2. Cutting the Air

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New Zealand
2012

The Problem

- When a piece of thread (e.g. nylon) is whirled around with a small mass attached to its free end, a distinct noise is emitted. Study the origin of this noise and the relevant parameters.

Presentation Structure

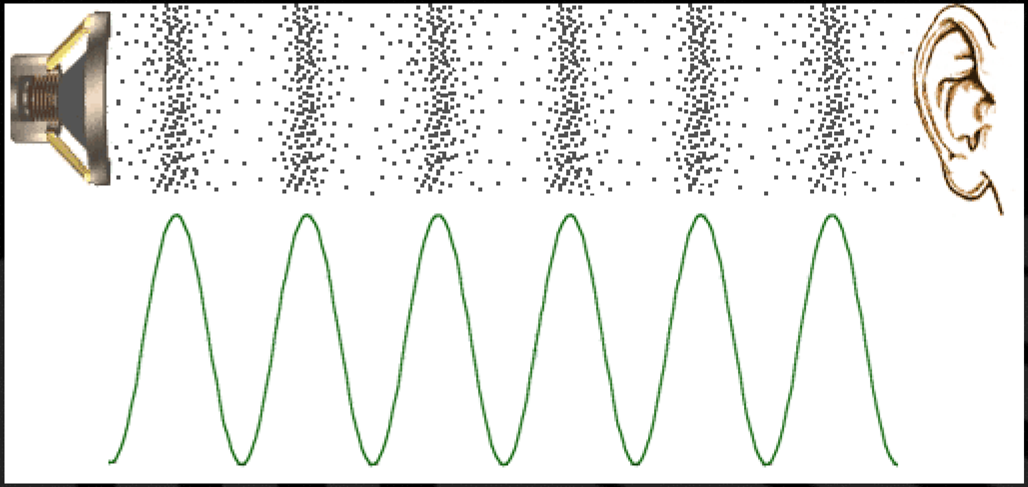
- Definitions
- Initial observations
- Experimental set-ups – 1, 2, 3
- Methods of data analysis
- Theories
- Results
- Conclusion

Definitions – “Noise”

- Unwanted sound
- Non-speech sound
- Everyday usage: synonym of sound
- Not necessarily a single frequency

Sound

- Mechanical vibration of air particles
- Oscillations, creating regions of high and low pressure



Definitions - Other

- “Whirled around” – in a circle
- “Thread” – flexible, long, thin piece of material. Not necessarily cylindrical cross-section.

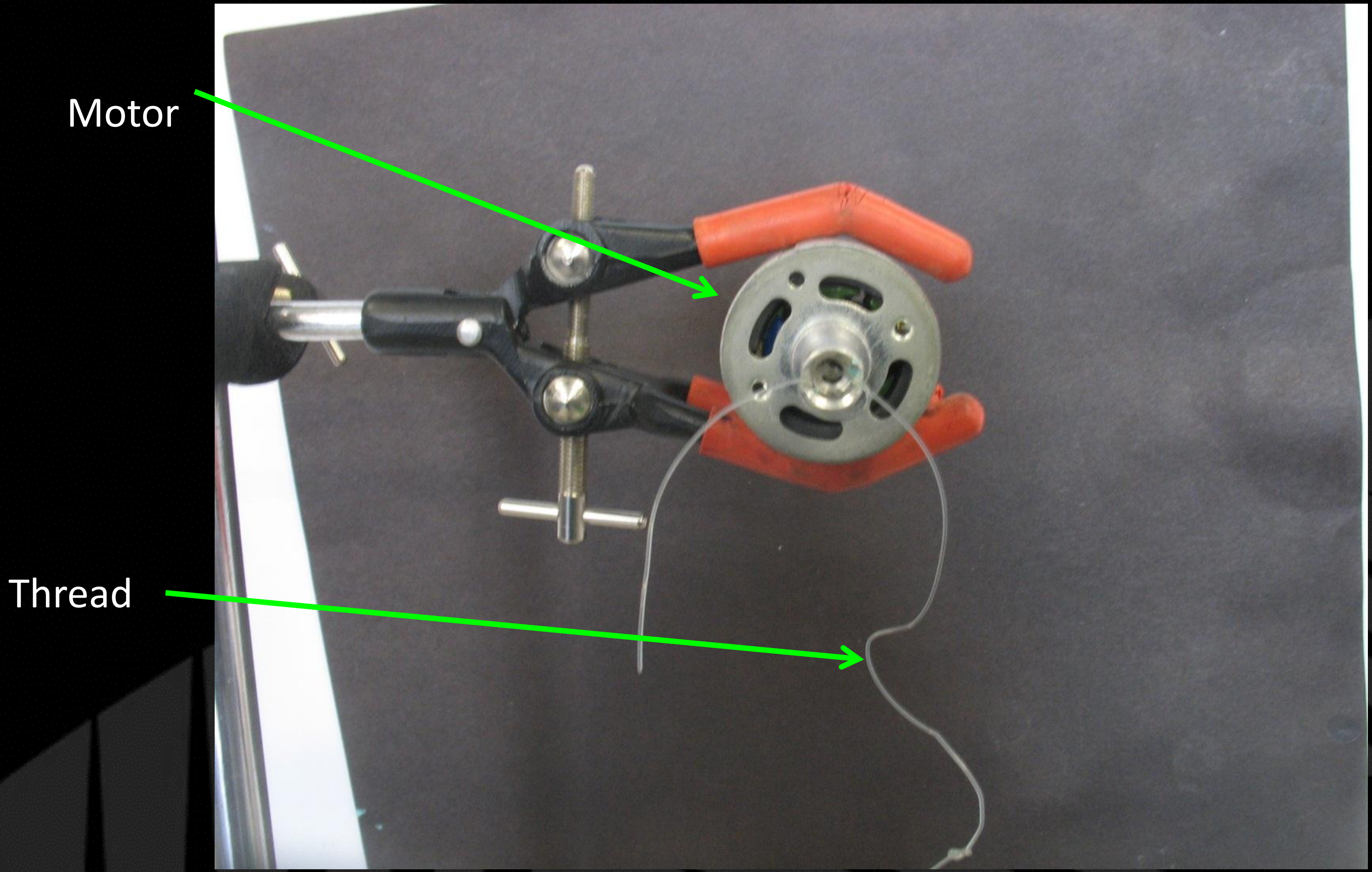
The Noise

- Similar to a whistle
- Not a “clean note” – multiple frequencies
- Not very loud – hard to record and differentiate from background noise

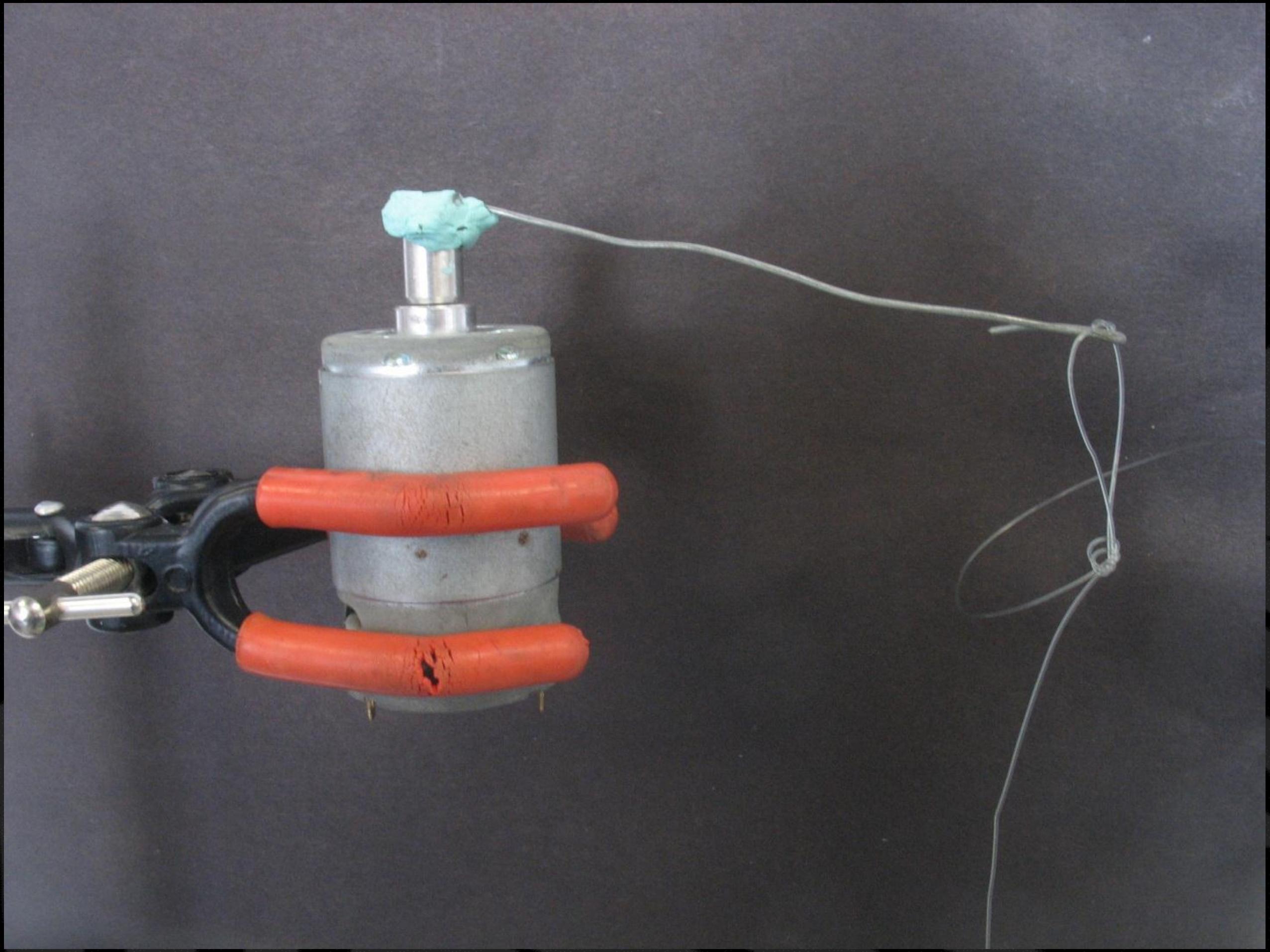
- LIVE DEMONSTRATION

Experiments - 1

Experiment 2



Experiment 3



This is so that the motor can actually whirl the thread around. Without the wire arm, the thread just wraps around the axle.

Masses

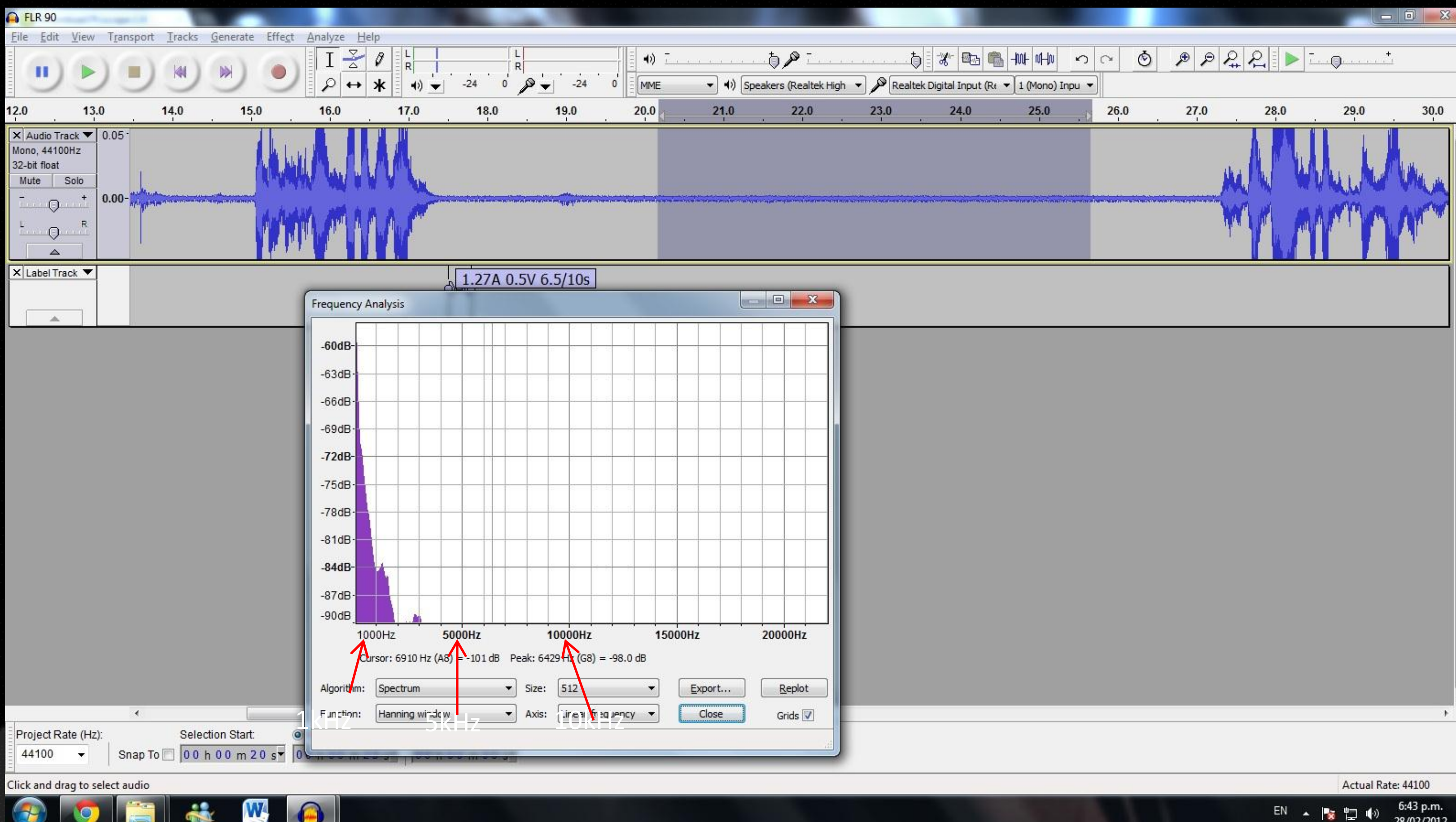
Mean mass = 6.7g

Focus on thread, because question says SMALL MASS

Variables Tested

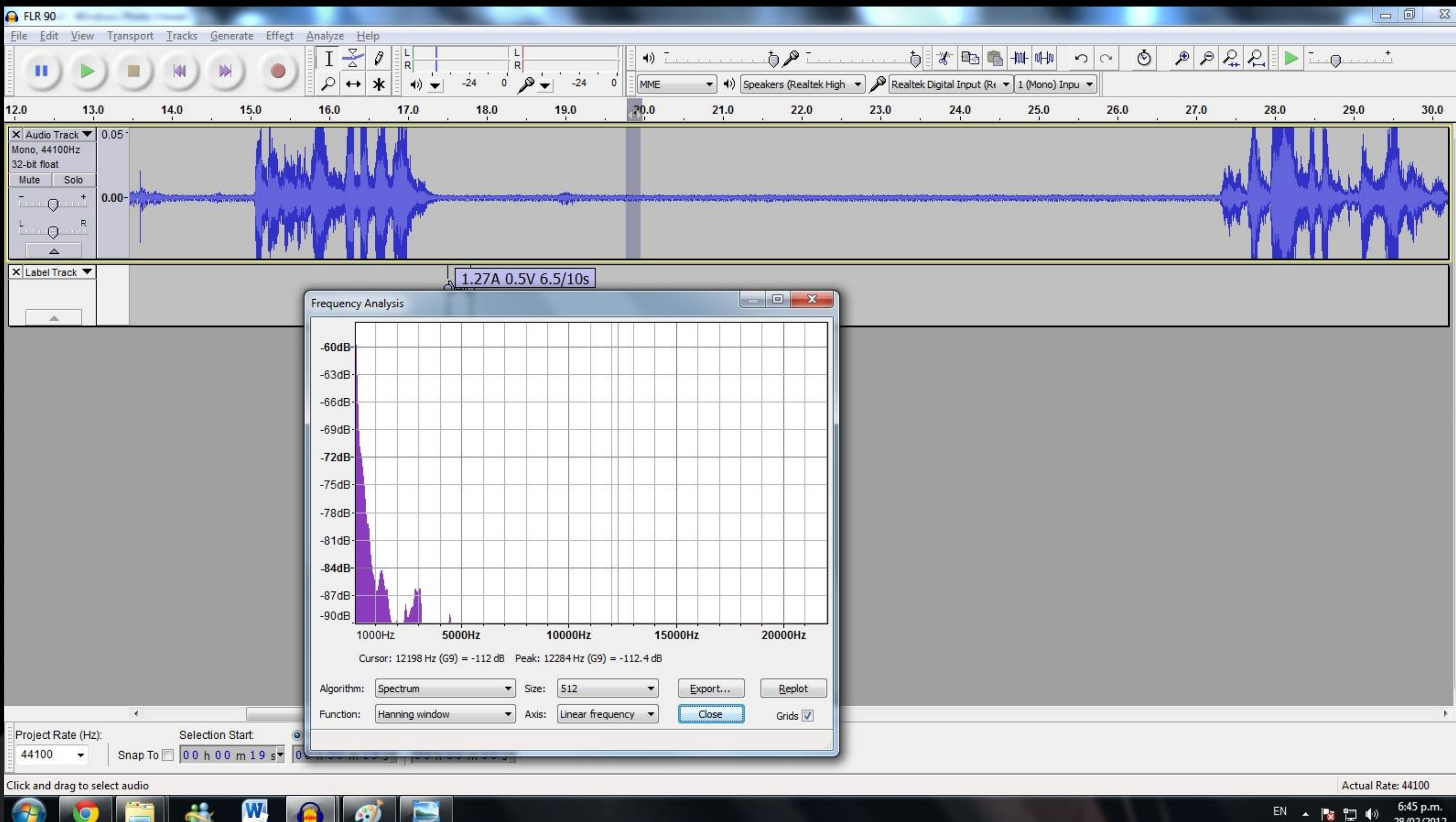
- Mass
- Thread length
- Thread diameter
- Speed of rotation
- Mass shape

Results Analysis



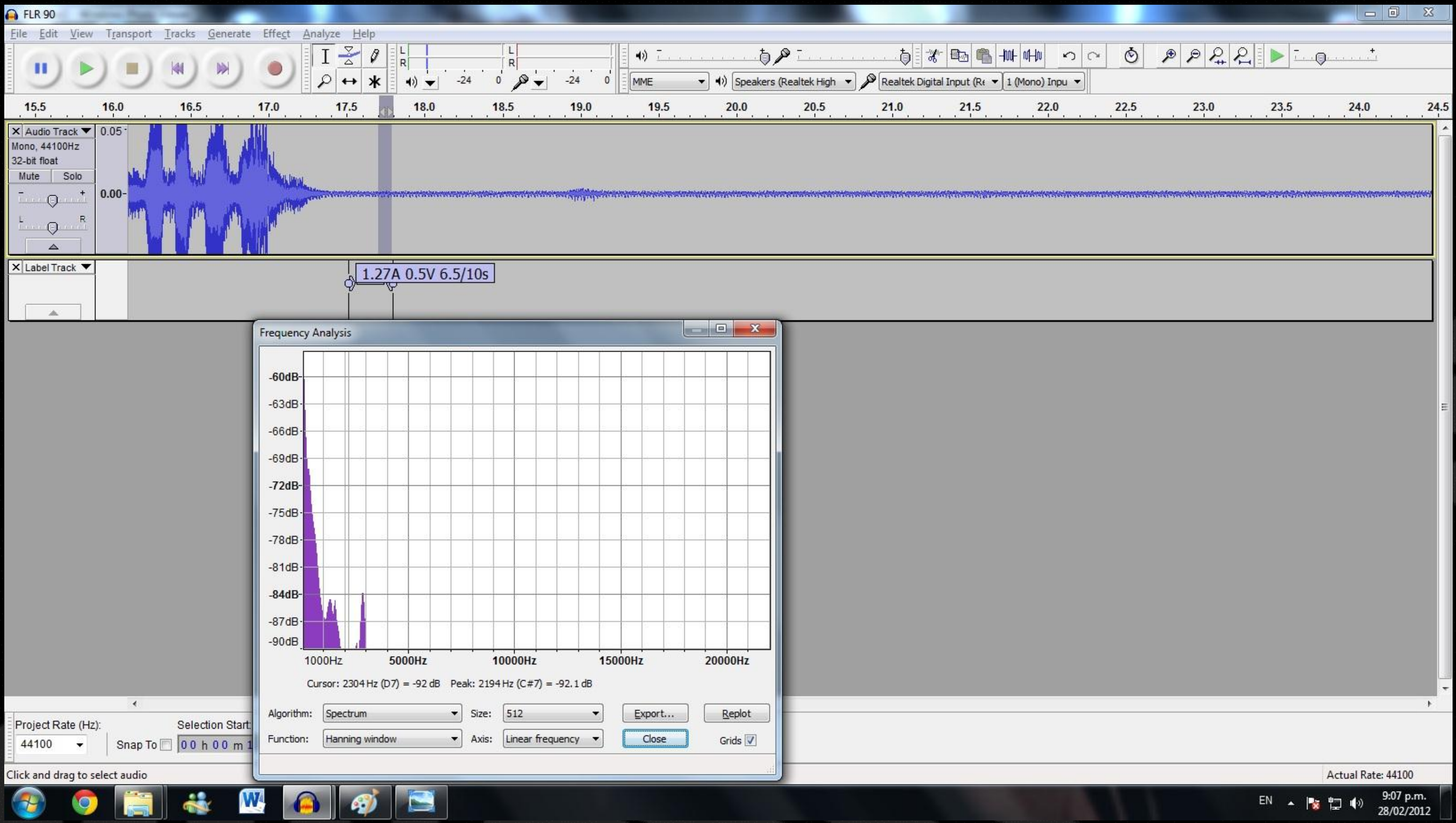
Frequency analysis in Audacity

Randomness - Demonstration

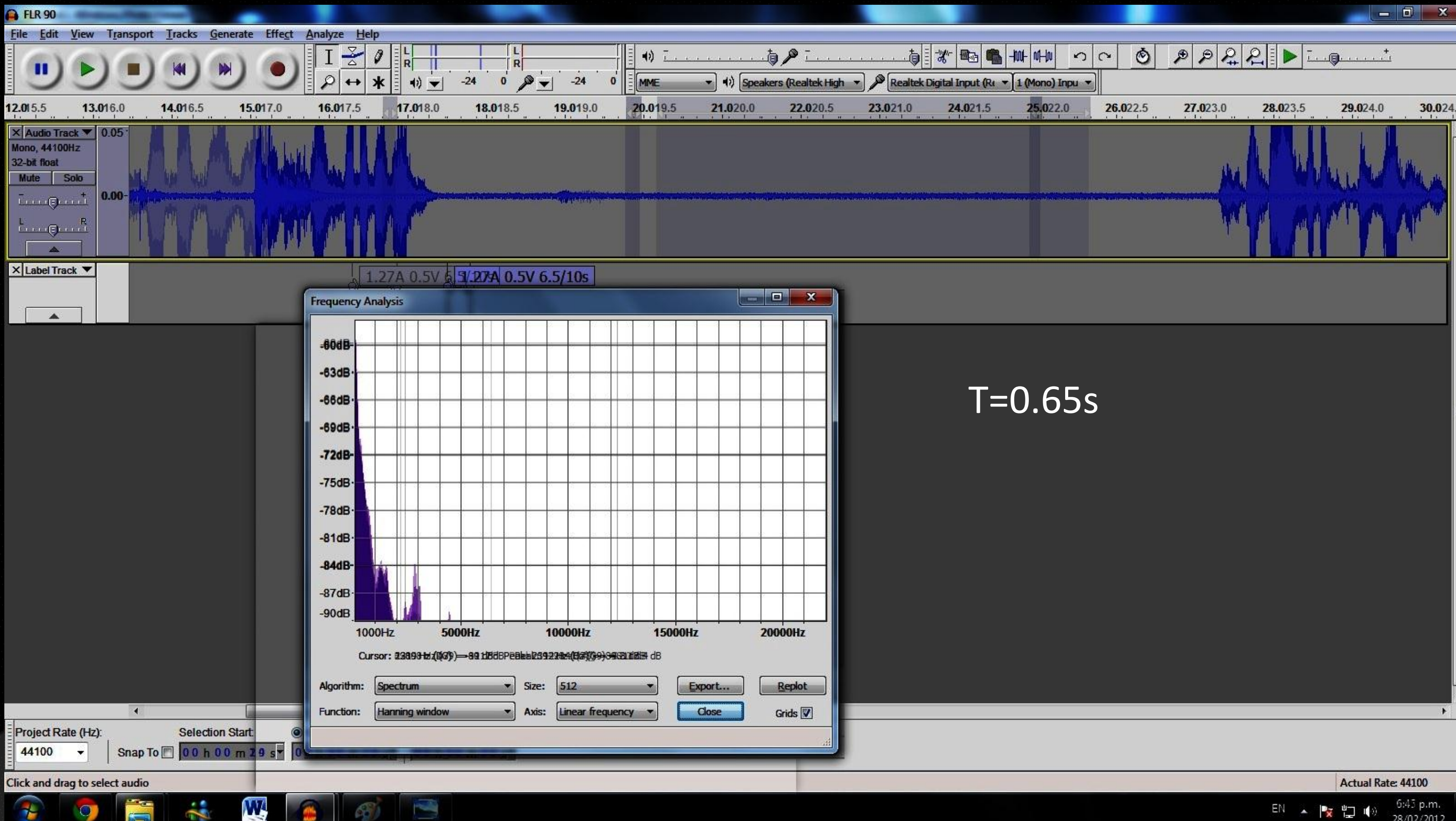


Depending on where you take the sound sample in the same recording, the frequency is subject to some random variation: compare with next slide

Randomness - Demonstration



Layering



T=0.65s

To get a picture of the overall distribution of frequencies, we used a Paint.Net to layer multiple spectra on top of each other. Overlapping peaks show up as darker purple. We can see where there is DEFINITELY a sound and where it might just be one random occurrence.

Theory 1

- Standing waves in the thread
- E.g. String instruments
- $f = \frac{n}{2L}\sqrt{\frac{T}{\mu}}$

T = $F_c = mr\omega^2$

Where f = frequency / Hz
n = harmonic no.#
L = string length / m
T = tension in string / N
μ = mass per unit length of string / kg m^{-1}

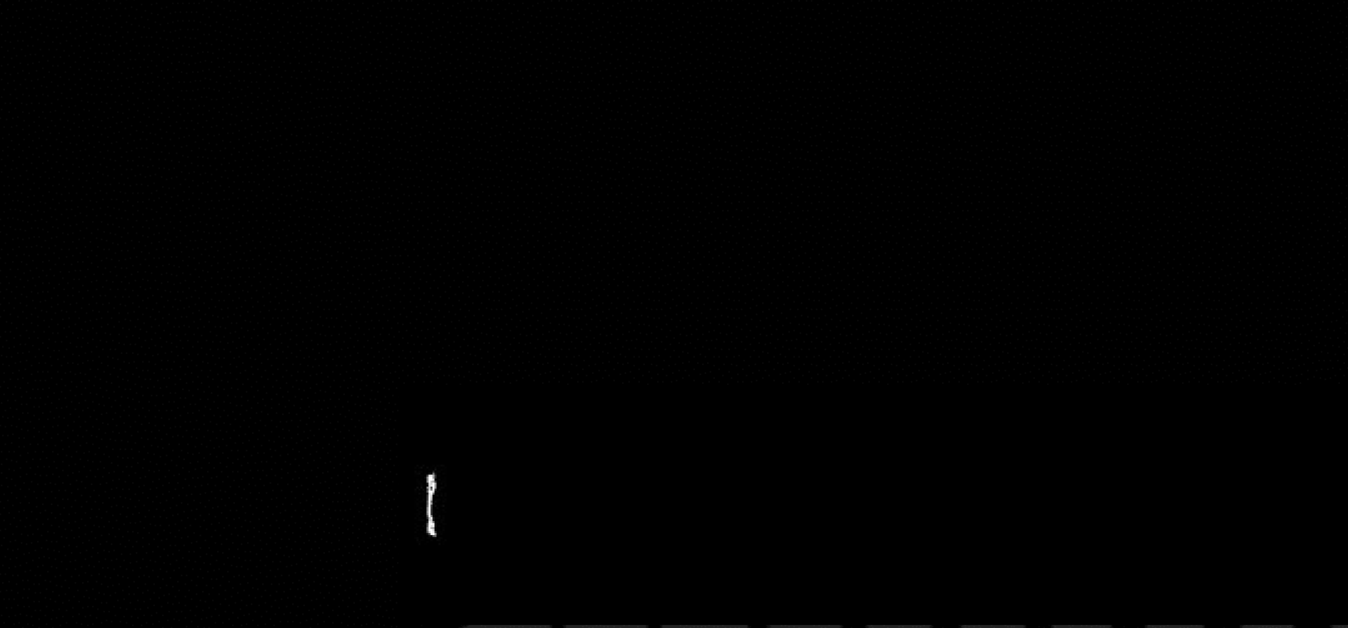
where T = tension in string
F_c = centripetal force / N
m = mass on the end / kg
r = radius of spin / m
ω = angular velocity/rads^{-1}

- Advanced Physics. S. Adams & J. Allday. Oxford University Press, 2000

Theory 2

- Von Kármán vortex streets
- Air moving past/around obstructing object results in turbulent flow in its “wake”

Theory 2



Gif plays in presentation mode.

