GaN drives energy efficiency to the next level

Steve Tom
Product Line Manager
GaN Solutions
Texas Instruments

Masoud Beheshti
Advanced Technology Product Manager
GaN Solutions
Texas Instruments

Johan Strydom
Advanced Development Manager
Kilby Labs
Texas Instruments

Seventy-three billion kilowatt-hours of energy. That's a whopping 73,000,000,000 kWh—the estimate of energy that will be consumed by U.S. data centers in 2020, according to a 2016 study by Lawrence Berkeley National Laboratory [1]. As long as our appetite for computation-intensive data services continues to increase, so will the need to deliver more energy in less space to run these centers as efficiently as possible.

And this usage represents only data centers. The same need to supply high-density power systems is also present in telecommunications, industrial automation, vehicles and numerous other systems.

One means to increase efficient delivery of power is to leverage new power semiconductor technologies, including gallium-nitride (GaN). GaN has intrinsically superior device properties related to switching performance when compared to traditional silicon solutions, which when deployed in a switching power supply takes power supply efficiency to a higher level than what was previously possible. For the end user this ultimately saves energy, lowers operating costs, and reduces the amount of carbon released into the atmosphere.

GaN is not immune to challenges. Historically, the challenges have been related to manufacturing and the ability to deliver high quality and reliable GaN. However, as manufacturing processes across the industry improve and adoption increases, the challenges have transitioned to implementation and system design. Achieving higher efficiency requires more than just switching silicon for GaN, as the technology also enables system level changes that also boost efficiency. The technology empowers the design engineer with the ability to increase slew rates and switching frequencies, and to minimize the sources of power loss. These new design challenges provide significant opportunity for end product innovation and differentiation.

Texas Instruments (TI) plays a leading role in driving GaN development and enabling system designers to use the new technology. TI's GaN-based power supply solutions and reference designs focus on enabling system designers to save space and achieve greater power efficiency while simplifying the design process. By focusing on the most challenging implementation problems with solutions that optimize performance, TI is helping customers design energy-efficient systems that make for a greener world.

Advantages of GaN technology and solutions in power supplies

GaN offers greater efficiency and superior performance in power supplies for several reasons. Fast rise times, low on-resistance, and low gate and output capacitance reduce switching losses

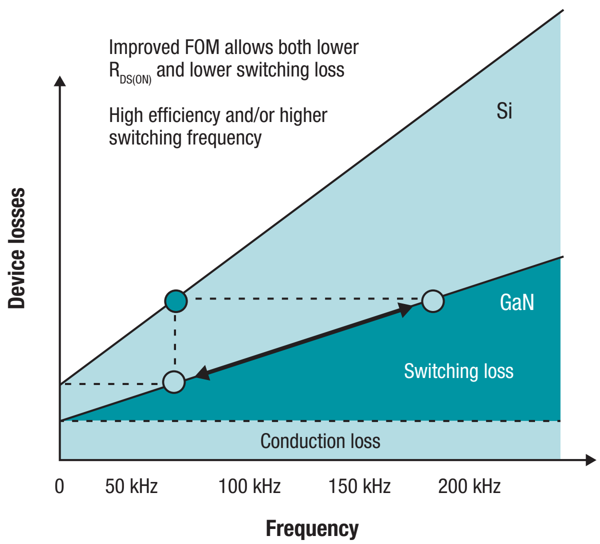

Figure 1*. Comparison of device losses in GaN vs. Si.*

and support operation at frequencies often times an order of magnitude faster than today's silicon-based solutions, as shown in **Figure 1**. Reduced losses equate to more efficient power distribution, producing less heat and simplifying active cooling solutions. Additionally, high-frequency operation can have a positive impact on solution cost by reducing the volume, weight and material required in the necessary magnetic elements such as transformers and inductors.

The application that benefits the most from the intrinsic benefits of GaN is the switch-mode power supply. The goal of an AC/DC power supply is to convert AC line power to a lower voltage that can power or charge low voltage electrical devices such as mobile phones or personal computers and is typically done in several stages. The first stage of a typical power supply involves feeding AC line power through a power factor correction (PFC) stage to create a high voltage DC bus nominally 380 V. In the second stage this voltage is then converted down to a lower level (often times 48 V or 12 V) via a high voltage DC/DC converter. These two stages are referred to as the AC-to-DC stages. They are usually located together and provide isolation to protect equipment and personnel. The 12 V or 48 V output from the second converter is distributed to end-use circuitry at the different points of load (POL), such as the different boards in an equipment cabinet. The third stage of the converter is where one or more DC-to-DC stages produce the low voltages required for electronics components.

