DATA COLLAR

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Produced by

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1 | Introduction

1.1 SpeakNoEvil

The Embedded Communicating Systems group of the Industrial Systems Institute of the Haute École d'Ingénierie of Sion has developed a data collar: *SpeakNoEvil*. The main purpose of this collar is to record the sound of vervet monkeys (see Figure 1). This should allow scientists to better analyze their communication and behavior.

Figure 1: Vervet monkey

To achieve this, the first version of the collar had different features:

- A microphone to record the sound.
- An SD card to save sound files.
- A release system to unhook the collar without touching the monkey (avoid putting him to sleep).
- A Bluetooth Low Energy communication to remotely control the collar (start/stop recording, see collar status, release collar, etc).

An nRF53 microprocessor allows all the different components to be coordinated and communicate with the device. An iOS application has also been developed to remotely control the collar using the BLE connection (see Figure 2).

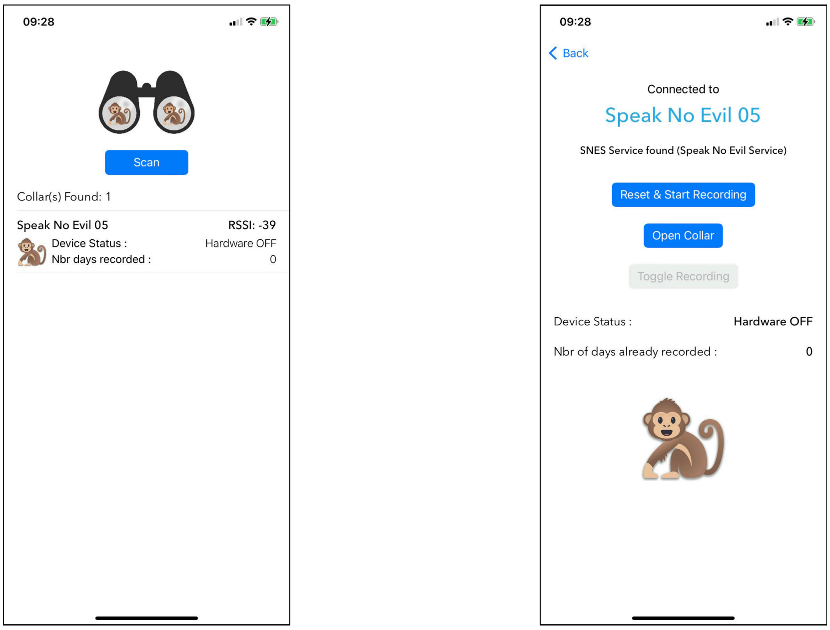

Figure 2: iOS app preview in scanning mode and connected to a collar.

The first version was tested on monkeys in South Africa during the summer of 2023. They allowed scientists to collect valuable data for their research.

Figure 3: Scientist collaring a monkey, that has been put to sleep, during field test

These field uses have made it possible to show the limits of the V1. Issues were detected at that time :

- Waterproofing of the housing
- Unexpected disconnection of the SD card
- Problem with starting recording
- Reduced BLE range (~15m)

A master Projet Interdisciplinaire, from the spring semester 2024, has already studied possible mechanics, electronics, and software optimizations.

1.2 Objectives

This project aims to prepare the development of a second version based on the PI results and the new customer needs. The important features of this recorder are the following:

- 10 days of operation on one single primary lithium cell
- Remote control by BLE
- Waterproof for rain and swimming
- Mechanical strength
- Simplicity of use
- Temperatures up to 50° Celsius
- Position tracking using Global Navigation Satellite System (GNSS) ➡️ new feature
- Data recovering without removing the SD card ➡️ new feature

Based on the results of the version 1 and PI, a updated version is planned. It will have to solve the problems encountered during field tests. Following a request from scientists, a GNSS module will also be integrated into the collar to allow positiong tracking. Until now, the collected data was recovered by reading the SD card on a PC. To avoid tampering and opening the case, the data must be recovered without removing the SD card. This should ensure a better seal of the housing.

To prepare the work to produce a second version prototype, the following task must be realized according to the initial project description:

1. Using the test hardware that will be provided, verify the GNSS functionality. Special attention must be paid to the antenna. Propose a final antenna design.
2. Using the test hardware, verify and qualify the Bluetooth functionality using a smartphone and the Bluetooth long-range remote control.
3. Using the test hardware, measure current consumption and predict battery lifetime.
4. Using a test hardware and a release mechanism prototype (the latter will be provided), verify the validity of the release mechanism concept.

Since writing the project description and during the project, the needs have evolved. To prepare the work to produce a second version prototype, the following tasks must be realized according to the new project description:

1. Using the test hardware that will be provided, verify the GNSS functionality. Special attention must be paid to the antenna. Propose a final GNSS antenna design.
2. ~~Using a test hardware, verify and qualify the Bluetooth functionality using a smartphone and using the Bluetooth long-range remote control.~~
   ➡️ New hardware has been used and needs to be integrated into the project first.
3. ~~Using a test hardware, measure current consumption and predict battery lifetime.~~
   ➡️ New hardware has been used and needs to be integrated into the project first.

4. ~~Using test hardware and a release mechanism prototype (this latter will be provided), verify the validity of the release mechanism concept.~~
   ➡️ New hardware has been used and needs to be integrated into the project first.
5. Develop and produce an autonomous power profiler that can be used in the field without a computer. This will enable more consistent and realistic field consumption measurements during the master's thesis. (Objective added during the project)

The PI *MobileSens* is running in parallel with this project to test certain functionalities and to integrate the new hardware. This Projet Approfondissement is linked with a future master thesis: *BLE connected GPS collar for small animals*.

The hardware utilized in the project is described at the beginning of this report. This is followed by a presentation of the GNSS-based positioning approach, which details the setup and methods utilized to provide accurate findings. After an explanation of the tests used to evaluate system performance, the results are analyzed and discussed. The use of batteries is then investigated, as well as possible methods for minimising energy use to improve efficiency. It then talks about the creation of the power profiler. Lastly, a summary of the key findings wraps up the research.

2 Hardware

Some hardware has been given for this project: a SpeakNoEvil development kit, a PCB with a CAM-M8 GNSS module, and one with an SM-M10Q GNSS module. The three PCBs are detailed in the following points. An NRf54L15 development kit has also been provided to test the new components on the SpeakNoEvil development kit.

2.1 SpeakNoEvil development kit PCB

This PCB will be mounted on an nRF development kit. It carries the new components to be tested.

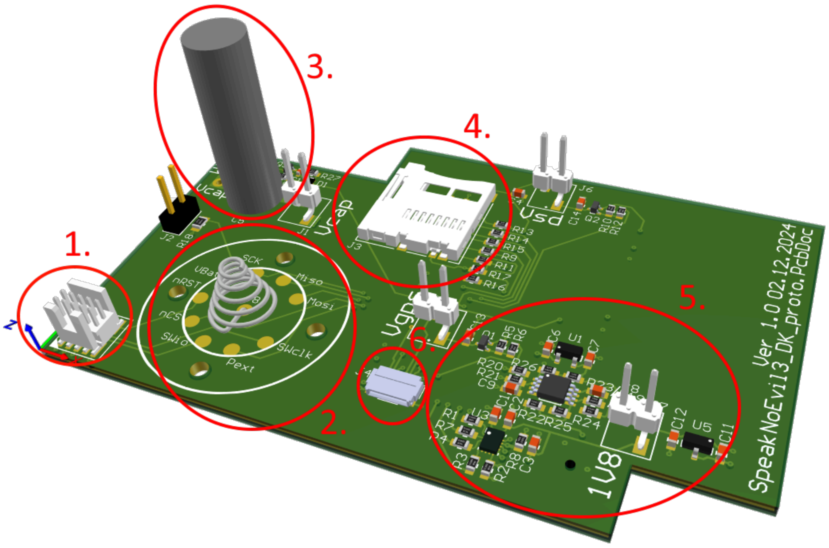

Figure 4: SpeakNoEvil3 development kit prototype

1. **Connector for the communication pins**

   It connect on nRESET, SWDIO, and SWCLK signals on the communication pins.

   ➡️ Tested in the PI *MobileSens*

2. **A battery connector with communication pins**

   These pins allow data stored on the SD card to be retrieved without removing it. In the new version, these pins will be in the battery compartment. As the collar must be waterproof, it will have only one accessible compartment, the battery compartment. This will allow to change the battery and access the communication pins without compromising waterproofness.

   ➡️ Tested in the PI *MobileSens*

3. **A supercapacitor with dedicated electronics to burn a nylon thread (released mechanism)**

   The supercapacitor stores enough energy to heat a copper wire on command. The latter can thus burn a nylon thread, which keeps the collar closed, as shown in the Figure 5. It releases the collar from the monkey's neck without having to put it to sleep.

   ➡️ Tested in the PI *MobileSens*

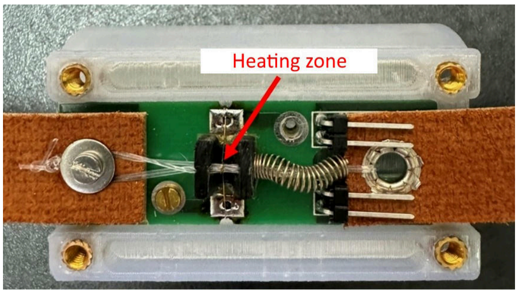

Figure 5: Release system

4. **An SD card mount to store the recorded sound**

   The recorded sounds with the microphone are stored in a file system on the SD card.

   ➡️ Tested in the PI *MobileSens*

5. **A new microphone with dedicated electronics**

   The microphone continuously records the sound emitted by the monkeys.

   ➡️ Tested in the PI *MobileSens*

6. **Connection port for the GNSS module**

   The GNSS module will not be directly mounted in the collar housing.

2.2 SpeakNoEvil GNSS CAM-M8 module PCB

This PCB was designed to receive a GNSS CAM-M8 module on top. A flat connector under the PCB allows the module to connect to the main board with a flat cable. The communication cable transmits signals between the module and the board (see Table 1).

Signal	Description
TIMEPULSE	Precise timing output pulse for synchronization
RXD	UART receive data input pin
TXD	UART transmit data output pin
VCC	Main power supply voltage input
V_BCKP	Backup power supply for RTC and memory retention
EXTINT	External interrupt input for wake-up or event triggering
RESET_N	Active-low reset input pin
GND	Ground reference and power return path

Table 1: Signal transmits between CAM-M8 module and processor in order

The antenna needs a ground plane to work correctly. This PCB allows one to weld one on the top face perimeter.

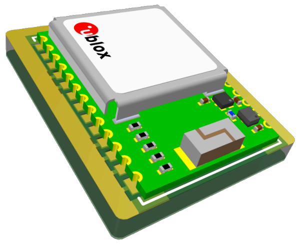

Figure 6: SpeakNoEvil GNSS CAM-M8 module

> The ground pin on the connector from the provided PCB is not connected to the rest of the ground. To work correctly, the GND pin from the connector has to be connected to a ground pin from the PCB.

2.3 SpeakNoEvil GNSS SM-M10Q module PCB

This PCB has the same purpose as the previous one, except that this one is dedicated to a GNSS SM-M10Q module. The communication cable also transmits signals between the module and the board (see Table 2).

