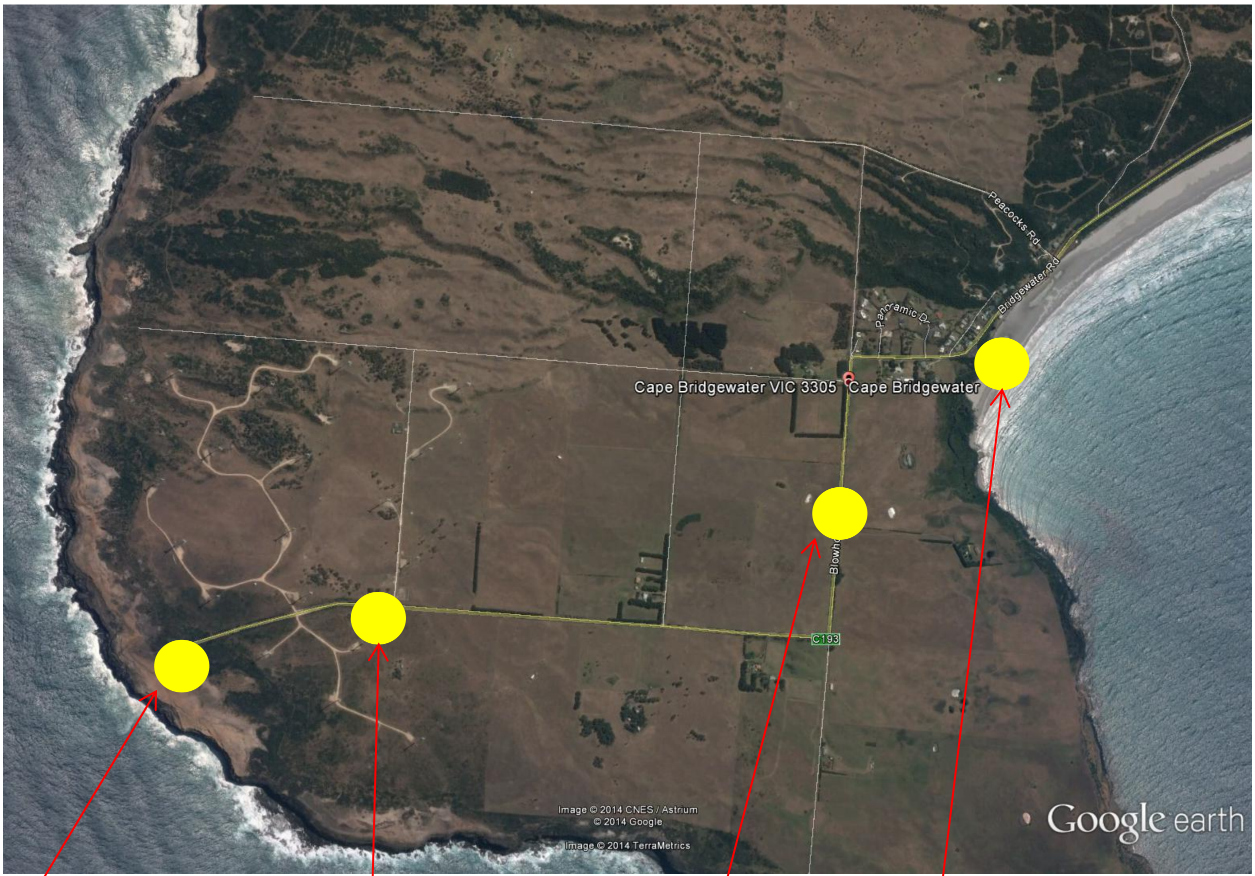
APPENDIX T: Off Site Ambient Tests



End of Blowholes road

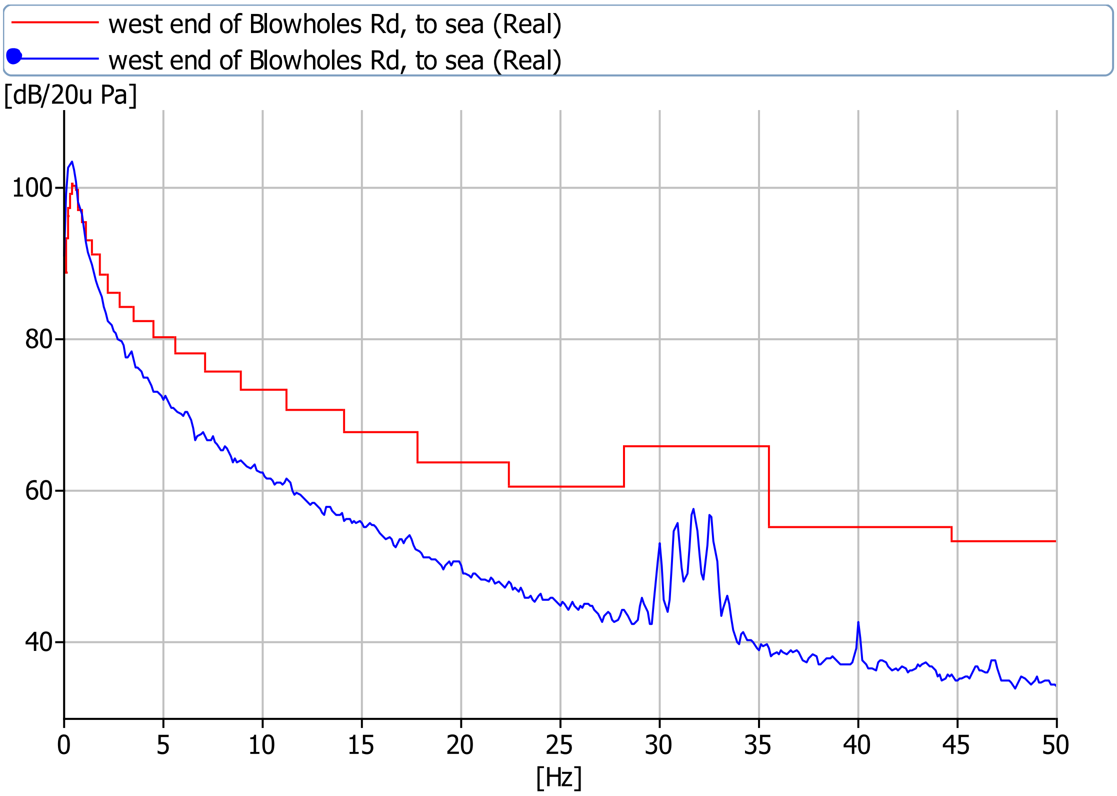
Substation access

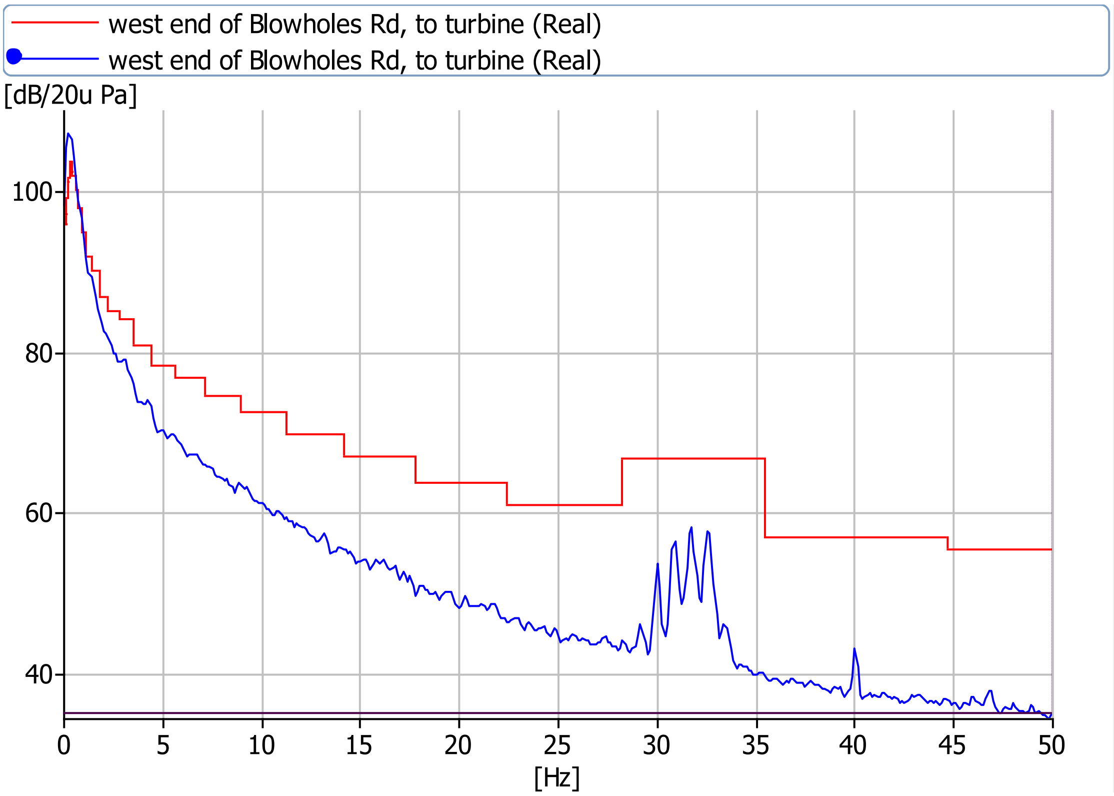
Surf Club

East end of Blowholes Road

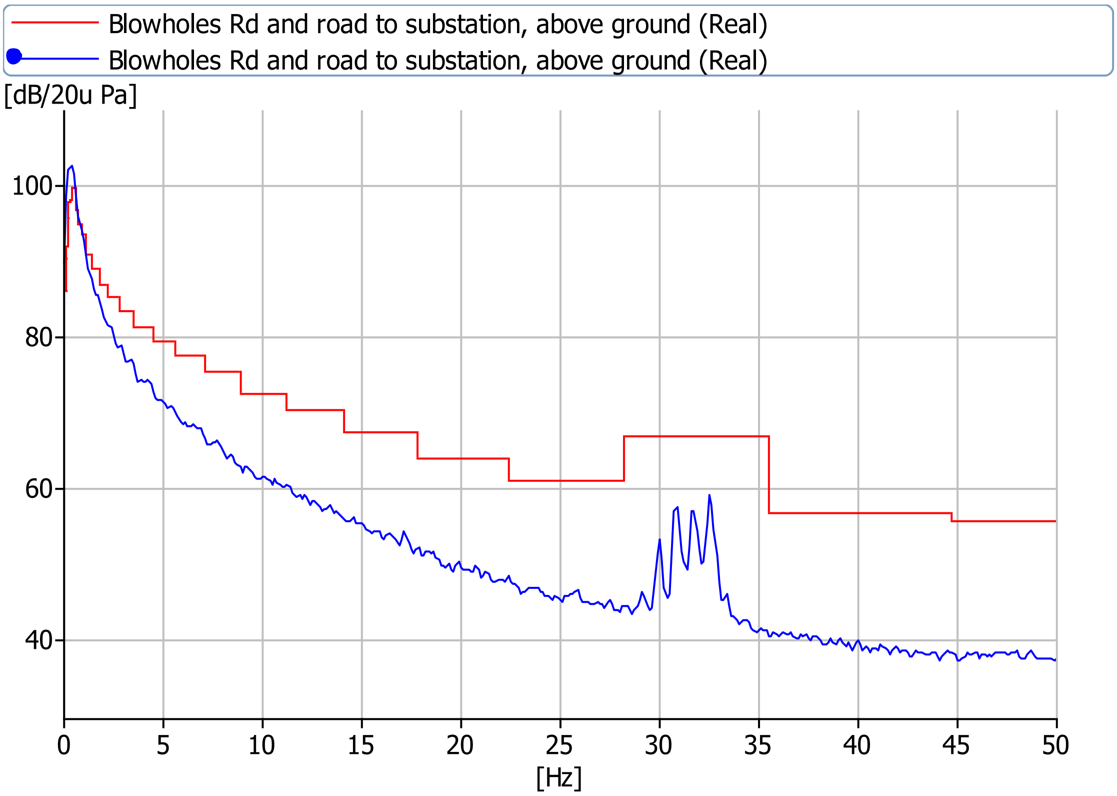
West end of Blowholes Road

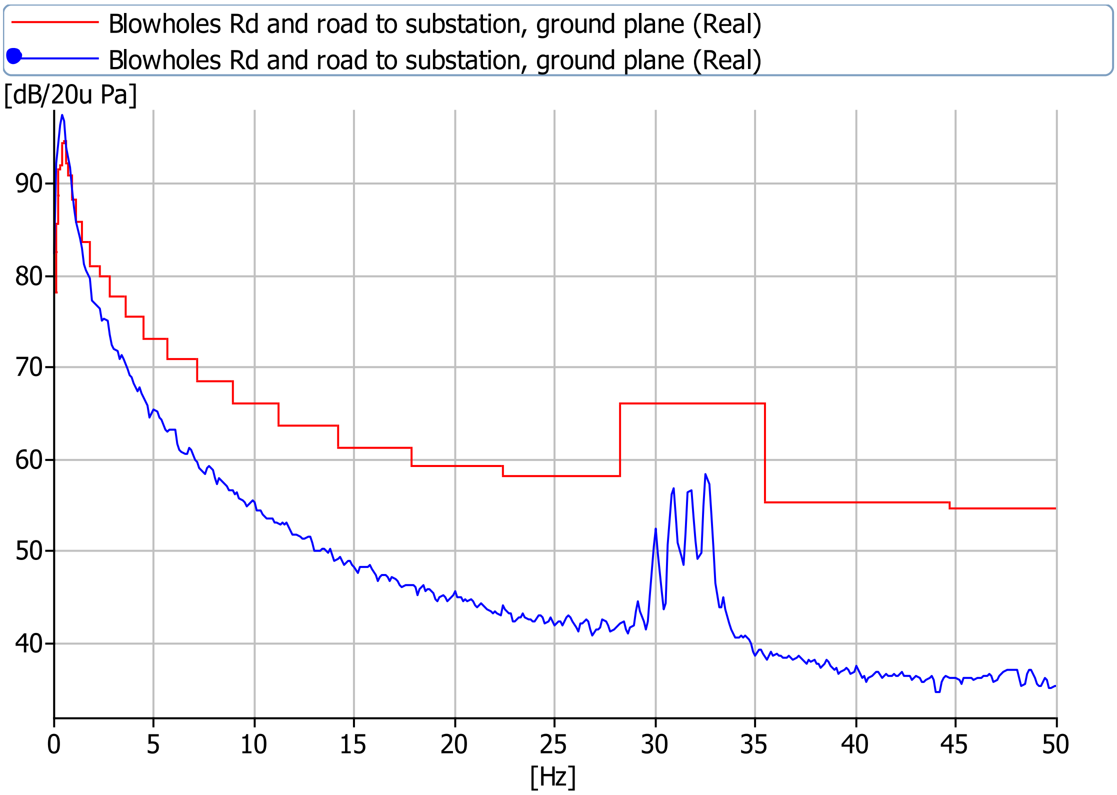
West end of Blowholes Rd



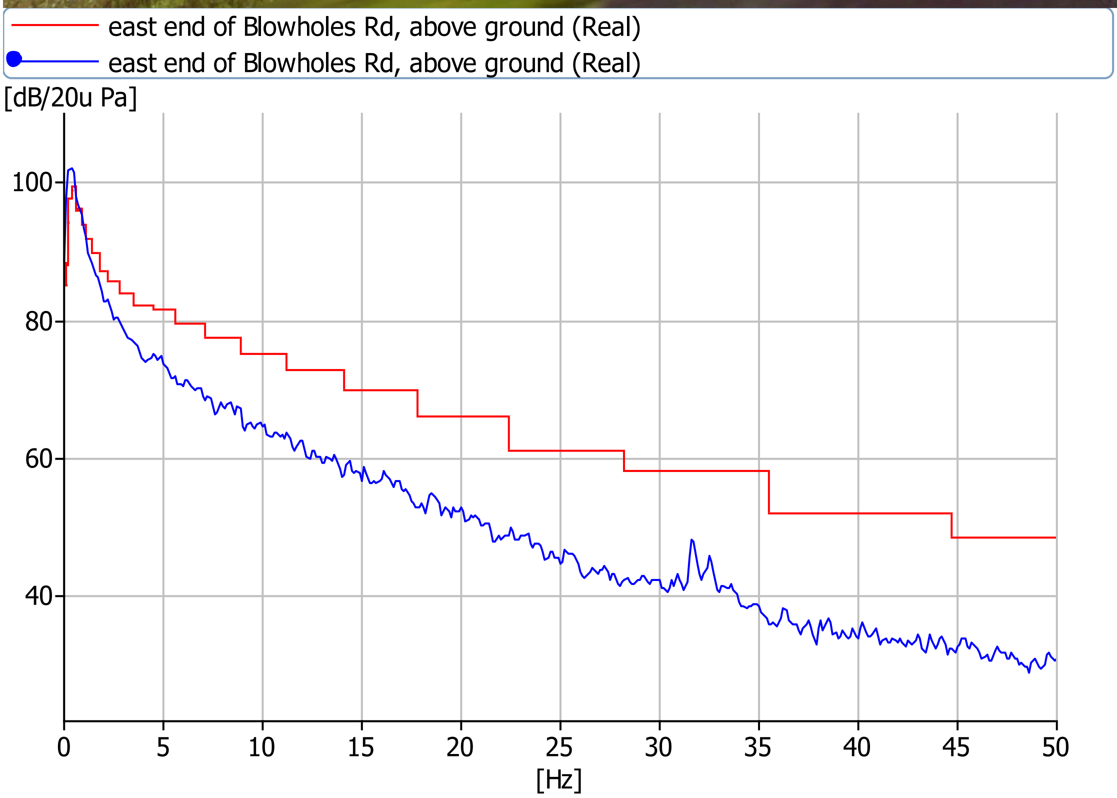


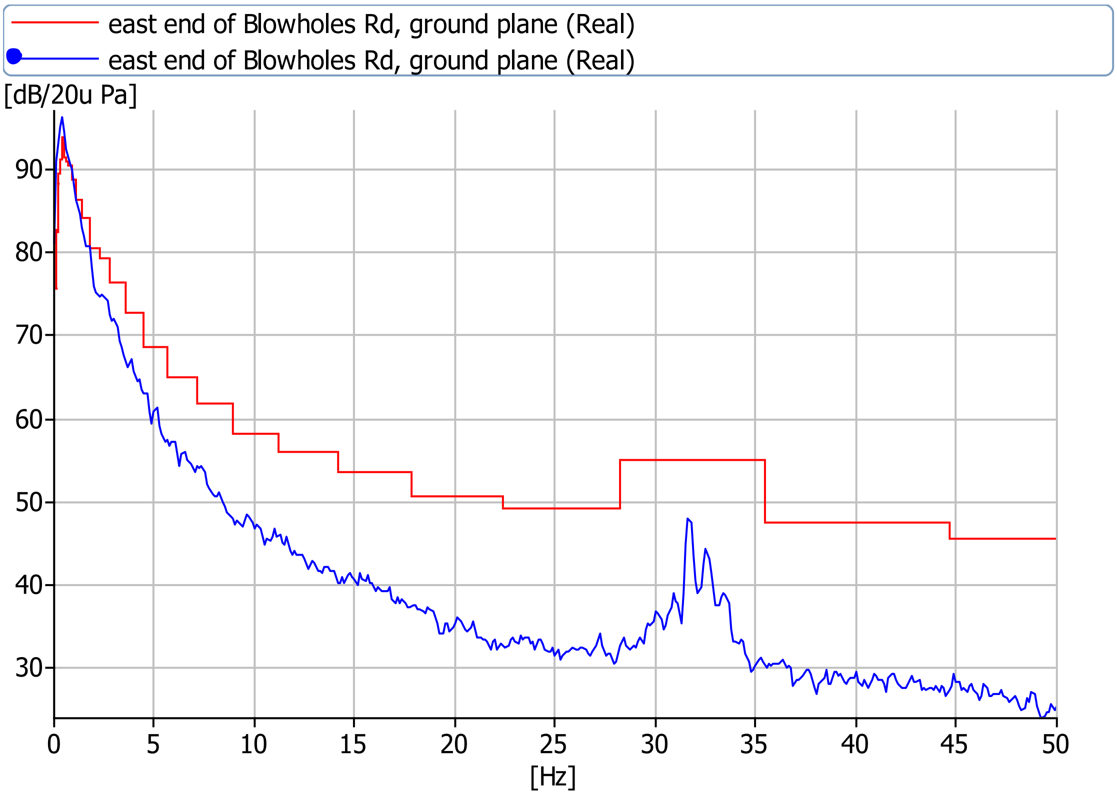
Blowholes road and substation road entrance


Blowholes Rd and road to substation, above ground (Real)
Blowholes Rd and road to substation, above ground (Real)
[dB/20u Pa]
100
80
60
40
0
5
10
15
20
25
30
35
40
45
50
[Hz]

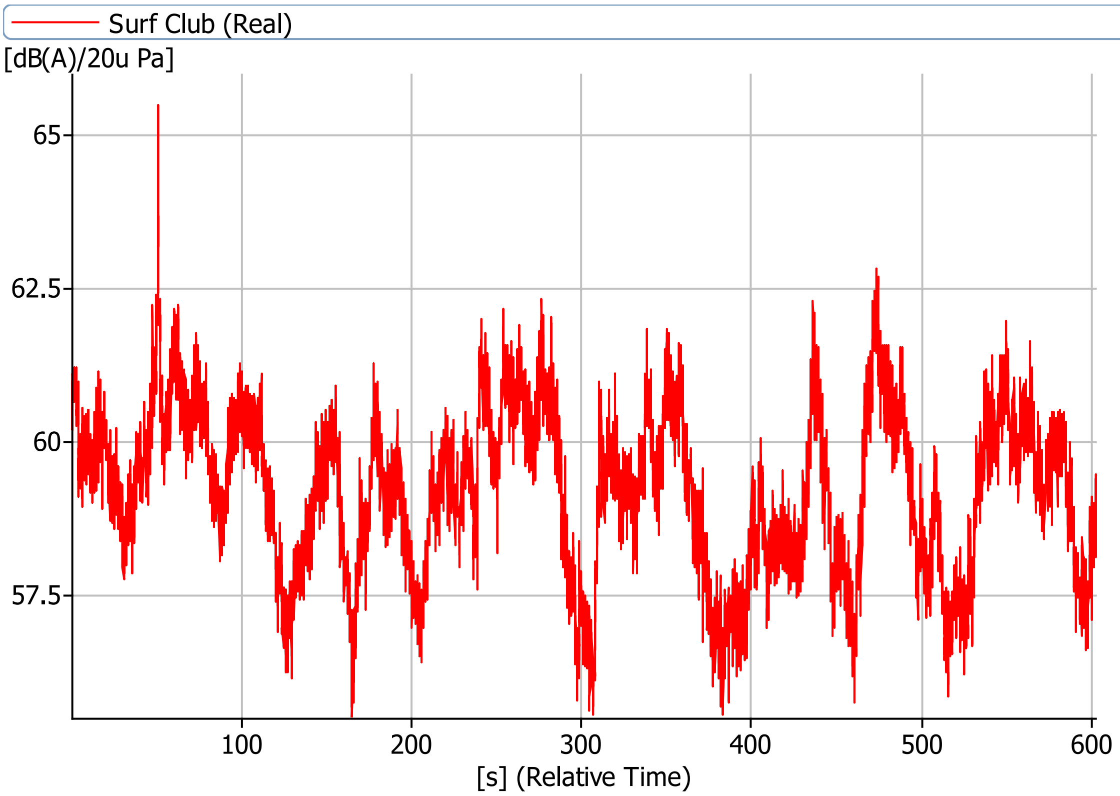

Blowholes Rd and road to substation, ground plane (Real)
Blowholes Rd and road to substation, ground plane (Real)
[dB/20u Pa]
90
80
70
60
50
40
0
5
10
15
20
25
30
35
40
45
50
[Hz]

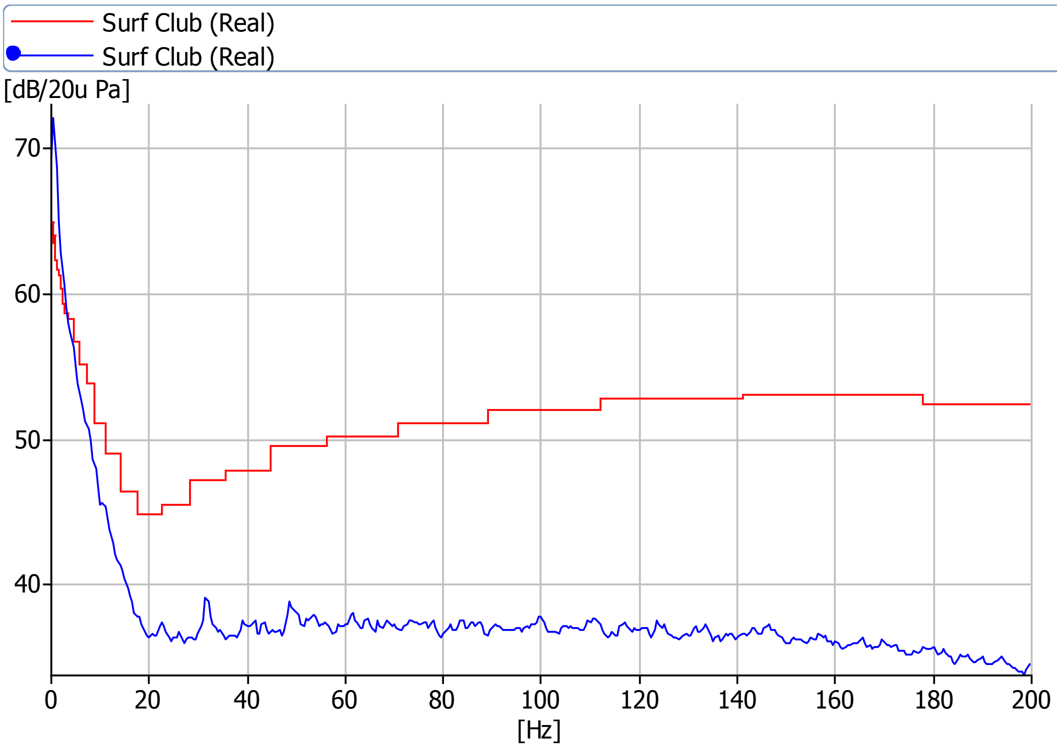

Google earth

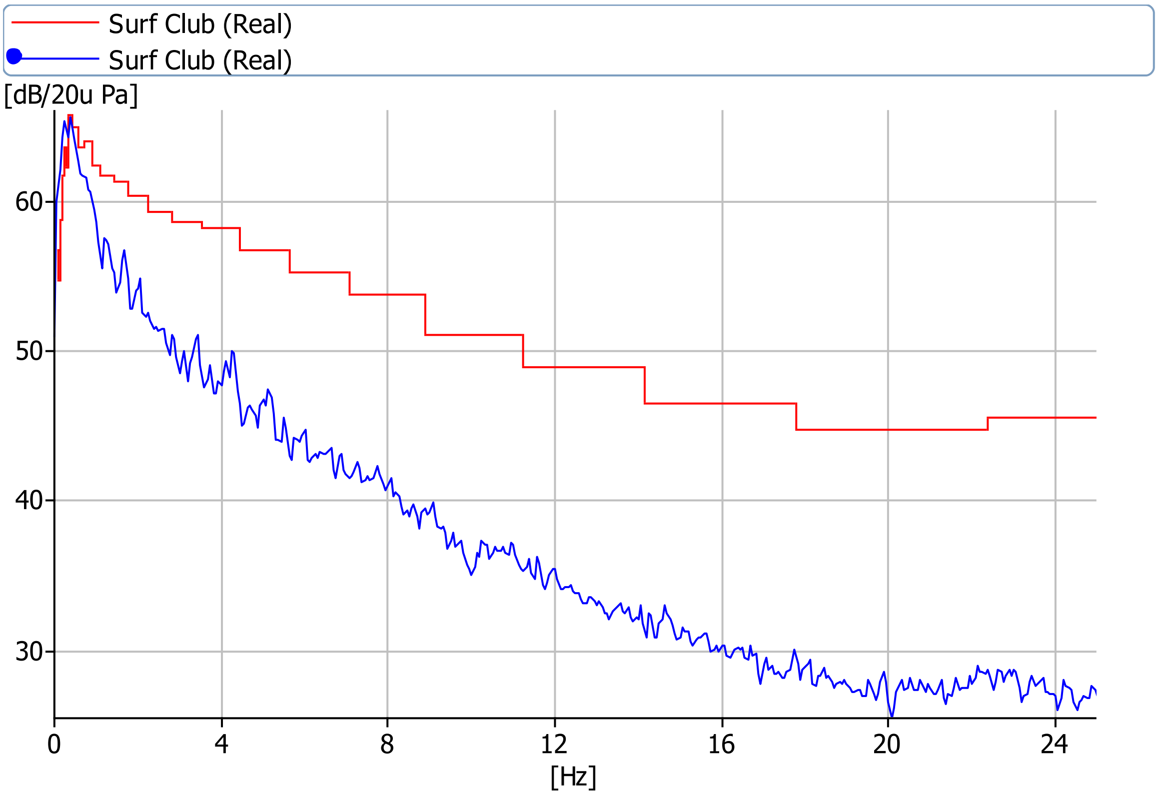

east end of Blowholes Rd, above ground (Real)
east end of Blowholes Rd, above ground (Real)
[dB/20u Pa]
100
80
60
40
0
5
10
15
20
25
30
35
40
45
50
[Hz]

