



D4.3

Rapid prototyping platform for feedback and stimulus generation

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ABSTRACT	This deliverable report describes the rapid prototyping platform (RPE) which is used within the CREAM project. This RPE platform is used for test the different modules developed in WP4 and to evaluate them with respect to the requirements for stimulation and recording identified and defined in WP2.
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1. Introduction

The objective of this deliverable report is to describe the rapid prototyping platform (RPE) which is used in CREAM for testing and evaluating the different modules developed in WP4. These modules include the acquisition of the electro encephalo gram (EEG) and electrical impedance tomography (EIT) data, the generation of visual, acoustic and electrical stimuli and blocks providing methods and algorithms for high resolution neuro- and brain-imaging.

A rapid prototyping environment has the advantage that each component can evolve and be exchanged independent from other components. It provides all interfaces necessary and handles the data transfer and transport between them. This simplifies the assembly and modification of the prototype used in WP5 to the study of the neural correlates of creativity in different domains.

2. Executive summary

This deliverable report describes the rapid prototyping platform (RPE) which is used within the CREAM project. This RPE platform is used for test the different modules developed in WP4 and to evaluate them with respect to the requirements for stimulation and recording defined in the deliverable D2.3. These modules include the acquisition of the electro encephalo gram (EEG) and electrical impedance tomography (EIT) data, the generation of visual, acoustic and electrical stimuli and blocks providing methods and algorithms for high resolution neuro- and brain-imaging. The RPE platform including all developed modules will also be used to assemble the prototype system used in WP5 to the study of the neural correlates of creativity in different domains.

3. Rapid prototyping platform

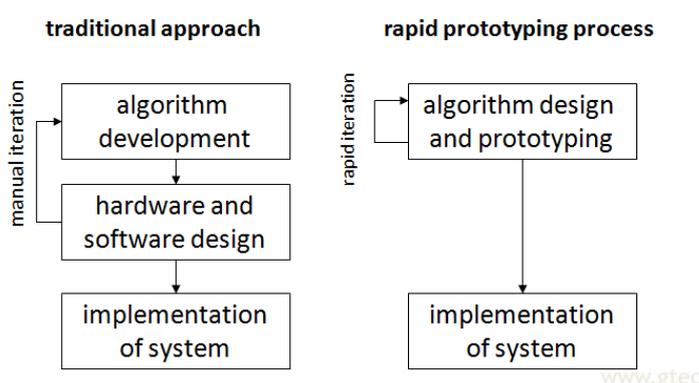


Figure 1: Comparison of a traditional development approach and a rapid prototyping process

This document describes the (RPE) used by the CREAM project shortly, the interfaces between the components of the CREAM RPE are documented. Figure 1 shows the difference between a traditional development process and a rapid prototyping development process. While in the traditional approach the algorithm has to be implemented on a software environment running on hardware to be designed, with the

rapid prototyping approach the developed algorithm can be directly implemented on the target system without further software and hardware development steps.

The rapid prototyping platform (RPE) used in CREAM is based upon Matlab/Simulink, which provide a large set of functions, tools and blocks to handle and process data offline and online. New algorithms and functions which are not natively provided by this basic system can easily be added through the well defined MEX application interface. The RPE used in cream in addition includes the following blocks and components.

3.1. Requirements

For running the RPE the following software requirements are necessary:

Matlab Licence: R2011a or newer (eg. 2013a). Following toolbox is mandatory

- ✓ Signal Processing Toolbox

Simulink Licence: R2011a or newer (eg. 2013a) Following blockset is mandatory

- ✓ Signal processing Block Set (since 2012a included within Signal Processing Toolbox)

Matlab/Simulink has to be installed either on Linux, or Microsoft Windows operating system.

3.2. Active electrodes

As reported in Deliverable D2.3, active electrodes will be responsible for:

- EEG signal pick-up (buffering/amplification)
- EIT signal pick-up (demodulation to low frequency)
- EIT current generation

Additionally, depending on how the final prototype will be designed, active electrodes will possibly be used for injecting DC and low frequency currents for tDCS and tACS.

