23rd International Congress on Acoustics

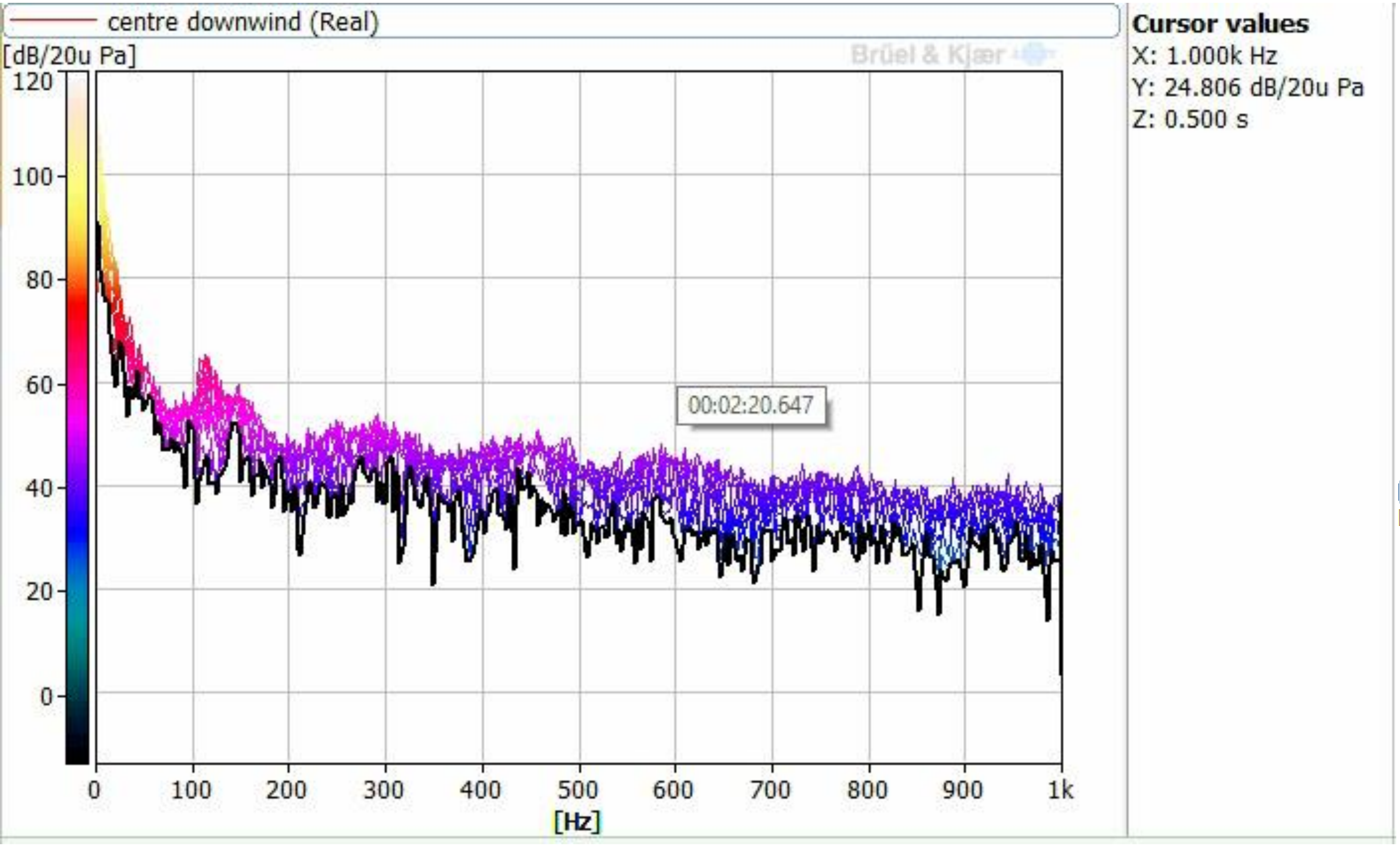
The Acoustic Group

CONSULTING ACOUSTICAL AND VIBRATION ENGINEERS

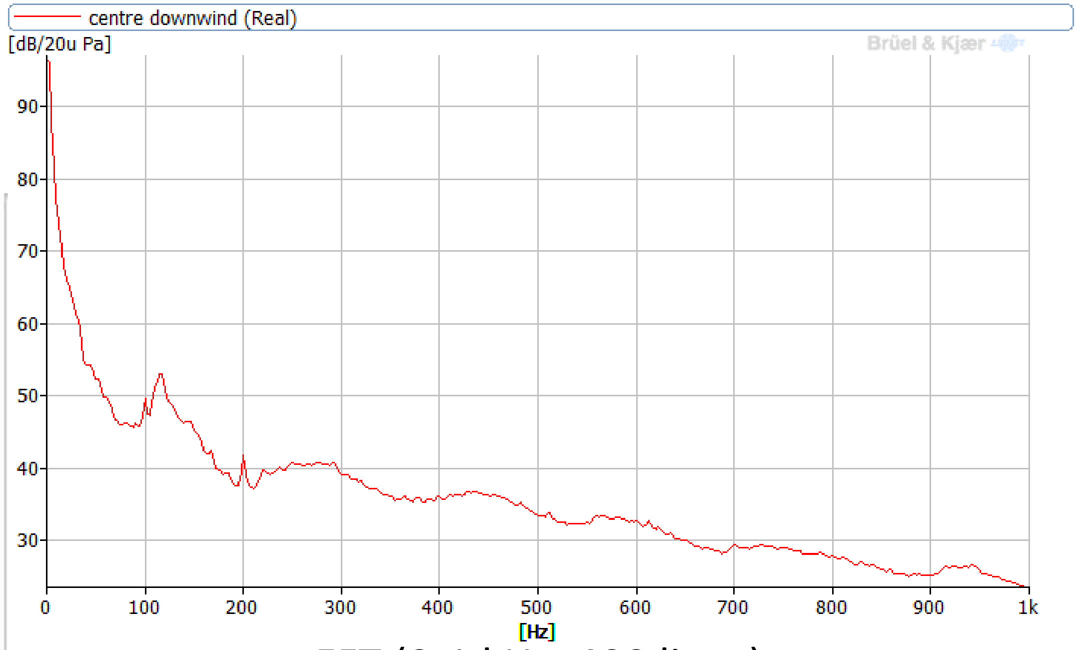
The use of synthesised or actual wind turbine noise for subjective evaluation purposes

Steven Cooper

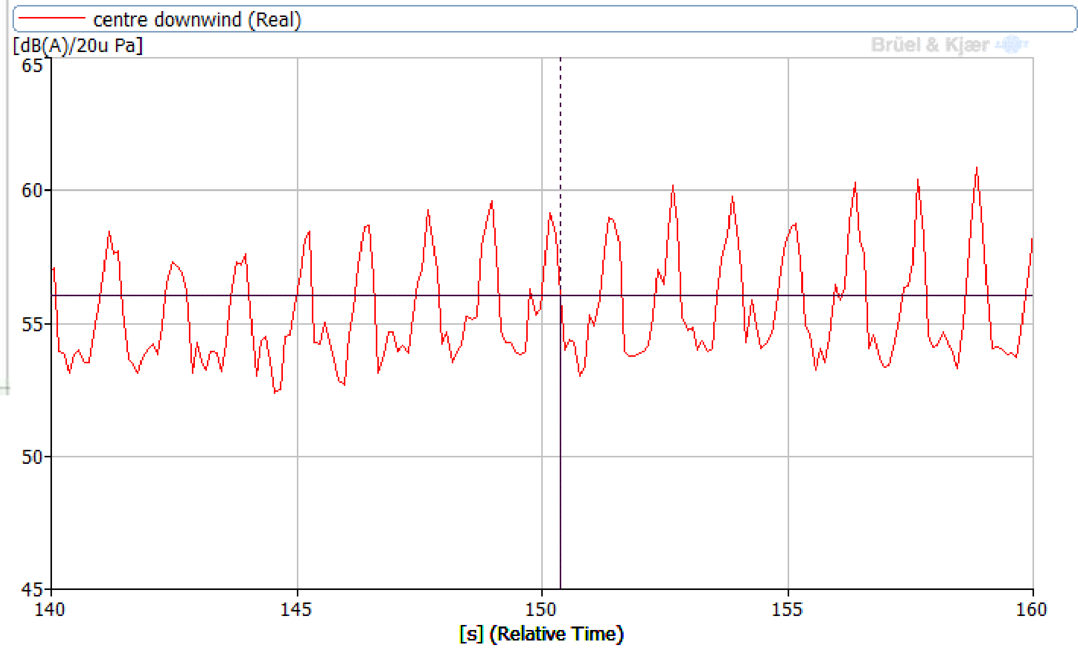
CBW Turbine 13 at 14% power



FFT vs Time (0-1 kHz, 400 lines)

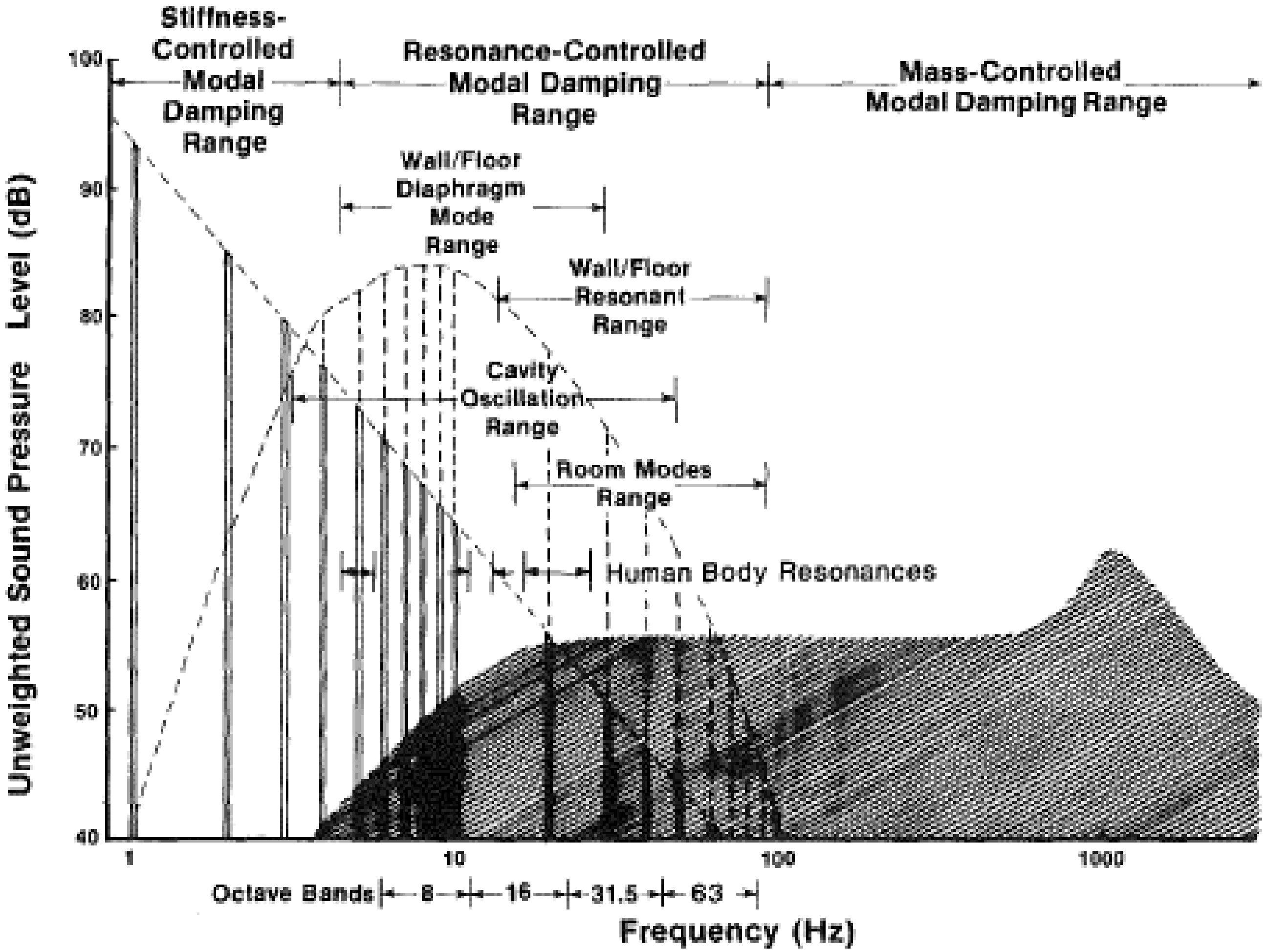


FFT (0-1 kHz, 400 lines)



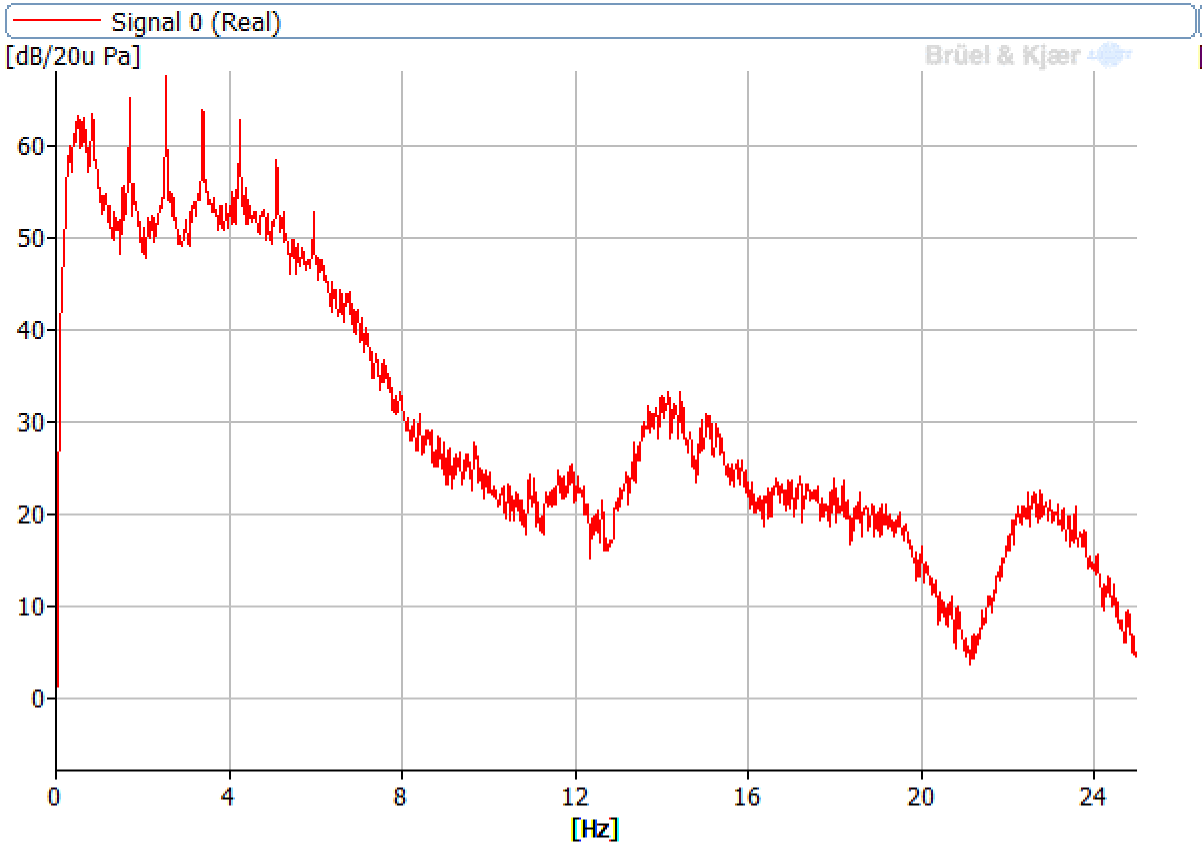
A-weighted Time Splice

Kelley N.D., Hemphill R.R. and McKenna H.E. A Methodology for Assessment of Wind Turbine Noise

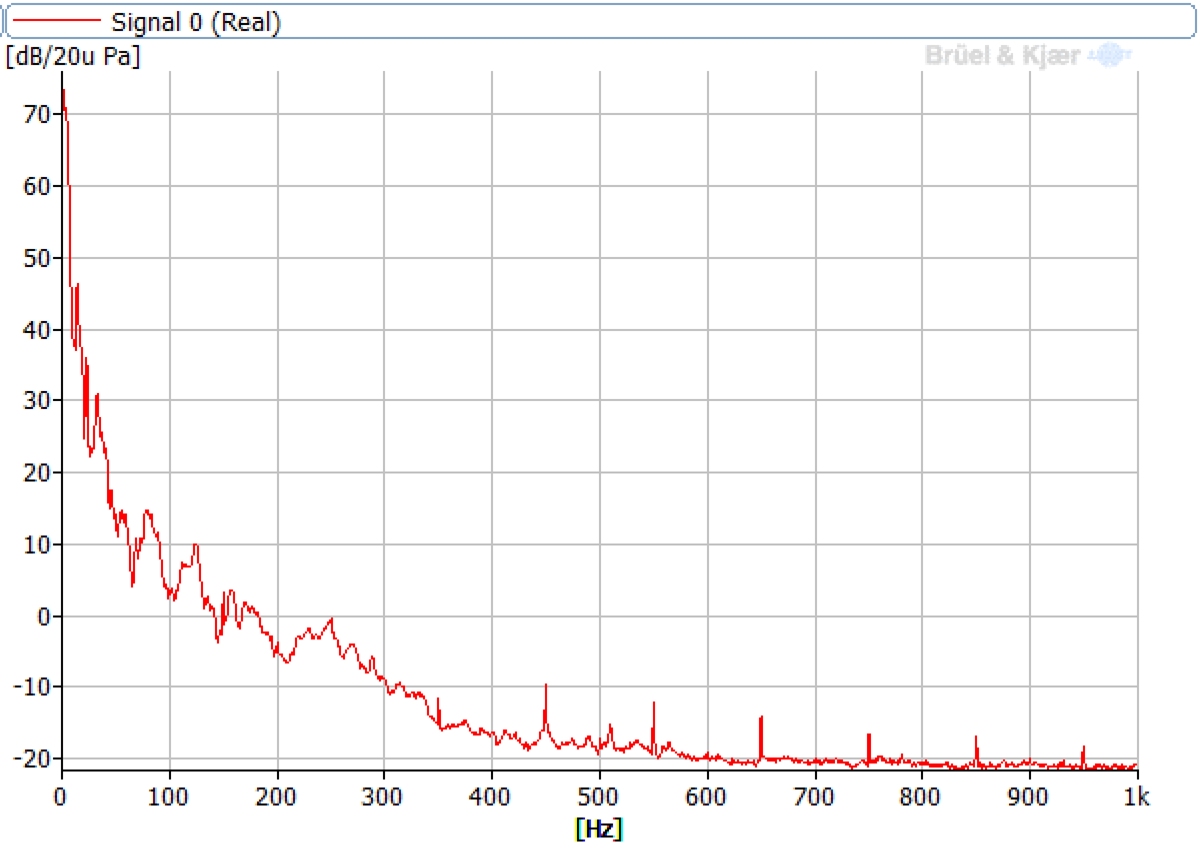


Turbine noise emission components with building and human body resonances superimposed

Cape Bridgewater Wind Farm, House 87 Bedroom, 5:30 am 22 May 2014, $L_{eq,\ 10\ minute}$ FFT (1600 lines)

