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Wind energy's harmful impacts

So much public money is spent on helping the wind industry further intrude into and disrupt rural communities and residents' health, well-being, quality of life and life-time investments in our properties. New turbines are 4MW and 586 feet tall and proposed 644 feet from neighboring properties. Where are the public funds and support for us to independently document the low-frequency noise, infrasound,vibrations, and electromagnetic interference that have been harming people, pets, livestock, and communications. Where are the Health Impact Assessments to document the harm being caused, including cancers on tribal land? Where is the valid research based on measurements taken at impacted homes? The State's biased support for the wind industry and against rural and predominantly low-income communities is discriminatory and negligent. Rejecting documents that are not searchable is also discriminatory for those of us who do not have the ability or knowledge to comply. The attached report documents some wind turbine impacts in and around rural Eastern San Diego County and Western Imperial County. PLEASE HELP US DEFEND OUR COMMUNITIES!

Additional submitted attachment is included below.

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KUMEYAAY AND OCOTILLO WIND TURBINE FACILITIES

NOISE MEASUREMENTS

28 February 2014

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES IN APPENDICES

APPENDIX A:

APPENDIX B:

APPENDIX C:

EXECUTIVE SUMMARY

Noise measurements were obtained for wind turbines (WTs) at the Kumeyaay Wind Farm (Kumeyaay Wind) and Ocotillo Wind Energy Facility (Ocotillo Wind or OWEF) between April 28 and April 30, 2013. This report conclusively documents the presence of infrasound and low frequency noise (ILFN) generated by the two facilities' wind turbines at residential and other locations up to 6 miles from the wind turbines.

It is clear from the measured noise data obtained from Kumeyaay and Ocotillo facilities that there is significant wind turbine-generated ILFN. This was to be expected as it has been documented by others such as in the McPherson noise study, the Shirley Wind Turbine study, and by Epsilon Associates.[1] And indeed the measured ILFN levels near Kumeyaay and Ocotillo wind turbine facilities are similar to those measured in previous studies after accounting for the proximity of the measurements to a wind turbine and the total number of the wind turbines in the facility.

Both the McPherson and Shirley wind turbine noise studies were conducted to investigate whether and at what levels the subject wind turbines (the turbines in Falmouth, Massachusetts, and those in the Shirley Wind Project in Brown County, Wisconsin) produce ILFN, and whether that ILFN was contributing to the significant health and other impacts reported by nearby residences. In some cases, the impacts were so severe that residents abandoned their homes. Both studies found high levels of wind turbine-generated ILFN at numerous nearby residences that correlated with residents' reported impacts.

Human health impacts from wind turbines had been reported previously in several countries with large wind facilities in proximity to residences. But these impacts were often attributed to certain individuals' aversion to the presence of a large industrial facility constructed in what was previously a quiet rural setting. Scientific understanding has developed significantly since then.

Recent research and investigations into human response to ILFN seem to provide strong evidence of a cause and effect relationship. In particular the work of Salt, et al.[2] has made a clear case for perception of ILFN below the threshold of hearing as defined by ISO 389-7 which is related to the response of the ear's inner hair cells (IHC). Salt has demonstrated that it is possible for the ears' outer hair cells (OHC) to respond to ILFN at sound pressure levels that are much lower than the IHC threshold. Salt has reported that ILFN levels (levels commonly generated by wind turbines nearby residences) can cause physiologic changes in the ear.[3] Salt and Kaltenbach "estimated that sound levels of 60 dBG will stimulate the OHC of the human ear."[4]

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[1] Epsilon Associates, A Study of Low Frequency and Infrasound from Wind Turbines, July 2009.

[2] Alec Salt, and J. Lichtenhan, Perception based protection from low-frequency sounds may not be enough, Internoise 2012, August 2012.

[3] Alec Salt, and J.A. Kaltenbach, "Infrasound from Wind Turbines Could Affect Humans," Bulletin of Science, Technology and Society, 31(4), pp.296-302, September 12, 2011.

[4] Ibid., p. 300, "As discussed below, G-weighting (with values expressed in dBG) is one metric that is used to quantify environmental noise levels. While it is a more accurate measure of ILFN than most other metrics, G-weighting still de-emphasizes infrasound."

Furthermore, Matsumoto et al.[5] have demonstrated in a laboratory setting that humans can perceive ILFN at sound pressure levels below the IHC threshold when the noise is a complex spectrum (i.e. contains multiple frequency components). From this laboratory research it was clearly demonstrated that humans can perceive sound pressure levels that are from 10 to 45 decibels (dB) less than the OHC threshold in the ILFN range. In fact, the Matsumoto thresholds clearly follow the OHC threshold down to the frequency below which the two diverge. The Matsumoto thresholds are lower than the OHC thresholds at frequencies below the point at which they diverge.

These studies and more recent studies demonstrate that wind turbines (specifically wind turbine-generated ILFN) have the potential to not only annoy humans, but harm them physiologically.

The data presented herein represent the conditions of measurement during the study and do not necessarily represent maximum noise conditions produced by the Kumeyaay and Ocotillo facilities. Higher wind speeds generally produce higher noise levels in particular higher ILFN. This is clearly demonstrated in the Ocotillo data when comparing the daytime and nighttime levels.

INTRODUCTION

As requested, Wilson, Ihrig & Associates (WIA) performed noise measurements in the vicinity of the Kumeyaay Wind Farm, located on the Campo Indian Reservation near Boulevard, California. We also took similar measurements in the vicinity of the Ocotillo Wind Energy Facility located near Ocotillo, California. The purpose of the measurements was to determine whether, and at what levels and under what conditions, the Kumeyaay Wind and Ocotillo Wind turbines generate ILFN[6], and how far the ILFN is propagated. A subsidiary goal was to accurately show the pressure fluctuations in the sound, so as to allow an accurate and robust analysis of the human health and other environmental impacts of the ILFN generated.

Between April 28 and April 30, 2013, we recorded noise samples at numerous residential and reference locations near each wind turbine facility. The wind turbines at both facilities were operating the entire time during which we took our noise measurements. Although it would have been our preference to also measure ambient noise conditions with all wind turbines taken out of operation, turbine operation was out of our control. In any event, even without measurements of the ambient noise sans wind turbines, we successfully measured and isolated wind turbine-generated noise.

Through a spectral analysis of the noise recordings, we obtained sound pressure level data demonstrative of the wind turbine-generated ILFN. In this report, we discuss the manner in which the data were obtained and present and analyze the study results.

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[5] Yasunao Matsumoto, et al, An investigation of the perception thresholds of band-limited low frequency noises; influence of bandwith, published in The Effects of Low-Frequency Noise and Vibration on People, Multi-Science Publishing Co. Ltd.

[6] Infrasound is defined as sound at frequencies less than 20 Hz. The focus of this report is frequencies less than 40 Hz, which includes low frequency sound as well.

WIND TURBINE DETAILS

Kumeyaay Wind Farm

Kumeyaay Wind is owned by Infigen Energy of Australia and operated by Bluarc Management of Texas, on 45 acres of land on the Campo Indian Reservation in southeastern San Diego County.[7] The nearest community outside of the tribal land is Boulevard, California. Currently there are 25 wind turbines operating at this facility. The wind turbines are located on a north-south ridge (Tecate Divide) at elevations ranging from 4,200 to 4,600 feet. The turbines started generating power in December 2005.

Kumeyaay Wind's turbines are Gamesa model G87X-2.0, with a rated power of 2.0 megawatts (MW). According to the manufacturer's published data, the G87X-2.0 has a hub height (height of the nacelle, which houses the gearbox, transmission and generator) that can vary from 217 to 325 feet depending on site conditions. The manufacturer also represents that the turbine has a rotor diameter of 283 feet, with three 138-foot-long, adjustable pitch blades. According to Councilman Miskwish the hub height of the Kumeyaay Wind turbines is typically 228 feet, and the blades are 145 feet long. Figure 1 shows some of the wind turbines.

The G87-2.0 model has a reported cut-in wind speed of 8.9 mph (5 mph according to former Campo tribal Councilman Miskwish, a.k.a. Michael Connolly) and achieves its rated (max) power generation at about 31 mph. The operational speed of the turbines is reported by the manufacturer to be in the range of 9 to 19 revolutions per minute (rpm) depending on wind conditions.

Figure 1 Wind Turbines at Kumeyaay Wind

[7] "Kumeyaay Wind Energy Project," PowerPoint presentation by Councilman Michael Connolly Miskwish, Campo Kumeyaay Nation, November 30, 2008., *available here:* http://www.certredearth.com/pdfs/Presentations/2007/KumeyaayWindEnergyProjectCampoKumeyaayNation.pdf

Ocotillo Wind Energy Facility

The Ocotillo Wind facility is owned and operated by Pattern Energy, on 10,200 acres of federal land located in southwestern Imperial County and managed by the United States Bureau of Land Management (BLM). Ocotillo Wind currently has 112 operating wind turbines. The wind turbines are located on the desert floor adjacent to the community of Ocotillo, California, at elevations ranging from approximately 300 to 1,400 feet above sea level. The Ocotillo Wind turbines are Siemens model SWT-2.3-108, with a rated power of 2.3 MW. Figure 2 shows some of Ocotillo Wind's turbines.

According to the manufacturer's published data, the SWT-2.3-108 model has a nominal hub height of 260 feet depending on site conditions, with a turbine rotor diameter of 351 feet and three 172-foot-long blades. The SWT-2.3-108 has a manufacturer-reported cut-in wind speed between 6.6 and 8.9 mph and achieves its rated power at wind speeds between 24 and 27 mph. The operational speed of the turbines reported by the manufacturer is in the range of 6 to 16 rpm depending on wind conditions.

Figure 2 Wind Turbines at Ocotillo Wind

MEASUREMENT LOCATIONS

Kumeyaay Wind-Area Residences

Both indoor and outdoor noise recordings were made at six residences in the Boulevard area near the Kumeyaay Wind turbines.

Table 1 lists the addresses of the residences at which the measurements were taken, along with the dates and times of the recordings. A map showing the Kumeyaay Wind-area measurement locations is provided in Appendix A.

Table 1 Addresses of Residences Used in Kumeyaay Measurements

Resident/Owner	Address	Distance to Closest Wind Turbine	Date	Recording Start Time	Recording End Time[1]
D. Elliott	Off of Crestwood, Campo Indian Reservation	2,960 feet	April 28	16:02	16:22
			April 30	11:00	11:20
G. Thompson	33 Blackwood Road, Manzanita Indian Reservation	2,880 feet	April 28	18:47	19:07
R. Elliott	25 Crestwood Road, Manzanita Indian Reservation	4,330 feet	April 28	17:30	17:50
D. Bonfiglio	40123 Ribbonwood Road, Boulevard	2.9 miles	April 29	9:15	9:35
K. Oppenheimer	39544 Clements Street, Boulevard	1.6 miles	April 30	15:11	15:31
M. Morgan	2912 Ribbonwood Road, Boulevard	1.7 miles	April 30	16:15	16:35
D. Tisdale	Morning Star Ranch, San Diego Co.	5.7 miles	April 30	13:45	14:05

[1] Recordings were nominally 20 minutes long

The Kumeyaay Wind-area residences at which we took measurements are located at distances of 2,880 feet to 5.7 miles from the nearest wind turbine at Kumeyaay Wind Farm. Additional recordings were made at two reference locations, which were closer to the wind turbines than the residential locations, as shown below in Table 2.

A recording was also obtained at the Tisdale ranch located 5.7 miles from the nearest wind turbine (see Table 1 above). The purpose of this recording was primarily to document existing ambient conditions; however, even at that great distance, analysis of the data indicates the presence of noise generated by the existing turbines.

A recording was also made at one of the guest cabins at the Live Oak Springs Resort. The purpose of this latter measurement was to obtain noise recordings in a condition with essentially no "local wind." By no local wind, it is meant that the wind at the microphone was either very light or non-existent even though there was wind at the wind turbine level, which was confirmed by observing the closest wind turbine rotating, thus providing a sample of wind turbine noise that was minimally affected by wind on the microphone. This latter recording was made at 10:10 pm on April 28. Cabin #2 at Live Oak Springs Resort is 5,950 feet from the nearest wind turbine.

Kumeyaay Reference Noise Measurements

To more fully document wind turbine-generated noise levels and spectra, we took noise measurements at locations closer to the subject wind turbines than the residences used in this study. Two reference locations were used near Kumeyaay Wind. Table 2 indicates the locations, distances to the closest wind turbine, dates and times of the reference recordings.

Table 2 Reference Locations for Kumeyaay Wind

Location	Distance to Closest Wind Turbine (feet)	Date	Recording Start Time	Recording End Time[1]
Kumeyaay (K-R1)	2,040	April 28	15:58	16:18
Kumeyaay (K-R2)	930	April 30	11:00	11:20

[1] Recordings were nominally 20 minutes long

The recording on April 28 at 10:00 pm at Live Oak Springs Resort (K-LOSR) also serves as a reference measurement.

Ocotillo Wind-Area Residences

Recordings were made at three Ocotillo residences near the Ocotillo Wind turbines. Table 3 lists the addresses of the residences at which the measurements were taken, along with the dates and times of recordings. A map showing the Ocotillo Wind-area measurement locations is provided in Appendix A.

Table 3 Addresses of Residences Used in Ocotillo Measurements

Resident/Owner	Address	Distance to Closest Wind Turbine	Date	Recording Start Time	Recording End Time[1]
J. Pelly	1362 Shell Canyon Road, Imperial County	3,220 feet	April 29	11:22	11:42
				20:00	20:20
P. Ewing	98 Imperial Highway, Ocotillo	3,590 feet	April 29	12:32	12:52
				21:00	21:20

D. Tucker	1164 Seminole Avenue, Ocotillo	1.2 miles	April 29	13:42	14:02
				22:20	22:40

[1] Recordings were nominally 20 minutes long

The Ocotillo Wind-area residences at which we took measurements are located at distances of 3,220 feet to 1.2 miles from the closest wind turbine at Ocotillo Wind. We also made measurements at three reference locations closer to the wind turbines, as shown in Table 4 below.

Ocotillo Reference Noise Measurements

We used three reference locations near Ocotillo Wind. Table 4 lists the locations, distance to the closest wind turbine, dates and times of the reference recordings.

Table 4 Reference Locations for Ocotillo

Location	Distance to Closest Wind Turbine (feet)	Date	Recording Start Time	Recording End Time[1]
Ocotillo (O-R1)	1,540	April 29	11:19	11:39
			20:00	20:20
Ocotillo (O-R2)	1,470	April 29	13:44	14:04
			21:30	21:50
Ocotillo (O-R3)	2,100	April 29	22:08	22:28

[1] Recordings were nominally 20 minutes long

NOISE RECORDING METHODOLOGY

We made all of the noise recordings with Brüel and Kjaer (B&K) type-4193, ½-inch, pressure-field microphones, which are specifically designed for infrasound measurement and provide a linear response from 0.07 cycles per second (Hz) to 20,000 Hz. A B&K type-UC-0211 adapter was used to couple the microphones to a B&K type-2639 preamplifier, providing a linear frequency response down to 0.1 Hz for the microphone/adaptor/preamplifier system. All recordings were calibrated with B&K type-4230 calibrators, which are checked and adjusted with NIST traceable accuracy with a B&K type-4220 pistonphone in the WIA laboratory in Emeryville, California.

We recorded all the noise samples with a TEAC LX10, 16-channel digital recorder, which provides a linear frequency response (i.e., ±0.1% or less) to a lower frequency limit of essentially 0.1 Hz when used in the "AC mode" (which we did). Twenty minute (nominal) noise recordings were made at each location. Using two different microphones, recordings were made simultaneously both indoors and outdoors at each subject residence. This same approach was also used in the Shirley Wind Farm study[8].

Using a third microphone and another recorder (SONY PCM D-50 digital recorder), recordings were made at reference locations closer to the wind turbines while the residential recordings were in progress. The frequency response of this third system is linear down to a frequency of 1.4 Hz, being limited by the SONY recorder.

For several of the residential and reference locations, recordings were repeated at a different time and/or date. All measurement data reported herein are based on an analysis of the noise recordings played back in the WIA laboratory.

Residence Location Measurements

For measurements conducted at the residences, a microphone was set up inside each residence mounted on a tripod at 4.5 feet above the floor, typically in the middle of the room. The indoor recordings were made in either the living room (mostly) or dining room of the residences. Indoors, the microphone was oriented vertically and covered with a 7-inch-diameter wind screen. Figure 3 shows the microphone and windscreen mounted on a tripod inside one of the residences.

A second microphone was set up outside of each residence. Following IEC Standard 61400-11, the outside microphone was rested horizontally (i.e., flush mounted) on a ½-inch-thick plywood "ground board" that is 1 meter in diameter. The microphone was oriented in the direction of the nearest visible wind turbine and the ground board was placed in a flat location between the residence and the wind turbines.

Also following IEC 61400-11, wind effects on the outdoor microphone were reduced using both a hemispherical 7-inch-diameter primary windscreen placed directly over the microphone, and a hemispherical 20-inch-diameter secondary windscreen placed over the primary windscreen and mounted on the ground board. The microphone and primary windscreen were placed under the center of the secondary windscreen.

The primary windscreen was cut from a spherical, ACO-Pacific foam windscreen with a density of 80 pores per inch (ppi). The secondary windscreen was constructed by WIA using a wire frame covered with ½ inch open wire mesh. A one-inch-thick layer of open cell foam with a density of 30 ppi was attached to the wire mesh. Figure 4 shows the outdoor microphone, secondary windscreen, and ground board outside one of the residences.

Both microphones used at the residences were powered by B&K type-2804 power supplies, with signals amplified by a WIA type-228 multi-channel measurement amplifier, and recorded on a TEAC LX10 16-channel digital data recorder. Inside and outside noise signals were recorded simultaneously to allow for correlation of interior and exterior sound levels during analysis.

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[8] Channel Islands Acoustics, et al, A Cooperative Measurement Survey and Analysis of Low Frequency and Infrasound at the Shirley Wind Farm in Brown County, Wisconsin, Report No. 122412-1, December 24, 2012.

Figure 3 Microphone Inside Residence

Figure 4 Microphone Outside Residence

Reference Location Measurements

A third B&K 4193 microphone was used to obtain simultaneous reference measurements at locations closer to the wind turbines during each of the residential measurements. This third microphone was powered by a B&K type-5935 power supply and amplifier, with the signal recorded on a Sony type PCM D-50 recorder. The same windscreen and ground board configuration (i.e., primary and secondary windscreen) used for the residential recordings, was also used for the reference locations. Reference measurements were obtained at different locations at each of the two facilities. Figure 5 shows the microphone, ground board and secondary windscreen at one of the reference measurement locations in Ocotillo.

Figure 5 Reference Location O-R2 with Microphone, Ground Board and Windscreen

NOISE MEASUREMENT BACKGROUND

Purpose of Measurements

The primary purpose of making the wind turbine noise measurements reported herein was to determine whether, and at what levels and under what conditions, the Kumeyaay Wind and Ocotillo Wind turbines generate ILFN, and how far the ILFN is propagated. In light of increasing evidence in the literature that ILFN can affect and harm humans[9] [10] [11] [12] [13], along with numerous complaints of health impacts from both Boulevard- and Ocotillo-area residents[14] since the wind turbines near their respective residences began operating, we had a subsidiary goal to obtain measurements that accurately show the pressure fluctuations in the sound, so as to allow an accurate and robust analysis of the human health and environmental impacts of the ILFN generated.

Noise Measurements in Presence of Wind

Some atmospheric pressure fluctuations are oscillatory in nature, whereas others are not. An example of a non-oscillatory pressure fluctuation is a change in barometric pressure; a change that occurs over a much longer time scale (e.g., hours) than the fluctuations being measured in this study. Wind and, in particular, gusts of wind cause another form of non-oscillatory pressure fluctuation, though it occurs on a much shorter time scale (e.g., fraction of a second). Local wind can cause a pressure change affecting the human ear similar to the pressure change that occurs in an airplane as it ascends or descends during takeoff and landing, but this pressure change is not sound.

Sound, in contrast to non-oscillatory fluctuations, consists of regular oscillatory pressure fluctuations in the air due to traveling waves. Sound waves can propagate over long distances depending on many factors. In the case of noise generated by machinery, the pressure fluctuations can be highly periodic in nature (i.e., regular oscillations). Sound that is characterized by discrete frequencies is referred to as being tonal. Although wind can generate sound due to turbulence around objects (e.g., trees, buildings), this sound is generally random in nature, lacks periodicity and is usually not in the infrasound range of frequencies.

However, the sound measurements we were interested in for this study (i.e. periodic wind turbine-generated ILFN) can be greatly impacted by non-oscillatory pressure fluctuations and extraneous noise caused by, for example, wind turbulence due to steady wind and particularly during gusts. The microphones we used in these measurements are highly sensitive instruments, with pressure sensor diaphragms that will respond to any rapid enough pressure change in the air regardless of the cause. To minimize the artificial (i.e. unrelated to the noise source being measured) noise or “pseudo sound” caused by wind gusts and other pressure fluctuations not associated with the wind turbine-generated noise itself, we employed special procedures. The

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[9] Salt, A.N., T.E. Hullar, Responses of the ear to low frequency sounds, infrasound and wind turbines, Hearing Research, 16 June 2010.

[10] Salt, A.N., J.T. Lichtenhan, Reponses of the Inner Ear to Infrasound, Fourth International Meeting on Wind Turbine Noise, Rome, Italy, April 2011.

[11] Salt, A.N., J.A. Kaltenbach, Infrasound from Wind Turbines Could Affect Humans, Bulletin of Science, Technology & Society, 31, 296-302, 2011.

[12] Salt, A.N., J.T. Lichtenhan, Perception-based protection from low-frequency sounds may not be enough, Inter-Noise 2012, New York, New York, August 2012.

