Reconformable Reflector for Millimetre and Submillimetre-Wave Reflector Antennas

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Abstract

The paper describes investigations and use of a reconformable reflector. Implementation is discussed for millimetre and/or sub-millimetre wave antenna configurations. The perspectives of alleviating requirements for the high-accuracy main reflector, which can be very expensive, are of great interest. This is the case in particular for space applications, with stringent environmental constraints. Applications for radiometers, sounders or ground-based radio-telescopes are of interest. The technological implementation is based on a galvanic electroformed nickel shell as developed by Media Lario, which permits deformation capabilities suitable for mm/sub-mm applications.

1. Introduction

The correction of the aperture phase front is possible in reflector antennas by means of a deformable main-, sub- or even additional reflector. Such approach is already in use in optical or near-infrared telescopes. Correction has been considered for millimetre and submillimetre wave applications in the Pico Veleta radio telescope [1]. The subject was as well investigated for telecommunication applications [2]. Here we discuss a reconformable reflector for correction of deviations in the main reflector of a tentative high-resolution radiometer configuration, based on the Admirals mm/sub-mm wave antenna configuration [3]. Such reconformable mirror has a potential to be operated in an adaptive mode, assuming that the main reflector surface to be corrected is known, either through test or through analysis.

Such a scenario is of interest for application in radiometers or sounders, operating at sub-millimetre wavelength in space. Requirements put on the main reflector can be very stringent, in order to maintain a demanding surface accuracy under severe environmental conditions in space.

2. Three possible directions noticed.

-1- Possibility for the relaxation of surface accuracy requirements for a main reflector. Correction of deviations - if any - with a reconformable sub-reflector is a way forward. Also an additional reconformable (tertiary) reflector can be used [1].

-2- Possibility to correct for pointing errors. High-resolution instruments operating in the sub-millimetre wave regime are demanding in terms of pointing requirements. The space platform may not or with difficulty be able to provide a stringent pointing capability. A re-conformable reflector assists to point the pattern of the instrument sensor in the direction as derived based on for instance star-sensor information.

-3- Possibility to shape or broaden the antenna pattern, as indicated already in the results derived below. For sensors operating from highly elliptical orbits, such a capability can be useful to provide a "zooming" antenna pattern. Such a result might be considered for telecommunication applications when it comes to operating at higher frequencies.

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2. Antenna configuration considered in this study and initial results.

The Admirals configuration (ESA contract [3]) is taken here as target configuration. A comparable antenna configuration was reported in [4]. If no reconformable subreflector is used, then the main reflector must have a surface accuracy requirement <10 μm (rms) to permit operation near 500 GHz with very high beam efficiency. The antenna has a 2.2 * 0.8 m main reflector and is shown in fig.1. A tentative related alternative configuration has been analysed, with a main reflector out of metal with electroformed nickel as reflecting surface. Thermal distortion analyses have been carried out to derive a surface shape at a epresentative hot and cold temperature for a 600 km polar orbiting spacecraft. The patterns in the two main planes were derived. Fig 2 and 3 show the patterns for the "nominal" and "cold" case for the two main planes respectively. The "nominal" situation gives the highest gain, the "cold" situation the lowest gain. A very strong broadening of the beam is noticed in the plane of the longest reflector dimension. The shape for the re-conformable sub-reflector that restores the pattern has been derived using the DORELA program from TICRA. The resulting desired shape for the sub reflector has been analysed. The patterns are shown in fig.4 and 5 for the nominal and the reconstituted pattern, applying that derived sub-reflector geometry. It is very clear, that it has been possible to correct theoretically for the deviating shape of the main reflector (for the "cold" case). Especially a comparison of fig.3 and fig.5 shows a nice reconstitution of the pattern with high beam efficiency. It is of course a result of a theoretically derived sub-reflector shape. This shape has been adopted for study of implementation of a thin Nickel electroformed reconformable shell to approach the desirable theoretical geometry as good as possible.

3. Reconformable Sub-Reflector Development

Media-Lario S.r.l has developed a thin reflective skin technology. It is based on galvanic electroforming of Nickel. Media-Lario has already demonstrated an accuracy near to 1 μm rms for reflectors of 200 – 300 mm in diameter. The design process includes optimisation of key parameters. The high degree of flexibility on parameter selection as connected to thickness, diameter, etc. as well as the low production costs makes Nickel electroforming technology with its properties extremely suitable for realisation of such a reconformable reflector (either to be used as sub or as additional reflector).

The thin shell can be suspended for instance on 20 to 30 actuators, each driven in closed loop under computer control, permitting even an adaptive capability of the deformation. The edge is left free, but can also be constrained somewhat if needed. For ground applications (a sub-millimetre wave radio telescope like used for ALMA for instance), gravity is taken into account in the analysis. This must be done, in particular when the metal skin is very thin.

The required surface shape for the subreflector can be described in relation to a combination of modes. A preliminary finite element analysis has assumed the presence of the first non-trivial Zernike modes (defocus and astigmatism). The analysis considered a use of displacement actuators and provided forces needed accordingly for these actuators as a result.

The transversal loading of the actuators is minimised by proper design of attachment points. The geometry of attachment points (fig.6) was analysed to find the residual deformation along a cross section of the Nickel shell (fig.7 and 8) for different values of the thickness of the shell.

