ADVANCES IN RADIATION HARDENED MIXED-SIGNAL TECHNOLOGY

D. Kerwin, A. Zanchi, A. Wilson, K. Merkel, J. Colley
Aeroflex Colorado Springs, Inc.
4350 Centennial Blvd.
Colorado Springs, Colorado 80919
USA

david.kerwin@aeroflex.com

August 28, 2012

Outline

- Introduction
- Case Study 1: Smart Sensor SoC ASIC
- Case Study 2: 16-bit Pipeline ADC
- Case Study 3: 4-Channel Voltage Supervisor
- Summary

Aeroflex Radiation Hardened Mixed-Signal ASICs

Introduction

- **Aeroflex**
  - Supplier of radiation hardened digital ASICs since 1985, and radiation hardened mixed-signal ASICs since 2000
  - Serving Space/Satellite, Medical, Security, and Industrial Markets
  - QML-V Approved Quality Management System
  - Over 700 space qualified ASICs since 1980
- **Aeroflex uses high volume commercial foundries**
  - QML-V Approved Foundry Partners
  - Active SPC programs
- **Aeroflex Radiation Hardened Technology**
  - Commercial RadHard Technology Libraries
  - One-Time Electrically Programmable Metal Fuse module

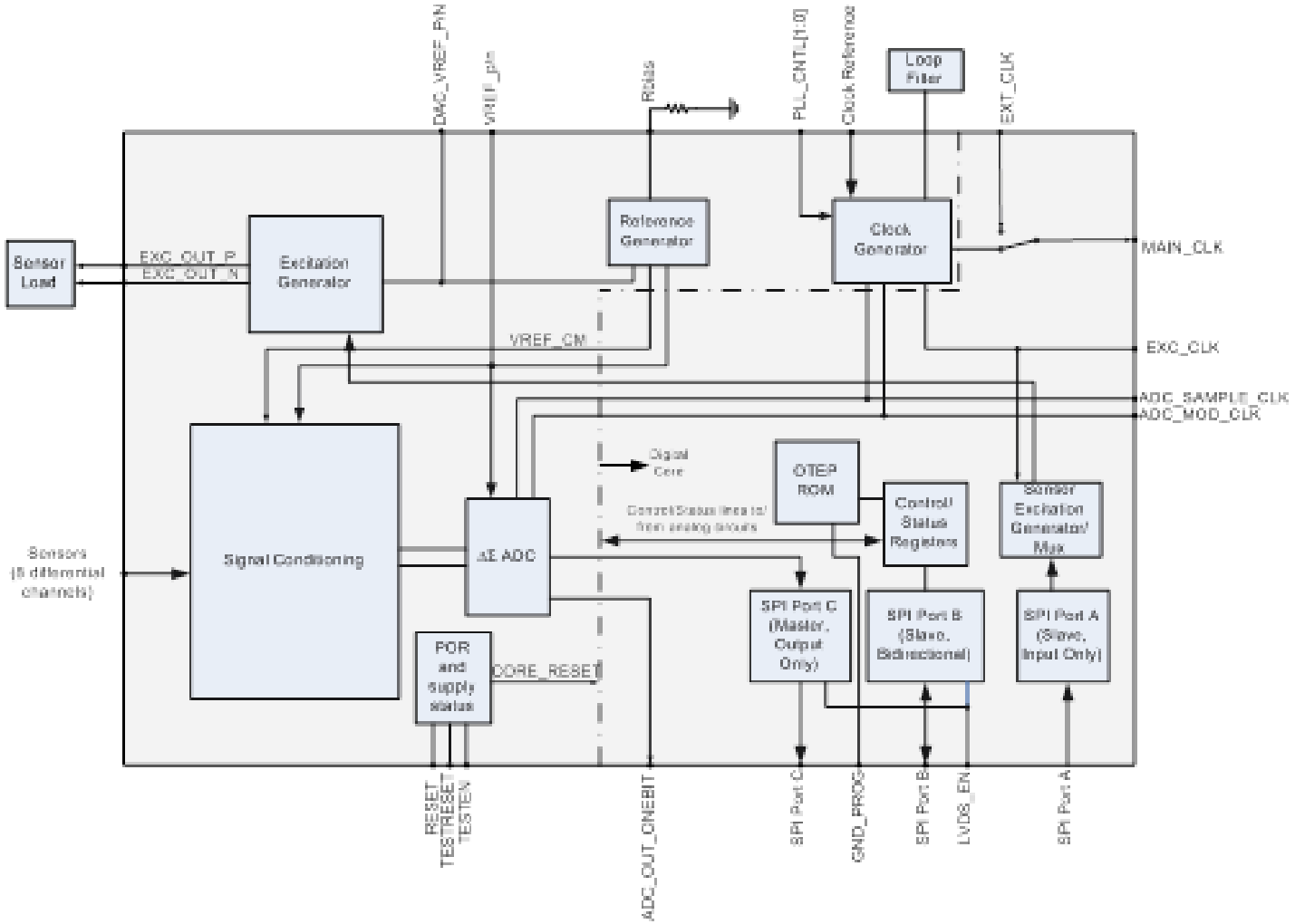
Introduction

- **Supply Chain:**
  - **Nine foundry partners world-wide (US, Europe, Asia)**
    - **Five QML-V foundry partners (US & Asia)**
  - **Aeroflex Assembly, Test, Qualification**
  - **In-House Reliability & FA Labs**
- **Strong Mixed-Signal Design Team**
  - **32 Mixed-Signal Designers, each with minimum 15 years experience in Radiation Hardened ASIC design**
- **Key Success Factors**
  - **Transistor Modeling in house**
  - **Qsim & SETsim for SET modeling**
  - **Reliability Analysis & Modeling: Aeroflex Reliability Design Rules and Safe Operating Area Simulations (Hot Carrier Models, Electromigration & TDDB Rules)**

Introduction

- **Radiation Testing:**
  - **Aeroflex Radiation Test facilities for Gamma & X-Ray TID, Low Dose-Rate TID, 14 MeV Neutrons, Flash X-Ray, Laser for SET**
  - **Partner Facilities for Heavy Ion, Proton, Thermal Neutron/Nuclear Reactor testing, pico-second Single and Dual Photon Absorption Laser Testing, High Dose Rate e-beam and flash X-Ray**
- **Radiation Hardened Analog & Digital IP:**
  - **Digital Libraries, I/O's and Extensive Library of Analog IP Blocks focused on high-precision, base-band signal conditioning, data conversion, and actuation**

Case Study 1: UT08SC14ADV045 Smart Sensor ASSP



UT08SC14ADV045 Smart Sensor ASSP

- **Complete Instrumentation System:**
  - **Includes circuitry to excite and precisely measure the response from 11 sensor types.**
  - **Supported Sensors:**
    - **Resistance Thermometer, Thermocouple, LVDT, Strain Gauge/Load Cell, Inductive and Transformer-based Position, Absolute and Relative Pressure Sensors, Hall Effect probe, Photodiode, Accelerometer, Tachometer, and other types of Sensors.**
  - **Excitation generator includes a 14-bit DAC with a high current, high-voltage differential output.**
  - **Eight high-voltage differential signal inputs are provided, with configurable signal conditioning.**
  - **14-bit 45 kSps delta-sigma analog-to-digital converter (ADC)**

