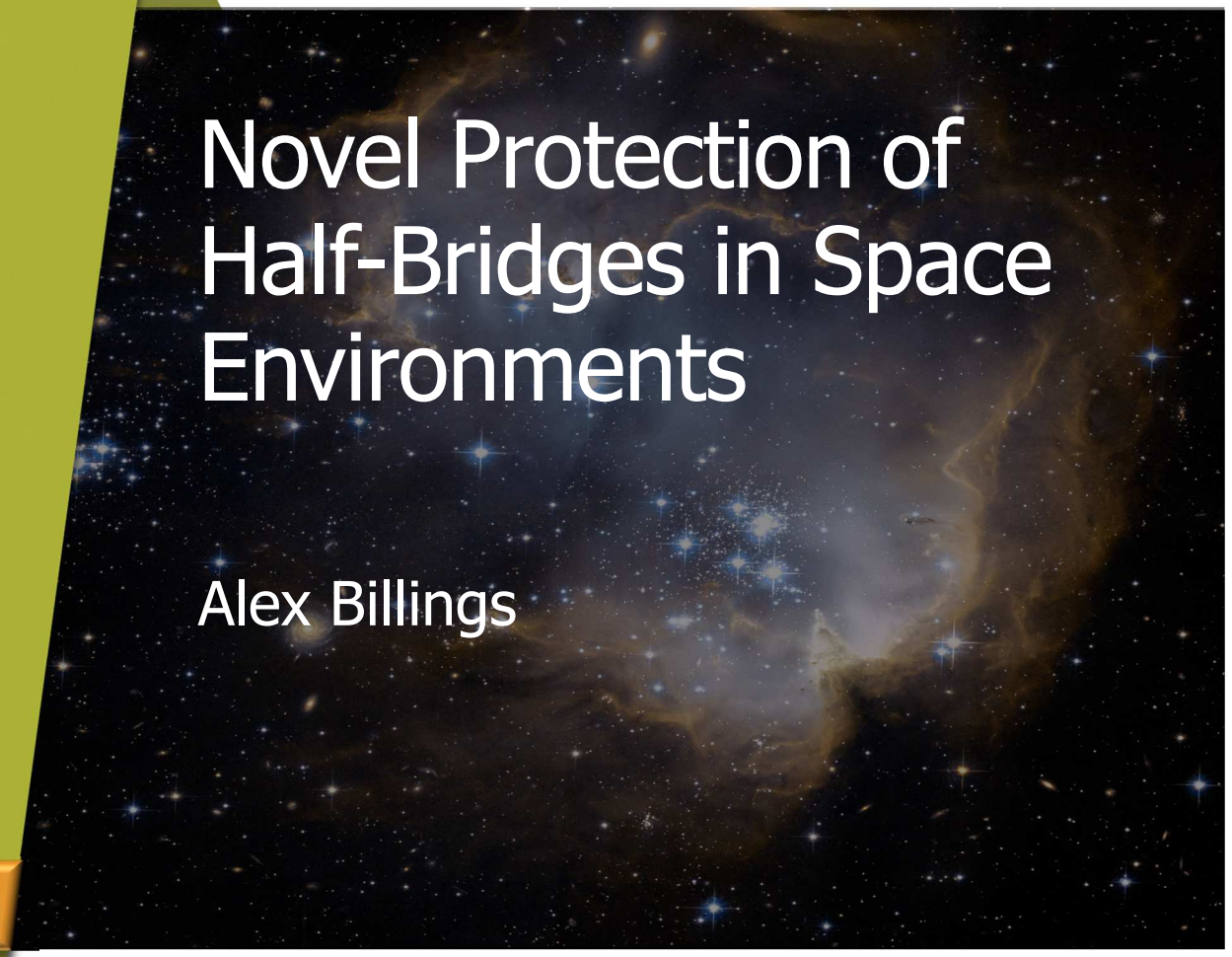
Novel Protection of Half-Bridges in Space Environments



