	DTUSAT_MDD Mission Definition Document	Ref: DTUsat_MDD Issue: 1.21 Date: April 20, 2007 No. of pages: 12

Solving the Mystery of Bird Migration: Tracking Small Birds from Space

Prepared by	Checked by	Date	Issue	Document Modifications
RWF	PME	3. Mar, 2006	1.00	First nominal version
KT	SYSENG	15. Mar, 2006	1.10	Revisions by PI after kick-off
PME	SYSENG	7. Apr, 2006	1.20	Revisions by project manager
RWF		20. Apr, 2007	1.21	Revisions by project manager

Scope of Document

This Mission Definition Document (MDD) presents the DTUsat bird-tracking mission. It encompasses a description of the mission, the CubeSat concept, the organisation structure, the list of the project partners, and the project timeline.

1 The Mission

Solving the Mystery of Bird Migration: Tracking Small Birds from Space

The aim of this project is to construct a satellite-based radio-tracking system capable of locating small birds with intercontinental migrations anywhere along the route. The system will use a receiver mounted on the satellite DTUsat for tracking small radio-transmitters mounted on birds, henceforth referred to as bird transmitters. The tracking system will be used for tracking cuckoos on their migration from Europe to Africa and to track the movements of birds that have been displaced from Denmark. Tracking displaced birds holds great promise to help solving some of the true mysteries of bird migration: how do inexperienced, young migratory birds manage to find their way to unknown wintering quarters on their own, thousands of kilometres from were they were born. Furthermore, such a system would have enormous potential in animal migration research and will greatly improve our possibilities for predicting effects of, e.g., future climate change on ranges of migratory species.

This mission has two general goals: The first, technical one is to design and construct the satellite DTUsat. More than 70 students as well as several employees from various departments at DTU are expected to be involved. This educational process constitutes an integrated part of the space technology specialization at DTU and hence enhances the space technology capability in Denmark. The second, scientific one is to contribute solving the mystery of bird migration, as outlined above.

The project has four parts: (i) To design the system and (ii) to construct the satellite as well as the bird transmitter, which will be tasks for students at the Technical University of Denmark (DTU). (iii) Making the system work on a number of test cases including using the system on real migratory birds; this will be done in collaboration between DTU and a team of biologists lead from the Zoological Museum (ZM) who will fit the transmitters to the birds. Biology students are expected to take part in this work, but additionally, the Zoological Museum collaborates with a number of volunteers to capture and ring birds. (iv) To perform a displacement experiment, in which a number of birds are physically moved to a location far east of Denmark, using the bird transmitters; this will be done by a team from the Zoological Museum.

The mission was elected among seven proposals by the DTUsat advisory board based on the score in eight different categories: Scientific vision, scientific value, public outreach, political attention, international attention, technical challenge, mass and volume constraints, and mission risk/reliability.

2 The Scientific Part

Bird migration is among the most fascinating natural wonders. Large numbers of even small migratory birds, not heavier than a normal letter, are every year travelling enormous distances from breeding areas in Europe to wintering quarters in, e.g., Africa. In geese and storks the route is learned from experienced conspecifics, but in many other species the young birds are travelling these distances alone, without any guidance from parents or other experienced conspecifics. A well-known example showing that the migratory orientation programme is inherited is the cuckoo *Cuculus canorus*, where the parents leave the nest long before the chick is able to fly.

Despite many years of research into how birds find their way, we are still lacking fundamental knowledge about the navigational capabilities in migratory birds. Thorough experiments have been performed to show how the migratory orientation programme is expressed in captive migrants, and we have much knowledge about the compasses used by migratory birds.

However, we have very little knowledge about how the migratory orientation programme is carried out in free-flying birds. Two possible hypotheses can explain how birds are able to follow their migratory routes. Either they fly in a certain direction for a certain amount of time or they fly towards a certain goal. An impressive experiment was carried out by the Dutch Perdeck [1] in the fifties and sixties, in which more than 11000 starlings *Sturnus vulgaris* were displaced away from their normal migratory route. These experiments showed that the young inexperienced starlings continued their migration in their original direction. This demonstrated that starlings are likely to locate their wintering area by flying in a certain direction. However, the starling is a social migrant where the migration direction is presumably much influenced by accompanying flock members. Furthermore, the starling is a short-distance migrant, and these experiments cannot necessarily be generalised to long-distance migrants with much stronger demands for precise orientation. Since these experiments, only very few experiments have been performed to increase our knowledge about the migration programme and the effect of external factors, as, e.g., topography, on how and where birds migrate.

