Intelligent Sensors and Components for On-Board ISHM

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Outline

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

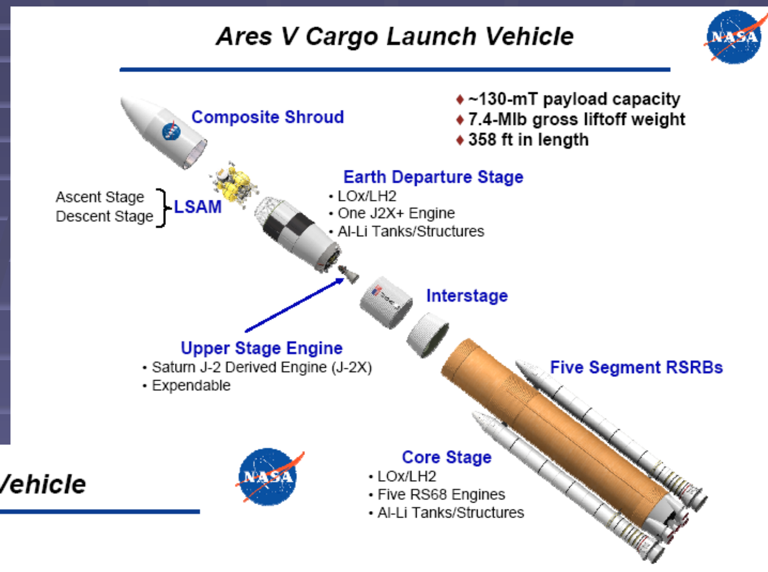
Origin:

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

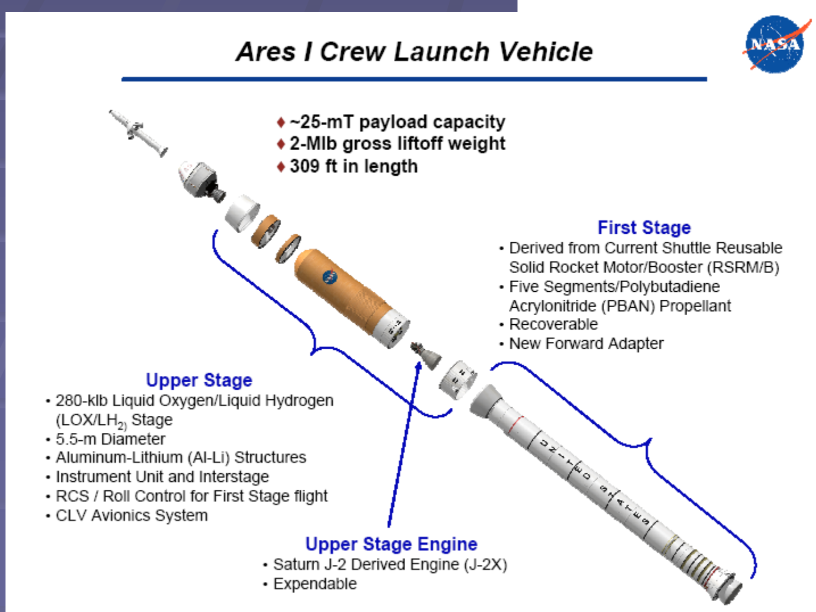
New Needs: Constellation Systems

Aries V:

