

# UPSIDE

Choose an item. **D3.1**

Grant Agreement No.	101070931
Start date of Project	1 September 2022
Duration of the Project	48 months
Deliverable name	D3.1
Partner Leader	TUD
Dissemination Level	PU

<i>Status</i>	Final
<i>Version</i>	V1.0
<i>Submission Date</i>	29-02-2024

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*UPSIDE project has received funding from the European Union's Horizon Europe EIC-PATHFINDER programme under grant agreement No 101070931.*





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Pink	247	181	192	#F7B5C0
Grey	161	161	161	#A1A1A1
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## History of Changes

Version	Change made	Date
V0.1	First draft	28/08/2024
V1.0	Minor corrections	03/03/2024

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## *Abbreviations*

EBI: Epidural Brain Interface

eFUS: Epidural Focused Ultrasound

eREC: Epidural Electrical Recording

GUI: Graphical User Interface

MCU: Microcontroller unit

MEA: Microelectrode Array

PCB: Printed Circuit Board

WP : Work Package

ZIF: Zero-Insertion Force

## Executive Summary

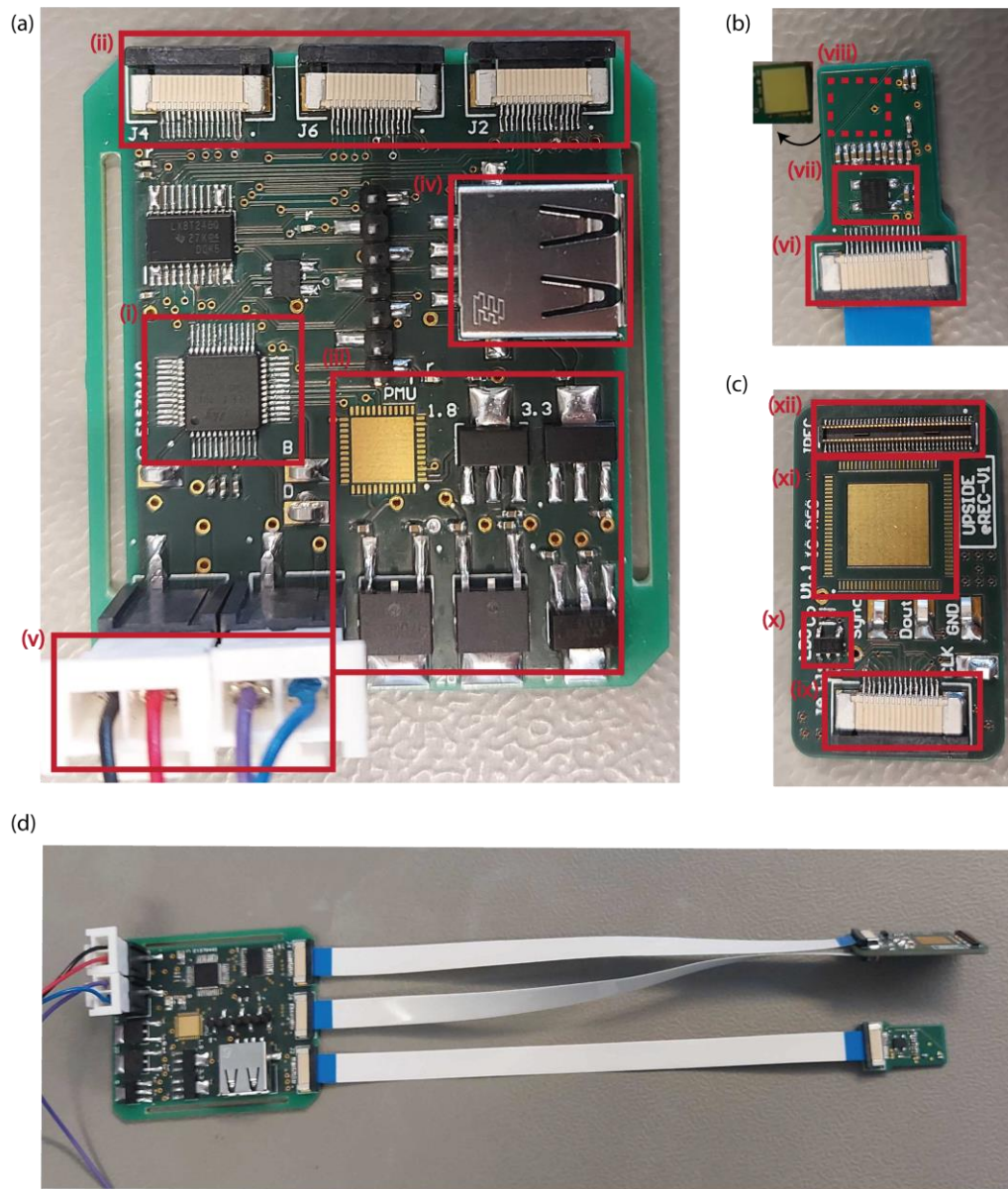
Behavioral experiments with rat models of depression featuring both implantable focused ultrasound neurostimulation and electrical recording devices, ideally require light and compact electronics that can simultaneously control the implantable devices and relay information to and from a computer for the proper control of the experiments and data analysis. We have conceived such electronic relay station as a miniaturized electronics board that is worn by the rat as a backpack. The relay station was designed with all the necessary electronics for powering, control and interface with ultrasound and electrical brain interfaces. This report describes its implementation and experimental validation, including a demonstration video describing the full system and showcasing a few test cases. This relay station electronics sets the stage for future behavioral experiments with freely moving rats, where neuroscientists can easily change the stimulation location in real-time by setting the desired stimulation coordinates for the focused ultrasound chip, and obtain the changes in brain activity in real-time, via a user-friendly software in a computer.