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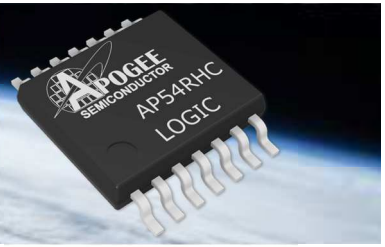
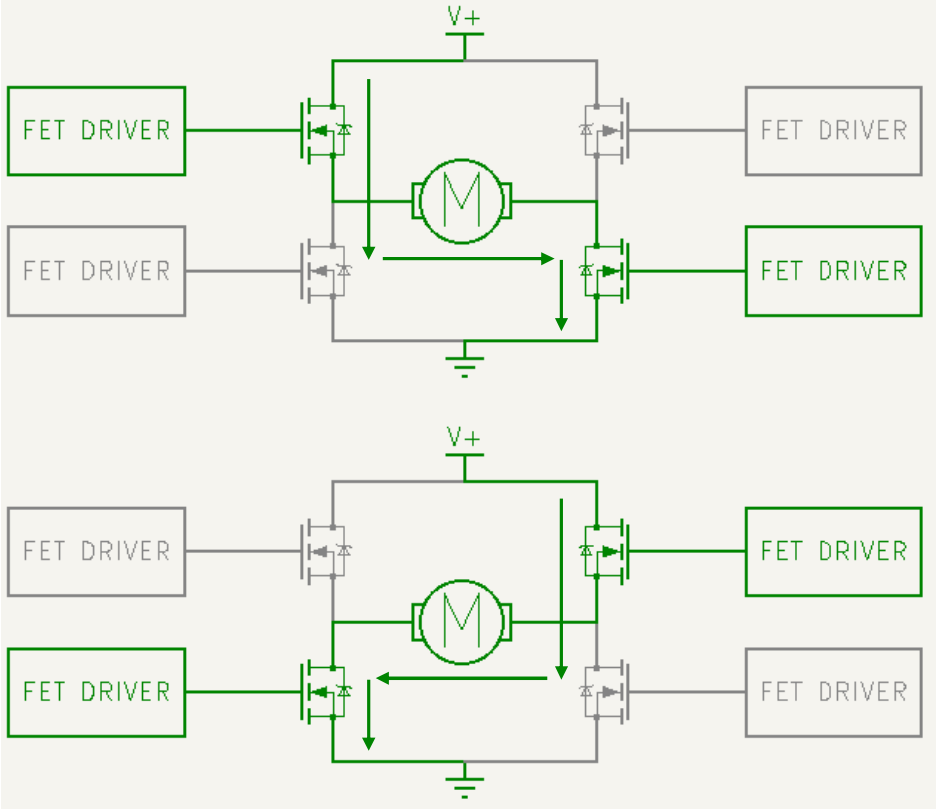
Shoot-Through

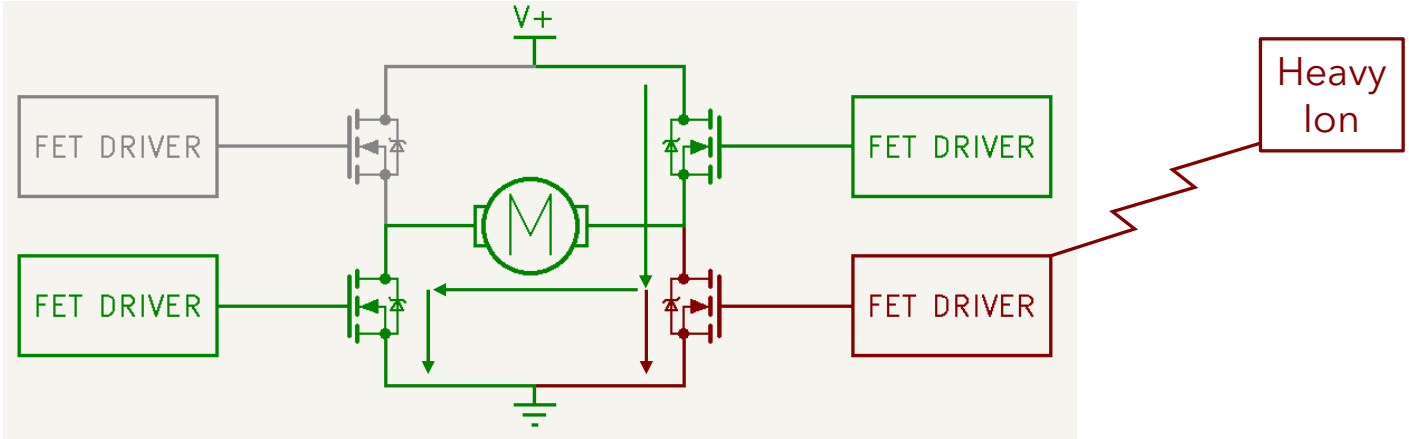


- High-reliability power systems where half-bridges or push/pull drivers are used commonly have issues with cross-conduction (or shoot-through)
- Switching between push and pull, or between the high-side and low-side devices could cause the power supply to temporarily short to ground
- Depending on the application, this could be fatal to a system



