SAE Mil-1394 For Military and Aerospace Vehicle Applications

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Agenda

- The SAE Mil-1394 Standard
- Mil-1394 On The F-35 Joint Strike Fighter
- Mil-1394 On The Space Shuttle

IEEE-1394 History

- IEEE-1394 began as a development by Apple Computer in the 1980s. The project was named FireWire.
- In 1995, the IEEE released a standard based on Apple's FireWire: IEEE Std 1394-1995.
- In 1997 the OHCI (PCI bus interface) was defined.
- In 1998 the 1st amendment for 1394a was made available.
- In 1999 the 1st draft of the 1394b standard was made available.
- In 2000 the IEEE Std 1394a-2000 was released.
- In 2002 the IEEE Std 1394b-2002 was released.

The SAE AS-1A3 Mil-1394 Task Group

The SAE AS-1A3 Task Group was formed to establish requirements for using 1394 in safety-critical/ mission-critical applications for military and aerospace vehicles.

- Quarterly meetings have been held since July, 2003.
- Task Group consists of 19 active members and 27 distribution members, representing aerospace and military corporations, test equipment vendors, and chip suppliers.
- Base Specification and accompanying Slash Sheet (S400 Copper) balloted in August, 2004.
- Future work includes drafting a Handbook and Slash Sheets for other media and bus speeds.

Additions To IEEE-1394 Standards

- Use of Asynchronous Streams
  - Asynchronous streams are used for most communication on the network. Asynchronous and isochronous packets are not required but may be utilized.
- A Fixed Frame Rate
  - This implementation provides a fixed frame rate for synchronization of the network.
- Synchronization Via Start Of Frame Packets
  - A Start Of Frame (STOF) packet is transmitted by the Control Computer on each bus at a periodic (e.g. 100 Hertz) frame rate. This packet informs all nodes on the bus that a new frame has started.

Additions To IEEE-1394 (Cont.)

- Static Assignment of Channel Numbers
  - The channel numbers for each node on the bus are pre-assigned, are application specific, and will be defined as required by the architecture.
- Pre-Assignment of Bandwidth
  - Transmit and receive times for each node on the bus are assigned as offsets from the start of each frame (STOF packet).
- Vertical Parity Check
  - Vertical Parity Checking (VPC) is performed on the data area of each packet as an adjunct to the Cyclic Redundancy Check (CRC) performed by the 1394 physical layer devices.

Additions To IEEE-1394 (Cont.)

- Anonymous Subscriber Messaging
  - Anonymous Subscriber Messaging (ASM) is a protocol in which a Remote Node on the network can subscribe to each message that it requires. The ASM software in the Remote Node will forward only the messages to which the Remote Node has subscribed.

Hardware Slash Sheets

- Hardware Slash Sheets are used to establish hardware guidelines for different system applications and bus speeds.
- While environmental requirements (electromagnetic compatibility, temperature, vibration, etc.) are vehicle- and even LRU-specific, the hardware requirements and examples in a Slash Sheet address many of the environmental conditions that military and aerospace vehicles may experience.
- The S400 Copper Slash Sheet is the first one created by the SAE AS-1A3 Task Group. Future Slash Sheets may be used for different bus speeds (S200, S800, etc.), bus media (copper, glass or plastic optical fiber, etc.), and applications.

S-400 Slash Sheet

The S400 Copper Slash Sheet establishes guidelines for the data bus cable and its interface electronics for a system utilizing S400 over copper medium over extended lengths.

- Cable Electrical Characteristics
- Cable Termination
  - Connectors/Contacts
  - Termination Method
- Bus Isolation (Transformers)
- Link Signal Specifications
  - Link Signal Transmitter Characteristics (TP2)
  - Link Signal Receiver Characteristics (TP3)

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Paper #

Mil-1394 On The F-35 Joint Strike Fighter (JSF) Aircraft

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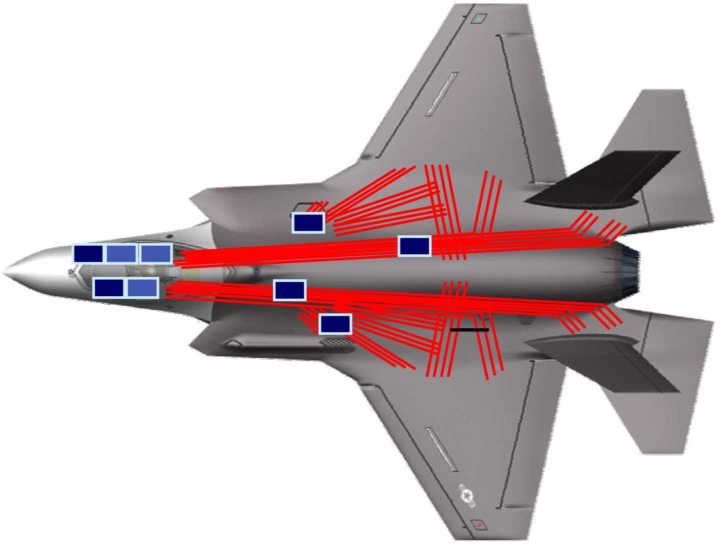
Paper #

Aircraft Avionics Data Bus Background

Legacy Aircraft Programs Employed "Federated" Subsystems:

- Architecture Made Use Of Federated Controllers For Specific Applications Requiring Dedicated, High-bandwidth Control Loops
- Data Shared Between Distributed Processing Required Minimal Bandwidth
- High Bandwidth Sensor Data Provided as Analog Inputs (e.g Air Data)

