變轉速振噪診斷與時頻分析

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TFA as X-ray machine

- Data acquisition for sound and vibration signal induced from working-speed changing machine
- Time-frequency analysis
- Diagnosis of potential defect
- QA/QC, Assurance of reliability (machine health report)
- Smart machine/component (built-in sensor and analysis)

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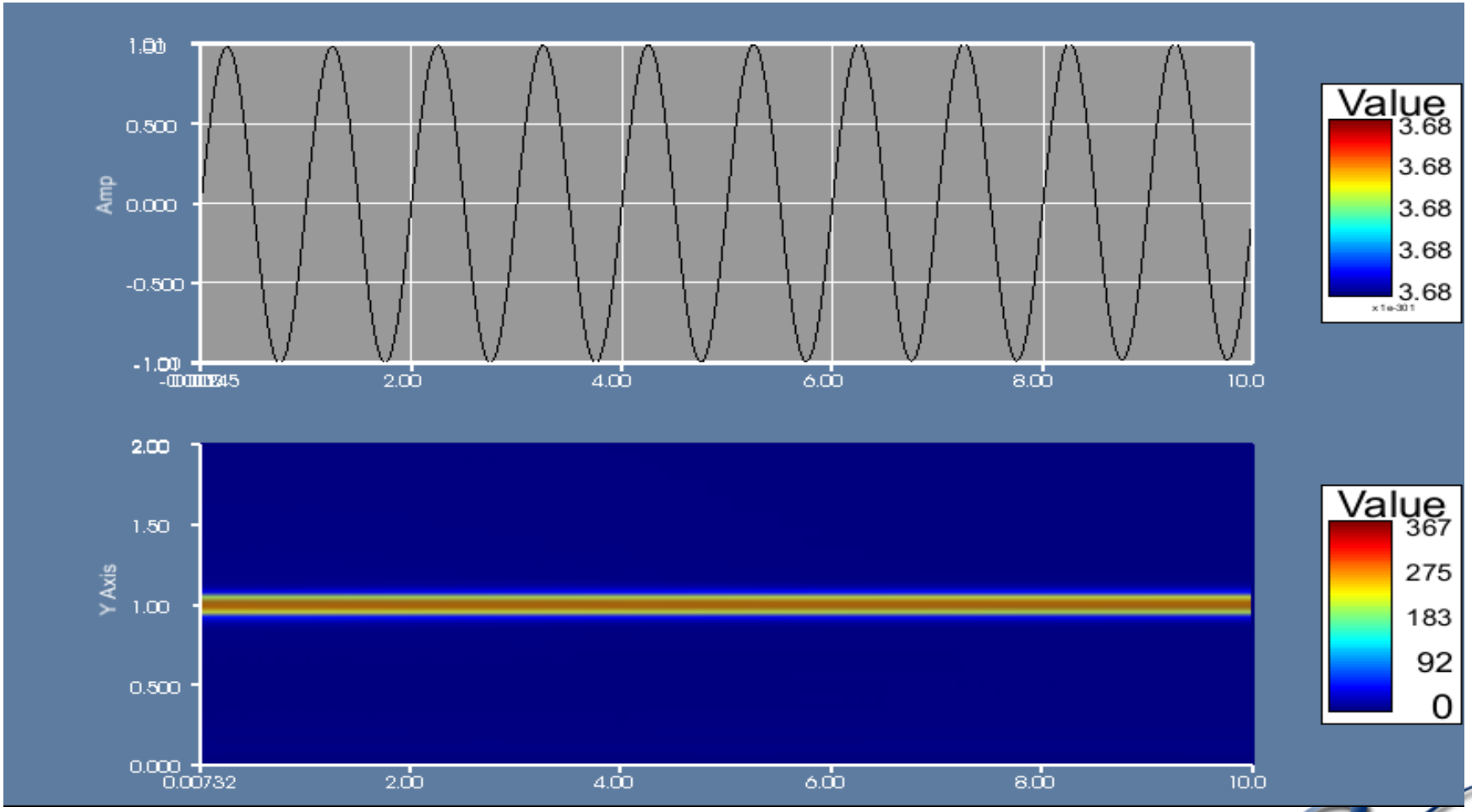
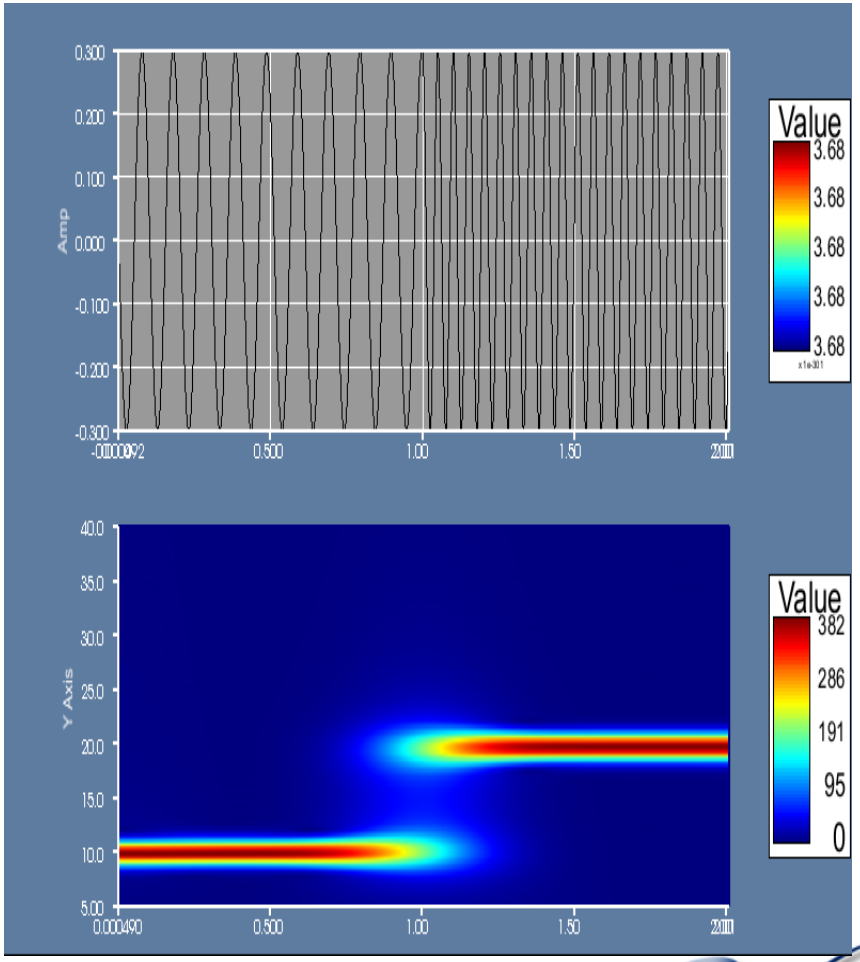
TF Plot: Single frequency



TF Plot: Change of frequency

- Signal with abrupt change of frequency.

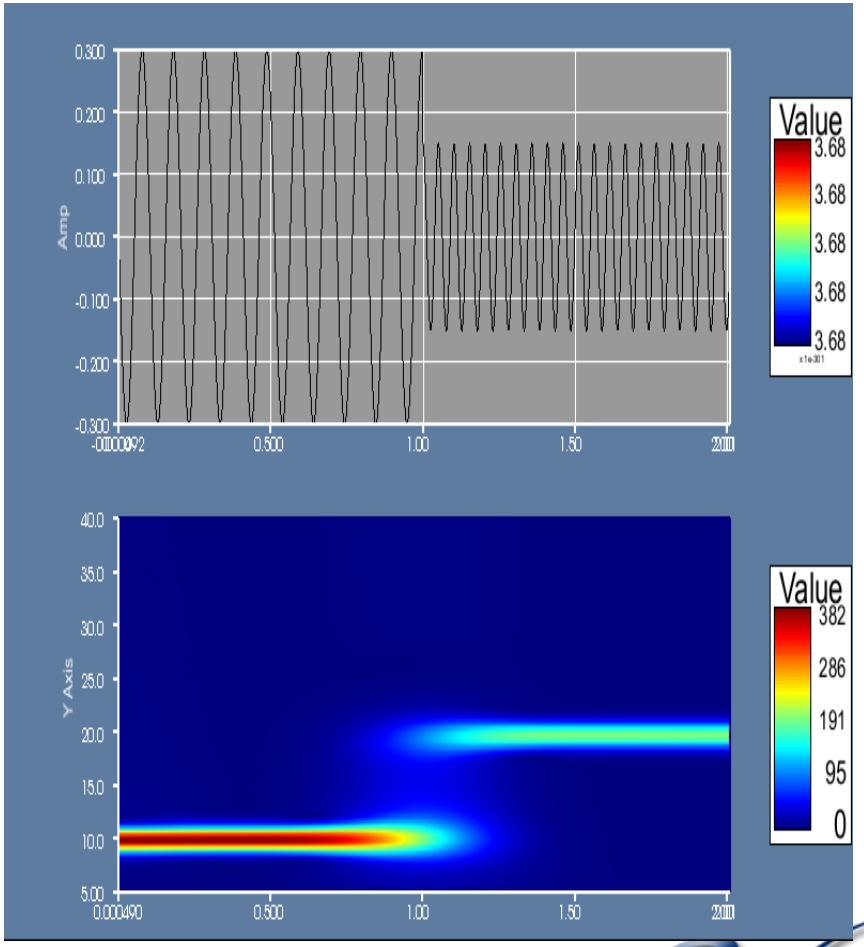
$$x(t) = \begin{cases} 0.30\cos(2 \times 10\pi t) & ,0 \le t < 1 \\ 0.30\cos(2 \times 20\pi t) & ,1 \le t < 2 \end{cases}$$



TF Plot: Change of frequency and amplitude

- Signal with abrupt change of frequency and amplitude

$$x(t) = \begin{cases} 0.30\cos(2 \times 10\pi t) & ,0 \le t < 1 \\ 0.15\cos(2 \times 20\pi t) & ,1 \le t < 2 \end{cases}$$

