
# Ax open-meeting Presentation to NRC

October 2017

# Presentation Outline

## Company & Technology Presentation

- Axetron Company
- The Ax Platform in Context
- Overview if Ax Platform architecture, and its 2 sub-architectures:
  - Distributed Safety Architecture
  - Star-based Monitoring Architecture
- Environmental Qualification
- Final comments….


# The Axetron Company

# Axetron Company Overview

## Axetron LLC

- Founded in Scottsdale, Arizona in 2013
  - Office in Scottsdale Airpark
- Founders and Key employees:
  - Steen Sorensen
    - ✓ Previous Founder and President of CS Innovations LLC (CSI)
    - ✓ Electrical Engineer with a background in Nuclear Safety Systems, RADAR, GPS and Wireless tech.
  - Sten Sogaard
    - ✓ Previous Design Manager at CSI
    - ✓ Electrical Engineer with a background in Nuclear Safety Systems, RADAR and SONAR
  - Employees/contractors are all ex-CSI
- QA program is [NQA-1] and [10CFR50AppendixB] compliant
- Main focus of Axetron:
  - Design & implementation of Nuclear Class 1E (Safety-Related) Instrumentation & Control (I&C) systems
  - The 'Ax Platform'


# The Ax Platform in Context

# Ax Platform

AXETRON

## Safety System Applications

- Ax platform is a modern safety platform designed for USNPP Class 1E safety-related applications

- Ax target applications are Plant Protection Systems:
  - Reactor Protection System (RPS) / Process Protection System (PPS) / Reactor Trip System (RTS)
  - Engineering Safety Features Actuation System (ESFAS)
  - Safe shutdown systems / Diverse Actuation systems
  - EDG sequencer controller
  - Thermocouple Core Monitoring (TCCM) / Post-Accident Monitoring (PAM) systems
  - other similar downstream systems.

- Ax platform supports standard field I/O types:
  - Input: analog current/voltage/temperature, contact inputs, etc.
  - Output: analog current/voltage, relay/SSR contact outputs, etc.

- Ax platform supports typical standard safety system functions:
  - Standard functions: Bi-stable trip, add/multiply/square-root function, lead-lag function, …
  - Application specific functions: EDG sequencer, ESF trip functions, …

# Ax Platform

## Ax Platform is an **Analog** Platform

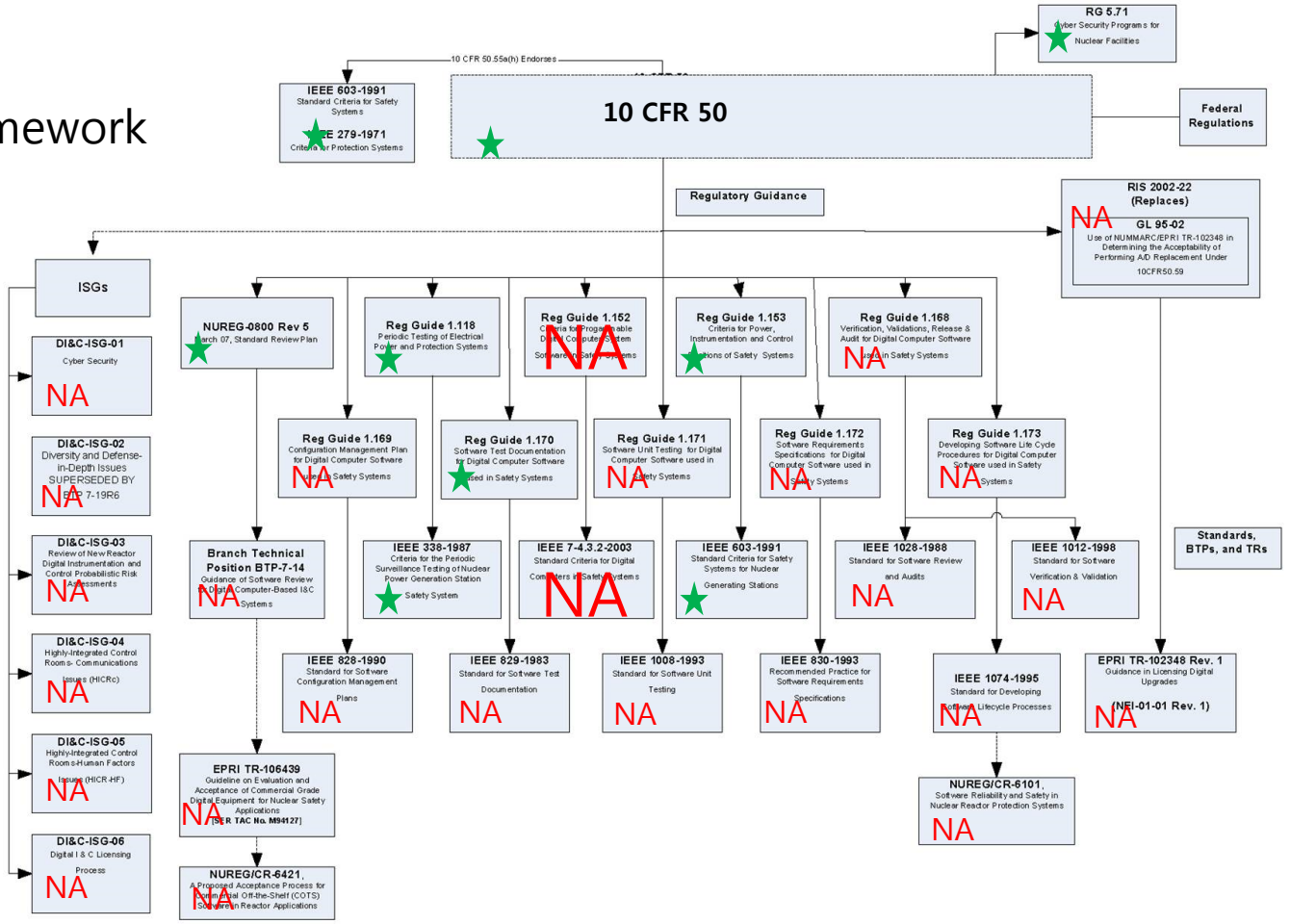
- Ax Platform is based on simple analog circuits, with discrete analog & logic components
  - This includes general-purpose components such as resistors, capacitors, inductors, BJT/FET transistors, analog switches and multiplexer, analog-to-digital converts (ADCs), digital-to-analog converts (DACs), operational amplifiers (OpAmps), as well as standard 7400 Series TTL/MOS binary/digital style devices, and Read Only Memories (ROM), whose functionality can be 100% verified and validated.
- Ax Platform is considered an analog platform, and does not rely on Programmable Digital Device (PDD)
  - No FPGAs/CPLDs/PALs (ALS, RadICS, NuPAC…)
  - No ASICs (7300ASIC, …)
  - No Microprocessors (TXS, Eagle21, CommonQ, Tricon, or other type PLC systems)
- Ax Platform does NOT fall in the Digital I&C (DI&C) licensing category!
  - The IEEE Std 603-1991 forms the basis for the Ax platform
  - Ax does NOT invoke the digital review and the software processes
    - ✓ No SRP7 Appendix 7.0-A, RG 1.152, IEEE 7-4.3.2 (or SRP7 Appendix 7.1-D), BTP7-14, BTP7-19, ...
    - ✓ No software plans (SPMP, SVVP, SQAP, SVVP, ....) or software processes!
    - ✓ No extended digital review process!
  - Ax is NOT susceptible to Software Common-Cause-Failure (CCF)!!
  - Ax is NOT susceptible to cyber security threats
  - The platform is designed specifically for installs under the 50.59 process… without a digital review!

# Ax Platform Licensing

AXETRON

No'SW' Regulatory Framework

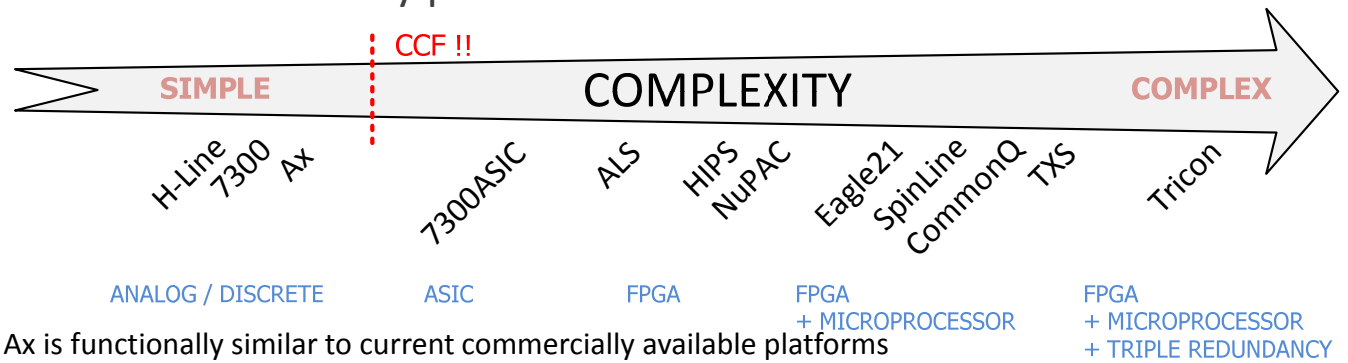
Analog★ vs. Digital[NA]