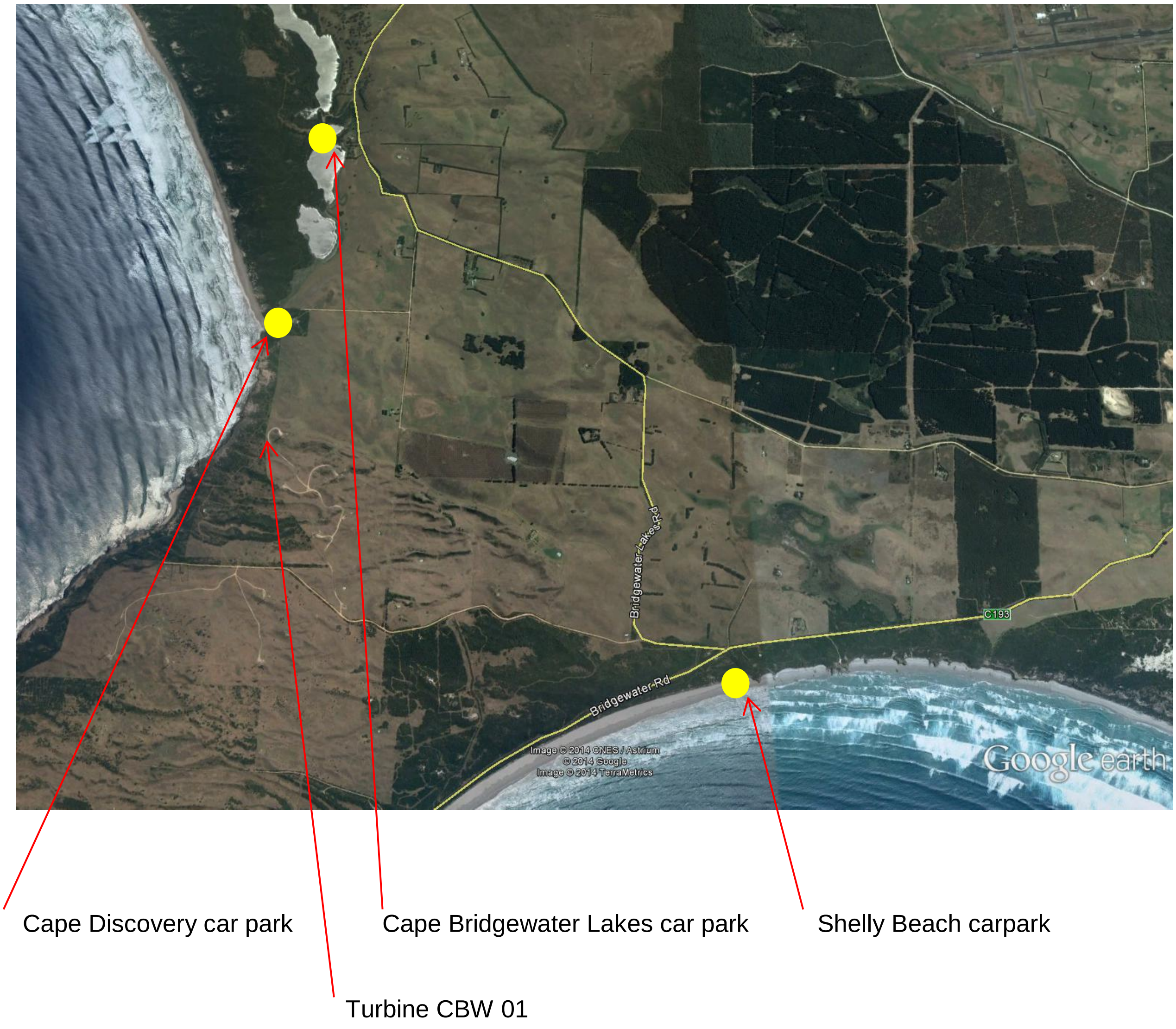

east end of Blowholes Rd, ground plane (Real)
east end of Blowholes Rd, ground plane (Real)
[dB/20u Pa]
90
80
70
60
50
40
30
0
5
10
15
20
25
30
35
40
45
50
[Hz]


Google earth

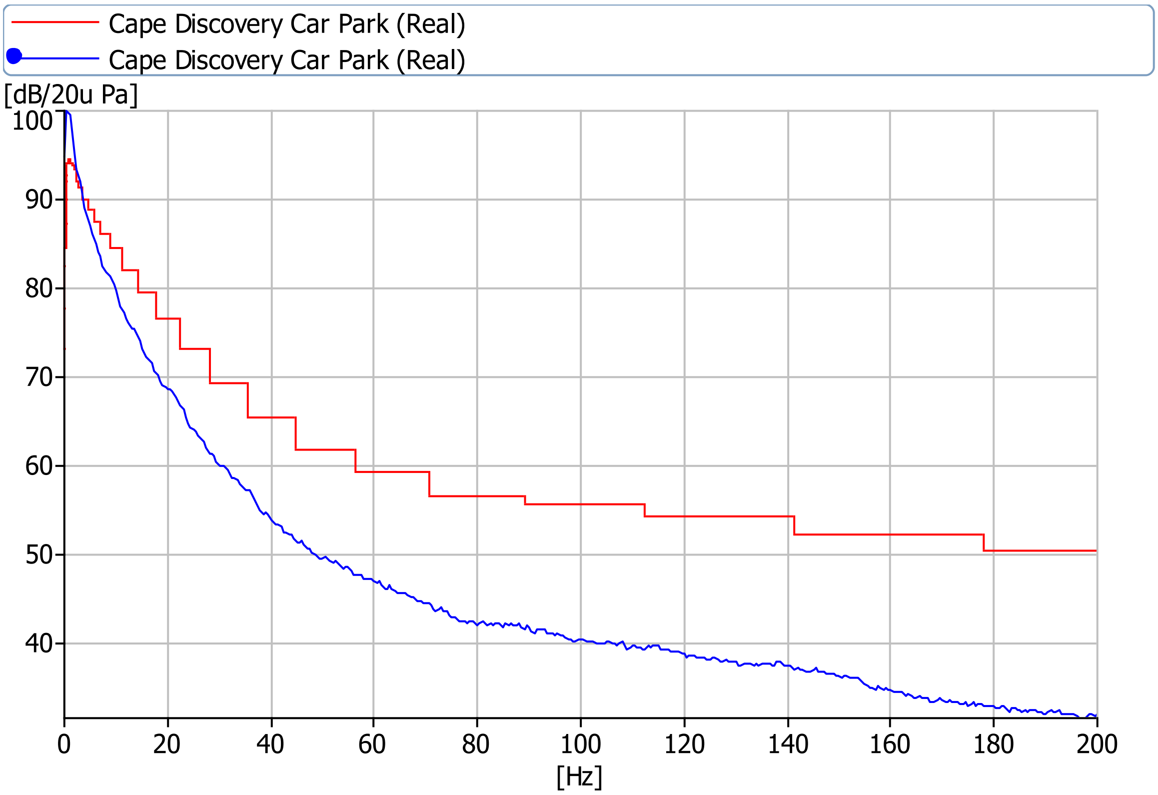

Surf Club (Real)
[dB(A)/20u Pa]
65
62.5
60
57.5
100
200
300
400
500
600
[s] (Relative Time)

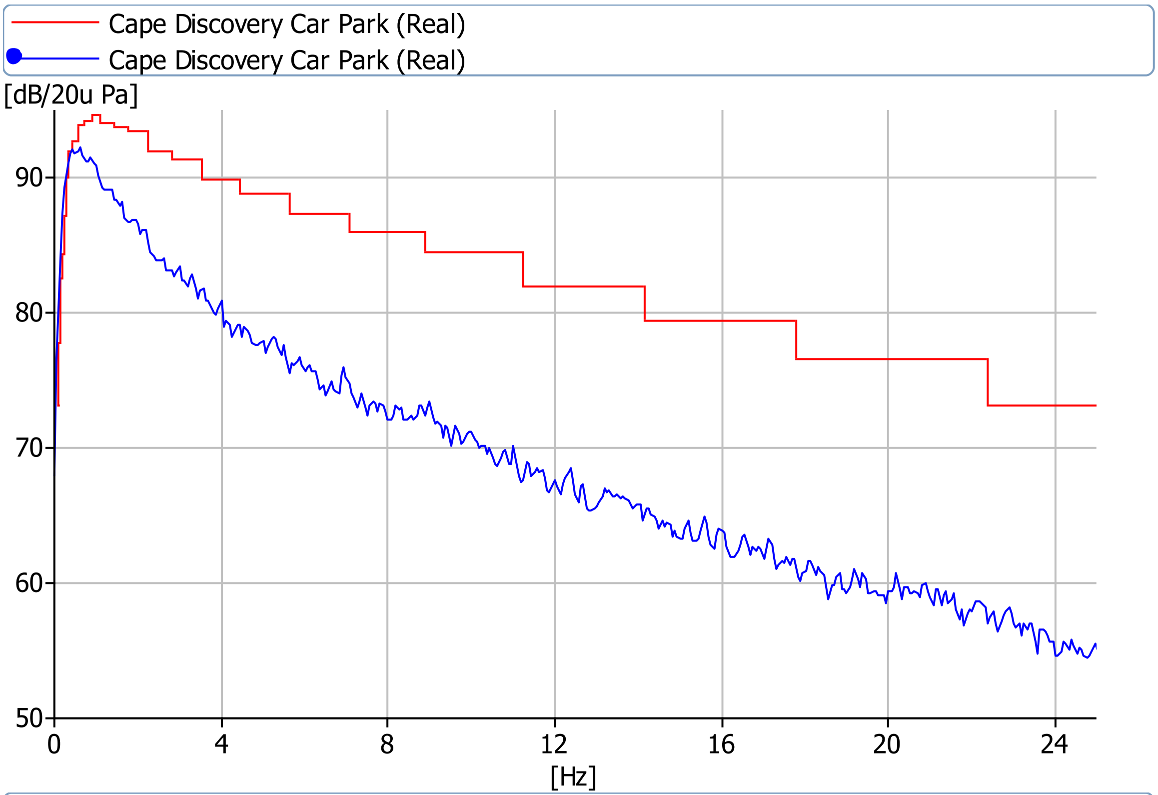

Surf Club (Real)
Surf Club (Real)
[dB/20u Pa]
70
60
50
40
0
20
40
60
80
100
120
140
160
180
200
[Hz]

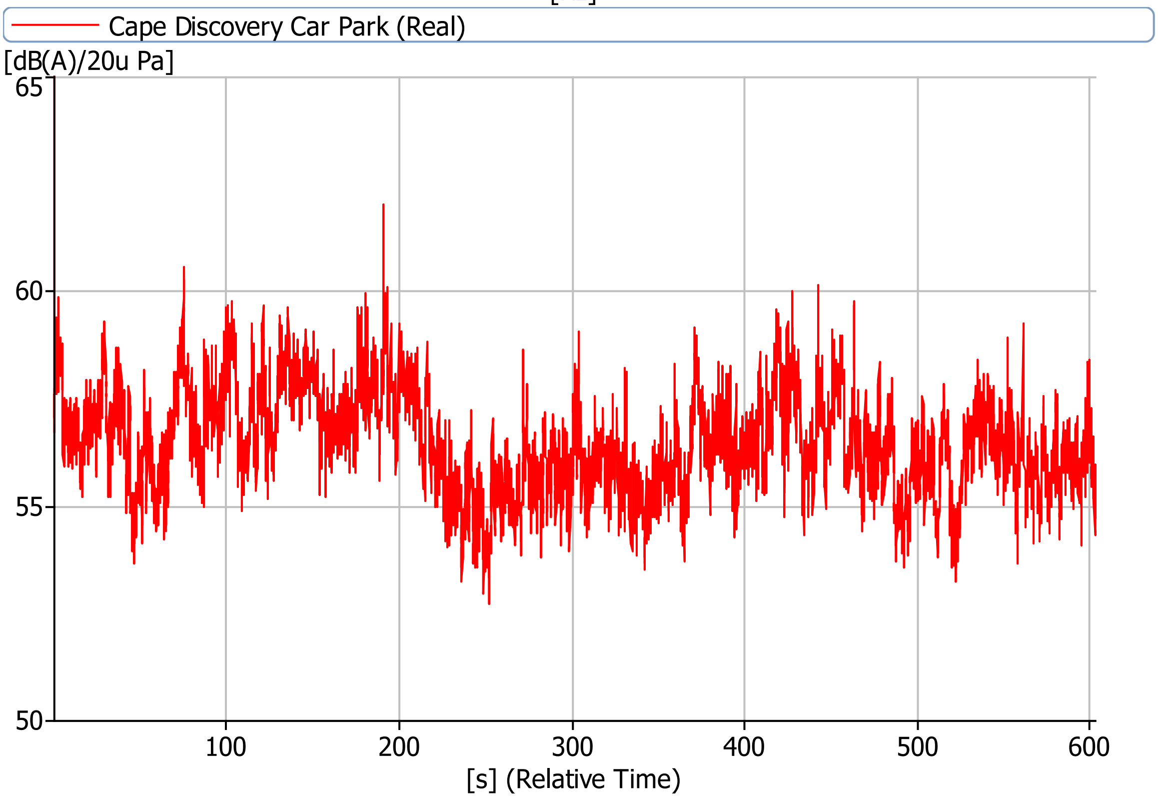

Surf Club (Real)
Surf Club (Real)
[dB/20u Pa]
60
50
40
30
0
4
8
12
16
20
24
[Hz]

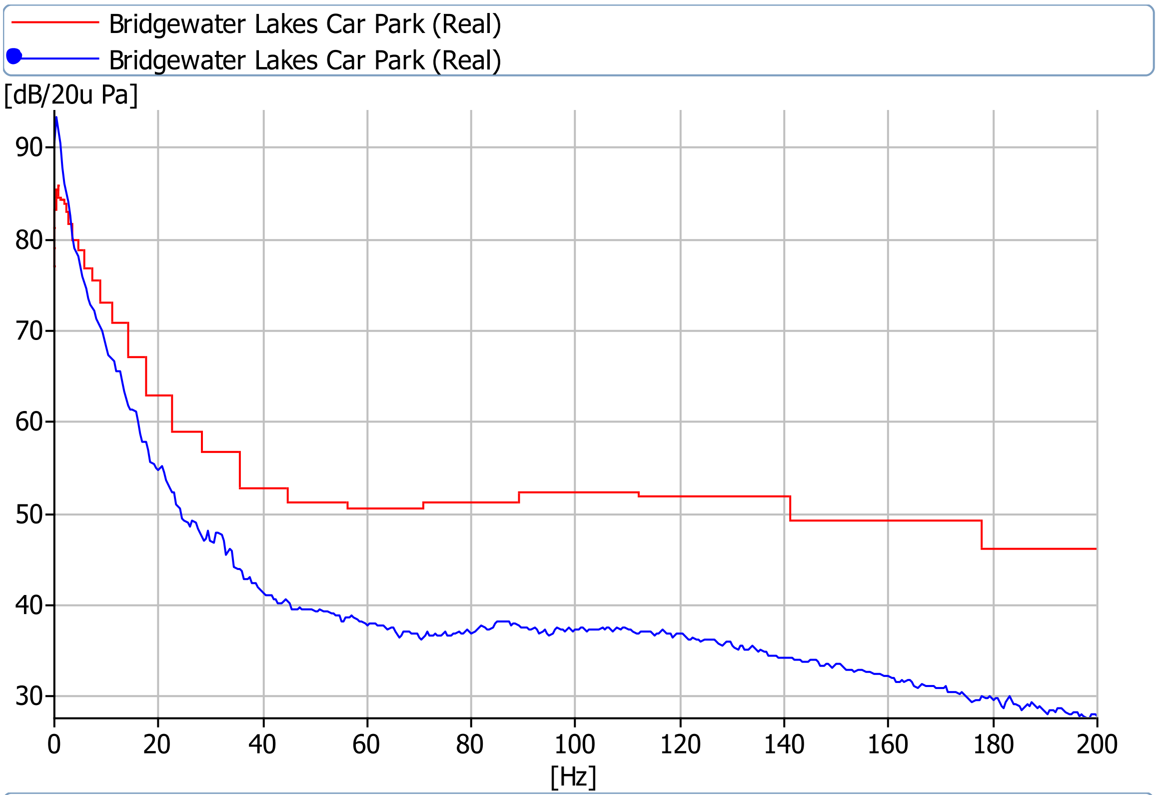

Bridgewater Lakes Rd
Bridgewater Rd
C193
Image © 2014 CNES / Astrium
© 2014 Google
Image © 2014 TerraMetrics
Google earth
Cape Discovery car park
Cape Bridgewater Lakes car park
Shelly Beach carpark
Turbine CBW 01

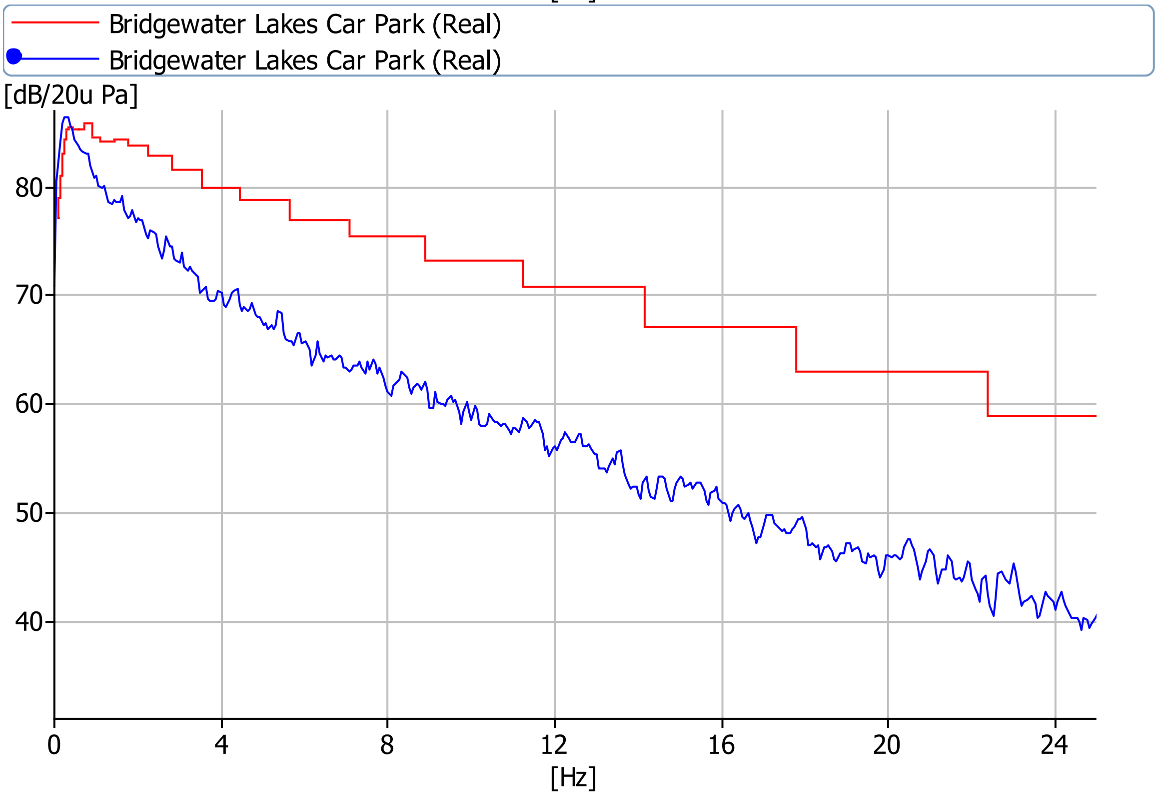
Cape Discovery

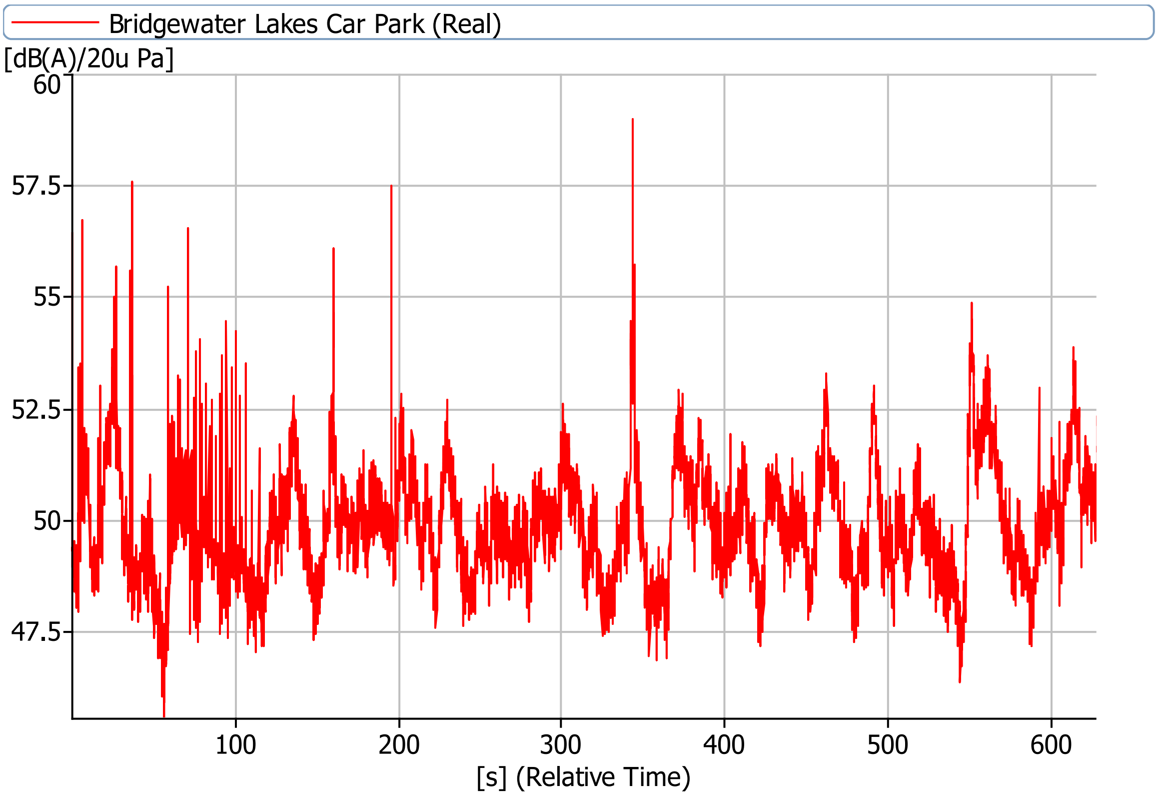



Cape Discovery Car Park (Real)
Cape Discovery Car Park (Real)
[dB/20u Pa]
90
80
70
60
50
0
4
8
12
16
20
24
[Hz]

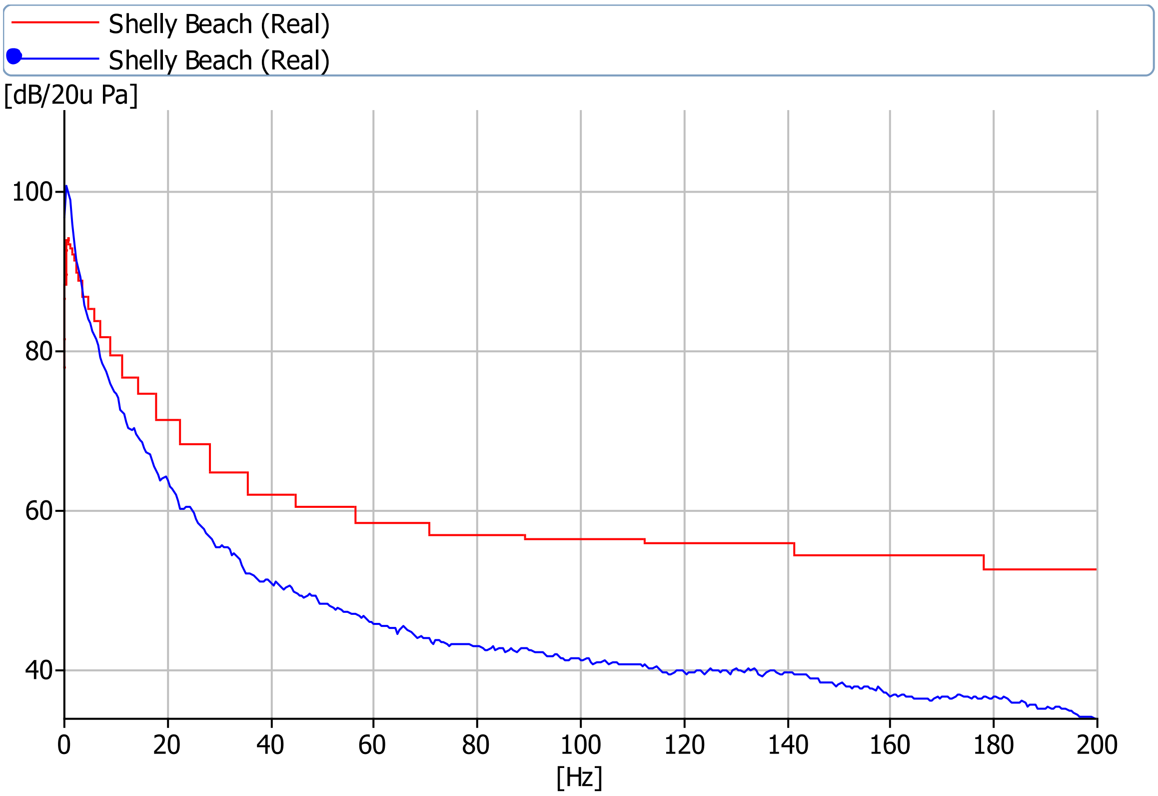

Cape Discovery Car Park (Real)
[dB(A)/20u Pa]
65
60
55
50
100
200
300
400
500
600
[s] (Relative Time)

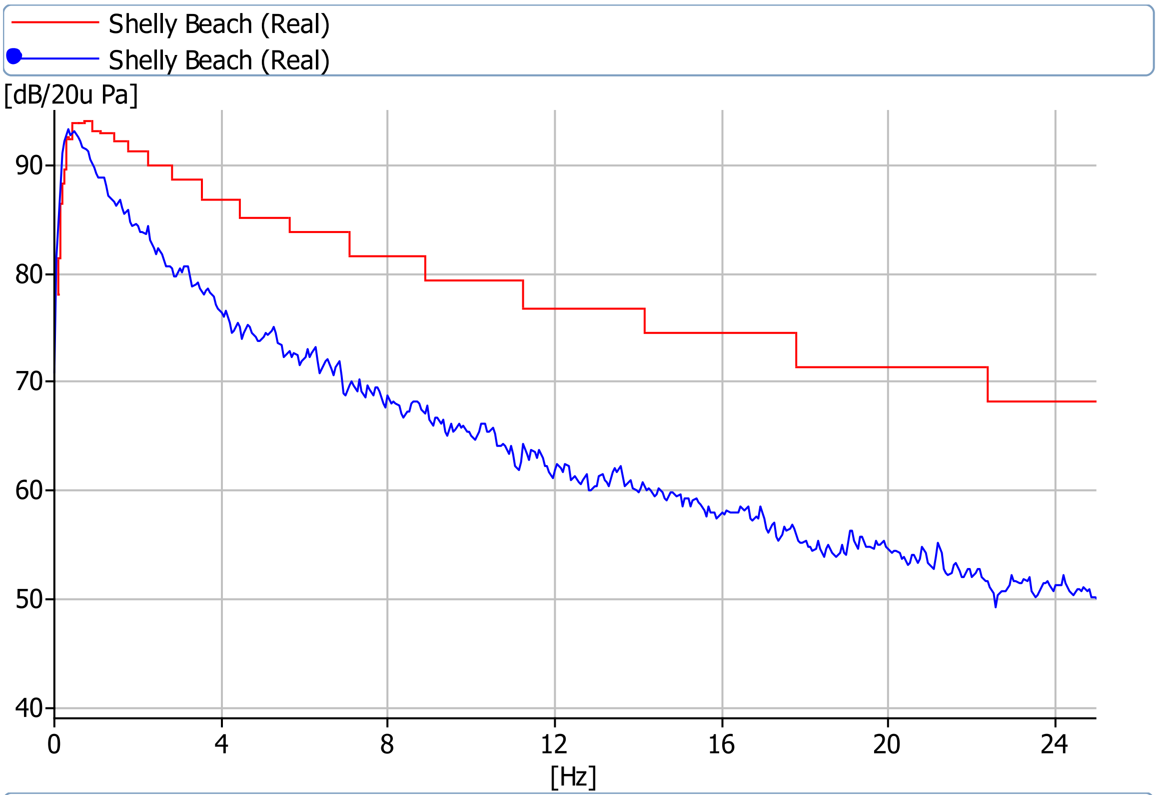

Bridgewater Lakes Car Park (Real)
Bridgewater Lakes Car Park (Real)
[dB/20u Pa]
90
80
70
60
50
40
30
0
20
40
60
80
100
120
140
160
180
200
[Hz]

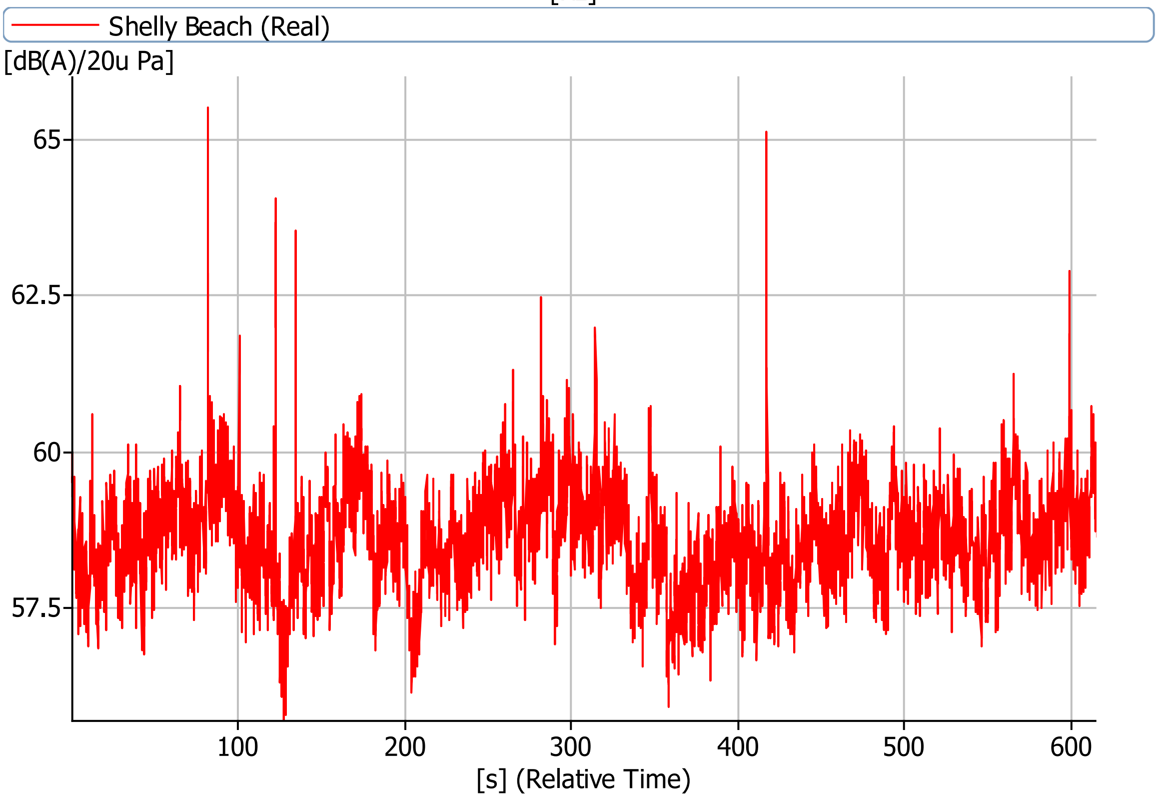

Bridgewater Lakes Car Park (Real)
Bridgewater Lakes Car Park (Real)
[dB/20u Pa]
80
70
60
50
40
0
4
8
12
16
20
24
[Hz]