The example below in **Figure 2** shows a 1kW GaN-based AC/DC and how GaN can improve power density in all three PFC, high voltage DC/DC and POL stages. What is most important about this example is not just that GaN is used, but more importantly how it is used. The PFC, DC/DC, and POL stages are still present, but the implementation

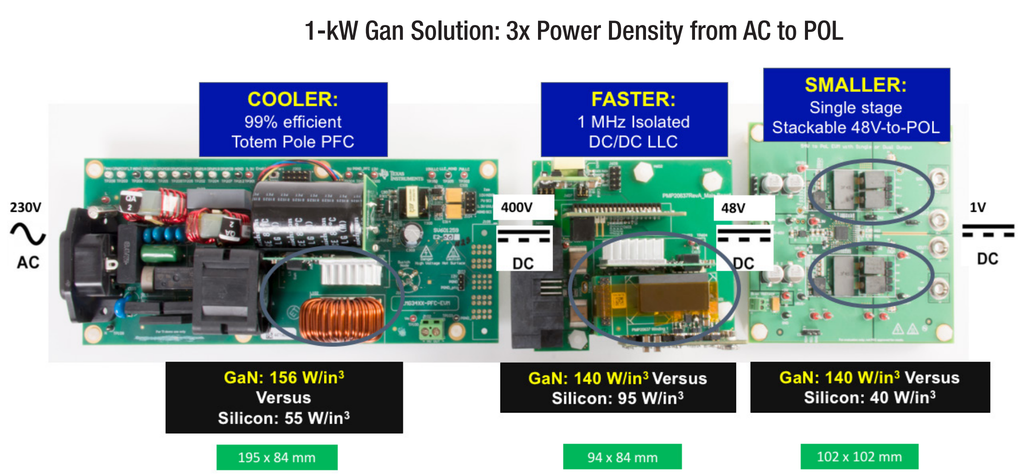

Figure 2*. In all stages of the power supply, GaN solutions can reduce scale and increase efficiency.*

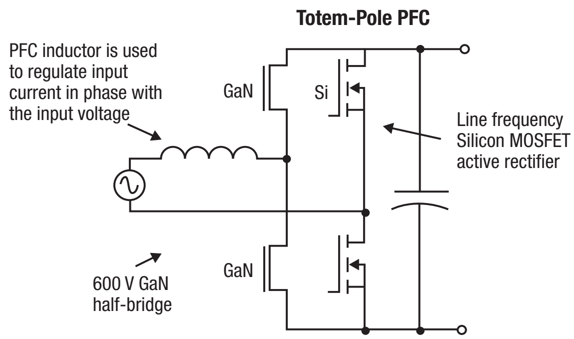

***Figure 3**. GaN PFC topology.*

or power supply topology used in each is different and optimized to maximize the performance of GaN.

The PFC stage (**Figure 3**) uses a highly efficient totem-pole topology to achieve a unique combination of high power density, high efficiency, and low power loss that is impractical to achieve by comparable silicon-based designs. This stage is over 99 percent efficient, reducing power dissipation by more than 10W compared to a traditional diode-bridge boost PFC with silicon.

The high voltage DC/DC stage uses a highly efficient resonant logic link control (LLC) converter (**Figure 4**). While it is also common to use silicon in LLC converters, the benefit that GaN enables is improving power density by 50% and increased switching frequency by a factor of ten. A 1-MHz GaN-based LLC requires a transformer less than one-sixth the size of the size of that required in a 100-kHz silicon-based LLC design.

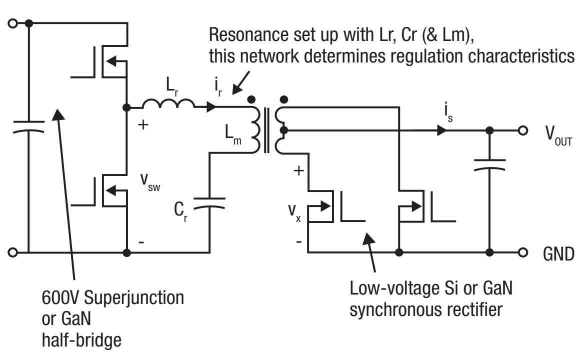

***Figure 4**. GaN LLC topology.*

The POL stage takes advantage of GaN's efficient switching properties to enable an efficient hard-switched 48 V converter directly to 1 V. Most silicon solutions require an intermediate fourth stage to convert 48 V to 12 V, but GaN enables a true single-stage conversion to directly to 1 V. In this way, a GaN-based design cuts the component count in half and increases power density by a factor of three (**Figure 5**).