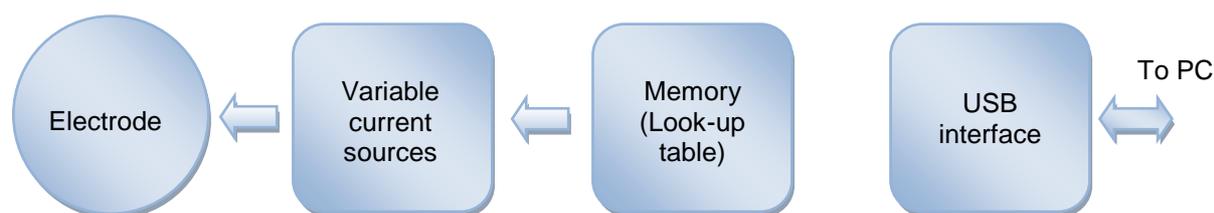


Figure 2: Control chain for electrical stimulus production

Figure 2 summarizes the control chain for producing the electrical stimuli for transcranial stimulation. The practical location of the single blocks will depend on whether the stimulating electrode will be active (electronics is placed directly on the electrode) or passive (electronics is in the back-end and the electrode simply provides electrical connection to the subject). As a function of this, variable current sources and the look-up table will be correspondingly located on the electrode itself or in the backend.

Variable current sources will be responsible for injecting the required current through the electrodes to the subject. Instantaneous current values will be directly synthesized from a sampled sequence of digital words (8 bit resolution minimum).

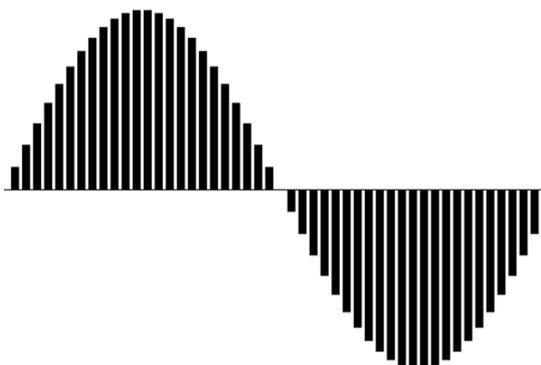


Figure 3: Example of digitized sine-wave. Current waveform samples are stored in memory at the beginning of the stimulation

This data will be streamed out of a sequential access memory which contains the samples necessary for current waveform reconstruction. The data will be transferred from the PC software interface to the memory which will then be continuously read to provide the correct output waveform current.

3.2.1 Electrode and Stimuli control

A graphic user interface (GUI) will be made available to program the electrode behaviour.

Basic programming options will be:

- Selection between EEG/EIT signal pick-up and EIT current injection
- In case of signal pick-up:
 - Extraction of EEG signal only
 - Extraction of EEG and EIT simultaneously
 - Electrode/Skin Impedance (ESI) measurement
- In case of EIT current injection:
 - Injected current frequency
 - Injected current amplitude

In the current version of active electrodes available at UNIBO [1], programming is provided through a LabView GUI (see

Figure 4). The GUI will be adapted in the course of the project to be directly run from Matlab/Simulink.

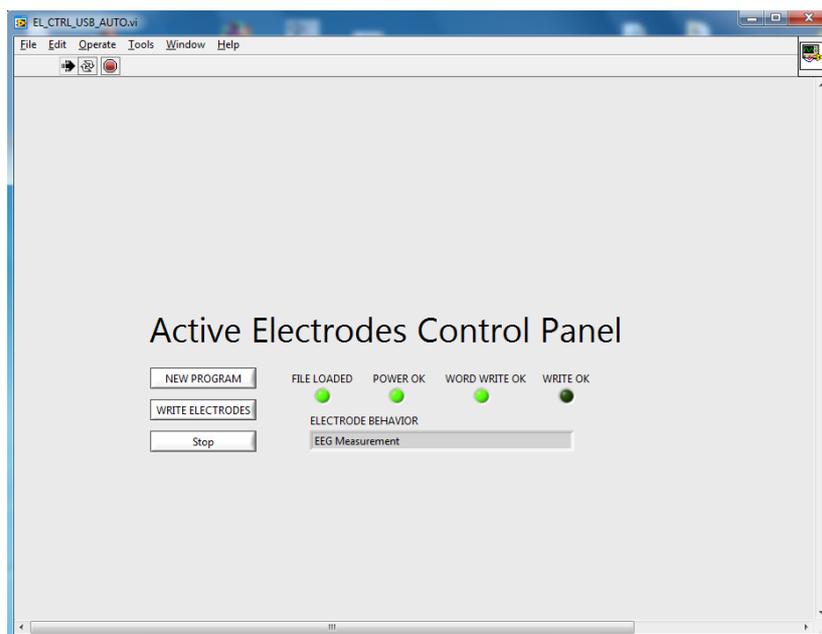


Figure 4: LabVIEW GUI for active electrode programming

If the active electrodes will be used for stimulation as well, the same GUI will be used to program stimulation currents. Otherwise a separate GUI will be provided.

