NORTHERN ALBERTA INSTITUTE OF TECHNOLOGY
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ELECTRONICS DEPARTMENT

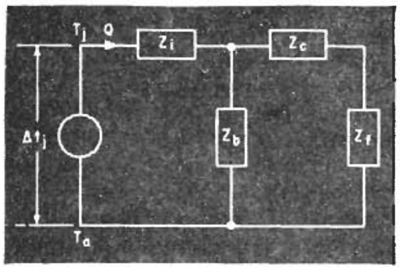

FIG. 1—Equivalent circuit of heat dissipation

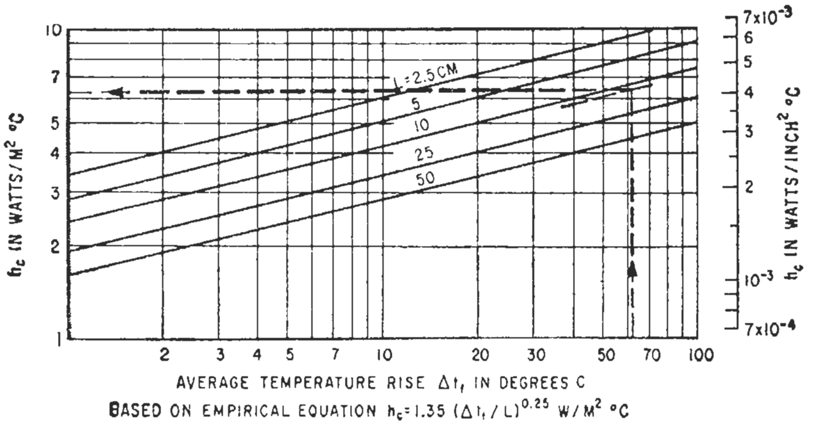

FIG. 2—Heat transfer coefficient (h_c) for free convection cooling of vertical plates in air at sea level

Taking the Heat Off Semiconductor Devices

Cooling fins will improve the performance and increase longevity of semiconductor devices. Here are the factors, equations, charts and nomograms needed to tailor a fin to a power transistor or diode without involved math

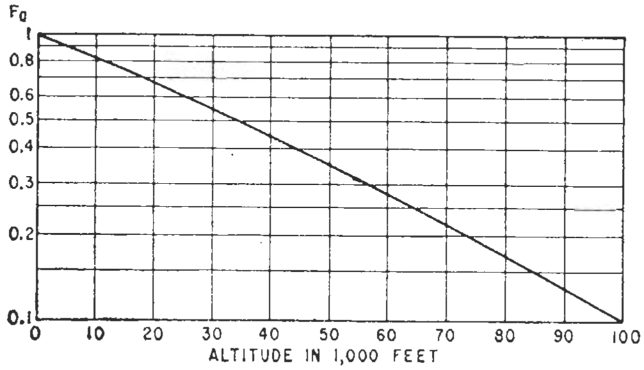

FIG. 3—Altitude correction factor (F_a) for convective heat transfer coefficient

POWER TRANSISTORS, semiconductor diodes and similar devices generate large quantities of heat within a small body. Since their surface areas are too small to dissipate heat without excessive temperature rise, they are mounted on fins, which increase heat dissipation surface.

This article shows how to calculate dimensions of fins cooled by free or fórced convection of air at altitudes from sea level to 100,000 feet. Fins must be large enough to dissipate heat without exceeding the device's safe junction temperature, as specified by the manufacturer. Current-carrying capacity of power transistors and diodes is limited by T_j.

HEAT CIRCUIT—Heat flow through a fin-mounted semiconductor device is represented by an equivalent

