Electronic Design

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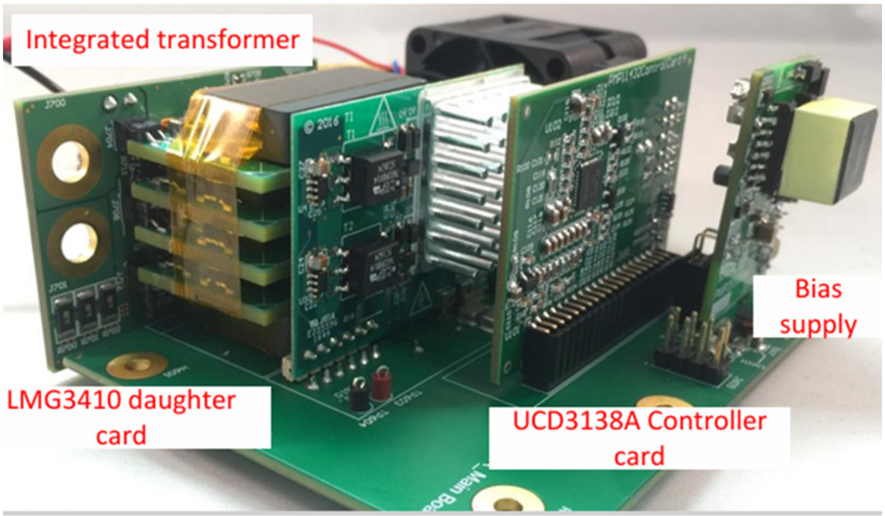
GaN HEMTs Bring Low-Noise Power to Switching Apps

Thanks to a combination of high-speed and low-loss switching, GaN high electron mobility transistors are able to excel in high-power switching systems.

Gallium-nitride (GaN) high electron mobility transistors (HEMTs) are a form of field-effect transistors, which combine high levels of performance along with a low noise figure while performing at microwave frequencies.

HEMTs are somewhat different than other types of FET devices, though, enhancing performance over and above standard junction or MOSFETs. These unique devices excel in microwave radio-frequency (RF) applications. Electrons from the n-type region move through the crystal lattice and many electrons remain close to the heterojunction (the heterojunction refers to the interface area formed via the contact coupling of two or more semiconductors). Such electrons, which are only one layer thick, form as a two-dimensional electron gas.



The LLC converter's operation depends on a resonant circuit, which enables soft-switching operation while reducing switching losses. GaN's superior switching characteristics will significantly reduce gate-driver loss as well as turn-off loss for LLC applications. A 1-MHz frequency will shrink the size of the magnetics.

Switching energy (E_{sw}) of a 650-V GaN-HEMT is measured in a hard switching condition. It can be compared with a 1,200-V and 650-V SiC-MOSFETs with the same current rating. In this case, the E_{sw} of a GaN HEMT device is smaller than a 1,200-V SiC MOSFET, which is smaller than a 650-V SiC MOSFET.

GaN switching devices[7] enable high frequency along with kilowatt power conversion. These devices plus material properties such as mobility, breakdown field, and speed lead to applications like high power switching along with a projected 100X performance advantage (V_{BR}^2/R_{on}) that's far above silicon-based power devices.

GaN devices have a winning combination of low-loss switching performance and high speed for an emerging breed of switching power supplies capable of ultra-high bandwidth in the megahertz regions. These types of power supplies enable an overall efficiency increase that needs a quick transient response for applications like RF base station power amplifiers as well as transmit/receive (T/R) modules for phased-array radar.

By designing with GaN switches, such as with ultra-high bandwidth power conditioners, designers can easily enable DC bias voltage modulation and even pulsed-load currents having slew rates far above 100 A/µs.

Switching speeds will be able to reach 10 MHz, leading to systems with power density higher than 500 W/in.^{2} along with a power-to-weight ratio of 10 kW/lb. GaN HEMTs can also reach blocking voltages higher than 600 V, which are perfect for high-voltage switching operation. In addition, high-current devices with low on-resistance have leveraged GaN HEMT technology on silicon as well as SiC substrates, which have a maximum current well above 30 A.

GaN FETs Offer the Best Path Toward High Power Density

GaN FETs have twice the power density of silicon transistors—magnetics can be 6X smaller—and they're very reliable. [8,9,10]

For example, an LLC converter is a resonant inverter that can be used in electrical equipment as well as power supplies.[10,11] The acronym "LLC" represents three major components: two inductors (L) and a capacitor (C).

The LLC is known for its effectiveness in regulating both current and voltage. Its operation depends on a resonant circuit, which enables soft-switching operation while reducing switching losses. GaN's superior switching characteristics will significantly reduce gate driver loss as well as turn-off loss for LLC applications. And a 1-MHz frequency will shrink magnetics *(see figure)*.

LLC converters can combine a linear network (i.e., a resonant tank and transformer) with both passive and active switches. The LLC resonant converter is nothing like standard switching converters, since it's able to control the output voltage via selecting the appropriate frequency for a switching signal.

DOSA Standardization for Power Converters

The Distributed-Power Open Standards Alliance (DOSA) promotes DC-DC product standardization and compatibility in power converters.[12,13] The alliance goal was meant to establish customer interface standards during an early development cycle; this includes pinouts, form factors, feature sets, footprints, and other parameters that would be able to permit alternative sourcing.

DOSA covers a wide range of power converters. They include non-isolated point-of-load (POL), isolated applications, and intermediate bus converters.

