Radiation Tolerant Enhancement Mode Gallium Nitride (eGaN®) FETs in DC-DC Converters

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Abstract:
Enhancement-mode GaN-on-Si (eGaN) FETs have shown superior performance and also demonstrated their ability to operate reliably under harsh environmental conditions and high radiation conditions. This paper presents new results comparing eGaN FET performance in a clamped forward converter with an output up to 40 W with performance achieved by the latest radiation tolerant silicon power MOSFETs.

Keywords:
Gallium Nitride, GaN, eGaN, MOSFET, FET, Radiation tolerance, SEE, Gamma radiation, clamped forward converter, DC-DC converter.

Introduction:
Enhancement mode gallium nitride transistors have been commercially available for over three years. In that time they have enabled significant efficiency improvement in commercial DC-DC converters in a variety of topologies and at a variety of power levels [1]. Enhancement mode transistors from Efficient Power Conversion Corporation (eGaN® FETs) have also been demonstrated to have remarkable tolerance to gamma radiation [2] and single event effects (SEE) [3].

Previously it was shown that 12 V_{IN} point of load converters (POL) achieved much higher efficiency when radiation tolerant power MOSFETs were replaced by eGaN FETs [4]. In this paper we compare the performance of a radiation tolerant silicon-based power MOSFET (IRHN57250SE [5]) with an enhancement mode eGaN FET from Microsemi Corporation (MGN2910 [6]) in a dual output clamped forward, 28 V_{IN}, 50 W DC-DC power supply (SA50-28-5/15D [7]). This power supply is designed for the +28 V satellite bus and is rated to 100 kRad(Si) and has an SEE rating of more than 80 MeV*cm^2/mg. It is shown that by replacing the radiation tolerant silicon power MOSFETs with eGaN FETs, power losses are significantly reduced.

Transistor Comparison:
Space applications are a unique challenge for system designers. Space hardware operates in extreme environmental conditions including exposure to ionizing radiation which necessitates the use of radiation-hardened components. Radiation tolerant power MOSFETs have been available since 1985 but have compromised electrical performance in order to achieve high radiation tolerance. As a result, space-level power supplies have significantly lower conversion efficiency than their commercial counterparts. Table 1 illustrates the performance differences between a 200 V radiation tolerant power MOSFET and a state-of-the-art eGaN FET with similar voltage and SEE capability, but greatly improved on-resistance, switching characteristics, and total dose immunity. It should be noted that the switching figure of merit (Q_{GD} x $R_{DS(ON)}$) is reduced by an astonishing 55 times. Due to the superior characteristics of gallium nitride as a material for making power transistors [8] the eGaN FET is also significantly lighter and smaller in size as can be seen in figure 1. The eGaN FET has a package that occupies only 24 mm^2 compared with the power MOSFET's 184 mm^2 outline and is 2 mm thinner than the MOSFET at only 1.6 mm resulting in a part that is less than 8 % the volume of the MOSFET.

Forward Converter:
The SA50-28-5/15D power supply from Microsemi is a dual output clamped forward converter with a block diagram as shown in figure 2. The input voltage can range from 17 V to 36 V and there is a dual output of 15 V and 5 V at a maximum output power of 50 W combined. For this comparison the efficiency was first measured with the native IRHN57250SE radiation tolerant silicon power MOSFET from International Rectifier. This transistor was then removed and replaced with an MGN2910 eGaN FET with an LM5114 driver IC as a buffer between the control circuit designed for the silicon MOSFET and the lower drive voltage requirement of the eGaN FET. The efficiency was then re-measured and the results are shown in figure 3.

Table 1: Comparison of key electrical and radiation characteristics between IRHN57250SE and EPC2910

	MGN2910	IRHN57250SE	Units	Performance Ratio	Method
BV_{DSS}	200	200	V		
$R_{DS(ON)}$	0.025	0.06	Ω	2	
Q_G	7.5	132	nC	18	
Q_{GS}	2	45	nC	23	
Q_{GD}	2.6	60	nC	23	
$Q_G*R_{DS(ON)}$	0.19	7.9	nC-Ω	42	
$Q_{GS}*R_{DS(ON)}$	0.05	2.7	nC-Ω	54	
$Q_{GD}*R_{DS(ON)}$	0.065	3.6	nC-Ω	55	
Demonstrated SEE SOA at 84 LET (V_G = 0 V)	190	200	V	1	MIL-STD750E Method 1080
Demonstrated TID Capability	>1000	1	kRAD(Si)	>1000	MIL-STD750E Method 1019

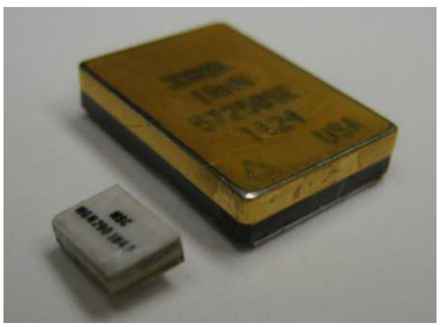

Figure 1: Size comparison between MGN2910 ($24mm^2$) and IRHN57250SE (184 mm^2).

The overall system efficiency was improved between 2.5% and 3.5%, but the losses related just to the switching transistor were reduced by 60% as shown in figure 4. Figure 5 shows a breakdown of these losses in the two different transistors at light, medium, and heavy loads. Judging by the small conduction losses associated with the eGaN FET and similar output capacitance losses, designers could reduce cost without degrading efficiency by using an even smaller eGaN FET such as the MGN2912. Even though the chosen eGaN FET is a larger equivalent device with about 40 % the $R_{DS(ON)}$ of the MOSFET, its switching losses are still about a quarter of that of the MOSFET. Future eGaN FETs based radiation tolerant converters can reduce size through increasing the switching frequency and thus reducing the size of the magnetic (transformers and inductors) and capacitors, thus resulting in an even smaller, lighter overall converter.

