TFA Time Frequency Analysis S61

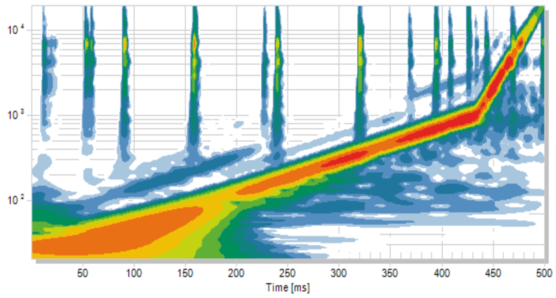
Software of the KLIPPEL R&D and QC SYSTEM (Document Revision 1.2)

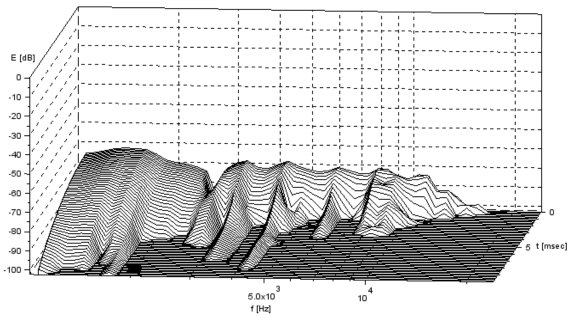
FEATURES

- Wavelet transform
- Filter bank
- Short-time Fourier transform (STFT)
- High resolution over-laced analysis
- 3D Display (time slices)
- Waterfall spectrum
- Spectrogram
- Group Delay
- Signal Characteristics (peak, bottom, rms, crest, etc.)

APPLICATION

- 3D defect analysis (Rub & Buzz)
- Detecting acoustical and mechanical resonators (room modes, rocking modes)
- Visualizing Harmonic and Intermodulation Distortion





DESCRIPTION

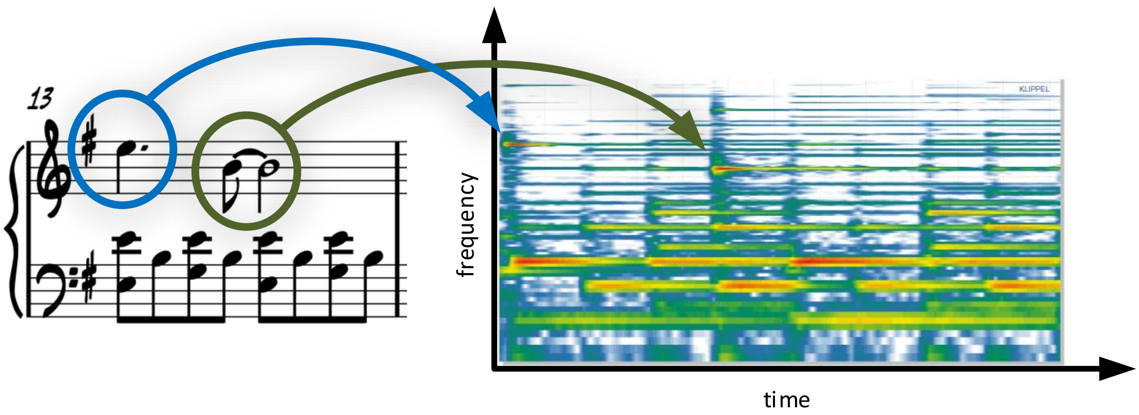
Time Frequency Analysis is a processing module that visualizes the characteristics of an audio signal over time and frequency.

Processing is based on three different methods (Wavelet Transform, Short Time Fourier Transform, Filter bank) and can be applied to any kind of time signal e.g. from a measurement operation or an external wav-file.

