

# Modular, Customisable, Accommodation-Friendly Antenna System for Satellite Avionics

## Development, Prototyping and Validation

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**Abstract**— In the frame of ESA program AO/1-6737/11/NL/MH, an innovative X-band antenna system for satellite avionics has been studied, demonstrated and validated at Proof of Concept Model level. The innovative contribution of such an antenna system relies on modularity, customizability and accommodation friendliness. The antenna concept is based on a Plug and Play architecture, where the basic module is a 2.7 cm-cube with a mass of 53 gr, which can be clustered in array configuration. A catalogue of predefined and ready-to-use clusters could be developed with the possibility of adapting the antenna systems to various platform types by tuning just a few control parameters. Different levels of customization are, in fact, easily achievable reducing the qualification effort. The proposed antenna system has been prototyped and has been validated through two measurement campaigns, in standalone configuration and accommodated on a platform demonstrator having the shape of an ESA Proba V satellite. The whole antenna system has been also simulated with the commercial program ADF-EMS and a good agreement with measurements has been achieved, proving that the characteristics of such an antenna system can be very accurately predicted even in the most complex configurations. A comparison between the proposed solution and a more conventional space avionic radiator has been carried out: even though the EM performances are comparable, mass and encumbrance are instead extremely reduced in MCAS.

**Keywords**—Avionics, Plug and Play architecture, modularity, customizability, bonding wires, PIFA, measurements, simulations.

### I. INTRODUCTION

In the frame of ESA program AO/1-6737/11/NL/MH, an innovative X-band antenna system for satellite avionics has

been studied, prototyped and validated at Proof of Concept Model level.

The antenna system is intended to cover the needs of Earth Observation and Science Missions in LEO, GEO, GTO and deep space. It can be suitable to different avionic services, comprising Telemetry and Telecommand TM-TC, Telemetry, Tracking and Control TT&C (low gain, full-sphere coverage), data-link (medium data rate, orbit dependent coverage), RF tracking, inter and intra-orbit links.

The innovative contribution of such antenna system relies on the following aspects:

- modularity: it is based on the single design of a radiator suitable to be clustered;
- customizability: it can be used in different satellites (in terms of dimensions, payload, configuration) since it relies on a tunable radiator for accommodating several missions, without requiring further qualification tests changing customization;
- accommodation friendliness: it can be accommodated in unobtrusive locations of the spacecraft (like edges or corners) usually not used for other purposes.

The above mentioned features point out how this antenna system carries advantages with respect to the state of the art in this field. A comparison between the proposed solution and a more conventional space avionic radiator, consisting of a choked waveguide aperture, has been carried out showing that the resulting full sphere radiation patterns and the overall coverage performance indicators are comparable. However the existing off-the-shelf antennas,

like the one analyzed above, have a predefined coverage, are not always optimal and not easily optimizable. Other antenna types, such as quadrifilar helices, may offer better EM performances but are not comparable in terms of mass and encumbrance with the proposed antenna system.

## II. ARCHITECTURE

The antenna concept is based on a Plug and Play architecture [1],[2], [3]. It is essentially an “open scheme” able to cluster small radiating elements (a cube with 2.7 cm sides) of identical layout within a non-uniform array, to achieve a palette of possible radiating modalities. The input impedance of each radiator, quite sensitive to the specific placement on the platform and to inter element coupling, is easily tunable by acting on hardware control parameters.



Fig. 1. Transmitting Capsule or Elementary Cell

The system may be hence conceived as a “multilevel architecture” wherein simple radiating elements are assembled into service-specific clusters through two different kinds of customization:

- at cluster level: modifying the Beam Forming Network (BFN) to form the required pattern;
- at radiator level: to provide broadband circular/linear polarization and impedance matching.

The main advantage of this approach is the modularity and the ease of accommodation of the resulting electromagnetic system. A catalogue of predefined and ready-to-use clusters may be developed with the possibility of adapting the antenna systems to various platform types by tuning just a few control parameters.

More in detail, the proposed system comprises two families of basic hardware components:

- 1) the encapsulated tunable radiators: Transmitting Capsule (T-cap) or elementary cell - see Fig.1;
- 2) a dielectric or metallic support provided with one or multiple sockets (Board).