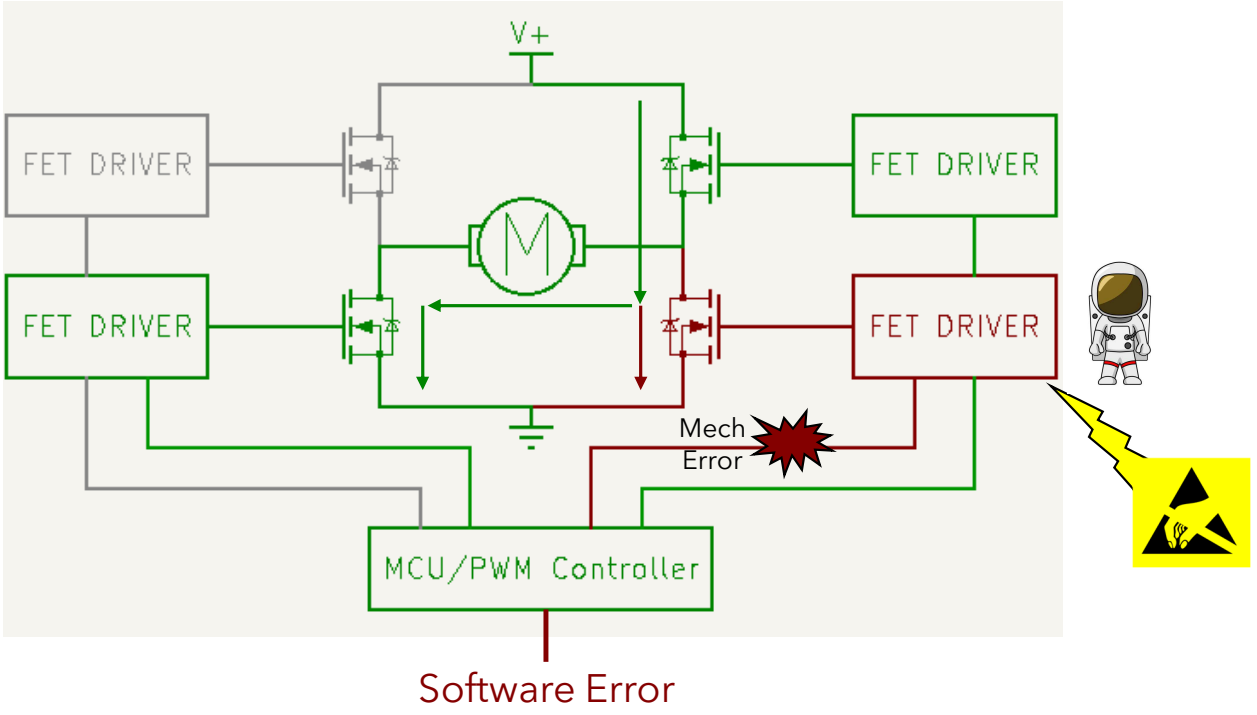
SET-Induced Cross-Conduction

- Single Event Transients (SETs) could also cause the high-side and low-side devices to conduct simultaneously
- Thus, space-based power systems are even more at-risk of permanent system degradation and shortened lifetimes



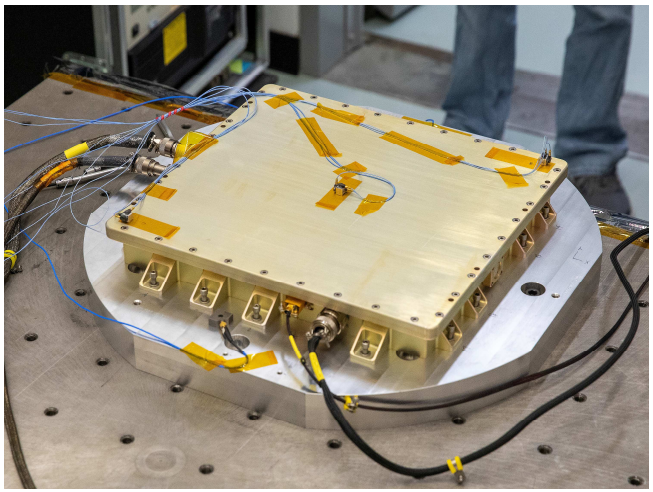
Other Sources of Error

- ESD/Static buildup
- Mechanical damage from spacecraft automation
- Human error
- Software error