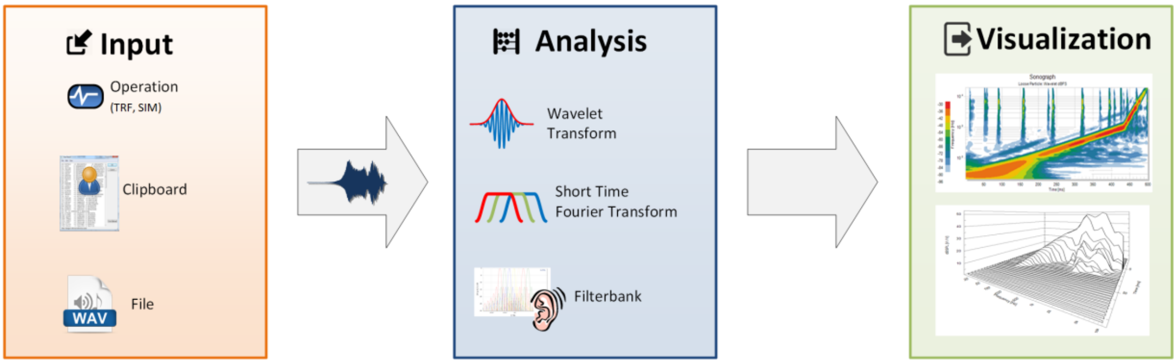
Article number:	1000-920

1 Principle

The Time Frequency Analysis is a calculation technique that provides a detailed view on the behavior of an audio signal. The method analyzes energy density in both frequency and time simultaneously. Similar to a music sheet it visualizes which frequency comes at which time.



Based on three different methods, the Wavelet Transform (WT), the Short Time Fourier Transform (STFT), or a Bark scaled Filter Bank Transform (FBA), the module decomposes the input signal and visualizes the signal characteristics over frequency and time.



2 Calculation Methods

2.1 Wavelet Transform (WT)

The Wavelet Transform is an analysis technique that correlates a signal with specified basic functions, so called Wavelets. Depending on the frequency, the length of the wavelet varies to optimize the relation between time and frequency resolution for each frequency band.

Basic Wavelet Transform [1]	$$W_x^{\psi}(a,b) = \frac{1}{\sqrt{\lvert a \rvert}} \int_{-\infty}^{\infty} x(t)\psi^*\left(\frac{t-b}{a}\right) dt$$ $x(t)$: *signal in time domain* $\psi^*\left(\frac{t-b}{a}\right)$: *conjugate complex wavelet function* a, b: *scaling parameters*
Complex Gaussian Morlet Mother Wavelet – Time Domain [2] [3]	The analysis uses the complex Gaussian Morlet Mother Wavelet which is represented in time domain by $$\psi(t) = \frac{1}{\sqrt{\pi B}} e^{j\omega_0 t} e^{-\frac{t^2}{B}}$$ and frequency domain by

	$$\Psi(\omega) = e^{-(\omega-w_0)^2\frac{B}{4}}$$ with $$B = \frac{4}{(\omega_0 BW)^2}$$ B: Bandwidth Parameter ω_0: Wavelet Centre Frequency BW: Bandwidth in Octaves
Energy of the wavelet transform [5]	The Energy density function is defined by: $$E_x^{\psi}(f,t) = \left\|W_x^{\Psi}(f,t)\right\|^2$$

2.2 Short Time Fourier Transform (STFT)

The Short time Fourier transform uses a window function that is shifted successively over a time signal. Calculating the Fourier Transform of each windowed section provides the spectral information at each time. Limited by the uncertainty relation the results of this method are a compromise between frequency resolution and time resolution. The Energy density function over time and frequency is defined by:

$$\boldsymbol{E(t,f)} = \left| \int_{-\infty}^{\infty} \boldsymbol{e^{-j2\pi f\tau} x(\tau)\, h(\tau - t) d\tau} \right|^2$$

2.3 Filter Bank (FBA)

Another method to separate the spectral components is set of FIR-filter, which provides high time resolution.

