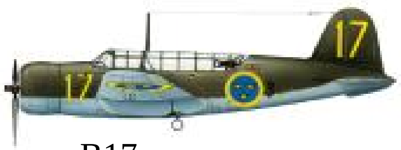
SAAB

AERONAUTICS
Dependable Aircraft Systems

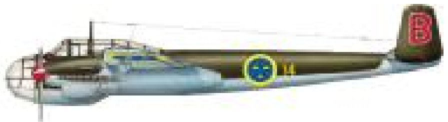
Lars Holmlund

October 15, 2012

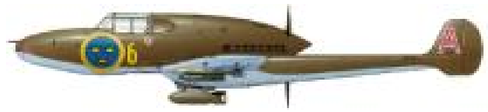
75 years of experience



B17
1940 (322)



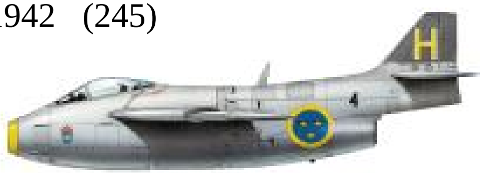
B18
1942 (245)



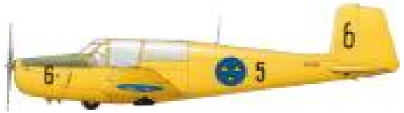
J21
1944 (229)

J21R
1947 (60)

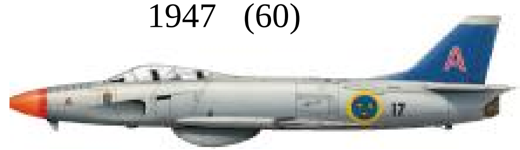
Saab 90 Scandia
1948 (18)



J29
1948 (664)



Saab 91 Safir
1945 (323)



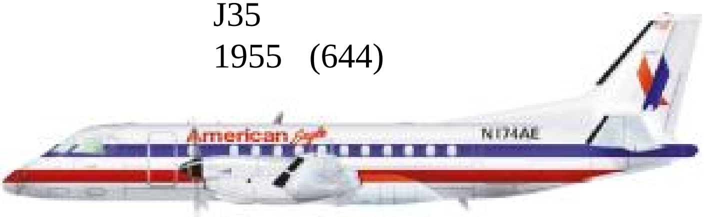
A32
1952 (447)

J35
1955 (644)

105 (SK60)
1963 (150)

AJ/JA37
1967 (329)

Supporter
1967 (105)



Saab 340
1983 (459)

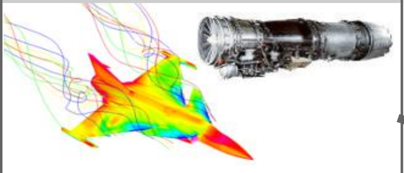
JAS39 Gripen
1988 (234)

Saab 2000
1992 (63)

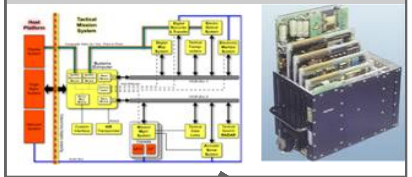
AERONAUTICS TECHNOLOGY AND COMPETENCE

Engineering Methods & Tools

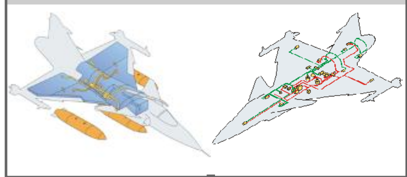
Aeronautical Engineering



Airborne & Gd. Based Computer Systems



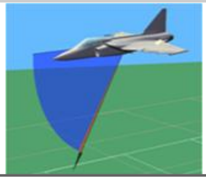
Vehicle Systems



Human-Machine Interaction

Simulators and Training

Flight Test and Verification



SYSTEMS INTEGRATION

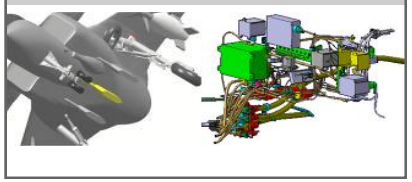
- Overall Design and Architecture
- Survivability
- Systems Safety and Reliability
- ILS, Availability and Maintainability

Tactical System

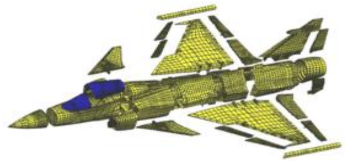
Maintenance Systems

Production Systems

Structural and Systems Installation Design



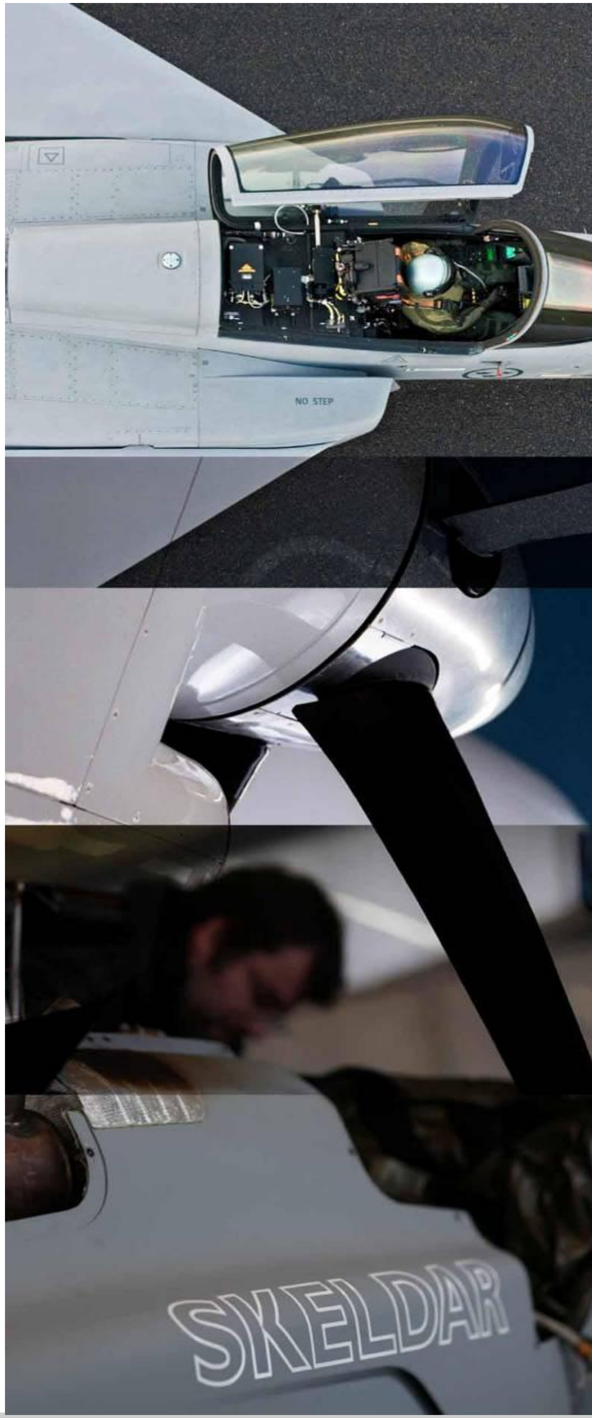
Structural Technology



Weapons Integration

AERONAUTICS PRODUCT AREAS

- The Gripen Fighter System
- Commercial Aeronautics
- Unmanned Aerial Systems (UAS)
- Airborne Mission Systems
- Training & Support systems
- Future Air Systems
- Saab 340/2000 and derivates
- SK 60, Trainer



Gripen in South Africa

Unnamed Aerial Vehicles

Ongoing projects

SKELDAR

NEURON

(www.youtube.com/saabgroup)

NEURON

- A common European UCAV –
  Unmanned Combat Aerial Vehicle
- Intended for evaluation of future cutting-edge technology, for example;
  - Advanced avionics
  - Autonomy
  - Stealth technology
  - Adaptation to network based defence

SKELDAR

- Short to medium-range UAV system consisting of two air vehicles and a mobile UAS control station.
- Take-off and landing without any field preparations or extra equipment.
- Modular design allowing different configurations and several options.
  - Mine/IED detection
  - Surveillance and reconnaissance
  - Battle damage assessment
  - Autonomous tracking of vehicles or vessels
  - Aerial photography and mapping
  - Area patrol
  - Communication

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The Gripen Flight Control System

A fault tolerant computer system

Lars Holmlund Saab Aerosystems
2009-10-12

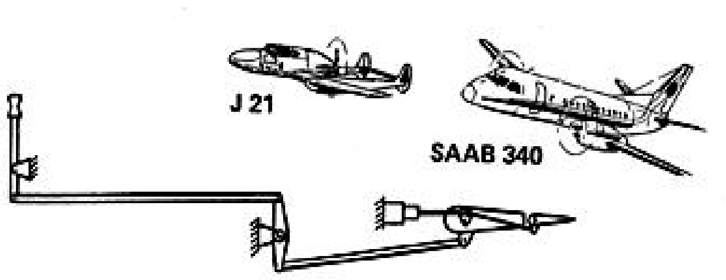
Scope

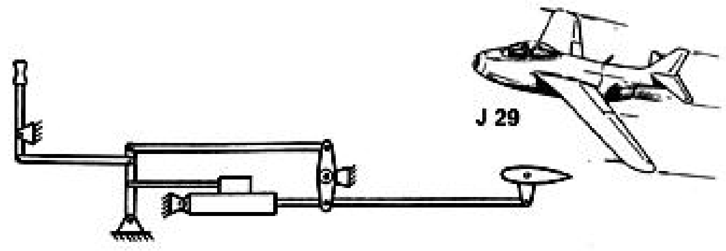
A retrospective of flight control system evolution