The interface will allow selection of:

- positions of injecting electrode;
- stimulation current waveform shape (DC, AC, pulse);
- waveform characteristics:
 - amplitude;
 - frequency;
 - duty-cycle.

Depending on the configuration parameters, the RPE will take care of preparing the data-stream to be written on the memory of

Figure 2 for current source programming.

3.2.2 Environment for simulation of electrical stimulation current patterns

A software framework already available for EIT forward problem solution on a subject-specific head model [2] has been adapted to provide simulation of current patterns in the head domain due to electrical stimulation.

The main objective is to provide a tool for determining the optimal current patterns and electrode location which can maximize current densities in certain region and/or minimize those in other.

The software workflow proceeds as follows:

Whenever a magnetic resonance scan of the subject is available, magnetic resonance imaging (MRI) images are segmented and classified to obtain a realistic volume

composed of five different types of tissue, namely scalp, skull, cerebrospinal fluid (CSF), grey matter and white matter. If subject-specific MRI data is not available, standard atlas models can be used. Where available, Diffusion tensor imaging (DTI) data can be used to track white matter fibre orientation, which results in an anisotropic behaviour of the white matter region.

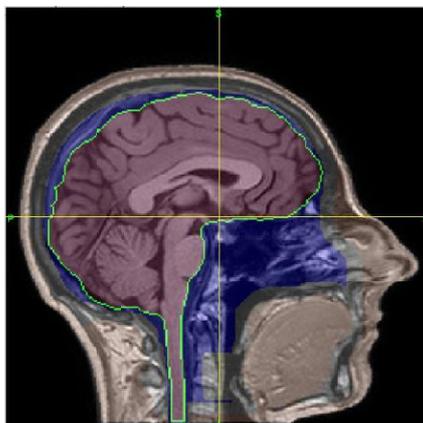


Figure 5: Segmentation of the volumetric MRI in the 6 main tissues

1. Conductivities are assigned to each different layer from literature data. If EIT data on the subject is available, conductivity estimates provided by this technique can be used to improve the specificity of the model to fit the subject.
2. The required number of electrodes is positioned on the head model. This can either be done manually to reflect exact positions of the electrodes or by an automated routine which equally distributes electrodes in order to provide uniform density.
3. A realistic Complete-Electrode-Model (CEM) for each electrode is built, in order to take into account the electrode shape and finite size and contact impedance.

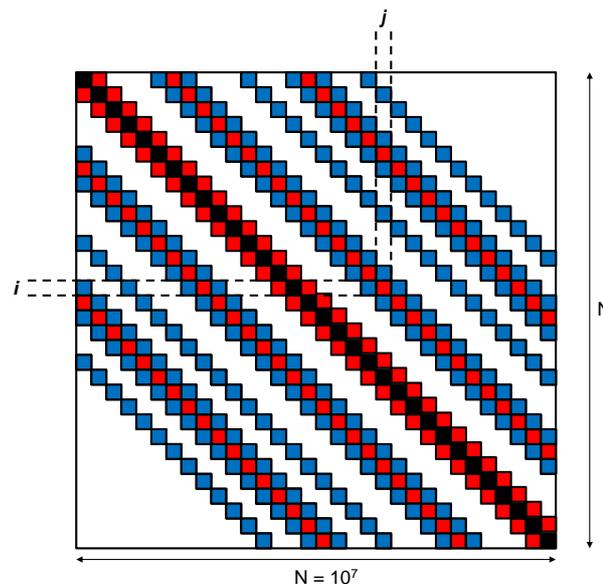


Figure 6: Structure of the matrix associated to the discretization of the Poisson's equation. It is a square banded symmetric matrix (definite positive considering real conductivity) of size N equals to the number of voxels of the MRI head volume. Each non zero elements represents an ohmic contact between the i -th node and the j -th node. Main plus the 7 red diagonals are enough in case of isotropic conductivity, 17 diagonals are present if tissue anisotropy is taken into account.