Federated Subsystems



Mil-Std-1553B Protocol Fulfilled Needs:

- Digital Data Transferred Between Multiple Avionics Units Over Common Data Bus Media Using Time Division Multiplexing (TDM)
- Half-duplex, Asynchronous, Command/Response Protocol, Dual Redundancy
- 1 Megabits Per Second (Mbps)
- Mil-Std-1553 Released In 1973, Mil-Std-1553a In 1975, Mil-Std-1553b In 1978

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F-35 JSF Processing Architecture

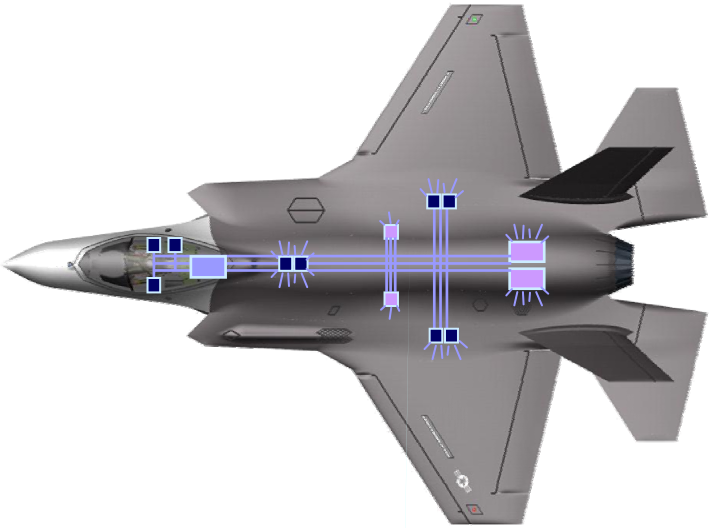
F-35 JSF Employs An "Integrated-Federated" Processing Architecture:

- An Integrated System; Triplex High-speed Serial Busses Interconnect Components
- Core Processors Incorporate Processing That Legacy Aircraft Performed Separately
- Core Processors Have No Analog I/O
- Architecture Makes Use of Federated Controllers for Specific Applications That Lessons Learned Have Shown To Require Dedicated, High-Bandwidth Control Loops

Advantages/Considerations In Using Distributed I/O Concept:

- Architecture Significantly Lowers Both Weight And Cost Of Control Systems Processing
- New Integrated Subsystems Technologies Improve Performance, Safety, And Operational Flexibility, Reduce Vulnerability
- Control System Computational Delay and Data Latency Must Be Minimized In Order To Maximize Aircraft Performance And Stability
- The New Architecture Requires High Speed Busses to Replace Analog Signals

Integrated-Federated Subsystems



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Why Was 1394b Selected For The F-35 JSF Vehicle Systems Data Bus?

To Support New Architectural Advantages, Vehicle Systems (VS) Needed A High-Throughput Data Bus That Could Fulfill The Following Requirements:

- No Loss Of Data Due To Bus Overflow/Collision
- Guaranteed Data Delivery/Detection Of Failed Delivery
- Availability Of Parity/Error Detection Codes
- Rapid Network Initialization
- Fault Tolerant Topology With No Single Point Failure Causing Loss Of An Entire Bus

A Supplier Trade Study Determined That The Most Cost-Effective VS Aircraft Network Protocol Is IEEE-1394b:

- IEEE-1394b Provides An Extremely High Bandwidth Bus - 400 Megabits Per Second (Mbps) Selected For VS Data Bus And Core Processor Cross Channel Data Link
- Topology And Features Of 1394b Fit Well With VS Connectivity, Fault Tolerance, And Environmental Requirements
- IEEE-1394b Is A Fully Arbitrated, Peer-To-Peer Serial Bus Communication Protocol
- IEEE-1394b Offers 8b/10b Encoding That Is Suitable For The EMI/EMC Environment Seen In The Application
- IEEE-1394b Physical Layer Is Compatible With The IEEE-1394a Link Layer
  - Use Of The 1394a Link Layer Enabled Software Development To Proceed Using Available 1394a Devices

Vehicle Systems Data Bus Trade Study

Network	Weight	Power	Volume	Latency	Topology Robustness	S/W Development Impact	H/W Devel Risk	EEE Robustness	Tech Refresh Path	Non Recurring Cost Impacts	Recurring Cost Impacts	Customer Acceptance	Comments	Score	Ranking
IEEE 1394b, 100Mbps Passive													Not Viable - S100 Parts Not Initially Available		n/a
IEEE 1394a													Not Viable - Failed Lightning Testing		n/a
IEEE 1394b, 400Mbps Passive													Passed EEE and Lighting. Selected For Root Proc Cross-Channel Data Link		1
IEEE 1394b, 400Mbps Active													Uses Active Xfmrs To Achieve 10+ Meters And Pass EEE And Lightning. Selected For VS Network.		2
IEEE 1394b, Optical													Needs Optical Xcvrs. Selected For Remote Flight Testing.		4
ATM, Optical													Switched Topology, No Flight H/W		8
Fibre Channel, Electrical													Loop Topology, Rehost ASM; power and s/w dev schedule concerns.		5
Fibre Channel, Optical													Loop Topology, Rehost ASM; power and s/w dev schedule concerns.		6
EtherNet													Hub Topology, No Determinism, EEE concerns, Possible Fallback?		3
USB													Switched Topology, No Flight H/W		7
Mil-Std-1553													Limited Bandwidth, Architecture Impacts, Latency & Weight Cons		9

