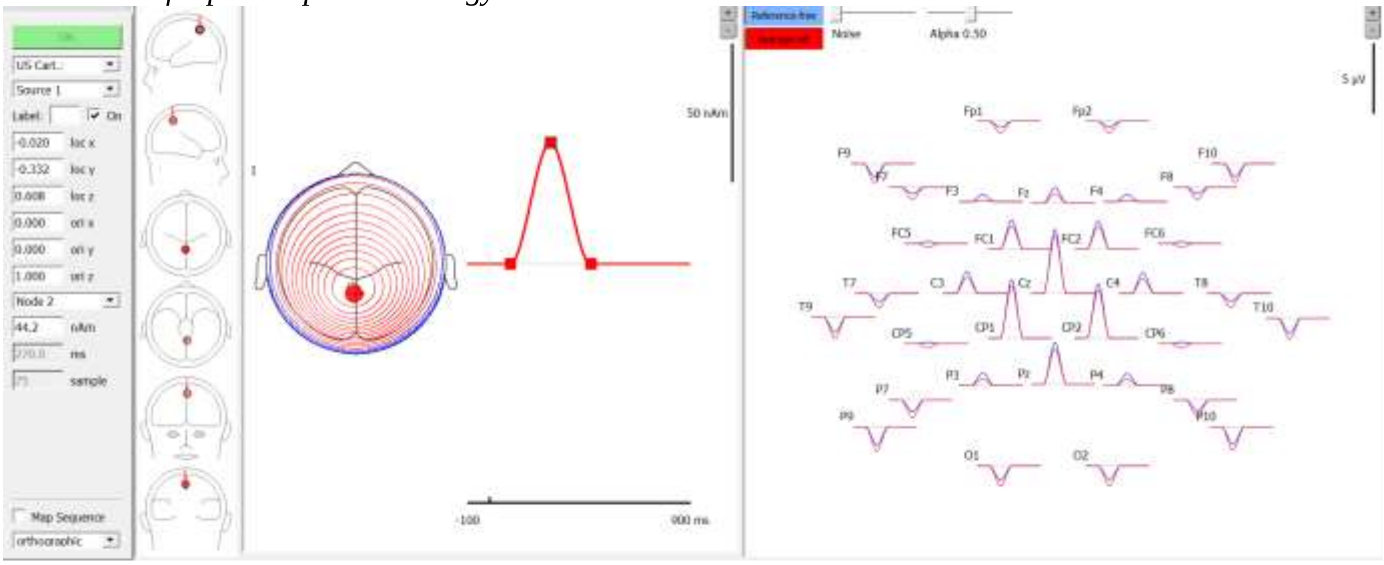
EEG - dipole, topography, re-referencing

1. Simulate a source in S1 – post-central gyrus
How does the topographical plot look like? Where is the maximal activation and why?

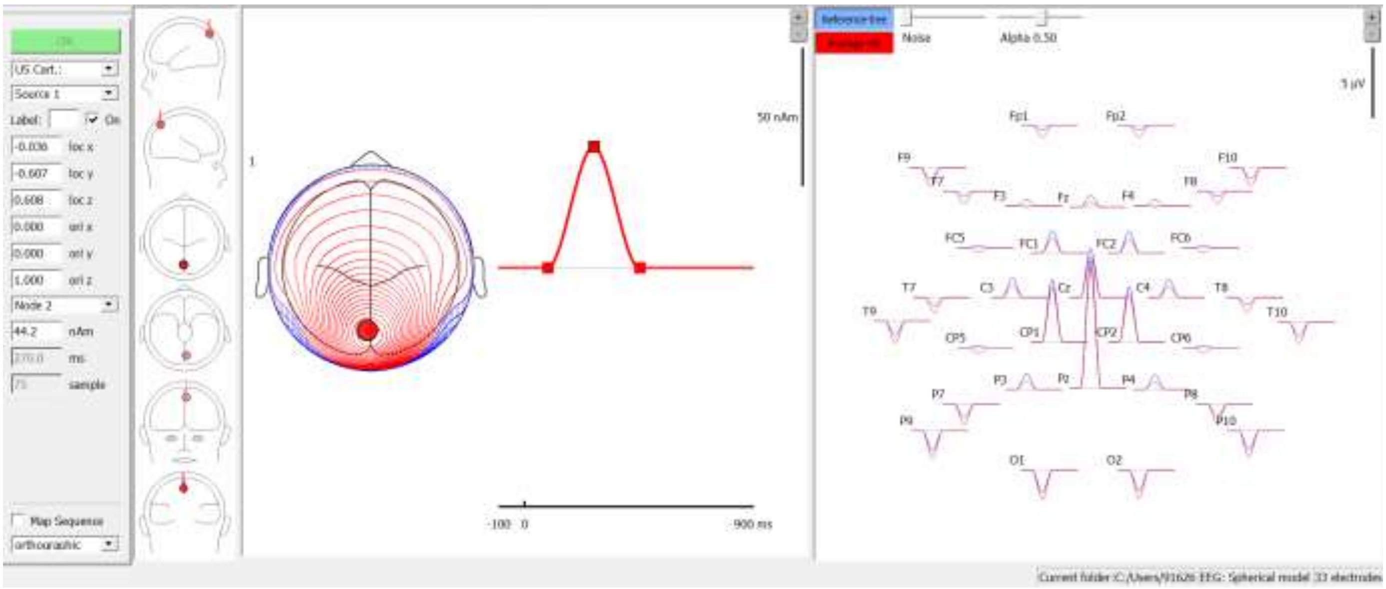
Simulation of dipole at post-central gyrus



Simulating a source in the S1 post-central gyrus region, we observe that the isopotential rings are dense towards the occipital lobe while it's wide in the frontal lobe. As we go far from the source we can see that the potential is dropping as a result we can observe the negative deflection in FP1, FP2 F9, F10, F3, F8, T7, T8, T9, T10, CP5, CP6, P7, P8, P9, P10, O1 and O2 in the topological plots. Also, we observe that as we go far from the source the amplitude of the deflection is decreasing and after a while, it's going in the negative direction.
We can see the maximum activation over the central sulcus (Cz, CP1, CP2), which separates the primary somatosensory cortex (S1) from the primary motor cortex (M1). This maximum activation is due to the location of the source in the S1 region, which is responsible for processing somatosensory information from the skin and muscles.

Move the dipole around to understand how the topo-plot changes with the dipole

Moving the dipole around
As we move the dipole to the parietal lobe now the topographical plots changes and we can see the maximum activity in the Pz area. Here also we can see the area near the dipole has a positive higher potential and as we go far away from the plot this becomes negative. The red lines show the high potential while the blue shows the low potential.