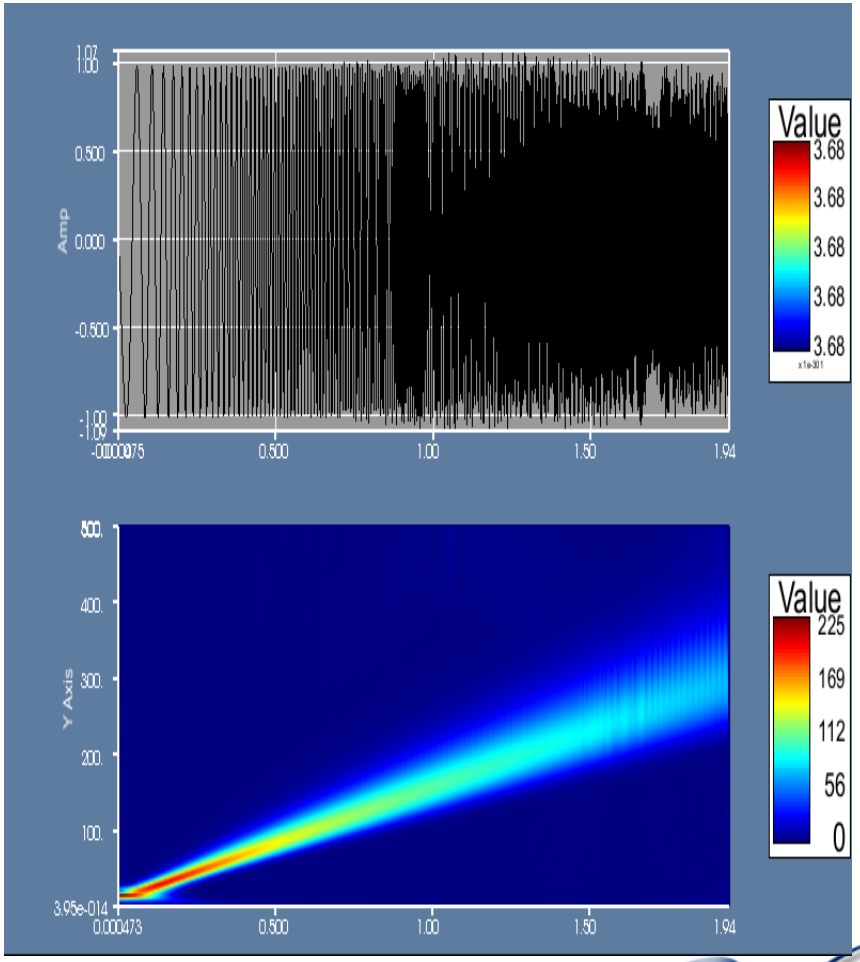


Time-Frequency Analysis Comparison

	Fourier Transform	STFT	Morlet / Enhanced Morlet	Hilbert Transform	HHT
Instantaneous frequency	n/a	distribution	distribution	Single value	Discrete values
Frequency change with time	no	yes	yes	yes	yes
Frequency resolution	good	ok	ok/good	good	good
Adaptive base	no	no	no	n/a	yes
Handling non-linear effect	n/a	no	no	yes	yes

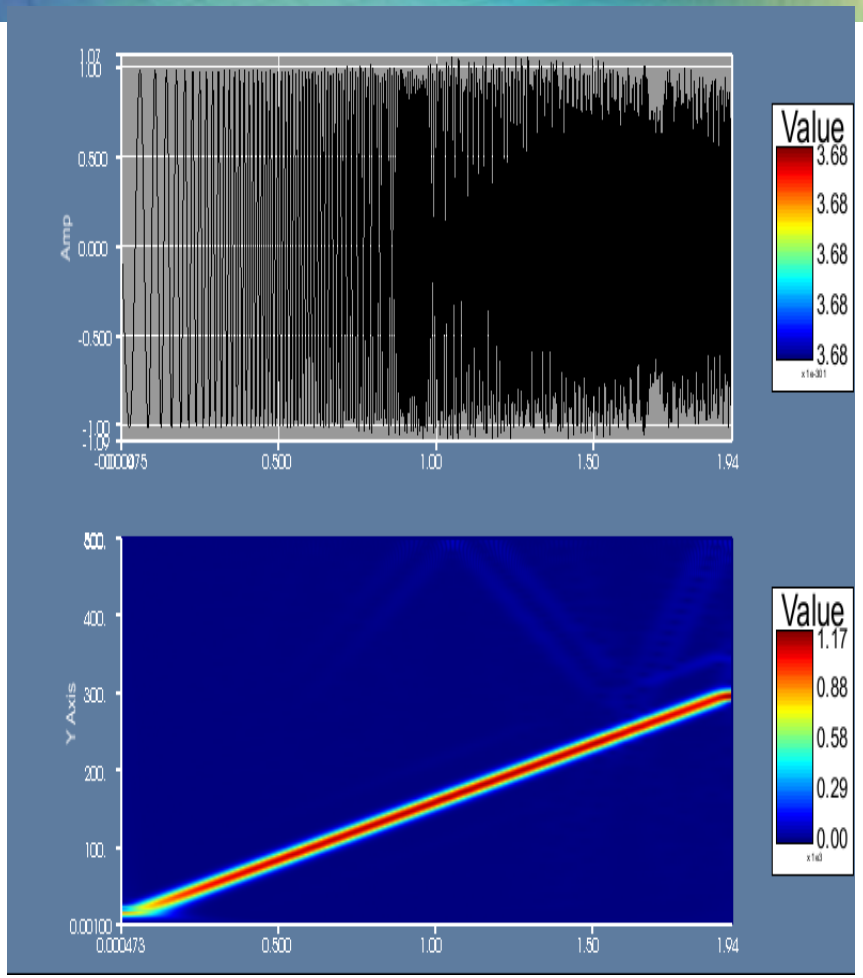
Morlet transform

- Morlet transform on a chirp signal.
- In catching the high frequency spectrum, mother wavelet of short duration of time is used. The spectrum of such wavelet suffers from wide span of frequency, resulting in low resolution, as shown in the right left plot.



Enhanced Morlet Transform

- By applying Gaussian windowing in frequency domain and knowing that the crossed term of convolution between mother wavelet and signal is the cause of blur, the resolution of Morlet transform can be greatly improved by neglecting the crossed term.
- The fine structure appears in high frequency region is caused by under sampling. The chirp signal is digitized with constant sampling rate.



Primary vs. Secondary frequency

Primary (主動頻率）

- Force vibration
- Normally with overtones or harmonics
- Frequency varies as driving frequency

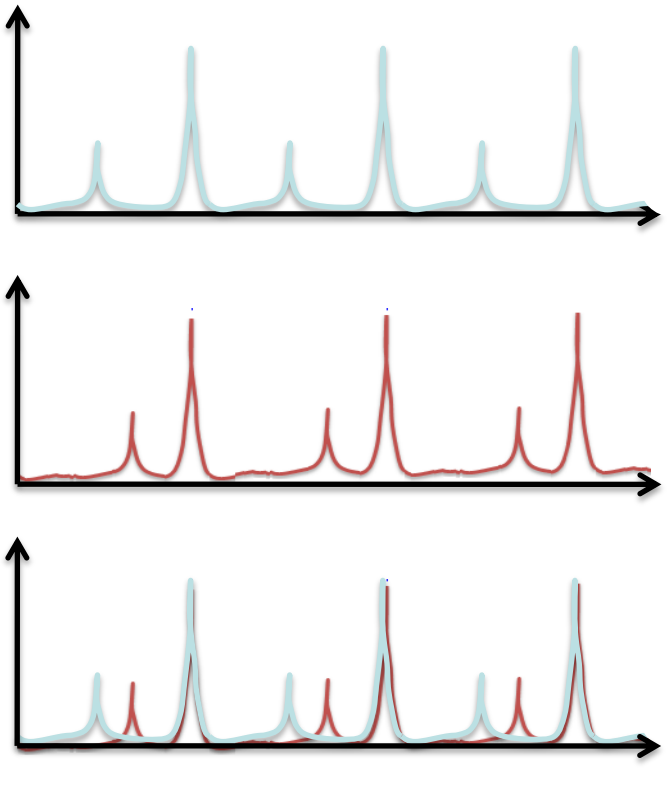
Secondary （被動頻率）

- Also known as Fundamental or Natural Frequency
- Induced by forced excitation
- Frequency remains the same with various speed of excitation.

Limitation of spectrum analysis

- Without time resolution, frequency changing with time cannot be revealed.
- Constant spindling velocity contains less system information.

