An inflatable parabolic reflector antenna: its realisation and electrical predictions

Citation for published version (APA):
van 't Klooster, C. G. M., Rits, W., Pagana, E., Mantica, P., & Bernasconi, M. (1990). An inflatable parabolic reflector antenna: its realisation and electrical predictions. *ESA Journal*, *14*, 211-216.

Document status and date:
Published: 01/02/1990

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 22. Aug. 2022

K. van 't Klooster & W. Rits
European Space Research and Technology Centre (ESTEC), Noordwijk, The Netherlands

E. Pagana & P.G. Mantica**
CSELT, Turin, Italy

M.C. Bernasconi
Contraves AG, Zurich, Switzerland

An Inflatable Parabolic Reflector Antenna: Its Realisation and Electrical Predictions*

Abstract An inflatable parabolic reflector antenna almost 6 m in diameter has been realised. It is a scale model (1:3) of the symmetrical reflector that was being considered for the Agency's Very-Long-Baseline Interferometry (VLBI) satellite 'Quasat'. The geometry of the model has been evaluated with theodolites and the reflector's geometrical data have been used for electrical predictions at 1.6, 5 and 22 GHz. Measured Quasat-feed patterns have been used as a realistic illumination in the antenna electrical predictions.

---

*Based on a paper presented at the 'International Meeting on Mirror Antenna Constructions', Riga, Latvia, USSR, 6–9 September 1990.

** E. Pagana and P.G. Mantica are now with FPM Space, Turin, Italy.

1. Introduction

Inflatable Space-Rigidised Structures (ISRS) are currently being investigated and exploited for antenna applications by Contraves (CH). Several antenna models have already been manufactured, and some have been rigidised under vacuum conditions to study the impact of the space environment. A 3 m offset reflector antenna has been electrically tested over a broad frequency range[1]. An offset structure is inherently asymmetrical in shape and is therefore a good basis on which to demonstrate the capabilities of new manufacturing techniques. The accuracy achieved for the surface of the offset reflector was 1 mm rms (Ref. 1).

A study was carried out for the Agency's proposed Very-Long-Baseline Interferometry (VLBI) satellite, called 'Quasat'[2,7], designed to operate in conjunction with Earth-based radio telescopes in order to provide a very high resolution capability. The inflatable antenna was selected as the baseline candidate[3,7] for the radio-telescope antenna on-board the spacecraft. A design for the full-size antenna has been elaborated, and a 1:3 scale reflector model with a diameter of nearly 6 m has already been designed and manufactured. The evaluation process has included mass-breakdown, geometry-assessment, and packaging and deployment studies, as well as the electrical-performance predictions. The rigidisation phase has not been included for this model.

Measured geometrical data from the reflector and realistic feed patterns have been used to derive the electrical predictions. Measured Quasat feed patterns (co- and cross-polar[4,8]) were used at 1.6, 5 and 22 GHz. The electrical performance predictions for the scaled reflector are presented below.

2. Reflector configuration

Figure 1 shows the overall configuration of the 6 m inflatable antenna, and Figure 2 its physical realisation (although its exact diameter is 5.83 m, it is commonly called the '6 m model'). There are two parabolic membranes connected by a toroidal structure; one is RF-transparent , the other is metallised with 60 μm aluminium and thereby acts as the reflecting surface. Kevlar/kapton layers are used as the primary construction material. Both membranes consist of 48 gores, joined together radially. The membranes have an attachment ring at their vertices. These rings are attached to a rigid mast in the 6 m model. For the full-size antenna, a low-loss dielectric support (tubular) structure of 1.5 m diameter is foreseen[7], mounted between the vertices of the membranes. Symmetry, size and torus diameter result in an *f/D* of 0.39 for this reflector configuration, but other membrane curvatures are also possible.

