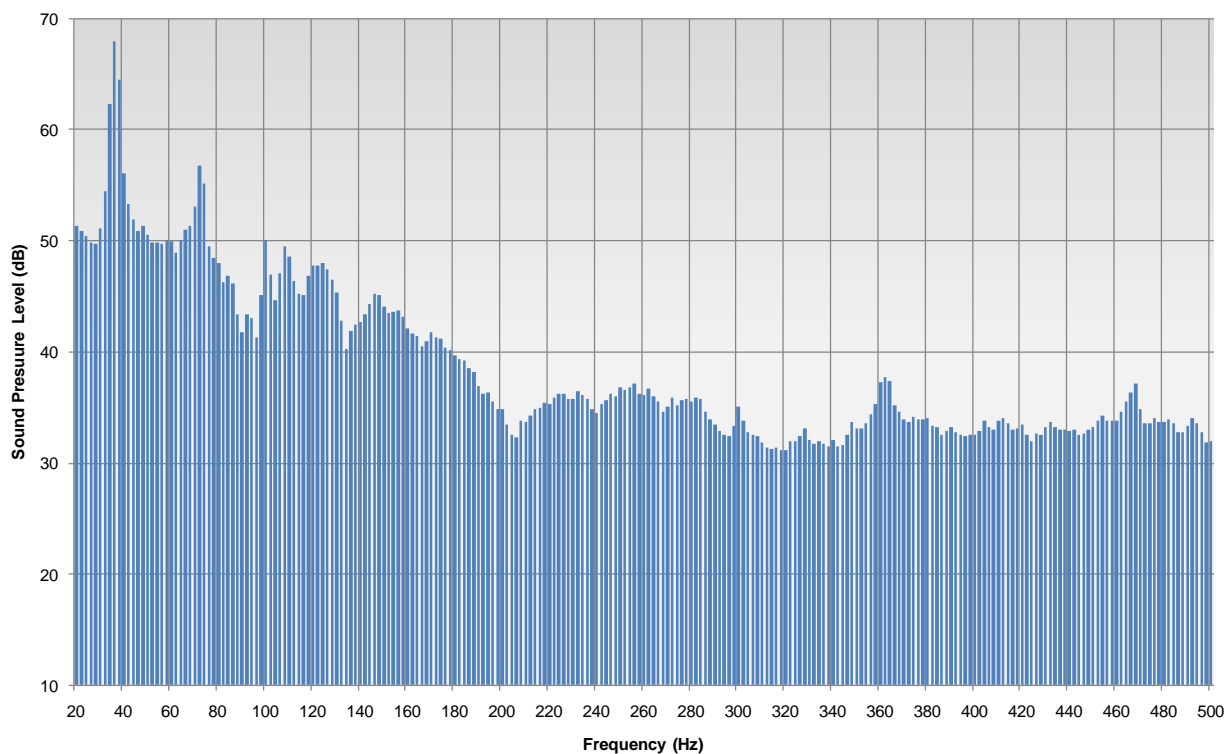
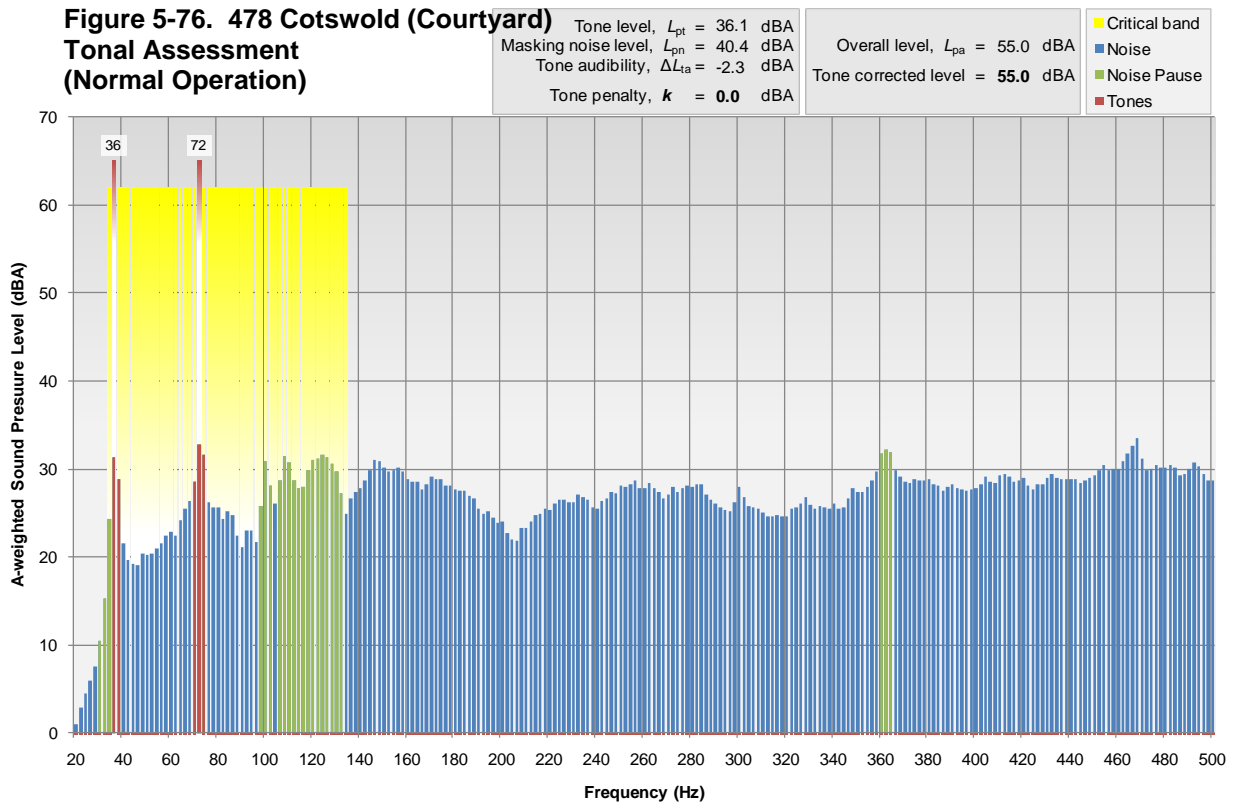


Figure 5-75. 478 Cotswold (Courtyard), Sound Pressure Level Frequency Spectrum (Normal Operation)

5.9.17. Tonal analysis of the frequency spectrum shown in Figure 5-75 has been undertaken in accordance with the Joint Nordic Method (v2). The resulting tonal assessment is presented in Figure 5-75, showing that the tones identified within the spectrum would lead to a **0 dB tonal penalty** for normal operation.

**Figure 5-76. 478 Cotswold (Courtyard)
Tonal Assessment
(Normal Operation)**



Sound Power Level calculations

5.9.18. Figure 5-77 presents a statistical analysis plot of the percentage of time that a specific sound power level would be recorded, when the ASHP is under operation.

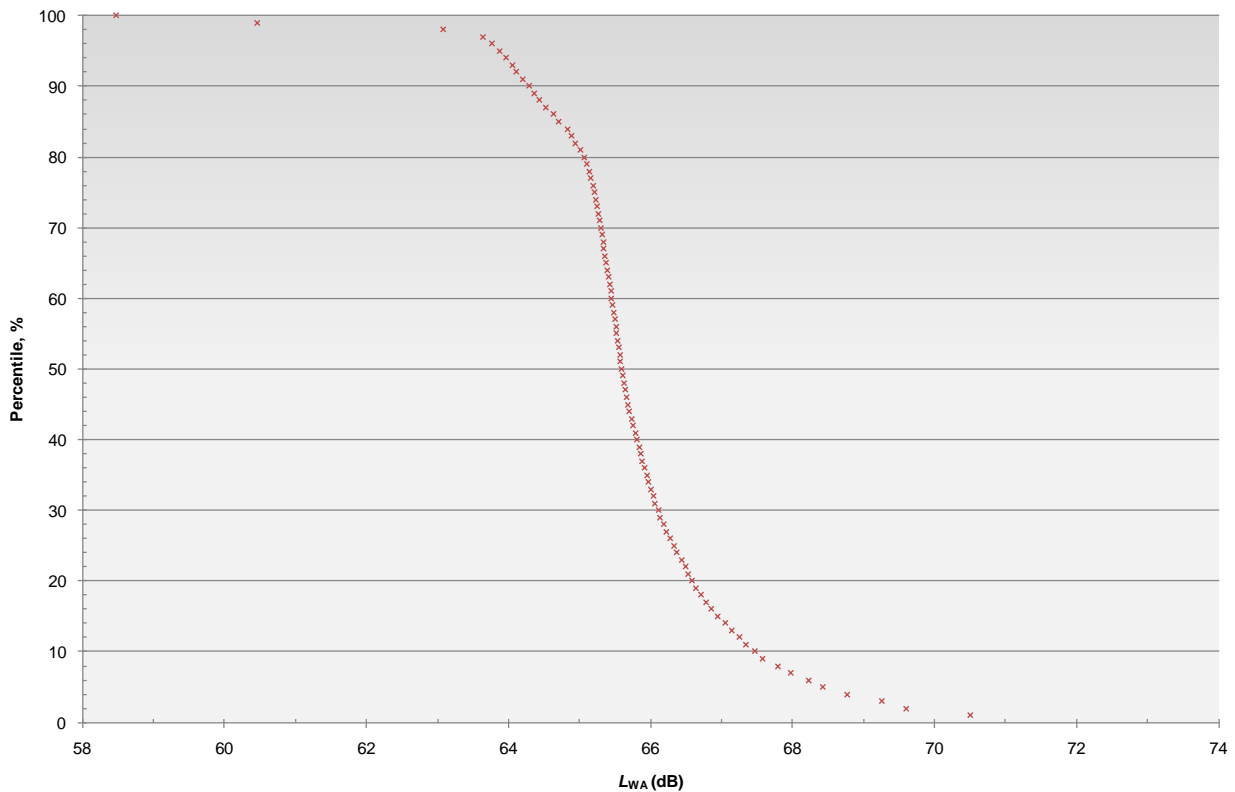


Figure 5-77. 478 Cotswold (Courtyard), Sound Power Level Statistical Analysis

- 5.9.19. The chart indicates that noise from the ASHP during operation will have a 90% certainty of being within around 3 dB of L_{WA} **66 dB**.
- 5.9.20. Use of Equation 1 leads to an estimation that noise levels from the unit operating normally would drop to L_{Aeq} 42 dB at a distance separation of approximately **9 m**. This assumes that the ASHP is located in the common mounting scenario as detailed in Section 3.42, which is not necessarily representative of the actual measured condition.

Vibration

- 5.9.21. An FFT analysis of the vibration levels recorded on the ASHP casing for normal operation is shown in Figure 5-78. No vibration was measureable at the wall surface which was likely to be due to the high mass of the wall and the ASHP isolation.

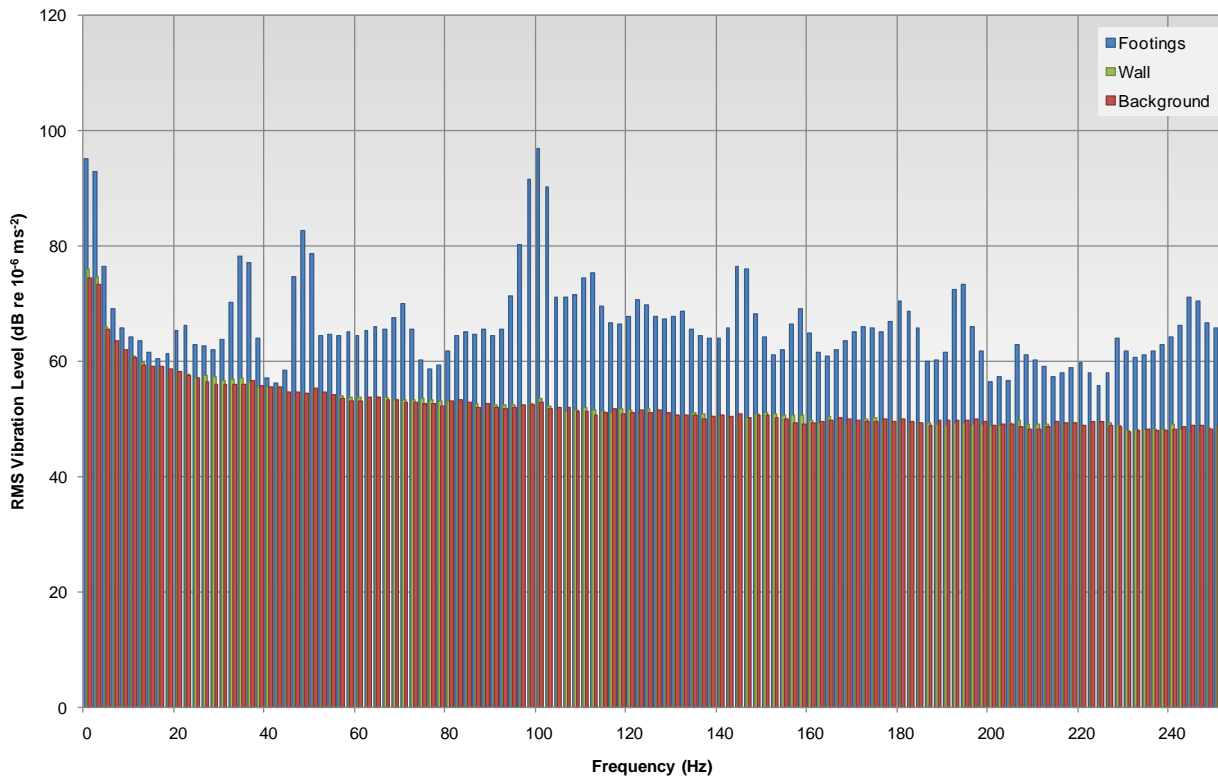


Figure 5-78. 478 Cotswold (Courtyard), Vibration Levels

Discussion

- 5.9.22. The manufacturer has not provided details of the fan speed rating. The compressor speed is 2900 rpm, which corresponds with a rotation frequency of around 48 Hz. It should be noted that tones related to this frequency are only seen in the vibration spectrum, not in the sound spectra. This indicates that tones from the compressor have either been well attenuated in the design of the ASHP, or that the frequencies seen in the vibration spectrum are due to an unrelated mechanism, for example, electrical noise.
- 5.9.23. It is likely that the tones observed at 36 and 72 Hz are due to the fan. Assuming that there are four fan blades, as is common for ASHP units, this corresponds to a rotation frequency of 540 rpm.

