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Thermal Design of a Thermoelectrically Cooled Low-Noise Amplifier

N.L. Hyman* and H.L. Hung†
COMSAT Laboratories, Clarksburg, Md.

Abstract

A COMPACT and low-cost package was developed which, at room temperature ambient, reliably maintains the preamplifier unit of an Earth station low-noise amplifier at −90°C. This is the first time that such a unit (1.0×1.8×8.4 cm; heat dissipation, 150 mW) has been thermoelectrically cooled to such a low temperature in so small an overall package (19×19×28 cm, including the heat exchanger and fan). Comprehensive thermal analyses have led to an insulation system of light powder-heavy gas with thermal shields; a high-capacity, six-stage thermoelectric heat pump; and an efficient 700-cm^3, 50-W/°C pin-on-plate heat exchanger. Low conductance waveguides and a thermal strain relief device have also been developed. Thermal design concepts, optimization procedures, supporting analyses, and examples of measured thermal performance are presented in the subject paper.

Contents

A low-noise amplifier for the front end of Earth station receivers[1] achieves its low-noise temperature by a three-stage preamplifier maintained in the range of from −80 to −90°C.

The cooling device within the package, shown schematically in Fig. 1, is a six-stage thermoelectric heat pump (TEHP) designed to the specifications presented in Table 1.

Previously, some TEHPs had been built to produce lower temperatures, and others to handle higher heat loads; none, however, had been built for this combination of extreme temperatures and loads.

Thermal design effort focused on achieving high thermal isolation between the preamplifier and ambient, and efficiently transferring dissipated heat from the TEHP first stage to the ambient. Design objectives were small overall package size, low production cost, and high reliability. Low TEHP input power, although desirable, was not to be achieved through increased size or cost.

Of the many thermal insulation schemes considered, the one chosen best combines low cost and high effectiveness. The space between preamplifier and package walls, as well as TEHP intramodular spaces, are filled with the inert, low conductance combination of low density perlite powder and krypton gas at slightly above atmospheric pressure. Other powders and gases could have resulted in lower conductances, but at an unacceptable cost. To exclude water vapor, the package is hermetically (O-ring) sealed.

A 7.6-cm-long waveguide with 0.13-cm-thick walls of epoxy resin and glass sphere filler was developed; its 2.3-mW/°C conductance is primarily from the silver and nickel internal surface plating. Package size was considered to be minimum because the TEHP, whose design was based on calculated heat loads, just fits within the package walls. The number and location of aluminum heat shields and their thermal contact with the waveguides were determined, as were all heat loads, from a series of predictions based on a nodal thermal model.

Temperature-induced strain in the waveguides and excessive TEHP-to-preamplifier thermal resistance are avoided with a flexible, high conductance connection. This composite of fifteen 0.05-mm copper sheets also allows for dimensional uncertainty during fabrication and assembly. A thin molybdenum plate is an intermediate thermal stress absorber between copper and the TEHP beryllia face sheet.

Total TEHP power and the pumped heat loads are rejected from the first stage into ambient air by a heat exchangeı designed for minimum temperature elevation within volume and cost constraints. A high surface area-to-volume ratio is realized with closely spaced, small diameter cylindrical pins normal to the TEHP first-stage plate. The optimum (most cost- and volume-effective) pin pattern, diameter, and length were analytically determined. Figure 2 shows the temperature

Table 1 Design specifications for six-stage TEHP

TEHP stage	Temperature, °C	Calculated heat loads, W
6 (cold side)	−85	1.5
1 (hot side)	60	...
4 (heat shield)	...	2.5
3 (heat shield)	...	17.0

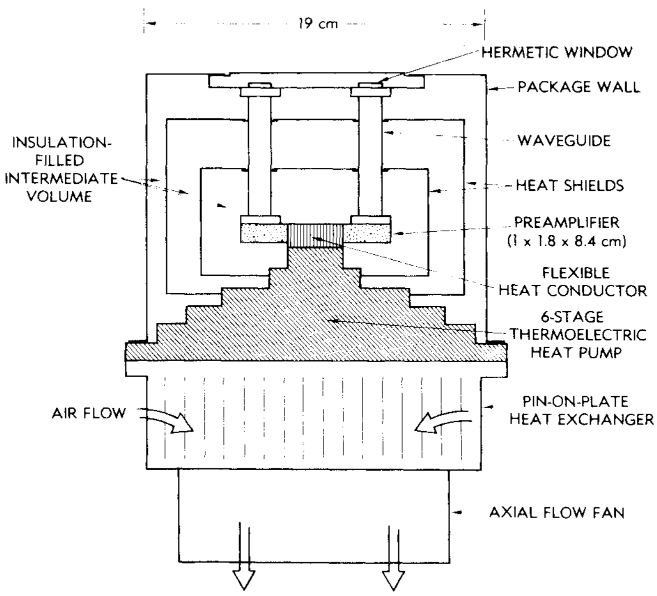

Fig. 1 Schematic of preamplifier/TEHP package (to approximate scale).

