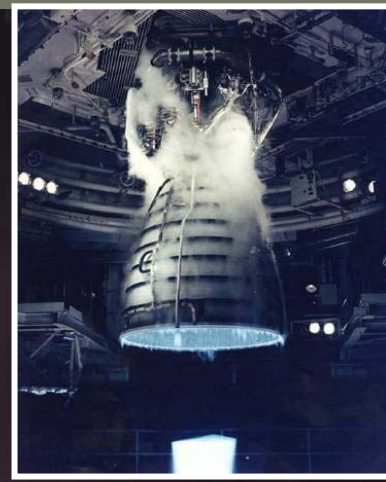
Design of Electrical Systems for Rocket Propulsion Test Facilities at the John C. Stennis Space Center

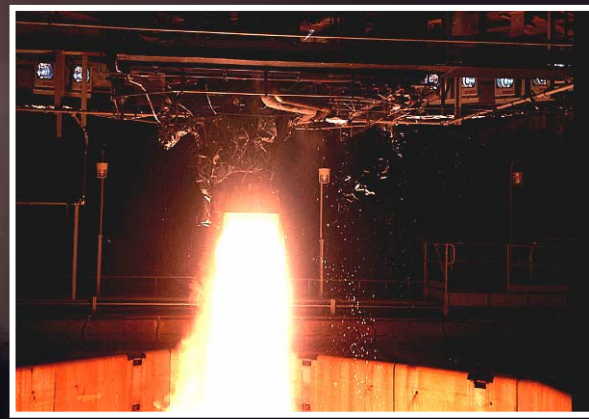
Stennis Space Center

Space Shuttle Main Engine Test
@ A2 Test Stand

RS-68 650 klbf
@ B1 Test Stand



Fastrac 60 klbf
@ B2 Test Stand



Design of Electrical Systems for Rocket Propulsion Test Facilities at the John C. Stennis Space Center

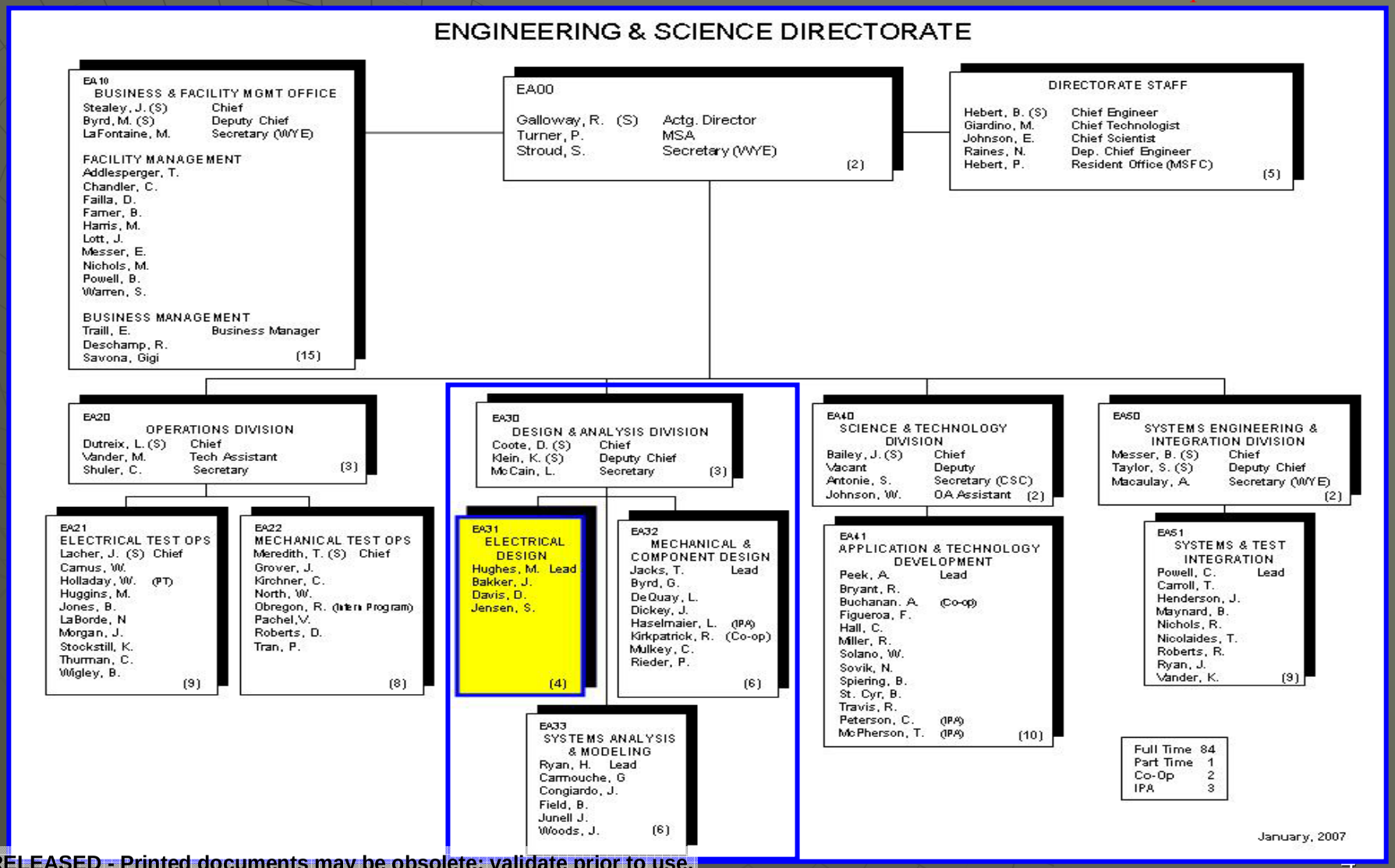
- NASA/SSC's Mission in Rocket Propulsion Testing Is to Acquire Test Performance Data for Verification, Validation and Qualification of Propulsion Systems Hardware
  - Accurate
  - Reliable
  - Comprehensive
  - Timely
- Data Acquisition in a Rocket Propulsion Test Environment Is Challenging
  - Severe Temporal Transient Dynamic Environments
  - Large Thermal Gradients
  - Vacuum to 15k psi pressure regimes
- SSC Has Developed and Employs DAS, Control Systems and Robust Instrumentation that Effectively Satisfies these Challenges
- The Following Presentation Reviews SSC's Data Acquisition and Controls Architectures

Agenda

- Background – SSC EE Org & Test Facilities
- High/Low Speed Data Acquisition Systems
- Control Systems
- Data Acquisition and Control Systems Lab
- Unique Sensor Development Activities

ENGINEERING & SCIENCE DIRECTORATE

Stennis Space Center



Design & Analysis Division

Stennis Space Center

Design and Analysis Division

- Configuration Management
- Records Retention DB Management

Mechanical and Component Systems

- Cryogenic Propellant Systems
- Storable Propellant Systems & HPIW
- Hydraulics/pneumatics Systems
- Press Gas/Purge Systems (TBA)
- Components
- Materials
- Ancillary Systems
  - TMS, Measurement Uncertainty
  - Standards & Specifications

Electrical Systems & Software

- **Data Acquisition**
- **Instrumentation & Signal Conditioning**
- **Controls & Simulation**
- **DACS Lab Management**
- **Data Systems Management**
- **Ancillary Systems/Electrical Power**

Systems Analysis & Modeling

- Modeling and Analysis development and integration into RPT
- Fluid Mechanics/Thermal Analysis of Propellant Systems
  - Liquid
  - Gas
- CFD
- Structures/Loads Analysis
- Thermal/Heat Transfer Analysis

Organization Goal:

- **Develop and maintain propulsion test systems and facilities engineering competencies**
  - Unique and focused technical knowledge across respective engineering disciplines applied to rocket propulsion testing. e.g.,
    - Materials selection and associated database management
    - Piping, electrical and data acquisition systems design for cryogenic, high flow, high pressure propellant supply regimes
    - Associated analytic modeling and systems analysis disciplines and techniques
    - Corresponding fluids structural, thermal and electrical engineering disciplines

SSC Test Facilities

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AB-Complex

A-1 Full Scale Engine Devt. & Cert **A-2**

J-2X SSME

B-1/B-2

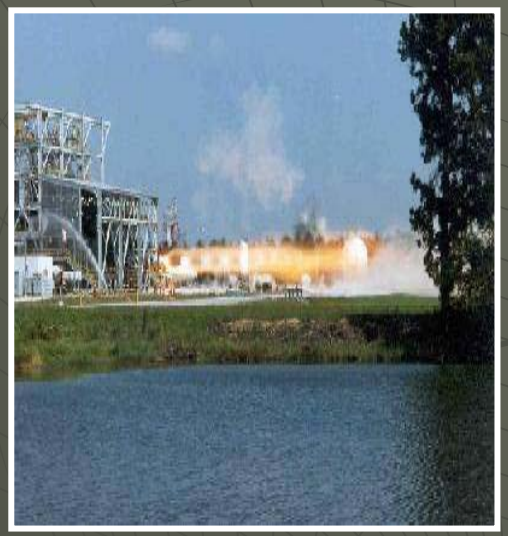
Full Scale Engine/Stage Devt. & Cert

RS-68/ARES

Components …Engines … Stages

E-Complex

Stennis Space Center



E-1
Cells 1, 2, 3

High Press., Full Scale
Engine Components

J-2X

E-2
Cell 1

High Press.
Mid-Scale
& Subscale

J-2X

E-2 Cell 2

Low Press. Mid-Scale
& Subscale, Stage

TGV

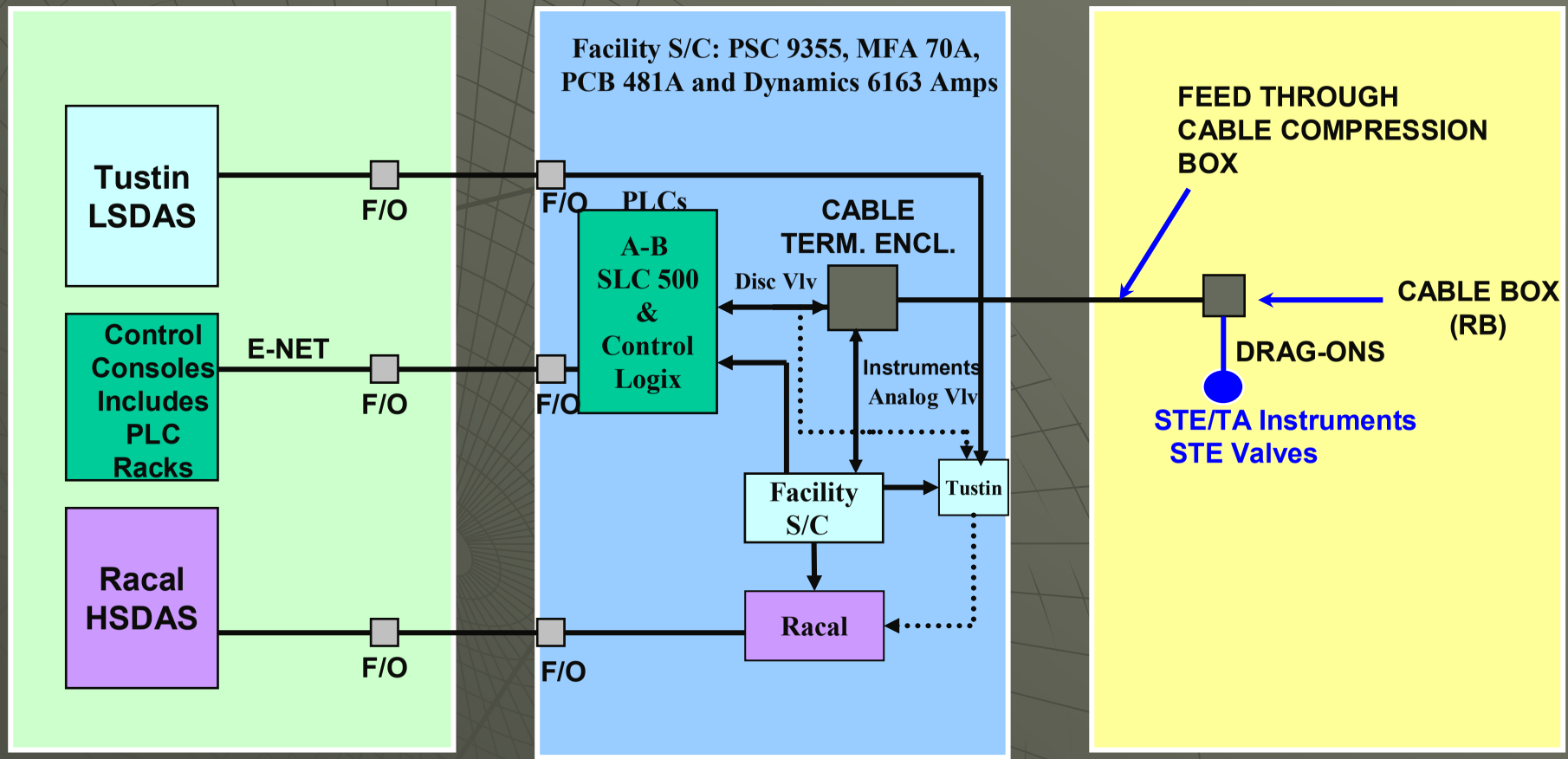
E-3
Cell 1

High Press. Small-Scale
Subscale

E-3
Cell 2

Test Facility Layout

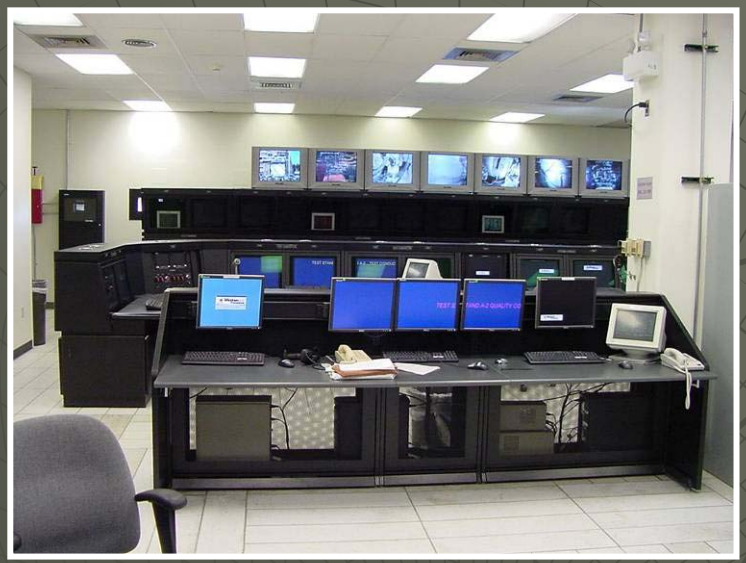
Stennis Space Center



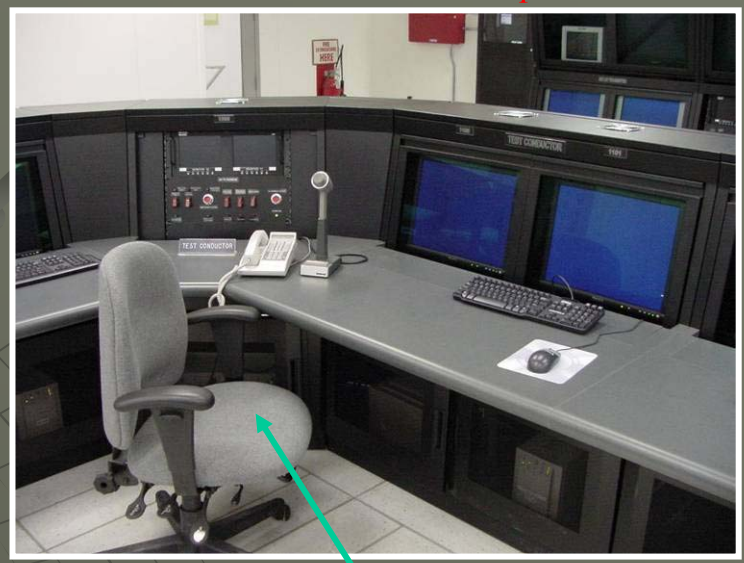
Test Control Center | Signal Conditioning Bldg | Test Article