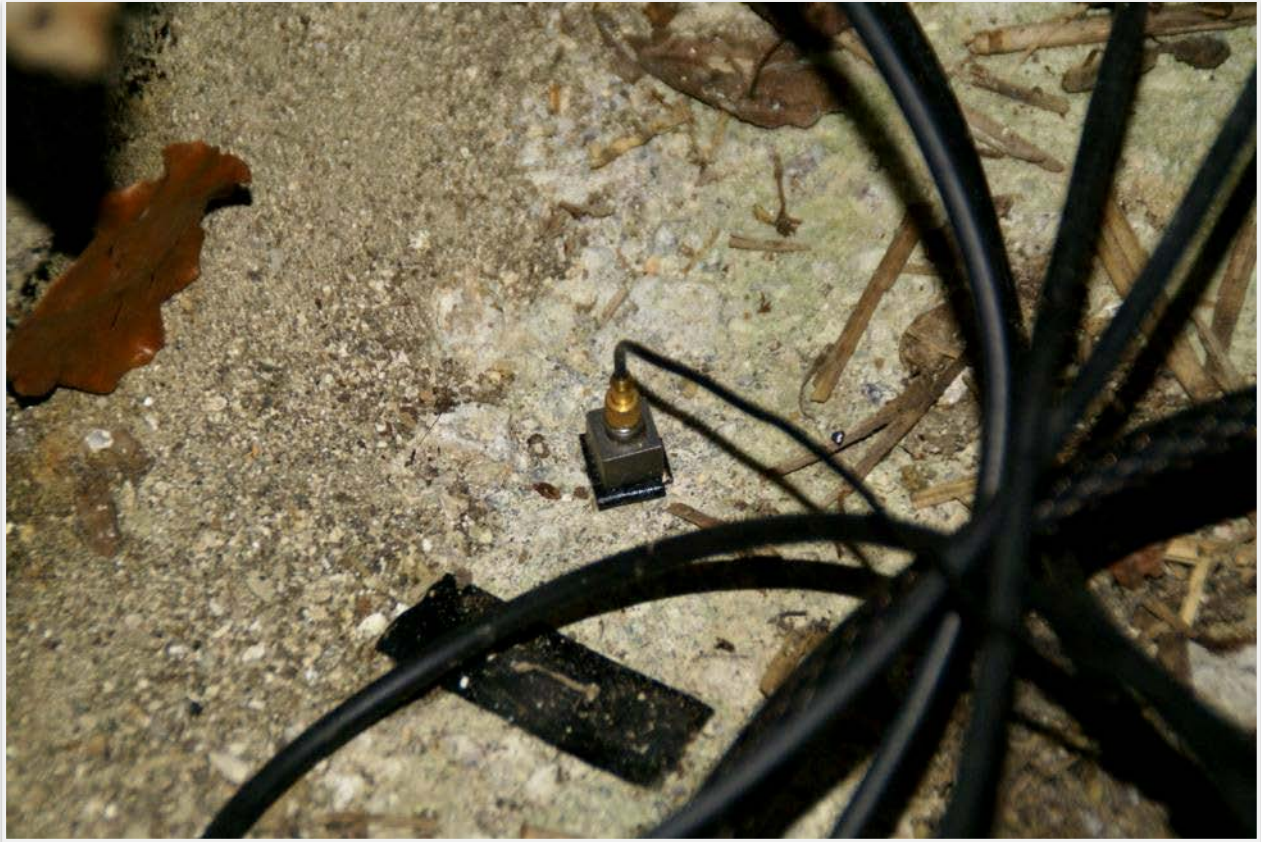
5.10 **478 Cotswold (Stables)**

Site description

- 5.10.1. The property is located at a farm in a rural location. The ASHP is located within an open stable area, which was constructed with a high corrugated metal roof. The unit is mounted onto concrete slab footings.
- 5.10.2. Subjectively the unit appeared to be operating normally with no audible rattle, resonance or fault.

Equipment set up

- 5.10.3. The 5 Channel PULSE system was used at this site.
- 5.10.4. The unit was mounted above a mixed ground surface of concrete and straw, in front of a stone wall.
- 5.10.5. Unlike most ASHP units, the fan at this site discharged to the top of the unit.
- 5.10.6. Accelerometers were fixed to the ASHP footings as shown in Picture 5-24. The accelerometer was fixed to the surface using cyanoacrylate cement.



Picture 5-24. 479 Cotswold (Stables), Footings-mounted Accelerometer

5.10.7. The microphones were mounted on temporary framework as shown in Picture 5-25. All microphones were positioned 1 m from the ASHP casing, with the exception of the microphone to the left, which had a separation of 60 cm.



Picture 5-25. 479 Cotswold (Stables), ASHP and Microphone Arrangement

Measurement Results

- 5.10.8. Figure 5-79 presents the $L_{Aeq(1min)}$ measured noise levels at the microphone 1m in front of the unit set against time, along with the per-minute logged ASHP power consumption. Equipment failure prevented recording of acoustical data between 1/2/11 and 4/2/11.

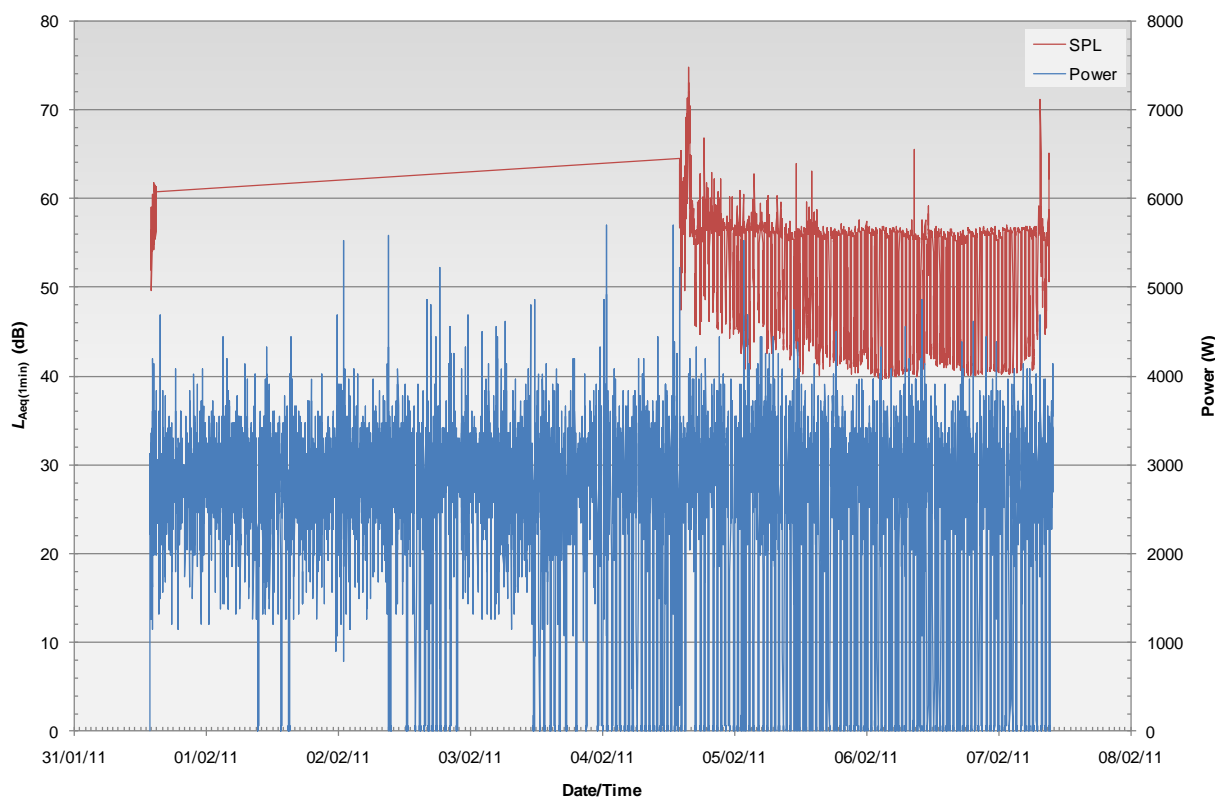


Figure 5-79. 479 Cotswold (Stables), SPL and Power Consumption vs Time

5.10.9. The chart highlights that the ASHP is cycling on and off, at a cycle interval determined by the power demands of the system. Throughout the measurement period, the ASHP was operational for approximately 62% of the time.

5.10.10. The data shows an increase in measured noise level during periods when the ASHP is operating.

Measurement Analysis

5.10.11. Figure 5-80 presents a scatter diagram showing the noise levels against the power consumption, for the periods when the ASHP was operating. The chart shows no apparent link between power and noise level.

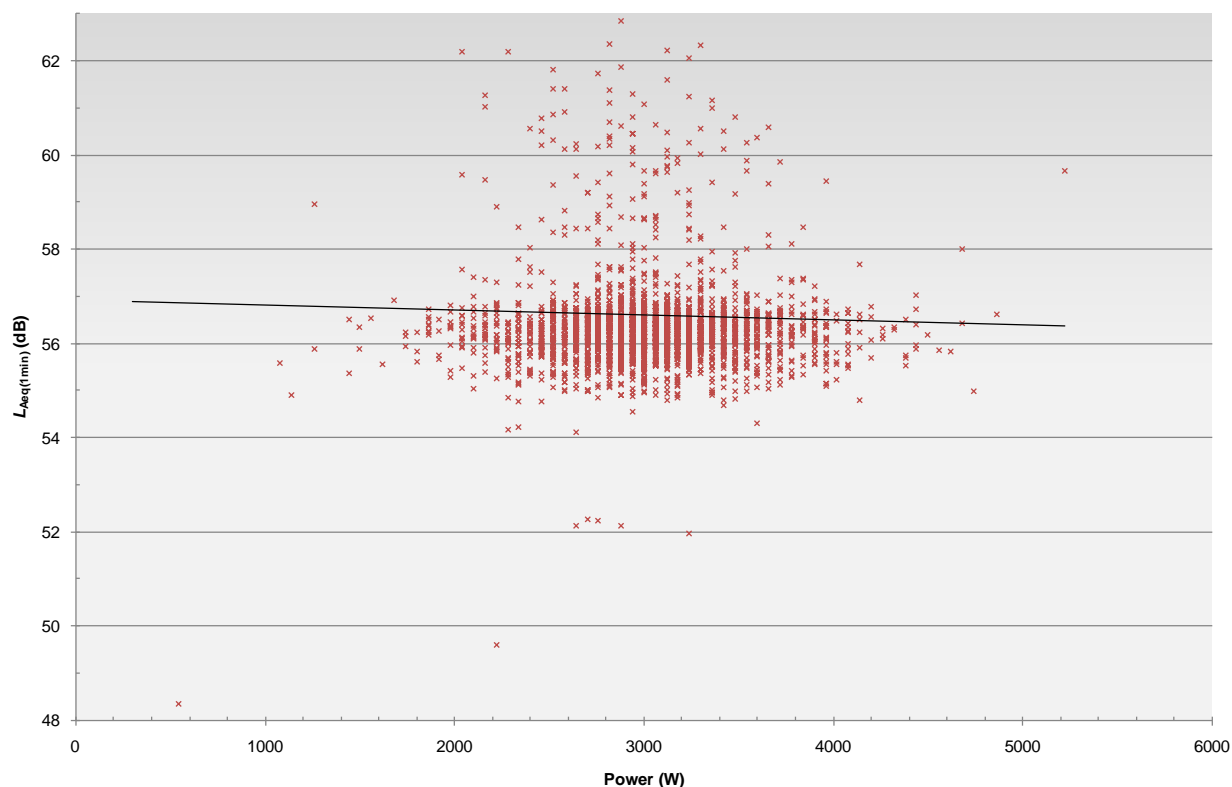


Figure 5-80. 479 Cotswold (Stables), SPL vs Power Consumption

5.10.12. Figure 5-74 presents a statistical analysis plot of the percentage of time that a specific noise level would be recorded, when the ASHP is under operation. From this confidence intervals can be presented for the typical noise levels.

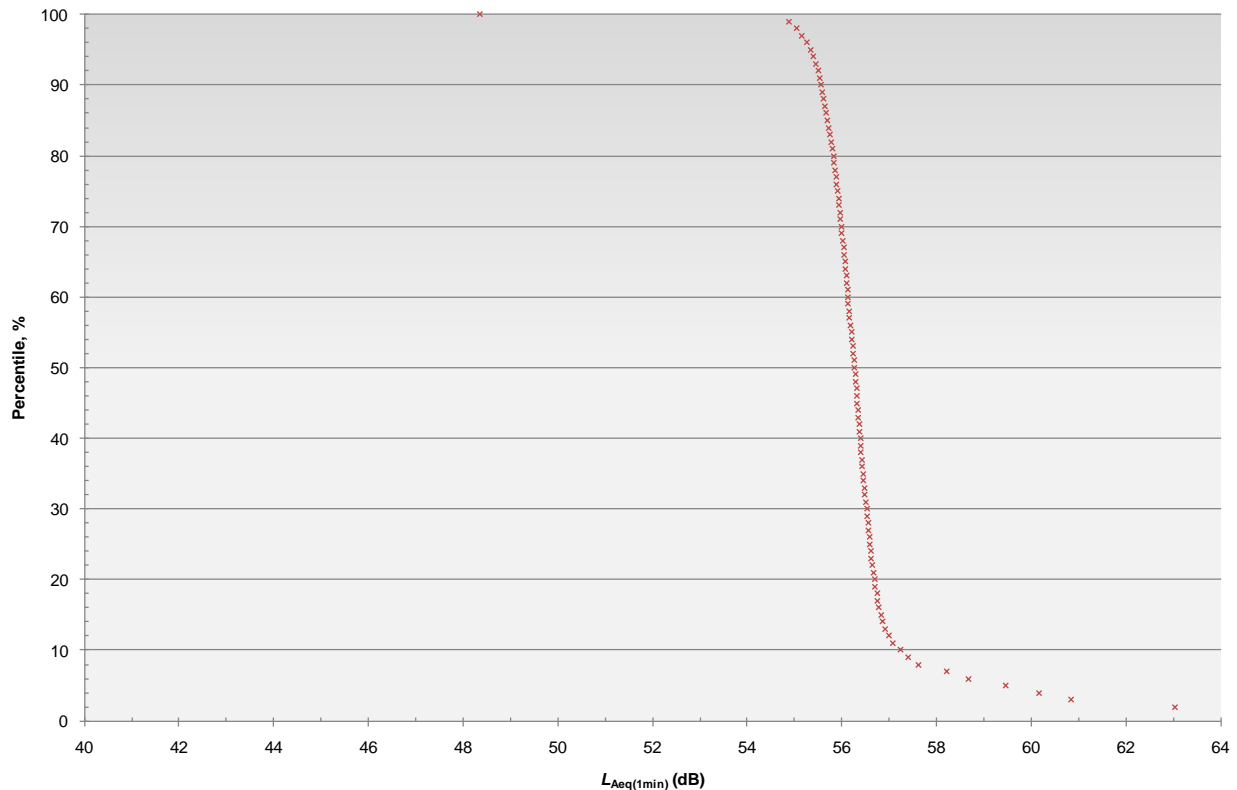


Figure 5-81. 479 Cotswold (Stables), SPL Statistical Analysis

5.10.13. The chart indicates that noise from the ASHP during operation will have a 90% certainty of being within around 3 dB of $L_{Aeq(1min)}$ **56 dB**. The corresponding total ASHP noise dose over the whole assessment period is calculated as $L_{Aeq(1week)}$ 54 dB.

Defrost Cycle

5.10.14. Analysis of the measurements failed to identify defrost cycles with any certainty. Whilst certain short periods of operation were revealed within the measurement data, the analysis has shown the noise to be very similar to that of a 'normal' operating condition. It is therefore likely that either no defrost cycles occurred during the measurements or that the sound characteristic during the defrost cycle is similar to that during normal operation.

Directivity

5.10.15. Table 5-10 shows the directivity in noise emissions from the unit by comparing the noise levels at the different microphones, for a typical period of ASHP operation.

| Table 5-10: Directivity Analysis of the ASHP Noise Emissions $L_{Aeq(1min)}$ dB 479 Cotswold (Stables), normal operation | | | | |
|--|--------------|-------------|--------------|--------------|
| Microphone Location | Front | Left | Right | Above |
| Typical Microphone Level | 51 | 54 | 52 | 56 |
| Change from front microphone | -5 | -2 | -4 | - |

5.10.16. It is seen that the ASHP exhibits some directivity, such that noise is greatest in line with the fan.

Frequency analysis

5.10.17. For the frequency analysis, a Fast Fourier Transform (FFT) of the signal was performed, averaged over a representative one minute period at a frequency resolution of 2 Hz. The resulting frequency spectrum for the ASHP operating under normal conditions is given in Figure 5-82.

