Introduction

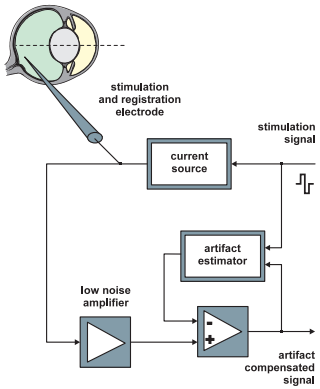
When stimulating neuronal tissue, it is often desirable to simultaneously record neuronal activity. The apparently easiest way is to use the same electrode for stimulation and recording. However, this approach causes a lot of problems due to the so called stimulation artifact superimposed on the neuronal signal. Since the artifact often is about 10,000 times larger than the neuronal activity (≈ 100 µV), the stimulus evoked response is hard to detect. Commonly used artifact suppression methods are based on positioning the recording electrodes on stimulus isopotential lines, or by blanking the artifact. The first method requires at least two electrodes, whereas the second does not allow the compensation of electrode properties.
Here, we present an approach which tries to take into account electrical properties of electrode / electrolyte interface and the limited input range and resolution of data acquisition systems.

Methods

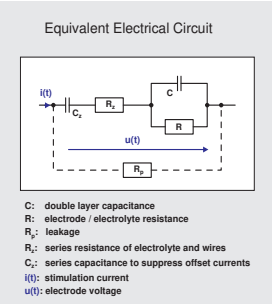
The main idea consists in the subtraction of a previously calculated artifact estimate from the recorded electrode voltage. This prevents the overload of the preamplifiers of the recording system by the artifact. Artifact estimates were generated on the basis of previously recorded artifacts or a parametric model of the equivalent circuit of the electrode / electrolyte interface. Parameters were estimated by a gradient method.

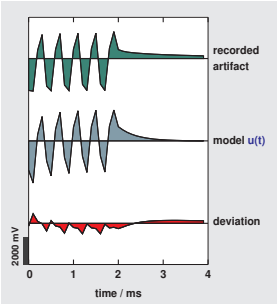
Method of Artifact Suppression

An estimation of the stimulus artifact is subtracted from the electrode signal to prevent an overload of the subsequent data acquisition system. The artifact estimator has access to the stimulation current and/or previous electrode voltage time courses for the calculation of the estimate.



Modelling Electrode, Tissue, and Current Source





Mathematical Description of Equivalent Circuit

$$u(t) = -a_2 \cdot \ddot{u}(t) - a_2 \cdot \dot{u}(t) + R_p \cdot i(t) + b_1 \cdot \dot{i}(t) + b_2 \cdot \ddot{i}(t)$$

with

$$a_1 = C_z \cdot \left[R_p + R_z + R\right] + R\,C$$

$$a_2 = R\,C\,C_z \cdot \left[R_p + R_z\right]$$

$$b_1 = R_p \cdot \left[C_z R_z + C R + C_z R\right]$$

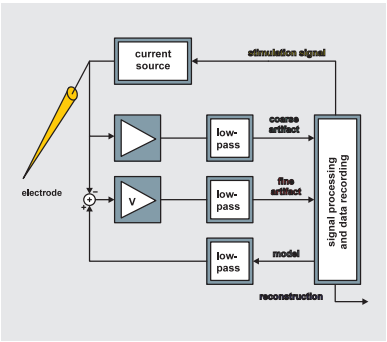
$$b_2 = R_p R\,C R_z C_z$$

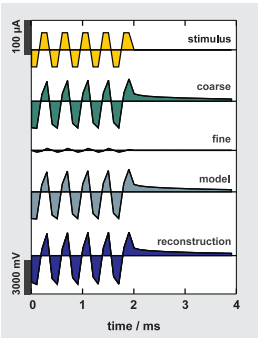
Estimation of Model Parameters Using Gradient Method:

R = 100 k
C = 3.2 nF
R_s = 18 k
R_p,C_z
i = -50 µA, rectangular burst

Adaptive Resolution Enhancement

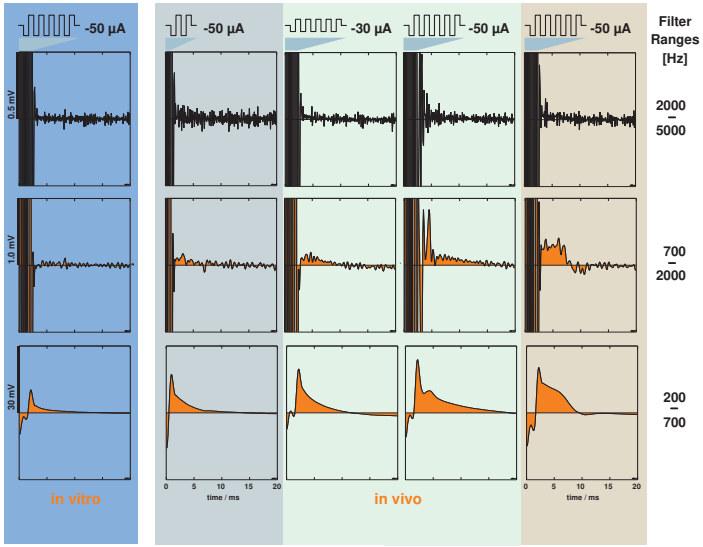
To achieve high amplitude resolution without limiting the signal range, the mean of several previous responses ("model") is subtracted from the current artifact in real-time. The resulting difference ("fine artifact") is amplified and subsequently recorded with high resolution. Since the "coarse artifact" and the model are also recorded, a high resolution voltage time course can be reconstructed for additional off-line data analysis.



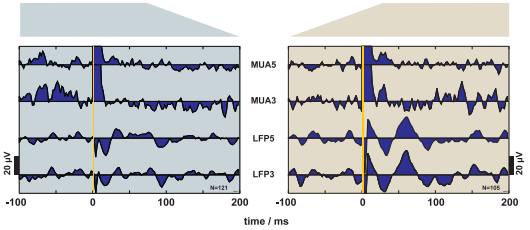


Results

Stimulation Electrode Voltages After Subtraction of Mean Artifact



Cortical Responses Evoked by Electrical Retinal Stimulation



Multi-Electrode Recordings of Slow Local Field Potentials (LFP) and Spike Activity of Local Groups (MUA)

Summary

Our approach allows to stimulate neuronal tissue and simultaneously record electrode voltages with high resolution from the same electrode.
Besides, it opens the possibility for a parameter based monitoring of electrode properties. The implemented resolution enhancement method leads to an increased signal to noise ratio without loss of information.
As expected, the quality of the artifact suppression is affected by the precision of the artifact estimation, i.e., it depends on the selection of an apropriate electrode / electrolyte interface model and subsequent parameter estimation. On the other hand, the estimation of electrode parameters depends on the stimulation current suggesting that non-linear processes at the electrode / electrolyte interface play an important role.

Conclusion

Future work should take into consideration non-linear electrode properties and time-varying processes for a more precise artifact estimation.