

Appendix A – Amended Acoustic Report (Acoustic Studio)

SYDNEY OPERA HOUSE

ACOUSTIC ASSESSMENT FOR MODIFICATION OF DA-445-10-2003

Issued

September 2016



acoustic studio

abn 76 106 325 982
address Unit 27, 43-53 Bridge Road, Stanmore NSW 2048 Australia
tel (+61) 2 9557 6421
fax (+61) 2 9557 6423
email mail@acousticstudio.com.au

Contact for this Report

Sav Shimada
sav.shimada@acousticstudio.com.au



abn 76 106 325 982
address Unit 27, 43-53 Bridge Road, Stanmore NSW 2048 Australia
tel (+61) 2 9557 6421
fax (+61) 2 9557 6423
email mail@acousticstudio.com.au

| | | | |
|------------------------|--------------------------------------------------------|-----------------------|----------------------|
| Proj & Code | Sydney Opera House Site Activation | SOH-2371 | |
| Doc Title | Acoustic Assessment for Modification of DA-445-10-2003 | | |
| Ref | 20160907.SOH2371.0001.Rep.rev1.docx | | |
| Date | 7 September 2016 | Revision: ISSUE REV I | |
| Author(s) | Sav Shimada and Dave Anderson | | |
| Circulation | Organisation | Location | Delivered Via |
| Chris Barling | Sydney Opera House | Sydney | e-mail |
| Attachment(s) | Appendices as listed in the Table of Contents | | |

*Acoustic Studio is a member of the
Association of Australian Acoustical Consultants*



*This report takes into account the particular instructions and requirements of our Client.
It is not intended for and should not be relied upon by any third party and no responsibility is undertaken
to any third party.*

Table of Contents

| | | |
|----------|---------------------------------------------------------------------------------|-----------|
| 1 | Executive Summary | 5 |
| 2 | Introduction | 6 |
| 3 | Project Description | 8 |
| 3.1 | Outdoor events | 8 |
| 3.2 | Operating Hours | 9 |
| 3.3 | Site Details | 10 |
| 4 | Acoustic Assessment Approach | 12 |
| 5 | Existing Noise Environment | 13 |
| 5.1 | Noise Review Approach | 13 |
| 5.1.1 | Reviews of existing data | 13 |
| 5.1.2 | Acoustic Environment Observations | 13 |
| 5.1.3 | Noise Monitoring Locations | 13 |
| 5.2 | Existing Ambient and Background Noise Levels | 14 |
| 5.2.1 | Long-term Measurement Data at Bennelong Apartments | 14 |
| 5.2.2 | Long-term Measurement Data at Kirribilli | 15 |
| 5.2.3 | Historical Attended Measurement Data | 16 |
| 6 | Project Noise Criteria | 18 |
| 6.1 | Noise Criteria Review Approach | 18 |
| 6.1.1 | Reviews of existing noise criteria | 18 |
| 6.1.2 | Reviews of existing noise monitoring reports and technical studies | 18 |
| 6.2 | External Noise Emission Criteria – General Noise | 19 |
| 6.2.1 | Environmental Planning and Assessment Act (EP&A) 1979 | 19 |
| 6.2.2 | Protection of the Environment Operation Act (POEO) 1997 | 19 |
| 6.2.3 | New South Wales Industrial Noise Policy (INP) | 20 |
| 6.2.4 | Sleep disturbance | 21 |
| 6.2.5 | New South Wales Interim Construction Noise Guideline (ICNG) | 22 |
| 6.2.6 | City of Sydney - Standard Conditions of Development Consent (CoS SCDC) | 23 |
| 6.2.7 | Road Traffic Noise | 24 |
| 6.2.8 | Noise criteria for patron noise | 24 |
| 6.2.9 | Summary of noise targets for general event noise | 25 |
| 6.3 | External Noise Emission Criteria – Sound System Noise | 25 |
| 6.3.1 | General Approach | 25 |
| 6.3.2 | Noise Emission Criteria for Sydney Opera House outdoor events (amplified music) | 26 |
| 6.3.3 | City of Sydney - Standard Conditions of Development Consent (CoS SCDC) | 27 |
| 6.3.4 | Days of the week | 28 |
| 6.3.5 | Noise limit value | 29 |
| 6.3.6 | Noise measurement method for outdoor events | 30 |
| 6.3.7 | Measuring environmental noise levels | 32 |
| 6.3.8 | Noise measurement location for outdoor events | 33 |
| 6.3.9 | Proposed noise limit for outdoor events | 34 |

| | | |
|----------|----------------------------------------------------------------------------------------------------------------|-----------|
| 6.4 | Internal Noise Intrusion Criteria – Opera House use..... | 36 |
| 6.5 | Summary of Environmental Noise Emission Criteria for Sydney Opera House outdoor events | 37 |
| 7 | Assessment and Recommendations | 38 |
| 7.1 | Assessment Methodology | 38 |
| 7.2 | Mechanical Plant Noise Compliance..... | 38 |
| 7.3 | Bump-in / Bump-out Noise Compliance | 39 |
| 7.4 | Patron and Sound System Noise | 41 |
| 7.4.1 | Source Noise Levels..... | 41 |
| 7.4.2 | Patron noise assessment | 41 |
| 7.4.3 | Sound system noise assessment..... | 44 |
| 7.4.4 | Typical allowable sound levels from amplified sound systems | 45 |
| 7.5 | Noise Intrusion to Sydney Opera House Internal Spaces..... | 46 |
| 8 | Noise Management Approach | 47 |
| 8.1 | Management Practices | 47 |
| 8.2 | Recommended Noise Management Approach..... | 48 |
| 9 | Summary and Conclusions..... | 50 |
| | Appendix | 51 |
| | Auditoria Pty Ltd acoustic report: Sydney Opera House Forecourt Events Front of House Recommended Levels | 51 |

1 Executive Summary

Sydney Opera House has a history of operating outdoor events that cater to public and private patrons. An iconic Sydney landmark, and a World Heritage building, the Sydney Opera House is a vibrant cultural hub for the City of Sydney. Outdoor events make the most of Sydney's climate and promote community involvement in the Sydney Opera House's operations.

The Sydney Opera House seeks to modify existing planning approvals for events held on the Southern Forecourt, Monumental Steps and Western Broadwalk.

Acoustic Studio has been commissioned to conduct an operational acoustic assessment for the proposed outdoor events at the Sydney Opera House, and is detailed in this report along with the findings and recommendations. It has been prepared as part of the Modification Application for the existing DA-445-10-2003, to be submitted to the Department of Planning and Environment.

The objectives of this assessment are to:

- Identify noise sensitive receivers (including internal spaces in the Sydney Opera House itself) that may be affected by the operation of the proposed Sydney Opera House outdoor events.
- Review existing environmental noise data to determine existing ambient and background noise levels at the nearest noise sensitive receivers that surround the site.
- Establish the appropriate noise assessment criteria in accordance with the relevant standards and guidelines.
- Carry out an assessment to determine whether the relevant criteria can be achieved based on proposed operations.
- Where applicable, provide recommendations for any necessary acoustic control measures that will need to be incorporated into the planning or operation of outdoor events in order to ensure compliance with the assessment criteria.

The outcome of the noise assessment is that the noise limits set in 2003 are difficult to measure consistently and that this has affected the noise management outcomes. This acoustic report proposes adopting a more robust 5-minute sound energy-averaged measurement method, measured at Front of House. It will ensure that event noise is more efficiently managed, and will reduce excessively bass-heavy sound that is known to cause increased annoyance in the community. Importantly, the proposed Front of House noise limits are equivalent to the L_{max} limits which have applied since 2003, and therefore does not constitute an increase in allowable event noise level.

2 Introduction

The Sydney Opera House seeks to modify existing planning approvals for events held on the Southern Forecourt, Monumental Steps and Western Broadwalk.

There are no proposed changes to the type of event, nor any increase to the total number of event days per annum, to be held at these locations. In fact the proposed number of events have been reduced from current allowances. At face value, the proposal would not change the existing noise environment.

Considering that the noise limits were set over ten years prior to this application for a modification, it is appropriate to review how successfully the noise limits set in DA-445-10-2003 have been applied until 2016, and whether the noise limits are suitable for the Sydney Opera House Forecourt and Western Broadwalk.

In addition, this acoustic assessment includes a review of potential noise impacts from event-related noise due to bump-in and bump-out activities, patrons, and mechanical plant and equipment. Applicable noise targets are presented and noise predictions are made for these noise sources in the assessment.

A sleep disturbance assessment is included for all event-related noise sources.

As part of review of sound system noise, a review of historical event management reports highlighted a common problem that it is very difficult to measure and discern “performance event noise” using the current L_{Amax} and L_{Cmax} measurement method.

The A-weighting filters out much of the bass (low frequency noise) characteristic of music events. The C-weighting has fairly equal weighting for low to high frequencies.

It is difficult to distinguish from environmental measurements whether an A-weighted level is from an outdoor event, or from some other event (ferry, bus, pedestrian, helicopter), because the existing ambient at Bennelong Apartments is about the same as the current A-weighted noise limit.

The C-weighted noise level best correlates with noise complaints received in the past from SOH outdoor events, because of the greater difference between the C-weighted event noise and existing ambient level (called “emergence above ambient”), and also because bass noise is known to be a common cause of disturbance - including inside a building because it is not well attenuated by typical windows.

The maximum event level measurement approach can capture events lasting for less than a second. In this Circular Quay environment, the measured L_{max} can often be due to a ferry horn, a bus, or other typical extraneous event that is unrelated to SOH operations.

The outcome of the assessment is the proposal to adopt an alternative noise limit, which is numerically the same as the DA-445-10-2003 but is measured differently.

The limit is to be a 5-minute sound energy averaged measurement (L_{eq}), because this is better at removing sudden spikes in sound which are rarely related to performance noise. The L_{eq} approach is in line with recent NSW EPA guidelines including the *Interim Construction Noise Guideline* (2009), which states that the L_{eq} measure has been shown to better correlate with annoyance than the maximum or typical maximum measure.

The proposed limit focuses on the C-weighted level because it “emerges” more from background and ambient, and is easier to detect at environmental locations and is generally considered to be more intrusive than the concurrent A-weighted level. An A-weighted level is still proposed, with an emphasis on ensuring an appropriate frequency balance that will better manage low frequency dominant environmental noise emissions.

The acoustic assessment reviews the typical differences between A- and C-weighted performance noise levels, to ensure that for a given C-weighted noise limit, the corresponding A-weighted performance noise level would still be aligned with existing ambient levels during SOH operational hours. The proposed noise limit approach will help redress the A/C weighted noise level imbalance (“low frequency dominance”, or bass heavy sound), which the EPA INP states is more disturbing.

Due to difficulties in accurately measuring amplified sound system noise levels at receiver locations, a Front of House limit has been proposed in consultation with the NSW Department of Planning. Measuring and limiting noise at Front of House removes significant uncertainties about the contribution of performance noise to measured environmental levels, and importantly also allows more efficient management of noise outputs by having the noise limits set and measured close to the sound engineer’s control desk.

This alternative Front of House $L_{A/Ceq(5min)}$ noise limit allows more accurate monitoring of event noise, and allows a feasible and reasonable environmental noise management approach for outdoor performances at the Sydney Opera House Forecourt, Monumental Steps and Western Broadwalk.

Management controls will continue to apply for Sydney Opera House outdoor events, including noise management plans, selection and orientation of directional loudspeaker systems, and noise monitoring for sound checks and events.

3 Project Description

3.1 Outdoor events

The Sydney Opera House seeks to modify the DA-445-10-2003 for outdoor events held in the Southern Forecourt, Monumental Steps and Western Broadwalk.

Specific examples of types of events included in this proposal are:

- Performances and Large Shows on the Forecourt: One off or short term events include the Australian Idol Final, the Aria Awards, and the Oprah Show; performance series lasting from a few days to three weeks include the Sydney Symphony, “Just for Laughs” and the Commercial Music Series.
- Community Events: Events involving installations or structures not covered by exempt development provisions, for example Greek National Day.
- Corporate Events and Private Functions.
- Festivals: Including the Sydney Festival, Summer at the House, Message Sticks, and Food and Wine Fairs.
- Long Term Large Installations: Including Spiegel tent, Architects of the Air, Ice Skating Rink. Not all installations, such as advertisers’ marquees and art installations, will generate “event noise”.
- Government Initiated Events, including World Youth Day, APEC, and FIFA Congress.

Approval is sought for the outdoor event days, including time on either side of the actual events for the associated set up and dismantling of temporary structures and installations.

The proposal does not include any new constructions beyond temporary set-up, such as tents, demountable stage and sets, outdoor seating, temporary noise barriers, ticket booths, and food / drink facilities. Nor does the proposal allow for an overall increase in outdoor event days per year – a reduction in event numbers is proposed instead.

The proposed outdoor events operated by the Sydney Opera House may take place at the the Western Broadwalk, the Lower Forecourt, the Southern Forecourt and the Monumental or Podium steps. Very large events would most likely be carried out on the Southern Forecourt and Monumental Steps.

A schematic of the Sydney Opera House precinct and associated outdoor event venues is provided below.

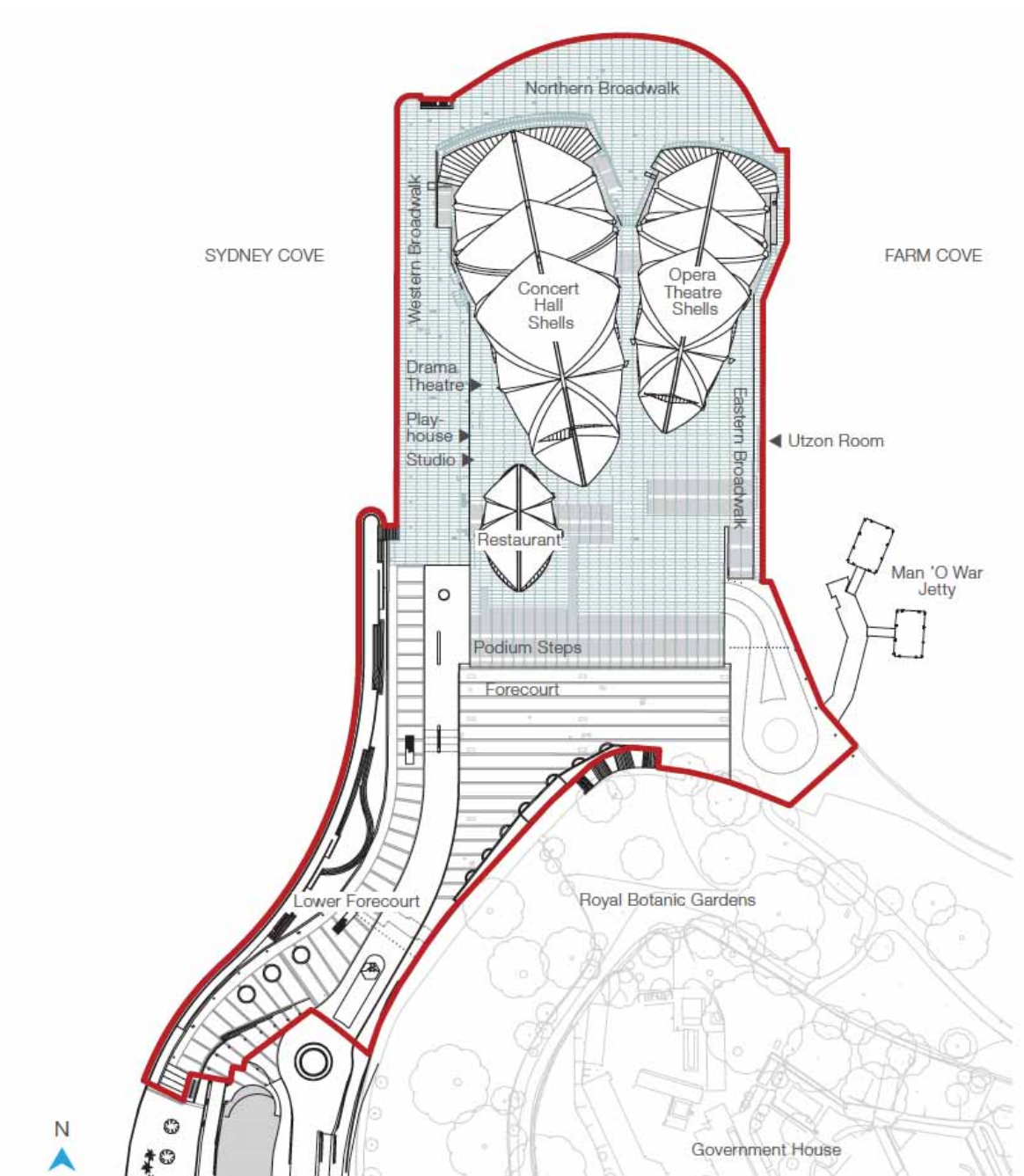


Figure 1: Sydney Opera House precinct outdoor event areas. (Source: Sydney Opera House Nomination by the Government of Australia for Inscription on the World Heritage List 2006, Australian Government Department of Environment and Heritage, figure 1.4)

3.2 Operating Hours

The Sydney Opera House seeks to re-activate approval to operate outdoor functions on any day of the week, with amplified sound systems off by 11pm and all noise-related activities ceased by 12am.

Set up and dismantling of temporary installations may occur at any time of day or evening, as long as conditions of approval (such as noise limits) are met. Bump in / out activities will not be carried out after midnight.

This acoustic assessment covers all operational scenarios, for day, evening and night to assist the Sydney Opera House plan events in a way that minimizes environmental noise impacts.

3.3 Site Details

The site is located within a vibrant urban environment characterised by high levels of activity throughout the day and decreasing noise levels in the evening and night.

Commercial receivers dominate around the site. There are also residential receivers, including Bennelong apartments to the south, and Kirribilli residential area across the Harbour to the north. Existing sensitive receivers that surround the site are as follows:

- Residential properties around Circular Quay and the Rocks, including Bennelong apartments to the south, the Park Hyatt Hotel to the west across the quay.
- Commercial receivers around Circular Quay and the Rocks include the public ferry terminal, and restaurants and offices at Circular Quay East and West.
- Residential areas to the north, across the harbour, include North Sydney, Kirribilli, Mosman and Cremorne waterfront areas.

Figure 2 shows the location of the Sydney Opera House and the surrounding area. The red points show the approximate locations of the proposed Sydney Opera House outdoor events and activities. A secondary outdoor event location, not associated with Opera House activities, is shown in yellow at Mrs Macquarie's Chair in the Domain. The residential receivers that will potentially be most affected by the operation of the proposal are shown in blue. Noise data survey locations are shown as P1, P2 and P3.



Figure 2: Location of Sydney Opera House outdoor events in relation to noise-sensitive receivers. Mark-up of Google Earth satellite view.

4 Acoustic Assessment Approach

The Sydney Opera House seeks to modify DA-443-10-2003 for outdoor events taking place in the Southern Forecourt, Monumental Steps, and the Western Broadwalk.

The key acoustic considerations for the proposal are external noise emissions from operation of the following spaces and equipment associated with the Sydney Opera House outdoor events:

- Sound system noise breaking out of the event areas.
- Breakout noise from building services and plant servicing the events.
- Patron noise from inside the event areas and approaches to ticket booths and entries.
- Noise from bump-in / bump-out activities (set up, installation and removal), rehearsals and sound checks.
- Sound system noise breaking out from other concerts, functions and general operations at the Domain, the Royal Botanic Gardens, and Circular Quay.

