HIGH PRECISION THIN SHELL REFLECTORS - DESIGN CONCEPTS, STRUCTURAL OPTIMIZATION AND SHAPE ADJUSTMENT TECHNIQUES

Michael Lang(1), Horst Baier(1), Thomas Ernst(2)

(1) Institute for Light Weight Structures (LLB)
Boltzmannstr. 15, D-85747 Garching, Germany
e-mail: Michael.Lang@tum.de
(2) HPS GmbH
Christian-Pommer-Str. 34
D-38112 Braunschweig, Germany

ABSTRACT

Future trends show the need for satellite reflectors capable for Q/V-Band applications. For this a tradeoff study for a 1.20m diameter offset reflector is in progress at LLB and HPS under ESTEC contract. Design goals are Q/V-band capability, high thermal and moisture stability and a mass of less than 3kg for the dish.

Different options for the structure have been evaluated and compared (e.g. different types of sandwich, thin shells with different support structures). One of these options is to combine a thin shell surface with a structure of ribs on the back side. The topology of this supporting structure was optimized by evolutionary algorithms. This paper deals with requirements, challenges, goals and solutions for the stiffened thin shell concept and also introduces a set of simulation tools which can be used for the integrated modeling of reflectors taking structural and basic electrical requirements into account.

In the first chapter, an overview of different candidate materials for the structure will be given, advantages and disadvantages be discussed. After that, different basic layouts for the stiffeners and the topology optimization of the supporting structure will be presented.

Also a new tool was developed to simulate a whole orbit of the reflector in space within the FE-environment considering sun radiation, shadowing, infrared and albedo as input.

As a last part, some design considerations taking post manufacturing and in orbit adjustments of precision structures shall be explained.

1. DEFINITIONS AND REQUIREMENTS

In a design study at HPS and LLB under ESTEC contract a promising new concept of a stiffened thin shell reflector for Q/V-Band is compared to a newly designed sandwich concept. This paper deals mainly with the results of the tradeoff study for the thin shell reflector concept which was carried out at LLB. The alternative Sandwich concept was developed at HPS. In this chapter the basic definitions, requirements as well as the material selection for the stiffened thin shell (TS)-concept are presented.

1.1 Geometry Definitions and Requirements

- Aperture Diameter 1200 mm
- Focal Length 1777 mm
- Offset 22°
- Total Mass < 3kg
- First eigenfrequency > 50Hz
- Manufacturing Accuracy RMS < 50µm
- In-Orbit Stability RMS < 30µm
- Pointing error < 0.015°
- Mech. Vibration Levels ECSS-E-10-03A

A detailed description of the radio-electrical requirements for this reflector can be found in [1]. All requirements combined are very demanding and can only be fulfilled by new optimized concepts specially designed for this task.

1.2 Basic Layout for the Thin-Shell-Reflector

![Fig. 1 Basic Layout of the Thin-Shell-Reflector](image-url)
As shown in Fig. 1, the TS-reflector consists of the reflecting surface and a supporting structure of stiffening ribs. Mass calculations have shown that the maximum thickness for the reflecting surface must not exceed 0.6mm in order to be able to apply a reflective coating on the surface and have reasonable weight reserves for the ribs. To reduce deformation incompatibilities between dish and stiffening ribs, a quasi isotropic CFRP-layup for all parts is chosen. To reduce variation of the laminate's mechanical and thermal material properties resulting from small ply angle deviations by the manual layup process, the number of layers for the 0.5mm thick layup was chosen to the highest possible maximum of 8 layers. This can be realized using commercially available extra thin prepregs with a ply thickness of 0.067mm.

Manufacturing of the surface is done by using the replica method, which is already successfully used for high accuracy composite mirrors as described in [2]. For this a highly accurate polished metal or glass mandrel is used as mould on which the composite laminate of the shell is manufactured. This method provides a very accurate smooth surface for the subsequent coating process.

