SEE TESTING OF WIDE BANDGAP COMPONENTS

...WHEN FAILURE IS NOT AN OPTION!! ™

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SPACE POWER WORKSHOP 2021
INTERSIL HIGH-RELIABILITY PRODUCTS
RENESAS ELECTRONICS AMERICA INC.

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AGENDA

- Introduction
  - Authors
  - Benefits of GaN FETS vs. Si MOSFETs
- Released GaN FETs
  - ISL70020SEH
  - ISL70023SEH
  - ISL70024SEH
- SEE Test Methodology
- Results & Worst Case Analysis
- Conclusion

INTRODUCTION – AUTHORS

PRESENTER

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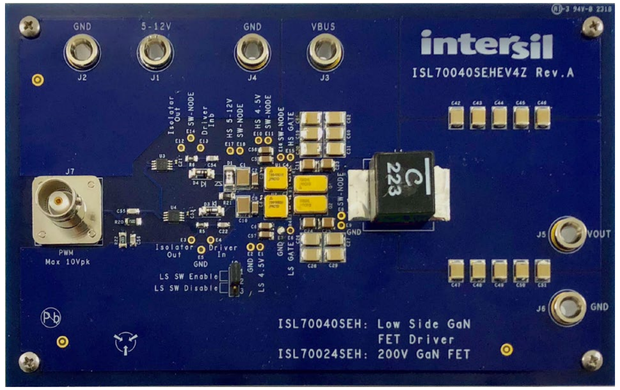
INTRODUCTION

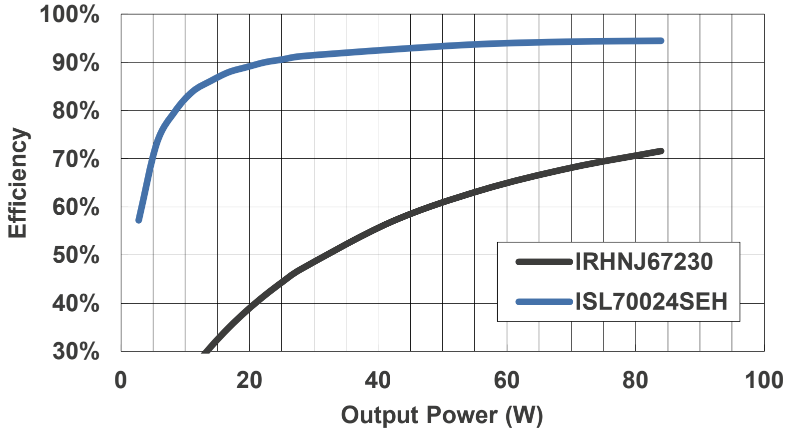
- The space and high reliability industry has been looking into using wide bandgap devices such as GaN in power management applications.

- Benefits of GaN FETs vs. Si MOSFETs
  - Compared to Si, the drain/source distance can be smaller by a factor of 10.
  - This translates to a much smaller channel width in GaN vs. Si MOSFETs for the same R_{DSON}.
  - The reduction in size also results in lower output capacitance and layout inductance.

- By cutting down on switching and conduction losses, the real world efficiency improvements are quite drastic:

GaN Driver:
ISL70040SEH





Conditions:
$100V_{IN}$ to $28V_{OUT}$
F_{SW} = 400kHz

PCB Footprint:
GaN: 42 mm^2
MOS: 79 mm^2

RENESAS GAN FETS

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Radiation Hardness Assurance:

100krad(Si) HDR & 75krad(Si) LDR

Single Event Effects Characterization:

SEB LET = 86MeV·cm^2/mg w/ V_{DS} = 100% of rating

GaN FET	VDS (V)	IDS* (A)	RDSON (mΩ)	QG (nC)	HDR (krad (Si))	LDR (krad (Si))	Package	Area (mm^2)
ISL70020SEH	40	65	3.5	19	100	75	4 Ld SMD	42
ISL70023SEH	100	60	5	14	100	75	4 Ld SMD	42
ISL70024SEH	200	7.5	45	2.5	100	75	4 Ld SMD	42

Table 1: Renesas' GaN FETs

Note:
*ID is limited by package

SEE TEST METHODOLOGY

- The objective was the characterize the behavior of I_{DSS} during exposure to heavy ions
  - The primary concern was Destructive Single Event Effects (DSEE), typified as a substantial increase in I_{DSS}
  - The secondary was the gradual increase of I_{DSS} with exposure to irradiation
- The testing was done to establish a Safe Operating Area (SOA) for DSEE and to quantify the gradual increase in I_{DSS} with respect to fluence, V_{DS} and LET.

