

Temperature Rise Estimations in Rogers High Frequency Circuit Boards Carrying Direct or RF Current

Frequently, designers are concerned about temperature rise of the conductor traces on devices built in microstrip or stripline configurations on RT/duroid® microwave material. The question arises when there are high bias line currents, but the bias line needs to be as narrow as possible to keep its characteristic impedance high. It also is of concern when RF power levels are high.

The following calculations may be used to give a conservative approximate answer to these concerns. It should be noted that these formulas are considerably simpler than a rigorous treatment of the subject. The estimates will be conservative, since the simplifying assumptions (except possibly the fourth) tend to yield higher values than a rigorous computation would yield.

Assumptions:

- All heat generated by current or RF power is conducted from the point of generation only in the Z-direction to the ground plane(s).** In reality, several additional paths for removal of heat exist. There will be a wider path of conduction due to fringing heat flow around the edges of the trace. Some heat is lost by radiation and convection above the line. Some heat may be carried away by terminations or other components connected to the copper line.
- All the insertion loss of RF power is accounted for as heat generated in the conductor trace.** Actually, some is lost by radiation and some by conversion to heat in the dielectric material, a function of dissipation factor. The dissipative heat will arise in the dielectric with a shorter path to the ground plane(s), making our assumption conservative.
- A steady state has been reached.**
- The heat generated is evident as a uniform temperature rise in the metal conductor and the ground plane(s) maintain(s) a uniform temperature.** This assumption is reasonable since thermal conductivity is so much greater for the copper than for the dielectric.

Definition of terms and units used in the calculations:

P_L	=	Power dissipated over length of line, Watt	W	=	Width of line under consideration, meter
P_I	=	Incident power, Watt	C	=	Conductor thickness, meter
P_T	=	Power transmitted, Watt	H	=	Dielectric thickness, meter
I	=	Direct current flowing along the line, Ampere	A	=	Thermal conductivity of the dielectric, Watt meter ⁻¹ Kelvin ⁻¹
G	=	Resistivity of the conductive trace foil, ohm • meter	ΔT	=	Temperature rise (not absolute) above ground plane temperature, Kelvin.
L	=	Length of line segment under consideration, meter	M	=	Insertion loss per unit length, dB/meter

Calculation for direct current heating in a microstrip bias line:

- $P_L = I^2 R$ [1] Heat generated by line resistance.
- $R = GL/(W C)$ [2] Resistance of the line based on dimensions.
- $\Delta T = P_L H / (L W A)$ [3] Temperature rise of the line based on heat flow and dimensions.
- $\Delta T = (I/W)^2 G H / (A C)$ [4] Combining equations 1,2, and 3.
(For stripline change [4] to read):
- $\Delta T = (I/W)^2 G H / (2 A C)$
- $I = W [A C \Delta T / (G H)]^{0.5}$ [5] Current for a given ΔT value.
(For stripline change [5] to read):
- $I = W [2 A C \Delta T / (G H)]^{0.5}$

Calculations for RF resistive heating in a microstrip transmission line:

- $P_L = P_i - P_T$ [6] Heat conversion energy loss.
- $P_L = P_i [1 - 10^{-ML/10}]$ [7] Where M value is given.
- $\Delta T = P_L H / (L W A)$ [8] All heat flow from conductor to ground plane.
- $\Delta T = HP_i [1 - 10^{-ML/10}] / (L W A)$ as $L \rightarrow 0^*$ [9] From 7 and 8.
(For stripline, change [9] to read):
- $\Delta T = HP_i [1 - 10^{-ML/10}] / (2 L W A)$ as $L \rightarrow 0^*$ [10]

** Note: For any given L, ΔT is the average rise for that length of line. Heating is greatest at the input end where the power level is greatest. A zero value for L cannot be used in [9] or [10] without getting infinity as an erroneous value. By calculating ΔT for a series of decreasing L values, one observes the ΔT converges to a limiting value. Our scheme is to start with L at the large value such as one metre and then keep reducing it to 1/10 the previous value until changes in ΔT are less than 10 parts per million.*

Example:

Determine the RF and DC temperature rise for a $Z_0=50$ Ohm microstrip line on 0.050 inch dielectric thickness RT/duroid 6010.2 clad with 1 oz/ft² rolled copper where input RF power is 100 Watts at 2 GHz and there is a bias current of 3 Amperes.

Use Rogers impedance software MWI as follows with the Units toggle set for inch. In the main menu of MWI, key T for selecting the microstrip transmission line as the type of design. The key N and pick the product RT/duroid 6010.2. Next select the available thickness of 0.050 in the submenu to the right of the product name list. A sub-menu for copper cladding appears. Select the 1 oz/ft² rolled copper which gives you the correct copper thickness and surface roughness values. This returns you to the main menu with settings for all parameters down to surface roughness of copper, and including known thermal conductivity of 0.78 W/m/K. Key G and enter 2 for GHz design if it is not that already. Now key Z and enter 50 for the characteristic impedance (Z_0) of 50 Ohms. MWI uses published formulas to determine for the 2 GHz frequency the required line width value 0.0464 inch for Z_0 of 50 Ohms. It also computes the various Q and values where a_0 is 2.4531 dB per meter. a_0 corresponds to the symbol M appearing in pages 1 & 2 of RT3.3.2. Show references for all formulas in MWI by keying O for Other menu, then R for Reference.

MWI uses the formulas in RT3.3.2 to get RF heating as 780.3 Kelvin per kilowatt (K/kW) and DC heating as 0.5957 Kelvin per DC Ampere squared. See text explaining these last values by keying A or B. For the example with 100 Watts incident RF power, the heating of the trace above the ground plane would then be 0.1 kWatt x 780.3 K/kW, which gives 78K above ambient ground plane. If the ambient ground plane is at 24°C, then the trace will be at 102°C (24+78). In the unusual case of considering a circuit with both RF and bias current, the DC rise would be 0.5957 x 3² or 5.36 K. Add this to the 102 to get 107.36°C, temperature of the trace from both RF and DC heating.

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