Space memory components for advanced AI/ML onboard processing solutions

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Infineon Technologies

Infineon at a glance

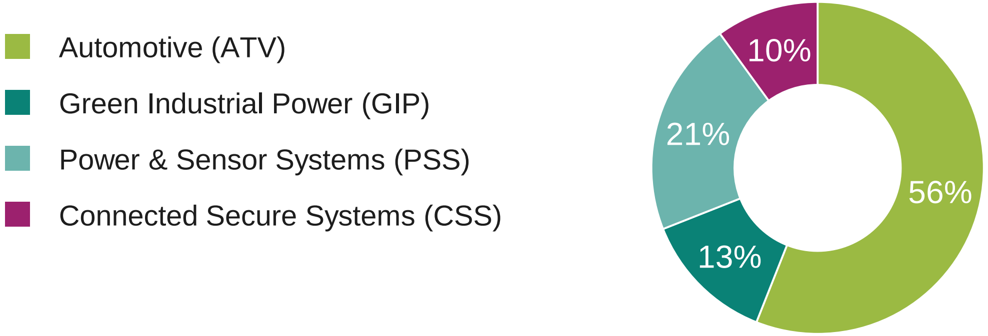
Growth areas

Energy
green and efficient

Mobility
clean and safe

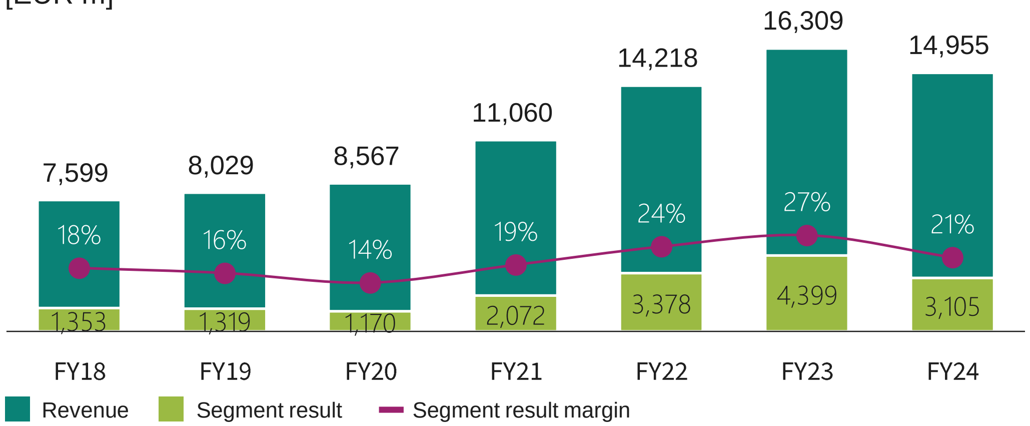
IoT
smart and secure

FY24 revenue by segment[1]



Financials

[EUR m]

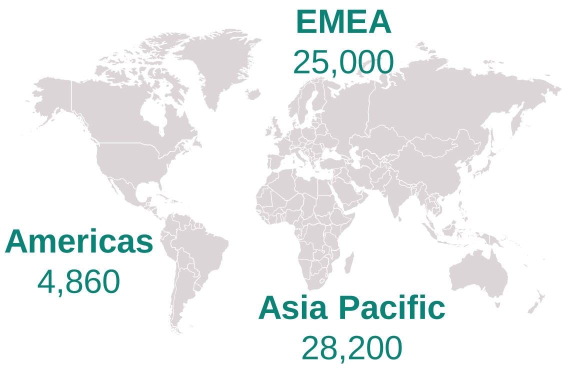


Employees[1]

58,060
employees worldwide

71
R&D and

15
manufacturing locations[2]

