Noise Impact Assessment for Outdoor Music

Oro Valley Marketplace

Prepared for

Town West Realty

Project Manager
Toby Horvath

Lance Willis, PhD

R. 1, November 24, 2021

Table of Contents

1. Introduction **4**
1.1 Summary 4
1.2 Version History 4
2. Site Summary **5**
2.1 Proposed Site Development 5
2.2 Area Summary 6
2.3 Zoning 7
3. Site Plan Analysis **9**
3.1 Methodology 9
3.2 Sound Sources 9
3.2.1 Amplified Music on the Patios 9
3.2.2 Amplified Music in the Courtyard 10
3.2.3 Patron Conversations 10
3.2.4 Other Zoning Code Requirements 11
3.3 The Model Space 11
3.4 Sound Pressure Level Contour Maps 14
3.5 Use Cases 14
3.5.1 Live Music on Patios 14
3.5.2 Live Music in Courtyard 17
3.5.3 Patrons Only on Patios and Courtyard 19
4. Conclusions and Recommendations **21**
4.1 Use Cases 21
4.1.1 Live Music on Patios 21
4.1.2 Live Music in the Courtyard Area 22
4.1.3 Patrons Only Without Amplified Sound 22
4.2 Roadway Noise 22
Appendix **24**
A1. Glossary of Acoustical Terms and Abbreviations 25
A1.1 Abbreviations 25
A1.2 Terms 26
A2. General Acoustics 31

Table of Figures

Figure 2.1. Proposed Site Plan........5
Figure 2.2. Proposed Site and Surrounding Area........6
Figure 2.3. Zoning........8
Figure 3.1. Model View of Venues........12
Figure 3.2. Model View of Surrounding Area........13
Figure 3.3. Legend for Sound Pressure Level Contour Maps........14
Figure 3.4. Adjusted LAeq Sound Pressure Level Contours - Patios with PA's........15

Figure 3.5. Adjusted 63 Hz Sound Pressure Level Contours - Patios with PA's....16
Figure 3.6. Adjusted LAeq Sound Pressure Level Contours - Courtyard with PA....17
Figure 3.7. Adjusted 63 Hz Sound Pressure Level Contours - Courtyard with PA....18
Figure 3.8. Adjusted LAeq Sound Pressure Level Contours - Patios and Courtyard with Patrons Only....20
Figure A2.1. ISO 226 Equal Loudness Contours....32
Figure A2.2. Frequency Weighting Filter Curves....33
Figure A2.3. Decrease of SPL with Distance Due to Spherical Spreading....34
Figure A2.4. Total SPL from Multiple Sources with Equal SPL Output....35

Index of Tables

Table 3.1. Unweighted Octave Band Sound Power Levels for a Typical Live Music Venue....10
Table 3.2. Unweighted Octave Band ANSI S3.5 Standard Speech Spectra....11
Table 3.3. Field Points....13
Table 3.4. LAeq Code Compliance for Patios with PA's....15
Table 3.5. 63 Hz Band Code Compliance for Patios with PA's....16
Table 3.6. LAeq Code Compliance for Courtyard with PA....18
Table 3.7. 63 Hz Band Code Compliance for Courtyard with PA's....19
Table 3.8. LAeq Code Compliance for Patios and Courtyard with Patrons Only....20
Table A2.1. Decrease of SPL with Distance Due to Spherical Spreading....34

1. Introduction

1.1 Summary

This report is a preliminary assessment of the community noise impact of live outdoor music at three proposed restaurants and a courtyard area at the Oro Valley Marketplace shopping center at Oracle Road and Tangerine Road with respect to Section 25.1 of the Oro Valley Zoning Code. The hosting of live amplified music on the patios of the restaurants is expected to comply with the Town of Oro Valley Zoning Code in regard to noise for typical live band performances in venues of this size. Hosting live music in the proposed courtyard area was found to require a dedicated, distributed sound system to better contain sound within the venue and no operation after 10:00 pm. Operating the proposed venues without amplified sound is not expected to result in any noise related issues.

1.2 Version History

- R. 1: 2021-11-24
    - Replace courtyard sound system with distributed speaker system
- R. 0: 2021-10-21
    - Preliminary analysis

2. Site Summary

2.1 Proposed Site Development

Three restaurants with outdoor patios are proposed to be built at the Oro Valley Marketplace shopping center as shown in Figure 2.1. Live outdoor music is planned for the patio areas and possibly the central courtyard area. The patio areas face the interior courtyard space between the group of restaurants thereby using the restaurant structures as acoustical shielding to keep the sound contained within the vicinity of the venues.

Figure 2.1. Proposed Site Plan

2.2 Area Summary

The land uses surrounding the shopping center site are shown in Figure 2.2. The shopping center and adjacent properties west of Oracle Road are in the Town of Oro Valley. Properties on the east side of Oracle Road are in unincorporated Pima County. There are single family homes to the west across Sausaulito Creek. Cool air collecting in this low lying area at night may increase the amount of refracted sound reaching the neighborhood. To the north and south along Oracle Road are commercial uses. To the northwest across Tangerine Road is a hospital and hotel. To the east is residential. These homes are shielded by a row of retail stores facing Oracle Road.

Figure 2.2. Proposed Site and Surrounding Area

2.3 Zoning

Zoning in the area is shown in Figure 2.3 [Pima County ArcGIS Online <https://pimamaps.pima.gov/geoapps/main>]. The proposed site and adjacent properties to the north, west, and south along Oracle Road are zoned PAD, planned area development. Also to the south and southwest are R1-36 and R1-144, single family residential. To the east in Pima County is SR, suburban ranch. To the northeast across Oracle Road are commercial uses zoned RVC, rural village center, and MR, major resort. The latter is an RV park and campground.