UT08SC14ADV045 Smart Sensor ASSP

- **Complete Instrumentation System:**
  - **Data I/O:**
    - **Digital data word transmitted through a Low-Voltage Differential Signaling, Serial Peripheral Interface (LVDS SPI) port.**
    - **A second LVDS SPI port is used for configuration, control, parameter trim, and access to internal registers**
  - **Clock Generation:**
    - **A clock generator block generates the necessary internal clocks from a low-frequency reference.**
  - **Voltage Regulators:**
    - **Internal regulators derive necessary supply voltages and references from +/-6V and +3.3V power supply inputs.**

UT08SC14ADV045 Smart Sensor ASSP

- **Complete Instrumentation System:**
  - **NVM:**
    - **Aeroflex Radiation Hardened One-Time Electrically Programmable Read-Only Memory (RH OTEP ROM) provides storage for reference trim data, configuration data, and user configurable program storage.**
  - **Applications:**
    - **Nuclear Power Instrumentation Monitoring**
    - **Spacecraft Telemetry**
    - **Radiation Oncology Equipment Motor/Motion Control**
    - **Nuclear Waste Monitoring**

UT08SC14ADV045: Key Performance Parameters:

Excitation Output	14-bit DAC with differential voltage-mode output up to 20Vp-p, up to 140mA. Sine/square/triangle or arbitrary function outputs.
Sensor Inputs	8 multiplexed differential high-impedance user inputs; input range -5V<Vin<+5V
Signal Channel	Programmable gain range 0.18 to 100, 15 kHz bandwidth, includes anti-alias filter
A/D Converter	14-bit, 3rd-order delta-sigma, 45kSps
Typical channel mismatch	0.04% to 100°C, 0.07% to 200°C
Typical absolute measurement error	1% to 100°C, 4% to 200°C

0.35 μm BCD Technology

Technology Type	0.35μm BCD (Bipolar-CMOS-DMOS)
Minimum Feature Size	0.35 μm
Well Structure	Triple-Well (Substrate Isolated)
Transistors Used	3V Enhancement Mode NMOS & PMOS (self-aligned) 8V Enhancement Mode NMOS & PMOS (self-aligned) 12V Enhancement Mode Drain-Extended NMOS & PMOS 20V PNP BJT (vertical)
Metallization and Interconnects	4LM, Tungsten Plugs, CMP Planarization
Resistors	Diffusion Resistors, Poly Resistors (non-salicided), Hi-Poly Resistors
Capacitors	PiP, MiM, MOS-caps
Aeroflex Enhancements	Aeroflex RH OTEP Metal Fuse

Wafer Foundry QML-V approved as a supplier to Aeroflex

Aeroflex RH Digital Library, I/O's, and Analog IP Blocks

UT08SC14ADV045 Radiation Requirements

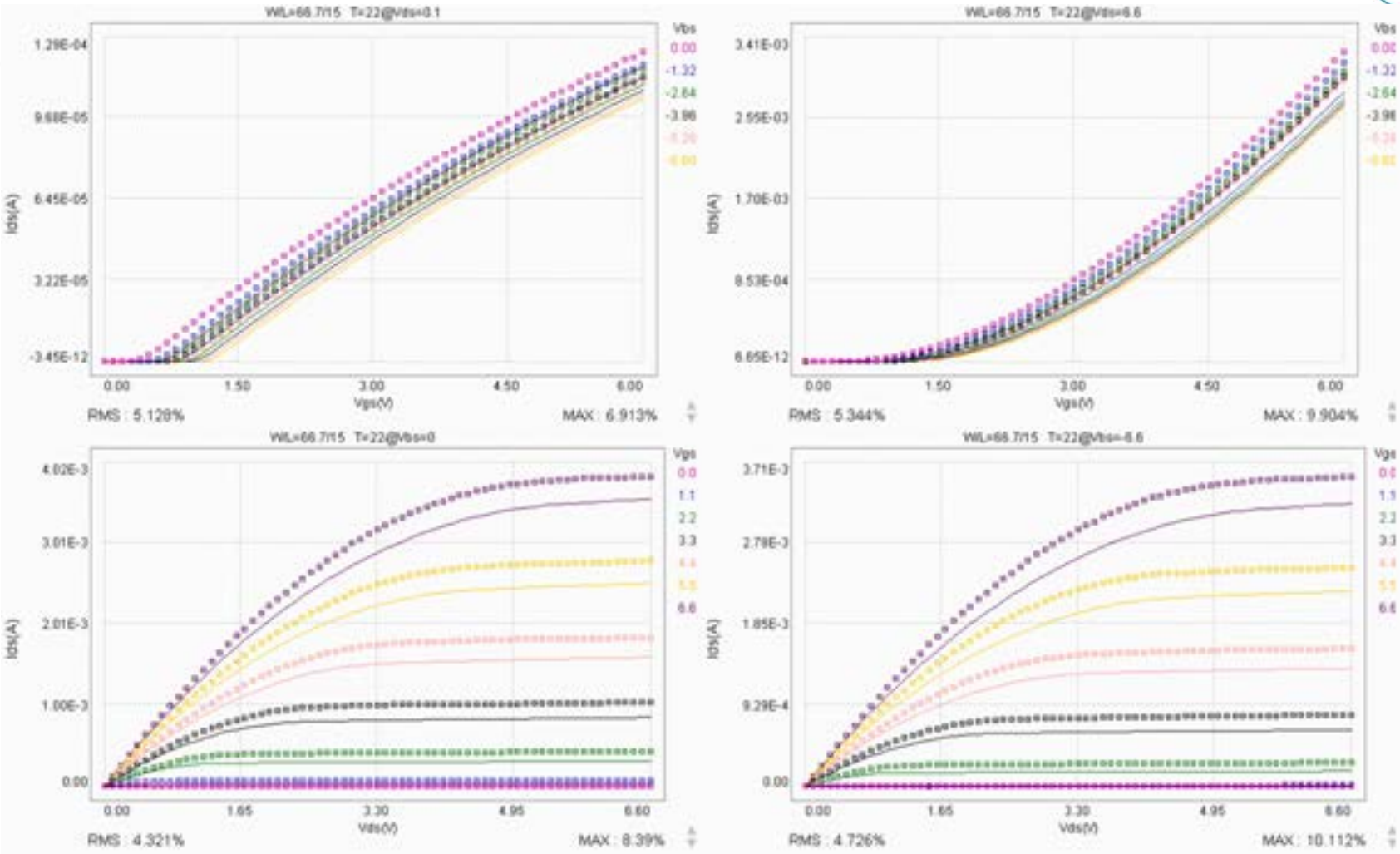
Environment	Requirement
Gamma Ray Total Ionizing Dose (TID)	100krad(Si) at a dose rate of 2.8mrad(Si)/sec
Neutron Induced Upset (NIU)	< 1E-11 errors/bit/day
Neutron Induced Latch-Up (NIL)	Immune (5E11 neutrons/cm^2, peak energy < 2MeV)
Temperature	200°C max. operating

Challenges:

Transistor characteristics change with total ionizing dose.