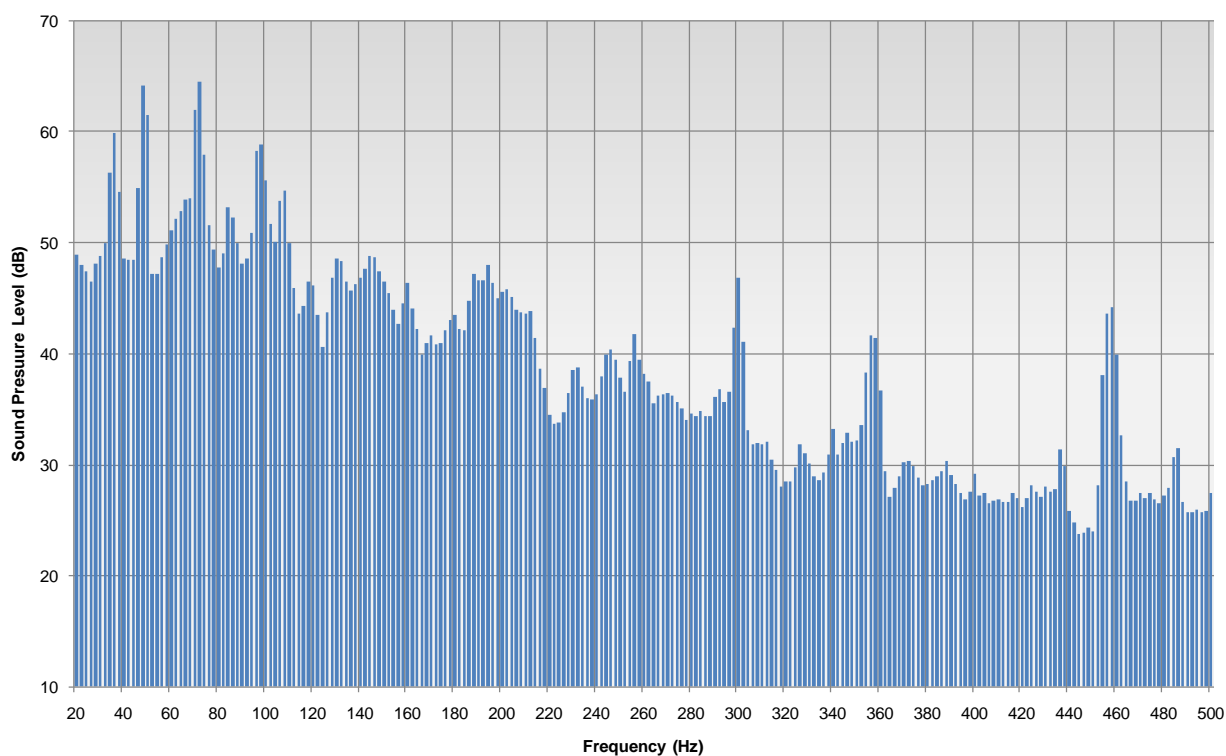
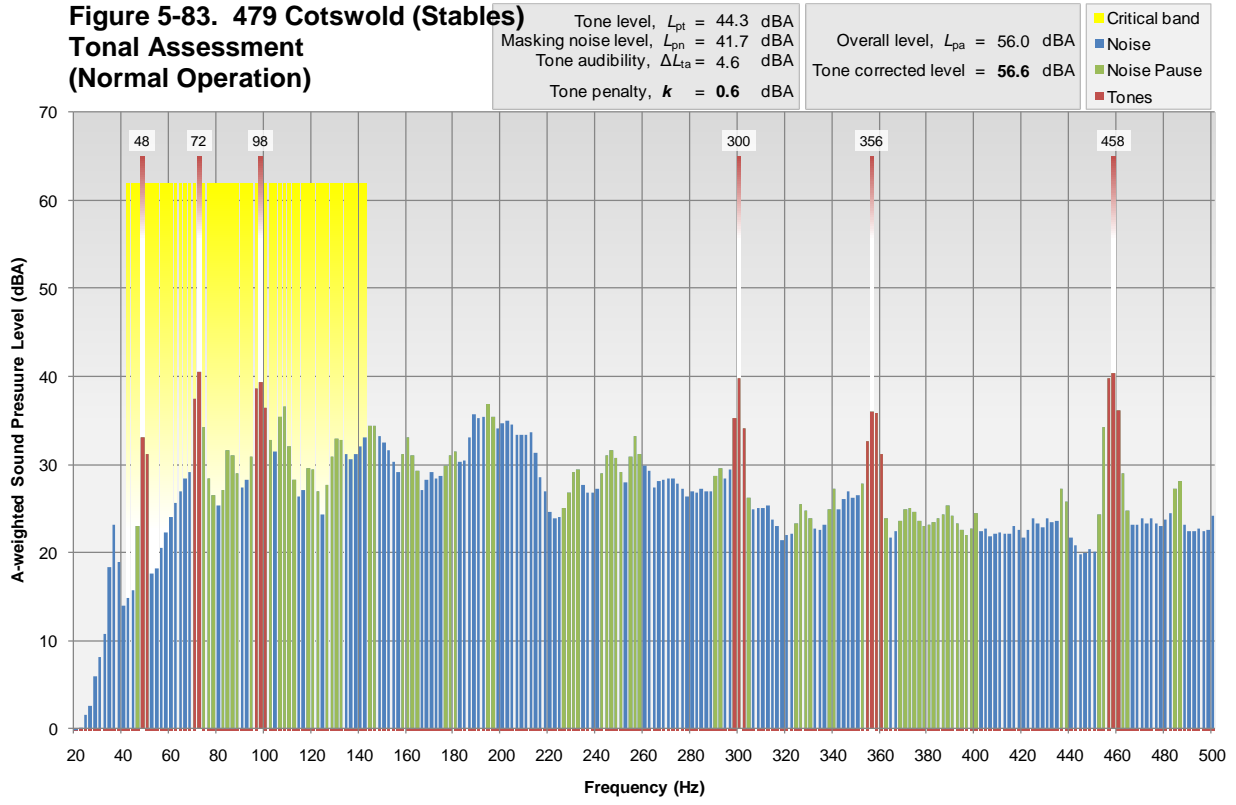


Figure 5-82. 479 Cotswold (Stables), Sound Pressure Level Frequency Spectrum (Normal Operation)

5.10.18. Tonal analysis of the frequency spectrum shown in Figure 5-82 has been undertaken in accordance with the Joint Nordic Method (v2). The resulting tonal assessment is presented in Figure 5-82, showing that the tones identified within the spectrum would lead to a **1 dB tonal penalty** for normal operation.

**Figure 5-83. 479 Cotswold (Stables)
Tonal Assessment
(Normal Operation)**



Sound Power Level calculations

5.10.19. Figure 5-84 presents a statistical analysis plot of the percentage of time that a specific sound power level would be recorded, when the ASHP is under operation.

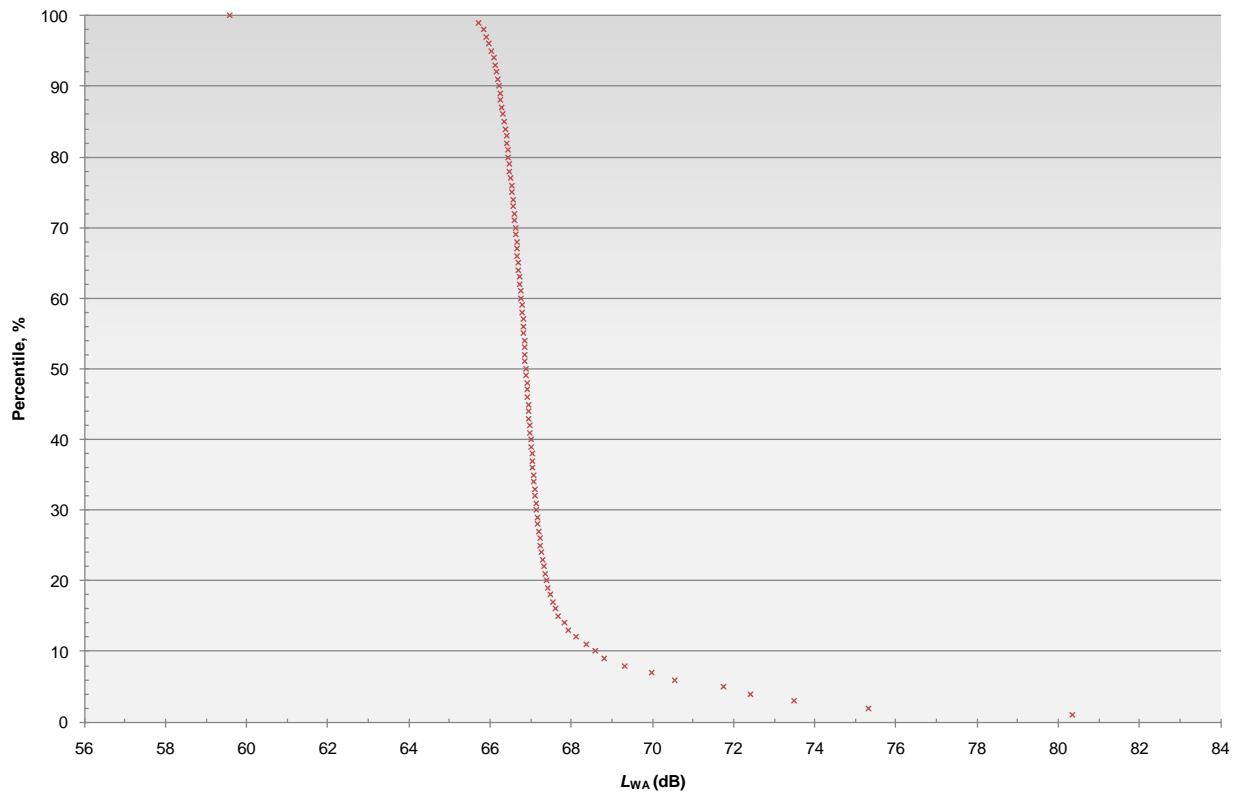


Figure 5-84. 479 Cotswold (Stables), Sound Power Level Statistical Analysis

5.10.20. The chart indicates that noise from the ASHP during operation will have a 90% certainty of being within around 2 dB of L_{WA} 67 dB.

5.10.21. Use of Equation 1 leads to an estimation that noise levels from the unit operating normally would drop to L_{Aeq} 42 dB at a distance separation of approximately **10 m**. If the tonal correction were to be applied, this distance would rise to **11 m**. This assumes that the ASHP is located in the common mounting scenario as detailed in Section 3.42, which is not necessarily representative of the actual measured condition.

Vibration

5.10.22. An FFT analysis of the vibration levels recorded for normal operation of the ASHP is shown in Figure 5-85. Only a small amount of vibration from the ASHP was measureable on the footings.

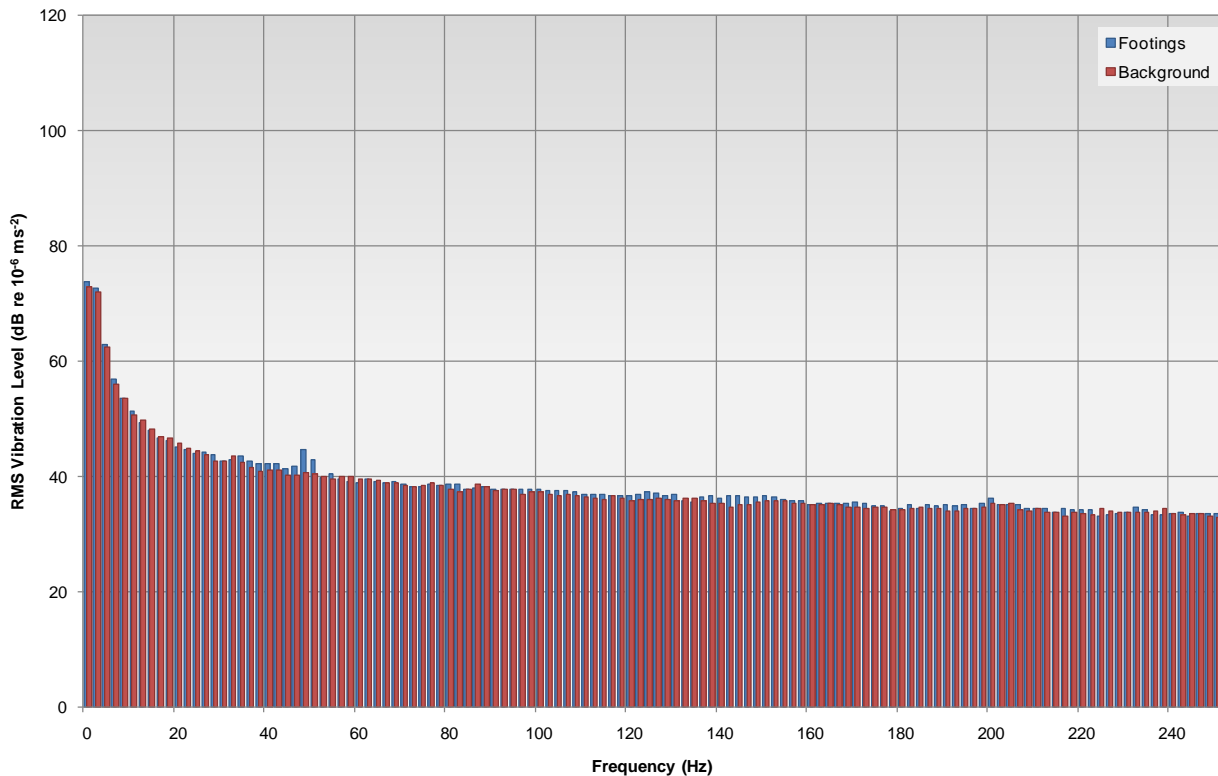


Figure 5-85. 479 Cotswold (Stables), Vibration Levels

Discussion

5.10.23. The manufacturer has not provided details of the fan speed rating. The compressor speed is 2900 rpm, which corresponds with a rotation frequency of around 48 Hz. Tones related to this frequency are seen in both the vibration spectrum, and the sound spectra.

5.10.24. It is likely that the tones observed at 36 and 72 Hz are due to the fan. Assuming that there are four fan blades, as is common for ASHP units, this corresponds to a rotation frequency of 540 rpm.

5.10.25. From analysis of the spectra, it is likely that the fan and compressor provide similar levels of noise and tonal content for this ASHP.

6.0 Suggestions and Conclusions

- 6.1 The report has found that site installations of the ASHPs are generally in line with predictions derived from manufacturers sound power data. However the manufacturer data does not identify if the ASHP produces significant acoustic tones.
- 6.2 A number of the ASHPs surveyed were identified as having significant acoustic tones, particularly during the defrost cycle. The tonal content was found to be typically in the low frequency region. This tonal content can adversely affect the subjective acceptability of the ASHP noise signature.
- 6.3 No correlation between an ASHP's noise output and ambient temperature or power consumption was identified.
- 6.4 The ASHP installations surveyed did not appear to give rise to significant levels of vibration in surrounding structures.
- 6.5 Manufacturers should be encouraged to present a uniformed set of noise data for their ASHPs in a similar manner to the Micro Wind Turbine Noise Labels. This should ideally include sound power levels, sound pressure levels at a range of distances in addition to a tonal penalty figure calculated in accordance with JMN2 or ISO 1996-2.
- 6.6 It is clear from the investigations of a GSHP that there is potential to improve the acoustic insulation of ASHPs. The designers of ASHPs should be encouraged to compartmentalise the compressor and internal workings of the system as much as possible such that an acoustic box is formed which prevents the compressor noise radiating out of the open fan enclosure.

- 6.7 A well designed acoustic enclosure would typically have a casing mass of at least 10 kg/m^2 . All pipe and electrical penetrations should be well sealed with rubber glands and incorporate flexible joints where possible. The enclosure design should include acoustic absorption material.
- 6.8 Whilst acoustic compressor jackets are available on the market, they would not be expected to provide the same level of attenuation as a well designed and constructed acoustic enclosure.
- 6.9 The ASHP which used a centrifugal fan type appeared to be a noisier arrangement than the ASHPs with axial fan types.
- 6.10 Whilst no amplitude modulation effects were identified within the measured data, ASHP designers should take care that the fan blade passing frequency does not coincide closely with the compressor rotation speed, which could otherwise cause wave interference resulting in a pulsing effect.
- 6.11 The study has shown that vibration effects are not likely to be perceptible with most current ASHP designs. We would recommend that anti-vibration mounts continue to be fitted to the framework for wall-mounted ASHPs, where the wall is common to noise sensitive occupants. Any anti-vibration mounts should have a natural frequency of less than half of the ASHP fan rotational frequency.
- 6.12 As part of further research it is suggested to carry out further dose response investigations in order to ascertain the subjective acceptability of air source heat pumps in a domestic environment. Such a study would ideally utilise auralisation trials. This would serve to further inform on the suitability of any suggested ASHP noise criteria.

