Online-Seminar

Psychoakustik 2 – Transiente Vorgänge, tonale Komponenten und Modulation

Andreas Langmann

Transiente Metriken

Time varying Loudness N10
Kurtosis
Wavelets

Tonale Metriken

Tonality
Tone to Noise
Prominence Ratio

Modulations Metriken

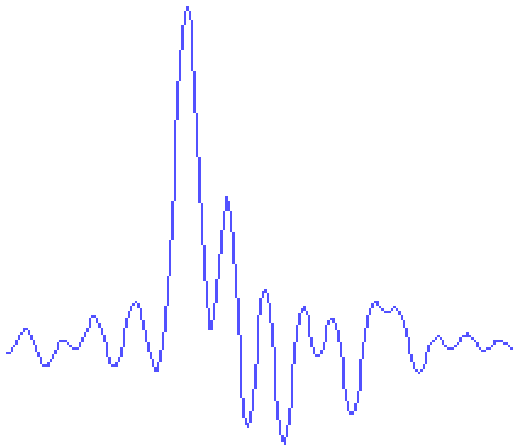
Hilbert Envelope & Modulation Theory
Fluctuation Strength and Roughness

Transiente Metriken

Time varying Loudness N10
Kurtosis
Wavelets

Clicks, Clunks and Pings! What is a Transient?

- Event less than 1 second in duration, usually in milliseconds
- Impulsive, changing amplitude rapidly
- Traditional FFT techniques are not always effective in analyzing
- Types of signals: keyboard clicks, injector ticks, piston slap, door slam, other human actuated sounds



Loudness N10

N10 Loudness

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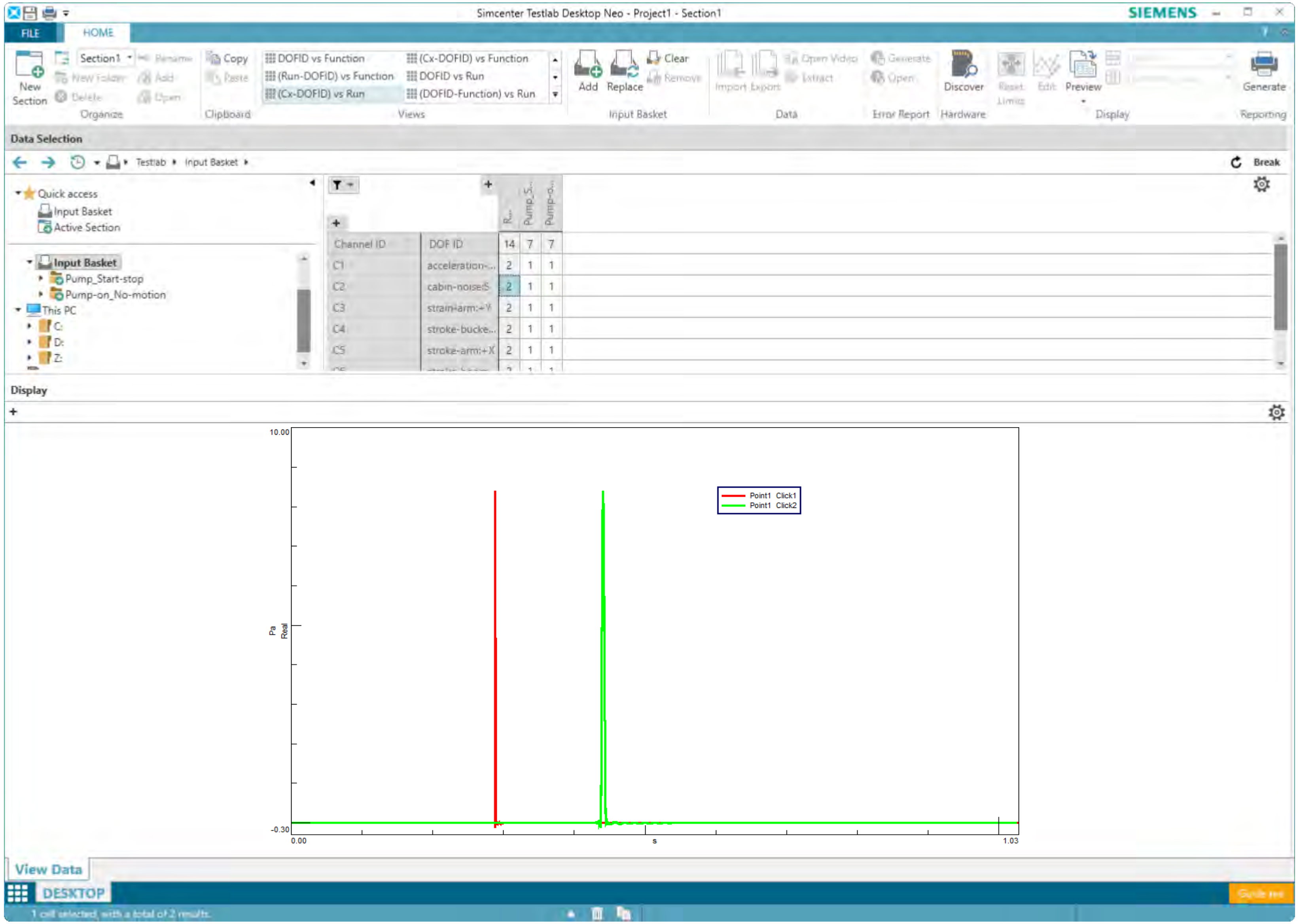
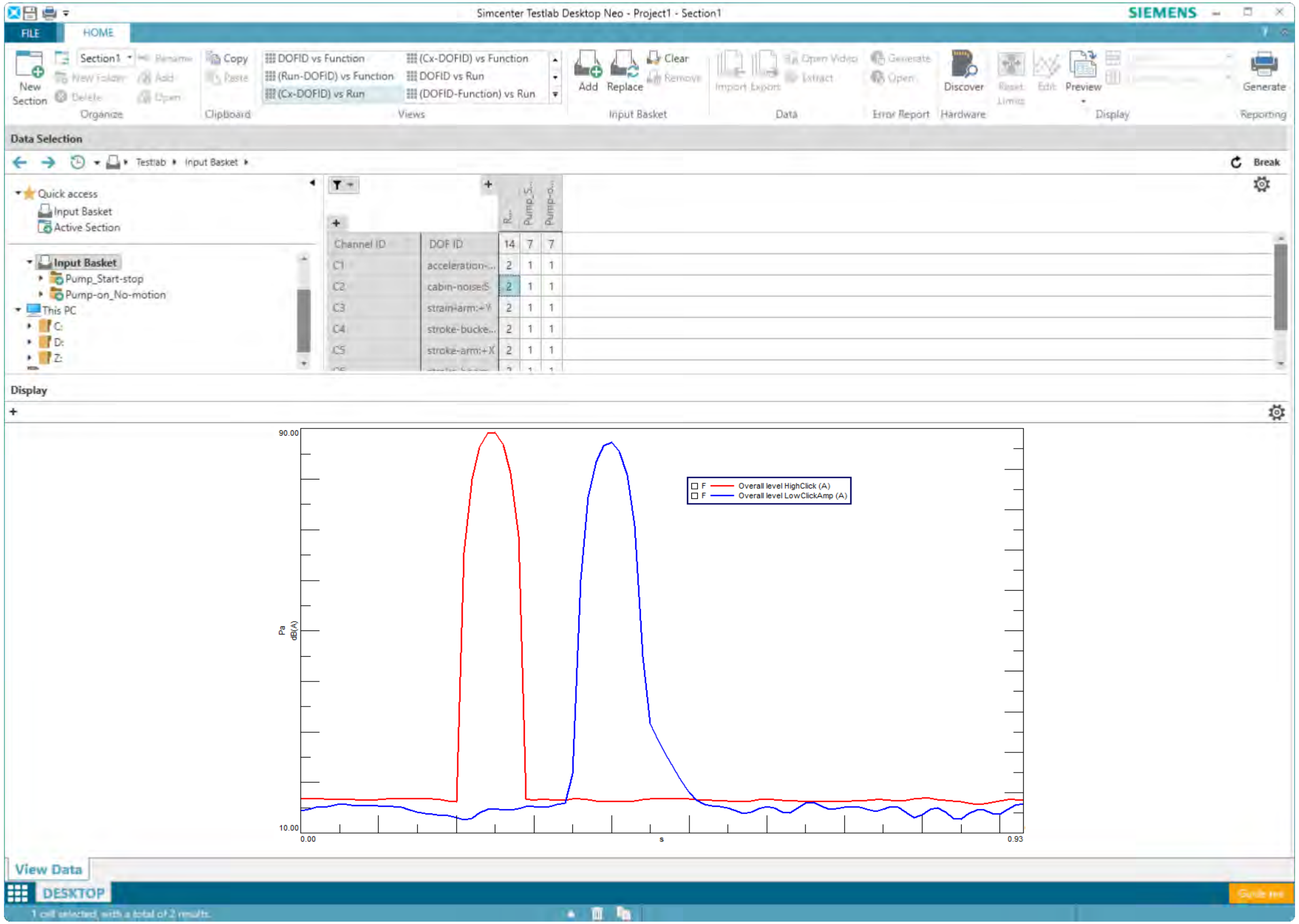
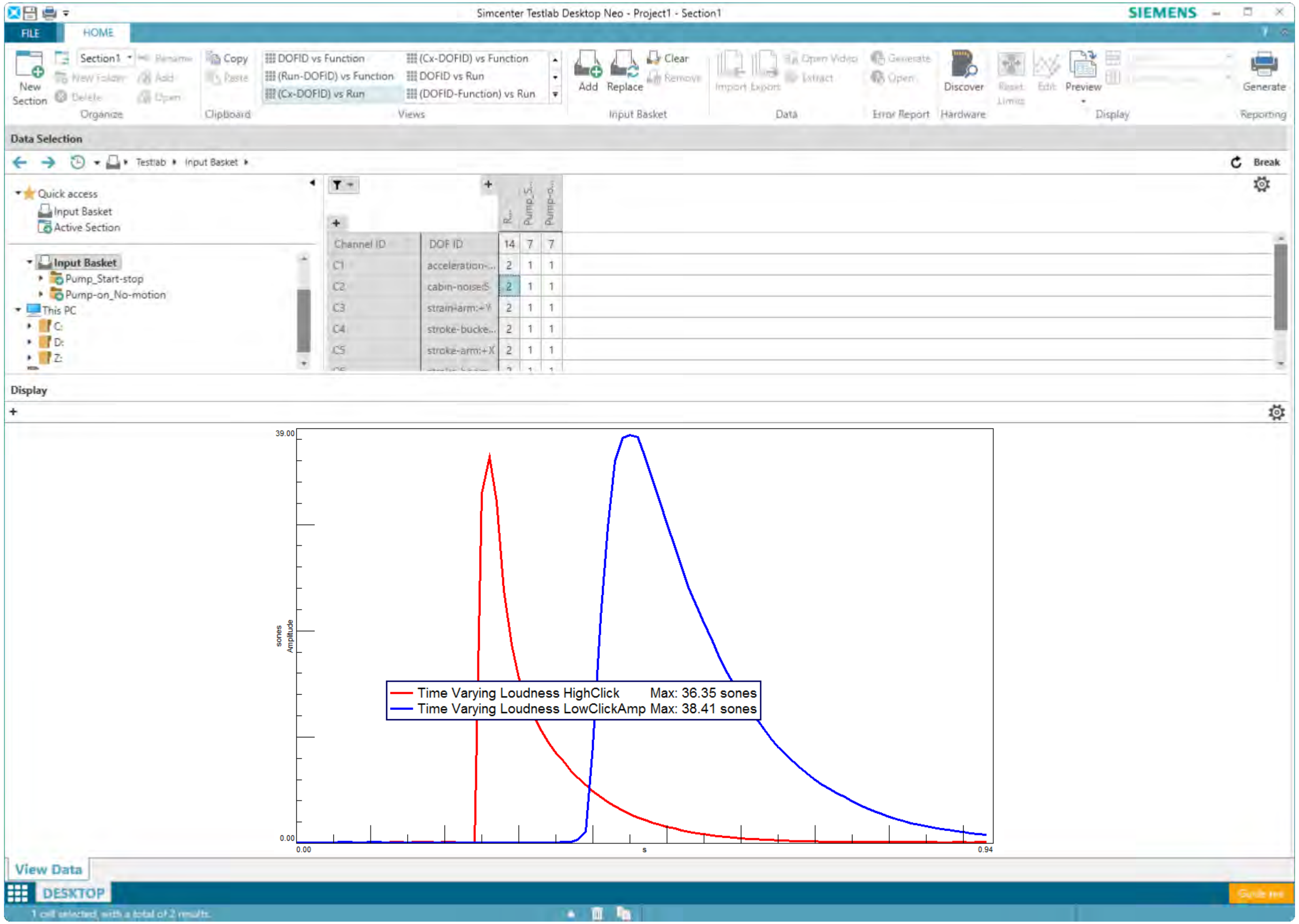