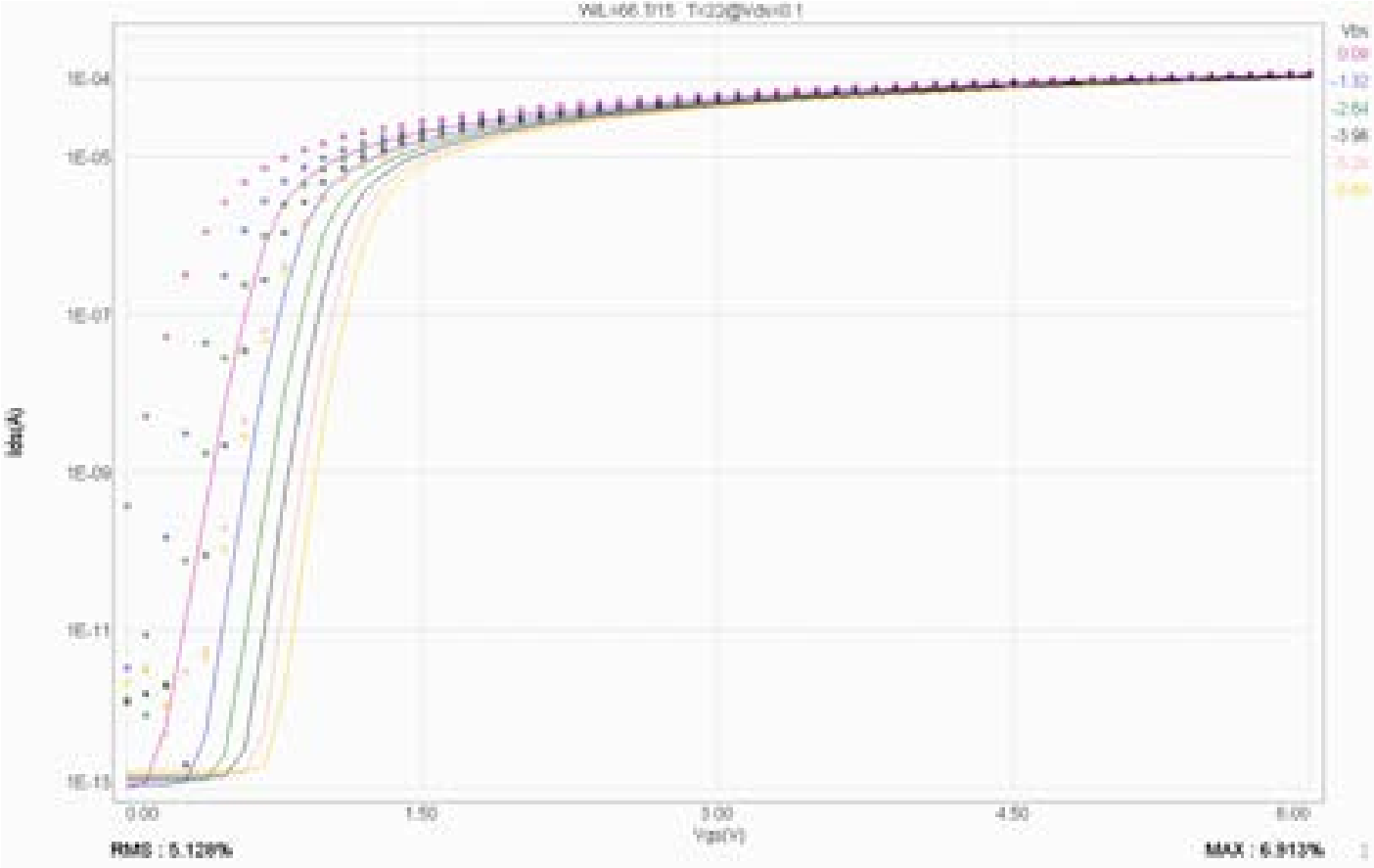
BSIM 3v3 models from foundry inadequate to model post-radiation performance.

Foundry Models compared to 100krad(Si) Data



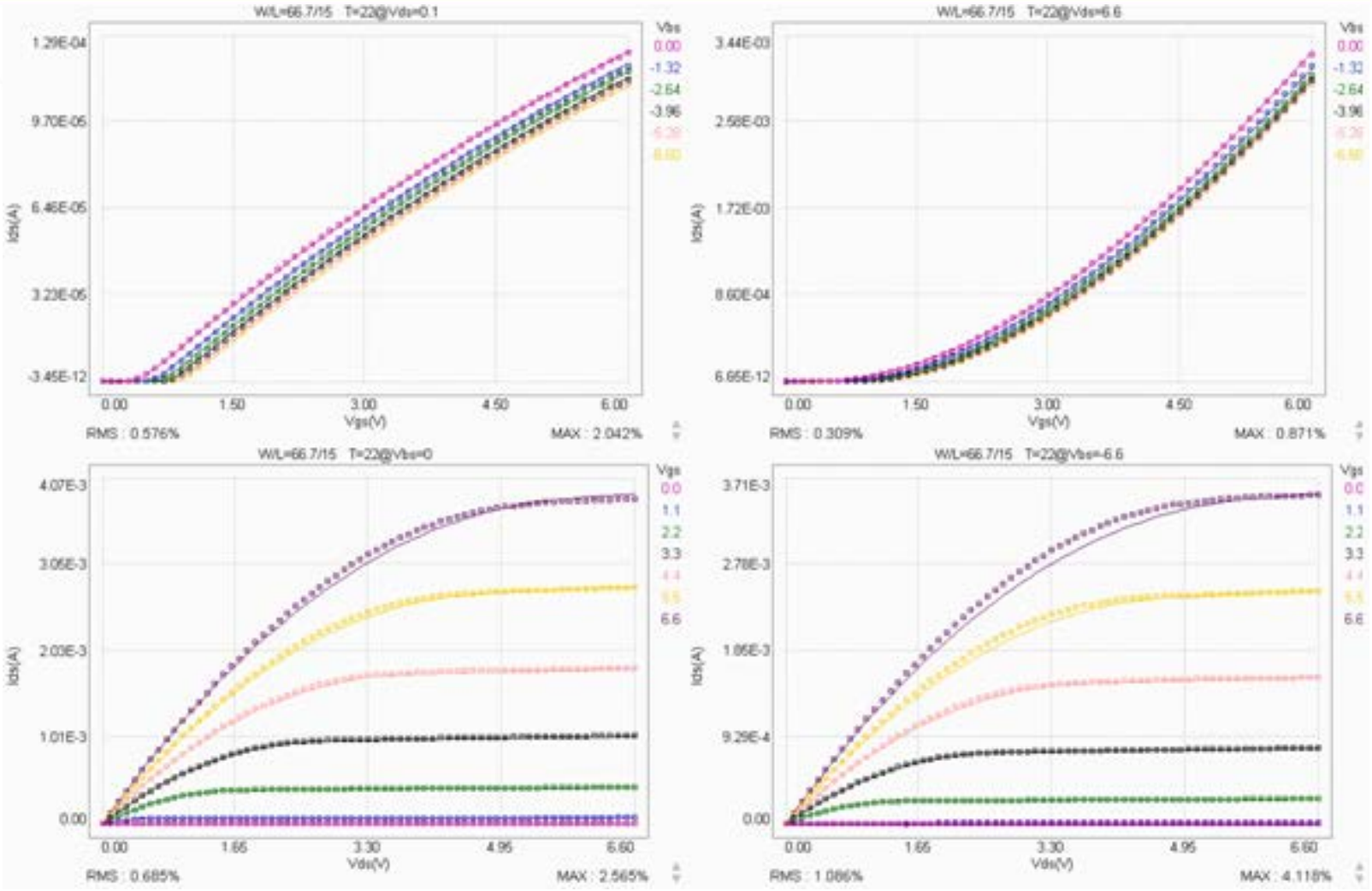
Poor Foundry Model Fit to Data after 100krad(Si)

