Phase Change Material for Temperature Control of Imager or Sounder on GOES Type Satellites in GEO

Michael K. Choi[1]
NASA Goddard Space Flight Center, Greenbelt, MD 20771

This paper uses phase change material (PCM) in the scan and telescope cavities of an imager or sounder on satellites in geostationary orbit (GEO) to maintain the telescope temperature stable. When solar flux entering the scan cavity exceeds the heat radiation from the scan cavity to space through the aperture and MI blankets, the PCM stores the heat at a constant temperature. When solar flux entering the scan cavity is less than the heat radiation from the scan cavity to space through the aperture and MI blankets, the PCM releases heat at a constant temperature. Paraffin PCM is compact and meets the temperature range required for scan and telescope cavities. It has no moving parts or bimetallic springs. It reduces heater power required to make up the heat lost by radiation to space through the aperture and MLI blankets. It is an attractive thermal control option to a radiator with a louver and a sunshade.

Nomenclature

C	=	carbon
H	=	hydrogen
GEO	=	geostationary orbit
GOES	=	Geostationary Operational Environmental Satellite
PCM	=	phase change material

I. Introduction

AN imager or sounder on satellites, such as the Geostationary Operational Environmental Satellite (GOES), in geostationary orbit (GEO) has a scan mirror and scan motor in the scan cavity. The GEO orbit has a 35,748 km altitude and a 0º inclination. The orbit period is 24 hours. During part of the orbit, direct sunlight enters the scan aperture and adds heat to components in the scan cavity. Solar heating increases the temperatures of the scan mirror, scan motor, primary mirror and secondary mirror. Overheating of the scan motor could reduce its reliability. The GOES-H imager scan mirror temperature was as much as 67˚C when sunlight entered its scan cavity (Fig. 1 and Fig. 2). GOES-I had pitch maneuvers to prevent overheating[1,2]**.** For GOES-N to P, a radiator with a thermal louver rejects the solar heat absorbed to keep the scan cavity cool. A sunshield shields the radiator/louver from the Sun[2,3] (Fig. 3 and Fig. 4). For the remainder of the orbit, sunlight does not enter the scan aperture. The scan cavity radiates heat to space through the scan aperture. Also the radiator/louver continues radiating heat to space because the louver effective emittance is about 0.12, even if the louver is fully closed[3]. This requires makeup heater power to maintain the temperature within the stability range.

The GOES sounder scan cavity radiator area is approximately 0.38 m^2. When the louver is fully closed, about 21 W of makeup heater power is required to maintain the radiator temperature at 27°C. Also heat radiates from the scan cavity to space through the scan aperture which has an approximately 0.2 m^2 area. It requires about 92 W of makeup heater power to maintain the scan cavity temperature at 27°C. Heat leak from the telescope and scan cavity to space through multi-layer insulation (MLI) to space is approximately 10 W, assuming an effective emittance of 0.03 and an area of 0.8 m^2 for the MLI. The total makeup heater power is about 123 W maximum.

[1] Senior Aerospace Engineer, Heat Transfer, Code 545, 8800 Greenbelt Road, Greenbelt, MD 20771.