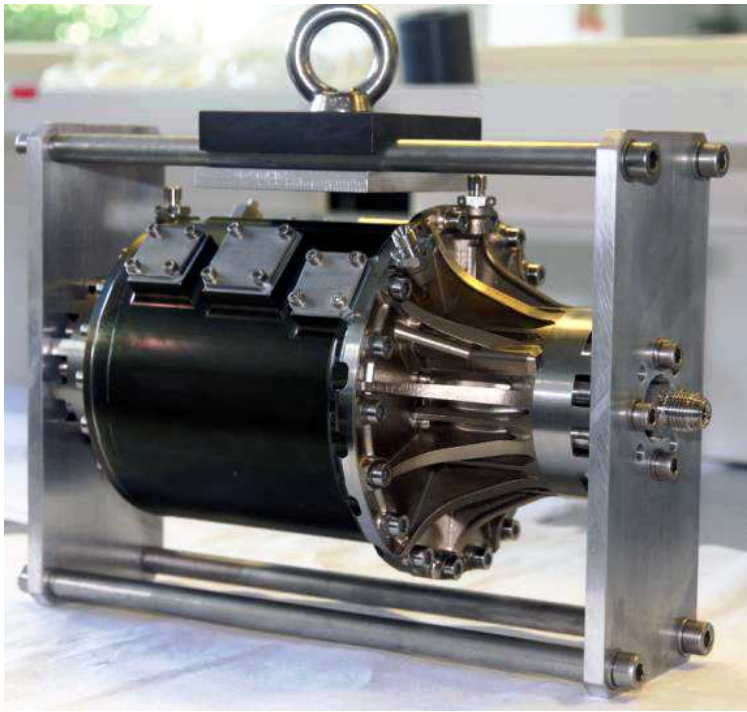


Applications

- Cross-conduction appears in a wide range of systems:
  - Motor controllers
    - *H-bridges*
  - Push-pull drivers
    - *Half-bridges*
  - Thrusters
  - Power converters
  - Inverters
  - Squib
  - Separation bolts



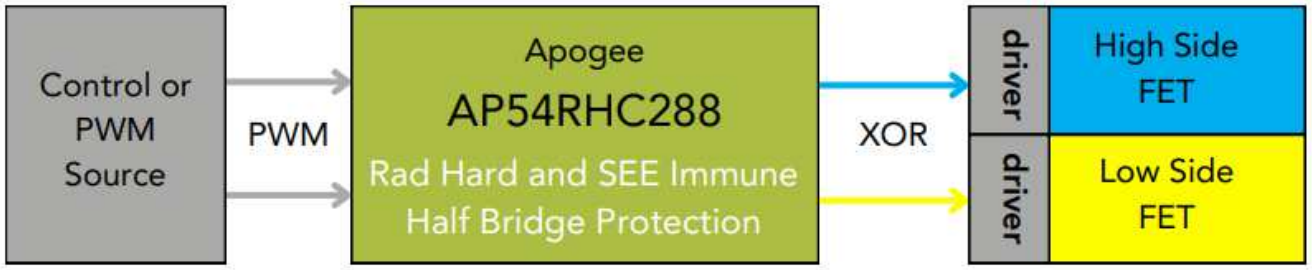
https://www.nasa.gov/centers-and-facilities/langley/clarreo-pathfinder-power-converter-unit-completed/



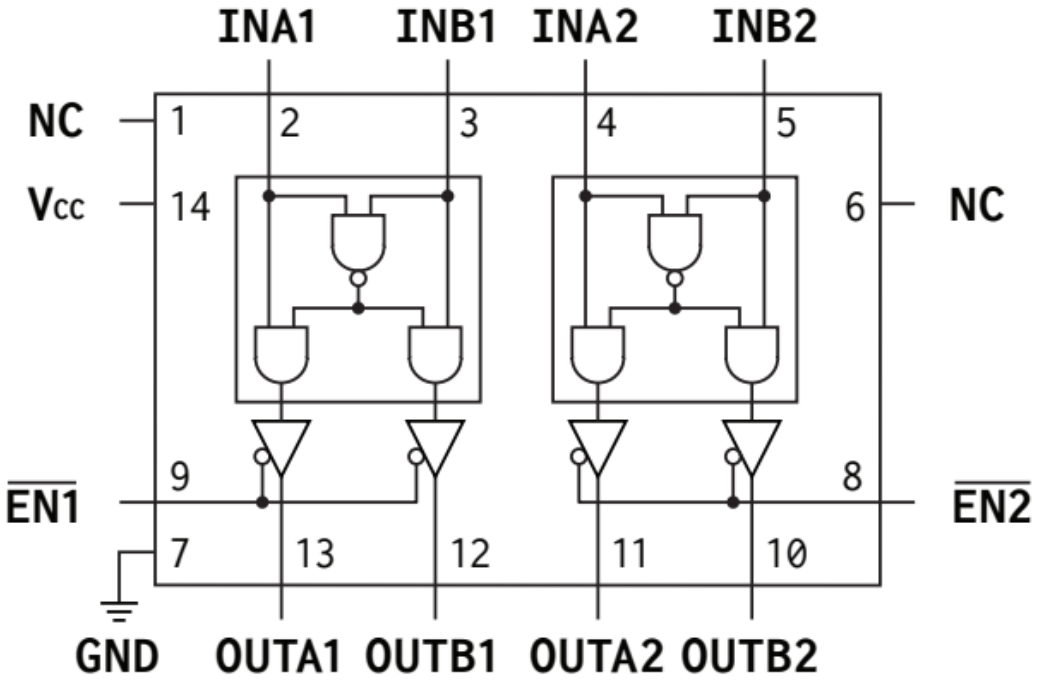
https://www.maccon.com/space-rated-motors.html

Simple Solution – AP54RHC288

- The AP54RHC288 Dual Channel Signal Arbiter protects half-bridges by employing a novel feedback solution
- Guarantees that only the high-side or low-side is active at any time, effectively preventing cross-conduction in half-bridge configurations
- Reliably driving half-bridges allows for the use of less radiation-tolerant components within the power system itself

