

Thermal Design and Application of Sixteenth Brick Converters

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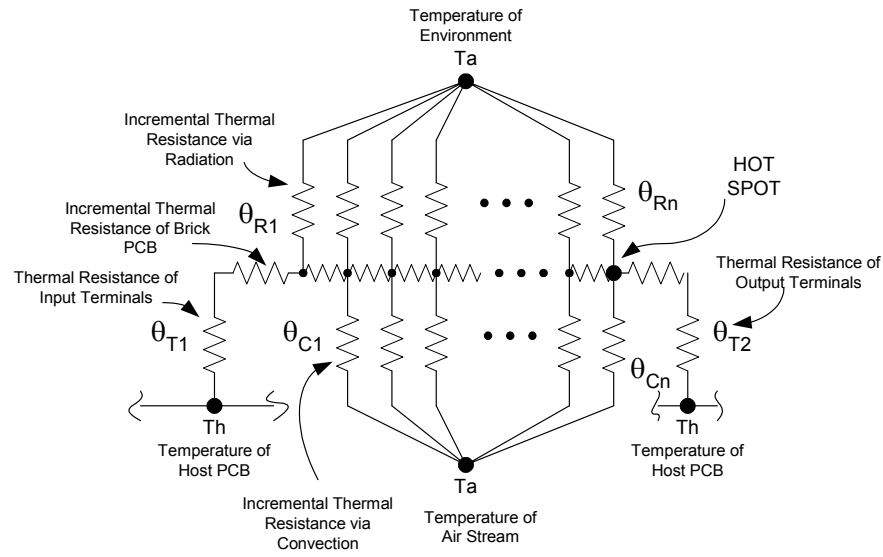
With the introduction of the Sixteenth Brick converter, the first question some may ask is "why would I want a smaller version of my 20A Eighth or Quarter Brick - won't it just run hotter?" "Isn't bigger better?" The answer is "not necessarily". Several factors including conductive path length, series heating of forced airflow, boundary layer effects, hot spots and, of course, overall unit efficiency influence the thermal performance of a converter in its operating environment. A smaller heat source in a real-world application can act more like the "ideal" or "uniform" heat source. Having presented an empirical case for "smaller-can-be-better", we will examine some of the key technical attributes of the new Sixteenth-Brick as they relate to achieving higher power density.

Apparent Thermal Resistance

Board-mounted converter modules can be said to have an "Apparent Thermal Resistance", θ_A , defined as the maximum "hot spot" temperature rise, (T_S above surrounding air temperature T_E) divided by the power being dissipated by the module, P_D , in watts.

$$\theta_A = (T_S - T_E) / P_D \quad ^\circ\text{C} / \text{W}$$

Of course, θ_A is composed of parallel thermal resistances that represent heat transfer by conduction, convection and radiation from all the heat generating sources on the DC-DC module. Those thermal resistance elements vary in magnitude with respect to each other in different size "bricks", with changing airflow and with more, or less, conductive host assemblies. Each node along the PCB chain has a thermal energy source associated with it. Those sources are not shown in the schematic but combine to equal total power dissipation, P_D .



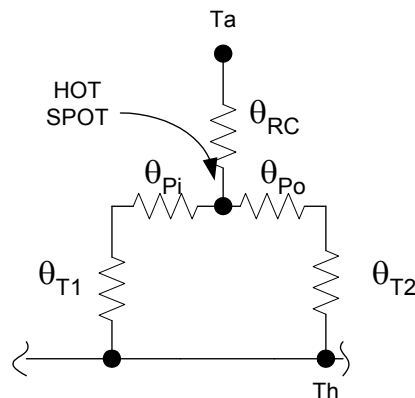
As a physical entity, θ_A does not exist being a mixture of elements that can be useful in describing a complete brick as if it were a component. Designers can compute the highest expected temperature within the module as they would any semiconductor device.

$$\theta_A \times P_D = \text{Temp Rise} \quad (@ \text{ "hot spot" })$$

Also, by examining θ_A , we can compare module performance by size and gain some insight into why smaller can be better.

