Application Note No.114
Title: Power Derating Calculations
Released: 26 October 2022
Tags: Power, Ratings, Combiners, Connectorsp

Premise

Product performance and power ratings typically refer to operation at Standard Temperature and Pressure (STP), namely 25°C and 1 atmosphere (760 Torr) of pressure, as is industry convention for everything from hybrid couplers to coaxial connectors. Power rating of a product must be adjusted in accordance with the conditions of temperature, pressure, and load VSWR, presented by each unique customer application. This convention is used across the high-power RF cabling and transmission line industry, but less often properly considered for internal components.

Theory

Maximum CW power is limited by two primary criteria, maximum temperature limit of the materials, and voltage breakdown by ionization or multipaction. Internal or maximum temperature is dependent upon ambient or mounting temperature, as well as self-heating due to net and localized current flow and internal losses. The working voltage is typically limited by ionization breakdown, the limit of which is dependent on frequency, temperature, and altitude. The threshold for ionization breakdown of air reduces with increasing temperature, and thus the power to achieve breakdown under CW conditions is lower than that for pulsed applications, due to self heating causing higher temperatures within the volume under CW operation. Breakdown by multipaction typically occurs only in space launch applications where low air pressure serves to extend the ionization threshold, and will be handled by individual consultation, with ionization being the dominant (and physically damaging) mechanism of concern for terrestrial applications.

Power Ratings

Distributed Elements power ratings typically include four points of reference, given with respect to maximum power input at STP into a matched load:

1. Maximum CW power, either full band or with specified band breaks
2. Maximum pulsed power, corresponding to voltage breakdown on a "cold" (25°C) part, for low-duty cycle applications with little or no self-heating.
3. A graph or table showing thermal power limit versus frequency
4. A graph or table showing CW (aka "hot") voltage breakdown power limit versus frequency

These items 3 and 4 are most often combined in a single graph, also showing the net power rating versus frequency, as the minimum of these two limits at each frequency. Discrepancy between the power limit associated with CW voltage breakdown (item 4) and the maximum pulsed power (item 2) are due to the self-heating that occurs under CW operation, as the ionization potential of air inside the connector varies with temperature.

A voltage safety factor of 1.25x to 2.00x (1.6x to 4.0x power) is applied to all published ratings, depending on method of qualification. These are employed to account for small mechanical tolerance and finish variations, which can impact actual withstanding voltages, and allow for safe operation right up to the limit of the specified rating.

Power is always measured with regard to total input power to the device, ignoring power reflected due to load VSWR, which is handled separately by the VSWR de-rating.

Application of Derating Factors

Graphs, tables, and/or equations are provided for de-rating (or pro-rating) of the thermal and voltage components of the power rating of the component, by ambient or mounting temperature, altitude, and load VSWR. These figures are labeled for the limits to which they are applied.

"Temperature" typically refers to case temperature of the component, measured at Thermal Reference Plane noted in product specification sheet drawing. Most devices are cooled by mounting to customer chassis or heat sink, at or near this Thermal Reference Plane.

These de-rating factors are applied cumulatively, such that if the thermal de-ratings for a given application are 75% for case temperature, 60% for altitude, and 50% for load VSWR, the cumulative thermal limit de-rating is .75 x .60 x .50 = 23% of thermal limit at STP. The minimum of this thermal limit and the voltage limit at commensurate de-rating, will dictate the product rating in this application.

When working simple CW applications, the voltage and thermal limits both follow the same simple equation:

CW limits @ STP
x __% for case temperature
x __% for altitude
x __% for load VSWR
____
= limits @ given conditions

When working under modulated conditions in which pulse lengths are sufficiently short for $T \sim T_{ave}$, simply compare the average power to the above calculation of the thermal limit, and the "Peak Power @ STP" rating for calculation of the voltage limit. Note that this "Peak Power @ STP" is based on breakdown at 25°C, and must be derated for any self heating due to average power, using the result of Figure 4: "Self-Heating Peak Power Derating" based upon average power to thermal power limit at STP.

Voltage (Peak) Limit
Peak Power @ STP
x __% for case temperature
x __% self-heating
x __% for load VSWR
x __% for altitude
____
V limit @ given conditions

Examples:

The following example specifications and tables were taken from one of our power combiners operating in the 1.0 – 6.0 GHz band:

From page 1:

Electrical Specifications:

Configuration: 16x N-type input / 1x DIN 7-16 output
Impedance: 50 ohm in / 50 ohm out
Frequency: 1000 – 6000 MHz, See Table 1
CW Power @ STP: 11.5 kW @ 6 GHz, See Table 2
Peak Power @ STP: 28.3 kW
Insertion Loss: max < 0.3 dB / typ. < 0.2 dB
Return Loss: min. > 18 dB / typ. > 20 dB
Port balance: ± 0.25 dB / 2.5° @ 6 GHz

From page 2:

