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Commentary

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GaN Is Revolutionizing Motor Drive Applications

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In last month's Safety & Compliance column, "WBG Semiconductors Pose Safety And EMI Challenges In Motor Drive Applications,"[1] Kevin Parmenter made some assertions about the difficulties of using SiC, and to a lesser extent GaN, power semiconductors in large motor-drive applications. This commentary is a response to that article, showing that GaN can be a game changer in low-voltage integrated motors.

Rethinking The Ordinary And Overcoming Mental Biases

For the past 20 years at several companies, I have worked on motor drive applications in different markets: industrial, appliance and automotive. Every time a new technology was proposed, it always faced much resistance to its adoption; after all, it is human nature to stick with what is known and resist change.

At the beginning of 2000, while at International Rectifier (now Infineon), we offered variable frequency drive (VFD) technology that was inverter-based and sensorless for brushless motors to all applications (i.e., pumps, washers and dishwashers) still using mains-operated induction motors or chopped dc brushed motors. Engineers and their managers rejected everything. "We do not need sensorless field oriented control" and "we do not need an inverter," they said.

In 2010, when we introduced the PQFN package in high-voltage motor applications, we again faced much resistance. There was also pushback in 2015, when we introduced flash-based ARM controllers and superjunction MOS in the same package.

It is happening again now—GaN technology is a game-changer for motor applications and the resistance to a new technology emerges as scare tactics of design complications, reliability concerns, and specifically in the case of motor drives, safety and EMI challenges.[1] In this article, I will dispel these myths as they relate to the use of GaN in low- to medium-voltage motor-drive applications and show why GaN is revolutionizing these applications.

Effect Of C_{RSS} In Switching: How To Get Motor Friendly dv/dt With GaN

When dealing with new technologies, such as the latest MOS, GaN and SiC devices, it is quite normal to get switches that are faster than previous generations. It is a common bias to think that a GaN device switches so fast that the gate driver cannot maintain control. In reality, when looking closer at a given device, it is essential to consider its reverse capacitance (C_{RSS}) characteristics, its linearity, and the ratio between its low-voltage value and its high-voltage value ($C_{RSSslow}/C_{RSShigh}$).

Conventional gate driving is done by applying a voltage to the gate of the switch through a resistor. If the value of the ratio $C_{RSSslow}/C_{RSShigh}$ is too high, either of the following conditions can occur:

- the switch is *too fast at the beginning of the turn-on event*, leading to high dv/dt
- the switch is *too slow at the end of the turn-on event*, leading to a tail effect and higher power dissipation.

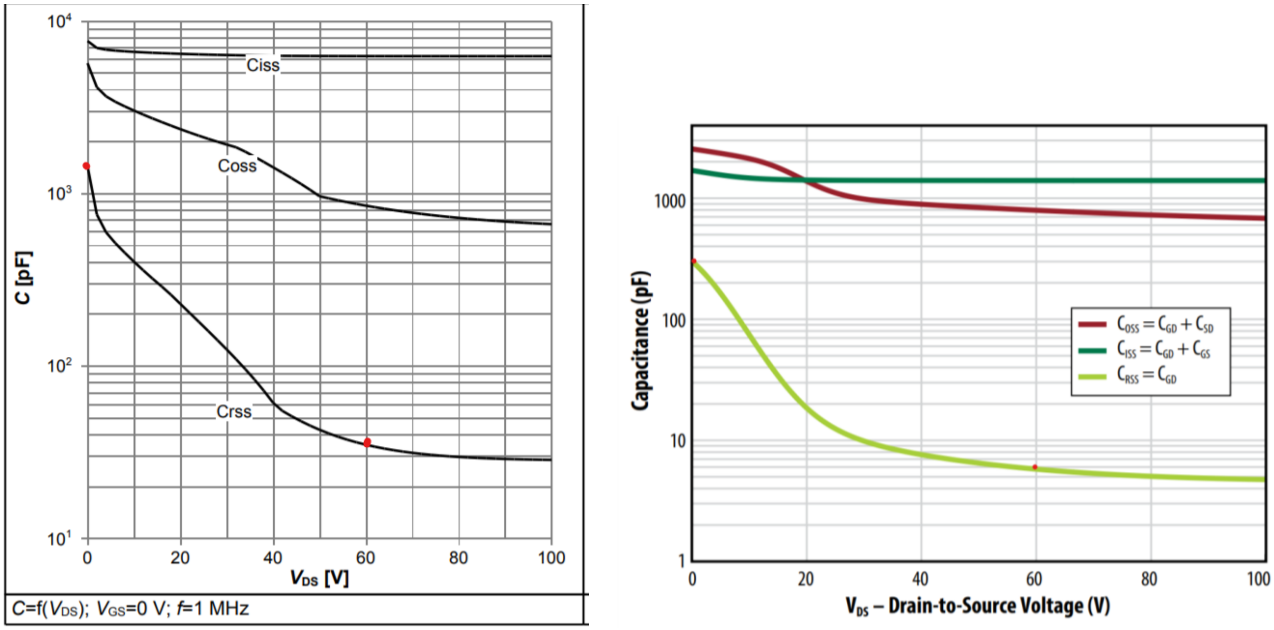
This is embedded in the multi-segment nature of the C_{RSS} curve.

