Development of the Payload Module Radiator for the Broadcasting Satellite

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Abstract

An aluminum skin honeycomb panel radiator has been fabricated and tested to develop the panel's thermal design and accompanying analysis techniques. Its configuration, with 14 parallel outboard and 8 crosswise embedded heat pipes, has been optimized through various trade-off studies and thermal and structural analyses. After assembling the radiator, highly dissipative equipment thermal dummies, and thermal materials into a thermal model of the payload module, a thermal vacuum test was performed in the vacuum chamber with liquid nitrogen shrouds to verify its thermal design. A rigorous thermal mathematical model has been generated and corrected with the test results. It has been confirmed from the good correlations that the thermal mathematical model has sufficient accuracy to simulate the on-orbit thermal behavior of the payload module. The on-orbit prediction results met the thermal design requirements for the payload module radiator.

Contents

The payload module radiator was developed for a north- or south-facing radiator on a broadcasting satellite in geosynchronous orbit. The payload module included three 150 W traveling wave tube amplifiers (TWTA) consisting of three traveling wave tubes (TWT), three high-voltage power supplies (HVPS), a low-voltage power supply (LVPS), and an output multiplexer (OUTMUX). See Fig. 1. The radiator was designed according to the thermal and structural design requirements listed in Table 1.

A number of trade-off studies were performed, covering, in particular, radiator types (a solid panel with stiffeners or an aluminum skin honeycomb panel) and arrangements of the heat pipes. The results showed that a honeycomb panel radiator was superior to a solid-panel radiator with stiffeners in the weight and cost savings. The design approach for the payload radiator is summarized as follows. First, the radiator basic dimensions such as skin thickness, honeycomb core height, and core density were roughly estimated by taking into account the total equipment weight under the structural design requirements. At the same time, the heat pipe performance and interval were roughly estimated based on the structural estimations. The heat pipe interval was determined by means of the solution of a one-dimensional, nonlinear or linearized thermal balance equation accounting for the radiation and conduction.[1,2] Second, the more rigorous mathematical models were generated and thermal and structural analyses were performed according to the detailed radiator configuration. From these results, it was found that the radiator needed a 15 mm thick honeycomb core and a 0.3 mm thick skin. This resulted in the heat pipe arrangement and performance shown in Figs. 1 and 2. The arrangement has been verified as meeting the radiator structural design requirements by structural dynamic and thermal vacuum tests.

After assembling the heat pipe integrated radiator, thermal control materials, and TWTA thermal dummies into the thermal model of the payload module, the thermal vacuum test was conducted in a vacuum chamber (2 m in diameter and 4 m long) with liquid nitrogen shrouds. The test objectives were: 1) to verify the performance of the individual heat pipes and the heat pipe network, 2) to verify the validity of the radiator thermal design, and 3) to measure the thermal conductance of the equipment mounting brackets. The radiator surfaces exposed to space were coated with silvered Teflon and the mounting surface was painted black and integrated with 14 parallel outboard heat pipes. Four long heat pipes were embedded perpendicular to the outboard heat pipes. Four long heat pipes were embedded perpendicular to the outboard heat pipes under the TWT and HVPS thermal dummies. Four short heat pipes were also embedded under the OUTMUX thermal dummy. The TWTA thermal dummies have been designed to have the same thermal properties as the real hardware. In particular, the TWT thermal dummies have external and internal configurations almost equivalent to the real TWT in a thermal sense. The mounting surface and the TWTA thermal dummies were insulated by a multilayer insulation blanket cover. The payload radiator was set up to adjust its level within 0.05 deg in the chamber in order to operate the heat pipes normally under a gravitation of 1 *g*. Each outboard heat pipe had three silicon rubber heaters on its peripheral, which were used to simulate the incident energies on the radiator and to control the radiator temperature within the required limits. The heat pipe function test and the solstice and eclipse simulation tests were performed at different heater power and two combinations of the three TWTAs. The radiator and thermal dummies temperatures were monitored every 10 min by 170 thermocouples.

Table 1 Radiator thermal and structural requirements

Thermal design requirements	
Design temperature limits	
TWT body	−5/55°C
HVPS	0/40°C
Total heat rejection[a]	600 W (min)
Structural design requirements	
Equipment mounting area	1.61×0.78m
Natural frequency[b]	70 Hz (min)
Design loads	30 *G* (in-plane)
	20 *G* (out-of-plane)

[a]The total heat rejection includes the equipment heat dissipations (Fig. 1) and the absorbed incident energies. A radiating efficiency of 0.9 was applied to the radiator as a design goal. [b]The stiffness requirement for the minimum natural frequency 70 Hz is required for the radiator detached from the spacecraft main structure.

