High Frequency 24 V-to-1 V DC-DC Converters Using EPC's Gallium Nitride (GaN) Power Transistors

EFFICIENT POWER CONVERSION

Edgar Abdoulin and Alex Lidow, Ph.D.

This article describes advantages of converters designed using EPC's GaN power transistors vs conventional silicon based power MOSFETs . EPC's GaN transistors are a new generation of power switches offering unsurpassed performance over their silicon counterparts in speed, switching and static losses (Rdson) with superior thermal characteristics.

Requirements of 24 V – 1 V converters

24 V input DC-DC converters find use in a variety of systems including pre-regulators for on board Voltage Regulating Modules (VRMs) of high performance systems. Additional conversion is then required to bring the voltage to levels suitable for operating the processor. In addition to demanding high currents, high performance processors require fast and responsive power sources to account for high current demand fluctuations specially when they switch from an inactive state to an active one. Transient response of the power source in such systems plays a detrimental role in the effectiveness and response of the overall system.

Since VRMs are required to provide high currents at a very short notice, they are generally "on board" products. With system sizes constantly in a downward motion, it is important that the VRM not consume a considerable portion of real estate on board to allow for integration of more and more functions as they become necessary.

EPC's GaN transistors offer the possibility to eliminate the intermediate stage and provide a VRM for direct conversion from 24 V to the final voltage levels, while preserving overall system response and performance. Furthermore, small space requirements of EPC's GaN transistors allow integration of the 24 V – 1 V converter on directly on-board, alongside the processor.

Structure of EPCs GaN power transistors.

EPC's GaN power transistors operation is similar to conventional, enhancement mode, silicon power MOSFETs. The basic structure of EPC's GaN transistor is shown in figure 1.

The gate (G), source (S) and drain (D) terminals, are defined in a conventional manner. A positive voltage higher than the threshold between the gate and source will turn the device on, and a voltage lower than that will turn the transistor off. A low resistance electron generating layer is incorporated to provide a channel to direct the current from the drain to the source when the gate is activated. Once on, the device can conduct current in either direction from Drain to source or visa-versa. EPC's GaN transistors also incorporate an integral, zero-recovery-charge body diode which can be used to conduct current in applications requiring such a feature.

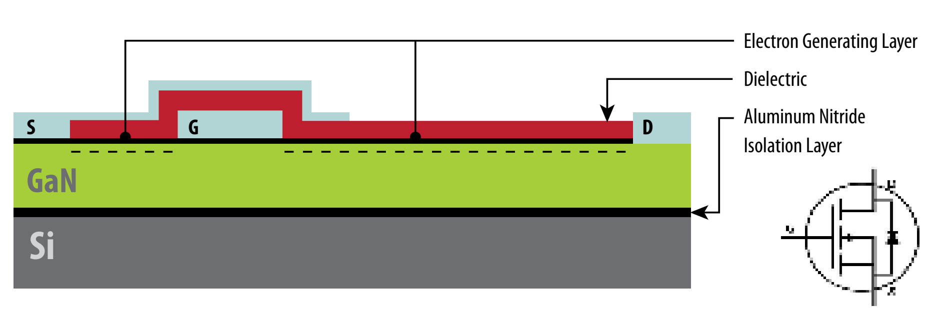

Fig 1 – EPCs' GaN Power Transistor Structure.

EPC's GaN power transistors are fabricated on a silicon substrate with an isolation layer in between. This feature simplifies thermal management by allowing heat sinks to be mounted directly on the back side of the device without fear of shorting power lines.

Further advantages offered by EPC's GaN transistors are:

1. Conventional Gate Drive with Lower Gate Charge

Gate to source equivalent circuit of EPC's GaN power transistor is similar to conventional power MOSFETS.

