Experiences in Combining Cubesat Hardware and Commercial Components from Different Manufacturers in order to build the Nano Satellite AISat/Clavis-1

Falk Nohka, Martin Drobczyk, Ansgar Heidecker
German Aerospace Center (DLR) – Institute of Space Systems
Robert-Hooke-Str. 7, 28359 Bremen, Germany; Phone: +49 421 24420-1199
falk.nohka@dlr.de

ABSTRACT

The off-the-shelf availability of a large variety of Cubesat components from different manufacturers enables building-block-like configuration of Cubesat systems. Is it possible to utilize these components to build a nano satellite for scientific payloads? The German Aerospace Center (DLR) internal engineering group Clavis, with the goal of developing a flexible, modular nano satellite platform, was confronted with implementing their design into the AISat mission. The challenges, solutions and lessons learned is what this paper shall transport. From the early steps in designing a satellite bus for DLR internal small payloads to adapting this concept to a real payload and implementing a lot of experience was gained with respect to cost of modularity, interdependency of commercially available components from different manufacturers, verification, and integration.

The initial Clavis concept was intended to be flexible with respect to the payload it may support, to be modular in order to provide for different mission scenarios, and to mainly consist of standardized components which enable a mission life time of up to one year (and possibly beyond). With the adoption of the AISat payload the conceptual design had to be adapted to the specific requirements of the payload since it was already defined.

DESCRIPTION OF CLAVIS AND BACKGROUND

In 2009 an interdisciplinary working group of engineers within the DLR Institute of Space Systems started investigating the possibility of utilizing commercially available Cubesat hardware with the goal of designing a nano satellite bus that could serve as a platform for various experimental instruments in the nano satellite class from within DLR. Due to the different nature of the payloads the platform had to be very flexible. The idea was to provide defined mechanical interfaces and one unified electro-mechanical interface to connect the bus to a payload. On the satellite bus side the electronics were arranged in a quad-stack configuration made up of PC/104 Cubesat boards with an interface board (back plane) connecting the four stacks and providing the electro-mechanical payload interface.

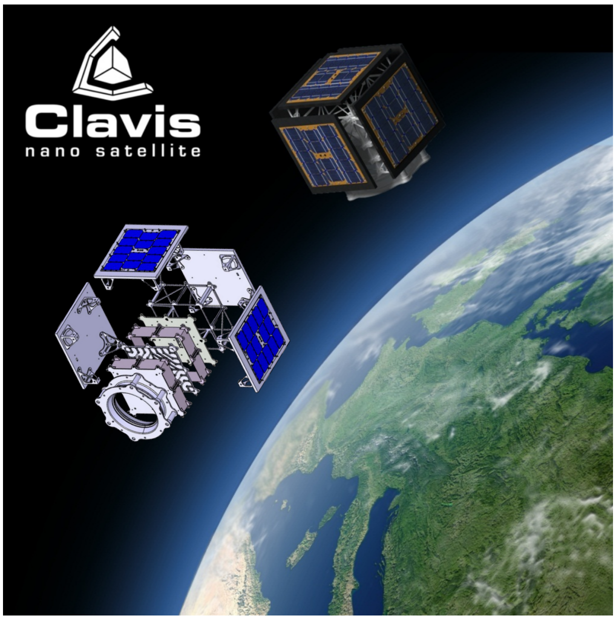

Figure 1, Artist impression of Clavis nano satellite platform

The design was clearly driven by budgetary constraints as well as little man power. Thus the design had to be not only modular and flexible, but also simple and easy to assemble and integrate. The PC/104 Cubesat form factor offered the advantage of a predefined interface and to some extends signal definition.

Different commercially available components were chosen to constitute the bus design. The power subsystem consists of a battery pack with a capacity of 40 Wh, 5 solar panels, whereas each of them can generate up to 15 Watts of power and a power distribution and control unit with regulated bus voltages. Also a switching board was foreseen to add switching functionality for power control. An on-board computer component was chosen, which is based on an ARM7 processor. It provides a storage capability of 8 MB for core avionics software as well as mission data. Also it partly provides attitude control functionality offering a magnetometer as well as pulse width modulators to control magnetic torquers. Two different transceivers were considered within the communications subsystem.