[13] Lichtenhan, J.T., A.N. Salt, Amplitude Modulation of Audible Sounds by Non-Audible Sounds: Understanding the Effects of Wind-Turbine Noise, Proceedings of JASA, 2013.

[14] San Diego Reader, Volume 42, Number 34, August 22, 2013.

main sources of artificial noise and the procedures we used to minimize its impact are discussed more fully below.

Artificial Noise due to Turbulence at the Microphone

One source of artificial noise caused by wind on the microphone – and the most commonly encountered artificial noise source in outdoor noise measurements – is the turbulence caused by wind blowing over the microphone. To minimize this effect of wind when conducting environmental noise measurements outdoors, it is standard practice to use a windscreen,[15] the size of which is usually selected based on the magnitude of the wind encountered. The higher the wind speed generally the larger the windscreen required to minimize artificial noise caused by air turbulence at the microphone.

The windscreen used must be porous enough so as not to significantly diminish the pressure fluctuations associated with the noise being measured, which is to say that the wind screen must be acoustically transparent. As indicated above, the measurements reported herein followed procedures on windscreen design and usage as recommended by IEC 64100-11.

Artificial Noise due to Air Gusts

There is another – and more problematic – source of artificial wind-based noise. This one is caused by non-oscillatory pressure fluctuations associated with wind gusts as well as the pressure associated with the air flow in a steady wind. Air gusts can have an effect on a microphone signal in two ways. Outdoors, the microphone diaphragm will respond to the direct change in pressure associated with air flow; whereas indoors, the microphone will respond to the indirect change in pressure associated with wind and particularly gusts of wind that pressurize the interior of the building. These wind effects induce artificial noise that appears in the electrical signal generated by the microphone that is in the ILFN frequency range. This pseudo noise can, in turn, affect the spectral analysis of the recorded data. This form of pseudo noise (i.e., pressure changes due to air flow) is not substantially reduced by the use of a windscreen or even multiple windscreens generally regardless of their size.

Here, as discussed more fully in the Method of Analysis of Recorded Data section below, we analyzed the sound recordings in this study using a fast Fourier transform (FFT) technique to resolve low frequency and infrasound data. The primary range of interest in these measurements was in frequencies between 0.1 and 40 Hz. An FFT analysis produces a constant bandwidth (B). A 400-line FFT was used in the analysis, which means the bandwidth was B = 0.1 Hz. This allows resolution of frequency components to fractions of one Hz.

When using a very narrow bandwidth (e.g., 0.1 Hz), the time required for filtering is long in order to obtain the frequency resolution. The FFT analysis time T required for a specific bandwith B is given by: $T = 1/B$. For a 0.1 Hz bandwidth the time required is 10 sec. At this time scale, the effects of air pressure changes due to air movement tend to linger in the filtering process as discussed in the Method of Analysis of Recorded Data section below.

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[15] ANSI S12.9-2013/Part 3, Quantities and Procedures for Description and Measurement of Environmental Sound, Part 3: Short-Term Measurements with an Observer Present, American National Standards Institute, 2013.

To reduce the wind gust-induced artificial noise that manifests in the data with such long filtering times, both physical means during recording and analytical post-recording methods can be employed to minimize this artificial noise. The most effective pre-measurement technique is to dig a hole in the ground and put the microphone into it.[16] If two pits and microphones are used, then a cross-spectral analysis is also possible. In this study, however, it was impractical and, in some cases, impossible to dig microphone pits at the 15 total measurement locations. We thus relied on post-measurement analytical methods to filter out the pseudo noise as much as possible.

Each of the two most effective analytical techniques takes advantage of the fact that wind turbines and other large rotating machinery with blades (e.g., building ventilation fans and helicopters) produce very regular, oscillatory pressure fluctuations that are highly deterministic,[17] whereas pressure changes due to air movement associated with local wind gusts are essentially random in nature. The sound produced by wind turbines is tonal in nature, meaning that it has a spectrum with discrete frequencies that, in this case, are interrelated (i.e., harmonics of the blade passage frequency). This difference between the random wind noise and the wind turbine noise provides a means to minimize the latter in the signal processing of the recorded data. It has been posited that it is the tonal nature of wind turbine infrasound that may have some influence on residents in the vicinity of large wind turbines[18].

The artificial noise associated with pressure changes at the microphone due to local wind gusts can be minimized in two ways when analyzing the recorded signal. The first technique is to average the noise measurements over a longer time period. This tends to reduce the effect of pseudo noise associated with random air pressure transients during wind gusts, but does not affect the very regular, periodic pressure fluctuations generated by wind turbines.

When averaging over time is not sufficient, a second technique can be used to further minimize the effect of random pressure fluctuations associated with local wind. This second technique uses "coherent output power," a cross-spectral process. Both time averaging and coherent output power are discussed below under the method of analysis of recorded data.

WIND TURBINE OPERATION DURING MEASUREMENTS

Video recordings were made several times during the study period to document the operation of the wind turbines. Using the video recordings, we determined both the rotational speed of the wind turbine rotors (Ω in rpm) and the so-called "blade passage frequency" (f_0, also referred to as "blade passing frequency" or BPF), which is calculated in cycles per second, where $f_0 = N \times \Omega /60$, and N is the number of blades. For a three-bladed rotor ($N = 3$) the blade passage frequency is given by the equation:

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[16] Betke, L. and H. Remmers, Messung and Bewertung von tieffrequentem Schall, Proceedings of DAGA 1998 (in German)

[17] Johnson, Wayne, Helicopter Theory, Dover Publications, New York, 1980.

[18] Hessler, G., P. Schomer, Criteria for Wind-turbine Noise Immissions, Proceedings of the Meetings on Acoustics ICA 2013, Montreal, 2-7 June 2013, Acoustical Society of America, Vol. 19, 040152 (2013).

$$f_0 = \frac{\Omega}{20} .$$

Associated with the blade passage frequency are harmonics, which are integer multiples of the blade passage frequency. In this study, we typically observed at least five discrete harmonics in the measurement data. This pattern was also observed in the aforementioned Shirley Wind Farm study.

The harmonic frequencies are given by:

$$f_n = (n + 1) \times f_0 , where\ n \geq 1 .$$

For example, if Ω = 17 rpm, then f_0 = 0.85 Hz and the frequencies of the first six harmonics (n = 1 through 6) are: 1.7, 2.6, 3.4, 4.3, 5.1 and 6.0 Hz.

Table 5 summarizes a selection of the wind turbine speeds observed during the recordings. We note that the turbine speed of 16.2 rpm observed in Ocotillo at 19:51 on April 29 is the maximum rated speed for the Siemens SWT-2.3-108.

Table 5 Rotational Speeds Observed for Nearest Wind Turbines

Facility	Date	Location[1]	Time	Speed (rpm)	BPF (Hz)
Kumeyaay Wind (Gamesa Turbines – rated speed of 9 to 19 rpm)	April 28	D. Elliott	14:14	17.3	0.87
			15:05	17.1	0.86
			16:29	16.8	0.84
			16:30	16.3	0.81
		R. Elliott	17:28	16.7	0.83
		Thompson	19:32	17.2	0.86
Kumeyaay Wind (Gamesa Turbines – rated speed of 9 to 19 rpm)	April 29	Bonfiglio	9.37	12.2	0.61

Ocotillo Wind (Siemens Turbines – rated speed of 6 to 16 rpm)	April 29	O-R1	11:26	9.8	0.49
			11:29	7.4	0.37
			11:32	6.5	0.32
		O-R2	12:40	13.3	0.67
			13:54	15.0	0.75
			14:02	12.5	0.63
		O-R1	19:51	16.2	0.81
Kumeyaay Wind (Gamesa Turbines – rated speed of 9 to 19 rpm)	April 30	D. Elliott	10:33	15.6	0.78
		K-R2	11:22	16.7	0.83
			11:24	13.6	0.68
		Tisdale	13:45	14 to 16.6[2]	0.7 to 0.83[2]
		Oppenheimer	14:50	16.7	0.83
			15:17	17.1	0.86
			15:27	16.7	0.83
		Morgan	16:12	17.1	0.86
			16:18	16.2	0.81
			16:28	17.1	0.86

[1] Locations refer to where video was recorded

[2] Based on observed rotor speeds before and after recording

METEOROLOGICAL DATA

Weather Underground provides publicly available weather data for the two measurement areas (Boulevard and Ocotillo) on its website (wunderground.com). Among other things, this data includes wind speed, wind direction, temperature, and pressure. Weather Underground reports that it measures the meteorological conditions for Boulevard and Ocotillo at respective elevations of 4,113 feet and 694 feet above sea level. The relevant Weather Underground weather data for the Boulevard and Ocotillo areas is provided in Appendix B and summarized below.

Meteorological Data for the Kumeyaay Wind-Area Noise Measurements

We obtained noise measurements in the vicinity of the Kumeyaay Wind turbines on two different days. We took measurements on April 28, 2013, in the mid-afternoon to early evening. On April 30, we took measurements from mid-morning to mid-afternoon.

April 28, 2013

The Weather Underground data for this date show wind from the northwest in the morning, shifting to the west in the afternoon when the noise recordings were made. Average wind speeds between 1pm and 7pm were approximately 15 mph, with some gusts reaching 25 mph.

April 29, 2013

The Weather Underground data for this date show that wind speeds were considerably lower than on April 28, typically averaging between 5 and 8 mph, with some gusts reaching 10 mph. The wind direction between 9 am and 10 am, when the lone Kumeyaay Wind-area noise recording on this date was made, was from west south west.

April 30, 2013

The Weather Underground data for this date show that the wind direction in the morning was from the west, with average wind speeds that were 5 mph or less during the second recording at Mr. Elliott's residence. In the afternoon, during recordings at the Oppenheimer, Morgan and Tisdale residences, the wind was from the southwest, with average wind speeds between 10 and 17 mph and gusts up to 25 mph.

Meteorological Data for the Ocotillo Wind-Area Noise Measurements

We took noise measurements only on April 29, 2013, for the Ocotillo Wind Energy Facility. We took measurements from mid-morning to mid-afternoon, and then again from early evening to late evening.

April 29, 2013

The Weather Underground data for this date show that between 11am and 2 pm the wind direction was from the southwest with average wind speeds between 10 and 15 mph, with gusts from 15 to 20 mph. In the evening, the wind was also from the southwest, but was much stronger, with average wind speeds between 15 and 25 mph and gusts up to 35 mph.

METHOD OF ANALYSIS OF RECORDED DATA

We analyzed the 20 minute (nominal) recordings in the WIA laboratory with a Larson Davis type-2900 2-channel FFT analyzer. We first viewed each recorded sample in digital strip chart format to visually locate periods of lower local wind gusts to minimize low-frequency wind pressure transient effects on the data. We set the FFT analyzer for 40-Hz bandwidth, with 400-line and 0.1-Hz resolution. We used linear averaging. A Hanning window was used during a one- to two-minute, low-wind period to obtain an "energy average" with maximum sampling overlap. We stored the results for each sample, including autospectra, coherence, and coherent output power for both channels of data at the residential locations (i.e., indoors and outdoors). We also obtained autospectra for the reference locations.

Autospectra and Coherent Output Power

One of the strengths of our indoor-outdoor sampling design is that it made possible the use of what is called the "coherent output power" to filter out of the data the effect of the low-frequency wind pressure transients caused by local wind gusts. If two closely correlated signals are available (such as we have here, with the indoor and outdoor measurements for each residential study location), it is possible to use the coherent output power to reduce the effects of uncorrelated or weakly correlated phenomenon associated with wind gusts.

Coherent output power is based on use of the coherence between two signals to weight the spectra of one of the signals based on coherent frequency components common to the two simultaneously recorded signals. Where, as here, the wind turbine-generated noise remains at fairly consistent frequencies over the recording periods, the effects on the recorded signal of the essentially random, non-oscillatory pressure fluctuations caused by wind gusts should be reduced using this analysis procedure. The result is sometimes referred to as the coherent output spectrum.[19] For an example of previous studies that have used coherent output power to obtain wind turbine noise spectra, see Kelley, et al. (1985).[20]

In discussing coherent output power we use standard signal processing terminology. Obviously, all of the terms are functions of frequency.

For two signals (signal 1 and signal 2), the coherent output power for signal 2 (i.e., G_2) is defined as:

$$G_2 = {\gamma_{12}}^2 G_{22} .$$

The term ${\gamma_{12}}^2$ is the coherence (also referred to as spectral coherence) between the two signals and the term $G_{22}$is the autospectral density of the second signal. The value of the coherence lies in the range of $0 \leq {\gamma_{12}}^2 \leq 1$. A value of ${\gamma_{12}}^2 = 1$ indicates there is a one-to-one correlation between the two signals, which could only occur within an ideal system. In practice, ${\gamma_{12}}^2$ will generally be less than 1.

The coherence is defined as:

$${\gamma_{12}}^2 = \frac{|G_{12}|^2}{G_{11} G_{22}}$$

The term autospectral density used here has the same meaning as sound pressure level spectrum, the units of which are dB (re: 20 µPa). The term G_{11} is the autospectral density of the first signal.

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[19] Bendat, J. and A. Piersol, Random Data – Analysis and Measurement Procedures, 2nd Edition, John Wiley & Sons, 1986.

[20] Kelley, N.D., et al., Acoustic Noise Associated with the MOD-1 Wind Turbine: Its Source, Impact and Control, SERI/TR-635-1166 report prepared for U.S. Department of Energy, Solar Energy Research Institute, February 1985.

The term G_{12} is the cross-spectral density between the two signals, and the term $|G_{12}|^2$ is the square of the magnitude of the cross-spectral density.

For two recorded signals, it is possible to determine the coherence of the first with respect to the second (γ_{12}) and switch the two and determine the coherence of the second with respect to the first (γ_{21}). Consequently it is possible to obtain an inside coherent output power spectrum and an outdoor coherent output power spectrum. The measurement data presented herein indicate when the data are the autospectra, and when they are determined from the coherent output power. Where coherence data are presented, it is the coherence of the indoor signal with respect to that of the outdoor signal.

Sound Level Corrections Due to Use of Ground Board

Placing an outdoor microphone on a ground board, as was done in this study, results in higher sound pressure levels (up to 3 dB greater) for frequencies in the range of 50 to 20,000 Hz when compared to those measured at 4.5 to 5.5 feet above the ground, a standard height used to make environmental noise measurements as indicated in ANSI S12.9-2013/Part 3. Consequently corrections to the sound level data at frequencies greater than 50 Hz obtained using a ground board would be required.

However, for frequencies less than 50 Hz, the sound pressure level at the ground surface is essentially the same as that at a height of 5 feet. This is because a microphone on a tripod 5 feet above the ground is at a height less than one-fourth the wavelength of the sound at this frequency (i.e., $0.25 \times \lambda_{50\,Hz} = 0.25 \times \frac{1{,}100}{50} = 5.5\,feet$) and there is little difference at frequencies less than 50 Hz between the sound field at ground level and the sound field at 5 feet above the ground. This fact has been confirmed by other measurements[21].

Because the data presented herein are in the ILFN range with frequencies less than 40 Hz, no corrections to the sound level data are necessary, even though the measurements were made with a ground board.

NOISE MEASUREMENT RESULTS

Noise Data for Kumeyaay Wind

The noise spectra data from the Kumeyaay Wind-area measurements are provided in Appendix C. The turbine blade passage frequencies – in the range of 0.7 to 0.9 Hz (see Table 5) – and their harmonics up to 5 Hz are evident in the sound spectra from both recording days. Indeed, they align almost exactly with the predominant spectral peaks. This is a very strong indication that the wind turbines produced the ILFN at those frequencies.

[21] Hansen, K., Z. Branko, C. Hansen, Evaluation of Secondary Windshield Designs for Outdoor Measurements of Low Frequency Noise and Infrasound, 5th International Conference on Wind Turbine Noise, Denver, 28-30 August 2013.

Data for Live Oak Springs Resort, Cabin #2 (K-LOSR)

It is instructive to first examine the spectra obtained at the Live Oak Springs Resort where there was virtually no local wind during the recording even though there was wind at the turbines as determined from observing the closest turbine rotating at the time. Live Oak Springs Resort is somewhat sheltered from wind, but has a direct line of sight to the closest wind turbine at a distance of 5,950 feet.

Looking at Figure C-1, it is evident in the autospectra for both indoor and outdoor measurements that the discrete frequencies predominating in the infrasound range correspond to the blade passage frequency of the nearest wind turbine (0.8 Hz) and its first five harmonics (1.6, 2.4, 3.2, 4.1 and 4.9 Hz). A blade passage frequency of 0.8 Hz corresponds to a rotational speed of 16 rpm. We note that the indoor levels at these frequencies are slightly higher than the outdoor levels, an indication of possible amplification associated with the building structure.

Figure C-2 presents the two coherent output power spectra and the coherence of the indoor to outdoor signals. At the blade passage frequency (0.8 Hz) and in the range of 1.6 to 5 Hz (including the first five blade passage frequency harmonics of 1.6, 2.4, 3.2, 4.1 and 4.9 Hz), the coherence is 0.75 or greater, indicating a strong correlation between indoor and outdoor sound levels.

A high coherence indicates that two signals are strongly correlated and contain the same frequency content. This is exactly what one would expect from a large rotating mechanical device such as a wind turbine that produces a steady, tonal (periodic) sound, whereas the effects of wind are very random in particular concerning signals from two different microphones, one of which is indoors. Hence, the correlation of the wind effects in the indoor and outdoor signals should be weak for the random effects of the wind. Thus there will be a low coherence associated with the wind and its effects on the two different signals. Averaging the total microphone signal over time and weighting the result by the coherence results in a diminished contribution from the wind, because of the low coherence of the wind effects.

Figure C-3 compares the autospectrum with the coherent output spectrum for the indoors measurement at Live Oak Springs Resort. It shows a very close match over the frequency range of 0.8 to 5 Hz at the discrete frequencies associated with the wind turbine ILFN.

Inside the guest cabin at Live Oak Springs Resort, sound pressure levels in the infrasound range measured between 45 and 49 dB. The outside sound pressure levels were somewhat lower in the ILFN range, seeming to indicate an amplification occurring from outside to inside, which became even more pronounced in the range of 5 to 8 Hz. There is also a strong peak at 26.4 Hz, which may be caused by an "amplitude modulation" similar to that identified in the Falmouth wind turbine study[22]. The coherence at this frequency is 0.95. Amplitude modulation occurs when a low frequency signal causes the level of a higher frequency signal to fluctuate. This fluctuation occurs at the frequency of the lower frequency signal. This has been the subject of many complaints concerning wind turbine noise[23] [24].

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[22] Ambrose, S. and R. Rand, The Bruce McPherson Infrasound and Low Frequency Noise Study, 14 December 2011.

[23] Gabriel, J., S. Vogl, T. Neumann, Amplitude Modulation and Complaints about Wind Turbine Noise, 5th International Conference on Wind Turbine Noise, Denver, 28-30 August 2013.

The ILFN levels at Live Oak Springs Resort's guest Cabin #2 would have been even greater if the cabin were closer to the nearest Kumeyaay Wind turbine than it is – 1.1 miles, or 5,950 feet. The ILFN levels would have also been greater under different wind conditions. According to the Weather Underground report for Boulevard, at the time we measured the noise at the guest cabin – starting at 10:10 pm on April 28 – the wind was blowing from the west with an average speed of approximately 7 mph and gusts up to 12 mph, which is at the lower end of the operating conditions for the Gamesa wind turbines. Because the closest wind turbine is north-northeast of the cabin, the cabin was crosswind and somewhat upwind of the turbine and thus receiving lower levels of turbine-generated noise than locations downwind of the turbines.

Data for Dave Elliott's Residence

Like the Live Oak Springs Resort guest cabin measurements, the April 30 (11 am) measurements at Dave Elliott's residence show pronounced peaks in the autospectra at frequencies corresponding to the blade passage frequency of the nearest wind turbine (0.78 Hz) and the first five harmonics. The inside level at 0.78 Hz was 54 dB. In this case, as displayed in Figure C-4, the sound levels were slightly higher inside than outside at 1.6 and 2.4 Hz. Above 3 Hz the inside levels were lower than outside. The maximum inside sound level of 59 dB occurred at 1.6 Hz (the first harmonic of the blade passage frequency).

Data for Ginger Thompson's Residence

As shown in the autospectrum in Figure C-5, the April 28 (6:50 pm) measurements at Ginger Thompson's residence demonstrate a similar discrete frequency pattern between 0 and 5.2 Hz that corresponds to the blade passage frequency of the nearest turbine (0.80 Hz) and the first three associated harmonics (1.6, 2.4, and 3.2 Hz), which corresponds to a rotational speed of 16.0 rpm. The lowest frequency peak in the spectrum occurs somewhat lower (i.e., at 0.78 Hz) than the blade passage frequency; a phenomenon seen in some of the other measurement data.

As also seen at Mr. Elliott's residence and at most other study sites, the measured ILFN levels at Ms. Thompson's residence were amplified indoors, with the inside levels higher than outside levels throughout the frequency range. The maximum inside sound level of 60 dB occurred at just below the blade passage frequency of 0.80 Hz.

Data for Rowena Elliott's Residence

In the April 28 (5:30 pm) measurement data from Rowena Elliott's residence, shown in Figure C-6, the autospectra peaks corresponding to WT infrasound from Kumeyaay protrude above the general wind noise spectrum. The inside coherent output power spectrum is also plotted in Figure C-6 with most of the same peaks that appear in the autospectrum. Also present in the spectrum is a peak at 1.0 Hz, which does not correspond to any of the harmonics of the BPF observed in Kumeyaay at that time. We suspect that this infrasound is coming from the wind turbines at Ocotillo Wind, which are 15 to 20 miles away. This peak would correspond to a BPF

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[24] Stigwood, M., S. Large, D. Stigwood, Audible Amplitude Modulation – Results of Field Measurements and Investigations Compared to Psycho-acoustical Assessment and Theoretical Research, 5th International Conference on Wind Turbine Noise, Denver, 28-30 August 2013.

of 0.5 Hz, which would be consistent with the somewhat slower rotational speeds for the WTs in Ocotillo. Detecting WT infrasound from 15 to 20 miles away is not surprising. Metelka[25] for example has measured WT infrasound at a distance of 77 miles from its source. The maximum inside sound level of 53 dB occurred at 1.6 Hz, the first harmonic of the Kumeyaay BPF (0.8 Hz).

