# QUALIFICATION OF IMAGING OPTICS FOR FIRST INTERPLANETARY MARS ORBITER MISSION OF ISRO

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**Abstract:** Mars Orbital Mission (MOM) is India's first interplanetary mission of ISRO. Three Electro-Optical Payloads Thermal Imaging Spectrometer (TIS), Methane Sensor for Mars (MSM) and Mars Colour Camera (MCC) were developed by Space Application Centre, ISRO (Ahmedabad). Several COTS (Commercial off the Shelf) optical components were used to realize these EO payloads. As these are COTS components, it had undergone rigorous screening and qualification tests to asses and ensure their worthiness in space use in terms of important optical performance parameters – MTF and transmission or spectral response. The overall qualification was conducted at three level; namely discrete optical component level, optical sub-assembly level and integrated optical payload level. This paper briefly describes the imaging optics qualification test plan and important integrated payload test results of all the three optical payloads and finally conclusion is drawn.

**Keywords:** COTS, Optics, Transmission, Mars, Screening, Qualification

**1. Introduction:** Mars Orbital Mission (MOM) is India's first interplanetary mission executed by ISRO. The main objective of this mission was development of technologies for an interplanetary mission. MOM had well-defined scientific goals of exploration of mars surface features, morphology, mineralogy and Martian atmosphere. The actual orbit for the mission is 421.7km × 76993.6km around Mars. Three Electro-Optical payloads, namely Thermal Imaging Spectrometer (TIS), Methane Sensor for Mars (MSM) and Mars Colour Camera(MCC) were developed by Space Application Centre, ISRO (Ahmedabad). TIS was designed to take thermal image [in IR band (7µm-14µm)] for mapping Mars surface composition and mineralogy, MSM to detect methane ($CH_4$) on mars atmosphere (in SWIR band 1640nm-1660nm) for prediction in existence of life and MCC for visible imaging (400nm – 700nm). Several COTS (Commercial of the Shelf) optical components were used to realize these EO payloads. Components had undergone rigorous screening and qualification tests before the project use.

The general qualification plan for Optics of MARS payloads may be classified as three levels; namely discrete optical component level, optical sub-assembly level and integrated optical payload level. This paper briefly describes the qualification processes and results. Also conclusion is drawn.

**2.Optical Systems:** Thermal Imaging Spectrometer (TIS) is a grating based hyper-spectral spectrometer operating in 7-14µm.TIS optics uses a fore optics, collimating optics, reflecting grating & focussing optics. Also a slit was placed at the focal plane of fore optics. A collimating optics, same as fore optics provides the collimated beam which falls on the plane reflection grating placed at 45° with optical axis and it disperses the incident energy which then refocused by focusing optics on a micro-bolometer array detector. All the lens components of the TIS payloads are made of germanium except one ZnSe lens in focusing optics, while the grating is of aluminium coated BK-7. Fig.1 shows the optical schematic of TIS payload.

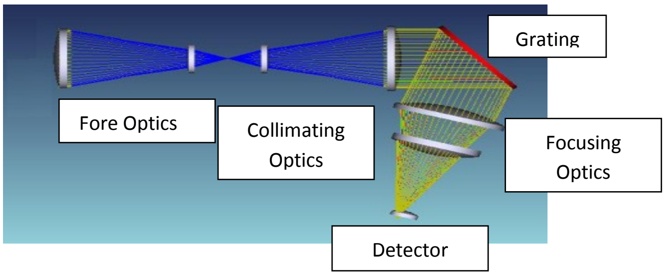


**Fig.1:Optical Schematic Of TIS –payload**

Methane Sensor for Mars (MSM) is a differential radiometer operated in SWIR band (1640nm -1660nm). It is meant to detect methane concentration in Martian surface in ppb accuracy. The schematic diagram of MSM is shown in Fig.2. The fore optics collects the input beam; the collimator collimates the beam which is then spectrally filtered using a band pass filter. Transmitted portion of the beam passes through the etalon whose transmission peaks are tuned to the methane absorption lines. The reflected part passes through the other etalon with shifted transmission peaks. Out coming beams from etalon passes though focussing optics and subsequently fall onto respective photodiode detectors. The signal is then processed.