Theory 2

Theory 2

- Vortices form on alternating sides
- High and low pressure regions, alternating at a set frequency, are perceived by ears as sound waves

Theory 2

- Frequency predicted by Strouhal number, Sr
- Dimensionless
- $Sr = \frac{fd}{V}$
- Sr=$0.198(1 - \frac{19.7}{Re})$
- ≈0.20 (accurate to 2 d.p.)
- $f_s = \frac{0.2V}{d}$

f= frequency of shedding /Hz
d= characteristic length–diameter of thread/m
V= flow velocity /m s^{-1}

- (Department of Mechanical Engineering NYU)
  Raichel, D.R. “The Science and Applications of Acoustics” (2000). Springer-Verlag New York Inc
- Blevins, R. D. (1990) “Flow-induced Vibration”. Van Nostrand Reinhold.

Theory 2

- $f_s = \frac{0.2V}{d}$
- Circular motion:
  Period of rotation T_r/s

$$V = \frac{2\pi r}{T_r}$$

$$\therefore f_s = frequency\ of\ shedding = \frac{0.2 \times 2\pi r}{dT_r}$$

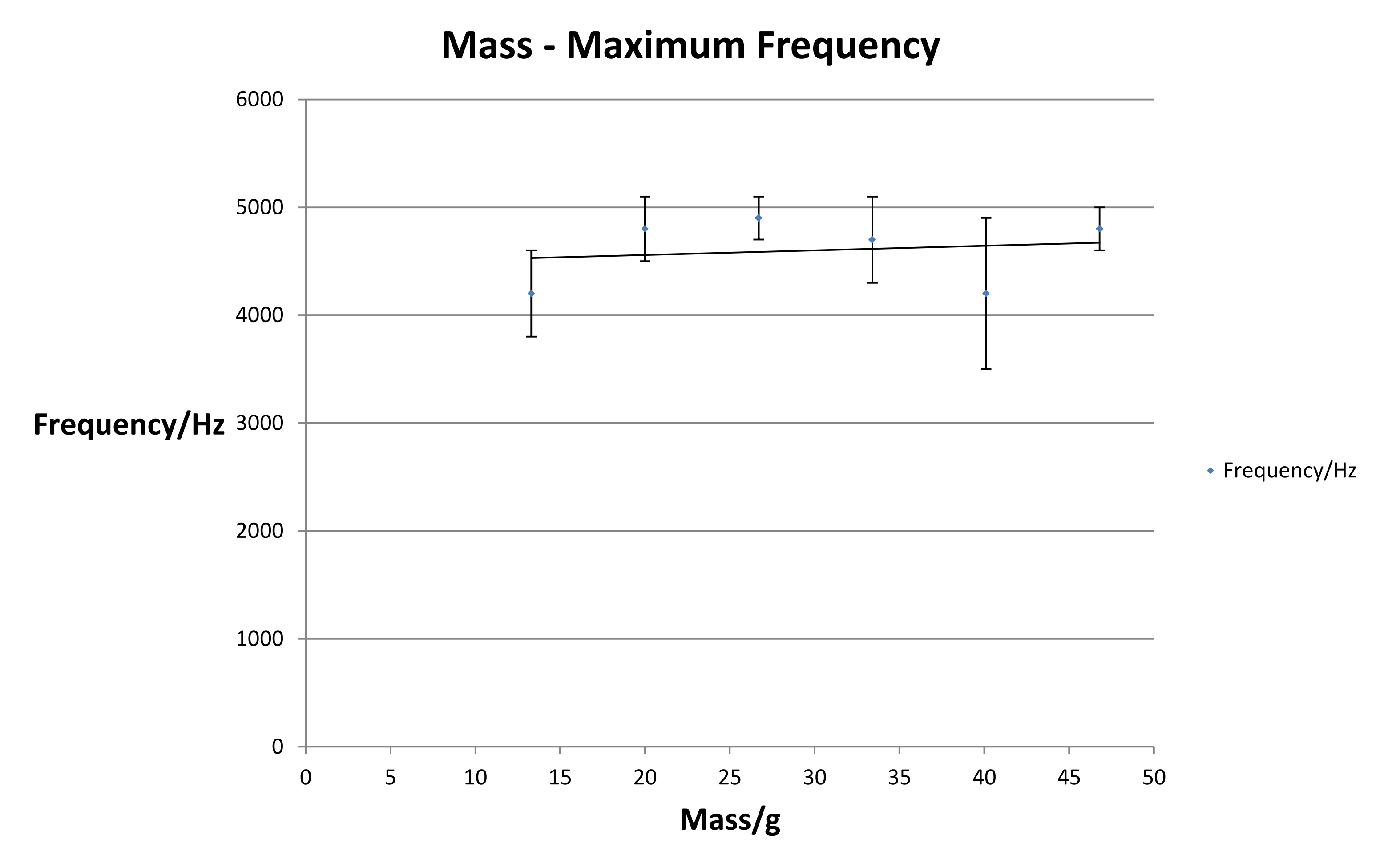
Theory 2

- Range of frequencies along the string
- Continuously variable with radius
- $f_s = \frac{0.2 \times 2\pi r}{dT_r}$
- Took maximum values

Mass

- $f_s = \frac{0.2 \times 2\pi r}{dT_r}$
- Varied the mass by adding masses to the end of the string

Mass

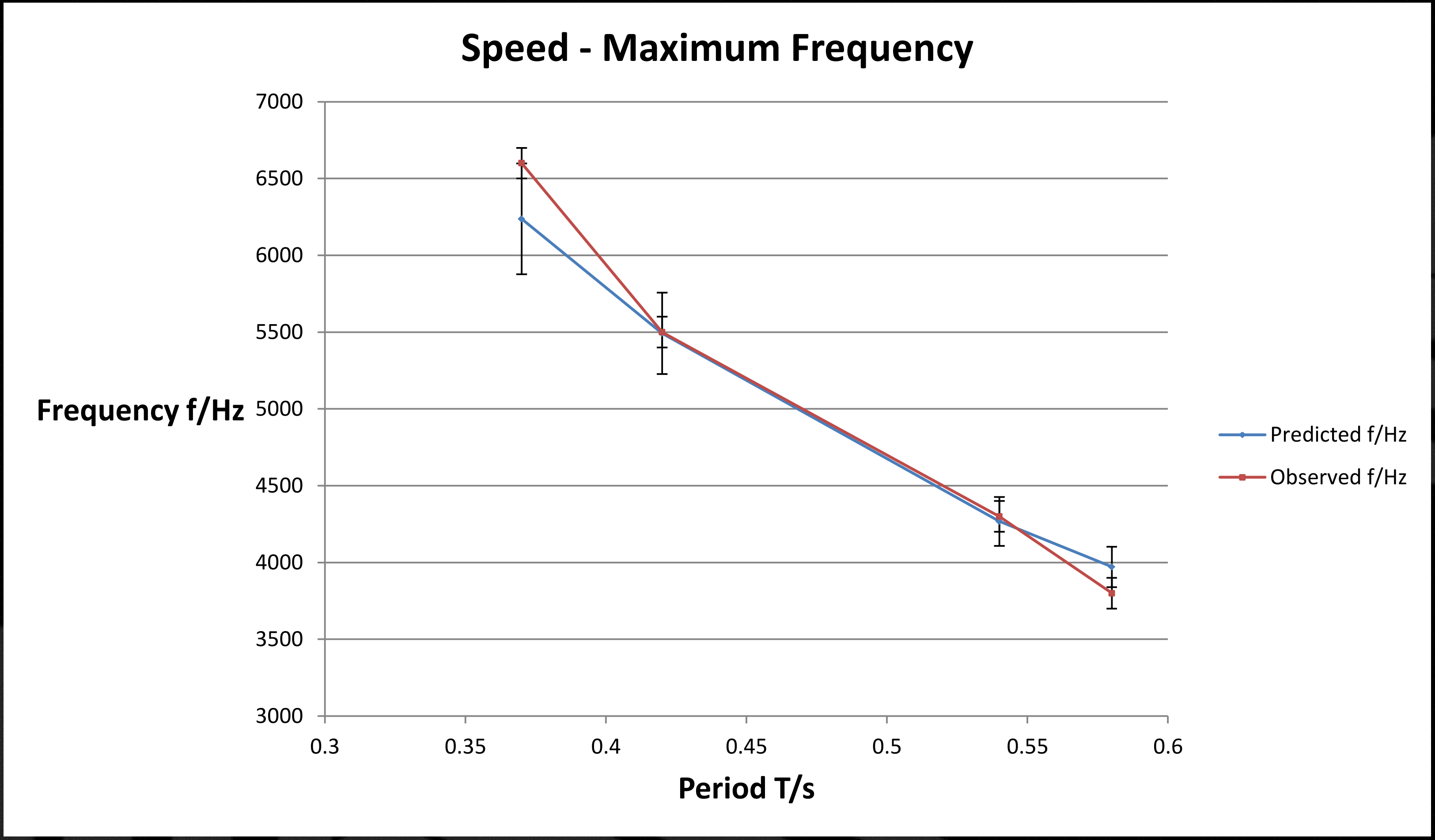

Mass - Maximum Frequency
Frequency/Hz
6000
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
30
35
40
45
50
Mass/g
Frequency/Hz

Speed of Rotation

- $f_s = \frac{0.2 \times 2\pi r}{d T_r}$
- Standardised mass, string diameter, radius – varied period

Speed of Rotation

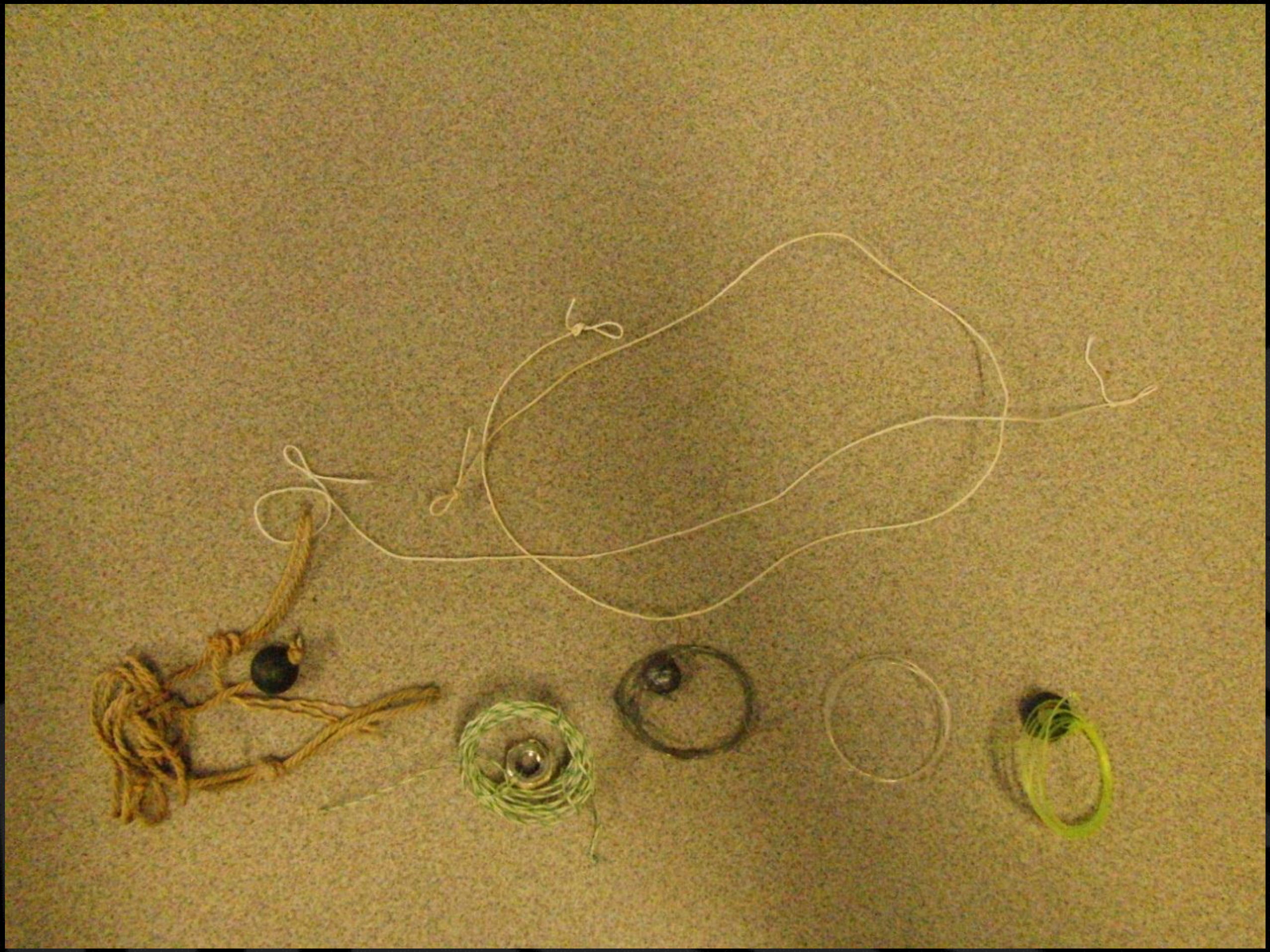
- For thread[FLB], r=1.005m, d=0.00054m,



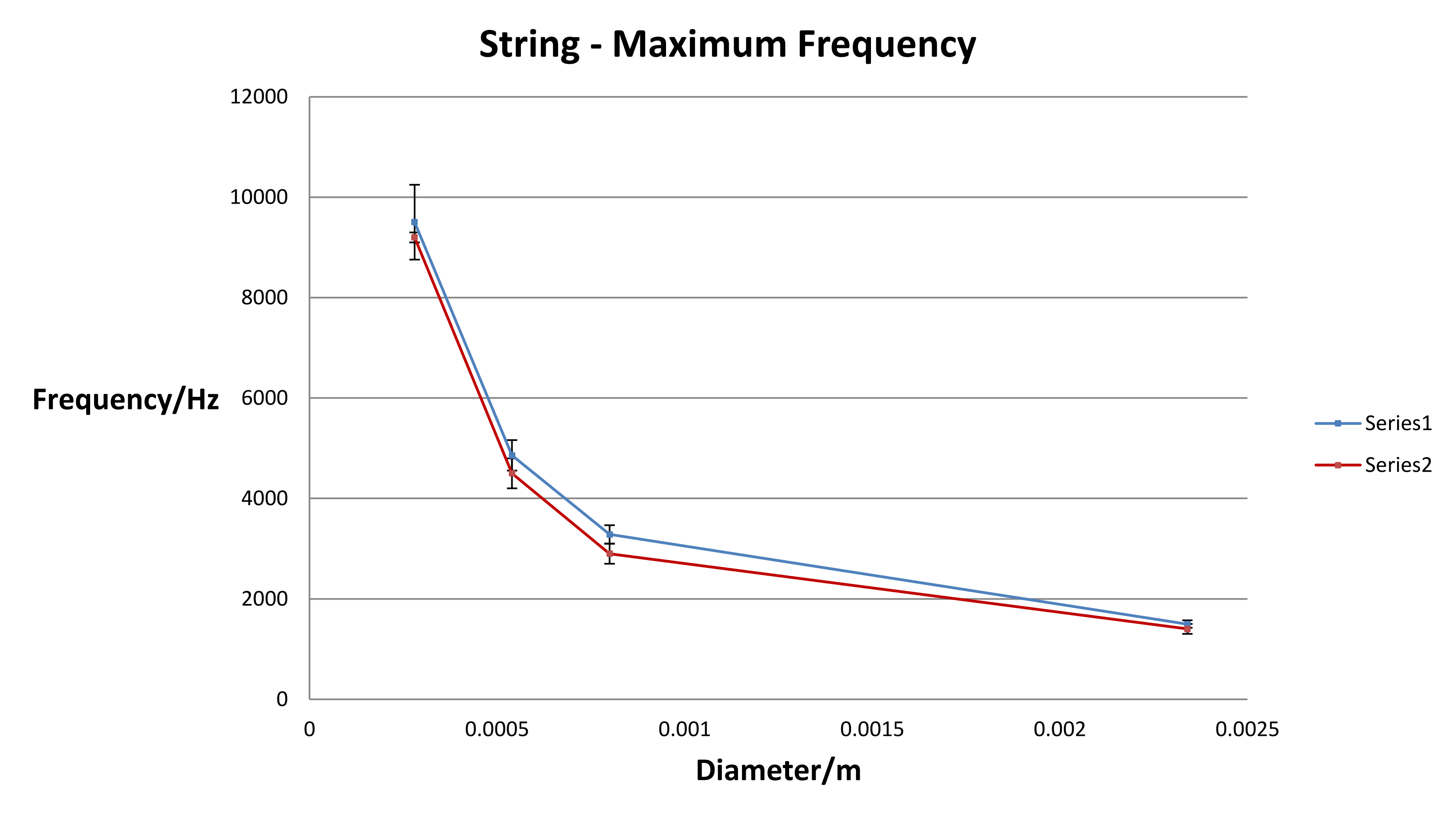
String Diameter

- $f_s = \frac{0.2 \times 2\pi r}{d T_r}$
- Standardised mass, period, radius – varied string diameter
- Tested 11 different strings, but some gave no observable sound: plotted observable results

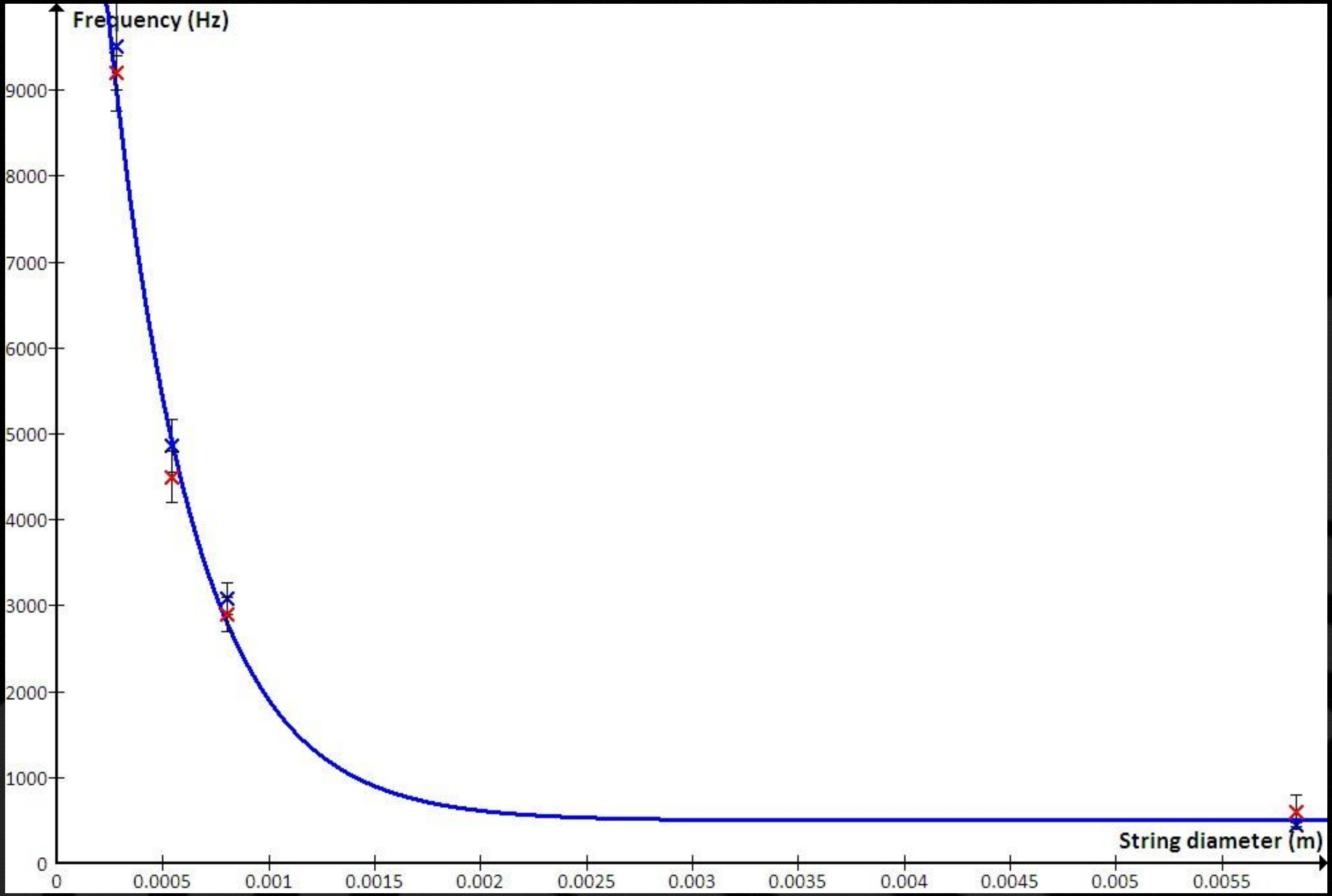
String Diameter



String Diameter



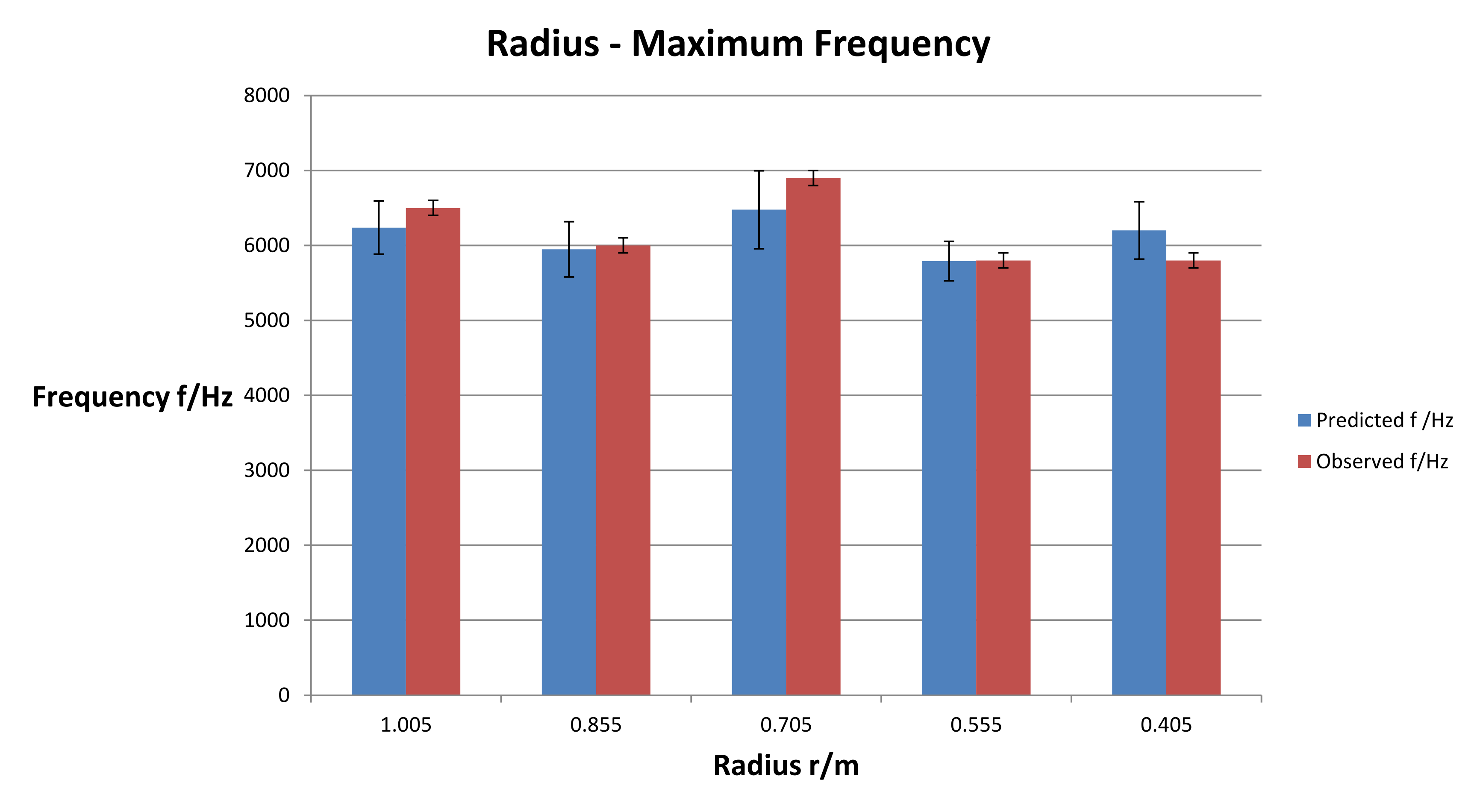
String Diameter



Radius

- $f_s = \frac{0.2 \times 2\pi r}{dT_r}$
- Standardised mass and string diameter
- Due to difficulty with machine, impossible to standardise period – measured instead.

Radius

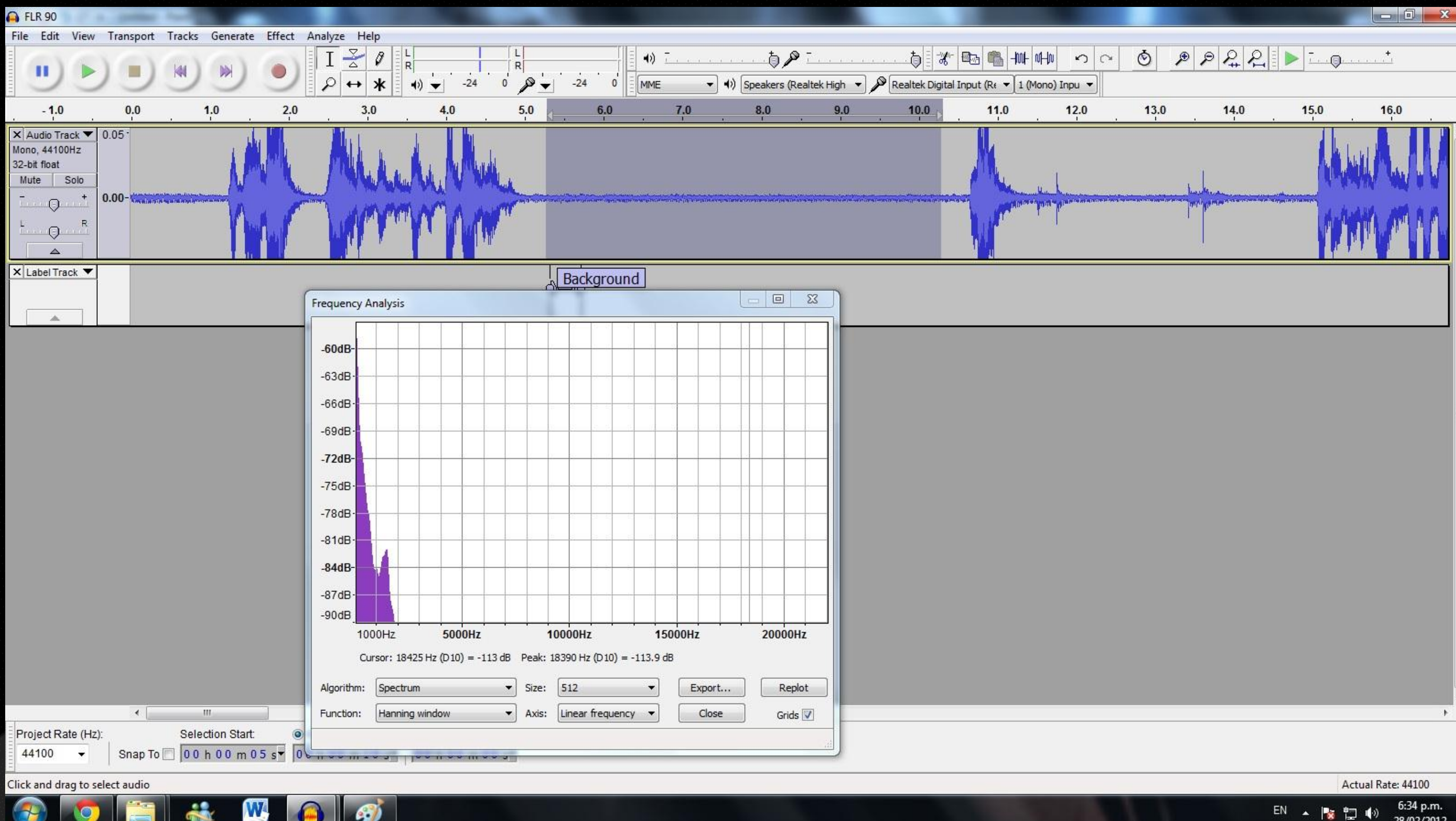

Radius - Maximum Frequency
Frequency f/Hz
8000
7000
6000
5000
4000
3000
2000
1000
0
1.005
0.855
0.705
0.555
0.405
Radius r/m
Predicted f /Hz
Observed f/Hz