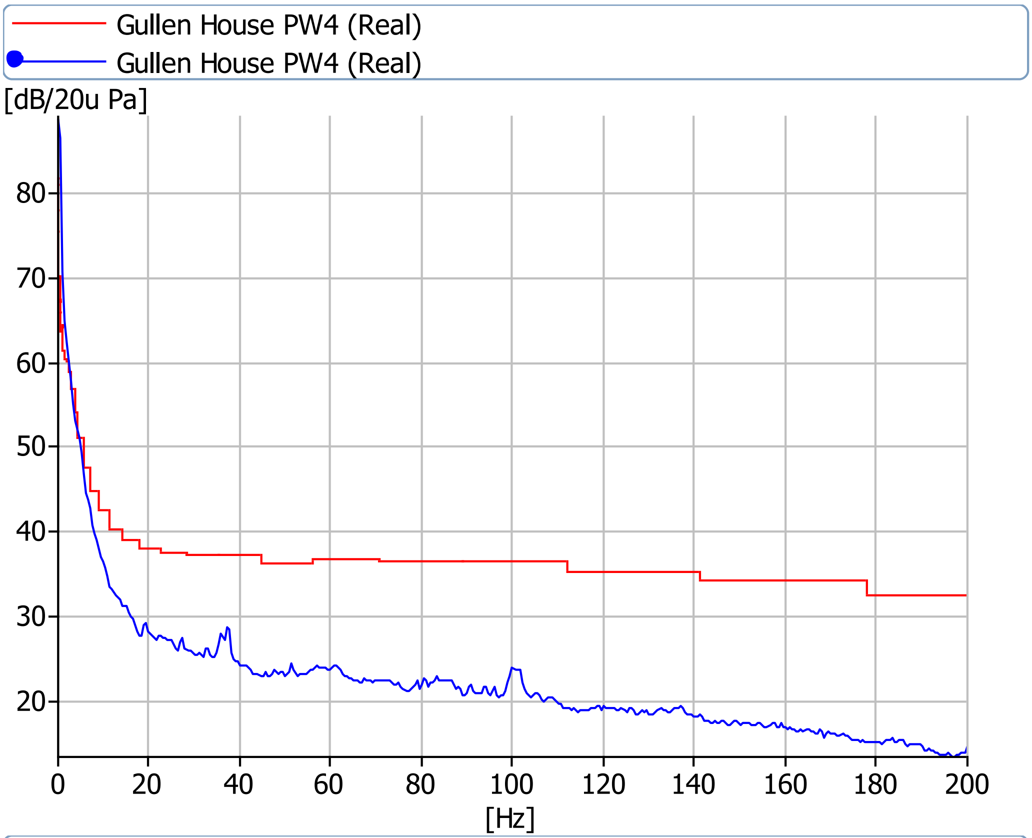

Bridgewater Lakes Car Park (Real)
[dB(A)/20u Pa]
60
57.5
55
52.5
50
47.5
100
200
300
400
500
600
[s] (Relative Time)

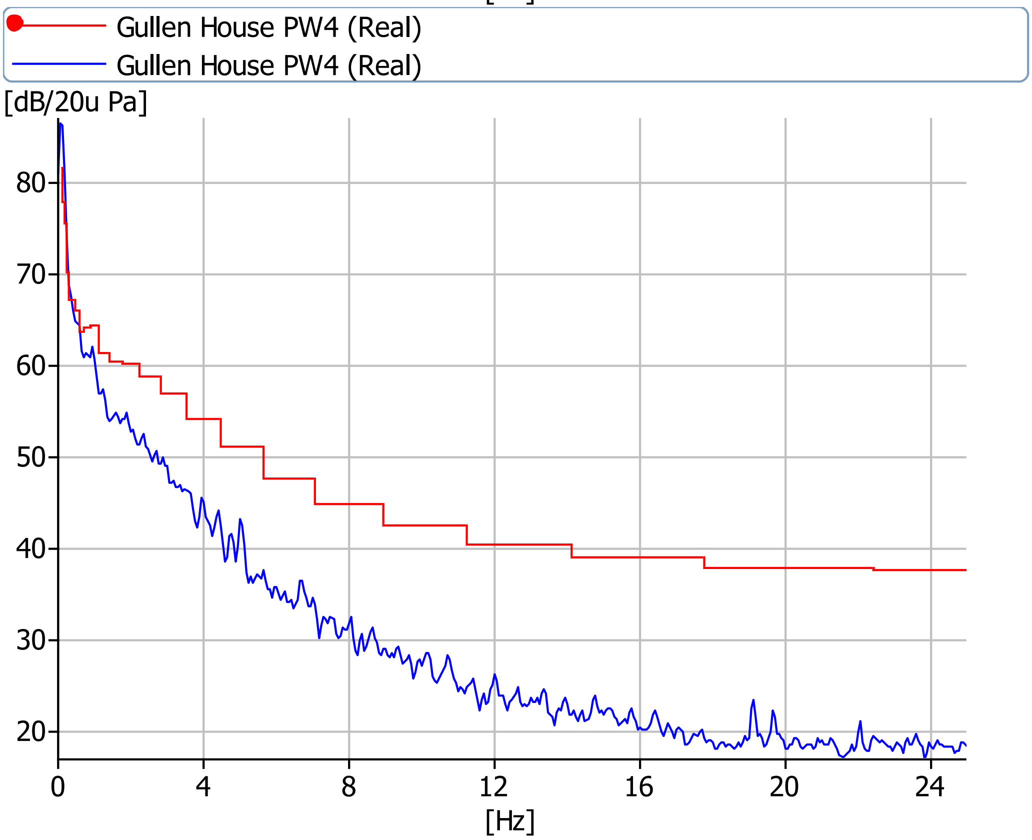
Shelly Beach

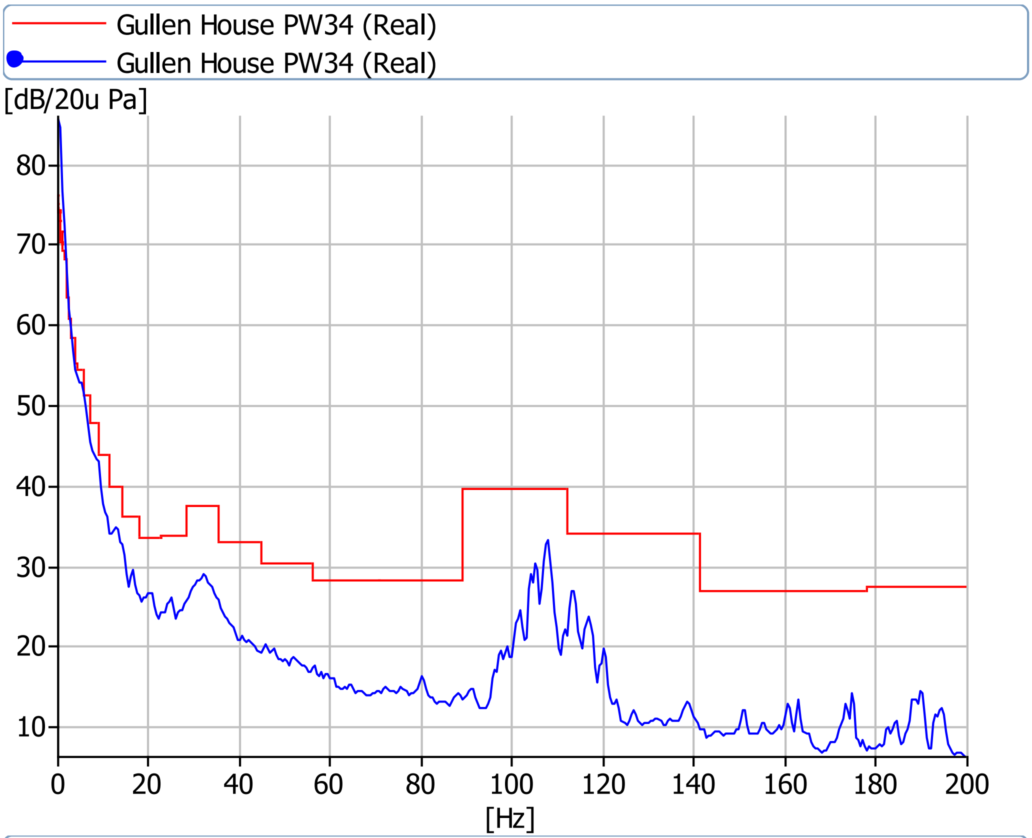


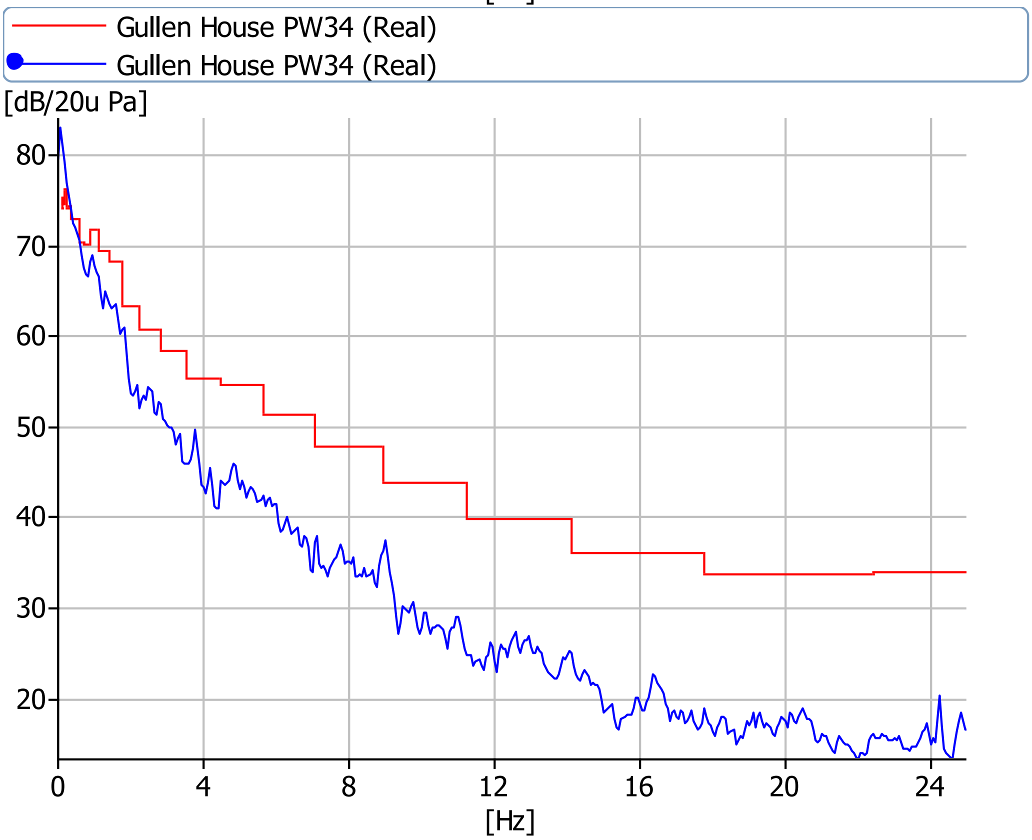

Shelly Beach (Real)
Shelly Beach (Real)
[dB/20u Pa]
90
80
70
60
50
40
0
4
8
12
16
20
24
[Hz]

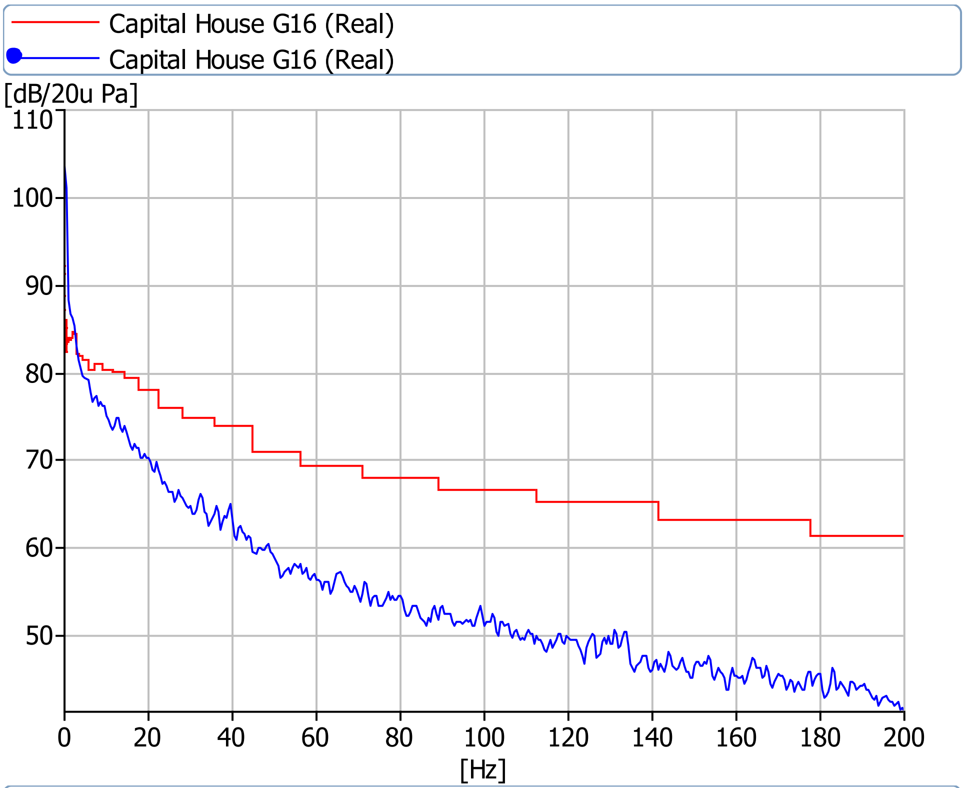

Shelly Beach (Real)
[dB(A)/20u Pa]
65
62.5
60
57.5
100
200
300
400
500
600
[s] (Relative Time)

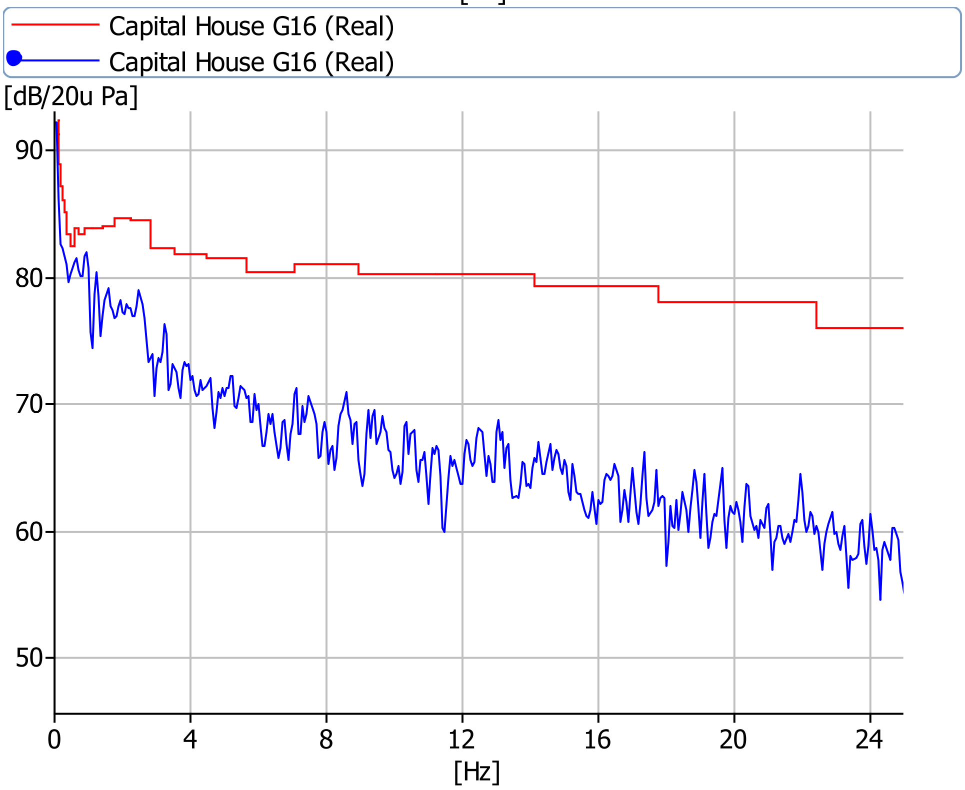

Gullen House PW4 (Real)
Gullen House PW4 (Real)
[dB/20u Pa]
80
70
60
50
40
30
20
0
20
40
60
80
100
120
140
160
180
200
[Hz]

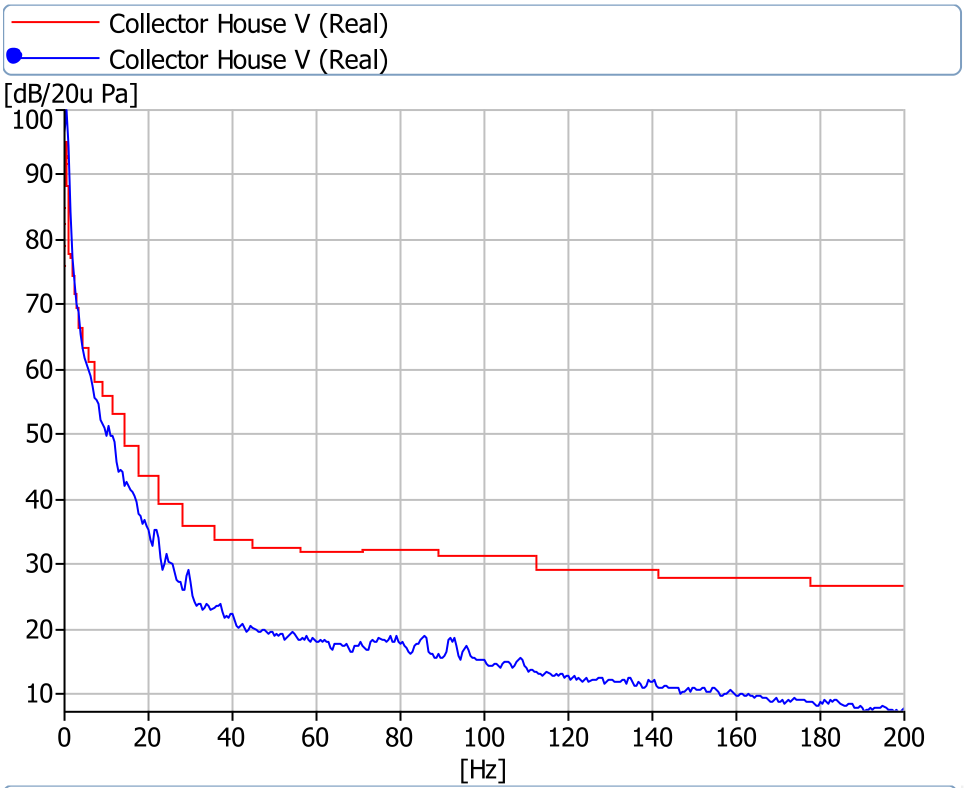

Gullen House PW4 (Real)
Gullen House PW4 (Real)
[dB/20u Pa]
80
70
60
50
40
30
20
0
4
8
12
16
20
24
[Hz]

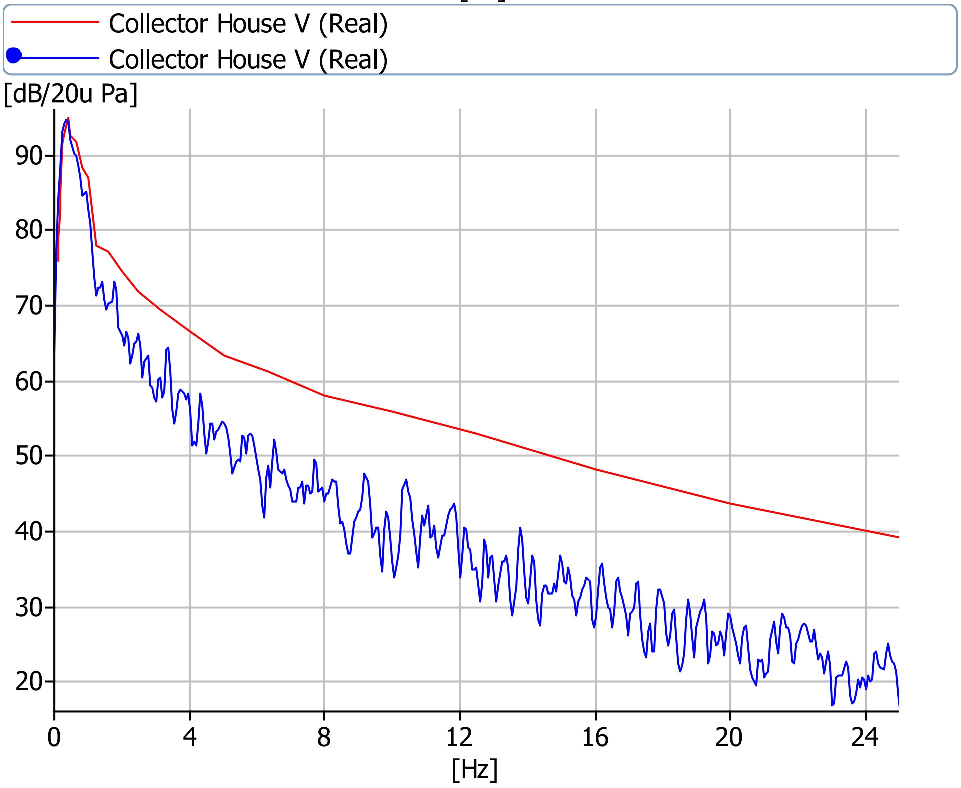

Gullen House PW34 (Real)
Gullen House PW34 (Real)
[dB/20u Pa]
80
70
60
50
40
30
20
10
0
20
40
60
80
100
120
140
160
180
200
[Hz]

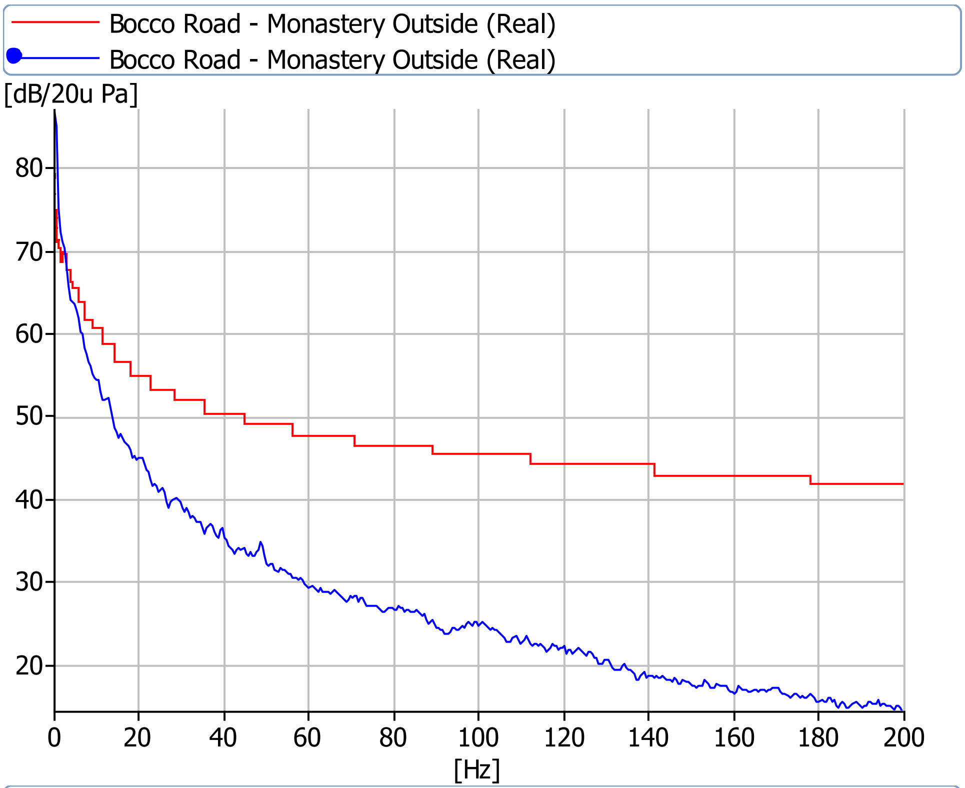

Gullen House PW34 (Real)
Gullen House PW34 (Real)
[dB/20u Pa]
80
70
60
50
40
30
20
0
4
8
12
16
20
24
[Hz]

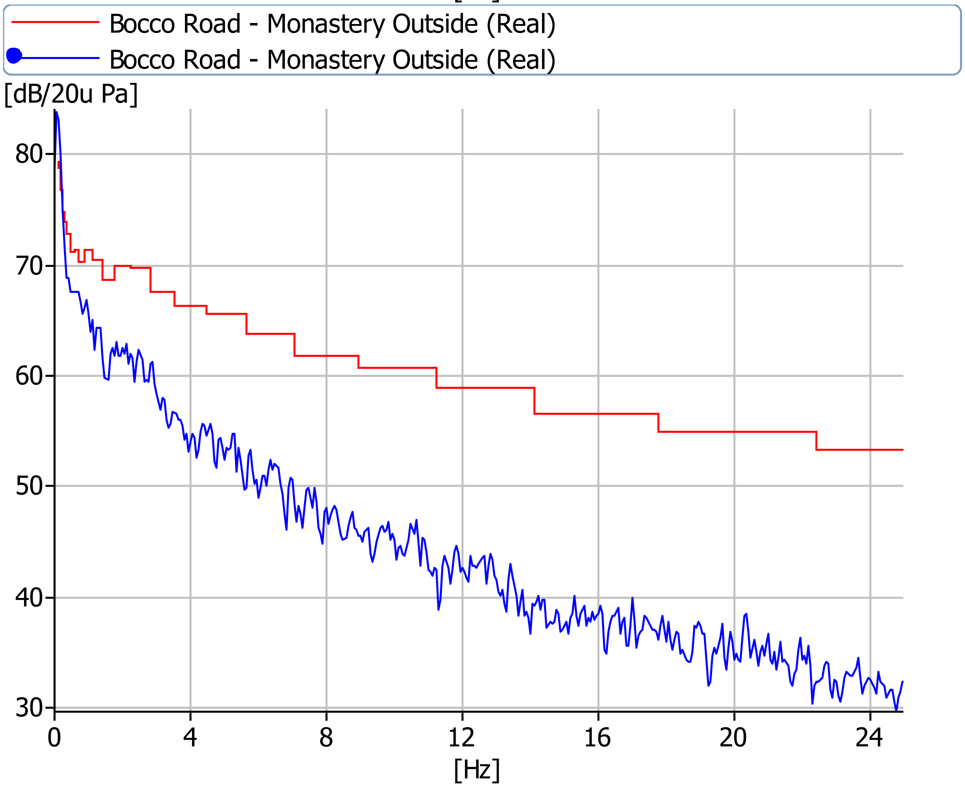

Capital House G16 (Real)
Capital House G16 (Real)
[dB/20u Pa]
110
100
90
80
70
60
50
0
20
40
60
80
100
120
140
160
180
200
[Hz]

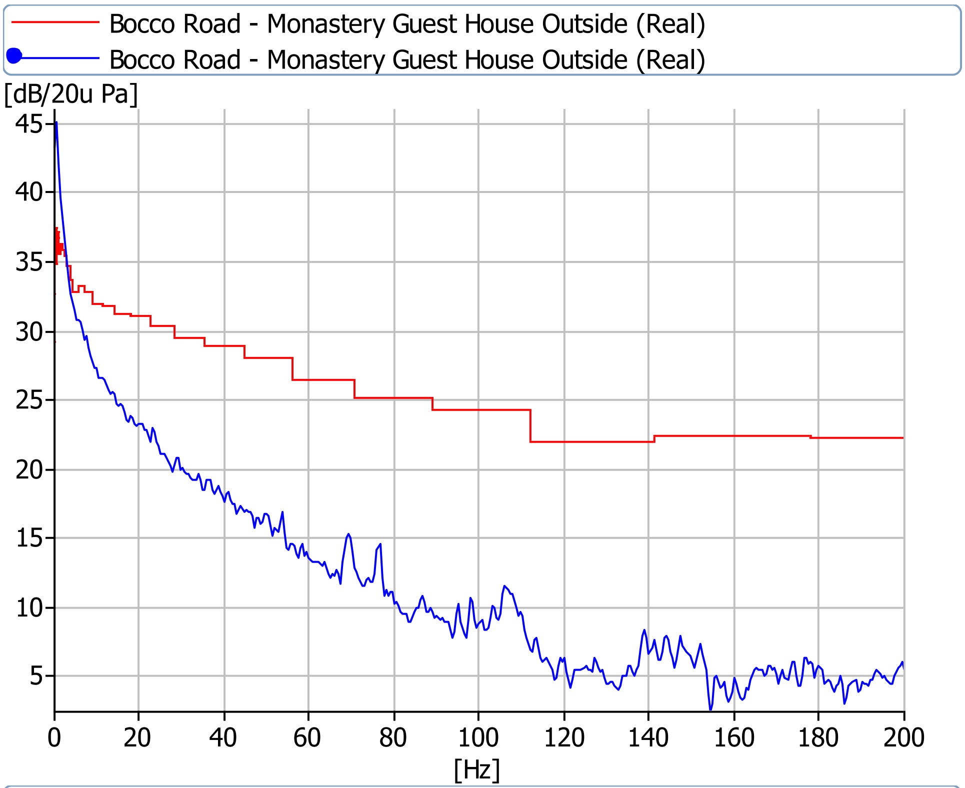

Capital House G16 (Real)
Capital House G16 (Real)
[dB/20u Pa]
90
80
70
60
50
0
4
8
12
16
20
24
[Hz]

