RASE 2009

Development of Sunshield Panels for Passive Radiant Cooler On Board Meteorological Instruments of ISRO.

Madhu Prasad[1], Basavaraj S.Akkimaradi[1],Santram[1]*, T.Selvan[1], Subramanya[1], S.C.Rastogi[1], K.Badrinarayana[1], D.R.Bhandari[1], M.Sugumar[1], B.Mallesh[1], K.S.Rajam[2], Indira Rajgopalan[2], V.K.W. Grips[2], J.N.Balaraju[2], A.K.Saxena[3], R. Ismail Jabilullah [3], M.Viswanathan[4],Ganesh Shanbhog[4]

1) *ISRO Satellite Centre, Bangalore.*
2) *National Aerospace Laboratory, Bangalore.*
3) *Indian Institute Of Astrophysics, Bangalore.*
4) *Laboratory for Electro Optics System, Bangalore.*

ABSTRACT

Radiant cooler is used to cool the infrared and water vapour detectors of meteorological payload. 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 third 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 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 surface, 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 hear 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°) solar absorptance (0.11) Emittance (0.03) and solar specularity (98%) were measured. The surface has met the requirement of IR detector cooling to 105 K in coolers onboard INSAT 2A/2B/2E, KALPANA-1, INSAT3A Satellites. The KALPANA-1 on board flight performance of cooler which shows a good match of predicted and observed thermal performance is discussed here.

To achieve IR detectors cooling requirement of 95 K for advanced Imager and Sounder Meteorological Payloads, the improved process was developed. It comprises of Precision Machining (Surface finish: <0.1µm, flatness 10µm), Single Point Diamond Turning (surface finish: 100 A°), Electroless Nickel Plating (100 µm thickness), Optical Polishing (finish: <20 A°) 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 sunshield (ETM and flight Models). The integrated cooler assembly with sunshields was subjected to the acceptance tests (Electrical Insulation test, Vibration test, Thermal cycling, thermal balance test under simulated space environment and it passed the tests successfully. The satellite is expected to be launched in 2009.

*e-mail: santhram@isac.gov.in.

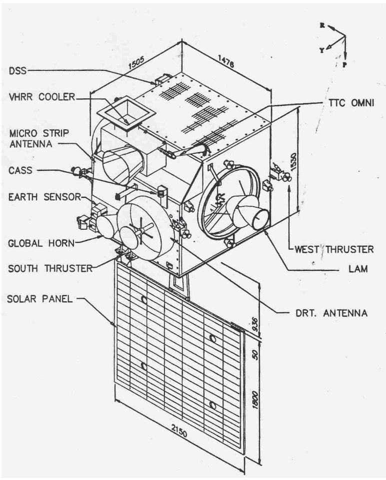
1.0 INTRODUCTION

Three channels Very High Resolution Radiometer (VHRR) comprises of visible channel (VIS) in 0.55 to 0.75 micro meter band, water vapour channel (WV) in 5.7 to 7.1 micrometer band and Thermal Infrared channel (TIR) in 10.5 to 12.5 micro meter band VHRR is the meteorological payload On board INSAT 2A/2B/2E 3A and METSAT Satellites to measure the following

- Cloud and earth /earth atmosphere surface mapping
- Sea surface temperature
- Snow and ice detection
- Wind speeds over oceanic region
- To detect the presence of moisture in the middle levels of atmosphere etc

1.1 Specification/requirement of VHRR Cooler

INSAT-2 VHRR Radiant Cooler is required to cool and maintain the infrared detector of VHRR payload at 105K during BOL and at 115K at EOL. The other specification/ requirements for the cooler are:



METSAT Spacecraft

- Patch temperature control from 105K upto 115K
- Decontamination control of cooler elements at 300K ±3K during initial mission phase and at a later time as and when required.
- Cooler assembly without sun shields to be leak proof for integrated bench level testing of VHRR payload.
- IR channel optics to be housed in the cooler. (Ref fig 1.1)

Figure 1.1

2.0 COOLER CONFIGURATION

The configuration of the cooler consisting of three stages are sun shields/housing, radiator and patch is shown in the figure. 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. 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 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.