The complex network shown above can be reduced to a simpler form by combining all of the parallel radiation and convection heat paths into one approximation called θ_{RC} in the simplification below. We also approximate resistance seen by the hottest component through the circuit board to its terminals as θ_{Pi} and θ_{Po} .

Apparent Thermal Resistance of our hypothetical brick is, then, net resistance at the HOT SPOT in the simplified network.



Smaller modules will exhibit higher values of θ_{RC} due to reduced surface area coupling to an air stream. On the other hand, shorter path length from hot spot to terminals makes θ_{Pi} and θ_{Po} have lower value giving a net result, θ_A , that may, as in the case of a Sixteenth Brick, be equivalent to, or even lower, than a larger module.

Conductive Path Length

DC-DC converters are typically mounted by attaching their electrical terminals (SMT or through-hole) at the edges of the converter to a host assembly. A significant amount of heat can be conducted through those terminals into the system “motherboard”. In fact, in recent press releases some dc-dc converter suppliers tout the low thermal impedance of their electrical connections and the associated benefit of added heat conduction away from the converter. Terminal conduction can be a significant thermal path for board-mounted power modules.

Comparing, for example, a Quarter Brick to a Sixteenth Brick, it is apparent that the larger module will have longer thermal paths from, at least, some components to the terminals. When

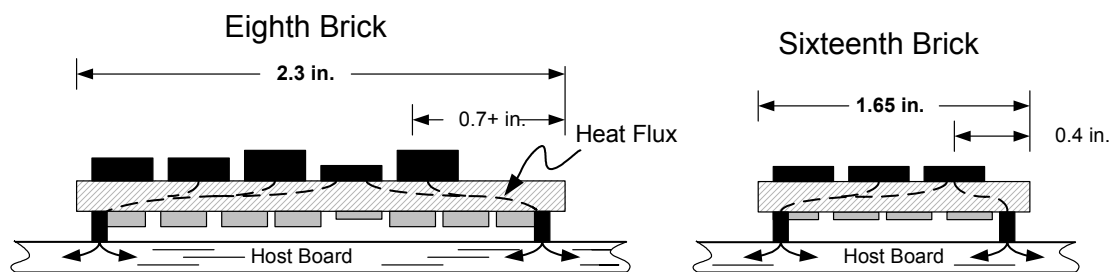


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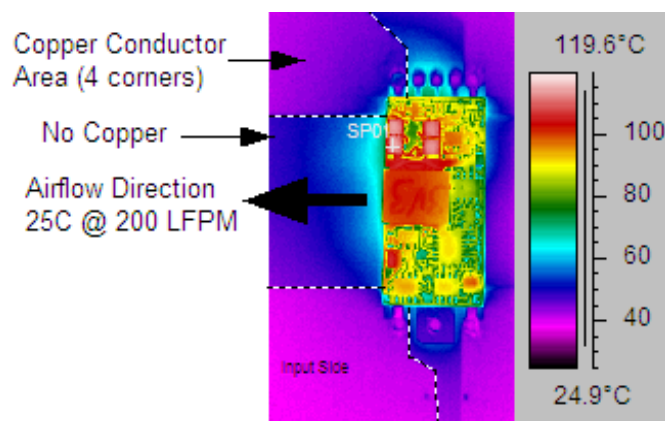
those are “hot” components there will be a greater temperature rise along the conducted heat path. Of course there are also convection and radiation heat paths involved, so the actual picture is more complex.

Looking at a side view of Quarter (or Eighth) Brick modules, a typical dimensional relationship between output synchronous rectifiers and output terminals measures almost 2:1. Some Eighth Bricks have as much as 0.9 inches of path length from rectifiers to the nearest terminal. In low output voltage bricks, the temperature rise of output rectifiers is most often the limiting element in thermal derating, i.e. the “hot spot” used to find Apparent Thermal Resistance. Given that module PCB construction and terminals are essentially the same in most standard open frame bricks, thermal resistance along that path is likely to be about 2:1 also.

Heavy copper conductors used to reduce I^2R loss within the PCB substantially lower its thermal resistance making conduction to the terminations effective.