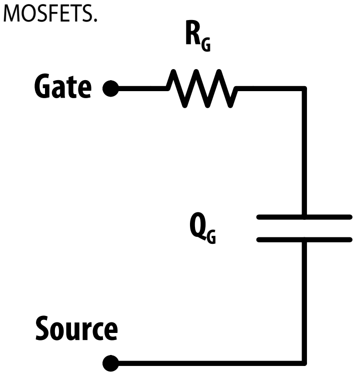

Fig 2 – GaN Gate to source equivalent circuit.

This allows direct replacement, in most cases, of conventional power MOSFETs as GaN transistors have a substantially lower gate charge requirement to turn on than their silicon counterparts. GaN required gate charge, to fully enhance the transistor, are in the sub 10 nanocoulomb range, whereas, a similarly sized conventional MOSFET will require a gate charge in the order of 10's of nC to turn on or off. EPC's GaN gate threshold voltages are in the 1.5 ~ 1.7 V_{DC} range. The devices are fully enhanced with 5.0 V between the gate and source, with an absolute maximum of 6 V.

2. High Switching Speed

Specially constructed EPC GaN power transistors have been shown to have unity current gains (f_T) in excess of 9 GHz (fig 3). This enables operation well beyond the 5~10 MHz switching frequencies possible with conventional MOSFETs. EPC's GaN transistors not only switch at much higher frequencies, but they also allow operation with substantially narrower pulses (<100 ns) to fully turn the device on and off, making possible applications that are out of reach of conventional silicon based power transistors. Increased switching frequency also shrinks inductors and cuts area occupied by capacitors substantially.

An extreme case is shown in figure 4, where a 48V supply is switched with rise and fall times below 5 ns to produce a 1 V output. 24 V to 1 V converters can be designed to run at frequencies well in excess of 5 MHz.