The antenna is packed into a small volume for launch and inflated in space using a pressurisation system. Special preparation of the antenna's construction material allows it to become rigidised once deployed in space, and thereafter no further pressurisation is needed to maintain the reflector's shape. The stowage volume needed for the 6 m model is less than 0.27 m^3. The rigid central tube imposes the critical limit on the folding efficiency in this 6 m configuration.

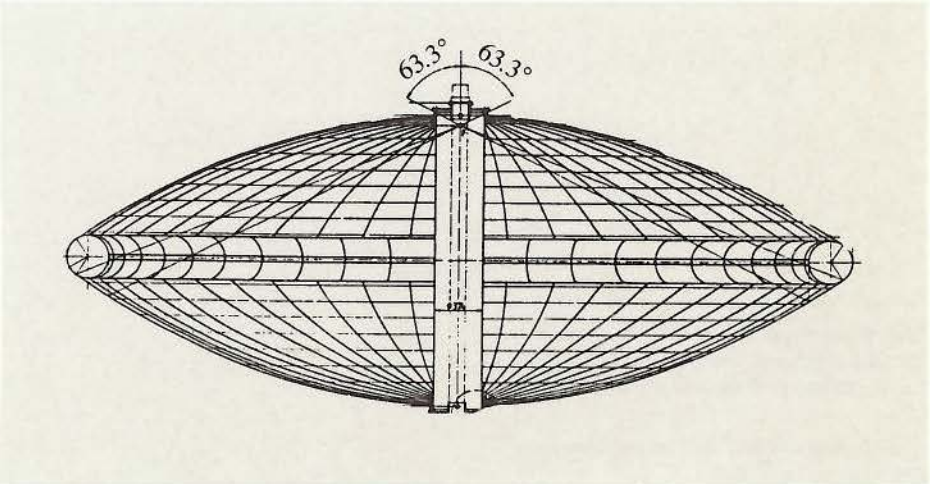

Figure 1. Geometry of the 6 m model of the inflatable antenna (courtesy Contraves)

Figure 2. The 6 m inflatable paraboloidal reflector antenna (courtesy Contraves)

An important characteristic of this type of reflector is its low mass. Without the two attachment rings (2 kg), the 6 m reflector antenna weighs only 11.125 kg, giving a mass per unit area of just 0.417 kg/m^2.

Volume estimates for the three-times larger Quasat antenna derived by Contraves lead to a figure of 1.286 m^3 for the stowed configuration (no rigid tube). An overall mass for the ISRS elements of 66.7 kg is expected, with an additional 48.5 kg being allocated to the pressurisation system, stowage container and an upper and lower attachment ring for interfacing. A realistic mass estimate for the complete 15.7 m Quasat antenna is therefore 115.2 kg.

3. Geometry assessment

The antenna's geometry has been measured with a theodolite system at various stages during the manufacturing process, the measurement points being distributed over the reflector's surface in such a way that equal areas are allocated to each target point. The three-dimensional data obtained have been used to derive the parameters of a Best-Fit Parabola (BFP).

4. Electrical-performance prediction

The antenna's ability to fulfil its electrical task at the operating frequencies in question is obviously of paramount importance; for the Quasat antenna, these are around 1.6, 5 and 22 GHz. The antenna's electrical radiation performance has been evaluated using physical optics. The complex vectorial far-field follows from the physical-optics integral:

$$\vec{E}_f(\vec{r}\,) = -j\omega\mu \, \frac{e^{-jkR}}{4\pi R} \int_{S'_r} [\vec{J}(\vec{r}\,') - (\vec{J}(\vec{r}\,') \, . \, \hat{\mathbf{r}})\hat{\mathbf{r}}] \exp jk(\hat{\mathbf{r}} \, . \, \vec{r}\,') \quad dS'_r \qquad (1)$$

The integration is carried out over reflector surface S_r' with r' as integration variable. R is the distance to the observation point in the far-field region given with unit direction vector $\hat{\mathbf{r}}$. The current at a particular point on the reflector is derived from the incident magnetic field at that point, assuming a local plane-wave behaviour of that field. The illuminating field in this case is the pattern of the Quasat feed, which was developed for this satellite as a critical item[4,8]. The current distribution on the reflector surface follows as:

$$\vec{J}\,(\vec{r}\,') = 2(\hat{\mathbf{n}} \times \vec{H}_i) \tag{2}$$

where $\hat{\mathbf{n}}$ is the local unit normal to the reflector surface being measured. The incident magnetic field strength $\vec{H}_i$ is known from the (complex vectorial) feed-pattern measurements. As deduced from the physical-optics integral (1), only θ and ϕ and no radial components result in the far-field region.

