ABSTRACT

Radiant cooler is used to cool the infrared and water vapour detectors of meteorological payload of several geosynchronous satellites of ISRO. A three stage cooler was developed at Thermal Systems Group, ISAC to achieve temperatures required for different missions. It consists of a patch (cold stage) on which detector is mounted, intermediate cooling stage radiator, vacuum housing to enclose optics of Meteorological payload and sunshields as the first stage. These sunshields are mounted on Vacuum Housing. The thermal control surfaces of sunshield facing patch is chosen to have low solar absorptance (α_s) and low emissivity (ε_{IR}) to minimize the thermal load on patch. Also to minimize the reflected solar radiation from sun shield surfaces on the patch, specular reflecting surface in solar spectrum wave length range is needed.

To achieve such a specularly reflecting metal mirror, a specialized process was developed by carrying out a sequence of operations in collaboration with NAL, IIA and LEOS. The precision machining on the aluminium sun shield panels was carried out to achieve good flatness and finish. The machined panels were plated with electroplated nickel and heat treated to relieve the stress. The panels after lapping were electroless nickel plated, polished to optical finish and coated with vacuum evaporated aluminium. The surface characteristics like surface finish (40 to 60 A^o), solar absorptance (0.11), Emittance (0.03) and solar specularity (98%) were measured. The surface so produced has met the requirement of IR detector cooling to 105 K in coolers onboard INSAT 2A/2B/2E, KALPANA-1(METSAT), INSAT-3A Satellites.

To achieve IR detectors cooling requirement of 95 K for advanced Imager and Sounder Meteorological Payloads, the improved processes was developed for specularly reflecting sunshields. It comprises of Precision Machining (Flatness 10µm), Single Point Diamond Turning, Electroless Nickel Plating (100 µm thickness), Optical Polishing (finish: <20 A^o) and improved Aluminium coating (α_s:0.078, ε_{IR}: 0.022, specularity >99%)

The new process was implemented on INSAT 3D Imager, Sounder and Filter Wheel Cooler sunshields (ETM and Flight Models). The integrated cooler assembly with sunshields was subjected to the acceptance tests (Electrical Insulation test, Vibration test, Thermal cycling and thermal balance test under simulated space environment) and it passed the tests successfully. The satellite is expected to be launched in 2010.

The report gives a comprehensive account of the development of metallic sunshields for earlier ISRO mission and the journey covered to reach the latest one. This report describes the methodology used in optical polishing and surface quality achieved. It discusses on orbit performance of KALPANA-1 cooler, which show a good match of predicted and observed temperatures. The results of ground tests conducted on the coolers of INSAT-3D are also presented along with on orbit predictions.

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1.0 INTRODUCTION

Radiant cooler is used to cool the infrared detectors of meteorological payload of several geosynchronous satellites of ISRO. A three stage cooler was developed to achieve temperatures required for different missions. It consists of patch (cold stage) on which detector is mounted, intermediate cooling stage radiator, vacuum housing to enclose optics of Meteorological payload and sunshields as the first stage. These sunshields are mounted on Vacuum Housing.

Radiant cooler for earlier INSAT class of satellites, is a sub assembly for 3 channel Very High Resolution Radiometer (VHRR), the meteorological payload on-board INSAT spacecraft. It comprises of visible channel in 0.55 to 0.75 micrometer band, Water Vapor channel (WV) in 5.7 to 7.1 micrometer band and thermal infra red (TIR) channel in 10.5 to 12.5 micrometer band. The payload is used to measure cloud and earth atmosphere surface mapping, sea surface temperature, snow and ice detection, wind speeds over oceanic region etc. The radiant cooler cools VHRR detector assembly and maintains it at 105-115 K during life of satellite. Fig 1a shows KALPANA-1 spacecraft with VHRR payload.

Figure: 1a
KALPANA-1 Spacecraft

INSAT-3D spacecraft has got two instruments for meteorological purposes i.e. Sounder and Imager mounted on Earth View panel towards North. These two instruments are mounted symmetrically about yaw axis on the separate isolated platforms (Fig 1b). Imager is a six-channel (1 visible and five infrared) imaging radiometer designed to sense radiated and reflected solar energy from sampled area of earth. Sounder is a 19-channel discrete filter wheel radiometer that senses specific data parameters for atmospheric vertical temperature and moisture profile, surface and cloud top temperatures and ozone distribution. The nineteen spectral bands [seven long wave (LW), five mid wave (MW), six short wave (SW) and one visible] produce the prime sounding products.

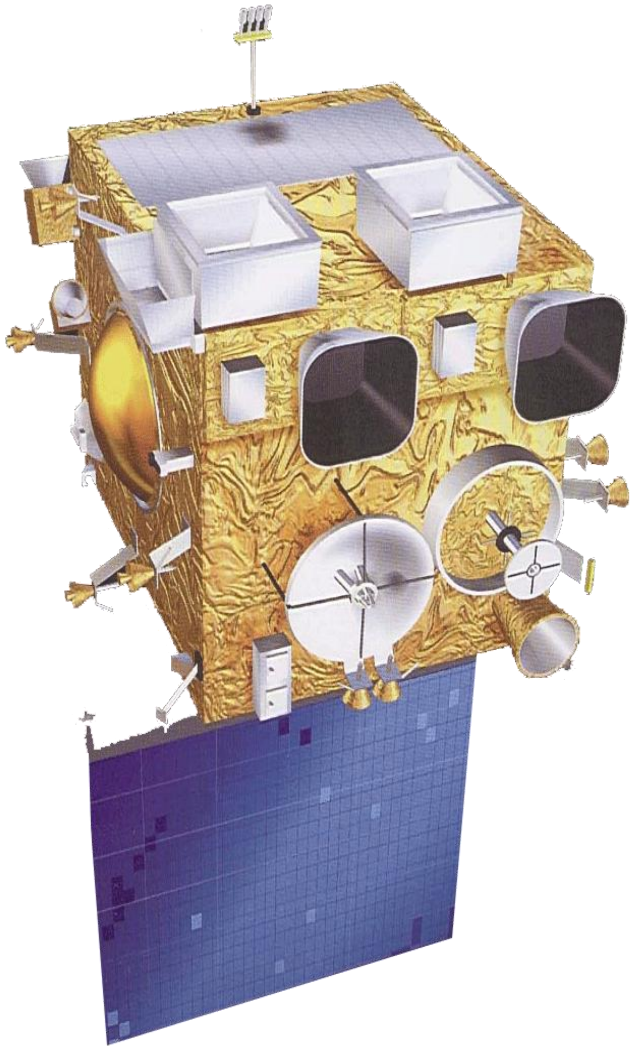


Figure : 1b
INSAT 3D Spacecraft

The detectors temperature requirement for Imager and Sounder coolers is 95-100 K during life of satellite which is provided by three stage passive radiant coolers. Also Sounder Filter Wheel needs to be maintained at a temperature of 213K for which purpose a two stage cooler is used. So, there are three coolers for INSAT-3D Meteorological Payload i.e.