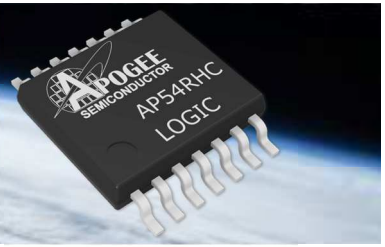


Logic Diagram



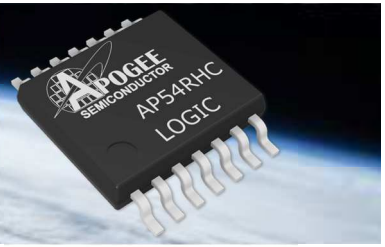
Input			Output	
INA_n	INB_n	$\overline{EN}_n$	$OUTA_n$	$OUTB_n$
L	L	L	L	L
L	H	L	L	H
H	L	L	H	L
H	H	L	L	L
X	X	H	Z	Z

Features

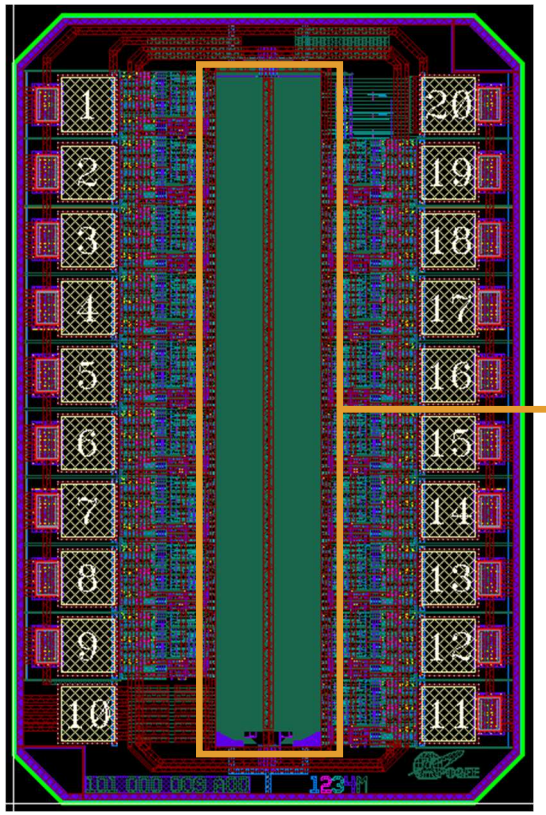


- Full range of voltage operation (1.65V to 5.5V)
- Extended temperature range (-55°C to 125°C)
- Class 2 ESD protection (4,000V HBM, 500V CDM)
- Built-in triple redundancy from pin to pin
- Internal Power-On-Reset circuit ensures reliable power-up and power-down responses in cold-sparing/hot-plugging applications
- Two enable pins – one for each individual device channel
- Dual-channel allows for mediation of both half-bridges in an H-bridge

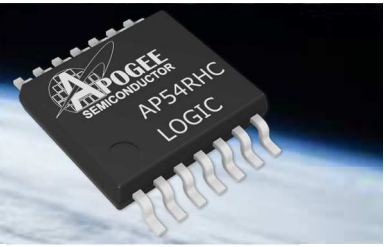
Warhol Family - RadFlex



- This device is a member of the Warhol AP54RHC family, which utilizes RadFlex technology
- RadFlex allows for quick-turn radiation-hardened custom logic designs by way of a "sea of logic" architecture
- All products in the Warhol family are manufactured with the exact same set of base layers
- Custom metal mask is created per unique design