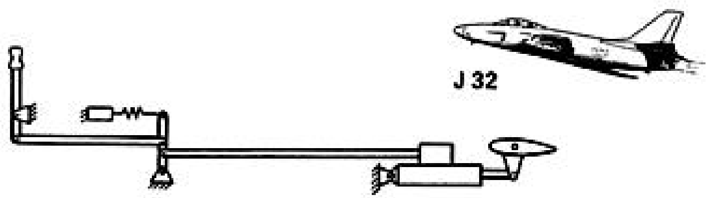
The Gripen Flight Control System

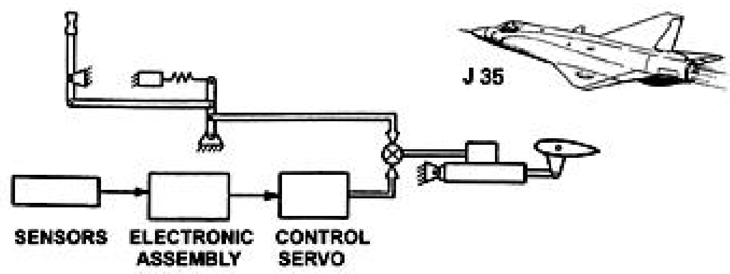
- Requirements
- Design decisions
- Principle of operation
- The philosophy behind redundancy - monitoring – fault accommodation
- System and computer architecture

The Evolution of FCS 1945-1990









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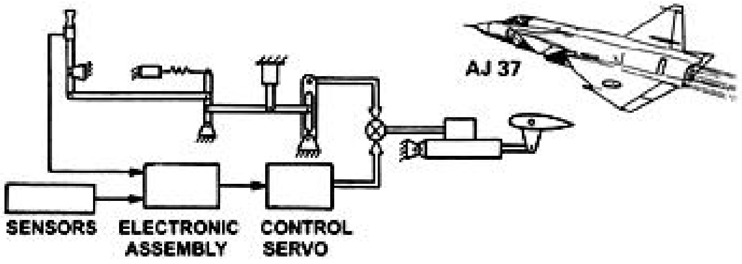
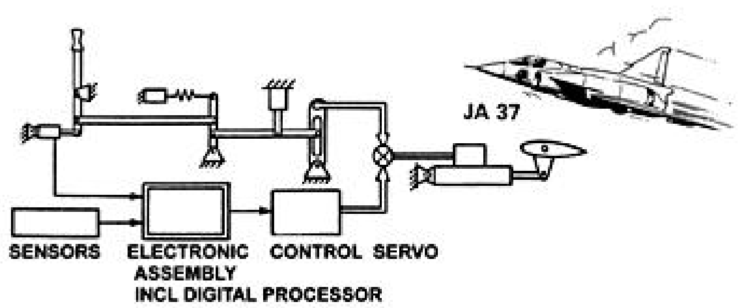
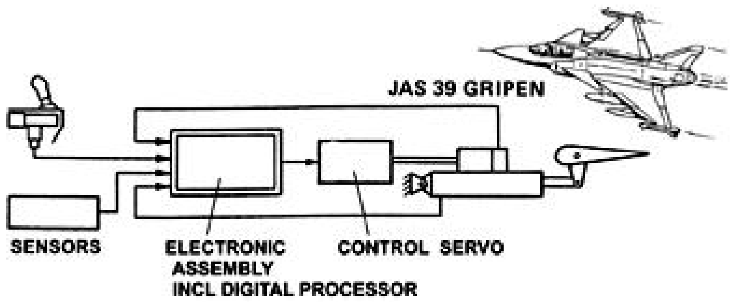
The Evolution of FCS 1945-1990







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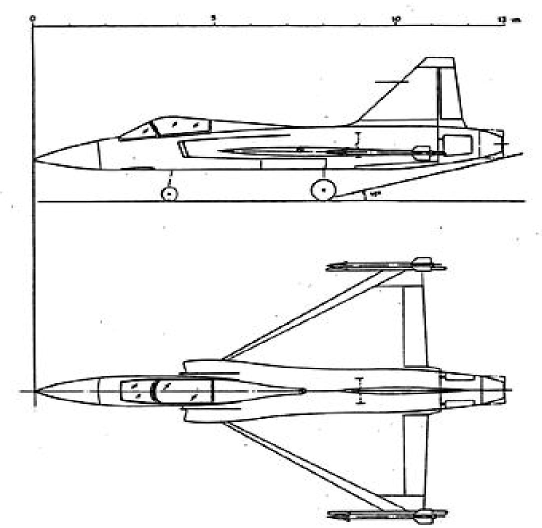
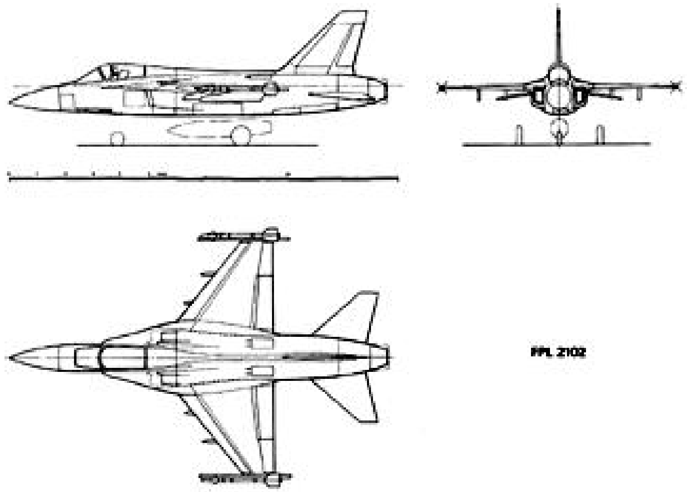
Requirement Design Drivers

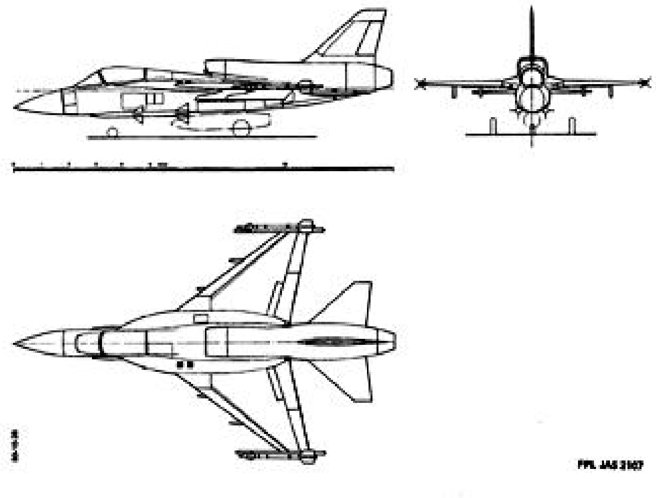
- Performance
  - ✓ E.g.: range, speed, altitude, acceleration, turn ratio
- Function
  - ✓ operative, pilot relief functions
- Safety/Availability
  - ✓ Prob. for loss of a/c , pilot survivability, “graceful degradation”
- Weight/ Volume
- Environment
  - ✓Temp., mech., electrical (EME, EMI,) EMP
- Maintenance and Testability

Design Decision

- Different a/c configurations were suggested







Design Decision

Decision to choose an a/c with :

- ✓ Relaxed stability in pitch, 7 primary control surfaces
  - turn ratio, better weight/volume ratio
- ✓ Electric control system
  - eliminates mechanical linkage and equipment
  - simplified installation and maintenance, less vulnerable
- ✓ Computerized flight control system
  - flexibility during development and design, good growth potential (40 years)

Control Surface Configuration

Primary Control Surfaces
Secondary Control Surfaces

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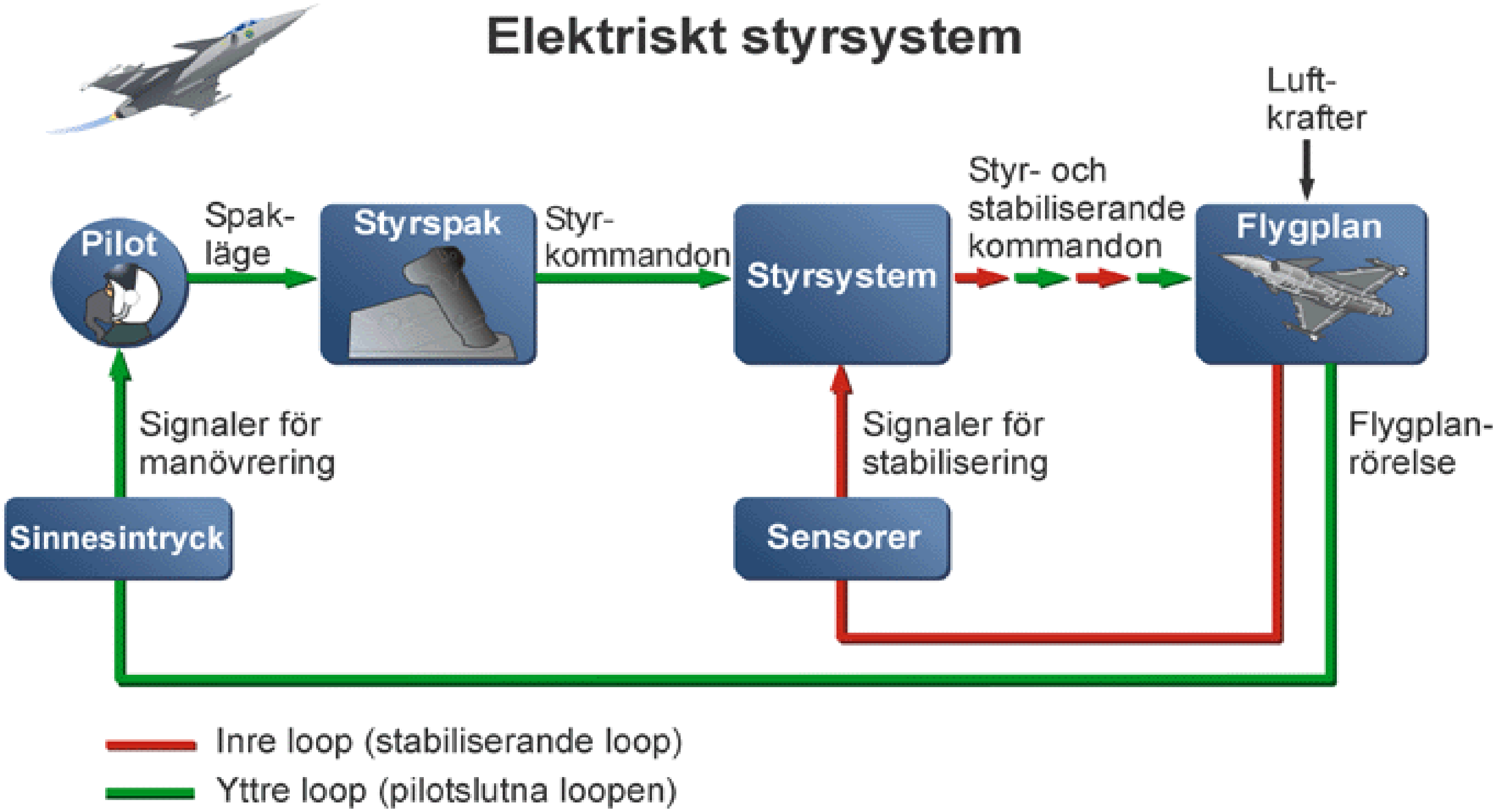
The Gripen flight control system’s control loops