Signal	Description
TIMEPULSE	Precise timing output pulse for synchronization
TXD	UART transmit data output pin
RXD	UART receive data input pin
VCC	Main power supply voltage input
V_BCKP	Backup power supply for RTC and memory retention
EXTINT	External interrupt input for wake-up or event triggering
RESET_N	Active-low reset input pin
GND	Ground reference and power return path

Table 2: Signal transmits between SM-M10Q module and processor in order

The copper ground plane is welded on the bottom face of the PCB.

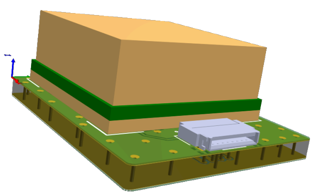

Figure 7: SpeakNoEvil GNSS SM-M10Q module

2.4 NRF54L15-DK

This development kit interfaces with various components on the SpeakNoEvil development kit PCB, which is connected through the DK header pins.

On the first version of the collar, another Nordic Semiconductor System on Chip was used: nRF5340. As nRF54 offers significantly higher processing power and lower power consumption support compared to nRF53, this new SoC is used in this project to move to series 54 for a future version of the collar. The nRF54 also delivers better RF performance and supports the latest Bluetooth LE 5.4 features.

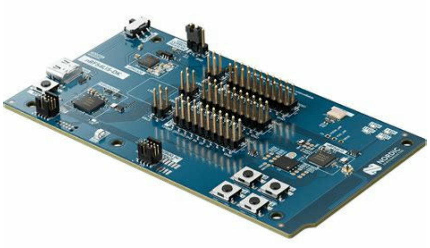

Figure 8: NRF54L15-DK

2.4.1 Development kit modification

The development kit must be modified to work correctly with the shield prototype (see Section 2.1). The following table lists all the used pins with their name on the development kit, the name of the corresponding signal on the SpeakNoEvil DK prototype PCB, and the modifications to make. No modifications are needed for some pins. For this project, only the necessary changes were made (see Table 3).

SpeakNoEvil signal name	Devkit proc pin number	Modification to do	Modification made
P0.00/UART0	P0.00/UART0_TX	No modif. needed	✗
P0.01/UART0	P0.01/UART0_RX	No modif. needed	✗
P0.02/UART0	P0.02/UART0_RTS	No modif. needed	✗
P0.03/UART0	P0.03/UART0_CTS	No modif. needed	✗
SD_DC	P0.04/Button3	No modif. needed	✗
P1.00/XL1	P1.00/XL1	No modif. needed	✗
P1.01/XL2	P1.01/XL2	No modif. needed	✗
nSDon	P1.02/NFC1	Remove R21 and add 0R R33	✗
SD_MOSI	P1.03/NFC2	Remove R22 and add 0R R34	✗
SD_CLK	P1.04/UART1_TX	Cut track P1.04 **between PORT P1 pin 04 and U5**	✗
SD_MISO	P1.05/UART1_RX	Cut track P1.05 **between PORT P1 pin 05 and U5**	✗

SpeakNoEvil signal name	**Devkit proc pin number**	**Modification to do**	**Modification made**
SD_nCS	P1.06/UART1_RTS	Cut track P1.06 **between PORT P1 pin 06 and U5**	❌
SCK	P1.07/UART1_CTS	Cut track P1.07 **between PORT P1 pin 07 and U5**	❌
MISO	P1.08/Button2	No modif. needed	❌
MOSI	P1.09/Button1	No modif. needed	❌
nCS	P1.10/LED1	Remove Q3 (also disable LED 3)	❌
POW_EXT	P1.11	No modif. needed	❌
BURN	P1.12	No modifi. needed	❌
GPS_TimePulse	P1.13/Button0	No modif. needed	✅
BATT_LOW	P1.14/LED3	Remove Q3 (also disable LED 1)	❌
GPS_nRESET	P2.00/QSPI_IO3	Removed SB16 and sold SB17	✅
GPS_TX0	P2.01/QSPI_CLK	Removed SB12 and sold SB18	✅
GPX_RX0	P2.02/QSPI_IO0	Removed SB13 and sold SB19	✅
GPS_INT	P2.03/QSPI_IO2	Removed SB15 and sold SB20	✅
nGPSon	P2.04/QSPI_IO1	Removed SB14 and sold SB21	✅
MIC_WAKE	P2.05/QSPI_nCS	Removed SB11 and sold SB22	❌
MIC_CLK	P2.06/TRACE_CLK	No modif. needed	❌
MIC_THSEL	P2.07/TRACE_D0/LED2/SWD	Remove Q2 (also disable LED 4) and remove SB24	❌
MIC_WS	P2.08/TRACE_D1	No modif. needed	❌
MIC_DATA	P2.09/TRACE_D2/LED0	Remove Q2 (also disable LED 2)	❌
MIC_OE	P2.10/TRACE_D3	No modif. needed	❌

Table 3: Development kit modification

2.4.2 Development kit blinky

The development kit has been tested with a standard blinky project using VS Code with the *nRF Connect extension*. This project has been modified to allow turning on and off the LEDs with buttons. Problems appeared during the build and the flash phase.

1.
```
_ERROR: it looks like . is a build directory: did you mean --build-dir .
instead? FATAL ERROR: refusing to proceed without --force due to above
error_
```

It can't create the build. This error message comes from the build tool, and it means that it is trying to run a command in a directory that it detects as an existing build directory, but it hasn't been told how to handle that properly.

> **Solution :**
>
> Delete CMakeCache.txt and build the project again [1].

2.
```
_FATAL ERROR: required program nrfutil not found; install it or add its
location to PATH_
```

It can't flash the card because the system is trying to run a command or script that depends on the *nrfutil* tool, but it can't find it in your system's environment.

> **Solution :**
>
> download *nrfutil* in `:\Program Files\Nordic Semiconductor\nrf-command-line-tools\bin` [2].

3.
```
_Error: nrfutil command device not found. See nrfutil list for full list of
installed commands, nrfutil search for installable commands, and nrfutil
install for installation of new commands._
```

It can't flash the card because the system tried to use a device subcommand with *nrfutil*, but that subcommand isn't installed or doesn't exist in the current version.

> **Solution :**
>
> run `nrfutil install device` in a terminal to install the device module for *nrfutil* [2].

3 | Global Navigation Satellite System (GNSS)

The first project objective was to verify the GNSS functionality of a given test hardware. Special attention must be paid to the antenna. Finally, a final GNSS antenna design must be proposed.

To do so, both given modules have been tested. The following tests have been made on the modules in order to be able to select a module and propose an antenna design..

1. **Initial manufacturer app connectivity test :**

   Validates the GNSS module's initial connection with the manufacturer's application. Ensures correct communication, packet format recognition, and basic initialization behavior upon first pairing.

2. **Ground plane performance test :**

   Measures GNSS signal quality and Time To First Fix under open-sky conditions. This test evaluates cold, warm, and hot start acquisition time and Carrier To Noise density for various ground plane sizes. It aims to enable the selection of the ideal size of the ground plane. The purpose of a ground plane is explained in Section 3.2.2.

3. **Integration test :**

   With a fixed ground plane size, it measures GNSS signal quality and TTFF when integrated into a wearable collar (see mounting solution in Section 3.2.3).

4. **Power consumption vs GNSS message type test :**

   Evaluate the GNSS module's power consumption based on the enabled NMEA or proprietary message types. This test identifies how varying output configurations affect average and peak power draw.

5. **On-field power consumption test :**

   Measures the module's power consumption across key states: fix time, tracking, and sleep. Identifies peak and average current draws to inform battery life expectations and optimize power management strategies in the future.

Before discussing the tests and their results, an explanation about GNSS, antennas, and their importance is needed.

3.1 GNSS basics

Global Navigation Satellite System refers to a network of satellites that transmit positioning and timing data to GNSS-enabled receivers on Earth. These receivers use signals from several satellites to determine their precise location (latitude, longitude, and altitude), speed, and time. The GNSS system in the United States is the most well-known GPS, while other systems include BeiDou (China), Galileo (EU), and GLONASS (Russia). Modern GNSS modules improve accuracy, dependability, and fix times by allowing them to support multiple constellations simultaneously, particularly in difficult-to-reach places like dense forests. [3]

One of the key features of GNSS, for this project, is Time To First Fix. A fix in GNSS refers to successfully determining the receiver's position using satellite signals. To obtain a GNSS fix, the receiver must acquire signals from at least four satellites to accurately calculate its position and time. There are three types of fixes:

- **Cold start :** the receiver has no prior data (location, time, or satellite information). It must search for all satellites from scratch, which takes the longest time.
- **Warm start** the receiver remembers some data (last location or satellite information), but needs to update it. Fix time is moderate.
- **Hot start :** the receiver has recent and valid data. It quickly reacquires satellites, resulting in the fastest fix.

3.2 GNSS antenna

Antennas are a critical part of any receiver design and their importance cannot be stated highly enough. A GNSS receiver should receive signals from as many satellites as possible. Poor visibility may cause position drift or a longer TTFF.

3.2.1 Antenna type

There are two main types of antenna: active and passive. Passive antennas contain only the radiating element, e.g. the ceramic patch. They occasionally have a passive matching network to match the electrical connection to a 50 Ohm impedance. Active antennas have an integrated Low-Noise Amplifier. There are two advantages to this. First, the total noise figure of the GNSS receiver system is no longer impacted by the cable losses following the LNA. Secondly, the antenna's LNA contributes to a lower system noise figure, which improves sensitivity.

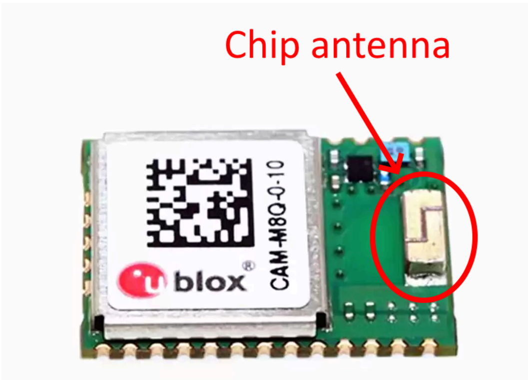

Figure 9: CAM-M8 module antenna

A passive antenna is already mounted on the tested modules (see Figure 9). An active antenna can't be used. In addition, an active antenna requires power, which is not a solution in a low-power system. Chip antennas are used in both modules. Their small size, as well as high gain and omnidirectional radiation patterns, make them a good solution to minimize the size of the module without worsening its performance. A ground plane is recommended for this kind of antenna. It will be detailed in the Section 3.2.2. The isolation distance can significantly impact antenna efficiency and, thus, performance, and needs to be carefully considered in designs.

3.2.2 Ground plane

A ground plane is crucial when using GNSS modules because it plays a significant role in signal integrity, antenna performance, and overall system accuracy. The ground plane serves several essential functions:

- **Signal reflection and antenna efficiency :**

  The ground plane acts as a reflective surface for the GNSS antenna, improving its ability to receive satellite signals. GNSS antennas generally use the ground plane's reflecting qualities to improve signal reception and efficiency. Without a sufficient ground plane, the antenna's performance might suffer dramatically, resulting in worse signal quality, longer TTFF, and decreased accuracy.

- **Reducing interference :**

  The ground plane protects the GNSS module from electromagnetic interference (EMI), which can distort signals received from satellites. This shielding is beneficial in areas with a lot of electrical noise, such as near motors and high-frequency components.