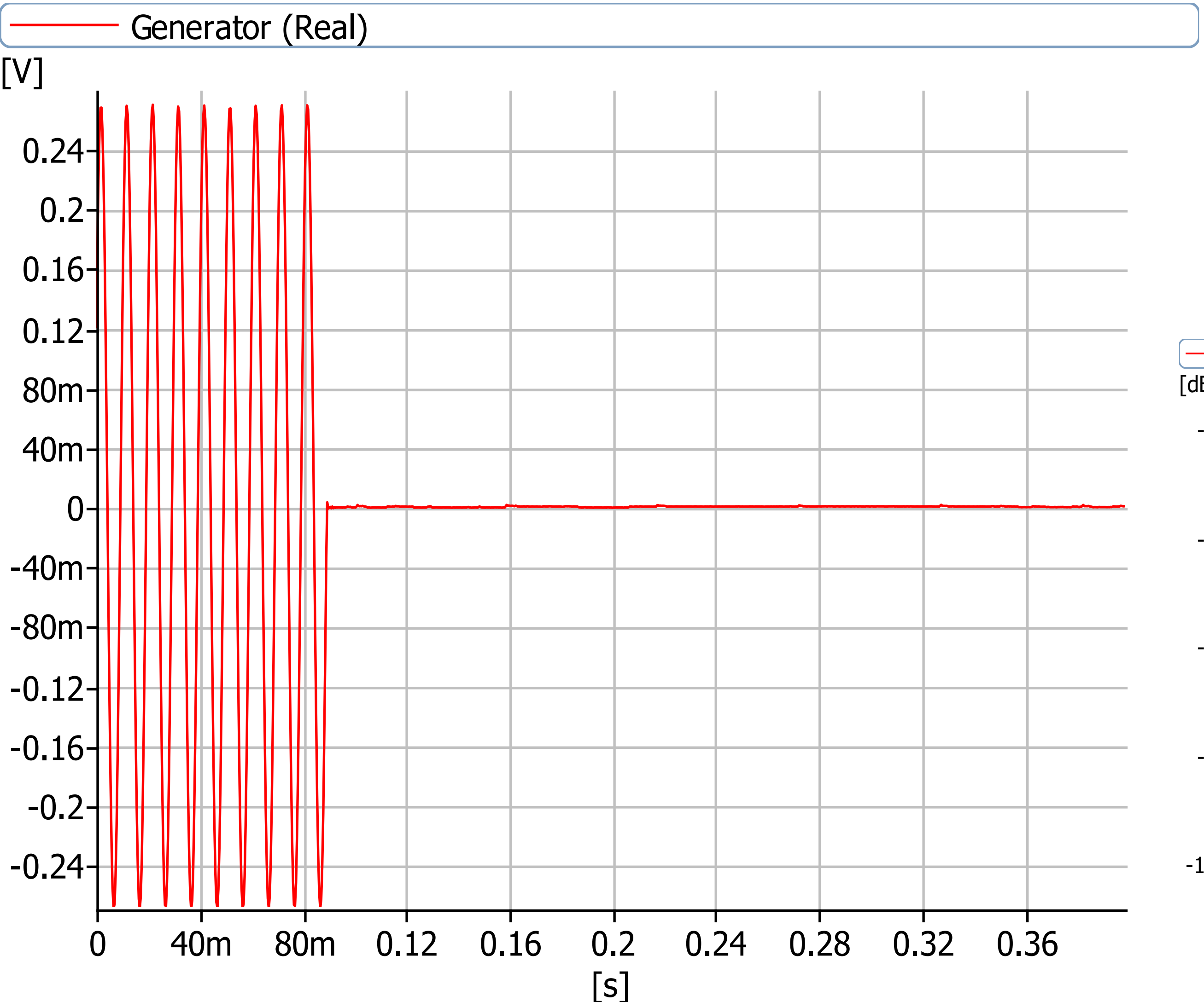


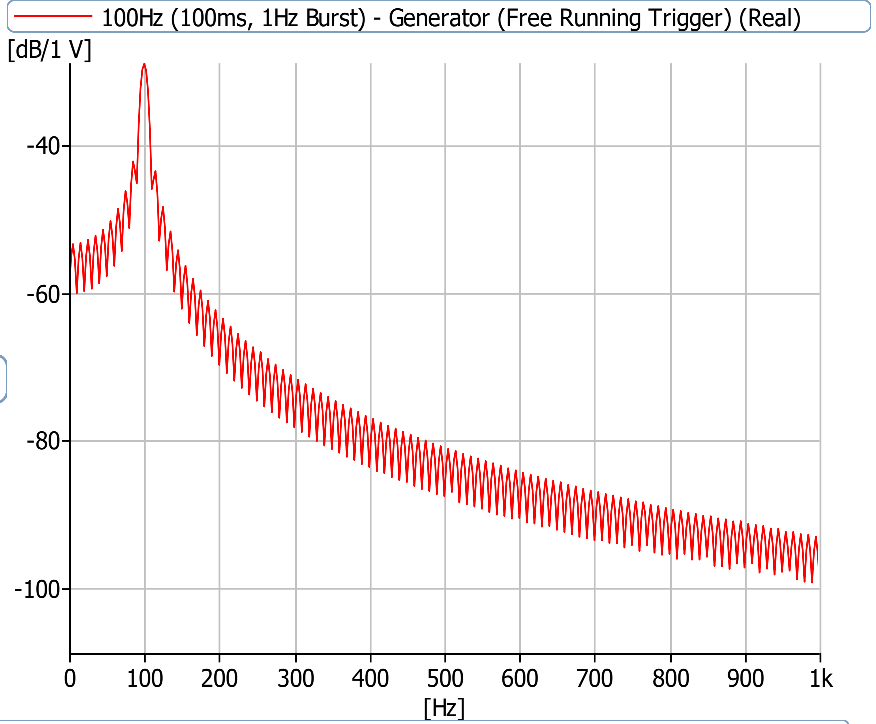
0 – 25 Hz

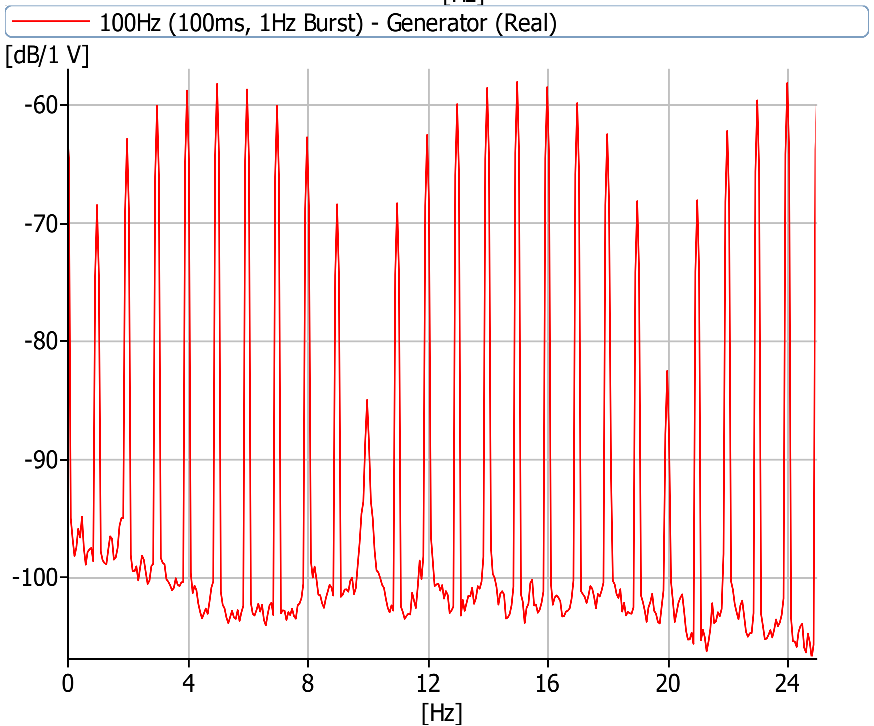


0 – 1 kHz

100 Hz 100 ms Burst







Health Psychology

0278-6133/13/$12.00 http://dx.doi.org/10.1037/a0031760

Can Expectations Produce Symptoms From Infrasound Associated With Wind Turbines?

Fiona Crichton, George Dodd, Gian Schmid, Greg Gamble, and Keith J. Petrie
University of Auckland

Method

A total of 54 university students (34 women, 20 men) were exposed to 10 min of infrasound and 10 min of sham infrasound (no sound). Exposure sessions, which were counterbalanced, were conducted at the Acoustic Research Centre University of Auckland, in a listening room designed for subjective listening experiments and constructed to International Electrotechnical Commission standards (IEC 268–13). Infrasound transmitted during exposure sessions (40dB at 5Hz) was created using a combination of the Adobe® Audition software package with a Presonus® Firepod audio interface, and a Mackie® HR 150 active studio woofer. Participants were told they were being exposed to infrasound during both 10-min exposure sessions and the experimenter was also unaware when exposure was to infrasound or to sham infrasound.

Health Psychology

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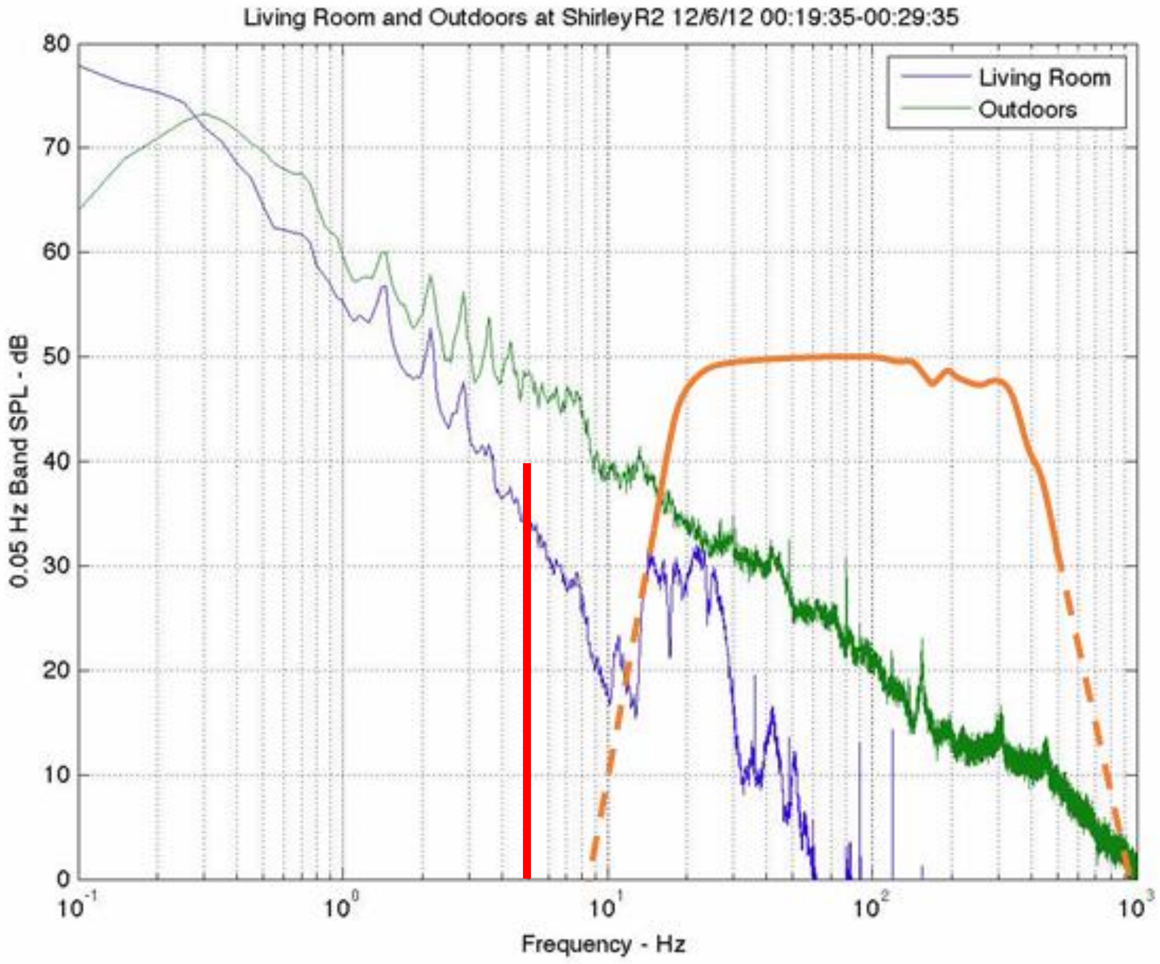
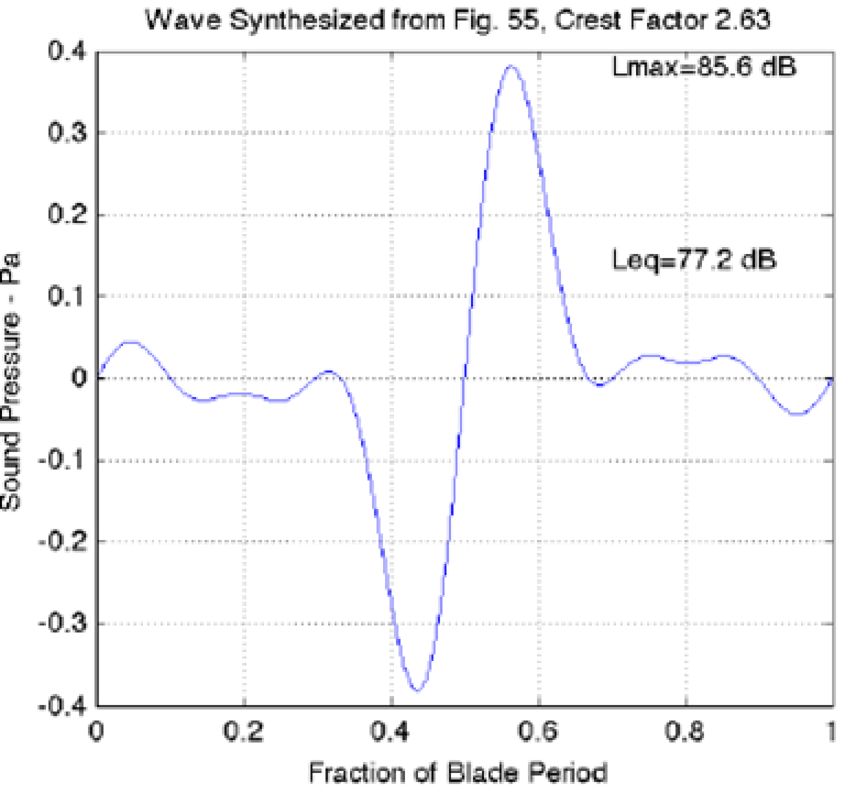
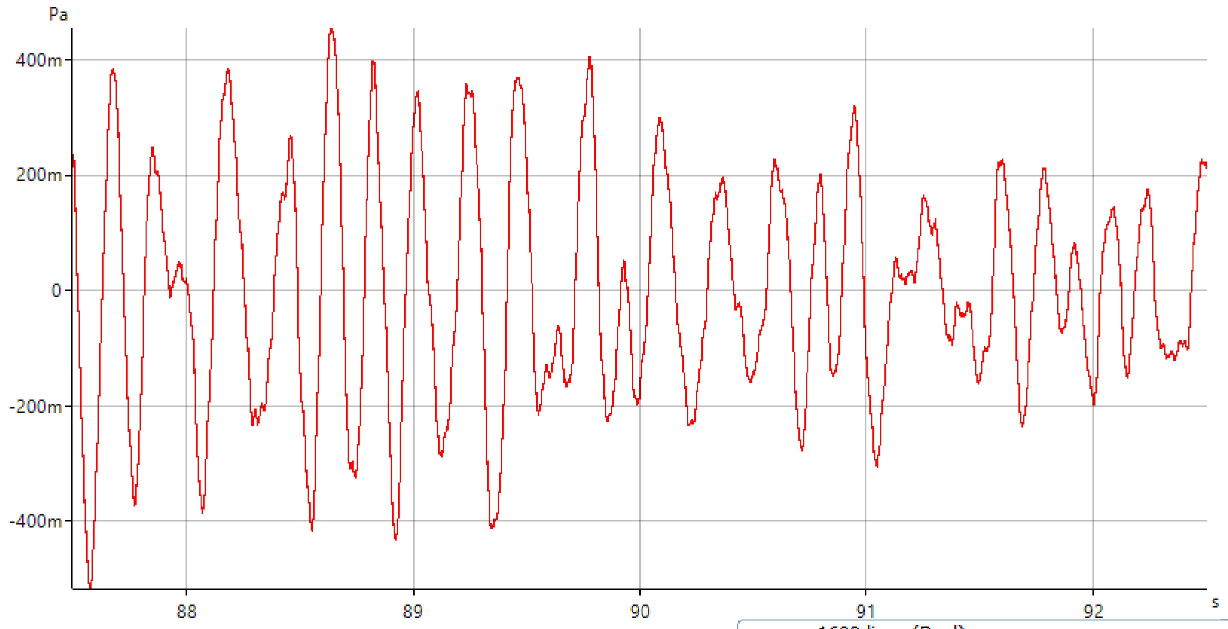


Shirley Wind Farm Report with manufacturers frequency response of speaker used in Crichton paper shown in orange trace

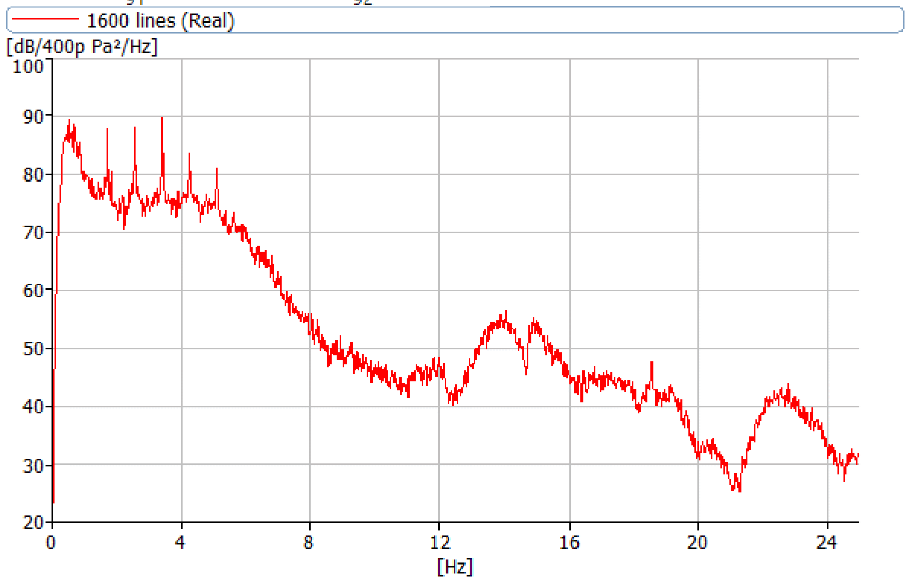
Walker B & Celano J "Progress Report on Synthesis of Wind Turbine Noise and Infrasound"



Walker Synthesised Waveform



Original Waveform



Original FFT (1600 lines, 0-25 Hz)

Original Article

Journal of LOW FREQUENCY NOISE, VIBRATION AND ACTIVE CONTROL

Journal of Low Frequency Noise, Vibration and Active Control
2016, Vol. 35(1) 77–90

DOI: 10.1177/0263092316628257
lfn.sagepub.com

SAGE

The effect of infrasound and negative expectations to adverse pathological symptoms from wind farms

Renzo Tonin[1], James Brett[2] and Ben Colagiuri[3]

Abstract

An investigation was conducted on the effect of reported pathological symptoms of simulated infrasound produced by wind turbines. There is ongoing debate in the scientific community concerning the cause of the negative health effects reported by people living near wind farms, whether those effects are caused by the infrasound itself, or alternatively by a psychogenic response (such as a nocebo effect) to a presumption that the infrasound is the cause. In this study, a simulated wind turbine infrasound pressure waveform was generated using a custom-built headphone apparatus. Volunteers were influenced into states of high expectancy of negative effects from infrasound, and low expectancy of negative effects and their reactions to either infrasound or a sham noise were recorded. It was found, at least for the short-term exposure times conducted here-in, that the simulated infrasound has no statistically significant effect on the symptoms reported by volunteers, but the prior concern volunteers had about the effect of infrasound has a statistically significant influence on the symptoms reported. This supports the nocebo effect hypothesis.