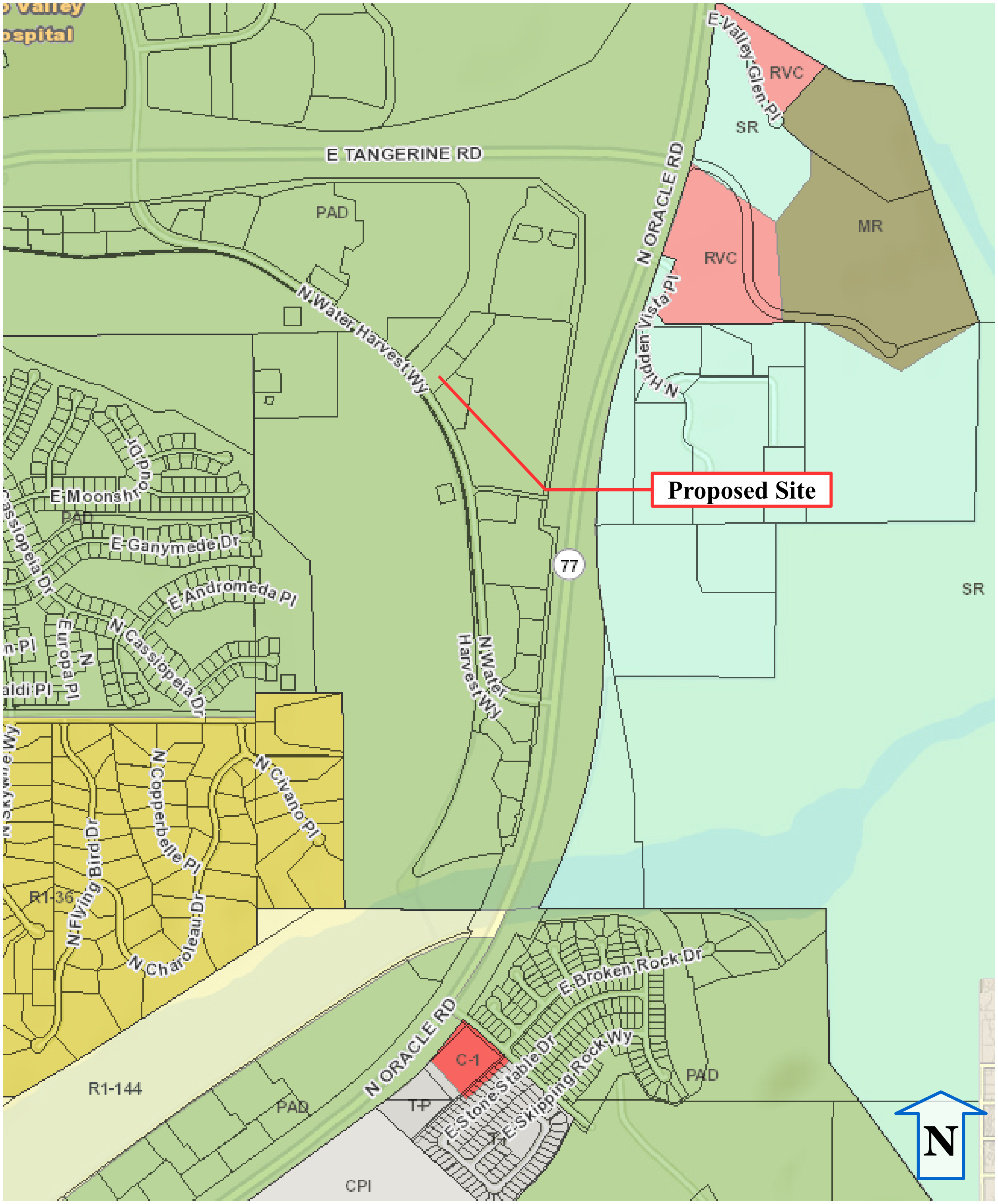

Figure 2.3. Zoning

3. Site Plan Analysis

3.1 Methodology

The acoustical site model has been constructed using the iNoise package version 2021.0 developed by DGMR. The sound propagation model is ISO 9613. This software conforms with the ISO/TR 17534-3 quality standard for implementing the ISO 9613 Part 2 outdoor sound propagation model.

3.2 Sound Sources

There are two sound sources that need to be considered for the patio and courtyard areas. One is the sound produced by the venue PA systems for amplified live music performances. The other is the sound of conversations between restaurant patrons.

3.2.1 Amplified Music on the Patios

The source model for this activity is based on measurements conducted at an outdoor venue in Oro Valley, Arizona. The band at the venue was a typical rock ensemble consisting of drums, bass, guitars, and vocals. The band performed popular songs from the 50's, 60's, and 70's. The sound reinforcement system had two loudspeakers on stands at about head height. Instrument amplifiers were also used for sound projection into the audience area.

The audience was also found to make a significant contribution to the overall sound emission in the form of conversation which was continuous during and between songs. This had the effect of reducing the directivity of the venue as a whole as it was not entirely the result of the directivity of the mains speakers at the stage. For this reason each patio has been modeled as an area source whose total sound power is in proportion to its size.

The size of the reference venue was about 2700 square feet (250 square meters). Table 3.1 shows the unweighted octave band equivalent-continuous sound power levels (PWL) for the reference venue. The total sound power has been normalized to one square meter. The Town of Oro Valley Zoning Code Section 25.1.A.3.g and the definition of regular impulsive sound in Section 31 require a 5 dB adjustment for speech and music sources. The final adjusted sound power per square meter is 84.4 dBA. The height of the area source is 6.5 feet (2 meters).

Center Frequency (Hz)	31	63	125	250	500	1000	2000	4000	8000	A-wgt
PWL	98.9	110.4	112.2	103.8	100.5	97.9	92.3	87.9	84.1	103.4
Venue Size (m^2)	250	250	250	250	250	250	250	250	250	250
PWL per m^2	74.9	86.5	88.2	79.8	76.5	73.9	68.3	63.9	60.2	79.4
Speech/music adjustment	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Adjusted PWL per m^2	79.9	91.5	93.2	84.8	81.5	78.9	73.3	68.9	65.2	84.4

Table 3.1. Unweighted Octave Band Sound Power Levels for a Typical Live Music Venue

3.2.2 Amplified Music in the Courtyard

The sound system chosen for the courtyard area uses a distributed sound system with six speakers at a height of 6.5 feet (2 meters). These speakers are directed inward and down in order to use the audience as sound absorption and to keep the sound within the courtyard. In this configuration the array of speakers only needs to project to the center of the courtyard. The target sound pressure level at the center of the courtyard is 83 dBA.

3.2.3 Patron Conversations

For speech communication among the venue patrons without amplified music present, the ANSI S3.5 standard speech spectrum for raised voice is used. Due to the cocktail party effect, the speech effort on the patios will tend to be higher than normal. The raised voice standard spectrum has therefore been used with the required 5 dB adjustment in Section 25.1.A.3.g for speech.

The number of sound sources has been determined using the fire code and the areas of the patios and courtyard. If one occupant is allowed per each 36 square feet and half of the occupants are talking at the same time, this leads to a source density of 0.014 per square foot (0.15 per square meter). Table 3.2 shows the sound power levels for the ANSI S3.5 standard speech spectra assuming a directivity index of 2. The height of this area source is 5 feet (1.5 meters).

Center Frequency (Hz)	31	63	125	250	500	1000	2000	4000	8000	A-wgt
			ANSI S3.5 Standard Speech Spectrum Level (PWL, DI = 2)							
Normal			56.0	64.8	67.0	62.0	56.7	51.4	44.9	67.1
Raised			57.4	68.3	72.8	70.5	65.1	59.2	49.5	74.3
Loud			58.9	72.4	78.2	78.6	74.1	67.4	55.8	81.8
Shout			54.4	74.4	83.2	87.1	84.0	77.0	65.2	90.1
Speech/music adjustment			5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
			Single Source Adjusted PWL							
Normal			61.0	69.8	72.0	67.0	61.7	56.4	49.9	72.1
Raised			62.4	73.3	77.8	75.5	70.1	64.2	54.5	79.3
Loud			63.9	77.4	83.2	83.6	79.1	72.4	60.8	86.8
Shout			59.4	79.4	88.2	92.1	89.0	82.0	70.2	95.1
Density factor (src/m^2)			0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
PWL correction (dB)			-8.2	-8.2	-8.2	-8.2	-8.2	-8.2	-8.2	-8.2
			Adjusted PWL per m^2 of Floor Space							
Normal			52.8	61.5	63.7	58.8	53.4	48.1	41.7	63.9
Raised			54.2	65.1	69.5	67.2	61.9	56.0	46.3	71.0
Loud			55.6	69.2	75.0	75.4	70.9	64.1	52.5	78.5
Shout			51.1	71.2	80.0	83.9	80.8	73.7	62.0	86.9

Table 3.2. Unweighted Octave Band ANSI S3.5 Standard Speech Spectra

3.2.4 Other Zoning Code Requirements

The Oro Valley Zoning Code Section 25.1 gives specific recommendations for maximum allowable sound pressure levels according to receiving land use, time of day, and the characteristics of the sound produced. Speech and music are considered regular impulsive sound. All equivalent-continuous levels have been adjusted by 5 dBA as described above.

The one minute sound pressure level limits apply to the unweighted 16, 31.5, and 63 Hz octave bands. Unamplified speech produces very little sound power in these frequency bands. Amplified music, however, does and will be examined for the most prominent band, 63 Hz, in addition to the A-weighted sound levels for case studies where a PA system is in use.

The maximum sound pressure levels for amplified speech and music are in general not exceedingly large compared to the equivalent-continuous levels used for the one hour criterion. A separate analysis is not performed here; however, given the sound sources planned for the site, compliance with the maximum sound limits should follow compliance with the one hour limits.

3.3 The Model Space

Figures 3.1 and 3.2 give an overview of the acoustical model. A set of field points has been selected to better quantify the sound pressure levels expected at specific locations. These are listed in Table 3.3 with their heights above grade and shown in the figures. Ground types in the model are asphalt and natural desert (default) having ISO 9613 ground factors of 0.1 and 0.3 respectively.

