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US Army Research Laboratory

Satellite Terminal Power Box Thermal Calculations

by Steven Callaway

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14. ABSTRACT
To determine the thermal behavior of the satellite terminal power box, constraints must be set on the internal temperatures, the thermal budget must be determined, and the thermal resistance network analyzed. The natural convection and conduction of the power box is determined, and an exhaust fan is sized to remove excess heat.

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1. Introduction

The satellite terminal trailer system involves removing the satellite terminal from a military vehicle and installing it on a flat-deck trailer. This new system includes a large auxiliary fuel tank and the tool storage space required for operation. With the auxiliary fuel tank in place, the system can run for a full day on generator power (as opposed to a few hours when used with the military vehicle), or on 120 VAC shore power. Overall, the system's range, operational time, and mobility are improved over the military vehicle configuration.

As part of a mechanical subsystem, exhaust fans are used to remove generator exhaust from the trailer. The exhaust fans require a power-conversion system—the satellite terminal power box—to allow the fans to operate on the available 120 VAC or 30 VDC power (Fig. 1).

To ensure reliable function of the exhaust system, a thermal system needed to be designed to remove excess heat from the satellite terminal power box during operation.

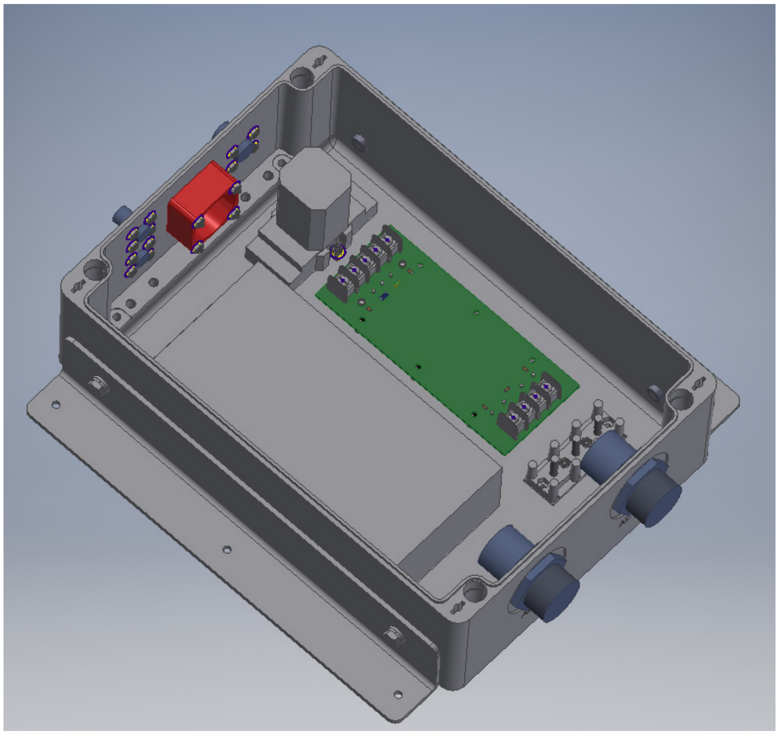

Fig. 1 3-D model of the satellite terminal power box (lid removed for clarity)

2. Thermal Requirements

To determine the thermal behavior of the satellite terminal power box, constraints must be set on the internal temperatures, the thermal budget must be determined, and the thermal resistance network analyzed.

The satellite terminal power box uses either 120 VAC or 30 VDC input power to produce 24 VDC, which powers two 24 VDC fans (Orion part no. OD254AP-24H).[1] The Orion fans require 63.6 watts (W) of current each, requiring the power box to supply 127.2 W total.

$$P_{Total} = 2\,(V \cdot I) \tag{1}$$

$$P_{Total} = 2\,(24\,Volts \cdot 2.65\,Amps) \tag{2}$$

$$P_{Total} = 127.2\,Watts \tag{3}$$

Using the efficiency rating of the 24 VDC power supply (Mean Well part no. SP-200-24) and the 24 V DC-to-DC converter (Vicor Corporation part no. V28A24200BG), the total heat that needs to be removed from the system can be determined. A total of 19.08 W must be removed from the 24 VDC power supply and 17.81 W must be removed from the 24 V DC-to-DC converter (Table 1).

