Computed Thermal Loads for Pure Gold Bond Wires in a Cryogenic Amplifier Module

J. R. Fisher, May 4, 2016

This report summarizes a number of thermal conduction calculations for pure gold bond wires used in NRAO cryogenic RF amplifier modules assembled at the NRAO Central Development Lab in Charlottesville, VA. The bond wire material can be either either pure gold or aluminum doped with 1% silicon, but the thermal conductivity of Si doped Al have yet to be found. The two ends of the bond wires are typically at different temperatures of 15, 80, or 300 Kelvin so they present thermal loads to the refrigerator stage at the lower of the two temperatures.

If the thermal conductivity were independent of temperature, then the heat flowing through the wire would be given by

$$P = K(T_1 - T_2)A/L$$

where P is power in Watts, K is the thermal conductivity of the wire material, in watts per meter, T_1 and T_2 are the temperatures, in Kelvin, at the ends of the wire, A is the cross-section area of the wire, and L is its length. However, the thermal conductivity of most materials depends on the temperature of the material so a simple algebraic relationship between temperature difference and heat load often will not suffice. The thermal conductivity of pure gold as a function of absolute temperature is shown in Figure 1 where it can be seen that a numerical modeling tool, such as Autodesk CFD, is needed to accurately compute the heat flow through the bond wires at temperatures below about 80 Kelvin. Figure 2 shows the temperature profile along a wire with the end-point temperatures fixed at 15 K and 300 K. The effect of higher conductivity of gold at low temperatures can be seen as a lower temperature gradient at the cold end.

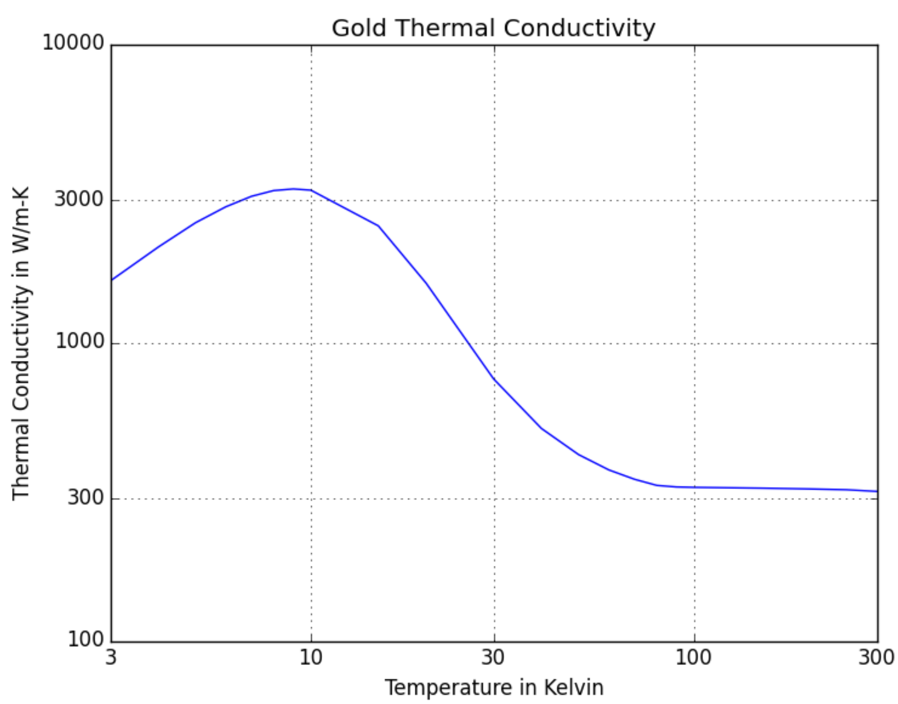
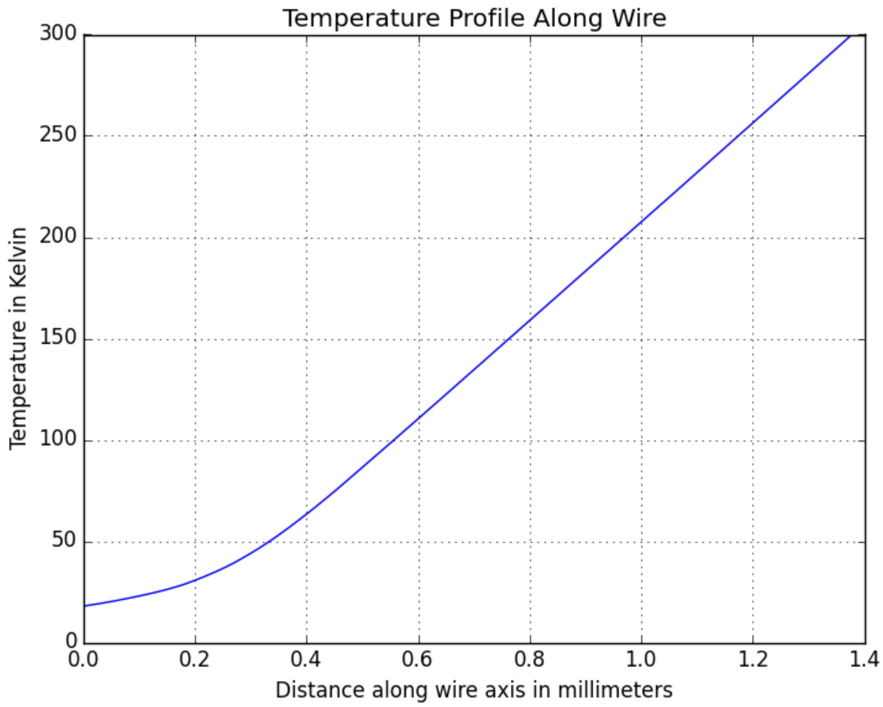


