

The Evolutionary Path to the 100 A μ Module Regulator

By **Tony Armstrong**

Introduction

A μ Module® device resembles a surface mount IC, but they include all the necessary support components that would normally be used to construct a power conversion circuit. This includes a dc-to-dc controller, MOSFET dice, magnetics, capacitors, resistors, and so on, all mounted on a thermally efficient laminate substrate. They are then encapsulated using a plastic mold cap. The result is a complete power supply that can be simply adhered to a printed circuit board (PCB).

Built to the industry's highest quality standards, this product family dramatically reduces risk, time, and effort to successfully design high performance, high power density solutions. It is as if we have taken all our power supply expertise and know-how within Analog Devices and put it into an IC-like form factor. For those of you who have had time constraints for designing power conversion circuits where mass production is only weeks away—and you have had to spend many late nights debugging your supply late into the early morning—those times will be a thing of the past if you use a μ Module regulator instead of a “do-it-yourself” discrete solution.

Taking a closer look at the internal construction of a typical μ Module product, you will notice that the package options are a land grid array (LGA) or ball grid array (BGA). The internal components used to form the internal switch-mode power conversion circuit can be in die form, while others are finished packaged products. Nevertheless, these components are all mounted onto a bismaleimide triazine (commonly known as BT) laminate substrate, which has excellent electrical and thermal properties. Moreover, μ Module products are not just about integration, as they provide other properties and performance characteristics over competing alternatives.

Power design expertise is declining on a global basis and there are simply not enough power supply design resources to develop every single power supply at most customers' sites. It is reported by the trade press that the average age of a degreed engineer is 57 years—and this is a global statistic, with China having the youngest average.

The top three concerns of power design engineers are:

- ▶ Insufficient people to get the job done.
- ▶ Finding the optimal components for their design.
- ▶ Time-to-market pressures.

Because of these trends, we wanted to deliver a complete power supply that is ready to use off-the-shelf and with all the performance criteria required for the end application. Furthermore, at the same time, PCB area is at a premium since everyone is trying to pack even more functionality and capability into a smaller space. If this is not bad enough already, thermal design constraints are becoming more complex as designers try to pack more capability into an ever-smaller space while delivering more power in an environment that has limited airflow for cooling purposes.

Finally, time-to-market pressures are intense as the power supply is one of the last items to be designed in a system and mass production starts can be just weeks away!

PCB area is a critical priority in most designs. For example, any given datacom or telecommunications board is bound to be laden with many digital processors, ASICs, and memory. All these need to be powered on the board while voltage levels vary from just north of 5 V to as low as 0.6 V, after an intermediate system bus voltage which varies from 12 V to 48 V. At the same time, system designers are continually being asked to pack more functionality into these ever-shrinking form factors—which are probably mutually exclusive!

Design Problems That Needed to Be Solved

Thermal design constraints are becoming more severe. As more and more functionality is packed onto the PCB, the overall power levels needed to power them on the board are increasing. Meanwhile, cooling is at a premium due to heat sinking space constraints and limited air flow volume. This is a headache for the designer, since there is a maximum internal ambient temperature constraint on the system that cannot be violated without compromising performance and long-term reliability.

Time-to-market pressures have increased dramatically in recent years due to both competitive pressures and the need for faster revenue streams. So, the power supply designer is under the gun for getting his power conversion circuits designed and functional in weeks, if not days!

Simply put, μ Module products provide a “simple and done” proven power conversion solution. So, using them means no more late nights of debugging power supplies in the lab!

Of course, these products need to have rigorous quality and long-term reliability to ensure long operational life once they have been deployed in an end system. Accordingly, ADI has engaged in rigorous quality and reliability testing to ensure long-term deployments in harsh environments.

