Power Matters.

Safety Critical Applications

Rufino Olay
Microsemi Industrial Business Manager
June 26, 2012

Agenda

- Introduction to functional safety
- Different safety standards
- Design techniques
- Deployment examples
- Further resources

History of Microsemi FPGAs in safety critical applications

Commercial Avionics

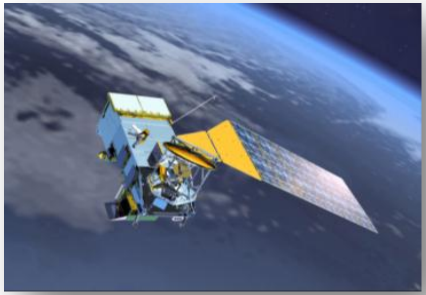
Military Avionics

Tactical Missiles

Medical Equipment

Military Ground Vehicles

Space Systems



Increasing safety critical design focus

Market Drivers:
Industrial manufacturers upgrading products to include more electronics for higher dependability involving reliability, safety, availability, and security

- **Safety-Critical Systems**
  - Avionics
  - Medical
  - Industrial automation
  - Power plants
  - Railmotive
  - Gas/Oil industry
  - More...

- **S-C System Characteristics**:
  - Reliability
  - Availability
  - Secure operation
  - System integrity
  - Data integrity
  - System recovery
  - Maintainability

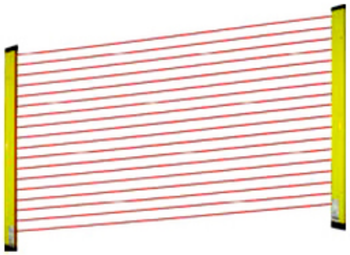
- **Device selection considerations**
  - Prior deployment in safety critical application
  - Length of time device has been in the market
  - Number of devices shipped over current product lifetime
  - Accessibility to reliability data

Industrial Application Examples

Configurable Safety Modules

Safety Laser Scanners

Safety Drives & Motors, Motor Control



Safety Light Curtains

Safety PLCs

Other Examples from IEC website:

- Emergency shut-down systems
- Fire and gas systems
- Turbine control
- Gas burner management
- Crane automatic safe-load indicators
- Guard interlocking and emergency stopping systems for machinery
- Medical devices
- Dynamic positioning
  - Control of a ship's movement when in proximity to an offshore installation
- Railway signaling systems (including moving block train signaling)
- Variable speed motor drives used to restrict speed as a means of protection
- Remote monitoring, operation or programming of a network-enabled process plant

Numerous Functional Safety Standards

Functional Safety Standards for Different Markets

- IEC 61508: Functional safety in industrial equipment
- DO-178B/DO-254: Functional safety in avionics
- IEC 6060: Functional safety in medical equipment
- EN 50128/9: Railway application - software for railway control & protection
- ISO 26262: Functional safety in road vehicles

Functional Safety Overview

- **All** systems will have a possibility of failure in time
  - It is impossible for a system with absolute zero failure rate
- Each application has a failure rate level
  - Goal is to significantly increase the time between any failures
  - Example in a US Nuclear power plant goal is failure in 110,000 years*
    - Many exceed this to 1 failure in 1M years with target of 1 failure in 10M years
- Tolerable failure rates/levels vary per application
  - Depends on potential for direct or indirect physical injury
- Safety Integrity Levels (SILs) are categories to quantify levels of risks

*Source: http://www.world-nuclear.org/info/inf06.html

IEC 61508: Industrial functional safety standard

- Developed by International Electrotechnical Commission (IEC)
  - Certification through TUV
- Functional safety in industrial equipment
  - Originally applied at system level but has been also applied to product & components
- Addresses Electrical, Electronic, Programmable Electronics including hardware and software

Safety Integrity Level (SIL) - IEC 61508

SIL Level	Availability	Probability of Failure	Consequence	Application Example
4	>99.99%	1 failure in 110,000 yrs	Potential for fatalities in the community	Nuclear Power Plant Control
3	99.9%	1 failure in 11,100 yrs	Potential for multiple on-site fatalities	Hazardous area laser curtain sensors
2	99%	1 failure in 1,100 yrs	Potential for major on-site injuries or fatalities	Hazardous liquid flow meter
1	90%	1 failure in 110 yrs	Potential for minor on-site injuries	Thermal Meter

Microsemi

Power Matters.