Foundry Models compared to 100krad(Si) Data



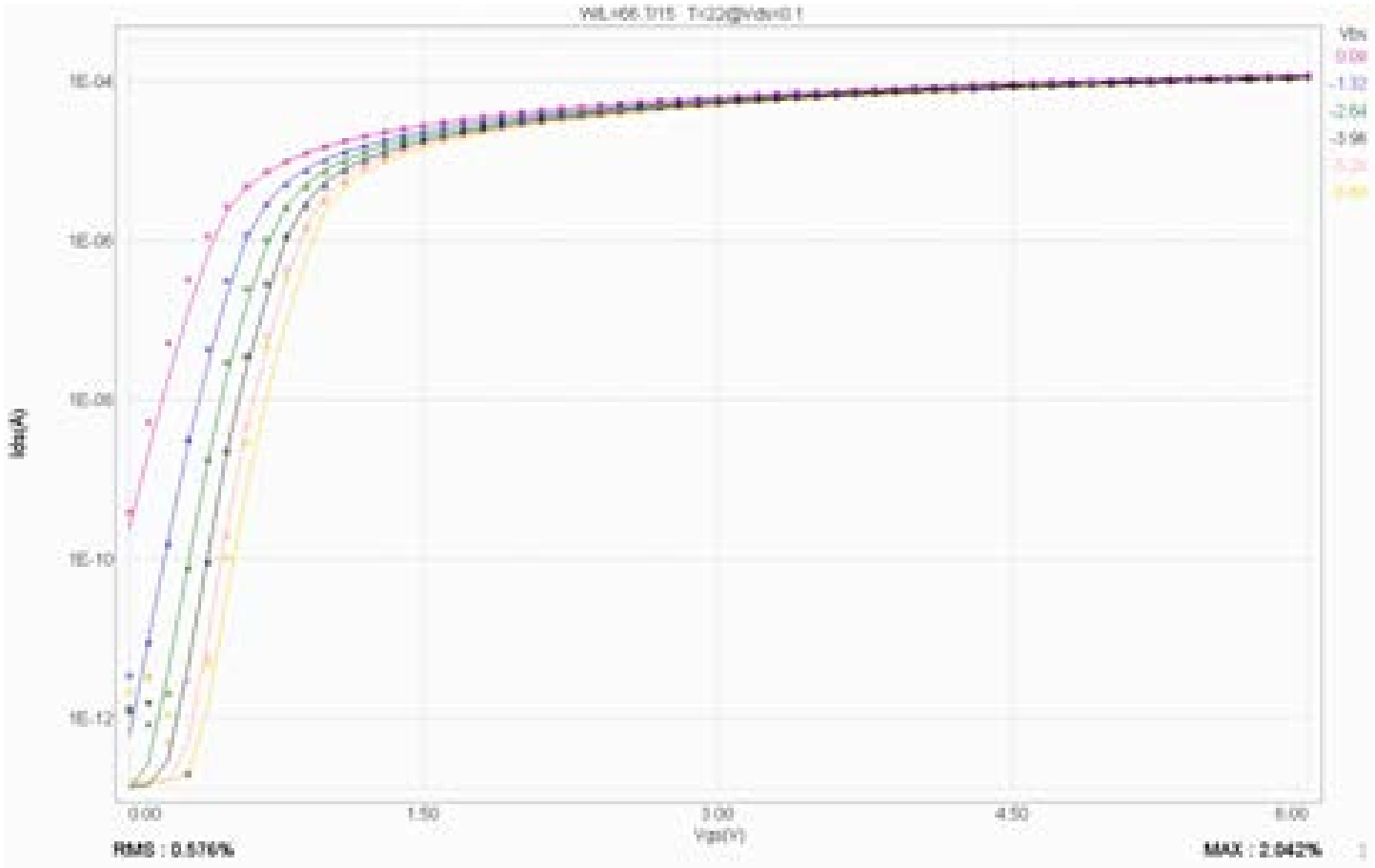
Poor Foundry Model Fit to Data after 100krad(Si)

Aeroflex Models compared to 100krad(Si) Data



Aeroflex Models Fit the 100krad(Si) Data well.

Aeroflex Models compared to 100krad(Si) Data



Aeroflex Models Fit the 100krad(Si) Data well.

UT08SC14ADV045 First Pass Silicon Results

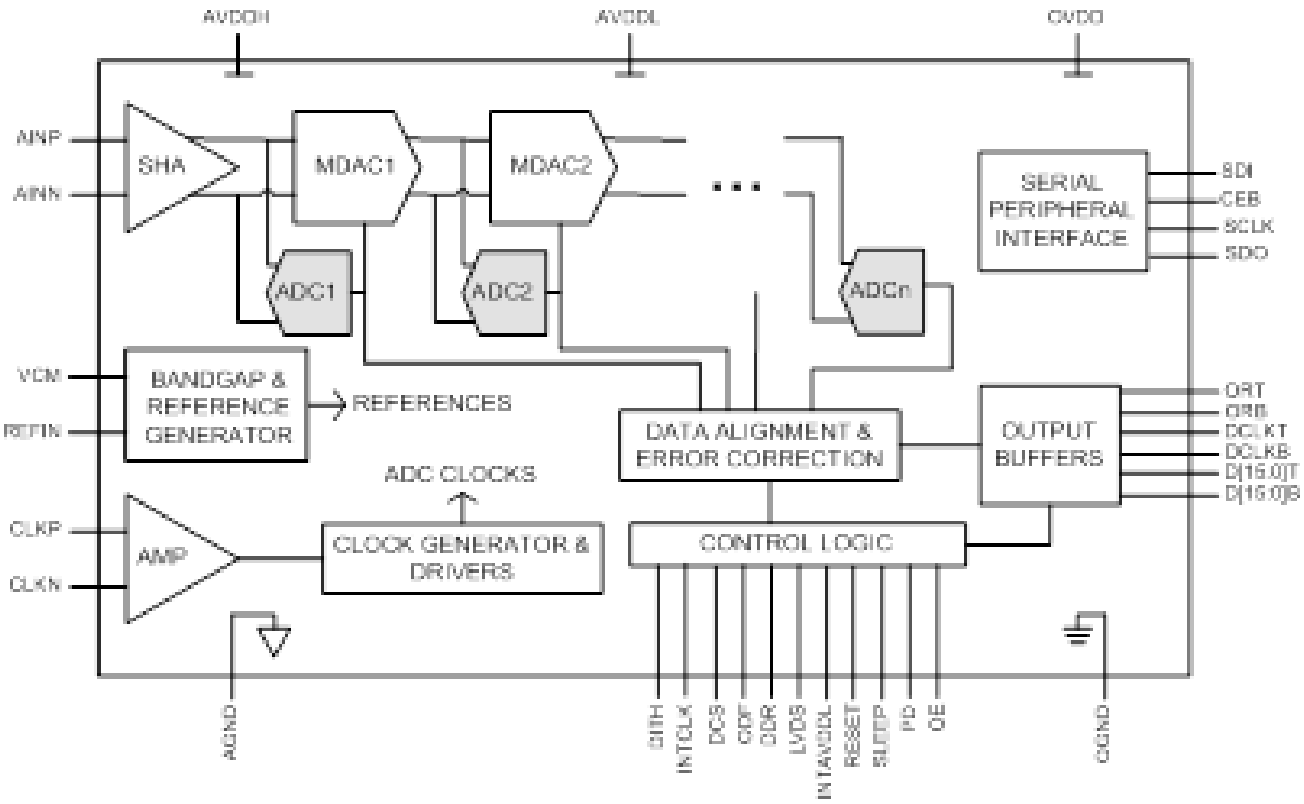
Test	Results
Total Ionizing Dose (TID)	PASSED 100krad(Si) at 200rad/sec
Low-Dose Rate TID	PASSED 100krad(Si) at 10mrad(Si)/sec
NIU	NO UPSETS after 6.8E11 n/cm^2
NIL	NO LATCH-UP after 6.8E11 n/cm^2