## 1. Introduction

This deliverable reports and demonstrates the design and test of a printed-circuit board (PCB) entitled “Relay Station”, which relays information between a host computer, and the epidural brain interface (EBI) composed of an epidural focused ultrasound (eFUS) and epidural electrical recording (eREC) chips. The communication between the host computer and the Relay Station is performed by means of a graphical user interface (GUI), custom designed for this purpose. The system was experimentally characterized by mounting the Relay Station as a backpack on a 3D printed model of a rat, as intended for the final application, and a benchtop setup featuring off-the-shelf electronic equipment was used to visualize signals of interest in the Relay Station. The eFUS and eREC PCBs were designed for demonstration purposes, only, and do not yet contain the respective eFUS and eREC application specific integrated circuits (ASICs), piezoelectric transducers and microelectrode arrays, which are being designed in the context of other tasks in the project. The final goal of the Relay station is to allow for the behavioral experiments with rat models of depression for both focused ultrasound stimulation and electrical recording, while biomarker detection takes place in the host computer. In the following two sections, details are provided about the printed circuit board prototyping, and characterization results. This written report is accompanied by a demonstration video, which can be accessed [here](#).

## 2. Relay Station Prototyping

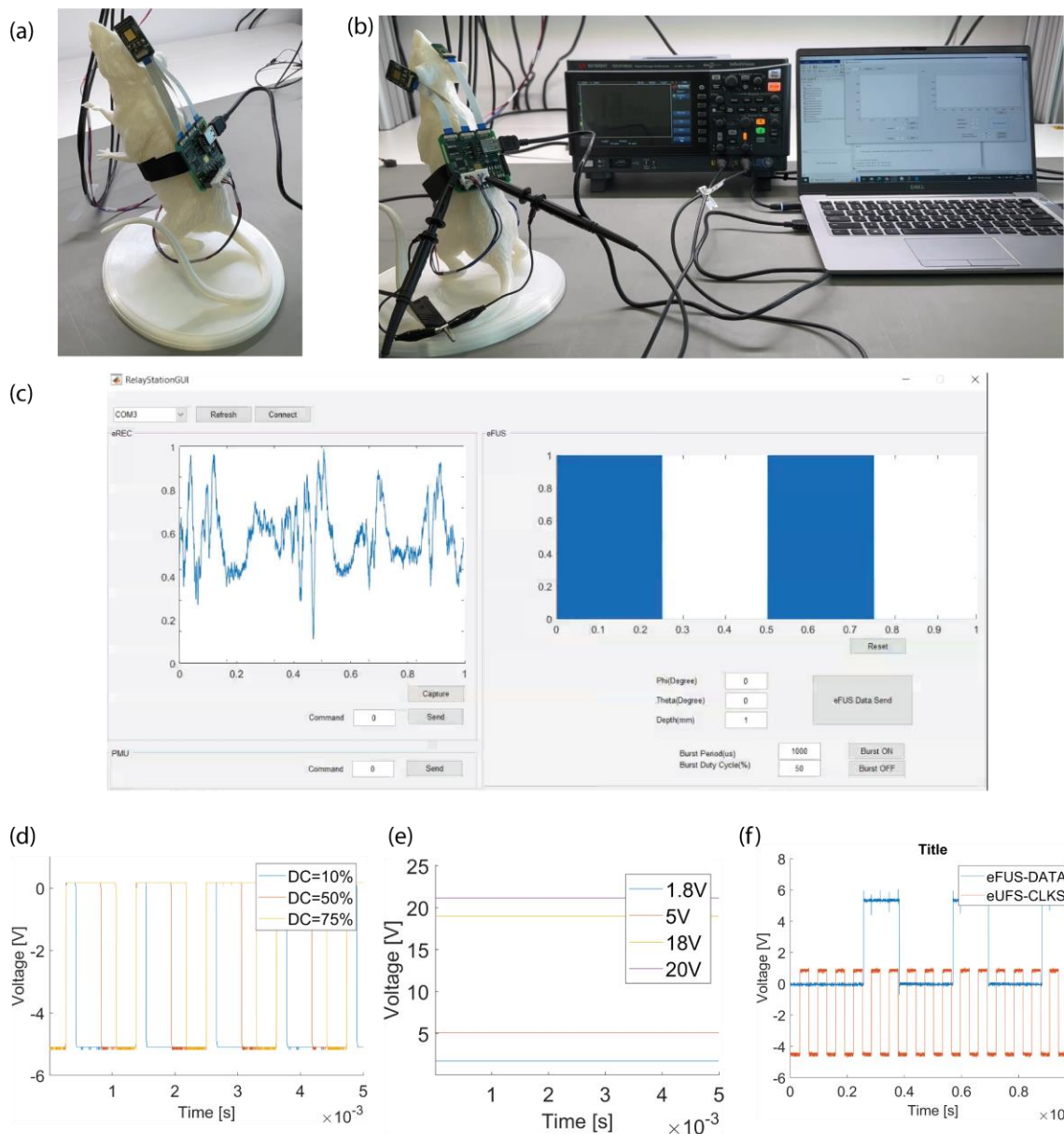
The Relay station design was conceptualized in order to be able to establish a communication link between a host computer and the eREC and eFUS chips, and to include a power management unit (PMU, designed in task 1.3), which provides the power for both chips, from a 3.7 V lithium battery. Since the PMU experimental tests are still ongoing, it’s use will be tested in a current version of the relay station, with the power currently being provided by a desktop power supply. The relay station includes 5 main sub-blocks, as seen in Figure 1a. A microcontroller unit (MCU) includes the firmware that receives commands from the host controller computer and configures the eREC and eFUS chips, and receives data from the eREC chip and relays it to the host controller (*Figure 1a,i*). A MCU from STMicroelectronics (STM32G0B0CE) was selected, due to its