Enabling Small, Cool and Quiet Power Modules with Enhanced HotRod™ QFN Package Technology

TEXAS INSTRUMENTS

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Balancing between efficiency, size and thermal performance are common and important considerations for designers working with power converters and modules. The Enhanced HotRod™ quad flat no-lead (QFN) package technology from Texas Instruments enables engineers to address those design challenges and take advantage of more efficient, cooler and quieter devices in their designs.

At a glance

This white paper demonstrates how the Enhanced HotRod™ QFN package technology addresses multiple power density design challenges for power converters and modules.

1 Size

Integrating bare silicon and using copper posts to connect the chip to the leadframe, lowers package parasitics and saves space on the PCB.

2 Efficiency

The placement of high-frequency bypass capacitors and direct copper connection to the die improves switch-node ringing and lowers switching losses.

3 Heat dissipation

Maximizing the contact area to the PCB facilitates thermal transfer, unlocking higher operating ambient range.

4 Noise

Features like bare silicon, ceramic capacitors and improved routing design rules help minimize high di/dt loops.

The best DC/DC power module should be small, efficient, cool and "quiet." Small, so that there is additional board space for other electronics in the application. Efficient, so that the power conversion results in less heat dissipation in the overall system, which can also unlock a wider operating ambient temperature range. Quiet – meaning low noise and low electromagnetic interference (EMI) – in order to avoid affecting the operation of other circuits and easily achieve compliance with EMI regulations.

The constant battle to balance size, efficiency, heat and noise levels in DC/DC regulators is especially true for power modules. The balance could heavily depend on the packaging technology used for the module construction. Enhanced HotRod™ quad flat no-lead (QFN) package technology from TI addresses multiple design challenges and enables power-converter and module manufacturers to push the industry envelope on package size, efficiency, thermal dissipation capability and noise performance.

Let's explore some of the challenges when designing power modules and see how Enhanced HotRod QFN technology addresses them.

Size

As **Figure 1** illustrates, a typical DC/DC power module can integrate a power-converter integrated circuit (IC), power inductor(s), some bypass capacitors and feature-programming resistors, all in the same package.

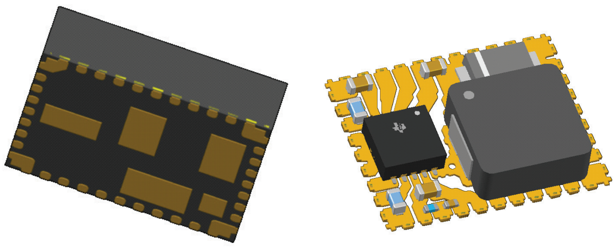

Figure 1. A typical power module with packaged silicon and an inductor side by side on a standard copper leadframe.

The overall size or "volume" of the power module is highly dependent on the converter's operating frequency and the size of the magnetics. Operating the power converter at high frequencies can reduce the size requirements of the power inductor, but there will be conversion efficiency and heat dissipation trade-offs. The overall module area also depends on the package construction. Packages that can integrate the power inductor such that it straddles over the internal module components will result in area savings, but at the expense of overall package height (**Figure 2**).

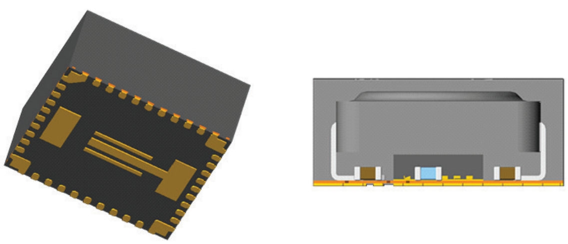

Figure 2. A power module with an inductor straddling internal module components.

The Enhanced HotRod QFN package integrates bare silicon into the module package, leaving more room to integrate the inductor and other passive components. The connection from the chip to the leadframe is realized with copper posts directly underneath the chip, instead of using bond wire. This results in lower package parasitic inductance and space savings inside the module (**Figure 3**).

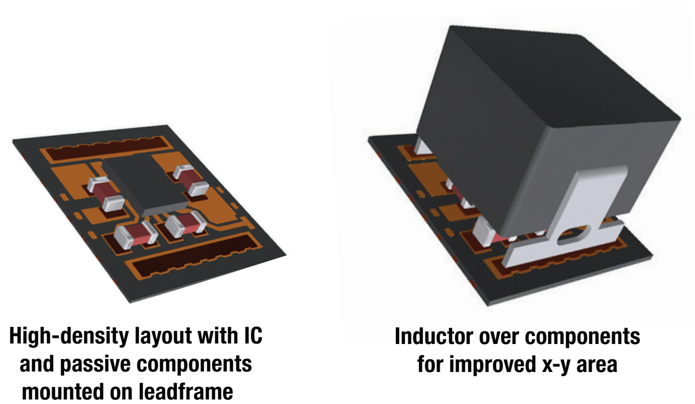

Figure 3. Inside an Enhanced HotRod QFN module: high-performance IC die, with the bypass capacitors and inductor located over the components.