3 Parameters

3.1 Input

Select	The Source of the wave data has to be specified. Further Parameters appear depending on selected source.	
	File	Absolute or relative path to a wave file.
	Directory	Absolute or relative path to a directory containing wave files.
	Clipboard	Paste waveform curve from other dB-Lab operations.
	Operation	Import waveforms from other measurement.
	Imported	Select data which is already imported.

3.2 Processing

Analysis Method	This parameter sets the time-frequency analysis method to calculate the results. • Wavelet Transform • Short Time Fourier Transform • Filter Bank
Range Settings	Parameter for selecting the frequency and time range of the signal for the analysis • Start Time • End Time • Frequency Minimum • Frequency Maximum

Wavelet Transform

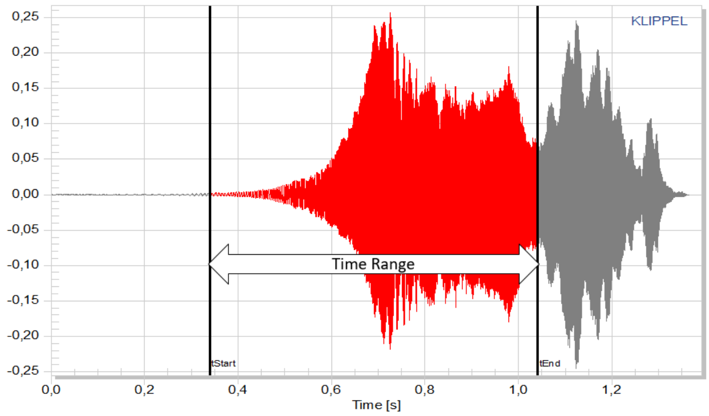
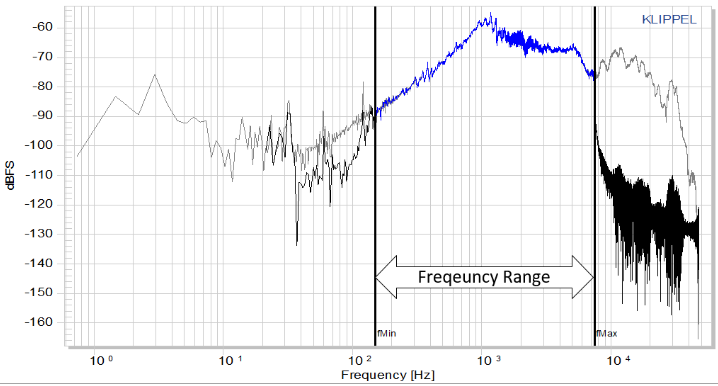
Bandwidth	This parameter defines the time- and frequency resolution ratio. E.g.: more Wavelets dividing one octave correspond to an increasing frequency resolution in return for a decreasing time resolution.