Appendix A. Measurement Equipment

For the acoustic measurements the following items of equipment were used.

| Equipment | Serial No. |
|--|-------------------|
| Brüel & Kjær Type 7537-A PULSE Controller Module | 2465210 |
| Brüel & Kjær Type 3109 PULSE Input/Output Module | 2420577 |
| Brüel & Kjær Type 7540-A PULSE Controller Module | 2498403 |
| Brüel & Kjær Type 4189 1/2" Prepolarized Free-field Microphone | 2505074 |
| Brüel & Kjær Type 4189 1/2" Prepolarized Free-field Microphone | 2505071 |
| Brüel & Kjær Type 4189 1/2" Prepolarized Free-field Microphone | 2471991 |
| Brüel & Kjær Type 4189 1/2" Prepolarized Free-field Microphone | 2505072 |
| Brüel & Kjær Type 4189 1/2" Prepolarized Free-field Microphone | 2496778 |
| Brüel & Kjær Type 4189 1/2" Prepolarized Free-field Microphone | 2496775 |
| Brüel & Kjær Type 4189 1/2" Prepolarized Free-field Microphone | 2505073 |
| Brüel & Kjær Type 4189 1/2" Prepolarized Free-field Microphone | 2471990 |
| Brüel & Kjær UA-1404 Outdoor Microphone Kits | |
| Brüel & Kjær Type 4508-B Miniature DeltaTron Accelerometer | 10230 |
| Brüel & Kjær Type 4508-B Miniature DeltaTron Accelerometer | 10022 |
| Brüel & Kjær Type 4508-B Miniature DeltaTron Accelerometer | 10233 |
| Brüel & Kjær Type 4231 Sound Calibrator | 1780570 |
| Brüel & Kjær Type 4294 Vibration Calibrator | 2532254 |
| Davis Vantage Vue Weather Station | D101109B038 |
| Davis Vantage Pro Weather Station | B40527A01A |

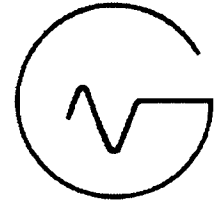
Appendix B. Calibration Certificates

Appendix C. Measurement Data

Raw PULSE format data is held on external hard disks supplied to DECC.

CERTIFICATE OF CALIBRATION

ISSUED BY Gracey & Associates BSI CERTIFICATE FS 25913
DATE OF ISSUE 27 January 2011 CERTIFICATE NUMBER 2011-0144
DATE OF CALIBRATION 27 January 2011
CALIBRATION INTERVAL 12 months PAGE 1 OF 2



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www.gracey.com

TEST ENGINEER APPROVING SIGNATORY
Jamie Bishop Greg Rice

J.B.

G.R.

Manufacturer Bruel & Kjaer UK Limited
Model B&K 4189
Serial Number 2502958
Description Microphone - 1/2" free-field - 0
VDC

Customer
Napier University
Craiglockart Campus, Colinton Road, Edinburgh, Scotland,
EH14 1DJ

Standards
BS EN 61672 Class 1

Conditions
Atmospheric Pressure 101.6 kPa
Temperature 22.5 °C
Relative Humidity 33.6 %

Calibration Data

Sensitivity -26.50 dB

Laboratory Equipment Used

| Equipment | S/N | Last Cal | Equipment | S/N | Last Cal |
|---------------|------------|-----------|----------------|-------|-----------|
| HP 34401 | 3146A16728 | 13-Jul-10 | Druck DPI 141 | 479 | 22-Jul-09 |
| B&K 4134 | 1935995 | 06-May-10 | Stanford DS360 | 33213 | 15-Jul-09 |
| Norsonic 1253 | 22456 | 19-May-10 | | | |

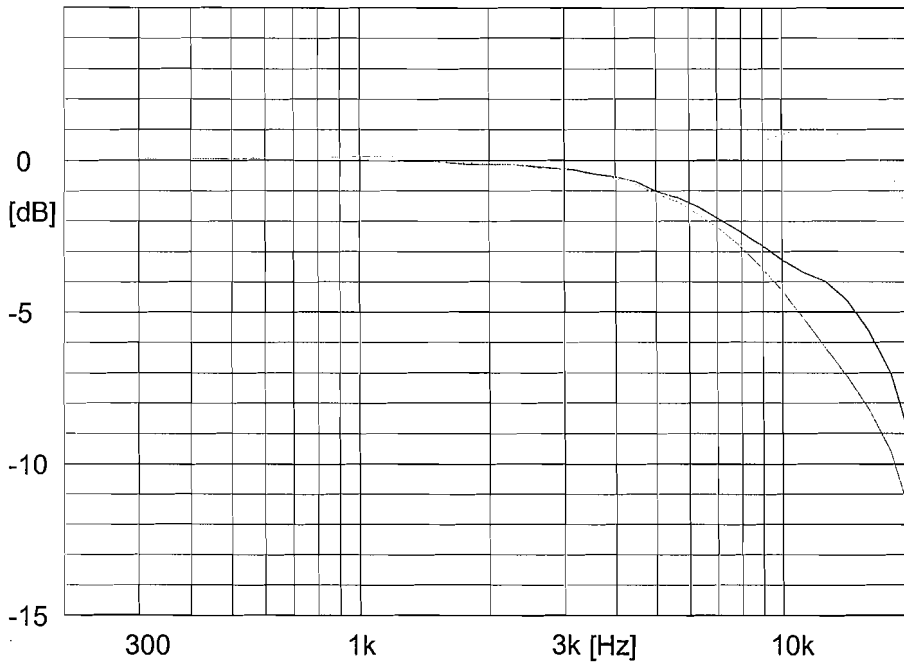
Notes

We certify that the above product was duly tested and found to be within the specification at the points measured (except where indicated). Measurements are traceable to UKAS reference sources from the UK National Physical Laboratory. Where no national or international standards exist, traceability is to standards maintained by the manufacturer. Our Quality Management System has been assessed to comply with BS EN ISO 9001:2008 - BSI Certificate number FS 25913. Tests were carried out in environmental conditions controlled to the extent appropriate to the instrument's specification. All relevant test certificates are available for inspection.

The uncertainties are for a confidence probability of not less than 95%.

This certificate is issued in accordance with the conditions of accreditation granted by the British Standards Institution which has assessed the measurement capability of the laboratory and its traceability to recognised national standards and to the units of measurement realised at the corresponding national standards laboratory. Copyright of this certificate is owned by Gracey & Associates and may not be reproduced other than in full except with their prior written approval.

Microphone Calibration Certificate



Bruel and Kjaer
Type : 4189

Serial no : 2502958

Sensitivity : 47.5 mV/Pa
-26.5 dB re. 1 V/Pa

Date : 27/01/2011

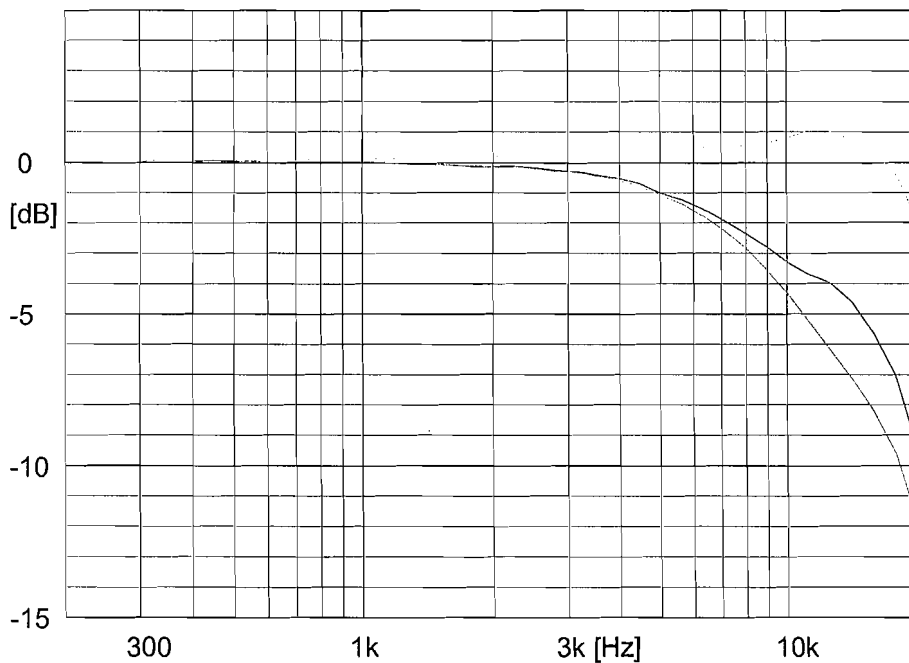
Signature :

Measurement conditions :
Polarisation voltage : 0.0 V
Pressure : 101.60 kPa
Temperature : 22.5 °C
Relative humidity : 33.6 %RH
Results are normalised to the reference conditions.

Free field response
Diffuse field response
Pressure (Actuator) response

Gracey & Associates
www.gracey.com

Microphone Calibration Certificate



Bruel and Kjaer
Type : 4189

Serial no : 2502958

Sensitivity : 47.5 mV/Pa
-26.5 dB re. 1 V/Pa

Date : 27/01/2011

Signature :

Measurement conditions :
Polarisation voltage : 0.0 V
Pressure : 101.60 kPa
Temperature : 22.5 °C
Relative humidity : 33.6 %RH
Results are normalised to the reference conditions.

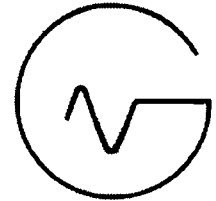
Free field response
Diffuse field response
Pressure (Actuator) response

Gracey & Associates
www.gracey.com

Comment :

CERTIFICATE OF CALIBRATION

ISSUED BY Gracey & Associates BSI CERTIFICATE FS 25913
DATE OF ISSUE 27 January 2011 CERTIFICATE NUMBER 2011-0145
DATE OF CALIBRATION 27 January 2011
CALIBRATION INTERVAL 12 months PAGE 1 OF 2



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Fax: 01933 624608
www.gracey.com

TEST ENGINEER APPROVING SIGNATORY
Jamie Bishop Greg Rice

Manufacturer Bruel & Kjaer UK Limited
Model B&K 4189
Serial Number 2502957
Description Microphone - 1/2" free-field - 0
VDC

Customer
Napier University
Craiglockart Campus, Colinton Road, Edinburgh, Scotland,
EH14 1DJ

Standards
BS EN 61672 Class 1

Conditions
Atmospheric Pressure 101.6 kPa
Temperature 22.2 °C
Relative Humidity 35.2 %

Calibration Data

Sensitivity -25.60 dB

Laboratory Equipment Used

| Equipment | S/N | Last Cal | Equipment | S/N | Last Cal |
|---------------|------------|-----------|----------------|-------|-----------|
| HP 34401 | 3146A16728 | 13-Jul-10 | Druck DPI 141 | 479 | 22-Jul-09 |
| B&K 4134 | 1935995 | 06-May-10 | Stanford DS360 | 33213 | 15-Jul-09 |
| Norsonic 1253 | 22456 | 19-May-10 | | | |

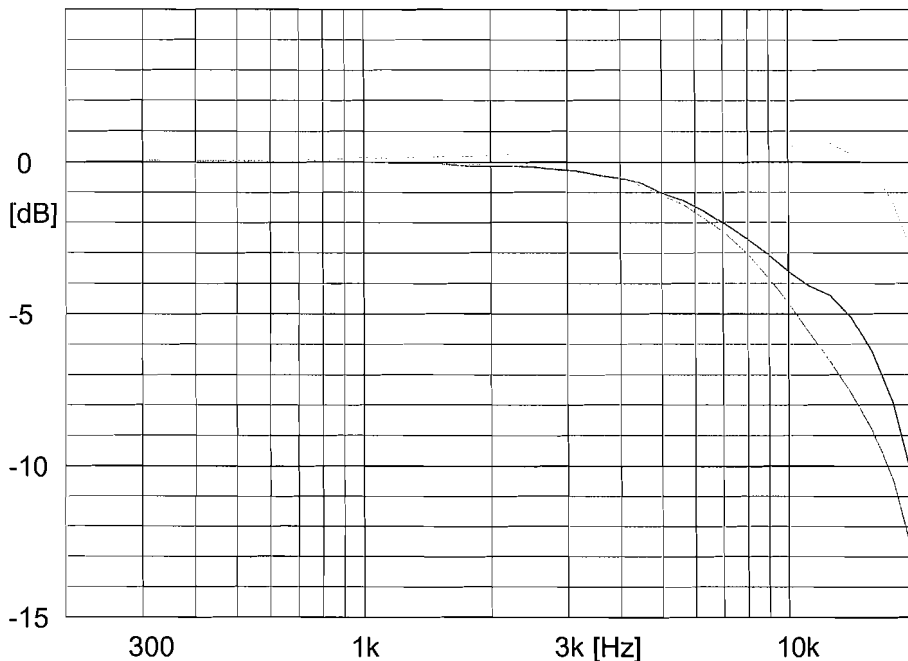
Notes

We certify that the above product was duly tested and found to be within the specification at the points measured (except where indicated). Measurements are traceable to UKAS reference sources from the UK National Physical Laboratory. Where no national or international standards exist, traceability is to standards maintained by the manufacturer. Our Quality Management System has been assessed to comply with BS EN ISO 9001:2008 - BSI Certificate number FS 25913. Tests were carried out in environmental conditions controlled to the extent appropriate to the instrument's specification. All relevant test certificates are available for inspection.

The uncertainties are for a confidence probability of not less than 95%.

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Microphone Calibration Certificate



Bruel and Kjaer
Type : 4189

Serial no : 2502957

Sensitivity : 52.8 mV/Pa
-25.6 dB re. 1 V/Pa

Date : 27/01/2011

Signature :

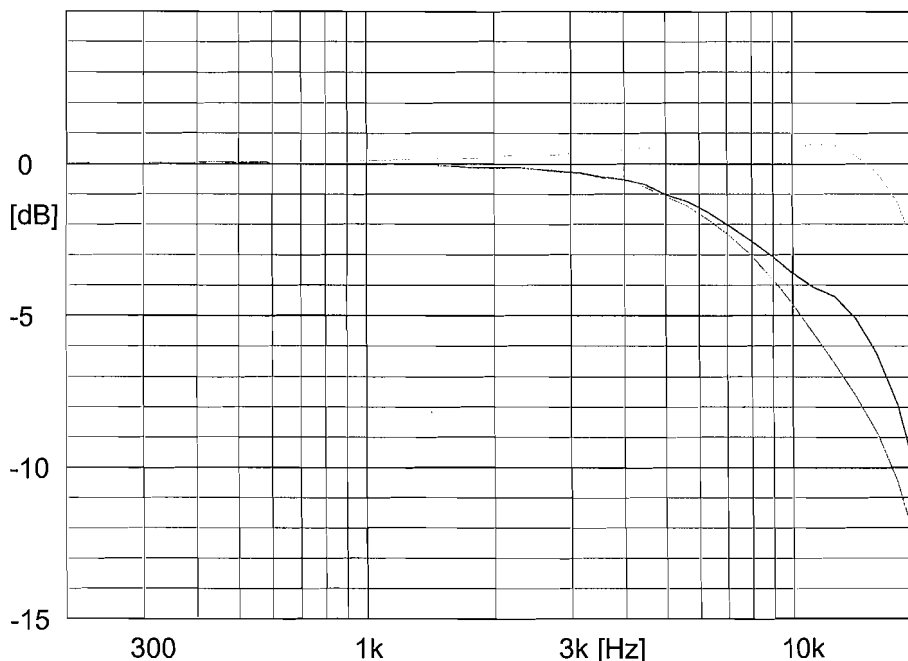
Measurement conditions :

Polarisation voltage : 0.0 V
Pressure : 101.57 kPa
Temperature : 22.2 °C
Relative humidity : 35.2 %RH
Results are normalised to the reference conditions.

Free field response
Diffuse field response
Pressure (Actuator) response

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Microphone Calibration Certificate



Bruel and Kjaer
Type : 4189

Serial no : 2502957

Sensitivity : 52.8 mV/Pa
-25.6 dB re. 1 V/Pa

Date : 27/01/2011

Signature :

Measurement conditions :

Polarisation voltage : 0.0 V
Pressure : 101.57 kPa
Temperature : 22.2 °C
Relative humidity : 35.2 %RH
Results are normalised to the reference conditions.