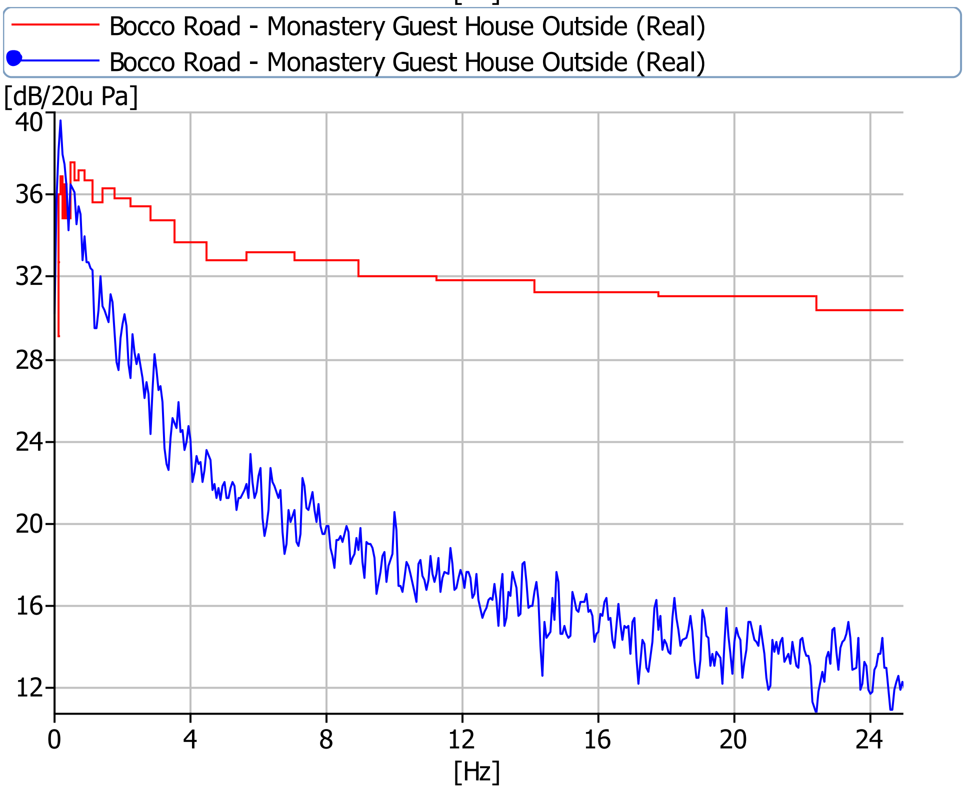

Collector House V (Real)
Collector House V (Real)
[dB/20u Pa]
100
90
80
70
60
50
40
30
20
10
0
20
40
60
80
100
120
140
160
180
200
[Hz]

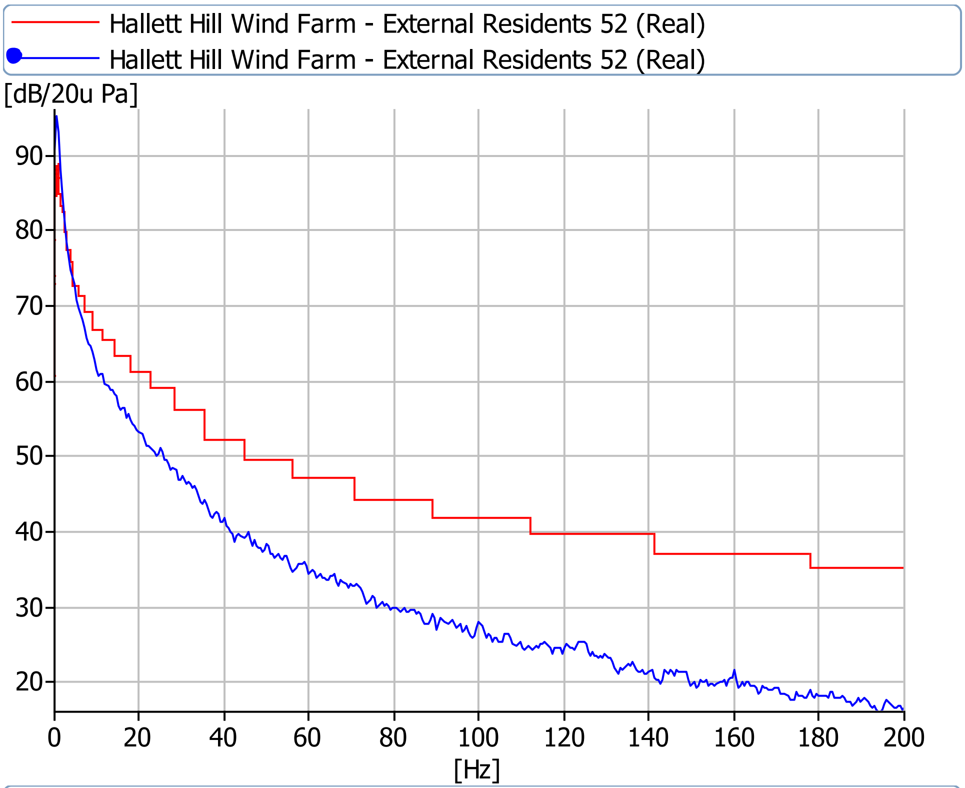

Collector House V (Real)
Collector House V (Real)
[dB/20u Pa]
90
80
70
60
50
40
30
20
0
4
8
12
16
20
24
[Hz]

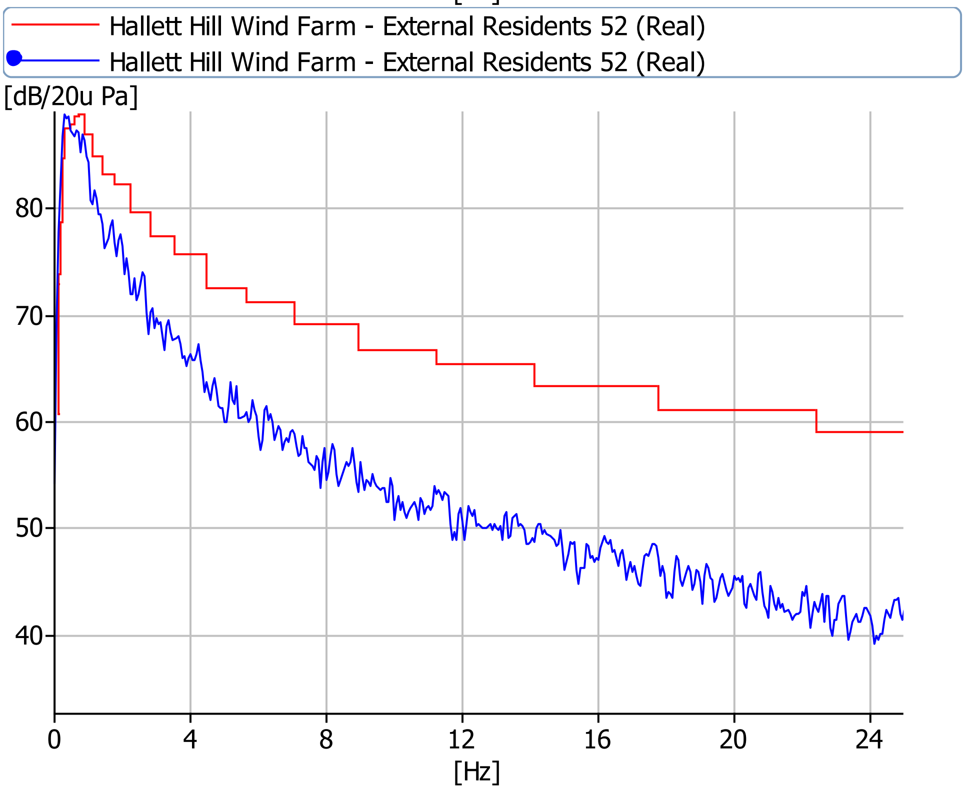

Bocco Road - Monastery Outside (Real)
Bocco Road - Monastery Outside (Real)
[dB/20u Pa]
80
70
60
50
40
30
20
0
20
40
60
80
100
120
140
160
180
200
[Hz]

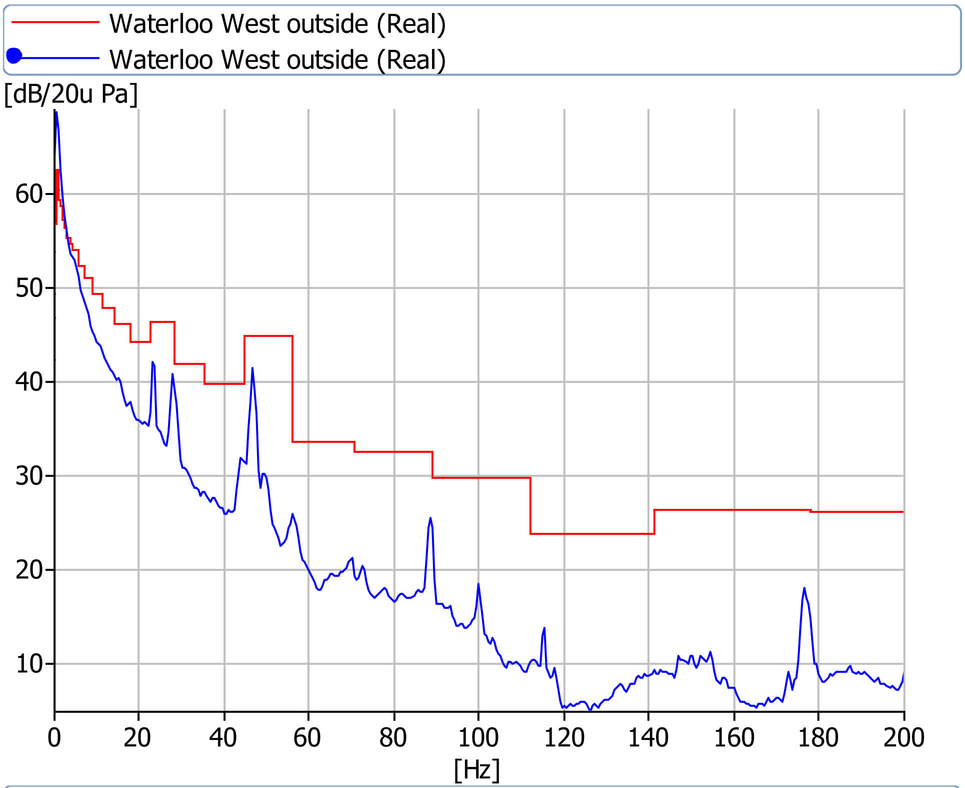

Bocco Road - Monastery Outside (Real)
Bocco Road - Monastery Outside (Real)
[dB/20u Pa]
80
70
60
50
40
30
0
4
8
12
16
20
24
[Hz]

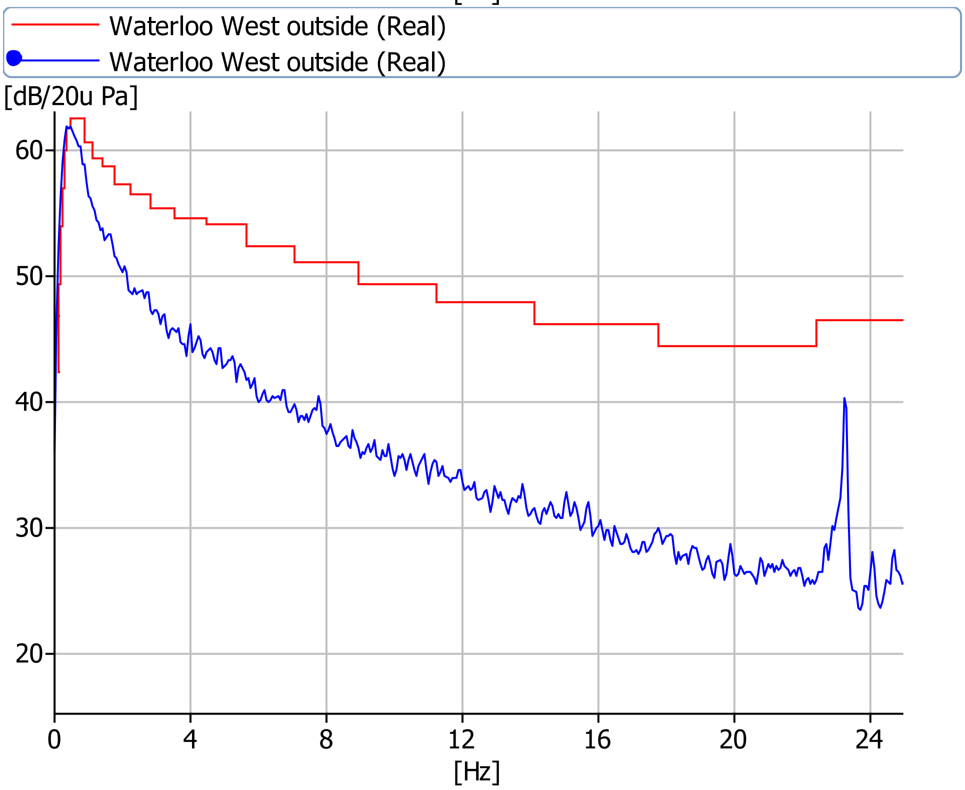

Bocco Road - Monastery Guest House Outside (Real)
Bocco Road - Monastery Guest House Outside (Real)
[dB/20u Pa]
45
40
35
30
25
20
15
10
5
0
20
40
60
80
100
120
140
160
180
200
[Hz]

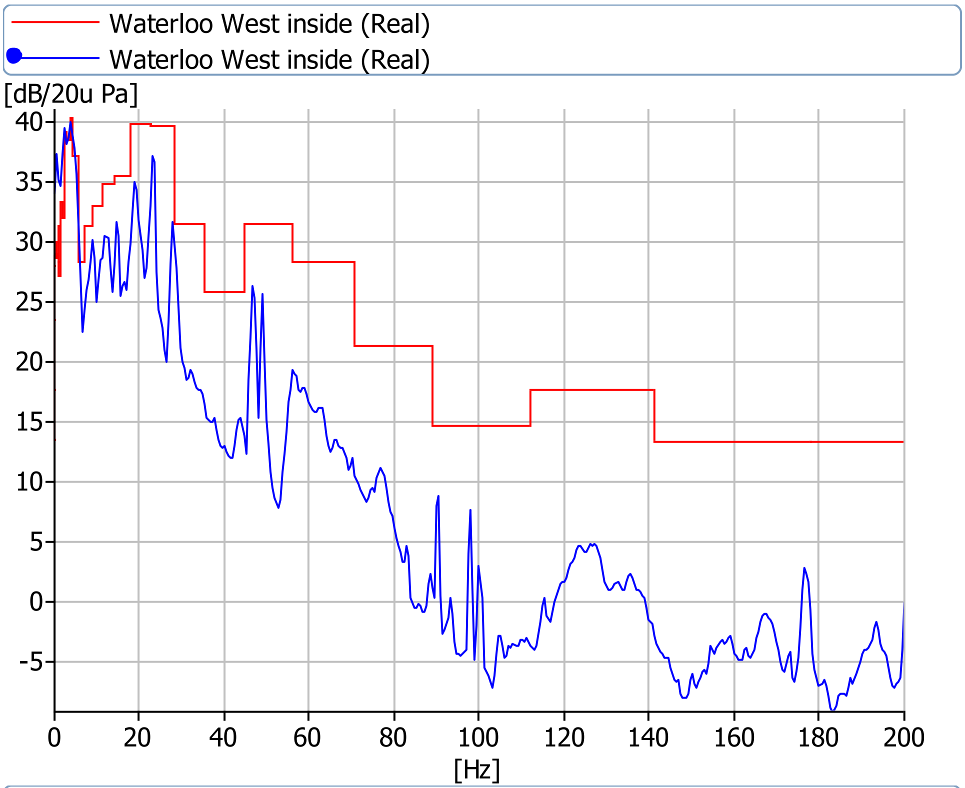

Bocco Road - Monastery Guest House Outside (Real)
Bocco Road - Monastery Guest House Outside (Real)
[dB/20u Pa]
40
36
32
28
24
20
16
12
0
4
8
12
16
20
24
[Hz]

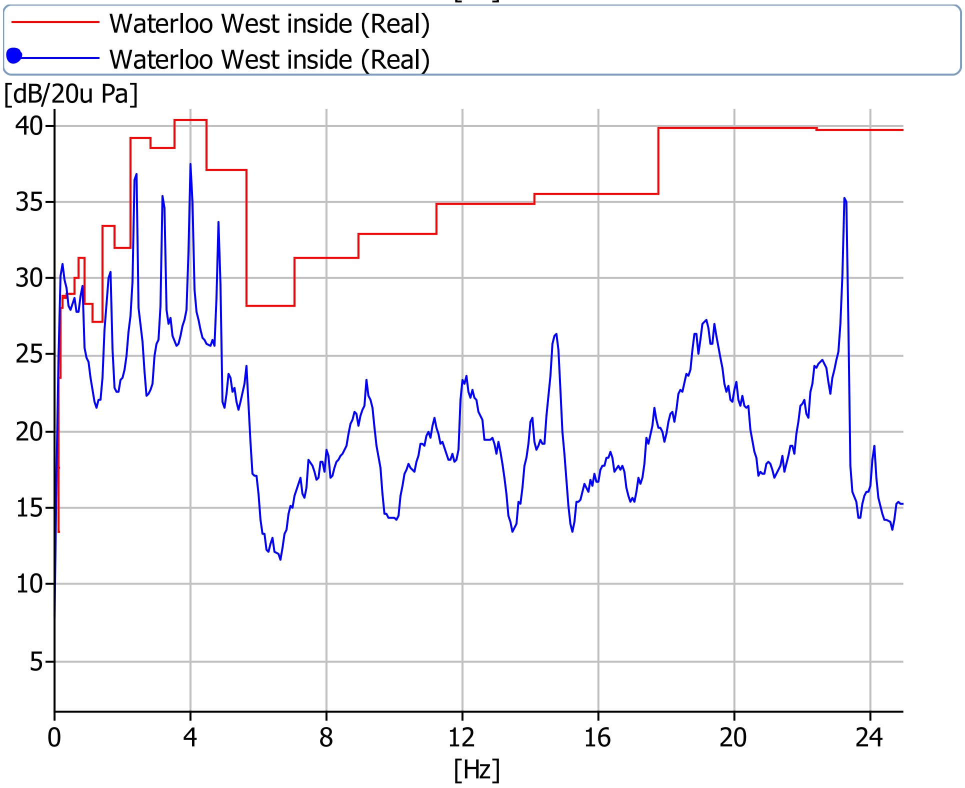

Hallett Hill Wind Farm - External Residents 52 (Real)
Hallett Hill Wind Farm - External Residents 52 (Real)
[dB/20u Pa]
90
80
70
60
50
40
30
20
0
20
40
60
80
100
120
140
160
180
200
[Hz]

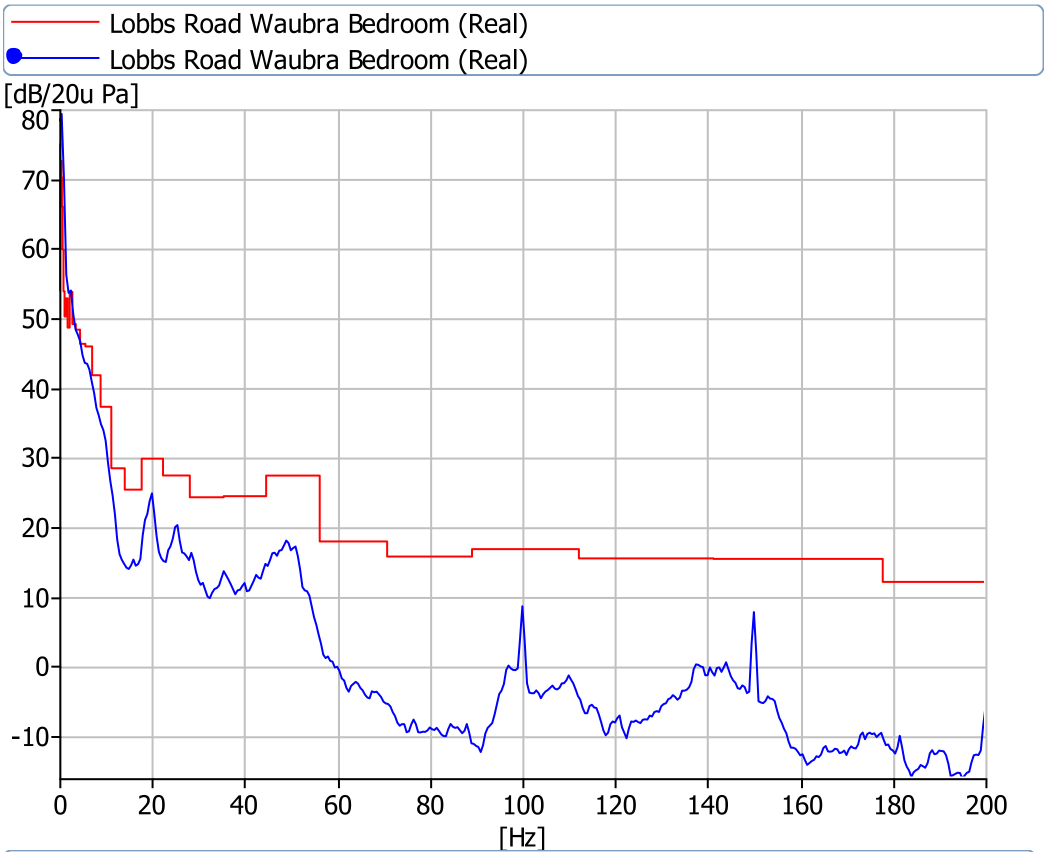

Hallett Hill Wind Farm - External Residents 52 (Real)
Hallett Hill Wind Farm - External Residents 52 (Real)
[dB/20u Pa]
80
70
60
50
40
0
4
8
12
16
20
24
[Hz]

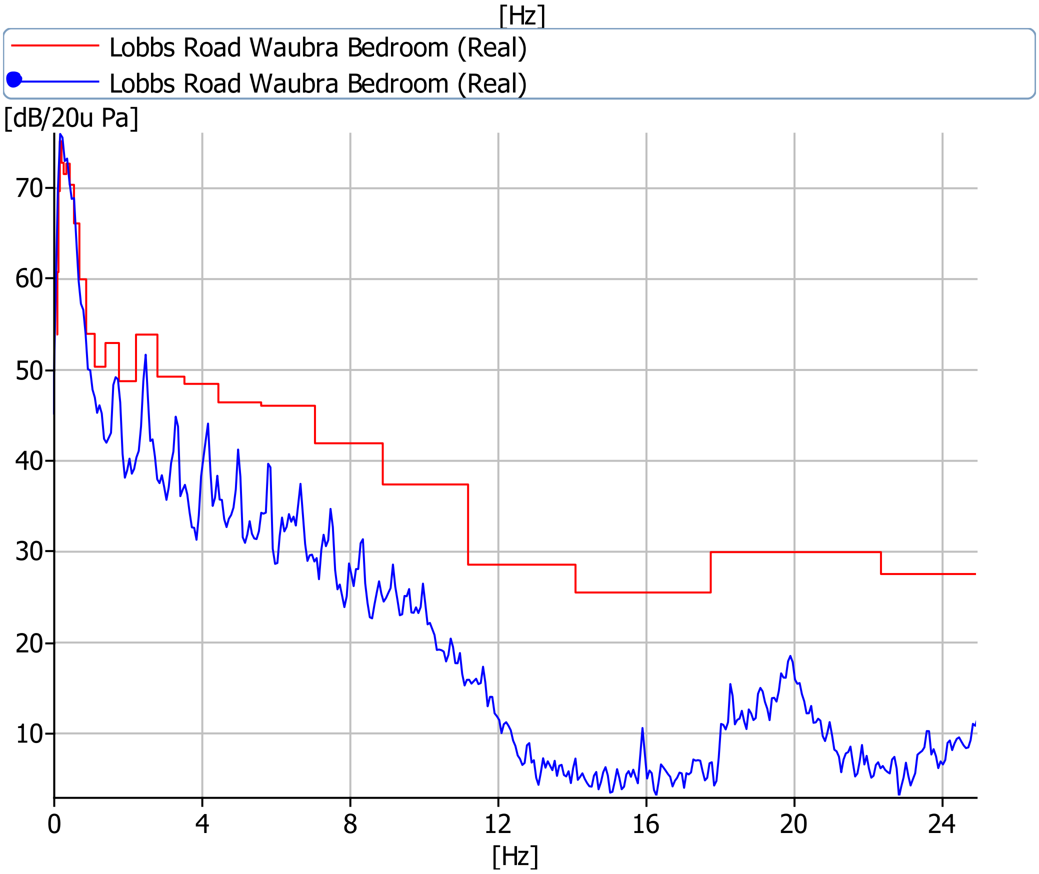

Waterloo West outside (Real)
Waterloo West outside (Real)
[dB/20u Pa]
60
50
40
30
20
10
0
20
40
60
80
100
120
140
160
180
200
[Hz]

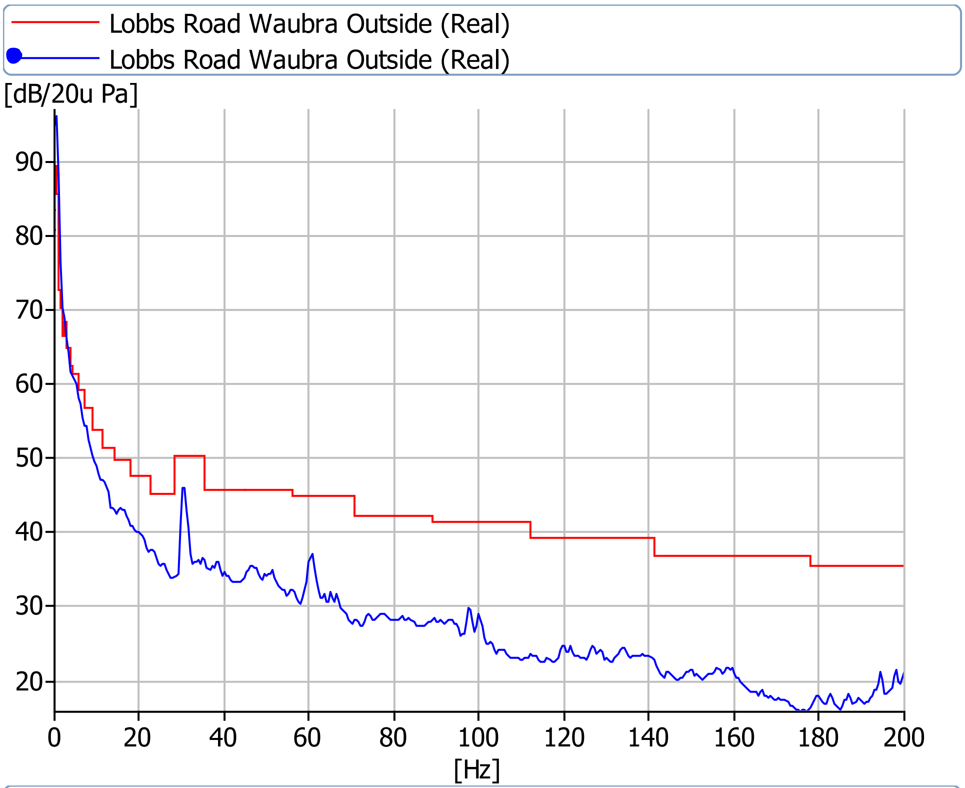

Waterloo West outside (Real)
Waterloo West outside (Real)
[dB/20u Pa]
60
50
40
30
20
0
4
8
12
16
20
24
[Hz]

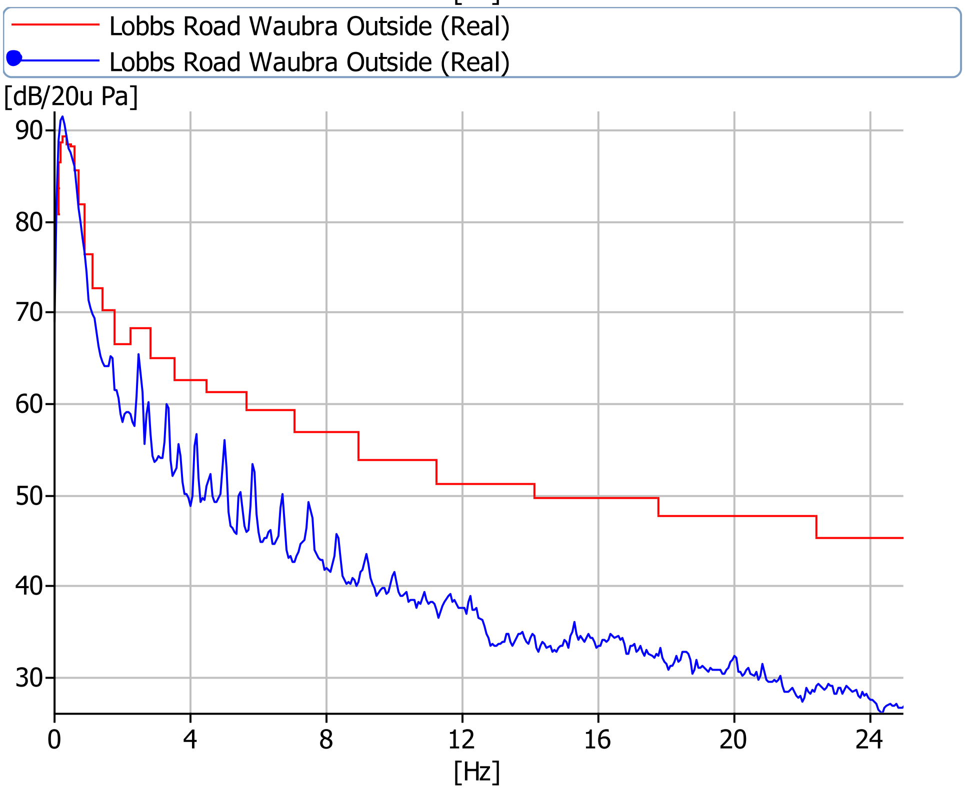

Waterloo West inside (Real)
Waterloo West inside (Real)
[dB/20u Pa]
40
35
30
25
20
15
10
5
0
-5
0
20
40
60
80
100
120
140
160
180
200
[Hz]

