H2020

D4.9 ELECTRONIC CONTROL SYSTEM

FLAIR - FLying ultrA-broadband single-shot InfraRed Sensor
GA732968

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Abstract:
The FLAIR sensor is an assembly of different subcomponents, each requiring its own power supply and additional features. A typical example is the supercontinuum source which needs protection against power surge and requires an external trigger signal. In addition, these subcomponents are linked together and must be operated harmoniously. A dedicated software has been developed for this purpose. The user interface is extremely simple, as the system is to be operated as standalone.
This document reports on both the electronic control hardware (the power supply distribution card) and the electronic control software. The final version of the software executable is delivered in electronic format together with this report.

Document History

Date	Version	Remarks
10/03/2020	0.1	Skeleton
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Executive Summary

The **FLAIR** project addresses the challenge of performing air quality monitoring in complex urban environments by mounting a high-performance air sampling sensor based on photonic technology on a drone for pervasive, high specificity and high sensitivity air quality sensing with large area coverage. Operating in the two atmospheric windows of 2–5 µm and 8–12 µm wavelength, **FLAIR** can detect minute traces of molecules in complex gas mixtures from their characteristic infrared (IR) absorption fingerprints and provide real time information to the operator of the drone. **FLAIR** can operate in remote or dangerous areas and outside of established monitoring networks.

This document reports on Task 4.7 – Control Electronic and, according to the statement of work, deals with *the monitoring of the FPAs, the control of the pumping system, and the synchronisation mechanism between all peripherals, power management of the system device, user interface and embedded software*.

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List of Acronyms

Acronym	Meaning
FLAIR	FLying ultrA-broadband single-shot InfraRed Sensor
V DC	Volt Direct Current
PC	Personal Computer
UAV	Unmanned Aerial Vehicle
MPC	Multipass cell

Table 1 – List of acronyms.

1 Introduction

The FLAIR sensor is an assembly of different subcomponents, each requiring its own power supply and additional electrical signals (Figure 1). A typical example is the supercontinuum source which needs protection against power surge and requires an external trigger signal. In addition, these subcomponents are linked together and must be operated harmoniously. A dedicated software has been developed for this purpose and installed on a fanless miniature industrial PC. The user interface (Figure 21) is extremely simple, as the system is to be operated as standalone.

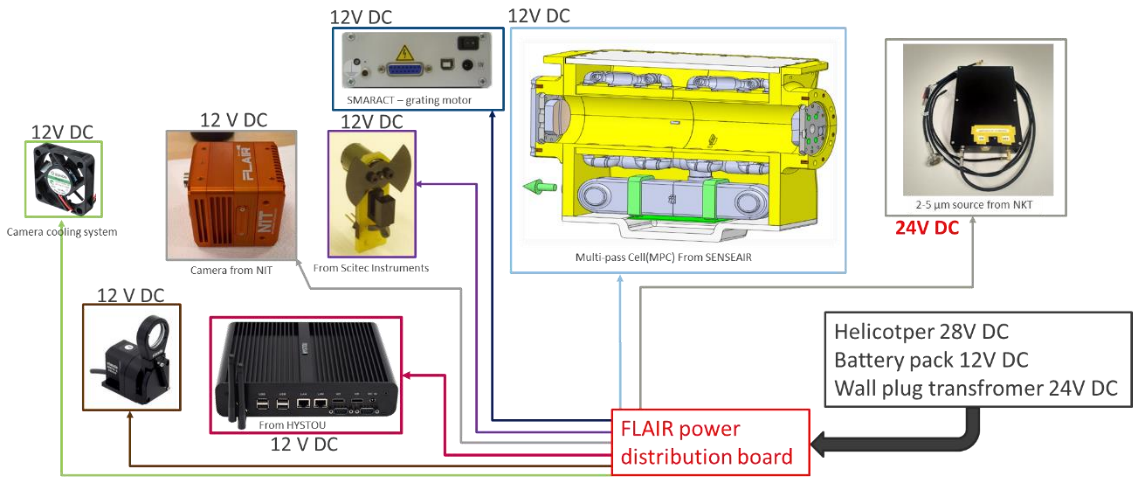

Figure 1 – Subcomponents requiring electrical power on the FLAIR prototype

This document reports on both the electronic control hardware (the power supply distribution card) in section 2 and the electronic control software in section 4. Some accessories developed to adapt the system to different situation are presented in section 3.

2 Power distribution board

The role of the power distribution board is to deliver the required power to each subcomponent, while optimizing its own power consumption. Where possible, the different subcomponents have been selected to operate under 12V DC to simplify the design of the power distribution board. A notable exception is the Supercontinuum source that operates at 24V DC. The board includes special features as described below.
Two boards have been fabricated, assembled, and tested. Board #1 is integrated in the FLAIR system, and board #2 serves as a backup.

2.1 Concept

The power supply board aims at providing specific power supplies to each sub-part of the FLAIR prototype. The sub-part can be switched ON or OFF independently through the main user interface of the onboard PC. The idea is to minimize power consumption on platforms with limited power availability, like an UAV or on battery operation. As an example, one would switch the camera group off (camera + camera fan + chopper + flipper mirror mount) while changing the position of the grating (Grating motor group). And then switch the Grating motor group off, and the camera group on again to perform measurements.

2.2 Description of the power board

The power supply accepts a wide input range, from 9 to 32V in order to be supplied either with a 24V wall outlet transformer for indoor usage, a 12V or 24V battery for remote field testing, or with the specific 28V power supplied either by a drone or a helicopter.
Sub-systems are grouped in 5 groups. Except for the computer power supply which is turned on by default once the card is powered, each of other 4 groups can be individually switched on or off via a USB interface. They are turned off by default at startup.

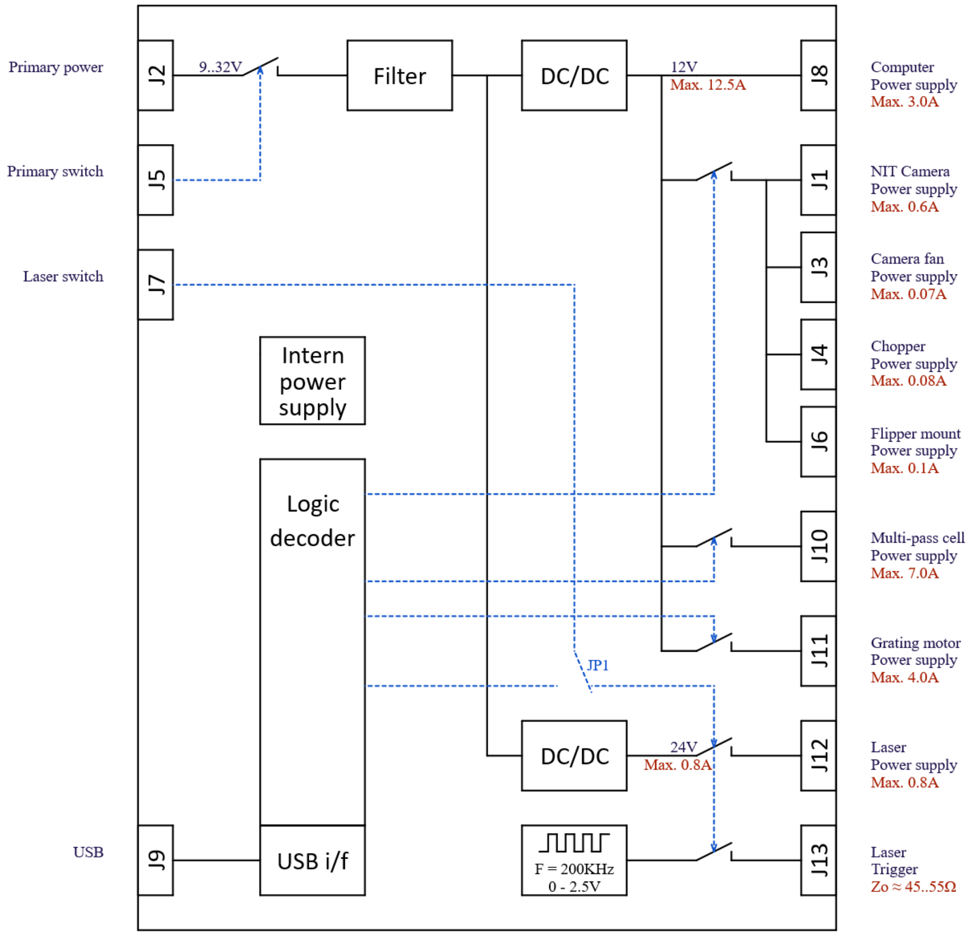

Figure 2 – Power board block diagram

A primary manual switch (Figure 3), with an integrated LED, connected on J5 turns on or off all power distribution board. The laser power supply and trigger signal can be controlled either by a manual switch connected to J7 or with USB telecommand depending JP1 configuration. The second option has been chosen for the finalized FLAIR prototype. Camera group, multi-pass cell and grating motor power supplies are controlled independently with USB telecommand.

Figure 3 – Power board main switch

The power distribution board can provide up to 12.5A for the 12V rail plus 0.8A on the 24V rail. The total output power is 170 W with an approximate board efficiency of about 85%.

2.3 Telecommand

USB telecommands are be sent to onboard logic trough FTDI FT240X device. According to his configuration, the device can be configured to receive command via COM port or via FTDI D2xx library. The device configuration can set by using FTDI FT-Prog tool.

FT240X is a serial to parallel converter, the received byte is written on Data 0 to data 7 pin. As the 0x00 is not send, it's strongly recommended to send the data byte preceded by a dummy byte like 0x1 (or 0x01).

dummy byte	Data byte							
0x01	Data7 pin	Data6 pin	Data5 pin	Data4 pin	Data3 pin	Data2 pin	Data1 pin	Data0 pin
	Not used	Not used	Key2	Key1	Laser	Grating	MPC	Camera

Table 2 – Command to send

To avoid inadvertently activating a power supply a specific bit configuration shall be set with Key1 and key 2 bit. To enable output, Key1 (Data4) shall be "0" and Key2 (Data5) shall be "1". All other configuration disables power supply for Camera, MPC, Grating and Laser.