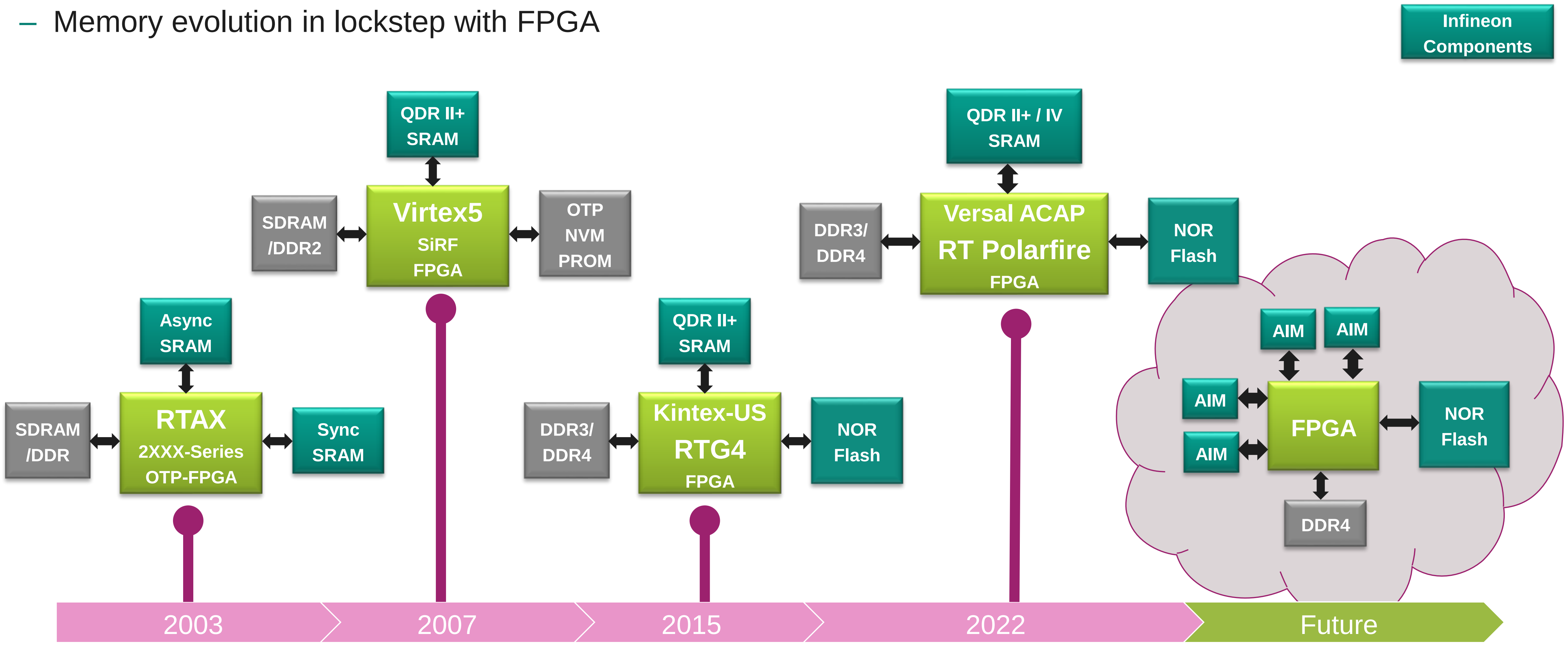


For further information: Infineon Annual Report.

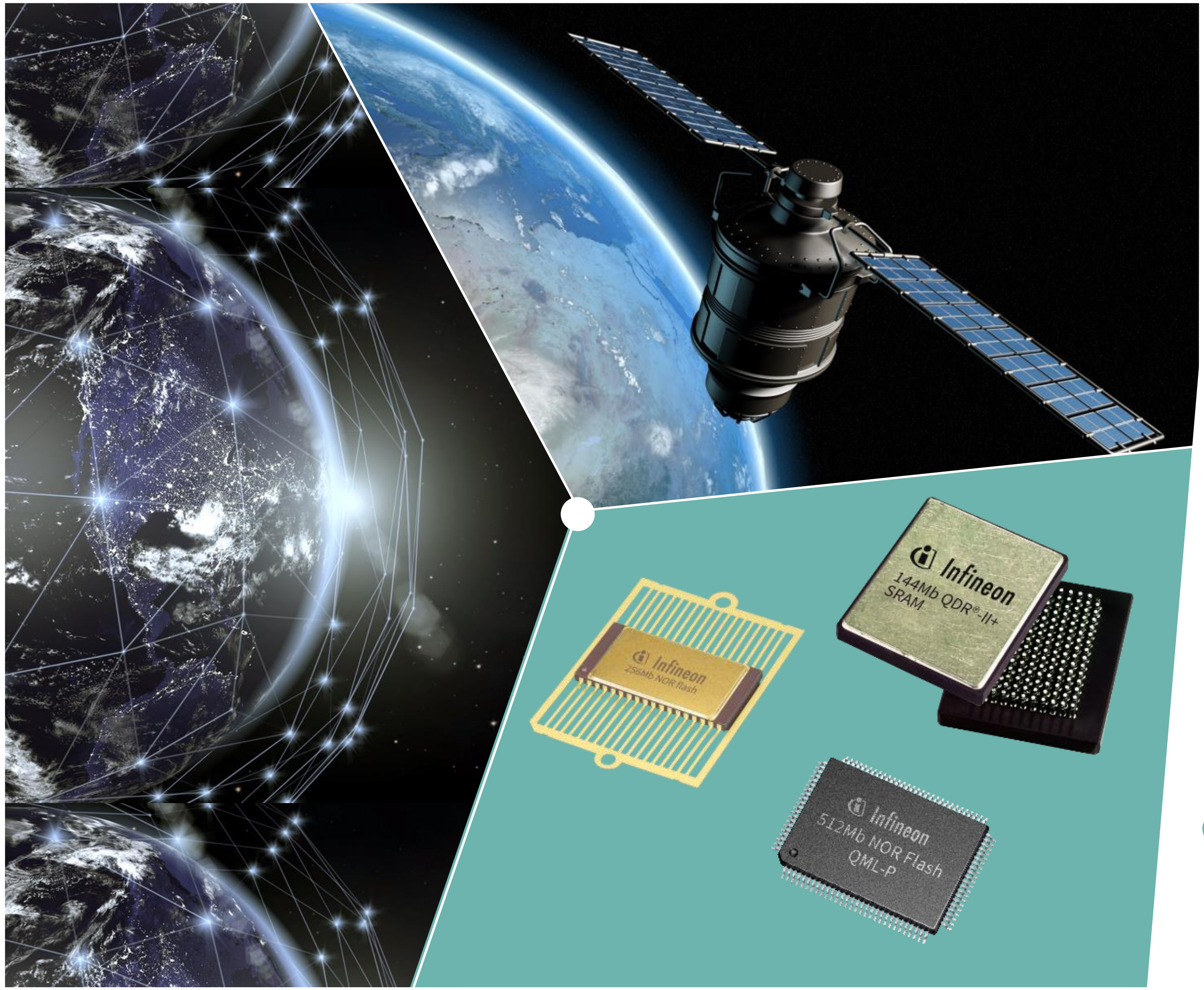
1 2024 Fiscal year (as of 30 September 2024) | **2** As of 30 September 2024

Space computing architecture evolution

– Memory evolution in lockstep with FPGA



High performance space memories must meet mission requirements for extreme environments



- Edge computing and inference in satellites enables real-time data analysis and decision making
- More and more commercial architectures getting adopted in space. Huge discrepancy of available vs. required components
- This becomes increasingly important as the number of connected devices and the amount of data generated continue grow
- The shift from on-ground to on-board processing and on-orbit reconfiguration demands high performance and high reliable memories

Memories must meet mission requirements
What risk are we willing to take?

