Neuroon Open Documentation

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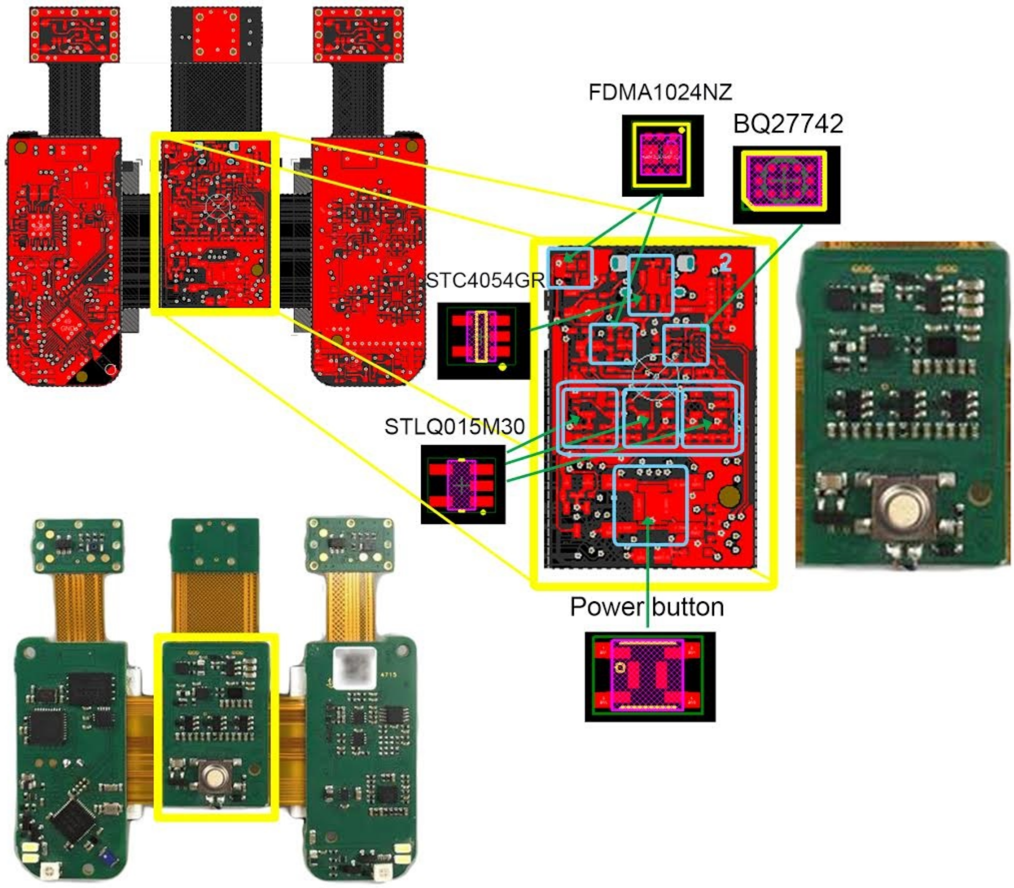
Inteliclinic

Table of Contents

1 Power section



1.1 Power management and battery charger

Power management is realised using following modules:

- BQ27742 used for battery protection,
- three STLQ015M30R LDOs used for power distribution,
- STC4054GR as battery charger,
- three STLQ015M30R as LDO,
- fuses and thermistors.

For user safety batteries are packed into special metal covers. Each battery pack has overheat thermistor attached directly to the cover. Due to safety reasons batteries are irreplaceable.

Neuroon open has three LDO (STLQ015), that craetes three sepated voltage sources with 3.0 V (±2%) output voltage and max. 150 mA current.

1.2 Power button

$OmronB3SN - 3012$ is sealed button used as power button. R1.10 is used as current limiter. C1.10 is used for debouncing. Bouncing is a natural phenomena that occurs when the user press the switch, which connect and reconnect many times before the connection is established. Wire and switch resistance together with capacitor are used in low-pass RC filter design, that cuts off fast changes and smooths the turn on signal.

Due to manufacturer documentation bouncing time should not exceed 5 ms, for software debouncing this should be minimal time to wait. 10 ms is recommended time.

Fig. 1. Battery with metal cover and thermistor attached to it under label

1.2.1 Features Power button circuit features:

- "on" when pressed,
- maximum bouncing time 5 ms,
- construction conforming to $IP67$ (IEC-60529),
- a stainless-steel spring provides a crisp clicking action,
- durability: 100,000 operations min.,
- contact resistance $100m\Omega$ max.

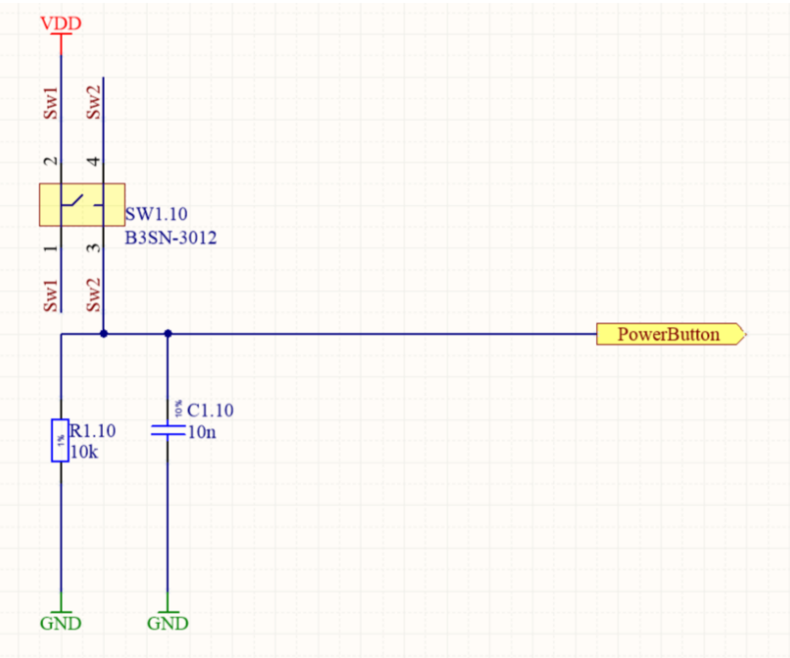
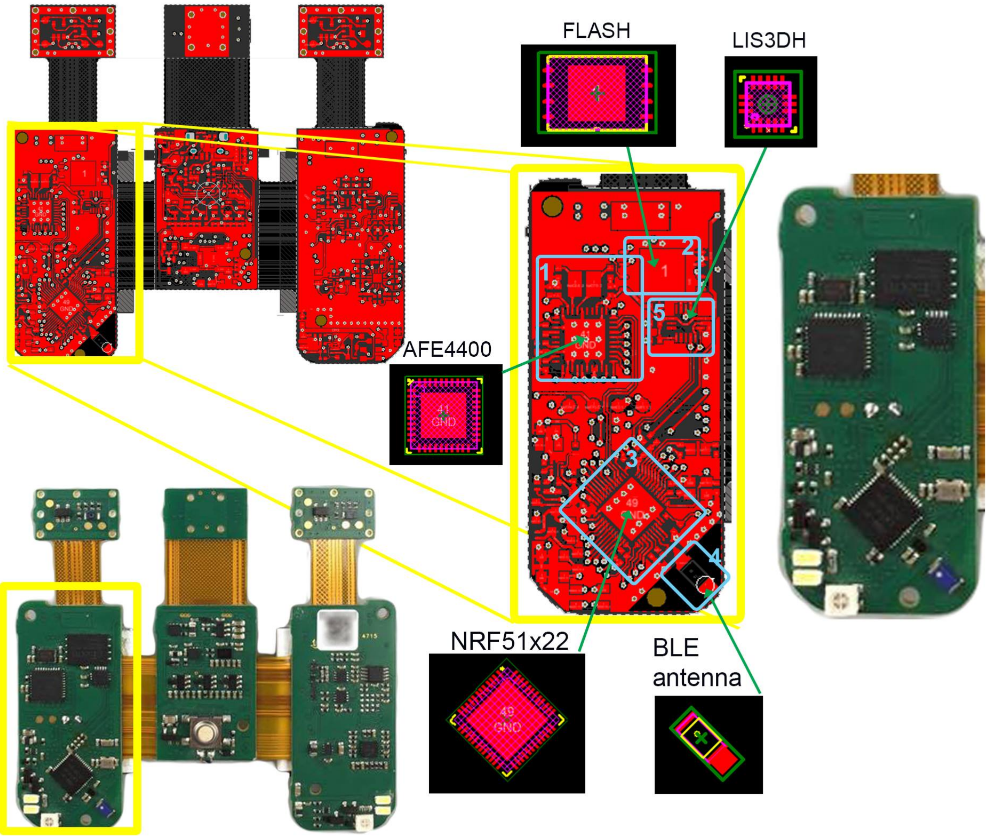


Fig. 2. Power button

2 Digital section



2.1 Movement Sensor (LIS3DH)

2.1.1 Functionality LIS3DH is MEMS (Micro Electro Mechanical Sensor) ultra-low-power high-performance 3-axis "nano" accelerometer. In NEUROON it is used to detect motion, its duration and intensivity, what is used for wake-up tracking. Remember that head movement usually implies strong muscule signals which may influence the EEG measurement (muscle signals may be even 1000 times stronger than EEG) and sometimes its good to know that disturbances may be a result of movement.

Movement sensor may be used in power management. Using its readings it is possible to put microprocessor to sleep mode and wake it up in most proper time.

For further application it is possible to use it to measure the position of the forehead, however it may be necessary to apply calibration algorithm.

2.1.2 Features LIS3DH features:

- 16-bit data output,
- I2C interface,
- free-fall interrupt generator,
- motion detection interrupt generator,
- output data rate from 1 Hz to 5.3 kHz,
- integrated 32-level FIFO buffer.