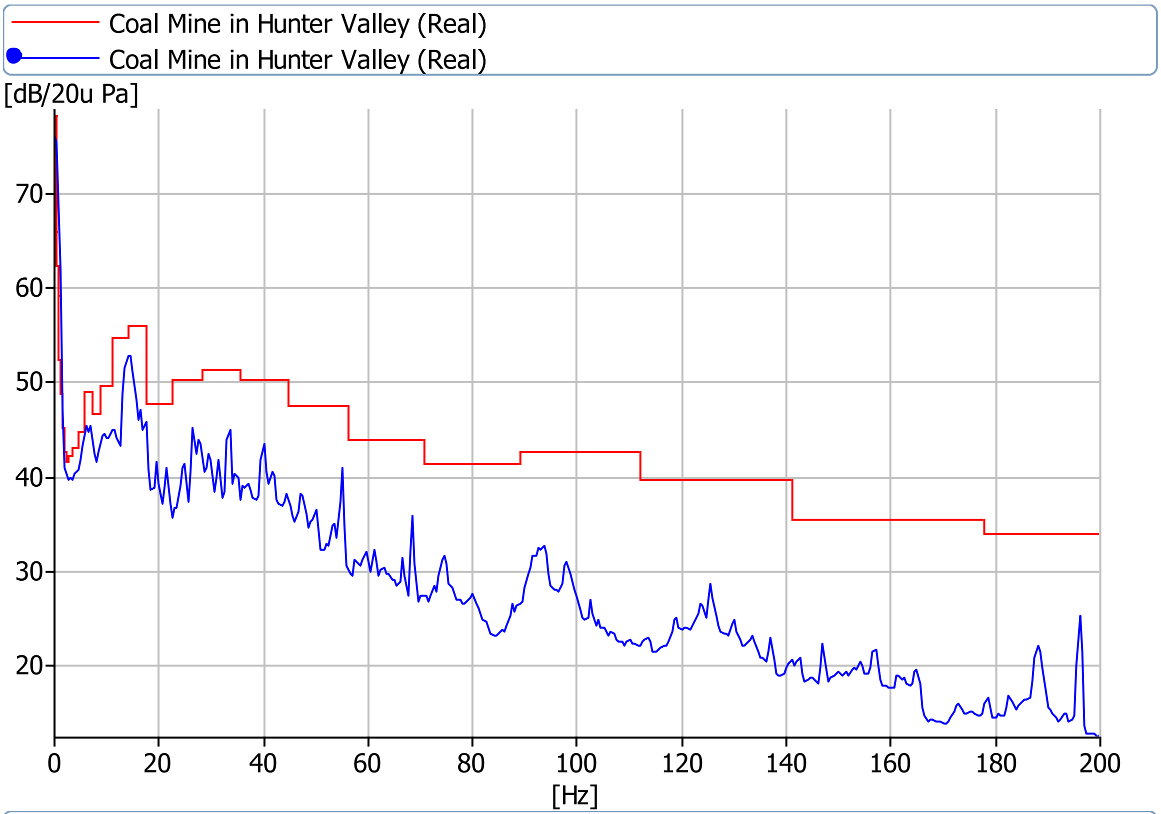

Waterloo West inside (Real)
Waterloo West inside (Real)
[dB/20u Pa]
40
35
30
25
20
15
10
5
0
4
8
12
16
20
24
[Hz]

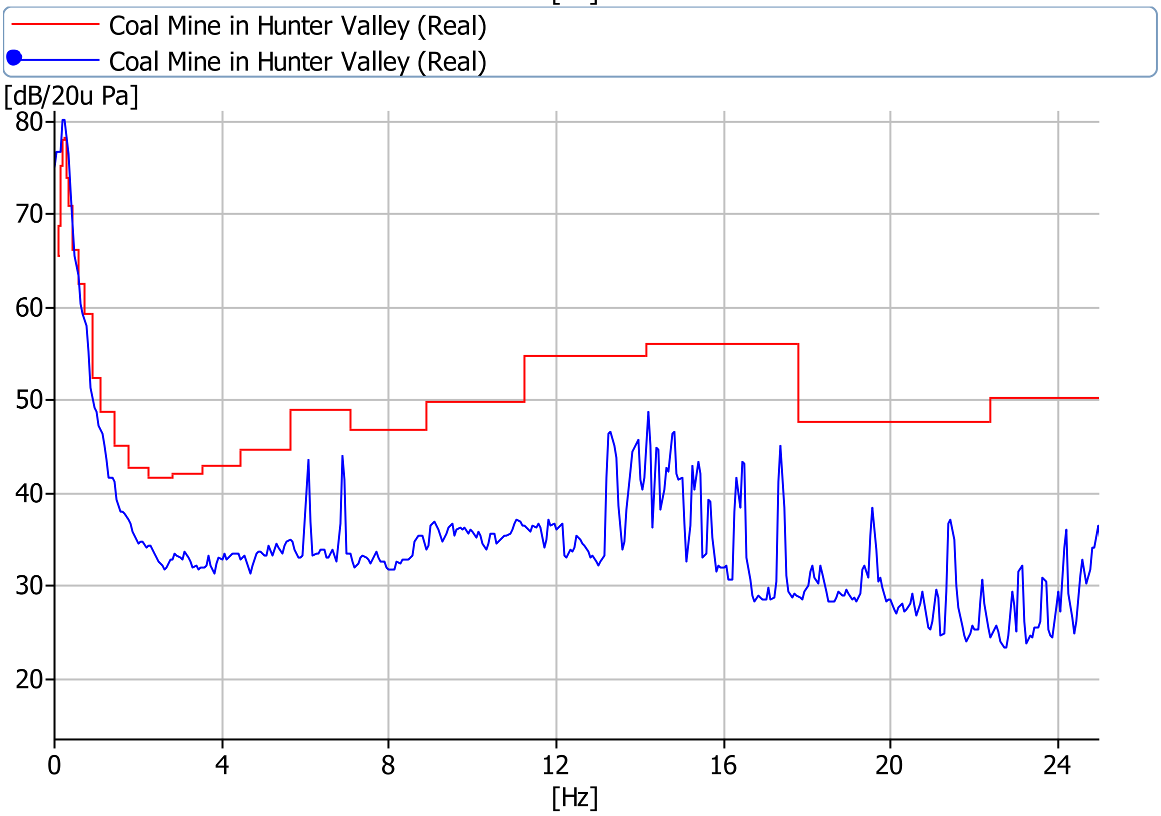

Lobbs Road Waubra Bedroom (Real)
Lobbs Road Waubra Bedroom (Real)
[dB/20u Pa]
80
70
60
50
40
30
20
10
0
-10
0
20
40
60
80
100
120
140
160
180
200
[Hz]


Lobbs Road Waubra Bedroom (Real)
Lobbs Road Waubra Bedroom (Real)
[dB/20u Pa]
70
60
50
40
30
20
10
0
4
8
12
16
20
24
[Hz]


Lobbs Road Waubra Outside (Real)
Lobbs Road Waubra Outside (Real)
[dB/20u Pa]
90
80
70
60
50
40
30
20
0
20
40
60
80
100
120
140
160
180
200
[Hz]


Lobbs Road Waubra Outside (Real)
Lobbs Road Waubra Outside (Real)
[dB/20u Pa]
90
80
70
60
50
40
30
0
4
8
12
16
20
24
[Hz]

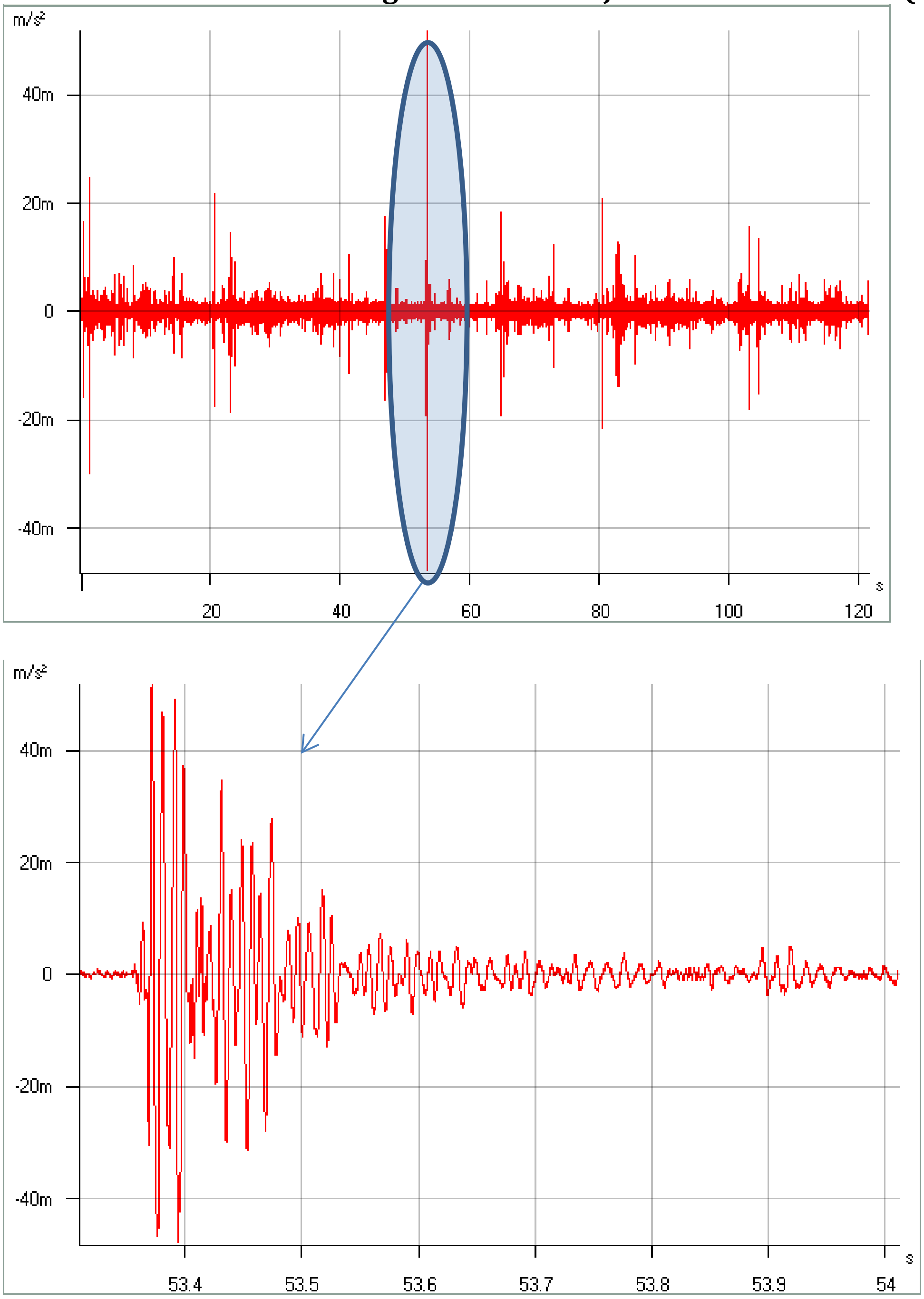

Coal Mine in Hunter Valley (Real)
Coal Mine in Hunter Valley (Real)
[dB/20u Pa]
70
60
50
40
30
20
0
20
40
60
80
100
120
140
160
180
200
[Hz]


Coal Mine in Hunter Valley (Real)
Coal Mine in Hunter Valley (Real)
[dB/20u Pa]
80
70
60
50
40
30
20
0
4
8
12
16
20
24
[Hz]

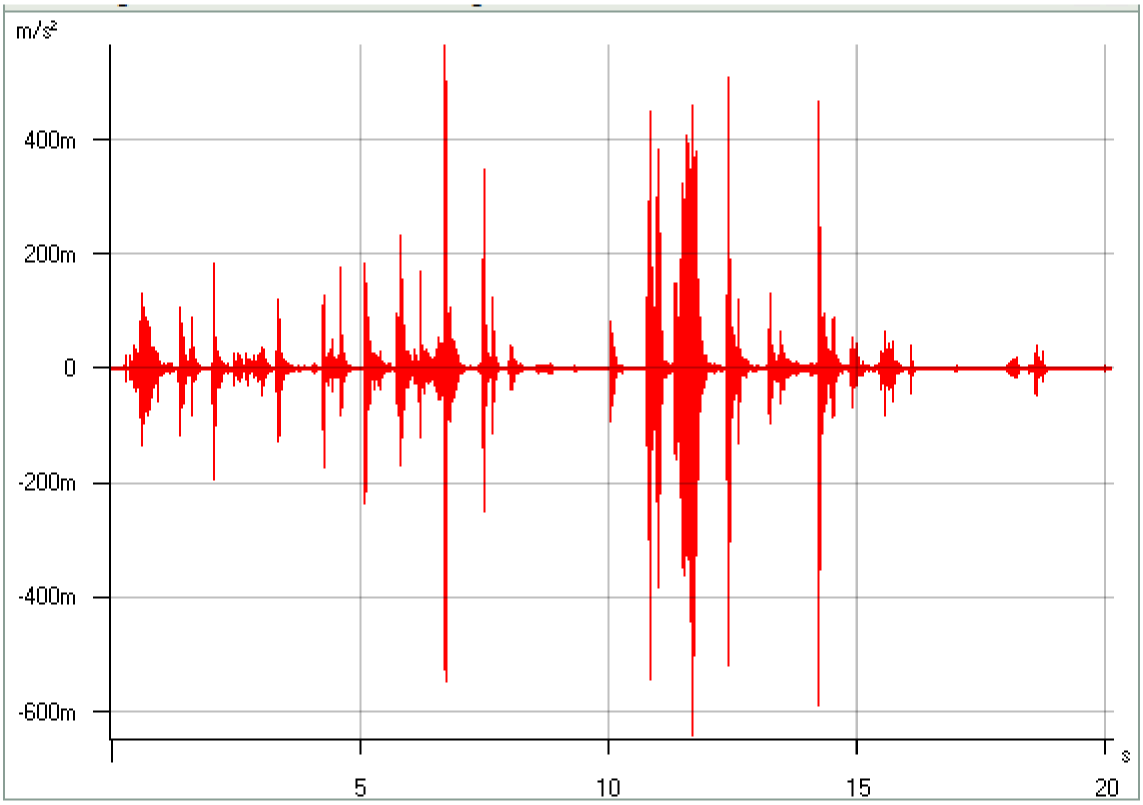
APPENDIX U: Resident's Hot Spots

House 87

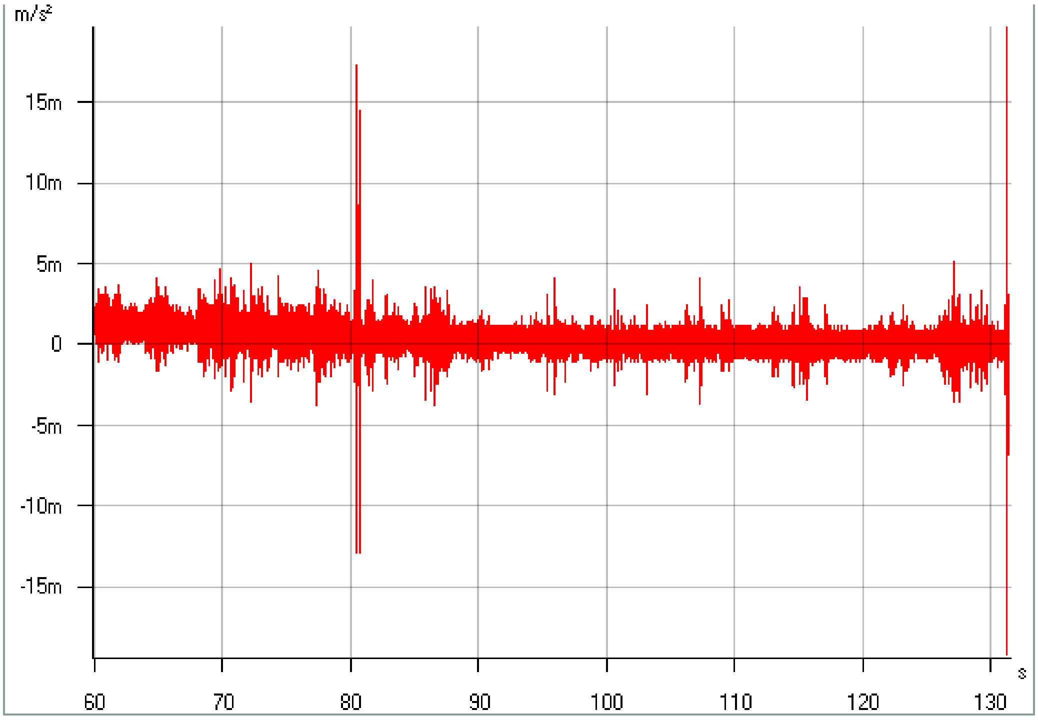
Ambient Vibration on Living Room floor adjacent Bedroom Wall (vertical)

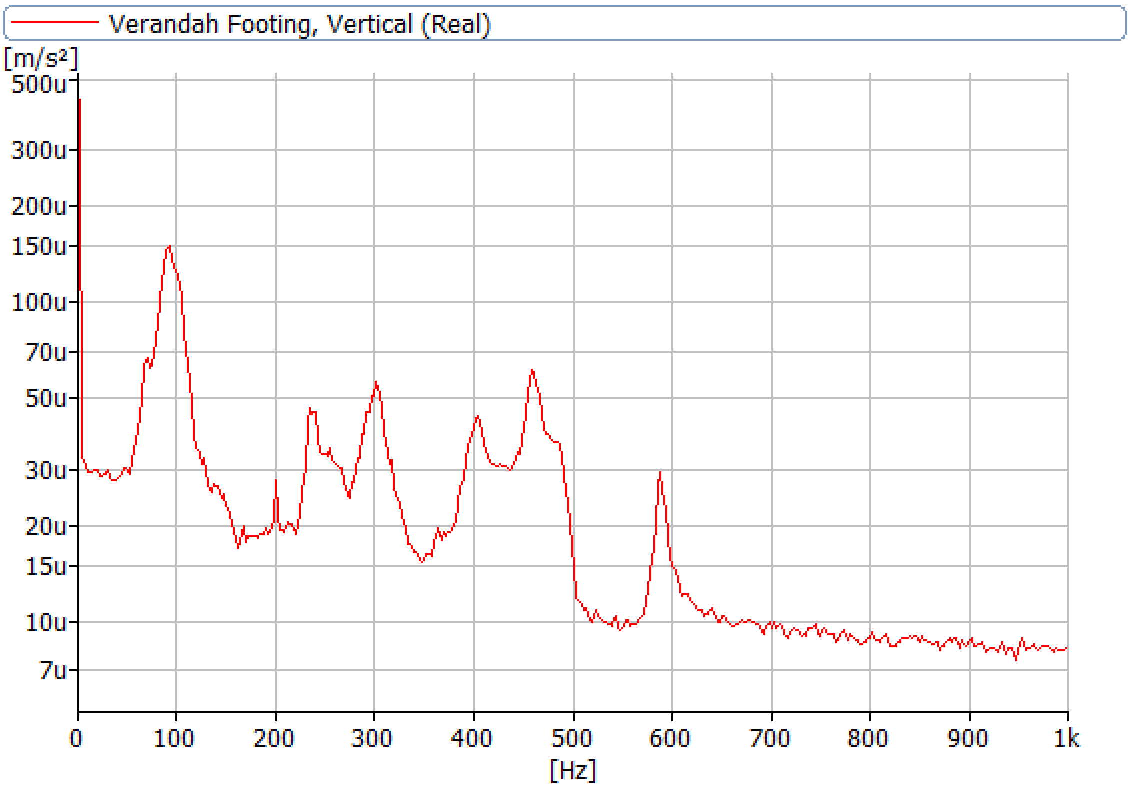


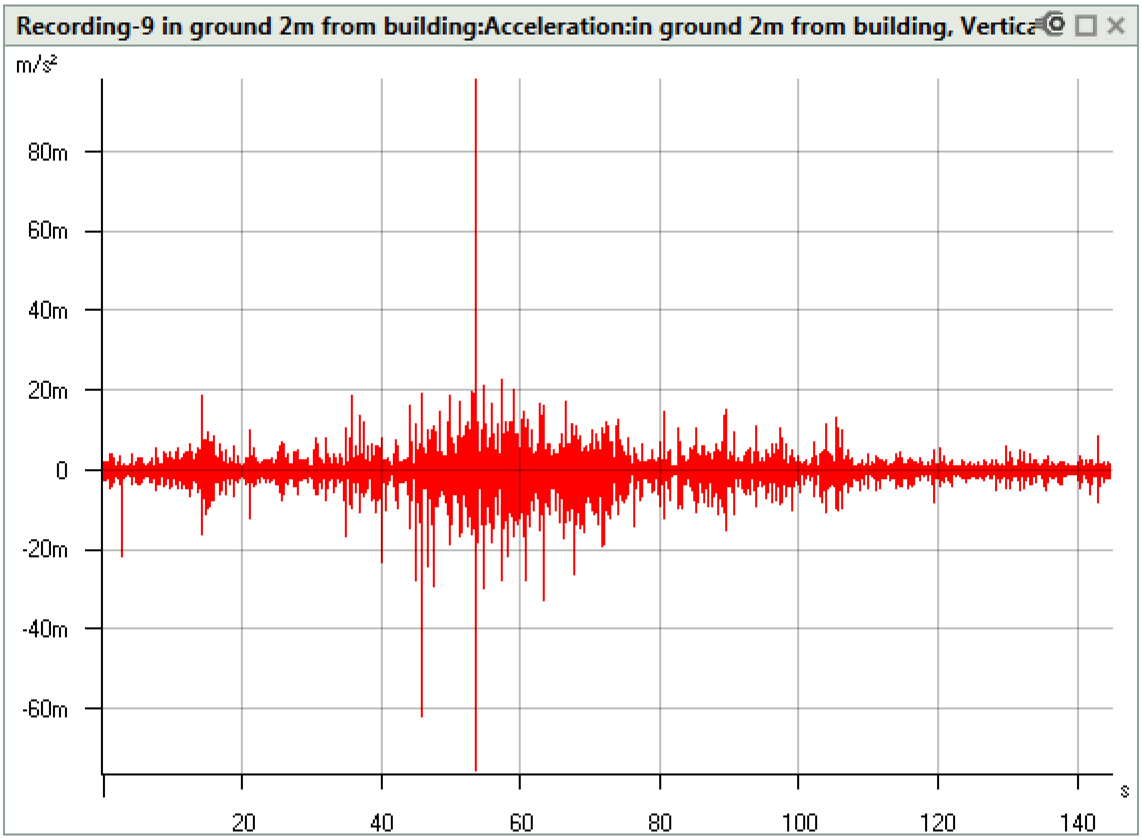
Vibration on Living Room floor adjacent Bedroom Wall (vertical) – walking on floor



Eastern verandah on footing - vertical

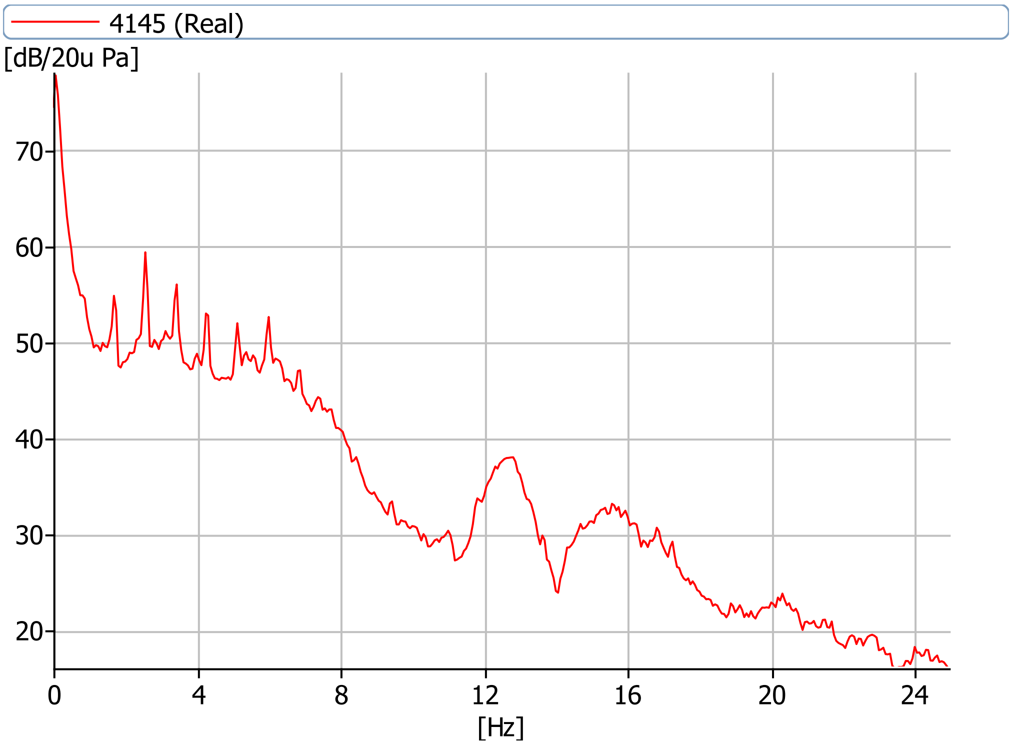



Verandah Footing, Vertical (Real)
[m/s²]
500u
300u
200u
150u
100u
70u
50u
30u
20u
15u
10u
7u
0
100
200
300
400
500
600
700
800
900
1k
[Hz]

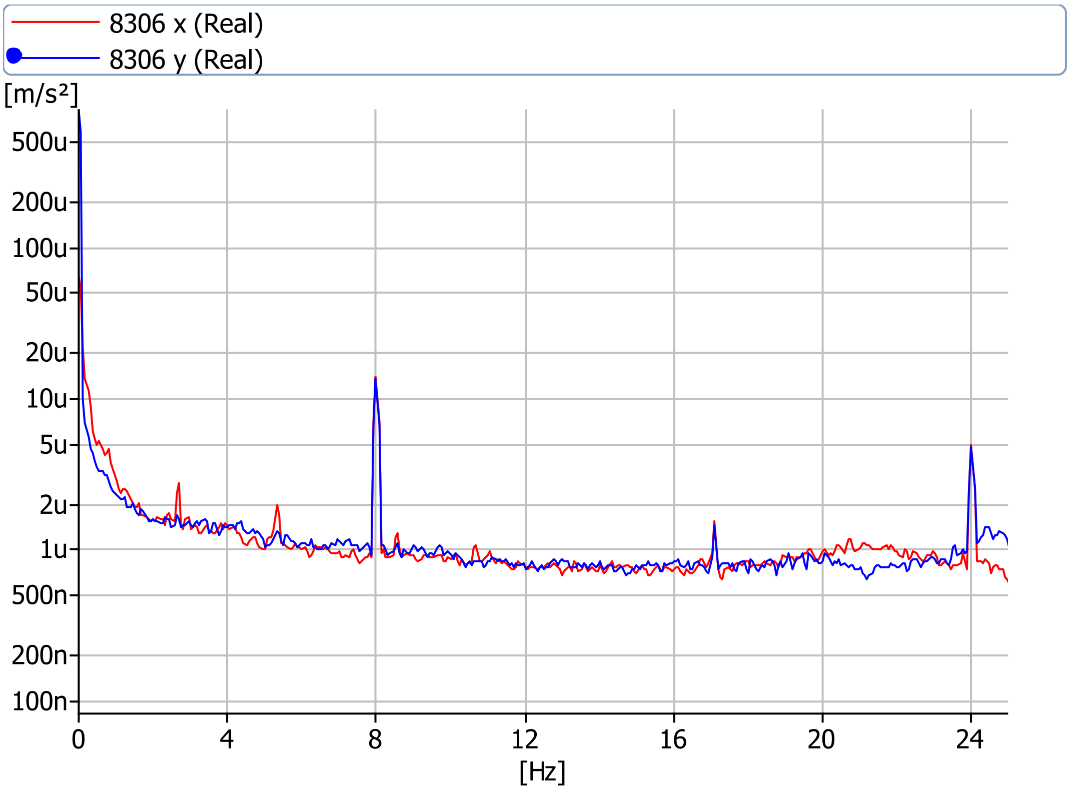

Recording-9 in ground 2m from building:Acceleration:in ground 2m from building, Vertica
m/s²
80m
60m
40m
20m
0
-20m
-40m
-60m
20
40
60
80
100
120
140
s