Test Control Centers

Stennis Space Center



A2 TCC



E2 TCC

Test Conductor's Station

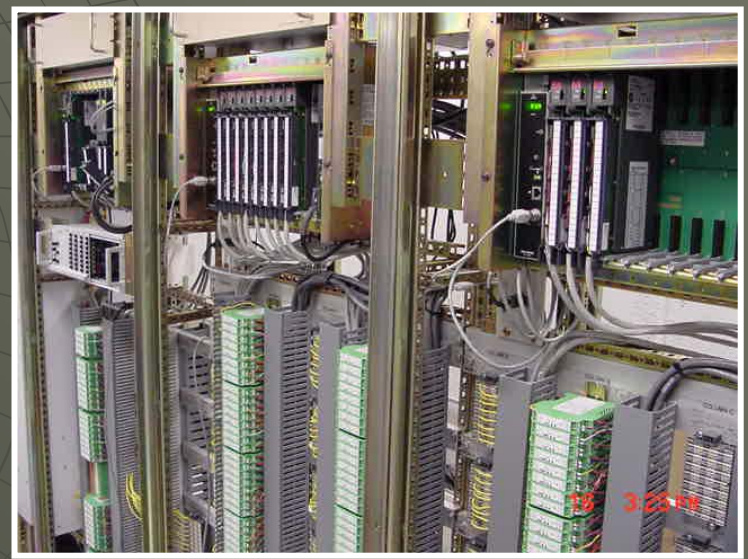
Signal Conditioning Buildings (SCB)

Stennis Space Center

E1 SCB Signal Conditioning Rack

E2 Cell 1 SCB 1 Controls Racks

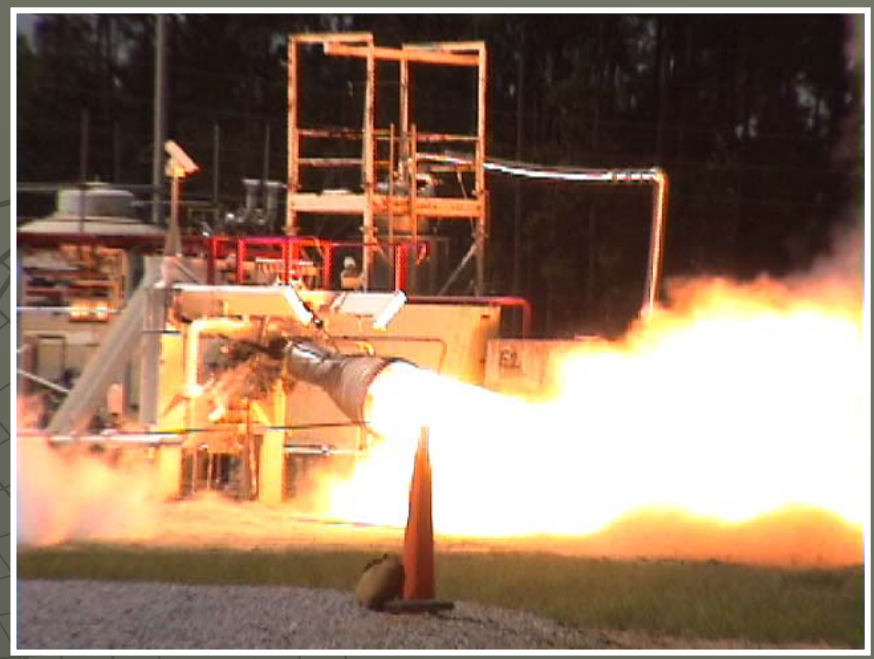
E2 SCB's 1 & 2



Typical Test Articles

Stennis Space Center

Integrated Powerhead Demonstrator



LR-89

Test Facility Electrical Systems

- Communications System
- Control System
- Facility Fire Alarm System
- Fire & Gas Leak Detect System
- Grounding System
- High Speed Data Acquisition System
- Lighting System
- Lightning Protection System
- Low Speed Data Acquisition System
- Oral Warning System
- Power Distribution System
- Uninterruptible Power System
- Video System
- DACS Lab/Sensor Development

High Speed Data Acquisition Systems (HSDAS)

Mark Hughes

High Speed Data Acquisition System

- The High Speed Data Acquisition System is used to record rocket engine or component data from a variety of dynamic sensors.
  - Sampling rates normally range from 5.12K to 204.8K samples per second (For Comparison, the Low Speed Data Acquisition System ranges from 1 to 250 samples per second.)
  - High speed data provides the Analyst with information about the dynamic environment/condition of a test article. The data feeds models that characterize the performance of the test article or allows the analyst to help determine the health of the hardware.
  - Challenges to recording good high speed data include the environment (high temperatures, vibration, high flow, cryogenic temperatures, high pressure), proper cabling, appropriate sensor election, and numerous other considerations.

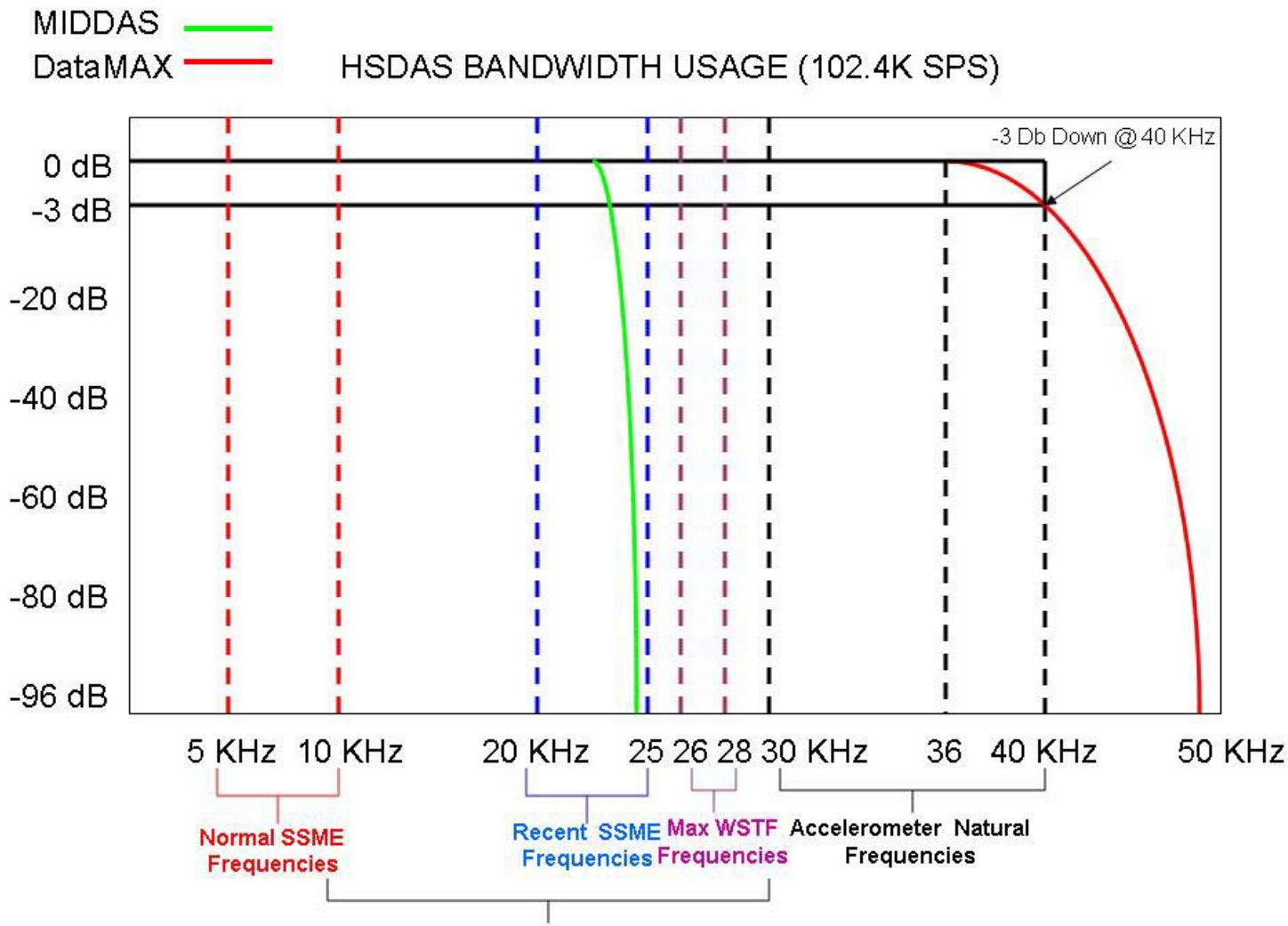
High Speed Data Acquisition Systems

- RACAL (Obsolete) - 100,000 Samples Per Second **(Decimal Sampling)**
  - AB-Complex (SSME)
  - E-Complex (TGV)

NOTE: This System is being replaced.

- MIDDAS (SSME Only)- 51,200 Samples Per Second **(Binary Sampling)**
  - A Complex (SSME Only)
- DataMAX II (New)- 204,800 Samples Per Second **(Binary & Decimal Sampling)**
  - AB Complex (RS-68, J-2X)
  - E Complex

Typical HSDAS Bandwidth Usage

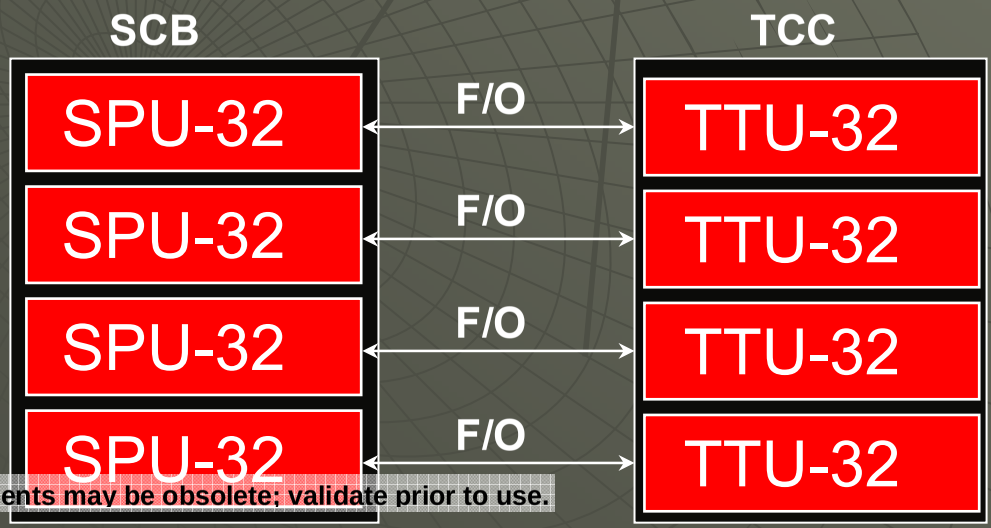


RACAL HSDAS

- **Obsolete-**Being Replaced by DataMAX II HSDAS
- Decimal Sampling Only
- AB-Complex Use Ends in 2007, E-Complex by 2010

Specifications

- ❑128 Channels
- ❑100K Samples Per Second
- ❑45.5 KHz Bandwidth
- ❑16 Bit Delta-Sigma A/D Conversion
- ❑.5, 1, 2, 5, 10, 20 50 Volts Peak



RACAL HSDAS

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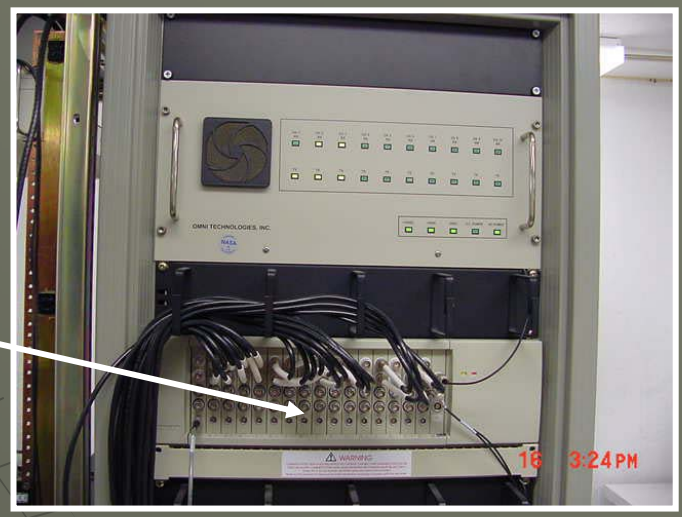
Tape
Transport Unit

Signal
Processing Unit



Handheld
Controller

Direct-to-Disk
System

MIDDAS HSDAS

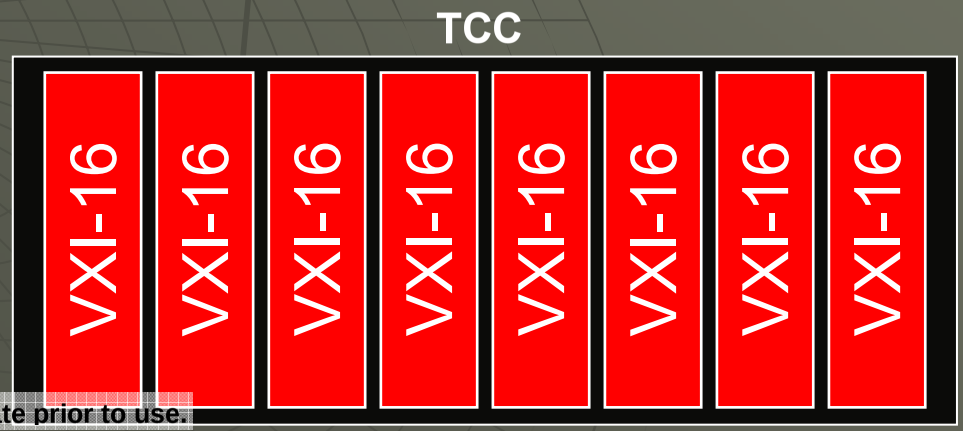
- SSME Use Only
- Binary Sampling
- Backed up by a DataMAX II
- Used for Quick Turnaround Data

Specifications

- ❑128 Channels
- ❑51.2K Samples Per Second
- ❑23 KHz Bandwidth
- ❑16 Bit Delta-Sigma A/D Conversion
- ❑.1, .2, .5, 1, 2, 5, 10, 20 Volts Peak

No SCB Hardware

Results in Cable Lengths of around 1700 FT



MIDDAS HSDAS

Stennis Space Center

128 Channel MIDDAS System

MIDDAS in Standalone Configuration

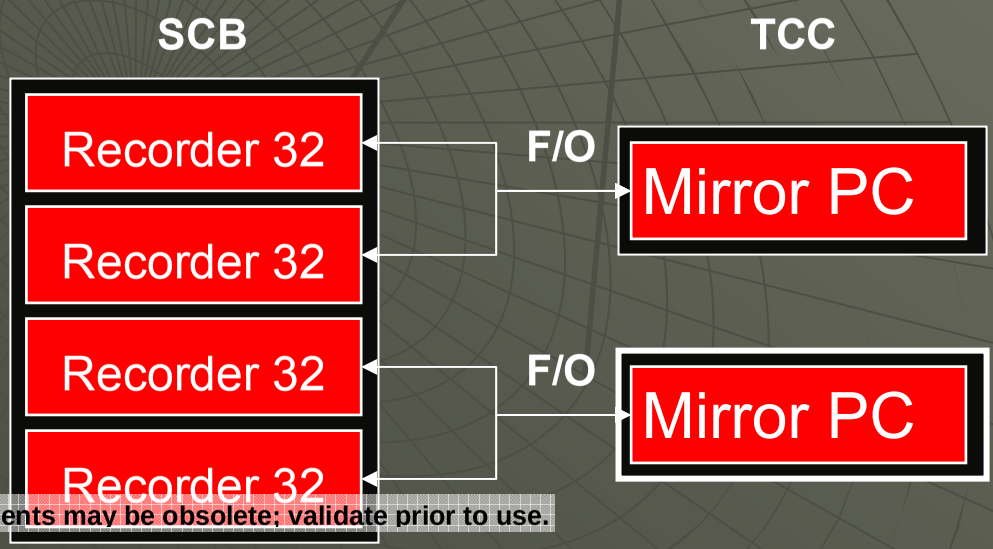
DataMAX II HSDAS

Stennis Space Center

- Mirrored Data Recording
- Binary & Decimal Sampling
- Rates up to 204.8 K SPS
- Fast Turnaround and Archive Data