Conclusions

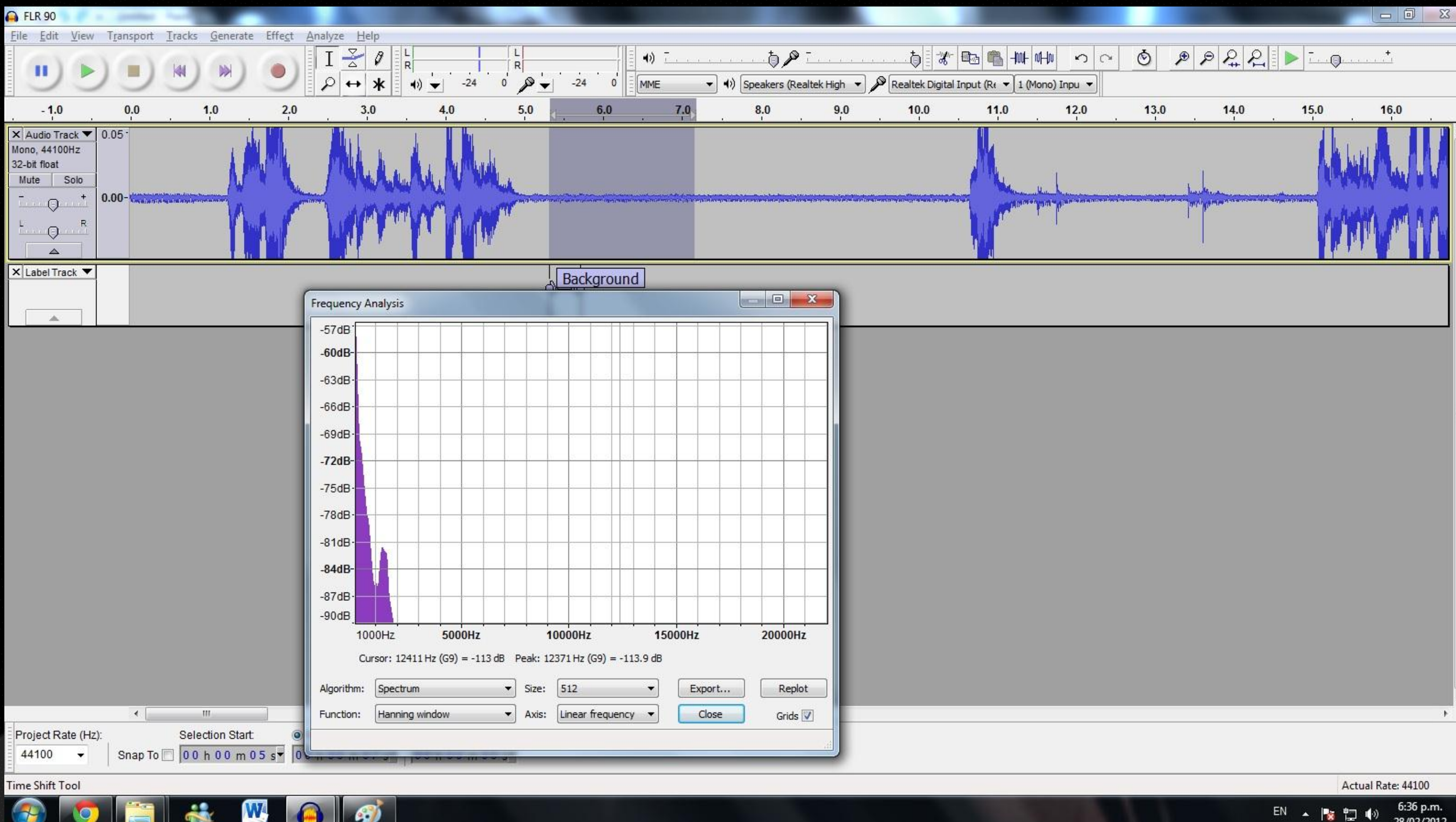
- Distinctive noise from thread – high-pitched whistle
- Mixture of frequencies
- Created not by standing waves, but by vortex shedding
- Affected by linear speed of rotation, thread diameter, radius of spin
- Independent of mass
- $f_S = \frac{0.2 \times 2\pi r}{d T_r}$

Thank you for listening

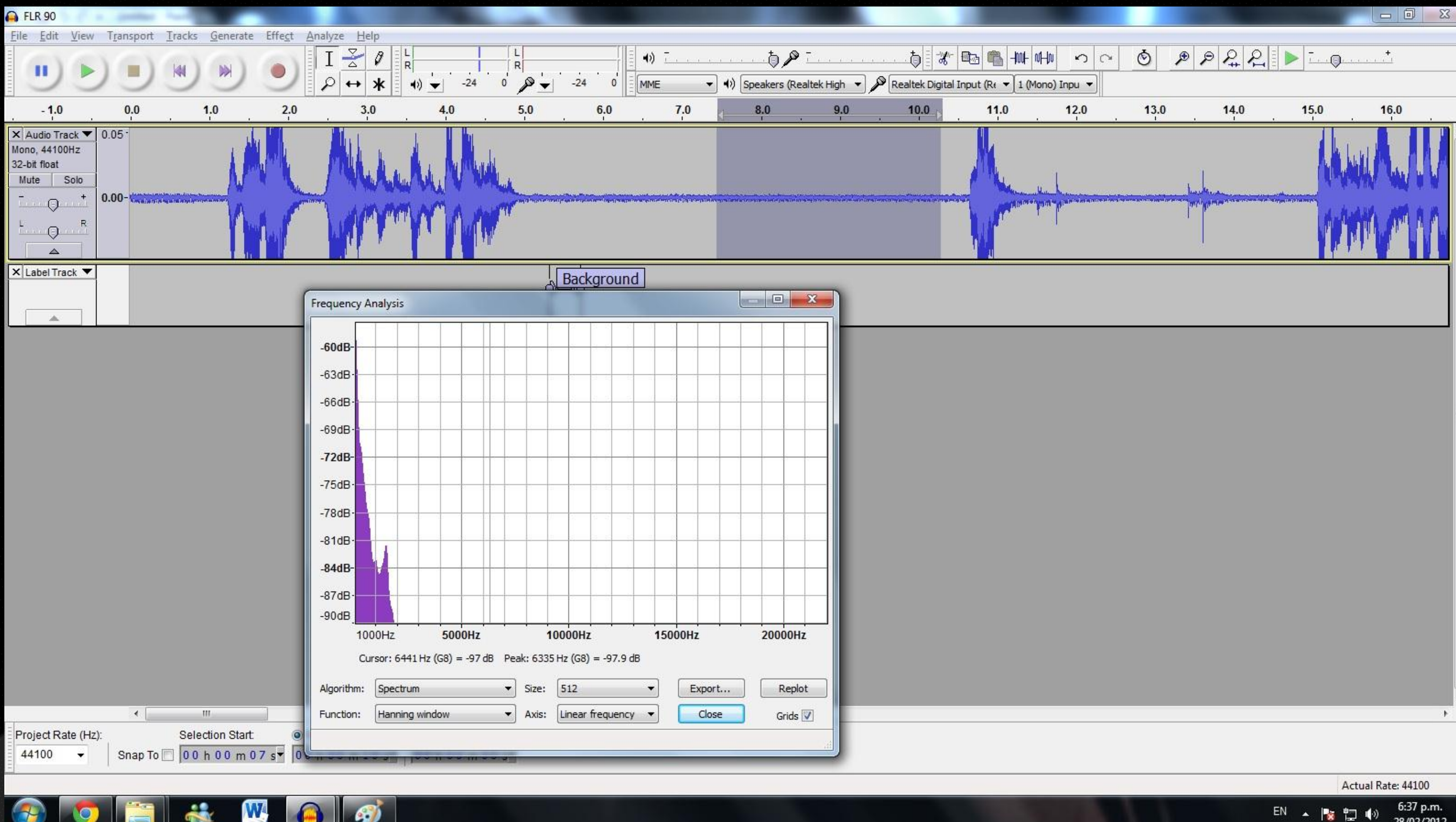
Background Noise 1/6



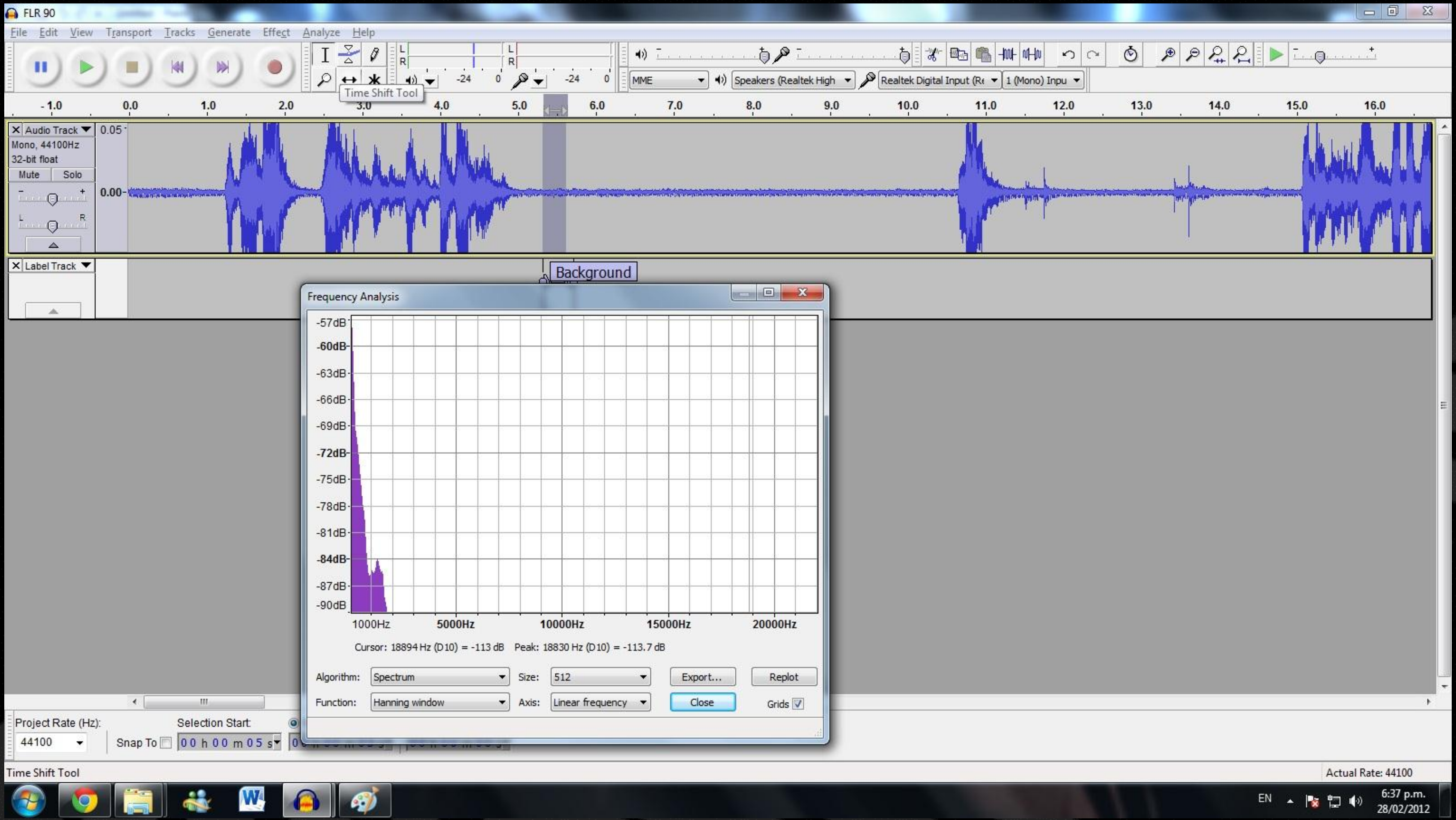
Background Noise 2/6



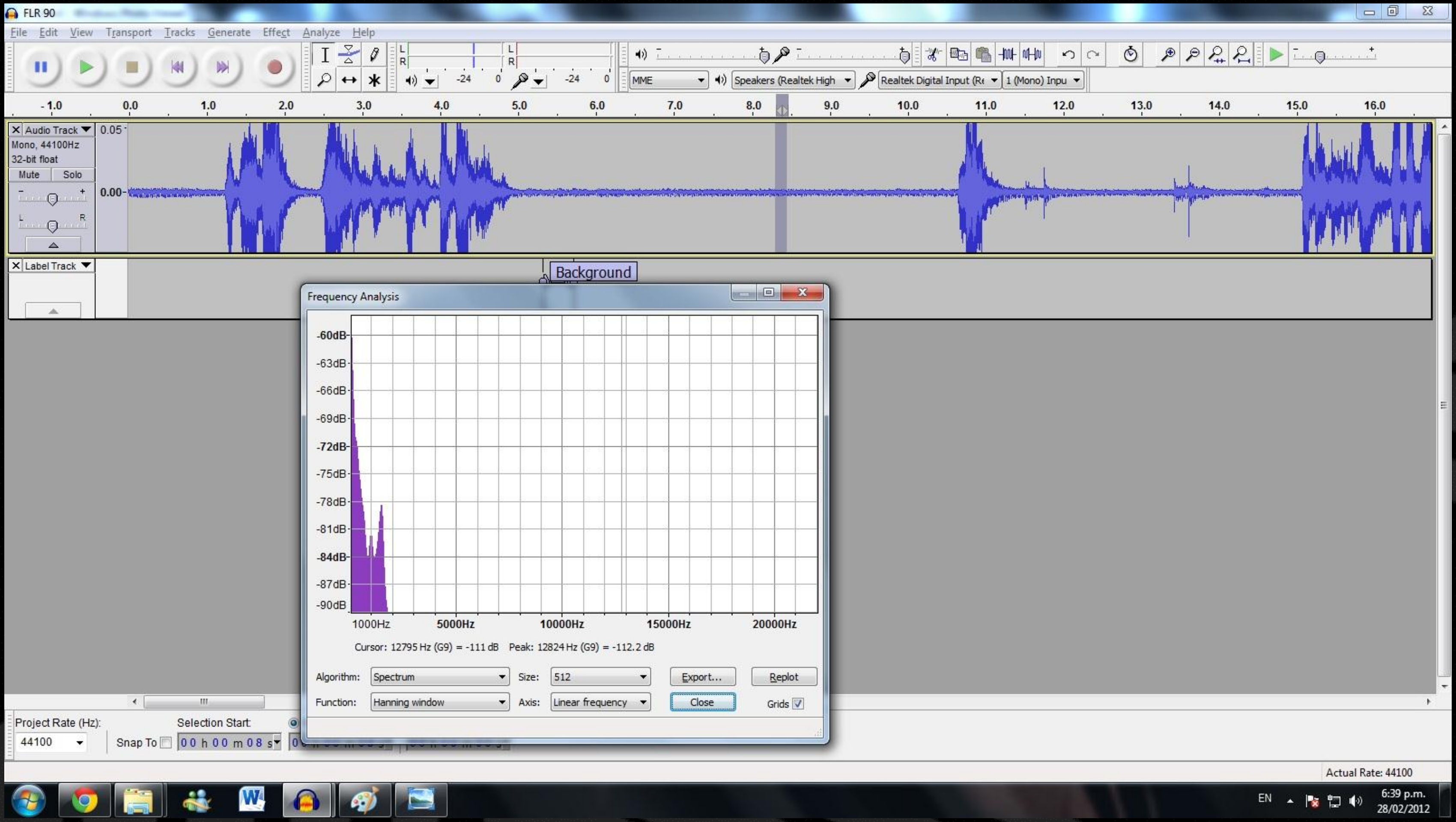
Background Noise 3/6



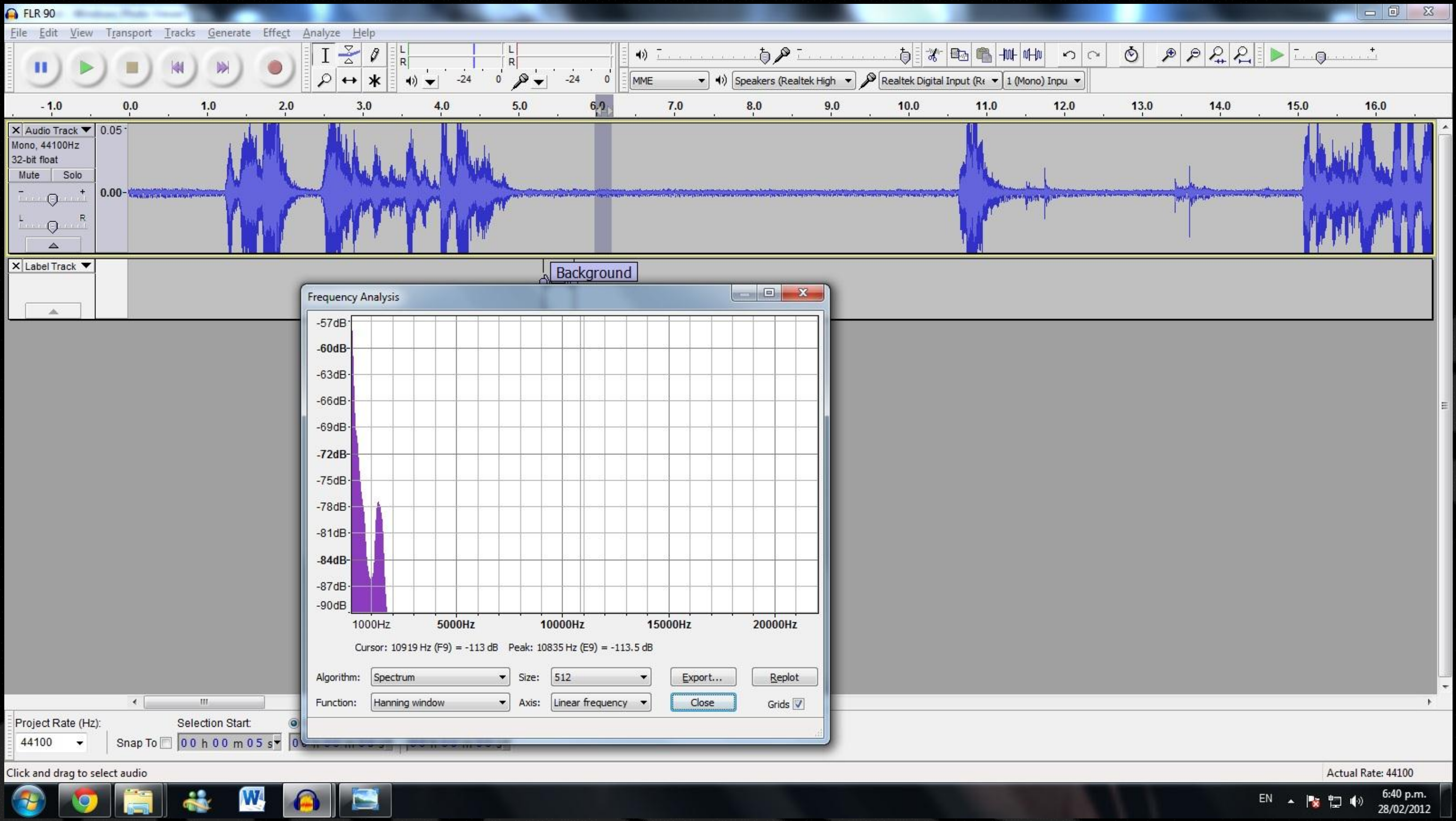
Background Noise 4/6



Background Noise 5/6



Background Noise 6/6



Theory 2

- $Sr = \frac{fd}{V} = 0.198(1 - \frac{19.7}{Re})$
- $Re = Vd \div \frac{\mu}{\rho}$ where $\frac{\mu}{\rho}$ =kinematic viscosity
- $f = 0.198\frac{V}{d}(1 - \frac{19.7}{Vd} \times \frac{\mu}{\rho})$

Theory 2

- (Department of Mechanical Engineering NYU) Raichel, D.R. "The Science and Applications of Acoustics" (2000). Springer-Verlag New York Inc
- Blevins, R. D. (1990) "Flow-induced Vibration". Van Nostrand Reinhold.
- Kaneko, Nakamura, et al. (2008) "Flow-induced vibrations: classifications and lessons from practical experiences". Elsevier Ltd.
- http://www.grc.nasa.gov/WWW/BGH/reynolds.html
- http://www.engineeringtoolbox.com/air-absolute-kinematic-viscosity-d_601.html
- http://www.essom.com/backend/data-file/engineer/engin12_1.pdf

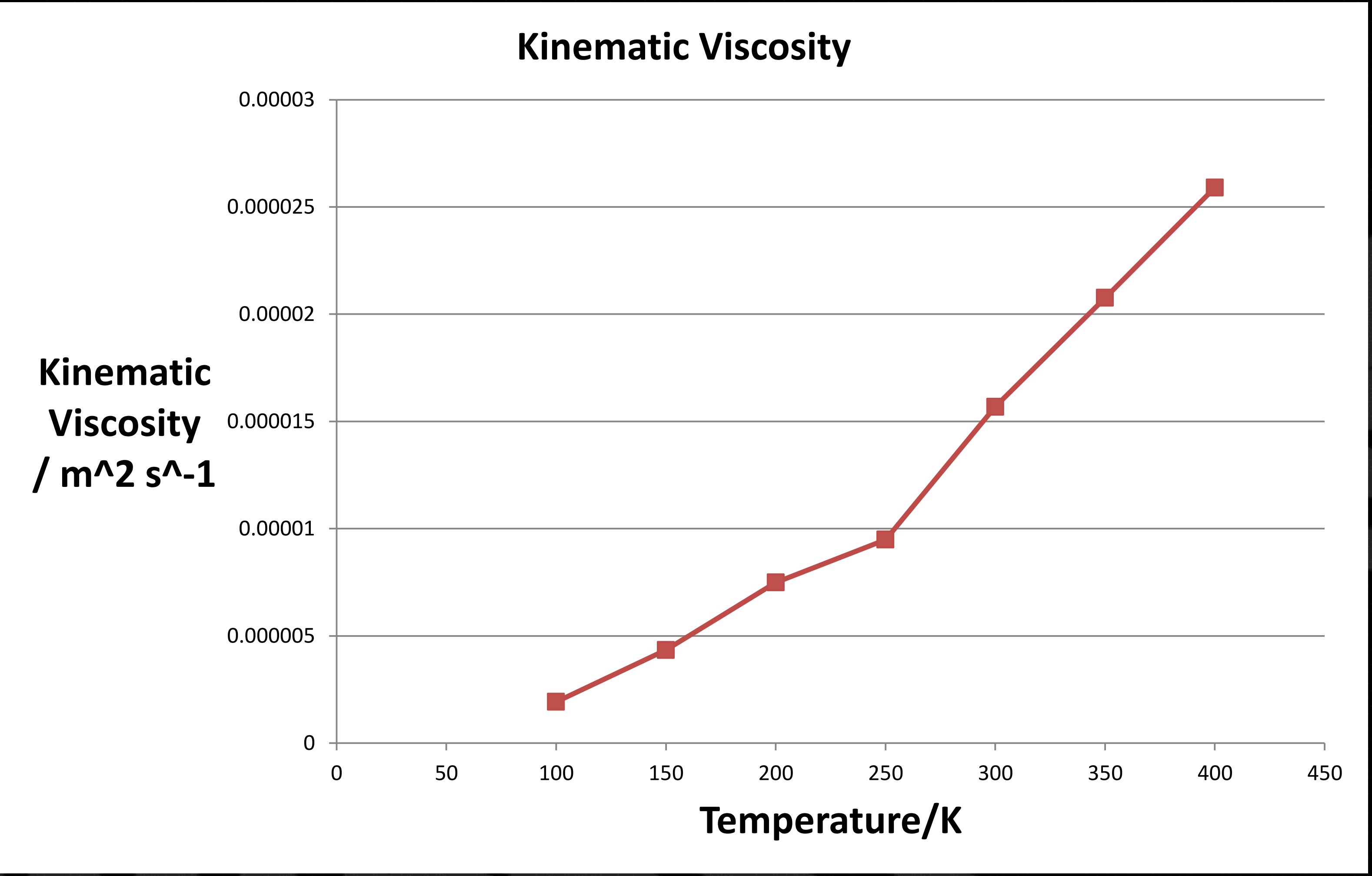
Theory 2

- Whether surface is smooth or rough makes no difference provided Re<2×10^5. Ours ≈ 700
- $Re = Vd \div \frac{\mu}{\rho}$
- Kinematic viscosity of air $= 15.6 \times 10^{-6} m^2 s^{-1}$
- $Re = 2\pi r(rps)d \div 15.6 \times 10^{-6}$
- $= 2\pi \times 1.01 \times 3 \times 0.54 \times 10^{-3} \div 15.6 \times 10^{-6}$
- $= 659$

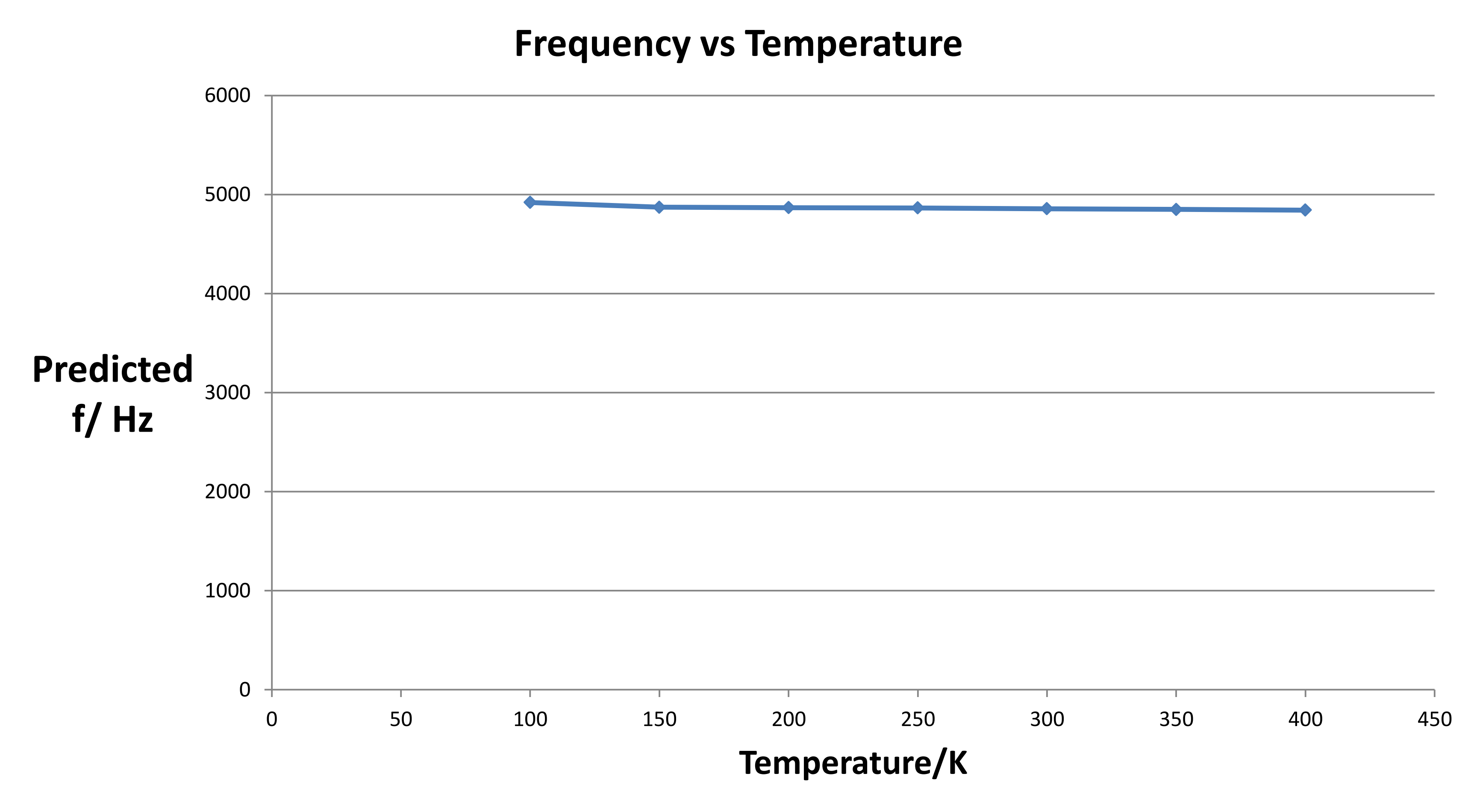
Theory 2

- Laminar flow: Re<2000 (for flow in a pipe)
- Vortex Shedding occurs at Re>90

Temperature



Temperature



Verifying Audacity

- Only available program
- Googled others but they were all hundreds of dollars

Verifying Audacity

- Tested that frequency analysis is working
- Made recordings of instruments at known notes and analysed them
- Clarinet, violin, tuning forks. Single notes and chords
- Audacity gave the correct frequencies

Sound Level

- Very quiet, barely shows up on spectograms
- No access to calibrated instrument

- Decibel scale is not absolute, but relative – often uses reference point of threshold of human hearing

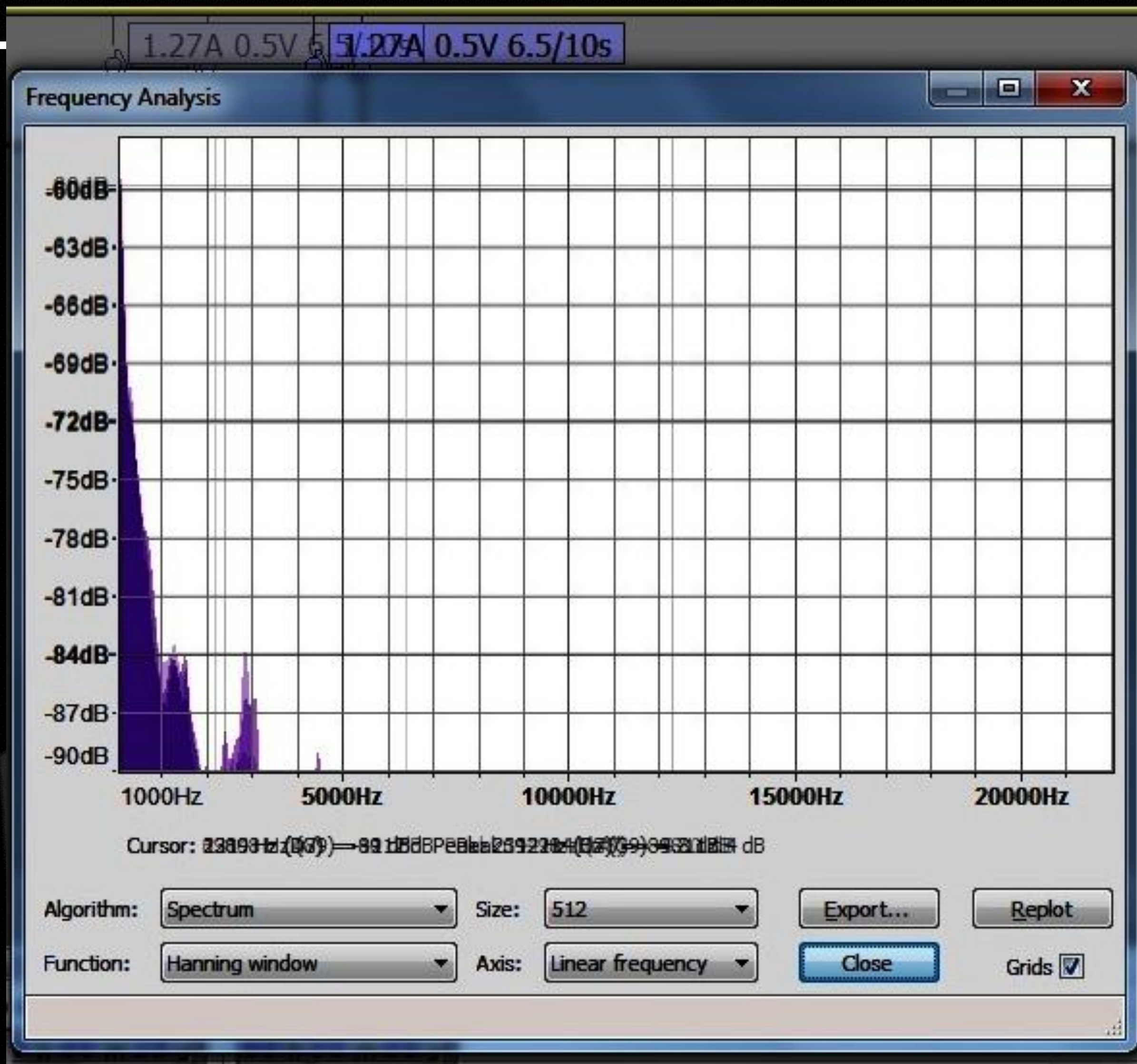
Sound Level

- Impossible with computer program, as input signal varies with microphone. Uses maximum possible reading; unsure how it relates to physical properties eg intensity, sound pressure level.
- 2 ways to look at sound level: by ear and program's relative dB

