P. Chorney 10/14/99

Thermal Resistance of a Waveguide Length

The temperature rise across a thermal conductor ΔT is given by

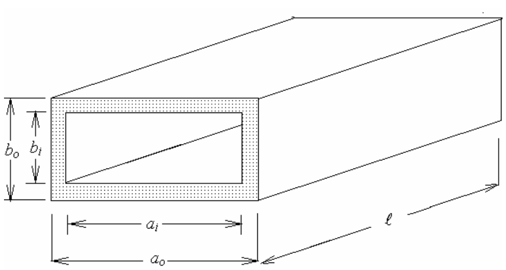
$$\Delta T = \theta Q$$

where Q is the thermal power (usually expressed as watts in electronics), and θ is the so-called thermal resistance (expressed in units of °C/watt). It is clear that this expression is analogous to Ohm's Law, with ΔT corresponding to voltage, Q to current and θ to electrical resistance.

The inverse relationship between thermal power and temperature difference becomes

$$Q = \frac{\Delta T}{\theta}$$

i.e., the heat flow through a thermal conductor is directly proportional to the temperature difference across the conductor and inversely proportional to its thermal resistance.



For a waveguide, the thermal resistance is a function of the cross-sectional area presented by the walls A_{cs} and the axial length ℓ through the relationship

$$\theta = \frac{\ell}{KA_{cs}}$$

The cross-sectional area A_{cs} is given by

$$A_{cs} = A_o - A_i = a_o b_o - a_i b_i$$

The subscript "o" denotes outside, the subscript "i" denotes inside, and the dimensions a and b are the usual designations for waveguide width and height. The cross-sectional area of interest is simply the area difference between the outer and inner rectangles that comprise the waveguide cross section.

The quantity K is the thermal conductivity of the waveguide material. Values for K are published in many references. For annealed copper, K is 3.88 watts/°C-cm, and for 304 stainless steel, K is 0.162 watts/°C-cm.

It is clear that if a waveguide protrudes into a temperature chamber and "heat robbing" is of concern, it would be advantageous to maximize the thermal impedance of the penetrating section. This is accomplished usually by using a thin-walled stainless-steel waveguide section in place of a section that would ordinarily be copper. Stainless steel has a low thermal conductivity, and the thin walls provide a small cross-sectional area. The attached Excel worksheet file (Thermal Resistance.xls) provides a quick calculation of thermal resistance for millimeter-wave waveguide sizes.

It of course has to be recognized that stainless steel is a much poorer electrical conductor than is copper. Thus, the length of any stainless steel section introduced for thermal-isolation should be minimized in order to minimize insertion loss. The accompanying Excel worksheet also provides the theoretical attenuation for the two waveguide materials.