Send data byte								
7	6	5	4	3	2	1	0	
Not used	Not used	Key2	Key1	Laser	Grat.	MPC	Cam.	Output
X	X	0	0	X	X	X	X	All output disabled
X	X	0	1	X	X	X	X	All output disabled
X	X	1	0	d	c	b	a	a: Camera group (0=OFF, 1=ON) b: Multi-pass cell (0=OFF, 1=ON) c: Grating motor (0=OFF, 1=ON) d: Laser (0=OFF, 1=ON)
X	X	1	1	X	X	X	X	All output disabled

Table 3 – Truth table

2.3.1 Python code example

The following is an example programmed in python to connect to and command the FTDI FT240X device:

```
import ftd2xx

def main():
    tableOfDevices=ftd2xx.listDevices() #Show FTDI device list (not used)

    #myDevice=ftd2xx.openEx(b'DO4W4G2E', 1) #FT_OPEN_BY_SERIAL_NUMBER = 1
    myDevice=ftd2xx.openEx(b'FLAIR2', 2) #FT_OPEN_BY_DESCRIPTION = 2
    # Use FTDI FT Prog software to configure the device or get SN.
    # https://www.ftdichip.com/Support/Utilities.htm#FT_PROG

    myDevice.setBitMode(0xFF,0x1) # Mode: Asynchronous Bit Bang

    resetAll(myDevice)
```

```
    # Exemple:
    writeByte(myDevice, 0x20) # Disable all output and unlock key
    writeBit(myDevice, 3, 1) # Enable grating power supply
    writeBit(myDevice, 0, 1) # Enable camera power supply
    writeBit(myDevice, 0, 0) # Disable camera power supply
    # End exemple

    myDevice.close() # Close device
    pass

def writeBit(device, bitPos, bitValue):
    """Set or reset the specific byte given by bit Pos.
    Return 1 in case of no errors.

    Keyword arguments:
    device -- An opened and suported FTDI device
    bitPos -- Position of the bit to change (0 .. 7)
    bitValue -- New bit value (0 or 1)
    """
    if ((bitPos>7) | (bitPos<0)):
        print("Unexpected bitPos value. Nothing changed.")
        return -1

    if (bitValue == 0):
        mask = ~(1 << bitPos)
        return device.write(chr(0x100+(device.getBitMode() & mask)))
    elif (bitValue == 1):
        mask = 1 << bitPos
        return device.write(chr(0x100+(device.getBitMode() | mask)))
    else:
        print("Unexpected bitValue value. Nothing changed.")
        return -1

def writeByte(device, byteValue):
    """Write the the whole output byte.
    Return 1 in case of no errors.

    Keyword arguments:
    device -- An opened and suported FTDI device
    byteValue -- New output value (0x00 .. 0xFF)
    """
    if ((byteValue>0xFF) | (byteValue<0x00)):
        print("Unexpected byteValue value. Nothing changed.")
        return -1
    return device.write(chr(0x100+byteValue))

def resetAll(device):
    """Clear all output.
    Return 1 in case of no errors.

    Keyword arguments:
    device -- An opened and suported FTDI device
    """
    return device.write(chr(0x100))


if __name__ == '__main__':
    main()
```

2.4 Interface description

This section presents main interfaces.

2.4.1 Power supply input

Includes: Reverse polarity protection, transient voltage suppression, EMI filter.

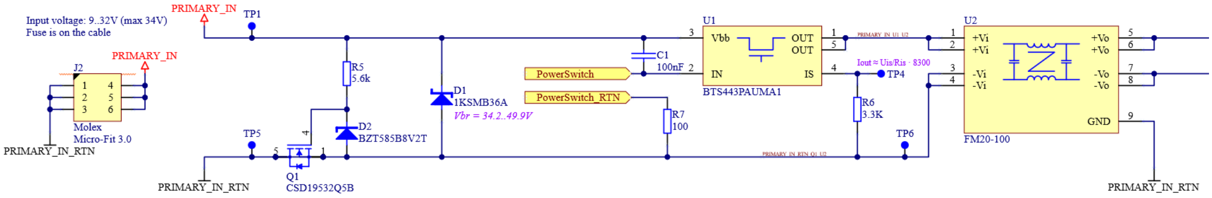

Figure 4 – Power supply input

2.4.2 12V/24V switched output (camera, MPC, grating, Laser)

Includes: Switch, transient voltage suppression, status LED

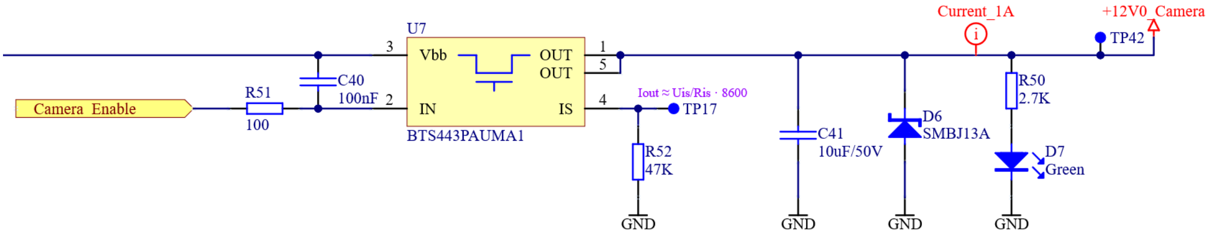

Figure 5 – 12V switched output

Note: Due to electronic switch leakage current (µA level), when switched off, the “no load” voltage can rise to approximately 1.7V at the output (limited to LED forward voltage).

2.4.3 Switch connectors

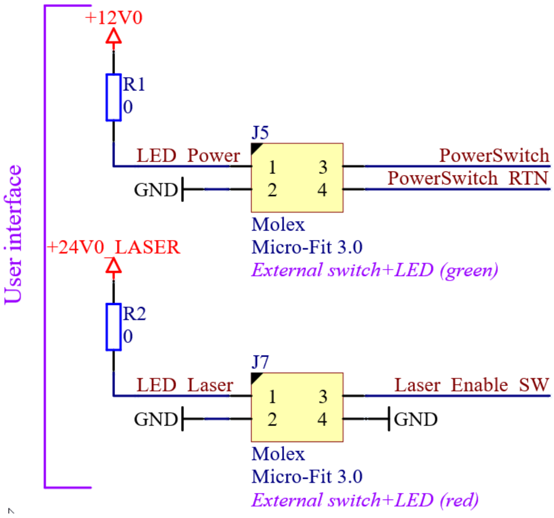

Figure 6 – Manual Switchs connectors

2.4.4 Output connectors pinout

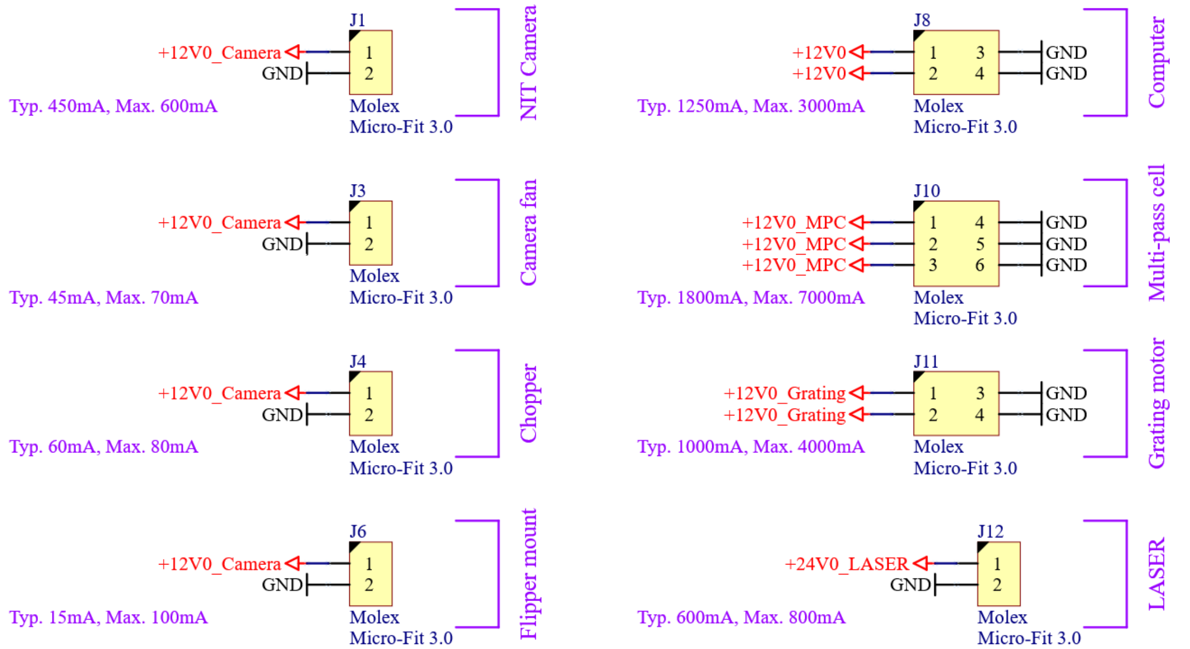

Figure 7 – Output connectors pinout

2.4.5 Laser trigger signal generator

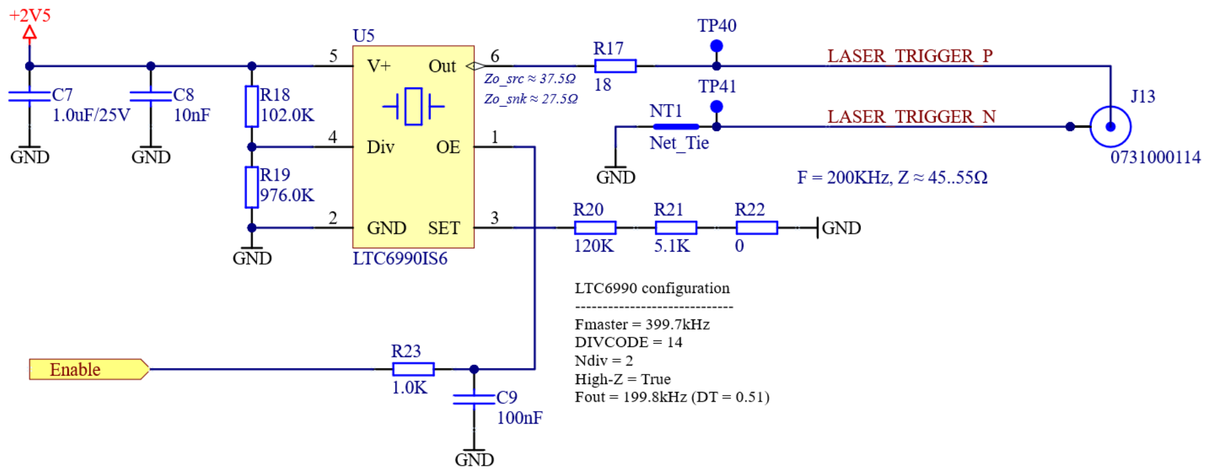

Figure 8 – Laser trigger signal generator

According to NKT, the supercontinuum laser requires an external trigger: 0-2.5 V (floor-ceiling) square wave, 200 kHz, on 50 Ohm load. The trigger generator has been built in the power supply board, and designed to start just after the 24V bias is applied to the laser.