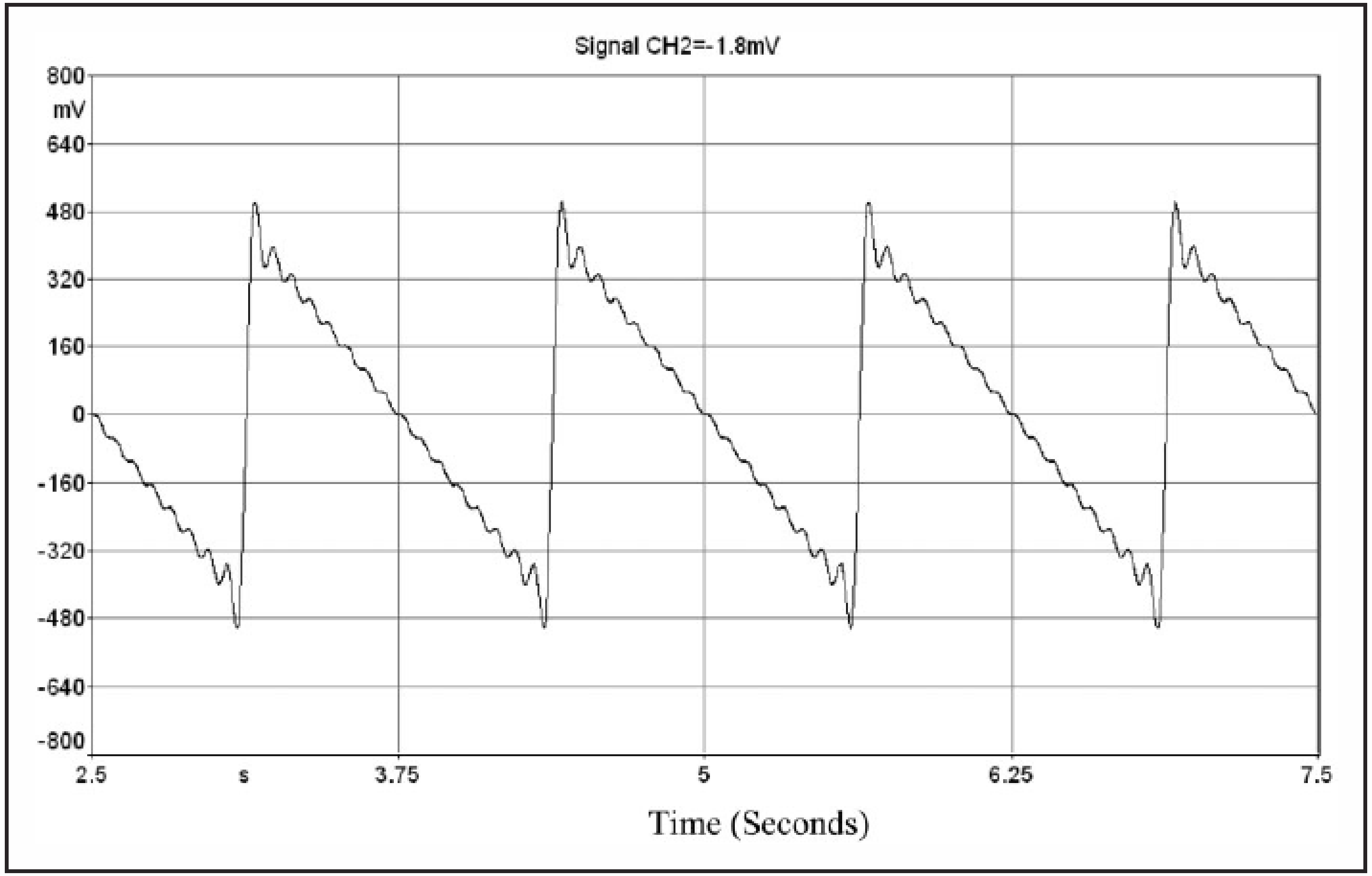
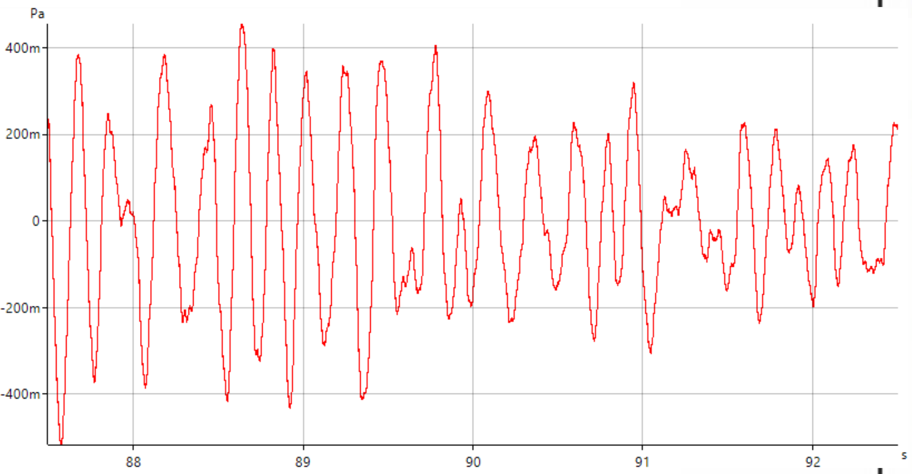


Figure 1. Infrasound signal used in experiment.

Cooper Results (field measurements)

Tonin Results (synthesised)



Waveform

FFT (0-25 Hz, 1600 lines)

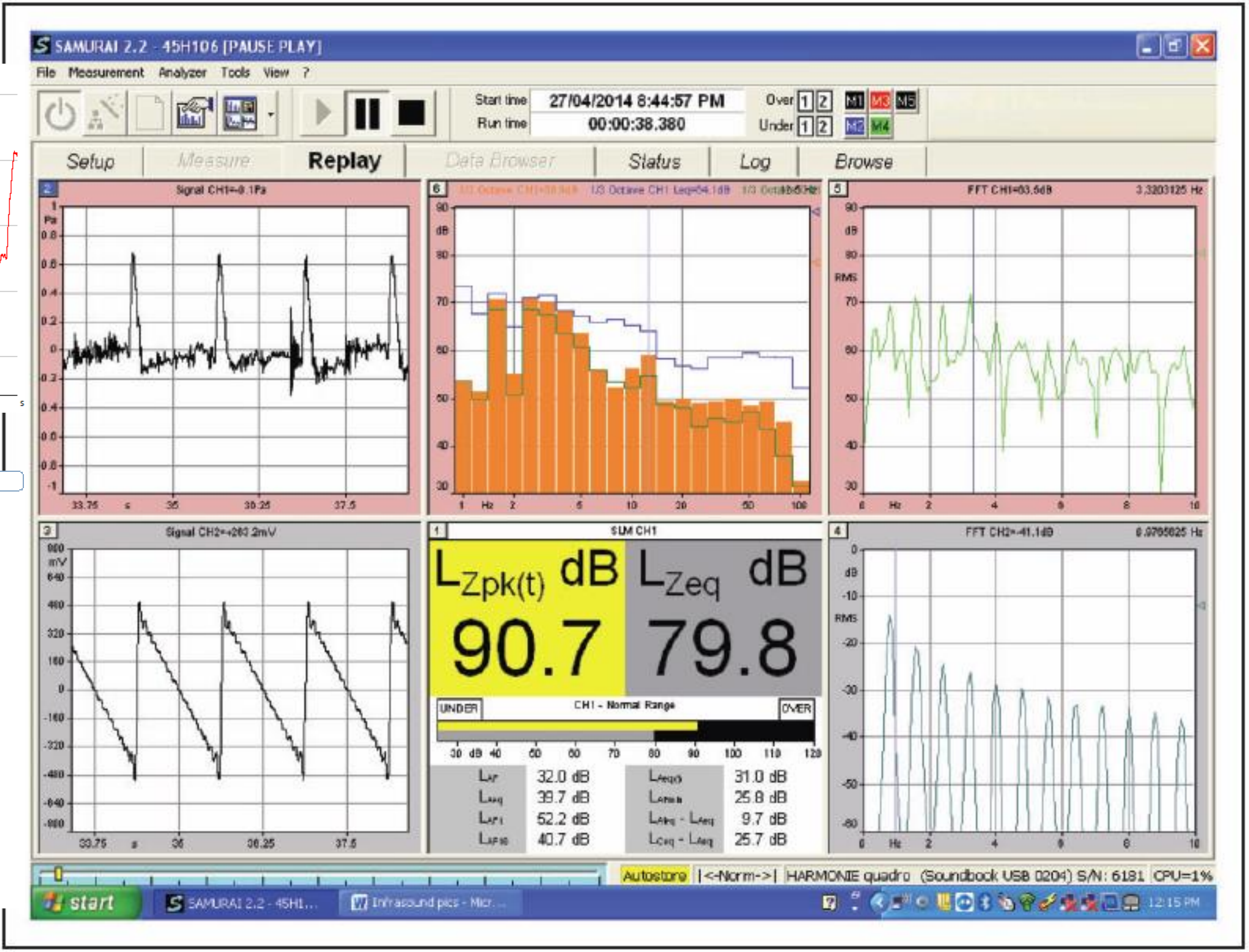


Figure 6. Soundbook with SAMURAI 2.0 software display during typical test.

Annexure D of ANSI/ASA S12.9-2016/Part 7 "Advanced Signal Processing Techniques"

It has been observed (Bray, Swinbanks, Walker, et al) that for complex low-frequency signals (those comprising multiple frequencies), the temporal relationship between the components can have a significant influence on their subjective assessment. (Indeed, al one needs do is listen to the difference between a gun-shot and an extended Galois sequence signal to observe the two signals with the exact same spectrum can sound dramatically dissimilar.)

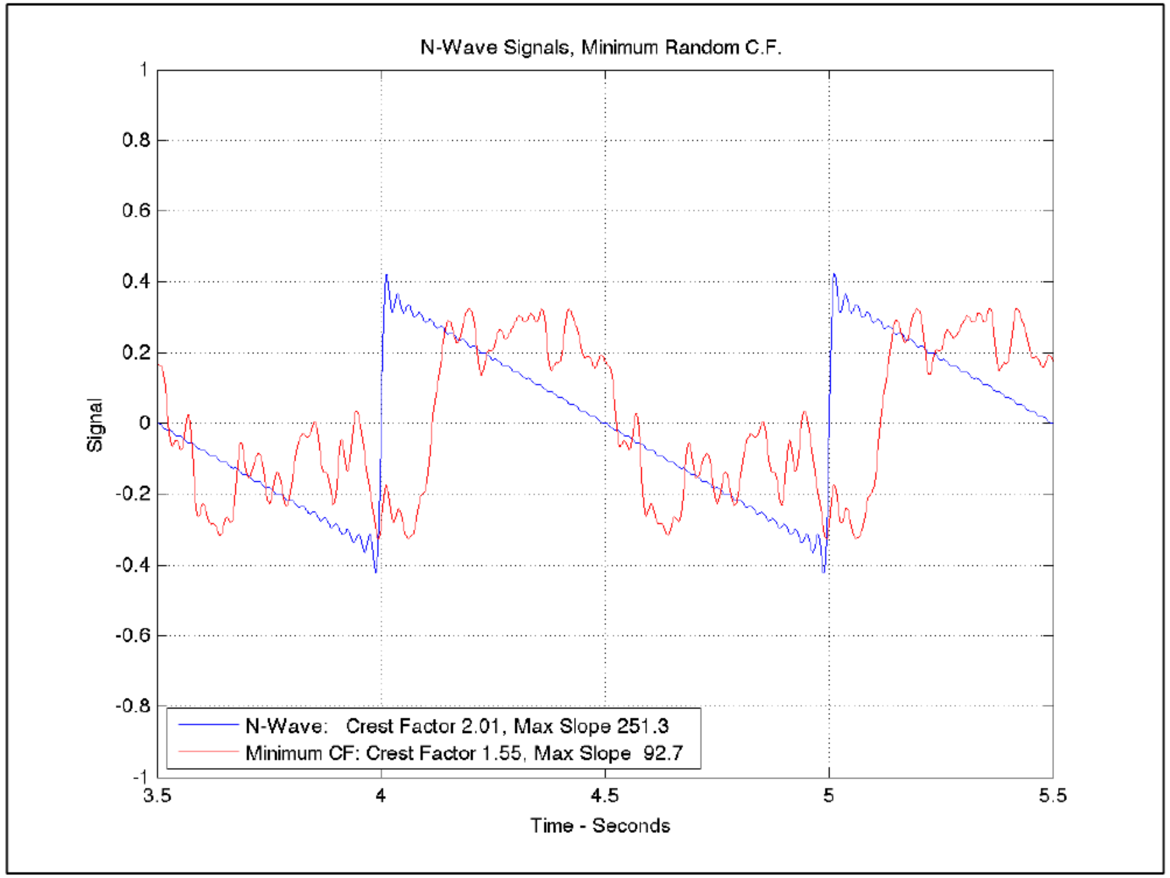


Figure D.1 – Two signals with exact same power spectrum and (therefore) autocorrelation function

Conclusion

- Testing of wind turbine infrasound should use actual signals of wind turbines and not a tone or a synthesised signal
- Infrasound levels attributed to wind turbine noise are less than the threshold of audibility for constant tones and therefore should be inaudible. Why test for infrasound only when wind turbine noise contains frequencies in the audible spectrum? The infrasound signature obtained by narrowband FFT analysis is the result of an analysis of transient pulses that can be derived by modulating sounds of much higher frequency
- For testing of wind turbine noise (including infrasound?) in a more practical sense, would be easier and realistic to simply use wave file recordings

REPRODUCTION OF WIND TURBINE INFRASOUND AND LOW FREQUENCY NOISE IN A LABORATORY

Presented at the 173rd Meeting of the Acoustical Society of America (Boston, Massachusetts)

Steven Cooper, The Acoustic Group, Australia
drnoise@acoustics.com.au

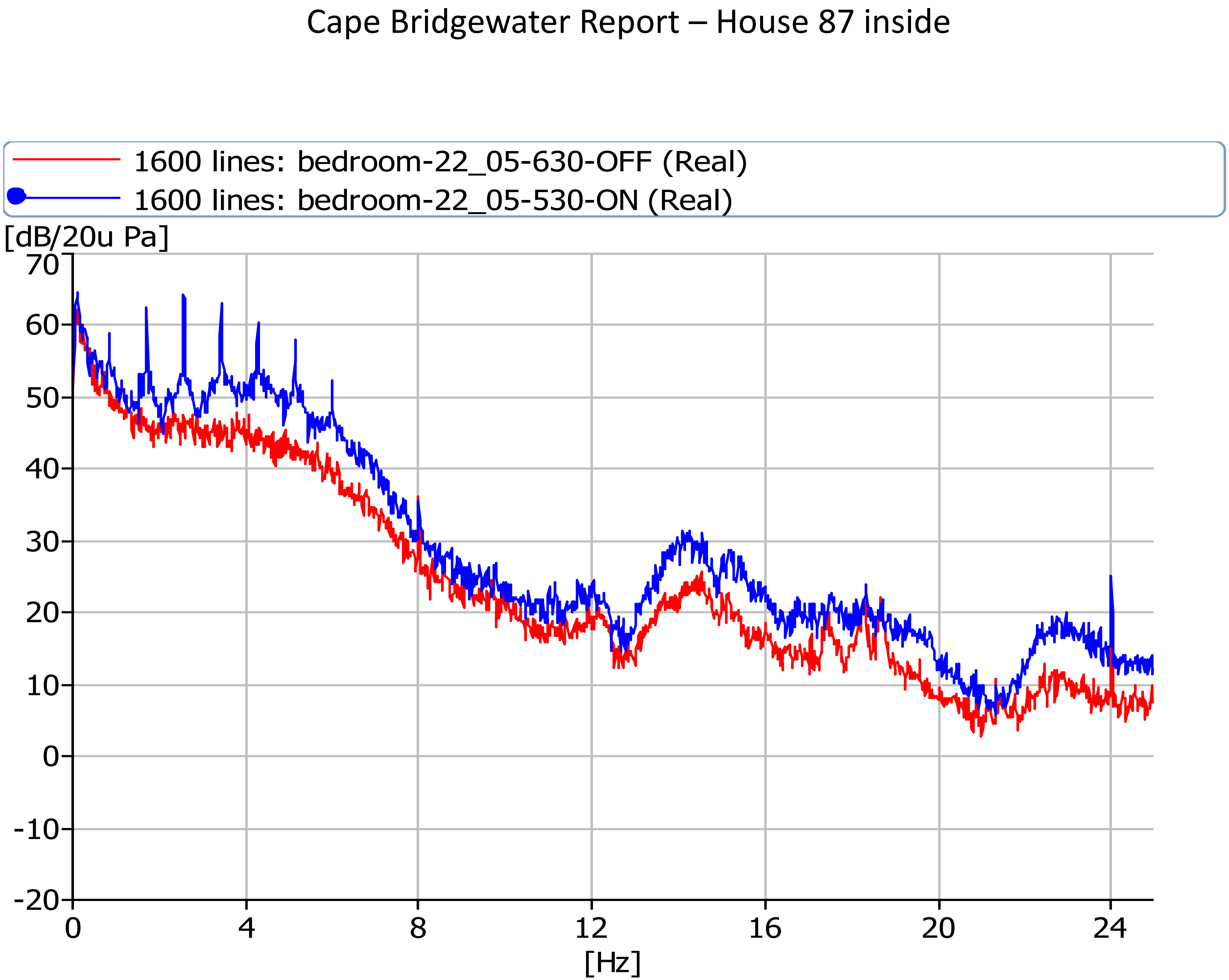
Issues of concern with the use of real infrasound or simulated “infrasound”

- Accurately reproducing the signal by the use of headphones or speakers. (D-A convertor, amplifiers and speaker/headphone response, transient response of pulsations)

- “infrasound” applied as single tones and attributed to wind farms

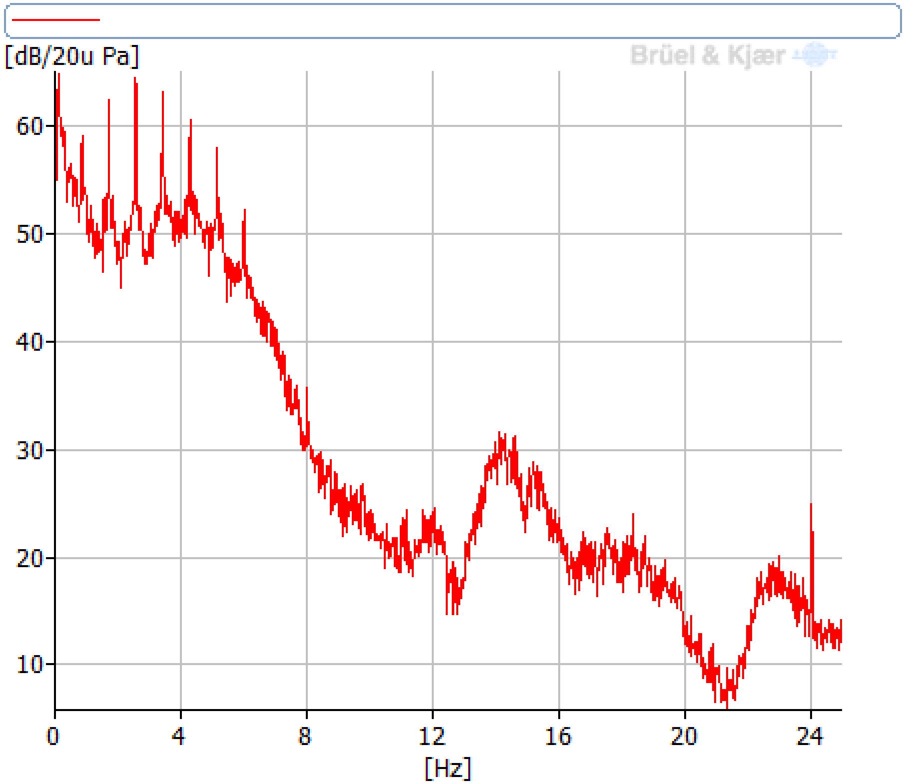
- Whether the synthesised signal (obtained from adding sine waves) reproduces the actual time signal that occurs in the field.