compactness and high-performance for the desired application. The physical interface with the eFUS and eREC PCBs is done by means of flexible cables. For the eFUS chip, one flexible cable was sufficient, however, for the eREC chip, the high-speed digital signals and the power supply levels were placed in different cables, to avoid interference. The three flexible cables are connected to the Relay Station by means of a zero-insertion force connectors (ZIF), as seen in *Figure 1a,ii*. The power supply voltages to power both eREC and eFUS chips are also included in the Relay Station, and are implemented by 5 voltage regulators to generate 1.8 V, 5V, 18 V and 20 V for the eFUS chip, and 3.3 V for the eREC chip. A voltage regulator to generate the required 1.1 V for the eREC chip is done locally in the eREC PCB, as seen in *Figure 1b,vi*. The footprint of the PMU developed by Silicongate (task 1.3) is also included for future integration. Finally, the USB connector (*Figure 1a,iv*) and power sockets (*Figure 1a,v*) are included for both USB communication with a host computer, and to receive power from a desktop power supply. With the future integration of the PMU, a 3.7 V Lithium battery will also be used instead of the desktop power supply.



**Figure 1** (a) overview of the Relay Station PCB featuring: (i) Microcontroller unit (MCU); (ii) Zero insertion force (ZIF) connectors to connect to eREC and eFUS PCBs; (iii) Power management unit, temporarily with off-the-shelf integrated circuits, and in a future version with the PMU chip designed in task 1.3; (iv) USB connector for communication with host computer; (v) power connectors for powering the board from a desktop power supply. In a future version, a battery will be used. (b) eFUS PCB, including: (vi) ZIF connector to interface with Relay Station; (vii) a local oscillator circuit to provide high-frequency (48 MHz) clock signal for the eFUS chip (Tasks 1.1 and 1.2); (viii) footprint for eFUS chip on bottom side of PCB. (c) eREC PCB, including: (ix) ZIF connector for interface with Relay Station (another one is present on the bottom side of the PCB); (x) a low-dropout regulator to generate a 1.1 V power supply for the eREC chip with low noise; (xi) footprint for the eREC chip (task 1.4); (xii) connector for interface with passive microelectrode arrays (MEA, Task 2.1). (d) full assembly of the Relay Station connected to the eFUS and eREC chips by means of flexible cables.