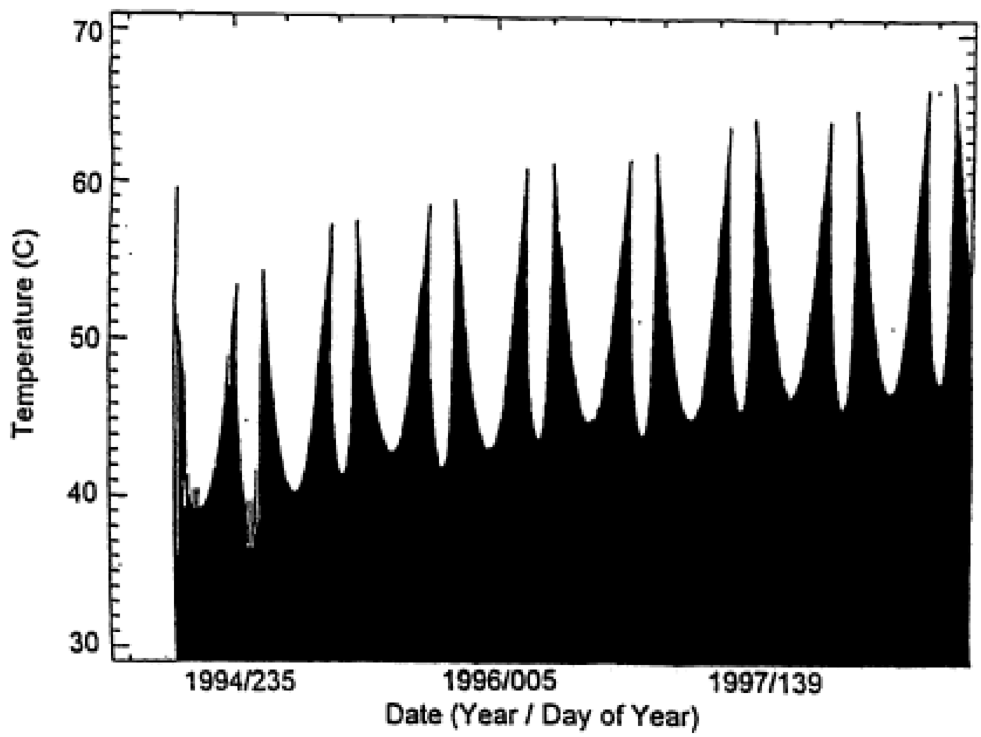

Figure 1. GOES-H Imager Scan Mirror Flight Temperature[1,2].

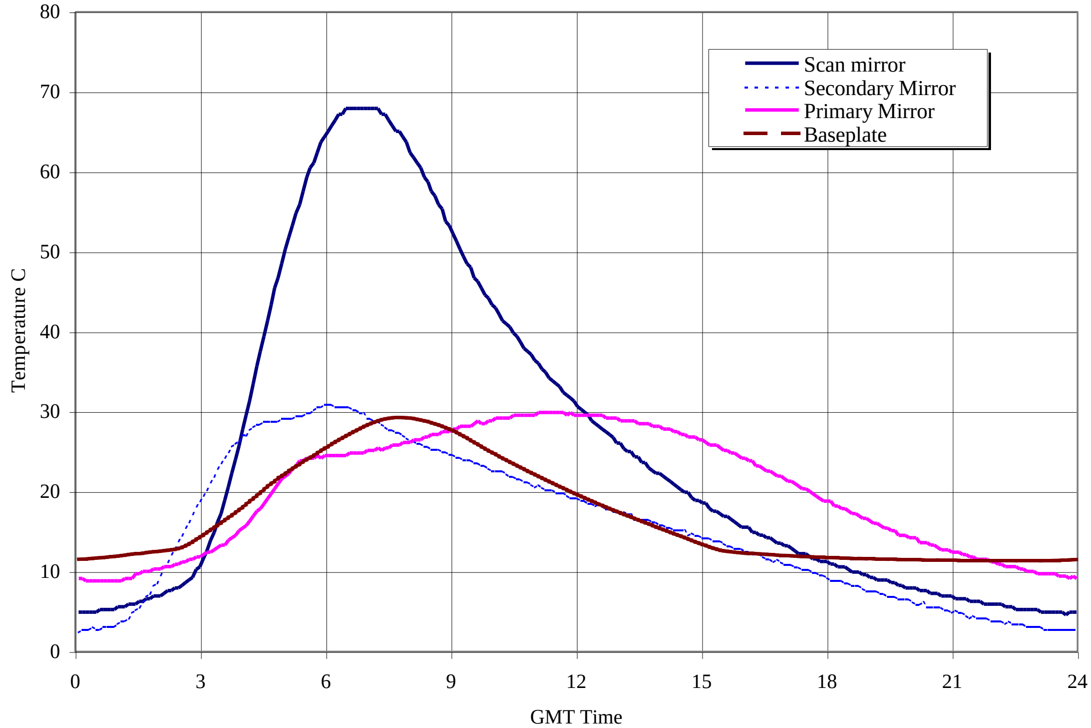

Figure 2. GOES-H Imager Scan Cavity Flight Temperature[1,2].