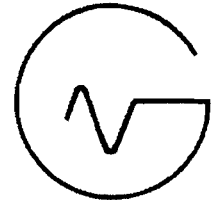
Free field response
Diffuse field response
Pressure (Actuator) response

Gracey & Associates
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Comment :

CERTIFICATE OF CALIBRATION

ISSUED BY Gracey & Associates BSI CERTIFICATE FS 25913
DATE OF ISSUE 27 January 2011 CERTIFICATE NUMBER 2011-0143
DATE OF CALIBRATION 27 January 2011
CALIBRATION INTERVAL 12 months PAGE 1 OF 2



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TEST ENGINEER APPROVING SIGNATORY
Jamie Bishop Greg Rice

Manufacturer Bruel & Kjaer UK Limited Customer
Model B&K 4189 Napier University
Serial Number 2502956 Craiglockart Campus, Colinton Road, Edinburgh, Scotland,
Description Microphone - 1/2" free-field - 0 EH14 1DJ
VDC

Standards Conditions
BS EN 61672 Class 1 Atmospheric Pressure 101.6 kPa
Temperature 21.9 °C
Relative Humidity 34.4 %

Calibration Data
Sensitivity -25.80 dB

Laboratory Equipment Used

| Equipment | S/N | Last Cal | Equipment | S/N | Last Cal |
|---------------|------------|-----------|----------------|-------|-----------|
| HP 34401 | 3146A16728 | 13-Jul-10 | Druck DPI 141 | 479 | 22-Jul-09 |
| B&K 4134 | 1935995 | 06-May-10 | Stanford DS360 | 33213 | 15-Jul-09 |
| Norsonic 1253 | 22456 | 19-May-10 | | | |

Notes

We certify that the above product was duly tested and found to be within the specification at the points measured (except where indicated). Measurements are traceable to UKAS reference sources from the UK National Physical Laboratory. Where no national or international standards exist, traceability is to standards maintained by the manufacturer. Our Quality Management System has been assessed to comply with BS EN ISO 9001:2008 - BSI Certificate number FS 25913. Tests were carried out in environmental conditions controlled to the extent appropriate to the instrument's specification. All relevant test certificates are available for inspection.

The uncertainties are for a confidence probability of not less than 95%.

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Microphone Calibration Certificate

Bruel and Kjaer
Type : 4189

Serial no : 2502956

Sensitivity : 51.5 mV/Pa
-25.8 dB re. 1 V/Pa

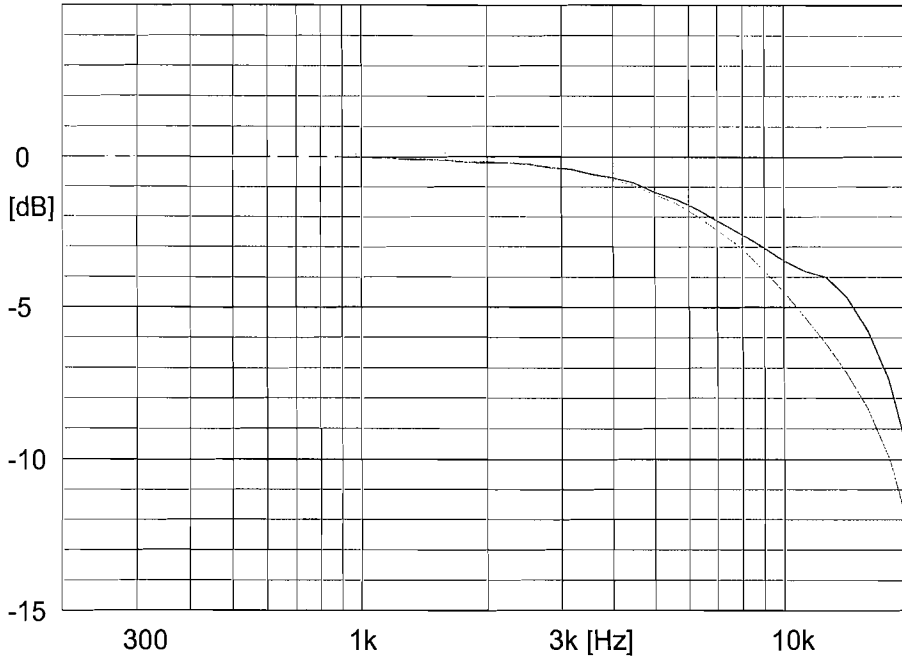
Date : 27/01/2011

Signature : 

Measurement conditions :
Polarisation voltage : 0.0 V
Pressure : 101.61 kPa
Temperature : 21.9 °C
Relative humidity : 34.4 %RH
Results are normalised to the reference conditions.

Free field response
Diffuse field response
Pressure (Actuator) response

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Microphone Calibration Certificate

Bruel and Kjaer
Type : 4189

Serial no : 2502956

Sensitivity : 51.5 mV/Pa
-25.8 dB re. 1 V/Pa

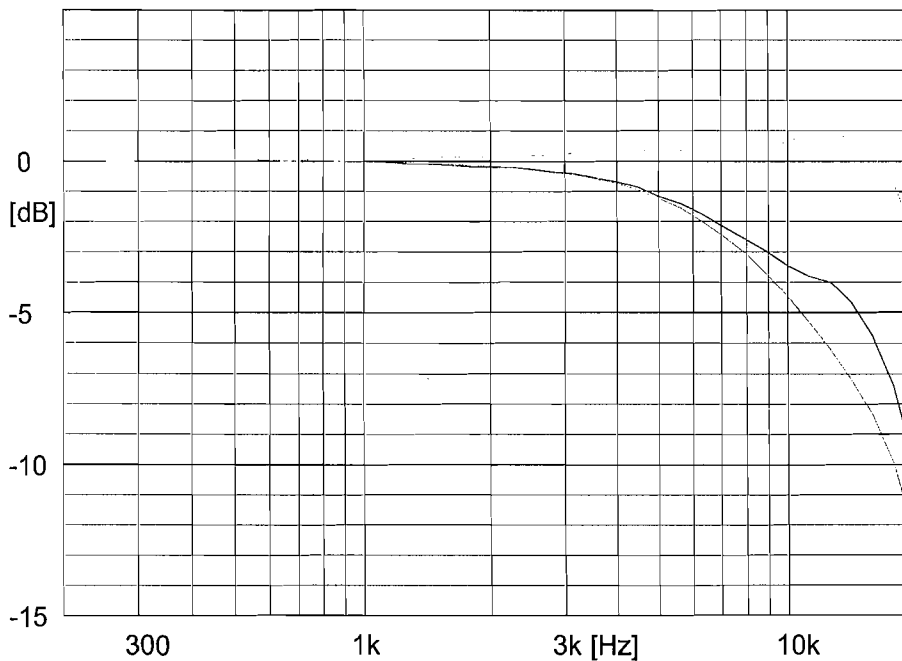
Date : 27/01/2011

Signature :

Measurement conditions :
Polarisation voltage : 0.0 V
Pressure : 101.61 kPa
Temperature : 21.9 °C
Relative humidity : 34.4 %RH
Results are normalised to the reference conditions.

Free field response
Diffuse field response
Pressure (Actuator) response

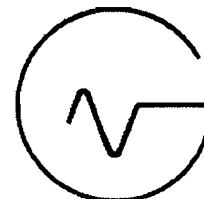
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Comment :

CERTIFICATE OF CALIBRATION

ISSUED BY Gracey & Associates BSI CERTIFICATE FS 25913
DATE OF ISSUE 27 January 2011 CERTIFICATE NUMBER 2011-0142
DATE OF CALIBRATION 27 January 2011
CALIBRATION INTERVAL 12 months PAGE 1 OF 2



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TEST ENGINEER APPROVING SIGNATORY

Jamie Bishop

Greg Rice

Manufacturer Bruel & Kjaer UK Limited
Model B&K 4189
Serial Number 2502955
Description Microphone - 1/2" free-field - 0
VDC

Customer
Napier University
Craiglockart Campus, Colinton Road, Edinburgh, Scotland,
EH14 1DJ

Standards
BS EN 61672 Class 1

Conditions
Atmospheric Pressure 101.6 kPa
Temperature 21.5 °C
Relative Humidity 35.8 %

Calibration Data

Sensitivity -26.40 dB

Laboratory Equipment Used

| Equipment | S/N | Last Cal | Equipment | S/N | Last Cal |
|---------------|------------|-----------|----------------|-------|-----------|
| HP 34401 | 3146A16728 | 13-Jul-10 | Druck DPI 141 | 479 | 22-Jul-09 |
| B&K 4134 | 1935995 | 06-May-10 | Stanford DS360 | 33213 | 15-Jul-09 |
| Norsonic 1253 | 22456 | 19-May-10 | | | |

Notes

We certify that the above product was duly tested and found to be within the specification at the points measured (except where indicated). Measurements are traceable to UKAS reference sources from the UK National Physical Laboratory. Where no national or international standards exist, traceability is to standards maintained by the manufacturer. Our Quality Management System has been assessed to comply with BS EN ISO 9001:2008 - BSI Certificate number FS 25913. Tests were carried out in environmental conditions controlled to the extent appropriate to the instrument's specification. All relevant test certificates are available for inspection.

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Microphone Calibration Certificate

Bruel and Kjaer
Type : 4189

Serial no : 2502955

Sensitivity : 47.6 mV/Pa
-26.4 dB re. 1 V/Pa

Date : 27/01/2011

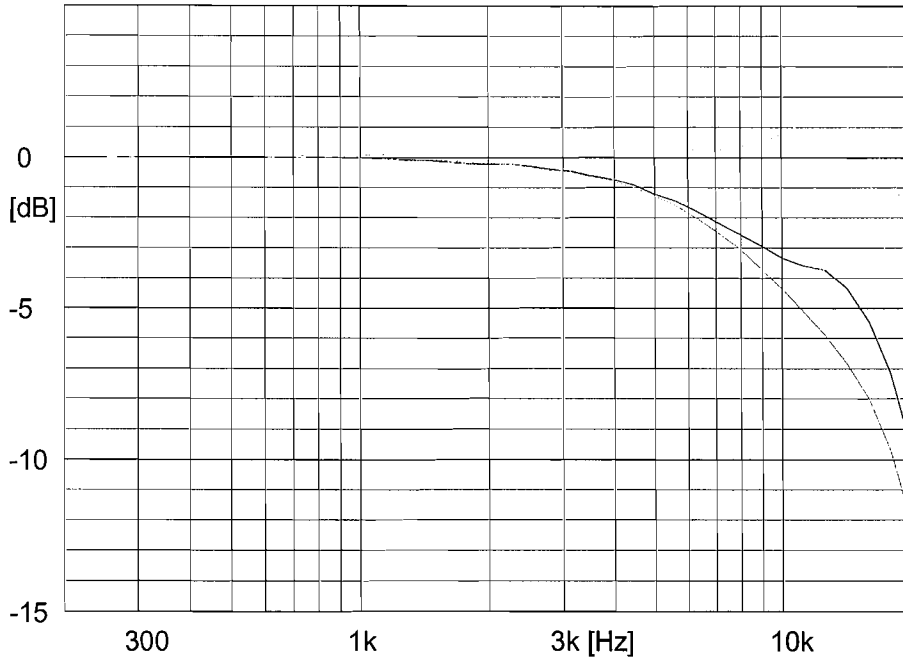
Signature : 

Measurement conditions :

Polarisation voltage : 0.0 V
Pressure : 101.60 kPa
Temperature : 21.5 °C
Relative humidity : 35.8 %RH
Results are normalised to the reference conditions.

Free field response
Diffuse field response
Pressure (Actuator) response

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Microphone Calibration Certificate

Bruel and Kjaer
Type : 4189

Serial no : 2502955

Sensitivity : 47.6 mV/Pa
-26.4 dB re. 1 V/Pa

Date : 27/01/2011

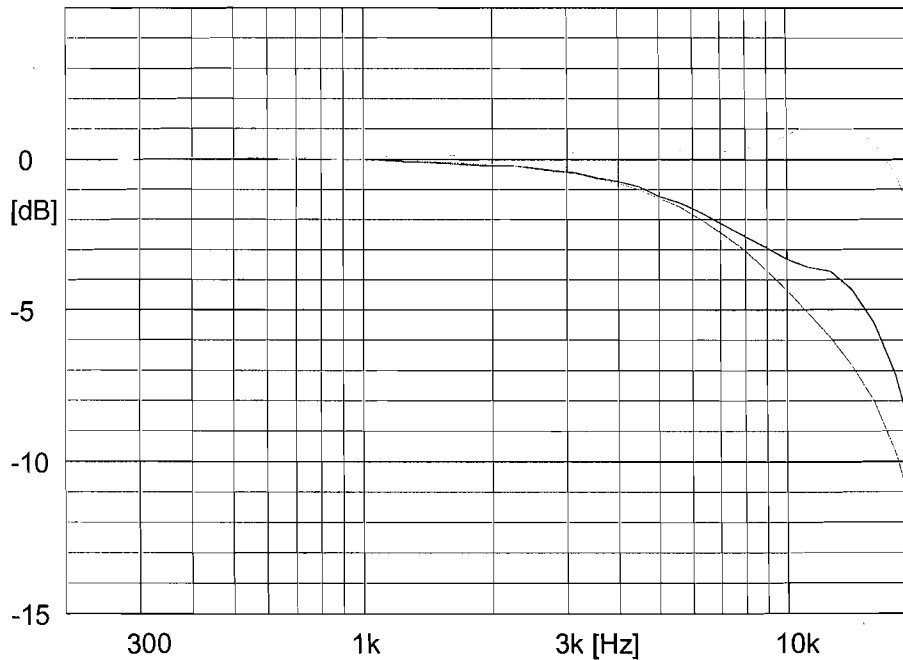
Signature :

Measurement conditions :

Polarisation voltage : 0.0 V
Pressure : 101.60 kPa
Temperature : 21.5 °C
Relative humidity : 35.8 %RH
Results are normalised to the reference conditions.

Free field response
Diffuse field response
Pressure (Actuator) response

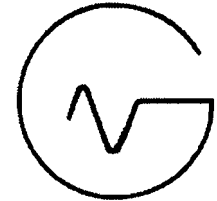
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Comment :

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DATE OF ISSUE 27 January 2011 CERTIFICATE NUMBER 2011-0147
DATE OF CALIBRATION 27 January 2011
CALIBRATION INTERVAL 12 months PAGE 1 OF 2



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TEST ENGINEER

Jamie Bishop

APPROVING SIGNATORY

Greg Rice

Manufacturer Bruel & Kjaer UK Limited
Model B&K 4189
Serial Number 2471102
Description Microphone - 1/2" free-field - 0
VDC

Customer
Napier University
Craiglockart Campus, Colinton Road, Edinburgh, Scotland,
EH14 1DJ

Standards

BS EN 61672 Class 1

Conditions

Atmospheric Pressure 101.6 kPa
Temperature 21.3 °C
Relative Humidity 35.4 %

Calibration Data

Sensitivity -26.00 dB

Laboratory Equipment Used

| Equipment | S/N | Last Cal | Equipment | S/N | Last Cal |
|---------------|------------|-----------|----------------|-------|-----------|
| HP 34401 | 3146A16728 | 13-Jul-10 | Druck DPI 141 | 479 | 22-Jul-09 |
| B&K 4134 | 1935995 | 06-May-10 | Stanford DS360 | 33213 | 15-Jul-09 |
| Norsonic 1253 | 22456 | 19-May-10 | | | |

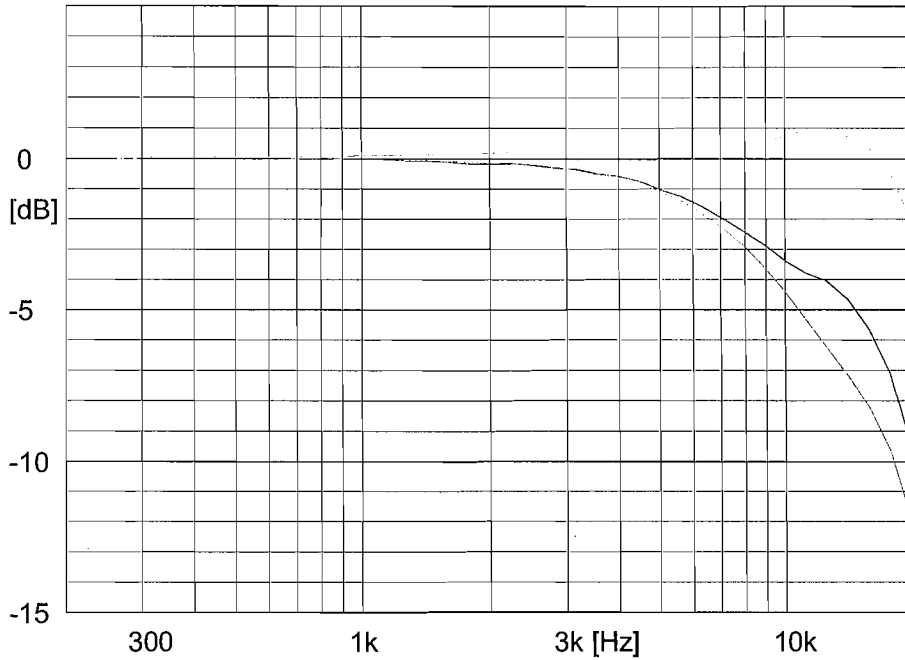
Notes

We certify that the above product was duly tested and found to be within the specification at the points measured (except where indicated). Measurements are traceable to UKAS reference sources from the UK National Physical Laboratory. Where no national or international standards exist, traceability is to standards maintained by the manufacturer. Our Quality Management System has been assessed to comply with BS EN ISO 9001:2008 - BSI Certificate number FS 25913. Tests were carried out in environmental conditions controlled to the extent appropriate to the instrument's specification. All relevant test certificates are available for inspection.