1. Imager Cooler
2. Sounder Cooler
3. Sounder Filter Wheel cooler

COOLER CONFIGURATION

The schematic diagram of cooler configuration consisting of three stages is shown in the figure 2a. The radiative power of the patch at the operating temperature of 105K is extremely small (123 mW) giving a sensitivity of 4.6mW/K. therefore, while designing the cooler, every possible effort was made to reduce the heat load reaching the cold stage patch.

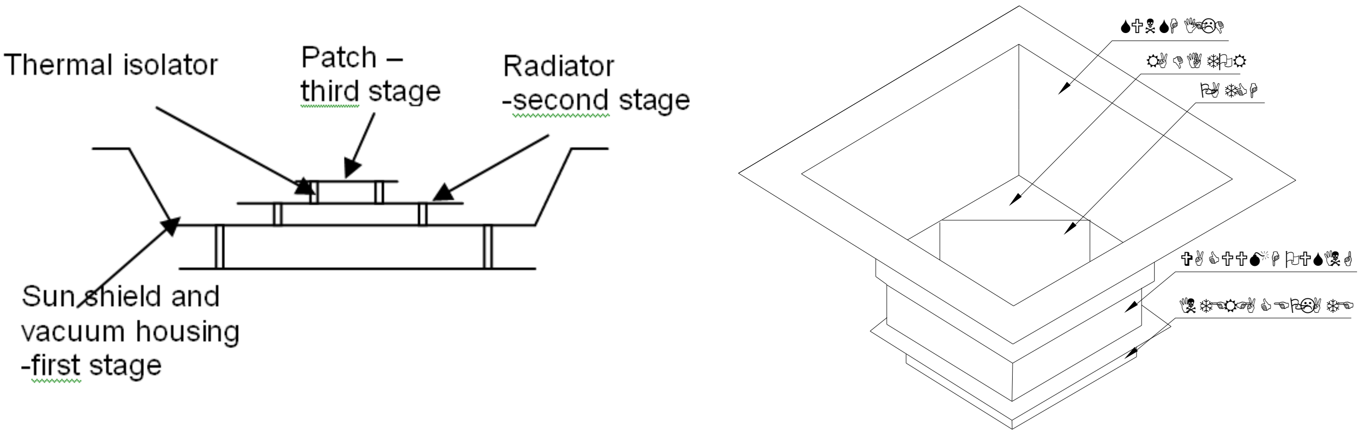


Figure : 2a
Schematic of three stage radiant cooler

All the stages are thermally isolated from each other to minimize the radiative and conductive coupling. The patch is the cold stage on which the IR detector assembly is mounted. To maximize the effective Emittance on patch facing space, an aluminium honeycomb core is fixed in patch cavity and coated with conductive black paint. The radiator is the intermediate stage and is co-planer with patch. The radiator surface facing space is coated with low solar absorptance (α_s) and high Emittance (ε_{IR}) white paint. The rear surfaces of patch and radiator is gold plated to minimize radiative input to the patch. The patch is connected to radiator through four very low conductance FRP tube supports. The vacuum housing houses patch/ radiator assembly through eight FRP support assembly and also the optomechanical mounts of IR channel elements like radiator window, vacuum window and focusing lens. The sun shield assembly, consisting of four trapezoidal panels, is mounted on vacuum housing. The sunshield/vacuum housing assembly is mounted on VHRR Electro-optics module through a cooler interface plate. Figure 2b shows the sectional view of KALPANA-1 Radiant Cooler.

To predict the on-orbit temperatures of the cooler, a thermal mathematical model is developed. The temperature of various elements of cooler is established by the balance of various heat inputs to them and the heat radiated by them to the environment.

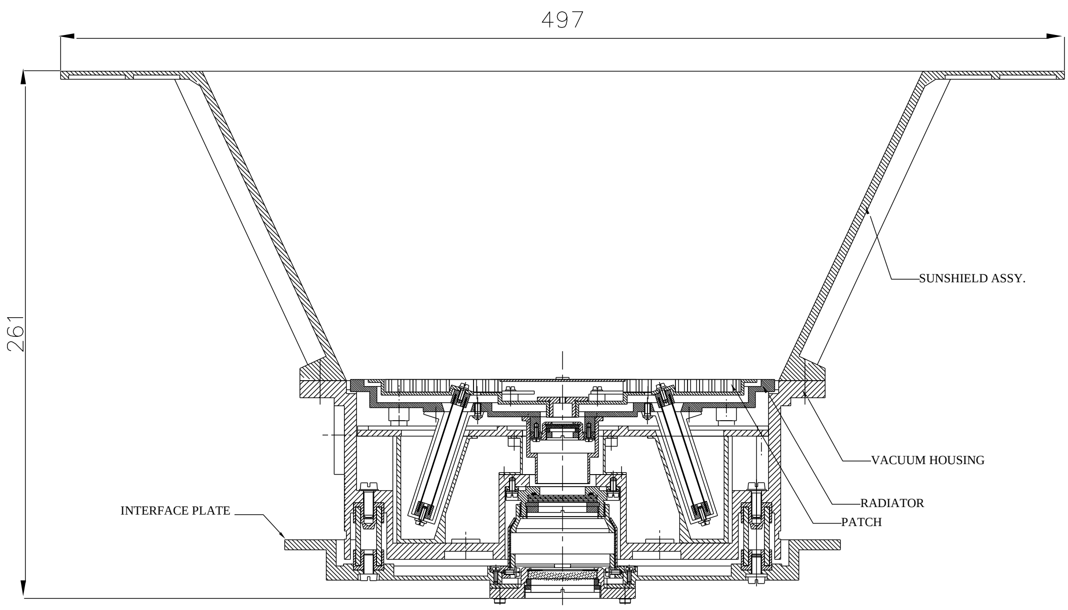
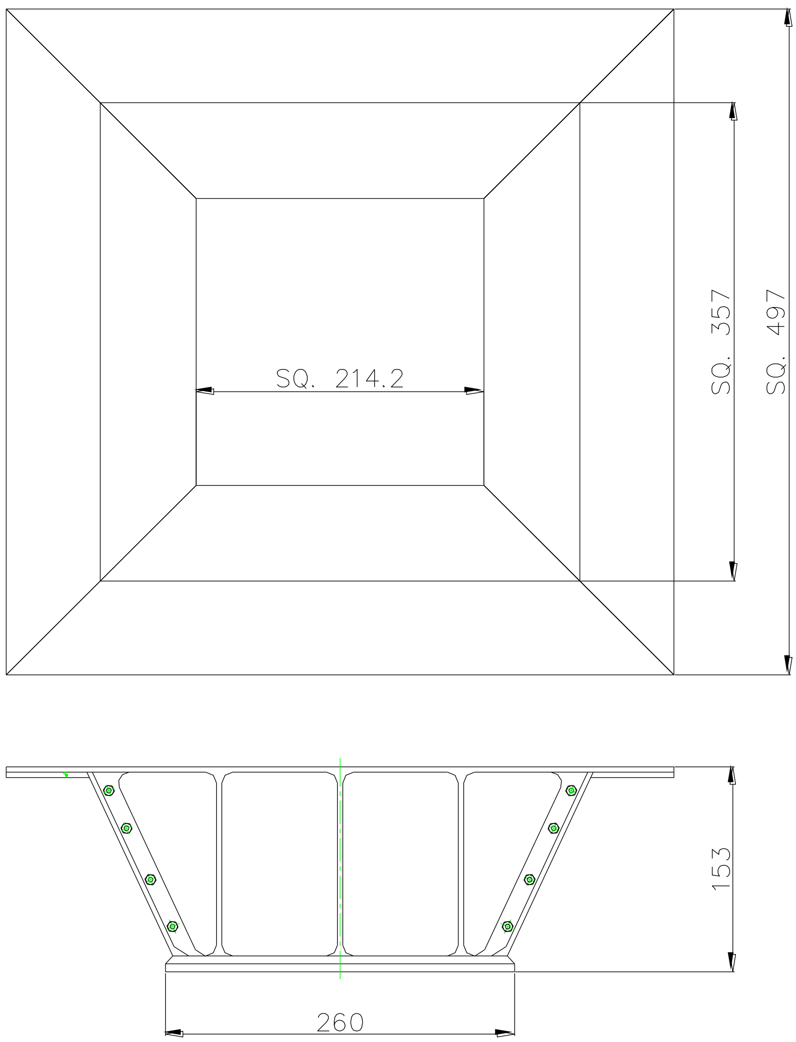


