

Enhanced HotRod™ QFN Package: Achieving Low EMI Performance in Industry's Smallest 4-A Converter



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ABSTRACT

It is a constant battle for the power designer to balance size, efficiency, heat, and noise levels in DC/DC regulators. This balance could heavily depend on the packaging technology used for the power converter or power module construction. The Enhanced HotRod™ (HR) QFN package technology addresses multiple design challenges and allows power converter and module manufacturers to push the industry envelope on package size, efficiency, thermal dissipation capability, and noise performance.

Texas Instruments' enhanced HotRod QFN package merges the noise benefits of a flipped chip on lead-frame (FCOL) package with the thermal benefits of a ground DAP on a standard QFN package. By leveraging the FCOL package technology, the enhanced HotRod QFN package eliminates package wire-bonds and achieves best-in-class EMI performance (Section 2), and by leveraging the standard QFN package technology, the enhanced HotRod QFN package uses a center PowerPad™ IC package to dissipate heat and achieves 4 A at an ambient temperature of 85°C (Section 4). The LM60440, LM60430, LM60440, and LM60430-Q1 are TI's first DC/DC converters with Enhanced HotRod QFN package technology, and their performance is evaluated throughout this application note.

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1 Introduction

Enhanced HotRod QFN is the latest advancement in semiconductor packaging which enables the industry's smallest 4-A, 36-V step-down converter. Figure 1-1 shows the semiconductor packaging technology evolution for high-power density step-down converters. The LM43603 was developed in a leaded HTSSOP package which uses a ground DAP for optimal thermal dissipation through the bottom side of the package. Second, the LMR23630 was released in a standard QFN package to eliminate the external leads while still having a thermal DAP. Consequently, the LMR23630 package size decreased by 73% compared to the previous generation converter. Third, the flip-chip on lead-frame (FCOL) technology has further improved the package-to-die ratio and removed package wirebonds connecting die to lead-frame to provide best-in-class noise performance. The Enhanced HotRod QFN package leverages the noise improvements of the FCOL package (Section 2) and the thermal advantages of the standard QFN package (Section 4). Figure 1-2 highlights the enhancements from FCOL and standard QFN packages to 'Enhanced' QFN. The latest TI part developed with Enhanced HotRod QFN package technology is the LM60440 device. It has a 4-A output current capability in an ultra-small 3-mm x 2mm package.