Figure 3.1. Model View of Venues

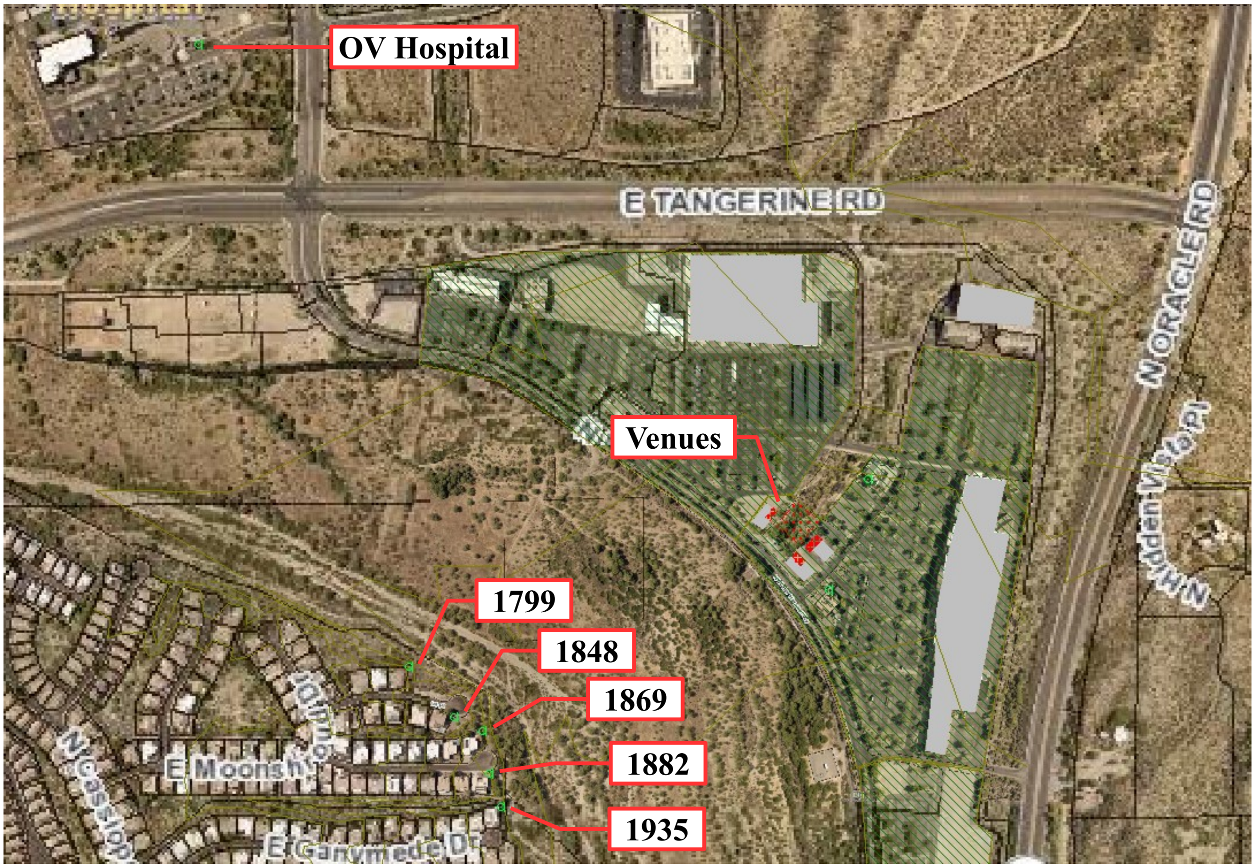

Figure 3.2. Model View of Surrounding Area

Location	Land Use	Height Above Grade (ft)
1799 Terrestrial Pl	Single Family	5
1848 Terrestrial Pl	Single Family	5
1869 Starmist Pl	Single Family	5
1882 Starmist Pl	Single Family	5
1935 Ganymede Dr	Single Family	5
Keg Steak House	Commercial	5
Olive Garden	Commercial	5
OV Hospital	Hospital, Hotel	5
OV Hospital	Hospital, Hotel	35

Table 3.3. Field Points

3.4 Sound Pressure Level Contour Maps

Sound pressure level contours in the figures below are displayed in 5 dBA increments. The legend identifying the map symbols is in Figure 3.3. All sound pressure levels are A-weighted unless otherwise noted. Sound walls are labeled as barriers in the iNoise software. The height of the contour grid points is 5 feet above grade.

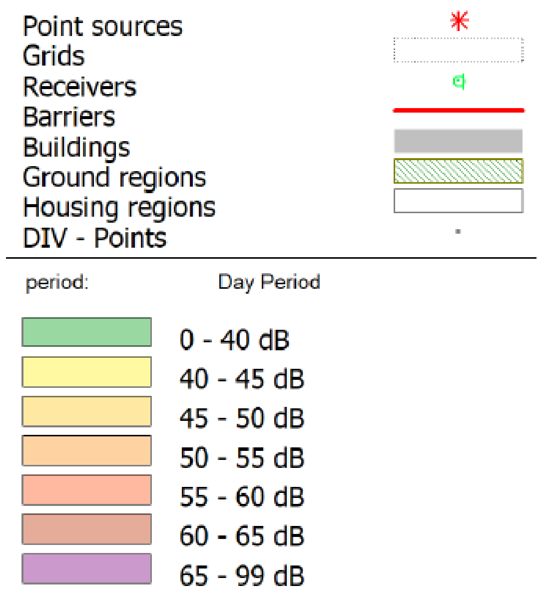

Figure 3.3. Legend for Sound Pressure Level Contour Maps

3.5 Use Cases

3.5.1 Live Music on Patios

For the case where there are three bands performing on the restaurant patios, sound pressure level contours for the A-weighted equivalent-continuous sound pressure levels (LAeq) are shown in Figure 3.4 and the unweighted 63 Hz octave band levels in Figure 3.5. The results for the corresponding field points are shown in Tables 3.4 and 3.5.

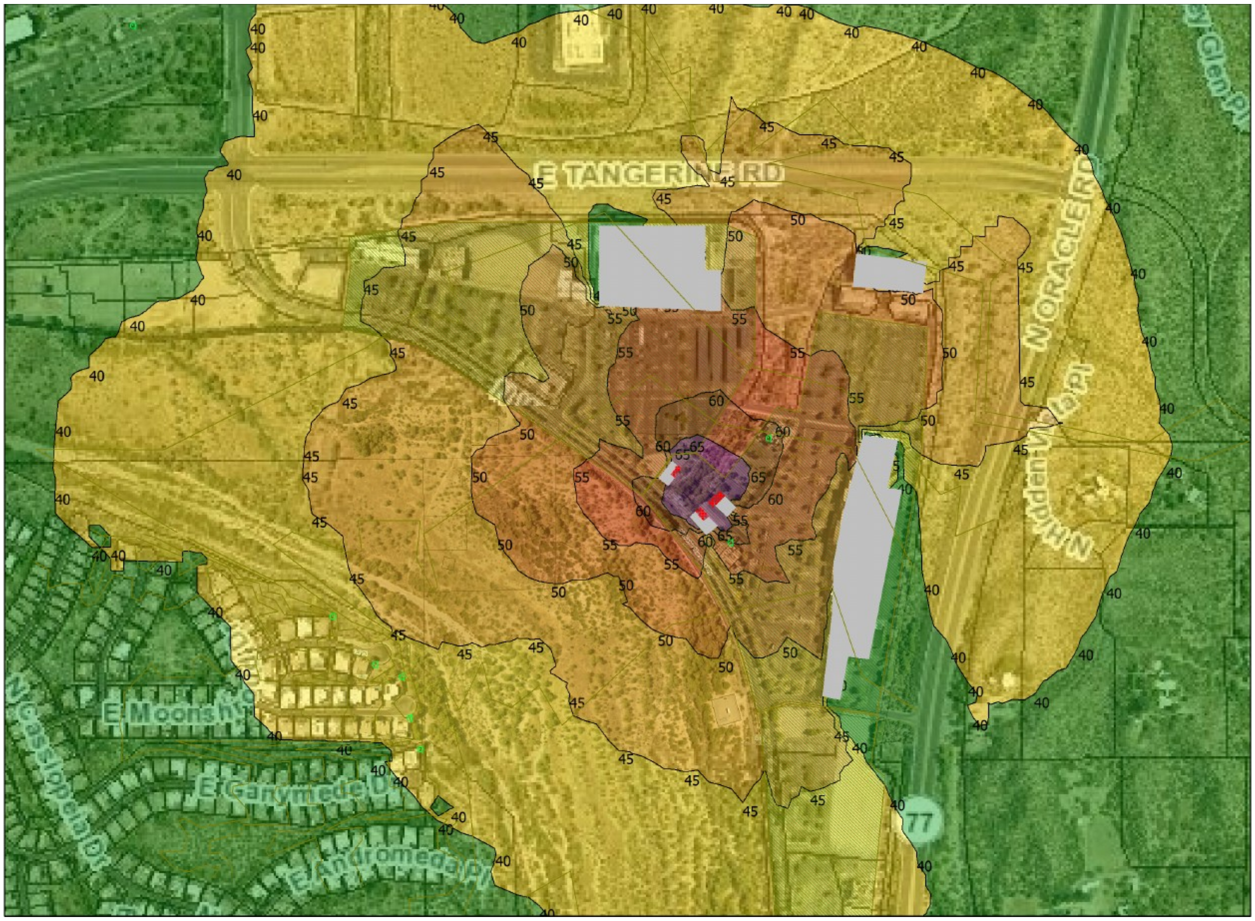

Figure 3.4. Adjusted LAeq Sound Pressure Level Contours - Patios with PA's

Location	Land Use	Height Above Grade (ft)	Adjusted Sound Pressure Level (dBA)	Daytime Hourly Limit (dBA)	Exceeds Daytime Limit	Evening Hourly Limit (dBA)	Exceeds Evening Limit	Nighttime Hourly Limit (dBA)	Exceeds Nighttime Limit
1799 Terrestrial	Single Family	5	44.2	55	no	50	no	45	no
1848 Terrestrial	Single Family	5	44.1	55	no	50	no	45	no
1869 Starmist	Single Family	5	43.3	55	no	50	no	45	no
1882 Starmist	Single Family	5	41.6	55	no	50	no	45	no
1935 Ganymede	Single Family	5	40.4	55	no	50	no	45	no
Keg Steak House	Commercial	5	61.2	65	no	65	no	65	no
Olive Garden	Commercial	5	60.3	65	no	65	no	65	no
OV Hospital	Hospital, Hotel	5	37.5	65	no	60	no	55	no
OV Hospital	Hospital, Hotel	35	38.2	65	no	60	no	55	no