The Sydney Opera House's proposal does not seek to increase the total number of outdoor event days in a year.

In principle, therefore, there is no risk of increasing the noise impacts on noise-sensitive receivers due to this proposal.

However, the Sydney Opera House has noted difficulties in monitoring and therefore managing event noise, which has prompted a review of the noise criteria. Difficulties in measuring event noise have been due to two factors:

- Maximum event level measurements are often related to extraneous environmental events such as bus / ferry / train noise, pedestrians and helicopters;
- A-weighted maximum noise limits are very similar to existing ambient noise, so that it is difficult to distinguish in a measurement.

This acoustic assessment contains a review of applicable event noise criteria, to ensure that high quality outdoor performances may be held in outdoor areas while preserving the acoustic amenity of residential receivers.

5 Existing Noise Environment

5.1 Noise Review Approach

5.1.1 Reviews of existing data

Environmental noise assessments require an understanding of existing environmental noise in the absence of the proposed activities, to determine how audible and noticeable the activities are for sensitive receivers.

Long-term (unattended) noise monitoring has been carried out by Acoustic Studio over several months in 2014 for the Sydney Opera House. Noise data from these surveys are supplemented by 2016 week-long environmental and various short-term event noise monitoring by other consultants, supplied by the Sydney Opera House.

5.1.2 Acoustic Environment Observations

Circular Quay is a vibrant, busy area governed by pedestrian noise, outdoor restaurant activities, and local buskers.

Traffic noise along Macquarie Street leading to the Opera House car park is largely screened by multiple-storey buildings along Circular Quay East. Constant traffic noise is audible from the Sydney Harbour Bridge and Eastern Distributor.

Intermittent rail noise is audible from the Sydney Harbour Bridge and from the Circular Quay viaduct. Trains operate between 5am and 12:30am.

Ferry noise from the harbour is distinctly audible throughout the day, operating from 5am to 1am the following day (ie only ceasing operations between 1am and 5am).

Aircraft noise from relatively low flying helicopters is quite frequent, while commercial seaplanes and passenger jets are heard from a distance.

There are no significant industrial noise sources in the near vicinity, beyond mechanical plant and equipment from commercial and residential buildings.

5.1.3 Noise Monitoring Locations

Environmental noise measurement times included the most sensitive period that the proposed events may occur, including for maintenance and cleaning (ie between 10:00 pm and 1:00 am).

Three measurement locations were selected as follows:

- Location P1 – Two locations: one at street level, and one in a vacant apartment on level 13, at Bennelong apartments. This represents the existing noise environment at these residential property boundaries.
- Location P2 – Within the Sydney Opera House, near the Stage Door. This location is used to assess outdoor event noise impacts on the internal spaces in the Opera House.
- Location P3 – Beulah St Wharf at Kirribilli. This represents the existing noise environment at residential receivers directly opposite the Northern Broadwalk events area at the Sydney Opera House.

Acoustic Studio Pty Ltd carried out the long term unattended surveys at P1 and P2, and attended surveys at P1 and P3 were carried out by others.

5.2 Existing Ambient and Background Noise Levels

5.2.1 Long-term Measurement Data at Bennelong Apartments

Acoustic Studio has carried out noise surveys in the Sydney Opera House precinct and at the nearest residential receiver at Bennelong Apartments (1 Macquarie Street) for the purpose of assessing and managing noise. Noise measurements have been obtained both with and without Sydney Opera House construction or operational activities. Periods affected by rain or wind have been discarded from the noise data set.

Ambient and background noise levels without Opera House activities are presented in the table below.

| Location | Period | Day | Noise Level, dB(A) | | | Measurement dates | |
|--------------------------------------------------------------|---------------------------------------------------------|----------------------------------|-------------------------|-------------------------|-------------------------|-------------------|--------------|
| | | | L ₉₀ (15min) | L _{eq} (15min) | L ₁₀ (15min) | | |
| P1: Southern SOH boundary, Representing Bennelong Apartments | 7am – 6pm Day | Sunday, Public holiday | 53-59 | 55-62 Up to 66 | 57-65 Up to 68 | 31/7-13/8/14 | |
| | | | 52-59 | 54-63 Up to 79 | 56-66 Up to 81 | 14-27/8/14 | |
| | 6pm – 7am Evening, Night | Saturday, Sunday, Public Holiday | 41-48 | 44-61 Up to 72 | 45-64 Up to 73 | 31/7-13/8/14 | |
| | | | 43-56 | 45-60 Up to 71 | 47-62 Up to 69 | 14-27/8/14 | |
| | P2: SOH Stage door, representing SOH internal receivers | 7am – 6pm Day | Sunday, Public holiday | 47-55 | 54-64 Up to 75 | Not recorded | 31/7-13/8/14 |
| | | | | 44-54 | 53-64 Up to 68 | Not recorded | 14-27/8/14 |
| 6pm – 7am Evening, Night | | Saturday, Sunday, Public Holiday | 44-53 | 51-62 Up to 68 | Not recorded | 31/7-13/8/14 | |
| | | | 46-53 | 52-63 Up to 68 | Not recorded | 14-27/8/14 | |

Table 1 Long-term unattended noise logger data from July and August 2014.

Acoustic Studio has been provided with a noise assessment report for the SOH Forecourt, by Auditoria Pty Ltd. This report compiles noise monitoring data measured more recently at Bennelong Apartments in 2015 and 2016. The following noise levels are reported in terms of A-weighted and C-weighted levels.

| Location | Period | Noise Level, dB(A) | | Noise Level, dB(C) | |
|--------------------------|---------------------------------------|--------------------|----------------------|--------------------|----------------------|
| | | RBL, LA90 | Ambient, LAeq(15min) | RBL, LC90 | Ambient, LCeq(15min) |
| P1: Bennelong Apartments | 7am – 6pm Day | 60 | 69 | 64 | 71 |
| | 6pm – 10pm Evening | 61 | 68 | 64 | 72 |
| | 10pm – 11:30pm Night (SOH operations) | 58 | 65 | 61 | 69 |
| | 11:30pm – 7am Night | 47 | 59 | 51 | 63 |
| | 10pm – 7am Night | 49 | 61 | 53 | 65 |

Table 2 Long-term unattended noise logger data collected by Auditoria Pty Ltd, 2015-2016. The data distinguishes between potential SOH outdoor operational night time hours and outside SOH operational hours.

The more recent noise monitoring data confirm that day time and evening noise levels at Bennelong Apartments have remained consistent through the past few years and are appropriate for assessing emergence of performance noise above background and ambient. They also provide C-weighted background and ambient noise level data which can be directly used to assess the suitability of applying a C-weighted performance noise criterion.

There is a 3dB range in A-weighted background noise levels, and 4dB range in C-weighted background noise levels, during Sydney Opera House outdoor event hours (8am to 11:30pm). There is a 4dB range in A-weighted ambient noise levels, and 3dB range in C-weighted ambient noise levels, during Sydney Opera House outdoor event hours (8am to 11:30pm). This fluctuation is small. In contrast, there is a clear drop in ambient and background noise levels between midnight and 7am.

It is of interest, in terms of assessing performance noise emissions, that the difference between C-weighted and A-weighted existing background and ambient noise levels is approximately 3-4dB. In contrast, the C-weighted performance noise criteria are set to 20dB above the A-weighted level. This is discussed further in Section 6.3.2.

5.2.2 Long-term Measurement Data at Kirribilli

Out of all the Lower North Shore residential areas identified in this assessment, Kirribilli is the nearest to the Sydney Opera House precinct, and most likely to experience the highest noise levels from SOH outdoor events. This area has therefore been selected as the Lower North Shore receiver location for a “worst-case” assessment.

Acoustic Studio has been provided with a noise monitoring data from Waruda Street near Beulah Street Wharf at Kirribilli, by Arup Acoustics. The following noise levels are reported in terms of A-weighted and C-weighted levels.

| Location | Period | Noise Level, dB(A) | | Noise Level, dB(C) | |
|---------------------------------|------------------------------------------|--------------------|----------------------|--------------------|----------------------|
| | | RBL, LA90 | Ambient, LAeq(15min) | RBL, LC90 | Ambient, LCeq(15min) |
| P4: Beulah St Wharf, Kirribilli | 7am – 6pm Day | 50 | 58 | 63 | 72 |
| | 6pm – 10pm Evening | 50 | 55 | 63 | 72 |
| | 10pm – 11:30pm Night (SOH operations) | 48 | 54 | 59 | 70 |
| | 11:30pm – 7am Night | 43 | 53 | 54 | 67 |
| | 10pm – 7am Night | 44 | 53 | 55 | 67 |

Table 3 Long-term unattended noise logger data collected by Arup Acoustics, 2016. The data distinguishes between potential SOH outdoor operational night time hours and outside SOH operational hours.

5.2.3 Historical Attended Measurement Data

Measurement data for four Sydney Opera House outdoor events from 2007 to 2013 were provided to Acoustic Studio. The following reports were provided:

- A. The P.A. People, 11/11/2013 Red Cross Concert on the Northern Broadwalk (for information as this venue is not part of the current DA modification), various performances including Taikoz drums, rock / pop / jazz bands, Chinese Lion dance, Tongan Haka, and speeches. Measurements at Front of House tent on the Northern Broadwalk, and the closest residence to Beulah St Wharf.
- B. The P.A. People, 16/12/2013, Jack Johnson Concert held at the Monumental Steps, amplified music. Measurements at Beulah St Wharf and Bennelong Apartment residences. Few measurement data are provided, but the report provides a useful qualitative description of the audibility of performance and external noise factors that have led to noise levels exceeding the requirement.
- C. Arup Acoustics, 23/1/2008, Bjork on the Forecourt, amplified music. The measurement location was at Bennelong Apartments at street level.
- D. Arup Acoustics, 1/3/2008, Slaughter at the Opera House Skateboarding Event, amplified speech and music. The measurement location was at Bennelong Apartments at street level.
- E. Arup Acoustics, 23/11/2008, Australian Idol Final, amplified speech and music. The measurement location was at Bennelong Apartments at street level.
- F. Arup Acoustics, 23&25/11/2007, Australian Idol Final, amplified speech and music. The measurement location was at Bennelong Apartments at street level.
- G. Arup Acoustics, 31/10/2007, Concert for the Cure, amplified speech and music. The measurement location was at Bennelong Apartments at street level.

Each report contains ambient noise and event noise measurements. The measured ambient noise levels at each location are provided in Table 1. (Event noise levels are presented and discussed in Section 7.4).

Maximum existing noise levels are also provided to demonstrate that in many cases, the existing environmental noise frequently exceeds the amplified music criteria (summarised in Section 6.3.2). At Beulah Street Wharf, ferry passby events are most often associated with levels above 60dB(A) and 80dB(C). At Bennelong Apartments, road traffic and pedestrian noise often results in levels above 60dB(A).

The attended noise measurement data indicate that the nearest residential receivers across the Harbour are in a relatively low-noise environment (when compared with the Bennelong Apartments in the CBD). The quietest receivers at Mosman and parts of Cremorne are relatively far from the Sydney Opera House site.

Auditoria Pty Ltd have prepared a detailed environmental noise report for the Bennelong Apartment area, and found that typical noise in the area regularly exceeds 65dB(A). They also found that the daily fluctuation in background and ambient noise levels from Monday through to Sunday (inclusive) is in the order of 2-3dB(A&C). This suggests a consistent urban hum throughout the week, and is supported by Acoustic Studio's observations of the area during evening and night time surveys.

| Location | Period | Day | Descriptor | Noise Level | | Report |
|---------------------------------|-----------------------------|--------------------|------------------|---------------|---------------|--------|
| | | | | Overall dB(A) | Overall dB(C) | |
| P1: Bennelong Apartments | 14:00-18:00 (Day) | Tuesday, Wednesday | L _{max} | 60 - 65 | 80+ | B |
| | 11:30-16:30 (Day) | Saturday | L ₉₀ | 63 - 66 | 81 - 83 | D |
| | 16:00-22:00 (Day / Evening) | Sunday | L ₉₀ | 61 - 64 | 75 - 76 | E |
| | 15:00-20:30 (Day / Evening) | Wednesday | L ₉₀ | 64 - 73 | 75 - 78 | G |
| | 18:00-22:00 (Evening) | Wednesday | L ₉₀ | 59 - 61 | 74 - 75 | C |
| | 18:00-22:00 (Evening) | Wednesday | L ₉₀ | 64 - 65 | 77 - 80 | C |
| | 19:00-22:00 (Evening) | Friday | L ₉₀ | 60 - 64 | 74 - 76 | F |
| | 18:00-22:30 (Evening) | Sunday | L ₉₀ | 64 - 68 | 74 - 78 | F |
| P2: Beulah St Wharf | 13:00-18:00 (Day) | Monday | L _{eq} | 57 - 61 | 69 - 73 | A |
| | 13:00-18:00 (Day) | Monday | L _{max} | 62 - 63 | 82 | A |
| | 14:00-21:30 (Day / Evening) | Tuesday | L _{max} | 60+ | 80+ | B |
| P3: SOH FOH ambient (no events) | 13:00-18:00 (Day) | Monday | L _{eq} | 69 | 77 | A |

Table 4: Ambient and background noise levels, measured for event noise monitoring reports.

6 Project Noise Criteria

6.1 Noise Criteria Review Approach

6.1.1 Reviews of existing noise criteria

The following standards and guidelines are considered relevant to the project and have been referenced in developing the project noise criteria:

- Protection of the Environmental Operations (POEO) Act 1997.
- Environmental Planning and Assessment (EP&A) Act 1979.
- Previous Planning Approvals for Sydney Opera House outdoor events on the Forecourt & Western Broadwalk, Notice of Determination for DA 445-10-2003 (6 June 2004).
- State Environmental Planning Policy (Major Development) 2005, Schedule 3 Significant Sites.
- City of Sydney (CoS) Standard Conditions of Development Consent (SCDC) 2012.
- NSW EPA Industrial Noise Policy (INP) 2000.
- NSW EPA Interim Construction Noise Guideline (ICNG) 2009.
- NSW EPA Road Noise Policy (RNP) 2011.
- Australian Standard 2107:2000 *Acoustics – Recommended design sound levels and reverberation times for building interiors*
- Australian Standard 3671:1989 *Acoustics – Road traffic noise intrusion – Building siting and construction*

6.1.2 Reviews of existing noise monitoring reports and technical studies

Environmental noise criteria require an understanding of existing environmental noise in the absence of the proposed activities, to determine how audible and noticeable the activities are for sensitive receivers.

The key question for the assessment concerns whether the current noise limits are appropriate for the site, and whether the method of measurement is robust for the purposes of monitoring and managing noise impacts from outdoor events.

Acoustic Studio has conducted a review of event noise monitoring reports by various external providers for the SOH, and also detailed background and event noise studies by Auditoria Pty Ltd. The aim of the review is to determine whether the DA-445-10-2003 noise limits are appropriate for this particular environment.

6.2 External Noise Emission Criteria – General Noise

6.2.1 Environmental Planning and Assessment Act (EP&A) 1979

The Environmental Planning and Assessment Act 1979 (EP&A Act) regulates the majority of planning approval and environmental impact assessment (EIA) requirements in NSW. Section 111 of the Act requires examination and consideration to the fullest extent possible of all matters affecting or likely to affect the environment by reason of its activities. Acoustic impacts are a common community concern to be addressed in an EIA.

6.2.2 Protection of the Environment Operation Act (POEO) 1997

The POEO Act defines “Offensive Noise” as follows:

- (a) *that, by reason of its level, nature, character or quality, or the time at which it is made, or any other circumstances:*
 - (i) *is harmful to (or is likely to be harmful to) a person who is outside the premises from which it is emitted, or*
 - (ii) *interferes unreasonably with (or is likely to interfere unreasonably with) the comfort or repose of a person who is outside the premises from which it is emitted, or*
- (b) *that is of a level, nature, character or quality prescribed by the regulations or that is made at a time, or in other circumstances, prescribed by the regulations.*

Defining “offensive noise” for the purpose of an acoustic assessment is not a simple matter. The “regulations” referred to in (b) above are the POEO (Noise Control) Regulations (2008). Very few of these apply to Sydney Opera House activities.

Whether noise from the Sydney Opera house activity is “offensive” therefore reduces, in most cases, to a question of whether it meets part (a) of the definition. There are no clear-cut criteria for this, but consideration can be given to:

- Whether the level of noise exceeds applicable goals and guidelines,
- Whether the nature, character or quality of the noise is “offensive” due to such characteristics as tonality, impulsiveness, heavy low-frequency or verbal content,
- Whether the time at which it is made is problematic, such that it could interfere with sleep, etc.

The Noise Guide for Local Government (Office of Environment and Heritage, 2013) provides a checklist for offensive noise, which can be applied to any noise-generating activities. In addition to the considerations listed above, the OEH checklist addresses:

- The loudness of the noise, especially compared with other noise in the area
- The character of the noise
- The time and duration of the noise
- Whether the noise is typical for the area

- How often the noise occurs
- The number of people affected by the noise

The remaining consideration relates to “reasonable measures”. It may be reasonable, for example, to manage a noise issue arising from night-time functions in the outdoor area. It may not be “reasonable”, on the other hand, to expect a significant reduction in noise from typical existing patron noise during normal operating hours.

6.2.3 New South Wales Industrial Noise Policy (INP)

The INP applies to fixed facilities, commercial premises and individual industrial sources such as heating, ventilating and air conditioning (HVAC) equipment. It is also typically applied for general maintenance noise such as cleaning activities, and in this case may be applied for activities associated with installation and dismantling temporary equipment and structures used for SOH outdoor events (bump-in, bump-out).

The NSW INP defines environmental industrial noise goals in two ways. The goals apply at the most-affected point on or within the residential boundary and are location-dependent. They also depend on the receiver occupancy: residential, commercial, etc.

The INP considers the following when establishing the criteria:

- The *time of day* that the noise generating development will be in operation.
- The existing *Ambient* (L_{eq}) and *Background* noise levels (L_{90}) that surround the site.
- The *type of noise source* and its characteristics. The INP provides modifying factors for noise with certain characteristics that may potentially cause annoyance.

The residential ***intrusiveness*** criterion aims to control short duration noise impacts and is based on the existing background noise level, and is defined as:

$$L_{Aeq,15 \text{ minute}} \text{ from new noise source} \leq \text{Existing long-term } L_{A90,Day/Evening/Night} + 5.$$

The residential ***amenity*** criterion aims to maintain noise amenity for a particular land use. It defines recommended noise levels, called Acceptable Noise Levels (ANL), for different neighbourhood types.

Bennelong Apartments is classified as an Urban Residential receiver, but the noise logger data suggest that it is an area with higher noise levels than are assumed in the INP. Similar high ambient noise levels were measured at Kirribilli, compared with suburban residential ANLs. The high ambient noise levels relative to the Urban ANL result in a situation where it is acceptable to apply a modified ANL, being 10dB below the existing ambient.

The INP adopts a 5dB “penalty” for low-frequency dominant noise, which it defines as when the difference between the C-weighted and A-weighted level is 15dB or more. This assessment considers whether the current noise limits encourage a low-frequency dominance which is considered by the NSW EPA to be more disturbing to residential receivers.

6.2.4 Sleep disturbance

Some short-duration noises that occur at night may comply with the overall criteria, but be undesirable because of the sleep arousal effect, particularly between the hours of 10pm and 7am.