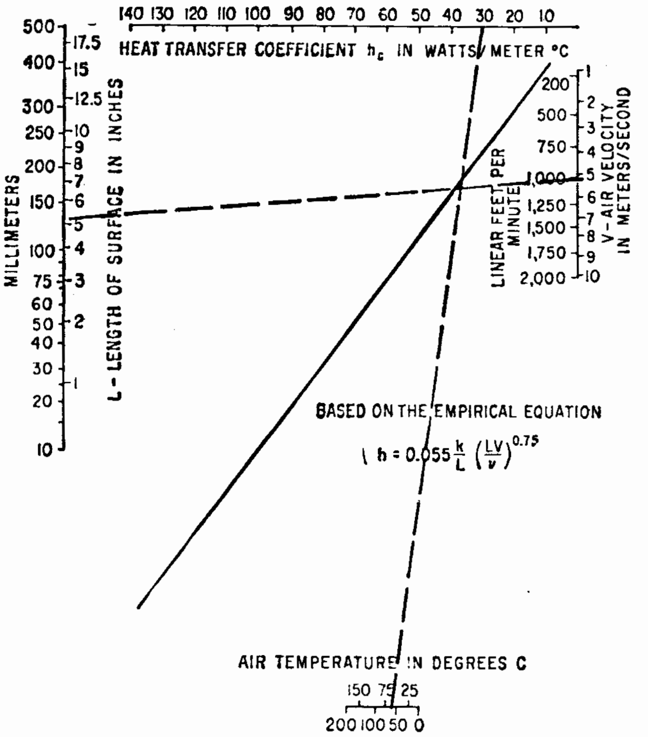

FIG. 4—Nomogram for obtaining heat transfer coefficient for forced convection cooling of plane surfaces in air at sea level with turbulent flow. Dashed lines show sample solution

circuit of heat dissipation (Fig. 1). The heat flows through a series of impedances, Z_i, Z_c, Z_b and Z_f, on its way from the heat source (the junction) to the final heat sink, the environment.

The temperature potential to maintain the heat flow through these impedances is $\Delta t_j = T_j - T_a$. If

Table I—Typical Values of Metal-to-Metal Contact Impedance for Power Diodes

Base Hex Size (in.)	Stud Size	Torque (inch-pounds)	Z_c (°C/w)
7/16	10-32	15	2.6
11/16	1/4-28	25	0.9
1	3/8-24	90	0.4
1 1/8	1/2-20	200	0.2
1 1/4	1/2-20	200	0.18
1 1/4	3/4-16	500	0.18

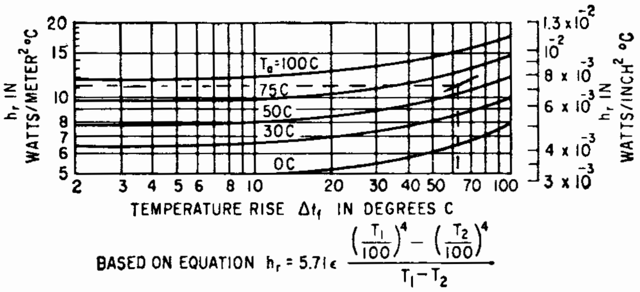

FIG. 5—Radiation heat transfer coefficient (h_r) for unobstructed radiation and an emissivity of 1

Glossary of Symbols

- Δt_j = temperature rise of junction, in °C
- T_j = junction temperature, in °C
- T_a = ambient temperature, in °C
- Δt_f = average temperature rise of fin, in °C
- Q = heat dissipated, in watts
- Z_t = total thermal impedance, in °C/w
- Z_f = fin impedance (fin to environment), in °C/w
- Z_c = contact impedance (device to fin), in °C/w
- Z_i = internal impedance (of device), in °C/w
- Z_b = external impedance of device without fin (to environment), in °C/w
- h = total heat transfer coefficient, in w/m²°C
- h_c = convective heat transfer coeff, in w/m²°C
- h_r = radiation heat transfer coeff, in w/m²°C
- k = thermal conductivity, in w/m°C
- ϵ = emissivity
- F_1 = correction factor for surface configuration
- F_a = correction factor for altitude
- F_r = form factor
- η = fin efficiency
- A = total fin area, in m²
- L = length, in m
- r_o = heat input radius, in m
- r_1 = outer fin radius, in m
- D_h = diameter of hole for stud, in m
- D_b = base diameter of device, in m
- R = natural fin radius, in m
- s = fin thickness, in m

T_j is the maximum permissible junction temperature and T_a the maximum ambient temperature, Δt_j becomes the maximum temperature rise allowed. This rise and the amount of heat to be dissipated determine the maximum total thermal impedance from the junction to the ambient air: $Z_t = \Delta t_j / Q$.

HEAT IMPEDANCES — The total impedance is $Z_t = Z_i + Z_b (Z_c + Z_f)/(Z_b + Z_c + Z_f)$ as seen by Fig. 1. Z_b is unusually large compared with $Z_c + Z_f$, and can be assumed infinite for a first approximation. Then, $Z_t = Z_i + Z_c + Z_f$.

Z_i depends on the size and internal design of the device and is usually given by the manufacturer. Z_c varies with the area of the device in contact with the fin and with the fin mounting method. Z_c of some semiconductor diodes in standard sizes mounted directly on fins are given in Table I.

