DISH SURFACE OPTIMIZATION SYSTEM

SURFACE CORRECTION ON A 10.4-METER LEIGHTON PRIMARY MIRROR

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ABSTRACT

A Dish Surface Optimization System (DSOS) is in operation at the CSO on Mauna Kea, Hawaii. The DSOS corrects the 10.4-meter primary surface for imperfections and deformations due to gravitational forces as the dish moves in elevation. Controlled heating and cooling of the steel rod standoffs that interface the dish panels to its backing structure applies the corrections. An improvement of twice the aperture efficiency is desired at 350 µm. This implies that the integration time could be reduced by a factor of four, and six times more new deep-field objects could be detected.

1. INTRODUCTION & BACKGROUND

The Caltech Submillimeter Observatory (CSO) is equipped with a Leighton primary mirror consisting of 84 hexagonal parabolic segments, together measuring 10.4 meters in diameter. The primary mirror has a surface error of 25 microns RMS. At 350 microns wavelength, the aperture efficiency of the telescope is 33%. By implementing a system that corrects the surface of the dish, twice the aperture efficiency could be achieved. With an improved efficiency of 66%, the integration time will be reduced by a factor of four, and detection of up to six times more new deep-field objects could be achieved. Today, a new design, that is able to heat or cool individual steel rod standoffs, mounted behind the dish, has been developed and is presently in use. It is named the Dish Surface Optimization System or DSOS.

Controlled heating and cooling of the steel rod standoffs that interface the dish panels to its backing structure applies the corrections. The heating and cooling expands and contracts, respectively, these standoffs, thereby adjusting the surface of the dish. The needed amount of correction for each standoff is determined through past holography maps of the dish surface.

Since February 2003, the DSOS has been operating with the CSO's SHARCII instrument at a wavelength of 350 µm. SHARCII is a 384 pixel submillimeter high angular resolution camera [1]. Although full system performance measurements have not been completed, the DSOS has always improved the detected signal power and the telescope beam pattern.

Recently, while observing Ganymede (one of Jupiter's moons) the average signal power improvement was about 35% with twenty-eight (28) activated thermal electric cooler (TEC) assemblies out of a maximum of 99. A reduction of 2 arcseconds in the FWHM of the telescope's beam was also obtained. Its original size was 12 arcseconds.

2. DESCRIPTION OF THE DESIGN

On other telescope primary segments, mechanical worm drives are in use as active optics systems. Heating and cooling is a new innovation to step away from mechanical gears. This helps preserve the primary's original alignment and tuning. If an observer prefers the dish without correction, the DSOS can be turned off, allowing the structure to return to its quiescent state.

The DSOS incorporates the use of Peltier cells, also known as thermal electric coolers or TECs. When a voltage is applied, the device will heat or cool the surface it is interfaced to, depending on the voltage's polarity.

As a TEC heats or cools an assembly, an embedded thermistor is read. The thermistor level and desired setting are subtracted and their difference is used as the control level to the TEC. The voltage will stabilize to a value that will keep the error signal to zero. See Fig. 1 for a block diagram of a single channel.

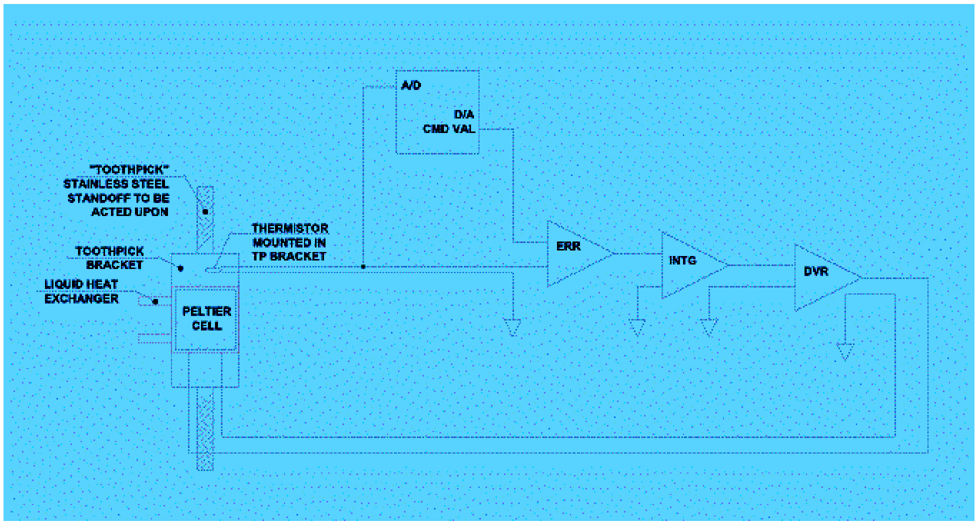


Fig. 1. DSOS Simplified Block Diagram of a single channel. The thermistor level and desired setting are subtracted and their difference is used as the control level to the TEC.