Data for Kenny Oppenheimer's Residence

As with the data for the previously discussed measurement locations, the April 30 (3:11 pm) measurement data for Kenny Oppenheimer's residence, shown in Figure C- 7, reveal sound pressure level peaks at the blade passage frequency of the nearest wind turbine (0.9 Hz) and its first three harmonics (1.8, 2.7 and 3.6 Hz). There is also a strong peak both indoors and outdoors at 13.6 Hz whose source, in contrast to the wind turbine-generated ILFN peaks at the blade passage frequency and its first three harmonics, we have been unable to identify. In this case, however, the outside sound levels were much greater than those inside the residence. The highest outside sound level was 57 dB and occurred at the blade passage frequency of 0.9 Hz. By contrast, the highest indoor sound level in the coherent output power spectrum was 44 dB, also at 0.9 Hz.

We have estimated the WT infrasound inside at 0.9 Hz to be approximately 51 dB using the coherent output power spectrum level and correcting for the coherence at that frequency. This seems to indicate that the residence is attenuating the wind turbine infrasound more substantially than at some of the other residences investigated, which could be due to a much more tightly sealed building envelope and/or a more substantial exterior wall construction. This effect was also evident in the data for one of the Ocotillo residences.

As a result of this disparity, the coherence of the indoor and outdoor ILFN signals is not as great as with closer measurement locations, including the Live Oak Springs Resort guest cabin and the residences of Mr. Elliott, Ms. Thompson and Ms. Elliott. Nonetheless, the coherence of the two signals at the blade passage frequency and its first three harmonics is still relatively strong, at 0.5 or greater. This evinces a definite correlation between outdoor and indoor sound levels even at great distance from the wind turbine noise source. Also evident in the data is a peak at 13.7 Hz. The may be caused by amplitude modulation.

Data from Marie Morgan's Residence

The April 30 (4:20 pm) measurement data from Marie Morgan's residence, including the inside and outside coherent output power spectra, are shown in Figure C-8. Like the data measured at the residences of Mr. Elliott, and Ms. Thompson, the data at Ms. Morgan's residence show higher levels of ILFN indoors than outdoors.

And like the data measured at Ms. Elliott's residences, there appear to be multiple – in this case three – different BPFs in the data. The lowest BPF, similar to the data measured at Ms. Elliott's residence, appears to be infrasound coming from Ocotillo Wind (i.e., BPF1 of 0.39 Hz). Above that frequency there are two BPF which are associated with Kumeyaay WTs. Note that not all

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[25] Metelka, A., Narrowband low frequency pressure and vibration inside homes in the proximity to wind farms, presentation at the 166th Meeting: Acoustical Society of America, San Francisco, 4 December 2013.

Kumeyaay WTs could be observed, and it is possible that some could be operating at a speed of 14 rpm and others at a speed of 18 rpm. The two BPF are at 0.68 Hz (BPF2) and 0.88 Hz (BPF3). A peak indoor level of 58 dB at the first harmonic of BPF 3 (1.7 Hz) was measured

In any event, the Morgan residence data demonstrate that under the right weather and topographical conditions, large wind turbines like those used at Kumeyaay Wind can produce high levels of ILFN inside buildings even miles away.

Data from Don Bonfiglio's Residence

As with the other Kumeyaay Wind-area study sites, the measurement data for Don Bonfiglio's residence, shown in Figure C- 9, display sound level peaks at the blade passage frequency of the nearest wind turbine (0.61 Hz) and the first three associated harmonics (1.2, 1.8 and 2.4 Hz). The sound levels, both indoors and outdoors, at these frequencies are in the range of 30 to 42 dB. The maximum inside level is 42 dB at 1.2 Hz (the frequency of the first harmonic of the blade passage frequency – BPF2).

While the coherence between the indoor and outdoor measurements is less than 0.5 at the blade passage frequency and associated harmonics, it is not surprising given the distance to the nearest wind turbine (2.9 miles, which is a greater distance than at any other Kumeyaay Wind-area study site except the Tisdale residence). Propagation effects (e.g., intervening terrain, atmospheric conditions) and interactions between infrasound from different wind turbines result in a more complex sound field at infrasound frequency as the distance increases. The wavelength of sound at 1 Hz is approximately 1,100 feet. At 2.9 miles the site is approximately 14 wavelengths from the sources of infrasound. Hence it is normal to witness declining coherence with increased distance due to this complexity. Also evident in the spectral data is a BPF peak at 0.39 Hz, which is most likely infrasound from Ocotillo Wind. There is also a harmonic at 0.78 Hz associated with the BPF.

Data from Donna Tisdale's Residence

The farthest (from a Kumeyaay Wind turbine) measurements we took were at the residence of Donna Tisdale, which is 5.7 miles from the nearest wind turbine. Yet even at that great distance, the data show as indicated in Figure C-10 peaks at the blade passage frequency (BPF2) of the nearest turbine (0.7 Hz) at Kumeyaay and its associated harmonics, albeit at lower sound pressure levels than observed at the closer study sites. The maximum measured indoor ILFN sound level was 43 dB at 0.7 Hz (the blade passage frequency). There is also a lower BPF at 0.39 Hz, which is most likely infrasound from Ocotillo Wind.

As similarly observed at the Bonfiglio residence, the coherence between the indoor and outdoor measurements at the Tisdale residence is mostly less than 0.5 for frequencies below 10 Hz. As indicated above, given the distance from the Tisdale residence to the nearest wind turbine (5.6 miles), this is not surprising. The Tisdale ranch is approximately 27 wavelengths from the wind turbines. The turbines are not visible from the ranch, because of intervening terrain. However the turbines are visible from some higher elevations of the ranch property.

Data from the Reference Sites

In contrast to the data for the Kumeyaay Wind-area residential measurement sites, the frequency and sound level data we present in the autospectra in Figures C-11 and C-12 for the two reference locations shows the autospectra values rather than the coherent output power. Because there was no option for making indoor sound measurements near the reference locations, we only used a single microphone to take measurements and thus did not measure a coherence or coherent output power. At both reference locations (K-R1 and K-R2), the data show clear sound level peaks at the blade passage frequency of the nearest turbine and the associated harmonics in the 0 to 5 Hz range. At K-R1, the sound levels of the peaks ranged from 53 dB to 60 dB (at the blade passage frequency, 0.84 Hz). At K-R2, which at 930 feet away was the measurement site closest to the Kumeyaay Wind turbines, the sound levels were even greater, between 60 dB and 70 dB for the spectral peaks below 3 Hz.

Tabulated Data

Table 6 lists the Kumeyaay Wind-area residential measurement locations, along with their distance from the nearest wind turbine, the highest measured indoor sound pressure levels, and the frequency of those peak sound pressure levels.

Table 6 Summary of Wind Turbine Noise for Kumeyaay Inside Residences

Residence	**Distance[1]**	**Highest Sound Pressure Spectrum Level Indoors[2,3,4]**	**Frequency (Hz) of Peak Spectrum Level**	**Rotor Rotational Component**
D. Elliott	2,960 feet	59 dB	1.6	1st harmonic
G. Thompson	2,880 feet	60 dB	0.8	BPF
R. Elliott	4,330 feet	53 dB	1.6	1st harmonic
K-LOSR	1.1 miles	48 dB	2.4	2nd harmonic
K. Oppenheimer	1.6 miles	51 dB	0.9	BPF
M. Morgan	1.7 miles	58 dB	1.7	1st harmonic
D. Bonfiglio	2.9 miles	42 dB	1.1	1st harmonic
D. Tisdale	5.7 miles	43 dB	1.4	1st harmonic

[1] Distance from closest wind turbine

[2] Decibels (re: 20 μPa)

[3] All but Live Oak Spring Resort, D. Elliott and G. Thompson data are coherent output power levels

[4] Oppenheimer data are estimated from coherent output power and correction for coherence

We note that while the Morgan residence data appears anomalous when compared with the trend of sound pressure levels as a function of distance from the wind turbines, it is not. Instead, the Morgan residence data demonstrates that under the right weather and topographical conditions, large wind turbines like those used at Kumeyaay Wind can produce high levels of ILFN inside buildings even miles away. It appears that one factor that contributed to the higher infrasound levels at the Morgan residence is the fact that this house was located downwind of multiple turbines, whereas the other residences except for Mr. Elliott's were either upwind of the turbines and/or had a more obscured line-of-sight to the full array of turbines compared to the Morgan's.

Noise Data for Ocotillo Wind

The noise spectra for the Ocotillo Wind-area measurements are displayed in Figures C-13 through C-21 in Appendix C. Table 7, below, summarizes much of the relevant data for the residential measurements.

In contrast to the relatively consistent wind conditions in the Kumeyaay Wind area throughout the measurement periods, the wind at the Ocotillo Wind Energy Facility varied greatly across the measurement periods. During the first recordings on the morning of April 29, the wind was generally light and the turbine blades were rotating slowly (less than 10 rpm). In the afternoon, however, the wind picked up considerably and the rotational speed of the turbine blades increased (e.g. 13 rpm). And later that night, when we took our last measurements, the wind speed had increased even more, causing the turbine blades to rotate even faster (i.e., 16 rpm observed at 7:51 pm just before dark). Between the first measurements in the morning and the last measurements at night, the turbines' average blade passage frequency increased from 0.5 Hz to 0.8 Hz.

The Ocotillo recordings were analyzed several different ways using cross-correlation, longer averaging times and 1/3-octave band filtering among other methods, without significantly changing the results. For the Ocotillo data, the coherence between the indoor and outdoor signals is low (i.e., less than 0.5). This, along with the spectral data, indicates a complex sound field with more than one BPF present, rather than a classical spectrum of tonal components including just one BPF and its harmonics. Note that it was only possible to observe a handful of turbines at a time out of the 112 turbines at Ocotillo Wind. Consequently, the BPF indicated in Table 5 for the Ocotillo recordings represent the BPF of the turbine or turbines closest to the reference location measurements and not the BPF for turbines in the entire facility.[26]

One possible explanation for low coherence is that Ocotillo Wind has so many turbines spread out over such a large area (with accompanying differences in wind speed and direction at each turbine), the ILFN produced by the turbines at Ocotillo has a greater probability of being less strongly synchronized as it is at Kumeyaay, for example, where the turbines are arrayed in a line on a ridge and experience a much more uniform wind configuration (i.e., speed and direction). At Ocotillo, it is much more likely that the wind turbines rotate at different speeds from one another. Thus where a residence or other receptor is exposed to ILFN from more than one

[26] After dark (approximately 8 pm) on 30 April 2013 it was not possible to observe the rotational speed of turbines at Ocotillo Wind. However, it was possible to deduce the rotational speed of the turbines from the measured data.

turbine, which will usually be the case with most Ocotillo-area locations, it will experience a complex sound field with varying tonal components derived not only from the different turbines directly, but also possibly from the interaction of tonal components from a multitude of turbines.

Another possible factor contributing to the lower coherence between outdoor and indoor sound levels at Ocotillo could be that the residential structures alter the frequency of the WT noise just enough as the sound energy passes through them that the sound indoors is at a slightly different frequency than the sound outdoors. Although this effect is not as apparent in the Kumeyaay data, it is possible that the distributed pattern of the Ocotillo wind turbines makes it more apparent here.

Data for the Residential Sites

As evidenced by the data in Table 7 and by comparing the coherent output power spectra from the morning and night measurements at the Pelley residence (Figures C-13 and C-14), as well as the afternoon and night measurements at the Ewing residence (Figures C-15 and C-16), the ILFN sounds pressure level increased substantially as the wind speed picked up and the blade passage frequency of the turbines increased. This indicates not only that the Ocotillo Wind turbines produced much of the measured ILFN, but that the turbines can create very high ILFN sounds levels even at substantial distance. The Tucker residence data are shown in Figures C-17 and C-18.

Looking specifically at the Pelly residence data for the daytime measurement (Figure C-14) it would appear that there are two blade passage frequencies present (0.5 and 0.6 Hz). This is not surprising considering the distribution of turbines over a large area where different turbines see different wind conditions. The spectral peaks above the blade passage frequencies are consistent with this assessment. The two blade passage frequencies indicate corresponding rotational speeds of 10 and 12 rpm.

Two distinct blade passage frequencies (0.68 and 0.88 Hz) are also evident from the nighttime measurements at the Pelley residence. These blade passage frequencies are indicative of rotation speeds of 13.6 and 17.6 rpm respectively. Although the higher rotational speed is slightly above the reported, operational speed range (6 to 16 rpm) for the Siemens turbines, there is no other source for the infrasound in this area. Note that the outdoor coherent output power spectrum is omitted for clarity in Figure C-14.

The spectra from the Ewing residence likewise indicate two different blade passage frequencies during both the day and night. In Figure C-15 we see the same frequency of the second BPF of 0.88 Hz in the daytime data, confirming that in fact this is infrasound from the Ocotillo WTs. The nighttime data at the Ewing residence as shown in Figure C-16 indicates two BPF also (0.39 and 0.49 Hz) and their associated harmonics.

The data for the Tucker residence similarly contain two BPF during the day (0.6 and 0.8 Hz) and two in the nighttime (0.39 and 0.68 Hz), with the lower BPF reflected in the data at the Ewing residence at night.

Whereas the Pelly residence data indicates an amplification of sound level between inside and outside, the data for other two residences indicate the opposite. Apparently the Ewing residence is more tightly sealed. It also seemed to be of a more substantial construction. The Tucker residence data also shows a reduction from outside to inside. An explanation for this effect could be the shielding provided by neighboring structures, which are more closely spaced than at the Pelly residence. The Tucker residence may also be more tightly sealed.

That the Ocotillo Wind turbines generated much of the ILFN measured at the Pelley and Ewing residences is strongly supported by the fact that the recorded data for both residences show sound level peaks at the turbine blade passage frequencies and many of the associated harmonics. The reference location measurement data also demonstrate this pattern, although not as clearly.

Data for the Reference Sites

At reference location 1 for the Ocotillo Wind-area measurements (O-R1), the nighttime ILFN levels were quite high, with multiple peaks above 60 dB including at frequencies that correspond to many of the harmonics of the blade passage frequency of the nearest wind turbine. The overall peak sound level of 74 dB occurred at the blade passage frequency (0.8 Hz). At O-R2, which at 1,470 feet away was the measurement site closest to the Ocotillo Wind turbines, the peak sound level of 78 dB was even greater, and also occurred at the blade passage frequency of 0.8 Hz. Similarly, at O-R3, which was adjacent to the Ocotillo substation, the peak sound level was 77 dB and occurred at the blade passage frequency of 0.8 Hz. These data are shown in Figures C-19 through C-21.

Tabulated Data

Table 7 lists the Ocotillo Wind-area residential measurement locations, along with their distance from the nearest wind turbine, the highest measured indoor sound pressure levels, and the frequency of those peak sound pressure levels. As expected given higher wind speeds at night, nighttime, indoor noise levels range from 15 to 27 dB higher than those measured during the day.

Table 7 Summary of Wind Turbine Noise for Ocotillo Inside Residences

Residence	**Distance[1]**	**Time of Day**	**Highest Sound Pressure Spectrum Level Indoors[2,3]**	**Frequency (Hz) of Spectrum Peak Level**	**Rotor Rotational Component**
Pelley	3,220 feet	Day	42 dB	0.6	BPF2
			49 dB	1.0	1st of BPF1
		Night	67 dB	0.68	BPF1
			69 dB	0.88	BPF2
Ewing	3,590 feet	Day	48 dB	0.59	BPF1
			51 dB	0.88	BPF2
		Night	42 dB	0.39	BPF1

			59 dB	0.78	1st of BPF2
Tucker	1.2 miles	Day	42 dB	0.6	BPF1
			48 dB	0.8	BPF2
		Night	66 dB	0.68	BPF2
			69 dB	1.37	1st of BPF2

[1] Distance from closest wind turbine

[2] Decibels (re: 20 μPa)

[3] All are coherent output power spectrum levels

DISCUSSION OF RESULTS

It is clear from the measured noise data obtained from Kumeyaay and Ocotillo facilities that there is significant wind turbine-generated ILFN. This was to be expected as it has been documented by others such as in the McPherson noise study, the Shirley Wind Turbine study, and by Epsilon Associates.[27] And indeed the measured ILFN levels near Kumeyaay and Ocotillo wind turbine facilities are similar to those measured in previous studies after accounting for the proximity of the measurements to a wind turbine and the total number of the wind turbines in the facility.

Both the McPherson and Shirley wind turbine noise studies were conducted to investigate whether and at what levels the subject wind turbines (the turbines in Falmouth, Massachusetts, and those in the Shirley Wind Project in Brown County, Wisconsin) produce ILFN, and whether that ILFN was contributing to the significant health and other impacts reported by nearby residences. In some cases, the impacts were so severe that residents abandoned their homes. Both studies found high levels of wind turbine-generated ILFN at numerous nearby residences that correlated with residents' reported impacts.

Human health impacts from wind turbines had been reported previously in several countries with large wind facilities in proximity to residences. But these impacts were often attributed to certain individuals' aversion to the presence of a large industrial facility constructed in what was previously a quiet rural setting. Scientific understanding has developed significantly since then.

Recent research and investigations into human response to ILFN have been conducted and seem to provide strong evidence of a cause and effect relationship. In particular the work of Salt, et al.[28] has made a clear case for perception of ILFN below the threshold of hearing as defined by ISO 389-7 which is related to the response of the ear's inner hair cells (IHC). Salt has demonstrated that it is possible for the ears' outer hair cells (OHC) to respond to ILFN at sound

[27] Epsilon Associates, A Study of Low Frequency and Infrasound from Wind Turbines, July 2009.

[28] Alec Salt, and J. Lichtenhan, Perception based protection from low-frequency sounds may not be enough, Internoise 2012, August 2012.

pressure levels that are much lower than the IHC threshold. Salt has reported that ILFN levels (levels commonly generated by wind turbines nearby residences) can cause physiologic changes in the ear.[29] Salt and Kaltenbach "estimated that sound levels of 60 dBG will stimulate the OHC of the human ear."[30]

Furthermore, Matsumoto et al.[31] have demonstrated in a laboratory setting that humans can perceive ILFN at sound pressure levels below the IHC threshold when the noise is a complex spectrum (i.e. contains multiple frequency components). From this laboratory research it was clearly demonstrated that humans can perceive sound pressure levels that are from 10 to 45 decibels (dB) less than the OHC threshold in the ILFN range. In fact, the Matsumoto thresholds clearly follow the OHC threshold down to the frequency below which the two diverge. The Matsumoto thresholds are lower than the OHC thresholds at frequencies below the point at which they diverge.

These studies and more recent studies demonstrate that wind turbines (specifically wind turbine-generated ILFN) have the potential to not only annoy humans, but harm them physiologically.

The data presented herein represent the conditions of measurement during the study and do not necessarily represent maximum noise conditions produced by the Kumeyaay and Ocotillo facilities. Higher wind speeds generally produce higher noise levels in particular higher ILFN. This is clearly demonstrated in the Ocotillo data when comparing the daytime and nighttime levels.

NOISE METRICS FOR MEASURING ILFN

There are several noise metrics which are used to quantify environmental noise levels. The most common metric is A-weighting (A-wt). The A-wt curve is shown in Figure 6. The A-wt metric is intended to approximate the loudness sensitive of the human ear for common environmental sounds in the range of 20 to 20,000 Hz. A-wt at 1 Hz is -149 dB. Hence a noise limit based on A-wt would not be appropriate to address ILFN, a major component of which is sound below 20 Hz.

A noise metric sometimes used when there is low frequency noise is the C-weighting (C-wt). While the C-wt metric does attempt to address low frequency noise better than A-wt, it would also not be appropriate for quantifying infrasound, since it still strongly de-emphasizes sound at frequencies below 20 Hz as shown in Figure 6. C-wt at 1 Hz is -52.5 dB.

One noise metric recently used to quantify ILFN is G-weighting (G-wt). The G-wt measure has been used in Europe. G-wt would certainly be a more representative measure of ILFN than

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29 Alec Salt, and J.A. Kaltenbach, "Infrasound from Wind Turbines Could Affect Humans," Bulletin of Science, Technology and Society, 31(4), pp.296-302, September 12, 2011.

30 Ibid., p. 300, "As discussed below, G-weighting (with values expressed in dBG) is one metric that is used to quantify environmental noise levels. While it is a more accurate measure of ILFN than most other metrics, G-weighting still de-emphasizes infrasound."

31 Yasunao Matsumoto, et al, An investigation of the perception thresholds of band-limited low frequency noises; influence of bandwith, published in The Effects of Low-Frequency Noise and Vibration on People, Multi-Science Publishing Co. Ltd.

either the A- wt or the C- wt metrics, but as shown in Figure 6 it too de-emphasizes the very low frequency infrasound by -40 dB at 1 Hz.

