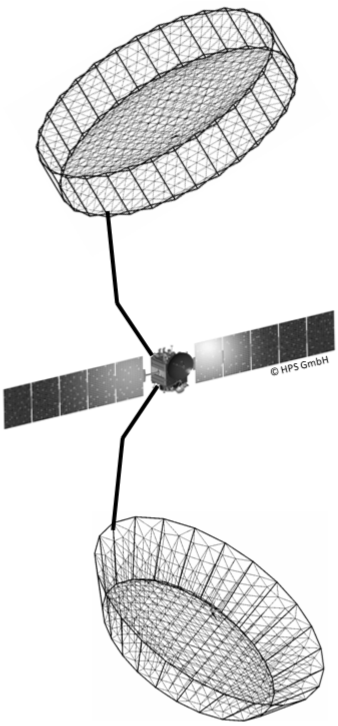
European Space Agency
ESA-ESTEC
ITT: AO 1-6282/09/NL/AF
ESA Contract N. 4000101324/10/NL/AF

# RESTEO

## REFLECTOR SYNERGY BETWEEN TELECOM AND EARTH OBSERVATION

# Executive Summary




March 2012

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# 1 INTRODUCTION

Within ESA-ESTEC project RESTEO, REflector Synergies between Telecom and Earth Observation, focus is made on the identification of the most promising reflector concept able to cope with the requirements of both telecommunication and earth observation future missions. Synergies and commonalities (as well as differences) between the two fields of application are pointed out and scalability and modularity of the deployable structures are taken into due consideration in order to identify potential reflector solutions covering broadcast and mobile application, active and passive remote sensing, from P to Ka band.

Telecommunication and earth observation future needs have been outlined in order to identify two classes of reflectors to be focused on.

The main sources of surface anomalies have been identified and after a trade-off among different reflector solutions, two baseline reflector concepts have been selected as the most promising ones, to be further investigated to achieve a viable solution for the development of a fully European Large Reflector Antenna solution.

# 2 MARKET NEEDS

Considering **telecommunication missions**, the main drivers for future applications are hereafter identified:

1. **Broadband Services**
   Whichever the coverage, to allow a real growth of the available band, TLC market is moving to smaller beams and to higher frequencies: from the well known L, C and S band to Ka band (Ka-SAT, INMARSAT-5, VIASAT-1), a natural choice considering the small portion of band available in the lower frequencies and the great amount of band made available at Ka-band.
2. **Handheld User Terminals**
   In both mobile broadcast and multi-spot systems the low gain typical of this kind of terminals requires an enhanced gain from the satellite antennas, compatible with larger reflectors.
3. **Replacement Satellites**
   To maintain backward compatibility and to provide growth.

Concerning frequency, **L and S band** applications for telecommunication missions are probably the ones which would have more advantages from the development of European large reflector technology: the market is already present and additional services could be implemented. On the other side it is evident that a consolidated tendency of the telecommunication satellite missions to move into an intensive use of higher frequencies exists. In particular, there is an evolution trend within the satellite market which leads to **Ka-band** application.

It is worth notice for high frequency applications there are additional factors to be taken into account in the development of the system, requiring parallel technological developments:

- on board flexibility is generally required for higher frequencies, to cope with the sensibility of the Ka-band to rain attenuation;
- lower RMS error is also required as the working frequency increases;
- less possibility to mitigate its effect by digital processing is present (at the moment);
- higher Pointing Accuracy is needed, because of the smaller beams.

In the **Earth Observation (EO**) field, there are a certain number of missions under feasibility study (BIOMASS and SMAP for example) which are evaluating the possibility to use a large reflector.
Even if mission needs are generally strongly dependent on the particular instrument, a common requirement is the compatibility with VEGA-like launcher, mainly because of budget problems.
Future generation of soil moisture and surface salinity missions, moreover, will require an integrated active radar and passive radiometer (as in SMAP) with dual polarization capabilities. Isotropic behavior of the reflecting surface with the polarization is, so, of primary importance, in particular when circular polarization is used.
In terms of frequency, EO mission generally exploit the lower part of the spectrum, from **P to X band**. Clearly in this case the required large apertures are related first of all to the low frequencies.
Starting from these considerations, two classes of reflector have been identified, divided on the basis of the deployed diameter, directly proportional to their operative wavelength: the first is in fact compatible with lower frequencies (from UHF to S band) and the second with the highest (from C to Ka band), as summarized in Table 1.

| Aperture Diameter [m] | Frequency Band |
|---|---|
| 9-25 | UHF-S |
| 4-7 | C-Ka |

Table 1: Identified classes of reflectors

As intuitive, the second class requires higher surface accuracy to cope with the more stringent requirements of the highest frequency.
Moreover, particularly important for the larger reflector, one of the most challenging requirements for LDR is the reflector stowability because of the limited space available in the launcher. This is particularly true for Earth Observation mission, requiring compatibility with Vega like launcher for budget contingency.

