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LIGHTWEIGHT CONSTRUCTION OF AN ANTENNA BOX FOR THE CUBESAT SATELLITE "MOVE"

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Abstract

This paper describes the development and construction of two integrated storage devices for the deployable antennas of the picosatellite **MOVE** (**M**unich **O**rbit **V**erification **E**xperiment). This CubeSat is currently being developed at the Institute of Astronautics at the Technical University of Munich. The Antenna Boxes shall help to store and protect MOVE's Nitinol antennas safely during the launch of the satellite until the deployment of the solar panels in orbit. The 'containers' are the most complex CFRP parts of the entire satellite. They are produced in several manufacturing steps and weigh only 7 g per piece. The development focus of this work is on the following aspects: weight, size, integration of the antennas into the Antenna Box and the mechanical interface of the Antenna Box to the main-frame of the satellite and the used material for the box.

1. INTRODUCTION

This paper is derived from a Bachelor Thesis [1] written in summer 2011 in cooperation with the University of Applied Sciences in Augsburg and the Institute for Astronautics at the Technical University of Munich.

1.1. The Munich Orbit Verification Experiment

At the Institute of Astronautics at the Technical University of Munich a CubeSat is being developed. The satellite called Munich Orbit Verification Experiment (MOVE) is a project with scientific and technical objectives. MOVE is designed as a platform, which shall carry different payloads during several missions. A very important factor of the project is the professional handling of different system levels, by using commercial space craft (S/C) components. The education of students in the field of systems engineering and S/C architecture knowledge is another objective of the MOVE mission. The first satellite in the MOVE history is called First MOVE. The CubeSat will fly a sun synchronous orbit at 635 km and is equipped with Triple Junction GaAs/Ge solar cells developed by EADS Astrium. The aim of the MOVE mission is to test and verify the solar cells in different work stages.

1.2. Objective of this work

MOVE is equipped with two Nitinol antennas for data transmission. In comparison to other CubeSats, which are mostly equipped with a taped spring antenna, MOVE's antennas have a circular diameter of less than 1 mm. The satellite has one downlink antenna with a total length of 940 mm and an uplink antenna with a total length of 330 mm. The antennas are mounted to the solar panels (SPs). The objective of the thesis is to construct two boxes in which the antennas can be stored in a safe position during the launch phase until they are deployed in the final orbit. The position of the antennas within MOVE can be seen in FIGURE 1. During the launch phase the solar panels are folded to the structure, so that the CubeSat has the specified cubic shape.

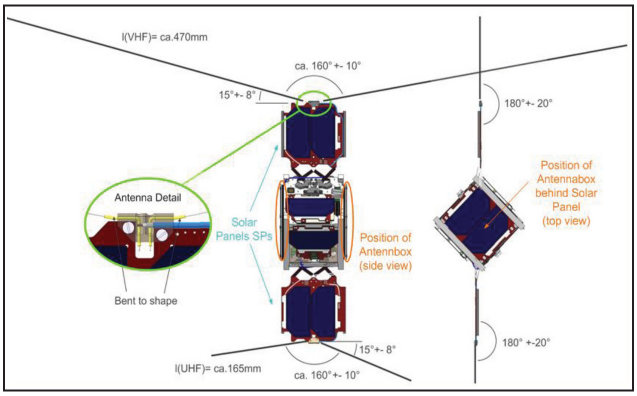

FIGURE 1. Position of MOVE's Antennas (unfolded stage) [2]

1.3. Approach

The Antenna Box development process is divided into four sub-processes: Research, Design, Production, Test and Verification. In-between the four processes design and requirements are matched and checked for consistency.

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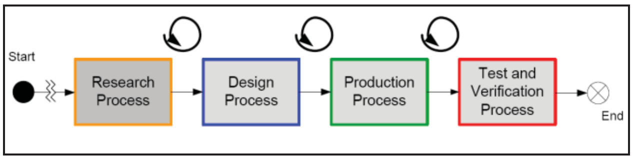

FIGURE 2. Proceeding of Antenna Box Development

In the beginning of the research process the requirements document [3] is used to define research information. Starting from the requirements for design and production of the AB, material and design information are collected.