The following is a summary of the testing and data we have accumulated since the introduction of our first μ Module product, the LTM4600, back in October of 2005. This includes:

- ▶ Over 22 million power cycles.
- ▶ Over 5 million device hours of hot temperature operational life.
- ▶ Over 2 million hours of mounted temperature cycles to ensure that these modules can operate 24 hours per day, 7 days per week, 365 days per year for a decade without having any intermittent contact issues from the package leads to the PCB.
- ▶ Over 25 million temp cycles from -65°C to $+150^{\circ}\text{C}$.
- ▶ Over 16 million thermal shock cycles from -65°C to $+150^{\circ}\text{C}$. And remember, this is liquid-to-liquid on a finished power supply!

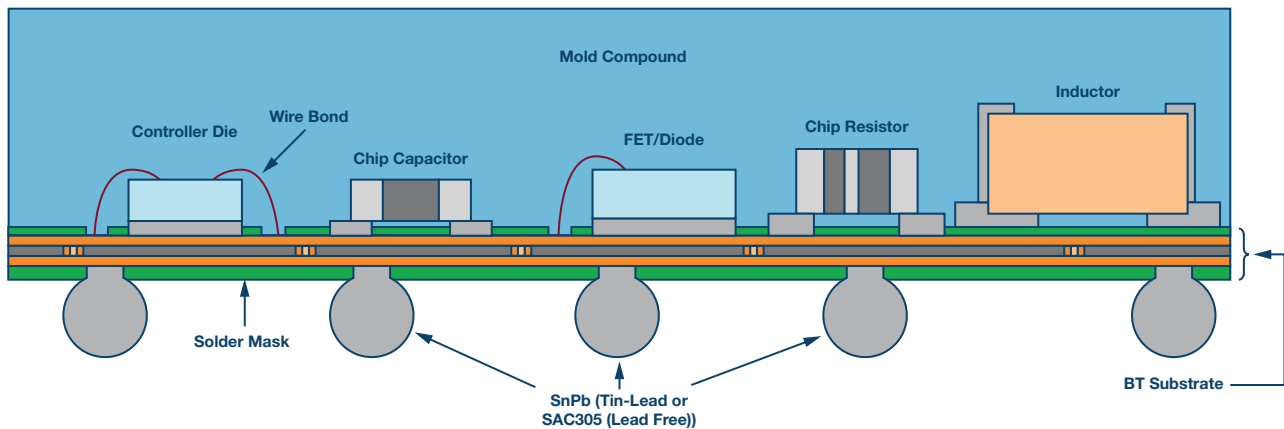


Figure 1. A μ Module regulator BGA package cross-section.

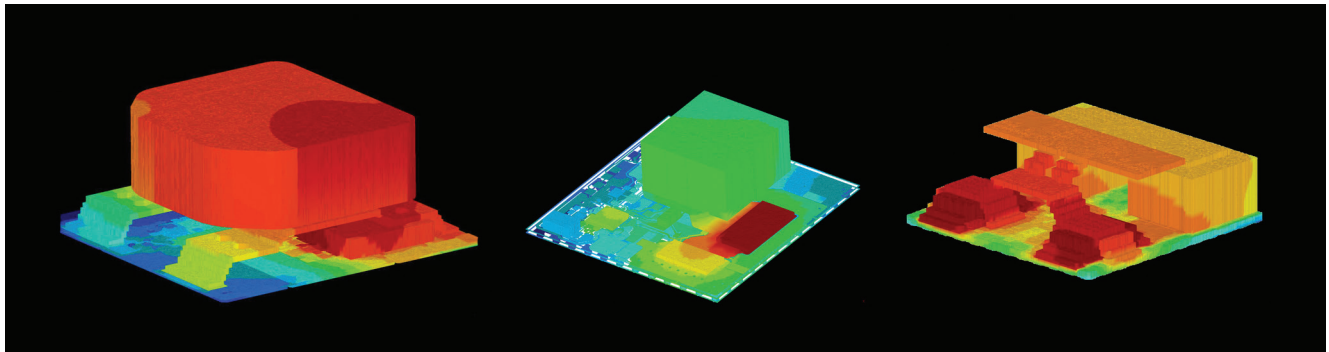


Figure 2. Thermal imaging of a μ Module regulator construction and heat dissipation.