Initial drawing taken from
John Connelly, Exelon
DI&C meeting, Dec 17, 2015

# Ax Platform

## Ax Platform vs. other safety platforms




- Ax is functionally similar to current commercially available platforms
- Ax operate as an analog/discrete type platform, similar to the 7300 platform
- Ax is flexible enough to handle Process Protection Systems, and can replace any 7300 or Eagle systems
- Ax has Licensing attributes similar to the 7300
- Ax has Cyber Security similarities with the 7300
- **Ax has Monitoring capability that far exceed 7300 and Eagle21, and is on par with TXS, ALS, CommonQ**
- **Ax has Accuracy and Response time that exceed 7300, and is on par with ALS**
- **Ax has superior Environmental Qualification capabilities compared to all available platforms!**

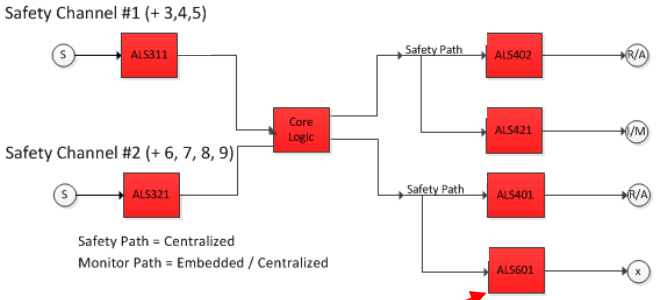
Note 1: Ax is not designed to perform highly complex algorithms (Microprocessor would be better suited!)

Note 2: Ax is not a copy (or ME-TOO) of H-Line, 7300 or other analog platforms. It is a new approach to modern analog safety platform that improves accuracy, reliability, and monitoring/diagnostics capability.

# Platform Comparison

## Safety Architecture Comparison (for none PLC architectures)

ALS

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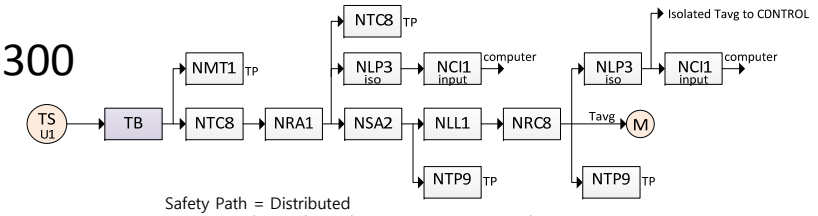
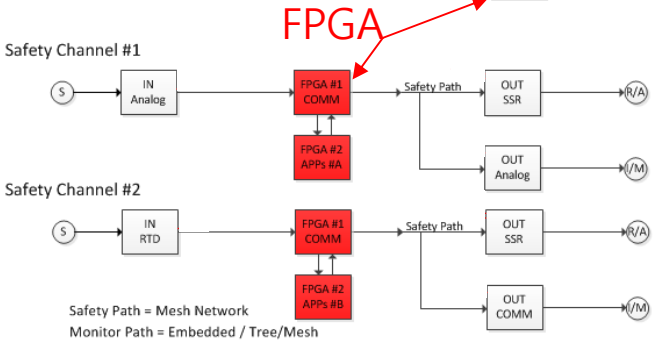
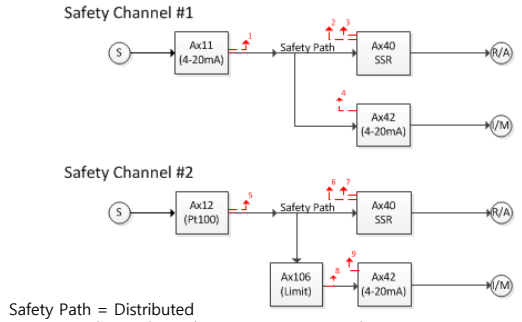



NuPAC




AxP




Note: The simplified architectures are shown for discussion & overview purposes, and does not necessarily show how actual implementation would be done.


# The Ax Platform Overview

# Ax Platform

## What is the ‘Ax Platform’

- The Base platform includes
  - AxChassis (Standard 3U 19” chassis, Compact 3U 7” chassis)
  - AxBoards (including temperature, analog and digital IO, bistable, lead-Lag, …)
  - AxTU termination units (cabinet mounted to support AxBoards, simplifies interfacing with existing systems)
  - AxPM panel mounted modules (meters/indication/calibration/setpoints)
  - AxMUX support components to facilitate monitoring and diagnostics
  - Ax auxiliary components

- Ax platform characteristics
  - Flexible:
    - ✓ The platform can be customized to any PPS application
  - Modular:
    - ✓ Cabinets can be implemented with the necessary number of Chassis
    - ✓ Chassis can be customized with the necessary boards
    - ✓ Boards can be customized to support the application requirements
  - Scalable:
    - ✓ Works well for both large (RPS) and small (PAMS) applications.
    - ✓ Many inputs/outputs versus few inputs/outputs

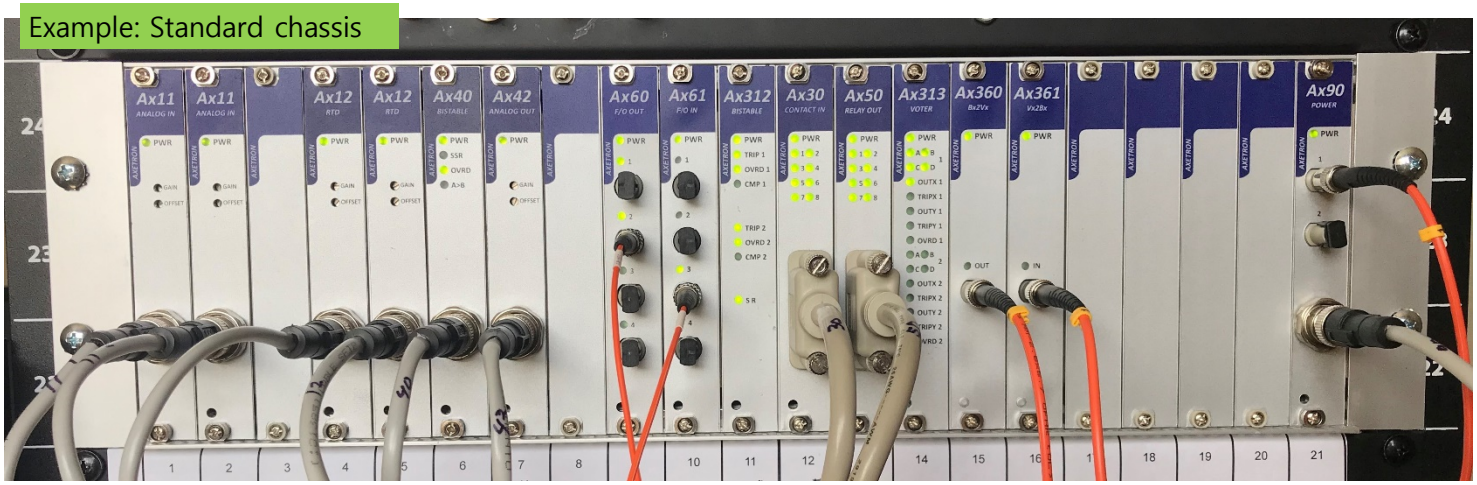
# Ax Platform

## Ax Chassis

- AxChassis types
  - Standard 3U 19” chassis (21 AxBoards)
  - Compact 3U 7” chassis (7 AxBoards)
- Standard/Dedicated BackPlane
  - No dangling wires!
- Front of boards make up the front of the Chassis
  - Connections to field or termination units

Example: Compact chassis


Example: Standard chassis



# Ax Platform

## Ax Board

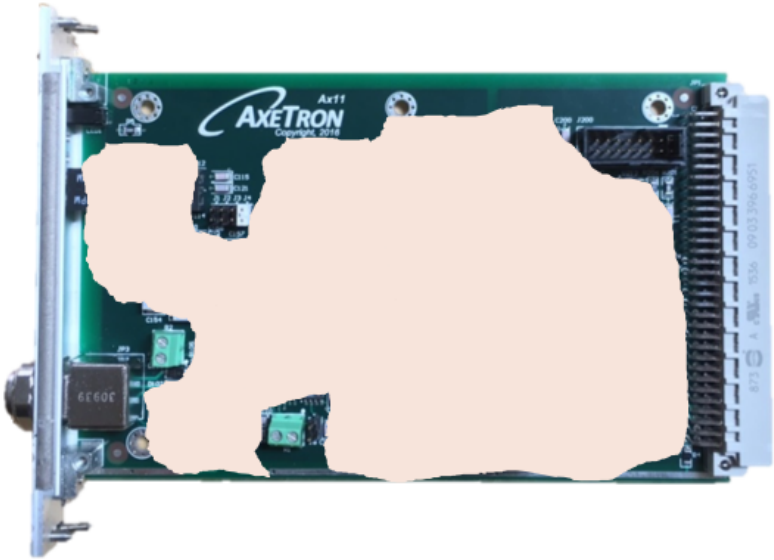
- Standard Euro size boards (approx. 5” by 7”)
  - Standard 4-6 layer PCBs with simple electronics
  - Front connections / Backplane connector

- AxBoard (off-line) Configuration
  - Filters/time delays, loop impedance, Voltage/Current mode, 3-/4-wire mode, RTD resistance range & curve, shunt resistor, trip points, limit values, etc
    - ✓ DIP switches
    - ✓ Resistors
    - ✓ ROM (OTP devices)

    Note: Configuration Work Instruction!