Table 3.4. LAeq Code Compliance for Patios with PA's

Figure 3.5. Adjusted 63 Hz Sound Pressure Level Contours - Patios with PA's

Location	Land Use	Height Above Grade (ft)	Adjusted Sound Pressure Level (dBZ)	Daytime Hourly Limit (dBZ)	Exceeds Daytime Limit	Evening Hourly Limit (dBZ)	Exceeds Evening Limit	Nighttime Hourly Limit (dBZ)	Exceeds Nighttime Limit
1799 Terrestrial	Single Family	5	54.4	65	no	65	no	65	no
1848 Terrestrial	Single Family	5	54.5	65	no	65	no	65	no
1869 Starmist	Single Family	5	53.9	65	no	65	no	65	no
1882 Starmist	Single Family	5	52.5	65	no	65	no	65	no
1935 Ganymede	Single Family	5	51.8	65	no	65	no	65	no
Keg Steak House	Commercial	5	67.7	70	no	70	no	70	no
Olive Garden	Commercial	5	68.6	70	no	70	no	70	no
OV Hospital	Hospital, Hotel	5	48.2	70	no	65	no	65	no
OV Hospital	Hospital, Hotel	35	47.4	70	no	65	no	65	no

Table 3.5. 63 Hz Band Code Compliance for Patios with PA's

The noise impact for this use case is not expected to exceed the limits set in the Town of Oro Valley Zoning Code.

3.5.2 Live Music in Courtyard

For the case where there is a single band performing in the courtyard area, sound pressure level contours for the A-weighted equivalent-continuous sound pressure levels (LAeq) are shown in Figure 3.6 and the unweighted 63 Hz octave band levels in Figure 3.7. The results for the corresponding field points are shown in Tables 3.6 and 3.7.

As seen in the tables, the use of a dedicated sound system with distributed speakers is expected to comply with the noise code during daytime and evening hours. Operation after 10:00 pm is not currently planned.

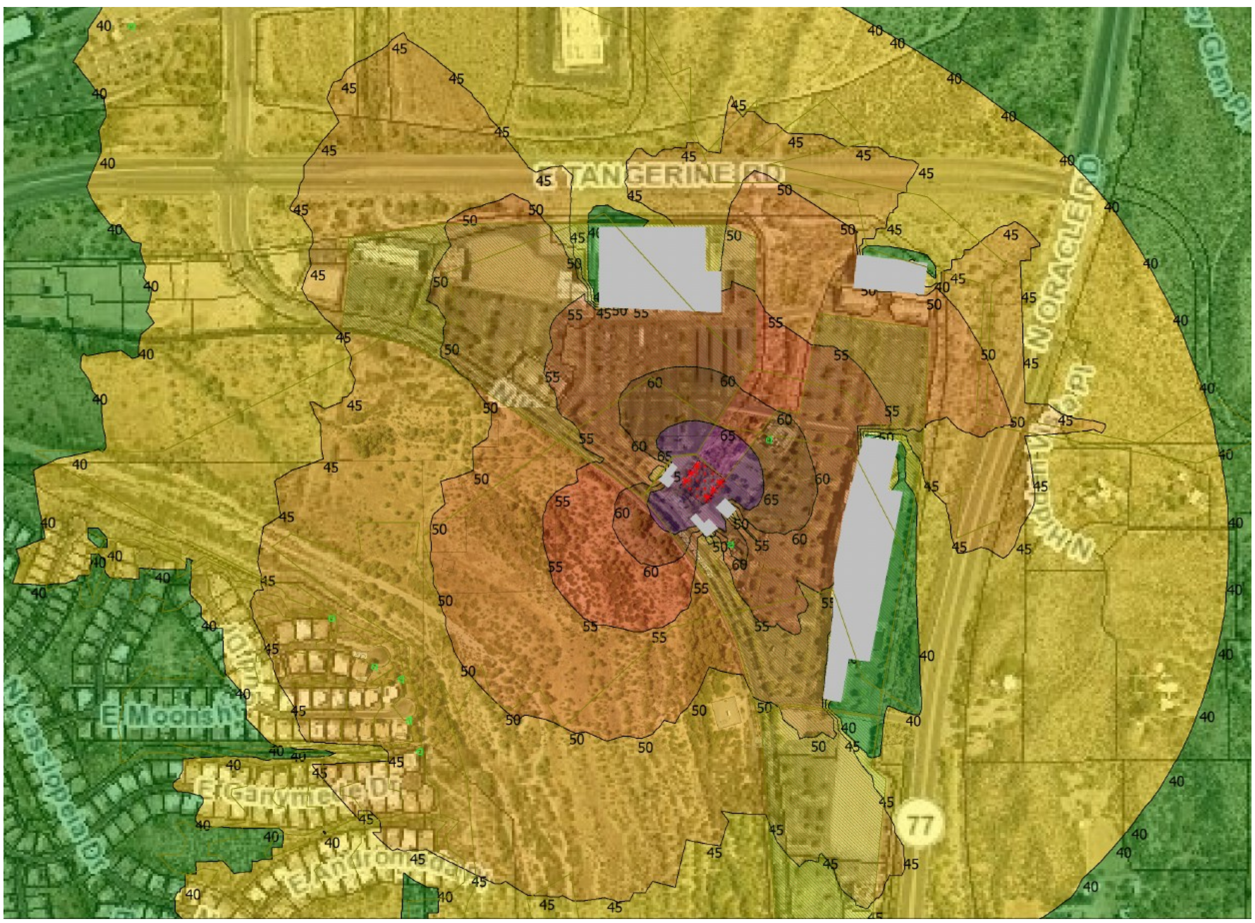

Figure 3.6. Adjusted LAeq Sound Pressure Level Contours - Courtyard with PA

Location	Land Use	Height Above Grade (ft)	Adjusted Sound Pressure Level (dBA)	Daytime Hourly Limit (dBA)	Exceeds Daytime Limit	Evening Hourly Limit (dBA)	Exceeds Evening Limit	Nighttime Hourly Limit (dBA)	Exceeds Nighttime Limit
1799 Terrestrial	Single Family	5	46.7	55	no	50	no	45	yes
1848 Terrestrial	Single Family	5	47.3	55	no	50	no	45	yes
1869 Starmist	Single Family	5	48.0	55	no	50	no	45	yes
1882 Starmist	Single Family	5	47.7	55	no	50	no	45	yes
1935 Ganymede	Single Family	5	47.3	55	no	50	no	45	yes
Keg Steak House	Commercial	5	62.5	65	no	65	no	65	no
Olive Garden	Commercial	5	63.0	65	no	65	no	65	no
OV Hospital	Hospital, Hotel	5	40.7	65	no	60	no	55	no
OV Hospital	Hospital, Hotel	35	41.0	65	no	60	no	55	no

