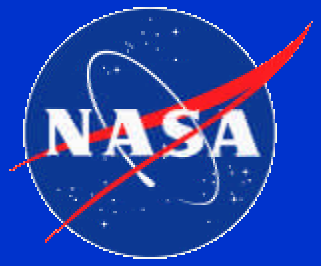

Evaluation of an Ultra-Low Power Reed Solomon Encoder for NASA's Space Technology 5 Mission*

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Outline

- Space Technology 5 (ST5) Mission
- CMOS Ultra-Low Power Radiation Tolerant (CULPRiT) Technology
  - Background
  - Reed Solomon (RS) Encoder Circuits
- Radiation Test Results
  - Total Ionizing Dose (TID)
  - Single Event Effects (SEE)
- Single Event Upset (SEU) Predictions
- Summary

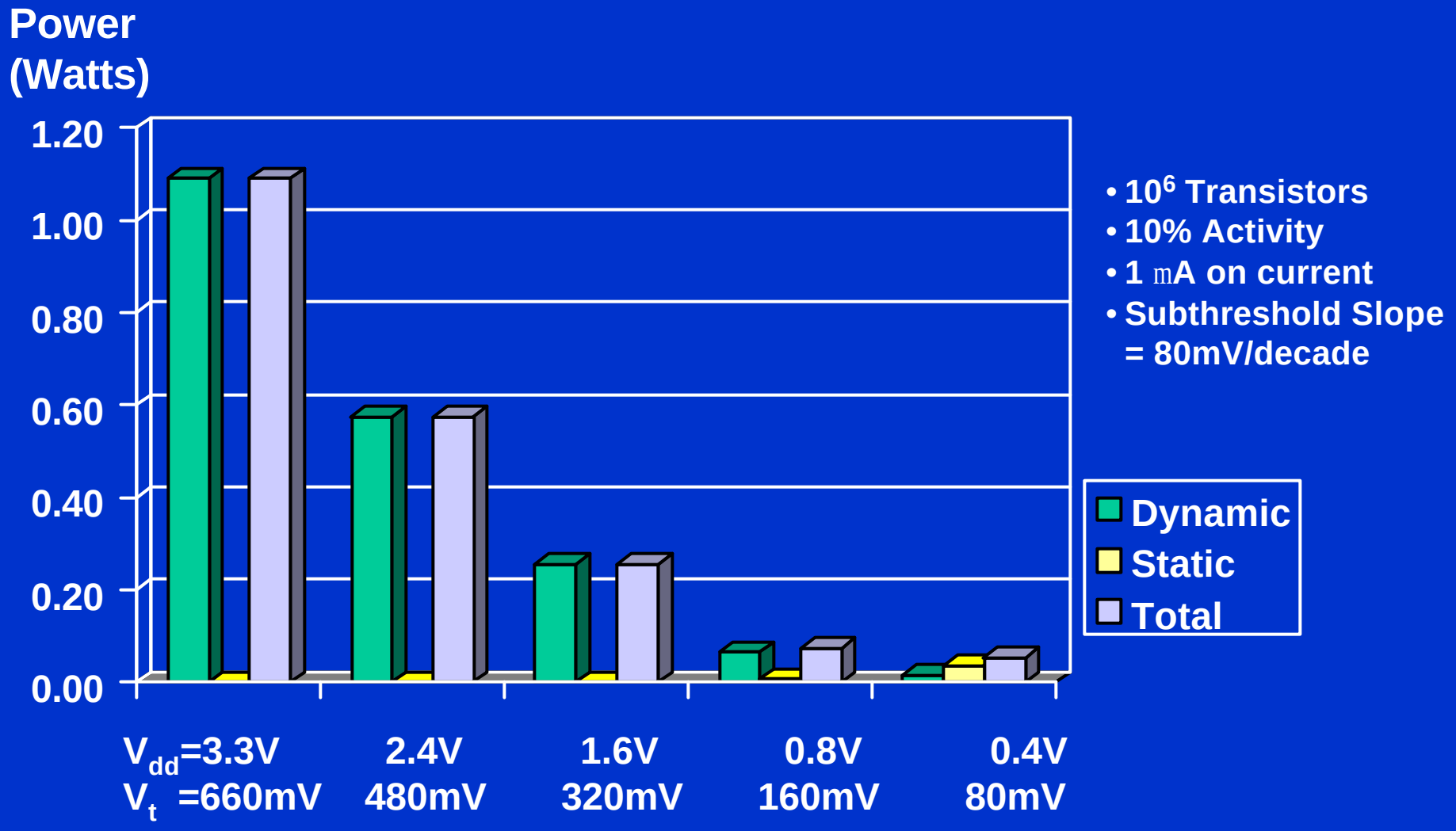
ST5 Mission

- Part of New Millenium Program.
  - Attempts to validate breakthrough technologies and infuse into future missions
- ST5 will consist of 3 micro-satellites, each weighing ~ 47 pounds.
- CULPRiT is a potentially enabling technology for micro-satellites.

Background

- Two significant issues for spacecraft microelectronics:
  - Power consumption
  - Radiation tolerance
- CULPRiT technology addresses these issues for CMOS circuits with high activity levels (microprocessors, RS encoders, etc.).
- The approach to minimize power consumption originated with Stanford's Ultra Low Power CMOS Project.

