FLITE-WISE

Deliverable D7.3

Final results report

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Abstract

This document is the official final project report on the Flite-Wise project, as required by the European Commission. The report describes the project technical outcome and impact.

The Flite-Wise project developed a wireless acoustic sensing platform for the in-flight tests of aircraft rotating and non-rotating frames.

Keyword list

Wireless Sensor Network, Aircraft, Low Power, Pressure Sensor, Flight Test

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1 Executive summary

(Please provide an executive summary. The length of this part cannot exceed 1 page.)

The Flite-Wise project consortium was coordinated by CSEM – Centre Suisse d'Électronique et de Microtechnique, a Swiss R&D centre dedicated to the transfer of cutting-edge micro/nano/bio and communications technologies into industrial products. The energy harvesting is developed by Imperial College London, the UK's premier science and technology university. The system is industrialised by SERMA INGENIERIE, a French aeronautic equipment manufacturer.

The project was under the supervision of its topic manager Airbus Operations GmbH from Germany.

The Flite-Wise project developed an autonomous wireless sensor node platform for continuous acoustic or pressure measurements on aircraft frames. The project addresses two use cases. The first one, aka the "propeller use case", concerns pressure measurements on rotating frames (propeller blades) using nodes powered by an energy harvester with multiple sensors.

The second use case, aka the "patch use case", defines acoustic pressure measurements along the aircraft skin using an ultra-thin, battery powered and wirelessly rechargeable sensor node.

The result is an integrated autonomous wireless system from existing, already proofed hardware and software combined with innovative concepts in the domains of robust and high performance networking, energy harvesting, sensor interfaces and data acquisition

The developed platform advances the state of the art in a number of aspects:

- energy harvesting and electronics capable of withstanding high accelerations and low temperatures;
- resilience to interferences and jamming;
- highly efficient and robust communication with ultra-low energy requirements;
- highly compact and slim design with fully wireless operations including charging;
- accurate synchronisation in WSN for the time-stamping of sensor data.

The evaluation done for both use cases demonstrated the good global performance of both sensor nodes. In particular, the nodes support 50 KHz sensor acquisition rate, logging in high-capacity SD card and deferred transmission at 40 KSamples/s. The power consumption of the devices in inactive state is as low as 27 µA. The total power consumption (active and inactive states) is compatible with the power supply capacity in both use cases. The network synchronisation accuracy is better than 40 µs. The patch use case batteries work at temperatures below -20°C and can be recharged by inductive coupling in about five hours.

Current flight test systems are wired and their installation is costly and cumbersome. The Flite-Wise project delivers a major contribution towards new wireless sensors with energy efficiency which allows them to be powered by batteries and energy harvesters. The wireless recharging feature helps reducing the thickness of the patch sensor by avoiding the need for connectors. Large on-board data storage allows high sensor sampling rates with deferred data transmission. The overall benefits of such sensors are reduced installation and maintenance costs.

From a short-term viewpoint, the Flite-Wise project allowed the consortium members to perform significant progress in their respective areas of expertise: ultra-low power communications and synchronisation (CSEM), energy harvesting and power regulation (Imperial College London) as well as electronics and industrialisation (Serma Ingénierie). The project partners wish to continue their collaboration and will keep in touch to monitor project opportunities.

2 Context and main objectives

(Please provide a summary description of the project context and the main objectives. The length of this part cannot exceed 4 pages.)

2.1 Project global objectives

The Flite-Wise project develops an autonomous wireless sensor node platform for continuous acoustic or pressure measurements on aircraft frames. This platform shall operate airborne on rotating blades in the long-term, thanks to the use of an embedded energy harvesting device. The same wireless technology shall also be used for connecting rechargeable battery-operated sensors located on the aircraft outer skin.

The technical strategy is to build an integrated autonomous wireless system from existing, already proofed hardware and software, and combine it with innovative concepts in the domains of robust and high performance networking, energy harvesting, sensor interfaces and data management, in order to provide a system specifically tailored to meet the objectives of the project. This strategy allows for saving costs and for benefiting from the past experience in designing and developing a wireless sensor network that is dedicated to aeronautics applications. This guarantees that a number of the aeronautics requirements are more easily met by the proposed system.

The resulting platform advances the state of the art in a number of aspects:

- energy harvesting and electronics capable of withstanding high accelerations and low temperatures;
- resilience to interferences and jamming;
- highly efficient and robust communication with ultra-low energy requirements;
- highly compact and slim design with fully wireless operations including charging;
- accurate synchronisation in WSN for the time-stamping of sensor data.

The project addresses two use cases.

2.1.1 Propeller use case

This use case involves acoustic pressure measurements along the blades of a turboprop engine propeller. The propeller is part of a new engine design based on an open contra-rotating rotor (Figure 1).

The measurements shall be correlated with acoustic measurements made on the ground along the take-off and landing paths of the test aircraft. Therefore, airborne and ground measurements have to share a common time for their correlation to be possible.

On a blade, up to 8 sensors can be distributed within the propeller length and wired to a Sensor Node (SN) integrated to the base of the blade. The sensor node is energy-autonomous and wireless. Sensor measurements are radio transmitted to a Wireless Data Concentrator (WDC) installed within the radio range of the engine.

The sensor node shall be autonomous, thus it shall be powered by an energy harvester located nearby.

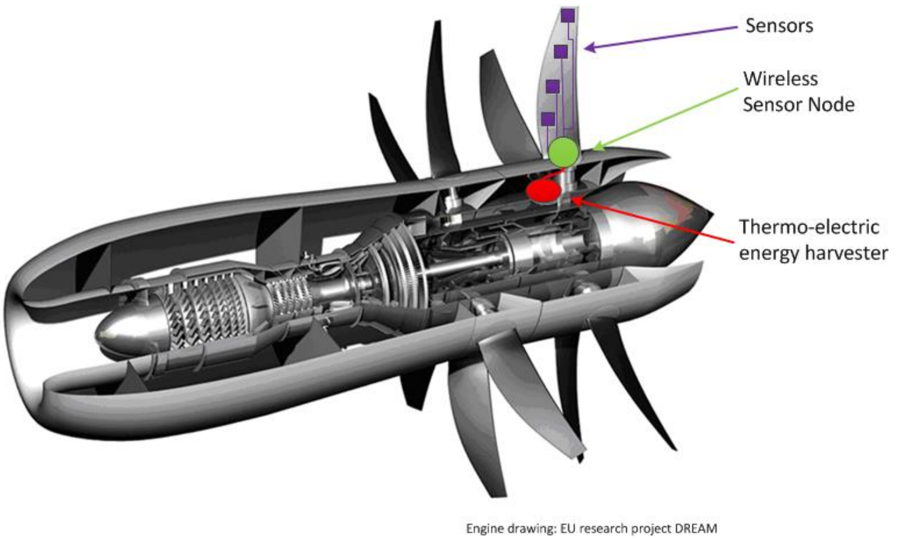


Figure 1: open rotor engine with wireless autonomous sensor installation on the propeller

2.1.2 Patch use case

The second use case, aka the “patch use case” involves continuous acoustic pressure measurements taken on the outside of the aircraft fuselage. The measurements are to be taken by a single wireless sensor stuck against the aircraft skin. For obvious reasons, the sensor and accompanying electronics must be as thin and as aerodynamic as possible. It shall take the form of a circular patch applied to the fuselage. Low vibrations at the envisaged location, a maximal thickness of 4 mm and the fact that a micro wind turbine would disturb the air flow being measured imply that the only solution is to use batteries to power the sensor node. They shall be recharged wirelessly by inductive coupling while the test aircraft is not in use. This method has the advantage of avoiding a potentially large connector that would also make the sealing of the patch more difficult.

Figure 2 shows an example of patch sensor applied to an airframe.

Figure 2: example of patch sensor

2.2 Consortium

The consortium is made of three highly qualified complementary entities. The members are CSEM Centre Suisse d'Électronique et de Microtechnique (CH), Imperial College London (GB) and Serma Ingénierie (FR). CSEM brings its expertise in WSN and ultra-low power electronics. SERMA, an experienced actor in the aeronautics technology, brings expertise in the aeronautics environment and constraints, as well as production and test facilities. Imperial College London, one of the world leading laboratories, provides the scavenging and energy management expertise.

2.3 Project structure

2.3.1 Roles of the project partners

The project is coordinated by CSEM. The building blocks are under the responsibility of Imperial College (power supply) and CSEM (electronics, wireless communications, embedded software). Serma Ingénierie is responsible for the system integration, the industrialisation and the tests.

Airbus if the topic manager. Although not a consortium member, Airbus proposed the project topic, and also advises and reviews the project.

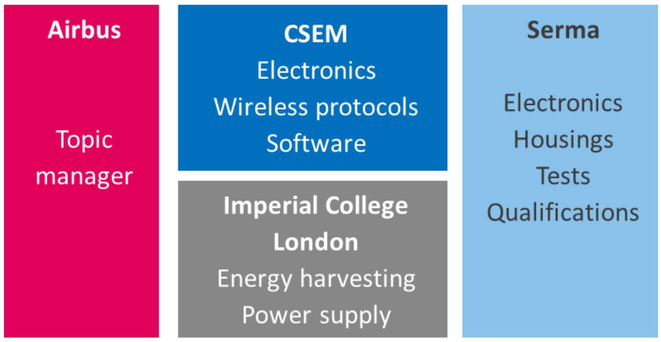


Figure 3: the roles of the project partners

2.3.2 Work packages

The Pert diagram in Figure 4 describes the project decomposition in work packages.

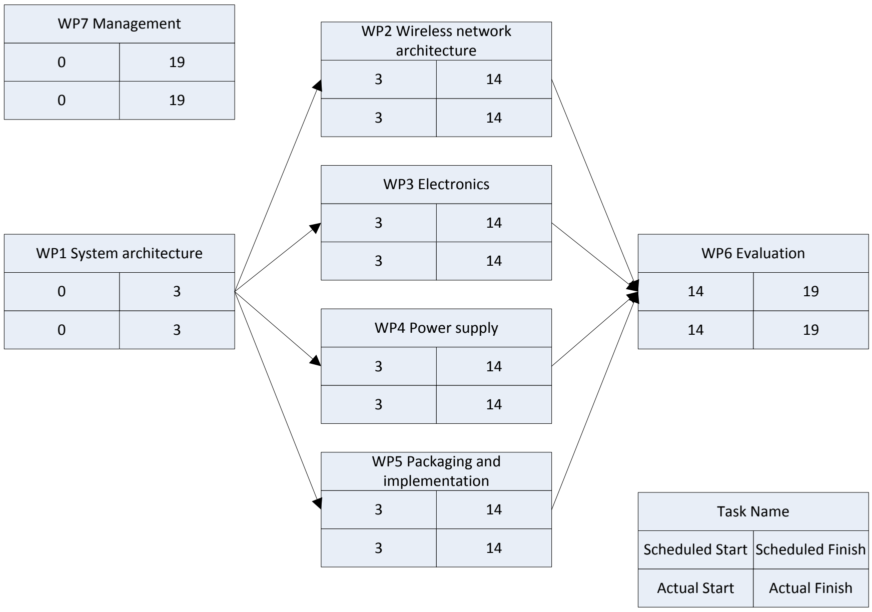


Figure 4: work packages decomposition

The contents of the different work packages are:

- WP1 – System architecture: analyse the requirements, derive assumptions, identify and select the system components.
- WP2 – Wireless Communications Systems: develop the wireless communication protocol derived from the existing protocol delivered by the StrainWISE[1] project. Design and implement the data acquisition algorithm and study potential data compression techniques. Design and implement the synchronisation feature. Study jamming awareness and detection.
- WP3 – Electronics: design and realise the electronic boards of the rotating frame (propeller) and non-rotating frame (aircraft skin) sensor nodes.

[1] StrainWISE: Hardware & Software Development of Wireless Sensor Network Nodes for Measurement of Strain in Airborne Environment, Cleansky SFWU project, grant number 270658.

- WP4 – Power supply: develop an energy harvester for the rotating frame sensor node. Propose a wireless-chargeable battery power supply for the non-rotating frame use case.
- WP5 – Packaging and integration: study and design the housing and fixing of the two sensor node types.
- WP6 – Evaluation: define and execute the tests that are necessary for the delivery of functional prototypes to the topic manager.

3 Main S & T results / foregrounds

(Please provide a description of the main S & T results/foregrounds. The length of this part cannot exceed 25 pages.)

This section describes the main scientific and technological results delivered by the Flite-Wise project. The main contributions pertain to the wireless communications and synchronisation, low-power electronics and energy scavenging domains. Moreover, the project integrated the patch sensor node and delivered it to Airbus flight test department for testing.

Before detailed the technical contributions, the system architecture is briefly described in the next subsection.

3.1 Architecture

The section presents the system architecture proposed by the project.

The Flite-Wise architecture specifies two entities:

- the Sensor Node (SN), an energy-autonomous pressure sensor node equipped with a radio. The SN comes in two variants: the first one supports up to 8 pressure sensors and is dedicated to the propeller use case. The other one supports only one sensor and is made for the patch use case;
- the Wireless Data Concentrator (WDC), a device equipped with a radio and an Ethernet network interface that acts as a cell master and relays the data sent by the sensor nodes over its wired link;

3.1.1 Sensor Node

The core of the sensor node reuses components from the previous project StrainWISE: TI MSP430F5438A micro-controller and Atmel AT86RF231 low power radio. In addition, a low power Digital Signal Processor (DSP) has been added to support the data acquisition and potential compression. In this project, data acquisition rates are significantly higher than in StrainWISE (50 KHz instead of 500 Hz), thus data compression may be necessary to speed-up the measurement data transfer over the wireless link. A DSP with reasonable computing power, FFT engine and low energy consumption was selected: Texas Instrument TMS320C5505.

