Large Area IR CAL SOURCE ACRS 2017Design and Development of Vacuum Compatible Large Aperture Infrared Calibration Source

Anish R Saxena[1], Prashanta Das, Sanjay Gupta, MCA Naidu,
Dinesh Nolakha, Surendra Sisodia, Arti Sarkar, H.K. Dave
Space Applications Centre (ISRO), Satellite Area
Ahmedabad- 380015, India
[1]Email: anish@sac.isro.gov.in

KEY WORDS: Blackbody, Infrared Background, GISAT, PID Controller, PRTs.

ABSTRACT: Current worldwide trend of large aperture (>700mm) Infrared Electro-Optical Imaging Systems for remote sensing and weather forecasting applications are in high demand. ISRO is also developing large aperture IR payloads in the spectral range from 3.5µm to 15µm for its current and future missions such as GISAT and CartoSat-3 series of satellites. The characterization and calibration of Large Aperture Infrared payloads is of great challenge because of thermal self-emission (IR background) of the payload and therefore it requires specialized characterization test benches and Infrared Calibration Source (IR Blackbody) with low self-emission. Considering the telescope aperture of 700mm, field angle and separation between Electro-Optical Module and Blackbody Source, the dimension of 900mm with scene dynamic range from 180K to 340K is required for full aperture calibration source. In order to meet the above requirements, design and development of a large aperture Infrared Calibration source has been taken up. The Thermal uniformity across the radiating surface, Effective Emissivity and temporal Thermal Stability are the three main performance parameters of the IR calibration Source. Major challenge in realization of large aperture blackbody calibration source is to achieve the thermal uniformity better than ±0.5K over a large aperture of 900mm. A specifically designed segmented interface plate, kept between the radiating plate and Liquid Nitrogen cooled sink plate will be required to control contact thermal resistance. A Proportional Integral Derivative Controller (PID Controller) along with pairs of Distributed heaters and Platinum Resistance Thermometers (PRTs) is proposed to be used for achieving the required thermal uniformity. For a calibration source emissivity of the surface is to be maximized and should be near to unity. Different design options such as pyramidal, conical and hexagonal honeycomb shapes with different aspect ratio is considered for the development. High conductive Al alloy is selected for better thermal conductivity and uniformity.
This paper discusses the IR source requirements and various design options studied; it also provides the details of finally chosen design, estimated performance and its development approach.

I. INTRODUCTION

A large aperture Infrared Calibration source is required for the characterization and calibration of large aperture Infrared Payloads. GISAT is ISRO's demonstrator mission for Earth observation from geostationary platform. The GISAT payload is a multi-spectral multi-resolution imaging instrument capable to image full or part of the earth disk. GISAT covers wide spectral coverage from Visible to long wave Infrared. The GISAT consist of multi-spectral visible and near-infrared (MX-VNIR), hyper-spectral visible and near-infrared (HyS-VNIR), hyper-spectral shortwave-infrared (HyS-SWIR) and multi-spectral longwave-infrared (MX-LWIR) bands, these cover broad spectral range from nearly 0.4 µm to 13.5 µm with different spectral resolutions in different instruments. A Telescope of 700 mm aperture will be used as collecting optics. MX-LWIR payload operates in the spectral range from 7.3 to 13.5 µm with scene dynamic range of 340K earth target. In order to characterize MX-LWIR payload, full aperture and field of the telescope should be filled by the calibration source. A cold shield / baffle is put to avoid any stray thermal radiation to enter inside the optical telescope. Considering the GISAT telescope aperture of 700mm, field angle and separation between Electro-Optical Module and Blackbody Source the dimension of 900mm active radiating surface is chosen for the full aperture calibration source.

Globally development of very large aperture blackbodies for the characterization and calibration of large aperture LWIR payload is a big challenge. Design and Developmental work for Large Aperture Vacuum Compatible Infrared Calibration Source was initiated at Space Applications Centre. Figure 1 shows the typical IR radiometric calibration test setup to be used schematic inside thermovac.