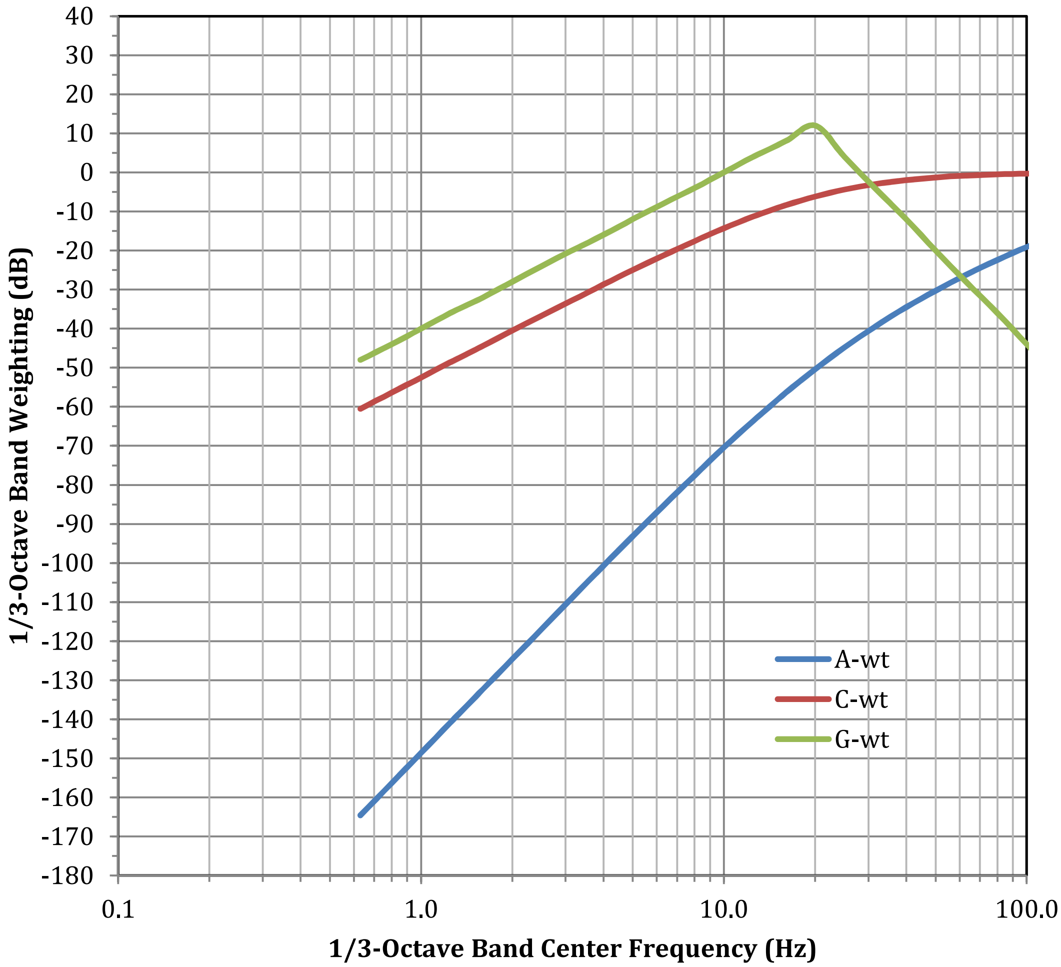


Figure 6 A, C and G Spectral Weighting Curves

CONCLUSION

The results of this study conclusively demonstrate that both the Kumeyaay and Ocotillo facilities' wind turbines generate ILFN at residential and other locations up to 15 miles away.

TERMINOLOGY

- Autospectrum: The autospectrum is the narrow band, energy average sound pressure level spectrum (in dB) measured for a specific time interval.
- Coherence: The spectral coherence is a statistic that can be used to examine the relation between two signals or data sets. It is commonly used to estimate the power transfer between input and output of a linear system. If the signals are ergodic, and the system function linear, it can be used to estimate the causality between the input and output.
- Cross-spectrum: In time series analysis, the cross-spectrum is used as part of a frequency domain analysis of the cross correlation or cross covariance between two time series.
- Cycles per second: A unit of frequency, same as hertz (Hz).
- 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 logarithm (to the base 10) of this ratio. For sound, the reference sound pressure is 20 micro-Pascals.
- FFT (fast Fourier transform): An algorithm to compute the discrete Fourier transform and its inverse. A Fourier transform converts time to frequency and vice versa; an FFT rapidly computes such transformations.
- ILFN: Infrasound and low frequency noise.
- Infrasound: Sound at frequencies lower than 20 Hz.
- Low frequency noise: Noise at frequencies between 20 and 200 Hz.
- Noise level: The sound pressure energy measured in decibels.