- Testing using synthesised signal and claiming the results apply to wind farms.

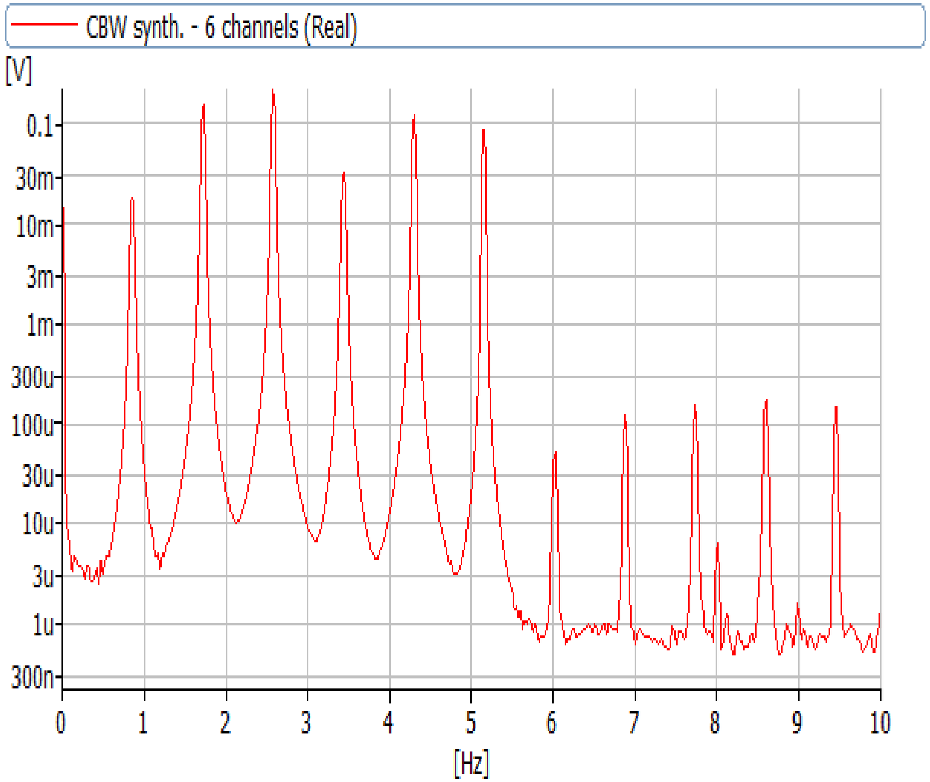

Cape Bridgewater Report – House 87 inside
1600 lines: bedroom-22_05-630-OFF (Real)
1600 lines: bedroom-22_05-530-ON (Real)
[dB/20u Pa]
70
60
50
40
30
20
10
0
-10
-20
0
4
8
12
16
20
24
[Hz]

Synthesis

House 87 Bedroom – 22 May 5:30 am



Graph from part 1



Combined output of 6 signal generators
B & K Pulse system in proportion to left figure

Mackie HRS 150

Specifications

Transducers

Low-frequency driver

Diameter:	15 in/381 mm
Sensitivity:	96 dB SPL (1 W, 1 M)
Nominal Impedance:	8 ohms
Voice Coil Diameter:	4 in/100 mm
Power Handling (Long Term/Program):	400/1000 watts
Frequency Range:	20 Hz to 500 Hz
Frame:	Die Cast
Magnet:	Ferrite

Passive Radiators (2)

Diameter:	12 in/305 mm mass-loaded

System Specifications

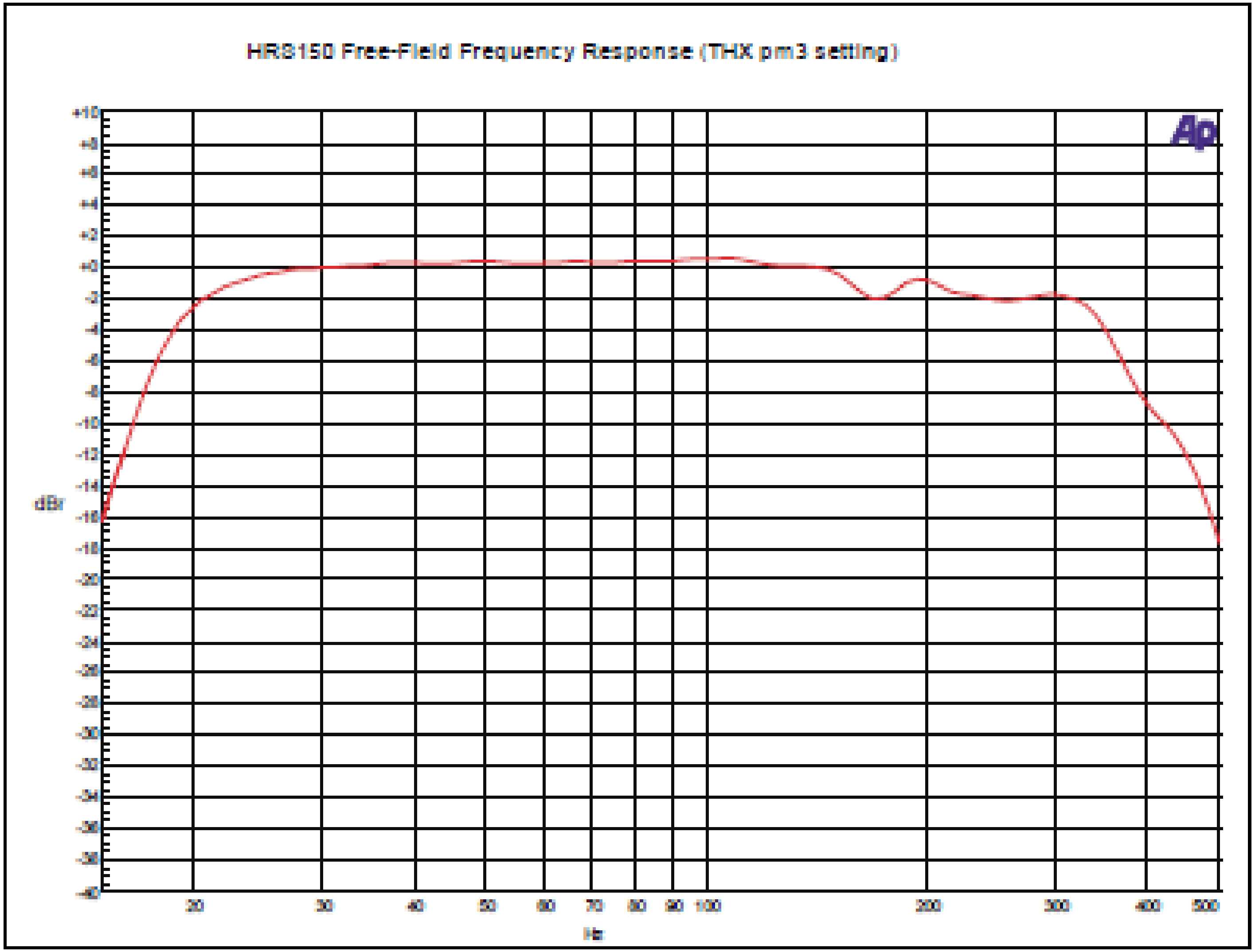
Crossover Type:	Linkwitz-Riley, 24 dB/octave, variable 55 Hz to 110 Hz
Input Type:	Balanced Differential (XLR), Unbalanced (RCA)
Input Impedance:	20 kΩ (Bal), 10 kΩ (UnBal)
Input Sensitivity:	89 dB SPL with a 100 mV (–17.8 dBu)

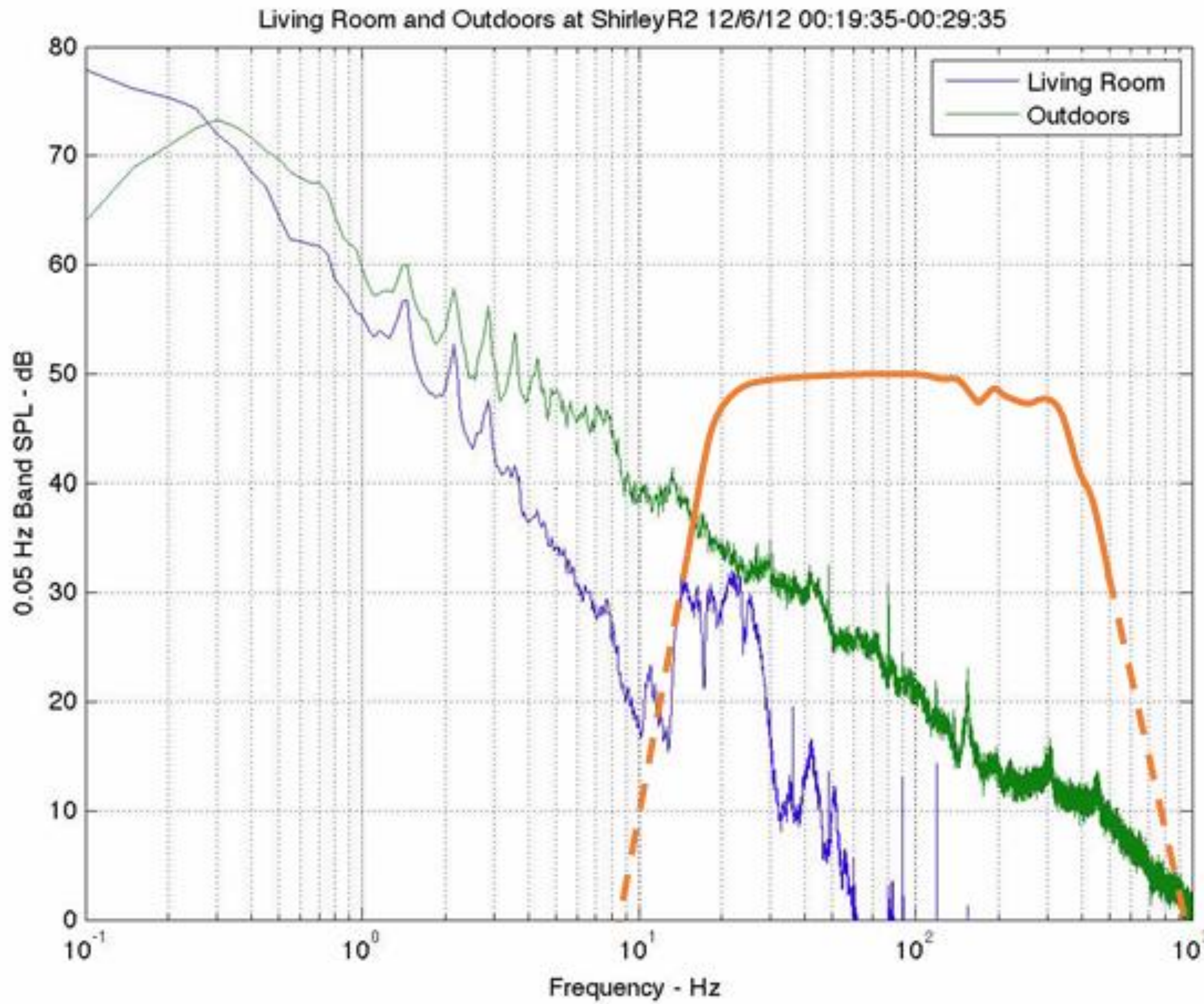
Acoustic Section

Acoustic Frequency Response:	20 Hz to 150 Hz, ±1.5 dB
–3 dB points:	19 Hz, 250 Hz
Maximum SPL:	122 dB @ 1 meter
Residual Noise:	< 8 dBA SPL

Power Amplifier Section

Rated Power Output (1% THD at 100 Hz):	950 watts rms into rated 8Ω load
Peak Power Output (100 Hz sine, Per RS-490):	1050 watts
THD (20 Hz to 300 Hz from 1 W to –1 dBr = 750 W):	< 0.05% (typically 0.007%)
Rated Load Impedance:	8 Ω
Signal-to-Noise Ratio:	107 dBr (0 dBr = 750 W)
Power Bandwidth (at 750 W):	–0.5 dB at 10 Hz –3.0 dB at 55 kHz
Damping factor (referenced to 8 Ω):	> 1000
Turn-On delay:	3-4 Seconds
Cooling:	Convection


HRS150 Free-Field Frequency Response (THX pm3 setting)
dBr
Hz
+10
+8
+6
+4
+2
+0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
-32
-34
-36
-38
-40
20
30
40
50
60
70
80
90
100
200
300
400
500


Living Room and Outdoors at ShirleyR2 12/6/12 00:19:35-00:29:35
0.05 Hz Band SPL - dB
Frequency - Hz
Living Room
Outdoors
80
70
60
50
40
30
20
10
0
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}

Walker
(Ref 2)

Figure 4. In-situ photo of synthesis system loudspeakers

Walker
(Ref 2)

Figure 6. Results of synthesis system frequency response measurement

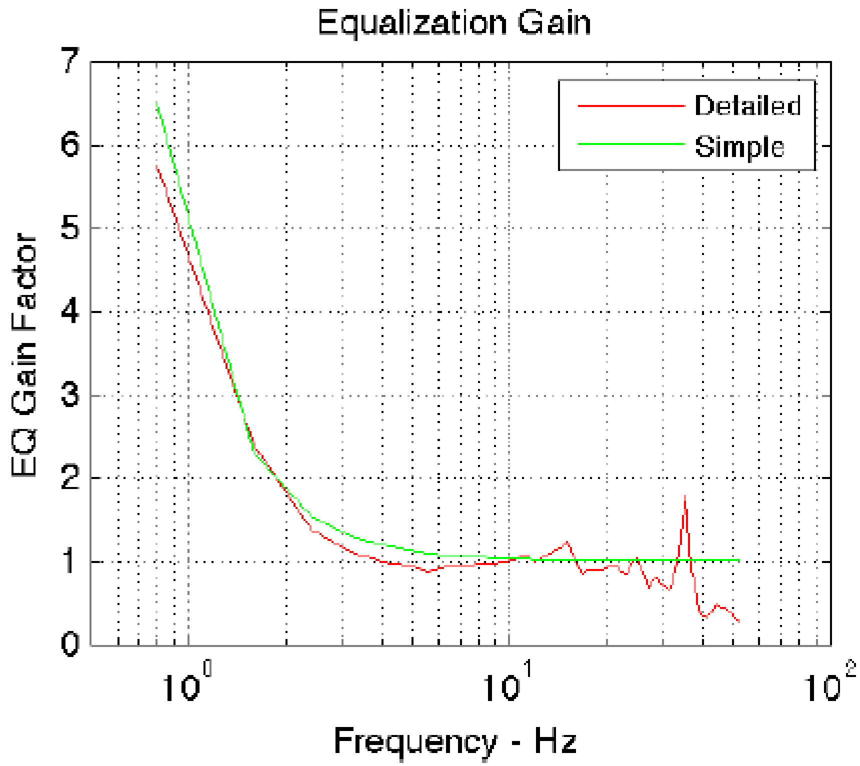


Figure 7. System equalization gain and phase

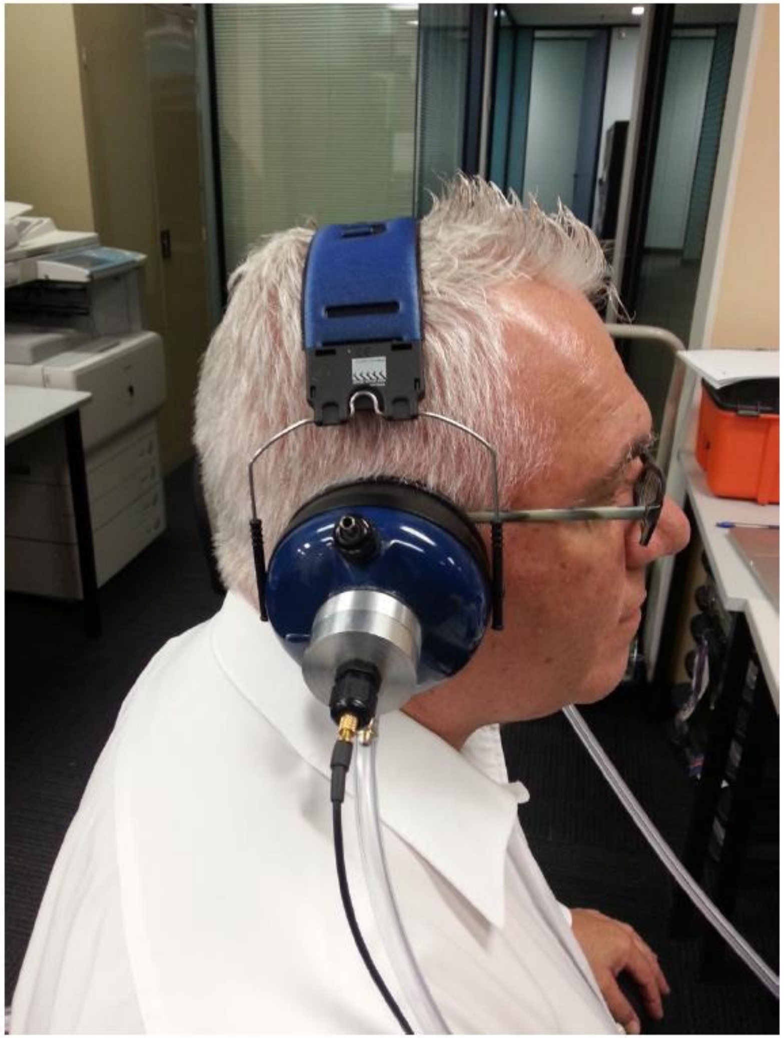


Figure 2 Complete acoustic headphones including 6mm nozzles on both ears with attached tubing, microphone and occlusion port (located just above the silver coloured microphone attachment).