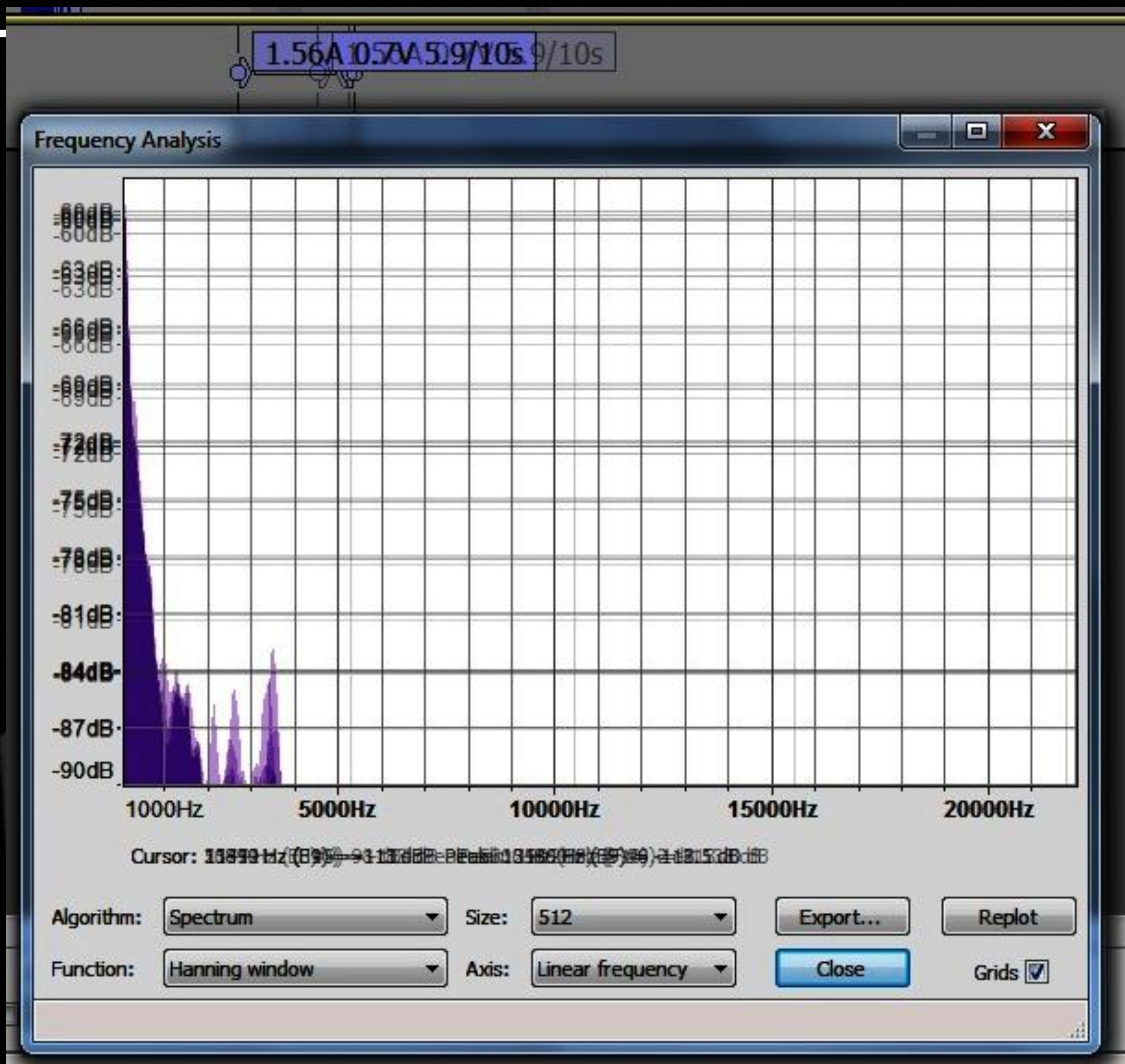
Sound Level - Speed

- By ear: clearly louder as speed increases

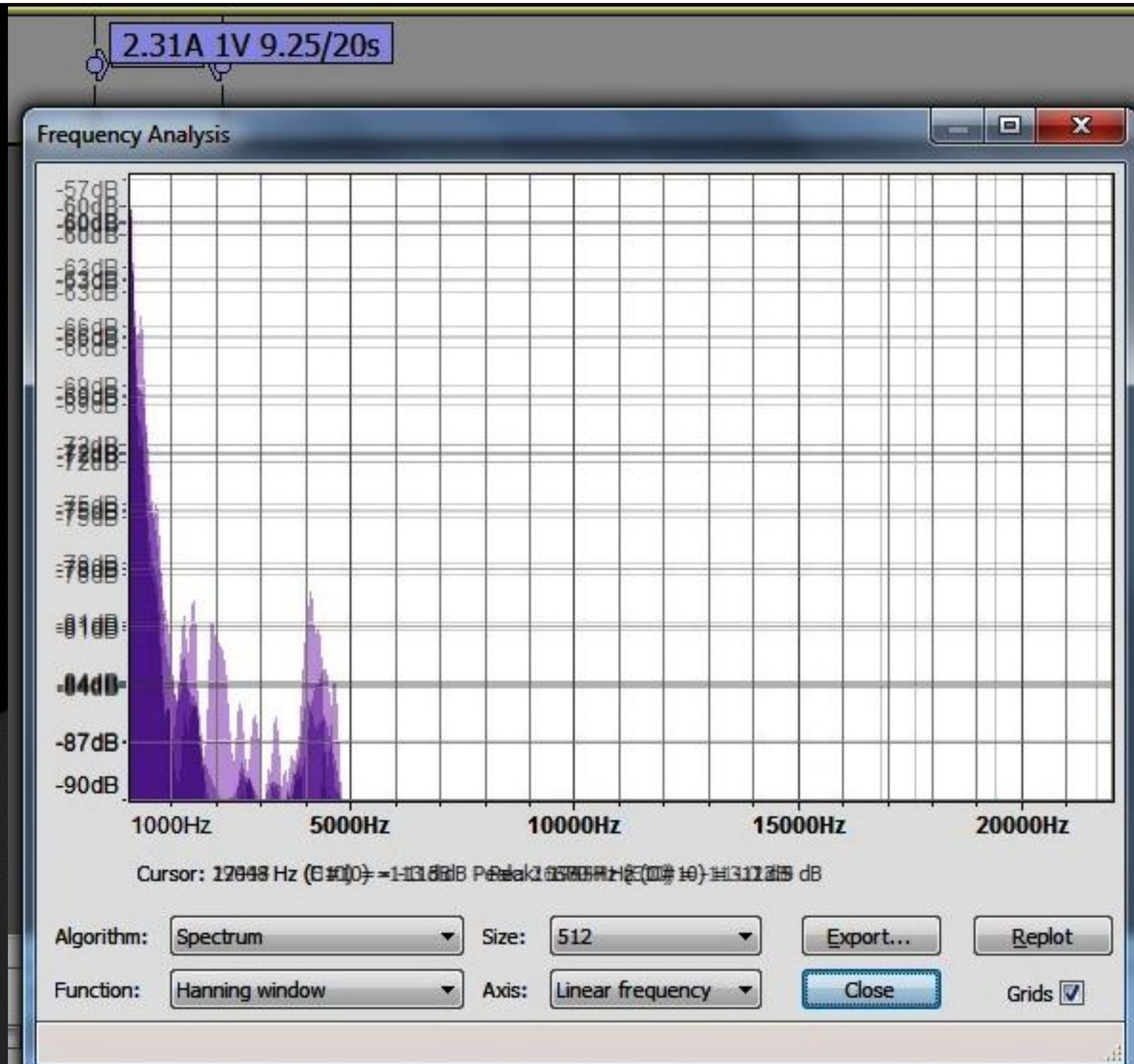
Sound Level - Speed



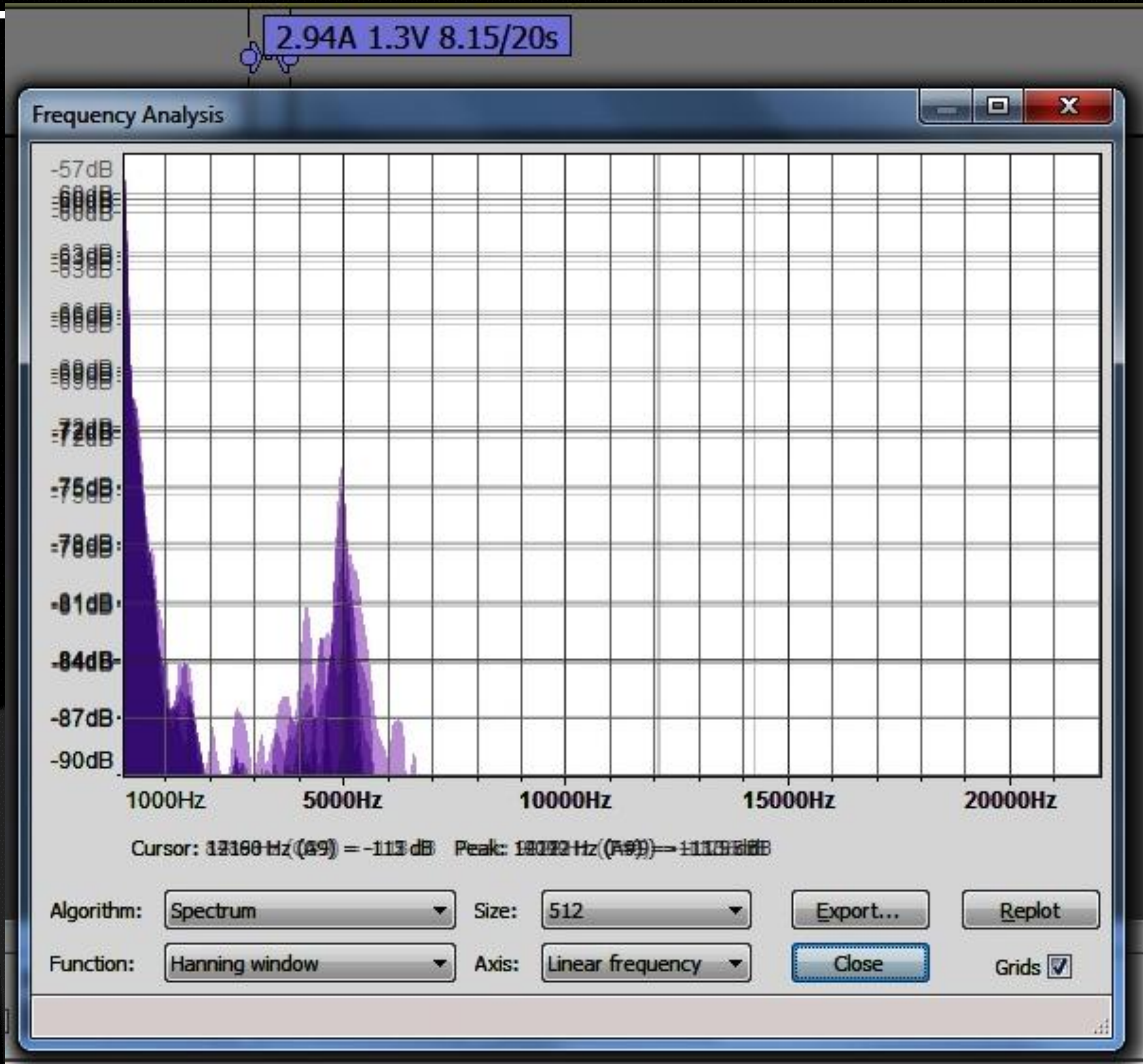
Sound Level - Speed



Sound Level - Speed

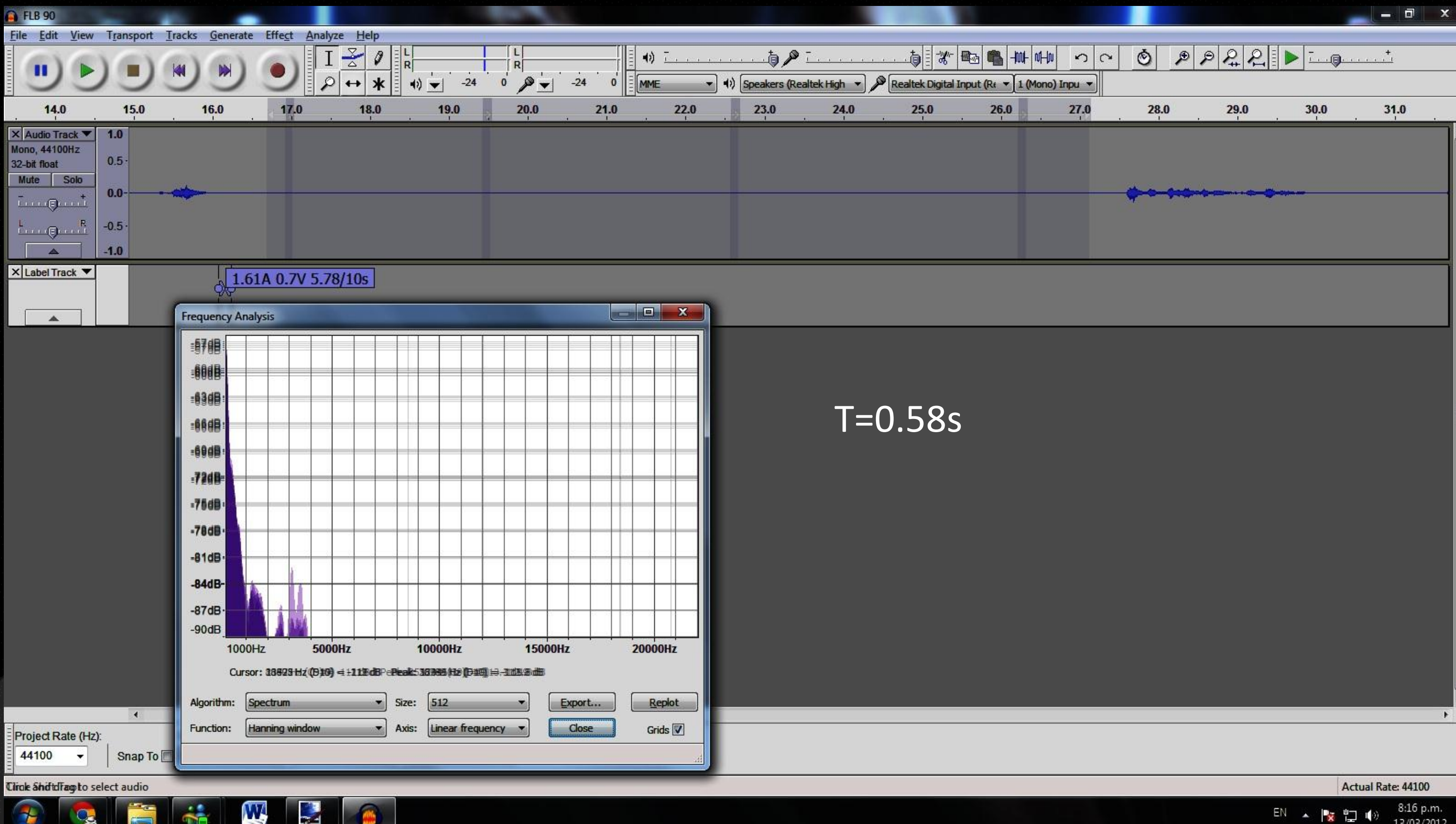


Sound Level - Speed

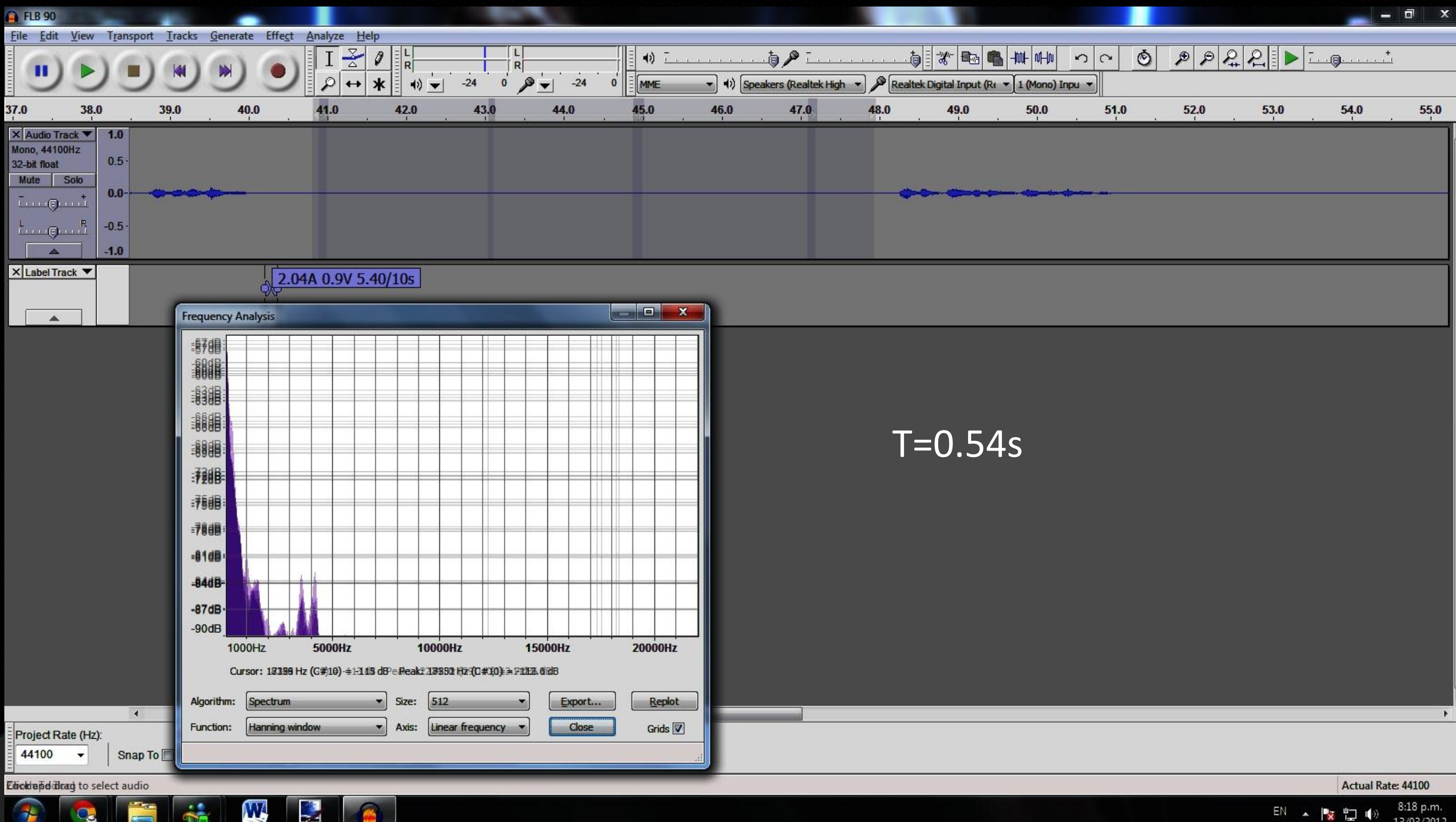


Speed 1/4

- Standardised mass, string, length

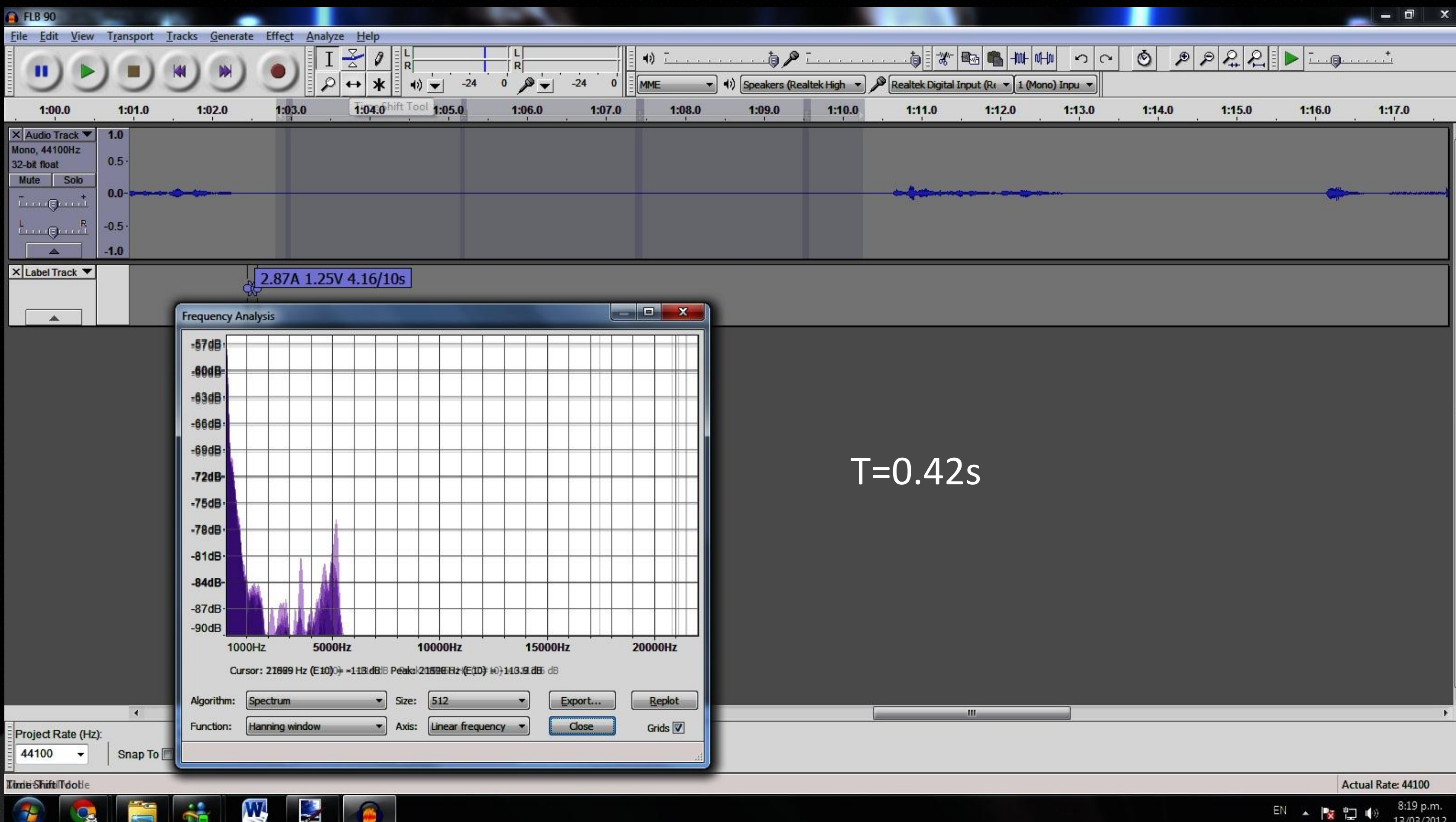


Speed 2/4



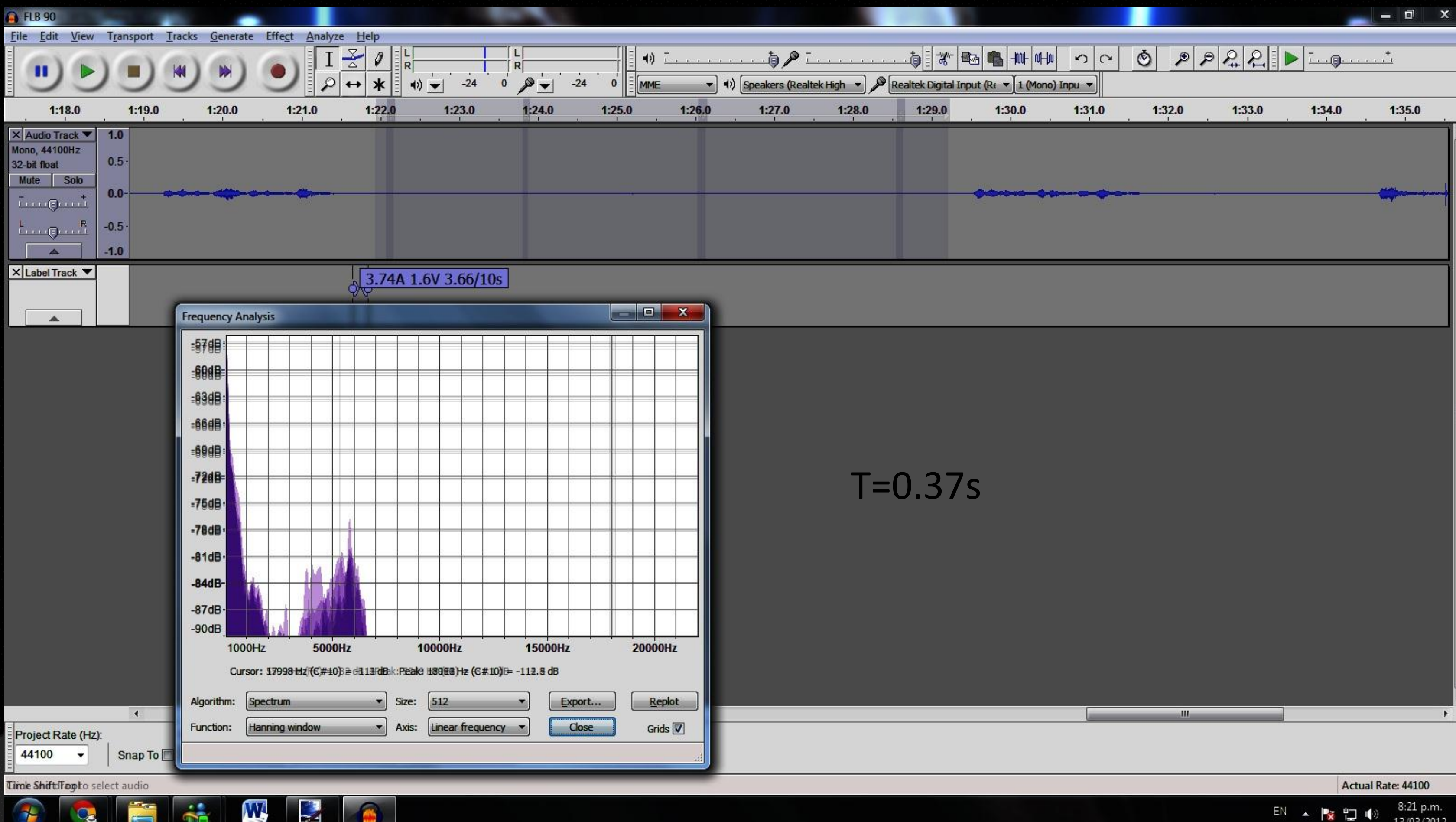
T=0.54s

Speed 3/4



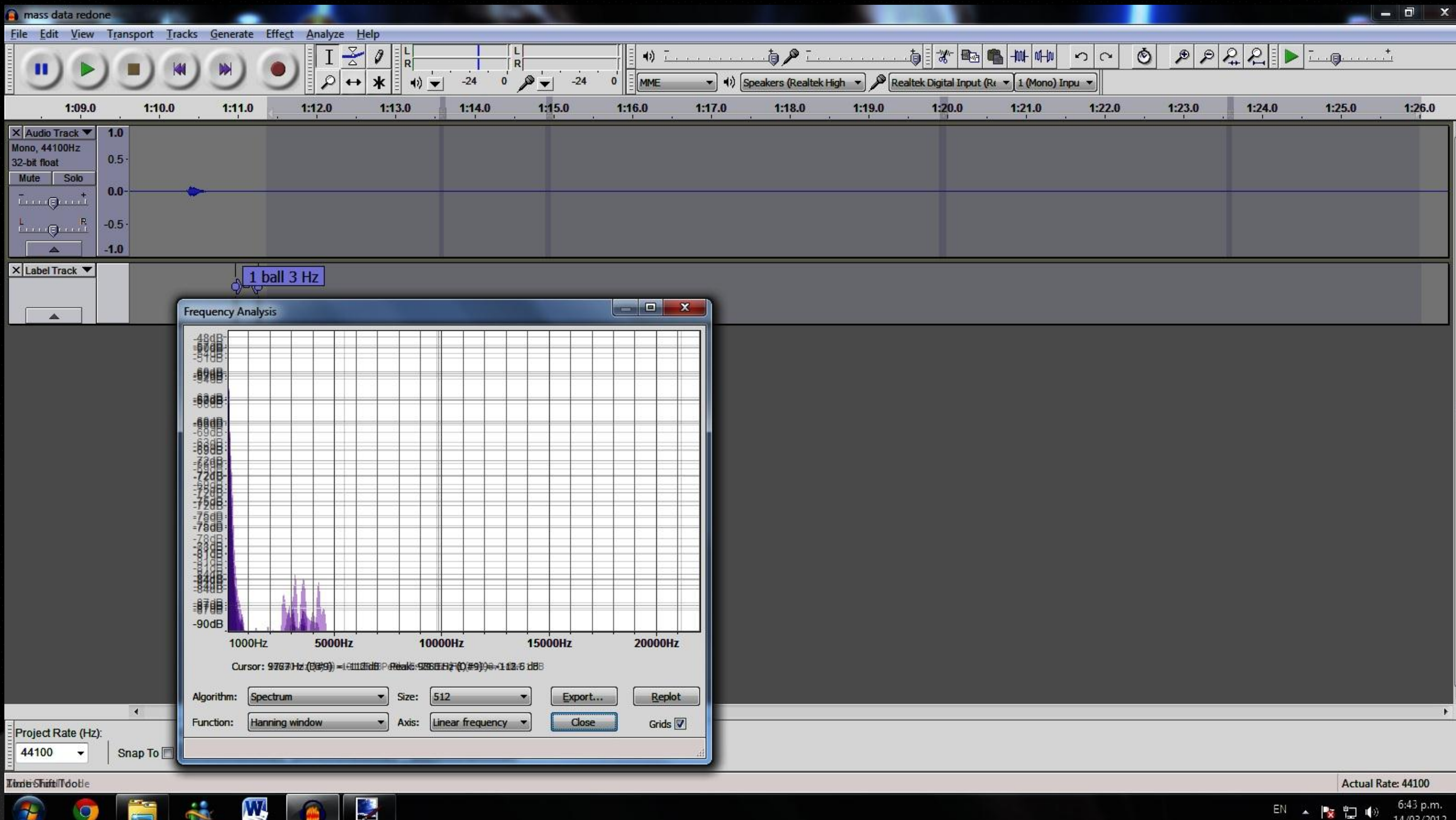
T=0.42s

Speed 4/4

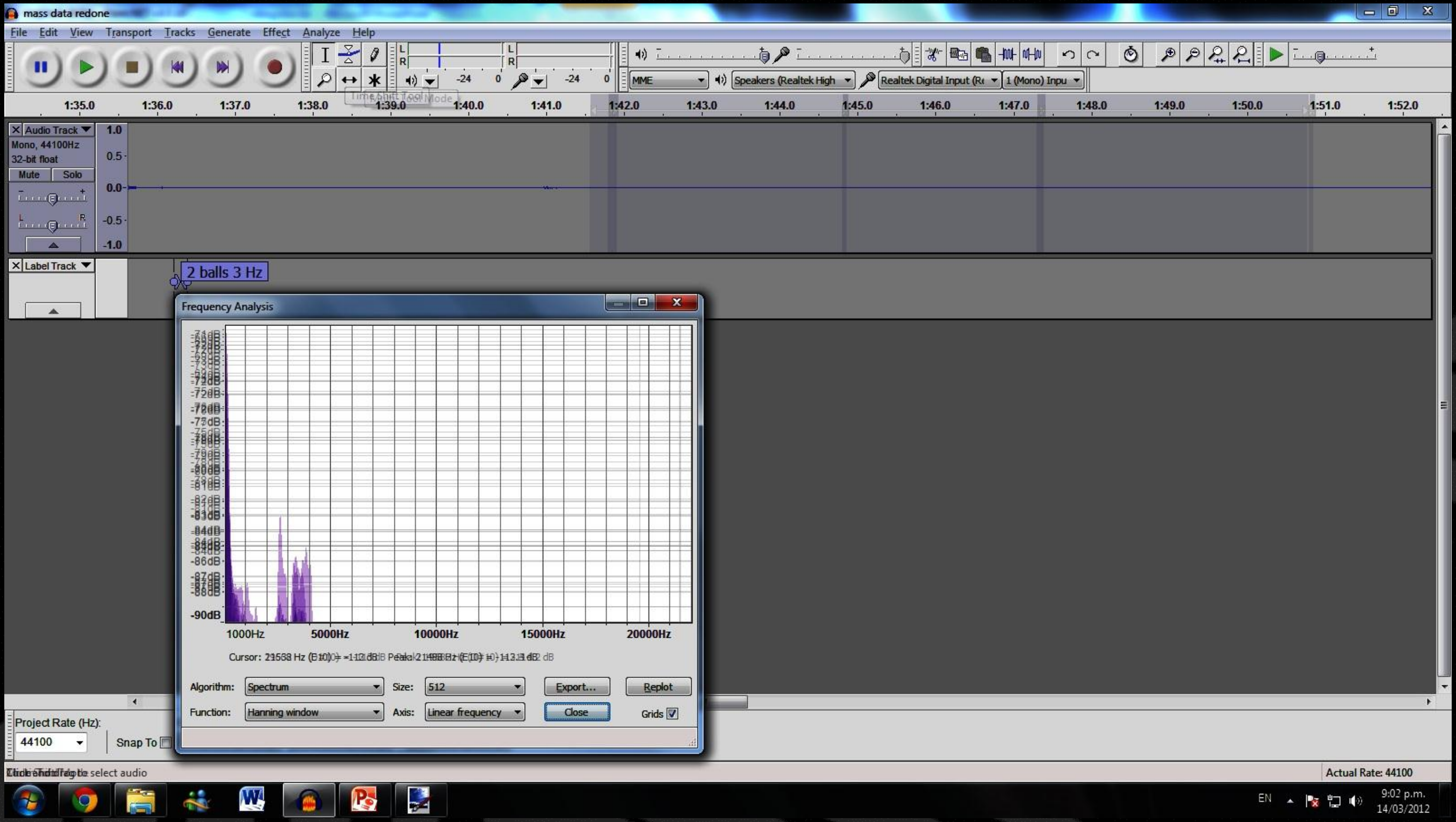


Experiments - 1

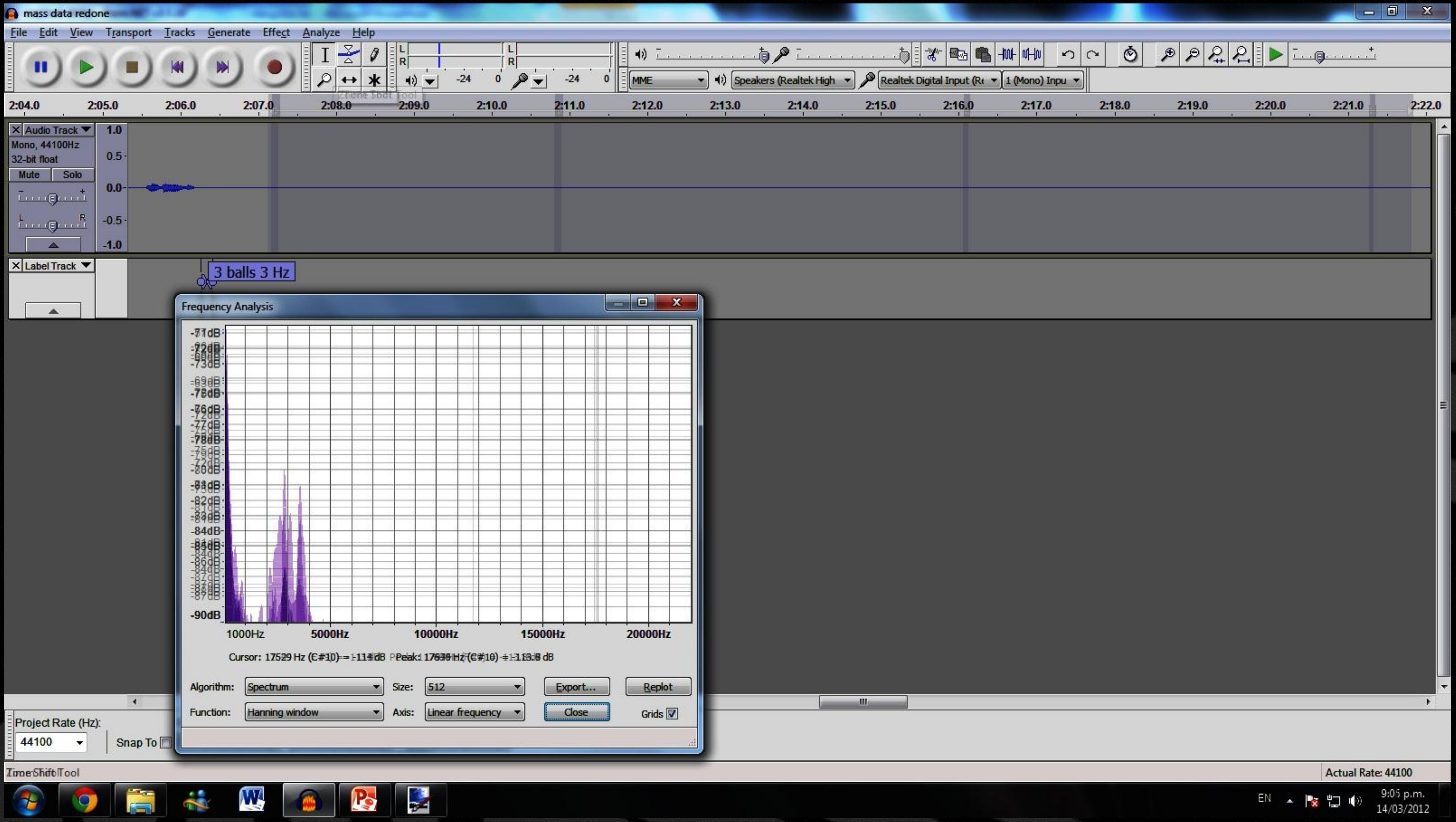
Mass 1/6


mass data redone
File Edit View Transport Tracks Generate Effect Analyze Help
Audio Track
Mono, 44100Hz
32-bit float
Label Track
1 ball 3 Hz
Frequency Analysis
-90dB
1000Hz
5000Hz
10000Hz
15000Hz
20000Hz
Algorithm: Spectrum
Size: 512
Export...
Replot
Function: Hanning window
Axis: Linear frequency
Close
Grids
Project Rate (Hz):
44100
Snap To
Actual Rate: 44100

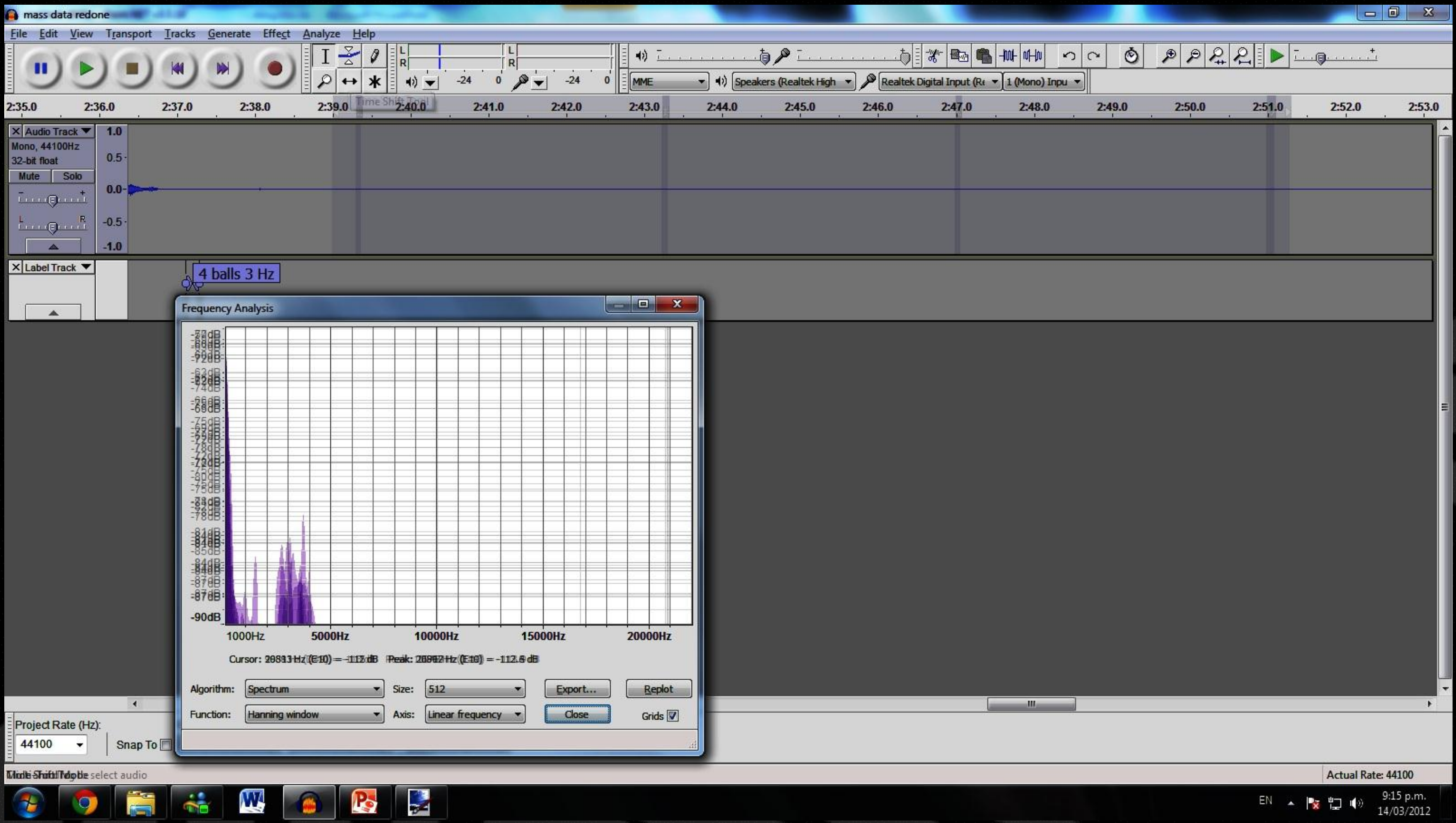
Mass 2/6


mass data redone
File Edit View Transport Tracks Generate Effect Analyze Help
Audio Track
Mono, 44100Hz
32-bit float
Label Track
2 balls 3 Hz
Frequency Analysis
-90dB
1000Hz
5000Hz
10000Hz
15000Hz
20000Hz
Algorithm: Spectrum
Size: 512
Export...
Replot
Function: Hanning window
Axis: Linear frequency
Close
Grids
Project Rate (Hz):
44100
Snap To