2.5 *Board overview*

All connectors, test points and LED are located on top. Power components are one bottom. The board is inserted in a mechanical frame machined in a block of aluminium for thermal power dissipation.

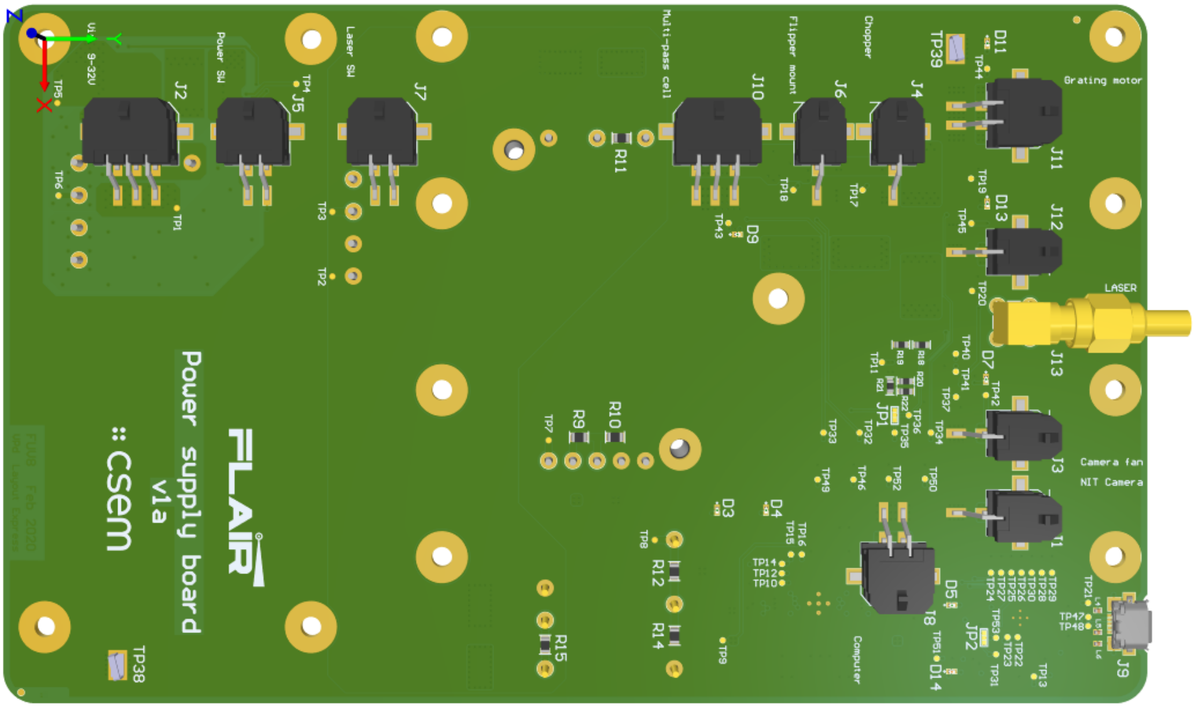

Figure 9 – Power supply board top view (CAD)

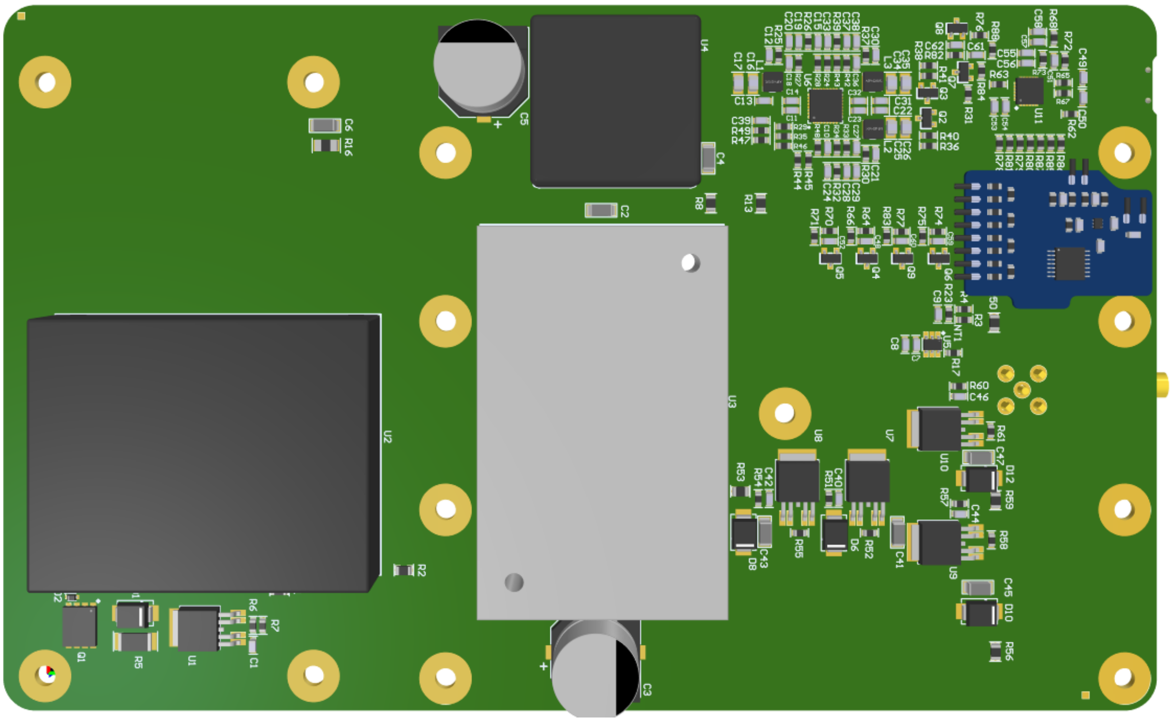

Figure 10 – Power supply board bottom view (CAD)

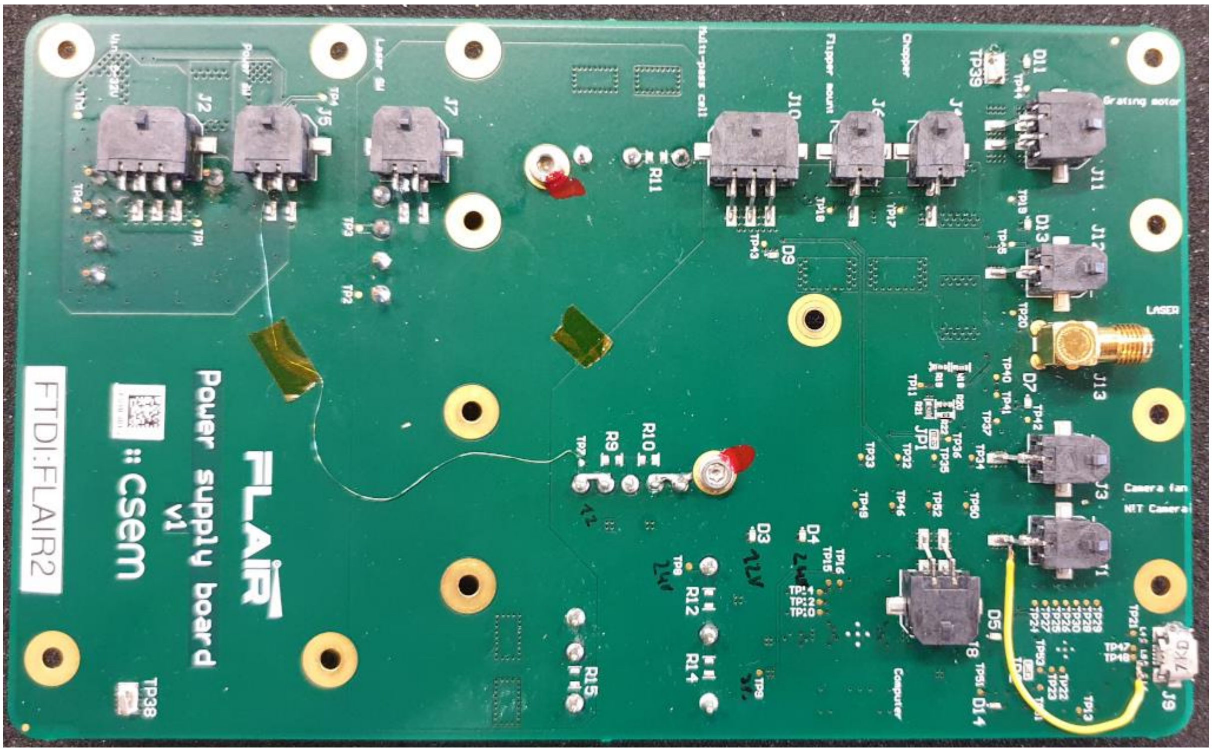

Figure 11 – Power supply board#2, top view (photo)