Identification of frequency via spectrum analysis

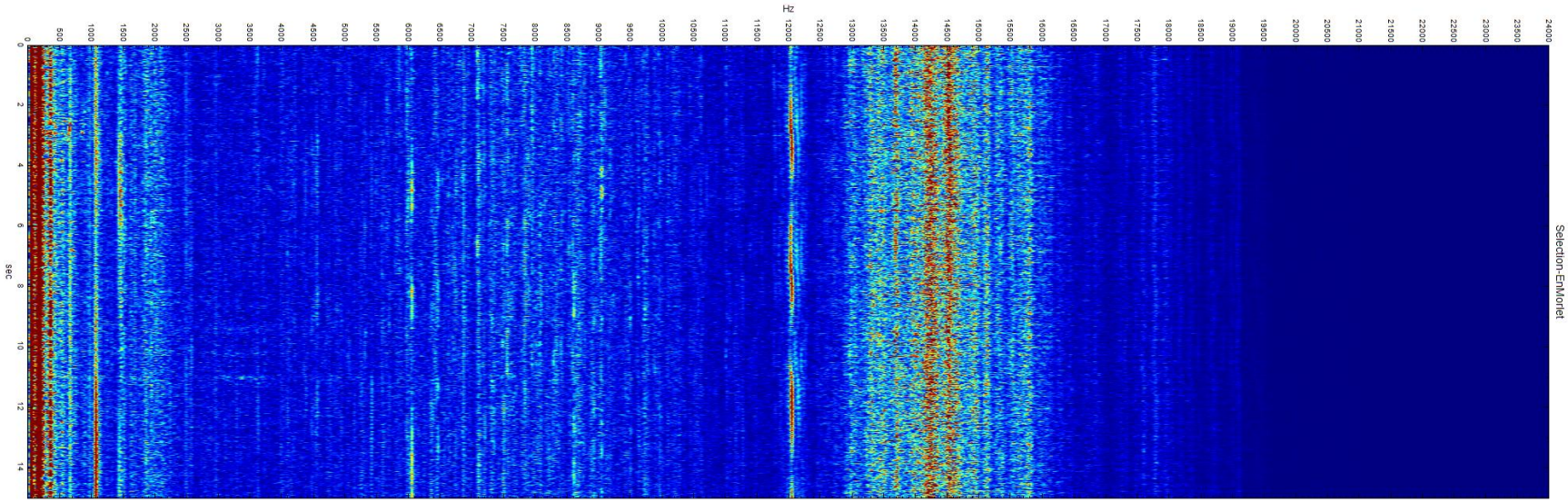


Rpm=10

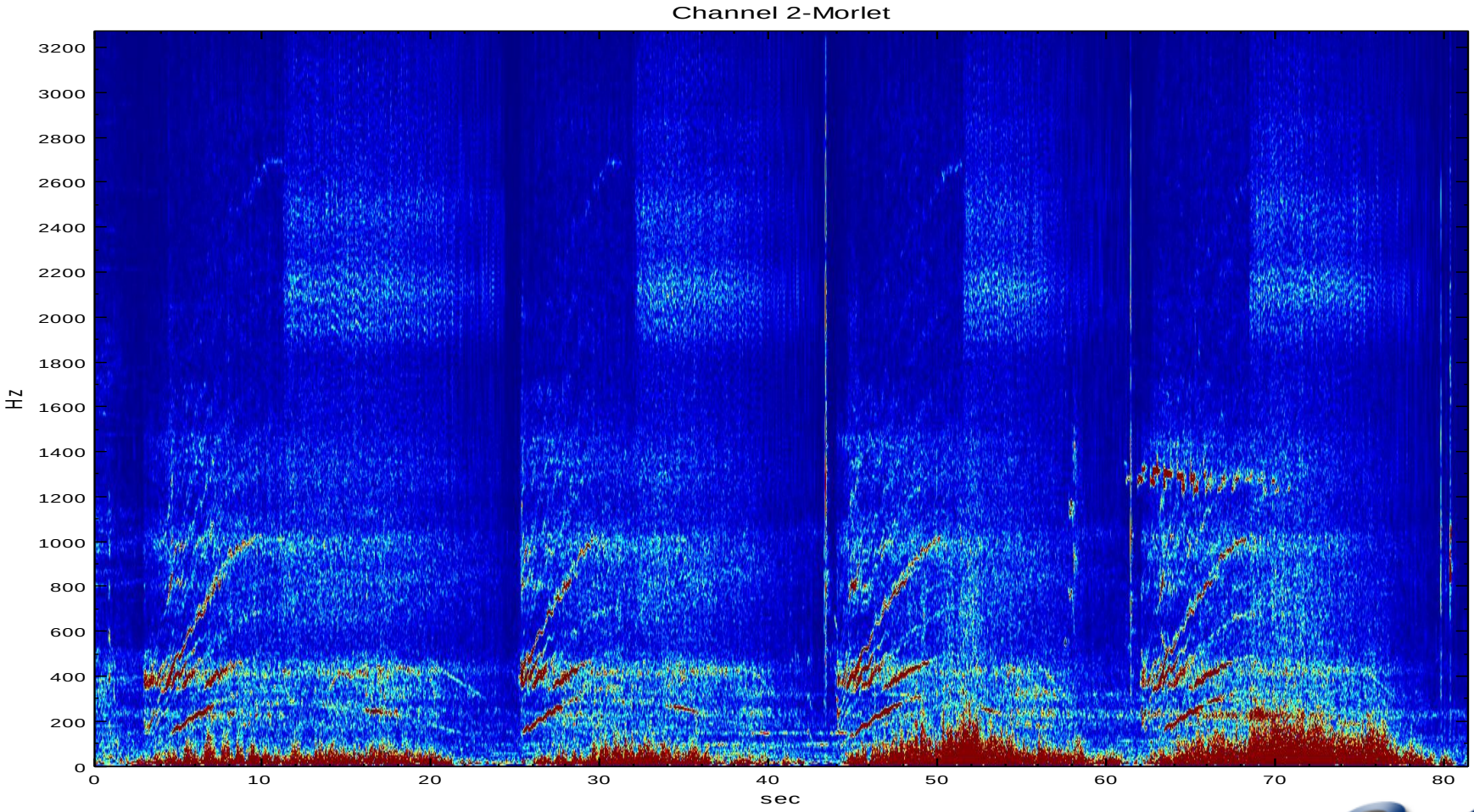
Rpm=15

Primary frequencies change with rmp, while secondary frequencies remain the same.

Rotational Motor



Primary and secondary frequency distinction



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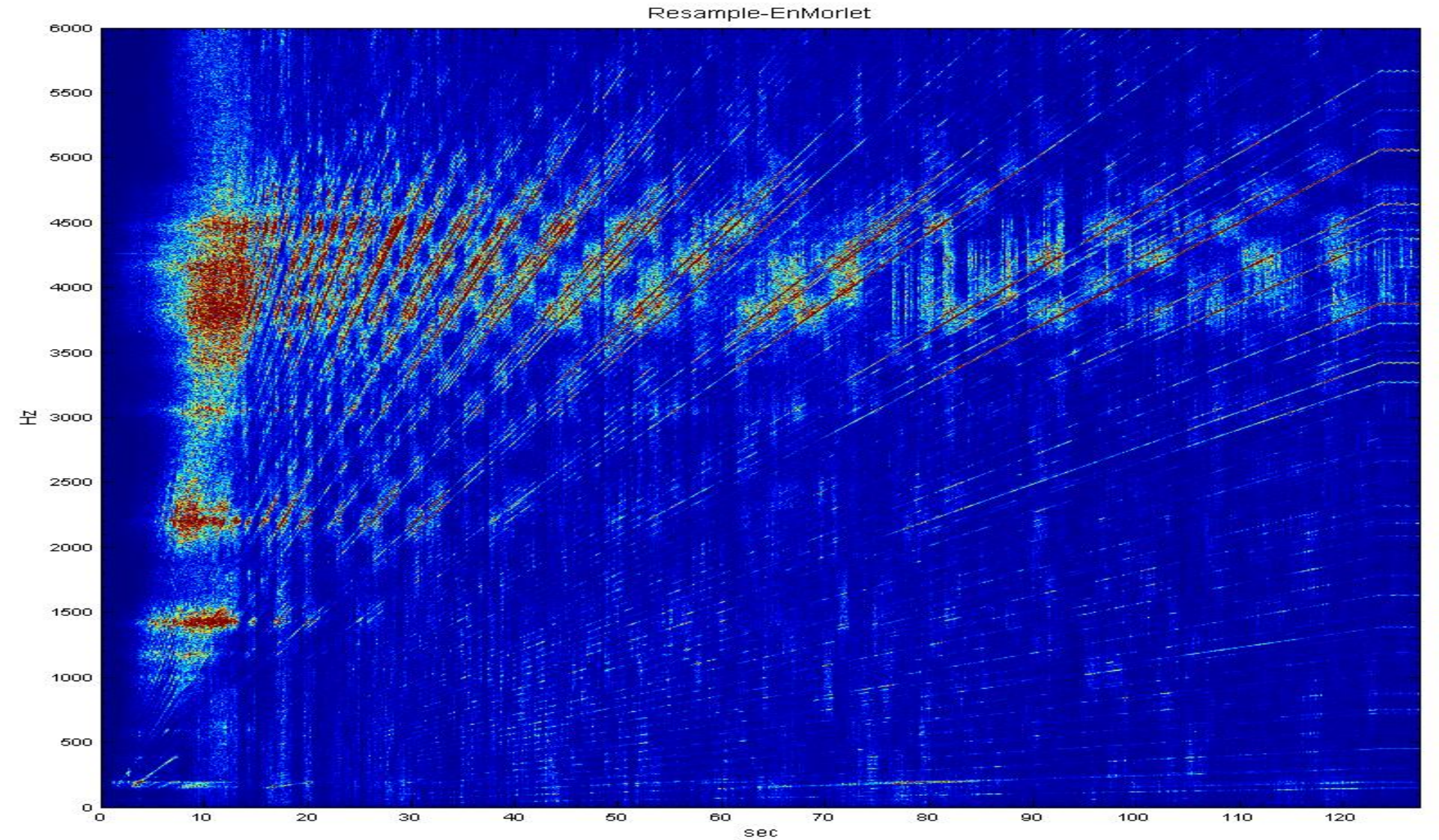
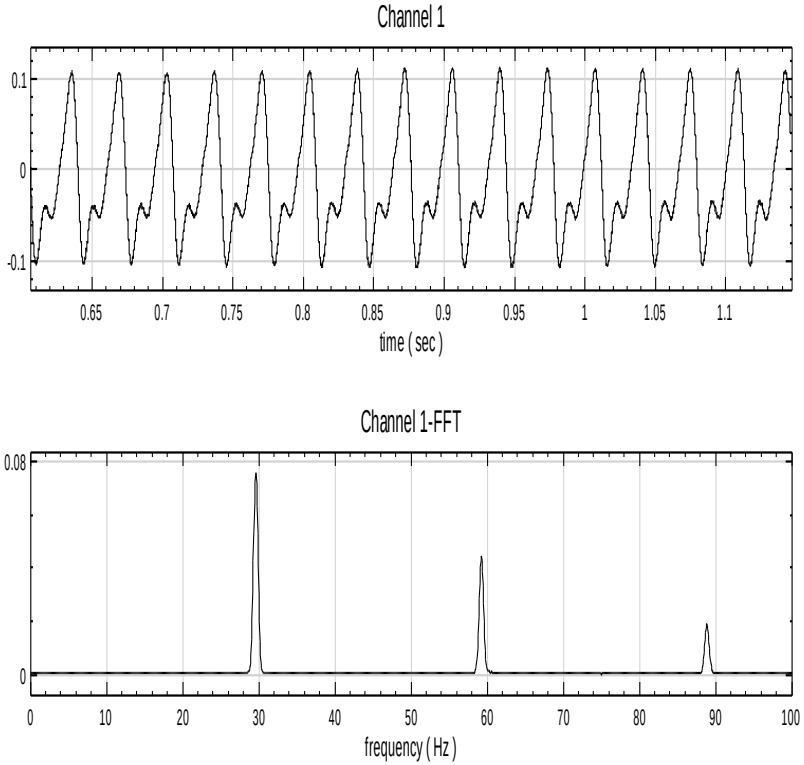
Bad

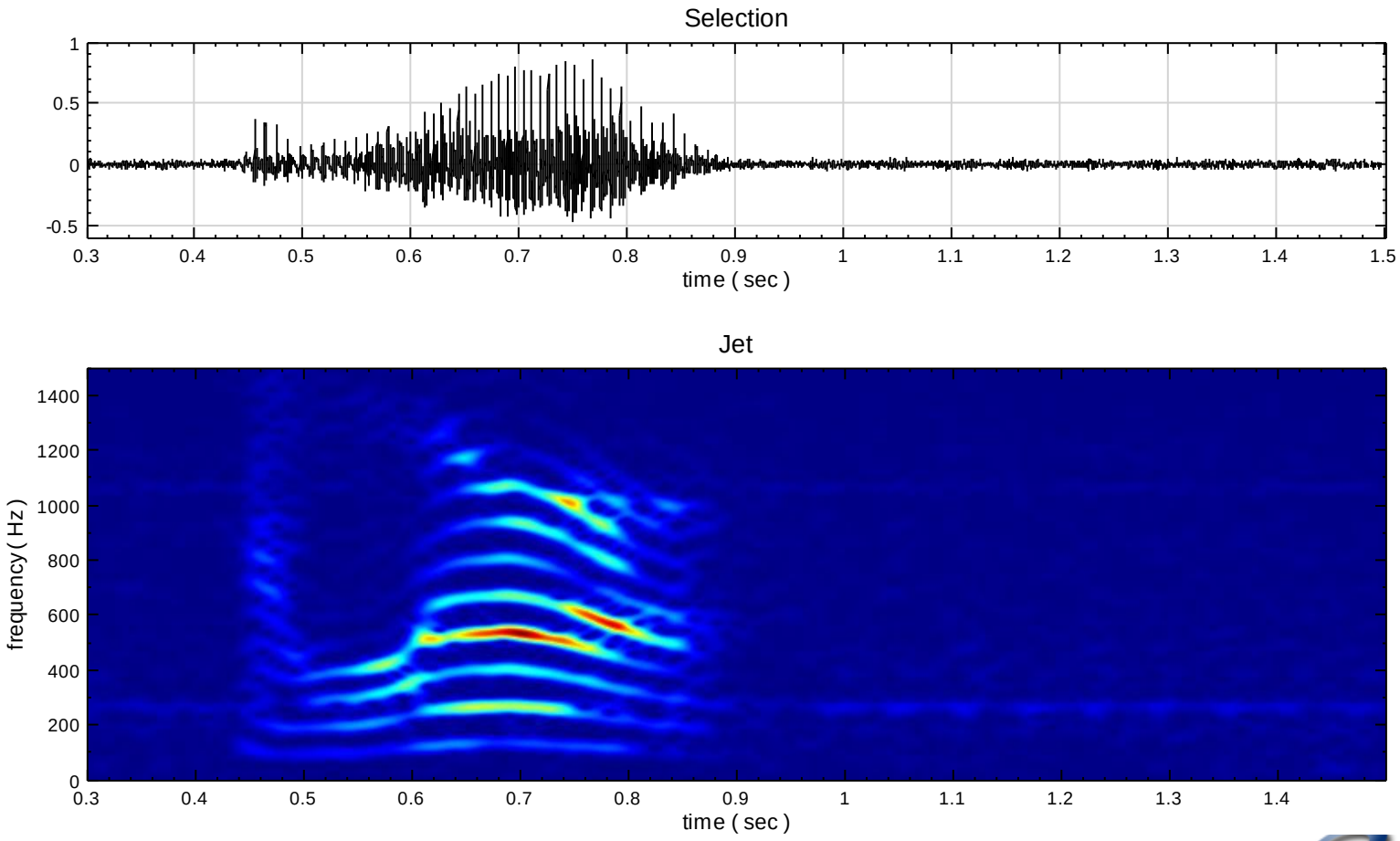

Resample-EnMorlet
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Hz
0
10
20
30
40
50
60
70
80
90
100
110
120
sec

Harmonic and Overtone

- Non-sinusoidal creates harmonics in spectrum domain.
- Overtone generally refers to high frequency peaks which is not exactly multiples of principle frequency. For example, drum beating.
- Both primary and secondary frequencies contain overtones.
- Primary excitation can only includes harmonics.