After the research process is completed the information can be used to start the design process for the AB. A CAD model is developed using the CATIA CAD System and the final model is saved as .dxf file[3]. Afterwards the .dxf file is converted into a .grv file, a data format that can be red by the milling machine. The program IWOS CadCam VS 3.81 09/2008 [4] is used for the conversion into the milling data. In parallel the necessary materials (CFRP plates and the adhesive) are ordered.

The production process includes milling, bonding and the curing of the AB. To assure a successful bonding, a bonding support mechanism (BSM) is developed and manufactured.

For the test and verification process a MOVE dummy is built which is used as ground test mechanism (GTM) model. After the testing and verification process is passed the final ABs are manufactured.

2. DESIGN PROCESS

2.1. Requirements

The requirements of the AB development are defined in the document “MOVE’s Antenna Box – Top Level Requirements” [3]. The requirements in this document are used to verify the Antenna Box after the development process. The requirements for the Antenna Box are separated into two parts: Functional requirements (FIGURE 3) and Nonfunctional requirements (FIGURE 4)

2.1.1. Functional Requirements

The top level functional requirements (FIGURE 3) of the AB are “storage during launch” and “deployment after separation”. The storage requirement is subdivided into the following requirement aspects: box volume (“room for antenna”), “protection from vibration” and “hinder deployment during launch”. The requirement “deployment after separation” includes the slip-out behavior (“slip-out easily”) and deployment behavior (“deployment without actively powered components”).

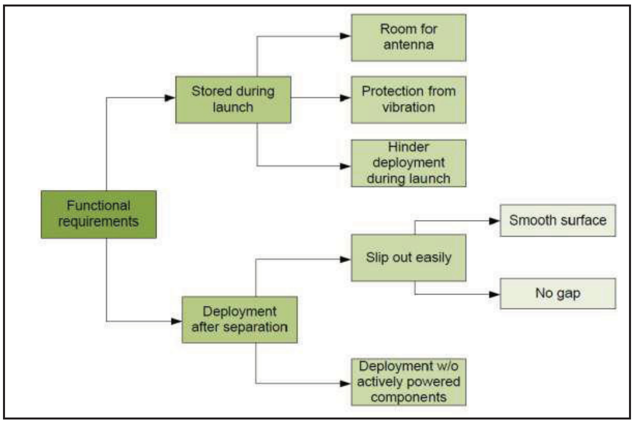

FIGURE 3. Functional Requirements

2.1.2. Nonfunctional Requirements

The top nonfunctional requirements are: “mass restrictions”, “volume restrictions”, “AB interfaces”, “manufacturability” and “environmental” aspects. Furthermore the requirement “volume restrictions” includes requirements concerning height, width and thickness of the box. The requirement “AB interface” is subdivided into “solar panel”, “multi layer insulation” (MLI), “power supply” and “structure” (mounting the AB to MOVE’s structure).

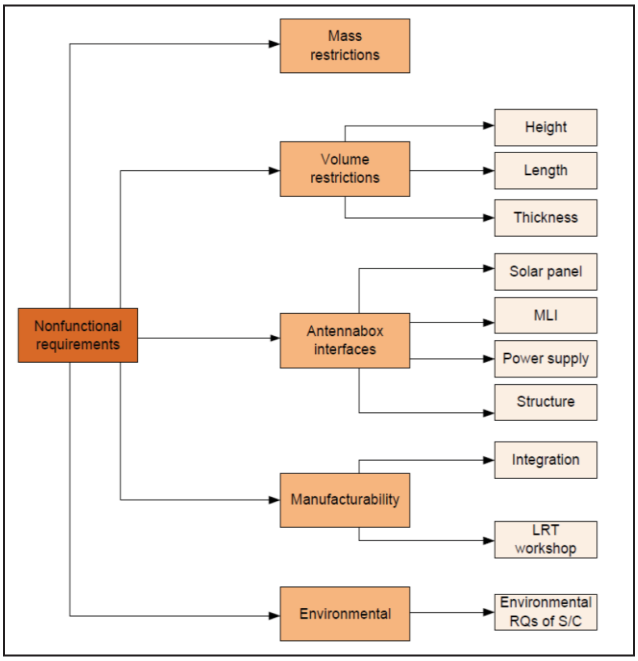

FIGURE 4. Nonfunctional Requirements

2.2. Conceptual Design

The conceptual design of the AB is deduced from the requirements described in the chapter above. All requirements, functional and nonfunctional, are clustered in two groups: basic design drivers and further design

[3] A .dxf file is a special format, developed by Autodesk, for data transfer from computers to machines.

drivers. The requirements and the implied restrictions on the design are listed in TABLE 1 and TABLE 2.