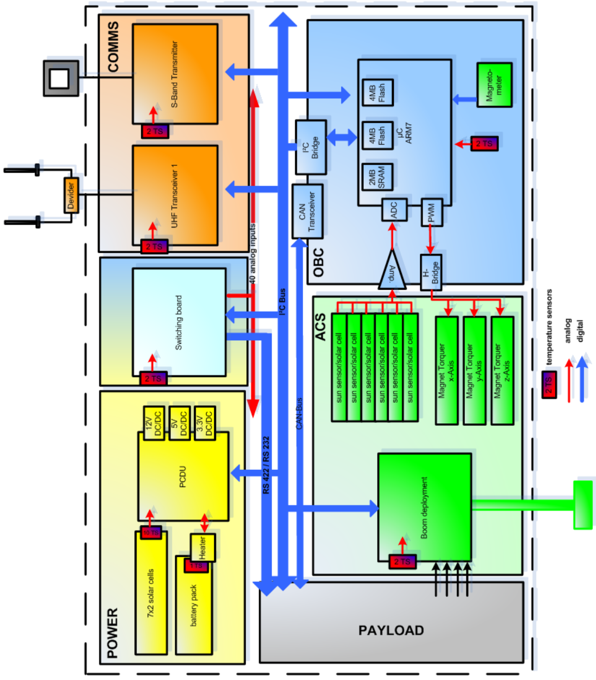

Figure 2, Conceptual overview of Clavis bus compartment

A low data rate UHF transceiver and monopole antennas with an omnidirectional coverage were chosen to handle the bus related communication to operate the satellite. An optional S-Band transmitter with an S-Band patch antenna and a higher data rate was able to cover the increased mission data transmission to ground. All components are directly used for or derived from Cubesat applications and conform to the modified PC/104 standard. Additionally an inertial measurement unit (IMU) based on MEMS technology was chosen as an attitude control sensor package which provides redundancy to the already availible on board magnetometer in a very cost efficient way. Although the Cubesat standard, which in general defines the physical aspects of this class of satellites, was very helpful in the mechanical design process, the electrical design was more challenging due to the fact that the standard does not account for electrical properties.

Different considerations lead to a non-redundant design. This in fact is untypical for conventional satellites, but keeps the system simple and can be applied for low-budget small satellite missions. However the decision was also driven by the current design principles of the commercial Cubesat components, which are not able to handle any kind of redundancy, not internal either external.

ADAPTING THE CLAVIS CONCEPT TO A SPECIFIC PAYLOAD

In 2010 the team was approached with the request of designing the satellite bus for an AIS payload which was under development at that time, thus constituting the AISat/Clavis-1 (AISat).