Example: “Hello”



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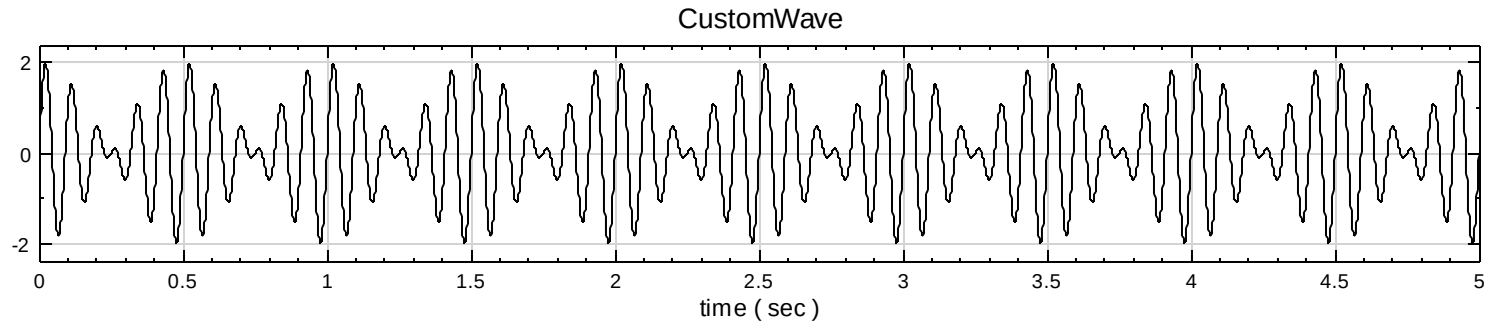
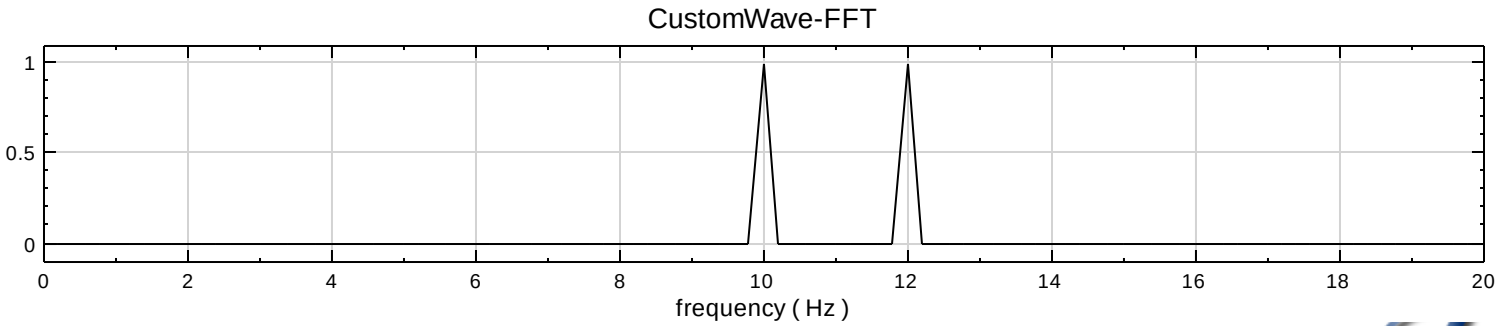
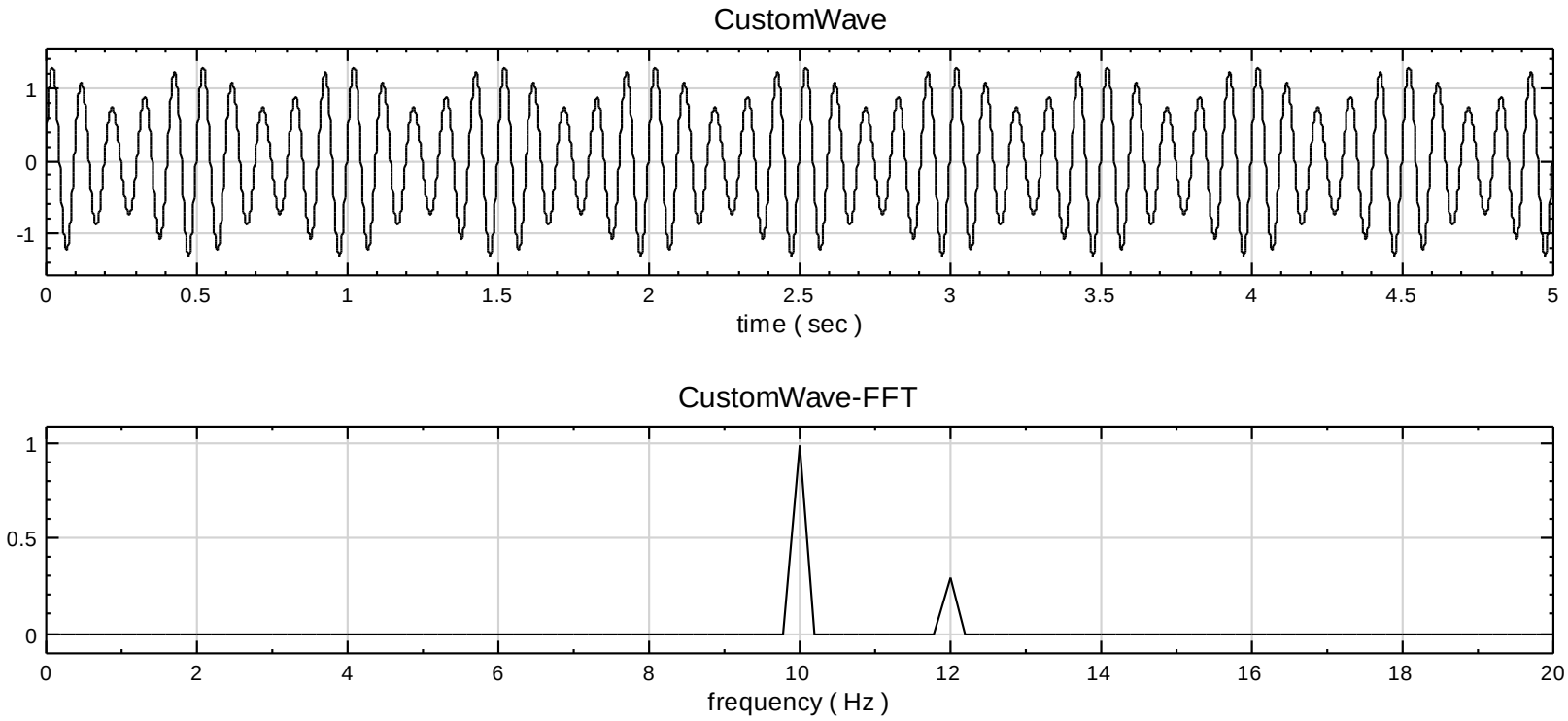
Beat wave

$$\cos(\omega t)+\cos((\omega+\delta\omega)t)\cong 2\cos(\omega t)\cos(\frac{\delta\omega}{2}t)$$