The main difference between basic design drivers (BDD) and further design drivers (FDD) is that the requirements in the BDD group cannot be changed; they are predefined by the interface requirements to the MOVE structure. The requirements have to be implemented as given. The requirements presented in the FDD chapter can be implemented in various ways.

2.2.1. Basic Design Drivers (BDD)

The basic design drivers are deduced from the following requirements: Volume restrictions, Antenna Box interfaces and Storage during launch. TABLE 1 presents the requirements in one column and the resulting restrictions for the Antenna Box in the second one as well as the solution.

Requirement	Restriction
Volume Restrictions	The layout of the whole AB, therefore height, width and thickness already defined: • Height: h_{max}=98 mm • Width: w_{max}=87 mm • Thickness: t_{max}=3 mm
Antenna Box Interfaces	1 The antennas – which shall be stored in the AB – are attached to the solar panels of the satellite. 2 The MLI is mounted to the Antenna Box using four M2.5 screws. **Solution:** Four threaded holes are necessary. 3 The power supply requires a squared space in the center of the box for the power connection. **Solution:** Space is left in at the place of the power connection. 4 The AB is connected to the satellite structure by four M3 screws. **Solution:** Four drillings are necessary.
Storage During Launch	1 The AB shall protect the antennas to make sure that they are not damaged due to vibrations during launch. **Solution:** A storage bag (SB) is integrated in the AB. 2 It is essential to keep the antennas in the correct position inside of the SB so that they cannot deploy during launch or in flight.

TABLE 1. Basic Design Drivers and Restrictions

2.2.2. Further Design Drivers (FDD)

Further design drivers for the AB construction are provided by the requirements: “mass restrictions”, “deployment after separation”, “manufacturing”, “storage during launch”, “environmental” aspects. TABLE 2 gives an overview of the requirements and the resulting restrictions:

Requirement(s)	Restriction(s)
Mass Restrictions	1 AB is not allowed to weigh more than 10 g 2 Material has to have a low density and a high Young's Modulus
Deployment in Orbit	1 No adhesive leftovers are allowed on the surface of the storage area 2 Antenna shall unfold easily 3 Antenna shall not stuck to a rough surface or edge (e.g.: left over from production)
Manufacturing	1 Produced by student 2 No money shall be spent for external manufacturing
Storage During Launch	1 Keep the antennas in the correct position inside of the SB 2 Reduce degrees of freedom (reduce vibrations) 3 Hinder deployment due to vibration
Environment	1 Needs to be temperature resistant in orbit 2 Materials have to be space proved and qualified

TABLE 2. Further Design Drivers

2.3. Solution Proposal for Storage Design

This chapter deals with the requirement “storage during launch”. Since this requirement is about the basic aspects of the Antenna Box – the Storage Bag – it is described separately from the other requirements in this chapter. One part deals with the Storage Bag (SB) and its layout. The other part describes the mechanical interface (MI) of the Antenna Box to the MOVE structure and the solar panel (SP).

Several design options are considered for the SBs and the MI. To determine the best solutions for the final design the different design options are evaluated. The chosen evaluation approach is an efficiency analysis developed by Zangemeister. The efficiency analysis is not part of the paper. In the following subchapters only the final solutions are presented.

2.3.1. Storage Bag Design

Two different storage bag designs are developed: One for the uplink and one for the downlink antenna. The SBs are integrated into the Antenna Box. The chosen way to design such a bag is to construct the AB by using several layers of CFRP UD.