The INP Application Notes provide guidance on the assessment of sleep disturbance based on the predicted event L_{Amax} or $L_{A1,1minute}$ noise levels at the receiver. It suggests setting a Sleep Disturbance criterion of:

$$\text{Event } L_{Amax} \text{ or } L_{A1,1minute} > \text{Night time RBL (background noise level) + 15 dB.}$$

If the maximum noise emergence above background is less than 15 dB, then the noise is considered unlikely to cause sleep disturbance. If the screening test level is exceeded, then further assessment of sleep disturbance effects is warranted.

Sydney Opera House outdoor events may operate later than 10pm, and there is the additional potential for patrons to create noise disturbances as they depart the Opera House precinct after late-night functions.

Patron noise impacts along east Circular Quay have therefore been assessed against the sleep disturbance screening criterion, ie $\text{Event } L_{Amax} \text{ or } L_{A1,1minute} > \text{RBL (background noise level) + 15 dB.}$

At Bennelong Apartments, during Sydney Opera House operational night-time hours (10pm to 11:30pm), the sleep disturbance screening level is $58+15 = 73\text{dB(A)}$.

At Kirribilli, during Sydney Opera House operational night-time hours (10pm to 11:30pm), the sleep disturbance screening level is $50+15 = 65\text{dB(A)}$.

The sleep disturbance criterion $L_{A1, (1 \text{ minute})}$ not exceeding the $L_{A90, (15 \text{ minute})}$ by more than 15 dB(A) is a screening criterion, not an absolute goal for the purpose of assessing impact from a project. It applies outside bedroom windows during the night-time period.

If the Sleep Disturbance screening criterion is exceeded, the detailed analysis should cover the extent to which the maximum noise level exceeds the background level and the number of times this happens during the night-time period. Some guidance on possible impact is contained in the review of research results in the *NSW Road Noise Policy* (2011).

Other factors that may be important in assessing the extent of impacts on sleep include:

- How often high noise events will occur
- Time of day (normally between 10pm and 7am)
- Whether there are times of day when there is a clear change in the noise environment (such as during early morning shoulder periods).

A further consideration for sleep awakening is whether the environmental noise has changed. The NSW *Road Noise Policy* (RNP, 2011) Section 5.3 “Response to a Change in Noise Level” states:

While people may express a certain tolerance for their existing noise environment, they may feel strongly about increases in noise. [...] The difference in reported awakenings from sleep was equivalent to a difference of 7 dB in maximum noise levels.

The RNP Section 5.4 “Sleep Disturbance” states that from the research on sleep disturbance to date it can be concluded that:

- Maximum internal noise levels below 50–55 dB(A) are unlikely to awaken people from sleep
- One or two noise events per night, with maximum internal noise levels of 65–70 dB(A), are not likely to affect health and wellbeing significantly.

The internal noise levels provided in the RNP are related to potential sleep awakenings.

It is understood that Bennelong Apartments planning approval will have included a requirement to consider existing environmental noise levels in the design of the façade elements. Existing ambient noise levels at Bennelong Apartments are between 53dB(A) at night and 58dB(A) during the day. To achieve internal noise levels in sleeping areas which meet Australian Standard *Acoustics – Recommended design sound levels and reverberation times for building interiors* (AS2107:2000), the façade will need to provide a minimum level difference of 23dB.

AS3671:1989 *Acoustics – Road traffic noise intrusion – Building siting and construction* was the applicable standard for building façade construction when Bennelong Apartments was designed and approved. Clause 3.3 of this Standard requires that with a required traffic noise reduction of 10-25dB(A), a façade noise reduction of 25dB(A) is required. This is a conservative assumption since apartment windows for inner city developments typically require glazing system performances that can achieve at least 25-30dB in situ sound attenuation.

Based on a minimum attenuation of 25dB(A) with windows and doors closed, the first conclusion of the RNP suggests that short term external noises of 75 to 80 dB(A) are unlikely to cause awakening reactions. In addition, external levels of 90 to 95dB(A) are unlikely to affect health and wellbeing significantly, provided that these events occur no more than twice in one night.

6.2.5 New South Wales Interim Construction Noise Guideline (ICNG)

The ICNG applies to construction, demolition and maintenance activities. It is not strictly relevant to the proposed outdoor events, but serves as a useful reference for assessing noise impacts for activities associated with installation and dismantling temporary equipment and structures used for SOH outdoor events (bump-in, bump-out).

The ICNG does not require quantitative impact assessments for construction activities lasting under three weeks, which is typical of SOH outdoor event bump-in and bump-out activities. A qualitative approach to identifying and managing high impact activities is suggested for short-term works.

However, where the risk of impacts warrants a quantitative review even for short duration works, the following $L_{Aeq(15\text{minute})}$ criteria apply.

- Day (7am to 6pm weekdays, 8am to 1pm Saturdays): background +10dB
- Evening (6pm to 10pm weekdays, typically interpreted as 1pm to 10pm Saturdays): adopt background + 5dB. Note that this time period may not be applicable to busy urban environments that do not experience large noise level variations between weekdays and weekends.
- Night (10pm to 7am): adopt background noise levels, and the Sleep Disturbance screening criterion of $L_{A1} \leq \text{background} + 15\text{dB}$.

Like the INP, the ICNG adopts a 5dB “penalty” to intermittent, tonal, or low-frequency-dominant noise emissions from construction activities.

The standard works hours in the ICNG would not apply to outdoor event bump-in and bump-out activities, since they are operational rather than construction activities.

6.2.6 City of Sydney - Standard Conditions of Development Consent (CoS SCDC)

The CoS SCDC were removed from the City of Sydney web site in mid-2014. However, the document offers a relevant reference for noise emissions from general noise sources.

General

The CoS SCDC notes the following general requirements for noise control.

“...(62) NOISE – GENERAL

- (a) *The emission of noise associated with the use of the premises including the operation of any mechanical plant and equipment shall comply with the following criteria:*
 - i. *The L_{Aeq} , 15minute noise level emitted from the use must not exceed the background noise level LA_{90} , 15minute by more than 5dB when assessed at the boundary of any affected residence.*
 - ii. *The L_{Aeq} , 15minute noise level shall be adjusted for modifying factors in accordance with Appendix 2 of the Noise Guide For Local Government published by DECCW.*
 - iii. *The background noise level shall be measured in the absence of noise emitted from the use in accordance with Australian Standard AS 1055.1-1997- Description and measurement of environmental noise.*
 - iv. *The use of the premises shall be controlled so that any emitted noise is at a level so as not to create an "offensive noise" as defined in the Protection of the Environment Operations Act 1997 to any affected residence.*

Internal Residential Amenity

- (b) *An L_{Aeq} , 15minute noise level emitted from the use must not exceed the LA_{90} ,*

15minute noise level by more than 3dB in any Octave Band Centre Frequency (31.5 Hz to 8 kHz inclusive) when assessed inside any habitable room of any affected residence provided that:

- i. Where the LA90, 15minute noise level is below the threshold of hearing Tf at any Octave Band Centre Frequency as defined in Table 1 of International Standard ISO 226 - Normal Equal-Loudness-Level Contours then the value of Tf corresponding to that Octave Band Centre Frequency shall be used instead.*
- ii. The LAeq,15minute noise level and the LA90,15minute noise level shall both be measured with all external doors and windows of the affected residence closed;*
- iii. The LA90,15minute noise level shall be measured in the absence of noise emitted from the use but with the (excluding air-conditioning equipment) normally servicing the affected residence operating...”*

6.2.7 Road Traffic Noise

This acoustic report does not quantify potential road traffic noise impacts. It is understood from the 2016 Draft Traffic Management Report for the Sydney Opera House that regular SOH patrons, staff and road traffic numbers are unlikely to change due to this project, and that patrons of outdoor events will be encouraged to use public transport. Noise from pedestrians moving to and from public transport has been assessed in this report.

Any potential increase in traffic will need to be assessed if the Sydney Opera House proposes that outdoor events will occur outside public transport operating hours. This is not part of the current proposal.

Applicable guidelines for road traffic noise impacts are:

- NSW EPA *Road Noise Policy* (2011)
- Australian Standard AS 3671-1989 *Acoustics – Road traffic noise intrusion – Building Siting and Construction* (for guidance only; applies to siting of the receiver buildings).

6.2.8 Noise criteria for patron noise

The impact of event patrons walking to and from the events should be assessed for the urban receivers near Government House, Bennelong Apartments, and around western Circular Quay.

There are no directly applicable guidelines or planning policies defining patron noise level criteria. It is generally understood that patron noise is controlled through management techniques. Examples of such management methods are presented in this report.

Acoustic Studio generally adopts a numeric assessment approach, to objectively determine whether expected patron noise levels have the potential to disturb sensitive receivers.

For night-time noise levels, the Sleep Disturbance screening method (background + 15dB) described in Section 6.2.4 provides a useful measure of patron noise intrusiveness.

In this busy urban environment, for day-time and evening periods (7am to 10pm), it is reasonable to adopt a target of background + 20dB. The background + 20dB target matches the 1994 EPA Environmental Noise Control Manual criterion for short term construction noise. It is reasonable to assume that such levels are considered to be acceptable during the day, provided they are temporary in nature (as is the case for the Sydney Opera House outdoor events).

Although it is understood that pedestrian noise is a constant feature of the Circular Quay Day and Evening and early Night-time ambient environment, Acoustic Studio also recommends management methods for patron noise. This is in recognition of the fact that events may increase the number of pedestrians passing Bennelong Apartments on their way to and from the events.

6.2.9 Summary of noise targets for general event noise

The overall approach for setting noise targets for general noise is related to the emergence of the noise above background. Noise targets are aligned with the overall A-weighted approach in the NSW EPA INP:

- Industrial-type noise such as for plant 5dB above the background: 63dB(A)
- Construction type noise during the day can be 10dB above background: 65dB(A)
- Bump-out noise at night can be 5dB above background for energy averaged sound levels: $63\text{dB}L_{Aeq(15\text{min})}$ and 15dB above background for maximum levels: $73\text{dB}L_{A1,1\text{minute}}$
- High noise events such as from patrons can be 20dB above background during day and evening, and 15dB above background during night-time operational hours: 80-81dB(A) 8am to 10pm, 73dB(A) 10pm – 11:30pm.

The noise target values listed above relate to Bennelong Apartments. The same approach is to be adopted at other residential receivers.

6.3 External Noise Emission Criteria – Sound System Noise

6.3.1 General Approach

This proposal seeks approval for up to 99 Performing Arts / Community Event / Corporate Function event days per year. Based on information provided by the Sydney Opera House, Acoustic Studio understands that there will either be a reduction or no change in the number of event days in a year.

Acoustic Studio recognises that there have been difficulties in the measurement of event noise since 2004.

This environmental noise assessment aims to determine appropriate numeric noise criteria for amplified and unamplified music from outdoor events. Criteria are to be based on local and state environmental noise policies, guidelines and conditions.

Technical acoustic studies by Auditoria Pty Ltd in this local area have been used to obtain local environmental noise data, event noise levels, and to review the suitability of the L_{Amax} and L_{Cmax} noise criteria at Bennelong Apartments.

This acoustic assessment seeks to establish suitable noise criteria for the amplified music.

The steps taken in reviewing the noise criteria have been discussed with the Department of Planning as the conclusion of the review indicated that current monitoring methods are not conducive to effective management of amplified sound system noise at events. The steps in the review are discussed in detail below.

6.3.2 Noise Emission Criteria for Sydney Opera House outdoor events (amplified music)

The DA-445-10-2003, which the Sydney Opera House seeks to modify, contains the following noise limits:

- Sunday to Thursday: $65dB_{LAmax}$ and $85dB_{LCmax}$ at Bennelong Apartments, and $60dB_{LAmax}$ and $80dB_{LCmax}$ at any other residential receiver. Up until 11pm.
- Friday to Saturday: $70dB_{LAmax}$ and $90dB_{LCmax}$ at Bennelong Apartments, and $65dB_{LAmax}$ and $85dB_{LCmax}$ at any other residential receiver. Until midnight for Corporate Events, until 11pm for Performing Arts / Community Events.

Acoustic Studio assumes that these levels also apply to music from sound checks as well as the event itself.

SEPP (Major Development) 2005 provides for two types of outdoor events at the Sydney Opera House: Non-ticketed public functions including New Years Eve celebrations; and up to 40 days of private or commercial “minimal impact” events related to the primary function of the Opera House as a performing arts centre (with up to 5000 people attending each event at any one time).

The SEPP noise limits are also $65-70dB_{LAmax}$ and $85-90dB_{LCmax}$ for the 40 “minimal impact” event days, depending on time of the day of the week.

The noise limits apply at a point within 1 metre of the residential boundary nearest to the Sydney Opera House at Bennelong Apartments, East Circular Quay, and other affected residential receivers such as:

- Beulah Street Wharf (off Waruda Street), Kirribilli,
- Cremorne Wharf (off Milson Road), Cremorne Point,
- Dawes Point Park (off Lower Fort Street), Millers Point.

Three elements to consider for the suitability of the noise limits to Sydney Opera House outdoor event noise are:

- Appropriate level, in the context of the local environment(s);
- Necessity for different criteria for different days of the week;
- Measurement method provides a robust way to identify event noise instead of general extraneous environmental noise.

6.3.3 City of Sydney - Standard Conditions of Development Consent (CoS SCDC)

The CoS SCDC offers a relevant reference for noise emissions from entertainment venues.

Licensed Premises

The CoS SCDC outlines the following noise criteria specific to the operation of a licenced premise:

“(61) NOISE – LICENSED PREMISES

- (a) The L_{A10} noise level emitted from the use must not exceed the background noise level (L_{A90}) in any Octave Band Centre Frequency (31.5 Hz to 8 kHz inclusive) by more than 5dB between the hours of 7.00am and 12.00 midnight when assessed at the boundary of any affected residence.*
- (b) The L_{A10} noise level emitted from the use must not exceed the background noise level (L_{A90}) in any Octave Band Centre Frequency (31.5 Hz to 8 kHz inclusive) between the hours of 12.00 midnight and 7.00am when assessed at the boundary of any affected residence.*
- (c) Notwithstanding compliance with (a) and (b) above, the noise from the use must not be audible within any habitable room in any residential property between the hours of 12.00 midnight and 7.00am.*
- (d) The L_{10} noise level emitted from the use must not exceed the background noise level (L_{A90}) in any Octave Band Centre Frequency (31.5 Hz to 8 kHz inclusive) by more than 3dB when assessed indoors at any affected commercial premises.*
- (e) The use of the premise must be controlled so that any emitted noise is at a level so as not to create an “offensive noise” as defined in the Protection of the Environment Operations Act 1997 to any affected receiver. ...”*

Acoustic Studio considers that the CoS environmental noise criteria for sound systems and patrons provide a useful reference in the review of the current Sydney Opera House outdoor event noise limits.

Aspects to note regarding the application of the CoS SCDC are:

- The “background level” is not explicitly defined in either document. Acoustic Studio determines the existing background noise level in accordance with the NSW Industrial Noise Policy (INP) 2000 (see section below). The Day, Evening and Night time background noise levels are used to determine environmental noise

criteria. In accordance with the INP, only the operational hours are considered in the assessment (ie 10pm to 11:30pm for night time hours).

- The method of comparing the noise source with background levels in octave frequency bands requires a greater level of detail with measurements than have been required for Sydney Opera House events in the past. This acoustic assessment therefore considers whether simpler overall A-weighted and C-weighted measurements are suitable measures of outdoor event noise, and compares the assessment procedure with the CoS frequency band requirements.

One point of difference between SEPP and CoS noise requirements is the assessment of premises noise and background noise in frequency bands. Acoustic Studio has compared measured noise levels from patrons and typical amplified music with background noise levels measured at representative receiver locations. In most cases the overall A-weighted and C-weighted criteria adequately reflect the intent of the frequency-based noise criteria, and simplifies measurements and compliance monitoring. Octave band measurements would still be required for fine-tuning sound output during sound checks and events.

6.3.4 Days of the week

Adopting a single noise limit for any day of the week would provide a simpler approach for monitoring and managing events.

The current DA-445-10-2003 noise criteria allow a 5dB increase in event noise level on Friday and Saturday. This is presumably based on the assumption that weekend background and ambient noise levels are up to 5dB higher than weekdays.

Auditoria's analysis of background and ambient noise level fluctuations through two typical weeks in summer and winter 2016 show variations of 2-3dB, which is considered minor and furthermore showed no consistent drops or elevations during certain days of the week; that is, there was no measured elevation in ambient noise levels over the weekend, compared with weekdays.

A single noise criterion for every day of the week would not increase existing impacts, provided that the maximum allowable noise value is appropriate for the local environment.

The graph below presents the measured background and ambient noise levels at Bennelong Apartments through the days of the week.

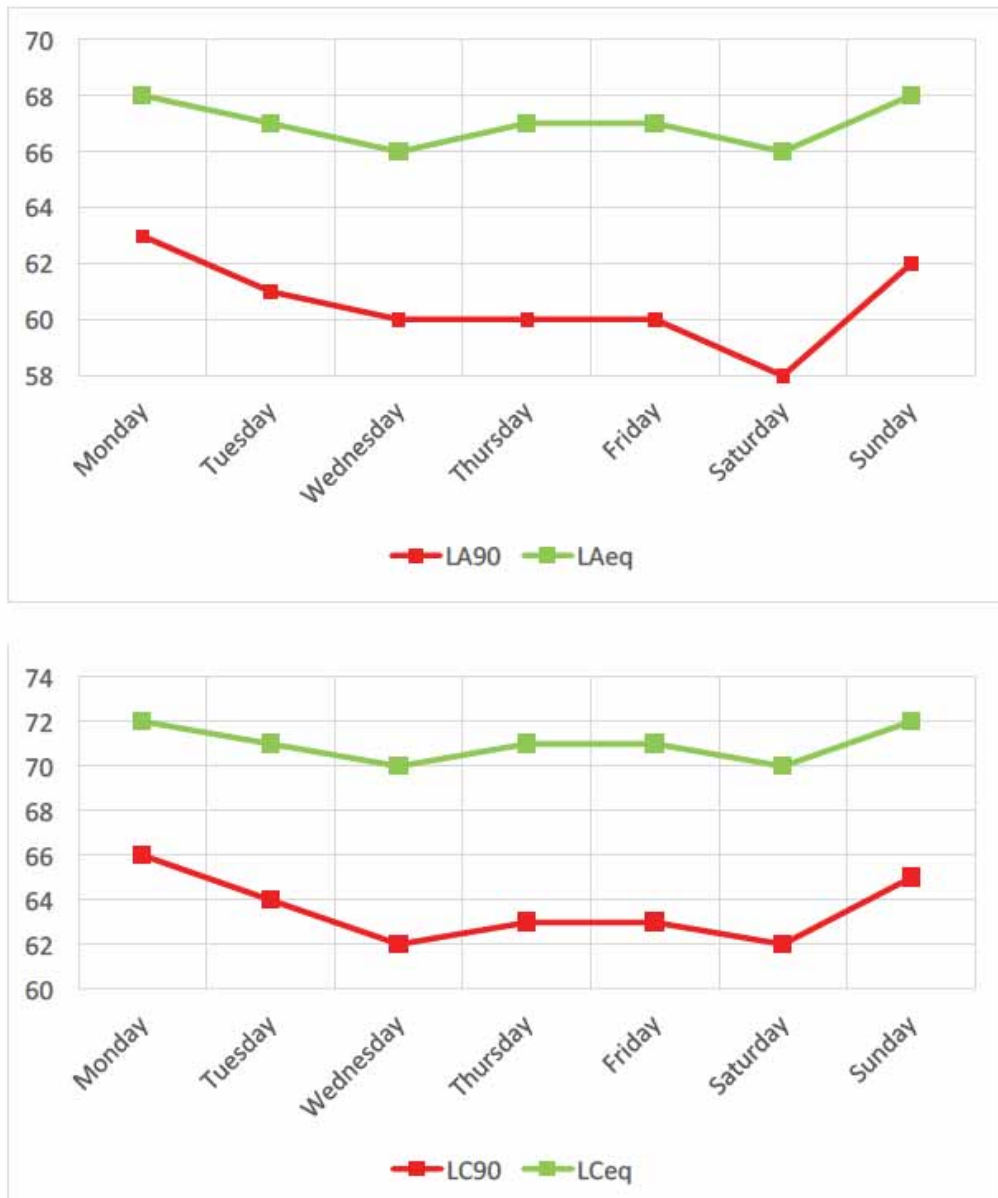


Figure 3: Fluctuations in noise level data (background $L_{A/C90}$) and ambient ($L_{A/Ceq}$) measured through a typical summer week at Bennelong Apartments. Courtesy of Auditoria Pty Ltd.