Amplitude modulation



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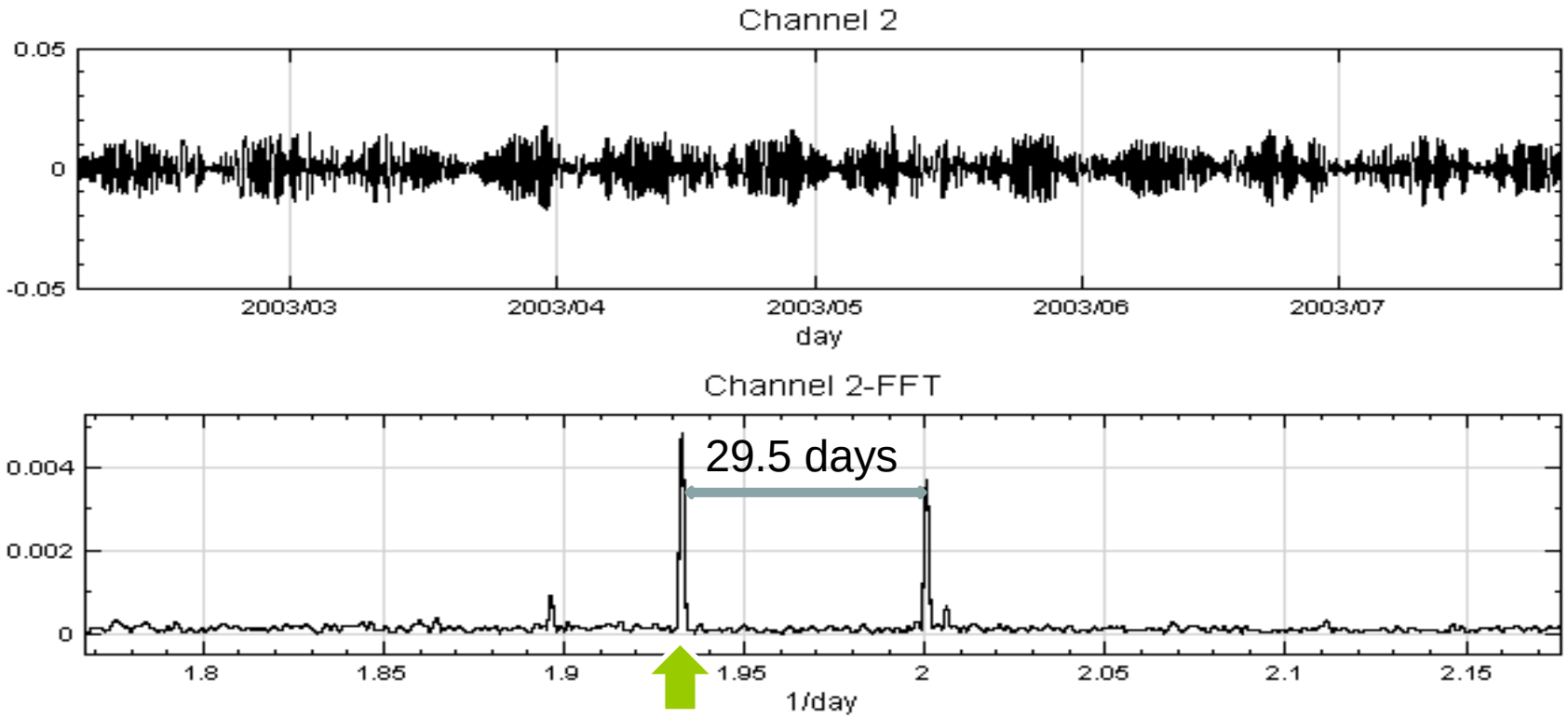
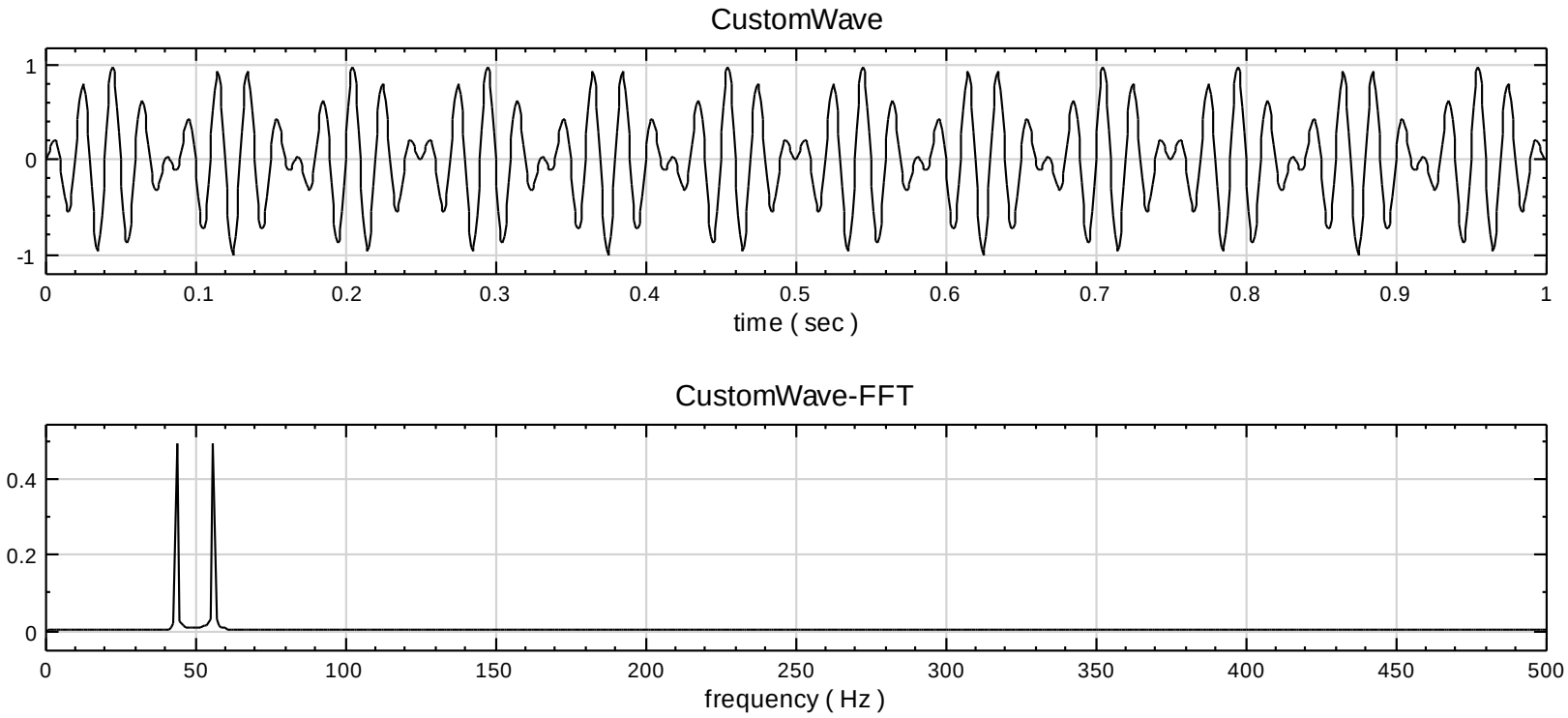
Semi-diurnal tide in ground water

Beat wave occurs twice per month.



1.9323

Single modulation



Sin(2*pi*50*t)*sin(2*pi*6*t)

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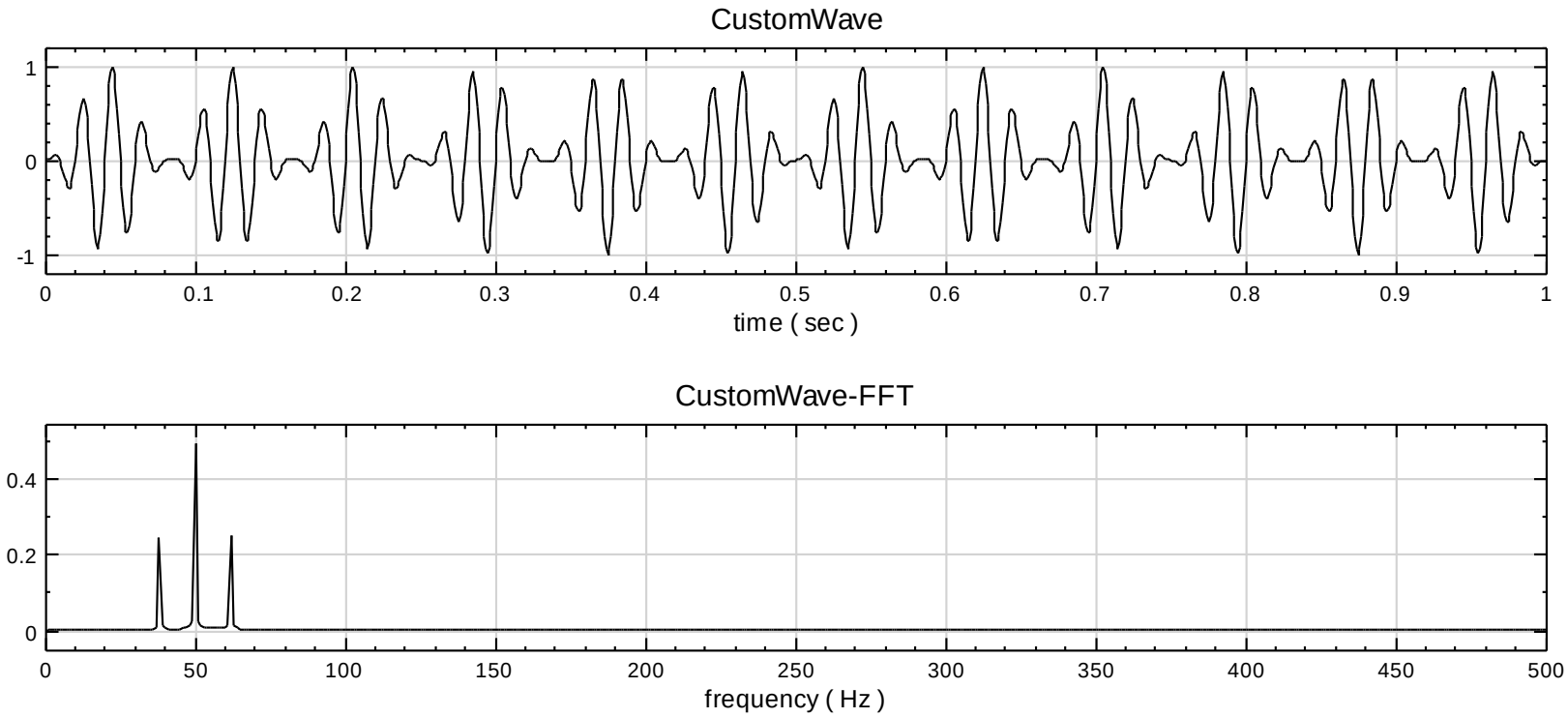
Double modulation



Sin(2*pi*50*t)*sin(2*pi*6*t)*sin(2*pi*6*t)