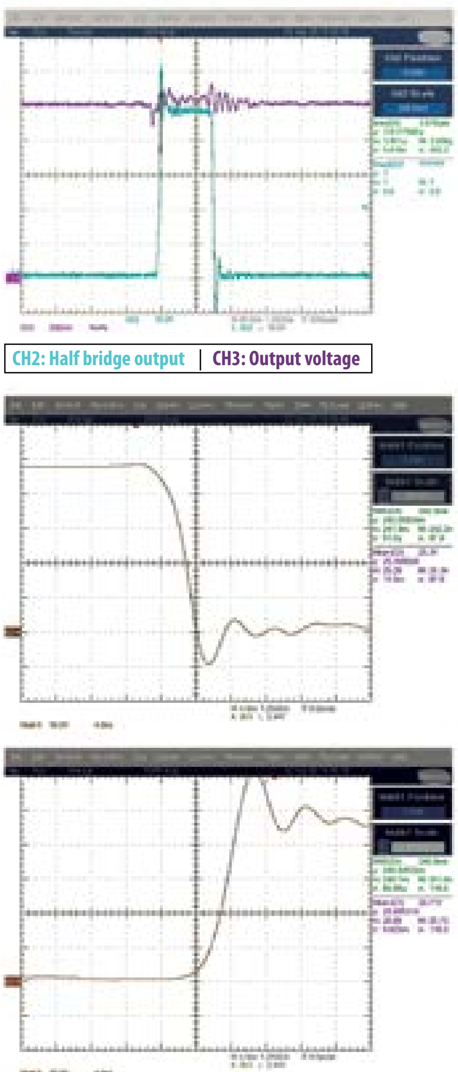

Fig 4 – 48 V supply switched in under 5 ns

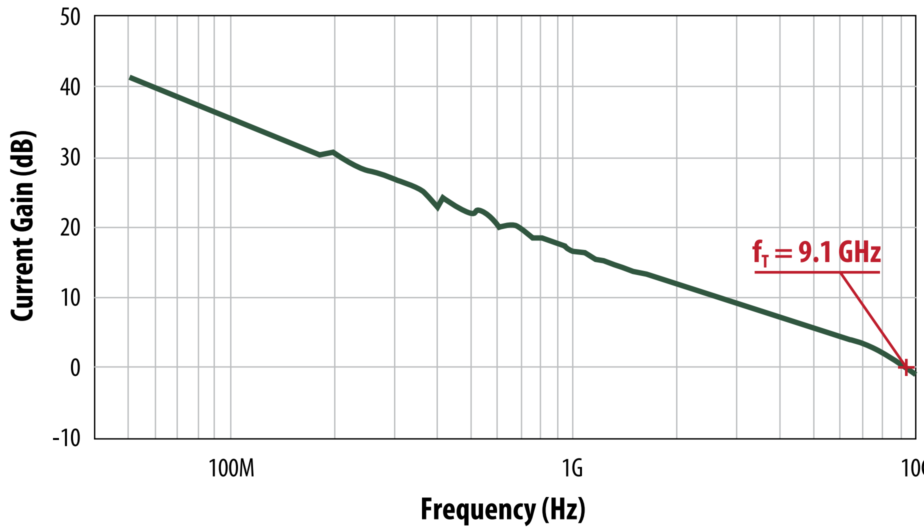

Fig 3 - EPC's GaN current gain (f_T)

High gains and fast switching speeds allows the design of high bandwidth systems with stable characteristics for 24 V - 1 V VRMs that can accommodate the requirements of modern processors.

3. Low Static and Switching Losses

EPC's GaN power transistor's low switching losses are possible due to the high switching speed and low Q_G requirements. Low Q_{RR} and Q_{OSS} losses of EPC's GaN transistors also contribute to increase in system efficiency.

A typical 4 mΩ silicon MOSFET has 36 nanocoulombs of Q_{OSS}. EPC's GaN transistors having the same on resistance reduces the Q_{OSS} to 19 nC. A figure of merit (FOM) generally used to gauge conventional silicon based power MOSFETS is ($R_{DS(on)}$ x Q_G). EPC's GaN power transistors have substantially lower ($R_{DS(on)}$ x Q_G) values in a smaller package. Table 1 compares FOM of some high performance silicon power MOSFETs to EPC GaN transistors. EPC's GaN transistors boast FOMs' which are, in some cases, an order of magnitude less.

4. Small Size

Space constraints pose a big problem for integrating VRMs on board with high performance processor. EPC's GaN power transistors allow

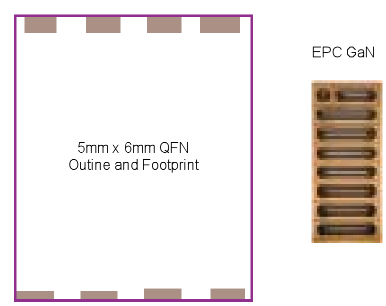

Fig 5 – Comparing footprint of standard 5x6mm QFN to a Typical EPC GaN Transistor.

V	Mfg	Part No.	Rmax	Qg Max	R x Qg
40	IR	IRF6613	4.1	63	258
40	Vishay	SUM70N04-07L	11	24	264
40	Fairchild	FDD8447L	11	28	308
40	Infineon	BSC027N04LSG	4.1	85	349
40	IR	IRLU3114Z	6.5	56	364
40	Infineon	IPD036N04LG	4.9	78	382
40	Vishay	SUB85N04-03	5	95	475
40	VIshay	SUM110N04-2m1P	2.4	240	576
40	**EPC**	**EPC1015**	**4**	**12**	**48**
40	**EPC**	**EPC1014**	**15**	**4**	**60**

Table 1 – Comparing Figure of merit of EPC's GaN transistors to silicon based Power MOSFETs (Source: Manufacturer's Data Sheets)

