Distributed Engine Control Session

Propulsion Control and Diagnostics Workshop
December 11-12, 2013

Cleveland, Ohio

Session Agenda

3:20 pm **Distributed Engine Control Overview** – Dennis Culley

3:40 pm **Modeling control elements with an outlook toward hardware-in-the-loop (HIL) operation** – Alicia Zinnecker

4:00 pm **Decentralized Engine Control System Simulator** - John McArthur

4:20 pm **HIL System Integration** – Eliot Aretskin-Hariton

4:40 pm **Power-Line Data Communication in High Temperature Environments** – Larry Greer

5:00 pm **High Temperature SiC Electronics: Update and Outlook** – Glenn Beheim

Distributed Engine Control Overview

Dennis Culley

Outline

- Motivation
- Technology Development
  - Modeling
  - Hardware-in-the-Loop
  - High Temperature Electronics
- Technical Interaction

Motivation

What is the problem we are trying to solve?

What can we do about it?

Customers Don't Buy Technology, They Buy Capability

Who cares?

What is the expected outcome?

Distributed Engine Control
A Collection of Underlying Technologies

Including, but not limited to …

- High Temperature Electronics
- Communications and Networking
- Control System Integration
- System Modeling & Analysis
- Verification & Validation
- System Certification
- Supply Chain Viability
- Engine – Airframe Integration

How do you solve a system problem if you don't have system knowledge?

Distributed Engine Control Working Group (DECWG)

a consortium based on pre-competitive technology

It is in our interest to develop a long term collaboration on controls

This is not about a point design… It is about a "*sustainable ecosystem*"

System Improvements - System Constraints

Research
- Aerodynamic improvements
- Materials improvements

Leading to
- Higher bi-pass ratio
- Smaller core
- Higher temperatures

Resulting in
- Lower SFC
- Higher power density core

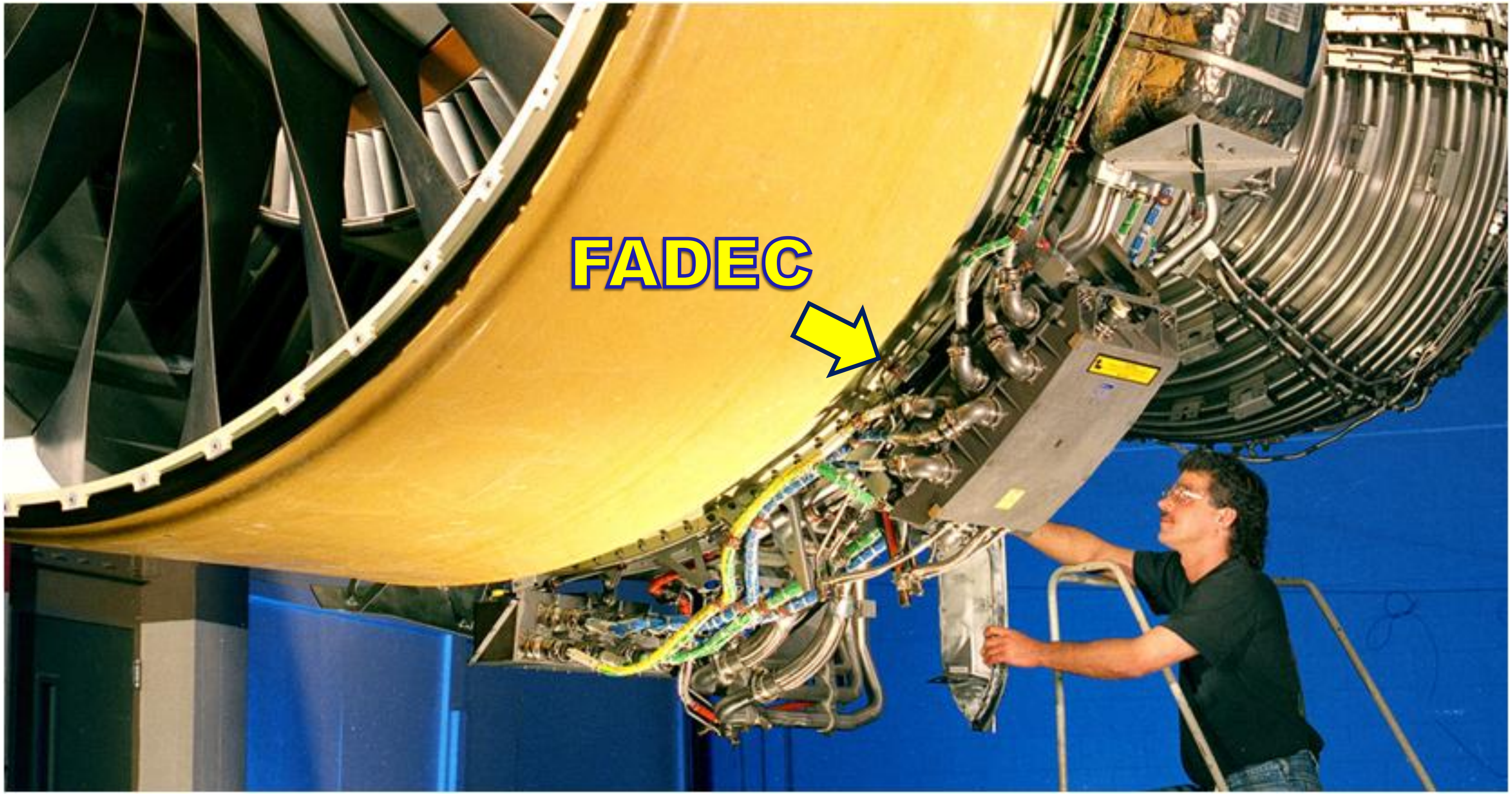
- **A more difficult environment for controls due to mounting restrictions and operational temperatures**