3.0 SUN SHIELD CONFIGURATION

The height and the cone angle of sun shield assembly (25º) is designed in such a way that no direct sun load falls on patch even with the maximum declination of sun (23.5º). 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. The external surfaces of vacuum housing and sun shields are covered with optical solar reflector (OSR) to emit heat into deep space. The internal surfaces of vacuum housing are gold plated to minimize radiative couplings between the elements of the cooler. The whole assembly is mounted on interface plate through eight FRP supports which, in turn, is mounted on VHRR Electro Optical Module (figure 3.1)

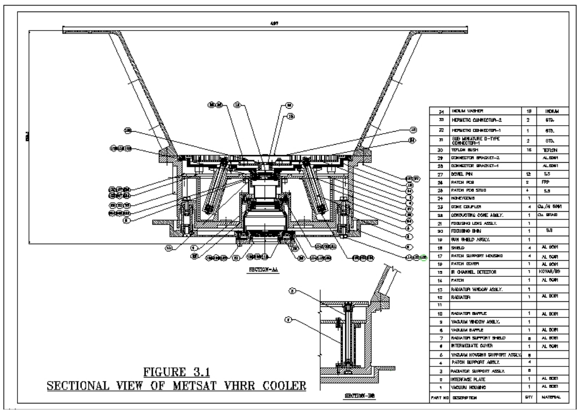


FIGURE 3.1
SECTIONAL VIEW OF METSAT VHRR COOLER

4.0 HEATER AND TEMPERATURE SENSORS

To control patch temperature and for decontamination of cooler during initial mission phase, heaters are fixed on each stage of the cooler. The temperatures are monitored by using platinum resistance temperature (PRT) sensor and thermistor. The heat leakages to patch by conduction through various leads is minimized by using fine gauge high resistance phosphor bronze lead wires and through increased length of leads by wrapping the leads on patch support tubes and radiator support tubes.

5.0 THERMAL ANALYSIS

To predict the on-orbit temperatures of the cooler, a thermal mathematical model consisting of 44 isothermal nodes were 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.

6.0 DEVELOPMENT OF SPECULARLY REFLECTING SUN SHIELD SURFACE

To achieve a surface, a specialized process was developed by carrying out a sequence of operations, in collaboration with GTTC, NAL, IIA, LEOS. The precision machining on the aluminium sun shield panels was carried out to achieve good flatness. The machined panels were 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.

7.0 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 is given by (Bennett & Bennett 1967; Bennett & Porteus 1961) for normal incidence.

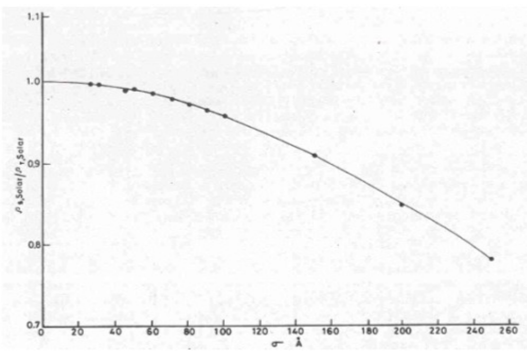


Figure 7.0
Variation of ρ_s solar / ρ_T solar for small values of surface roughness

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

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.

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

Where E_λ is solar spectral irradiance, $\lambda_1 = 0.2\mu$ and $\lambda_2 - 2.5\mu$. Figure 7.0 shows the variation of $\rho_{s,}$ solar/ρ_T, solar as a function of surface roughness i.e., 50 °A gives 99% specularity, 100 °A leads to 96% specularity etc. figure 7.0 shows variation of ρ_s solar / ρT solar for small values of surface roughness.

8.0 SURFACE CHARACTERISATION OF SUN SHIELD

Highly specularly reflecting surface for sun shield panels.