Flux (ion/(cm²•s))	Fluence (ion/cm²)	V_{DSS} (V)	Time (sec)
0	0	100	30
0	0	60 / 80 / 100	30
$1x10^4$	$2.5x10^6$	60 / 80 / 100	250
0	0	60 / 80 / 100	30
0	0	100	30

Table 2: Sequence of Events for Characterizing the Behavior of I_{DSS} for the ISL70023SEH

To get the gradual increase in I_{DSS}, the minimum value of I_{DSS} pre irradiation was subtracted from the maximum I_{DSS} post irradiation. This value was then divided by 2.5 to yield the I_{DSS} rise per $1x10^6$ ions/cm^2. This number is reported at ΔI_{DSS} in subsequent sections in this presentation.

RESULTS – ISL70020SEH (40V GAN FET)

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- No I_{DSS} Increase:
  - LET 28 MeV•cm²/mg ($24V_{DS}$, $32V_{DS}$, $40V_{DS}$)
  - LET 43 MeV•cm²/mg ($24V_{DS}$, $32V_{DS}$, $40V_{DS}$)
  - LET 60 MeV•cm²/mg ($24V_{DS}$, $32V_{DS}$, $40V_{DS}$)
  - LET 86 MeV•cm²/mg ($24V_{DS}$)
- Gradual I_{DSS} Increase:
  - LET 86 MeV•cm²/mg ($32V_{DS}$, $40V_{DS}$)
- I_{DSS} increase shown is per $1x10^6$ ions/cm²
  - Un-highlighted cells: no significant change in I_{DSS}.
  - Highlighted cells: a significant increase in I_{DSS}.

ISL70020SEH (V_{DSS} = 24V) (µA)				
LET	DUT1	DUT2	DUT3	DUT4
28	-0.30	-0.26	-0.28	0.11
43	-0.46	-0.80	-0.36	-0.40
60	-0.21	0.29	-0.39	-0.38
86	-0.13	-0.30	-0.08	-0.09

ISL70020SEH (V_{DSS} = 32V) (µA)				
LET	DUT1	DUT2	DUT3	DUT4
28	-0.61	-0.76	-0.96	-0.73
43	-0.45	-0.49	-0.24	0.04
60	-0.14	-0.23	0.03	-0.06
86	4.76	5.36	2.32	1.92

ISL70020SEH (V_{DSS} = 40V) (µA)				
LET	DUT1	DUT2	DUT3	DUT4
28	-0.34	-0.82	-0.49	-0.59
43	-0.12	-0.06	-0.10	0.11
60	0.10	0.04	-0.72	0.40
86	5.48	8.97	1.97	5.97

Table 3: ISL70020SEH Δ I_{DSS} (µA) at V_{DSS} per Irradiation with $1x10^6$ ions/cm²

RESULTS – ISL70023SEH (100V GAN FET)

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- No I_{DSS} Increase:
  - LET 28 MeV•cm²/mg ($60V_{DS}$, $80V_{DS}$, $100V_{DS}$)
  - LET 43 MeV•cm²/mg ($60V_{DS}$, $80V_{DS}$, $100V_{DS}$)
- Gradual I_{DSS} Increase:
  - LET 60 MeV•cm²/mg ($60V_{DS}$, $80V_{DS}$, $100V_{DS}$)
  - LET 86 MeV•cm²/mg ($60V_{DS}$, $80V_{DS}$, $100V_{DS}$)
- I_{DSS} increase shown is per $1x10^6$ ions/cm²
  - Un-highlighted cells: no significant change in I_{DSS}.
  - Highlighted cells: a significant increase in I_{DSS}.