6.3.5 Noise limit value

Auditoria Pty Ltd has reviewed noise complaints made in response to events held at the SOH Forecourt, and concluded that an event noise level of $90\text{dB}L_{C,\text{max}}$ at Bennelong Apartments correlates with when noise complaints may be made. This is in line with the Friday / Saturday C-weighted noise limit. The existing 6pm – 11:30pm ambient noise levels at Bennelong Apartments is $67\text{--}70\text{dB}L_{Ceq}$, and background levels are $54\text{--}59\text{dB}L_{C90}$.

The corresponding A-weighted noise limit for Friday / Saturday is $70\text{dB}L_{A,\text{max}}$ at Bennelong Apartments.

Auditoria found no correlation between exceeding the A-weighted noise limit and receiving noise complaints at this location. This is most likely due to the limit being so

similar (within 3-5dB) to existing ambient noise levels in the area.

The C-weighted noise limit represents a reasonable balance between the requirements of the music experience and preserving residential amenity. However, the A-weighted noise limit could be lifted by 5-10dB, and still achieve acceptable acoustic amenity for residential receivers, in terms of emergence above existing ambient and reducing low-frequency dominance. Setting the A-weighted limit 20dB below the C-weighted limit promotes a more annoying, low-frequency dominant noise output, applying NSW EPA INP definitions (refer Section 6.2.3).

A night time A-weighted noise limit of $75\text{dB}L_{A\text{max}}$ is 8-10dB above the existing 7am-11:30pm ambient levels at Bennelong Apartments.

Receivers located farther away from the SOH than the Bennelong Apartments experience lower background and ambient noise levels. Therefore it is appropriate to adopt lower event noise criteria at other residential receiver locations.

Therefore Acoustic Studio proposes retaining the existing approach for any other residential receiver area other than Bennelong Apartments, with noise limits being set to 5dB less than at Bennelong Apartments.

Acoustic Studio recommends the following environmental noise targets:

- $75\text{dB}L_{A\text{max}}$ and $90\text{dB}L_{C\text{max}}$ at any time, at Bennelong Apartments, and
- $70\text{dB}L_{A\text{max}}$ and $85\text{dB}L_{C\text{max}}$ at any time, at other residential receiver locations.

6.3.6 Noise measurement method for outdoor events

This section considers whether the L_{max} is an appropriate measure of event noise in the context of Circular Quay, which already has many high noise events. It takes into account detailed studies by Auditoria Pty Ltd into the local ambient noise environment and Sydney Opera House Southern Forecourt event scenarios.

Existing C-weighted ambient noise levels are significantly lower than the current C-weighted performance noise criteria. That is because there are few sustained low-frequency noise sources in the local environment, whereas music events tend to have a strong low-frequency (bass) content. This makes the C-weighted performance noise more straightforward to measure and identify. There is still, however, the risk that many maximum noise events are not associated with performance noise.

SOH has provided Acoustic Studio with the results of an acoustic assessment by Auditoria Pty Ltd, which details an alternative noise assessment approach for events taking place at the Forecourt or Monumental Steps. This assessment makes the same observations, that measuring A-weighted event maximum levels is extremely difficult due to ambient levels being similar to the criterion. It also reports that C-weighted event levels are easier to identify as performance-related, due to the emphasis on low-frequency music sound content.

Auditoria suggest an alternative approach to measuring performance noise from the SOH outdoor events, which provides a robust method for ensuring that the reported noise measurement is related to the performance (and not an extraneous environmental event such as a car or ferry horn).

Auditoria suggest applying a 5-minute measurement of performance noise, and reporting L_{eq} levels rather than L_{max} levels. This means that sudden, isolated high noise events not typically associated with event noise are discarded from the reported levels.

It may be argued that L_{10} (the highest 10 percent of the sound) would be a more appropriate measure of the “typical noisiest” event level in the five minute measurement period. For reference, the CoS requires that the top 10% of the noise (L_{A10}) generated before midnight does not exceed background noise levels by more than 5dB.

There are three reasons for considering that the $L_{eq(\text{five minute})}$ measure is appropriate for this type of noise source:

- The five-minute measurement interval is long enough to capture reasonably continuous event noise levels, but not so long that the L_{eq} sound energy-averaging integration method does not obscure the instances of high noise events. For most music noise, the $L_{eq(5\text{min})}$ would be numerically similar to the $L_{10(15\text{minute})}$.
- The L_{eq} is a noise level measurement that describes sound energy averaging, and can be used in calculations. For example, it may be used to calculate the contribution of different noise sources to produce a cumulative effect. The L_{10} is a statistical measure, representing the 90th percentile noise. It cannot be used for many further analyses, modelling or calculations.
- Recent guidelines issued by the NSW EPA suggest that, according to the latest research into annoyance due to environmental noise, the L_{eq} descriptor is a reliable indicator of community annoyance. For example, the 2009 NSW EPA *Interim Construction Noise Guideline* departed from the previous *Environmental Noise Control Manual* L_{A10} and / L_{Amax} criterion to adopt an $L_{Aeq(15\text{ minute})}$ noise management level for construction noise emissions.
- A 15-minute measure is considered to be too long to effectively manage amplified sound system outputs as there is a potential 15-minute delay between measurement and actions to reduce levels at the source.

Care is required to note the numeric difference between L_{max} and $L_{eq(5\text{ minute})}$ for typical outdoor event noise. This is to ensure that the event noise criterion is appropriately set, and not unintentionally increased through the use of a different measurement method.

Auditoria’s analysis of music noise levels from the Forecourt has concluded that an event noise level of $86\text{dB}L_{Ceq(5\text{ minute})}$ is approximately equivalent to $90\text{dB}L_{C,max}$ at Bennelong Apartments.

This acoustic assessment report aims to preserve the current environmental noise limits,

although adopting an alternative method of measuring and reporting these noise limits which would be more robust and effective.

The equivalent noise levels at residential receivers would be:

- 71dB $L_{Aeq(5min)}$ and 86dB $L_{Ceq(5min)}$ at any time, at Bennelong Apartments, and
- 66dB $L_{Aeq(5min)}$ and 81dB $L_{Ceq(5min)}$ at any time, at other residential receiver locations.

6.3.7 Measuring environmental noise levels

The difference between C-weighted and A-weighted existing background and ambient noise levels at Bennelong Apartments is approximately 3-4dB. In contrast, the C-weighted performance noise criteria are set to 20dB above the A-weighted criteria (refer Section 6.3.2).

A-weighted background noise levels at Bennelong Apartments are 58-61dB(A) between 7am and 11:30pm, which is 9-10dB below a 70dB L_{Amax} event noise criterion. Ambient noise levels at this location are 65-69dB L_{Aeq} , which is 1-4dB below a 70dB L_{Amax} event noise criterion.

The fact that the A-weighted noise criterion is so similar to existing ambient, particularly during the Day, Evening and early Night (10pm to 11:30pm), makes it very difficult to measure in practice, and very difficult to meet Condition 34(a) of DA-445-10-2003:

34. The L_{Amax} and L_{Cmax} must be measured:

a) in the absence of any influential sound, that is audibly distinguishable and extraneous to the sound from the amplification equipment associated with the event or function

Acoustic Studio has conducted a review of recent SOH outdoor performance noise environmental monitoring reports. The reports confirm Acoustic Studio personnel experience in that SOH event maximum noise levels rarely coincided with performance noise, but was rather associated with unrelated events such as ferry horns at Beulah Street Wharf, or a noisy passer-by at Bennelong Apartments.

Auditoria Pty Ltd have also found that the A-weighted noise limit is so close to the ambient that it is in most cases impossible to measure accurately, either as a maximum event level or an $L_{Aeq(5min)}$ level. Performance noise levels reaching the A-weighted noise limit are not subjectively intrusive above the prevailing ambient, unless there is a heavy low frequency content that is clearly audible.

In contrast to the A-weighted levels, C-weighted background noise levels at Bennelong Apartments are 61-64dB(C) between 7am and 11:30pm, which is 26-29dB below a 90dB L_{Cmax} event noise criterion. Ambient noise levels at this location are 69-72dB L_{Ceq} , which is 18-21dB below the 90dB L_{Cmax} event noise criterion.

From the A- and C-weighted noise level comparison, it is clear that the C-weighted measurement provides the clearest indicator that the noise being measured is from event noise rather than other typical environmental noise features.

The A-weighted measurement at environmental receiver locations has little meaning, being difficult to measure above ambient, and does not generally assist with effective management of amplified noise levels from outdoor events.

6.3.8 Noise measurement location for outdoor events

The previous section concluded that A-weighted noise measurements at environmental receivers has little benefit for effective amplified sound noise management control.

One option which has been examined is removing the A-weighted criterion altogether, and simply adopt a C-weighted environmental noise criterion.

It is important to review potential impacts due to removing an A-weighted environmental noise criterion, to ensure that this would not result in acceptably high A-weighted noise levels.

Acoustic Studio and Auditoria have conducted independent reviews of measured amplified rock and pop performance noise levels. The difference between A-weighted and C-weighted levels is typically 10-15dB. Smaller differences occur for quieter types of music which are unlikely to exceed (or come close to) the applicable noise limits at any residential receiver. Performance sound with a large difference between A- and C-weighted levels, aiming to meet environmental noise limits set 20dB apart, has in the past led to a bass-heavy sound which is both unnatural for the audience and more likely to generate environmental noise complaints due to low frequency dominance.

Based on this analysis, Acoustic Studio concluded that removing the A-weighted environmental noise limit would not represent a change in outcome for residents.

However the problem remained relating to the fact that environmental monitoring for outdoor events is in itself problematic. This difficulty is evident in the historical data and matches the experience of Acoustic Studio and Auditoria in measuring outdoor event noise.

The variables that affect the measured event noise level at environmental receivers make it difficult to monitor for compliance.

In addition, effective control of the sound system output depends on the skill of the environmental noise monitoring consultant in examining measured sound level in frequency bands, and effectively communicating to the sound system operator which frequency bands need to be turned down.

The Sydney Opera House therefore proposes to adopt Front of House noise limits, which are set to achieve acceptable environmental noise levels at the most affected residential receivers. At Front of House it is clear that the dominant noise source being measured is the sound system. An A-weighted criterion can be adopted, and also either a C-weighted limit or a 63Hz and 125Hz limit which appropriately deals with low frequency (bass) noise impacts.

Acoustic Studio considers that the Front of House noise limit approach has several advantages, and notes its successful application for outdoor event venues in Queensland.

An advantage for noise compliance and auditing is being able to confidently and robustly measure amplified noise levels being close to the source.

A major advantage for noise management is that the measurement is taken close to the sound system operator, which allows effective communication and therefore action about the amplitude and frequency of the sound levels with respect to the limits. The sound system operator can confidently understand which frequency/ies to reduce, and by how much, because the measured level is not affected by event-specific variables such as local screening, sound system set up, and so on.

It is essential that the Front of House noise limit would be adopted in conjunction with stringent outdoor event noise management plans, which would ensure that effective noise management controls are required for all outdoor events. Noise management requirements would include selecting directional loudspeakers and subwoofers, and appropriate sound system set up to minimise environmental noise spill. Event managers would also be required to consider feasible and reasonable noise controls such as local screening.

A 63Hz and 125Hz limit was considered and compared with a C-weighted limit. It is the opinion of Acoustic Studio that the C-weighted criterion adequately reflects the intent of managing low frequency (bass) noise emissions. Furthermore, a wide range of equipment is available which measures A- and C-weighted levels, while measuring octave band levels is often not a standard feature.

6.3.9 Proposed noise limit for outdoor events

Acoustic Studio has reviewed noise measurements from various event types, with amplified pre-recorded music, live music, and audiences from 500 people to several thousand. The sound spectrum in octave bands was analysed for the different jazz / pop / rock music types which were the noisiest events measured.

The sound spectrum showed that, unsurprisingly, the bass content was the most variable element of the different music types. The mid to high frequency output tends to vary according to audience size while the bass (low frequency) content increases for rock and some dance performances when compared with pop, jazz and “acoustic” genres. That is, the A-weighted level increases with audience size, while the C-weighted level or the individual 63Hz and 125Hz linear levels increase both with audience size and with bass-heavy music genres such as rock with bass and drums, classical with heavy percussion elements such as timpani, or non-western musical genres such as taiko drums.

Auditoria Pty Ltd conducted noise modelling and reviewed historical noise data for Front of House and environmental measurement locations. Three configurations were assessed:

1. Typical Large Events (north-south orientation)
2. Australia Day (east-west orientation with Sydney Harbour Bridge as a backdrop)
3. Opera on the Stairs (north-south configuration, stage at top of the stairs)

Auditoria's analysis found that the following noise limits should apply for each configuration, with measurement locations at a stage distance of 40m, assuming that the stage configurations detailed in the Auditoria report are applied. Auditoria's report is attached as an Appendix to this acoustic assessment.

1. $96\text{dB}_{\text{L}_{\text{Aeq}}(5\text{min})}$ and $102\text{dB}_{\text{L}_{\text{Ceq}}(5\text{min})}$
2. $92\text{dB}_{\text{L}_{\text{Aeq}}(5\text{min})}$ and $98\text{dB}_{\text{L}_{\text{Ceq}}(5\text{min})}$
3. $82\text{dB}_{\text{L}_{\text{Aeq}}(5\text{min})}$ and $90\text{dB}_{\text{L}_{\text{Ceq}}(5\text{min})}$

The Sydney Opera House also holds outdoor events with small stages and performance areas, which do not fall under the three Southern Forecourt concert configurations. These include events on the Western Broadwalk such as the Summer Playground and Homeground, which has a stage and sand circle on the Western Broadwalk, and market stalls to the south.

Acoustic Studio proposes Front of House noise limits on the Western Broadwalk that will be applied in a similar way to the concert set up, aiming to achieve compliance with the same environmental noise emissions criteria for the sound system noise.

A typical set up for the Western Broadwalk is shown below. The location of the stage is typically on the northern end and faces south.

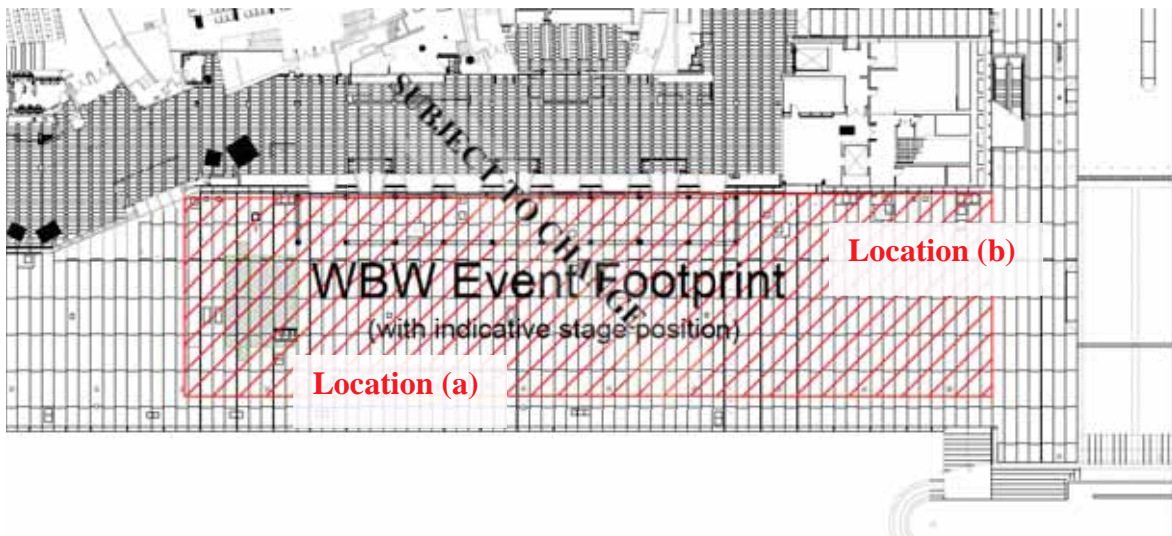


Figure 4: Indicative Western Broadwalk event footprint with indicative stage position located at the northern end, facing south. The proposed measurement locations are shown indicatively as Front of House locations (a) and (b).

For these events, the following three Front of House locations and corresponding sound system noise limits are proposed:

- a) Northern end of the Western Broadwalk: $90\text{dB}_{\text{L}_{\text{Aeq}}(5\text{min})}$ and $100\text{dB}_{\text{L}_{\text{Ceq}}(5\text{min})}$
- b) Southern end of the Western Broadwalk: $85\text{dB}_{\text{L}_{\text{Aeq}}(5\text{min})}$ and $95\text{dB}_{\text{L}_{\text{Ceq}}(5\text{min})}$

These limits are to be measured at Front of House for each operating scenario, or if there is no Front of House at the boundary of the event layout. If sound systems are operated up to 10pm (ie only Day and Evening hours), then an increase of 5dB in A-weighted and C-weighted FOH limits may apply to these events.

Acoustic Studio recommends adopting the A- and C-weighted noise limits above, to be measured by noise monitoring systems at agreed locations to enable accurate measurements and prompt management actions in the event of noise levels approaching or exceeding the applicable limits.

Importantly, the proposed Front of House noise limits are equivalent to (or less than) the L_{max} limits which have applied since 2003, and therefore does not constitute an increase in allowable event noise level from amplified sound systems.

6.4 Internal Noise Intrusion Criteria – Opera House use

An assessment of the impact of Sydney Opera House outdoor events on internal spaces within the Opera House itself is required to complete the review.

There are seven primary venues in the Sydney Opera House: the Concert Hall, the John Sutherland Theatre, the Drama Theatre, the Playhouse, the Studio, the Exhibition Hall, and the Utzon Room.

Internal noise criteria for these performance spaces are relative to the existing background noise levels, and require a high standard of acoustic isolation. The design of the newer venues such as the Drama Theatre, the Playhouse and the Studio all consider intrusive noise from typical outdoor activities, and will be protected from outdoor events as long as they are no louder than events which already take place in the SOH precinct.

The original Concert Hall and Joan Sutherland Theatre should aim for inaudible external noise, but in reality the construction of the building envelope (particularly the roof and ceiling structures) do not always achieve this for high environmental noise events. It will be important to ensure that outdoor event noise levels are managed to consider the potential for noise intrusion to these important internal venues in the Sydney Opera House.

Since the Sydney Opera House has control of the planning of both indoor and outdoor events at the Sydney Opera House, any large outdoor event that has the potential to impact on internal spaces can be planned in such a way to avoid concurrent internal and outdoor events. However, based on history, excessive noise impacts from outdoor events on internal spaces is not expected. Sydney Opera House representatives report that noise from outdoor events has not adversely impacted on internal operations in the past.