2.1.3 Module placement LIS3DH module is placed just below Flash memory on the same board as Nordic NRF51822QFAC SoC.

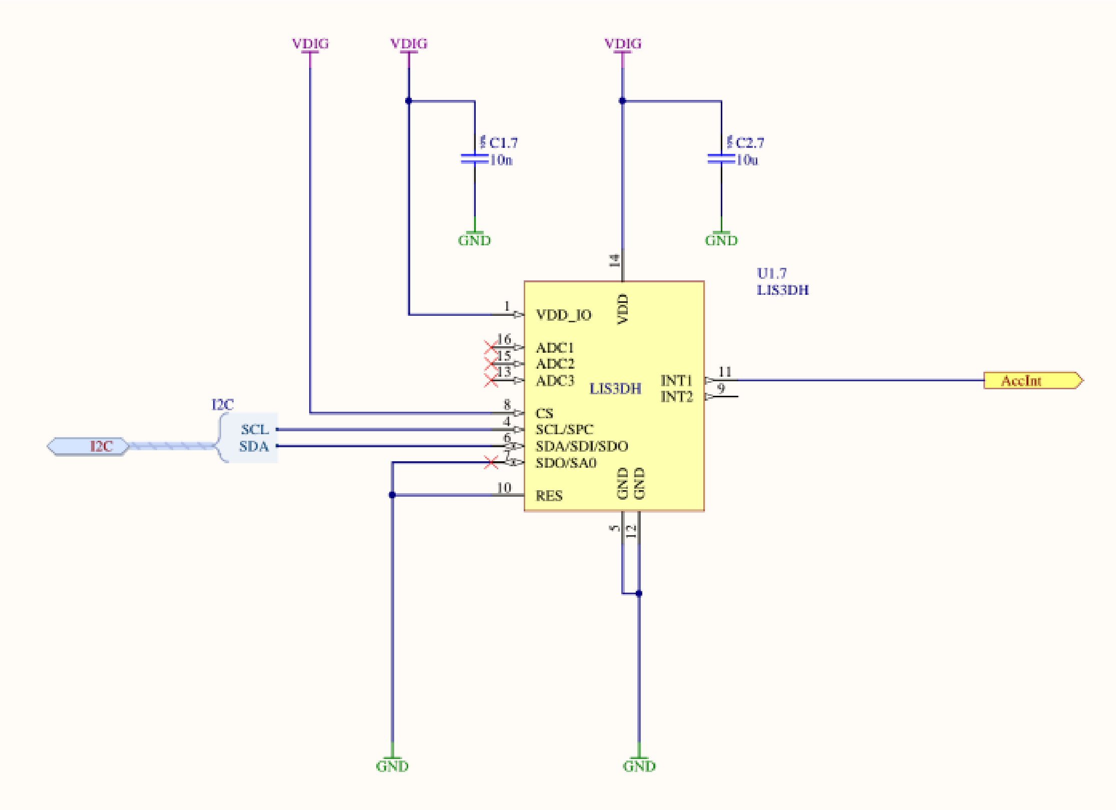


Fig. 3. Movement sensor schematic

2.2 Temperature sensor

Neuroon has two independent temperature sensors. Each of them works as independent uncompensated Wheatsone bridge with platinum thermistor PT1000. PT1000 is placed on bottom layer on separate PCB. PT1000 is very precise and linear thermistor. Temperature sensors are connected to ADC in NRF SoC.

2.2.1 Functionality Humans are homeotherms, that means they regulate precisely their inner body's temperature. The day-night cycle is regulated by suprachiasmatic nucleus (SCN) located in the same region of the hypothalamus, where "cold" and "hot" reception is integrated, creates a balanced output, like a thermostat. It's no coincidence. Every cell of the mammalian body uses internal circadian oscillators to govern their circadian pattern of gene expression, which is crucial to metabolic activity control. These cellular oscillators are controlled by core body temperature. Because the temperature might vary due to different reasons, like fever or poor environmental conditions, it is crucial to gather other clinical data before making any assumptions concerning one's health. Changes in core body temperature might be connected to the disturbed circadian rhythm, as observed in high fever, autoimmune diseases. Unfavorable conditions like hot and moist environment might disturb your sleep.

2.2.2 Design and LTspice simulation Temperature sensor can be easily simulated in LTSpice like program:

As you may see, in our bridge we used two resistances: 9.1 kΩ and 1.1 kΩ. It simply means that measurement bridge is in equilibrium when left and right branch has the same resistance. Equilibrium means that the voltage difference between measurement points placed in each branch is equal almost zero. PT1000 has 1.1k resistance in 26 °C, what means that our bridge starts to measure temperature when is higher than 26 °C degrees.

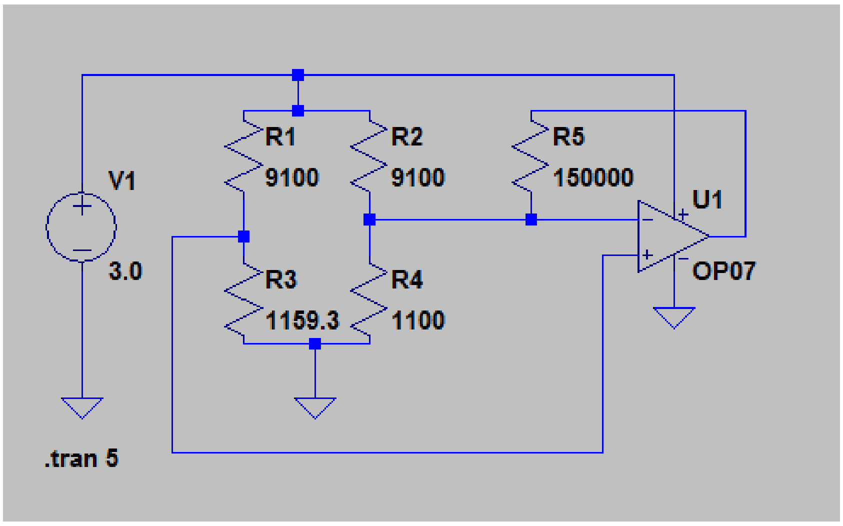


Fig. 4. LTspice simulation of Wheatsne Uncompensated Bridge with an amplifier

26 °C was set as minimal temperature to measure temperatures below typical human forehead temperatures.

Maximum measure temperature is 40 °C.

Finally the voltage signal (from range 0V up to 3V) enters 10bit Analog to Digital Converter in N51822 SoC. That simply means that ADC reference has 2 to power 10 ($2^{10} = 1024$) voltage levels. Possible references are 1V, 2V, 3V

Small voltage quants make our thermometer really vulnerable to very small changes in temperature. The highest sensitivity is reached for 1V and 2V reference. Neuroon Open may simply change ADC reference to higher (or lower) depending on reading.

2.2.3 Heat transfer design

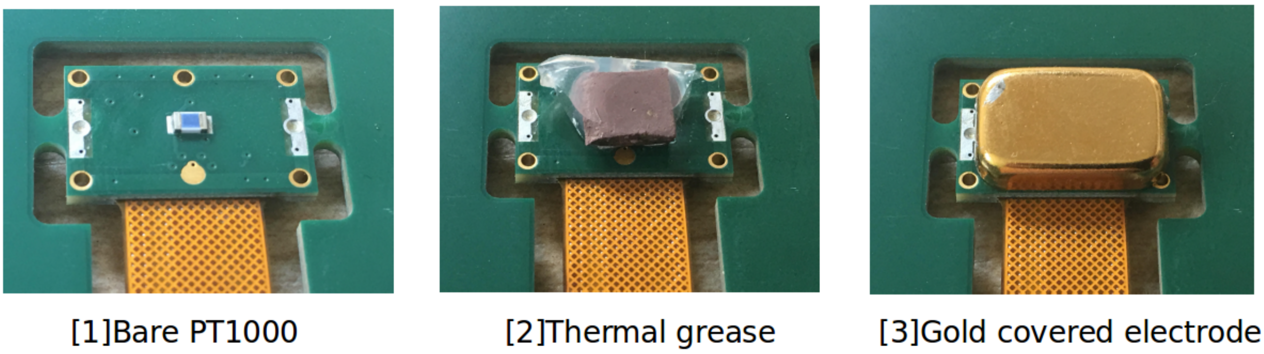


Fig. 5. Heat transfer design

To avoid allergic skin reactions electrode is covered with thin gold layer. Electrodes are used for both: electrical signal measurements and temperature sensing. To measure the temperature accurately the distance between temperature sensor and electrode is filled with thermal grease.

2.3 Pulse oximeter module

Pulse oximeter is realized on separated PCB. It is composed of two LEDs: red and infrared and photodiode. Pulse oximeter sensor is connected to AFE4400 input. AFE4400 is an integrated analog front end for heart rate monitors and pulse oximeters. KPT-1608SRC-J4 is used as RED LED, KPT-1608SRC-J4 as IR LED and VBPW34S as photodiode.