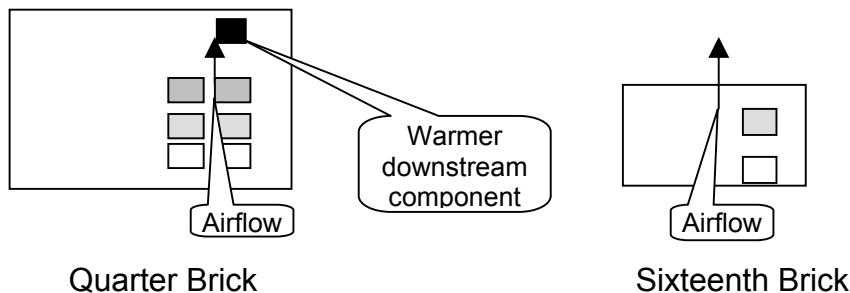
A shorter thermal path to the host PCB for “hot” components allows the Sixteenth Brick to look larger thermally by more effectively spreading a portion of its thermal dissipation into the host PCB’s copper planes. Unlike larger converters though, power being spread from a Sixteenth-Brick is relatively small, typically 2 or 3 watts, and does not create a significant temperature rise in large, multi-layer host circuit boards.



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Series Heating of Forced Airflow

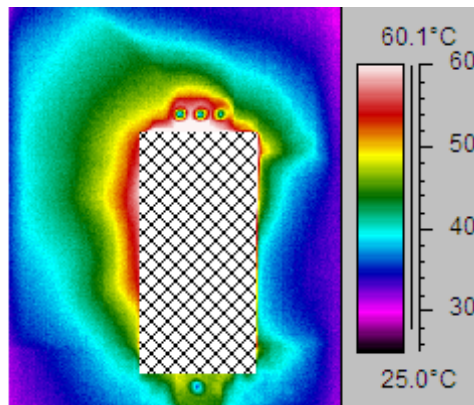
Clearly it is best to have air flowing across the brick in an orientation that provides the best thermal performance. In practical circuit card layouts this is not always possible. Also, other components or card mounting hardware can influence airflow direction, speed and turbulence. A component with smaller X & Y dimensions has less surface area to conduct heat into the passing air stream, but, at the same time, with reduced air stream path length, it will experience less series (cascade) heating of downstream components.



Also, air that travels underneath the converter is significantly slower moving than the air stream above the module due to back pressure from bounding surfaces in close proximity. Passing through a longer distance, such as under a Quarter Brick, air sees more cumulative heating than it does passing under a Sixteenth Brick.

Effect of downstream heating on host PCB

Surface is cooler on the right (upstream) side but some conducted heating can be seen around the output terminals at the top of the module.



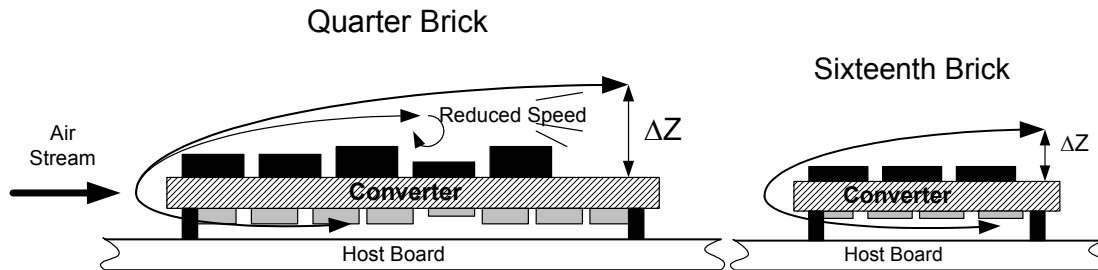
Boundary Layer Effects

As an air stream breaks across the leading edge of a converter, laminar flow lines are “pushed” away from the surface of the converter creating a parabola whose origin is the leading edge of the converter and whose “tails” are the trailing edge of the converter (and beyond). Airflow



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downstream from the leading edge will be lower in velocity near the surface of the converter. Features on the converter such as components and magnetic cores will push the air even farther away from the PCB surface (and create small eddy currents that could actually be helpful in some cases). Converters with larger components and/or magnetic structures can significantly affect the “washing” of the heat away from the surface of the PCB. At minimum, uniformity of airflow across the converter will be affected.