- **Stabilizing radiation pattern :**

  GNSS antennas typically have a specific radiation pattern for optimal satellite communication. The ground plane helps maintain this pattern by providing a stable reference point, improving the antenna's radiation consistency and the receiver's ability to calculate an accurate position.

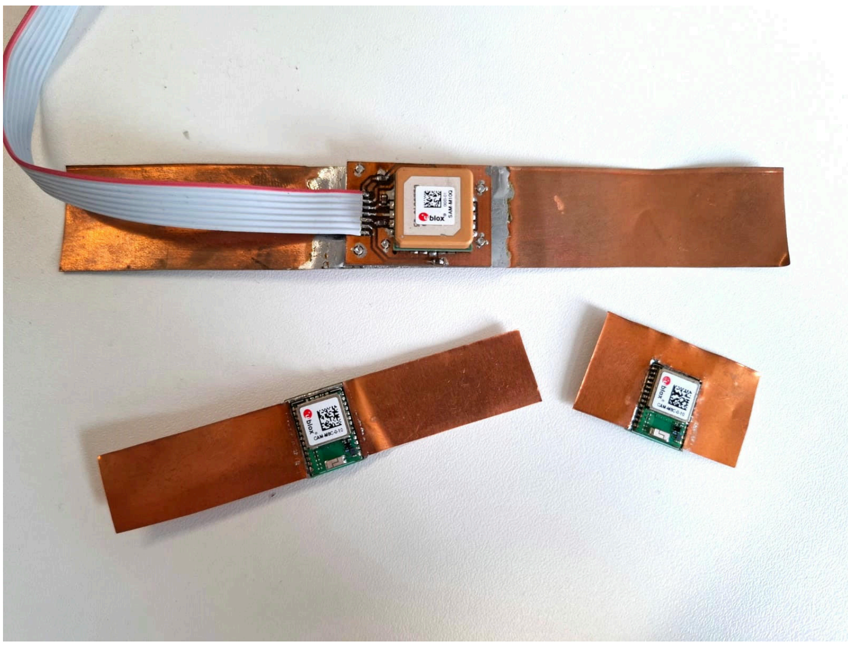

Figure 10: Modules with their extended ground plane

The ground plane is, in principle, the PCB on which the module is mounted, but if the PCB is too small, it can also be extended by adding copper foil (see Figure 10).

3.2.3 Antenna placement

The antenna's location is crucial for peak performance. Patch antennas (such as those used in project modules) should have their antenna plane parallel to the horizon. It must have the best sky view and direct access to as many satellites as possible.

This housing, containing all components, is placed beneath the monkey's lips and fixed around his neck using a leather strap (see Figure 11). The housing cannot be moved due to the microphone's presence. The leather strap is the only possible means of attachment. It is the least invasive for the vervet monkey. The placement of the GNSS module must adapt to these constraints.

Figure 11: Monkey with a collar

Two mounting locations were considered and analyzed:

On-collar solution : The module is attached to the monkey's collar strap and connected to the housing via a flat cable.
In-housing solution : The module is placed in the collar housing with its antenna and ground plane.

This particular collar was created to be carried by a vervet monkey. The Figure 12 illustrates a seated and walking vervet with a collar. The position of the module for both placement solutions can be visualized. In the first solution, the module is placed in position 1. In the second solution, the module is placed in position 4.

Figure 12: Seated and walking vervet carrying a data collar

On-collar solution
When the monkey sits, the GNSS module forms an angle of approximately 50° with the horizon. This is not optimum, but it is correct. Furthermore, when the monkey is stationary (sitting or lying down), GNSS data is less essential. Tracking the monkey is most effective while it is moving. When the latter moves, the module is nearly parallel to the horizon. This is the best-case situation because it has a clear sky view. Only the monkey's head or an obstacle above him might obstruct a portion of the sky.

> ✓ When the monkey moves, the module is nearly parallel to the horizon, maximizing satellite view.
> ✓ The module is placed on the back of the head, offering better exposure to the sky in dynamic conditions.
> × When the monkey is sitting, the module tilts at ~50°, suboptimal for GNSS accuracy.
> × The external positioning may expose the module to more mechanical wear or displacement. This also complicates its integration.

In-housing solution
The position in the housing can be chosen so the angle between the module and the horizon can be tuned as needed. We can, therefore, improve the quality of the GNSS signal during movement or a static position. Thus, the parallelism between the module and the horizon can be guaranteed. While tracking the monkey is most effective when moving, the moving position must be prioritized.

The monkey's head will be an obstacle. It might obstruct a portion of the sky and decrease the module's performance. This solution is a compromise that is not debatable because the housing position cannot be modified.

> ✓ The module's angle relative to the horizon can be adjusted for optimal GNSS performance during movement.
> ✓ The module is securely integrated into a protected housing, reducing mechanical stress or damage.
> × The monkey's head obstructs part of the sky, limiting satellite visibility.
> × The module's position is fixed due to the microphone, restricting further optimization.

Other essential points
Placing the module near a human body or any biological tissue will reduce the module's performance. The antenna's radiation is reduced due to signal losses in the biological tissue. A distance of 10mm is recommended between the module and the monkey's body. [4]

With the in-housing solution, the module embedded in the housing, the 10mm distance can almost always be ensured. However, the monkey's movement could sometimes lead to situations where this distance is temporarily violated. This is not a controllable situation. It is a necessary compromise with this solution.

For the on-collar solution, the module has to be spaced enough from the monkey's neck and the leather strap to give the module the best performance. Leather is derived from animal skin, which retains properties similar to biological tissues. It absorbs and reflects electromagnetic waves, leading to signal attenuation and reduced antenna radiation. It is, therefore, necessary to provide an assembly that spaces the module by at least 10mm from the strap and not just the monkey's neck.

In summary, both solutions have benefits depending on the monkey's activities. The first option guarantees safety and consistent orientation, but because of head occlusion, it has poorer sky visibility. While tracking is most important when the monkey moves, the second option offers the best GNSS performance. However, special attention must be paid to the spacing of the collar to the strap. This can be a challenge for collar design.

3.3 CAM-M8

The CAM-M8 module is built around the u-blox M8 GNSS engine and is offered in a compact, surface-mounted form factor with an integrated chip antenna. This is ideal for this project as the collar has to remain as small and light as possible so that a small animal can carry it.

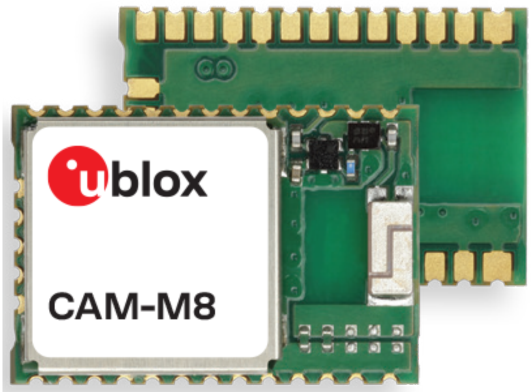

Figure 13: CAM-M8 module

The provided PCB containing the CAM-M8 module (see Section 2.2) allows the module to be connected to the SpeakNoEvil development kit prototype PCB (see Section 2.1). The PCB is 12.80 x 16.00 x 4.50mm for 3 grams.

As explained previously (see Section 3.2.2), a ground plane is mandatory to ensure the module's performance. As the module PCB is small to allow easy integration, the ground plane surface is augmented by adding a copper sheet. In the datasheet [4], the embedded GNSS chip antenna provides optimal radiation efficiency of 80% with an 80 x 40mm ground plane (3200 mm2). The suggested minimum size is 45 x 20 mm (900 mm2). Below this minimum, the module may still work, but performance will be reduced. TTFF and accuracy may be impacted. It is, therefore, necessary to test the different configurations to ensure that the module provides acceptable performance for this use case.

To do so, two solutions are possible :
1. Using the manufacturer's application *U-center 1* to communicate with the module
2. Using the development kit NRF54L15 to communicate with the module

The first solution was chosen because it is faster to set up and simplifies the module's communication and configuration process. The second option requires programming the devkit to configure and communicate with the module. This option would have had the advantage of facilitating the module's future integration into the project.

3.3.1 Initial manufacturer app connectivity test

The module communicates with the application, which sends position, timing, etc. The application can configure the module.

> ✅ **Test done :**
>
> The module communicates and sends GNSS data.

3.3.2 Ground plane performance test

Various ground plane sizes have been tested for both solutions discussed in Section 3.2.3. The tested sizes are listed in the Figure 14. This project could not use the biggest ground plane because of its size, but its results should be a reference. All sizes of 15 or 20mm height suit the on-collar solution. The height of the collar strap cannot exceed 20 mm, the height is therefore limited. The length is also limited because the collar is adjusted to the size of the monkey's neck (~100 to 120mm). The smallest ground plan (35 x 20 mm) is for the in-housing solution. It corresponds to the battery size, the biggest component of the device. Therefore, this is the maximum size the ground plane can have in the housing.

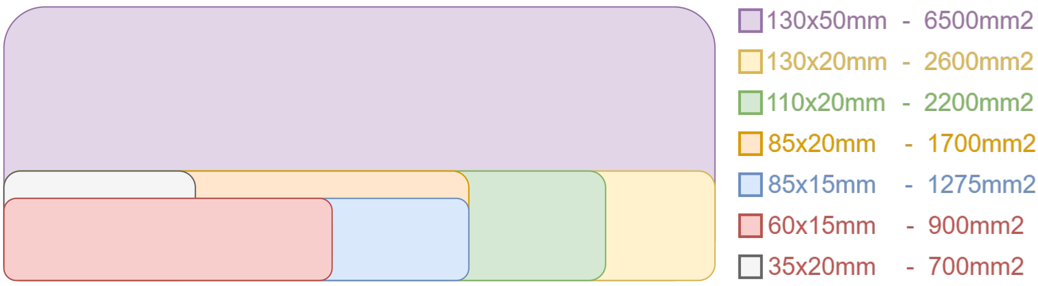

Figure 14: Tested ground plane size

The module is placed in the center of the length, and the antenna is flush with the edge, as shown in Figure 15. The CAM-M8 module is intended to be placed at the center of the top edge of the motherboard. [4]

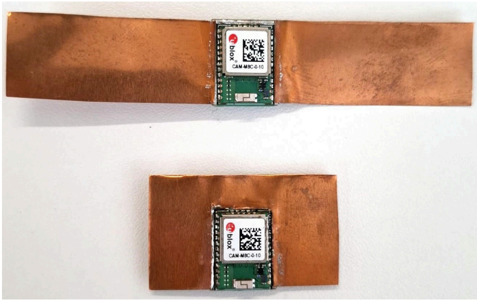

Figure 15: CAM-M8 module placement (85x15mm and 35x20mm ground plane)

The Figure 16 shows the results of the test. The TTFF for a cold, warm, and hot start, as well as the signal quality, C/N0, are plotted for each ground plane size. Each result is an average of three measurements.

