

Intelligent Sensors and Components for On-Board ISHM

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Outline

- Motivation
- ISHM
- Intelligent Components
- IEEE 1451
- Intelligent Sensors
- Application
- Future Directions

Origin:

Support rocket engine test mission with highly reliable, accurate measurements.

A1



B1/B2 Test Stand

A1 Test Stand

A2 Test Stand



A2



E - Test Complex



E2



E3

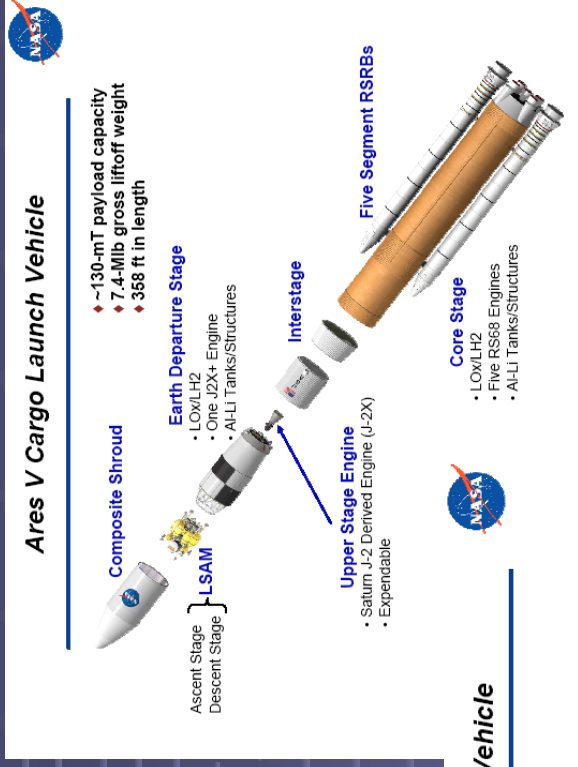


E1

New Needs: Constellation Systems

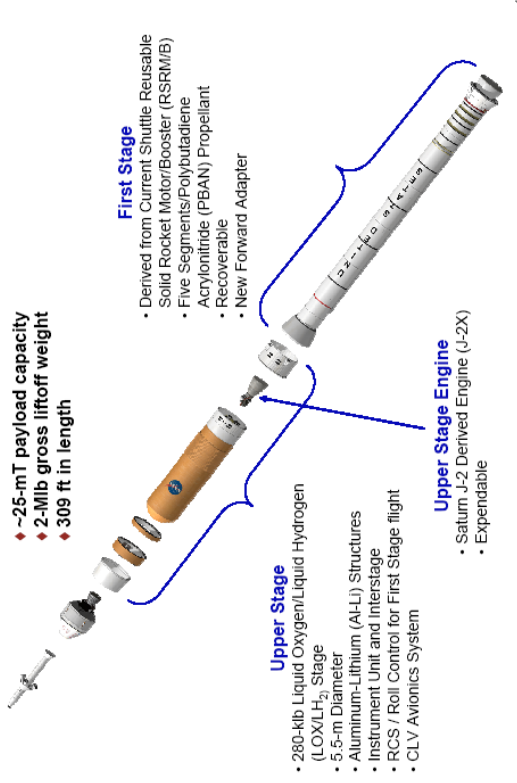
Aries V:

Cargo Launch Vehicle



Lunar Habitat

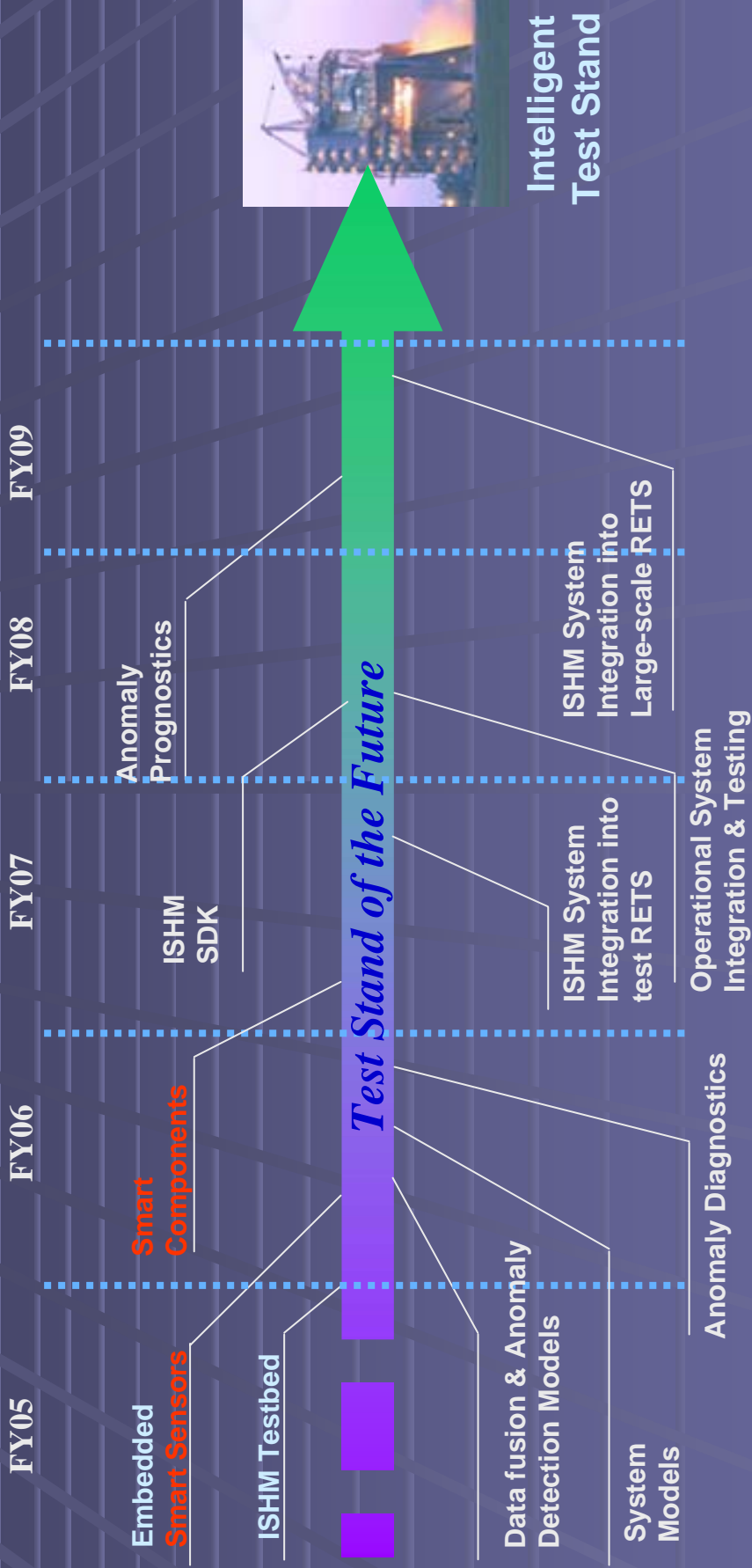
Aries I Crew Launch Vehicle



Aries I: Crew Launch Vehicle

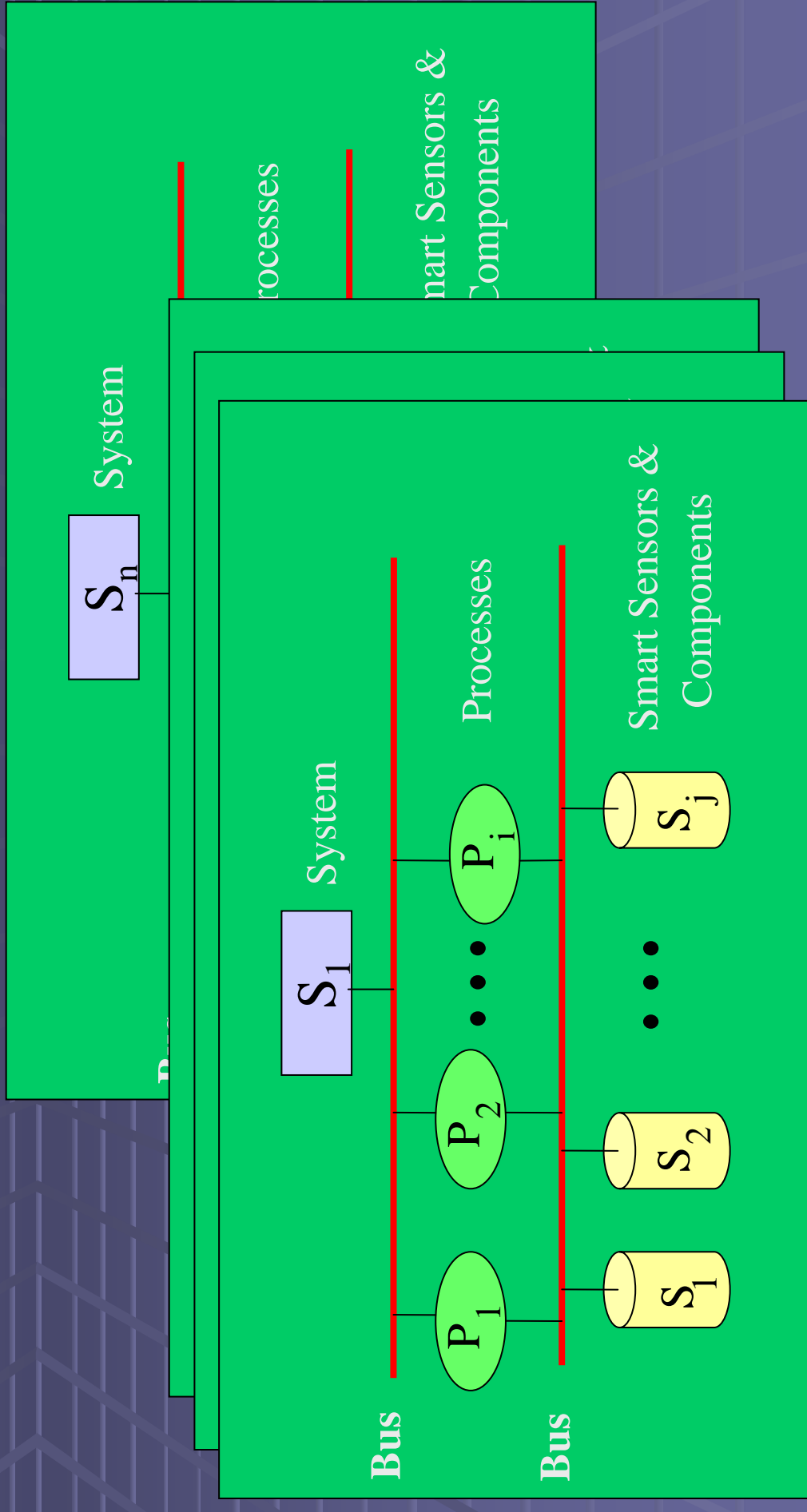


Rocket Engine Test Stand Technology Roadmap



System-of-System

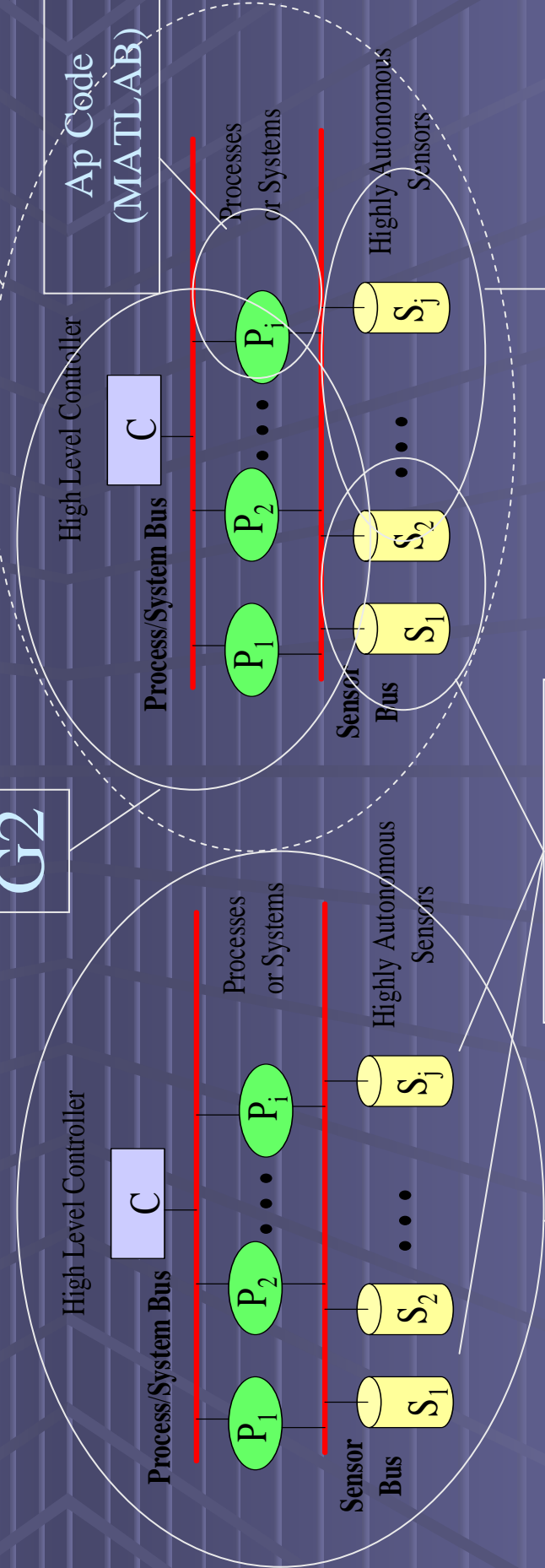
Integrated Systems Health Management (ISHM)