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Note: Study Focused on Lower Bandwidth Vehicle Systems – Not Applicable to Mission Systems Applications

Vehicle Systems Data Bus Overview

Vehicle Systems Data Bus Protocol

- Asynchronous Streams Used As Main Method Of Data Transport
  - Asynchronous Streams Are Isochronous Data Packets (Same Addressing Scheme, Packet Size, Etc) That Are Transmitted Under Asynchronous Transaction Rules (Asynchronous Size Limitations, After Isochronous Packets, No Ack)
  - Addressed Via Channel Number, So No Node Discovery Is Necessary (As Would Be The Case For Asynchronous Transactions); Easily Filtered By LLC.
  - Asynchronous Transactions Required "Extra" Overhead That Was Not Necessary To Carry Around
  - No Guaranteed Delivery So Extra Failure Management Requirements Must Be Levied
- Asynchronous transactions are addressed to specific memory locations thus permitting memory corruption by incorrectly addressed packets
  - Asynchronous streams, however, are addressed to channel numbers
  - If a packet is sent to an incorrect channel number, the receiving node will ignore it – no chance of damage

Bandwidth and Latency Management

Channel Numbers are pre-assigned in the VSN ICD

- Improves VSN Start Up because discovery is not required

Bandwidth is assigned via the STart Of Frame (STOF) offsets

- The VSN implementation does not utilize an Isochronous Resource Manager

STOF message transmission establishes VS frame

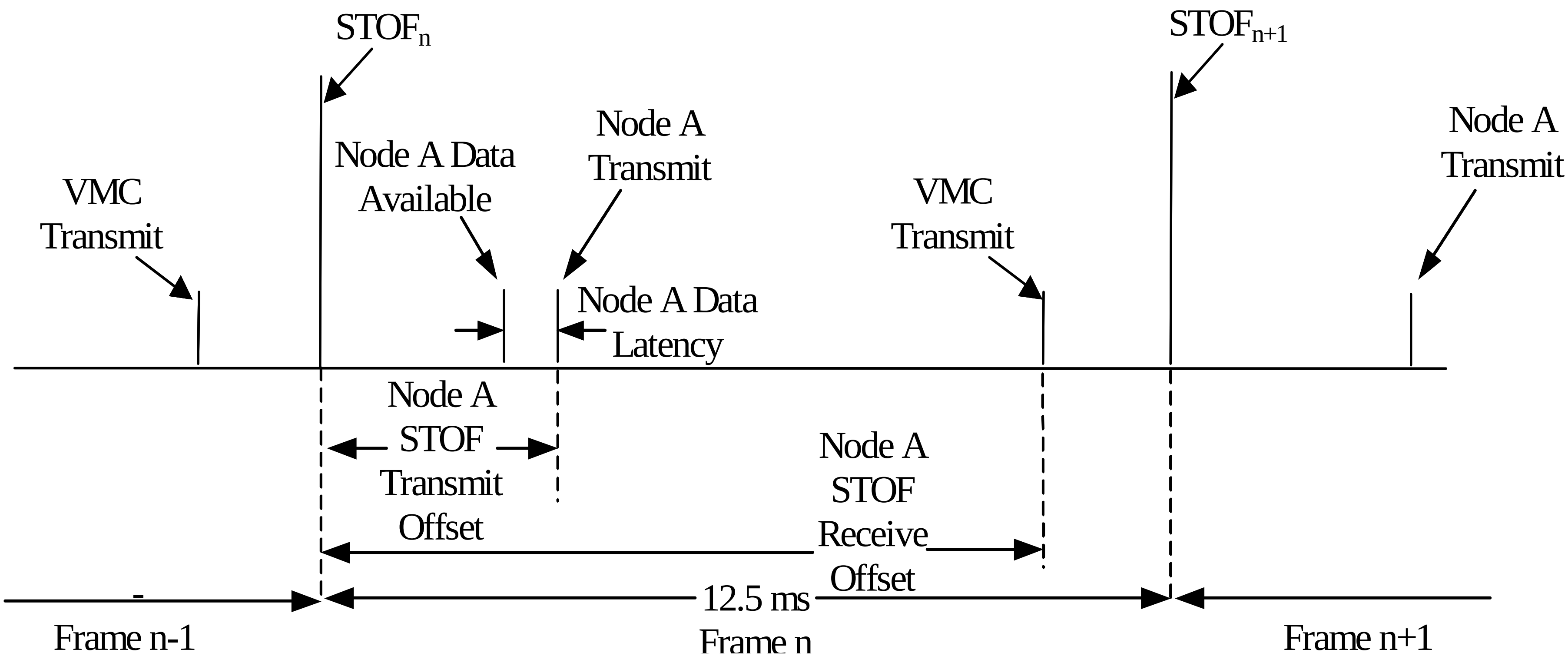
- No Cycle Start packet is transmitted every 125 usec. Instead, a STart Of Frame (STOF) packet is transmitted every 12.5 milliseconds

STOF Offset allocations enable low latency performance

- Each node on the bus is assigned a time, relative to the STOF, when it can expect to have receive data in the LLC's FIFO,
- Another time, relative to the STOF, when it is permitted to transmit data, and
- A third time, also relative to the STOF, when it may transmit its Data Pump packets

VSN Bus Timing

This figure illustrates the concept of STOF offset timing as utilized on the JSF Vehicle Systems Network