The uncertainties are for a confidence probability of not less than 95%.

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Microphone Calibration Certificate



Bruel and Kjaer
Type : 4189

Serial no : 2471102

Sensitivity : 50.1 mV/Pa
-26.0 dB re. 1 V/Pa

Date : 27/01/2011

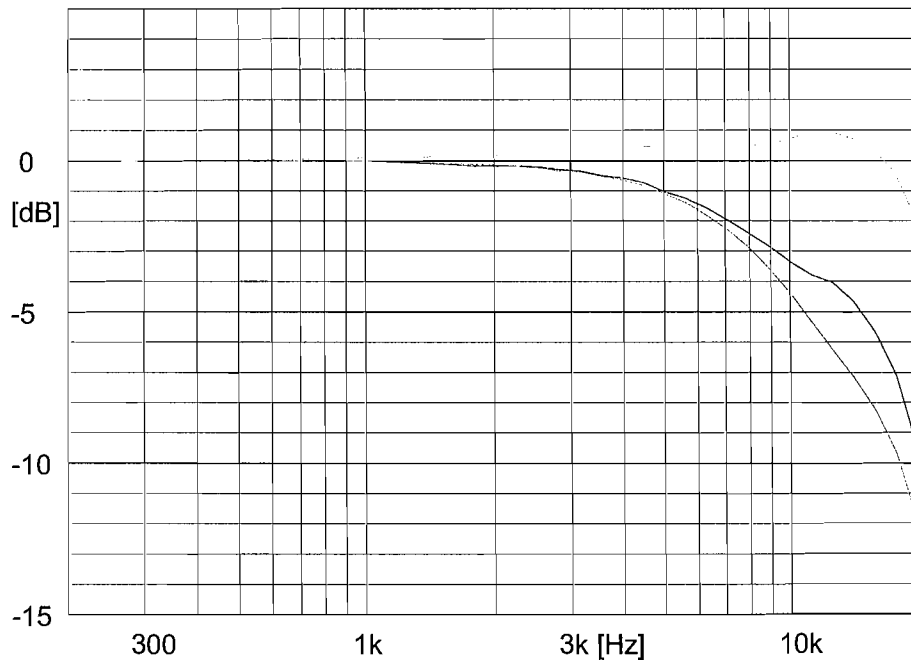
Signature :

Measurement conditions :
Polarisation voltage : 0.0 V
Pressure : 101.61 kPa
Temperature : 21.3 °C
Relative humidity : 35.4 %RH
Results are normalised to the reference conditions.

Free field response
Diffuse field response
Pressure (Actuator) response

Gracey & Associates
www.gracey.com

Microphone Calibration Certificate



Bruel and Kjaer
Type : 4189

Serial no : 2471102

Sensitivity : 50.1 mV/Pa
-26.0 dB re. 1 V/Pa

Date : 27/01/2011

Signature :

Measurement conditions :
Polarisation voltage : 0.0 V
Pressure : 101.61 kPa
Temperature : 21.3 °C
Relative humidity : 35.4 %RH
Results are normalised to the reference conditions.

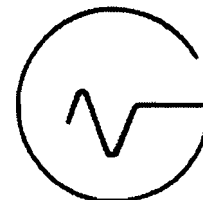
Free field response
Diffuse field response
Pressure (Actuator) response

Gracey & Associates
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Comment :

CERTIFICATE OF CALIBRATION

ISSUED BY Gracey & Associates BSI CERTIFICATE FS 25913
DATE OF ISSUE 27 January 2011 CERTIFICATE NUMBER 2011-0141
DATE OF CALIBRATION 27 January 2011
CALIBRATION INTERVAL 12 months PAGE 1 OF 2



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TEST ENGINEER

Jamie Bishop

APPROVING SIGNATORY

Greg Rice

Manufacturer Bruel & Kjaer UK Limited
Model B&K 4189
Serial Number 2471101
Description Microphone - 1/2" free-field - 0
VDC

Customer
Napier University
Craiglockart Campus, Colinton Road, Edinburgh, Scotland,
EH14 1DJ

Standards

BS EN 61672 Class 1

Conditions

Atmospheric Pressure 101.6 kPa
Temperature 22.3 °C
Relative Humidity 34.1 %

Calibration Data

Sensitivity -25.30 dB

Laboratory Equipment Used

| Equipment | S/N | Last Cal | Equipment | S/N | Last Cal |
|---------------|------------|-----------|----------------|-------|-----------|
| HP 34401 | 3146A16728 | 13-Jul-10 | Druck DPI 141 | 479 | 22-Jul-09 |
| B&K 4134 | 1935995 | 06-May-10 | Stanford DS360 | 33213 | 15-Jul-09 |
| Norsonic 1253 | 22456 | 19-May-10 | | | |

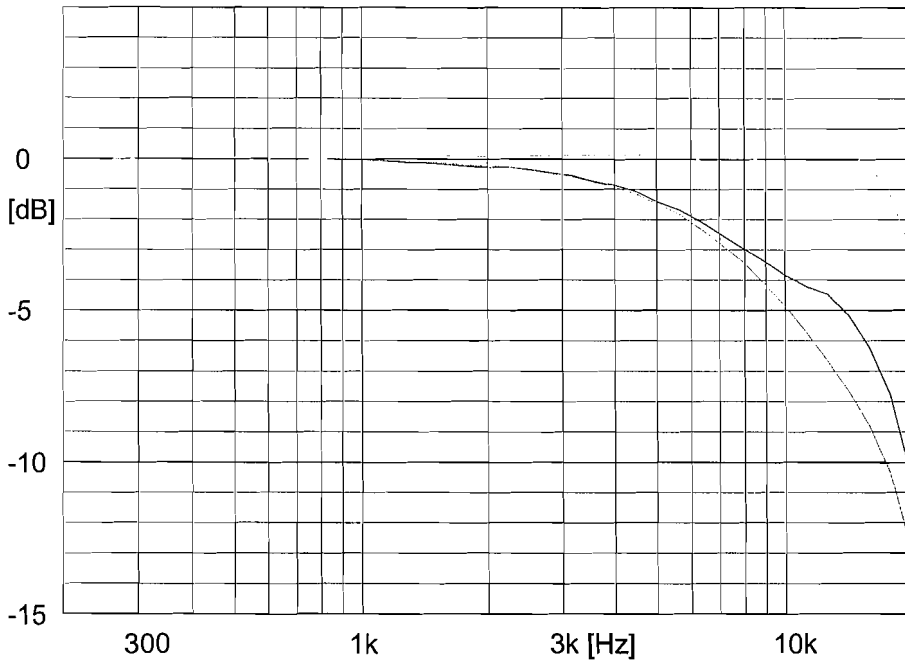
Notes

We certify that the above product was duly tested and found to be within the specification at the points measured (except where indicated). Measurements are traceable to UKAS reference sources from the UK National Physical Laboratory. Where no national or international standards exist, traceability is to standards maintained by the manufacturer. Our Quality Management System has been assessed to comply with BS EN ISO 9001:2008 - BSI Certificate number FS 25913. Tests were carried out in environmental conditions controlled to the extent appropriate to the instrument's specification. All relevant test certificates are available for inspection.

The uncertainties are for a confidence probability of not less than 95%.

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Microphone Calibration Certificate




Bruel and Kjaer
Type : 4189

Serial no : 2471101

Sensitivity : 54.0 mV/Pa
-25.3 dB re. 1 V/Pa

Date : 27/01/2011

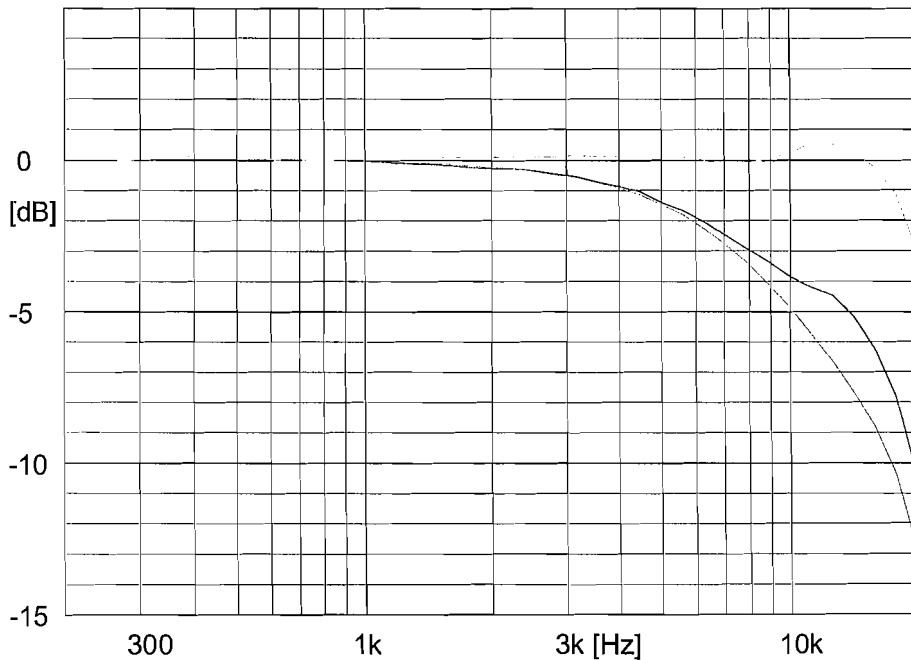
Signature : 

Measurement conditions :
Polarisation voltage : 0.0 V
Pressure : 101.60 kPa
Temperature : 22.3 °C
Relative humidity : 34.1 %RH
Results are normalised to the reference conditions.

Free field response
Diffuse field response
Pressure (Actuator) response

Gracey & Associates
www.gracey.com

Microphone Calibration Certificate



Bruel and Kjaer
Type : 4189

Serial no : 2471101

Sensitivity : 54.0 mV/Pa
-25.3 dB re. 1 V/Pa

Date : 27/01/2011

Signature :

Measurement conditions :
Polarisation voltage : 0.0 V
Pressure : 101.60 kPa
Temperature : 22.3 °C
Relative humidity : 34.1 %RH
Results are normalised to the reference conditions.

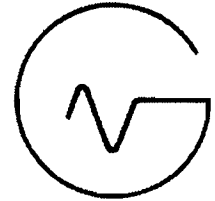
Free field response
Diffuse field response
Pressure (Actuator) response

Gracey & Associates
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Comment :

CERTIFICATE OF CALIBRATION

ISSUED BY Gracey & Associates BSI CERTIFICATE FS 25913
DATE OF ISSUE 27 January 2011 CERTIFICATE NUMBER 2011-0139
DATE OF CALIBRATION 27 January 2011
CALIBRATION INTERVAL 12 months PAGE 1 OF 2



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TEST ENGINEER

Jamie Bishop

APPROVING SIGNATORY

Greg Rice

Manufacturer Bruel & Kjaer UK Limited
Model B&K 4189
Serial Number 2470245
Description Microphone - 1/2" free-field - 0
VDC

Customer
Napier University
Craiglockart Campus, Colinton Road, Edinburgh, Scotland,
EH14 1DJ

Standards

BS EN 61672 Class 1

Conditions

Atmospheric Pressure 101.6 kPa
Temperature 22.6 °C
Relative Humidity 34.3 %

Calibration Data

Sensitivity -26.70 dB

Laboratory Equipment Used

| Equipment | S/N | Last Cal | Equipment | S/N | Last Cal |
|---------------|------------|-----------|----------------|-------|-----------|
| HP 34401 | 3146A16728 | 13-Jul-10 | Druck DPI 141 | 479 | 22-Jul-09 |
| B&K 4134 | 1935995 | 06-May-10 | Stanford DS360 | 33213 | 15-Jul-09 |
| Norsonic 1253 | 22456 | 19-May-10 | | | |

Notes

We certify that the above product was duly tested and found to be within the specification at the points measured (except where indicated). Measurements are traceable to UKAS reference sources from the UK National Physical Laboratory. Where no national or international standards exist, traceability is to standards maintained by the manufacturer. Our Quality Management System has been assessed to comply with BS EN ISO 9001:2008 - BSI Certificate number FS 25913. Tests were carried out in environmental conditions controlled to the extent appropriate to the instrument's specification. All relevant test certificates are available for inspection.

The uncertainties are for a confidence probability of not less than 95%.

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Microphone Calibration Certificate

Bruel and Kjaer
Type : 4189

Serial no : 2470245

Sensitivity : 46.4 mV/Pa
-26.7 dB re. 1 V/Pa

Date : 27/01/2011

Signature : 

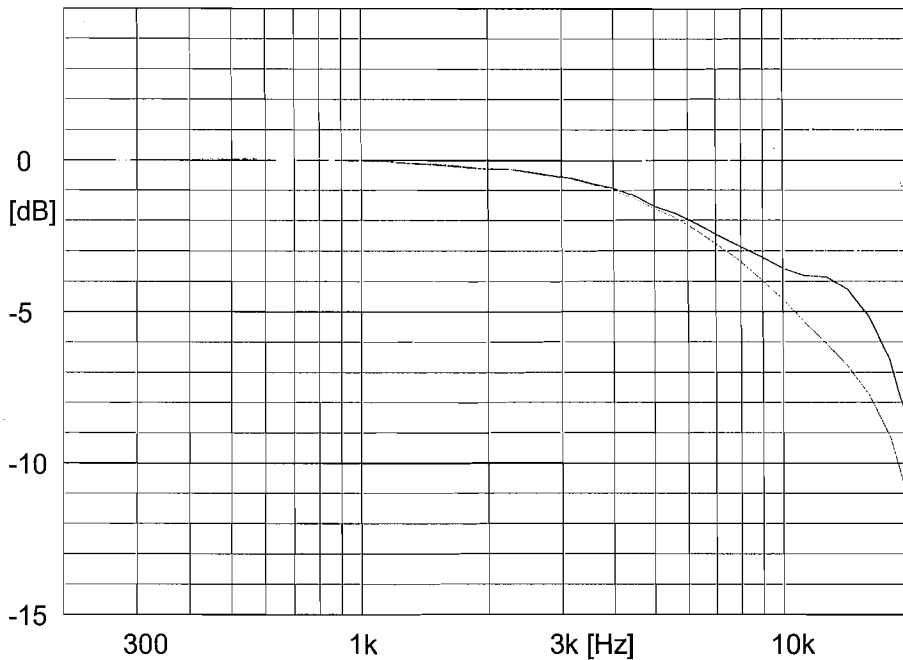
Measurement conditions :

Polarisation voltage : 0.0 V
Pressure : 101.57 kPa
Temperature : 22.6 °C
Relative humidity : 34.3 %RH

Results are normalised to the reference conditions.

