FPGA-Based Embedded Systems for Testing and Rapid Prototyping

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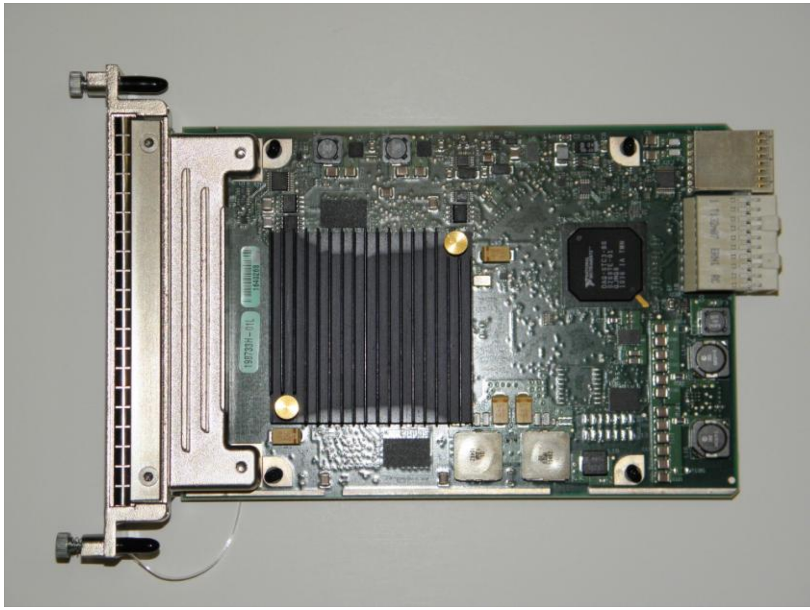
Executive Summary

- Need to streamline testbed development for Flight Software Verification & Validation
- Novel testbed development paradigm:
  - *Field Programmable Gate Array (FPGA) technology*
  - *Reduce cost/schedule vs. heritage approach*
  - *Enable earlier involvement in system design, integration, & test*
- Proof of concept complete and operational
  - *FPGA-based Hardware-in-the-Loop (HIL) testbed for a Space Vehicle*
- Design approach allows evolution to COTS development
  - *Increases commonality among programs*
  - *Further reduces cost & schedule*

Agenda

- Background
  - *Field Programmable Gate Arrays (FPGAs)*
  - *Legacy avionics & Hardware-in-the-Loop (HIL) simulations*
- Implementation of an FPGA-based HIL for a Space Vehicle
  - *Design overview*
  - *Results*
- Benefits & Drawbacks of FPGA-based HIL systems
- Prospects & plans for further development
  - *Flexible, modular, COTS-based evolution*

Introduction to FPGA Technology

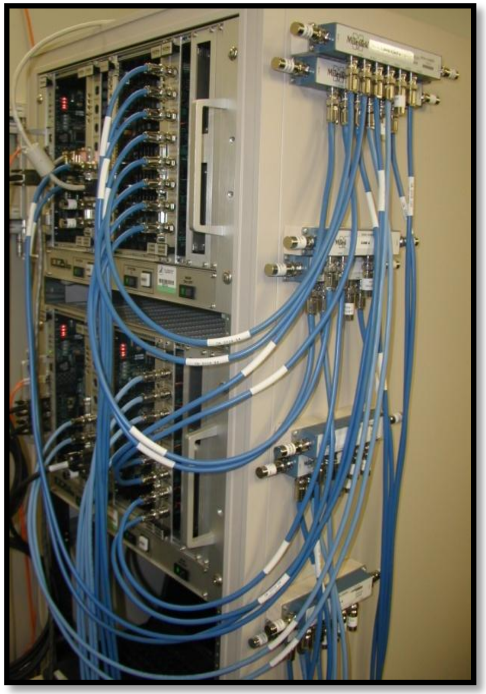


- User-configurable integrated circuit
  - *"Field-programmable" after manufacturing*
- Configuration specified via HDL software
  - *Hardware Description Language*
- Can be programmed to implement any logical function using high-level tools
  - *HDL specification represents same design built into typical ASIC* chip*
- Any portion of the design can be reprogrammed or updated easily
  - *Eliminates re-manufacturing hardware during design iterations*
  - *Offers advantages for many applications*

* Application-Specific Integrated Circuit (ASIC)

