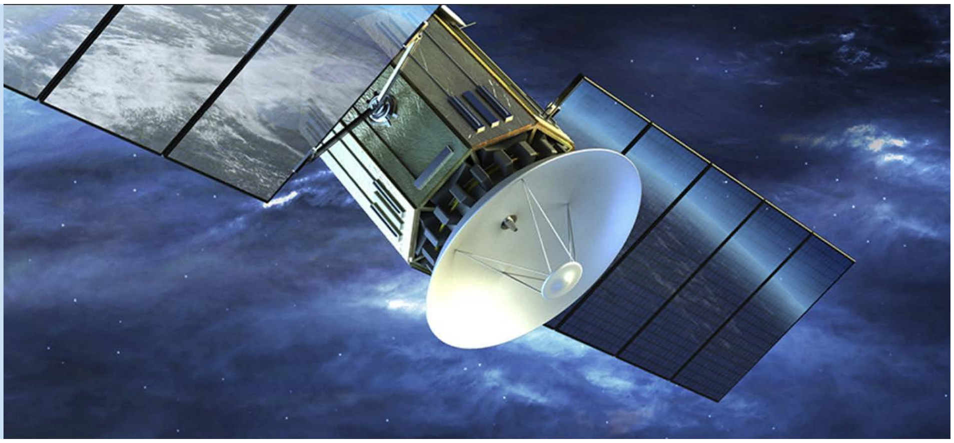
Radiation Performance of Enhancement-Mode Gallium Nitride Power Devices

EPC Space's family of enhancement mode gallium nitride FETs and ICs have been specifically designed for critical applications in the high reliability or commercial satellite space environments. These devices have exceptionally high electron mobility and a low temperature coefficient resulting in very low $R_{DS(on)}$ values.



GaN power transistors and ICs are the best choice for power conversion applications in space-based systems. eGaN devices in packaged form from EPC Space offer dramatically improved performance over the aging rad hard silicon MOSFET.

GaN technology enables a new generation of power converters in space operating at higher frequencies, higher efficiencies, and greater power densities than ever achievable before.

eGaN devices exhibit superior radiation tolerance compared with silicon MOSFETs.

In this application note some of the failure mechanisms in GaN and how they impact radiation performance are explored. Further, the superior electrical performance of eGaN transistors is compared with the most popular Rad Hard MOSFETs in the market.

Radiation in Space

There are several types of radiation experienced by semiconductors in space. Devices in satellites in orbit around our earth, or in exploration satellites visiting the most distant parts of our solar system, all experience some form of high-energy radiation bombardment. Three of the primary types of radiation are gamma radiation, neutron radiation, and heavy ion bombardment.

Failure Mechanisms

An energetic particle can cause damage to a semiconductor in three primary ways; it can cause traps in non-conducting layers, it can cause physical damage to the crystal – also called displacement damage, or it can generate a cloud of electron-hole pairs that will cause the device to momentarily conduct, and possibly burn out in the process.

In eGaN devices, energetic particles cannot generate momentary short-circuit conditions because mobile hole-electron pairs cannot be generated. Thus, this application note will focus on the first two failure mechanisms, trapping and physical damage.

Gamma Radiation – Trapping in Si MOSFET

Gamma radiation consists of high energy photons that interact with electrons. Figure 1 is a cross section of a typical silicon MOSFET. It is a vertical device with the source and gate on the top surface, and the drain on the bottom surface. The gate electrode is separated from the channel region by a thin silicon dioxide layer.

In a silicon based MOSFET, the gamma radiation knocks an electron out of the silicon dioxide layer leaving behind a positively charged 'trap' in the gate oxide. The positive charge reduces the threshold voltage of the device until the transistor goes from normally off – or enhancement mode – to normally on – or depletion mode states. At this point the system will need a negative voltage to turn the MOSFET off. Typical ratings for Rad-Hard devices range from 100 kilo Rads to 300 kilo Rads. In some cases, devices can be made to go up to 1 M Rad, but these tend to be very expensive.