House 88

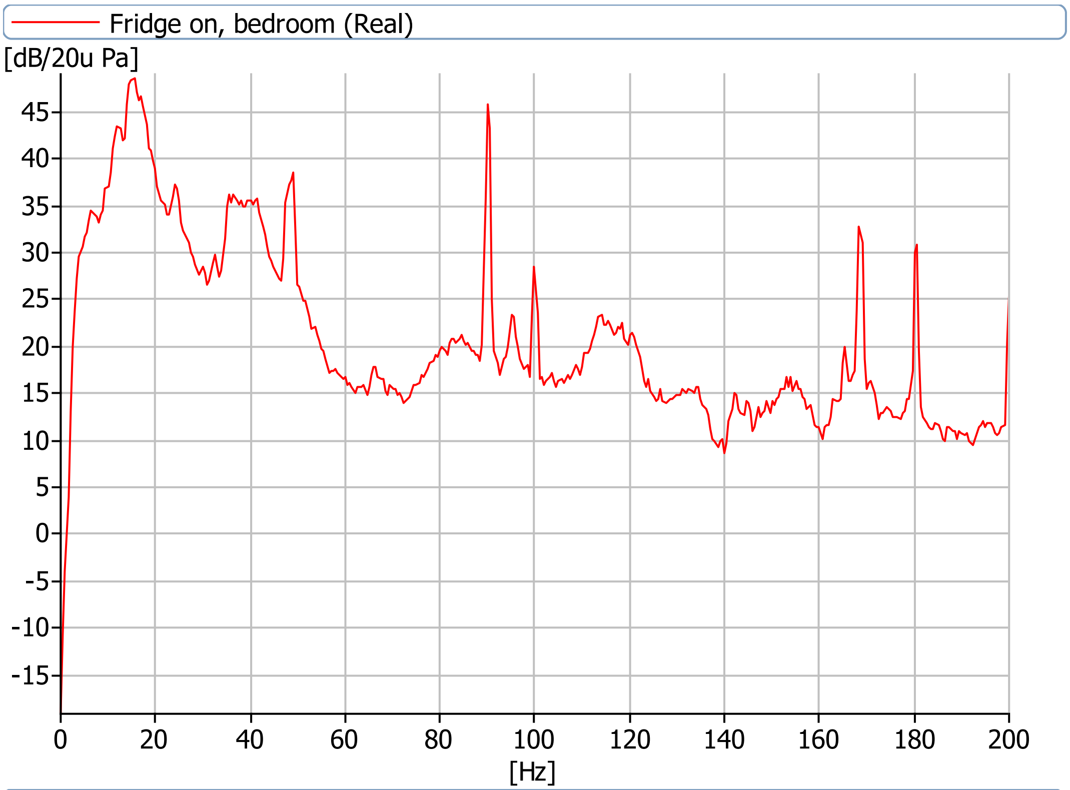
Bedroom Noise

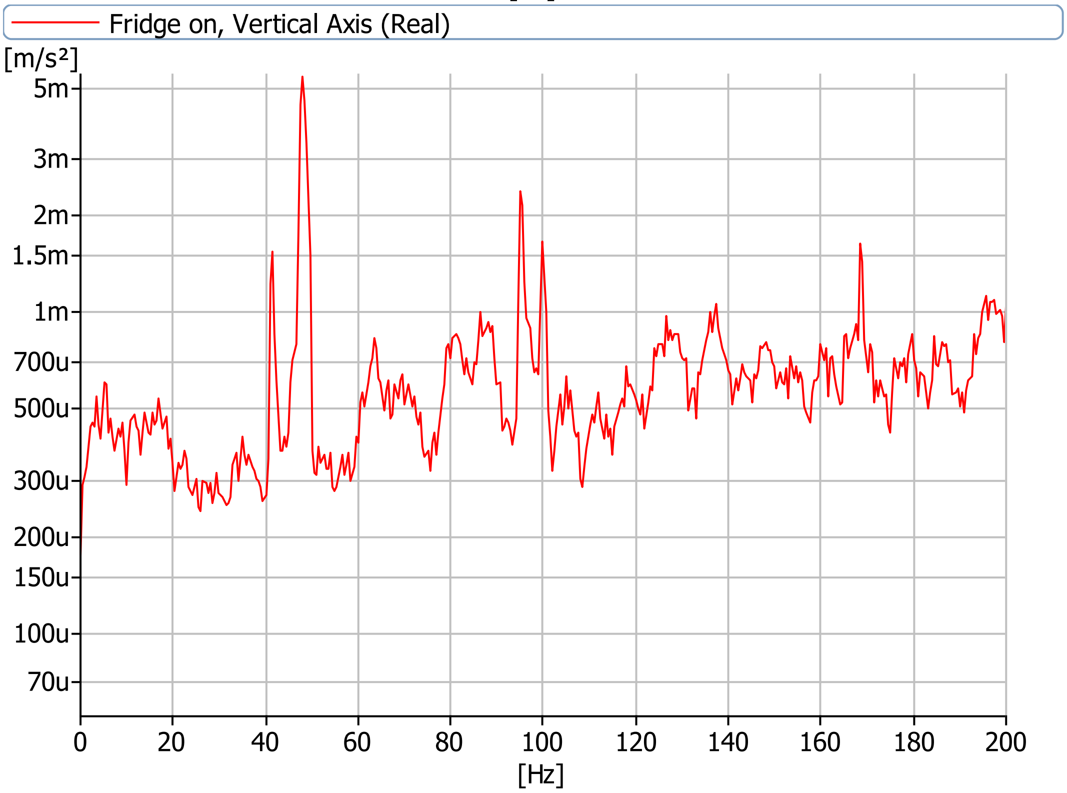


Floor vibration

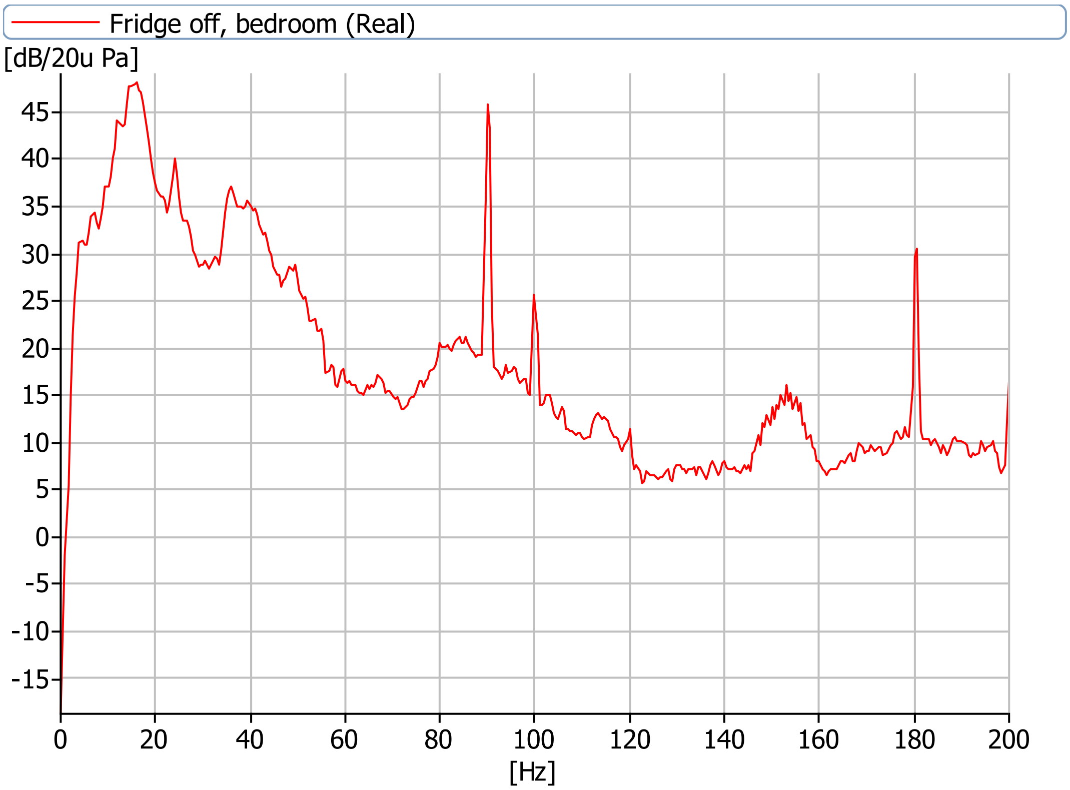


Fridge ON


Fridge on, bedroom (Real)
[dB/20u Pa]
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
0
20
40
60
80
100
120
140
160
180
200
[Hz]

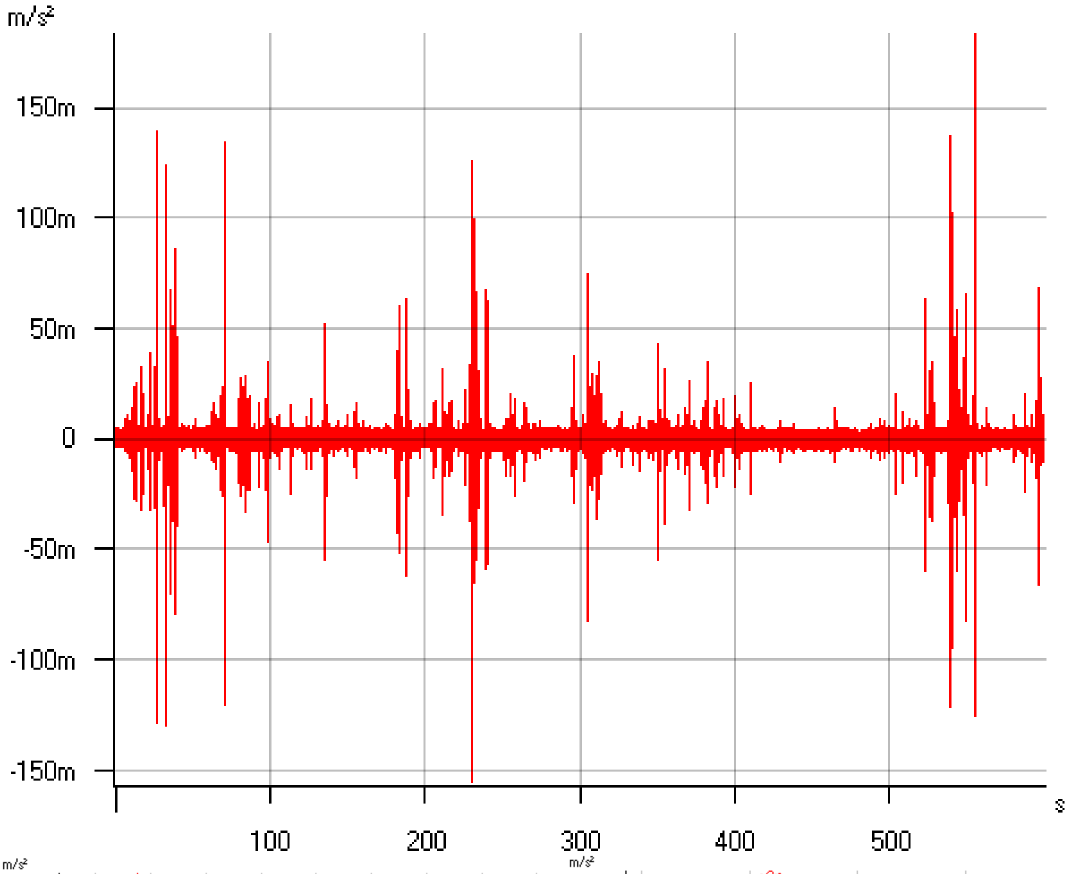

Fridge on, Vertical Axis (Real)
[m/s²]
5m
3m
2m
1.5m
1m
700u
500u
300u
200u
150u
100u
70u
0
20
40
60
80
100
120
140
160
180
200
[Hz]

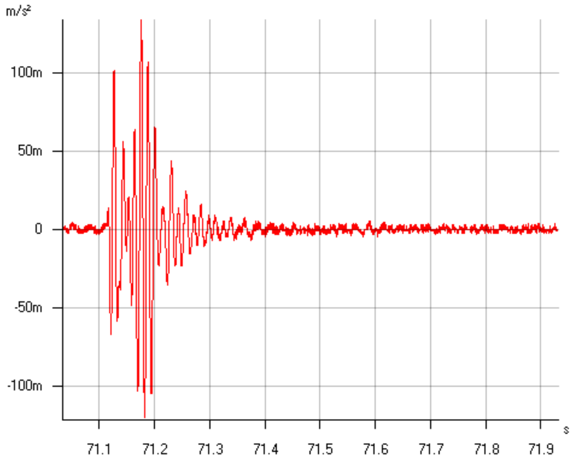
Fridge OFF

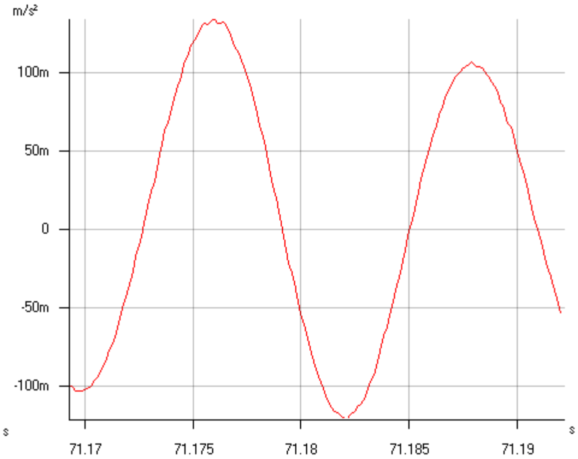

Fridge off, bedroom (Real)
[dB/20u Pa]
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
0
20
40
60
80
100
120
140
160
180
200
[Hz]

Outside – East/West Accelerometer

10 Minute Sample

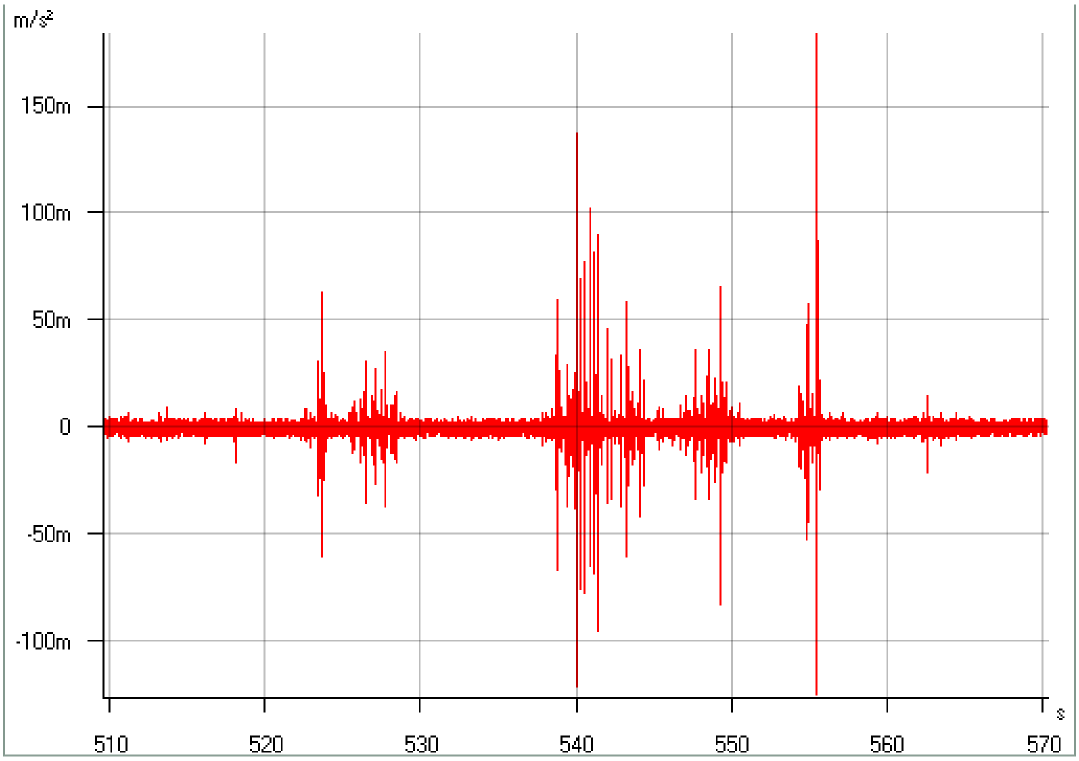




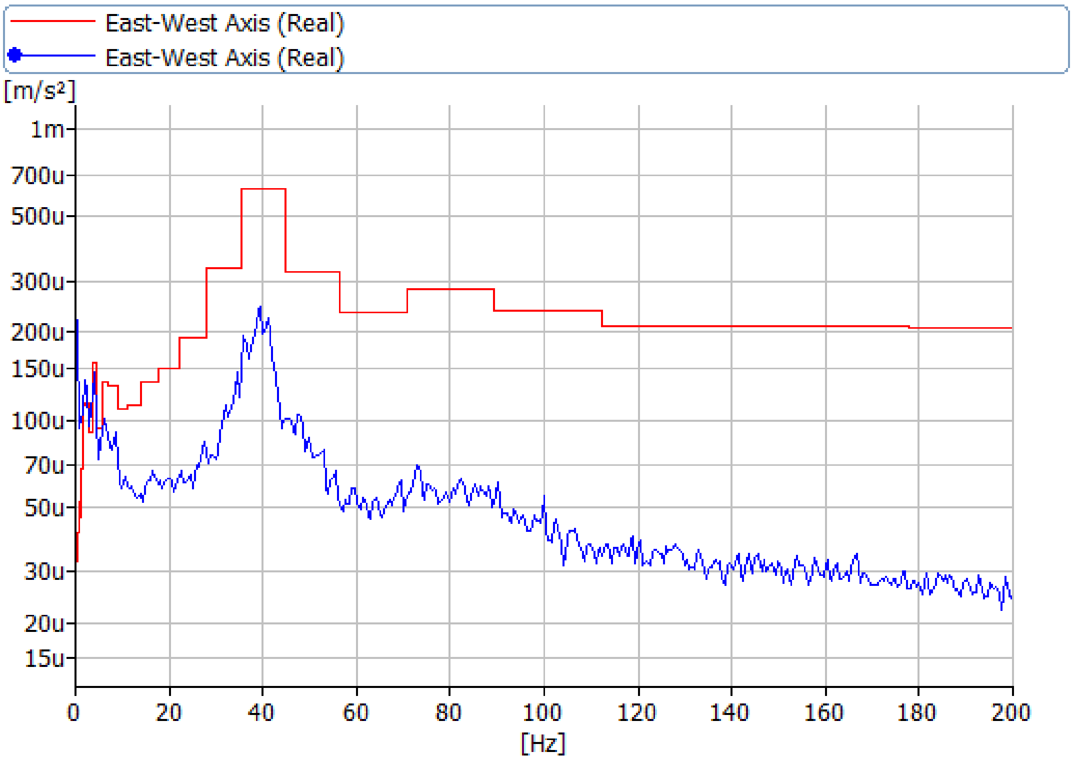


Dominate impulse resonance frequency calculated ≈ 83Hz

1 Minute sample at end of previous 10 minute sample

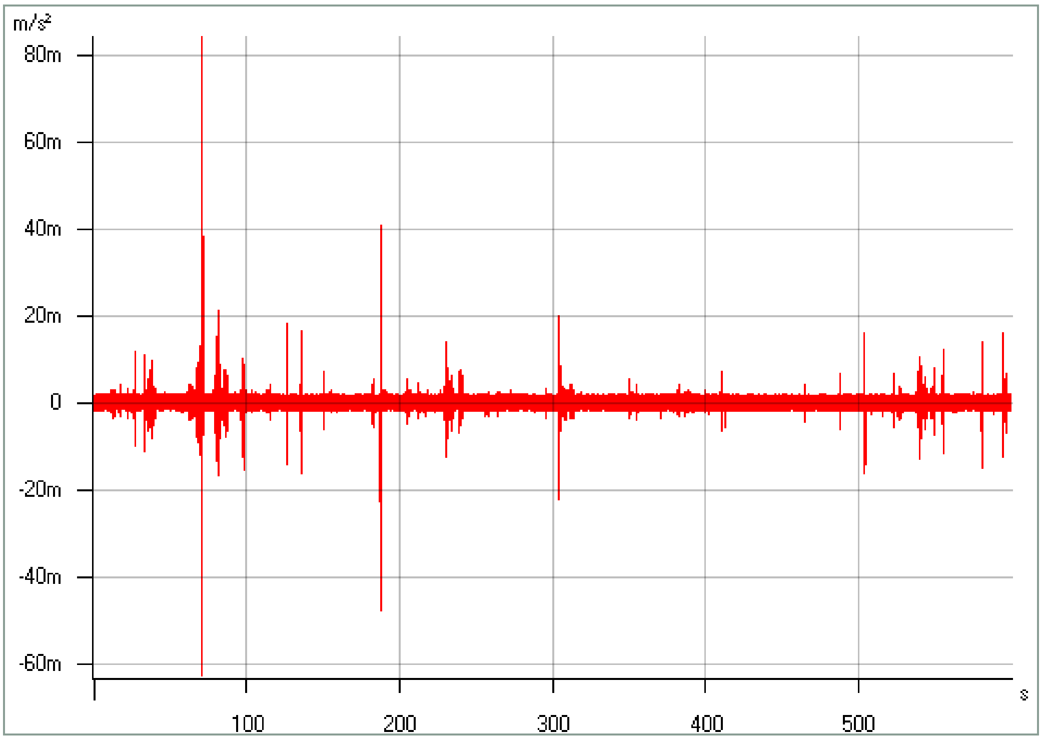


Frequency Analysis of above 1 minute sample

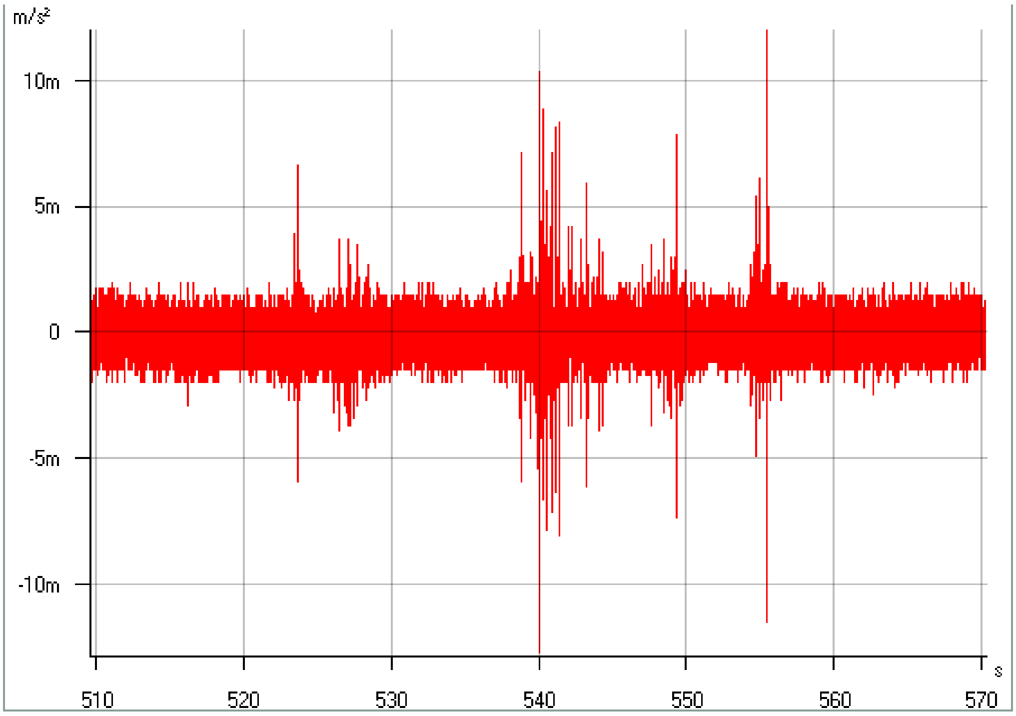


Outside – North/South Accelerometer

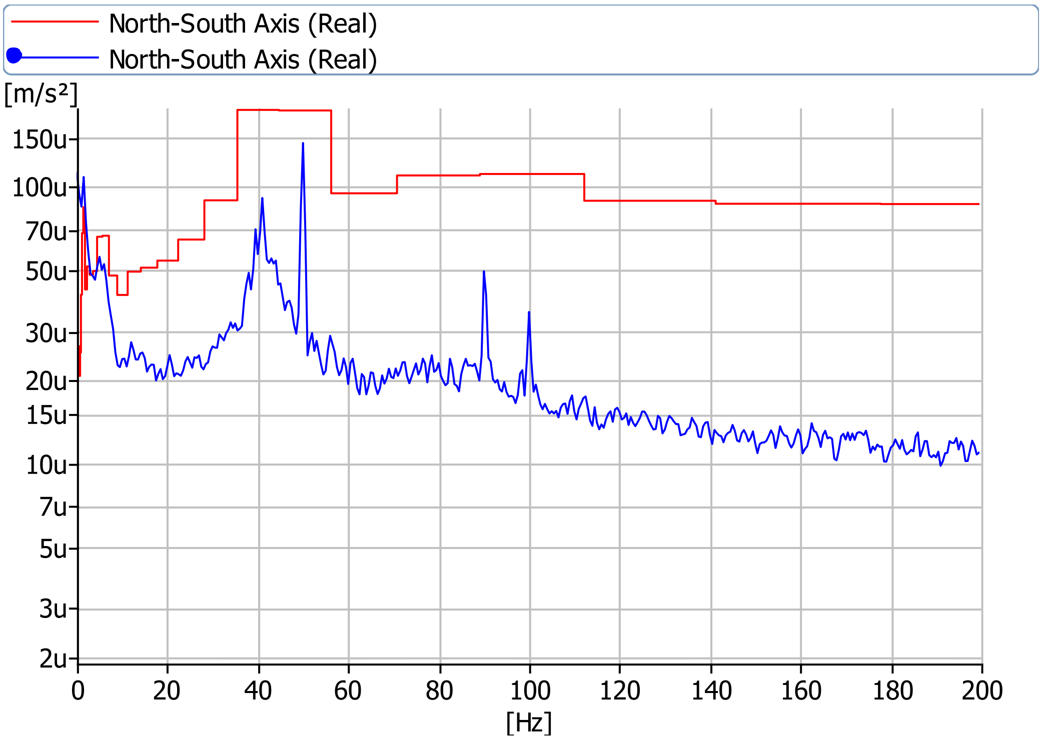
10 Minute Sample



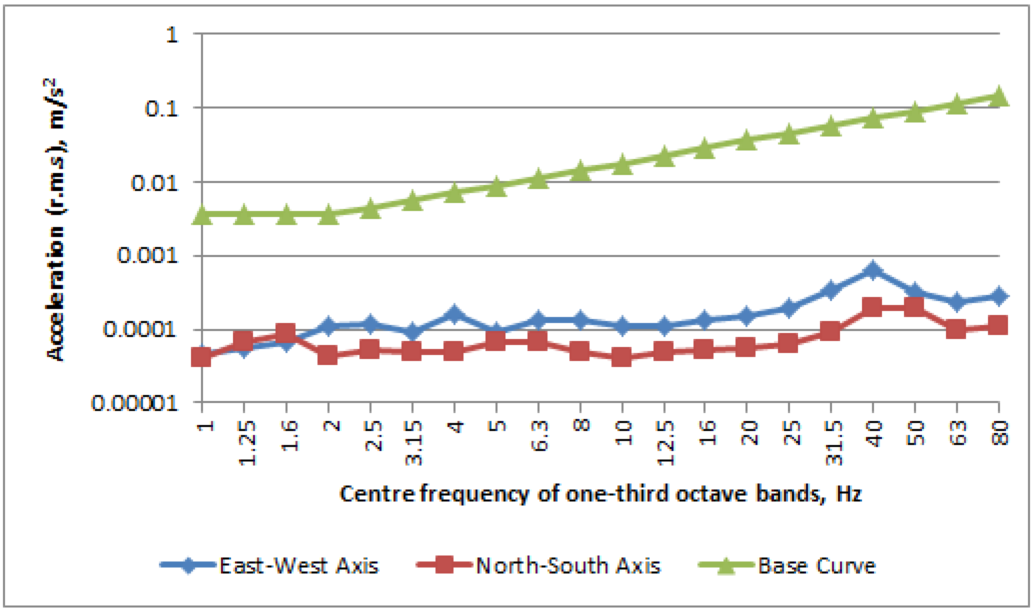
1 Minute sample at end of previous 10 minute sample



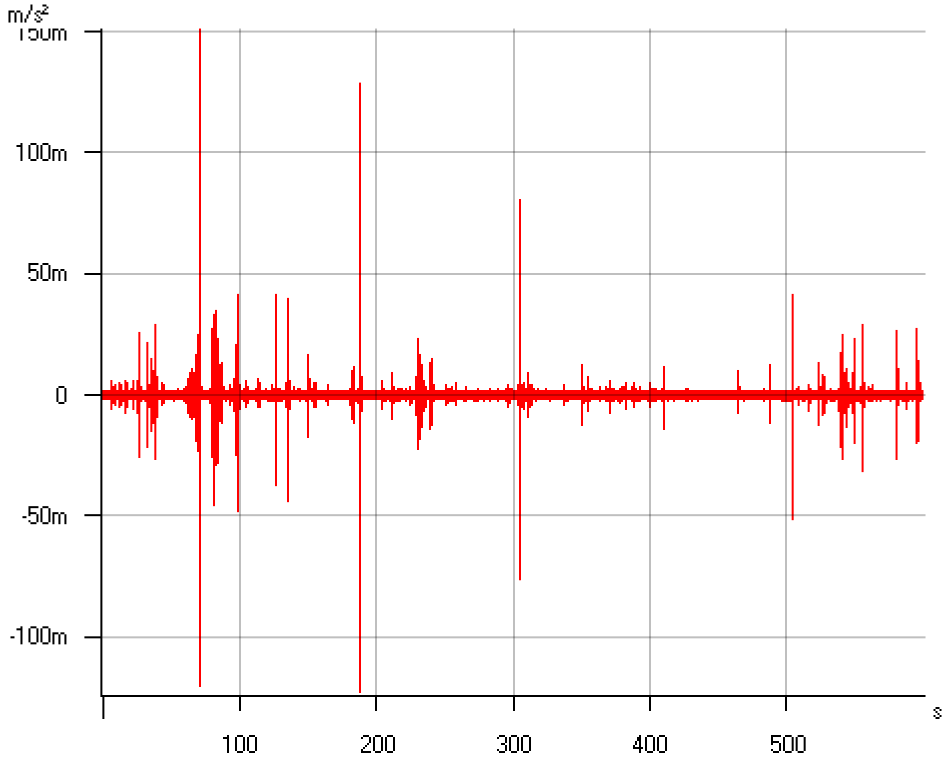
Frequency Analysis of above 1 minute sample