PLUS

- **Commercial electronics obsolescence (typical 2 – 5 years)**

Podded Engine

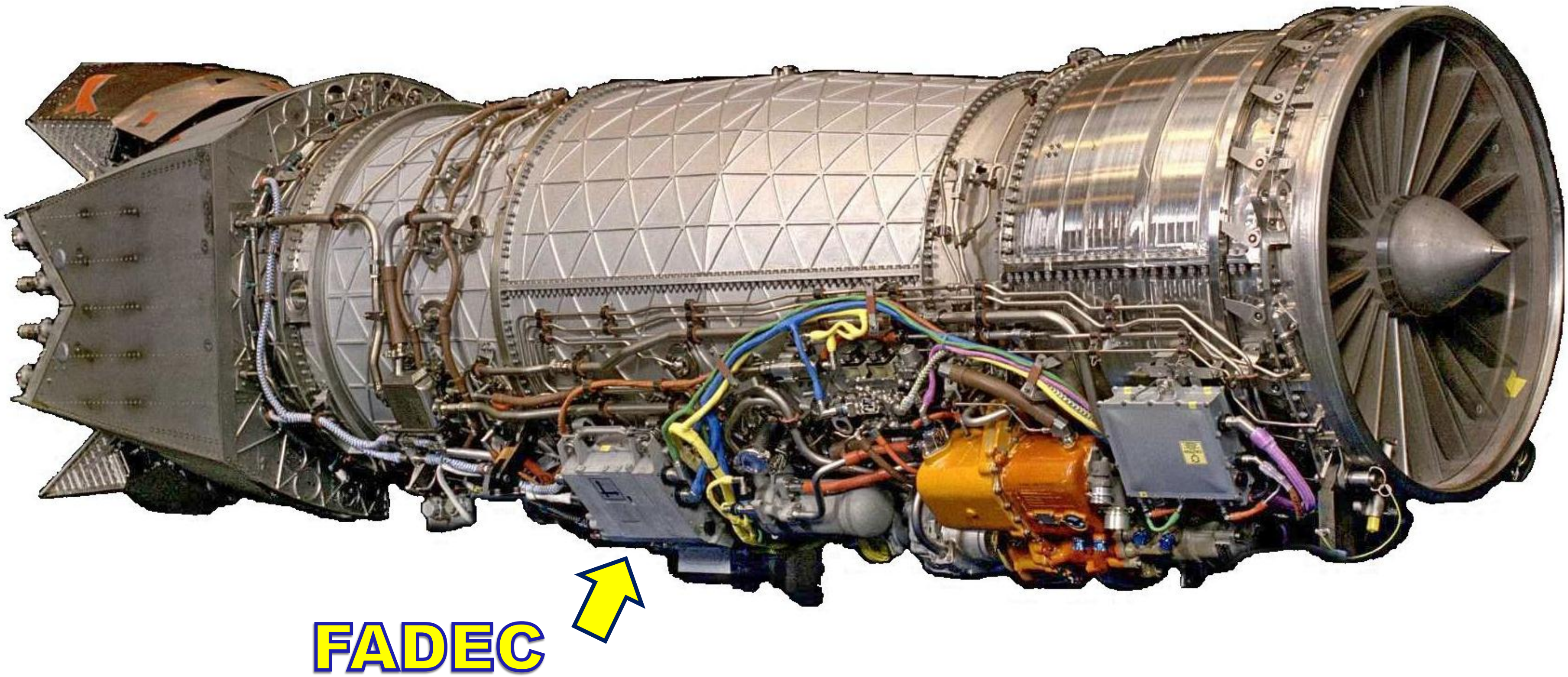
Controller Mounted on Fan Casing - Air Cooled



Public Release Photo Courtesy of Pratt & Whitney

Embedded Engine

Controller Mounted on Core - Fuel Cooled



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Distributed Engine Control

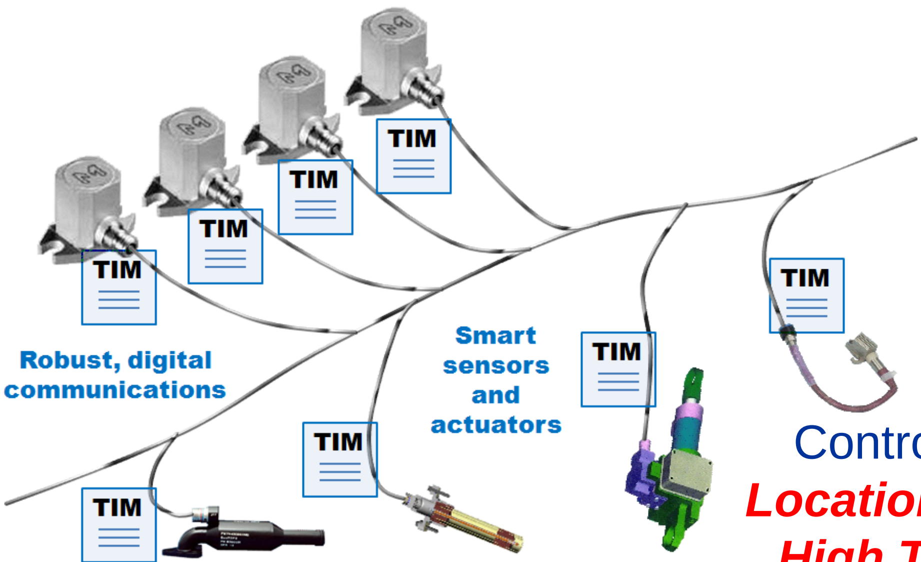
New Capability that Directly Addresses Unique Constraints Imposed on the Control System