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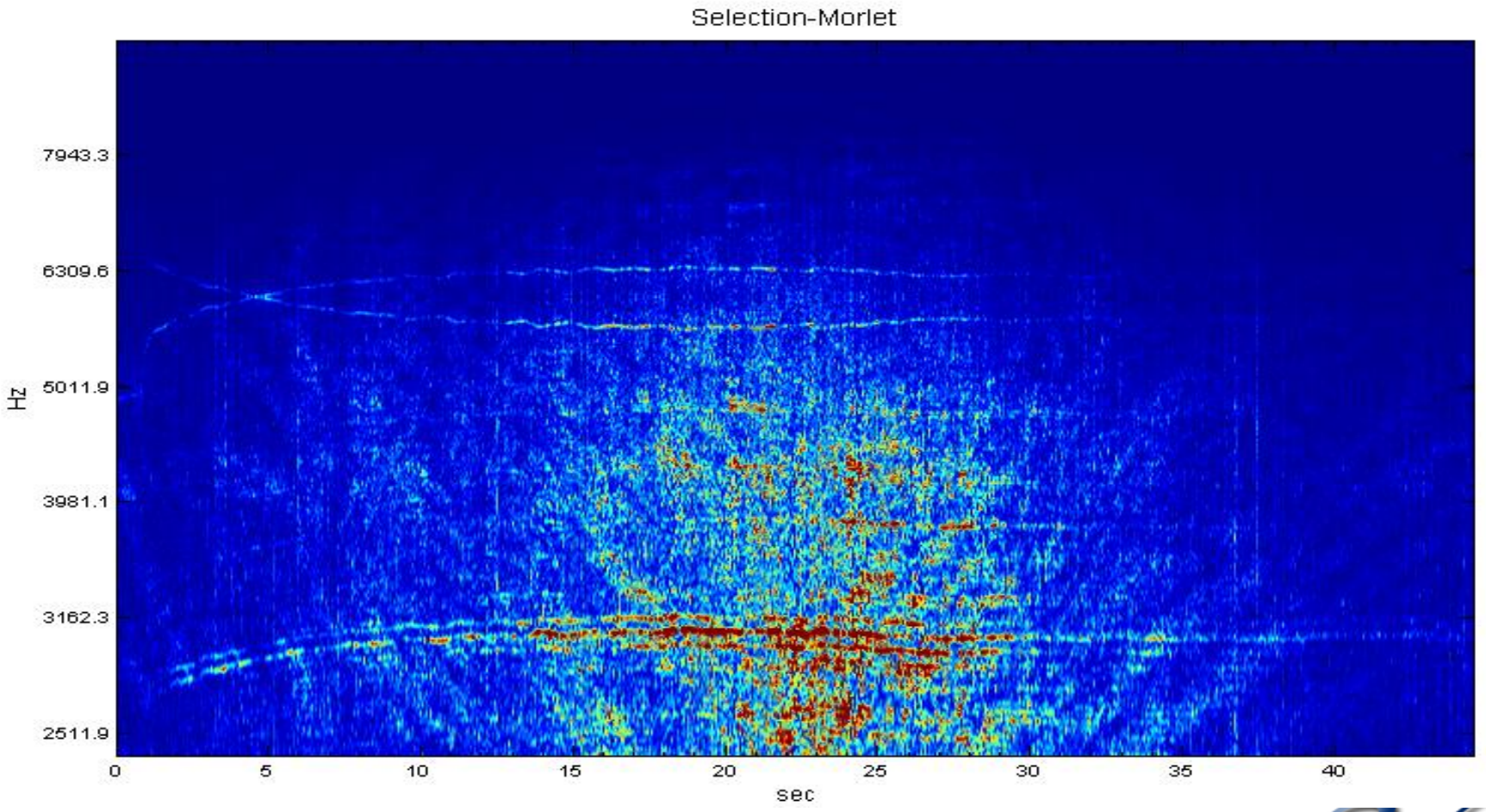
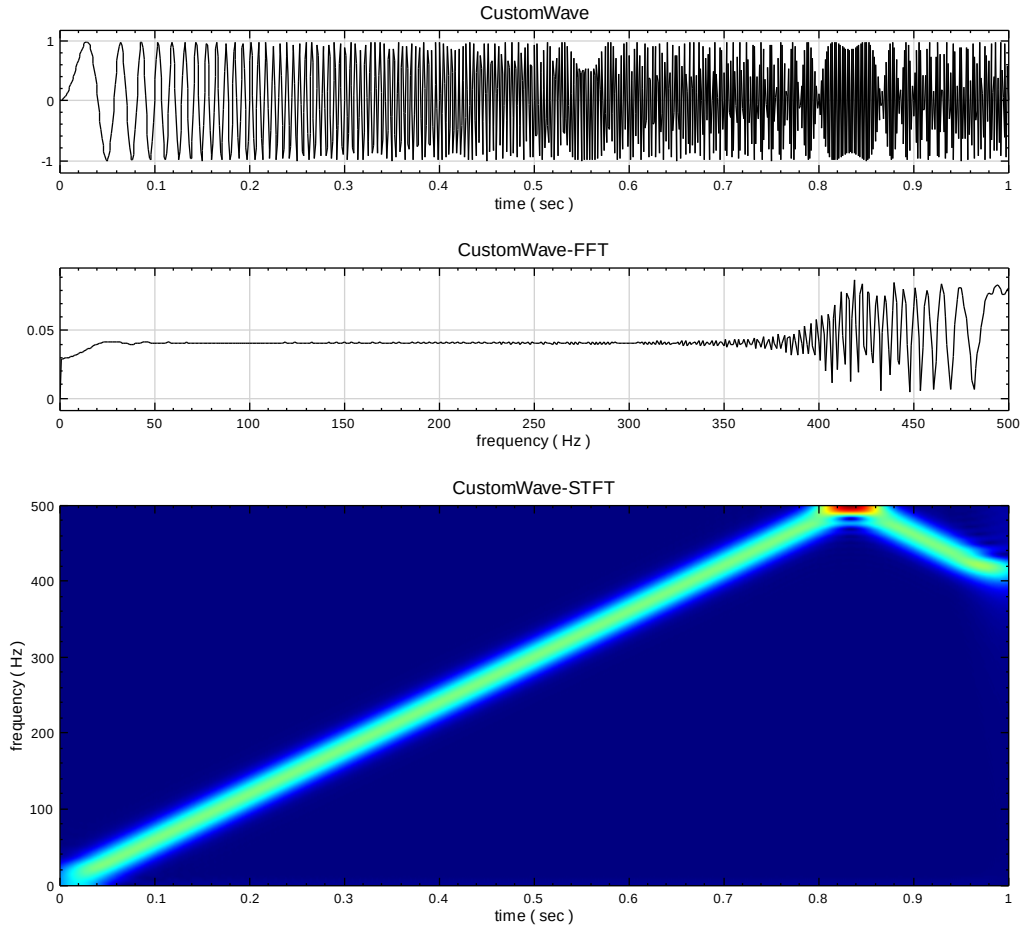
Underwater Acoustic



Aliasing



sin(2*pi*300*t*t)

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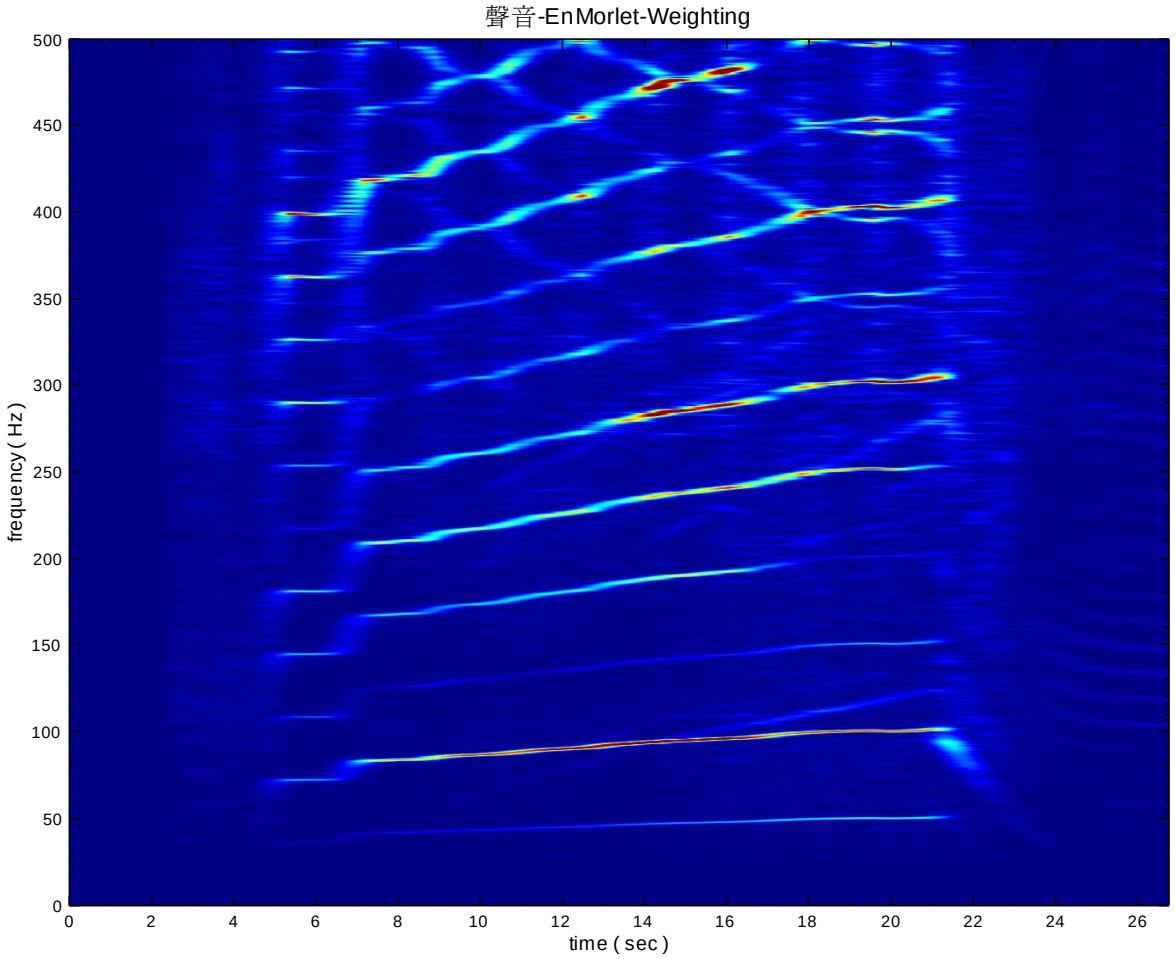
DAQ without anti-aliasing



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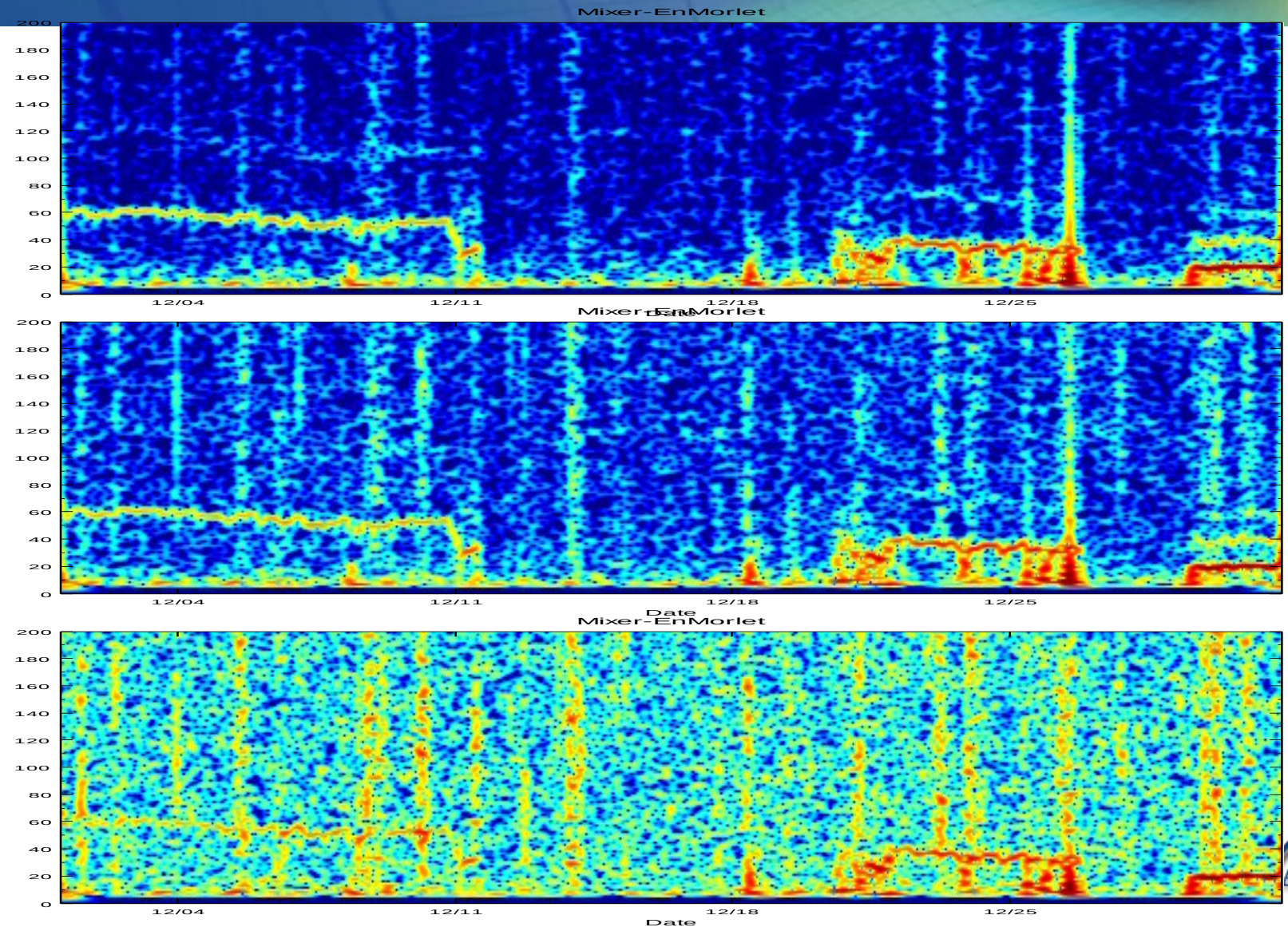
Aliasing with different sampling rate (2sec,10sec,100sec)



