Secure Attachment in Pulsed Power Applications

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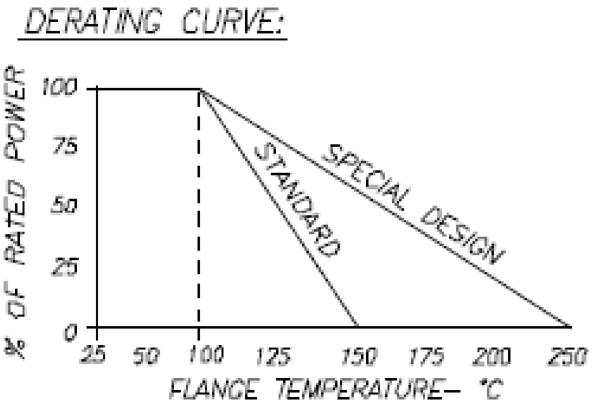
In applying high power attenuators and terminations to RF and Microwave circuits there are a number of requirements to be observed to obtain satisfactory life. These are heat-generating devices so the removal of excess heat is key to maintaining a safe film temperature. This heat removal is often accomplished by mounting the resistive element (chip) to a heat sink, which is then in turn mounted to a cold plate.

Overheating of the resistive film is to be avoided as it can cause a resistance shift. This shift will interfere with the carefully designed RF impedance match.

Figure 1 - Derating Curve



For the highest performance in the smallest size we want to load the chip to the near maximum film temperature and use the highest conductivity heat sink to redistribute and remove the heat. Materials properties work against here as shown in table 1

Table 1

	Material	Abbr.	Thermal conductivity - W/m*K	CTE - cm/cm/C
Ceramics				
	Aluminum Oxide	Al2O3	39	6.50E-06
	Beryllium Oxide	BeO	196	4.70E-06
	Aluminum Nitride	AlN	180	5.60E-06
	Thick Film Resistor Metal	????	46	4.70E-06
Potential Heat Sinks				

	Tungsten Copper - 80/20	W/Cu	220	7.60E-06
	Copper-Molybdenum-Copper 33-33-33 in plane	Cu-Mo-Cu	311	8.60E-06
	Copper-Molybdenum-Copper 33-33-33 perp.	Cu-Mo-Cu	251	8.60E-06
	Aluminum	Al	205	2.40E-05
	Copper (110)	Cu	397	1.68E-05
Solder and Braze Alloys				
	Gold Germanium 88-12	AuGe	276	1.28E-05
	Lead Indium 50-50	Pb-50 at%In	35	3.06E-05
	Indalloy #7	50 In 50 Pb	22	2.70E-05
	Indalloy #4	100 In	86	2.48E-05
Other Metals				
	Platinum Silver	Pt/Ag	73	1.40E-05
	Nickel	Ni	89	1.27E-05
	Gold	Au	316	1.41E-05

Ideally we would use an aluminum heat sink as it is the high thermal conductivity with low density and thus low weight. Unfortunately the corresponding Coefficient of Thermal Expansion (CTE) for aluminum is quite high. This results in a very high stress level in the attachment between the chip and the heat sink leading to joint or chip failure at a very early lifetime. This situation can be remedied somewhat by using one of the Aluminum Silicon materials for a lower expansion with some loss in conductivity. These applications have been successful with some difficulty and at a cost for very high value applications where weight is at an absolute premium. Typically this occurs in spacecraft, missiles and other airborne applications. As this article intends to address more commercial applications we will not consider this solution further here.

For many commercial applications the chip is mounted to a copper heat sink with a solder or braze material. The stress level is still high here however many applications are successful this way. The stress can be reduced by judicious selection of attachment alloy and method as shown in the referenced article.

Figure 1 – Power Chip mounted on High Conductivity Heat Sing

There are however a class of applications where this approach may not be adequate. These are low frequency cycling and pulsed power applications. In these applications the relationship between the heating frequency and the thermal time constant of the chip/heat sink assembly is such that they heat and cool frequently enough to build up a lot of stress cycles in a short period of time. These are not the typical startup and shut down machine cycles; rather, they are operational needs.

In the typical AC, RF or microwave CW circuit the power passes through a zero at 60, 120, a million or even a billion times a second. For resistors this is very much shorter than the thermal time constant and the heating and resultant temperature is essentially constant as a result. Although there are a great many electrical cycles here, the magnitude of the stress variation is very small and there is little fatigue damage.

In the case of equipment startup the power on and off times are much longer than the thermal time constant and the assembly goes through the entire stress cycle each time. However except in the most extreme cases it is difficult to build up enough cycles to do any damage.

The applications where damage occurs exhibit power variations that are longer than the thermal time constant but occur at a high enough frequency to build up a significant number of cycles in a short period of time. Some applications where this may occur are:

Temperature Regulating Induction Heaters
Pulsed Power Transmitters - Radar
Plasma Generators

These applications can cause failure of the chip to heat sink joint or of the chip itself. In most cases this results in thermal runaway of the device and catastrophic failure.