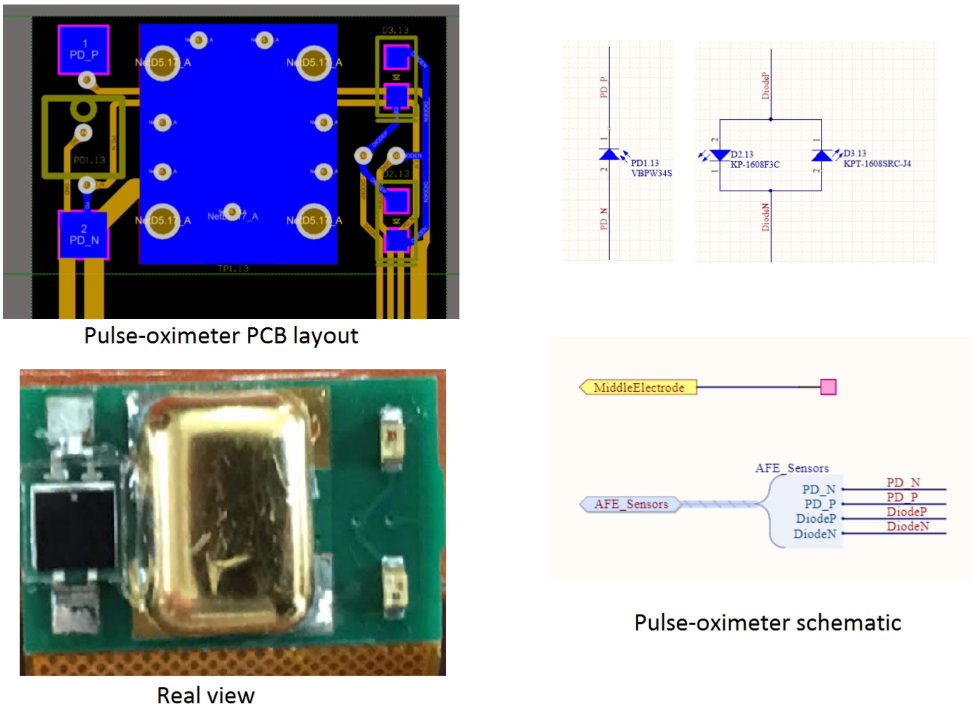


Fig. 6. Diodes layout

AFE4400 bases its functionality on following components:

- Receiver,
- Ambient Light Cancellation Loop,
- Timers,
- LED Transmit section,
- LED diagnostics and fault diagnostics.

2.3.1 Features

AFE4400 circuit features:

- pulse measurement,
- monitoring of oxygen in blood (usually 92 or less is considered as low level, more than 95 as normal)
- photopletysmography research,
- may be used for apnea detection,
- integrated LED driver (H-bridge) Push-Pull,
- low power consumption,
- 13 noise-free bits,
- uses SPI interface,
- 22bits ADC as input,
- 5kSPS.

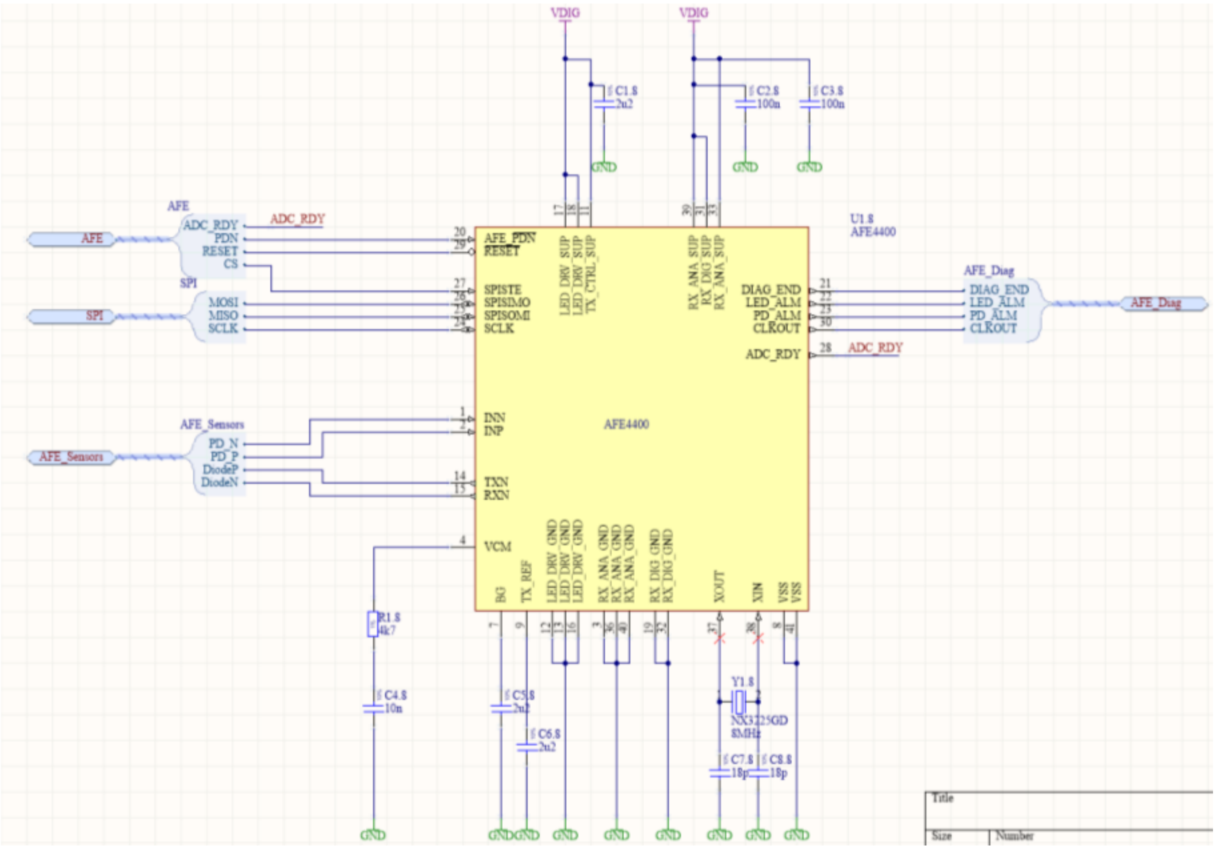


Fig. 7. AFE section schematic

2.4 NRF MCU (SoC)

NRF 51822 is system-on-chip that performs many functionalities. It control all pherypheria, like: battery manager, FLASH memory, LED and vibrator driver, but also realises wireless, low energy BLE likecommunication interface (thats why blue antenna is connected so closely to it). The nRF51822QFAC is built around a 32- bit ARM® Cortex™ M0 CPU with 256kB flash + 32kB RAM for improved application performance. NRF is responisble for saving data on FLASH memory placed just below.

2.4.1 Features

NRF51822 circuit features:

- 32-bit ARM® Cortex™ M0 CPU with 256kB flash + 32kB RAM battery protection,
- responsible for low energy wireless communication,
- responsible for LEDs and vibrator management,
- communicate with external ADC,
- its internal 10-bit ADC is connected with temperature analog front end,
- responsible for collecting data from movement sensor.

Table 1. NRF communication interfaces pinout

communication interfaces		
interface	NRF	function
SPI	23	MOSI
	22	MISO
	6	SCKL
I2C	29	SCL
	28	SDA
UART	19	Rx
	20	Tx

Table 2. AFE pinout

	NRF	function
AFE	2	CS
	10	PDN
	30	Reset
	0	ADC_RDY
AFE Diag	9	DIAG_END
	8	LED_ALM
	7	PD_ALM
	21	CLKOUT

2.4.2 Pinout

2.5 Flash memory

EN25QH256 is 256MB Flash memory IC with over 100k write cycles. Flash is connected with MCU using SPI interface. The HOLD pin allows the device to be paused while it is actively selected. The Write Protect (WP) pin can be used to prevent the Status Register from being written.

2.5.1 Features

EN25QH256 flash memory features:

- 33,554,432 bytes,
- HOLD option,
- WP option,
- 104MHz clock rate for Standard SPI.

Table 3. Other pinout

	NRF	function
Temperature	4	AnalogR
	5	AnalogL
Electrode test	3	TEST E1
	1	TEST E2
	14	TEST GEN
Flash	13	Flash CS
	18	FlashHold
Power distribution	15	AnalogON
	16	DigitalON
other	25	LEDs ON
	24	Direct ON
	11	USB connected
	17	ACC INT
	12	POWER button

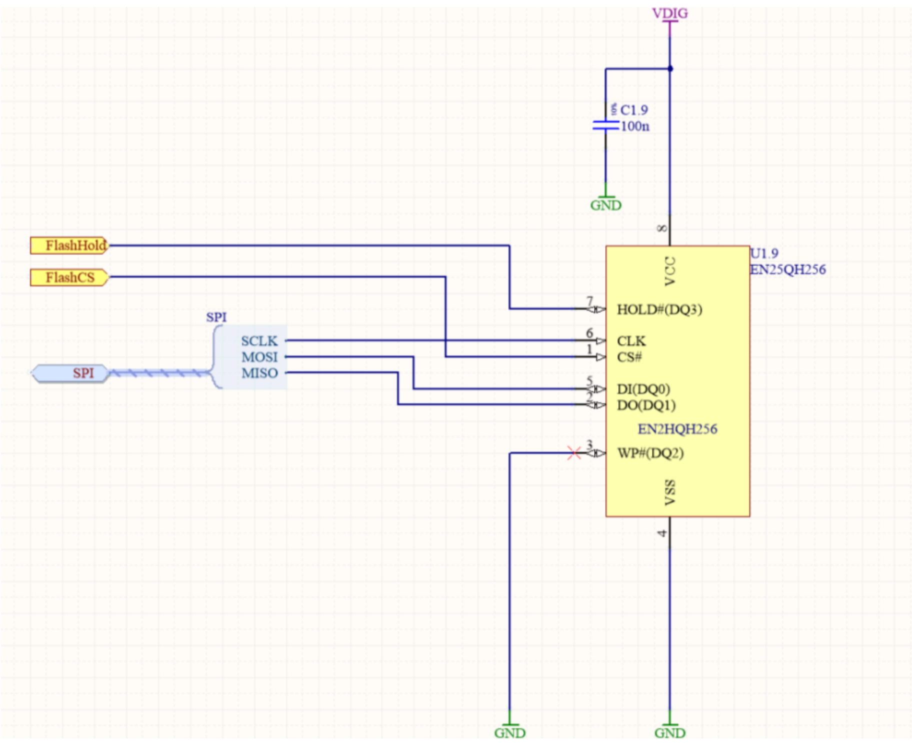


Fig. 8. Flash memory schematic

2.6 LED and Vibrator Drivers

3 Biological Amplifier overview

Biological amplifier circuit performs core functionality of Neuroon Open. It is responsible for taking measurements of EEG (Electroencephalography), EOG (Electrooculography), and EMG (Electromyography), due to that fact signal conditioning plays crucial role.