R&D PROGRAM: Co-Development of a Centralized G2- based IIHMS System with Highly Autonomous Sensors

ISHM

G2



Conventional Sensors

G2 ISHM

Highly Autonomous Sensors
Smart Sensors
(Hardware, Software)



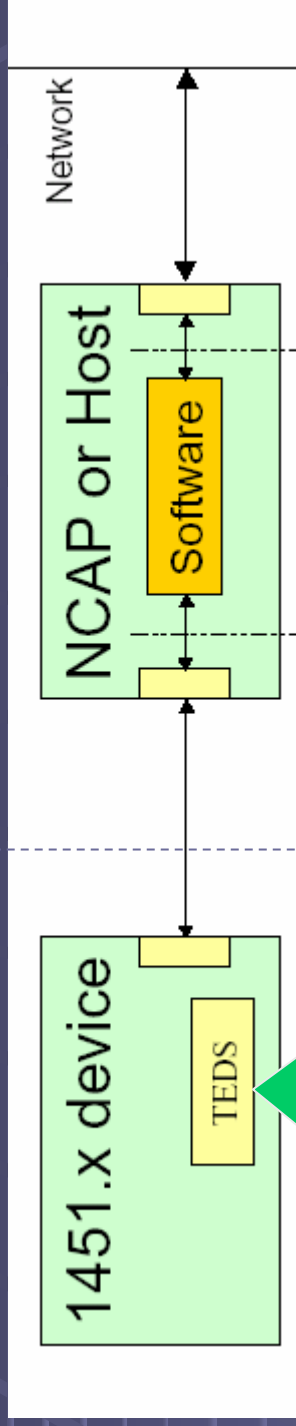
Development Path

Key Components & Technologies

- SSC Test environment
 - Production and developmental rocket engine testing—many different facilities, many sensors and actuators
 - Long documentation history of transducer/actuator failures, fault signatures
 - Physical model opportunities—e.g., Trailer-mounted test stand (TMTS) for development/prototyping and validation
- Knowledgeware system software- Gensym G2
- Smart sensors
 - Network-enabled embedded processors w/ operating systems and high-level language development tools
 - IEEE 1451.2: Smart transducer interface for sensors and actuators—Transducer to μ P communication protocols and transducer electronic data sheet (TEDS)
 - IEEE 1588, Precision clock synchronization protocol for networked measurement and control systems

Smart Sensor

STIM

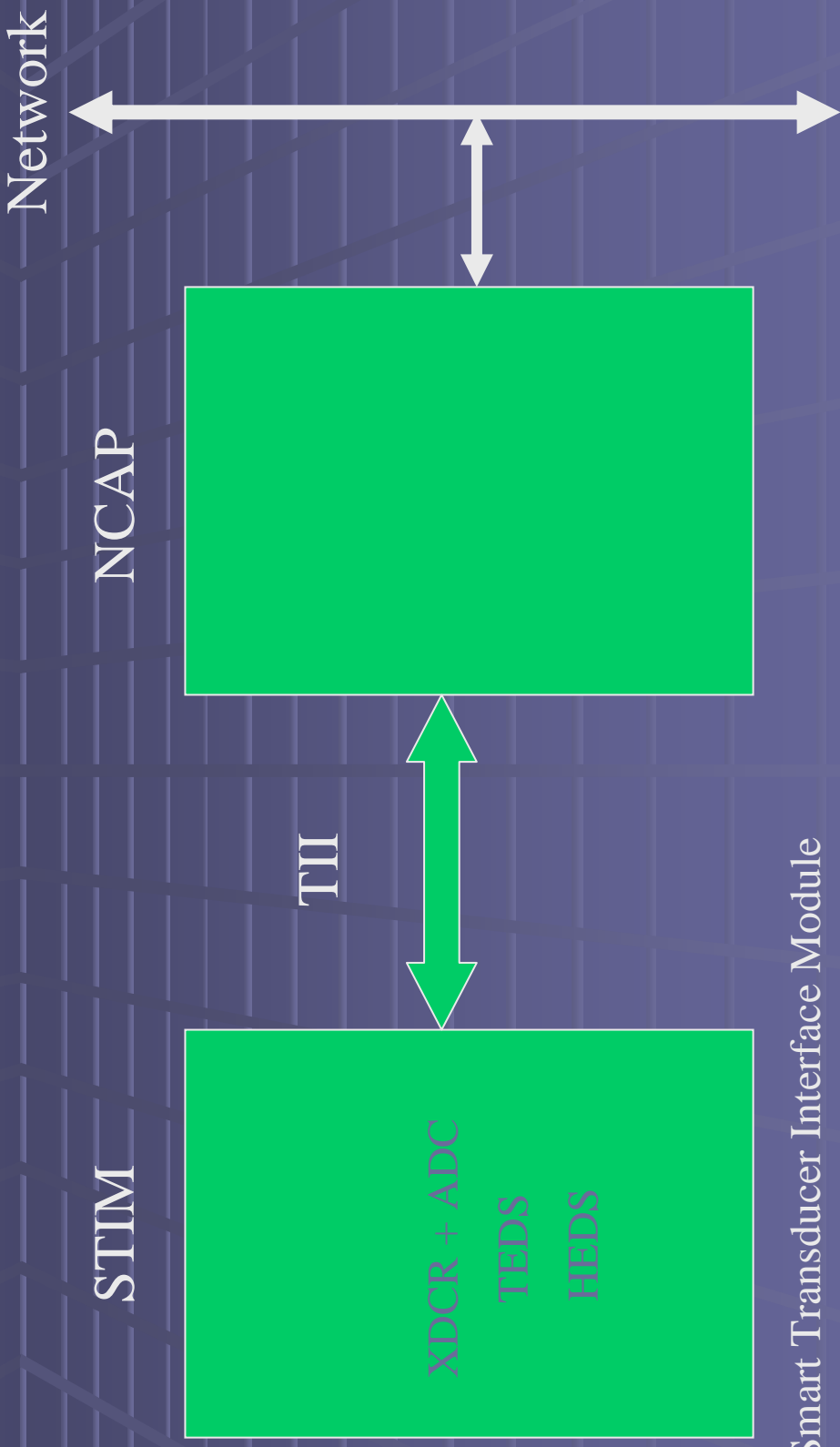


TEDS: Manufacturer, S.N.,
Cal date, Calibration factors
+ HEDS: Health parameters-
Bandwidth, Max rise time, etc.