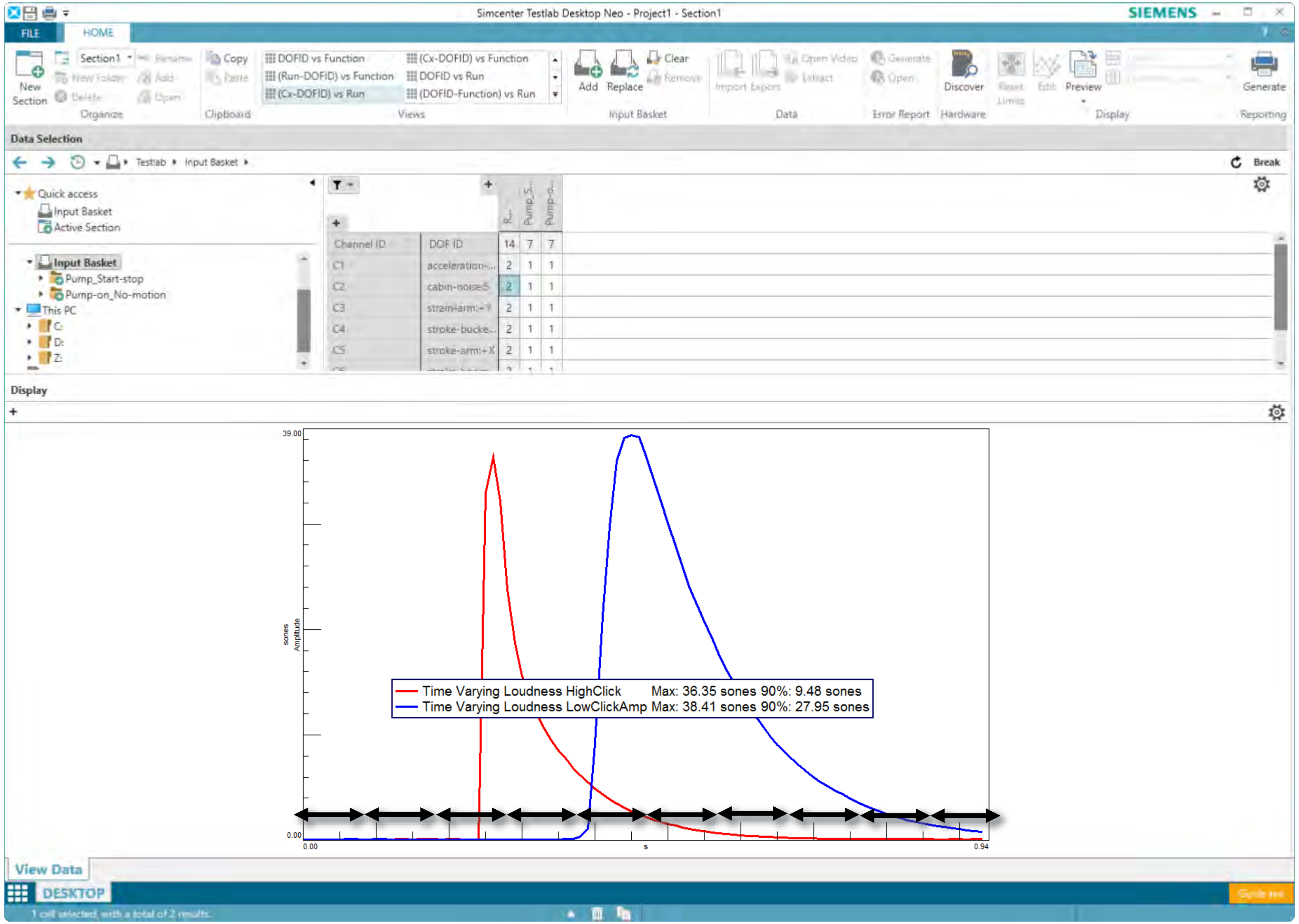
N10 Loudness



N10 Loudness



N10 Loudness



N10 Loudness

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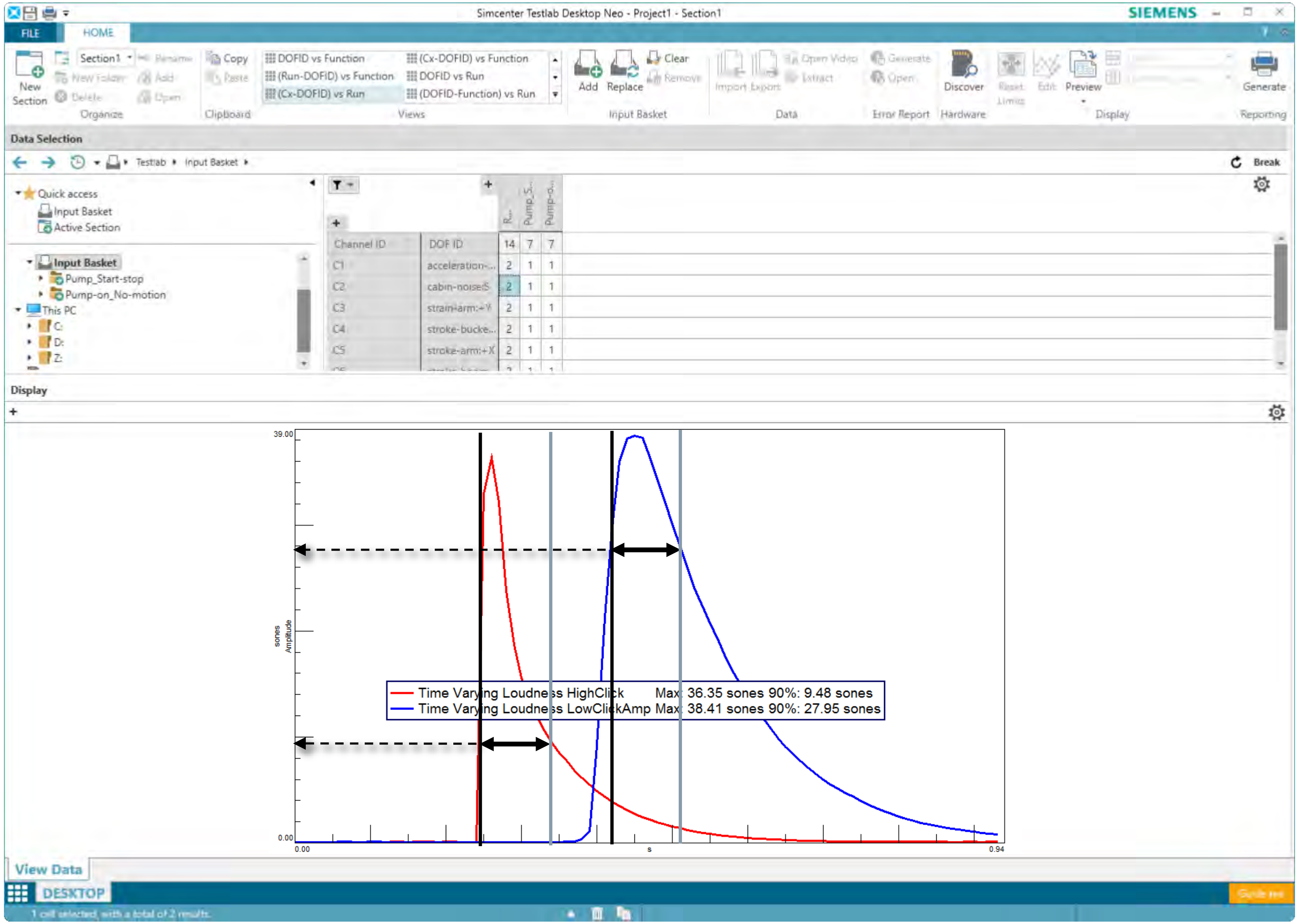
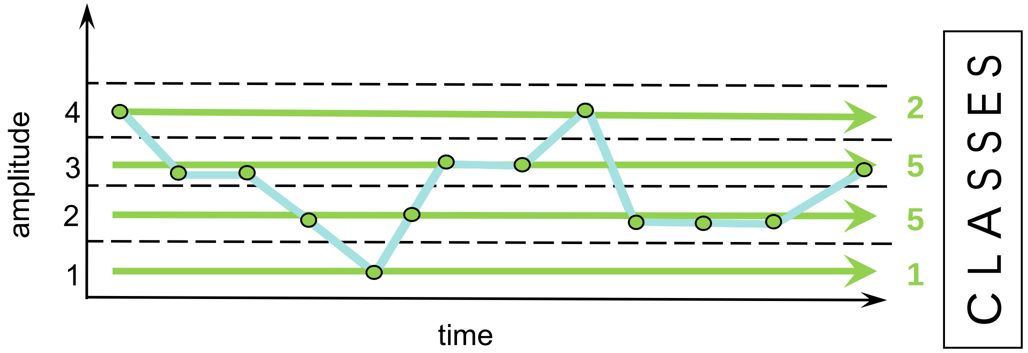
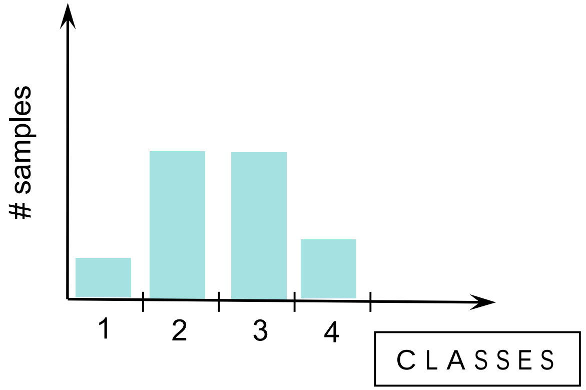


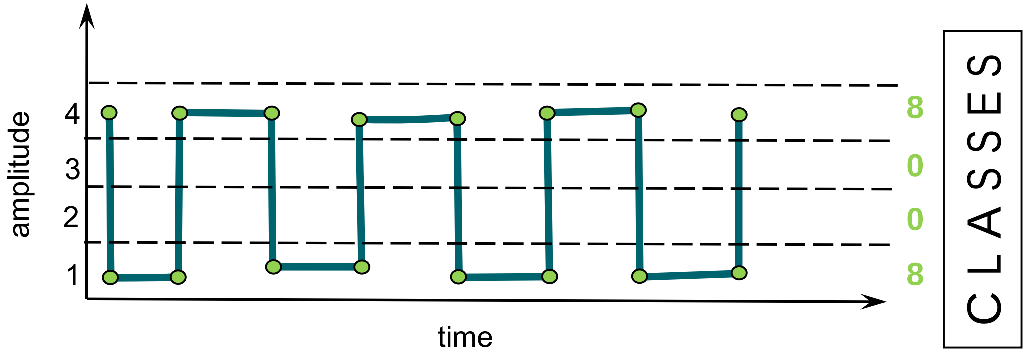
Kurtosis

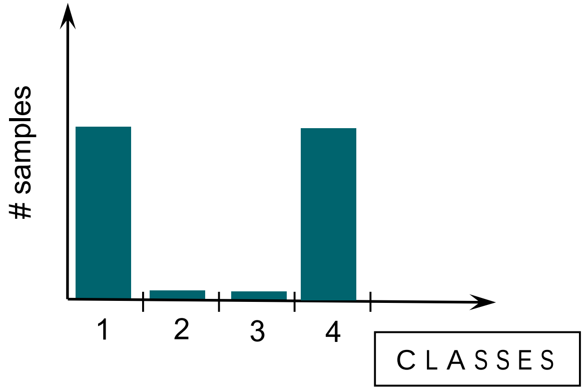
Kurtosis - Histogram





Histogram: Square Wave





Histogram: Impact

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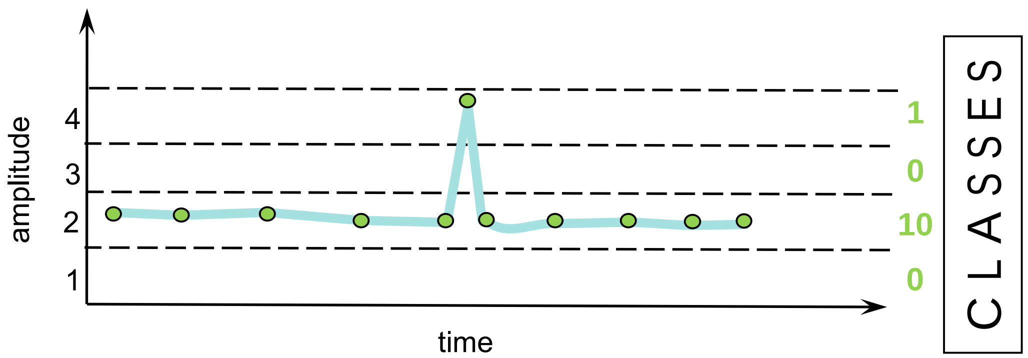
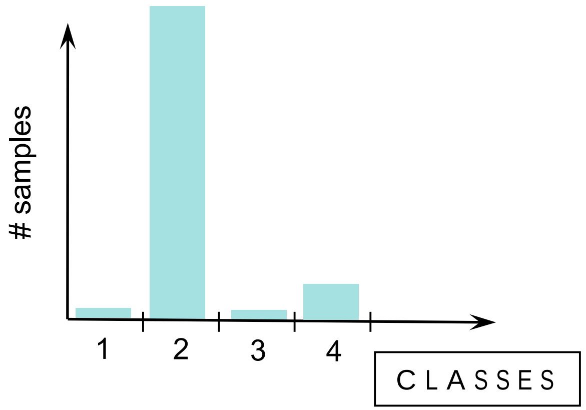
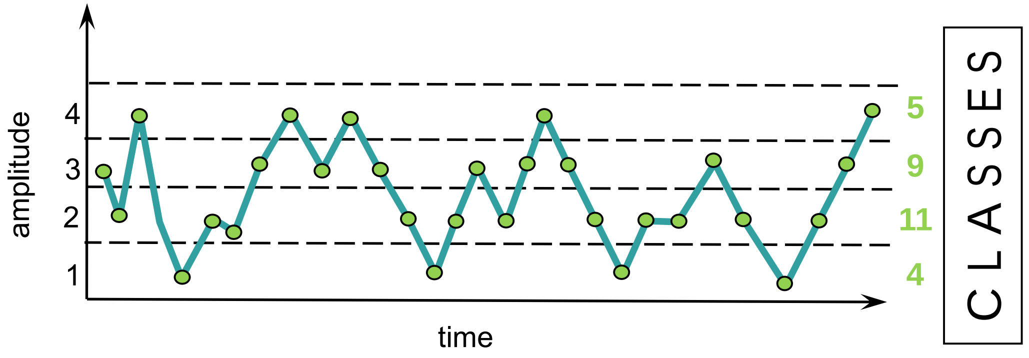
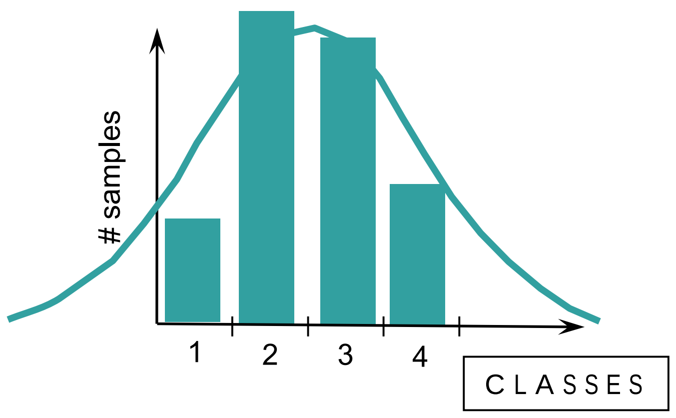