For the stiffeners of the support structure different crosssections (L-, T-, Ω-shaped, etc.) were considered. Finally it was decided to use T-shaped stiffeners, because they have an acceptable mass to stiffness ratio, have a symmetric crosssection and it's easier to manufacture and continuously apply them on a parabolic surface compared to Ω-shaped or other hollow section stiffeners. Joints and crossings between stiffeners can also be made with less effort for a T-stiffener than for hollow section stiffeners.

The laminate of the stiffeners consists of 16 layers. In the web, we have a doubled quasi isotropic layup Laminate layup [0 45 -45 90]s whereas the two flanges consist of the two halves of the laminate. So 8 layers [0 45 -45 90], are used each for the left and right flange still providing quasi isotropic material properties there. A picture of the T-section of the stiffener can be found in Fig. 2.

Manufacturing of the stiffeners was planned in 4 steps: First, create two L-shaped halves for each stiffener, combine them to a T-shape and then build all necessary joints and crossings between stiffeners to gain the complete support structure, which is finally glued to the dish. When joining support structure and reflecting surface, different shape adjustment controls can be applied to reduce manufacturing errors, which produce low level Zernike terms.

### 1.3 Fiber and Matrix selection

Different fiber materials were evaluated for the tradeoff study. A summary of some of their properties can be found in Table 1. The selection range included Carbon fibers (Ultra High Modulus pitch fibers, PAN fibers,...), aramid-fibers and PBO-fibers. Aramid- and PBO-fibers disqualified themselves very fast because of their low Young's modulus, their degradation under UV-radiation and especially for PBO a lack of long time experience in space, available suppliers as well as the need for special manufacturing/cutting equipment.

Out of the very big range of carbon fiber materials M55J fibers from Toray were chosen. They provide a good compromise between stiffness and flexibility. This is, because calculations showed, that M55J fibers with a Young's modulus of 540 MPA give a theoretical laminate coefficient of thermal expansion (CTE) of below $\pm 1*10^{-6} \text{/K}$ in all directions for a [0 45 -45 90]s laminate with a fiber volume fraction of 60%.

Some stiffer pitch fiber types like K13C2U from Mitsubishi Dialead or YSH-70A from NGF would also be a very good choice, giving isotropic CTE's even closer to zero or slightly negative. Pitch fibers generally also have increased electrical and thermal conductivity compared to PAN fibers. Because of the better conductivity, radio-reflective properties would also be better as for PAN fibers when considering a non metallized reflector. An extensive test program for the radio-reflective properties has been conducted lately by Nippon Graphite fibers (NGF) whose results can be found in [3].

Unfortunately these very stiff fibers tend to break very easily under bending, which is absolutely necessary for manufacturing of the stiffeners. With the selected M55J fibers a measured mean CTE of $-0.2*10^{-6} \text{/K}$ in the range of -150°C to +150°C for a [0 45 -45 90], laminate and a minimum bending radius of about 4mm could be achieved without fiber damage.

Fig. 2 Section of a T-shaped stiffener
Carbon fiber paper / carbon fleece, in which short cut 5-10mm long carbon fibers are arbitrarily distributed within the ply, also seems to be an interesting alternative because of its naturally quasi isotropic behavior for stiffness, strength, CTE and coefficient of moisture expansion (CME). Unfortunately the manufactured flat test samples showed very big warping deformations (see Fig. 3) while and after curing and couldn't be used for mechanical or radio-electrical testing.

As results from Composite Mirror Applications [3] and [4] show the feasibility of carbon fleece even for optical applications, a more intense test program on this type of material is planned for the near future.

Finally LTM123/M55J(6K)-70g/m²-35%RW, 300mm wide and 0.067mm thick unidirectional carbon-prepreg, which is commercially available from ACG was chosen for the TS-concept. The bad draping properties, a disadvantage of most UD-materials, don't have a big effect for the chosen design, as the curvature of the reflecting surface is very small but could be a problem for smaller f/d ratios.

