High frequency EEG signals

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EEG signals with frequencies in the (0 – 5) kHz range were recorded using our new designed instrumentation amplifier with differential input. Measurements were performed in an anechoic chamber to ensure that only brain activity will be recorded. Spontaneous brain activity, and visual evoked potentials were recorded. Raw EEG signals, together with their filtered version, are presented in this paper, in an attempt to compare the results with the EEG signals and evoked potentials already known from the scientific literature.

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1. Introduction

Both research and commercial available EEG amplifiers use filters to limit the frequency range of the recorded signals. Our new designed EEG amplifier [1,2] uses no filters to limit the signal frequency. Therefore, it can be used to study frequency components of the EEG signals that could not be recorded until now. Spontaneous brain activity in the (0 – 40) Hz frequency range was studied in detail over the last decades. Many diagnostics are today based on the analysis of these frequencies. Lately, brain activity happening at higher frequencies was discovered: (30 – 100) Hz gamma band is correlated to cognitive task execution [3], (80 – 200) Hz ripples were recorded from human epileptic patients [5], 600 Hz oscillations modulated by somatosensory stimulation measured in intracerebral monkey brain [6] and human median nerve somatosensory evoked potentials (SEPs) containing a low-amplitude (< 500 nV) high-frequency (~ 600 Hz) burst of repetitive wavelets (HFOs) which are superimposed onto the primary cortical response 'N20' [7]. Therefore, finding a confident way to record EEG signals over a large frequency band (0 – 5) kHz it is challenging to continue research in this field.

2. Spontaneous brain activity

All measurements were done in an anechoic chamber (Fig. 1), which ensures that only the brain activity is recorded. The anechoic chamber's walls were built using the following layers (from outside to inside): silicon and iron concrete alloy (100 mm width), reinforced concrete (100 mm width), iron layer (2.5 mm width), copper layer with $\sigma = 5.998 \cdot 10^7$ S/m electric conductivity (0.5 mm width) [4]. The chamber was grounded and all the equipment used inside was powered by batteries.

Fig. 1. The anechoic chamber.

The EEG electrodes used are non-polarisable Ag/AgCl, model WBT-DSC ("The Electrode Store"), placed in the Fp1 and Fp2 scalp positions, according to the "10-20" EEG standard. All the cables used in the experiment are screened with the screen connected to ground.

The signal coming from the electrodes is amplified and sent to an oscilloscope (Lecroy Wavejet 332), where the signal is saved on a USB memory stick for further analysis on the computer.

For the first EEG signals, ten seconds of spontaneous brain activity was recorded, with a sampling rate of 10 kHz. The frequency spectrum of the signals is shown in Fig. 2.

It is interesting to notice that the (0 – 40) Hz frequency band (which contains the usual EEG rhythms) has equal amplitudes with (0.9 – 1.2) kHz and (2.9 – 3.5) kHz frequency bands (Fig. 2). This means that part of the brain is responsible for these bands, and the information contained in them might be as rich as the information in the lower (0 – 40) Hz band.

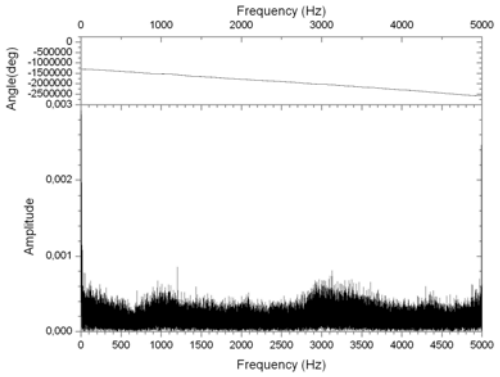

Fig. 2. Frequency spectrum of the raw EEG signals.

After low-pass filtering of the raw EEG signal, at 45 Hz, the remaining time domain signals resemble the known EEG signals from the literature. Five seconds of these filtered signals are shown in Fig. 3. Fig. 4 presents the frequency spectrum of the filtered signals. Along with the 1/*f* noise, normal alpha and beta rhythms peaks can be seen, as small peaks around 7 Hz and 12 Hz.