Histogram: Gaussian Random





Distribution

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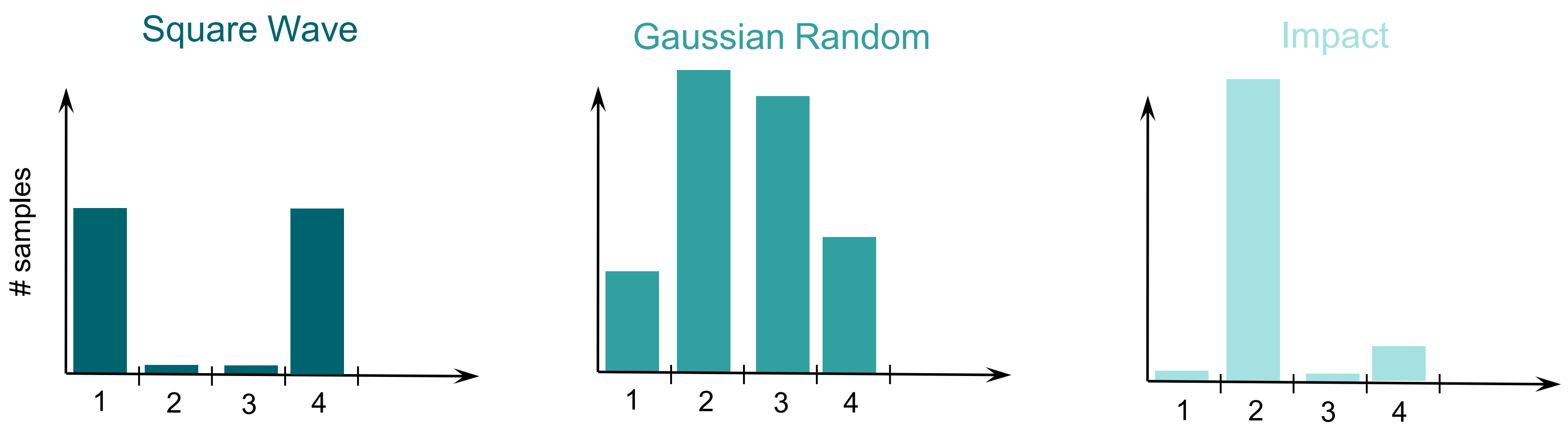
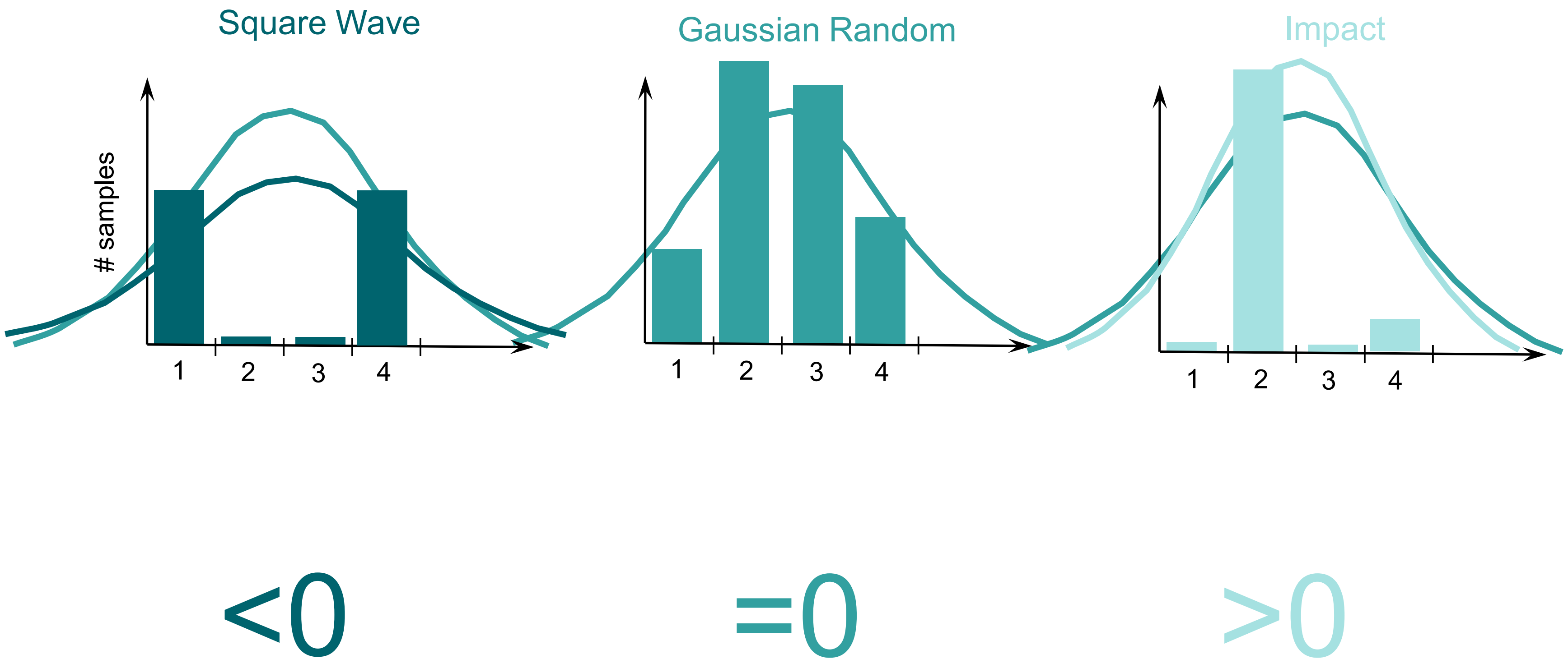


$$k = \frac{n\sum_{i=1}^{n}(x_i - \bar{x})^4}{\left(\sum_{i=1}^{n}(x_i - \bar{x})^2\right)^2} - 3$$

Kurtosis (k) is a unitless parameter that measures the relative sharpness or flatness of a distribution for a signal relative to a normal or Gaussian one.

Kurtosis


Square Wave
Gaussian Random
Impact
samples
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Kurtosis

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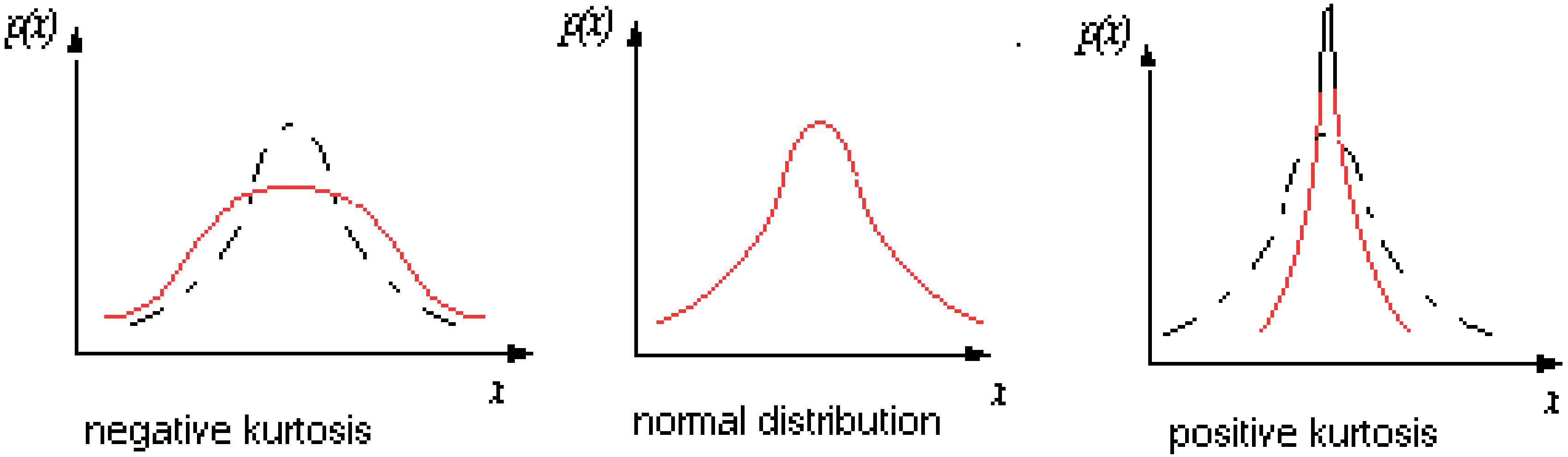
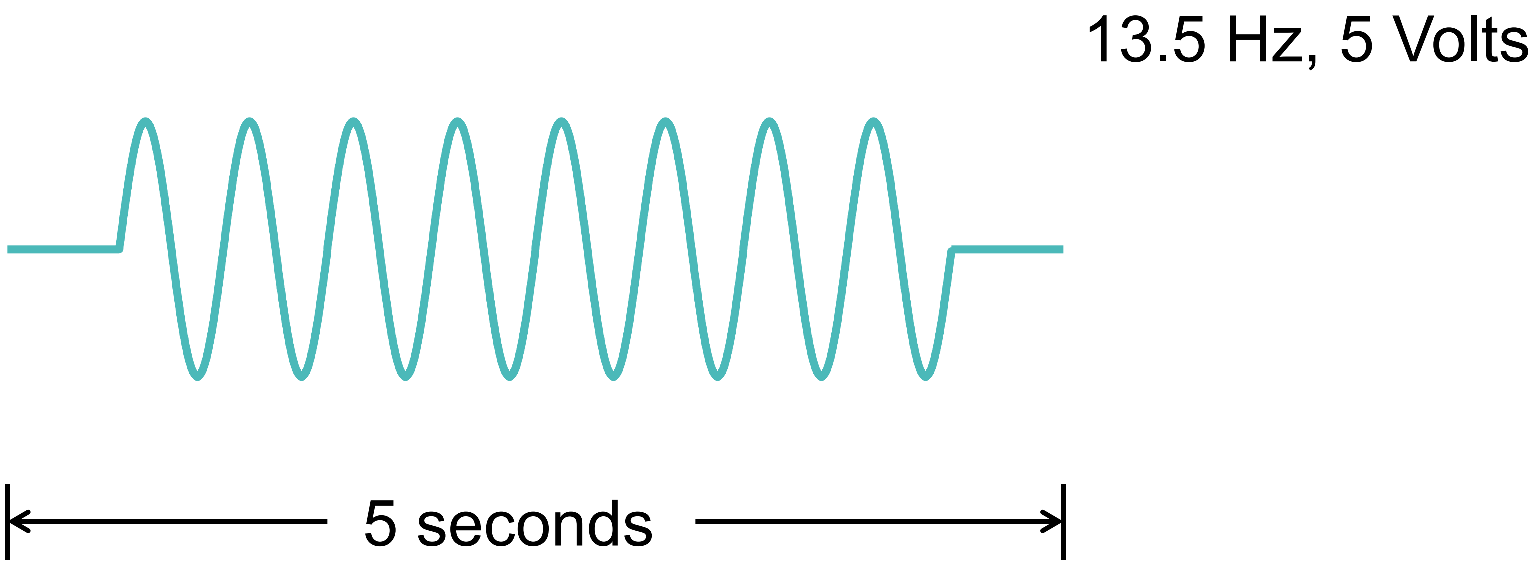


- Equal 0 -> Normal Distribution, "mesokurtic.“; example signal: Guassian Random
- Negative (“<0”) – Wide Distribution, "platykurtic“; example signal: Square/Sine Wave
- Positive (“>0”) – Narrow Distribution, "leptokurtic“; example signal: Impact

Time-Frequency Analysis: Wavelets

Time-Frequency Analysis: Wavelets



Time-Frequency Analysis: Wavelets

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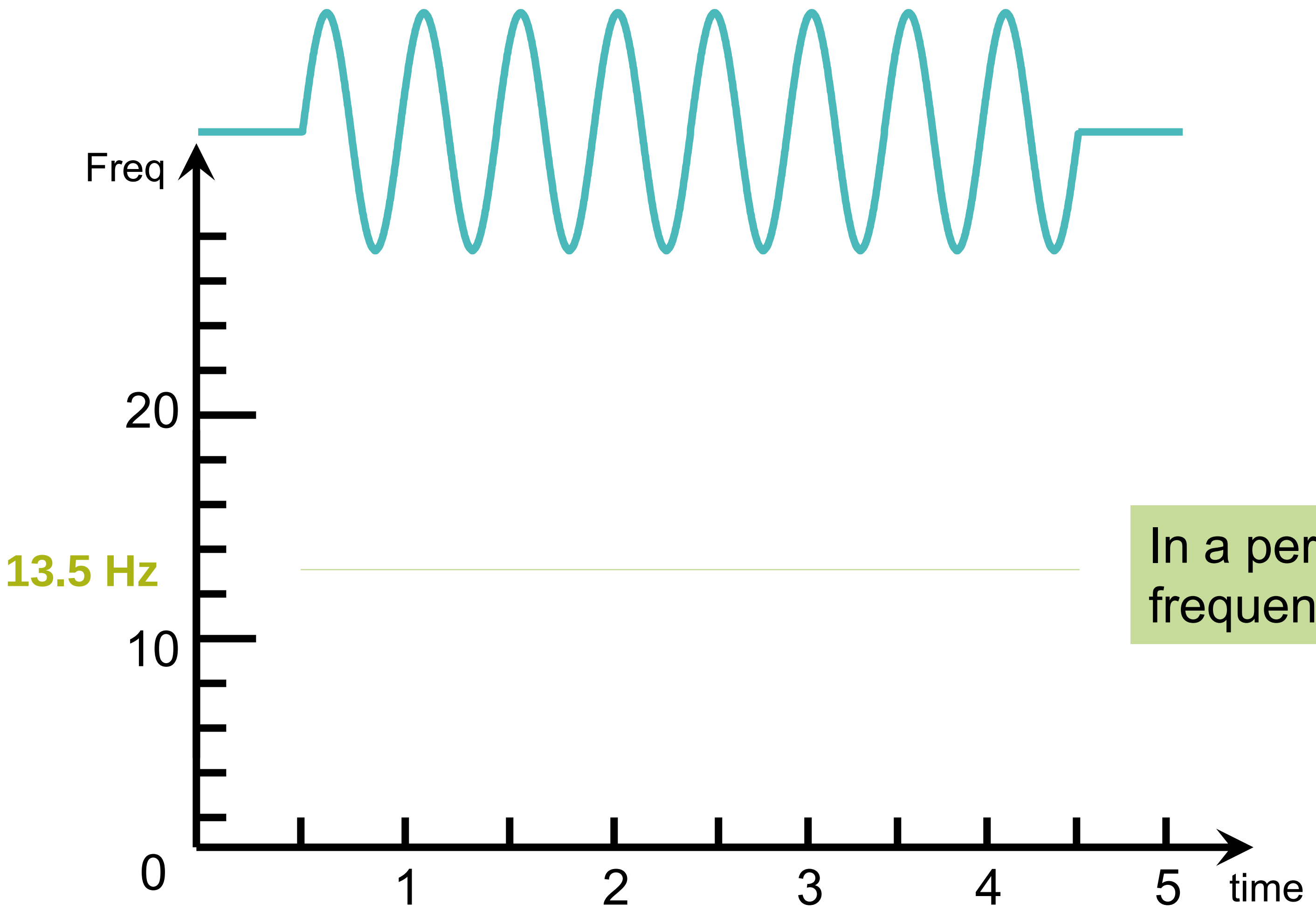