Smart Sensor \equiv Sensor + SC + DAQ + Comm + Diagnostics

IEEE-1451 Model of Smart

Sensor: STIM <-> NCAP

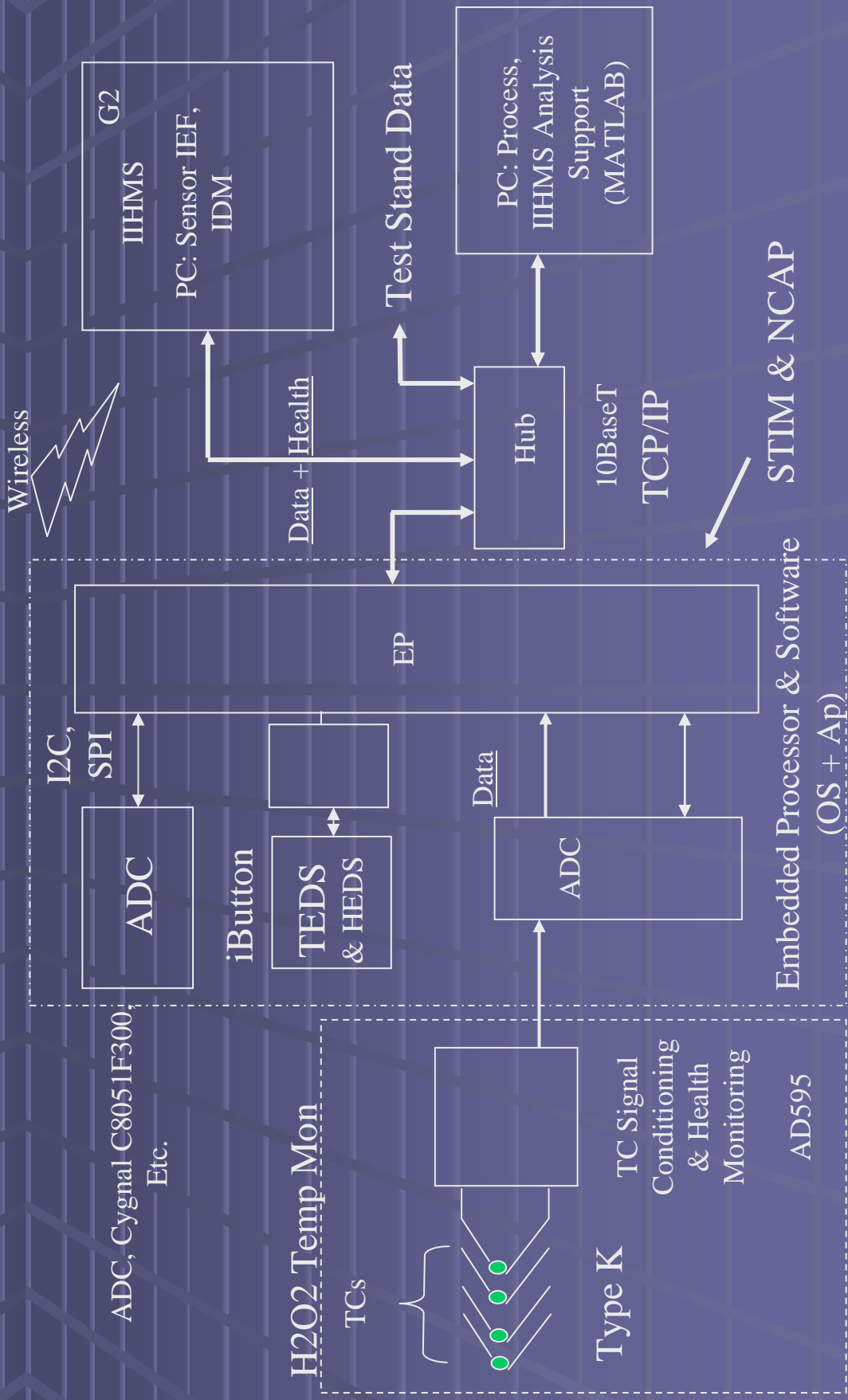


STIM: Smart Transducer Interface Module

TII: Transducer Independent Interface

NCAP: Network Capable Application Processor

Prototype Smart Sensor Arch:



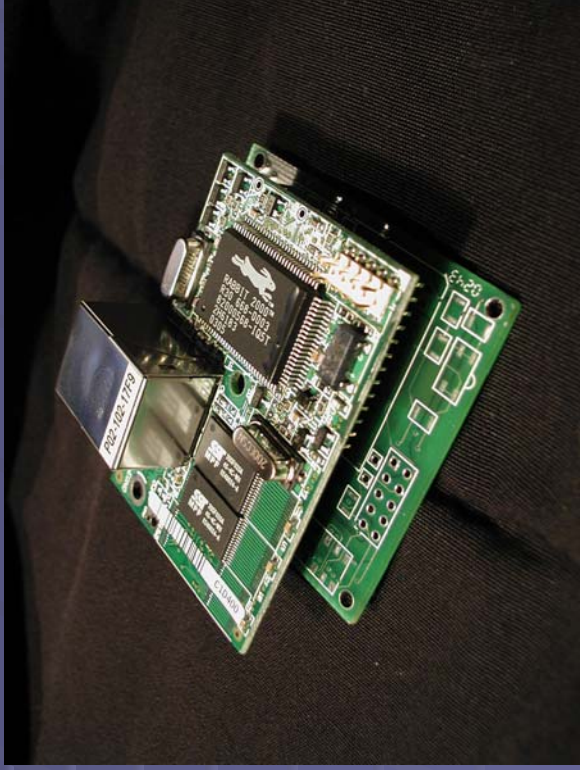
Sensor Architecture

- Embedded processor architecture
 - Z-World Rabbit 2000
- Embedded operating system
 - Dynamic C
 - MicroC/OS-II (FAA RTCA DO-178B)
- Sensor system partition (mono-, multi-processor)
 - Redundant EP architecture
- Library functions
 - Network, Basic math, I/O
 - Health assessment

