

## Thermal Resistance of a Waveguide Length

The temperature rise across a thermal conductor  $\Delta T$  is given by

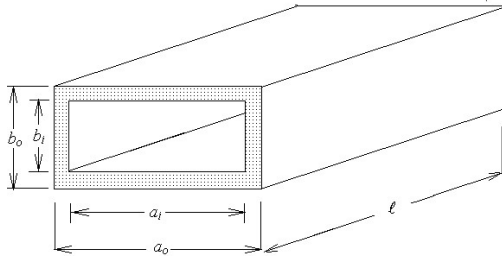
$$\Delta T = \theta Q$$

where  $Q$  is the thermal power (usually expressed as watts in electronics), and  $\theta$  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  $\Delta T$  corresponding to voltage,  $Q$  to current and  $\theta$  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  $\ell$  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.