A Reconformable Reflector for a Sub-MM Wave Reflector Antenna

Fabio Zocchi, Pietro Binda (1), Hans-Henrik Viskum (2), Kees van 't Klooster *(3)

(1) Media Lario, Bosisio Parini, Italy, Fabio.Zocchi@media-lario.it
(2) Ticra, Copenhagen, Denmark, Hhv@ticra.com
(3) ESA / ESTEC, Noordwijk, The Netherlands, Kees.van.t.Klooster@esa.int

Abstract

Results are presented of investigations with a laboratory model of a reconformable reflector for MM and sub-MM applications. A configuration with 19 actuators to control the surface has been realised. Several configuration shapes have been evaluated to prove the concept, using an accurate 3D measurement machine of Media Lario. With a reconformable reflector as sub-reflector one can alleviate requirements for a main reflector in a dual reflector system, which otherwise would be very challenging and expensive for sub-mm applications. This is of interest for instance for radiometers, sounders or ground-based radio-telescopes. The technological implementation here makes use of an electroformed Nickel shell that allows a deformation as needed at sub-MM wavelength. The subject was reported before [4,5] but without realised results. Here we present the latest status, which confirms the interesting and promising approach.

1. Introduction

The aperture phase front in reflector antennas can be controlled to a good extent with a deformable main-, sub- or even additional reflector. Such approach is already followed in optical or near-infrared telescopes. Correction has been considered for millimetre and submillimetre wave applications in the Pico Veleta radio telescope [1]. Reconfiguration is of interest in telecommunication applications [2]. Possibilities for pointing correction, for distortion correction or for beam-shaping/adaptation were mentioned [4]. Here we discuss results for a reconformable subreflector for correction of deviations due to thermal distortion in the main reflector of a tentative high-resolution radiometer configuration comparable to the ADMIRALS sub-MM wave antenna [3]. The reconformable reflector could even be operated in adaptive mode, when the main reflector surface to be corrected is known, either through test or through analysis. Satellite antennas for radiometers or sounders operating at sub-MM wavelength can benefit from the approach. Requirements put on a main reflector can be very stringent. A demanding surface accuracy under severe environmental conditions in space could be alleviated, if one could correct with an adaptive subreflector.

2. Antenna configuration considered in this study and initial estimation

The ADMIRALS configuration [3] with a main reflector of 2.2×0.8 m^2 is shown in Fig.1. Without a reconformable subreflector, the main reflector should have a surface accuracy requirement less than about 10μ rms for operation near 500 GHz with very high beam efficiency. A tentative related alternative configuration has been analysed, with such a main reflector out of a sandwich construction with a honeycomb Aluminium core and electroformed Nickel skins as reflecting surfaces. Thermal distortion analyses for such metal construction have been made, which provided surface shapes at different orbital situations with representative temperature distributions, assuming a 600 km polar orbit. Fig. 2 and Fig. 3 show the antenna patterns for a nominal and a –85 °C load case ("cold" case in the following), for the two main planes respectively. The pattern for the nominal gain has a level near 70 dBi, the pattern for the "cold" case is about 5.5 dB lower. A very obvious beam broadening is observed in Fig. 3.

The shape for the reconformable subreflector that restores the original pattern was derived by TICRA with the DORELA program. The resulting desired shape for the subreflector has been analysed and the corresponding patterns are shown in Fig. 4 and Fig. 5 for the nominal and the recovered pattern, using the synthesised desired subreflector geometry for the deformed main reflector. Clearly it is theoretically possible to correct with a particular subreflector surface the deviating shape of the main reflector for the mentioned "cold" load case. From Fig. 4 and Fig. 5 the 'nominal' reconstitution of the pattern is clear, with a high beam efficiency, in case of a theoretically derived subreflector shape. Such a theoretical shape has been adopted as a reference shape in the study of the deformable thin Nickel electroformed reconformable shell with as a target to approach the theoretical geometry as good as possible. Several other load cases have been tested as well. The alternative application of shaping is very clear from Fig. 3.

