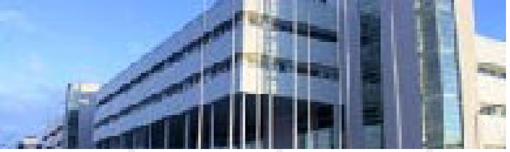

Postgraduate Seminar

Frequency Response based Wavelet Decomposition

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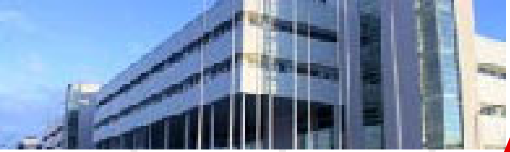

Acknowledgement

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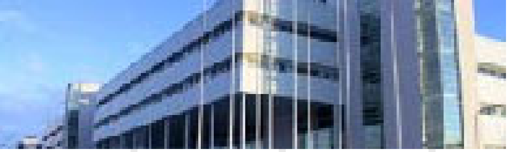
  - Professor Amir Averbuch



Contents

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- Why is wavelet chosen?
- How to detemine the number of levels for the wavelet decomposition?
- How to determine certain levels for the reconstruction of the desired signal?
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  - Frequency responses based method
- Real brain signal analysis
- Wavelet packet decomposition

Information about dissertation-1/2

- Topic of the PhD thesis
  - Study of mismatch negativity through exploiting timing, spectral, time-frequency representation, and spatial information
  - (Mismatch negativity--MMN is the event-related potential—special electrical brain signal)
- Format (collection of papers or monograph)
  - Collection of papers
- Supervisor(s)
  - Professor Tapani Ristaniemi, Dept. M.I.T.
  - Professor Heikki Lyytinen, Dept. Psychology
- Status of the thesis and the expected finishing time
  - Writing the dissertation
  - In this summer

Information about dissertation-2/2

- Background
  - Biomedical engineering
- Main scientific contribution of the PhD thesis as well as results expected to be obtained
  - Extract MMN with better properties
- Applicability of the results to be obtained
  - Reduce the recording time for the clinical research in the event-related potential—special electrical brain signal.
- which part of the thesis is the talk related to
  - Timing and spectral information

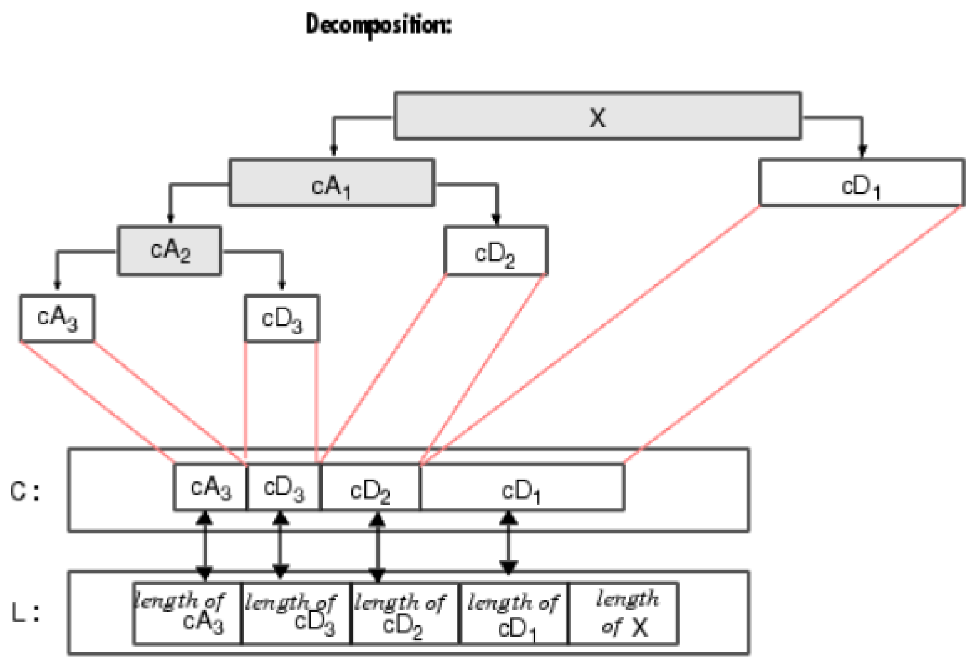
Why is wavelet studied?

- Nowdays, a digital filter is greatly extensively used in many disciplines. But it has two drawbacks:
  - Conventional digital filter works under the assumption that the signal is stationary, however, it is not in practice.
  - The output of such a filter is the reconstruction of certain frequency components of the input. As a result, if the desired signal is overlapped with other interference in the frequency domain, the digital filter could not separate them.
- These motivate us to study the signal through wavelet decomposition (WLD).
  - WLD has been applied in the various disciplines to extract the desired signal.
  - The wavelet represents functions that have discontinuities and sharp peaks, and for accurately deconstructing and reconstructing finite, non-periodic and non-stationary signals.

Wavelet Decomposition Procedure

- Usually, three steps consist of WLD:
  - 1) decompose the raw signal into some levels;
  - 2) choose certain levels for the reconstruction of the desired signal;
  - 3) the reconstruct the desired signal with the selected levels.

Paradigm for Wavelet Decomposition in MATLAB



Step1: How to choose levels for decomposition?

In WLD, an optimal decomposition with L levels is allowed under the condition that

$$N = 2^{L},$$

where, N is the length of the decomposed signal (Tikkanen and Sellin, 1997). In our study, the recordings had 130 samples (Kalyakin et al., 2007), thus, the signal could be decomposed into seven levels, i.e., $L = 7$.

During the signal decomposition by a wavelet, at each level the signal is indeed divided into different frequency bands. The bandwidth at different levels in WLD can be roughly defined through two to the power of corresponding frequency levels (Wang et al., 2009). For example, if the sampling frequency is F Hz, the relationship between all number of levels L and F could be

$$B = F / 2^{L+1}.$$

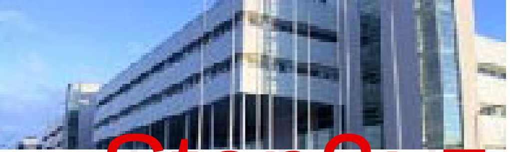
Step1: Bandwidth of seven levels under 200Hz sampling frequency

Levels	Bandwidth (Hz)	
D7	$2^{0.6439}$	0.78
D6	$2^{1.6439}$	1.56
D5	$2^{2.6439}$	3.13
D4	$2^{3.6439}$	6.25
D3	$2^{4.6439}$	12.5
D2	$2^{5.6439}$	25
D1	$2^{6.6439}$	50

Step2: Conventional methods

- The most used methods for this step could be categorized into two groups:
  - 1) calculate the correlation among the selected wavelet coefficients and the assumed desired signal (Burger et al., 2007);
  - 2) calculate the frequency band of each levels of the signal (Wang et al. 2009; Vision Analyzer).

- Comments:
  - If the desired signal was known, the first procedure could be very good. However, this assumption is too strong in practice;
  - the second method is according to the criterion mentioned in the previous slides— the bandwidth at different levels in WLD can be roughly defined through the sampling frequency and two to the power of corresponding frequency levels. This method does not take into account of the information of the wavelet. In fact, to different wavelets, the frequency bands under the same level could be different.



Step2: Frequency responses based method

- WLD can be regarded as a special digital filter too. So, the new methodology is based on the frequency responses of a digital filter.
- We investigate the frequency responses of each level for every wavelet, and choose the one matching the spectral features of the desired signal.
- The assumption is that the spectral features are roughly known.

Step2: Frequency responses of a digital filter

- When the input is the unit impulse, the output of the filter is the unit impulse response.
- After the Fourier transformation is performed on the unit impulse response, the frequency responses of the system can be obtained from the magnitude of the Fourier-transformed responses.