Presented as Paper 85-1013 at the AIAA 20th Thermophysics Conference, Williamsburg, VA, June 19-21, 1985; synoptic submitted Dec. 15, 1985.

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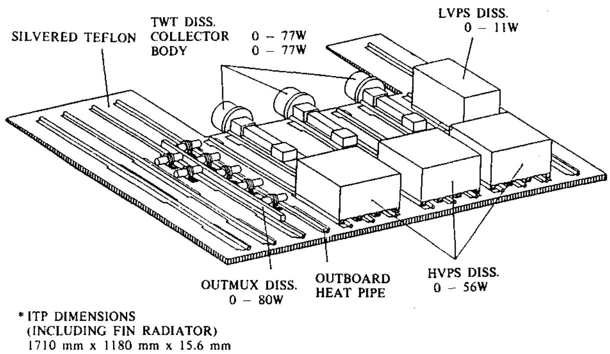
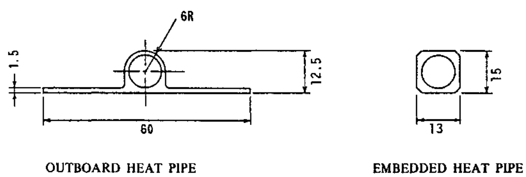


Fig. 1 Layout of thermal model of payload module.



Pipe material	A 6063—T 5
Working fluid	Ammonia
Thermal performances	
Temperature range	
Operate	−15° to 45°C
Survival	−40°C to 60° C (135°C)*
Heat transport	Min 60 W.M.
Temperature drop	Max 4°C

*The manufacturing temperature in embedding heat pipe in honeycomb panel

Fig. 2 External configurations and thermal performances of heat pipes: a) outboard heat pipe, b) embedded heat pipe.

A thermal mathematical model coded for the STAN computer program, which has 643 nodes, was generated for the payload module thermal model and the test fixture. Each embedded heat pipe was modeled with two circumferential pipe wall nodes and a constant-temperature node representing the vapor.[3,4] Both honeycomb panel facesheets were modeled to evaluate the temperature gradient through the radiator. Values of 0.85 and 0.14 $W/cm^2 \cdot K$ were used for the thermal conductances between the embedded heat pipe and the facesheet and between the outboard heat pipe and the facesheet, respectively. A value of 0.70 $w/cm^2 \cdot K$ was used for the heat pipe film coefficient. Thermal conductance values for the equipment mounting brackets were derived from the thermal test. Three 10 nodes TWT models, three 1 node HVPS models, a 1 node LVPS model, and a 12 nodes OUTMUX

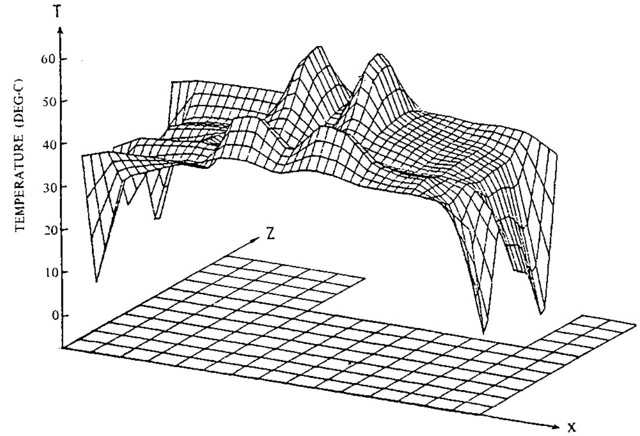


Fig. 3 Predicted temperature profile for worst hot case.

model were incorporated into the radiator model at their locations. The steady and unsteady thermal analyses were performed for the solstice and eclipse simulation tests, respectively, by means of the aforementioned thermal mathematical model and then correlated with the test results. The temperature profiles on radiator depend on the incident energy flux and the operation mode of the powered TWTAs. The predicted temperature profile for the worst hot case is shown in Fig. 3. From the test data correlation, it was found that more than 80% of the 109 predicted temperatures were within the 5°C temperature difference relative to the measured values for all test cases.

The on-orbit prediction results obtained with the modified mathematical model met the thermal design requirements for the payload module radiator. These results indicate that the developed techniques for the thermal design, thermal analysis, fabrication, and thermal test can be applied to the development of future broadcasting satellites.

References

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