## 3 LDR

The technology trade-off among different possible implementations of large reflectors for the reference missions has been carried out on the basis of a comprehensive view of the identified solutions, jointly evaluating the mechanical and the RF-related aspects.
LDRs can be divided into a set of subgroups as follows:

- Mesh Reflectors
- Membrane and inflatable Reflectors,
- Shell-Membrane deployable Reflectors,
- Largely deformable Shell Deployable Reflectors, and
- Solid Surface Deployable Reflectors.

The development of a believable large reflector concept requires the clear understanding of all the main factors which can influence its performance.
As well known, in a LDR the reflecting surface is stowable and opportunely tensioned during the deployment of the reflector. The mechanical structure is the responsible of its tensioning.

Any deformation of the structure has an impact on the surface as in general, tolerances and anomalies of the LDR structure lead to a deformation of the ideal parabolic surface that, in a first approximation, can be generally expressed by RMS error. This allows using Ruze's derivation to have a first evaluation of their impact on the reflector performance in terms of gain degradation.
Three main sources of surface anomalies can be identified:

- **Mechanical tolerances,** due to manufacturing achievable precision and reproducibility, deployment repeatability, life time degradation of components and materials and gravity effect. Being non deterministic errors, these are generally described by RMS errors, uncorrelated on the reflector surface.
- **- Thermo-elastic deformations,** due to "slow" thermal variation across the reflector surface. Daily and seasonal variation can be identified acting on all the main components of the reflector, from the reflector arm to the mechanical structure to the reflecting surface and its supporting structure.
- **- Surface anomalies** related to the reflecting surface**.**

In terms of thermo-elastic deformation, the ones of the reflector arm can be considered the most critical one for large reflectors. The long boom, in fact, can significantly deflect due to thermal environment. Hence the design of Large Deployable Reflector is based on ultra high modulus carbon fibers composites with near zero coefficient of thermal expansion. Moreover, the implementation of a tracking system with an actuation mechanism can be envisaged, as well as the implementation of a digital beamforming network allowing dynamic compensation of errors by mean of "real-time" variation of the excitation coefficients.
All these solutions lead to a more complex system and their implementation have to be carefully evaluated in the frame of the particular program, mainly because of their impact on the overall cost budget.
With regard to accommodation requirements, needed reflector size, scalability and TRL, LDRs based on mesh and shell-membrane deployable surfaces were selected. Reviewing and trading-off existing LDR architectures known from the literature and flown in the past lead to the conclusion that deployable peripheral ring type architectures are the most promising for both EO and telecommunication missions and are scalable to various sizes.
For the deployable ring structure two concepts were selected and assessed for the targeted LDR apertures: Double Pantograph and Conical Ring shown in Figure 1.

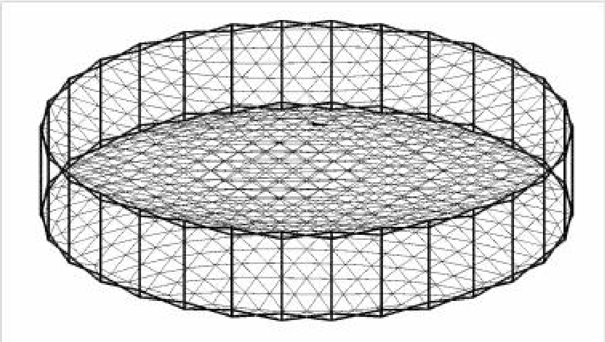
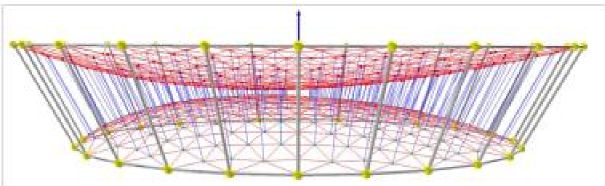
| | |
|---|---|
|  **Double pantograph ring LDR structure (ESA Patent 596)** |  **Conical ring LDR structure (ESA Patent 568)** |

Figure 1: Promising alternative LDR ring structures

Both, pantograph and conical ring are promising concept that may be scaled to cover different aperture sizes and frequencies.