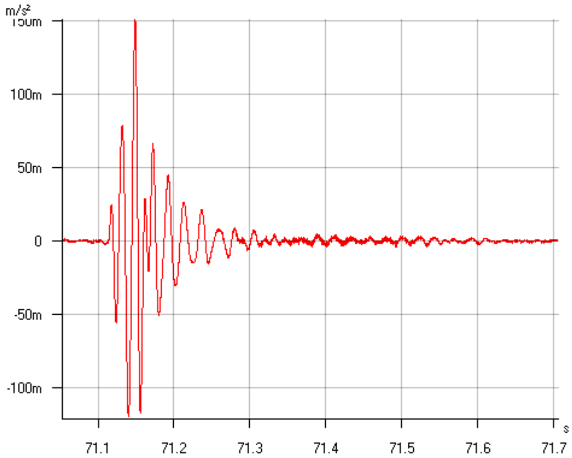


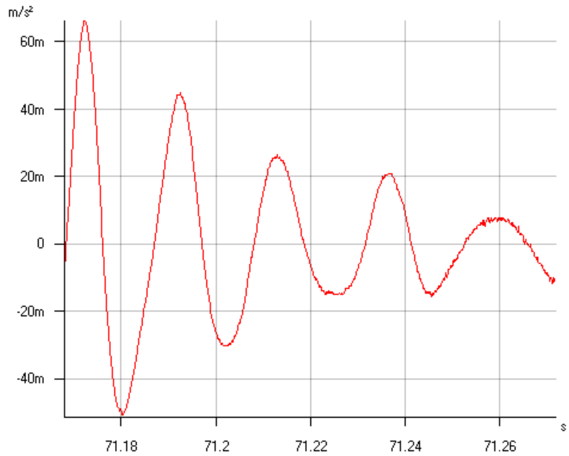
1/3octave horizontal 1 minute Leq versus AS2670-2 base curve



Outside – Vertical Accelerometer

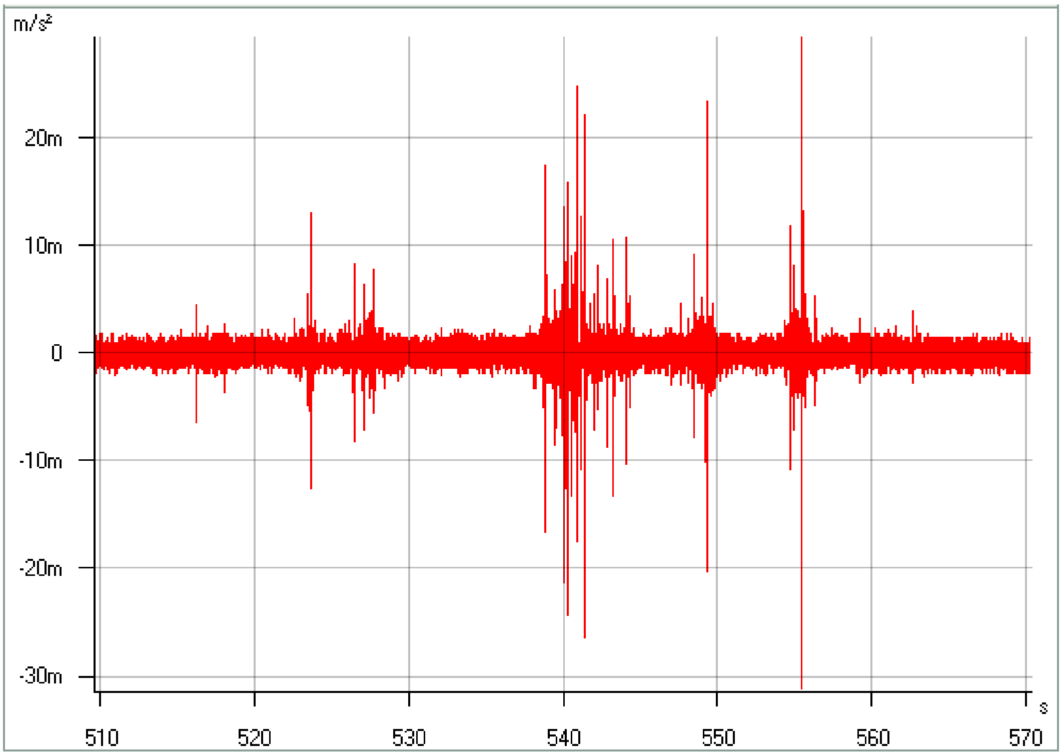




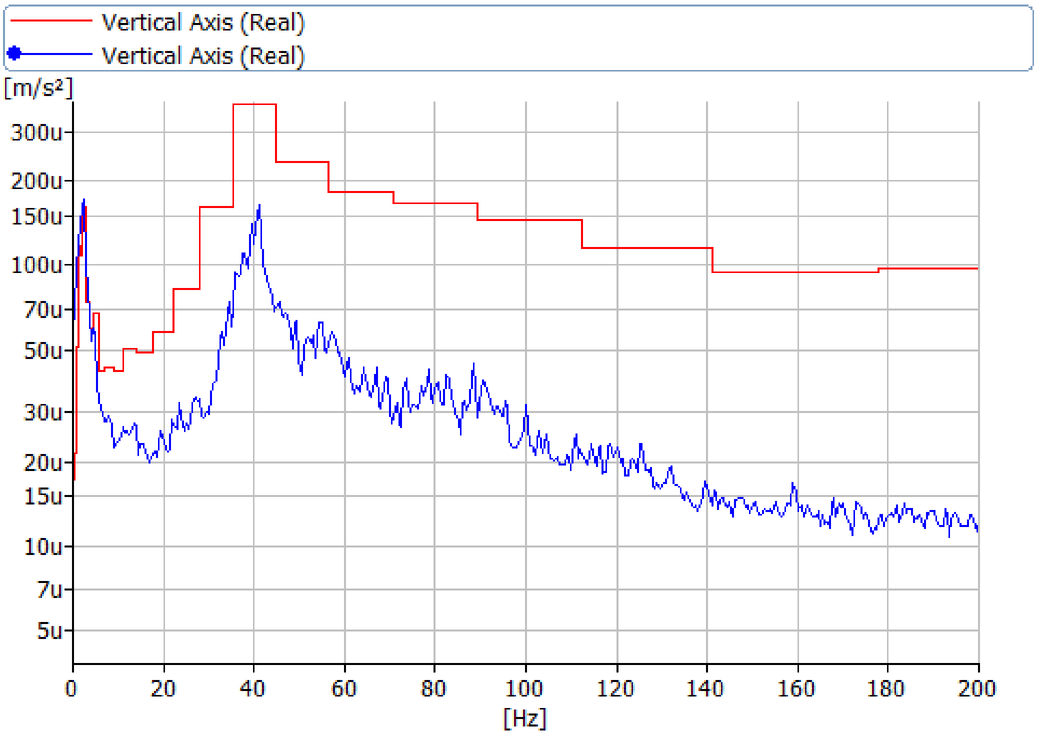


Dominate impulse resonance frequency calculated ≈ 47Hz

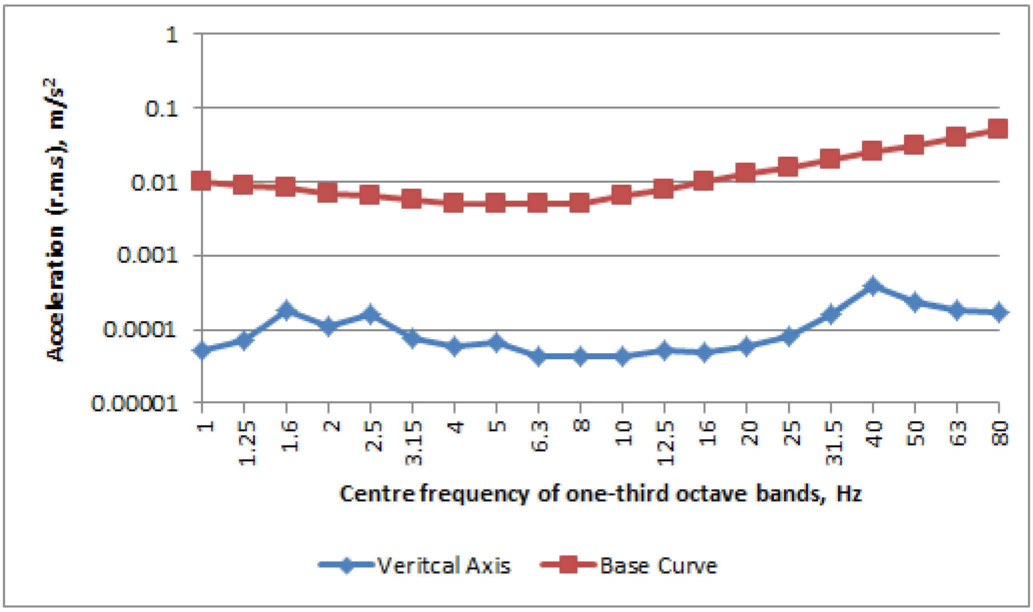
! minute sample from end of ten minute sample



Frequency Analysis of above 1 minute Leq sample

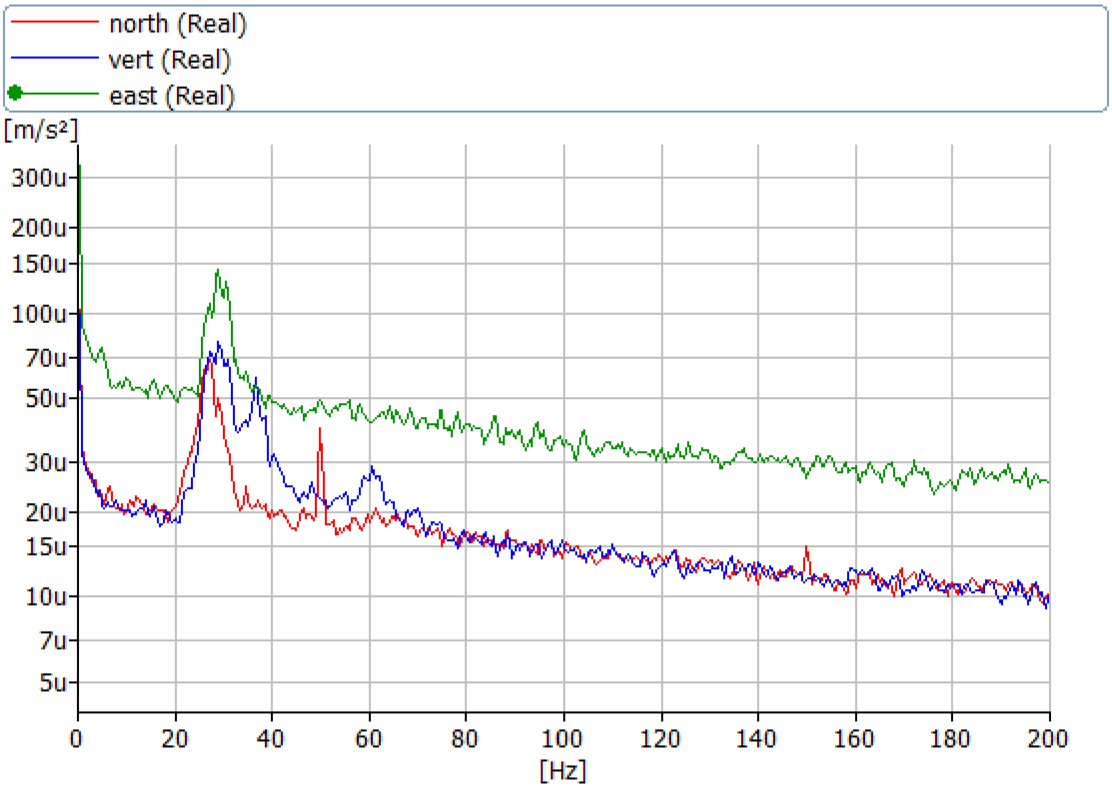


1/3 octave Leq versus base curve of AS2670.2



House 89

Ground vibration spectra (Leq 10 minute) external to dwelling (north side)



APPENDIX V: FFT Synthesis

In the initial stages the subject study utilised constant percentage bandwidth analysis to examine the acoustic signatures obtained at residential properties.

A refinement of the analysis to provide an increased level of frequency resolution was undertaken by the use of narrowband analysis. Narrowband analysis is normally presented in the linear frequency domain to identify discrete frequencies associated with operation of the turbines at Cape Bridgewater.

Originally acoustical analysers for narrow band analysis used a limited bandwidth tracking filter that swept across the analogue signal range of concern.

Since the mid 1980's with the advent of digital techniques for both constant percentage bandwidth and narrow bandwidth assessments there are different mathematical techniques used to derive the resultant data.

In the context of this study the narrow band analysis has used mathematical tools incorporated in the analysers that are based upon a Fast Fourier Transform ("FFT").

In considering the relevance of the FFT results with respect to the operation of the turbines this Appendix presents a basic analysis concept (on a theoretical basis) of the FFT as applied to different time signals on a theoretical basis using an analysis package similar to the National Instruments Labview program that is embedded in the B & K Pulse and Reflex programs.

Basic Frequency Analysis of Periodic Signals

The common tool used for frequency analysis is the Fast Fourier Transform (FFT). A technical explanation of the FFT when applied to a time signal is that it deconstructs the signal into its equivalent frequency domain components. A generalised concept of the application of the FFT in acoustic analysis is to extract periodic patterns that occur in time domain that are then shown as discrete frequencies (in the frequency domain).

Figure V1 show the time signal of a pure sinusoid at 0.8Hz with Figure V2 showing the corresponding FFT.

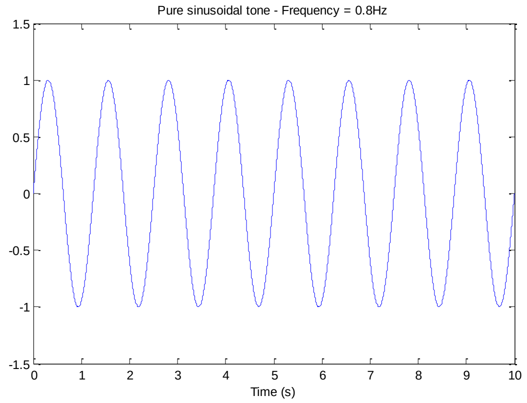


Figure V1: Pure tone sinusoid at a frequency of 0.8Hz

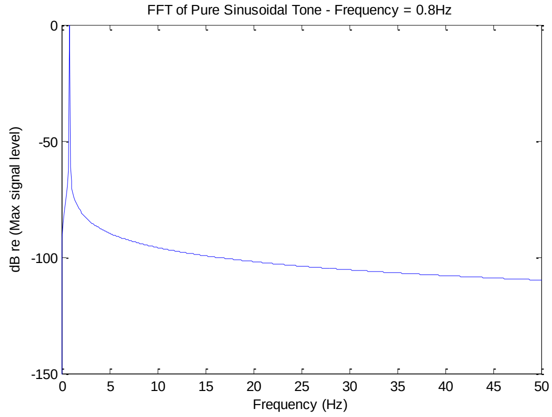


Figure V2: FFT of Figure V1

The underlying theory of the FFT (re a Fourier series) states that any periodic function can be reconstructed with sinusoidal, pure tone signals. A non-sinusoidal periodic signal at a particular frequency can be reconstructed by adding together pure tones at integer multiples (harmonics) of the signal frequency.

The nature of the dynamic wind forces across the turbine blades can be described as generating pressure pluses. Figure V3 shows a square wave at 0.8Hz with its FFT shown in Figure V4.

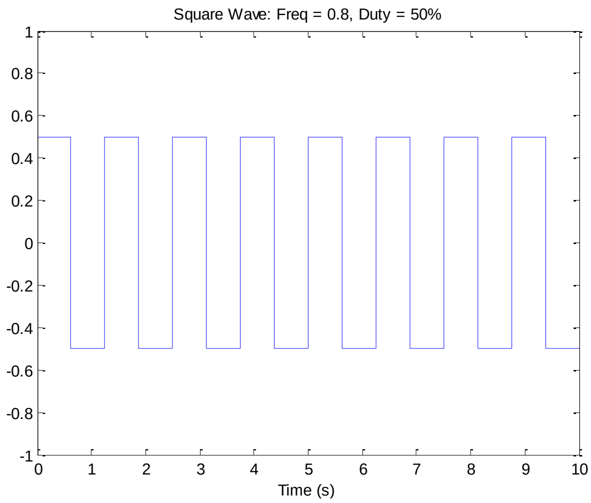


Figure V3: Square wave at 0.8 Hz

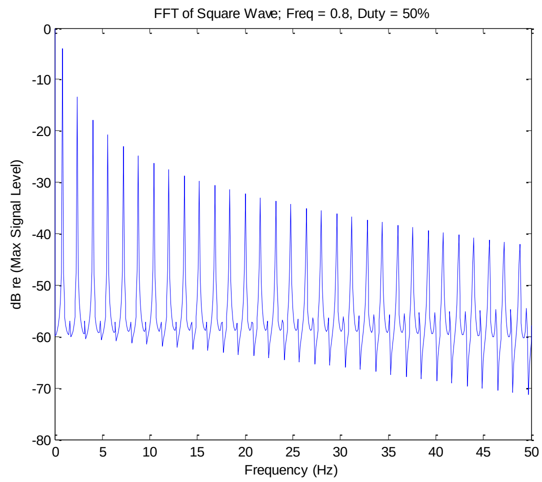


Figure V4: FFT of square wave in Figure V3

The FFT shows a component at the fundamental frequency (of the square wave 0.8Hz) and components at integer multiples of the fundamental. In this case the odd harmonics (identifying 1.6Hz as the second harmonic) are lower in magnitude, since the square wave has a duty cycle of 50% (i.e. 50% on, 50% off).

NB: In dealing with the description of harmonics which is described as integral multiples of the fundamental frequency there are two definitions that may be applied. Australian Standard AS1633 "Acoustic – Glossary of terms and related signals" notes in the definition of harmonics:

> *Of a periodic quality: a sinusoidal component of the periodic quality having a frequency which is an integral multiple of the fundamental frequency.*
>
> *NOTE: In science, the nth harmonic implies a frequency equal to n times the fundamental frequency; in music the nth harmonic usually implies a frequency equal to (n+1) times the fundamental.*

The scientific definition of harmonic has been used in the study.

Figure V5 shows a pulse wave with a 20% duty cycle at 0.8Hz, being a smaller duty cycle than the previous example. The corresponding FFT shown as Figure V6 reveals a similar result to Figure V4, however the relationships between the harmonic peaks is different.

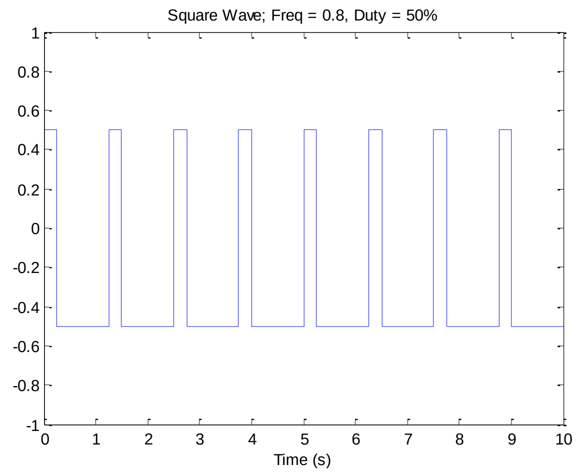


Figure V5: Pulse wave at 0.8Hz (20% Duty cycle)

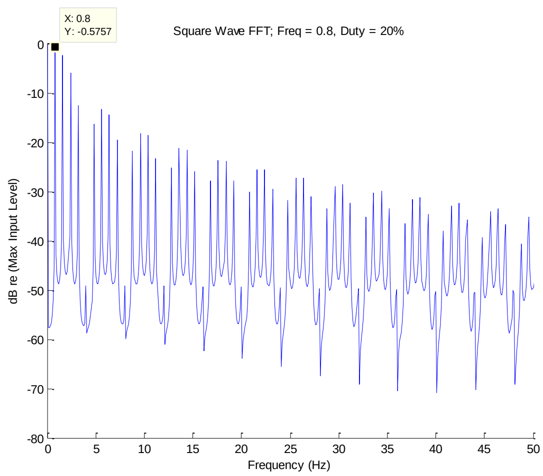


Figure V6: FFT of Figure V5

Standard FFT plots for acoustic assessments, as shown here, are typically concerned with representing the magnitude of the frequency components, corresponding only to the amplitude of the sinusoid. The result of an FFT is in fact a complex value with real and imaginary components for each frequency line. This can be written in the form:

$$Ae^{i\phi}$$

Where: $A =$ Amplitude of the sinusoid

$\phi =$ Phase of the sinusoid

The FFT plots present the amplitude of the signal at the various frequencies determined as a function of the analysis of the time signal. If one were to reconstruct the original signal using the FFT result as described by the Fourier series the phase ϕ should be included, where phase is with respect to the effective zero time point of FFT analysis.

Changing the duty cycle causes changes in the harmonic components in terms of their phase and amplitude. This is demonstrated when comparing Figure V4 and Figure V6 where it is noted only the magnitude is shown.

By taking the fundamental and first 3 harmonics of the FFT in Figure V6 as sinusoidal waves having the application shown Figure V7, an approximation of the Figure V5 pulse wave can be made. Figure V7 shows the relative relationships between the first four harmonic tones given from the FFT (Figure V6) of the 20% duty cycle pulse wave shown in Figure V5.

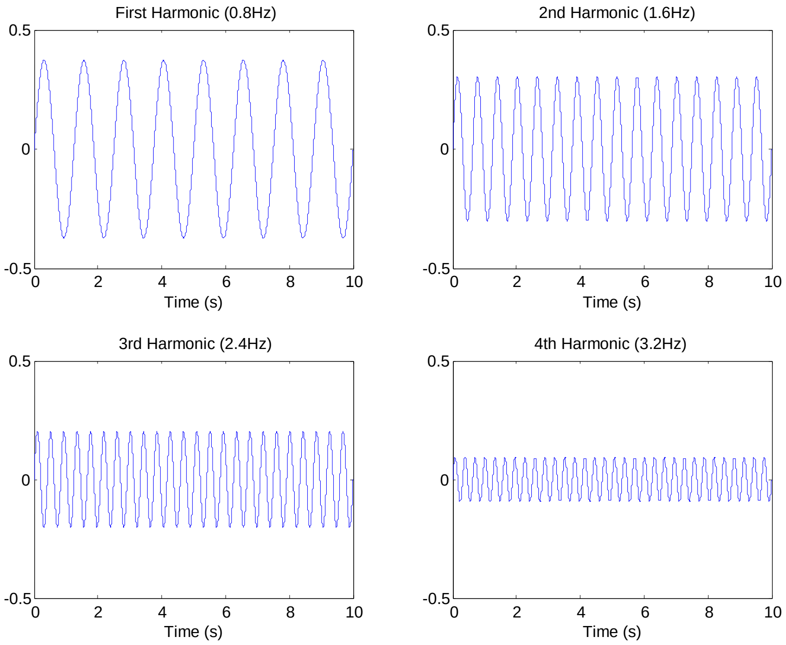


Figure V7: Harmonic components from Figure V6 FFT (Fundamental, 2^{nd}, 3^{rd} and 4^{th} harmonics)

The linear addition of the fundamental and first three harmonics of the 20% duty cycle pulse wave is shown in Figure V8.

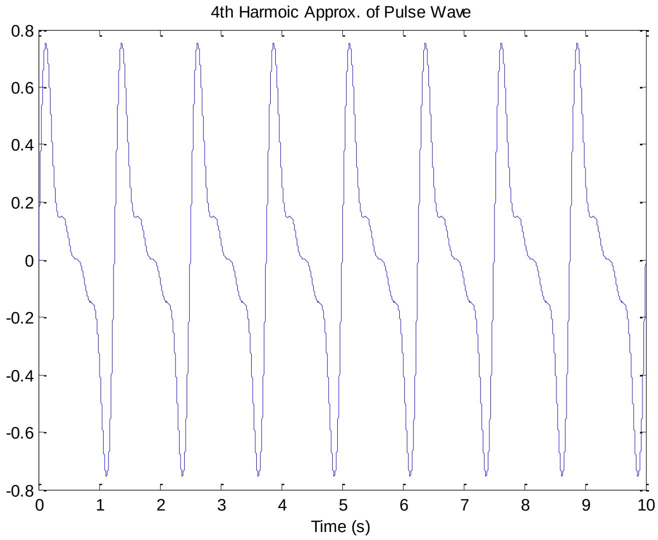


Figure V8: 4^{th} harmonic approximation to 20% duty cycle pulse wave

By adding higher order harmonics the approximation of the pulse wave will become more accurate. The FFT shown in Figure V9 (of the signal in Figure V8) demonstrates that the Figure V8 signal can be deconstructed into the sinusoidal terms used to create it.

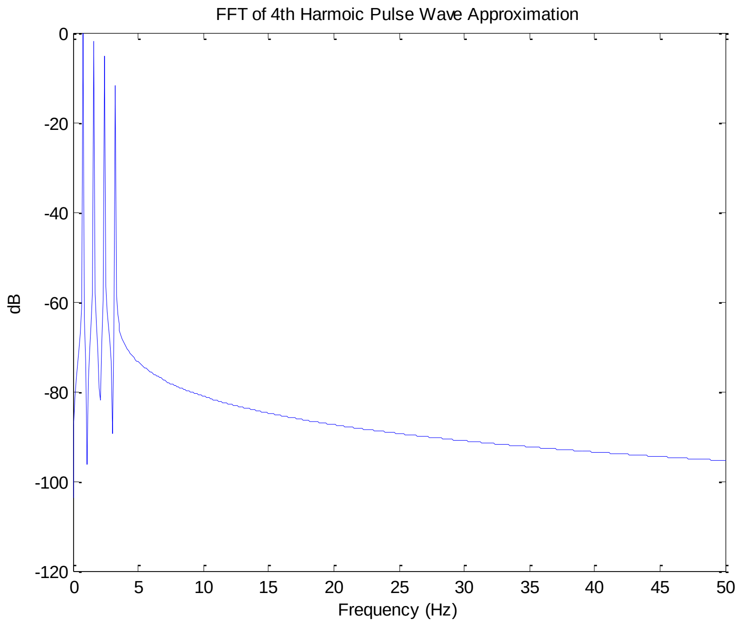


Figure V9: FFT of 4th harmonic approximation to 20% duty cycle pulse wave

The material above shows that, when using the FFT as a tool for signal analysis, that the analysis method (by design) breaks a signal into discrete frequency components.

However the result shown in Figure V9 identifies that the time signal in Figure V8 can be created from the four pure tones in Figure V7 being generated separately (by mechanisms which are not related) and existing at the point of measurement as sound pressures simultaneously. The resulting sound pressure measurement then in the time domain would be that shown in Figure V8 (blue) and its FFT in Figure V9. However it is also possible that the signal shown in Figure V8 be generated acoustically by a single mechanism creating a pulse like pressure disturbance at a rate of 0.8Hz.

Amplitude Modulation

The term amplitude modulation (AM) generally refers to the technique used in telecommunications to transmit information using radio frequency electromagnetic waves by modulating the amplitude of a high frequency carrier wave (that is much higher than signal of information e.g. an audio tone of 1000Hz added to a carrier frequency of 702,000Hz).

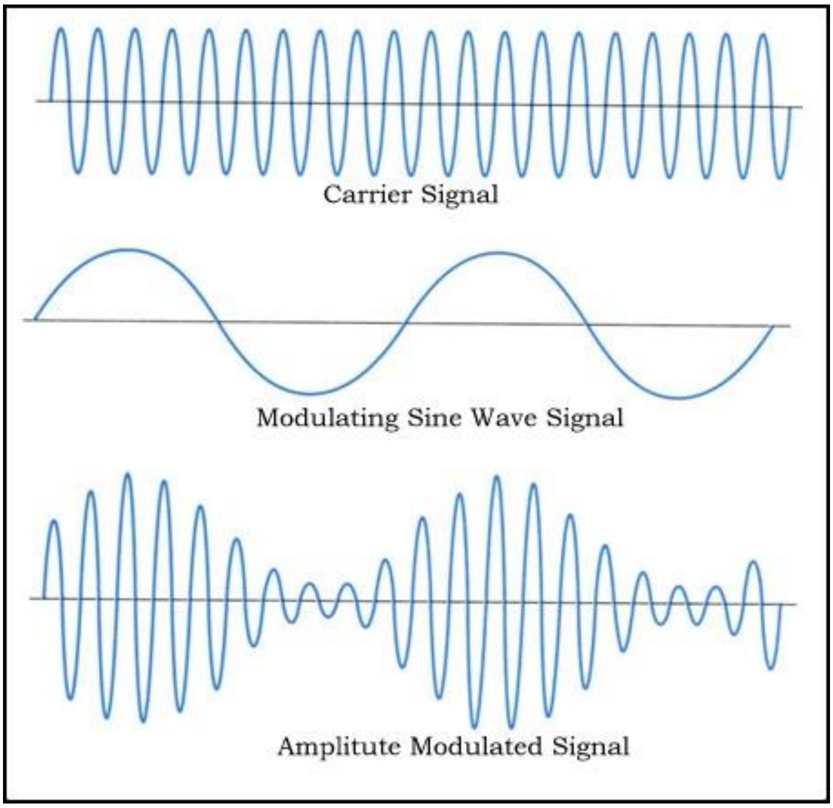


Figure V10: Typical representation of AM for a radio wave

For telecommunications the information signal is embedded in the carrier wave by modulation of its amplitude using a modulation circuit containing a multiplier. The embedded signal is extracted using a demodulation circuit.

However, the term amplitude modulation in a broad sense can apply to any tone which changes its amplitude (generally on a periodic basis) over time.

For example if the volume of a pure tone issued from loudspeaker is turned up and down on a periodic basis over the entire sample time, then the resultant tone could be described as being amplitude modulated.

Common notation for amplitude modulation is;

$c(t) = A_c \sin(2\pi f_c t)$ [Carrier Signal]

$m(t) = A_m \sin(2\pi f_m t)$ [Modulation Signal]

Where: $f_c =$ The carrier frequency

$f_m =$ The modulation frequency

$A_c =$ The carrier amplitude

$A_m =$ The modulation amplitude

The modulated signal is created by adding an offset to the modulation and multiplying this by the carrier wave.