Power Consumption Scaling at Constant Performance

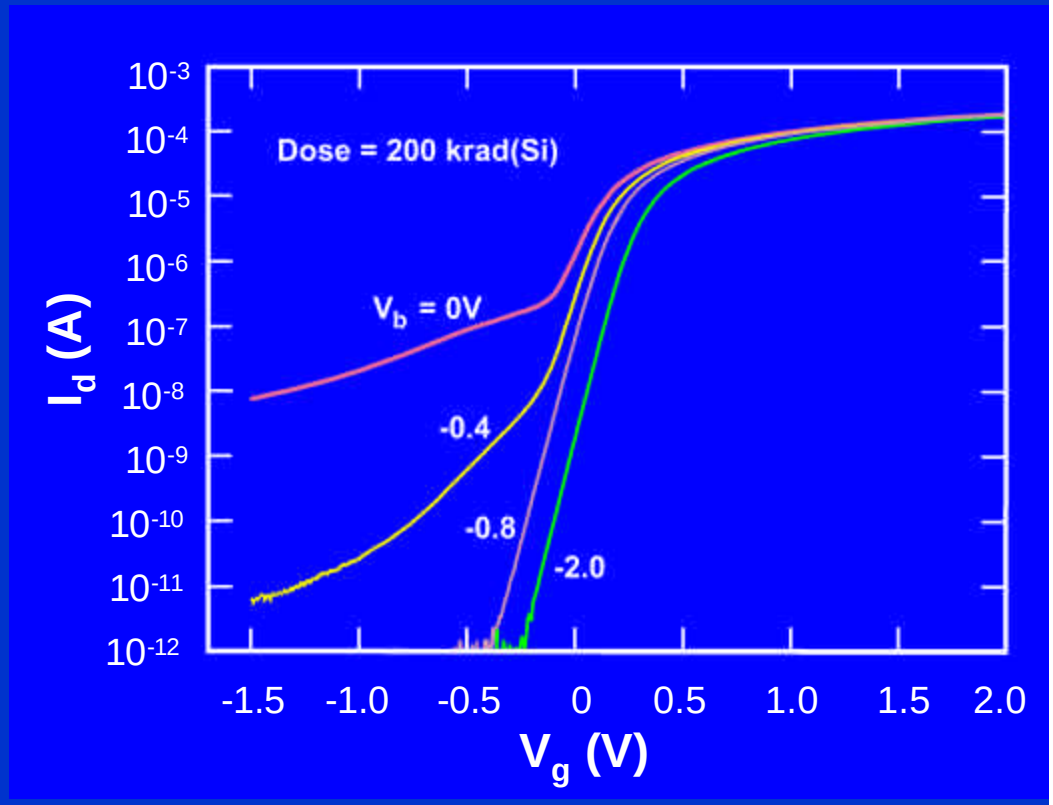


CULPRiT RS Encoder Circuits

- Circuit design at University of Idaho, including SEU mitigation
- Processing expertise at Solid State Scientific Corporation
- Fabricated at AMI Semiconductor in Pocatello, ID:
  - 0.35 μm CMOS process
  - V_{dd} = 0.5 V and V_t near 0 V
- V_t tuned for optimal circuit performance by application of back-bias:
  - 2.0 V applied to n-wells to lower p-channel thresholds
  - -1.4 V applied to substrate to raise n-channel thresholds
- Power consumption at 12 MHz:
  - Encoders fabricated in standard 0.35 μm process – 252 mW
  - CULPRiT 0.35 μm process – 2.1 mW => x120 savings