- **Pitch, Roll, Yaw Rate**
- **AoA**
- **Normal and Lateral Acceleration**
- **Airspeed**
- **Altitude**

Design Decisions

Pros :

- Light and “small” system
- Advanced control law calculations
    - ✓ Automatic stability in pitch
    - ✓ Optimized control and stability characteristics
    - ✓ Gust alleviation
    - ✓ Maneuvering load limits
    - ✓ Outer loop functions
- Simplified and improved maintenance and test

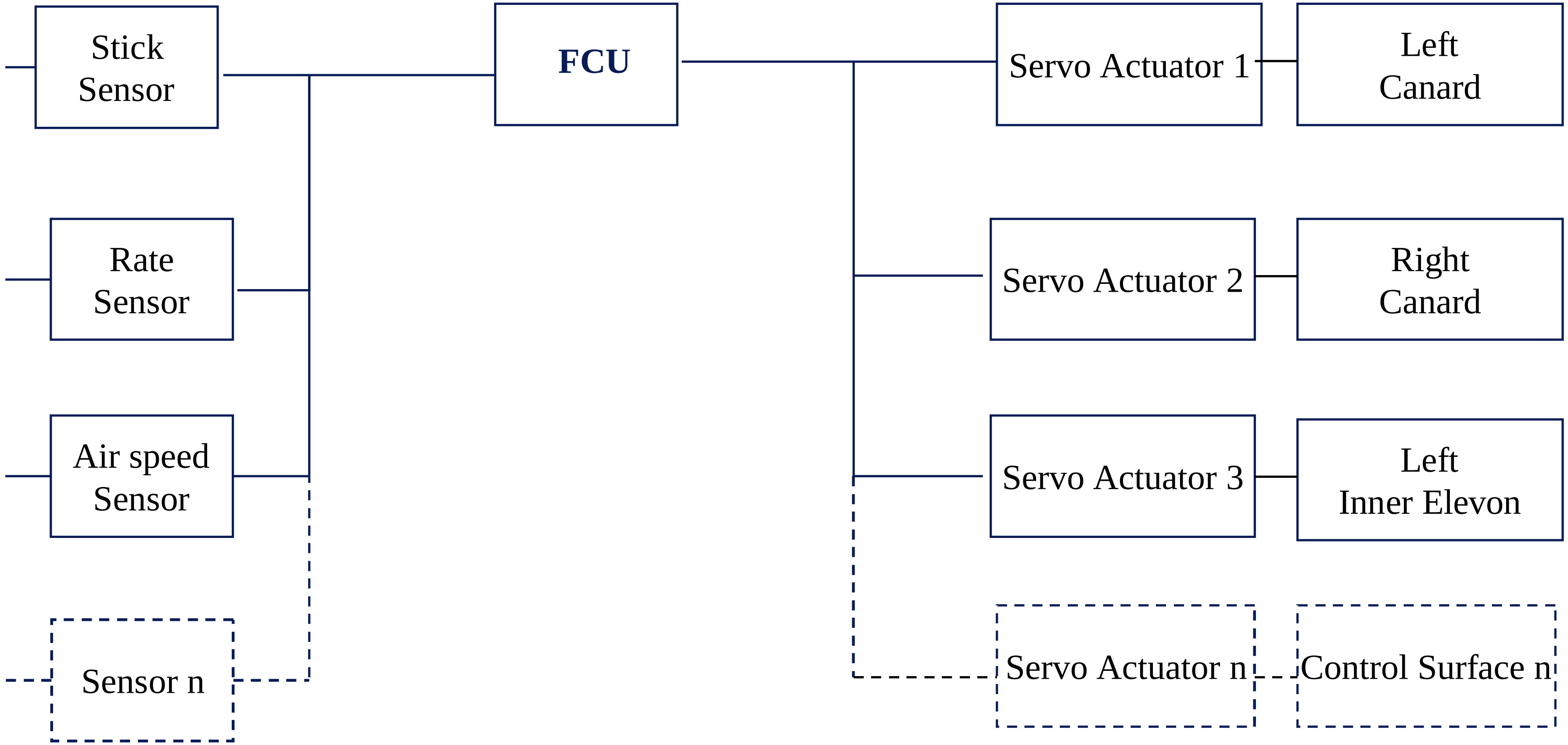
Design Decisions

Cons:

- Requires a reliable power supply
- Needs precautions when handling:
    - ✓ EME and EMI
    - ✓ Cosmic and nuclear radiation
- Extensive qualification/verification

Fault Tolerance

A simplex system will meet functional and performance requirements



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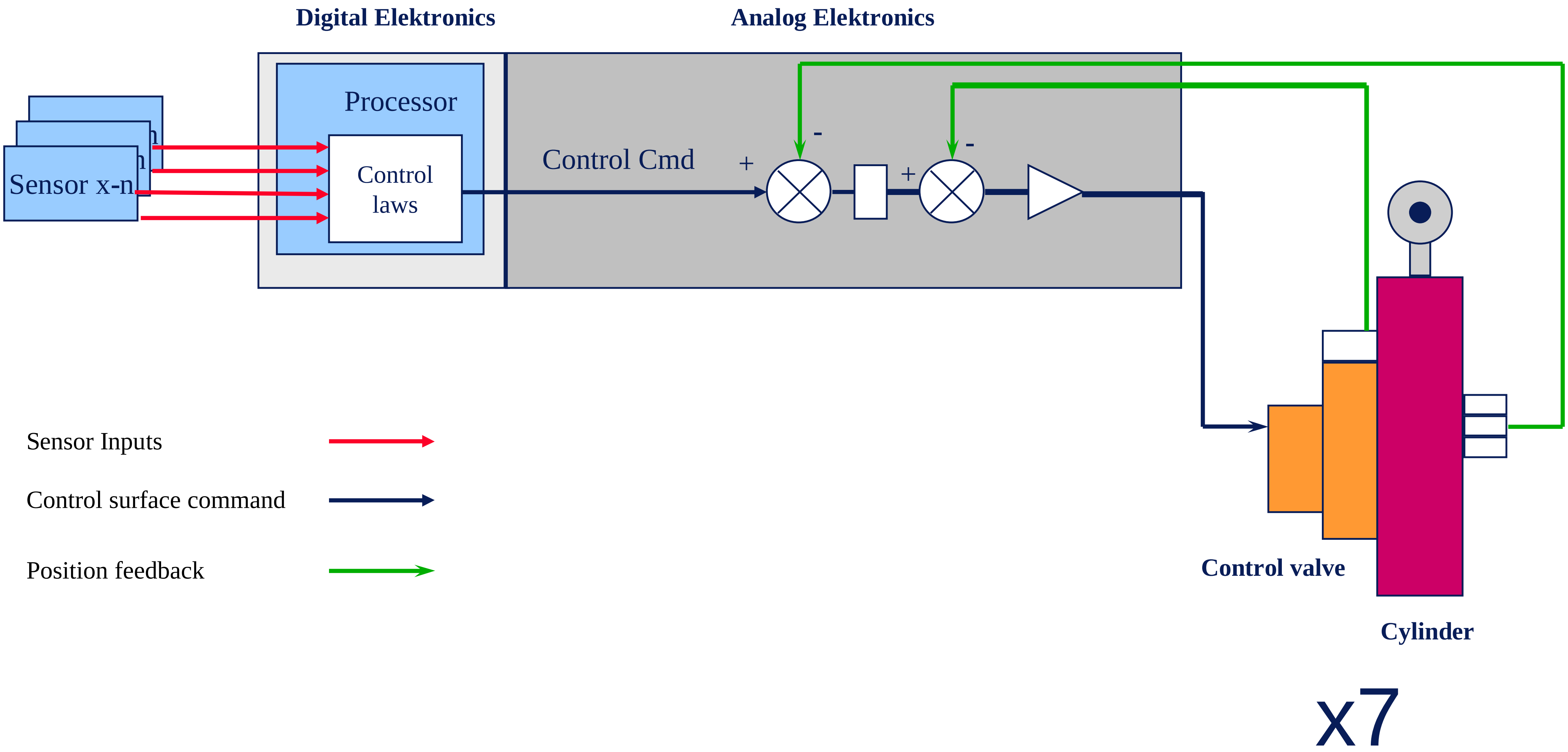
Concept of redundancy, simplex system