The end outcome is an FIT rate of <0.4 . To put this in perspective, this equates to 0.4 device failures in every billion device hours of operation. And this is on a complete power supply. To put this in context, many of our competitors' integrated circuits (single silicon in a package) have higher FIT rates!

Packaging Evolution

Let's take a closer look at the μ Module packaging options. When we first introduced the LTM4600 way back in 2005, we used an LGA package option. The thinking at the time was that since a lot of the VLSI digital ICs had similar LGA form factors, it would be easy for the user to use our μ Module products. While this was true some of the time, it was not true all of the time.

Accordingly, it was decided that having a BGA package option would be an innovative idea, too. This turned out to be fortuitous for two reasons. First, it was easier for users who were not used to high volume production of the LGAs. And, secondly, it was easier to put solder balls on the round pin pads. Moreover, it allows for both leaded and lead-free solder balls. And since many μ Module device users are in the aerospace and military market segments, they were very happy about this.

Accordingly, the first part we introduced in this product category was named the LTM4600: a 4.5 V to 20 V input/0.6 V to 5.5 V output and up to 10 A of continuous output current. It was in a $15\text{ mm} \times 15\text{ mm} \times 2.82\text{ mm}$ surface-mount LGA package. Its application was 12 V_{IN} to $3.3\text{ V}_{\text{OUT}}$ at 10 A with 90% efficiency. Remember, this was October 2005, so this level of performance was ground breaking stuff.

Nevertheless, one of our key metrics was to improve the μ Module regulator's thermal performance so that we could increase its output current density while remaining in same the $15\text{ mm} \times 15\text{ mm}$ footprint. Since there was clearly a significant thermal issue, we needed to address getting the

heat out of the package. To facilitate this goal, our designers had decided to use a BT laminate substrate because it had excellent thermal properties and facilitated taking heat through the bottom of the μ Module package and into the PCB where it could be dissipated. While this was acceptable in the mid-2000s, by the time another 5 years went by, our customer-base informed us that they could no longer dissipate most of the heat through their PCB. Instead, it needed to be able to pull heat out of the top of the package and dissipate it into the air! Therefore, we designed a special heat sink that was encapsulated inside the package and connected to the top of the internal MOSFETs and inductors. This heat sink was exposed on the top side of the μ Module regulator. Now the user could add their own heat sink on top of the μ Module device to improve pulling heat out of it. If they had 200 LFM or airflow, they could also facilitate better thermal performance. Truly, a win-win scenario.

Regardless of this enhancement, we continued to evolve and developed μ Module regulators with inductors on top since these acted as heat sinks to further improve thermal dissipation qualities.

Finally, it should be mentioned why we introduced our ultrathin μ Module devices. We realized that, in many cases, our customers would only utilize the underside of their PCBs with discrete components due to space limitations. It turns out that for many rack-mounted systems, there was a 2.2 mm height restriction for mounting components on the underside of a PCB. Therefore, we developed μ Module regulators with 1.8 mm and 1.9 mm maximum heights so that they would easily fit while also helping with space and density issues.

Now, with this background, it is easy to comprehend what is going on with a μ Module devices' thermal performance. This can be thought of as an evolutionary pathway that has allowed for a continuous improvement of our μ Module thermal performance from inception through to our current offerings—a decade plus journey.

Figure 2 shows three thermal imaging photographs, representing several types of μ Module regulators with varying types of construction with the goal of increasing the device's ability to pull heat out of the top of the μ Module into free air where it can facilitate additional cooling from air flow within the system, or could also have an additional heat sink that is shared with the VLSI digital ICs that are usually present. The color blue shows low temperature (minimal power dissipation) and colors orange through red show elevated temperatures (high power dissipation). Of course, this is what we want to occur when we want the heat generated by the power conversion process to be pulled out into free air and not into the PCB.

While we have been improving the thermal performance characteristics of this product offering, we have simultaneously continued to increase μ Module regulators' power density by putting them into ever-shrinking form factors. Figure 3 shows the LTM4627, a 20 V input device that can deliver a 15 A output current as low as 0.6 V with an efficiency in the nominal 90% range depending on the specific V_{IN} and V_{OUT} conditions. Next to this is the LTM4638, which is also a 20 V input device and can deliver a 15 A output as low as 0.6 V with nominal 86% efficiency—pretty close! However, volumetrically, the LTM4638 is 5.6 times less than the LTM4627. See Figure 3 for a size comparison.