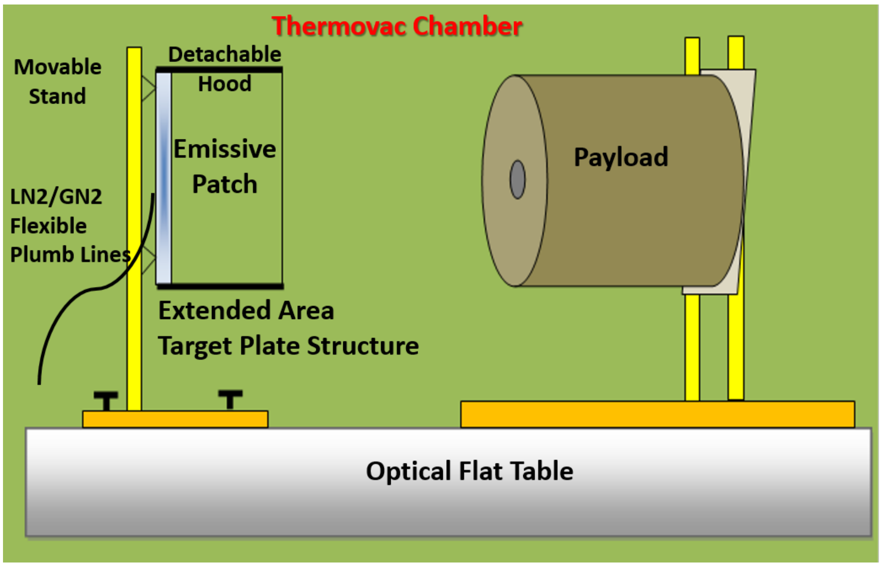

Figure 1: Typical IR radiometric calibration test setup schematic inside Thermovac

II. DESCRIPTION AND METHODOLOGY OF THE INNVOVATION

An ideal blackbody is a radiator whose radiant exitance in all parts of the spectrum is the maximum. The black body is invariably called a standard radiator or an ideal radiator. An ideal blackbody sends out radiation - in a defined wavelength region - which only depends on its temperature. Its emissivity is 1. Total broad band power emitted from a Blackbody surface is expressed by the Stefan-Boltzmann Equation.

$$Q = \sigma \epsilon T^4 \quad \text{Watts/m}^2 \quad \ldots. \quad (1)$$

Spectral energy distribution of an ideal source is governed by Planck's Equation (2)

$$L(\lambda, T) = \frac{2hc^2}{\lambda^5 \left(e^{hc/\lambda kt} - 1\right)} \quad \ldots. \quad (2)$$

Where h is Planck's constant, λ is wavelength, k is the Boltzman constant, c the velocity of light, T the absolute temperature and σ Stefan-Boltzmann constant. Practically no such radiator exist that radiate all part of the spectrum at maximum. A real surface does not emit at this maximum rate. The emission from a real surface is characterized with respect to a black body through the term emissivity. Emissivity (ε) is defined as the ratio of radiant exitance of the material of interest to the radiant exitance of a black body at the same temperature. Thermal uniformity across the radiating surface, effective Emissivity and temporal thermal stability are the three main performance parameters of the IR calibration Source (blackbody).

An interface plate was specifically designed to control the thermal resistance and kept between the radiating and Liquid Nitrogen cooled sink plate. 900mm aperture of Interface plate is segmented into 25 complementary scooped sub regions on both sides to control contact thermal resistance between radiating and Liquid Nitrogen based sink Plate. The un-scooped areas are having controlled thermal resistance with the LN2 plate for heat flow. The other side of plate will have the controlled thermal resistance for heat flow to the radiator plate. All structural design was done in Creo parametric 3D Modelling Software and thermal design was done using ANSYS simulation and Comsol analysis software. A Proportional Integral Derivative Controller (PID Controller) along with Distributed heaters and PRT pairs are used to achieve the thermal uniformity of better than ±0.5K over the entire 900x900 mm^2 radiator Target plate. Figure 2 shows basic functional schematic of IR calibration source.