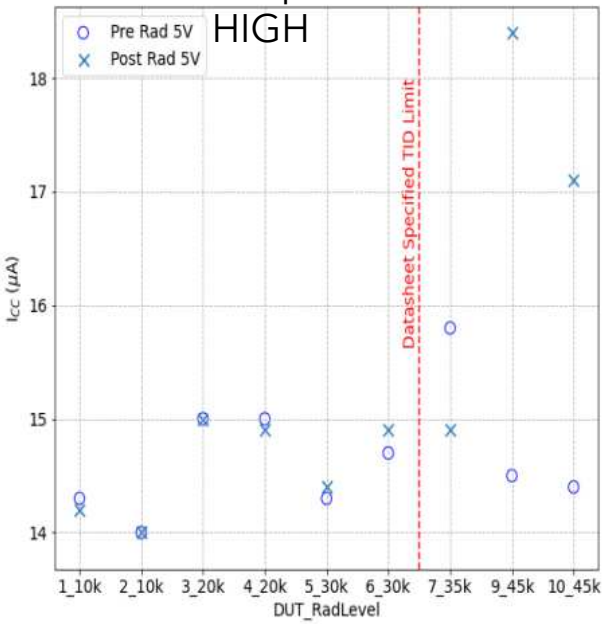


TID Results

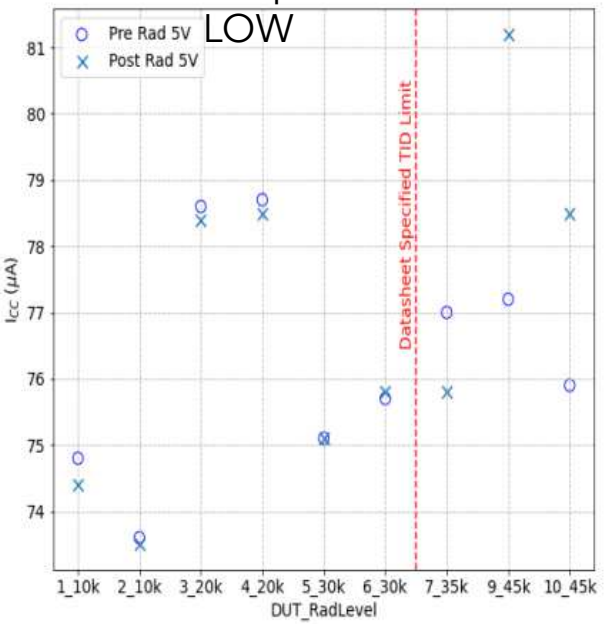


- TID resilience of up to 30 krad (Si)
- <1% shift in all measured parameters during dosing up to the datasheet-specified limit

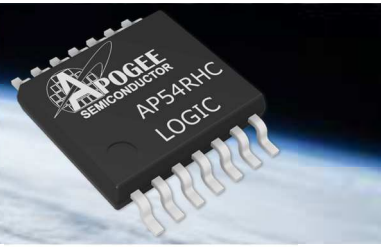
Outputs HIGH



Outputs LOW



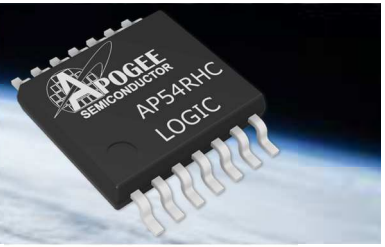
SEL Results



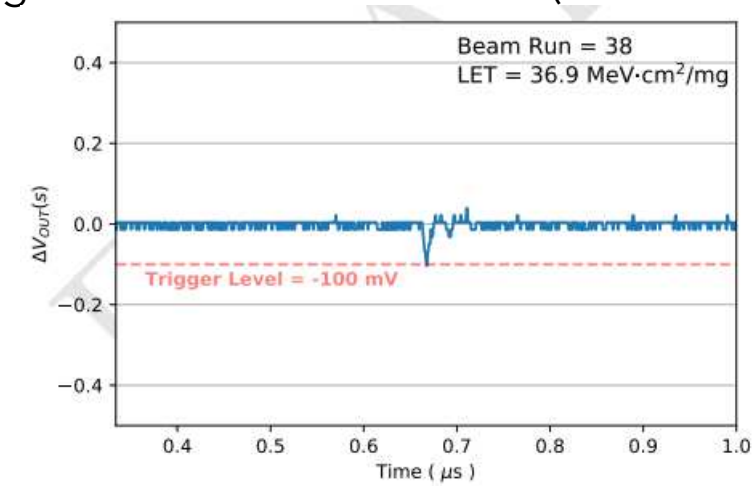
- SEL immune up to LET of 74.7 MeV▪cm^2/mg
- No SELs were observed across 7 DUTs and 26 total beam runs
- Tested at worst-case biasing conditions, voltage supplies, and temperature

Unit 1 AP54RHC504 Assembly Lot 06 Unit-Label L6A										
Run #	**Ion**	**LET**	**Temperature**	**VDDA**	**VDDB**	**Angle**	**Air Gap**	**Flux**	**Fluence**	**Result**
120	Ho	75	105°C	1.65 V	1.65 V	0°	2.5 cm	1.55e+05	9.98e+06	No Latchup
121	Ho	75	105°C	5.5 V	1.65 V	0°	2.5 cm	1.59e+05	1.0e+07	No Latchup
122	Ho	75	105°C	1.65 V	1.65 V	0°	2.5 cm	1.57e+05	1.0e+07	No Latchup
123	Ho	75	105°C	5.5 V	1.65 V	0°	2.5 cm	1.55e+05	1.0e+07	No Latchup
Unit 2 AP54RHC504 Assembly Lot 216 Unit-Label L13										
124	Ho	75	105°C	1.65 V	1.65 V	0°	2.5 cm	1.59e+05	9.96e+06	No Latchup
125	Ho	75	105°C	5.5 V	1.65 V	0°	2.5 cm	1.61e+05	9.98e+06	No Latchup
126	Ho	75	105°C	1.65 V	1.65 V	0°	2.5 cm	1.51e+05	1.0e+07	No Latchup
127	Ho	75	105°C	5.5 V	1.65 V	0°	2.5 cm	1.58e+05	9.95e+06	No Latchup
Unit 3 AP54RHC504 Assembly Lot 216 Unit-Label L7)										
128	Ho	75	105°C	1.65 V	1.65 V	0°	2.5 cm	1.66e+05	9.91e+06	No Latchup
129	Ho	75	105°C	5.5 V	1.65 V	0°	2.5 cm	1.71e+05	9.97e+0	No Latchup
130	Ho	75	105°C	1.65 V	1.65 V	0°	2.5 cm	1.70e+05	1.0e+07	No Latchup
131	Ho	75	105°C	5.5 V	1.65 V	0°	2.5 cm	1.17e+05	1.0e+07	No Latchup