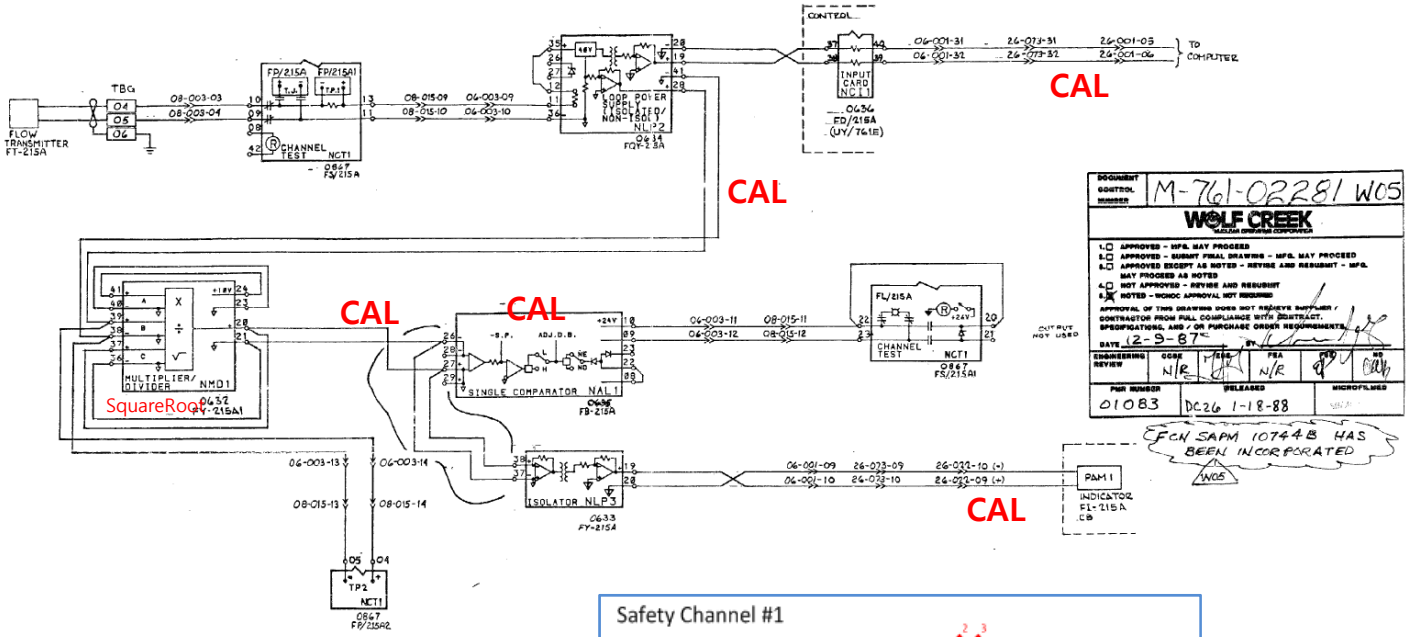
- AxBoard (on-line) Calibration
  - Calibration (of analog circuits)
    - ✓ Front-panel trimmers

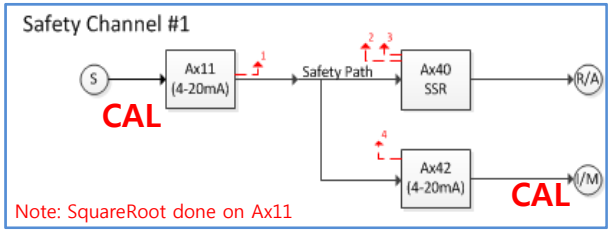
- AxBoards are simple dedicated circuits
  - Instant-on when powered
  - No (central) control unit
  - Hot-swappable

# Ax Platform

Example: Seal Injection Flow / Steam line break

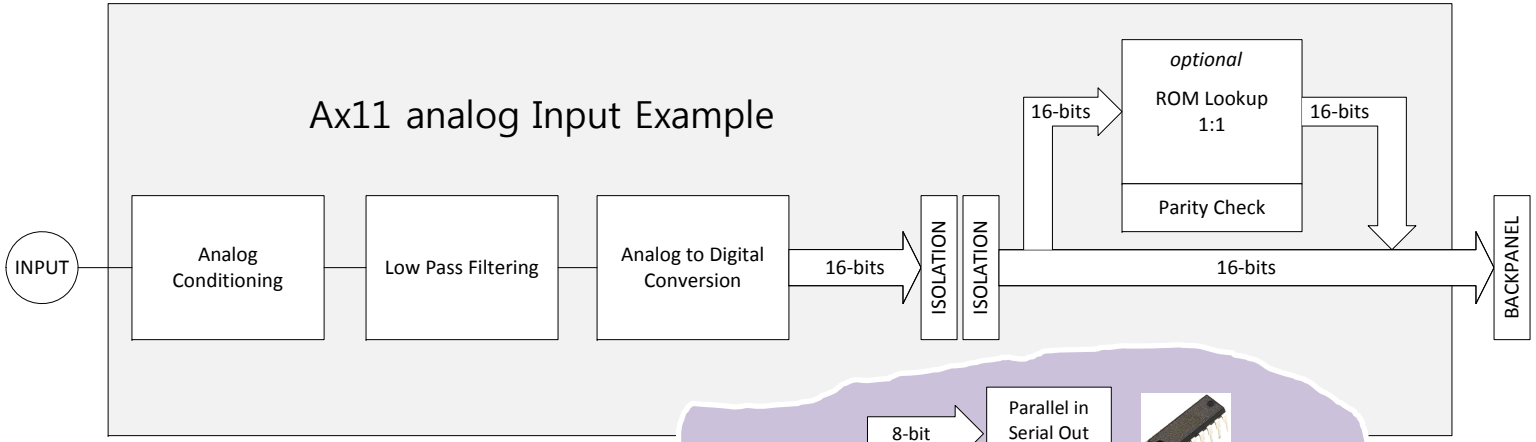


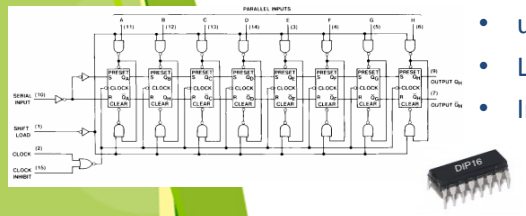
# Ax Platform

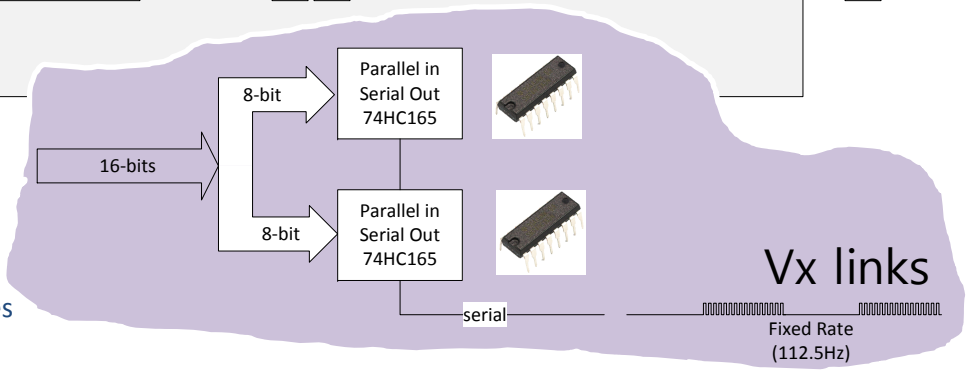
## The Vx link - Ax Board communication

- Receives analog value, conditions it and converts it to a 16-bit representation….. Then send it out serially




- Vx spec
  - 1-bit serial bus
  - used to send 16-bit values
  - Low update rate 112.5 Hz
  - Implemented with TTL devices





# Ax Platform

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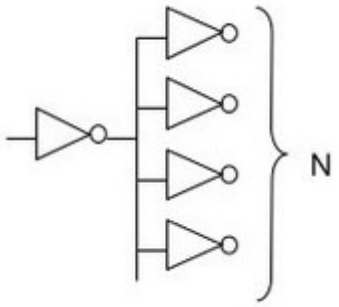
## The Vx Link