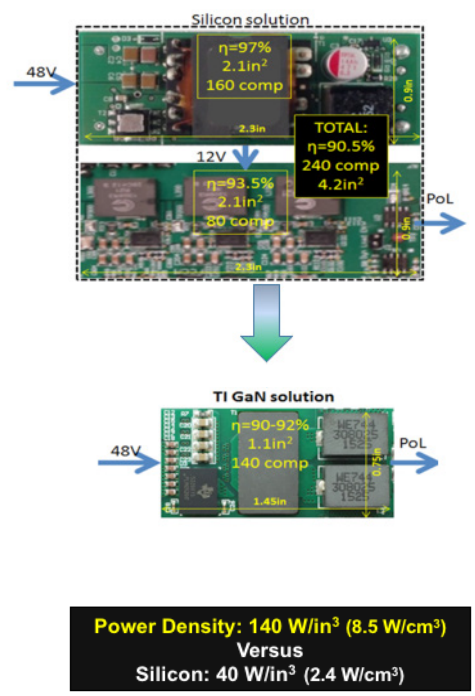

***Figure 5**. Two POL stages to a single stage.*

Satisfying a range of application requirements

The benefits of GaN are not just limited to AC/DC power supplies. Numerous other applications, shown in **Figure 6**, can benefit from higher efficiency and power density that GaN delivers. The end equipments referenced below or some of the more exciting and areas where adoption is increasing rapidly.

Figure 6. Actual and potential GaN application areas.

Motors and motion control

In motors for robotics and other industrial uses, size and power efficiency are important, but other factors come into play as well.

Using a GaN solution allows for increased pulse-width modulated (PWM) frequencies and reduced switching losses aid in driving very-low-inductance permanent magnet and brushless DC motors. These features also minimize torque ripple for precise positioning in servo drives and steppers, and they enable high-speed motors to achieve high voltages in applications such as drones.

LiDAR

An increasingly narrow width requirement is rapidly making GaN FETs and drivers a necessity in LiDAR, which many associate with sensing for self-driving vehicles, though it is also used for sensing in robotics, drones, security, mapping and a variety of other areas. Next generation LiDAR requirements include greater range and resolution to increase the ability of the instruments to sense farther ahead and recognize objects more effectively. The low input and high capacitance of GaN enables higher peak optical output power in a shorter pulse, which improves higher-resolution imaging while still maintaining eye safety.

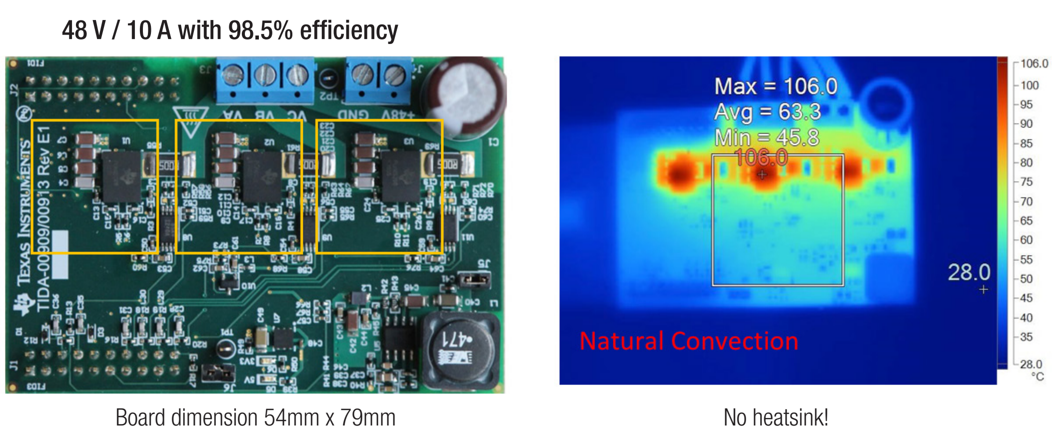

Figure 7. GaN inverter. 100kHz 3-stage design.

High-fidelity audio

Amplifiers for high-performance audio require nearly ideal switching waveforms to reduce distortion as the harmonics of any unintended frequency can result in the audible band. GaN simplifies this challenge through its ability to efficiently switch at much higher slew rates with more predictable switching behavior for reducing harmonic distortion. This leads to more ideal audio performance because noise content can be limited to higher, non-audible frequencies.