Standard computer codes with the flexibility needed to cope with a number of reflector configuration problems are available. The code used by CSELT has been developed by TICRA[5] and is called 'GRASP'. The problem with the physical-optics approach is the computation time involved for reflectors that are large in terms of the wavelengths with which they are working. The measured geometry must be known at a large number of points to ensure convergence of the physical-optics integral (1).

In our case, the measured geometry data have been interpolated to increase the number of data and for the derivation of local information on the integration grid for the physical-optics integral. A separate check on convergence has been carried out to ensure good data quality. In our case, the number of geometry points in the centre is insufficient to determine the surface around the vertex of the reflector by interpolation. This causes problems, especially for the highest frequency band. However, the less accurately interpolated part in the centre of the reflector is masked by 'blockage' in our case, and it therefore contributes less to the result for physical-optics integral (1). Table 1 shows the results of calculations for the antenna based on the measured feed patterns.

Table 1. Physical-optics calculation results (nominal and distorted geometry)

Frequency	D_{nom}	D_{dist}	ΔD	ϵ_{rms}	η
1.6 GHz	37.74 dBi	37.73 dBi	0.007 dB	0.577 mm	72.4%
5.0	47.41	47.27	0.131	0.822	71.7
22.0	60.21	57.93	2.280	0.786	43.1

The effect of surface distortions is shown by the difference in directivity between the first and second columns for nominal and distorted geometry. The difference is given in the third column. The assumed aperture diameter in the analysis was 5528 mm, the focal length (BFP) 2129.7 mm. The value of 5528 mm is the maximum diameter of the ring at which targets were present for geometry measurements. A surface accuracy of 0.99 and 1.13 mm rms was found before and after packaging, respectively. The latter configuration is expected to be more accurate after curing, as was shown on the 3 m offset model.

The fourth column relates to the surface accuracy via Ruze's formula, in which a correction is used to take into account the depth of the reflector[6,9]. The factor is about 0.88 for the *f/D* considered and $\epsilon_{rms}/0.88$ shows the agreement with the rms error evaluated from geometrical data. It should be noted that the degradation reported is due to surface errors only; no other error sources have been taken into account. The last column gives the antenna efficiency.

Pattern predictions are shown in Figures 3–6 for the reflector with and without surface errors, respectively, at 5 and 22 GHz. Results for the lowest frequency (1.6 GHz), for which the effects of surface distortions are clearly very low, are not shown here.

The feed has been measured (co- and cross-polar) in four planes (all frequencies) and this information used to derive estimates for the polarisation behaviour of the 6 m model. Good polarisation performance is observed around the forward direction, where the secondary pattern for the X_{pol} has a deep dip. The interferometer beam (VLBI configuration) is so narrow that it can be kept within this region, provided the pointing accuracy for the overall antenna system allows one to do so.