Figure : 2b
Sectional View of KALPANA-1 Radiant Cooler

SUN SHIELD CONFIGURATION

The height and the cone angle of sun shield assembly (25^{o}) is designed in such a way that no direct sun load falls on patch even with the maximum declination of sun (23.5^{o}). The sun shield surfaces facing patch are highly specular reflecting surfaces (like mirror) with low solar absorptance and low Emittance so that the incident solar radiation is reflected back to deep space without scattering and shield emitted IR load reaching the cold stage patch is minimized. Since INSAT 3D will be rotated every six months around yaw axis, the height of sunshield is reduced. The cone angle remains the same. Due to large size of sunshield panel in INSAT 3D, the panel had to be split into two ie each panel is made up of two semipanels.

The size and shape of sunshield varies with the mission and temperature requirement on cold stage of cooler. The polishing fixture and handling is modified to suit each configuration. Figures 3a, 3b and 3c give the details (dimensions, shape etc) of sunshields of KALPANA-1 cooler, Imager/ Sounder cooler and Filter Wheel cooler for INSAT 3D



<u>Figure : 3a</u>
<u>Sunshield configuration of KALPANA-1 Cooler</u>

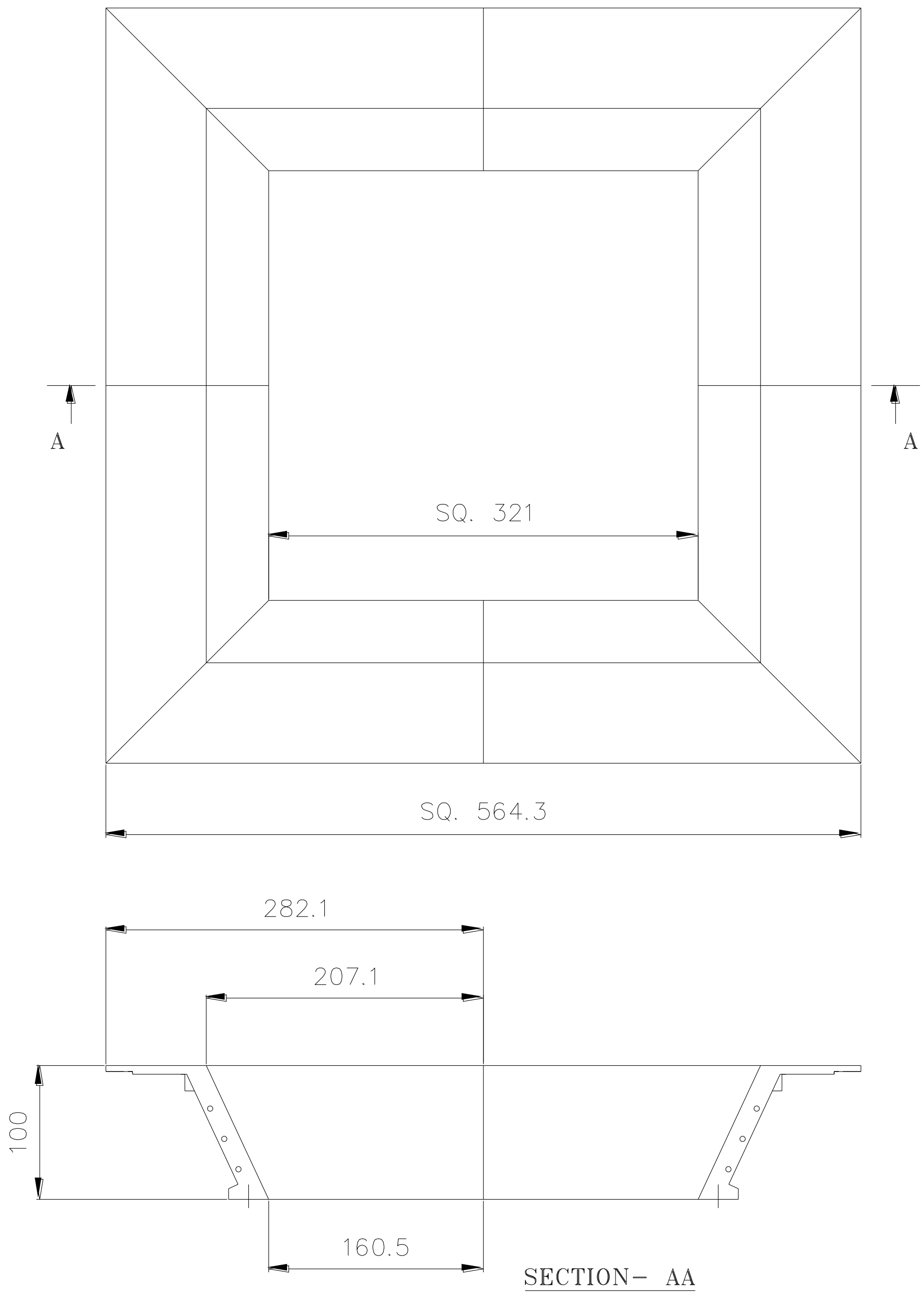


Figure : 3b

Sunshield configuration of Imager / Sounder Cooler

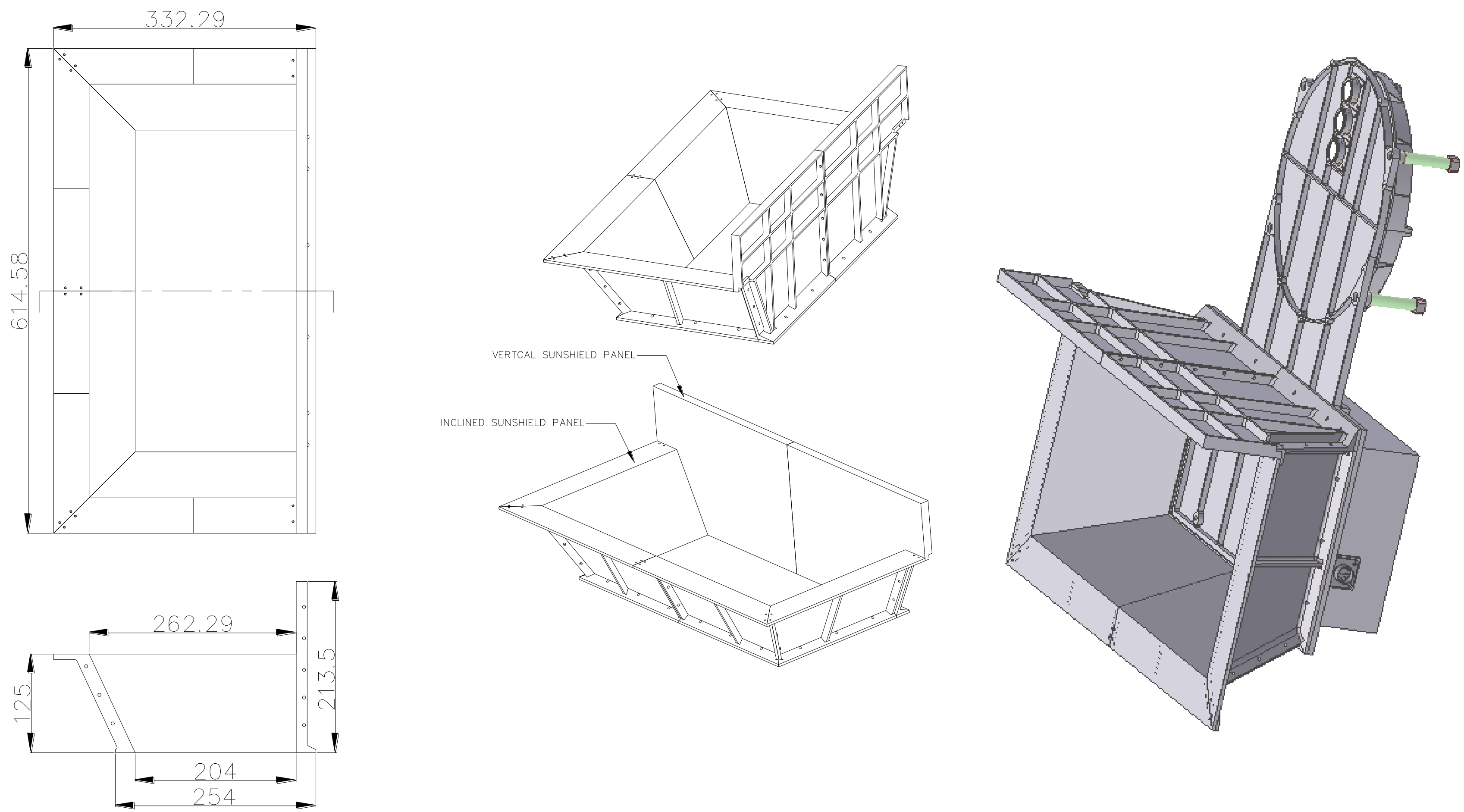


Figure : 3c

Sunshield configuration of Filter Wheel Cooler

4.0 EFFECT OF SURFACE ROUGHNESS ON OPTICAL PROPERTIES

The specular component $\rho_{s\lambda}$ of the total reflected radiation $\rho_{T\lambda}$ at wavelength λ is a function of the rms surface roughness σ of the surface and for normal incidence is given by [1]

$$\rho_{s\lambda} = \rho_{T\lambda} e^{-\left(\frac{4\pi\sigma}{\lambda}\right)^2} \qquad (1)$$