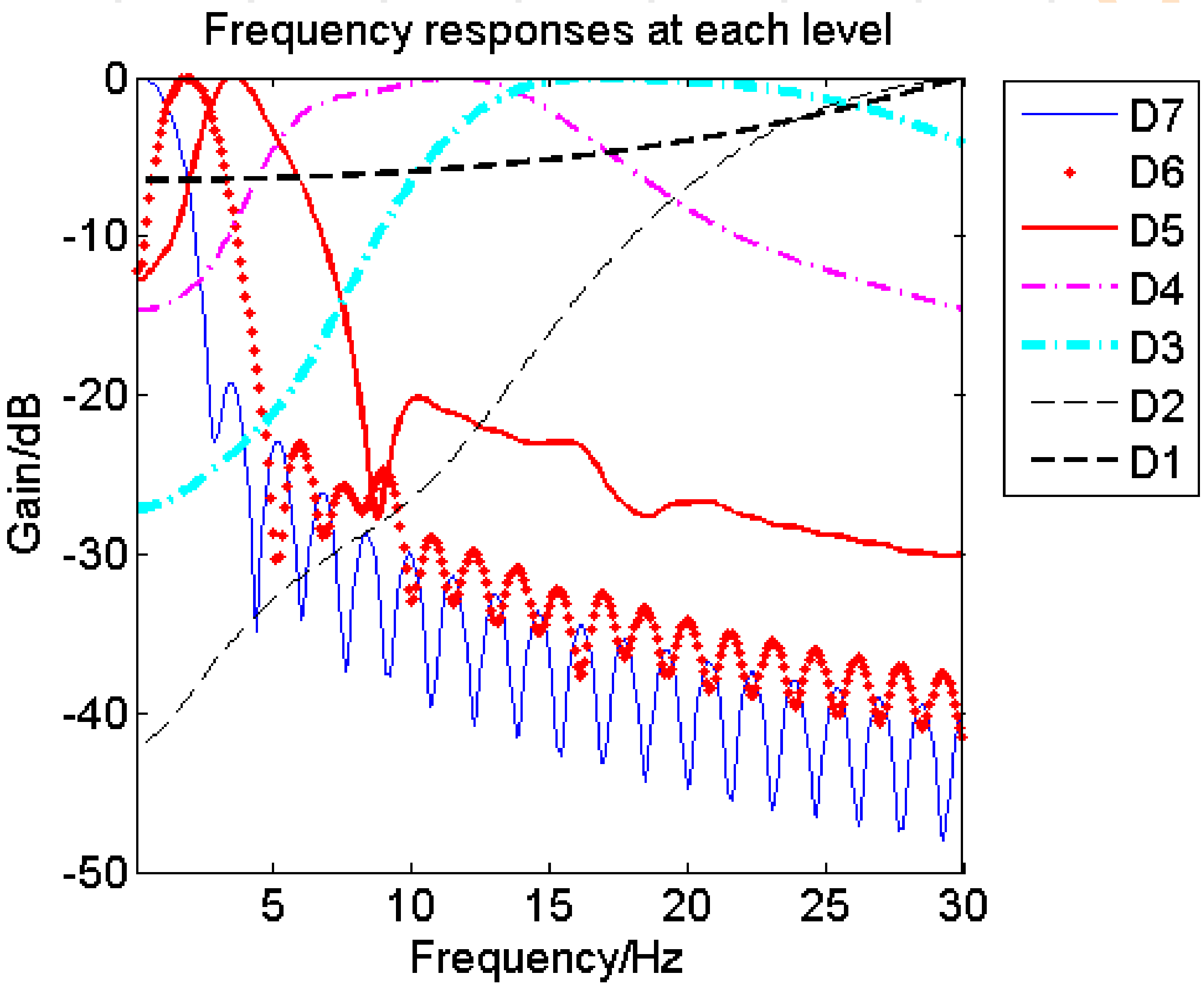
Step2: Frequency responses based method-four steps

- The new methodology composes four steps:
  - 1) the unit impulse is decomposed into levels;
  - 2) each level is used for the reconstruction;
  - 3) calculate the Fourier transformation of the reconstructed signal to obtain the frequency responses at each level;
  - 4) select the proper levels for the reconstruction of the desired signal.

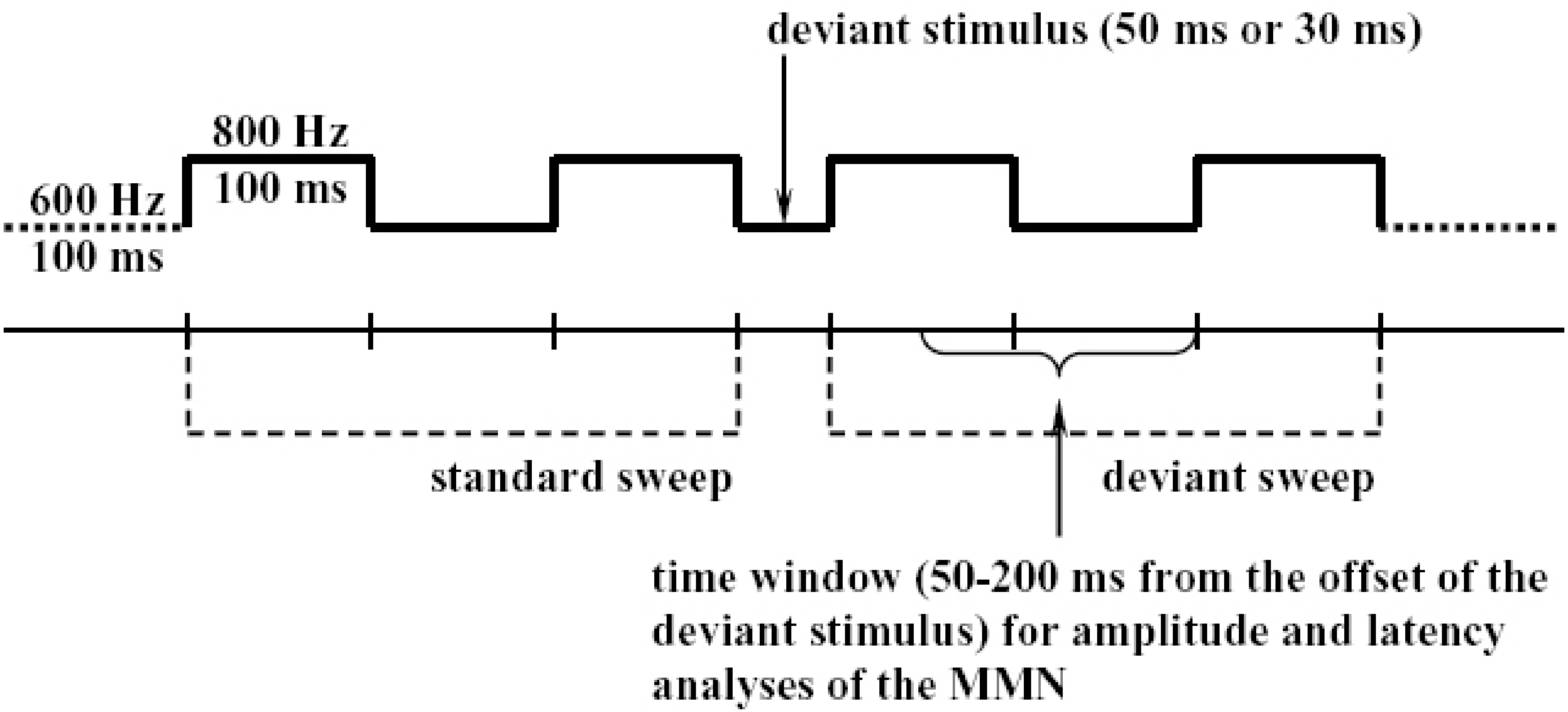
Step2: Frequency responses based method-four steps

- Decompose unit impluse with a number of levels;
- Reconstruct unit impulse with the coefficients at each level to obtain the response of the unit impulse under such a filter;
- Perform Fourier-transformation on the response of the unit impulse to convert it into frequency domain;
- Calculate the magnitude of the Fourier-transform responses to gain the frequecy responses of such a filter.

