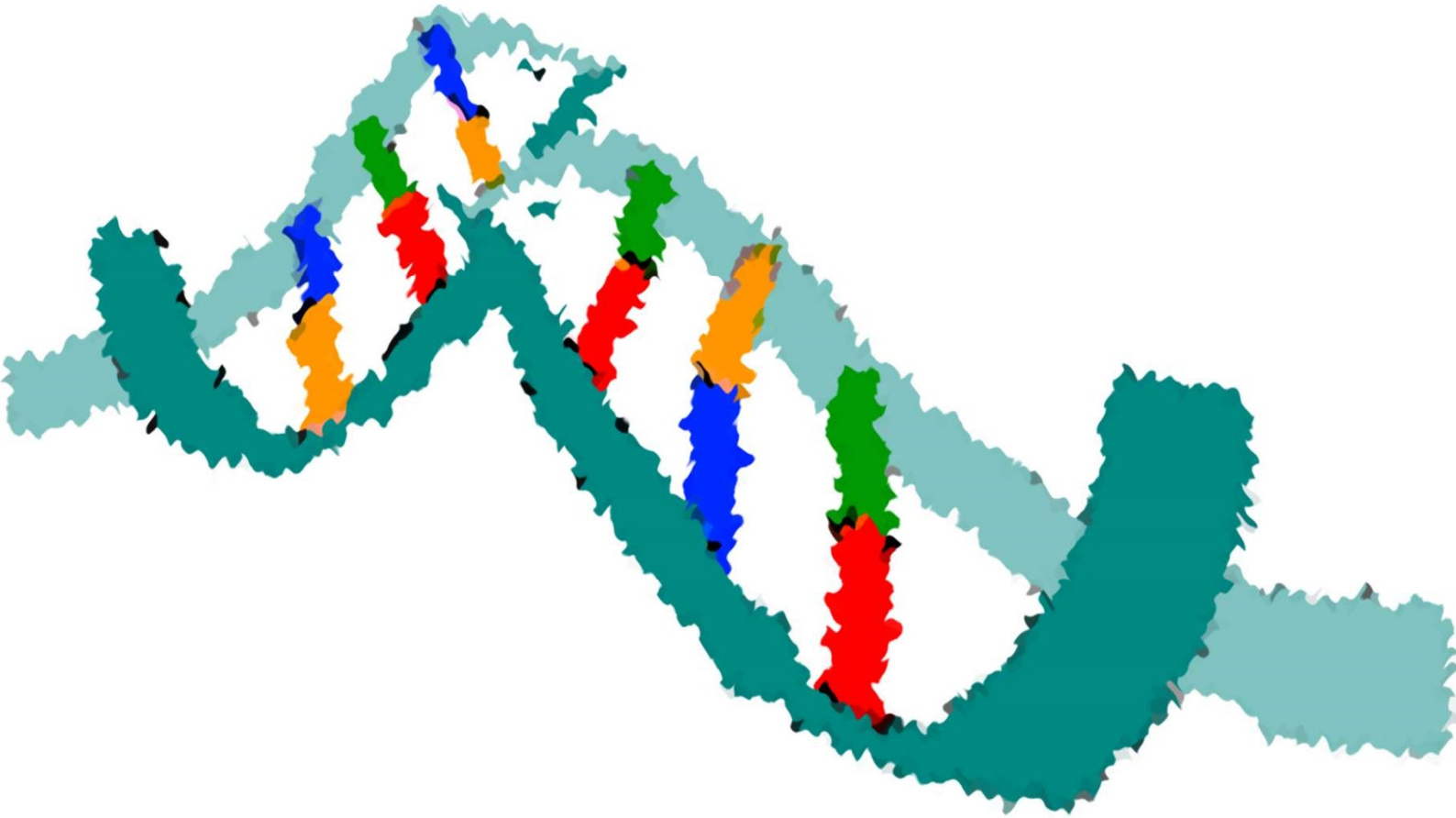
User Manual



Animal Presence RFID Data Logger

Application Smart Nest Box

(Only for internal usage)

Created by. Philipp Rimkus, M.Eng

on January 28,2016

In order of the

Max Planck Institute for Ornithology at Seewiesen (Germany)

Disclaimer

The Animal Presence RFID Data Logger is to be used only as that described in this document. Any other method of usage is not permitted. If damage occurs due to incorrect usage, the manufacturer of the Animal Presence RFID Data logger is not liable.

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List of abbreviations

SNB	Smart Nest Box
LBO	Light Barrier Outer
LBI	Light Barrier Inner
RFID	radio-frequency identification
EFM	Energy Friendly Microcontroller
PCB	printed circuit board
DCF	D for Deutschland (Germany), C for long-wave transmitter, F due to the vicinity to the Town Frankfurt
LCD	Liquid Crystal Display
ARM	Advanced RISC Machines
SD-CARD	Secure Digital Memory Card
PIT	Passive Integrated Transponder
LEUART	Low Energy Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus

1 System Overview

1.1 General Description of Functions

The Animal Presence RFID Data Logger has been developed to record the behaviour of animals. When animals are equipped with transponders, they can then be identified by a reading device. Every animal equipped with a transponder can be identified individually. Whenever the individual passes a short tube containing the RFID Reader, the transponder code, date and time are saved on a SD-card.

The Animal Presence RFID Data Logger is designed for flexible, mobile operation in field. Therefore, the Data Logger uses rechargeable lithium-ion batteries to supply the electrical energy.

The use of electronic devices in the field and nature requires special features in order to operate correctly. Special developments are needed in order to cope with changes in ambient temperature, humidity, pressure and when the electrical power grid is unavailable. However, such developments can be time-consuming and cost-intensive.

Video recordings and visual observations have long been used by biologists to document behaviour of animals at their nests, and answer questions about territory, distribution and reproductive behaviour. However, these methods are time consuming, often inexact, and cannot be used when visibility is low (e.g. at night).

In a population of animals tagged with RFID devices the Animal Presence RFID Data Logger (APRDL), can detect, record and identify different individuals. This technology can be used for any species as long as the RFID tag (which is similar in size to a grain of rice) can be attached to the animal. The APRDL can be placed in any area where individuals are expected to frequent, such as a food source, nest or roosting area.

One major application of the APRDL is the Smart Nest Box, which is a wooden structure used by birds to rear their young. The APRDL records the presence of RFID-tagged adults, providing data on questions on many aspects of reproductive behaviour, including nest site selection, incubation and feeding behaviours. If the young are also equipped with RFID tags, behaviour, fledging data and movement in an out of the nest can also be recorded.

A key strength of the APRDL is that it runs autonomously, and requires only periodic battery and memory card changes. This allows for data collection over long periods of time with little effort, making the APRDL ideal for use in remote areas. It also allows data to be collected simultaneously at many sites without requiring the presence of a technician. During the development, special attention was paid developing an energy saving operation, so that a battery pack would only have to be changed every two weeks during periods of very high activity levels of the Animal Presence RFID Data Logger. The SD cards used have enough memory space to save data for several months of data collection. These low operating expenses makes the Animal Presence RFID Data Logger ideal for use in isolated locations without grid connection.

Another strength of the APRDL is how the data is recorded: the output of the APRDL is only the events (e.g. the time, date, and the individual present). This output is simple to work with, and does not require time-consuming processing, unlike video recordings where each video must be watched in order to document events. Thus the APRDL allows for easy collection of large amounts of data, making it easier to increase sample size with lower effort and higher accuracy.

Biological data is optimally collected when disturbance to the animal's behaviour is minimised. As the APRDL is automated and requires only occasional battery and SD card changes, large volumes of data can be collected with little disturbance. It is also more accurate than many other methods of recording animal presence and identifying individuals, such as re-sighting colour bands or other markings, as these methods are prone to mistakes caused by poor visibility and human error.

Currently, the APRDL is being used on animals smaller then 70mm, however this technology could be adapted for use in any animal that can be marked with an RFID and returns to a specific area where the reader is located.

Some examples of potential uses of the APRDL

- nest boxes of birds
- bird feeders
- roosting boxes of bats
- dens of burrowing mammals or birds (i.e. rodents, badgers, rabbits, seabirds)
- fish such as pacific salmon that return to a stream to breed
- fish farms

- snake and reptile research
- bird movement and range

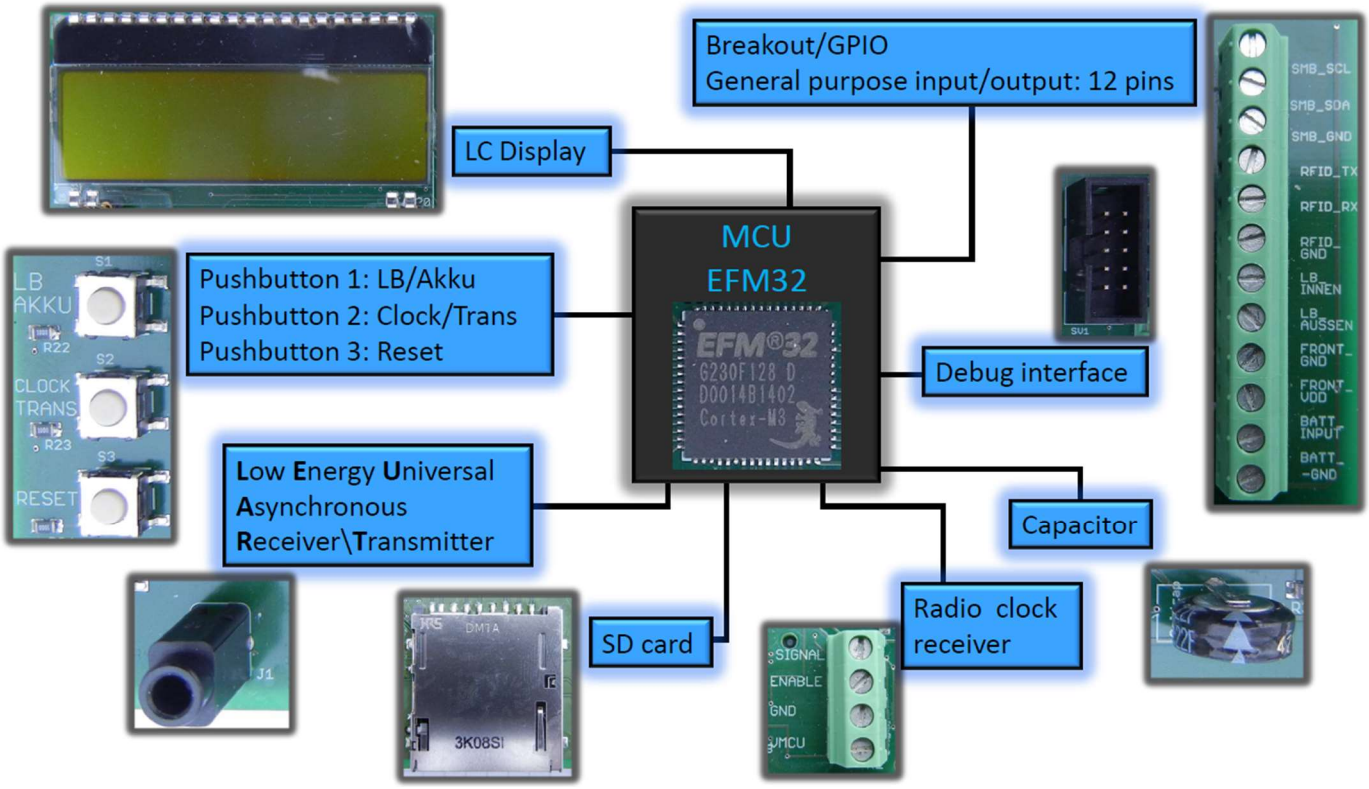
The APRDL can be used to collect data on many types of animal behaviour. Some of these include:

- Reproductive behaviours, such as incubation timing, feeding trips and the duration of parental care.
- Dispersal and range size (the movement of animals within an area).
- Survival and return rates of individuals to an area.
- Selection of nesting or roosting locations

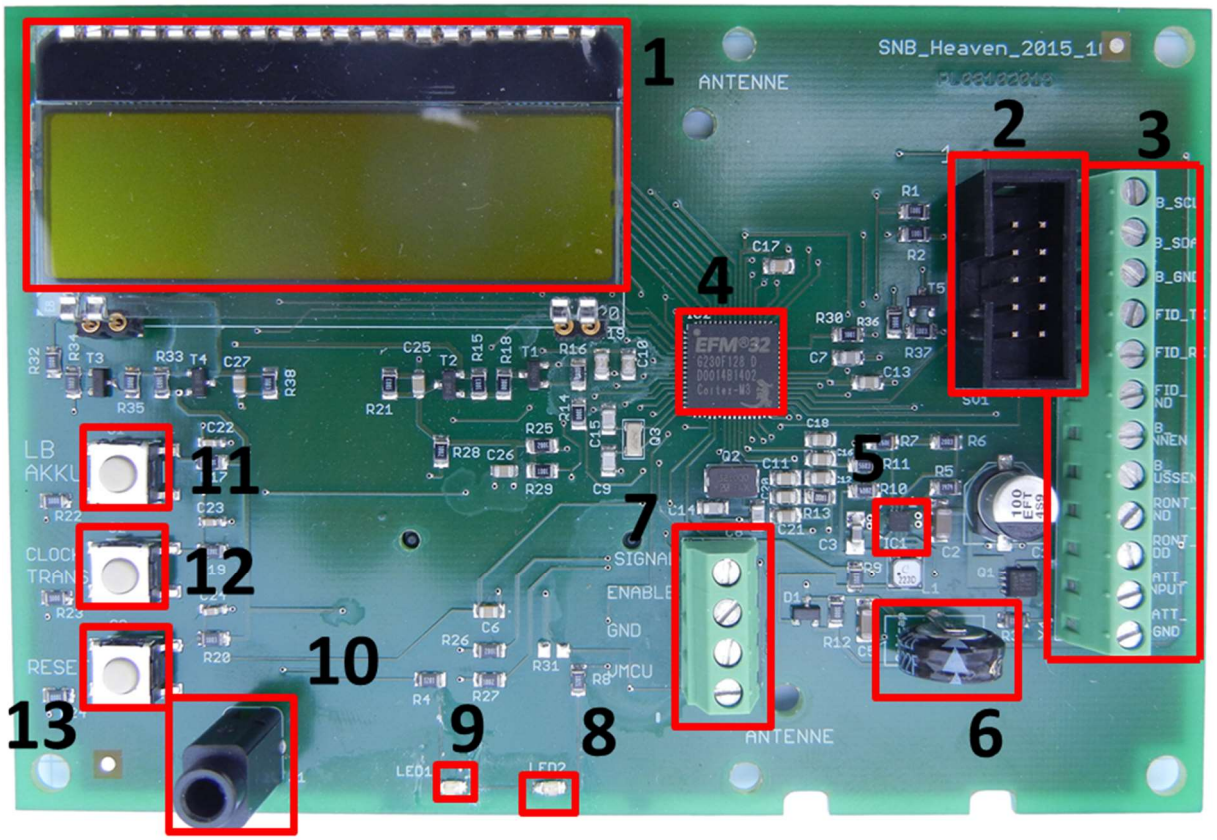
1.2 System configuration main circuit board

The Smart Nest Box application of the Animal Presence RFID Data Logger was developed over several years. After five years of development a relatively reliable and efficient version was completed, which is described comprehensively in this manual. Additional detailed information, particularly concerning the electronic configuration, can be found in the datasheet for the Animal Presence RFID Data Logger.

1.2.1 Block diagram



1.2.2 Hardware Illustration



1.	LC Display	8.	LED 2
2.	Debug interface	9.	LED 1
3.	Connecting terminal for periphery	10.	LEUART connector
4.	EFM32G230	11.	Pushbutton for battery indicator
5.	Down converter	12.	Pushbutton for radio clock display
6.	Capacitor	13.	Reset push button
7.	Connecting terminal for the radio clock		

1.2.3 EFM32 microcontroller

A microcontroller is a small computer (SoC) on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. Program memory in the form of Ferroelectric RAM, NOR flash or OTP ROM is also often included on the chip, as well as a typically small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to microprocessors used in personal computers or other general purpose applications consisting of various discrete chips

The EFM32 MCUs by Energy Micro are the world's most energy-friendly microcontrollers. With a unique combination of the powerful 32-bit ARM Cortex-M3, innovative low energy techniques, short wake-up time from energy saving modes, and a wide selection of peripherals, the EFM32G microcontroller is well suited for any battery operated application as well as other systems requiring high performance and low-energy consumption. EFM stands for Energy Friendly Microcontrollers. The ARM Cortex-M3 processor has several energy modes that can be quickly switched back and forth between them. It is possible to connect several peripheral devices. The ARM Cortex-M3 processor is developed by Energy Micro and has been bought by Silicon Labs.

Within the Animal Presence RFID Data Logger the EFM32G230 microcontroller is used with 128 KB Flash Memory, 16 KB RAM Memory and 32 MHz.

The EFM32 series is also known as "Gecko" by the developer, as these animals consume only 10% of the energy used by a mammal of similar size.

The EFM32 microcontroller based on the ARM Cortex processor is well suited for energy saving applications such as:

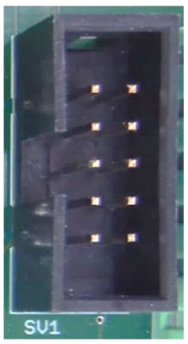
- Electricity-, gas- and water-meters
- factory automation and building automation systems
- alarm and security technology

Energy Micro states that benchmark measurements with other leading energy saving MCU's, found that the EFM32-MCU consumes only a quarter of the energy consumed by the other 8-, 16-, or 32-bit-MCU's.

The EFM32G230 contains a kind of UART-interface for communication with other systems, this is especially designed for energy saving. The interface is referred to as LEUART-interface. LEUART is a serial interface, a kind of bus system. Through the LEUART-interface, a jack connector and a USB cable can be used to establish a connection to a computer.

1.2.4 Debug Interface (DBG)

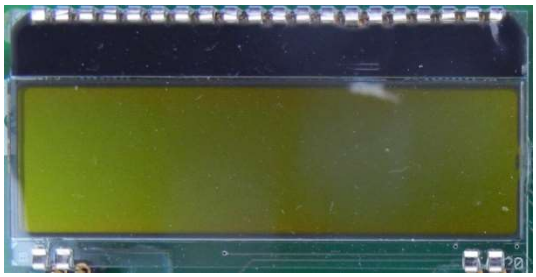
The debug interface software is stored on the microcontroller flash memory. Only after the flash memory contains this information, the hardware can be operated. The connection is either realised directly with a USB cable to the debug interface or with a debugging probe. If the connection is realized directly through the USB cable only HEX files and BIN files can be transferred.



1.2.5 Liquid Crystal Display (LCD)

This kind of display screen utilizes liquid crystals, which influence the polarization direction of light when a certain amount of electrical voltage is applied.

LCD's consist of segments which can independently change their transparency. This is done by a change in the orientation of each segment of the liquid crystals when an electrical voltage is applied. This then changes the permeability for polarized light, which is created by a backlight.



In the Smart Nest Box application of the Animal Presence RFID Data Logger, the LCD shows the results depending on which buttons are pressed, as described in chapter 1.2.7.

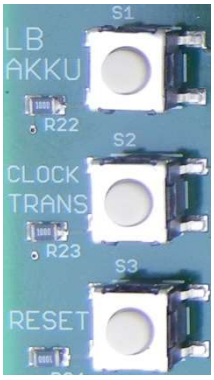
1.2.6 SD Memory Card Connector

The data from the RAM memory is stored in form of TXT files on the SD-card, this is located in the SD Memory Card Connector. The size of the memory influences the energy consumption; the smaller the memory size is, the smaller the energy consumption. Therefore, it is recommended for the Animal Presence RFID Data Logger to use the smallest possible SD memory size of 2 GB. Memory sizes are supported from 2 GB to 32 GB.

1.2.7 Buttons

Three pushbuttons are installed on the mainboard of the Animal Presence RFID Data Logger. A LB Akku button, a Clock Trans button and a reset button

- **LB Akku:** Displays the status of the light barriers and the status of the accumulator on the LCD.
- **Clock Trans:** Displays the date, time and the number of the most recent transponder to enter the Smart Nest Box.
- **Reset:** Restarts the Animal Presence RFID Data Logger.