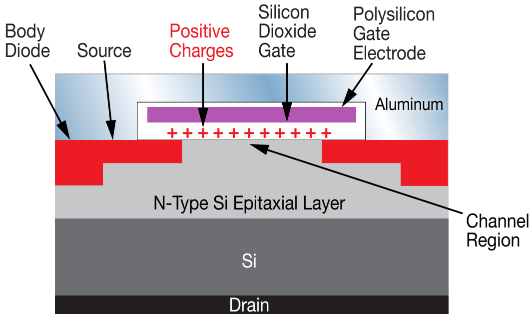


Figure 1: Cross section of a typical silicon MOSFET

Gamma Radiation – eGaN Transistors

Enhancement mode GaN (eGaN®) devices are built very differently from a silicon MOSFET. All three terminals; gate, source, and drain, are located on the top surface. Like in a silicon MOSFET, conduction between source and drain is modulated by biasing the gate electrode from zero volts to a positive voltage – usually 5 V. Notice that the gate is separated from the underlying channel by an aluminum gallium nitride layer. This layer does not accumulate charge when subjected to gamma radiation.

To demonstrate the performance of eGaN devices, EPC Space's 100 V family of eGaN transistors were subjected to 500 kRad of gamma radiation. Throughout the testing, leakage currents from drain to source and gate to source, as well as the threshold voltage and on-resistance of the devices at various checkpoints along the way were measured, confirming that there are no significant changes in device performance.

Since the initial testing, eGaN devices have since been subjected to 50 Mrads, confirming that eGaN devices will not be the first part to fail due to gamma radiation in any space system. Examples of the testing results are shown in figure 3.

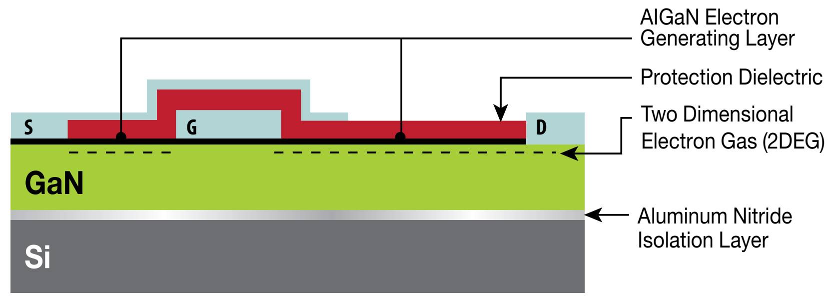
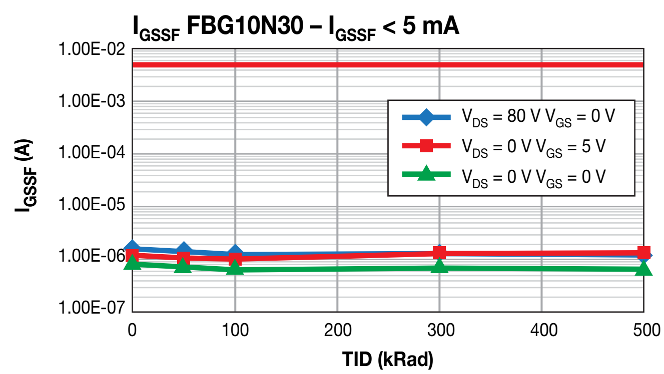