If an electrical insulator is placed between the device and its fin, Z_c increases considerably. A 1-mil-thick Mylar washer will triple contact resistance and a 3-mil mica washer will quadruple it. To determine Z_c directly, the temperature difference between the device base and the fin directly below the base is measured with thermocouples.

Having determined Z_t, Z_i and Z_c, the maximum Z_f is obtained from the equation given above.

FIN AREA—Fin dimensions giving a desired Z_f for the cooling method selected can now be established. The total fin area required is $A = 1/Z_f h \eta$. Determination of h and η is described below. The equation for h is $h = F_1 F_a h_c + F_r \epsilon h_r$.

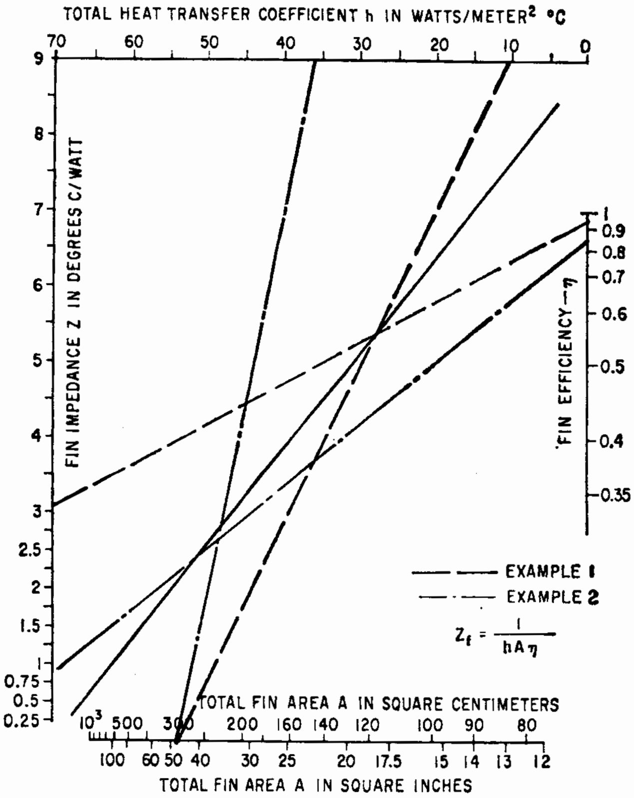

FIG. 6—Nomogram for obtaining total fin area

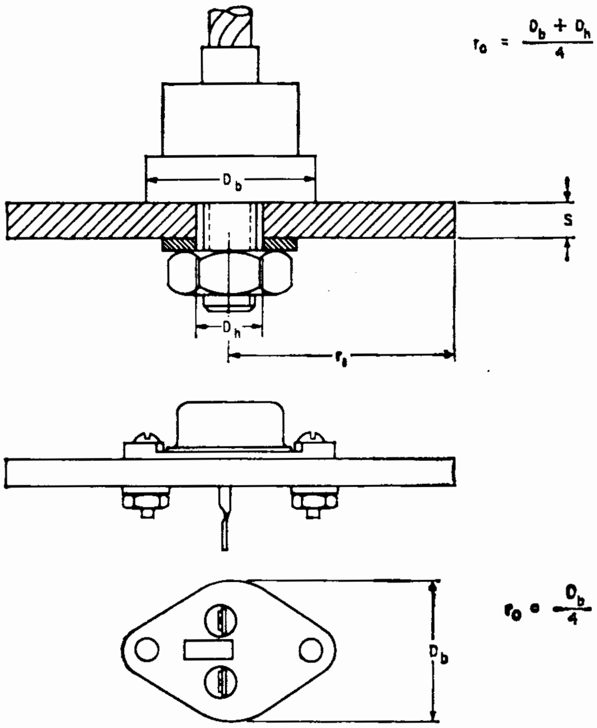

FIG. 7—Relation of device dimensions to heat input radius

HEAT CONVECTION—Heat is transferred from the fin to the environment by convection and radiation. Transfer coefficient h_c for free convection at sea level for vertical fins is obtained from Fig. 2. For other fin geometries or positions, the value obtained from Fig. 2 must be multiplied by F_1 (Table II). The significant fin dimension L (Table II) and Δt_f must be estimated. If the estimation of L proves wrong when the fin area is finally established, the calculation must be made over. Δt_f may be taken as $\Delta t_j/2$.

Forced convection h_c for air cooling at sea level is obtained from Fig. 4. Here also, L must be estimated. Heat transfer by convection decreases as altitude increases. To find h_c at other altitudes, multiply the sea level value obtained from Fig. 2 or Fig. 4 by F_a (Fig. 3).