Successful 1st Pass Silicon due to Aeroflex developing its own compact transistor models using transistor test structures on its Technology Characterization Vehicle

Case Study 2: 16-bit Pipeline ADC

- **Ideal for Telecommunication and Imaging applications:**
  - **16-bit, 40-MSps CMOS pipeline ADC**
  - **Excellent noise (76dBFS SNR) and distortion (95dBc SFDR)**
  - **2.5Vp-p input**
  - **Sample-and-Hold Amplifier (SHA)**
  - **Duty-Cycle Stabilization produces 50% clock phases even with 20% - 80% duty cycle skew in external clock**
  - **Internal dither function for improved linearity of the conversion of small signal analog inputs**
  - **Linerity: ±2.5LSB INL and ±0.25LSB DNL.**
  - **Two output data formats: straight binary and 2's complement**

UT16AD80P, UT16AD40P, UT14AD20P



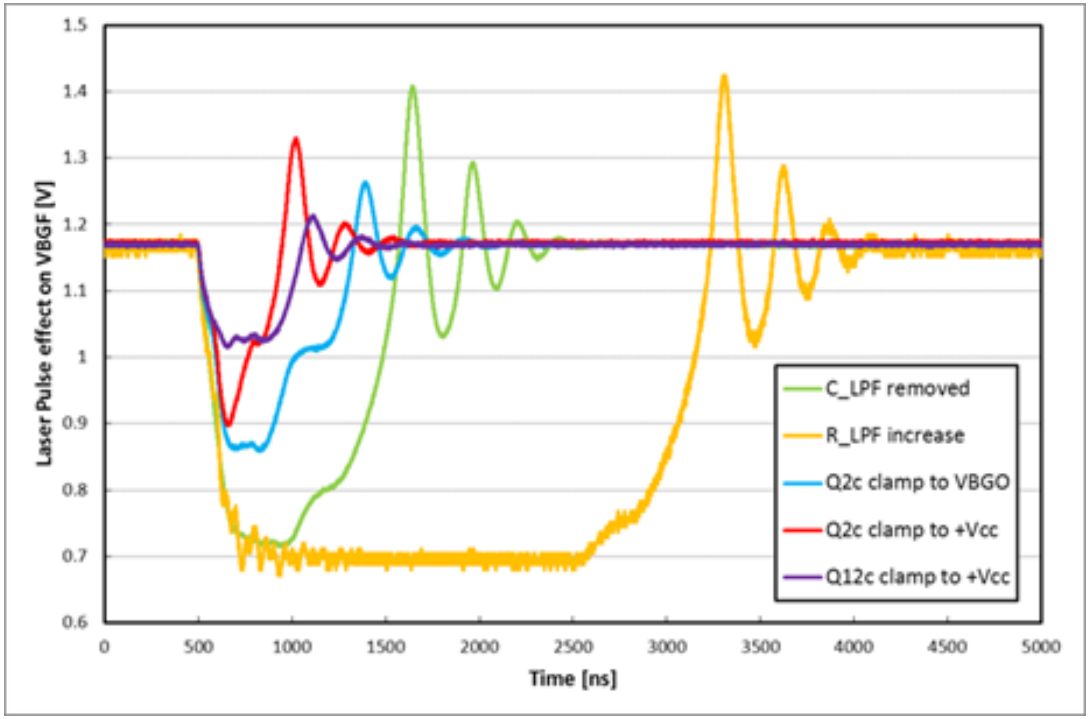
0.18μm Triple-Well 6LM Mixed-Signal CMOS

Table VI: Key Technology Features for UT16AD40P

Technology Type	0.18μm Mixed-Signal CMOS
Minimum Feature Size	0.18 μm
Well Structure	Triple-Well (Substrate Isolated)
Transistors Used	1.8V Enhancement Mode Isolated NMOS & PMOS (self-aligned) 1.8V Enhancement Mode non-isolated NMOS (self-aligned) 3.3V Enhancement Mode Isolated NMOS & PMOS (self-aligned) 3.3V Enhancement Mode non-Isolated NMOS (self-aligned) Native non-isolated NMOS Bipolar NPN (vertical)
Metallization and Interconnects	6LM, Tungsten Plugs, CMP Planarization
Resistors	Diffusion Resistors, Poly Resistors (non-salicided), Hi-Poly Resistors
Capacitors	MiM, MOS-caps
Aeroflex Enhancements	P-type varactors, Low Dielectric Absorption MiM Capacitors, RH OTEP Metal Fuse

Wafer Foundry QML-V approved as a supplier to Aeroflex

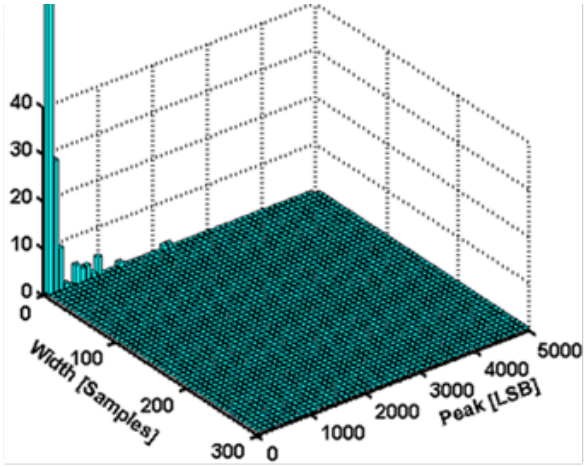
UT16AD40P Design Challenges



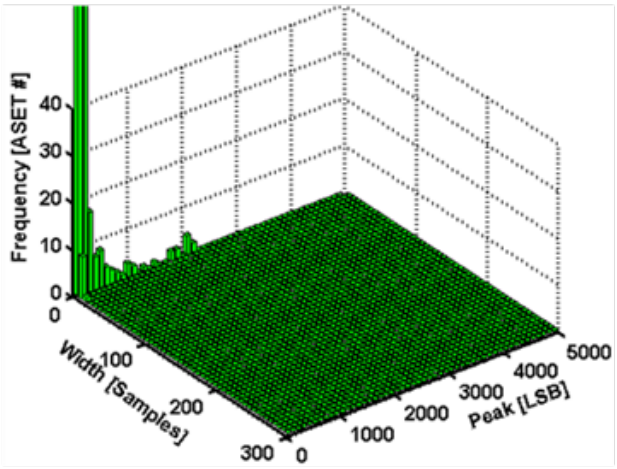
Laser testing of Bandgap on TCV showed Long Duration SET Pulse (LDP – yellow line >).