Figure 2: Cross section of a typical enhancement mode GaN (eGaN®) device



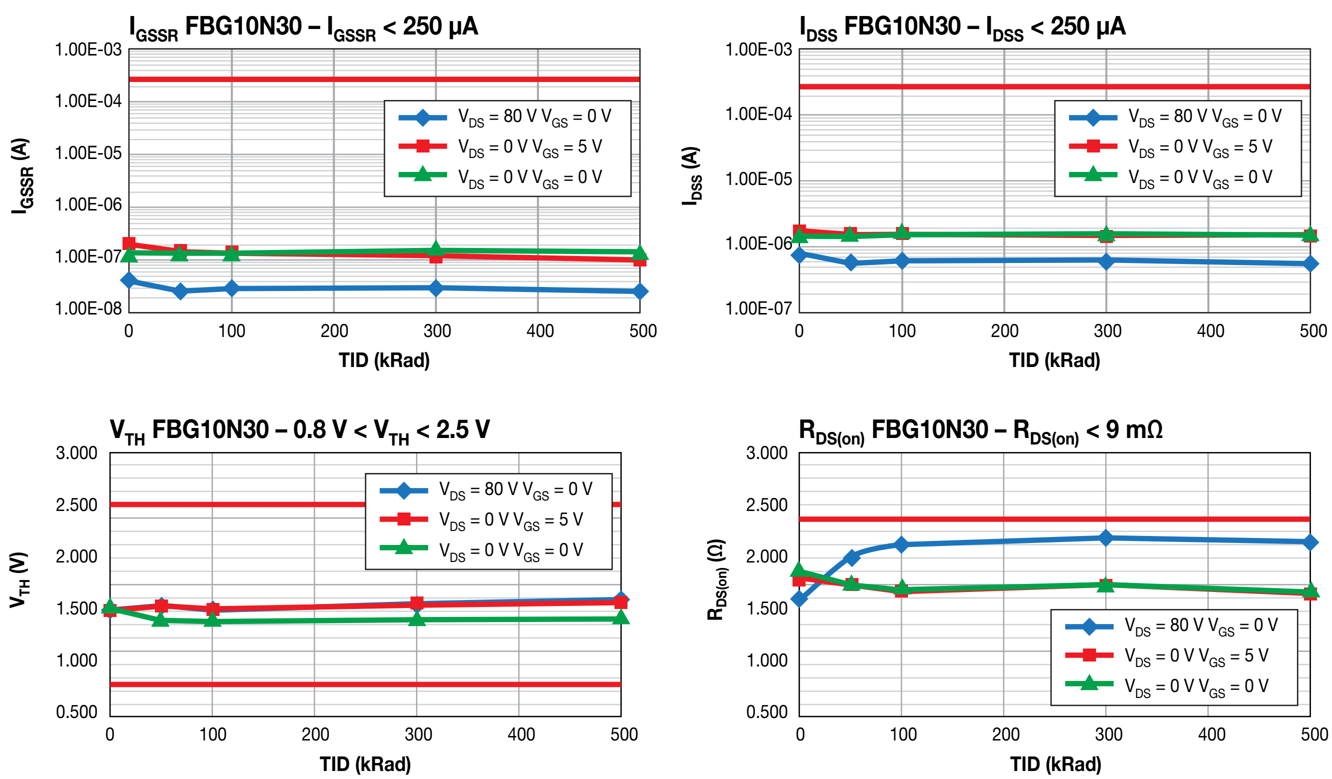


Figure 3: Results of gamma radiation testing of eGaN devices to 50 Mrads

Neutron Radiation

The primary failure mechanism for devices under neutron bombardment is displacement damage. High energy neutrons will scatter off atoms in the crystal lattice and leave behind lattice defects. Figure 4 shows the impact of neutron radiation at doses up to 1 x 10^{15} per square cm. As with gamma radiation, the impact of neutrons on the GaN crystal and the entire device structure is minimal.