So, how do silicon and GaN compare in reality?

Silicon: A typical 100-V MOS (BSC027N10NS5) has $C_{RSSlow}/C_{RSShigh}$ = 1500 pF/35 pF = 43.

GaN: The corresponding EPC 100-V eGaN FET, an EPC2022,[2] has $C_{RSSlow}/C_{RSShigh}$ = 300 pF/6 pF = 50 (see the figure).

Therefore, the eGaN FET can be slowed better than the MOS counterpart, while keeping a lower switching dissipation. In addition, the commutation waveforms of GaN are smoother because the C_{RSS} curve is more linear than the MOSFET. An added advantage is that there is no reverse recovery from any intrinsic body diode, which further reduces EMI and acoustic noise.



(a) *(b)*

Figure. Capacitance vs. voltage for the BSC027N10NS5 silicon MOSFET (a) and the EPC2022 eGaN FET (b). The ratio of $C_{RSS(low)}/C_{RSS(high)}$ *as measured at 0 V and 60 V is 43 for the MOSFET and 50 for the eGaN FET.*

Effect Of dv/dt On Radiated EMI

The dv/dt can be slowed in a GaN inverter to reach each customer's needs. The question then becomes “what is the target?” In high-voltage motor applications (i.e., a 320-V dc bus and higher), it is a common requirement to have less than 5 V/ns for insulation reliability. Moreover, since usually there are long cables between inverter and motor, this target helps in reducing reflections that cause overvoltage spikes.

Despite this limit, in the past companies I worked with, we successfully released FredFET and superjunction MOS-based smart modules switching at 15 V/ns for high-voltage applications where the inverter was close to the motor and the power was below 1 kW. Those parts are sold in the millions today and are widely accepted by motor-drive customers.

While in high-voltage large-motor applications dv/dt needs to be limited, posing a challenge in the use of high-voltage WBG devices, I believe it is important to make a distinction and clarify that in low- to medium-voltage motors, conditions are different and more favorable to the use of low-voltage GaN devices, particularly in battery-operated applications where the inverter is close to the motor.

So, what about low-voltage (i.e., 48-V) motors in battery-operated applications? There is no similar dv/dt target and 10 V/ns to 20 V/ns is quite typical. It is a dv/dt target successfully reached by the GaN inverter without compromising the switching dissipation.

But is dv/dt an accurate predictor of radiated EMI? The answer is yes and no. Having spent many hours in EMC anechoic chambers, I can say that it is difficult to predict the EMI behavior of a drive by merely looking at dv/dt. When the inverter is integrated in the motor, it is even harder.

So, a common bias repeated in Kevin Parmenter’s article, "With their fast rise and fall times, WBG power switches generate serious EMI that not only threatens a product's electromagnetic compliance (EMC) but could also lead to power switch failures" is clearly not applicable to low-voltage GaN applications.

But is there any advantage in having the fastest allowed dv/dt in a motor application?

The common bias repeated by Kevin Parmenter is that "…variable frequency drive (VFD) that hangs on the wall in the pumphouse really doesn't need to have a 15-ns commutation time”[1] is unfortunately common also for low-voltage applications.

In reality, the fastest allowed dv/dt enables eliminating the dead time, which is no longer needed when dealing with a GaN inverter.

Effect Of Short Dead Time In 48-V To 100-V Motor Inverters

Using a GaN inverter, it is possible to remove dead times (DT = 10 ns), and hence apply a voltage, to the motor that has lower harmonic distortion than in a MOS inverter (DT = 200 ns). The superior linearity of the GaN inverter allows the lowest acoustic noise operation, especially at low speed. Moreover, the lowest harmonic content of the applied voltage is reflected in a lower harmonic distortion on the motor's current. Thus, a GaN inverter with no dead time leads to fewer vibrations, less heat and less EMI.