In a perfect world, this is our frequency spectrum vs. time

Time-Frequency Analysis: Wavelets

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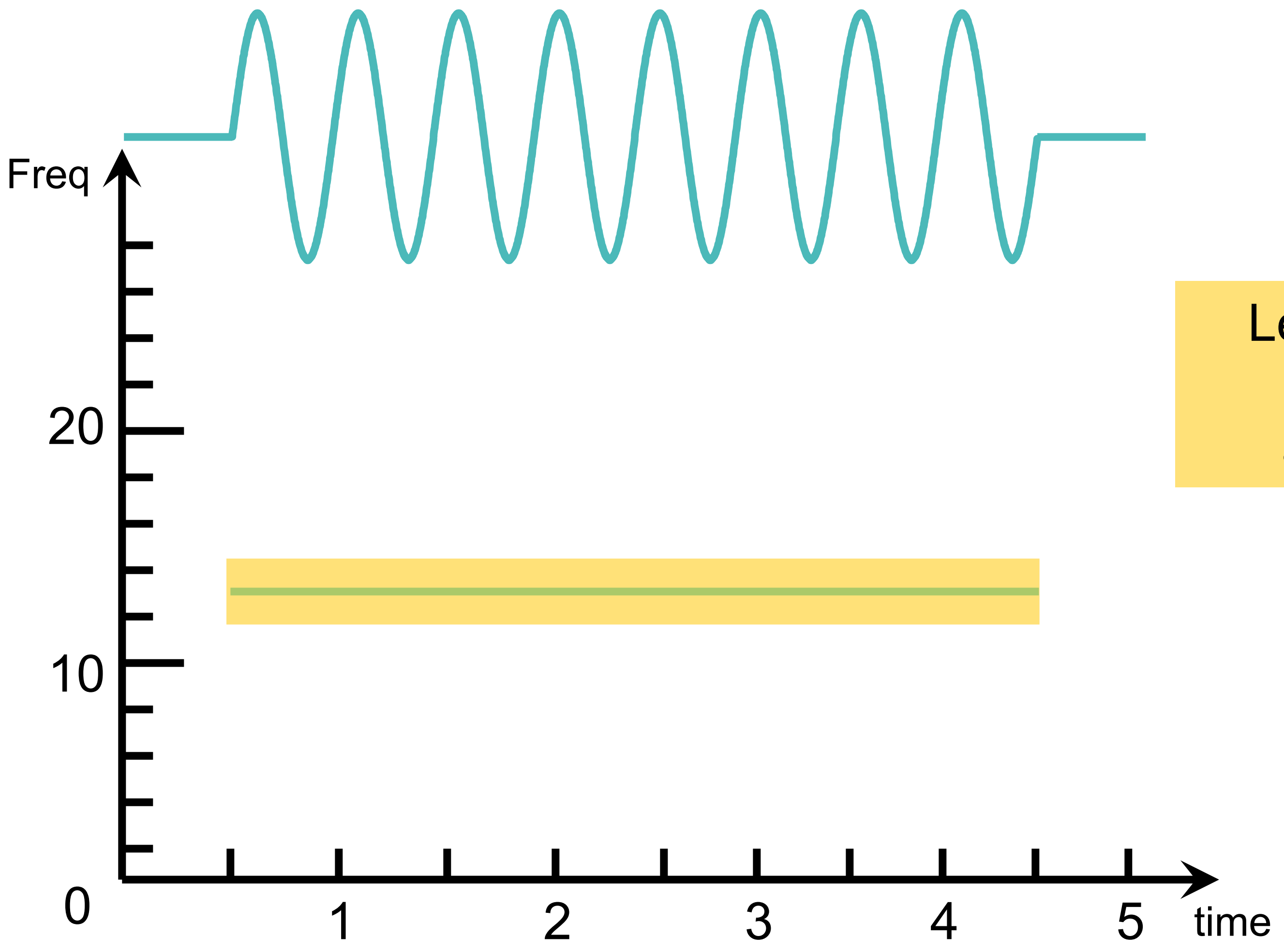
Perform FFT

T=0.5 sec

T=1/(Δf)

Δf = 2 Hz



Leakage in frequency domain due to Δf, amplitude reduced

Time-Frequency Analysis: Wavelets

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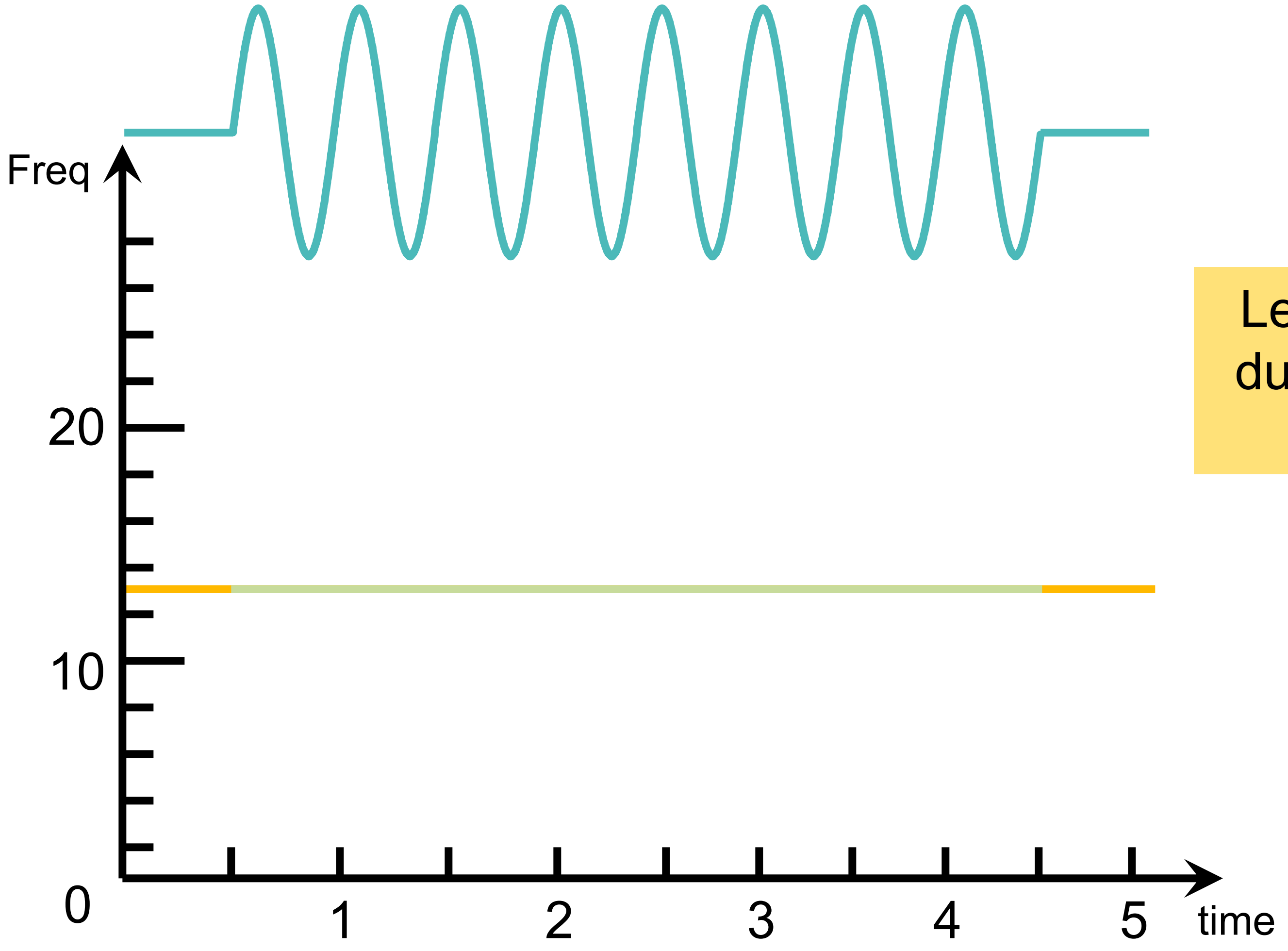


Leakage in time domain due to T, incorrect signal determination

<u>Perform FFT</u>

Δf = 0.5 Hz

T=1/(Δf)

T= 2 sec

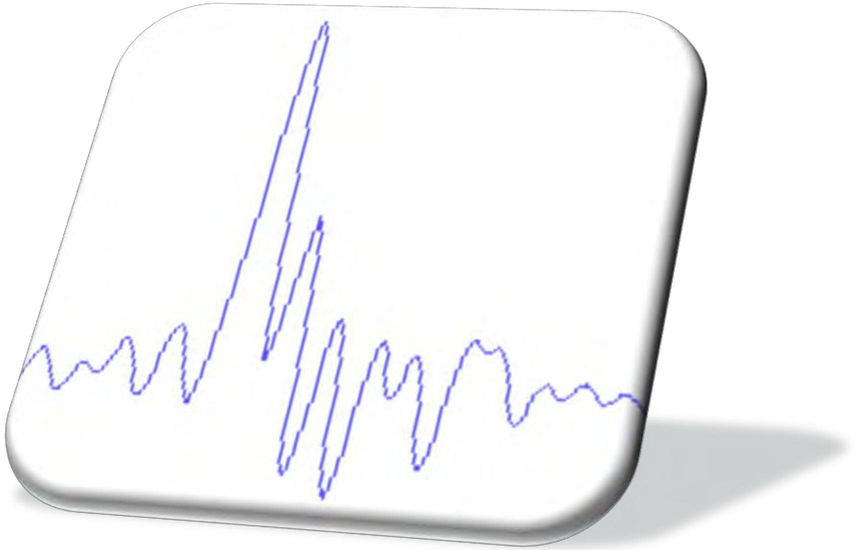
Time-Frequency Analysis: Wavelets

Traditional FFT methods do not work well on transient events:

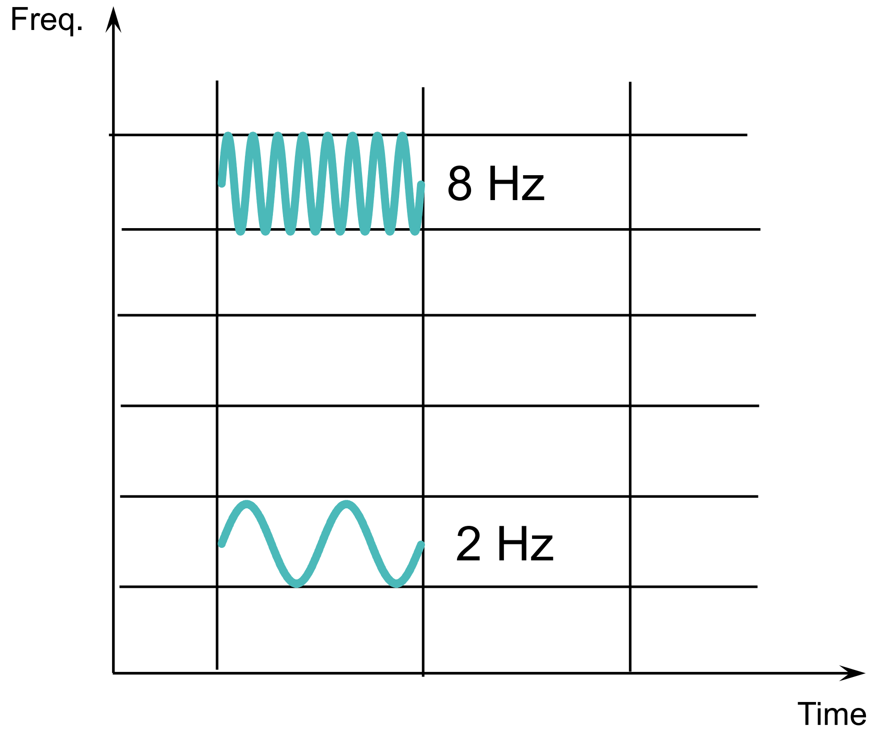
- Good Time Resolution → Bad Frequency
- Good Frequency Resolution → Bad Time