For space work, the wavelength region of interest is over solar spectrum. Therefore it is necessary to determine the specularity of a surface over solar spectrum.

$$\rho_{s,\ solar} = \frac{\int_{\lambda 1}^{\lambda 2} \rho_{s\lambda}.E_{\lambda}.d_{\lambda}}{\int_{\lambda 1}^{\lambda 2} E_{\lambda}.d_{\lambda}} \qquad (2)$$

Where E_λ is solar spectral irradiance, $\lambda_1 = 0.2\mu$ and $\lambda_2 = 2.5\mu$.

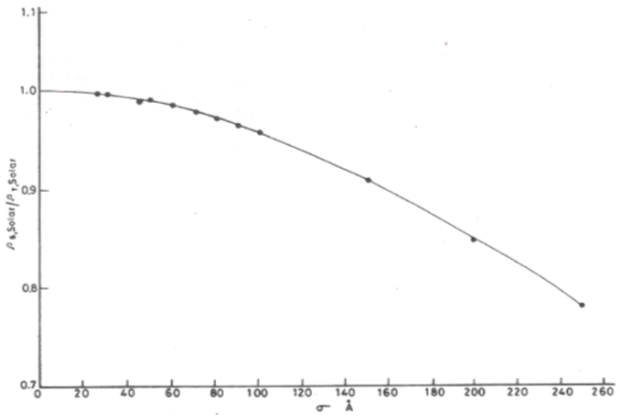


Figure : 4.0
variation of $\rho_{S,solar}/\rho_{T,\ solar}$ for small surface roughness

Figure 4.0 shows the variation of $\rho_{s,solar}$ / $\rho_{T,solar}$ as a function of surface roughness i.e., 50 °A gives 99% specularity, 100 °A leads to 96% specularity etc.

This criterion was used as a guideline for deciding the value of surface microroughness to be achieved on sunshield panels in order to meet the temperature requirement of the mission specific cooler. The sunshield panels so produced were characterized by using noncontact optical profilometer to assess the surface quality. Total and diffuse reflectance were measured using UV/VIS/NIR spectrophotometer on co processed witness coupons on polished nickel before and after aluminization.

5.0 DEVELOPMENT OF SPECULARLY REFLECTING SUN SHIELD SURFACE

To achieve required specular surface of <50 A^0 for sunshield, a specialized process was developed by carrying out a sequence of operations, in collaboration with GTTC, NAL, IIA, LEOS in initial stages of work. The precision machining on the aluminium sun shield panels was carried out to achieve good flatness (around 100 microns). The machined panels were electro-plated with nickel and heat treated to relieve the stresses. The panels, after lapping, were electroless nickel plated, polished optically and coated with vacuum evaporated aluminium. Figure 5.1 gives the sequence of operations in the flow chart.