With the development of satellite-based bird transmitters, providing accurate location information anywhere on Earth, time seems ripe to test orientation performance with data obtained using advanced tracking techniques. Most important would be to perform displacement experiments similar to those performed by Perdeck [1]. Such an experiment involving displacing very large numbers of birds is not feasible today due to ethical and logistic reasons, but the use of satellite telemetry can drastically reduce the number of animals needed for experimentation. A similar study has recently been conducted with white storks *Ciconia ciconia* [2] but with highly unexpected results that could not be attributed to any single hypothesis. However, the white stork is, like the starling, a highly social migrant, and selection on a narrow migration route in that species probably is not as strong as on other long-distance migrants with restricted wintering quarters. Thus, to further investigate the innate migratory orientation programme we should ideally conduct displacement experiments with long-distance, non-social migrants with concentrated migration routes. An ideal study species for investigating the inherited migratory orientation programme would be the cuckoo. It is a long-distance migrant, but we have very little knowledge about actual migration routes and wintering grounds. Furthermore, the cuckoo is one of the largest species among the night migrants where we are certain that individuals migrate singly without any guidance from experienced conspecifics. Presently, such tracking experiments involving the cuckoo cannot be performed due to the lack of low-weight satellite-based bird transmitters. The development of a satellite-based system relying on even lighter bird transmitters than those in use today will enable us to follow cuckoos on their migration all the way to the wintering areas. Such a development is indeed the purpose of the DTUsat project. The detailed tracks available from this new system will reveal many surprises and new insights into the function of the migratory orientation programme in free-flying birds. The migration routes of the cuckoo are depicted in Figure 1.

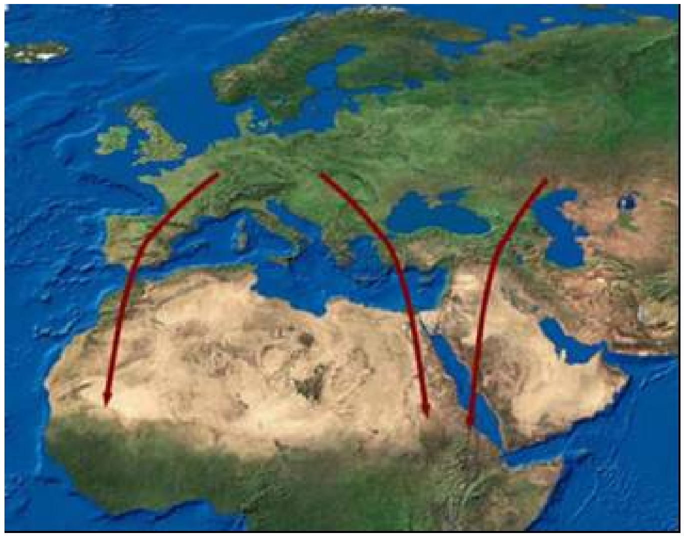

Figure 1. Migration routes of European cuckoos. The exact routes and wintering quarters as well as separation between wintering populations are not known.

2.1 Method

The cuckoo is approximately 330 mm in length and has an approximate weight of 110 g. Birds should not carry more than an absolute maximum of 5% (preferably not more than 2%) of their weight and the transmitter should not be longer than the bird. Hence, the requirements for the radio-transmitter to be carried by the birds are then:

- The transmitter should have a weight of less than 5 g
- The antenna should be less than 170 mm long

When the technical issues have been resolved, and a functional radio-tracking system is in operation, the scientific part can start (presumably summer 2008). Preferably young cuckoos shall be tracked. Young cuckoos are fed by their foster-parents until late summer (from end of June). It will be the task for a team from ZM to find the nests and mount the bird transmitters. Using these bird transmitters, five to ten cuckoos will be followed from their breeding grounds in Denmark to the wintering area in Africa (the control group). Another group (the experimental groups) of five to ten birds shall be attempted to be displaced far East, possibly to near Moscow to follow the reactions to this displacement.