The point being that there is only a small delta in conversion efficiency between these two parts under the same operating conditions, but the footprint and space required for its implementation are orders of magnitude less. All this improvement has all been attained in less than 4 years.

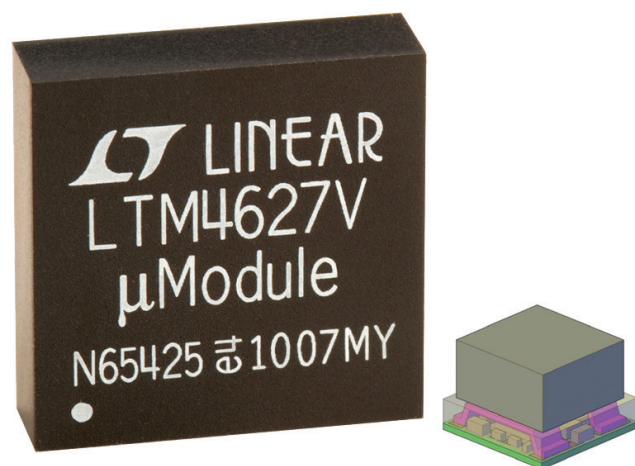


Figure 3. LTM4627 (15 mm × 15 mm × 4.92 mm) vs. its new, smaller equivalent, the LTM4638 (6.25 mm × 6.25 mm × 5.02 mm).

Sojourn to a Single 100 A μ Module Device

For a long time, our existing users of high power μ Module packages kept asking us for smaller, more efficient, and higher current density devices—even though this feature set might be considered mutually exclusive. Nevertheless, our design team took this request to heart and began to figure out a way to get us there.

From a historic perspective, back in the 2013 to 2016 timeframe, we had μ Module regulators in the 15 mm × 15 mm footprint that are capable of delivering output currents in the 26 A to 50 A per device range. It should also be noted that a key matrix measurement for our high power μ Module devices is that they should be able to deliver full rated output current from a 12 V input to a 1 V output with 90% conversion efficiency. The reasoning is that dealing with 10% power lost as heat is usually thermally acceptable within most applications. By late 2016, our 40+ A μ Module regulators had efficiencies in the 88% to 89% range—which is very close to this goal.

The progression to get to a 100 A single μ Module regulator required us to use multiple devices, as shown below:

Thus in 2010, having 12 LTM4601s in a Polyphase® parallel configuration allowed us to deliver a 100 A output from a 12 V to 1 V output.

In 2012, only four LTM4620s in a Polyphase parallel configuration allowed us to deliver a 100 A output from a 12 V to 1 V output.

In 2014, only three LTM4630s in a Polyphase parallel configuration allowed us to deliver a 100 A output from a 12 V to 1 V output.

In 2016, only two LTM4650s in a Polyphase parallel configuration allowed us to deliver a 100 A output from a 12 V to 1 V output. And we have $\pm 1\%$ total dc error over line, load, and temperature.

Finally, in November 2018, we introduced the LTM4700—a dual 50 A or single 100 A output μ Module regulator. See Figure 4 for an image of the actual device.

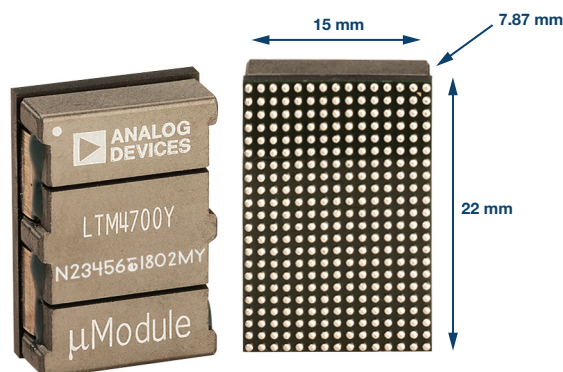


Figure 4. The LTM4700 is capable of delivering up to 100 A output current in a single package.