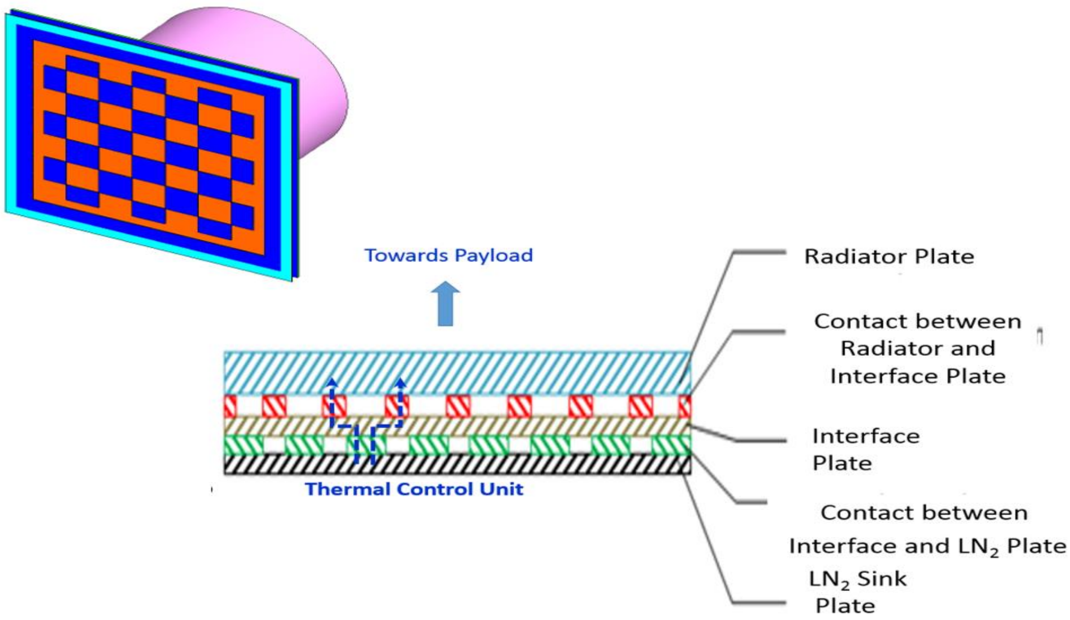

Figure 2: Basic functional schematic of IR calibration source

The working area and the sub- cavities should be isothermal for better uniformity. In order to minimize the thermal gradient, fast thermal transition between two setting, over all weight of the structure and ease in implement ability high conductive aluminium alloys are typically selected for the interface plates and radiator plate.

It is desirable for a good IR calibration source emissivity of the surface is maximized and should be as close as possible to unity. In order to improve the effective emissivity of the emitting area of the extended source, in addition to use black paint, reflectivity of surfaces inside the blackbody cause the cavity effect and causes the improvement in effective emissivity of the surface. Effective emissivity of the surface depends mainly on three parameters aspect ratio (depth/radius) of the radiating structure, wall or paint emissivity and reflectivity of the walls / cavity. All the three parameters will create a cavity effect for enhancing the effective emissivity of the surface near to Unity.

Different options such as pyramid and hexagonal honeycomb shapes with different aspect ratio is considered for the development, hexagonal honeycomb shapes are widely used for IR wavelength. Vacuum compatible thermally conductive Black paint is used for the enhancing the emissivity of the emitting area. For the experimentation different depth / size Hexagonal black painted honeycomb with different emissivity and surface finish are studied. For lower depth Rough diffuse finish high emissive paint provides better effective emissivity as compared to smooth finish paint. While for higher depth structures smooth finish (more reflection) provide better effective emissivity. In order to study effect of cell shape and surface finish effect on effective emissivity of the target more than 6 samples of hexagonal cell size 4mm with different depth were machined; Table 1 shows the test results of emissivity measured.

Table1: Test samples Emissivity measurement

Sr. No.	Coupon Size (mm)	Emissivity Before process	Type of Process #	Emissivity after process
1	Diameter: 52 Cell Depth: 5	0.54	BA	0.93
2		0.53	BTP	0.95
3	Diameter: 52 Cell Depth: 8	0.65	BA	0.97
4		0.60	BTP	0.96
5	Diameter: 52 Cell Depth: 10	0.66	BA	0.96
6		0.64	BTP	0.97
# BA: Black Anodising BTP: Black Thermal Paint				

The results show the increase in effective emissivity with depth. Therefore, Hexagonal black painted honeycomb with order of 10-15 mm depth was selected for the structure. The effective emissivity approaches from 0.97 to 0.99. Figure 3 show the typical pyramid shape and Honeycomb shape cavities