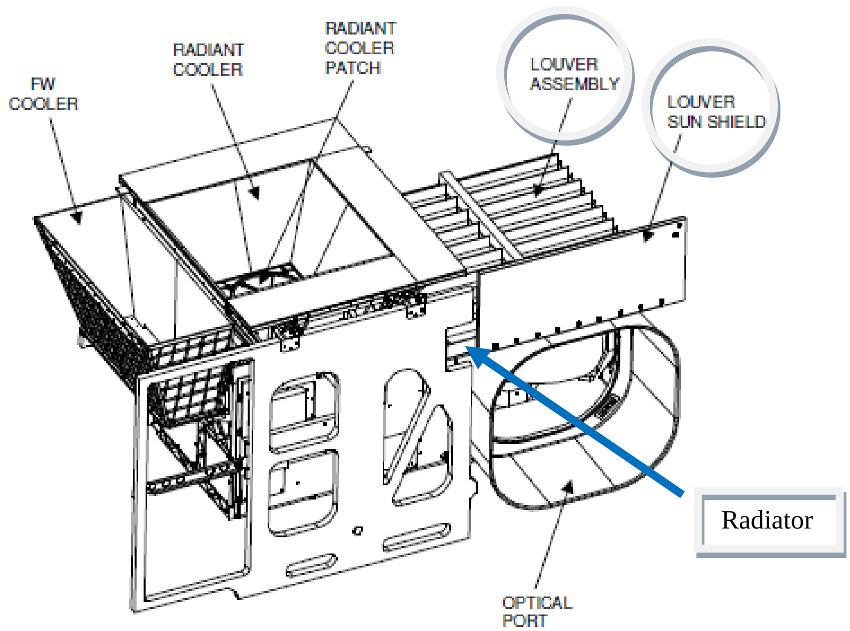

Figure 3. GOES-N to P Imager Radiator, Louver and Sunshield[2,3].

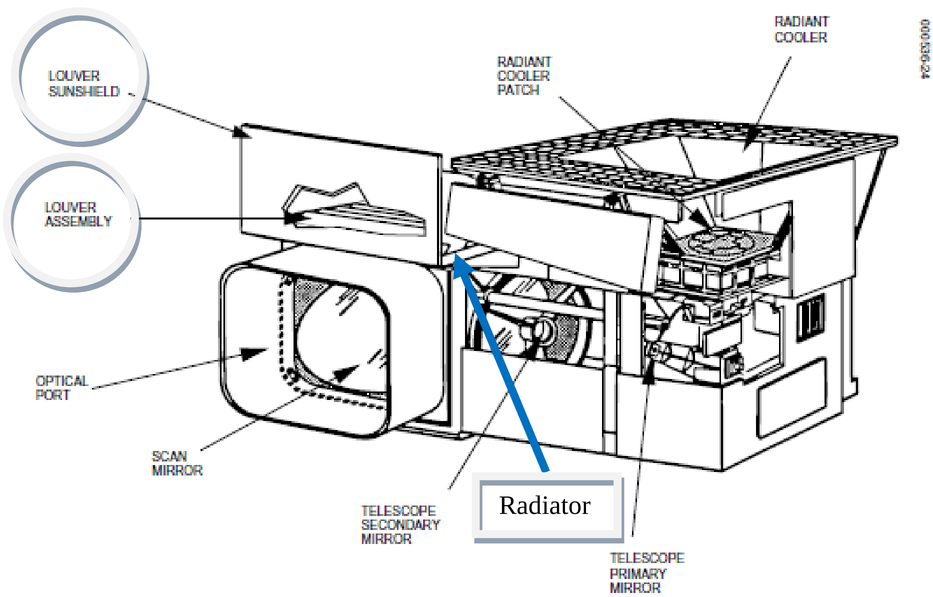

Figure 4. GOES-N to P Sounder Radiator, Louver and Sunshield[2,3].

II. Objective

The objective of this paper is to present a thermal control concept of using phase change material (PCM) in the scan cavity of an imager or sounder on a satellite in GEO to maintain the temperature stability of the scan mirror, scan motor, primary mirror and secondary mirror.

III. Thermal Concept of Using PCM in Scan Cavity

The thermal concept of using PCM in the imager or sounder scan cavity in GEO is as follows. Phase change of PCM occurs at a constant temperature. When sunlight enters the scan aperture, solar heating causes the PCM to melt. When sunlight stops entering the scan aperture, the PCM releases the thermal energy stored to keep the components in the scan cavity warm. It reduces the heater power required to make up the heat lost by radiation to space through the aperture. It has no moving parts or bimetallic springs. PCM is compact because it has a high solid-to-liquid enthalpy. Also, it could be spread out in the scan cavity. These are advantages when compared to a radiator with a louver and a sunshade.

Paraffin waxes, which have a carbon number from 14 to 19, provide a melting point in the 6˚C to 32˚C range[4-9] (Fig. 5) used in the thermal control concept presented in this paper. For even carbon numbers, 14, 16 and 18, the solid-to-liquid enthalpy is about 230 to 250 kJ/kg (Fig. 6).[4-9] For odd carbon numbers, 15, 17 and 19, the solid-to-liquid enthalpy is about 162 to 181 kJ/kg (Fig. 6).[4-9] Unless a specific melting point is required, even carbon numbers are used to minimize mass.