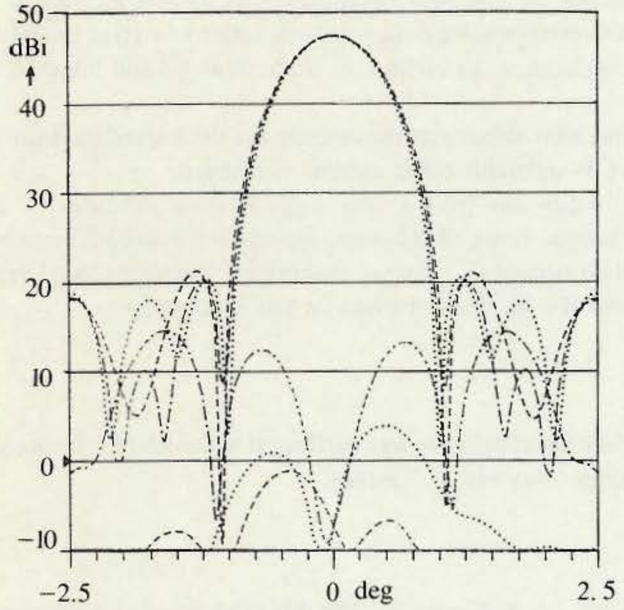

Figure 3. Predictions at 5 GHz, nominal parabola (courtesy CSELT)

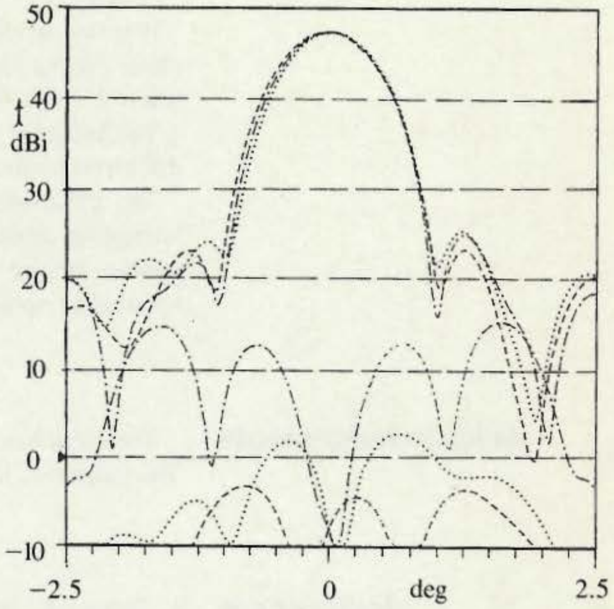

Figure 4. Predictions at 5 GHz, surface errors included, feed at BFP focus (courtesy CSELT)

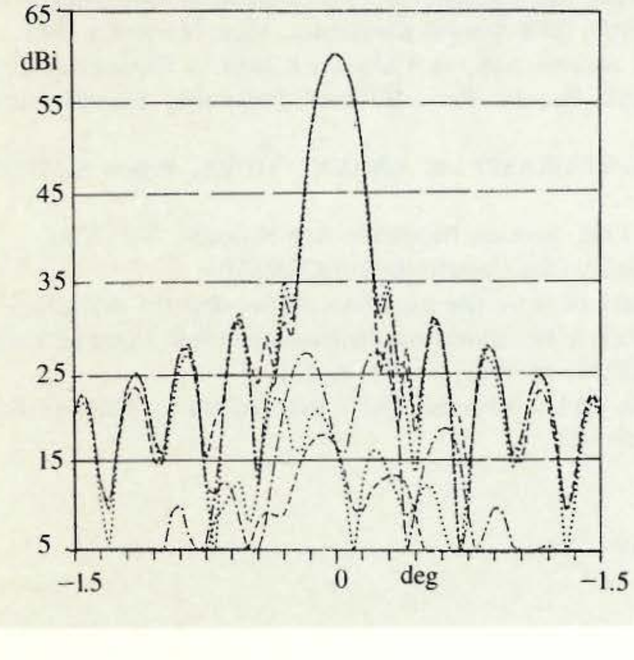

Figure 5. Predictions at 22 GHz, nominal parabola (courtesy CSELT)