Generic Smart Sensor

3d-generation smart accelerometer (NASA: 2000;
NJDOT/NJSP: 2002-2003)

Ethernet Core NCAP + Custom STIM piggy-back card

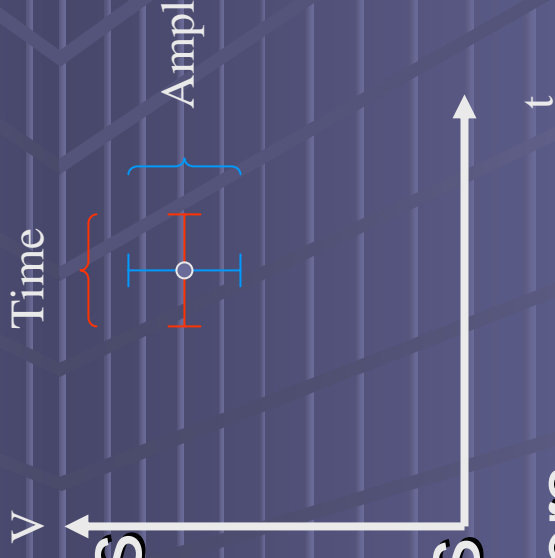


Sensor function:

3-axis Accelerometer

Smart Sensor Issues

- Uncertainties of smart sensors
 - Uncertainty in data domain
 - Uncertainty in the time domain
- Health-Enabled smart sensors
 - Evolving catalog of fault behaviors
 - Algorithms for health assessment



SSC Test Environment: Discrepancy Reports (DRs)

- Rigorous method of documentation to identify and solve problems—especially sensor/actuator failures
- Complete files available for test stands
- DR Review methodology
 - +150 DRs reviewed/summarized from E1 focusing on sensor problems and descriptions
 - Failure (“health”) descriptors (Aerospace Corp.)

Sample DR

| | | | | |
|-----|-----------|-------------|--|----------------------------------|
| 184 | 8/29/2000 | TE-202-IGM | Reads over scale entire duration of recording | Replaced amp |
| | | TE-103B-CHM | Reads over scale entire duration of recording | Checked connections |
| | | TE-103B-INJ | Becomes very hashy at T+1s. Possible loose conn. | Checked connections |
| | | TE-103E-INJ | Reads over scale entire duration of recording | Checked connections: Swapped amp |
| | | TE-103L-INJ | Reads around -260F entire duration of rcd. Very noisy | Checked connections. Reconnect |
| | | TE-104-CHM | Reads opp dir of TE-105-CHM and gets noisy at T+2s | TC wired backwards |
| | | | Prob. Has TC leads swapped and a loose connection | |
| | | TE-203A-INJ | Should be close to 204B. It goes in the opp. Direction | MSID file error, wrong units |
| | | TE-204A-INJ | Appears to be identical data to TE-204B-INJ | |
| | | TE-204B-INJ | Appears to be identical data to TE-204A-INJ | Wrong filename |

■ Sample fault behavior descriptions

- Overscale
- Hashy, Noisy
- Readings deviate from expected
 - Polarity
 - Value
- Suspected alias

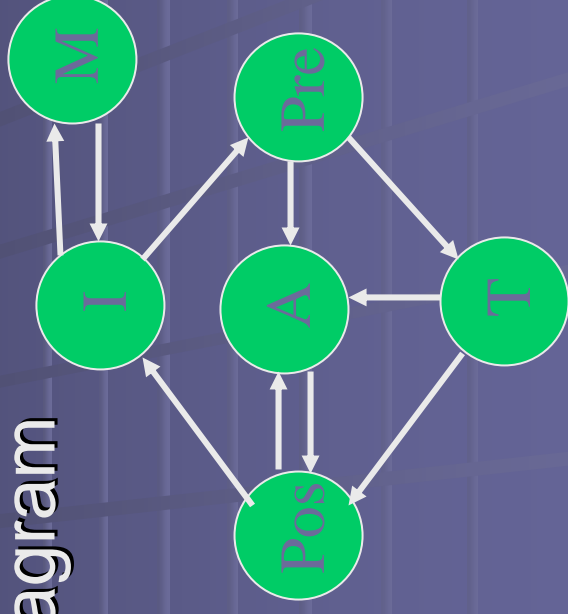
Summary of Typical Fault Behaviors

- Limits (signal, noise) - (High, Low)
 - Nominal values (Mean, Variance)
- Saturation (High, Low)
 - Alias
 - Impossibility
- Bandwidth (signal, noise)
 - Instrumentation
 - Flat
 - Static (offset) error
 - Gain (slope) error
- Spike noise limit
- Attack, t_r (Max, Min)
- Decay, t_f (Max, Min)