The sensor nodes for both use cases share this computing and communication architecture. They differ in their sensor front-end and power supply. Also, the patch sensor node has no DSP for size reason. Consequently fancy data compression is not possible for this sensor node which has an impact on the data transmission delay.

3.1.1.1 Propeller sensor node

The propeller sensor node supports up to 8 Kulite LQ/LE 062 pressure sensors. The Analogue to Digital converter (ADC) is the Texas Instruments ADS7945 which has a very simple SPI interface, an essential feature for quick acquisition and supports up to 2 MSPS[2] which is enough for 8 sensors acquiring at 50 KHz.

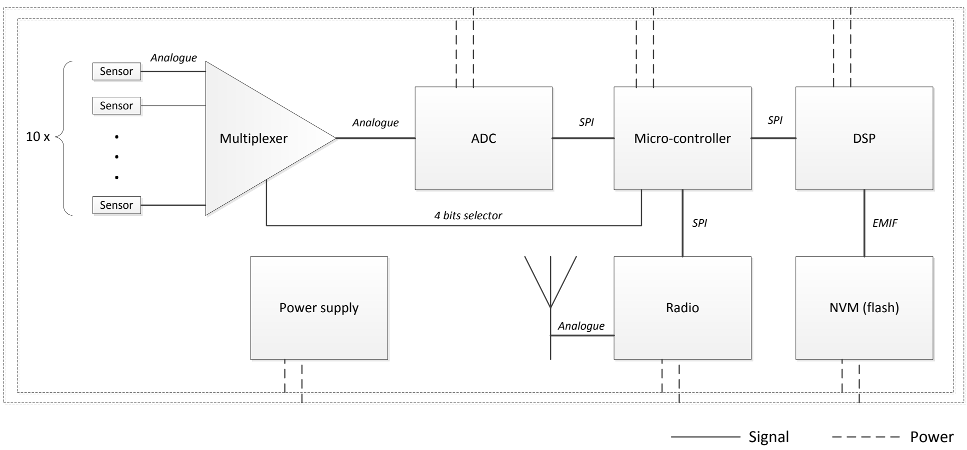


Figure 5: sensor node architecture for the propeller use case

[2] Mega-samples per second

Figure 5 shows the architecture of the propeller sensor node. The power supply is external and provided by the energy harvester developed in WP4.

Figure 6 depicts the multiplexers for the 8 sensor signals.

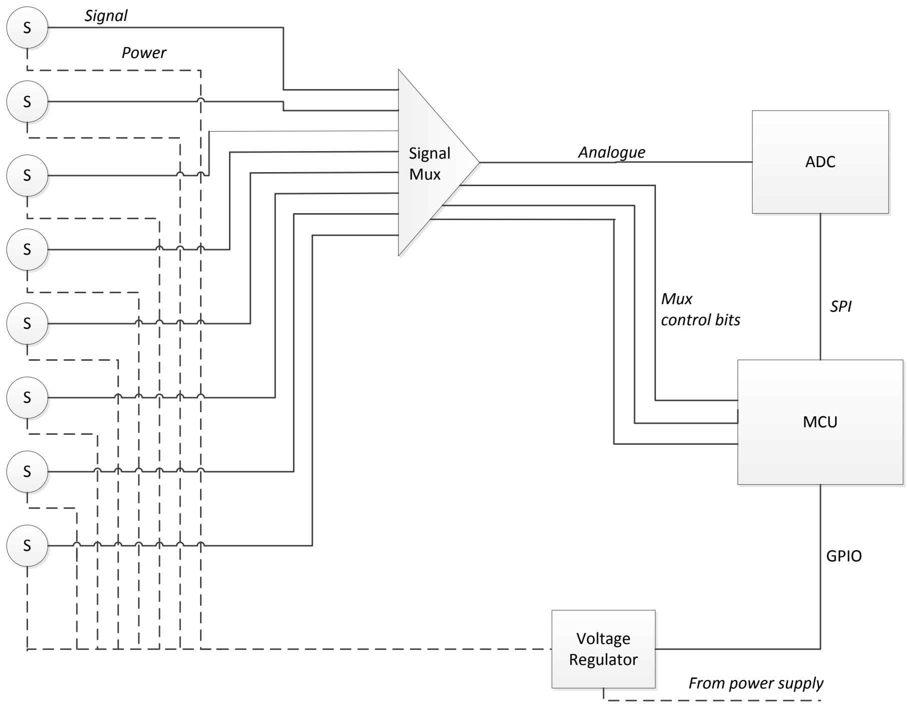


Figure 6: sensor front-end for the propeller use case. The front-end will be able to accommodate 8 sensors.

3.1.1.2 Patch sensor node

The patch sensor node has the same ADC as in the propeller use case, but it does not include the multiplexing hardware as it has only one sensor. A DC-DC converter has been added to power the Bruel & Kjaer B&K4948 microphone specified by Airbus. The mass storage is a micro MMC/SD card slot.

Figure 7 shows the patch use case sensor node architecture.

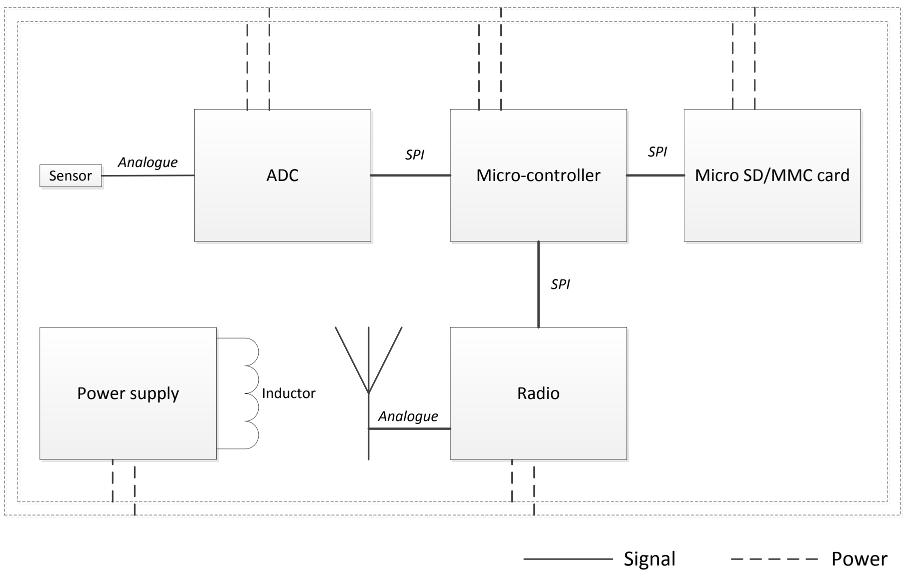


Figure 7: sensor node architecture for the patch use case

The power source can only be batteries because an energy harvester would not be able to respect the 5 mm thickness specification. Moreover, a device such as a micro-turbine would disturb the airflow that the node is supposed to measure. To avoid a thick connector and to ease maintenance, the batteries will be charged wirelessly by inductive coupling.

3.1.2 Wireless Data Concentrator (WDC)

Due to the high traffic load, the StrainWISE WDC cannot be reused as the Ethernet port module uses UART which is a bottleneck. However, a similar architecture is used, but the Ethernet module is connected to the microcontroller with SPI. The chosen device is a Wiz 500io.

Figure 8 depicts the architecture of the WDC.

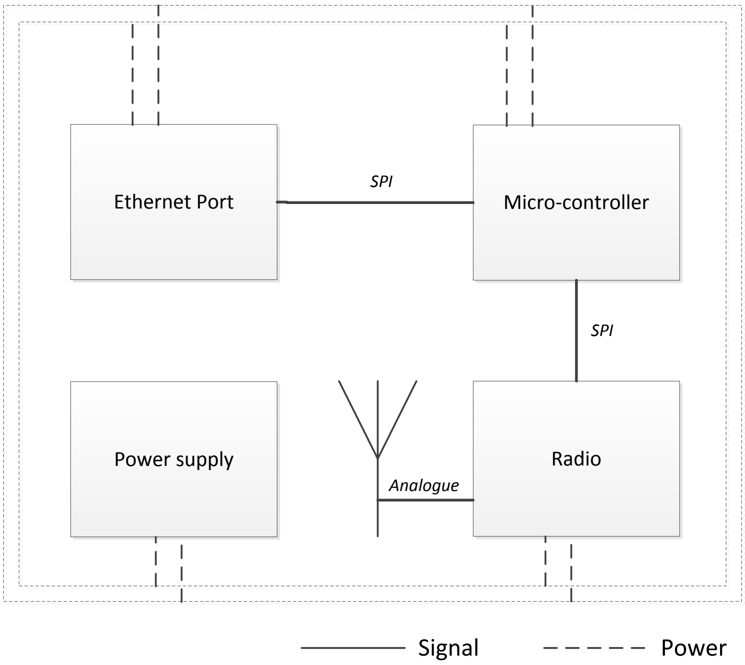


Figure 8: Wireless Data Concentrator architecture

3.1.3 Power consumption analysis

A power consumption estimation has been conducted for the sensor nodes to give an input to the power supply work package. Two kinds of information were used to derive the estimate: the power consumption of the devices composing the sensor nodes for each of their operating modes and the time each device would spend in its different modes during a typical test flight as specified by Airbus for each use case. The first information was extracted from the data sheets and the second resulted from the analysis of the requirements, taking the most pessimistic values and adding a required margin of 20 %. For the communication part, the estimate was based on the communication protocol developed for StrainWISE and with settings adapted to the use cases.

The energy needs for each use case are summarised in Table 1 and Table 2. The energy required by the sensors is included.

Activity	**Average current [mA]**	**Average power [mW]**	**Duration [s]**	**Total Energy [J]**
Connecting	0.033	0.1	1800	0.2
Waiting	0.058	0.2	17100	3.4
Acquiring	60	198	2700	534.6
Transmitting	27	89.1	9000	801.9
TOTAL				1339.2

Table 1: propeller sensor node overall energy needs

Activity	Average current [mA]	Average power [mW]	Duration [s]	Total Energy [J]
Connecting	0.033	0.1	64800	6.48
Waiting	0.058	0.2	3600	0.72
Acquiring	41.4	136.6	43200	5901
TOTAL				5908

Table 2: patch sensor node overall energy needs

3.2 Wireless communications and synchronisation

3.2.1 Wireless communications protocol

The protocol is of TDMA type to cope with airworthiness regulations which impose deterministic protocols. Also, it is single hop since none of the foreseen use cases imposes multi-hop requirements. To keep sensor node energy consumption to a minimum, the main idea is to adapt the duty cycling to the operation phase whilst benefiting from the fact that the WDC is powered. The WDC is selected to be the master of the TDMA cell because it is powered and has a wired connection to the avionics meaning that it can be synchronised with it.

Four modes of operation that relate to the different phase of operations have been identified after a careful use case analysis:

- **Configuration**: sensor nodes are on, but not yet associated to a WDC (e.g. before installation in a test aircraft). WDCs are either off or awaiting the association with all their assigned sensor nodes to complete.
- **Sleep**: during a test flight, a cell is in a low power mode while not acquiring any measurements, but it can be awakened with a short delay.
- **Data transfer**: a cell is performing and transferring strain measurements.
- **Ultra-low power sleep**: SNs and WDCs are associated, but the aircraft test installation is not in use. The network sleeps deeply with a long wake-up delay.

In all four modes, the WDC broadcasts a beacon every 5 ms on a channel assigned by the WSN server. In **Configuration** mode, the list of addresses of the nodes pertaining to the cell is sent to the WDC from the server and broadcasted in the beacon. In this mode, each SN sleeps for 360 seconds, then wakes-up and listens to each channel for 5 ms. If a beacon that advertises the node address is received, the sensor node registers to the WDC, stays on the current channel and goes into **Sleep** mode. If no beacon is received after trying all channels, the node goes back to sleep for 360 seconds. A WDC switches to **Sleep** mode once every sensor node of its list has registered.

In **Sleep** mode, each sensor nodes synchronises on the *super frame* beacon which is a special beacon sent every k^{th} beacon by the WDC. The SN sleeps between two super frame beacons. In the current implementation, the super frame period is 200 beacons, meaning that the cell can be woken-up within one second.

By changing a couple of bits in the beacon header, the WDC can switch its sensor nodes into **Data transfer** mode in which the SNs listen to every beacon. In this mode, the beacons contain a slot assignation section to allow the sensor nodes to transmit measurements or any command responses. The sensor nodes wake-up, either to listen to the next beacon, transmit a packet in their slot or acquire a measurement sample. The mode also supports an acknowledgement and repetition scheme to provide reliable data transmission. In Data transfer mode, the nodes are synchronised with the WDC for data time-stamping. For data transfer, the slot allocation follows the acknowledgements received during the previous TDMA round and several slots can be assigned to the same node.

When a sensor node loses connection with its assigned WDC, for instance when the latter one is turned off with the aircraft, the sensor node enters **Ultra-low power sleep** mode in which it listens for 5 ms on the assigned channel every 360 seconds and sleeps in between. It changes to **Sleep** mode as soon as a beacon from the assigned WDC is detected.

3.2.2 Data acquisition algorithms and synchronisation

3.2.2.1 Propeller use case

The propeller sensor node (rotating use-case) uses the architecture depicted in Figure 5, page 8.

The data acquisition is done by the DSP which saves the acquired data in the non-volatile memory, possibly after compression. In parallel, the MCU handles the beacon reception.

After the measurement session, the data is transferred from the non-volatile memory to the DSP, then forwarded to the MCU which handles the data transmission. An SD card slot is available to add more flexibility to the system.

In addition, two interrupt lines of the DSP are connected to the MCU.

Data acquisition

The first interrupt line is used by the MCU to trigger the acquisition by the DSP. Each interrupt triggers the acquisition of 250 samples, that is the number of samples until the reception of the next beacon after 5 ms.