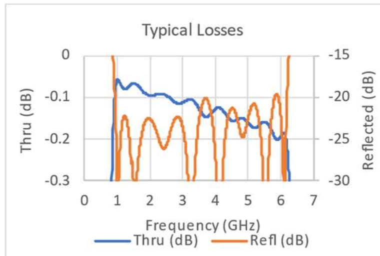


Figure 1

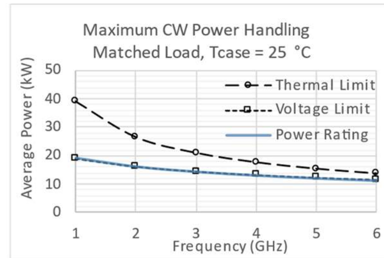


Figure 2

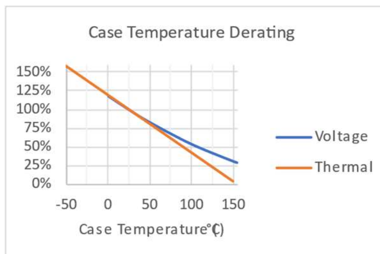


Figure 3

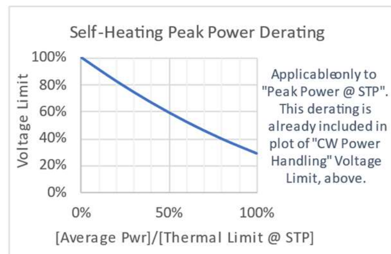


Figure 4

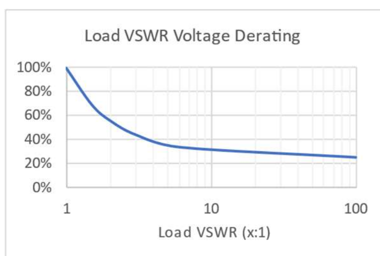


Figure 5

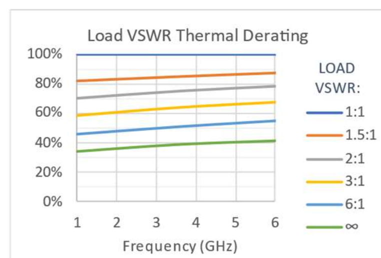


Figure 6

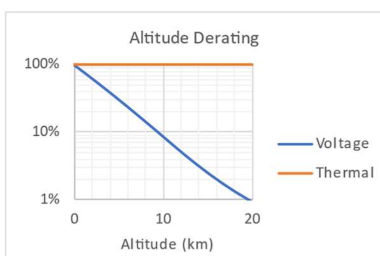


Figure 7

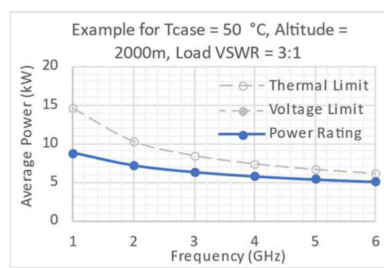


Figure 8

The “CW Power @ STP” specification found on page 1 will reflect the minimum in-band CW power limit shown in Figure 2: “Maximum CW Power Handling”, whereas the “Peak Power @ STP” specification will represent maximum pulsed power based on voltage breakdown, for low duty cycle and pulse width applications. The “CW Power @ STP” may be a function of the thermal or voltage limit, the latter being calculated at elevated temperature under CW operation, whereas the "Peak Power @ STP" is only a function of the voltage limit on a part with no self-heating at STP.

The "Self-Heating Peak Power Derating" applies only to this "Peak Power @ STP", when calculating a voltage limit for pulsed applications. This derating is already pre-applied to the voltage limit curve shown in Figure 2: "Maximum CW Power Handling", so its use for calculating CW power limits would be redundant, and yield falsely conservative power specifications. All other derating figures are labeled separately for their scaling on the voltage and current limits.

Example Problem 1: Determine suitability of this product for use in an amplifier producing up to 2000 watts CW power, when installed at 40°C ambient temperature at up to 2000 meter elevation, with loads up to VSWR = 6:1, and operated 2 – 4 GHz.

Example Solution 1: Insertion loss of power combiner is approximately 0.13 dB at 4 GHz, corresponding to a 3% power loss, or up to 59 watts thermal power into the customer chassis with 2000 watts input. Analysis of the customer chassis shows less than 10°C rise over ambient for this dissipation, corresponding to a mounting temperature below 50°C for this power combiner. Starting with the voltage and thermal limit curves in Figure 2: "Maximum CW Power Handling," and skipping the derating for self heating (which is already applied in "Maximum CW Power Handling"), the corresponding CW power rating will be:

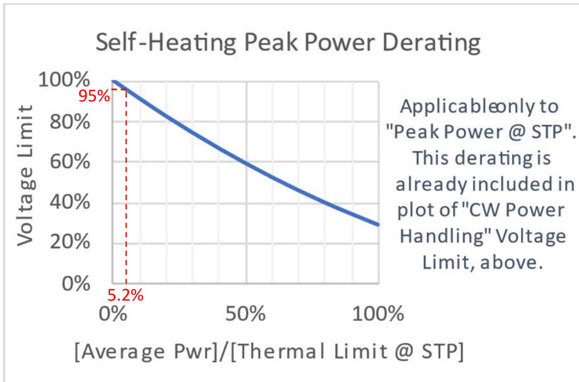
Voltage Limit	Thermal Limit
13.1 kW @ 4 GHz	17.7 kW @ 4 GHz
x 83% for case temperature	x 81% for case temperature
x 63% for altitude	x 100% for altitude
x 34% for load VSWR	x 52% for load VSWR
2.32 kW @ 4 GHz	7.46 kW @ 4 GHz

The net average power rating of this device in this application would be 2.32 kW @ 4 GHz, a very comfortable 15% margin for this application. These simple calculations should be repeated elsewhere in band, due to competing slope of curves for load VSWR and CW power.