Safety standards for different markets

International (Generic)

- **IEC 61508 (-3)**
  Functional safety of electrical/electronic/ programmable electronic safety related systems
- **ISO/IEC 15504**
  SPICE/Automotive SPICE
- **ISO/IEC 12207**
  Software lifecycle process

Medical

- IEC 62304
  Software for medical devices

Machines

- **ISO 13849**
  IEC 62061
  Safety of machines

Gas measure techniques

- **EN 50271**
  EN 50402
  Functional safety of gas warning systems

Process industry

- **IEC 61511**
  Safety instrumented systems for the process industry sector

Railway

- **EN 50128**
  Railway applications - Software

Automotive

- **ISO DIS 26262-6/-8**
  Functional safety "road vehicles"

Avionics

- **DO 178B**
  Software considerations in airborne systems

Nuclear Power

- **IEC 60880**
  Nuclear power–control technology, Software aspects
- **IEC 61513**

Source: TUV

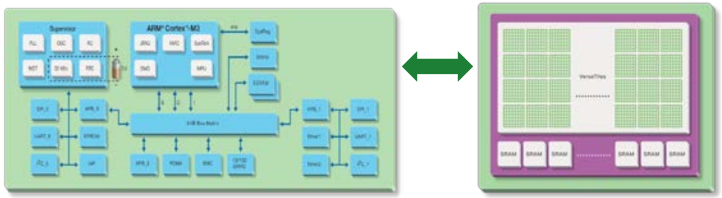
Microsemi

Our Devices Deployed at the Highest Reliability Levels

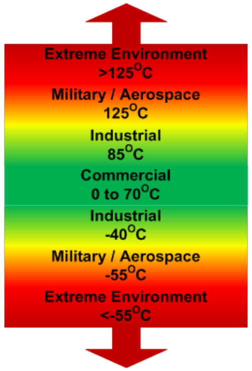
Safety Integrity Level (SIL) - IEC 61508

SIL Level	Availability	Probability of Failure	Consequence	Application Example
4	>99.99%	1 failure in 110,000 yrs	Potential for fatalities in the community	Nuclear Power Plant Control
3	99.9%	1 failure in 11,100 yrs	Potential for multiple on-site fatalities	Hazardous area laser curtain sensors
2	99%	1 failure in 1,100 yrs	Potential for major on-site injuries or fatalities	Hazardous liquid flow meter
1	90%	1 failure in 110 yrs	Potential for minor on-site injuries	Thermal Meter

<u>Microsemi FPGA Inherent Strengths</u>



- **Immunity to Firmware Errors**
  - Ensures Data & System Integrity & Control
  - Fully functional to 100KRads
- **Fault Tolerance through Redundancy**
  - Hardware redundancy through parallel, dissimilar processes
  - Cortex-M3 & FPGA running in lockstep



- **Extreme Temperature Operation**
  - Fully operational in harshest conditions
  - Up to 200°C