Since the EEG signals are relatively weak (about 1000 times weaker in comparison to muscle signals or noise signals) proper filtration is necessary. Amplification is realized by active, 4-th order low-pass filter.Moreover instrumentational amplifiers and another are used. Analogue circuit is placed on separated PCB.

Below annotation represents functionality of circuits modules mentioned in blue on above figure.

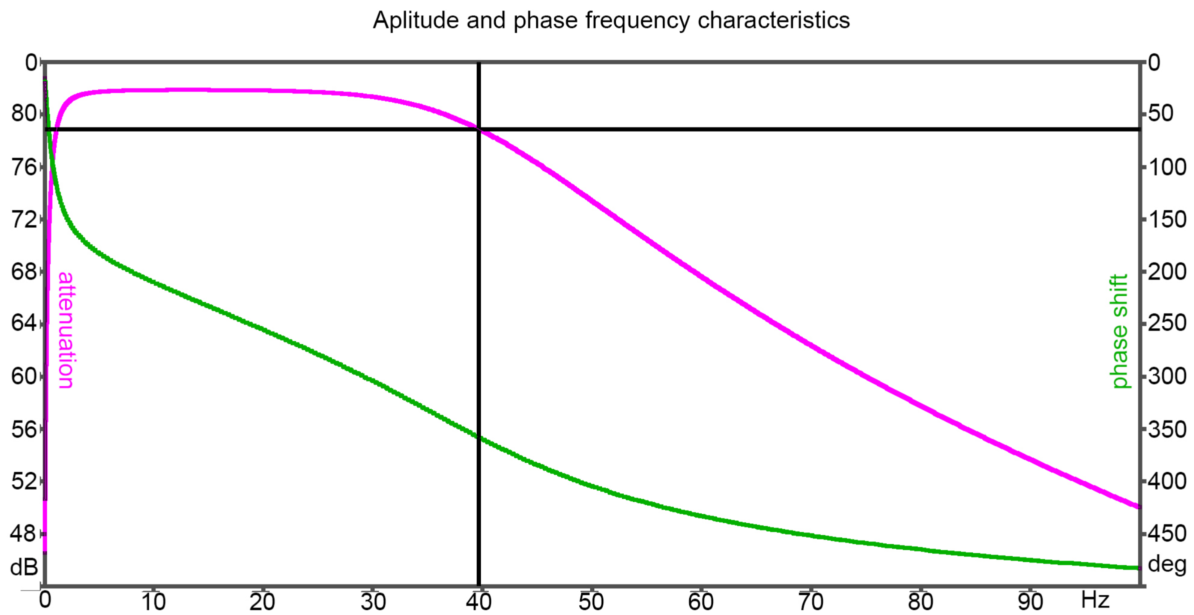
1. Virtual Ground Circuit using $TSZ122$
2. First stage amplifier (buffer,impedance transformer) using $TSZ122$
3. Second stage amplifier (instrumental amplifier $INA326$)
4. Unassembled Notch filter
5. Voltage follower and low-pass filter using $TSZ124$
6. Analog Digital Converter $ADS1115$ with PGA

3.0.1 Amplifier characteristics

Analogue amplification: $81.87dB (\approx 12400 \frac{V}{V})$
3dB bandwidth: $0.72Hz - 40Hz$
Butterworth chracteristic.
Input resistance:
Common mode rejection ratio: $114dB$

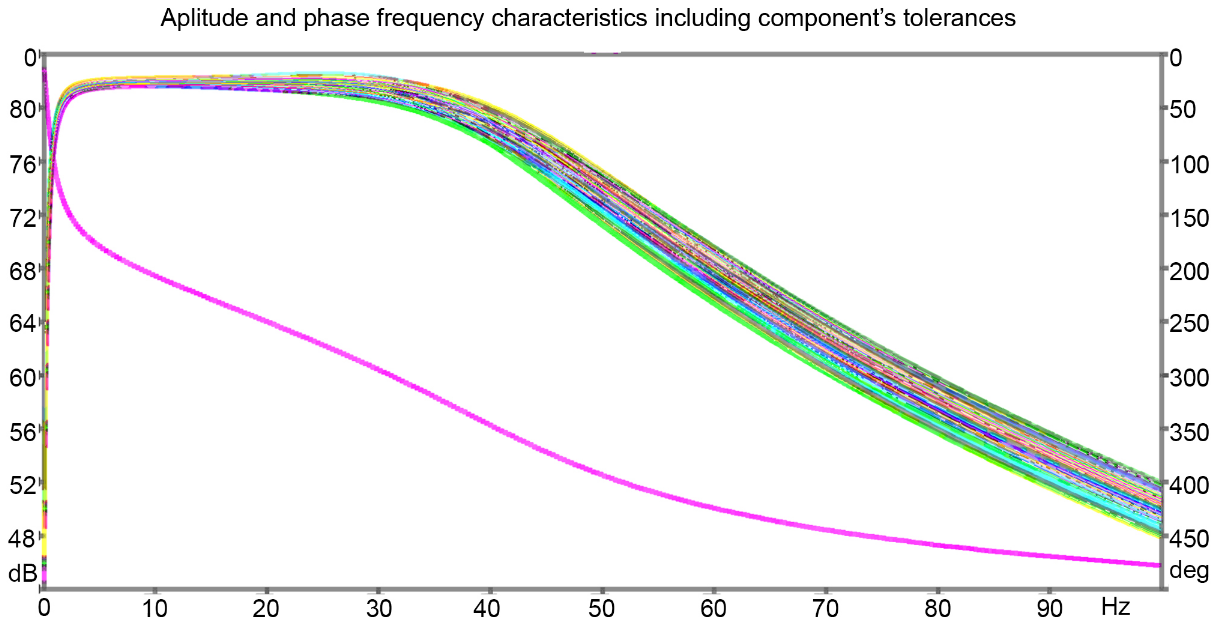
Label Name	Assigned function	Source
Power		
VCC	Analogue power supply	
GND	Reference	
Input		
SCL	I2C (clock)	MCU
LeftElectrode, RightElectrode	EEG data collection	Electrodes
TestGen	MCU generated test signal	MCU
Output		
SDA	I2C (data output)	MCU
MiddleElectrode	(DRL)Virtual ground electrode	Electrodes
TestE11,TestE12	Test electrodes signals	MCU

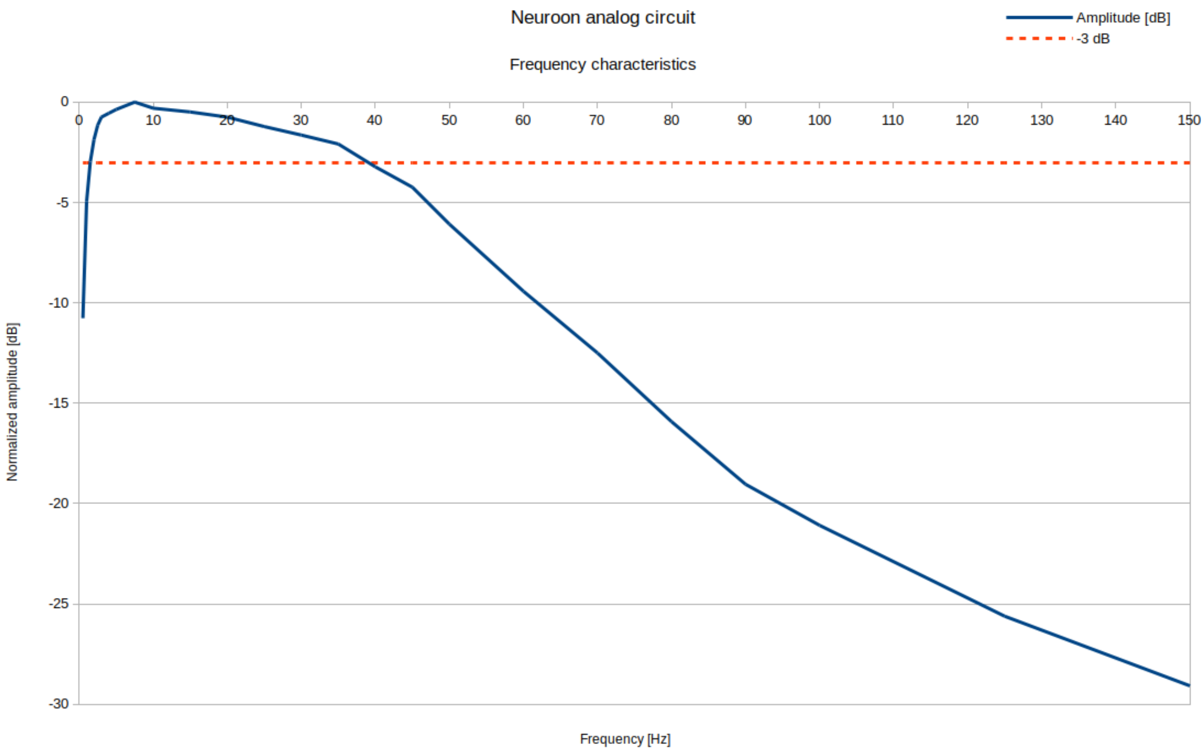
3.0.2 LTspice simulation



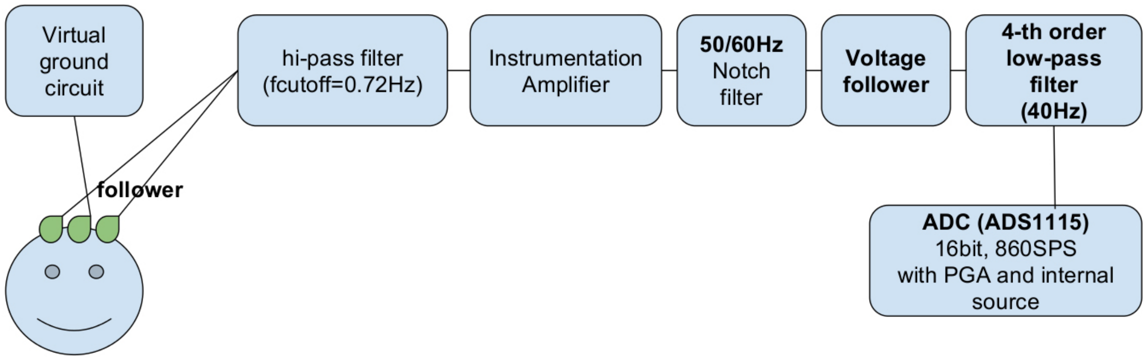
3.0.3 LTspice simulation including tolerances