Because the TEC is mounted on a precision structure at high altitude, heatsinks could not be used. To save on weight and to obtain a higher cooling capacity, a liquid heat exchanger with refrigerated bath, were incorporated into the TEC assembly.

3. DESCRIPTION OF THE SYSTEM

There are 99 steel rod standoffs that interface the dish to its backing structure. These standoffs are where the TEC assemblies are mounted. The assembly consists of a mounting bracket, embedded thermistor, TEC, and heat exchanger. The mounting bracket clamps around the steel rod standoff while giving the TEC a flat surface to mount to. See Fig. 2. The bracket also has a glass bead thermistor embedded in it to supply feedback to the controller unit. A heat exchanger is mounted on the TEC to remove heat produced when cooling.

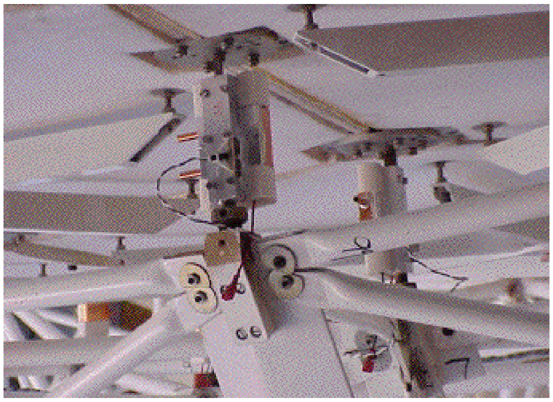


Fig. 2a. TEC Assembly Installed on Primary Standoff

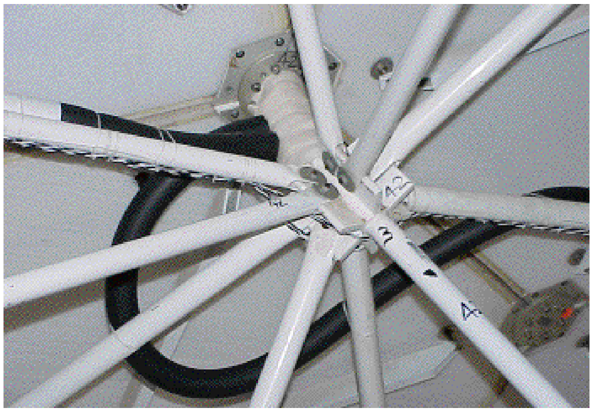


Fig. 2b. Insulated TEC Assembly

Fig. 2a. Displays the TEC assembly mounted on the back of the primary. The mounting bracket, liquid heat exchanger and wiring are visible. Fig. 2b. Displays the assembly fully insulated along with its coolant lines.

From the 99 TEC assemblies, routed along the dish backing structure, there are long wire harnesses for thermistor feedback and TEC power, plus lines of insulated tubing for plumbing the heat exchangers to their refrigerated baths. A 50/50 mixture of glycol and distilled water is used.