Tonin
(ref 4)

Tonin
(ref 4)

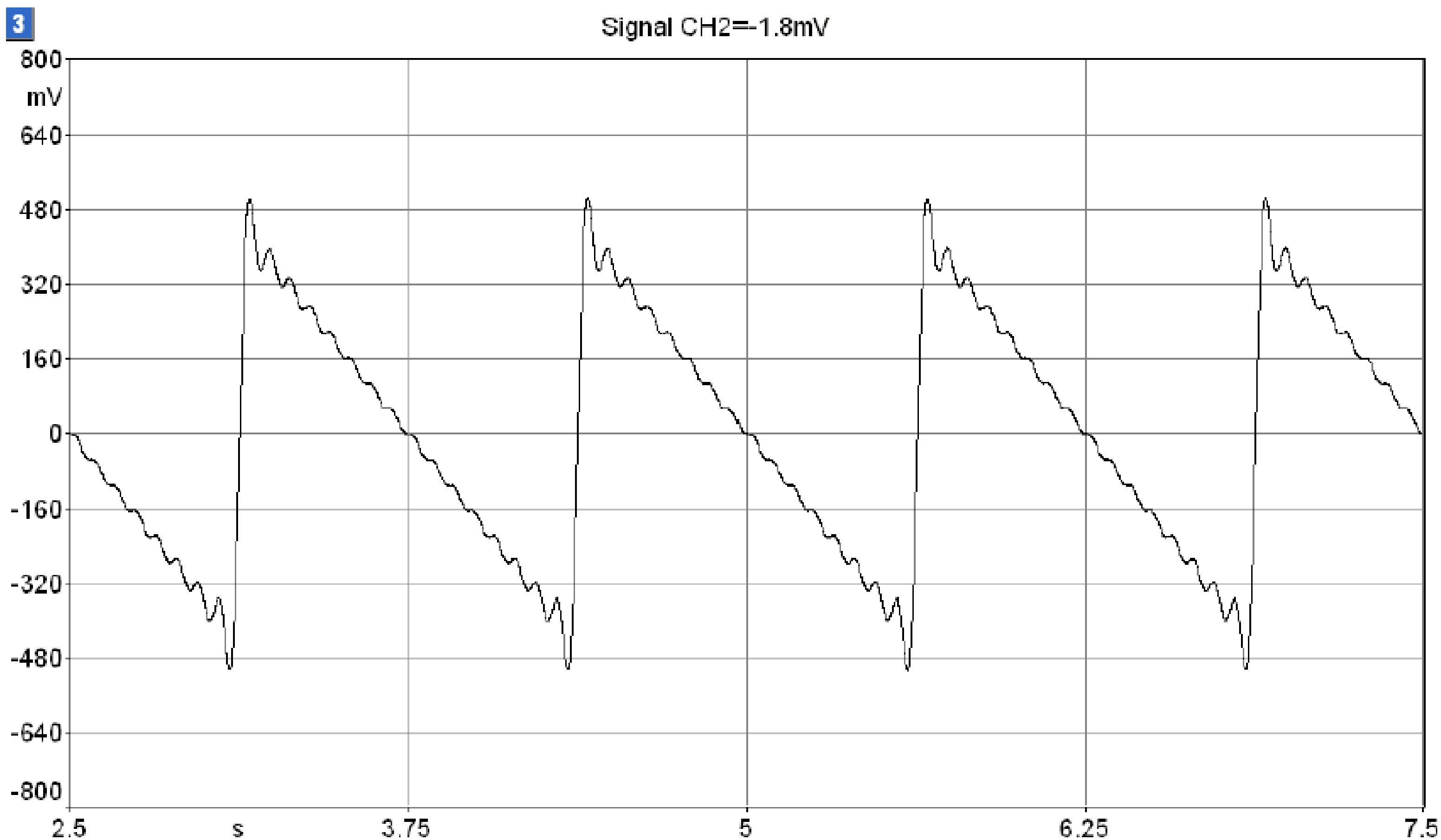
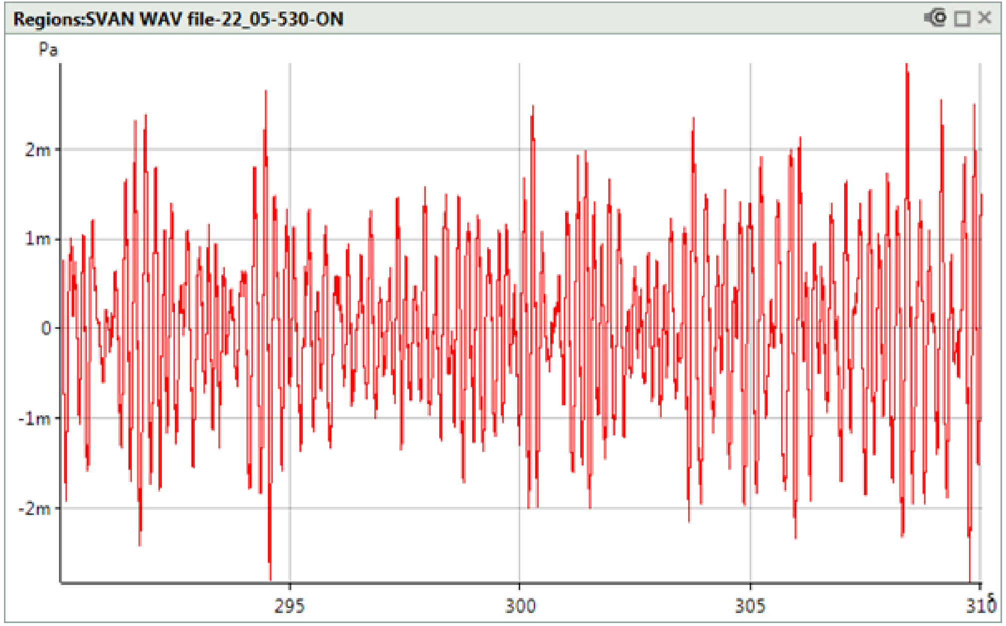
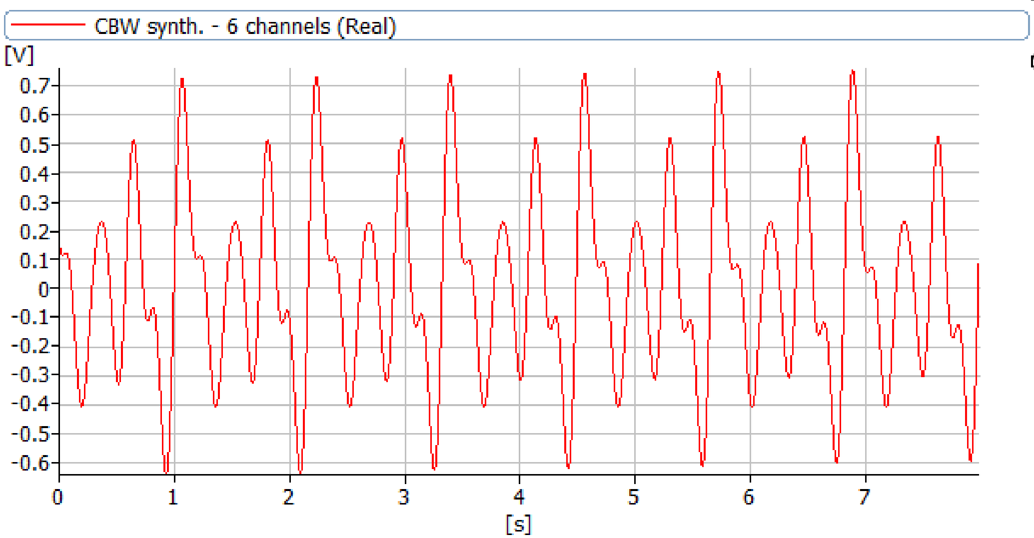


Figure 1 Infrasound signal used in experiment

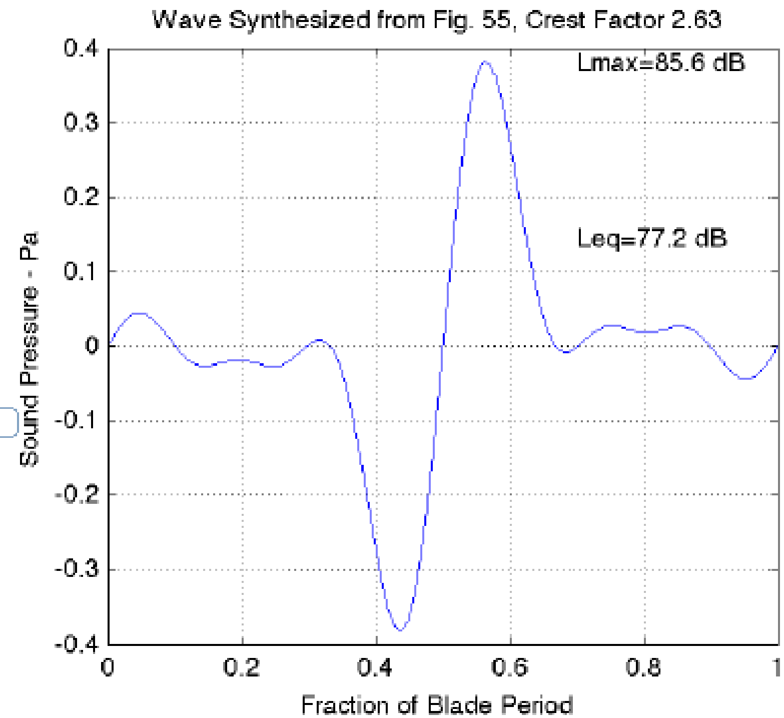
Time signals



Field Measurement



Synthesis



Walker

Tachibana
(Ref 1)

Picture 1 Loudspeaker system and the listener's position in the receiving room.

Tachibana
(Ref 1)

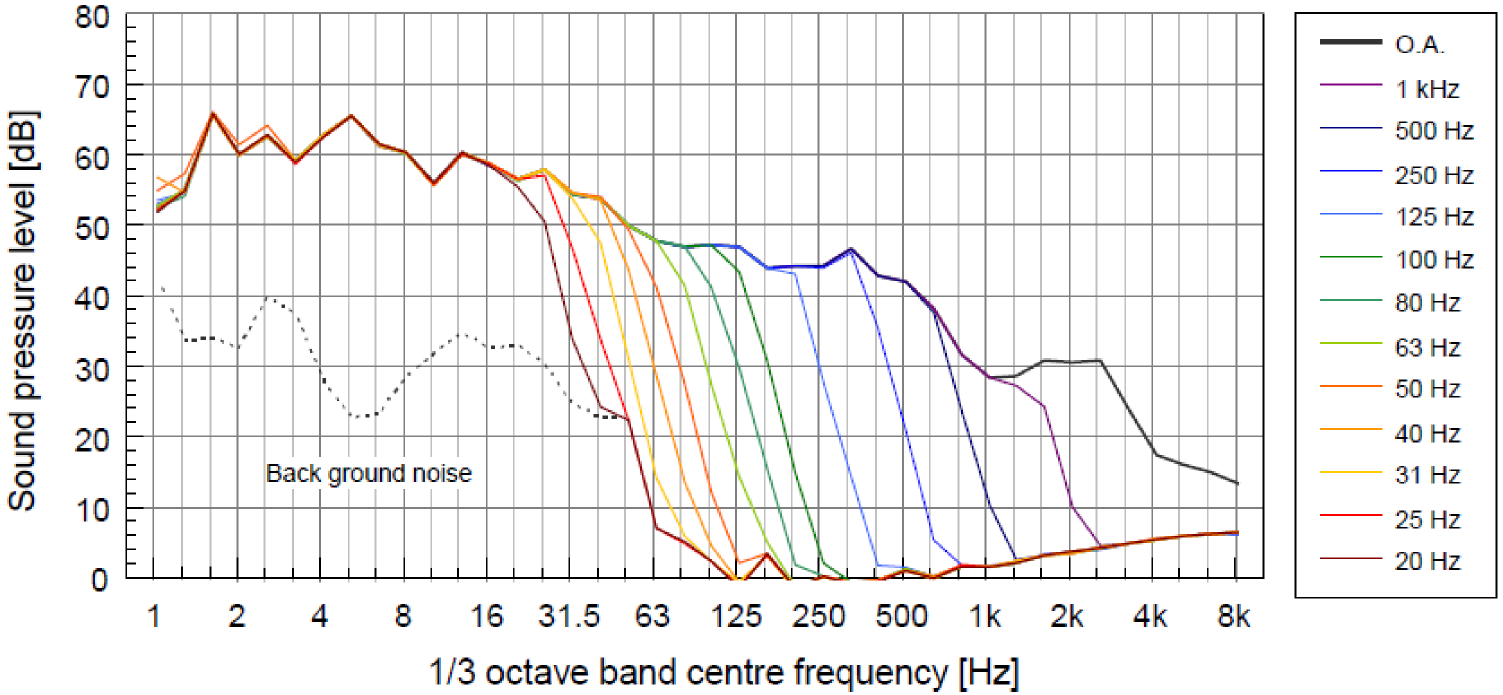
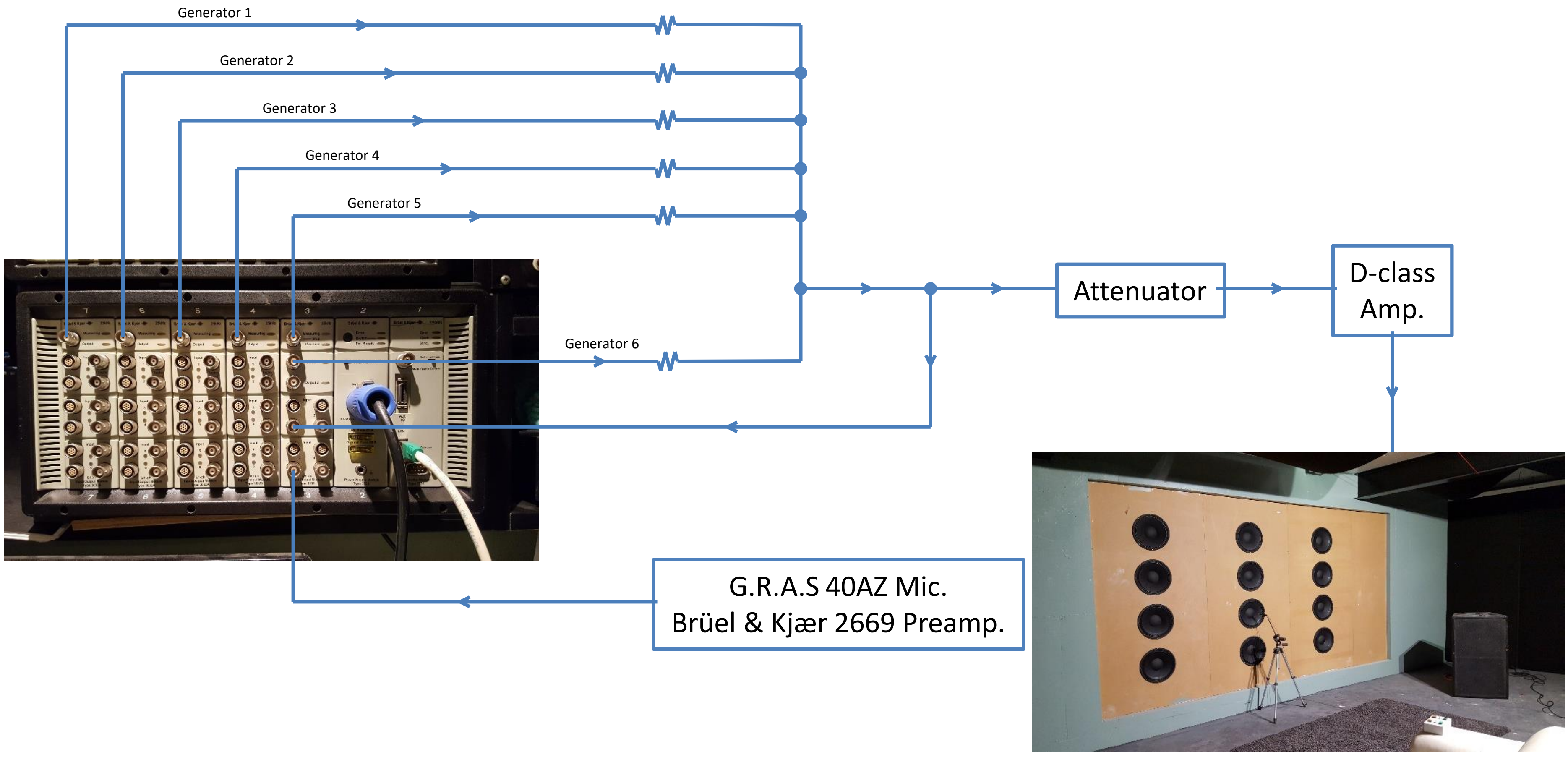


Figure 4 Sound pressure levels in 1/3 octave bands of the original test sound No.1 and its variations made by low-pass filtering.

Experiments Undertaken

- Wave files of real and synthesised infrasound, use for listening tests.
- Take above wave files and speed up 100 times then listen as raw signals + with graphic equalisation enhancements
- Use tone burst at 100 Hz and evaluate amplitude and frequency responses

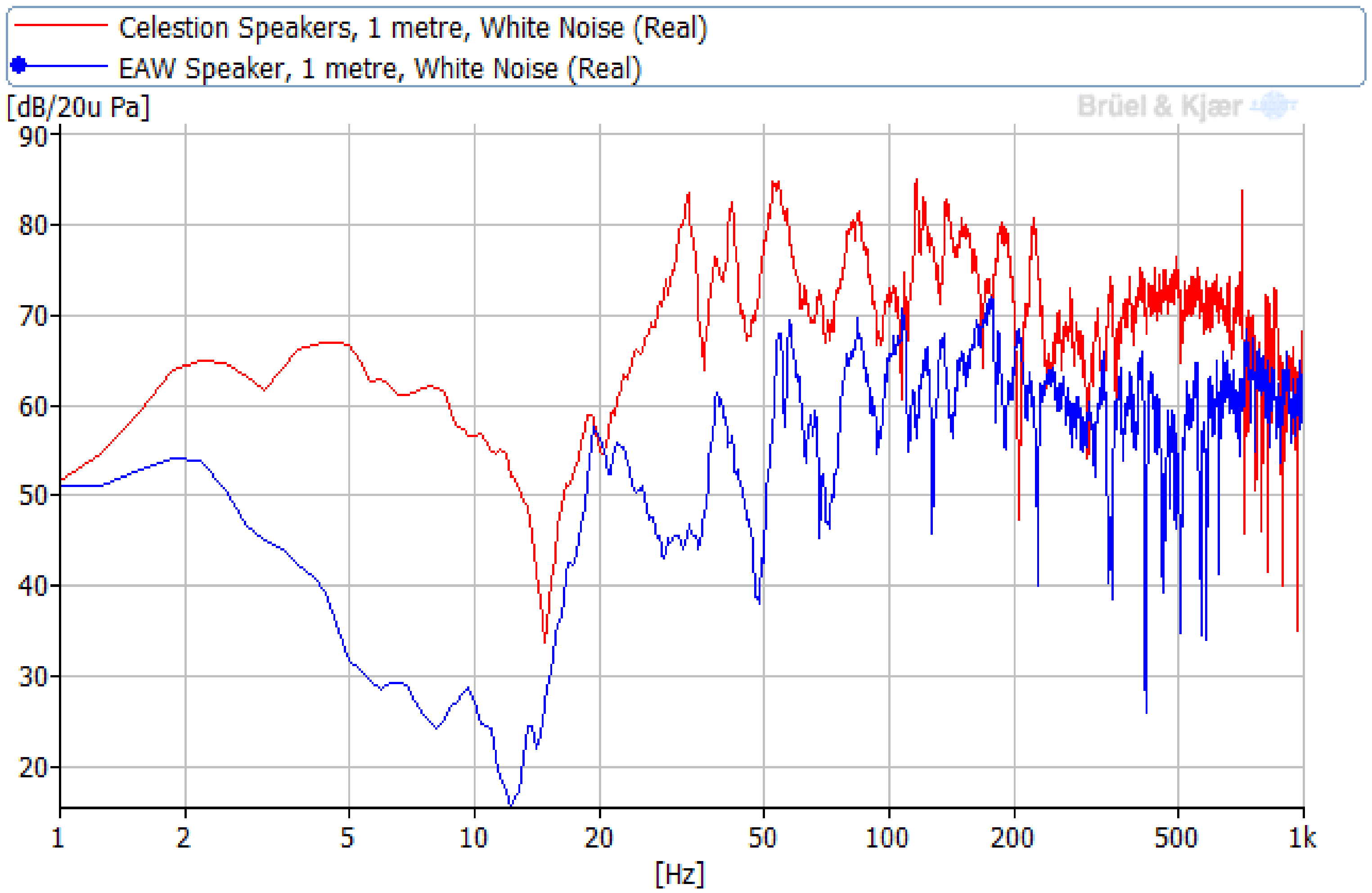
Synthesised Leq FFT and compare with original



