HF-VHF Compact Tubular Deployable Antenna Mechanism

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ABSTRACT

HF-VHF CTDA: High Frequency-Very High Frequency Compact Tubular Deployable Antenna is a "low" frequency radar that has been developed within an ESA-s TRP. The goal is to achieve a global signal penetration for Near Earth Asteroid (NEA) of 260-600 m diameter from a few kilometres distance. This ground penetrating radar can be embarked within several cubesat (about 6U), or small satellite, with a volume allocation of 1-2 U. A set of identical nanosatellites is deployed and orbit around the target.
Compact HF-VHF Tubular Deployable Antenna has been developed from a basic concept up to a mature design. SENER Aeroespacial has been assigned by ESA to develop a Bread Board model to demonstrate the validity of the design.
This paper presents the design, development and verification results of the Compact HF-VHF Tubular antenna, which is a dipole antenna that can work at 100MHz, 50MHz or 25MHz frequencies. Each dipole arm can be deployed and retracted, and the length can be adjusted to the three frequencies mentioned above which correspond to 66cm, 137cm and 2800cm length each boom.

1. INTRODUCTION

The CTDA design shall minimize the mass and stowed envelope of the dipole antenna while providing a relatively long length deployment capability and length control. After a trade off between different deployable boom technologies, a STEM (Storable Extendible Tubular Member) concept was selected. It is based on the same principle as the tape measure. The strip is coiled on a drum for storage and can be deployed and retracted by rotation of the drum in a compact mechanism. Strain energy is stored within the strip, this energy must be contained by the stowage cassette. The stowed STEM fits into a small space and can extend many times. The concept provides optimum stowed envelope vs deployed length ratio.

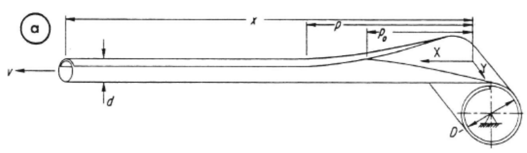

Figure 1 Deployment of single STEM

However, the mechanism needed for the deployment control is more complex compared to other boom concepts like hinged booms.

The STEM booms and its deployment mechanism has a long history and was used in space from the earliest small satellites in the 1960s as antennas and gravity gradient booms to the current GPS series of spacecraft.

The objective of this activity was to optimize the mechanism design to provide the required functionalities while keeping a low stowed envelope and mass.

2. DESIGN REQUIREMENTS

The major requirements for the HF-VHF CTDA can be summarised as follows:

2.1 Functional Requirements

- Boom deployment length at 25MHz configuration: 2,8m
- Boom deployment length at 50MHz configuration: 1,37m
- Boom deployment length at 100Mhz configuration: 0,66m
- Length control accuracy at each position: < 3cm

2.2 Structural stiffness

- First natural mode frequency in stowed configuration higher than 60 Hz.
- First natural mode frequency in maximum length configuration higher than 0,5 Hz.

2.3 Mass

- Mass less than 1 kg per boom.

2.4 Volume

- 2Us: 200x100x100mm

2.5 Environmental requirements

- Quasi-static acceleration of 30 g in any direction.
- Random vibration environments of 24,4 grms
- Sinusoidal accelerations of 30g.

2.6 Electrical requirements

- Electrical insulation: Antenna path shall be insulated from the structure by > 0,25 Mohm.
- Electrical resistance from boom tip to RF balun connection shall be: < 30 Ohm

3. DESIGN DESCRIPTION

The design is based on a gear system moved by a stepper motor. The original mechanism design was

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based on the collapsible tube mast mechanism developed at SENER in the past.