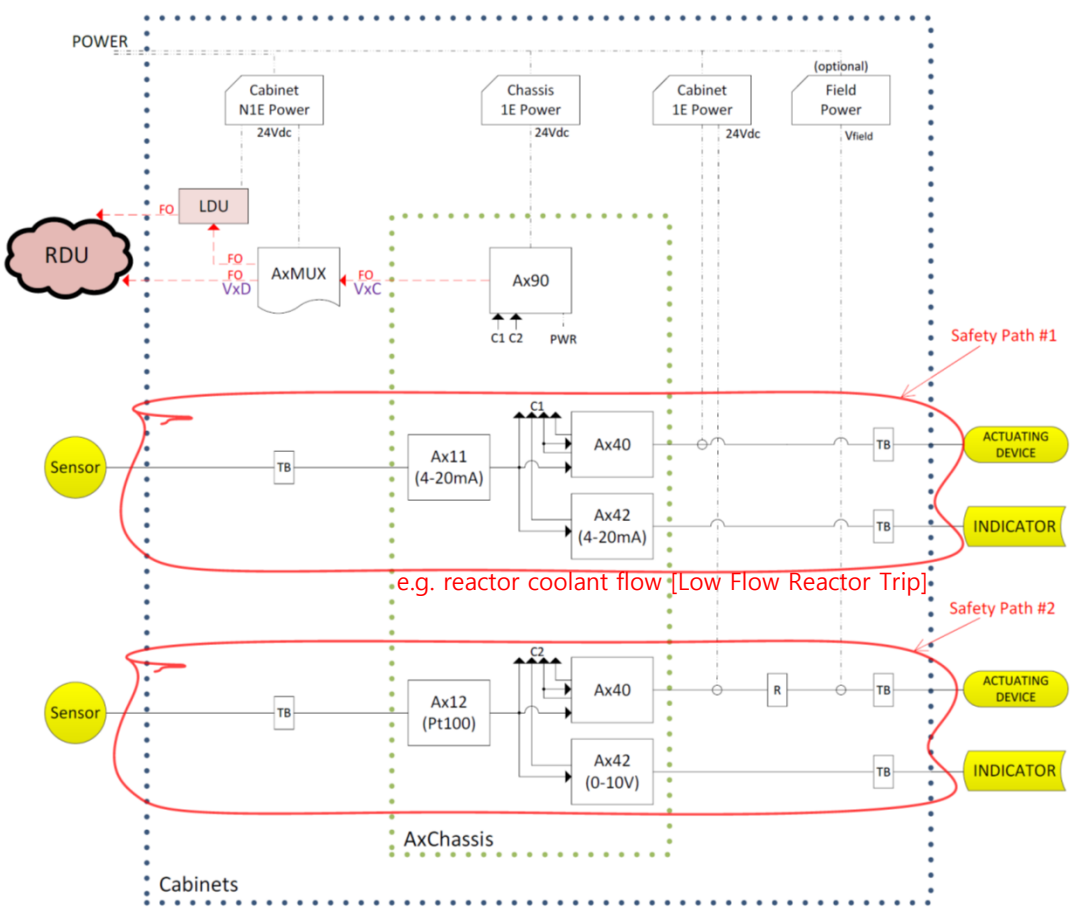
- Vx links is the Ax Platforms method of sending information
  - Similar to 7300 Westinghouse boards that uses 0-10V to send values between boards
  - The Ax Platform uses simple logic gate devices similar to what was used in 7300
- Vx link (pulses) is similar to 0-10V (analog) with notable differences:
  - Simpler
  - Accurate
  - No drift (Temp, Age, EMI effects, …)
  - Repeatable
  - 100% testable
  - Allows for direct conversion to fiber optic and back
  - No fanout or load issues (Receiving input does not affect the Vx driver)
- ONE MORE THING…..
  - The Vx link is the key to the important non-intrusive ‘Monitoring feature’



# Ax Platform Architecture

## Ax Platform Architecture

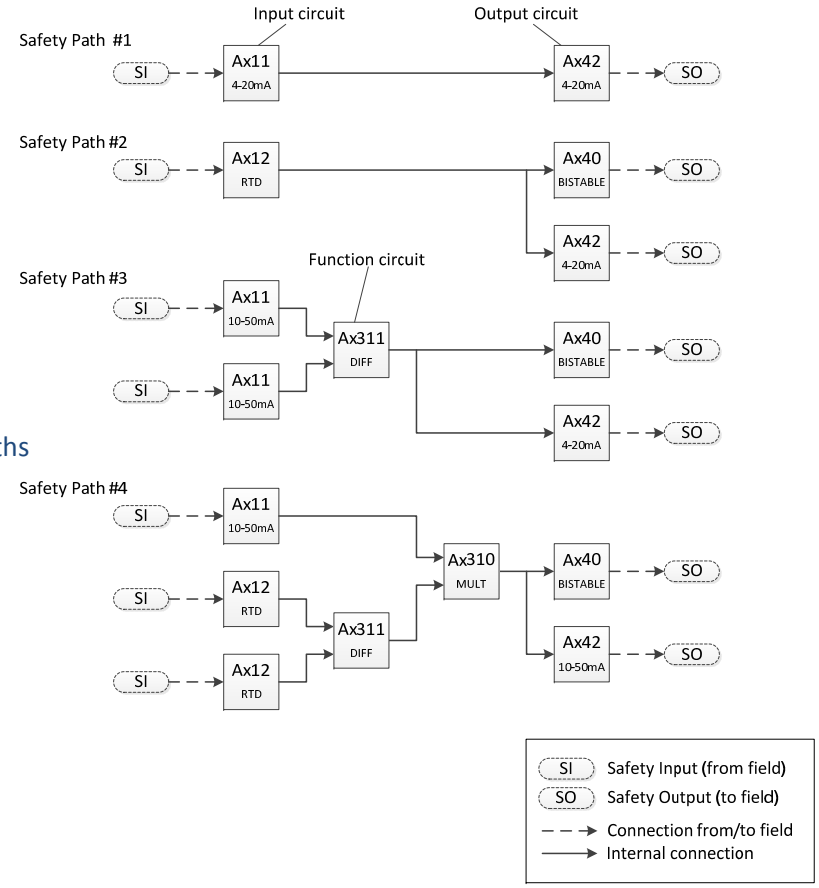
- Ax Platform has 2 sub-architectures:
  - The Distributed Safety Architecture
    - ✓ 1E (Safety function!)
  - The Star-based Monitoring Architecture
    - ✓ N1E
- Both sub-architectures are independent and unaware of each others existence!
  - In terms of operation
  - In terms of data-flow
  - In terms of purpose
- Important NOTE!!
  - If the Star-based Monitoring were removed, then the Distributed Safety Architecture would continue unaffected



# Ax Platform Architecture

## Distributed Safety Architecture

- Channelized discrete controls and indications
  - performs a predefined Safety Function
    - ✓ A trip function
    - ✓ A display/indication function
    - ✓ Both a trip and a display/indication function
- Each Safety Path :
  - is implemented with 1 or more Ax boards
  - operates independent and unaware of other safety paths
    - ✓ Do not (need to) share hard
    - ✓ Data flow is unrelated
    - ✓ Control is unrelated
    - ✓ Timing is unrelated
- Distributed…. No central processing units !
    - ✓ Contrary to FPGA/Microprocessor type platforms



# Ax Platform Architecture

## Ax Platform Monitoring … the what?

- Monitoring functions are all considered N1E
- Ax Platform is designed with modern Monitoring capabilities:
  - Support for On-line monitoring ( Information display, Diagnostics, Trending, Log, Blackbox, … )
  - Support for Off-line monitoring ( Maintenance )
- Supports Local and/or Remote Monitoring stations/displays
  - Cabinets, Aux-room, Control-room, Engineering building, …
- **Continuous Real-time** monitoring of information inside the platform
  - Measured values, Set Points, Trip decisions, Calculated information, Logic states, Status, …
- Monitoring information is an **actual** representation (i.e. true copy) of the Safety information!
  - No additional error sources, such as: calibration errors, offset error, measurement error, etc.
- Monitoring information is gathered in a **star-based**, **passive** and **non-Intrusive** manner
  - Monitoring functions cannot interfere with the Safety functions!!
  - Monitoring circuits are isolated from (and cannot interfere with) the safety path
  - Monitoring information are collected, multiplexed, transmitted, processed and displayed completely separate from the Safety circuits
- Monitoring path is **Cyber-safe**!! (No cybersecurity issues can ever occur)
- Monitoring path is **does NOT require calibration**!!