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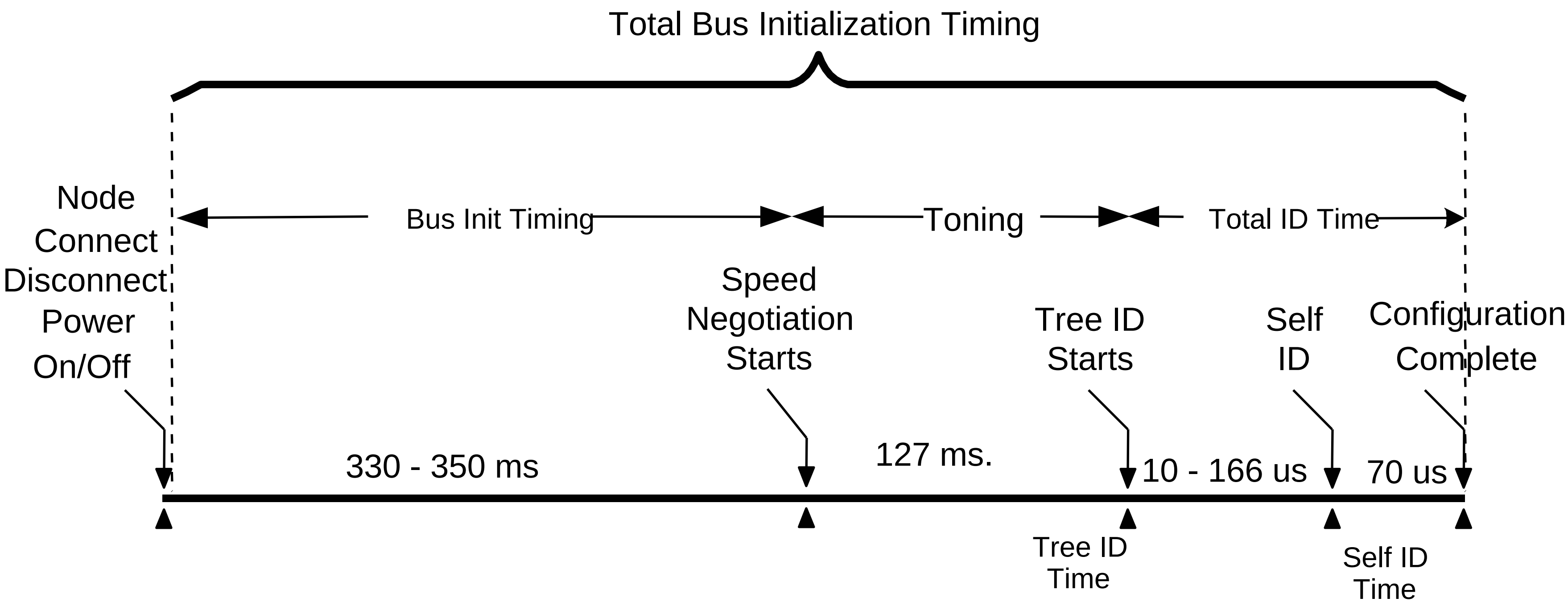
1394b Total Initialization Timing



- As each Remote Node is connected or powered on, it internally generates the 350-millisecond debounce delay. Upon completion of the debounce delay, it sends the reset signal onto the bus. Because not all nodes are powered on at the same time, the initialization of the bus will continue until the final node is powered on.
- During the final component of bus initialization, nodes begin sending tones to one another to negotiate maximum usable speed.
- Following bus initialization, nodes begin the tree-identify and self-identify phases to identify the root node and the topology of all attached nodes.