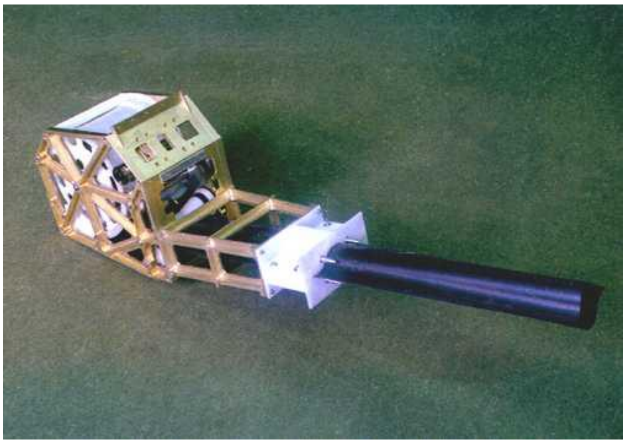


Figure 2 SENER Collapsible Tube Mast (1998)

This mechanism uses a selector device to transfer the movement coming from the motor either to the extraction rolls (for deployment) or to the spull (for stowing).

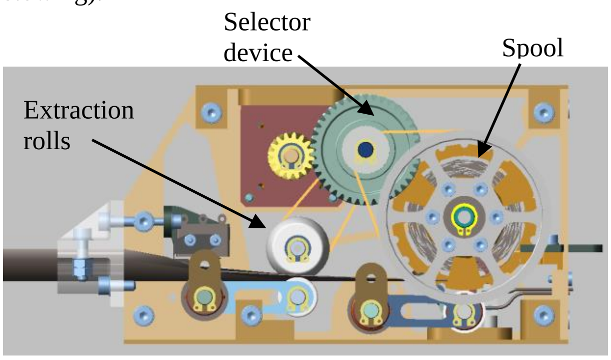


Figure 3 CTDA mechanism

The mass of the boom assembly is specially driven by the mechanical components required for the correct deployment and retraction control. The width of the STEM blade when flattened also affects the mass as the mechanism structure width and moving components shafts length is hardly conditioned by this parameter.
Considering this, the design optimization has been focused in two actuations:

3.1 STEM design

On the one hand, the design of the STEM has been adjusted to provide sufficient stiffness with the shortest width of the blade to minimize the mass and the size of the mechanism.

The Titanium grade 5 (Ti6Al4V) has been selected as the STEM manufacturing material among other options such as CuBe, CFRP or GFRP.

The Titanium and the Berillium Copper provided very similar RF performances. Considerably better performances when compared to CFRP solution of GFRP with embedded metal filaments solutions even if the composite material solutions where a better option from the pure thermo-mechanical point of view.
Finally, due to the slightly lower mass and safety issues when manufacturing, the Ti6Al4V was selected as a preferred material against the CuBe.

The STEM shape was adjusted to minimize the stowed envelope while maintaining the deployed minimum natural frequency.

A Back-up option was also defined based on CFRP with external metallic coating to improve RF performances. In the following table the natural frequencies for the Titanium and for the back-up solution are shown.

Table-1. Deployed STEM natural frequencies

	CFRP (0.4 mm)	Titanium (0.15 mm)
Mode N	Freq (Hz)	Freq (Hz)
1	1.2	1.15
2	2.51	2.08
3	6.24	4.27
4	7.53	7.25
5	9.26	8.03

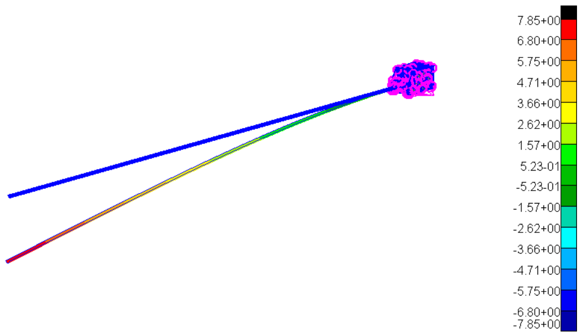


Figure 4 Deployed STEM first natural mode

3.2 Mechanism design optimization

On the other hand, the mechanism design was also optimized
The motor size was reduced to the minimum required to cover the motorization margin.
The spool diameter and other components such as preloading rolls size was also reduced to a relatively small size but guarantying their functionality.