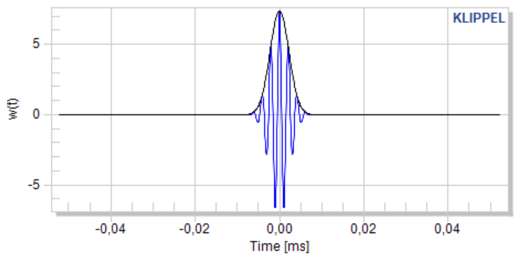
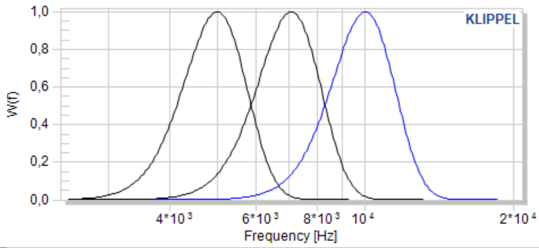
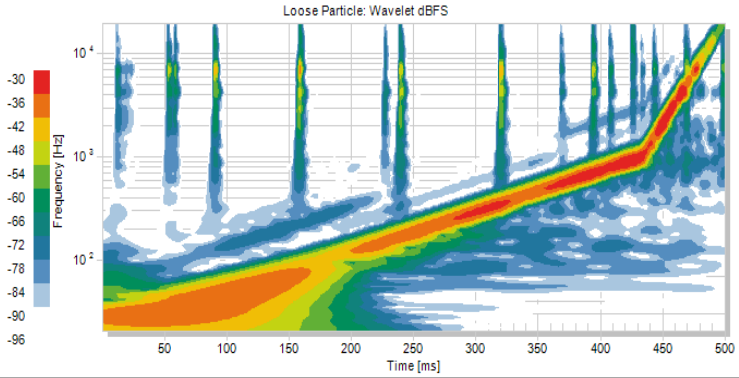
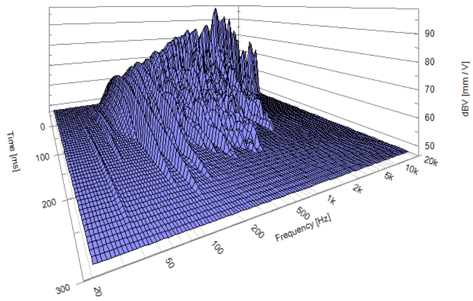
Short-Time Fourier Transform	
Window Type	Window function which is used for the STFT (e.g. Hann, Rectangular, Tukey)
Window Time	Length of the time windows
Window Overlap	Overlapping of the windows in percent
Filter Bank	
Number of Filters	Number of filter bands used for the analysis

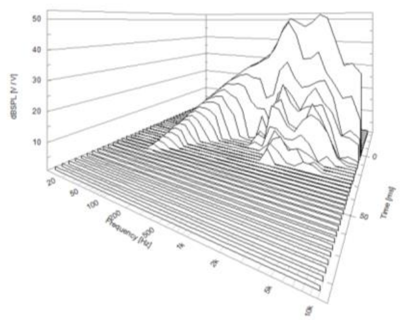
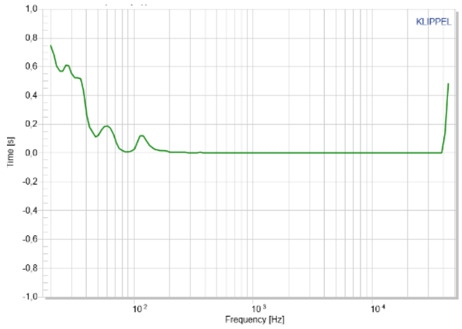
3.3 Display

Normalization	None	No normalization
	To 0 dB	Maximum is set to 0 dB
	To Peak Time Value	Each frequency band is normalized to its maximum
	To fundamental	Result is normalized to t = 0 s
SPL Range	Displayed SPL range in dB	
Result Max	maximum displayed SPL value in dB	
3D: Number of Slices	Visualized time slices	
Spectrogram: Colormap	Selection of the colormap of the spectrogram plot	
Spectrogram: Number of Colors	Definition of the color step size either low, mid, high or fixed in dB	
Spectrogram: Highlight Max Value	Checkbox to highlight the maximum value of the spectrogram plot	

4 Results

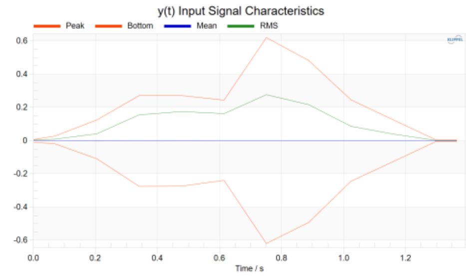
Waveform(t) Time Domain	The graph shows the imported waveform. The time cursors are corresponding to the settings in the property page. You may move them with the mouse as well. 
Waveform(f) Frequency Domain	The Fourier Transform of the imported waveform. The frequency cursors for f_{max} and f_{min} are corresponding to the settings in the property page. You may move them with the mouse as well. 