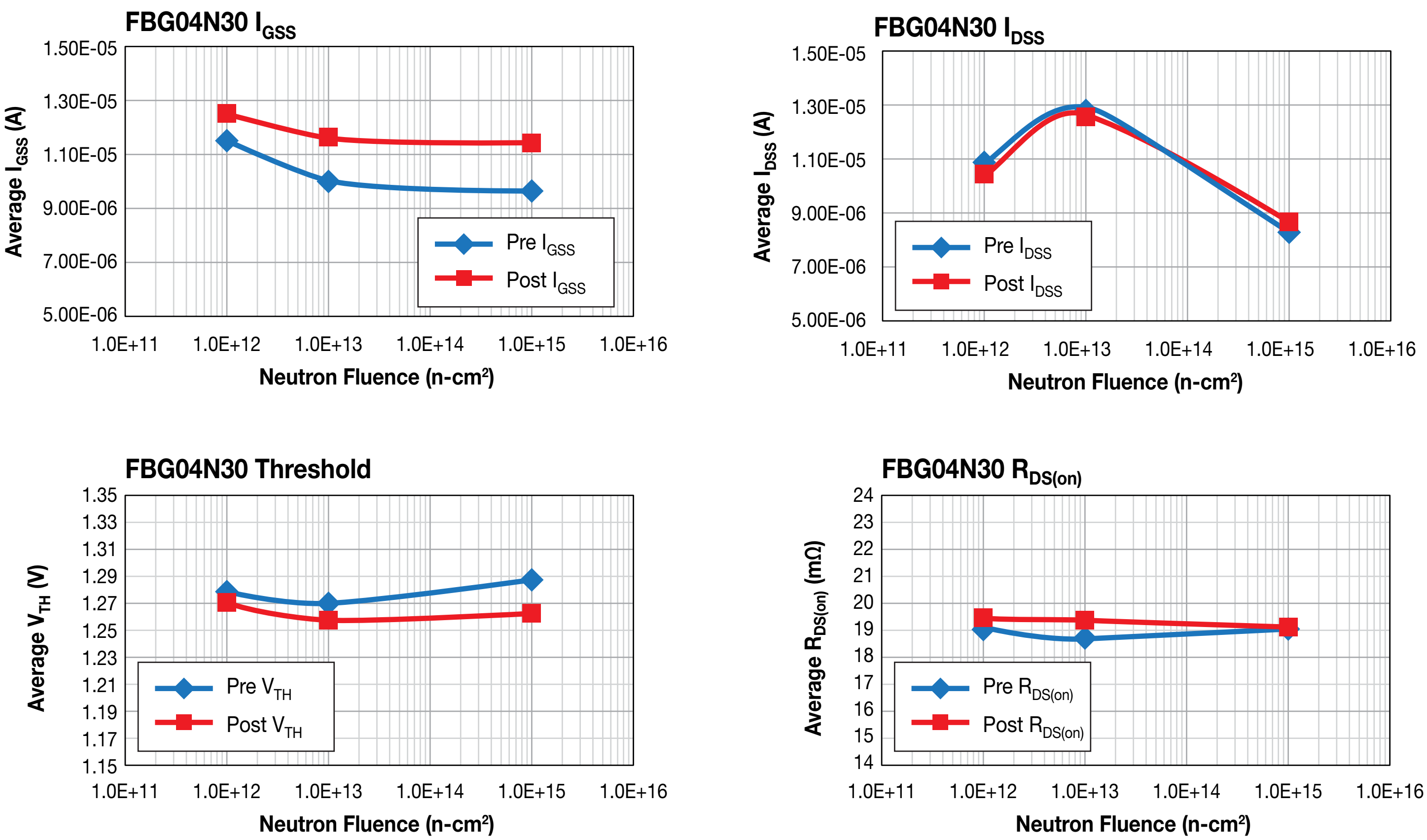


Figure 4: Impact of neutron radiation on eGaN devices at doses up to 1 x 10^{15} per square cm

The reason for GaN's superior performance under neutron radiation is that GaN has a much higher displacement threshold energy compared with silicon. In figure 5, the displacement energy on the vertical axis is compared with the inverse of the lattice constant for various crystals. Note how much higher the displacement energy of GaN is compared with silicon.

