



Memo 106

Composite Applications for Radio Telescopes (CART):

The Mk2 Reflector Results.

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01/09

SKA Memo 106

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National Research Council of Canada

January 19, 2009

ABSTRACT

This document describes the design, fabrication and measurement results of the CART Mk2 10 m radio reflector prototype constructed at the Dominion Radio Astrophysical Observatory.

Introduction

The Composite Applications for Radio Telescopes (CART) project at the Herzberg Institute of Astrophysics' (HIA) Dominion Radio Astrophysical Observatory (DRAO) in Penticton Canada is an ongoing effort to investigate the application of composite materials to radio telescope structures to provide cost effective collecting area for the Square Kilometer Array (SKA). The first phase of the project is focused on reflectors as they are seen to have the highest potential for cost/performance gains from the application of composite materials. The first 10-m prototype reflector was completed in the summer of 2007. The result was a light (~1000 kg), stiff reflector with a surface accuracy of 1.2 mm RMS. While the RMS value of the surface was low the deviations were not uniformly distributed and some large scale deviations existed. In addition many lessons were learned during the construction process and there were seen to be opportunities for improvement. The design of a second reflector, dubbed the Mk2, was initiated immediately after completion of the first with the focus on improvements in surface accuracy, structural design and manufacturability.

The Mk1 prototype proved the feasibility of the concept. On the Mk2, design and process were further optimized, which will enable designers to develop SKA specific reflectors with a high degree of confidence. The CART Mk 2 reflector is an improvement on the Mk1 in all aspects. The change of design approach to separately fabricated beams and hub bonded to a monolithic surface and rim improved manufacturability and yielded a more accurate surface.



Design

Table 1 CART Prototype Reflector Design Goals

Reflector Diameter	10 m.
Optics	Center-fed parabolic reflector.
f/D ratio	0.45
Max operating frequency	10 GHz (using a 1/20 feed-weighted RMS deflection criterion).
Operating wind speed	35 km/hr (22 mph or 10 m/s)
Slew to stow at	50 km/hr (31 mph or 14 m/s)
Survival wind speed	160 km/hr (100 mph or 44 m/s)

The Mk2 reflector was designed to the same design goals as the Mk1, (Table 1). However, the design of the Mk2 is different from that of the Mk1 in several important aspects, (Figure 1). The Mk1 consisted of six solid foam core beams that were molded in place. These were of three different heights. The tallest two of which were bent out to pick up the feedleg loads. At the time of the Mk 1 design the reflector mount had not been identified. To accommodate different potential mounts the design incorporated a universal 2-m square box structure at the centre of the reflector into which a mounting interface frame could be fitted. The Mk2 features eight radial beams arranged around a central hub. The beams and the central hub are molded as separate parts, and then bonded on to the one-piece surface/rim. The hub was designed to interface directly with the MV-1 mount.

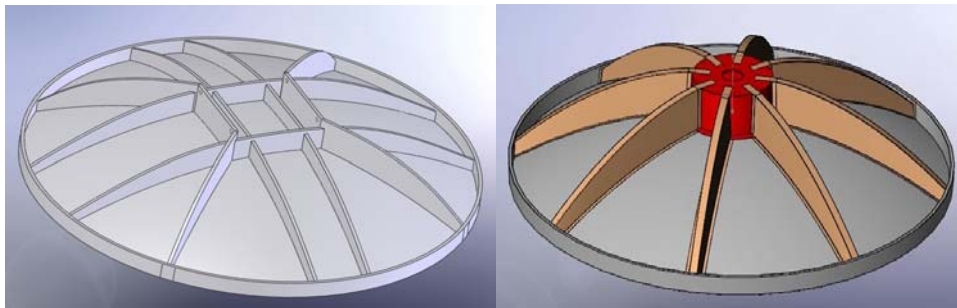


Figure 1 Mk1 (left) and Mk2 (right) reflector designs.

Construction of the Mk1 was labour intensive. The four smaller beams were infused with the surface/rim and the two larger beams were added in a secondary infusion. The molded-on beams required a lot of setup time and a more complicated infusion scheme. In addition, the large scale deviations that were measured in the Mk1 surface are partly attributed to the curing of the secondary infusion.

For the Mk2 the reflector surface and rim were infused as one piece to reduce labour, the elapsed time, and the time-in-mold. The hub and beams were fabricated in parallel and then bonded on to the surface/rim while it was still on the mold, capturing the surface shape.



The separately molded beams are made with thin core in their webs and caps to stabilize their surfaces from local buckling. As a result they are stronger, stiffer and lighter than the molded-on foam-core Mk1 beams.

Few material changes were made between the Mk1 and Mk2 except where the design changes required it.