Actual Rate: 44100
9:02 p.m.
14/03/2012

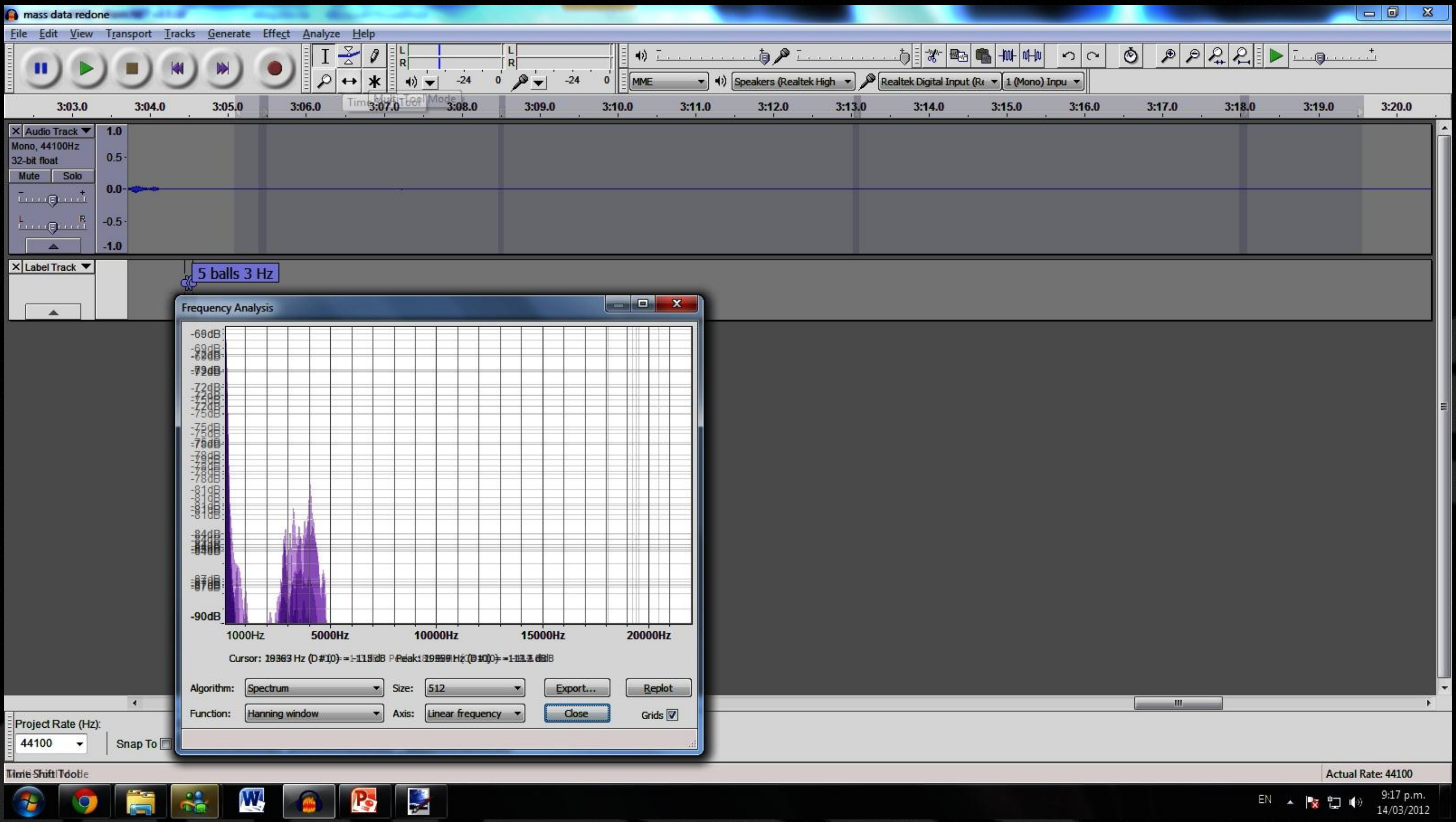
Mass 3/6


mass data redone
3 balls 3 Hz
Frequency Analysis
1000Hz
5000Hz
10000Hz
15000Hz
20000Hz
-90dB
Algorithm: Spectrum
Size: 512
Function: Hanning window
Axis: Linear frequency
Export...
Replot
Close
Grids
Project Rate (Hz):
44100
Actual Rate: 44100

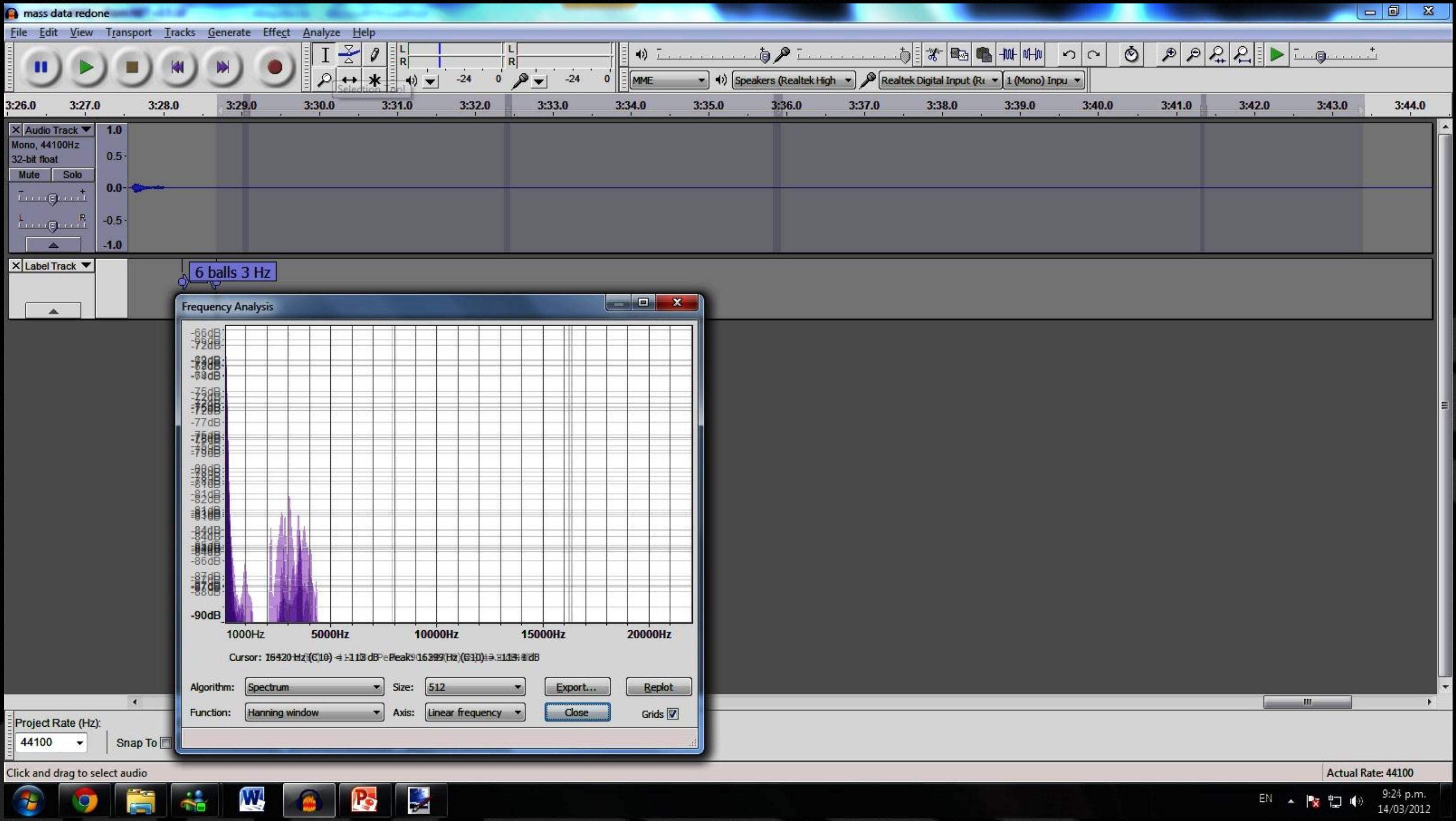
Mass 4/6


mass data redone
File Edit View Transport Tracks Generate Effect Analyze Help
Audio Track
Mono, 44100Hz
32-bit float
Label Track
4 balls 3 Hz
Frequency Analysis
-90dB
1000Hz
5000Hz
10000Hz
15000Hz
20000Hz
Algorithm: Spectrum
Size: 512
Export...
Replot
Function: Hanning window
Axis: Linear frequency
Close
Grids
Project Rate (Hz):
44100
Snap To
Actual Rate: 44100

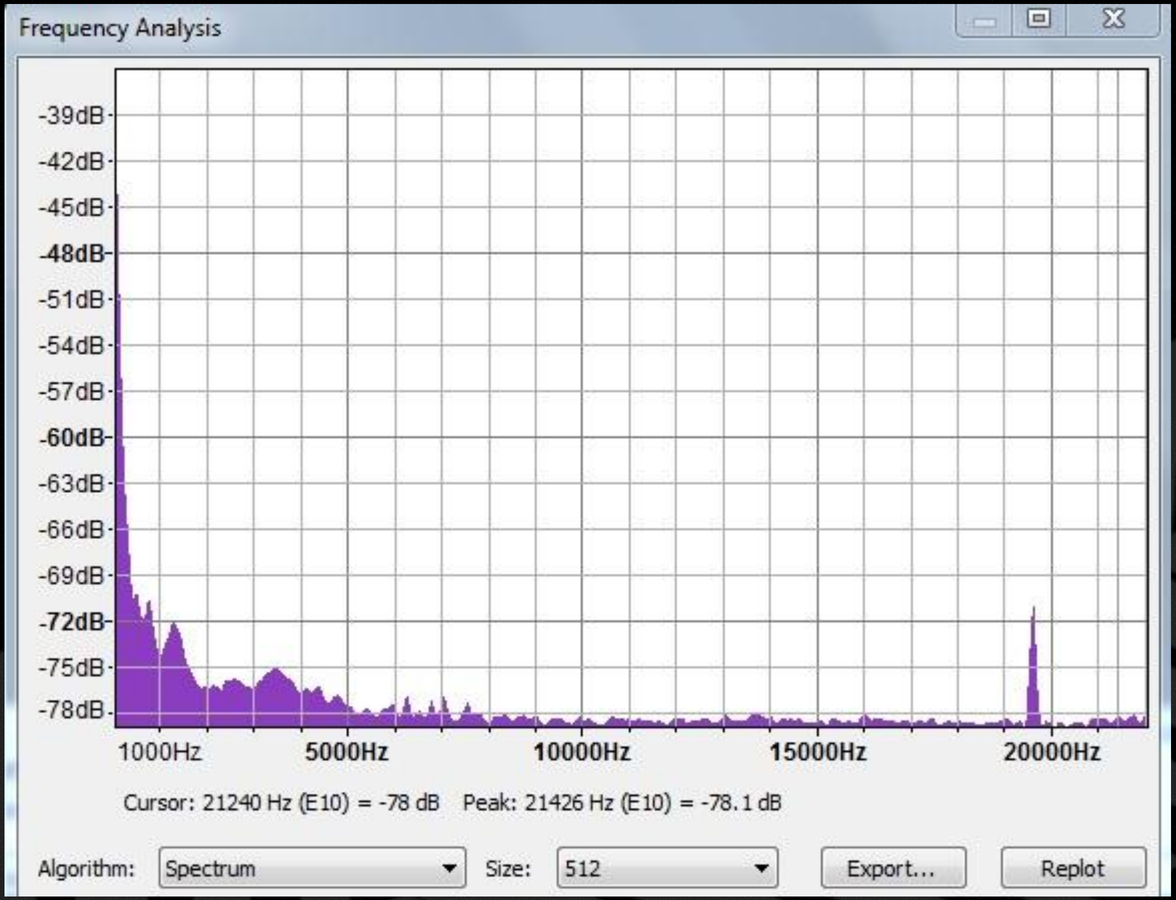
Mass 5/6


mass data redone
File Edit View Transport Tracks Generate Effect Analyze Help
Audio Track
Mono, 44100Hz
32-bit float
Label Track
5 balls 3 Hz
Frequency Analysis
-60dB
-90dB
1000Hz
5000Hz
10000Hz
15000Hz
20000Hz
Algorithm: Spectrum
Size: 512
Export...
Replot
Function: Hanning window
Axis: Linear frequency
Close
Grids
Project Rate (Hz):
44100
Snap To
Actual Rate: 44100

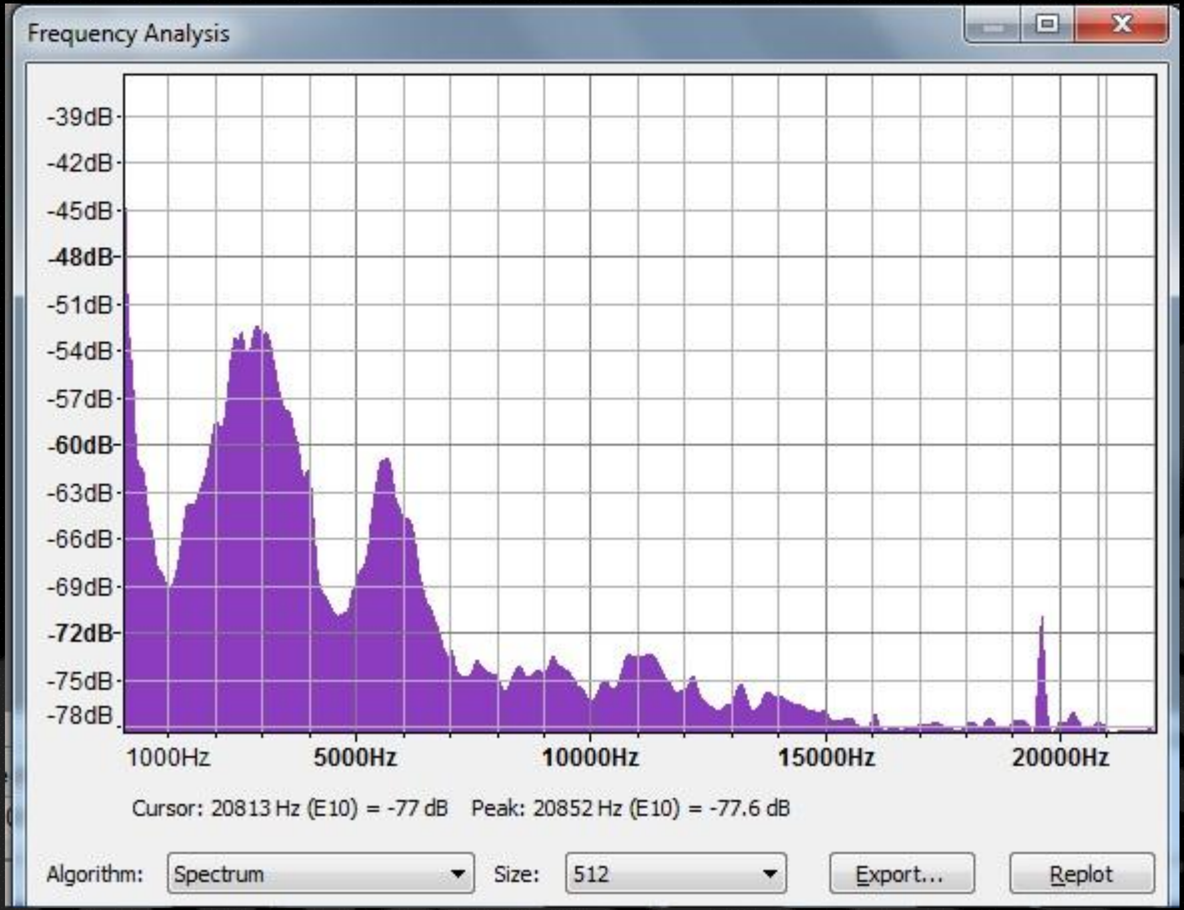
Mass 6/6


mass data redone
6 balls 3 Hz
Frequency Analysis
1000Hz
5000Hz
10000Hz
15000Hz
20000Hz
-90dB
Algorithm: Spectrum
Size: 512
Function: Hanning window
Axis: Linear frequency
Project Rate (Hz): 44100
Click and drag to select audio
Actual Rate: 44100