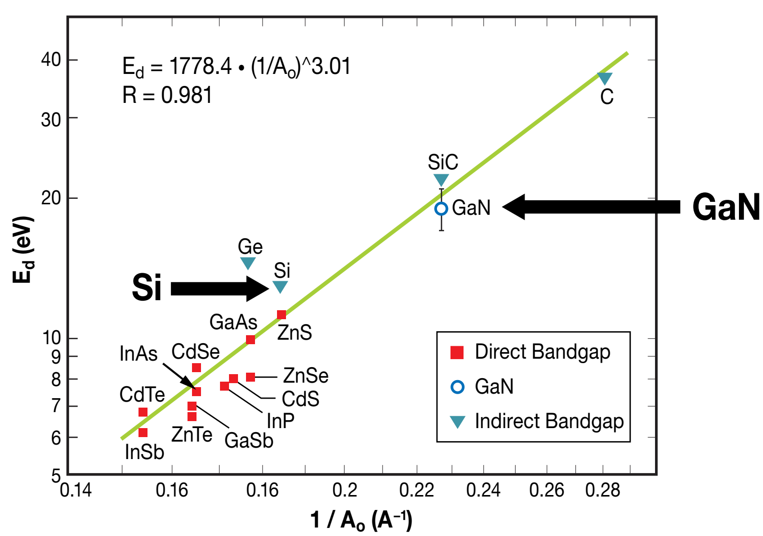


Figure 5: Displacement energy compared with the inverse of the lattice constant for various crystals

Single Event Effects (SEE) – Si MOSFETs

SEE are caused by heavy ions generated by the impact of galactic cosmic rays, solar particles or energetic neutrons and protons. This can be simulated terrestrially by using a cyclotron to create beams of different ions. Two of the most common ions used to evaluate radiation tolerance of electronics components are Xenon, with a linear energy transfer (LET) of about 50 MeV·cm^2/mg, and Gold, with an LET of about 85 MeV·cm^2/mg.

In a silicon MOSFET there are two primary failure mechanisms caused by these heavy ions, single event gate rupture, or SEGR, and single event burnout, or SEB. Single event gate rupture is caused by the energetic atom causing such a high transient electric field across the gate oxide that the gate oxide ruptures, as illustrated in figure 6.

Single event burnout, or SEB, is caused when the energetic particle transverses the drift region of the device where there are relatively high electric fields. The energetic particle loses its energy while generating a large number of hole electron pairs.

These hole electron pairs crossing the drift region cause the device to momentarily short circuit between drain and source. This short circuit can either destroy the device, called a single event burnout, or the device can survive, appearing as a momentary short circuit that can cause damage to other components in the system. This latter case is call single event upset, or SEU.

Single Event – eGaN Devices

Since eGaN devices do not have a gate oxide, they are not prone to single event gate rupture. Since eGaN devices to not have the ability to conduct large numbers of holes very efficiently, they are also not prone to single event upset.

Shown in figure 8 is the primary failure mechanism for eGaN devices under heavy ion bombardment. The conditions are about the maximum conditions possible, with an 85 LET beam of gold atoms pummeling the device biased at the maximum data sheet limit.

The vertical axis in figure 8 is the device leakage current while the horizontal axis is the number of heavy ions absorbed by the device per square centimeter. The dotted line shows the gate-to-source leakage current, and the solid line shows the drain-to-source leakage current for three separate FBG10N30 100 V eGaN transistors. Note that the gate leakage does not go up during bombardment. The drain-source leakage, however, does start to rise as the displacement damage from the heavy ions increases.

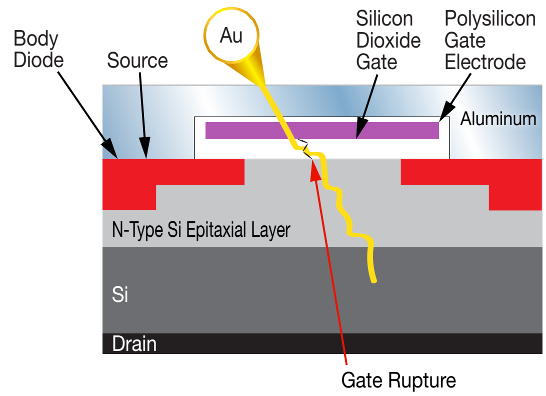


Figure 6: Single event gate rupture (SEGR) in a MOSFET caused by the energetic atom creating a high transient electric field across the gate oxide that, rupturing the gate oxide