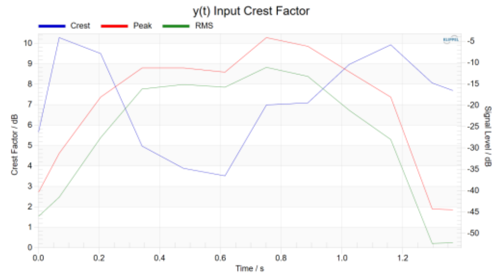
<table>
<tr><td rowspan="2">Mother Wavelet (for Wavelet Transform only)</td><td>Time domain

</td><td>Real part $\Re(\psi(t))$
Imaginary part $\Im(\psi(t))$
Envelope $\lvert\psi(t)\rvert$</td></tr>
<tr><td>Frequency domain

</td><td>Mother Wavelet $\Psi(\omega)$ + scaled Wavelets of one octave below</td></tr>
<tr><td>Spectrogram Plot</td><td colspan="2">2D color representation of the Energy $E(t,f)$ as a function of time and Frequency

</td></tr>
<tr><td>Waterfall Plot</td><td colspan="2">3D representation of the Energy Density.


</td></tr>
<tr><td>Group Delay (for Wavelet Transform only)</td><td colspan="2">The group delay is the time where the mean energy of each particular wavelet frequency arrives. Also referred to as the 1st moment or the center of gravity.

</td></tr>
</table>

Signal Characteristics

The TFA is calculating standard signal characteristics (e.g. mean, rms, peak, etc.) of the input waveform. This result window is showing these characteristics over time. In addition, the values of the signal characteristics are shown in the **Fehler! Verweisquelle konnte nicht gefunden werden.** window.