The RF reflective surface, a major key technology, could either be in a knitted metal mesh or a carbon fibre reinforced silicone (CFRS) based shell membrane. Metal meshes have a wider heritage in terms of units flown and operating. However CFRS technology is currently under development while a reliable source of high performance knitted metal mesh needs to be established in Europe.
Whereas CFRS is inherent shape keeping, mesh requires tension in two directions in order to take the desired shape and fulfil PIM requirements. Therefore, a dedicated tensioning net system is required. Number of net bands and resulting facet size is directly related to the surface accuracy. The tension net also serves the purpose of stiffening the ring against torsion (c.f. spokes of a bicycle wheel). Also for the conical ring the nets system contributes to the LDR stiffness, which is already larger than the one of the cylindrical ring. This is especially of interest for a CFRS reflective surface which is requiring only an attachment at the perimeter.

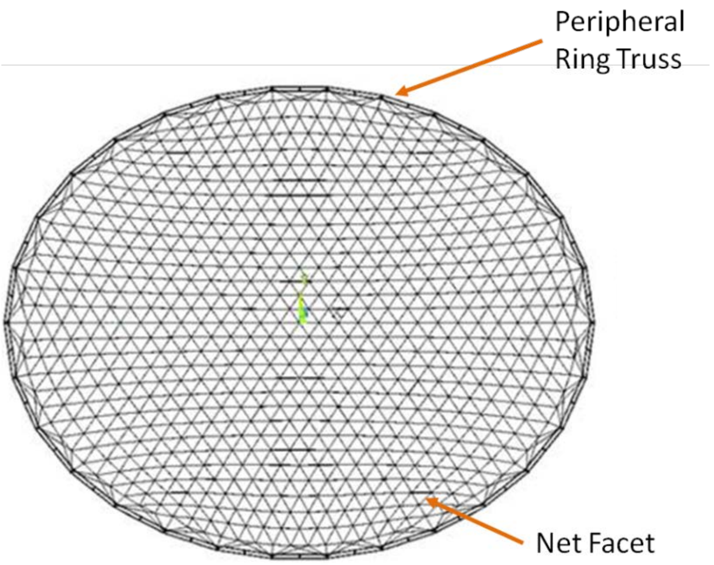



Figure 2: Triangular Facets

Faceting the curved surface with flat triangular sections means to introduce a systematic deviation from the ideal surface regularly displaced across the surface. In terms of reflector parameters, the larger is the focal length, smaller the curvature, then smaller the faceting error impact.
The intrinsic periodic structure of the faceting error induces grating lobes on the antenna radiating pattern, whose position can be analytically determined by analogy with the phased array theory.
The so called “pillow effect” is a mesh-related surface anomaly due to the reaction of the mesh to the imposed tensions and to the distance among the control point it can be minimized increasing the number of control points or using tensioning nets. RMS error due to pillow effect is much lower than the one due to faceting and in general has lower impact on the overall gain reduction.
CFRS reflecting shell-membrane is a very promising solution composed by two materials: triaxially woven carbon fiber fabric (TWF) and silicone as a matrix material.

The in orbit thermo-mechanical behavior of the CFRS flexible shell-membrane is determined mainly by thermal properties of the carbon fibers as the silicone resin though having a large expansion coefficient has a very small Young's modulus. The main advantages of the triaxial CFRS are:

- The quite isotropic behavior, reducing polarization-dependent issues.
- It is free of faceting and pillow effects because the reflector membrane achieves its profile by the intrinsic bending stiffness of the carbon fibers locked in shape during the resin curing process.
- The intrinsic stiffness of the CFRS should in principle allow to not using tensioning cables for its use.

CFRS is considered an interesting alternative to mesh and its development is in progress to prove its applicability up to higher frequencies and larger diameters. The development shall mainly identify the membrane stability under various temperatures distributions expected on orbit.
For the aim of the RESTEO project, metal mesh has been considered the baseline solution for the development of the LDR.