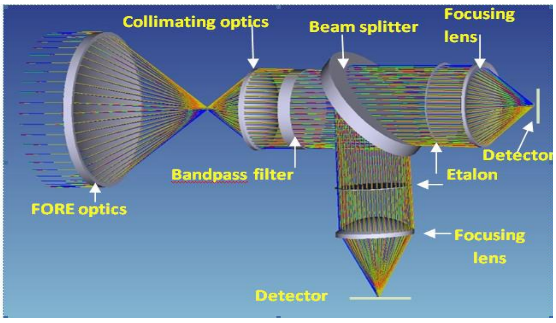


**Fig.2: Optical Schematic Of MSM –payload**

MARS Colour Camera(MCC) is a medium resolution camera, designed to work in visible band (0.4µm to 0.7µm). The optical system consists of a single lens assembly (six lens elements) with thermal & IR cut-off filter.

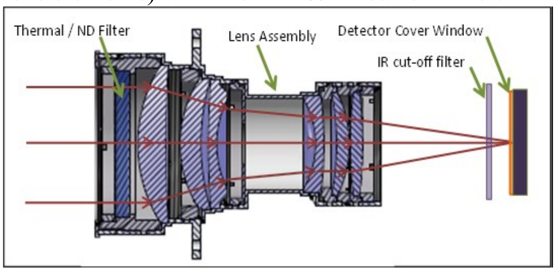


**Fig.3: Optical Schematic Of MCC –payload**

**3.Qualification Plan:** Same qualification philosophy is followed for all three optical systems of mission. First verification models (VM) were developed using commercial of the shelf (COTS) elements. After successful completion of verification models (VM), flight models(FM) & FM-like models were developed. FM-like model undergone qualification level environmental tests whereas FM model undergone acceptance level tests.

In Several discrete optical components like Germinium lenses, ZnSe lenses, fused silica thermal filter, borosilicate IR cut-off filter aluminium field stop optics, silicon Etalon, aluminium reflection grating, N-BK7 band pass filter & beam splitter were used in the development of optical system of three payloads. COTS optical sub-assemblies are procured and ruggedized. Each sub-

assembly were dismantled to isolate individual optical elements. New optical assembly barrel of aluminium made was designed, black anodised and again re-assembled Various environmental tests were carried out for component level and sub-assembly level as well as integrated payload level. Visual inspection and the major optical parameters like focal length, optical efficiency/ transmission/spectral responses, MTF (whatever applicable for a particular optical component) were measured in a pre-post environmental test mode.

**4. Qualification tests:**

**TIS:** To qualify the lenses as well as coating following tests were planned to be carried out: -

i)Humidity
ii)Thermo-vac
iii)Adhesion &
Iv)Abrasion.

Following are the major steps followed: -

- **Dismantling of COTS fore optics, collimating optics & focusing optics:** After isolation of components in-depth visual inspection (following MIL-standard, with 10× magnification) was carried out. Cleanings of the components using alcohol was done carefully, quantitatively (not more than once) and qualitatively to avoid degradation of coating.
- **Assembly of fore, collimating & focusing optics:** Initially compatibility was checked with black anodised aluminium lens housing and then lens elements are assembled sequentially. After each lens element assembly quality inspection was done and thoroughly verified so that no foreign particles (lint, dusts etc.) were introduced on the surfaces of the lenses.
- Amount of torque applied during re-assembly of each component was verified in accordance with mechanical guidelines to avoid extra stresses introduced on the lens components. EC2216 glue (space qualified) was used for bonding of each component and the process of bonding was qualified. During glue application on the lens mounting holes, uniformity of glue, purity (so that no lint or dusts lie or immerged in glue) was observed. The whole process of assembly and disassembly was done in class 100000 clean room.