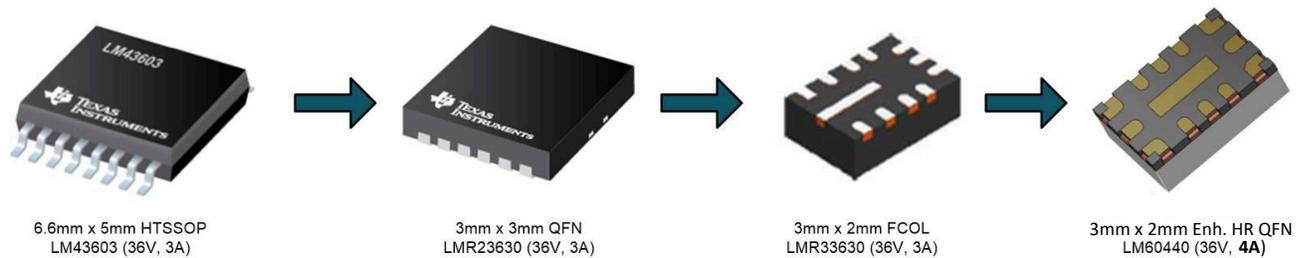


Figure 1-1. Texas Instruments Package Evolution

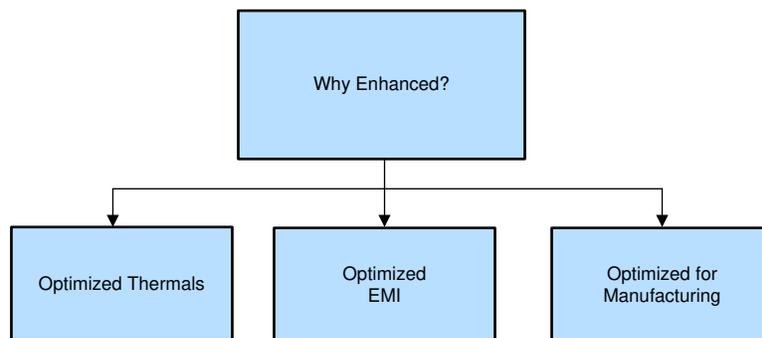


Figure 1-2. Feature Set of Enhanced HotRod QFN

2 Enhanced HotRod QFN – Optimized EMI Performance

2.1 Introduction

MOSFET technologies for wide input DC/DC converters enable the design of fast switching and high-efficiency power systems. Consequently, the latest DC/DC converters lead to fast switch voltage slew rates (dv/dt) and high-current slew rates (di/dt) which exacerbates the EMI emissions from a switch mode power supply and can cause problems to peripheral modules. For more details on the sources of EMI in DC/DC converters see the [EMI Guide technical article series](#). EMI filters are inevitably part of a power electronic system, but since filtering adds unwanted size and cost, it is incumbent on the designer to look for all possible avenues including package technology for EMI noise reduction and mitigation. Regulatory compliance to electromagnetic compatibility (EMC) standards—for example, CISPR 32 for multimedia equipment and CISPR 25 for automotive applications is vitally important, as the efforts required to achieve compliance affect both product development costs and time to market. CISPR-25 is one of the most stringent emission standards for vehicles and devices targeting radio disturbance characteristics. The limits and methods of measurements are intended to protect onboard receivers from disturbances produced by components, such as a switching regulator in a power-supply design. For a deeper understanding of CISPR and other emission standards, see [An overview of conducted EMI specifications for power supplies](#) and [An overview of radiated EMI specifications for power supplies](#) white papers.

Low-EMI switching regulators utilize package technology, optimized pin-outs, and layout guidelines to minimize conducted and radiated noise from DC/DC converters which can enhance power system's performance to meet stringent EMI standards. TI's latest converter, LM60440, leverages the latest Enhanced HotRod QFN technology, and the pinout and package of the LM60440 regulator have been diligently optimized to minimize the parasitic inductance of switching loops to achieve the best-in-class low-noise performance.

2.2 Enhanced HotRod QFN Package

As discussed in [Section 1](#), the Enhanced HotRod QFN package has evolved from the standard QFN package and the FCOL package. Before delving into the latest package technology, it is important to understand the merits of the construction of each of its parent packages.

A standard QFN package has wire-bonds connecting the silicon to the lead frame ([Figure 2-1](#)). These wire-bonds can have inductance in order of 2 nH, and during a switching event, its commutating current can be in the order of 2 A/ns which can result in voltage overshoot up to 4–5 V on switch-node. Furthermore, device package wire bonds contribute significantly to the parasitic inductance of the power loop where fast switching (current and voltage) edges—and possible leading-edge ringing related to body diode reverse recovery and MOSFET COSS charging—is rich in harmonic content. The corresponding switch node ringing poses a severe threat of H-field and E-field coupling and consequently increases conducted and radiated emissions ([Figure 2-2](#)).

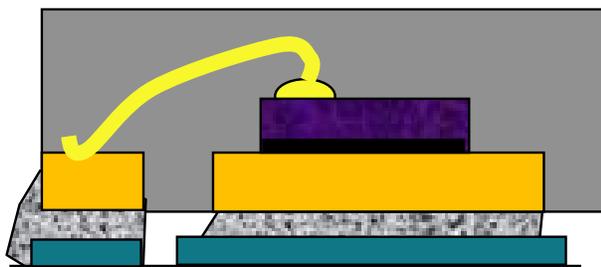


Figure 2-1. Standard QFN Package Diagram

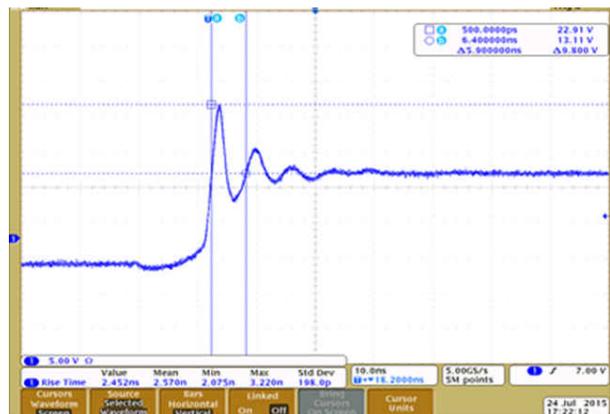


Figure 2-2. Switch Node Waveform (Standard QFN Package)

The LMR33630 utilized FCOL package technology, as shown in [Figure 2-3](#), to eliminate the wire bonds by flipping the die on the lead frame to achieve the best possible EMI performance. The switch node waveform is

shown in [Figure 2-4](#) and the ringing has been eliminated. The trade-off of this technology is that the heat needs to dissipate through all the pins of the package. Due to the physical size limitation of each pin and absence of dedicated ground DAP for heat dissipation, the thermal performance of the FCOL package is limited compared to the standard QFN package. This observation is discussed in more detail in [Section 4](#).