Step2: Frequency responses at each level

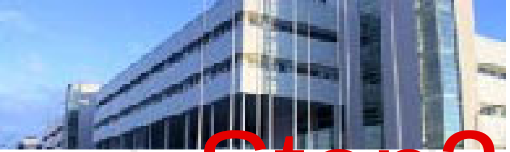


Step2: real brain signal generation —mismatch negativity(MMN)



Step2: Frequency range of MMN

- Choosing the proper levels for the signal reconstruction should be based on its frequency range.
- Kalyakin et al. (2007) made deep analysis on the cutting off frequency for the MMN frequency band, and they concluded that the optimal frequency band of MMN of children was 2-8.5Hz;
- Stefanics G. et al. (2007, 2009) adopted the 2.5-16Hz and 1.5-16Hz to achieve MMN of neonates respectively;
- for visual inspection of MMN, Sinkkonen and Tervaniemi (2000) recommended a 1-20Hz band;
- Picton et al. (2000) considered that the most of MMN's energy lied in the 2-5 Hz frequency range;
- Tervaniemi et al. (1999) had ever used 2-10Hz band pass digital filter for subsequently analyzing MMN peak amplitude and latency;
- Sabri and Campbell (2002) set the band of MMN as 3-12Hz.



Step2: Rough Level selection

- Thus, D6 and D5 are chosen for the reconstruction

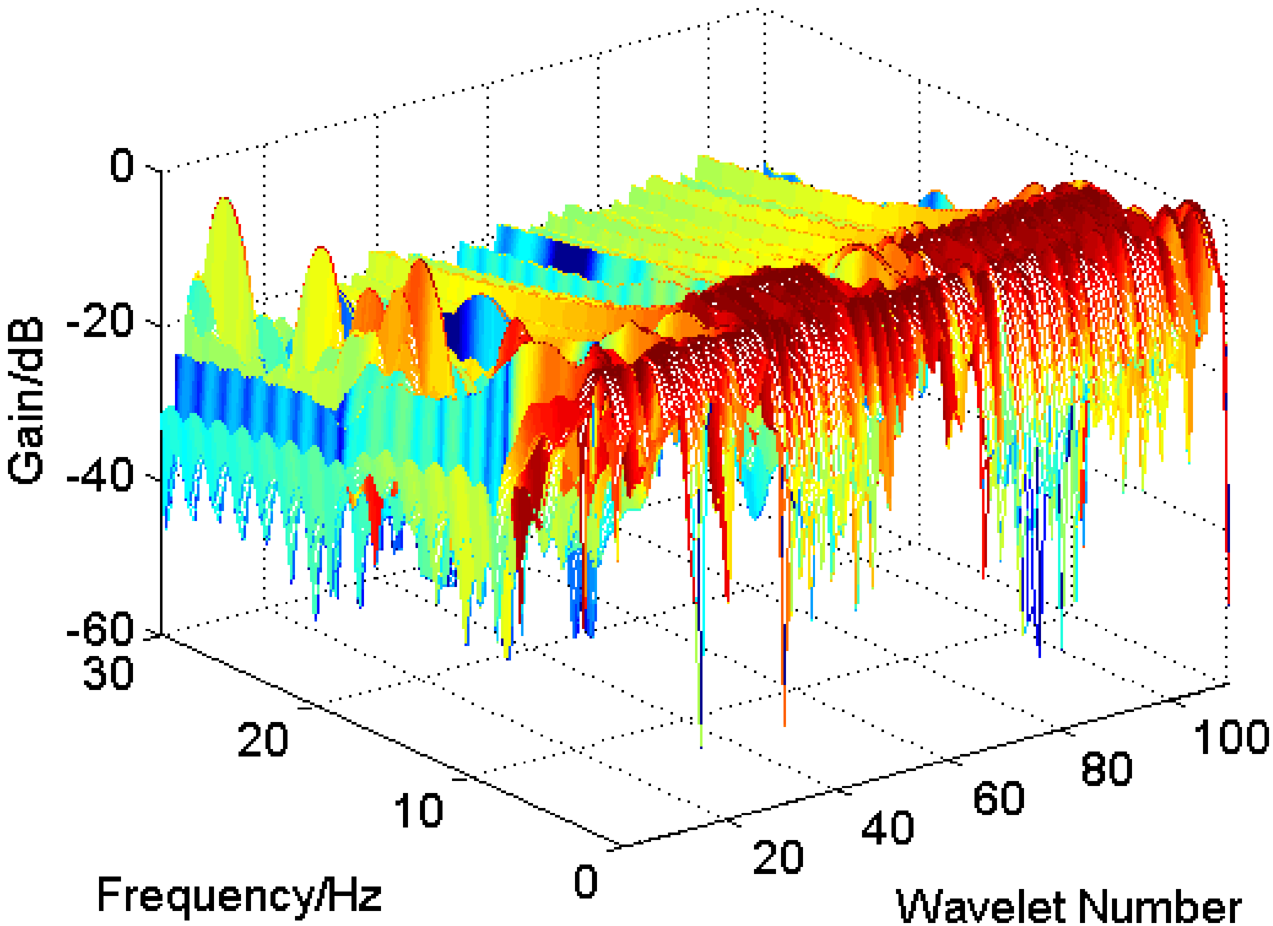
Step2: Types of Wavelets for decomposition

- Daubechies: ‘db1’ or ‘haar’, ‘db2’, ... ,’db45’;
- Coiflets: ‘coif1’, ... , ‘coif5’;
- Symlets: ‘sym2’, ... , ‘sym8’, ... ,’sym45’;
- Discrete Meyer wavelet: ‘dmey’;
- Biorthogonal: ‘bior1.1’, ‘bior1.3’, ‘bior1.5’, ‘bior2.2’, ‘bior2.4’, ‘bior2.6’, ‘bior2.8’, ‘bior3.1’, ‘bior3.3’, ‘bior3.5’, ‘bior3.7’, ‘bior3.9’, ‘bior4.4’, ‘bior5.5’, ‘bior6.8’;
- Reverse Biorthogonal: ‘rbio1.1’, ‘rbio1.3’, ‘rbio1.5’, ‘rbio2.2’, ‘rbio2.4’, ‘rbio2.6’, ‘rbio2.8’, ‘rbio3.1’, ‘rbio3.3’, ‘rbio3.5’, ‘rbio3.7’, ‘rbio3.9’, ‘rbio4.4’, ‘rbio5.5’, and ‘rbio6.8’.