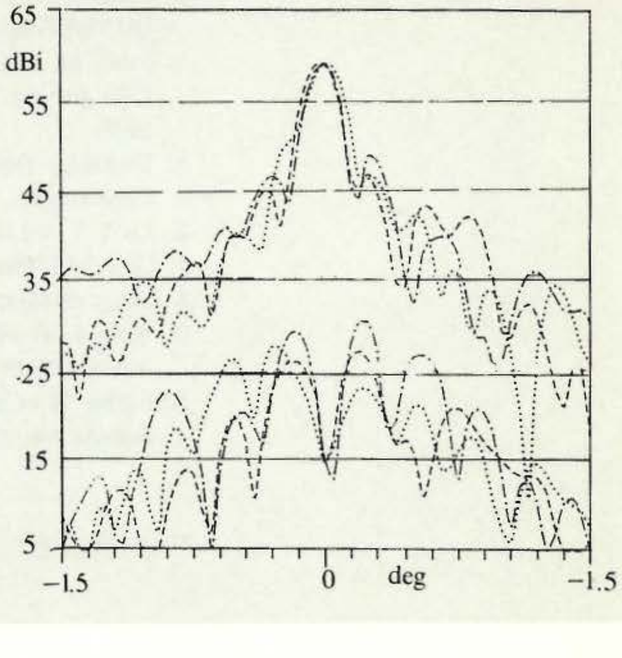

Figure 6. Predictions at 22 GHz, surface errors included, feed at BFP focus (courtesy CSELT)

5. Conclusions

An inflatable rotationally symmetric parabolic reflector antenna of nearly 6 m diameter has been designed and manufactured successfully. Surface deviations in the reflector give rise to a degradation of 2.3 dB in directivity at 22 GHz. The feed was positioned at the BFP focus and blockage has been introduced into the prediction. Predicted results are in line with expectations, based on geometrical data. The 6 m reflector's performance is at the limit for application at 22 GHz. However, study results have revealed areas in which further improvements are possible.

A full-size (15.7 m) antenna has also been designed for the Quasat mission.

A recent development at Contraves is the design and realisation of a 10 m inflatable offset antenna for L-band application. Its surface has been measured and found to be below 2.2 mm rms.

The inflatable antenna has been selected as the baseline for the L-band payload on the Artemis mission[10]. A 6 m inflatable offset antenna is planned.

The inflatable antenna, which can have a very large physical diameter, is an interesting candidate for various types of missions, including telecommunications, remote sensing and radio astronomy. Large radiometer antennas for Earth-observation applications can also be realised based on this technology.

Acknowledgements

The major part of the work reported above was performed under ESTEC Contract. The Contraves Study Manager was Mr. P. Tatalias.

References

1. Bernasconi M C, Hammer J A & Pagana E 1986, RF Performance of 2.8 meter Offset Inflatable Rigidised Reflector, *Proc. JINA Antenna Conference,* Nice, November 1986.
2. Schilizzi R T & Burke B F 1985, Quasat — A Space-borne Element for World-wide Very Long Baseline Radio Interferometry, *Proc. ISAP,* Kyoto, Japan, p. 983.
3. Anselmi A, Orefice M & van 't Klooster K 1988, Antenna System Analysis for QUASAT Satellite, *Proc. JINA Antenna Conference,* Nice, November 1988.
4. Savini D, Figlia G, v. Ardenne A & van 't Klooster K 1988, A Triple Frequency-Feed for the QUASAT Antenna, *Proc. IEEE-AP Symposium,* Syracuse, June 1988.
5. Technical Description of GRASP7 and GRASPC, TICRA, Report S-359-03, Copenhagen.
6. Lo Y T & Lee S W 1988, Antenna Handbook, Van Nostrand, New York.
7. QUASAT Phase-A Study, ESA Contract Report CR(P)2914.
8. Study of Multifrequency Feed for Quasat, ESA Contract Report CR(X) 2915.
9. Wested J H 1966, Effects of Deviation from the Ideal Paraboloid Shape for Large Antenna Reflectors, IEE Conf. Proc. No. 21, p. 115
10. Lechte H et al. 1990, ESA's Advanced Relay and Technology Mission, *ESA Bulletin No. 62*, pp. 51−57.

Manuscript received 26 June 1990