The technical solution should at least provide one position of each bird per day along the whole migratory route. Ideally, a position every hour, or more often, is desired.

A number of ethical considerations applies to the project. Most species can carry a 5% extra load without any problems. Furthermore, the cuckoo is a common breeding bird in Denmark. The displaced birds will not be moved outside of the breeding area of cuckoos and expected possible outcomes will not provide unusually long or difficult migratory routes regardless of the migratory orientation programme used.

2.2 Mission Success Criteria (Scientific Part)

The criteria for a successful scientific mission are listed below.

1. Several position determinations of a bird transmitter giving indications of the migration route
2. Migration route tracked for one bird
3. Migration route tracked for several birds
4. Migration route tracked for several displaced as well as non-displaced birds
5. Migration routes as in item 4 over two years

3 The Technical Part

The DTUsat primary payload is related to the bird-tracking mission and consists of two parts. The terrestrial part the bird-transmitter unit, mounted on the back of the cuckoo, consisting of GPS receiver, microprocessor, and radio transmitter. The maximum allowable weight of the bird transmitter is 5 g. This constraint drastically reduces the design space and any commercial off the shelf solution is immediately excluded, leaving custom design as the only option. The space segment part is the radio receiver mounted on board DTUsat. The receiver will be developed as a stand-alone radio system, which will not utilize any parts of the communication system used for telemetry and telecommand. Once in orbit and operational, DTUsat will listen for signals from the bird transmitters. Since the experiment involves between 10 and 20 bird transmitters, each transmitter will have a unique label. Each received signal is stamped with time and position. The data is stored locally and transmitted to the ground station during next pass. Figure 2 shows an artistic impression of DTUsat picking up data from bird transmitters.

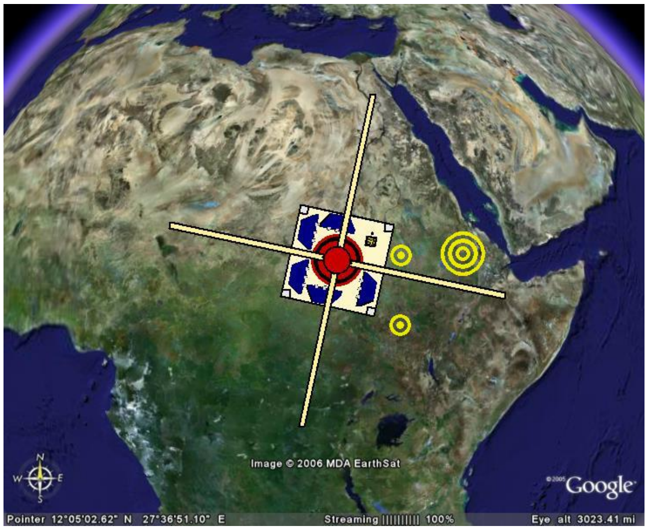

Figure 2. Artistic impression of DTUsat in orbit picking up data from bird transmitters.

DTUsat also carries two secondary payloads, not related to the bird-tracking mission. The secondary payloads serve the purposes of demonstrating the on-orbit functionality of a DTU-developed miniature Charged Coupled Device (CCD) camera, referred to as PICOCAM, and a Micro-Electro-Mechanical-System (MEMS) sun-sensor.

The DTUsat primary ground station is located at DTU in Lyngby. However, this location only gives two satisfactory passes per day (that is, passes of duration larger than 10 minutes). Hence, to increase the number of passes, a secondary ground station is planned to be established in Sisimiut, Greenland, in relation to DTU's on-going activities in Arctic Technology. The ground station in Sisimiut will give additional four satisfactory passes per day.

3.1 Mission Success Criteria (Technical Part)

The criteria for a successful technical satellite mission are listed below.