### 1.4 Coating and Coating Process

The surface finish not only defines the radio-reflective performance but also affects the thermo-mechanical behavior, depending on absorption and emissivity values (α/ε) as well as CTE and stiffness of the laminate. In a later chapter, a simulation tool will be presented which is able to give approximations for the orbit thermo-mechanical behavior. Based on this tool resulting needs/requirements for the surface finish will be discussed.

So from design point of view a coating as thin as possible having a very small Young's modulus and CTE, in order to not influence the laminates mechanical properties, is desired. Radio-electrical simulations showed, that already a coating with a thickness of some nanometers should be able to provide the needed conduction. So thickness of the coating is merely limited by the manufacturing process.

Common coating processes, which were evaluated for the tradeoff study include:

- Vacuum Metallization (PVD, VDA)

A vacuum chamber big enough for the structure is needed for this process. There is no minimum layer

### Table 1. Summary of fiber properties

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<tr>
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<tbody>
<tr>
<td>Kevlar 149 DuPont</td>
<td>Aramid</td>
<td>179</td>
<td>&lt;0</td>
<td>Low</td>
</tr>
<tr>
<td>Zylon HM Toyobo</td>
<td>PBO</td>
<td>280</td>
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<td>M55J Toray</td>
<td>PAN</td>
<td>540</td>
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<td>156</td>
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<tr>
<td>YSH-70A NGF</td>
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<td>720</td>
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<td>K13C2U Mitsubishi</td>
<td>Pitch</td>
<td>900</td>
<td>-1.4</td>
<td>620</td>
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A final selection for the resin type can only be done in connection with the selection of the lamination and curing process (prepreg, resin injection process,...). Different resin systems were evaluated within the tradeoff study and it was chosen to use a cyanate-ester resin with low moisture uptake compared to most epoxy matrix systems.

As some sample pieces for mechanical and radio-electrical tests had to be manufactured at LLB within the scope of the project, a prepreg system had to be selected. The space approved LTM-123 resin system from the Advanced Composites Group (ACG) was used because of its superb low moisture uptake (~0.2%), high thermal stability and low initial curing temperature of 80°C. After postcuring at 150°C, a glass transition temperature of T_g=170°C or alternatively by postcuring at 200°C a T_g of 210°C can be achieved. With this compared to most other cyanate-ester resins very low curing temperature, thermal stresses and microcracking for the cold case, where the whole reflector is shadowed and temperatures as low as -120°C and less can occur, will be reduced very much.

Different material types like woven fabrics, triaxially woven fabric, unidirectional UD-layers or carbon fiber paper have been considered for the structure. As for a coated reflecting surface only the thermal and mechanical properties of the laminate are of interest, considerations taking possible influence of manufacturing and handling errors on the laminates mechanical properties and surface roughness were taken into account.

So for woven fabrics yarn crimpage and also a possible misalignment of the rovings inside the weave structure does have influence on the stiffness properties of the laminate and if cure cycle parameters and resin content are not properly adjusted, the surface quality for the subsequent coating will get worse. For non coated reflecting surfaces, the reflective properties (especially for triaxially woven fabrics) depend on the fabric's cell size. Commercially available triaxially woven fabrics can be used without coating up to Ka-Band.

**Fig. 3** Heavily warped carbon fiber paper test samples

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thickness, maximum thickness per coating process is 0.25\(\mu\)m. Subsequent coating processes to increase coating thickness are possible.

- **Indirect Metallization of the mould**
  A minimum thickness of 1\(\mu\)m or even less is possible. For this process the metal layer is applied to the mould. After that the laminate is build on the mould.

- **Electroless Plating with etching fluids**
  The minimum thickness is in the range of 3-5\(\mu\)m. Big disadvantage is, that the whole structure has to be bathed in strong acid by which the surface is damaged / degraded. Non coated areas have to be protected from this acid.