Radiation risk of memories

Traditional (Old) Space: RHBD – built to last

- >60 LET SEL 1e7 ions 125C
- SEU immune w/ built-in scrubber
- 100krad to 1Mrad TID
- Slow, expensive, huge footprint

NO RISK

LIMITED PERFORMANCE

LIMITED DENSITY

New Space: Commercial/Automotive

- >26 LET SEL 5e6 ions RT
- SEU acceptable as long as I can recover/survive
- 2-5krad TID
- Fast, cheap, efficient packages

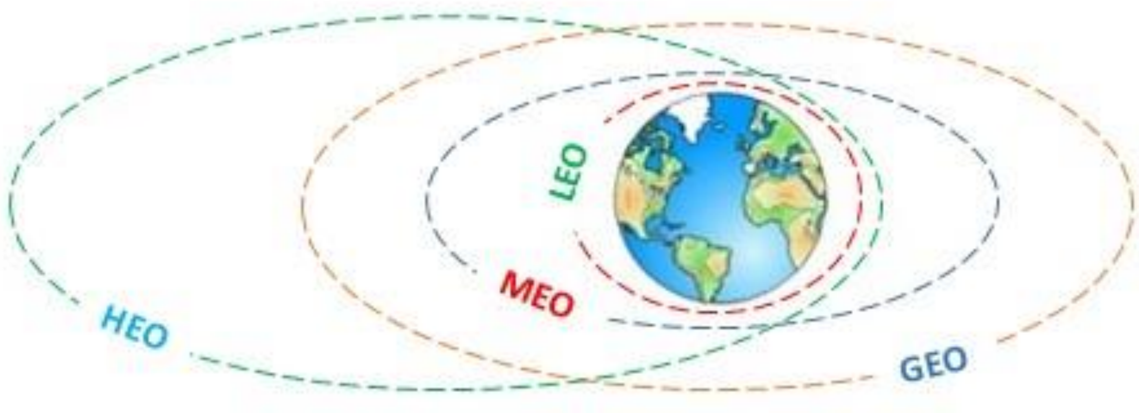
HIGH RISK

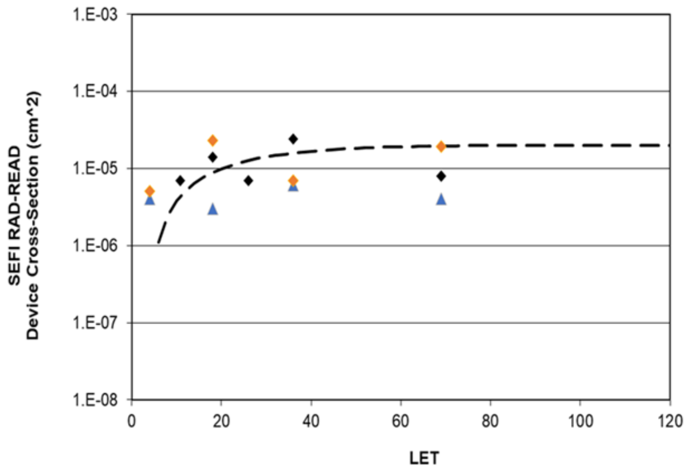
LIMITED RELIABILTY

HUGE DENSITY – NAND/DRAM

Solution: Mission dependent components

- Require detailed SEE analysis and testing
  - SEL characterization and rate predictions
  - SEFI characterization and rate predictions
  - Proton test results for MEO/Polar orbits
- TID less of an issue
  - Almost all CMOS <180nm pass 100krad
- CREME96 orbit calculations
  - Wild wild west of Weibul fits
  - Maybe industry guidance needed (JC13)
- 3 different grades required
  - Rad Hard/Tolerant QML-V/P/Y
  - Rad Tolerant plastic (ECoLEO)
  - Up-screened or un-screened COTs