6.5 Summary of Environmental Noise Emission Criteria for Sydney Opera House outdoor events

Acoustic Studio recommends adopting the following noise criteria for the proposed outdoor event days and associated bump-in / bump-out days associated with these events.

| Noise source / activities | Period | Environmental noise criteria at receiver | | |
|----------------------------------------------|-----------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | | Residential receivers other than Bennelong Apartments | Bennelong Apartments | Criterion reference |
| Amplified music, including sound checks* | Day / Evening / Night (8am-11pm) *No night time sound checks | Measured Front of House in Configurations 1, 2 and 3, and Western Broadwalk a) and b): 1. 96 dBL _{Aeq,5 minute} and 102 dBL _{Ceq,5 minute} 2. 92 dBL _{Aeq,5 minute} and 98 dBL _{Ceq,5 minute} 3. 84 dBL _{Aeq,5 minute} and 90 dBL _{Ceq,5 minute} a) 90 dBL _{Aeq,5 minute} and 100 dBL _{Ceq,5 minute} b) 85 dBL _{Aeq,5 minute} and 95 dBL _{Ceq,5 minute} | | ISEPP (Major Development) – <i>Front of House noise limits aim to be equivalent to the ISEPP environmental noise limits for sound systems, INP / AS1055, Sleep Disturbance</i> |
| Installation, bump-in / bump-out activities* | Day / Evening (6am-10pm) | $L_{Aeq} \leq \text{background} + 5: 53\text{dB(A)}$ | $L_{Aeq} \leq \text{background} + 5: 63-66\text{dB(A)}$ | INP / ICNGL |
| | Night (10pm to 12am) | $L_{Aeq} \leq 43\text{dB(A)}$ $L_{A1} \leq 60\text{dB(A)}$ | $L_{Aeq} \leq 63\text{dB(A)}$ $L_{A1} \leq 73\text{dB(A)}$ | ICNGL, INP ANL, Sleep Disturbance background + 15 |
| Mechanical plant, Cleaning and maintenance | Day (7am-6pm) | $L_{Aeq} \leq 53\text{dB(A)}$ | $L_{Aeq} \leq 65\text{dB(A)}$ | INP background + 5 |
| | Evening (6pm-10pm) | $L_{Aeq} \leq 53\text{dB(A)}$ | $L_{Aeq} \leq 66\text{dB(A)}$ | INP background + 5 |
| | Night (10pm-12am) | $L_{Aeq} \leq 43\text{dB(A)}$ $L_{A1} \leq 60\text{dB(A)}$ | $L_{Aeq} \leq 55\text{dB(A)}$ $L_{A1} \leq 73-76\text{dB(A)}$ | INP ANL, Sleep Disturbance background + 15 |
| | Night (12am-7am) *No activities or operations 12-7am | $L_{Aeq} \leq 43\text{dB(A)}$ $L_{A1} \leq 60\text{dB(A)}$ | $L_{Aeq} \leq 55\text{dB(A)}$ $L_{A1} \leq 73-76\text{dB(A)}$ | INP ANL, Sleep Disturbance background + 15 |

Table 5: Proposed environmental noise criteria and reference levels for outdoor event days and associated bump-in / bump-out days.

7 Assessment and Recommendations

7.1 Assessment Methodology

The acoustic assessment has considered the following:

- The Sydney Opera House outdoor events will be open and in use during standard business hours up until 11pm. Occasionally, events or associated clean up / maintenance activities may last up to midnight.
- Noise levels from simultaneous outdoor events have been considered to provide a worst-case noise level at representative receivers.
- Noise predictions at the nearest receiver boundaries consider the total noise contribution from all noise sources, including those not associated with Sydney Opera House activities.
- Conservative estimates have been adopted for attenuation due to shielding from distance, buildings, intervening topography and ground absorption.
- Lowest expected background noise levels have been used for each time period to provide a worst-case scenario.
- Amplified music ceases by 11pm.

7.2 Mechanical Plant Noise Compliance

Plant associated with the operation of the Sydney Opera House outdoor events should be controlled to ensure external noise emissions are not intrusive and do not impact on the amenity of neighbouring receivers.

The plant will potentially operate at any time until midnight, to performances, events and maintenance and cleaning.

Plant and equipment varies for each event; therefore a detailed assessment has not been carried out. In the absence of plant noise data or locations, Acoustic Studio makes the following general comments:

- The most restrictive criteria for the plant is the night-time criterion of 45 dBA at the nearest residential receivers at Bennelong Apartments, assuming that the plant operates between midnight and 7am. Between 7am and midnight the applicable plant noise criterion is 10dB below the lowest existing ambient, ie 51dB(A). Achieving

this criterion will ensure compliance with the relevant criteria at all other receivers, at all times.

- Attenuation and / or internally-lined ductwork may be required for fans in order to meet the both internal and environmental noise criteria.
- Noise emissions from the external plant may be controlled via a combination of:
 - Locating the units as far from the Bennelong Apartment boundary as possible;
 - With natural screening provided by existing buildings, structures and topography;
 - Additional localised acoustic screening as required.

Event planners and managers must ensure that noise emissions from mechanical plant are effectively controlled to meet the relevant criteria at the nearest receiver boundaries.

Noise emissions from general maintenance and cleaning activities may need management controls such as time restrictions particularly for external area maintenance activities.

7.3 Bump-in / Bump-out Noise Compliance

Noise generated by bump-in / bump-out will be no greater than currently occurs, as the type of installation will not change significantly to current outdoor events. The timing of bump-in / bump-out activities will also be nominally the same as currently occurs, with most bump-in activities taking place during the day and bump-out activities taking place directly after events, which may be between 8am and midnight.

Efforts to minimise bump-out noise at night will continue to be a necessary part of event noise management. Actual noise levels, timing or frequency of bump-in / bump-out activities will not change due to the current proposal.

The highest noise levels at Bennelong Apartment would be generated by road vehicles moving to or from the site for bump-out activities after events. Large events may have semi-trailer trucks, while smaller Western Broadwalk events are likely to have smaller utility vehicles.

These vehicles are assessed in accordance with the INP background + 5dB $L_{Aeq(15min)}$ and the INP / RNP Sleep Disturbance Level of background + 15dB $L_{A1,1minute}$.

10pm-midnight bump-out noise targets are: 63dB $L_{Aeq(15min)}$ and 73dB $L_{A1,1minute}$.

According to the Australian Standard AS2436:2010 *Guide to noise and vibration control on construction, demolition and maintenance sites*, the source noise level of bump-out vehicles are:

- Truck >20 Tonne 107dB(A) SWL and 79dB(A) SPL at 10m
- Light commercial (eg 4WD) 106dB(A) SWL and 78dB(A) SPL at 10m

The source for the AS2436 data is the UK Department for Environment Food and Rural Affairs *Update of Noise Database for Prediction of Noise on Construction and Open Sites* (2005). Table 2 in this document notes that truck (eg 4-axle “lorry”) movement sound levels are presented as a maximum passby level (L_{max}) rather than an energy average level (L_{eq}).

The L_{eq} is therefore derived in terms of the passby duration in a 15-minute period.

The most exposed residential apartments at Bennelong Apartments are two storeys from ground level, approximately 9m to 12m from the nearest lane on Macquarie Street. The near lane is where vehicles heading into the site will travel, between 10:30pm and 11pm. The far lane is approximately 10m from the nearest residential apartment façade, and is the lane along which departing vehicles will travel, between 11pm and midnight.

Assuming up to two vehicle passby events at slow speeds (below the City of Sydney local speed limit of 40 km/hr or 11m/s), up to 20 second passby events would generate 61-62dB $L_{Aeq(15min)}$. This meets the background + 5dB target and is also below the existing ambient, ie would not significantly add to the existing noise levels from other vehicular activity in the area.

Similarly, the $L_{A1,1minute}$ needs to be derived from the maximum passby level.

The predicted typical maximum sound pressure level for bump-out vehicles on approach and departure at these nearest receivers are:

- Truck >20 Tonne 77-80dB $L_{A1,1minute}$
- Light commercial (eg 4WD) 76-79dB $L_{A1,1minute}$

This maximum level analysis suggests that the Sleep Disturbance Screening Level may at times be exceeded by 6-7dB on arrival, and 4-5dB on departure. This suggests that further assessment for Sleep Disturbance is warranted.

Assuming a 25dB minimum attenuation through the façade as discussed in Section 6.2.4, the expected internal noise levels at Bennelong Apartments is 54-55dB L_{Amax} for vehicles approaching the Sydney Opera House between 10:30pm and 11pm, and 52-53dB L_{Amax} for vehicles leaving (the latest bump-out events, typically between 11pm and midnight).

These levels meet the internal Sleep Awakening Level of 55dB L_{Amax} and are not expected to cause awakening events.

The Sydney Opera House outdoor event management plan includes requirements for bump-in / bump-out activities that effectively control noise generated on site, by staff (voice) as well as tools and equipment and switching off vehicle engines when on site. These management controls will ensure that bump-in / bump-out activities carried out on site are unlikely to generate noise levels above existing ambient events at any residential receiver location, and would meet the INP and Sleep Disturbance Screening levels.

7.4 Patron and Sound System Noise

7.4.1 Source Noise Levels

Table 6 shows typical sound levels expected from different uses and sources in the Sydney Opera House precinct, at 1 metre from the source for voice sources, and at the event boundary for music sources.

The patron source noise levels are considered to be very conservative (ie higher than expected in practice), as it is generally unlikely that all patrons will be speaking at once – there will generally be at least one listener for each speaker. However this conservative approach has been adopted to account for the potential for worst-case scenario, where an audience responds simultaneously to an event or speaker (eg laughter, applause, etc).

| Event type | Noise source | Reference dBL _{A1} | Overall dBL _{A1} |
|------------------------------|----------------------------------------------------------------------|-----------------------------|---------------------------|
| n/a: reference level | 1 adult male speaking with moderate voice (unamplified patron noise) | 64 | n/a |
| | 1 adult male speaking with raised voice (unamplified patron noise) | 73 | |
| Arrival and departure | 200 patrons speaking in moderate voices at once | +23 | 90 |
| Small event, eg on Broadwalk | 1000 patrons speaking in moderate voices at once | +29 | 93 |
| Medium event, eg on Podium | 3000 patrons' raised voices all at once | +35 | 108 |
| Large event, eg on Forecourt | 6500 patrons' raised voices all at once | +38 | 111 |
| Small event, eg on Broadwalk | Small bands at medium sized event (amplified) | 80 | 80 |
| Medium event, eg on Podium | Small bands at typical large event (amplified) | 90 | 90 |
| Large event, eg on Forecourt | Large, major event (amplified music) | 100 | 100 |

Table 6: Sound levels (L₁) likely to be generated at source, by patrons and live music due to Sydney Opera House outdoor events

7.4.2 Patron noise assessment

Patron noise from the Sydney Opera House outdoor areas and walkways has been estimated for the following scenarios.

- General patron noise from up to 200 people, speaking in moderate voices, waiting *before events in each outdoor event area*;
- Patron noise from up to 6500 persons, speaking in raised voices at *events in one or more outdoor areas*;
- Noise *from the walkways to and from the event* has been estimated for 200 persons walking along a distributed path, speaking in moderate voices as they walk to or from the Opera House precinct up to midnight (this assessment assumes that some management controls will be in place to ensure that patrons consider the residential neighbours as they depart functions at night).

While there are no environmental noise criteria established for patron noise (all prior approvals have been for amplified music), it is informative to estimate patron noise levels at receivers for different scenarios, and compare with reference indicators for when noise levels may be considered intrusive.

Tables 3 and 4 show that local environmental noise at Bennelong Apartments is typically driven by existing traffic and pedestrian noise, which frequently exceeds the 65dB_{L_{Amax}} amplified music noise criterion. Up to around 11:30pm, patron noise is not expected to change from current levels. The sleep disturbance screening level at Bennelong Apartments between 10pm and 11:30pm is 73dB(A).

62dB(A) is the screening level for sleep disturbance from patron noise from around 11:30pm to 2am.

The table below shows expected noise levels from patrons, heard at the nearest residential receivers along Macquarie Street. The most exposed residential apartments are two storeys from ground level (approximately 6 to 8m from pedestrians on the footpath). Two aspects are clear from this conservative estimate:

- Patron / audience noise is loudest during the event itself. This noise level would only be expected at limited times, eg at the performance open / close, or when big announcements are made (such as the winner of Australian Idol). Such key points in the performance should be planned around less sensitive times, and would never occur past midnight.
- Patron arrival and departure is a potential concern, and measures should be made to manage patron behavior and routes, particularly as they leave the event late at night.

| Event type | Noise source | Source level dB(A) | At-receiver dB(A) | Excess above 73dB(A) Sleep Disturbance Screening level |
|------------------------------|--------------------------------------------------------------------|--------------------|-------------------|--------------------------------------------------------|
| Arrival and departure | L ₁ of 200 patrons speaking in moderate voices at once | 90 | 80 | 7 |
| Small event, on Broadwalk | L ₁ of 1000 patrons speaking in moderate voices at once | 93 | 72 | - |
| Medium event, eg on Podium | L ₁ of 3000 patrons' raised voices all at once | 108 | 87 | 14 |
| Large event, eg on Forecourt | L ₁ of 6500 patrons' raised voices all at once | 111 | 90 | 17 |

Table 7: Sound levels (L₁) likely to be heard at Bennelong Apartments from patrons for different scenarios, and excess above the Sleep Disturbance Screening level between 10pm and 11:30pm.

The table above shows that there are instances when the external noise level from patrons may exceed the Sleep Disturbance Screening Level. Therefore, in accordance with the NSW INP and RNP, a more detailed analysis is required to assess the potential for Sleep Awakening.

Sleep Awakening assessments are conducted inside the sleeping area (bedroom). The Bennelong Apartment on the northern-most end are the most exposed to Sydney Opera House activities.

It is understood that the standard layout of these northern apartments has the kitchen and living area facing the Opera House, with bedrooms located further away on the southern end. Therefore patron noise from Forecourt or Western Broadwalk events would be shielded externally and also have internal sound attenuation through the living area.

A conservative assumption is that levels at the eastern and western facades are 5-10dB less than the most exposed northern façade, due to shielding effects. With reflective (hard) surfaces such as plasterboard walls and ceilings, timber or tiled floors, and open bedroom doors, the most conservative assumption for sound attenuation through the living areas to the bedroom is also 5-10dB (although for most layouts and fitouts a greater attenuation would be expected). Therefore Acoustic Studio has conservatively applied a 5-10dB attenuation in noise in bedrooms from events held at the Forecourt, Podium or Western Broadwalks.

Patron noise along Macquarie Street or Circular Quay are not shielded in this way.

As discussed in Section 6.2.4, the façade of Bennelong Apartments will have been constructed to achieve a minimum of 25dB level difference in order to meet Australian Standard internal continuous background noise levels. Therefore the worst case predicted internal noise levels inside the most exposed bedrooms at Bennelong Apartments are shown in the table below. They are compared with the Sleep Awakening Level.

| Event type | Noise source | External Noise Level dB(A) | Internal Noise Level dB(A) | Excess above 55dB(A) Sleep Awakening level |
|---------------------------------|--------------------------------------------------------------------|----------------------------|----------------------------|--------------------------------------------|
| Arrival and departure | L ₁ of 200 patrons speaking in moderate voices at once | 80 | 55 | - |
| Small event, each on Broadwalks | L ₁ of 1000 patrons speaking in moderate voices at once | 72 | 37 | - |
| Medium event, eg on Podium | L ₁ of 3000 patrons' raised voices all at once | 87 | 52 | - |
| Large event, eg on Forecourt | L ₁ of 6500 patrons' raised voices all at once | 90 | 55 | - |

Table 8: Sound levels (L₁) likely to be heard at Bennelong Apartments from patrons for different scenarios, and excess above the Sleep Disturbance Screening level between 10pm and 11:30pm.

This analysis shows that patron departure noise does not exceed the internal Sleep Awakening Level and are therefore not likely to cause awakening events. This assumes the minimum allowable façade attenuation for a building at this location; it is most likely that the internal noise levels will be lower due to better performance façades.

The Sydney Opera House has long understood the potential for disturbance due to patrons exiting events, and will continue to employ management principles for ensuring that patrons are moved along quickly in one group away from the residential areas, and for controlling their behaviour. The outdoor event management plan includes details on how patron departure is managed to minimise disturbance to nearby residential receivers.

7.4.3 Sound system noise assessment

The Sydney Opera House has provided Acoustic Studio with noise monitoring reports for various outdoor events held between 2007 and 2013.

One report contained simultaneous measurements of source and receiver noise at Beulah Street Wharf. The reports do not present simultaneous measurements of source and receiver noise at Bennelong Apartments, but simple distance attenuation calculations indicate 10-15dB(A) and 5-10dB(C) reduction from front of house source levels. The expected A-weighted sound attenuation corresponds with SOH construction noise attenuation between the southern Opera House precinct boundary and Bennelong Apartments, measured by Acoustic Studio in July and August 2014.

Greater attenuation could be expected with directional speakers that minimise noise spill to the apartment buildings, and with local installations that shield noise.

The reports indicate that Bennelong Apartments at 1 Macquarie Street are most exposed to event levels from the southern side of the Sydney Opera House. This is to be expected due to its close proximity and the direction of speakers.

The highest reported noise levels were within 5dB of both A-weighted and C-weighted noise criteria. There were occasions when applicable criteria were exceeded, and efforts were made to reduce the amplified sound level at source.

The reports indicate that the Sydney Opera House pro-actively monitors and manages sound system noise from outdoor events.

Acoustic Studio recommends that the existing noise management system be formalised and augmented to include other noise sources in addition to amplified music, and to ensure that sound system checks are carried out in a way that will avoid marginal non-compliances with the applicable criteria.

Based on information provided by the Sydney Opera House, Acoustic Studio considers that the number of events at which outdoor event noise may be audible at any given residential or commercial receiver will not significantly change from previously approved outdoor events run by the SOH.

Not all events will generate the same noise levels at every receiver.

For example, events held on the Western Broadwalk are likely to generate noise levels at Beulah Street Wharf of 45-55dB_{L_{Aeq,5min}}, ie similar to the existing background or ambient

levels at that location. Typical corporate events on the Forecourt are unlikely to exceed the existing background noise at Beulah Street Wharf.

In practice, not all events will be held at night, and not all night-time events will generate the highest allowable noise levels. Some events such as art installations are by their nature low noise events, with little or no amplified music.

Acoustic Studio considers that meeting the recommended Front of House noise criteria will result in an appropriate balance between maintaining residential and commercial acoustic amenity over the majority of the year, and allowing the Sydney Opera House to continue to operate as a major cultural hub for the City of Sydney and New South Wales. While the FOH limits may be relatively restrictive for some types of event, the Sydney Opera House commits to meeting these limits in order to maintain the existing levels of acoustic amenity for residential receivers.

7.4.4 Typical allowable sound levels from amplified sound systems

Provided that the management practices in Section 8.2 are followed, events are expected to comply with applicable noise criteria. Maximum allowable sound levels have been proposed in Section 6.3.9 and are expected to achieve acceptable environmental noise levels.

In all cases, the proposed Front of House / on site noise limits aim to preserve the environmental noise limits which applied to the 2003 DA.

Acoustic Studio recognises that the Front of House noise limits may be at the lower acceptable limit for the patron experience for some event types. The Front of House noise limits are aligned with the existing emissions limits at the most affected residential receivers, and represent the minimum allowable Front of House level that will enable a quality audience experience.