Cargo Launch Vehicle

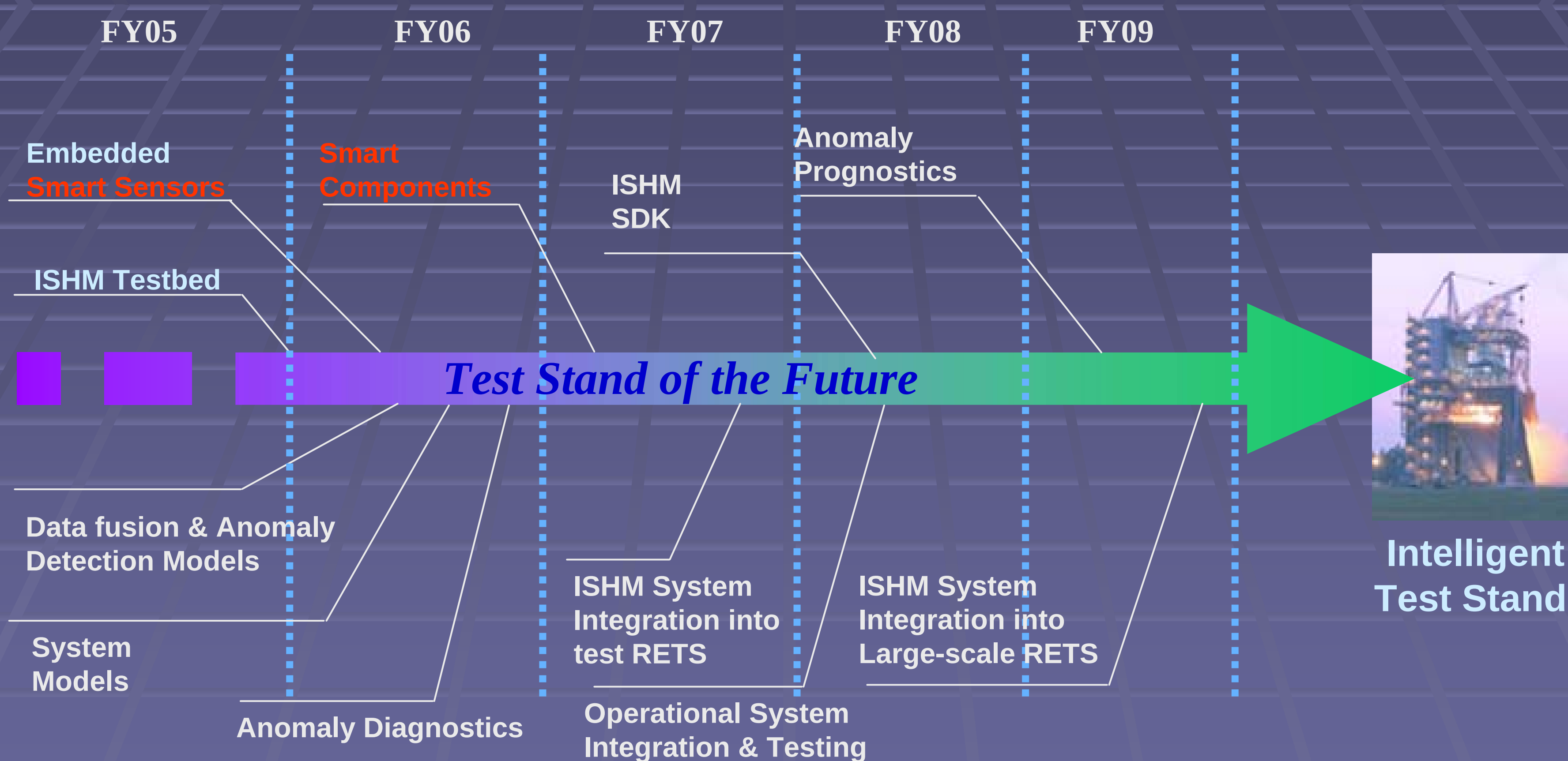


Lunar Habitat

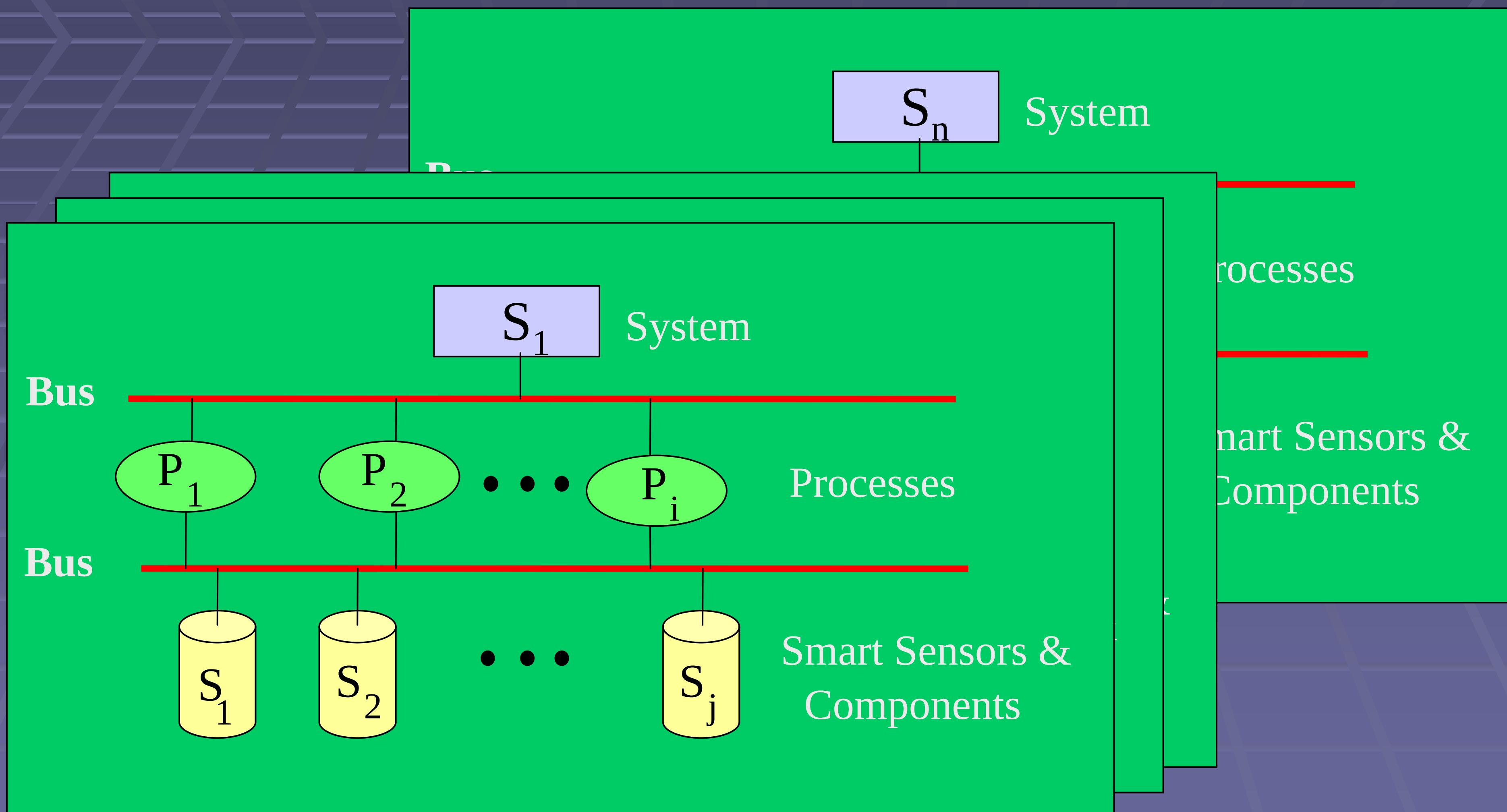


Aries I: Crew Launch Vehicle

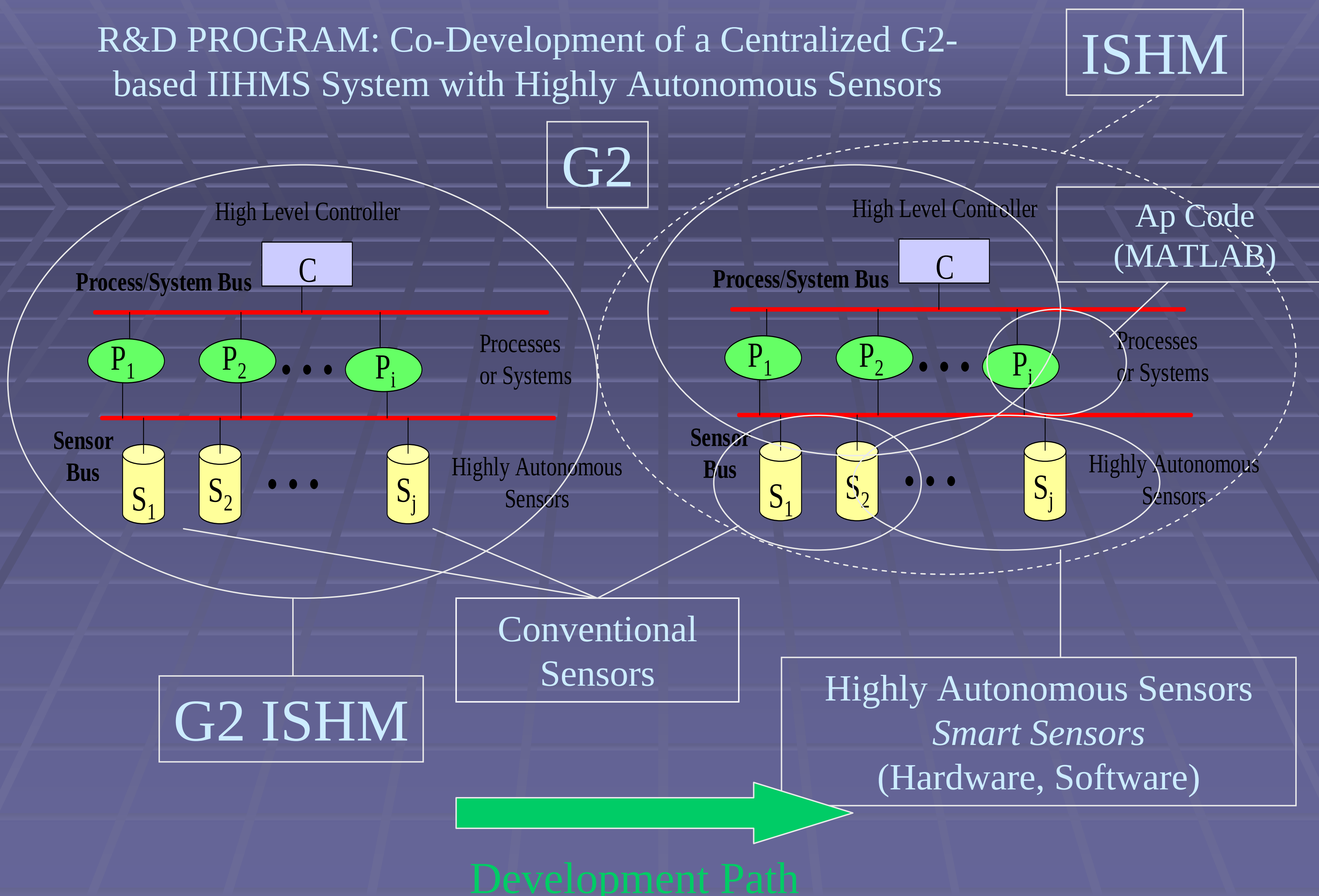
Rocket Engine Test Stand Technology Roadmap



System-of-System
Integrated Systems Health Management (ISHM)