APPENDIX A – MEASUREMENT LOCATIONS

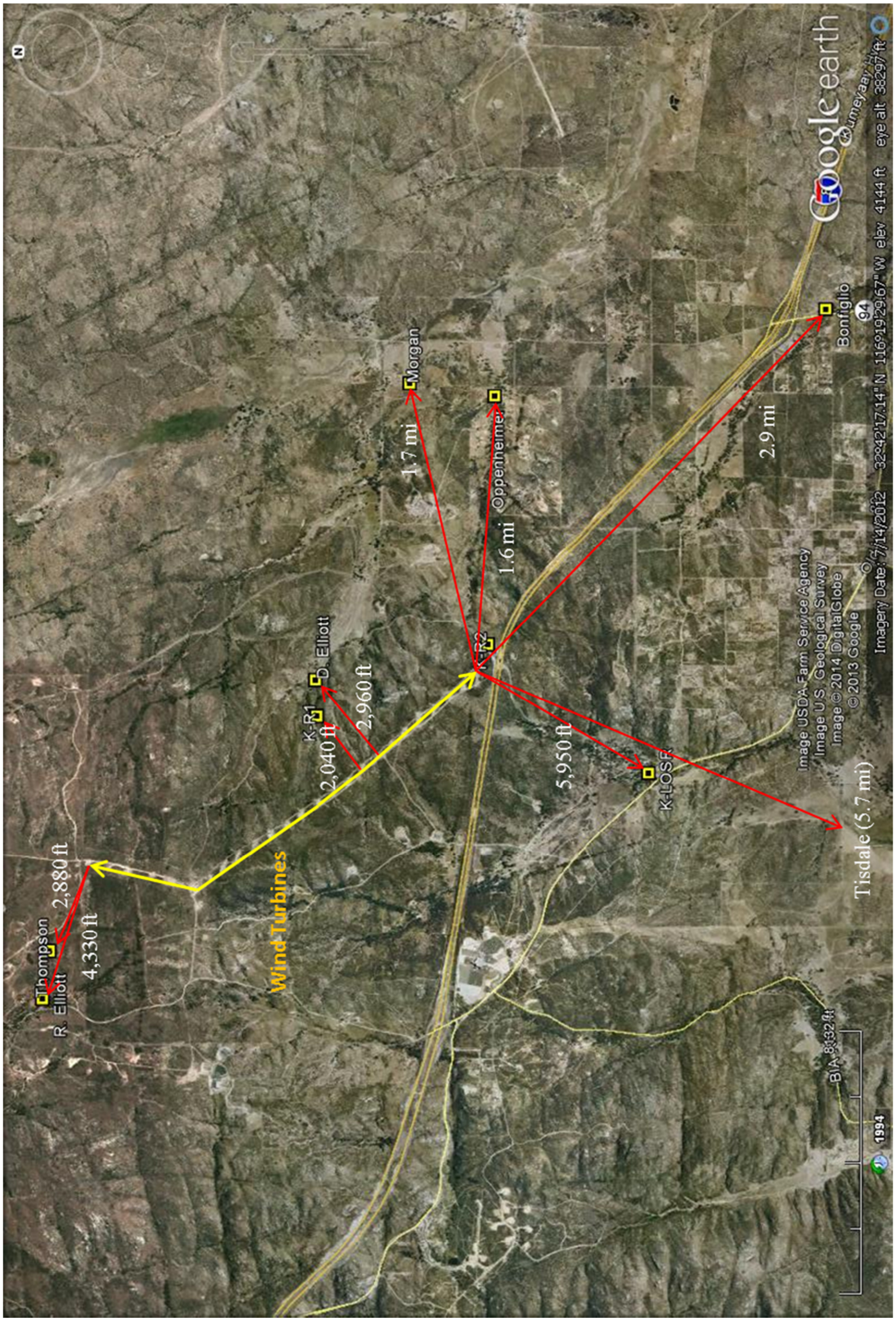


Figure A - 1 Kumeyaay Measurement Locations

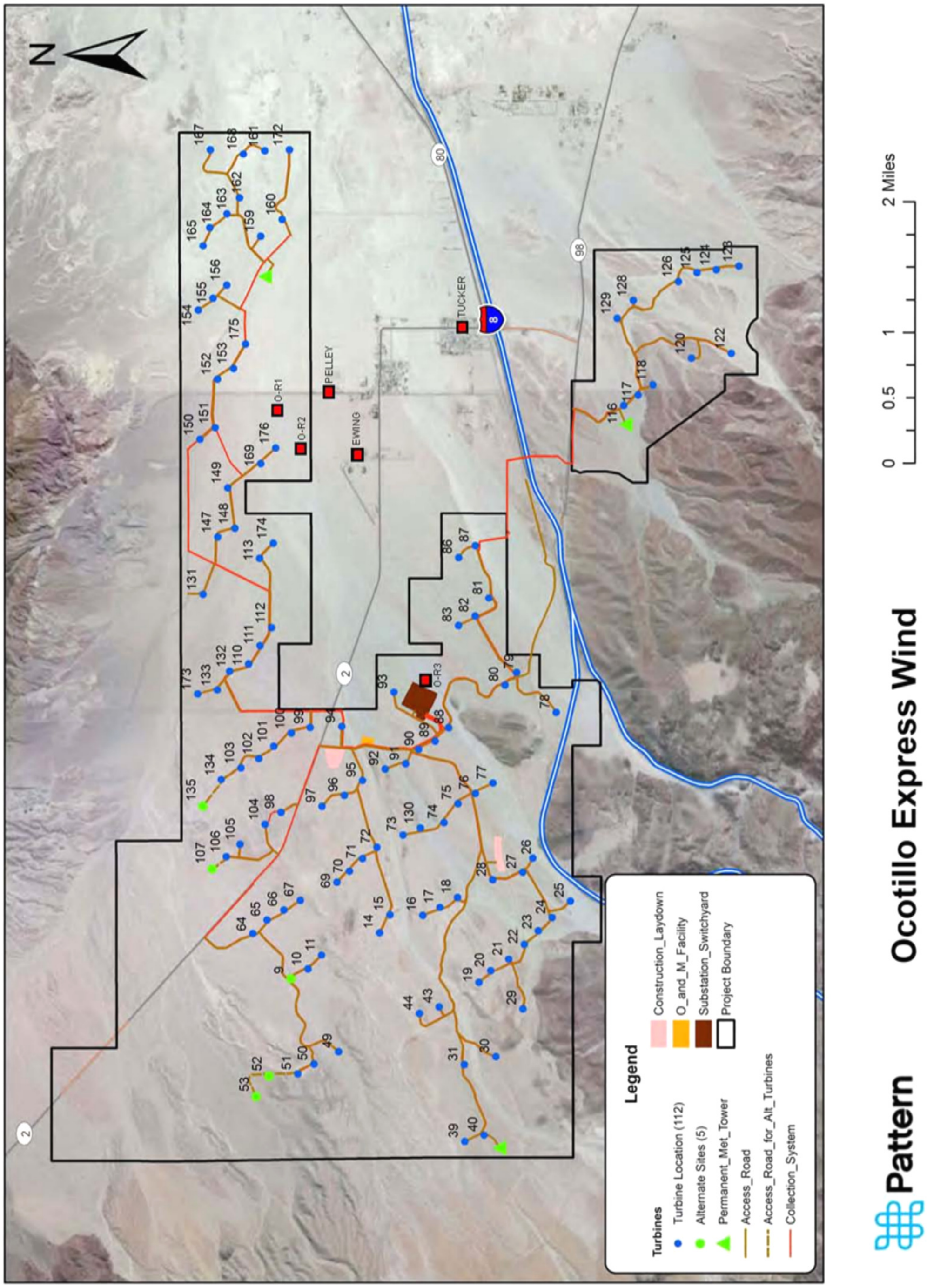


Figure A - 2 Ocotillo Measurement Locations

APPENDIX B – METEOROLOGICAL DATA

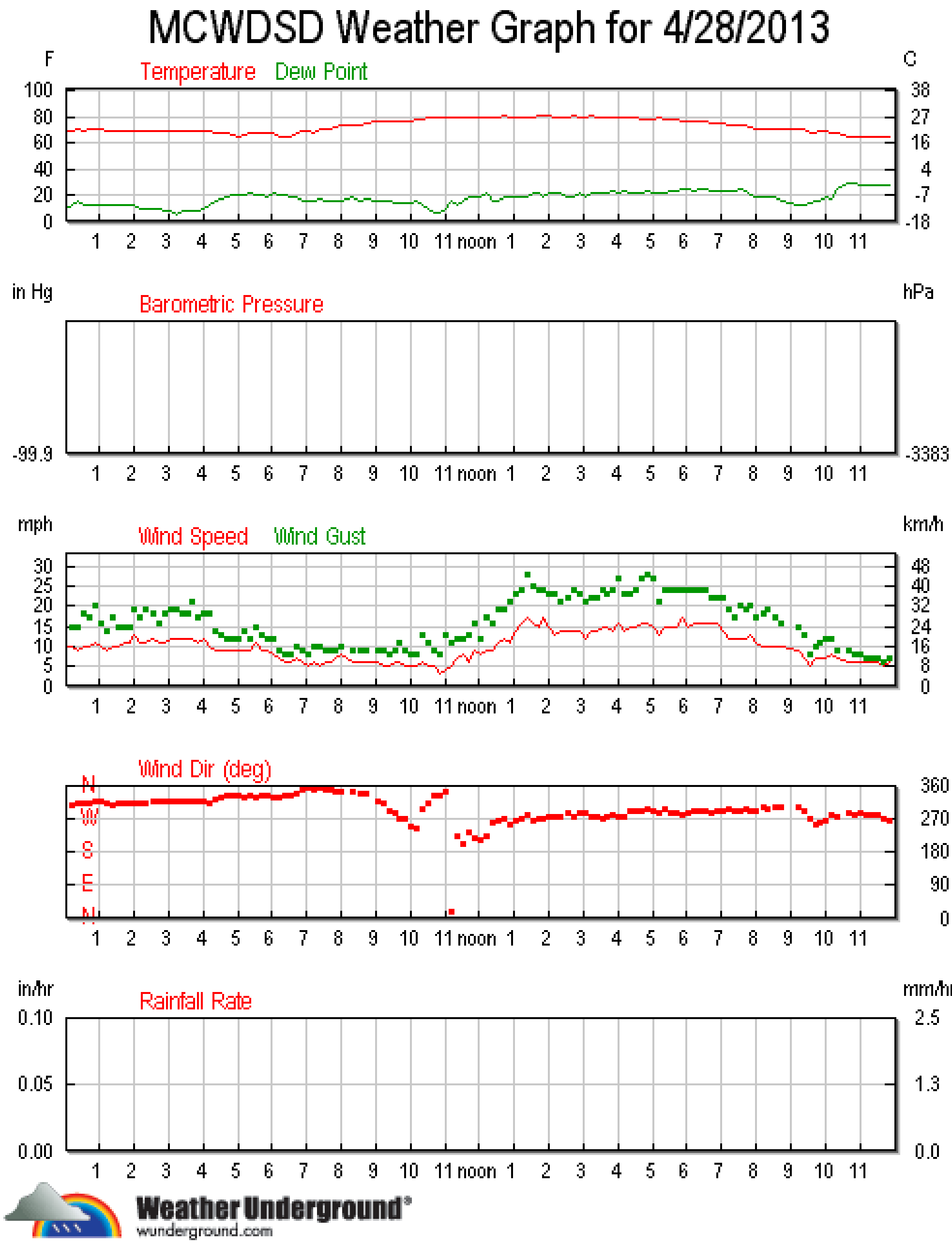


Figure B - 1 Weather Data for Kumeyaay 28 April 2013

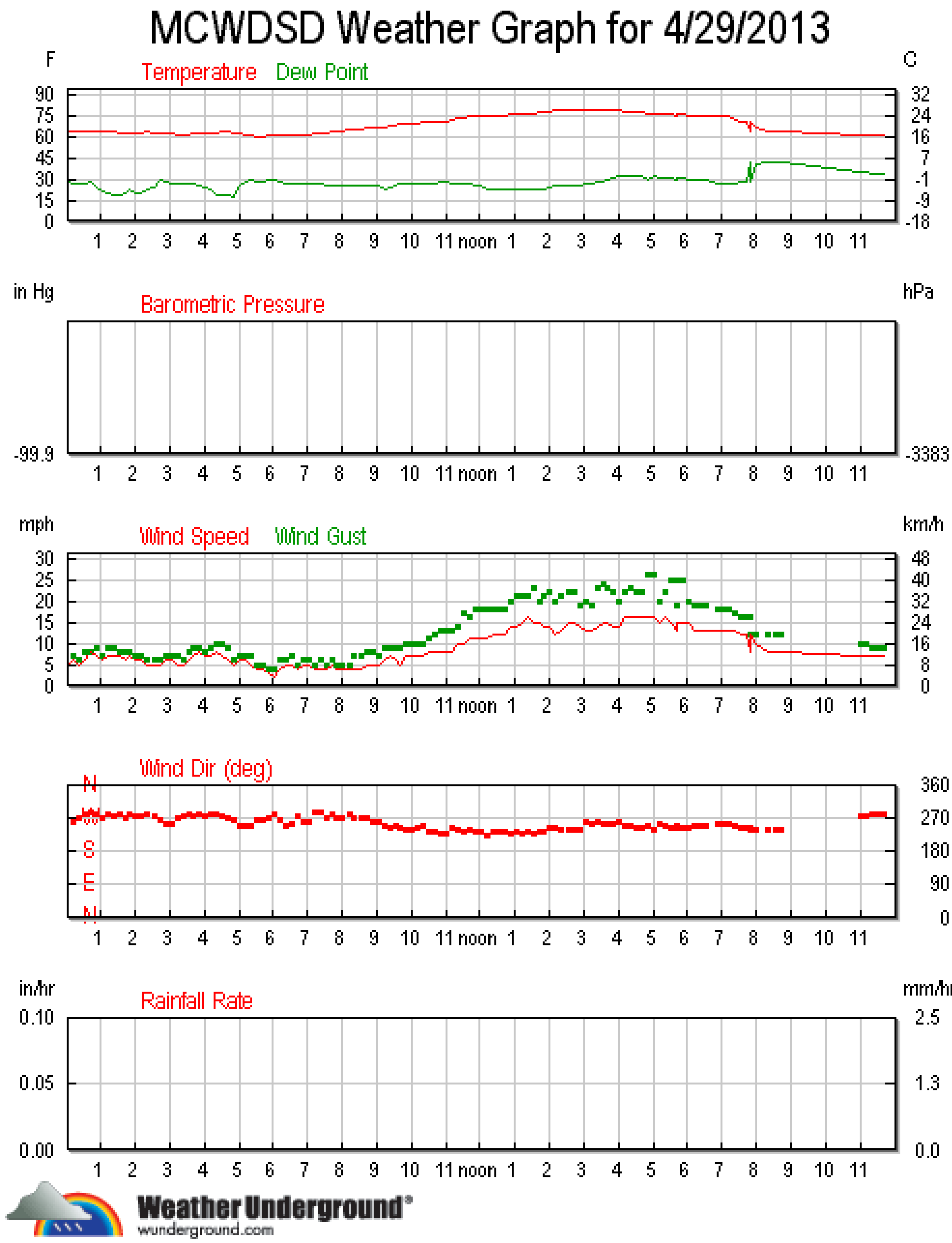


Figure B - 2 Weather Data for Kumeyaay April 29 2013

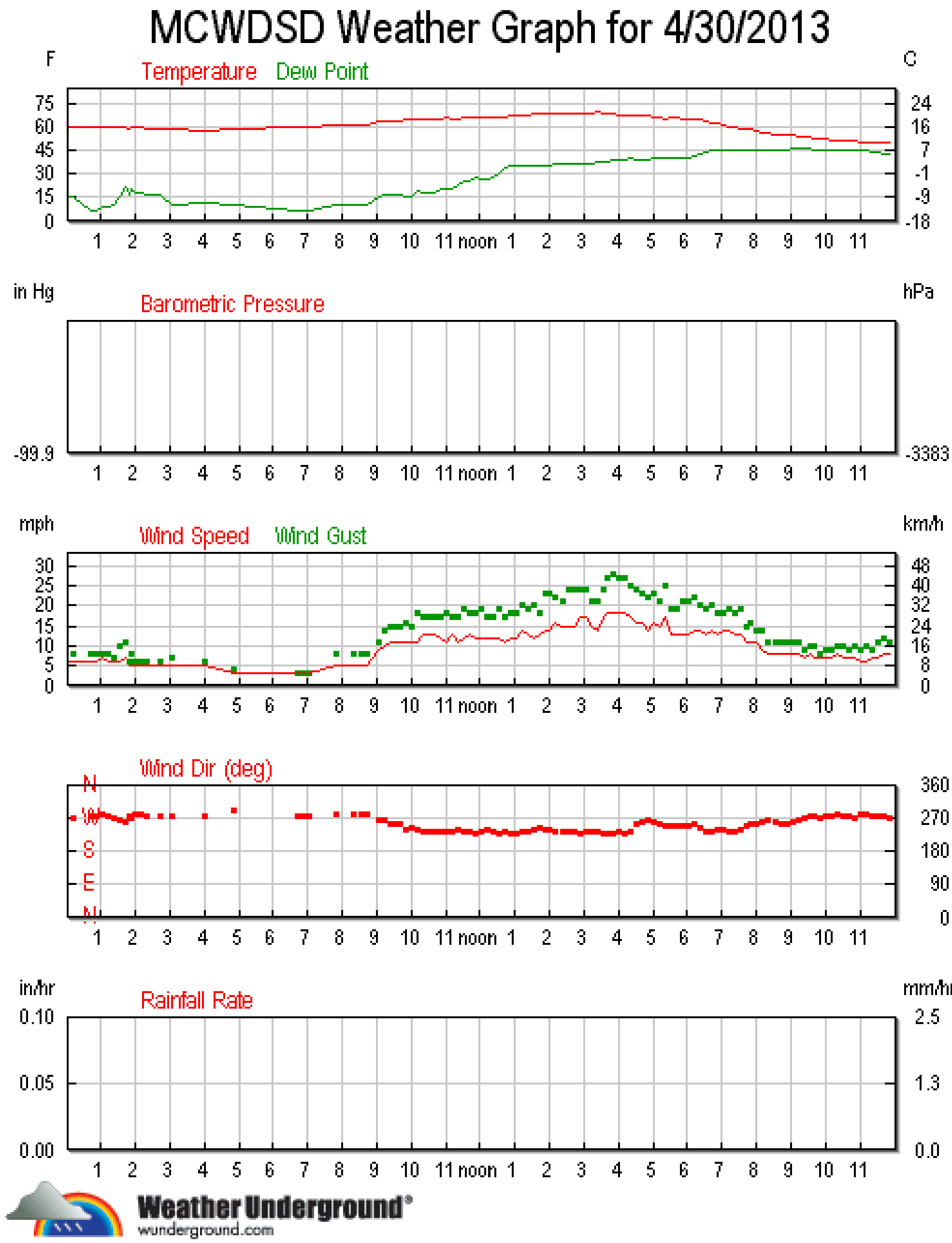


Figure B - 3 Weather Data for Kumeyaay 30 April 2013

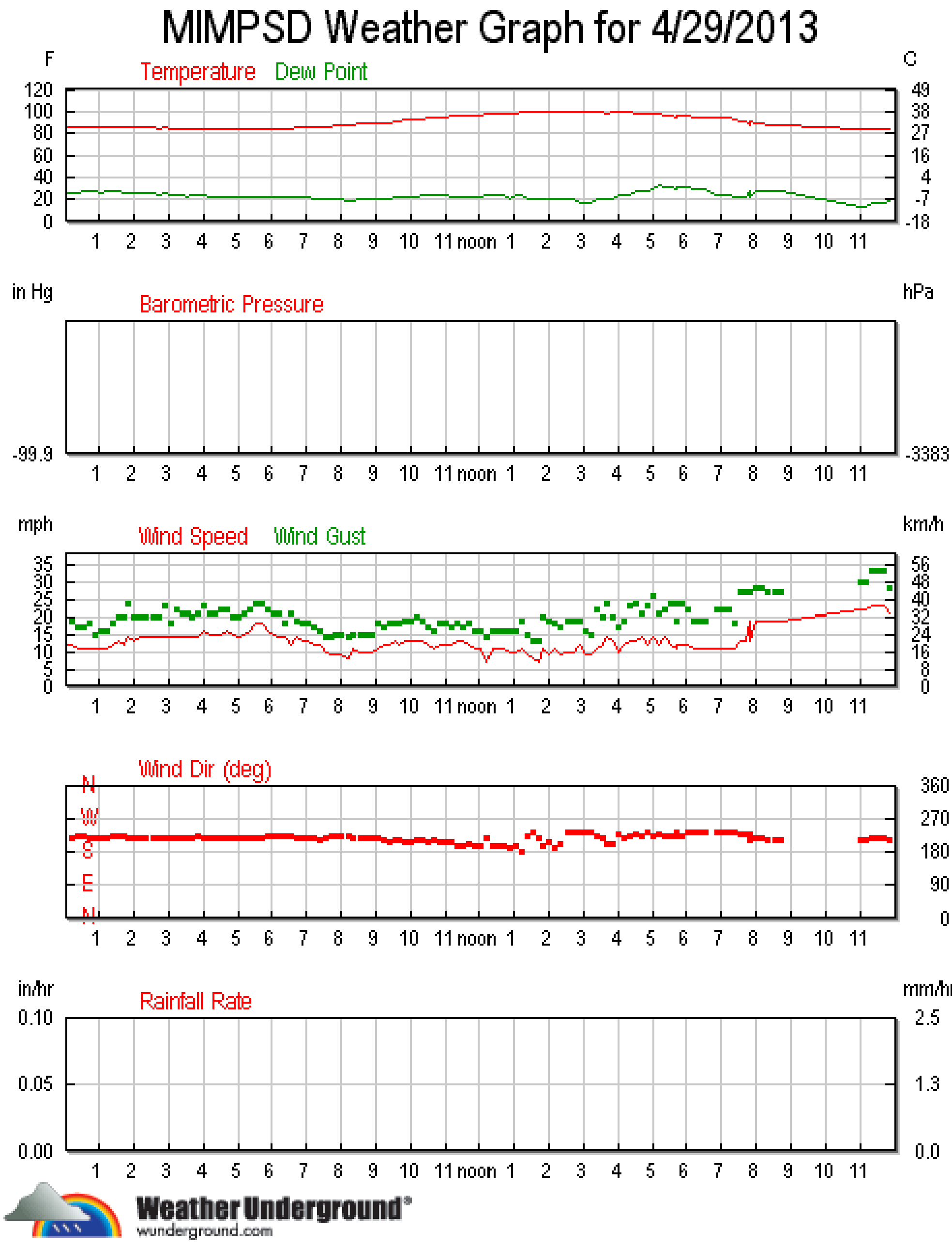


Figure B - 4 Weather Data for Ocotillo 29 April 2013

APPENDIX C – NOISE DATA

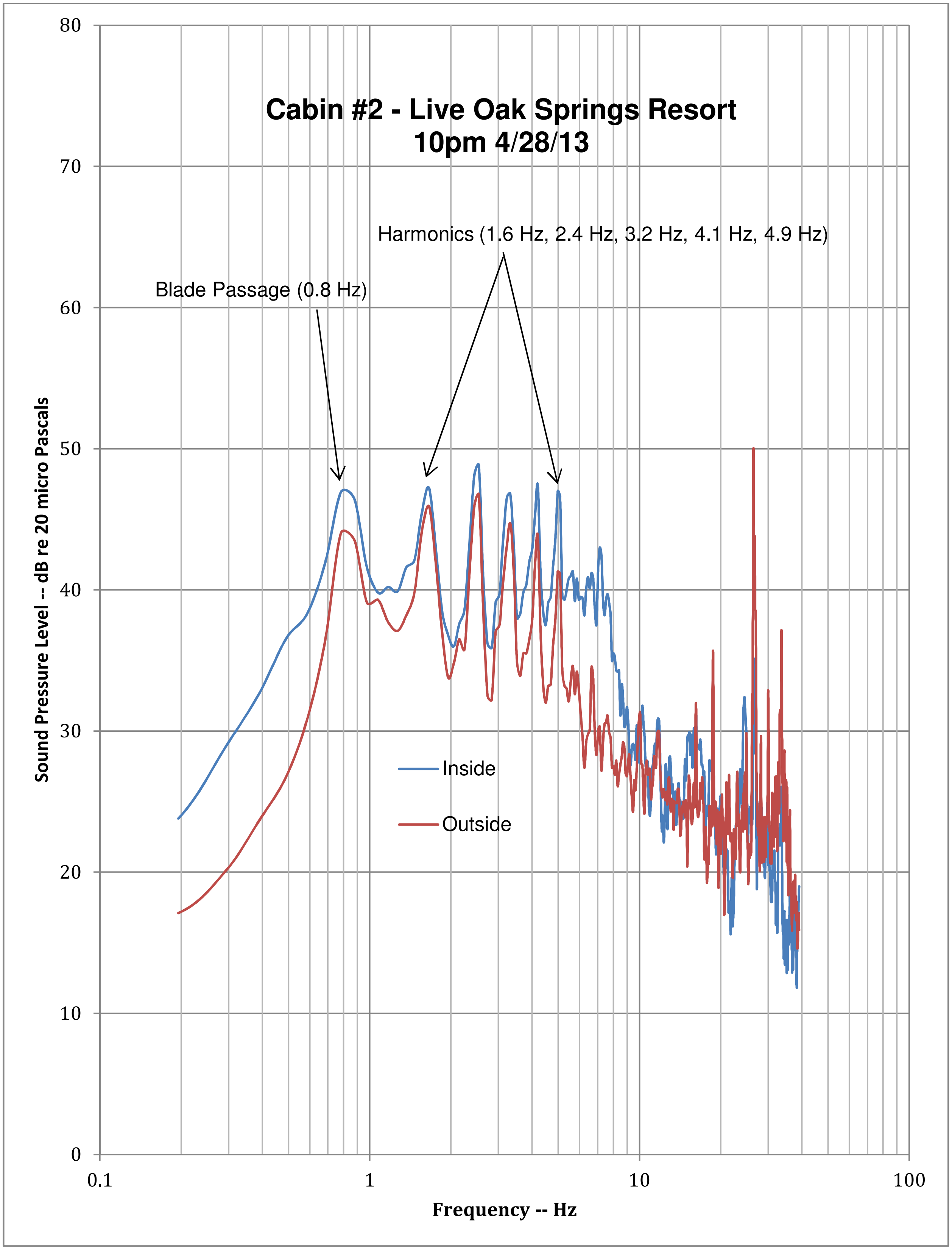
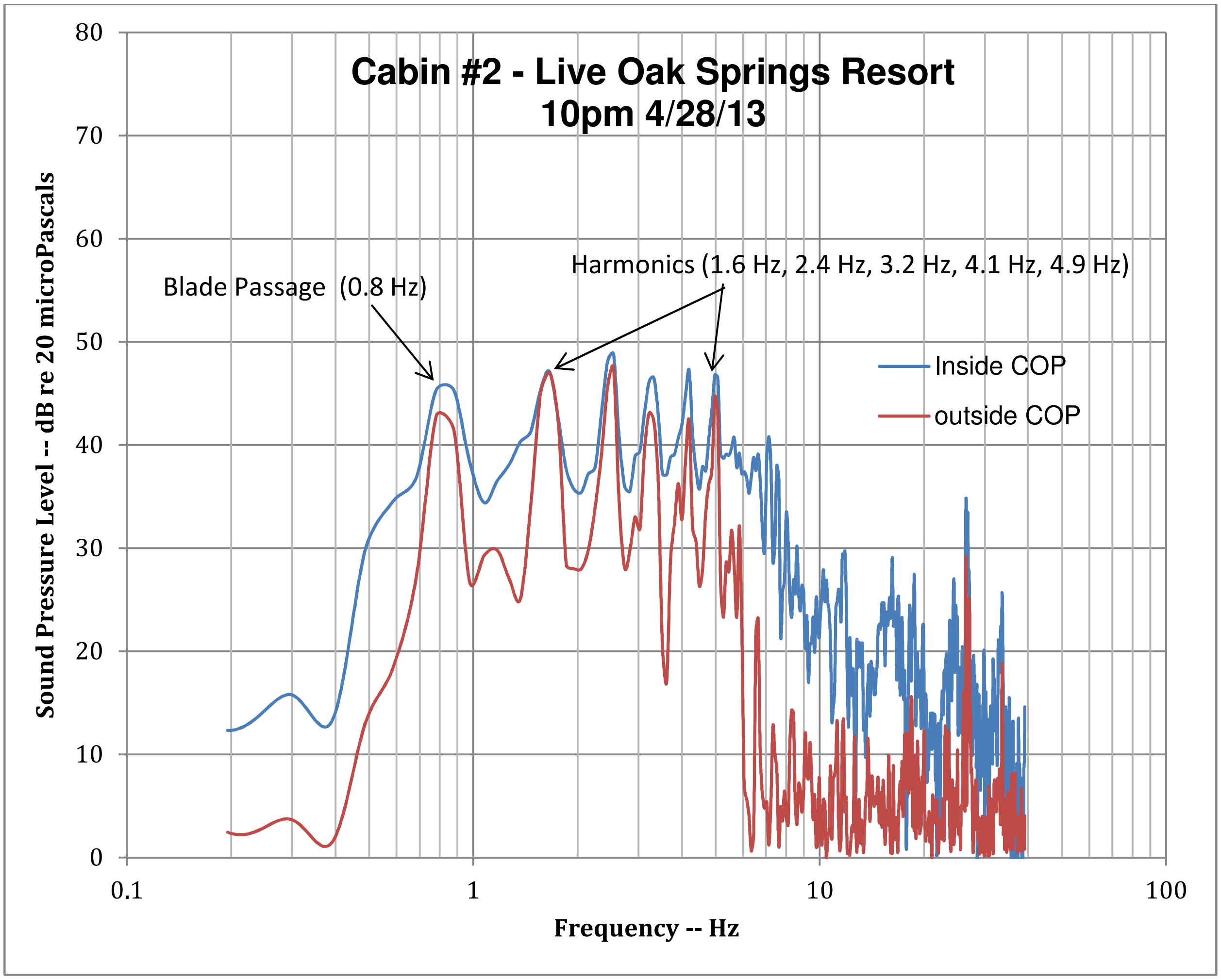


Figure C - 1 Live Oak Springs Resort – Cabin #2 – Autospectra



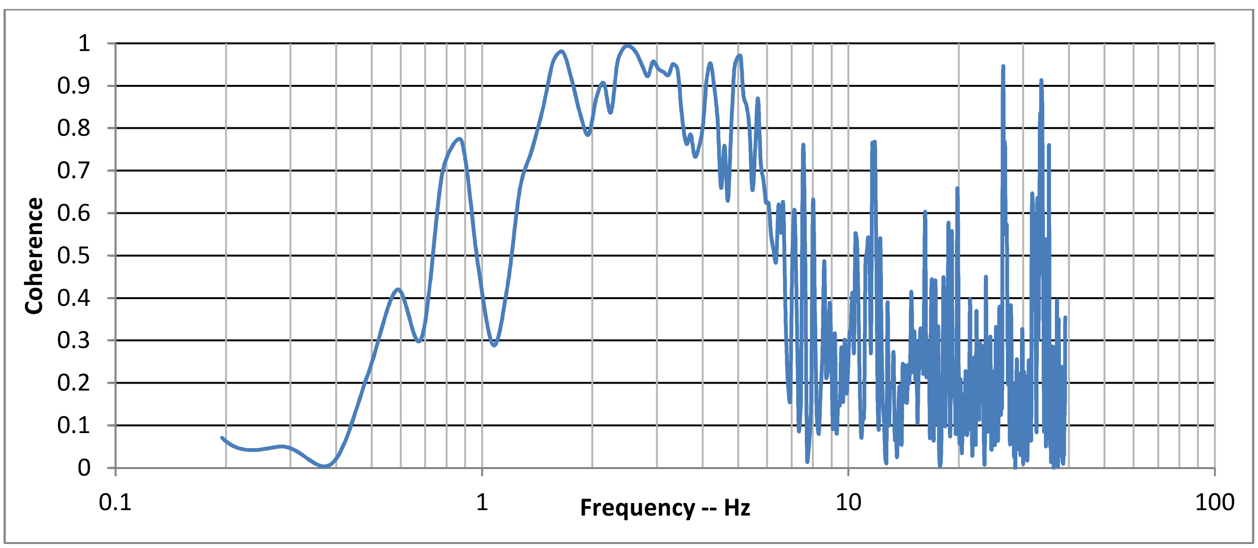


Figure C - 2 Live Oak Springs Resort – Cabin #2 – Coherent Output Power

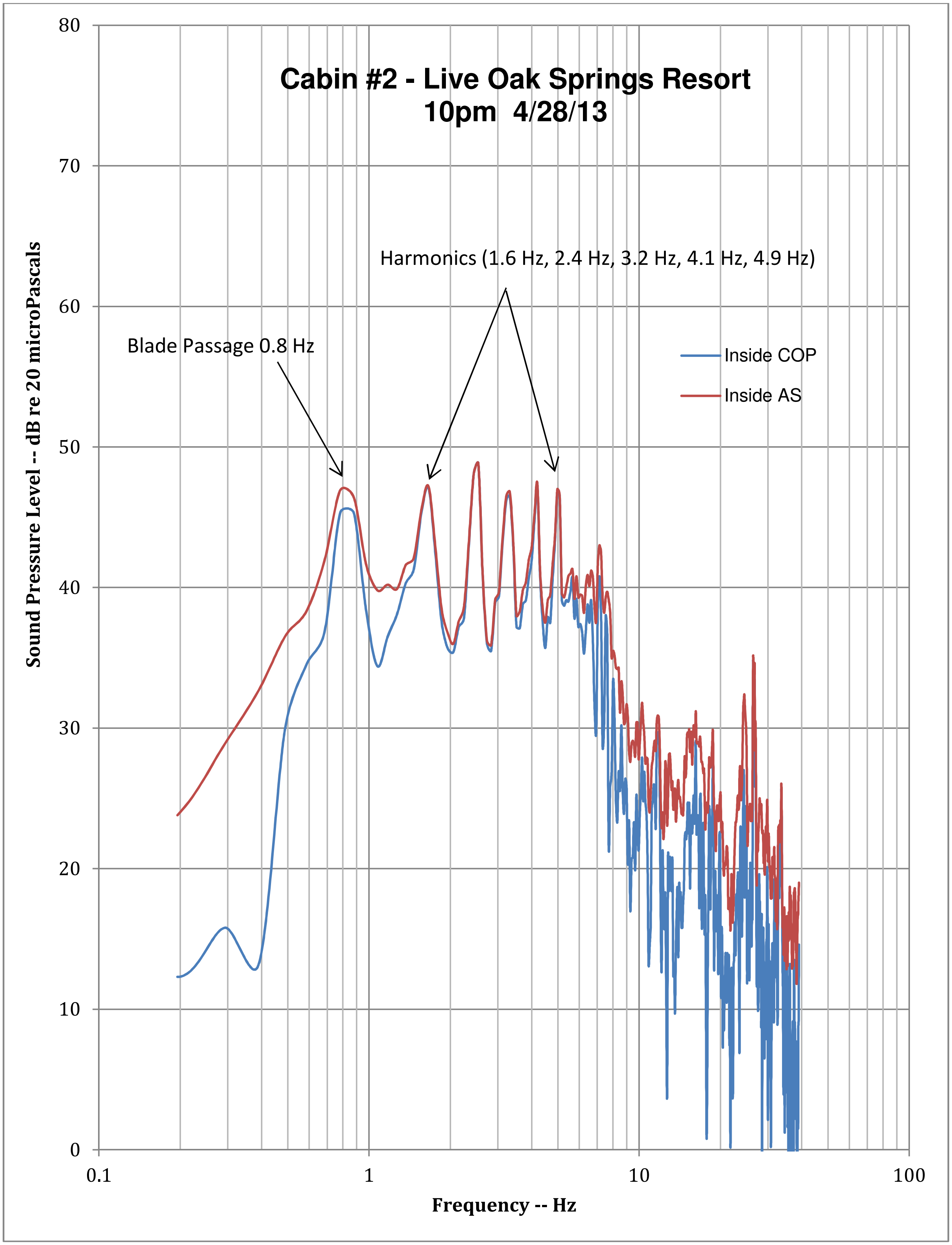


Figure C - 3 Live Oak Springs Resort – Cabin #2 – Comparison of Autospctrum and COP