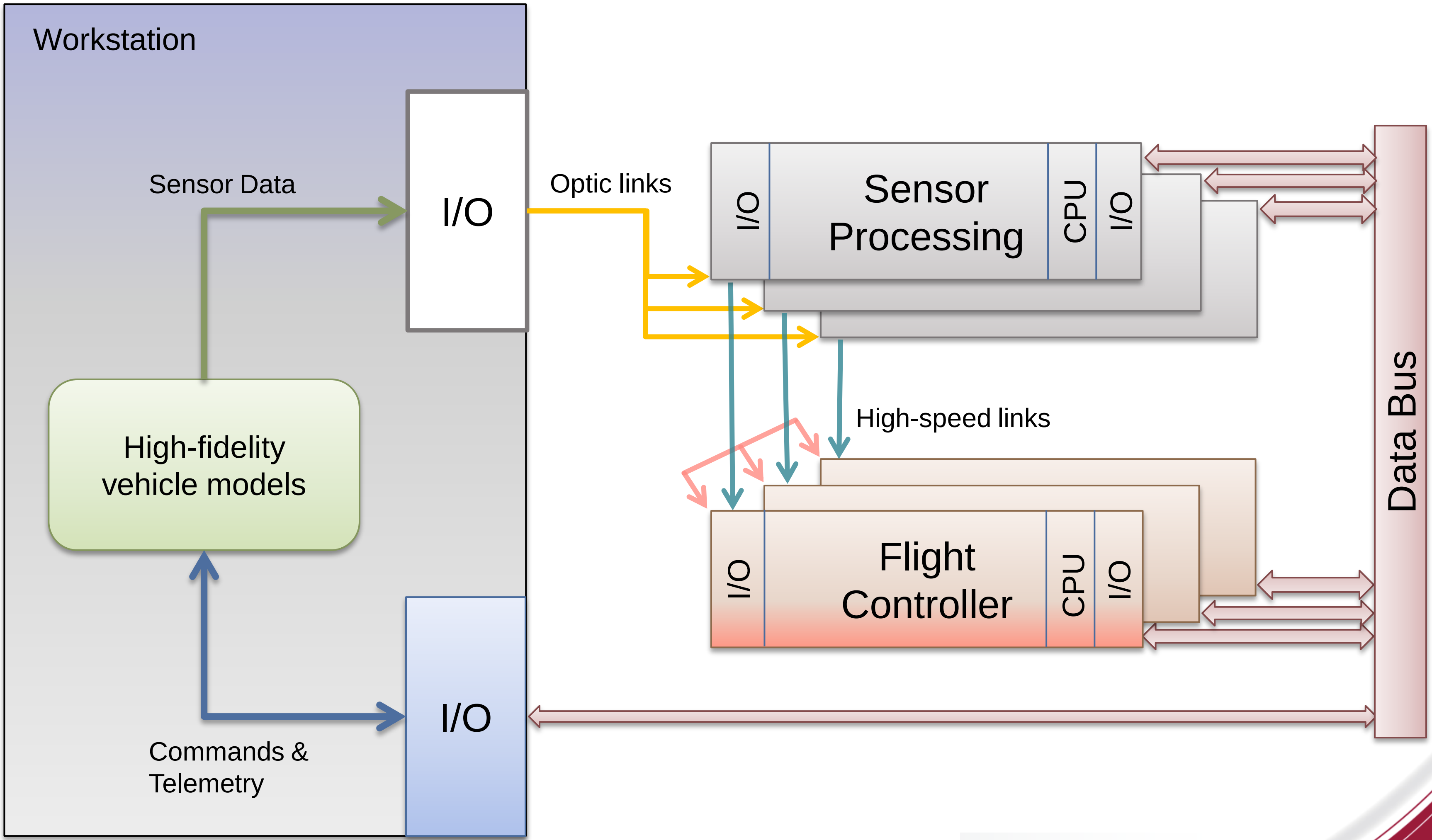
> *Flexibility of software combined with timing & performance of hardware*