Table 3.6. LAeq Code Compliance for Courtyard with PA

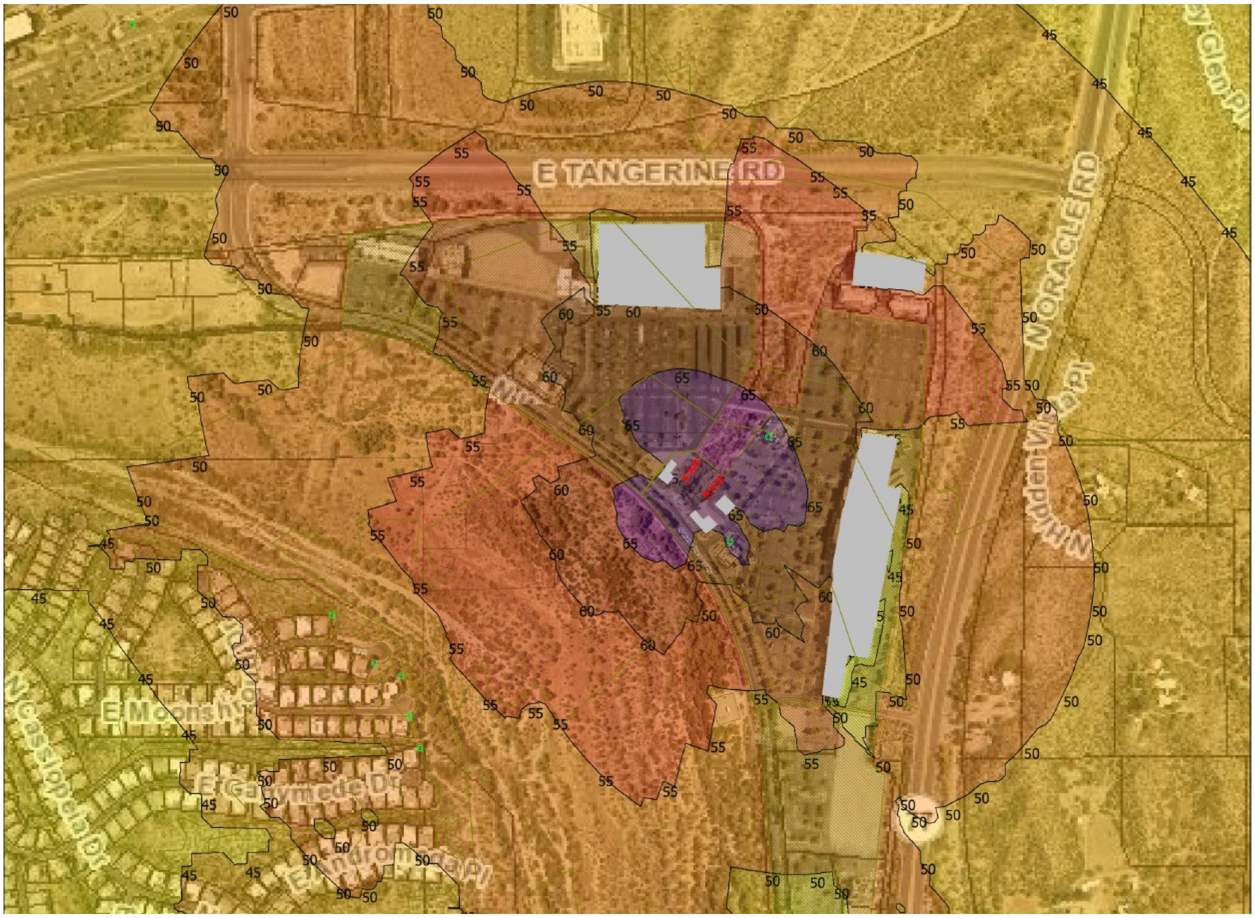

Figure 3.7. Adjusted 63 Hz Sound Pressure Level Contours - Courtyard with PA

Location	Land Use	Height Above Grade (ft)	Adjusted Sound Pressure Level (dBZ)	Daytime Hourly Limit (dBZ)	Exceeds Daytime Limit	Evening Hourly Limit (dBZ)	Exceeds Evening Limit	Nighttime Hourly Limit (dBZ)	Exceeds Nighttime Limit
1799 Terrestrial	Single Family	5	53.0	65	no	65	no	65	no
1848 Terrestrial	Single Family	5	52.9	65	no	65	no	65	no
1869 Starmist	Single Family	5	53.4	65	no	65	no	65	no
1882 Starmist	Single Family	5	53.3	65	no	65	no	65	no
1935 Ganymede	Single Family	5	53.0	65	no	65	no	65	no
Keg Steak House	Commercial	5	66.8	70	no	70	no	70	no
Olive Garden	Commercial	5	68.3	70	no	70	no	70	no
OV Hospital	Hospital, Hotel	5	49.3	70	no	65	no	65	no
OV Hospital	Hospital, Hotel	35	48.4	70	no	65	no	65	no

Table 3.7. 63 Hz Band Code Compliance for Courtyard with PA's

3.5.3 Patrons Only on Patios and Courtyard

In this use case there are no bands performing or amplified music. Only restaurant patrons are present on the patios and in the courtyard area. Sound pressure level contours for the A-weighted equivalent-continuous sound pressure levels (LAeq) are shown in Figure 3.8 and the results for the corresponding field points are shown in Table 3.8. These sound pressure levels are considerably lower than for amplified music and are not expected to exceed the limits set in the Town of Oro Valley Zoning Code.

Figure 3.8. Adjusted LAeq Sound Pressure Level Contours - Patios and Courtyard with Patrons Only

Location	Land Use	Height Above Grade (ft)	Adjusted Sound Pressure Level (dBA)	Daytime Hourly Limit (dBA)	Exceeds Daytime Limit	Evening Hourly Limit (dBA)	Exceeds Evening Limit	Nighttime Hourly Limit (dBA)	Exceeds Nighttime Limit
1799 Terrestrial	Single Family	5	38.0	55	no	50	no	45	no
1848 Terrestrial	Single Family	5	38.7	55	no	50	no	45	no
1869 Starmist	Single Family	5	39.2	55	no	50	no	45	no
1882 Starmist	Single Family	5	38.7	55	no	50	no	45	no
1935 Ganymede	Single Family	5	38.3	55	no	50	no	45	no
Keg Steak House	Commercial	5	54.3	65	no	65	no	65	no
Olive Garden	Commercial	5	53.6	65	no	65	no	65	no
OV Hospital	Hospital, Hotel	5	31.0	65	no	60	no	55	no
OV Hospital	Hospital, Hotel	35	31.3	65	no	60	no	55	no

Table 3.8. LAeq Code Compliance for Patios and Courtyard with Patrons Only

4. Conclusions and Recommendations

An ISO 9613 noise assessment has been performed for three proposed restaurants with patios and a courtyard area at the Oro Valley Marketplace shopping center. Noise impact on the surrounding properties has been evaluated for several use cases.

4.1 Use Cases

4.1.1 Live Music on Patios

The analysis showed the restaurant structures provide enough shielding for the neighborhood to the west to allow PA systems to be used while complying with the Town of Oro Valley Zoning Code. This analysis assumes a typical sound level produced by a live band at a comparable sized venue. It is, however, the responsibility of the venue to manage the operation of sound equipment in accordance with the applicable noise codes. To this end there a few recommendations that can make compliance easier.

The most common type of loudspeaker system used for live bands and DJ's at small venues is two speakers on stands on either side of the stage that push sound to the back of the audience area. In this setup most of the sound goes over the heads of the audience and into the adjacent properties. If the stage area is movable or the loudspeaker system consists of varying components brought in by performers for different shows, the emission of sound into the surrounding neighborhood is not likely to be well controlled. If using a pair of mains at the front of the audience, arrange the stage to face away from houses to the west. Directional subwoofers will reduce also the amount of low frequency sound going toward noise sensitive areas.

Distributed speaker systems are better for keeping sound within a venue. Rather than a couple of high power cabinets aimed over the heads of the audience, this type of system uses many loudspeakers placed around the perimeter of the audience area with the speakers aimed directly at the audience. This provides two benefits. First, the individual speakers are closer to the audience and therefore do not need as much amplification to provide full coverage of the audience area. Second, the audience itself will absorb much of the sound before it can leave the space. This also has the benefit of reducing bleed over between patios if multiple acts are performing at the same time.

The wash that lies between the venues and the neighborhood to the west will likely affect the sound propagation to the west. At night cool air collects in these low lying areas resulting in a thermal lapse condition that creates a stratification of the atmosphere. Sound refracts toward regions of lower sound speed, e.g. cooler air. This will cause sound to arc over the wash, possibly increasing the amount of sound reaching the neighborhood when conditions are favorable. The increase in sound pressure level during these times may be in the 3 to 5 dBA range.

The analysis indicated that nighttime sound system operation would be 3 to 5 dBA less than the acceptable limits in Table 25-1.A of the Oro Valley Zoning Code. The analysis is not able to account entirely for the nighttime thermal lapse condition; however, the results indicate that minimal noise abatement would be needed depending on the final use case parameters. A complete analysis will involve conducting propagation measurements at night to fully characterize how sound traverses the path over the wash. These measurements are not recommended until the design phase of the project.