3.2.1 Deployment length control

For the deployment length control, the boom is perforated in three different positions that define each of these nominal lengths.
A micro switch is installed in contact with the boom in the transition zone between the deployment rolls and the boom base support. The micro-switch is located in the centre line of the boom, aligned with the three perforations that indicate the three nominal positions.
Each time a perforated area arrives to the switch position, the lever of this device will be introduced in the hole and a signal will be sent to the electronics to stop the movement, either in deploying direction or in stowing direction.

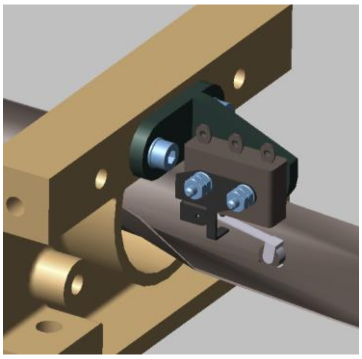


Figure 5 Length control micro switch

This control system avoids the need of using more complicated position sensors which are heavier and make the drive electronics heavier and more complicated as well.

3.3 Electric insulation of the boom

One of the most important requirements for the boom was to provide good electrical conductivity from the boom tip to the balun connection point on the other extreme of the mechanism structure. But good electrical insulation shall be guaranteed between the RF path and the mechanical components.
All the mechanical parts in contact with the boom where made in Teflon or Peek.
Teflon was used for the boom support at the front of the mechanism structure as the boom must slide on these parts.
Peek was used in the rest of the mechanism parts in contact with the boom, which were basically the extraction rolls, the compression rolls and the spool.
A slip contact is used between the spool cylinder and the balun connection point. The Spool cylinder, which is made in peek (plastic material), is covered by a metallic layer, and a pair of contact pins are slightly preloaded on this metallic surface to ensure a good electrical conductibity.

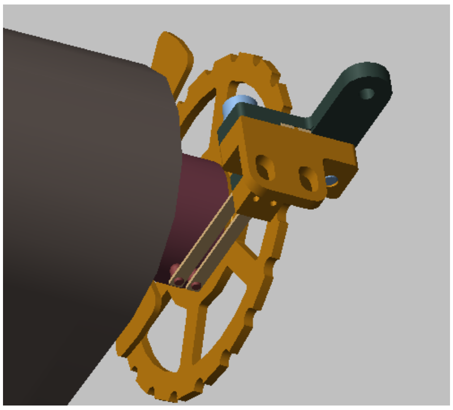


Figure 6 Electrical contact between spool and the end connection

Balun is based on Fair-Rite FT140-43 ferrite toroid. 10 turns of bifilar windings (enamelled AWG20 copper wire) were used to construct current type balun

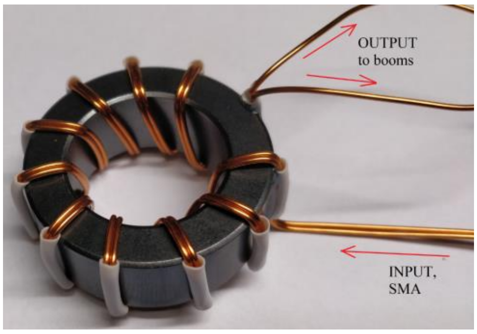


Figure 7 Balun details

The balun is supporteed in a housing made of peek, with the SMA connector on the top and tow wire ends, one at each side of the howsing that are connected to each boom end connector.

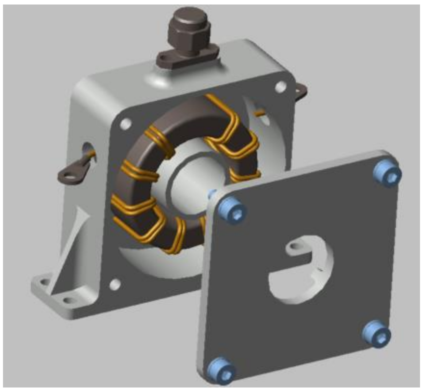


Figure 8 Balun Housing

The housing with the balun is located between both booms as seen in the figure below.