- Two outer layers (OL), CFRP t_{OL}= 0.3 mm
- Two inner layers (IL), CFRP t_{IL}= 1 mm

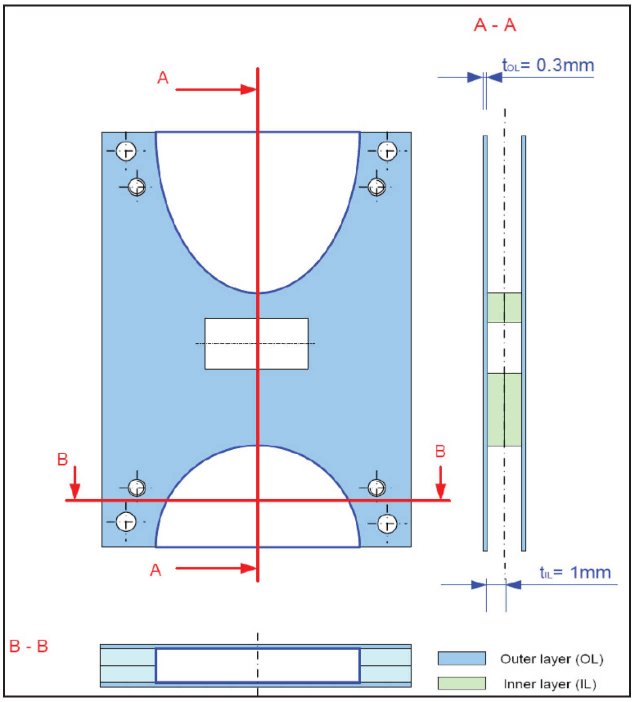

FIGURE 5. First Sketch of Layer Design with SBs

In that stacked compound of four CFRP layers (FIGURE 5) two SBs are integrated That is achieved by milling parabola shaped bags into the inner layers.

The center part of the inner layer that was between the two storage bags was removed. Only two small bone stripes on the edges of the box are kept (FIGURE 6). This solution has the tremendous advantage, that the overall weight of the AB will be reduced. Since the inner layers of the Antenna Box are three times as thick as the outer layer a high amount of mass can be saved by omitting the “inner filling”.

The next step in the design process is to design the inner layout (e.g.: surface smoothness) of the SB in a way that the antennas do not stick to the inside when they are deployed. A design layout for the inner surface has to be found that holds the antenna safe during launch and allows it to be easily deployed when the final orbit is reached.

The chosen design solution integrates rivets into the storage bags. The rivets are located approximately 5 mm above the bond line and shall offer a smooth, friction free, tack free, particle free and smooth support area for the antennas.

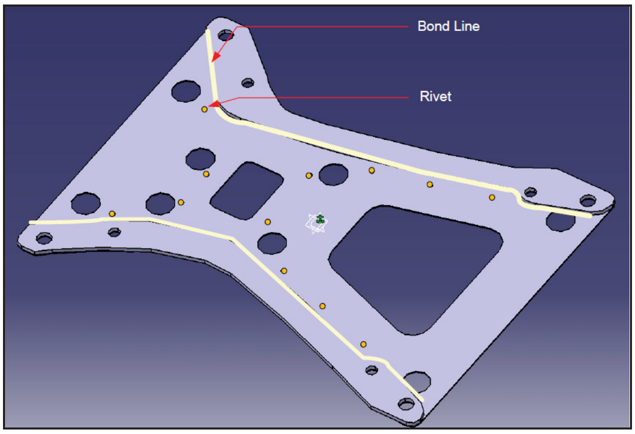

FIGURE 6. Final design of Antennabox with Storage Bags

2.3.2. Mechanical Interface to MOVE Structure

The mechanical interface (MI) design covers the interface of the Antenna Box with the satellite structure. The first step is to attach a CFRP antenna channel (AC) to the solar panel. This AC shall keep the antenna in a straight position above the AB. A three dimensional view of MOVE with the AC can be seen in FIGURE 7 and FIGURE 8. This AC setup is for all further design proposals.