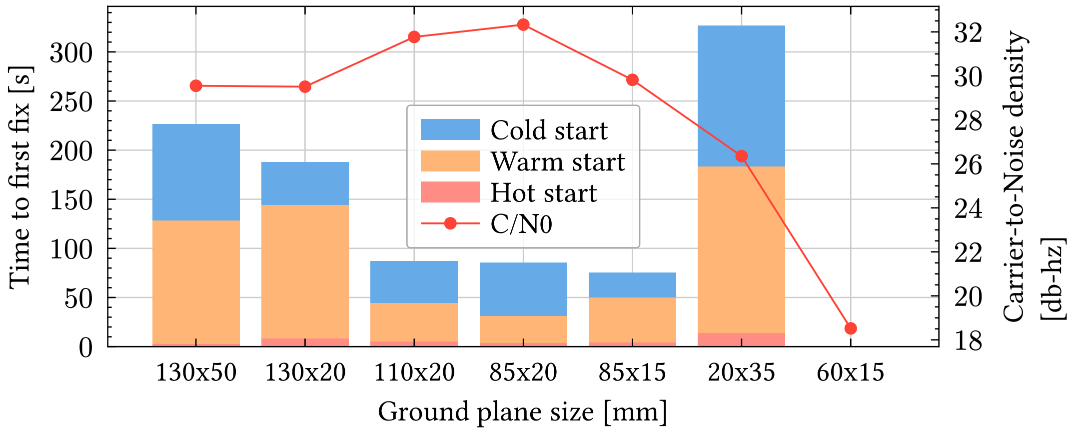

Figure 16: Measured TTFF and C/N0 relative to the antenna ground plane size

The results do not entirely match what would be expected. Theoretically, the TTFF should increase while the C/N0 should decrease when the size of the ground plane decreases. These differences can be due to different factors. These tests were conducted over several days with the number of measures to be done (3 measures for cold, warm, and hot start for each variant) and the time needed to get a fix. Particular attention was paid to the weather on the test days. The measurements were always carried out in the same place with the clearest possible sky to allow the test conditions to be reproduced as closely as possible. However, environmental conditions and satellite positions may have differed between different measurements. This partly explains the difference in performance and a deviation from the expected results. Despite these deviations, drawing conclusions from these measurements is still possible.

- The measurements for the two largest sizes (130x50mm and 130x20mm) are incorrect. Moreover, these cannot be used in the collar because their dimensions exceed the maximum allowable (120x20mm for the on-collar solution and 35x20mm for the in-housing one).
- The difference between a height of 20mm and 15mm is negligible (85x20mm VS 85x15mm). Therefore, a 15mm leather strap can be used as in the V1 while maintaining correct GNSS performance for an on-collar mount.

- No fix was obtained with a width of 65mm. This option can be removed from the final options list. Since the results for the 110mm and 85mm widths are relatively close, the most compact solution for the on-collar solution can be chosen: 85x15mm.
- The 35x20mm solution gives some decent results for the in-housing solution. Even though this option has the smallest surface area tested, it allows positions to be obtained in reasonable times.

> ✅ **Test done :**
> - 35 x 20mm ground plane for the in-housing solution
> - 85 x 15mm ground plane for the on-collar solution

3.3.3 Integration test

When the collar is worn, elements can attenuate or interfere with the signal. Placing the module near a body (or any biological tissue) decreases performance. It is accepted by keeping a minimum distance of 10mm between the motherboard and the body. With smaller distances to the body, the antenna's radiation efficiency reduces due to signal losses in the biological tissue. For example, a d = 5 mm to biological tissue reduces GNSS signal levels by about 6 dB. [4] For this project, as a monkey wears the collar, special attention must be paid to the position of the module relative to the monkey's body.

On-collar solution

The collar is on the monkey skin, and the collar strap is made of leather, a biological tissue. So the module must be spaced from the collar (not just from the animal). The module and its ground plan (85 x 15mm) have then been tested in this configuration. The Figure 17 shows the cold, warm and hot TTFF and the C/N0 for four cases:

1. the module on a non-biological support (reference)
2. the module is directly on the skin
3. the module is on the leather strap, which is on the skin
4. the module is spaced with a 10mm plastic foam spacer from the leather strap, which is on the skin

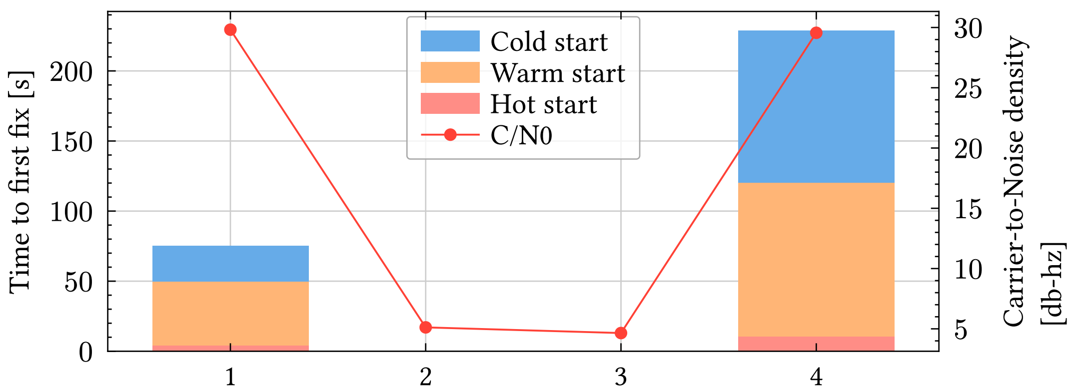

Figure 17: Measured TTFF and C/N0 for a 85x15mm ground plane in different configurations

Without proper spacing, the module can't have a fix. The quality of the received signal is very poor. On the other hand, the module's performance, which is at a distance of 10mm from all biological bodies, is worse than during the reference measurement. The TTFF is still reasonable. Given the results on the skin and without spacing from the strap (no fix), the 10mm distance is a non-negotiable imperative. This implies a mounting on the collar strap, which allows this spacing to be respected.

In-housing solution

With the in-housing assembly, the 10mm distance can be ensured almost always. In rare cases, the distance may not be guaranteed temporarily due to the monkey's movement. No test is needed to ensure the performance is still good when the collar is worn. However, since the module will be in a case, tests were performed with the module in a 3D-printed case (V1 housing). It is compared to the reference test. The Figure 18 shows the result of :

1. The module outside the housing oriented toward the sky (reference)
2. The module in the housing oriented toward the sky
3. The module in the housing oriented toward the ground

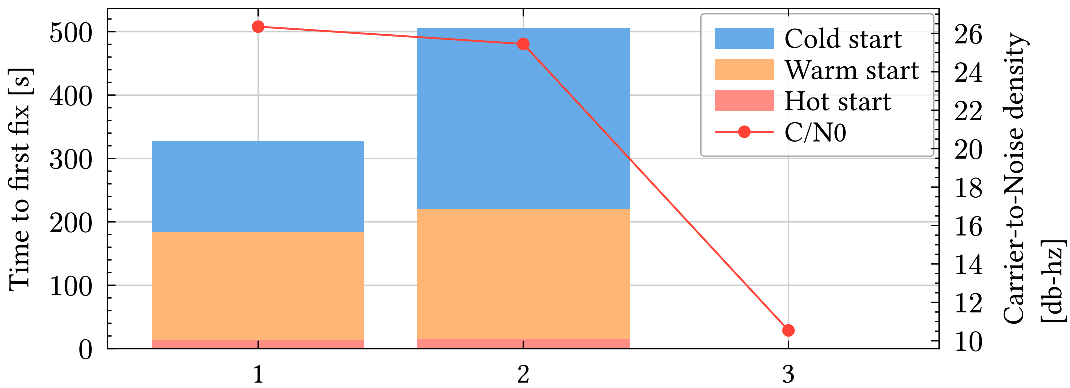

Figure 18: Measured TTFF and C/N0 for a 35x20mm ground plane in differents configurations

The case reduces the module's performance but still allows a fix in a reasonable time and an acceptable signal quality when the module is facing the sky. The big difference is the cold start. With a warm or hot start, the performances are similar. No fix is possible if it is not pointing toward the sky, the signal is too poor. This mounting solution is, therefore, viable, provided that the module is facing the sky.

> ✅ **Test done :**
>
> - 10mm spacing required between the module and the collar strap for the on-collar solution
> - the module must point the sky in the housing for the in-housing solution

3.3.4 Power consumption vs GNSS message type test

Test not performed.

Request to program the devkit to work with the GNSS module to have a consistent measure.

3.3.5 On field power consumption test

Test not performed.

Request to program the devkit to work with the GNSS module and the use of the portable power profiler (under development, see Section 5).

3.4 SAM-M10Q

The SAM-M10Q module is built around the u-blox M10 GNSS engine and comes in a compact, surface-mounted package with an integrated patch antenna. It coulb be a option for this project. As this module has better performance, this could compensate for its slightly larger size.

The provided PCB, which contains the SAM-M10Q module (see Section 2.3), enables connection to the SpeakNoEvil development kit prototype PCB (see Section 2.1). It is 22.30 x 18.40 x 8.00 mm for 9 grams.

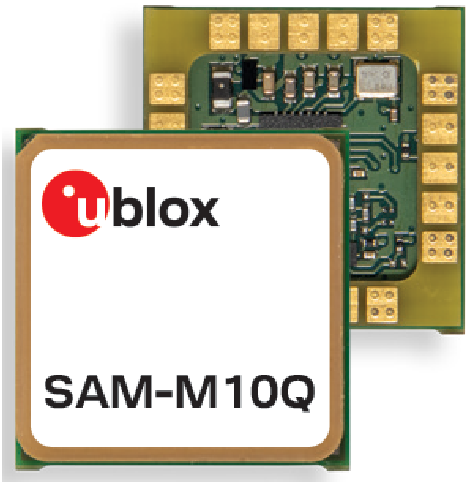

Figure 19: SAM-M10Q module

3.4.1 Initial manufacturer app connectivity test

Test failed :

The module is unable to communicate with the manufacturer's application.

3.4.2 Ground plane performance test

> **Test not performed :**
> Initial manufacturer app connectivity test has failed.

3.4.3 Integration test

> **Test not performed :**
> Initial manufacturer app connectivity test has failed.

3.4.4 Power consumption vs GNSS message type test

> **Test not performed :**
> Initial manufacturer app connectivity test has failed.

3.4.5 On field power consumption test

> **Test not performed :**
> Initial manufacturer app connectivity test has failed.

The hardware provided for this module was not working. The *U-Center 2* application received no messages once the module was connected. Checks and debugging attempts were made but without success.

Since this module is larger (18.40 x 22.30 x 8.00mm VS 12.80 x 16.00 x 4.50mm) and heavier (9g VS 3g) than the M8 , it was not the first choice. It would complicate integration on the collar or require a much larger housing. Therefore, it was decided to focus on testing the M8 and not spend more time debugging/testing the M10 module.

4 Battery utilisation and optimisation

The data collar is a low power device. The capacity of the SD card dictates the battery life. Once the latter is full (~12 days of recording), the device is put in ultra-low power mode. It then waits to be woken up by a BLE connection, which releases it from the monkey's neck and allows it to be picked up by the scientists. The battery is as small as possible. Its capacity is, therefore, chosen to allow the SD card to be filled and then release the collar. A supercapacitor is used to provide the energy to burn the wire.