Paraffin PCM panels are assumed in this paper. Six such panels, 25.4 cm x 25.4 cm x 1 cm each (Fig. 7), were built by Energy Science Laboratories for the Vegetation Canopy Lidar program at Goddard Space Flight Center (GSFC). The mass of each panel is 0.65 kg, including 0.43 kg of paraffin (hexadecane; melting point 18.2˚C).[7] The thermal conductivity of paraffin is only 0.15 $Wm^{-1}K^{-1}$. Hence each panel consists of a fine pore aluminum honeycomb core embedded with K1100 carbon fibers and aluminum facesheets. The carbon fibers enhance the through thermal conductance[7] and allows paraffin within the entire thickness melt. A thermal vacuum cycling test, with 5,000 cycles, was performed on the paraffin PCM panels for the Vegetation Canopy Lidar at GSFC. They passed with no significant degradation. For comparison purpose, the number of cycles in the GEO orbit is one per day or 365 per year.

Solar heating incident on exposed surfaces of a paraffin PCM panel will increase its surface temperature up to the melting point, at which time a liquid-solid phase front will propagate inward from the exposed surface. Some non-uniformity could occur near the side walls of the enclosure. The surface temperature will steadily increase in proportion to the increasing thermal resistance between the surface and the receding phase front. When solar heating stops the temperature of the heat sink will equilibrate at the melting point, and the phase front will then stop until heat is again added or removed. Then temperature gradient will reappear and propagation of the phase front will resume.

Paraffin PCM has spaceflight heritage. Fig. 8 shows a paraffin pack flown on an instrument in the NASA MESSENGER mission to Mercury. The technology readiness level (TRL) of paraffin PCM for spaceflight is at least 6.

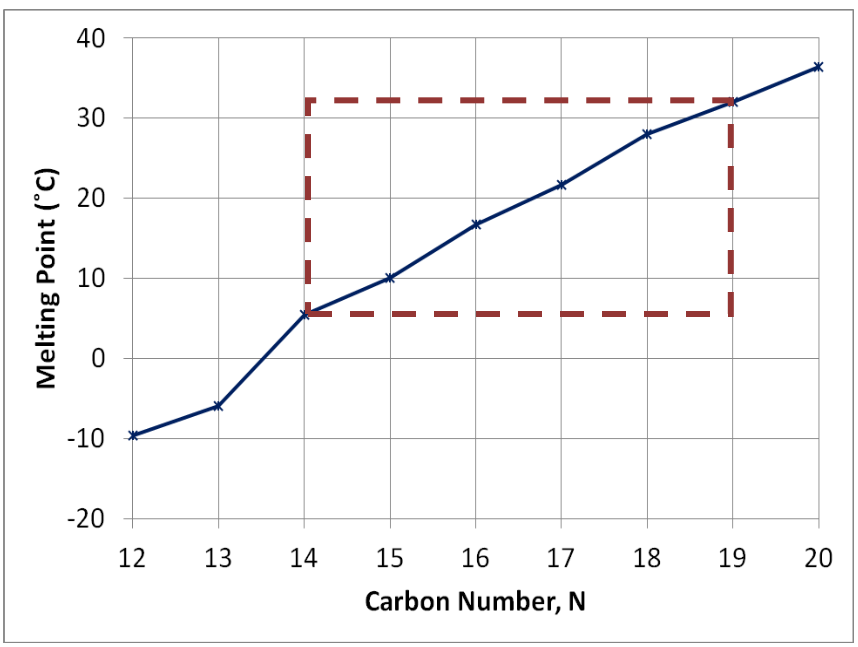

Figure 5. Melting Point of Paraffin (C_NH_{2N+2})[4-9].

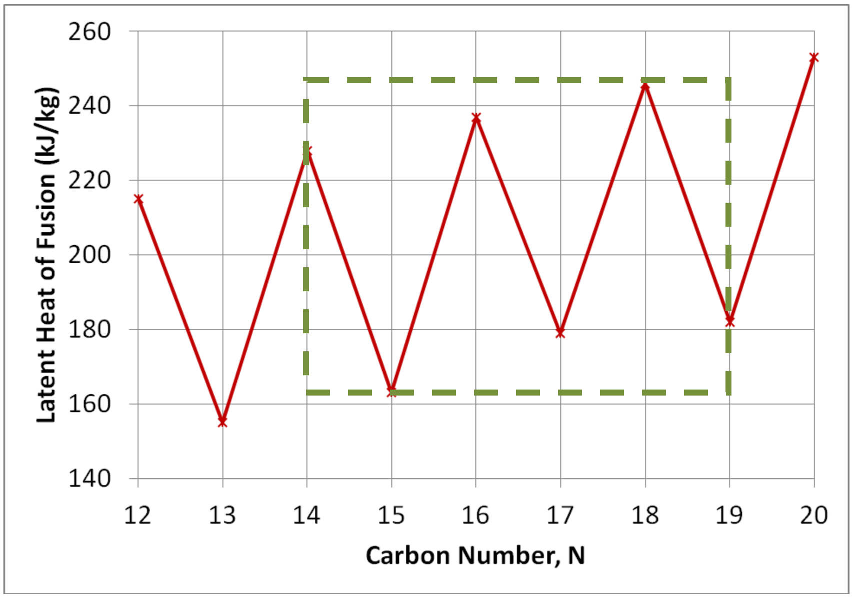

Figure 6. Latent Heat of Fusion of Paraffin (C_NH_{2N+2})[4-9].

