Benefits and trade-offs of various power-module package options

Texas Instruments

Kelvin Odom
Product Marketing Engineer
Buck Switching Regulators
Texas Instruments

Texas Instruments has developed innovative power module solutions in a variety of package options. Choosing the right package involves trade-offs in size, power density, and ease of use.

Advances in power-module packaging technology have enabled increasingly robust, small, and easy-to-use DC/DC solutions. Power modules integrate a DC/DC converter integrated circuit (IC) with passive components in one compact package to simplify the design process and accelerate time to market.

There are now several different module package options on the market, each with their own benefits and drawbacks, and it's not always easy to determine which solution is the best fit for your design. This white paper discusses a few package options – embedded, leaded and quad flat no-lead (QFN) – and the benefits and trade-offs of each in terms of module size, component integration, thermal performance and electromagnetic interference (EMI) considerations.

Embedded modules

Embedded modules such as the TPS82150 offer the smallest total solution size available of all module packages. This is due largely in part to a novel manufacturing technique [1], as illustrated in **Figure 1**.

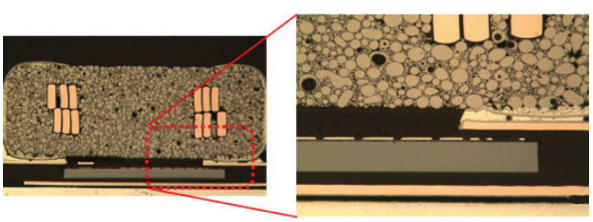

Figure 1. Cross-sectional view of an embedded module package.

A printed circuit board (PCB) serves as the base of the module, and as the name implies, the converter IC is embedded directly within the PCB. This frees up space on the top of the board for passive components, as shown in **Figure 1,** where the inductor is mounted directly on the PCB. In some embedded modules, TI also uses these top-side space savings to place input and output capacitors on either side of the inductor (one example of this is the TPS8268090). The end benefit of such a layout is that these modules offer best-in-class size and high component integration.

The unique architecture of embedded modules places some limitations on where you can use them. The material in which the IC is embedded is FR-4, which has a relatively higher junction-to-ambient thermal resistance (θ_{JA}) than the copper lead frames found in other module package options. As a result, today's embedded modules have a peak output current of around 3A, so other module package options are a better fit for high current applications. However, these modules' very small size and low quiescent current make them great for battery-powered personal electronics applications and digital systems that require multiple output voltages from a common 5V or 12V bus.

Leaded modules

Leaded modules such as the LMZ14203 are the easiest to use of all of the module packages, as they provide the same benefits engineers have come to expect from leaded ICs. Leaded modules are manufactured by attaching the die to the underside of the top lead frame, which is then mated to the top of the bottom lead frame. The bottom lead frame serves as a base for the module, and has a large exposed pad that enables the module to dissipate heat effectively during operation. The inductor and resistors are placed on the top side of the top lead frame, which is molded with epoxy to encapsulate the components while leaving the leads exposed. **Figure 2** illustrates the final result of this manufacturing process.

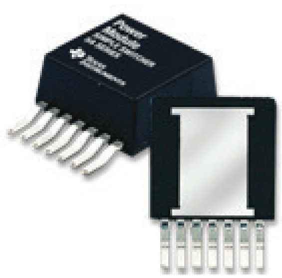

Figure 2. View of a leaded module with an exposed ground pad.

As with embedded modules, the "3-D" manufacturing approach by which the inductor is placed above the converter die shrinks the footprint of the module relative to an equivalent discrete solution. Visible external leads mean that soldering and debugging circuits by hand is much simpler than it would be using a no-lead module such as a QFN. Visible leads also means that making changes to prototype boards is easy. External leads are beneficial in manufacturing, where solder integrity can be verified by visual inspection.

The largest drawback of leaded modules is their relatively low current density. While the footprint of the module is smaller than a comparable discrete solution, the leaded package size is larger than other module packaging options, making it a less attractive choice for size-constrained applications. Leaded modules can serve higher current rails than embedded modules (TI's offerings today cover up to 10A) although you may still get slightly better thermal performance out of a QFN module. Another drawback of leaded modules is cost: multiple lead frames and a complex internal configuration can make manufacturing leaded modules more costly than alternative solutions. In spite of these limitations, leaded modules' ease of layout and rework and visual inspection capabilities make them very attractive for industrial applications such as factory automation equipment and electricity meters.

QFN modules

QFN modules such as the TPSM84A22 offer the highest density of all module package options. There are three slightly different approaches to manufacturing QFN modules: overmolded lead frame, overmolded laminate and open frame laminate. Regardless of manufacturing technique, QFN modules are unique in that they use pre-packaged, tested silicon rather than unpackaged die and have a footprint similar to QFN ICs. QFN modules' higher current density enables the powering of applications that other modules can't touch, such as high-end field-programmable gate arrays (FPGAs).