based on

Modular, Flexible, Scalable Control Architecture

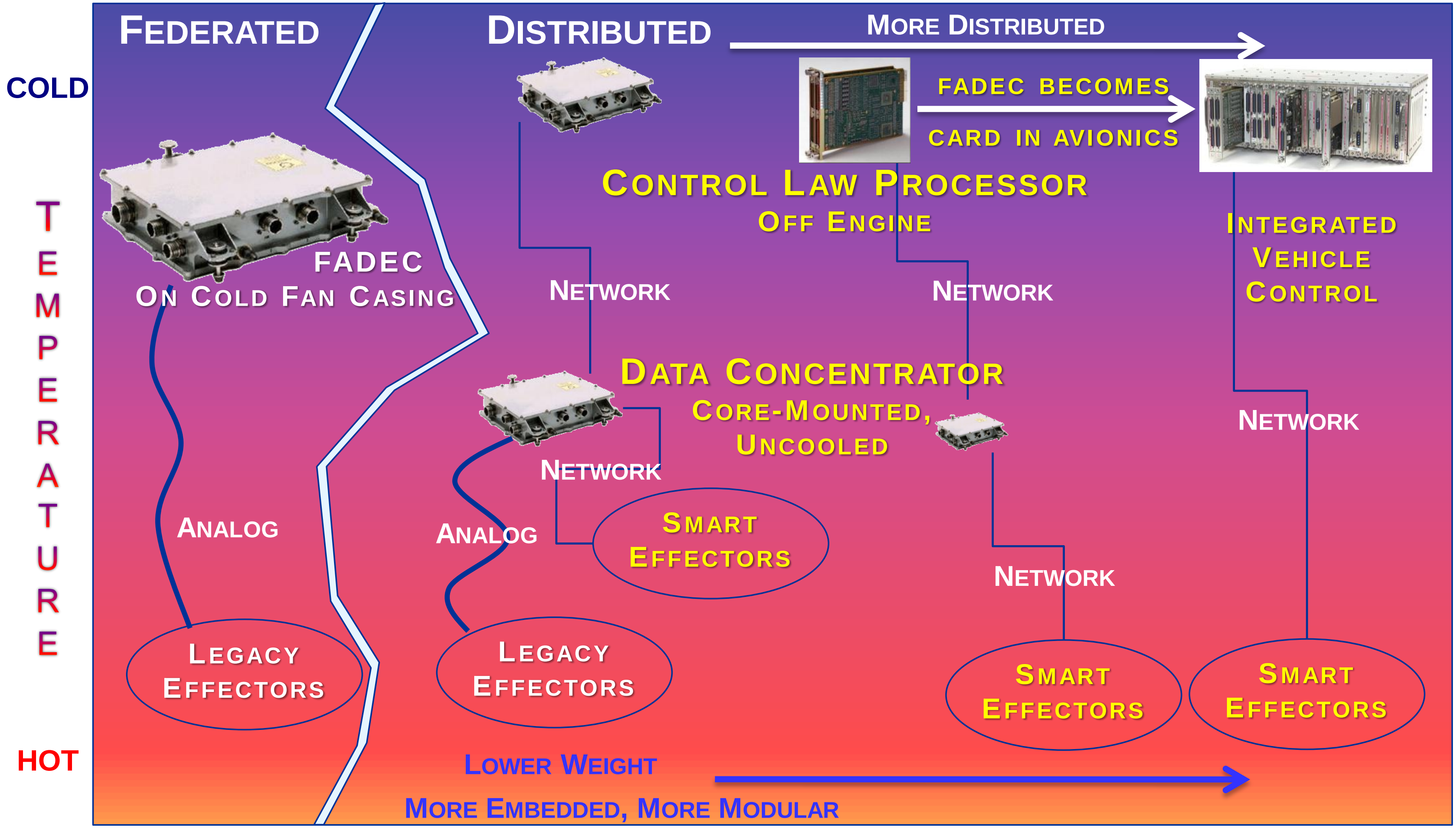
Public release photo Intel.com

Processing-Intensive control functions based on commercial electronics are ***Location Independent***



Control Effector functions are ***Location Dependent*** and require ***High Temperature Capability***

Distributed Engine Control Roadmap



Control System – Future Growth

Engine system integration

- Focuses on "***how to integrate the control system***" **– a network issue**
- Not "*how does control integrate with the engine system*" – a hardware issue

For example:

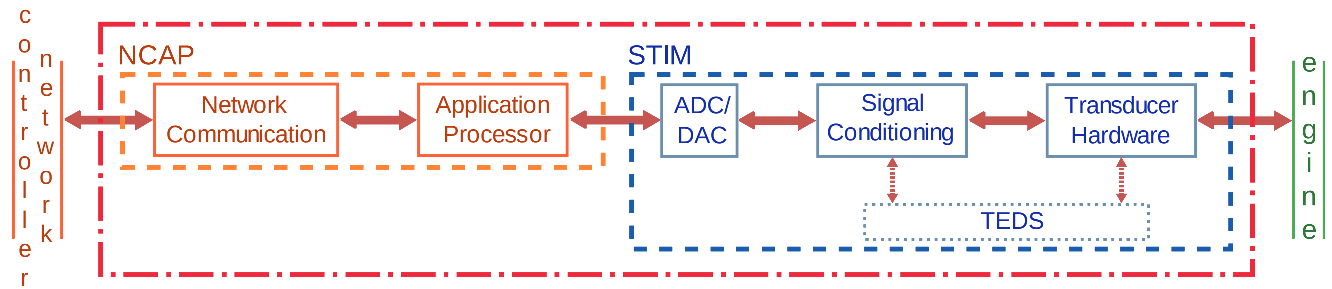
- A "smart" Ps3 sensor produces scaled, linearized pressure data in engineering units for direct use in the control system
- The device is integral to the compressor
- The data is integral to the control system

This shift in approach opens up the possibility of simplifying the evaluation of new technology insertion at an earlier stage of development.

The potential for a smart Ps3:

- Compressor stability detection by sensing pip / modal pressure fluctuation
- Stability control by embedded FFT processing, control logic, and closed loop control of a stability actuator (bleed or flow control)

Component Modeling



The **objective** is to develop guidelines for the modeling of smart system components so that they behave in the system in a predictable way and can easily be interchanged with hardware. **Emphasis is on defining the interfaces.**

IEEE 1451 standard: Smart Transducer Interface for Sensors and Actuators

- Smart Transducer Interface Module (STIM) defines the analog functionality between the plant and the embedded processor
- Network Capable Application Processor (NCAP) defines the digital/software functionality up to the network

The **goal** is to encourage collaborators to provide *sharable models* for their embedded control functions and *a growth path for control applications*.

