APPLICATION NOTES

Thermal Resistivity Table Simplifies Temperature Calculations

How much power can a microwave device handle before it overheats?
Here is a good approximation of the technique for determining "hot spots" of different structures.

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Electrical engineers are usually introduced to heat flow either as studies in physics or problems to be solved by a mechanical engineer. Heat is shown to flow via the mechanisms of radiation, convection and conduction—each with their own equations and coefficients.

The subject is made more confusing by the use of c.g.s. units in physics and British Thermal Units in engineering. Most of the important temperature calculations faced by a microwave engineer result from the need to determine how hot a particular point in a structure will get when power is being dissipated. While the ultimate heat sink usually expels its energy to the outside world by free or forced convection to air or liquid, the internal circuit elements, whose temperature rises usually set a limit on power handling capability, most often are conduction cooled. Radiation plays a relatively insignificant role below 300°C.

Quick estimates of temperature rises in conduction heat flow situations can be made easily when it is realized that the steady state Fourier heat flow equation is the mathematical equivalent of Ohms Law for electrical circuits with temperature differences replacing voltage differences and heat flow (expressed in calories, per second, B.T.U. per hour or watts) replacing current flow. In usual form the one dimensional steady state flow equation is:

$$Q = K\,(A/L)\,\Delta T \qquad (1)$$

where
- Q = heat flow
- K = thermal conductivity
- A = cross section of heat flow path
- L = path length
- ΔT = temperature drop along path of length, L.

Inverting the relationship to:

$$\Delta T = (1/K)\,(L/A)\,Q$$

then (1/K) equals thermal resistivity and (1/K) (L/A) equals thermal resistance. (By anology to V = (ρ) (L/A) I and V = R · I). By preparing a table of thermal resistivity (1/K) in units of °C – inches/W for the materials encountered in microwave work, temperature drops can be readily estimated in series heat conduction situations. The application of these concepts can best be illustrated by the following two examples.

EXAMPLE PROBLEM 1.

Figure 1 shows a thin film resistor in a microwave integrated circuit. How hot will it get with 2 W dissipated over its 0.1 x 0.2 in. surface (100 W/in.^{2})?

$$\Delta T_{1-4} = \Delta T_{1-2} + \Delta T_{2-3} + \Delta T_{3-4}$$

$$\Delta T_{1-2}\text{ (in ceramic)} = \frac{(2.13)(0.025)(2)}{(0.1)\,(0.2)} = 5.3°C$$

$$\Delta T_{2-3}\text{ (in grease)} = \frac{46\,(0.002)(2)}{(0.1)\,(0.2)} = 9.2°C$$

$$\Delta T_{3-4}\text{ (in aluminum)} = \frac{(0.23)(0.125)(2)}{(0.1)\,(0.2)} = 2.9°C$$

Therefore,

$$\Delta T_{1-4} = 5.3 + 9.2 + 2.9 = 17.4°C$$

Adding to this an estimate of maximum absolute temperature of 80°C for the aluminum ground plane leads to an estimated 100°C for the maximum resistor temperature. This is a conservative estimate since it neglects transverse heat spreading, but it serves to illustrate the ease and value of quick estimates. The major temperature drop occurs at the grease interface between the ceramic and the metal. Changing from Aluminum Oxide to Beryllium Oxide with 1/10 the thermal resistivity wouldn't help in this situation as much as working to minimize the interface resistance.

Thin Film resistor as heat source in microwave integrated circuit

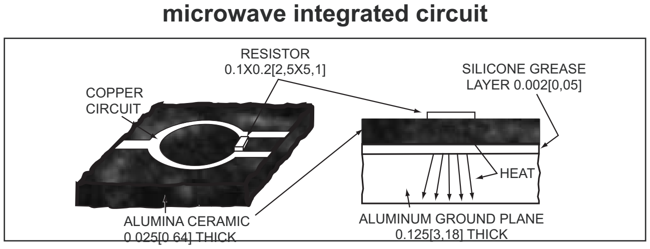

Figure 1

EXAMPLE PROBLEM 2.

A miniature rod resistor terminates a coaxial line as shown in Fig. 2. Estimate the temperature rise at the front end of the resistor relative to a point on the outer shell when 5 W is being dissipated:

$$\Delta T_{1-5} = \Delta T_{1-2} + \Delta T_{2-3} + \Delta T_{3-4} + \Delta T_{4-5}$$

Since the power is uniformly dissipated along the resistor, ΔT_{1-2} can be estimated by assuming that the full 5 W travels 1/2 the length of the resistor to the mid plane of the end wall:

$$\Delta T_{1-2} = \frac{(0.24)\,(0.020 + 0.031)\,(5)}{\pi(0.020)^2} = 48.7°C$$

$$\Delta T_{2-3}\text{ (solder joint)} = \frac{(0.78)\,(0.005)\,(5)}{\pi\,(0.040)\,(0.062)} = 3.2°C$$

For the radial path 3-4, use an average diameter of 0.120 for the area calculation and a path length of 0.080.

$$\Delta T_{3-4} = \frac{(0.11)\,(0.080)\,(5)}{\pi\,(0.120)\,(0.062)} = 1.9°C$$

$$\Delta T_{4-5} = \frac{(0.11)\,(0.040 + 0.031)\,(5)}{\pi\,(0.062)\,(0.2)} = 1°C$$

Then

$$\Delta T_{1-5} = 48.7 + 3.2 + 1.9 + 1 = 54.8°C$$

A review of the results reveals that the manner of estimating the area and length of the metal paths and the solder joint are relatively unimportant since they contribute only 11 percent to the total ΔT. For this configuration the greatest potential reductions in temperature drop can be made by increasing the resistor diameter or reducing its length.

Resistor as heat source in coaxial line

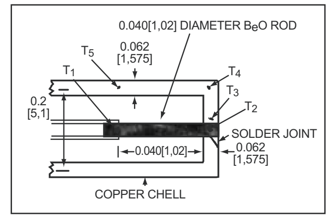

Figure. 2

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KEY: Inches [Millimeters] .XX ±.03 .XXX ±.010 [.X ±0.8 .XX ±0.25]

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Table 1. Thermal Resistivity (R) – Typical Values

R in °C - inches
Watt
conversion from thermal conductivity K to R

$$R = \frac{22.8}{K} \text{ for K in } \frac{\text{BTU - ft}}{\text{hr - ft}^2\text{ - °F}}$$

$$R = \frac{0.094}{K} \text{ for K in } \frac{\text{cal - cm}}{\text{sec - cm2 - °C}}$$

Material	R	Material	R	Material	R
Diamond	0.06	Lead	1.14	Quartz	27.6
Silver	0.10	Indium	2.1	Glass (7740)	34.8
Copper	0.11	Boron nitride (isotropic)	1.24	Silicon thermal grease	46
Gold	0.13	Alumina ceramic	2.13	Water	63
Aluminum	0.23	Kovar	2.34	Mica (avg)	80
Beryllia ceramic	0.24	Silicon carbide	2.3	Polyethylene	120
Molybdenum	0.27	Steel (300 series)	2.4	Teflon	190
Brass	0.34	Nichrome	3.00	Nylon	190
Silicon	0.47	Carbon	5.7	Silicone Rubber	190
Platinum	0.54	Ferrite	6.3	P.P.O.	205
Tin	0.60	Pyroceram (9606)	11.7	Polystyrene	380
Nickel	0.61	Epoxy—high conductivity	24	Mylar	1040
Eutectic lead tin solder	0.78			Air	2280

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