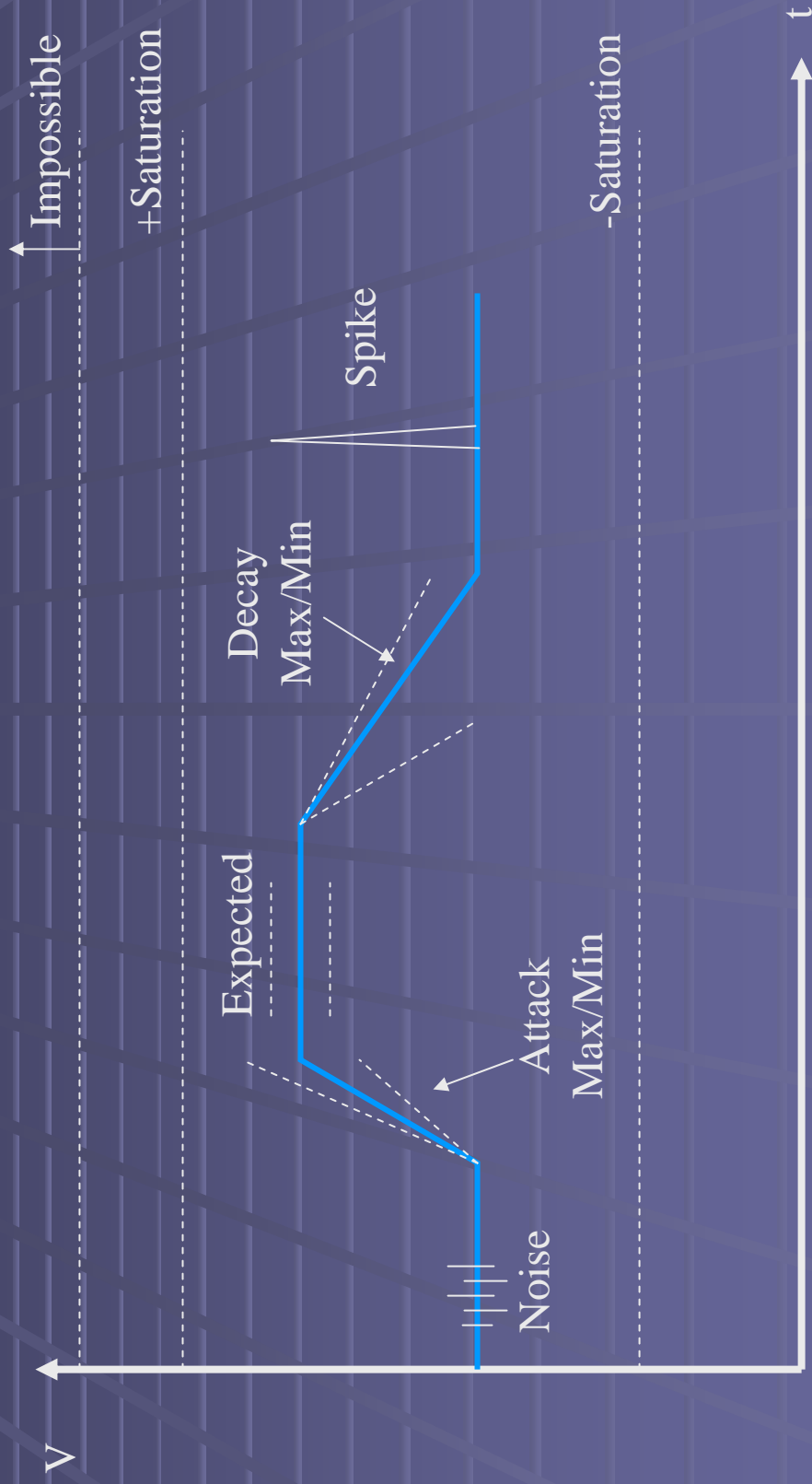
Fault Behaviors Modified by Phase

Phase

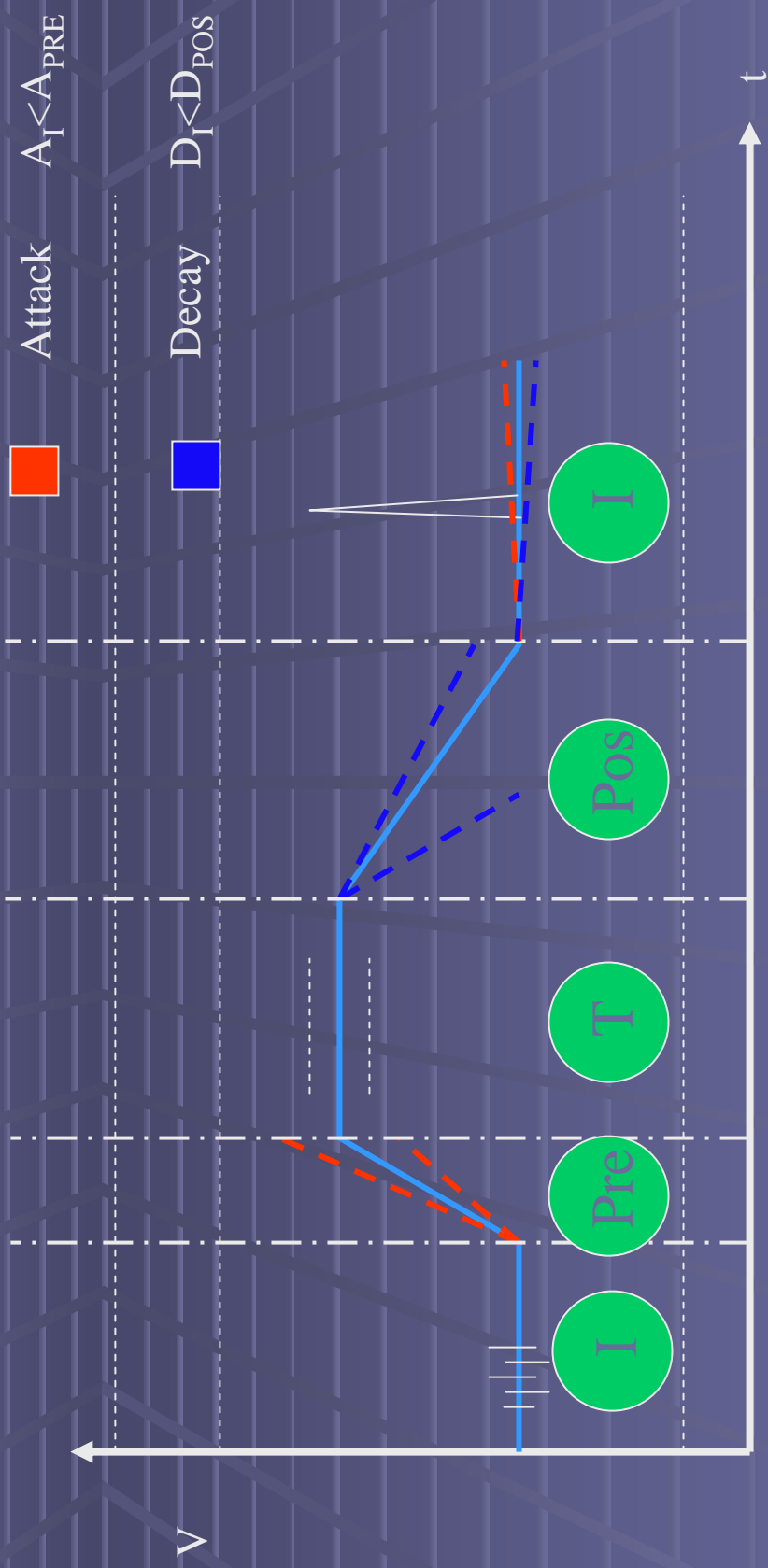
- Condition faults and values modified by context of the measurement—i.e., the *state* of the process or system modifies interpretation of signal/fault properties
- Example system state diagram
 - Idle
 - Pre-test (chill down)
 - Test
 - Post-test
 - Maintenance
 - Abort