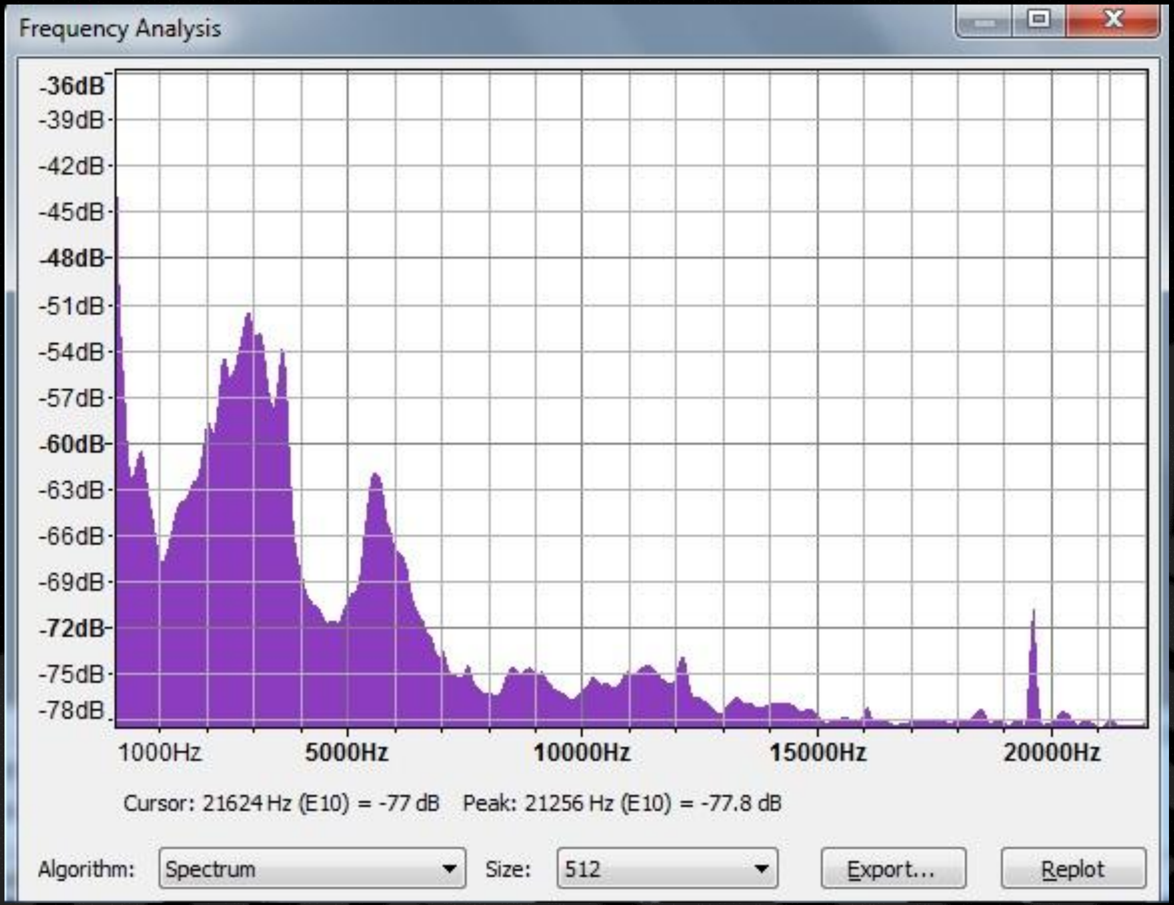
2nd Mass Test



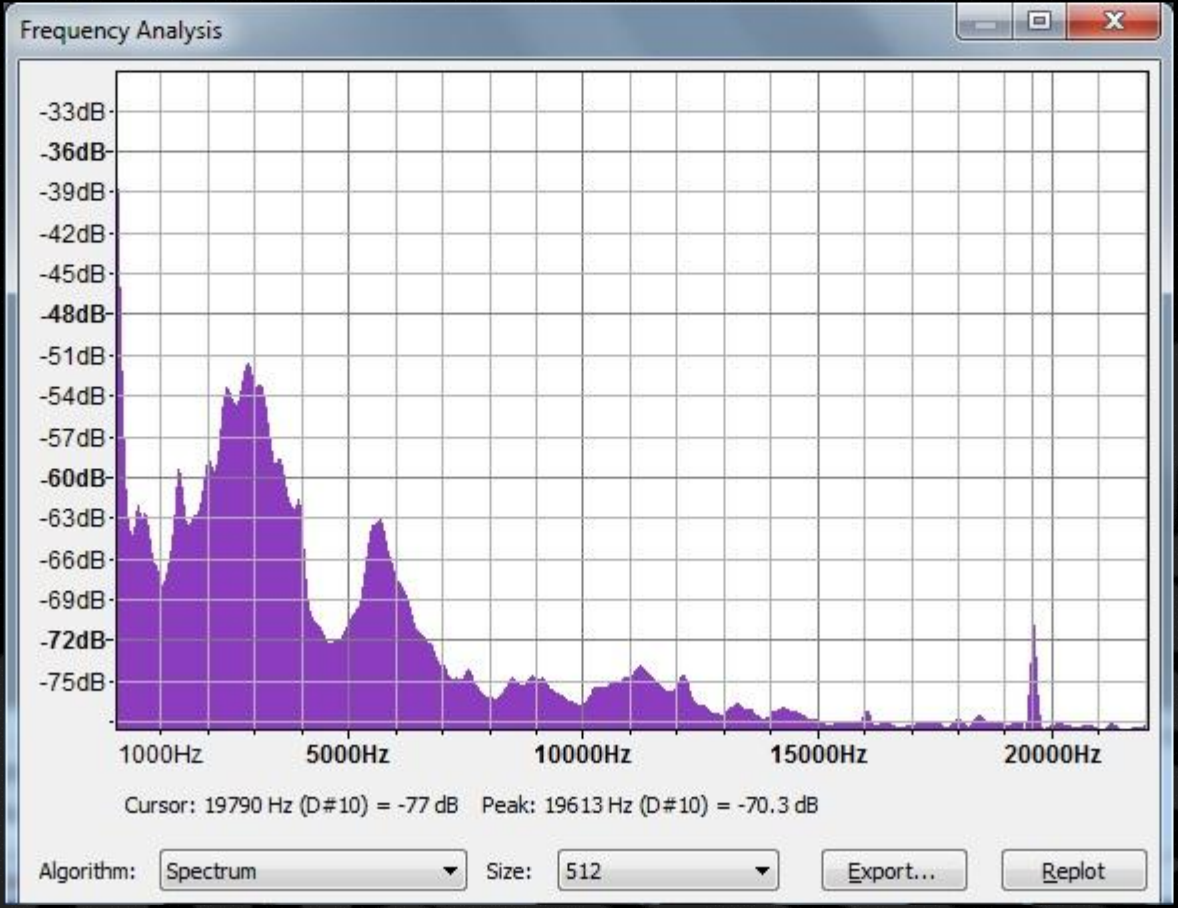
2nd Mass Test



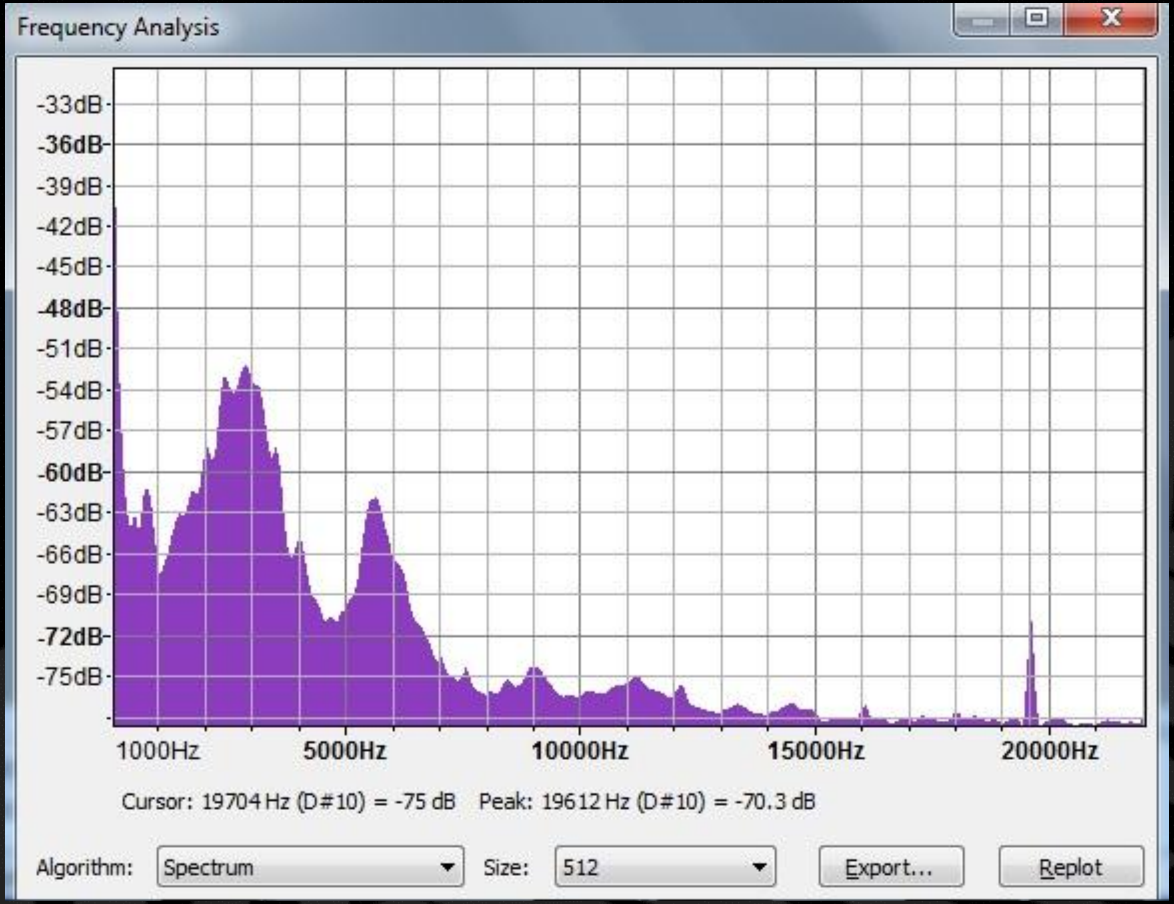
2nd Mass Test



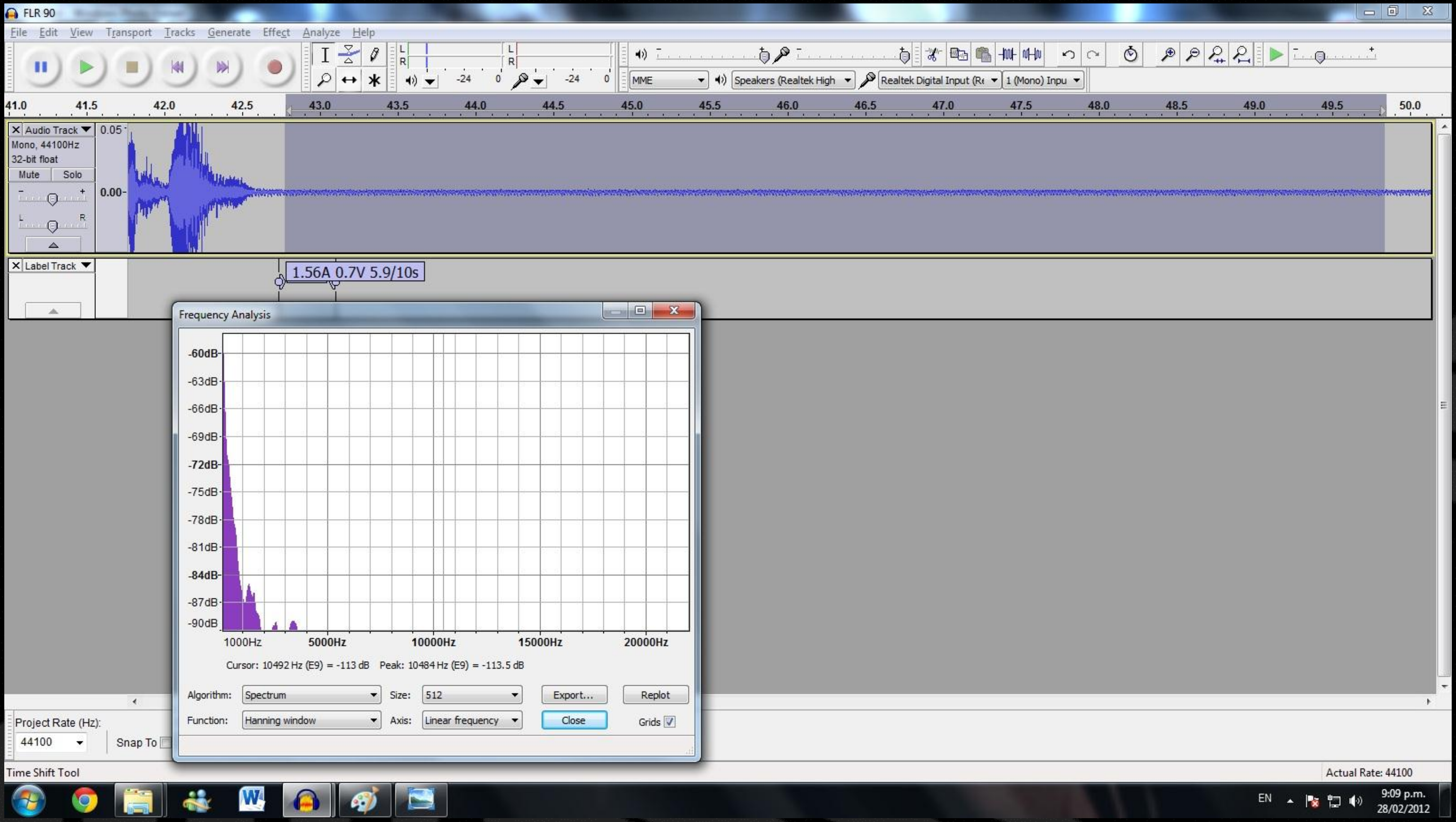
2nd Mass Test



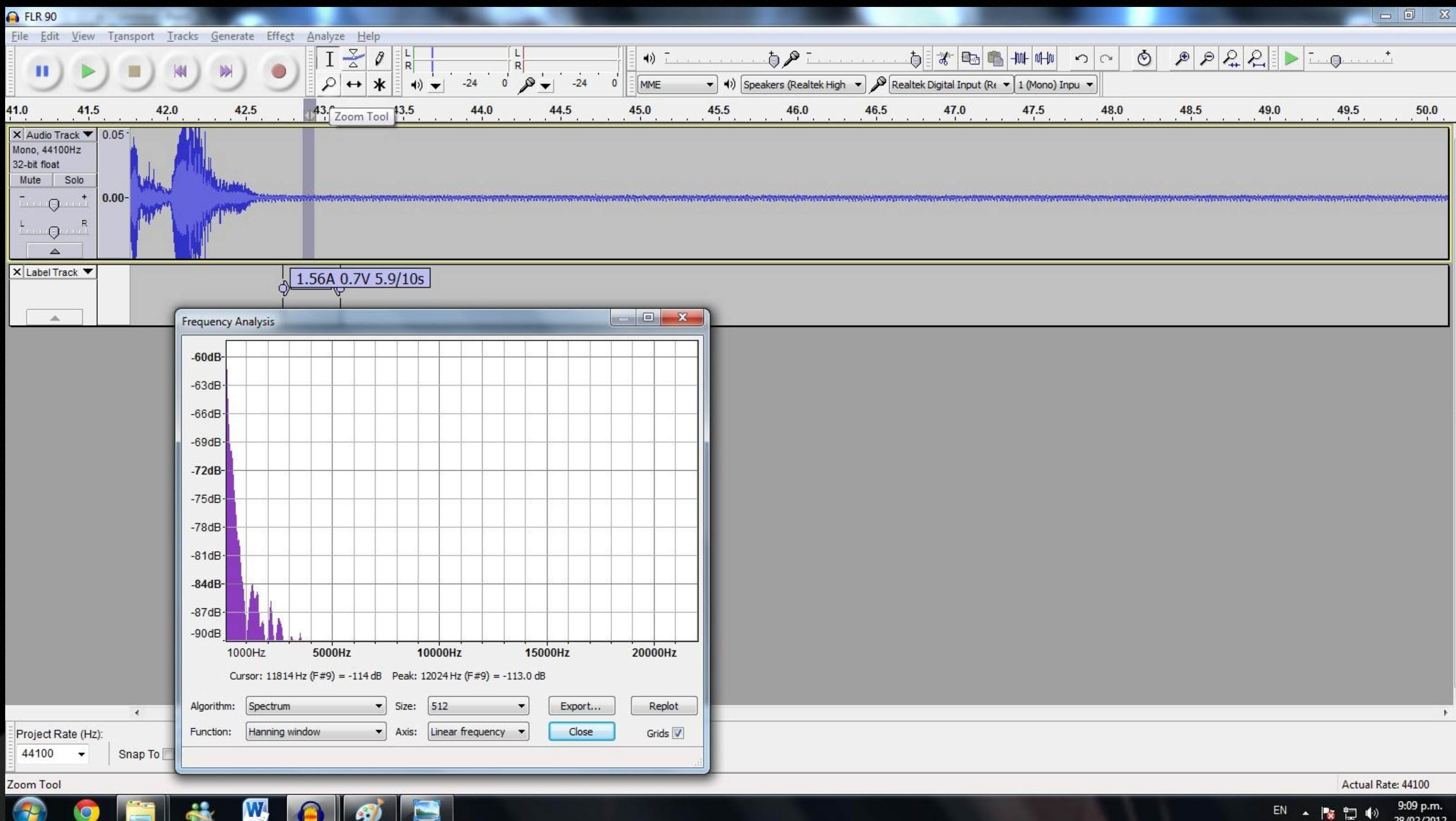
2nd Mass Test



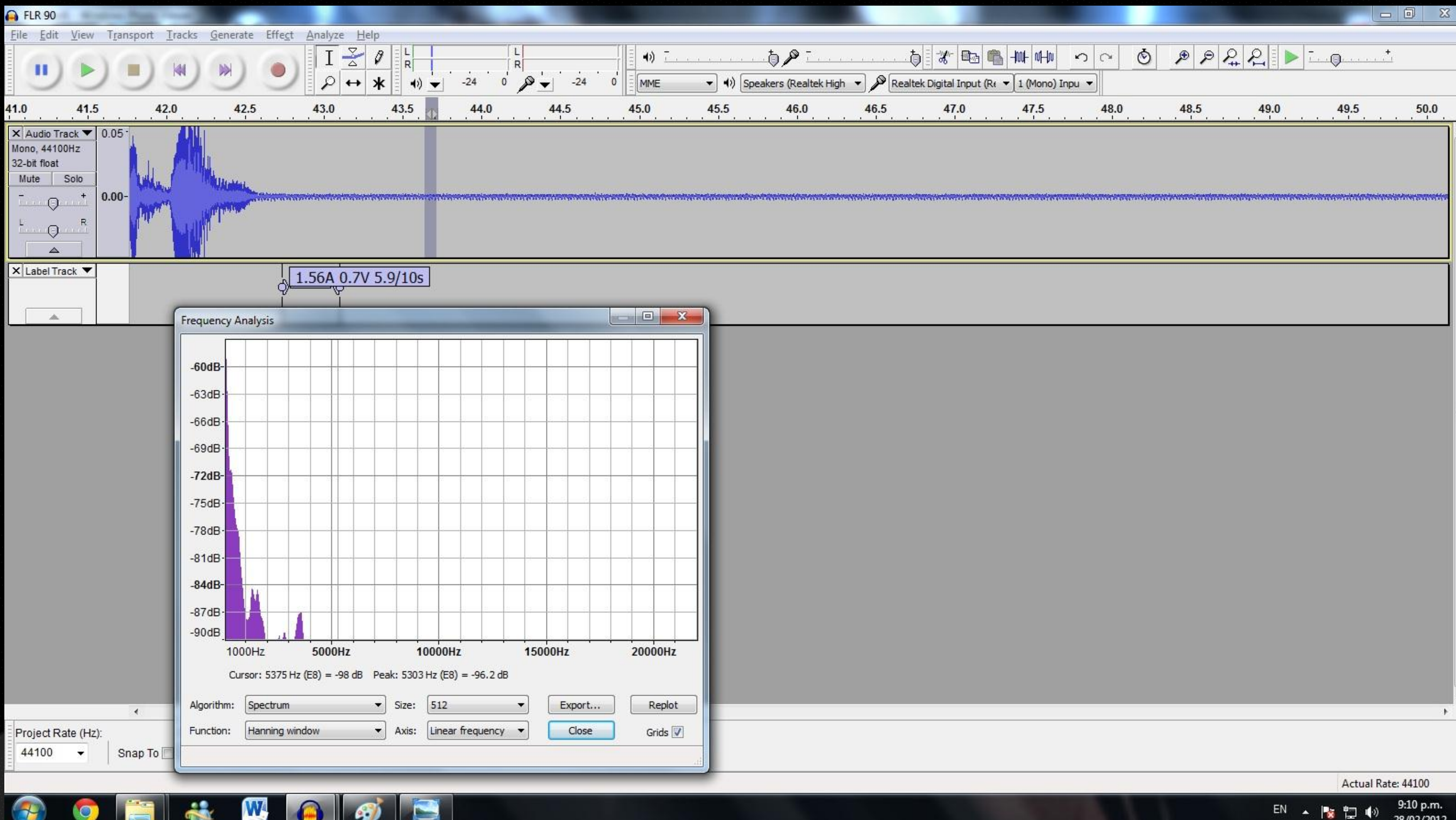
Layering 1/6


FLR 90
1.56A 0.7V 5.9/10s
Frequency Analysis
-60dB
-63dB
-66dB
-69dB
-72dB
-75dB
-78dB
-81dB
-84dB
-87dB
-90dB
1000Hz
5000Hz
10000Hz
15000Hz
20000Hz
Cursor: 10492 Hz (E9) = -113 dB Peak: 10484 Hz (E9) = -113.5 dB
Algorithm: Spectrum
Size: 512
Function: Hanning window
Axis: Linear frequency
Export...
Replot
Close
Grids
Project Rate (Hz): 44100
Time Shift Tool
Actual Rate: 44100

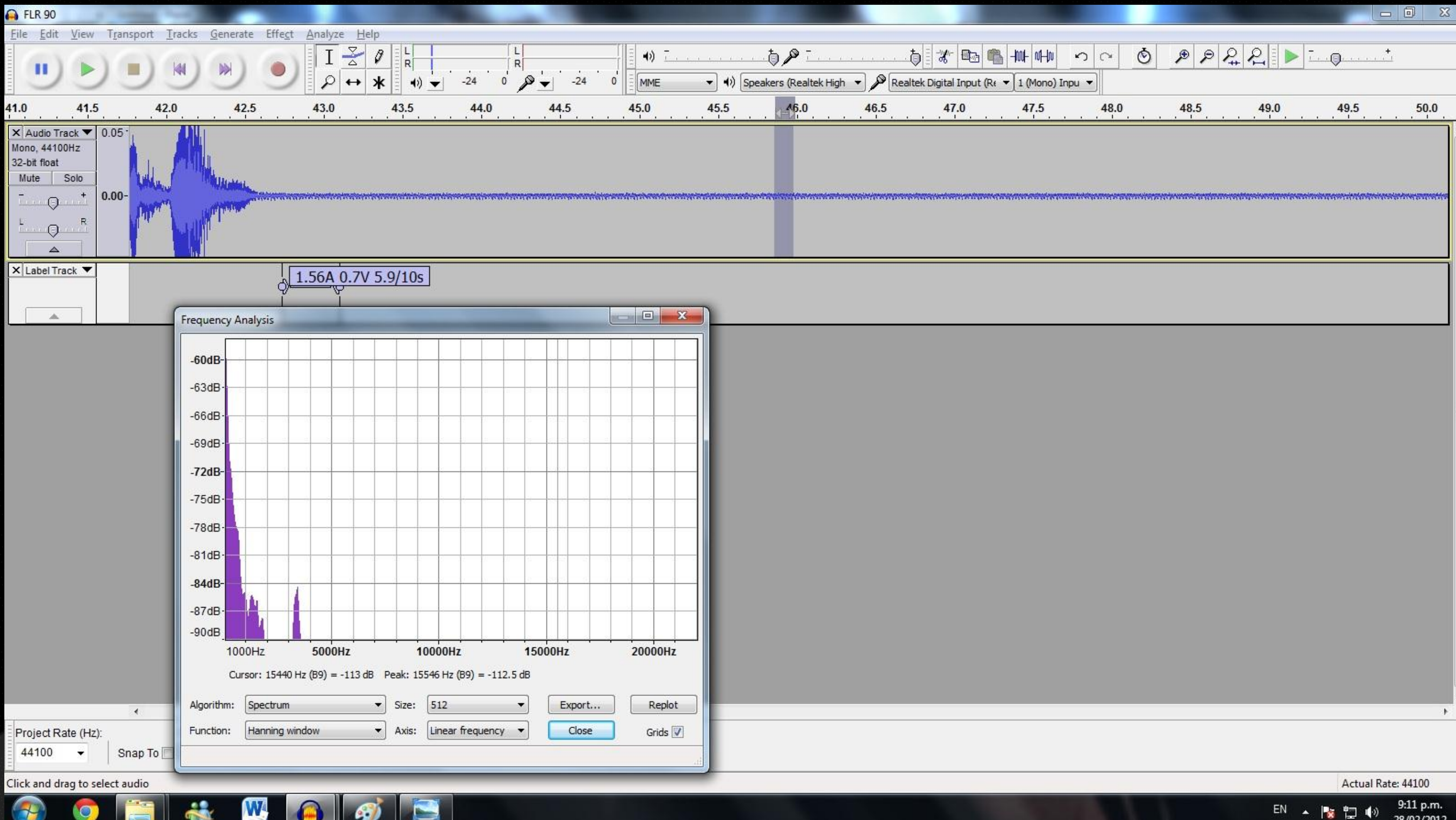
Layering 2/6


FLR 90
File Edit View Transport Tracks Generate Effect Analyze Help
Audio Track
Mono, 44100Hz
32-bit float
Label Track
1.56A 0.7V 5.9/10s
Frequency Analysis
-60dB
-63dB
-66dB
-69dB
-72dB
-75dB
-78dB
-81dB
-84dB
-87dB
-90dB
1000Hz
5000Hz
10000Hz
15000Hz
20000Hz
Cursor: 11814 Hz (F#9) = -114 dB Peak: 12024 Hz (F#9) = -113.0 dB
Algorithm: Spectrum
Size: 512
Export...
Replot
Function: Hanning window
Axis: Linear frequency
Close
Grids
Project Rate (Hz):
44100
Snap To
Zoom Tool
Actual Rate: 44100
9:09 p.m.
28/02/2012