- **Thermal Spraying (HVOF)**
  The coating can be applied very uniformly with an industrial robot, therefore nearly no size limits for the structure occur. Minimum nominal thickness is given as 30mm, but the coating seems to be very porous, as the measured additional mass for a 30mm thick coating complied with the mass of a 5\(\mu\)m solid coating.

The given values for the minimum painting thickness were acquired from manufacturers.

To get data for combinations of several laminates and coating types a big series of radio-electrical as well as some optical and mechanical tests was carried out within this study. Also a layer of thermal white paint (SG121FD), which has excellent \(\alpha/\varepsilon\) ratio was applied on some sample surfaces to check it's influence on the radio-reflective properties.

Unluckily the first series of radio-electrical tests showed, that none of the coatings was able to fulfill all of the demanding requirements, so a new set of tests is planned. Also the thermal white paint turned out to be a real frequency killer, increasing the reflection losses too much in the frequency range of interest (37.5-50.2GHz). The paint also can be applied only with a minimum thickness of \(\sim 100-150\mu\)m (measured value for some test samples were even higher), which drives up the total mass by about 270-370g/m\(^2\) (measured even \(\sim 500g/m^2\)) and therefore definitely can't be used for this kind of reflector.

Surprisingly it could be seen, that some of the uncoated specimens made from pitch fibers performed very well compared to some of the coated specimens. So for less strict requirements, different types of uncoated surfaces should be considered even in this high frequency range.

Next to electrical and optical tests, the program included a thermal cycling test and measurement of CTE, where very good agreement between test results and simulations with micromechanic models and CLT for the uncoated specimens was found.

Detailed results of the extensive test program will be published in a later paper from HPS and LLB. As the topology and stiffness optimization, which is one of the main topics of this paper was done before most of the tests, we focused only on uncoated specimens. Influence of an electroless plating (5\(\mu\)m Ni, 0.1\(\mu\)m Au) or indirect metallization (2\(\mu\)m Cu, 1\(\mu\)m Au) coating on thermal deformations was evaluated afterwards. For a complete design cycle of course the coating has to be included in the model, which is used for the topology optimization of the structure.

2. **TOPOLOGY OPTIMISATION**

To reduce thermal deflections of the TS-reflector and increase its stiffness, the shell is supported by a rib structure on the back. The topology, that means the layout and crosssection of radial and circumferential stiffeners was optimized by evolutionary algorithms.

2.1 **Description of the parametric FE-model**

For this, a parametric FE-model, defined by continuous as well as discrete parameters and 4 reference thermal load cases was defined. The interface was not part of the tradeoff study and no definitions or requirements existed. Therefore it was implemented in the FE-model as statically determined fixation in 3 points simulating a simple tripod structure, which is connected to the support structure.

Next to the quasi isotropic material behavior, a rotationally symmetric layout is a constraint for the supporting structure. Therefore number and alignment of ribs as well as their height and thickness can be varied within some range.

Also included in the model is the option to have different laminate layups for reflecting surface and stiffeners by changing only one of the parameters. By this it's possible to include the laminate layup also as input parameter within the optimization cycle.

Goals for the optimization cycle were lowest RMS-values for four given load cases, which are described in the next paragraph, indepently as well as a mass constraint of 2kg for the CFRP structure and a 1st eigenfrequency >50Hz. In different manual calculations it was shown before, that the 1st eigenfrequency of the structure had an effective mass >5% and therefore could be taken as goal.

Temperature distributions for hot and cold cases depend on the structure's layout and could be calculated only by implementing a full thermal model in a thermal code like Thermica. As this was no option, it was decided to define four load cases manually. The temperature distributions of all load cases are shown in Fig. 4.
They represent 50K thermal gradient in X-direction (LC 1), 0.2K/mm gradient through the height of the structure (LC 2), 0.155K/mm gradient through the height of the reflecting surface only (LC 3) and a constant temperature change of -50K (LC 4). By minimizing RMS-values for all four load cases independently we hoped to find the best suited topology for all thermal distributions.