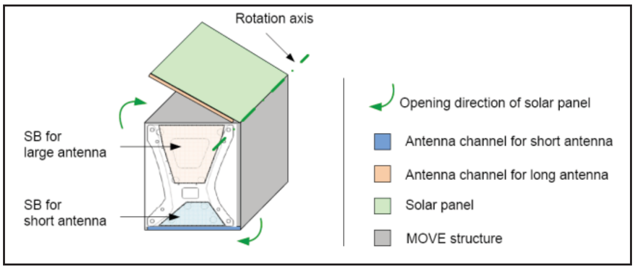

FIGURE 7. Position of Antenna Channel on MOVE’s Solar Panel

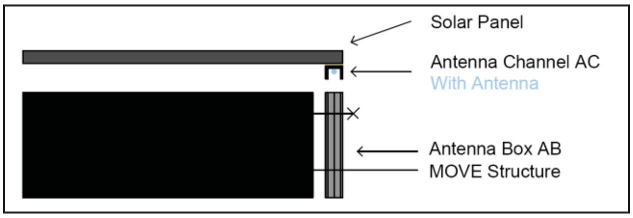

FIGURE 8. Antenna Channel mounted to the Solar Panel

The mechanical interface is designed as Spring Interface Design (SID) (FIGURE 9), a metal spring is attached to MOVEs structure. This has the following advantages:

- The AC does not have to be reworked (no damage to the SP and solar cells)
- The AB does not have to be fitted to a special AC, a quick exchange of an AB is therefore possible

- The metal spring can be adjusted for perfect fitting to the AC and antenna

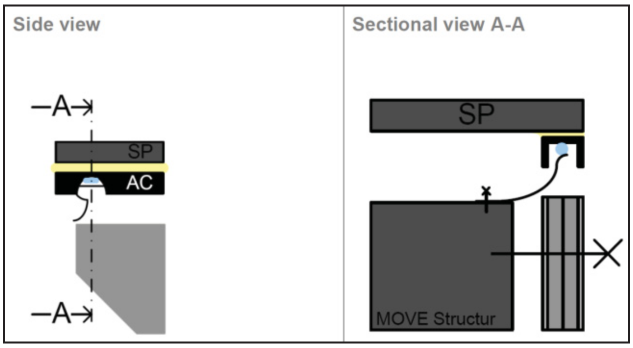

FIGURE 9. Views of Spring Interface Design

3. MANUFACTURING PROCESS

This chapter shows the steps of the manufacturing process of the Antenna Box. The following chapter describes in detail the:

- Milling Process,
- Bonding Process,
- Riveting/ Clinching Process
- Integration of the antenna into the Antenna Box.

3.1. Milling Process

From the CATIA model the outline drawing of both layers is transferred to a .grav file. This makes it possible to read the outline data with the IWOS CadCam Program [4] which is used to operate the milling machine. FIGURE 10 shows the OL of the AB after the milling process.

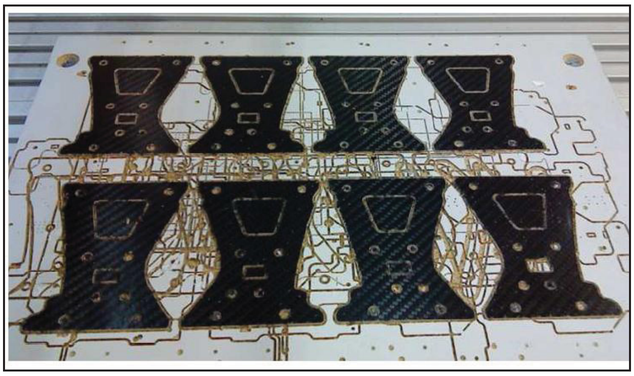

FIGURE 10. Outer Layers after Milling Process

3.2. Bonding Process

FIGURE 11 shows the bonding support mechanism (BSM) developed during this thesis. The BSM adds pressure to the bonded compound and minimizes the amount of air enclosures in the adhesive layer between the CFRP layers. It helps to keep the layers together so that no gap can be formed in between.