SET Results

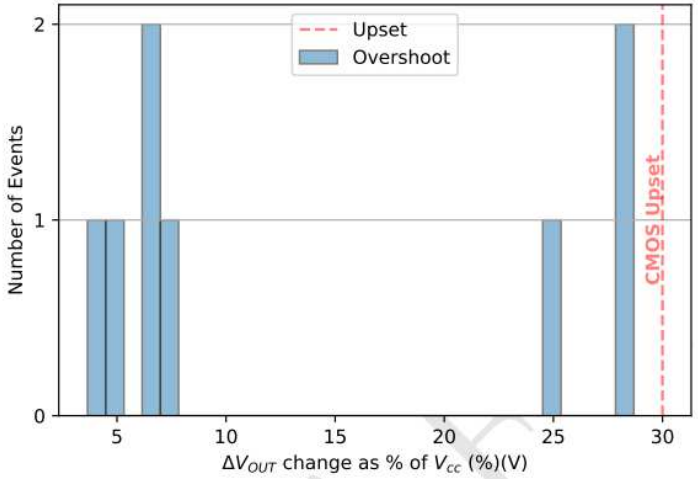


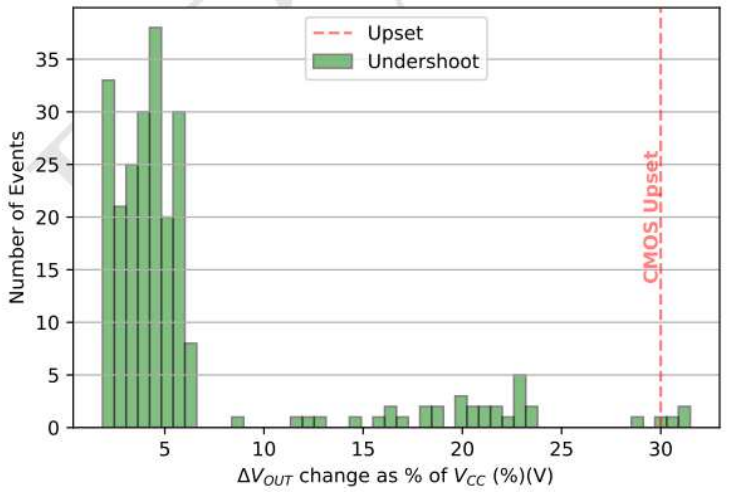
- SET immune up to LET of 36.9 MeV·cm^2/mg
- Over 12 total beam runs, the largest event captured in this LET range had a maximum undershoot magnitude of 103mV, corresponding to a 1.88% of V_{CC} change in V_{OUT}
  - Not large enough to be classified as a SET (or CMOS upset)



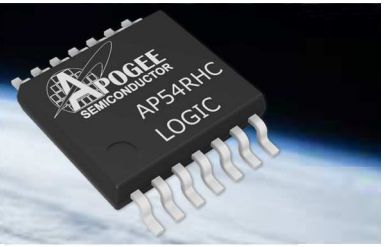
SET Results Pt. 2

- SET resilience of up to LET of 74.7 MeV·cm^2/mg
- An event which causes V_{OUT} under-shoot or over-shoot by 30% of V_{CC} is characterized as a CMOS-disruptive upset (SEU) or transient (SET)
- Over 66 total beam runs, 4 such events were captured





SET/SEL Cross-Section



- SET cross-section was calculated with onset LET of 36.9 MeV•cm^2/mg, where no SETs were captured
  - LET of 74.7 MeV•cm^2/mg is assumed in the calculation of the maximum observed saturated (upper limit) SET cross-section

- SEL cross-section was calculated with onset LET of 74.7 MeV•cm^2/mg, where no SELs were captured

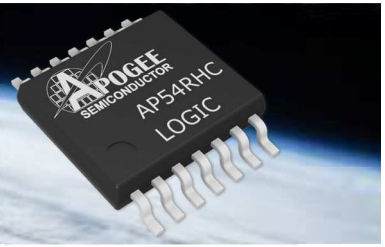
SET Event Rate:

Application	Integral Flux @ LET 36.9 [particles/cm^2-day]	Upper Limit σ_{sat} [95% CI] [cm^2]	Event Rate [per day]	MTTU [Years]
GEO	4.78e-03	7.95e-07	8.31e-10	**721e+03**
LEO (ISS)	1.04e-03	7.95e-07	3.80e-09	**3.30e+06**