Synergies for future LDRs for EO and Telecom missions were assessed in terms of system aspects.
Analysis models and methods for major tasks like:

- Net Assembly form finding,
- Static & Modal Analysis,
- Kinematic simulation, and
- Thermo-elastic distortion

have been elaborated, implemented and tested. The results have been used to check the conformance with the reflector requirements like stiffness, mass and surface accuracy, and also to optimize the peripheral ring structure of the double layer pantograph candidate reflector.
Along a huge number of quantitative and qualitative results, most of them very promising, a list of aspects for further investigation has been identified, some of which are:

- Further integration and consolidation of the simulation models,
- Better and more detailed understanding of the mesh and net assembly,
- Consolidation of the kinematic simulation and tensioning strategies for all configurations and
- Detailed mechanical design, especially of actuation and latching elements and ring to arm interface.

It is however noteworthy that during this work both concepts have been identified to be very promising for future European developments in the fields of LDRs: The pantograph ring and the conical ring solution are considered suitable solutions for 5 to 15 or even 25 m class. The conical ring architecture offers higher stiffness and a significantly lower mass. The conical ring concept might also be extended to classes large than 25 m since several units can be used in a modular configuration with the advantage of the assembled rings following the curvature of the RF surface.
A validation of the two architectures through functional demonstrators is recognized a mandatory step.
The technology trade-off among different possible implementations of large reflectors for the reference missions has been carried out always taking as backbone the RF-related aspects. In particular, for each reference mission, the followed approach was:

- Identification of the nominal antenna optics
- Evaluation of the corresponding nominal performances, used as reference for the successive evaluations
- Identification and discussion of the sources of errors with impact on the antenna performances.

The RF analyses of the two selected classes of LDR have been carried out for the considered reference missions, i.e.:
- P-Band SAR for Biomass (Reflector Diameter 11.5 m)
- S-Band broadcasting Mission (Reflector Diameter 12 m)
- Ka-band Mobile Interactive Mission (Reflector Diameter 4.5 m)

Besides the nominal antenna performances, the impact on the antenna performances of the calculated thermo elastic distortions (TED) of the two reference reflector architectures (without considering arm distortions) have been assessed, i.e.:
- Mesh-based Conical Ring Reflector, based on the ESA patent
- Mesh-based Double Pantograph Cylindrical Ring

In order to allow a one-to-one comparison of the TED results, the analyzed reflector structures were referred to two reflector configurations reported in the following Table 2:

| | Configuration 1 | Configuration 2 |
|---|---|---|
| **Diameter** | 12 m | 6 m |
| **F/D** | 0.5 | 1 |
| **Clearance** | 3 m | 0.675 m |
| **Facet Dimension** | 0.5 m | 0.2 m |

Table 2: Selected Reflector Configurations

Moreover, the TEDs considered for the RF analyses have been computed using a best-fit processing in which the reference paraboloid was derived by only rotational adjustments of the nominal paraboloid (in the range of 0.015°). As example, in Figure 3 the TED referred to the 12m Pantograph Ring Cold case is shown. Worst case RMS due to TED is 0.28 mm.
Table 3 lists an overview of the first three eigenfrequencies, mass and total RMS results for the Double Layer Pantograph (DLP) and Conical Ring (CR) reflectors in 12 m and 6 m diameter.

| LDR Architecture | 12 m DLP | 12 m CR | 6 m DLP | 6 m CR |
|---|---|---|---|---|
| 1./2./3. eigenfrequency [H | 0.34 / 0.65 / 1.07 | 0.56 / 0.66 / 1.04 | 0.96 / 1.32 / 2.18 | 1.59 / 1.92 / 3.13 |
| Mass [kg] | 96 | 46 | 36 | 18 |
| Total RMS [mm] | 2.754 | 2.419 | 0.533 | 0.649 |