Mounting bare silicon with copper posts on a standard copper leadframe is not a new module technology. In the Enhanced HotRod QFN case, however, the leadframe enables a very user-friendly footprint, with near-perfect routing between the module's internal components and an optimized thermal connection. Another benefit is that the inductor can be packaged over the rest of the components, enabling x-y area space savings. The result can be a compact module structure with integrated high-frequency bypass capacitors (**Figure 4**).

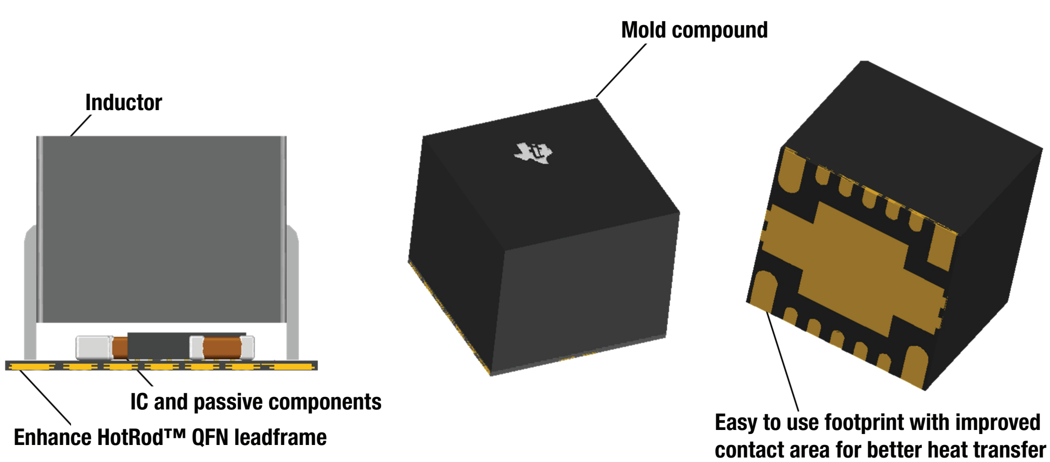

Figure 4. Power module example in the Enhanced HotRod QFN package.

Efficiency

Efficiency is an important specification for a power converter. Conversion losses occur mainly in the converter IC and the power inductor. These losses fall into two general categories – switching and conduction – and depend on the IC process and inductor specifications. Not all power-converter ICs are created equal. Having access to a silicon process with a better figure of merit (such as $R_{DS(on)}$ × gate charge) can result in a more optimized balance between switching losses and conduction losses in the IC.

You can also choose to run the converter at a lower switching frequency to minimize switching losses. Operating at a lower switching frequency demands higher inductance from the power inductor, however. A higher inductance results in more wire turns and a physically larger inductor for the same current rating. The challenge is how to achieve better efficiency than previous-generation converters while decreasing the overall size and maintaining viable thermal performance.

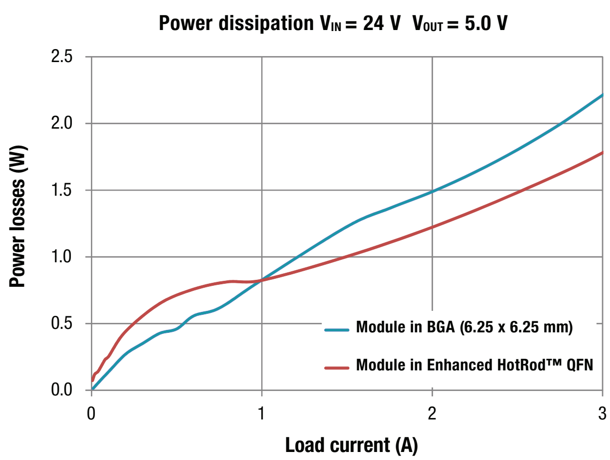

Figure 5. *The power dissipation of a 6.25-mm-by-6.25-mm ball grid array (BGA) package with side-by-side inductors vs. a 5-mm-by-5.5-mm Enhanced HotRod QFN package with an over-the-top inductor.*

Integrating a high-performance IC is a first step to achieving good efficiency. The IC inside an Enhanced HotRod QFN package connects to the leadframe with copper pillars, resulting in lower parasitic inductance. The placement of a high-frequency bypass capacitor together with the direct copper connection to the die results in greatly improved switch-node ringing and lower switching losses. Also, the ability to mount the inductor over the rest of the components enables additional area for the inductor without sacrificing the overall x-y package area. Because the inductor has a major effect on overall efficiency, this two-level packaging approach allows you to integrate a larger-size inductor with lower power losses (**Figure 5**).

Heat dissipation

Thermal design is an inevitable aspect of power-converter designs. No converter is 100% efficient. Conversion power losses will dissipate as heat, which has to be managed properly. The heat generated in the converter has to be transferred to the rest of the environment so that the power converter stays within its safe operating area (SOA) and the overall system temperature is acceptable for the particular application. At best, the module package should enable a low-enough thermal resistance to dissipate the generated heat into the board and ambient air. Also, the pinout of the package should be friendly enough to enable a thermally viable layout without introducing breaks in the thermal dissipation path.