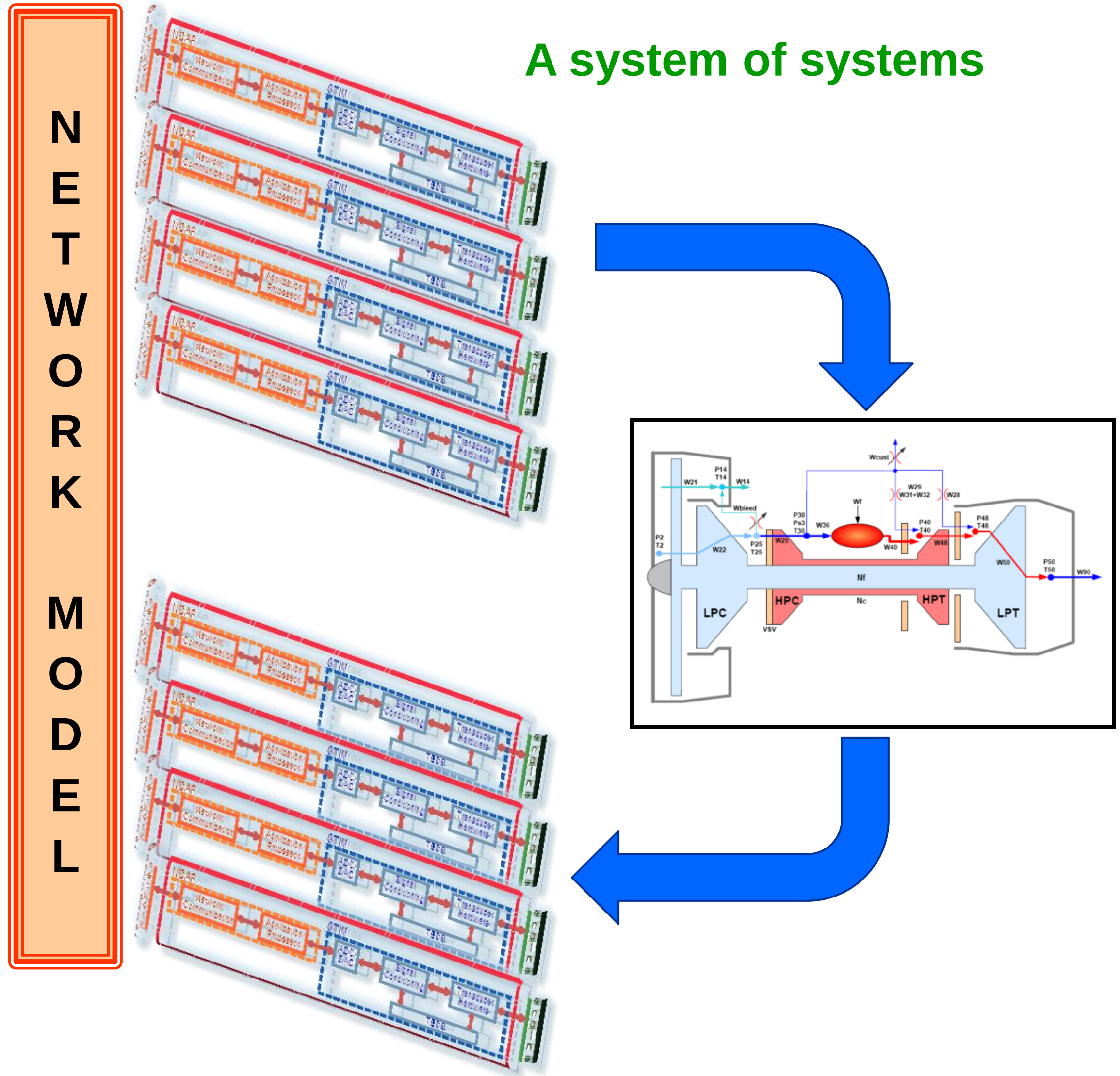
System Modeling

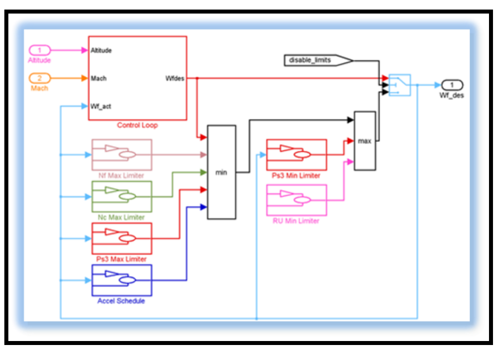
The network:

- the “glue” that defines the control architecture
- controls **data flow** and **synchronization**