1. Beacon received and decoded
2. Two-way communication established
3. House-keeping data received and decoded
4. Active attitude stabilisation of the satellite performed
5. Picture(s) from PICOCAM received
6. Data from MEMS sun-sensor received
7. Gravity gradient boom released and satellite stabilized
8. A single determination of the position of a bird transmitter located at DTU
9. A single or a few position determinations of a transmitter mounted on a live bird

3.2 A Student-Built Satellite

The DTUsat project offers students at DTU to participate in the realization of the satellite, as an integrated part of the space technology specialization at DTU. The satellite is divided into a number of subsystems. For each subsystem a group of students is established to undertake the subsystem specification, design, fabrication, and testing. The development of each subsystem is divided into several projects. A certain level of skills is required of students to participate in the projects. The mandatory prerequisites vary with the projects. Projects and prerequisites are described at the DTUsat website, www.dtusat.dtu.dk.

3.3 The CubeSat Concept

DTUsat will be located in the Poly Pico Satellite Orbital Deployer (P-POD) when launched. The P-POD carries three satellites and is designed to fit on a number of launchers as a piggy-bag. The P-POD design imposes a number of constraints outlined by CubeSat.org, the initiators of the CubeSat concept.

The CubeSat concept provides a standardized launch vehicle (LV) interface and introduces a physical barrier between the LV and the student-built satellite. By adhering to the CubeSat concept, the number of viable launch opportunities are expected to increase. This may allow the DTUsat team to select the orbit and thereby the launch from a scientific point of view rather than from availability. Furthermore, the standardized interface immediately resolves the LV-integration issue, which in turn reduces the necessary testing and qualification.

3.4 Product Assurance

While terrestrial engineering to a large extent benefits from the possibility of correcting design errors after completion of the product, this is reduced to minor software revisions for space engineering. Hence, the DTUsat project will focus on Product Assurance (PA). In particular, three areas are of interest:

- Project documentation
- Subsystem standardization
- Testing

The DTUsat project is expected to last between 2 and 3 years. The subsystem groups will have students assigned in blocks of one semester. Consequently, the manpower will be replaced several times throughout the project. In order for the DTUsat project to effectively benefit from the available manpower, documentation and knowledge management are mandatory. To this end, various documents are prepared, among those the System Requirements Document (SRD), describing the technical design requirements of the satellite, and the Interface Control Document (ICD), describing the chosen technical implementation. The SRD contains a section specifying the needed documentation from each subsystem group. Additionally, a system engineer from each subsystem group will be assigned. The role of the system engineer is to establish the communication between the subsystem group and system engineering (SYSENG) group. For a description of the role of SYSENG, please see the section on organisation below. The individual subsystem groups assign their SYSENG representative. The DTUsat group will not issue any formal demands on the election of the system engineer; however, devotion to space engineering and the possibility of remaining within the project for more than one semester is desirable.

Managing a satellite project is a time-consuming task to which it is difficult to assign students. The reason for this is two fold. First, the management must be continuously present and it cannot suffer from lack of manpower due to non-available students. Second, the management task contains too many assignments of non-technical nature, and since the DTUsat project is defined as being highly technical, it cannot be justified to give DTUsat-students credit points for their management efforts. To overcome these problems, the DTUsat-project implements a professional management. This professional management, employed by DTU, is described in further details in Section 4.

3.5 Time Plan in Phases

Figure 3 below shows the time plan of the mission. As observed, the project is divided into various phases. Pre-phase A is meant for preliminary studies, solution surveys, parameter estimates, etc. Phase A includes system specification and proof of concept. The SRD is created in this phase. Phase B is devoted to a detailed study and description of a specific solution. By the end of this phase, the ICD is presented to the SYSENG group at a Preliminary Design Review (PDR). The SYSENG group will assure compatibility between the SRD and the ICD. Phase C/D is the fabrication and test phase. In the first part of Phase C the Flat-Sat functional model is created. The Flat-Sat functional performance is reviewed during the Critical Design Review (CDR). Following a successful CDR the engineering model is realized. The engineering model is subject to a number of tests including a 150% launch load test. Once the engineering model has passed all tests, the flight model is assembled and given the final test and inspection. Phase E consists of the launch and the orbit phase. For the DTUsat mission this phase has an expected duration of up to 18 months.

Once a launch has been procured, the launch date is fixed. The launch date is a hard deadline. In order not to impose considerable stress on the project in the early phase, launch procurement will be postponed until after CDR.