4. A complete electrical model for the head and the electrodes is built. Finite Method Volume is adopted to discretise the Poisson equation which regulates current density distribution in the volume.
5. The result of the linearization process is a linear system represented by a banded matrix (see Figure 6), whose structure makes it suitable for parallel processing on multi-GPU/CPU systems. The linear system is solved through Conjugate Gradient (CG) method, providing the electrical potential distribution inside the head volume as a function of the injection pattern.
6. Local current densities are computed per each voxel of the head volume. Current densities are then estimated in the skin regions underneath the electrodes (for eventual minimization for reducing patient discomfort) and in the cortical regions which are target of the stimulation.
7. Optimal electrode location and current patterns can be estimated through repeated simulations.

UNIBO's current system configuration for the simulator summarizes to:

- Two Intel Xeon E5520 CPUs @ 2.4 GHz
- Two NVIDIA GTX 590 graphics cards
- 24 GB RAM.

Once the head model is built, solution of the linear system requires between 5 and 10 seconds, depending on the required accuracy. Hundreds of different current patterns

can be simulated in one hour, exploring a large number of combinations between stimulation and reference electrode.

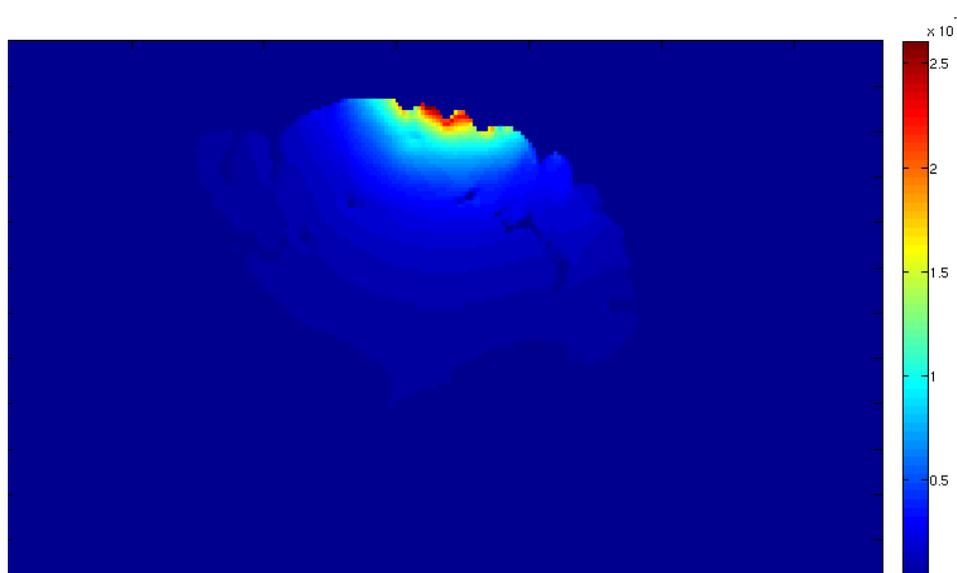


Figure 7: Examples of current distribution for standard HD-tDCS electrode placement