3. Reconformable subreflector development

Media Lario developed a thin reflective skin technology as one of their capabilities with galvanic electroforming of Nickel. Media Lario did already demonstrate accuracy of 1 μm rms for reflectors of 200–300 mm in diameter for optical terminals by optimisation of the design process. Good flexibility in parameter control (thickness, diameter, shape, etc.) as well as low production costs make Nickel electroforming technology with its properties extremely suitable for such a reconformable reflector.

The schematic geometry for the conformable reflector is depicted in Fig. 6. The thin shell is suspended on 19 actuators, each of them driven in closed loop under computer control, allowing an adaptive capability. The edge of this reflector is left free, but it can also be constrained if needed. Gravity is taken into account in the analysis for ground applications, for instance for sub-MM wave radio telescope like the ones planned for ALMA (Atacama Large Millimetre Array). Gravity has a stronger impact when the shell is thinner, but its effect can be neglected when larger displacements are used [4,5].

The required surface shape for the subreflector can be described on a basis of set of Zernike modes. By finite element analysis the target shapes have been applied to the nominal subreflector geometry assuming uni-directional displacement actuators. The output of the analysis is the expected actual shape of the subreflector and the forces required by the actuators. In addition to the target shapes, the preliminary analysis has also considered separately the first two non-trivial Zernike modes (defocus and astigmatism) to better understand the shell behaviour. (Today mechanical and electrical analyses are not coupled on the basis of Zernike modes, but this is worth to consider, also when it comes to fast adaptation).

The transversal loading of the actuators is minimised by proper design of interface attachment points. To this end a magnetic spherical joint has been implemented. In addition the details of the geometry of the interfaces and the reflector thickness have been optimised to minimise the rms error between the expected shape and the target one. Electroforming techniques allow to control locally the thickness of the shell, thus to obtain local increase in shell stiffness, this is appropriate for the design of the attachment points for the actuators.

Finite element analyses show, that the displacements needed to correct slow varying errors (in cases with a low content of high-order Zernike's modes) can be handled with such a monolithic thin Nickel shell. The needed displacements are installed with a finite number of actuators to shape the shell. Reasonable low forces are needed, less than 30 N, to displace the shell. The resulting rms error of the reconformable subreflector between the target and expected shape is obviously greater for larger displacements of the actuators. In the worst case the expected rms error was less than 17 μ ("cold" case) in the analysis.

4. Realised Reconfigurable Subreflector and its Demonstrator Configuration

Fig. 7 shows the demonstrator configuration with drive electronics and control PC. The selected actuator is a laboratory model, suitable for the application considered here and not space-qualified. It consists of a DC motor with built in optical encoder and gear-stage. A travel range is possible over 25 mm, but for the specific application only a few millimetres are needed. The actuators are mounted on a support plate and magnetic joints to the reflector with appropriate interfaces reduce residual stress caused during relative changes in position. A PC manages the 19 actuators with dedicated software, controlling the actuators via dedicated driving boards and allowing a safe installation of the desired surface shapes, to ensure that any damage of the membrane is avoided.

With this configuration we have installed a number of surface shapes and we have measured these shapes with a 3D measurement. The measured 3D geometry has been fed into the PO software of Ticra and the corresponding patterns have been analysed with promising results. Fig. 8 and Fig. 9 show the antenna pattern for the "cold" case based on the measured data. Clearly the nominal desired reference pattern shape could not be realised. The difference with the reference pattern was less than 0.9 dB for the worst case ("cold" case). The sidelobe levels were higher than for the reference pattern, indicating, that due to finite grid with the 19 actuators, there is a slow varying quasi-periodic error distribution super-imposed, with an impact on the sidelobe level. For the current design with its asymmetry, there is a preferred localisation of the 19 sample points wrt the symmetry plane, as was proved by testing as well.