Fault Tolerance

Other requirements affect the design of the system, e.g. safety req. :

- ✓ No single failures may cause loss of a/c
- ✓ Maximum allowed probability for loss of a/c
- ✓ Maximum allowed A/C transients as a result of a fault in the system

- ✓ Probability for mission success

Fault Tolerance

Fault tolerance in the Gripen FCS is built up by:

- Redundancies
- Voting planes
- Monitoring
- Redundancy Management
- Asynchronous operating FCU
- Pre flight test

The Philosophy Behind The Redundancy Concept

- Good flying qualities with 6 out of 7 primary control surfaces operating
- Maneuverable with 5 out of 7 primary control surfaces operating
- Able to cope with all single faults and most double faults
- QUAD vs TRIPLEX
  - ✓ Economical system – slim as far as resources are concerned
  - ✓ Brain power instead of muscles
- Safety critical function must be tripled
- Important functions are doubled, “tie break”

Redundancies within the system

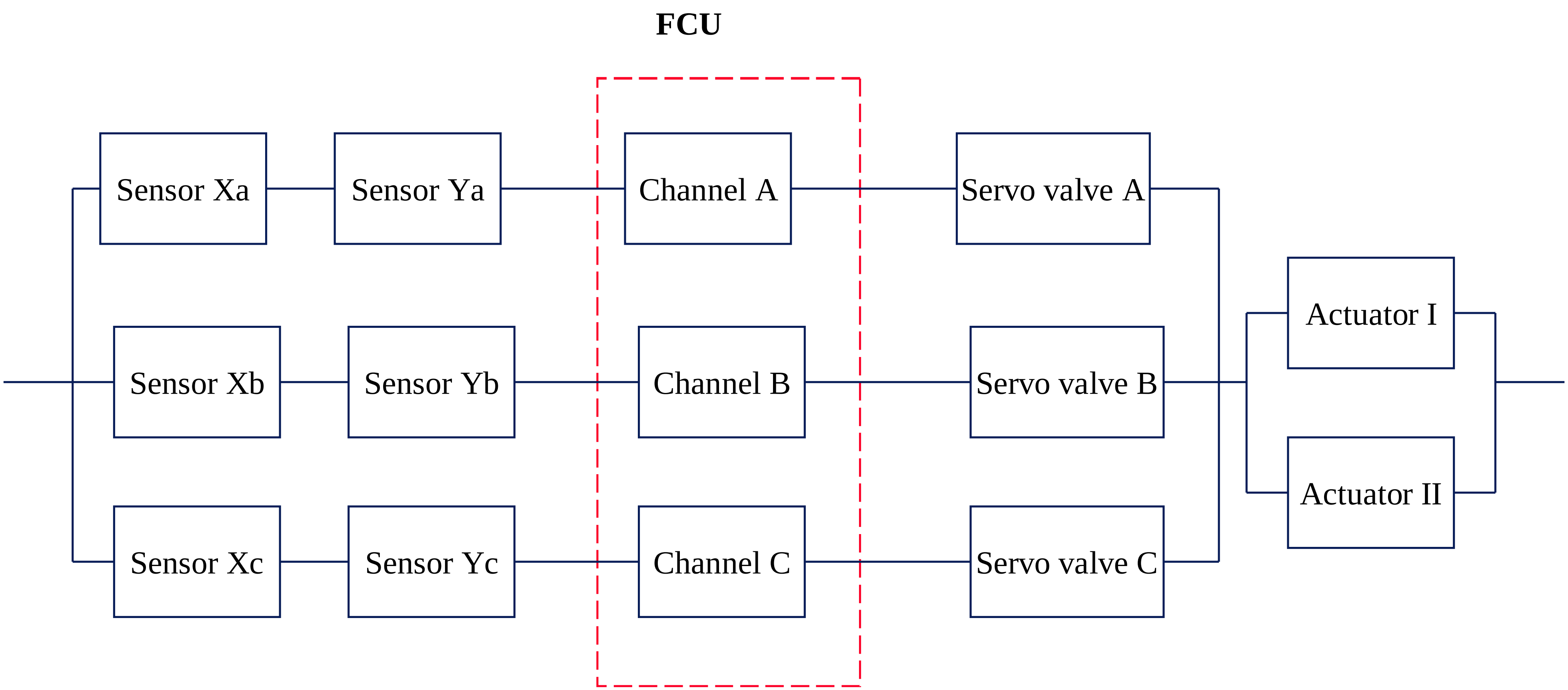
- Example of tripled functions (lack fail-safe position)
  - ✓ Three channel FCU
    - - Independent BU-mode (HW/SW)
  - ✓ Control stick sensors
  - ✓ Rate gyro
  - ✓ Electrical power supply

Redundancies within the system

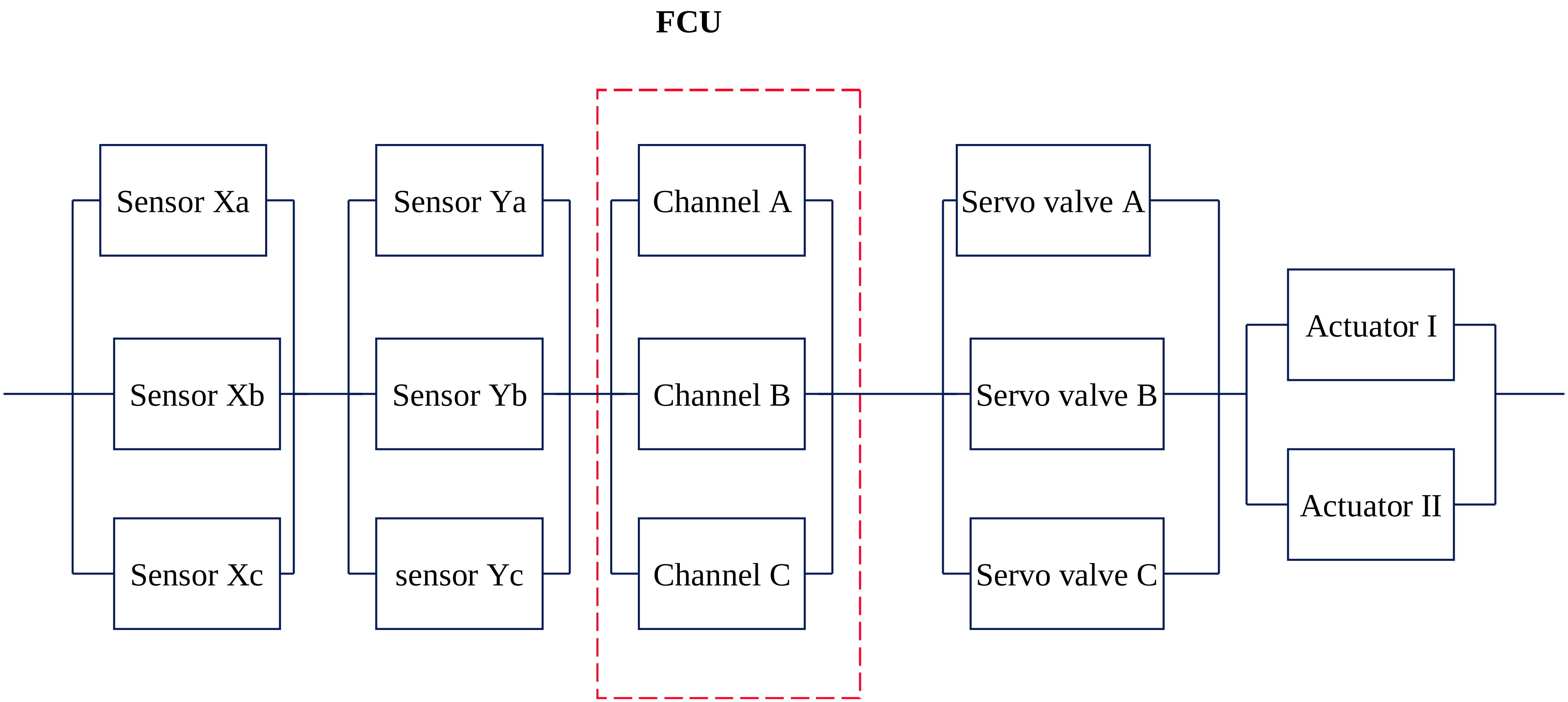
- Example of doubled functions (have a ”fail-safe” position*)
  - ✓Accelerometers
  - ✓Angle of attack sensors
  - ✓Air data (speed and altitude)
  - ✓Hydraulic power supply

* as long as we can detect a fault

General simplified architecture



General simplified architecture II



Fault Tolerance

Fault tolerance is built up by:

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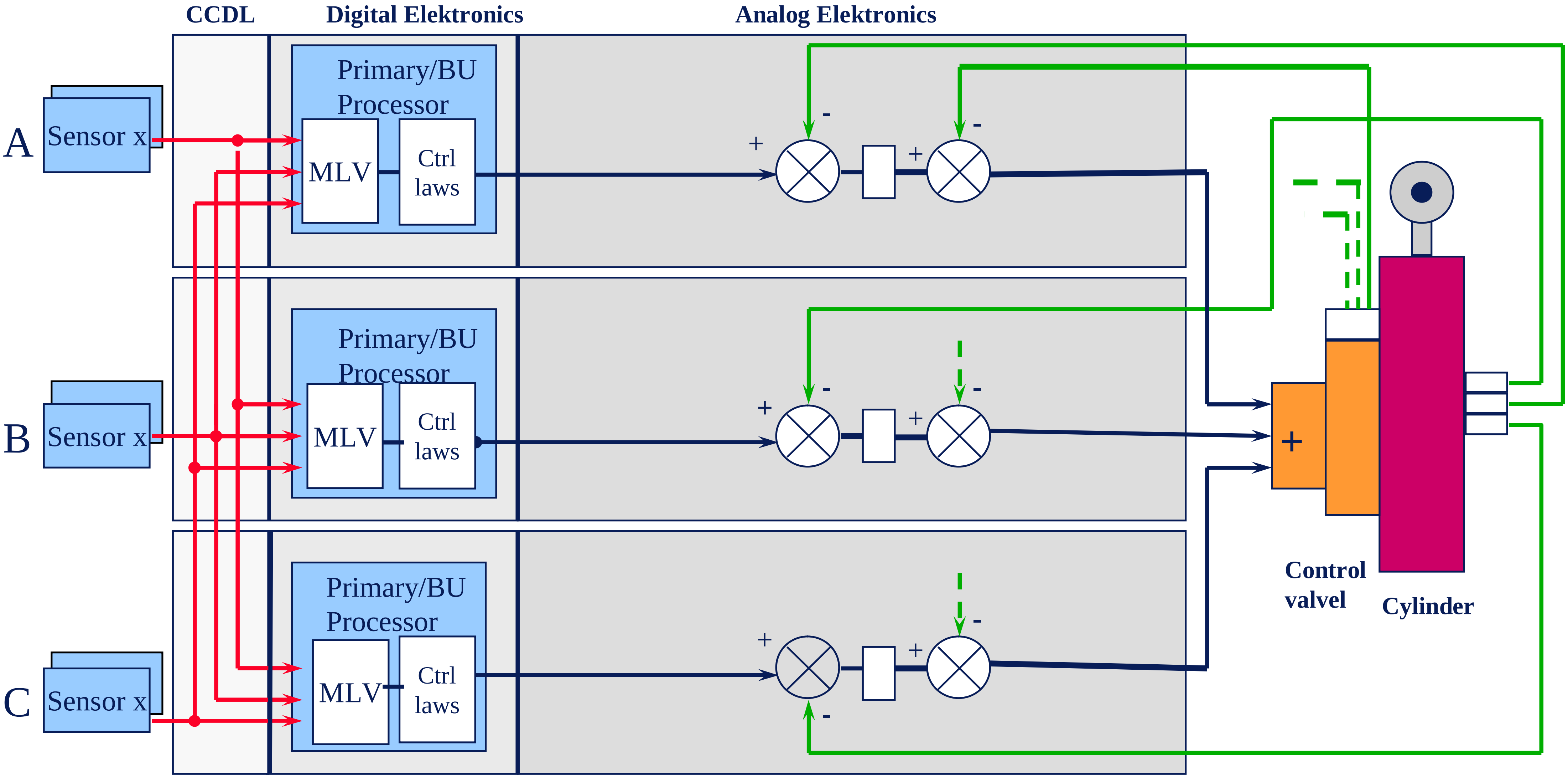
Voting planes

MLV – Mid Level Voting

- ✓ Input signal voting (S/W)
- ✓ Voting of computed control signals (H/W)

”Flux summing” (H/W)

Concept of redundancy, triplex EFCS



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Fault Tolerance

Fault tolerance is built up by:

- Redundancies
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Functional Monitoring and Redundancy Management

- Extensive functional monitoring and redundancy management compensates for lack of redundancy

- Functional monitoring detects the fault and informs the A/C system and pilot about the fault.

- Redundancy management allows for reconfigurations, graceful degradation and high survivability

Functional Monitoring

- Methodology
  - ✓ Cross channel monitoring
  - ✓ In line monitoring
  - ✓ Direct monitoring
  - ✓ Reasonableness monitoring
- Self healing
  - ✓ Minimizes the effect of nuisance trips
  - ✓ Creates resilience within the system

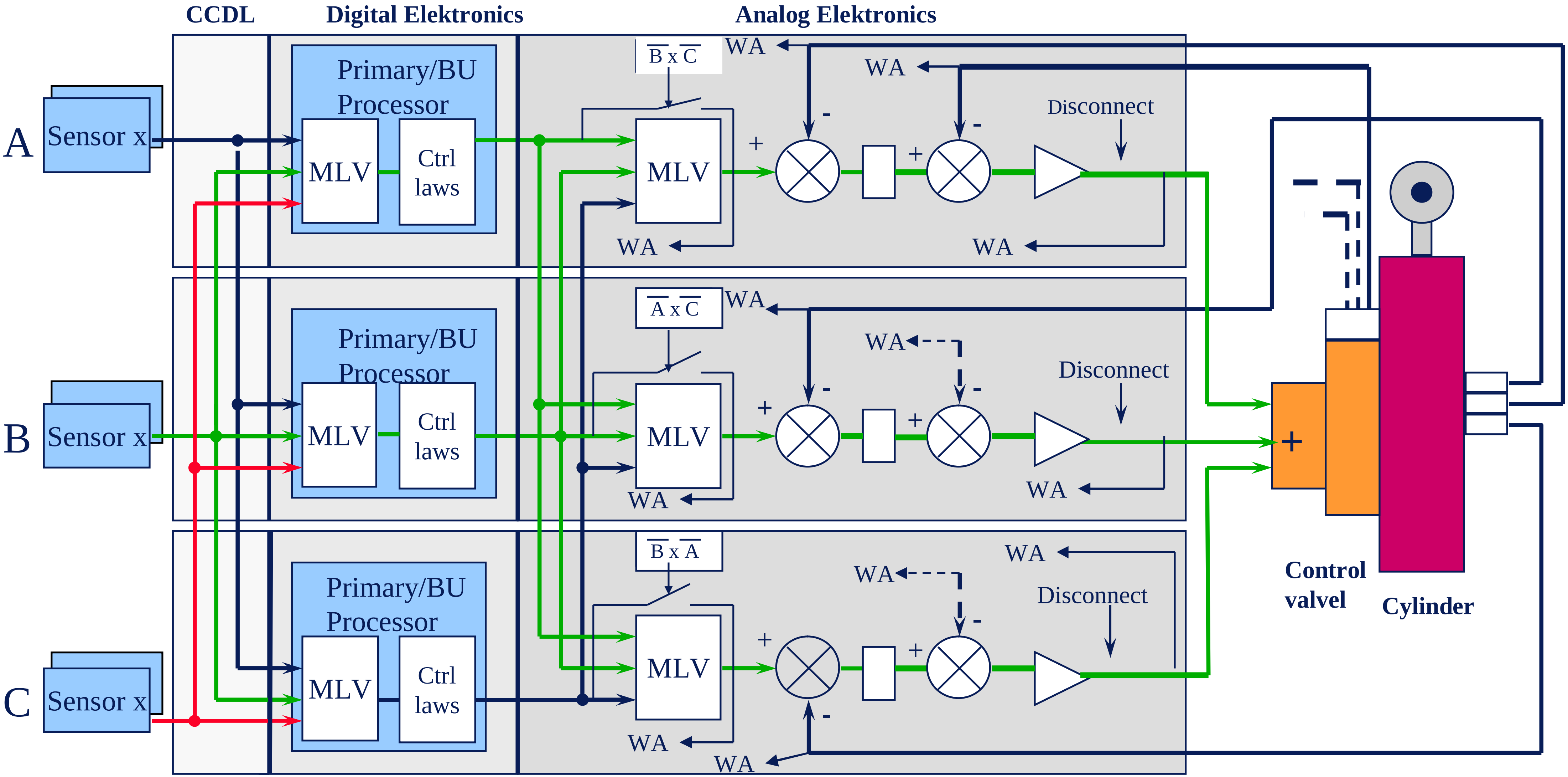
Redundancy Management

- Reconfiguration helps minimizing the possible effect of a fault
  - ✓ Selects and removes the faulty signal. Continues operation with the remaining ones or substitutes the faulty signal with another similar signal
- Reconfiguration can also compensate for lack of resources
  - ✓ Control surfaces, fail-safe values, model based signals

Redundancy Management

- Example of reconfigurations:
  - ✓Sensor faults, i.e:
    - oRate gyro
    - oAngle of attack
    - oAngle of side slip
    - oAccelerometer
  - ✓ Data bus faults
  - ✓ Servo actuator faults
  - ✓ Computer faults