Free field response
Diffuse field response
Pressure (Actuator) response

Gracey & Associates
www.gracey.com



Microphone Calibration Certificate

Bruel and Kjaer
Type : 4189

Serial no : 2470245

Sensitivity : 46.4 mV/Pa
-26.7 dB re. 1 V/Pa

Date : 27/01/2011

Signature :

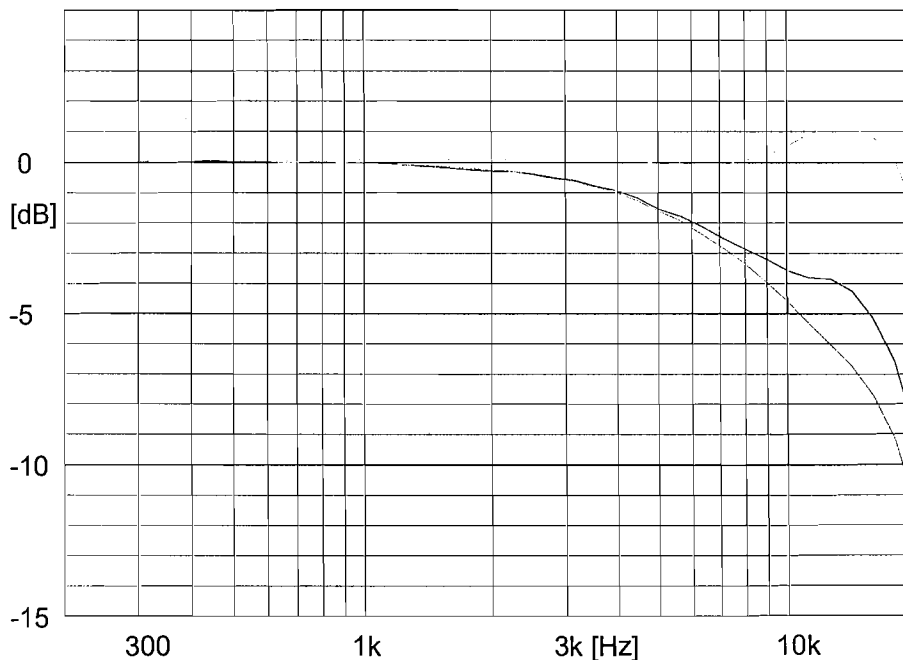
Measurement conditions :

Polarisation voltage : 0.0 V
Pressure : 101.57 kPa
Temperature : 22.6 °C
Relative humidity : 34.3 %RH

Results are normalised to the reference conditions.

Free field response
Diffuse field response
Pressure (Actuator) response

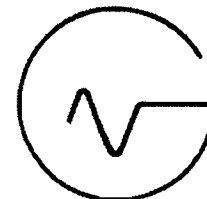
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Comment :

CERTIFICATE OF CALIBRATION

ISSUED BY Gracey & Associates BSI CERTIFICATE FS 25913
DATE OF ISSUE 27 January 2011 CERTIFICATE NUMBER 2011-0138
DATE OF CALIBRATION 27 January 2011
CALIBRATION INTERVAL 12 months PAGE 1 OF 2



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TEST ENGINEER APPROVING SIGNATORY

Jamie Bishop

Greg Rice

Manufacturer Bruel & Kjaer UK Limited
Model B&K 4189
Serial Number 2431002
Description Microphone - 1/2" free-field - 0 VDC

Customer
Napier University
Craiglockart Campus, Colinton Road, Edinburgh, Scotland,
EH14 1DJ

Standards
BS EN 61672 Class 1

Conditions
Atmospheric Pressure 101.6 kPa
Temperature 21.9 °C
Relative Humidity 34.8 %

Calibration Data

Sensitivity -25.50 dB

Laboratory Equipment Used

| Equipment | S/N | Last Cal | Equipment | S/N | Last Cal |
|---------------|------------|-----------|----------------|-------|-----------|
| HP 34401 | 3146A16728 | 13-Jul-10 | Druck DPI 141 | 479 | 22-Jul-09 |
| B&K 4134 | 1935995 | 06-May-10 | Stanford DS360 | 33213 | 15-Jul-09 |
| Norsonic 1253 | 22456 | 19-May-10 | | | |

Notes

We certify that the above product was duly tested and found to be within the specification at the points measured (except where indicated). Measurements are traceable to UKAS reference sources from the UK National Physical Laboratory. Where no national or international standards exist, traceability is to standards maintained by the manufacturer. Our Quality Management System has been assessed to comply with BS EN ISO 9001:2008 - BSI Certificate number FS 25913. Tests were carried out in environmental conditions controlled to the extent appropriate to the instrument's specification. All relevant test certificates are available for inspection.

The uncertainties are for a confidence probability of not less than 95%.

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Microphone Calibration Certificate

Bruel and Kjaer
Type : 4189

Serial no : 2431002

Sensitivity : 55.3 mV/Pa
-25.2 dB re. 1 V/Pa

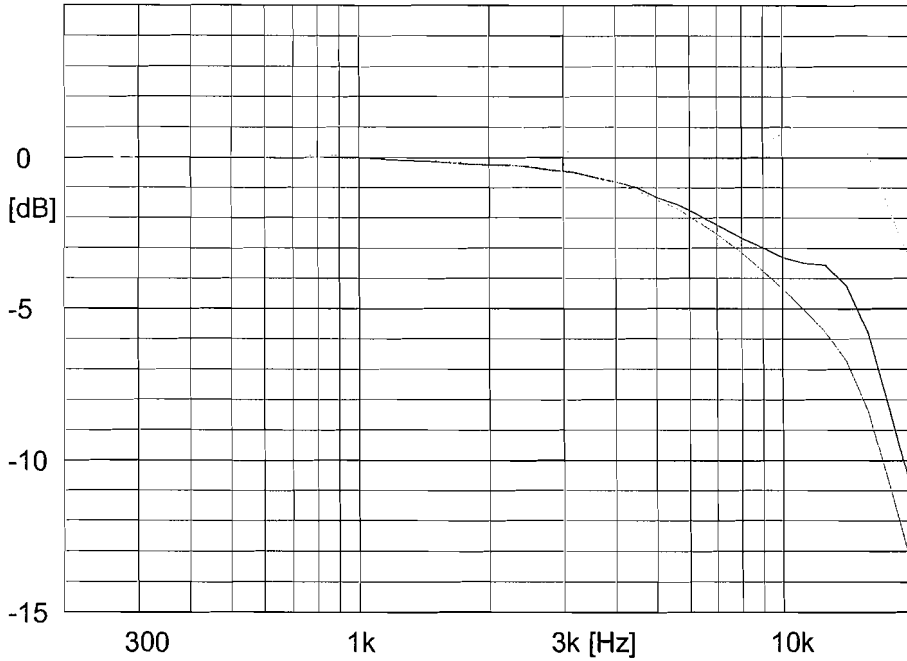
Date : 27/01/2011

Signature : 

Measurement conditions :
Polarisation voltage : 0.0 V
Pressure : 101.60 kPa
Temperature : 21.9 °C
Relative humidity : 34.8 %RH
Results are normalised to the reference conditions.

Free field response
Diffuse field response
Pressure (Actuator) response

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Microphone Calibration Certificate

Bruel and Kjaer
Type : 4189

Serial no : 2431002

Sensitivity : 55.3 mV/Pa
-25.2 dB re. 1 V/Pa

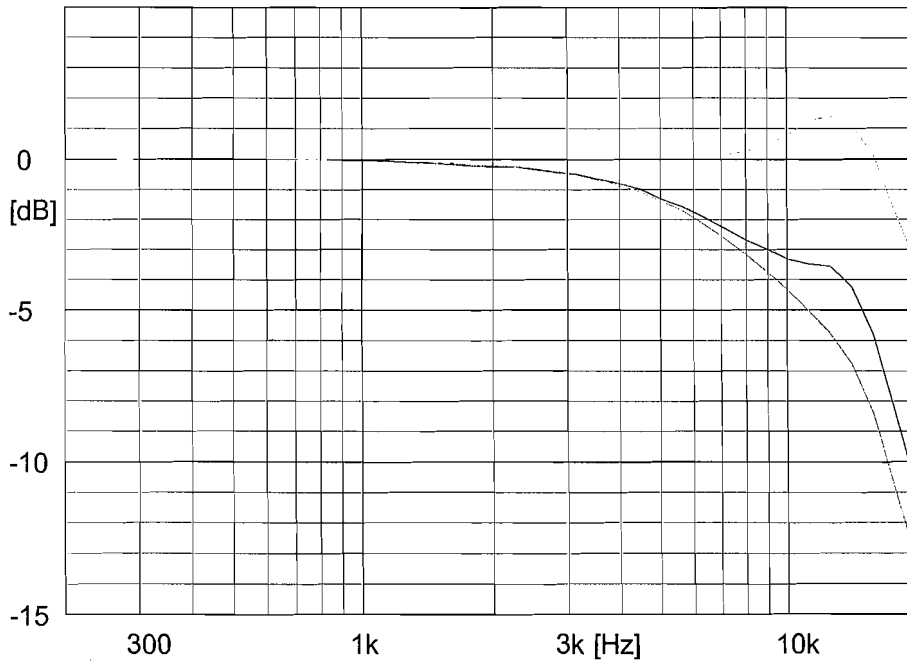
Date : 27/01/2011

Signature :

Measurement conditions :
Polarisation voltage : 0.0 V
Pressure : 101.60 kPa
Temperature : 21.9 °C
Relative humidity : 34.8 %RH
Results are normalised to the reference conditions.

Free field response
Diffuse field response
Pressure (Actuator) response

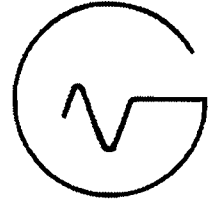
Gracey & Associates
www.gracey.com





Comment :

CERTIFICATE OF CALIBRATION

ISSUED BY Gracey & Associates BSI CERTIFICATE FS 25913
DATE OF ISSUE 27 January 2011 CERTIFICATE NUMBER 2011-0146
DATE OF CALIBRATION 27 January 2011
CALIBRATION INTERVAL 12 months PAGE 1 OF 2



Gracey & Associates
High Street, Chelveston
NN9 6AS
Tel: 01933 624212
Fax: 01933 624608
www.gracey.com

TEST ENGINEER APPROVING SIGNATORY
Jamie Bishop Greg Rice
 

Manufacturer Bruel & Kjaer UK Limited
Model B&K 4189
Serial Number 2429952
Description Microphone - 1/2" free-field - 0 VDC

Customer
Napier University
Craiglockart Campus, Colinton Road, Edinburgh, Scotland,
EH14 1DJ

Standards
BS EN 61672 Class 1

Conditions
Atmospheric Pressure 101.6 kPa
Temperature 22.4 °C
Relative Humidity 34.2 %

Calibration Data

Sensitivity -25.70 dB

Laboratory Equipment Used

| Equipment | S/N | Last Cal | Equipment | S/N | Last Cal |
|---------------|------------|-----------|----------------|-------|-----------|
| HP 34401 | 3146A16728 | 13-Jul-10 | Druck DPI 141 | 479 | 22-Jul-09 |
| B&K 4134 | 1935995 | 06-May-10 | Stanford DS360 | 33213 | 15-Jul-09 |
| Norsonic 1253 | 22456 | 19-May-10 | | | |

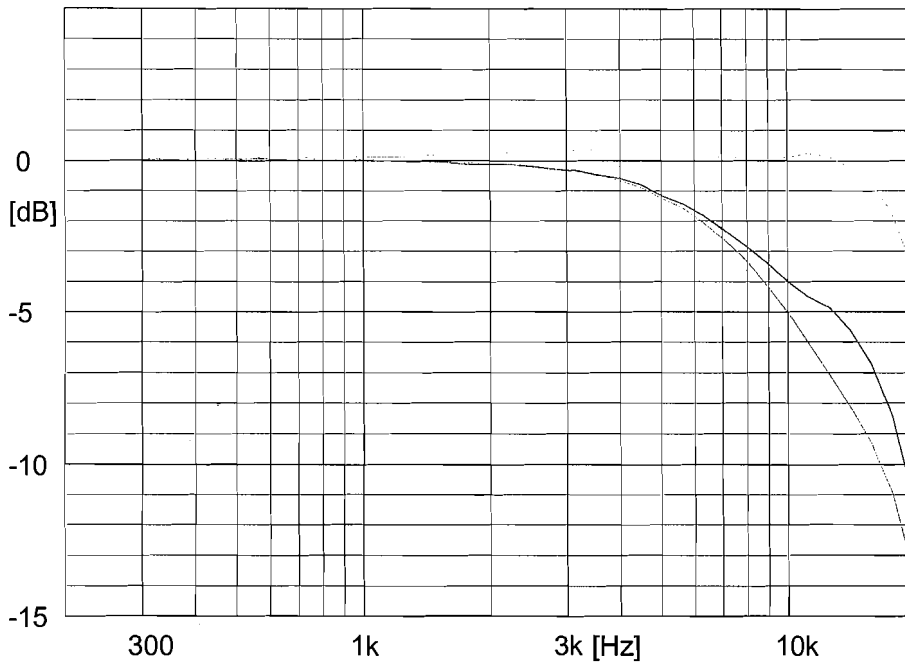
Notes

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Microphone Calibration Certificate



Bruel and Kjaer
Type : 4189

Serial no : 2429952

Sensitivity : 52.1 mV/Pa
-25.7 dB re. 1 V/Pa

Date : 27/01/2011

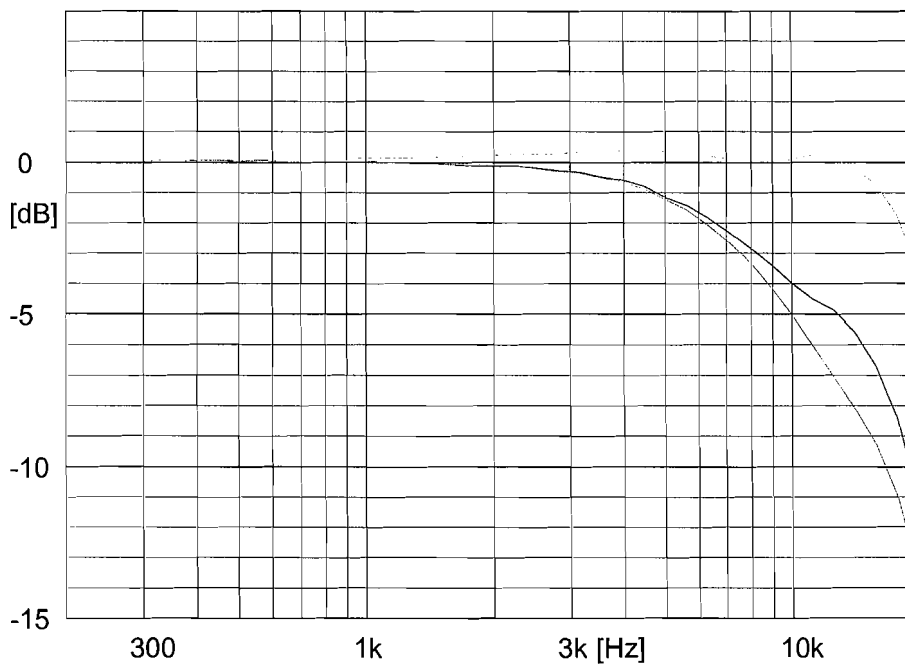
Signature :

Measurement conditions :
Polarisation voltage : 0.0 V
Pressure : 101.58 kPa
Temperature : 22.4 °C
Relative humidity : 34.2 %RH
Results are normalised to the reference conditions.

Free field response
Diffuse field response
Pressure (Actuator) response

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Microphone Calibration Certificate



Bruel and Kjaer
Type : 4189

Serial no : 2429952

Sensitivity : 52.1 mV/Pa
-25.7 dB re. 1 V/Pa

Date : 27/01/2011

Signature :

Measurement conditions :
Polarisation voltage : 0.0 V
Pressure : 101.58 kPa
Temperature : 22.4 °C
Relative humidity : 34.2 %RH
Results are normalised to the reference conditions.