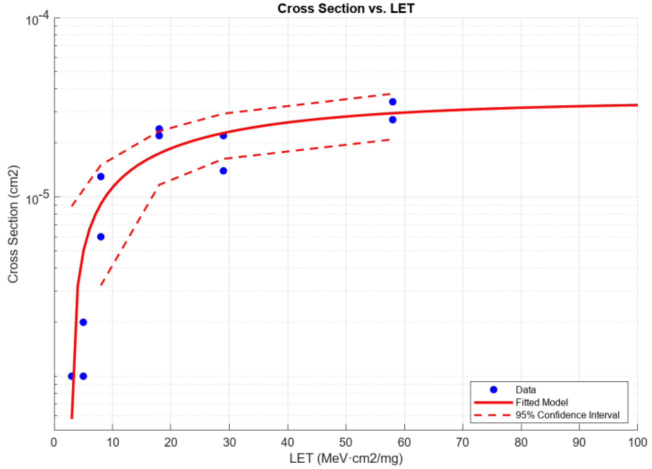
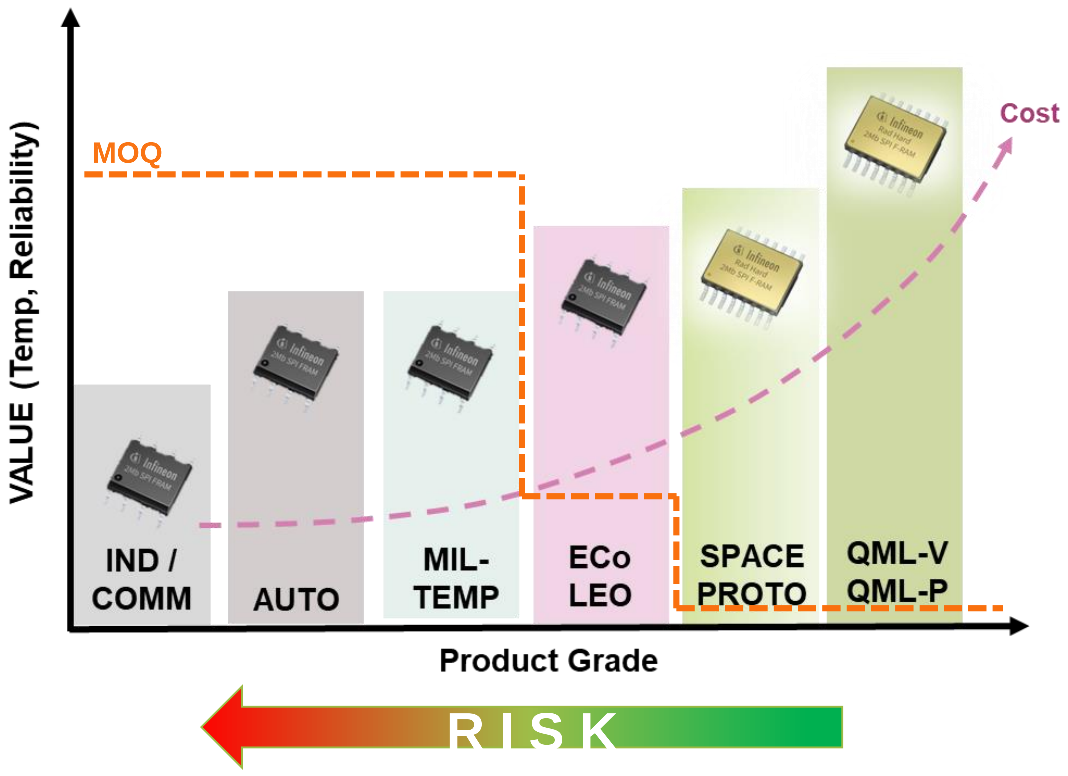


Figure 4 Cross Section vs. LET for SET

Risks with COTS memories (COTS=COST)



Space memory requirements

- Commercial performance/functionality
- Single Wafer Lot Date Code (SLDC)
- 100% electrical test
- Radiation performance “good enough” for given mission
- Non lead finish
- Manageable MOQ

Value proposition/solution - ECoLEO

- Guaranteed reliability above the current automotive/industrial parts
- Balance between cost, reliability and radiation performance
- Upgrade path for customers for programs requiring higher reliability and radiation performance
- Shorter time to market

Infineon's HiRel memory solutions portfolio

	Non-volatile memory			Volatile memory		
Space	**Rad hard NOR Flash** – 512Mb/1Gbit density – QSPI – 300Krad (Si) TID – QML-V / QML-P	**Rad tol NOR Flash** – 256/512Mb densities – QSPI, dual QSPI – 30Krad (Si) TID* – QML-V equiv	**Rad hard F-RAM** – 2Mb density – SPI / Parallel – 150Krad (Si) TID – QML-V	**QDR-II+ sync SRAM** – 72/144Mb densities – 250MHz parallel – 300/200Krad (Si) TID – QML-V	**QDR-IV sync SRAM** – 144Mb density – 667MHz parallel – 30Krad (Si) TID – QML-V	**Fast async SRAM** – 4/16Mb densities – 10ns parallel – 300Krad (Si) TID – QML-V
New Space	**ECoLEO NOR Flash** – 256Mb/512Mb density – FG / SONOS memory – QSPI – 30 / 100Krad (Si) TID	**ECoLEO LPDDR4 Flash** – 288Mb/576Mb density – eCT memory – LPDDR4 + QSPI – 30Krad (Si) TID	**ECoLEO F-RAM** – 1Mb/2Mb density – F-RAM memory – SPI / Parallel / I2C – 50Krad (Si) TID	**ECoLEO Serial PSRAM** – 256 / 512Mb densities – DRAM memory – HYPERBUS™ (x8), Octal xSPI (x8) interfaces		
Mil-temp	**nvSRAM** – 256Kb/1Mb densities – Parallel interface – QML-Q	**NOR Flash** – 128/256/512Mb & 1/2Gb densities – Serial and parallel interfaces	**F-RAM** – 1/2Mb densities – Serial and parallel interfaces	**QDR-II+ sync SRAM** – 72/144Mb densities – Parallel interface – On-chip ECC SER <0.1 FIT/Mbit	**Sync SRAM** – 9/18/36Mb densities – Parallel interface	**Fast async SRAM** – 16Mb/1Gb densities – Parallel interface – 10ns access speed
COTs	**nvSRAM** – 256Kb - 16Mb densities, parallel interface – 64Kb – 1Mb densities, serial interface	**NOR Flash** – 64Mb - 2Gb densities w/ serial interfaces – 64Mb – 4Gb densities w/ parallel interface	**F-RAM** – 4Kb - 16Mb densities w/ serial & parallel interfaces	**Sync SRAM** – 72/144Mb densities – Parallel interface – On-chip ECC SER <0.1 FIT/Mbit	**HYPERRAM™** – 64 - 512Mb densities – HYPERBUS™ (x8, X16), Octal xSPI (x8), interfaces	**Fast async SRAM** – 256Kb - 64Mb densities – Parallel interface – On-chip ECC

RISK

Memory solutions NewSpace portfolio radiation performance

- Radiation Summary
  - Other radiation effects data can be requested (prompt dose, neutron displacement, ELDRS)