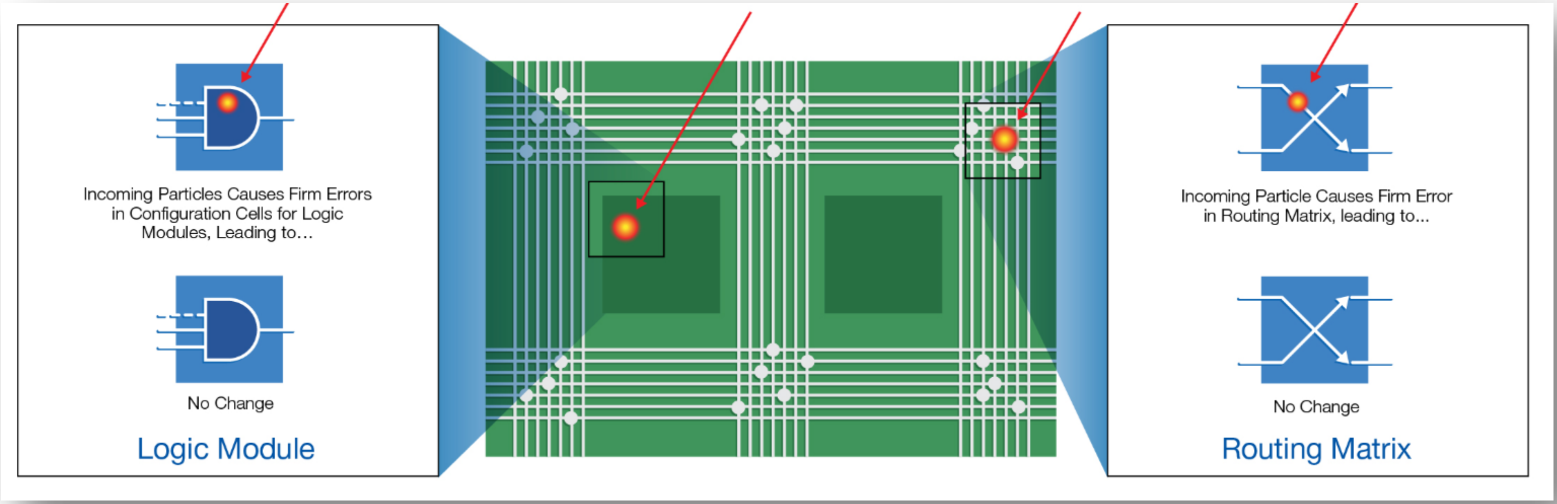
Neutron Induced Single Event Upset Background

- Single Event Upset issue was first discovered in 1979 by Intel and Bell Labs as failures in DRAM's
- In 1999 Sun Microsystems noticed errors in cache SRAM's for mission critical servers
- 2000's saw an increasing concern over SEU in logic devices like FPGAs
- Historically neutron interactions have been associated with electronics used in Aircrafts due to the high neutron flux at these altitudes
- As more electronics is incorporated in everyday applications, likelihood of interference has increased

Microsemi

Flash FPGAs immune to Single Event Upset

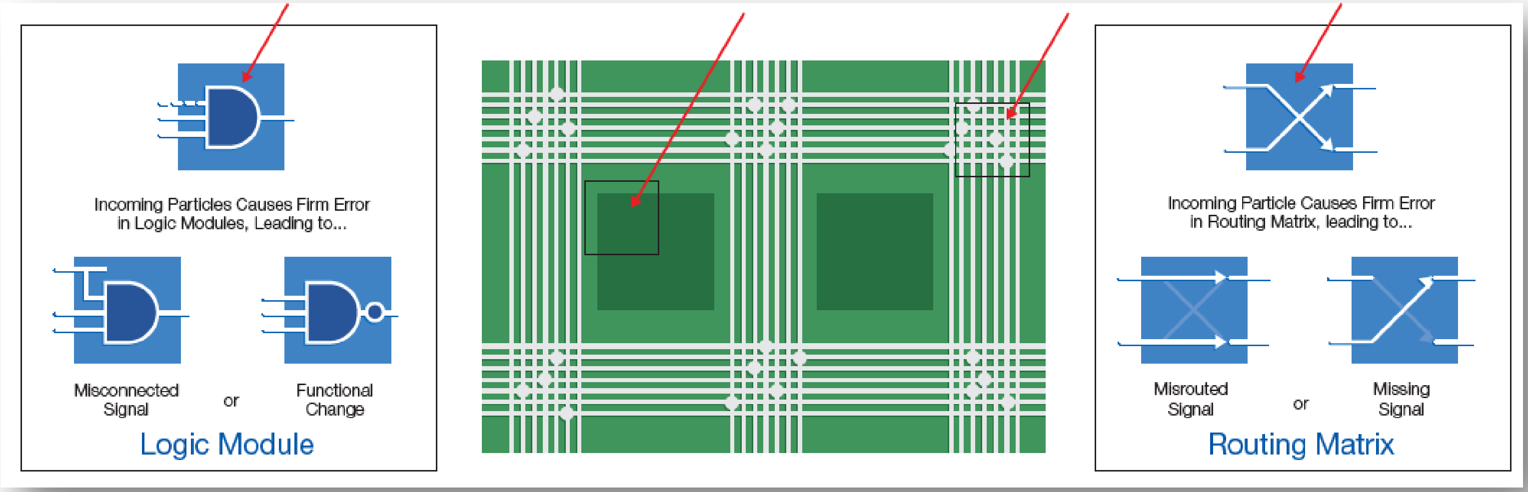
- As nodes shrink, the amount of charge on each node is smaller, but charge in Cosmic rays remain same thus causes a bigger “disturb”
- As nodes shrink, circuits require less charge per switch to operate
- In FLASH FPGAs when neutron or alpha particles strike Configuration Cells in:
  - Routing Matrix → No change
  - Logic Block → No change