The eFUS PCB includes a local oscillator to produce a 48 MHz clock for the proper operation of the eFUS chip (**Figure 1b,vii**). Transmitting this clock via a long flexible cable could lead to reduced performance.

Furthermore, the eFUS PCB also includes decoupling capacitors, the ZIF connector for the corresponding flexible cable (**Figure 1b,vi**), and the footprint for the future integration of the eFUS chip (**Figure 1b,viii**). Finally, the eREC PCB, besides two ZIF connectors (one on each side of the PCB, (**Figure 1c,ix**), and the



**Figure 2** (a) Relay Station, eFUS and eREC PCBs mounted on a 3D printed model of a rat of similar size as Sprague-Dawley rats used in WP4; (b) complete measurement system with the Relay Station connected to a host computer via an USB cable, and to an oscilloscope for capturing data; (c) graphical user interface for controlling and acquiring neuronal data from the eREC chip (eREC section, left), to control and set the stimulation parameters and location for the eFUS Chip (eFUS section, right), and to configure the PMU to generate the correct power supply voltages in a figure version (PMU section, bottom left). (d) Measurement on the Relay Station PCB of control signals for the eFUS chip that set the duty cycle of the ultrasound waveform, with examples for 10%, 50% and 75%. (e) power management unit generating the necessary power supply voltages for the eFUS and eREC chips. For the eREC chip, a 1.1 V power supply is then generated locally on the eREC PCB. (f) an example of a digital bitstream (eFUS-DATA) being transmitted to the eFUS PCB via the Relay Station. The eFUS-DATA bitstream contains the digital information regarding the focal spot coordinates for the generated focused ultrasound beam.

local voltage regulator, also includes the footprint for the future integration of the eREC PCB (**Figure 1c**,xi), and a connector for interfacing with the microelectrode arrays (MEA) developed in WP2 (**Figure 1c**,xii).

Both the eFUS and eREC PCBs were design for demonstration purposes only and were made large for easy of testing. In future versions, the PCBs will be made with a smaller dimension such that it matches the requirements for implantation, set in WP4. In **Figure 1d**, the full system is shown, with the Relay Station connected to the eFUS and eREC PCBs. Furthermore, both the Relay Station and GUI will be developed further throughout the project as required by the performance of the system and the different requirements of the experiments. For example, in the case of the eFUS chip, given its beam-steering capabilities in 3D, the GUI might include in the future automated focusing search patterns where the focal spot is automatically changed in 3D according to specific spatial and time steps, such that the expected electrical recording signature is obtained.

### 3. Experimental Characterization

To demonstrate how the proposed Relay Station can be used in rat experiments, it was mounted with Velcro straps on the back of a 3D printed model of a rat, with similar dimensions to the Sprague Dawley rats used in the experiments of WP4 (**Figure 2a**). The Velcro straps were placed in two slits in the Relay Station PCB, one on the left side and one on the right side, clearly visible in **Figure 1a**. After this assembly, the Relay Station was connected to a host computer via a USB cable, and to an oscilloscope with two voltage probes, for measuring relevant signals in the Relay Station **Figure 2b**. The Host computer featured a graphical user interface, custom designed for interfacing with the MCU in the Relay Station, and with the PMU in a future version (**Figure 2c**). The interface with the Relay Stations allows for the control of the eREC (programming the chip and requesting data) and eFUS chips (setting ultrasound waveform shape and focal spot coordinates), as shown in **Figure 2c**. Measurements have also shown that the MCU can produce the control signal required by the eFUS chip to define the ultrasound waveform duty cycle, with examples shown for a duty cycle of 10%, 50% and 75% (**Figure 2d**). The power supply levels required by the eFUS chip were also measured with the correct levels (**Figure 2e**), as expected, and a digital bitstream produced by the MCU and encoding the focal spot coordinates was also recorded, with a partial section shown in **Figure 2f**.

### 4. Conclusions

This report described the design and test of a Relay station PCB to be used as a wearable backpack during behavioral rat experiments. The design was described including the different blocks of the system, as well as the interface between relay station and eREC and eFUS PCBs. The system was showcased by being mounted on a 3D printed model of a rat, and controlled by a custom-designed graphical user interface, for which future versions will be used in future *in vivo* experiments. This report is accompanied by a demonstration video which is disseminated via the UPSIDE project social media accounts.