Introduction

This Application Note describes the thermal model of Roboteq's AX2550/2850 controllers and show the relation between the transistor's temperature based on various combination of heat dissipation techniques and air ambient temperature.

Air Convection

The AX2550 is composed of a pc board contained inside a metal blue aluminum box to which the power MOS are mechanically connected (through a low thermal resistance insulator).

Here is a sketch of the structure:

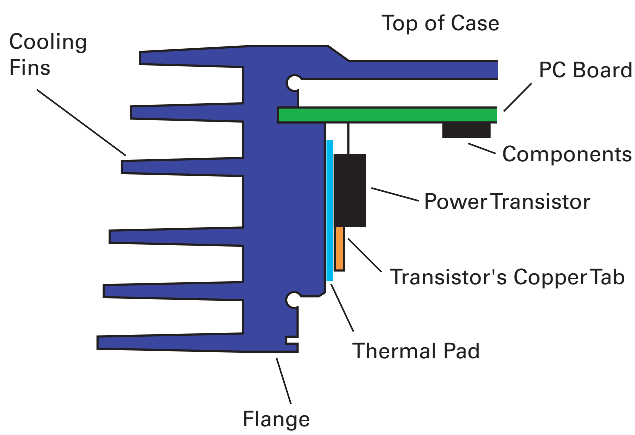

FIGURE 1. AX2550 transistor and heat sinking case assembly

The main source of heat is the power MOS which in turn heats the pc board to which it is attached and the box which provides for the main path for the heat to escape.

Maximum temperature allowed

The maximum allowable temperature varies among the different components; from 125 to 175o C. Consequently the maximum temperature allowed at the pc board must be kept below 125o C.

Some amount of heat is generated in the PC board, in the power tracks carrying the motor current. The pc board will be therefore some 10o C above the temperature of the tab of the power MOS.

This means the max temperature that is allowed at the copper tab of the power MOS is 100o C. The junction temperature of the power MOS will be higher as well as the temperature of the pc board.

Since the AX2550 is mostly cooled by air convection, we assume as max air temperature 35o C; consequently, the maximum temperature delta between power MOS tab and air is 65o C.

Measuring conditions

We measured thermal resistance tab-air and flange-air assuming both channels on and tab temperature approximately 100o C, by utilizing four 1-Ohm resistors dissipating an overall power of 77.4 Watt.

Three measurements have been done:

- Cooling by natural air convection.
- Forced air convection through a 12 Volt 12 cm computer type fan mounted on the top at 3 cm from the metal surface.
- Conduction through the top by having the top touch water.

Thermal resistance

Below is shown a simplified thermal equivalent circuit of the AX2550 structure:

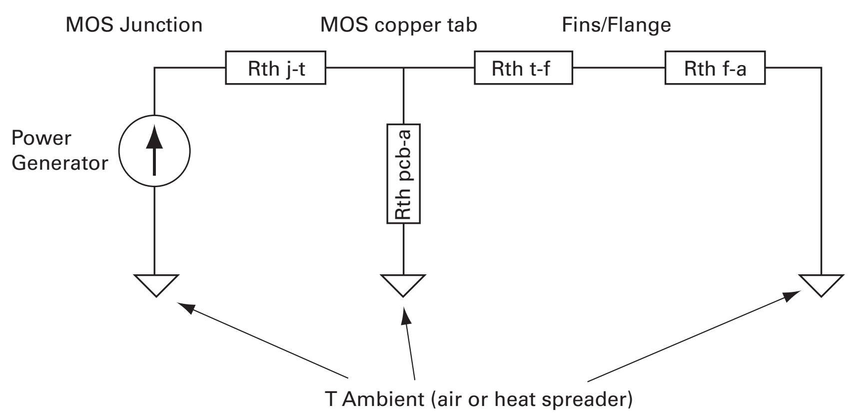

FIGURE 2. Thermal Equivalent Model

Where:

- Rth j-t is the thermal resistance from power MOS junction to its copper tab.
- Rth t-f is the thermal resistance from power MOS tab to the flange of the aluminum box.
- Rth f-a is the thermal resistance flange to air (or to heat spreader) of the aluminum box.

Equivalence between Ohm' s law and Thermal law:

$$I = V / R \rightleftarrows P = \text{Delta } T / Rth$$

Values of thermal resistance

Here are the values we have found:

TABLE 1.