Solution: **Wavelets**

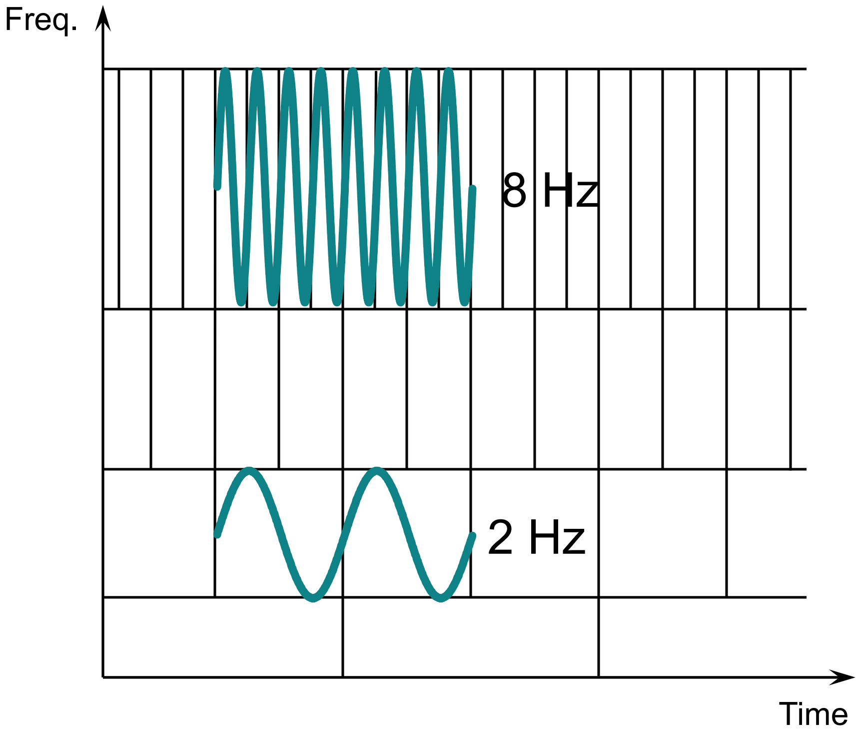
- Alternative Time-Frequency Methods
- Not FFT based (per se)
- Generate large amount of information over small time duration (I.e., analyze only milliseconds worth of data)



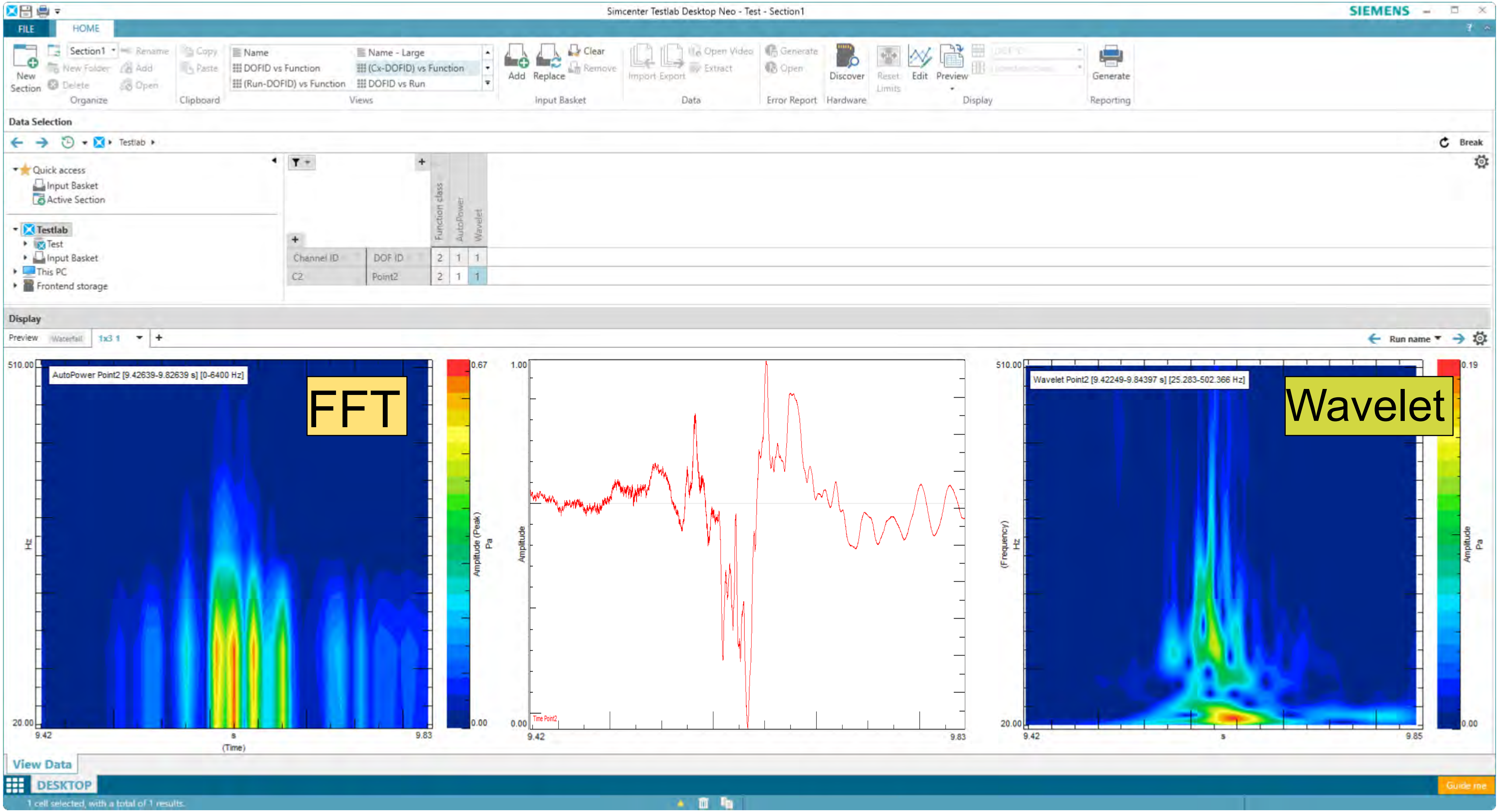
Time-Frequency Analysis: Wavelets



Traditional FFT



Wavelet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FILE
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New Section
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Name - Large
(Cx-DOFID) vs Function
DOFID vs Run
Views
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Replace
Clear
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Error Report
Discover
Hardware
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Quick access
Input Basket
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Testlab
Test
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This PC
Frontend storage
Function class
AutoPower
Wavelet
Channel ID
DOF ID
C2
Point2
Display
Preview
Waterfall
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Run name
AutoPower Point2 [9.42639-9.82639 s] [0-6400 Hz]
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Hz
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s
(Time)
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0.00
Amplitude (Peak)
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Amplitude
Time Point2
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9.83
Wavelet Point2 [9.42249-9.84397 s] [25.283-502.366 Hz]
Wavelet
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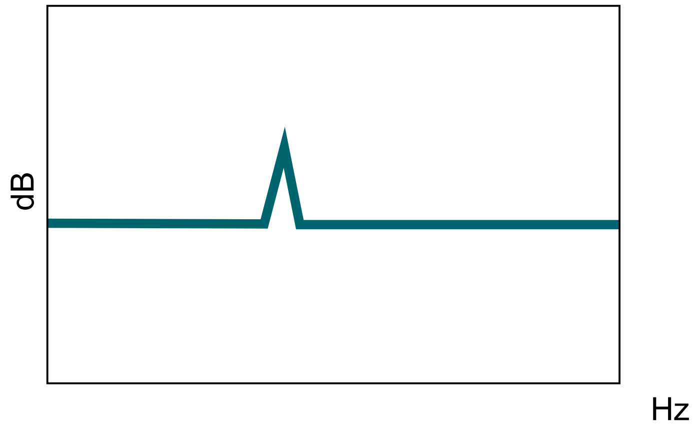
Tonale Metriken

Tonality
Tone to Noise
Prominence Ratio

Tonal Examples

Tonal noise issues characterized by:

- Distinct audible peaks at discrete frequencies
- Opposite of broadband



Vuvuzela

Turbocharger

Mosquito

Gear Whine

TONAL METRICS

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Tonality	Tone-to-Noise	Prominence Ratio
DIN 45681 provides an iterative method to detect tones by comparing the levels of each spectral line	ECMA-74 and ISO 7779 describe the calculation	ECMA-74 and ISO 7779 describe the calculation
1 Tonality Unit (t. u.) has the tonality of a 1 kHz sine tone @ 60dB	Levels of the prominent discrete tones are compared to the noise level in the same critical band	Average SPL of the critical band centered around the tone is higher than surrounding critical bands

TONALITY

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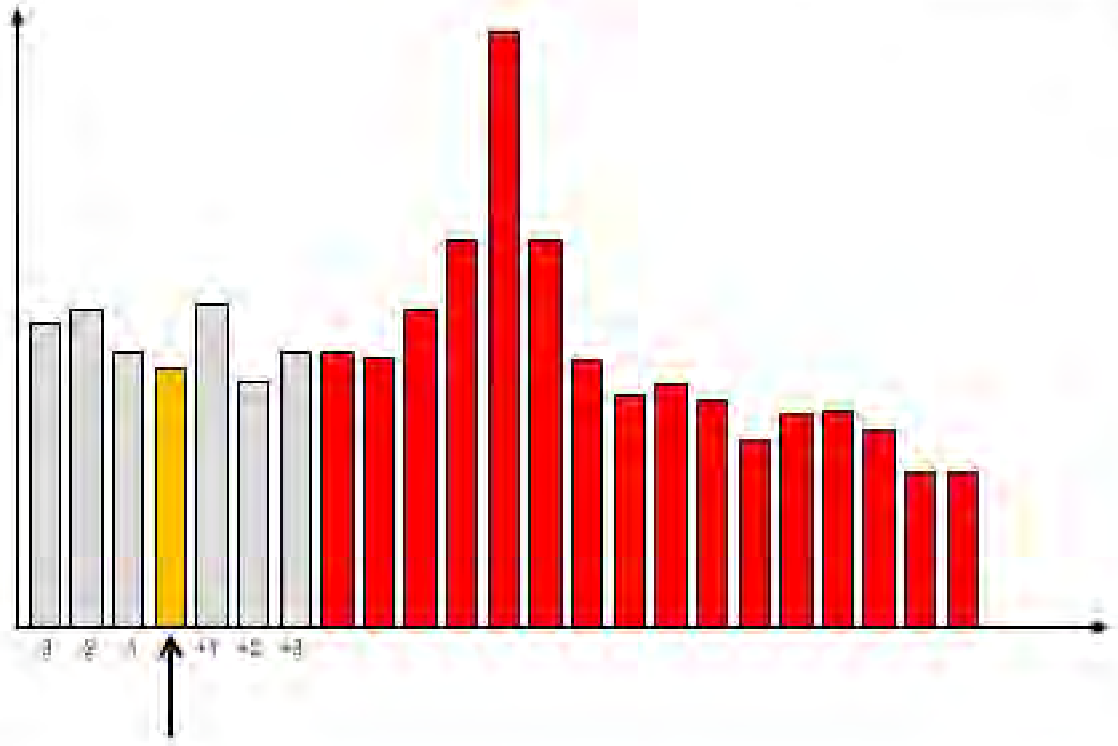
Tonality

DIN 45681 provides an iterative method to detect tones by comparing the levels of each spectral line

1 Tonality Unit (t. u.) has the tonality of a 1 kHz sine tone @ 60dB

Criteria: $S > S_{\pm 1}$

$S > 7\text{ dB } S_{\pm 2,3}$



Tonality Calculation

Pure tones produce a tonality value of 1.0

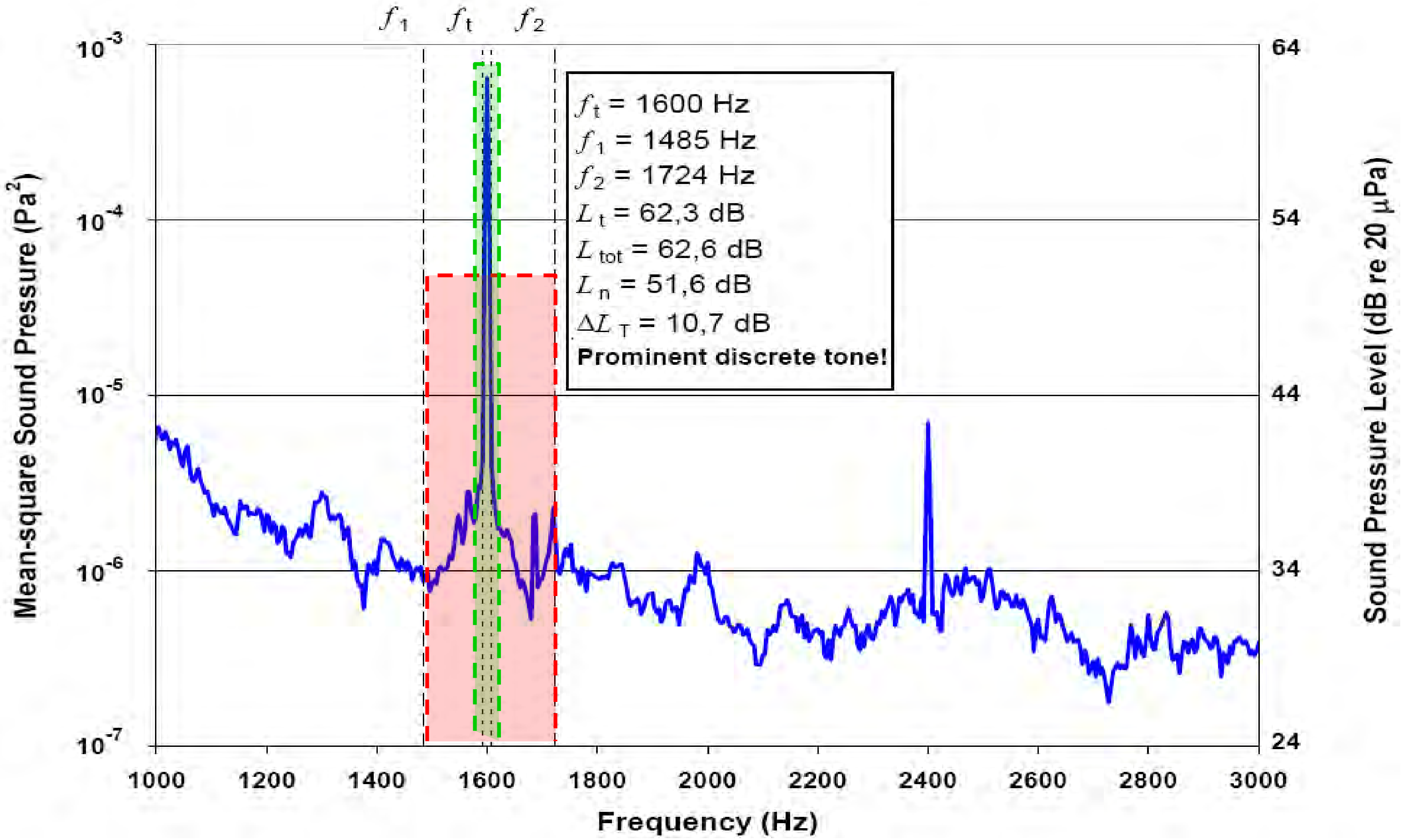
Pure random noise produces a tonality value of 0.0

TONE-TO-NOISE

Tone-to-Noise

ECMA-74 and ISO 7779 describe the calculation

Levels of the prominent discrete tones are compared to the noise level in the same critical band



Critical Bands

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The inner ear can be considered to act as a set of overlapping constant percentage Bandwidth filters. The noise Bandwidths concerned are approximately constant with a Bandwidth of around 110 Hz, for frequencies below 500 Hz, evolving to a constant percentage value (about 23 %) at higher frequencies. This corresponds perfectly with the nonlinear frequency-distance characteristics of the cochlea. These Bandwidths are often referred to as 'critical Bandwidths' and a 'Bark' scale is associated with them as shown in Table 1.1.