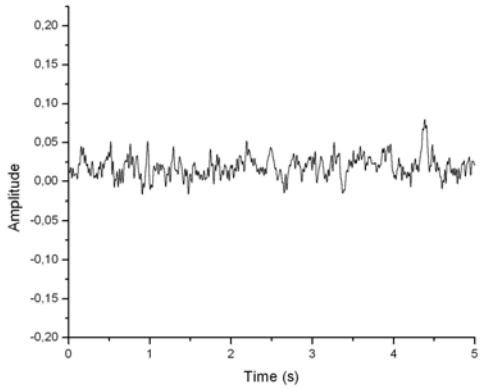

Fig. 3. EEG signal, low pass filtered at 45 Hz.

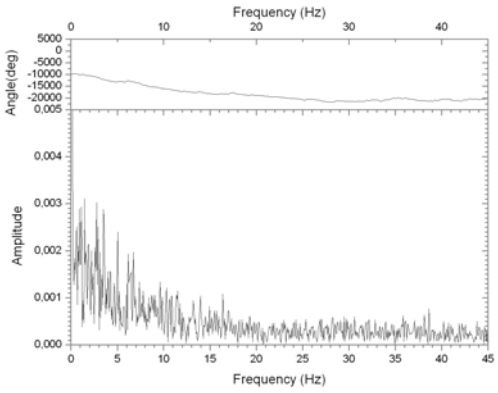

Fig. 4. Frequency spectrum of the filtered signals.

3. Visual evoked potentials

The visual evoked potentials measurements were also made inside the anechoic chamber.

The evoked potentials are obtained by averaging a great number of EEG signals. By averaging, the random spontaneous brain activity is reduced, while the brain response to the visual stimulus, (which are locked in time to the moment when the stimulus ends), grow in amplitude. Usually, it is necessary to average about 200 signals to clearly view the evoked potentials. Using our new designed amplifier, we were able to spot the evoked potentials by averaging 40 signals on the first subject, respectively 50 signals on the second human subject. The stimulus was 200 ms of red light, presented to the subject without any periodicity. Wavelet decomposition and denoising algorithms were used to separate noise from the evoked potentials in the averaged signal.

For the first human subject, a 5 level approximation using "symlet 5" wavelet was used for decomposition and denoising. Fig. 5 contains the extracted evoked potential signals extracted from the averaged signals, while Fig. 6 is representing the extracted noise components.

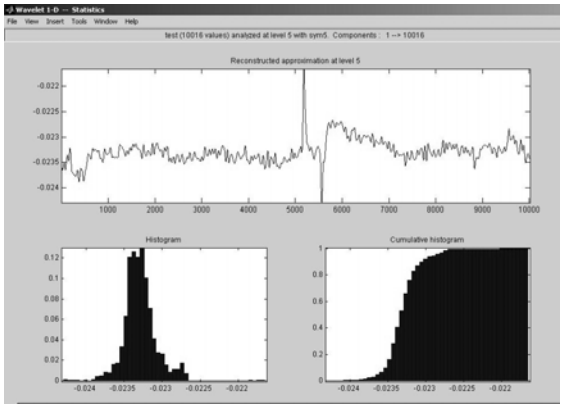

Fig. 5. Visual evoked potentials signals extracted from the averaged signals (first human subject).

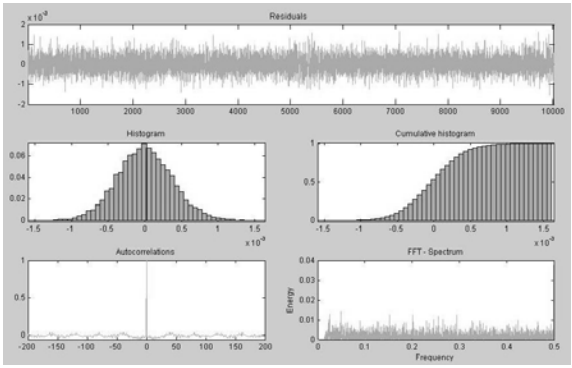

Fig. 6. Noise components extracted from the averaged signals (first human subject).

Bottom graph row, in Fig. 5, are histogram and cumulative histogram. To be noticed that the extracted signal is not centered on a certain value and the histogram contains a small peak in the right part of it. This peak is assigned to the evoked potential values that emerge during the stimulus and approximative 400 ms after the light stimulus (Fig. 7).

Middle graph row, in Fig. 6, are histogram and cumulative histogram, while bottom graph row are autocorrelation and the frequency spectrum. One can see that the noise has no correlated components and no frequency component is favored, while the amplitude values are centered on zero. The extracted noise is a white noise.