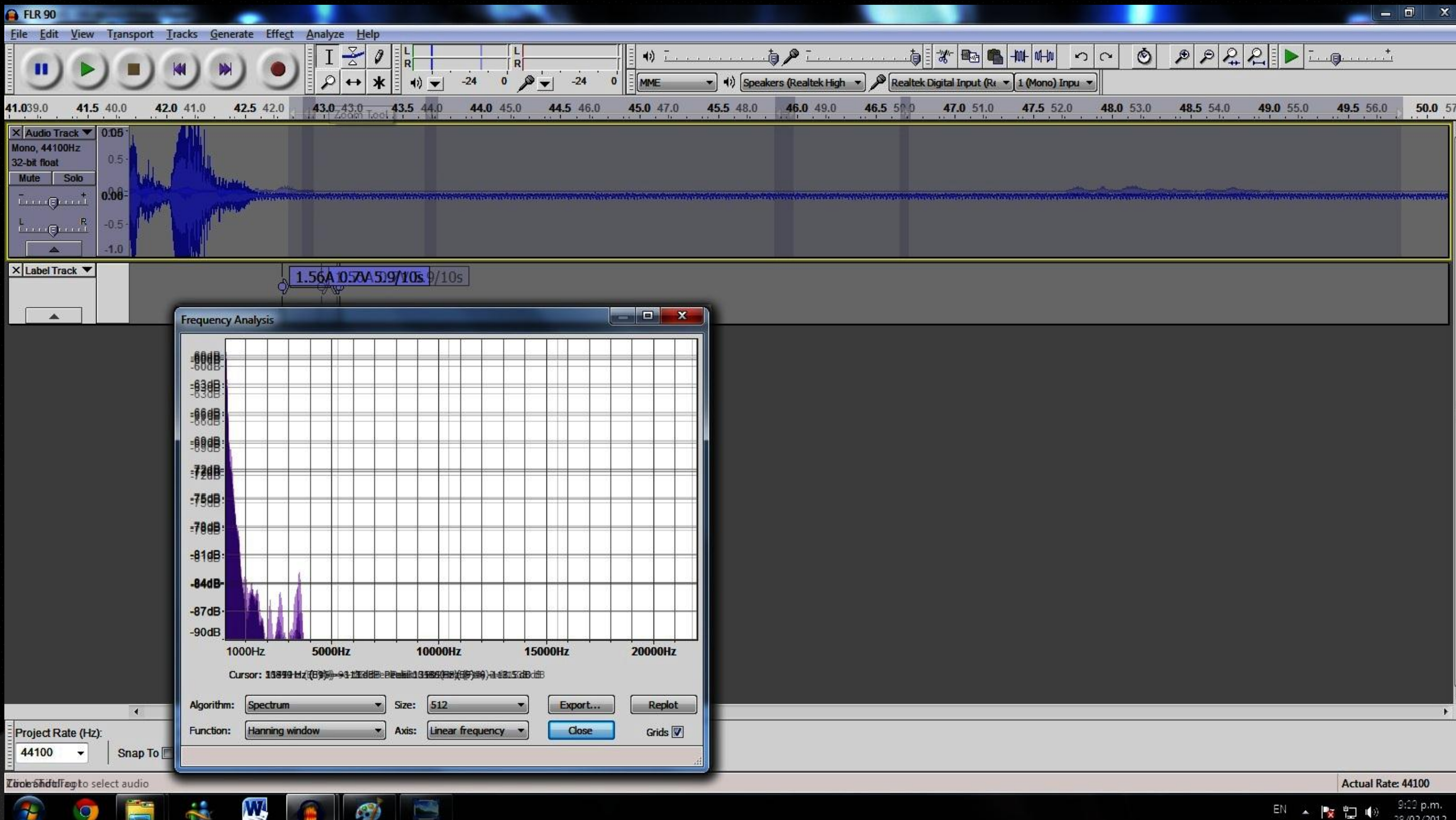
Layering 3/6


FLR 90
File Edit View Transport Tracks Generate Effect Analyze Help
Audio Track
Mono, 44100Hz
32-bit float
Mute Solo
Label Track
1.56A 0.7V 5.9/10s
Frequency Analysis
-60dB
-63dB
-66dB
-69dB
-72dB
-75dB
-78dB
-81dB
-84dB
-87dB
-90dB
1000Hz
5000Hz
10000Hz
15000Hz
20000Hz
Cursor: 5375 Hz (E8) = -98 dB Peak: 5303 Hz (E8) = -96.2 dB
Algorithm: Spectrum
Size: 512
Export...
Replot
Function: Hanning window
Axis: Linear frequency
Close
Grids
Project Rate (Hz):
44100
Snap To
Actual Rate: 44100

Layering 4/6


FLR 90
File Edit View Transport Tracks Generate Effect Analyze Help
Audio Track
Mono, 44100Hz
32-bit float
Label Track
1.56A 0.7V 5.9/10s
Frequency Analysis
-60dB
-63dB
-66dB
-69dB
-72dB
-75dB
-78dB
-81dB
-84dB
-87dB
-90dB
1000Hz
5000Hz
10000Hz
15000Hz
20000Hz
Cursor: 15440 Hz (B9) = -113 dB Peak: 15546 Hz (B9) = -112.5 dB
Algorithm: Spectrum
Size: 512
Function: Hanning window
Axis: Linear frequency
Export...
Replot
Close
Grids
Project Rate (Hz): 44100
Click and drag to select audio
Actual Rate: 44100
9:11 p.m.
28/02/2012

Layering 5/6


FLR 90
File Edit View Transport Tracks Generate Effect Analyze Help
Audio Track
Mono, 44100Hz
32-bit float
Mute Solo
Label Track
Frequency Analysis
-60dB
-63dB
-66dB
-69dB
-72dB
-75dB
-78dB
-81dB
-84dB
-87dB
-90dB
1000Hz
5000Hz
10000Hz
15000Hz
20000Hz
Algorithm: Spectrum
Size: 512
Export...
Replot
Function: Hanning window
Axis: Linear frequency
Close
Grids
Project Rate (Hz):
44100
Snap To
Actual Rate: 44100

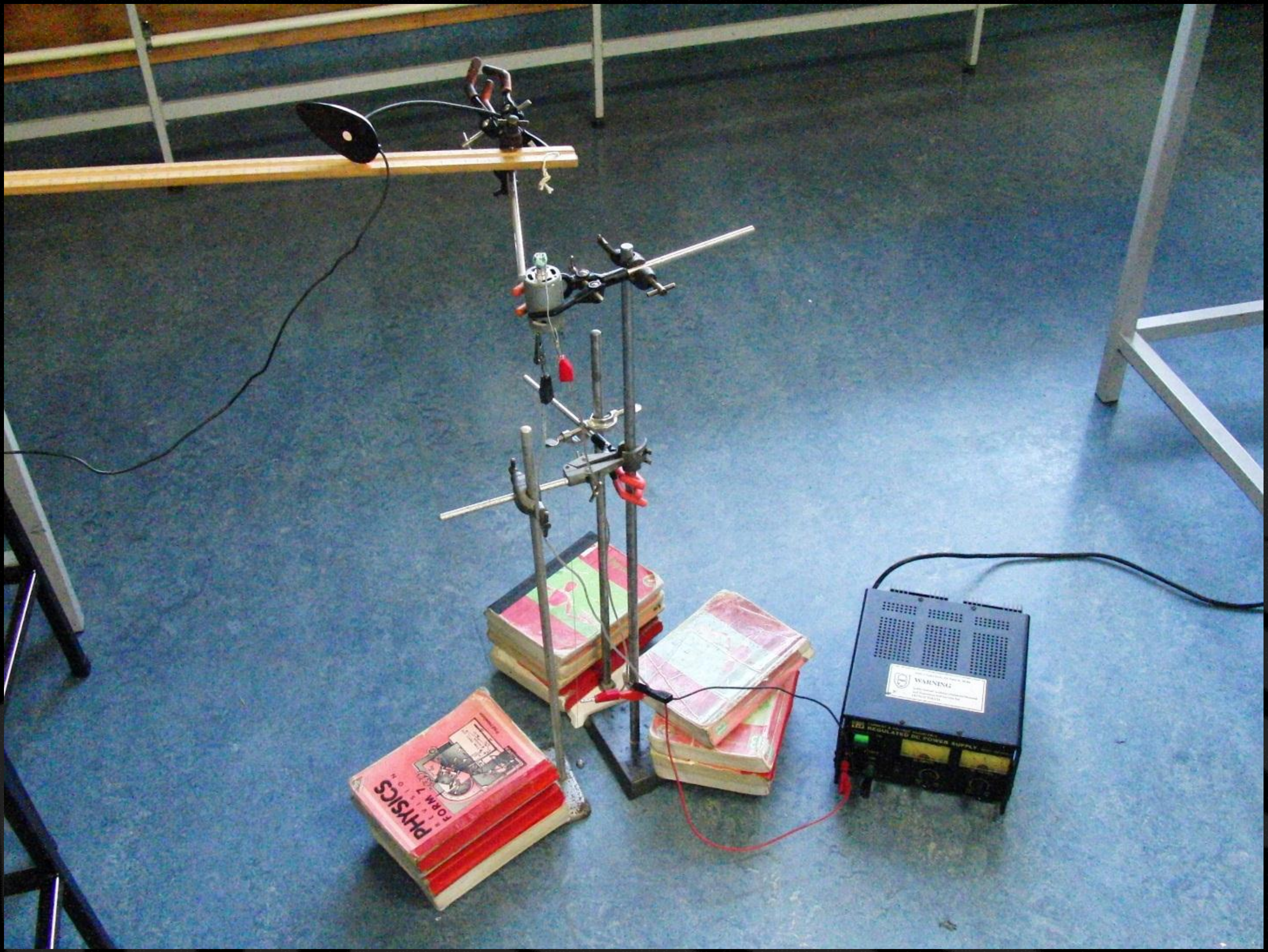
Experiments - 1

- Problems: a) hard to keep constant ω
- b) especially while taking measurements – need helpers.
- c) Holding microphone - pulse
- d) Hurts hand – used handle

Experiments - 2

- Motor
- Thread wraps around axle: it spins too fast.

Exp 3 Setup



Radius Tests: Crazy Apparatus

Radius Tests: Crazy Apparatus

Radius Tests: Crazy Apparatus

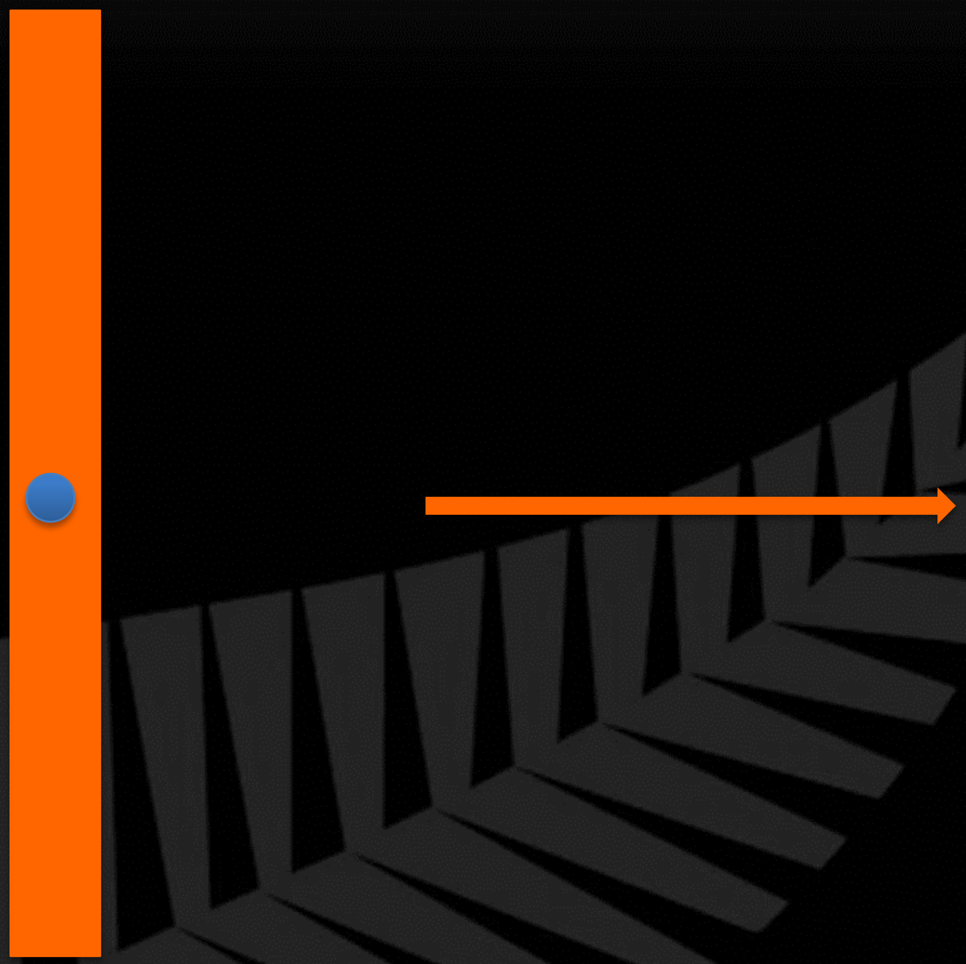
Radius Tests: Crazy Apparatus

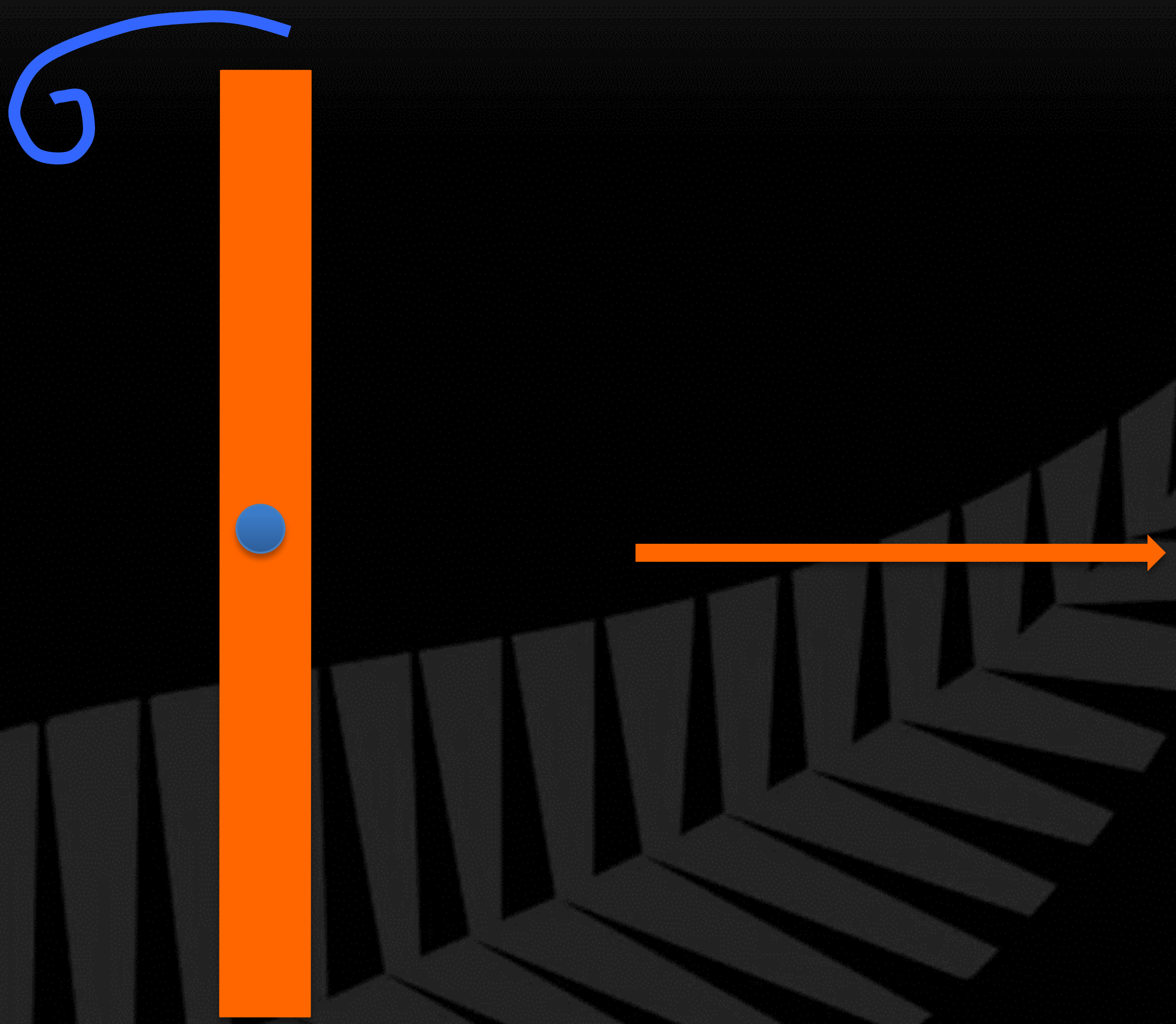
String Diameter

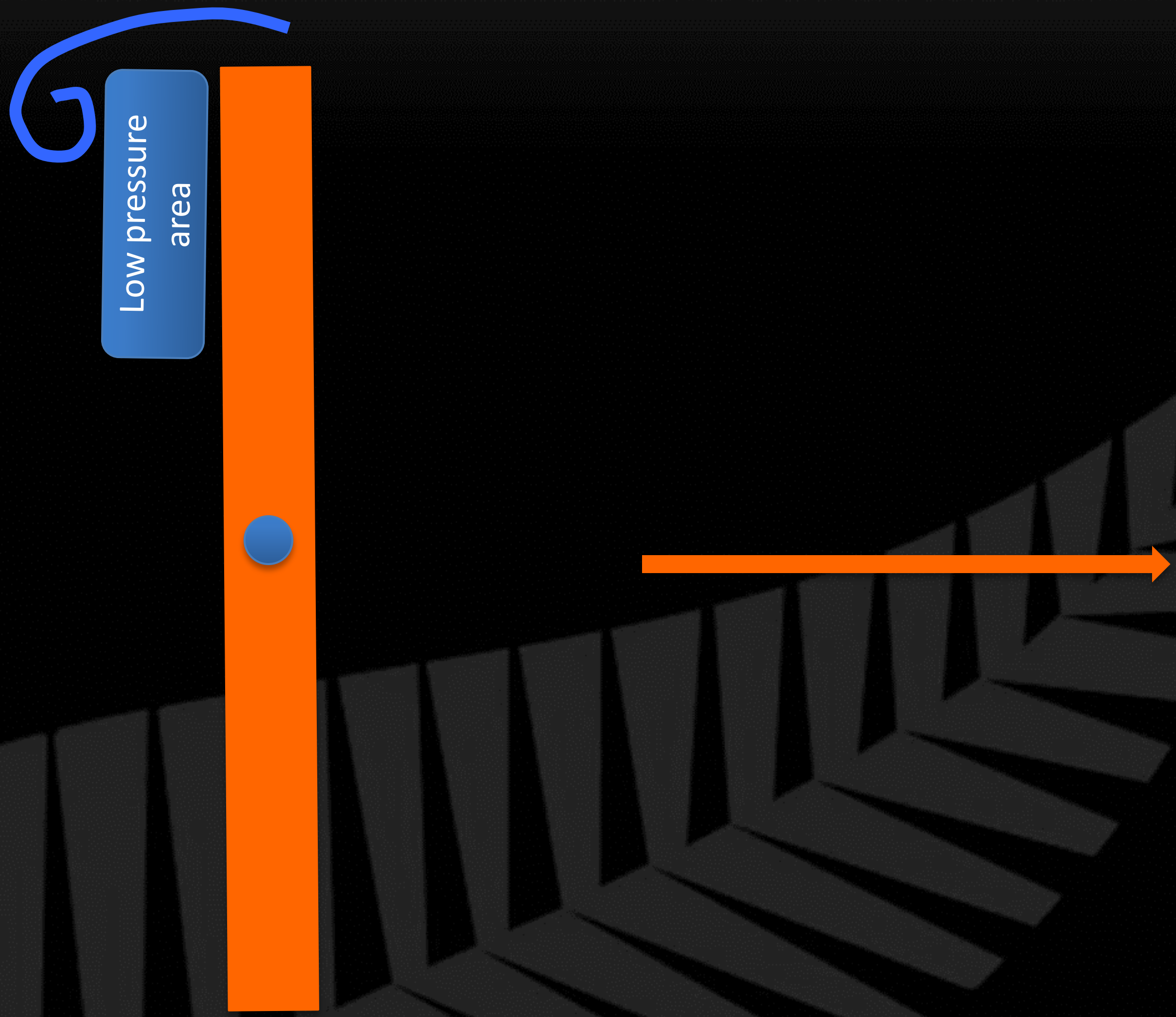
- Predict $f \propto \frac{1}{d}$
- Tested with threads and 2 ropes. Mean diameters:
  1 (RB) 0.19mm
  2 (FLR) 0.28mm
  3 (FLB) 0.54mm
  4 (Badm) 0.80mm
  5 (EdgG) 1.97mm
  6 (EdgO) 2.34mm
  7 (RpThn) 4.08mm
  8 (RpThck) 5.85mm

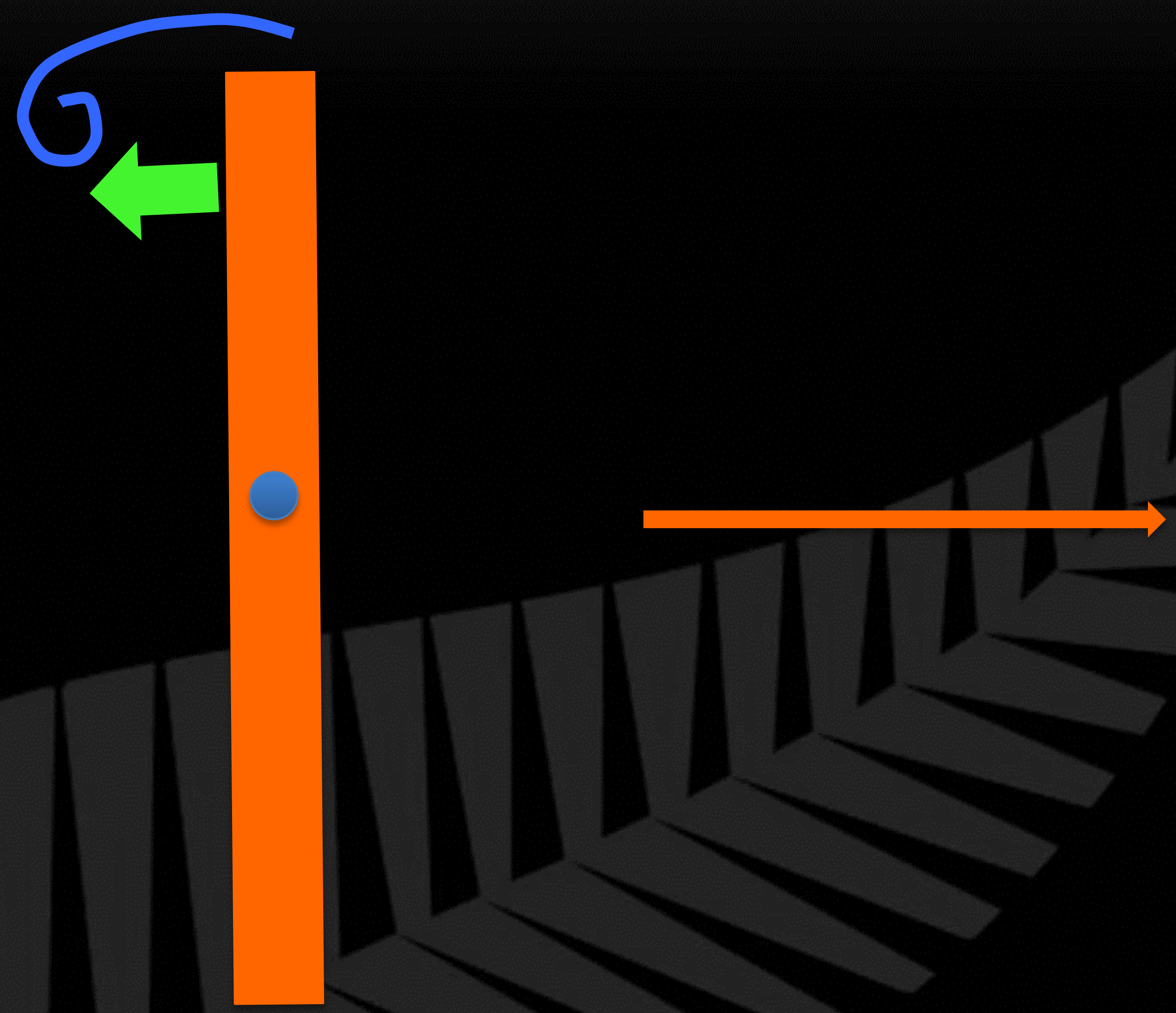
Mass Noise

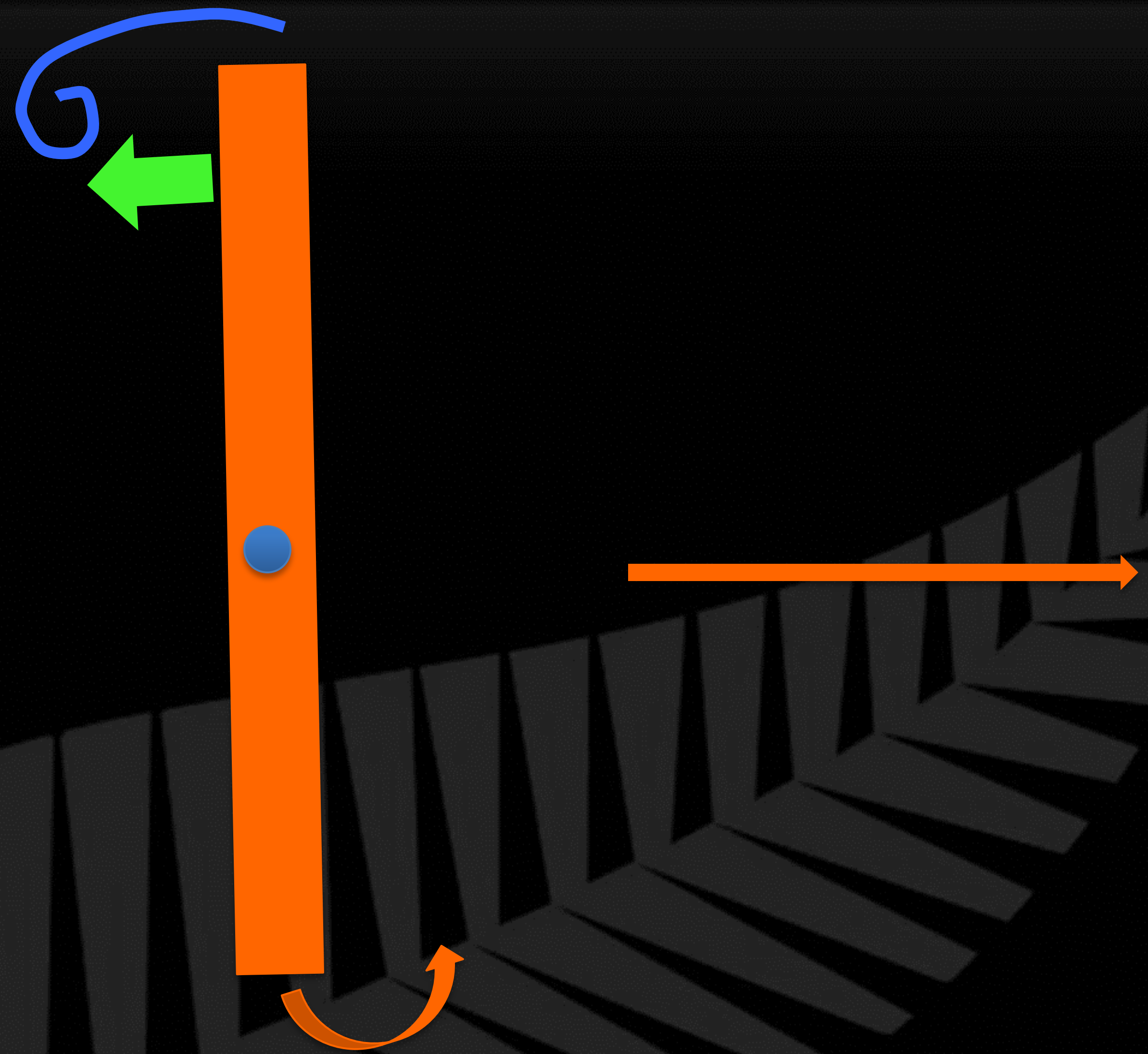
- Flat/irregular mass spins as it moves through the air
- Changing the shape and dimensions of the mass creates different pitches of noise