Subsequent TCV modifications with clamps to V_{BGO} or V_{CC} gave the needed improvement (purple line, < 500nsec) before tape-out.

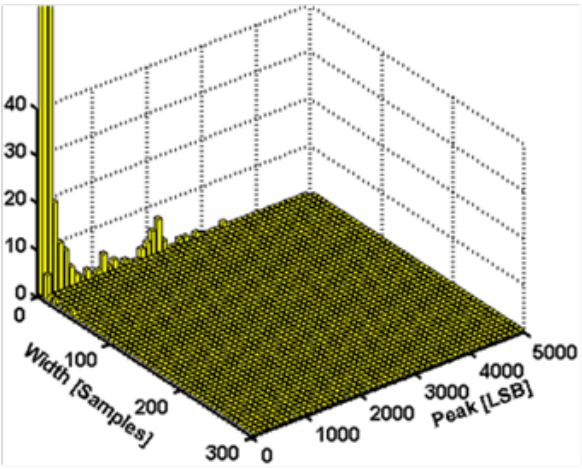
3D Methodology for Rating SET



(a) LET = 30 MeV-cm²/mg



(b) LET = 60 MeV-cm²/mg

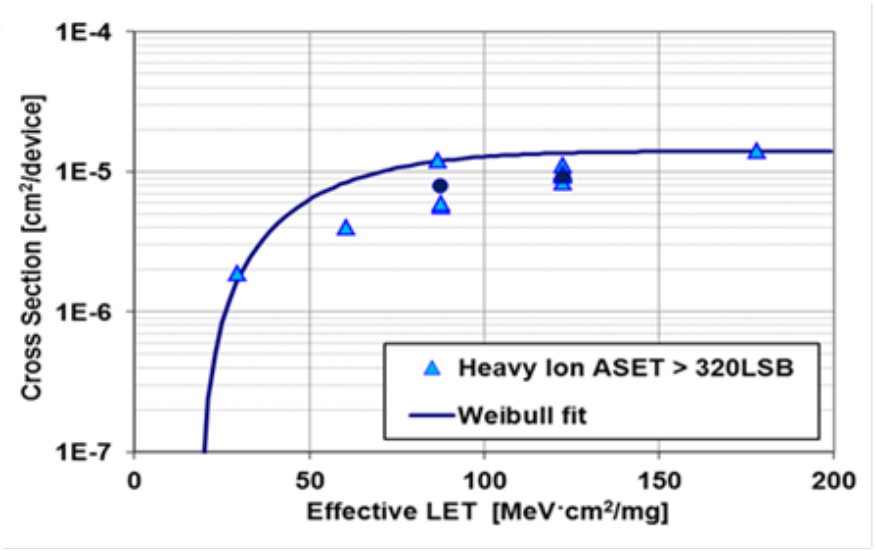


(c) LET = 87 MeV-cm²/mg

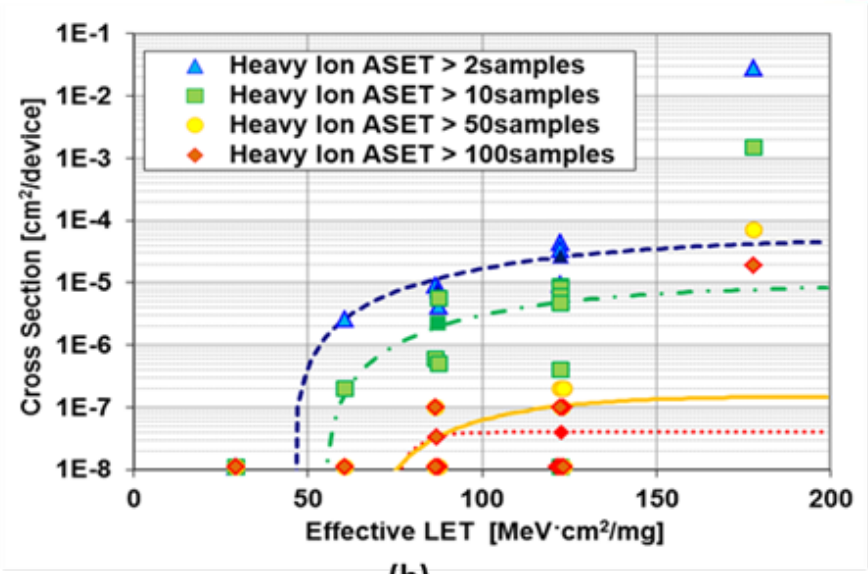
Aeroflex using 3D SET Rating Methodology for providing the user detailed information about SET performance of its ADC's

User can see both duration and extent (e.g. in LSB peak of ASET) as a function of LET as shown above.

Generation of 2D Cross Section Curves



(a)



(b)

Generation of traditional 2D Cross Section Curves is easily accomplished by integrating 3D histograms over desired duration and/or extents

(a) Cross Section for extents > 320 LSB's (regardless of duration)

(b) Cross Section for durations of 2, 10, 50, 100 sample clocks (regardless of extent)