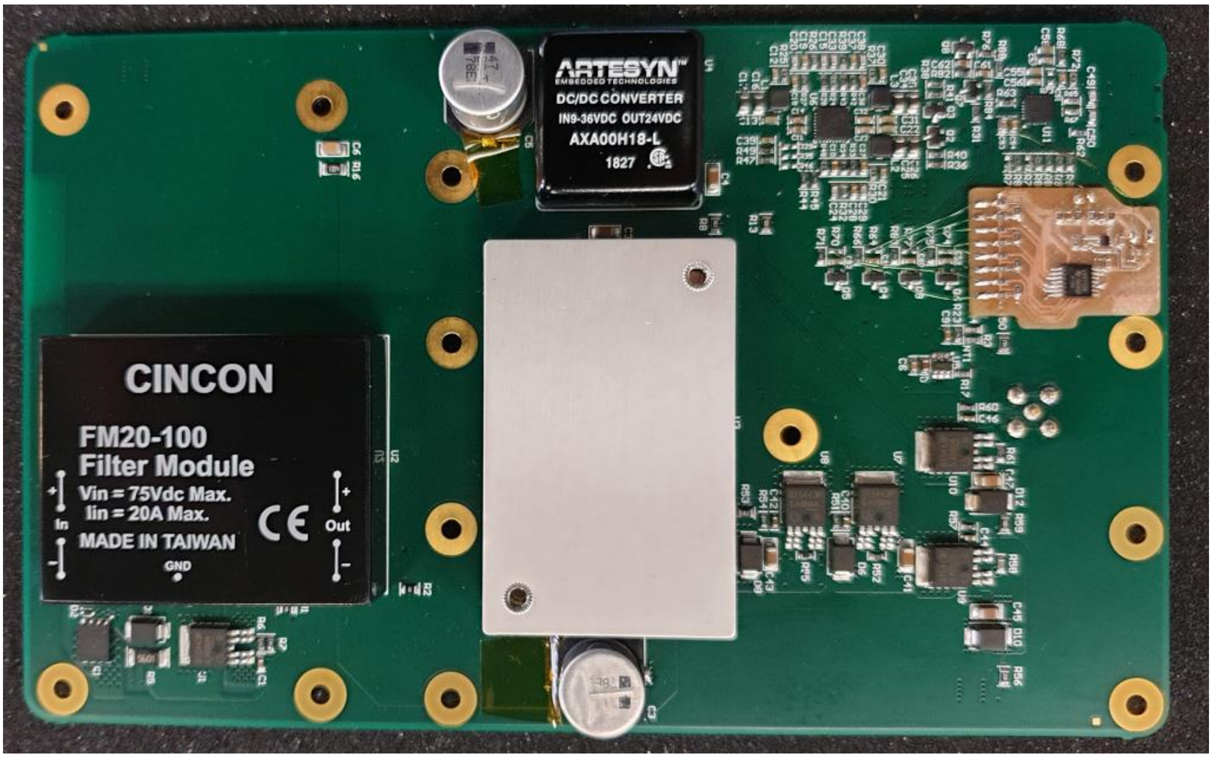

Figure 12 – Power supply board#2, bottom view (photo)

As visible on the photo of the top view (Figure 11), a correction was needed (thin green wire). This is due to a mistake in the footprint of one of the elements during the layout definition. The Yellow wire is only needed on board #2 and resulted from a shortcut within the USB plug during some testing. Board #1, used on the FLAIR system, was not affected.

The mezzanine board visible in Figure 12 (white board on the top right side) is a series of logic inverters. This was necessary to correct the behaviour of the switches turning the different sub-systems on and off. At start-up, the default state was all switches on, after correction we get the desired behavior (see section 2.2). This has been corrected on both boards #1 and #2.

2.6 Testing

2.6.1 Laser trigger

Measured frequency trigger signal: 199.7 kHz
Measured amplitude trigger signal: 2.65V on a 1MOhm oscilloscope.

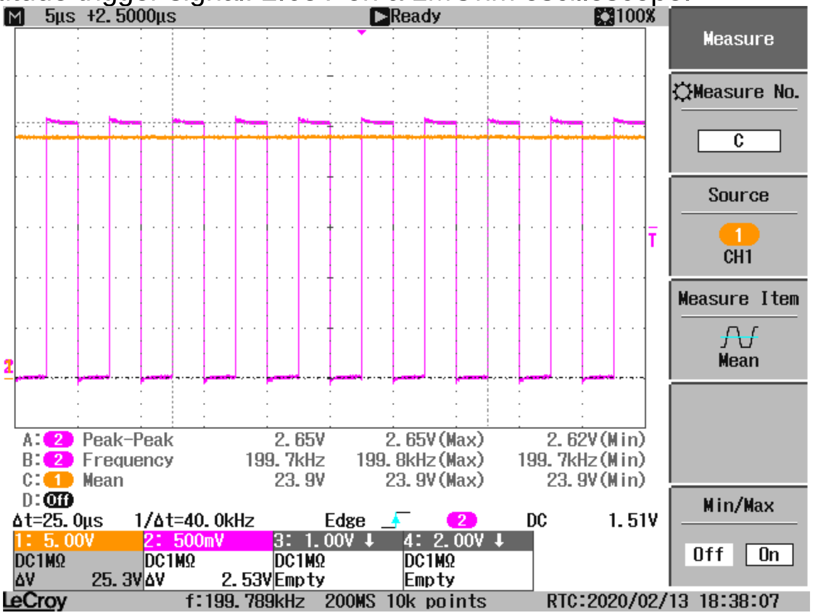

Figure 13 – Laser trigger measured signal

Measured delay 24V to trigger signal: 1.2ms. This was designed to first turn the Laser On before applying the trigger signal.

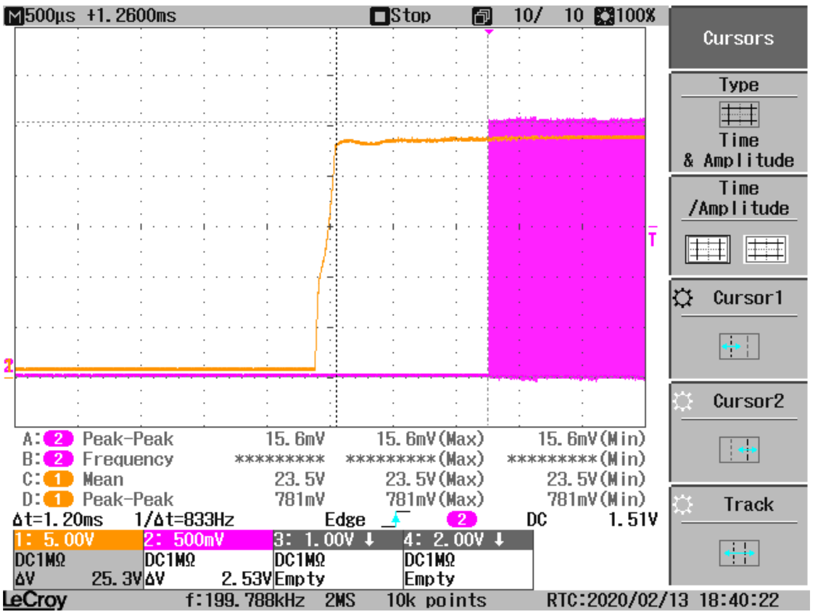

Figure 14 – 24V rise time and laser trigger signal delay

2.6.2 Output voltage

Sub-System	Power OFF	Power ON
+12V camera (J1, J3, J4, J6)	1.599V, 2.1µA	11.96V
+12V MPC (J10)	1.596V, 2.0µA	11.96V
+12V Grating (J11)	1.593V, 2.1µA	11.96V
+24V Laser (J12)	0.2650V, 2.0 µA	24.0015V

Table 4 – Output voltage

As expected (Section 2.4.2), when switches are off a remaining voltage is present when the output are not connected to a load.

2.7 Power consumption

The system has been powered with the 24V DC wall-plug transformer, and the current monitored with the help of the special cable assembly that allows to insert an amperemeter (see section 3, e)).
The measurements results are presented in Figure 15 for the power consumption at startup when switching the different sub-systems ON, and in Figure 16 under steady-states conditions.

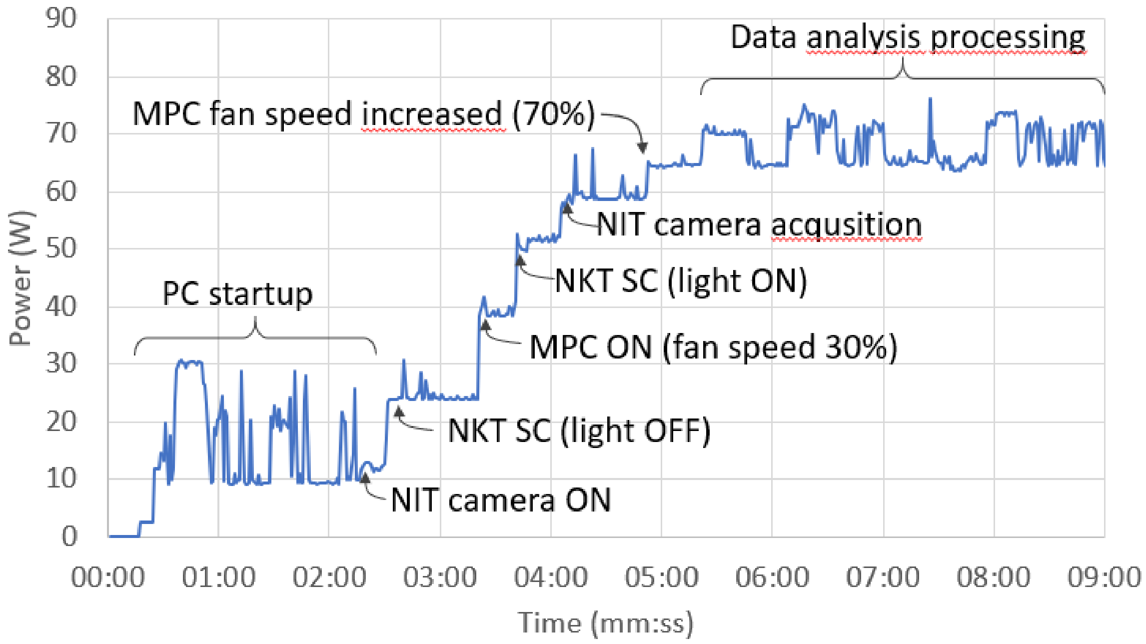

Figure 15 – Power consumption at start-up under laboratory conditions. The board is powered by the 24V DC wall-plug transformer.