Step2: Frequency responses with different wavelets under levels D5 and D6

- Decompose unit impluse (130 samples) with different wavelets under seven levels
- Reconstruct unit impulse under the coefficients at D6 and D5
- Perform Fourier-transformation on the response to unit impulse into frequency domain
- Obtain the magnitude of the Fourier-transform responses

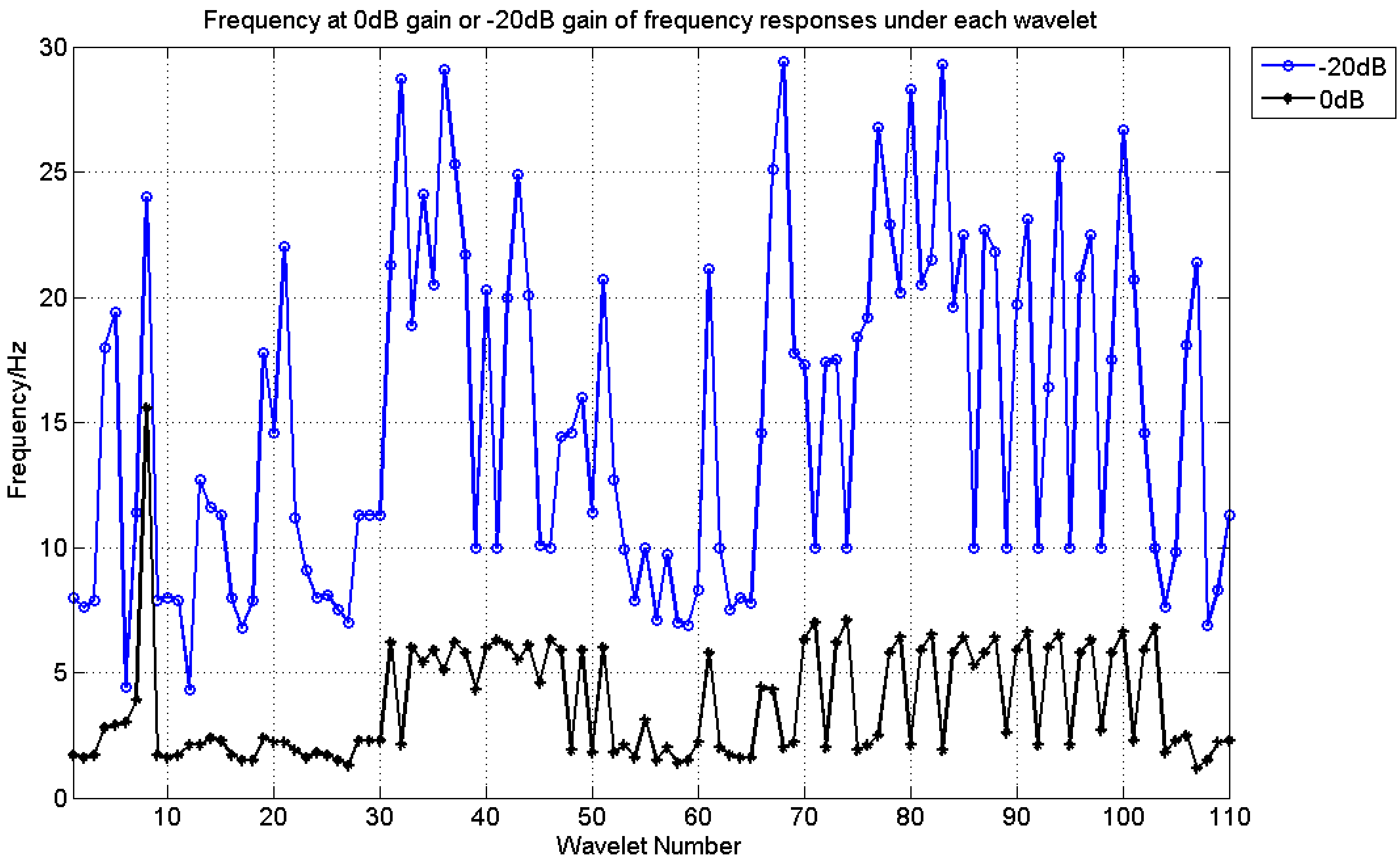
Step2: Frequency responses of 110 wavelets



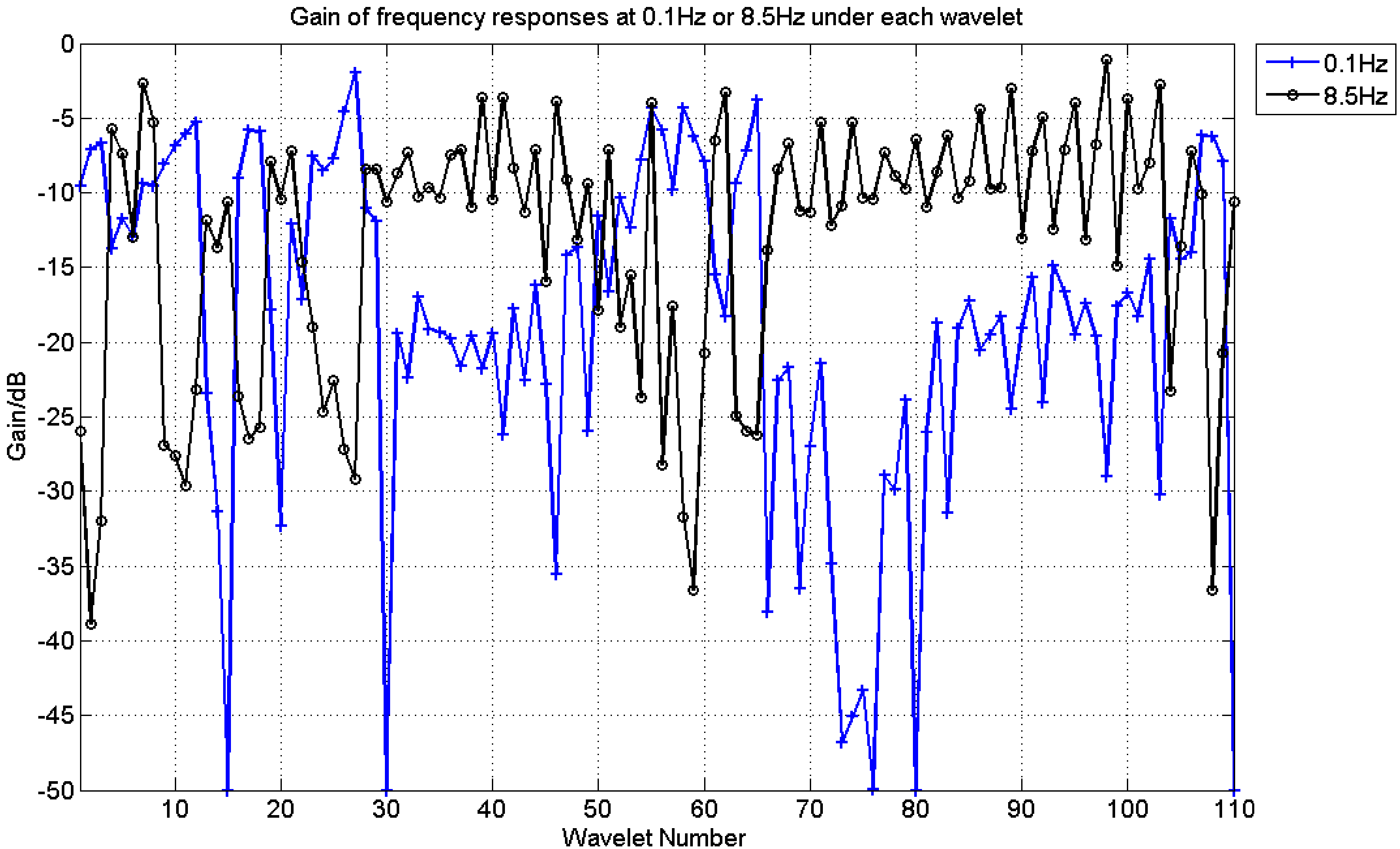
Step2: Criteria to choose wavelet

- In Kalyakin et al. (2007)
  - 0.1-2Hz, low frequency drift
  - 2-8.5Hz, MMN
  - 8.5-11.5, responses to repeated stimuli
- In raw data
  - Low frequency drift, MMN, and responses to repeated stimuli, P3a may overlap with each other
  - At a certain frequency bin, the power should be contributed by them together, not a single component
  - To extract one component at the same frequency bin, one way is to reduce the power of the magnitude, i.e., the gain of frequency responses of the filter at this frequency bin should be attenuated

