Smaller heatsinks for intermittent operation

In many instances, the thermal capacity of a heatsink can be utilised to design a smaller heatsink for intermittent operation than would be necessary for the same level of continuous power dissipation. The average power dissipation in Eq. 6 is replaced by the peak power dissipation to obtain the value of the thermal impedance between the heatsink and the surroundings

$$Z_{th\,h-amb} = \frac{T_{mb} - T_{amb}}{P_{totM}} - R_{th\,mb-h} \qquad 9$$

The value of $Z_{th\ h\text{-}amb}$ will be less than the comparable thermal resistance and thus a smaller heatsink can be designed than that obtained using the too large value calculated from Eq.6.

Heatsinks

Three varieties of heatsink are in common use: flat plates (including chassis), diecast finned heatsinks, and extruded finned heatsinks. The material normally used for heatsink construction is aluminium although copper may be used with advantage for flat-sheet heatsinks. Small finned clips are sometimes used to improve the dissipation of low-power transistors.

Heatsink finish

Heatsink thermal resistance is a function of surface finish. A painted surface will have a greater emissivity than a bright unpainted one. The effect is most marked with flat plate heatsinks, where about one third of the heat is dissipated by radiation. The colour of the paint used is relatively unimportant, and the thermal resistance of a flat plate heatsink painted gloss white will be only about 3% higher than that of the same heatsink painted matt black. With finned heatsinks, painting is less effective since heat radiated from most fins will fall on adjacent fins but it is still worthwhile. Both anodising and etching will decrease the thermal resistivity. Metallic type paints, such as aluminium paint, have the lowest emissivities, although they are approximately ten times better than a bright aluminium metal finish.

Flat-plate heatsinks

The simplest type of heatsink is a flat metal plate to which the transistor is attached. Such heatsinks are used both in the form of separate plates and as the equipment chassis itself. The thermal resistance obtained depends on the thickness, area and orientation of the plate, as well as on the finish and power dissipated. A plate mounted horizontally will have about twice the thermal resistance of a vertically mounted plate. This is particularly important where the equipment chassis itself is used as the heatsink.

In Fig. 4, the thermal resistance of a blackened heatsink is plotted against surface area (one side) with power dissipation as a parameter. The graph is accurate to within 25% for nearly square plates, where the ratio of the lengths of the sides is less than 1.25:1.

Finned heatsinks

Finned heatsinks may be made by stacking flat plates, although it is usually more economical to use ready made diecast or extruded heatsinks. Since most commercially available finned heatsinks are of reasonably optimum design, it is possible to compare them on the basis of the overall volume which they occupy. This comparison is made in Fig. 5 for heatsinks with their fins mounted vertically; again, the graph is accurate to 25%.

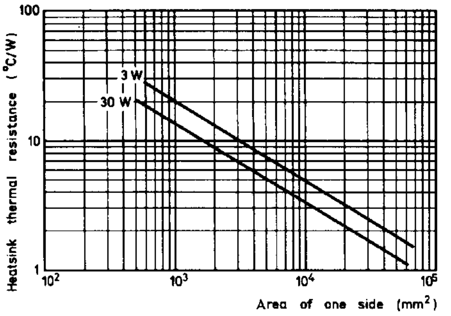

Fig. 4 Generalised heatsink characteristics: flat vertical black aluminium plates, 3mm thick, approximately square