UT16AD40P Radiation Results

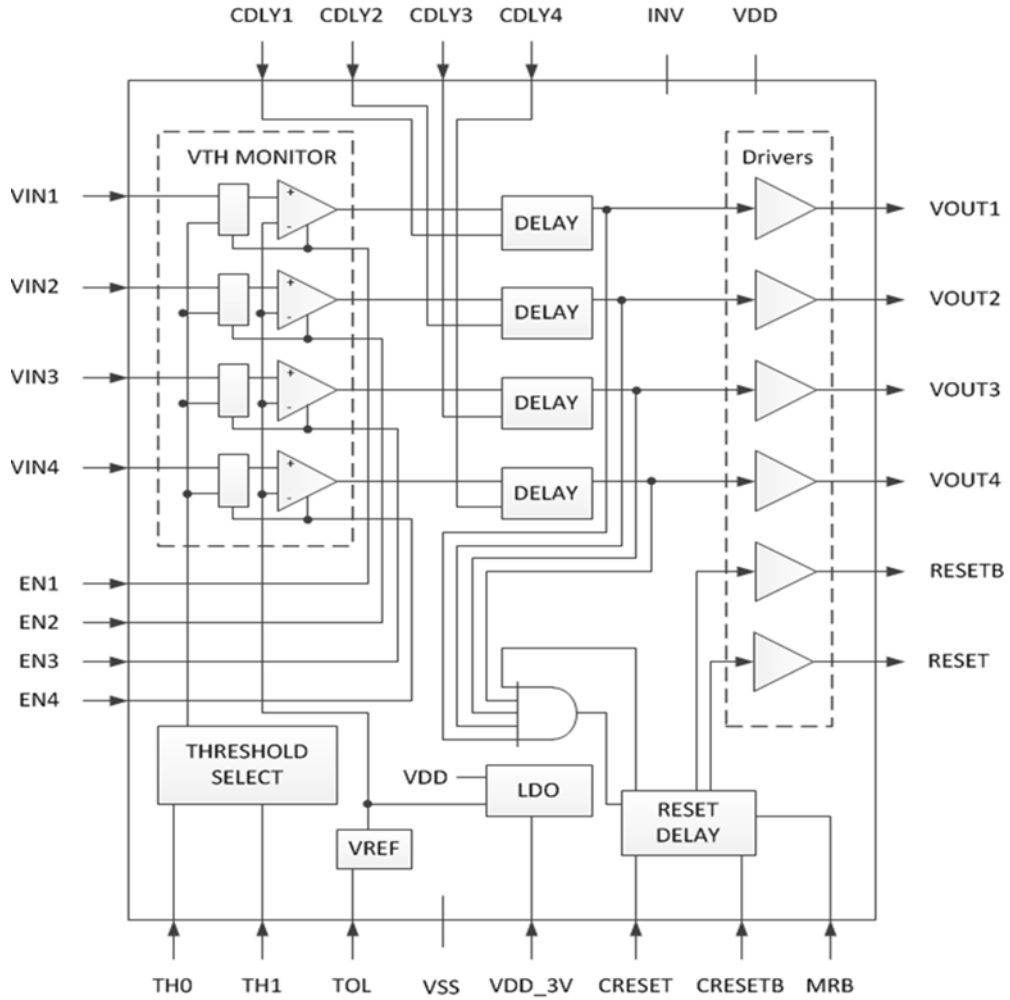
- **SEL immune up to 121MeV·cm²/mg LET (Au ion)**
  - Tested **statically, and in every dynamic operational mode**

- **Fully functional after 2Mrad(Si) TID**
  - Bandgap shift increase with dynamic activity (from junction leakage)
  - No other ADC block shows any shift (proved by restoring VBGO)
  - No rebound – dynamic thermal anneal most efficient (back to <1%)
  - Performance vs. TID minimally affected: even with VBGO shift, observed up to **74.1dBFS SNR, 92dBc SFDR to 2Mrad(Si)**

Case Study 3: UT04VS33P Voltage Supervisor

- **Monitors 1 to 4 Power Supplies (or other System Signals)**
  - **Timed output signals to sequence voltage regulators**
  - **Output signals can be programmed active-high or active-low**
  - **Timed RESET_B & RESET signals**
  - **Under-voltage thresholds: Pre-Set or User Defined**
  - **Over-voltage mode: 2-Channels monitored for BOTH under- and over-voltage conditions**
  - **MASTER_RESET_B pin allows for easy daisy-chaining to sequence more than 4 supplies**

UT04VS33P Block Diagram



0.35 μm Triple-Well 4LM CMOS

Technology Type	0.35μm Mixed-Signal CMOS
Minimum Feature Size	0.35 μm
Well Structure	Triple-Well (Substrate Isolated)
Transistors Used	3.3V Enhancement Mode Isolated NMOS & PMOS (self-aligned) 5.0V Enhancement Mode Isolated NMOS & PMOS (self-aligned) Bipolar NPN (vertical)
Metallization and Interconnects	4LM, Tungsten Plugs, CMP Planarization
Resistors	Diffusion Resistors, Poly Resistors (non-salicided), Hi-Poly Resistors
Capacitors	MiM, MOS-caps
Aeroflex Enhancements	RH OTEP Metal Fuse

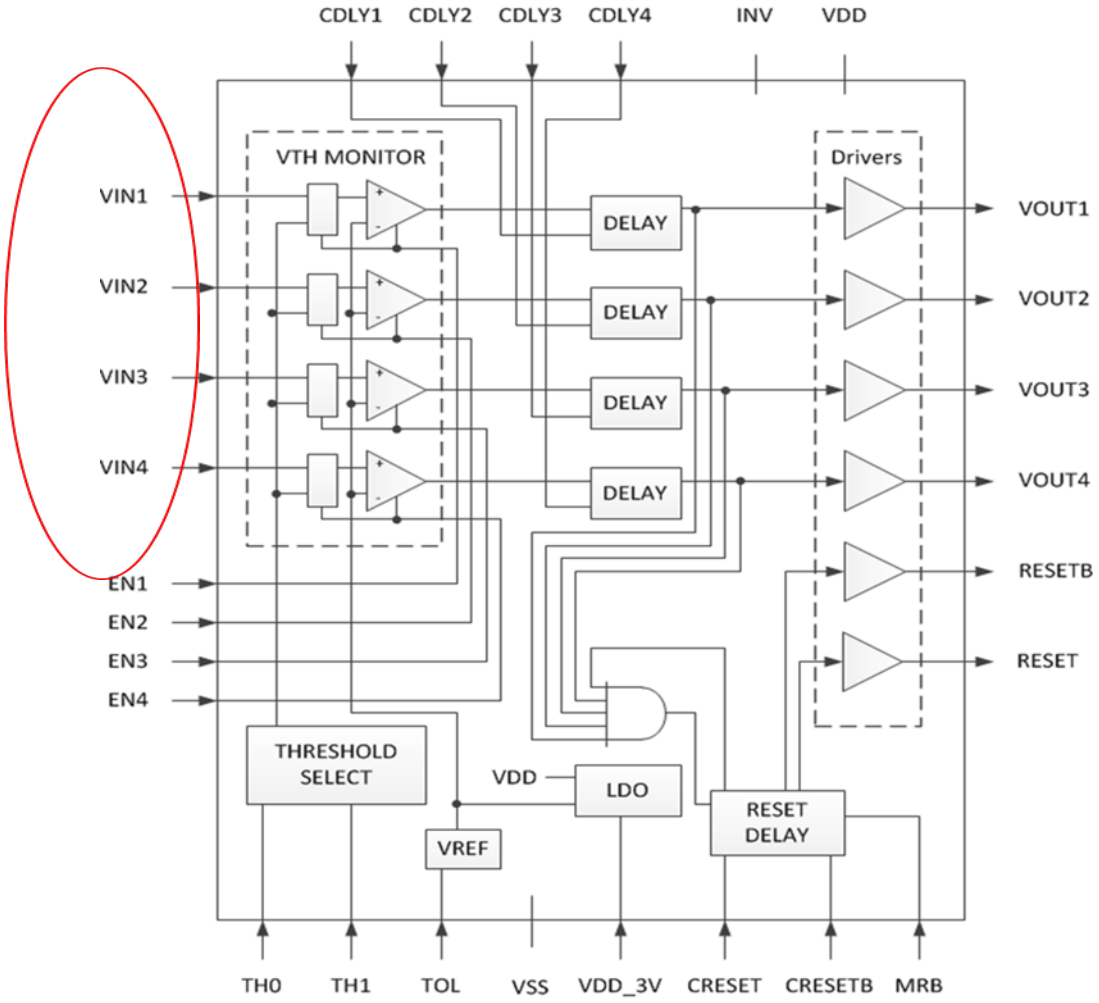
Wafer Foundry QML-V approved as a supplier to Aeroflex