Example Fault Behaviors: Condition



Phase Modifies Condition



Define, quantify, and model condition codes for each phase

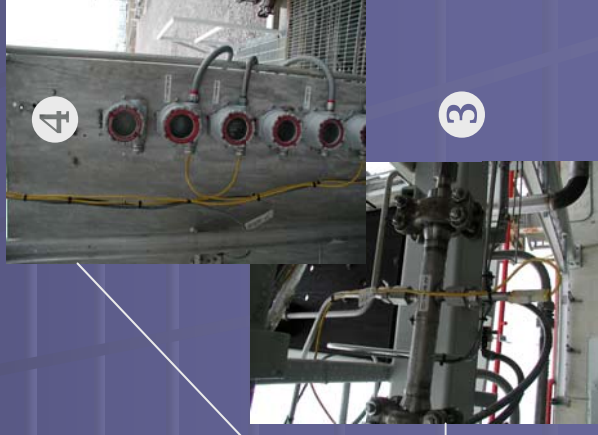
Example: During Idle, expect Max/Min Attack/Decay to be function of environmental forcings; During Pre-Test chill down, expect Max/Min Attack/Decay to be function of internal (pipe flow) forcings

Uncertainties of Smart

Sensors

Problem: Shared references of existing data acquisition systems are replaced with distributed—non shared—references

① Signal conditioning building (SCB) provides controlled environment for centralized data acquisition system (DAS) ② that converts signals from test stand transducers such as thermocouples ③. A smart sensor would be placed on the test stand similar to existing 4-20 ma transmitters ④.

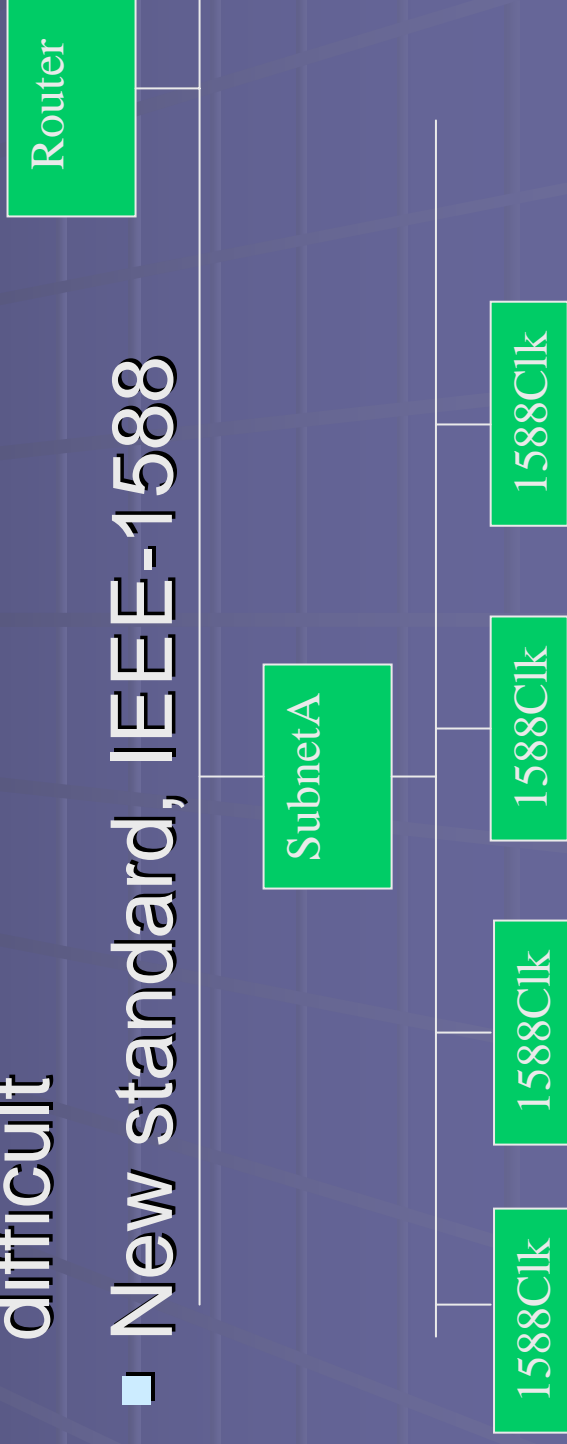


E2

Timing

- Deterministic structure of conventional DAS makes time-stamping easy
- Nondeterministic networks supporting smart sensors makes time-stamping difficult