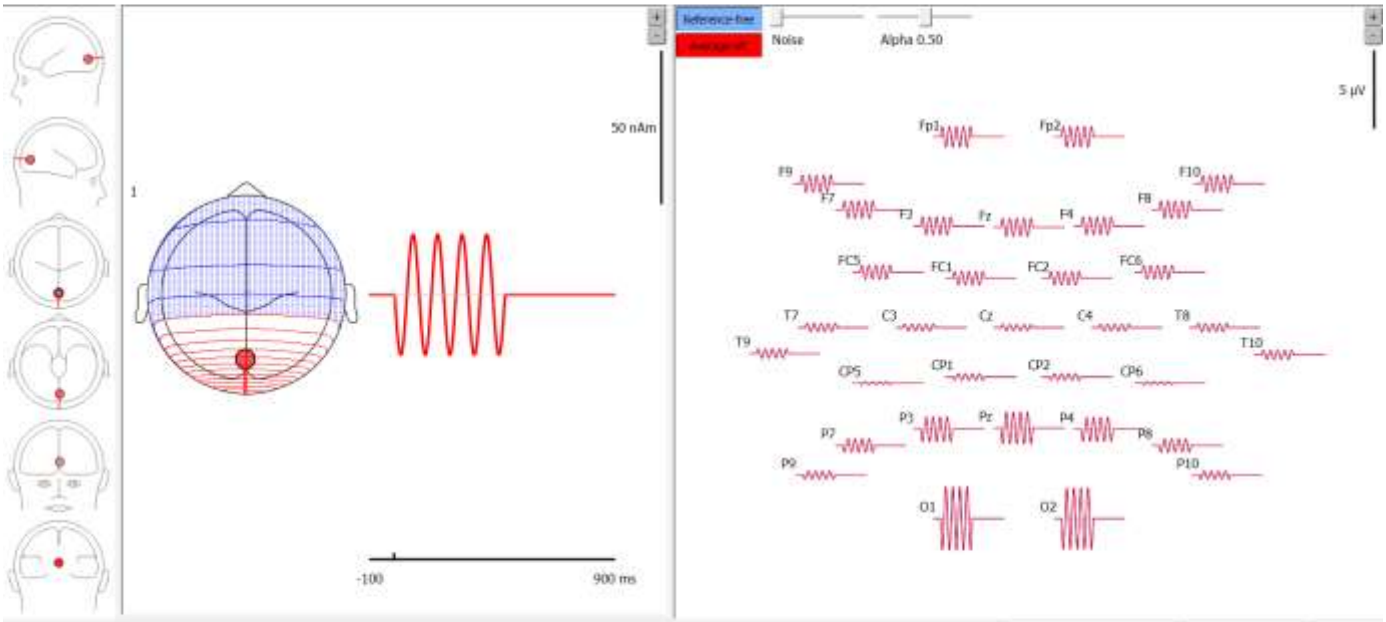


Can you reduce the topo-plot to a simple electric vector in each case?

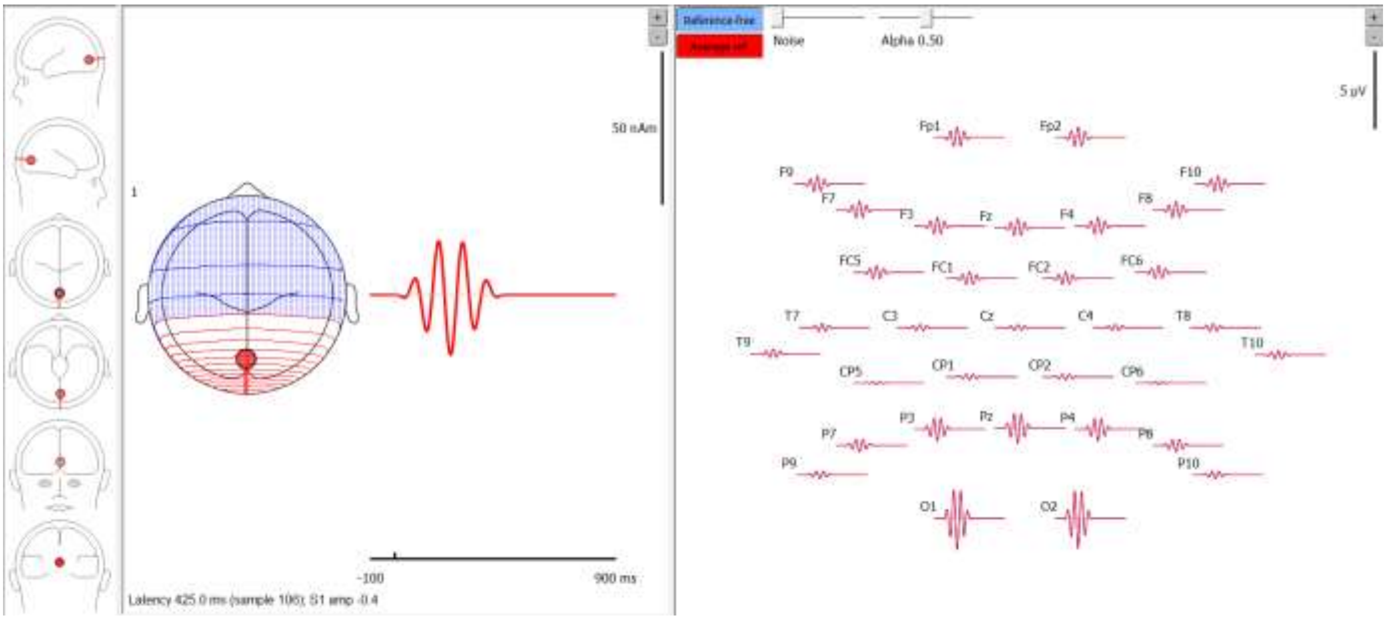
Yes, In each case we can reduce the topographical plot to a simple electric vector. This is because the signal is generated by the synchronized activity of a large number of neurons in the brain which result in the synchronized change in electric potential at the scalp. So we can represent these changes in potential as a single electric vector which summarizes the overall direction and magnitude of the signal. We can also think of pyramidal cells which are more like a dipole and represent a large number of such cells as a single electric vector by taking their net resultant.

2. **Simulate an oscillating sinusoidal source (8-12 Hz) in the visual cortex**
   - **How does the topographical plot look like? Where is the maximal activation and why?**