1.2.8 Capacitor

A capacitor (German “Kondensator”) is a passive electric component with the ability to store electrical charge and electrical energy in an electrical field.

When the electrical power supply through the accumulator for the Animal Presence RFID Data Logger is missing, the capacitor ensures an alternate power supply. The capacitor is charged when the accumulator supplies energy to the system. This allows energy to be obtained for a certain time from the capacitor if it is required.

A Gold Cap is a double-layered capacitor, developed by Panasonic in 1972, then in 1978 it was brought released to the market. It is often known as “super cap” by a number of manufacturers. The name “Gold Cap” is the official trade name of the capacitor, trademarked by Panasonic. Cap is the shortcut for Capacitor. The gold refers to the gold plating of these capacitors. Gold is not contained in this capacitor.

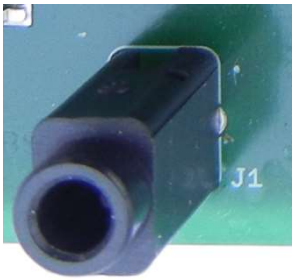
The double-layered capacitor or Gold Cap is a mixture of a battery and a conventional capacitor. It combines speed and a large energy storage to form a super capacitor. With respect to its properties, it is ordered between electrolytic capacitors and rechargeable batteries.

Some applications only become possible through double layered capacitors. Despite its large capacity, it is very small in size. The dielectric strength is not exceptionally high however, with only a few volts. Through its large capacity, the Gold Cap is present to maintain the power supply when the main energy source fails. In devices in which data storage should remain in switched off status, the Gold Cap is particularly well suited.

Life expectancy is limited from roughly 8 to 10 years. When the operating temperature is above optimal or the discharge current is high, the life expectancy and the capacity begin to decline over time. The Gold Cap most appropriate when it is rarely discharged and used with low currents.

1.2.9 Jack connector as interface to a PC

For the development of the Animal Presence RFID Data Logger an Interface for connection to a computer is intended. Through the data communication interface LEUART, which is provided by the EFM32G230 out of chapter 1.2.3.



The jack connector is used to interlink the signal from the LEUART interface with a computer. Specifically, a jack connector of 3.5 mm is used, as those used in many audio applications.

1.2.10 Down converter

The TPS62125 from Texas Instruments, is a high efficiency synchronous step down converter optimized for low and ultra-low power applications providing up to 300 mA output current. It has a wide range of input voltages, from 3V to 17V, sup-

ports four cell alkaline, and 1 to 4 cell Li-Ion batteries in series configuration as well as 9V to 15V powered applications. The device includes a precise low power enabled comparator which can be used as an input supply voltage supervisor (SVS), this addresses system specific power up and down requirements.

1.2.11 LED's

The Animal Presence RFID Data Logger is equipped with two LED's, one red and one orange. The orange LED (LED 2) indicates, that something is written on the SD card. If the red LED (LED 1) flashes, this indicates that the radio clock is transmitting a signal to the MCU. If the LED 1 blinks longer than 5 minutes or flashes continuously, this indicates a malfunction.

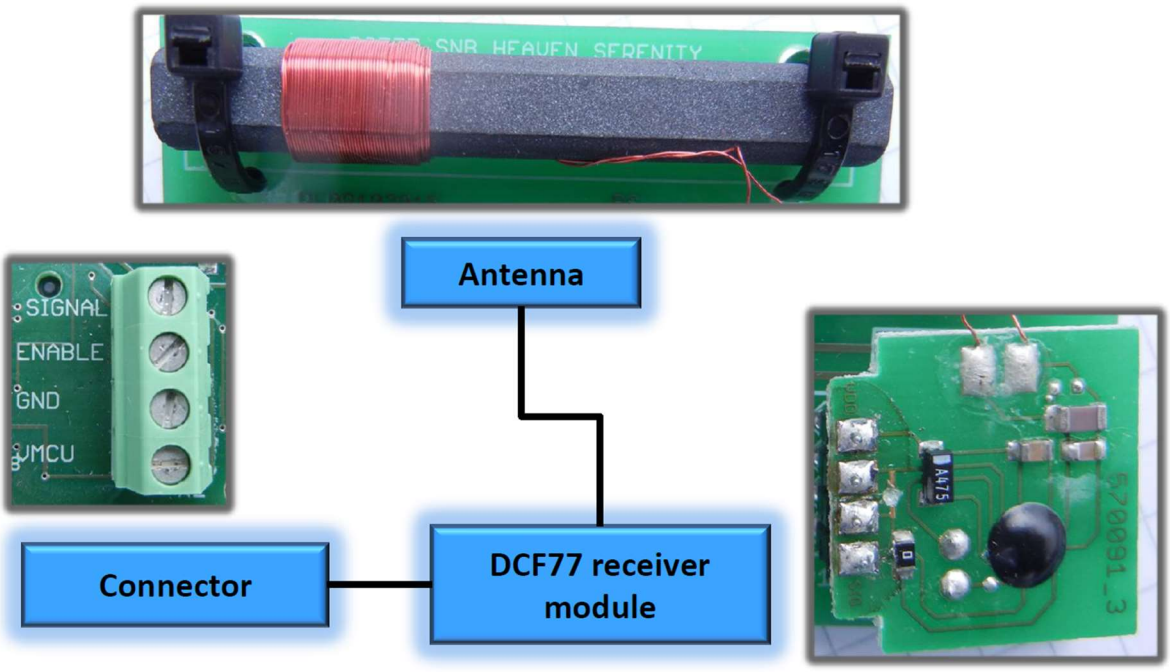
1.2.12 Connector for the peripherals

At the connector for the peripheral devices, devices such as a batteries, light barriers and RFID's are connected here. The connected cables are collected and lead out of the housing in a cable conduit. A sealing against water and moisture is present here and very important.

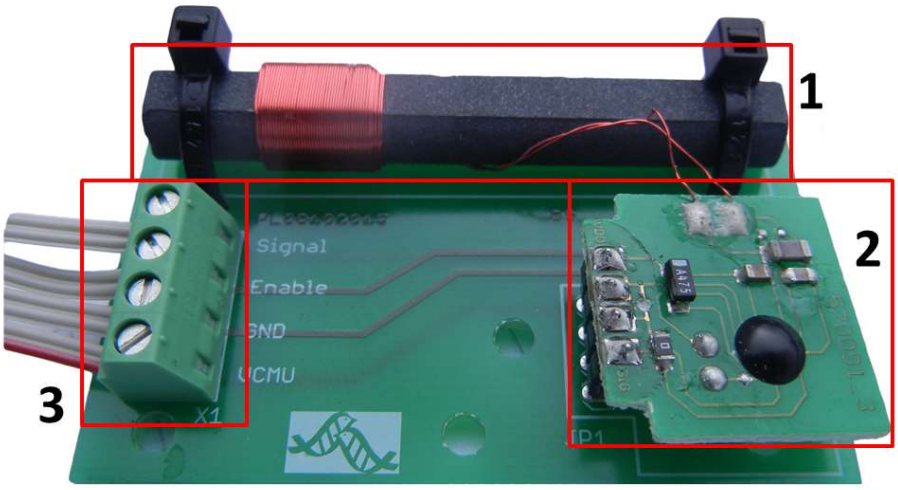
1.3 System configuration secondary board with radio clock

On the mainboard a secondary board is installed, this secondary board is attached by spacers. The antenna is located on the secondary board at the DCF77 receiver module . The distance between the DCF77 receiver module and the mainboard is necessary to improve the reception quality of the antenna.

1.3.1 Block diagram



1.3.2 Hardware Illustration



1.	Antenna for the radio clock
2.	DCF77 receiver module
3.	Connector for the connection with the main-board

1.3.3 Radio clock DCF (77.5KHz)

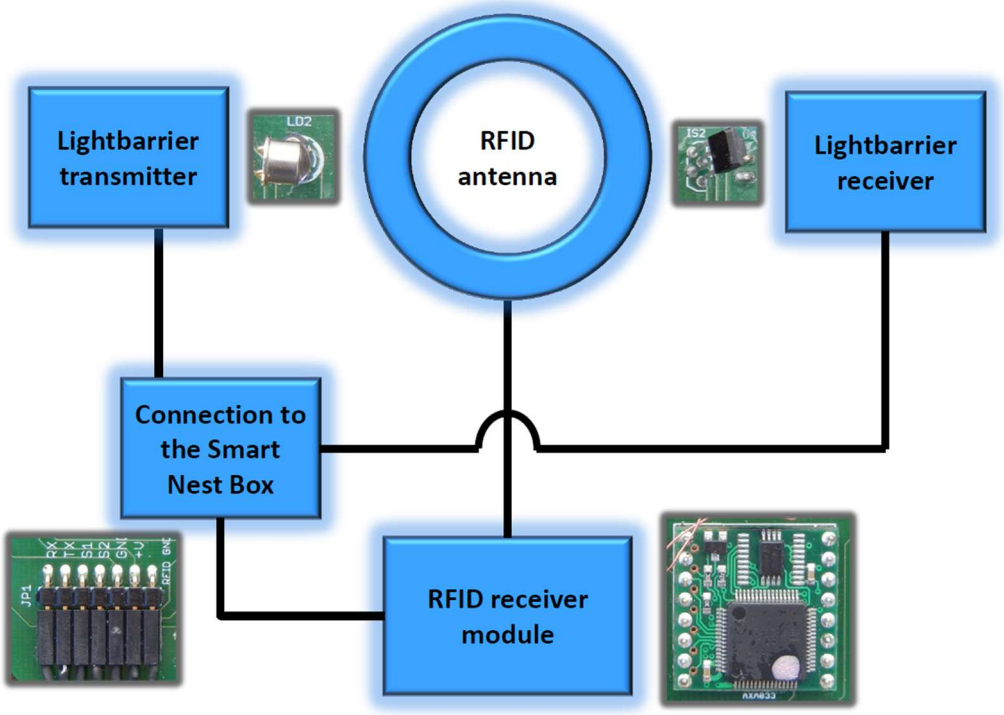
The current version of the Animal Presence RFID Data Logger features a radio clock, which works in a similar way as normal radio alarm clocks. In periodic intervals a signal to Europe from the long wave antenna in Mainflingen with a frequency of 77.5 kHz is received and synchronized. Long wave signals have been compared to short waves and medium waves, and have a relatively high range. So it is possible to receive the signal from Mainflingen with a range up to 2000 km. In other continents the time signals can be also received, however with different frequencies. The radio clock is powered via an accumulator, which is also used for the other electrical consumers and is described in chapter 1.5.