… and impacts **performance**

A system of systems



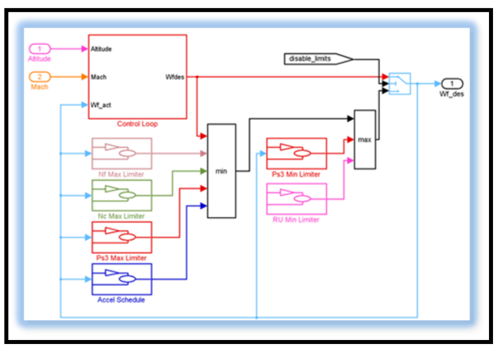


Hardware-in-the-Loop

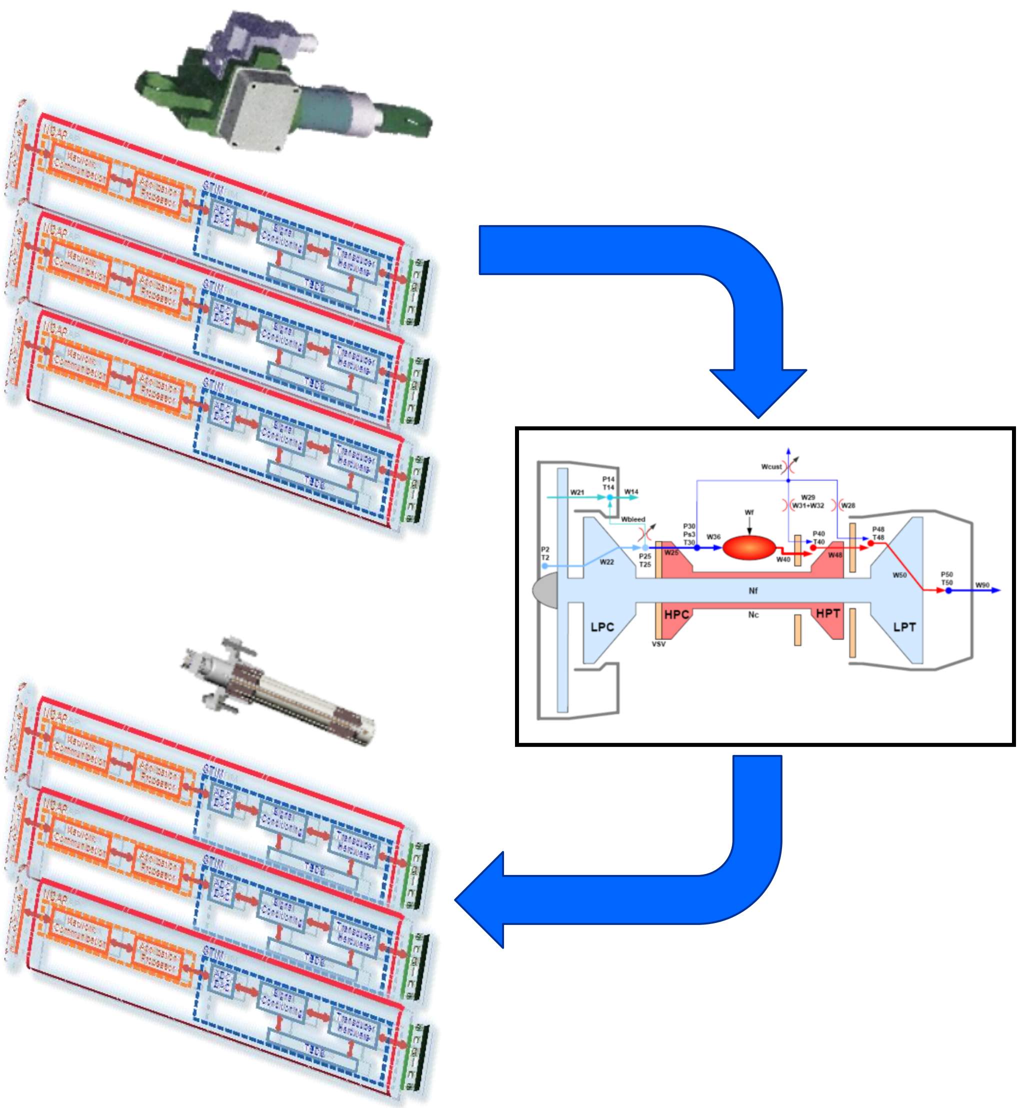
The network also:

- enables the integration of hardware into the control system simulation

Embedded processing in sensors and actuators affects internal control interfaces but not the interfaces between the control system and the engine plant