The interrupt is triggered at the same time on each node. The trigger time is based on the beacon reception interrupt and a precision timer.

Synchronisation: propeller angle stamping

In this use case it is possible to stamp the data with the angle of the propeller at the time the measurement was taken.

The rotating inductive energy harvester that powers the node can be used to detect when the node completes one round or a fraction of a round because the induced voltage reaches a peak when the magnets are facing the coils. This peak is fed to a Schmitt trigger which triggers an interrupt on the DSP.

Upon receiving the interrupt, the DSP starts a precision timer (e.g. 12.5 MHz). Each time the first sample of a data acquisition block of 250 samples is acquired, the timer is stopped and read. The angle of the propeller can thus be computed from the time since the round completion and the propeller rotation speed as long as the latter is constant.

The angle stamp is valid for the first sample of the block. The stamps for the following ones are derived during post processing from the first sample stamp, the acquisition period and the propeller rotation speed.

3.2.2.2 Patch use case

Data acquisition

Given the high sensor acquisition rate (50 KHz) and limited computing resources (no DSP, one MCU), sensor data will be acquired and recorded in the micro SD card, and transmitted only after the acquisition session is finished.

Although deferred acquisition does not allow the real-time monitoring of acquired data, it has the advantage of potentially reducing the number of WDCs, since real-time transfer limits the number of SNs to 1 per cell (WDC). This is due to the high throughput per sensor (around 800 Kbit/s).

The data acquisition process involves four tasks. They are summarised in order of priority in Table 3.

Priority	Task	Detail	Period
1	Beacon reception timestamp	Mark the time of the start receiving frame event of the beacon reception	5 ms
2	Sensor acquisition	Read the sensor through its ADC circuit and save the value in RAM	20 µs
3	Beacon reception and processing	Read the beacon from the radio FIFO, analyse/verify the relevant fields, extract and save timestamp information	5 ms
4	Write data block to SD	Once the equivalent of a micro SD card block size of data has been acquired, transfer it to the card via SPI	~5ms

Table 3: patch sensor acquisition tasks and priorities

The order of priority is chosen so that the data acquisition and time-stamping jitter is minimised. The task scheduling is summarised in Figure 9.

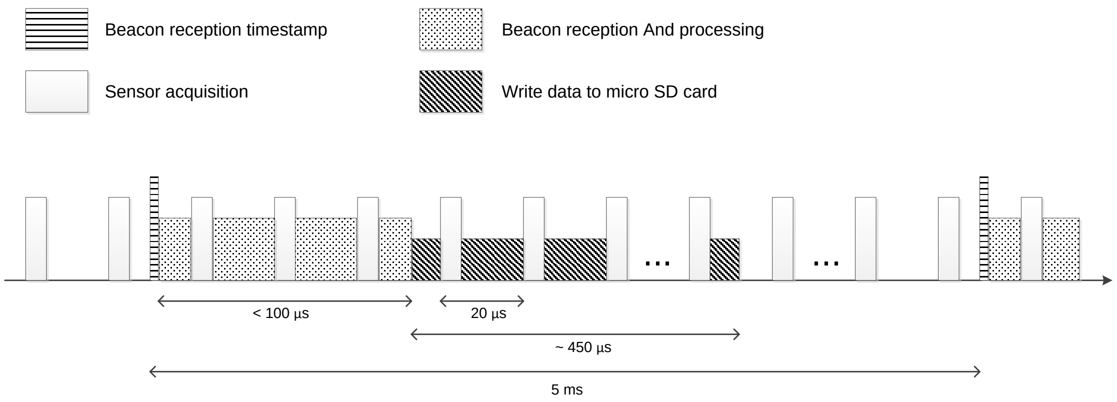


Figure 9: patch sensor node acquisition tasks schedule

Synchronisation

Synchronisation information is received with every beacon in the form of a timestamp representing the system time when the first byte of the beacon carrying the timestamp was sent.

A precision timer controlled by the master clock of the MCU or its derivative (SMCLK) triggers the 50 KHz sensor acquisition every 20 µs. Hence, during one beacon period, only the first sample acquired after the reception of the first beacon byte shall be stamped. The timestamps of the 249 following ones shall be derived from the timestamp of the first one by adding 20 µs to the timestamp of the preceding sample.

The first sample timestamp is obtained by adding the time elapsed between the start of the beacon reception and the sample acquisition (the offset) to the timestamp carried by the beacon. This is depicted in Figure 10.

Practically, the offset is available before the timestamp because the beacon processing task has a lower priority. This has no impact in the acquisition performance or the accuracy.

The offset is obtained by capturing the value of the acquisition timer when the first byte of the beacon is received. The Flite-Wise hardware supports this with high precision and with minimal processing time using a timer capture input of the micro-controller.

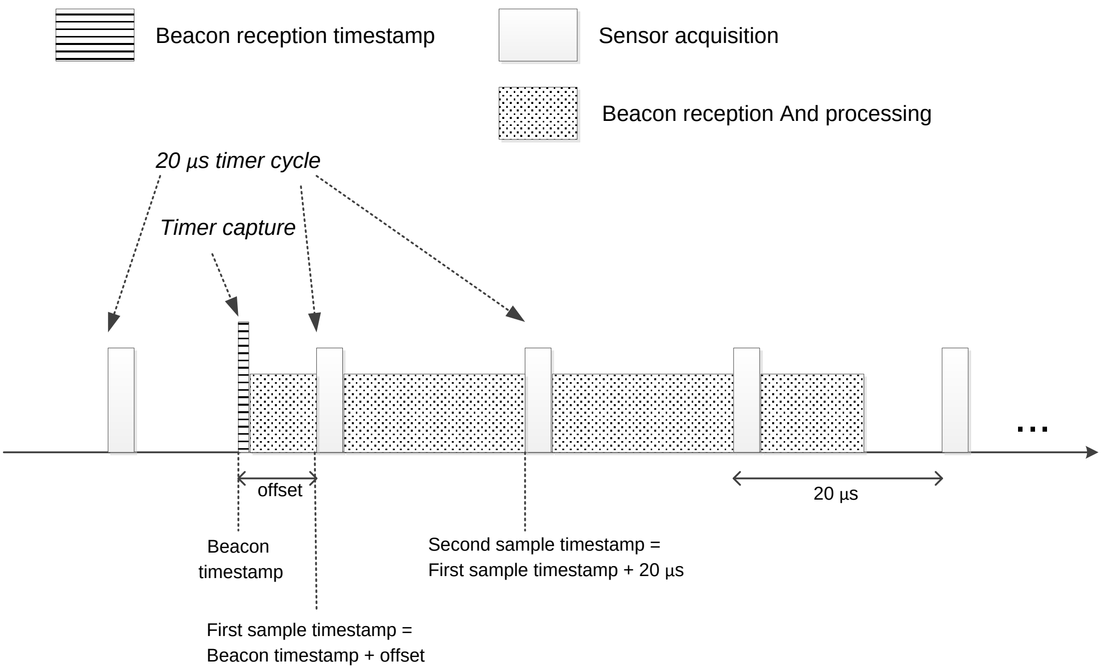


Figure 10: patch sensor timestamps

3.2.3 Data compression study

Because sample signals for the propeller use case were not available, the compression topic was addressed through a paper study. Traditional lossy sound compression algorithms such as

MP3 and AAC do not fit the project needs because they are designed to suppress signal components that the human ear supposedly cannot hear, thus they may destroy signal components that are relevant to the project application.

Most promising for the project context is LEC, a lossless algorithm by Marcelloni and Vecchio[3]. The results presented by the authors show compression ratios between 50 % and 70 % on various temperature and relative humidity signals. Whether such good results (for a lossless compression) would be obtained on acoustic pressure measurements is unknown, but this is surely an interesting approach to test, especially because the algorithm is designed to be implemented on devices with low computing resources.

The study also investigates future techniques such as compressive sampling. This implies sampling the signal in a concise or sparse domain in which its representation is compact. Then the signal is transmitted reconstructed in the original domain.

3.2.4 Jamming awareness

Resilience to jamming is an important topic for wireless systems installed in aircrafts. There are numerous defence strategies, from preventive to reactive measures. Although preventive measures may reduce the impact of jamming, none of them can guarantee free-from-jamming operations. Hence, even if preventive measures are in place, jamming detection is essential to enable the implementation of reactive measures. Even though it may not be possible to suppress the attack, jamming awareness enables retreat kinds of measures such as graceful shutdown or informing the avionics and crew.

The project sketched a jamming detection solution built from the state of the art that takes advantage of the characteristics of a the TDMA protocol described in section 3.2.1.

In this scheme, entities run tasks that are well adapted to their computing and energy resources. Most of the intelligence runs on the central WSN server which is the most powerful entity and which has most of the information. Moreover, the server is connected to the avionics and is therefore the only entity that can inform the external world of a jamming attack. The intelligence that runs on the sensor nodes helps preserving their energy and minimises jamming detection related communication that can be made impossible by the jamming itself. This problem is also addressed by allowing the nodes to search for another cell of the same network on a different channel and use unallocated TDMA slots to send jamming alarms. On the contrary, Wireless Data Concentrators have a wired connection and thus are able to inform the server even when they are jammed. Especially, the idea of using a redundant WDC to improve robustness is an asset to jamming detection because both master and redundant WDCs can “watch” each other.

3.3 Electronics

The project produced electronic boards for the propeller and patch use cases. In the second case, a thin PIFA antenna radiating along the aircraft fuselage was designed.

3.3.1 Propeller sensor node mock-up

The propeller use case PCB supports up to 8 Kulite pressure sensors. Five mounted boards are available for the laboratory tests. Since information on the target engine and the mounting were not available, the PCB is a laboratory mock-up. The two faces of the propeller use case PCB are shown in *Figure 11*. Its size is 105 x 55 mm.

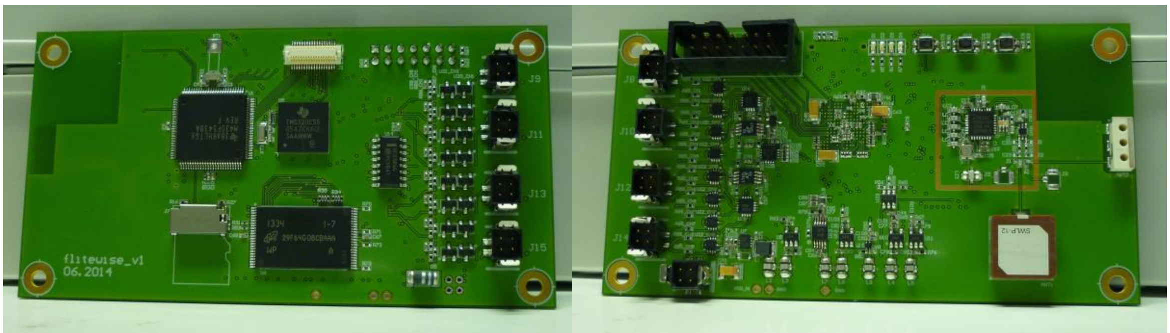


Figure 11: Propeller use case PCB

[3] Marcelloni, F., & Vecchio, M., “An efficient lossless compression algorithm for tiny nodes of monitoring wireless sensor networks”, The Computer Journal, 52(8), 969-987, 2009.

3.3.2 Patch sensor node

The sensor node is a circular patch of diameter 230mm and maximal thickness 4 mm which supports 50 KHz acquisition with logging in a micro SD/MMC card and deferred transmission. The patch board also supports wireless charging.

The patch board design includes the sensor front-end and 20V power supply for the B&K acoustic pressure sensor indicated by Airbus.

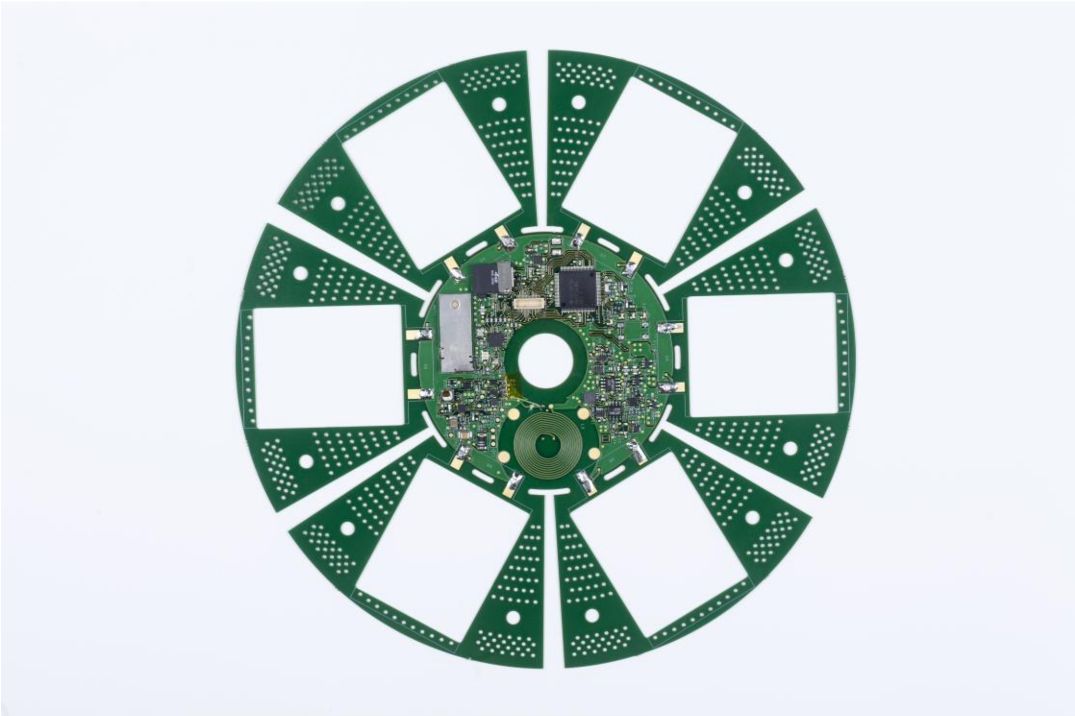


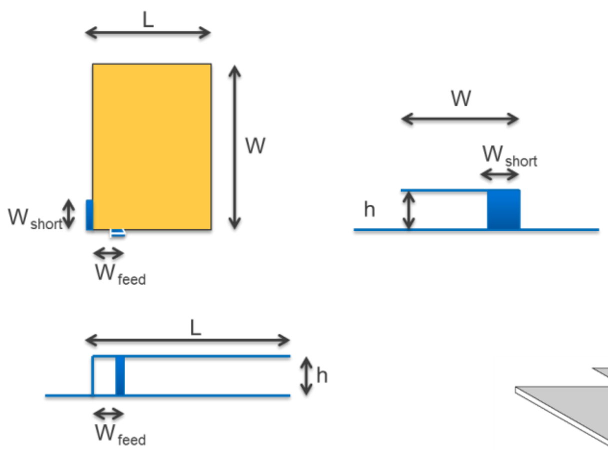
Figure 12: patch sensor node board

3.3.3 PIFA antenna

The main constraints for the patch sensor node antenna are:

- 2.5 mm max thickness
- Compact size
- Placement near a metallic surface (aircraft skin, PCB ground plan)
- Shall radiate along the fuselage to ease WDC placement

Figure 13 shows the antenna concept and its characteristics and Figure 14 gives the radiation pattern. On Figure 12, the antenna is the gray rectangle on the right-hand side of the electronics section of the patch sensor node.