$y(t) = [1 + m(t)] \cdot c(t)$ [Amplitude modulation signal]

$$y(t) = [1 + A_m \sin(2\pi f_m t)\,] \cdot A_c \sin(2\pi f_c t)$$ **Equation V1**

It can be shown that $y(t)$can be represented by the sum of three sinusoids.

$$y(t) = A_c \sin(2\pi f_c t) + \frac{A_c A_m}{2}[\sin(2\pi(f_m + f_c)t) + \sin(2\pi(f_m - f_c)t)\,]$$ **Equation V2**

The result frequency content of the AM signal can be deconstructed into a tone at the carrier frequency f_c and two tones at $(f_m + f_c)$ and $(f_m - f_c)$ known as sidebands.

In dealing with modulation of audio frequencies including infrasound associated with the turbines, the difference between the signal and the carrier is much smaller (than the radio wave) such that in many cases the amplitude modulation of the time signal is not that obvious.

For a theoretical application of amplitude modulation, when restricted to the acoustic frequencies of concern for a wind turbine assessment, the following analysis considers the application of a carrier tone of 31.5Hz and a modulation tone of 0.8Hz as shown in Figures V11 and V12.

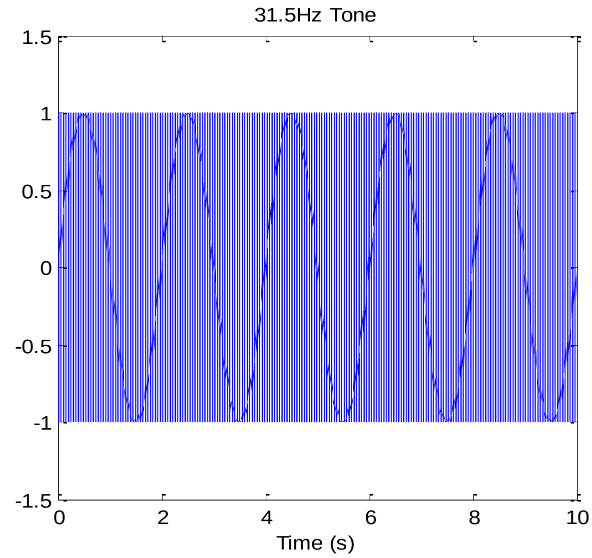


Figure V11: 31.5Hz carrier tone

$[c(t)\text{: } f_c = 31.5;\ A_c = 1]$

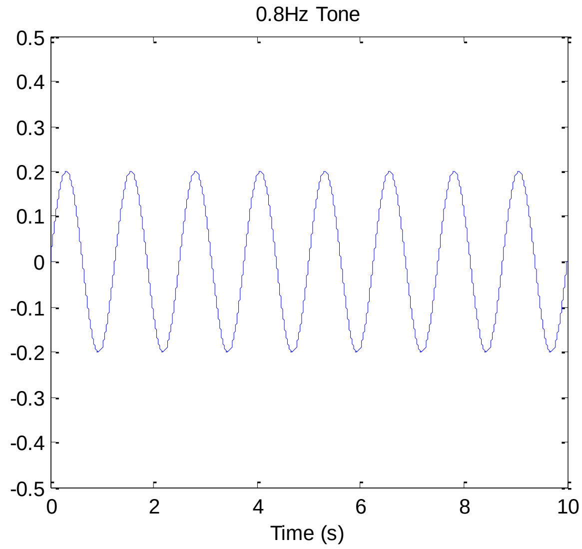


Figure V12: 0.8Hz modulation tone

$[c(t)\text{: } f_c = 31.5;\ A_c = 1]$

The analysis of the modulation and the carrier signals in Figure V11 and Figure V12, results in the modulated time signal (and the expanded view) shown in Figure V13 with the corresponding FFT in Figure V14.

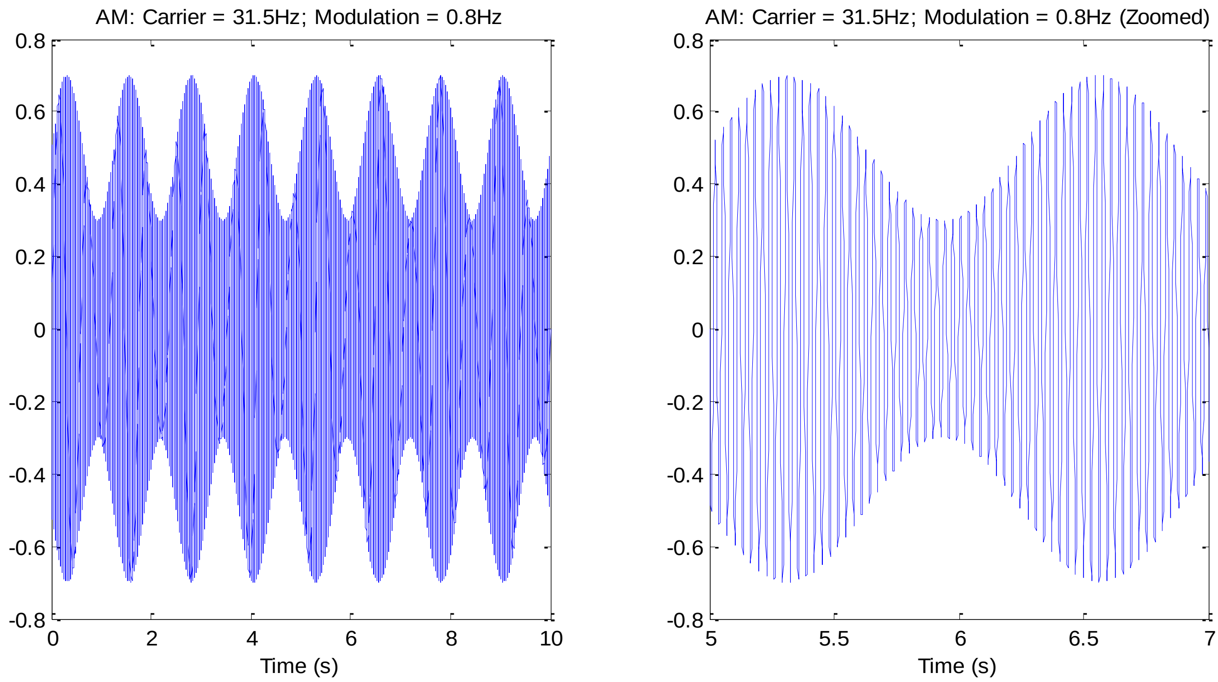


Figure V13: AM signal $[y(t)\text{: } (f_c = 31.5;\ A_c = 1)\ (f_m = 0.8;\ A_m = 0.2)]$

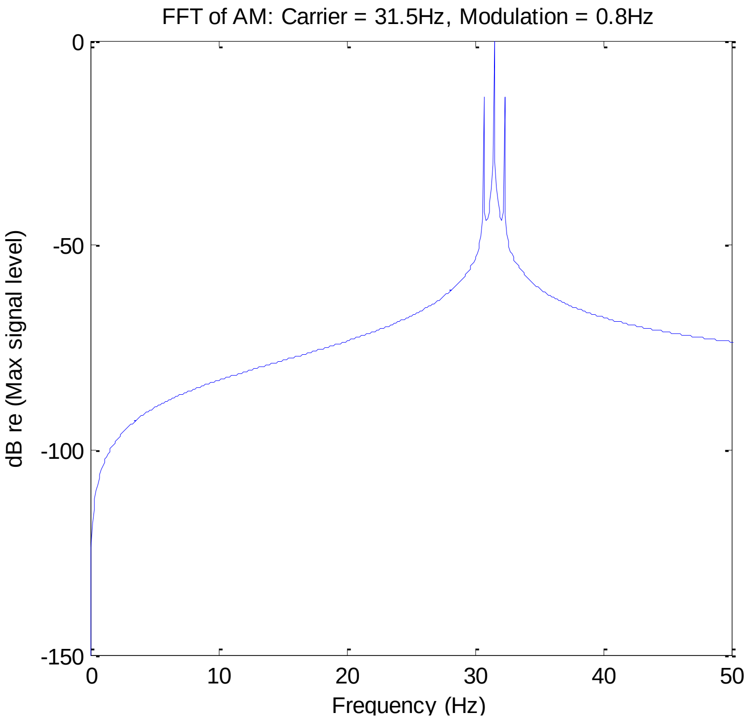


Figure V14: FFT of AM signal $[\boldsymbol{y(t)}: (\boldsymbol{f_c = 31.5};\ \boldsymbol{A_c = 1})\ (\boldsymbol{f_m = 0.8};\ \boldsymbol{A_m = 0.2})]$

The 31.5Hz tone was used as a carrier wave and modulated by the 0.8Hz tone. This results in a time signal as shown in Figure V13 which shows the amplitude of the 31.5Hz tone is modulated at the 0.8Hz rate. This corresponds to the following time signal from Equation V1;

$$y(t) = [1 + A_m \sin(2\pi f_m t)\,] \cdot\ A_c \sin(2\pi f_c t)$$

$$= \left[\frac{1}{2} + (0.2)\sin(2\pi(0.8)t)\right] \cdot\ \sin(2\pi(31.5)t)$$

Or by substituting the modulation and carrier signal values into Equation V2;

$$y(t) =\ \sin(2\pi f_c t) + \frac{A_c A_m}{2}[\sin(2\pi(f_m + f_c)t) + \sin(2\pi(f_m - f_c)t)\,]$$

$$=\ \sin(2\pi(31.5)t) + \frac{0.2}{2}\left[\sin\left(2\pi\left((0.8) + (31.5)\right)t\right) + \sin\left(2\pi\left((0.8) - (31.5)\right)t\right)\right]$$

$$=\ \sin(2\pi(31.5)t) + 0.1[\sin(2\pi(32.3)t) + \sin(2\pi(30.7)t)\,]$$

$$=\ \boldsymbol{\sin(2\pi(31.5)t) + 0.1\sin(2\pi(32.3)t) + 0.1\sin(2\pi(30.7)t)}$$

This is shown in the FFT result in Figure V14.

Figure V15 shows the time signal result of a similar exercise, that is, amplitude modulating a 31.5Hz tone using the signal shown in Figure V8 (spectrum shown in Figure V9) for modulation. The FFT (Figure V16) shows multiple side bands corresponding to the spectrum of the modulated signal centred around the 31.5Hz tone.

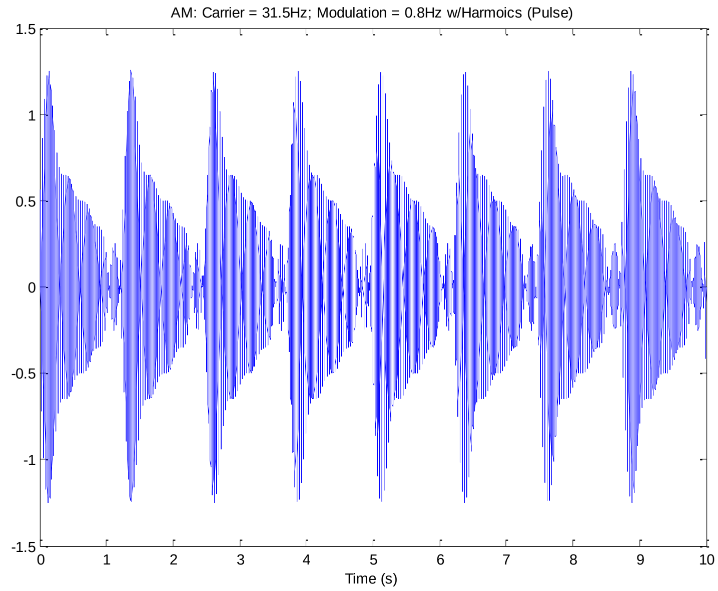


Figure V15: AM signal $\left[y(t)\!:\left(f_c = 31.5;\ A_c = 1\right)\right]$

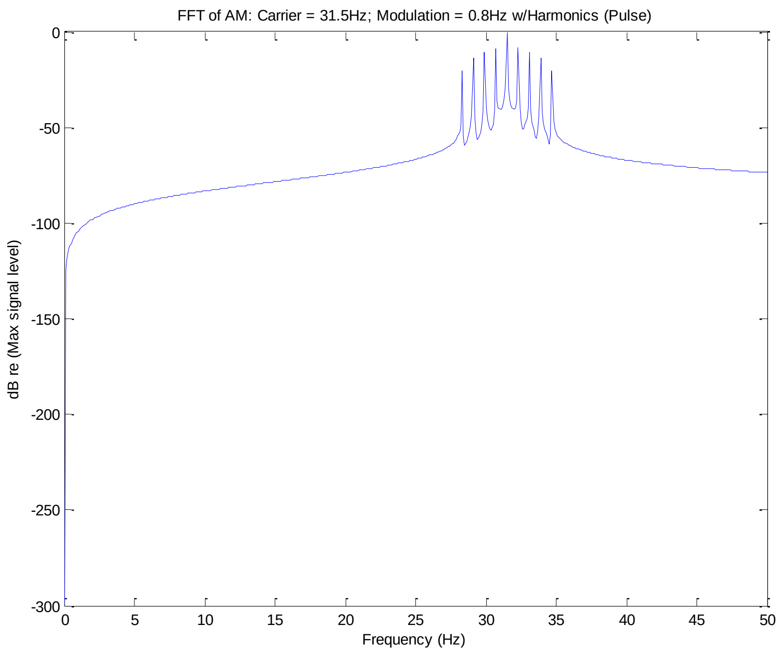


Figure V16: FFT of AM signal $\left[\left(f_c = 31.5;\ A_c = 1\right)\right]$ **(modulation using Figure V8)**

In the case of AM modulation where a tone is modulated, frequency analysis will show the spectrum of the modulation signal as side bands around the carrier frequency. This is well described by detailed AM modulation theory and analysis not shown here. However the result of the outcome is demonstrated by the preceding quantitative analysis.

Signals & Systems – Basic Concept

A fundamental result when dealing with linear systems is that, for a single sinusoidal signal at a particular frequency, the steady state output will be a sinusoid at the same frequency as the input tone, with an amplitude scaling and phase shift associated with the system. Any combination of sinusoidal signals at discrete frequencies passed through a linear system will result in an output containing those particular discrete frequencies with amplitude scaling and phase shift associated with the system.

This result can be extended to any signals passed through linear systems and importantly in this context, to signals which are perhaps not sinusoidal but periodic in nature and can be deconstructed into discrete sinusoidal tones. No intermodulation tones are created by passing signals through linear system e.g. no intermodulation tones are created by passing two tones into an RLC filter circuit (operating linearly) simultaneously.

If a system has nonlinearities, intermodulation (e.g. sideband terms) are created (note the multiplication in the AM discussion is a nonlinear operator).

For example if the two tones used to create amplitude modulation in Figure V11 and Figure V12 are added together (i.e. linearly combined) the FFT will show simply the two discrete tones (Figure V17).

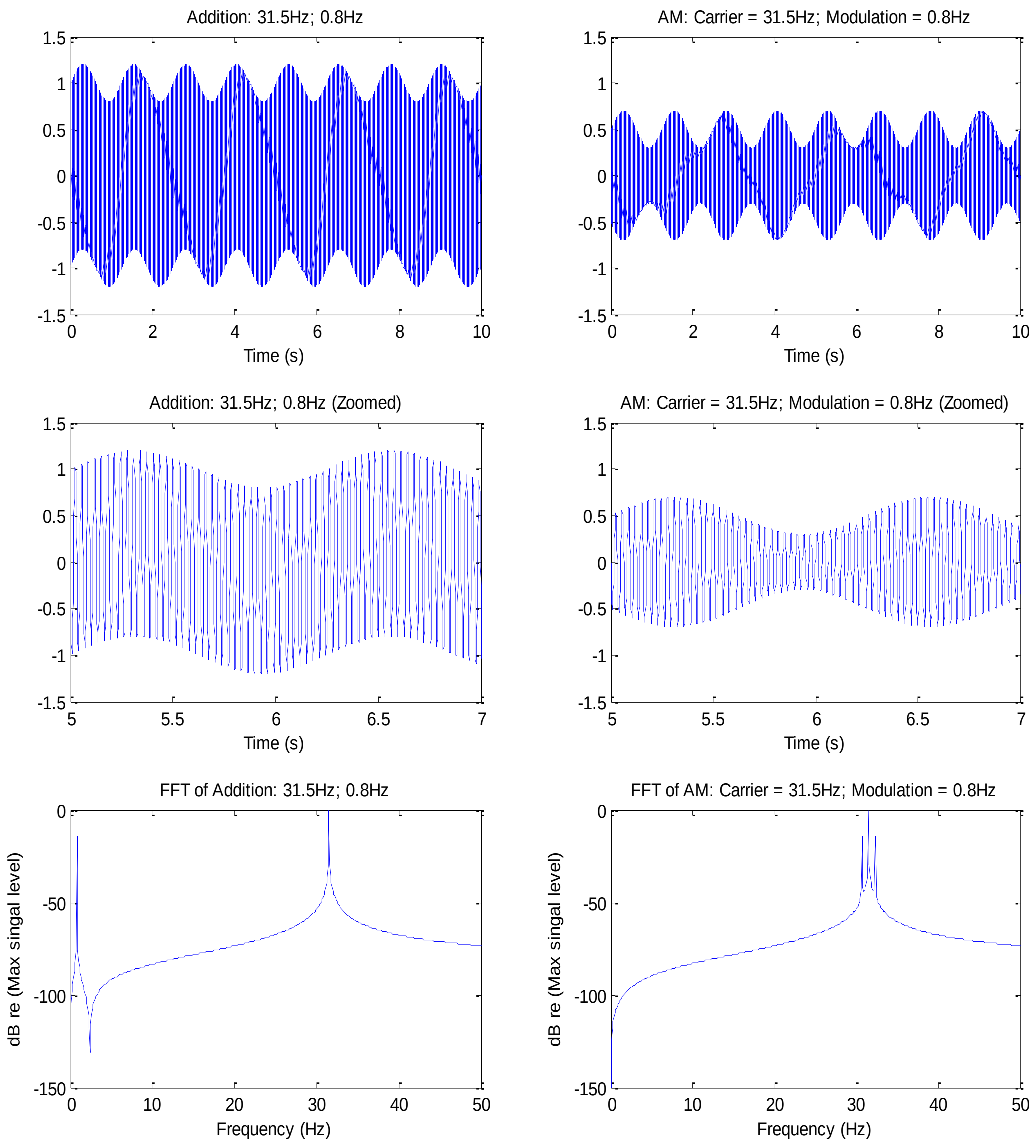


Figure V17: Two signals added linearly (Left) vs. AM Modulation (Right)

Figure V17 shows a time signal and frequency analysis comparison between signals which are linearly added and those which are modulated (i.e. non-linearly combined). The left-hand side graphs show the addition of the signals shown in Figure V11 and Figure V12 i.e. 31.5Hz and 0.8Hz tones. The right-hand side shows the AM modulation of the same signals.

No intermodulation terms are created when the two signals are added. The FFT of the addition of the signals shows only the discrete tones at 31.5 and 0.8Hz. Whereas the AM modulation shows the carrier frequency 31.5Hz with side bands of the modulation at 0.8Hz. Importantly for considering turbines the AM shows no 0.8Hz tone.

Blade Pass Frequency Signal

Using the theory presented in the analysis of wind turbine noise measurements an explanation is proposed of what is giving rise to the acoustic signature.

Frequently measurements for turbines when operating show peaks in the infrasound region associated with the blade pass frequency and its harmonics. The blade pass frequency and harmonics suggest there is a periodic signal at the blade pass frequency which is not a pure tone (the fact it has harmonic content suggests this). Generally the spectra show the first 4-5 harmonics of the nominal blade pass frequency, depending on prevailing wind conditions, with the fundamental frequency at Cape Bridgewater being approx. 0.85Hz.

An example of this concept is demonstrated in Figure V18 showing a linear averaged 10 minute FFT result of a measurement taken using a pressure detector in the living room of House 87. A sample of the time signal giving the FFT result in Figure V18 is shown in Figure V19.

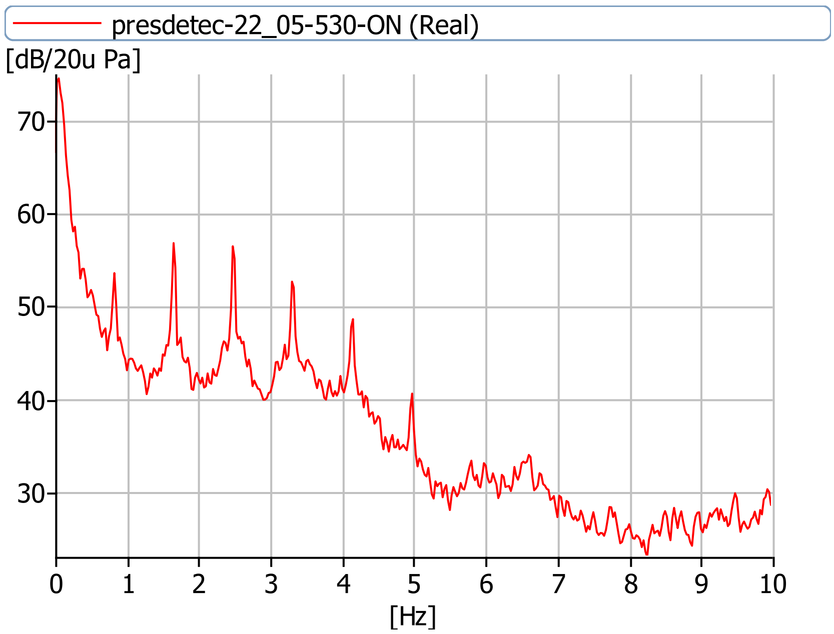


Figure V18: House 87 Pressure Detector – 22/05/14 05:30am (Turbines ON) - 10min FFT result

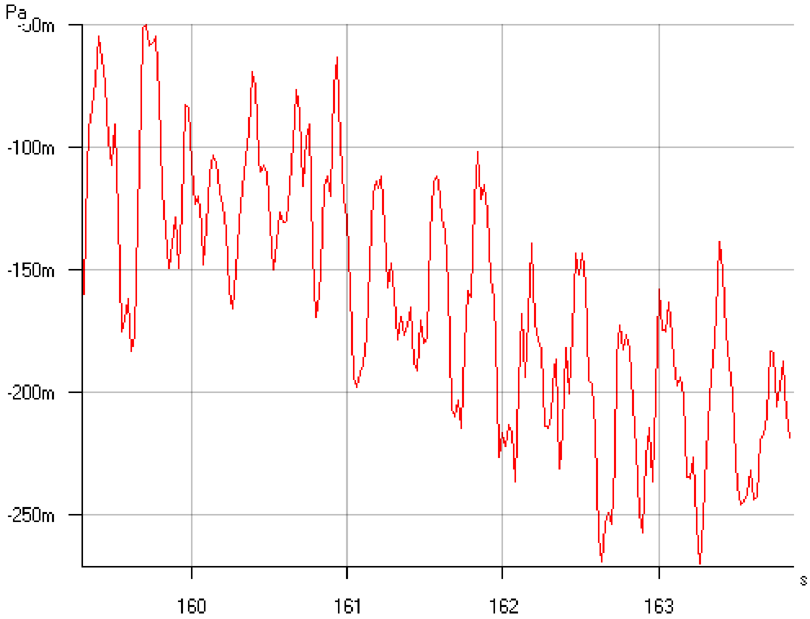


Figure V19: House 87 Pressure Detector – 22/05/14 05:30am (Turbines ON) – Time signal sample

By taking the amplitude at the peaks corresponding to the blade pass frequency and its harmonics an approximation to the underlying signal can be synthesised.

In Figure V20 the first fundamental and first 5 harmonics have been added to produce an approximation of the pressure signal responsible for the harmonic peaks seen in Figure V18.

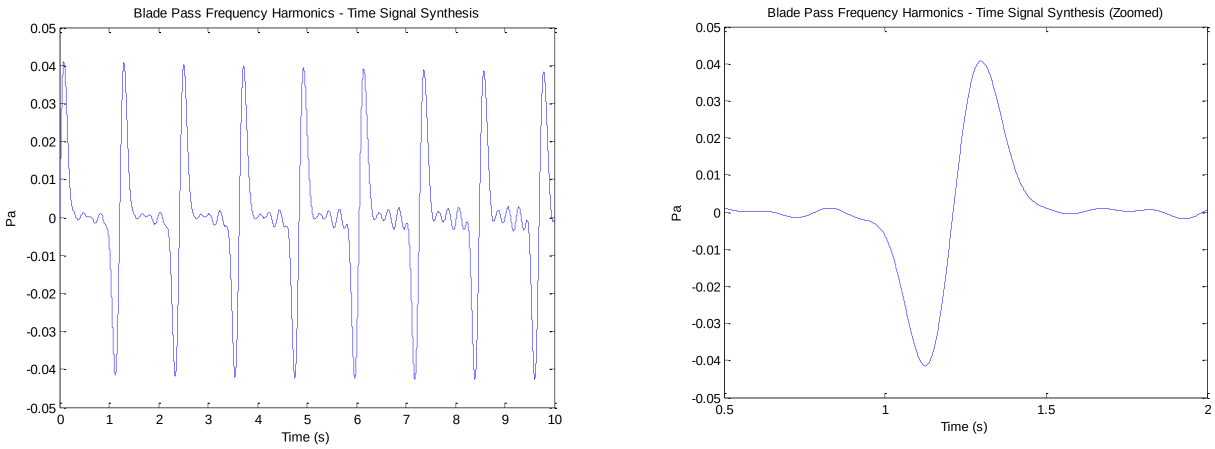


Figure V20: Blade pass harmonics time signal synthesis - House 87 Pressure Detector – 01/06/14 08:20pm

As discussed regarding the FFT results, it is possible that each sinusoidal tone used to synthesis the time signal shown in Figure V20 is the result of the harmonic components being discretely generated simultaneously, producing the time signal and FFT result. However considering the mechanics of a wind turbine, another possibility is that the harmonics of the blade pass frequency shown in FFT analysis are the result of a pulse wave at the blade pass frequency.

In many cases the FFT results that show the fundamental peak at the blade pass frequency is lower in magnitude than the magnitude of the harmonics. This is not explained by single pulse waves at the blade pass frequency, which would show the fundamental peak having the largest magnitude. However if one uses the hypothesis that a single turbine radiates a pulse like pressure disturbance at the blade pass frequency, then when considering measurements in the sound field of multiple turbines, one would need to consider phasing effects likely to occur due to the spacing of the turbines and the measurement position. The variation in the blade pass frequency and potentially the orientation of the turbines would also have an impact on the amplitude and phasing relationship of the harmonics.

The BFP in Figure V19 is not as obvious as it is when represented in Figure V20. However, due to the stochastic nature of the way multiple turbines interact and operate under this hypothesis when viewed from a purely acoustic measurement perspective, it is unlikely that the patterns that appear in the FFT would be observed by looking at time signals. This is in fact the utility of the FFT analysis, in that it can extract underlying patterns in a signal which contain stochastic processes (or randomness) which in this case includes the general ambient noise and wind effects. However it should also be noted that using linear averaged FFT results will be affected by wind gusts, which may mask the blade pass harmonics.

Variation in the speed of the turbines, phasing effects and turbine orientations further complicate the appearance of the time signal. These variations occur throughout the measurement period, causing any particular sample that is observed as a time signal to appear perhaps, as having random pressure fluctuations or no significance depending on the wind conditions and turbine operation.

Nonetheless, Figure V19 shows a general pulse like signal similar to that which may be expected. The peak-peak variation over a small period (i.e. excluding the slow variation) in Figure V19 is close to the synthesised peak-peak level (0.08Pa) in Figure V20.

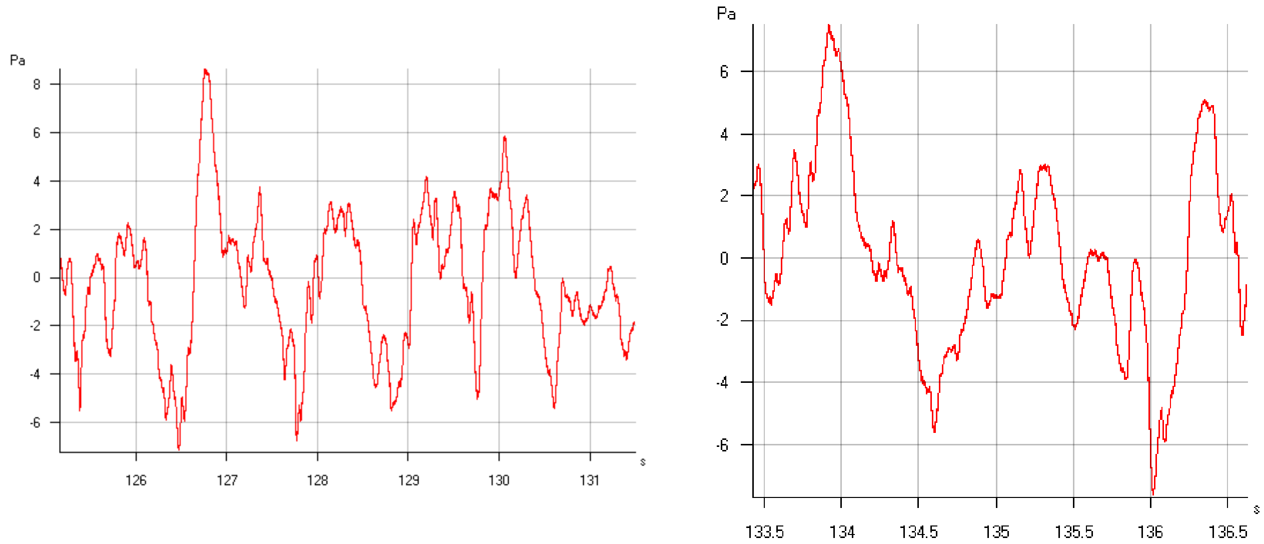


Figure V21: Turbine 13 – Downwind Centre (09/07/2014 3:46:19 PM) – Time signal samples

Figure V21 shows the results of the time signal recorded under CBW Turbine 13 where significant peak-peak pressure pulses similar in nature to those estimated in Figure V20. Not all of the time signals recorded around turbine CBW 13 exhibit the pulse characteristic shown in Figure V21 suggesting the infrasound noise source exhibits directionality.

If measurements were made to establish the acoustical nature of a pressure pulse occurring from a turbine, it is suggested that the measurements were in the field of only a single turbine. The measurements should specifically identify any operational variation and directionality effects that occur, to ensure an accurate model is obtained.