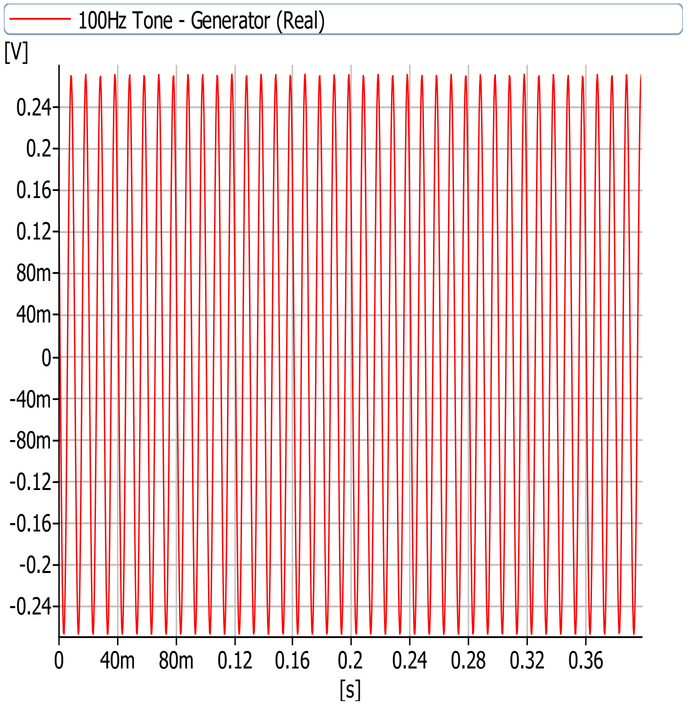
12x 15” 1000W Subwoofers (infinite baffle)

Test Setup

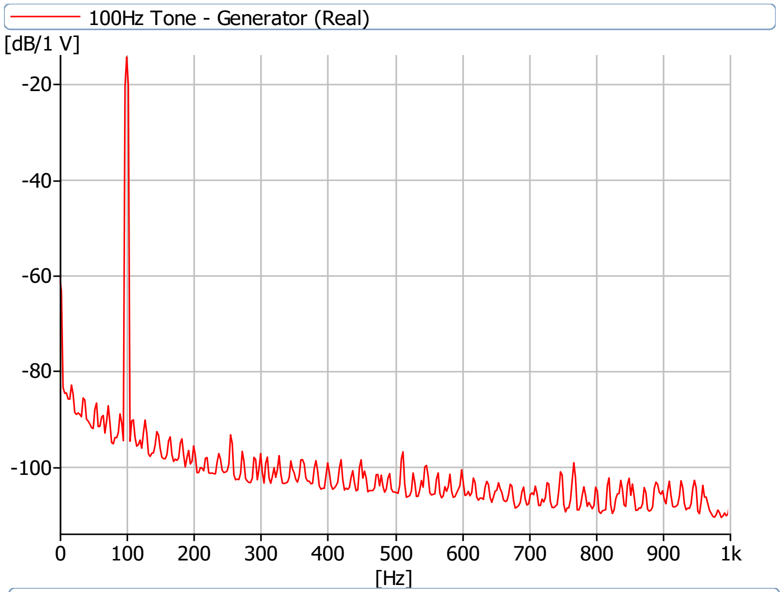
Infinite Baffle v AEW Sub Woofer



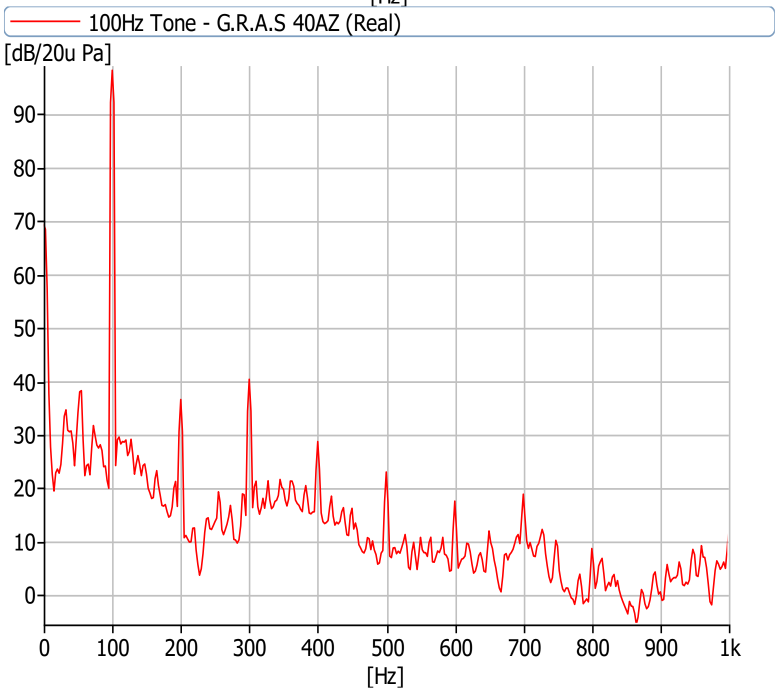
100Hz Tone



100Hz Tone - Generator (Real)
[V]
0.24
0.2
0.16
0.12
80m
40m
0
-40m
-80m
-0.12
-0.16
-0.2
-0.24
0 40m 80m 0.12 0.16 0.2 0.24 0.28 0.32 0.36
[s]

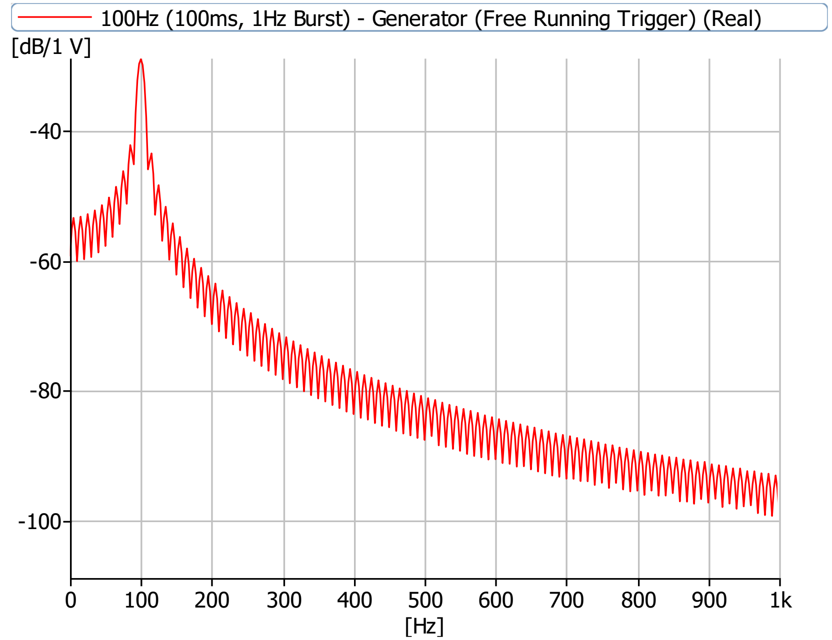


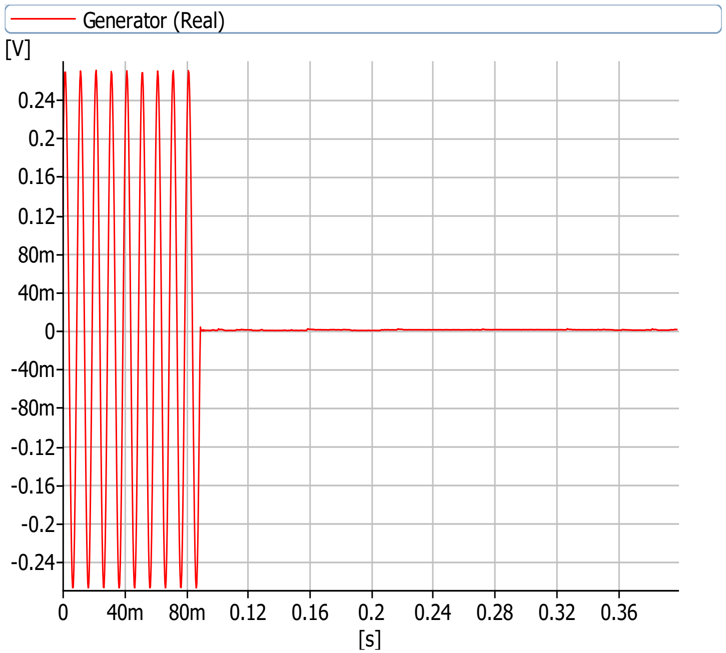
100Hz Tone - Generator (Real)
[dB/1 V]
-20
-40
-60
-80
-100
0 100 200 300 400 500 600 700 800 900 1k
[Hz]

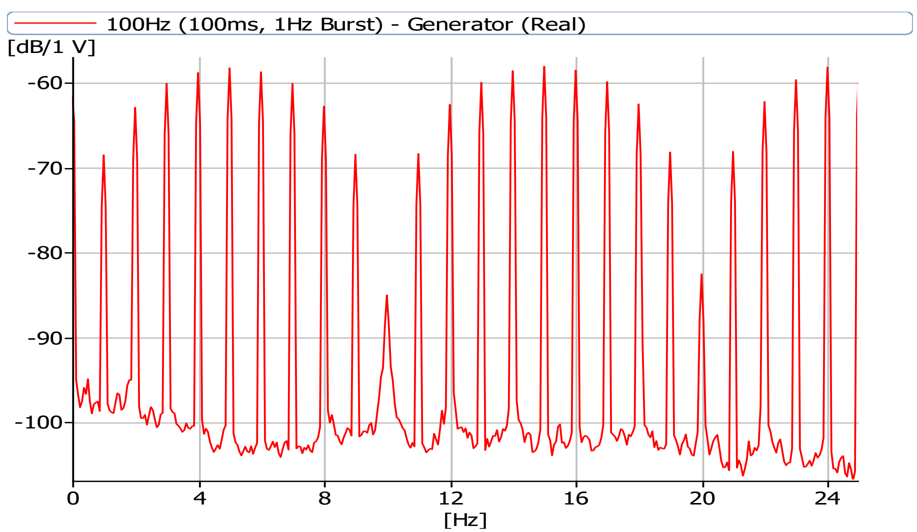


100Hz Tone - G.R.A.S 40AZ (Real)
[dB/20u Pa]
90
80
70
60
50
40
30
20
10
0
0 100 200 300 400 500 600 700 800 900 1k
[Hz]