- **Thermo-vacuum of the assembled lens component:** Re-assembled lens component undergone thermo-vac (from -5°C to 45°C with dwell time 2hrs., 5 number of cycles and vacuum better than $10^{-5}$ torr) to verify its vacuum compatibility. Before and after thermo-vacuum transmission and square wave responses (SWR) were measured. After successful completion of this test, the assembled lens was subjected to vibration test. Before and after vibration test SWR & transmission were measured and compared. No significant changes observed.

- For reflection gratin initial visual inspection, dimentional measurements (groove width & groove density) were carried out using a microscope along with profile projector. Initial Diffraction efficiency measurement was carried out using a Spectrometer. The efficiency of the grating is calculated for various wavelengths of 7-11 micron. After initial measurements it was subjected to thermo-vac test in the temperature range -10°C to +50°C. Once again the dimensional & diffraction efficiency was measured and compared with initial measurements. The results were matched. The remaining components of TIS i.e. air slit also undergone thermo-vac test.

**MSM:** The qualification philosophy for MSM imaging optics was same as TIS.

- In this payload lenses used were ZnSe lenses. They are coated with anti-reflection coating to increase the transmission from 70% to 96%. For coating qualification standard tests like humidity, adhesion, abrasion and thermo-vac tests were carried out on its witness samples. They successfully pass all the tests as their pre-post-tests transmission results matches. Similar to TIS, verification model (VM) was developed using commercial of the shelf (COTS) elements. All optical lenses assemblies were ruggedized and reassembled and had thermo-vac & vibration tests. Finally, they assembled get FM-like & FM payloads.
- Band pass filter & beam splitter were also undergone thermo-vac & vibration tests. They qualified for payload level assembly as their spectral/transmission results before & after tests remained almost unchanged.
- Etalon was the one of the most important component of MSM. It is also ruggedized from its COTS form and it also undergone thermo-vac & vibration tests to qualify. For etalon monitoring parameters for qualification were Free Spectral Range (FSR) & bandwidth.

**MCC:** MCC is basically a lens-assembly accompanied by thermal filter & IR cut-off filter.

- Each elements of the COTS assembly were disintegrated, cleaned and visually observed at 10× magnification. Dimensional measurements and inter spacing distances, thickness were measured. An aluminium made lens housing was developed and again all the elements were assembled and glued using EC2216. The lens system as a whole then undergone thermo-vacuum test (-10°C to 50°C, transition rate less than 1°C/min, pressure better than $10^{-05}$ torr, 5 no. of cycles). and vibration tests. Optical performance parameters like -MTF and transmission were -measured for pre and post thermo-vacuum and vibration tests.
- Thermal filter & IR cut-off filter of MCC were qualified in a similar process like TIS or MSM filters.

## 5. Results and Discussion:

**TIS:** For TIS payload Spectral Alignment Stability Specification is < ± 2 pixels and the spectral range is 7 µm - 13µm. After aligning the air slit of the spectrometer, laser wavelengths were varied at 10.3, 10.4, 10.5and 10.6 micron in steps of 100 nm and shift in line image in spectral direction was recorded. Fig.4 shows spectral alignment stability during payload testing. Spectral alignment stability is well above the specification of **<±2 Pixels** during payload testing.

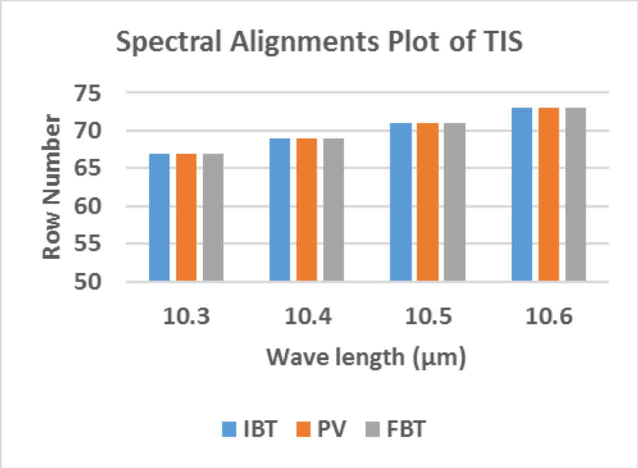


**Fig-4: Spectral Alignment Plot**

**MSM:** Two channels (Methane and Reference) are required to be registered within ± 0.5 pixel**.** Channel to channel registration was evaluated during the process of performance optimization under lab conditions and under thermo-vacuum conditions. Channel to channel registration meets the specification ie. < ± 0.5 pixel.