Under normal working conditions, the system power consumption remains below 80W. This value can increase significantly if the temperature of the incoming airflow is well below the setpoint of the MPC.
The numerous spikes visible on the power consumption are attributed to the industrial miniature PC and most likely related to read/write access to its hard drive.

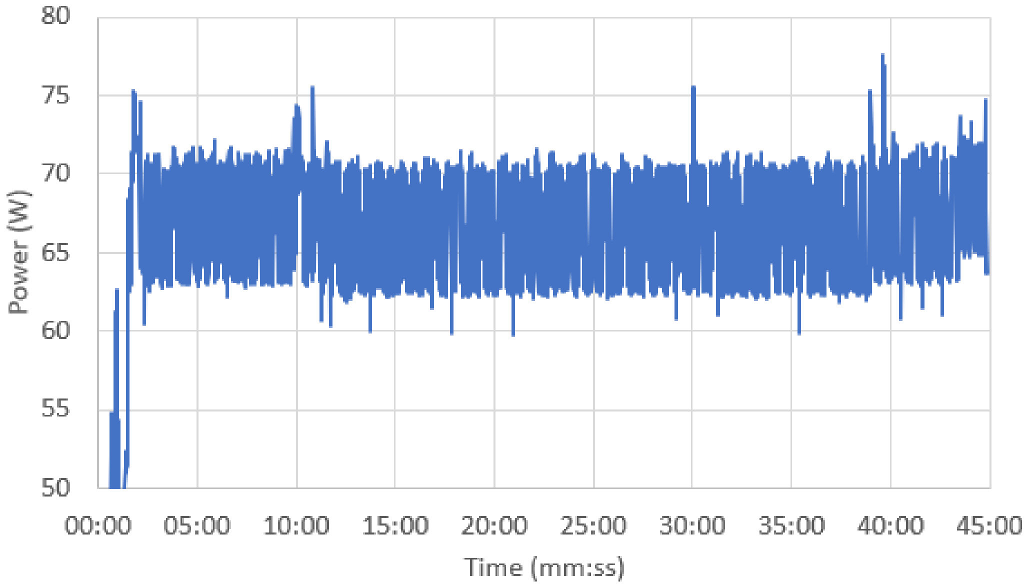

Figure 16 – Steady-state power consumption under laboratory conditions. The board is powered by the 24V DC wall-plug transformer.

3 Accessories

Several accessories and cables have been developed to power the FLAIR system. A collection is shown on Figure 17 and summarized in Table 5.

Table 5 – Description of the accessories

a)	Redundancy power board, as described in section 3.1
b)	Basic power cable (6 wires)
c)	Adapter for power supply d)
d)	AC/DC Wall-plug power supply, 24V DC, 280W
e)	Cable for power consumption measurement. The amperemeter can be mounted in series for current monitoring.
f)	Cigar plug cable. It has been used for powering FLAIR through the cigar plug of a car, e.g. during transportation between CSEM and EMPA, and during the Zeppelin test through the cigar plug of the battery pack.
g)	Cable with Amphenol MIL connector that has been used to power FLAIR during the helicopter tests in Denmark.
h)	Manual switch to power on FLAIR electrical board. A green LED indicates the status.
i)	Power cable with fuse and fuse box for electrical protection of the FLAIR system.

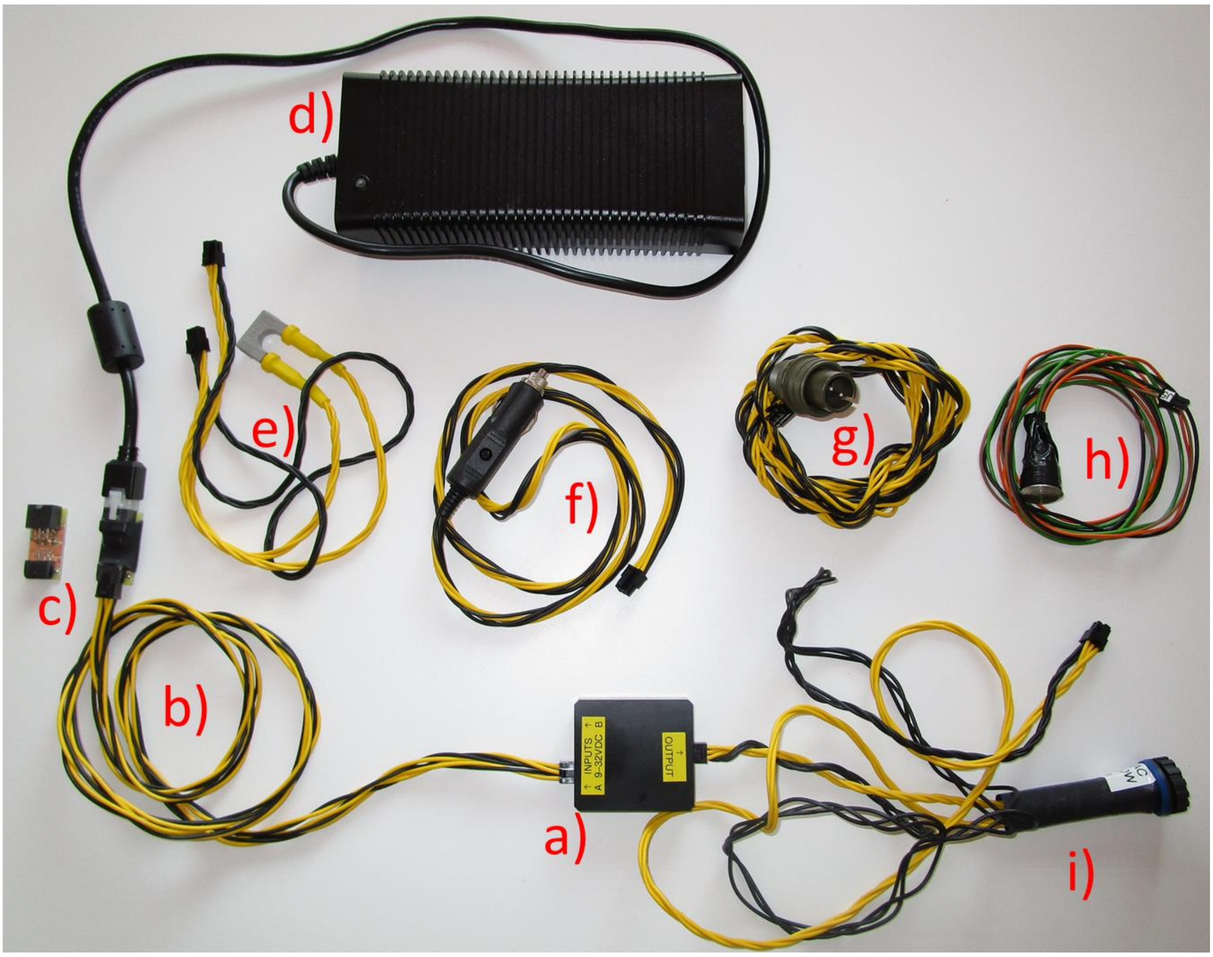

Figure 17 – Collection of cables and accessories used to power the FLAIR system

3.1 Redundancy power board

As small external board aims to supply the board with 2 power sources. This board is basically two ideal diodes (using a power MOSFET with LTC4357IMS8 driver). It can be used for switching power supply mid measurement. For example, it has been used to switch the power supply from the laboratory wall plug transformer (instrument preparation and warming up) to a battery (field measurements) without switching off the system.

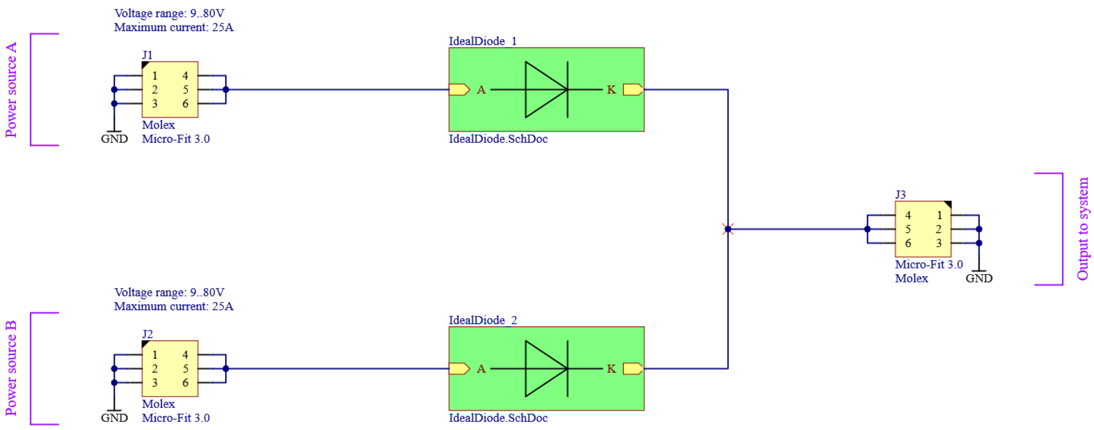

Figure 18 – Redundancy power board block diagram

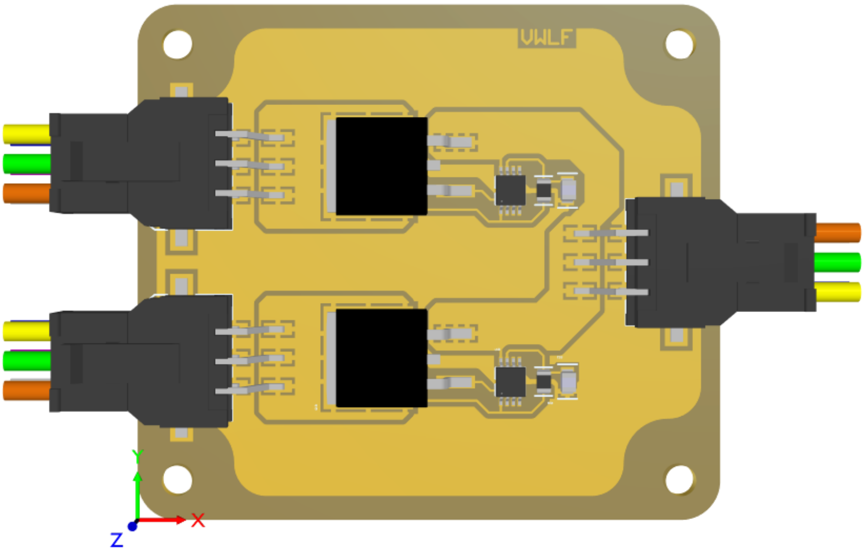

Figure 19 – Redundancy power board 3D view

4 LabVIEW® control software

The control system software has been programmed in LabVIEW®. It manages the switching on-and-off of the different subsystems through the commands described in section 2.3. It drives the NIT camera, performing initialization, regular auto-shutter, and frame acquisition at typically 1000 fps. It launches the Python® analysis algorithm and transfers the frames by packs of 1000. It collects the gas concentrations calculated by the Python® analysis, and the measured spectrum, at typically 1 Hz frequency, and displays them on the GUI. It also controls the multipass cell parameters and log the data (temperatures, humidity, fan velocity, etc), typically each second.