countries	designation	frequency
Germany	DCF	77.5 kHz
France	TDF	162 kHz
China	BPC	68.5 kHz
Japan	JJY	40 und 60 kHz
USA	WWVB	60 kHz
Russia	Beta	25 kHz
England	MSF	60 kHz

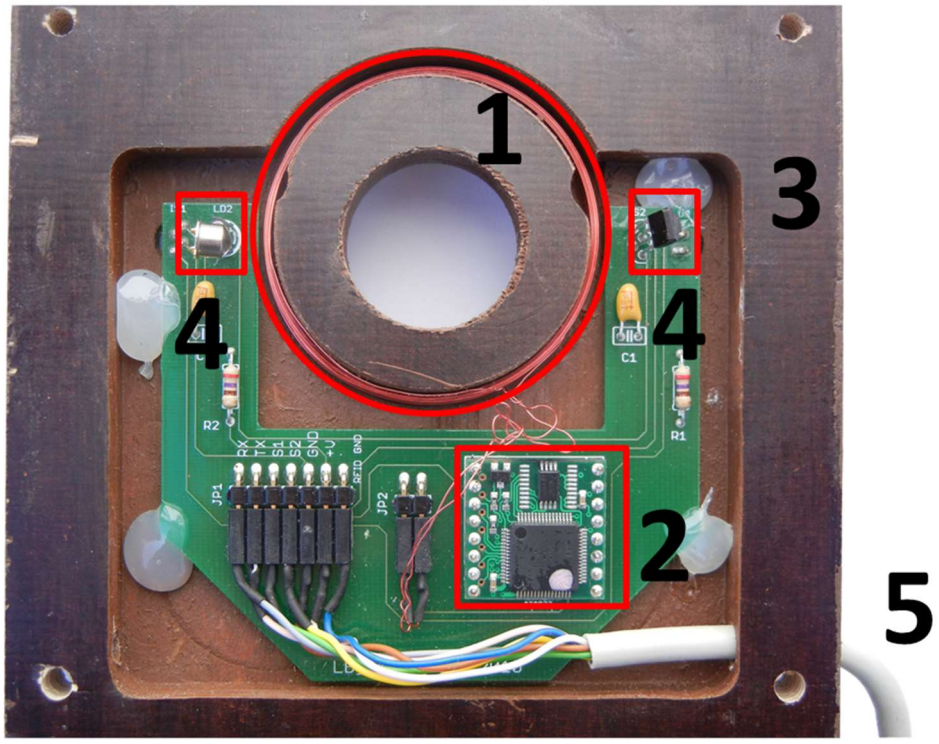
1.4 Peripheral equipment Smart Nest Box

Some peripheral devices are necessary for the operation of the Animal Presence RFID Data Logger with the Smart Nest Box application. These are the accumulator, two light barriers and an RFID reader.

1.4.1 Block diagram Smart Nest Box front panel



1.4.2 Hardware illustration



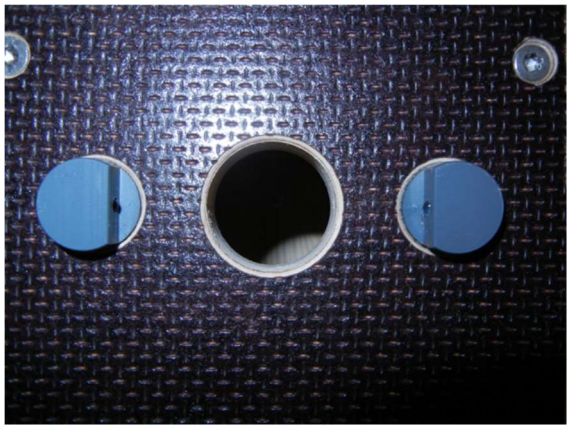
The front panel may become damaged by squirrels, so much that the front panel had to be displaced. In recent versions the board and the antenna are sealed with plastic resins to avoid damages through oxidation.

1.	Antenna with 70 mm diameter
2.	RFID receiver module
3.	Front panel of the Smart Nest Box consisting of wood
4.	Light barrier
5.	Cable connection to the mainboard

1.4.3 Light barrier

A light barrier is an optoelectronics systems, these indicate an interruption in the beam of light and communicates this event through an electrical signal. Light barriers are composed of a beam source (transmitter) and a photodiode (emitter) to receive the beam.

In the Smart Nest Box application, the light barriers detect the movements of the birds, including the direction of motion. On each side of the front panel there is one light transmitter and a light emitter, these detect the flight direction.



The light barriers can scan with a frequency of up to 100 Hz. The current consumption at 10 Hz is less than 30 µA (calculated). The covering of the light barriers is submitted through an open collector output.

After the light barrier detects an object in the entrance of the Smart Nest Box, the RFID reader is activated. This needs to occur in a relatively short time, as often birds will fly very quickly through the entrance into the Smart Nest Box. If signal transmission is slower, the RFID can't receive the transponder signal from the bird because the bird may already be out of range.

The light barriers work with adaptive selectivity, which means that pollution of the transmitter and emitter, aging or fluctuations due to temperature can be largely compensated for. This reduces the possibility of false detections for example through sunlight.

1.4.4 RFID

Radio-frequency identification (RFID) uses electromagnetic fields to automatically identify and track transponders attached to objects. The transponders contain electronically stored information. Passive transponders collect energy from a nearby RFID reader's interrogating radio waves. Active transponders have a local power source such as a battery and may operate at hundreds of meters from the

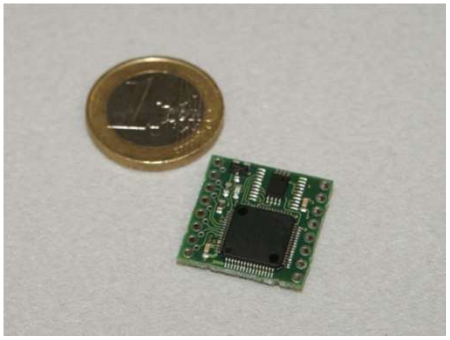
RFID reader. Unlike a barcode, the transponder does not need to be within the line of sight of the reader, so it may be embedded within the tracked object.

RFID's are also used in other areas such as electronic locks, ski passes, cashless payment transactions, electronic immobilizers and in libraries as theft protection.

In the Smart Nest Box application of the Animal Presence RFID Data Logger the transponder frequency is not exactly the same as the RFID reader frequency. The RFID Reader works with a frequency of 125 kHz and the transponder with 134.2 kHz. However, both systems are compatible and function together.

1.4.4.1 RFID receiver module

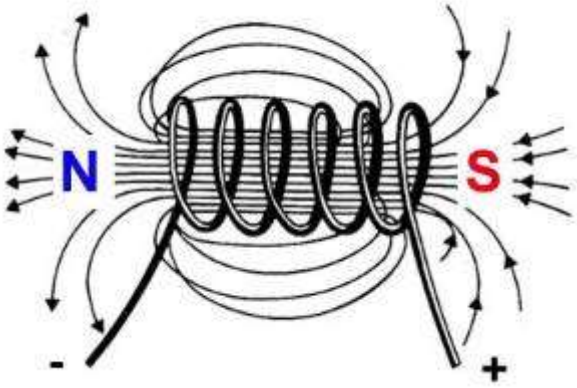
A RFID receiver module with a frequency of 125 kHz is used in the application Smart Nest Box. The used receiver module from Elatec is designed with a small size, small price and versatile applications.

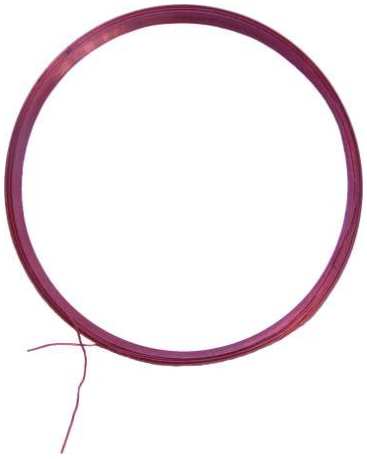


1.4.4.2 RFID antenna 490µH

The used antenna has a diameter of 70 mm and is directly soldered on the RFID reader. If a voltage source is connected to the antenna, which is an air core coil and current begins to flow, an electric field is generated. The electric field is the energy source for the transponder.

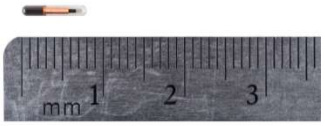
If a transponder with its own antenna transmits a signal at a certain frequency, the RFID reader's antenna collects the signal and the RFID reader transmits it further to the MCU.





1.4.4.3 RFID transponder

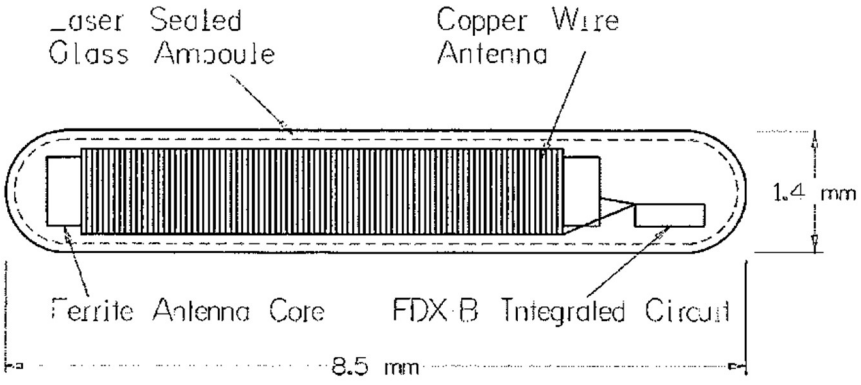
This is the highest performing RFID transponder on the market today for fish and wildlife research in an 8 mm 'skinny tag'. These transponders are encapsulated in biocompatible glass and provide 100% unique identification. Because of the small size of 8 mm x 1.4 mm and a very low weight of only 30 mg the tagged animals are minimally affected. So it is possible to tag even very small animals such as red ants.