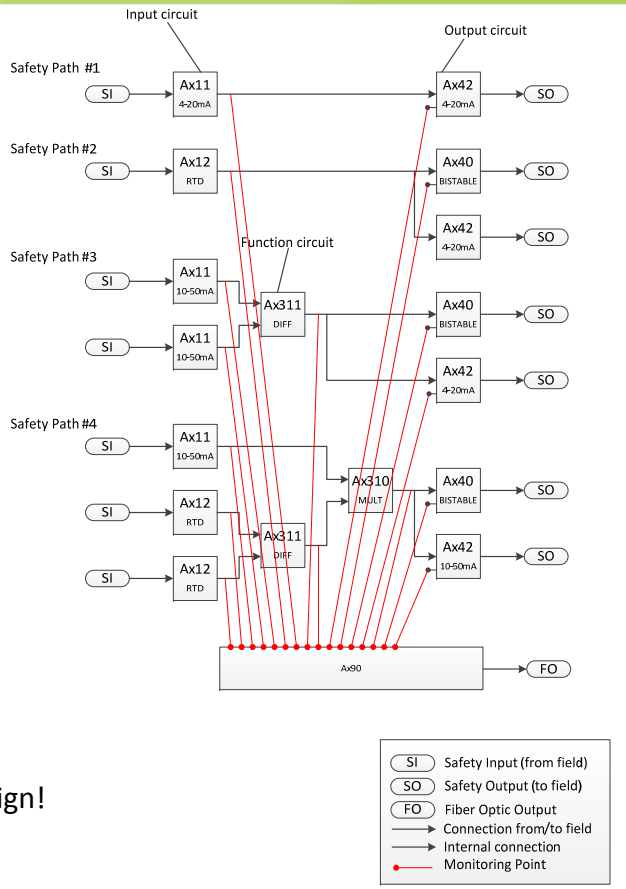
# Ax Platform Architecture

## Ax Platform Monitoring … the how?

- Star-based Monitoring Architecture

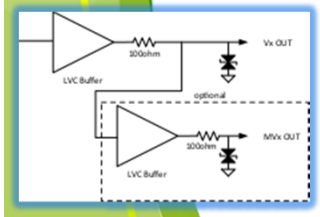
- The monitoring information flow:
  - The Vx link is generated on the Ax Board
  - The Vx link is 'sniffed' on the board by the monitring circuit
  - The 'Sniffed' Vx is wired ONE-WAY to the Ax90
  - The Ax90
    - ✓ Multiplexes a number of channels together (NO Complex devices!)
    - ✓ Send out the multiplexed VxC link on a ONE-WAY Fiber optical cable
  - The VxC is sent to AxMUX (separate rack mounted equipment)
    - ✓ Multiplex a number of channels together (Complex devices is used!!!)
    - ✓ Send out the multiplexed VxD link on a ONE-WAY Fiber optical cable

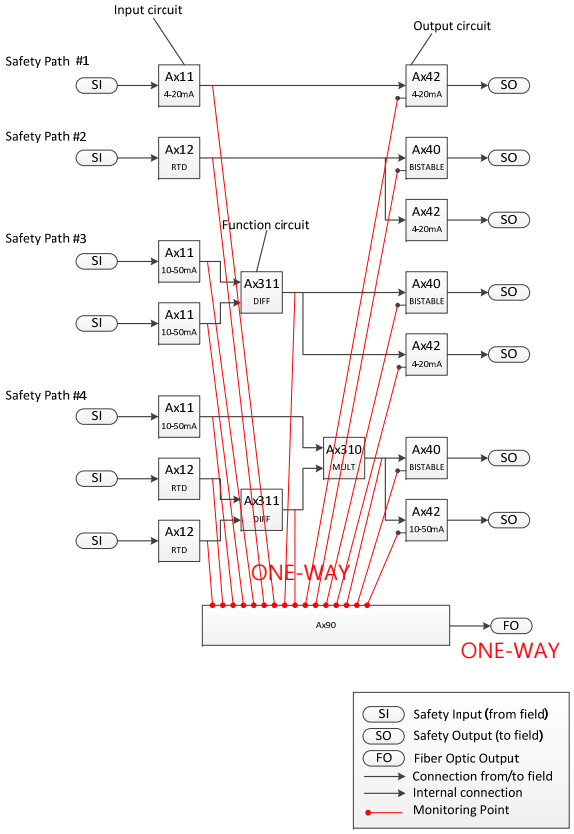
- "Safety System Functional Independence from the Non-safety Systems"
  - ✓ IEEE Std 603 Section 5.6.3 - Check!!
- Non-safety monitoring/control workstations
- Electrical Isolation and separation and independence are provided by the design!

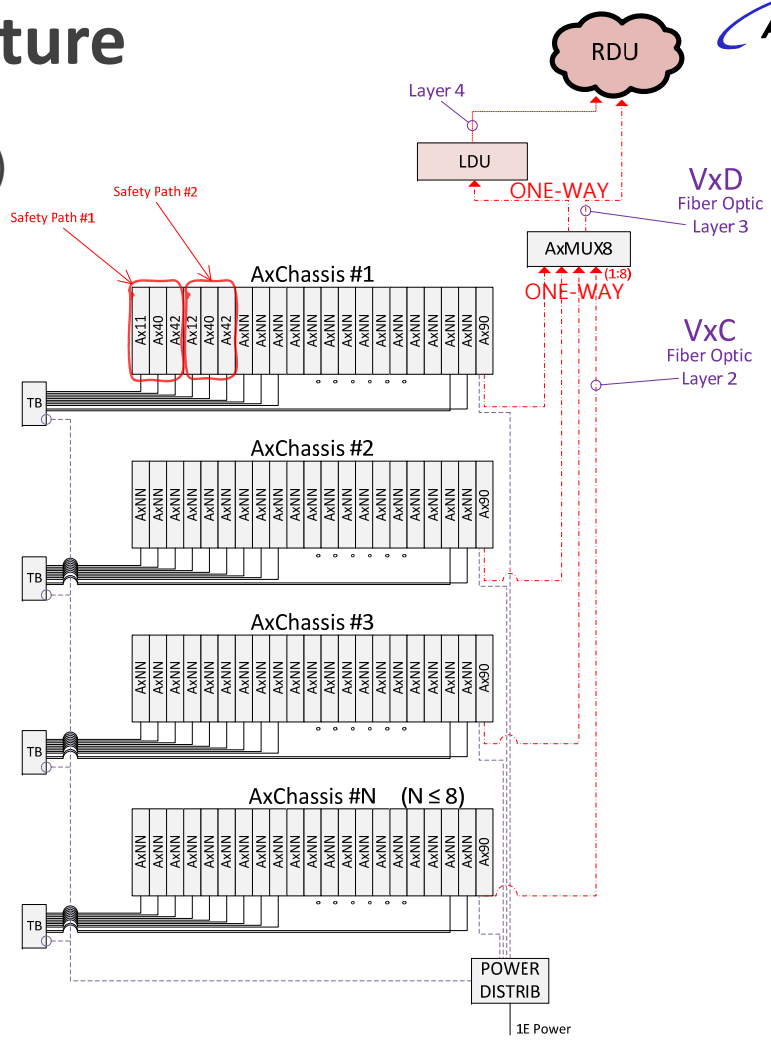


# Ax Platform Architecture

## Ax Monitoring Example (Division)

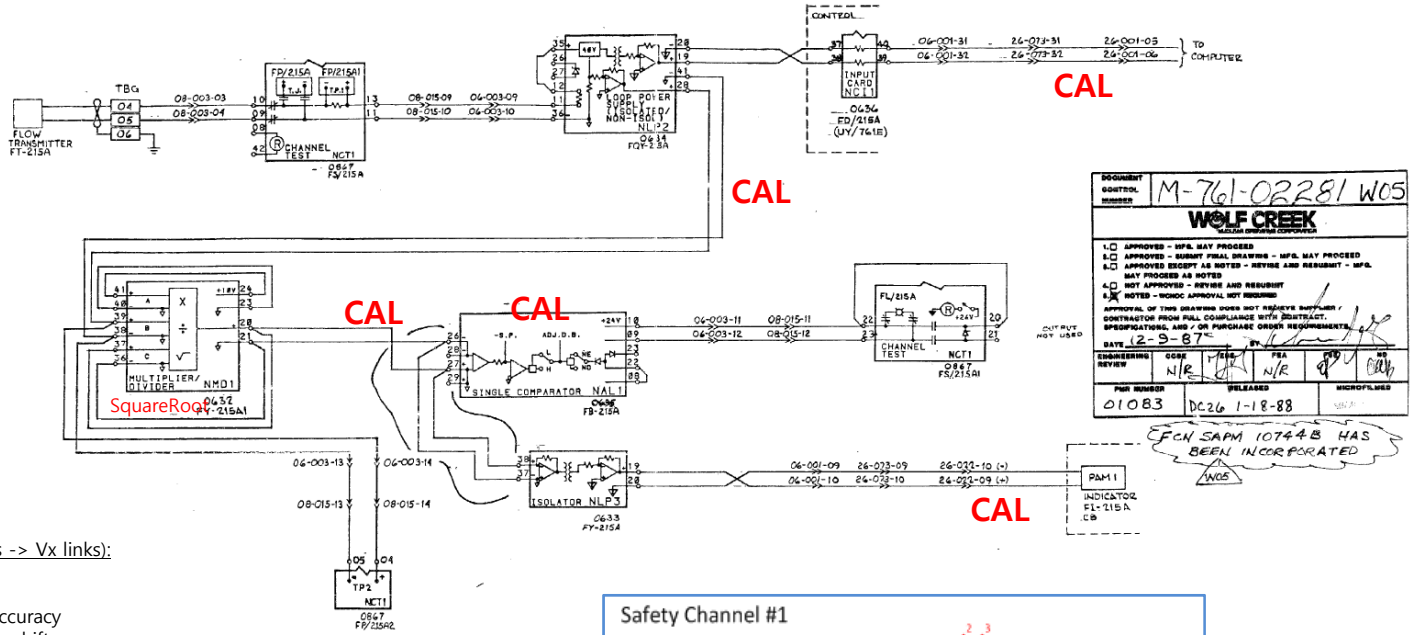


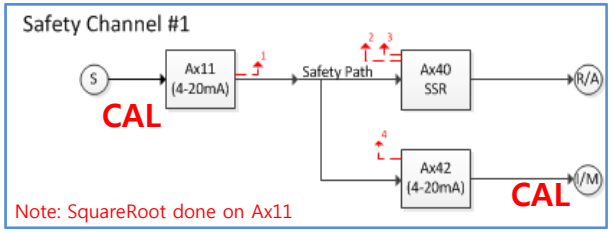
# Ax Platform Architecture

## Example: Seal Injection Flow / Steam line break




Recap (0-5V links -> Vx links):