A series of parameters can be set with the help of text files that are loaded by the software at startup. They include typically the COM port numbers used for communication with the different sub-system, and parameters like some camera attributes (frame rate, exposure time, bias level, etc). The path to the Python file performing the spectrum calculation and concentration analysis is also set in these files.

The software is installed on a Low Power Mini PC i5-7200u (Figure 20), with 16GB DDR4 Memory and a 512GB SSD storage drive.

Figure 20 – Low Power Mini PC i5-7200u

The following subsection is a copy of the user manual of the FLAIR control software.

4.1 GUI (graphical user interface)

Run-icon (Flair shortcut) can be found on the desktop of FLAIR prototype sensor PC, as shown in Figure 21.

1. When the icon is double-clicked, the GUI will be open.
2. Click **Laser Power**.
    2.1. This button will turn on the communication between PC and NKT Laser.
    2.2. “Laser ON/OFF switch” will turn on the laser.
3. Click **Camera Power**.
    3.1. This button will turn on the NIT camera and chopper.
        3.1.1. Turning on “Camera Power” takes approximately 45 seconds.
    3.2. To start a measurement, “Processing ON/OFF” switch must be switched on.
        3.2.1. Switching on “Processing ON/OFF” takes approximately 15 seconds.
4. Click **MPC Power**.
    4.1. This button will turn on sensors and heaters, which are integrated in the MPC.
    4.2. “Fan Speed” is to adjust the capacity of air circulation through the MPC.
        4.2.1. It is not calibrated.
        4.2.2. 50% corresponds to approximately 1.3 liter/second at atmospheric pressure.
    4.3. “Inlet and Air Temperature” is to adjust the temperature of gas inlet and inside of MPC.
        4.3.1. It is not calibrated.
        4.3.2. 0% and 30% corresponds to approximately 20°C and 26°C, respectively.

Figure 21 – GUI of FLAIR Prototype Sensor

4.2 Data management

4.2.1 Spectrometer data

When "Processing ON/OFF" switch is switched on, the measurement gets started. Then, simultaneously, the results get started to be saved into 3 different binary files, which can be found in a folder, indicated in Figure 22.

1. "concentration.dat" is the computed concentration of CH_4 and H_2O.
2. "demodulated_images.dat" is the 2D images (128x128 pixels), which is the outputting result of lockin demodulation out of 1000 consecutive images.
   2.1. Camera speed is fixed to 1000 fps.
   2.2. Measurement rate is fixed to 1 Hz.
   2.3. So, the lockin demodulation is performed out of 1000 consecutive images.
3. "profiles.dat" is the normalized transmission spectrum in wavenumber.
   3.1. One spectrum is 128 pixels.

When the "Processing ON/OFF" switch is switched off, the data saving will be terminated.

NOTE:

⇨ The measurement rate is fixed at 1Hz; therefore, the concentration of CH_4 and H_2O will be measured every 1 second.

⇨ The measurement must be terminated by switching off the "Processing ON/OFF" switch.
- If the measurement would be terminated abruptly, the saved data won't be lost.
- But, the number of measurements saved in the 3 files would be different. Some last measurements won't be saved for "demodulation_image.dat" and "profiles.dat". 3 files in binary format will be saved, as described below.
- But, by comparing the timestamp that is registered in each file, each data can be timely synchronized to each other.

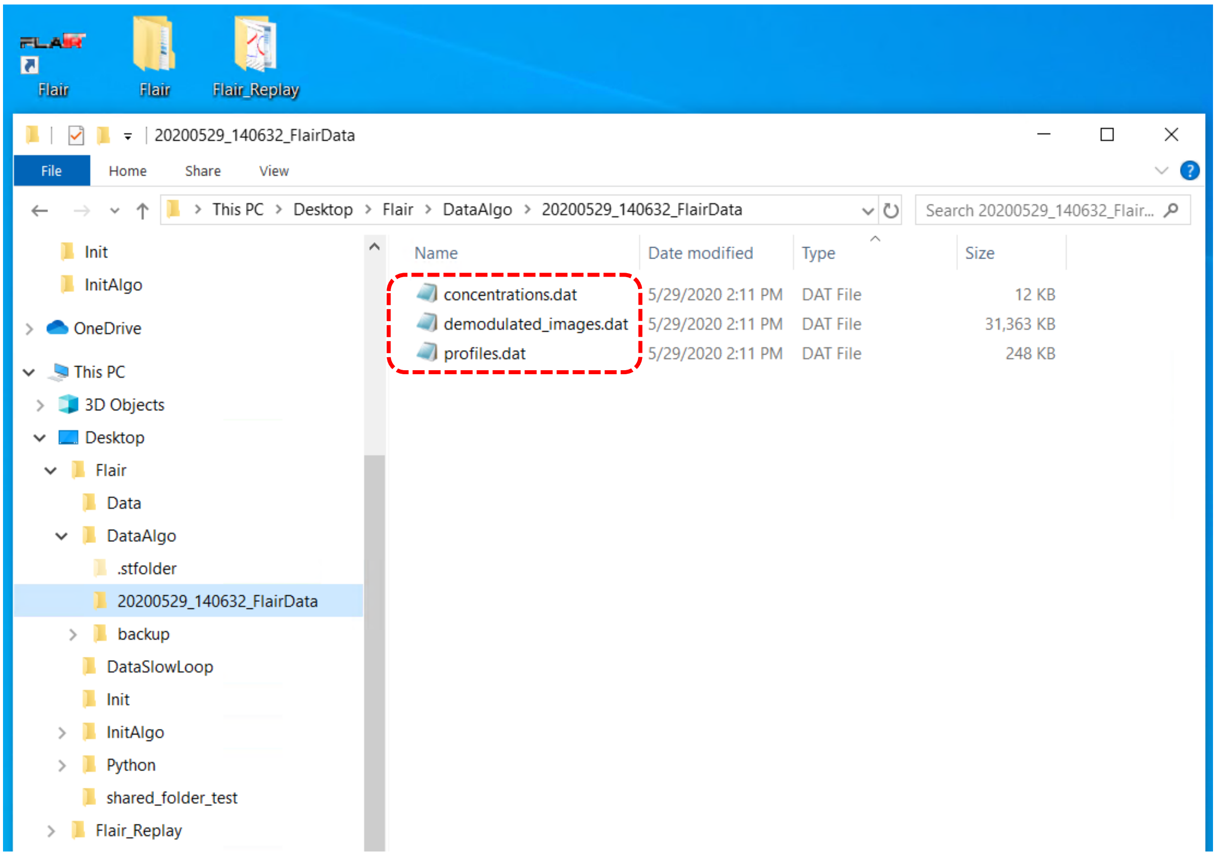

Figure 22 – Folder to save spectrometer measurement data

4.2.1.1 Decoding binary files

Python 3.7 or later version is required to convert the binary files (*.dat) to csv file.

1. Run “Spyder (Anaconda3) program” from the taskbar (See Figure 23).
2. Open a script, “FLAIR_dat_csv_converter.py”.
3. Run the script (shortcut is to press F5).
   3.1. It will open a file explore folder (See Figure 24).
   3.2. Then, select all 3 *.dat files.
4. Then, 4 csv files will be generated in the same folder (See Figure 25).
   4.1. “measured_timestamp_elapsed.csv” is the relative time, starting from 0 to the end of the measurement in millisecond.
   4.2. “measured_timestamp.csv” is the absolute time of the measurement, consisting of 7 columns: Year / Month / Day / Hour / Minute / Second / ms.
   4.3. “measured_profiles.csv” is the normalized transmission spectrum in wavenumber (not in wavelength).
   4.4. “measured_concentrations.csv” is the computed concentration of CH4 and H2O, consisting of 4 columns: CH4 / H2O / DC offset positive / DC offset negative.