The transponder contains a non-volatile flash memory. A combination of letters and numbers is stored on the flash memory during the production of the transponder.

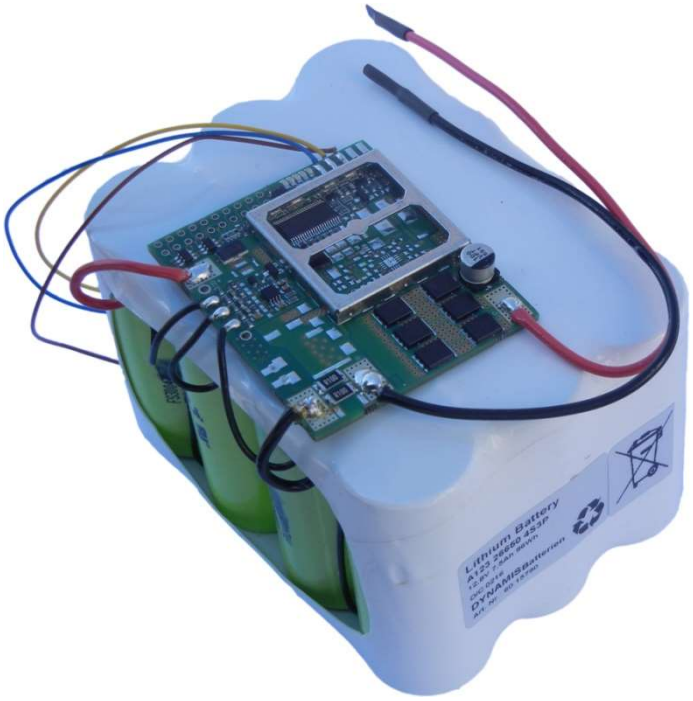
The transponders are known as FDX-B MINIHPT8 and are made by the company Biomark. The FDX-B indicates that the full duplex technique is used.

In duplex mode operating systems the electric field is always present. The transponder sends its signal continuously as soon as it gets energy through the field and enters the reception area of the RFID reader. Therefore, the system works very rapidly.



1.5 Accumulator

The lithium-ion battery from the company Dynamis Batterien supplies the Animal Presence RFID Data Logger with electrical energy. The amount of energy chosen was to ensure that there is enough energy to supply the Animal Presence RFID Data Logger in a very active period for two weeks. Through the little specific energy of 108 Wh/kg the change of the accumulators is much less energy-sapping than with lead-acid batteries with a specific energy of 30 – 40 Wh/kg.

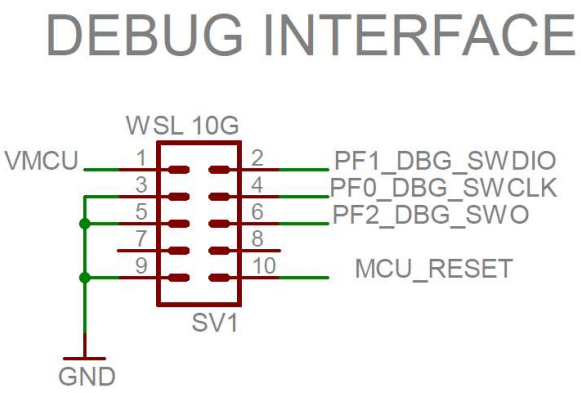


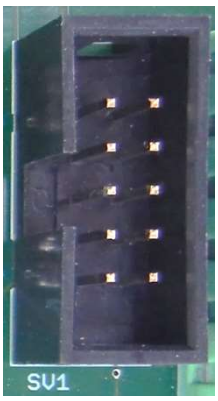
The three LED's on the accumulator's board indicates the state of charge. One lit LED indicates that the accumulator is fully charged. Two LED's indicate the accumulator is halfway charged. Three LED's indicate an almost empty state of charge.

1.6 Pin assignment and connectors

1.6.1 Pins for debugging

connection	designation
SV1-1	VMCU
SV1-2	SWDIO
SV1-3:	GND
SV1-4	SWCLK
SV1-5	GND
SV1-6:	SWO
SV1-7	free
SV1-8	free
SV1-9	GND
SV1-10	MCU_RESET



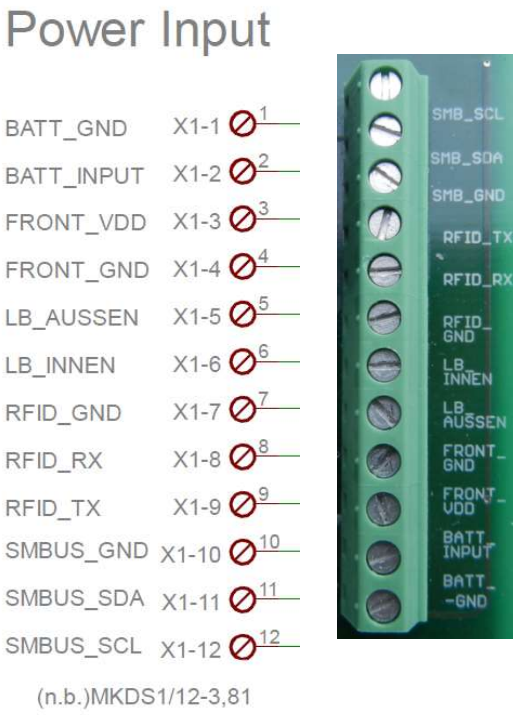


1.6.2 Pin assignment

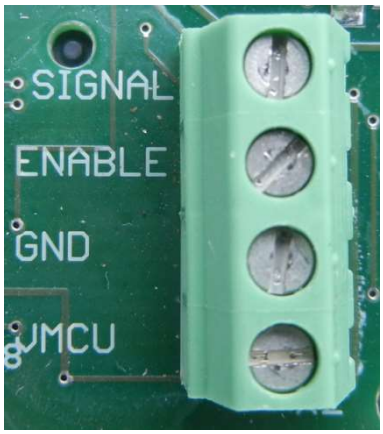
1.6.2.1 Energy supply connector

connection	designation	Cable color
X1-1	BATT_GND	brown
X1-2	BATT_INPUT	red
X1-3	FRONT_VDD	white
X1-4	FRONT_GND	brown
X1-5	LB_AUSSEN	green
X1-6	LB_INNEN	yellow
X1-7	RFID_GND	blue
X1-8	RFID_RX	grey

X1-9	RFID_TX	pink
X1-10	SMBUS_GND	grey
X1-11	SMBUS_SDA	blue
X1-12	SMBUS_SCL	yellow



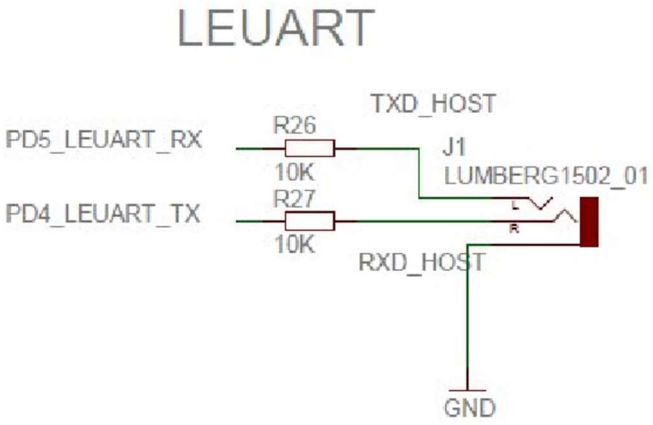
1.6.2.2 Connector for the radio clock



connection	designation
X2-1	PD2_DCF77_Signal
X2-2	PD1_DCF77_Enable
X2-3	GND
X2-4	VMCU

1.6.2.3 Jack connectors for LEUART

connection	designation
J1	LEUART_RX
J1	LEUART_TX



1.7 Housing

1.7.1 Housing for the main board

The housing from the main board consists entirely of opaque polycarbonate. The lid is lockable with bayonet locks which are quick and easy to use. The screws are secured from falling out and prevents loss of any screws.

1.7.2 Housing for the accumulator

The housing from the accumulator consists entirely of polycarbonate, with the lid being made from transparent polycarbonate so the LED's inside may be seen without needing to open the lid. The lid is also lockable with bayonet locks. The same screws are used here and are also secured against falling out.

2 General working conditions

Component designation	Animal Presence RFID Data Logger
Manufacturer	MPIO http://www.orn.mpg.de/
Dimensions main board (L X B x H)	121 mm x 81 mm x 1.5 mm
Overall temperature range	-10°C to 60°C (DCF77 and RFID) DCF is not absolutely essential -20°C to 60°C
Storage temperature range	-20°C to 60°C
Overall moisture	Relative moisture 35% to 85% (at 5°C to 35°C)

Detailed information, in particular information concerning the electrical properties can be found in the Animal Presence RFID Data Logger datasheet.

The working conditions from single devices can be found in the datasheets in chapter 7.

3 Energy supply

The Animal Presence RFID Data Logger is especially designed to have low energy requirements. The electrical power requirements are explained more precisely in this chapter.

The EFM32G230 has five different economical energy modes, where only two of which are used for the Animal Presence RFID Data Logger with the Smart Nest Box application. These are the Deep Sleep Mode and the Sleep Mode whereby the Sleep Mode is the Active Mode and the Deep Sleep Mode is the Inactive Mode. In these energy modes different consumers are active. The Smart Nest Box switches between the Active Mode and the Inactive Mode through light barrier activity. If the RFID reader and the light barrier detect no activity for 6 minutes the Smart Nest Box switches into the Inactive Mode again to save energy.

The energy-intensive consumers like the RFID reader are only supplied with electrical Energy when required. The RFID reader is the largest consumer of electrical energy in the Smart Nest Box application.

The electrical energy required is supplied by a lithium-ion-battery. If the energy demand and the energy storage capacity are known, the remaining range of the accumulator can be estimated.

In the following sections, the current supply and the voltage supply will be examined separately.

3.1 Current supply

3.1.1 ARM Cortex Processor

From the five available modes of operation only the Deep Sleep Mode and the Sleep Mode are used.