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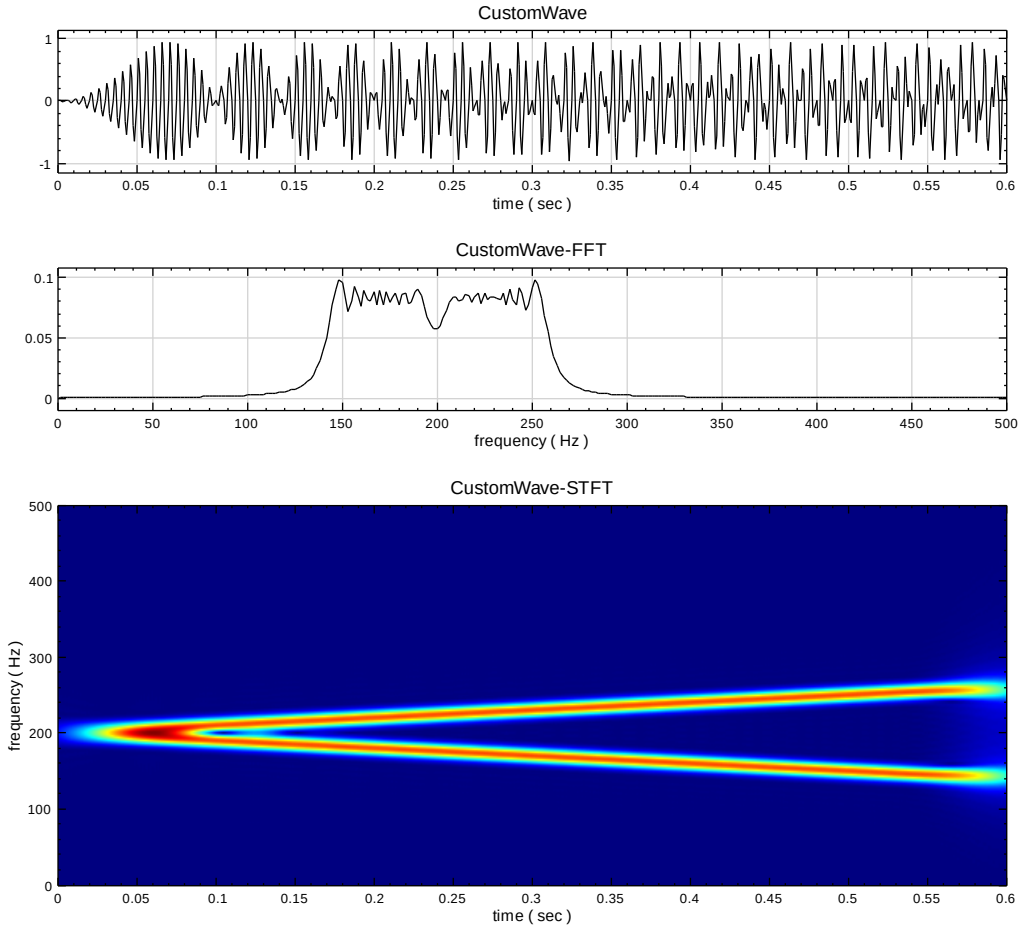
Single modulation



sin(2*pi*50*t*t)*sin(2*pi*200*t)

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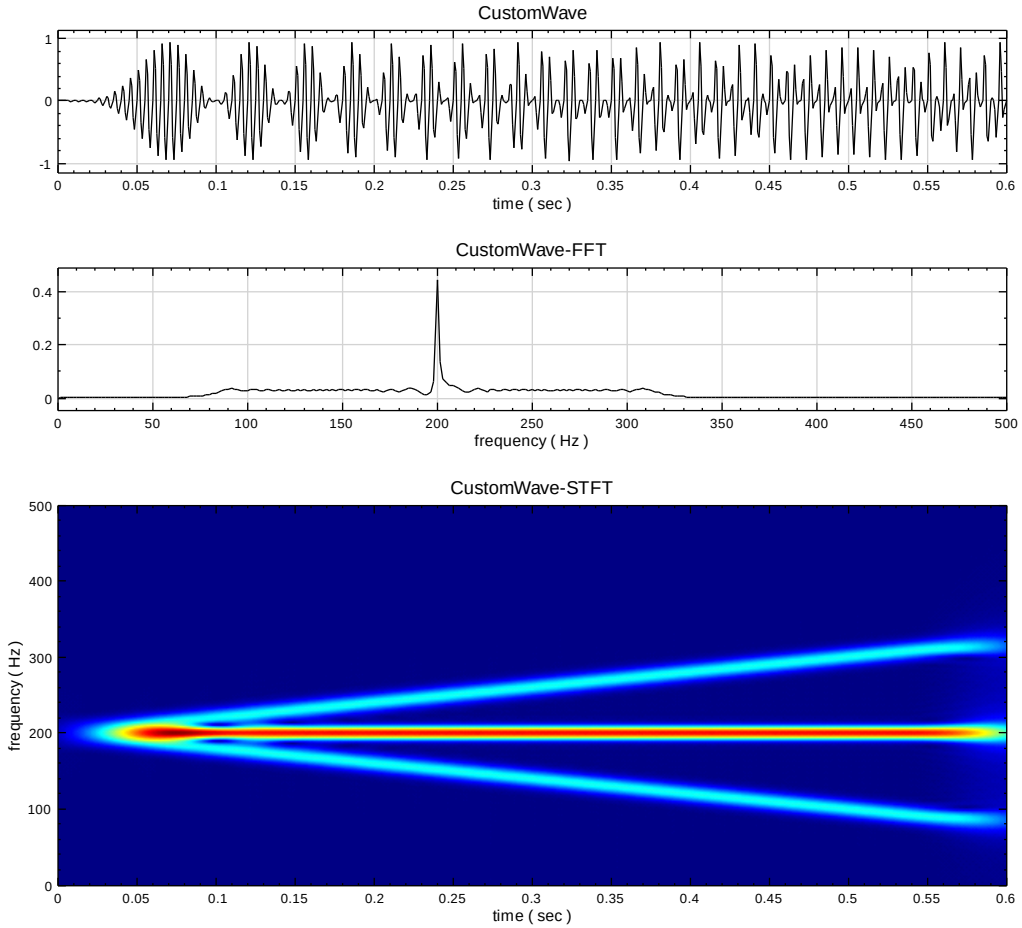
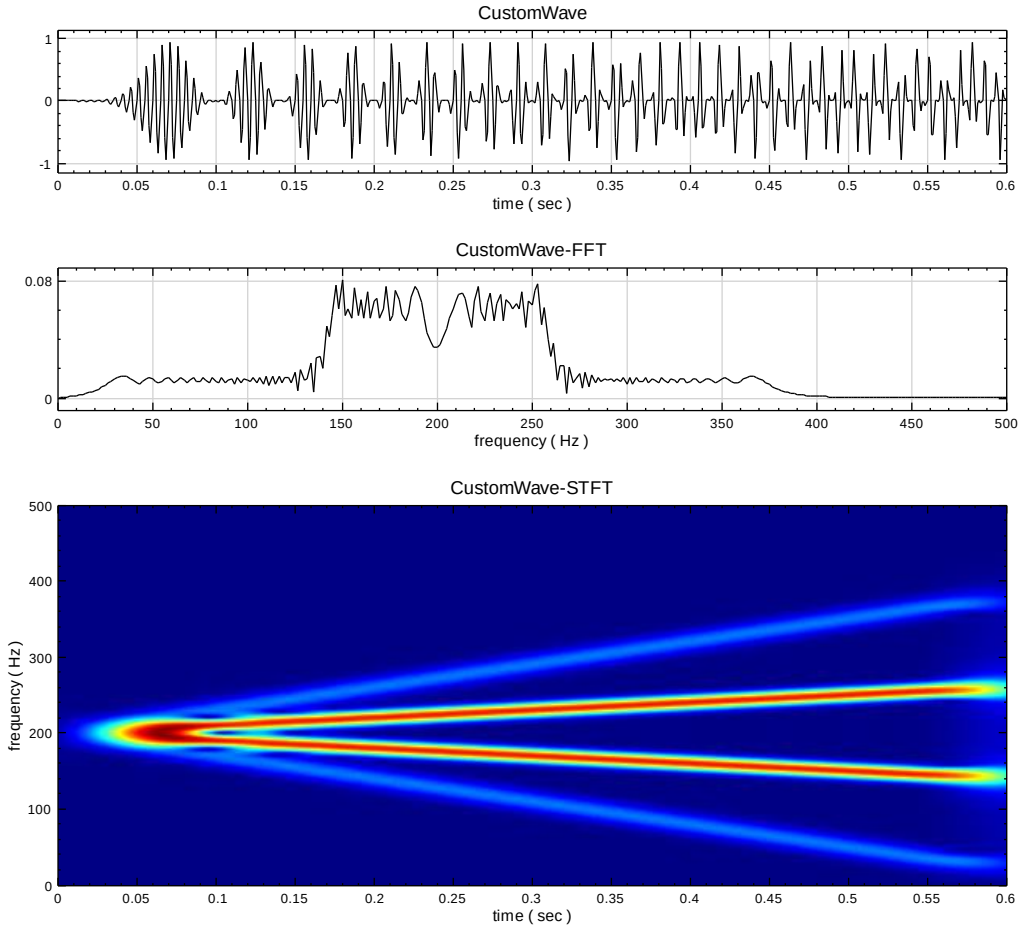
Double modulation



sin(2*pi*50*t*t)*sin(2*pi*50*t*t)*sin(2*pi*200*t)

Triple modulation



sin(2*pi*50*t*t)^3*sin(2*pi*200*t)