Thermal resistanceo C / Watt	**Natural air convection**	**Forced air convection**	**Conduction through water**
Rth tab to airor water	0.9	0.6	0.4
Rth flange to air or water	0.7	0.4	0.2
Rth tab to flange	0.2	0.2	0.2

Maximum current allowable.

The maximum power, which can be dissipated when both channels are On, depends on the thermal resistance, and the maximum temperature delta allowable.

Pmax = DeltaTemp / Rth

Likewise, the maximum current per channel Imax can be calculated as:

Imax = ½ x (square(Pmax / Rds))

Where Rds is the equivalent resistive value drain-source and if both channels are on at 100o C is 4 milli-Ohm. (each transistor is 8 milli-ohm, each bridge is 8 milli-ohm, two bridges in parallel are 4 milli-Ohm).

The pc board is assumed to be 10o C above the flange and the junction temperature of the power MOS is given by the thermal resistance j-case of the power MOS (0.45 C / Watt) multiplied by Pmax / 8.

In fact, if both channels are On, then there are eight power MOS sharing the load.

TABLE 2.

	Natural air convection	**Forced air convection**	**Conduction through water**
Rth tab-air	0.9	0.6	0.4
Temperature air or water	35	35	35
Temperature tab	100	100	100`
Temperature delta	65	65	65
Pmax Watt both channels	72	108	162
Imax Ampere per channel	68	83	100
Temperature PC board	110 - 115	110-115	110-115

TABLE 2.

	Natural air convection	Forced air convection	Conduction through water
Power in a single mos	9	10.4	20.3
Power MOS junction temperature	104	105	110

Conduction through the bottom

A more efficient way to remove air from the aluminum case is to attach the flange to a metal plate, which has the dual function of mechanical support and heat spreader.

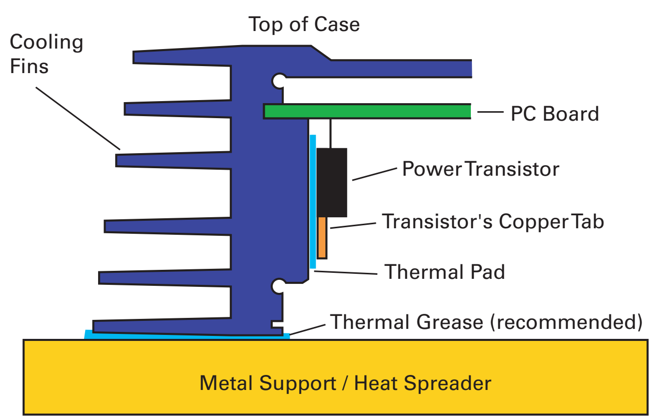

FIGURE 3. Switching circuit schematic

The thermal resistance tab-support will depend on the flatness, the pressure and the presence of thermal grease between flange and support.

It is reasonable to assume that conduction is at least as good as forced air convection and therefore the limit should be between 83 and 100 Ampere / channel.

Rule of thumb

Here are some simple rules.

Natural air convection

The maximum continuous current per channel is 65 Ampere per channel as long as the air temperature is below 30 o C. It should be reduced if the temperature of the flange exceeds 85 o C.

Forced air convection

The maximum continuous current per channel is 83 Ampere per channel as long as the air temperature is below 30 o C. It should be reduced if the temperature of the flange exceeds 75 o C.

Conduction through a heat-spreader

The maximum continuous current per channel is 100 Ampere per channel as long as the heat-spreader temperature is below 30 o C. It should be reduced if the temperature of the flange exceeds 65 o C.

Rule of thumb calculation of Power Transistor tab temperature

It is useful to show an approximate but quick method to calculate the relation between the air or heat-spreader temperature and the temperature of the tab, which should not exceed 100o C.

TABLE 3.

	Natural convection	**Forced convection**	**Conduction**
Air or heat-spreader temperature	a	a	a
Flange temperature	b	b	b
Power = (b-a) / Rth flange-air	(b-a) / 0.7	(b-a) / 0.4	(b-a) / 0.2
Tab temperature = Tflange + Rth tab-flange x Power	Tflange+ 0.3 x (b-a)	Tflange + 0.5 x (b-a)	Tflange + (b-a)

Example:

TABLE 4.

	Natural convection	**Forced convection**	**Conduction**
Temperature air or heat-spreader	35	35	35
Temperature flange	85	75	65
Power Watt	71	100	150
Temperature tab	100	95	95