3.0.4 Measured characteristics


Aplitude and phase frequency characteristics including component's tolerances
0
80
76
72
68
64
60
56
52
48
dB
0
50
100
150
200
250
300
350
400
450
deg
0
10
20
30
40
50
60
70
80
90
Hz

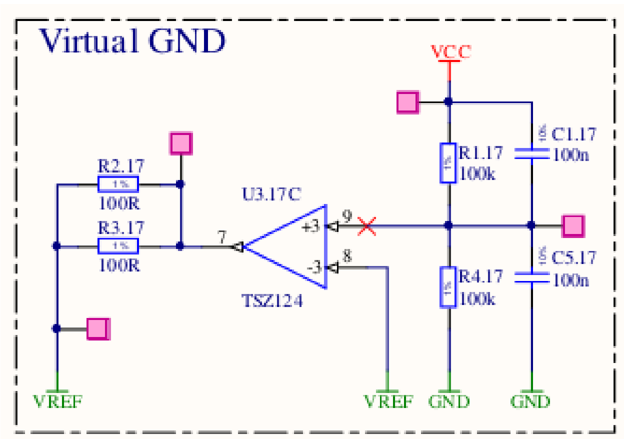

Neuroon analog circuit
Frequency characteristics
Amplitude [dB]
-3 dB
Normalized amplitude [dB]
0
-5
-10
-15
-20
-25
-30
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Frequency [Hz]

3.0.5 Simplified idea schematic



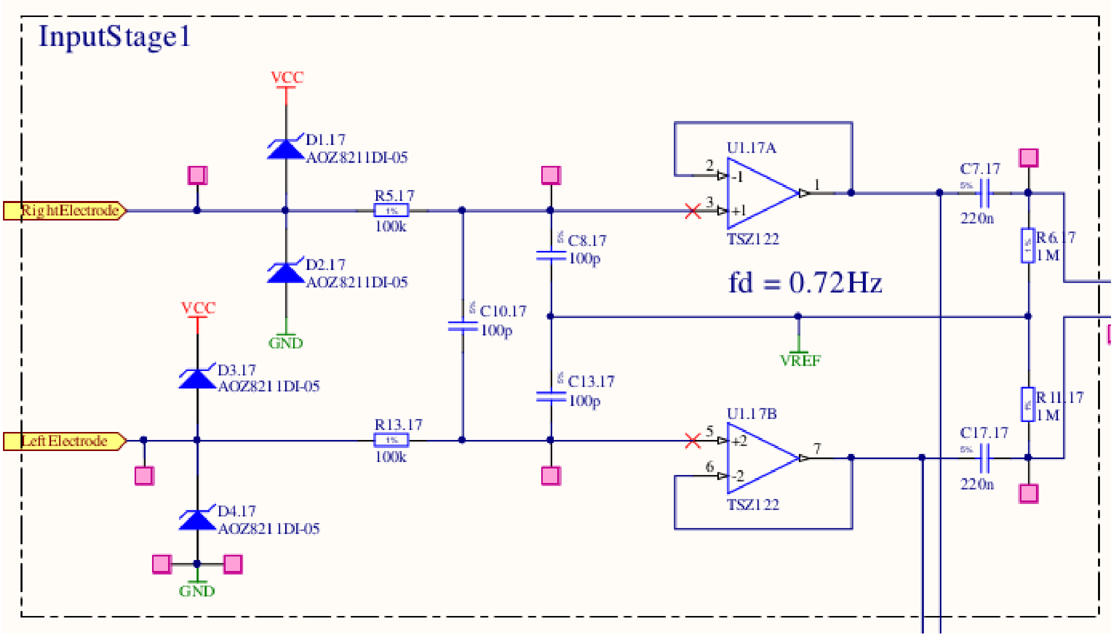
A Bioamplifier is an electrophysiological device, a variation of the instrumentation amplifier, used to gather and increase the signal integrity of physiologic electrical activity for output to various sources. Neuroon has one differential channel to measure both EEG, EOG and EMG. To cancel constant offset component from the measurement Virtual Ground Circuit has been applied. This circuit is not only canceling the constant component, but also is a signal reference for electrodes. Signal condition section is buildt up as on diagram below. Initially signal is separated, filtrated, and finally digitalised.

3.0.6 Virtual ground



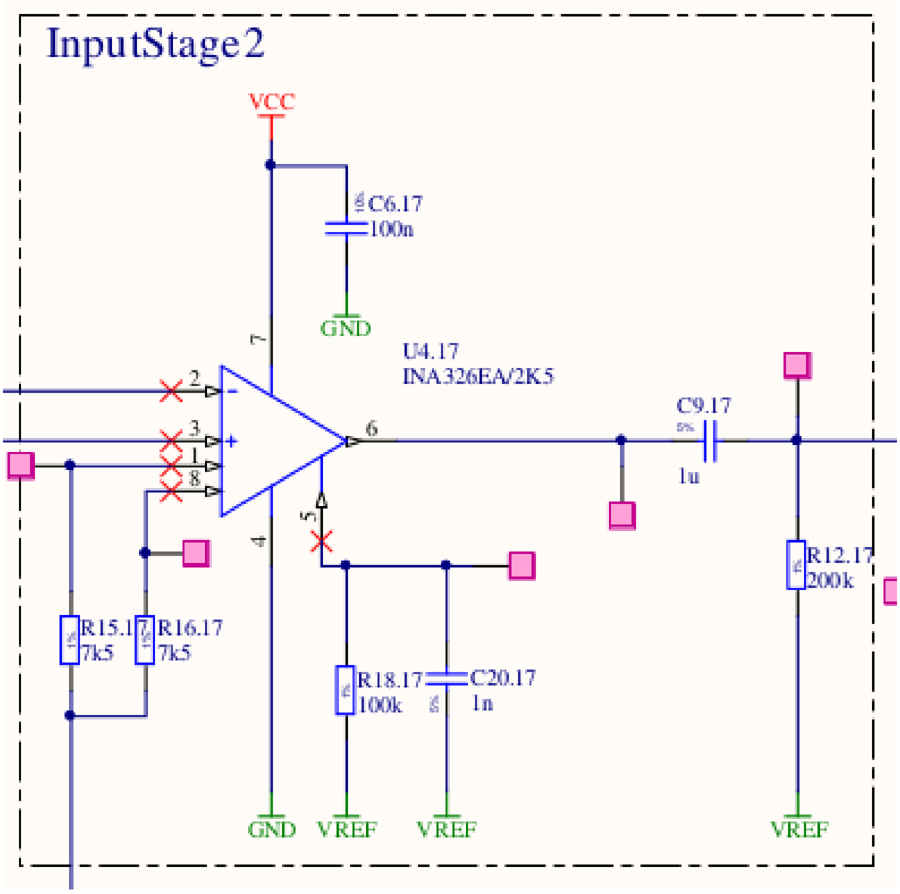
Virtual ground plays key role in differential biological measurements. It creates reference signal and may be used for compensation of constant signal offset what is used in instrumentation amplifier in second stage of amplification.

3.0.7 First stage amplifier with hi-pass filter ($f = 0.72Hz$)



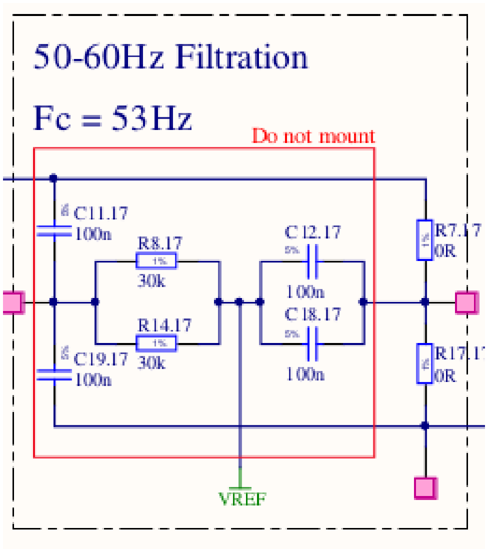
First stage buffer increases input impedance and plays the role of analog buffer. To avoid amplifiers saturation the constant offset component is cutted off from input signal. ESD input protection is realized using protection diodes AOZ8211DI (TVS). In hardware realization signal lines are as short as possible, what reduces possible vulnerability to parasitic electromagnetic signals. Amplifiers that are used in high-pass filter application come from one package (chip) what guarantees that will be of similar parameters and what is required by INA326EA2K5 instrumentation amplifier design. RC filter is realized using $R6$ resistor, $C7$ capacitor and $R17$ resistor, $C17$ capacitor. Hi-pass filter low-cut frequency $f = 0.72Hz$. The purpose of this filter is to get rid of slowly changing electric signals that naturally appear on humans body. Additionally $C8, C10, C13$ capacitors together with previous stage output impedance (f_{cutoff} of this RF filter may vary).