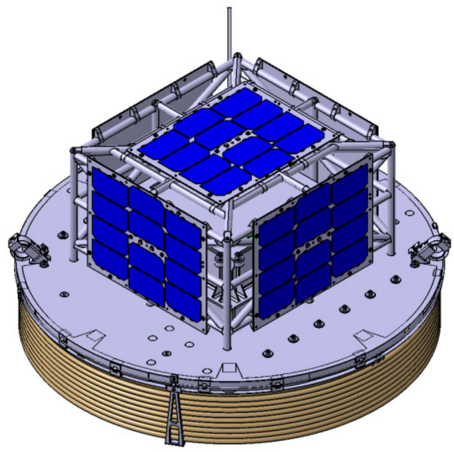

Figure 3, AISat top side with retracted payload antenna

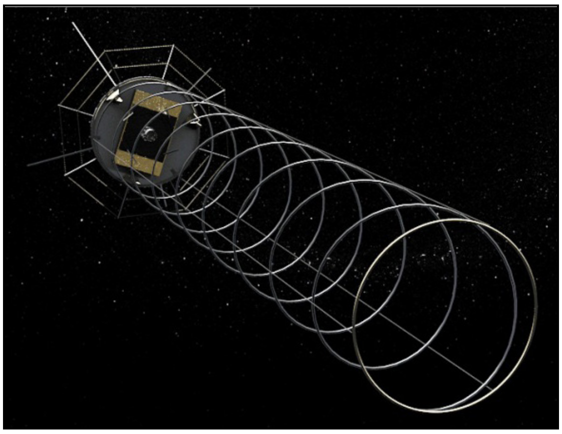

Figure 4, AISat with deployed payload antenna

Most of the concept which had been developed so far could be re-used, but some fundamental approaches to achieve maximum modularity and thus flexibility for future applications had to be dropped because of different reasons. For one the payload design was in a stage where its interface to the satellite bus was already defined and the Clavis engineers had to adapt to this. This led to abandoning the unified interface to the payload as it is connected to the platform through two connectors. Also the dedicated bus electronics compartment was dropped and the bus electronics mixed with payload components, as one experiment was also implemented in PC/104 Cubesat dimensions. On the opposite side some bus functions where implemented in the payload volume, as for example an attitude control sensor package, and the release mechanisms for UHF and payload antennas. In a later design step the retractable UHF antennas for telecommand reception and telemetry transmission were replaced by fixed antennas. The majority of the changes affecting the modularity concept were made in favour of weight savings. Also some essential components like the S-Band transmitter with its patch antenna were removed, and different structural design optimizations lead in a bus compartment weight of approx. 3kg. This in fact is the magnitude order of a 3U Cubesat, without considering the payload compartment as well as the interface adapter to the launcher.

CHALLENGES

Due to the different levels of development of the platform and the payload the bus design had to be adapted to the payload, as stated earlier. Because the bus was designed with flexibility in mind, a lot of features originally asked for by suppliers were not needed to the level once foreseen. This led to complex solutions, which had been derived from Cubesat hardware, especially concerning the available interfaces. For instance the number of analog input channels asked for were essentially used to 2.5 %. The over-definition of interfaces was also apparent in the number of available power switches initially planned, although the ratio was better with 58 % used. This of course resulted in densely used stack connectors, where some pins were assigned to signals which differ from pin assignments on other components. The solution to this was the utilization of the interface board as a router of signals.

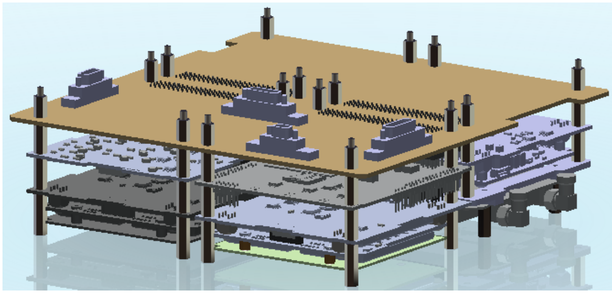

Figure 5, AISat/Clavis-1 bus in quad-stack configuration

The components which share similar pin allocations on their stack connectors were grouped into stacks. So the stack connector of each individual component stack on the interface board became unique, which was a contradiction of the original idea of having identical stack connectors.

Nevertheless this investigation minimized the harness between the different stacks and through its routing more than 104 pins could be allocated, since components on different stacks could allocate a specific connector pin for a different purpose. The interface board then routed the pins to its foreseen destinations. As this routing is very specific and varies with its components and mission-specific requirements, the design of the interface board is very much customized, and this of course limits modularity, respective flexibility for future application of the bus electronics since the interface board is designed specifically for the AISat mission. This is also true for the external interface to the payload (see **Figure 7**), as stated earlier.