Unlike leaded modules, lead frame-based QFN modules only use a single lead frame. The packaged IC and passives are placed directly on top of the lead frame and are typically covered by a stilted inductor. The lead frame is then molded with epoxy, leaving only the flat electrical pins on the bottom side of the module exposed. **Figure 3** illustrates these steps.

Figure 3. The manufacturing of a typical overmolded lead frame QFN module.

Internally, laminate-based QFN modules look similar to a circuit laid out on a PCB. That's one advantage of using a laminate base in module construction – it is easier to lay out complex circuits on laminate than it would be on a copper lead frame. Open frame laminate QFN modules are very similar to overmolded lead frame modules; both feature a packaged IC surrounded by discrete components under an inductor. Today's overmolded laminate modules (and some overmolded leadframe modules) differ from other module packaging technologies because they often use 2-D construction with standard inductors, rather than the stilted inductors found in other modules. While the footprint of these modules may grow as a result, their height can shrink significantly, enabling novel applications such as mounting the module on the back side of a board for space savings. These modules also differ from their peers in the number of discrete components inside (**Figure 4**), often including input and output capacitors in addition to the resistors and inductors that are standard in all power modules.

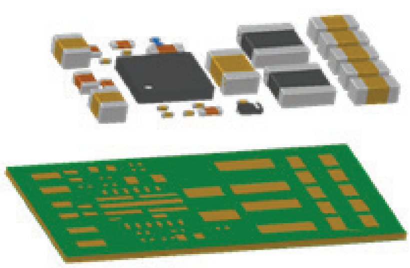

Figure 4. Overmolded laminate QFN modules include many discrete components.

These modules' similarity to traditional QFN ICs carries both benefits and challenges. Not only are QFN modules significantly smaller than their equivalent leaded counterparts, their superior θ_{JA} enables the supply of higher power than what's possible with other packaging approaches. However, if you don't have experience working with QFN packages, you may find working with them slightly more challenging than with leaded modules. Also, QFN modules can also appear more expensive than modules in other packages, but this is frequently a symptom of their higher power output and greater component integration rather than an indication of a "premium" associated with the package. All things considered, the small size and high current density offered by QFN modules aligns nicely with the needs of applications such as test and measurement and communications, where power-hungry FPGAs sit at the core of the design.

EMI considerations

When powering noise-sensitive, high-power loads such as FPGAs and application-specific integrated circuits (ASICs), it's critical that your power supply meets EMI performance standards. The biggest contributor to EMI radiation is the slew rate of the switch node – the faster it is, the more likely you are to run into issues. TI modules have several precautionary features to help mitigate these issues.

The inductors used in most TI modules are shielded – that is, they have a noise-insulating layer between the noisy inductor coil and the rest of the circuit, which helps reduce emissions. Additionally, many modules minimize the switch-node area to help reduce the antenna effect. If necessary, you can also add an external snubber to slow the slew rate of the switch node. You're most likely to need this solution with higher-power QFN modules, where fast switch-node transition is necessary to reduce switching losses.

When taking steps to mitigate EMI radiation, the actual performance can vary from module to module. Review the radiated emissions data for any device you may be considering to ensure that it won't cause issues in your system.

Summary

In general, integrated power modules provide benefits over discrete solutions because they are easy to use, and their 3-D construction (where the inductor is placed on top of the converter IC) saves board space relative to equivalent discrete solutions. However, there are several different module package options that can optimize different facets of your power design. If having the absolute smallest size is critical (even if it means limiting power output), an embedded module is the best option. If ease of prototyping and more robust manufacturing are priorities (even if it means using a relatively larger package), a leaded module will be a better fit. And if you desire the highest power density and most highly integrated power solution available (even if it will make manufacturing a bit more challenging), try using one of several QFN module package options.

To learn more about specific devices and see TI's full power-module portfolio, visit www.ti.com/powermodules.

References

1. Goacher, Steve. "Power Modules: How We Build Them and Why You Need Them." March 2017. Lecture.

About the author

Kelvin Odom is a product marketing engineer within TI's Buck Switching Regulators group. Kelvin received his bachelor's degree in electrical engineering from the University of Texas at Austin, and can be reached at kelvin.odom@ti.com.

Important Notice: The products and services of Texas Instruments Incorporated and its subsidiaries described herein are sold subject to TI's standard terms and conditions of sale. Customers are advised to obtain the most current and complete information about TI products and services before placing orders. TI assumes no liability for applications assistance, customer's applications or product designs, software performance, or infringement of patents. The publication of information regarding any other company's products or services does not constitute TI's approval, warranty or endorsement thereof.

The platform bar is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

© 2017 Texas Instruments Incorporated

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ('TI") technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI's standard terms for semiconductor products http://www.ti.com/sc/docs/stdterms.htm), evaluation modules, and samples (http://www.ti.com/sc/docs/sampterms.htm).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2017, Texas Instruments Incorporated