Deep Sleep Mode or Inactive Mode

0.9 µA @ 3 V Deep Sleep Mode, including Real Time Clock with 32.768 kHz oscillator, Power-on Reset, Brown-out Detector, RAM and CPU retention

Sleep Mode or Active Mode

45 µA/MHz @ 3 V Sleep Mode

3.1.2 RFID reader

RFID on measured: 35.4mA

RFID off measured: 1.36mA

(From schematics)

3.1.3 Light barrier

The light barriers are always supplied with electricity independently from the two energy modes. To save energy, the status of the light barrier is not assessed continuously but 10 times per second thus with a frequency of 10 Hz. Therefore, one light barrier has a very small electrical energy demand of roughly 30 µA.

3.1.4 LC display

The LC display has no background light whereby results a low electrical energy demand of 0.500 mA when the LC display is switched on

If no button is pressed for 20 seconds, the LC display fades out.

Measured On 0.342mA Measured Off: 0.016mA (From schematics)

3.1.5 Radio Clock

The clock of the microcontroller is updated at a certain time in the night through the time signal DCF77 from Mainflingen. The time will be also updated when the Animal Presence RFID Data Logger is reset.

Nominal current 100µA Quiescent current 5 µA

3.1.6 LED

Each LED has an electric current demand of 2 mA.

3.1.7 Accumulator LED's and self-discharge

LED's	electric current demand
Without LED	271 µA
Only LED1	308 µA
LED1 + LED2	343 µA
LED1 + LED2 + LED3	384 µA

The self-discharge by lithium-ion-batteries at 20°C is less than 2% per month.

3.1.8 Overview of the nominal currents

This table contains the maximum current demands of the most important devices. If all are active at the same time the maximum current demand behind the down converter at 3,3 V is 51 mA and with that the power input of the Animal Presence RFID Data Logger with the Smart Nest Box application is around 0,1683 W.

devices	currents
RFID	35.4 mA
LC display	0.500 mA
2* LED	2 x 2 mA
ARM Cortex M3	45 µA/MHz (1.44 mA)
Radio clock	0.1 mA
Light barrier	2 x 30 µA
Total current behind the down converter with 3.3V	42.2 mA (When all consumers are active at the same time without down converter losses)
Total input in front of the down converter with 12.8 V	155 mW (When all consumers are active at the same time with down converter losses)

3.1.9 Overview of the currents in the different operating modes

	Shutoff Mode	Stop Mode	Deep Sleep	Sleep Mode	Run Mode
RFID	Not used	Not used	off	Can be on	Not used
ARM Cortex M3	Not used	Not used	On	On	Not used
LCD	Not used	Not used	Can be on	Can be on	Not used
Radio clock	Not used	Not used	Can be on	Can be on	Not used
LED's	Not used	Not used	Can be on	Can be on	Not used
Light barrier	Not used	Not used	On	On	Not used
Down converter	Not used	Not used	On	On	Not used
Accumulator board	Not used	Not used	On	On	Not used

	Deep Sleep Mode (Inactive Mode)	Sleep Mode (Active Mode)
RFID	0	An (35.4mA)
ARM Cortex M3	0.9 µA	45 µA/MHz (1.44 mA)
LCD	1.2 mA (if on)	1.2 mA (if on)
Radio clock	0.1 mA (once a day, take 5 min.; also at restart)	0.1 mA (once a day, take 5 min.; also at restart)
LED	2 mA (2 units; if on)	2 mA (2 units; if on)
Light barrier	30 µA (2 units)	30 µA (2 units)
Down converter	13 µA	13 µA
Total current behind the down converter (without down converter losses and 3.3 V)	0.0609 mA (2 x light barriers and und MCU	36.88 mA (RFID active, MCU active, 2 x light barriers, down converter)
Total input behind of the down converter (without down converter losses and 3.3 V)	0.0609 mA x 3.3 V = 0.000201 W = 201 x 10^-6 W	36.88 mA x 3.3 V = 0.122 W
Total input in front of the down converter (with down converter losses and 12.8 V)	(with η = 50%) 0.000201W/0,5 = **0.000402 W** = 402 x 10^6 W	(with η = 90%) 0.122 /0.9 = **0.136 W**
Total current in front of the down converter (with down converter losses 12.8 V) **(theoretical)**	(with η = 50%) **0.0314 mA**	(with η = 90%) **10.6 mA**
Measured **total current** in front of the down converter (with down converter losses 12.8 V) **(real)**	**0.070 mA = real measured Inactive Mode** (connected radio clock but inactive, controller in Deep Sleep Mode, Gold Cap, connected LED but off, buttons, down converter)	**12.3 mA = real measured Active Mode** (connected radio clock but inactive, controller, LED connected but off, capacitor, without LCD, SD card, down converter, light barrier, RFID on)
Accumulator board with LED's current demand	(0.271 mA – 0.384 mA)	(0.271 mA – 0.384 mA)
Total current with accumulator board	0.3024 mA – 0.4154 mA	10.87 mA – 10.98 mA
Total Input ink. accumulator board with 12.8 V **(theoretical)**	**0.00387 W – 0.00532 W**	**0.139 W – 0.141 W**
Total Input with measured value + theoretically accumulator board demand with 12.8 V **(real)**	**0.004 W – 0.0058 W**	**0.161 W – 0.162 W**

3.2 Voltage supply

All consumers are supplied with 3.3 Volts which is produced by the down converter from the 12.8 Volts from the lithium-ion-accumulator. The minimum input voltage for the down converter is 5 Volts.

3.3 Electrical energy storage

The main power supply is ensured by the lithium-ion-accumulator. If the accumulator is removed a capacitor can supply the Animal Presence RFID Data Logger for around 30 seconds.

3.3.1 Accumulator

If the whole capacity of a lithium-ion-accumulator is completely used it can have negative effects on the lifetime of the accumulator. Therefore, a certain percentage is not used. The accumulator of the Animal Presence RFID Data Logger uses 83% of the total capacity.

voltage	12.8 V
Nominal capacity	7.5 Ah
Total capacity	8.97 Ah
stored energy	96 Wh

The lithium-ion-accumulator has its own board which is able to communicate with the Animal Presence RFID Data Reader via a data bus.

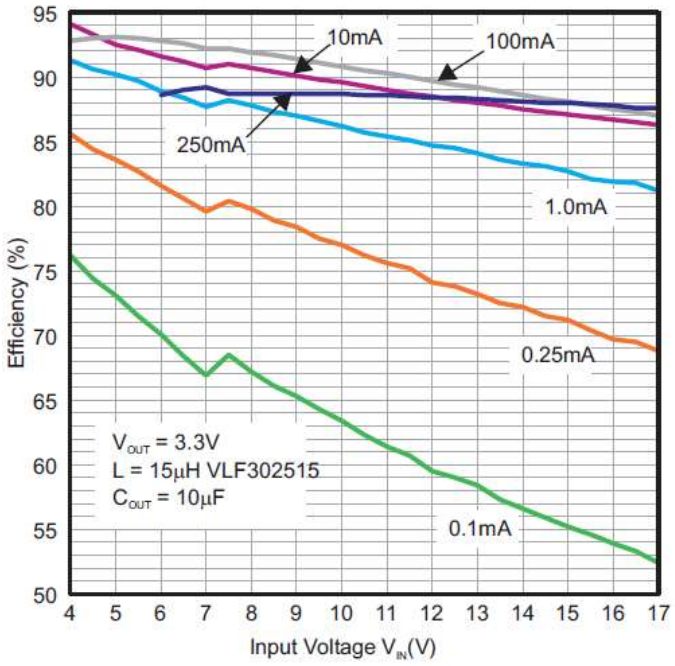
3.3.2 Capacitor

If the energy supply from the accumulator is no longer available, a capacitor with 0.22 farad supplies the Animal Presence RFID Data Logger for around 30 seconds. During the discharge, the voltage declines from 3.6 Volts to 1.8 Volts. 1.8 Volts is the minimum working Voltage for the MCU.

3.3.3 Conversion loss

The accumulator provides electrical energy with a voltage of 12.8 Volts. The EFM32G230 and other consumers require a significantly smaller voltage of around 3.3 Volts. This reduction of voltage is achieved by a down converter which

is described in chapter 1.2.10. The down converter doesn't work with transformers but with resistors.



3.3.4 Range estimation of the accumulator

Range at maximum power (If the Animal Presence RFID Data Logger is always active and there is no maintenance; connected radio clock but inactive, controller, LED connected but off, capacitor, without LCD, SD card, down converter, light barrier, RFID on)	96 Wh / 0.162 W = 592 hours = **24.66 days**
Range at minimum power (If the Animal Presence RFID Data Logger is always inactive and there is no maintenance; radio clock, only MCU and light barrier are on)	96 Wh / 0.0058 W = 16552 hours = **690 days** = 1.889 years

The value for the range at minimum power can only theoretically be achieved. In reality the self-discharge causes the accumulator to be discharged earlier.

4 Operation of the Smart Nest Box

The operation of the Animal Presence RFID Data Logger with the Smart Nest Box application will be explained in this chapter. This includes the information detailing accumulator replacement, SD card change, software updates, the loading of the accumulator and troubleshooting.

4.1 Accumulator replacement

The accumulator has to be replaced in periodic intervals. The range of an accumulator depends on several factors, including ambient temperature, activity of the Smart Nest Box and energy demand of the Smart Nest Box. The activity of the Smart Nest Box is adapted to vary, depending on the season of the year; as the birds have a higher level of activity during the breeding season. Therefore, the SNB is often in the Active mode and needs more energy. During the wintertime the activity level of the birds is lower and thus the energy demand for the SNB is also lower.

4.1.1 Reason for accumulator replacement

The accumulators have boards with three LED's which indicate the state of charge. If three LED's are blinking this shows that the accumulator is almost empty. When two LED's are blinking the accumulator is half full and one LED blinking indicates an almost full accumulator. If there are no LED's blinking the accumulator is no longer able to supply energy.

When all LED's are lit permanently this indicates a defect at the accumulator or at the accumulator board. In this case the whole accumulator needs to be changed.

4.1.2 Placement of the accumulator

The wind, rain, snow and mist in Europe primarily come from the west. This can be seen visibly on trees where the western-facing sides are often moss-covered. Therefore, placement of the accumulator on the eastern side can minimize the possibility of damage due to oxidation.

Moreover, the accumulator can be placed in a way that water can drain away at an edge, the connector is not on top and the water can flow off from the connector.