8.1 Solar Reflectance:

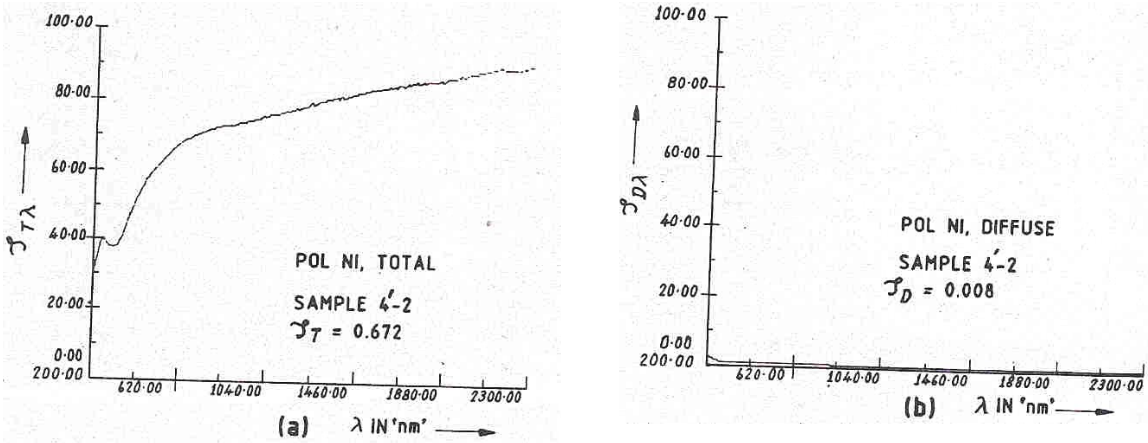


Figure 8.1A

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

Figure 8.1A shows a typical diffuse and total reflectance curve for polished nickel sample. Figure 8.1B shows the diffuse and total reflectance curve after aluminization for the same sample. The calculated ρ_D value lies in 1-1.5% for these samples.

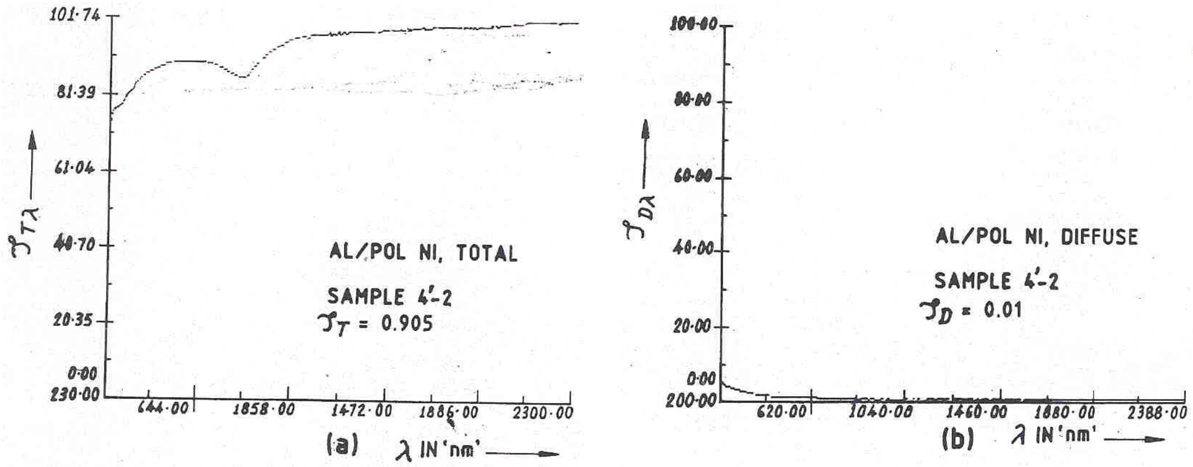
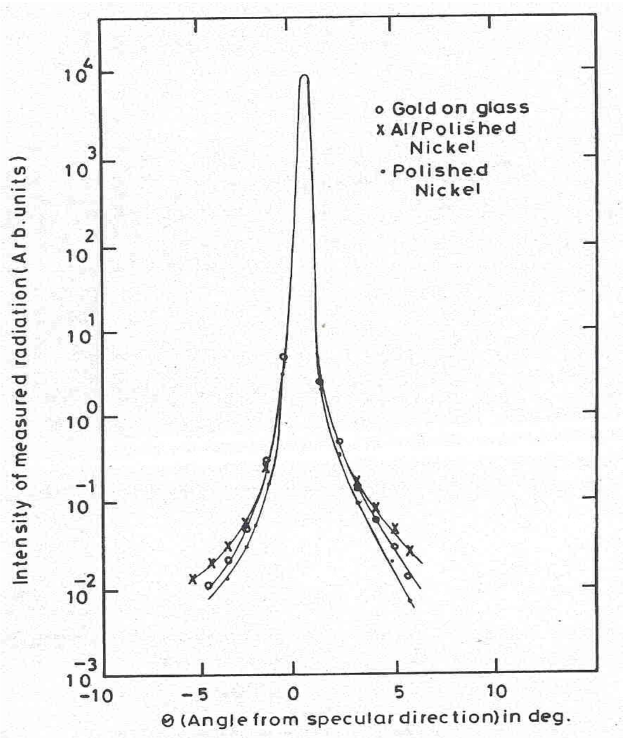