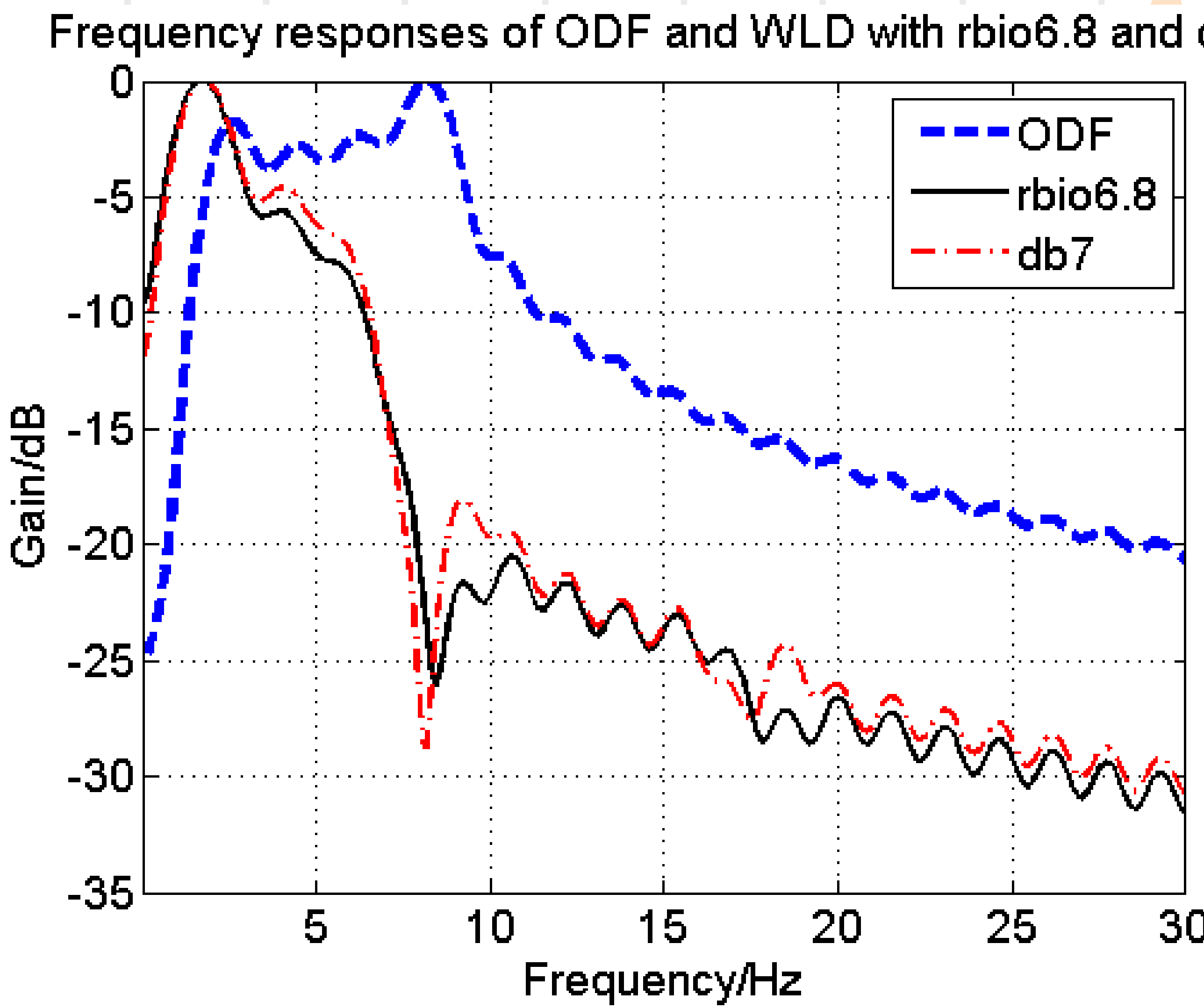
Step2: To a digital filter, the attenuation between the pass band and stop band is usually more than 20dB (http://en.wikipedia.org/wiki/Stopband).



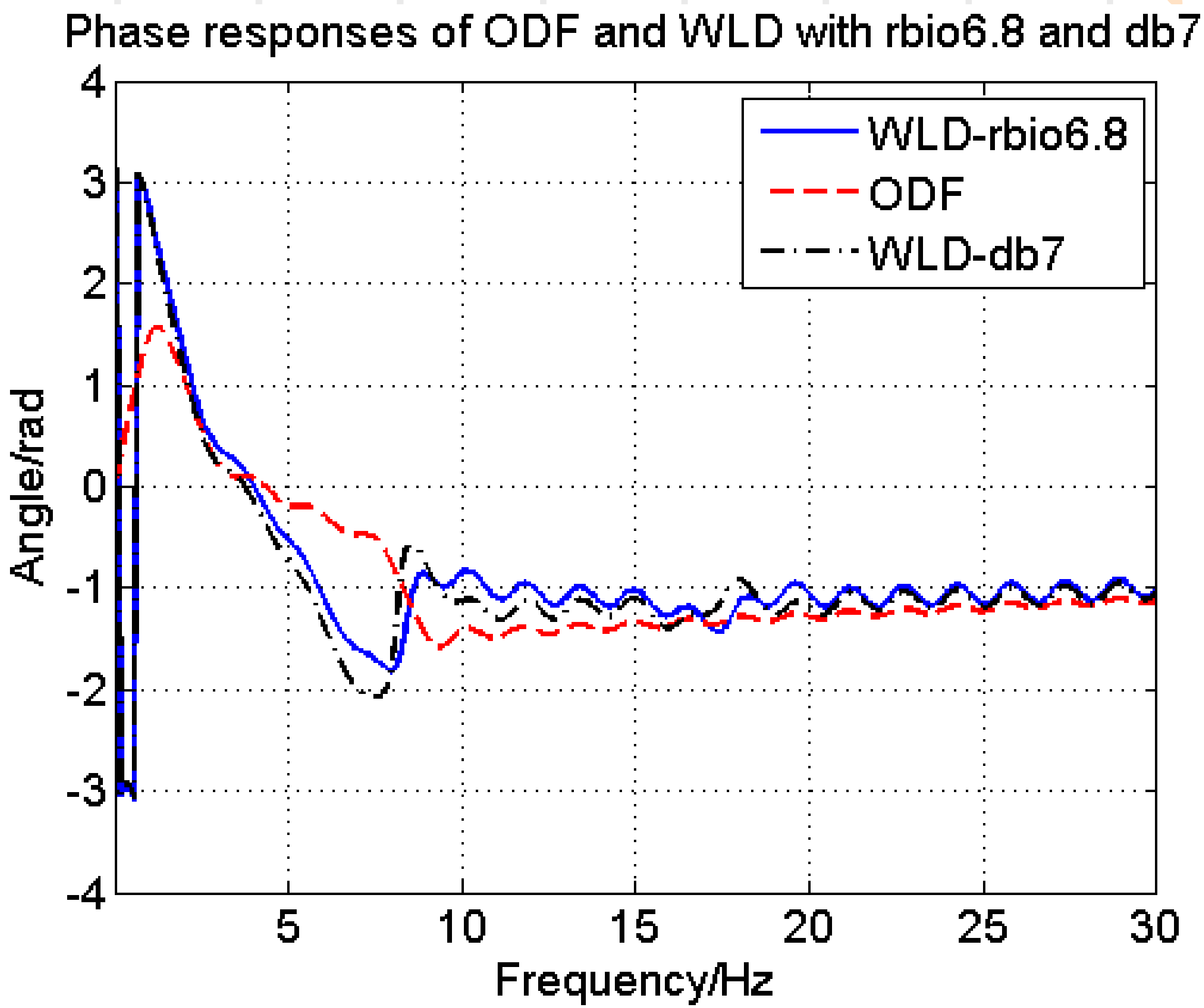
Step2: gain of the frequency responses at the cutoff frequency