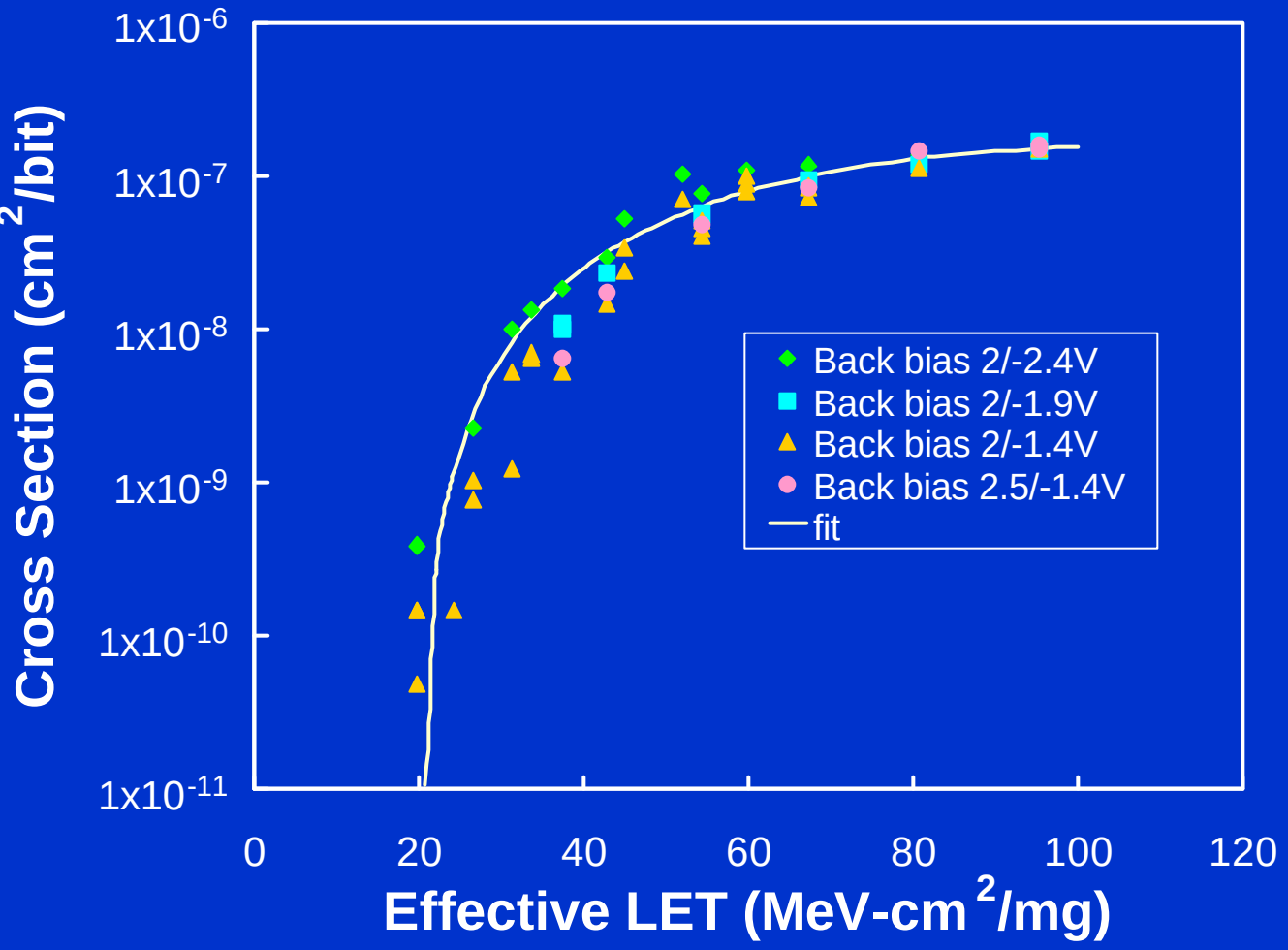
TID Results

- CULPRiT devices are significantly more total dose tolerant than standard CMOS devices.
  - Low gate bias reduces yield of holes in field oxide
  - Back-bias raises threshold voltage of field oxide
- RS Encoders show no degradation for doses up to 100 krad(Si)
  - Functionality
  - Leakage current
  - Timing
- 3D ray trace simulations of model spacecraft structure using NOVICE predict < 7 krad(Si) for CULPRiT board.



From M.A. Xapsos et al., IEEE Trans. Nucl. Sci. **46**, pg.1697 (Dec. 1999)

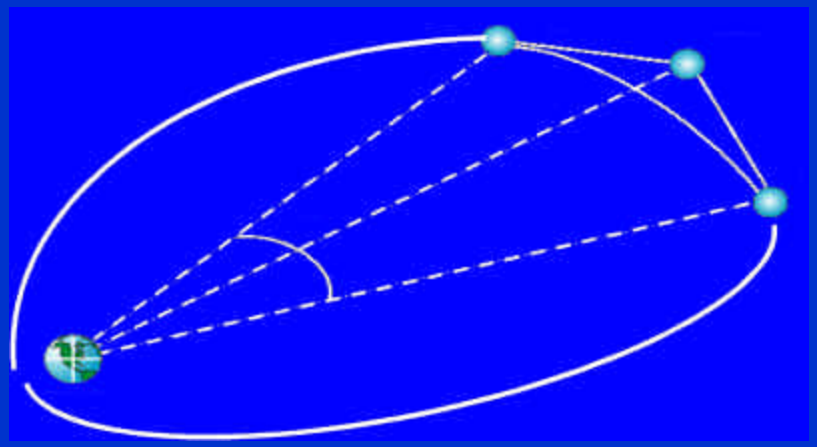
SEU Results


Cross Section (cm 2/bit)
1x10-6
1x10-7
1x10-8
1x10-9
1x10-10
1x10-11
0
20
40
60
80
100
120
Effective LET (MeV-cm 2/mg)
Back bias 2/-2.4V
Back bias 2/-1.9V
Back bias 2/-1.4V
Back bias 2.5/-1.4V
fit

Calculated SEU Rates – ST5 Mission
2048 bit CULPRiT RS Encoders

- Elliptical orbit:
  - 200 km perigee
  - 35,790 km apogee
  - 0° inclination
  - 2004 launch date
  - 3 month mission

Constellation Geometry at Apogee



CREME96 Results:

Condition:	#SEU/(bit-day):
Galactic cosmic rays (solar min.)	1.46E-9
Galactic cosmic rays (solar max.)	1.80E-10
10/89 Solar particle event (worst 5 min.)	6.59E-6
10/89 Solar particle event (worst day)	1.83E-6
10/89 Solar particle event (worst week)	5.33E-7

Summary

- CULPRiT RS Encoders have been evaluated for use on NASA's ST5 Mission.
- The technology is promising for space applications
  - Substantial power savings
  - Total dose tolerance without using hardened process
  - No observed latch-up
  - Low SEU rate
- It is possible to trade off circuit performance and total dose tolerance by varying back-bias.