If the accumulator becomes over heated it is possible that the accumulator may be damaged. The operating temperature range of the accumulator is between minus 30°C and 55°C according to manufacturer specifications. When the sun shines directly on the accumulator it is possible to exceed this range. Therefore, the accumulator should be protected against direct sunlight through placement on the north-facing side the tree or by shading it in another way.

When placing the accumulator, one should be aware of these external environmental influences and place the accumulator appropriately, because of the high costs of the accumulators.

4.2 SD card change

The SD cards have a large memory size so that the memory may be filled only after several months or even years.

As continuous recording of data is desired and as unexpected malfunctions are always a possibility the time between SD card changes should be as small as possible, so that malfunctions may be detected early through the gathered data. Ideally SD cards should be changed every two or three weeks. Through the gathered data, recording gaps or absurd data can be detected and analysed, then the faulty hardware may be repaired.

4.3 Software update

There are three possible methods to write software code on to the flash memory. The debug probe method from IAR systems and the debug interface method without debug probe are always possible. If software has already been written on the flash memory by either of these methods, an additional method using SD cards is also available.

The microcontroller EFM32G230 contains a flash memory with a memory size of 128 KB. This memory contains the software by which the microprocessor works. 128 KB of memory is a sufficient size for operation, even with very complicated applications such as the Animal Presence RFID Data Logger.

The update options are described in chapter 5.8.

4.4 Placement of the accumulator

The Smart Nest Boxes are fastened to trees in a height of around 1,8 meters.

4.4.1 Mounting options

The Smart Nest Box is fastened with ropes or tapes which don't damage the tree. The SNB should be fixed in a way to the tree so that movement due to wind is not possible.

4.5 Loading the accumulator

The accumulators should be changed and charged in regular intervals. The accumulator has to be visually checked for damage when it is changed.

4.5.1 Recharger

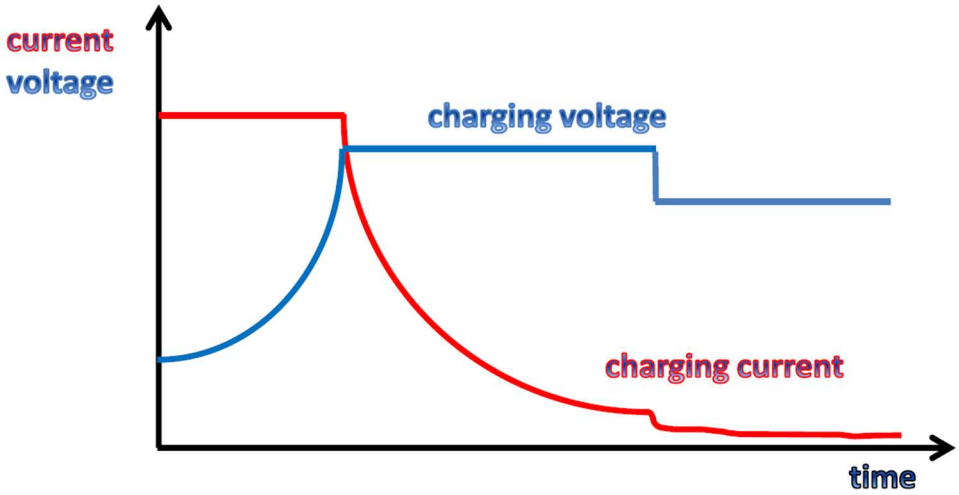
Device description	Mascot type 2541 Li, 4 cell, 2A, Lithium Ion Battery Charger, 35W
Manufacturer	Mascot http://www.mascot.no/home/
Nominal power	35 W
Battery voltage	12V
Charging current	Up to 2 A
Recommended battery capacity	1 – 10 Ah
Loadable cells	4
Charging characteristic	IUoU

The charge process is separated in to three sections.

1. Charging current is 2 A until the voltage reaches 14.7 V
2. Voltage will be held at 14.7 V; Current declines slowly
3. A yellow display shows that the charging current is declined under 1 A
4. If the charging current is below 250 mA the recharger switches off.
5. In the maintenance charging module the accumulator voltage will be kept at 13.7 V.

4.5.2 Charging method IUoU

UIoU means that the initial charging current is constant similar to the CCCV charging method until the final charging voltage is reached. Then the voltage is held at the charging end voltage. This constant high voltage can be harmful for the accumulator and reduce the capacity. Therefore, the voltage will be reduced after a certain amount of time; with that the maintenance charging is initiated. With the reduced voltage the accumulator can be charged permanently and the amount of current is roughly like the self-discharge. The “I” in IUoU stands for constant current, “Uo” stands for constant voltage with charging end voltage and “U” for reduced constant Voltage.



4.5.3 Charge time

The accumulators can be charged in roughly one day to ensure that the accumulators are securely fully-loaded.

7.5 Ah / 2A = 3.75 h

The charge time is approximately 3.75 hours when the accumulator is totally discharged.

4.6 Troubleshooting at the SNB

The current version of the Smart Nest Box has taken five years of development. Some malfunctions could be encountered and thus lead to experience in troubleshooting and development of specific procedures for malfunctions which may be detected.

4.6.1 Troubleshooting in the field

The field troubleshooting takes place after a malfunction is detected through information from the data collected in the SD cards. Incorrect data indicates a malfunction at the SNB.

In older versions of the SNB which have no buttons and no LC display the status of time, date, accumulator status and RFID status were read out through a mobile card reader handheld device. In current versions of the Smart Nest Box the troubleshooting occurs through the three buttons described in chapter 5.7 as well as the LC display described in chapter 1.2.5.

- Button 1 displays the accumulator voltage, remaining accumulator capacity in mAh and time
- Button 2 displays the date, time and last received transponder code.
- Button 3 can restart the entire system
- The connecting cables from the housing of the mainboard to the front panel of the Smart Nest box, as well as to the housing of the accumulator must be checked for visible damages.
- If the cause of the failure can't be found directly the normal procedure is to replace suspected faulty devices and then check whether the SNB is working correctly.
- Thermal damage as well as damage due to oxidation can be seen easily at the boards.
- If the failure is not found after replacing the devices it is common to analyse the affected SNB in the laboratory.

4.6.2 Troubleshooting in the laboratory

Via the LEUART-interface the Smart Nest Box can be connected to a PC. This makes it possible to transfer information transmitted by the MCU. This allows for a detailed view into the Smart Nest Box.

If the failure can't still be found it is recommended to electronically test the hardware to find the malfunction and avoid it in future Smart Nest Box versions.

5 Software

The Software on the flash memory in the Animal Presence RFID Data Logger is programmed with the programming language C. The software is diverse for different versions of the Animal Presence RFID Data Logger. The software needs to be smaller than 128 KB for the flash memory. The software for the Animal Presence RFID Data Logger with the Smart Nest Box application will be described in this chapter. It includes reset options, the reset process, how data is stored and what occurs when the SD card is changed. Also described is how regular queries are stored, what the buttons do and what possible software updates are available exist.

5.1 Reset

The reset can be used to restart the system of the Animal Presence RFID Data Logger when a failure occurs. The procedure for a reset is always the same. The reset is a new start and can be compared with the start of a PC.

5.1.1 Possibilities to perform a manual reset

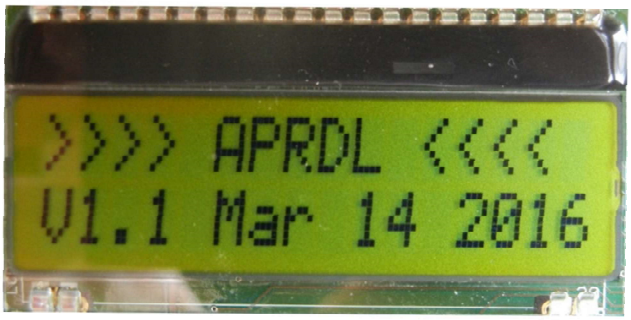
The Animal Presence RFID Data Logger can be restarted manually in two ways:

- Via pushbutton
- Restart after total power loss

5.1.2 Procedure after reset

After a reset the following procedure takes place:

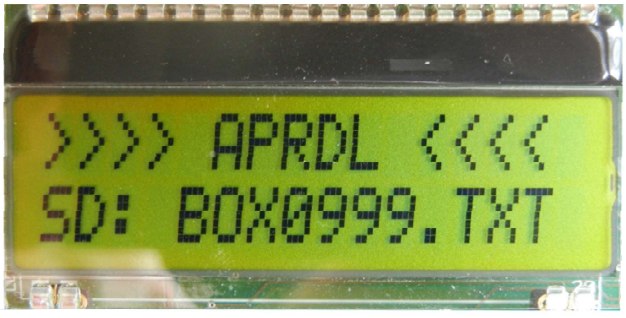
1. Both LED's (red and orange) will be illuminated to show that the hardware or software is active and the LED's are working.
2. The hardware version number and the date are displayed for 4 seconds. Afterwards the LED's are deactivated.



3. In the case that a SD card is detected the data system will be mounted and the free space on the SD card will be displayed. The same procedure occurs whenever a SD card is inserted.

4. Afterwards it will be searched for a log file with the name “BOX*nnnn*.TXT” (*nnnn* is a random decimal number). In the case that the file exists on the SD card the name will be displayed on the LC display otherwise the file “BOX0999.TXT” will be created.

   The radio clock will then be activated to update the date and time. The red LED now flashes to the rhythm of the transmitted data.



5. After the date and time are updated, this information is displayed on the LC display for 30 seconds. Then the display is switched off and the red LED switched off as well.

5.1.3 Reset protocol

If a start or a reset of the Animal Presence RFID Data Logger is carried out some protocol lines are written on the SD card to comprehend the process of the maintenance.