These noise limits have been based on detailed modelling by Auditoria Pty Ltd for Forecourt events using typical sound systems, to meet the Bennelong Apartment environmental criteria. This assumes no noise barriers are installed. In practice the Sydney Opera House events may use noise barriers.

A detailed outdoor event noise management plan has been prepared for the different concert configurations, and provide restrictions on sound system selection and orientation, speaker delays, and other sound system requirements to ensure that environmental emissions are controlled.

7.5 Noise Intrusion to Sydney Opera House Internal Spaces

As noted in Section 7.5, the Sydney Opera House building and performance space envelopes have been designed to meet strict intrusive noise criteria. The proposed outdoor event days will be operated in a similar manner to the outdoor events that have been operated in previous years, and the Sydney Opera House has not reported any disturbance from outdoor events held in the past. The proposed outdoor event days are therefore not expected to adversely impact on the performance and function spaces in the Sydney Opera House.

8 Noise Management Approach

The following observations assist with a review of potential noise impacts:

- Noise levels from the proposed outdoor function days are not expected to be any higher than occur from outdoor Sydney Opera House functions previously permitted under separate development approvals.
- The potential impact, therefore, is not related to the *absolute* noise level from patrons, sound systems, plant or bump-in / bump-out activities.
- The potential impact reduces to the subjective response of residents to the perception that the proposed noise limits would result in increased A-weighted noise level related to outdoor events.

The perception of environmental noise events relates in part to what is expected of the local area. Inner city Sydney residents near the Sydney Opera House and the Royal Botanical Gardens know the area to be a vibrant place with the opportunity for locals and tourists to enjoy frequent outdoor entertainment events. Residents are also aware that most events must adhere to strict planning approval conditions that aim to preserve their amenity without unduly hampering the cultural role of the Sydney Opera House.

A detailed acoustic review by Auditoria Pty Ltd and Acoustic Studio has concluded that by adopting an $L_{A/Ceq(5min)}$ noise limit, event operators can more reliably and successfully manage the environmental noise emissions from sound systems.

By setting Front of House A-weighted and C-weighted noise limits, the resulting emissions will be less bass-heavy, reducing a noise characteristic which is known to be a source of increased community annoyance and disturbance.

The impact of the outdoor event days can be managed best through a combination of meeting appropriate environmental noise level criteria (quantitative) and applying best practice management methods for minimising activity impacts.

8.1 Management Practices

The Sydney Opera House has provided environmental noise monitoring reports to inform the preparation of this report.

Previous planning approvals for outdoor events included noise conditions on amplified music only, and did not cover patron, plant, or bump-in / bump-out noise.

Acoustic Studio recommends that the Sydney Opera House conducts high level reviews of event proposals, which should include installation and dismantling practices, the proposed plant and equipment for each installation, and proposed timing and methods of clean-up

after events. A review of patron noise management should also be required as part of the event planning process.

The noise monitoring reports demonstrate that the Sydney Opera House enforces strict procedures for managing impacts from sound system noise. The typical procedure is for an independent noise consultant to measure noise during sound checks, as well as during the event itself, and contact the sound system manager when environmental levels are within 5dB of the criterion.

Acoustic Studio notes that when noise levels exceeded criteria for two events, the sound system levels were noticeably reduced but still did not meet the criteria.

Acoustic Studio also notes that where sound level criteria were exceeded, this was frequently due to extraneous events not associated with SOH outdoor activities. For example, ferry noise at Beulah Street Wharf and traffic noise at the Bennelong Apartments frequently exceed 60dB(A) and 80dB(A), in the absence of any event noise.

8.2 Recommended Noise Management Approach

Acoustic Studio recommends adopting a similar approach to previous Sydney Opera House management events. Some requirements have been suggested to make maximise event managers' understanding of how to control sound system noise to meet night time targets, and to review the impacts of other related noise such as patron and plant noise.

The Sydney Opera House should require that event managers provide a statement of compliance for plant, equipment, and bump-in/out noise as part of their application to hold an event in the Sydney Opera House precinct. Bump-in/bump-out plans should clearly state the hours of these activities, and outline the highest noise sources and what measures will be taken to minimise bump-in/out noise levels.

The event manager should also provide a traffic and pedestrian management plan that demonstrates that:

- Traffic impacts will be no worse than existing;
- Patrons will be encouraged to use routes that will minimise patron noise impacts on nearby residential receivers; and
- Excessive noise from patrons near residential apartments on east Circular Quay will be managed, eg with the assistance of event security staff.

During noise monitoring, it is important to establish a communications and action protocol between the noise measurement staff and the sound system operator. The noise measurement staff need to monitor the overall noise limit (ie Front of House $L_{A/Ceq(5min)}$ level), as well as the sound spectrum in octave bands from 31.5Hz to 8kHz if required. If the overall level comes within 5dB of the limit, staff review the shape of the sound spectrum in order to advise the sound system operator which frequencies need to be turned down, and by how much.

The Sydney Opera House Outdoor Events Manual v2.5 refers to noise management requirements for outdoor events. These would be augmented and strictly adhered to. Management / engineering controls include orientation of the stage, appropriate selection and assessment of loudspeakers and constructing temporary noise barriers.

9 Summary and Conclusions

A noise assessment has been carried out for the proposed Site Activation for Outdoor Events at the Sydney Opera House.

A review of short- and long-term ambient noise monitoring has been carried out, to establish the existing background noise levels of the nearest affected residential and commercial premises, and to review whether current performance noise limits represent a reasonable approach to managing noise impacts to the community.

A key outcome of the ambient noise and noise limit review is a proposed alternative method to measure the performance noise, namely $dB_{L_{A/Ceq}(5min)}$ noise limits measured at Front of House, with different limits applied for different performance configurations. This is numerically equivalent to the previous $dB_{L_{A/Cmax}}$ noise limit, but represents a more robust method for identifying and measuring event noise above extraneous events, and for directly managing the sound system output.

The background and ambient noise levels at East Circular Quay do not vary significantly over the week and levels do not rise on Fridays and Saturdays. Therefore it is proposed to have one noise limit which applies every day of the week.

Source noise levels outdoor events and patrons have been based on patron noise measured by Acoustic Studio in the Sydney Opera House precinct and at other busy outdoor areas in Sydney, and acoustic literature on male and female voices.

The noise impacts have been assessed at the most sensitive boundary positions, taking into account distance attenuation, building and ground reflections, directivity and, where applicable, shielding by local buildings / structures.

Noise levels from the proposed outdoor event days will be no higher than the outdoor events already held at the Sydney Opera House.

A management approach for events would continue to assist the Sydney Opera House ensure that environmental noise meet relevant criteria as well as minimises the perceived impacts due to extended hours and / or more frequent event days. Management approaches which are being currently drafted approach build on existing measures taken by the Opera House, and add some steps to provide more certainty about sound system environmental noise levels, and to consider the impacts from road traffic, patrons, plant and equipment, and bump-in/bump-out activities.

Provided the recommendations detailed in this report are correctly implemented, it is anticipated that the Sydney Opera House outdoor events operations will have no adverse noise impact at the nearest residential receivers.

Appendix

Auditoria Pty Ltd acoustic report: Sydney Opera House Forecourt Events Front of House Recommended Levels



Sydney Opera House

Forecourt Events FOH Recommended Levels

| | |
|------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Client | Sydney Opera House Bennelong Point NSW 2001 |
| Project Manager | Heather Clarke Manager, Event Operation & Planning ☎ +61 2 9250 7426 ✉ HClarke@sydneyoperahouse.com |
| Document | Forecourt Events Sound Management Report |
| Reference | SOH Forecourt FOH Recommended Levels_Ver E_030916.docx |
| Page Count | 23 |

| Revision | Date | Prepared by | Approved by | Notes |
|----------|-----------|---------------------------|--------------|-----------------------------|
| A | 19-Aug-16 | S.Willsallen L.Miranda | S.Willsallen | Internal review document |
| B | 24-Aug-16 | S.Willsallen L.Miranda | S.Willsallen | Draft for SOH consideration |
| C | 25-Aug-16 | S.Willsallen L.Miranda | S.Willsallen | Report issue |
| D | 31-Aug-16 | S.Willsallen L.Miranda | S.Willsallen | Issued with amendments |
| E | 6-Sep-16 | S.Willsallen L.Miranda | S.Willsallen | Issued with amendments |

TABLE OF CONTENTS

| | | |
|-----------|------------------------------------------------------------------------------------------------------------|------------------|
| A. | <u>INTRODUCTION</u> | <u>4</u> |
| A.1 | SITE OVERVIEW | 5 |
| B. | <u>DEFINITIONS</u> | <u>6</u> |
| C. | <u>CONFIGURATIONS UNDER INVESTIGATION</u> | <u>7</u> |
| C.1 | TYPICAL LARGE EVENTS CONFIGURATION | 7 |
| C.2 | AUSTRALIA DAY CONFIGURATION | 8 |
| C.3 | OPERA ON THE STAIRS CONFIGURATION | 9 |
| D. | <u>ANALYSIS OF HISTORICAL EVENT DATA</u> | <u>10</u> |
| D.1 | A AND C-WEIGHTED DATA | 11 |
| D.2 | LEVEL STATISTICS | 13 |
| E. | <u>ANALYSIS OF TYPICAL MUSIC SPECTRA</u> | <u>15</u> |
| F. | <u>PA LAYOUT AND EFFECT ON NEAREST RESIDENTS</u> | <u>17</u> |
| F.1 | SUMMARY OF SYDNEY OPERA HOUSE – FORECOURT EVENTS SOUND MANAGEMENT REPORT, PREPARED BY AUDITORIA PTY LTD | 17 |
| F.2 | SOUND SYSTEM MODELLING METHODOLOGY | 17 |
| F.2.1 | SOUND SYSTEM DIRECTIVITY | 17 |
| F.2.2 | SIMULATED NOISE LEVELS AT 1 MACQUARIE ST | 19 |
| F.2.3 | GROUND STACKED SUBWOOFER SYSTEM | 21 |
| F.2.4 | ADDITIONAL CALCULATION ASSUMPTIONS | 21 |
| G. | <u>SUGGESTED FOH LEVEL LIMITS</u> | <u>22</u> |
| G.1 | CORRECTIONS FOR FOH TO STAGE DISTANCE | 23 |

A. Introduction

This document provides recommended levels at the FOH location for events to be held at the Forecourt of the Sydney Opera House. These levels are intended to serve as part of the sound management plan to be implemented for these events. The proposed levels are aimed at providing the best experience possible to patrons while limiting the impact of sound sources to nearby residents.

The document has been prepared taking into consideration data from previous events as well as extensive modelling of sound systems based on typical sound systems used for these events. The stage location has also been taken into consideration. This document forms part of an ongoing investigation of events at the Forecourt. In previous reports the output of several typical loudspeaker systems has been analysed in terms of output towards the audience area and output toward the nearest residents.

An important point to be made is that all of the recommended levels included in this report are intended to provide similar amenity at the residents as the limits set by the Sydney Opera House for events in their Outdoor Event Guide, which is based on their current DA conditions. The main departure from the previous measurement and limiting scheme is an easier way to establish and measure limits,

A.1 Site Overview

A site overview is presented in the following figure. The figure includes locations of interest including the nearest residences to the north and south as well as the typical stage location. The southern residences are approximately 120 m from the back of the stage. The northern residences are located approximately 800 m from the front of the stage. All the recommendations in this document are based on these two residential areas as they have been identified as the most susceptible to be impacted by the events held at the Forecourt.

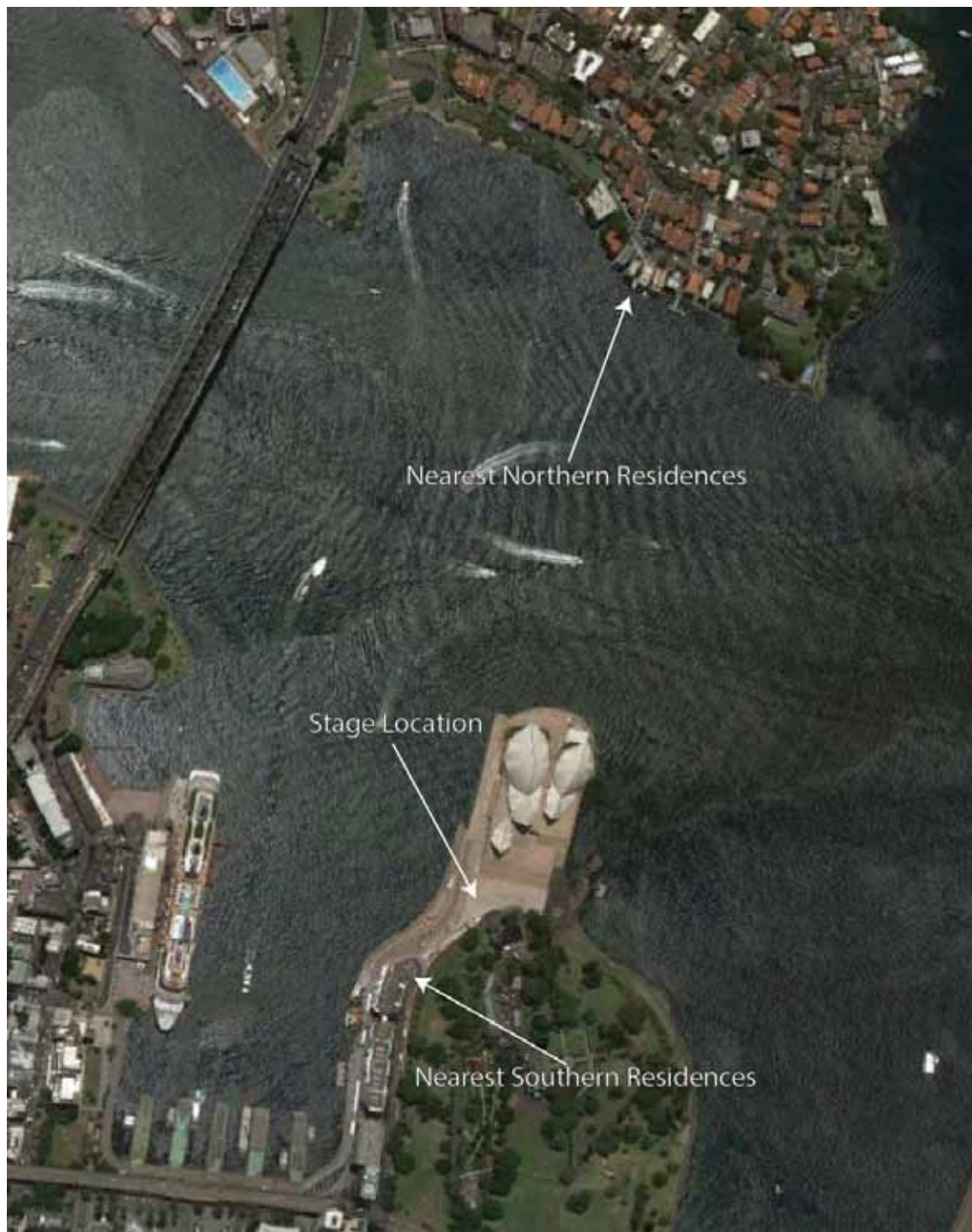


Figure 1. Site overview

B. Definitions

The following definitions are used through the document and are included in this section as a reference for the reader.

Background noise – According to the NSW Industrial Noise Policy, the background noise is: ‘the underlying level of noise present in the ambient noise, excluding the noise source under investigation, when extraneous noise is removed’. This obviously excludes the noise generated from the Forecourt events and also excludes typical high level noise events in the area such as large vehicles or loud passers-by. This is typically described using the L_{90} descriptor.

Ambient noise – According to the NSW Industrial Noise Policy, the ambient noise is: ‘the all-encompassing noise associated within a given environment’. This evaluation would include noise from all sources in the environment. This is typically described using the L_{eq} descriptor.

Noise Event – A brief period of high sound pressure level.

Typical measurement location – The typical measurement location is the location where the logger has been placed to regulate the levels of the concert events held at the Forecourt. The location has been constant for the last several years and is intended to represent the levels experienced at the locations that have the potential to be affected the most by sound sources related to Forecourt events.

L_{eq} – The L_{eq} descriptor is the average of levels (calculated in underlying energy units) over a measurement period.

L_n – The L_n , where n is a given percentile is the sound pressure level that is exceeded by the n percent of the level observations in a measurement period. If, for example, n is equal to 90, the figure represents the value over which 90 percent of the level observations in the period are over this level. Another way of thinking about it is, using the same 90 percent example, the highest level of the lowest 10 percent of the observations.

dB – Is the abbreviation for decibel, which is a unit of sound measurement. The decibel is a logarithmic unit and in this document is used to describe sound pressure levels. The reference for the logarithmic unit is 0.02 mPa.

dB(A) – The A-weighted version of the sound pressure descriptor, is a spectral adjustment applied to the signal to make it more attune to the human hearing characteristics at medium sound levels.

dB(C) – The C-weighted version of the sound pressure descriptor, is a spectral adjustment applied to the signal to make it more attune to the human hearing characteristics at high sound levels.

Hours of Interest – The hours of interest is the period that is more relevant to this document. This is the period where the concert events at the Forecourt are typically held.

Day – The day period is defined as in the NSW Industrial Noise Policy and it is the hours from 0700 to 1800 from Monday to Saturday and from 0800 to 1800 on Sunday.

Evening – The evening period is defined as in the NSW Industrial Noise Policy and it is the hours from 1800 to 2200.

Night – The night period is defined as in the NSW Industrial Noise Policy and it is the hours from 2200 to 0700 from Monday to Saturday and from 2200 to 0800 on Sunday.

Rating Background Level (RBL) – The RBL is the single value background noise descriptor as defined in the NSW Industrial Noise Policy. This level is calculated as the median value for each measurement period (Day, Evening and Night), over a given time frame (in this case a one-week period).

C.2 Australia Day Configuration

Australia Day events are typically televised and benefit from the inclusion of the Harbour Bridge as a backdrop. This configuration is shown below.

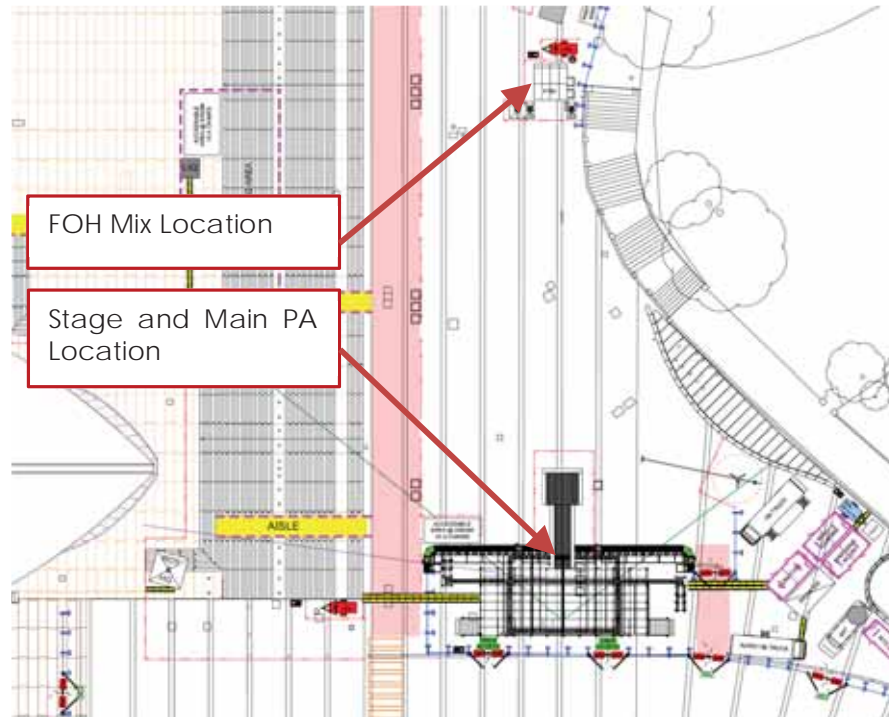


Figure 3. Australia Day event configuration

C.3 Opera On the Stairs Configuration

An additional configuration is included in the analysis in later parts where the stage is located at the top of the stairs with a FOH location in the vicinity of the audience area. An example of this is shown below. This last layout is just an approximation as no events have taken place using this configuration.