HEAT RADIATION—Fin emissivity varies with surface finish and fin material. It is always less than 1. Painted fin ϵ is approximately 0.90. Figure 5 gives h_r for $\epsilon = 1$ and unobstructed radiation. The values of Fig. 5 must be multiplied with the actual ϵ.

If radiation from the fin is obstructed by other bodies of the same temperature, h_r must also be multiplied by a form factor smaller than 1. Consider an unobstructed fin's radiation as originating at the center of the fin and being spherical (hemispherical on each side of the fin). An obstruction will interrupt radiation, or subtract a sector from the sphere. F_r is approximately the ratio of the solid angle remaining in the obstructed sphere to the solid angle (4π steradians) of the complete sphere.

The fin should be shielded from bodies of higher temperature. Otherwise, the fin will be heated by

Table II—Significant Dimension L and Correction Factor F_1 for Convective Heat Transfer Coefficient h_c

Significant Dimension L		
Surface	Position	L
Rectangular Plane	vertical	height—max 2 ft
	horizontal	$\frac{\text{length} \times \text{width}}{\text{length} + \text{width}}$
Circular Plane	vertical	$\pi/4 \times$ diameter
Cylinder	horizontal	diameter
	vertical	height—max 2 ft

Correction Factor F_1		
Surface	Position	F_1
Horizontal Plate	facing upward	1.29
	facing downward	0.63
Cylinder	horizontal	0.82
	vertical	0.82 to 1