A GNSS module consumes a lot of energy, especially when searching for satellites for a fix. A CAM-M8Q has a consumption of approximately 30mA during an acquisition period (from start-up until the first fix) [5]. With a TTFF between 200s and 500s, depending on the mounting solution, this results in a significant energy expenditure for a low-power system. Additionally, the average power consumption of the SpeakNoEvil V1 is 4 mA (see Figure Figure 20).

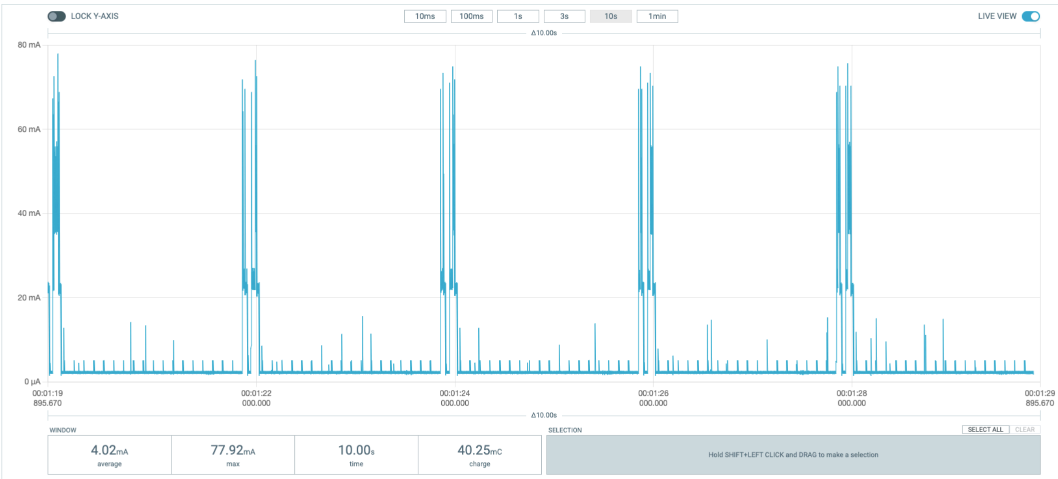

Figure 20: V1 data collar recording consumption

A 32 kHz oscillator that uses an external RTC crystal powers the RTC in the CAM-M8Q. Parts of the receiver turn off if the main supply voltage drops and a battery is connected to V_BCKP. However, the RTC continues to function, providing the receiver with a time reference. This operating mode, known as *Hardware Backup Mode*, permits all pertinent information to be stored in the backup RAM in order to facilitate a hot or warm start at a later time. This feature is quite helpful for reducing energy consumption. When the module is not in use, the main power supply will be purposefully shut off. At that point, the module consumes only 15 µA of current [5].

4.1 Energy use estimation

To demonstrate the need for a device that conserves energy, an estimate of the GPS module's consumption is made. The Equation 1 displays the formula for calculating the consumed energy over time in Joules.

$$E = P * t = U * I * t \tag{1}$$

With this formula, the energy consumed by the M8 module was calculated for cold, warm, and hot starts based on the TTFF measured during the test. In those tests, a wide range of configurations has been tested. In the following estimation, only the chosen in-housing and on-collar solutions values are used. The module's current comsumption is taken from the datasheet [5].

On-collar solution energy

Operation Mode	Current comsumption	Duration	Energy @ 3.3 V	Use Case
Cold start acquisition	30 mA	230 s	22.8 J	First fix after power-on
Warm start acquisition	28 mA	120 s	11.1 J	Fix after waking-up
Hot start acquisition	28 mA	10 s	0.9 J	Fix after short sleep (RTC+context retained)
Normal collar operation	4 mA	12 days	13.7 kJ	Recording sounds

Table 4: Energy for different cases with the on-collar solution

In-housing solution energy

Operation Mode	Current comsumption	Duration	Energy @ 3.3 V	Use Case
Cold start acquisition	30 mA	500 s	49.5 J	First fix after power-on
Warm start acquisition	28 mA	220 s	20.3 J	Fix after waking up
Hot start acquisition	28 mA	15 s	1.4 J	Fix after short sleep (RTC+context retained)
Normal collar operation	4 mA	12 days	13.7 kJ	Recording sounds

Table 5: Energy for different cases with the in-housing solution

Energy comparison over 12 days
For each solution and number of positions per day, a good and a bad case is evaluated. In the best case, the first fix is a cold one, and the others are warm ones. In the worst case, all the fixes are cold ones.

<table>
<tr><th></th><th>Positions/day</th><th>GNSS Case</th><th>Energy (J)</th><th>% of 13.7 kJ</th></tr>
<tr><td rowspan="6">On-collar</td><td rowspan="2">4</td><td>Good (1 cold + warm)</td><td>544.5</td><td>4.0%</td></tr>
<tr><td>Bad (all cold)</td><td>1094.4</td><td>8.0%</td></tr>
<tr><td rowspan="2">8</td><td>Good (1 cold + warm)</td><td>1077.3</td><td>7.9%</td></tr>
<tr><td>Bad (all cold)</td><td>2188.8</td><td>16.0%</td></tr>
<tr><td rowspan="2">16</td><td>Good (1 cold + warm)</td><td>2143.1</td><td>15.6%</td></tr>
<tr><td>Bad (all cold)</td><td>4377.6</td><td>32.0%</td></tr>
<tr><td rowspan="6">In-housing</td><td rowspan="2">4</td><td>Good (1 cold + warm)</td><td>1003.6</td><td>7.3%</td></tr>
<tr><td>Bad (all cold)</td><td>2376.0</td><td>17.3%</td></tr>
<tr><td rowspan="2">8</td><td>Good (1 cold + warm)</td><td>1978.0</td><td>14.4%</td></tr>
<tr><td>Bad (all cold)</td><td>4752.0</td><td>34.7%</td></tr>
<tr><td rowspan="2">16</td><td>Good (1 cold + warm)</td><td>4926.8</td><td>35.9%</td></tr>
<tr><td>Bad (all cold)</td><td>9504.0</td><td>69.4%</td></tr>
</table>

Table 6: Energy comparison over 12 days for both solutions

The energy analysis reveals significant differences between the on-collar and in-house systems, with the on-collar strategy consistently demonstrating greater energy efficiency in every scenario. The in-housing solution consumes 7.3% of the usual operational energy for GNSS functionality, which is approximately twice as much as the on-collar solution, with four positions each day. In the worst-case scenario, the in-housing solution consumes up to 69.4% of regular operating energy for 16 daily positions with all cold starts, while the on-collar solution consumes 32.0%. This efficiency difference increases significantly.

4.2 Battery optimisations strategies

These estimates showed that integrating a GNSS module is a challenge in terms of consumption. However, it is possible to implement strategies to reduce consumption.

- It will be necessary to limit the number of positions per day. For 4 fixes per day, this represents, on average, 5-10% of the total collar consumption over 12 days, which is significant. The maximum number of fixes per day will need to be defined more precisely through field tests using a more advanced version of the new collar.
- The module has to be completely shut down between two measurements. The backup tension must remain powered at all times. *Hardware Backup Mode* enables the storage of all pertinent information in the backup RAM, facilitating a hot or warm start at a later time. This cuts the time for a fix in half or even more if a hot start can be performed.
- An intelligent motion-triggered GNSS system using IMU sensors can significantly enhance module performance by detecting specific monkey postures and activities to

optimize positioning strategies. The accelerometer patterns can distinguish between positions. The acquisitions can then be performed during a specific activity (e.g., walking) or when the monkey is in a particular position (e.g., seated). This allows positioning when the monkey is in a position that favors signal quality, such as sitting for in-housing mode or walking for on-collar mode (see Section 3.2.3).

- Modern GNSS modules support multiple satellite constellations (GPS, GLONASS, Galileo, BeiDou). Rather than using all available systems simultaneously, only a constellation with a strong signal in the region of use could be used. It reduces the number of available satellites but also reduces the power consumption for a fix.
- Before initiating a complete GNSS positioning sequence, the system should conduct a preliminary radio frequency environment evaluation to assess satellite signal quality and multipath interference conditions. This pre-assessment involves a brief scan of available satellite signals to determine signal-to-noise ratios and identify potential obstacles, such as dense canopy cover, that may compromise positioning accuracy or extend acquisition time.
- To manage GNSS energy use effectively, a power budgeting strategy can be applied. A predefined daily budget is established. As long as the budget is available, measurements are taken periodically. Once the budget is cleared, the module is put to sleep until the budget becomes available again. A consumption limit per measurement can also be set. This limits consumption if the signal quality is poor.

All of these strategies can be combined to optimize energy consumption. This work will need to be done when adapting the software to integrate the GNSS module.

5 Power profiler

To optimize module consumption, on-field power consumption tests must be performed. This should allow for a detailed understanding of the module's consumption in different configurations. Power profilers have already been used in the SpeakNoEvil project (*Power Profiler Kit II*). This device from Nordic Semiconductor requires a USB connection to a host computer to function. It is, therefore, impossible to conduct field tests easily and accurately for future use with this device.

Several alternative solutions exist, but they do not precisely meet the needs of this project. It was, therefore, decided to develop a custom autonomous system that allows the module's consumption to be measured precisely and without requiring an interface connection. This system will use a custom board mount on a microcontroller. The custom board has all the measurement devices on it. All the signals are read by a microcontroller, processed, and saved.

5.1 Principle

The principle has been discusted with the project responsable. It is represented in a simplified schema in the Figure 21. The system utilizes a shunt resistor to generate small voltage drops proportional to the currents.

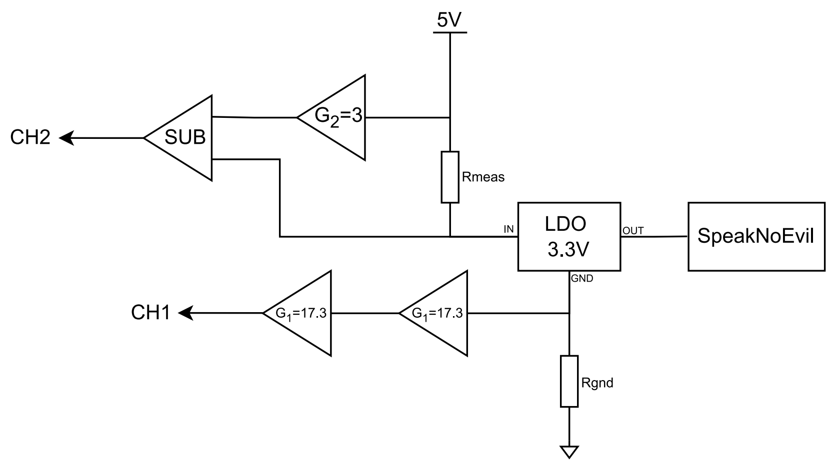

Figure 21: Principle schematic

- **CH1** : Measures the tiny voltage that goes in the ground to determine the ground current loss. It utilizes high amplification ($G_{\text{CH1}} = 17.3 \times 17.3 \approx 300$) to detect small currents accurately.
- **CH2** : Measures the small voltage drop created by the shunt resistor. The current can be determined. It uses a lower gain ($G_2 = 3$) to cancel out common-mode noise and provide a clean reference. A subtractor allows to output only the voltage drop of the measuring resistor.

- **Power Supply**: 5V regulated down to clean 3.3V to minimize noise in the sensitive current measurement.