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

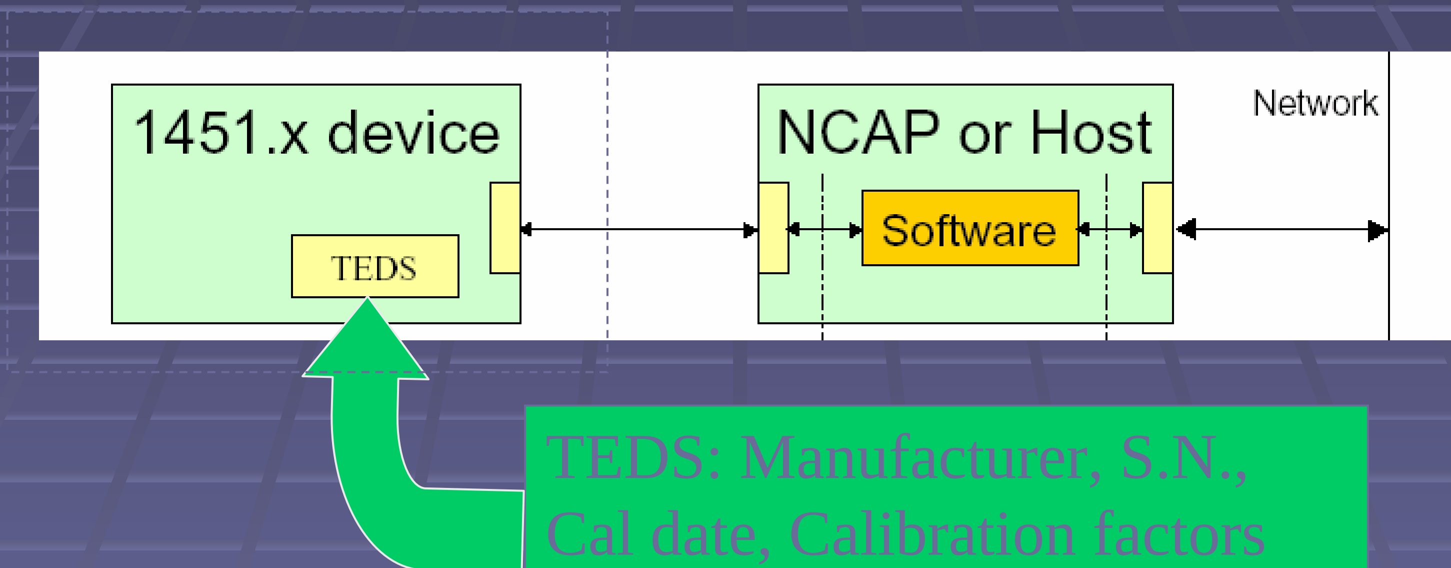


Key Components & Technologies

- 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 µP communication protocols and transducer electronic data sheet (TEDS)
  - IEEE 1588, Precision clock synchronization protocol for networked measurement and control systems