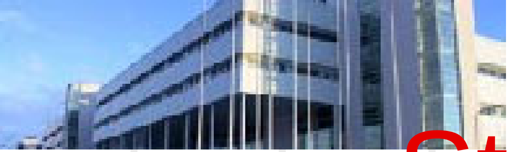


Step2: Frequency responses of selected filters



Step2: Phase responses of selected filters

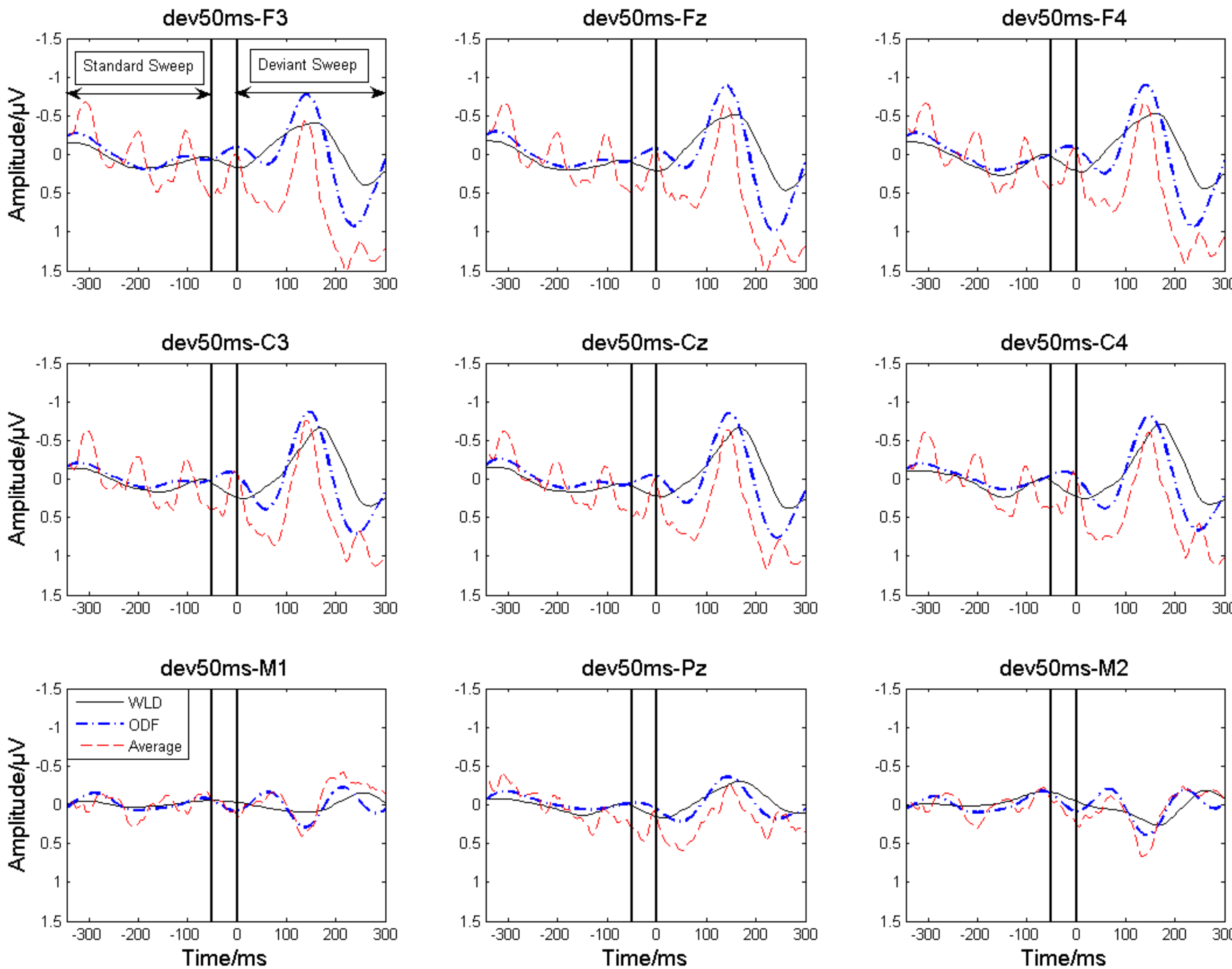




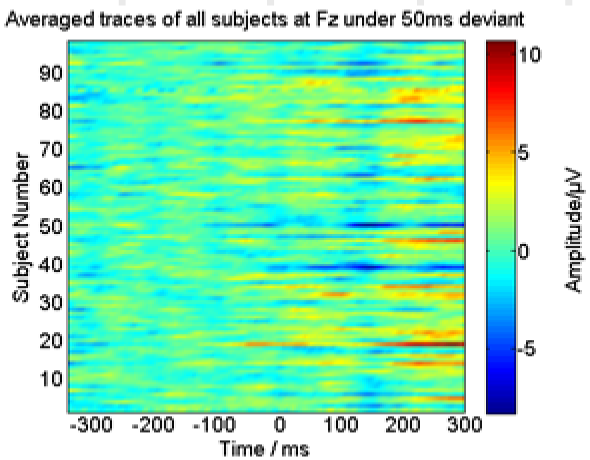
Step2: Final selection

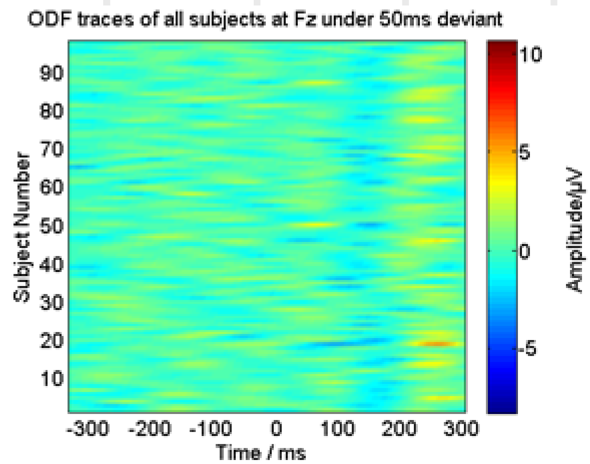
- Wavlet for decomposition and reconstruction
  - rbio 6.8
- Levels for reconstruction
  - D6 and D5