The system is inspired to the LEGO™ building toys, where the role of the bricks is played by the T-caps which are plugged in the Board in stand-alone or cluster configuration. Moreover, a further level of customization can be achieved adding some “accessories”, which, keeping in mind the previous analogy, can be associated to the LEGO™ adapters. For example, these elements have proven

to be effective in reducing the back radiation or in shaping the antenna radiation pattern.

An exploded view of the T-cap is shown in Fig.2. The selected radiators are four PIFAs: printed inverted F antennas capacitively fed by a mushroom-like monopole. The four PIFAs are fastened on the top face of an aluminum body. The cube top-face dimensions are 27x27 mm with a height of 30 mm approx., excluding the SMA connector. The cube is extremely light, weighting only 53 grs. The metallic body acts as housing for the element-level phasing network, which is formed by an input branch-line coupler, to select right or left circular polarization, and a rat-race to generate the required phase distribution with appropriate matching.

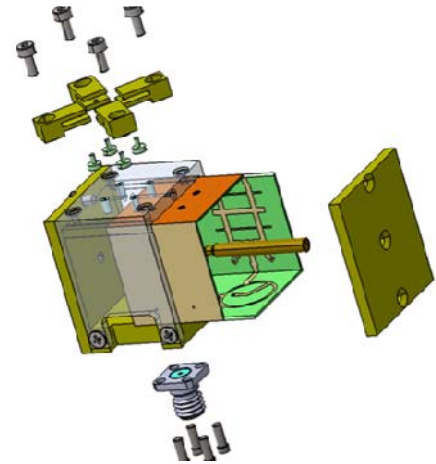


Fig. 2. Exploded view of the T- Cap.

For the sake of reconfigurability, Bonding Wire technology [4] has been chosen: golden wires of 25 micron-diameter by discretising the connection between two adjacent printed lines (see Fig.3). By selectively removing some bonding wires, both circular (LH and RH) and linear polarization can be “programmed”.

Without any need of modifying the inner BFN and the radiating element, it is possible to change the antenna radiation pattern including some add-on components, like a choked ground plane for back radiation control (see Fig. 4) or a larger circular ground plane to get an isoﬂux coverage (see Fig. 5). The total encumbrance and weight remain about the same.

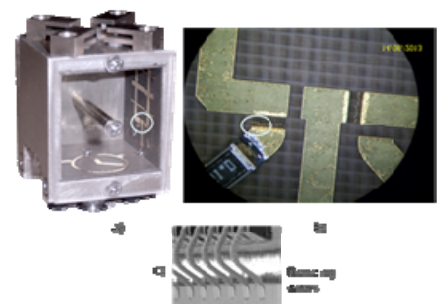


Fig. 3. Bonding Wires in the element-level phasing network.

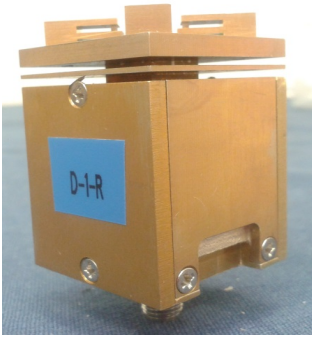


Fig. 4. Chocked T-cap element.

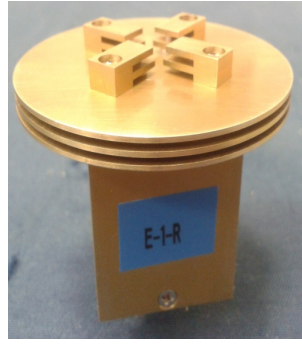


Fig. 5. Isoflux T-Cap element.

In order to achieve a directive coverage, the elementary cell must be clustered in array configuration (Fig. 6) fed by a global BFN.

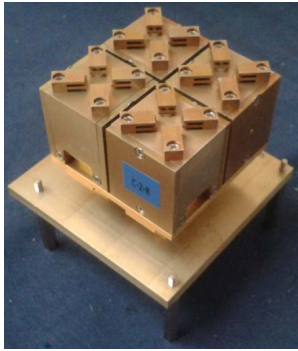


Fig. 6. Cluster configuration.

### III. EXPERIMENTAL RESULTS

#### A. Measurement Campaigns

Two different measurement campaigns have been performed. To validate the system at element level, the T-caps have been measured in stand-alone configuration in SL18 facility @ Microwave Vision Italy (Pomezia), see Fig.7. Tests in embedded configuration have been carried out in SG64 facility @ SATIMO Industries (Paris), accommodating the antenna system on board of a demonstrator having the shape of ESA Proba-V satellite, see Fig. 8.