Specifications

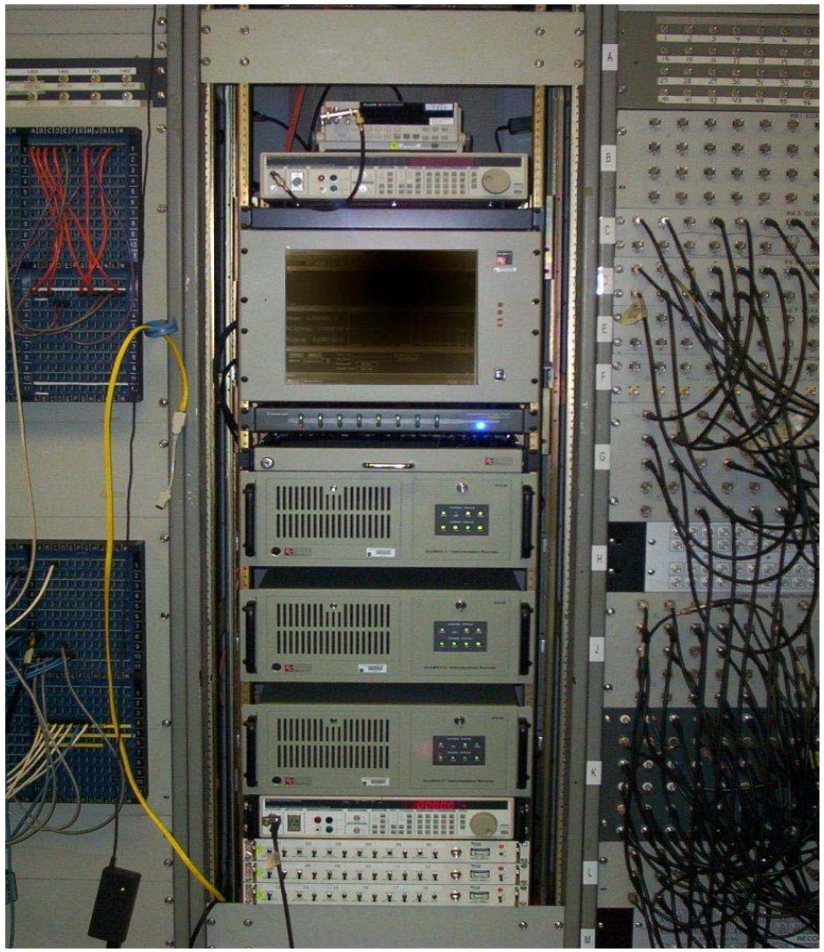
- ❑192 Channels
- ❑204.8K Samples Per Second
- ❑90 KHz Bandwidth
- ❑16 Bit Delta-Sigma A/D Conversion
- ❑1, 4, 10, 40 Volts Peak