Figure 8.1B

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

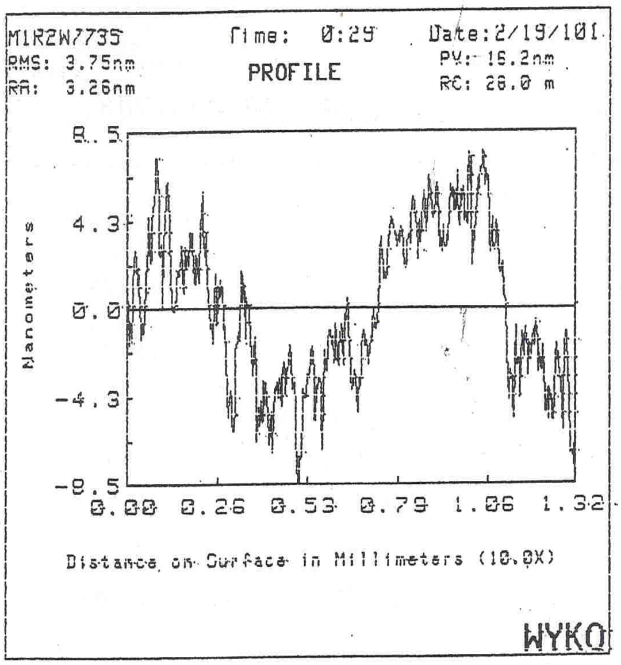
8.2 Angular Reflectance:



The measurement of reflected light distribution was done using He-Ne laser. Figure 8.2 shows the curves for polished nickel, and a gold deposited glass slide. As can be seen from the above, the reflected diffused radiation lies in a cone of about 5^0 about the specular direction. Also the reflected energy distribution from polished samples compares extremely well with that from the gold on glass sample thereby demonstrating excellent finish

Figure 8.2
Experimental scattering curve for diffuse radiation about specular direction samples

8.3 Measurement of Surface Finish Profile



The surface finish of optically polished surface was measured by using non contact optical profilometer WYKO TOPO2D and VEECO Optical profilometer. Measurements on sun shield panel indicate a surface finish of 40-60°A. Theoretical analysis of surface finish showed specularity of 98% in the solar spectrum range. Figure 8.3 shows the surface profile.