Parameter	Value
W	21 mm
L	15 mm
W_{short}	3.7mm
W_{feed}	1.4mm
h	2.3mm

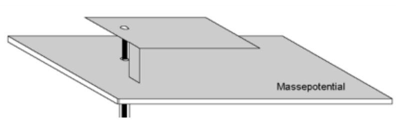


Figure 13: patch sensor node antenna concept and characteristics

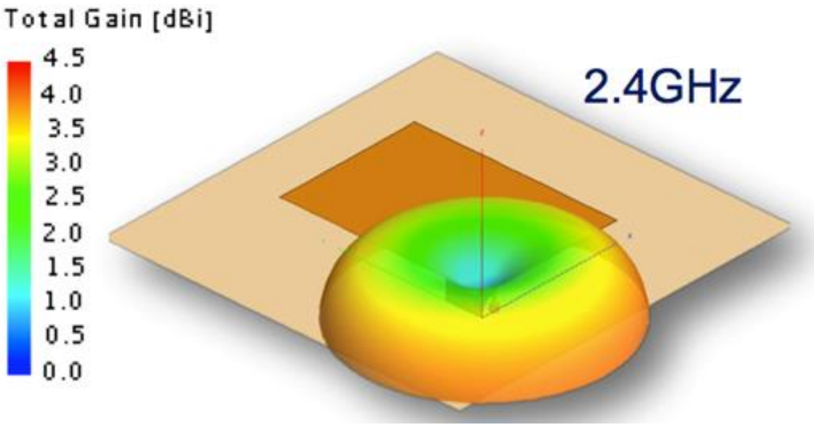


Figure 14: patch sensor node antenna radiation pattern

3.4 Power supply

3.4.1 Propeller Sensor Inductive Power Supply

The propeller sensor part of the FliteWISE project involves developing an energy harvesting system that will supply power to the propeller sensor node throughout several operational scenarios. The chosen energy harvesting solution is capable of power generation as soon as the propellers rotate and it involves a simple construction using low-profile wire coils and permanent magnets. An outline of device performance results is presented in this section. A detailed analysis of the device concept, design procedure, simulation and experimental results can be found in the FliteWISE deliverable D4.2.

The propellers are fitted to and driven by a counter-rotating open rotor (CROR) engine. The energy harvesting power supply is based on the induction of voltage across one or more coils, as one or more magnets passes each coil. The coils will be mounted on one propeller hub whereas the magnets will be mounted on the other counter-rotating propeller hub. This device concept and setup is illustrated in Figure 15. To evaluate the power supply performance, a down-scaled setup measuring 0.3 m in diameter was designed and implemented as shown in Figure 16. There is only one rotating plate in the setup in order to simplify the construction and experimental measurements. In relation to the actual implementation with two counter-rotating propellers, the laboratory setting merely results in only half the achievable rotating speed, i.e. the measured data can be extrapolated to reflect two counter-rotating propellers. This setup has an adjustable coil–magnet gap of between 0.2 cm and 10 cm. The position of the coils and magnets from the rotation axis is also adjustable, up to 15 cm. One or more coils and one or more magnets can be fixed either on the stator or on the rotor for the evaluation of different device and installation options. The rotation speed is voltage-controlled and ranges between 0 and 1200 rpm.

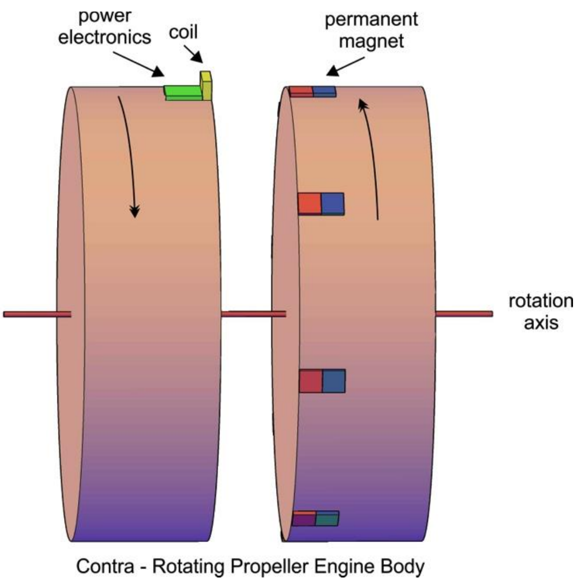


Figure 15: Device concept of a relative rotation inductive harvester for contra-rotating propeller shafts. The gap between the engines is exaggerated for illustration purposes.

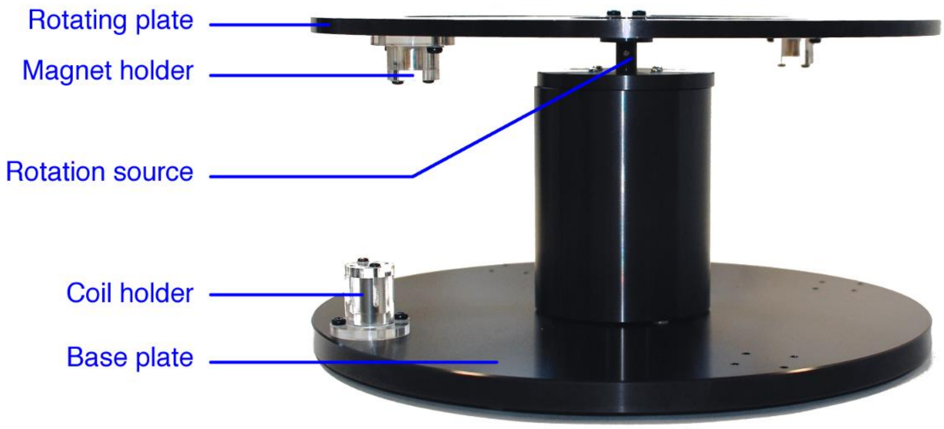


Figure 16: Inductive harvesting evaluation setup.

A prototype was constructed using a 1000 turn coil wound around a cylindrical ferrite core. Specifications of the coil wire and magnet are listed in Table 4.

Table 4: Coil and magnet specifications.

Parameter	**Value**
Coil wire diameter	0.1 mm
Coil wire material	Copper
Coil wire resistance	79 Ω
Magnet material	N42 Nd (cylindrical)
Magnet diameter	10 mm
Magnet length	10 mm

Two magnets were mounted on the rotating plate whilst the 1000 turn coil was stationary. The testing procedure involves measuring the induced voltage across the coil as the magnets rotates past, for different distances from the rotation axis, coil – magnet gap values and rotation speeds.

The results are presented in

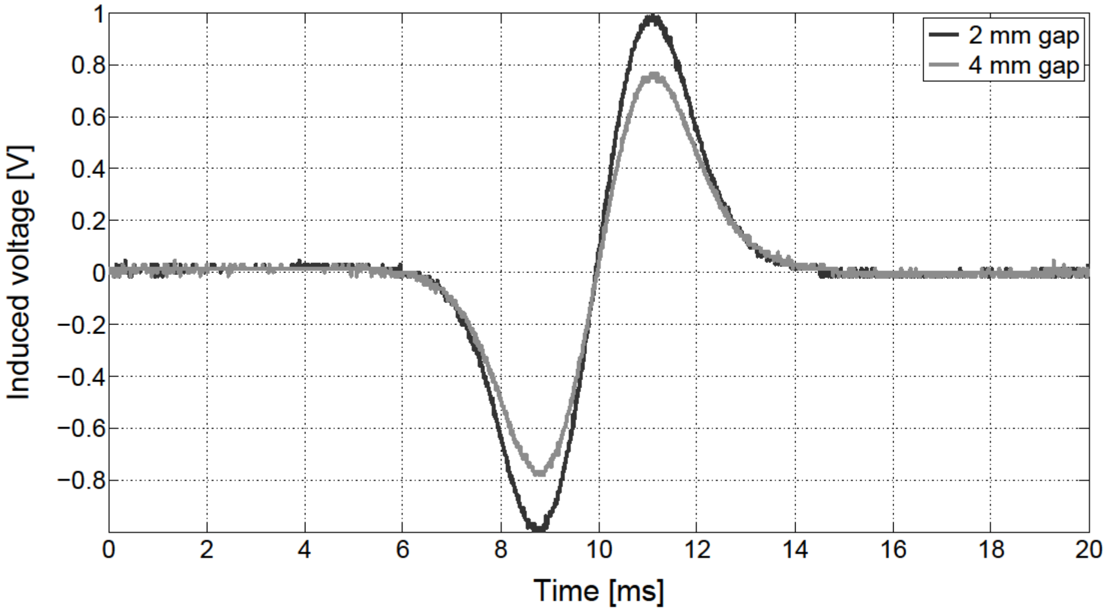


Figure *17* and

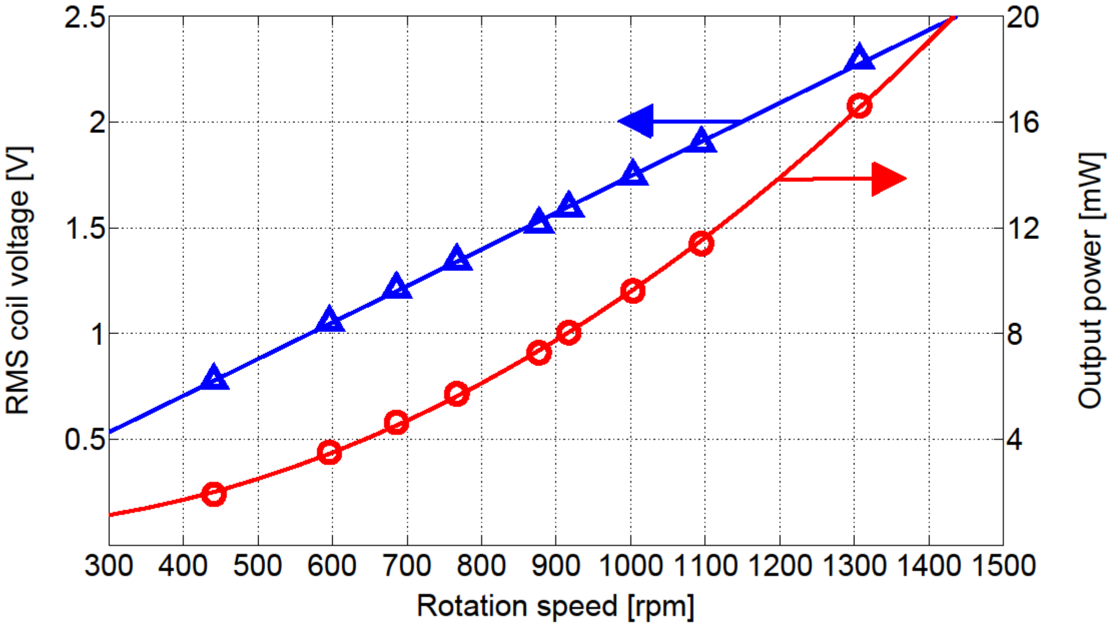


Figure *18*. An output of 16 mW was obtained from 1200 rpm, at a radial distance of 50 mm, from a setup consisting of two magnets and one coil, with a magnet-coil gap of 15 mm. The total magnet volume is around 1.6 cm3. The theoretical analysis presented in D4.2 demonstrates linear power scaling with number of magnets, number of coils, radial distance, and with the square of rotation speed. The latter is confirmed in

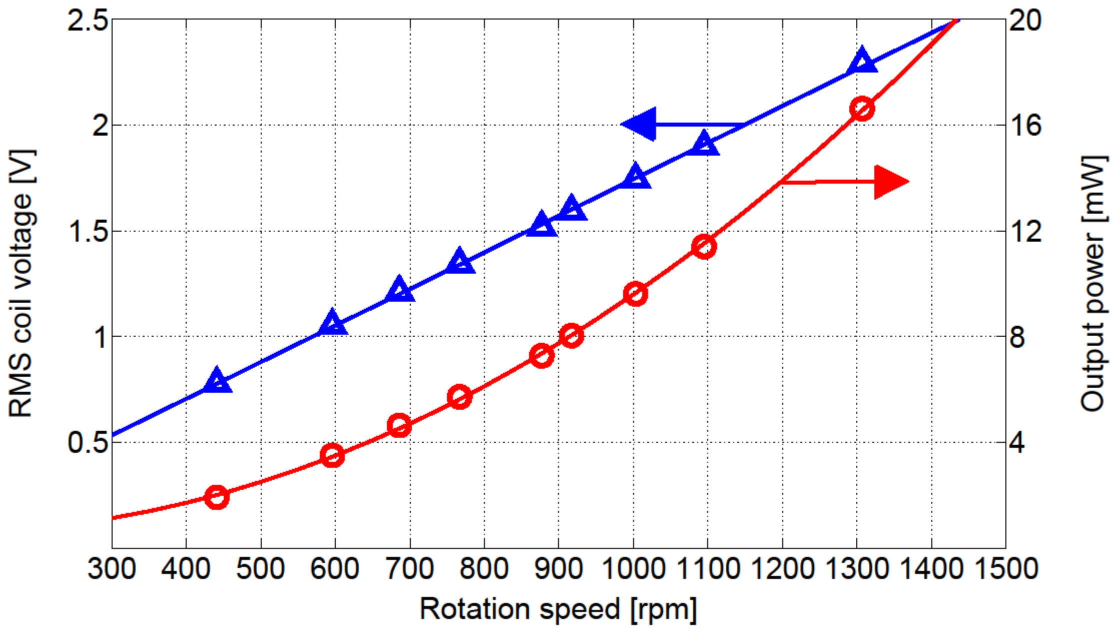


Figure 18.