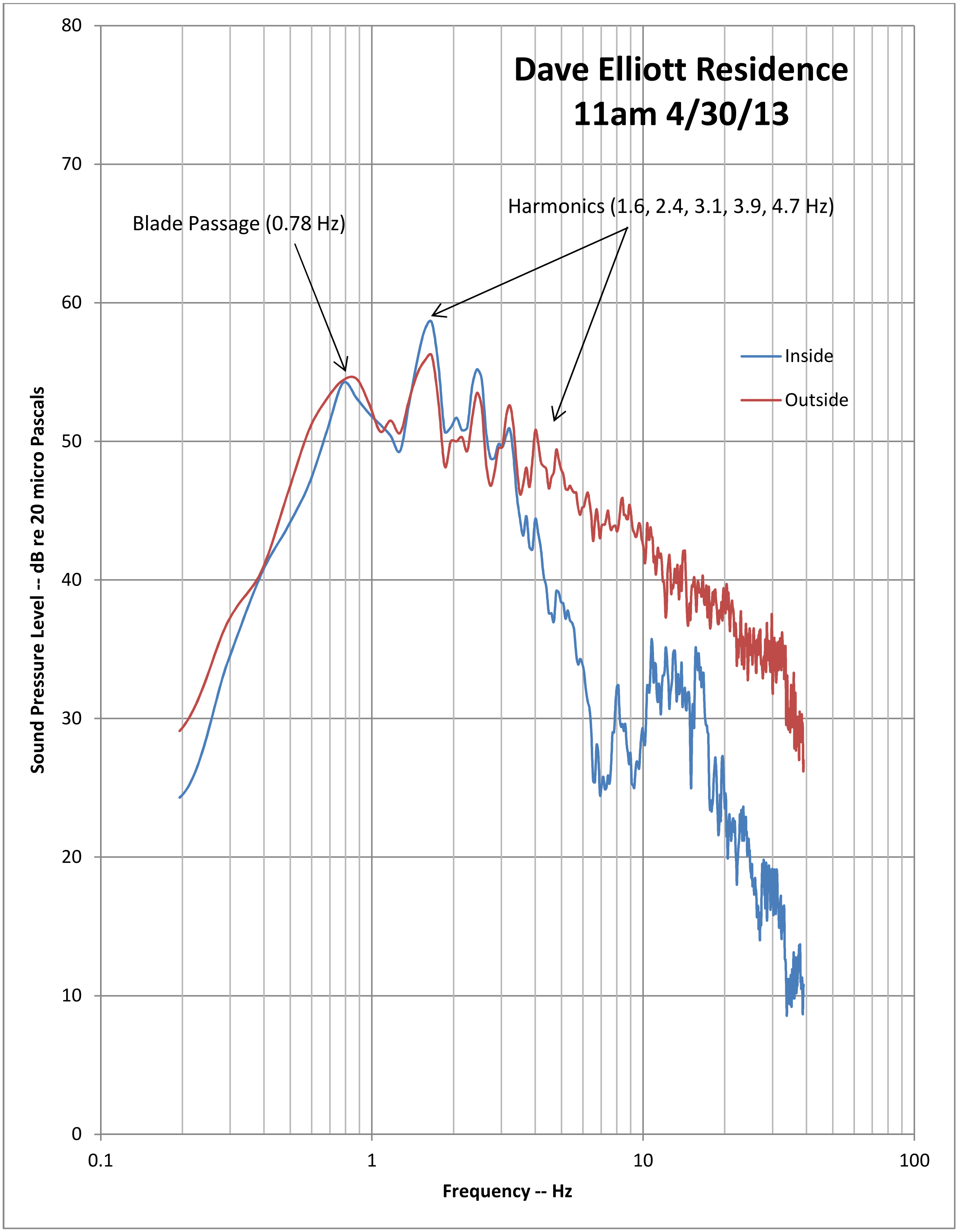


Figure C - 4 Dave Elliott Residence Autospectra

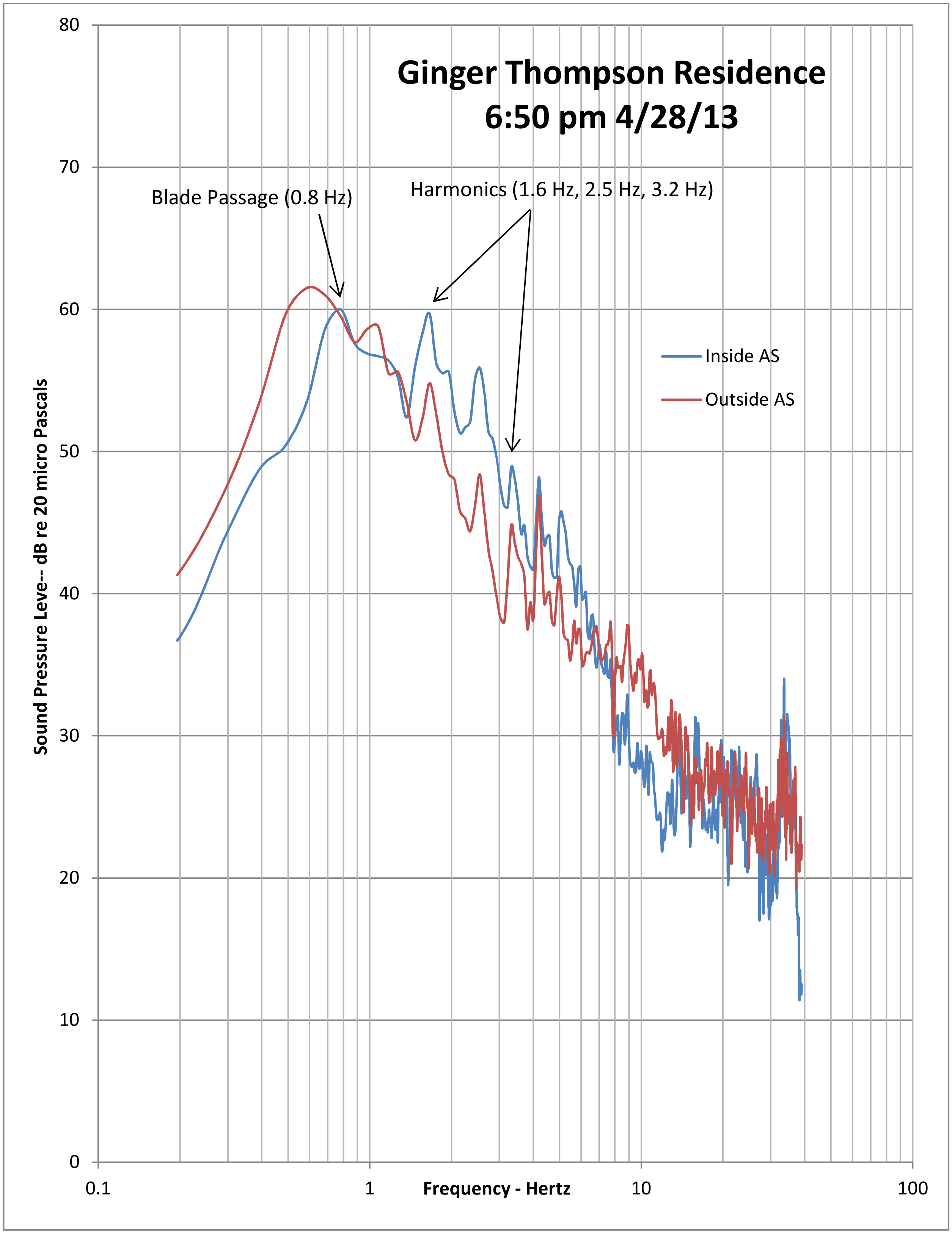


Figure C - 5 Ginger Thompson Residence Autospectra

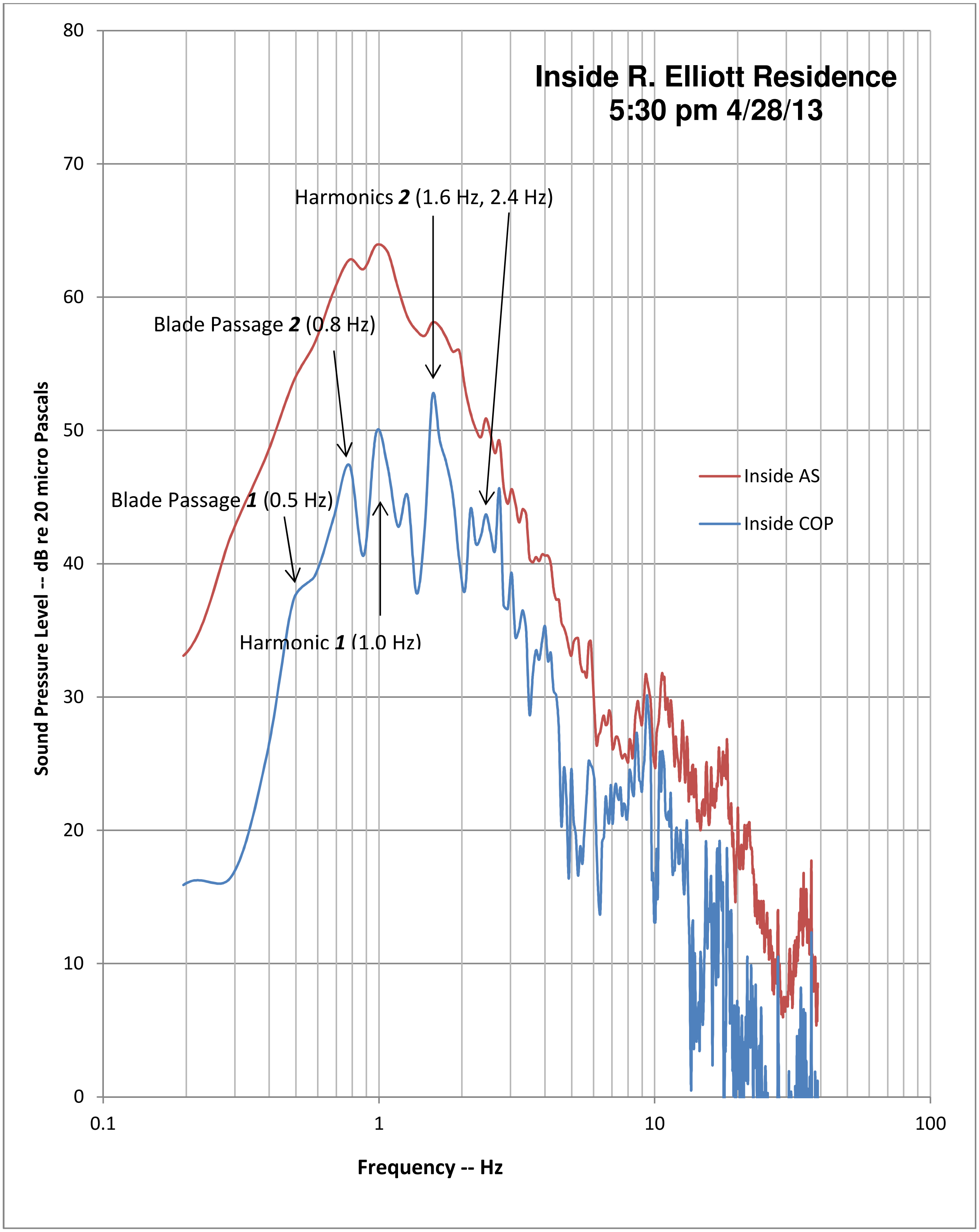


Figure C - 6 R. Elliott Residence Comparison of Autospectrum and Coherent Output Power