This report is a noise impact study to identify potential issues and the feasibility of mitigating them. A complete noise abatement plan should be prepared during the design phase of the project based on the final planned use of the venues. It is the responsibility of the venues to operate sound reinforcement systems within the sound pressure level limits in the Oro Valley Zoning Code.

4.1.2 Live Music in the Courtyard Area

Analysis of this use case with a roughly designed dedicated distributed sound system indicated that the full courtyard area can be used for amplified music during the daytime and evening hours. Amplified music after 10:00 pm is not expected in the courtyard.

Sound walls have not been recommended at this stage. If the transit center is to be improved and expanded at a later date, sound mitigation measures may be incorporated into that site planning. Ultimately, it will be the responsibility of the venue to ensure that the sound system operates within the sound pressure level limits in the Oro Valley Zoning Code.

This report is a noise impact study to identify potential issues and the feasibility of mitigating them. A complete sound system design and noise abatement plan should be prepared during the design phase of the project based on the final planned use of the venues. It is the responsibility of the venues to operate sound reinforcement systems within the sound pressure level limits in the Oro Valley Zoning Code.

4.1.3 Patrons Only Without Amplified Sound

This use case was assessed using a standard speech spectrum for raised voices. With all three patios and the courtyard fully occupied sound pressure levels were found to be within the limits set in the Oro Valley Zoning Code.

4.2 Roadway Noise

The nearest homes likely to be affected by the proposed venues are about 1400 feet away. They are about 2300 feet from Oracle Road and 2200 feet from Tangerine Road. Sound radiating from a small cluster of point sources such as the proposed venues decreases 6.0 dB for each double of distance from the center of the cluster. Sound radiating from a line source such as a roadway (in this case a distribution of point sources along a line) decreases 3.0 dB for each doubling in distance from the roadway centerline. Sound from both roadways will also be subject to the refraction effects of the wash described above for the proposed venues.

Given the relative distances of the proposed venues and the roadways to the neighborhood, it is possible that the sound from the venues could be overwhelmed by road noise before it gets to the neighborhood. Background noise levels in the area have not been measured; however, this may be a mitigating factor affecting the applicable sound pressure level limits in Oro Valley Zoning Code.

Appendix

A1. Glossary of Acoustical Terms and Abbreviations

A1.1 Abbreviations

AI: articulation index

ASEL: A-weighted sound exposure level

ASTC: apparent sound transmission class

dB: decibel

DNL: day - night level

FSTC: field sound transmission class

Hz: Hertz

IIC: impact insulation class

kHz: kilohertz

L_{eq}, LA_{eq}, LC_{eq}: equivalent sound pressure level

NC: noise criteria

NIC: noise isolation class

NIPTS: noise induced permanent threshold shift

NR: noise reduction

Pa: Pascal

POE: probable occupant evaluation (see room criteria)

PTS: permanent threshold shift

PWL: sound power level

QAI: quality assessment index (see room criteria)

RC: room criteria

RT_{60}: reverberation time

SEL: sound exposure level

SII: speech interference index

SIL: speech interference level

SLM: sound level meter

SPI: speech privacy index

SPL: sound pressure level

STI: speech transmission index

TTS: temporary threshold shift

A1.2 Terms

A-weighting: see frequency weighting

absorption coefficient: see sound absorption coefficient

acoustical coupler: a cavity of predetermined shape and volume used for the calibration of earphones or microphones in conjunction with a calibrated microphone adapted to measure the sound pressure developed within the cavity

anechoic room: a room whose boundaries absorb practically all of the sound incident thereon, thereby providing essentially freefield conditions

articulation index (AI): a number (ranging from 0 to 1) which is a measure of the intelligibility of speech- the higher the number the greater the intelligibility. This metric has been replaced by the Speech Intelligibility Index (SII) defined in ANSI S3.5.

average sound level: see equivalent continuous sound level

background noise: the total noise from all sound sources other than a particular sound that is of interest

band: a subsection of the frequency spectrum

C-weighting: see frequency weighting

coupler: see acoustical coupler

day-night level (DNL): the 24 hour equivalent (average) A-weighted sound pressure level. A 10 dBA penalty is incurred between the hours of 10:00 PM and 7:00 AM. The DNL system has been adopted by the U.S. Department of Housing and Urban Development, the Department of Defense, and the Federal Aviation Administration.

decibel (dB): a unit of level which denotes the ratio between two quantities that are proportional to power; the number of decibels is 10 times the common logarithm (base 10) of this ratio.

diffuse field: a sound field which has statistically uniform energy density and in which the directions of propagation of the sound waves are randomly distributed. In a practical sense, the sound pressure levels at all points in the room are nearly the same except near the room boundaries and a sound wave reaching a given point in the room is equally likely to arrive from all directions.

direct sound: sound which reaches a given location in a direct line from the source without any reflections.

equivalent continuous sound level (L_{eq}): the level of steady sound which, in a stated time period and at a stated location, has the same sound energy as the time varying sound. If frequency weighting is applied, the equivalent continuous sound level may be designated LA_{eq} to indicate A-weighting or LC_{eq} to indicate C-weighting, etc. See also frequency weighting.

field sound transmission class (FSTC): a single number rating similar to sound transmission class (STC), except that the transmission loss values used to derive this class are measured in the field. FSTC ratings are typically lower than STC ratings which are measured under laboratory conditions.

flanking path: A wall or floor/ceiling construction that permits sound to be transmitted along its surface; or any opening, which permits the direct transmission of sound through the air.

freefield: a sound field in which the boundaries have negligible effect over the frequency range of interest.

frequency: the number of times that a waveform repeats itself in a given period of time, usually one second, i.e. the number of cycles per second). Unit: Hz.

frequency weighting: a prescribed frequency dependent attenuation or amplification applied to measured sound data usually intended to better approximate the sensation of loudness in a human listener. For example, A, B, and C weighting approximate the frequency dependent shape of the equal loudness contours for soft, moderate, and loud sounds.

Hertz (Hz): unit of frequency, cycles per second.

impact insulation class (IIC): a single number metric used to compare the effectiveness of floor-ceiling assemblies in providing reduction of impact-generated sounds such as footsteps. This rating is derived from values of normalized impact sound pressure levels in accordance with ASTM E492.

insertion loss: the reduction in sound level at the location of the receiver when a noise reduction measure such as a barrier, attenuator, muffler, etc. is inserted into the transmission path between the source and receiver. Unit: dB.

level: the logarithm of the ratio of a given quantity to the reference quantity of the same kind. Levels represent physical quantities such as sound pressure on a logarithmic scale and are therefore expressed in decibels. Unit: dB.

loudness: that attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from soft to loud. Unit: sone.

masking: the process by which the threshold of hearing for one sound is raised by the presence of another sound.

noise criteria (NC): a single number criteria for the HVAC or mechanical noise level in a room derived from measured octave band data. The octave bands are weighted to de-emphasize low frequencies because the human ear is least sensitive to these frequencies. This metric is not valid for outdoor measurements.

noise induced permanent threshold shift (NIPTS): the permanent hearing loss resulting from noise exposure.

noise isolation class (NIC): a single number rating derived from measured values of noise reduction between two enclosed spaces that are connected by one or more paths. This rating is not adjusted or normalized to a standard reverberation time.

noise reduction (NR): the difference in sound pressure level between any two points along the path of sound propagation, e.g. the difference in level between the interior and exterior of a building where the sound level inside is due only to exterior noise.

octave: the frequency interval between two tones whose frequency ratio is 2.

omnidirectional microphone: a microphone whose response is independent of the direction of the incident sound wave.

Pascal (Pa): a unit of pressure. 1 Pascal = 1 Newton per square meter ($1 \text{ N} / \text{m}^2$).

permanent threshold shift (PTS): a permanent increase in the threshold of hearing at a given frequency.

point source: a source that radiates sound as if from a single point.

receiver: a person (or persons) or equipment which is affected by sound.

refraction: (1) the phenomenon by which the direction of propagation of a sound wave is changed as a result of a spatial variation is the speed of sound. (2) The angular change in direction of a sound wave as it passes obliquely from one medium to another having different sound speed.

reverberation time (RT_{60}): of an enclosure, for a sound of a given frequency or frequency band, the time that is required for the sound pressure level in the enclosure to decrease by 60 dB after the source has stopped. Unit: second.

room criteria (RC, RC Mark II): an octave band metric for evaluating HVAC noise inside a room. RC is a two dimensional metric consisting of a curve number that is the arithmetic average of the 500, 1000, and 2000 Hz octave band sound pressure levels and a qualitative descriptor identifying the character of the sound spectrum. The descriptor can be (N) for neutral, (LF) for low frequency dominance (rumble), (MF) for midfrequency dominance (roar), and (HF) for high frequency dominance (hiss). In addition, acoustically induced vibration can be designated by (LFV_B) for moderate, but perceptible vibration and (LFV_A) for clearly perceptible vibration. As an example, the maximum RC prerequisite for LEED is designated as RC 37(N) indicating curve number 37 with a neutral spectrum.