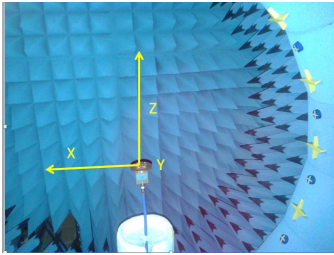


Fig. 7. Measurement campaign in the standalone configuration @SL18, MVI (Pomezia).

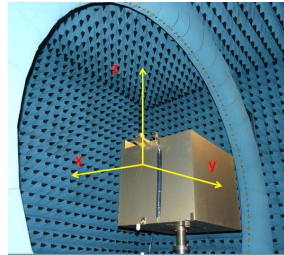


Fig. 8. Measurement campaign in the embedded configuration using an ESA Proba-V mock-up satellite @SG64, SATIMO Industries Paris.

#### B. S-parameters Results

The S-parameters of the standalone and embedded simple T-cap (Fig.1) are reported in Fig. 9. The reflection coefficient is lower than -10dB in the full operational band (7-8.5 GHz) with better performances in the upper part of the band. A significant contribution to the overall mismatch is due to the input SMA to BFN transition, which could be easily improved by a further design effort of this specific segment. The coupling S parameters between the elements, shown in Fig. 10, are very low. The yellow and grey curves are referred to the coupling between every pair of choked T-caps forming a radiating couple (further explications in next section), while the red, blue and green lines represent the coupling between adjacent elements.

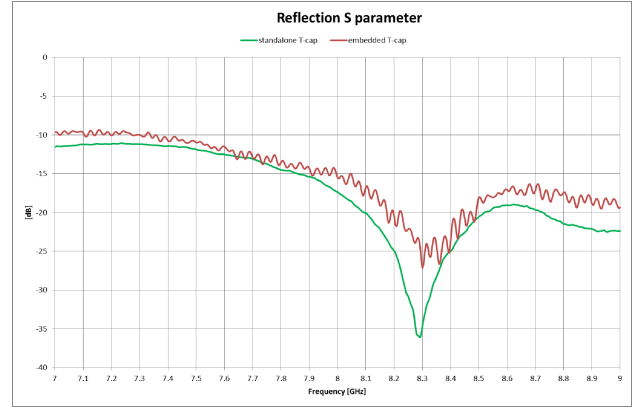


Fig. 9. Reflection S-parameter of an elementary cell in standalone and in embedded configuration.

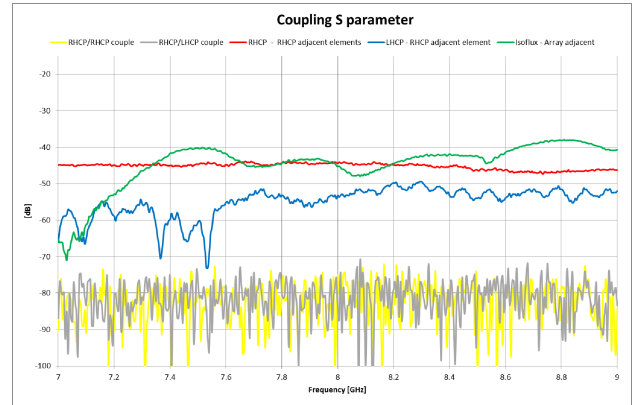


Fig. 10. Coupling S-parameters of the elements in embedded configuration.

#### C. Radiation Pattern Results

##### 1) Standalone configuration

The directivity radiation pattern @ 7212.5MHz for a left polarized chocked T-cap (Fig. 4) is shown in Fig. 11 in terms of measured results and ADF-EMS numerical simulations [5]. The agreement between the data is very good and the addition of a choked ground plane shows positive effects in reducing the back radiation.