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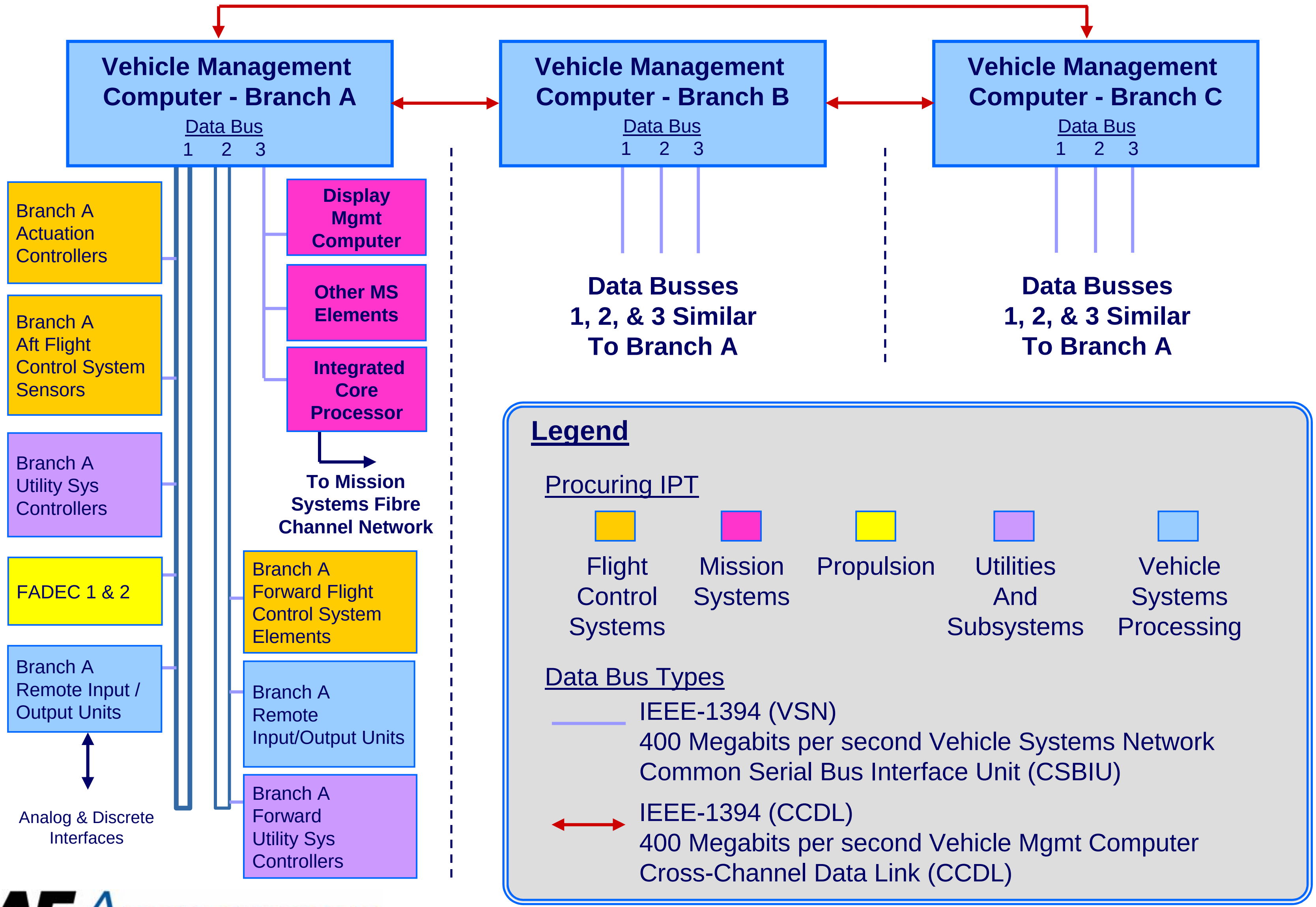
High-Level VS Processing Architecture



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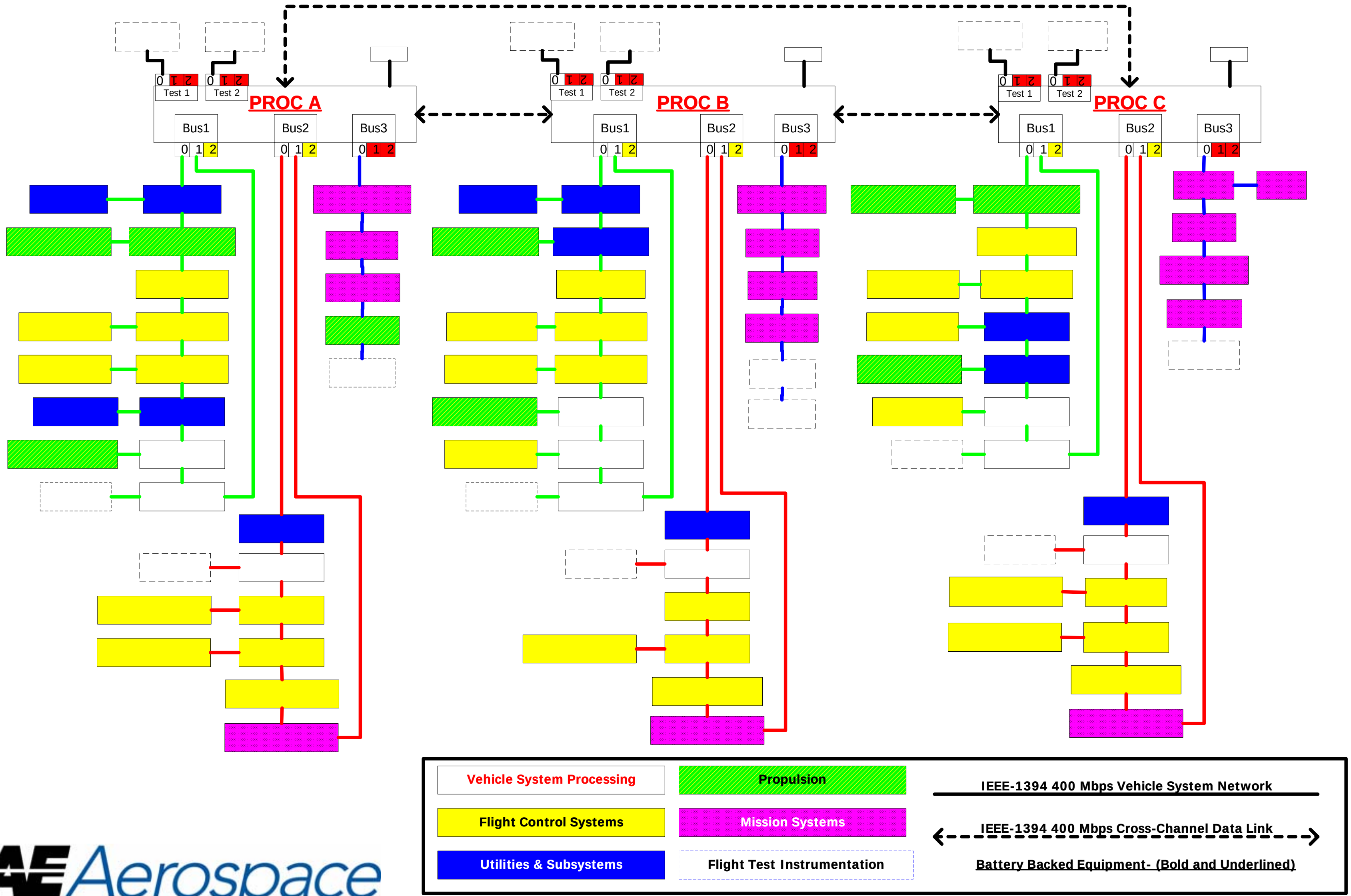
Vehicle Systems Network Architecture