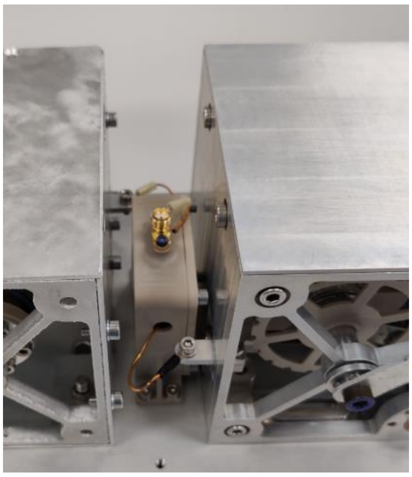


Figure 9 Balun position on the dipole antenna

3.4 Alternative design solution for mass reduction

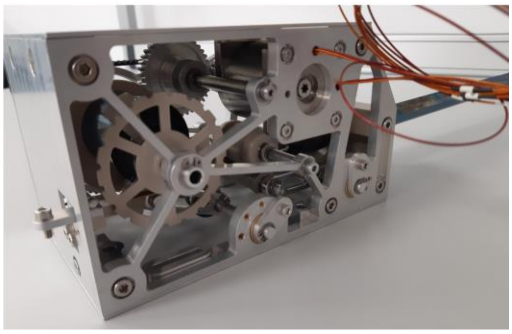
Based on the mechanism design of the CTM, an alternative design solution of the extraction mechanism to reduce components and mass was also considered. In this case, the selector device was removed, and the motion was directly transferred from the motor to the spool. This means that both the extraction and stowing movements were managed directly by the spool rotation. This concept carries some problems during deployment. As the spool tries to push the boom out, the boom strip, which is rolled around the spool tends to unroll inside the mechanism housing. This problem is solved reducing the friction of the boom on the way out from the spool to the tip of the mechanism. The compression rolls also must provide sufficient force to avoid this undesired unrolling effect.
This alternative design was finally adopted as a baseline design for all the test campaign, which was successfully passed as described in the following paragraphs.
It was learned, on the one hand, that the initial design concept which used the selector device to switch from deployment to stowage configuration, involves some difficulties. Specially, on the extraction rolls, if the motion principle to pull the boom is the friction force, a silicone base material or something similar must be used to increase the force and avoid any risk of having slippage between the rolls and the boom sheet, which would mean a fail in deployment.
On the other hand, it was concluded that the compression rolls are of special importance if both the deployment and the stowing movements are managed by the spool cylinder. This compression avoids undesired unrolling of the boom inside the mechanism, and ensures therefore, a successful deployment.

4. BBM MODEL VERIFICATION

4.1 BBM Model

The Bread-Board model is used for environmental and functional verification of the design and RF performance comparison.

The BBM main components, such as structure, gears, shafts, motor and boom are Flight hardware representative. The bearings, bushings and the micro switch are not flight representative.



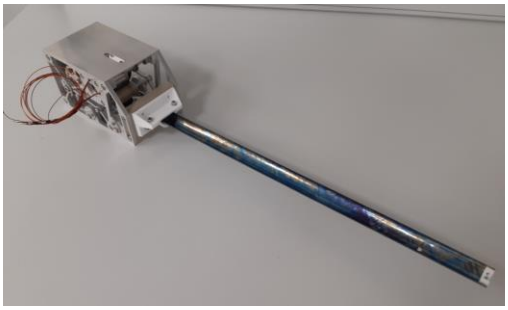


Figure 10 HF-VHF CTDA BBM

4.2 Mass

The mass of the complete dipole antenna including the RF balun and two identical booms is 2,38Kg.

Table-2. Mass Budget

Assembly	Mass (gr)
Boom assembly (without HDRM)	1143
Balun with cage	94,5
Dipole (2 booms + balun)	2380,5

4.3 Functional Testing

The functional testing consisted in several different tests that were performed in a clean room.

4.3.1 Alignment, Accuracy and Deployment length measurement

The Boom was deployed in both upwards and downwards directions. A partial gravity compensation was required in the last stage of the upwards direction deployment to avoid the boom strip being unrolled around the spool cylinder and the mechanism being blocked.

In this deployment tests, the length accuracy and lateral deviations were measured.