Smart Sensor

STIM

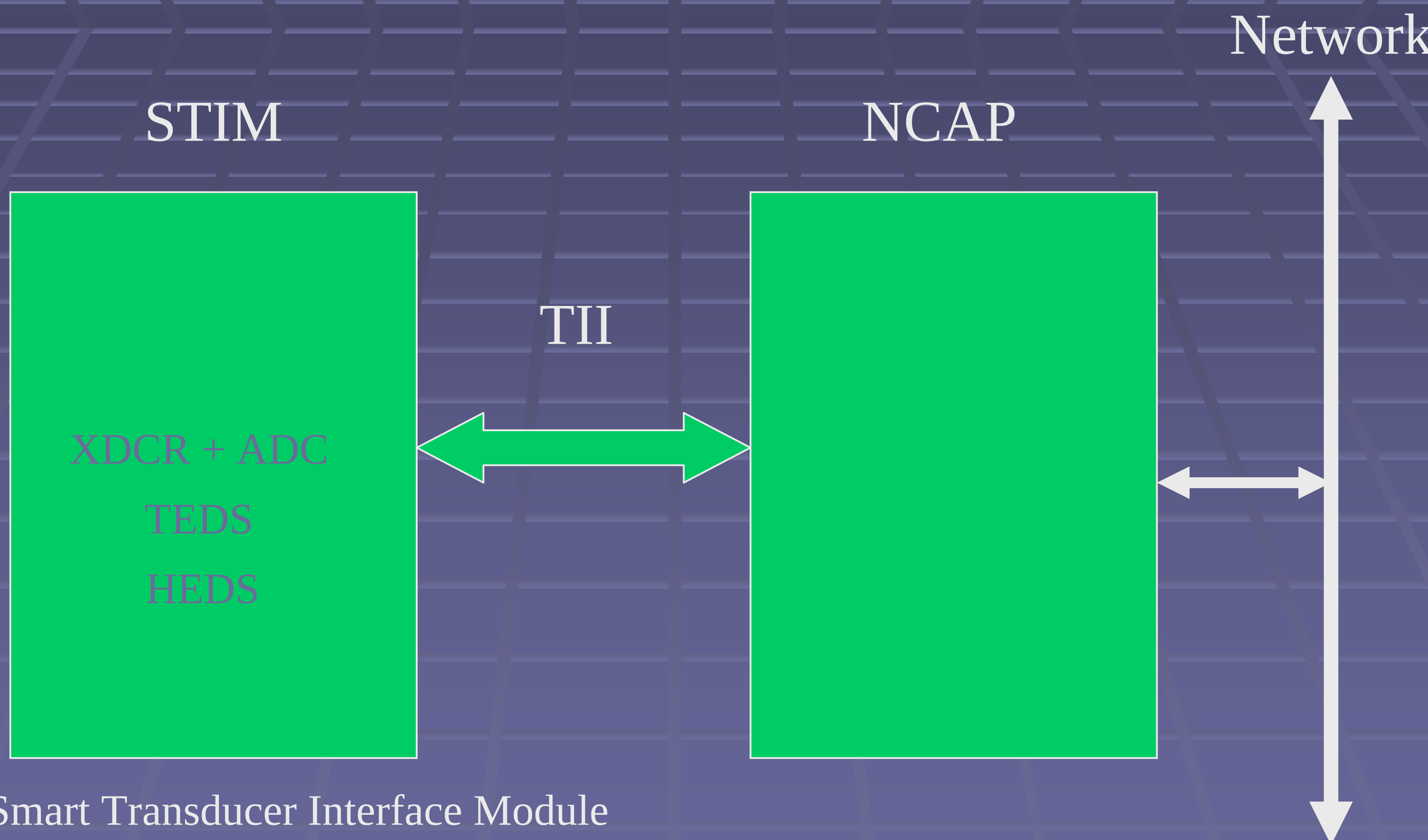


TEDS: Manufacturer, S.N., Cal date, Calibration factors

+ HEDS: Health parameters- Bandwidth, Max rise time, etc.