3.0.8 Second stage amplifier (instrumentation amplifier)



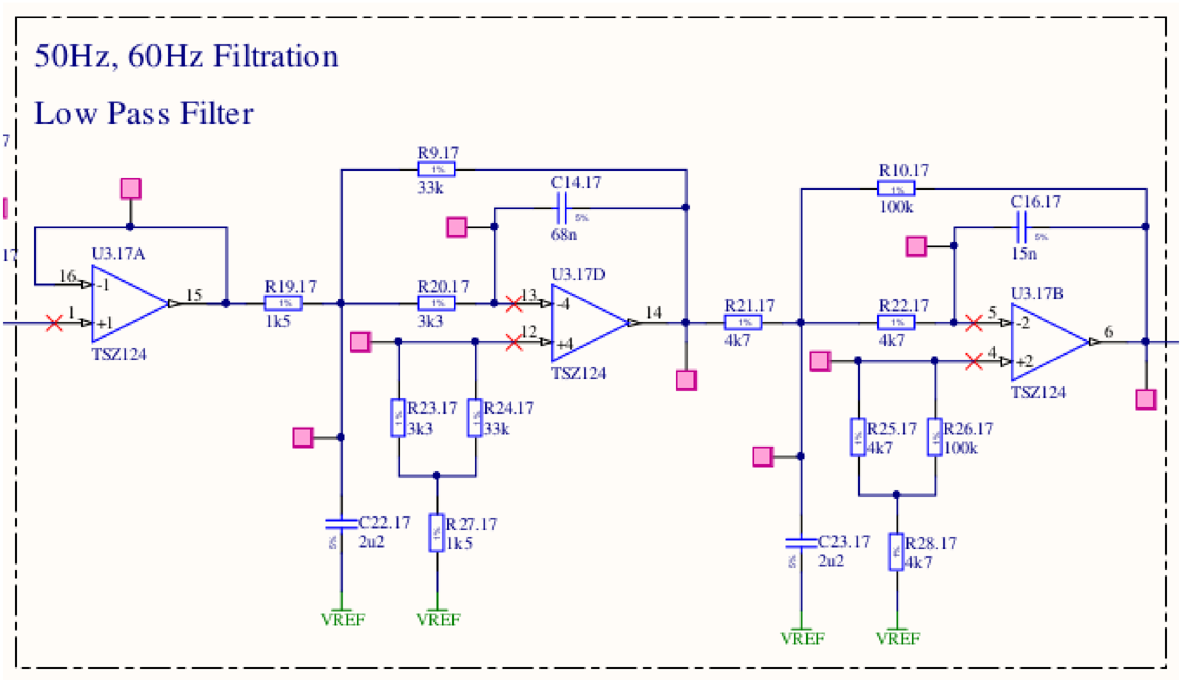
Second stage amplifier is based on $INA326EA2K5$ Texas Instruments rail-to-rail instrumentation amplifier. In our application gain $G = 13\frac{1}{3}$ is set using $R18$ and $R15 + R16$ resistors and $C20$ capacitor. $INA326EA2K5$ is high performance precision InAmp with excellent stability over time, very low $\frac{1}{f}$ nose and large CMRR (Common Mode Rejection Ratio) parameter, what makes this amplifier eligible to amplify small differential signal "hidden" in large surrounding of other signals.

3.0.9 Notch filter



Notch filter is a band rejection filter. Its idea is to reject power line parasitic electromagnetic components. In Neuroon Open design notch filter remains unassembled. Its functionality is realized by next module (low-pass filter) and digital filter. This solution is more than satisfying. Assembling notch filter may strongly influence measured signal by removing part of valuable signal spectrum. DRL is a perfect fit for this.

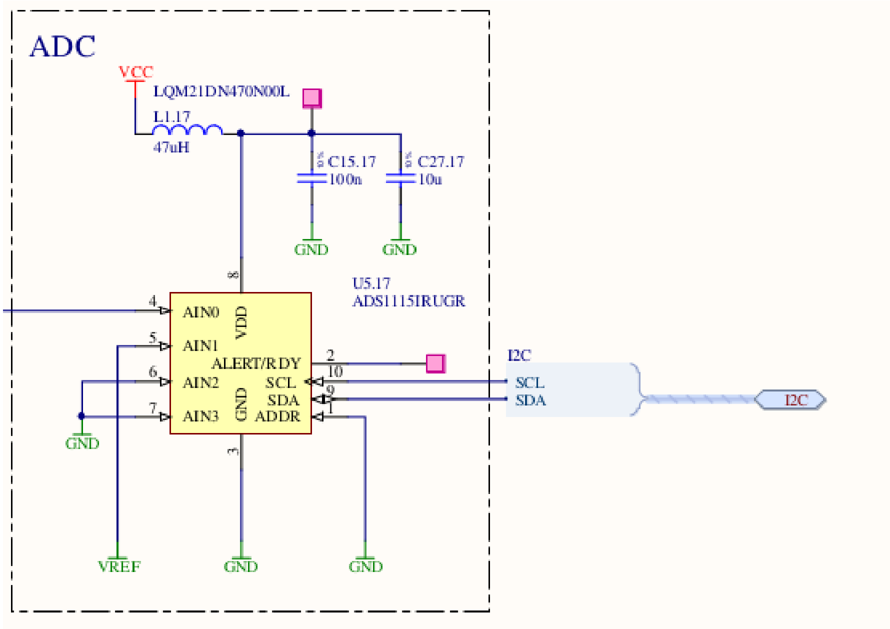
3.0.10 Voltage follower and 4-th order low-pass filter ($f_{cutoff} = 40Hz$)



This module is composed of three precised operational amplifiers. First amplifier is used as voltage follower,that buffers previous voltage divider; second and third op-amps are used in low-pass filter architecture with $f_{cutoff} = 40Hz$. This cut-off frequency seems reasonable for following reasons: measured EEG signals and EOG signals from eye movement do not exceed more than $32Hz$, parasitic power line electromagnetic components ($50Hz$ or $60Hz$) are filtered, moreover fast noises are strongly reduced what is crucial for actualizing.

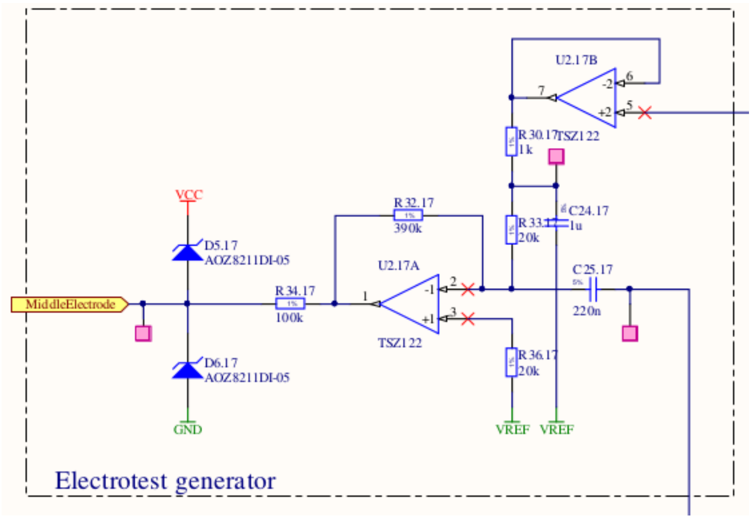
$TSZ124$ is a type of used amplifier. Its major advantages are: very high accuracy, high stability, zero drift, very low input offset and low power consumption. Low $\frac{1}{f}$ noice is crutial for operation of low frequency applications like EEG devices.

3.0.11 ADC



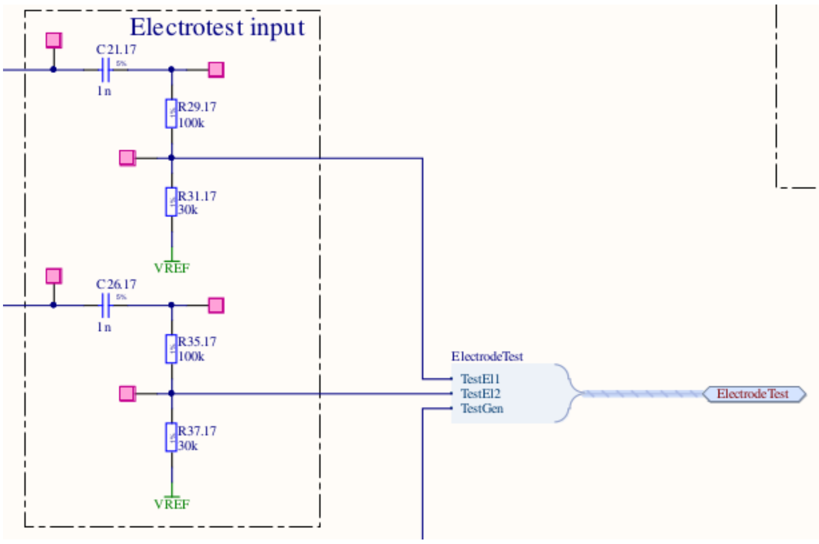
$ADS1115IRUG$ is $16-bit$ delta-sigma type ADC. Communication is realized using $I2C$ protocol. Sampling rate $8SPS$up to $860SPS$. Oscillator and internal reference and are built in. Recommended gain of PGA is 4 - in this setting signal has large dynamics. Modifying PGA during measurement is not recommended. $ADS1115$ has 4 single-ended inputs that may operate as two differential channels. Neuroon Open uses one differential input that measures analogue front-end output in reference to V_{REF} generated by virtual ground circuit.