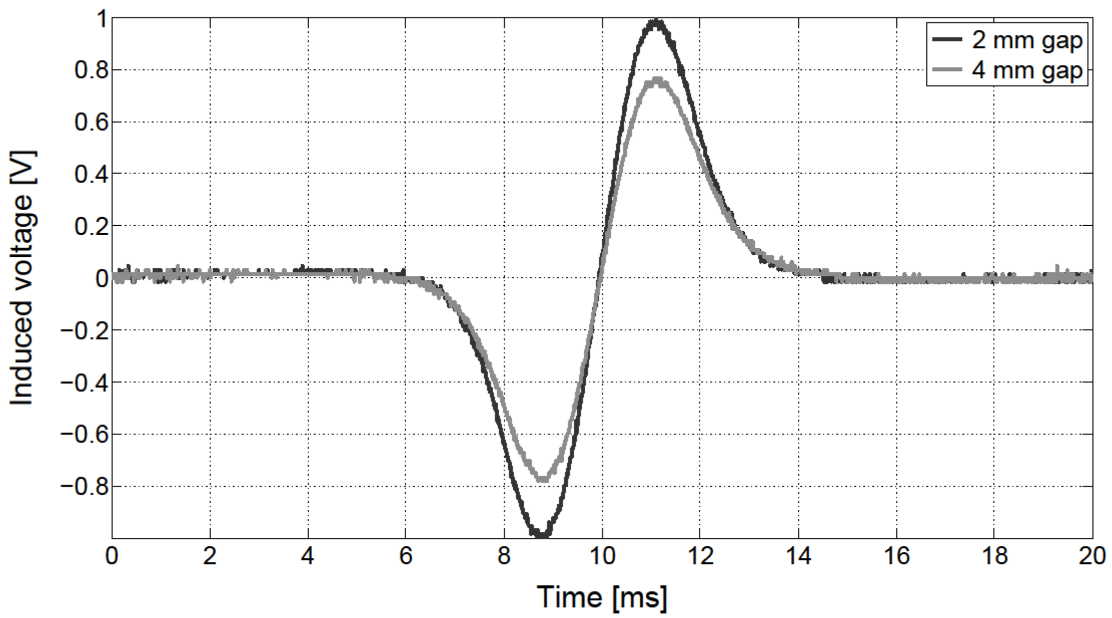


Figure 17: Open-circuit induced voltage from a magnet – coil interaction at 750 rpm rotation speed, 200 turns and a rotation radius of 50 mm.

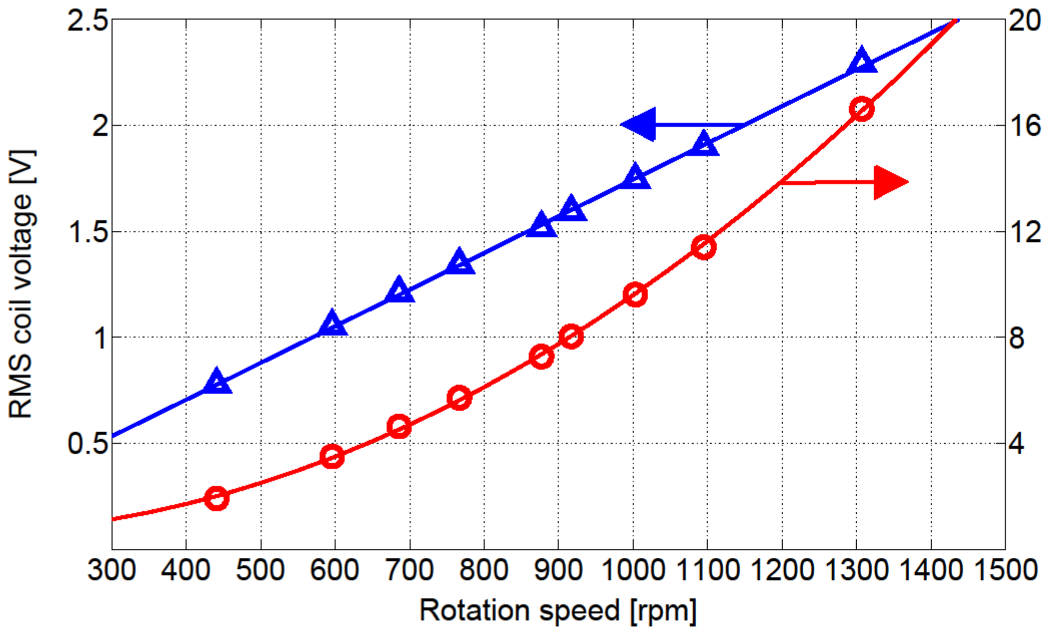


Figure 18: Open-circuit voltage amplitude as a function of rotation speed.

In order to condition the harvested power and store excess energy in a super-capacitor, a power management circuit was designed and implemented. The super-capacitor energy storage solution was preferred over a rechargeable battery due to high temperatures that are expected at the installation location. A circuit schematic is presented in Figure 19. It consists of a bidirectional Zener diode for voltage protection, a full-bridge Schottky rectifier stage, an LTC 3127 buck boost regulator and a super-capacitor. Results using the inductive energy harvesting system for two rotation speeds are shown in Figure 20. Successful charging is demonstrated, achieving full capacity within a few minutes of operation.

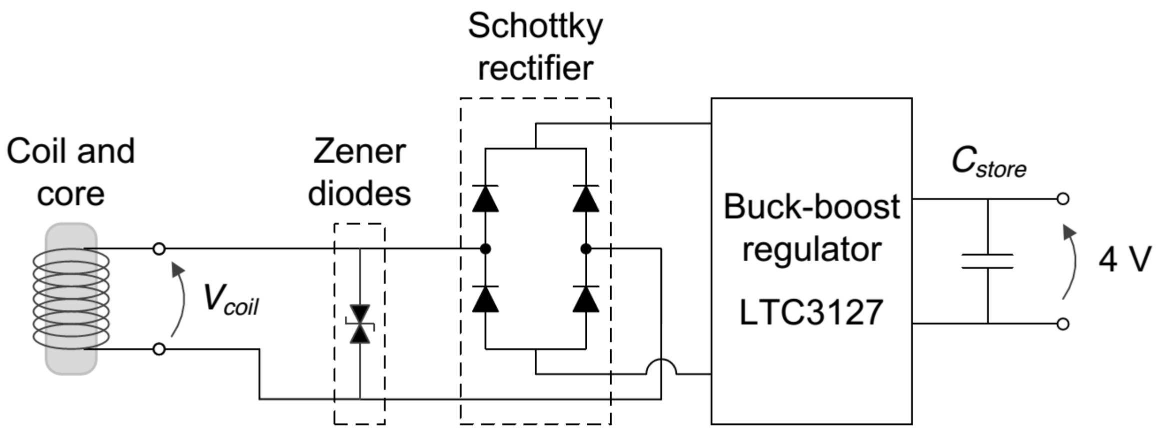


Figure 19: Schematic of the propeller sensor inductive harvester power management system.

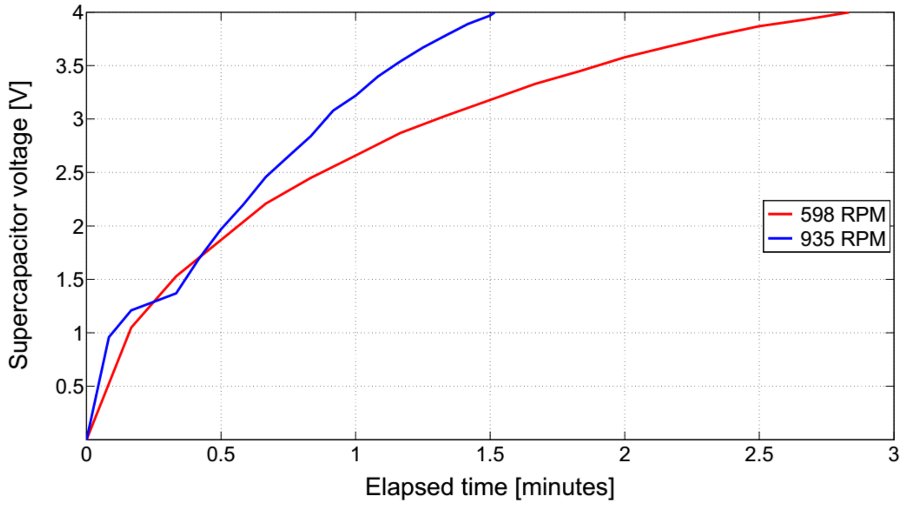


Figure 20: Charging of a super-capacitor through the power management system of Figure 19.

A performance estimation of a full scale implementation can be extrapolated from the experimental results above, measured from a setup consisting of only one 1000 turn coil and two magnets, taking into account the linear dependence of power output on the distance from rotation axis, number of magnets and number of coils and a square dependence with rotation speed (FliteWISE Deliverable D4.2).

Indicative results, showing the scaling of output power with speed for a case of 0.5 m distance from axis, 12 permanent magnets and 1 coil are presented in Figure *21*. It is concluded that a full scale device installation can easily provide the specified senor node power requirements, taking into account the actual size and rotation speed of the intended engine.

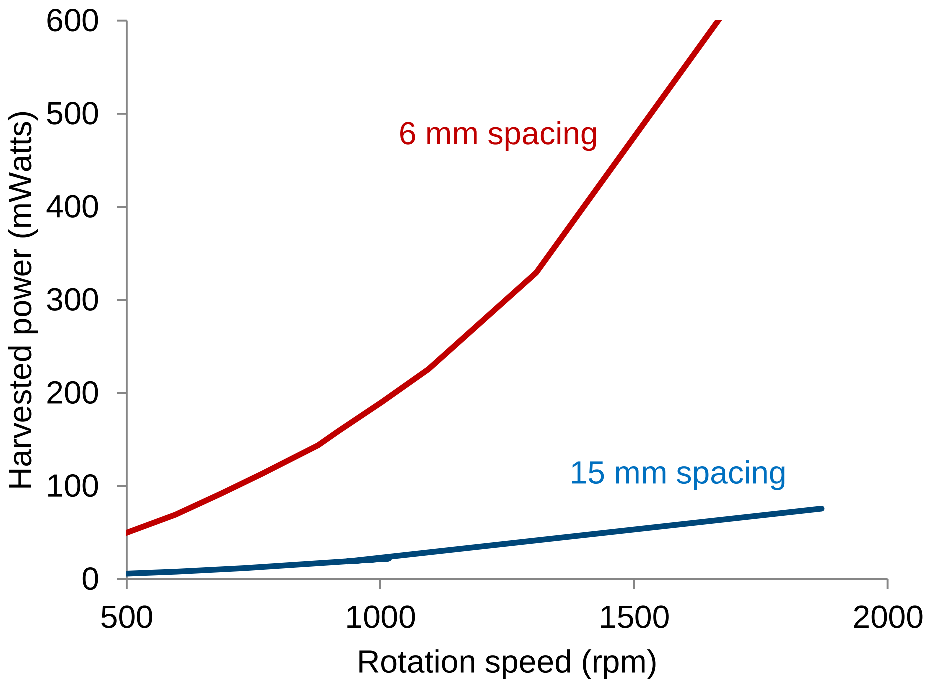


Figure 21: Power harvesting capability, projected from experimental results. Single 1000 turn coil with 12 PMs on a 1 m diameter rotating structure.

3.4.2 Patch sensor node power supply

An overall description of the patch power supply system architecture is presented in Figure 22. The system is based on a battery array, an RF charging module using a commercially available charger and receiver and a output voltage regulator to provide power for the sensor system, which includes a separate voltage output for the acoustic sensor.