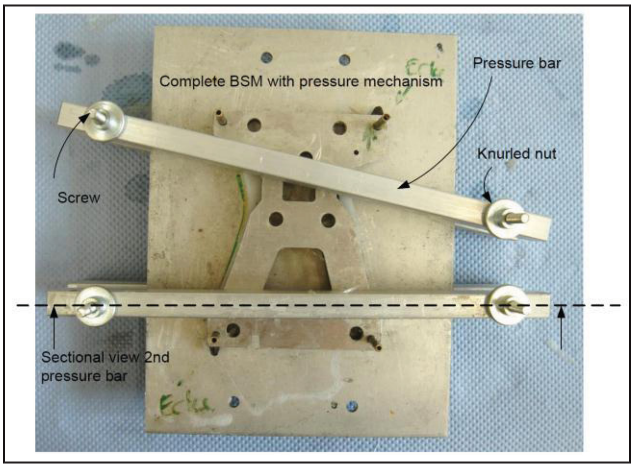

FIGURE 11. Bonding Support Mechanism

The milled parts (OLs and ILs) and the pressure components of the BSM are stacked to the BSM plate (with copper pipes). If all parts fit well together, all parts are removed from the BSM Plate and the preparation for bonding starts.

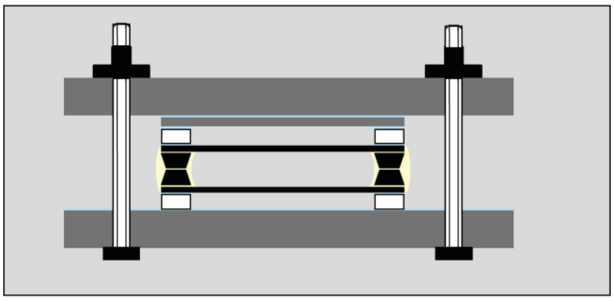

FIGURE 12. Sectional Cut Through the BSM

The used space qualified adhesive is Rütapox® L20 and SL75. To achieve the right mixing of the adhesive the mass of the raisin and the hardener is measured. The mixing ratio of Rütapox® L20 and SL75 is according to the datasheet 100:32.

After the bonding process is completed the curing process is started right away. The bonding support mechanism with the integrated AB (FIGURE 11) is placed in the preheated oven for four hours at a temperature of 60°C. After the first heating stage the temperature is increased to 130°C. The BSM with AB has to stay for three more hours in the oven during the last stage.

After the curing process the rivets are integrated into the AB which will provide a clean tack free and friction depleted surface for the antenna in the SB.

3.3. Antenna Integration

The Antenna is integrated into the Storage Box using a unique winding approach which will be explained in the following chapter using the storage bag for the downlink VHF Antenna with a length of 470 mm as example.

The antenna end will be placed in a CFRP antenna channel (AC), which is bonded to the solar panels (SP). The position of the channels is shown in FIGURE 13.

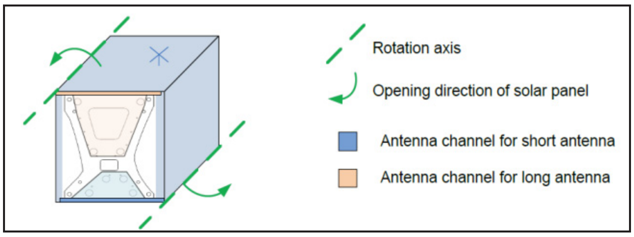

FIGURE 13. Position of the Antenna Channels

The antenna is on one end fixed to the solar panel, the other end will be fixed in the CFRP channel by a small metal spring (MS). The MSs are mounted to the satellite structure. Their position can be seen in FIGURE 14 and FIGURE 15.

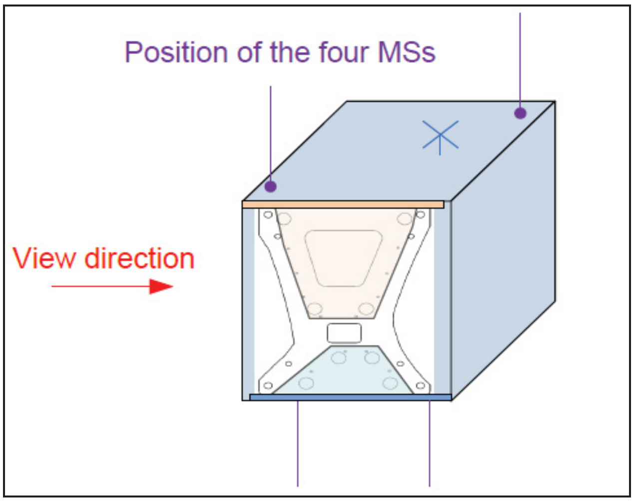

FIGURE 14. Position of the four Metal Springs (MSs)