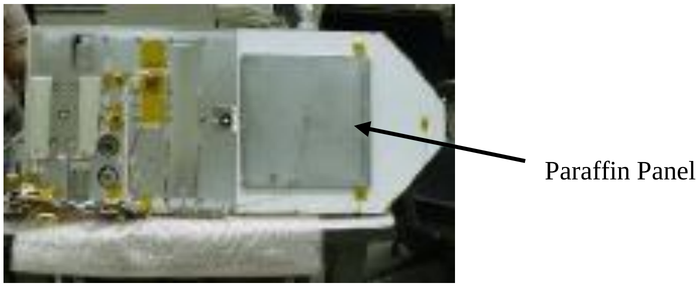

Figure 7. Paraffin Panel.[7]

Figure 8. Paraffin Packs Flown on an Instrument in MESSENGER Mission[7].

IV. Case Study for PCM in Scan Cavity in GEO

A case study of using paraffin PCM for thermal control of the GOES sounder scan and telescope cavities is presented. Figure 9 shows the beta angle versus time of year for satellites in the GEO orbit. It varies from -23.45° to +23.45°. Figure 10 shows the eclipse duration versus time of year. There is no eclipse for nine months. The longest eclipse is close to 70 minutes.

A beta angle of 10°, which has no eclipse, is used in the case study. Figure 11 shows the orbital thermal model with the GOES type satellite at this beta angle in the GEO orbit. Figure 12 presents the total solar flux absorbed by the scan and telescope cavities versus orbit time. From this graph, solar flux enters the scan cavity for approximately 10 hours, which is 38% of the orbit time. The total solar energy absorbed by the scan and telescope cavities is approximately 4,400 kJ per orbit. Figure 13 shows solar flux, approximately 1,840 kJ total, rejected by the radiator/louver currently on GOES. It is utilized by the paraffin PCM thermal design concept.

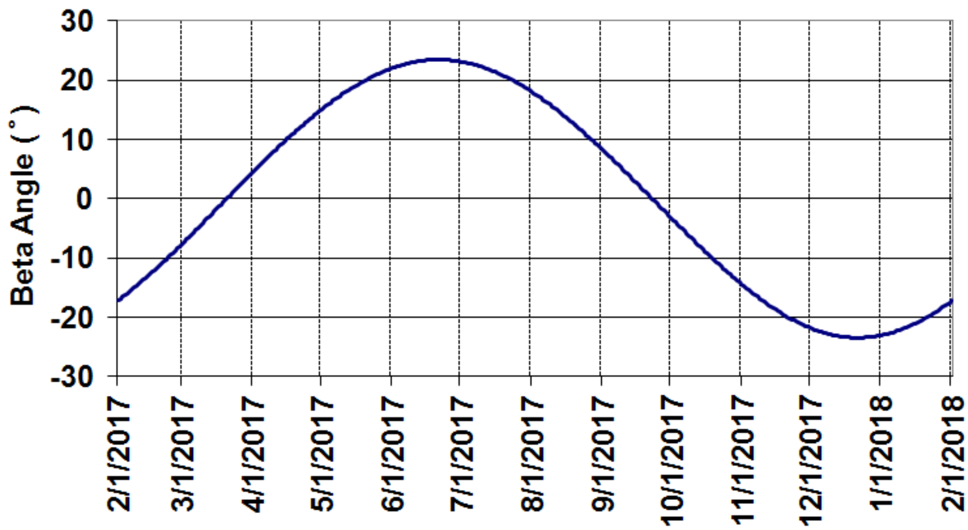

Figure 9. Beta Angle for Satellites in GEO.