Concept of redundancy, triplex EFCS



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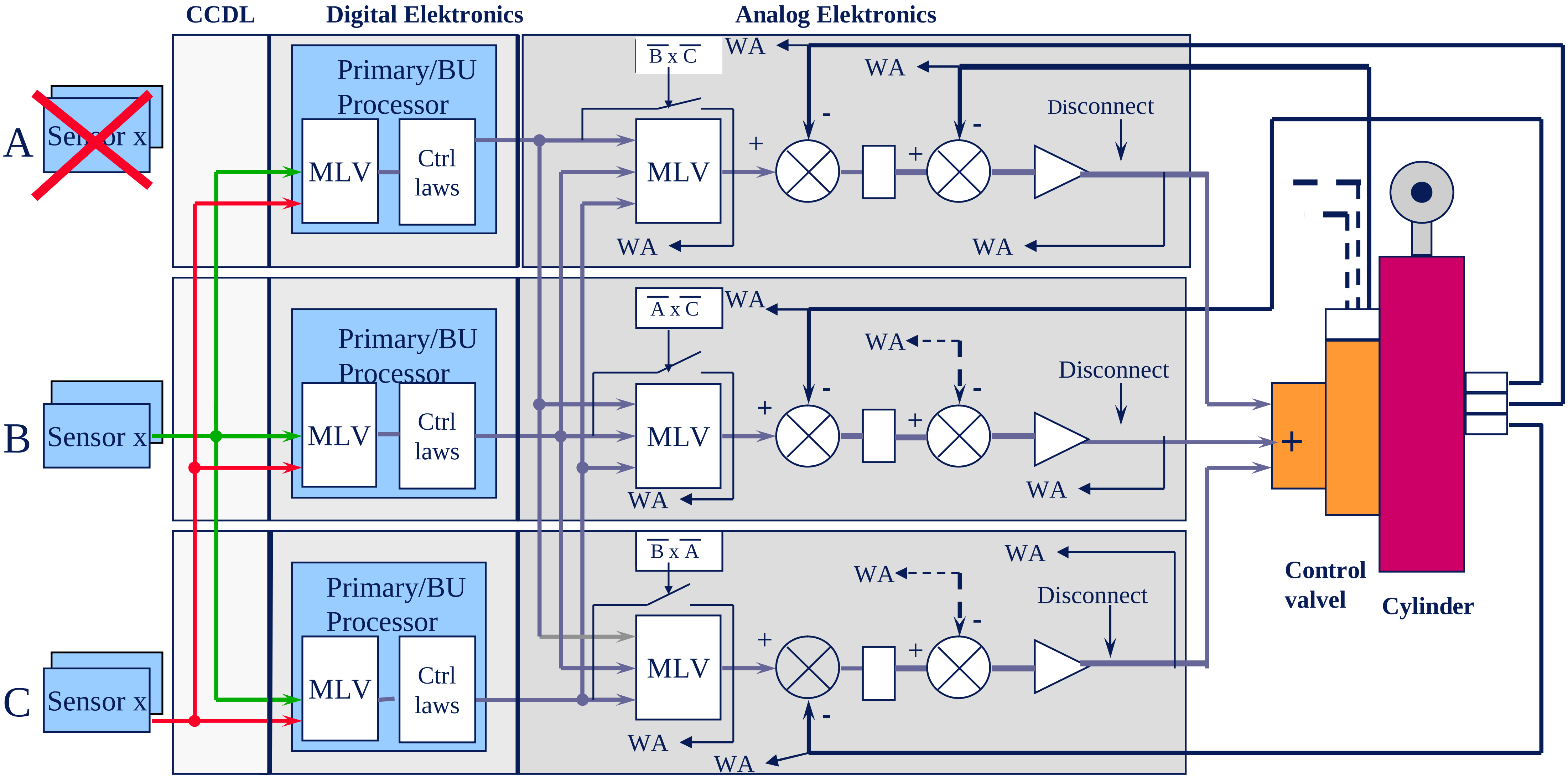
Concept of redundancy, Sensor fault



Stick, AoA, RateG, self heal

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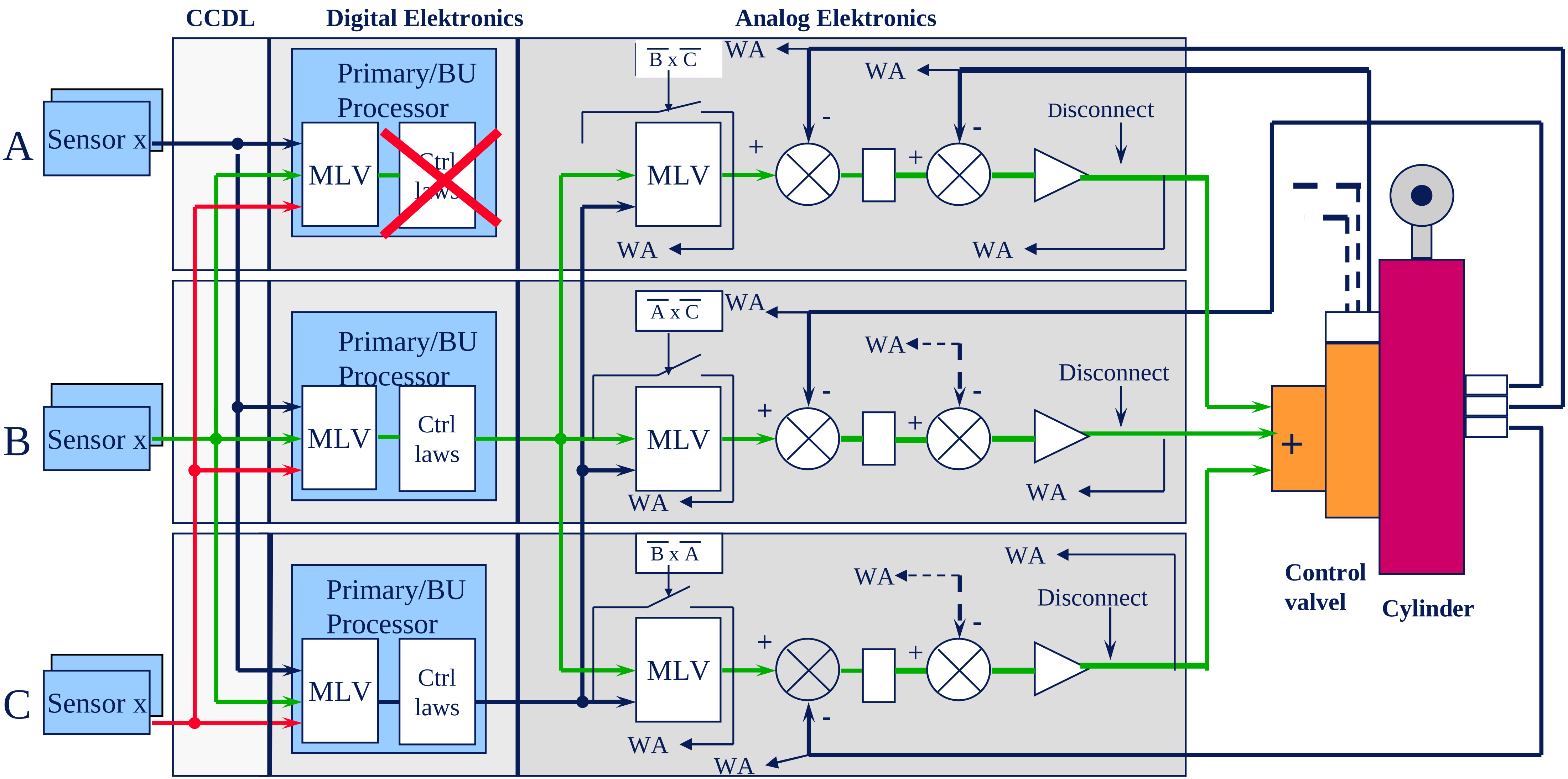
Concept of redundancy, Processor fault



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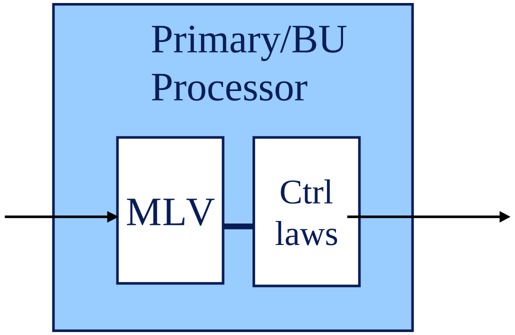
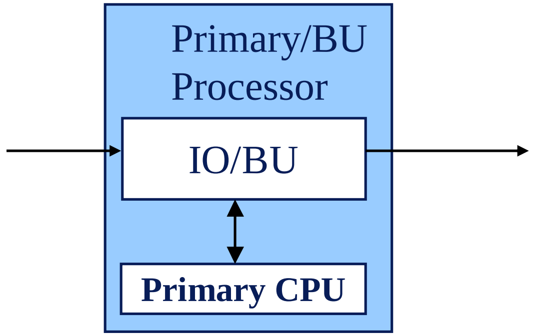
Concept of redundancy, Processor monitoring



IO/BU monitors NM PSA Commands (in line monitoring)