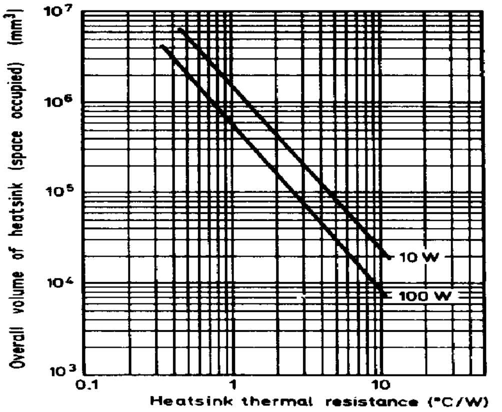

Fig. 5 Generalised heatsink characteristic: blackened aluminium finned heatsinks

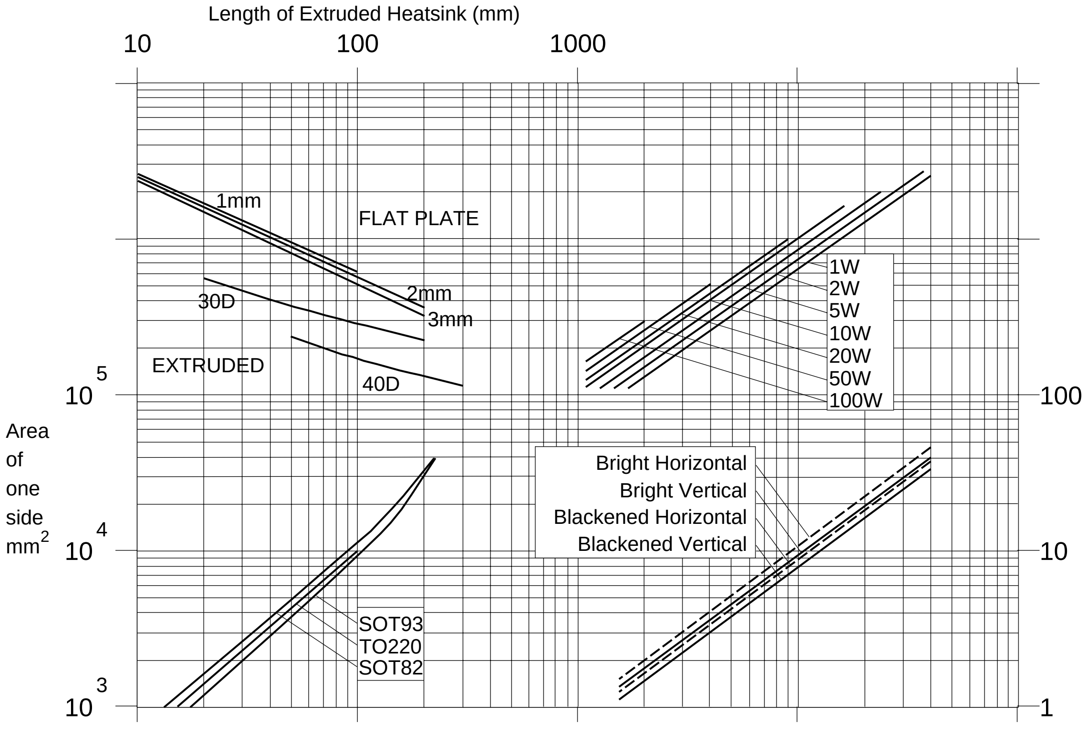

Fig. 6 Heatsink nomogram

Heatsink dimensions

The maximum thermal resistance through which sufficient power can be dissipated without damaging the transistor can be calculated as discussed previously. This section explains how to arrive at a type and size of heatsink that gives a sufficiently low thermal resistance.

Natural air cooling

The required size of aluminium heatsinks - whether flat or extruded (finned) can be derived from the nomogram in Fig. 6. Like all heatsink diagrams, the nomogram does not give exact values for $R_{th\ h\text{-}amb}$ as a function of the dimensions since the practical conditions always deviate to some extent from those under which the nomogram was drawn up. The actual values for the heatsink thermal resistance may differ by up to 10% from the nomogram values. Consequently, it is advisable to take temperature measurements in the finished equipment, particularly where the thermal conditions are critical.

The conditions to which the nomogram applies are as follows:

- natural air cooling (unimpeded natural convection with no build up of heat);
- ambient temperature about 25˚C, measured about 50mm below the lower edge of the heatsink (see Fig. 7);
- atmospheric pressure about 10 N/m^2;
- single mounting (that is, not affected by nearby heatsinks);
- distance between the bottom of the heatsink and the base of a draught-free space about 100mm (see Fig. 7);
- transistor mounted roughly in the centre of the heatsink (this is not so important for finned heatsinks because of the good thermal conduction).

The appropriately-sized heatsink is found as follows.

1. Enter the nomogram from the right hand side of section 1 at the appropriate $R_{th\ h\text{-}amb}$ value (see Fig. 8). Move horizontally to the left, until the appropriate curve for orientation and surface finish is reached.
2. Move vertically upwards to intersect the appropriate power dissipation curve in section 2.