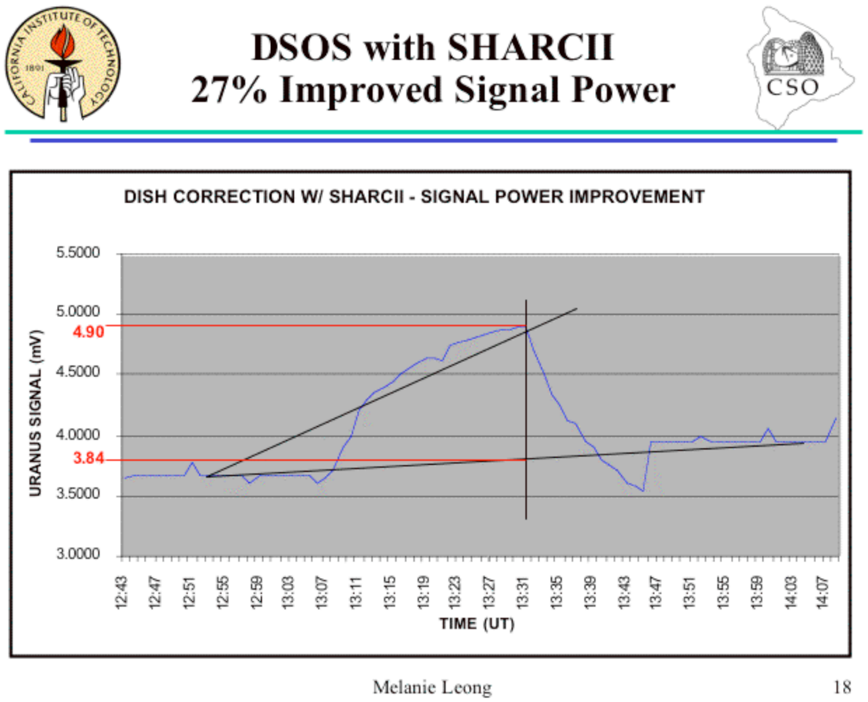
The rest of the system is located on the CSO's third floor mezzanine. This consists of a Controller rack, two Driver racks, two refrigerated baths for the Driver racks, four refrigerated baths for each quadrant of the dish, and their respective pump and manifold.

The 99 Channel Controller Unit houses (10) ten channel controller PCBs. The channels are selected via a zero board, containing a Xilinks chip that queries individual A/Ds and commands their respective D/As. The Controller Unit receives the thermistor levels from the TEC assemblies and outputs the difference between the thermistor reading and desired command setting. This control voltage is input to a power amplifier to drive the TECs. As the difference between the thermistor reading and the desired command setting gets driven to zero, so does the power driving each channel's TEC.

There are four 25 Channel Driver Units. Each unit is dual air and liquid cooled. This is due to 25 power amplifiers mounted on a large heatsink plate that operates at 13,800 feet elevation. A single Driver Unit powers one quadrant of the dish. The dish is sectioned into four quadrants. This was done for intermediate integration and test, hardware groupings, and wiring purposes.

4. FIRST LIGHT

The full DSOS build was completed in May 2002, 14 months after its start. Holography could not be done due to unavailability of planets. Efficiency with the CSO's SHARCII camera was used to measure improved signal power when the DSOS is on. In July 2003, with 19 channels activated, there was a 27% improvement of signal power from the planet Uranus. Fig. 3 is a plot of the improved signal power with the DSOS on.



DSOS with SHARCII
27% Improved Signal Power

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Fig. 3. SHARCII Signal Power Improvement. With 19 out of 99 activated channels, at 350µm, a 27% improvement in signal power was measured.

5. PERFORMANCE

In February 2003, signal power and FWHM improvements were measured from Ganymede, one of Jupiter's moons. This was done with 28 calibrated DSOS channels activated and the SHARCII. The data was taken in the zenith angle range of 30 to 4, then 4 to 28 degrees. Signal power improved by as much as 50% and the best FWHM improvement was 3.4 arcsec from an originally 14 arcsec measurement. The best improvement occurred while the dish was tipped close to zenith. This is the range where the dish incurs more deformations from gravitational sag. The dish's mechanical tuning is in the 40 degree zenith angle range, so less improvement from the DSOS is expected there.