SRAM FPGAs are effected by stray particles

- In SRAM FPGAs when neutron or alpha particles strike the CM's in
  - Logic Block → results in a misconnected signal which in turn results in functional failure
  - Routing Matrix → results in a misrouted or missing signal

- In both cases it's a CM upset leading to severe consequences!
  - These errors persist until detected
  - Need rebooting OR power cycling of the FPGA



Microsemi

No SEU Configuration Failures in Microsemi FPGAs

FPGA	Technology	Equivalent Functional Failure – FIT Rates per Device			
		Ground-Level Applications		Commercial Aviation	Military Aviation
		Sea Level	5,000 Ft	30,000 Ft	60,000 Ft
Microsemi Antifuse FPGA 1M-Gate	150nm Antifuse	No Failures Detected	No Failures Detected	No Failures Detected	No Failures Detected
Microsemi Flash FPGA 1.5M-Gate	130nm Flash	No Failures Detected	No Failures Detected	No Failures Detected	No Failures Detected
Microsemi Upcoming Next Gen Flash FPGA	65nm Flash	No Failures Detected	No Failures Detected	No Failures Detected	No Failures Detected
SRAM FPGA Vendor 1 1M-Gate	90nm SRAM	320 FITs	1,100 FITs	47,000 FITs	150,000 FITs
SRAM FPGA Vendor 2 1M-Gate	90nm SRAM	730 FITs	2,500 FITs	108,000 FITs	346,000 FITs

Neutron Testing Results: iRoC Technologies: www.irochtech.com
Regular testing at Los Alamos National Labs neutron test facility

Microsemi

Power Matters.

Fewer Requirements for Flash Based FPGAs

Due to Non Volatility & SEU Immunity

- IEC61508 Annex E04
  - *7.4.5.4 Especially for application of FPGAs and PLDs in E/E/PE safety related systems the following systemic faults shall be controlled*

Requirement	Applicability to Microsemi
Loss of information in Configuration RAM (RAM Based FPGAs)	na: SEU immune
Malfunction of erase feature (EEProm based FPGAs/PLDs)	na: Flash is non-volatile
Power supply drops, EMC (RAM based)	na: Flash is non-volatile
Incorrect initialization during power-on (RAM based)	na: Live at power-up
Faults in individual programming / configuration bits (all technologies)	Yes
Modification of coarse functionality (macro cells, FPGA & CPLD)	Yes
Coupling between “independent” channel (temperature, supply voltage, EMC, cross-talk) if implemented on a single chip (all technologies)	Yes
Single point of failure (e.g. compare logic, efficient self testing even if system uses long time static data during normal operation)	Yes
Malfunction in design and implementation tools	Yes

Meeting Security Requirements

From IEC 61508, Part 1, P. 8

- …this standard demands that any malicious and unauthorized actions are to be examined during the hazard and risk analysis.

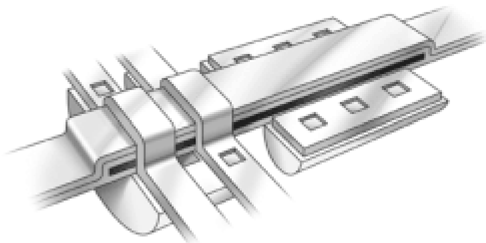
  The application scope of this analysis includes all relevant phases of the security life cycle;

- **Protection against**
  - Reverse engineering
  - Tampering
  - Overbuilding
  - Cloning