10 Hz sinusoidal source in the visual cortex



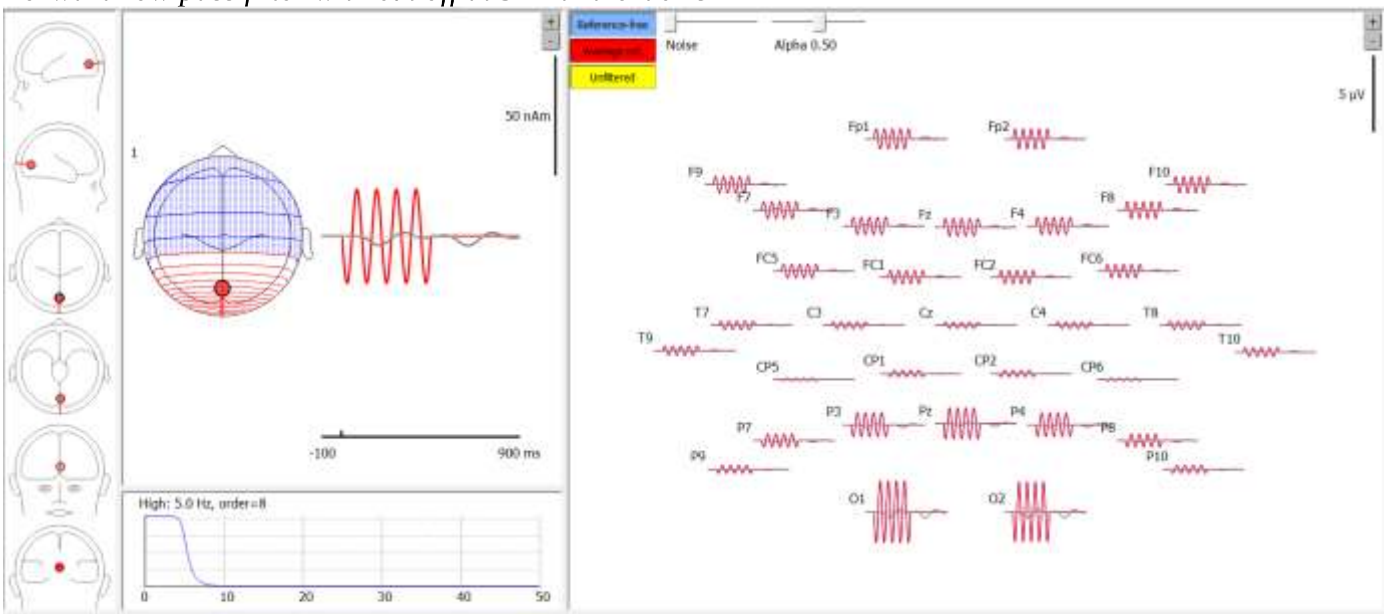
10 Hz sinusoidal source with hanning window in the visual cortex



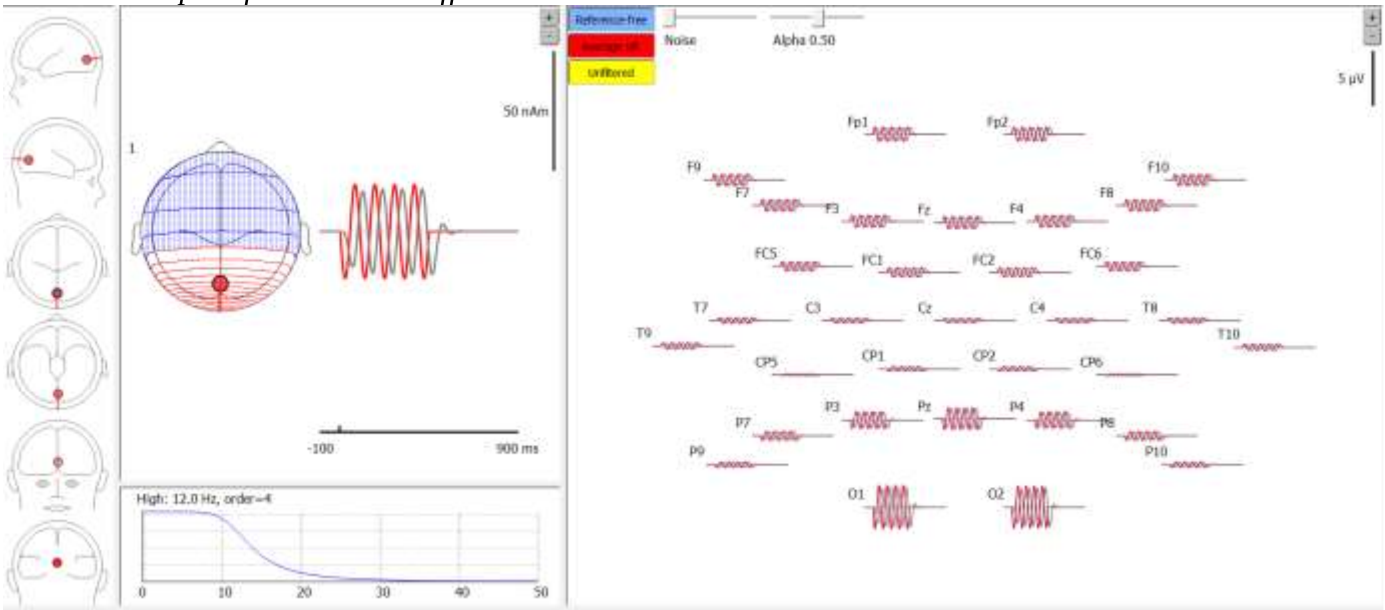
The potential in frontal lobe and pre-central gyrus is low while the potential post-central gyrus is high. So we can see very low activity in central nervous system(C_x), frontal lobe(Fp1, Fp2, F_x) and temporal lobe(T7,T8,T9,T10). While we see the most activated area is occipital lobe where the visual cortex is present. So it shows the activity in visual cortex doesn't activate much of the other brain areas while it only gave higher activation in occipital lobe(O1, O2) since visual cortex lies in occipital lobe, most of the visual processing happens there.

3. **Effect of filtering on evoked potential**
   1. **Low-pass, high-pass**

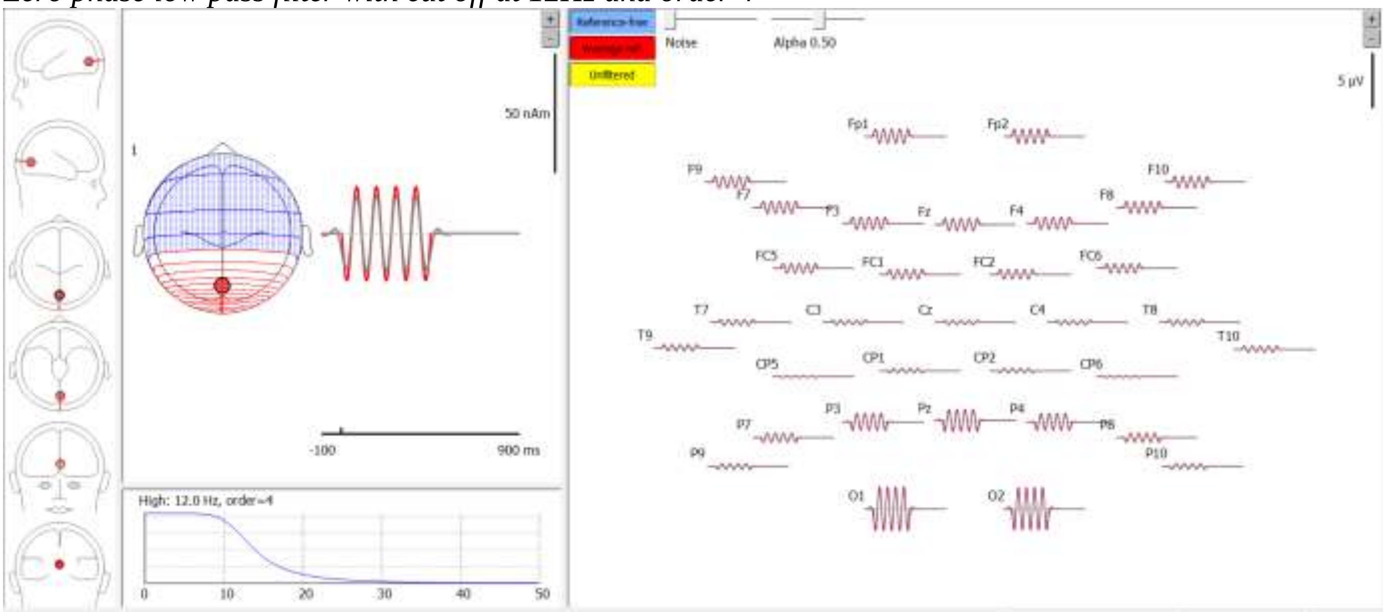
Forward low pass filter with cut off at 5Hz and order 8