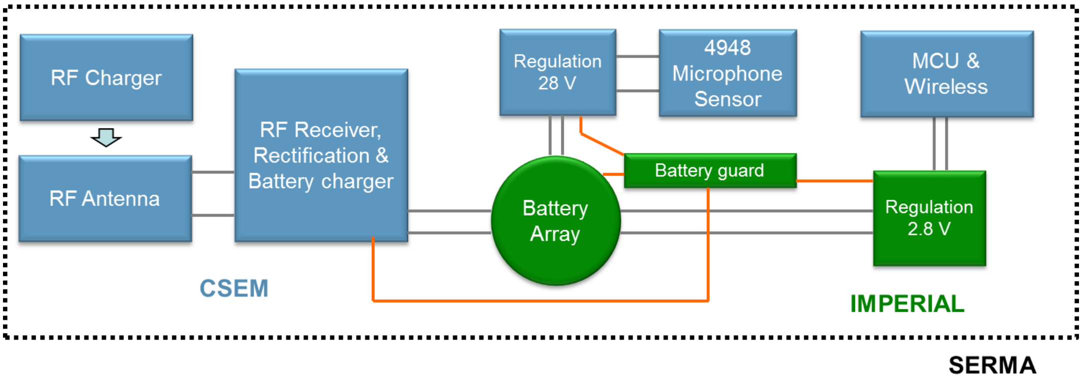


Figure 22: Patch sensor power supply architecture

A complete wireless power system consists of a transmitter, a transmit antenna, a receive circuit and its receive antenna. Wireless power transmission requires a transmitter that generates an alternating magnetic field, which is directed to a receiving antenna.

3.4.2.1 RF Charger

The RF charger is a DC1968A evaluation board from Linear Technology. This wireless transmitter can deliver an output power up to 2 W. It is based on a push-pull current-fed resonant converter, operating at approximately 130 kHz and it uses a receiver coil of 45 mm diameter. A photograph and a schematic of this wireless transmitter are presented in Figure 23.

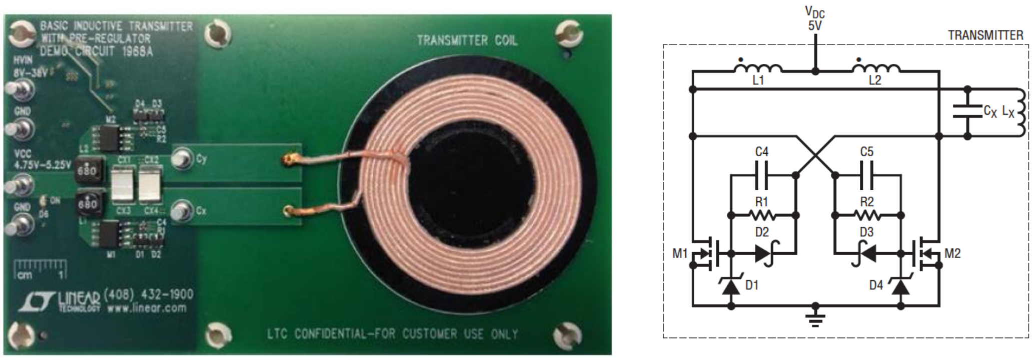


Figure 23: Linear DC1968A RF charger demo kit

To maximise the radiated field, the current in the transmit coil has to be maximised. In a resonant system, the current is directly proportional to the quality factor of the resonant components. So, a large Q-factor will result in a stronger magnetic field. In the proposed RF charger, the coil is wound using litz wire and the quality factor is approximately 10 at the resonant frequency leading to a current of around 6A peak-to-peak at full load.

3.4.2.2 RF Antenna

In order to maximise the power transfer between the wireless RF charger and the RF receiver, the ratio of both antenna (transmit and receive coils) diameters should be as close to 1 as possible. The value of the receive antenna should also maximised. The design of this antenna will consist of a coil with 43 turns added with a 25mm ferrite disk with the objective to reach a value of approximately 47 µH. The purpose of this ferrite disk is to increase the power gathered by the receiver. It is possible to harvest more energy by applying a bigger disk. By using a 35mm disk, it is possible to increase the received power by approximately 20%. By superposing the 35mm on top of the 25 mm disk will increase the power by 30%.

3.4.2.3 RF Receiver, Rectification & Battery charger

The receiver consists of a coil configured in a resonant circuit followed by a rectifier and the LTC4120. The hart of the RF receiver is the LTC4120 from Linear Technology. The LTC4120 circuit is a constant-current/constant voltage wireless receiver and battery charger. Figure 24 shows the typical application diagram of such a receiver.

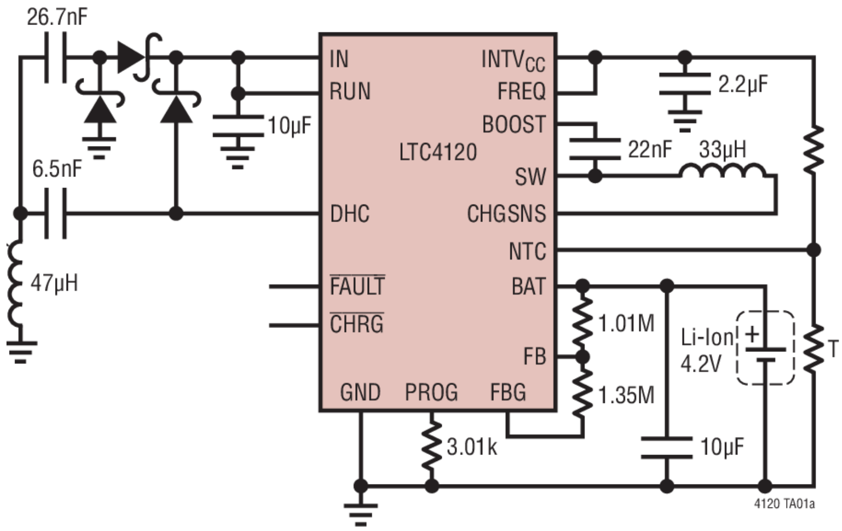


Figure 24: Linear LTC4120 RF receiver, rectifier and battery charger

3.4.2.4 Batteries

The battery array consists of six thin, rechargeable Li-ion batteries from Power Stream in parallel connection. The selected model is PGEB014461. A summary of specifications is given in Table 5.

Brand/Model:	Power Stream PGEB014461 (Cat.: PGEB016144)
Technology:	Polymer Li-ion
Size:	44 x 61 x 1 mm
Nominal temperature range:	-20 °C – 60 °C
Nominal voltage:	3.7 V
Nominal energy:	200 mAh
Nominal discharge (max):	2C
Nominal output resistance	< 180 mΩ
Measured energy at -13 °C	393 mWh
Number of devices required	6

Table 5: Summary of the Power Stream PGEB014461 battery specifications.

3.5 Integration and packaging

The integration work was realised for the patch sensor node only because the propeller use case would not go further than laboratory mocks-up during the project because of the unavailability of the target engine.

The integration work for the patch sensor node covers the following aspect:

- Install the batteries.
- Develop a sensor simulation board to enable the evaluation of the node in data acquisition. This was done for both use cases.
- Prepare the coating process for the patch sensor node installation against the aircraft fuselage and perform a coating attempt.

3.5.1 Batteries installation

Batteries installation is complicated due to inconsistencies in the spread distance between the contact pads among the different samples. The patch sensor node with its batteries is shown in Figure 25.

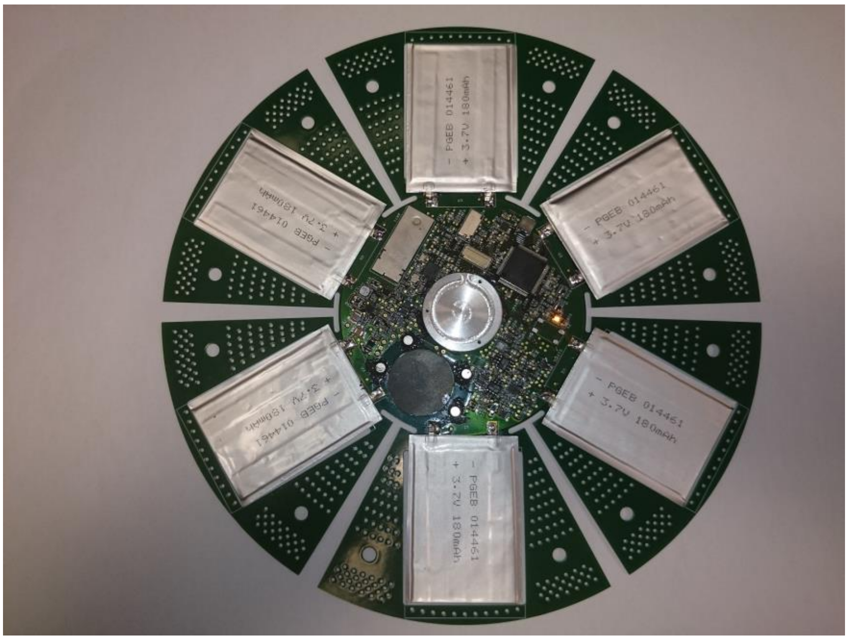


Figure 25: patch sensor node with batteries

3.5.2 Sensor simulation board

A specific board has been developed by Serma for test and validation purpose for both use cases. This board simulates the microphone with IEPE interface for Patch sensor and simulates 8 pressure sensors for the propeller uses case.

This board is controlled by USB to modify the generated signal.

Difficulties of this two kind of simulation are first the IEPE interface, and after resistor bridge simulation with frequency constraints.

A DSP controls DAC and Digital resistor (On SPI Bus) at high frequency rates (about 100KHz) to provide an output signal frequency up to 50KHz.

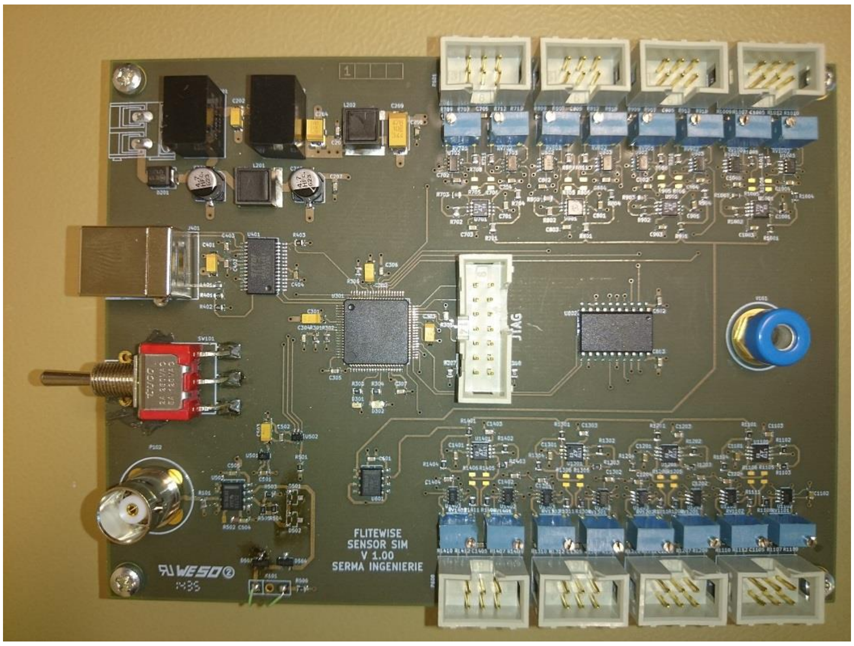


Figure 26: Sensor Sim Board

3.5.3 Coating process preparation

A mould has been designed for the coating process. It was produced in aluminium. A specific profile has been designed to minimise the air resistance in flight caused by the Patch Sensor.

Figure 27: Aluminium mold

3.6 System performance

This section reports on the system performance as measure during the system evaluation work package.

3.6.1 Propeller use case

3.6.1.1 Data acquisition

Data acquisition rate

Using the DSP on board the propeller sensor board, the system supports the required acquisition frequency of 50 KHz without any difficulty.

Sensor interface

The analogue interface test result is:

- The frequency is not altered as expected.
- The amplifiers do not alter the DC components, which is correct.
- The ADC input signal is not symmetrical. A careful observation of the input shows that it comes from the SensorSim board which generates an asymmetric signal which is then amplified.
- The gain of the analogue sensor-front end can be adapted to a precise type of sensor by selecting the correct resistor values.

Analogue to digital converter

The ADC operation is correct. It has measured values between -6025 and +8191, which corresponds to the input signal amplitude varying between -2.21V and +2.98V, given the 3V reference voltage.

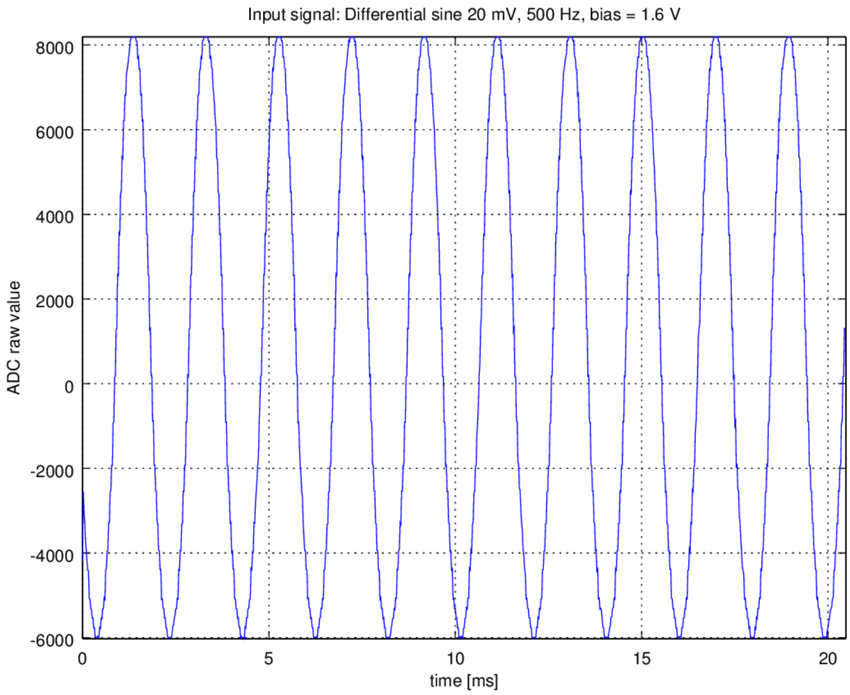


Figure 28: ADC output for a single sensor measurement. The ADC input signal is a 500 Hz sine with values between +2.98V and -2.21V

3.6.1.2 Data transmission and synchronisation

Data transfer

The system useful throughput for a network with a single SN is: 84.8 KB/s = 678.4 Kbps when the slot duration is equal to 1 ms and the TDMA beacon period is equal to 5 ms. The sample transmission rate is thus 40 KSamples/s, hence 5 KSamples/s if 8 sensors are used in parallel.