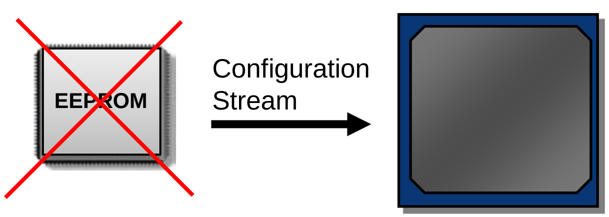
Cloning & Overbuilding

Microsemi Security Features

- **Secured IP**
  - FlashLock® controls access to security settings of the device

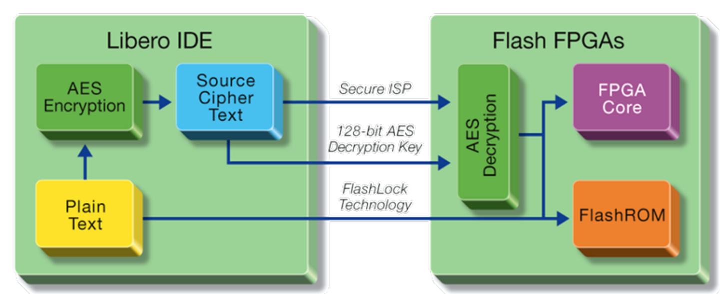


  - No bitstream communicated from external configuration device



  - Flash cells more secure against micro-probing than other FPGA technologies

- **Secured manufacturing flow**
  - AES-encrypted programming file sent to manufacturer
  - Devices pre-programmed with matching AES key sold direct to manufacturer
  - Protects against overbuilding and cloning



Redundancy Techniques

- Redundancy is mandatory for safety critical systems
  - Provides fault-tolerant systems
  - Operate properly in the event of a failure

- Dual Modular Redundancy
  - Duplicated designs work in parallel
    - The same inputs are provided to each processing element
    - Fail safe certification engine checks for consistency

- Triple Modular Redundancy
  - Three control systems
  - Error in one component can be out-voted by the other two

Diversity Concept

- What is it – "Diversity"?
  - Fundamental differences or dissimilarity between two devices
    - usually to implement the same functions
  - In case of FPGAs: Silicon (technology & architecture), Software, Hardware development tools

- Without Diversity:
  - In a system is designed with TMR or DMR redundancy,
  - if ALL FPGA's behave similar, then if 1 type of failure causes 1 FPGA to fail,
  - then ALL the redundant (backups in case of failures) could possibly also FAIL, and the system would shut down.
  - **Redundancy in this case did not keep the system running.**

- With Diversity:
  - If a system is designed with redundancy, and all FPGA's are DIVERSE, then 1 type of failure mode is DIFFERENT between 2 DIFFERENT devices
  - If 1 type of failure causes 1 FPGA to fail, the redundant FPGA behaves DIFFERENTLY.
  - **The system would still RUN.**

Diversity through two different Microsemi FPGA technologies

- Microsemi manufactures Antifuse & Flash FPGAs
- Antifuse technology and flash technology are completely different in terms of the manufacturing process, how the devices store the design, and how the devices are programmed with the design.
- Antifuse devices are 1-time-programmable (OTP) and the device design is stored by permanently creating a conductive path.
- Flash devices are re-programmable and the device design is stored by storing a charge on a floating gate of a flash transistor.

Evolution of Programmable Logic

Increasing Levels of Integration

1st Generation
Low Power FPGA

2nd Generation
First Mixed Signal FPGA

3rd Generation
Customizable System-On-Chip (cSoC)

Flash FPGA Fabric
- Hardware Acceleration
- Customized Pulse Width Modulation
- I/O Expansion

Higher Integration

Programmable Analog
- Voltage & Current Monitoring
- Temperature Monitoring

Flash FPGA Fabric
- Hardware Acceleration
- Customized Pulse Width Modulation
- I/O Expansion