- New standard, IEEE-1588



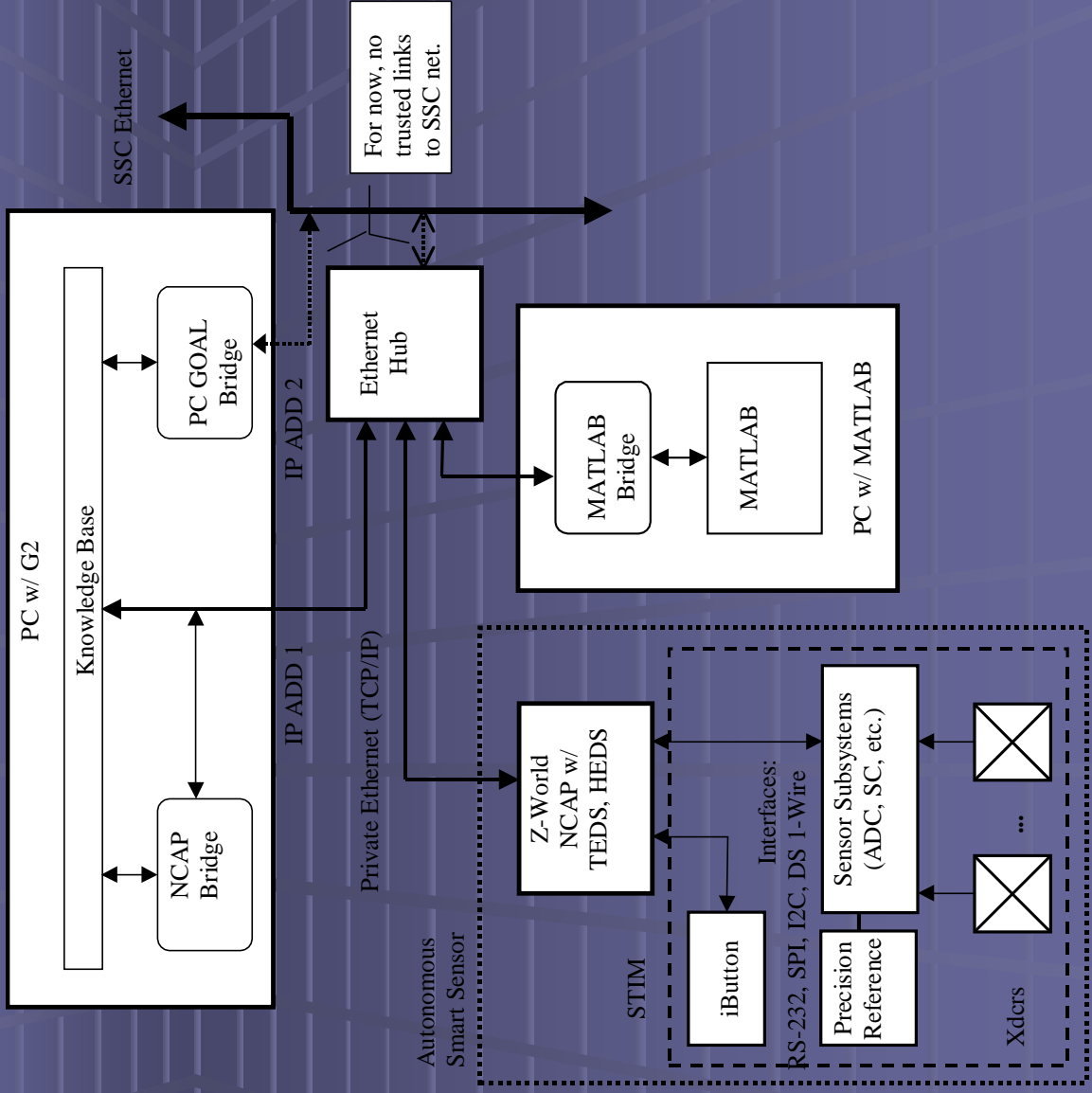
IEEE-1588

- For spatially-localized networks (e.g., Test stand)
- μs to sub- μs accuracy
- Applicable to high- and low-end devices
- Local oscillators are synchronized to reference oscillator(s) by measuring network transport delays

Recommendations & Future Work

- Development
 - Expert system (G2)
 - Baseline smart sensor (incl. HEDS)
 - Network issues
- Test support
 - Smart sensor evaluation (Vref, Time)
- Application
 - Lab
 - Field

Recap: G2- centric View



Task: Models

- Sensor data fusion and health assessment
 - Artificial Neural Nets (ANNs)
 - Wavelet transforms for feature extraction
- Models for failures; methods for detection

Smart Sensor Development

- Design/Implement smart sensor suite
 - Smart sensor architecture
 - TEDS/HEDS
 - Selected smart sensor

Task: HEDS Extensions to IEEE-1451

Data Structure Model for IEEE-1451

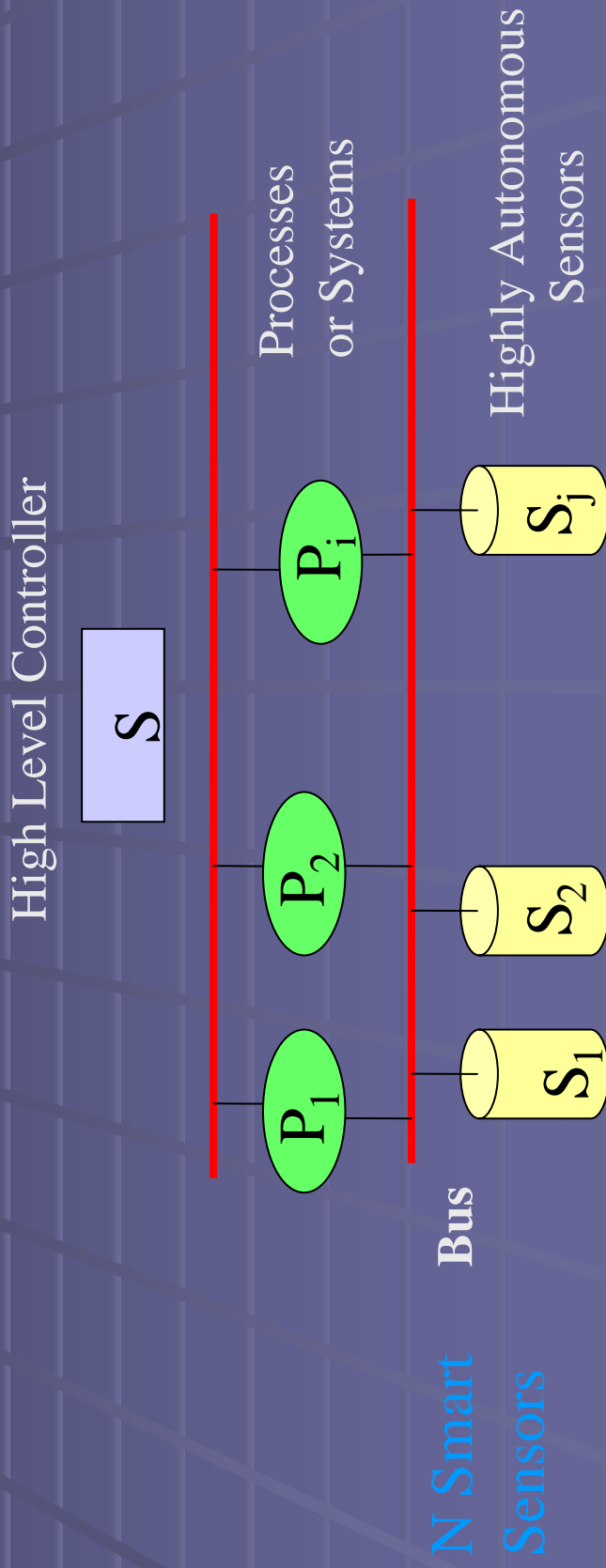
| Field No. | Description | Type | No. of Bytes |
|--|---------------------------------|--------|--------------|
| Data structure related data sub-block | | | |
| 1 | Extension: TEDS length | U32L | 4 |
| 2 | Extension TEDS ID Number | U16E | 2 |
| 3 | Extension TEDS version number | U16E | 2 |
| Application related data sub-block | | | |
| Fields 4-8 repeat for each health condition. | | | |
| 4 | Phase code | U8C | 1 |
| 5 | Condition code | U8C | 1 |
| 6 | Detection algorithm + arguments | STRING | Varies |
| Data integrity data sub-block | | | |
| N | Checksum for the extension TEDS | U16C | 2 |

Adapting IEEE-1451 for HEDS

- Full catalog/analysis of exemplar sensor (and actuator) faults
- Codify fault conditions and system phases
- Define HEDS as TEDS extensions
- Submit to IEEE-1451 WG

Task: Networking

- Timing per IEEE-1588
- Modeling of large number of sensors



Sensor Test Suite

- Smart Sensor development/validation suite
 - NCAP w/ TII to support arbitrary STIM
 - Characterization capability
 - ENOB: Oven capability (-55°C to +125°C)
 - Jitter: Timing capability

Summary & Discussion