The collar's current consumption can be determined as in the Equation 2.

$$I_{\text{collar}} = \frac{\frac{U_{\text{CH2}}}{G_2}}{R_{\text{meas}}} - \frac{\frac{U_{\text{CH1}}}{G_1^2}}{R_{\text{gnd}}} \tag{2}$$

Additional hardware allows the system to be supplied with three 18650 batteries (two for V+, one for V-). It contains Low-Dropout Regulator to provide the stable supply voltage for the 3.3V LDO and the operational amplifiers. An additional circuit protects the batteries to avoid excessive discharge. It is not represented in the Figure 21.

5.2 Functional requirements

The power profiler functional requirements were discussed and defined at the beggining of the project (see Table 7).

Requirement	Comment
General	
Autonomous operation	Must function without USB or host computer
User interface	Must include a simple user interface to control the device
Visual feedback	Must include visual feedback
Power measurement	
Measure time	Must be able to measure a 10s intervall
Sampling rate	Must be as much as possible (min. 10kHz)
Resolution	Must measure current from 1 µA, range up to 500 mA
Data logging	
Measure logging	Must log data to local storage
Measure timestamp	Must include timestamped samples for later analysis
File format	Must facilitate analysis
Field-ready design	
Battery powered	Must be battery powered (at least 4h autonomy)
Enclosure	Must be compact with a rugged enclosure

Table 7: Power profiler requirements

5.3 Components

According to the requirements, the differents components have been chosen. The choice of the three main components is detailed in the following points.

5.3.1 Microcontroller

The microcontroller is the main component of this power profiler. Its aim is to :
- sample data at high frequency using Analog to Digital Converter
- buffer measurements to prevent data loss during logging
- assign timestamps to each sample
- write timestamped power data to a memory

Based on this need, three main critera have been taken into account for microprocessor selection:
- **ADC** : min. 2 channel with minimum 12 bits of resolution
- **ADC frequency** : min. 10kHz
- **RAM size** : min. 512kB (see Equation 3)

$$\begin{aligned} \text{RAM capacity} &= f_{\text{sampling}} * t_{\text{aquisition}} * n_{\text{measure}} * \text{measure}_{\text{size}} \\ &= 10\text{kSps} * 10s * 2 * 2\text{bytes} = 400\text{kB} \end{aligned} \quad (3)$$

Only STM and nRF options were analyzed. These are cards that the ECS group is used to working with and has in stock. All the options are listed in the Table 8.

	RAM capacity	ADC	ADC frequency	Processor frequency
nRF5340-DK	512 kB	8 x 12 bit channels	200 kSps	128 MHz
STM32U575	756 kB	8 x 12 bit channels + 8 × 14 bit channels	2.5 MSps	160 MHz
nRF52840-DK	256 kB	8 x 12-bit channels	200 kSps	64 MHz
nRF54L15-DK	256 kB	8 x 14 bit channels	2MSps	128 MHz
STM32F446	128 kB	16 x 12-bit channels	2.4 MSps	180 MHz
STM32L432	64 kB	10 x 12-bit channels	5.33 MSps	80 MHz

Table 8: Microcontrollers choice

The nRF5340-DK and the STM32U575 are the only two variants that satisfy the minimal RAM requirements required for continuous data gathering. The inadequate RAM capacity of all other variants would limit either:
- Acquisition duration as a result of reduced buffer sizes;
- Sample frequency since the limited memory would be rapidly overloaded by quicker acquisition.

The STM32U575 was chosen out of the two viable alternatives for the following reasons:
- More RAM (756 kB vs. 512 kB) enables longer acquisition sessions.
- Improved ADC performance increases accuracy and flexibility by supporting both 12-bit and 14-bit resolution at a greater overall sampling rate (2.5 MSPs).
- A higher CPU frequency (160 MHz) improves responsiveness and data processing throughput.

In conclusion, the STM32U575 provides a better balance of processing power, memory, and ADC capabilities, making it more flexible and future-proof to meet a range of profiling needs.

5.3.2 LDO

LDO needs to be used in this project for different reasons:
- Produce a stable 5V measure voltage
- Produce a stable 5V to supply the STM board
- Produce a stable −3V to supply operational amplifiers
- Produce a stable 3.3V required by the module

These LDO have been selected in contrast to the ECS group's usage habitude. The chosen models and essential parameters are listed in the Table 9.

Model	LDO Usage	Important Parameters
BD450M5FP-CE2	5V measure 5V STM	• Input Voltage: **3.0 V to 42 V** • Output Voltage: **5.0 V** • Dropout Voltage: 0.5 V max • Output Current: **500 mA** • Quiescent Current: 38 µA • Operating Temp: −40 °C to +150 °C
XC6902N301MR-G	−3V amp. op.	• Input Voltage: −16 V max • Output Voltage: **−3.0 V** • Dropout Voltage: 0.2 V max • Output Current: 200 mA • Quiescent Current: 100 µA • Operating Temp: −40 °C to +85 °C
ADM7171ACPZ-3.3-R7	3.3V module	• Input Voltage: 2.3 V to 6.5 V • Output Voltage: **3.3 V** • Dropout Voltage: **0.042 V at 500 mA** • Output Current: **1 A** • Quiescent Current: 0.7 mA • Operating Temp: −40 °C to +125 °C

Table 9: LDOs choice

5.3.3 Operational amplifier

To perform the voltage measure, the power profiler uses four operational amplifiers. Zero-drift amplifiers have been used because they exhibit ultra-low drift over time and temperature, making them ideal for this case. The choice was the OPA2735AIDR. The parameters in the Table 10 have allowed us to select this model.

Parameter	**Value**	**Comment**
Input Offset Voltage	5 µV (max)	Ensures minimal error in low-voltage measurements
Offset Drift	0.05 µV/°C	Maintains precision across temperature changes
Input Bias Current	±200 pA (max)	Reduces voltage drop across shunt resistor
Rail-to-Rail Output	Yes	Allows full use of ADC input range for better resolution

Table 10: OPA2735AIDR importants parameters

With this amplifier, the minimum current that can be measured is 2.5 µA (see Equation 4).

$$I_{\text{min}} = \frac{U_{\text{min}}}{R_{\text{meas}}} = \frac{5\mu\text{V}}{2\Omega} = 2.5\mu\text{A} \tag{4}$$

This is above the desired minimum but remains acceptable for this project.

5.4 LTSpice

Before designing the PCB, the measurement circuit was tested using *LTspice*. The component's values and gains could thus be validated. The schematic can be found in the annexes. The figures below compare the measured tension and the output on both channel 1 and channel 2. The SpealNoEvil module's consumption was simulated with a 2 ms pulse of 500 mA.

Channel 1 :

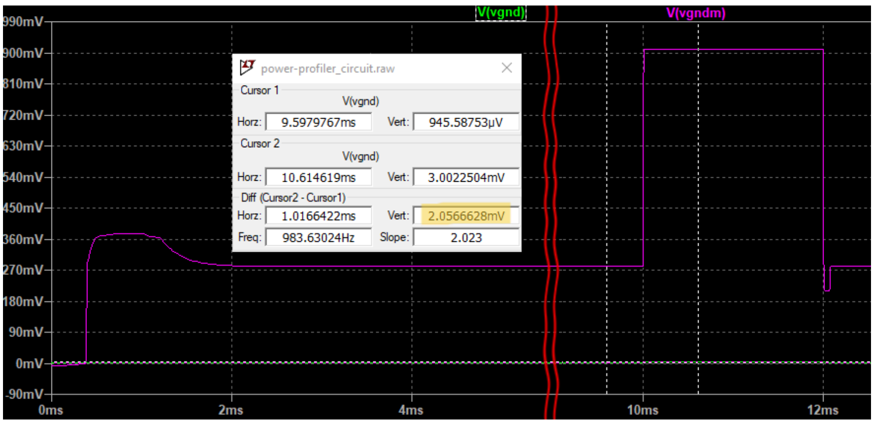

Figure 22: Ground pulse voltage

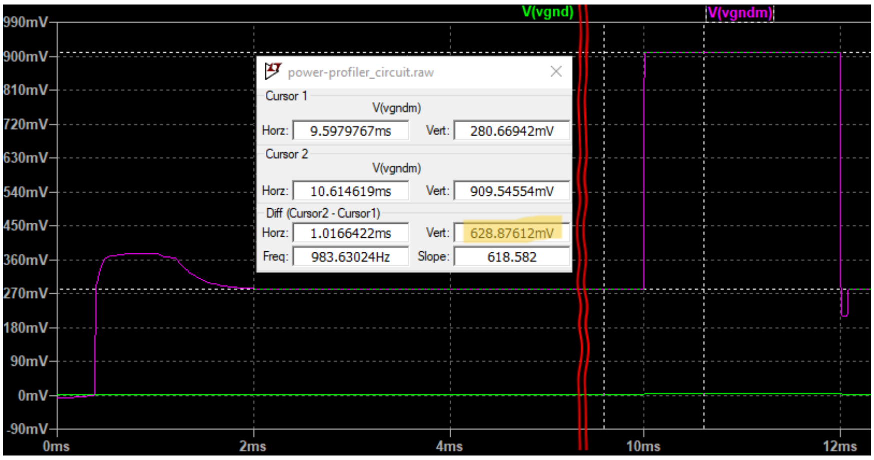

Figure 23: CH1 pulse voltage

The Figure 22 and Figure 23 shows two instances of the same signals, one with the GND voltage measurements (green trace) and the other with the CH1 voltage measurements (pink trace). The measures for both cursors are visible, one before and one during the pulse. The delta bewteen them is highlighted in yellow.

The value for the GND voltage is 2.0567mV. The value on channel 1, after the amplifiers, is 628.876 mV. Both amplifers have a gain of 17.3. Combined, the total gain is theoretically 299,29 (the ideal gain is 300).

$$V_{\text{CH1}} = V_{\text{GND}} * G^2 = 2.0567\text{mV} * 17.3^2 = 615.539\text{mV} \qquad (5)$$

The expected value (see Equation 5) is slightly smaller that the measured value. The error is +2.12% compared to the expected value. Despite this slight offset, the measurement can be validated. This difference can be compensated for using software when calculating the GND current.

Channel 2 :

As shown in previous figure, both signals from the measurement voltage are displayed. The measures for both cursors are visible, one before and one during the pulse. The delta bewteen them is highlighted in yellow.