Gravity has the strongest impact when the shell is the thinnest, but is effect can be neglected for larger displacements to be used. Electroforming techniques permit to control thickness parameters (local increase of shell stiffness), very appropriate for design of attachment points for the actuators.

The Finite Element Analysis performed suggests indeed, that displacements as needed to correct slow varying errors (in case of the low content of high-order Zernike's modes) can be handled with a monolithic thin Nickel shell, obtained with an electroforming process. Necessary displacements can be installed to shape the shell with a limited number of actuators using reasonable low forces to displace the shell.

The resulting rms value of the reconformable subreflector with installed deformation – as derived from the required nominal shape from the analysis – is obviously larger for the situation of larger displacement of the actuators. This is currently under detailed investigation.

5. Conclusions

The excellent agreement between nominal and distorted-but theoretically corrected patterns in fig.4 and 5 fully justify an approach to use a compensating sub-reflector. The actual realisation of such sub-reflector based on a nickel electroforming skin is here a solution being explored. The proposed configuration with actuators permits a situation with a dynamic correction of pattern deformations, provided of course, that deformations of a reflector to be corrected are known and the desired correcting shape is available.
The chosen antenna configuration has a high beam-efficiency, or a pattern with relatively low sidelobes. Consequently, it is imperative to carefully checkout the performances of a shell with a selected number of actuators. Further progress will be presented during the conference.

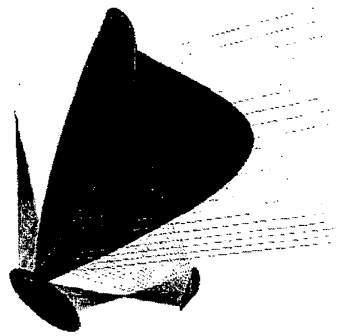

Fig.1 Submillimetre-wave Reflector Antenna

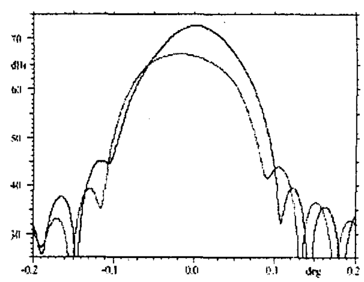

Fig.2 Predicted pattern (vertical plane in fig.1) for nominal and cold case of assumed metal main (Nickel reflective surface) reflector.

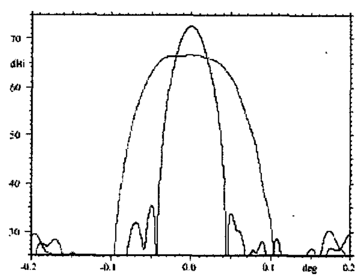

Fig.3 Predicted pattern (horizontal plane in fig.1) for nominal and cold case of assumed metal main (Nickel reflective surface) reflector.

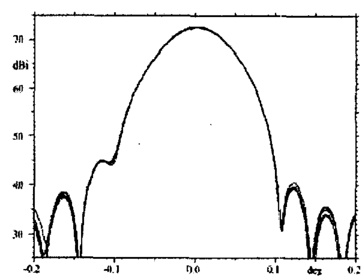

Fig.4 Corrected pattern, using theoretical data for reconformable subreflector (vertical plane in fig.1) for nominal and cold case of fig 2.

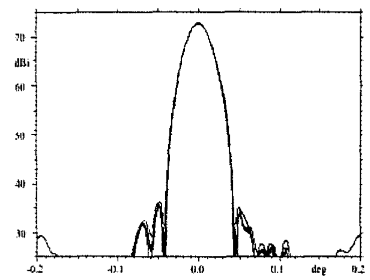

Fig.5 Corrected pattern, using theoretical data for reconformable subreflector (horizontal plane in fig.1) for nominal and cold case of fig. 3.

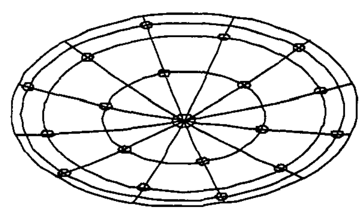

Fig.6 Assumed geometry concept for concave subreflector used in the preliminary Finite Element Analysis.

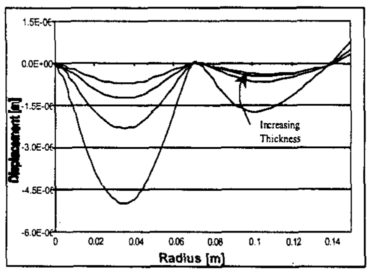

Fig.7. Residual deformation after correction of defocus error (low order Zernike mode) along a radius, assuming the configuration of fig.6.

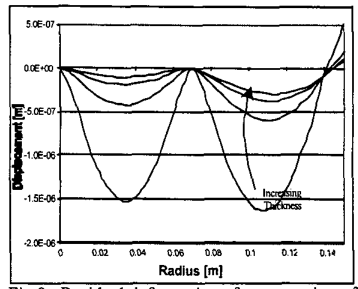

Fig.8. Residual deformation after correction of an astigmatism error (low order Zernike mode) along a radius, assuming configuration of fig.6.

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