Redundant Data Storage

DataMAX II HSDAS

Stennis Space Center

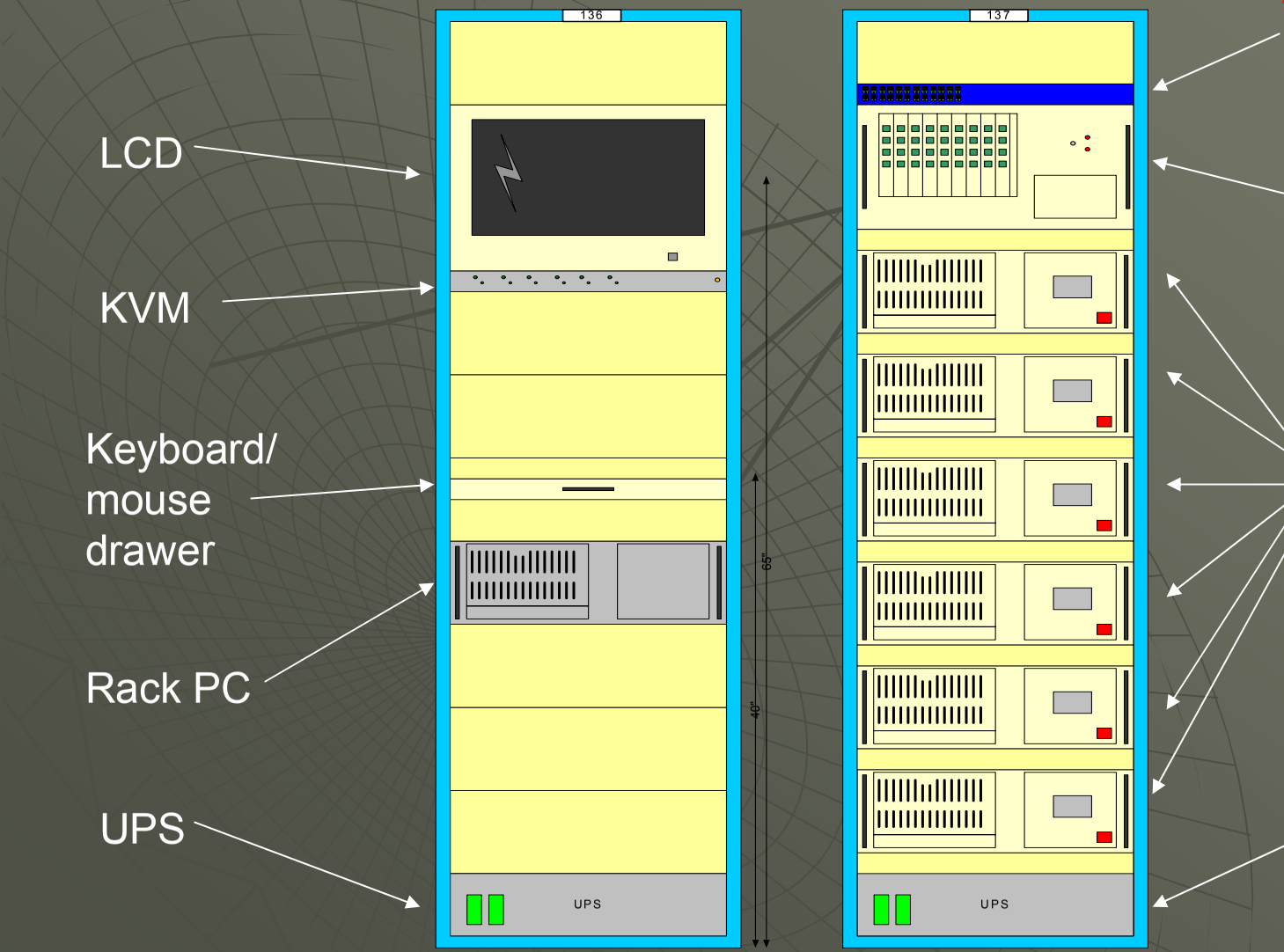


32 Channel Recorders

Mirrored Drives in the TCC

DataMAX II
Planned for B2 Test Complex

Stennis Space Center

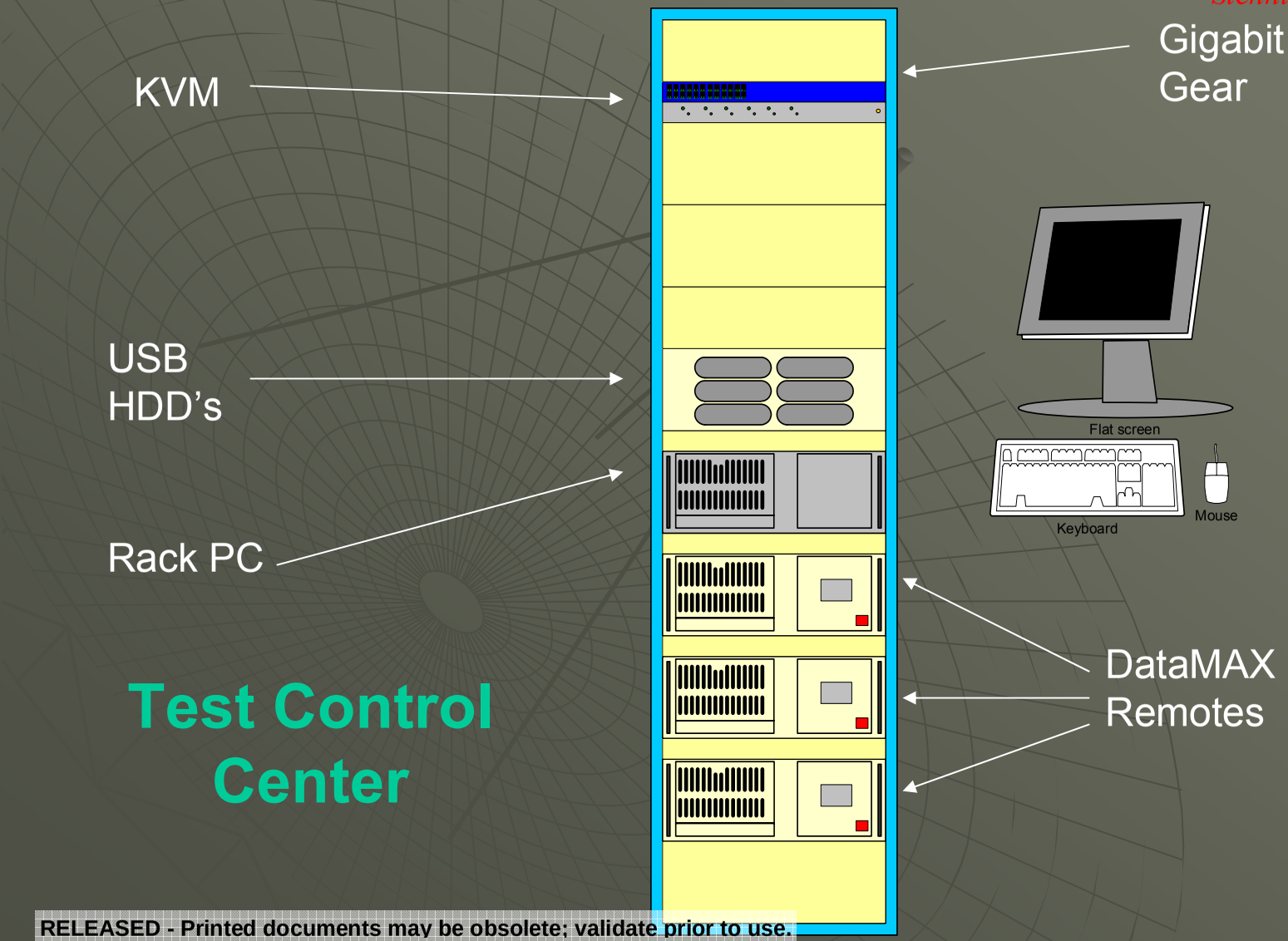


Test Facility

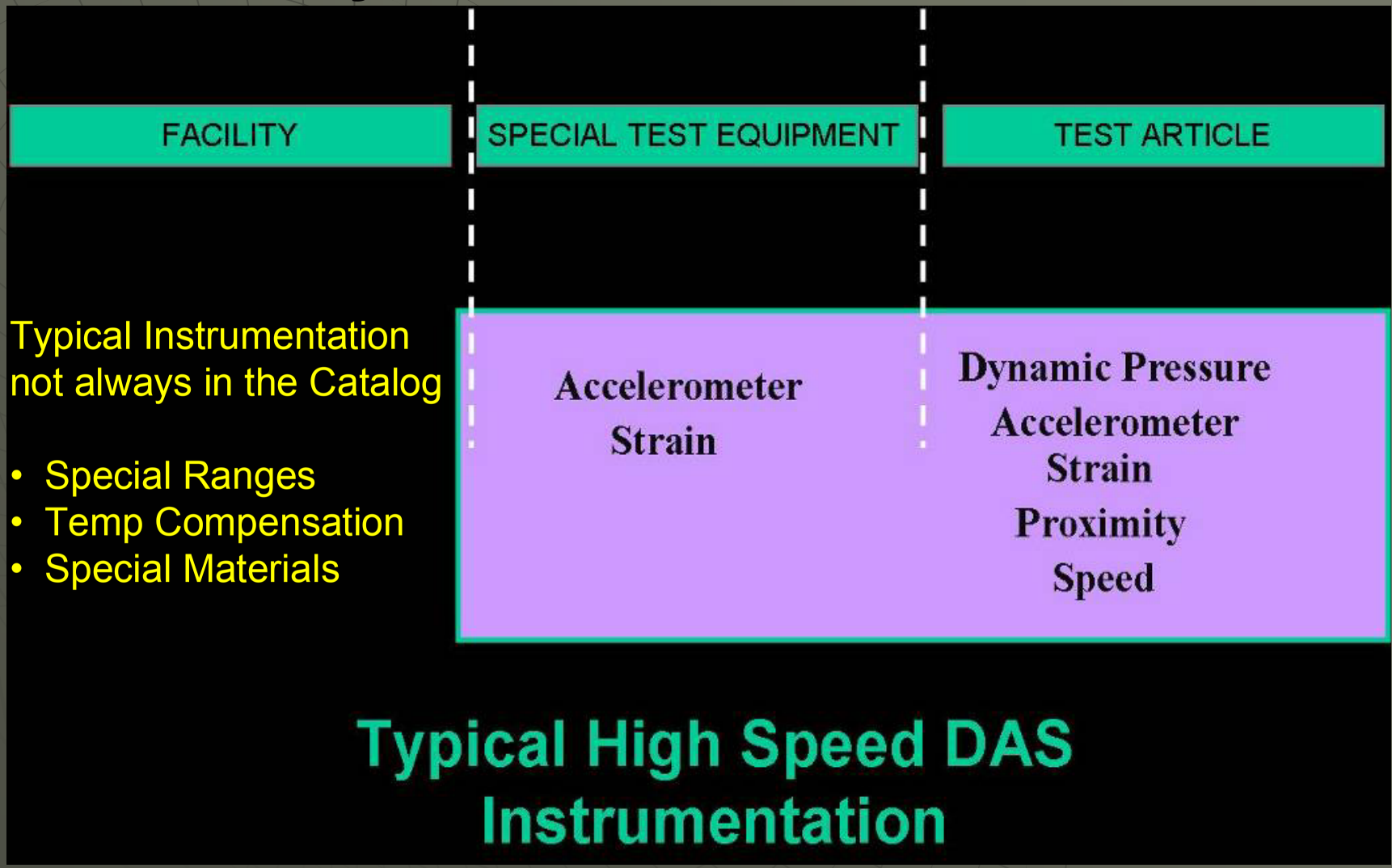
192 Channels

DataMAX II
Planned for B2 Test Complex

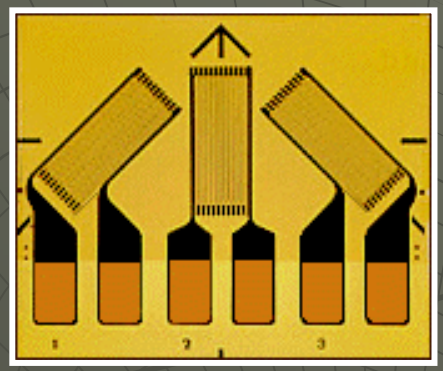
Stennis Space Center



Typical High Speed Data Acquisition System Instrumentation



Typical High Speed Data Acquisition System Instrumentation



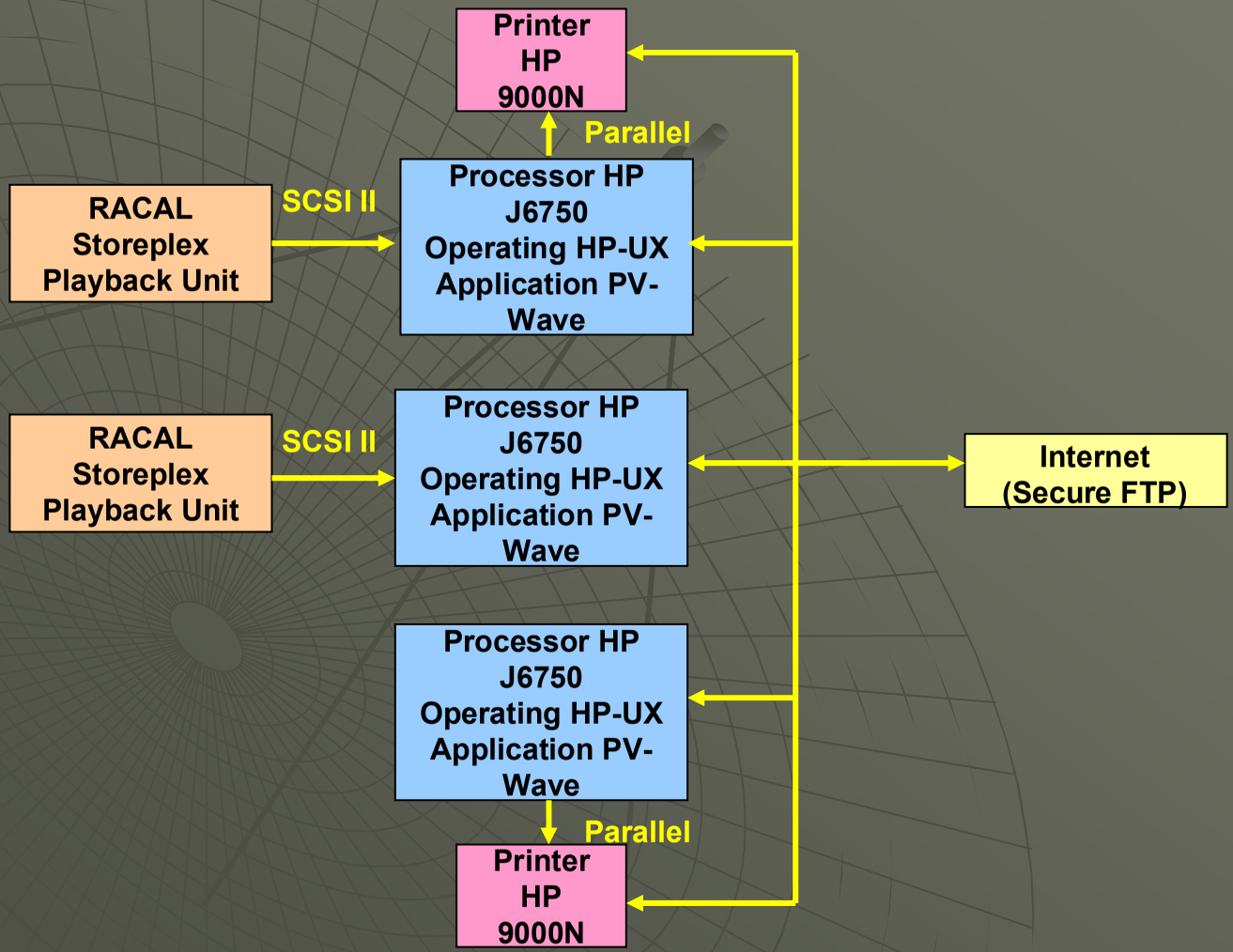
Strain

Dynamic Pressure

Speed

Accelerometer

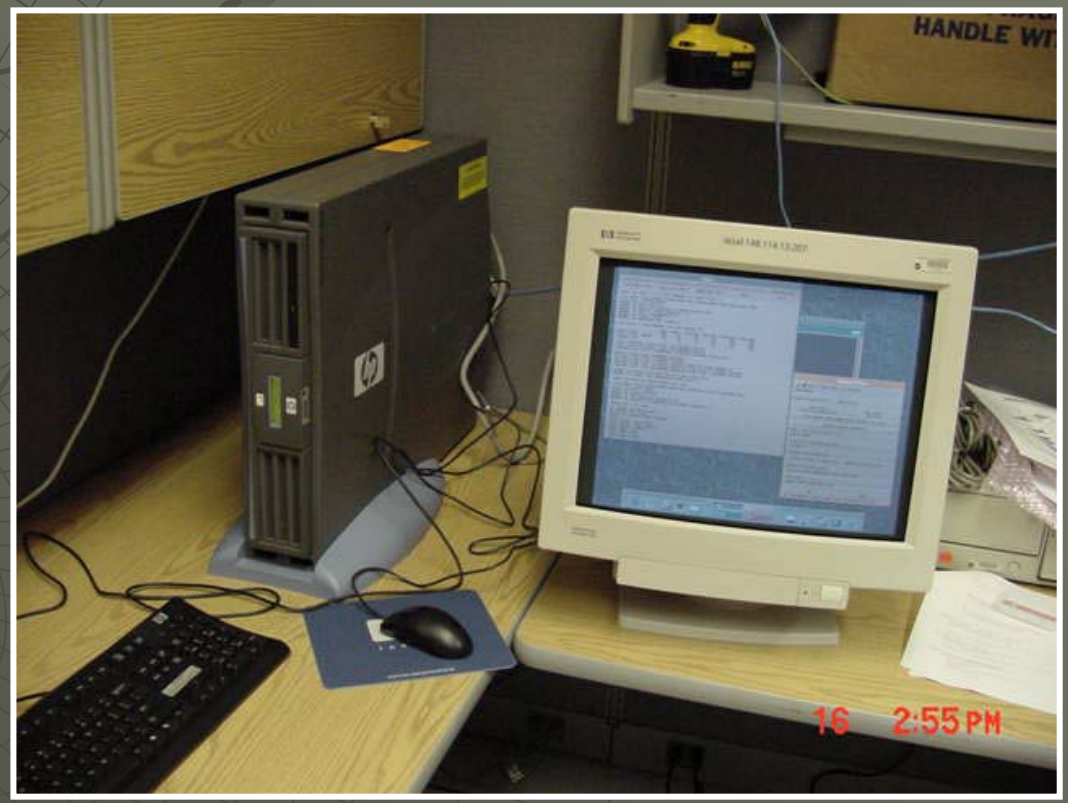
E-Complex High Speed Data Processing System



E-Complex High Speed Data Processing System

HP J6750 Unix Workstations

- Twin 875 MHz RISC Processors
- 4 GB RAM
- 72 GB Storage



Low Speed Data Acquisition Systems

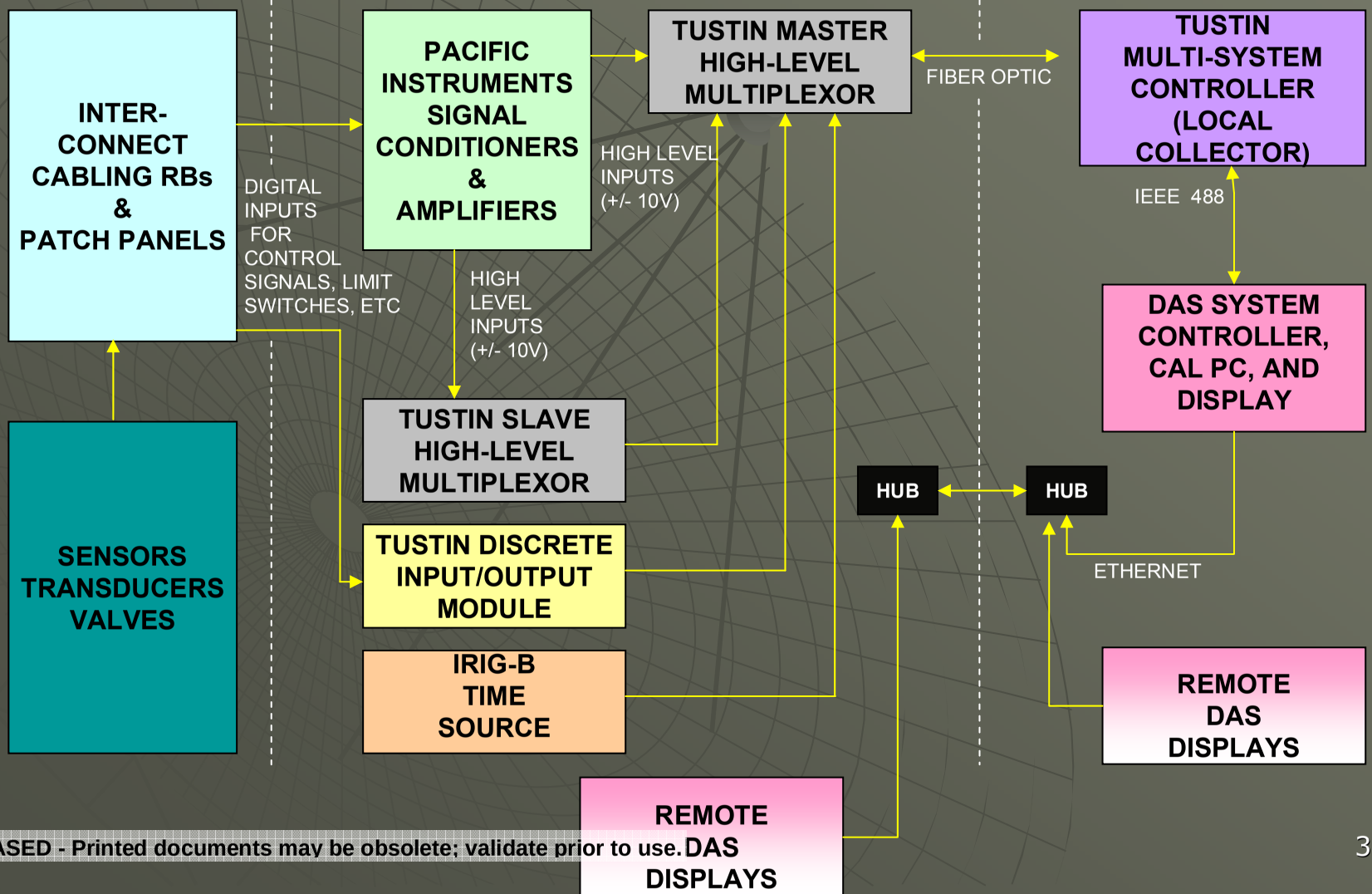
Dawn Davis

SSC's Low Speed Data Acquisition Systems

- Data acquisition, recording, real time display
  - **Data types:** Low frequency Analog Data, Discrete (event) Data, Pulse Data from flow meters and speed sensors
    - **E-Complex Tustin** - 250 samples per second
    - **AB-Complex PreSys 1000** - 250 samples per second

E-Complex Low Speed Data Acquisition System Architecture

Stennis Space Center

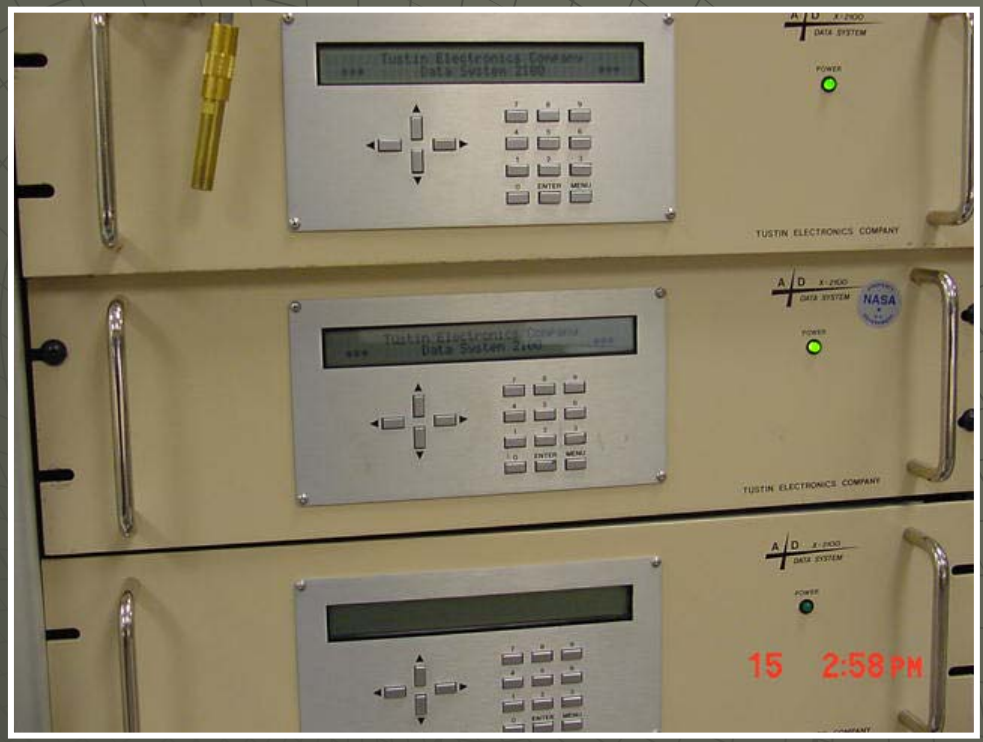


E-Complex Low Speed Data Acquisition System Architecture

- The E-Complex consists of three test stands
  - **E1**
    - Contains four separate data systems: facility, Cell 1, Cell 2, Cell 3
    - Each system contains 512 analog input channels and 320 discrete channels
    - Two systems run during a test: Facility and cell
  - **E2**
    - Contains two separate data systems: Cell 1 and Cell 2
    - Each system contains 400 analog input channels and 420 discrete channels
    - Systems include both facility and test cell measurements
  - **E3**
    - Contains one data systems for both cells
    - System contains 400 analog input channels and 312 discrete channels

E-Complex
Low Speed Data Acquisition System

Tustin Data System



- Fully populated analog box
  - 128 analog input channels
- Fully populated discrete box
  - 320 digital input channels

E-Complex
Low Speed Data Acquisition System

Pacific Instruments Signal Conditioners

- Model 9355
  - **Programmable**
    - Gain, filter, excitation
  - **Automated Calibration**
    - Voltage Insertion
    - Shunt
    - Rcal
  - **Various Completion Cards**
    - Full Bridge, Half Bridge
    - Internal or external shunt resistors
    - ICP
  - **Measurements**
    - RTD's
    - Pressure Transducers
    - Strain Gauges

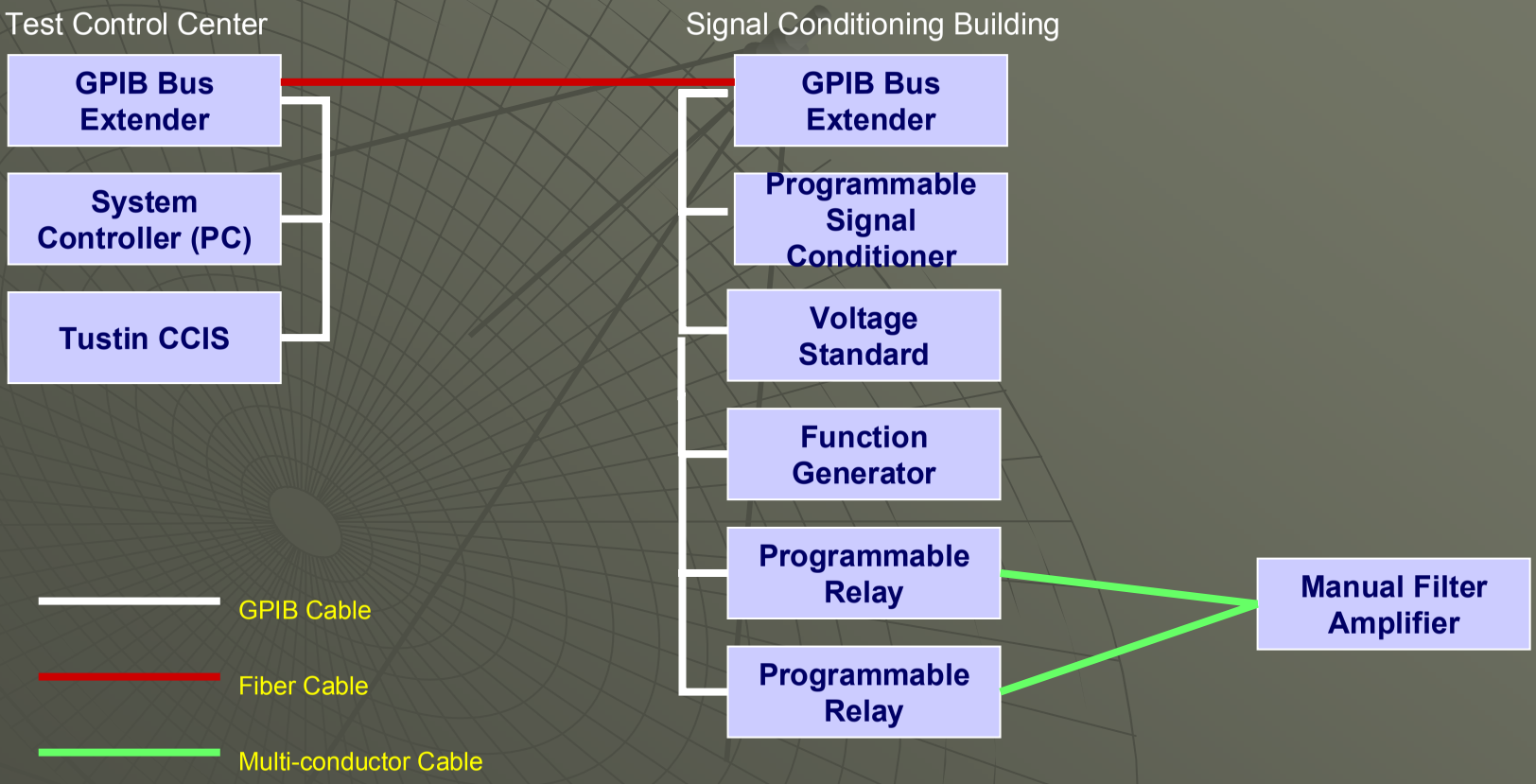
E-Complex
Low Speed Data Acquisition System

Pacific Instruments Amplifiers

- Model 70A
  - **Manual Settings**
    - Gain, filter
  - **Calibrations**
    - Automated through use of additional hardware
  - **Measurements**
    - TC's
    - Transmitters
    - Require no excitation

E-Complex
Low Speed Data Acquisition System

Calibration Bus



E-Complex
Low Speed Data Acquisition System

Software

- All of the E-Complex Low Speed DAS software is developed in LabVIEW
  - LSDAS Control Software
  - Display Screens
  - Calibration Software
  - Measurement System Analysis (MSA's)Software