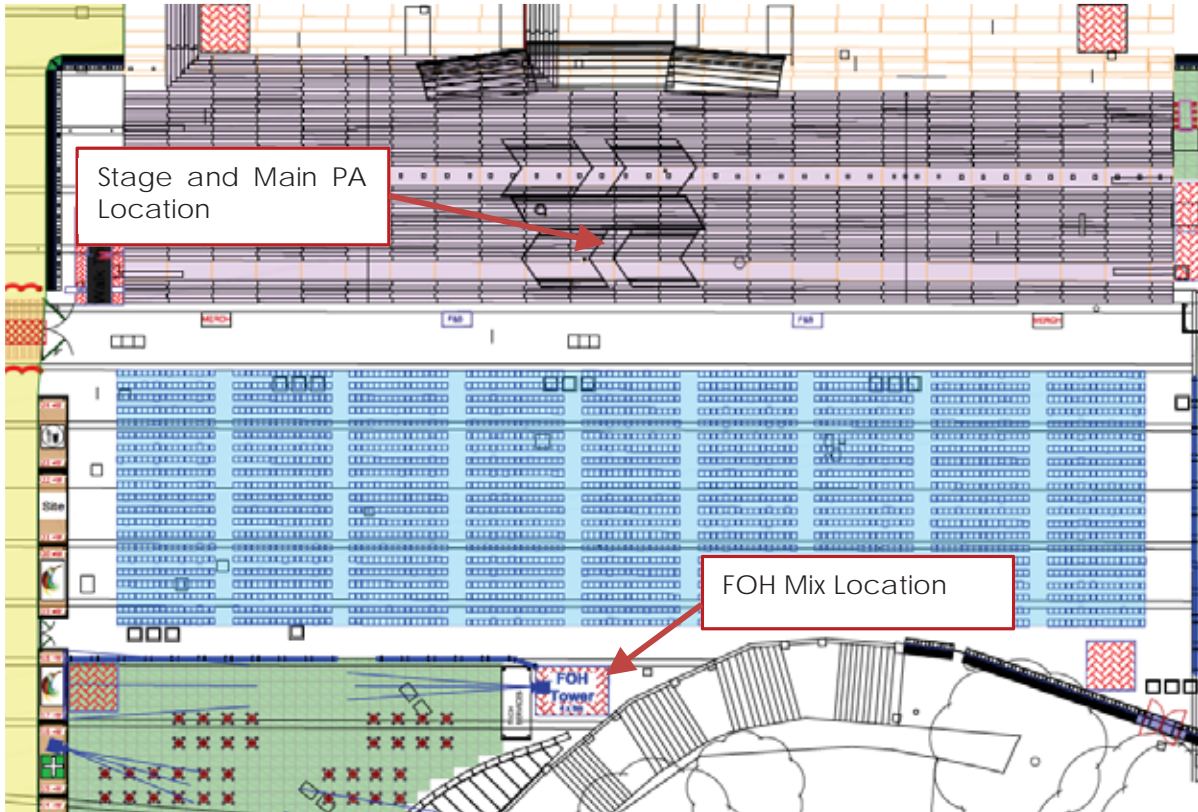


Figure 4. Opera on the Stairs event configuration

D. Analysis of Historical Event Data

Data for FOH measurements of several previous events has been obtained. This data includes A and C-weighted measurements using a fast integration time. The data was collected by the PA People. The events considered are included in the table below. An individual ID number is included which is used to reference the events in the document as required. The distance from the FOH location to the stage is also include in the table.

| Event | ID | FOH Distance (m) |
|-----------------------|-----------|-------------------------|
| Angus and Julia Stone | 1 | 38 |
| Tim Minchin | 2 | 38 |
| Tim Minchin | 3 | 38 |
| Roxette | 4 | 38 |
| Chet Faker 1 | 5 | 47 |
| Chet Faker 2 | 6 | 47 |
| Tame Impala 1 | 7 | 47 |
| Tame Impala 2 | 8 | 47 |
| Florence 1 | 9 | 47 |
| Florence 2 | 10 | 47 |
| Florence 3 | 11 | 47 |
| Australia Day 2015 | 12 | 30 |
| Australia Day 2016 | 13 | 54 |

D.1 A and C-Weighted Data

In this section we present the historical data for the events measured. We present the L_{eq} data, averaged over 5 minutes. We use L_{eq} in this section as we assume that, when the sound systems are being used, the principal contribution at the FOH location are the sound systems. The data has been plotted for the hours between 18:00 and 23:00. The measurements are presented in the following plots.

To make the data comparable all levels have been adjusted for distance. We have adjusted all levels to a distance of 40 m as we deemed this a good representation of all distances as shown above. Inverse square law propagation was assumed. We believe this is an appropriate approach as the venue is an open air venue and can be thought of as relatively reflection free environment with the sound of the main PA dominating.

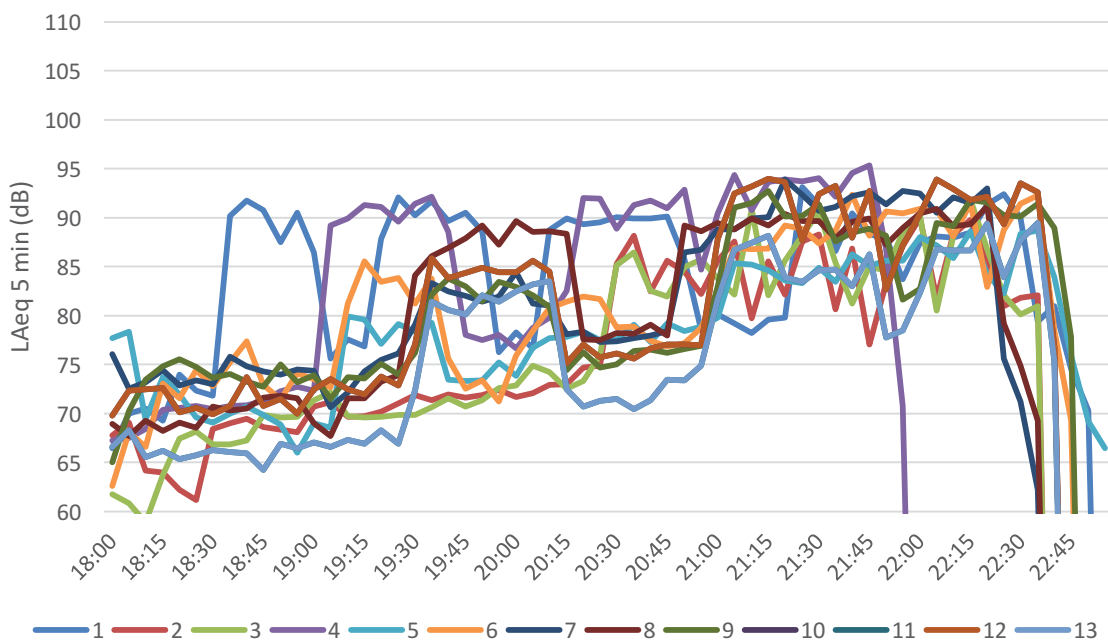


Figure 5. $L_{Aeq-5min}$ FOH historical measurements

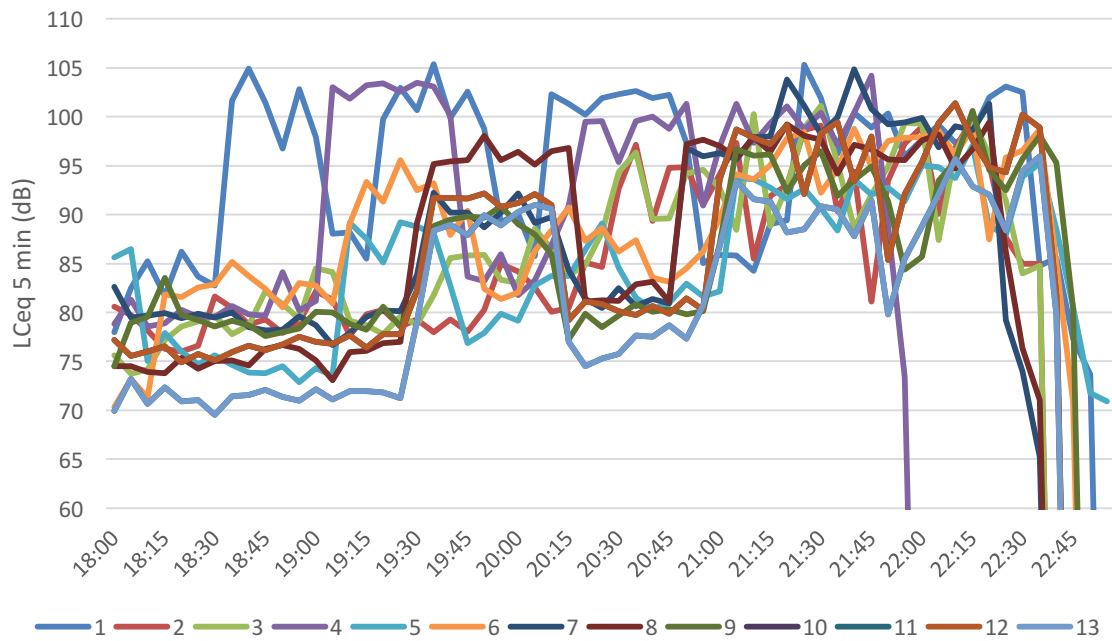


Figure 6. LC_{eq-5min} FOH historical measurements

From these plots we can clearly see periods when bands are playing and when bands are switching over. It is also clear that the period from approximately 21:00 and 22:30 is the period when most activity is recorded. This would be expected from typical act programming and is confirmed with the measurements.

D.2 Level Statistics

Based on the plots shown above we now derive statistics of all the events with the intention of arriving to single figure values. We have calculated median, 90 and 10 percentile values signifying the typical, medium and maximum excluding outliers. We have set thresholds for the values to be used for these calculations so that low level values (e.g. when the bands are switching) are not taken into account. The thresholds were selected by visual inspection and are 78 and 88 dB.

The following charts show the median, 90 and 10 percentiles for the A and C-Weighted L_{eq} values.

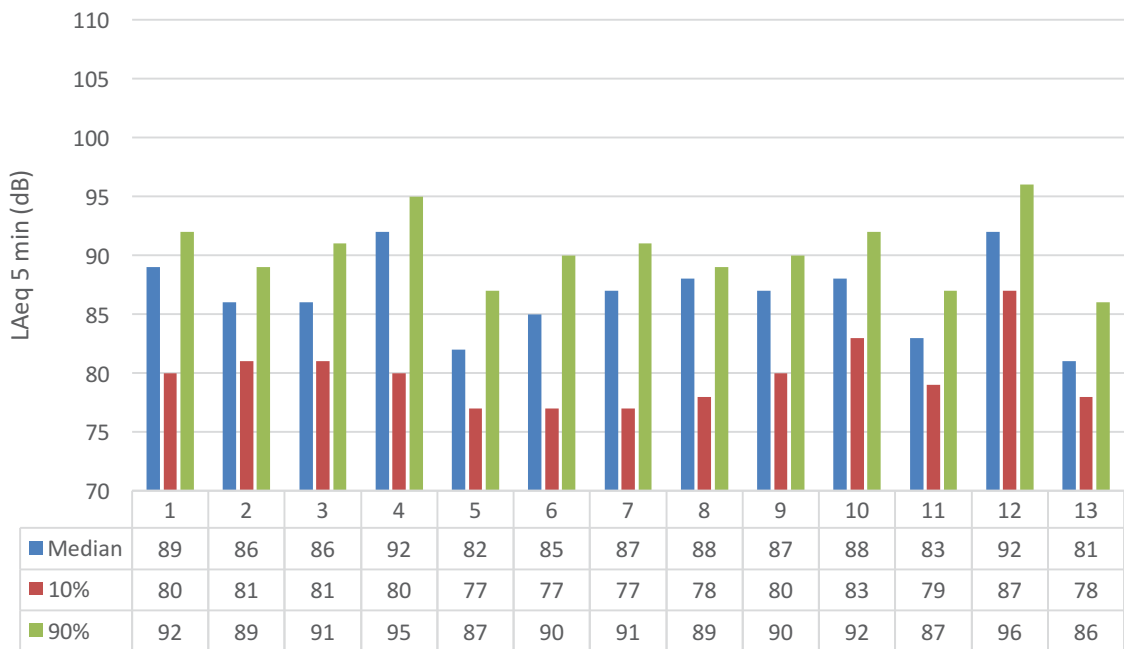


Figure 7. $L_{Aeq-5min}$ FOH statistical summary

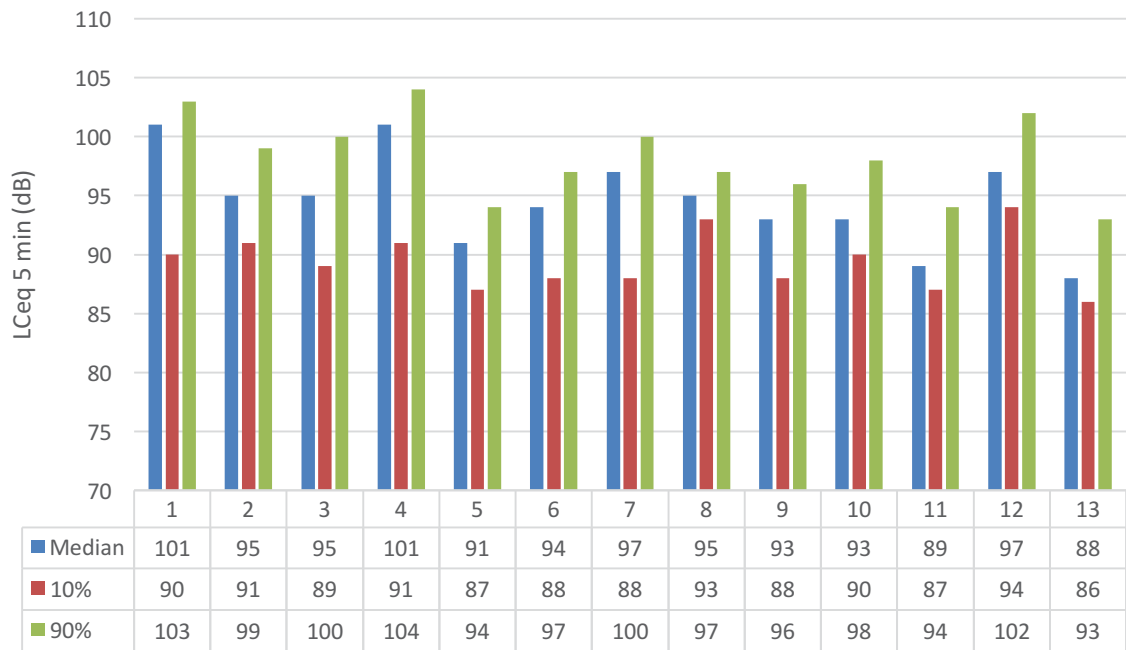


Figure 8. $LC_{eq-5min}$ FOH statistical summary

The plots above show in a succinct manner the measured values for the events under consideration. In following sections, we use this data to arrive to the proposed values to limit emissions from events to be held at the Forecourt.

The values contained in this section show the values typically measured for different Forecourt events. It is assumed that within these range of values acceptable levels that allow for a good patron experience have been achieved. These statistical values have been considered when recommending the proposed limiting values.

E. Analysis of Typical Music Spectra

An analysis of music spectra can be beneficial to understand the expected levels from events to be held at the forecourt. The data presented here has been sourced from a loudspeaker manufacturer and confirmed using spectral analysis of recorded music. The manufacturer's data has been derived from live events while the analysis done on music files has been done using a combination of pre-recorded music for the rock, pop and dance genres and live recordings as is typically the case for classical music. The music file analysis confirms the findings of the manufacturer's data and is not included in the following plots.

The following plot shows the typical spectrum shape for three groups of music: classical, rock/pop and dance/metal. All the spectra have been normalised to the 1kHz value.

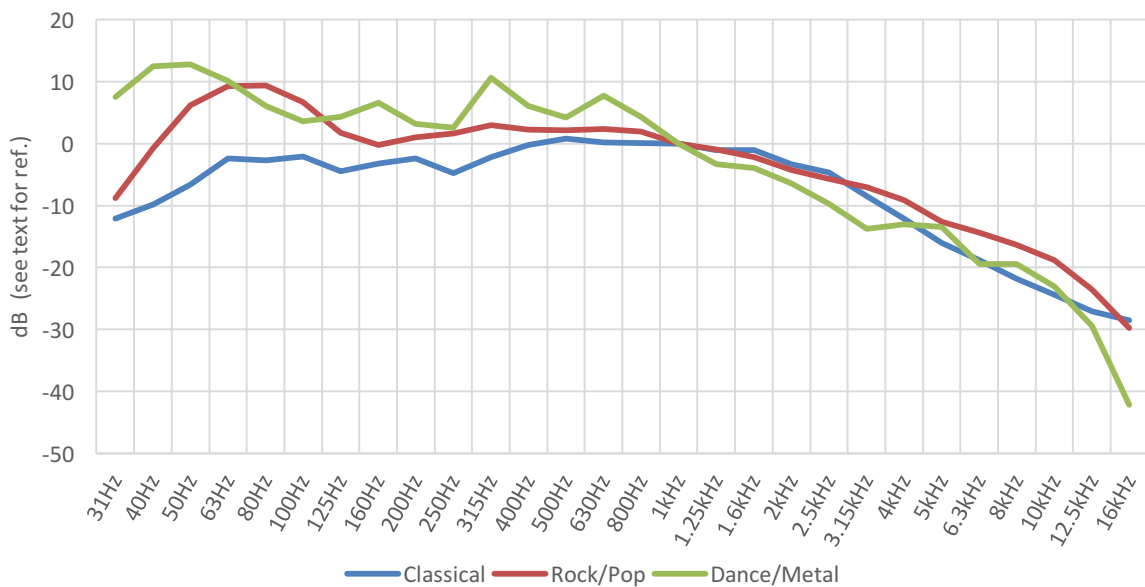


Figure 9. Spectrum for three different music groups

It is clear that Rock/Pop and Dance/Metal types of music have a larger bass content while classical music has higher content at higher frequencies. The A and C-weighted summed values for this spectra normalised to the 1 kHz value are shown in the figure below.