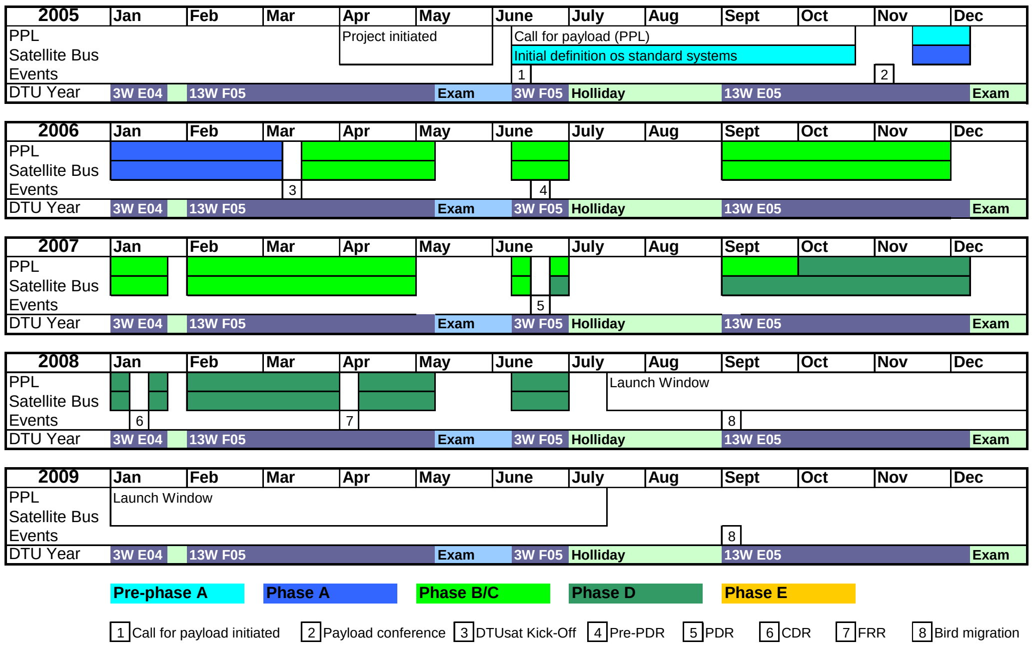

Figure 3 The project is divided into various phases.

3.6 Perspective

The developed primary payload will have a huge international impact since it will be the first satellite-based tracking system involving a transmitter of as low weight as 5 g. Hence, apart from contributing to solve an important scientific mission, the DTUsat primary payload will also constitute a commercial platform for a new low-weight generation of satellite-based tracking systems. Since this system can be used to track all species (not only small birds) it will give researchers the means to find the answer to several other biological mysteries, as well as to initiate new research areas.

Being a student-built satellite, conforming to the CubeSat concept, DTUsat is one of approximately 100 similar projects in the world. However, DTUsat does outdistance the other projects in several ways. First, DTUsat is the first student-built satellite with a dedicated scientific mission involving a principle investigator (PI). Second, DTUsat is one of the few student satellites implementing product assurance, as described in Section 3.4 above. Third, DTUsat has a professional staff to assure continuity of management across semesters and to relieve students from non-technical management tasks so that they are allowed to focus on the technical issues to which their education is devoted.

4 Organization

Figure 4 below shows the organisation chart of the project. The Principal Investigator (PI) is Kasper Thorup, Zoological Museum, University of Copenhagen. The project management team consists of

- René Fléron, Project Manager, DRC•DTU
- Hans Henrik Løvengreen, Software Coordinator, IMM
- Jonas B. Bjarnø, Chief System Engineer

The SYSENG group consists of

- The project management team
- Supervisors for each subsystem
- A designated student from each subsystem appointed by the subsystem group