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Mil-1394 On The Space Shuttle

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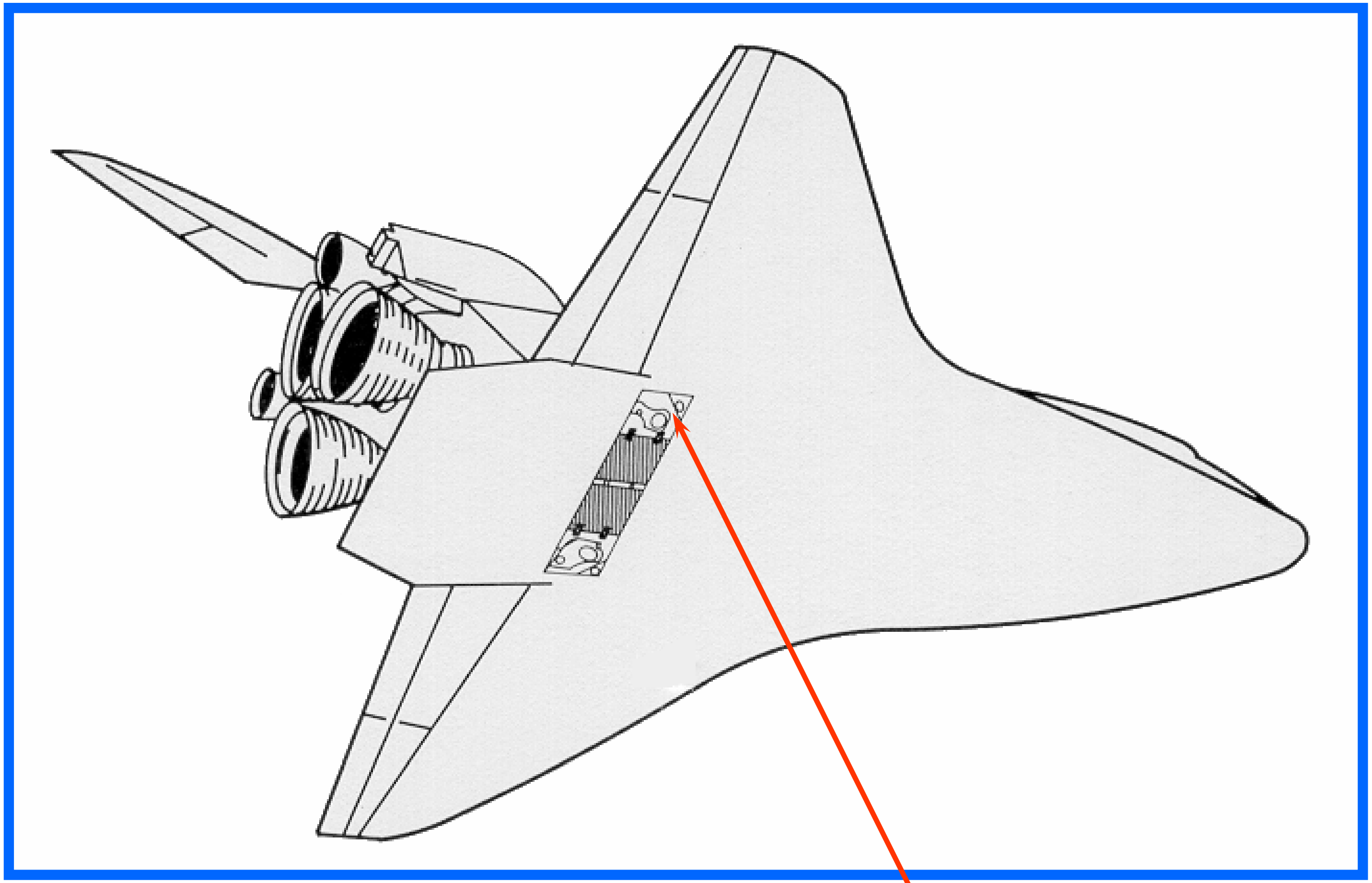
Space Shuttle Return To Flight

- NASA is installing a digital camera in the aft compartment of the Space Shuttle to take pictures of the external tank separation. The pictures will be downlinked to the ground for analysis while the shuttle is still in orbit.
- The camera is in the umbilical well and the laptop is in the crew cabin. This requires a 125 foot cable run with 10 interconnects.
- COTS Camera and laptop both run 1394a that is converted to 1394b S100 for the cable run.

Background

- External Tank Thermal Protection System (ETTPS) Film Cameras have flown since STS-1
- Film is processed post flight
- Upgraded to digital camera to allow ETTPS images to be downlinked and debris imagery analysis on the external tank to be completed within hours of launch.