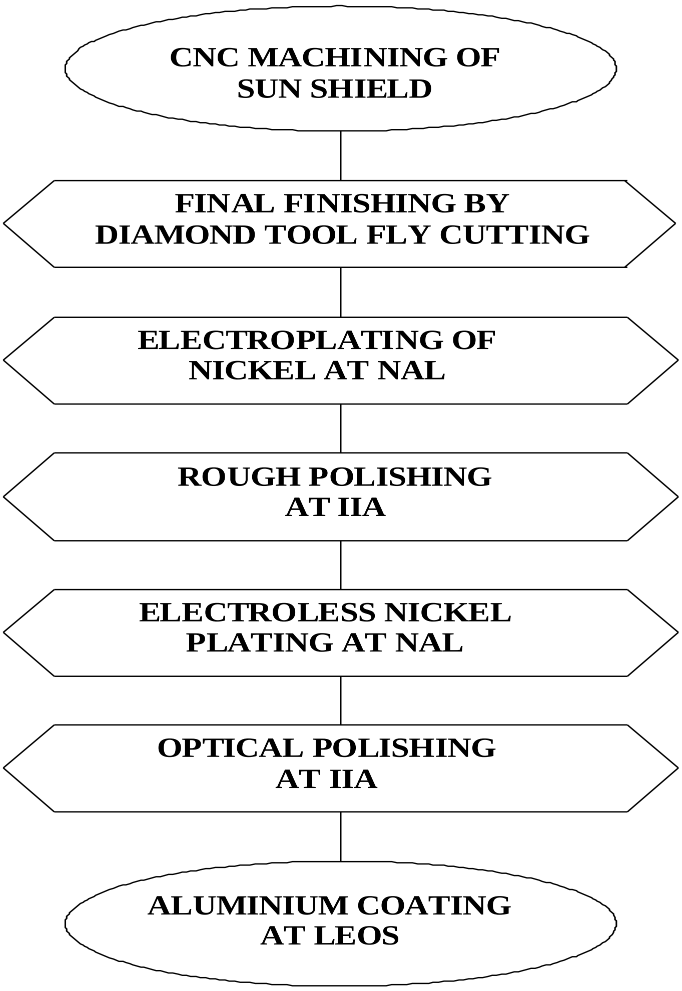


Figure : 5.1

Flow chart of Development of Specularly Reflecting Sun Shield surface

Sunshield edge cleaning needed to be carried out to enable assembly of four trapezoidal sunshield panels after 600 microns of nickel electroplating was done at NAL. For carrying out this exacting operation, first milling operation was done followed by edge grinding. This was a laborious and pain staking process. The rough polishing was carried out on a surface plate in steps using lapping powders of different grades. The flatness requirement on lapped sunshield surface was better than 20 microns which was monitored using a digital spherometer. This flatness value was necessary for next step of eletroless nickel plating.

Optical polishing was taken up after electroless nickel plating was carried out at NAL. The mounting and polishing operation was done in a class 10,000 clean room using specially designed fixtures for holding the sunshield panel along with witness coupons. Polishing machines were reconfigured to accommodate the sunshield and coupon mount. The eccentric motion and turn table type polishing machine were used. The calibration for parameters of machine was carried out to suit polishing during different stages of polishing ie speed of rotation, polishing pad material and grade of abrasive. High quality alumina powder was used as abrasive.

The process so developed was used to produce specular sunshields for INSAT 2A, 2B, 3A and KALPANA-1 coolers. All coolers have shown excellent on orbit performance[3, 4]. Since IR detectors cooling requirement for advanced Imager and Sounder Meteorological Payloads in INSAT 3D is lower than earlier coolers (95 K against 105K), a surface finish of less than 20 A^0 is required on sunshield surface. For achieving this, an improved process was developed for specularly reflecting sunshields. The step of diamond turning was introduced on the front surface of sunshield using diamond turning machine. This operation resulted in a better flatness and hence elimination of rough lapping after electroplating. It resulted in smaller processing time and a target of fabricating almost 100 highly specular sunshields for INSAT 3D could be achieved[2]. The new process flow chart is shown in Figure 5.2

New machines were installed to accommodate larger size panel. A noncontact Veeco optical profilometer was also installed at IIA to carry out quality checks at IIA during polishing. The polishing operation was carried out in class 1000 clean room.

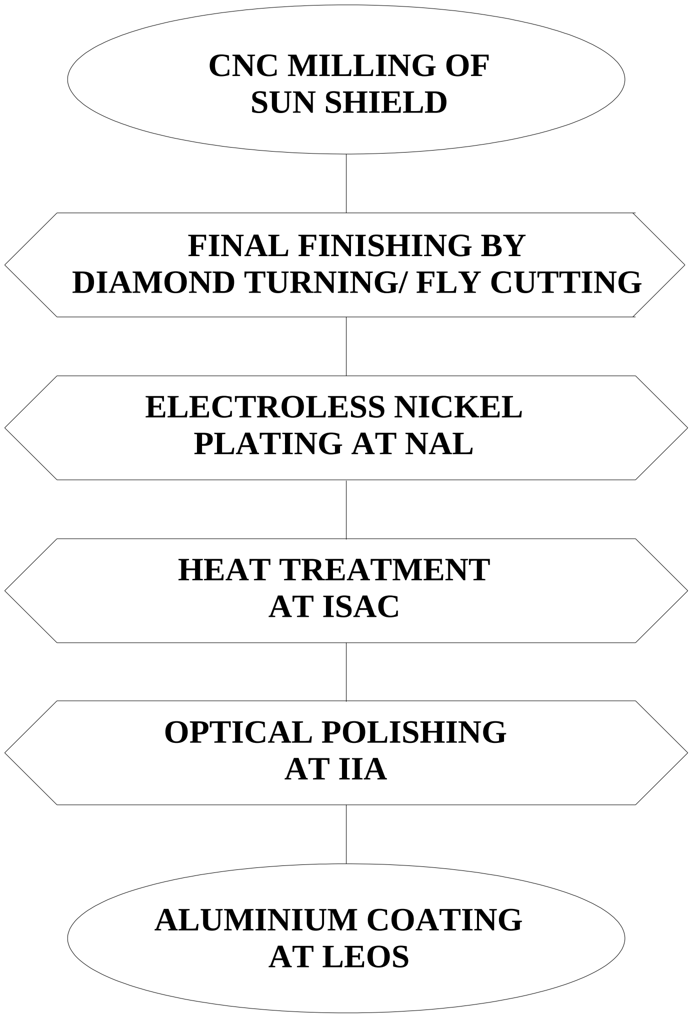


Figure : 5.2
Flow chart of Improved Process of Specularly Reflecting Sun Shield surface

6.0 RESULTS OF SURFACE CHARACTERISATION OF SUN SHIELD

6.1 Measurement of Surface Finish Profile

The surface finish of optically polished surface was measured by using non contact optical profilometer WYKO TOPO2D at ISRO and VEECO Optical profilometer at IIA. Measurements on sun shield panel indicate a surface finish of 20-60°A for panels processed by first process and less than 20°A by second process. Theoretical analysis of surface finish showed specularity of better than 98% and 99% respectively in the solar spectrum range. Figure 6.1 shows a typical surface profile for a sunshield surface measurement. KALAPANA-1 flight model Sunshield and INSAT-3D Imager Cooler (ETM) Surface Finish after Optical Polishing at IIA shown in Table 6.1 and 6.2 respectively