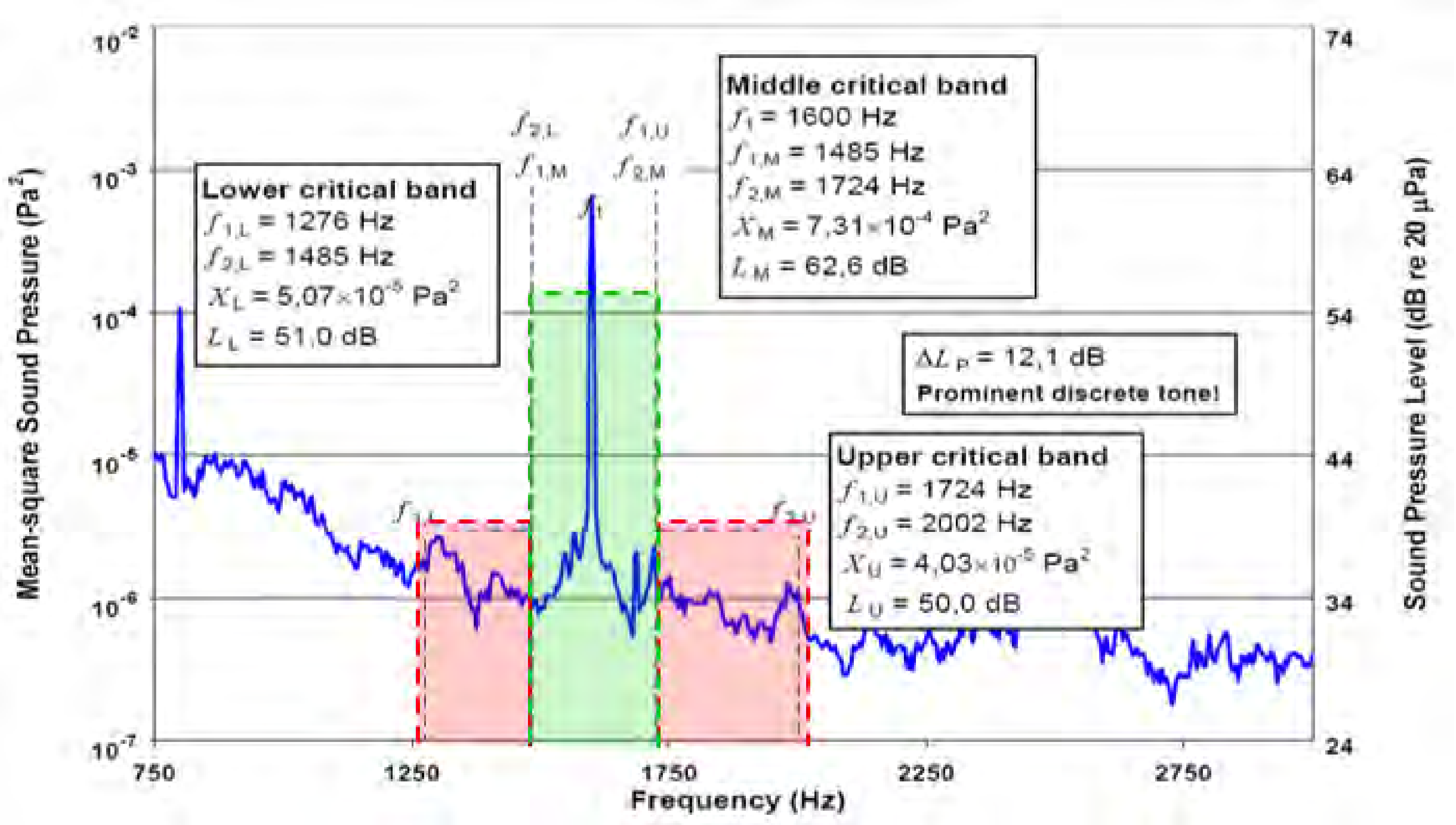
Critical Band (Bark)	1	2	3	4	5	6	7	8
Center Frequency (Hz)	50	150	250	350	450	570	700	840
Bandwidth (Hz)	100	100	100	100	110	120	140	150
Critical Band (Bark)	9	10	11	12	13	14	15	16
Center Frequency (Hz)	1000	1170	1370	1600	1850	2150	2500	2900
Bandwidth (Hz)	160	190	210	240	280	320	380	450
Critical Band (Bark)	17	18	19	20	21	22	23	24
Center Frequency (Hz)	3400	4000	4800	5800	7000	8500	10500	13500
Bandwidth (Hz)	550	700	900	1100	1300	1800	2500	3500

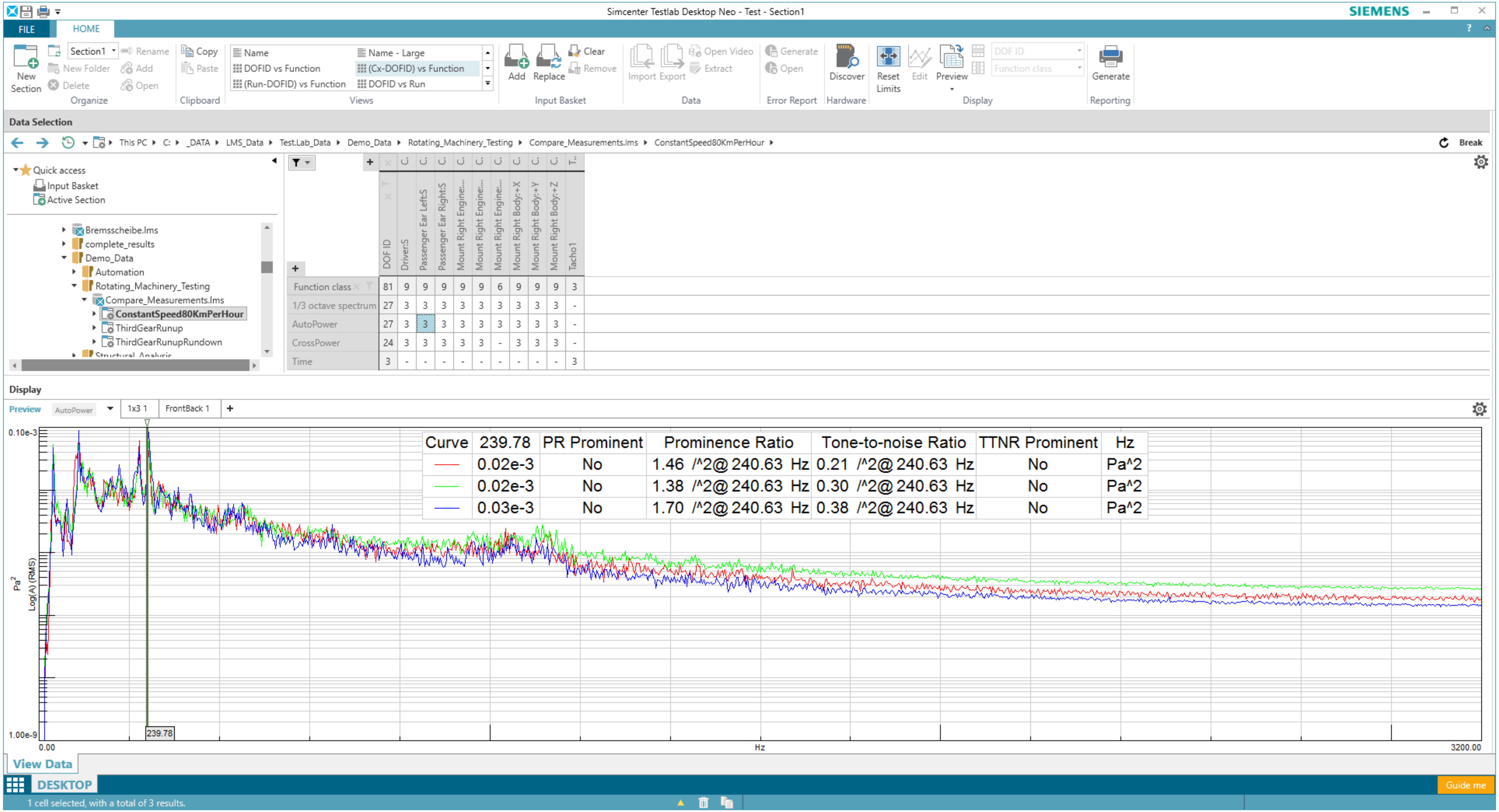
PROMINENCE RATIO

Prominence Ratio

ECMA-74 and ISO 7779 describe the calculation

Average SPL of the critical band centered around the tone is higher than surrounding critical bands




Simcenter Testlab Desktop Neo - Test - Section1
SIEMENS
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New Folder
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Rename
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DOFID vs Function
(Run-DOFID) vs Function
Name - Large
(Cx-DOFID) vs Function
DOFID vs Run
Views
Add
Replace
Clear
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ConstantSpeed80KmPerHour
ThirdGearRunup
ThirdGearRunupRundown
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Passenger Ear RightS
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Mount Right Engine...
Mount Right Engine...
Mount Right Body:+X
Mount Right Body:+Y
Mount Right Body:+Z
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Function class 81 9 9 9 9 9 6 9 9 9 3
1/3 octave spectrum 27 3 3 3 3 3 3 3 3 3 -
AutoPower 27 3 3 3 3 3 3 3 3 3 -
CrossPower 24 3 3 3 3 3 - 3 3 3 -
Time 3 - - - - - - - - - 3
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Curve 239.78 PR Prominent Prominence Ratio Tone-to-noise Ratio TTNR Prominent Hz
0.02e-3 No 1.46 /^2@ 240.63 Hz 0.21 /^2@ 240.63 Hz No Pa^2
0.02e-3 No 1.38 /^2@ 240.63 Hz 0.30 /^2@ 240.63 Hz No Pa^2
0.03e-3 No 1.70 /^2@ 240.63 Hz 0.38 /^2@ 240.63 Hz No Pa^2
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Modulations Metriken

Hilbert Envelope & Modulation Theory
Fluctuation Strength and Roughness

MODULATION METRICS

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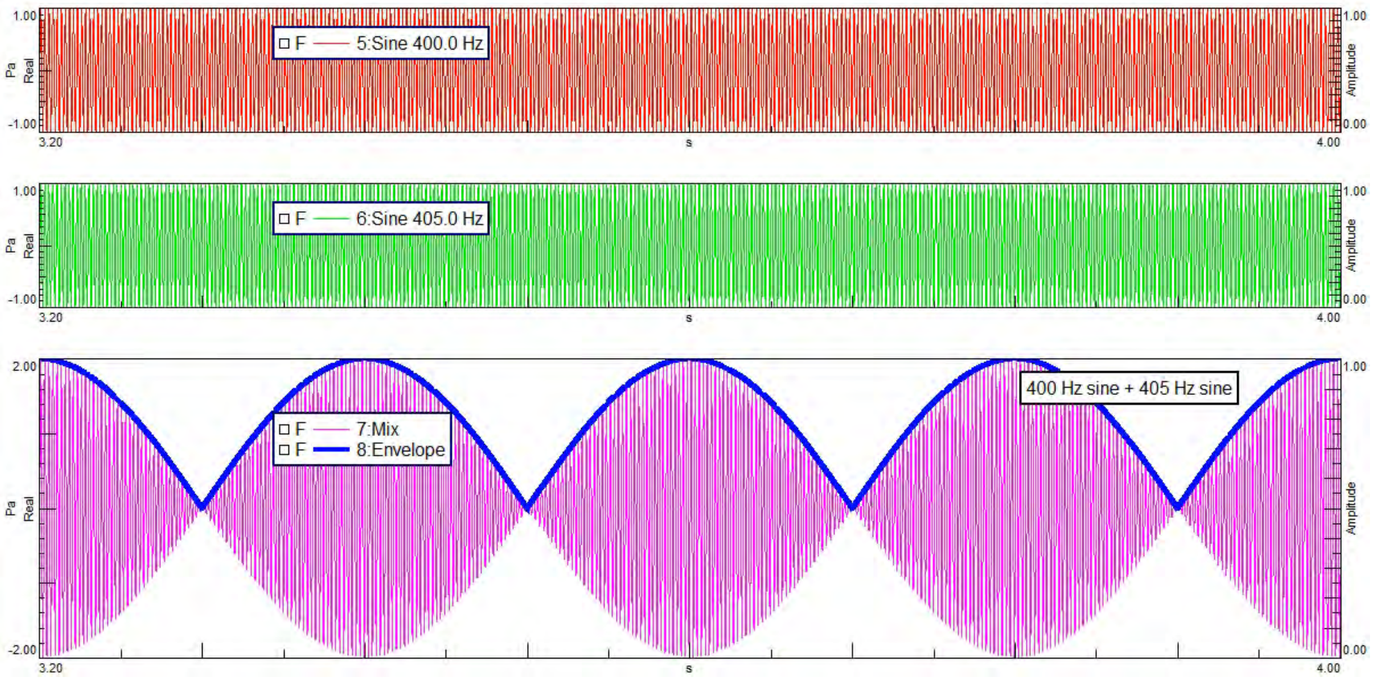
Phase shift between signals causes modulation in amplitude – these can be often perceived as annoying