Figure 8.3
Surface characteristic of specular surface of sunshield (surface profile)

8.4 Implementation of Process on Sun Shield

Sun shield involves the following treatment as shown in figure 8.4

- Anodizing
- Electroplating of nickel at NAL
- Heat treatment
- Optical polishing at IIA
- Electroless nickel plating at NAL
- Heat treatment
- Optical polishing at IIA (40-60 °A)
- Vacuum Evaporated aluminium coating at LEOS. After measurement of surface characteristics of sun shield, the cooler assembly integrated with sun shield was subjected successfully to the following qualification tests

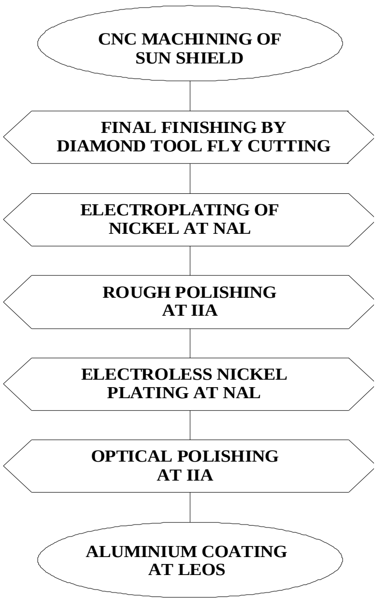


Figure 8.4

- ✓ Electrical insulation test
- ✓ Vibration test
- ✓ Thermal cycling/ Thermal balance test
- ✓ Vacuum leak test
- ✓ Alignment test

8.5 On-Orbit Performance of Metsat Cooler

In flight, the patch temperature is controlled at a constant temperature using a heater. The observed patch control power required to maintain the patch at a specified uniform temperature throughout the orbit during various seasons is shown in figures 8.5 (A-D). Along with the observed profiles, the estimated control power using the mathematical model by imposing the radiator and sunshield at flight observed temperatures, are also presented. There is good agreement between these the observed and the estimated control power profiles. It is seen that the infrared Emittance of the interior surfaces of the sunshield is varying from a value of 0.023 to 0.029 from equinox / winter solstice to summer solstice. This is due to the dependence of Emittance on temperature because during summer solstice the sunshield is warmer than during either equinox or winter solstice. The temperature, the patch would have achieved in case there is no control power is plotted in figures.

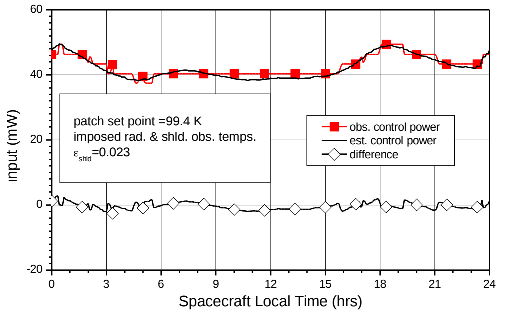


Figure 8.5A
Control power to patch (September 21, 2002)

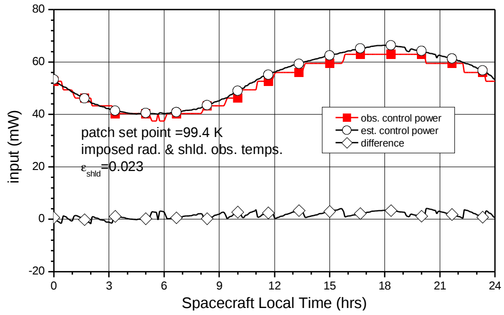


Figure 8.5B
Control power to patch (December 21, 2002)

The flight performance of the VHRR radiant cooler has been satisfactory till date. Analysis of flight data indicates that a patch temperature less than 105K has been achieved during the first summer solstice the spacecraft experienced after the launch. The patch temperature at the first equinox has been less than 89K. Also for the first two winter solstices, the patch temperature remained below 89K.