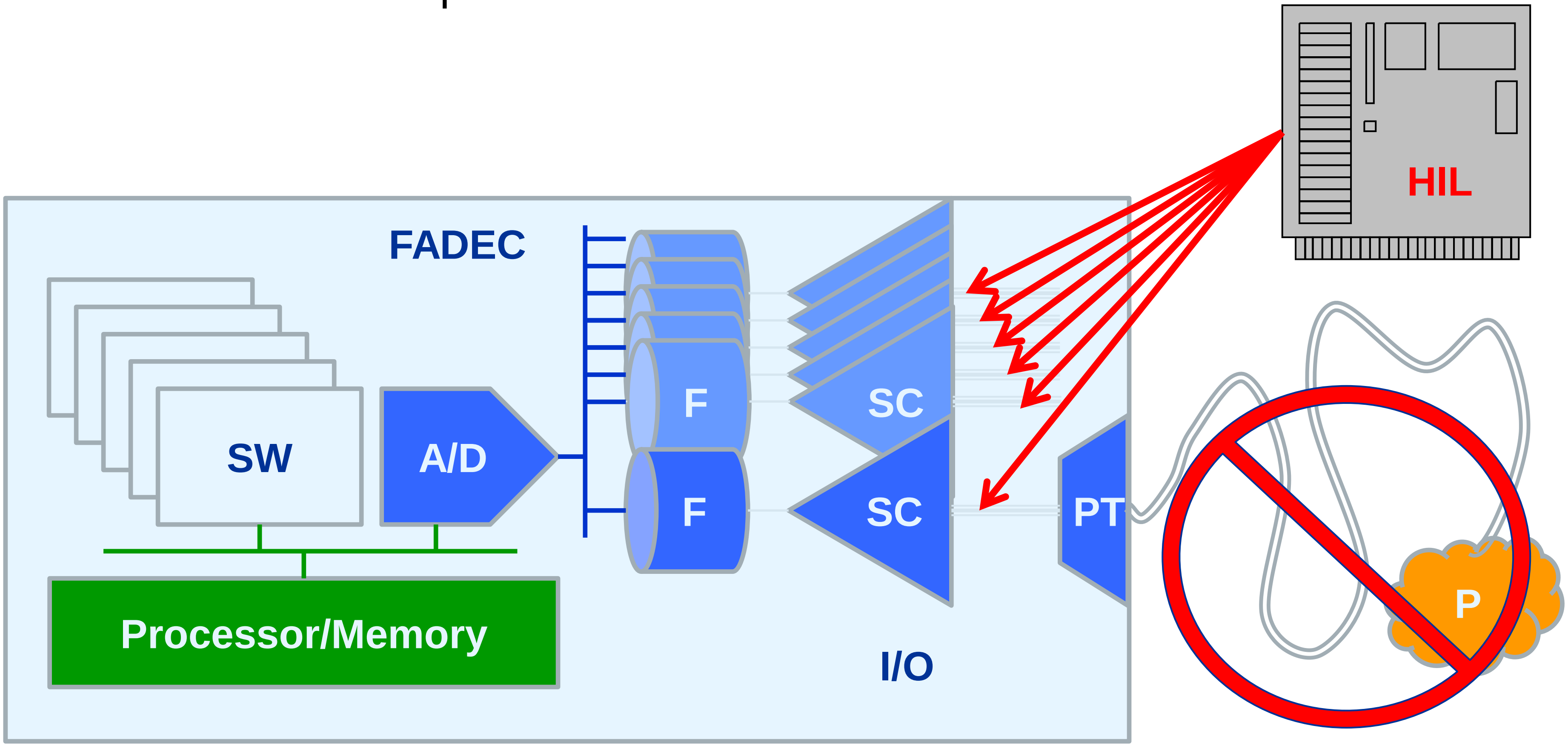


NETWORK MODEL



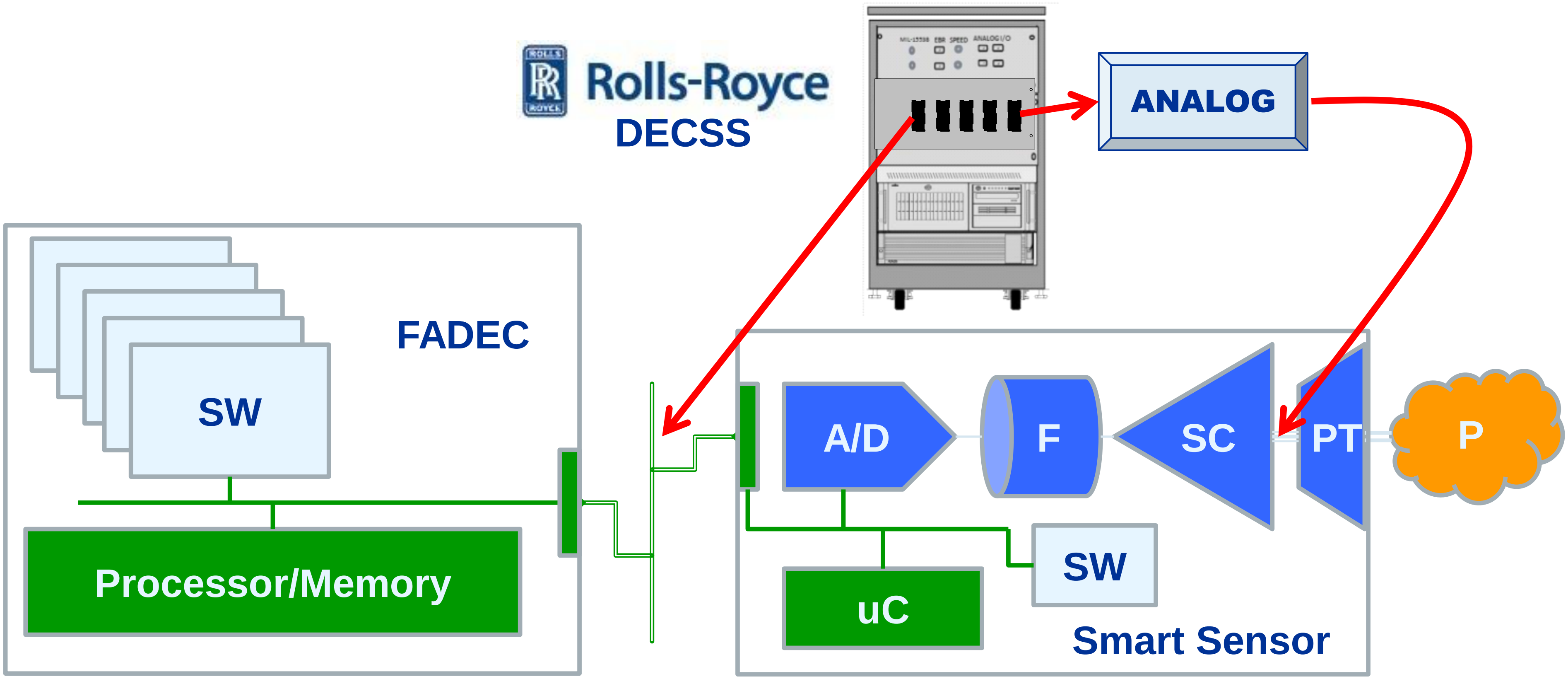
HIL in a Centralized System

In typical centralized control systems, the HIL system interfaces to a FADEC because it performs all the sensor/actuator I/O