ISL70023SEH (V_{DSS} = 60V) (µA)				
LET	DUT1	DUT2	DUT3	DUT4
28	0.08	0.09	0.08	-0.09
43	0.06	-0.23	0.07	0.24
60	1.18	-0.17	1.20	1.32
86	1.16	1.57	3.06	2.85

ISL70023SEH (V_{DSS} = 80V) (µA)				
LET	DUT1	DUT2	DUT3	DUT4
28	-0.56	-0.28	-0.33	-0.22
43	-0.11	-0.30	0.12	-0.20
60	-0.21	0.54	-0.05	-0.04
86	3.73	4.17	4.63	2.78

ISL70023SEH (V_{DSS} = 100V) (µA)				
LET	DUT1	DUT2	DUT3	DUT4
28	-0.14	-0.08	0.32	-0.06
43	0.23	-0.12	0.03	0.20
60	1.72	1.94	1.17	0.78
86	3.15	3.07	1.46	5.88

Table 4: ISL70023SEH Δ I_{DSS} (µA) at V_{DSS} per Irradiation with $1x10^6$ ions/cm²

RESULTS – ISL70024SEH (200V GAN FET)

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- No I_{DSS} Increase:
  - LET 28 MeV•cm²/mg ($120V_{DS}$, $160V_{DS}$, $200V_{DS}$)
- Gradual I_{DSS} Increase:
  - LET 43 MeV•cm²/mg ($120V_{DS}$, $160V_{DS}$, $200V_{DS}$)
  - LET 60 MeV•cm²/mg ($120V_{DS}$, $160V_{DS}$, $200V_{DS}$)
  - LET 86 MeV•cm²/mg ($120V_{DS}$, $160V_{DS}$)
- Destructive SEE:
  - LET 86 MeV•cm²/mg ($200V_{DS}$)
- I_{DSS} increase shown is per $1x10^6$ ions/cm²
  - Un-highlighted cells: no significant change in I_{DSS}.
  - Highlighted cells: a significant increase in I_{DSS}.

ISL70024SEH (V_{DSS} = 120V) (µA)				
LET	DUT1	DUT2	DUT3	DUT4
28	0.14	-0.19	-0.47	0.02
43	2.00	0.27	0.61	0.50
60	1.24	5.08	2.71	7.40
86	7.30	8.87	8.61	6.78

ISL70024SEH (V_{DSS} = 160V) (µA)				
LET	DUT1	DUT2	DUT3	DUT4
28	0.12	-0.02	0.04	0.28
43	0.86	0.59	0.89	0.86
60	3.14	2.45	2.56	2.61
86	14.51	32.37	28.14	11.73

ISL70024SEH (V_{DSS} = 200V) (µA)				
LET	DUT1	DUT2	DUT3	DUT4
28	0.16	-0.06	-0.07	0.05
43	2.50	6.70	2.91	3.70
60	7.11	9.52	10.45	15.26
86	DSEE	DSEE	DSEE	DSEE

Table 5: ISL70024SEH Δ I_{DSS} (µA) at V_{DSS} per Irradiation with $1x10^6$ ions/cm²

WORST CASE ANALYSIS

- As all tested GaN FETs exhibited some increase in I_{DSS} under certain conditions of V_{DS} and LET, it is important to put the I_{DSS} increase in the context of a typical Geosynchronous Orbit (GEO).
  - Using the data gathered on the GaN FETs alongside the parameters for a GEO mission in the single event simulation program CREME96, it is possible to show that the I_{DSS} increase is inconsequential.
- Figure 3 shows a CREME96 spectrum file generated for a satellite in GEO with all species of heavy ion particles from atomic number 2 through 92 with a minimum energy value of 0.1 MeV/nuc.
  - Assumptions included solar minimum conditions for worst case cosmic flux through 100 mils of aluminum shielding.
  - The integral flux in Figure 3 is in terms of the number of particles incident in a solid angle about a line normal to a small area on the surface of a sphere. The LET on the x axis is MeV•cm²/g. The colored lines on the plot represent the flux of particles at a given LET.