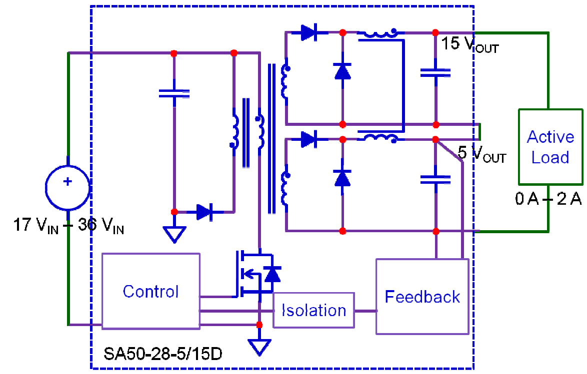

Figure 2: Block diagram of SA50-28-5/15D dual output clamped forward converter from Microsemi Corp.

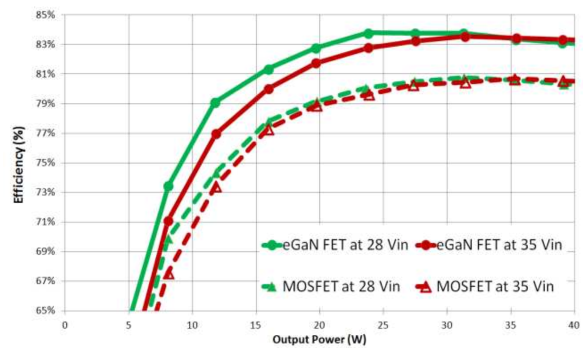

Figure 3: Efficiency comparison between standard SA50-28-5/15D dual forward converter with IRHN57250SE radiation tolerant MOSFET compared with MGN2910 eGaN FET.

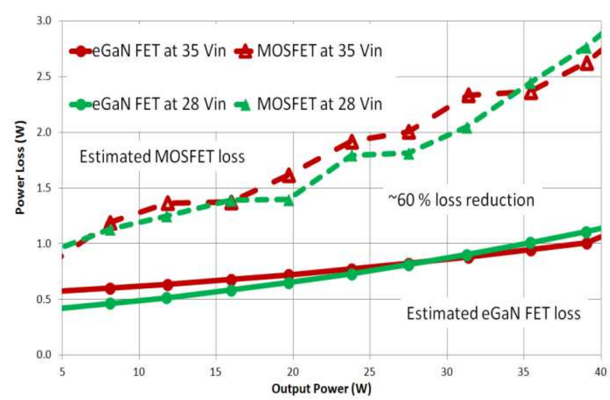

Figure 4: Power losses related to the switching transistor for eGaN FETs compared with radiation tolerant MOSFETs.

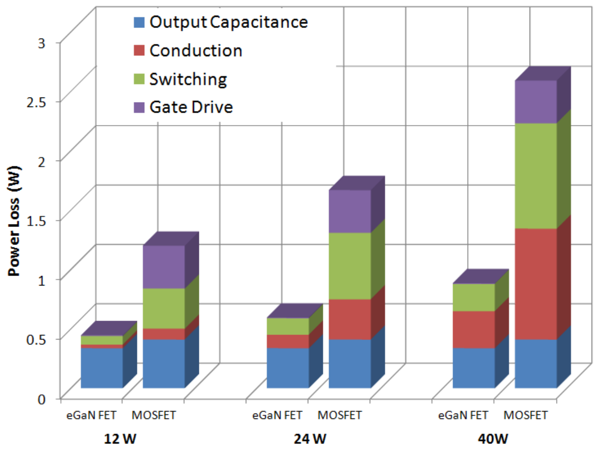

Figure 5: Sources of power losses at 28 V_{IN} at light, medium, and heavy loads for eGaN FETs compared with radiation tolerant MOSFETs.

Conclusions:

eGaN FETs have demonstrated their ability to withstand harsh radiation environments as well as deliver uncompromised state-of-the-art switching performance in a space-rated 50 W DC-DC power supply. In addition to higher power conversion efficiency, the eGaN FETs have a significantly smaller footprint and, due to their superior switching characteristics, enable power supplies that operate at higher frequencies resulting in even further power density improvements.

References:

[1] Lidow, Strydom, de Rooij, and Ma, “GaN Transistors for Efficient Power Conversion”, Power Conversion Publications, 2012.

[2] Alexander Lidow, J. Brandon Witcher, and Ken Smalley, “Enhancement Mode Gallium Nitride (eGaN) FET Characteristics under Long Term Stress”, GOMAC Tech Conference, Orlando, Florida, March 2011.

[3] Alexander Lidow and Ken Smalley, “Radiation Tolerant Enhancement Mode Gallium Nitride (eGaN®) FET Characteristics”, GOMAC Tech Conference, Las Vegas, Nevada, March 2012

[4] Alexander Lidow and Ken Smalley, “The eGaN FET Journey Continues in Space”, GOMAC Tech 2012 Conference Proceedings, http://epc-co.com/epc/documents/presentations/GOMAC%20Tech%20Presentation%202012.pdf

[5] IRHN57250SE data sheet, www.irf.com

[6] MGN2910 data sheet, www.microsemi.com

[7] SA50-28 series data sheets, http://www.microsemi.com/documents/products/SA50-28-515T.pdf

[8] Sam Davis, “Enhancement Mode Gallium Nitride MOSFET Delivers Impressive Performance, Power Electronics Technology, March, 2010, http://powerelectronics.com/power_semiconductors/power_mosfets/enhancement-mode-gallium-nitride-032010/