2.2 Optimization algorithm and computer hardware

The optimization was run on a 32-node cluster at LLB. We made use of the GAME toolbox [5], which is developed at LLB. The toolbox provides a simple to use interface to a genetic algorithm, and is able to grain parallelize the objective function evaluations on our LINUX-cluster.

2.3 Results of the Topology Optimization

As it would be a far too big optimization problem to keep every possible parameter of the FE-model as input parameter for the optimization, it was decided to narrow the input range by predefining some different basic configurations and optimize each of these individually.

A plot of the basic configurations can be found in Fig. 5.

For the basic model no optimization but a manual parameter variation was conducted to examine the influence of different input parameters like stiffener radii, position for fixation, stiffener height, etc. In principal from the results could be concluded, that stiffness and thermal stability have an opposed behavior, so very stiff configurations tend to have big thermal deflections whereas thermal very stable configurations tend to be very flexible.

From manufacturing side of view a connection of all radial ribs at the reflector's centre like in the basic model is not possible. Therefore, keeping the basic model's results in mind, new different configurations called "no central joint", "stiff inner ring", "constant height" and "variable height" with improved manufacturing feasibility were defined as base for four independent optimization runs.

The results of all optimization runs were compared and evaluated within Fig. 6.
Still each radial rib has to be fitted between and connected to the two circumferential ribs, giving high manufacturing challenges. The design also shows very bad eigenfrequency performance. It's evident, that the central connection has a very large influence on the reflectors stiffness. RMS performance shows a small improvement in gradient through height compared to the basic model because of the inner circumferential stiffener moving out of the middle.

Stiff inner ring: With this configuration we tried to reverse the observed loss of stiffness between the basic model and the no central joint model by connecting all radial stiffeners to a very stiff ring which replaces the bending stiffness, achieved in the basic model by the continuous ribs through its torsion stiffness. For the ring of course we have to take additional mass into account. Manufacturing as before is challenging because of the radial ribs connection to ring and circumferential stiffener. As expected, the 1st eigenfrequency is improved by this measure drastically, but RMS performance decreases, compared to the previous model.

Constant height: Despite removing the inner circumferential stiffener, the optimized configuration still shows an acceptable 1st eigenfrequency, although the requirement of 50Hz is not fulfilled. The inner radius of the radial stiffener is moved by the optimization algorithm towards the centre compared to the "no central joint" configuration. The saved mass of the second circumferential stiffener is transferred into the increased height of all stiffeners. This model also generally shows a better RMS performance in all load cases.

2.4 Selected Configuration

Variable height: By introducing a variable height of the radial stiffeners the previous design could be improved. The model of the winning configuration is presented in Fig. 7. It has one circumferential stiffener at 0.83·R, connected to 12 radial stiffeners with radius of 0.2·R at the inner end.

The height of the circumferential stiffener as well as the outer end of the radial stiffeners was driven by the optimization algorithm to the chosen maximum constraint of 140mm and at the inner end of the radial stiffeners to the chosen minimum constraint of 5mm. Mass of the CFRP structure is very close to the chosen maximum constraint of 2kg.

Simulation results show a 1st eigenfrequency of 39Hz and average thermal deformations lower than 3µm in means of RMS at a mass of 2kg for the CFRP structure. These values of course sound very good, but an aspect that mustn't be neglected for high precision thin shell structures is accuracy of manufacturing and material tolerances. Therefore this design has to be rechecked in a sensitivity analysis for influence of manufacturing errors on accuracy.