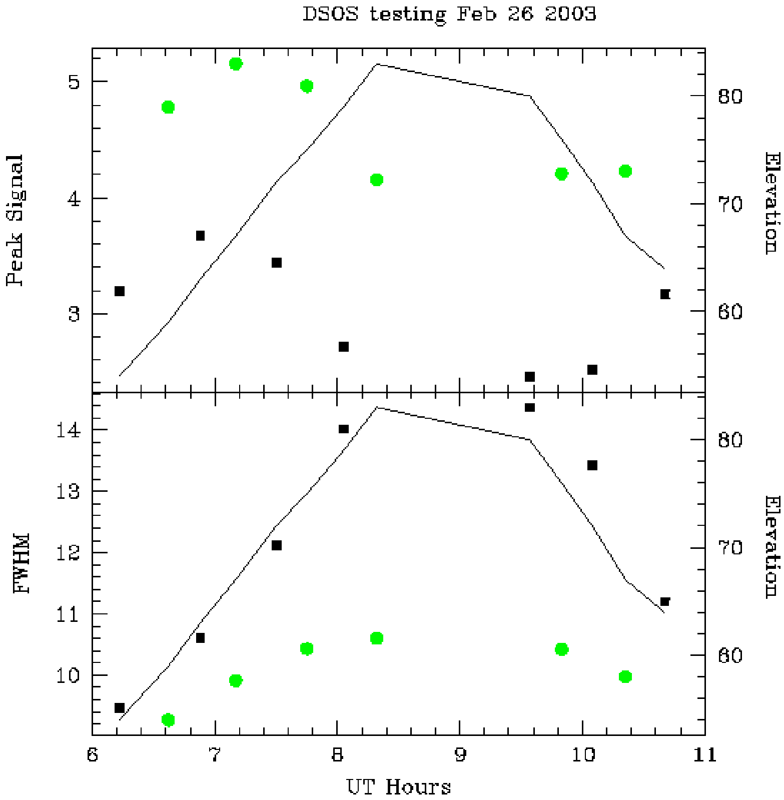

Fig. 4. DSOS Performance Results with 28 Activated Channels. Black squares depict levels with the system off. Green circles depict levels with the DSOS on. At small zenith angles the DSOS was able to improve the signal power by as much as 50%. Best FWHM improvement was 3.4 arcsec, 14 arcsec object condensed to 10.6 arcsec.

In April 2003 a quick map of Ganymede, a moon of Jupiter, was taken by the SHARCII at 350µm. With 52 of 99 DSOS Channels activated, a much cleaner image was recorded, as shown in Fig. 5.

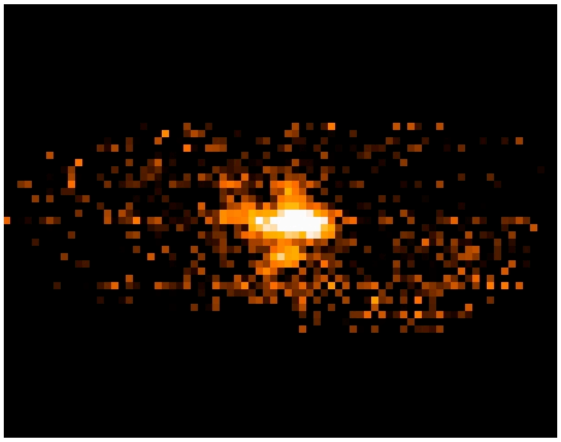

Fig. 5a. DSOS OFF - Ganymede

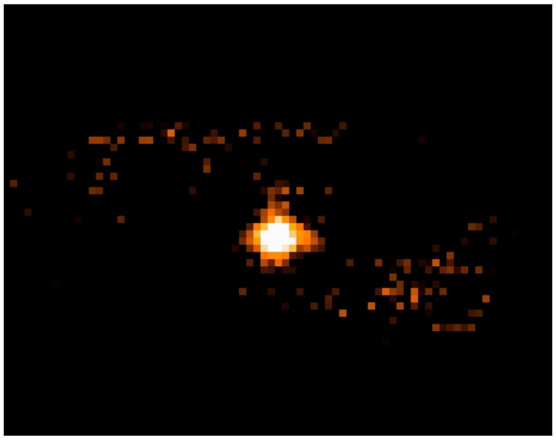

Fig. 5b. DSOS ON (52 of 99 Channels Activated)

Fig. 5a. Ganymede, a moon of Jupiter, with no primary correction. Fig. 5b. A cleaner picture of Ganymede at 350µm with 52 of 99 DSOS Channels on.

This August 2003, holography with all 99 DSOS channels activate, was performed and the results show an overall improvement in the reduction of surface deformations. See Fig. 6. Compare its top row maps with the corresponding bottom row maps. Preliminary calculations resulted in a best improvement value of 2.8 µm RMS, from 16.0 µm to 13.2 µm RMS. The numbers don't reflect the improvements seen visually. This could be explained by different water vapor levels and filters used. The water vapor level was 1.1 mm when the DSOS off scans were taken. The water vapor level, for the DSOS on scans, was 2.0 mm. A higher frequency filter was also used for the DSOS on measurements, which is intrinsically more sensitive to sky noise.