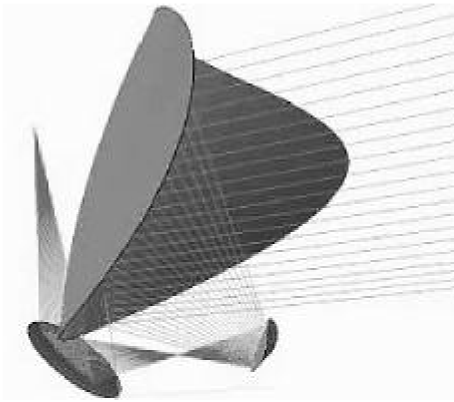

Fig.1. ADMIRALS submillimetre-wave reflector antenna.

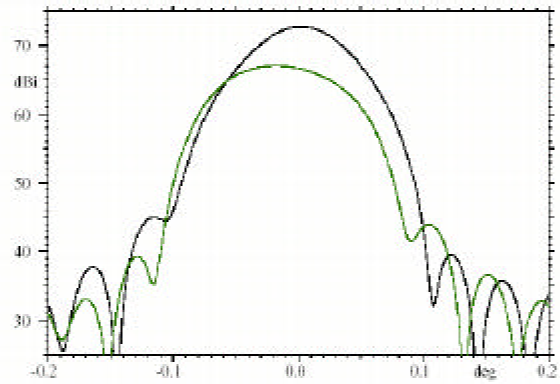

Fig. 2. Predicted pattern (vertical plane in Fig.1) nominal and "cold" case, nominal subreflector.

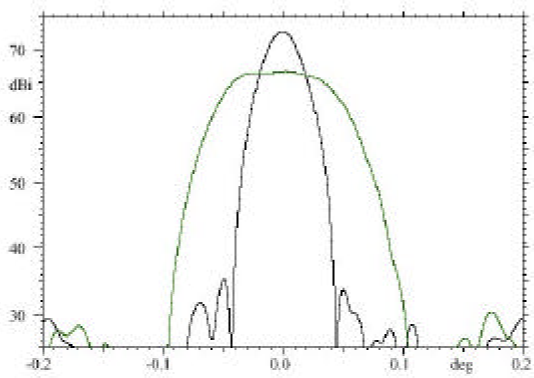

Fig. 3. Predicted pattern (horizontal plane in Fig.1) for nominal and "cold" case and nominal subreflector.

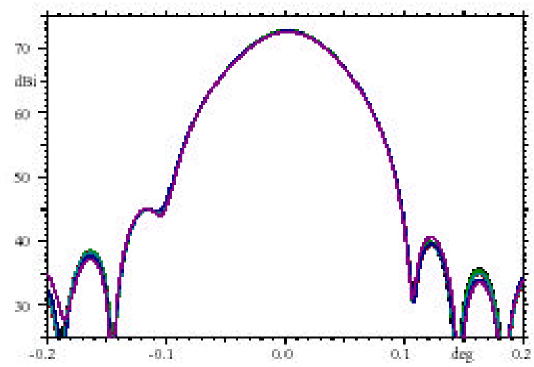

Fig. 4. Corrected pattern, using theoretical data for reconformable subreflector (vertical plane in Fig.1) for nominal and "cold" case of Fig. 2.

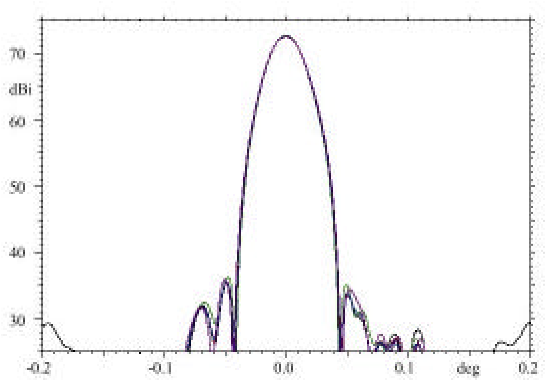

Fig. 5. Corrected pattern, using theoretical data for reconfigured subreflector (horizontal plane in Fig.1) for nominal and "cold" case of Fig. 3.