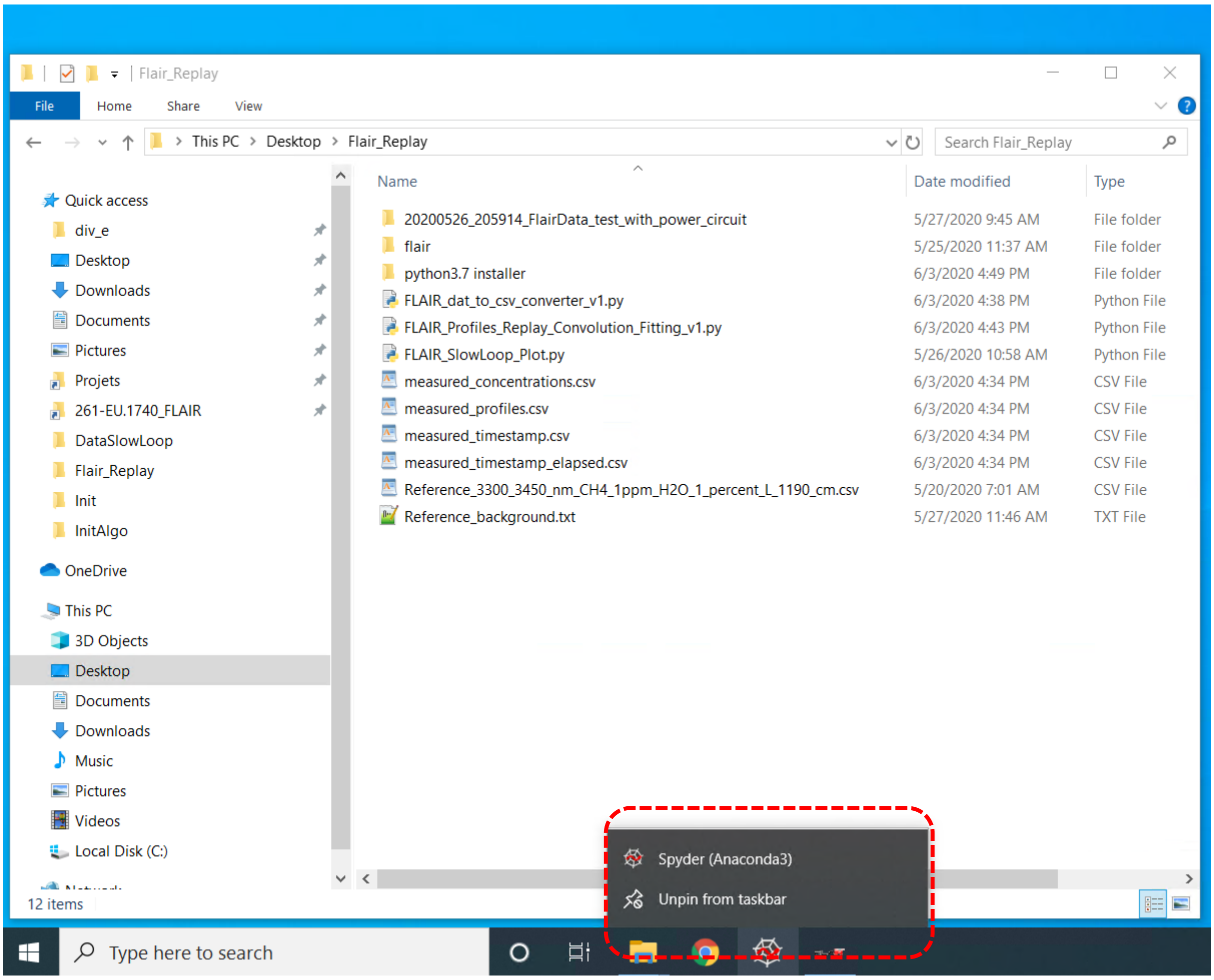

Figure 23 – Spyder to run Python script

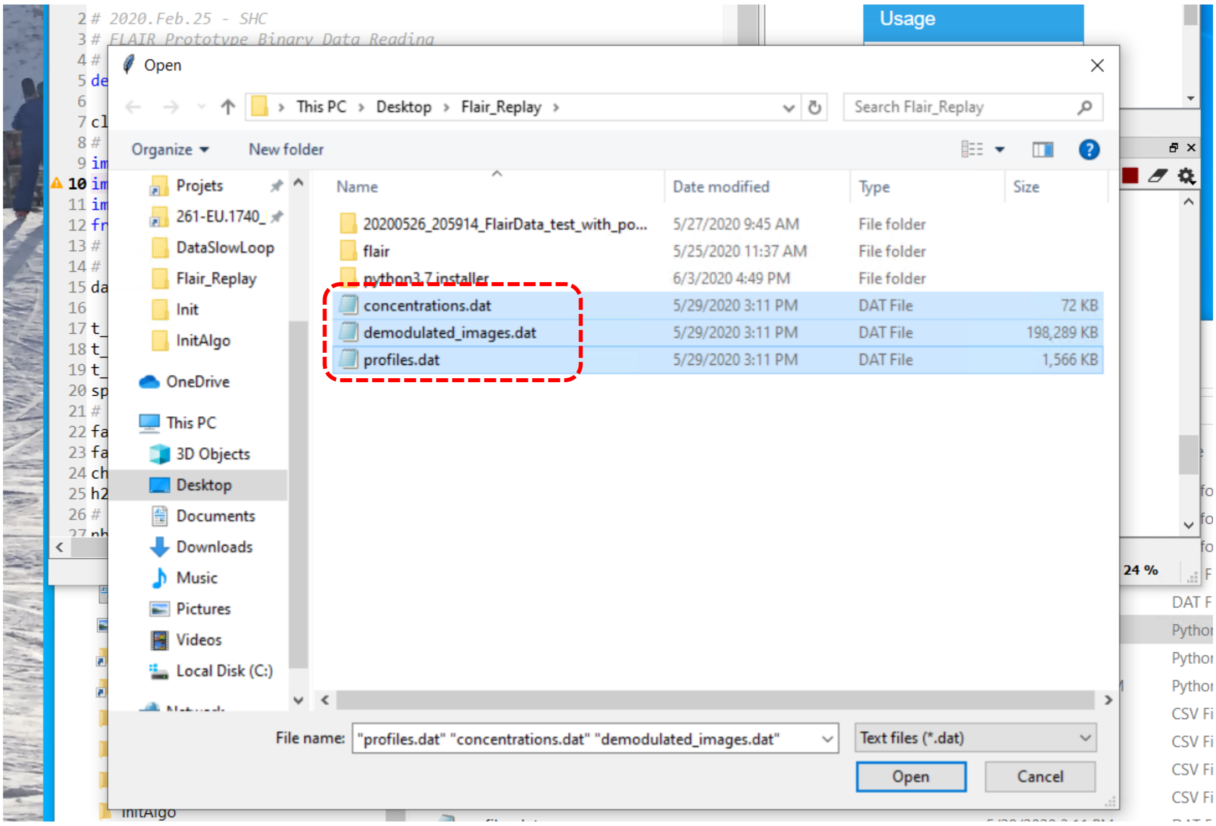

Figure 24 – Select all *.dat files for the conversion to csv

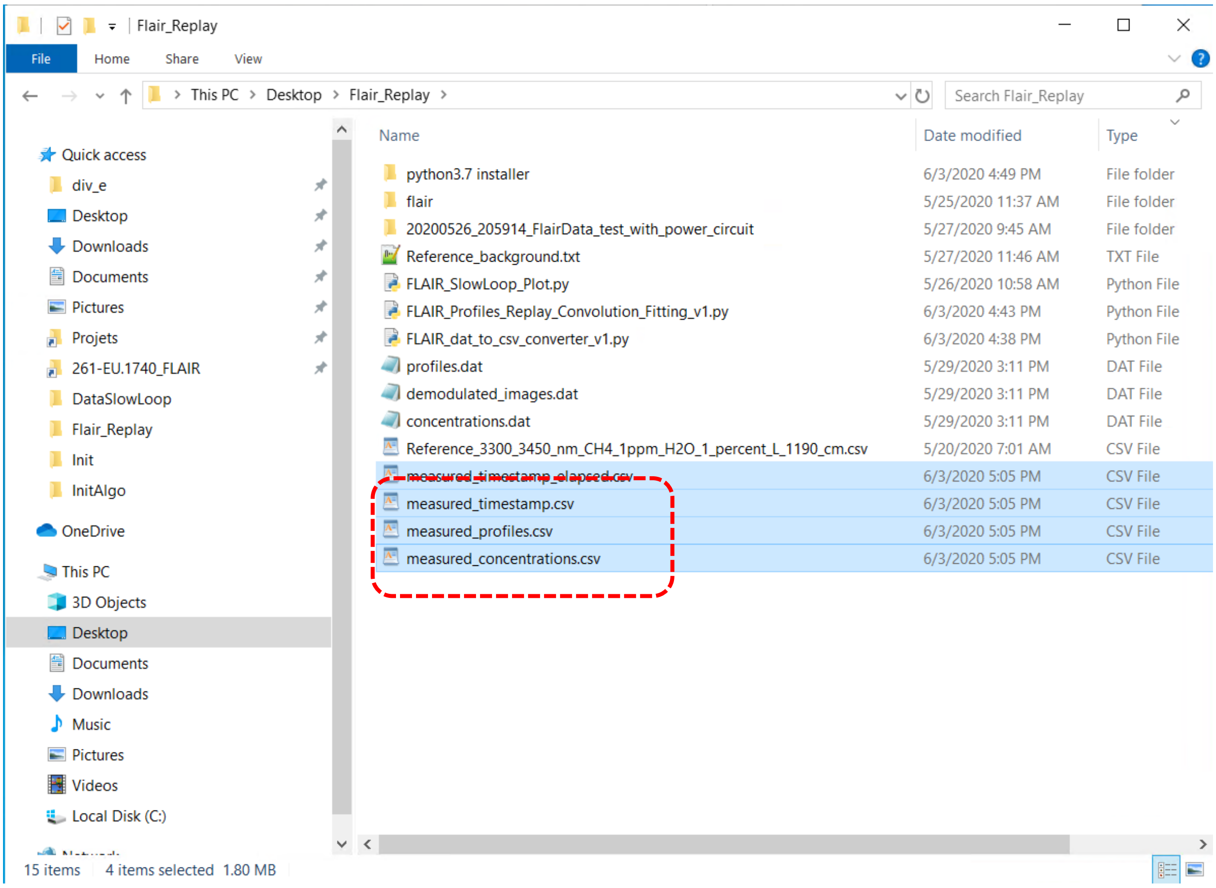

Figure 25 – csv files, converted from *.dat files

4.2.2 Laser and MPC sensor data

Laser operation conditions and MPC sensor data is saved in a folder, indicated in Figure 26.