Considering that all of the major power-dissipating components are packaged together in a module, thermal management can be a huge bottleneck in the module's ability to deliver the designed power output. The Enhanced HotRod QFN package lets you design a footprint that maximizes the contact area to the printed circuit board (PCB). A larger contact area facilitates thermal transfer so that heat can dissipate into its surroundings before pushing the converter outside of its thermal SOA. When compared to a similar size BGA-style module package, an Enhanced HotRod QFN package module can have a much larger contact area with the PCB, as illustrated in **Figure 6**. This can unlock either a higher operating ambient range or increased output power for the same-sized converter.

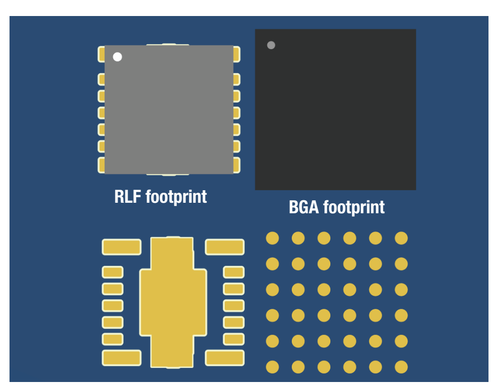

Figure 6. *Thermal contact area advantage of a 5-mm-by-5.5-mm Enhanced HotRod QFN package over a 6.25-mm-by-6.25-mm BGA package.*

The simplicity of the Enhanced HotRod QFN package footprint also enables continuous unbroken copper under the module (**Figure 7**), without cuts and breaks in the thermal path. This further maximizes the usable copper area on the board for proper heat sinking.

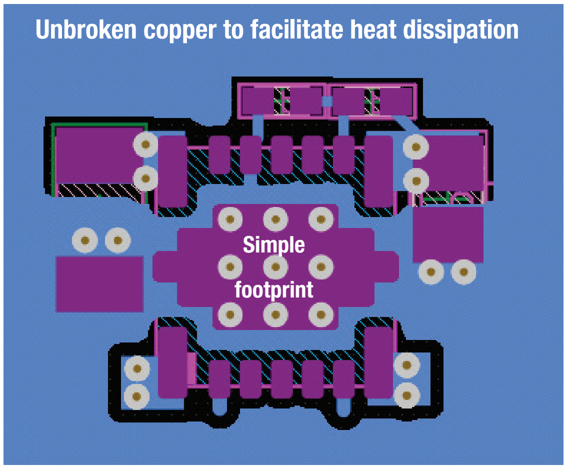

Figure 7. *Easy layout with continuous copper for good thermal design.*

Noise

Due to the switching action, high transient currents (di/dt), and package and layout parasitics, switch-mode power converters can be noise generators. Noise can affect the proper operation of other noise-sensitive circuits around the power converter, so there are application-dependent noise limits that each product has to meet in the form of EMI standards.

The noise generated by one converter can vary significantly when compared to another. Even with the same converter, noise levels can vary depending on the board layout and components used in the design. Noise generation is typically worse at higher switching speeds (assuming faster switching rise and fall times) and greatly depends on the parasitic elements in the high di/dt loops.

The parasitic elements of the package depend on the package construction, internal routing, internal components used and eventually the board layout. The converter package should minimize the internal parasitic elements in critical high di/dt loops and allow an optimal pinout for proper bypass capacitor placement. Some packages can also enable the integration of high-frequency bypass capacitors, with placement as close as possible to the IC.

Minimizing the area of high di/dt current loop(s) in the switching regulator is a critical first step for mitigating noise (**Figure 8**). Through the integration of bare silicon, ceramic capacitors and improved routing design rules, the Enhanced HotRod QFN package minimizes high di/dt loops in the converter design. Another advantage of the Enhanced HotRod QFN construction over a standard copper leadframe package is the ability to have a ground plane immediately underneath the IC and bypass capacitors, which results in lower switching noise, lower output noise and better EMI.

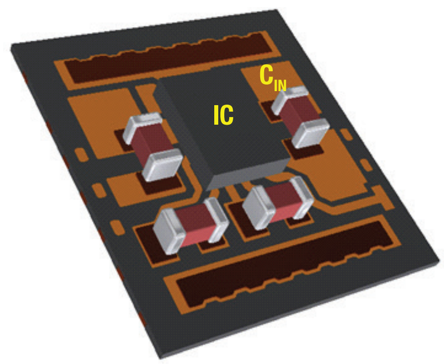

Figure 8. *Placing a high-frequency bypass capacitor as close as possible to the chip minimizes the high di/dt loop area.*

Summary

Balancing between efficiency, size, and thermal and EMI performance presents many design challenges for power-converter designers. Enhanced HotRod QFN package technology enables power-module manufacturers to take on these design challenges and ultimately produce smaller, more efficient, cooler and quieter power-converter modules resulting in easy-to-use and highly-optimized power converters such as TPSM53604 that greatly simplify the process of DC/DC converter design.