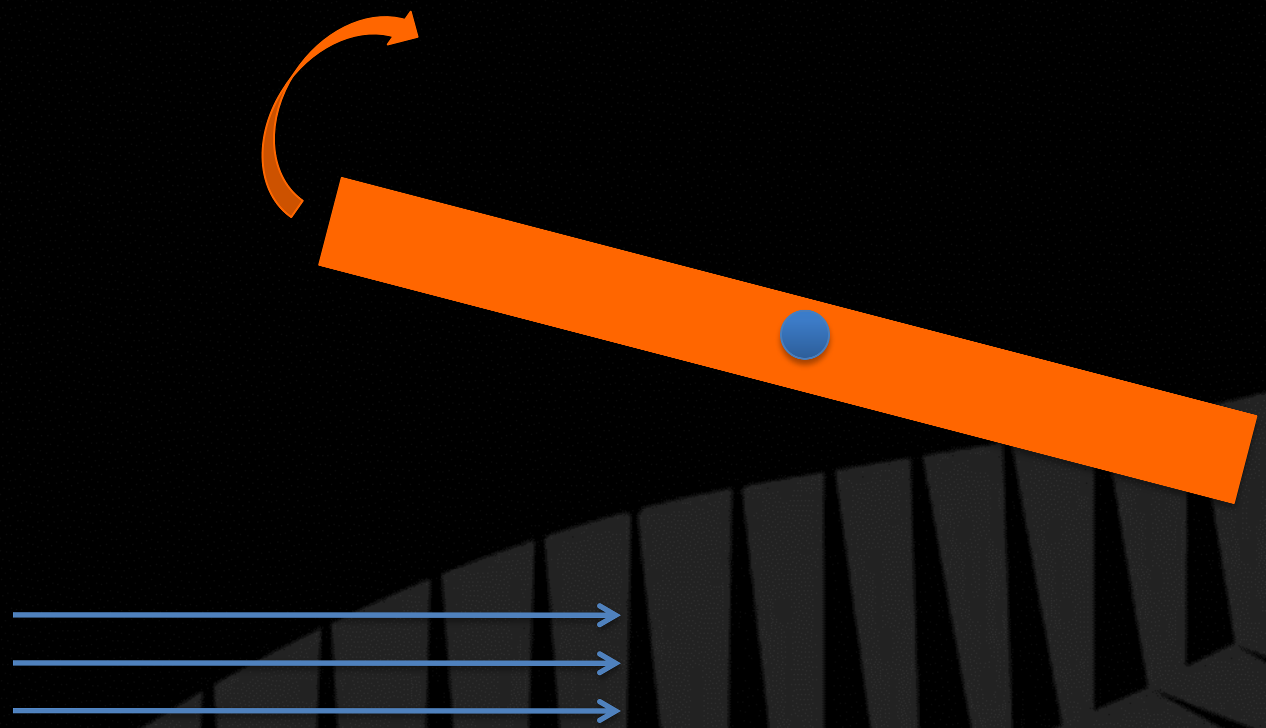


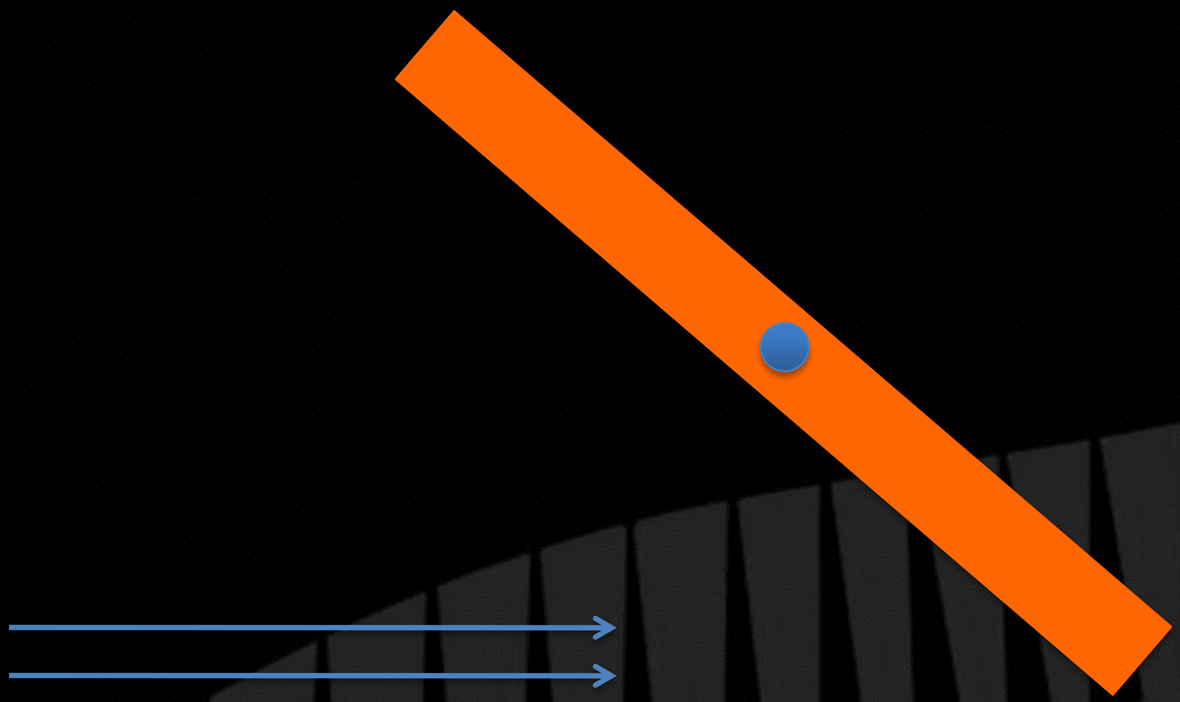


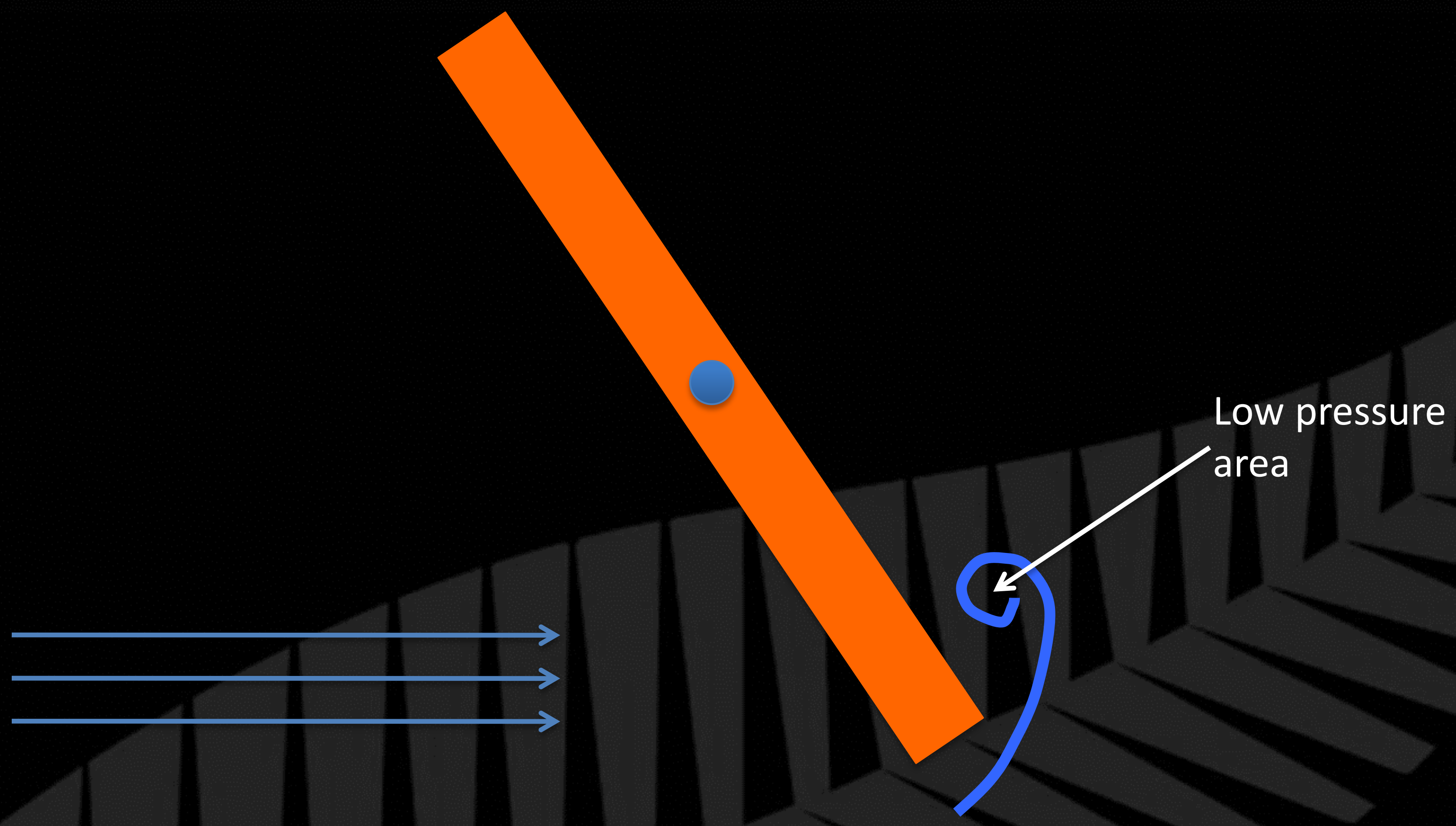

Low pressure area

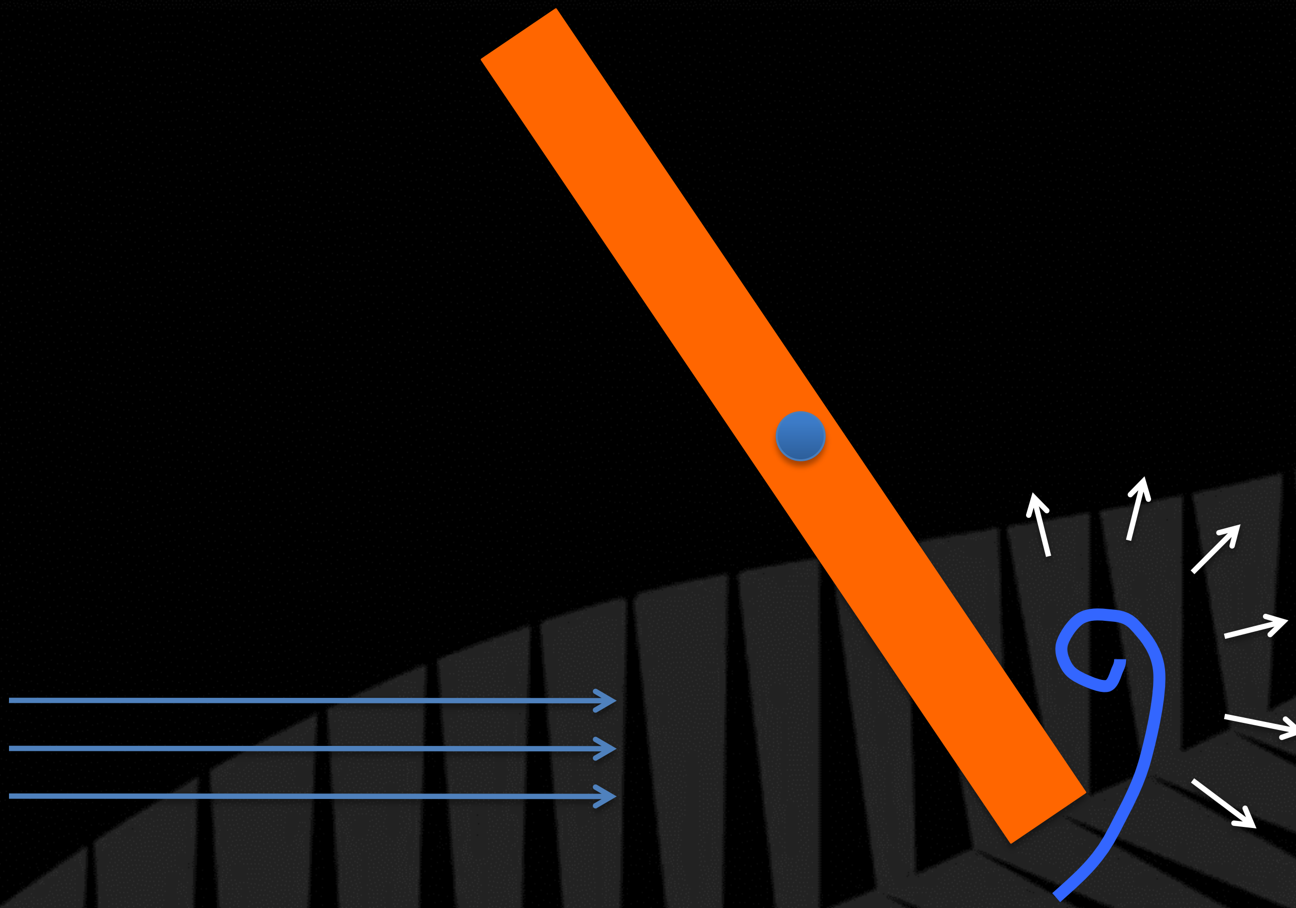


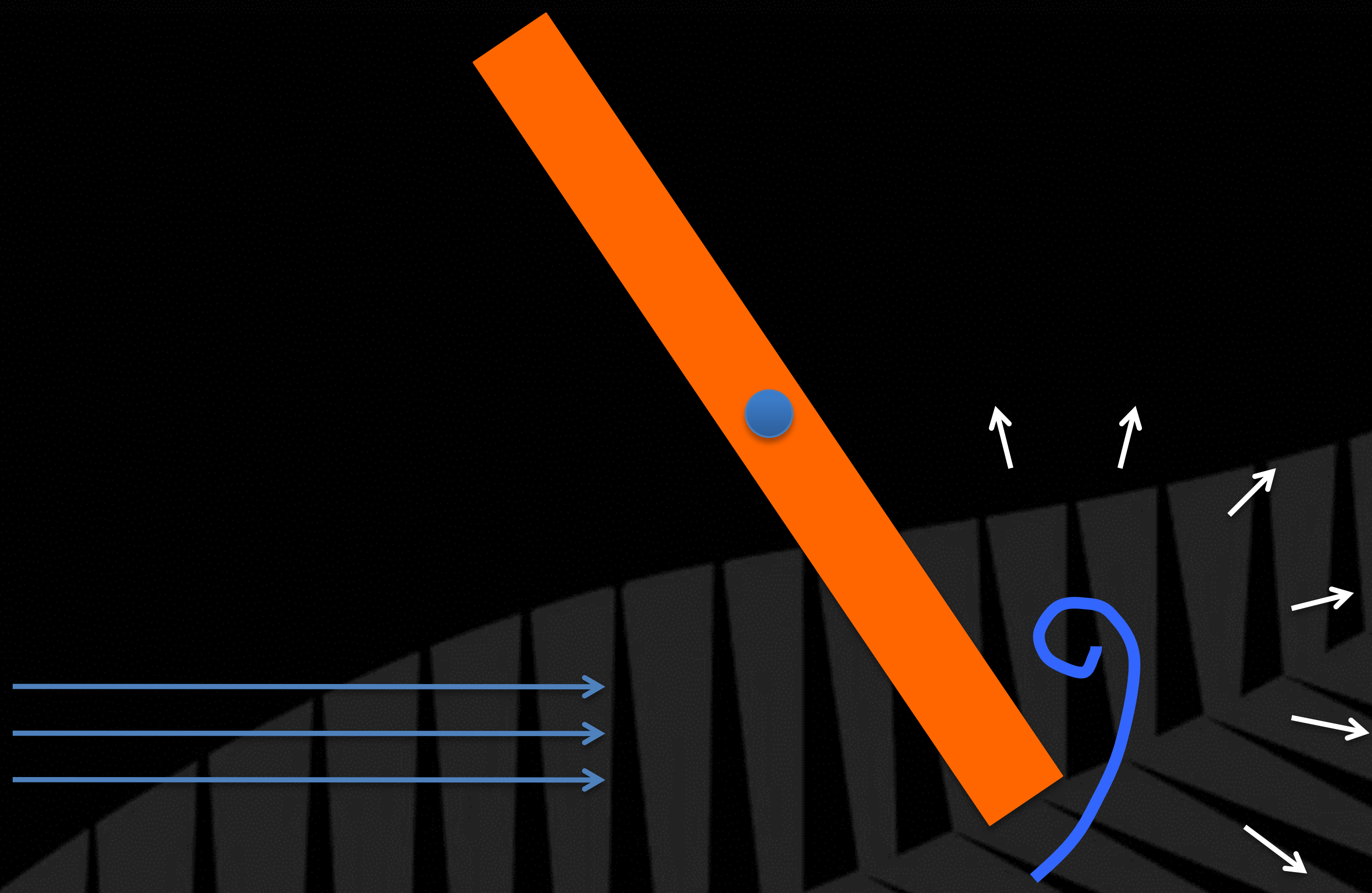


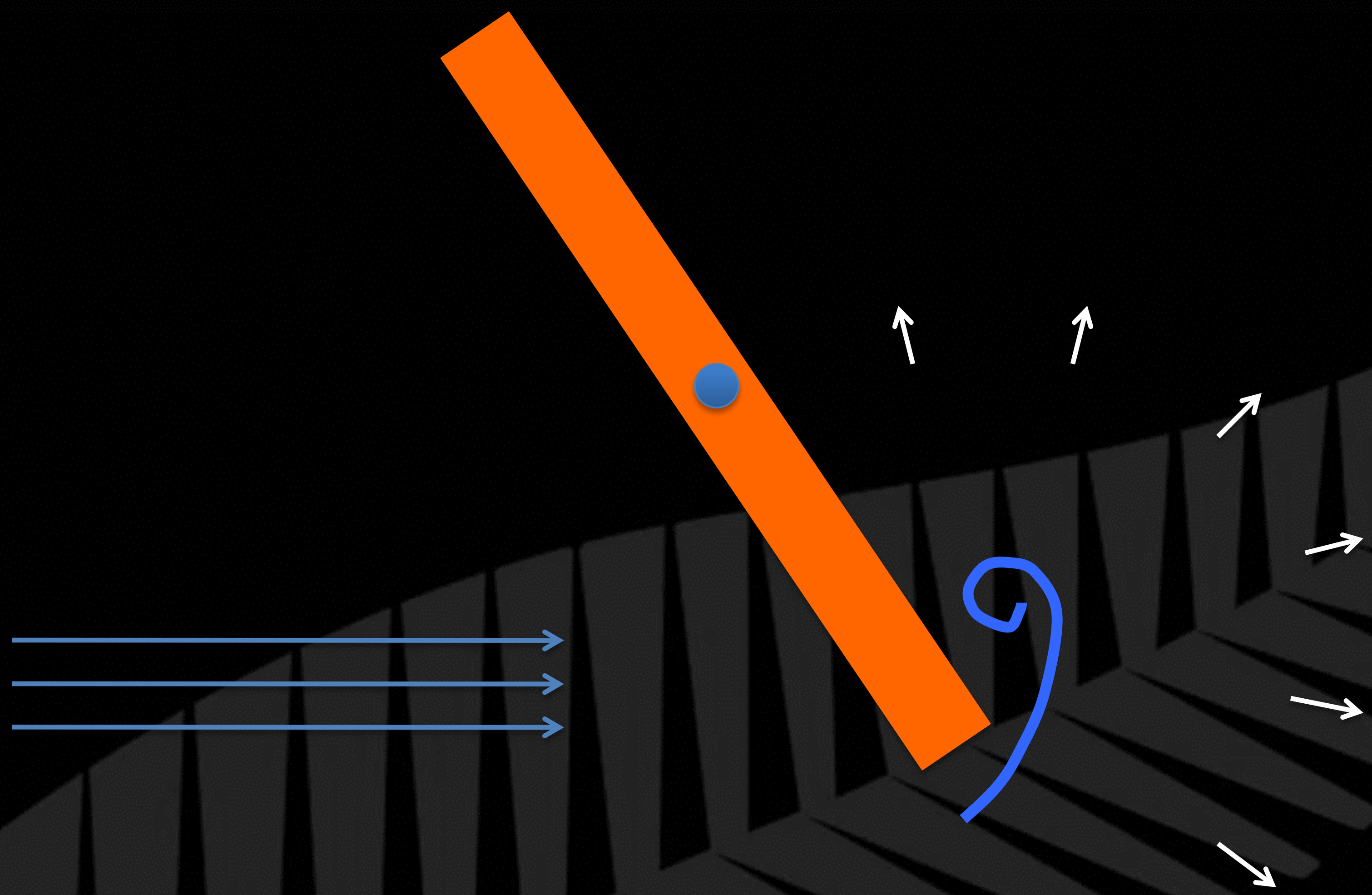




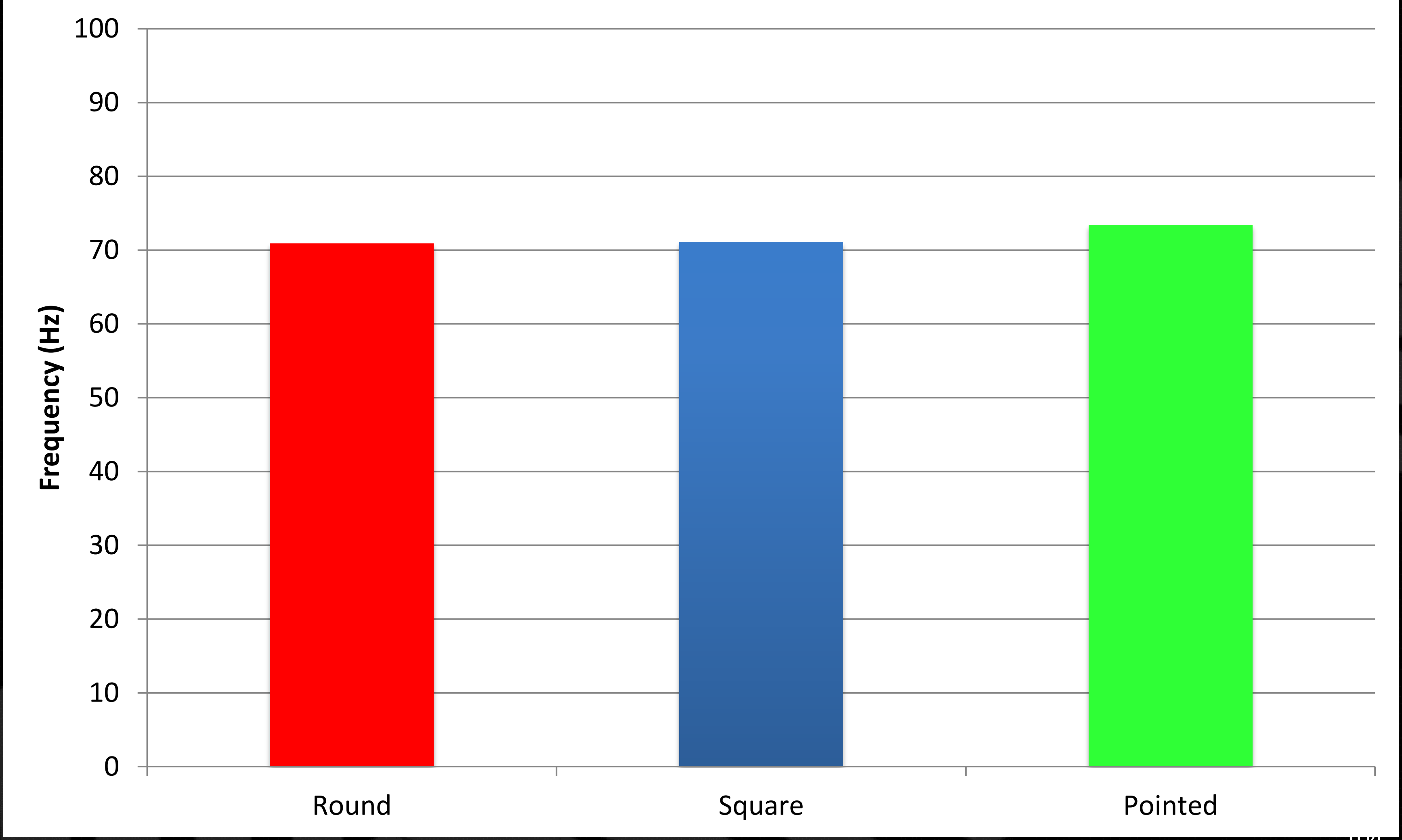

Low pressure
area



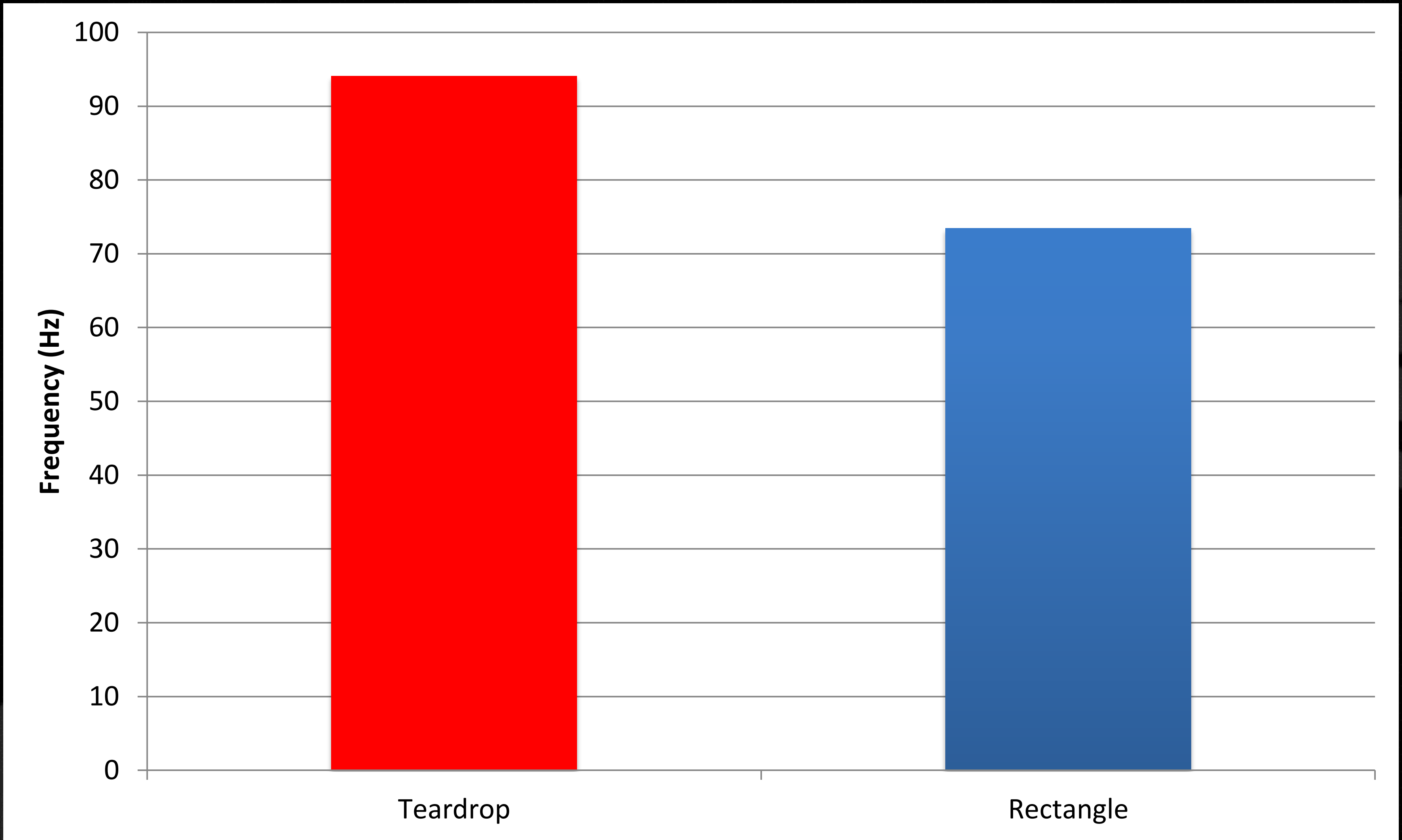




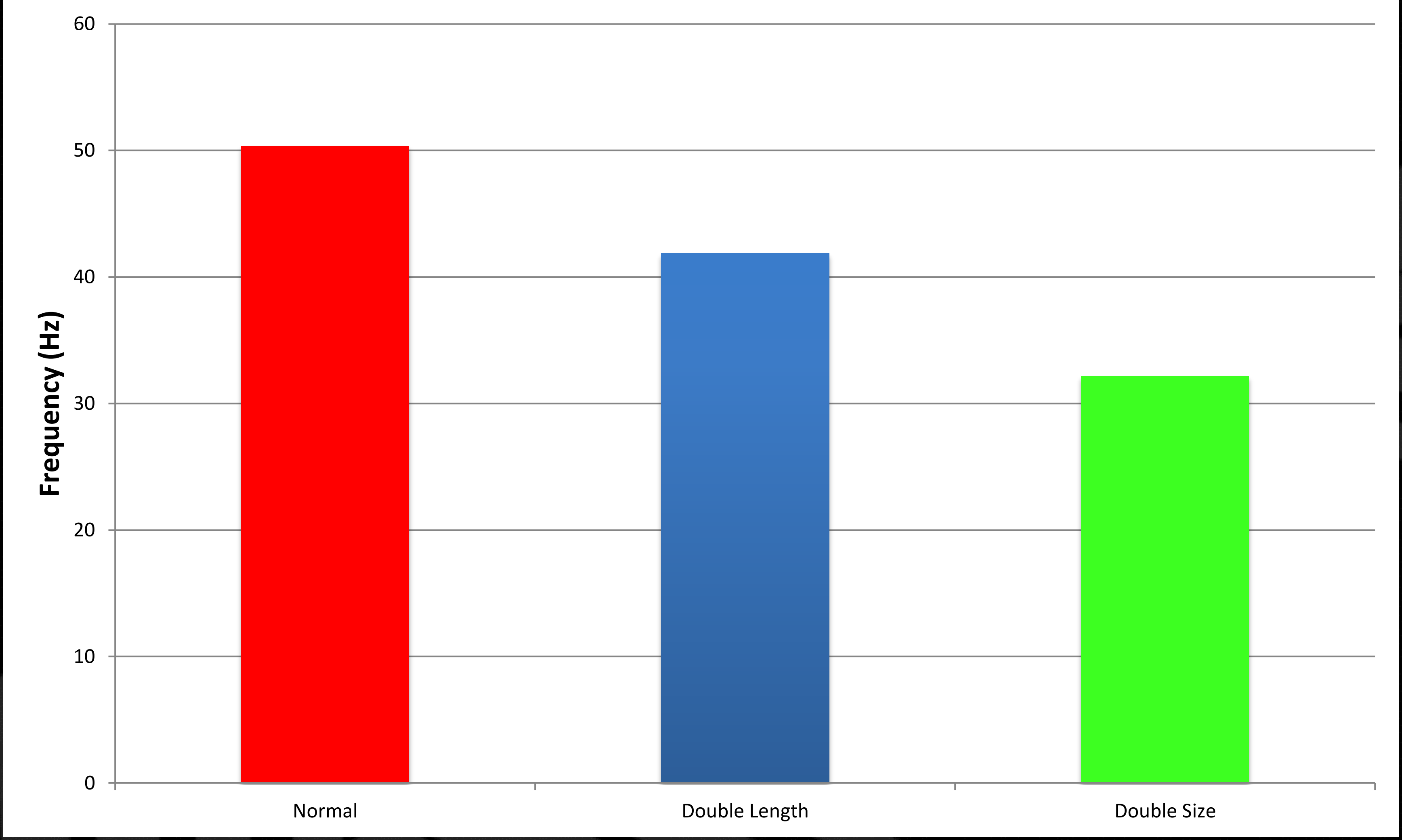
Edges of Mass



Overall Shape



Dimensions


60
50
40
30
20
10
0
Frequency (Hz)
Normal
Double Length
Double Size