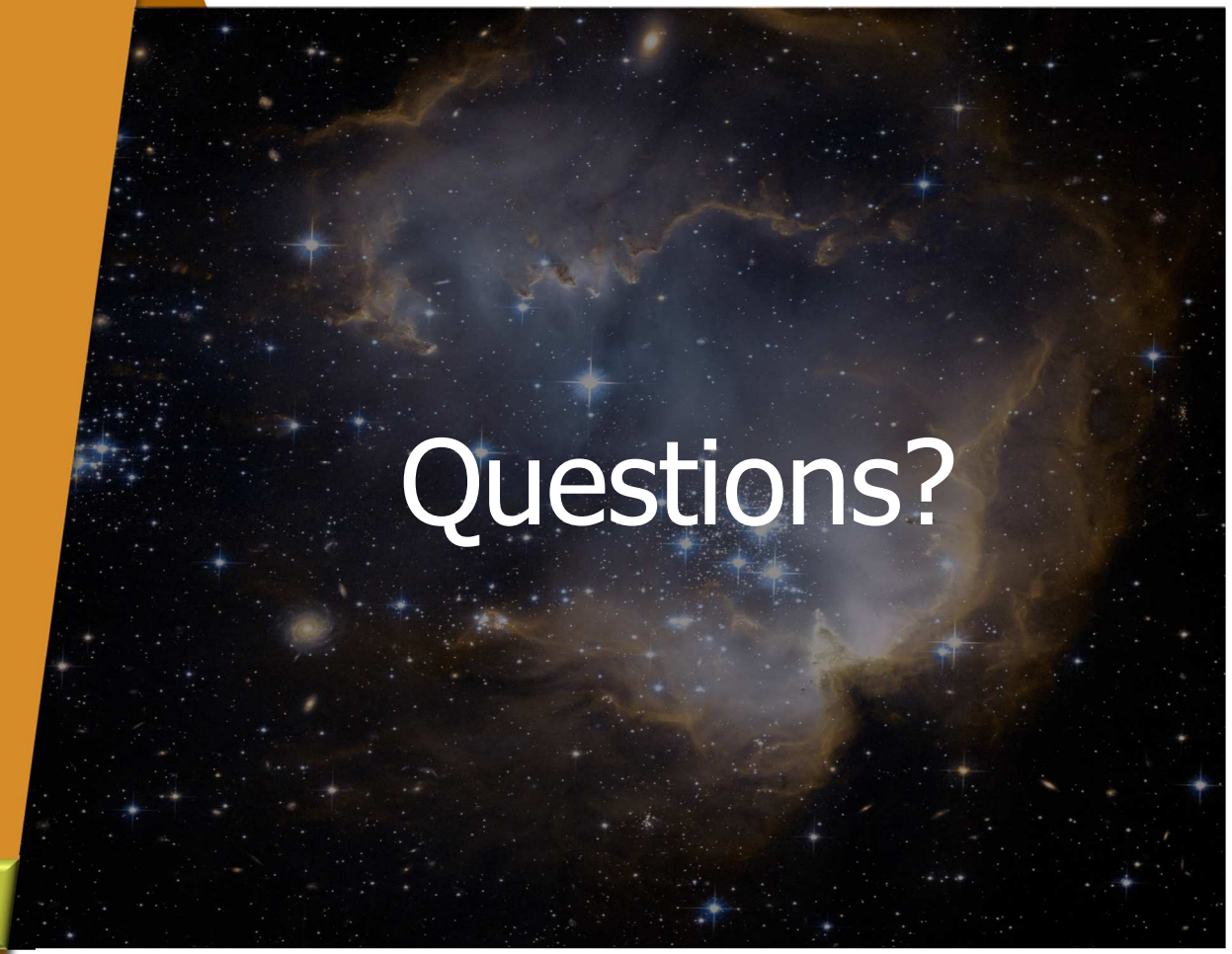
SEL Event Rate:

Application	Integral Flux @ LET 74.7 [particles/cm^2-day]	Upper Limit σ_{sat} [95% CI] [cm^2]	Event Rate [per day]	MTTU [Years]
GEO	1.80e-04	3.70e-08	6.61e-12	**414e+06**
LEO (ISS)	6.02e-05	3.70e-08	2.22e-12	**1.24e+09**

Conclusion



- Cross-conduction in half-bridges is a common issue in power systems
- The AP54RHC288 is a PEM logic device that provides a simple solution to solve this relevant problem – one device protects an entire H-bridge
- Asynchronous arbitration logic ensures that neither the high-side or low-side devices in a half-bridge could be enabled at the same time
- Radiation-Hardened by Design – TID/SEL/SET tested for high-reliability LEO applications
- Coming soon in 300krad PEM GEO family, and both families will be available in ceramic packaging



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