- ✓ Safety path:
  - Accuracy
  - no drift
  - no calibration
- ✓ Monitoring:
  - ✓ simpler
  - ✓ accurate
  - ✓ timely
  - ✓ no calibration is needed
  - ✓ easier trouble shooting



# Ax Platform Architecture

## Ax Platform Display Capability


- Display functions are all considered 1E
- Continuous Real-time display of information
  - Measured or calculated values (temperature, power, pressure, …)
- Ax Platform is designed with support for old-style and modern displays:
  - Ax42 (analog) can drive any vintage type display using 20mA / 50mA / 10V / etc
  - Ax60 (binary) can drive 'modern' 7segment displays
- Ax60 based Display information has lots of advantages:
  - Actual representation of the Safety information!
    - ✓ No additional error sources, such as: calibration errors, offset error, measurement error, etc.
  - Display information is gathered in a passive and non-Intrusive manner
    - ✓ Display functions does interfere with other Safety functions
    - ✓ Display circuits are isolated from (and cannot interfere with) the safety path
  - Display circuits do not require calibration or surveillance testing!!
  - Ax60 is connected to the Display using Fiber Optic cable (i.e. can be made isolated and 1E/N1E!)

# Ax Platform

## Ax Platform Performance

- Ax Platform performance is similar (or better) than existing platforms
  - Response time is commensurate with requirements of USNPP protection systems.
  - Analog accuracy has outstanding performance characteristics
  - Precise and easy calibration (stable, accurate and has excellent long term stability, ...)

| Board Type | Target Accuracy | Measured Accuracy | Temperature Drift Effect |
|---|---|---|---|
| Analog Input | 0.1% | 0.025% | 10ppm/°C |
| Analog Output | 0.1% | 0.025% | 10ppm/°C |
| Bistable | 0.005% | 0.005% | 0ppm/°C |
| Lead-Lag Time Constant | 3% | 1% | 0ppm/°C |

Note: 10ppm/°C is equivalent to 0.03% over 30°C (54°F)

# Ax Platform

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## ROM (Read Only Memories)

- Can implement any single argument transfer function:
  - Linearization, Limiter functions, Non-linear 1 operand functions, Unit conversion, …
  - I.e. Square root, RTD Linearization curves (R→Celcius), limit high/low, …
- The Ax Platform uses One Time Programmable Read Only Memories (OTP ROM)
  - OTP ROM – An old and well proven ROM technology.
  - ROM cannot be reprogrammed. They must be replaced.
- ROM advantages over resistor banks or complex analog circuits (e.g. analog square-root or RTD Linearization)
  - Precise
  - No Drift (temperature, age, EMI)
  - Integrity (Can and will "never" change, and is off/on-line testable)
- Simple operation:
  - Input: Input data (16bit) used as the address into a Lookup Table
  - Output: Data located and that particular address
- Testing: *Note: There are no memory/registers in the OTP ROM
  - Off-line testing: 16-bit input with 16-bit output (acts combinatorial). Can be 100% tested and verified!
  - On-line testing: Online parity checking ensures no latent ROM errors exists.
    - ✓ Monitoring will see a ROM failure immediately

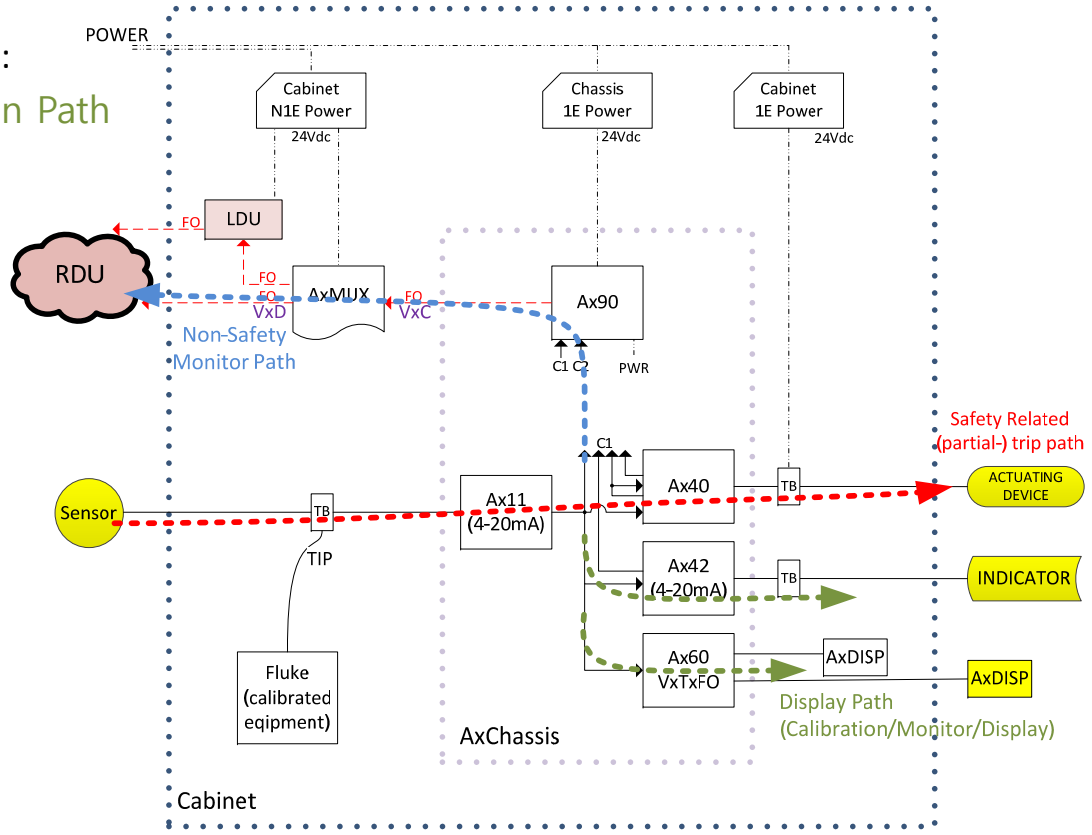
# Ax Platform

## Calibration

- 2 ways of performing calibration:
  - Direct Display/Indication Path
  - Monitoring Path

Note: simple calibration using:

- calibrators
- work instructions




# Environmental Qualification

# Environmental Qualification

## EQ Overview

- Qualification standards
  - Environment Qualification (Mild) – IEEE-323
  - Seismic Qualification – IEEE-344 / RG 1.100
  - Separation – IEEE-384 / RG 1.75
  - EMI/RFI/Surge – TR-102323 / **RG 1.180**

- 'OPEN CABINET' qualification!
  - No credit for cabinet protection/shielding
  - Performance would be even better within a closed cabinet
  - This is what retrofit customers need…. Customers can keep existing cabinets!!

- AxP is fully Operational in the "Normal" temperature range [10°C to 60°C]
  - The Test Plan has multiple temperature tests that provide extend testing to 75°C

- The Ax Platform outperforms <u>all</u> existing Safety platforms when it comes to EMI/RFI/Surge/Seismic properties!!!
  - ✓ Which is exceptional for an analog/discrete platform !!

# Environmental Qualification

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EQ Test Plan (RG 1.180 rev 1 related tests)  *awaiting 1.180 rev 2!

| | EMC Type Test | Details | Performed in Pre-EQ |
|---|---|---|---|
| Required per [RG1.180] | Conducted Emissions Low Frequency | [MIL-STD-461E], CE101 | YES |
| | Conducted Emissions High Frequency | [MIL-STD-461E], CE102 | YES |
| | Radiated Emissions Magnetic Field | [MIL-STD-461E], RE101 | YES [1] |
| | Radiated Emissions Electric Field | [MIL-STD-461E], RE102 | YES [1] |
| | Radiated Susceptibility Electrical Field | [MIL-STD-461E], RS103 | NO [2] |
| | Electrical Fast Transient (EFT) | [IEC/EN 61000-4-4] | YES |
| | Surge (Combination Wave) | [IEC/EN 61000-4-5] | YES |
| | Conducted Immunity High Frequency | [IEC/EN 61000-4-6] | YES |
| | Surge (Ring Wave) | [IEC/EN 61000-4-12] | YES |
| | Conducted Immunity Low Frequency | [IEC/EN 61000-4-13] | NO [3] |
| | Conducted Immunity Low Frequency | [IEC/EN 61000-4-16] | YES |
| | Radiated Immunity Power Frequency | [IEC/EN 61000-4-8] | NO [4] |
| | Radiated Immunity Magnetic Field | [IEC/EN 61000-4-9] | NO [4] |
| | Radiated Immunity Magnetic Oscillatory | [IEC/EN 61000-4-10] | NO [4] |
| | Radiated Immunity Radio Frequency | [IEC/EN 61000-4-3] | YES [5] |
| Optional | Electrostatic Discharge | [IEC/EN 61000-4-2] | YES |
| | Power Supply Immunity | [IEC/EN 61000-4-11] | NO |
| | Conducted Emissions | [EN 55011] | NO |
| | Radiated Emissions | [EN 55011] | NO |