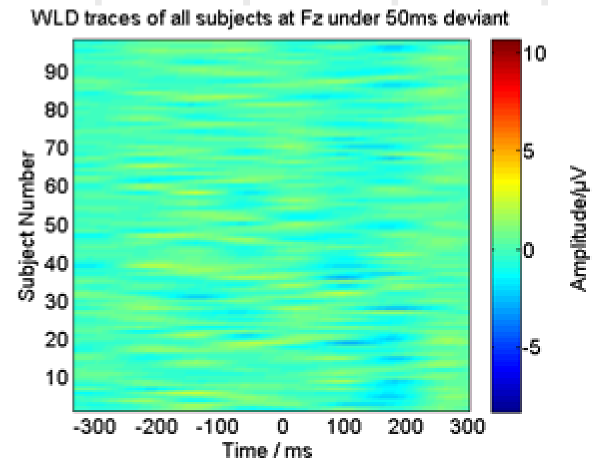
Final results-waveform

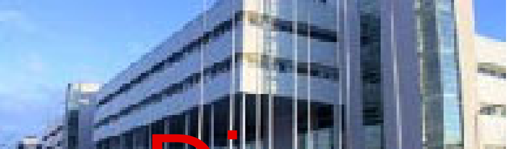


Final results-image trace



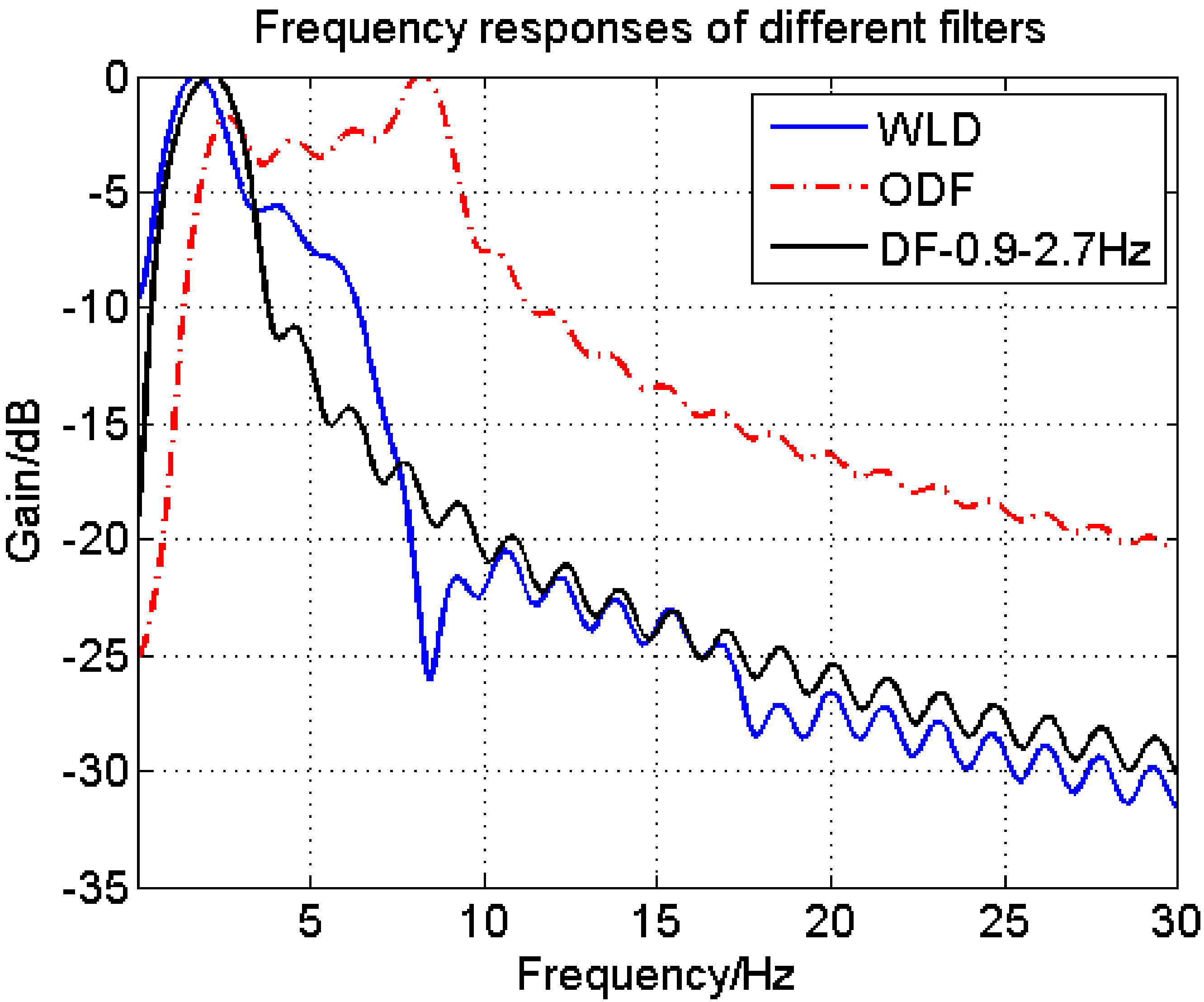




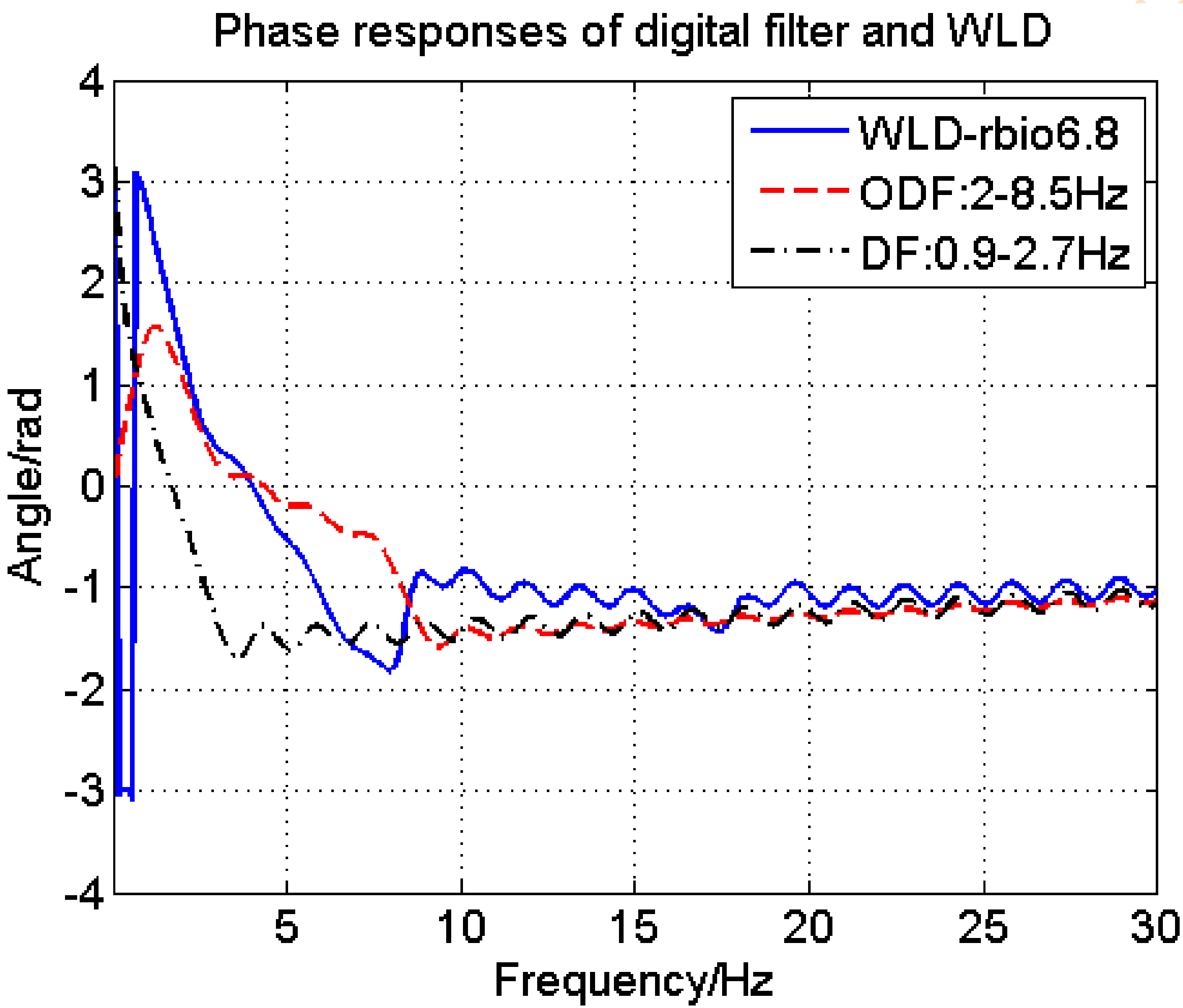


Disucssion on the cutoff frequency

- According to the definition of the cutoff frequency, i.e., the 3dB attenuation corner, (http://en.wikipedia.org/wiki/Cutoff_frequency)
- for the ODF, the cutoff frequencies could be 2.1 and 9.1 Hz, and the stop frequencies could be about 0.8Hz and 28Hz, respectively;
- for the WLD, the cutoff frequencies could be 0.86 and 2.69 Hz, and the stop frequencies could be about 0.1Hz and 8 Hz, respectively
- It is worth designing the cutoff frequencies with 0.86 and 2.69 Hz with a digital filter to make the comparison with WLD.