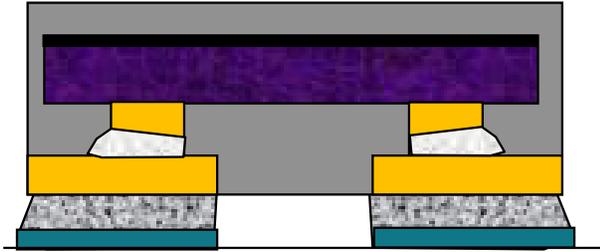


Figure 2-3. FCOL Package Diagram

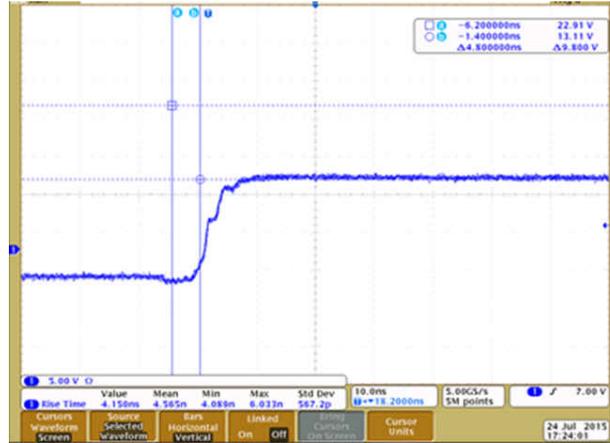


Figure 2-4. Switch Node Waveform (FCOL Package)

TI's latest Enhanced HotRod QFN package offers next-generation technology to provide a low-EMI, high-power density solution in a standard QFN pinout for design familiarity and flexibility. The LM60440 and LM60440-Q1 devices are wide-VIN synchronous buck converters designed for low noise and EMI. The LM60440 device has an input voltage range of 3.8 V to 36 V capable of up to 4 A of load current. The LM60440 device has the same FCOL technology to eliminate the wire bond (expect same EMI performance), but utilizes a PowerPad (pin 13) consistent with a standard QFN package for better thermal relief and performance. In conclusion, Enhanced HotRod QFN package technology offers the best possible EMI performance and best possible thermal performance (as detailed in [Section 4](#)). In the following section, the Enhanced HotRod QFN Pin-Out ([Figure 2-5](#)) is examined in more detail.

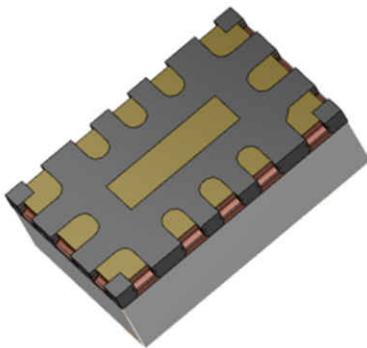


Figure 2-5. LM60440 Package

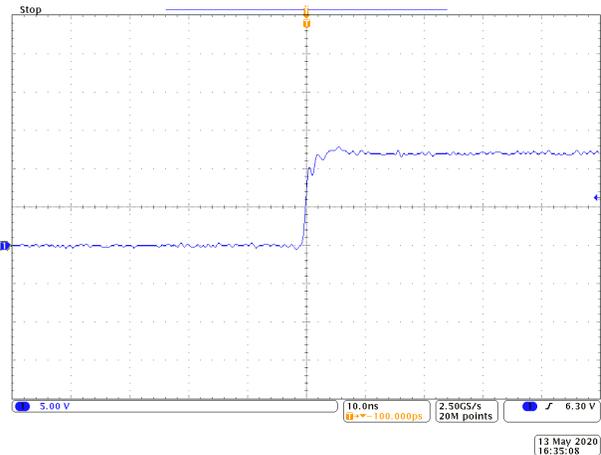


Figure 2-6. LM60440 Switch Node

2.3 Enhanced HotRod QFN Pin-Out

Another key feature for best-in-class EMI performance is the ability to optimize the pin-out. The optimized pin-out of the LM60440 device is shown in [Figure 2-5](#). The LM60440 has parallel pins for the input power and GND pins which enables the symmetrical placement of high frequency input capacitors, and the equivalent parasitic loop inductance of the two equal, parallel inductances, is halved. Consequently, the circulating input currents create opposing magnetic fields that result in H-field cancellation and reduced radiated emissions. Furthermore,