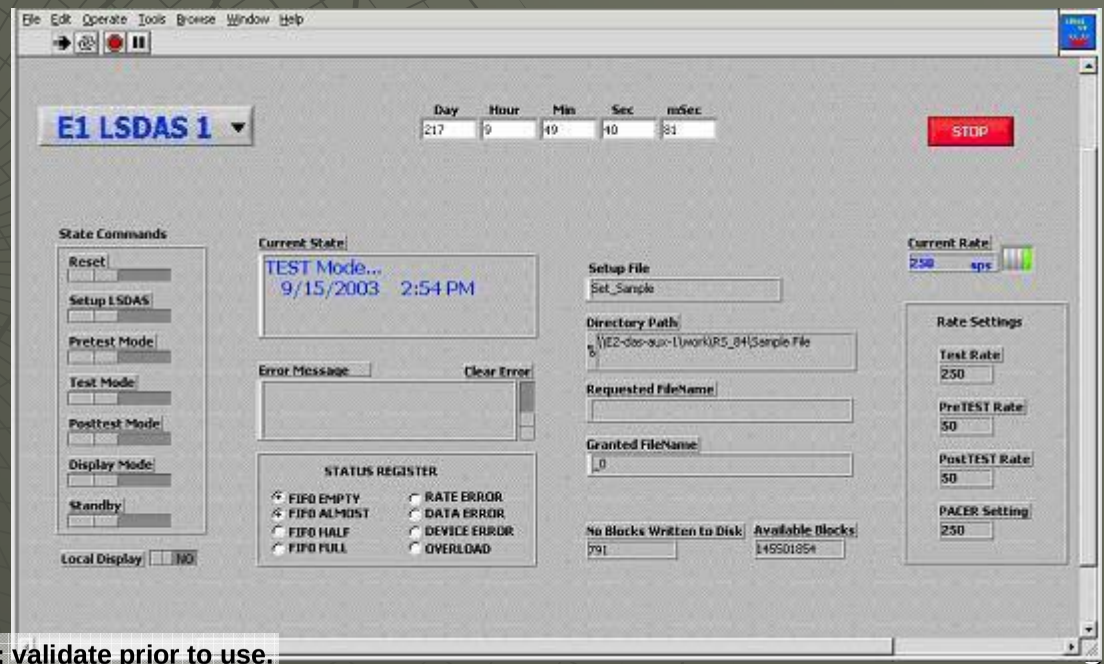
LabVIEW® Graphical Programming for Instrumentation

E-Complex
Low Speed Data Acquisition System

Stennis Space Center

Software

- Low Speed DAS Control Software
  - Used for operation and configuration of the LSDAS Hardware
  - Capability to place system in various modes: Standby, Test, Pre-test, Post-test, Display
  - Saves data to hard-drive
  - Distributes data for remote display

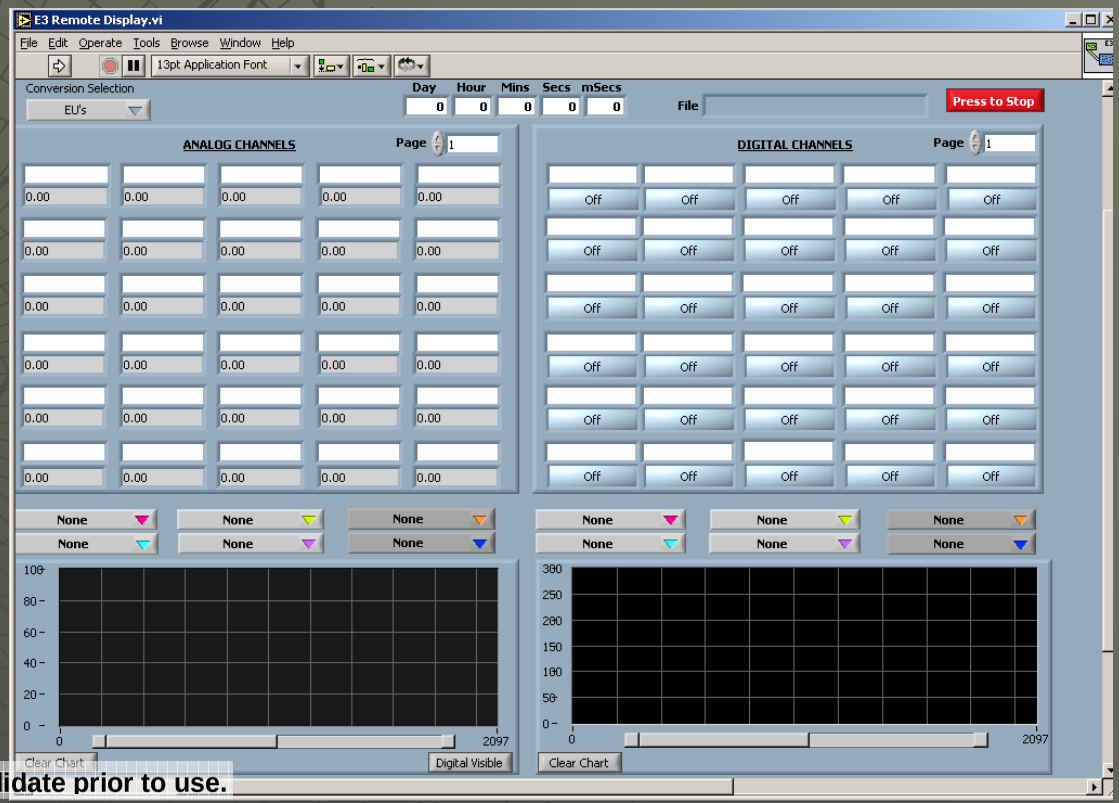


E-Complex
Low Speed Data Acquisition System

Stennis Space Center

Software

- Low Speed DAS Display Software
  - Tabular and numerical display of measurements
  - Analog and digital data



E-Complex
Low Speed Data Acquisition System

Software

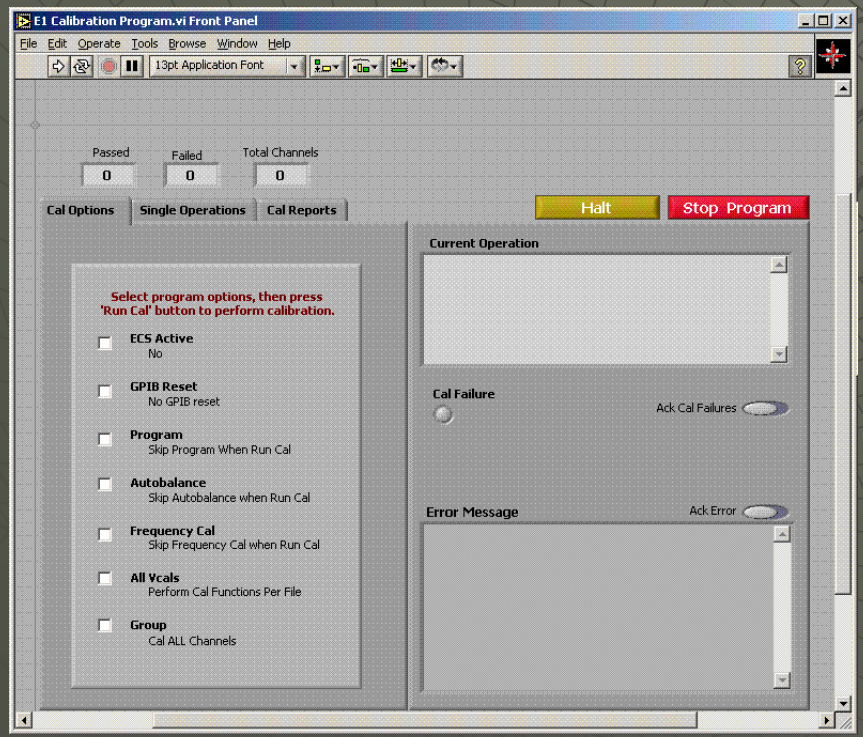
- Calibration Software
  - Voltage insertion, shunt calibration
  - Calibrate to a tolerance
  - All or subset of channels
  - Generates Report
- Additional Functions
  - Setup of programmable amplifiers : gain, filter, excitation
  - Auto-balance
  - Single Channel Diagnostics

E-Complex
Low Speed Data Acquisition System

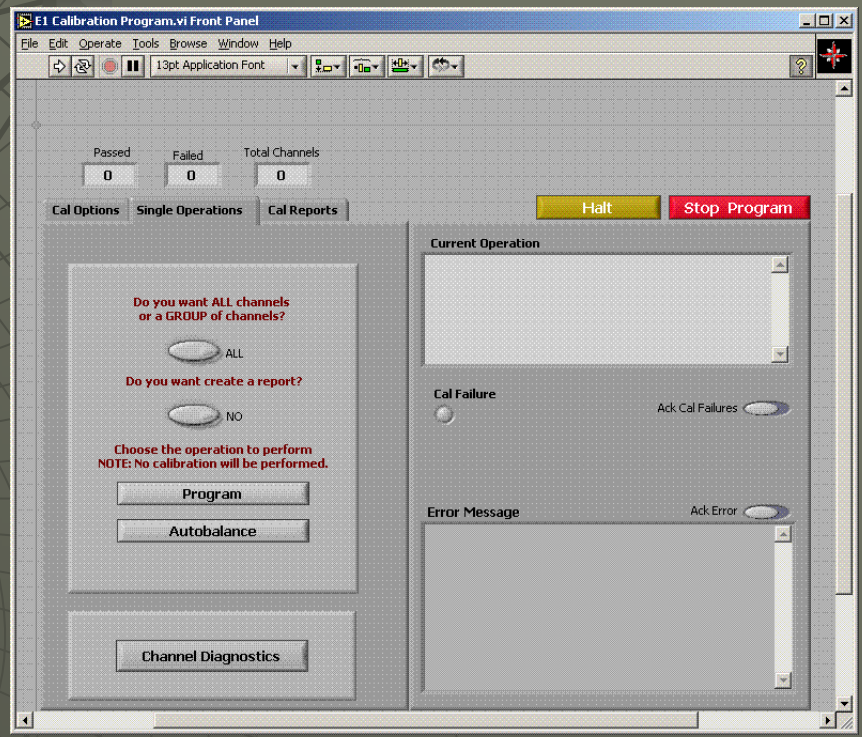
Stennis Space Center

Software

- Calibration Software



Main Page



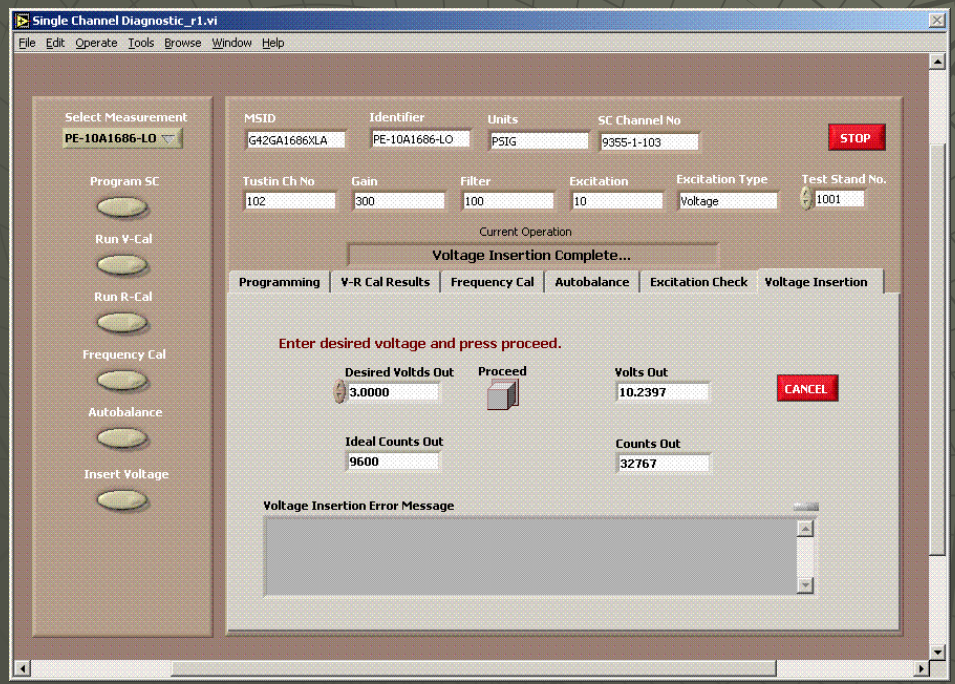
Single Channel Operations

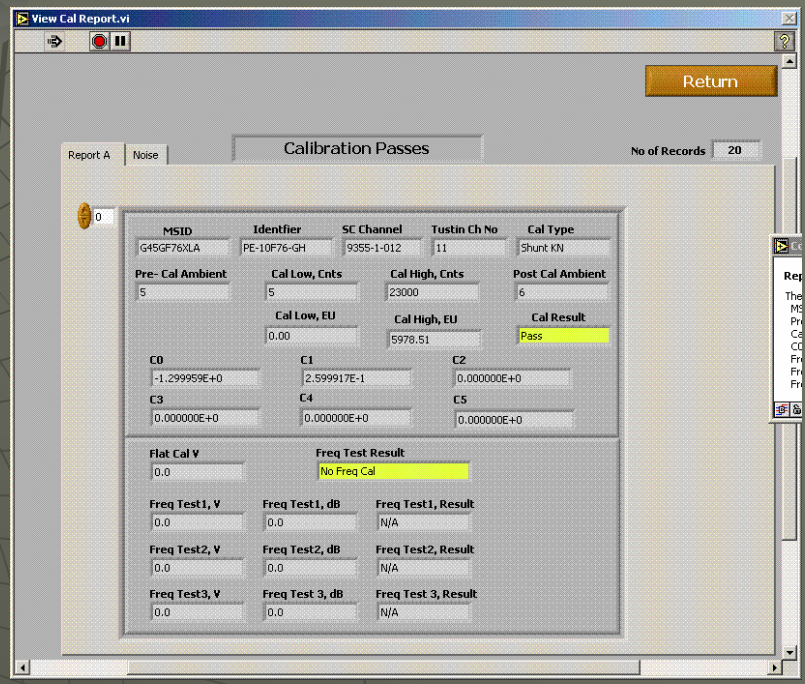
E-Complex
Low speed Data Acquisition System

Stennis Space Center

Software

- Calibration Software





Channel Diagnostics **Report**

E-Complex
Low Speed Data Acquisition System

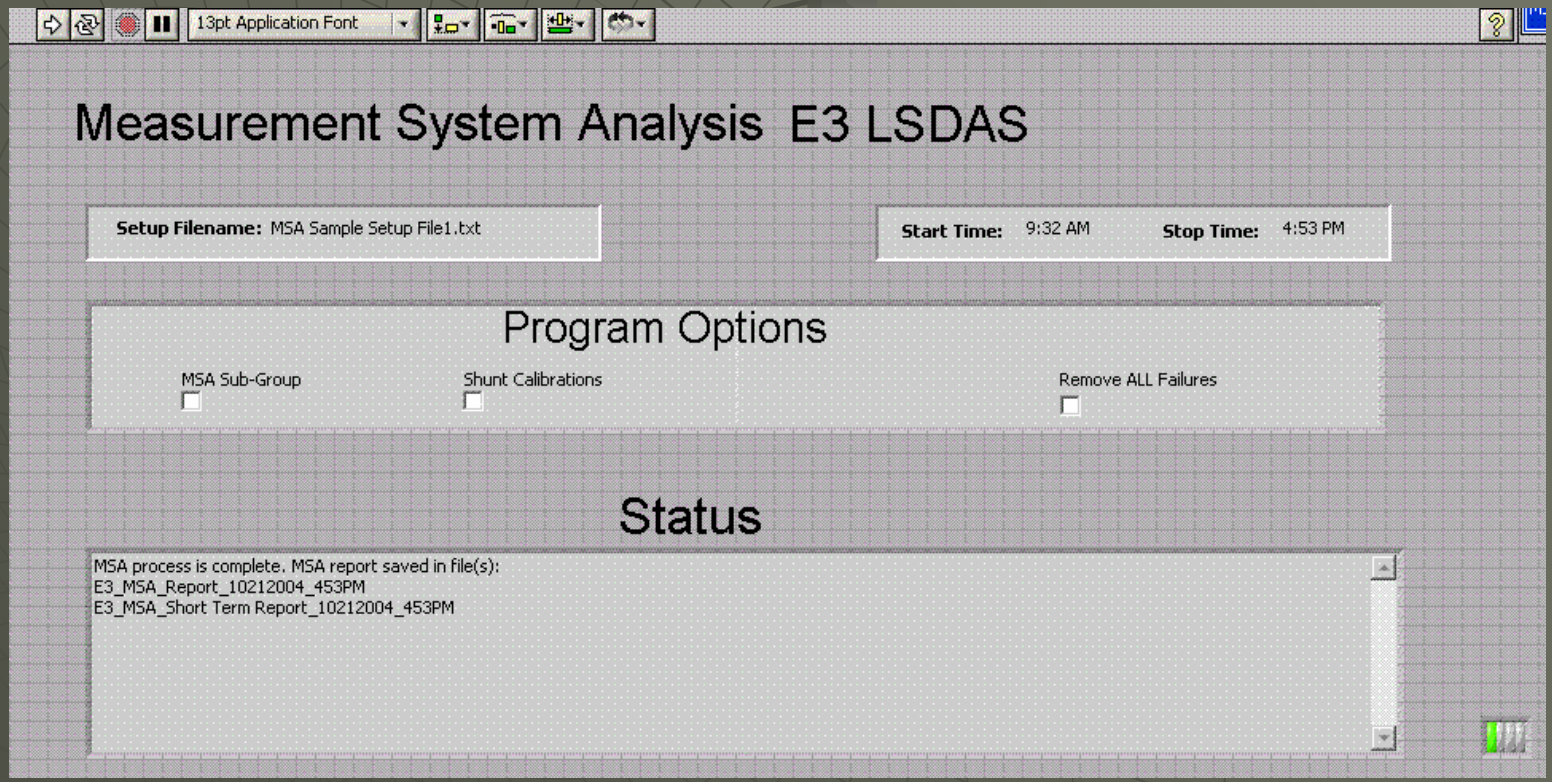
Software

- Measurement System Analysis Software
  - Purpose is to quantify a system precision for the LSDAS by evaluating the drift over time of the data system.
  - It consists of a two point calibration performed every hour during an eight hour time span. This is to simulate the maximum time between a pre-test calibration and a test.
  - MSA is performed every thirty days.
  - Reports are generated and data is stored in database.
  - Data from previous runs are used to generate the system precision and to maintain a history of the data system's response.