The supervisors of the subsystem groups are as follows

- Primarily Payload (PPL)
    - Peter Meincke, Ørsted•DTU
    - José M.G. Merayo, DRC•DTU
    - Knud J. Larsen, COM•DTU
- Secondary Payload (PICOCAM)
    - John Leif Jørgensen, DRC•DTU
- Secondary Payload (MEMS sun-sensor)
    - René Fléron, DRC•DTU
    - Jan Harry Hales, MIC
- Mechanical (MECH) subsystem
    - Brian Nyvang Legarth, MEK
    - Jon Juel Thomsen, MEK
    - René Fléron, DRC•DTU
- On-Board Computer (OBC) subsystem
    - Gøsta Thuesen, DRC•DTU
- On-Board Data Handling (OBDH)
    - Hans Henrik Løvengreen, IMM
- Attitude Control Subystem (ACS)
    - Mogens Blanke, Ørsted•DTU
    - José M.G. Merayo, DRC•DTU
- Electrical Power Subsystem (EPS)
    - Ole C Thomsen, Ørsted•DTU
- Communication (COM) subsystem
    - Jens Vidkjær, Ørsted•DTU
    - Peter Meincke, Ørsted•DTU
    - Knud J. Larsen, COM•DTU
    - Olav Breinbjerg, Ørsted•DTU
- Ground Station (GS)
    - Hans Henrik Løvengreen, IMM
    - Peter Meincke, Ørsted•DTU
    - Knud J. Larsen, COM•DTU

The SYSENG group is the turning point of the entire DTUsat project. The information flow between the subsystem groups and to and from the management group and PI goes through SYSENG, see Figure 4. The SYSENG group meets on a weekly basis to discuss project development and to help solve problems that involves several subsystems. It is also the role of the SYSENG group to verify that all subsystems have been qualified to fly on DTUsat.

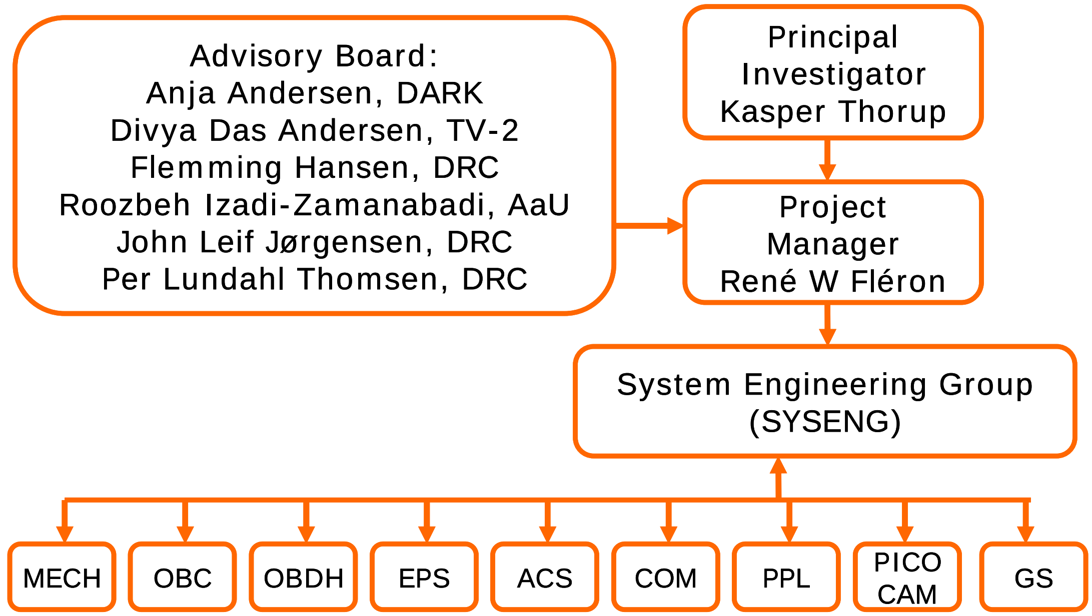

Figure 4. The organisation chart of the DTUsat project.

5 DTUsat Topology and Configuration

The technical details and specifications of the DTUsat subsystems are described in the SRD. The short list below and the two figures describe the main characteristics of DTUsat. Figure 5 gives an overview of the different subsystems and their interconnections in the space segment of DTUsat. Figure 6 shows the physical placement of the subsystems in a cross-sectional view.