by performing the symmetric layout of the high di/dt input loops, the magnetic fields generated (of opposing directions) can cancel each other. To further reduce parasitic inductance place a continuous ground plane for return current underneath the L1 and L2 loops on layer 2 of the PCB - immediately below the top layer power circuit (Figure 2-8). Additionally the LM60440 device has conveniently routed the switch node pin internally. The second switch node pin is placed directly adjacent to the BOOT pin (boot-strap supply voltage for internal high-side driver). This simplifies routing the boot capacitor and reduces the SW area. The close placements of both the boot and VCC capacitors reduces the parasitic inductance for the gate driver circuitry and the commutating power loop carrying high-frequency currents during the MOSFET switching and ultimately reduces the conducted and radiated emissions.

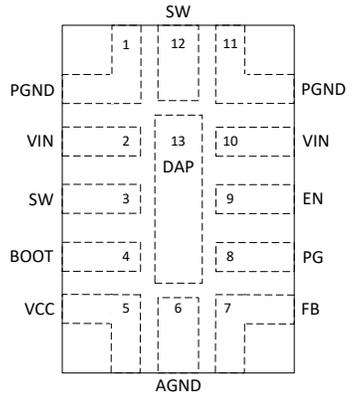


Figure 2-7. LM604x0 Pin-out

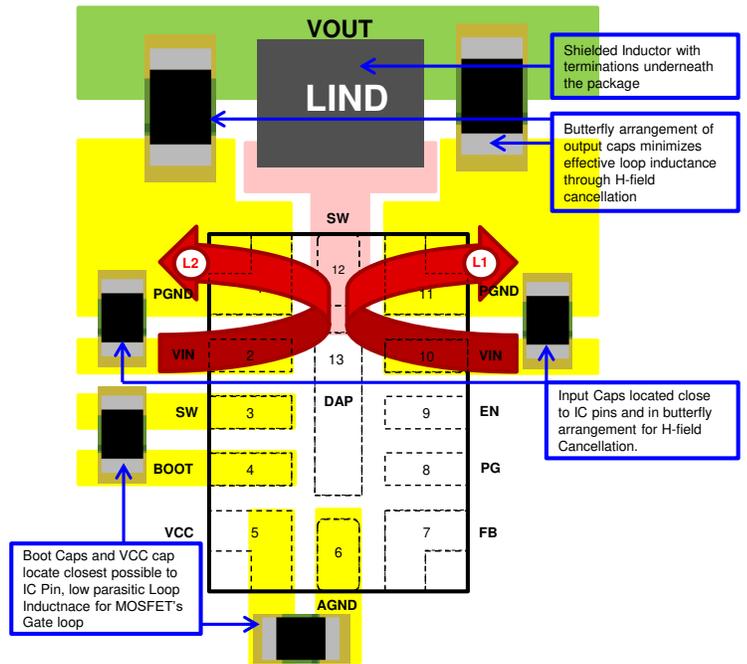


Figure 2-8. LM604x0 Layout With Parallel Input Loops

The optimized pin-out of the LM60440 allows for a dense layout and a compact total solution size (Figure 2-9).

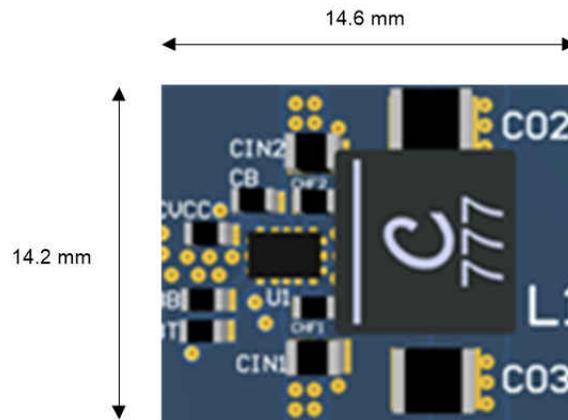


Figure 2-9. LM60440AQEVM Solution Size

2.4 Comparative Analysis of EMI Results between FCOL Package and Enhanced HotRod QFN Package

A PCB board was developed to compare the EMI results of the LMR33630 and LM60440 devices with identical EMI input filters and PCB layout. Figure 2-10 and Figure 2-11 show the results. The results show near identical EMI performance in the high-frequency region. Consequently, the elimination of the wire bonds in the FCOL package and Enhanced HotRod QFN package lead to at least 10 dB of margin across the entire high-frequency range.