Further, two intermediary metrics are used in calculating the room criteria. The quality assessment index (QAI) is a measure of the deviation from the given RC curve. The probable occupant evaluation (POE) is based on the magnitude of the QAI and can be 'Acceptable,' 'Marginal,' or Objectionable.'

Sabin: a unit of measure of sound absorption; a measure of sound absorption of a surface. It is the equivalent of 1 square foot of a perfectly absorbing surface; a metric Sabin is the equivalent of 1 square meter of a perfectly absorbing surface.

sone: the unit of loudness. One sone is the loudness of a pure tone presented frontally at a frequency of 1000 Hz and a sound pressure level of 40 dB referenced to 20 micropascals.

sound absorption coefficient (α): ideally, the fraction of diffusely incident sound power that is absorbed (or otherwise not reflected) by a material or surface.

sound exposure level (SEL): over a stated time period or event, 10 times the logarithm base 10 of the ratio of the time integral of the sound pressure squared to the product of the reference sound pressure, 20 μPa, squared and the reference time, one second. This quantity is used to characterize single events of short duration where the averaged level (L_{eq}) is inadequate.

sound level meter (SLM): an instrument that is used to measure sound level, with a standard frequency weighting and standard exponentially weighted time averaging.

sound power level (PWL): the total acoustical power emitted from a sound source expressed in decibels relative to 10^{-12} Watts.

sound pressure level (SPL): the acoustical pressure amplitude expressed in decibels relative to 20 micropascals.

sound transmission class (STC): a single number rating used to compare sound insulation properties of walls, floors, ceilings, windows, or doors. See also field sound transmission class.

speech intelligibility index (SII): metric defined under ANSI S3.5 to quantifiy the intelligibility of speech under adverse listening conditions such as noise masking, spectral filtering, and reverberation. The SII is defined for a scale of 0 to 1 where values greater than 0.75 indicate good communication and values below 0.45 indicate generally poor communication conditions.

speech intelligibility test: a procedure that measures the portion of test items (such as syllables, monosyllabic words, or sentences) that are heard correctly.

speech interference level (SIL): an index for assessing the interference effects of noise on the intelligibility of speech, derived from measurements of the background noise level of contiguous octave bands; i.e. the arithmetic average of the octave band sound levels for the bands centered at 500, 1000, 2000, and 4000 Hz (four band method) or the corresponding average for the octave bands centered at 500, 1000, and 2000 Hz (three band method). If other octave bands are used they must be specified. Unit: dB.

speech privacy index (SPI): The SPI is essentially the opposite of the speech intelligibility index and is defined as 1 - SII and usually represented as a percentage. An SPI above 80% is considered normal privacy while an SPI above 95% would meet the requirements of confidential privacy.

speech transmission index (STI): an index for rating the intelligibility of speech that takes both noise and reverberation into account.

temporary threshold shift (TTS): a temporary increase in the threshold of hearing at a given frequency.

threshold of hearing: for a given listener, the minimum sound pressure level of a specified sound that is capable of evoking an auditory sensation. The sound reaching the ears from other sources is assumed negligible.

transducer: a device designed to receive an input signal of a given kind and to furnish an output signal of a different kind in such a manner that the desired characteristics of the input signal appear in the output signal. For example, a microphone takes an acoustic pressure as an input and produces an electrical voltage as an output that is direct proportion to the instantaneous acoustic pressure amplitude. Other common examples in noise measurement would be a loudspeaker, accelerometer, or laser Doppler vibrometer (LDV).

transmission loss: the reduction in sound level from one side of a partition to the other.

wavelength: the distance a sound wave travels in the time it takes to complete one cycle.

weighting: see frequency weighting

A2. General Acoustics

Sound Pressure Level (SPL)

Sound is small, rapidly varying perturbations of atmospheric pressure with respect to the slowly changing ambient pressure. The ambient pressure is measured with a barometer while the small acoustic perturbations are measured with a microphone.

The unit of sound pressure is the Pascal (Pa). However, due to the wide range of acoustic amplitudes that can be heard by the human ear, sound pressure is normally expressed on a logarithmic scale having units of decibels (dB). Sound pressure expressed this way is known as the sound pressure level (SPL) and has the following relation to sound pressure.

$$SPL = 20\log_{10}\left(\frac{p}{p_{ref}}\right) \qquad \text{(A2.1)}$$

Here p is the sound pressure in Pascals. p_{ref} is a reference pressure, the threshold of hearing at 1000 Hertz (Hz), 20×10^{-6} Pa.

A-Weighting

The above formulation of SPL is a purely physical quantity. Due to the nonlinear and frequency dependent characteristics of the human ear it does not always correlate well with the perception of loudness. To improve the correlation for noise assessment purposes, a frequency weighting is often applied called A-weighting. The A-weighting function is based on listening tests in which human subjects adjusted tones throughout a range of frequencies to have equal loudness compared to a tone having an SPL of 40 dB at 1000 Hz. Figure A2.1 shows equal loudness contours according to ISO 226.

Thus applying A-weighting to measured sound pressures more closely represents the frequency response of the human ear for low to moderate amplitude sound. Sound pressure levels that have been A-weighted are denoted by the symbol, dBA. Figure A2.2 shows the A frequency weighting and several other common weightings.