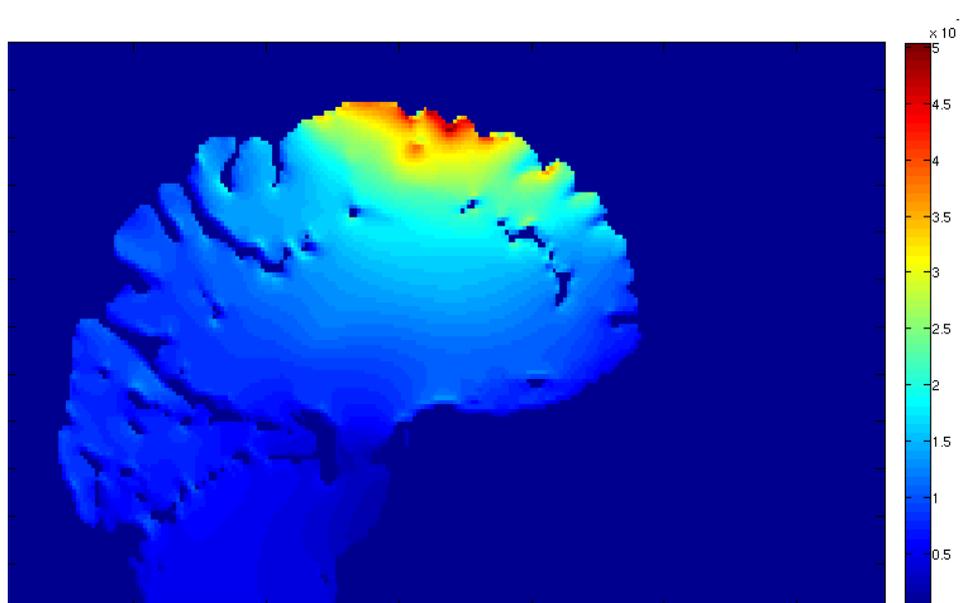


Figure 8: Examples of current distribution for modified HD-tDCS electrode placement

As an example,

Figure 7 shows simulated current distributions inside grey and white matter due to standard high density (HD) transcranial direct current stimulation (tDCS) electrode placement [3] with one stimulating electrode and four close-by electrodes for current return.

Figure 8 shows a different current distribution obtained by the same stimulating electrode but with several return electrodes located approximately 10 cm apart from the first. In the first case, stimulation is much more concentrated in the target area underneath the stimulating electrode, however the peak current density is significantly lower (factor 2) due to the fact that a larger amount of the current is shunted through skin and CSF rather than reaching the cortical region of interest.

These very first preliminary results already show how important is the location of not only the stimulating electrode but also of the reference ones.

Having this tool at hand can be of help in improving the understanding of the differences among different stimulation patterns and electrodes' shapes, sizes and placements.

3.3. Biosignal amplifier

One key component of a system for minimally invasive Neuroimaging and stimulation system is the biosignal amplifier. The EEG signals will be recorded using a g.HIGHamp biosignal amplifier. Figure 9 shows the g.HIGHamp device used within CREAM. It offers 144 general purpose input channels and sends the digitized data via USB to the processing unit.



Figure 9: g.HIGHamp

3.4. Software

The signal flow oriented Simulink, which runs under MATLAB, allows people to create block diagrams for signal processing. The amplifier is pacing the whole block model, which guarantees the real-time processing. The utilized algorithms represented via the Simulink blocks can be written in MATLAB code or in C code and are called s-functions (system functions). Simulink provides also a large library of signal processing blocks including filtering, down-sampling, online fast Fourier transform (FFT), which can be integrated by drag-and-drop into the models. A further big advantage is the exchangeability of the blocks. Each Simulink block also represents an encapsulated object which can be used and tested individually.

3.4.1 *g.HIGHamp High-speed On-line Processing*

After installing the Highspeed Processing Toolbox, within Simulink, a specific library called gHIGHampLib is available. The four included blocks are enlisted below (see Figure 10). They can be applied to a Simulink model by drag and drop.

- g.HIGHamp driver block
- Calibration block
- Impedance Check in case of passive electrodes
- Scope Scaler

Before starting the simulation it is necessary to connect the g.HIGHamp to the laptop, to switch it on and to provide the amplifier settings (see Figure 11). For explanation of the single settings the reader should refer to the user manual.