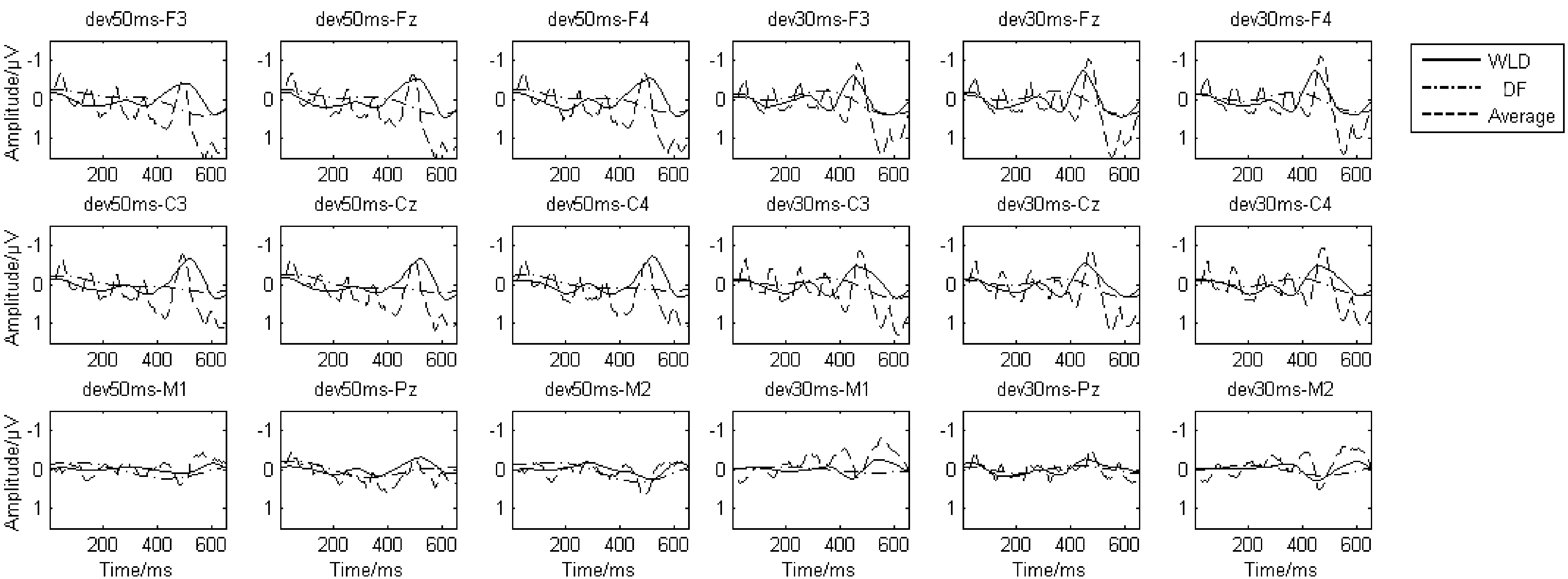


Frequency responses of different filters
WLD
ODF
DF-0.9-2.7Hz
Gain/dB
0
-5
-10
-15
-20
-25
-30
-35
5
10
15
20
25
30
Frequency/Hz

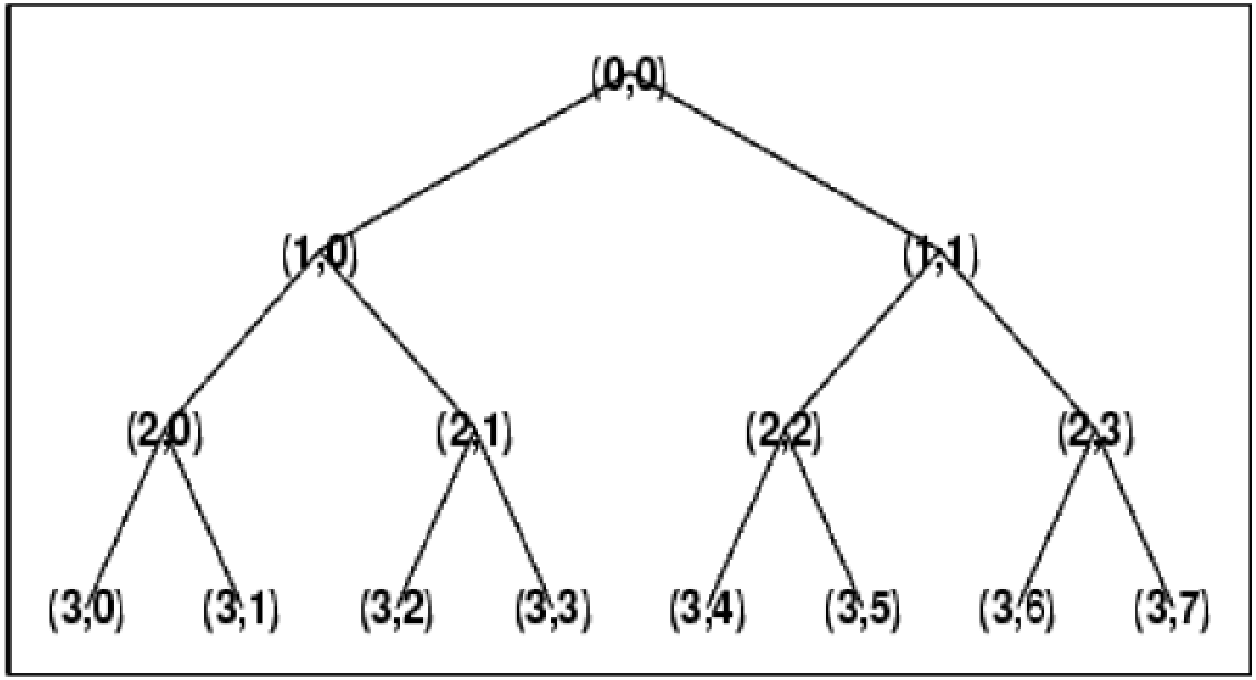


Phase responses of digital filter and WLD
WLD-rbio6.8
ODF:2-8.5Hz
DF:0.9-2.7Hz
Angle/rad
Frequency/Hz
4
3
2
1
0
-1
-2
-3
-4
5
10
15
20
25
30

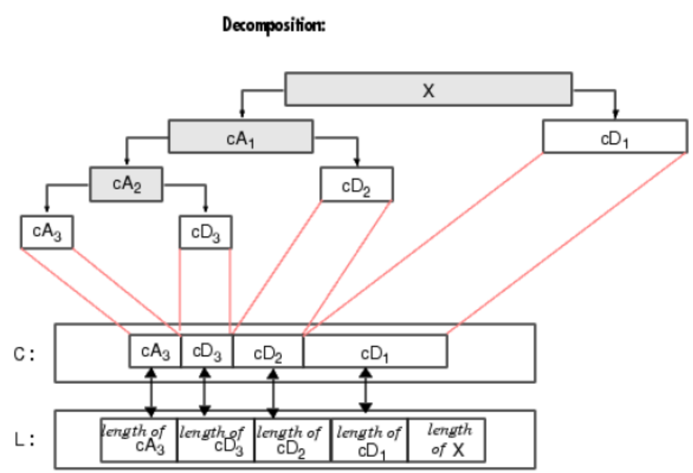
Waveforms

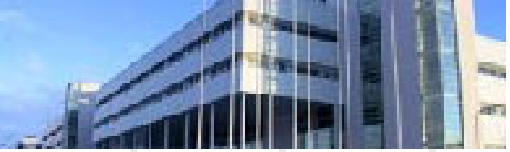

dev50ms-F3
dev50ms-Fz
dev50ms-F4
dev30ms-F3
dev30ms-Fz
dev30ms-F4
dev50ms-C3
dev50ms-Cz
dev50ms-C4
dev30ms-C3
dev30ms-Cz
dev30ms-C4
dev50ms-M1
dev50ms-Pz
dev50ms-M2
dev30ms-M1
dev30ms-Pz
dev30ms-M2
Amplitude/μV
Time/ms
-1
0
1
200
400
600
WLD
DF
Average

Wavelet packet decomposition



Wavelet decomposition:





- Thank you!