Product	Density	Interface	Part Number	Description	TID Krad (Si)	SEU Err/bit.day (GEO Solar min)	SEL LET	SEFI Err/dev.day (GEO Solar min)	Note
F-RAM	2Mb	SPI (x1)	CYEL15B102Q-SXM	2Mb, SPI, ECoLEO F-RAM	50	Immune	>114 (115ºC)	<1.34e-4 (active/stdby) <5.88e-8 (sleep)	Read SEFI
	2Mb	Parallel (128K x 16)	CYEL15B102N-SZ60XM	2Mb, parallel, ECoLEO F-RAM	50	Immune	>96 (115ºC)	<5.3e-5 (active/stdby) Immune (sleep)	Read SEFI
	1Mb	I2C	CYEL15B101J-SXI	1Mb, I2C, ECoLEO F-RAM	50	Immune	>58 (110ºC)	<6.1e-4	Read SEFI
NOR Flash	256Mb	QSPI	CYEL16B256-133SXE	256Mb, QSPI, rad tol NOR Flash	30	<1e-16	>60 (85ºC)	<1.1e-4	Erase function SEFI
	512Mb	QSPI	CYEL17B512-133AZM	512Mb, QSPI, rad tol NOR Flash	100	Immune	>81 (125ºC)	<2.77e-5	Read SEFI
	1Gb	QSPI	CYEL17B01G-133AZM	1Gb, QSPI, rad tol NOR Flash					
	2Gb	Dual QSPI	CYEL17B02G-133AZM	2Gb, Dual QSPI, rad tol NOR Flash					
Serial pSRAM	256Mb	x8 HyperBus x8 xSPI	CYEL18V2562-200BKXE CYEL18V2563-200BKXE	256Mb, x8, rad tol Pseudo SRAM	100	<1.54e-14	>58 (125ºC)	<6.9e-5	Static SEFI
	512Mb	x8 HyperBus x8 xSPI	CYEL18V5122-200BKXE CYEL18V5123-200BKXE	512Mb, x8, rad tol Pseudo SRAM					
SEMPER X1	288Mb	LPDDR4 / QSPI	CYEL19B288-820BGXE	288Mbit, LPDDR4 NOR Flash	30	Immune	>58 (125ºC)	<3.1e-4	Read SEFI
	576Mb	LPDDR4 / QSPI	CYEL19B576-820BGXE	576Mbit, LPDDR4 NOR Flash	30	Immune	>58 (125ºC)	<3.1e-4	Read SEFI

Infineon's rad tolerant Serial PSRAM

External buffer memory

Key applications

- Buffer memory w/ 8 channel SPI (HyperBus) interface
- Real-time processing
- Replaces standard DDR2/3/4 memories with low pin count

Key Features

- 256Mbit/512Mbit density
- x8 SPI interface (HyperBus or Octal)
- 200 MHz per channel
- Single chip select
- 24-pin FBGA plastic package
- -40°C to +125°C
- Radiation performance
  - TID: >100Krad (Si)
  - SEU: 1.3 x 10^{-14} err/bit-day
  - SEL: >58 MeV.cm^2/mg [LET] @ 125ºC
  - SEFI: 6.9 x 10^{-5} err/dev-day

Best in Class

- Enables 256M/512M DRAM speeds through low pin count connectivity
- Controller IP available free of charge from Infineon
- Verified to operate with major FPGAs

High Performance

- 200MHz x8 SPI data interface provides fast data throughput of max 1.6Gbps

Flexible

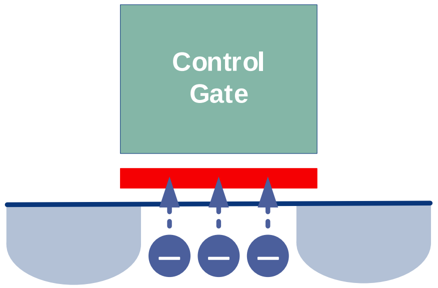
- Low pin count connectivity < 24 pins to operate DRAM