Table 3 Deployment length and lateral deviation measured in [mm]

Configuration	100 MHz (660mm) (645 to 700 allowed)		50MHz (1370mm) (1340 to 1410 allowed)		100MHz (2800mm) (2760 to 2840 allowed)	
	downwards	upwards	downwards	upwards	downwards	upwards
Length	664	661	1369	1368	2797	2798
Y axis deviation	-3	-1	-5	-2	10	11
Z axis deviation	-2	-3	-4	-2	4	6

The nominal lengths were 660mm, 1370mm and 2800mm for each of the tree configurations. The boom deployment accuracy was -3mm to +4mm. This is inside the allowed length variation (indicated in the first row of the table) according to the RF analyses.

4.3.2 Electrical resistance measurement

The electrical resistance measurement is used as a rapid check of the antenna integrity before and after the test campaign together with a reduced functional test (partial deployment).
The electrical resistance was measured by a multimeter between the CTDA balun connection point and the boom.

Figure 11 Boom electrical resistance measurement

The measured resistance values in the different configurations of the boom are shown in the table below. The electrical resistance value was measured between the boom tip and the balun connection bolt close to the back panel.

Table 4 Boom electrical resistance from tip to back RF connection point

Configuration	Measured resistance
100 MHz	2,9 ohm
50 MHz	6,3 ohm
25 MHz	39,4 ohm

The electrical resistance between the boom and the mechanism external structure was also measured. The value obtained was above the multimeter measurement range, so good insulation, higher than 2MOhms is guaranteed.

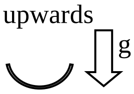
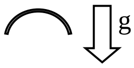
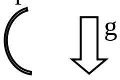
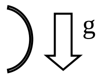
4.3.3 Buckling Test

The buckling test was performed with the boom deployed in horizontal direction in the 4 different configurations shown below.

1. With the Z axis upward.
2. With the Z axis downwards.
3. With the Y axis upwards
4. With the Y axis downwards

The boom was deployed until buckling happened and the deployed length at the buckling point was measured and is shown in the table below.

Table 5 Boom buckling test results

Configuration	Maximum length until bickliong
Z axis upwards 	No buckling happened
Z axis Downwards 	1292mm 
Y axis upwards 	1150 mm 
Y axis Downwards 	1145 mm 

4.4 Vibration Test

The following test sequence was applied in each axis (X,Y and Z):

1. Sine survey 0-2000Hz at 2oct/min (0,5g input)

2. Sine intermediate level 5-100Hz 2 oct/min
3. Sine full level 5-100Hz 2 oct/min
4. Sine survey 0-2000Hz at 2oct/min (0,5g input)
5. Random low level (-10d B 20 sec + 1 min)
6. Random intermediate level (-6 dB 20 sec +1 min)
7. Random full level (0 dB 20 sec +2 min)
8. Sine survey 0-2000Hz at 2oct/min (0,5g input)

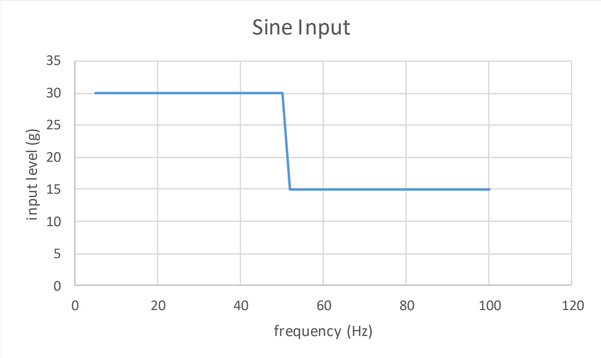


Figure 12 Sine test input (max 27g reached)

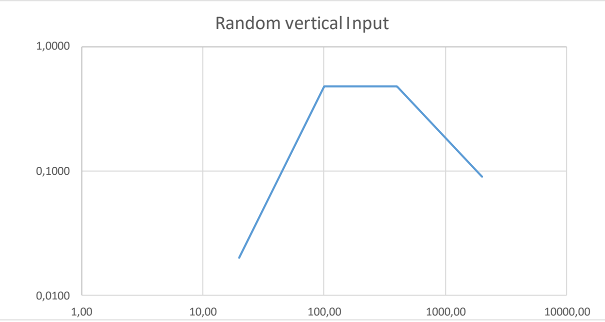


Figure 13 Out of plane random input (21,43 grms)