Smart Sensor ≡ Sensor + SC + DAQ + Comm + Diagnostics

IEEE-1451 Model of Smart Sensor: STIM <-> NCAP

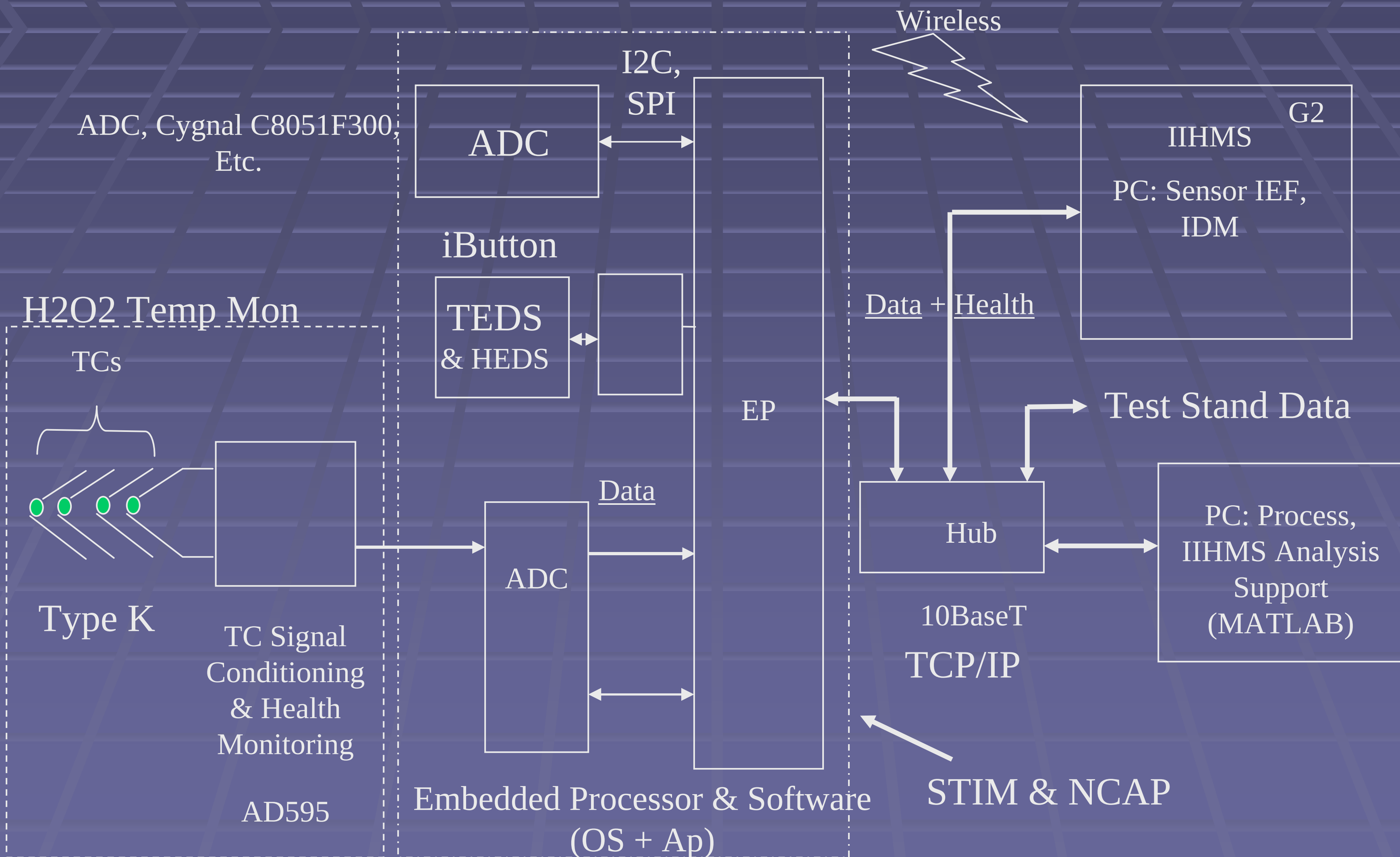


STIM: Smart Transducer Interface Module

TII: Transducer Independent Interface

NCAP: Network Capable Application Processor

Prototype Smart Sensor Arch:



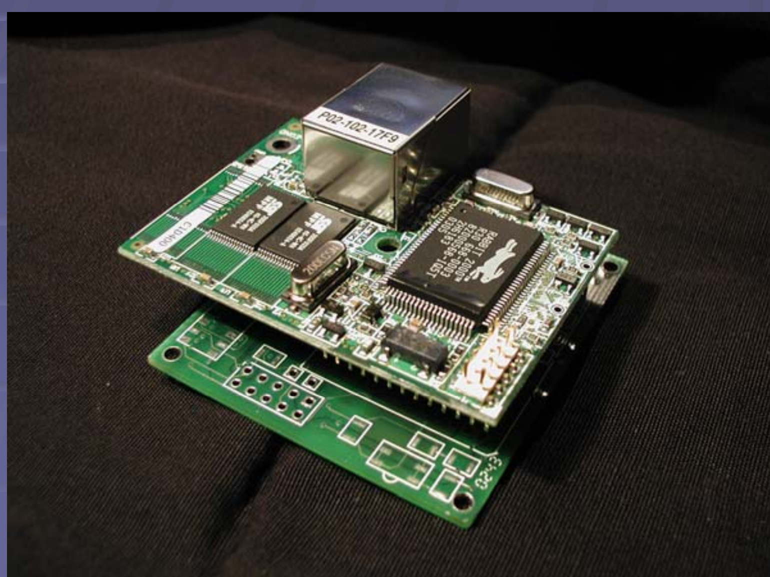
Sensor Architecture

- 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

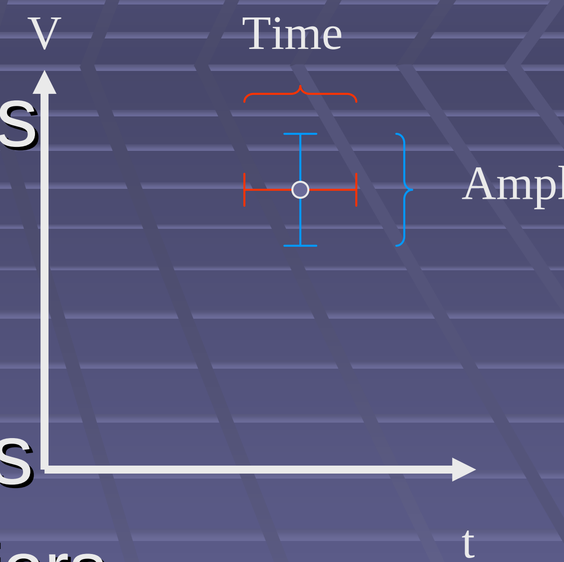


Sensor function:

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

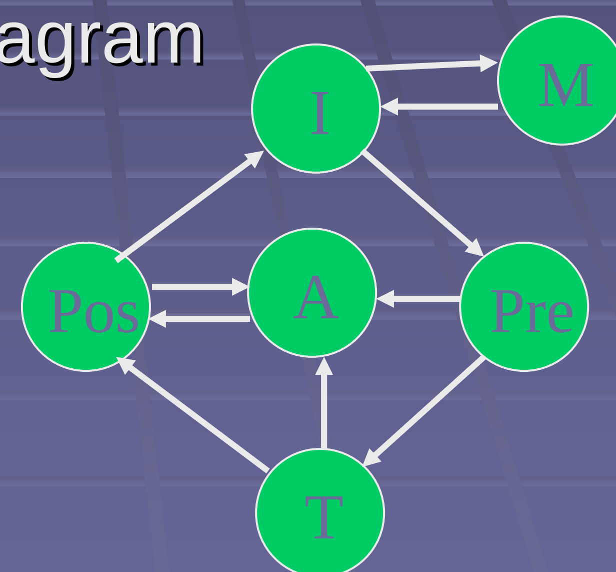
- Sample fault behavior descriptions
  - Overscale
  - Hashy, Noisy
  - Readings deviate from expected
    - Polarity
    - Value
  - Suspected alias