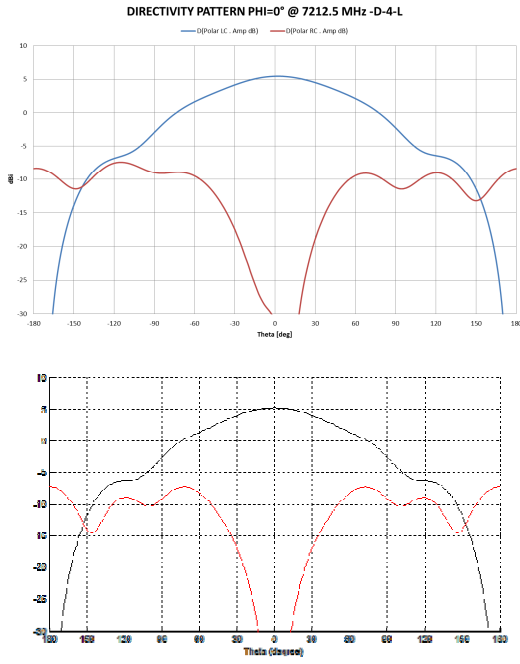


Fig. 11. Directivity radiation pattern cut of a left polarized choked T-Cap @ 7212.5 MHz: (up) measurements and (bottom) ADF simulations.

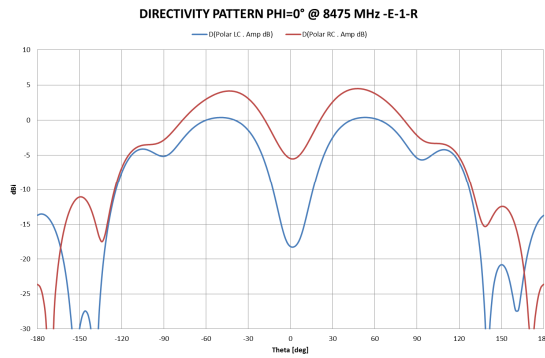


Fig. 12. Directivity radiation pattern cut of an isoflux T-Cap @ 8475 MHz.

The effect of adding a circular and larger ground plane (Fig. 5) is visible in Fig. 12, showing an isoflux radiation pattern cut @ 8475MHz.

## 2) Embedded configuration

Four choked T-Caps, an isoflux T-Cap and four simple T-Caps arranged as array have been accommodated over the edges/corners of the satellite demonstrator.

As expected, the shading of the satellite body is visible in the cut at  $\phi=0^\circ$ , according to the reference system shown in Fig. 8. The interference due to the platform results also in a ripple that spreads all over the envelope.

Fig. 13 illustrates the measured and the simulated radiation pattern at  $\phi=0^\circ$  @ 8450MHz of a choked T-Cap: as in the standalone configuration, also in the embedded one the agreement is pretty good.

The choked T-caps have been placed in order to form, in pairs, two couples to get the full sphere coverage, radiating the same or complementary polarization. In Fig. 14, the pattern of a couple formed by two choked T-Cap having the same polarization (RHCP) and placed on opposite edges of the mock-up satellite, @ 7190MHz, at  $\phi=90^\circ$  is shown. The directivity is higher than -5dBi in most part of the diagram.

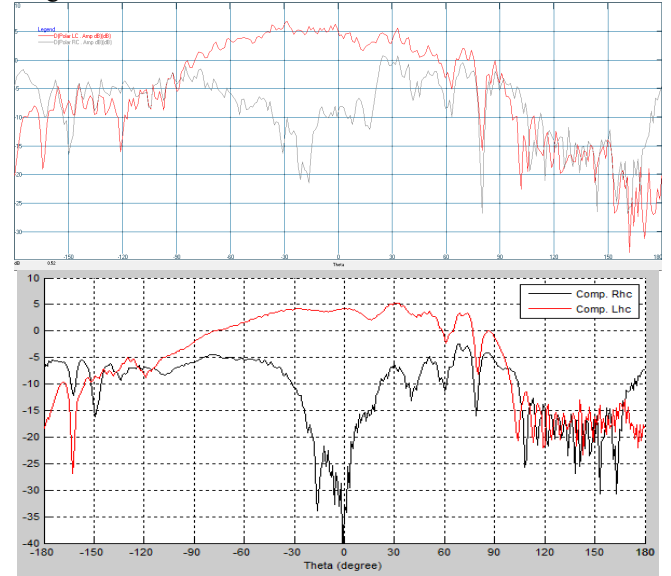


Fig. 13. Directivity radiation pattern cut of a choked T-cap in the embedded configuration, @8450 MHz,  $\phi=0^\circ$ : (up) measurements and (bottom) ADF simulations.