Another common bias is that "…impedance mismatches will then cause reflections at both the motor (read as voltage spikes on the edges) and then reflected back to the drive output (and possibly avalanche on those delicate WBG power switches!!)" [1] But as said before, in low-voltage applications, the dv/dt of a GaN inverter can be adapted to the motor without any problem and without the need for using any filter between inverter and motor.

And no, there is no avalanche in the GaN device!

Effect Of Low PWM Frequency On A Battery-Operated Motor Inverter

The typical MOS-based inverter for a battery-operated motor drive application runs at a PWM frequency of 20 kHz, and in some cases it may go as high as 40 kHz.

A commonly expressed bias is that "We do not need to go faster, because motor mechanical frequency pole is low."

In a battery-operated inverter running at 20-kHz PWM, there is a critical voltage and current ripple across the inverter's battery cables. Usually, the voltage ripple is a square wave, and the current ripple is a triangular wave. These ripples on the battery cable are a source of EMI (radiated and conducted), and the typical habit is to put an input LC filter made of an electrolytic capacitor and an inductor. This LC input filter reduces both ripples at the expense of the system's efficiency, reliability, and lifetime.

Increasing PWM Frequency In A Battery-Operated Motor Inverter

A 100-V GaN inverter can be easily operated at a 100-kHz PWM frequency thanks to its lower switching dissipation and smoother switching at the allowed dv/dt. An immediate result is that voltage and current ripples at the battery cables are drastically reduced, so there is no need for any LC input filter based on an electrolytic capacitor. A simple ceramic 22-µF capacitor with a low capacitance value can replace one 330-µF (or sometimes two) bulky electrolytic capacitors, thus saving costs, increasing efficiency, reliability and lifetime.

The 100-kHz frequency range is where ceramic capacitors exhibit the lower ESR. At 100-kHz, ceramic capacitors are the best decoupling companion for GaN inverters.

In my lab, I ran the EPC9146 eval board, using the EPC2152[4] 80-V ePower Stage IC without filters, and measured 15-V/ns dV/dt in the fastest commutation at the motor terminals. The dead time could be reduced to 10 ns, and the PWM frequency increased from 20 kHz to 100 kHz, enabling lower voltage and current ripple on the battery cables using 22-µF ceramic capacitors at 100 kHz when compared to one electrolytic 330 µF at 20 kHz.

There are two videos available to show the operation of this GaN-based motor drive. The first discusses how using GaN increases power density[5] and the second shows how using GaN can reduce audible noise[6] in motor drive designs.

Conclusion–GaN Is On the Road To Innovation

The road to innovation is paved *with the skulls and bones of those who resist.* As the adoption of GaN devices continues to accelerate, incumbent MOSFET producers recognizing that their products are nearing irrelevance, generate scare tactics to encourage designers to stick to the ordinary habit of doing things as they have always been done.

However, the promised benefits of GaN are easily achievable in actual circuit design. With devices that are smaller, faster, reliable and comparably priced, it is becoming increasingly difficult to find reasons not to use GaN FETs and ICs—it is a technology on the road to innovation!

Reference

1. "WBG Semiconductors Pose Safety And EMI Challenges In Motor Drive Applications" by Kevin Parmenter, How2Power Today, January 2021.

2. EPC2022 - Enhancement Mode Power Transistor page.

3. "eGaN FETs Are Low EMI Solutions!" by Michael de Rooij, May 19, 2020, EPC's GaN Talk blog, May 19, 2020.

4. EPC2152x: 70 V, 12.5 A ePower Stage page.

5. "How to Increase Power Density in Motor Drive Designs Using Gallium Nitride-based Integrated Circuit" by Marco Palma, YouTube video, January 25, 2021.

6. "How to Reduce Audible Noise in Motor Drive Designs Using GaN Transistors and ICs" by Marco Palma, YouTube video, October 29, 2020.

About The Author

Marco Palma joined EPC in 2019, where he is director of motor drives systems and applications. He has over 20 years of experience in motor control power electronics ranging from switches to gate drivers, controllers, and algorithms. At Infineon Technologies, he worked on the smallest programmable 100-W fully integrated motor control power module in 2018. Prior to that, at International Rectifier, Marco worked on the smallest 100-W, fully integrated fan drive module in 2009, the first industrial sensorless FOC controller IC in 2004, and the smallest 13-kW fully integrated and programmable motor drive power module in 2002. He is the author of several articles and patents in the field of motor control. Marco received a MSEE from Politecnico di Torino and an MBA from Bocconi Milano.