2.5 Sensitivity Check for manufacturing errors and spread of material properties

A first simple check, for which a systematic mismatch of the CTE-values between surface and stiffening ribs was simulated, showed promising results for the thin shell design. This is because the tailored CTE of the CFRP-structure is close to zero, so only very big relative changes in CTE cause larger deflections. Results of this simulation can be found in Table 2. It can be seen that load case 2 and 3 are not much affected by this mismatch. A change of the fibers CTE even of +100% in the reflecting surface and -100% in the stiffeners still gives relatively small changes in RMS. Whereas a change of ±100% for load case 1 and 4 introduces a strong non symmetric expansion behavior resulting in bending deformations rising up the RMS from 0.47 to 7.44µm for LC 1 and 0.74 to 14.36µm for LC 4 respectively.
To already include the effects of manufacturing into the design of the reflector it’s planned for the future to not only optimize for the best performance but also for the best robust design, which is least affected by randomly distributed manufacturing errors. Sensitivities due to manufacturing errors and statistical variation of material parameters are considered by integrating mathematical models for these errors into the FE-model and the optimization code. For example, Gaussian distributed angle deviations for complete laminate layers can be introduced or even a distribution for the single finite-elements’ stiffness and CTE properties can be introduced. There are also some methods to increase manufacturing accuracy by folding the prepreg layers in a special way, which were e.g. examined in [6].

3. EFFECTS OF COATING ON THERMO-MECHANICAL BEHAVIOUR

The coating defines the radio-reflective properties as well as the coefficients of absorption and emissivity α/ε and can have a big influence on the thermo-mechanical properties (CTE) of the laminate. It also has to give protection against atomic oxygen if flying in a lower earth orbit and acts as a moisture barrier reducing deformations due to moisture loss in space.

In a preliminary parameter study, the effect of two different coatings and SG121FD thermal paint on the thermal stability of the reflector was examined.

The two chosen example coatings are based on an electroless plating process, having a 5µm Ni-layer combined with a 0.1µm Gold layer and an indirect metallization process, having a 2µm Cu together with a 1µm Ag layer. Results for the simulations can be found in Table 3. Results for LC3 are not printed, because no significant changes were found due to the very small absolute RMS values.

### Table 2. RMS values for CTE mismatch check

<table>
<thead>
<tr>
<th>Coating Type</th>
<th>Thickness [µm]</th>
<th>RMS [µm]</th>
<th>Initial ± 5%</th>
<th>± 10%</th>
<th>± 100%</th>
</tr>
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<tbody>
<tr>
<td>Ni-Au Paint</td>
<td>8</td>
<td>0.1</td>
<td>140</td>
<td>31</td>
<td>7</td>
</tr>
<tr>
<td>Ni-Au Paint</td>
<td>8</td>
<td>0.1</td>
<td>100</td>
<td>31</td>
<td>7</td>
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<tr>
<td>Ni-Au Paint</td>
<td>6</td>
<td>0.1</td>
<td>140</td>
<td>24</td>
<td>6</td>
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<tr>
<td>Ni-Au Paint</td>
<td>8</td>
<td>0.1</td>
<td>140</td>
<td>9</td>
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<tr>
<td>Ni-Au Paint</td>
<td>6</td>
<td>0.1</td>
<td>140</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Cu-Ag Paint</td>
<td>2</td>
<td>1</td>
<td>140</td>
<td>9</td>
<td>3</td>
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<td>Cu-Ag Paint</td>
<td>2</td>
<td>1</td>
<td>140</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

In Table 3, line 1 and 2 the thickness of the thermal paint was changed from 140 to 100µm. Obviously this doesn’t have any influence on the RMS because of the very low stiffness of the paint. The 1st EF is increased by 2Hz because of the saved paint mass (~0.150kg).

From line 1 to 3 the thickness of the Ni-layer was changed from 8 to 6µm. This change has a small positive effect for the RMS due to the high stiffness of Ni. Coating thickness therefore should be chosen as small as possible, keeping all other relevant properties in mind.

Looking at lines 1 and 4 or 3 and 5 one can see, that a double sided coating of course is much better because of still having symmetric properties for the reflecting surface. RMS especially for LC1 and LC4 can be dropped, whereas the 1st eigenfrequency is reduced in both cases due to the additional mass of the second side coating.