Deflection analysis, stress analysis, first ply failure, normal modes etc. were calculated using Finite Element Analysis (FEA) to ensure that the reflector would meet all of the performance criteria under all operating conditions.

Fabrication & Costing

Fabrication of the Mk2 reflector took place during the period of May to August of 2008 with a crew of three working one shift/day five days/week. As with most prototypes much of the time was spent in technique development and actual construction time was less than six weeks.

Table 2 Mk2 Reflector Fabrication Cost Breakdown.

	Cost US\$	US\$/m ²
Materials	\$48,689	\$619
Labour	\$35,339	\$450
Total	\$84,028	\$1,069

Table 2 shows the cost breakdown for the Mk2 prototype; preliminary investigation indicates that the cost can be reduced by as much as 40%. As part of its PrepSKA work HIA has engaged an industry partner to carry out a detailed study of manufacturing composite reflectors for the SKA. The results of this study are expected in mid-2009.

Surface Measurement Results

Measurements of the Mk2 reflecting surface were conducted using a laser tracker. Previous experience with the Mk1 showed that this method revealed the same results as holography but is easier to perform. The laser tracker was mounted in the centre of the reflector and tracks a retro-reflector as it is drawn over the surface. Point coordinates were recorded every 50 mm of motion (Figure 2).

A parabola is best fit to the point cloud data taking into account the retro-reflector offset and the deviations of each point from the parabolic surface is calculated. From this the Root Mean Square (RMS) of the deviations, and the RMS half-pathlength error σ , (half-pathlength error is the normal component of the deformation vector times the direction cosine with respect to the focal axis) were calculated. The Ruze efficiency [1], a quantification of reflector efficiency in terms of wavelength λ and half-pathlength error, was then calculated at $\lambda = 3$ cm (10 GHz), Equation 1.



$$\eta = \exp\left(-\left(\frac{4\pi\sigma}{\lambda}\right)^2\right) \quad \text{Eq. 1}$$

The same technique was used to analyze the deviations of the nodes on the reflector surface from the finite element analysis results.



Figure 2 Measuring reflector surface with laser tracker.

An initial surface scan of the reflector was performed with the reflector pointing straight up resting on the hub mounting face. A plot of the deviation from a best-fit parabola is shown in Figure 3. The RMS of the deviations is calculated to be 0.54 mm. The half-path length error is 0.50 mm, giving a Ruze efficiency of 0.96 at $\lambda = 3$ cm.

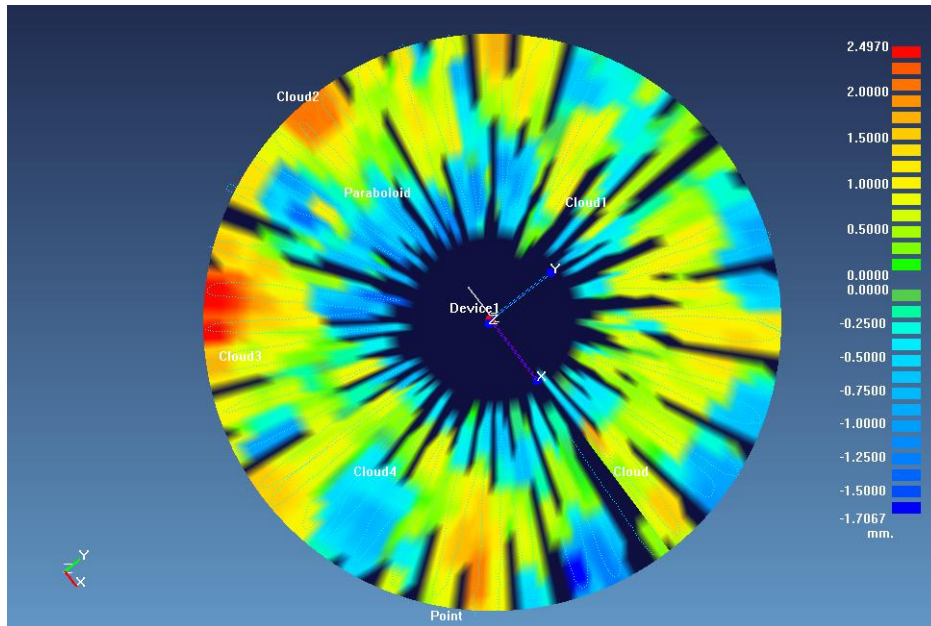


Figure 3 Measurement with no feed structure.

The reflector was then lifted on to the mount and the Phased Array Demonstrator (PHAD) installed (Figure 4). The surface was then rescanned. Figure 5 shows a plot of the results.



Figure 4 Mk2 Reflector on Positioner with PHAD in place.