Shorter flow distance & more uniform height profile allow more efficient heat transfer from a given surface area. Component selection in the Sixteenth Brick has been made specifically to maintain a low, uniform profile.

Hot Spots

Brick designers strive to distribute heat load evenly across any converter module surface. Their success is, of course, substantially influenced by space constraints, component package format and electrical operating considerations. It is entirely possible that a device that is dissipating a relatively small amount of power can become the limiting factor in a brick's Apparent Thermal Resistance.

Larger converter footprint does not necessarily imply good hot-spot design. Leadless copper pad style packages, such as Power Pak, for power semiconductors provide better thermal performance than leaded packages like SO8. Thermally effective packages have a much lower junction-to-case thermal resistance. Proper thermal via placement within a brick layout will provide lower resistance to heavy copper planes within its PCB. 3,4 or 5 oz. copper conductors and planes help spread heat throughout the PCB making the module temperature more homogeneous and reducing hot spots. This allows each electrical device to be closer to the average PCB temperature. Heat can then be convectively coupled to the passing air stream as well as coupled through well-designed power terminations to the host PCB.

Components with Poor thermal coupling as well as devices that are “trapped” between other heat-dissipating devices (isolated from airflow and/ or conductive thermal paths) can create hot-spots which raise the module's Apparent Thermal Resistance.



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Efficiency

If hot spot management is done effectively, overall conversion efficiency becomes dominant in determining actual temperature rise in an operating converter. Justifiably, engineers designing with bricks have come to regard published efficiency numbers as a primary differentiator in selection of product. Less dissipation in the brick means lower temperature rise and higher useable power.

Efficiency in the Sixteenth Brick is improved by:

1. Shorter copper trace lengths within the output side circuits in particular
2. Lower high-frequency parasitic losses in part because magnetic structures are smaller
3. Use of switching devices that exhibit low parasitic losses. Effective cooling allows use of small power FET switches with low gate charge and on-state resistance, $R_{ds(on)}$.

Efficiency penalties from small size:

1. Smaller cross-section power conductors mean higher I^2R loss that is difficult to offset with parallel winding layers.
2. Less room for power devices. Not enough space to use parallel parts.
3. Higher frequency operation (to shrink magnetic structures) causes slightly higher switching loss. Careful attention must be paid to maintaining ZVS.

The first Sixteenth Brick to be released to the market uses a double-ended power circuit topology for smaller magnetic components with less penalty to overall efficiency.

In lower power converters like the 50 watt Sixteenth Brick, housekeeping power contributes a larger percentage of total power dissipation than in higher power bricks. However, control power tends to be evenly distributed across the PCB surface among low dissipation components. Slightly lower overall efficiency due to housekeeping power does not necessarily indicate reduced thermal performance of the brick because Apparent Thermal Resistance is governed by the hottest component and that is almost never a housekeeping device.

Summary

Combining the effect of factors described above, the new Sixteenth Brick dc-dc converter is designed with a relatively uniform temperature distribution. Shorter thermal conduction paths to its host PCB, and a smaller airflow profile, give the Sixteenth Brick converter a θ_A value equivalent to a typical 15 or 20 amp rated Eighth Brick and therefore, essentially the same thermal derating curves.

Double-ended circuit topology simulates two parallel converters in one small package. The power transformer core is fully utilized allowing for a smaller structure that uses less PCB area.



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Careful planning of thermal path lengths, power loss distribution and conduction into terminations allows the converter to look thermally “larger” than it actually is when mounted onto a host PCB. Terminals themselves are designed to be effective conductors of heat as well as electrical current.

The Sixteenth Brick uses the latest power device packages with very low on-resistance and extremely small footprints. These component packages also have very low thermal resistance, which allows them to be well coupled to the converter PCB despite their small size.

A high bandwidth feedback loop, allowing for a minimum number of output filter components, leaves more available surface area for power devices.



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