For the Cu-Ag coating we see same tendencies, but the initial deformations are much smaller than for the Ni-Au coating. This is because Cu and Ag have a much smaller Young’s modulus (Cu: 110GPa, Ag: 76GPa) and also the initial thickness of the layer is smaller than that for Ni and Au. (Ni: 207 GPa, Au: 77.2GPa )

For thermo-mechanical properties it can be concluded, that a double sided coating with minimal thickness and stiffness has to be chosen.
3.1 On Orbit Thermo-Mechanical Analysis

As already mentioned, the coating not only has influence on thermo-mechanical behavior, it also influences the expected minimum and maximum temperatures on the orbit by it’s absorption and emissivity. To examine both effects in one combined simulation, a new tool was developed at HPS and LLB to simulate a reflector’s orbit within the FE-code ANSYS. [7]

By replacing the structural layered shell elements of the FE-model (SHELL 91) with the relatively new thermal layered shell element (SHELL 132), a thermal FE-model can be gained very easily. Effects of radiation, shadowing, infrared and albedo can be included. Also an earthdeck geometry with thermal properties can be provided for the calculation.

The resulting temperature distributions and thermal results are transferred back as thermal loads for the structural shell model and deformations are calculated. This procedure was implemented into a set of macros with which very easily different configurations (also in different orbits) can be evaluated.

The output (temperature distribution, structural deformations, stresses, RMS-values, Zernike coefficients, best-fit paraboloid and even a basic sidelobe and pointing error approximation) is saved to a file and plots are created automatically. A flow chart of the developed tool can be found in Fig. 8.

Temperature and RMS over orbit graphs as well as temperature distribution and deformation plots for all orbit positions are created automatically. An assembly of the tools results can be seen in Fig. 9 for a one sided Ni-Au coating of the reflecting surface, in Fig. 10 for a double side coated reflecting surface, in Fig. 11 for a non coated structure and in Fig. 12 for a double sided reflecting surface as well as support structure Ni-Au coating.

![Fig. 8 Integrated Analysis of Thermal, Structural and Electrical Performance](image)

![Fig. 9 Thermo-mechanical Analysis for a one sided Ni-Au coating](image)

![Fig. 10 Thermo-mechanical Analysis for a double sided Ni-Au coating](image)

![Fig. 11 Thermo-mechanical Analysis for a non coated reflector](image)
Angle of Incidence: 350°

Tmin = -63 °C, Tmax = 157 °C

RMSmax = 54 µm at 350°

Temperature distribution
Z-Displacements

Orbit RMS µm

Orbit Tmin/Tmax °C

0° 25 5 45 35 15 125 175 75 107 -91 0° 360° 120° 240°

Coating: 6mm Ni 0.1mm Au on complete structure

Hot Case

Fig. 12 Thermo-mechanical Analysis for a complete Ni-Au coated reflector

First results of the Orbit Simulation Tool confirm, that RMS with a double sided coating drops for all orbit positions except hot case. This is due to big temperature differences between reflecting surface and backside structure, which is not coated, and therefore some global bending deformation, which already could be seen in chapter 2.5 for the CTE-mismatched structure, occurs.

When also coating the support structure, the overall temperature rises because of the worse α/ε-ratio for the reflective Gold layer of 0.21/0.07=3 compared to the α/ε-ratio of CFRP 0.95/0.83=1.14. But the big gradient between reflecting surface and support structure is minimized and RMS therefore reduced by nearly 50%. To decrease the structure's temperature, some new surface treatments to reduce the shininess are in evaluation and will be tested on some samples for optical and electrical properties. As already mentioned, for lower requirements on radio-reflective properties of the reflector, a non metallized CFRP structure can also provide good electrical performance combined with a very good thermo-mechanical performance because of it's low α/ε-ratio.