Propeller angle stamps precision

A measurement is stamped with the propeller angle relative to the point where the energy harvester magnets and coils are facing each other at the time it is taken. A 12.5 MHz timer is used to compute the time between the 0° propeller position and the data sampling time. The angle is inferred from the time and the (constant) propeller rotating speed.

This test measured the accuracy of the propeller angles stamps.

The maximal propeller angle error measured was 0.1°. This result from a maximal timer error of 20 µs which is due to multi-tasking.

3.6.1.3 Power supply and consumption

Power supply

Imperial college built a test set-up for the rotating energy harvester. It is depicted in Figure 29.

The results show that an output of 16 mW was obtained from a 1200 rpm rotation, at a radial distance of 50 mm, from a setup including two magnets and one coil, with total magnet volume of around 2 cm^3. The magnet-coil gap was 15 mm.

It was concluded that a full scale device installation can easily provide the specified senor node power requirements, by taking into account the actual size and rotation speed of the intended engine. For example, a radius of 1 m and a rotation speed of 1600 rpm would yield a factor of 6 increase in output power, providing around 96 mW from an identical device. Further increase can be obtained by straight forward options such as device size increase or using more magnets or coils.

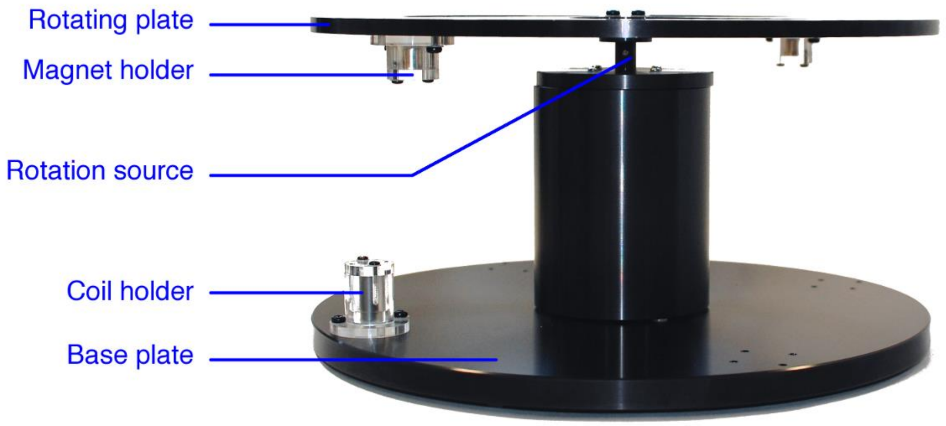


Figure 29: Inductive harvesting evaluation setup.

Power consumption

The power consumption was measured for each operational phase. It is summarised in Table 6.

Mode	Configuration	ULP Sleep	Sleep	Acquisition	Transmission
Current consumption	27 µA	25 µA	29 µA	56.5 mA	33.2 mA
Power consumption	0.09 mW	0.08 mW	0.09 mW	186.5 mW	109.6 mW

Table 6: propeller sensor node power consumption in each operational phase

In Configuration, ULP Sleep and Sleep modes, the measured consumption is equal or below the estimate given in project Deliverable D1.1, section 5.2.

In acquisition, the board consumes 186.5 mW, which is the highest consumption mode. As the energy harvester in its current configuration provides 96 mW, it should be mounted with twice as many coils or magnets to provide the power required by the sensor node. Therefore the node and its energy harvester are compatible as long as the latter is equipped with enough magnets and coils.

3.6.1.4 Summary

The propeller sensor node board provides the expected functionality for the data acquisition and transmission on 8 sensors at 50 KHz. The measurement data can be stamped with the current propeller angle assuming that the rotation speed is precisely known and constant. In that case, the stamping feature has an accuracy of less than 0.1°, corresponding to a delay of about 20 µs. The power consumption in operation is within the expected range and the energy harvester can provide enough energy when equipped with enough coils and magnets. The power consumption in the inactive states is even lower than expected which allows longer node service intervals when the system is not operating. Relevant future work includes the study and implementation of data compression algorithms for the DSP of the sensor node to reduce the amount of data to transfer.

3.6.2 Patch sensor node

3.6.2.1 Data acquisition

Data acquisition rate
The patch sensor node uses a single processor to handle the reception of beacons, acquire data at 50 KHz and save the acquired measurements to a micro MMC memory card.

The time to write a buffer is less than 3 ms. As each buffer contains 250 samples, i.e. 5 ms of acquisition, the saving operation is fast enough. Also, it does not disturb the beacon reception as it is started in the background only once the beacon has been received and processed.

The time spent in the three interrupts caused by the beacon reception (start-frame delimiter detected, end of reception, end of microcontroller DMA transfer) causes the data acquisition to miss 6 samples. Several techniques have been tried to mitigate this problem:

- Nested interrupts, but this is not advised on the MSP430 MCU.
- Receiving beacons at a slower rate is the preferred technique. The slowest possible rate is defined by the synchronisation requirements and the quartz performance.

Sensor interface
This interface transforms microphone signal +/-5V with 12VDC Bias on 0/3V signal for ADC with 1.5V DC Bias. This interface also provides a 4mA DC current Source to microphone.

The tests confirmed the current source correctness (error < 1%), and AC accuracy. The AC error is about 3%. It is due to the uncertainty on the resistor bridge divider. This is easily corrected by calibration.

Analogue to digital converter
The input signal is simulated by the SensorSim board with +/-5V output voltage. An acquisition is performed by the sensor node, recorded in the SD card, then transferred to the laptop. Finally, an Octave script plots the output after a rightward shift of two bits of each received sample (the ADC is 14 bits MSB first).

The resulting amplitude peak to peak is about 1.58V, so the RMS value is 0.558V for 0.556V on the ADC input (error of 0.36%). This error can also easily compensated by software thus the ADC is valid.

Thermal test
This test checks the operation of the sensor node on batteries at low temperature using a climatic chamber and the setup depicted in Figure 30.

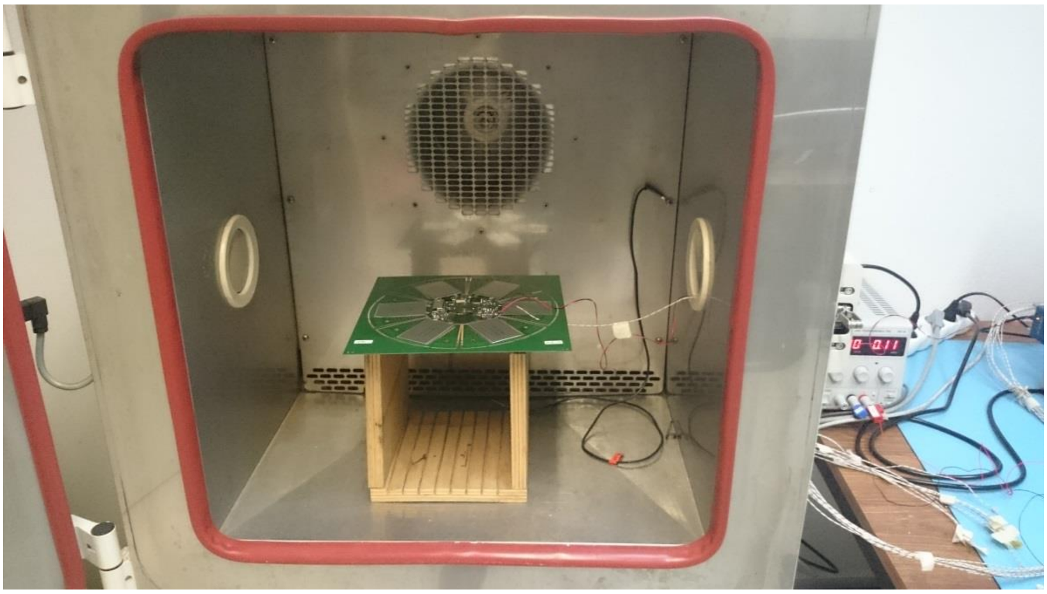


Figure 30: Patch Sensor in Climatic chamber

At low temperature (-20°C), we obtain same voltage batteries after 14h30min and a secure operational time (cut off at 3,5V) of 18h45min (Figure 31).

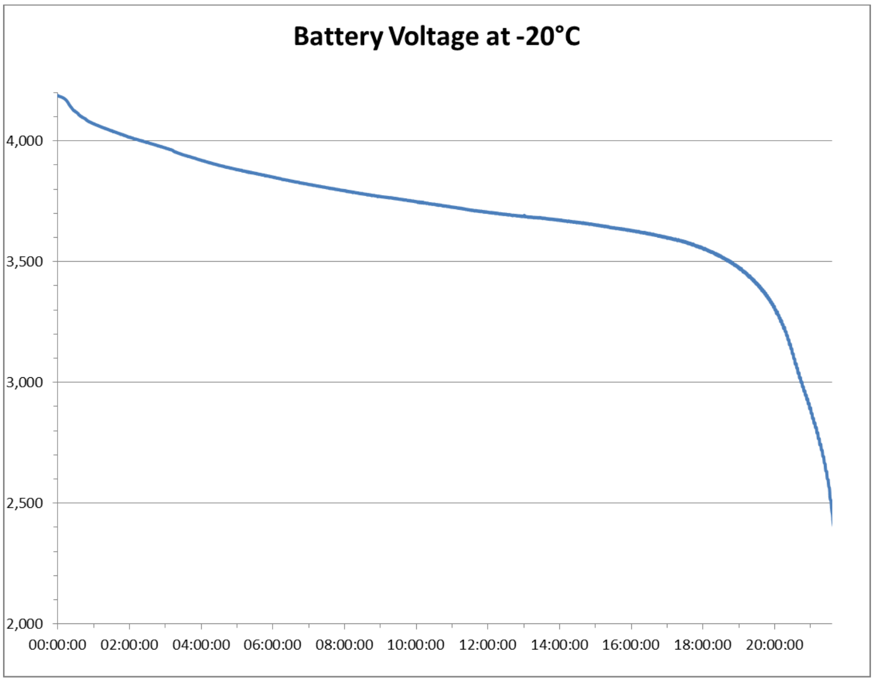


Figure 31: low temperature discharge

3.6.2.2 Data Transmission and synchronisation

Communication with the WDC, data transfer

The system useful throughput for a network with a single SN is: 84.8 KB/s = 678.4 Kbps when the slot duration is equal to 1 ms and the TDMA beacon period is equal to 5 ms. The sample transmission rate is thus 40 KSamples/s with one sensor.

Synchronisation

This test uses the network synchronisation mechanism to let two sensor nodes trigger a pulse on one MCU output at a certain system time specified by the WDC. The WDC also sends the pulse at the required time to give a reference.

The pulse outputs are connected to a logical analyser.

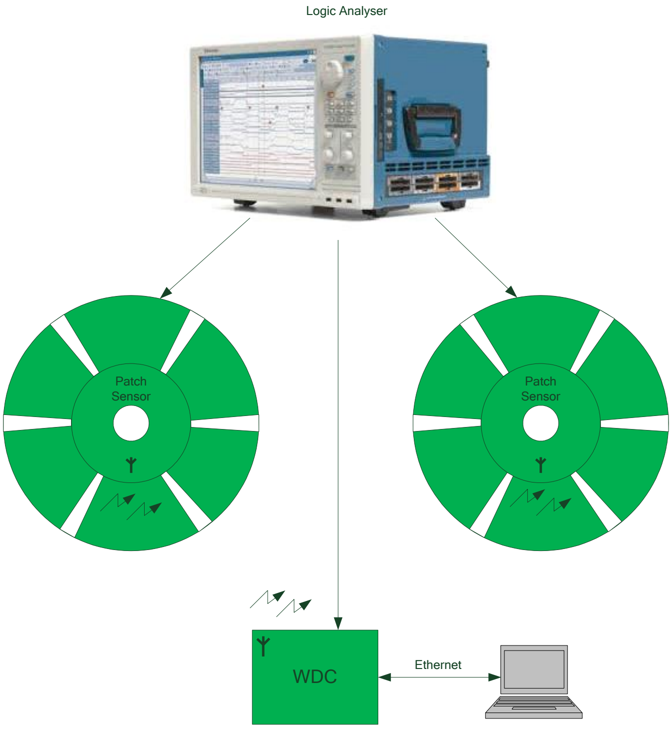


Figure 32: synchronisation test setup

For this experiment, the pulse is triggered 3.2 ms after the WDC sends the beacon. The beacon period is 5 ms and a pulse is generated for each beacon in data transfer mode. The logical analyser is active for about 20 seconds to provide significant statistics.

The synchronisation error is measured as the time difference between the rising edges of the pulses by the logical analyser. The data is exported to Octave for easy statistical computation.

Table 7 shows the error statistics taken over more than 20 seconds of measurement in data transfer mode with a beacon period of 5 ms and one pulse per beacon period.

Error [µs]	WDC – SN 4	WDC – SN 5	SN 4 – SN 5
Mean	23.4	23.3	1.1
Standard deviation	1.3	1.3	0.9
Minimum	11.8	12.7	0
Maximum	27.8	36.5	12.2

Table 7: synchronisation error statistics for one WDC and two sensor nodes taken on 4605 samples (more than 20 seconds of measurement)

The relatively small error (23 µs in average) is due to the selection of the radio interrupt as the time reference instants coupled with the usage of a precision timer (3.75 MHz).