Space Vehicle FPGA HIL Background

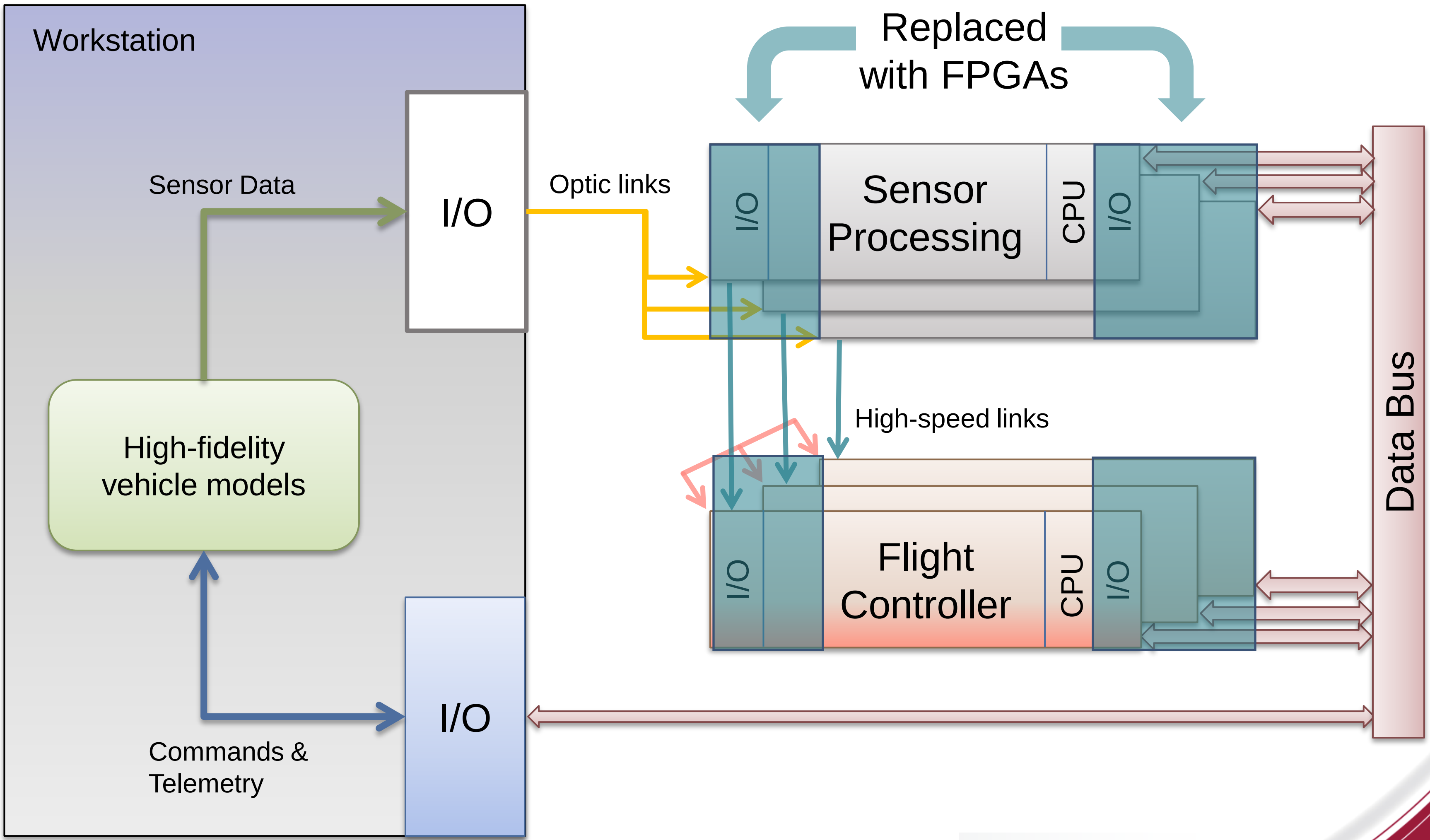


- Legacy HIL shortcomings:
  - *Parts obsolescence*
  - *Limits on hardware signal capture & logging*
  - *Custom hardware is costly*
- Replacement/upgrade opportunities:
  - *Capitalize on technology advances*
  - *Pathfinder for cost-effective development approaches*
  - *Maintain Aerospace expertise versus current state-of-the-art*
- FPGA-based HIL advantages:
  - *Executes flight code natively, in real-time, without software modifications*
  - *Enhanced debug/probe/analysis capabilities impossible on flight computer*
  - *Telemetry output compares very well with expectations*

Legacy Space Vehicle HIL Implementation



FPGA-based Space Vehicle HIL Implementation



FPGA-based HIL Implementation Features

- Uses same processors as the vehicle
- FPGAs perform all input/output and interface functionality of the Space Vehicle Avionics package
  - *Internal and external, including multiple channels*
- Implemented as VHDL* code executing on each FPGA chip
  - *Developed independently at Aerospace*
- FPGA logic performs most core Space Vehicle avionics tasks:
  - *Interrupt service routines (ISRs)*
  - *Voting logic for redundancy*
  - *Sensor first-in-first-out (FIFO) logic*
  - *System Clocks*
  - *Dual-port RAM*
  - *Interrupt generation*

* Very High Speed Integrated Circuit (VHSIC) Hardware Design Language (VHDL)

> System is operational – proves feasibility and demonstrates value

Unique FPGA-Enabled HIL Capabilities

- Simulation of hardware failures modes
  - *Memory fail modes*
  - *DPRAM failure*
  - *Voter failure*
  - *Sensor FIFO failure*
  - *Radiation hits, etc.*
  - *Legacy HIL can only represent these via flight software patches*
- Built-in data logging for debugging & diagnostics
  - *FPGA records & outputs every bus transaction in each lane throughout flight*
  - *Far exceeds the debugging and data logging capability of the actual flight avionics*
  - *Similar capability for other programs is easily achievable through the FPGA code*