CHvalid

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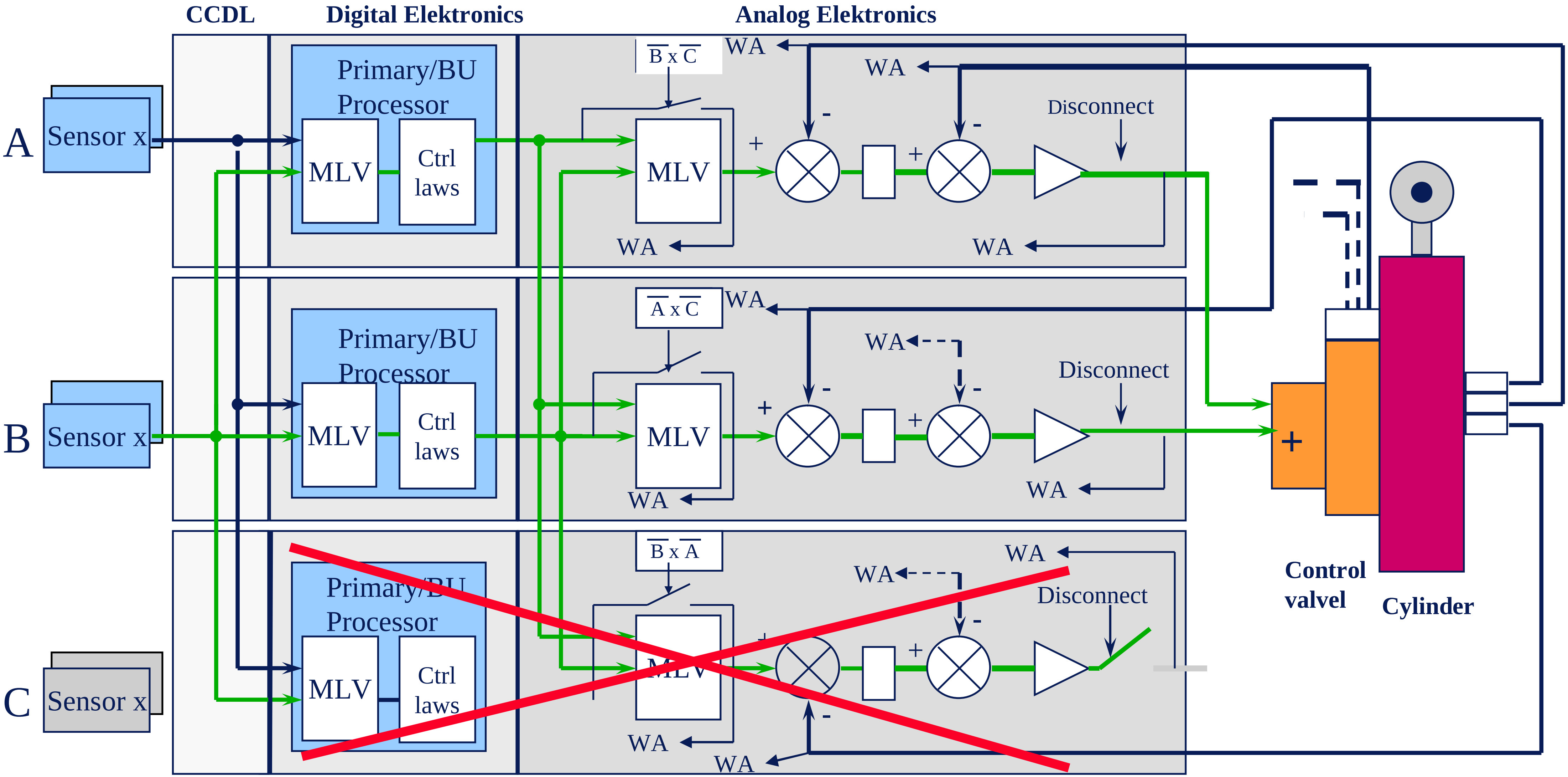
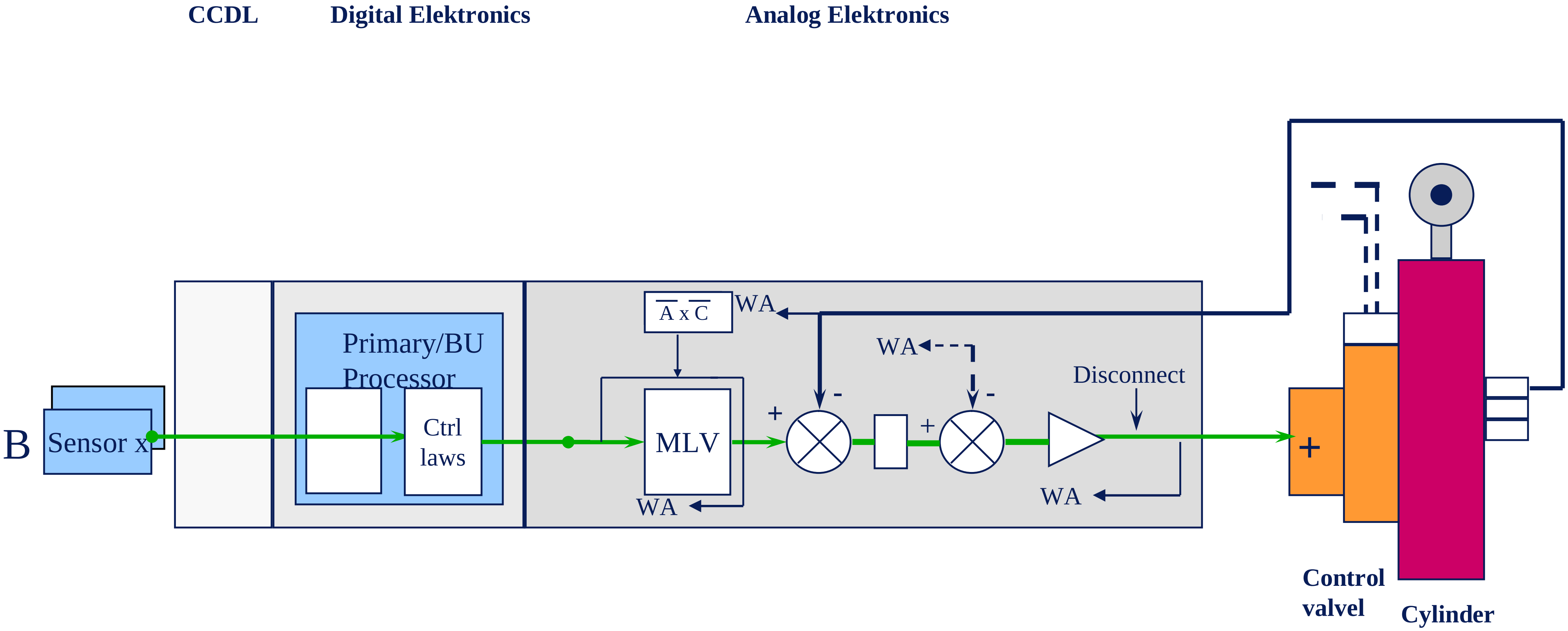
Concept of redundancy, loss of channel

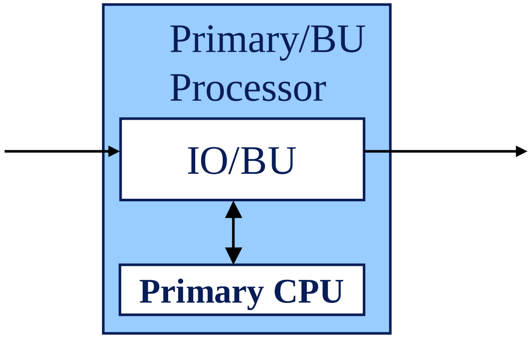


CHVALID

Concept of redundancy, loss of two channels



Concept of redundancy, Processor monitoring



Ch A	Ch B	Ch C
NM	NM	NM
BU	NM	NM
-	NM	NM
BU	BU	BU
-	BU	BU
-	-	BU

CHvalid

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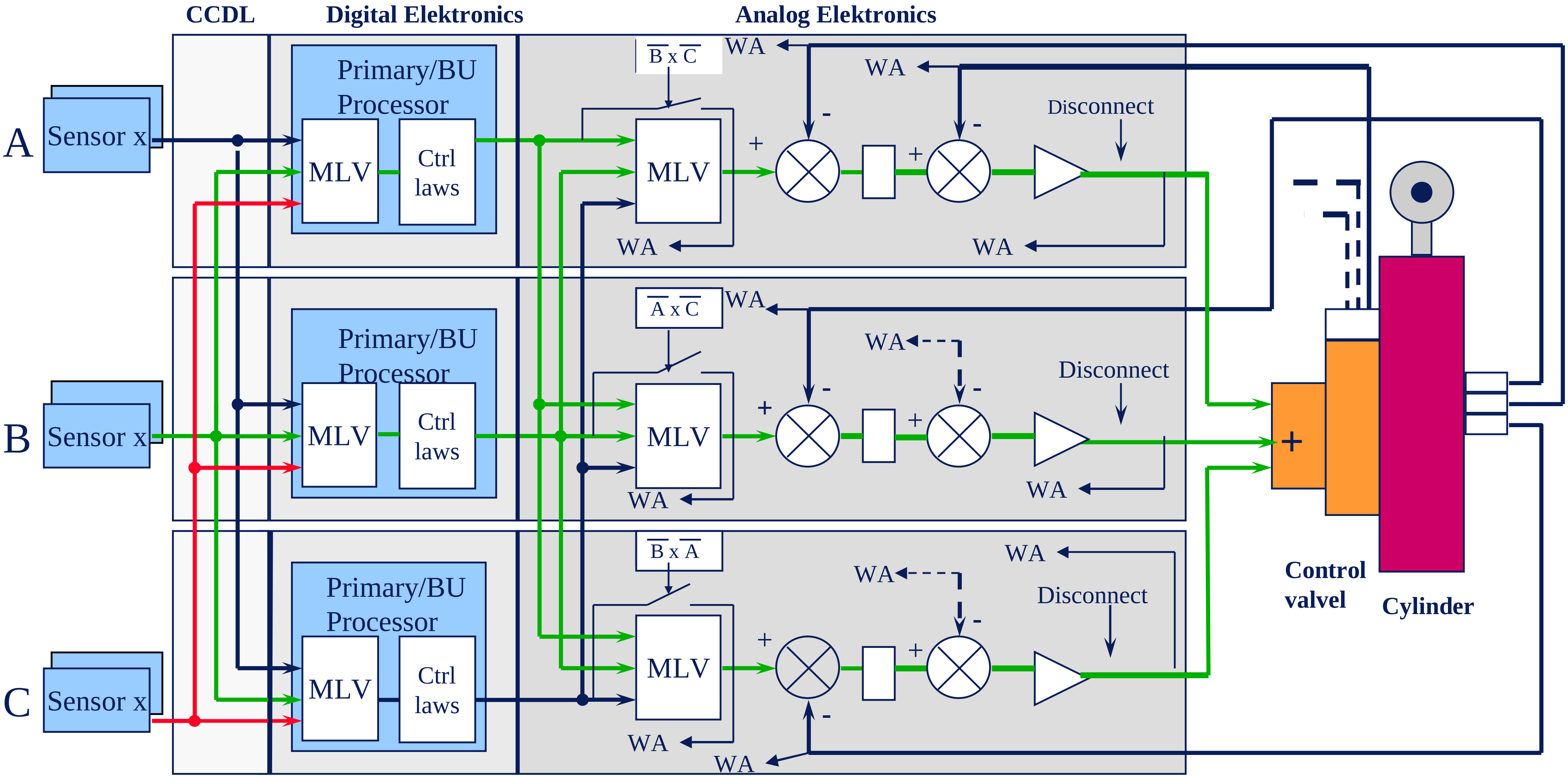
Concept of redundancy, output monitoring