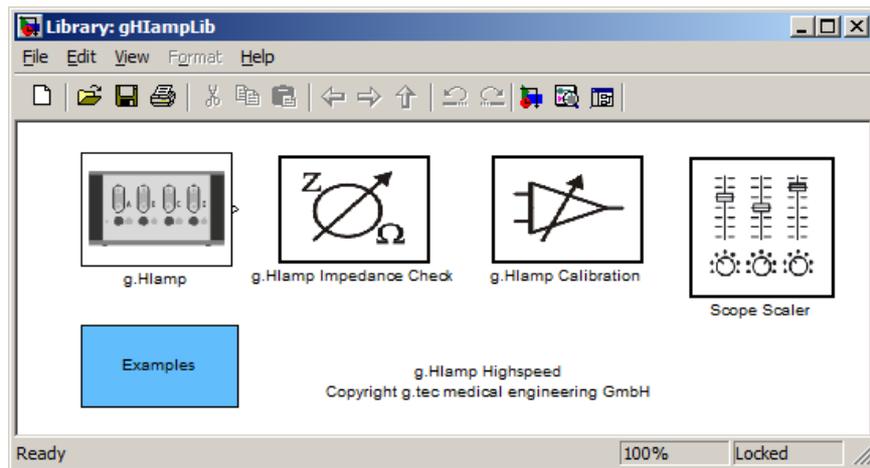


Figure 10: Simulink library for g.HIGHamp

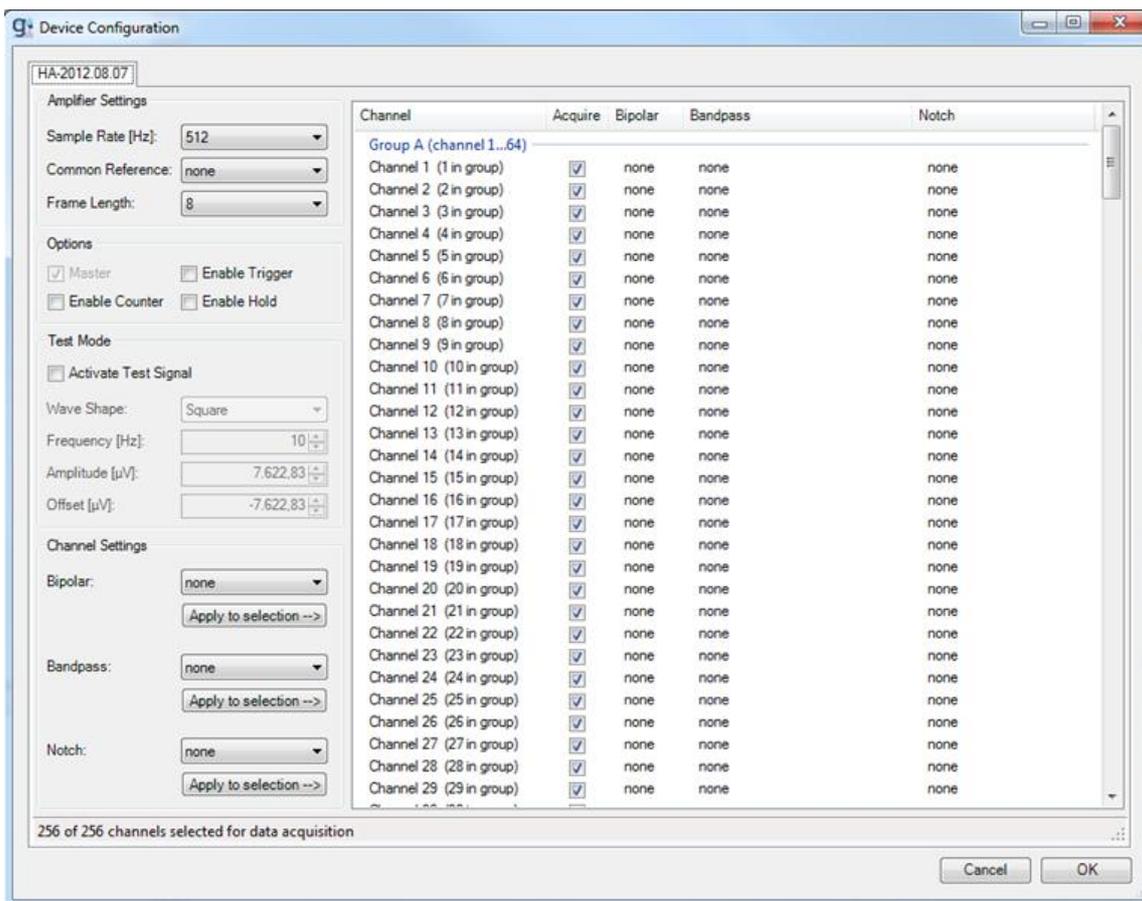


Figure 11: Settings of the g.HIGHamp

3.4.2 Active electrode signal reconstruction

As described in D3.2, active electrodes will use a single acquisition channel for EEG, EIT and ESI signals relative to one electrode by adopting frequency division multiplexing techniques. The three signals are amplitude modulated by carriers at different frequencies on the active electrode. After analog-to-digital conversion, the three signals are separated and recovered. Figure 12 shows a Simulink model performing such features.