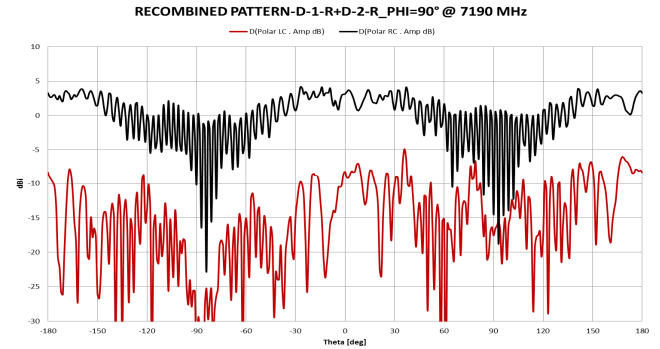


Fig. 14. Recombined pattern for a couple of choked T-Caps having the same polarization (RHCP) in the embedded configuration, @7190 MHz,  $\phi=90^\circ$ .

## IV. COMPARISON WITH A SPACE AVIONICS STANDARD CHOKED HORN ANTENNA

A numerical simulation comparison with a more conventional space avionic standard choked horn antenna (visible in Fig. 15) for hemispherical coverage has been performed. The embedded configuration has been considered for the comparison. The results are shown in Fig. 16, which shows the radiation patterns @7190MHz,  $\phi=90^\circ$ . The resulting full sphere patterns of both antennas are comparable.



A performance analysis has revealed that the overall coverage indicators are quite similar for the two devices except for the AR in the TX band, because of optimization issues of our antenna system.

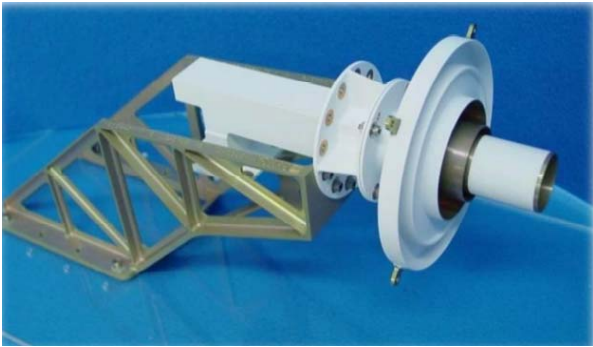


Fig. 15. Standard Chocked Horn Antenna

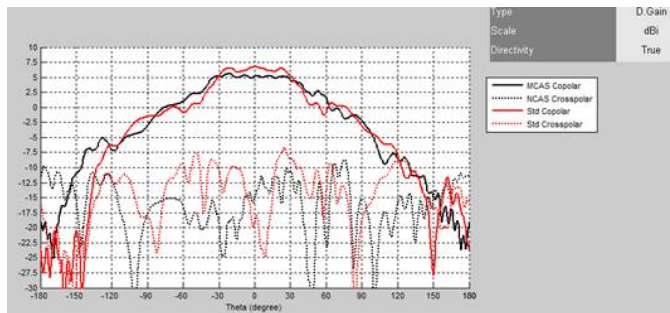


Fig. 16. Comparison between MCAS and Chocked Horn Antenna, @7190MHz,  $\phi=90^\circ$ .

## V. CONCLUSIONS

An innovative modular, customizable, accommodation friendly, miniaturized X-band antenna system for satellite avionics has been presented.

The Plug and Play architecture, which the design is based on, allows for easy tuning and time efficient customization, reducing the qualification effort and making the system suitable for different kinds of missions and satellite platforms.

All the configurations have been prototyped and validated through measurement campaigns.

The tests have shown very good agreement with numerical modeling, hence demonstrating how a complete control over the antenna system characteristics is achievable in all configurations through electromagnetic simulations.

The system is characterized by EM high performances, at least comparable to the existing off-the shelf antennas used in this field, with a clear advantage in terms of mass, overall dimensions and coverage flexibility.

Future developments will regard a global optimization of the design and manufacturing process of the antenna system, aiming at further improving electrical and radiated performances. Also the investigation of potential applications at Ku-band will be considered.

## ACKNOWLEDGMENT

This work has been performed under ESA Contract 4000104703, "Modular and Customizable accommodation-friendly Antenna System for satellite avionics".

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