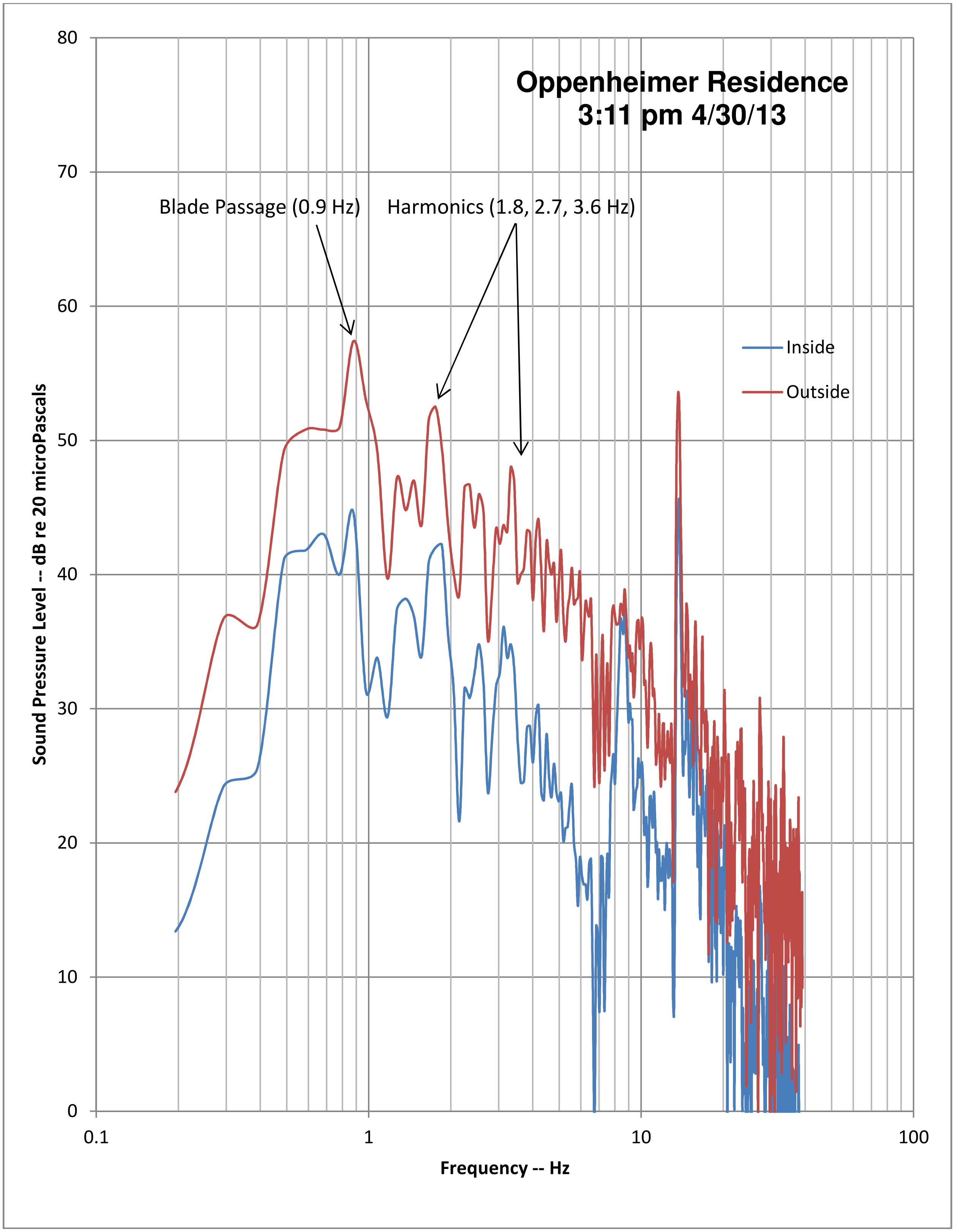


Figure C - 7 Ken Oppenheimer Residence during Day – Coherent Output Power

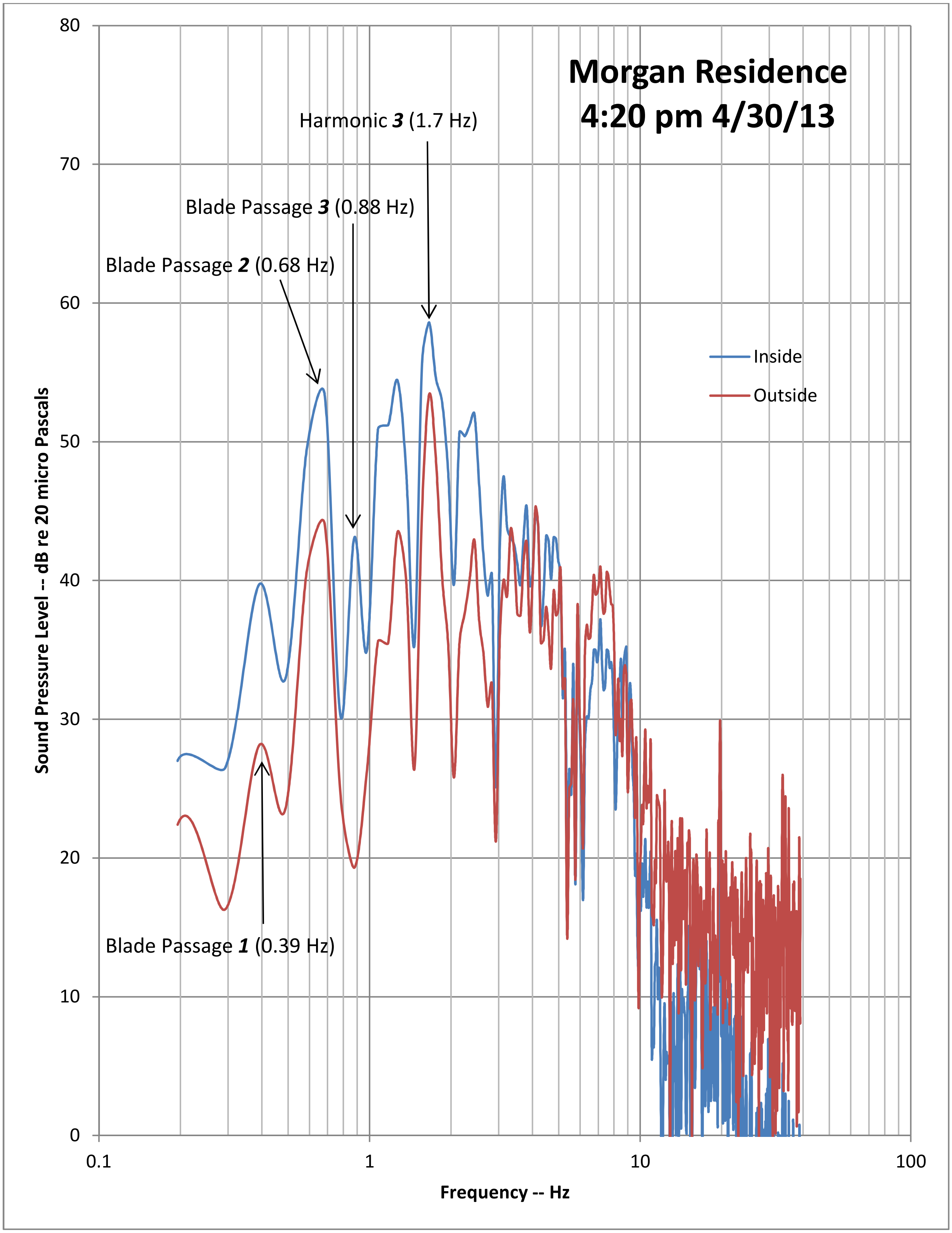


Figure C - 8 Marie Morgan Residence during Day – Coherent Output Power

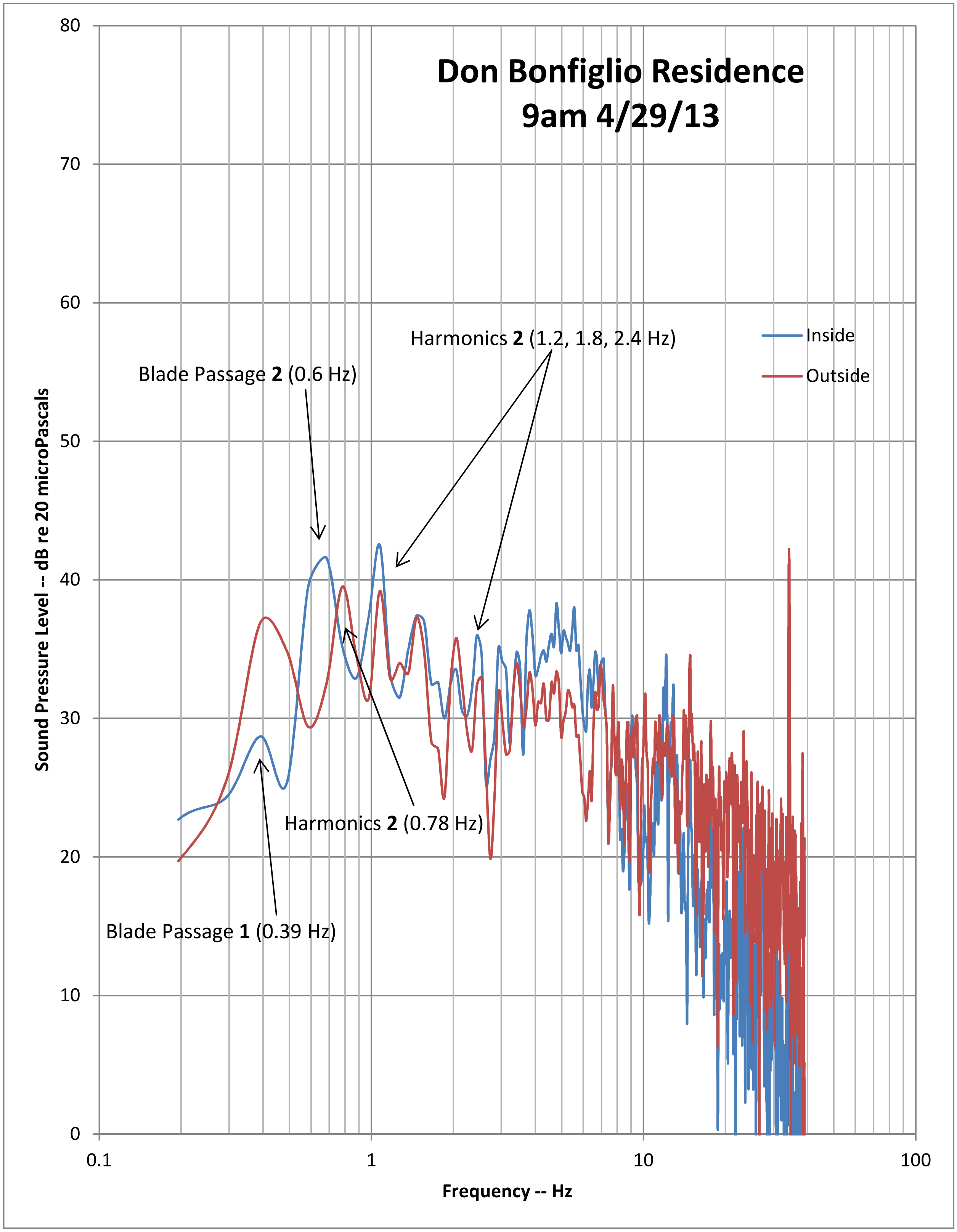


Figure C - 9 Don Bonfiglio Residence during Day – Coherent Output Power

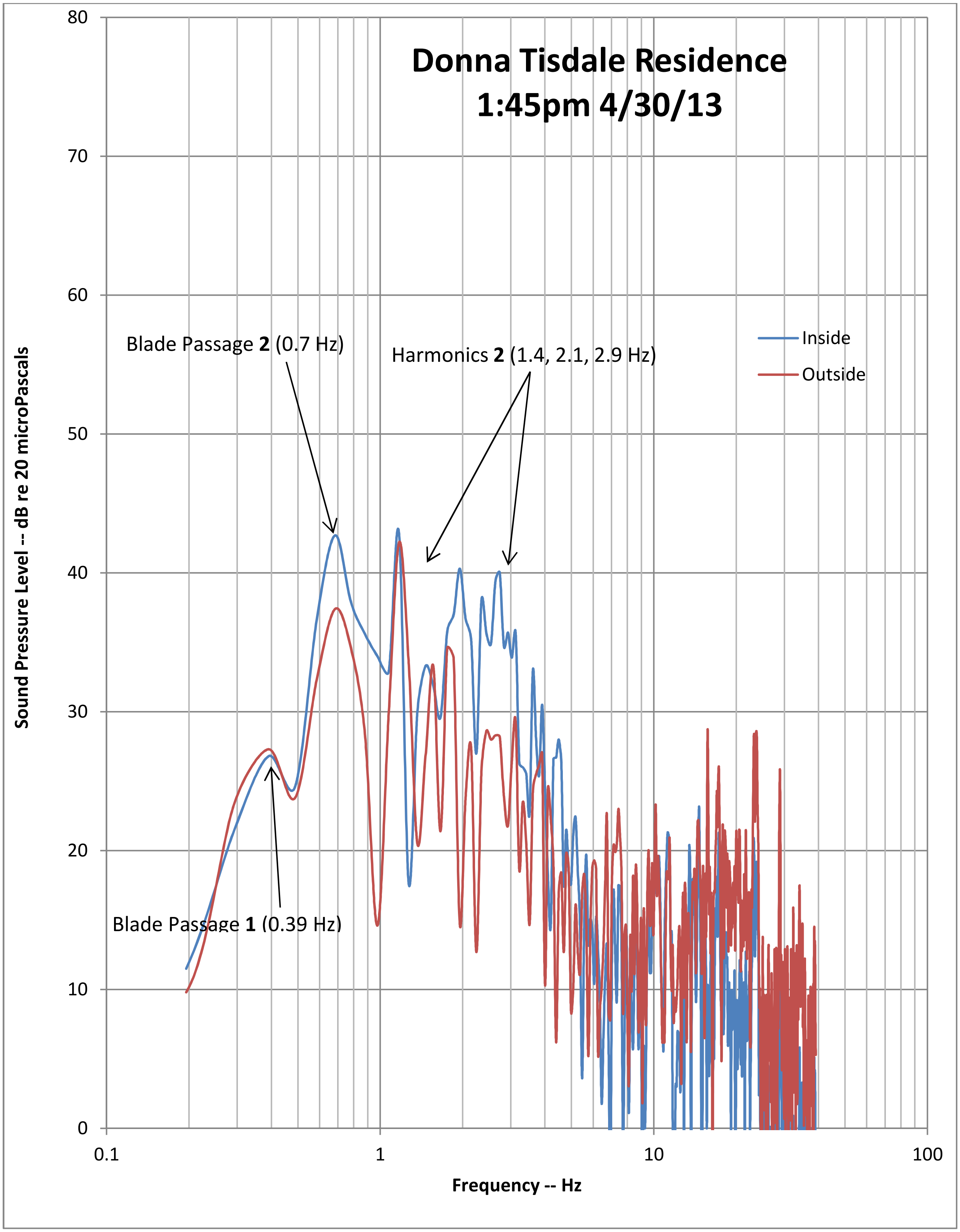


Figure C - 10 Donna Tisdale Residence during Day – Coherent Output Power

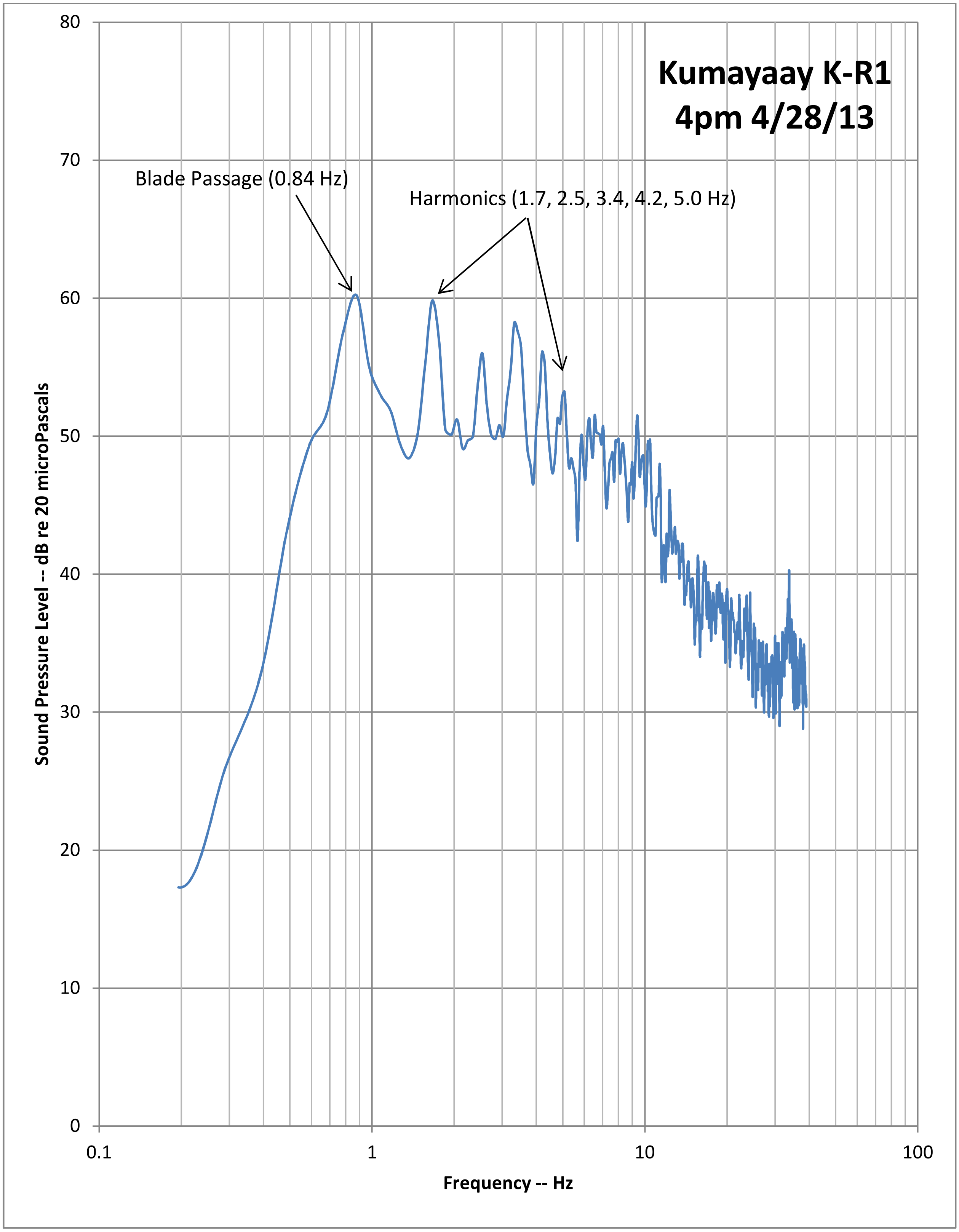


Figure C - 11 Kumeyaay Reference Location 1

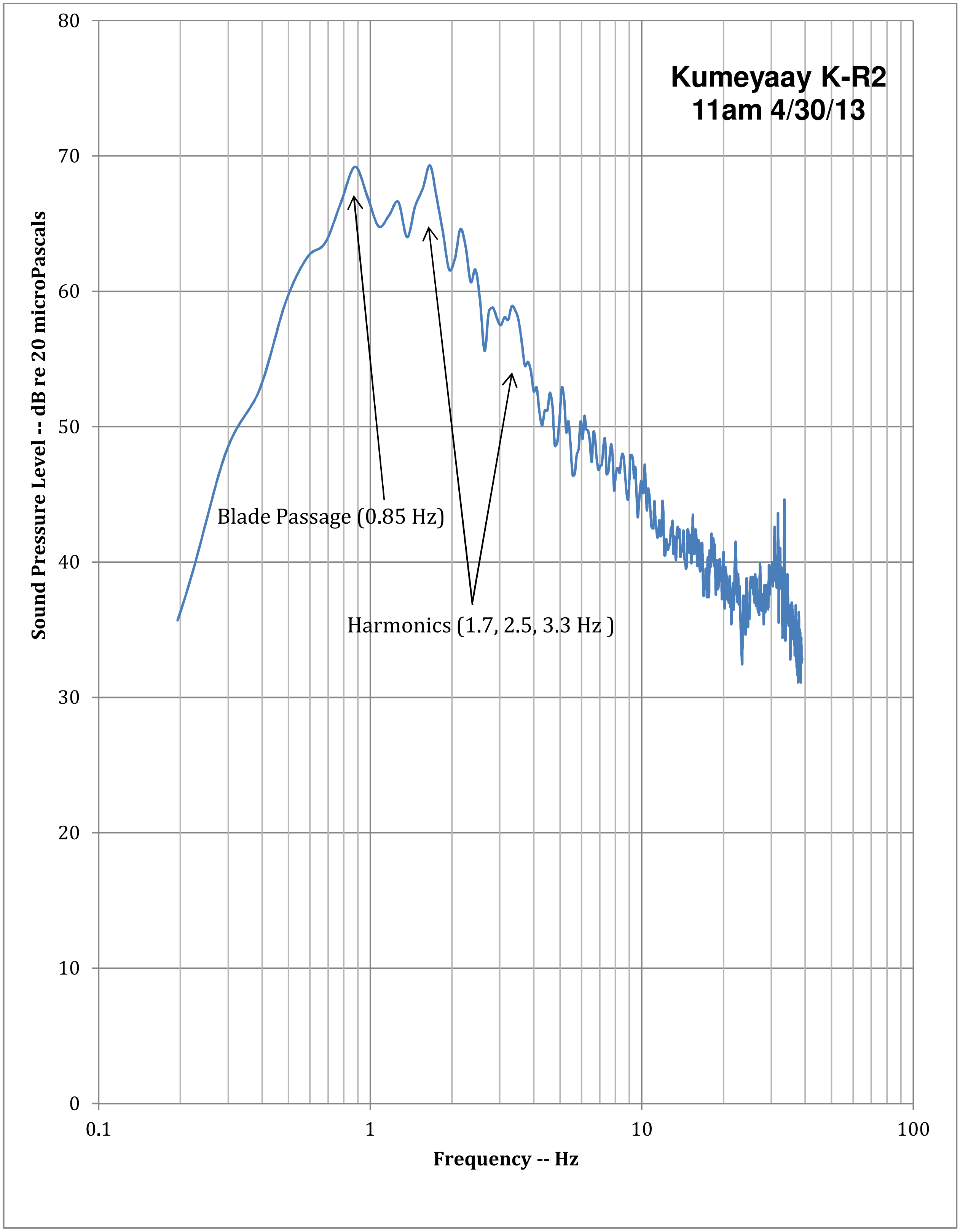


Figure C - 12 Kumeyaay Reference Location 2

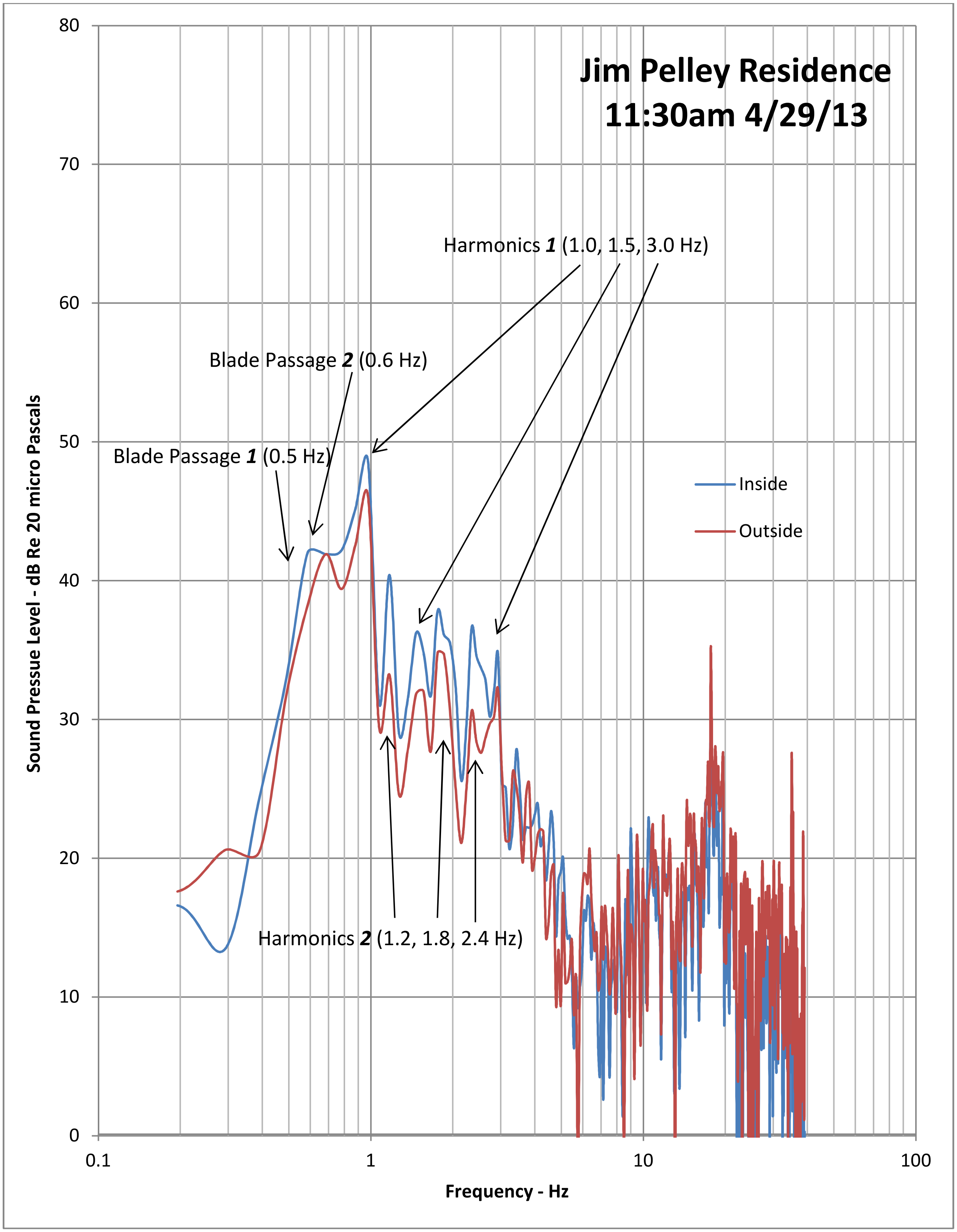


Figure C - 13 Jim Pelly Residence during Day – Coherent Output Power

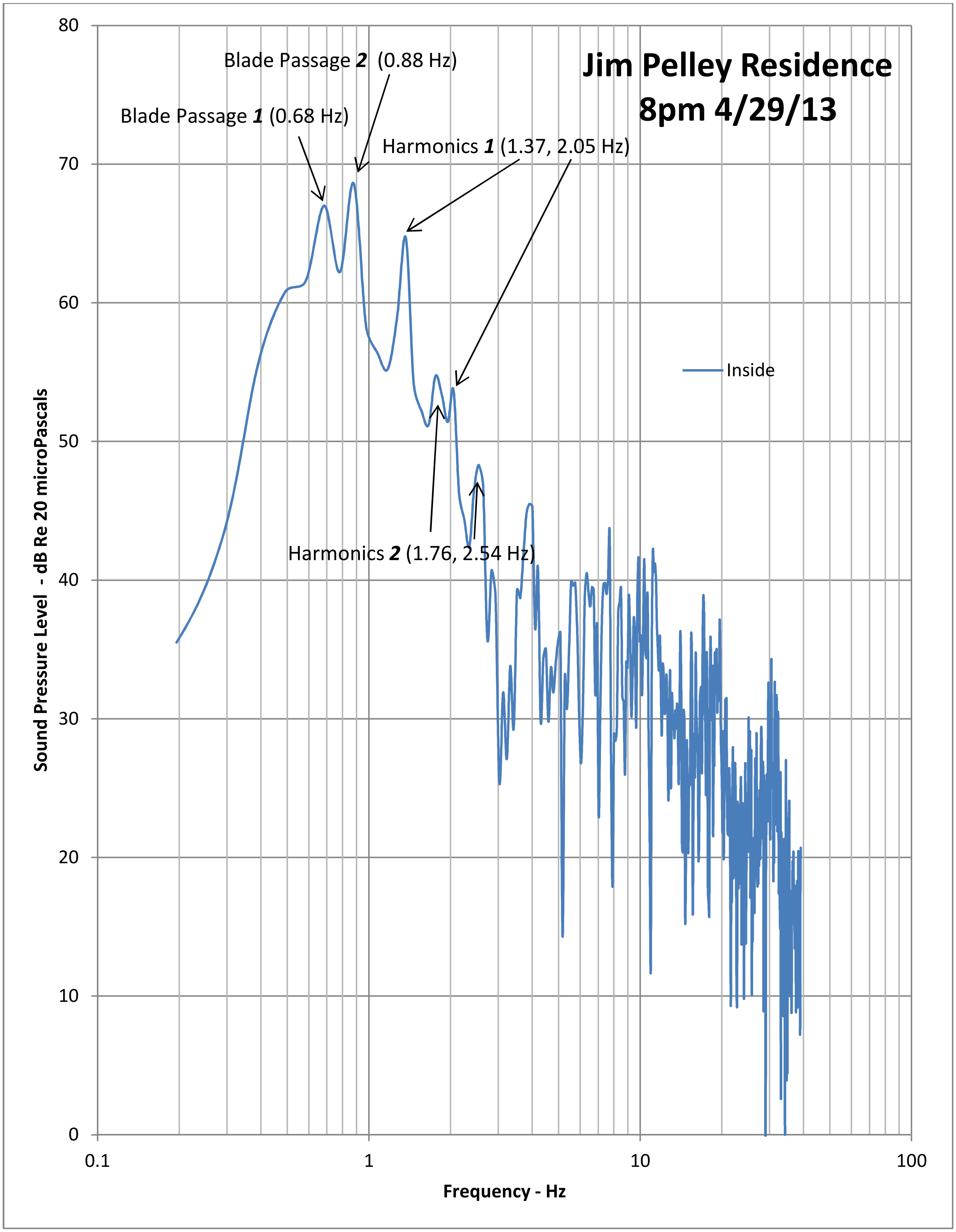