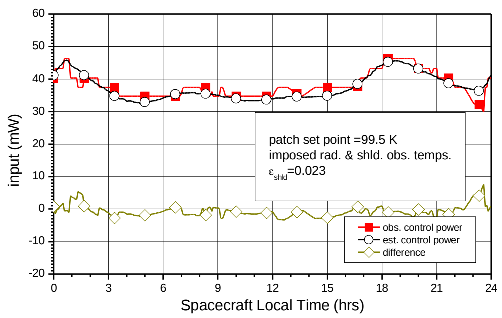


Figure 8.5C
Control power to patch (March 21, 2003)

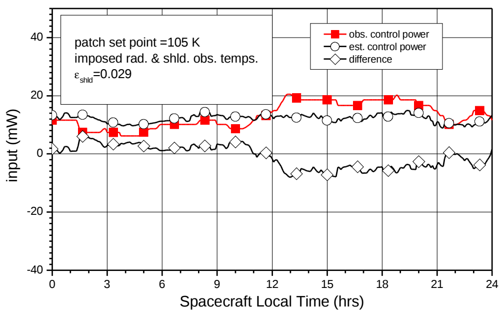


Figure 8.5D
Control power to patch (June 21, 2003)

9.0 PASSIVE RADIANT COOLER FOR INSAT 3D

Passive radiant cooler is used to cool the infrared detectors of imager and sounder instruments. The detectors temperature is maintained at 95K (BOL) and 100K (EOL). Also, to maintain the sounder filter wheel temperature at 213K, cooler is used.

Following is the detail of imager and sounder instrument

9.1 Imager

Imager is a six channel (1VIS, 1SWIR, 4IR in MIR, WV, TIR-1, TIR-2) multispectral imaging radiometer designed to sense emitted thermal energy and reflected solar energy from sampled area of the earth’s surface and atmosphere. The imager provides data for use in determining cloud cover, cloud temperature and height, surface temperature and water vapour.

9.2 Sounder

Sounder is a 19 channels (IVIS, 18 IR in MWIR, SWIR, LWIR) discrete filter radiometer, designed to sense emitted thermal energy and reflected solar energy from sampled area of the earth’s surface and atmosphere to provide data for computing vertical profile of temperature and moisture, surface and cloud top temperature and ozone distribution.

9.3 Development of INSAT-3D Coolers Sun Shield

To meet the stringent IR detector cooling at 95K (BOL) and 100K (EOL) requirement of imager and sounder cooler, the improved sun shield surface is developed by incorporating

1. Single point diamond turning and
2. Enhanced aluminium vacuum evaporation coating

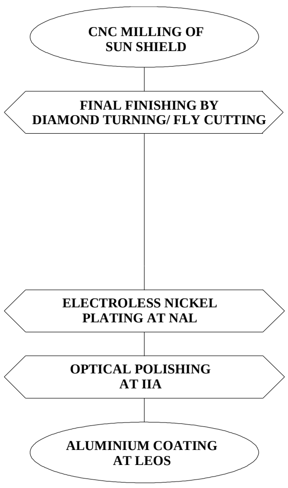


Figure 9.3A

Development Process of Sunshield

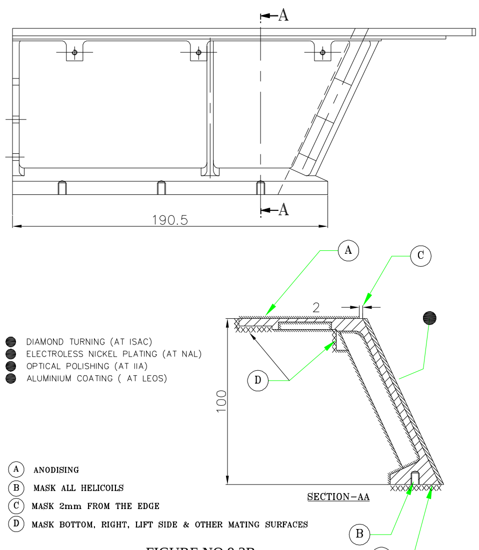


FIGURE NO:9.3B

THERMAL TREAMENT ON SUNSHIELD (1&2)

The process developed for INSAT 3D sun shield panels is as follows:

1. Precision machining

2. Single point diamond turning
3. Electroless nickel plating at NAL
4. Heat treatment
5. Optical polishing at IIA
6. Enhanced vacuum evaporation of aluminium to achieve the following properties:
    - Solar absorptance, α_s : <0-10
    - Emissivity, ε_{IR} : <0.02
    - Surface finish, σ : <20 A^{o} (Ra, maximum)
    - Solar specular reflectance, φs: >99%