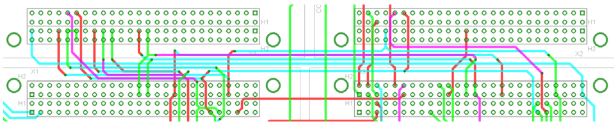

Figure 6: stack connectors of the interface board layout in detail

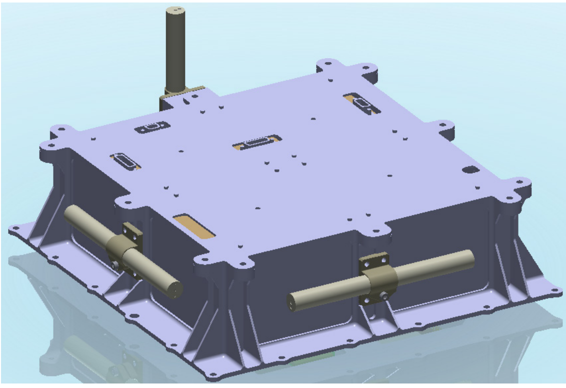

Figure 7, AISat/Clavis-1 bus box with external interfaces

Another challenge was the uncertainty regarding the launch and pre-launch phases, which resulted in modifications of the power subsystem. In classical Cubesats the spacecraft is deactivated by a switch, which is mechanically triggered once the orbital deployer is opened and the Cubesat is activated. In the case of AISat the satellite is launched from the upper stage of the launch vehicle by a separation ring with pyrotechnical release. Late in the design it became apparent that the launch service provider will supply neither power nor a separation signal to the satellite during per-launch and launch phases. Since no mechanical separation switch was introduced in the design so far, the supplier of the power subsystem was contacted and together a solution was agreed, which led to a minor modification of the design but resulted in a new hardware order.

The problem was that the current draw of the power subsystem was too high even in under voltage protection (UVP) mode to sustain a period of up to 14 days (pre-launch phase) out of batteries. By the time of the launch the batteries would be depleted and would have lost their complete capacity resulting in failure of the mission. Together with the manufacturer a second threshold level for UVP was introduced with greatly reduced current draw. This enables on one hand the survival of the long pre-launch phase but also ensures that the batteries are almost fully charged when the satellite is activated. As a trigger for the activation of the spacecraft the sun is used. Once it shines on the solar panels the batteries are charged to the point of activation, leaving UVP mode. The satellite will then perform a series of measurements on various sensors to ensure it is in orbit before LEOP operation begins.

Designing the platform with components from different manufacturers resulted in the challenge of getting the components to talk to each other, not only internally but also on the space link. This of course may be solved through software, but specifically the utilization of CCSDS down to the packet layer was not fully possible due to custom protocols. The user data block of the custom protocol had to be utilized to implement some pseudo CCSDS packets and to distinguish the spacecraft from other satellites utilizing the custom protocol.

But also the CCSDS physical layer is not yet established by the Cubesat community and most transceiver components operate in the amateur frequencies in UHF to establish the RF communication. Indeed, it makes not only the antenna design less complex. But some restrictions due to occupied bandwidth and thus the need of half-duplex communication have important impacts on the operational concept. Also in S-Band, available components only cover the downlink, but there exists no S-Band receiver to manage the TC command link according to the CCSDS recommendations and standards. [2] Because of this also the ground station concept leads to an isolated solution, without any support of the standardized DLR ground station network.

Regarding the communication of the components with the central on-board computer (OBC) the translation had to be written in software. Here the challenge was to extract the information from the user manuals or from the manufacturers as some information was incorrect or insufficiently documented as a result of the components being based on Cubesat hardware and being extended in functionality in order to meet our requirements.

The internal communication was also a challenge with respect to data rates and volumes. The dominant data interface on Cubesat components is Inter-Integrated

Circuit (I2C) bus which operates in standard mode (100 kbit/s) or fast mode (400 kbit/s). In that case the whole bus data rate drops to the lowest available. In cubesats this may be sufficient, but AISat is flying a sensor that generates data at a rate of up to 115.2 kbit/s. Originally it was foreseen to utilize the I2C bus by converting the data stream from UART, but the low data rate of the I2C bus resulted in an alternative solution utilizing the Serial Peripheral Interface (SPI) of the OBC. Another drawback lies in the nature of the I2C bus itself: although it is possible to operate I2C devices in multi-master mode, only one master device is able to communicate with a slave device at once, i.e. the process of sending a request to the slave and returning the reply to the master. This is especially critical when great data packets have to be transferred from one node to another. It results in great delay times on the bus for other data transfer processes. Furthermore it lacks the capability of ensuring data integrity during data transfer. This might be an issue with radiation effects (bit flips). These drawbacks are not critical to the AISat, but may be an issue in future applications.

