How-to: design FIR-filters (with firfilt EEGLAB plugin and EEProbe xfir)

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firfilt EEGLAB plugin

- FIR: Finite Impulse Response
  - Finite number of filter coefficients
  - No recursion as in IIR (Infinite Impulse Response) filters

- No longer in EEGLAB standard distribution

- [http://www.uni-leipzig.de/~biocog/widmann/eeglab-plugins/index.html](http://www.uni-leipzig.de/~biocog/widmann/eeglab-plugins/index.html)
- Unzip to EEGLAB plugin folder
- `>> pop_firws(EEG)`
- `>> pop_xfirws`
Filter types

- **Bandpass**
  - Frequency (Hz) vs. Amplitude
  - Highpass
  - Lowpass
  - Bandstop
Definitions

- Passband
- Stopband
- Transition band
- Cutoff frequency
Ideal frequency response

- Rectangular window in frequency domain
- Fourier series in time domain: sinc-function \( \text{sinc}(x)/x \)
- Infinite length!
- BUT: finite number of filter coefficients
Ideal frequency response

- Rectangular window in frequency domain
- Fourier series in time domain: sinc-function \( \frac{\sin(x)}{x} \)
- Infinite length!
- BUT: finite number of filter coefficients
  - Ripple (ringing, Gibbs phenomenon/effect)
Ripple

- Deviation from expected frequency response
- Passband ripple
- Stopband ripple/stopband attenuation

⇒ Windowing
Ripple

- Deviation from expected frequency response
- Passband ripple
- Stopband ripple/
  stopband attenuation

⇒ Windowing
## Window types

<table>
<thead>
<tr>
<th>Beta</th>
<th>Max stop-band attenuation (dB)</th>
<th>Max passband deviation</th>
<th>Transition width (normalized freq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>-21</td>
<td>0.0891</td>
<td>0.9 / m*</td>
</tr>
<tr>
<td>Bartlett</td>
<td>-25</td>
<td>0.0562</td>
<td>(2.9** / m)</td>
</tr>
<tr>
<td>Hann</td>
<td>-44</td>
<td>0.0063</td>
<td>3.1 / m</td>
</tr>
<tr>
<td>Hamming</td>
<td>-53</td>
<td>0.0022</td>
<td>3.3 / m</td>
</tr>
<tr>
<td>Blackman</td>
<td>-74</td>
<td>0.0002</td>
<td>5.5 / m</td>
</tr>
<tr>
<td>Kaiser</td>
<td>5.653</td>
<td>-60</td>
<td>0.001</td>
</tr>
<tr>
<td>Kaiser</td>
<td>7.857</td>
<td>-80</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

* m = filter order

** estimated for higher m only
Transition band width

- Is a function of (window type and) filter order
- Filter order = filter length – 1
- Filter order must be even
- Cutoff frequency – transition band width / 2 must NOT be < 0!
Filter design

- DEFINE filter type and cutoff frequencies (−6 dB)

- Define acceptable passband ripple and required stopband attenuation
  - Select window type

- Define/calculate transition band width
  - Estimate filter order (pop_firwsord)
Remarks

- Computation time is a function of filter length
  ⇔ As short as possible and as long as necessary!
- Stopband attenuation is NOT a function of filter length
- When reporting, state all relevant parameters: windowed sinc FIR-filter (cutoff frequencies, window type, and filter order or length)
- NB: Bandwidths are identical for all transition bands (in a Type I, windowed sinc FIR-filter)
- NB: Passband and stopband ripple are identical (in a Type I, windowed sinc FIR-filter)
- NB: (Type I, windowed sinc) FIR-filters have linear phase
Impulse, magnitude and phase response

- Impulse response is the filter kernel in the time domain
- Magnitude response is the logarithm of the modulus of the frequency response
- Phase response is the filter’s phase delay (and should always be zero in the passband!; \( \pi \) corresponds to a negative frequency response)