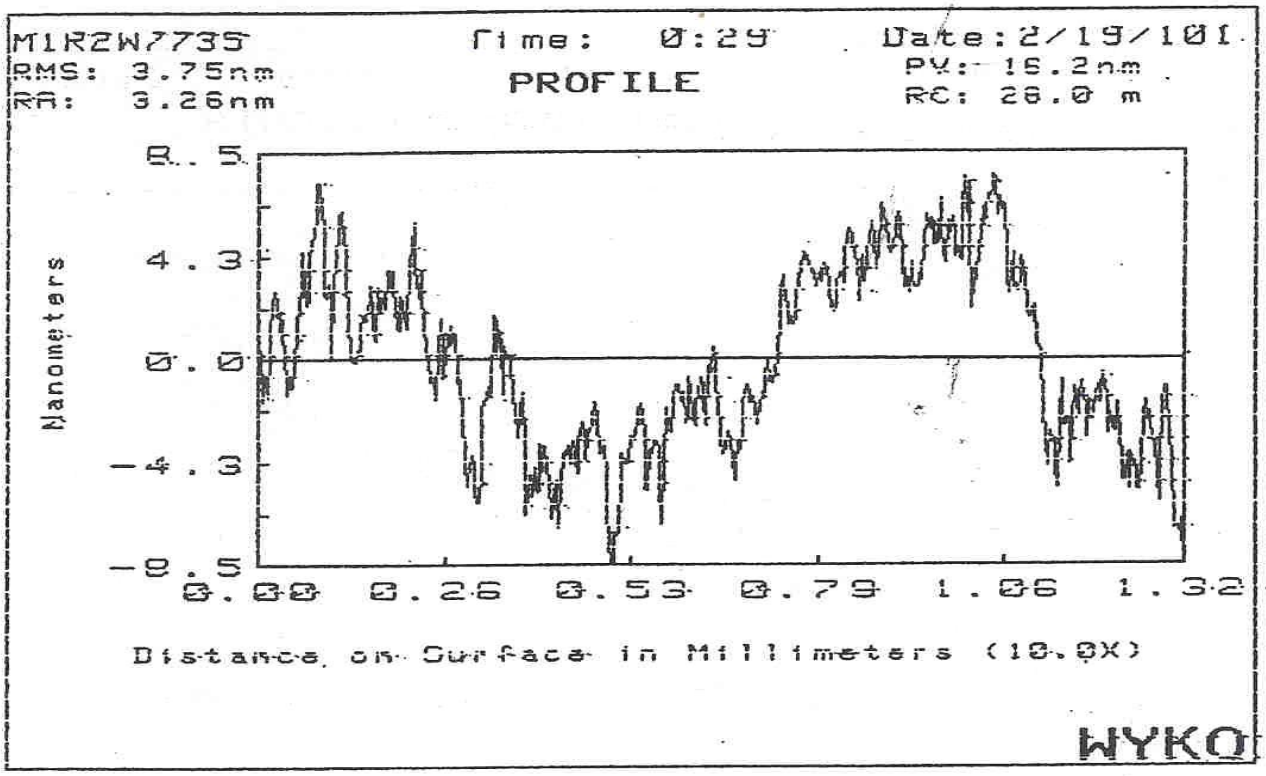


Figure : 6.1
Typical surface profile for polished surface

Table No : 6.1

Surface Finish of KALPANA-1 Sun Shield Panels (Flight Model)

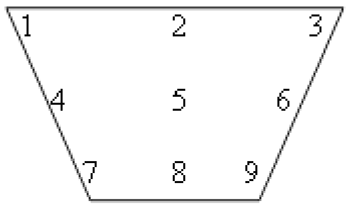
PROCESS : Electroplating of Nickel X Electroless nickel plating X Optical polishing

MEASUREMENT : Using VEECO PROFILOMETER instrument at IIA.

SURFACE FINISH IN (A°)(rms)

LOCATION	SS-1 F 77/1-SS1-01	SS-2 F 77/2-SS2-01	SS-3 F 77/3-SS3-01	SS-4 F 77/4-SS4-01
1	20.8	23.6	33.0	30.6
2	30.7	24.4	31.0	35.0
3	16.4	34.0	30.4	33.6
4	24.3	28.1	26.4	38.0
5	19.1	31.8	37.5	32.8
6	23.6	28.7	25.7	19.3
7	21.7	21.6	48.0	33.3
8	30.9	20.9	21.4	43.4
9	25.7	32.9	60.1	41.1

Location of Surface Finish (Ra) Measurement Points:



Sunshield Panels (SS)

Table No : 6.2

INSAT-3D Imager Cooler (ETM) Sunshield Surface Finish after Optical Polishing at IIA

PROCESS : Diamond turning X Electroless nickel plating X Optical polishing

MEASUREMENT : Using VEECO PROFILOMETER instrument at IIA.

LOCATION	SURFACE FINISH IN (A°)							
	Sunshield -1 (SS-1)				Sunshield -2 (SS-2)			
	(E 2537-SS1-01)	(E 2537-SS1-02)	(E 2537-SS1-03)	(E 2537-SS1-04)	(E 2537-SS2-01)	(E 2537-SS2-02)	(E 2537-SS2-03)	(E 2537-SS2-04)
1	16.4	17.2	14.3	14.0	10.0	17.0	15.0	17.0
2	17.0	18.7	14.0	13.0	14.4	14.0	12.0	18.0
3	19.0	18.5	15.5	17.0	10.3	15.0	17.0	18.0
4	17.0	18.0	15.0	15.0	14.0	14.0	14.0	12.0
5	16.0	18.0	16.0	14.0	15.0	16.0	15.0	12.0
6	16.8	17.5	15.0	13.0	17.0	16.0	15.0	15.0
7	17.6	16.0	18.0	16.0	15.0	16.0	18.0	13.0
8	17.0	19.0	15.0	14.0	18.0	14.0	14.0	19.0
9	18.0	18.0	17.0	17.0	14.0	16.0	16.0	18.0

Location of Surface finish (Ra) measurement points

Sunshield -1 (SS-1) Sunshield -2 (SS-2)

6.2 Measurement of Total and Diffuse Solar Reflectance:

Figure 6.2A shows a typical diffuse and total reflectance curve for polished nickel sample. Figure 6.2B shows the diffuse and total reflectance curve after aluminization for the same sample. The calculated diffuse reflectance, ρ_D value lies in 1-1.5% for these samples.