Optimal solutions for designing with GaN

Since high-frequency power system design brings new types of challenges, even for experienced power designers, ready-to-use solutions can shorten design cycles considerably. TI supplies complete power stage products that help designers simplify many of these difficulties. Solutions exist to meet different voltage levels and requirements in the power chain, integrated with built-in protection in small-footprint, low-inductance packages. In addition, TI's GaN FET drivers and high-frequency analog and digital controllers that pair seamlessly with the drivers support designers who choose to build the power system from basic components.

The LMG3410, shown in **Figure 8**, single-channel power stage couples a 70 mΩ, 600 V GaN FET with an optimized driver in the same module, minimizing parasitics that can plague high speed designs with standalone components. Built-in features provide temperature, current and under voltage lockout (UVLO) fault protection for reliable, safe operation.

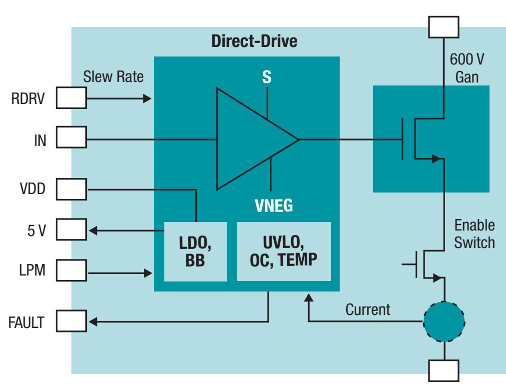

***Figure 8**. LMG3410: 600V/70 mΩ 12A GaN Power Stage.*

For designers of applications requiring highly-efficient operation in a small form factor, the LMG5200, shown in **Figure 9**, is a fully integrated half-bridge power stage and provides an 80-V, 10-A solution including half-bridge gate driver and high- and low-side GaN FETs. The LMG5200 interfaces directly to both analog controllers like TI's TPS53632G for DC/DC conversion applications and digital controllers like TI's C2000™ real-time microcontrollers for audio and motor control applications.

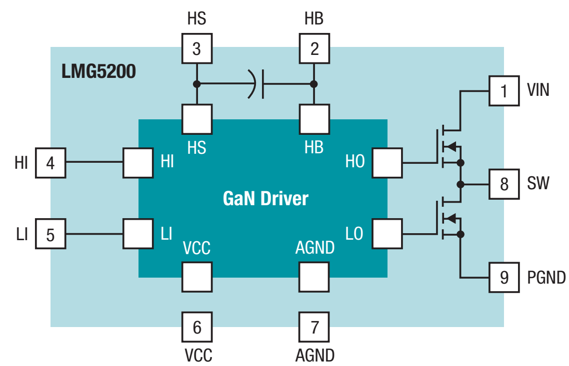

***Figure 9**. LMG5200: 80 V/10 A GaN Half-Bridge Power Stage.*

Nearly as important as the products themselves in simplifying design is a full complement of development tools. Evaluation modules (EVMs) help designers see the solutions in operation and make important decisions. Reference designs provide proven, ready-made circuits to work from in applications such as radar, automotive, uninterrupted power supply (UPS), motor control, current measurement and other areas. In-depth support in all regions helps make customer design of GaN power systems as productive as possible.

GaN for the future is here today

GaN technology already plays an important role in shrinking systems and increasing power efficiency. The savings that result have an important effect in all applications, especially data centers, base stations and other high-density systems. In addition, GaN's high-frequency operation aids in precise motor control and greater resolution for LiDAR and audio. Other types of applications will quickly follow as innovative topologies and new approaches are invented and adopted.

Power system designers no longer have to wait for the GaN revolution to begin. GaN solutions are here today, and TI's continued efforts to drive innovation with the technology means more advances are in development. Integrated solutions save development time and are ready to use, along with reference designs for a range of applications that is steadily growing. As the need for power efficiency becomes more and more pressing, TI technology and solutions continue to be among the leading innovations that are helping to make the world smarter and more green.

Related resources

- TI's LMG3410 and LMG5200 GaN solutions
- TPS53632G product folder
- TMS320C2000 C2000™ real-time MCUs
- White paper: GaN and SiC enable increased efficiency in power supplies

References

1. Shehabi, A., Smith, S.J., Horner, N., Azevedo, I., Brown, R., Koomey, J., Masanet, E., Sartor, D., Herrlin, M., Lintner, W. 2016. United States Data Center Energy Usage Report. Lawrence Berkeley National Laboratory, Berkeley, California. LBNL-1005775