LESSONS LEARNED

Looking back at the process we have gone through so far there are certain things we would do different in future projects. The first is to not underestimate manpower: from the beginning in 2009 the number of engineers taking part in the working group increased to 5 part-time and a hand full of students. This may be sufficient as long as there is no hardware involved, but once this starts part-time work slows the process and leads to delays due to late discovery of flaws and missing cross-checks due to time constraints. So once hardware comes into play (phase C) it is wise to enlarge the team in order to prevent over-work and demotivation.

Another important factor is completeness of documentation. Not only in terms of documenting the process, which is essential, but also checking if the documentation that is available or supplied by manufacturers of used components is complete and contains the information to the detail which is needed. The process of catching up on documentation takes up valuable time for important things, such as incoming inspections, which is also a lesson learned. Performing incoming inspections on any procured or manufactured item is essential. Most importantly: doing it as soon after reception of the respective item as possible. This will prevent flaws in external processes or designs from going undetected until the item is put to use and time is short already. This of course requires certain quality management processes to be established and supported by all people involved.

Finally it is important to have hardware to “play” with besides the flight hardware. It should be considered when estimating costs and should be planned for from the beginning.

CONCLUSION

Having gone through the process of applying Cubesat- and other commercially available hardware in order to build a nano satellite, we think there are several points to improve or at least to think about. This should be regarded not only as a note to ourselves for future development, but also as a reference to the community of developers of pico- and nano satellite components. It may be interesting to consider the following points:

Standardization of cubesat header.
The current PC104 standard limits the number of signals in the header. A more powerful connector could help to handle the increased needs which would lead in a more flexible interface board layout. Also a more detailed list of predefined signals in the header would ease the cooperation between different components.

Introduction of CAN as data bus.
A bus topology always adds advantages in a distributed system. Due to the increasing data rate requirements in future missions, the I^2C bus becomes obsolete as the main bus for data rates above 400kbps. Instead CAN bus is recommended to be introduced, where higher data rates are possible. Also a CRC check makes the bus communication more reliable and a multi-master operational mode offers a more flexible bus architecture. Also sometimes it is more beneficial to make use of serial point-to-point connections, when applications are exchanging a lot of data, or are time-critical. This for example is both the case for transmitters and receivers in a satellite system. But also sensors with a high readout rate would benefit from this approach.

Introduction of redundancy.
The components shall introduce the possibility of the utilization of redundancy concepts. They should at least

support external redundancies, when having two separate components. But also internal redundancy with fault detection and recovery mechanisms would lead to an improved performance. With respect to data busses which are very sensitive to connection defects, as one defect on a specific component can lead to blackout of the entire bus communication, a redundant bus concept might lead to a more reliable design.

Improvement in quality assurance.

Several standards exist for the space business. Here some of them are not applicable for smaller low-budget projects, but still some of these are mandatory to improve the quality and assurance of the products. One main aspect to be considered in future components development is the standardization of quality assurance measures (e.g. test philosophy) in order to produce trust among customers.

High-Rel options

To make the Cubesat components also interesting for larger satellite projects, also rad-hard solutions could be investigated. The miniaturization, introduced by the Cubesat community is one of the main aspects, which make the components such attractive. But the use of COTS disqualifies them to be used in more reliable missions. Therefore a rad-hard version of the components could be the next step to improve the reliability, extend the lifetime and make them more robust against radiation effects in space.

Documentation

From the experiences, the documentation of the components was not detailed enough to operate them smoothly. A comprehensive documentation would avoid many misunderstandings from the beginning and might have the effect of speed-up the test and integration process for the customers and so lead to a more confidential collaboration.

CCSDS compatibility

The space link builds one of the most important definitions for the spacecraft, as it acts as the interface to ground and the operator. Here the well-defined standard CCSDS exists for the different protocol layers (see [1], [2]). It includes definitions due to the choice of modulation techniques, bandwidth allocation as well as the protocols for telemetry and telecommanding of the spacecraft. Using this standard makes the mission operations more reliable and any project has access to the worldwide established professional ground station networks.

REFERENCES

1. CCSDS, CCSDS 130.2-G-1: *Space Data Link Protocols—Summary of Concept and Rationale*, CCSDS, 2007

2. CCSDS, CCSDS 401.0-B-21: *Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft*, CCSDS, 2011