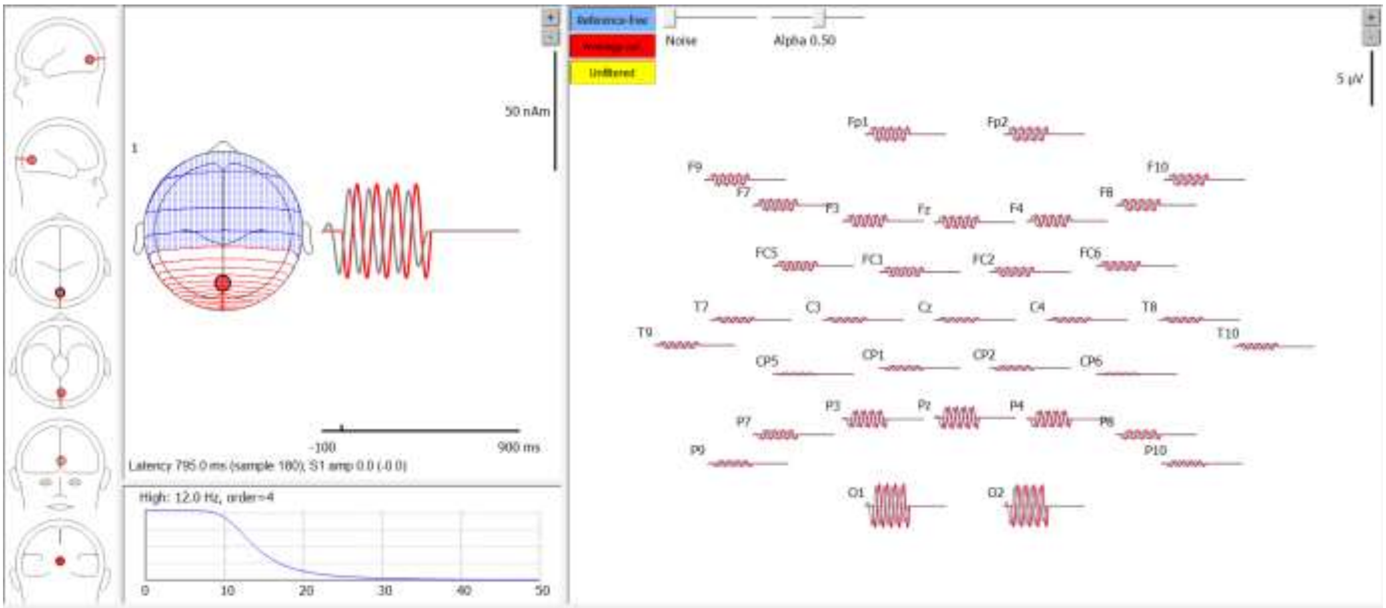
Forward low pass filter with cut off at 12Hz and order 4



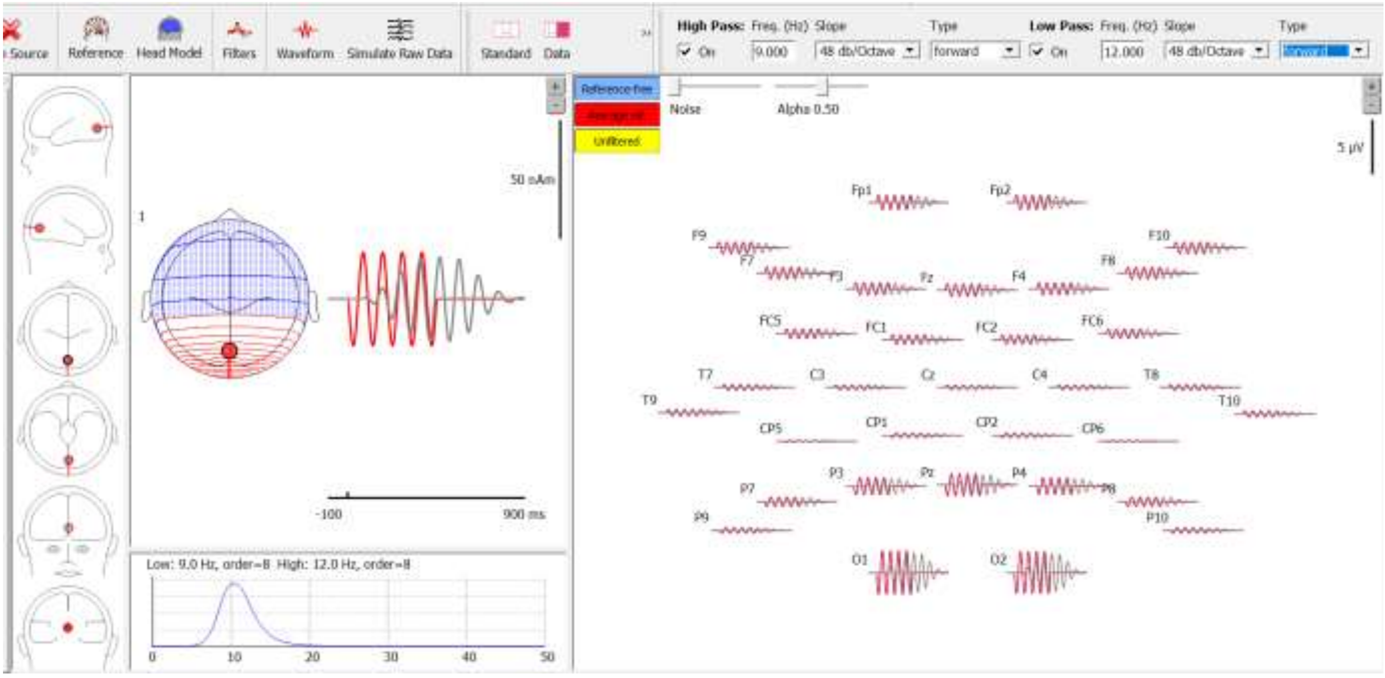
Zero phase low pass filter with cut off at 12Hz and order 4