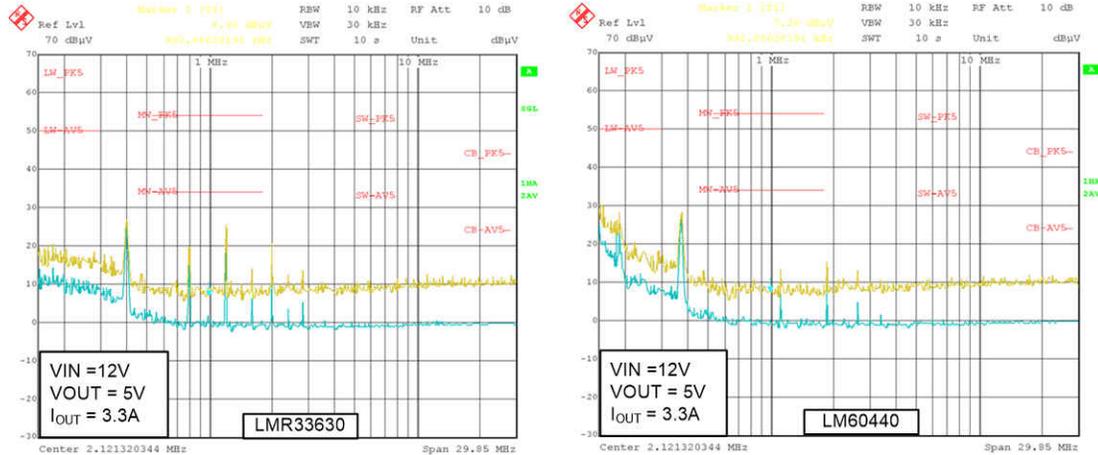


Figure 2-10. Conducted EMI Low Frequency

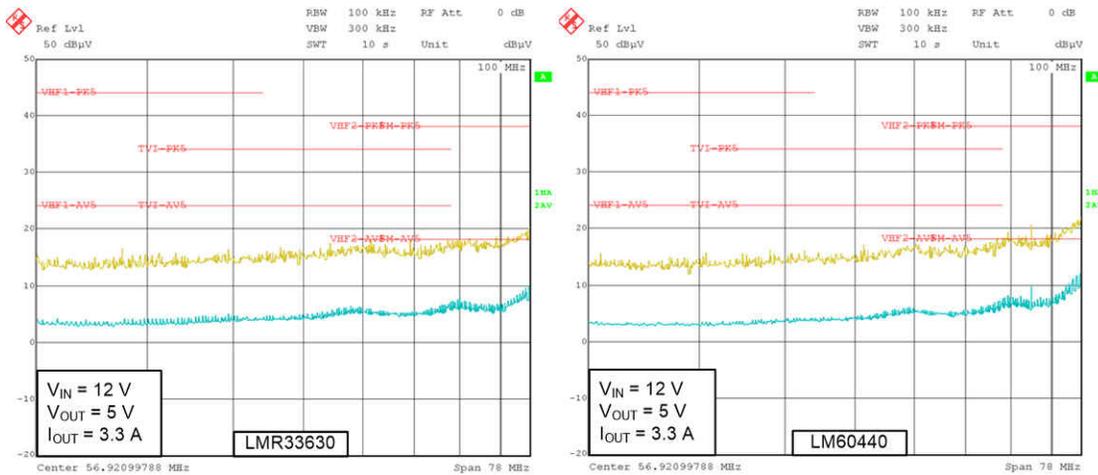


Figure 2-11. Conducted EMI High Frequency

3 Enhanced HotRod QFN - Optimized for Manufacturing

The construction of the package is also optimized for manufacturing with the inclusion of wettable flanks using step cut technology. Wettable flanks ensure visible side-wetting at good solder joints and enable 100% visual inspection while using an Enhanced HotRod QFN package. The wettable flank step cuts are visible on the package pinout in [Figure 3-1](#). [Figure 3-2](#) shows the side view of the solder joint.