DTUsat specifications:
- Maximum mass: 1.000 kg
- Overall dimensions during launch: 100 mm x 100 mm x 113 mm
- Overall dimensions in orbit after boom deployment: 100 mm x 100 mm x 1400 mm
- Power bus voltage: 3.3 V
- Available power: 700 mW
- Uplink frequency: 1.268900 GHz
- Downlink frequency: 2.401835 GHz
- Primary payload frequency: 868 MHz
- Mission lifetime: 18 months

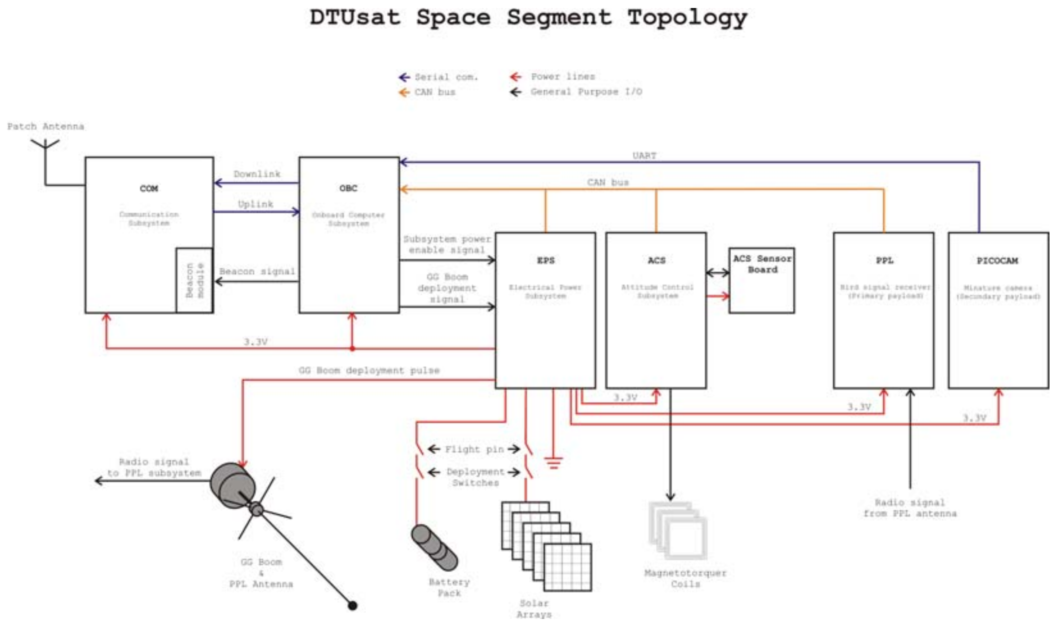

Figure 5. The DTUsat topology, the subsystems, and their interconnections.

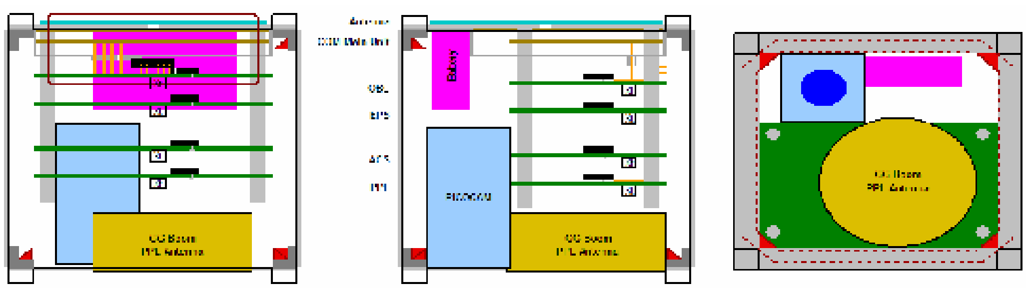

Figure 6. The configuration of DTUsat. The brown and green slabs indicate printed circuit boards seen edge on. The red triangles denote the electromagnetic coils for the attitude control.

References:

[1] PERDECK, A. C. (1958). Two types of orientation in migrating starlings, *Sturnus vulgaris* L., and chaffinches, *Fringilla coelebs* L., as revealed by displacement experiments. *Ardea* **46**, 1-37.

[2] CHERNETSOV, N., BERTHOLD, P. & QUERNER, U. (2004). Migratory orientation of fist-year white storks (*Ciconia ciconia*): inherited information and social interactions. *J. Exp. Biol.* **207**, 937-934.