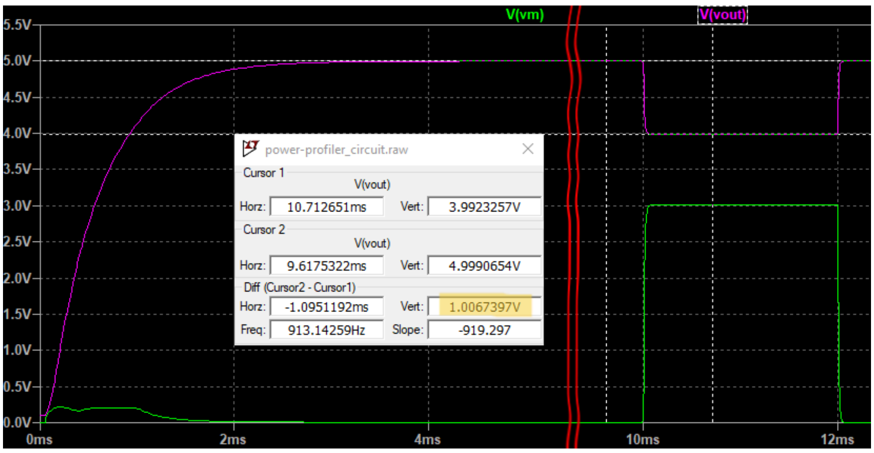

Figure 24: Shunt pulse voltage

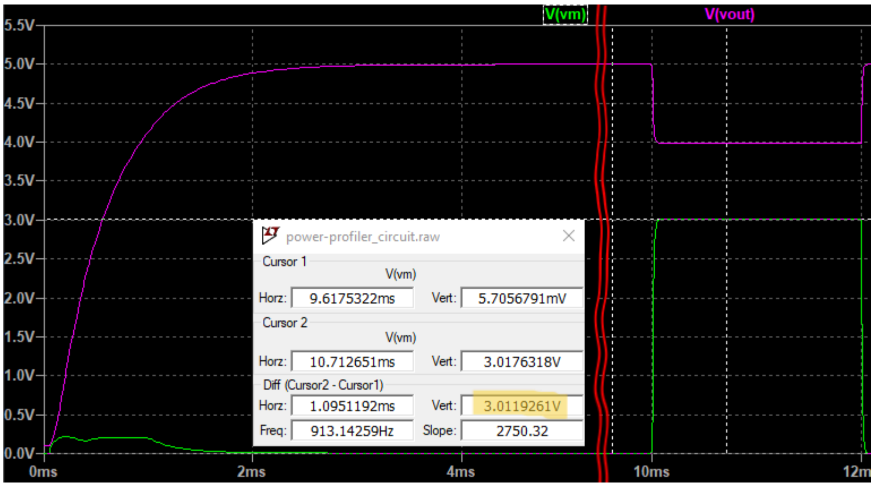

Figure 25: CH2 pulse voltage

The measured voltage is 1.00674 V. The value on channel 2, after the amplifier and subtracter, is 3.012 V. The amplifier has a gain of 3.

$$V_{\text{CH2}} = V_{\text{meas}} * G = 1.00674\text{V} * 3 = 3.0202\text{V} \tag{6}$$

The expected value (see Equation 6) is slightly higher that the measured value. The error is -0.83% compared to the expected value. Despite this slight offset, the measurement can be validated.

To ensure maximum accuracy for both channels, the final gains of the system must be determined once the PCB has been produced and mounted. This gain will then be applied to the final current calculation.

5.5 PCB

Once the schematic is validated with *LTSpice*, the PCB is designed in *Altium Designer*. It was designed to be approximately the same size as the nRF development kit. The schematics can be found in the annexes.

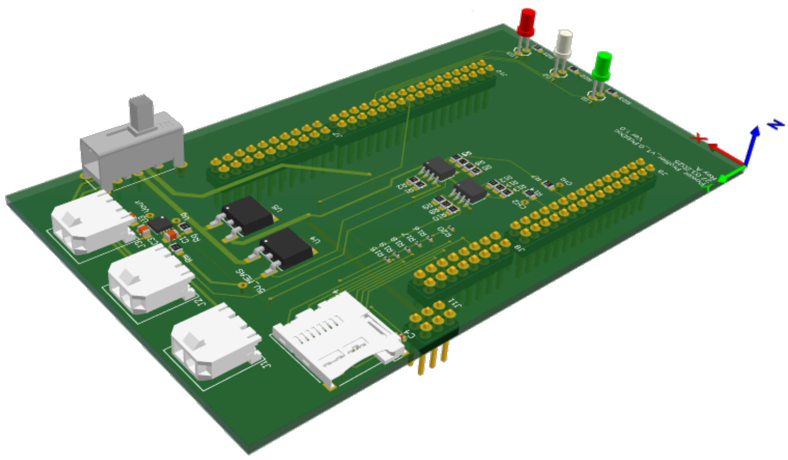

Figure 26: Power profiler PCB at the time of writing this report

The larger components are the batteries. Dedicated support has been developed by a member of the ECS group to prevent short-circuit problems that can occur when changing the battery with commercially purchased holders. Space has been left around the LDO to allow for additional heat dissipation if needed.

The design shield is placed on top of the microcontroller board, connected via the header. A small 2x3 header (J11) has been added to allow the supply of the microcontroller via the 5V_EXT pin as this pin is not on the main headers. The corresponding pins have to be sold on the development kit. The design allows access to the reset and user buttons. This simplifies the system by avoiding the need for additional hardware and space for these two buttons, which are intended for the user interface. To complete the user interface, three LEDs are added: green, blue, and red. A main switch allows the power of the card and processor.

The board has been routed by a member of the HEI electronics workshop. This saved time and ensured high-quality routing. The 2 layers PCB will be produced via *EuroCircuit.* At the time of writing this report, the final routing has not yet been completed and therefore the PCB has not yet been produced.

5.6 Software

The Figure 27 shows the program principle. It acquires some data, stores it in RAM, and then writes it to the SD card. The initial objective is to be able to record data for 10 seconds before writing it on the card. The LED manager is independant and manages the LEDs.

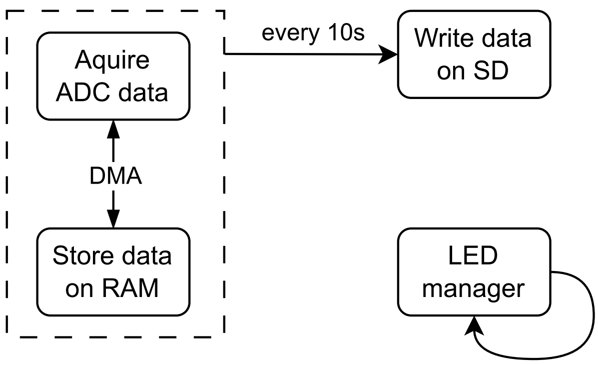

Figure 27: Software principle

FreeRTOS has been used to manage the acquisition of the data. A Real-time operating system guarantees tasks are completed within strict, predictable time deadlines. This ensures that all the program's steps are executed correctly. The program is, therefore, divided into multiple tasks. It will be detailled in the following points.

Two tasks are created to run this program: the LED task and the SD task. Direct Memory Access allows not to use tasks for reading ADC and transferring these values into RAM memory. This saves CPU usage and allows more time to be spent writing to the SD card.

5.6.1 ADC

Two 12-bit ADC channels are used for the CH1 and CH2 measurements (ADC4). The frequency has been calculated and set according to the project requirement (see Section 5.2). The Equation 7, Equation 8 and Equation 9 detailled the calculation to parameter the frequency.

$$f_{\text{ADC}} = \frac{f_{\text{HSI}}}{\text{prescaler}} = \frac{16 \text{ MHz}}{2} = 8\text{MHz} \tag{7}$$

$$t_{\text{conv}} = t_{\text{sampling}} + 12.5 = 841.5 + 12.5 = 854 \text{ cycles @8MHz} = 106.75 \text{ us} \tag{8}$$

$$f_{\text{sampling}} = \frac{1}{t_{\text{conv}}} = \frac{1}{106.75 \text{ us}} = 9.37 \text{ kHz} \tag{9}$$

5.6.2 GPDMA

Initially, the power profiler was supposed to record ADC data to RAM for 10s using simple DMA transfert. It would then stop aquiring while writing the values to the SD card. The U5 families use General Purpose DMA instead of DMA. It enables more complex operations, such as linked lists. They allow the chaining of multiple DMA transfer descriptors together, where each descriptor contains transfer parameters plus a pointer to the next descriptor in memory. These linked lists will allow continuous recording without the need for interruption to write data to the SD card.

To achieve this, double buffering is used. Two memory buffers are used: *adc_buffer1* and *adc_buffer2* . Where GPDMA fills one buffer while the CPU processes data from the other buffer, then they swap roles continuously. The linked list comes into play at this point. The *ADCQueue* (linked-list) contains two nodes: *ADCNode1* and *ADCNode2*. Each one performs a peripheral-to-memory transfer. An event is generated at the end of each linked list item when it switches to the new node. This event will start writing to the SD card.

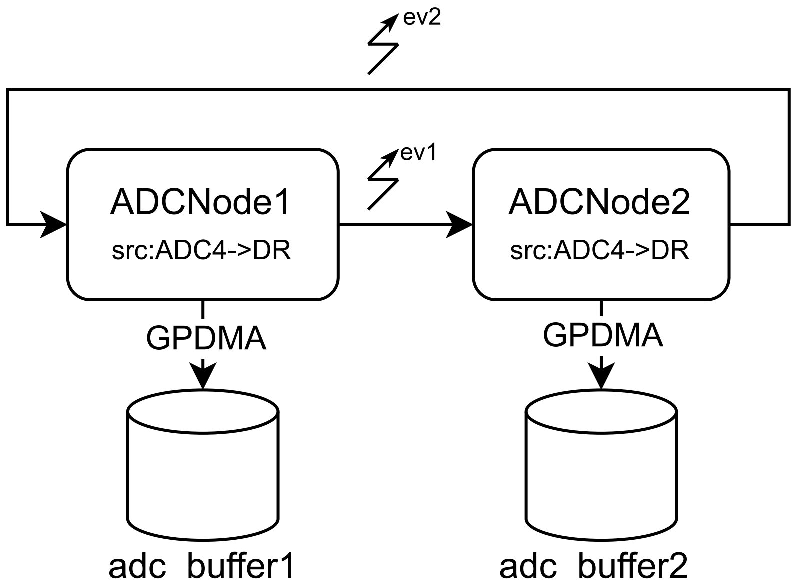

Figure 28: Linked-list principle

With a frequency of 10kHz and a buffer size of 2048 samples, the time to fill a buffer and, therefore, to write these values on the SD is 218ms (see Equation 10).

$$t_{\text{fill}} = t_{\text{conv}} * \text{size}_{\text{buffer}} = 106.75\mu s * 2048 = 218.57ms \tag{10}$$

This time should be more than enough to write the values to the SD card. The size of the buffer and the frequency of the ADC can then be tuned to increase the rate.

5.6.3 SD task

The purpose of this task is to write values from a buffer to the SD card. It also adds a timestamp to the sample collected by the ADC. This task has the higger priority. It must take precedence over all other tasks because no data wants to be lost.

The init function of this task starts the DMA and the ADC. They are started at this time because the system need to be sure that the SD task is ready to write when data begins to arrive. It continuously receives ADC data buffers to write from a message queue and writes them to files on an SD card. The message is put in the queue when the linked list interrupt occurs. The address of the buffer to write on SD is contained in the message.

Once the SD card is mounted, it creates numbered files (data_000.bin, data_001.bin, etc.), writes incoming ADC data buffers, and switches to a new file when the current file exceeds the size limit. Timestamps are added at this moment. It provides precise timestamps relative to boot time, as there is no way to get the exact time. This still allows to have a time interval between the measurement points.

5.6.4 LED task

This task is a LED manager. It manages 3 LEDs (red, green, and blue) with configurable GPIO pins for either external or onboard STM32 LEDs. The priority of this task is lower than the other, as the LEDs are not an essential feature.