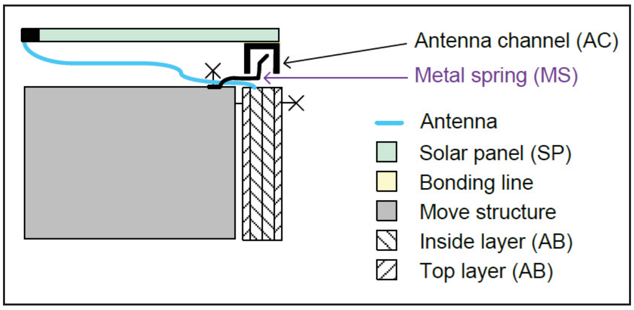

FIGURE 15. Side View of MS and AC Interface

3.3.1. Preparation

For preparation of integration the satellite is positioned on a straight surface (FIGURE 16). The solar panel is positioned in an angle of approximately 20° as shown in the picture below. This position can be fixed by using a screw or by using tape. The SB in which the antenna will be positioned points upward.

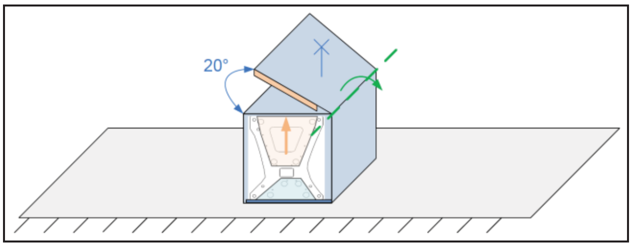

FIGURE 15. Satellite Preparation Position for Antenna Integration

3.3.2. Integration

Integration of the antenna into the box is performed in 7 single steps. The final result of the winded and integrated antenna can be seen in the figure below. An Antenna Winding Manual (AWM) is developed so that the Antenna integration is performed in the right way.

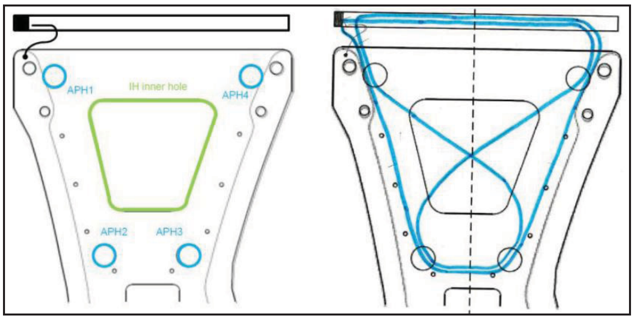

FIGURE 16. Picture of winded Antenna inside the SB

4. RESULTS OF THIS WORK

The main results of this work are four ready-for-integration Antenna Boxes for the first MOVE Satellite Mission. Two AB will be directly integrated into MOVE. The spare AB manufactured will be used as back-up parts, e.g. in case of damage during transportation of MOVE to the launch site.

To assure proper manufacturing and usage of the AB two manuals were developed during the development:an Antenna Box Bonding Manual (ABBM) and Antenna Winding Manual (AWM).

The ABBM [5] was prepared to support the bonding process of the AB. With help of the manual it is easier to keep track to the single steps which have to be followed during the bonding process of the AB. It assures that, if all the given guidelines are complied, a proper functional AB will be the result.

The AWM [6] for the antenna integration shall support the assembly team. The AWM includes six steps which have to be completed to assure a proper and secure positioning of the antennas during launch and in flight. The antennas shall be winded into the SB of the AB the same way as described; only this winding approach was tested during the thesis, and for this reason it can be stated as reliable (tested 25 times per produced AB). FIGURE 17 shows the final version of an Antenna Box and FIGURE 18 shows the Antenna Box integrated into the MOVE satellite.