3. Move horizontally to the left into section 3 for the desired thickness of a flat-plate heatsink, or the type of extrusion.
4. If an extruded heatsink is required, move vertically upwards to obtain its length (Figs. 9a and 9b give the outlines of the extrusions).
5. If a flat-plate heatsink is to be used, move vertically downwards to intersect the appropriate curve for envelope type in section 4.
6. Move horizontally to the left to obtain heatsink area.
7. The heatsink dimensions should not exceed the ratio of 1.25:1.

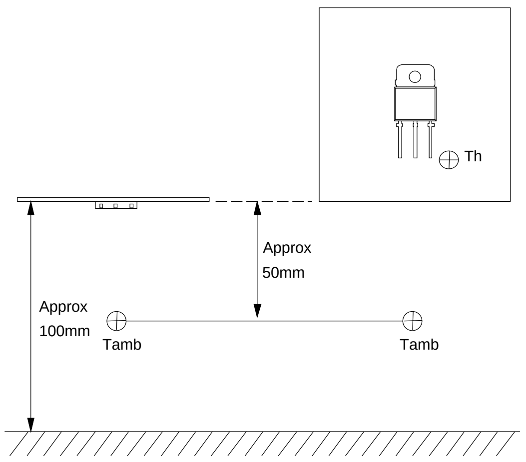

Fig. 7 Conditions applicable to nomogram in Fig. 6

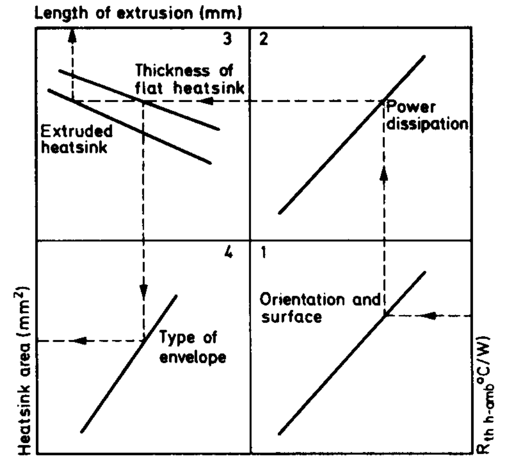

Fig. 8 Use of the heatsink nomogram

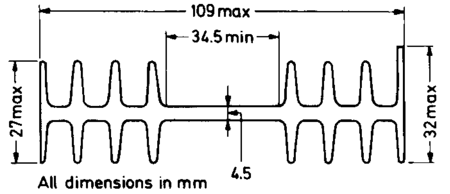

Fig. 9a Outline of Extrusion 30D

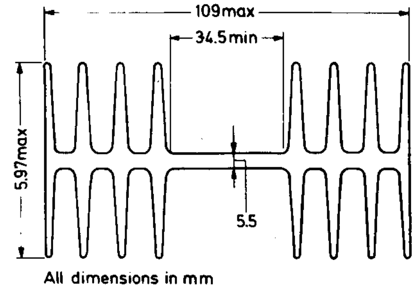

Fig. 9b Outline of Extrusion 40D

The curves in section 2 take account of the non linear nature of the relationship between the temperature drop across the heatsink and the power dissipation loss. Thus, at a constant value of the heatsink thermal resistance, the greater the power dissipation, the smaller is the required size of heatsink. This is illustrated by the following example.

Example

An extruded heatsink mounted vertically and with a painted surface is required to have a maximum thermal resistance of $R_{th\ h\text{-}amb}$ = 2.6 ˚C/W at the following powers:

$$(a) P_{tot(av)} = 5W \quad (b) P_{tot(av)} = 50W$$

Enter the nomogram at the appropriate value of the thermal resistance in section 1, and via either the 50W or 5W line in section 2, the appropriate lengths of the extruded heatsink 30D are found to be:

(a) length = 110mm and (b) length = 44mm.

Case (b) requires a shorter length since the temperature difference is ten times greater than in case (a).