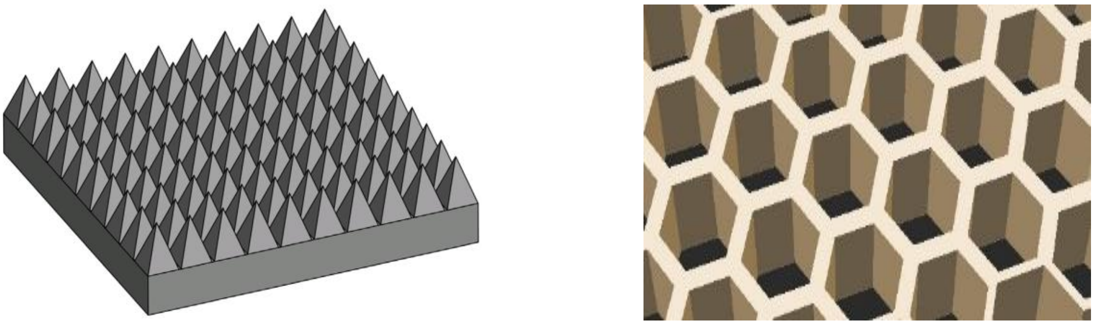

Figure 3: Pyramid shape and Honeycomb shape cavities

Multiple inlet-outlet pipes carrying Liquid Nitrogen / Gaseous Nitrogen (173 K to 343 K) are sandwiched between two aluminium plate is selected for cooling the blackbody to lowest temperature while heaters located on Interface plate will be used for set temperature in the range of 180K to 340K. spatial and temporal gradients or variations of the blackbody, depend on the thermal mass and heater power used on the active structure (radiator, Interface plate and LN2 Sink Plate), also it depends on the surrounding coupling / view factor of the radiator surface.

Around 1 m thermally isolated baffle is planned over the active radiating area. GFRP washers of appropriate length will be used for the required thermal isolation between radiator and baffle. This baffle will avoid surround coupling and view factor to the radiating surface. Along the wall of Baffle fins with appropriate angle and surface finish are planned. It is also found that by use of baffle uniformity over the radiating surface is to be improved by few tens of mK. Figure 4 shows the exploded view of IR Blackbody source.