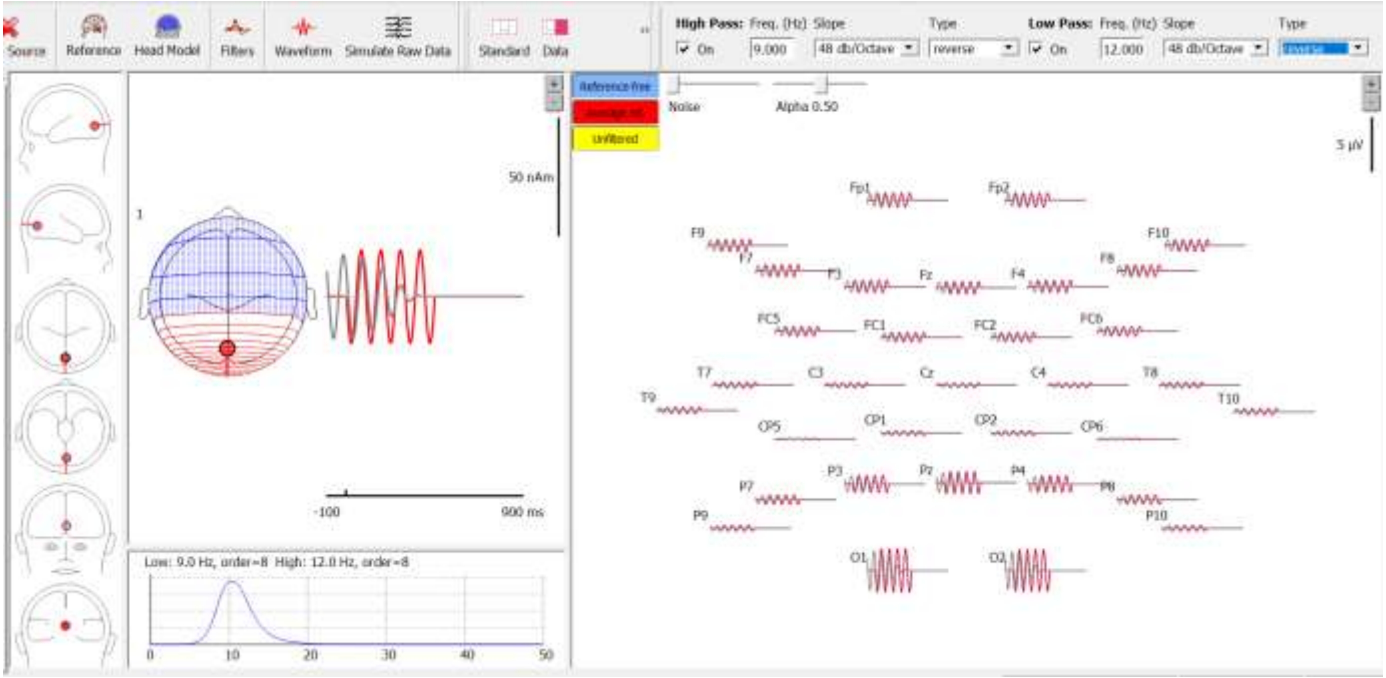
Reverse low pass filter with cut off at 12Hz and order 4



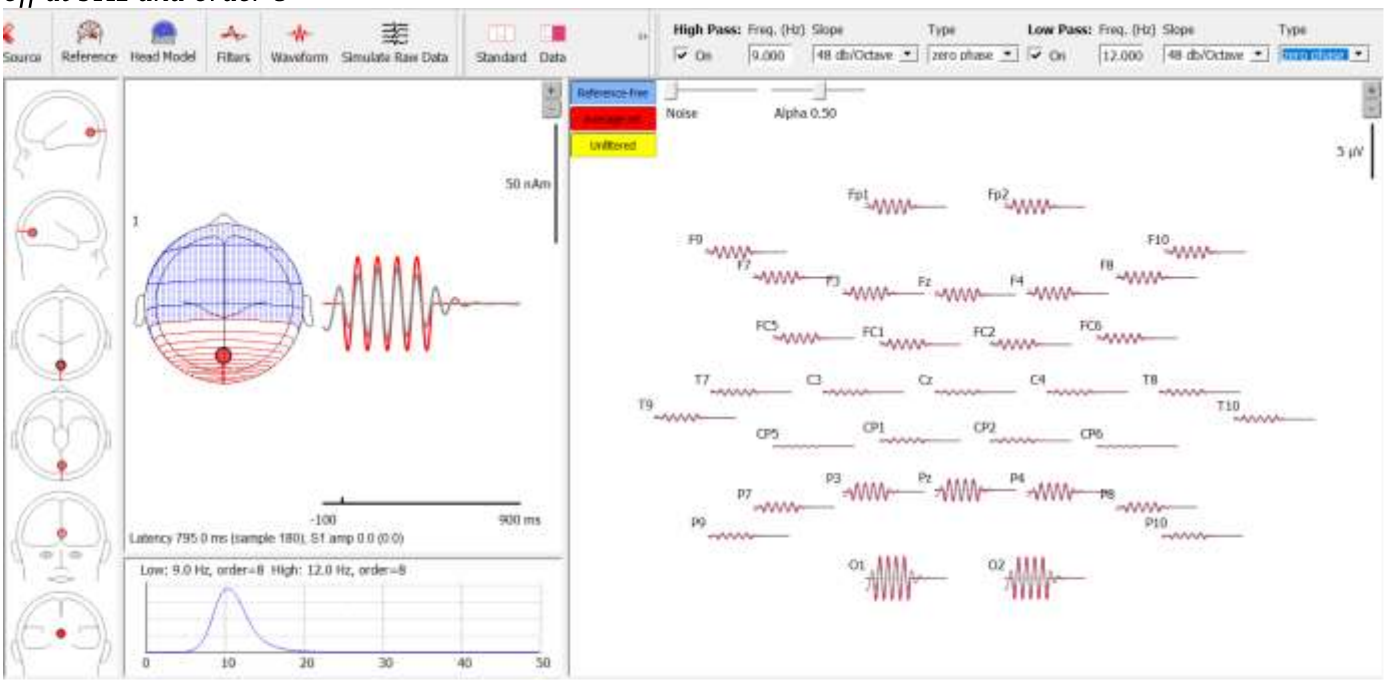
Forward low pass filter with cut off at 12Hz and order 8 along with Forward High pass filter with cut off at 9Hz and order 8



Reverse low pass filter with cut off at 12Hz and order 8 along with Reverse High pass filter with cut off at 9Hz and order 8



Zero phase low pass filter with cut off at 12Hz and order 8 along with Zero phase High pass filter with cut off at 9Hz and order 8



We can see that the forward and reverse filtering is introducing the phase distortion so it's not good to use while the zero-phase filtering preserves the temporal resolution of the signal so it doesn't distort the phase and will be preferred for the evoked potentials.

Low pass filters are removing the high frequency components here the cut-off is 12Hz and order is 8 so the roll off rate is fast enough and we mostly get components of frequency less than 12 Hz only. But it looks like low pass filters are introducing little bit of time-domain distortions.