E-Complex
Low Speed Data Acquisition System

Software

- Measurement System Analysis Software



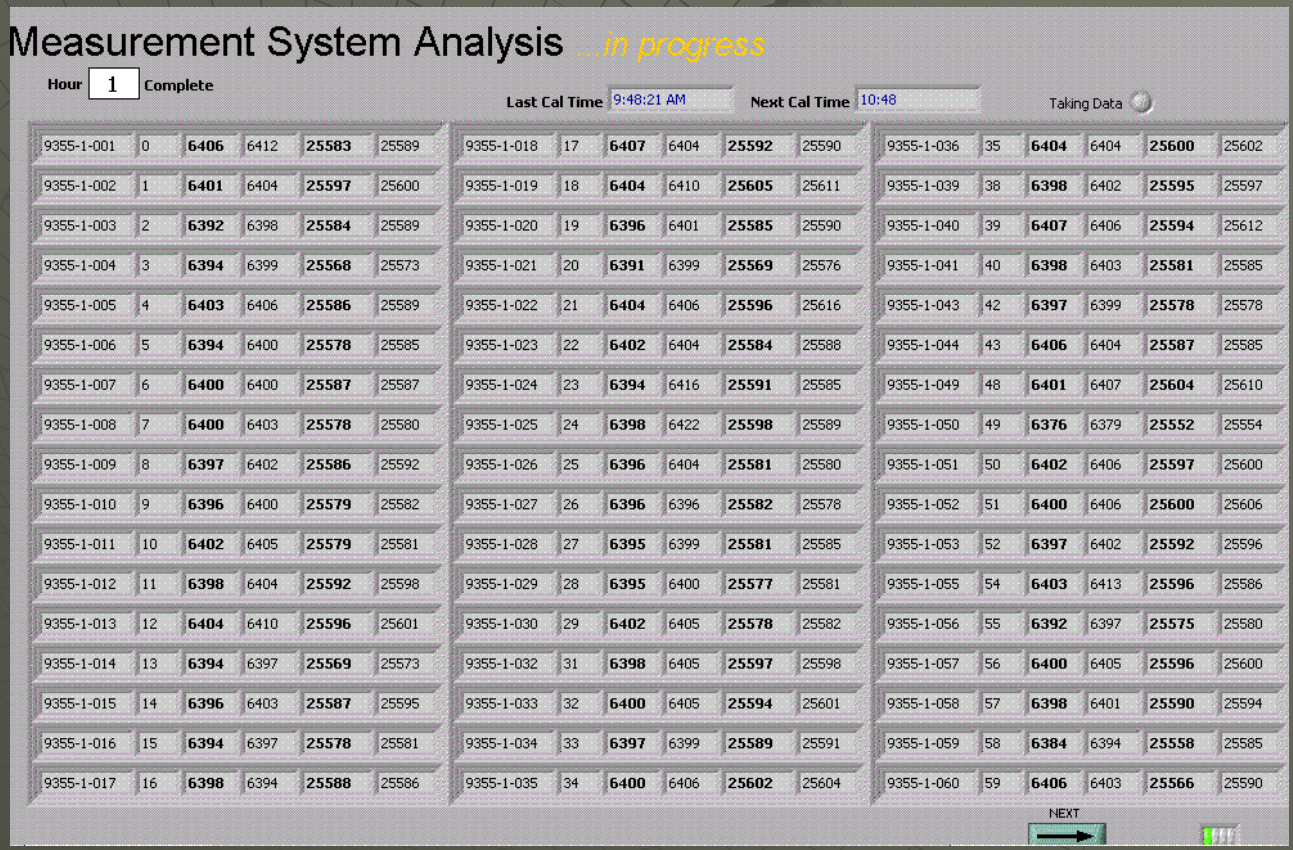
Main Screen

E-Complex
Low Speed Data Acquisition System

Stennis Space Center

Software

- Measurement System Analysis Software



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9355-1-010	9	6396	6400	25579	25582	9355-1-027	26	6396	6396	25582	25578	9355-1-052	51	6400	6406	25600	25606
9355-1-011	10	6402	6405	25579	25581	9355-1-028	27	6395	6399	25581	25585	9355-1-053	52	6397	6402	25592	25596
9355-1-012	11	6398	6404	25592	25598	9355-1-029	28	6395	6400	25577	25581	9355-1-055	54	6403	6413	25596	25586
9355-1-013	12	6404	6410	25596	25601	9355-1-030	29	6402	6405	25578	25582	9355-1-056	55	6392	6397	25575	25580
9355-1-014	13	6394	6397	25569	25573	9355-1-032	31	6398	6405	25597	25598	9355-1-057	56	6400	6405	25596	25600
9355-1-015	14	6396	6403	25587	25595	9355-1-033	32	6400	6405	25594	25601	9355-1-058	57	6398	6401	25590	25594
9355-1-016	15	6394	6397	25578	25581	9355-1-034	33	6397	6399	25589	25591	9355-1-059	58	6384	6394	25558	25585
9355-1-017	16	6398	6394	25588	25586	9355-1-035	34	6400	6406	25602	25604	9355-1-060	59	6406	6403	25566	25590

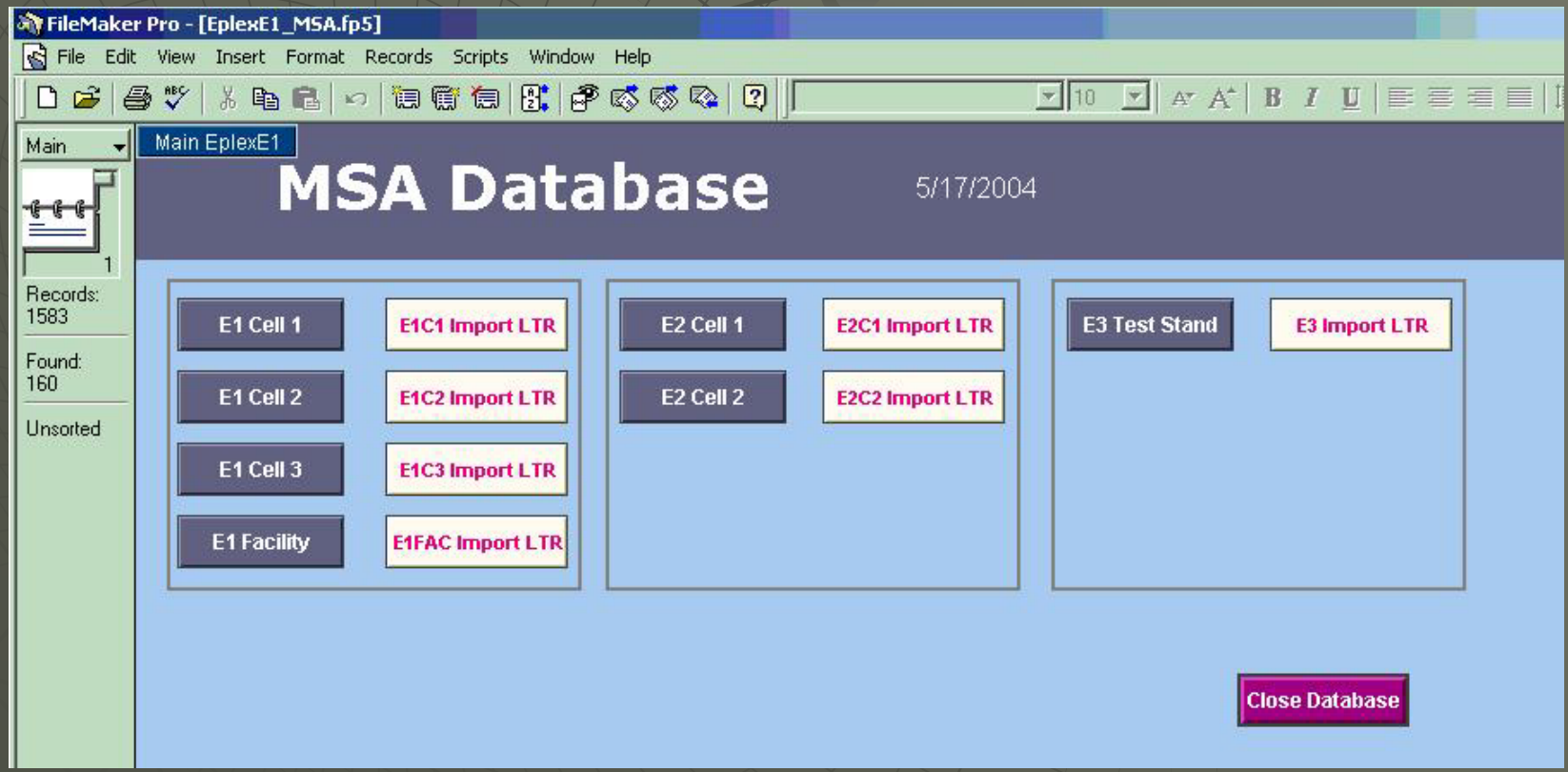
Hourly Report

E-Complex
Low Speed Data Acquisition System

Stennis Space Center

Software

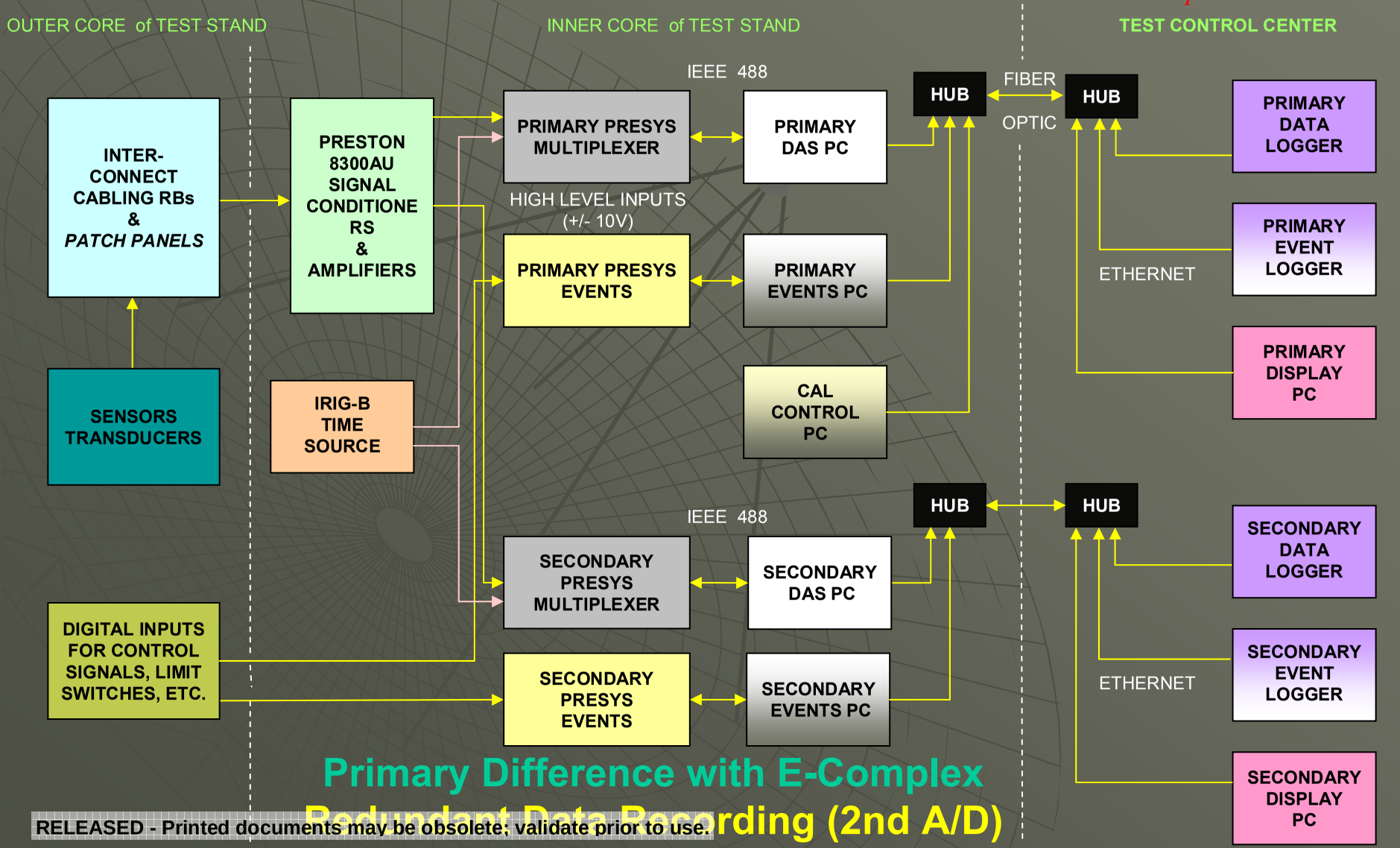
- Measurement System Analysis Software



MSA Database

AB-Complex Architecture
Low Speed Data Acquisition System

Stennis Space Center



Primary Difference with E-Complex
Redundant Data Recording (2nd A/D)

AB-Complex Architecture
Low Speed Data Acquisition System

- The AB-Complex consists of four test stands
  - A1, A2, B1, B2 (B1/B2 one structure with two distinct sides)
    - Systems contain 512 analog input channels and 736 digital input channels
    - Each system contains a primary and secondary system for redundancy. Data from the secondary system is only processed if a problem occurs on the primary system.

