

How GaN technology is transforming power supply design

The constant drive towards smaller, more efficient power supplies is linked to a series of technological innovations in power supply design. A major change in the past ten years has been the gradual replacement of analogue control ICs with digital signal processors (DSPs). Perhaps the most significant advance in recent years, though, has been the use of gallium nitride (GaN) technology.

In this white paper, which is intended for electronics engineers and designers working with power systems for medical, scientific, broadcast or general industrial equipment, Jin He, Vice President of Engineering at TDK-Lambda USA follows the technological journey of the power supply from its origins to the compact and efficient designs available today.

References

www.emea.lambda.tdk.com/uk//medical
www.emea.lambda.tdk.com/uk/industrial
www.emea.lambda.tdk.com/uk/PFH500F

How GaN technology is transforming power supply design

Jin He, Vice President of Engineering at TDK-Lambda USA

AC-DC power supplies used in the industrial and medical industries have always had three basic requirements: reliability, compactness and the ability to remain cool. Various technological leaps have made possible massive improvements in these areas, from the switch mode power supplies of the 1970s to today's gallium nitride (GaN) solutions.

The more efficient the power supply, the smaller it can be. However, if the package becomes too small it is difficult to cool. As internal temperatures rise, the electrolytic capacitors dry out and semiconductor junctions overheat, shortening its lifespan. An efficient power supply reduces the amount of heat wasted, and components such as heatsinks and filters can be smaller. For example, a 75% efficient 1000W power supply will consume 1,333W to output 1000W, 333W of which will be losses. Meanwhile a 95% efficient product will consume 1,053W with just 53W losses.

The constant drive towards smaller, more efficient power supplies is linked to a series of technological innovations in power supply design. The first of these came in the 1970s, when switch mode power supplies began to be mass produced, replacing linear supplies which were bulky, inefficient and had a narrow input range. Later, an increase in operating frequency from 20 kHz to more than 100 kHz was made possible by high-speed MOSFETs, which took over from bi-polar power transistors.

Further improvements were based on increased electrolytic capacitor life – from 2,000 hours to more than 10,000 hours, the introduction of surface mount technology, and the increasing affordability of multiple layer printed circuit boards. Even higher-frequency switching and lower losses have been facilitated by evolving core shapes and new ferrite materials.

The benefits of technological advances must always be weighed against the associated increase in complexity. For example, synchronous rectification is now fairly standard in both AC-DC power supplies and DC-DC converters. Figure 1 shows how the low forward voltage drop Schottky diodes (which replaced silicon diodes) have been replaced by low resistance (RDSON) MOSFETs. The FETS need drive circuits, but in this case the improvement in efficiency and performance justifies the added complexity.

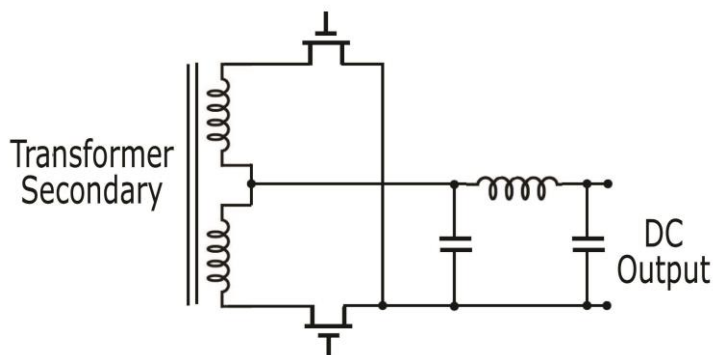


Figure 1: Secondary circuit synchronous rectification

A major change in the past ten years has been the gradual replacement of analogue control ICs with digital signal processors (DSPs). Digital control loops are more stable, more flexible (software can be modified without the need to change circuitry) and they enable PMBus™ interfaces to be included in the power supply design.

Perhaps the most significant advance in recent years, though, has been the introduction of gallium nitride (GaN) technology. This replaces silicon-based power devices, and later silicon carbide (SiC) versions. GaN is a wide-bandgap (WBG) semiconductor, which in practice means more efficient 100V to 650V rated devices are possible.

GaN is now achieving widespread success simply because it enables increased efficiency at a reduced size – two of the key power supply requirements. Datacentres, the military and manufacturers of equipment requiring fanless operation, lower operating cost and smaller size have been early adopters of this technology. Transphorm Inc., a leader in GaN development and a global producer of semiconductors, recently announced that it has shipped more than 250,000 650V GaN high electron mobility transistors (HEMTs). It currently has a 15 million annual part capacity base. TDK-Lambda

partnered with Transphorm Inc. to develop its PFH500F series of third-generation 500W AC-DC conduction cooled power modules.