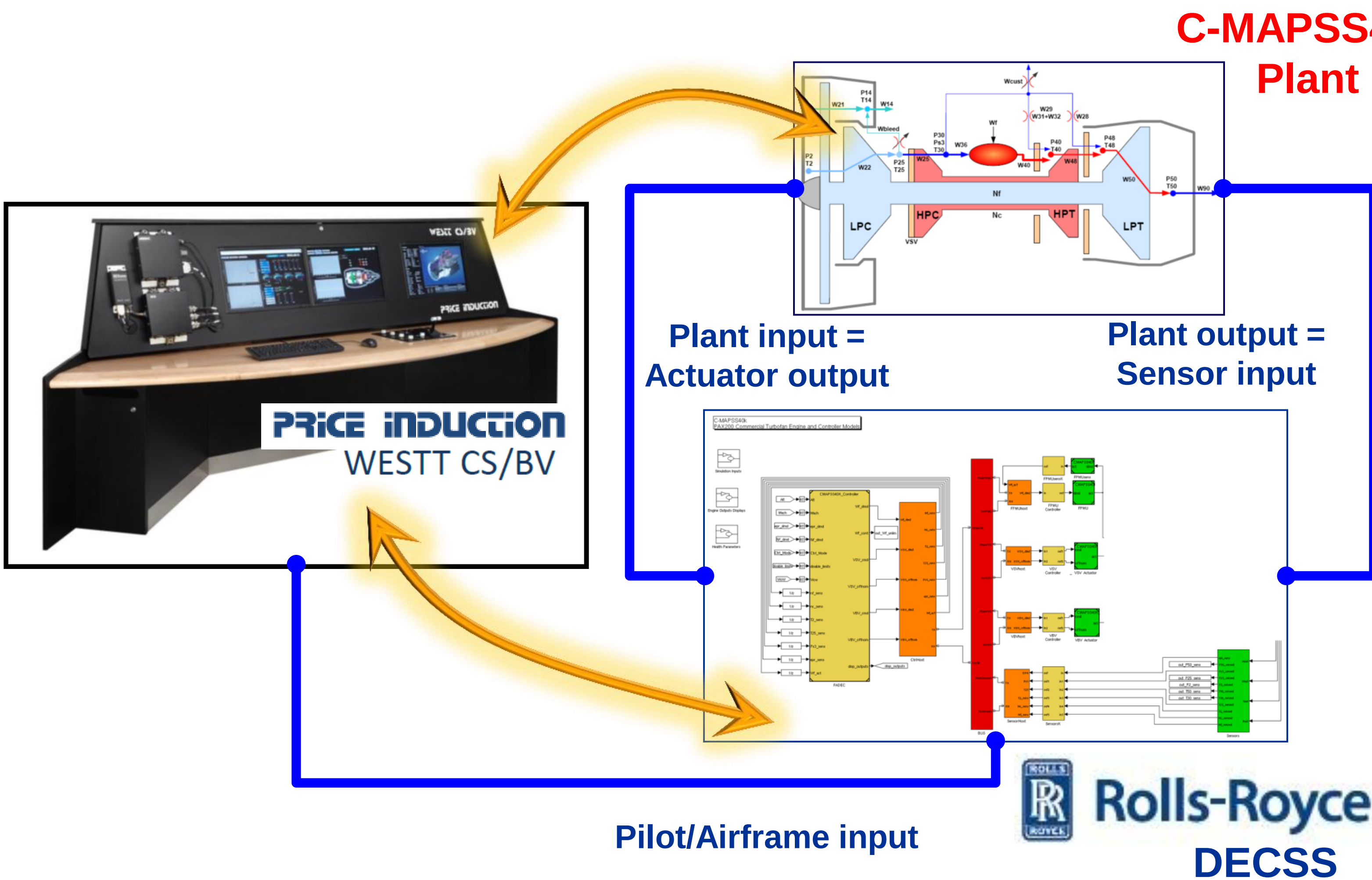


HIL in a Distributed System

In a distributed control system, the HIL must to interface to smart elements as well as the FADEC



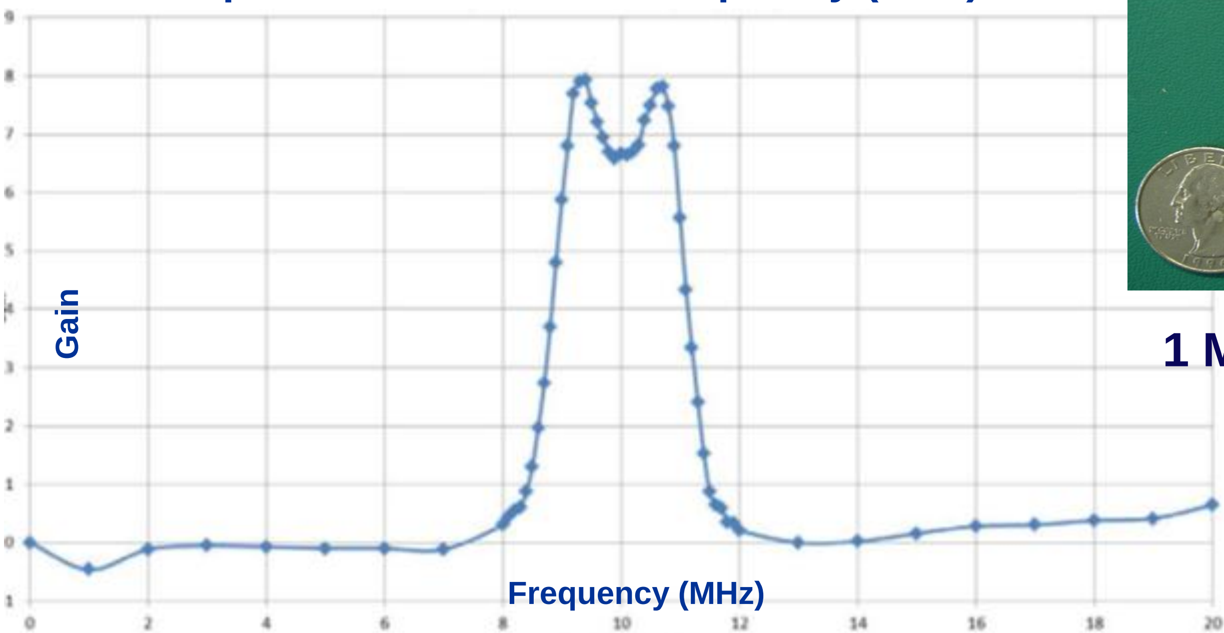
HIL System Architecture
Design Choices

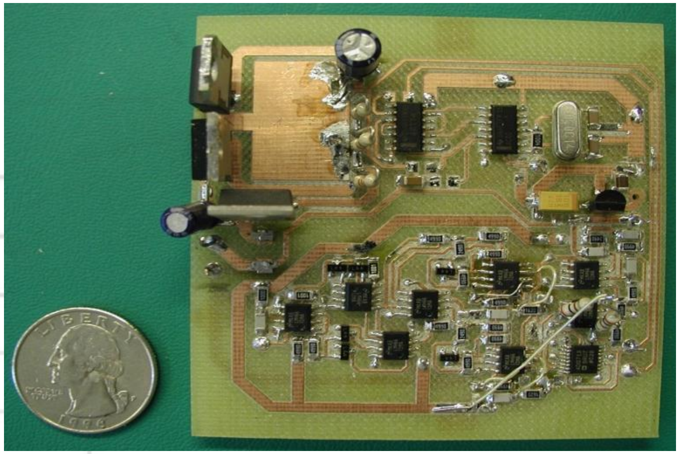


High Temperature Electronics Communications Over Power Line

Creating a sensor subnet for ultra-high temperature 500 ^oC sensors communicating to embedded, distributed smart nodes

Modem Frequency with 10 MHz Local Oscillator Output Gain Vs. Carrier Frequency (MHz)