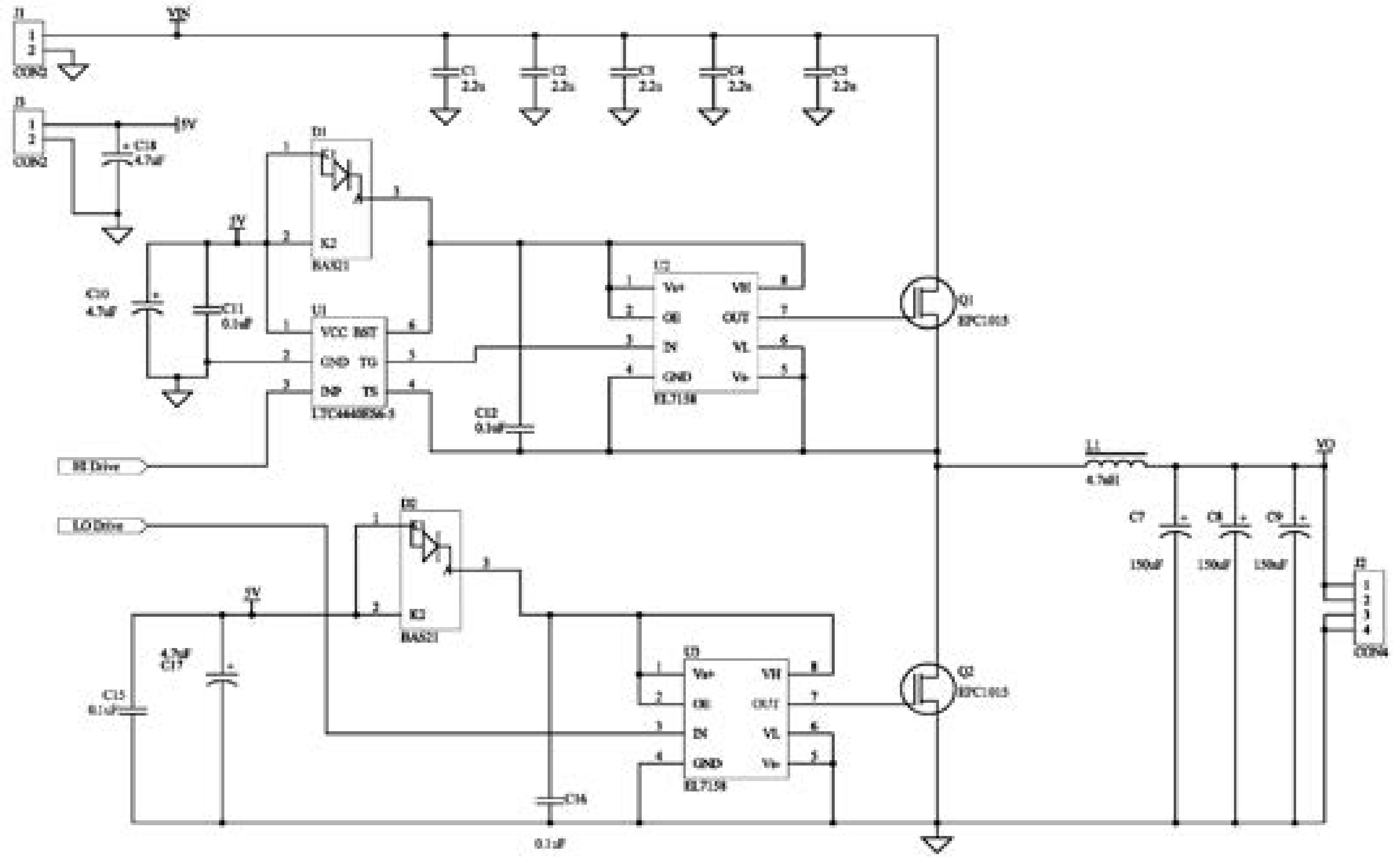

Fig 6 – 12 V to 0.7~1 V , 1MHz converter schematic diagram

integration of high speed and high efficiency VRMs close to the load to precisely provide the power demand, on time and with minimal disturbance caused by parasitic effects. Figure 5 shows the relative size of a standard 5x6 mm QFN package compared with a typical EPC GaN flip-chip die. In applications where multiple silicon MOSFET QFN die are paralleled to increase current carrying capacity, reduced number of EPC's GaN transistors can offer substantial space savings and reduced parasitics. One benefit of the isolation characteristics of EPC's GaN transistors is the ability to integrate multiple devices (high side and low side switch) on one silicon substrate. This not only reduces size but also eliminates parasitic inductance between the devices which is detrimental to noise free operation at high currents.