The main functions of the Simulink model are:

- Data acquisition from backend
- Carrier recovery and demodulation of the signals
- Scaling and filtering

Data acquisition (blue box) exploits the Highspeed Processing Toolbox; the red box provides the carrier recovery for demodulation of the three signals. Processing of the three signals is performed after signal down-conversion to baseband (green boxes).

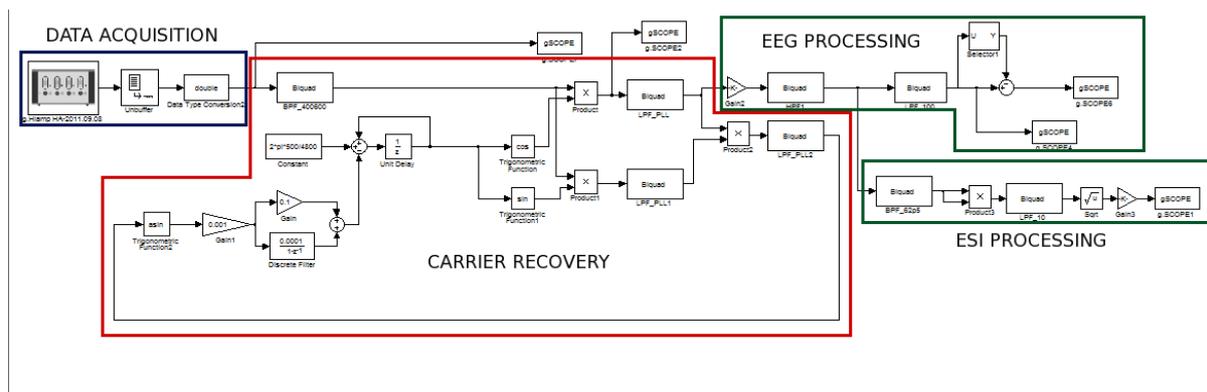


Figure 12: Simulink model for EEG/ESI data extraction from active electrode output

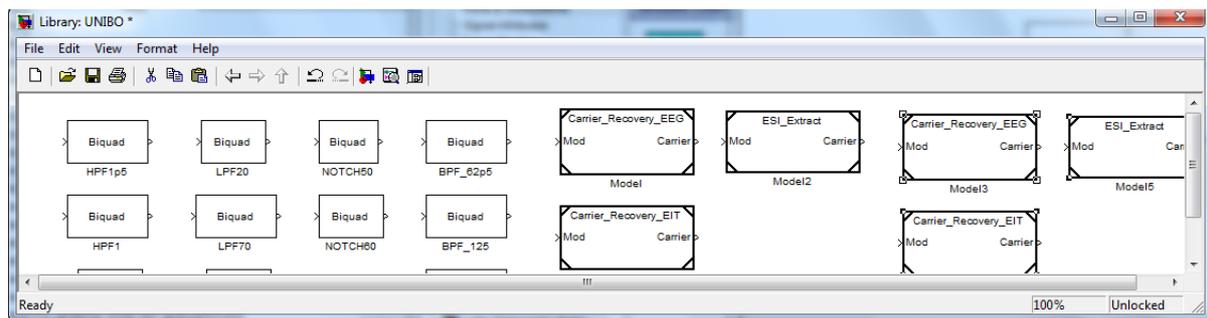


Figure 13: Simulink Library for EEG/EIT/ESI reconstruction from active electrode output

These functionalities and post-processing (e.g. filters) are collected in an ad-hoc Simulink library (see Figure 13)

4. Concluding section

The presented RPE offers the necessary flexibility to implement new and advanced algorithms for minimal invasive neuroimaging and stimulation. It provides all necessary hard and software components to record EEG and ETI data and to process it online. The flexibility and power of Matlab/Simulink environment makes it possible to implement, combine and to adjust the different modules and algorithms used to process EEG and EIT data online and to deliver visual, acoustic and electrical stimuli independently. The combination of the different modules easily be adopted to the stimulation paradigms and protocols used in WP5.

5. References

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- [3] P. Minhas et al., "Electrodes for high-definition transcutaneous DC stimulation for applications in drug delivery and electrotherapy, including tDCS," *Journal of Neuroscience Methods*, vol. 190, no. 2, pp. 188-197, 2010.