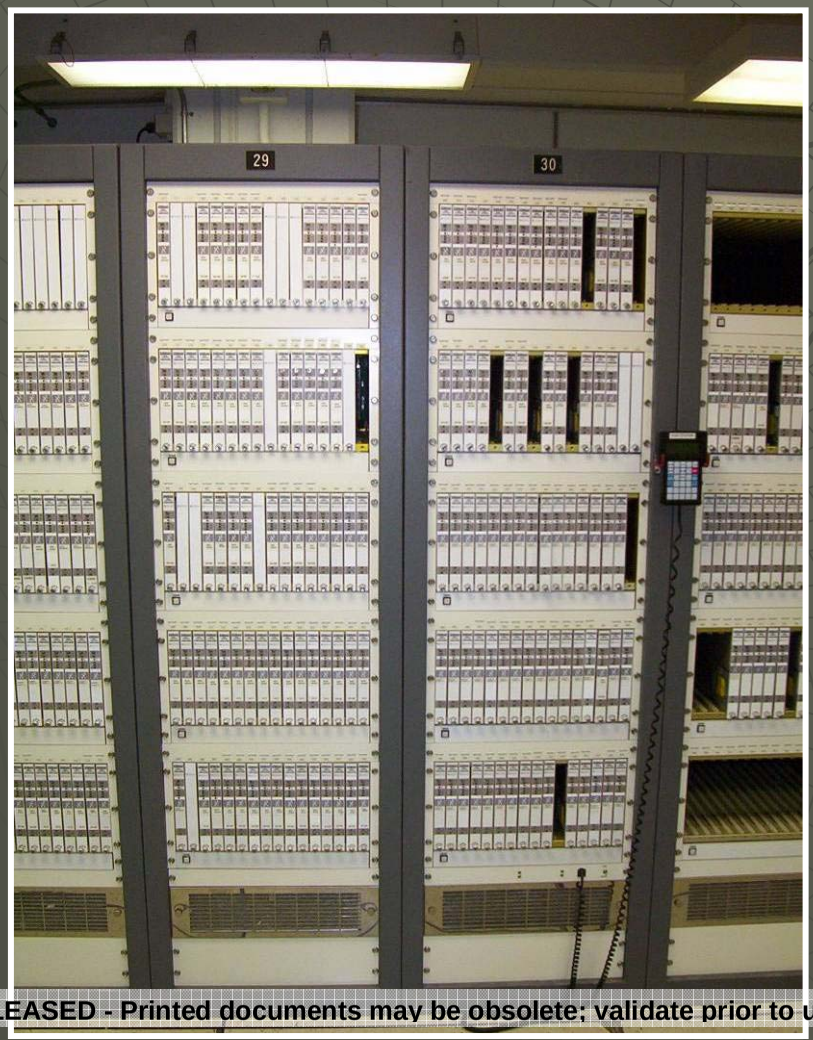
AB-Complex Architecture
Low Speed Data Acquisition System

PreSys 1000

- Fully populated analog box
  - 256 analog input channels
- Fully populated discrete box
  - 480 digital input channels

AB-Complex Architecture
Low Speed Data Acquisition System

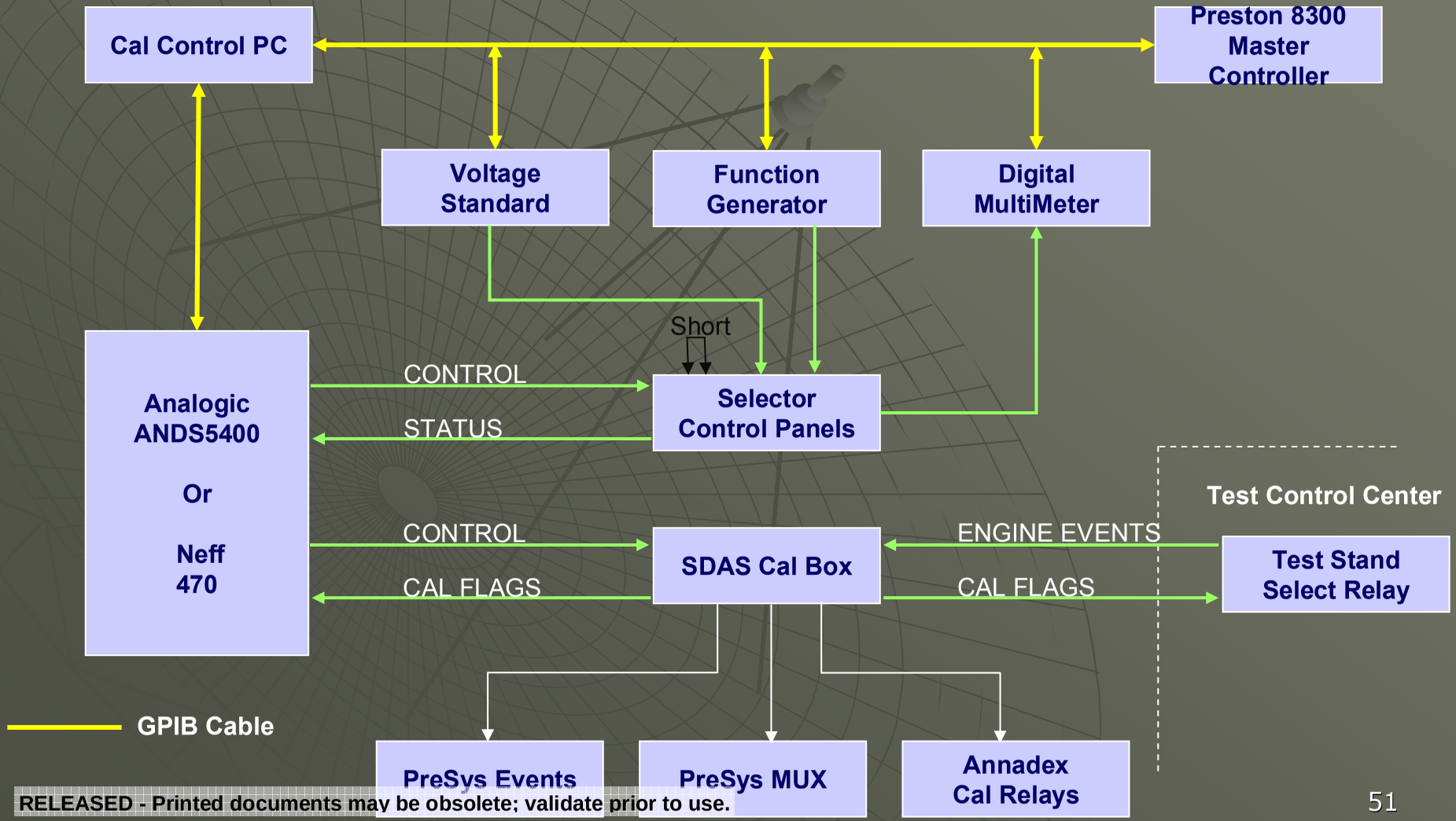
Preston Amplifiers



- Model 8300
  - **Programmable**
    - Gain, filter, excitation
  - **Automated calibration**
    - Voltage Insertion
    - Shunt
    - Rcal
  - **Various Mode Cards**
    - Strain Gauge
    - Full Bridge , Half Bridge
    - RTD
    - Thermocouple
  - **Measurements**
    - Strain Gauges
    - Pressure Transducers
    - RTD's
    - Thermocouples

AB-Complex Architecture
Low Speed data acquisition System

Calibration Control



AB-Complex Architecture
Low Speed Data Acquisition System

Software

- Software consists of :
  - Signal Conditioning Setup
  - Measurement Calibration
  - Data Acquisition and Real-time Display
  - Measurement System Analysis

AB-Complex Architecture
Low Speed Data acquisition System

Software

- Software written in Microsoft Visual Basic provides computer controlled setups and calibration of the Preston signal conditioners and amplifiers

- Signal Conditioning Setup – *Set8300*
  - Select gain, filter
  - Setup and adjustment of individual signal conditioners and amplifiers

- Calibration – *CalMon*
- Automatic calibrations on any number of selected signal conditioners
- Calibrate all active measurements pre-test
- Calibration Types
  - Shunt Calibration
  - Voltage Substitution
  - Excitation Power Supply Calibration
  - External Calibration

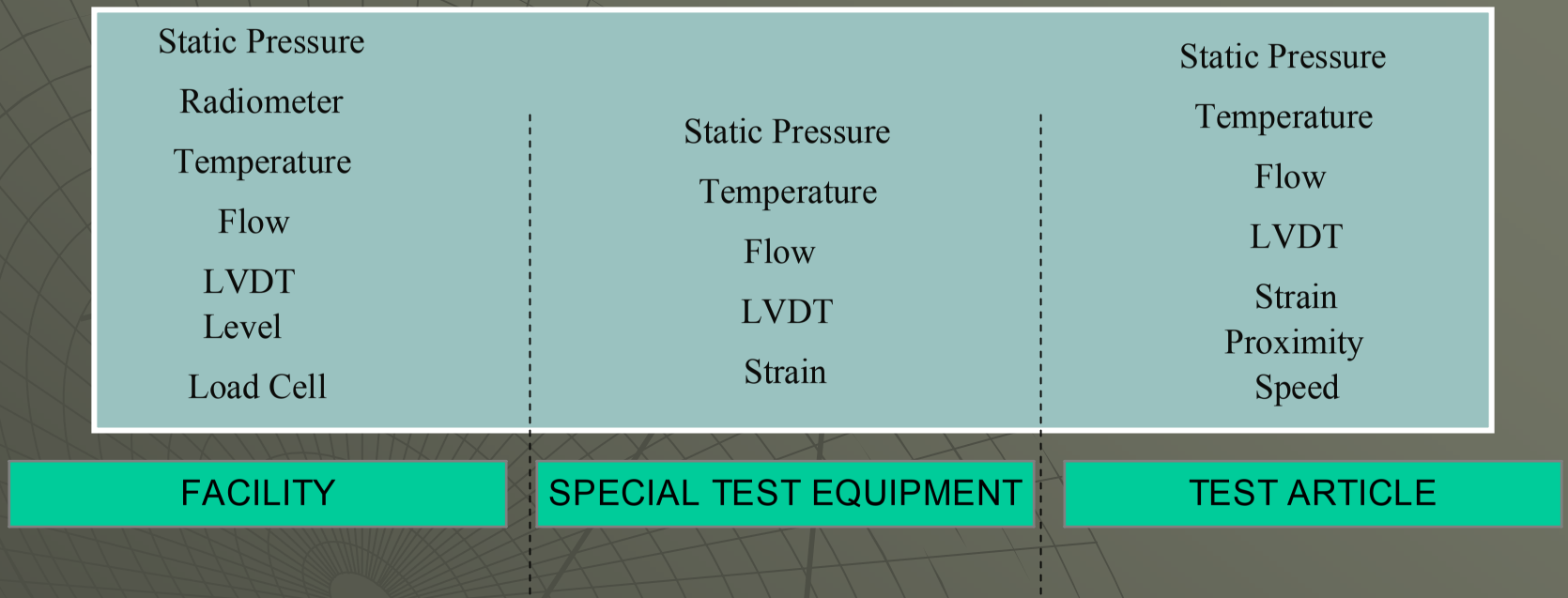
AB-Complex Architecture
Low Speed Data Acquisition System

Software

- Data Acquisition and Real-time Display – *DDAS*
  - Provides for the control of the data acquisition process and the distribution of data for real-time display
  - Combines both the analog and discrete data
- Measurement System Analysis
  - Software originally developed by Rocketdyne
  - Purpose is to quantify a system precision for the LSDAS by evaluating the drift over time of the data system.
  - It consists of a two point calibration performed every hour during an eight hour time span. This is to simulate the maximum time between a pre-test calibration and a test.

Typical Low Speed Data Acquisition System Instrumentation

Stennis Space Center



- **Standard Instrumentation - Not always in the Catalog**
  - **Special Ranges (Cryogenics, Hundreds of Degrees F)**
  - **Special temperature compensation circuits**
  - **Special Materials**
  - **Extremely High Pressures**

Typical Low Speed Data Acquisition System Instrumentation

Stennis Space Center

Pressure

Transmitter

Delta P

Pressure

Temperature

Thermocouples

RTD's

Transmitter

Flow

Venturi Flowmeter

Turbine Flowmeter

Strain

Strain Gauges

Speed

Speed Probe

Control Systems

John Bakker

Control Systems

- The Control System manages the test complex and rocket engine or component systems during day-to-day operations and testing while maintaining a safe environment allowing for orderly test shutdown and making facility systems safe in emergency situations.
  - Programmable Logic Controllers (PLCs) form the backbone of the SSC Control Systems.
  - PLCs primary functions are to sequence rocket engine or component tests and maintain daily operations.
  - Hard-wired controls are provided as a backup to the PLCs.

Control Systems Functions

- Day to Day Operations
  - Unloading cryogenics/propellants (Oxygen, Hydrogen, Nitrogen, Methane, etc.)
  - Propellant transfers from storage to run tanks
  - Pumping up bottle pressures (Nitrogen, hydrogen, helium etc.)
  - Gas leak and fire detection.
  - Engine drying
  - Facility Readiness Test (FRTs)
  - Redline cut checks (Redlines are measurements that are monitored by the PLC for the purpose of initiating an immediate shut down when out of tolerance.)

Control Systems Functions

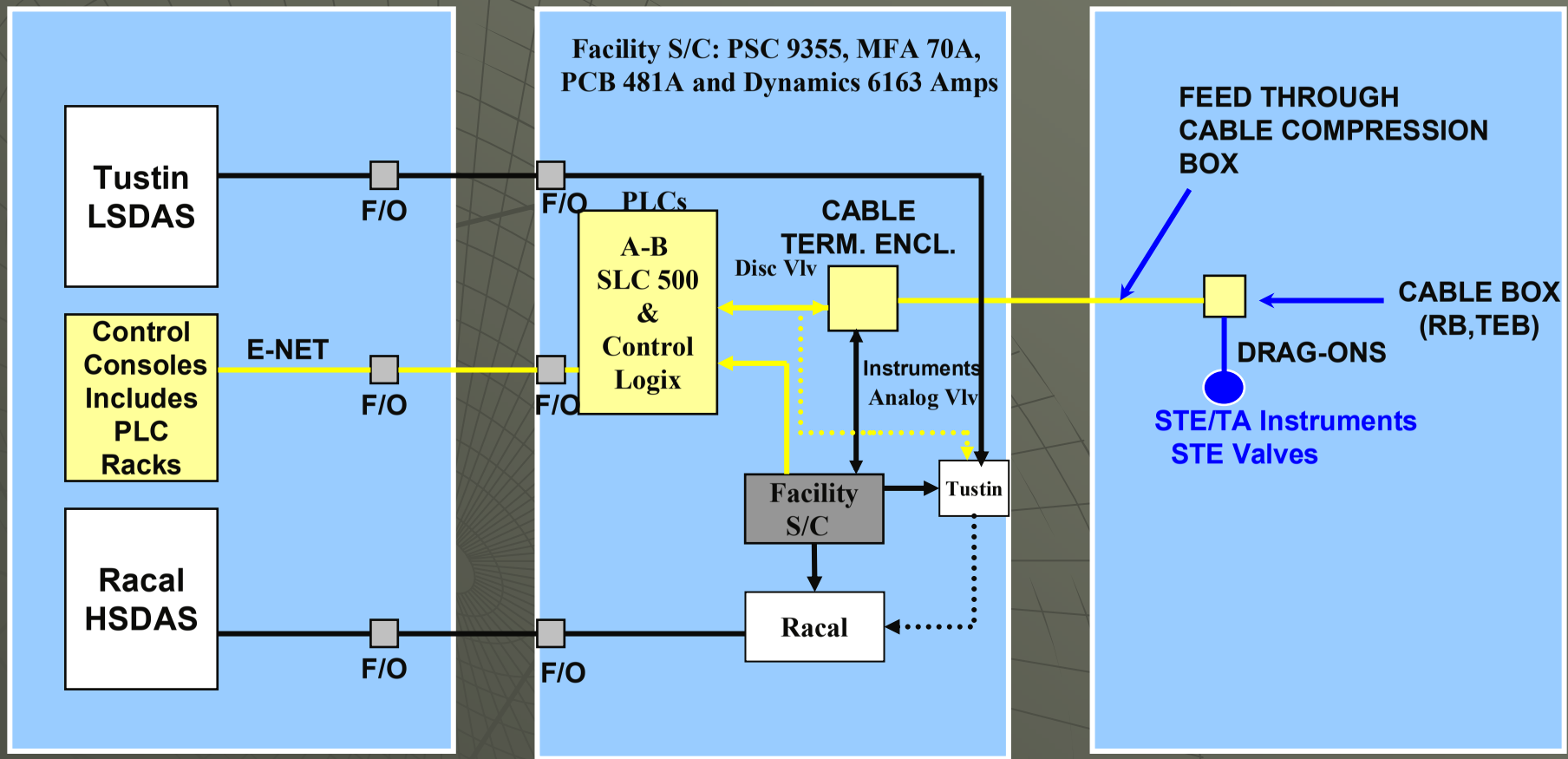
- Test Day Operations
  - Propellant Transfers
  - Engine chill down and prep
  - Greenline monitoring (Permissives to start test.)
  - Test stand valve sequencing and control during hot fire test
  - Redline monitoring during hot fire test
  - Performs a controlled shutdown of the engine
    - Critical valves are also wired to a backup PLC or relays

E1 Test Stand Control System

- Three Independent Test Cells
  - Can support three different test programs simultaneously
  - All test cells share the same propellant run tanks, high pressure bottles, Control System etc.
  - Control system must be flexible enough to switch between test cells in twenty four hours
- Most Generic PLC (Ladder Logic) of Any Test Facility
  - System is configured entirely through Excel
  - Excel tables can be configured in advance and downloaded on test day.
  - Excel tables can be archived for historical reference