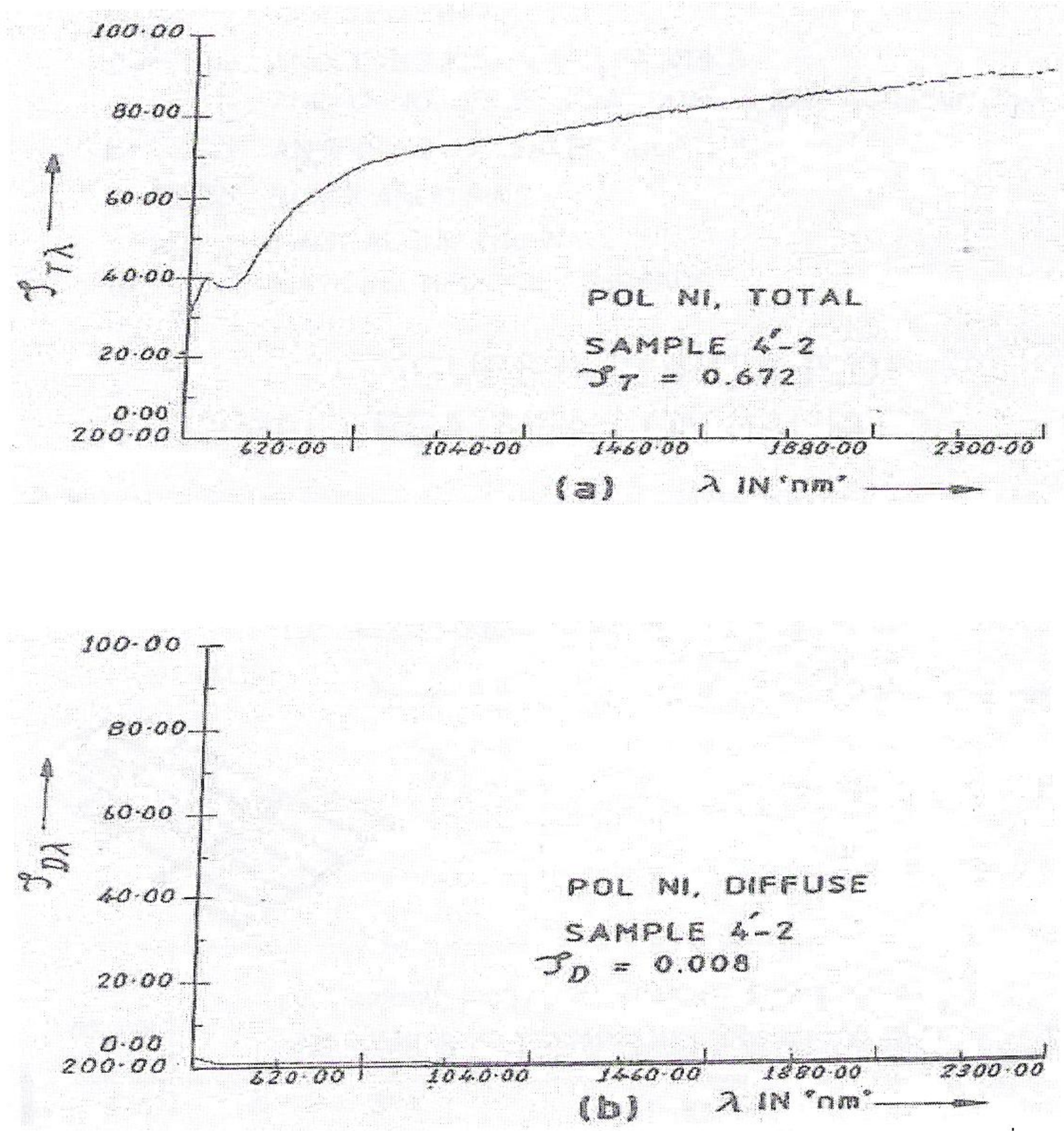


Figure : 6.2A

(a) Total spectral reflectance curve for polished nickel sample.
(b) Diffuse spectral reflectance curve for polished nickel sample.

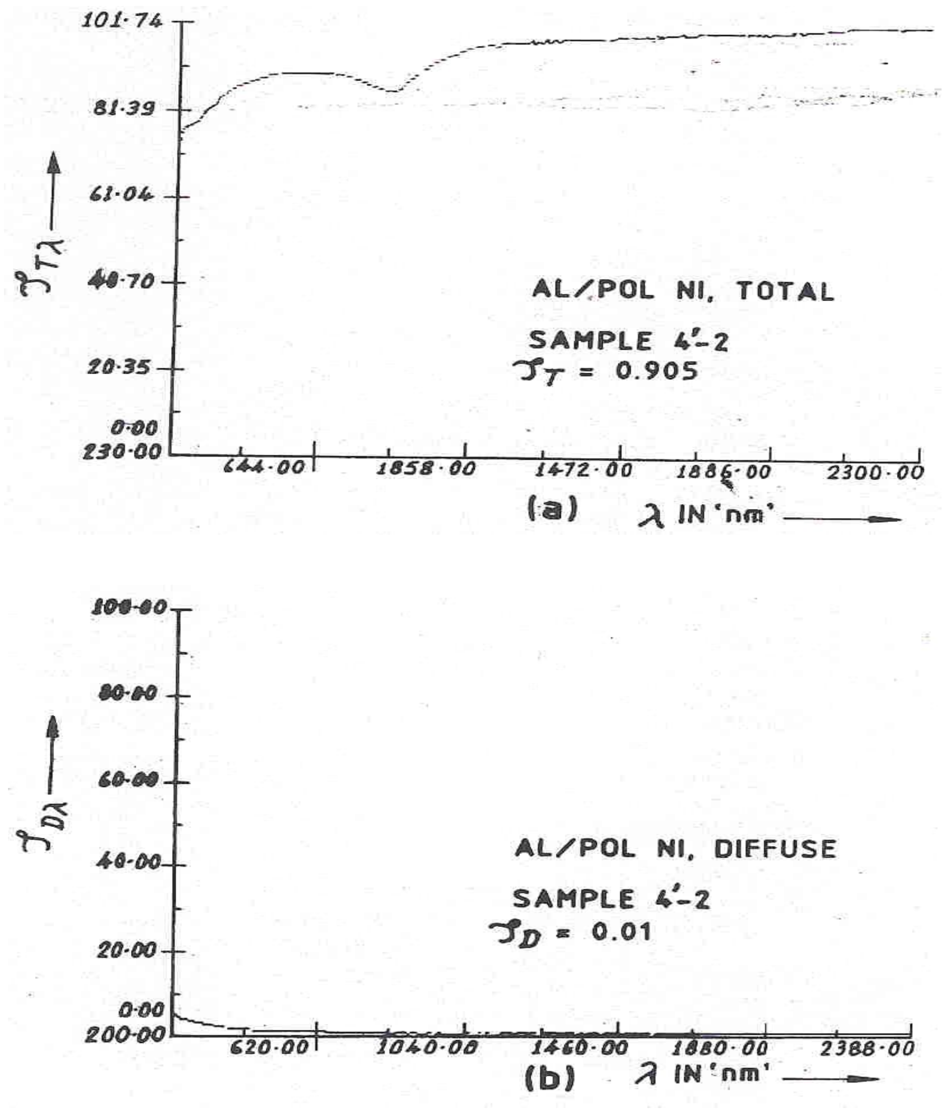


Figure : 6.2B

(a) Total spectral reflectance curve for aluminized polished nickel sample.

(b) Diffuse spectral reflectance curve for aluminized polished nickel sample.

7.0 On-Orbit Performance of METSAT (KALPANA-1) Cooler

KALPANA-1 was launched in September 2002. The temperature of cooler elements increases due to degradation of thermal control surfaces with time. Figure 7a shows the patch temperature of KALPANA-1 cooler for 2003 and 2009 summer solstice (the hottest season). The data for other years fall in between the two graphs and not given here for clarity. The performance of cooler is as per predictions and a testimony to excellent sunshield surfaces achieved. Figures 7b and 7c give the variation of patch, sunshields and vacuum housing maximum temperatures for summer solstice from 2003 to 2009.