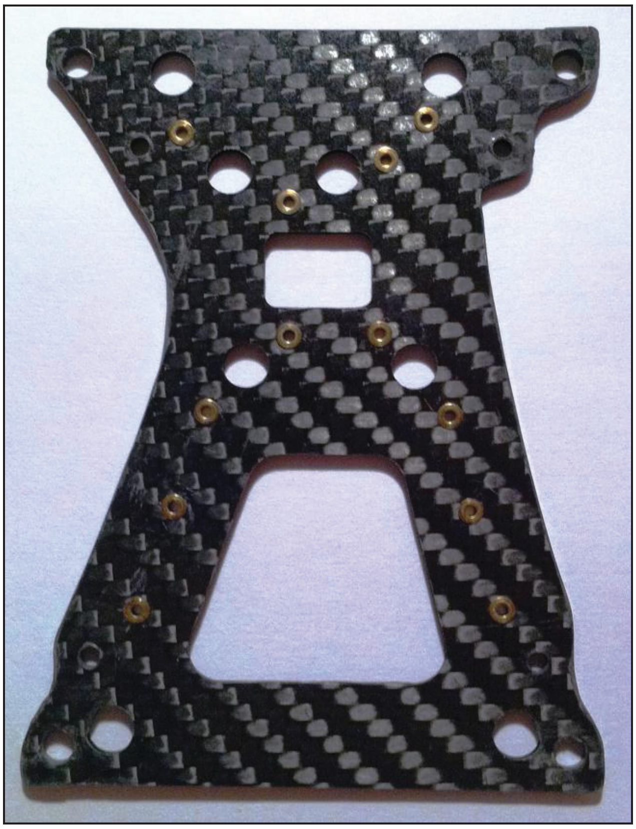

FIGURE 17. Picture of the Final Version of the AB

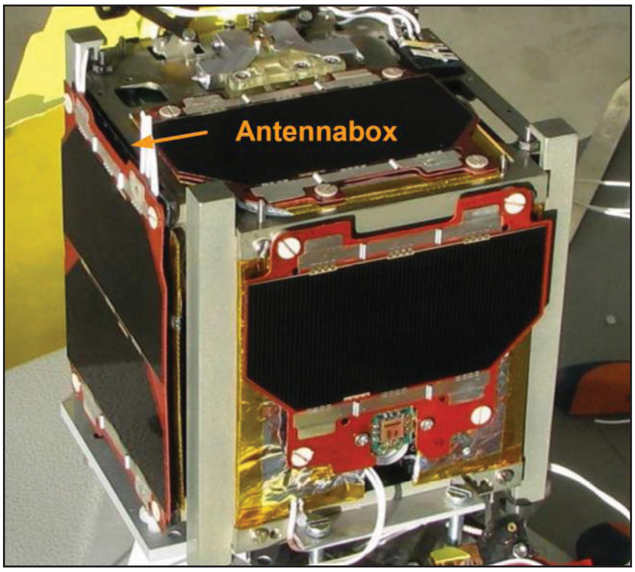

FIGURE 18. Integrated Antenna Box

5. CONCLUSION AND OUTLOOK

5.1. Conclusion

As conclusion it can be stated that a space qualified Antenna Box for the CubeSat MOVE has been developed, which is reliable in keeping the antennas save and is adaptable to the solar panel release mechanism of MOVE. That means if the SPs are deployed in orbit, the antennas will be released out of the AB to reach their final position. All other functional requirements were also met and verified.

The design of the AB also meets all non-functional requirements, which was also verified. The total mass measured is 6.998 g and therefor 30 % below the requirement target of 10g per AB. In addition to the Antenna Box design the necessary manufacturing and integration processes have been developed and qualified. This enables a reliable production of further ABs for future missions.

5.2. Outlook

Whether the Antenna Boxes operate well in orbit will be shown when First-MOVE is launched in the End of 2012[4]. If they operate successfully, the design of the Antenna Boxes can be used again for the next MOVE Missions MOVE-On and MOVE-Further.

6. REFERENCES

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[4] No exact launch date has yet been defined.