By assigning peaks in certain time windows (known from the literature), the P1, P2, P3 and N1, N2 visual evoked potentials are obtained, right after the stimulus goes off (Fig. 7). These peaks are well known by neurologists and their appearance is associated with the response of different parts of the brain to the visual stimulus.

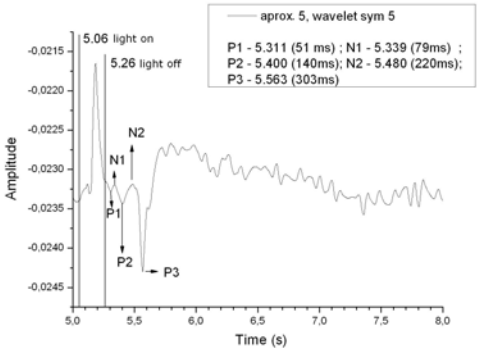

Fig. 7. P1, P2, P3 and N1, N2 visual evoked potentials (first human subject).

For the second human subject, a 6 level approximation using "bior 3.5" wavelet was used for decomposition and denoising.

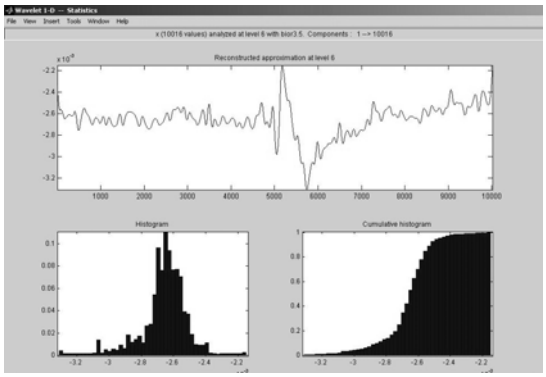

Fig. 8. Visual evoked potentials signals extracted from the averaged signals (second human subject).

Fig. 8 contains the evoked potential signals extracted from the averaged signals.

Again, the peaks were assigned after the stimulus went off, and P1, P2, P3 and N1, N2 visual evoked potentials being obtained (Fig. 9). Although these peaks appear at a different time moment than the peaks in Fig. 7, they are still inside the well known time windows in which they are supposed to appear. The difference between the two subjects can be explained by different speed reaction of the subjects to the visual stimulus.

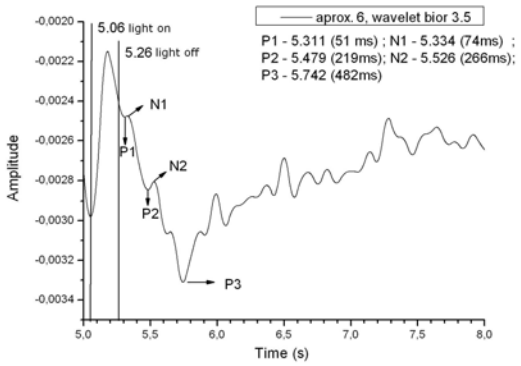

Fig. 9. P1, P2, P3 and N1, N2 visual evoked potentials (second human subject).

4. Conclusions

Raw human EEG signals, containing frequencies in the (0 – 5) kHz range were recorded. By lowpass filtering the raw signals, at 45 Hz, regular EEG signals were recorded. These signals have both shape and frequency spectrum as those known in the literature. Apart from that, in the raw EEG signal frequency spectrum, two higher frequency bands, namely, (0.9 – 1.2) kHz and (2.9 – 3.5) kHz were found to have similar amplitudes as the (0 – 40) Hz band. Similar amplitudes, from a mathematical point of view, means similar amount of information. Further studies of brain activity within these frequencies ranges might correlate them with certain brain functions or pathological diseases.

Being able to obtain visual evoked potentials from our recorded signals, it means that we can successfully record the brain electrical activity with our new designed amplifier. The visual evoked potentials from the two subjects were found within the time windows known from the literature. These results come as a validation for the amplifier as a confident EEG measurement tool.

Taking into account the frequency spectrum obtained from the raw EEG signal containing spontaneous brain activity and the success of recording visual evoked potentials, we can conclude that (0.9 – 1.2) kHz and (2.9 – 3.5) kHz frequency bands are related to brain activity.

Further studies should be conducted over these frequency bands, as they are likely to contain information about how certain parts of the brain work both in its normal state and in a wide variety of brain diseases.

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