Summary of Typical Fault Behaviors

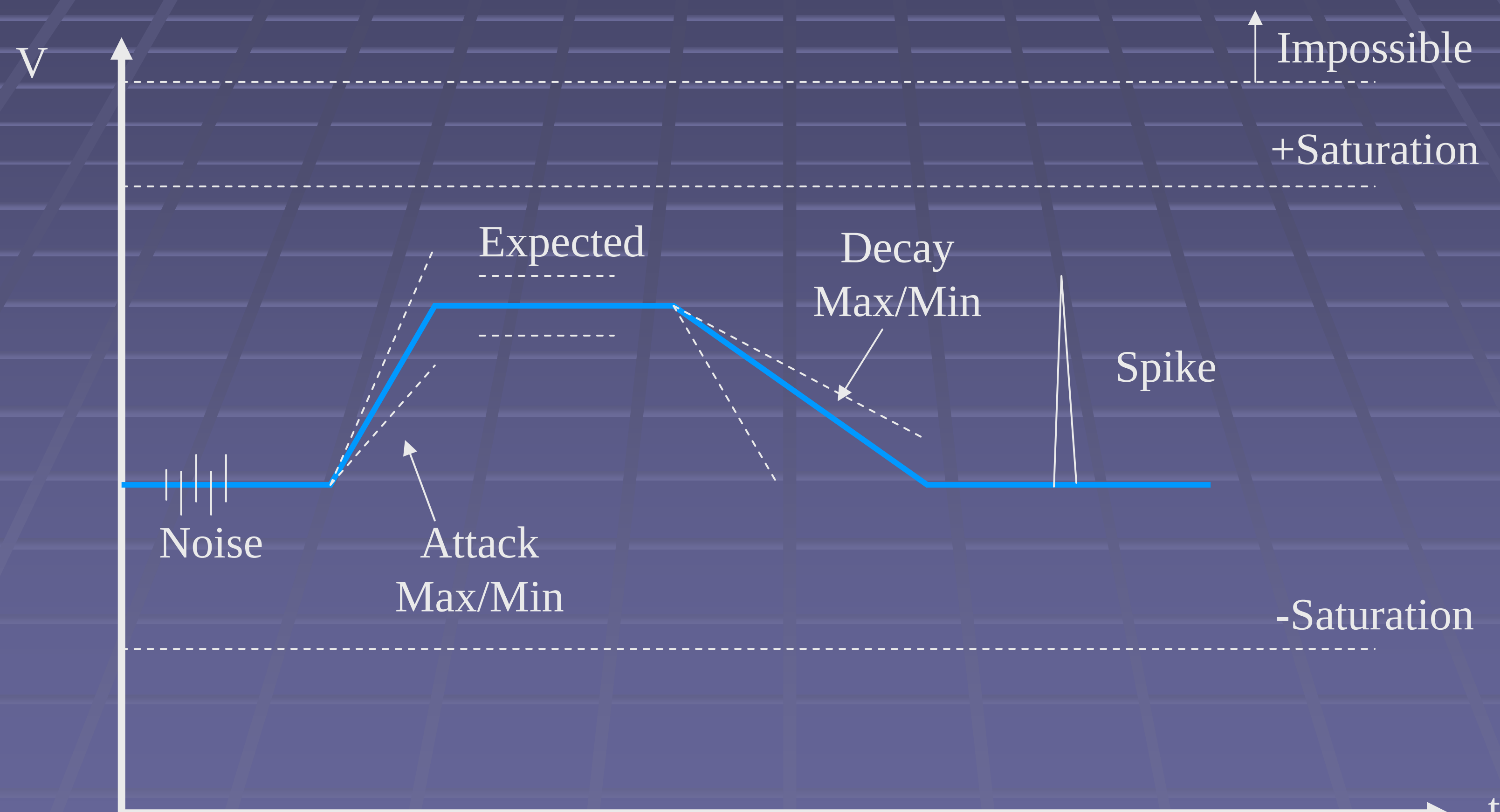
- Limits (signal, noise)- (High, Low)
- Saturation (High, Low)
- Bandwidth (signal, noise)
- Spike noise limit
- Attack, t_r (Max, Min)
- Decay, t_f (Max, Min)
- Nominal values (Mean, Variance)
- Alias
- Impossibility
- Instrumentation
  - Flat
  - Static (offset) error
  - Gain (slope) error

Fault Behaviors Modified by Phase

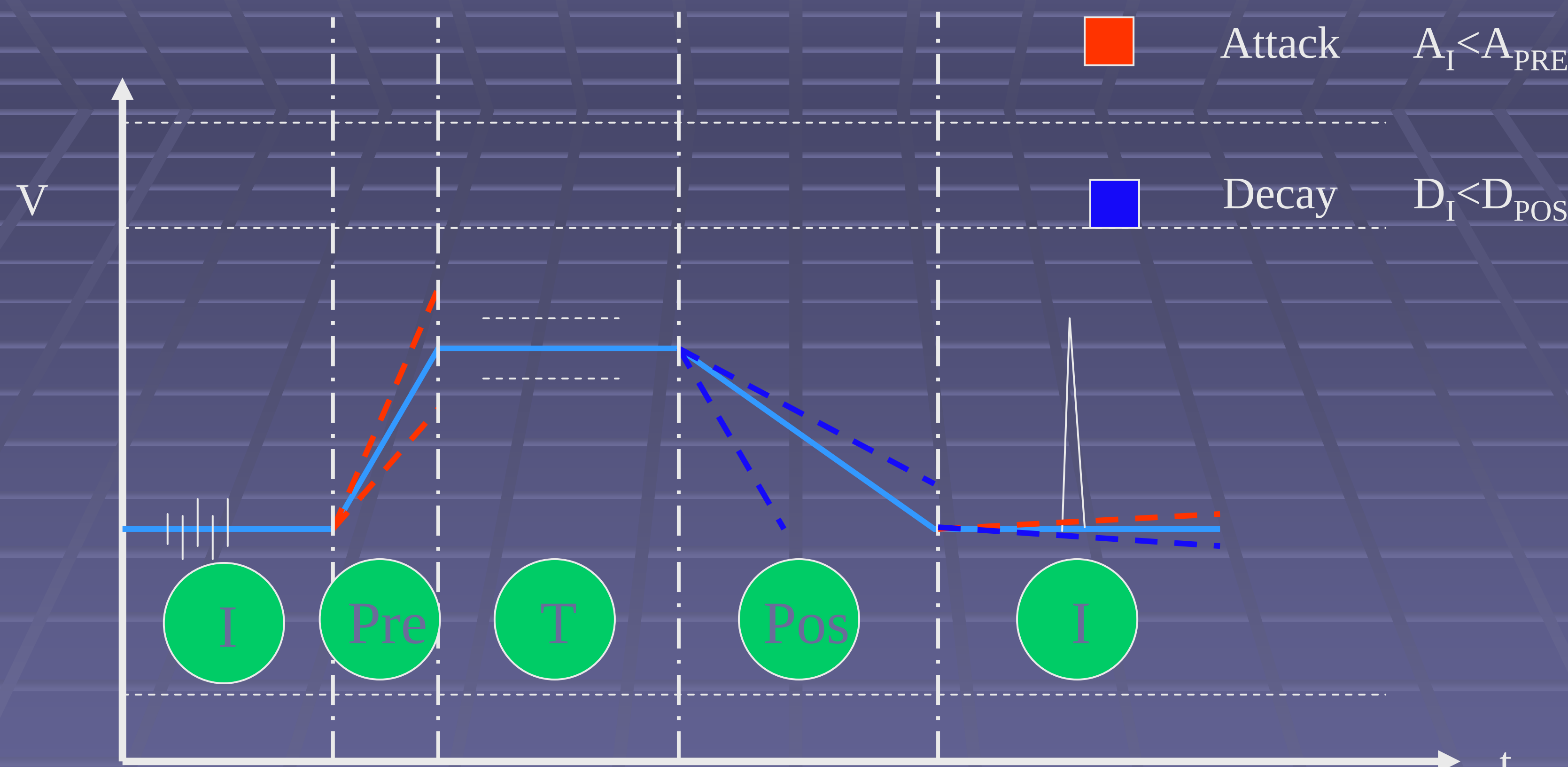
- Condition faults and values modified by context of the measurement—i.e., the *state* of the process or system modifies interpretation of signal/fault properties
- Example system state diagram
  - Idle
  - Pre-test (chill down)
  - Test
  - Post-test
  - Maintenance
  - Abort