- More info on all memories: www.Infineon.com/hirelmemory

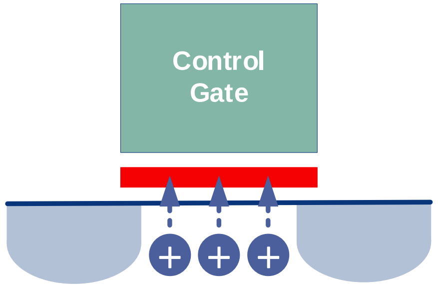
AIM – Analog in Memory Compute

Next generation memory

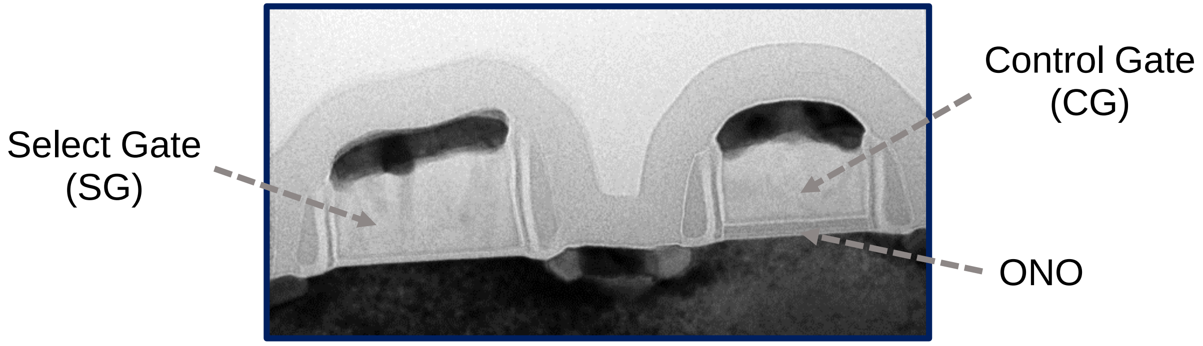
SONOS - an ideal SLC and Analog MLC NVM



Program by Uniform Channel FN Tunneling

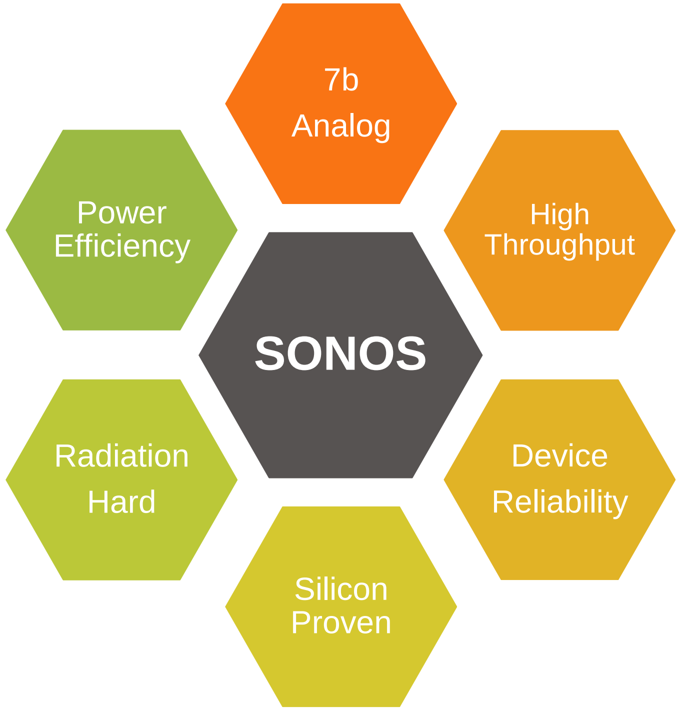


Erase by Uniform Channel FN Tunneling



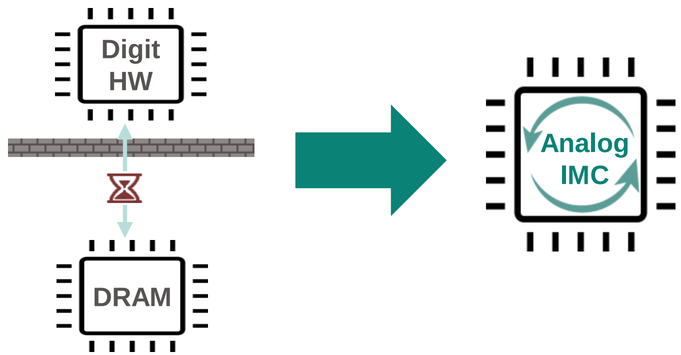
40 nm SONOS Cell

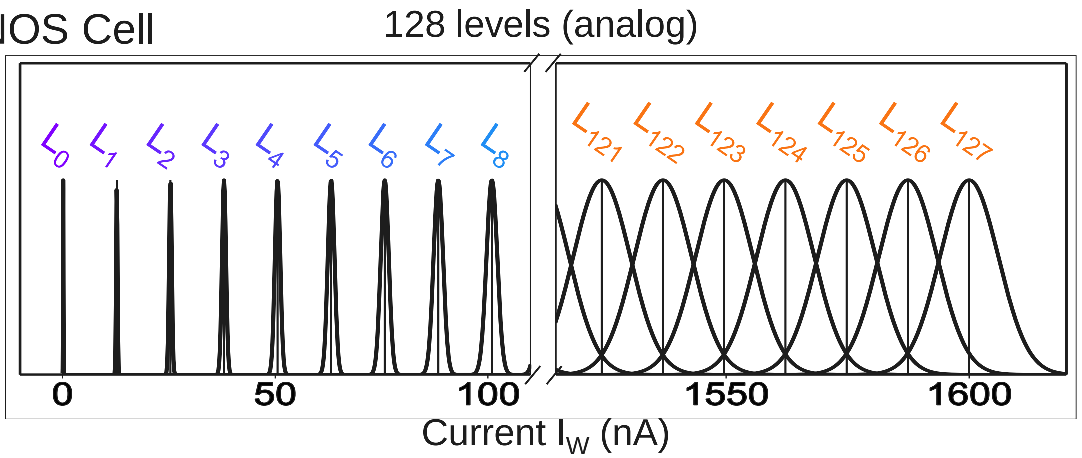
- Reliable SLC memories up to 2Gbit monolithic density (22nm planar)
- Extremely low unit currents with large Ion / Ioff ratio of 10^7
- Robust intrinsic endurance / radiation hardness
- US owned and controlled memory IP
- No read disturb, low bit cell noise, immune to magnetic fields
- Viable solution with >100 TOPS/W for radiation and power limited applications