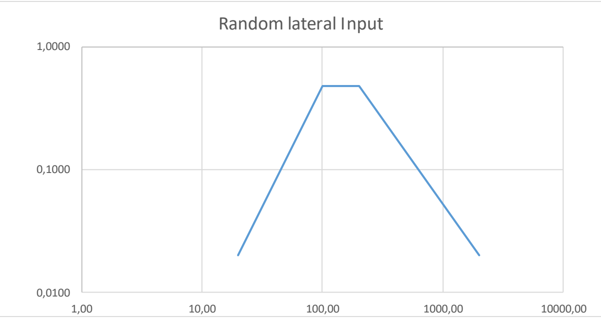


Figure 14 In plane random input (14,54 grms)

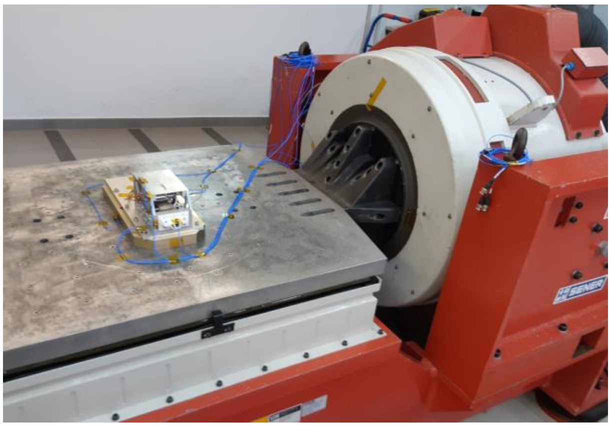


Figure 15 BBM on vibration table

No notching was applied in any of the tests.

A partial deployment test was performed after each axis vibration test and no failure or any changes on the performances was observed.

4.5 Shock Test

The shock test was performed in a shock table with a dropping mass. The test equipment was calibrated with a dummy mass.

A single shot was used to generate a three directional shock. This shot was repeated three times.

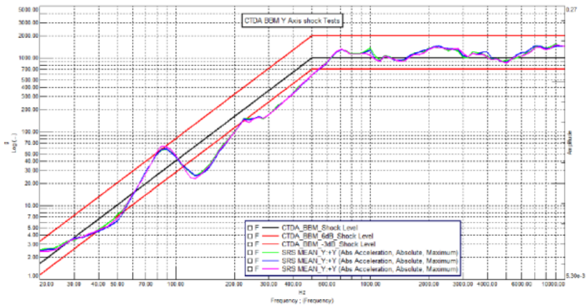


Figure 16 Shock test input graph

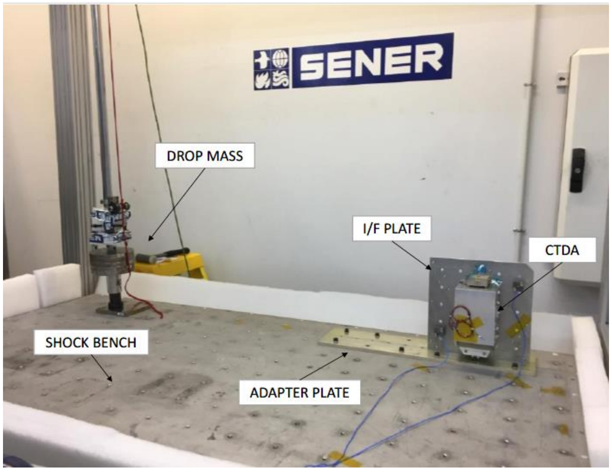


Figure 17 Shock test set-up

4.6 Thermal Vacuum Test

The deployment length was limited by the vacuum chamber size, and the difficulties to use a 0g device inside the chamber, so a reduced functional test with consisting in a partial deployment up to 66cm length was performed at cold and hot temperatures.
Also, a short life test was performed during the Thermal vacuum test which consisted in deploying and stowing the antenna inside the chamber in vacuum conditions, 9 deployments in hot temperature, 9 deployments in cold temperature and 8 deployments in ambient temperature were performed.