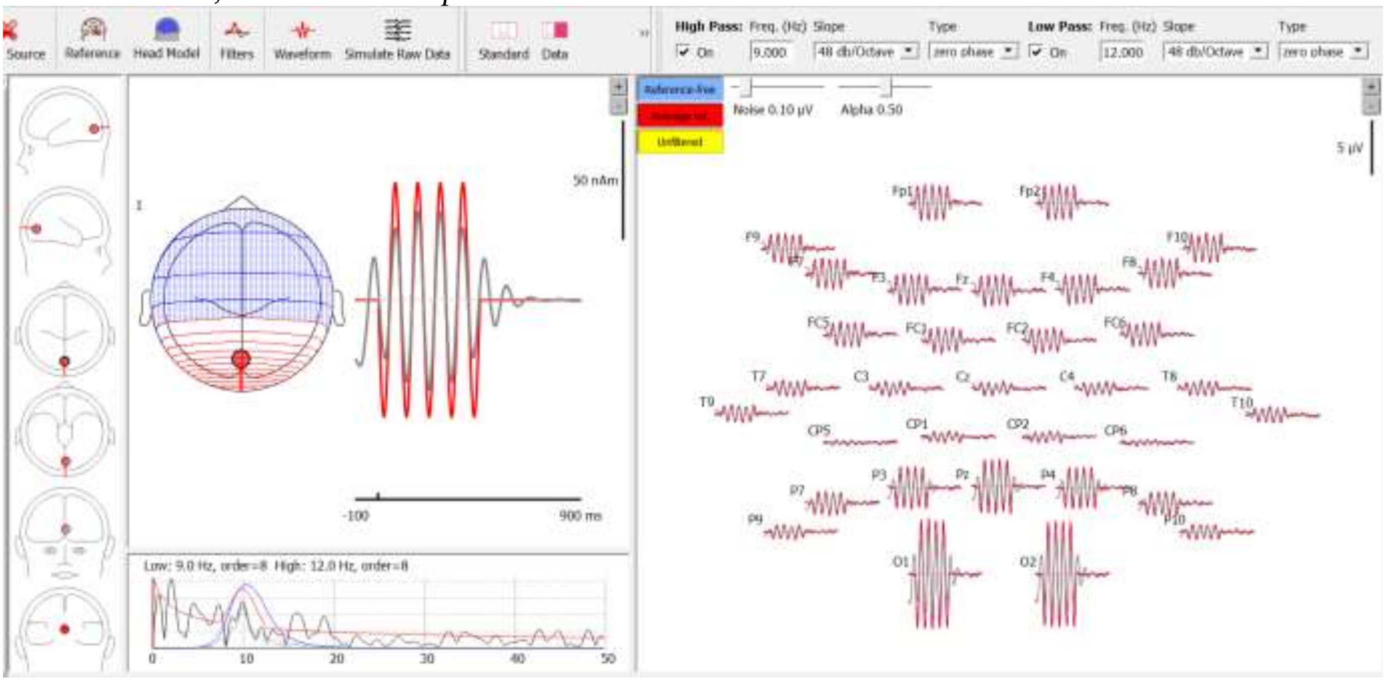
High pass filters are removing the low frequency components here the cut-off is 9Hz and order is 8 so the roll off rate is fast enough and we mostly get components of frequency more than 9 Hz only. It can be used to remove baseline drift or any low-frequency noise. But it looks like low pass filters are introducing little bit of time-domain distortions.

Optional

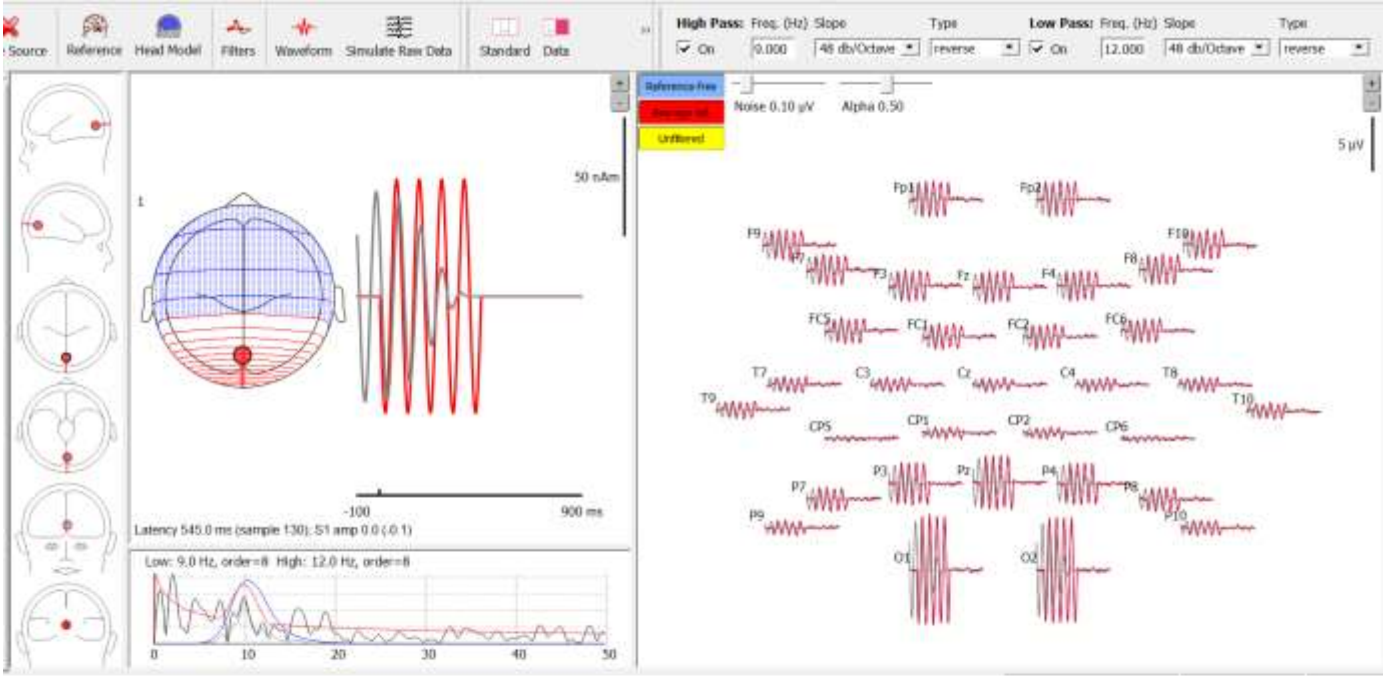
Effect of noise on re-reference techniques

1. **Add noise**
2. **Which of the re-referencing techniques handles noise best? (Use the reference button)**