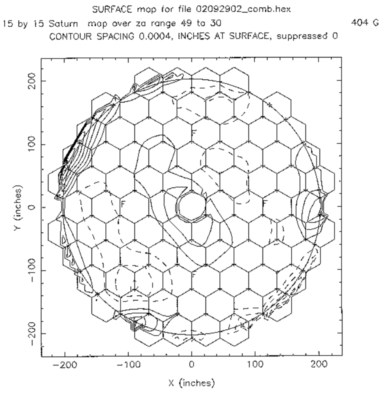

Fig. 6a. DSOS Off – ZA 49 to 30

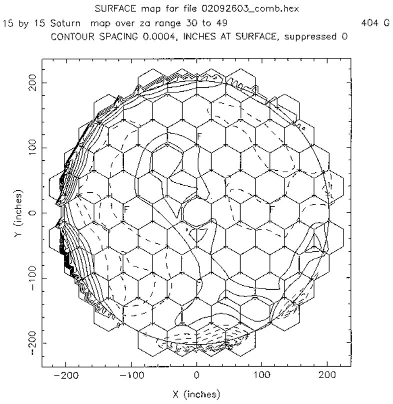

Fig. 6b. DSOS Off – 30 to 49

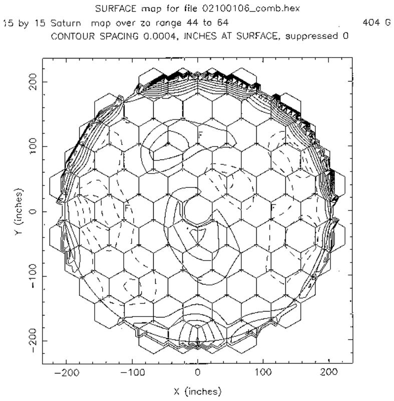

Fig. 6c. DSOS Off – ZA 44 to 64

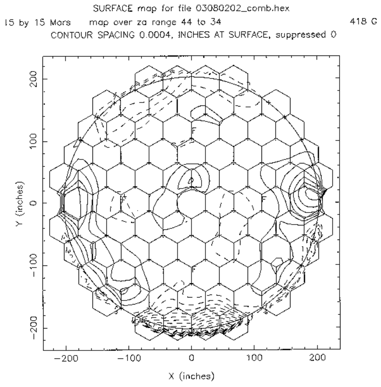

Fig. 6d. DSOS On – ZA 44 to 34

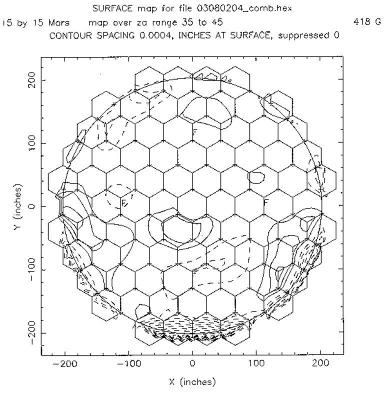

Fig. 6e. DSOS On – ZA 35 to 45

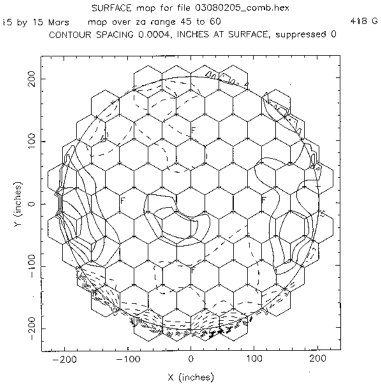

Fig. 6f. DSOS On – ZA 45 to 60

Fig. 6a. to 6c. are contour maps of the primary with no correction applied. Fig. 6d. to 6f. are contour maps with the DSOS On. For comparison, these are shown in approximately the same zenith angle ranges.

6. SUMMARY

The DSOS has shown significant improvements in signal power and beam shape at 350μm wavelength. It has been in use for scientific observations since February 2003.

7. REFERENCES

1. Dowell, C. D., Allen, C. A., Babu, S., Freund, M. M., Gardner, M., Groseth, J., Jhabvala, M., Kovacs, A., Lis, D. C., Moseley Jr., S. H., Phillips, T. G., Silverberg, R., Voellmer, G., Yoshida, H.: 2003, in *Millimeter and Submillimeter Detectors for Astronomy*, eds. T. G. Phillips and J. Zmuidzinas, Proc. SPIE 4855, 73