Sounds which vary in amplitude “slowly” over time

- Electric Motor “warble”
- Exhaust/Intake “Growl”
- Aircraft Turbo Props
- Cooling fan and engine running at same speed

Modulation Theory

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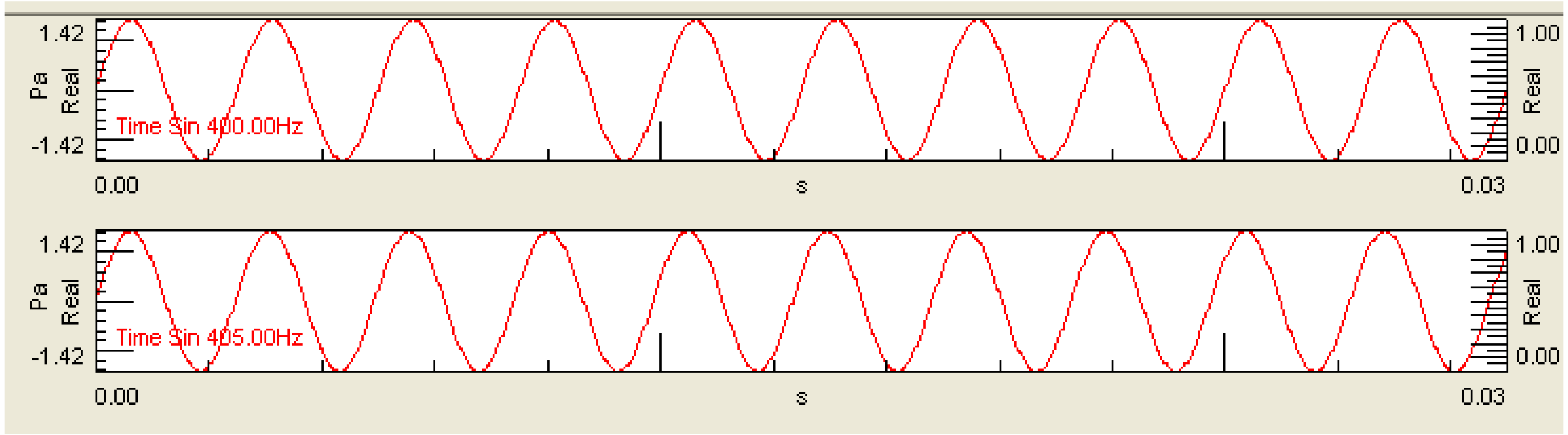
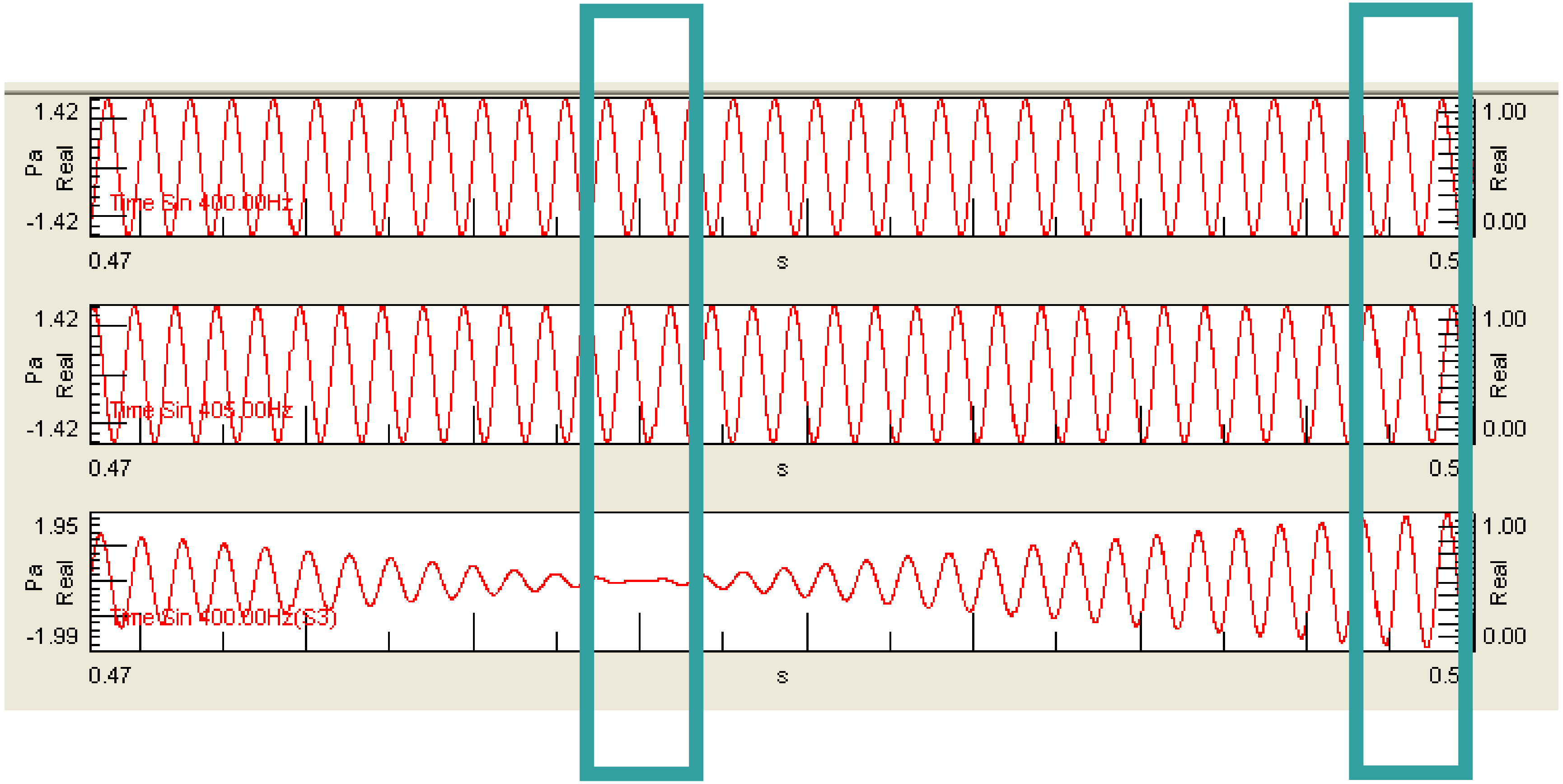


400 Hz

405 Hz

- What does the sum of a 400 Hz sine wave and 405 Hz sine wave look like?
- What do you hear?

Modulation Theory



Modulation Theory

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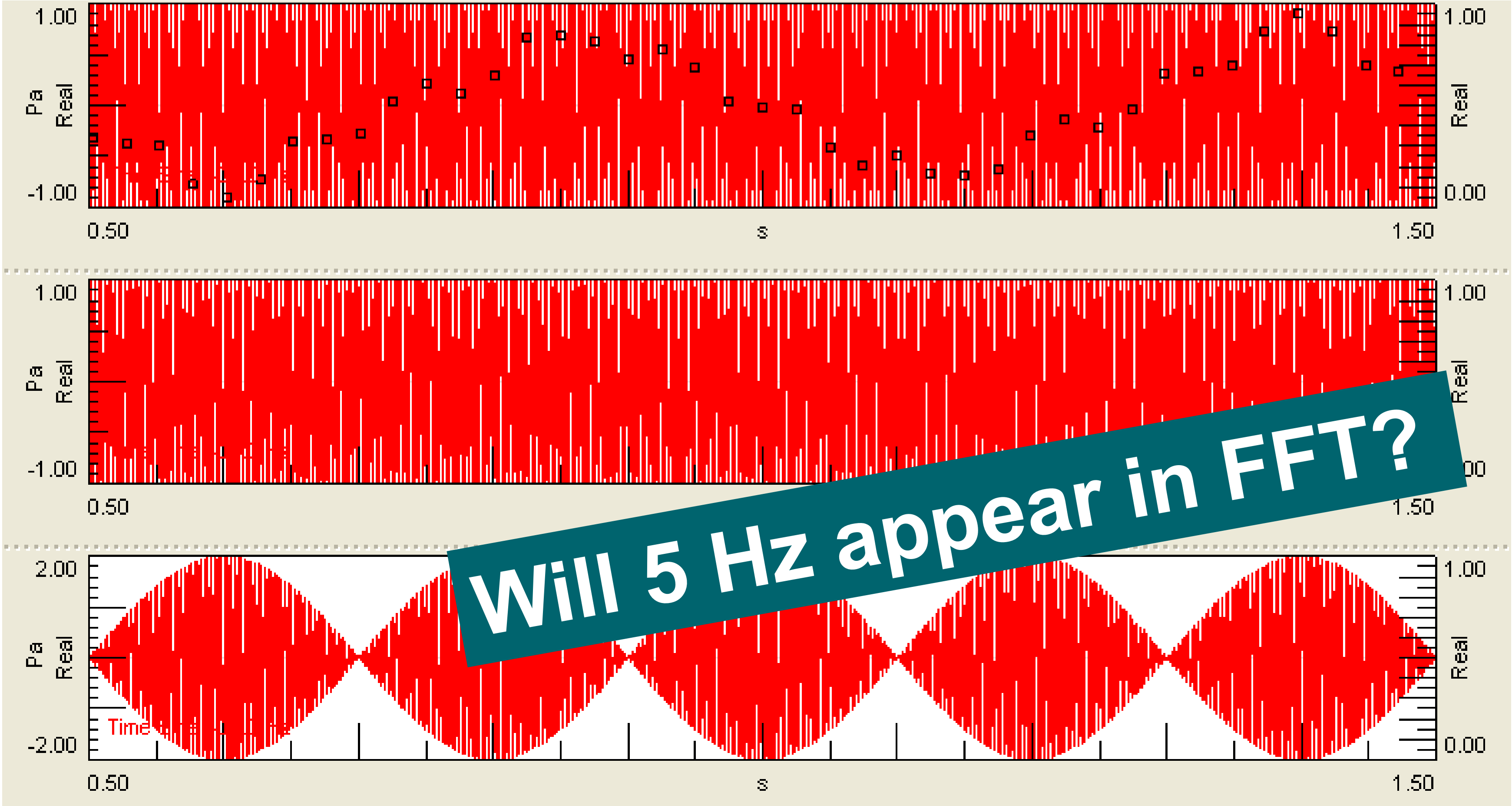


Will 5 Hz appear in FFT?

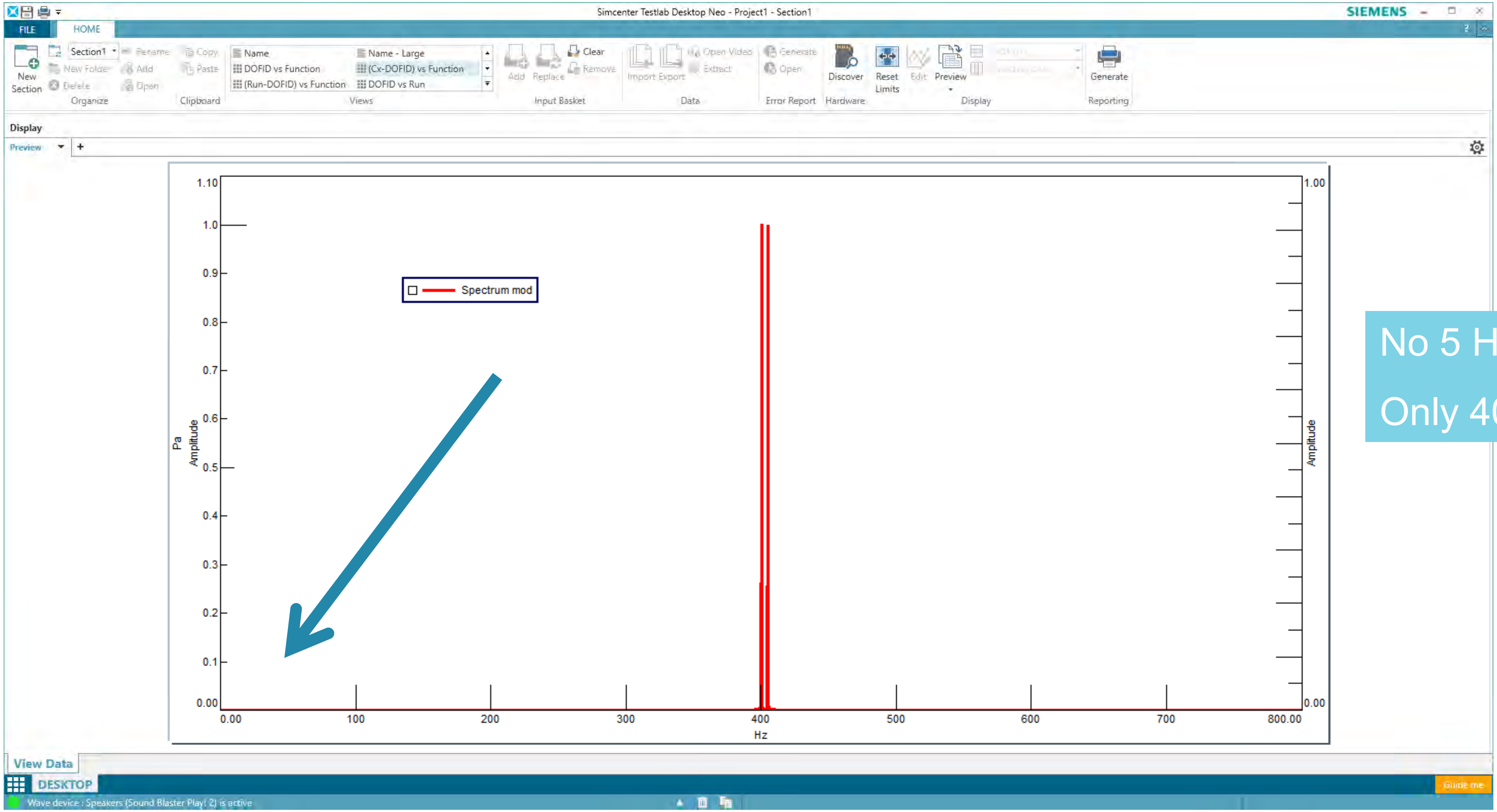
400 Hz

405 Hz

400+405 Hz

5 Modulations per Second

Modulation Theory



No 5 Hz in FFT!