Higher Integration

Embedded ARM® Cortex-M3
- Complex Algorithms
- System Management

Programmable Analog
- Voltage & Current Monitoring
- Temperature Monitoring

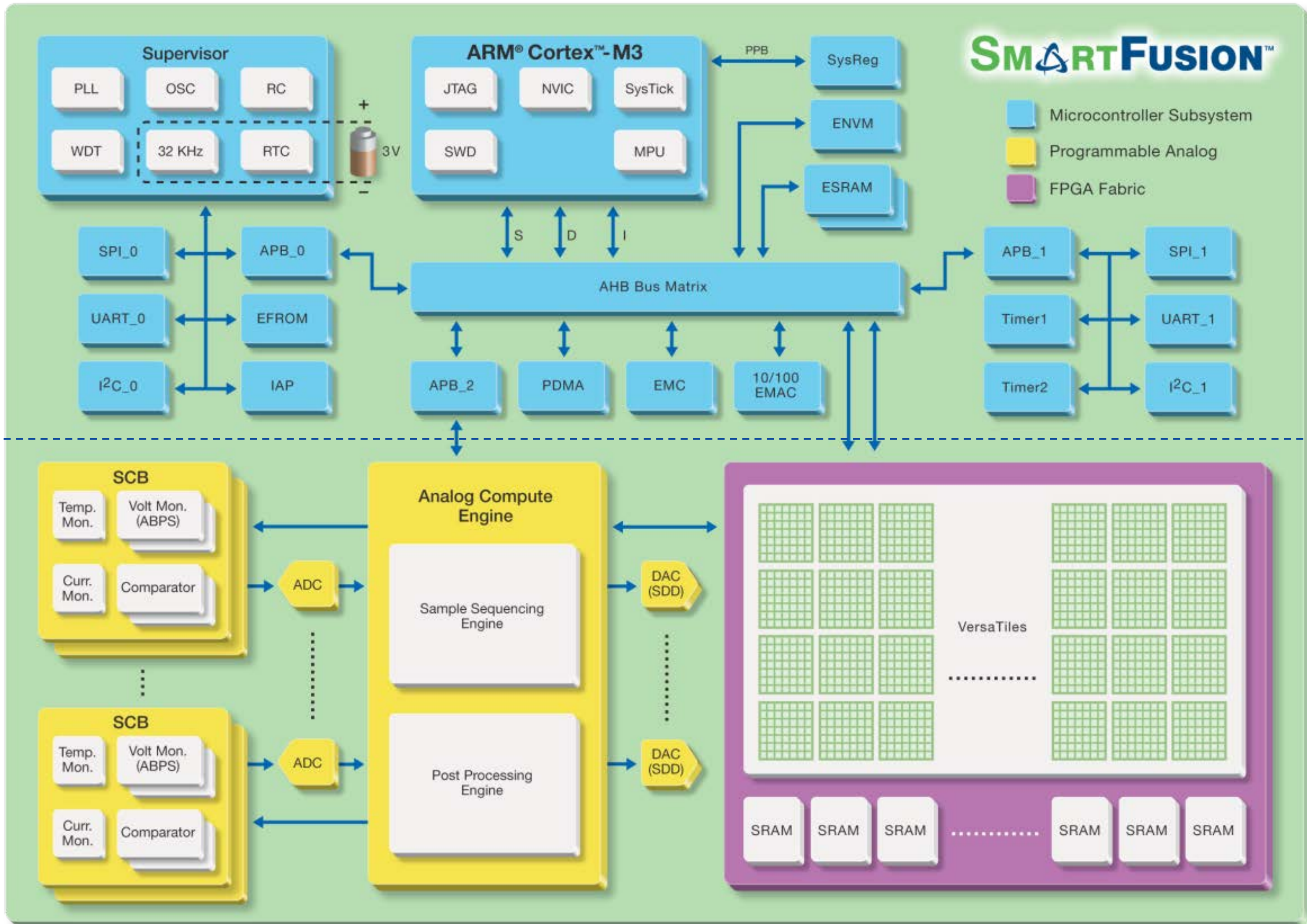
Flash FPGA Fabric
- Hardware Acceleration
- Customized Pulse Width Modulation
- I/O Expansion

Microsemi

Power Matters.