3.0.12 Electro test generator



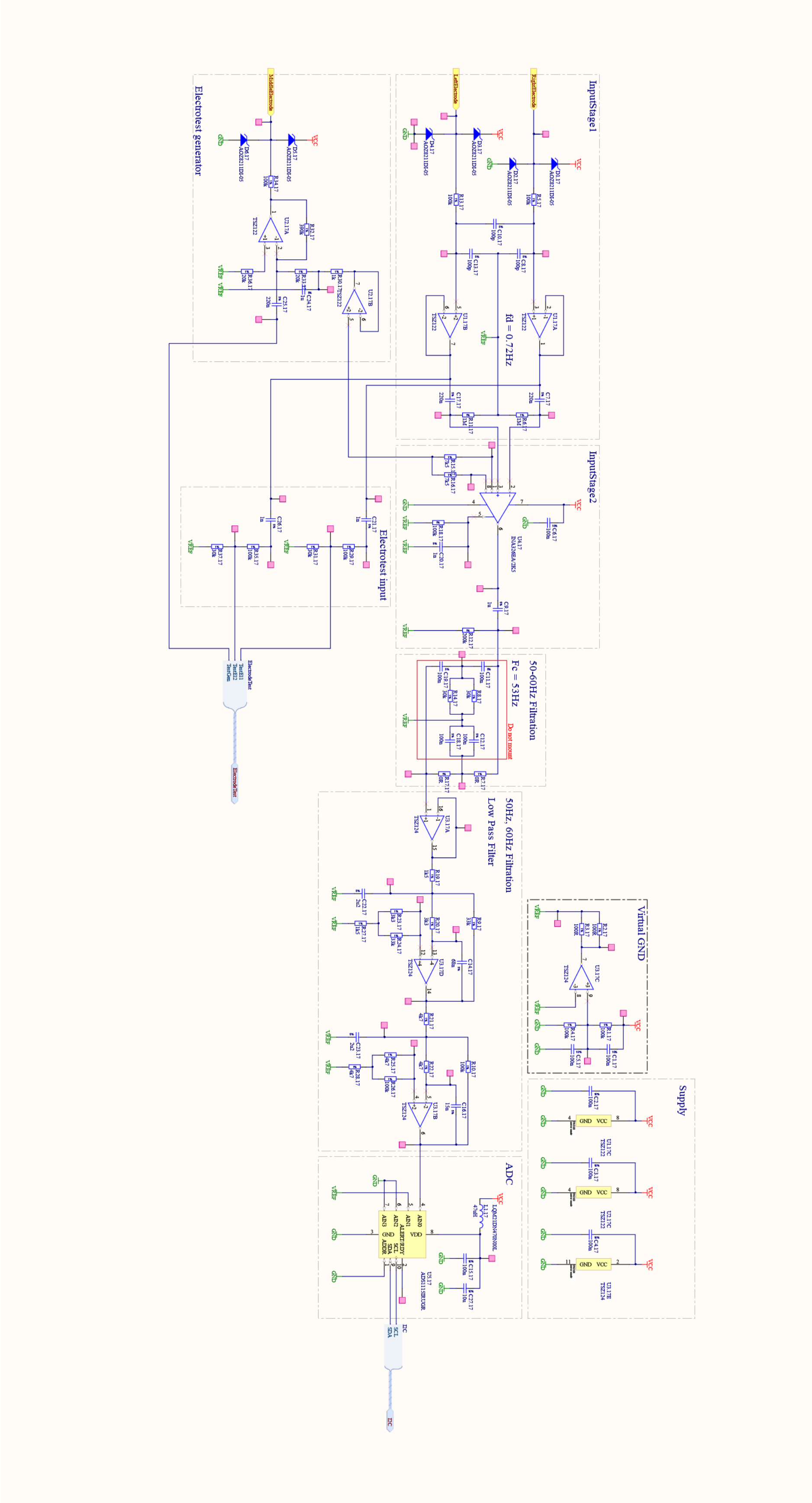
The middle electrode, that is connected with MCU performs function of stimulating electrode or common mode compensation function. First amplifier is used as voltage follower, second one as amplidier with gain $G = -18.5$. Diodes AOZ8211DI (TVS) are used as ESD protection.

3.0.13 Electro test input



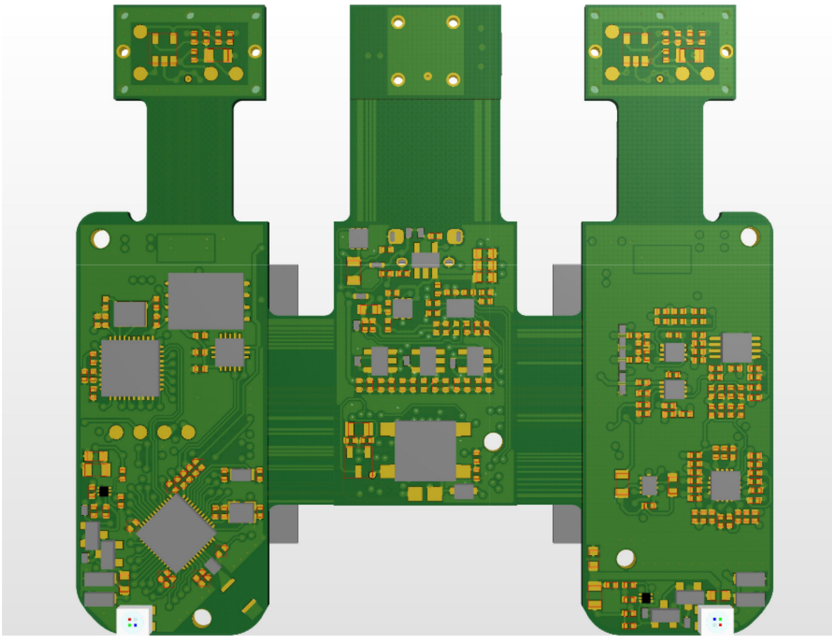
The measured signal has strong constant component. Constant offset is removed by AC filter. The output is connected to MCU ADC.