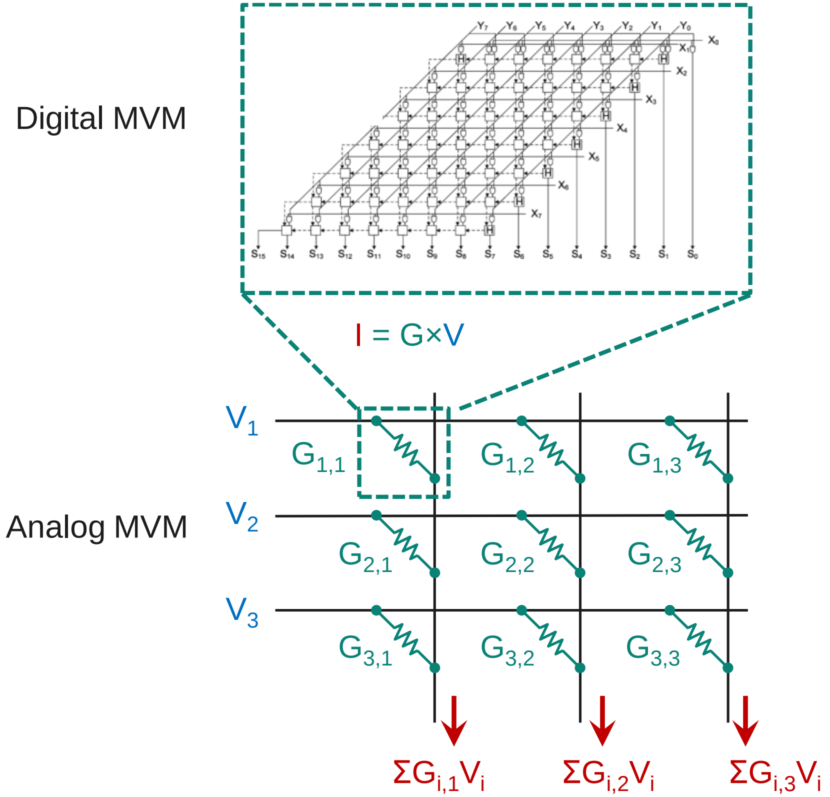


Analog In-Memory-Compute – The ultimate MLC NVM

- Traditional CPU, GPU, and digital ASIC accelerators require external memory accesses that lead to high power consumption and eventually hitting the “Memory Wall”
- AI/ML rate of adoption will increase in the future and will be customized to enhance performance for specific applications. Low power and low cost will be key
- Classical AI/ML concepts will not work in power and radiation limited environments (Space, Missiles, etc)
- **Radiation Hard Analog NVM (SONOS) can solve this problems**
  - 7bit per SONOS Cell





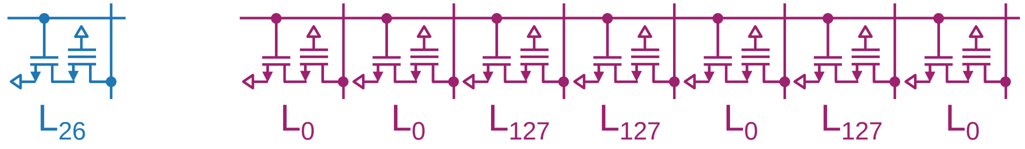


TID Radiation response of SONOS determines NN accuracy

Two ways to represent a 7-bit integer

One 7-bit cell — *w* = 26

Seven 1-bit cells — *w* = 0011010



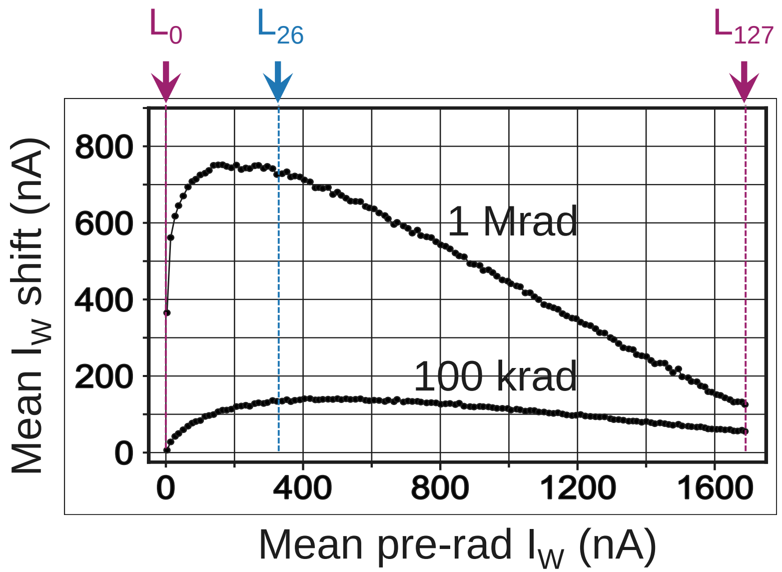
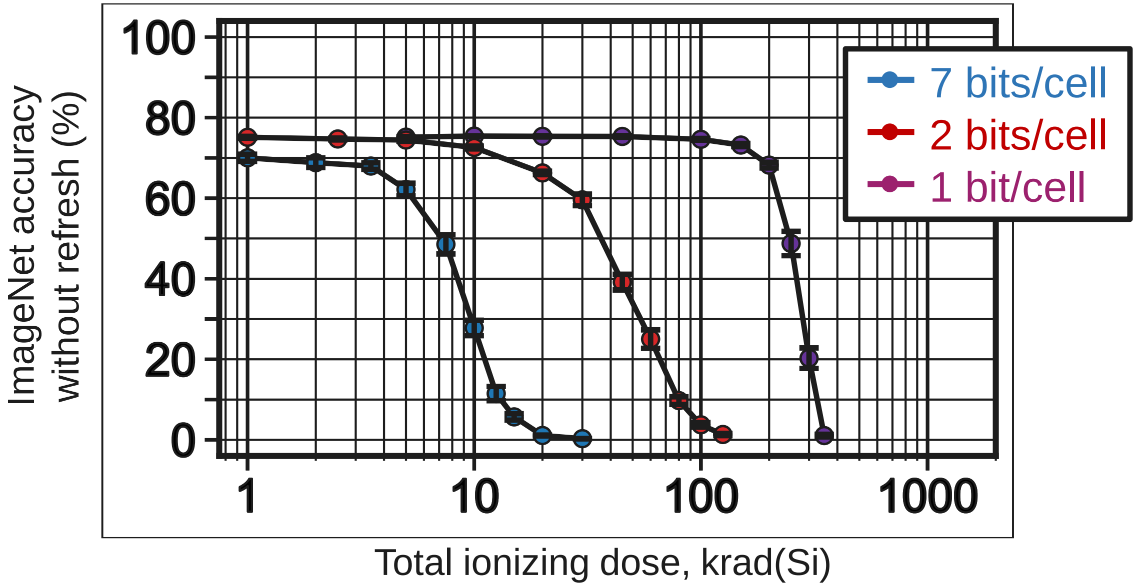