Figure C - 14 Jim Pelly Residence at Night – Coherent Output Power

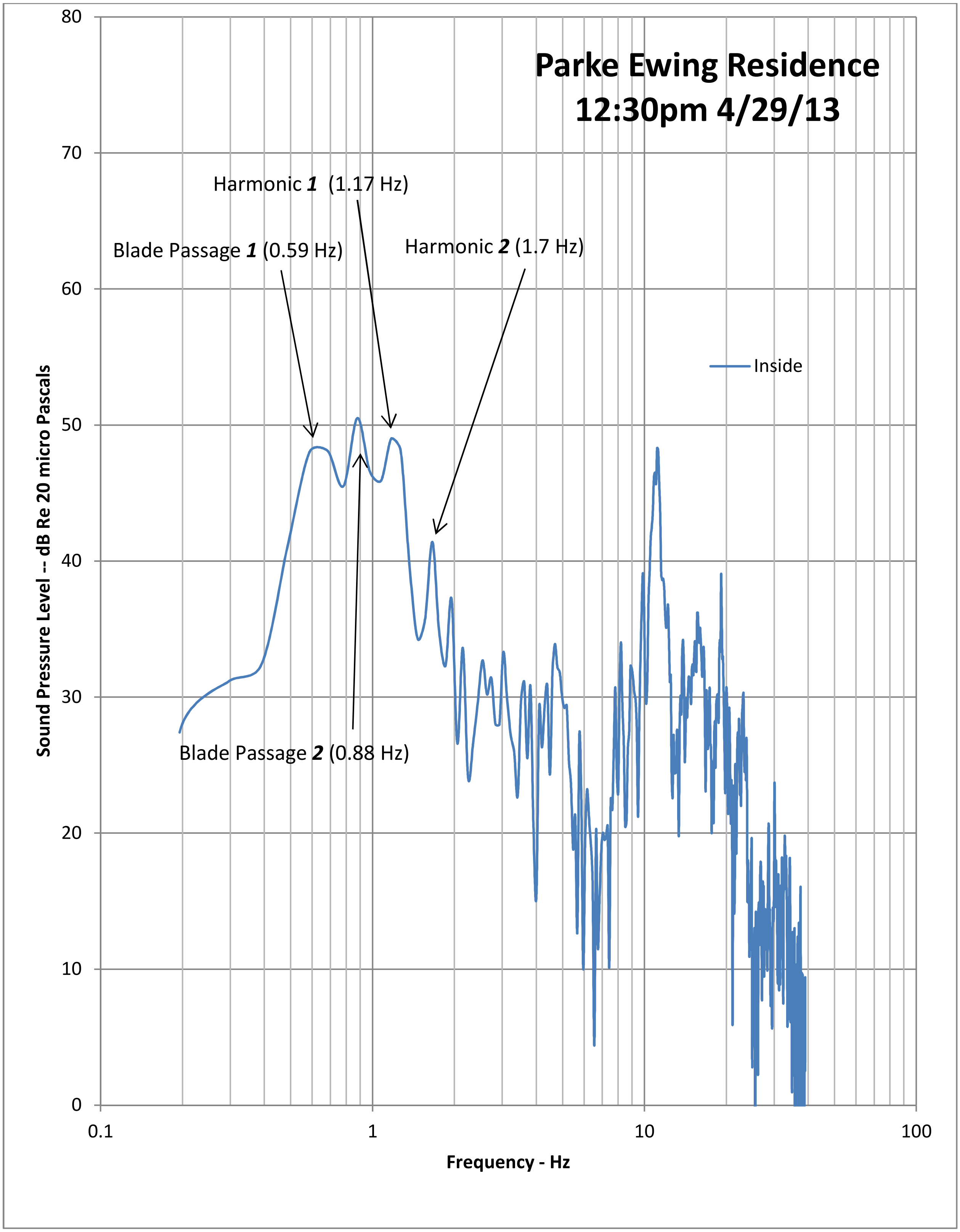


Figure C - 15 Parke Ewing Residence during Day – Coherent Output Power

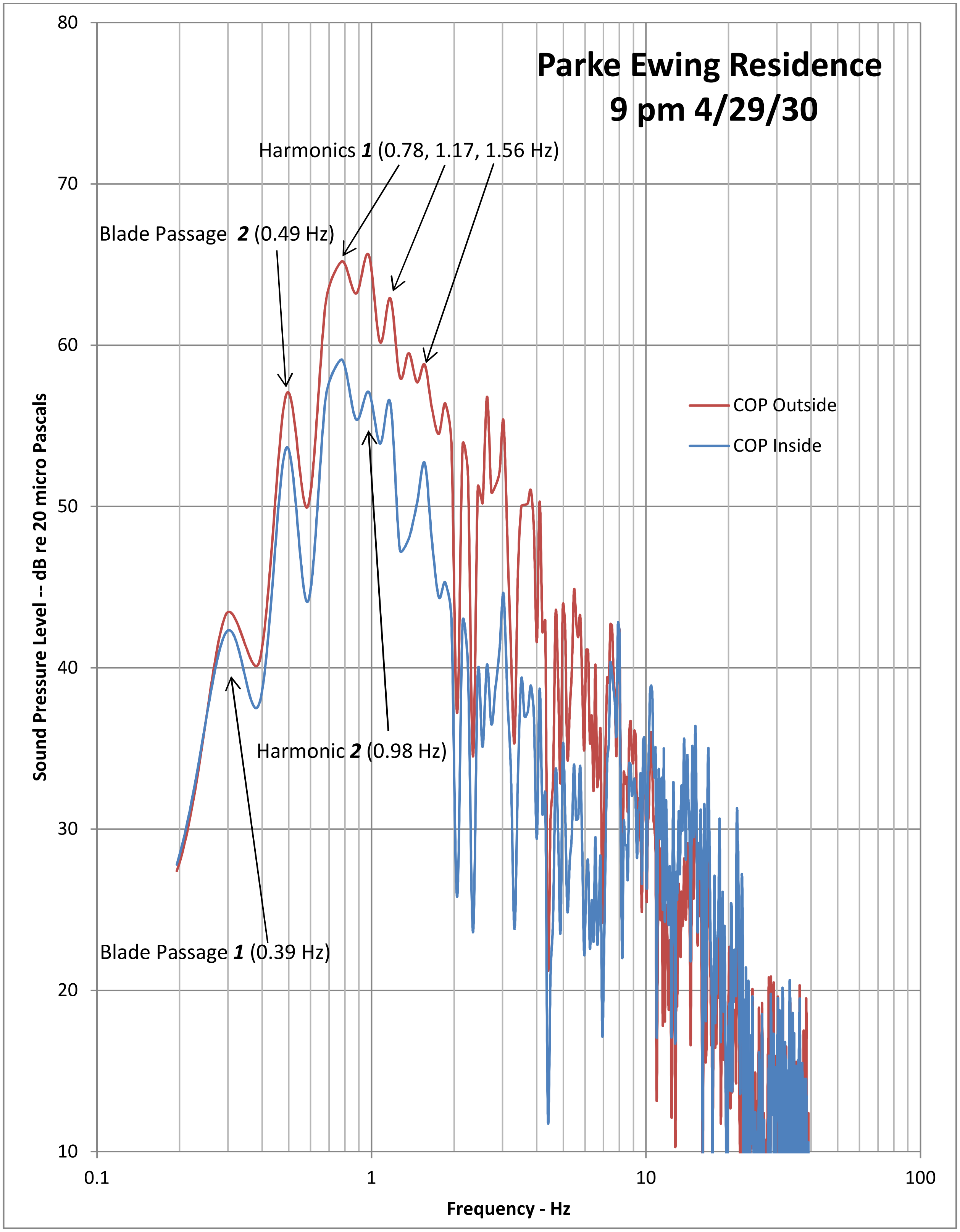


Figure C - 16 Parke Ewing Residence at Night – Coherent Output Power

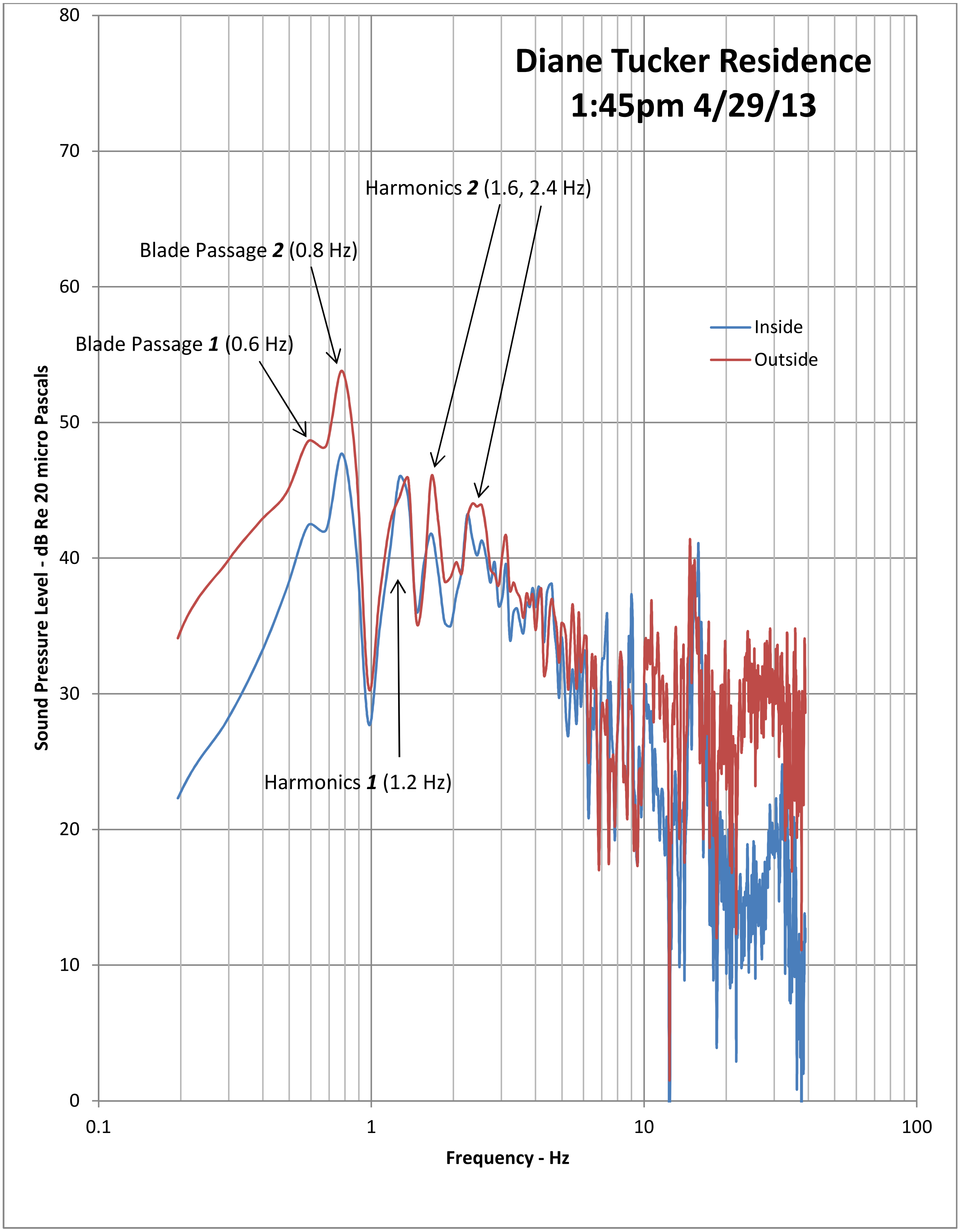


Figure C - 17 Diane Tucker Residence at Day – Coherent Output Power

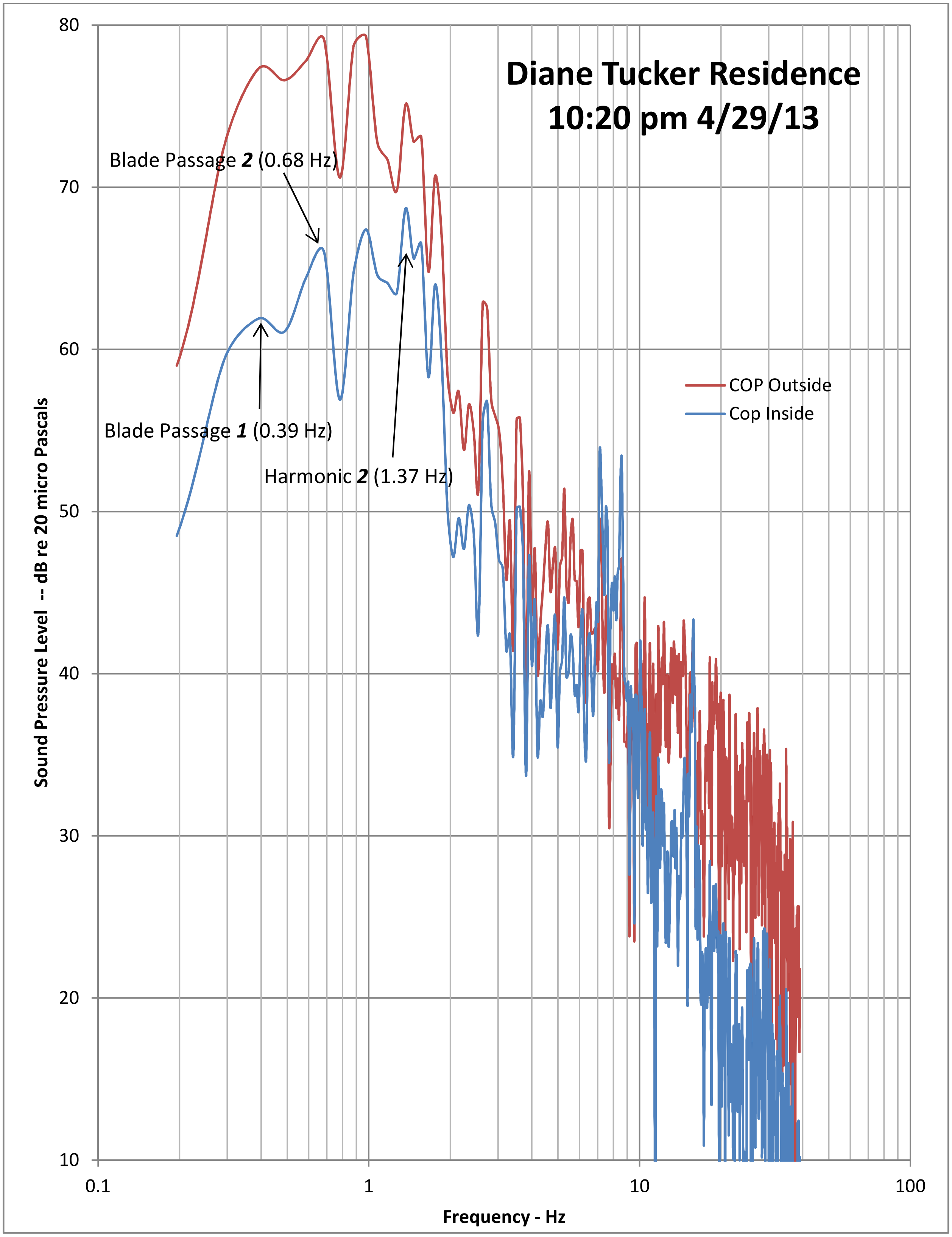


Figure C - 18 Diane Tucker Residence at Night – Coherent Output Power

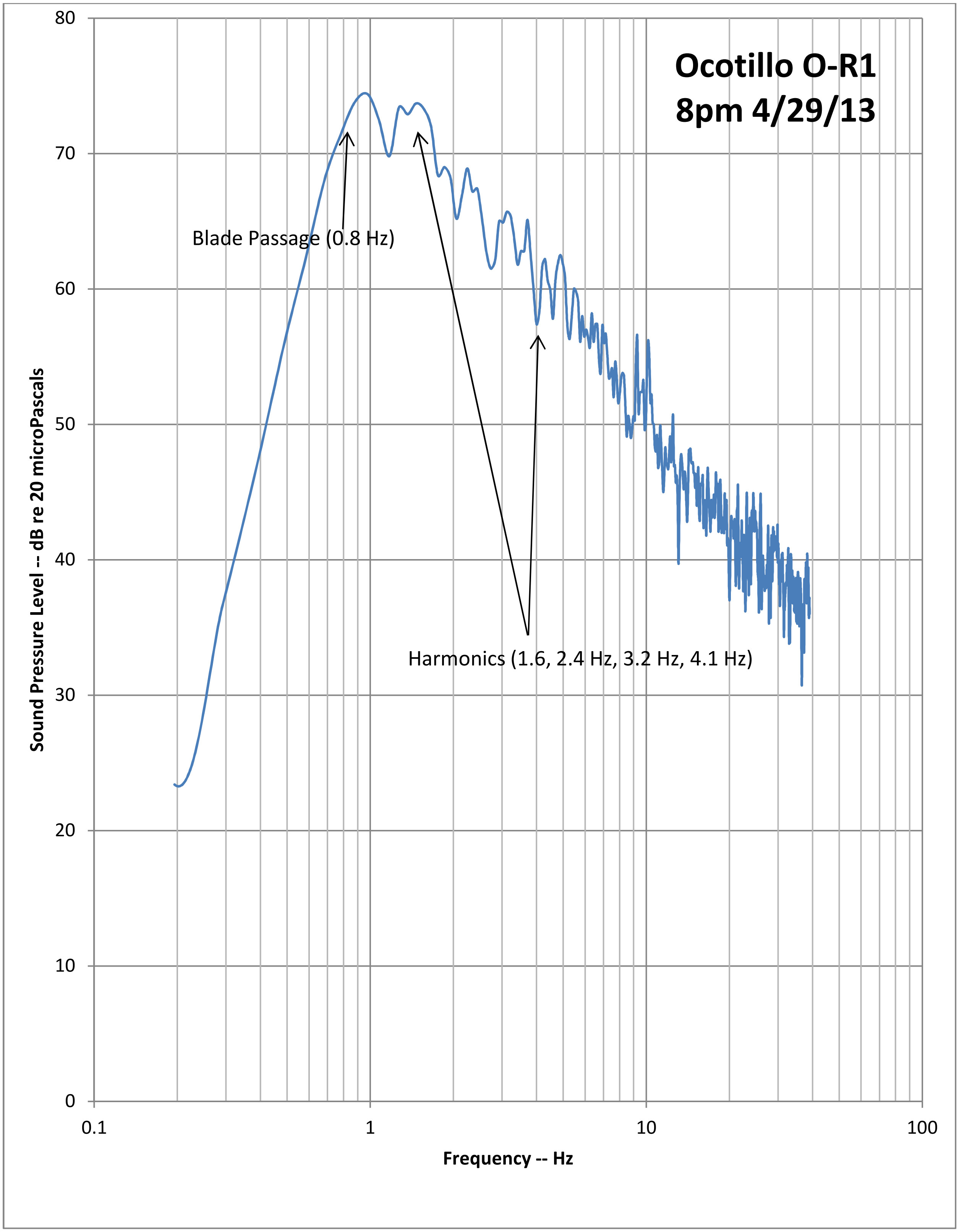


Figure C - 19 Ocotillo Reference Location 1 at Night

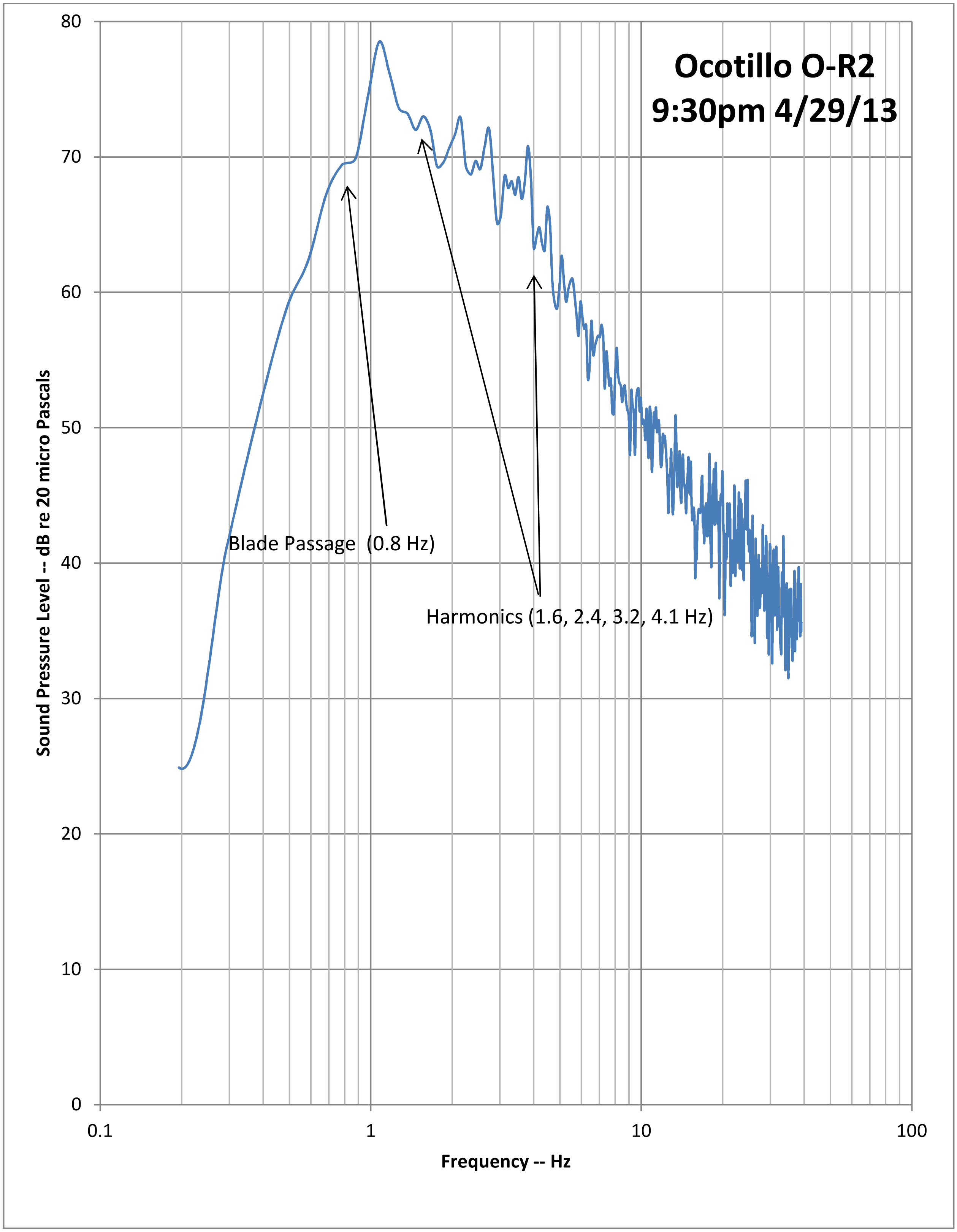


Figure C - 20 Ocotillo Reference Location 2 at Night

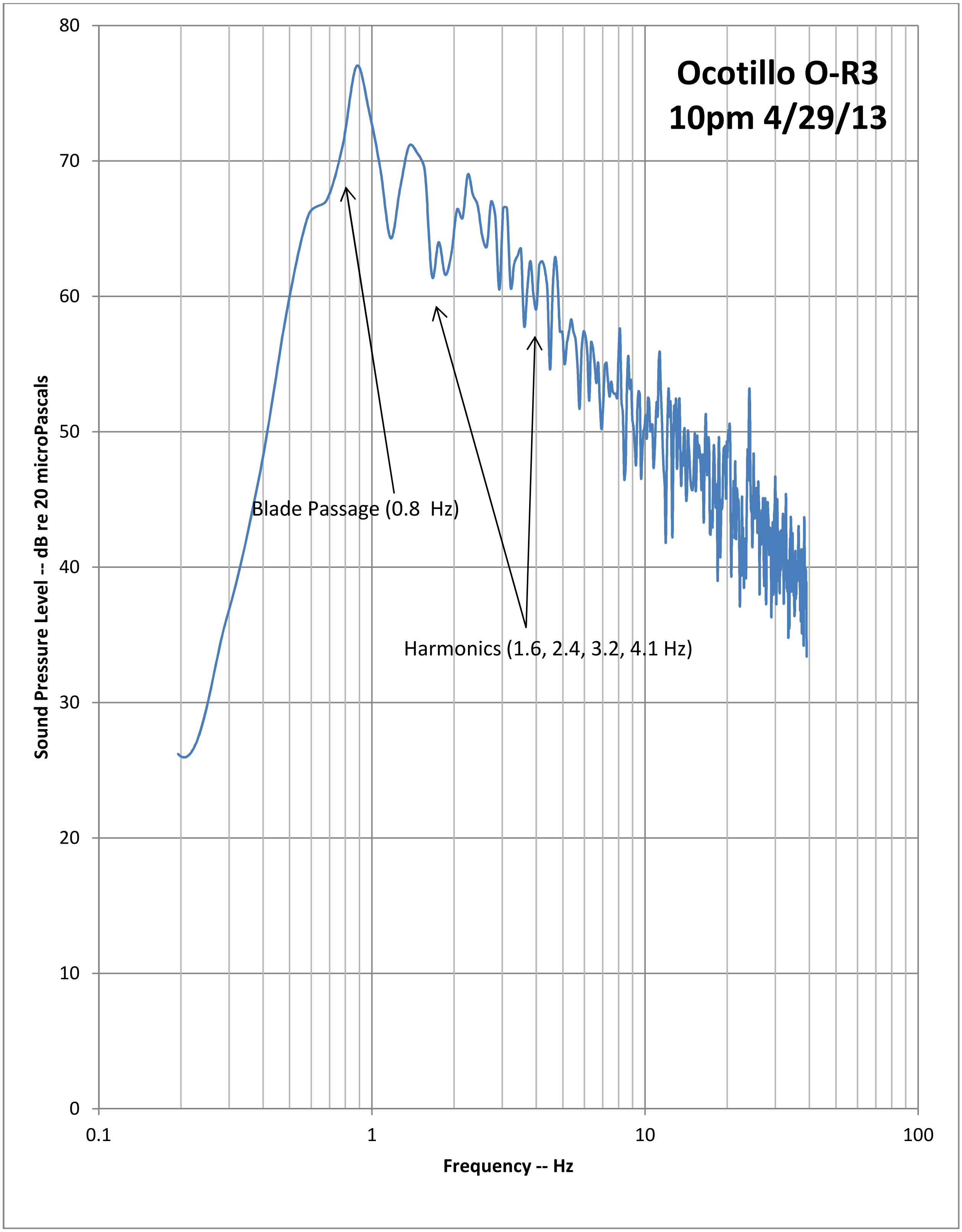


Figure C - 21 Ocotillo Reference Location 3 at Night