Table 1 Thermal requirements for satellite terminal power box components

Component	Power draw (W)	Efficiency[2,3]	Heat dump (W)
24 VDC power supply	127.2	85%	19.08
24 V DC-to-DC converter	127.2	86%	17.81

Using the datasheets for the temperature-sensitive items in the satellite terminal power box, the maximum operational temperature is determined. The maximum internal power box temperature, T_{in}, is set to 60 °C (Table 2). As a worst-case scenario, the ambient temperature, T_{out}, is set to 48 °C.

Table 2 Maximum temperature requirements of satellite terminal power box components

Component	Manufacturer	Part no.	Maximum temp (°C)[2–4]
24 VDC power supply	Mean Well	SP-200-24	60
24 V DC-to-DC converter	Vicor Corporation	V28A24200BG	100
Relay	TE Connectivity	KEUP-7D15-24	70

3. Enclosure Thermal Calculations

A resistance thermal network is used as a base calculation for the thermal behavior of the satellite terminal power box. The heat removed from each power supply is analyzed individually. The heat from the power supply, q_{ps}, is assumed to either conduct through the base of the enclosure directly below the power supply ($R_{cond,ps}$) or to travel through the air to the enclosure wall, conducting through the wall material ($R_{conv,in} + R_{cond,wall}$). The heat from either path will then convect from the outside wall of the enclosure to ambient air ($R_{conv,out}$). The thermal resistance network is illustrated in Fig. 2.

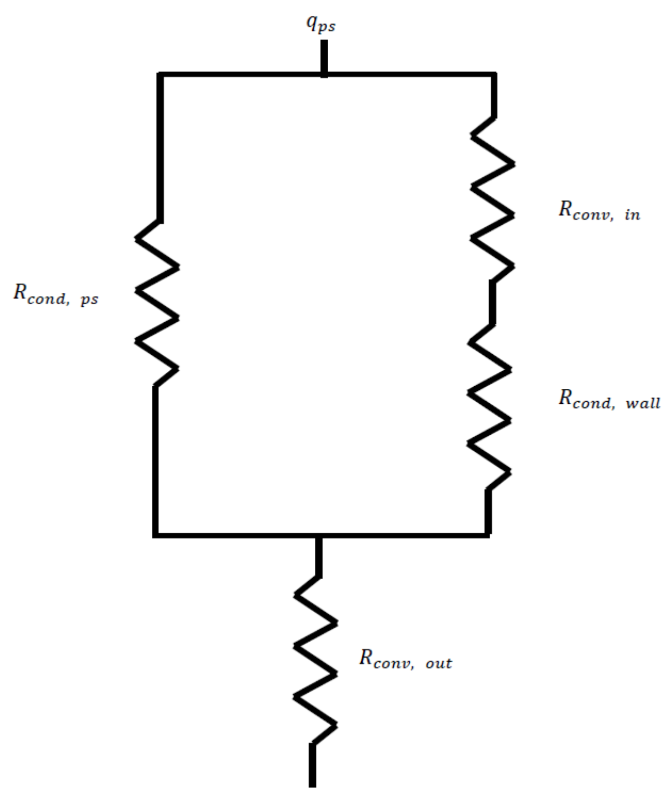

Fig. 2 Satellite terminal power box's thermal-resistance network

The thermal resistance for each element in the network is determined.

$$R_{conv,in} = \frac{1}{h_{in}\ SA} \tag{4}$$

The internal convective heat transfer coefficient, h_{in}, is set to a conservative value of 35 $\frac{W}{m^2-K}$, and the surface area of the enclosure, SA, is measured as 0.0325 m^2. The bottom surface of the enclosure is ignored.