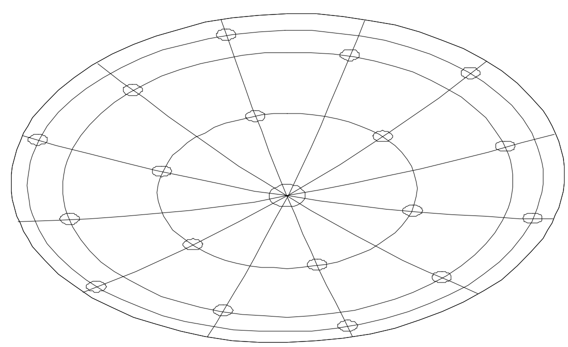

Fig.6. Geometry configuration for concave subreflector used in the preliminary Finite Element Analysis.

5. Conclusions

A good agreement between nominal and distorted (but theoretically corrected) patterns in Fig. 4 and Fig. 5 fully justifies the approach to use a compensating subreflector. The actual realisation of a sub-reflector based on a Nickel electroforming skin has been explored as a solution. The proposed configuration with actuators allows even a dynamic correction of the pattern provided, of course, that deformations of the reflector to be corrected are known and the desired correcting shape is available.
The selected ADMIRALS antenna configuration has high beam efficiency and a pattern with relatively low sidelobes. Fig. 8 and Fig. 9 show that full recovery of the pattern is not realised with 19 actuators. Consequently, it is imperative to carefully checkout the performances of a shell with a selected finite number of actuators. We have shown PO analysis results based on geometrical measured data. A next step can be to carry out a direct radiation pattern measurement. This is a subject for further work.

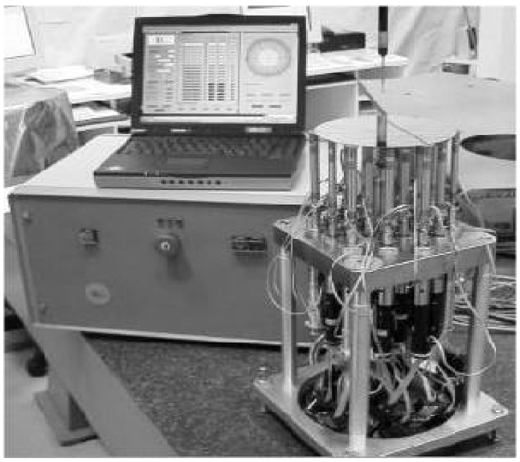

Fig.7. Reconfigurable subreflector demonstrator

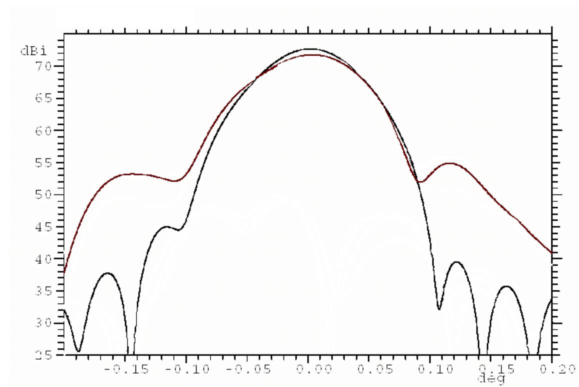

Fig. 8. Predicted pattern (vertical plane in Fig.1) for nominal and “cold” case of Fig. 2 after subreflector correction.

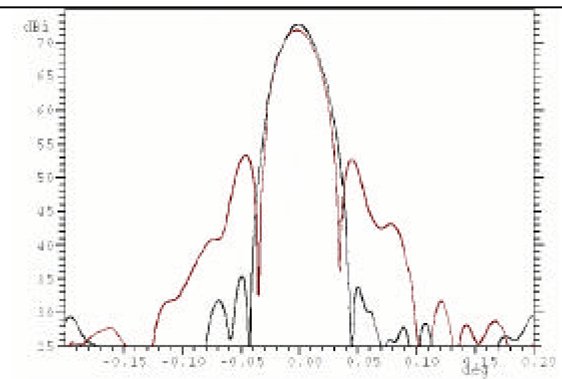

Fig. 9. Predicted pattern (horizontal plane in Fig.1) for nominal and “cold” case of Fig. 3 after subreflector correction.

References

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