Thermal Design of the Motor Board
Spartan IR Camera for the SOAR Telescope

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Abstract

The motor board reduces heat transfer between the warm vacuum bulkhead and the cold motors. A thermal model of the motor board shows that the duty cycle d of the motors over a 1.5-hour period must be limited to $d < 0.25(2.5\,\mathrm{A}/I)^2$ in a cold instrument and $d < 0.15(2.5\,\mathrm{A}/I)^2$ in a warm instrument, where I is the peak current. Exceeding this restriction will cause the motor board to overheat.

The requirements for the motor board are (1) that it reduce heat transfer between the warm vacuum bulkhead and the cold motors, (2) that it handle a maximum motor current of 2.5 A (peak) for intermittent use. The motor board burned when used continuously, and this note clarifies what intermittent is.

Long, thin traces (0.25×0.04×220 mm) carry current and act as thermal resistors. The heat load is about 100 mW.

The motor board is wrapped in a single layer of aluminized polyester to reduce the radiative heat load. Were the board not wrapped, the radiative heat load on the coldest 90×90 mm of the board would be 6 W. The heat load of the entire instrument is 14 W.

Since the Joule heating in the four traces for a motor is 1.8 W, the temperature rise in the active traces is considerable. (The resistance of a trace is 0.22 Ω.) To distribute the heat to the inactive traces, there are electrically inert traces that are perpendicular to the current-carrying traces. These traces are on the reverse side of the board. See Figure 2.

We computed the temperature distribution $T(x)$ along the length of a trace. The temperature changes with time as

$$wC\frac{dT}{dt} = 4\rho I^2/A + N\kappa A/L^2\frac{d^2T}{d^2x} - \epsilon w\sigma(T^4 - T_{\mathrm{a}}^4),$$

where wC is the specific heat per unit length of the FR4 circuit board, ρ is the resistivity, I is the RMS current in one trace, $A = 0.0090\ \mathrm{mm}^2$ is the cross sectional area of one trace, $N = 20$ is the number of traces that share in conducting heat, κ is the thermal conductivity, $L = 220\,\mathrm{mm}$ is the length of the traces, $\epsilon = 0.03$ is the emissivity, $w = 50$ mm is the width of the radiating region, and T_a is the temperature of the ambient radiation. The temperatures at the boundaries x=0 and 1 are specified. At equilibrium, $dT/dt = 0$.

Four cases are considered. (A) The unmodified motor board with a peak current of 2.5 A in a cold instrument. (B) The modified motor board with a peak current of 2.5 A in a cold instrument. The traces that carry the same voltage are wired together to reduce the Joule heating. (C) The modified motor board with a peak current of 2.5 A running at 25% duty cycle in a cold instrument. (D) The modified motor board with a peak current of 2.5 A running at 15% duty cycle in a warm instrument. For cases A–C, $T(0) = 17\,\mathrm{C}$, $T(1) = T_\mathrm{a} = -113\,\mathrm{C}$. For case D, $T(0) = T(1) = T_\mathrm{a} = 25\,\mathrm{C}$. See Figure 1 for the equilibrium temperature. Including the effects of radiation flattens the temperature distribution. Were radiation neglected, the distribution would be quadratic.

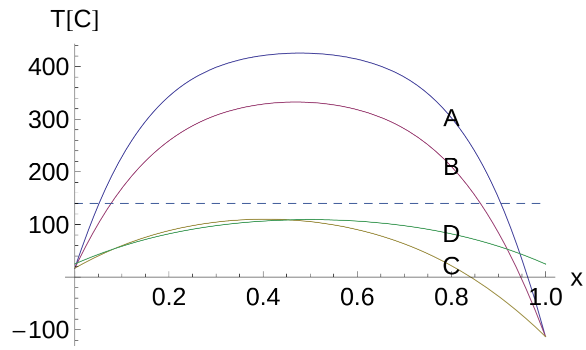

Figure 1: Equilibrium temperature distribution on the motor board. The dashed line is the maximum allowed temperature for FR4 circuit boards. Cases A–C apply to a cold instrument, and case D applies to a warm instrument. The peak current is 2.5 A. The duty cycle is 100, 100, 25, and 15% for cases A–D.

The time to heat or cool is quite long. When the current is first turned on, the temperature changes by 6, 9, 37, and 62 s/C for cases A–D. The heating time is 0.8, 1.0, 1.5, and 2.7 hr for the four cases. The cooling time is the same as the heating time.