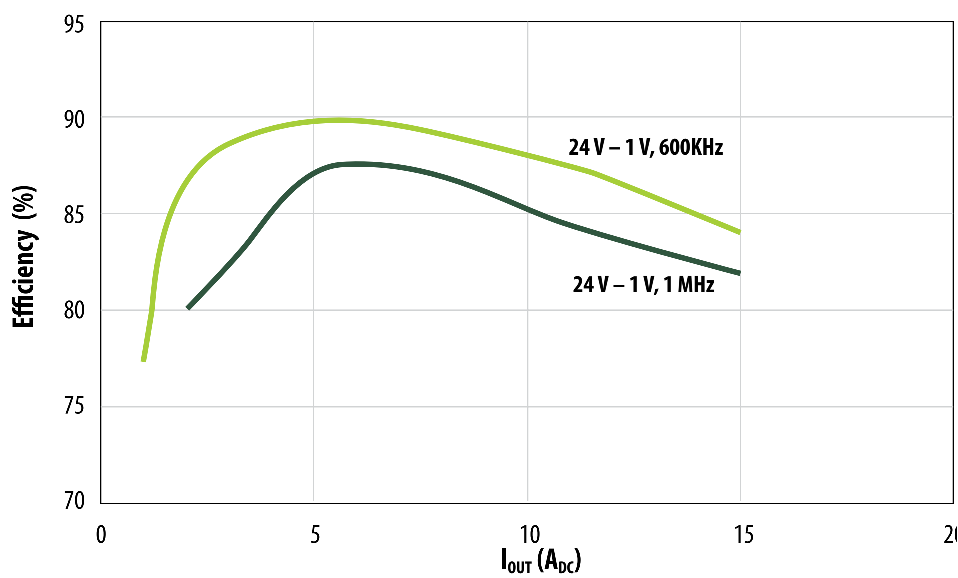

Fig 7 – 24V to 1V converter efficiencies at various frequencies

5. A 24V to 0.7V~1V Converter Using EPC's GaN Power Transistor

A 24 V to 1 V converter was built to test the capabilities of EPC's GaN power transistors. The schematic diagram is shown in figure 6. The converter is open loop and requires a HI and LO signal from an external source to operate and regulate the output voltage. The purpose of the design is to show simplicity of operation and high efficiency of EPC's GaN transistors at high switching frequencies.

Figure 7 shows efficiencies at various output voltage and operating frequencies up to 15 A of output current. The design uses a single GaN transistor (EPC1015) in each socket. The 1 V output conversion at 1 MHz is quite notable, since the pulse width requirements for the converter are in the 40-50 ns range. EPC's GaN power transistors are quite capable of turning on and off during these short pulse whereas, conventional MOSFETs will require quite elaborate drive circuitry to operate at such speeds. Light loads will amplify the problem by requiring even narrower pulse widths. Figure 8 shows switching waveforms for the 1 MHz converter at 1A and 12 A output currents converting 24 V input to 1 V output.

Conclusions:

Silicon power MOSFETs have reached maturity and their performance is limited by silicon's own capabilities. The conversion from silicon power MOSFET based designs to EPC's GaN power transistors is a trivial task. In return, EPC's GaN power transistors can provide impressive improvements in and cost savings by eliminating intermediate circuitry for 24 V – 1 V converters and allowing higher frequency and low loss operation. Thermal management is also simplified by built-in isolation of EPC's GaN.

Fig 8 (right) – Switching waveforms of 1 MHz, 24 V to 1 V DC-DC Converter using EPC's GaN power transistors. Pulse width is 47.2 ns for 12 A output current and 43.2 ns for 1 A.