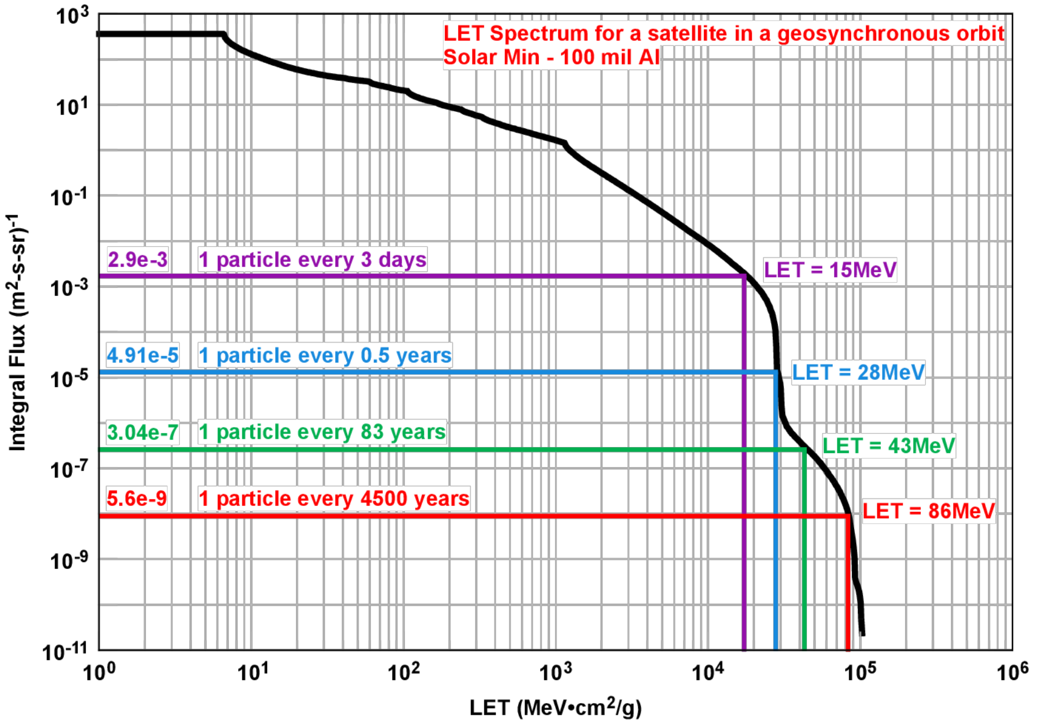

Figure 3: CREME96 LET Spectrum for a Satellite in GEO Assuming Solar Minimum Conditions with 100 mils of Aluminum Shielding

WORST CASE ANALYSIS – CONT'D

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- Using LET 43 MeV•cm^2/mg (green line) which was the lowest LET that resulted in an I_{DSS} increase, we get the following:
  - Flux = $3.04x10^{-7}$ particles/m^2-s-sr

    = $3.04x10^{-11}$ particles/cm^2-s-sr

$$Fluence = Flux * Time$$

$$= (3.04x10^{-11} \frac{particles}{cm^2-s-sr}) * (3600 \frac{s}{hr}) * (24 \frac{hrs}{day}) * (365.25 \frac{days}{year}) \quad \text{(Eq. 1)}$$

$$= 9.59x10^{-4} \frac{particles}{cm^2 - yr - sr}$$

  - Since the number calculated above is for a sphere and the area of interest is a 1 cm^2 area on that sphere, we need to multiply by 4π sr (solid angle of the entire sphere) to remove steradian from the units and provide the time to encounter 1 single particle:

$$Time\ to\ encounter\ 1\ particle = (9.59x10^{-4} \frac{particles}{cm^2-yr-sr} * 4\pi\ sr)^{-1} \quad \text{(Eq. 2)}$$

$$= 82.98 \frac{yrs•cm^2}{particle} \approx \boxed{83 \frac{yrs•cm^2}{particle}}$$