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*Member, Technical Staff, Spacecraft Technology Division. Member AIAA.

†Manager, Advanced Microwave Techniques, Microwave Technology Division.

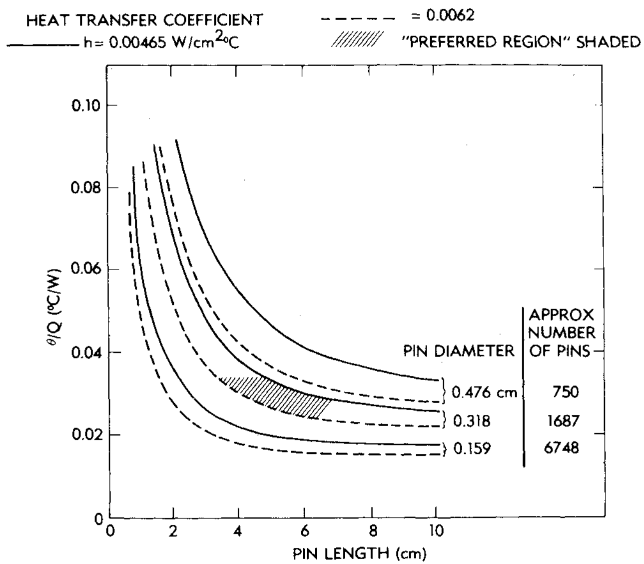

Fig. 2 Temperature elevation/heat flow rate (θ/Q) as a function of aluminum pin geometry.

elevation of the pin base per unit of heat flow rate, θ/Q, as a function of pin length for various diameters, and two representative heat transfer coefficients. Pin geometry was selected from a logically defined "preferred region."

Heat exchanger effectiveness (total dissipated power divided by average temperature elevation) with a small axial fan was 39 W/°C, and with a larger centrifugal blower, 51 W/°C. As fan diameter decreases, improved air flow over the critical central area increases effectiveness. Air enters at the sides and exhausts at the center through the air mover. Effectiveness is included in the input power vs hot side temperature curves of Fig. 3.

The design principles of this cooled preamplifier package can be applied to other electronic and optical components for which temperatures must be maintained as low as -100°C.

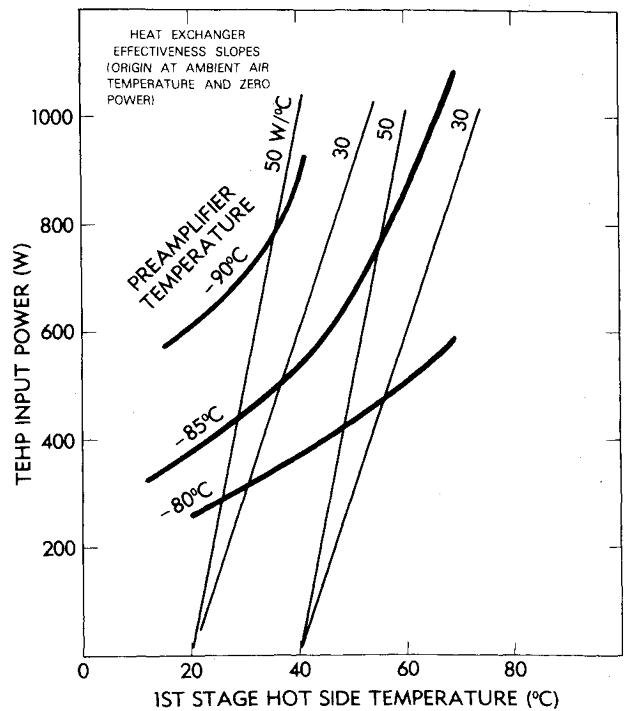

Fig. 3 Preamplifier temperature as a function of input power, ambient temperature, and heat exchanger effectiveness.

Acknowledgment

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Reference

[1] Hung, H.-L. and Hyman, N.L., "Thermoelectrically Cooled MESFET Low-Noise Amplifier for Earth Stations," *COMSAT Technical Review*, Vol. 10, Fall 1980, pp. 299-320.