The temperature is acceptable for case C, but the equilibrium temperatures for cases A and B are too high for FR4 circuit boards. The maximum temperatures are 430, 330, and 110 C for cases A, B, and C. The temperature at which the resin softens is 140 C for FR402 and 170 C for FR406. The temperature at which the material decomposes is 320 and 294 C.[1]

The modified motor board may be used with the restriction on its duty cycle d

[1] Advanced Circuits (4pcb.com), undated.

over a 1.5-hour period that

$$d < 0.25(2.5\,\mathrm{A}/I)^2 \quad \text{in a cold instrument}$$
$$d < 0.15(2.5\,\mathrm{A}/I)^2 \quad \text{in a warm instrument}$$

where I is the peak current. The restriction applies to all motors. If all five motors run for the same amount of time at 2.5 A, then over a 1.5-hour period, each motor may run for 0.07 hr. If a single motor is used, it may run for 0.4 hr. If the current is lower, the duty cycle is greater.

There is no limitation on the heater, which also uses the motor board. The maximum possible peak current on the heater is $110\,\mathrm{V}/(90\Omega) = 1.2\,\mathrm{A}$. Since it uses one pair of traces, whereas the motors uses two pairs, its Joule heating is half. The above limit on the duty cycle in a warm instrument allows 1.4 A.

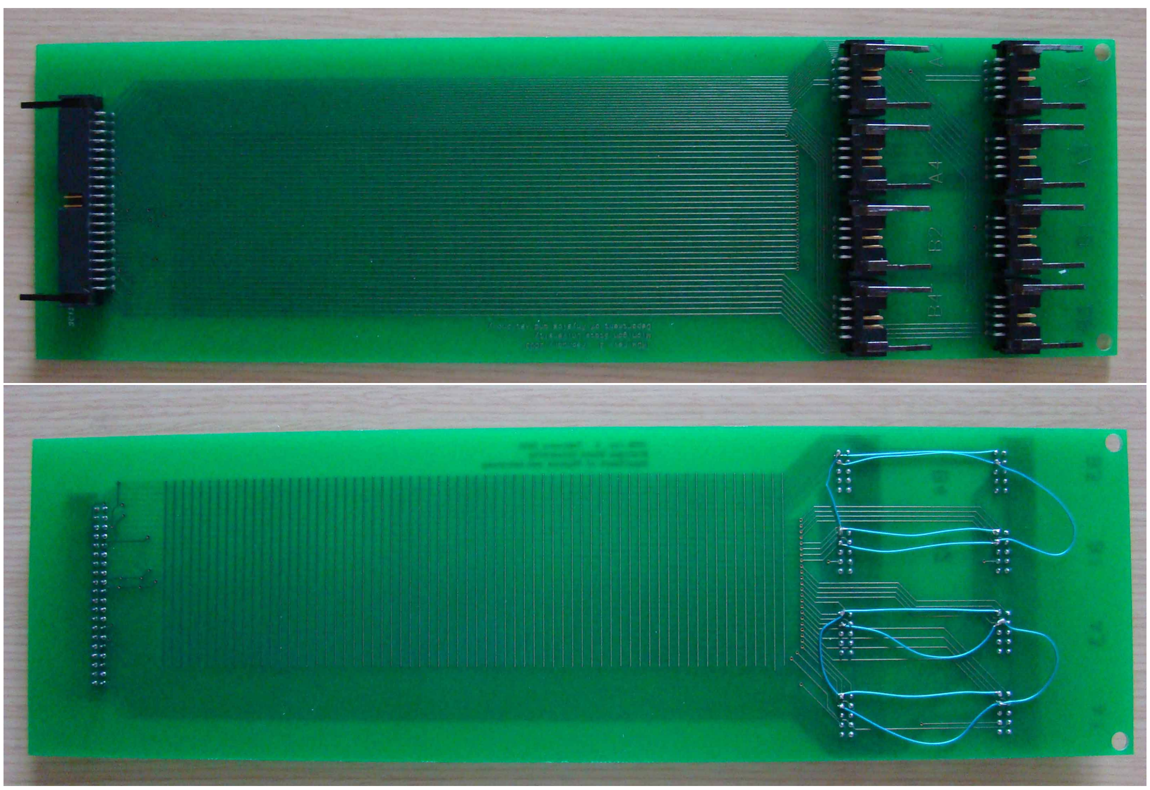

Figure 2: Front (top) and back (bottom) of the motor board. The left side is warm, and the right side is cold. The electrical traces that are thermal resistors are on the front. The heat-spreading, electrically inert traces are on the back.