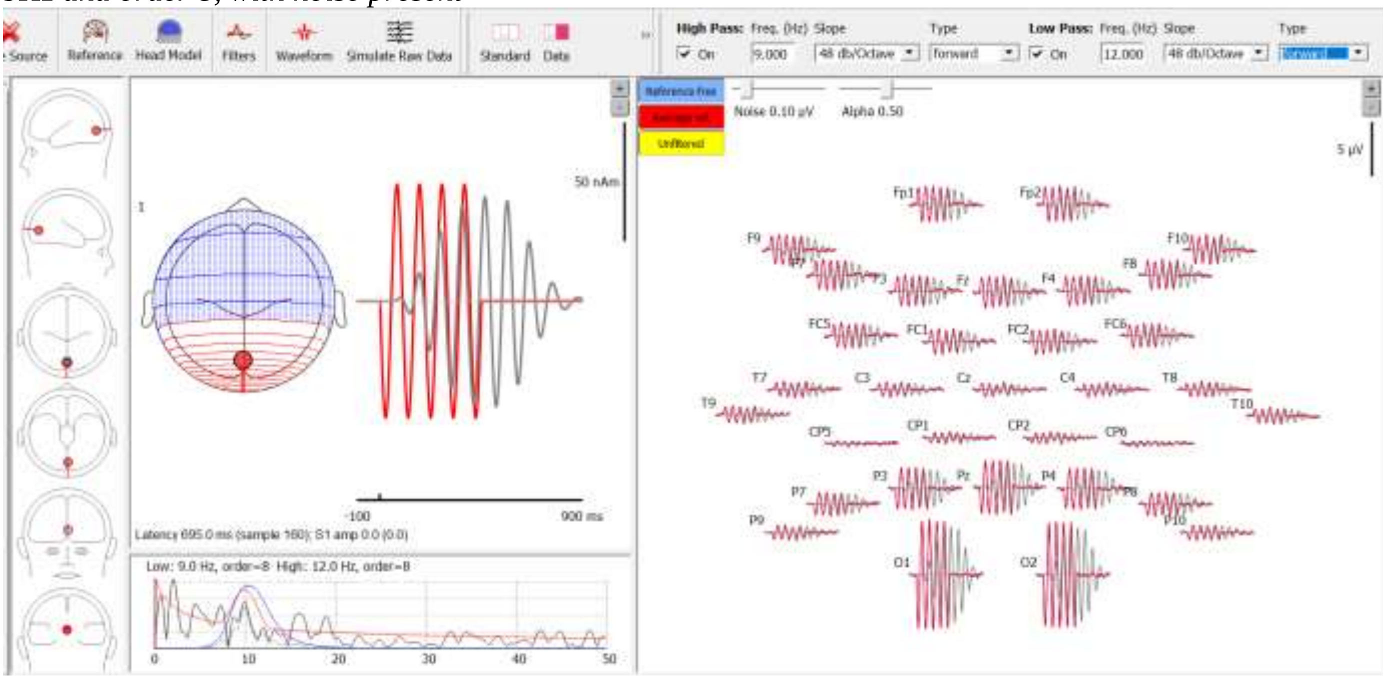
Zero phase pass filter with cut off at 12Hz and order 8 along with Zero phase High pass filter with cut off at 9Hz and order 8, also the noise is present



Reverse low pass filter with cut off at 12Hz and order 8 along with Reverse High pass filter with cut off at 9Hz and order 8, with noise present



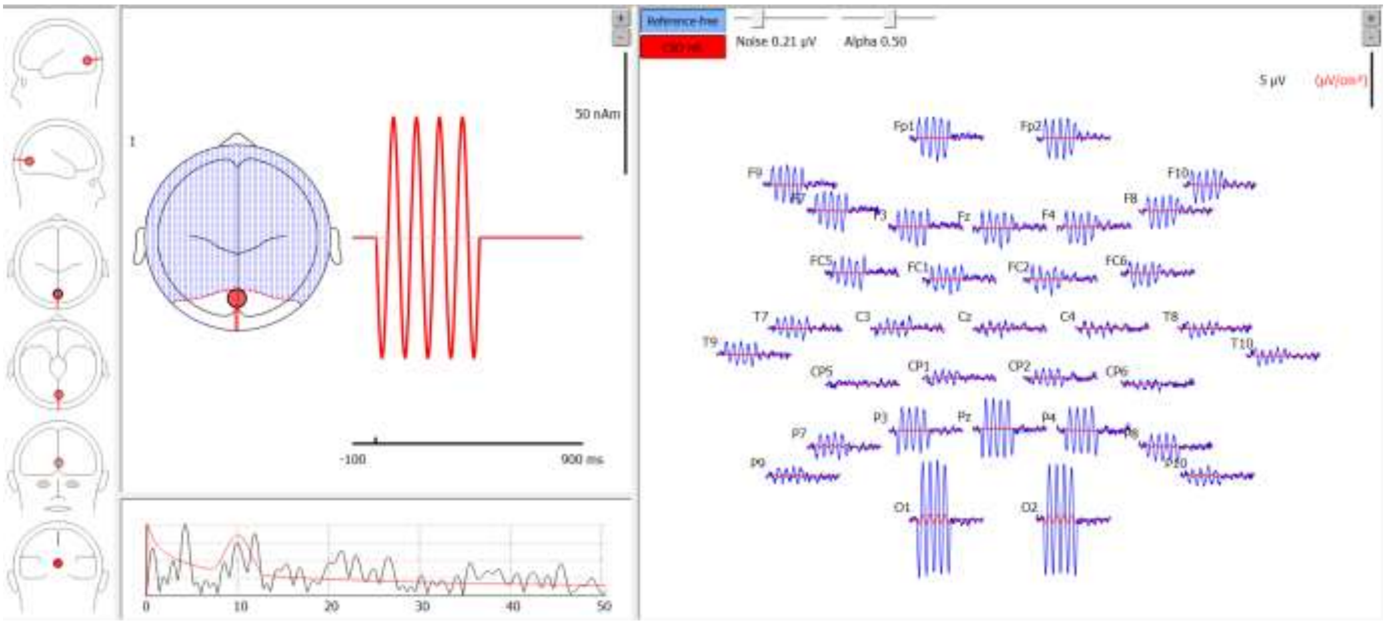
Forward low pass filter with cut off at 12Hz and order 8 along with Forward High pass filter with cut off at 9Hz and order 8, with noise present



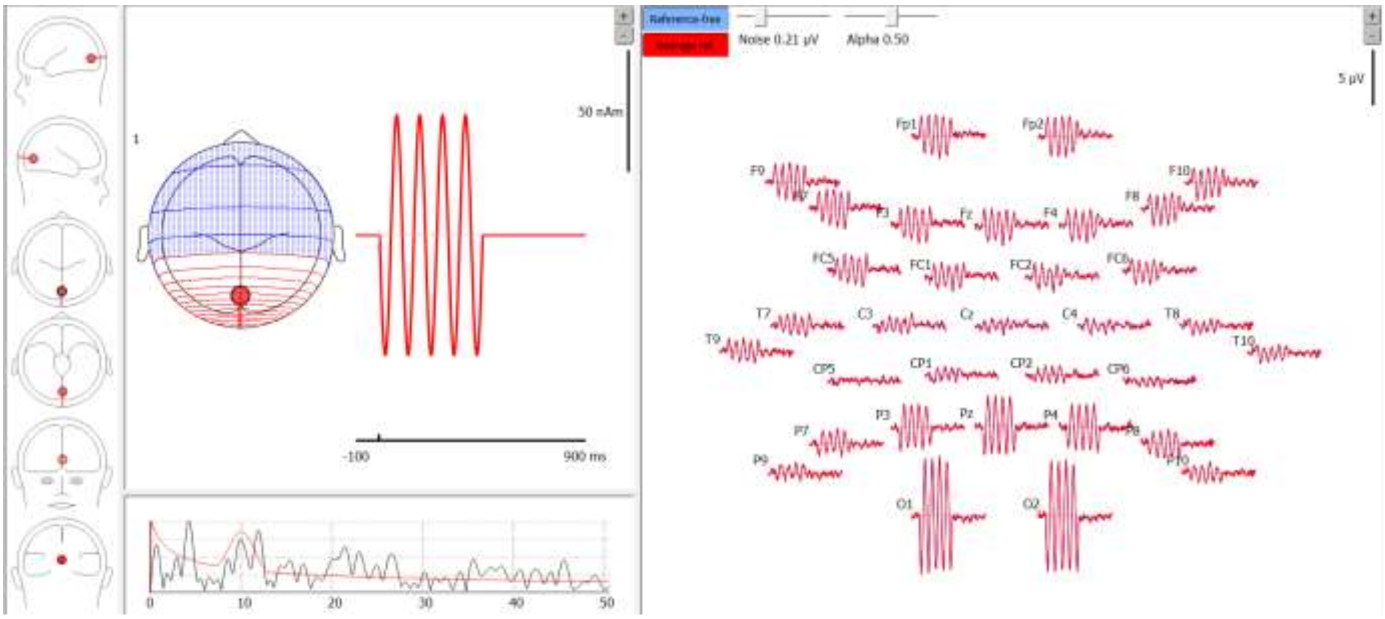
We can see that the signal doesn't change much after adding high pass and low pass filter to the signal with noise. But the average reference technique helps in removing the noise. Filters just reduce the noise which has the frequency outside the range of bandpass filter.