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

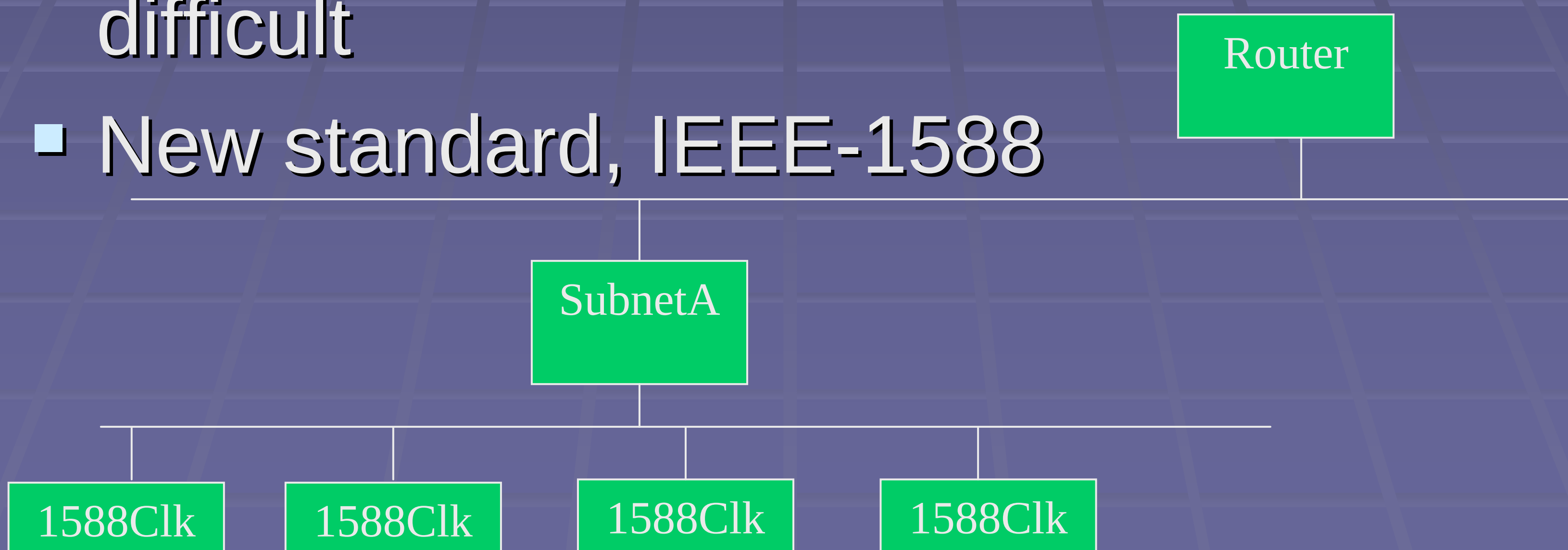
Problem: *Shared references of existing data acquisition systems are replaced with distributed—non shared--references*

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

E2

Timing

- Deterministic structure of conventional DAS makes time-stamping easy
- Nondeterministic networks supporting smart sensors makes time-stamping difficult
- New standard, IEEE-1588