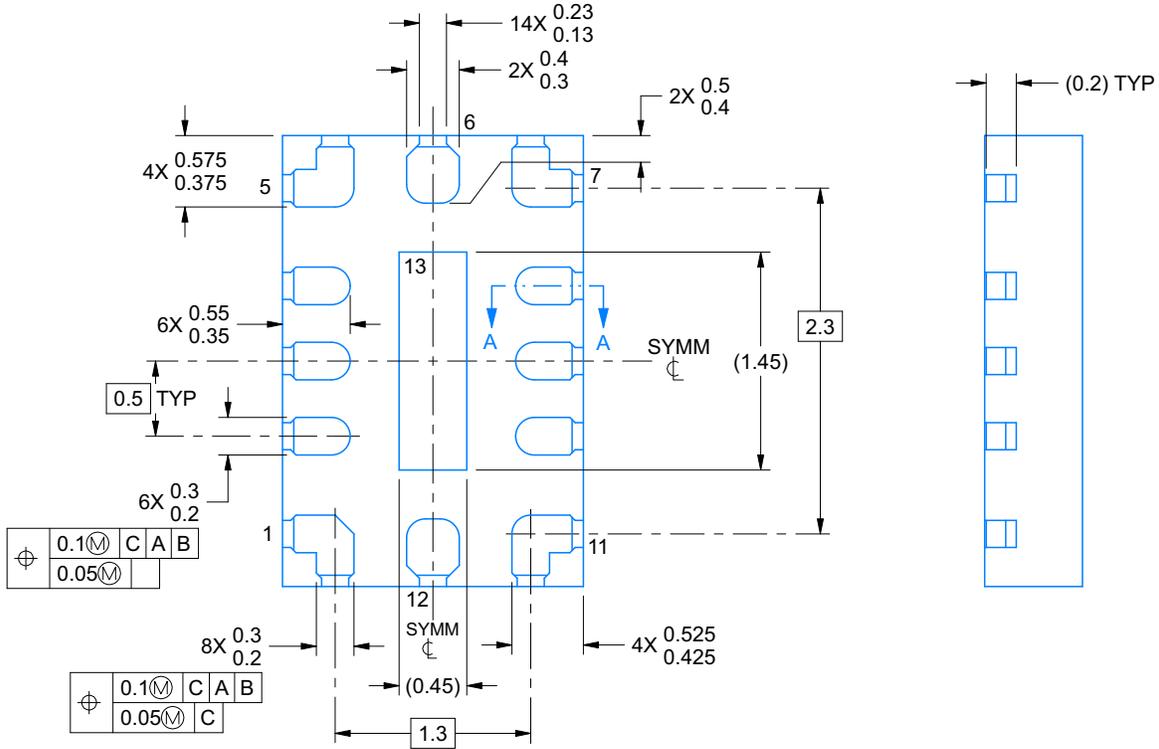


Figure 3-1. LM604x0 Package Drawing With Step Cut Illustration

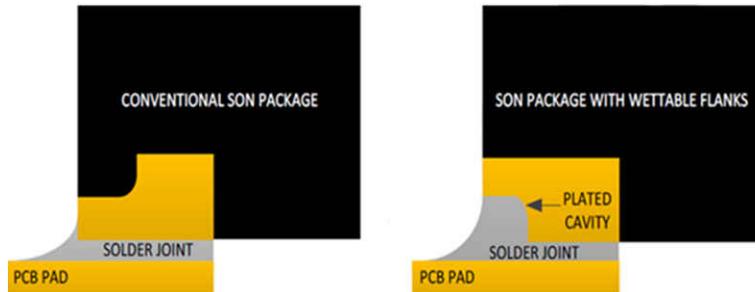


Figure 3-2. Wettable Flanks Solder Connection

4 Enhanced HotRod QFN - Optimized for Thermals

4.1 Introduction

As discussed through this application note, one of the tradeoffs between the QFN package technology and FCOL package technology is the thermal performance. The Enhanced HotRod QFN package leverages a PowerPad to increase thermal dissipation through this ground connection. [Section 4.2](#) will quantify the thermal advantage of the PowerPAD with the LM60440.