SmartFusion

Ideal platform to partition software & hardware architecture requirements



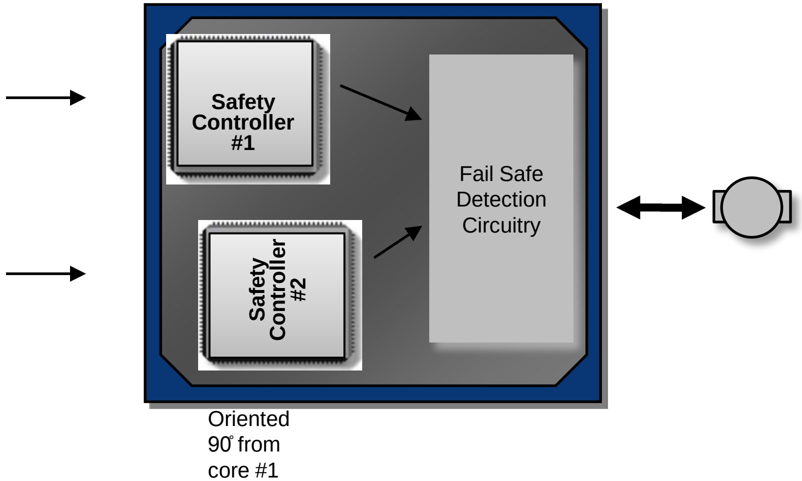
Software Platform
- System layer
- Application Layer

Hardware Platform
- Co-Processing
- Customized Drivers

Safety Implementation Comparison

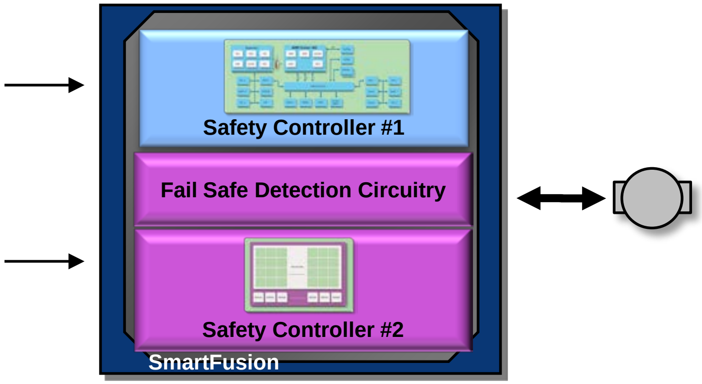
Microcontrollers

- Two core implementation
  - Redundant ***Similar*** Processes
- Same code / Algorithm
  - Potential duplication of code error
- Multiple different code / algorithms
  - Requires higher speed processors
  - Increases Power Consumption



cSoC (FPGA & MCU)

- MCU & FPGA implementation
  - Redundant ***Dissimilar*** Processes
- Same algorithm designed twice
  - H/W & S/W implemented on same die
- Multiple different code / algorithms
  - Build parallel processing elements
  - Lowers power consumption



Safety Critical Application Example #1

FPGA Logic
Programmable Analog

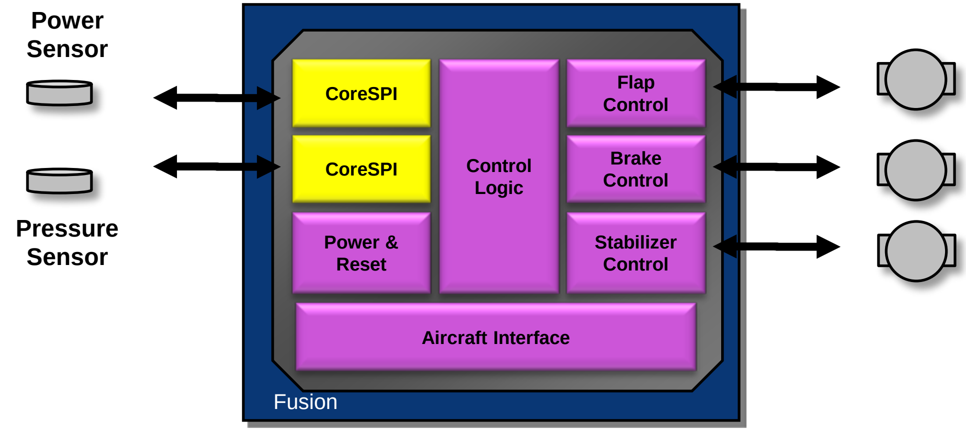
Safety Critical System Requirement

- Firm Error Immunity
- Non-Volatile & Live at Power-up

Solution

- Flight Control Actuator
  - Aircraft flaps & spoiler control
  - Trim for speed brakes and horizontal stabilizer
  - Yaw & roll trim