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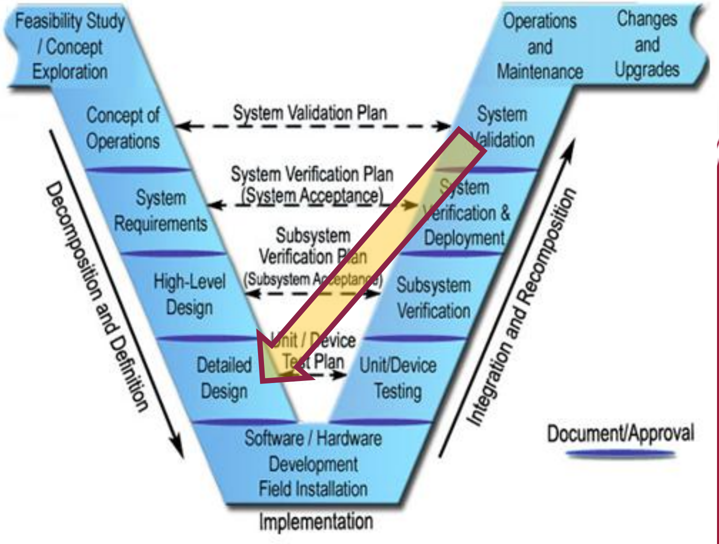
Applications and Advantages

- Approach is equally applicable to launch vehicle and spacecraft programs
- FPGA flexibility enables early, incremental testbed development
  - *Shift Validation &Verification earlier in systems engineering process*
  - *HIL development in parallel with avionics design & FSW implementation*
- More available, responsive Validation & Verification
  - *Reusable, reconfigurable hardware minimizes non-recurring effort*
  - *Cost savings makes FSW validation feasible for lower-budget programs*
  - *Flexibility enhances analysis capabilities*
- Potential applications/customers:
  - *Launch Vehicles*
  - *Spacecraft*
  - *Alternate launch vehicles*
  - *Anomaly resolution*



Next Step – Evolution toward COTS

- National Instruments (NI) HIL platform
  - *Industry-standard LabVIEW software*
  - *Widely used modular PXI hardware*
- Modern, COTS system
  - *Low-cost, easy to use*
  - *Significant reduction in development & validation effort*
  - *500+ compatible products cover various interfaces, I/O architectures, communications buses, shared memory, etc.*
- FPGAs are integral to NI hardware/software paradigm
- Pathfinder project is in development and integration stage:
  - *Launch Vehicle*

> *NI's flexible rapid-prototyping architecture applied to HIL development*

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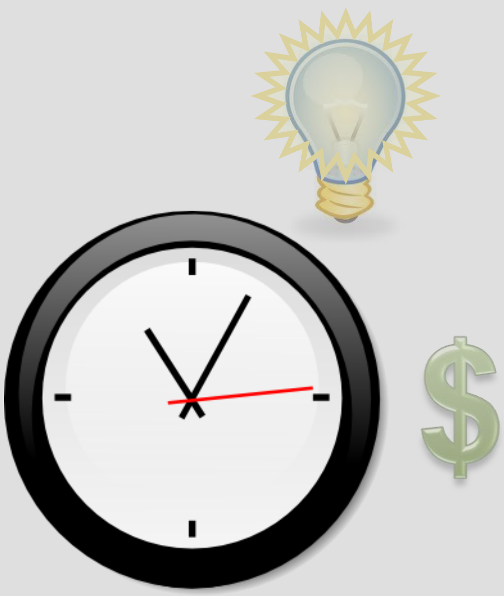
Big Picture – HIL Testbed Options for Flight Software Validation & Verification at The Aerospace Corporation

Custom Hardware

- High development NRE
- Static capabilities
- Parts obsolescence



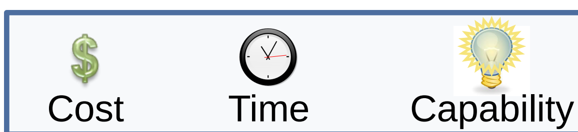
FPGA-based

- Flexibility
- Design insight
- Inexpensive COTS parts

Contractor EDU*

- Limited design insight
- Needs contract foresight
- Lacks independence

* *Engineering Design Unit* (EDU)



Conclusions

- The FPGA-based HIL is an important step in Aerospace's response to increasingly constrained cost & schedule environment
  - *Pathfinder for future testbed development approaches*
  - *Promising prospects for significant cost/schedule improvements*
- Approach is well aligned with strategic goals
  - *Realignment toward the left-hand side of the systems engineering "V" diagram*
  - *Reinforce expertise in industry-standard and state-of-the-art technology*
  - *Shift to reusable, modular architectures vs. custom & ad-hoc systems*
  - *Lower-cost, more responsive assets to meet customer needs*

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