The stability of the central wavelength monitored during various phases of T&E. Fig-5 shows spectral peak stability during payload testing. It was observed that Stability of spectral peaks is well above the specification ie. ± 0.04 nm during payload testing.

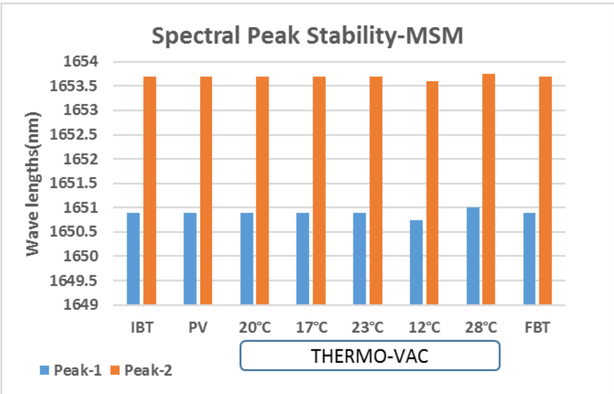


**Fig.5 Spectral peak stability**

**MCC:** Optical performance of MCC payload was evaluated in terms of MTF. MTF values of MCC payload during IBT, under thermo vac., post thermo vac and Post vibration (FBT) are well above the spec. values (MTF Spec.: > 15% at N/2). Fig.6 shows the MTF measurement plot under thermo- vac conditions which shows the MTF specification is met.

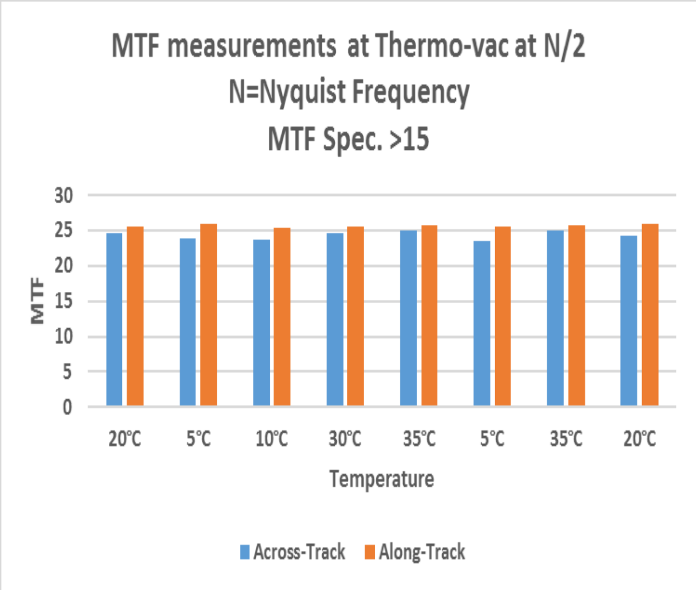


**Fig.6 MTF MEASUREMENT PLOT**

**6. Conclusion:** Optical performance of all the three payloads was evaluated at various stages of testing. All the results are satisfactory & within specification.

**It is concluded that optical performance of TIS, MSM and MCC payloads was satisfactory and qualified for space use.**

**7. Acknowledgements:**

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**8. References:**

**1.** Preliminary Design Report of MARS ORBITAR MISSION of ISRO.

**2.** T&E documents of Thermal Imaging spectrometer (TIS), Methane Sensor for Mars (MSM) and Mars Colour Camera (MCC) payloads.