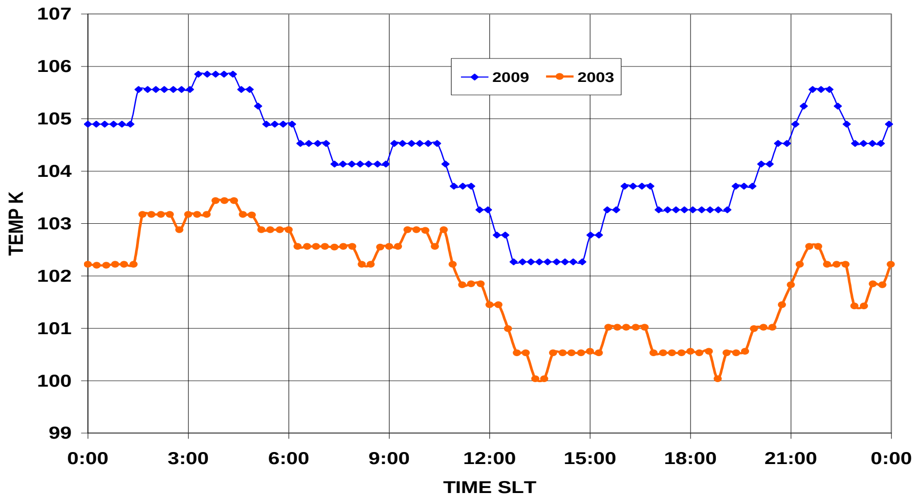


Figure : 7a KALPANA-1 VHRR Radiant Cooler Patch Temperature during Summer Solstice

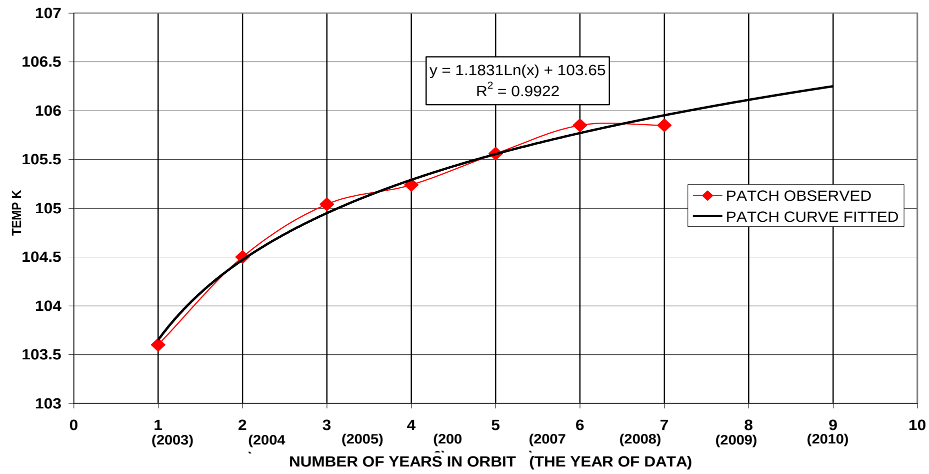


Figure : 7b KALPANA-1 VHRR Radiant Cooler Patch Temperature (Max) variation over years during Summer Solstice

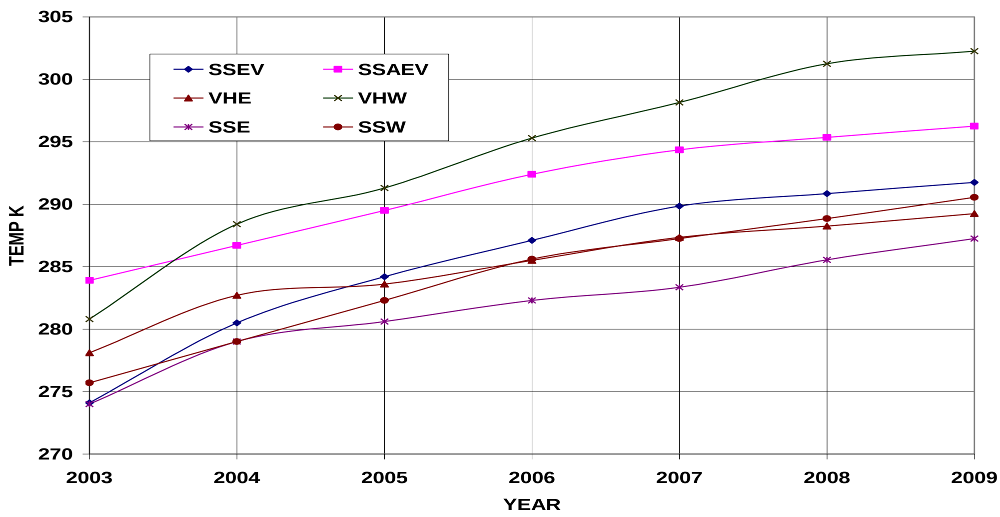


Figure : 8c KALPANA-1 VHRR Radiant Cooler Temperature (Max) Variation over Years during Summer Solstice

8.0 PREDICTED ON ORBIT PERFORMANCE OF INSAT 3D COOLER

Based on the thermal balance tests conducted on cooler, the mathematical model is updated and using the updated model the on-orbit prediction is done for temperatures. First sunshield and vacuum housing temperatures are estimated through cooler-spacecraft interface model and then, on imposing these estimated sunshield and vacuum housing temperatures, the patch and the radiator temperatures are calculated for different seasons[5].

The on orbit prediction for seasons of equinox and winter solstice both at beginning of life (BOL) and end of life (EOL) conditions for Imager cooler are given in Table 8.0

Table No : 8.0
Imager cooler predicted temperature

Period	Patch		Radiator		Sunshield	
	BOL (K)	EOL (K)	BOL (K)	EOL (K)	BOL (K)	EOL (K)
Winter Solstice	80	82	116	121	186	192
Equinox	80	83	118	123	190	200

As can be seen from above table, predicted temperatures are lower than the specifications

9.0 CONCLUSION

The report consolidates the efforts put towards development of specular surfaces for sunshields. It gives a brief account of polishing procedures used for various cooler sunshields. All coolers have shown excellent on orbit performance. Observed on orbit performance of one of the coolers (KALPANA-1) has been presented which is testimony to excellent sunshield surfaces achieved. INSAT 3D spacecraft is expected to be launched in the year 2010. INSAT 3D cooler performance is expected to meet the design requirement of 95 K (BOL) and 100 K (EOL) as in case of KALPANA-1 cooler.

10.0 ACKNOWLEDGMENT

We acknowledge the technical support provided by colleagues at ISAC, GTTC, NAL, IIA, LEOS, and other organization in realization of Sunshields for ISRO Spacecrafts. The efforts, support and contribution of the staff of Photonics division, IIA is acknowledged with deep appreciation.

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