# Environmental Qualification

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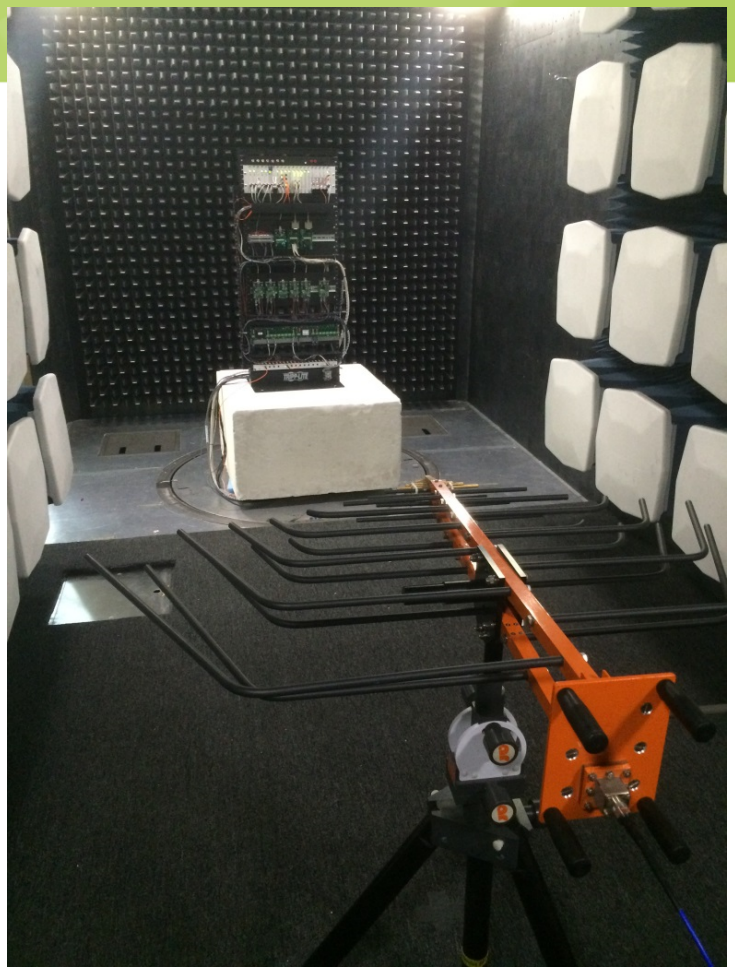
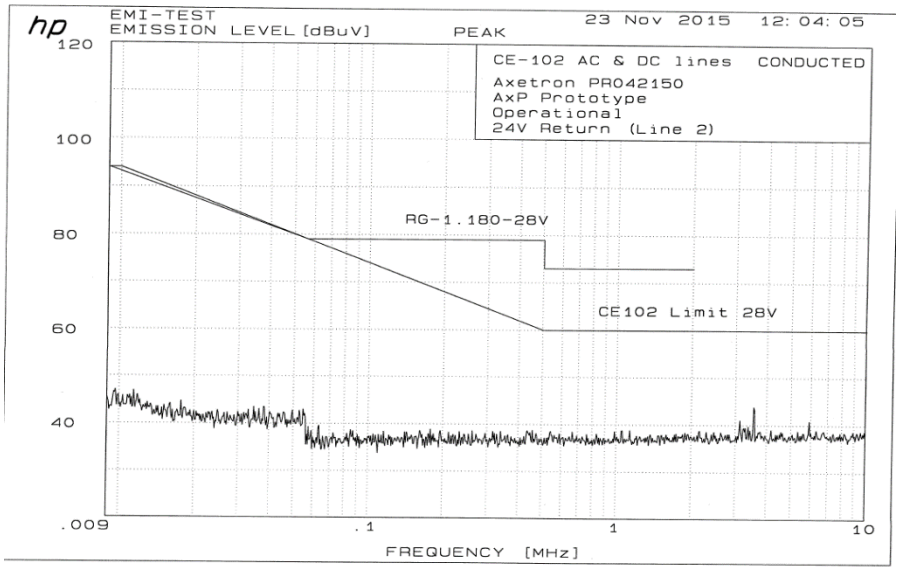
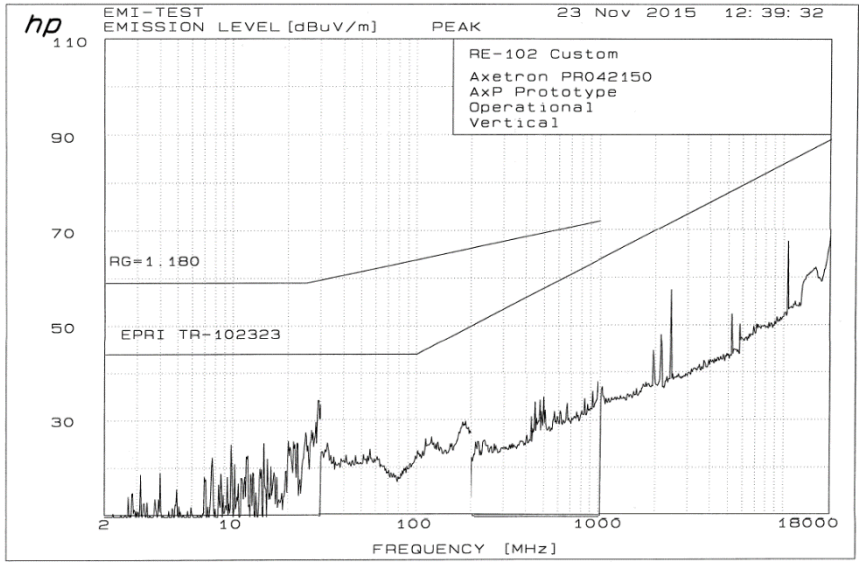
Conducted & Radiated Susceptibility



# Environmental Qualification

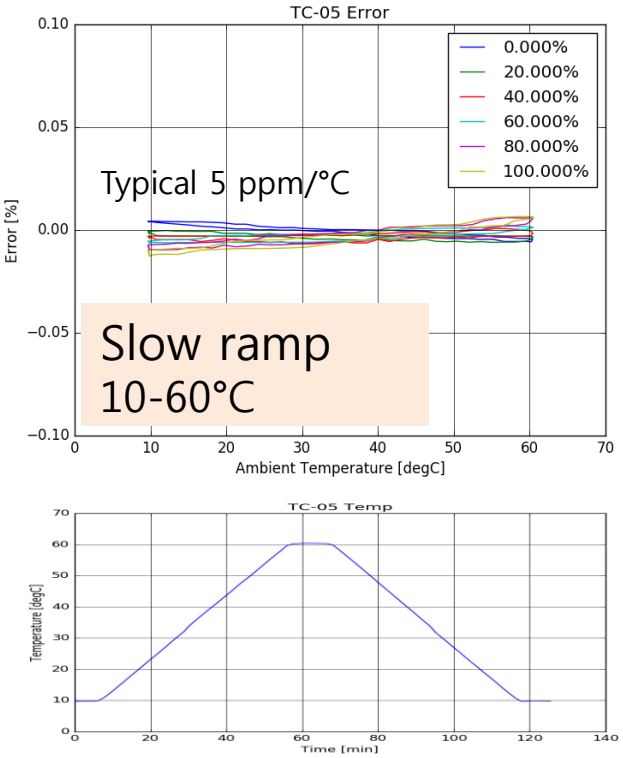
Example MIL-STD-461E : CE-102 & RE-102

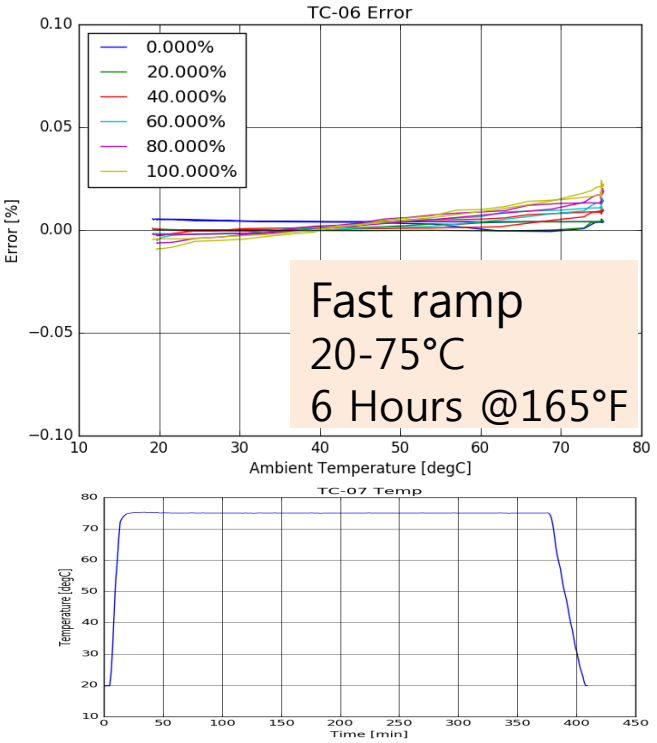


# Environmental Qualification

Example: Ax11 [0-20mA] test in temperature chamber Ref: [TR-00289]




Final comments….