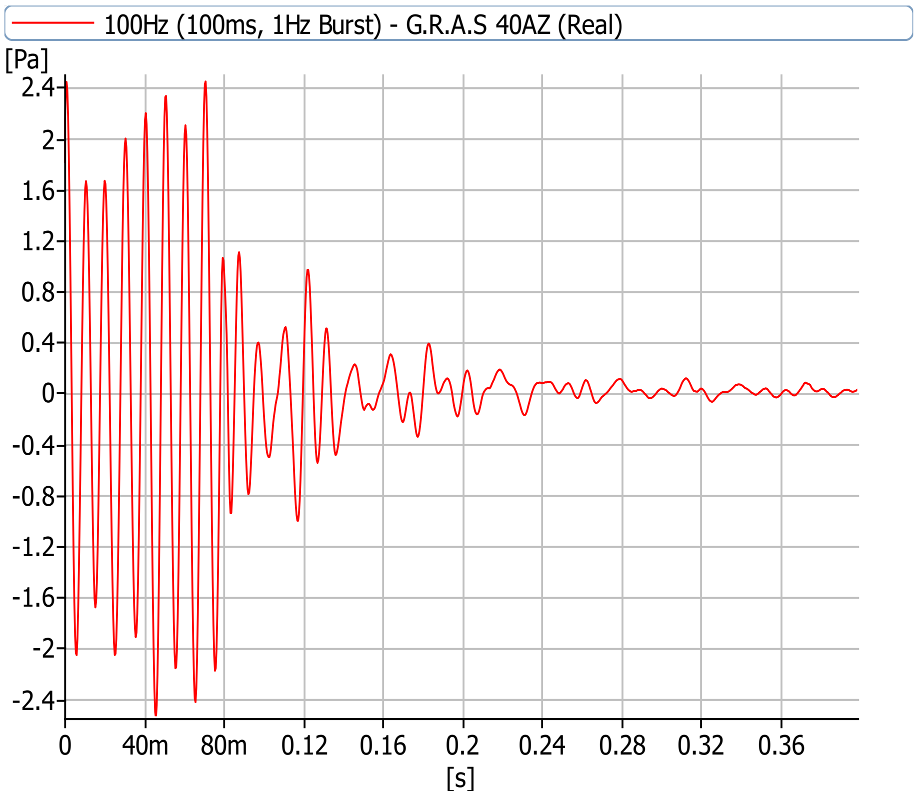
100 Hz 100ms burst - generator

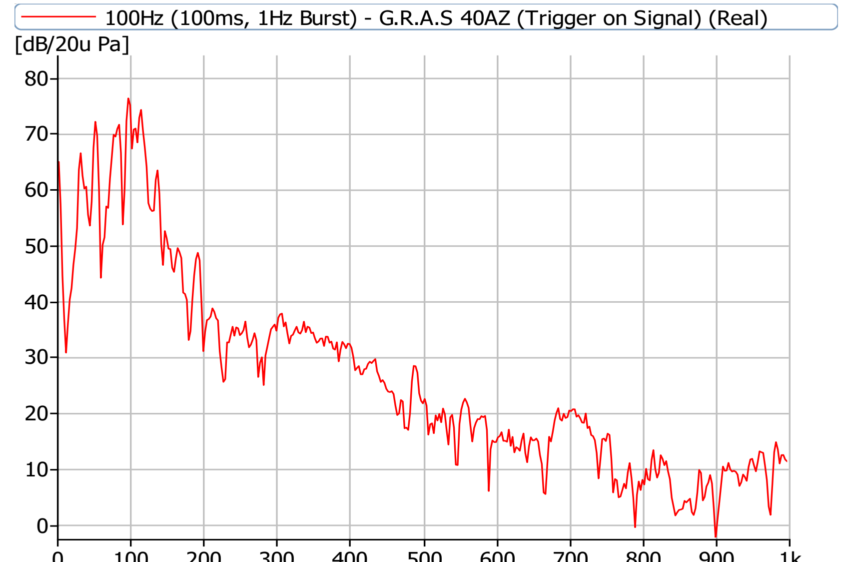


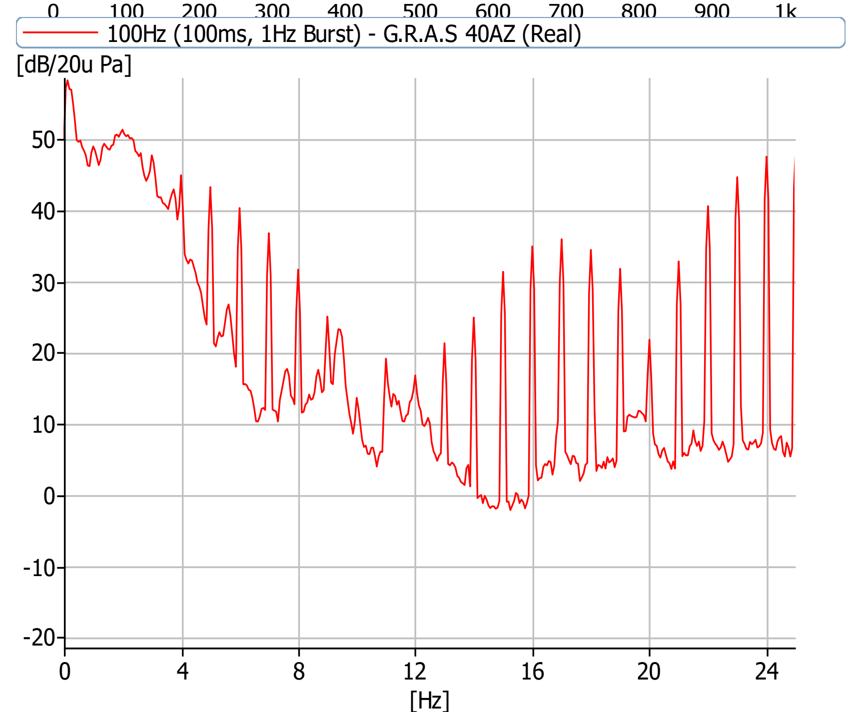




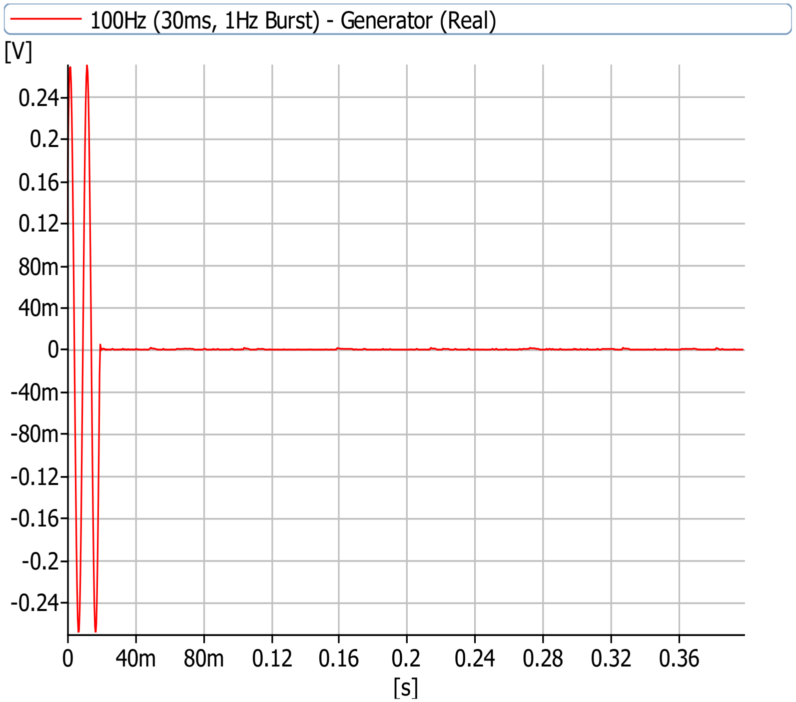
100 Hz 100ms burst – speaker

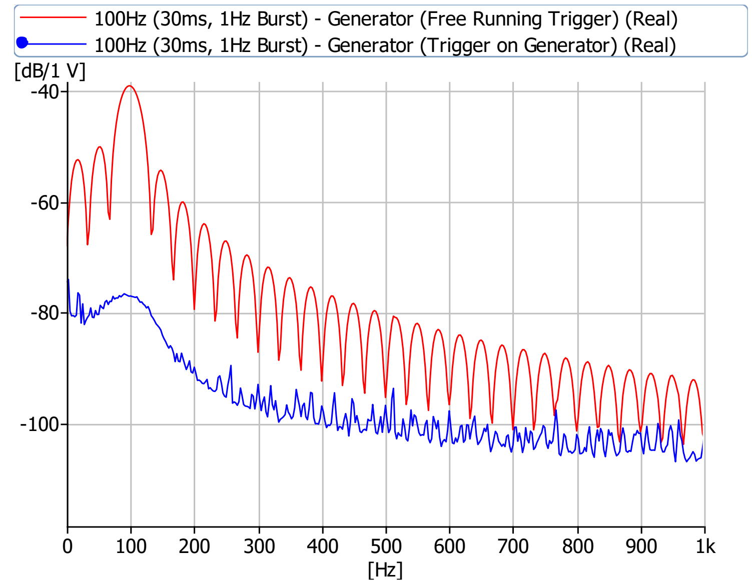


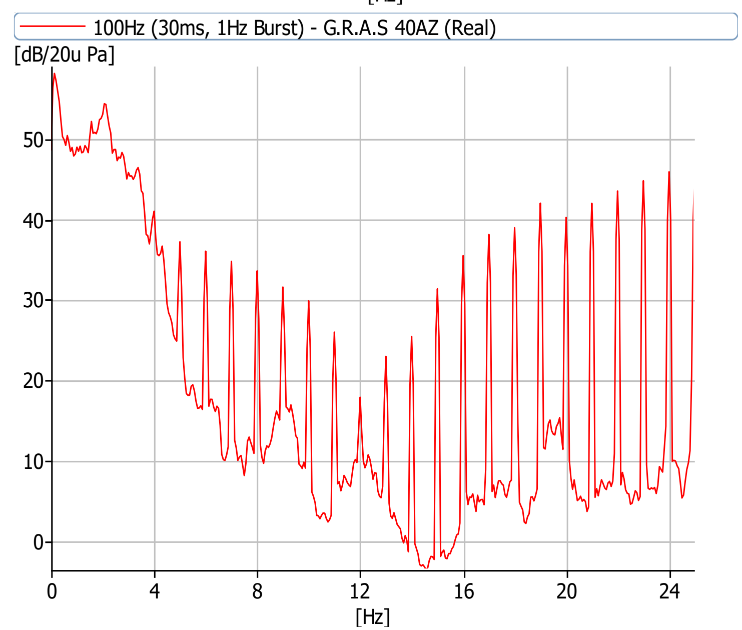




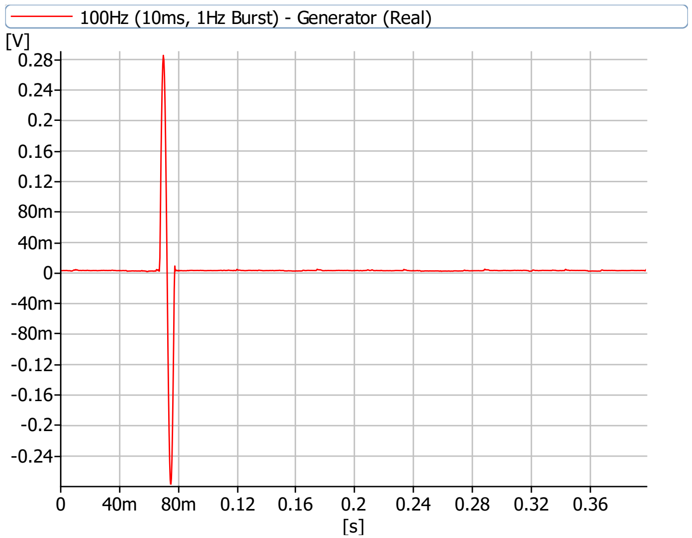
100 Hz 30ms burst

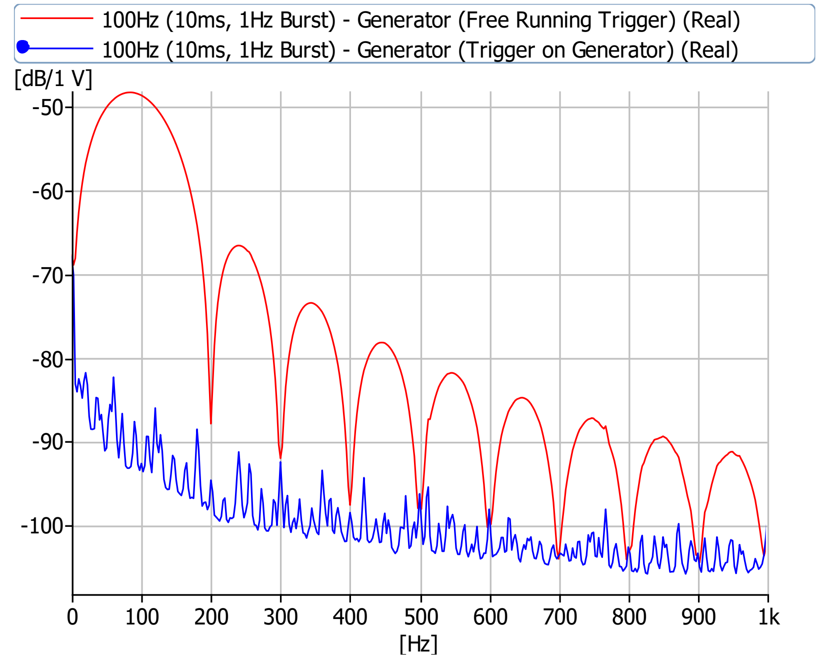


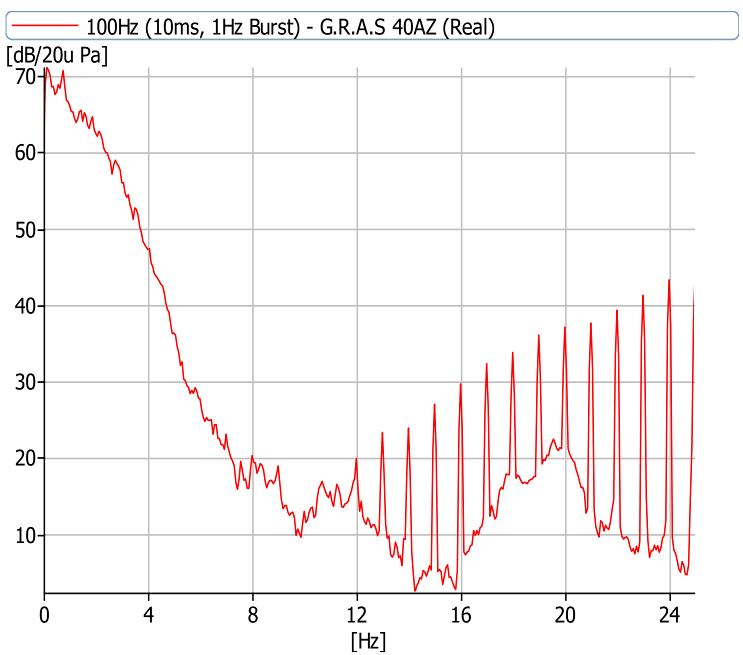


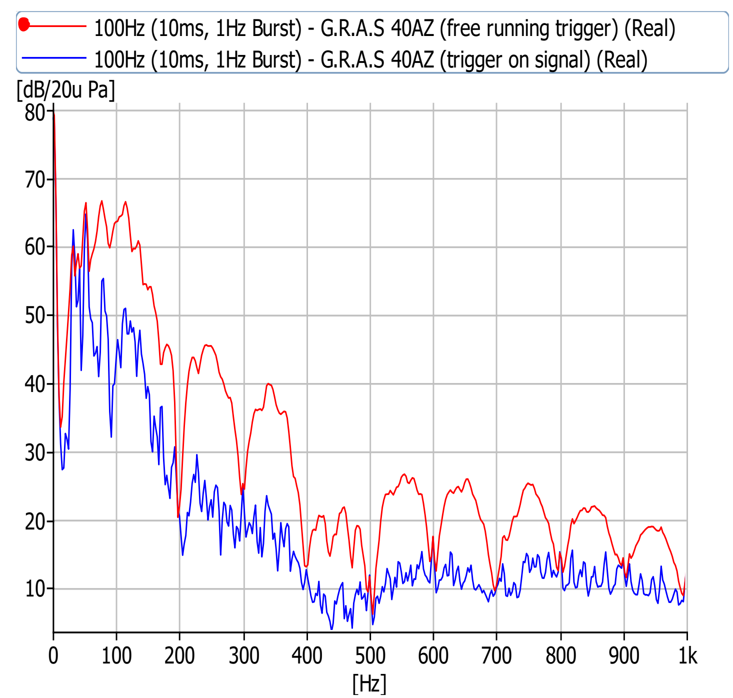


100 Hz 10ms burst

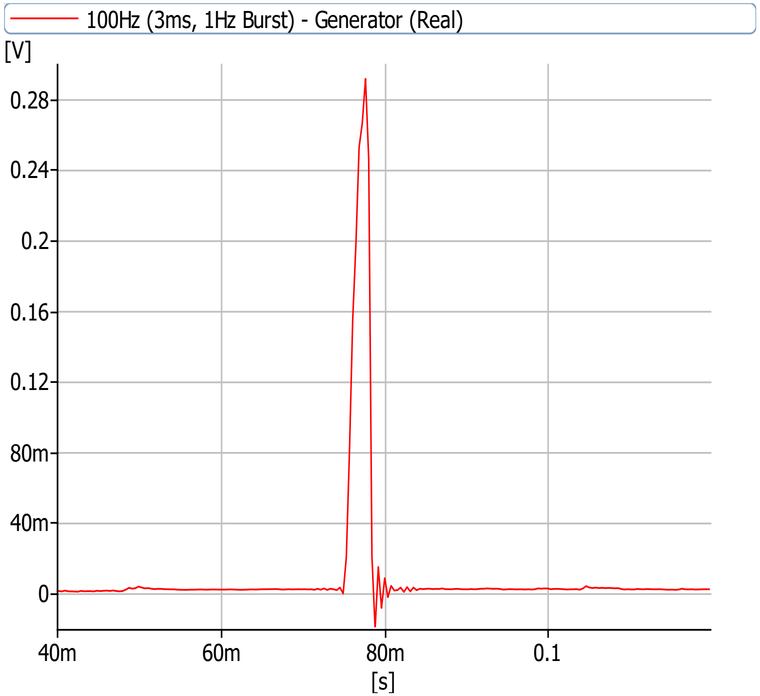


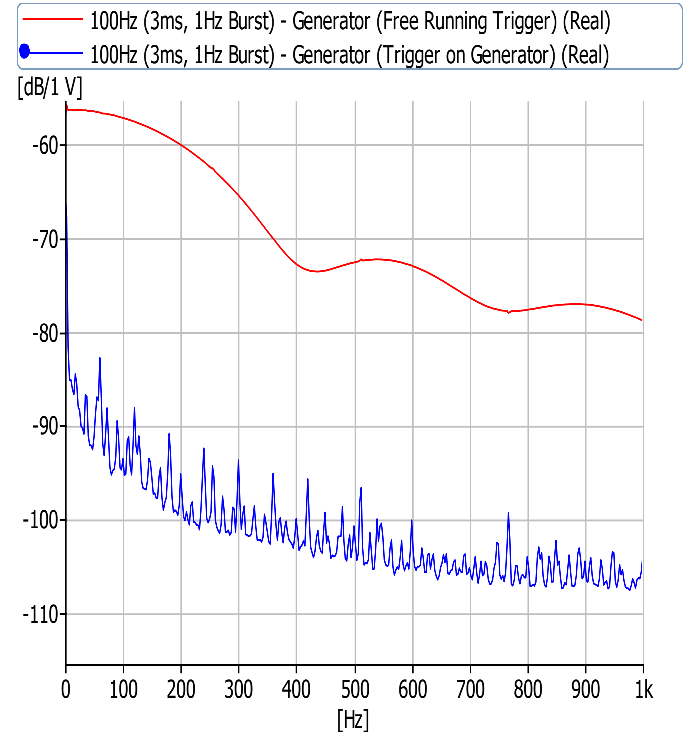


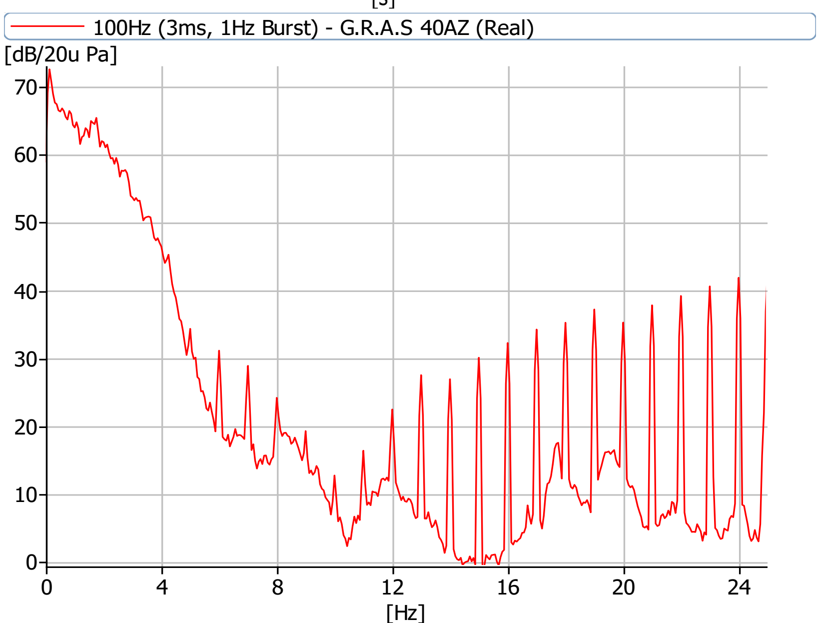


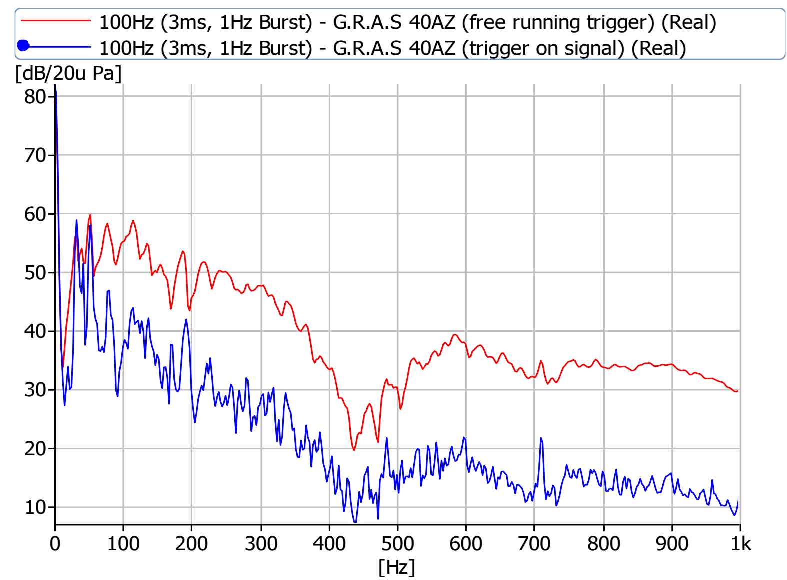


100 Hz 3ms burst

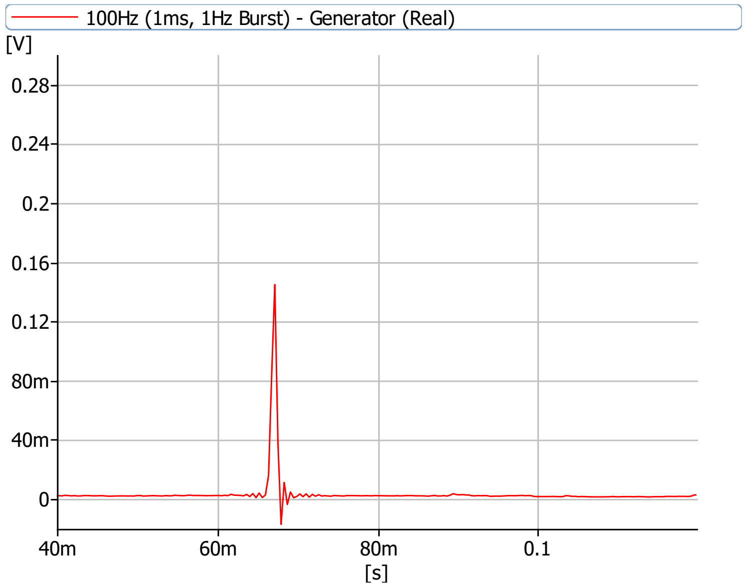


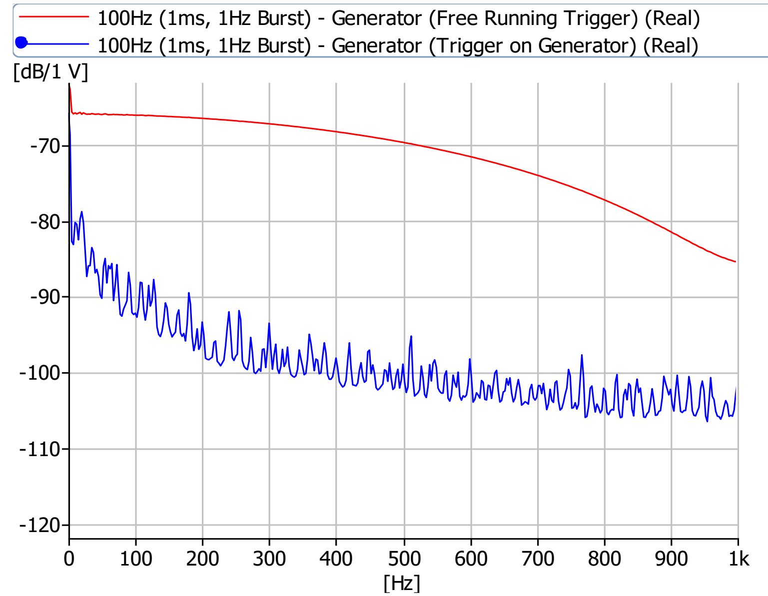


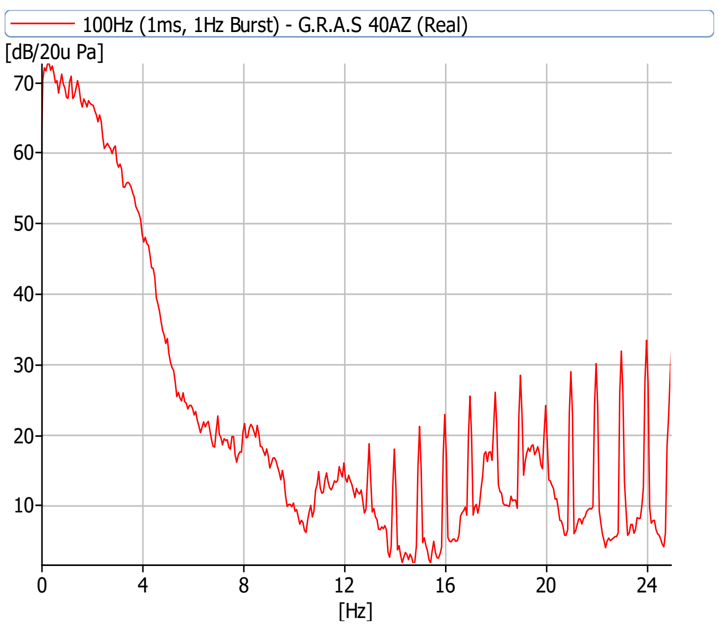


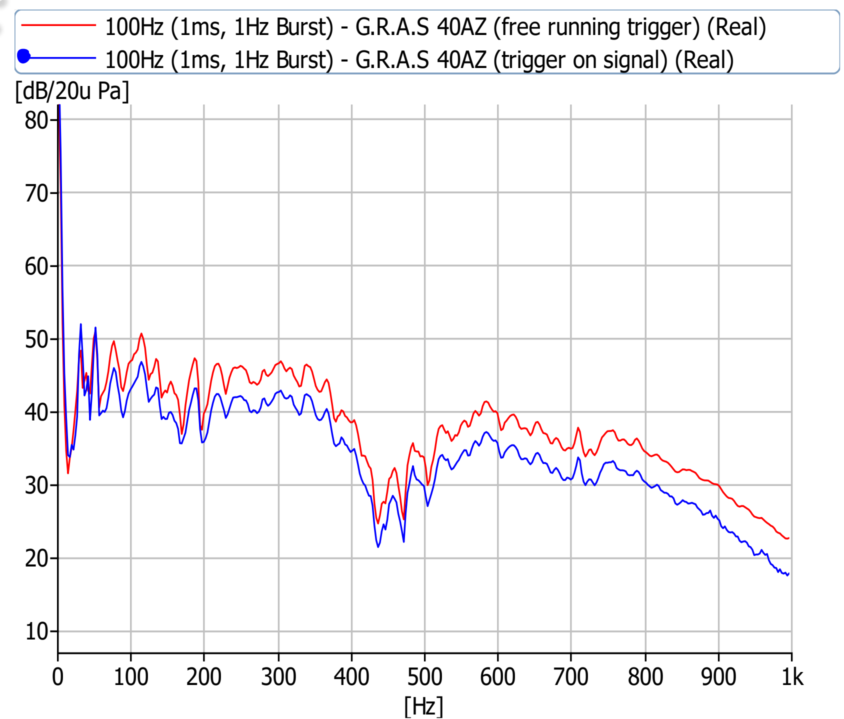


100 Hz 1ms burst









One of the features which people have not fully understood is the significance of when a repetitive impulse is regarded as a short sharp pulse repeated with gaps in between, and when it is regarded as a set of harmonics as displayed by an FFT analyser.