In 2004, the DOSA standard for high-current quarter bricks offered a number of benefits over competing designs. This standard specifies the function and location of the added pins—two additional power pins were located 0.15 in. (3.81 mm) outside of, and in line with, the 2004 quarter-brick power pin locations.

Also, the extra output pins exploit the opposite polarity of their adjacent power pin. The overall loop inductance, from converter to board to converter, was reduced by a factor of 10. This enhances the module's transient response performance, lowers the output ripple, and improves load current balance between the pins.

The additional output pins reduce total power dissipation in the load board, too, which boosts thermal performance, lowers cost of ownership, and enhances reliability. Since the two extra output pins aren't positioned behind existing pins, it eases the burden of rework and visual inspection. The remainder of the other pins keep the same placement and function as the current quarter-brick standard, which simplifies the board layout so that both types of modules can be used.

The maximum output power in a 1/8th DOSA power brick DC-DC converter has doubled from 300 W to 600 W over the last decade while also maintaining 95% to 97% peak efficiency.

High Efficiency with GaN

GaN FETs, along with integrated gate drivers and GaN power devices, often lead to the highest-efficiency GaN solutions. GaN transistors can switch far faster than silicon MOSFETs, while bringing about lower-switching losses. GaN power stages will fit in a wide range of applications, from telecommunications, motor drives, and servers to laptop adapters and on-board chargers for electric vehicles.

References

1. "A Compact GaN Bi-directional Switching Diode with a GaN Bi-directional Power Switch and an Isolated Gate Driver," Shuichi Nagai, Yasuhiro Yamada, Miori Hiraiwa, Hiroaki Ueno, Songbaek Choe, Yasufumi Kawai, Osamu Tabata, Go Yamada, Noboru Negoro, and Masahiro Ishida, Power Electronics Solution Center, Panasonic Corporation, Proceedings of the 2016 28th International Symposium on Power Semiconductor Devices and ICs (ISPSD) June 12-16, 2016, Prague, Czech Republic, IEEE 2016.

2. "Minimizing Switching Losses in High Switching Frequency GaN-based Synchronous Buck Converter with Zero-Voltage Resonant-Transition Switching," Woongkul Lee, Student Member, IEEE; Di Han, Student Member, IEEE; Casey Morris, Bulent Sarlioglu, Senior Member, IEEE Wisconsin Electric Machines and Power Electronics Consortium (WEMPEC), University of Wisconsin – Madison, 9th International Conference on Power Electronics-ECCE Asia June 1-5, 2015 / 63 Convention Center, Seoul, Korea, IEEE 2015.

3. "Soft-Switching Losses in GaN and SiC Power Transistors Based on New Calorimetric Measurements," Julian Weimer and Ingmar Kallfass, Institute of Robust Power Semiconductor Systems, University of Stuttgart, Germany, Proceedings of the 31st International Symposium on Power Semiconductor Devices & ICs May 19-23, 2019, Shanghai, China, IEEE 2019.

4. "GaN power transistor switching performance in hard switching and soft-switching modes," Peter Sojka, Michal Pipiska, Michal Frivaldsky, Department of mechatronics

and electronics, Faculty of electrical engineering and information technologies, University of Zilina, IEEE 2019.
5. "High-Speed, High-Reliability GaN Power Device with Integrated Gate Driver," Gaofei Tang, M.-H. Kwan, Zhaofu Zhang, Jiabei He, Jiacheng Lei, R.-Y. Su, F.-W. Yao, Y.-M. Lin, J.-L. Yu, Thomas Yang, Chan-Hong Chern, Tom Tsai, H. C. Tuan, Alexander Kalnitsky, and Kevin J. Chen, Department of Electronic and Computer Engineering, The Hong Kong University of Science and Technology, Hong Kong, Analog Power & Specialty Technology Division, Taiwan Semiconductor Manufacturing Company Limited, Hsin-Chu, Taiwan, IEEE 2019.
6. "SiC and GaN Power Transistors Switching Energy Evaluation in Hard and Soft Switching Conditions," Ke Li, Paul Evans, Mark Johnson, Power Electronics, Machine and Control group, University of Nottingham, UK, IEEE 2016.
7. "GaN Switching Devices for High-Frequency, KW Power Conversion," K.S.Boutros, S.Chandrasekaran, W.B.Luo, and V.Mehrotra, Rockwell Scientific Company LLC, Proceedings of the 18th International Symposium on Power Semiconductor Devices & ICs, June 4-8, 2006, Naples, Italy, IEEE 2006.
8. "GaN: The path to high power density," Ted Chen, Systems and applications engineer, Texas Instruments, 2018.
9. "Recent Advances in GaN- Based Power HEMT Devices," Jiaqi He, Wei-Chih Cheng, Qing Wang, Kai Cheng, Yang Chai, Hongyu Yu, January 2021.
10. "Why use GaN SR in LLC converters? Advantages of GaN power transistors in low-profile SMPS solutions," By Dr. Gökhan Sen, Milko Paolucci, and Sriram Jagannath, Infineon, May 2024.
11. "GaN for DC-DC Conversion, LLC Converters," Michael de Rooij, Alex Q. Huang, Qingyun Huang, Penkun Liu, Qingxuan Ma, Amir Negahdari, Andreas Reiter, Jianjing Wang, Zhihong Yu, and Yuanzhe Zhang, Efficient Power Conversion (EPC).
12. Distributed-Power Open Standards Alliance (DOSA).
13. "DOSA Standard for High-Current Quarter Bricks," *Electronic Design*, November 3, 2004.