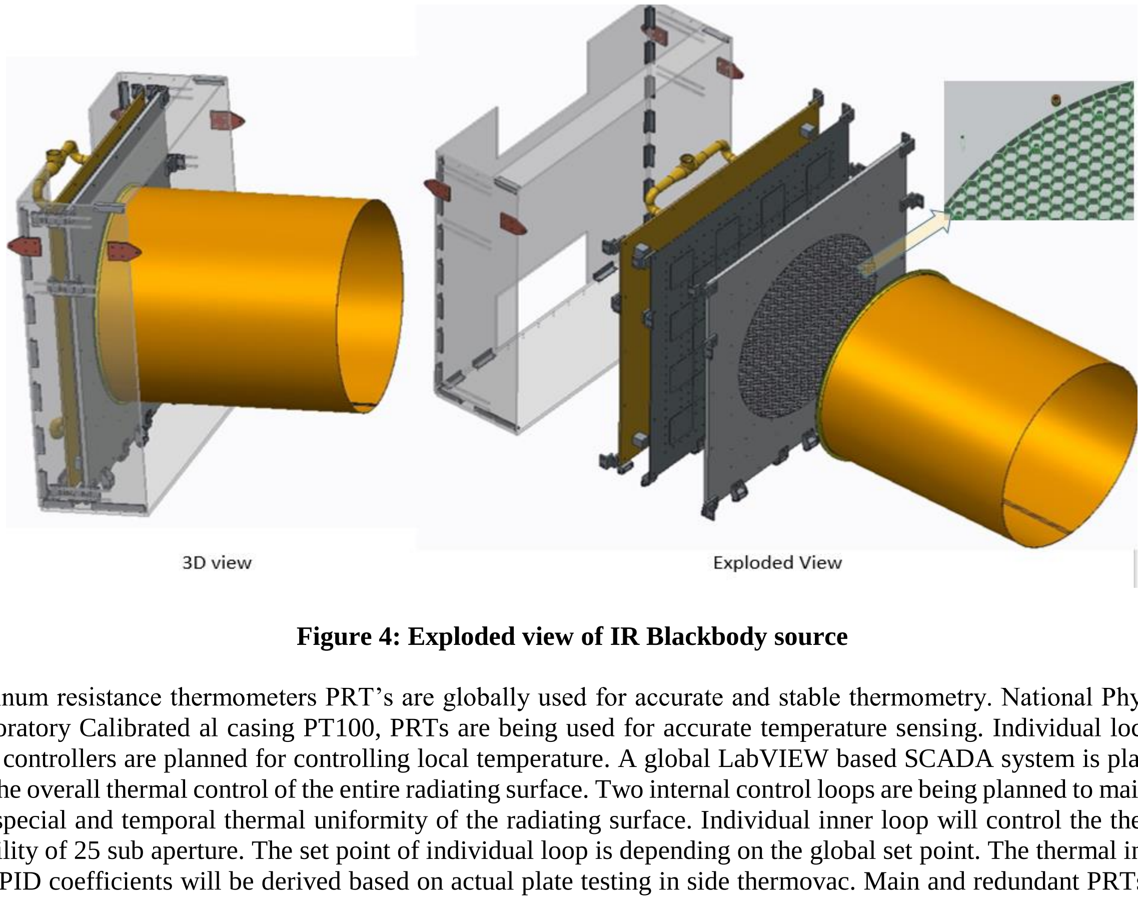

Figure 4: Exploded view of IR Blackbody source

Platinum resistance thermometers PRT's are globally used for accurate and stable thermometry. National Physical Laboratory Calibrated al casing PT100, PRTs are being used for accurate temperature sensing. Individual localize PID controllers are planned for controlling local temperature. A global LabVIEW based SCADA system is planned for the overall thermal control of the entire radiating surface. Two internal control loops are being planned to maintain the special and temporal thermal uniformity of the radiating surface. Individual inner loop will control the thermal stability of 25 sub aperture. The set point of individual loop is depending on the global set point. The thermal inertia and PID coefficients will be derived based on actual plate testing in side thermovac. Main and redundant PRTs and heaters are planned considering sensor failure in future. One sensor and actuator failure per sub loop is considered for the design. Figure 5 shows instrumentation and control schematic of typical setup.