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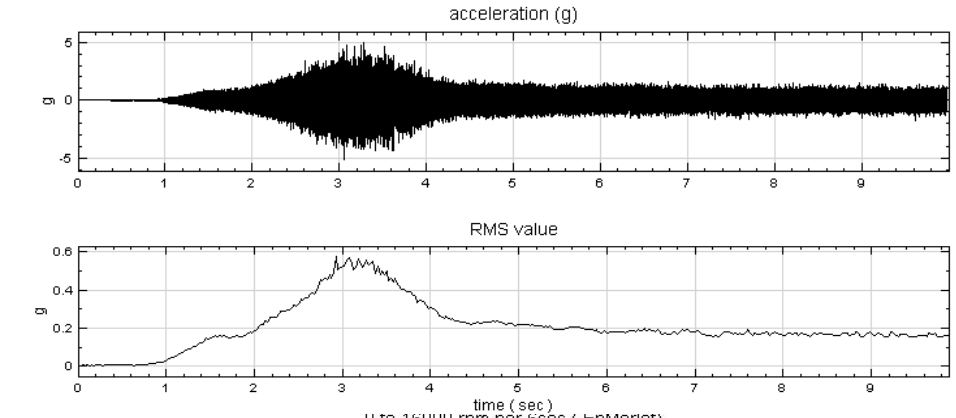
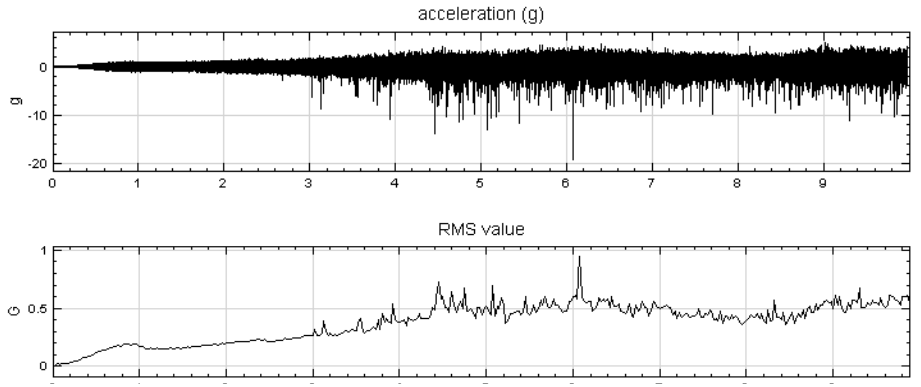
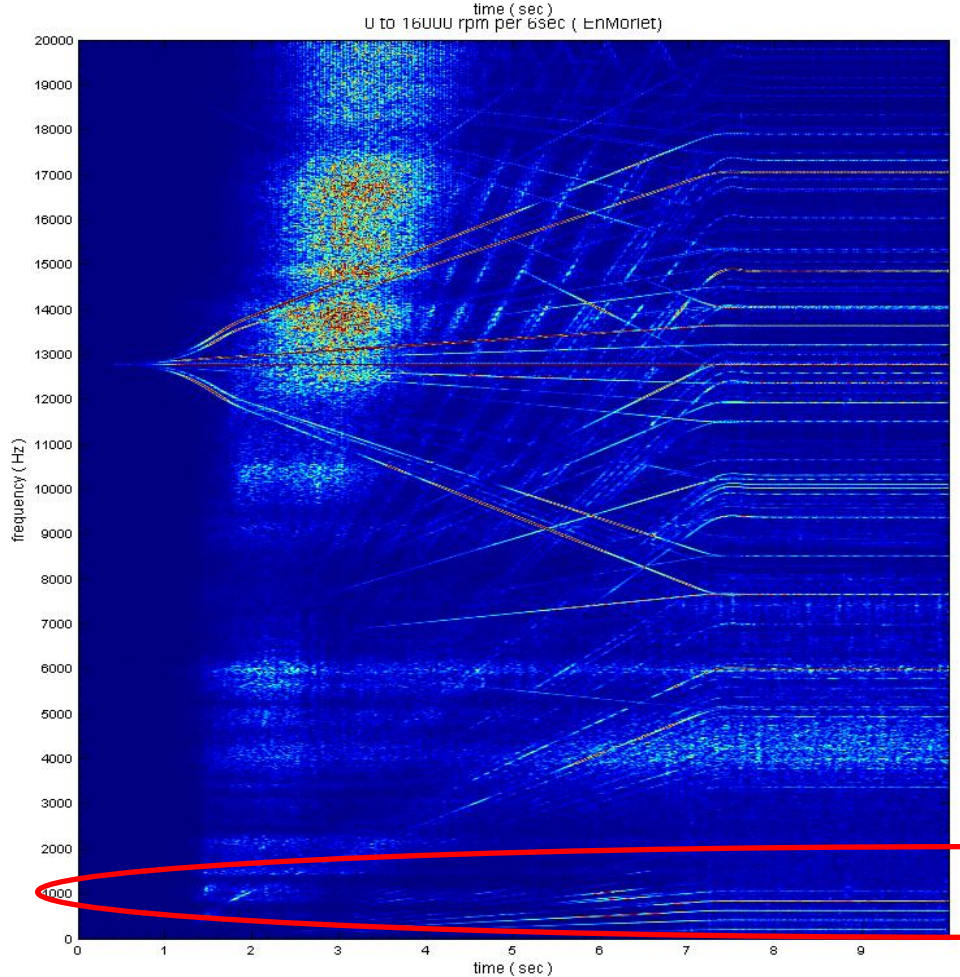
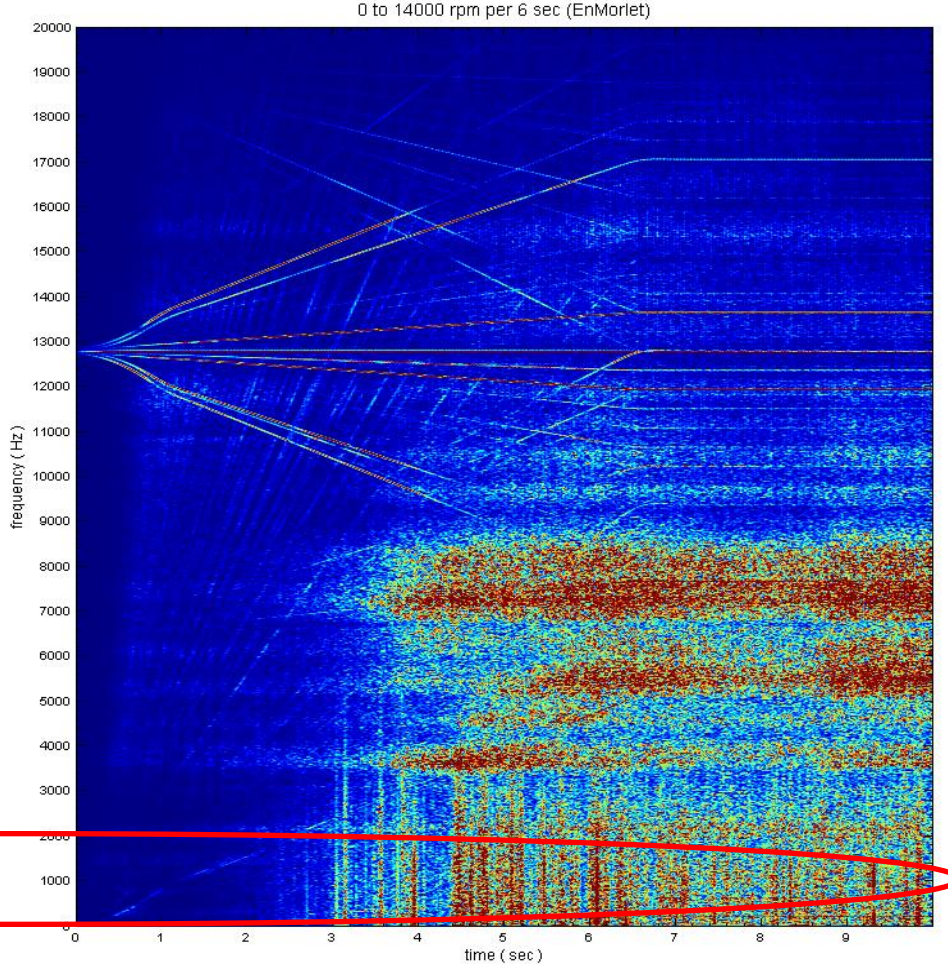
M3_14_a & b Acc 通過品質檢測 v.s. 未通過品質檢測









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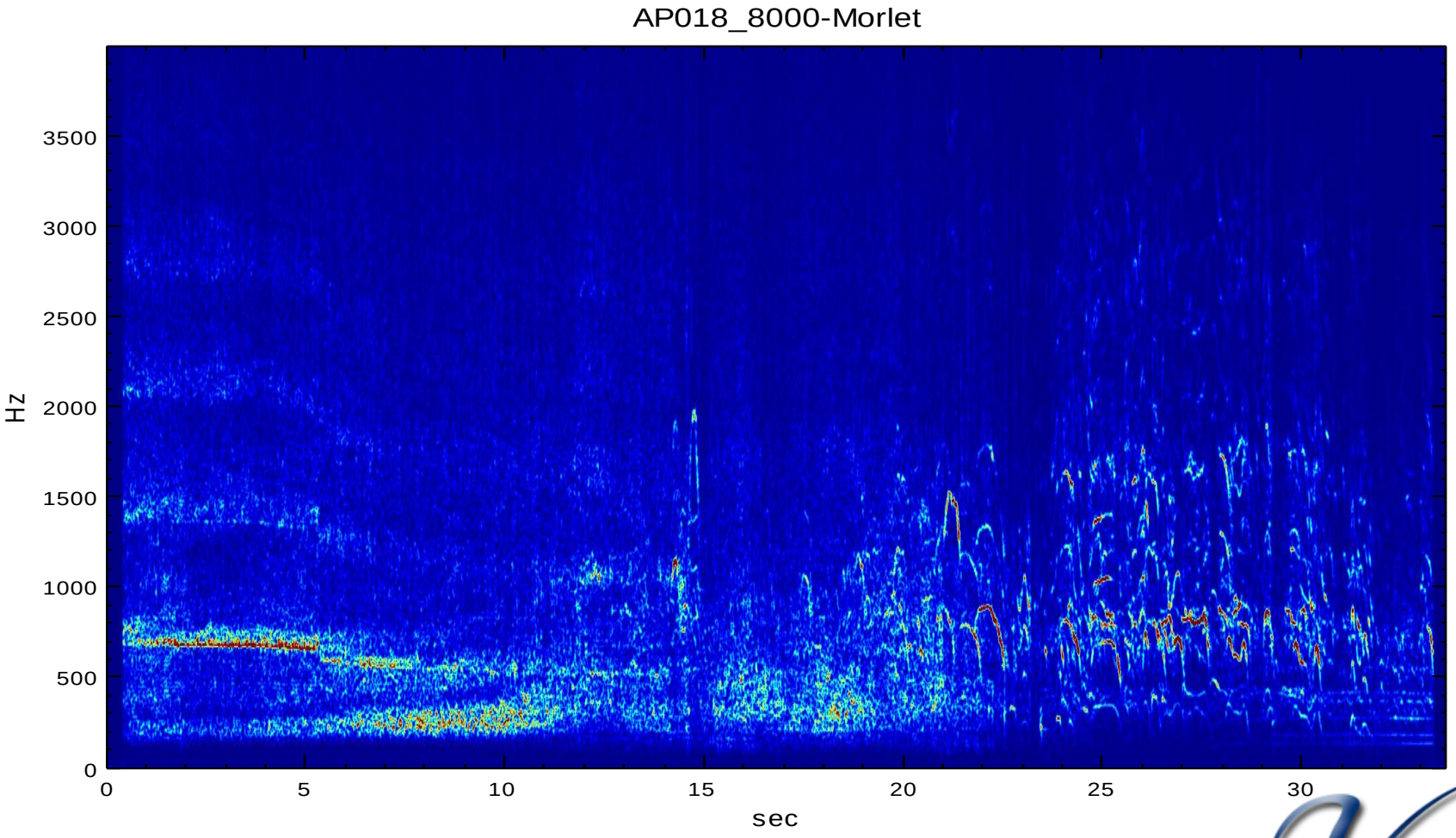

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Thank you!