$$R_{cond,wall} = \frac{t}{k\ SA} \tag{5}$$

The enclosure wall thickness, t, measures 0.0048 m. The thermal conductivity of the aluminum enclosure is set to 205 $\frac{W}{m-K}$.

$$R_{cond,ps} = \frac{t}{k\ A_{ps}} \tag{6}$$

The area under each power supply, A_{ps}, is determined from the datasheet for each item.

$$R_{conv,out} = \frac{1}{h_{out}\ SA} \tag{7}$$

The external convective heat transfer coefficient, h_{out}, is set to a conservative value of 25 $\frac{W}{m^2-K}$.

$$R_{Total} = \frac{1}{\frac{1}{R_{cond,ps}} + \frac{1}{R_{conv,in} + R_{cond,wall}}} + R_{conv,out} \tag{8}$$

$$Q = \frac{T_{in} - T_{out}}{R_{Total}} \tag{9}$$

Summing the resistive values gives R_{Total}, so that the heat removed through the enclosure, Q, is determined. For the 24 VDC power supply, 9.73 of the required 19.08 W is removed. For the 24 V DC-to-DC converter, 9.71 of the required 17.81 W is removed. This leaves 17.45 W of heat that still must be removed from the enclosure.[5]

4. Fan-Sizing Calculations

An exhaust fan is used to remove the remaining heat from the enclosure. The following equation is used to determine the minimum flow rate, $\dot{m}$, required.

$$\dot{m} = \frac{q}{\rho\, c_p\, (T_{in} - T_{out})} \tag{10}$$

The heat to be removed, q, is set to 40 W to provide an adequate factor of safety in the design. The density of air, ρ, and the specific heat, c_p, are determined for the internal enclosure temperature at atmospheric pressure. A minimum flow rate of 0.003121 $\frac{m^3}{s}$, or 6.612 CFM, is calculated. A 40-mm box fan from San Ace is selected (part no. 109P0424D601).[6]

5. Conclusion

To guarantee operation of the satellite terminal power box, the thermal behavior of the system is analyzed. It is determined that 19.08 W of heat must be removed from the 24 V DC power supply and 17.81 W must be removed from the 24 V DC-to-DC converter to maintain a safe operating temperature.

Calculations determine that 19.54 W of heat are removed from the box through natural conduction and convection alone. The remaining heat is removed via an exhaust fan on the satellite terminal power box, removing 40 W of heat from the system.

The satellite terminal power boxes have operated without thermal issues and with no complaints from end users.

6. References

1. OD254 Series, Orion Fans (Dallas, TX). [June 2017]. http://www.orionfans.com/media/parts/dcfans/OD254.pdf.
2. SP-200 series, Mean Well USA Inc (Fremont, CA). [May 2017]. http://meanwellusa.com/productPdf.aspx?i=436#1.
3. Maxi Family 28V Wide Input, Vicor Corporation (Andover, MA). [May 2017]. http://cdn.vicorpower.com/documents/datasheets/ds_28vin-maxi-family.pdf.
4. General Purpose Relays and Industrial Relays, TE Connectivity Relay Products USA (Berwyn, PA). [May 2017]. http://www.te.com/commerce/DocumentDelivery/DDEController?Action=showdoc&DocId=Data+Sheet%7FKUEP_series_relay_datasheet%7F0815%7Fpdf%7FEnglish%7FENG_DS_KUEP_series_relay_datasheet_0815.pdf%7F8-1393113-3.
5. Incropera FP, Dewitt DP, Bergman TL, Lavine AS. 2007. Fundamentals of heat and mass transfer. 6th ed. Hoboken (NJ): John Wiley & Sons; c2007.
6. San Ace 40, Sanyo Denki. Mouser Electronics (Mansfield, TX). [June 2017]. https://www.mouser.com/datasheet/2/471/San_Ace_40P20_E-1286772.pdf.

List of Symbols, Abbreviations, and Acronyms

3-D	three-dimensional
CFM	cubic feet per minute
DC	direct current
V	volts
VAC	volts alternating current
VDC	volts direct current
W	watts

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