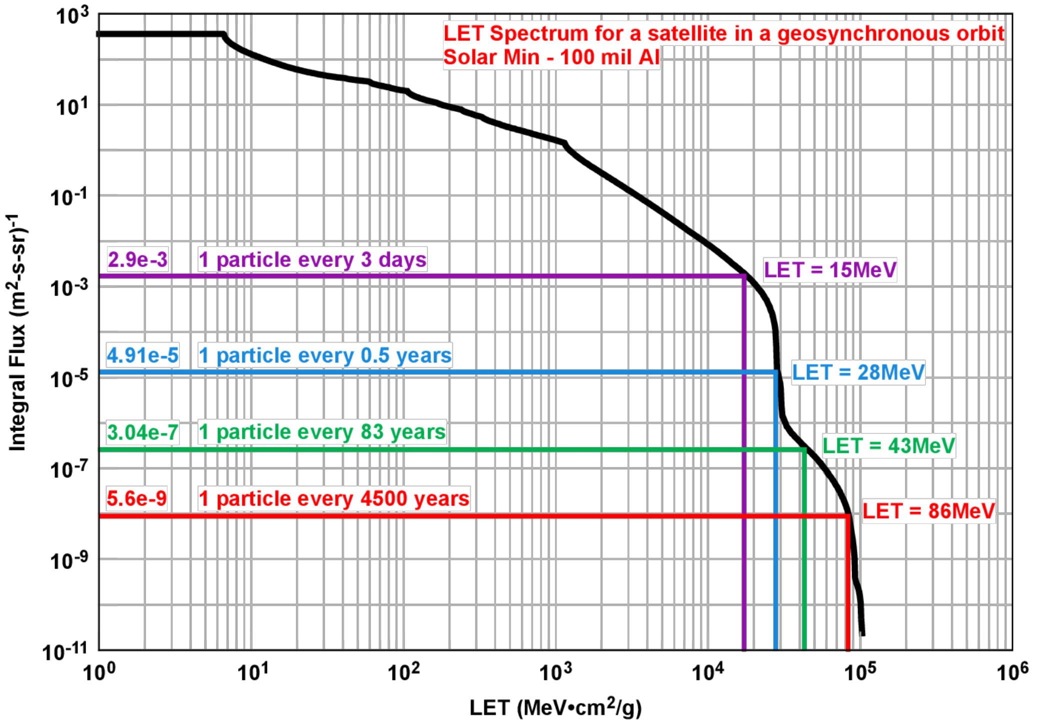

Figure 3: CREME96 LET Spectrum for a Satellite in GEO Assuming Solar Minimum Conditions with 100 mils of Aluminum Shielding

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WORST CASE ANALYSIS – CONT'D

- Using equation 1 and 2 for an LET of 86MeV, we can approximate that the electronics in the satellite would encounter a particle ≥ 86 MeV•cm^2/mg once every 4500 years.
  - While these high energetic ions can have major impacts on electronics with regards to Single Event Latch-up, they are insignificant for a cumulative event like I_{DSS} current increase.
  - To get the current increase shown in tables 3-5, it would take:
    - 292 million years to encounter 1x10^6 ions that have an LET ≥ 60 MeV•cm^2/mg
    - 4 billion years to encounter 1x10^6 ions that have am LET ≥ 86 MeV•cm^2/mg
- To calculate the I_{DSS} increase for a typical 20 year GEO mission we get the following table:

		Current Increase in Amps			
Part Type	**V_{DSS} (V)**	**LET 28**	**LET 43**	**LET 60**	**LET 86**
ISL70020SEH	40	$3.19 \cdot 10^{-11}$	$2.89 \cdot 10^{-14}$	$4.93 \cdot 10^{-14}$	$4.00 \cdot 10^{-14}$
ISL70023SEH	100	$1.25 \cdot 10^{-11}$	$5.54 \cdot 10^{-14}$	$1.33 \cdot 10^{-13}$	$2.62 \cdot 10^{-13}$
ISL70024SEH	160	$1.09 \cdot 10^{-11}$	$2.14 \cdot 10^{-13}$	$2.15 \cdot 10^{-13}$	$1.45 \cdot 10^{-13}$
ISL70024SEH	200	$6.23 \cdot 10^{-12}$	$1.61 \cdot 10^{-12}$	$1.05 \cdot 10^{-12}$	SEB

Table 6: GaN FET I_{DSS} Increase After 20 Years at 1x10^6 ions/cm^2

I_{DSS} increase is in picoamps or less!

CONCLUSION

- SEE testing of the ISL70020SEH, ISL70023SEH and the ISL70024SEH showed evidence of an increase in I_{DSS} at energies above 43 MeV•cm^2/mg.
- Normalizing the I_{DSS} increase during SEE testing for a typical 20 year GEO mission results in an I_{DSS} increase of picoamps or less.
- As the objective was to establish a safe operating area for the GaN FETs, the analysis shows that:
  - Unconditional SOA:
    - ISL70020SEH: LETs ≤ 60 MeV•cm^2/mg, 86 MeV•cm^2/mg with VDS ≤ 24V.
    - ISL70023SEH: LETs ≤ 60 MeV•cm^2/mg
    - ISL70024SEH: LETs ≤ 28 MeV•cm^2/mg
  - Conditional SOA (picoamps of I_{DSS} increase in a typical 20 yr GEO mission)
    - ISL70020SEH: LETs 86 MeV•cm^2/mg
    - ISL70023SEH: LETs 60, 86 MeV•cm^2/mg
    - ISL70024SEH: LETs 43, 60 MeV•cm^2/mg, LETs 86 MeV•cm^2/mg with VDS ≤ 160V.

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