4.2 Enhanced HotRod QFN Thermal Performance

The LM60440 device is the industry's smallest 4-A, 36-V converter with a package size of 3 mm × 2 mm. The package size is enabled by QFN package technology and the implementation of a PowerPad. The PowerPad is a ground connection in the middle of the IC used to improve thermal dissipation ([Figure 2-7](#)).

The symmetric QFN pin-out eases the layout – particularly to enable optimized thermal design. [Figure 4-1](#) illustrates the LM60440AQEVM layout. The blue outline represents the placement of the LM60440 IC. Three thermal vias are placed under the IC from the PowerPad to the ground plane. The PowerPad is then connected to the larger ground plane through the AGND pin (pin 6). In addition the top corner ground pins are also used to remove heat from the IC.

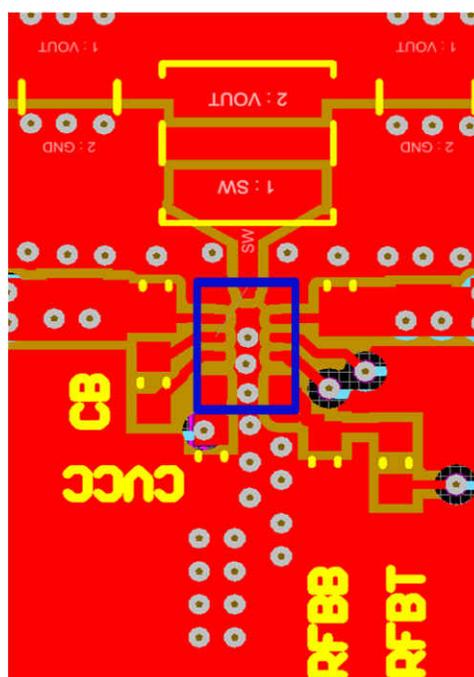


Figure 4-1. LM60440AQEVM Layout

[Figure 4-2](#) illustrates the thermal image of the LM60440AQEVM. At a 12-V input, 5-V output, 4-A load, the IC temperature raises approximately 60°C. The maximum operating junction temperature of the LM60440 and LM60430 devices is 150°C. At the operating conditions of $V_{IN} = 12\text{ V}$, $V_{OUT} = 5\text{ V}$, and $I_{OUT} = 4\text{ A}$, the efficiency of the LM60440 device at 87°C will be 89% ([Figure 4-3](#)).

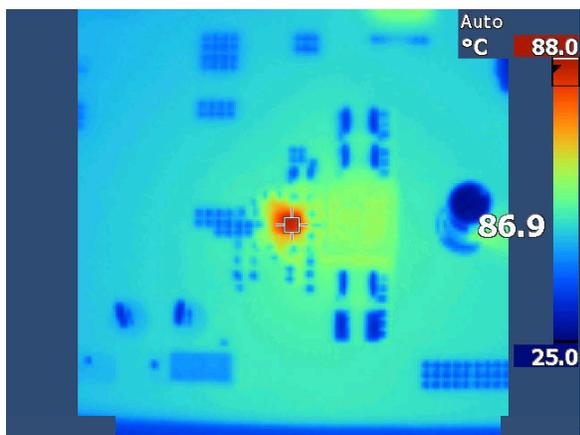


Figure 4-2. LM60440AQEVM Thermal Image ($V_{IN} = 12\text{ V}$, $V_{OUT} = 5\text{ V}$, $I_{OUT} = 4\text{ A}$)

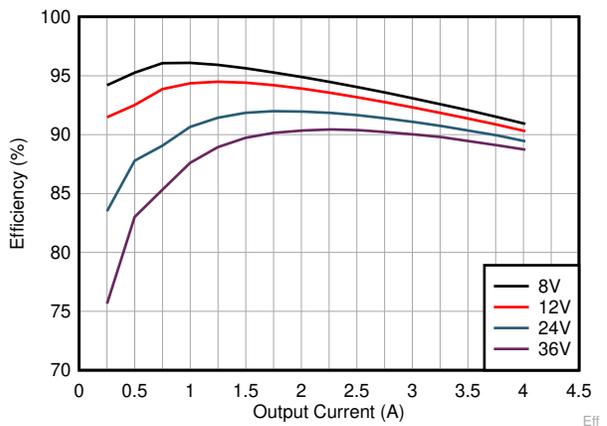


Figure 4-3. LM60440 Efficiency vs Output Current ($V_{IN} = 12\text{ V}$, $V_{OUT} = 5\text{ V}$, $I_{OUT} = 4\text{ A}$)