10.0SPACE QUALIFICATION TESTS ON COOLER ASSEMBLY

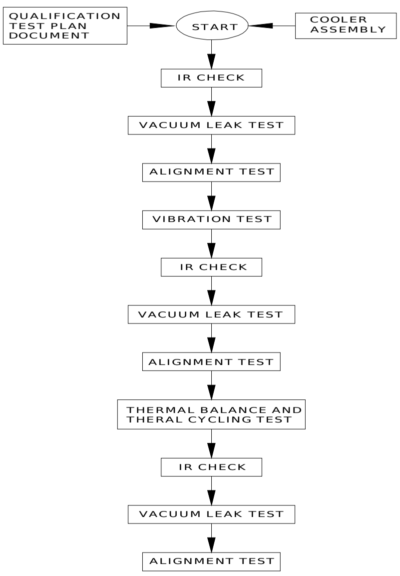


Figure 10.0

Different models will be fabricated to fully qualify any newly designed subsystem before using in the spacecraft. Similarly three models of INSAT 3D coolers are fabricated. They are structure model (STM), electrical thermal model (ETM) and flight model (FM).The test sequence is shown in figure 10.0

11.0 PREDICTED ON ORBIT TEMPERATURE

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 on-orbit temperature predictions. 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.

The on orbit prediction for seasons of equinox and winter solstice both at beginning of life (BOL) and end of life (EOL) conditions are given in table 11.0

Table 11.0
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

12.0 EUTELSAT W2M LNA COOLER

The process was used for INSAT 3D cooler was implemented on EUTELSAT W2M LNA cooler sun shields successfully and was launched in December 2008 (figure 12.1)

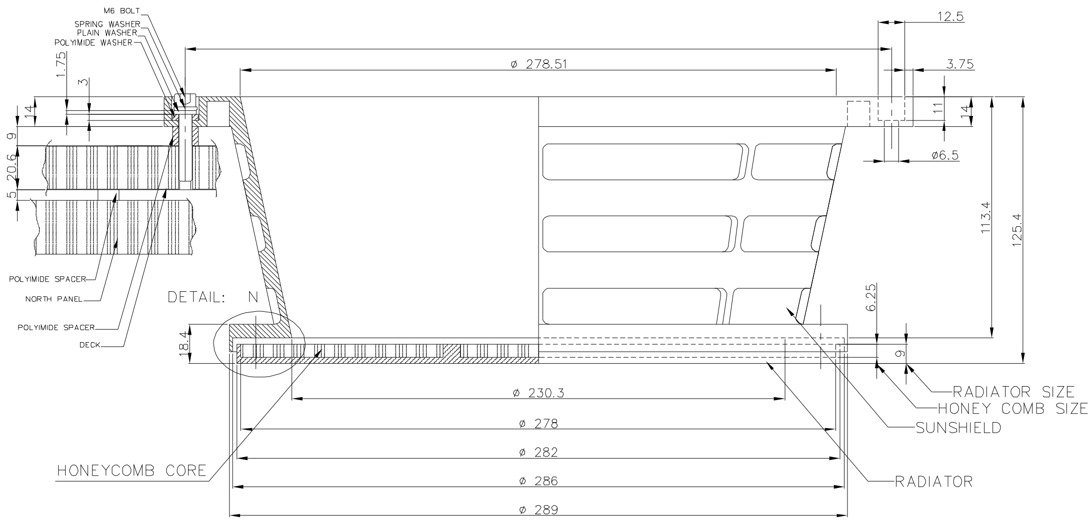


Figure 12.0
LNA Cooler

13.0 CONCLUSION

INSAT 3D spacecraft is expected to be launched in the year 2009. INSAT 3D cooler performance is expected to meet the design requirement of 95 K (BOL) and 100 K (EOL) as in case of METSAT cooler.