Example Problem 2: Determine suitability of this product for use in an amplifier producing up to 5000 watts pulsed power with short pulses up to 20% duty cycle, when installed at 35°C ambient temperature at sea level, with loads up to VSWR = 3:1, and operated 2.7 – 3.5 GHz.

Example Solution 2: The average power of this application is P_{av} = 20% x 5000 watts = 1000 watts, and with insertion loss approaching 0.12 dB at 3.5 GHz, dissipated power will be approximately 27 watts. The customer mounting is determined to hold 5°C over ambient at 27 watts dissipation, so 40°C will be used for case temperature derating.

Voltage limit for pulsed applications will be determined by "Peak Power @ STP", scaled for self-heating according to Figure 4: "Self-Heating Peak Power Derating", along with other applicable deratings. The thermal power limit at 3.5 GHz is approximately 19.2 kW, according to the Thermal Limit curve in Figure 2: "Maximum CW Power Handling". Thus we evaluate the self-heating power derating curve at $P_{av}/P_{therm.lim.}$ = 1000W/19.2kW = 5.2%, as shown, yielding a 95% scaling for power:



Integrating the appropriate peak and average spec's with this and all applicable deratings, we have:

Voltage (Peak) Limit	Thermal (Average) Limit
28.3 kW	19.2 kW @ 3.5 GHz
x 93% for case temperature	x 93% for case temperature
x 95% self-heating @ 3.5 GHz	x 64% for load VSWR
x 44% for load VSWR	x 100% for altitude
x 100% for altitude	11.4 kW @ 3.5 GHz
11.0 kW @ 3.5 GHz	

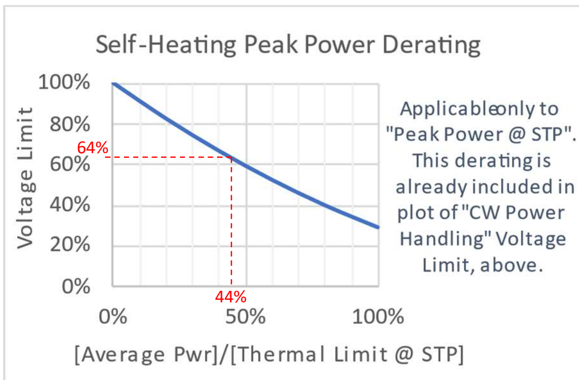
This product is more than suitable for the listed application.

Example Problem 3: Determine maximum allowable duty cycle for use at 10 kW at 3.5 GHz with maximum operating mounting temperature of 45°C and maximum elevation of 1.2 km with VSWR = 1.2:1 or less. Assume no long pulse duration, such that $T_{max} \sim T_{case}$.

Example Solution 3: Again for pulsed applications, start with "cold" voltage limit given by "Peak Power @ STP" specification for pulsed application. In this case we will apply all known derating factors, and then solve for the remaining unknown of self-heating due to average power as dictated by duty cycle. *For simplicity, we will assume customer mounting runs a nominal 5°C rise over ambient at anticipated dissipation, and then verify our assumption once the maximum allowable duty cycle (and thus average power and dissipation) is determined.*

Voltage Limit	Thermal Limit
28.3 kW @ 3.5 GHz	19.2 kW rating @ 3.5 GHz
x __% for self-heating	x 86% for case temperature
x 87% for case temperature	x 100% for altitude
x 76% for altitude	x 94% for load VSWR
x 84% for load VSWR	= 15.5 kW @ 3.5 GHz
= 10.0 kW @ 3.5 GHz	= duty x 10.0 kW
__% for self-heating = 64%	duty = 65% @ 3.5 GHz

The answer for the thermal limit is directly calculated, however we must resort to Figure 2: “Maximum CW Power Handling” to translate the de-rating for self-heating into an average power limit, and eventually duty cycle at 10 kW peak power:



Average Power / Thermal power scales near 44%. The thermal power limit at 3.5 GHz is approximately 19.2 kW (as noted previously), yielding an average power limit of 0.44 x 19.2 kW = 8.4 kW, or 84% maximum duty on 10 kW.

As always, the minimum of the thermal and voltage limits will dictate the rating, thus the maximum duty cycle for this part in this application is 65%, according to the thermal power limit. The customer would want to verify that their mounting temperature within this duty cycle limit does not exceed expectation by enough to affect this rating, or adjust accordingly.

Support

In all cases, detailed power ratings for your application can be obtained or confirmed by contacting applications@distributed-elements.com. Understanding the basis of these ratings will help the user with supplying the proper information for any required rating.