A struct defines each LED. With this structure, a new LED could be easily added if needed. It continuously browses the array of LEDs and updates the state according to the information saved in the structure. To change the state of an LED, the *led_setState(LedName led, LedState newState)* function can be used, as shown in the following example.

```
led_setState(LED_GREEN, LED_OFF)
led_setState(LED_BLUE, LED_OFF)
led_setState(LED_RED, LED_BLINK_FAST)
```

The options available for both parameters are given in the Table 11. The blinking rate can be modified in the configuration file.

	Value	Comment
LedName	*LED_GREEN*	Green LED identifier
	LED_RED	Red LED identifier
	LED_BLUE	Blue LED identifier
	LED_COUNT	Return the number of LEDs
LedState	*LED_OFF*	Turn off the LED
	LED_ON	Turn on the LED
	LED_BLINK_FAST	Blink at 10Hz
	LED_BLINK_NORMAL	Blink at 2Hz
	LED_BLINK_SLOW	Blink at 1Hz

Table 11: Options for LedName and LedState

This task is called every 20ms. When an LED is blinking fast, it needs to be updated at least every 100 milliseconds. With a ratio of 1/5, this ensures smooth and even flashing.

5.6.5 Configuration file

A configuration file enables to modify the configurations associated with the project. It is located at the root of the project. It contains the configuration listed in the figure Table 12.

Configuration	Default value	Comment
USE_GPIOS	1	Use GPIOs in the project
USE_LEDS	1	Use LEDs in the project
USE_EXTERNAL_LEDS	1	Use external LEDs
LED_BLINK_FAST_MS	100	LED fast blink rate in ms
LED_BLINK_NORMAL_MS	500	LED normal blink rate in ms
LED_BLINK_SLOW_MS	1000	LED slow blink rate in ms
ADC_DATA_BUFFER_LEN	2048	ADC data buffer length
ADC_DATA_SIZE	sizeof(uint16_t)	ADC data size in byte
TOTAL_LL_NODES	2	Total Link listed node
FILE_SIZE_LIMIT	32 * 1024 * 1024	File size limit (32MB)

Table 12: Configuration and their default value

5.6.6 User interface

Two buttons and three LEDs composes the user interface: a user button, a reset button, a blue, red and green LED. The user button allows you to start and stop data sampling. The reset buton restarts the processor and the programm. The LEDs status are detailed in the Table 13.

	Patterns	LedState	Status
GREEN	● ○ ● ○ ● ○ ●	LED_BLINK_FAST	Initializing
	● ● ● ● ● ● ●	LED_ON	Ready to record
	● ○ ○ ○ ○ ○ ●	LED_BLINK_SLOW	Recording
BLUE	● ○ ● ○ ● ○ ●	LED_BLINK_FAST	No SD card detected
	● ● ● ● ● ● ●	LED_ON	SD card full
	● ○ ○ ○ ○ ○ ●	LED_BLINK_SLOW	Writing to SD card
RED	● ○ ● ○ ● ○ ●	LED_BLINK_FAST	Low battery warning
	● ● ● ● ● ● ●	LED_ON	General error
	● ○ ○ ○ ○ ○ ●	LED_BLINK_SLOW	SD card error

Table 13: Power profiler requirements

These statuses may change in the future by including normal blinking or LEDs combinations.

5.6.7 Encountered problems

During the software development process, several problems have been encountered. The issues and their solutions are listed below.

1. GPIOG doesn't work, there is no signal on the pin.

> **Solution :**
>
> Need to enable VDDIO2 supply by adding those lines in the *MX_GPIO_Init()* function under */* USER CODE BEGIN MX_GPIO_Init_2 */* [6].
>
> ```
> __HAL_RCC_PWR_CLK_ENABLE();
> HAL_PWREx_EnableVddIO2();
> ```

2. The user button on PA0 doesn't work, as there is no signal on the pin.

> **Solution :**
> Desolder SB58, solder SB59 on the STM32U575 [7].

3. *HAL_getTicks()* always return 0. FreeRTOS requires the SysTick timer to generate periodic interrupts, typically at a rate of 1 ms, to handle the tick interrupts. By default, FreeRTOS uses SysTick; however, if the HAL is also attempting to manage it, the timer configuration can conflict.

> **Solution :**
> Use TIM2 instead of SysTick as a timebase source in *SYS* in the .ioc file.

4. No FATFS middleware packs available for the STM32U575 board. In the STM32CubeU5 firmware, the file system has been migrated from FATFS to FileX. It requires the use of AzureRTOS.

> **Solution :**
> Get the FATFS source code and include it in the project [8], [9].

6 Conclusion

6.1 Project summary

This project aimed to develop a second version of the SpeakNoEvil data collar to add a GNSS module. The first objective was to verify the GNSS functionality and propose a final antenna design. To achieve this objective, different tests were conducted on the given hardware. The results were then analyzed. After extensive testing, the CAM-M8 module was found to be appropriate for the collar application. The on-collar setup, with an 85x15 mm ground plane, and the in-housing setup, with a 35x20 mm ground plane, were both confirmed to be workable antenna mounting options. The in-housing option is preferred. It facilitates the integration of the module and protects it from external elements at the expense of signal quality. However, the quality remains satisfactory enough to choose this option. One significant limitation was found to be power consumption, especially when using GNSS. According to a thorough calculation, reaching the desired 10-day battery life requires careful control of the fix frequency. Strategies must be applied to achieve this objective.

The second objective was to develop and produce an autonomous power profiler that could be used in the field without the need for a computer. The PCB was designed. The software is under development. As this objective came during the project, the PCB has not yet been produced, and the software development has not yet been finalized. The other goals cannot be achieved because the hardware was not provided or no modifications were made.

6.2 Comparison with the initial objectives

Not all the objectives were reached. As the needs and the objectives evolved before and during the project, tasks had to be prioritized.

1. **Using the test hardware provided, verify GNSS functionality. Special attention must be paid to the antenna. Propose a final GNSS antenna design.**

   The nRF54 was initially programmed to receive GNSS messages. This was later abandoned to focus on module testing with the manufacturer application. The M8 module has been tested, and two variants of the antenna design were proposed, one for each mounting option. The M10 module was not working. It was then abandoned. It was larger than the M8 and, therefore, less interesting in the context of this project, where size and weight are essential features.

5. **Develop and produce an autonomous power profiler that can be used in the field without a computer. This will enable more consistent and realistic field consumption measurements during the master's thesis.**

   The PCB was designed. At the time of writing, the second iteration still needs to be routed through the electronics workshop before it can be sent to production. The software is also under development. It is currently being developed using the development kit only. It will need to be finalized and tested with the finished PCB.

6.3 Encountered difficulties

The nRF board has caused issues, particularly during the build phase. This may be due to the configuration of the PC used for development. These problems may not recur. Testing the GNSS module was challenging because it requires a significant amount of time. The data, therefore, has drifts, which are probably due to the weather variation during the different days of testing. To obtain more accurate results, it would have been necessary to conduct these tests over a much shorter period. But with the time required for each fix, it is almost impossible to do so. Unless the number of modules can be multiplied to allow parallel testing. Finally, the M10 module posed a problem because the hardware was not working. Time was invested in trying to debug it before giving up to focus on the M8. The development of the power profiler also caused problems on the software side. In addition to the pin issues, the lack of the FATFS library for the STM32U575 was a time-consuming problem. All the files had to be integrated manually, and conflicts had to be resolved.

6.4 Future perspectives

Looking ahead, there are three primary areas for further enhancement:

- **Fix and test the M10 module to allow comparison with the M8**

  Before comparing the M10 module to the M8, it must be debugged and validated to guarantee correct operation. To assess the M10′s feasibility as an upgrade path, the comparison will focus on key parameters, including power consumption, processing speed, and feature compatibility.

- **Test the produce power profiler's PCB and finalize the software using the produce board**

  To ensure the behavior, the recently constructed power profiler PCB requires extensive testing with the produced PCB. To ensure dependable data acquisition, appropriate calibration, and seamless integration with measurement procedures, the software stack must be finalized and tuned for the production board after hardware validation is complete. To create a reliable measuring platform, this step is essential.

- **Conduct field consumption tests with the modules and the power profiler to gain a better understanding of the modules' consumption in various scenarios.**

  To capture real usage patterns outside of lab settings, both modules must undergo real-world power consumption testing in various operational scenarios. At different stages, the power profiler must track current demand. This extensive field data will help refine power management strategies for deployment scenarios and offer insights into real battery life expectations.

In conclusion, this project has achieved significant advances in preparing version two of the data collar. However, efforts are still needed to finalize the preparatory work. The integration of the GNSS module will be significantly facilitated by the preparatory work carried out during this work.

Glossary

The descriptions in the glossary were written by a generative AI.

***ADC* – Analog to Digital Converter**: ADC (Analog-to-Digital Converter) converts continuous analog signals into discrete digital values that microprocessors can process.

***BLE* – Bluetooth Low Energy**: A wireless communication protocol designed for low-power devices, BLE is commonly used in fitness trackers, smartwatches, and IoT devices. It allows short-range data exchange with minimal energy consumption.

***C/N0* – Carrier To Noise density**: A key performance metric in satellite and wireless communications that measures the ratio of received signal power to noise power spectral density, typically expressed in dB-Hz. This parameter determines the quality of signal reception and directly affects bit error rates, with higher C/N_0 values indicating better signal quality and communication system performance.

***DMA* – Direct Memory Access**: DMA (Direct Memory Access) allows hardware devices to transfer data directly to/from memory without involving the CPU, freeing the processor for other tasks.

***ECS* – Embedded Communicating Systems**

***GNSS* – Global Navigation Satellite System**: A system that provides geolocation and time information to receivers anywhere on Earth using satellite signals. GNSS includes systems like GPS (USA), Galileo (EU), GLONASS (Russia), and BeiDou (China).

***GPDMA* – General Purpose DMA**: Advanced DMA in newer STM32 families with enhanced features. Supports 2D transfers, linked-list operations, better arbitration, more flexible channel routing, and improved performance for complex data movements.

***HEI* – Haute École d'Ingénierie**

***ISI* – Industrial Systems Institute**

***LDO* – Low-Dropout Regulator**: A Low-Dropout Regulator (LDO) is a type of voltage regulator that maintains a steady output voltage even when the input voltage is very close to the output.

***LNA* – Low-Noise Amplifier**: A Low-Noise Amplifier (LNA) is an electronic amplifier designed to boost weak signals while adding minimal noise to the signal chain.

***PA* – Projet Approfondissement**

***PI* – Projet Interdisciplinaire**

***RTOS* – Real-time operating system**: RTOS (Real-Time Operating System) is a specialized OS that guarantees tasks complete within strict, predictable time deadlines, unlike regular operating systems that prioritize overall efficiency over timing precision.

***SoC* – System on Chip**: A System on Chip (SoC) is an integrated circuit that combines multiple electronic components and systems onto a single chip, including processors, memory, input/output interfaces, and other specialized circuits.

***TTFF* – Time To First Fix**: The time a GNSS receiver takes to acquire satellite signals and calculate its initial position after being powered on. TTFF depends on factors like satellite visibility, signal strength, and whether the device has previous location data.

***USB* – Universal Serial Bus**: A standard interface used to connect computers with external devices such as keyboards, flash drives, and cameras. USB supports data transfer and power supply, with various versions offering increased speed and functionality.

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A | Appendix

- Original project report
- Source code
- PCB designs
- Test files

All the appendices are available in the git repository at the following link:

https://github.com/DrinkDark/Master_PA_Data-collar