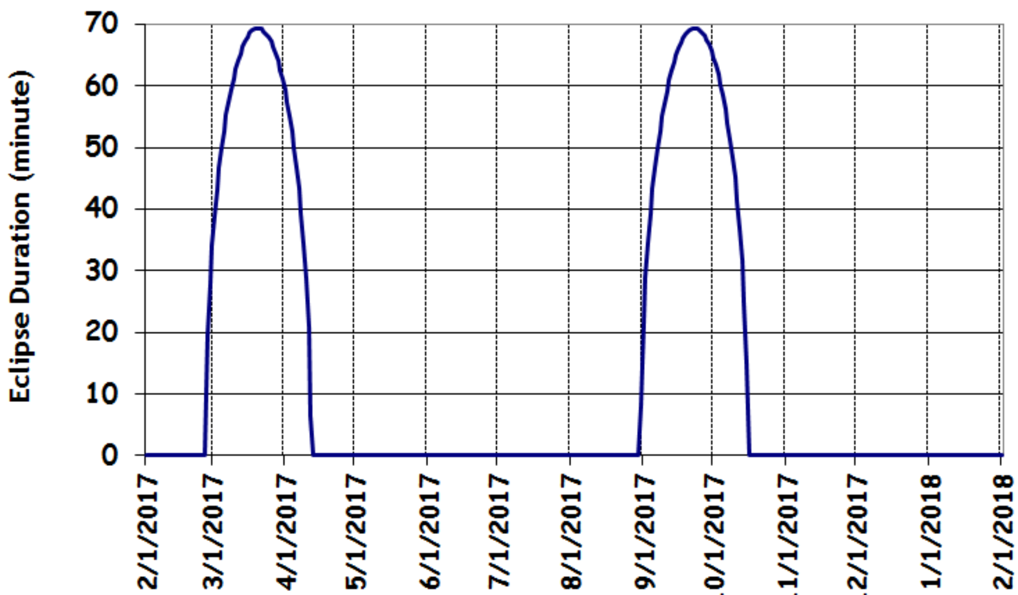

Figure 10. Eclipse Duration for Satellites in GEO .

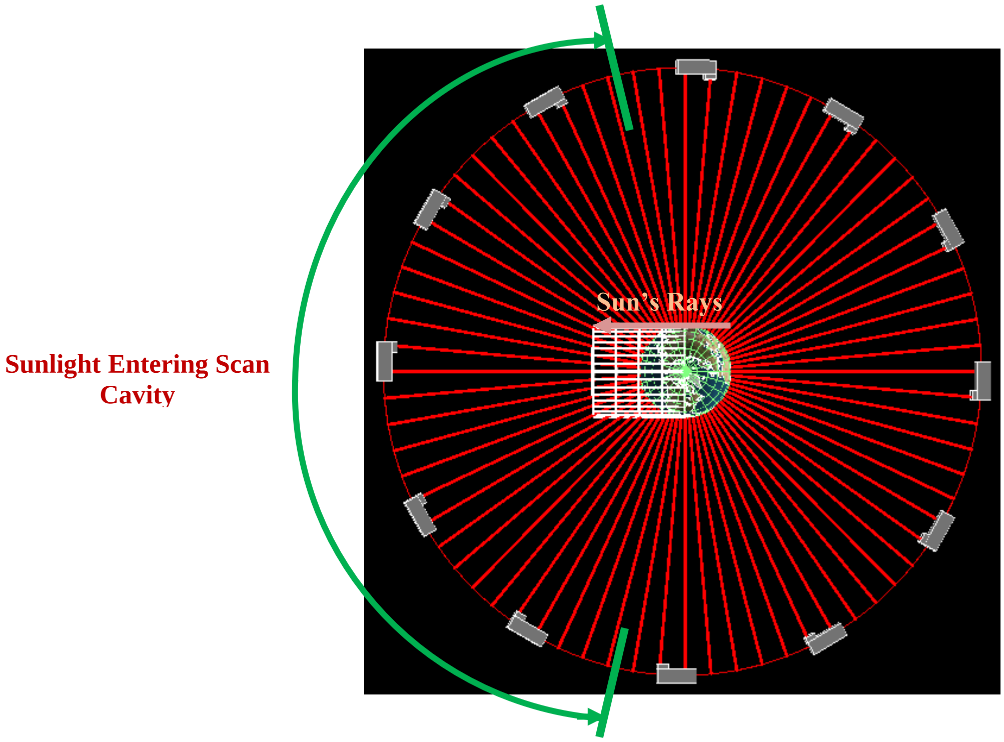

Figure 11. Satellite with Imager or Sounder Nadir Pointing in GEO (10° Beta Angle).