# Ax Platform

AXETRON

## Final comments….

- Ax is a modern analog platform with outstanding performance characteristics
- Maintains existing simplicity of safety-systems
  - “How many microprocessors does it take to turn on a lightbulb?”
  - Easy configuration, calibration,
- Safety system performance and accuracy on par with new digital systems
- Modern Monitoring capability is built-in
  - Monitoring truly passive, non-Intrusive, isolated and independent from the Safety circuits!
- No programmable or complex devices (PDDs)
  - Not subject to Software Common Cause Faults
  - Not subject to Cyber Security threats
- Ax systems should be installed using the 50.59 process

# Ax Platform

## Final comments….

- Provide a clean licensing strategy
  - Meet the applicable requirements establish the NRC for I&C systems:
    - ✓ 10 CFR Part 50
    - ✓ 10 CFR Part 52
    - ✓ 10 CFR Part 50 Appendix A General Design Criteria (GDC)
    - ✓ IEEE Std 603-1991, “IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations,” along with the correction sheet dated January 30, 1995
    - ✓ IEEE Std 279-1971, “Criteria for Protection Systems for Nuclear Power Generating Stations”
  - Conformance to
    - ✓ regulatory requirements (RG)
    - ✓ branch technical positions (BTP)
    - ✓ Interim Staff Guidance (ISG)
  - Clean Enviomental Qualification (Seismic, Temperature, EMI/RFI, Surge, ...)
  - Developed under the Axetron QA program [NQA-1] / [10CFR50AppB].

- An Ax Platform review does not invoke:
  - RG 1.152, IEEE 7-4.3.2, BTP7-14, BTP7-19, ....
  - SRP Appendix 7.0-A - Review Process for Digital Instrumentation and Control Systems
  - SRP Appendix 7.1-D - Guidance for Evaluation of the Application of IEEE Std 7-4.3.2


# Backup slides

# Axetron Company Overview

## Brief summary of CS Innovations (a Westinghouse company)

- Founded in Scottsdale, Arizona in 2005
  - Initial project with Wolf Creek on MSFIS project
  - Sold to Westinghouse Electric Company in 2009
- Focused on design, development, test & qualification of Class 1E safety systems
  - Specific focus on Digital design with **FPGA** & **Microprocessors**
- Key CSI technologies:
  - Advanced Logic System (ALS)
    - ✓ 1st (and only) FPGA-based platform to be approved by NRC (2009)
    - ✓ Delivered MSFIS and TCCM at Wolf Creek
    - ✓ Delivered RPS upgrade to Diablo Canyon (ALS/Tricon hybrid)
    - ✓ Delivered DAS to Westinghouse AP1000 (China/US)
  - Component Interface Module (CIM)
    - ✓ FPGA-based CIM module that combine 1E/N1E priority and actuation functions
    - ✓ Delivered CIM to Westinghouse AP1000 (China/US)

# Process Protection Systems - Background

AXETRON

## Analog / Discrete based systems

Disadvantages :

- Ageing (error-prone and stability issues)
- Obsolescence (spare parts, qualified personnel, …)
- Calibration is time-consuming
  - Multiple calibration points thru the analog chain
- Surveillance test (amount and frequency).
- Troubleshooting and repair:
  - Cumbersome, lengthy, and often difficult!
- Lack effective monitoring capability
  - Analog monitoring add error sources and delays
  - Limited trending available
  - Limited post-trip information
- Upgrades & modifications:
  - Limited flexibility, lack of expansion space etc.
- Accuracy (good enough!)
  - Errors accumulate thru the analog chain
  - Complex math functions add extra error sources
  - Temperature & Seismic sensitive

Advantages :

- Systems are simple!! (KISS)
  - Simple to work with, to understand, to replace
  - Systems are testable
  - System behavior is predictable
- Configuration control is simple
  - Configuration Procedures with jumper settings
  - Test Procedures with manual test steps
- Licensing is reasonable!
  - 10CFR50AppendixB
  - NRC Standard Review Plan NUREG0800 Chapter7
  - IEEE 603-1991
  - **No** RG1.152, IEEE7-4.3.2, BTP7-14, BTP7-19, …

# Process Protection Systems - Background

AXETRON

## Microprocessor/FPGA/ASIC based systems

Disadvantages :

- Licensing, Licensing, Licensing & Licensing!
  - Common Cause Failures → IEEE 7-4.3.2 → ~~50.59~~
- Significant additional effort and uncertainty!
  - Significant Design, TEST, EQ effort
  - Huge IVV, CM, QA, PM effort
  - Huge licensing effort
- Co$$$t
  - Large teams are needed…. for longer!
    - ✓ Substantial PM, QA, CM organization
    - ✓ Design team A & Design team B
    - ✓ Substantial IVV team
    - ✓ Additional licensing cost
- Potential need Diverse Actuation system
  - Dedicated DAS
  - Additional hardware:
  - ALS-A & ALS-B & Aux

Advantages :

- 'State of the Art' performance!!
  - Accuracy
  - Response time
  - Flexibility
    - ✓ Modular system design
    - ✓ Complex functions implemented in Software
  - Stability (filters, calculations, setpoints, …)
    - ✓ No drift due to Temperature or aging.
- Typical systems include: (90% useful)
  - Automatic surveillance
  - (sometimes) Self-calibration
  - (partly) Self-diagnostics
  - Monitoring capability
    - ✓ Run-time monitoring (display, trending, log)
    - ✓ Off-line monitoring (maintenance)

# Platform Comparison

AXETRON

## Comparison – Safety Architecture

| | 7300 | Ax | ALS | NuPAC | Eagle/CommonQ |
|---|---|---|---|---|---|
| Topology | Distributed | Distributed | Central | Mesh-Mix-Daisy | Central |
| Circuits | Analog / TTL | Analog / CMOS | Digital | Digital | Digital |
| Complexity | Discrete components | Discrete components | FPGA | Complex FPGA | Microprocessor + Multiple FPGA's |
| Software | - | - | FPGA tools (SW) | FPGA tools (SW) | FPGA tools (SW)<br>Software tools (SW)<br>Firmware (SW) |
| Inter-board communication | Analog driver ±10V (OpAmp) | One Way Link<br>0-5V (CMOS gate) | Dual Bi-direction complex serial bus w. Req/Ack<br>FPGA-2-FPGA | Complex multi-scheme protocol communication<br>FPGA-2-FPGA | Parallel data bus w. Req/Ack |
| Cyber security | Safe<br>(Nothing to attack!) | Safe<br>(Nothing to attack!) | Development process is not safe.<br>Generally deemed susceptible to a wide range of cyber attacks.<br>Significant review! | Development process is not safe.<br>Generally deemed susceptible to a wide range of cyber attacks.<br>Significant review! | Development process is not safe.<br>Generally deemed susceptible to a wide range of cyber attacks.<br>Significant review! |
| Redundancy | None | None | None | None | None |

# Platform Comparison

AXETRON

## Comparison – Monitoring Architecture

| | 7300 | Ax | ALS | NuPAC | Eagle/CommonQ |
|---|---|---|---|---|---|
| Topology | Star-network (Monitoring NOT in Safety Path) | Star-network (Monitoring NOT in Safety Path) | Central FPGA collects information (in Safety Path) | Central FPGAs collects info and communicates in daisy-chain (in Safety Path) | Central Microprocessor collects information |
| Circuit | Analog isolated | FO isolated | Non-isolated Central data bus | Non-isolated Central data bus | Non-isolated Central data bus |
| Effect on the Safety Path | Virtually none | None | Yes - Safety data and monitoring information is mixed | Yes - Safety data and monitoring information is mixed | Yes - Safety data and monitoring information is mixed |
| Accuracy | Inaccurate & Delayed (Isolator and separate ADC chain) | Full accuracy | Full accuracy | Full accuracy | Full accuracy |
| Automated on-board BIST | None | None | Limited boards implement low-level self-test circuit. | Limited boards implement low-level self-test circuit. | Practically none |
| Application level BIST | None | LDU on isolated side monitor the information and can issue alarm. | LDU on isolated side monitor the information and can issue alarm. | LDU on isolated side monitor the information and can issue alarm. | LDU on isolated side monitor the information and can issue alarm +CommonQ: Test computer perform tests |

# Platform Comparison

AXETRON

## Comparison – Build-in Self-Test

| | 7300 | Ax | ALS | NuPAC | Eagle / CommonQ |
|---|---|---|---|---|---|
| Automated on-board BIST | None | Practically none. (only wire/coil break detection, but its not a part of the safety path) | Some features. That only cover certain rudimentary features. Boards implement limited low-level self-test circuit. | Some features. That only cover certain rudimentary features. Boards implement limited low-level self-test circuit | Some features. That only cover certain rudimentary features. Boards implement limited low-level self-test circuit |
| LDU level BIST | None | LDU on isolated side monitor the information and can issue alarm. | LDU on isolated side monitor the information and can issue alarm. | LDU on isolated side monitor the information and can issue alarm. | LDU on isolated side monitor the information and can issue alarm +CommonQ: Test computer can perform tests |