Figure 1

Figure 2



For simple geometries, like a constant diameter wire, one can compute an effective conductivity, K_{eff}, for a given T_1 and T_2, from the equation above and one CFD modeling operation.

$$K_{eff} = \frac{PL}{A(T_1 - T_2)}$$

This K_{eff} can then be used for different wire lengths and cross-section areas without the need to run the CFD model again. The following table shows the values of K_{eff} for pure gold from heat transfer calculations for the three cases that apply to existing LNA packages. Using CFD to compute the heat flow through a 1 mil (0.0254 mm) diameter by 50 mil (1.27 mm) pure gold wire with three different end-point temperature pairs we get the following values for K_{eff}

K_{eff} for pure gold (Watts/meter-Kelvin)		
T_1	T_2	K_{eff}
15K	80K	655
15K	300K	390
80K	300K	312

The equations for heat flow through pure gold wires of constant diameter, d, and length, L, for the three temperature differences are then

$$P = \frac{\pi d^2}{4L} K_{eff}(T_1 - T_2) \quad in\ units\ of\ Watts, meters, and\ Kelvin.$$

For the three temperature ranges this equation then becomes

$$P_{15-80K} = 3.344x10^4 \frac{d^2}{L} \quad in\ units\ of\ Watts\ and\ meters.$$

$$P_{15-300K} = 8.730x10^4 \frac{d^2}{L} \quad in\ units\ of\ Watts\ and\ meters.$$

$$P_{80-300K} = 5.391x10^4 \frac{d^2}{L} \quad in\ units\ of\ Watts\ and\ meters.$$

The unit conversion for d and L to milli-inches is $1\ mil = 2.54x10^{-5}\ meters$ so these equations can be converted to the commonly used mixed units of mils and milliwatts.

$$P_{15-80K} = 849.3 \frac{d^2}{L} \quad in\ units\ of\ milliWatts\ and\ mils.$$

$$P_{15-300K} = 2217 \frac{d^2}{L} \quad in\ units\ of\ milliWatts\ and\ mils.$$

$$P_{80-300K} = 1369.3 \frac{d^2}{L} \quad in\ units\ of\ milliWatts\ and\ mils.$$

Hence, a 1 mil diameter by 50 mil long gold wire connected between temperatures of 15 and 300 K will carry a heat load of 44.3 mW.