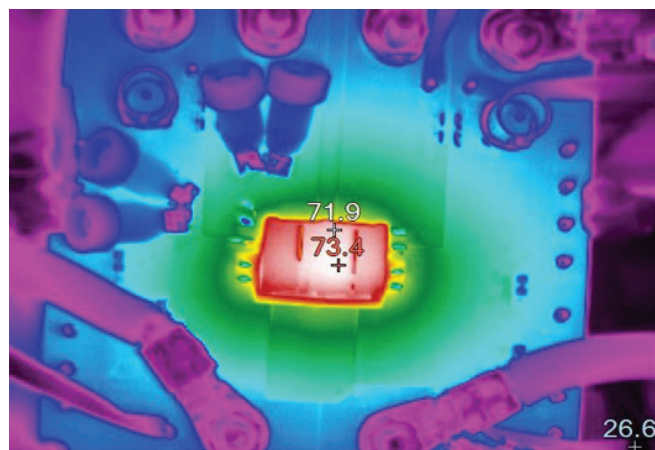


Figure 5. The LTM4700 100 A μ Module (89.6% efficiency).

Figure 5 shows a thermal image of the LTM4700 during normal operation. The operation conditions are 12 V to 1 V delivering 100 A of current with high conversion efficiency and only 200 LFM of airflow. As a result, its best-in-class energy efficient performance makes it an excellent choice to reduce data center infrastructure cooling requirements.

Taking a closer look at some of the LTM4700's key specifications:

- ▶ It is a single 100 A output capable μ Module device. It can also be used as two 50 A outputs.
- ▶ It is very close to 90% conversion efficiency when stepping down from 12 V to 1 V at 100 A with only 200 LFM air flow. And it has $\pm 0.5\%$ maximum dc error over temperature.
- ▶ Its x, y, z footprint is 15 mm × 22 mm × 7.82 mm.

In addition to having a dual 50 A, or single 100 A output, the LTM4700 also incorporates a PMBus I²C interface or power system management (PSM).

This enables many different capabilities, including:

- ▶ Configure voltages, define complex on/off sequencing arrangements, define fault conditions such as OV and UV limits, and set important power supply parameters such as switching frequency, current limit, etc., over a digital communication bus.
- ▶ Over the same communication bus, you can readback important operating parameters such as input voltage and output voltage, input and output current, input and output power, internal and external temperature, and, in some of our products, measure energy consumed.
- ▶ Users can implement very precise closed-loop margin testing of their designs, as well as trim power supply voltages to very precise levels.
- ▶ PSM devices enable higher reliability and quality.
- ▶ Our built-in servo loops will maintain higher power supply accuracy over the life of the product, improving reliability.

- ▶ The readback features of our PSM devices can be used to improve test coverage at in-circuit test and screen out possible defective devices before they get into the field.
- ▶ During the life of the customer's product, our PSM devices continue to monitor important parameters. Trends in voltage, current, and temperature can be used to profile the power system. Once a good system signature can be found, a flawed system, or one that is about to fail, can be identified.

Conclusion

We introduced our first μ Module regulator back in 2005, the LTM4600. It came in a 15 mm \times 15 mm \times 2.8 mm LGA package and could deliver 10 A of output current from a 12 V input to a 1.2 V output with 89% efficiency. Fast forward 13 years, and the LTM4700 can deliver 100 A from 12 V to 1 V with 89.6% efficiency (and 200 LFM air flow). But that's not all: our designers are already working on other modules that can enable even more performance and capabilities.

Tony Armstrong [tony.armstrong@analog.com] is currently the product marketing director for Analog Devices' Power by Linear™ product group. He is responsible for all aspects of power conversion and management products from their introduction through obsolescence. Prior to joining ADI, Tony held various positions in marketing, sales, and operations at Linear Technology, Siliconix Inc., Semtech Corp., Fairchild Semiconductors, and Intel. He attained his B.S. (Honors) in applied mathematics from the University of Manchester, England.



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