Output monitoring

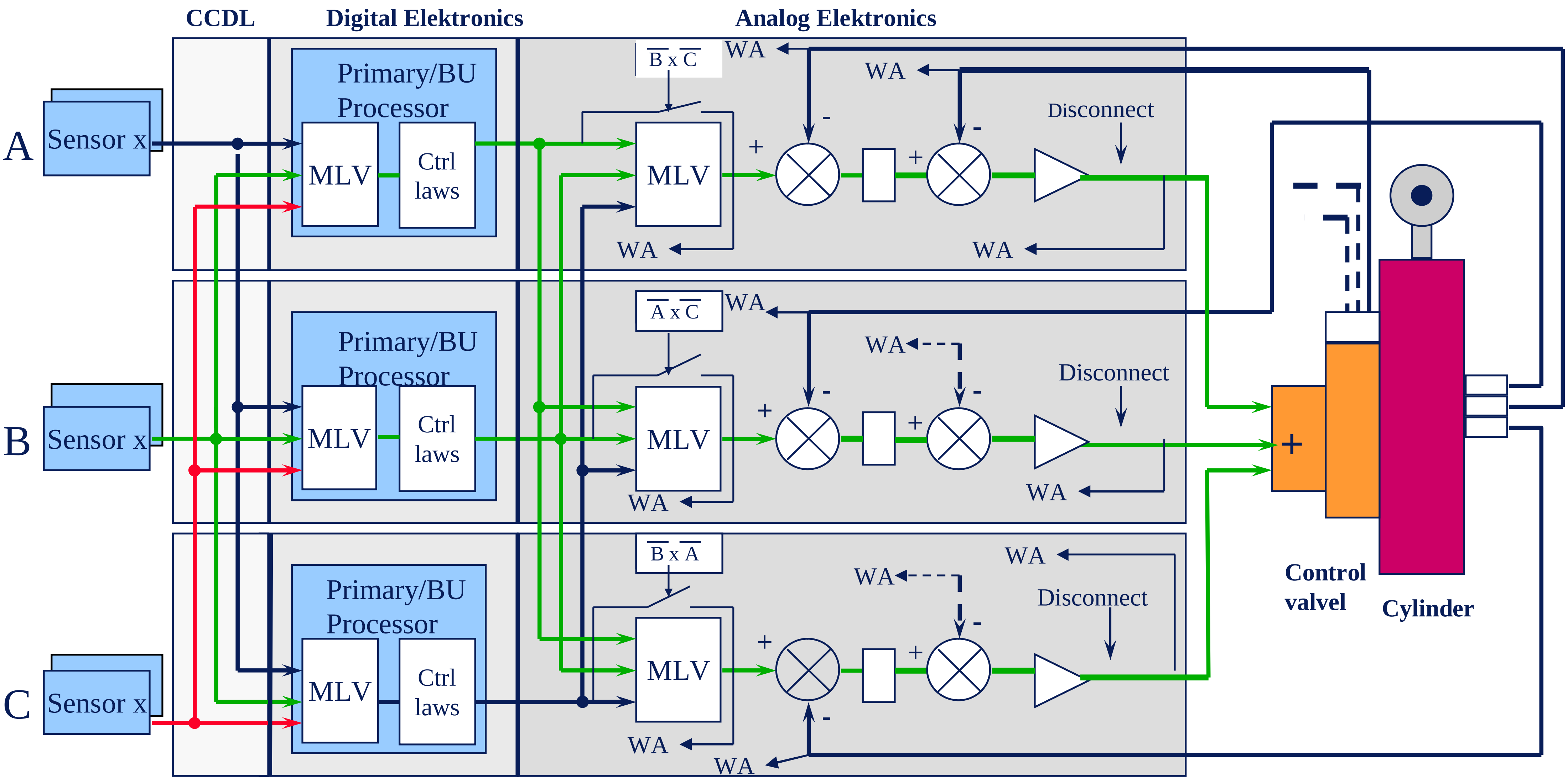
ACTMON, MCVMON; CURR

Fault Tolerance

Fault tolerance is built up by:

- Redundancies
- Voting planes
- Monitoring
- Redundancy Management
- Asynchronous operating FCU
- Pre flight test

Concept of redundancy, output monitoring



Asynchronous operating FCU

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Asynchronous operating FCU

- EMI/EME, Lightning, EMP
  - ✓ Filtering the effect
- Electrical power outage/transients
  - ✓ Fast in flight power up < 50 ms
  - ✓ No risk of conflicts between channels trying to get synchronous

Fault Tolerance

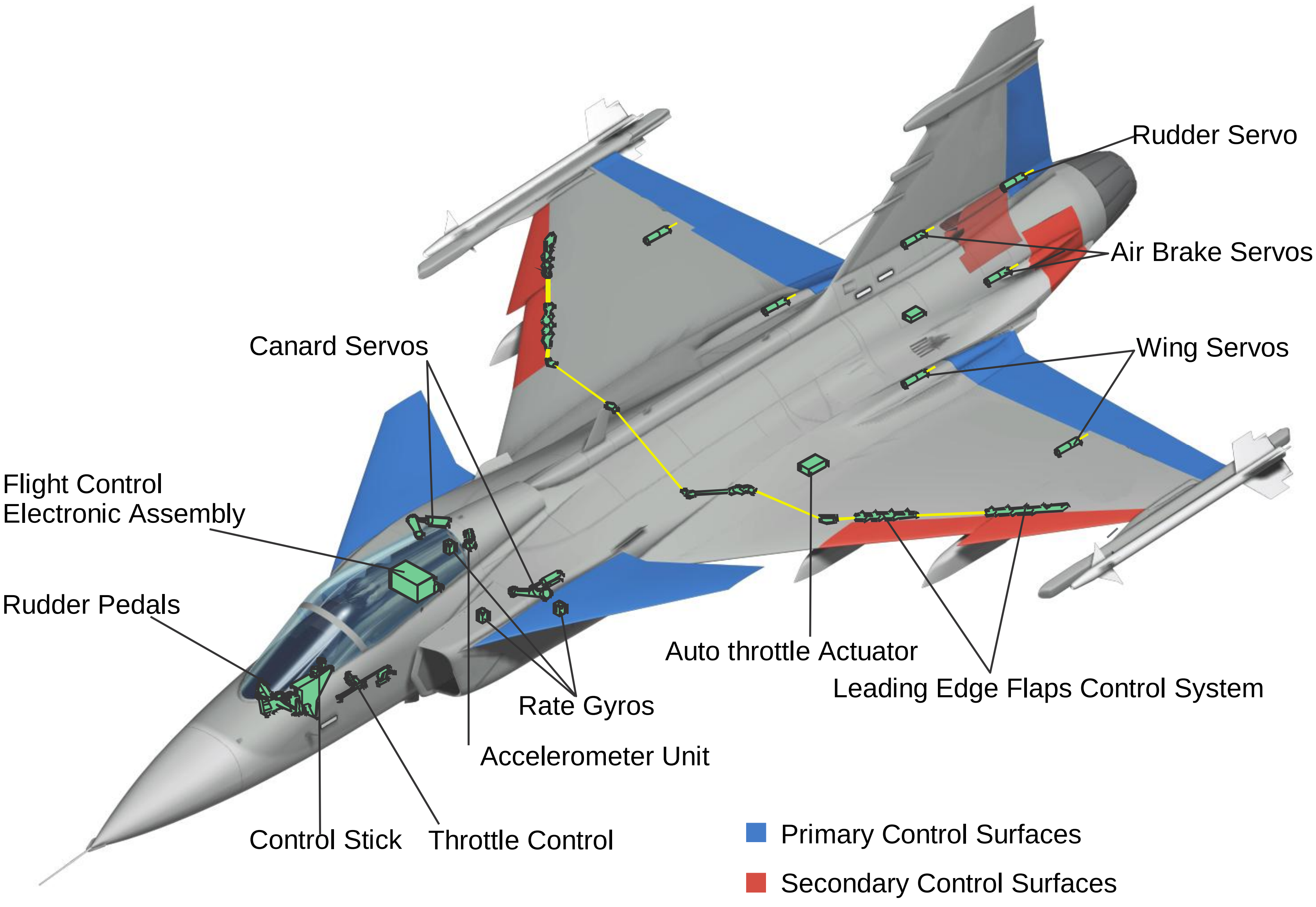
Fault tolerance is built up by:

- Redundancies
- Voting planes
- Monitoring
- Redundancy Management
- Asynchronous operating FCU
- Pre flight test

Fault Tolerance

- Extensive pre-flight test guarantees safe function of flight critical functions, redundancies and monitoring circuits

- Approx. 30% of H/W components and 50% of the S/W within the FCEA is dedicated to Built in Test, Functional Monitoring and Redundancy Management



Rudder Servo
Air Brake Servos
Canard Servos
Wing Servos
Flight Control
Electronic Assembly
Rudder Pedals
Auto throttle Actuator
Leading Edge Flaps Control System
Rate Gyros
Accelerometer Unit
Control Stick
Throttle Control
Primary Control Surfaces
Secondary Control Surfaces

Summary: The Gripen FCS - A Hybrid System

Static Redundancy

- Basically a triplex system – but not a fully TMR system
- MLV- used to isolate faults
- Asynchronous System

Dynamic Redundancy

- Fault Detection – Application specific due to an asynchronous system
- Reconfiguration (Graceful Degradation)
- S/W redundancy – but not a real N-version programming
- Warm standby system for processor and S/W faults

Byzantine faults

- The system is not sensitive to single Byzantine faults–
  due to three independent asynchronous channels + MLV