Deployed Example in Fusion



Flight Control Actuator Example

Safety Critical Application Example #2

Safety Critical System Requirement

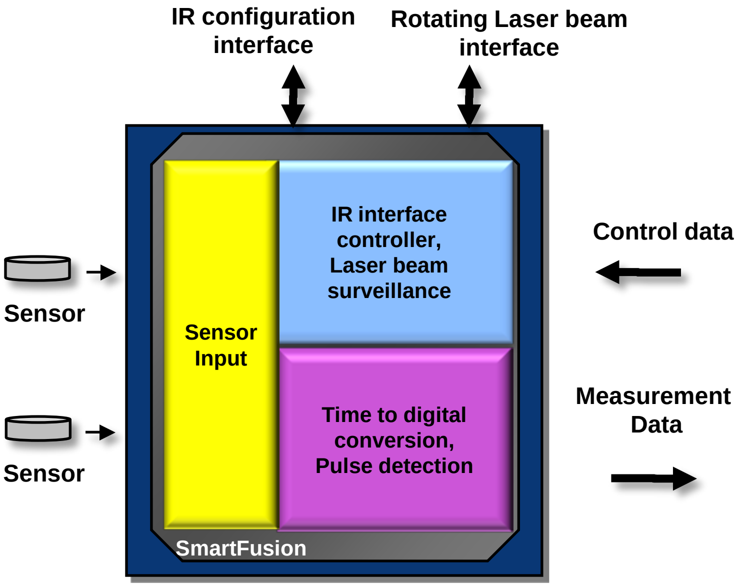
- Firm Error Immunity
- Non-Volatile & Live at Power-up
- Dissimilar processing elements

Solution

- Two processing elements
  - MCU: IR Interface & laser beam surveillance
  - FPGA: Signal processing and pulse detection

Deployed Example in SmartFusion

- Laser Safety Curtain: SIL3
- Second Highest Safety Integrity Level



Laser Safety Curtain Example

Quality Management Systems & Certification

- Quality management system
  - ISO-9001 (2002)
  - TS 16949
  - SAE / AS9100
  - QML

- Qualification and certification
  - MIL-STD-883 Class B
  - PURE:
    - European packaging Standard
    - Commercial components in rugged environments
  - QML Class Q
    - Cert for components in high reliability / military
  - AEC-Q100
    - Automotive certification for ProASIC3 devices

Resources: For more information

- Web pages
  - Safety Critical Solutions: http://www.actel.com/products/solutions/safetycritical/default.aspx
  - Quality & Reliability Data: http://www.actel.com/techdocs/qualrel/default.aspx
  - Single Event Effects: http://www.actel.com/products/solutions/ser/default.aspx
  - Operating in Extreme Environments: http://www.actel.com/products/solutions/extremeenv/default.aspx
  - Design Security: http://www.actel.com/products/solutions/security/default.aspx

- Numerous documentation

  White Paper
  - Basics on single event effects
  - Understanding SEE impact in avionics, networking applications (ground level apps)
  - Increasing Fault Tolerance by Using Diverse Design Programmable Logic Technologies

  Frequently Asked Questions
    - Neutron FAQ

Microsemi

Power Matters.

3rd Party Articles, Publications

- Military & Aerospace
  - Radiation Article
- Medical
  - FDA articles on radiation emitting products
- EE Times
  - Automotive
    - Cosmic Rays Damage Electronics
    - Alpha particles, DRAMs, SEU, Toyota Acceleration
  - General
    - Neutron Storm Swirls Around FPGA Reliability
    - Soft Errors become hard truth for logic
    - Space Particles hit logic chips
    - Reliability and Redundancy
- Others
  - Electronic Products : Battling Single Event Upsets in Programmable logic
  - Tech Focus Media : Gearing up for rain, new soft error tolerant circuits
  - EDN : Cosmic Radiation comes to ASIC and SOC Designs

Summary

- Flash Based FPGAs are an excellent high reliability platform
- History of deployments in Safety Critical Applications
  - Industrial & Medical
  - Avionics
  - Military
  - Space



- Dedication to Quality Systems
  - Quality management systems & certification
- Next Steps
  - Microsemi exploring IEC 61508 certification for FPGAs & dev S/W
    - Leveraging knowledge and techniques from other certifications for Industrial
  - Developing safety documentation package

Microsemi