These situations can be detected at the design stage by analyzing the intended operating profile of the equipment and comparing it to the thermal time constant of the chip. If the chip will heat and cool significantly a large number of times the stress level must then be compared to the S-N curve to see if a problem is likely. At this stage a large safety factor is recommended due to the dispersion of typical fracture failures. If a problem is thought to exist, the stress level must be reduced as the power and machine operation is essentially fixed by now.

One method of reducing the stress is to select a large resistor chip. This chip will run at a lower temperature and thus will have a lower stress when mounted on copper. The disadvantage is one of increasing size and expense for the larger chip and heat sink.

An alternative and highly favored solution is to choose an assembly where the chip is brazed to a CuW heat sink. In this case the braze joint is much stronger than the typical solder and the CTE mismatch and resulting stress is lower as well.

The following study reinforces this:

The authors set out to compare the two different construction methods of their Flanged and leaded Resistors. Construction “A” consists of a Copper/Tungsten (Cu/W) flange with Gold/Germanium (Au/Ge) preforms and .060” thick BeO, 270-ohm chip resistor with leads. Construction “B” consists of a Copper (Cu) flange with Lead/Silver preforms and .060” thick BeO, 270-ohm chip resistor with leads. Four resistors of each type construction were cycled for a period of 9 seconds on and 9 seconds off. Each resistor had 150 Watts of applied power for the 9 second on cycle.

Construction “A” (Cu/W)

Initial Data:	Final Data	Delta	% Delta	# Cycles
#1 = 270.82 ohms	#1 = 271.00	+0.18	+.066%	494,000

#2 = 270.91 ohms	#2 = 271.09	+0.18	+.066%	494,000
#3 = 270.48 ohms	#3 = 270.67	+0.19	+.070%	494,000
#4 = 271.27 ohms	#4 = 271.00	+0.18	+.066%	494,000

Construction “B” (Cu)

Initial Data:	Failure Mode	# Cycles completed
#5 = 271.39	Detached from flange and lead fell off	3,550
#6 = 271.22	Detached from flange and resistor failed	3,833
#7 = 271.39	Detached from flange and lead fell off	2,567
#8 = 271.23	Detached from flange and resistor failed	3,192

Results:

Construction “A” Cu/W Flange:

After 494,000 cycles on all four resistors for a total of a 1.976 million cycles, all the resistors survived. By monitoring the current in the loop that was still set to 2.98 Amps, we could see that all the resistors were performing as when they were originally setup.

Construction “B” Cu Flange:

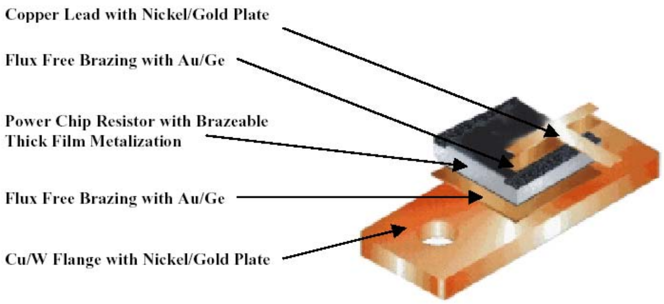
The chips all broke away from the flange. Once the chip broke away from the flange it was no longer in contact with the heat sink and one of two things happened. The resistor would heat up and the resistor would fail by arcing open or the lead would fall off from overheating. Resistors failed after an average of 3,286 cycles.

Conclusion:

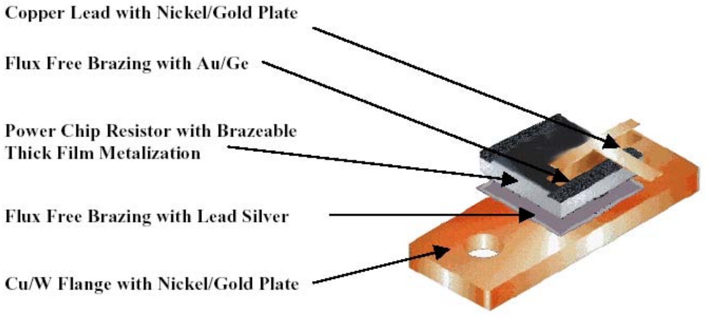
While Resistors built on Copper flanges may be good for CW power applications, they do not survive in applications where the power is constantly being cycled. The main reason for this is the disparity in the Thermal Coefficient of Expansion (TCE) between the Copper flange and the substrate material. The construction “B” type resistors are not recommended for Pulsed Power Applications.

The Resistors built on Copper/tungsten flanges have a TCE that is matched to that of the BeO Substrate. This matching forms a bond that moves in unison as the Assembly is heated and cooled by the applied power. The Construction ” A” samples are greatly superior when the application requires the power to be pulsed or cycled. The Copper/Tungsten flanged resistors lasted an average of 150 times longer.

Construction “A” (CU/W)



Construction “B” (Cu)



References
1) Wireless Design & Development 6/98, PP 69-72
2) Barry Technical Report BTR-Cu/W vs. Cu-001
3) BAN-TCA-1.1 Barry Application Note - Copper vs. Copper Tungsten Flange Material
4) Barry Data Sheet R1000-800-1E