Re-referencing

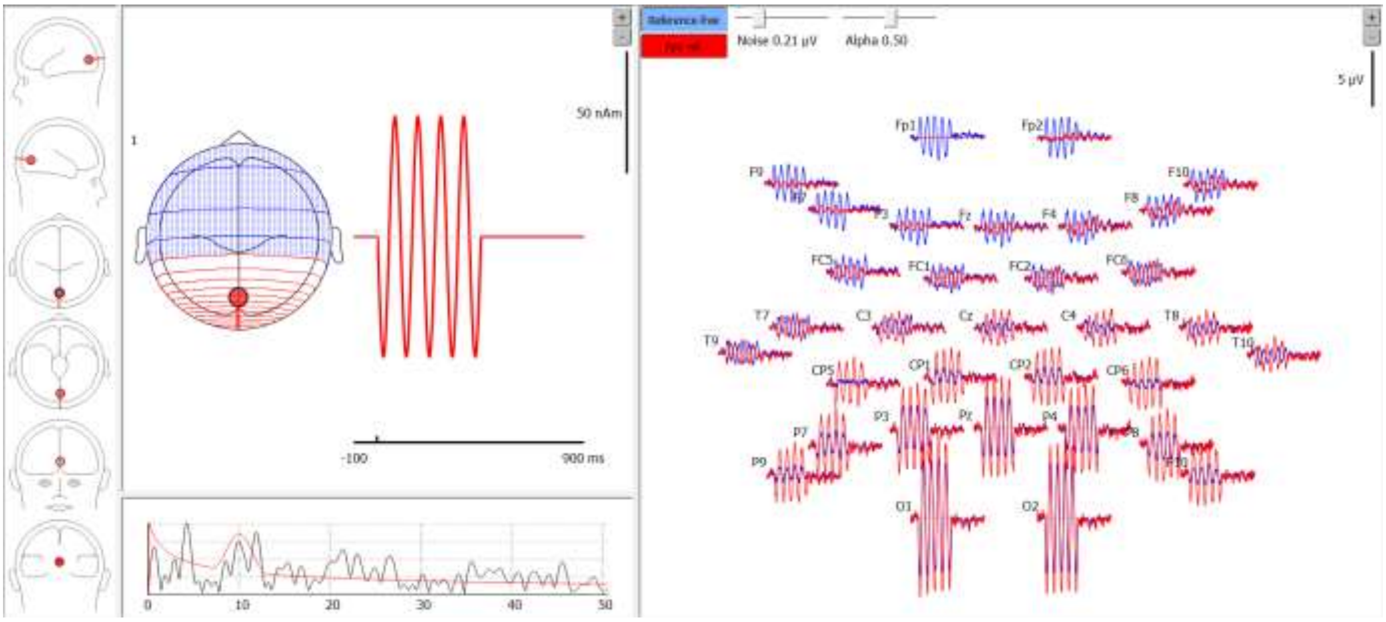
Re-referencing using CSD/Laplacian reference



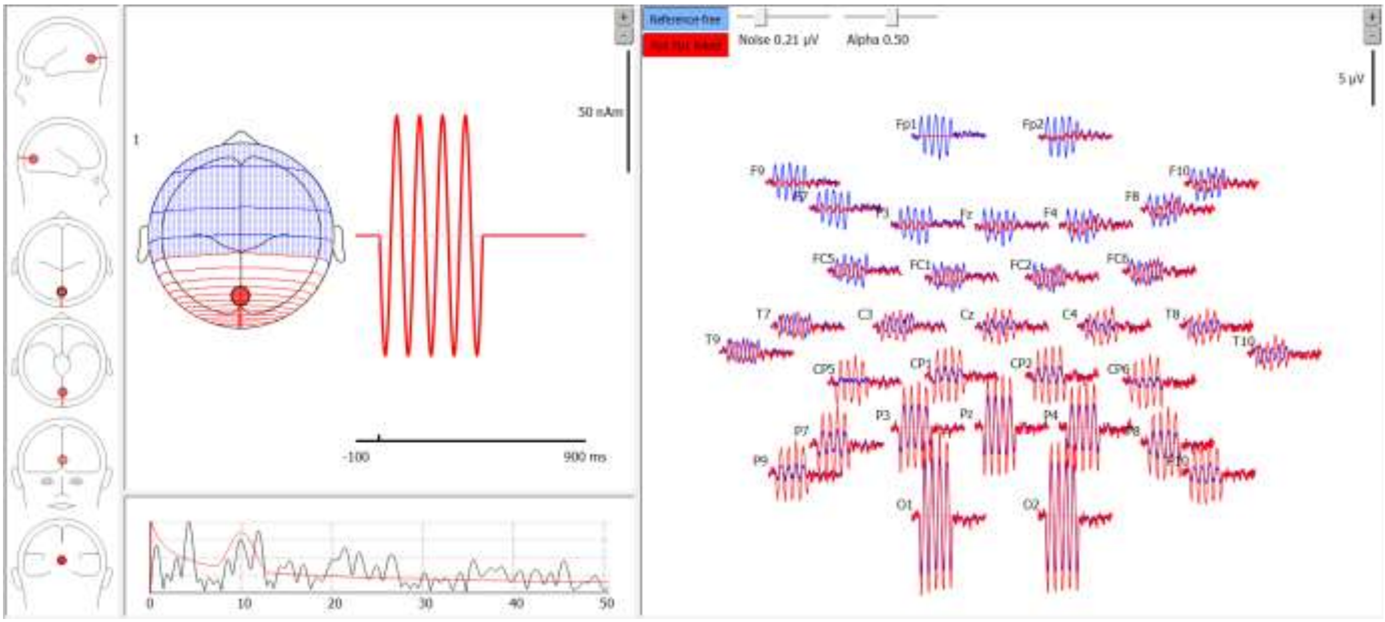
Re-referencing using Average reference



Re-referencing using Single reference



Re-referencing using Linked reference



From the above plots, we can conclude that the Average reference technique handles the noise best. This is because it preserves the phase relationship which plays an important role in the sinusoidal source. In the plot, we can clearly see that the reference-free plot and average reference plots overlap mostly. So for the sinusoidal signal with noise, the average reference is the best.

Among the rest of them, we can order them from best to worst like linked reference then single reference and at last the Laplacian reference.

In the Laplacian, we can see the signal is distorted and there are phase shifts so it’s the worst among all for a sinusoidal signal.