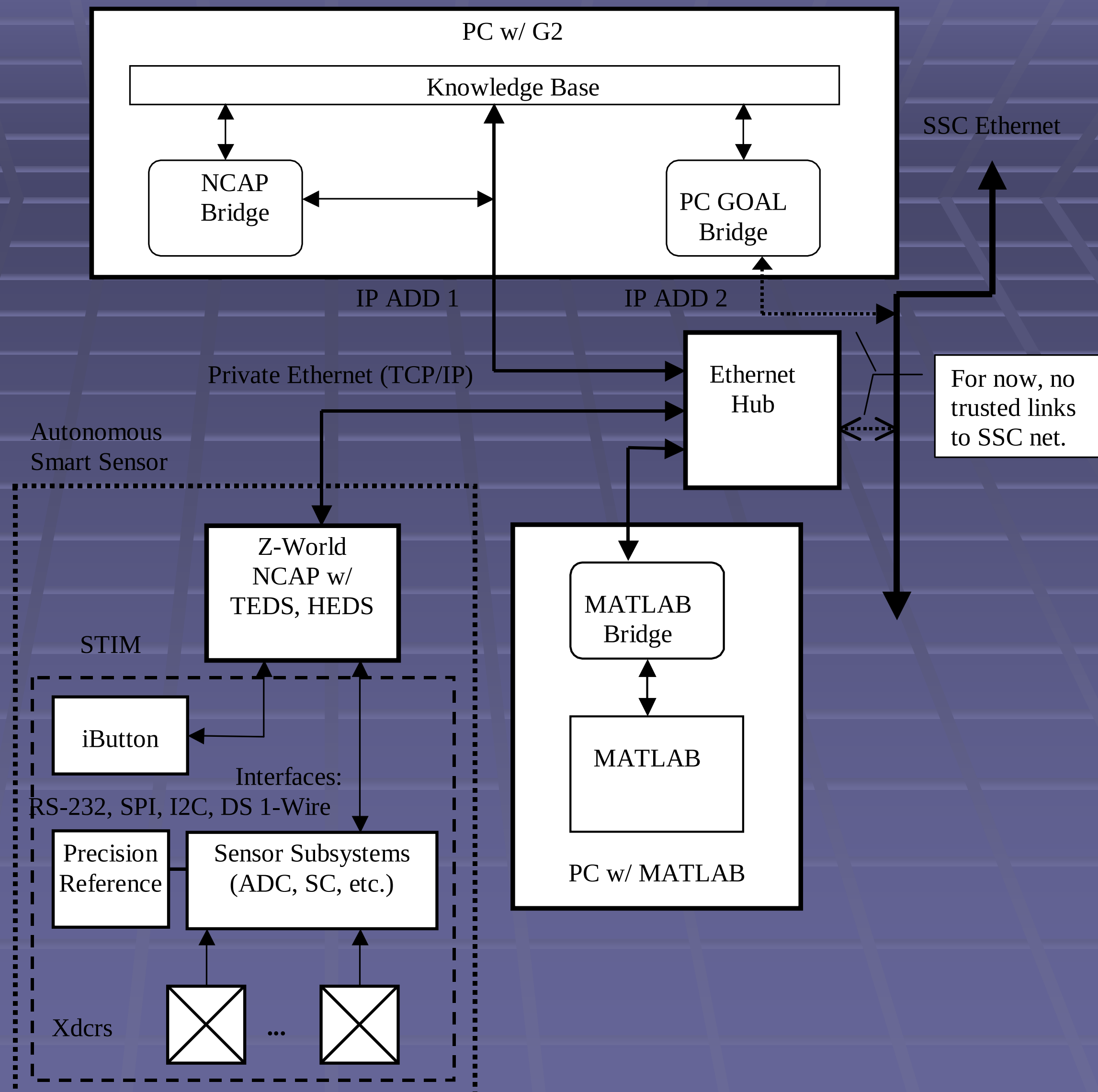
IEEE-1588

- 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

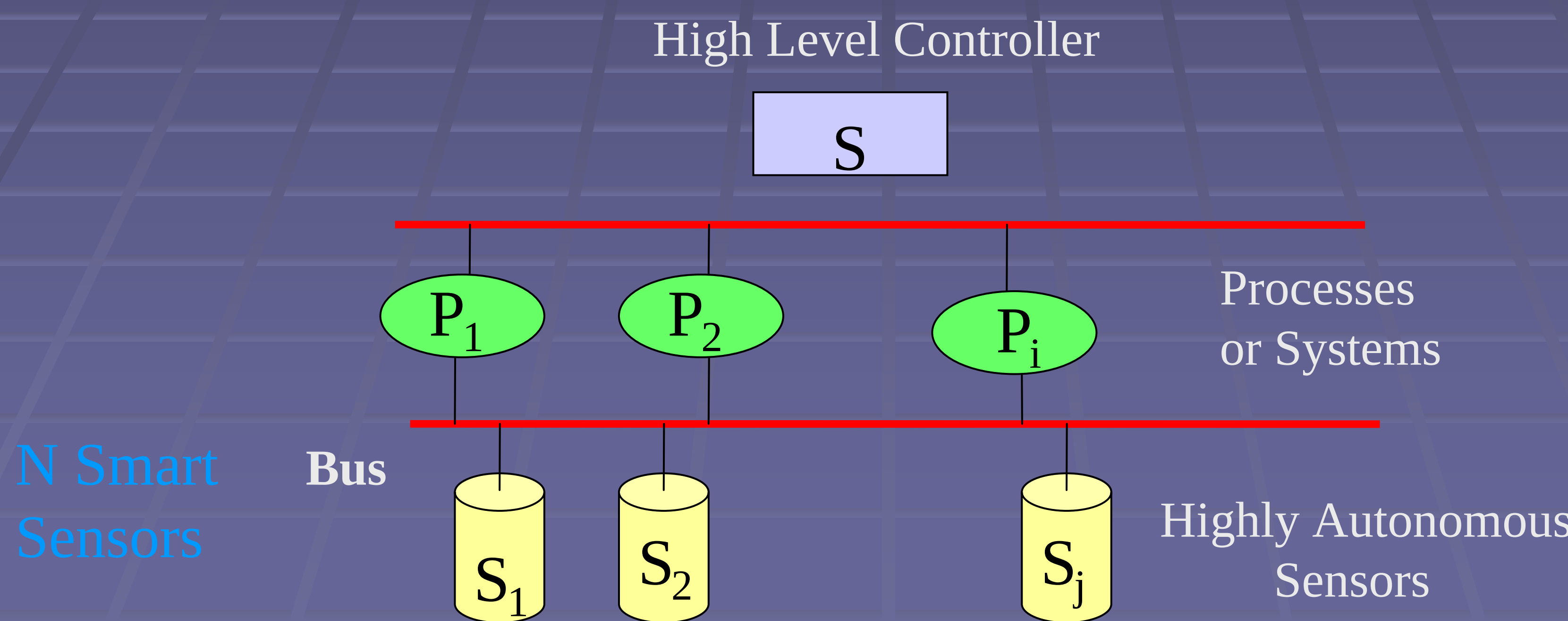
Field No.	Description	Type	No. of Bytes
	Data structure related data sub-block		
1	Extension: TEDS length	U32L	4
2	Extension TEDS ID Number	U16E	2
3	Extension TEDS version number	U16E	2
	Application related data sub-block		
	Fields 4-8 repeat for each health condition.		
4	Phase code	U8C	1
5	Condition 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