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

> Modern hardware, enhanced capabilities, reduced cost
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

- Workstation
  - Sensor Data
  - High-fidelity vehicle models
  - Commands & Telemetry

- Sensor Processing
  - Optic links
  - CPU
  - I/O

- Flight Controller
  - High-speed links
  - CPU
  - I/O

Data Bus

Does Not Contain US Export Controlled Information
FPGA-based Space Vehicle HIL Implementation

Does Not Contain US Export Controlled Information
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)  – System Clocks
  – Voting logic for redundancy  – Dual-port RAM
  – Sensor first-in-first-out (FIFO) logic  – 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
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*
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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