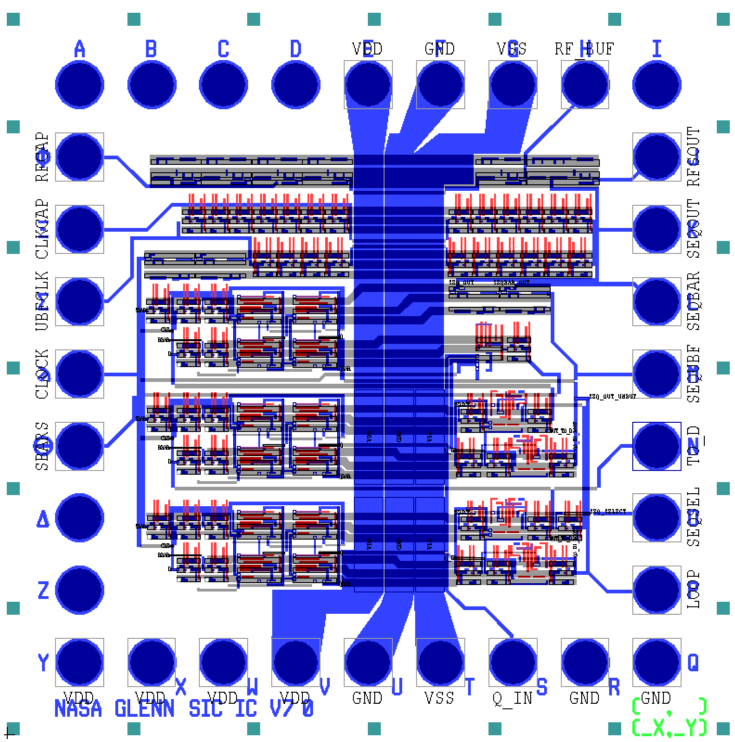


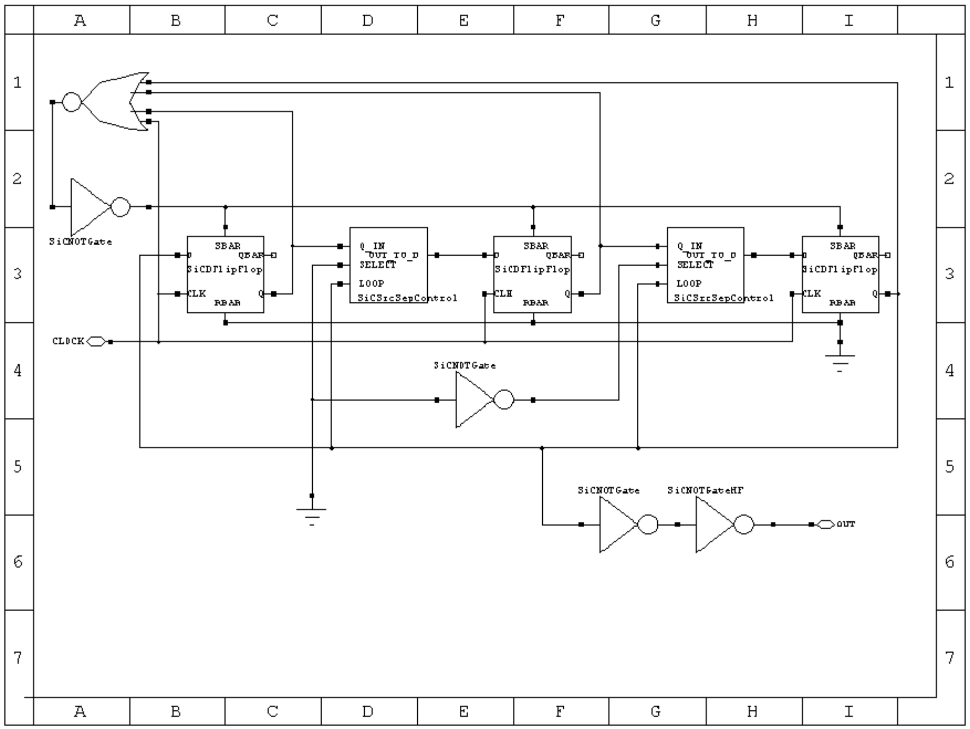
1 Mbps power-line modem

High Temperature Electronics

Progress in 500 C Silicon Carbide Integrated Circuits

Fabrication of ultra-high temperature 500 °C integrated circuits for embedded applications in distributed control





Technical Interaction

We would be interested in establishing collaborations:

A. Modeling control components
   1. To define structured methodologies for simulating smart components
   2. To establish libraries of smart control components
      a) To increase the fidelity of simulation
      b) For testing control architectures
      c) For demonstrating a growth path for control technology

B. Real-time network simulation capability

C. Application of parallel processing techniques for the modeling distributed systems

Research Activities

Hardware in the Loop (HIL) system initial release is October 2014.

Hardware-in-the-Loop is expected to be ready to perform a critical role in the pre-integration activities for initial distributed control elements produced by industry, including capabilities for:

- Development and testing of industry standards for communication networks for control systems
- Development and validation of interface definition requirements and standards for distributed control elements

The HIL system connects the simulation environment of C-MAPSS40k with high fidelity simulation of the control system. This leads to a collaborative tool for the conceptualization, requirements definition, and validation of new control technologies within a common framework.

NASA plans to demonstrate the capabilities of multiple 500 ^{o}C silicon carbide sensors operating at temperature and communicating over power lines on a 225 ^{o}C capable sub-network in FY 17.

Summary

- Distributed Engine Control (DEC) is a revolutionary change to control system architecture which can
  - alleviate engine system constraints on the control system.
  - offers significant potential to insert new beneficial control applications on the engine with reduced system impact.
- DEC drastically alters the engine integration environment across the supply chain and the engine life cycle.
- New tools are needed to fully understand DEC technology and to produce quantitative information for engine system decision makers regarding when and how to apply new control technology.
- NASA and Rolls-Royce are developing comprehensive tools, for both simulation and control hardware, designed to understand and evolve DEC technology and to promote industry-wide collaborations toward the advancement of turbine engine capability.