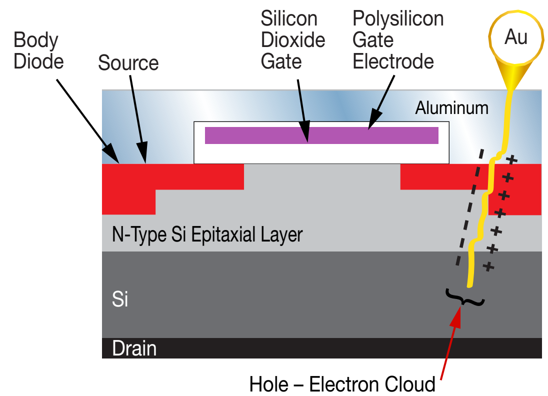


Figure 7: Single event burnout, or SEB, caused by energetic particles crossing the drift region of a device where there are relatively high electric fields

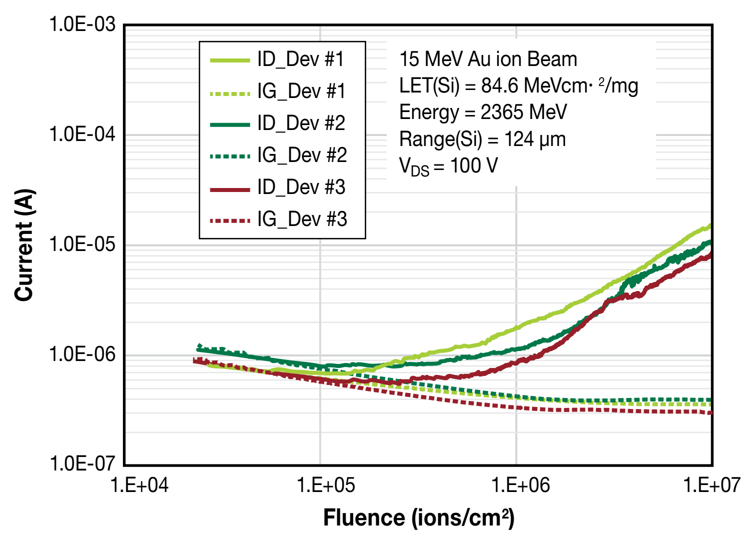


Figure 8: SEE primary failure mechanism for eGaN devices under heavy ion bombardment

SEE Safe Operating Areas

EPC Space has tested many specially produced EPC Gen 4 eGaN products for SEE under varied conditions.

40 V and 100 V product did not fail under any conditions up to full rated voltage and 87 LET. Figure 9 shows the results from several FBG20N18 200 V products. In the red circle you can see that the first failures occurred at 85 LET and 190 V. The FBG30N04 300 V product failed at 85 LET and 310 V.

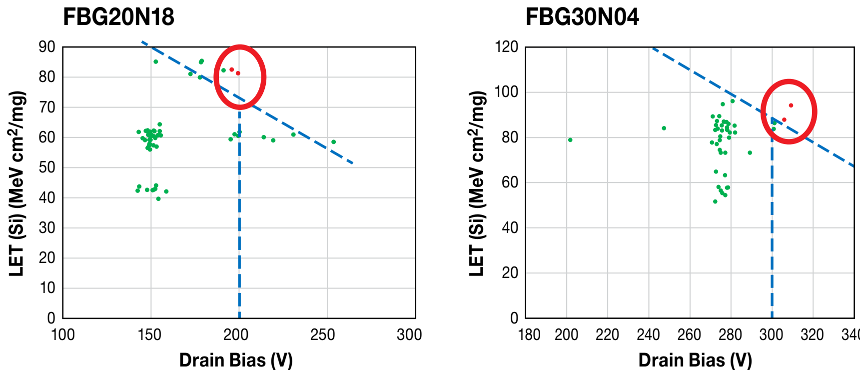


Figure 9: Results from several FBG20N18 200 V products and FBG30N04 300 V products when bombarded with heavy ions ranging from 40 LET to 87 LET