Location of the Umbilical Well Camera



Location of the External Tank Thermal Protection System (ETTPS) Camera

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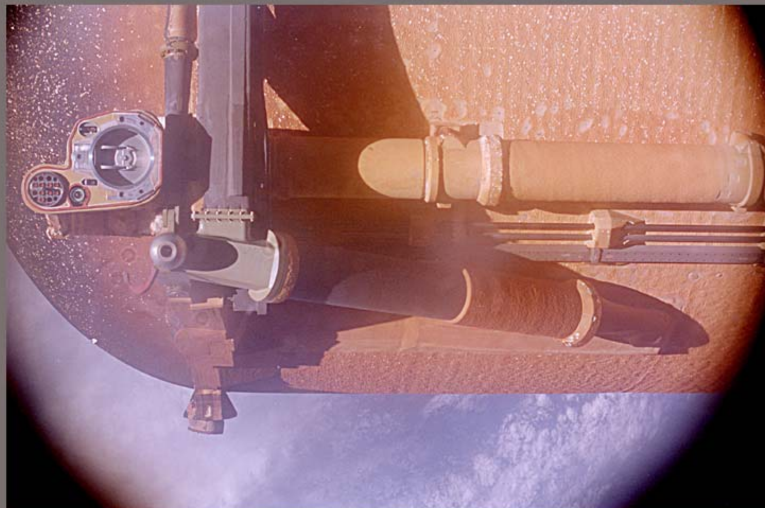
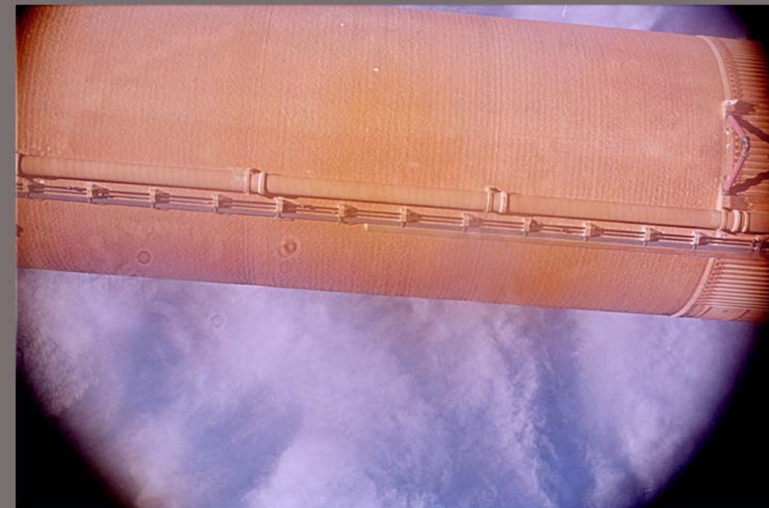
35mm Umbilical Well Camera Imagery