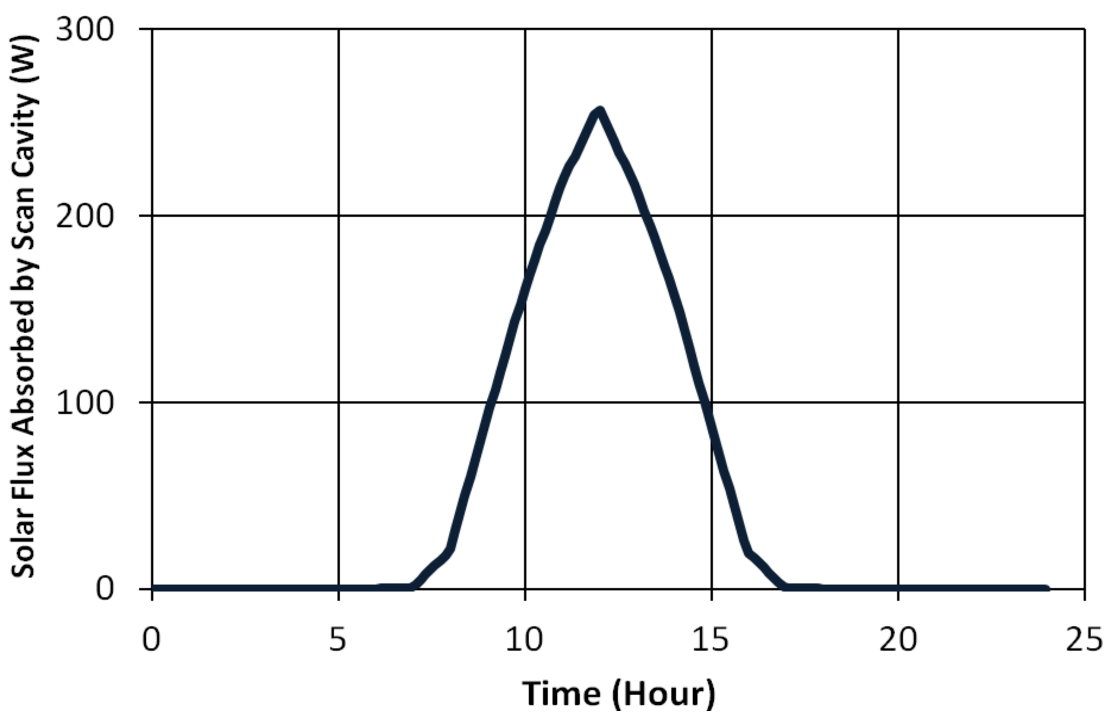

Figure 12. Solar Flux Absorbed by Scan and Telescope Cavities in Orbit.

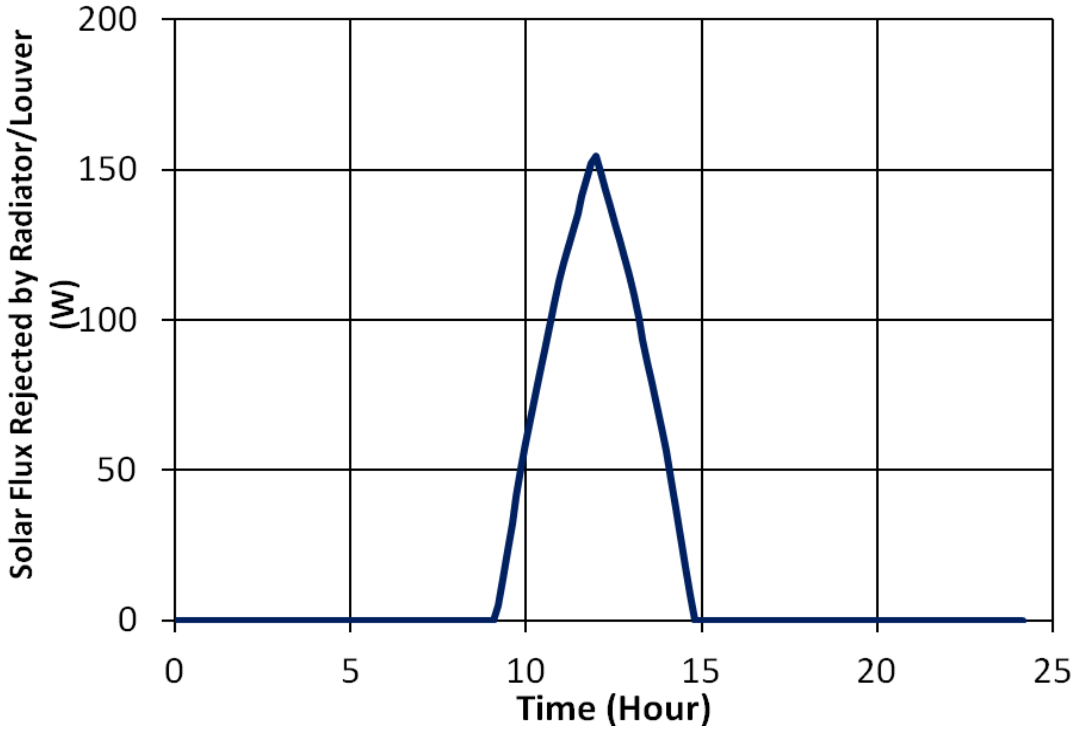

Figure 13. Solar Flux Rejected by GOES Type Sounder Radiator/Louver in Orbit.