Table 3: Estimated eigenfrequencies, mass and total RMS

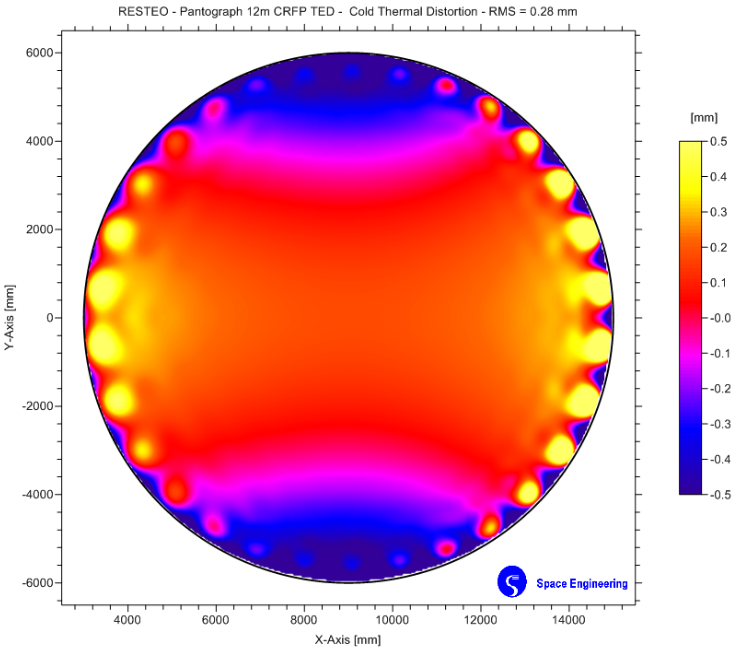



Figure 3: 12m Pantograph Ring – TED Cold Case

The RF analyses performed to evaluate the impact of the calculated TED confirm both the reflector concepts considered as reference in the RESTEO study (Conical with V-folding and Double Pantograph Cylindrical Rings) can be considered applicable.
Overall surface errors are reported in Table 4. They have been updated with the results of the TED simulations, reporting the calculated RMS. These exceed (for P and S band) or are in line with (for Ka-band) expectations.

| | **MESH BASED REFLECTORS** | | |
|---|---|---|---|
| | **BIOMASS 11.5m P-band 0.5 m facetting** | **S-BAND TLC 12m S-band 0.5 m facetting** | **Ka-BAND TLC 4.5m <0.2 m facetting** |
| **Manufacturing** | 0.4 | 0.4 | 0.4 |
| **Thermo-elastic Deformation** | 0.27 | 0.28 | 0.08 |
| **Repeatibility, life time & gravity** | 0.3 | 0.3 | 0.2 |
| **Faceting systematic error** | 0.7 | 0.7 | 0.1 |
| **Pillowing Effect** | 0.07 | 0.07 | 0.01 |
| **Total RMS error [mm]** | 0.90 | 0.91 | 0.47 |

Table 4: Mesh Based Reflector – Estimated Errors

# 4 CONCLUSIONS

Starting from the overview of the market needs in telecom and earth observation missions, two classes of reflector have been identified.

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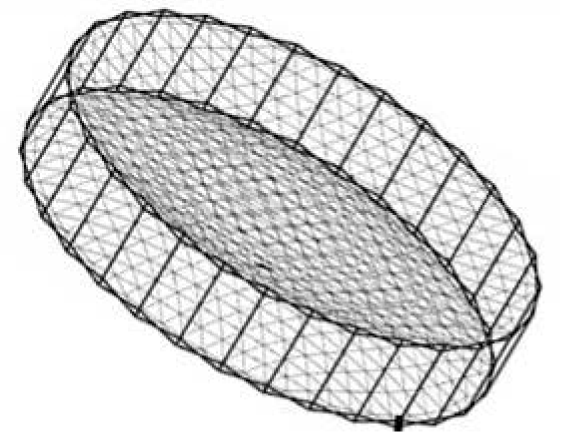
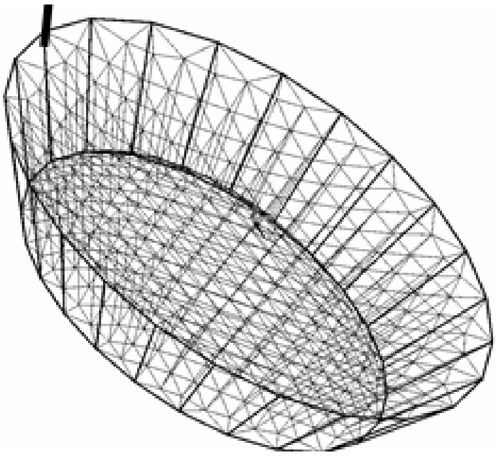
Then, the most promising concepts able to match market needs have been pointed out, in terms of reflecting surface and peripheral ring. The two concepts are:



cylindrical double pantograph



"V" fold conical ring

both based on metal mesh and peripheral ring structure and they have been investigated in the present project.

Both proposed concepts are highly scalable, so applicable for reflectors to be used in EO and TLC missions ranging from P to Ka band frequenciesTable 1.

Obviously a denser mesh should be used for Ka band missions even if same materials and knot type can be used.