As the ambient temperature increases beyond 25˚C, so does the temperature of the heatsink and thus the thermal resistance (at constant power) decreases owing to the increasing role of radiation in the heat removal process. Consequently, a heatsink with dimensions derived from Fig. 6 at T_{amb} > 25˚C will be more than adequate. If the maximum ambient temperature is less than 25˚C, then the thermal resistance will increase slightly. However, any increase will lie within the limits of accuracy of the nomogram and within the limits set by other uncertainties associated with heatsink calculations.

For heatsinks with relatively small areas, a considerable part of the heat is dissipated from the transistor case. This is why the curves in section 4 tend to flatten out with decreasing heatsink area. The area of extruded heatsinks is always large with respect to the surface of the transistor case, even when the length is small.

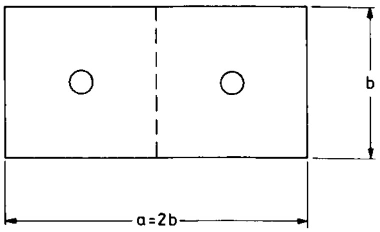

Fig. 10 Arrangement of two equally loaded transistors mounted on a common heatsink

If several transistors are mounted on a common heatsink, each transistor should be associated with a particular section of the heatsink (either an area or length according to type) whose maximum thermal resistance is calculated from equations 5 or 6; that is, without taking the heat produced by nearby transistors into account. From the sum of these areas or lengths, the size of the common heatsink can then be obtained. If a flat heatsink is used, the transistors are best arranged as shown in Fig. 10. The maximum mounting base temperatures of transistors in such a grouping should always be checked once the equipment has been constructed.

Forced air cooling

If the thermal resistance needs to be much less than 1˚C/W, or the heatsink not too large, forced air cooling by means of fans can be provided. Apart from the size of the heatsink, the thermal resistance now only depends on the speed of the cooling air. Provided that the cooling air flows parallel to the fins and with sufficient speed (>0.5m/s), the thermal resistance hardly depends on the power dissipation and the orientation of the heatsink. Note that turbulence in the air current can result in practical values deviating from theoretical values.

Fig. 11 shows the form in which the thermal resistances for forced air cooling are given in the case of extruded heatsinks. It also shows the reduction in thermal resistance or length of heatsink which may be obtained with forced air cooling.

The effect of forced air cooling in the case of flat heatsinks is seen from Fig. 12. Here, too, the dissipated power and the orientation of the heatsink have only a slight effect on the thermal resistance, provided that the air flow is sufficiently fast.

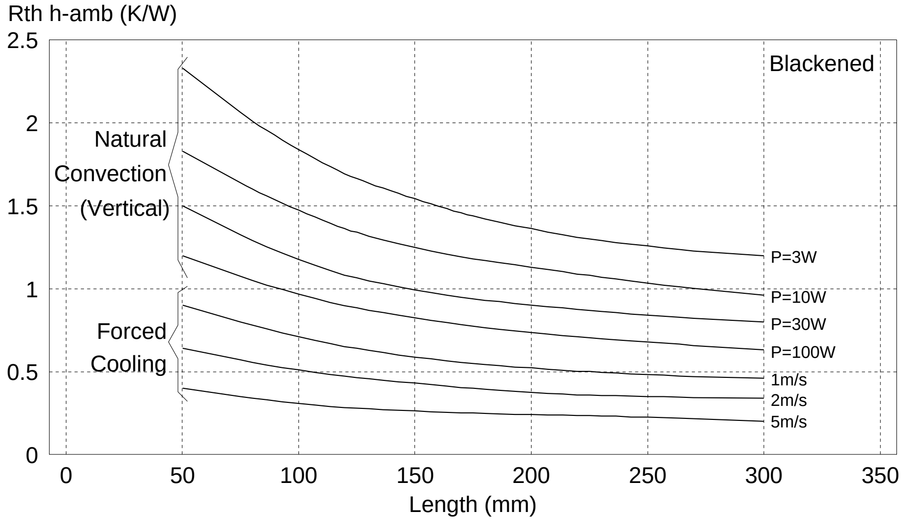

Fig. 11 Thermal Resistance of a finned heatsink (type 40D) as a function of the length with natural and forced air cooling