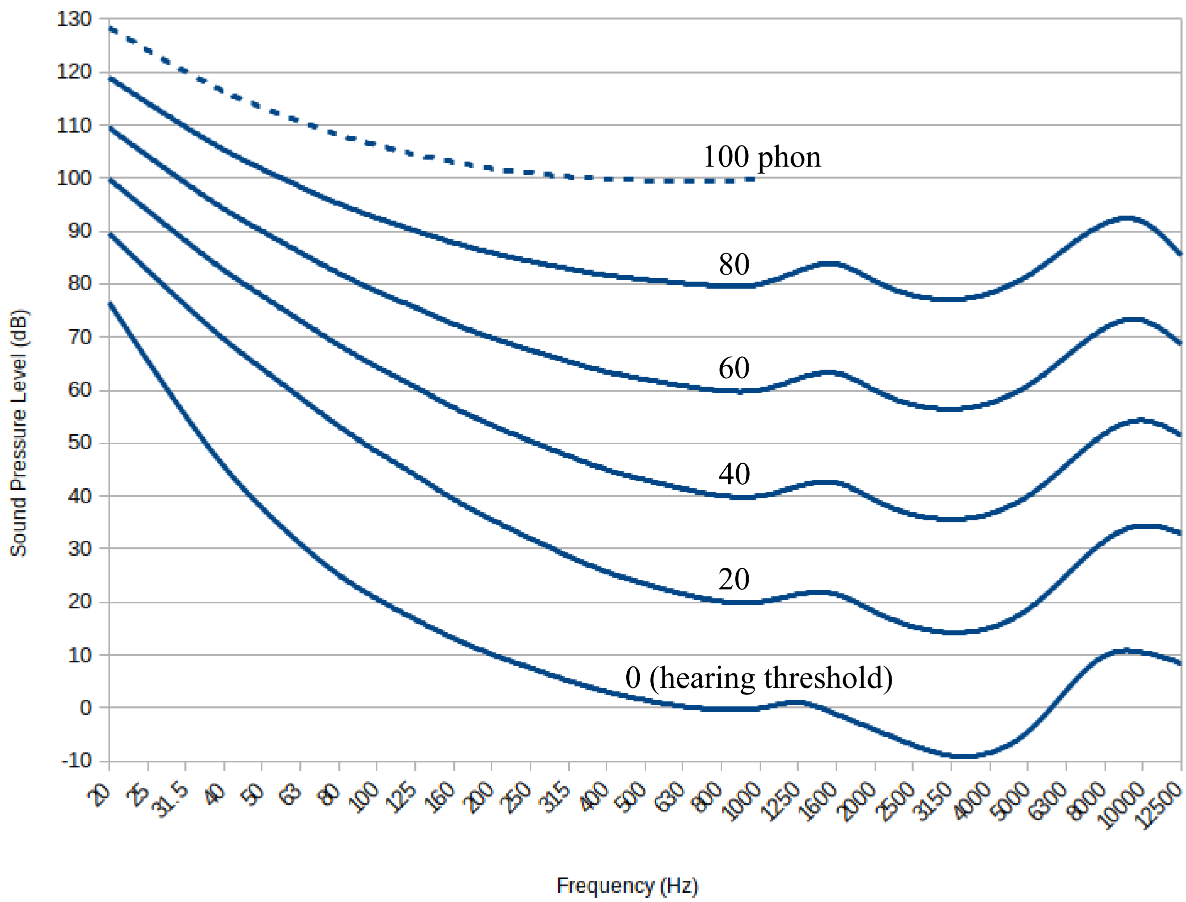

Figure A2.1. ISO 226 Equal Loudness Contours

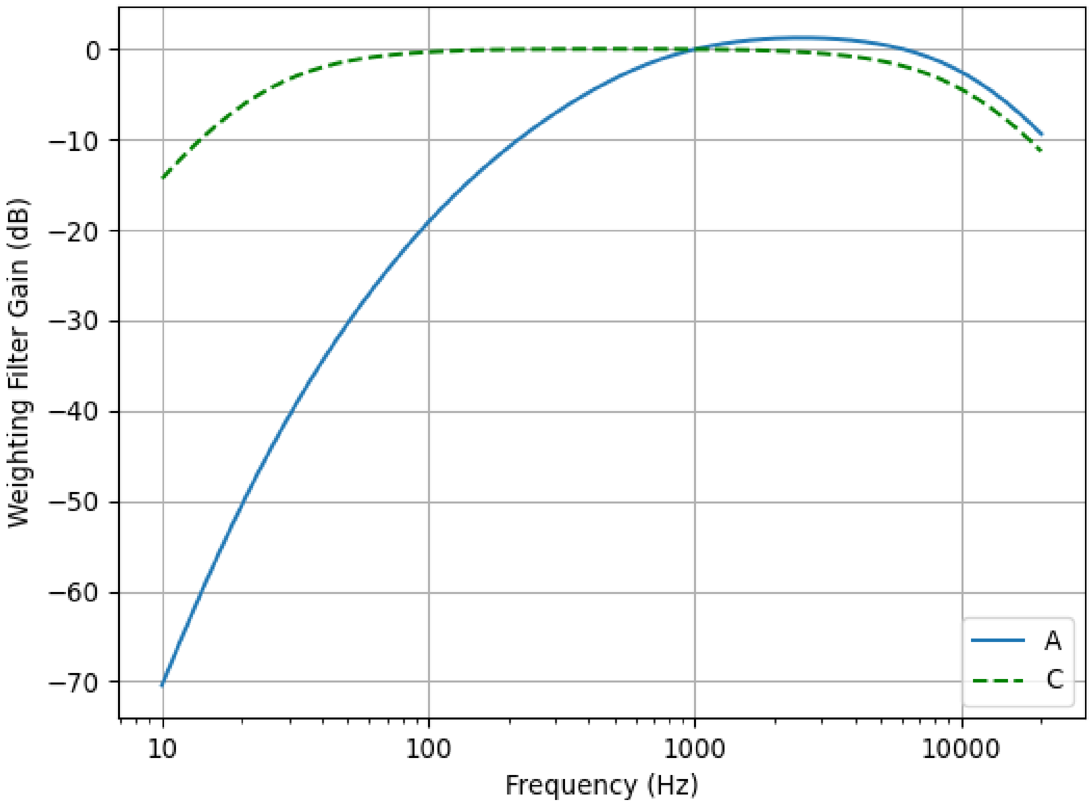

Figure A2.2. Frequency Weighting Filter Curves

The Perception of Sound

The most basic descriptions of sound are loudness (amplitude) and pitch (frequency). The frequency range of human hearing is roughly 20 to 20,000 Hz, although most people can not hear this full range because high frequencies are lost as a natural part of aging and other factors such as illness and exposure to high levels of noise that may cause permanent hearing loss.

Amplitude Attenuation with Distance

Sound originating from a small point source will spread spherically in all directions, absent any nearby surfaces. The conservation of energy requires the sound pressure spreading out from such a source to decrease by half with each doubling of distance. This is known as the inverse square law and is demonstrated in Table A2.1 and Figure A2.3.

Distance from Source (ft)	SPL (dBA)	SPL Loss Relative to 10 ft
10	90	
20	84	6
40	78	12
80	72	18
160	66	24
320	60	30

Table A2.1. Decrease of SPL with Distance Due to Spherical Spreading

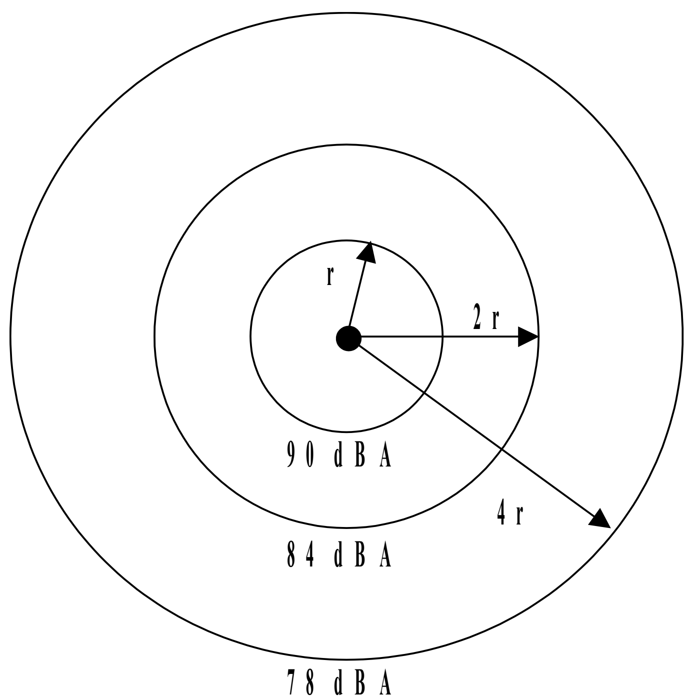

Figure A2.3. Decrease of SPL with Distance Due to Spherical Spreading

Adding Decibels

Summing the contributions from multiple sound sources to obtain the total SPL is *not* done simply by adding the decibel levels because SPL is a logarithmic quantity.

Imagine a fan produces a moderate SPL of 65 dBA at 6 feet. If a second identical fan were turned on the resulting SPL would not be 130 dBA. This would be equivalent to a commercial jetliner taking off at close range.

The correct method of adding the SPL from each source is to sum the acoustic power produced by each source. This implies that each time the number of sources having equal SPL is doubled, the SPL will increase by 3 dBA. Therefore, in the example with two fans, the correct total SPL would be 68 dBA. More examples with multiple sources producing equal SPL are shown in Figure A2.4.

$$65 \text{ dBA} + 65 \text{ dBA} \neq 130 \text{ dBA} \quad \textbf{WRONG} \qquad \text{(A2.2)}$$

$$65 \text{ dBA} + 65 \text{ dBA} = 68 \text{ dBA} \quad \textbf{RIGHT} \qquad \text{(A2.3)}$$

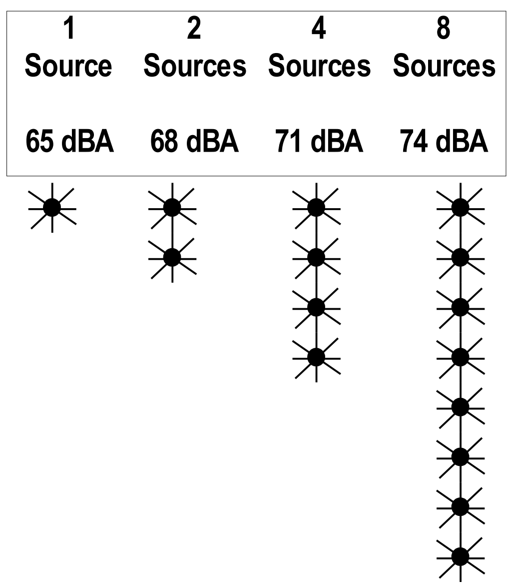

Figure A2.4. Total SPL from Multiple Sources with Equal SPL Output

Further Reading

Bruel and Kjaer, "Measuring Sound." Covers topics in this appendix in more detail. Available on the Bruel and Kjaer website, www.bkhome.com. Find this and other primers under the library section of the site.

Cyril M. Harris, Ed. Handbook of Acoustical Measurements and Noise Control, 3rd Edition. Acoustical Society of America, Melville, NY, 1998.