Only 400 and 405 Hz.

Modulation Theory

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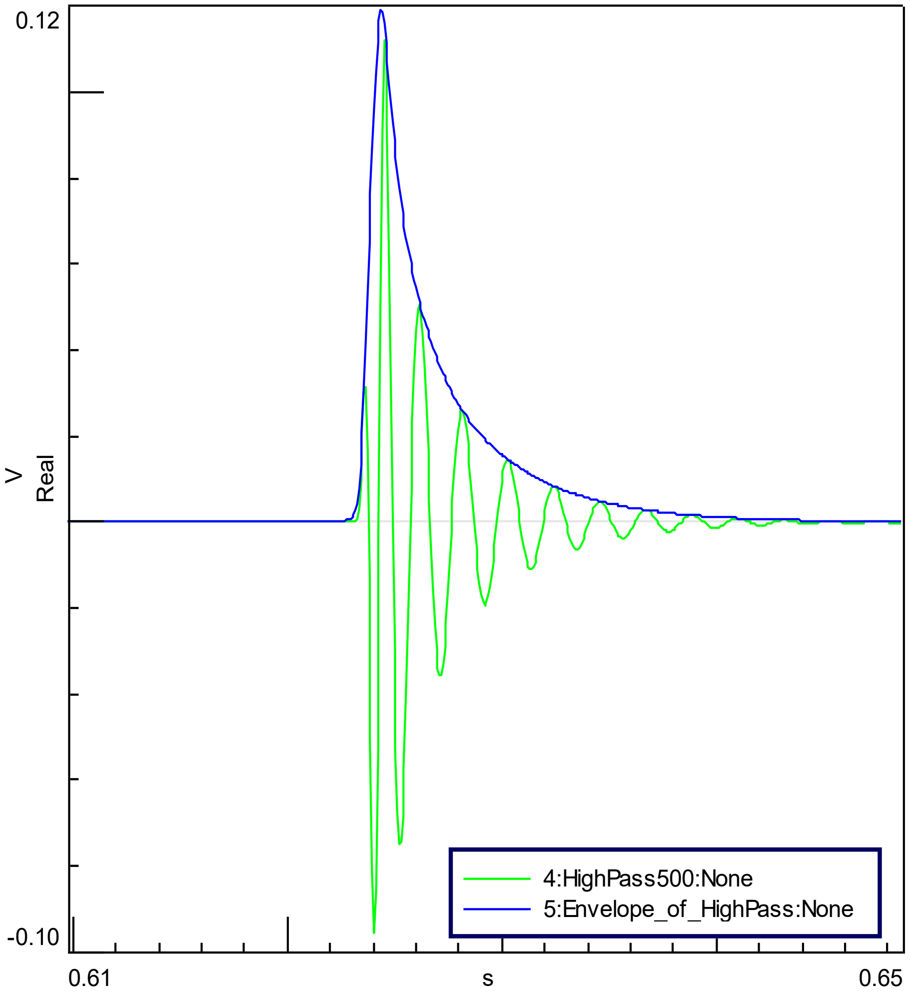


- Envelope done by Hilbert Transform
- Hilbert Transform separates slowly varying envelope from rapidly varying signal

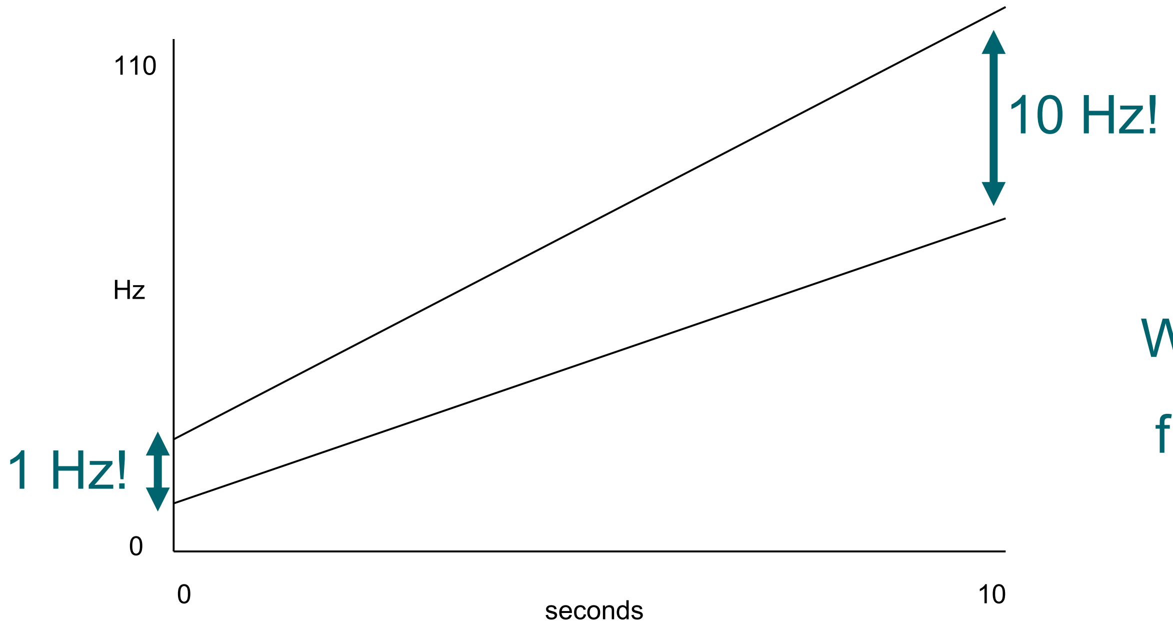
Fluctuation Strength and Roughness

Roughness and Fluctuation Strength

Let's take two sweeping sine tones over 10 secs:

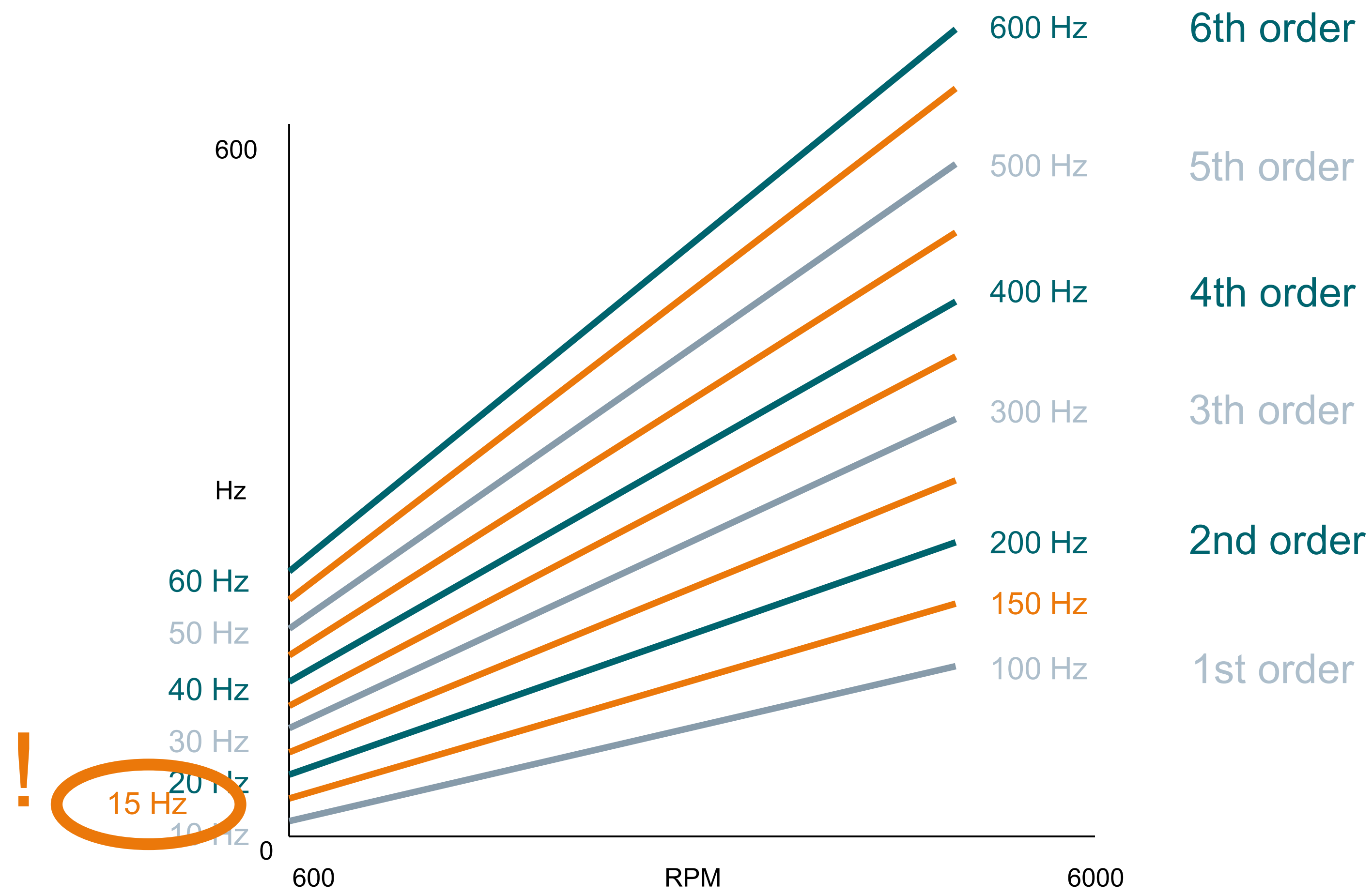
- 10 Hz to 100 Hz
- 11 Hz to 110 Hz

What is initial modulation frequency?



What is the end modulation frequency at 10s?

Engine Harmonics



ROUGHNESS and FLUCTUATION STRENGTH

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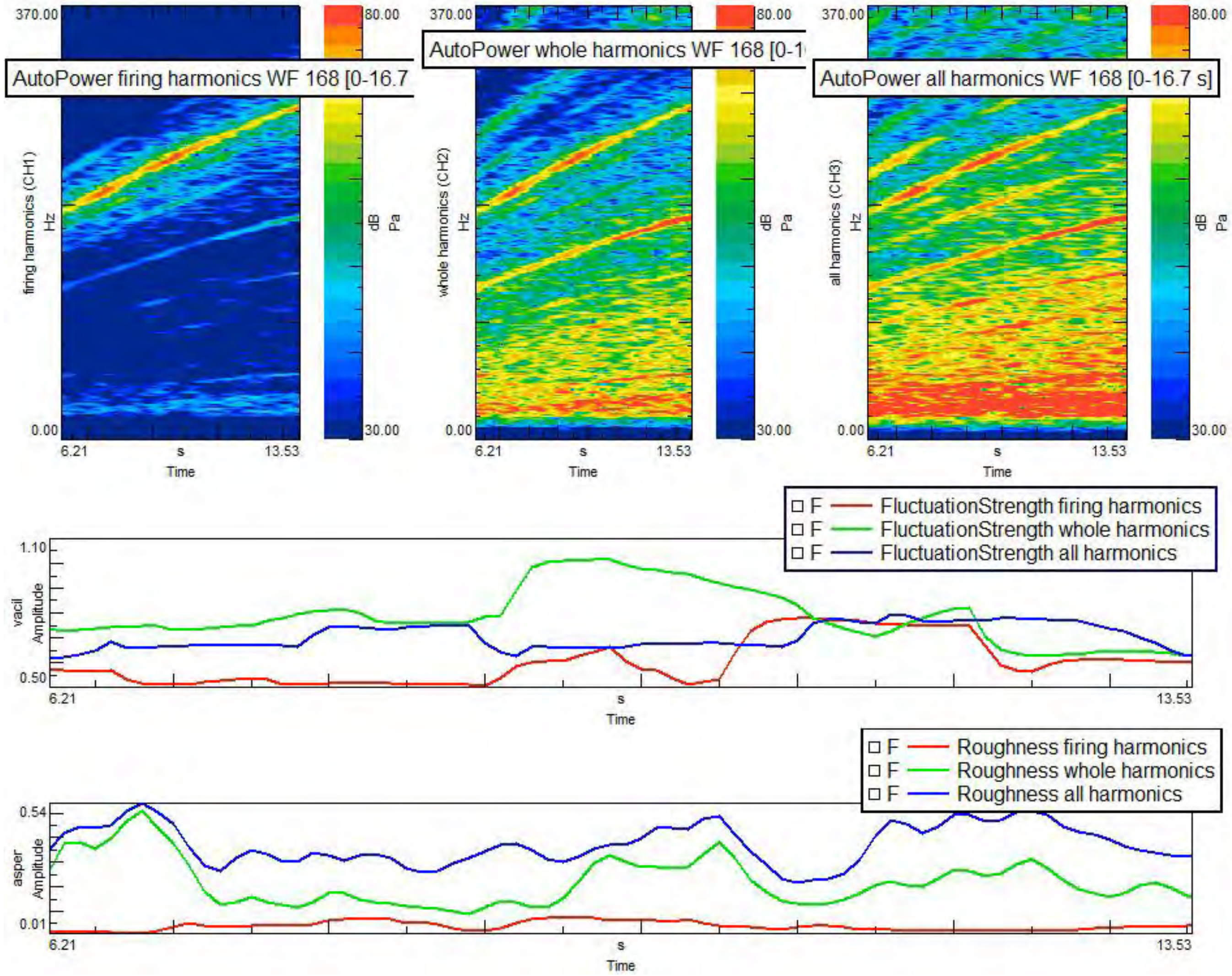
Fluctuation Strength focuses on slower modulations, between 0 and 20 Hz, max at 4Hz

1 vacil is

fluctuation strength produced by a 1000 Hz tone of 60 dB which is 100% amplitude modulated at 4Hz



Roughness focuses on faster modulations, between 20 and 300 Hz, max at 70 Hz

1 asper is

roughness produced by a 1000 Hz tone of 60 dB which is 100% amplitude modulated at 70 Hz

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PreSales Solution Consultant

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Simulation & Testing Solutions

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Thank you