The heat radiation from the scan cavity aperture to space is approximately 92 W, and the heat radiation from the scan and telescope cavities through the MLI blankets to space is approximately 10 W. A 27˚C scan and telescope cavities is assumed. The total heater power required is approximately 102 W maximum. It is 21 W smaller than that of the radiator/louver design presently used. If a 20˚C temperature for the scan and telescope cavities is assumed, heater power is 19 W smaller than that of the radiator/louver design presently used.

Paraffin PCM can be attached to the telescope baseplate, scan support plate, housing panels and backside of scan mirror to increase the telescope thermal stability (Fig. 14). The distribution of PCM mass can be estimated from the solar flux absorbed in each location by using a detailed thermal model.

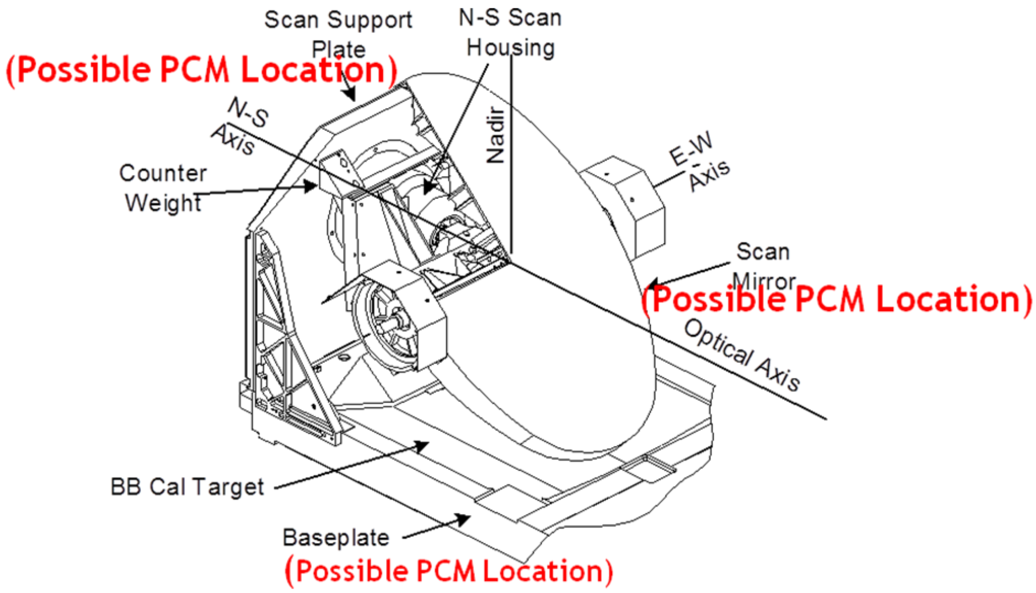

Figure 14. Possible PCM Locations.

If octadecane ($C_{18}H_{38}$) with a 28°C melting point is used, for example, approximately 7.5 kg is required. When solar flux entering the scan cavity is less than the heat radiation from the scan cavity to space through the aperture and MLI blankets, the paraffin PCM begins to freeze. Just prior to sunlight entering the scan cavity in the next orbit, all the solar energy stored in the paraffin PCM has been released. The paraffin PCM "melt-and-freeze" cycle repeats in each orbit. The mass of aluminum core, facesheets and K1100 carbon fibers required to encapsulate the paraffin is approximately 3.75 kg. The total mass of paraffin PCM panels is approximately 11.25 kg.

If heptadecane ($C_{17}H_{36}$) with a 22°C melting point is used, the mass of paraffin will increase by 38.9% since its solid-to-liquid enthalpy is only 180 kJ/kg (Fig. 6).

V. Conclusion

Paraffin PCM can be used to maintain thermal stability of an imager or sounder on satellites, such as GOES, in GEO. When solar flux entering the scan cavity exceeds the heat radiation from the scan and telescope cavities to space through the aperture and MI blankets, the PCM stores the heat at a constant temperature. When solar flux entering the scan cavity is less than the heat radiation from the scan cavity to space through the aperture and MI blankets, the PCM releases heat at a constant temperature. The PCM can be attached to different components in the telescope. It reduces the maximum orbital heater power by approximately 21 W, if the temperature of the scan and telescope cavities is 27°C. It is an attractive thermal control option to a radiator with a thermal louver and a sunshade.

References

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