Free field response
Diffuse field response
Pressure (Actuator) response

Gracey & Associates
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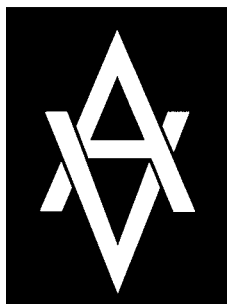
Comment :

CERTIFICATE OF CALIBRATION

ISSUED BY AV CALIBRATION

Date of issue 12 April 2010

Certificate N° 05165



AV Calibration
2 Warren Court
Chicksands, Shefford
Bedfordshire SG17 5QB
U.K.
Tel: +44 (0)1462 638600
Fax: +44 (0)1462 638601
Email: lab@avcalib.co.uk
www.avcalibration.co.uk

Page 1 of 7 pages

Approved Signatory
G. Parry

A handwritten signature in black ink, appearing to be 'G. Parry', written over a horizontal line.

CLIENT Napier University
Robin Mackenzie Partnership
42 Colinton Road
Edinburgh
EH10 5BT

F.A.O. Scott McCall

REF. Order N° NU13086 Job N° UKAS10/03086/02

DATE OF RECEIPT 29 March 2010

PROCEDURE AV Calibration Engineer's Handbook, Section 3: verification of sound level meters to BS 7580:Part 1:1997

IDENTIFICATION Sound level meter B&K type 2260 [serial no. 2120171] connected via a preamplifier type ZC 0026 [id. no. 2891] to a half-inch microphone type 4189 [serial no. 2431001] fitted with a foam windshield type UA 0237. Associated calibrator B&K type 4231 [serial no. 1780570] with one-inch housing and adapter type UC 0210 for half-inch microphone.

CALIBRATED ON 12 April 2010

PREVIOUS CALIBRATION Calibrated on 26 March 2008
Certificate N° 03738 issued by UKAS laboratory N° 0653

This certificate is issued in accordance with the laboratory accreditation requirements of the United Kingdom Accreditation Service. It provides traceability of measurement to recognised national standards, and to units of measurement realised at the National Physical Laboratory or other recognised national standards laboratories.
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UKAS ACCREDITED CALIBRATION LABORATORY No 0653

Certificate Number 05165

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The sound level meter was set to frequency weighting A and adjusted to read 93.6 dB (corresponding to 93.6 dB at standard atmospheric pressure) in response to the sound calibrator supplied. This reading was derived from the Calibration Certificate no. 05161 supplied by this laboratory and manufacturers' information on the free-field response of the sound level meter when fitted with the windshield.

The sound level meter was then tested, and its overall sensitivity adjusted, in accordance with clause 5 of BS 7580:Part 1:1997†.

The acoustic calibration at 1 kHz specified in subclause 5.6.1 of the standard was performed by application of a standard sound calibrator, whilst the tests at 125 Hz and 8 kHz (subclause 5.6.2) were performed by the electrostatic actuator method.

At the end of the test, the sound calibrator was reapplied to the sound level meter and the meter reading was recorded. The final sensitivity setting in calibration mode was -26.4 dB rel 1 V/Pa.

RESULTS

The sound level meter was found to conform to BS 7580:Part 1:1997† for a Type 1 meter.

The self-generated noise recorded in the test specified in subclause 5.5.2 was:

11.5 dB (A) ; 12.4 dB (C) ; 18.3 dB (Lin)

The sound level meter reading obtained at the end of the test in response to the sound calibrator was 93.6 dB (corresponding to 93.6 dB at standard atmospheric pressure). This reading, corrected for ambient pressure, should be used henceforth to set up the sound level meter for field use.

The expanded level uncertainty of the Laboratory's 1 kHz sound calibrator used during this verification is ± 0.22 dB; that of the calibrator supplied with the sound level meter is ± 0.22 dB.

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.

All measurement data are held at AV Calibration Ltd for a period of at least six years.

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Certificate Number 05165

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Typical case reflection factors specified by the manufacturer have been used for this verification.

The reference range, linearity range and primary indicator range specified by the manufacturers have been used.

The B&K 2260 sound level meter design has successfully undergone pattern evaluation at Physikalisch-Technische Bundesanstalt (PTB). It was found to meet the requirements of BS EN 60651* and BS EN 60804* and was granted pattern approval as a Type 1 sound level meter.

No component of uncertainty for manufacturer-specified corrections has been included in the uncertainty budget and, in accordance with Amendment No. 1 to BS 7580:Part 1:1997[†], the measured values obtained during the verification have not been extended by any measurement uncertainty when assessing conformance to the standard.

NOTES

- *1 BS EN 60651:1994 and BS EN 60804:1994 were formerly numbered BS 5969:1981 and BS 6698:1986 respectively.
- †2 BS 7580:Part 1:1997 was formerly numbered BS 7580:1992.
- 3 No suitable microphone frequency response information was supplied with the instrument. It was therefore measured by this laboratory using the electrostatic actuator method. This response in isolation is not covered by our accreditation.
- 4 The instrument was running BZ 7206 software version 2.2, post 1.6
- 5 It should be noted that although the requirements of the standard were met, the overload indicator was triggered during the tests of time averaging at the specified signal levels, and also during the tests of linearity for a reading of 110.0 dB on the reference range.
- 6 The attenuator type ZF 0023 supplied was not used or taken into account during the verification.
- 7 The securing mechanism for the adaptor on one side of the body of the 4231 calibrator is broken, resulting in the adaptor not being retained securely. It is recommended that the calibrator is only used horizontally, aperture facing downward, with the microphone under calibration being held vertically.
- 8 The microphone response was set to *Frontal* throughout the tests.
- 9 The windscreen correction filter was set to *90 mm* throughout the tests.

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UKAS ACCREDITED CALIBRATION LABORATORY No 0653

Certificate Number 05165

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Measurement data - linearity at 4 kHz

| Reference range (30-110 dB) | | |
|-----------------------------|---------------|---------------|
| Instrument reading, dB | Leq error, dB | SPL error, dB |
| 30.0 | 0.2 | 0.2 |
| 31.0 | 0.2 | 0.2 |
| 32.0 | 0.2 | 0.2 |
| 33.0 | 0.2 | 0.2 |
| 34.0 | 0.2 | 0.2 |
| 35.0 | 0.2 | 0.2 |
| 39.0 | 0.2 | 0.2 |
| 44.0 | 0.2 | 0.2 |
| 49.0 | 0.2 | 0.2 |
| 54.0 | 0.1 | 0.1 |
| 59.0 | 0.1 | 0.1 |
| 64.0 | 0.1 | 0.1 |
| 69.0 | 0.0 | 0.1 |
| 74.0 | 0.1 | 0.1 |
| 79.0 | 0.0 | 0.0 |
| 84.0 | 0.0 | 0.0 |
| 89.0 | 0.0 | 0.0 |
| 94.0 | 0.0 | 0.0 |
| 99.0 | 0.0 | 0.0 |
| 104.0 | 0.0 | 0.0 |
| 105.0 | 0.0 | 0.0 |
| 106.0 | 0.0 | 0.0 |
| 107.0 | 0.0 | 0.0 |
| 108.0 | 0.0 | 0.0 |
| 109.0 | 0.0 | 0.0 |
| 110.0 | 0.0 | 0.0 |

| Other measurement ranges | | |
|--------------------------|--------|---------------|
| Instrument reading, dB | Range | Leq error, dB |
| 94.0 | 20-100 | 0.0 |
| 94.0 | 40-120 | 0.0 |
| 94.0 | 50-130 | 0.0 |
| - | - | - |
| 78.0 | 0-80 | 0.1 |
| 88.0 | 10-90 | 0.1 |
| 98.0 | 20-100 | 0.0 |
| 118.0 | 40-120 | 0.0 |
| 128.0 | 50-130 | 0.0 |
| - | - | - |
| 27.5 | 0-80 | 0.2 |
| 27.5 | 10-90 | 0.2 |
| 27.5 | 20-100 | 0.2 |
| 42.0 | 40-120 | 0.2 |
| 52.0 | 50-130 | 0.2 |

| Largest overall errors, dB | | |
|----------------------------|----------|----------------|
| Positive | Negative | Tolerance |
| 0.3 | -0.1 | $\pm 0.7^*$ |
| 0.1 | 0.0 | $\pm 1.0^{**}$ |

*= within primary indicator range

**= outside primary indicator range

The estimated expanded measurement uncertainty for linearity measurements is ± 0.20 dB

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UKAS ACCREDITED CALIBRATION LABORATORY No 0653

Certificate Number 05165

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Measurement data - frequency response. The following data include all corrections for microphone response, linearity errors, windshield and case reflections.

| Frequency, Hz | Largest error in A-weighting, dB | | Largest error in C-weighting, dB | | Largest error in Lin-weighting, dB | | Tolerance, dB |
|------------------|-------------------------------------|----------|-------------------------------------|----------|---------------------------------------|----------|------------------|
| | most +ve | most -ve | most +ve | most -ve | most +ve | most -ve | |
| 31.5 | -0.1 | -0.2 | -0.2 | -0.3 | -0.1 | -0.1 | ± 1.5 |
| 63 | 0.1 | -0.1 | -0.1 | -0.1 | 0.0 | 0.0 | ± 1.5 |
| 125 | -0.1 | -0.2 | -0.1 | -0.1 | -0.2 | -0.2 | ± 1.0 |
| 250 | 0.1 | -0.2 | 0.0 | -0.2 | 0.1 | -0.1 | ± 1.0 |
| 500 | -0.1 | -0.6 | 0.0 | -0.4 | -0.1 | -0.5 | ± 1.0 |
| 1000 | 0.2 | -0.2 | 0.2 | -0.2 | 0.2 | -0.2 | ± 1.0 |
| 2000 | 0.6 | 0.2 | 0.7 | 0.3 | 0.7 | 0.3 | ± 1.0 |
| 4000 | 0.3 | -0.3 | 0.3 | -0.3 | 0.3 | -0.3 | ± 1.0 |
| 8000 | 0.1 | -0.5 | 0.1 | -0.6 | 0.2 | -0.4 | + 1.5, - 3.0 |
| 12500 | -0.1 | -0.7 | 0.1 | -0.6 | -0.1 | -0.6 | + 3.0, - 6.0 |

The estimated expanded measurement uncertainty for frequency response measurements is ± 0.23 dB except for those shaded above, where ± 0.26 dB applies.

Measurement data - Time weightings F, S and I

| Time weighting | Signal type | Reading 1, dB | Reading 2, dB | Reading 3, dB | Requirement, dB |
|----------------|------------------|------------------|------------------|------------------|--------------------|
| F | Single toneburst | 88.0 | 88.0 | 88.0 | 88.0 ± 1.0 |
| S | | 84.9 | 84.9 | 84.9 | 84.9 ± 1.0 |
| I | | 84.1 | 84.1 | 84.1 | 84.2 ± 2.0 |
| | Pulse chain | 90.2 | N/A | N/A | 90.3 ± 1.0 |

The estimated expanded measurement uncertainty for measurements of Time Weighting F, S and I is ± 0.20 dB

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Certificate Number 05165

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Measurement data - Peak response

| Signal type | Reading 1, dB | Reading 2, dB | Reading 3, dB | Requirement, dB |
|-----------------|---------------|---------------|---------------|-----------------|
| +ve 10 ms pulse | 91.7 | 91.8 | 91.9 | ≥ 90.0 |
| -ve 10 ms pulse | 91.9 | 92.1 | 92.0 | |

The estimated expanded measurement uncertainty for measurements of Peak response is ± 0.29 dB

Measurement data - RMS accuracy for signal of crest factor 3

| Instrument reading, dB | Requirement, dB |
|------------------------|-----------------|
| 91.0 | 91.0 ± 0.5 |

The estimated expanded measurement uncertainty for measurements of RMS accuracy is ± 0.23 dB

Measurement data - Time averaging

| Burst duty factor | Instrument reading, dB | Requirement, dB |
|-------------------|------------------------|-----------------|
| 1/1000 | 79.8 | 80.0 ± 1.0 |
| 1/10000 | 69.8 | 70.0 ± 1.0 |

The estimated expanded measurement uncertainty for measurements of time averaging is ± 0.23 dB

Measurement data - Pulse range

| Background sig., dB | Reading 1, dB | Reading 2, dB | Reading 3, dB | Requirement, dB |
|---------------------|---------------|---------------|---------------|-----------------|
| 30.0 | 57.9 | 57.9 | 57.9 | 58.0 ± 1.7 |
| 50.0 | 78.1 | 78.1 | 78.1 | 78.0 ± 1.7 |

The estimated expanded measurement uncertainty for measurements of pulse range is ± 0.23 dB

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Certificate Number 05165

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Measurement data - Sound exposure level

| Background sig., dB | Reading 1, dB | Reading 2, dB | Reading 3, dB | Requirement, dB |
|---------------------|---------------|---------------|---------------|-----------------|
| 30.0 | 67.9 | 67.9 | 67.9 | 68.0 ± 1.7 |
| 50.0 | 88.1 | 88.1 | 88.1 | 88.0 ± 1.7 |

The estimated expanded measurement uncertainty for measurements of SEL is ± 0.23 dB

Measurement data - Overload indicator (non-integrating)

| Instrument reading, dB | Target, dB | Tolerance, dB |
|------------------------|------------|---------------|
| 98.7 | 98.7 | ± 0.4 |

The estimated expanded measurement uncertainty for measurements of overload indicator response in non-integrating mode is ± 0.23 dB

Measurement data - Overload indicator (integrating)

| Reading 1, dB | Reading 2, dB | Reading 3, dB | Target, dB | Tolerance, dB |
|---------------|---------------|---------------|------------|---------------|
| 68.1 | 68.1 | 68.1 | 68.2 | ± 2.2 |

The estimated expanded measurement uncertainty for measurements of overload indicator response in integrating mode is ± 0.23 dB

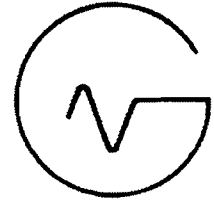
Measurement data - Electrostatic actuator tests at 125 Hz and 8 kHz. The following data include all corrections for microphone response, linearity errors, windshield and case reflections.

| Frequency, Hz | Averaged reading, dB | Target, dB | Tolerance, dB |
|---------------|----------------------|------------|---------------|
| 125 | 79.3 | 79.3 | ± 1.0 |
| 8000 | 79.1 | | +1.5, -3.0 |
| | 78.6 | | |

The estimated expanded measurement uncertainty for electrostatic actuator measurements is ± 0.22 dB

CERTIFICATE OF CALIBRATION

ISSUED BY Gracey & Associates BSI CERTIFICATE FS 25913
DATE OF ISSUE 19 April 2011 CERTIFICATE NUMBER 2011-0425
DATE OF CALIBRATION 15 April 2011
CALIBRATION INTERVAL 12 months PAGE 1 OF 1



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Fax: 01933 624608
www.gracey.com

TEST ENGINEER APPROVING SIGNATORY
Greg Rice Greg Rice

Manufacturer Bruel & Kjaer UK Limited
Model B&K 4294
Serial Number 2532254
Description Calibrator - Vibration

Customer
Robin Mackenzie Partnership
Acoustical Consultants, 42 Colinton Road, Edinburgh,
Scotland, EH10 5BT

Standards
Manufacturer's Original Specifications

Conditions
Atmospheric Pressure 101.2 kPa
Temperature 20.2 °C
Relative Humidity 44.2 %

Calibration Data

Output Level 9.88 ms⁻²
Frequency 160.00 Hz

Calibration Reference Sources

| Equipment | S/N | Last Cal | Equipment | S/N | Last Cal |
|----------------|------------|-----------|---------------|---------|-----------|
| B&K 4370 | 2260763 | 16-Jun-10 | B&K 4294-002 | 1608724 | 09-Feb-11 |
| HP 34401 | 3146A16728 | 13-Jul-10 | | | |
| Stanford DS360 | 33213 | 15-Jul-09 | Druck DPI 141 | 479 | 22-Jul-09 |

Notes

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