⇨ Temperature, current, etc from the laser
⇨ Temperature, pressure, relative humidity (RH), etc from the MPC
⇨ The timestamp of the measurement start is the filename of the saved csv file.
  - Only elapsed time is saved in the file in millisecond.
  - This way, this data can be timely synchronized to spectrometer data. Figure 21

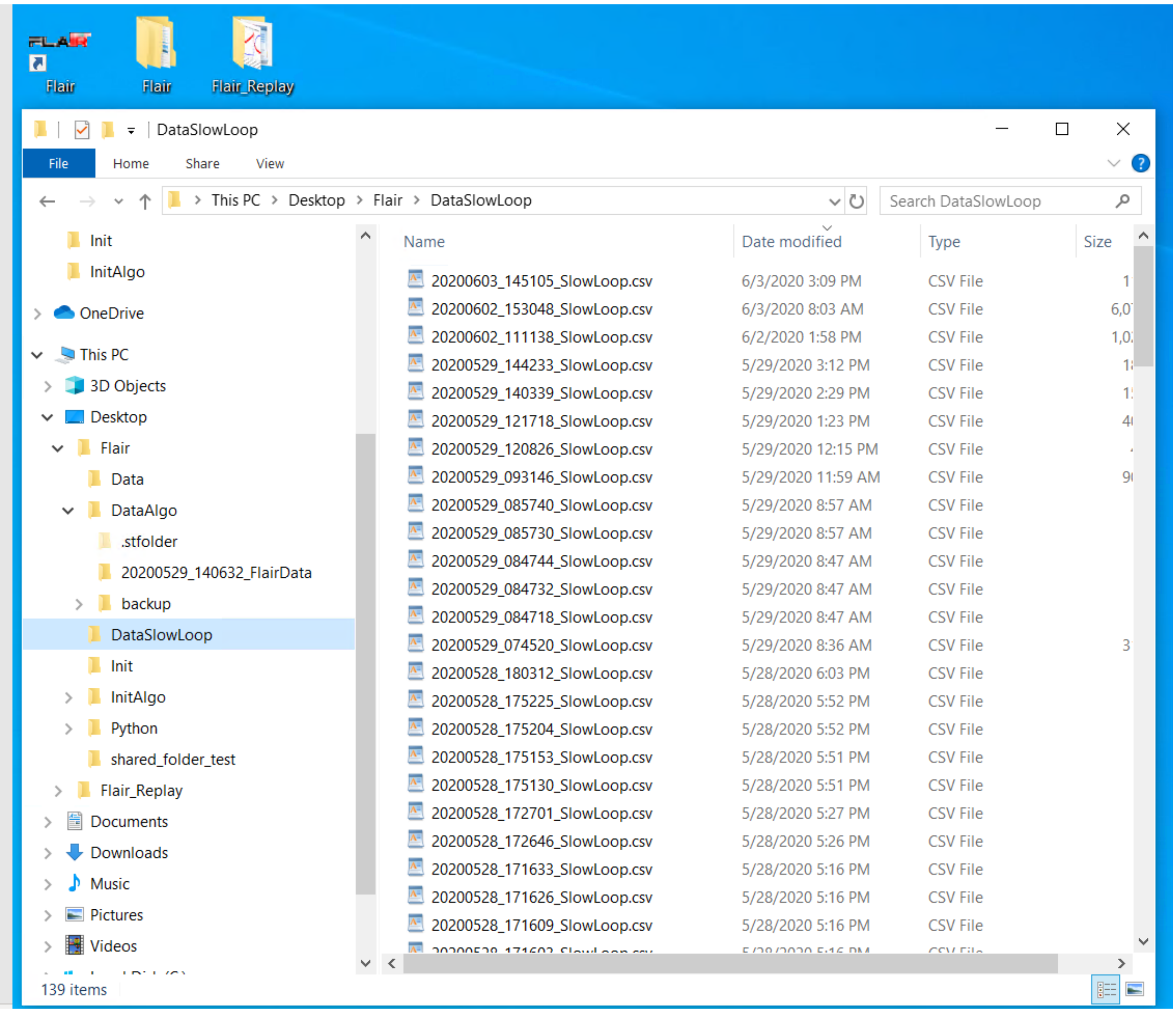

Figure 26 – Folder to save MPC sensor data

4.3 GPS log

A GPS logger with 6 sensors (https://aaronia.com/gps-logger/) is implemented in FLAIR prototype. When it is turned on (turn on device and turn on the logger switch), the following information will be logged at 10Hz:

- GPS coordinates with altitude
- acceleration and speed
- compass, gyro and tilt.

The information is saved in a micro-SD card in the device. The memory card can be connected to any PC using USB reader, and then the information can be extracted in csv file.

4.4 Access to FLAIR prototype PC

4.4.1 Remote access

The PC can be accessed remotely, either through ethernet connection, WiFi, or via the 4G cellular network through the Huawei E3372 LTE USB stick provided with the system.
"AnyDesk" program version v5.5.3 is installed. It is recommended to use the same version for the connection. Any external PC having the internet can be connected to FLAIR PC.
FLAIR PC AnyDesk information:

- ID: 369 989 522
- PW: flair_csem

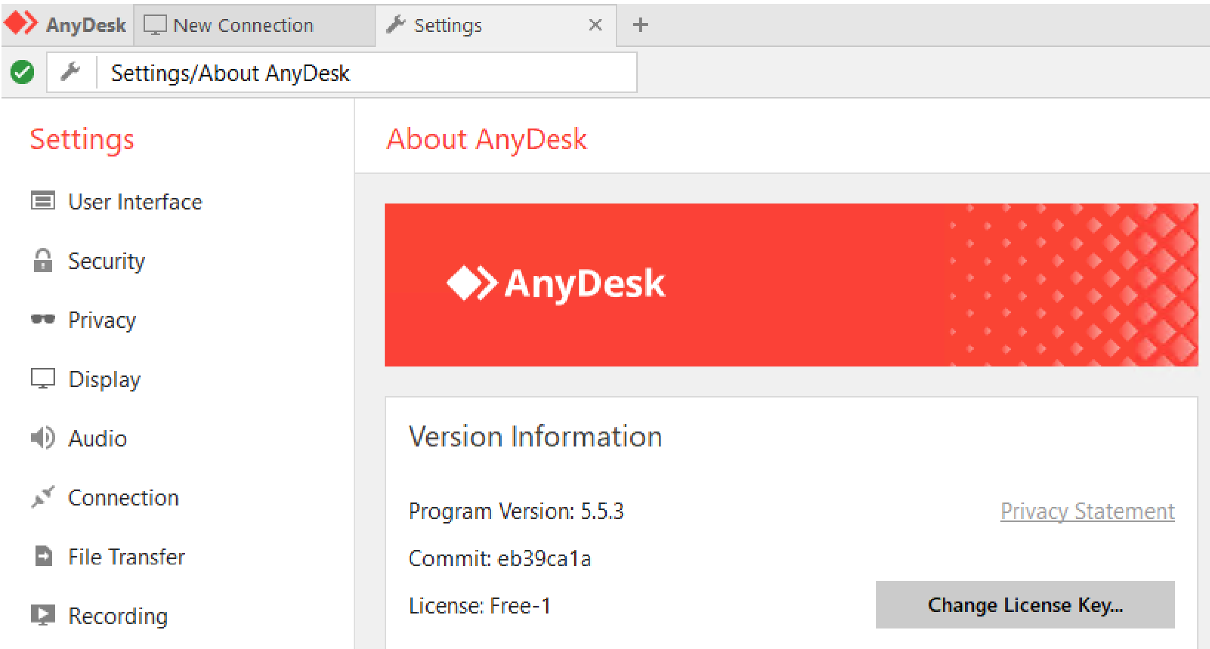

Figure 27 – Access to FLAIR PC, using AnyDesk

4.4.2 Remote Desktop Connection

Any external PC without the internet can be physically connected to FLAIR PC, using "Remote Desktop Connection". The IP address of USB-LAN converter is set to 192.168.1.100. So, the IP address of the LAN port of the external PC must be set to 192.168.1.xxx (xxx can be any number except 100) / 255.255.255.0. Then, the two PCs must be physically connected, using a LAN cable.

- Computer: 192.168.1.100 / 255.255.255.0
- Password: csem

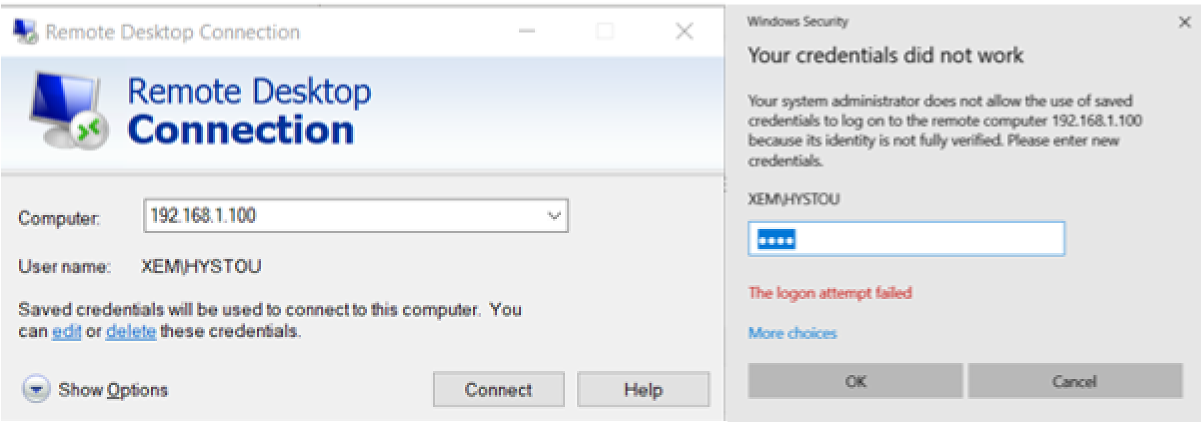

Figure 28 – Access to FLAIR PC, using Remote Desktop Connection

4.5 *Data transfer*

All measured data is configured to be automatically synchronized to a PC at CSEM.
This link has been de-activated after the end of the field tests in Denmark.

4.6 *Installer*

In addition to the software being installed on the miniature industrial PC, a standalone installer with the latest version of the LabVIEW software has been delivered in electronic format together with this report.

5 Conclusion

The current version of the electrical control system (Hardware + Software) is fully functional, and allows for standalone operation on a multitude of platforms (cars, UAVs, batteries, laboratories, helicopter, …)
The hardware is installed on the FLAIR system (board #1), and the software is available on the Desktop of the embedded computer.