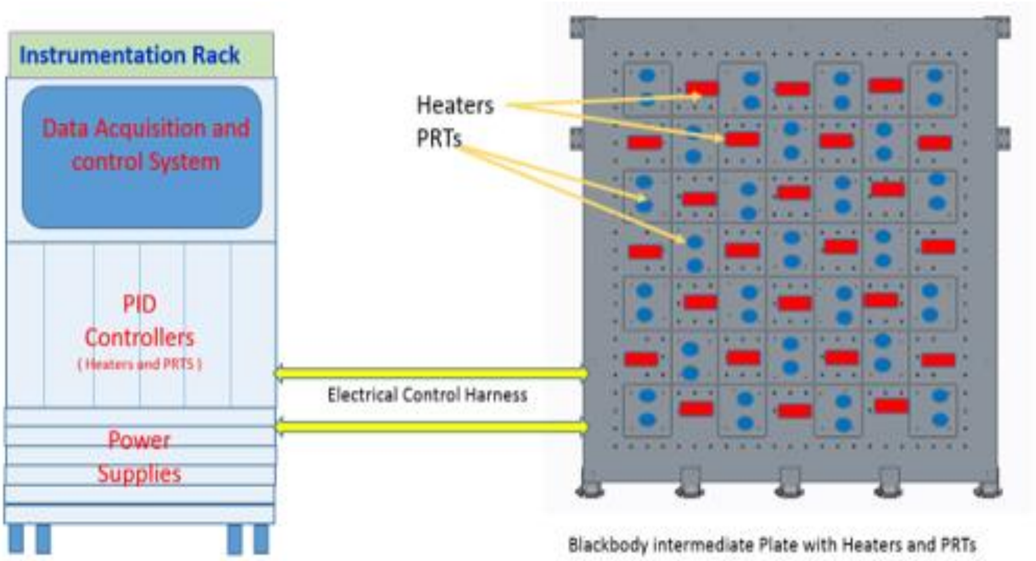

Figure 5 Instrumentation and control schematic

III. SIMULATION RESULTS AND DISCUSSIONS

Active temperature control is found to have the potential for introducing high spatial and temporal temperature gradients, because of phase lags with respect to the control cycle. An analysis was carried out considering the conductivity of Al alloy as base material, monolithic isothermal cavity, thermal contact resistance between sink and radiator plate, flow of LN_2, Heater power and control accuracy of thermal controller. The thermal gradient of better than ±250mK is achieved over the entire 900 x 900 mm^2 surface. However, the uniformity around short range is better than few tens of mK. In addition, the rms temporal variation is found to be better than few mK per minute. Finite-element analysis showed that the design is able to meet the stringent thermal uniformity and gradient requirement. Figure 6 shows the simulated FE result analysis.

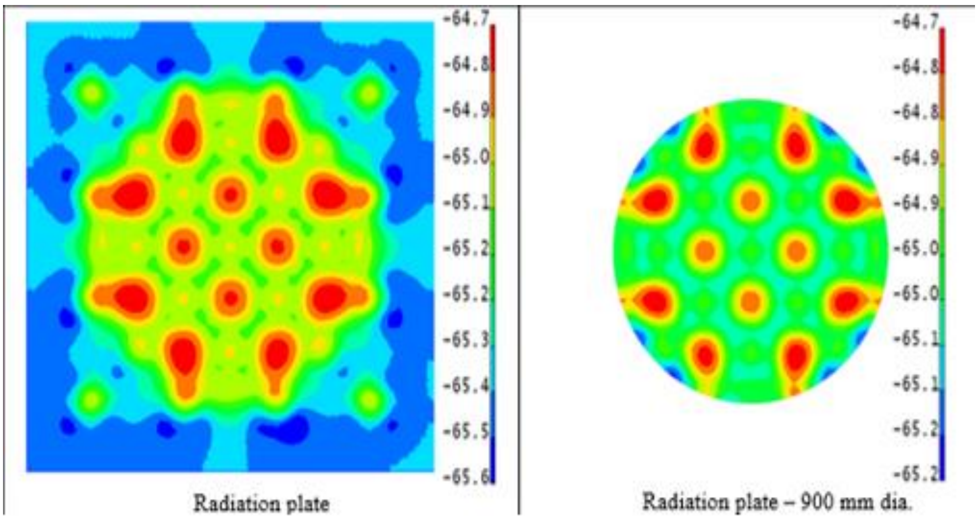

Figure 6: Simulated FE result analysis.

IV. CONCLUSION

Based on our design analysis and computations, it is clear that the vacuum compatible Large Aperture Infrared Calibration Source will achieve the desired performance goal of full aperture uniformity better than 0.5K over the entire operating range from 180K to 340K; emissivity better than 0.98.

V. ACKNOWLEDGEMENTS

We are extremely thankful to Dr. Tapan Mishra Director SAC for entrusting this task to us. We are grateful to Mr. S.S. Sarkar DD SEDA and APD GISAT for their guidance and constant support and suggestions. We are specifically thankful to Mr. R.R Bhavsar, Mr. A.P. Vora, Mr. C.P. Diwan and S R Joshi for their extremely useful support and cooperation.

VI. REFERENCES

1. Joe LaVeigne et. al; "An Extended Area Blackbody for Radiometric Calibration" Proc. of SPIE Vol. 8706 870609-1
2. I. M. Mason et. al; "Blackbody calibration sources of high accuracy for a space borne infrared instrument: The Along Track Scanning Radiometer" 1 February 1996 @ Vol. 35, No. 04 @ APPLIED OPTICS
3. J. Tuttle et. al; "The Total Hemispheric Emissivity of Painted Aluminum Honeycomb at Cryogenic Temperatures" NASA Goddard Space Flight Center, Code 552 Greenbelt, Maryland, 20771, USA870609-1
4. J. M. Kendall et. al; "Two Blackbody Radiometers of High Accuracy" APPLIED OPTICS / Vol. 9, No. 5 / May 1970