Electrical Performance Comparison at 100 V

In addition to the superior rad hard advantages of gallium nitride over silicon, GaN has superior electrical performance as well. As an example, the electrical performance comparisons of two 100 V Rad Hard eGaN transistors against the IRHNA67160 power MOSFET from Infineon are shown in table 1. Highlighted in **green** are the characteristics of the eGaN transistor that are superior to their MOSFET counterpart.

On the left, the FBG10N30 packaged part from EPC Space has half the on-resistance, yet is one-tenth the size and has about one-twentieth the gate and gate-drain charges that determine switching speed. In addition, the radiation resistance is significantly higher. The device on the right is a smaller part in the 100 V range, yet displays similar relative superiority.

100 V

Parameter	FBG10N30	IRHNA67160	Units
I_D	30	35	A
I_{DM}	120	140	A
BV_{DSS}	100	100	V
$R_{DS(on)}$	**9**	18	mΩ
Q_G	**9**	160	nC
Q_{GD}	**2**	65	nC
Q_{RR}	**0**	1.9	µC
$R_{\theta JC}$	2.12	0.5	°C/W
Radiation Level	**>10 M**	300 k	Rad (Si)
SEE @85 LET	100	100	V
Size	**23**	236	mm²

Parameter	FBG10N05	IRHNJ67130	Units
I_D	5	22	A
I_{DM}	40	88	A
BV_{DSS}	100	100	V
$R_{DS(on)}$	**38**	42	mΩ
Q_G	**2.2**	50	nC
Q_{GD}	**0.6**	20	nC
Q_{RR}	**0**	3	µC
$R_{\theta JC}$	3.6	1.67	°C/W
Radiation Level	**>10 M**	300 k	Rad (Si)
SEE @85 LET	100	100	V
Size	**12**	78.5	mm²

Table 1: Electrical performance comparisons of two 100 V Rad Hard eGaN transistors against power MOSFETs from Infineon

Electrical Performance Comparison at 200 V

At 200 V, the difference in electrical performance of the eGaN transistors is even greater, as seen in table 2. The device on the left has similar on-resistance to its MOSFET counterpart, yet is one-tenth the size, and has about 30 times better switching performance while demonstrating superior radiation resistance.

200 V

Parameter	FBG20N18	IRHNA67260	Units
I_D	18	56	A
I_{DM}	72	224	A
BV_{DSS}	200	200	V
$R_{DS(on)}$	**26**	28	mΩ
Q_G	**6**	240	nC
Q_{GD}	**1.95**	60	nC
Q_{RR}	**0**	11.7	µC
$R_{\theta JC}$	2.12	0.5	°C/W
Radiation Level	**>10 M**	300 k	Rad (Si)
SEE @85 LET	175	170	V
Size	**23**	236	mm²

Parameter	FBG20N18	IRHNJ67230	Units
I_D	18	16	A
I_{DM}	72	64	A
BV_{DSS}	200	200	V
$R_{DS(on)}$	**26**	130	mΩ
Q_G	**6**	50	nC
Q_{GD}	**1.95**	20	nC
Q_{RR}	**0**	3.5	µC
$R_{\theta JC}$	2.12	1.67	°C/W
Radiation Level	**>10 M**	300 k	Rad (Si)
SEE @85 LET	175	170	V
Size	**23**	78.5	mm²

Table 2: Electrical performance comparisons at 200 V Rad Hard eGaN transistors against power MOSFETs from Infineon

eGaN Devices for Space

In summary, GaN power transistors and ICs are the best choice for power conversion applications in space-based systems. eGaN devices have proven to be more rugged than rad hard MOSFETs, when exposed to various forms of radiation. In addition, the electrical performance of eGaN devices is many times superior to the aging silicon power MOSFET.