The total power dissipation is 2.2 W. The inductor used is the XAL6060-682MEB which has a DCR of 20.8 m Ω . To accurately calculate the temperature characteristic of the IC, the power dissipation of the IC alone must be calculated as Equation 1 and Equation 2 show.

$$P_{Diss_IND} = DCR \times I_{OUT}^2 = 20.8\text{ m}\Omega \times 4^2 = 332.8\text{ mW} \quad (1)$$

$$P_{Diss_IC} = P_{Diss_Total} - P_{Diss_IND} = 2.2\text{ W} - 332.8\text{ mW} = 1.87\text{ W} \quad (2)$$

The IC losses are 1.87 W. Then the characteristic θ_{JA} of the PCB can be calculated as Equation 3 shows.

$$\theta_{JA} = T_{Rise} \div P_{Diss_IC} = 61.9\text{ }^\circ\text{C} \div 1.87\text{ W} = 33\text{ }^\circ\text{C/W} \quad (3)$$

Both the LMR33630 and LM60440 device are in a 3-mm \times 2-mm package. For comparison, a similar procedure was completed for the LMR33630 device, and Figure 4-4 shows the thermal image.



Figure 4-4. LMR33630 Thermal Image

The LMR33630 θ_{JA} was found to be 38.6 $^\circ\text{C/W}$. The Enhanced HotRod QFN package offers approximately a 13% improvement in thermal characteristics compared to the FCOL package technology. Figure 4-5 shows the LM60440 and LM60430 maximum load current versus ambient temperature curve. The LM60440 device is capable of operating at full load current at 85 $^\circ\text{C}$ and the LM60430 device is capable of operating at full load current at 100 $^\circ\text{C}$.

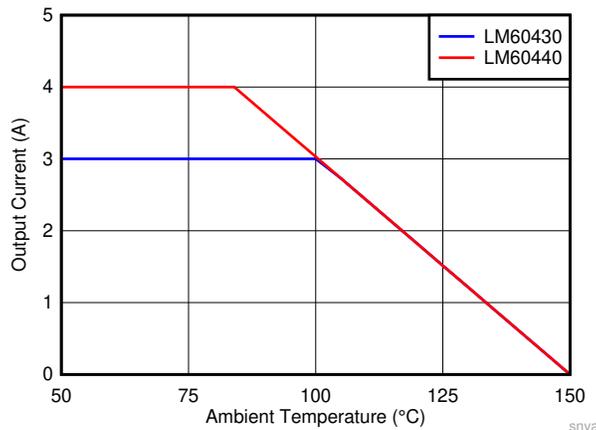


Figure 4-5. Maximum Current vs Ambient Temperature

5 Summary

Texas Instruments' Enhanced HotRod QFN package technology leverages the low noise performance of the FCOL package and the thermal benefits of a standard QFN package with a thermal DAP. The LM60440, LM60430, LM60440-Q1, and LM60430-Q1 are TI's first DC/DC converters with the Enhanced HotRod QFN package. As illustrated throughout the application note, the LM60440 product family achieves best in class EMI performance and passes the most stringent CISPR 25 Class 5 limits. In addition the thermal pad of the LM60440 and LM60440-Q1 enables 4-A output current capability in ultra-small 3-mm × 2-mm Enhanced HotRod QFN package. Ultimately, the Enhanced HotRod QFN package leverages the low-noise enhancements of FCOL technology and the thermal enhancements of a standard QFN package to enable best-in-class low EMI in industry's smallest 4-A converter, the LM60440.

For more information on the LM60440 product family, please visit the product folders of the [LM60440](#), [LM60440-Q1](#), [LM60430](#), and [LM60430-Q1](#).

6 References

- Texas Instruments, [An overview of conducted EMI specifications for power supplies white paper](#)
- Texas Instruments, [An overview of radiated EMI specifications for power supplies white paper](#)
- Texas Instruments, [EMI: The Fundamentals](#)
- [The Engineer's Guide To EMI in DC-DC Converters](#)
- Texas Instruments, [There are more ways than you think to reduce conducted EMI](#)
- Texas Instruments, [How a DC/DC converter package and pinout design can enhanced automotive EMI performance](#)

7 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (June 2020) to Revision A (July 2021)	Page
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|--|---|
| • Updated the numbering format for tables, figures and cross-references throughout the document..... | 1 |
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