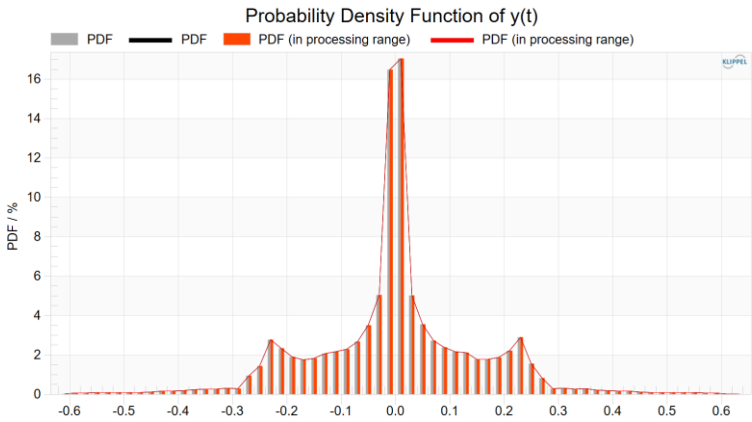




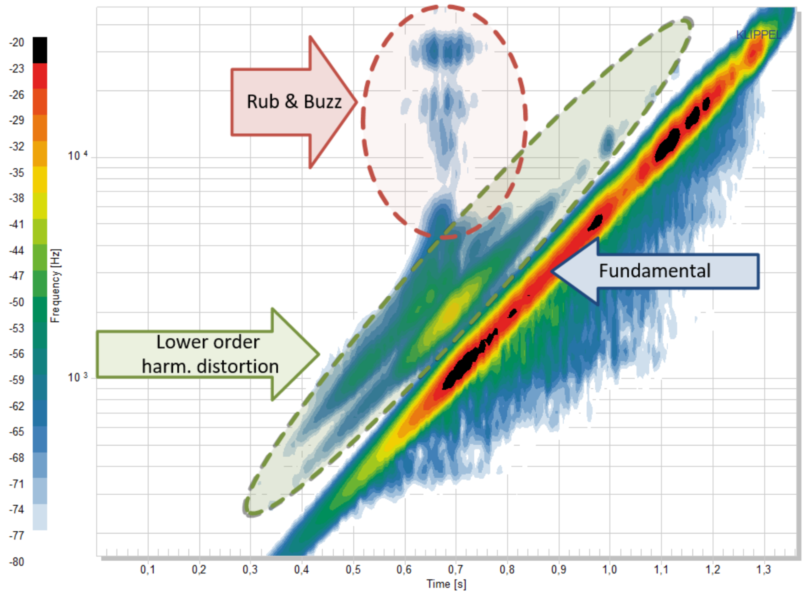
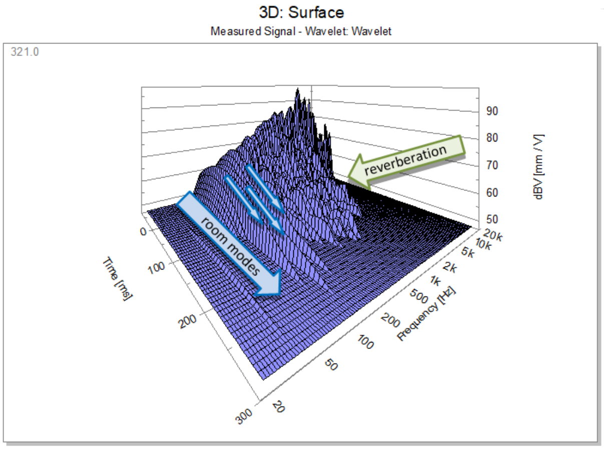
Parameter	Value	Unit
y(t) Input Waveform		
Length	3.49995	s
Channels	1	
Samples	154348	
Sample Frequency	44.1	kHz
Bit depth	16	
Signal Characteristics (Full Signal)		
Peak	0.84918	
Mean	0.00003	
Bottom	-0.99997	
RMS	0.18507	
Abs. Peak	0.99997	
Crest Factor	14.65298	dB
Kurtosis	3.96700	

PDF Probability Density Function

The graph shows the probability density function of the input signal.



5 Applications

Defect Analysis – Rub & Buzz	The picture shows the time frequency analysis of microphone signal of a chirp measurement. You can see that the chirp changes its frequency over time. At a fundamental frequency of 100Hz at t=0.7s, the loudspeaker excites a lot of high frequencies, which is a typical symptom for Rub and Buzz. 
Waterfall spectrum - Room Response	The graph shows the waterfall spectrum of a loudspeaker measured in a normal office room. Below 200 Hz the plot shows distinct resonances with low damping which are caused by interaction with the room. 

6 References

[1] P. Goupillaud, J. Morlet and A. Grossmann, "Cycle-Octave and related transforms in seismic signal analysis," *Geoexploration,* vol. 23, pp. 85-102, April 1984.

[2] D. B. Keele, "Time-Frequency Diskplay of Electroacoustic Data Using Cycle-Octave Wavelet Transforms," in *Audio Engineering Society Convention 99*, 1995.

[3] S. J. Loutridis, "Decomposition of Impulse Responses Using Complex Wavelets," *J. Audio Eng. Soc,* vol. 53, no. 9, pp. 796-810, September 2005.

[4] S. G. Mallat, „A theory for multiresolution signal decomposition: the wavelet representation,“ *IEEE Transactions on Pattern Analysis and Machine Intelligence,* Bd. 11, Nr. 7, pp. 674-693, #jul# 1989.

[5] O. Rioul und M. Vetterli, „Wavelets and signal processing,“ *IEEE Signal Processing Magazine,* Bd. 8, Nr. 4, pp. 14-38, #oct# 1991.

[6] L. Cohen, Time-Frequency Analysis, Prentice Hall PTR, 1995.

Find explanations for symbols at:

http://www.klippel.de/know-how/literature.html

Last updated: June 04, 2021