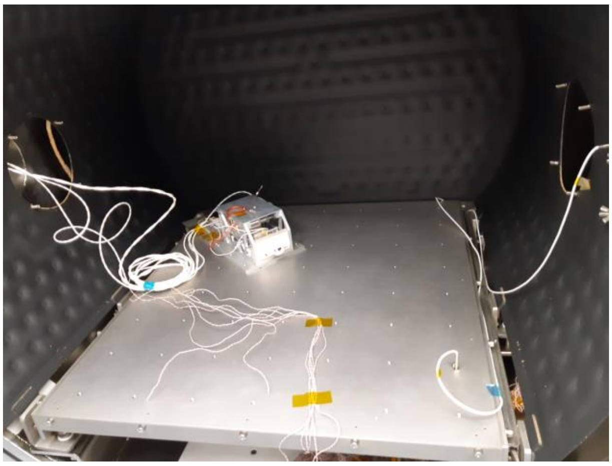


Figure 18 TVAC Test configuration

The thermal cycling hot and cold temperatures and stablished limits are shown in the table below:

Table 6 Boom Thermal cycling Temperatures

	Target Tº	Upper Tolerance	Lower Tolerance
Hot	+80ºC	+5ºC	-5ºC
Cold	-50ºC	+5ºC	-5ºC

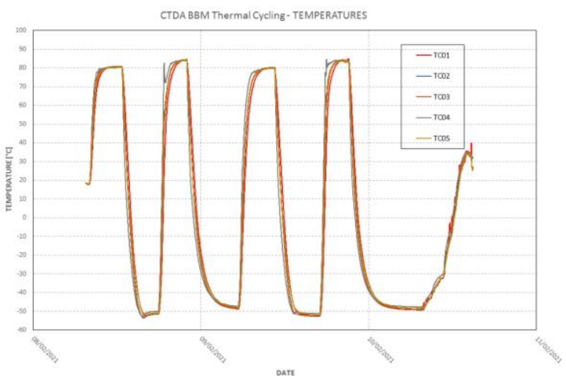


Figure 19 Thermal cycling Temperature measurements

The functional tests performed inside the chamber showed a good performance of the CTDA in ambient and hot temperatures.

During the cold temperature test at -50ºC the mechanism was not able to deploy. Several deployment attempts were performed during the warming up process and finally at -30ºC the mechanism deployed and stowed normally.
The reason for this blocking at cold temperature is thought to be the thermo elastic distortions between different materials. All the mechanism housing is made in Aluminium while the bearings are made in stainless steel. The motor itself has been tested on its own at -50ºC and it did work with no issues.

5. CONCLUSIONS

A STEM concept requires a very low mass, power and envelope w.r.t. the large deployment length it provides.

It shall be used in applications were no high stifness in deployed configuration is required.

The mass measured during the test campaign was 2,38Kg for the complete dipole antenna (no drive electronics considered), which can be extended up to 6m. However, it was demonstrated that the boom is able to deploy and stow driven only by the spool cylinder, and there is no need of extraction rolls or selector device. This means a considerable mass and envelope reduction.

Mass reduction due to this modification is estimated in around 400gr for the complete dipole antenna, which would weight less than 2Kg.

On the other hand, during the vibration test it was demonstrated that the motor back-driving torque is enough to keep the mechanism in stowed configuration and no hold down and release mechanism is needed.

6. REFERENCES

1. Small Planetary Platforms Assessment for NEO Inactive Bodies. CDF Study Report: CDF-178(A) January 2018
2. ADVANCED DEPLOYABLE STRUCTURAL SYSTEMS FOR SMALL SATELLITESW. Keith Belvin(1) , Marco Straubel(2) , W. Keats Wilkie(1) , Martin E. Zander(3) , Juan M.Fernandez(1) , and Martin F. Hillebrandt(2)

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