Complete schematic

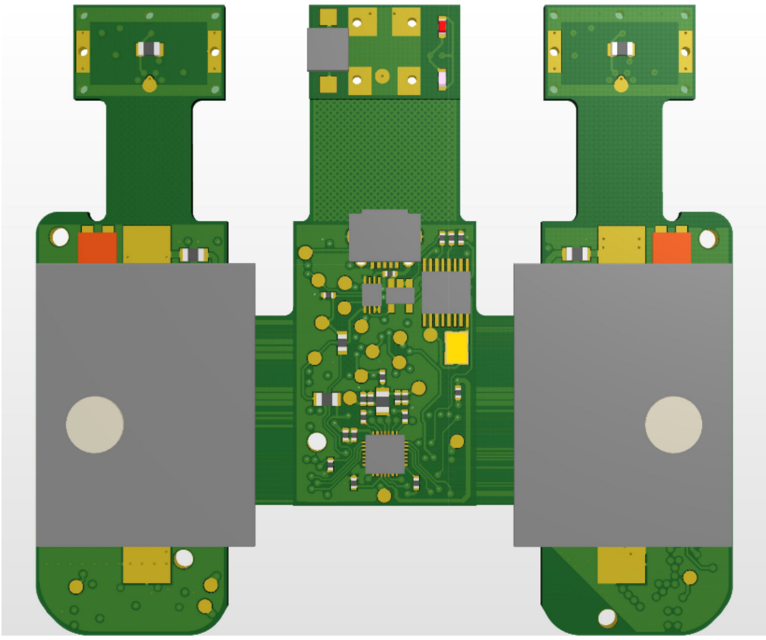


4 Pinout connection summary

5 3D model overwiev



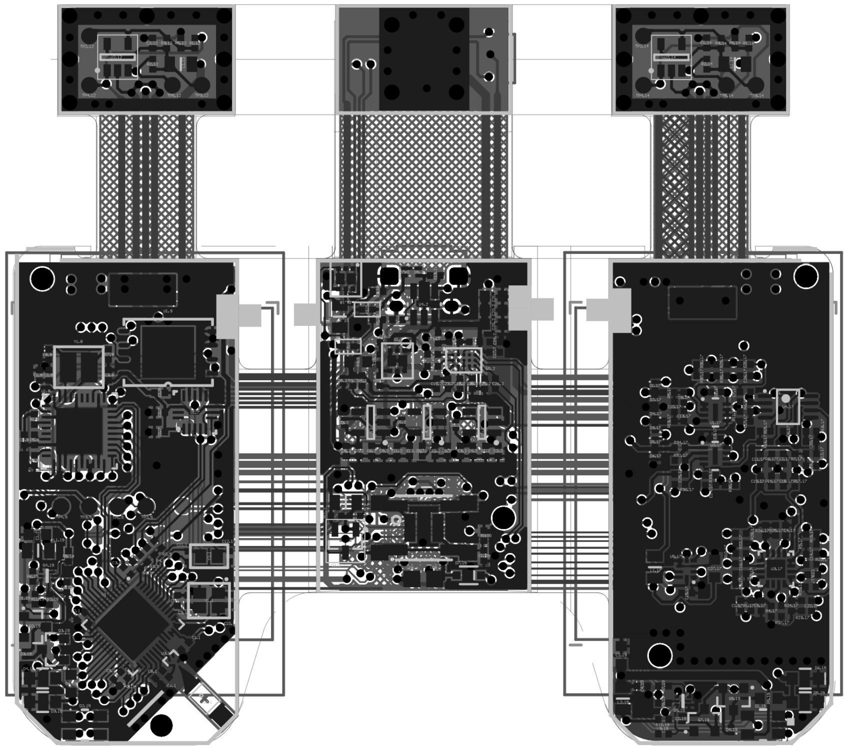
Front 3D view



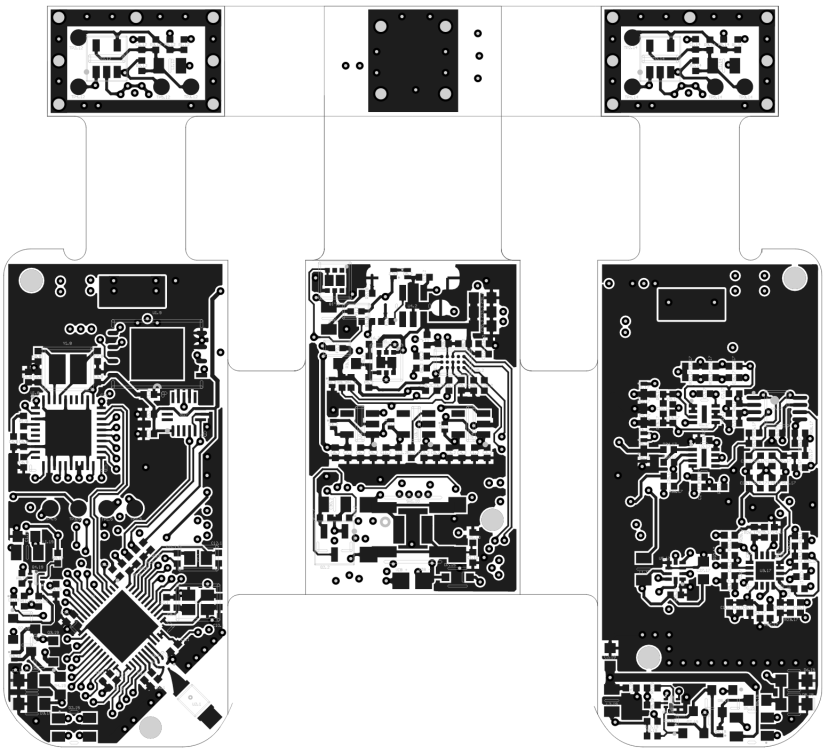
Back 3D view

6 Layout

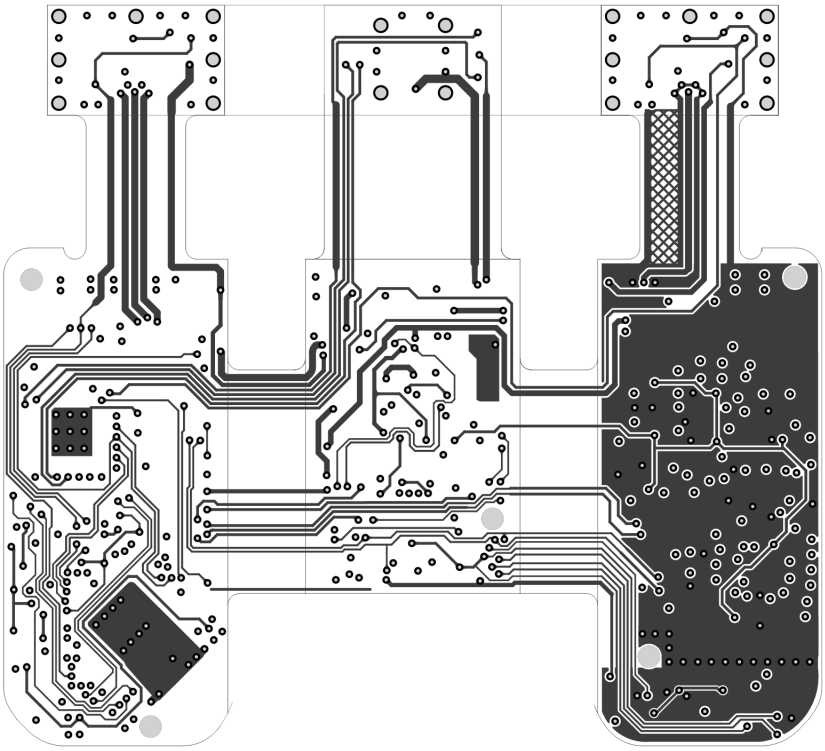
Following graphics represents all PCB layers layout. May be not in sacle! For more information please chceck: `https://github.com/inteliclinic/NeuroonOpenHardwareDocumentation/tree/master/gerber`



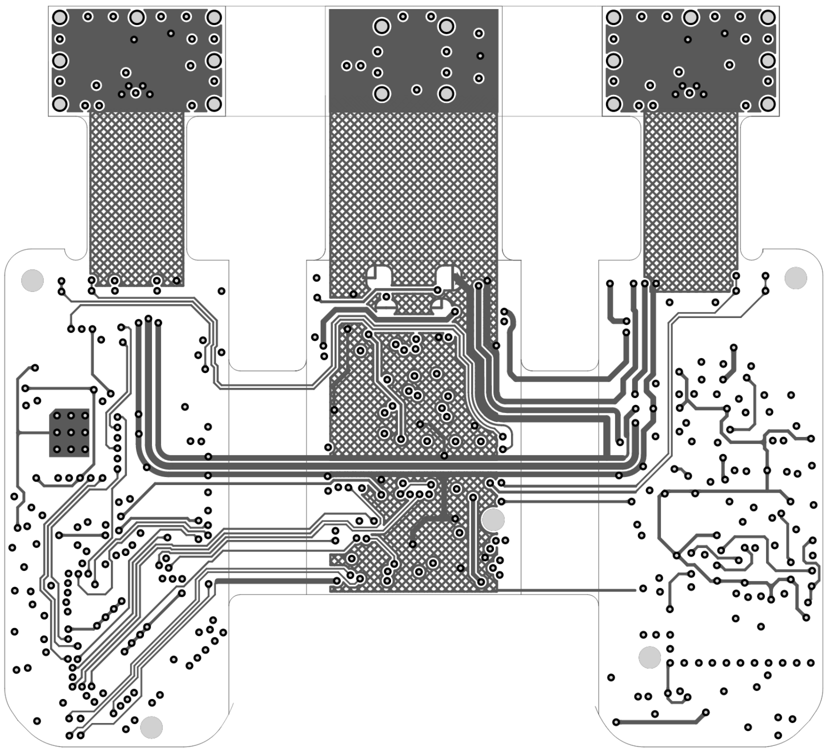
Layout complete



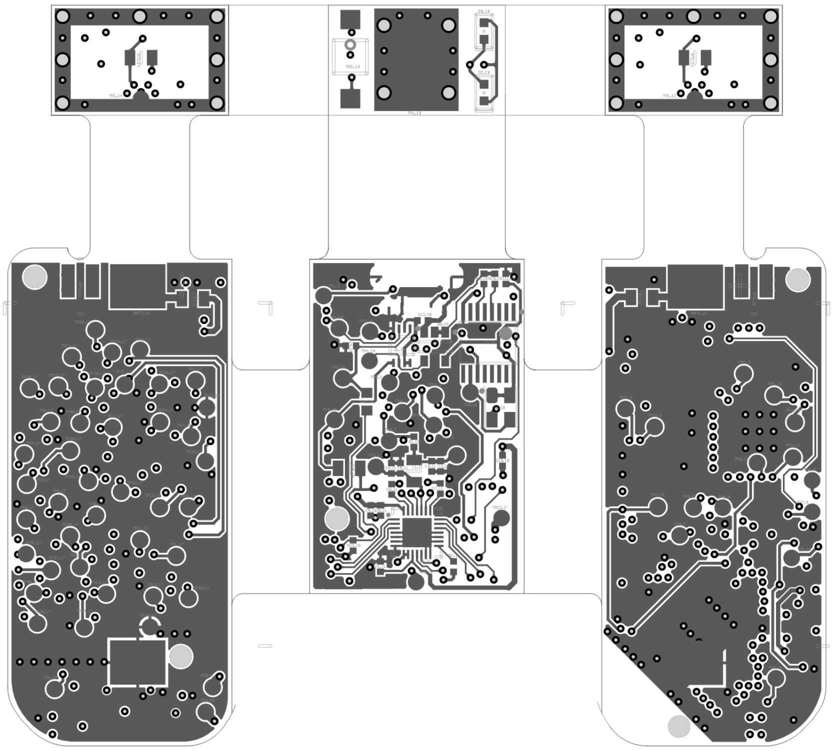
Layout layer 1



Layout layer 21



Layout layer 3



Layoutlayer 4

7 Gerber files

Gerber files are available on GIT repository:
`https://github.com/inteliclinic/NeuroonOpenHardwareDocumentation/tree/master/gerber`

8 BOM files

Bill of materials files are available on GIT repository:
`https://github.com/inteliclinic/NeuroonOpenHardwareDocumentation/tree/master/`

9 Certificates

9.1 OSHW US000068 | Certified open source hardware

Open Source Hardware (OSHW) is a term for tangible artifacts — machines, devices, or other physical things — whose design has been released to the public in such a way that anyone can make, modify, distribute, and use those things.

9.2 CE

CE is the 'European Union EMC Safety Compliance Declaration'. This certification is required for all products that have an input of 50-1,000 Vac or 75-1,500 Vdc, as well as for products that could be affected by an electromagnetic disturbance.
`https://www.dropbox.com/s/sbmh0fhutcyj75q/CE.pdf?dl=0`

9.3 UL UL-EMC-RP10885493JD02A

UL is North American Product Safety Certification, a common North American certification from Underwriter Laboratories. This mark shows that a product was tested by UL, that it meets US and Canadian safety standards, and that the manufacturer's facilities have undergone periodic checks to ensure that everything is in working order as well.
`https://www.dropbox.com/s/eik9nf5x8g4751w/UL.pdf?dl=0`

9.4 FCC 2AF73-NEUR1

FCC is a certification from the U.S. Federal Communications Commission which relates to electromagnetic interference regulations regarding a range of transmitters, receivers, and IT. Anything that has a radio or connectivity will often need to go through a range of tests, this would include products such as a computer, a smartphone, or of course, a radio. All IoT wearable devices would need to obtain this certification before hitting the market.

`https://www.dropbox.com/s/hwr2f1qbassyqot/FCC.pdf?dl=0`

9.5 IC 20848-NEUR1

Industry Canada (IC) Introduction. The Certification and Engineering Bureau of Industry Canada provides certification services for radio equipment. The testing of the device is usually done by 3rd-party labs.

`https://www.dropbox.com/s/ykwt3z9cgmqansx/IC.pdf?dl=0`

9.6 Giteki 007-AE0008

Japan has adopted a similar policy as the FCC regarding the labeling of host devices which contain a certified radio module. As of now the host device may bear the GITEKI mark and certification number so that it is clear that a host device contains a certified radio module.

`https://www.dropbox.com/s/vt7yzumdtny5wa1/GITEKI.pdf?dl=0`