Finally all the results confirm, that the reflector's behavior should be as isotropic and as homogeneous as possible with a non shiny coating of low α/ε-ratio for the complete structure. In the near future, more simulations with measured real material properties for selected coatings will be conducted and the final results presented in a separate paper.

4. SHAPE ADJUSTMENT METHODS

In this last chapter some design considerations taking post manufacturing and in orbit adjustments of thin shell precision structures shall be explained. Of course it's important to have a very robust passive reflector design, but depending on manufacturing accuracy it can be necessary to improve the shape of the reflecting surface by including active structure control.

For this the application of piezoceramic patches on the structure is a feasible method. Big disadvantage is the additional mass not only of the patches but also for the necessary feed cables as well as power source, amplifier and a controlling unit, which could be a decision criterion especially in border cases like the Q/V-band, where the accuracy may also be achieved by a stable passive design.

The actuators can be applied at two different positions to the reflector.

- The patches are glued directly to the reflecting surface.
- The patches are glued to the support structure.

When applied to the surface, the biggest part of the piezos' force is transferred into membrane stresses of the shell. By gluing them to the support structure, the patches have a much bigger lever arm to create bending modes. Still rather big patches have to be used to generate the necessary big membrane stresses inside the stiffeners.

By reducing the ratio of membrane stiffness to bending stiffness of the stiffeners, e.g. by creating small trenches in the stiffener's crosssection, the necessary size and capacity of the piezos also can be decreased. First simulations on a square 500x500mm plate with one 50mm high stiffener, displayed in Fig. 13, showed a promising agreement between simulation results and experimental tests for midpoint displacements caused by 5x2 piezo patches, which are glued on both sides of the stiffeners crossection.

For this static shape control, of course the relaxation / discharge of the piezoceramics has to be taken into account. So for the measurements best results were achieved, by first discharging all patches, applying voltage for measurement, discharge again and increase the voltage.

Fig. 13 Test setup for a static shape controlled stiffened plate with piezos applied to the stiffener
Number and voltage of necessary patches can be minimized also by a topology optimization, e.g. if only some of the lower Zernike modes shall be controlled.

For this, position and number of patches as well as applied current must be introduced as parameters to the parametric FE-model of the reflector. As objective function goals, displacement fields according to the low order Zernike displacement fields have to be defined. The patches can be either modeled by using the thermal analogy, where the introduced strain is replaced by a local thermal load or by including special electro-mechanically coupled piezoelectric solid elements.

By minimizing the difference between simulated displacement and goal function value, the layout and the voltage level for a configuration with a minimum number of patches and lowest energy consumption for controlling the desired Zernike modes can be found.

5. CONCLUSIONS AND OUTLOOK

In this paper needs and requirements for a thermal stable, high precision Q/V-Band reflector structure were evaluated. A promising stiffened shell concept was presented and numerical simulations conducted.

It's obvious, that different disciplines have to be taken into account simultaneously and combined to an efficient reflector design:

These are:
- Radio-reflective properties
- Optical properties for thermal stability
- Thermo-mechanical properties

Simulations show an opposing trend between stiffness and thermal stability. Therefore a suitable compromise has to be found, keeping stiffness as high as needed and thermal deformations as low as possible. For the design process a numerical optimization for the integrated model easily can be utilized to increase stiffness, reduce thermal deformations and also check some basic radio-electrical properties like sidelobe level and depointing.

A sensitivity analysis to check the robustness of the design can be conducted by integrating mathematical models to simulate manufacturing errors and deviations of material properties.

Also an Orbit Simulation Tool was developed which calculates temperature deformations, RMS and a sidelobe level assessment for different orbits. With this tool different designs and coating types can be evaluated and compared for design selection.

For the future more measurements for different coatings have to be conducted and the results implemented into the parametrical model. Also different methods to evaluate manufacturing properties for the model will be examined more closely.

6. REFERENCES