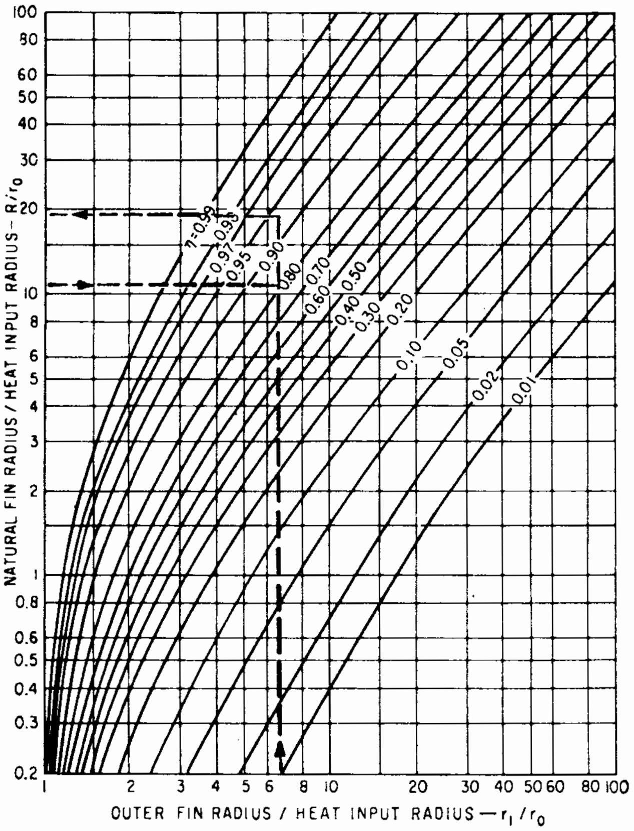

Fig. 8—Fin efficiency η as a function of R/r_o and r_1/r_o

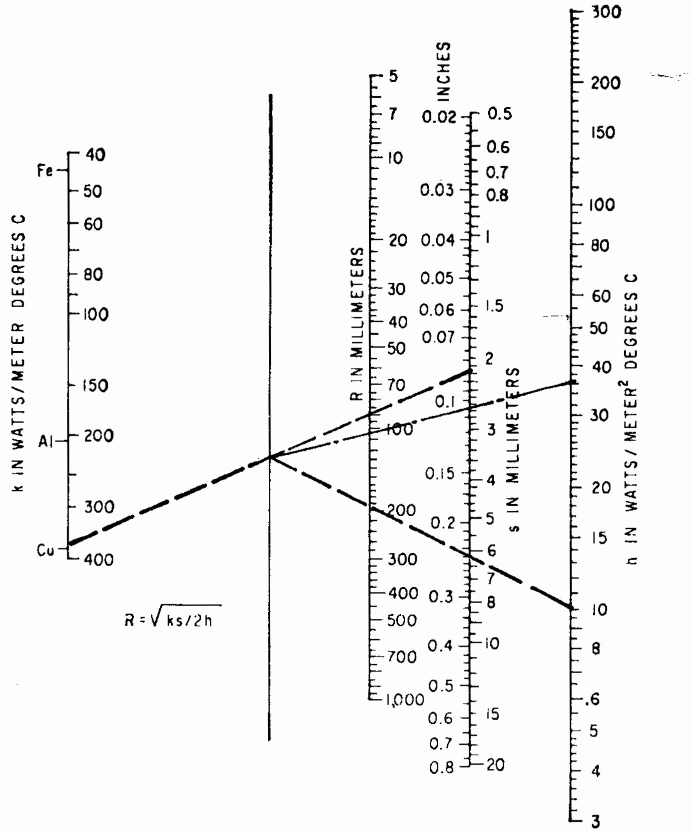

FIG. 9—Nomogram for obtaining fin thickness

EXAMPLE 1: Find fin size required to dissipate 35 w from a power diode, 1⅛-inch hexagonal base, ½-20 stud, cooled by free convection in air at sea level. T_j = 190 C; T_a = 65 C; Z_c = 0.2; Z_i = 0.25.

SOLUTION: $\Delta t_j = T_j - T_a$ = 190-65 = 125C
$Z_t = \Delta t_j/Q$ = 125/35 = 3.57°C/w
$Z_f = Z_t - Z_c - Z_i$ = 3.57 − 0.2 − 0.25 = 3.12°C/w
assume Δt_f = 125/2 = 62C
and L = 5 inches = 12.5 cm
For vertical fin h_c = 6.1 w/m²°C (Fig. 2)
h_r = 11.3 w/m²°C for ϵ = 1 (Fig. 5)
assume ϵ = 0.9 and F_r = 0.39
h_r is then (0.9) (0.39) (11.3) = 4 w/m²°C
$h = h_c + h_r$ = 6.1 + 4.0 = 10.1 w/m²°C
Desired fin efficiency η = 0.95
A = 334 cm² = 51.7 in.² (Fig. 6) corresponds to a 5.09 × 5.09-in. fin, close enough to the assumed L
r_o = (1.125 + 0.515)/4 = 0.41 in. = 10.5 mm
r_1 = 5.09/2 = 2.55 in.
r_1/r_o = 2.55/0.41 = 6.22 in.
R/r_o = 19 (Fig. 8)
R = (19) (10.5) = 200 mm
assume the fin to be of copper.
s = 0.086 in. (Fig. 9)
thus, a 5.1 × 5.1 × .086-inch vertical copper fin is required.

EXAMPLE 2: Find how much heat the diode and fin of Example 1 will dissipate if cooled by forced air at 1,000 linear feet per minute, other conditions equal.

SOLUTION: h_c = 32 w/m²°C (Fig. 4)
$h = h_c + h_r$ = 32 + 4 = 36 w/m²°C
R = 108 mm (Fig. 9)
R/r_o = 108/10.5 = 10.3
η = 0.83 (Fig. 8)
Z_f = 1.0° C/w (Fig. 6)
$Z_t = Z_f + Z_c + Z_i$ = 1 + 0.2 + 0.25 = 1.15°C/w
$Q = \Delta t_j/Z_t$ = 125/1.15 = 86 watts can be dissipated from the diode.

radiation instead of being cooled.

FIN DIMENSIONS—When the desired fin efficiency is chosen, required fin area can be found with Fig. 6. Reasonable values of η, when fins are copper or aluminum, are 0.95 for free convection and 0.75 to 0.85 forced convection. Higher values of η make the fins too thick and uneconomical.

Fin dimensions are calculated from the area of the fin's two sides. Length of one side of a square fin, for example, is $L = \sqrt{A/2}$. The calculated dimension should compare satisfactorily with the value of L assumed while using Fig. 2.

FIN THICKNESS—Fin thickness is determined by the assumed efficiency η. The mathematical relationship between these quantities is complicated; however, fin thickness can be easily determined from Figs. 7, 8 and 9.

Fig. 7 defines r_o according to device mounting. It equals $D_h/4$ for a transistor without a stud and $(D_h + D_s)/4$ for a stud-mounted transistor or diode. Radius of the fin for circular fins is r_1. Rectangular fins with sides a and b have $r_1 = \sqrt{ab/\pi}$.

R is determined from Fig. 8. Fin thickness s is found in the equation $R = \sqrt{ks/2h}$ and Fig. 9.

EXAMPLES—The nomographs, curves and equations can be used equally well to determine the amount of heat a fin-mounted device can dissipate for a given temperature rise. Sample problem calculations are traced above, and by dashed lines on the figures.