As ever, the objective was to reduce the size and increase the power conversion efficiency of the existing AC-DC power modules in the TDK-Lambda PFE series. The GaN HEMTs meant that TDK-Lambda could use a bridgeless totem-pole power factor correction (PFC) topology, instead of traditional full-bridge rectification. The PFC circuit converts the AC input into a regulated high voltage DC (380 to 400VDC). A DC-DC power converter lowers the high voltage DC to a regulated low DC output voltage with electrical isolation, usually at between 5 and 48V.

Figure 2 shows how diodes can be configured for full wave rectification in a PFC circuit. With power to the switching converter, there are two diode drops in the rectifier part of the circuit and one diode drop in the boost stage. This results in three diode drops in total.

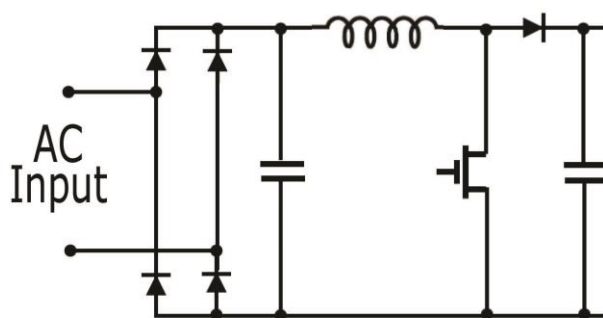


Figure 2: Diode rectifiers in a PFC circuit

The GaN HEMT devices make possible a design that could not have been realised using traditional silicon MOSFETs, because of the high bus voltage and their large reverse recovery charge. There is just one diode drop in the totem-pole PFC topology, as seen in Figure 3. Replacing the remaining line frequency diodes with Si FETs operating at AC-line low frequency will result in no diode drop. But in the totem-pole PFC topology, two of the slow diodes are replaced with GaN HEMTs. The DC bus voltage is always higher than the input AC-line voltage. Si FETs can only be used in the totem-pole PFC circuit in discontinuous mode operation, as they cause too much peak current in the switching devices, boost inductor and input filtering components, meaning EMI becomes unmanageable.

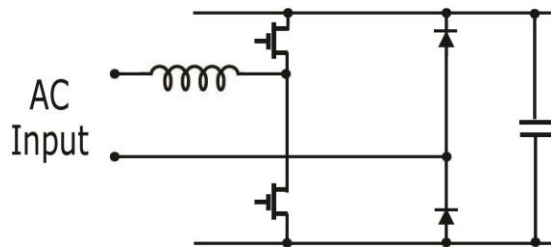


Figure 3: Totem-pole bridgeless PFC (two diodes and two GaN HEMTs)

Looking at the performance in comparison to the PFE500F AC-DC power module, it is possible to appreciate a significant improvement.

Power efficiency	Up to 92% (5% increase)
Power density	100W/cubic inch (30% increase)
Size reduction	28%
Thermal impact	Waste heat reduced by 38% (makes it easier to cool)
Space savings	Savings mean that PMBus™ monitoring and programming (read/write) can be included

As with any new technology, GaN was used carefully at first in the power supply industry, with an eye on its limitations as well as potential benefits. Product development had to accommodate the fact that replacing a silicon MOSFET with a GaN FET is not straightforward. For example, the switches are more sensitive to internal and external parasitic impedances. The drive circuit also requires greater timing precision. Cost was also a factor, as in the early days GaN devices were produced in much lower volumes than silicon MOSFETs so there were no economies of scale.

Now, however, increased confidence and expertise in the deployment of GaN technology in power supply devices means that prices will drop dramatically. Production volumes will increase, but so too will environmental regulation, encouraging ever greater efficiency and ongoing design innovation. GaN in power supply design is here to stay.

For more information about medical power supplies from TDK-Lambda, please visit:

www.emea.lambda.tdk.com/uk//medical
www.emea.lambda.tdk.com/uk/industrial
www.emea.lambda.tdk.com/uk/PFH500F

You may also contact the author with any questions or comments at:
powersolutions@uk.tdk-lambda.com

TDK-Lambda

TDK-Lambda UK Ltd
Kingsley Avenue
Ilfracombe
Devon EX34 8ES UK
+44 (0)1271 856600
powersolutions@uk.tdk-lambda.com
www.emea.lambda.tdk.com/uk