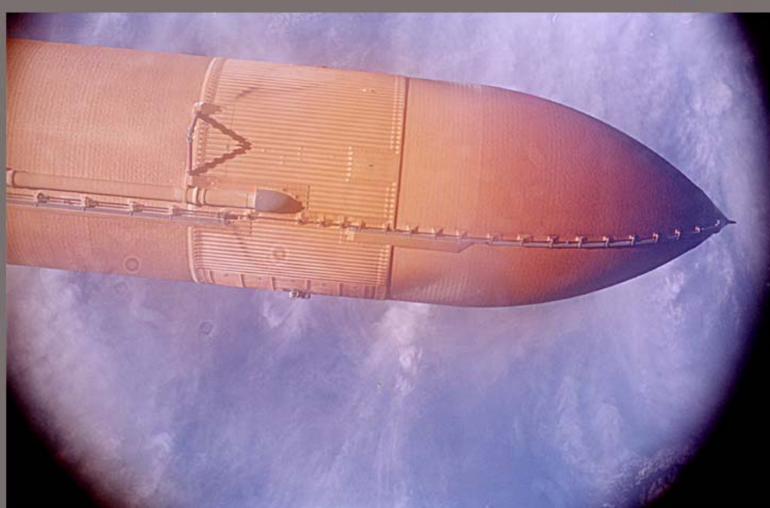
Frame #8 STS-112

35mm Umbilical Well Camera Imagery



Frame #22 STS-112

35mm Umbilical Well Camera Imagery

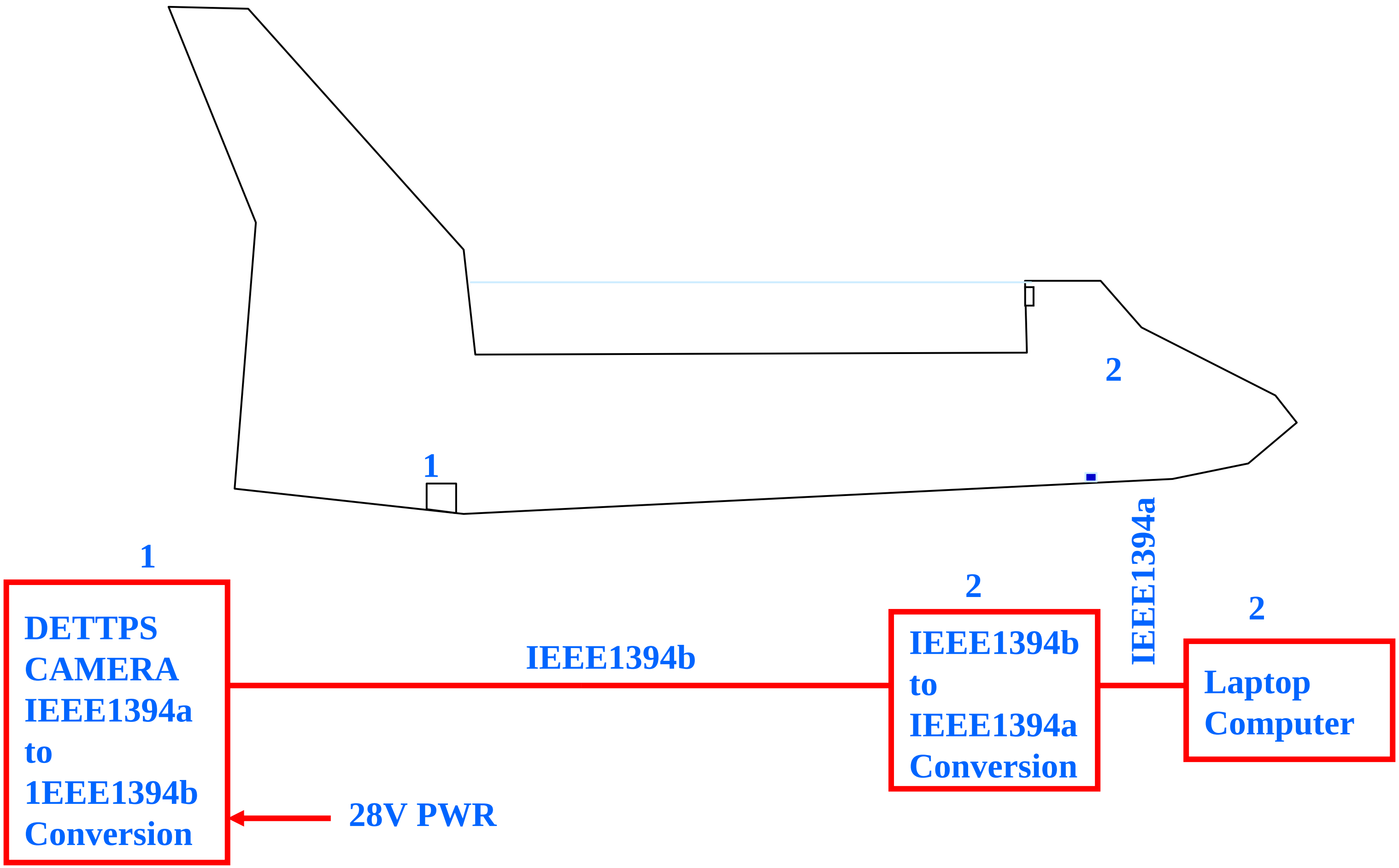


Frame #30 STS-112

35mm Umbilical Well Camera Imagery

Frame #34 STS-112

Architecture



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IEEE1394 Overview

- COTS Laptop and Camera have IEEE1394a only
- Utilizes in-house designed 1394a to 1394b converters
- S100 selected because testing showed it would drive 190' with 15 interconnects.
  - S200 would drive 125' of cable but with no signal margin.
- Reasons for converting to 1394b:
  - Necessary to make the distance of the cable run
  - AC coupled
    - Eliminated DC coupling issues
      - EMI problems
      - Lightning hazards
      - ESD

Overview (Continued)

- NASA design only using the Physical Layer (PHY)
  - Meets requirements for the Space Shuttle Return to Flight.
  - PHY mode permanently set to S100.
- PHY could be controlled by a Link Layer Controller (LLC)
  - PHY and LLC combinations being utilized by LM-Aero.
  - PHY and LLC combinations planned for future camera upgrades on Space Shuttle and Space Station.

Radiation Testing

- 1394 chipset was tested at the Indiana University Cyclotron Facility (IUCF) with 200MeV protons
- Total Ionizing Dose of 590 Rads(Si) (fluence of 1.0E10 protons/cm**2) was placed on the parts.
- No Single Event Effects or Total Dose Effects were found.
- Part MTBF > 10 years of Space Station Low Earth Orbit assuming 0.1” Aluminum shielding.

Cable Design

- Two parallel cables installed in vehicle during modifications for future utilization.
- High frequency terminations require complete shield termination coverage.
  - Open or not complete shield braids in existing technologies including TAG Ring, combed and weaved braids common to RFI backshells and open non-RFI backshells are not compatible for high frequency communication.

Cable Design

- Current Space Shuttle wiring is all low frequency or DC level.
- Non-Impedance matched mil standard connectors utilized.
  - Connectors were pre-existing in Space Shuttle from previous applications.
  - Unique pinouts allow impedance matching and prevent cross talk issues.

LM-Aero Overview

- In researching data transfer methods it was identified that Lockheed Martin-Aero had been developing IEEE1394b protocols.
- LM-Aero was contacted by LM-Space Operations in direct support of NASA-JSC and a formal work agreement was put in place.
- The information transfer allowed board and cable design to quickly be completed without experiencing a several month learning curve normally associated with high speed digital design projects.
- The parts cost was reduced because LM-Aero has completed parts testing and design certification on the IEEE1394b chipsets being utilized.
- LM-Aero participated at the NASA Project Peer and System Design Reviews.
- LM-Aero has benefited from the lessons learned during the fabrication and testing of hardware.

Summary

- Unique opportunity to utilize new technology while increasing vehicle and crew member safety.
- Demonstration of new technology that can be utilized for Crew Exploration Vehicle and other future manned vehicles.
- Future work for other cameras in the vehicle that can be IEEE1394 based without major vehicle modifications.
- Demonstrates that LM can share information and knowledge between internal groups and NASA to assist in providing a product in support of the NASA Return to Flight Activities.
- This upgrade will provide a flight active data bus that is 100 times faster than any similar bus on the vehicle.

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