Aeroflex RH Digital Library, I/O's, and Analog IP Blocks

QML-V New Technology Qualification: June 2012

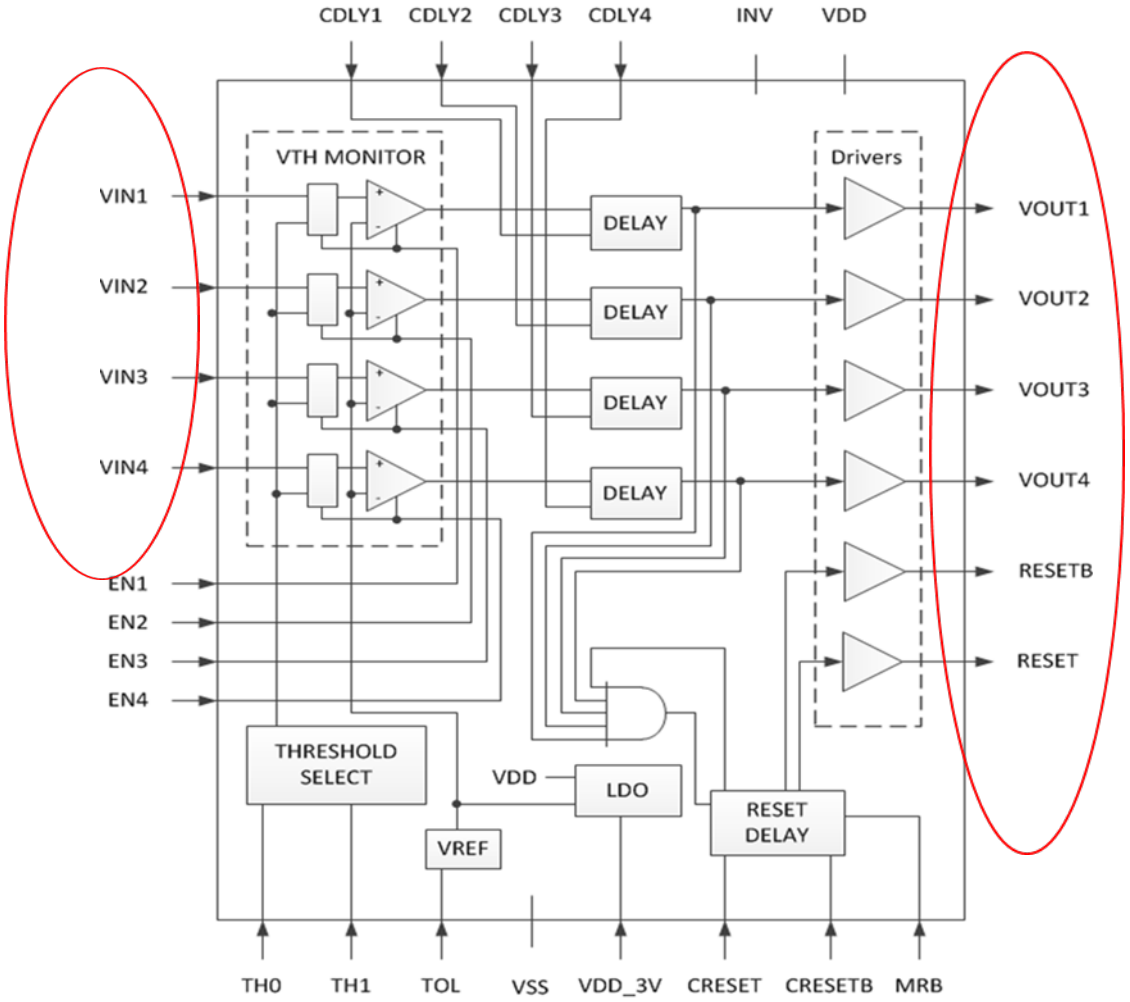
UT04VS33P Block Diagram

Inputs set to 50mV above comparator trip point



UT04VS33P Block Diagram

Inputs set to 50mV above comparator trip point

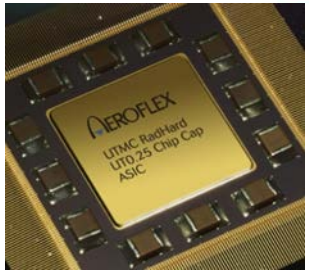


Outputs monitored for SET (either glitches or change in state)

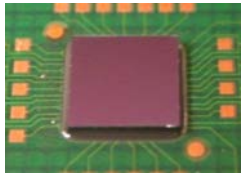
UT04VS33P Radiation Performance

- **Asynchronous Part:**
  - **100% exposed to SET events: SET could cause inadvertent system RESET**
- **Tools Used:**
  - **Qsim (Critical Charge) & SETsim (Rate vs Charge)**
- **Design Goal:**
  - **No SETs below 80 MeV cm^2/mg**
- **1st Pass Silicon Success:**
  - **300krad(Si)**
  - **No SETs with less than min. VDD (2.7V) at > 110 MeV cm^2/mg for 4E7 ions/cm^2**

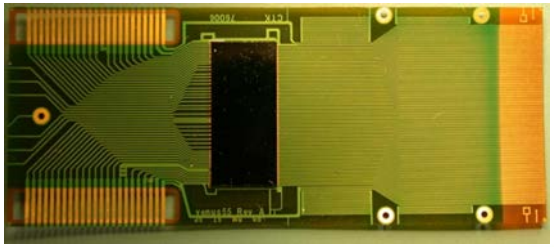
Assembly



- **Current Packaging Technology**
  - Hermetic ceramic packages from 12 to 377 user I/O, CQFP, CCGA
  - PEM's: BGA (81 to 484 ball), QFN (12 to 28 pin), PQFP (40 to 208 pin), etc. in pitches ranging from 0.4 to 1.27 mm
  - QML-V level external passive attach (resistor, capacitor)
- **Plug & Sense^{SM} Packaging**
  - Flip Chip with Under Bump Metallurgy (UMB) and various underfills
  - Flip-Chip on Flex, PCB, or Ceramic
  - Hermetic photonic device packaging for space



- **Advanced Packaging Technology**
  - Cantilever and Pyramid Stacked die
  - CCGA Solder Column attachment
  - Seam Sealing



Summary

- **Aeroflex:**
  - **Turn-Key Supplier for Radiation Hardened Mixed-Signal ASICs**
- **QML-V ASIC Technologies:**
  - **0.35 μm Triple-Well, 4LM BCD (3.3V up to 40V)**
  - **0.35 μm Triple-Well, 4LM CMOS (3.3V & 5V)**
  - **0.18 μm Triple-Well, 6-7LM CMOS (1.8V & 3.3V)**
- **Key Success Factors:**
  - **12 Years of Radiation Hardened Mixed-Signal ASIC Experience**
  - **Extensive Analog IP Library: signal conditioning, data conversion, and actuation**
  - **Modeling (Compact Transistor Models, SET Error Rates using Qsim/SETsim, Safe Operating Area using Hot Carrier Models TDDB, and Electromigration Rules)**
  - **In-House Radiation Test Facilities + Access to Heavy Ion, Proton, Nuclear Reactor Testing**

Dank U!
Thank you!
Danke!
Merci!
Grazie!
Gracias!
Tack!
Ευχαριστούμε!
תודה!