Image classification accuracy (simulation)

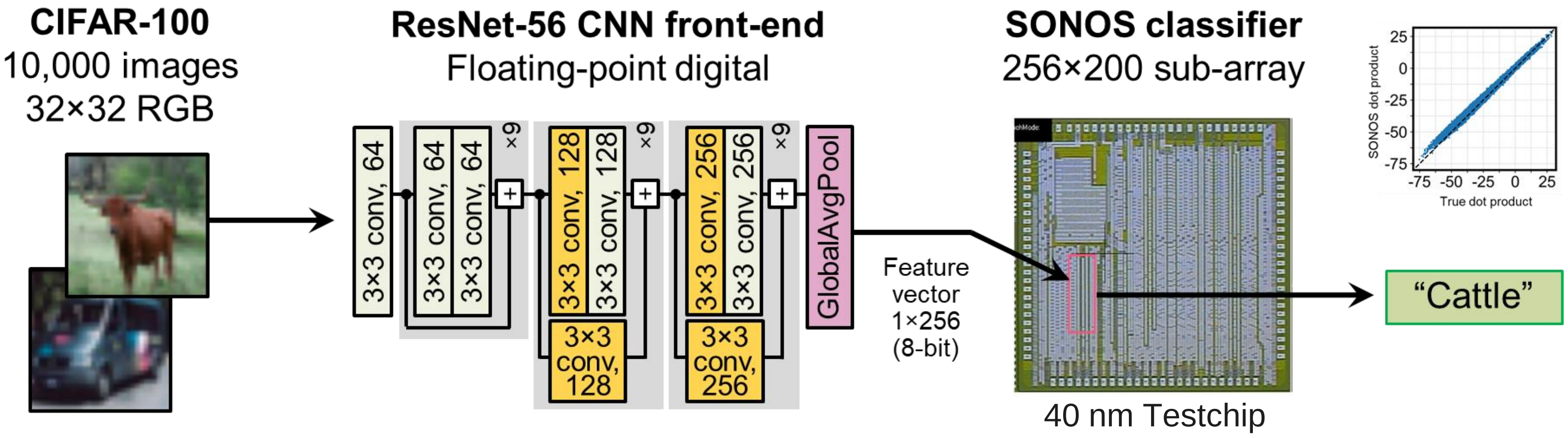
ResNet50 on ImageNet

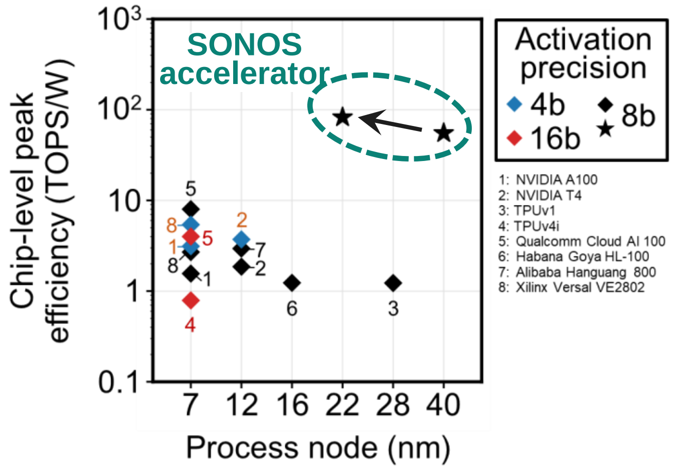


Refreshing of weights has to be implemented for high accuracy large CNNs

Curtesy of Xiao, Sandia National Labs

Accuracy of AIM vs. Digital IM





CIFAR-100 top-1 accuracy

Fully digital, floating point	**73.89%**
SONOS classifier (6-10 bits) test chip	**73.01%**
SONOS classifier model	**73.11% ± 0.17%**

CROSS SIM cross-sim.sandia.gov

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SONOS based IMC meets near digital inference accuracy while delivering unprecedented power efficiency

AIM - Applications and Use Cases

Security and surveillance

- Real-time threat detection enabled by low-latency and edge device processing
- Object recognition on the ground or in the air to identify groups of people, equipment, count, distribution of masses, tracking as well as identifying intent or gestures
- Secure data processing without the need of cloud communication

Autonomous navigation

- Lag-free tracking and navigation for Smart missiles, ICBMs, NGI, Drones, aircrafts and satellites
- High reliability for operation within elevated radiation levels
  - TID > 500krad w/ refresh
  - Low sensitivity to Heavy Ions (limited charge deposition) w/ refresh
  - High Neutron Displacement and Prompt dose resistance

SONOS based IMC is the only viable solution for radiation / power limited environments

Summary and Conclusions

- New space ECoLEO components are a good alternative to QML components when mission requirements are lower (LEO, SDA)

- QML components still required for mission critical functions

- High volume plastic package manufacturing flows enable
  - Automotive quality
  - Better SWaP, performance and cost
  - Shorter time to market for space components

- New computing architectures will feature AI/ML co-processors to boost performance in power limited environments

Infineon