I have always found it easiest to consider an FFT analyser as simply a parallel set of very narrow band filters. They happen to be generated digitally, and have the particular feature that their transient response is to ring at fixed amplitude for a fixed length of time, and then stop.

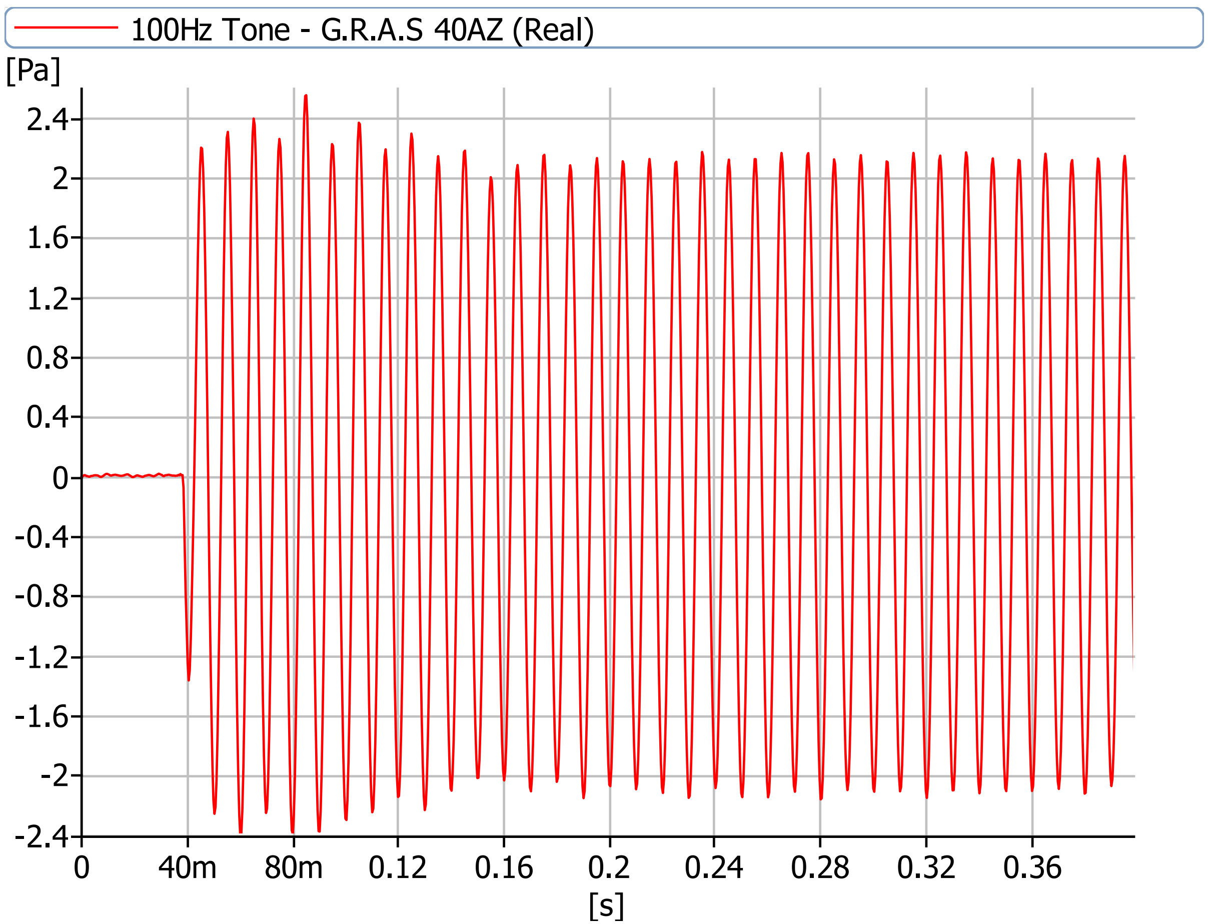
Consider a single sharp half-sine impulse hitting this bank of filters. It will cause every one of the filters to "ring" at its centre frequency. So in that respect a single sharp impulse can be considered to contain a full range of frequencies.

If one now considers a repetitive half-sine impulse of very short duration, repeated at 1 second intervals, it preferentially excites the filters which are harmonically related to the repetition frequency. This includes the very lowest frequency filter, the fundamental, and its immediate harmonics, so it is correct to say that a 1Hz repetitive infrasonic component is generated. But if the duration of the impulse is very short, there will be a wide range of higher frequency harmonics also generated, extending out to (say) 500Hz for a 1 millisecond pulse.

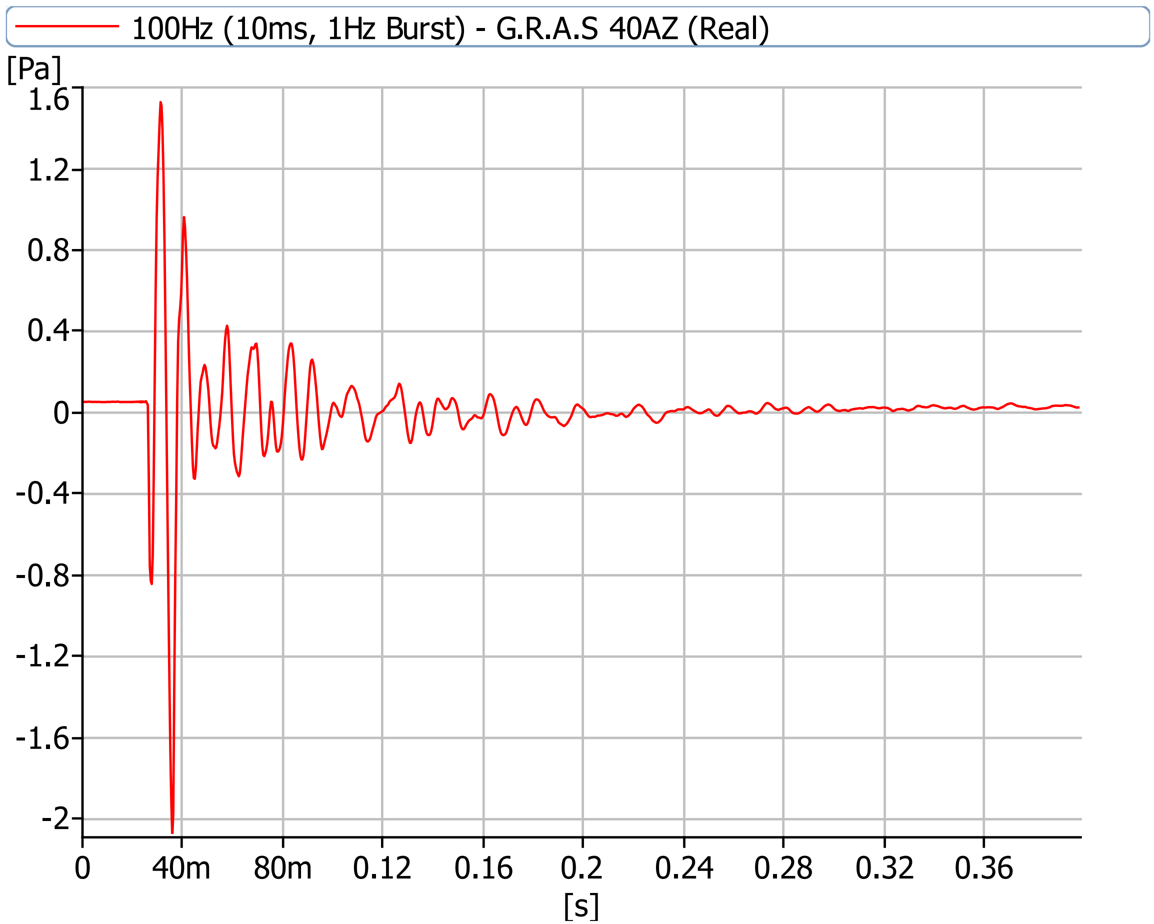
The net contribution from the higher harmonics will contain much more total power than the immediate infrasonic components, so perception will be dominated by that of a sharp, high frequency impulse repeated at the 1Hz time intervals.

Dr M.A. Swinbanks

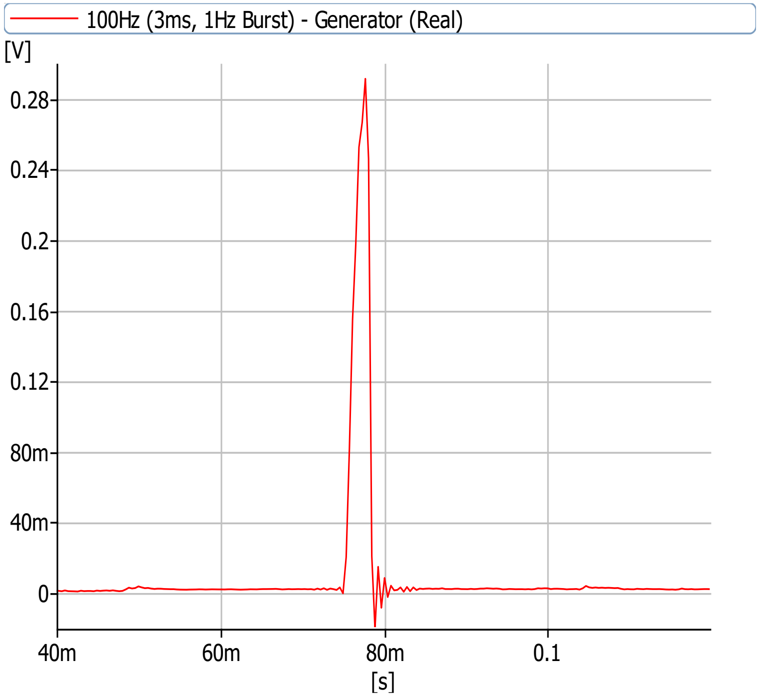
Signal Build-up in Room - 100Hz Constant Tone

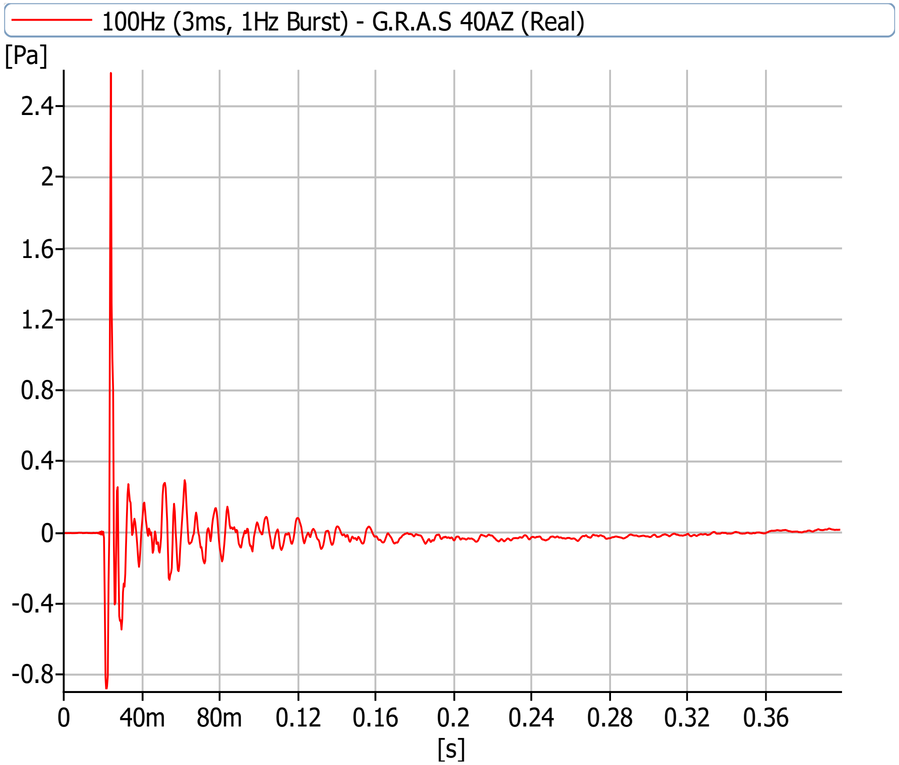


Signal Build-up in Room - 10ms burst reduced level

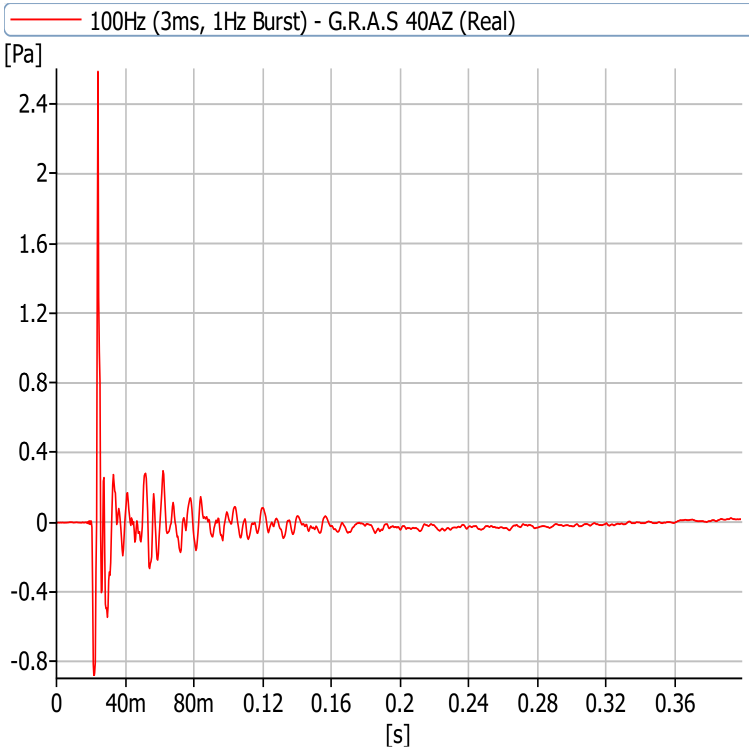


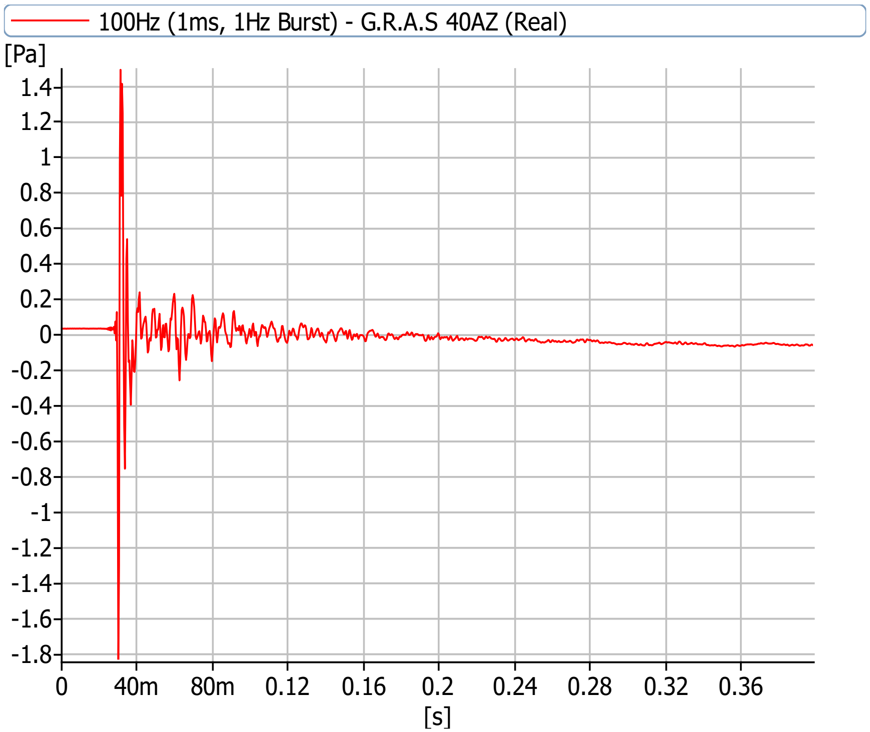
Signal Build-up in Room - 3ms Burst





Room/Speaker Response





Speaker Testing Conclusions

- Cannot accurately reproduce the infrasound signature in the laboratory. Cannot accurately reproduce the low frequency narrow band signature in the laboratory – due to limitation of speaker performance and response.

- Using tone burst 100 Hz signals there was still an infrasound signature at multiples of the 1 Hz on rate, even with 80 Hz high pass filter in the signal chain.

- Could not get a Digital to Analogue convertor to give us an appropriate audio output of the “infrasound and low frequency” signal from 0.86Hz – noise and gain issues.

- For infrasound and low frequency testing we have gone back to using a B & K FM reel to reel tape recorder (FM Modules not Direct Modules) to obtain full spectrum audio samples, as having an audio/signal output flat down to 1 Hz. But via speakers still have frequency response issues

Speaker Testing Conclusions

- If restricted to just infrasound (or infrasound + low frequency sound) best to undertake in-situ testing.

- The Japanese testing of modulated wind turbine noise using a wall of speakers has problems in creating the “’infrasound” – but they were only testing for audible modulation.

- With the phase problems, and back pressure issues for an infinite baffle, it would seem better to use one speaker system for audio listening tests.

- For audible noise, preference to use a hemi-anechoic room

- If infrasound not really there, then line array speakers (mono signal or preferably real stereo) in hemi anechoic room works well – can conduct medical testing on audible (and inaudible) wind turbine noise – pulsation of signal (amplitude modulation) still present.