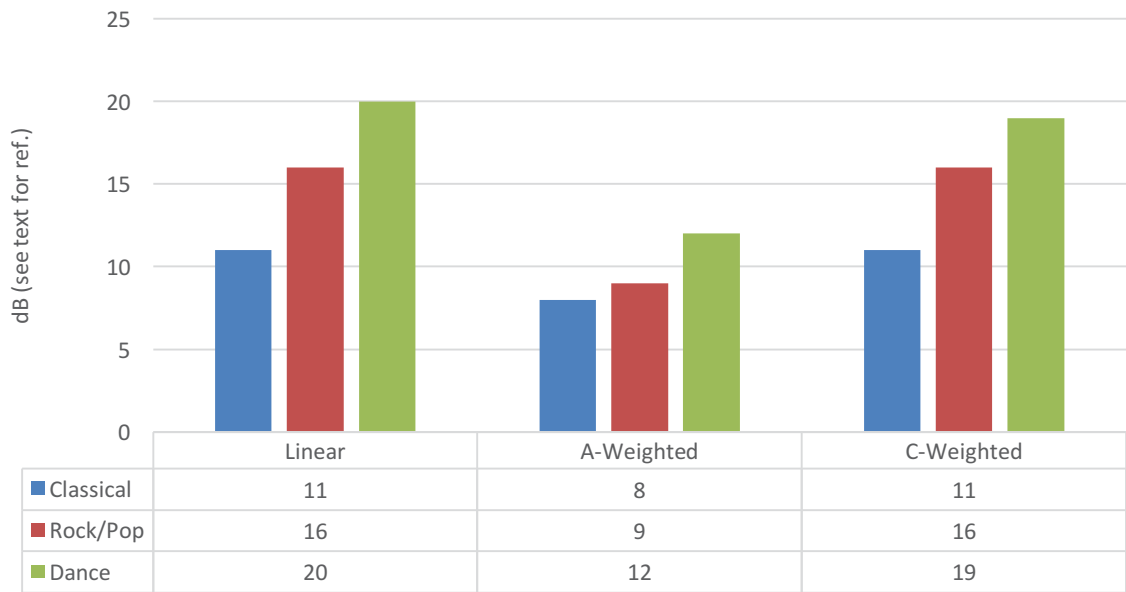


Figure 10. Summed values for three different music groups

It is clear that when using a mid-band frequency as the reference, any of these measurement strategies will limit the production of lower frequencies for typical music spectra. This is particularly true since, from the spectra plot, we can see that higher frequencies roll-off as frequency increases for all types of music. This reinforces the utility of A and C-weighted values as the only limiting values.

F. PA Layout and Effect on Nearest Residents

We have conducted an extensive investigation of audio systems typically available in the Australian rental market which can be used for events held at the Forecourt. For the complete information the reader is referred to: Sydney Opera House – Forecourt Events Sound Management Report, prepared by Auditoria Pty Ltd and dated 09/Aug/2016. In this section we provide a short review of that report with a special emphasis on the matters pertaining this report.

F.1 Summary of Sydney Opera House – Forecourt Events Sound Management Report, prepared by Auditoria Pty Ltd

We have conducted an investigation of loudspeaker systems with the intention of understanding their characteristics in terms of output towards the front (audience area) compared to output towards the sides or back (residents). In that report we arrived at available maximum levels at the FOH location based on the previous SOH restrictions at the residents. In that report we assumed a FOH location at 35 m from the PA. Additionally, sound from other sources (e.g. audience and services) was taken into account. We conducted assessments for 6 different loudspeaker systems and in all our calculations we assumed cardioid sub-woofers were used if available from each particular brand. We conducted calculations for the large event and Australia Day layouts as described in sections C.1. and C.2. The opera layout will be considered separately and is somehow easier to model as the loudspeakers, FOH location and nearest residential locations would be approximately in-line.

The data obtained from our modelling exercise has informed the levels proposed in the following section. It is important to note that in all our recommendations in the following section we have included the influence of the entire system including subs and levels from other sources. Also, it should be noted that all modelled systems are available rentals and include the most used systems for these events.

F.2 Sound System Modelling Methodology

F.2.1 Sound System Directivity

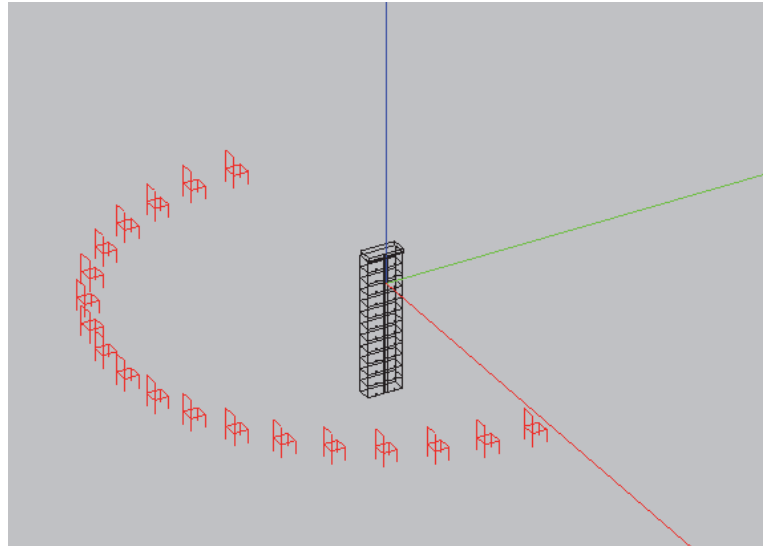
Modelling and simulation was used to analyse the directivity performance of various concert loudspeaker systems likely to be used for Forecourt events. The following systems were analysed:

- d&b J-Series with J-Series subwoofers
- L`Acoustics K1 with KARA downfill and SB28 subwoofers
- L`Acoustics K2 and SB28 subwoofers
- L`Acoustics VDOSC with dVDOSC downfill and SB28 subwoofers
- L`Acoustics KUDO with SB28 subwoofers
- Meyer Sound MILO and 700HP subwoofers.

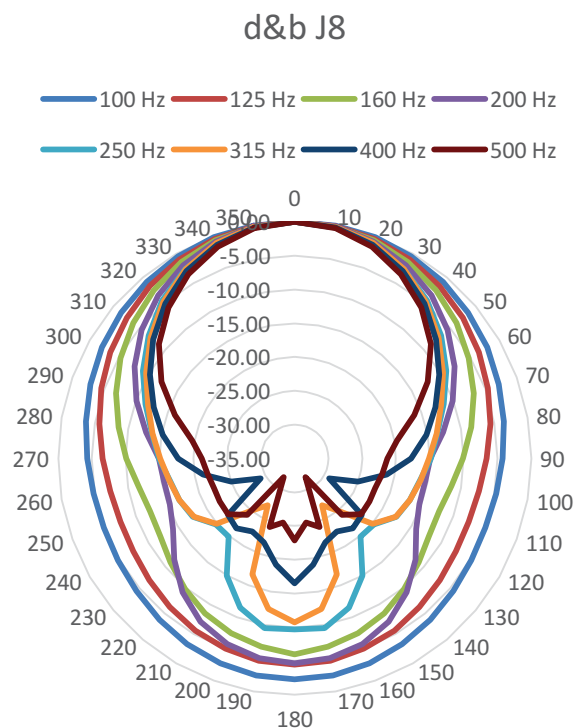
The analysis in this section was conducted primarily using the EASE software by AFMG Technologies GmbH. The polar data used for the analysis in this section was directly extracted from the manufacturers' data provided as EASE data.

The data was extracted by placing an array in the middle of several receivers around an array and obtaining the direct sound data across frequencies. The line length for each array was based on the arrays used for Music at the House 2015, which consisted of 12 L`Acoustics

K1, with an approximate total length of 5.25 m. The dimensions of all other arrays were adjusted to the nearest similar length based on the element height for each array. The horizontal polar data was taken 1 m from the top of the array. This ensured that the diffraction path over the top of the top element was appropriately represented.



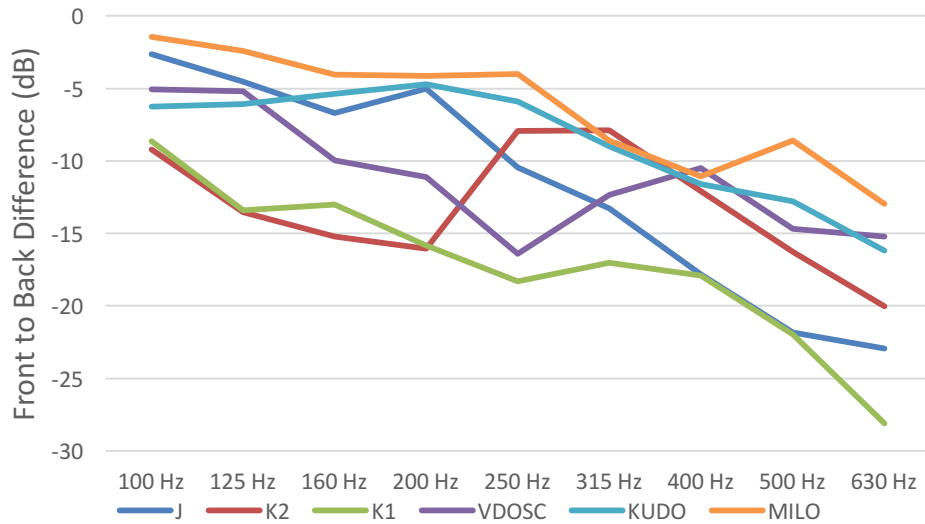
An example plot of the data obtained are presented below for a loudspeaker system at the low and low mid frequency third octave bands.



Using the above plot as an example, it is clear that a loudspeaker system exhibits greater attenuation towards the back than others. A simple way of quantifying this is by comparing the front to back ratios for each loudspeaker. We have compiled data for all loudspeaker systems considered and calculated ratios based on the front at 90° compared to the back

90°, this allows us to generalise a system's output and provide a better understanding of the expected levels at a wide resident area.

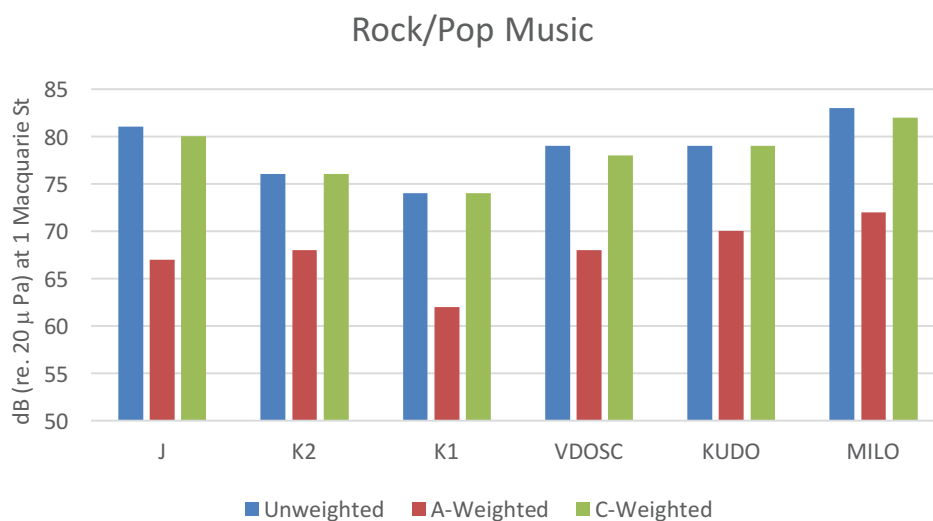
The front to back ratios for all systems under consideration are shown in the following plot. The plot focuses on the lower end of the spectrum as this is the range where break-out from the back of the box and diffraction around the array are more prominent.



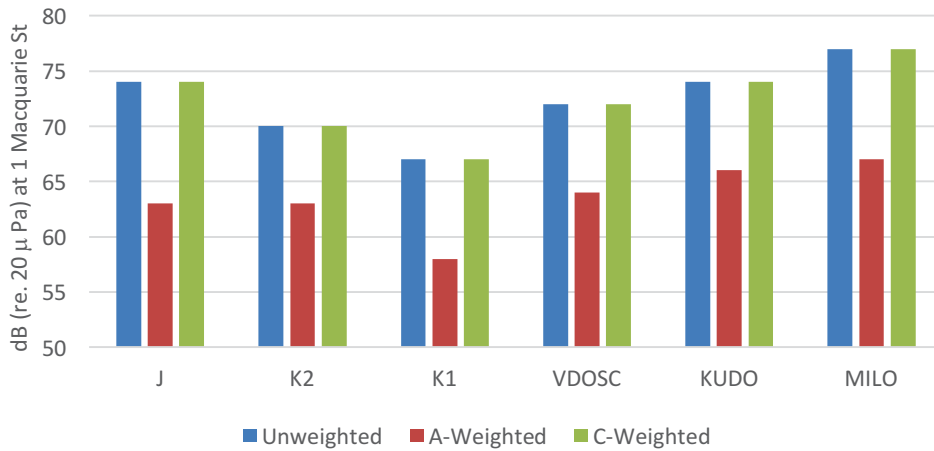
F.2.2 Simulated Noise Levels at 1 Macquarie St

If we set a scenario where we keep the input to each loudspeaker constant, we can calculate the levels that will be experienced from the direct radiation for each loudspeaker system. For the calculations in this section, we set a FOH location 40 m from the stage and set an A-weighted level of 95 dB at this location.

We have prepared calculations using a pink noise spectrum and a spectrum typical for Rock/Pop music. The latter places special emphasis on lower frequencies. We then average the results obtained at a distance similar to the distance from the typical stage location to the residents at 1 Macquarie St. The summed results are shown in the following plots.

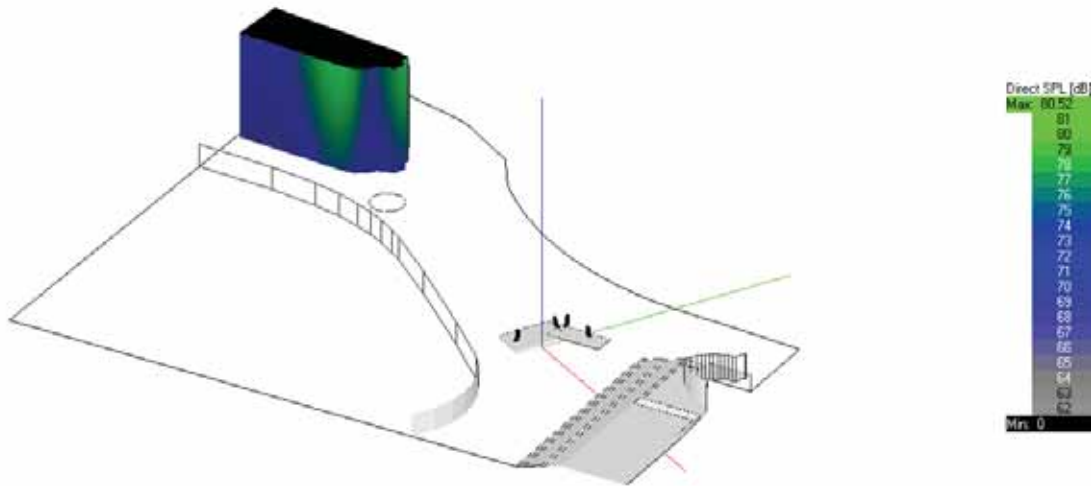


Pink Noise



To illustrate this scenario in three dimensions, loudspeaker system simulations have been prepared in EASE. The following plots show the levels for two loudspeaker systems producing pink noise and the resulting noise at the building façade shown in an A-weighted and unweighted scale.

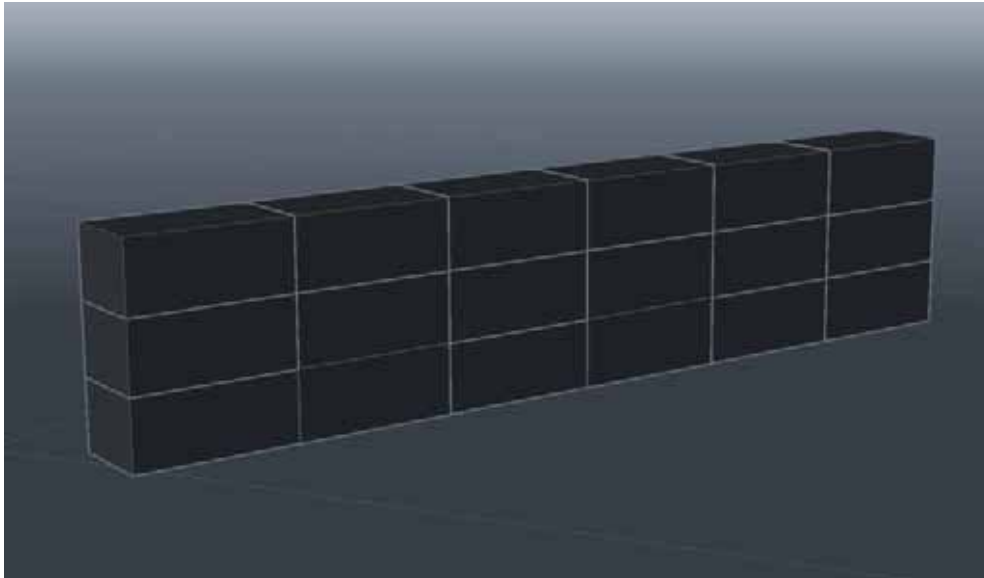
The following plot shows a d&b J-Series array and the unweighted levels at the façade.



F.2.3 Ground Stacked Subwoofer System

A ground stacked subwoofer system has been included in our modelling exercise. The subwoofer system follows the typical Rock/Pop music spectrum. All our subwoofer system calculations have taken into account our recommendations for cardioid subwoofers.

Indicative system configurations are provided to communicate the design intent. An example of a design with a single block of 18 subwoofers as shown in the image below. As an example, the bottom row of subs would be reversed to enable cardioid operation if using L'Acoustics products or configured as cardioid if using d&b products.



F.2.4 Additional Calculation Assumptions

For our calculations and limits proposed we assume a FOH location 40 m from stage and contribution from other sources of 75 dB(C). All calculations include subwoofer output.

G. Suggested FOH Level Limits

The proposed strategy for events held at the Forecourt is included in the following table. We propose three type of events to aid the SOH in providing a succinct programming methodology to clients hiring the space. **It should be noted that all proposed levels are for a FOH to stage distance of 40 m. Please note that his levels take into account the directivity of the loudspeaker systems, the location of the stage in relationship to the nearest resident and additional mitigation measures. These numbers are closer to the source and therefore appear larger than the previous limits established at the resident's boundary. However, the expected outcome is comparable.**

| Type of Event | A-Weighted Leq-5min (dB) | C-Weighted Leq-5min (dB) | Linear (dB) | 63 Hz (dB) |
|---------------|-----------------------------|-----------------------------|-------------|------------|
| Location 1 | 96 | 102 | 103 | 98 |
| Location 2 | 92 | 98 | 99 | 94 |
| Location 3 | 82 | 90 | 91 | 86 |

These additional requirements are proposed:

Location 1: Location 1 events can only be staged using the configuration proposed in section C.1.

Location 2: Location 2 events can be staged using the configuration proposed in section C.2.

Location 3: The Location 3 events are proposed specifically for the configuration in section C.3.

G.1 Corrections for FOH to Stage Distance

If the FOH to stage distance is different to 40 m the following table contains adjustments for the values in the previous table.

| Distance (m) | Adjustment (dB) |
|---------------------|------------------------|
| 20 | 6 |
| 25 | 4.1 |
| 30 | 2.5 |
| 35 | 1.2 |
| 40 | 0 |
| 45 | -1 |
| 50 | -1.9 |
| 55 | -2.8 |
| 60 | -3.5 |
| 65 | -4.2 |
| 70 | -4.9 |