Antenna

The Antenna designed for the patch sensor board was matched. The matching of the impedance to 50 ohms is important to avoid losing too much energy while feeding the antenna. The resulting matching network is:

C67 = 3.9pF

R51 = 1 nH

C58 = 1.8 pF

3.6.2.3 Power supply

Power consumption

When inactive, the power consumption of the patch sensor board is equivalent to that of the propeller board (see section 3.6.1.3). This is not surprising since both boards share the same basic components (MCU, radio). Specific components differ (e.g. sensor power supply), but they are not supplied with current in inactive mode.

During the acquisition, the power consumption linked with sensor supply is correct:

- Sensor consumption is about 26mA: the sensor is supplied with 22V-3.94mA, so ~86.7mW. With 3.7V on voltage input, input current due to sensor is at minimum 86.7mW / 3.7V = 23.7mA → about 26 mA with efficiency of DC/DC converter
- Mean Radio consumption (see below) with CPU (CPU without radio 10.5mA) is about 17mA. Mean consumption of radio is about 6mA. Max consumption is about 60mA. Peak due to data transmission (~17mA).

So a maximum mean consumption of 43mA at full rate data acquisition and data transmission every 40ms is measured. For the battery capacity of patch sensor, a 60mA max consumption has been taken into account. Hence the power consumption is in accordance with the batteries capacity.

Wireless charging

The test checks the correct function of the Wireless charging feature of the patch sensor node. The battery voltage versus battery charging time as measured during the tests is depicted in Figure 33. The batteries charging time is about 5 hours.

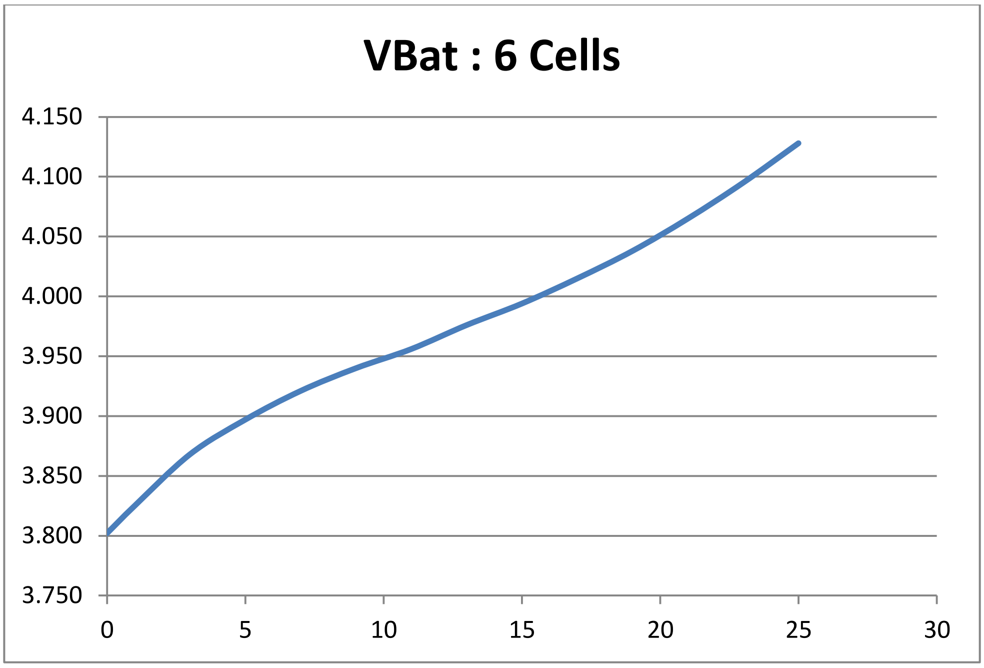


Figure 33: Batteries charging time of Six Cell (X-axis: minutes. Y-axis: Volts)

3.6.2.4 Mechanics

<u>Size and weight</u>

The final size of patch sensor is 230mm diameter with about 4mm height. The weight of the Patch sensor with coating is 146g.

<u>Coating attempt</u>

The coating attempt realised with the specific bi-component gel Dow Corning 3-4207 failed unfortunately. This is due to the component not giving enough time for its application before turning into gel. Also some bubbles appeared. At the final project meeting, Airbus suggested the use of epoxy or similar material. Airbus may conduct this experiment after the project end on one of the prototype delivered.

3.6.2.5 Summary

All subsystems of the patch sensor node function satisfactorily, although some data samples can be lost during the data acquisition while a beacon is received. The impact of this problem can be reduced by increasing the beacon interval.

Assuming that only one node is connected to the WDC and that the channel conditions are not exaggeratedly adverse, the network provides a useful bitrate of 678.4 Kbps, meaning 40 KSamples/s and 1 hour and 25 minutes to transmit one hour of acquisition. This rate can be sensibly increased if the MAC protocol uses a larger beacon interval. Slot duration reduction is apparently not possible with the current radio device and data packet size. Thus in its current state the system cannot support simultaneous data acquisition and transmission.

The PIFA antenna was matched and its correctness checked.

The synchronisation mechanism is accurate with a maximal error of the order of 27 µs, which is a significant improvement over the preceding project “StrainWISE” (more than an order of magnitude).

The capacity and low temperature performance of the batteries as well as the wireless charging duration of less than 5 hours coupled with satisfyingly low board power consumption ensures that the system can operate for more than 12 hours.

The size and weight of the patch sensor are correct with respect to the system specifications.

Future work includes the testing of alternative architecture to ensure a flawless acquisition (dual processor and single processor with a more powerful MCU) and attempt simultaneous data acquisition and transmission. Finally, a functional process for coating the electronics should be designed using alternative materials.

4 Potential impact, dissemination and exploitation

(Please provide a description of the potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and the exploitation of results. The length of this part cannot exceed 10 pages)

The present section discusses the project impact with respect to what was expected when writing the proposal. Then a summary of the dissemination activities follows. Finally, the section concludes with the presentation of the current and future exploitation plan.

4.1 Impact

The first project outcome is a laboratory demonstrator of the rotating use case sensor node. The mock-up gives a good idea of the size and performance the chosen architecture can achieve. The experience gathered during the project will be extremely valuable to the development of a fully integrated system once the information on the engine and the form factor requirements become available.

The second outcome is a fully integrated wireless sensor node dedicated to acoustic measurements along the fuselage of an aircraft. The device is a circular flexible patch designed to be applied to the aircraft skin. It accommodates one acoustic sensor, communication capability and mass storage. It is powered by ultra-thin batteries which can be wirelessly recharged by inductive coupling. An attempt was made to coat the sensor node to protect it from the harsh environmental conditions. The specific gel application and de-moulding was difficult and did not convince. Alternative solutions such as epoxy can be tried in the future. The prototype will be tested on the ground by Airbus Flight Test department.

Current flight monitoring systems are wired and their installation is costly and cumbersome. They also involve high maintenance costs and they add a significant weight burden. The results of the Flite-Wise project consist a milestone step towards wireless monitoring, in demonstrating highly efficient sensor nodes that can operate within strict energy budgets. In particular, the combination of a low power protocol with energy aware duty cycling of operation with wirelessly recharging flat batteries has permitted integration of a complete system in a very flat package, which opens up new possibilities in system integration shapes and locations of installations. It also demonstrates that cable – free, energy autonomous propeller sensor systems are possible by harvesting the significant relative rotation motion that is internally available. Furthermore, large on-board data storage allows high sensor sampling rates with deferred data transmission. The overall benefits of such sensors are reduced installation and maintenance costs.

Finally, the study on jamming awareness for wireless sensor networks in the aeronautics will be used by the topic manager to support its internal developments in the cabin connectivity area.

From a short-term viewpoint, the Flite-Wise project allowed the consortium members to perform significant progress in their respective areas of expertise: ultra-low power communications and synchronisation (CSEM), energy harvesting and power regulation (Imperial College London) as well as electronics and industrialisation (Serma Ingénierie). The project partners wish to continue their collaboration and will keep in touch to monitor project opportunities.

4.2 Dissemination

Though not formally described in the description of work, the project conducted various dissemination activities. They are listed and classified below according to their nature.

4.2.1 Scientific papers

The following scientific paper has emerged from the FliteWISE project:

T. T. Toh, S. W. Wright, M. E. Kiziroglou, P. D. Mitcheson and E. M. Yeatman, Inductive Energy Harvesting for Rotating Sensor Platforms, Nov. 18–21, PowerMEMS, Hyogo, Japan, 2014.

This paper was presented as a poster in the PowerMEMS 2014 conference and has been published in the IOP Journal of Physics: Conference Series, 557 (2014) 012034

Two more scientific papers, one on the development and performance of the patch sensor node and one on the presentation of the full inductive energy harvesting power supply are expected to be prepared in 2015.

Moreover, an article describing the overall results of the previous project "StrainWISE" was submitted by the consortium to the AIAA Journal, a high impact periodic published by the American Institute of Aeronautics and Astronautics.

4.2.2 Within the topic manager Airbus

The topic managers were issued from Airbus departments "Materials & Processes, NDT and Mechanical Testing" and Cabin Design Office Connectivity. Also the project was closely followed by the Flight Test Instrumentation department in Toulouse who will evaluate the patch sensor node prototype on the ground.

The project was widely disseminated within Airbus. The project deliverables have been made available on a dedicated section of Airbus internal portal "iShare".

In addition, specialists from other Airbus departments attended several project meetings remotely. Their interests ranged from analytical structural health monitoring to landing gear.

A joint brainstorming meeting was held between CSEM and Airbus Group Innovations in Munich.

4.2.3 To the general public

The previous project StrainWISE received the "Mechatronics Award 2013" in September of the same year at the European Mechatronics Meeting in Toulouse[4].

This award had an important impact on the consortium visibility and gave an opportunity to advertise the Flite-Wise project during the award ceremony.

Also, the consortium published a joint press release[5] to inform the specialised and general media. The press release was taken over by the specialised press in Europe and the USA:

- http://www.lembarque.com/initie-par-airbus-le-projet-strainwise-sur-les-capteurs-sans-fil-communicants-a-ete-recompense_001216
- http://www.microwave-eetimes.com/en/strainwise-project-yields-autonomous-communicating-sensor-networks-for-aeronautics.html?cmp_id=7&news_id=222904447
- http://www.energie-und-technik.de/smart-energy/artikel/104007/

4.3 Exploitation

The content of this section is confidential.

There are several on-going and future plans for the exploitation of the Flite-Wise results. They are presented below in chronological order.

4.3.1 Patch sensor node prototype delivered to Airbus flight test

The prototype will be evaluated on the ground by Airbus. The consortium will provide limited post-project support.

4.3.2 Industrial partner Serma

Serma Ingénierie is the industrial partner of Flite-Wise. As such its plans for the exploitation of the project results are:

- Demonstrate to our main customers Airbus Helicopters and Airbus Toulouse, that SERMA and its partners have acquired sufficient maturity to be able to propose industrial sensors, within wireless networks and low consumption.
- Furthermore, the Flite-Wise development shows the capabilities to our team to manage, industrialise and test efficiently this kind of problem.
- The promising result of this study, allow a good positioning of our consortium for as example on Future Helicopter, a new research program for Airbus Helicopters (former Eurocopter).

Then at medium-term, SERMA intends to provide several type (temperature, strain gauge, pressure, acceleration, etc.) industrial autonomous sensors, allowing easily installation without bundle.

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[4] http://www.mecatronique.fr/mechatronics-awards-2013-une-annee-exceptionnelle-977

[5] http://www.csem.ch/site/card.asp?bBut=yes&pId=25633

With this experience, we more easily find supplementary budgets, to pursue this research axis.

4.3.3 Imperial College London

Imperial has gained significant know-how from the FliteWISE project. In particular, it has developed a novel inductive energy harvesting method for rotating structures and a battery guarding system for wireless power transfer based power supplies in wireless sensor nodes. This know how is exploited in on-going energy harvesting related research and development activities at Imperial.

The joint development of two new self-powered wireless sensor node solutions by the FliteWISE partners has advanced the collective scientific and technical know - how of the consortium. In addition, the communication and collaboration level among partners has matured, with significant gains in trust, coordination on the interfacing of systems and cooperative problem solving. These benefits are being exploited in further joint scientific activities, including joint participation in Horizon 2020 proposals, conferences and journal publications.

4.3.4 CSEM

Partner CSEM will benefit from the results of FliteWISE through the application of its increased know-how and experience in the fields of low-power Wireless Sensor Networks (WSN), power management and sensor electronics. Low power WSN technology is needed to realize dependable, autonomous solutions for monitoring and surveillance capable of operation over extended periods and wide geographic areas. In accordance with CSEMs mission to bridge the gap between research and Industry, the technology developed in StrainWISE and Flite-Wise is already being transferred into industrial developments in collaboration with the Swiss aeronautics industry and the Swiss Federal Government innovation support commission (KTI/CTI). The results of StrainWISE and FliteWISE have also been used in a currently running project for ESA in which a MAC protocol was proposed for UWB system using IEEE 802.15.4a physical layer for intra-satellite communications and wireless connections of ground test sensors.

Technically, CSEM has added a new platform to its WSN solutions toolbox thanks to the FilteWISE project. This new platform complements the existing Wisenet system which is based on the ultra-low power random access MAC WiseMAC as the TDMA nature of the new platform will allow CSEM to work where deterministic systems are mandatory. Potential applications for this technology extend beyond the domains of aeronautics to, for example, safety, health, automotive and transport applications.

5 Project public website

Not applicable.

However, the project material including reports, meeting minutes, PCB schematics and layout and user's guide had been uploaded into a section of Airbus supplier's portal dedicated to the project (access reserved to project's stakeholders):

https://w4.airbus.com/sites/Structural/JTICS/default.aspx