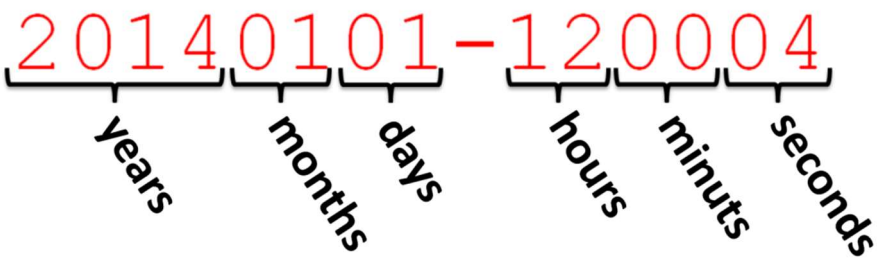
```
00000000-000000 APRDL V1.1 (Mar 14 2016 14:41:54)

20140101-120004 DCF77: Enabled

20140101-120004 SD-Card Inserted

20140101-120004 SD-Card Initialized

20140101-120004 SD-Card File System mounted

20140101-120004 SD-Card 1883MB free

20140101-120004 Using Filename BOX0999.TXT

20140101-120004 MCU: EFM32G230F128 HW-ID: 0x241E6D0354224957

20140101-120004 Battery Manufacturer Name :  Dynamis

20140101-120004 Battery Manufacturer Data :  61.90002/15790

20140101-120004 Battery Device Name       :  BMS2-4_V1.0

20140101-120004 Battery Device Type       :  Lithium-Ion

20140101-120004 Battery Serial Number     : 00008

20140101-120004 Battery Design Voltage    : 3.300V per cell

20140101-120004 Battery Design Capacity   : 7500mAh

20140101-120004 Battery Full Charge Capac.: 7500mAh

20140101-120004 Battery Remaining Capacity: 4306mAh

20140101-120005 Battery Runtime to empty  : More than 6 weeks

20140101-120005 Battery Actual Voltage    : 13.1V

20140101-120005 Battery Actual Current    :    3mA
```


5.2 Data storage

All important information from the RAM memory will be saved in a txt-file on the SD card.

Every event or stored message begins with the date and time of the event.

Following the date and time will be the actual status message.



5.3 Procedure after SD card change

After a new SD card is plugged in the following procedure starts.

1. It displays that a new SD card has been detected.

```
20140101-120004 SD-Card Inserted
20140101-120004 SD-Card Initialized
20140101-120004 SD-Card File System mounted
```

2. The following line shows how much free space remains on the SD card.

```
20140101-120011 SD-Card 1880MB free
```

3. Afterwards it will search for a log file with the name „BOX*nnnn*.TXT“ (*nnnn* is a random decimal number). In case that the file exists on the SD card the name will be displayed on the LC display otherwise the file „BOX0999.TXT“ will be created.

```
20140101-120011 Using Filename BOX0999.TXT
20140101-120011 Media Change: BOX0999.TXT -> BOX0020.TXT
```


4. The hardware ID will be displayed, which is a unique number allocated to each Animal Presence RFID Data Logger, so they can be identified individually.

```
20140101-120011 MCU: EFM32G230F128 HW-ID: 0x24B4010253FD82EE
```

5. The status of the accumulator is then displayed, including the manufacturer name, manufacturer data, device name, device type, serial number, design voltage, design capacity, total capacity, remaining capacity, remaining time at actual current and at least the measured actual voltage.

```
20140101-120011 Battery Manufacturer Name :  Dynamis
20140101-120011 Battery Manufacturer Data :  61.90002/15790
20140101-120011 Battery Device Name       :  BMS2-4_V0.3
20140101-120011 Battery Device Type       :  Lithium-Ion
20140101-120011 Battery Serial Number     : 00008
20140101-120011 Battery Design Voltage    : 3.300V per cell
20140101-120012 Battery Design Capacity   : 7500mAh
20140101-120012 Battery Full Charge Capac.: 8968mAh
20140101-120012 Battery Remaining Capacity: 4122mAh
20140101-120012 Battery Runtime to empty  : More than 6 weeks
20140101-120012 Battery Actual Voltage    : 13.149V
20140101-120012 Battery Actual Current    :    3mA
```

6. The time of the microcontroller is updated through the signals from the radio clock. This process usually only takes a few minutes.

```
20140101-120856 DCF77: Time Frame 1 is 20160315-143100
20140101-120956 DCF77: Time Frame 2 is 20160315-143200
20160315-143200 Initial Time Synchronisation
20160315-143200 DCF77: Time Synchronization 14:32:00
20160315-143200 DCF77: Disabled
```


5.4 Periodic routine queries

5.4.1 Time update

Every 24 hours, during the night the time from the MCU is updated by the signals from the radio clock.

```
20160319-015500 DCF77: Enabled

20160319-015701 DCF77: Time Frame 1 is 20160319-015700

20160319-015801 DCF77: Time Frame 2 is 20160319-015800

20160319-015800 DCF77: Time Synchronization 01:58:00

20160319-015800 DCF77: Disabled
```

If the radio clock is not available, no update occurs and there will be no synchronization message.

5.4.2 Battery status query

In regular intervals the status of the accumulator is written into the RAM memory and on the SD card. In addition to this message the actual current is displayed. The remaining runtime of the accumulator is calculated from data from the accumulator board. The remaining capacity and the actual current are used for this calculation.

```
20160316-120000 Battery Remaining Capacity: 4337mAh

20160316-120000 Battery Runtime to empty  : More than 6 weeks

20160316-120000 Battery Actual Voltage    : 13.1V

20160316-120000 Battery Actual Current    :    1mA
```

5.5 Recorded events

The main task of the Animal Presence RFID Data Logger is to record the behaviour of animals. In the Smart Nest Box application this is made through the recordings from the light barrier activity and transponder detections.

5.5.1 Light barrier activity

The light barriers are always active and are always supplied with electrical energy. They are the trigger for the RFID Reader which is by far the largest energy consumer.

```
20160323-112408 LBO:ON       # Light barrier outer on
20160323-112408 LBI:ON       # Light barrier inner on
20160323-112408 LBO:off            # Light barrier outer off
20160323-112408 LBI:off            # Light barrier inner off
```

5.5.2 Transponder activity

The RFID reader is switched on by light barrier activity. This needs to occur very quickly as the transponder may be rapidly moving through the barrier and its numberneeds to be read completely. Particularly for transponders in birds, it needs to be to read out entirely during the flight into the nest box through the entrance hole with the RFID reader. The birds have a high velocity while entering in the nest box. However, their velocity when leaving the nest box is not as fast.

```
20150723-154010 RFID is powered ON
20150723-154010 Transponder: D5CD24B43A6F0001
20150723-154122 RFID is powered off
```

Because it is likely to detect further activity after a transponder is detected, the RFID remains on for an additional 6 minutes after the last transponder signal

5.5.3 Standard recording

In the following lines there are typical status messages from the Animal Presence RFID Data Logger with the Smart Nest Box application. It is an exemplary record from an incoming bird which is remaining in the box for more than 6 minutes.

```
LBO:ON           # Light barrier outer on
RFID is powered ON                # RFID active
Transponder: D5CD24B43A6F0001   # Transponder reading
LBI:ON                       # Light barrier inner on
LBO:off                      # Light barrier outer off
```



```
LBI:off                          # Light barrier inner off

RFID is powered off              # RFID inactive
```

By using two light barriers, the direction of the flight path can be detected. In the example above a subject is flying initially through the outer and then through the inner light barrier. This shows that the subject has flown into the nest box.

5.6 Occurrences when it is not possible to write on the SD card

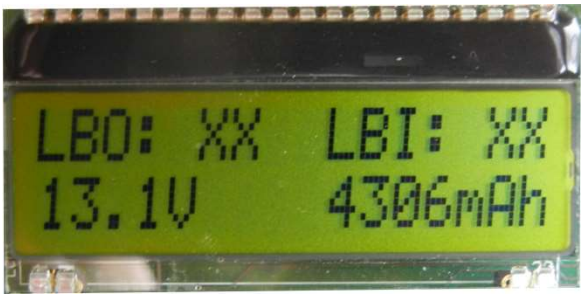
When the SD card is full or if there is no SD card is in SD card slot an error message is written on the LEUART-BUS. This message is not written on the SD card and can only be seen on the LEUART-BUS. It is not common that data is lost due to the absence of an SD card, and the internal memory is full because the 2 KB of provided memory is enough for many messages to be stored.

5.7 Expiry after keystroke

The Animal Presence RFID Data Logger has three buttons to display messages on the LC display or to restart the system. The buttons are explained in chapter 1.2.7 and the installation site can be seen in chapter 1.2.2.

5.7.1 Display the light barrier status and the accumulator status with button S1

After pressing the S1 button the current status of the two light barriers (LBO = Light Barrier Outer, LBI = Light Barrier Inner, "XX" = active, "" = inactive) are displayed on the LC display. The status of the accumulator is also displayed through current voltage and remaining capacity in mAh.



5.7.2 Display the date, time and the last received transponder number with button S2

After pressing the S2 button the current date and time as well as the last received transponder number will be displayed on the LC display. When the S2 button is pressed for more than 5 seconds the last received transponder code will be deleted. This allows it to test the RFID reader with the same transponder more than once. If no button is pressed for more than 20 seconds, the LC display will be shut off.

5.7.3 Initiating a restart of the system

After pressing the S3 button the whole data system of the Animal Presence RFID Data Logger will be restarted. The procedure of the restart is described in chapter 5.1.2.

5.8 Update options

There are three possibilities to write software code on the flash memory.

The microcontroller EFM32G230 contains a flash memory with 128 KB memory size. This memory contains the software by which the microprocessor has to work. 128 KB memory is sufficient memory space to realize even very complicated applications with the Animal Presence RFID Data Logger.

5.8.1 IAR Systems Debug Probe

Through the debug probe from IAR systems it is possible to load compiled software code on the flash memory. The software from IAR for the debug probe is necessary for this.

IAR Systems also distribute the software IAR Embedded Workbench to create and compile C code. The compiled C code can be loaded on the flash memory by the debug probe.

5.8.2 With an USB cable and the 10-pole Interface connector

This method only allows HEX and BIN files to be transferred to the flash memory. The original C code cannot be transmitted without the debug probe.

5.8.3 Per SD card and boot loader

If software has already been written on the flash memory by either of the methods from chapter 5.8.1 or 5.8.2 a third method through a boot loader is available. The boot loader searches potential software code on the inserted SD card.

6 Contact details

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7 Links to the datasheets

EFM32G230

IAR J Tag ARM

LC display

SD memory card connector

Button

Capacitor

Jack connector

USB cable

Down converter

LED'S

Radio clock

Light barrier

RFID reader

RFID-transponder

Housing for the main board

Housing for the accumulator

Battery charger Fronius

Battery charger Mascot

Battery cell

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