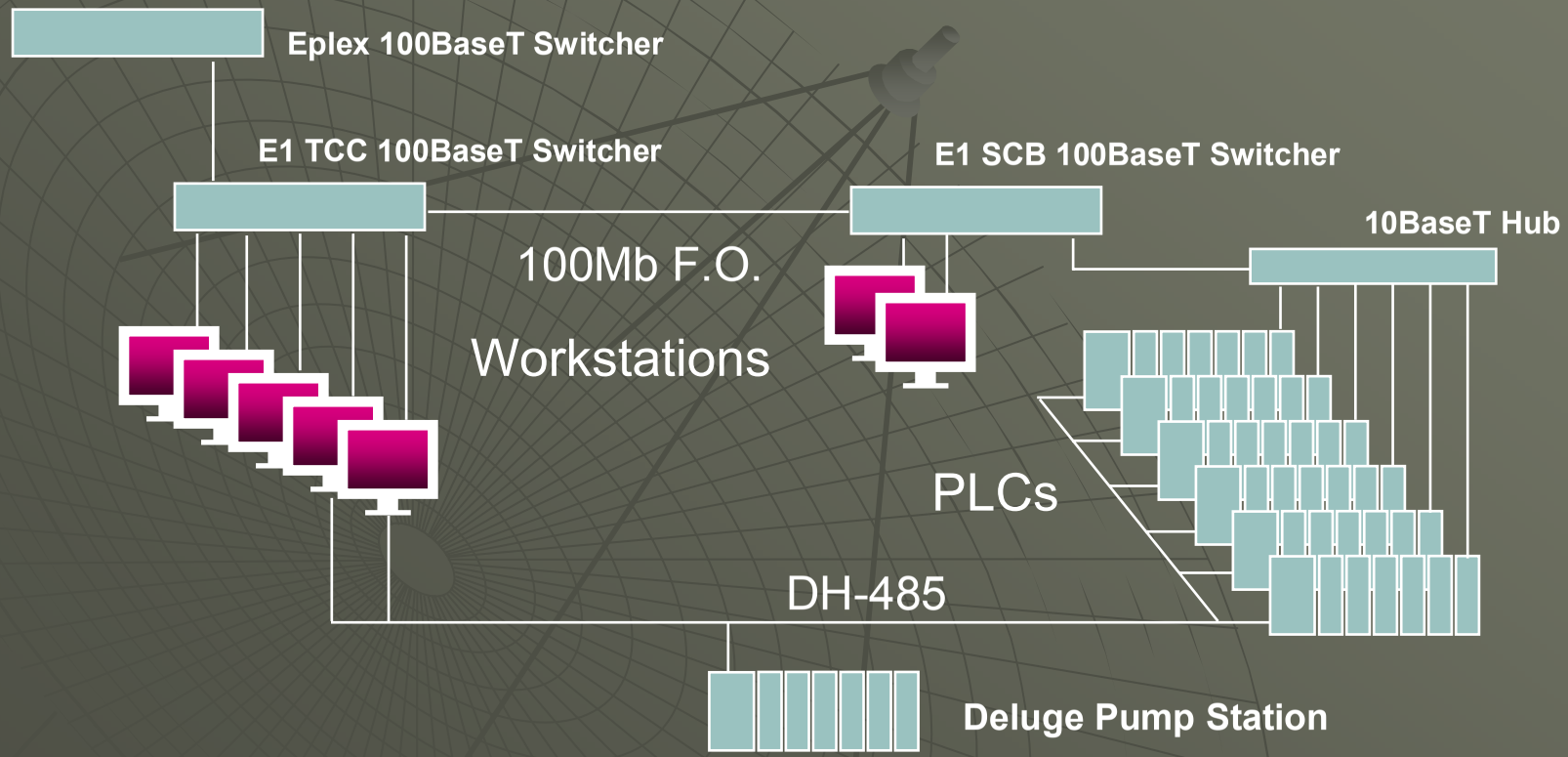
E1 Control System Layout

Stennis Space Center



E1 PLC Network Design

Stennis Space Center



Typical E1 SLC Programmable Logic Controller (PLC) Installation

Stennis Space Center

E1 A-B SLC PLC Cabinet

- **Dedicated STE PLC for Cell 2**

64 DO **80 AI**

12 AO **128 DI**

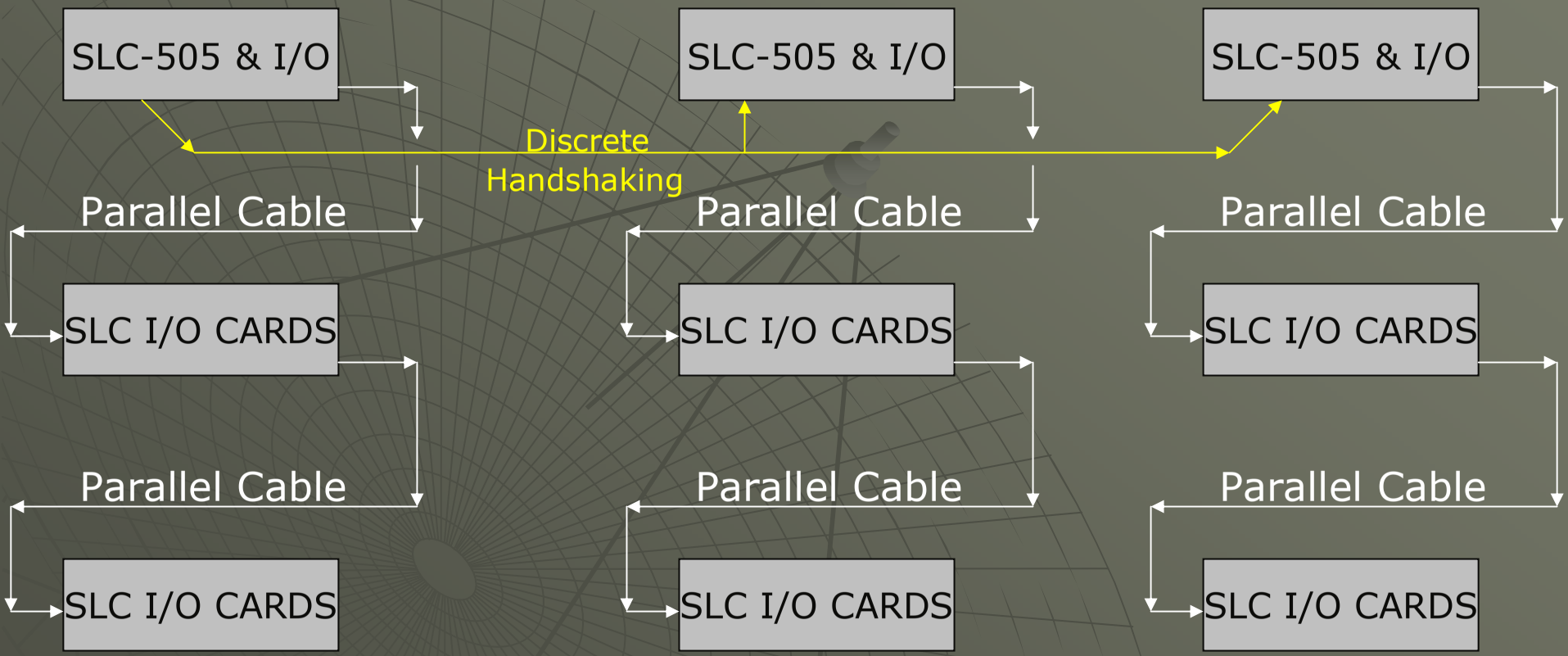
- **Shared Display PLC**

80 AI

32 DI

E1 PLC Architecture with Parallel SLC Input/Output (I/O) Cards

Stennis Space Center



Advantage: Fast Throughput

Multiple Processors

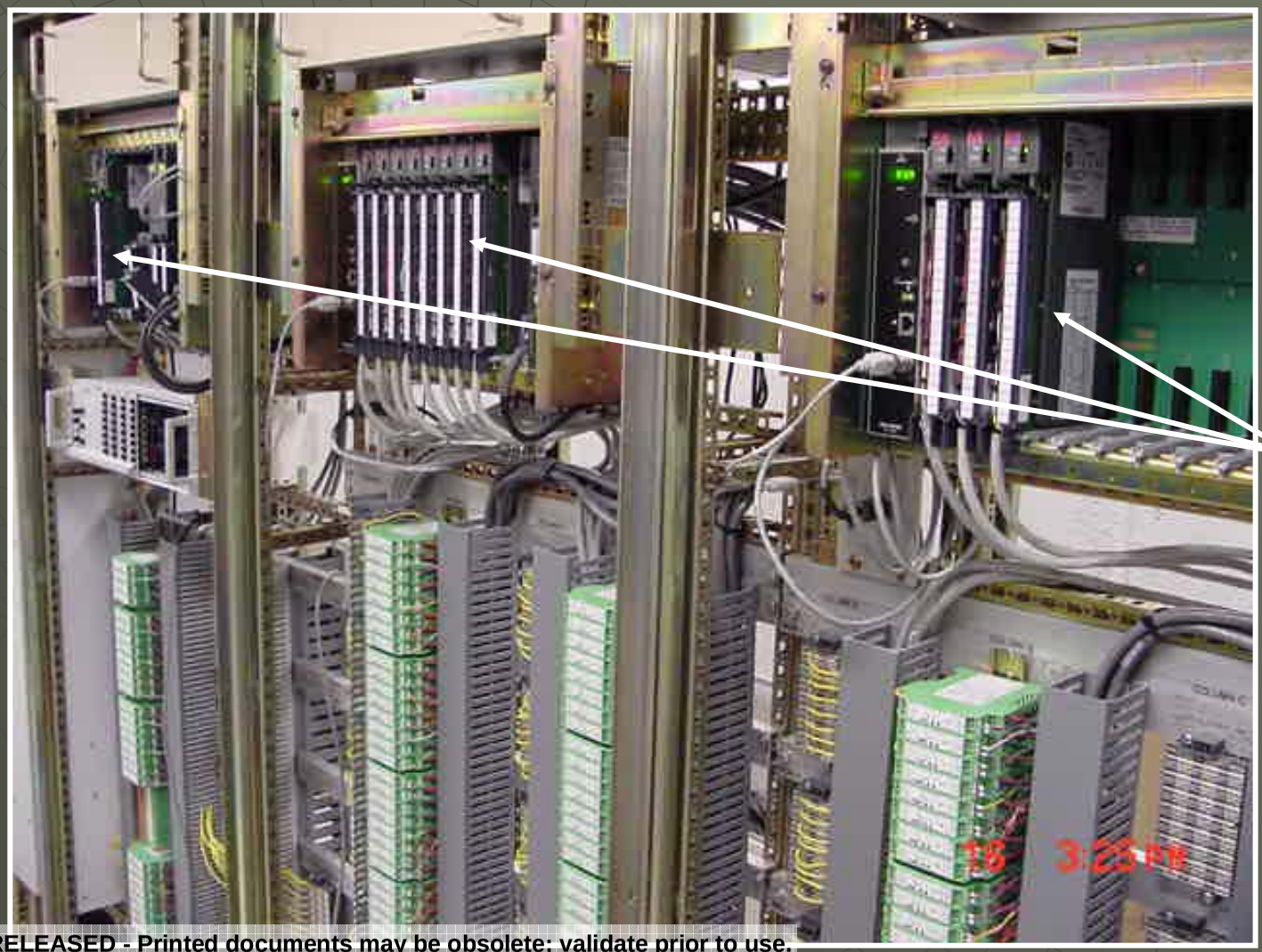
No remote I/O

Disadvantages:

Only three racks of I/O per processor

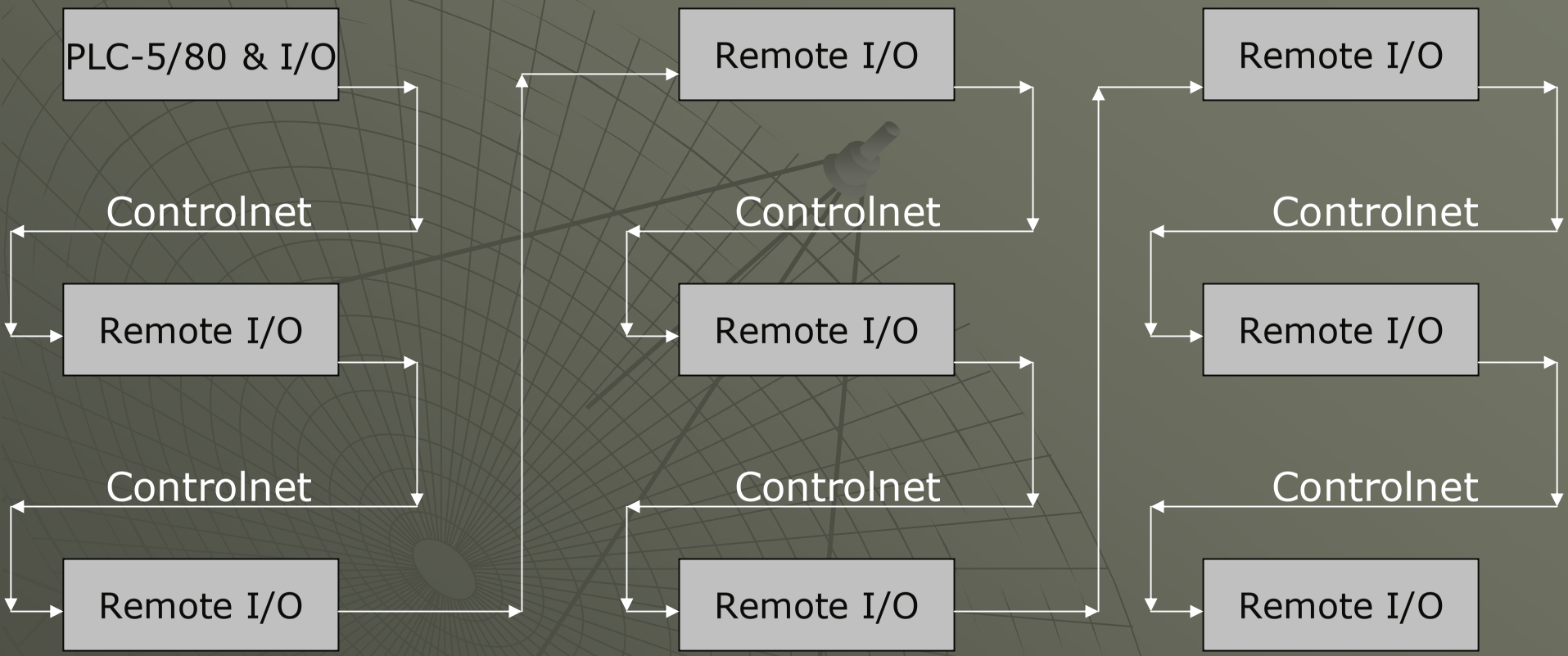
Parallel cables are short

Test Stand E2 Cell 1 Signal Conditioning Bldg 1 Controls I/O



A/B/E2 PLC Architecture

Stennis Space Center



Advantages: One Processor

Much larger I/O count

Much greater distances

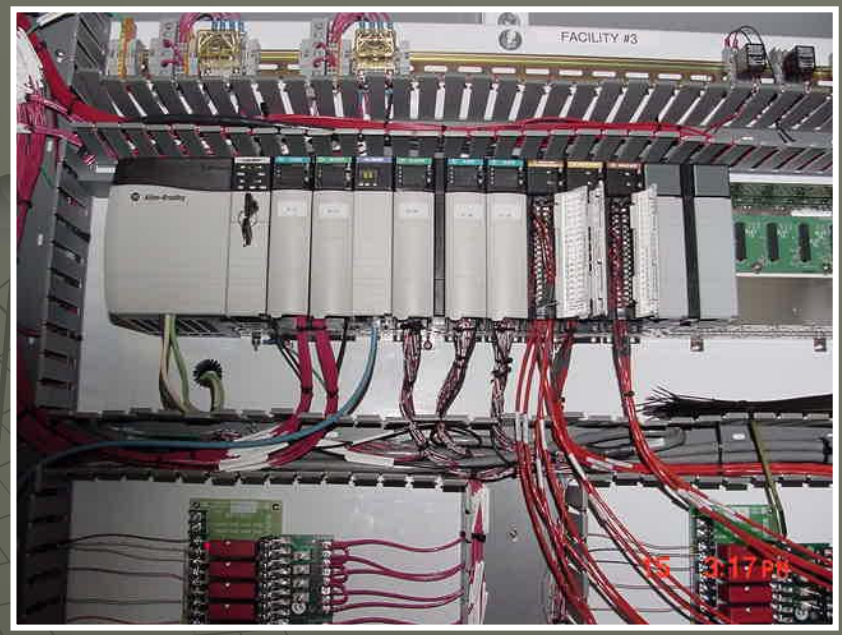
Disadvantages:

Throughput slowed by serial communications

SSC PLC Architecture Changes

- **Migration to faster PLCs in a Distributed Architecture outside the E1 Test Facility**

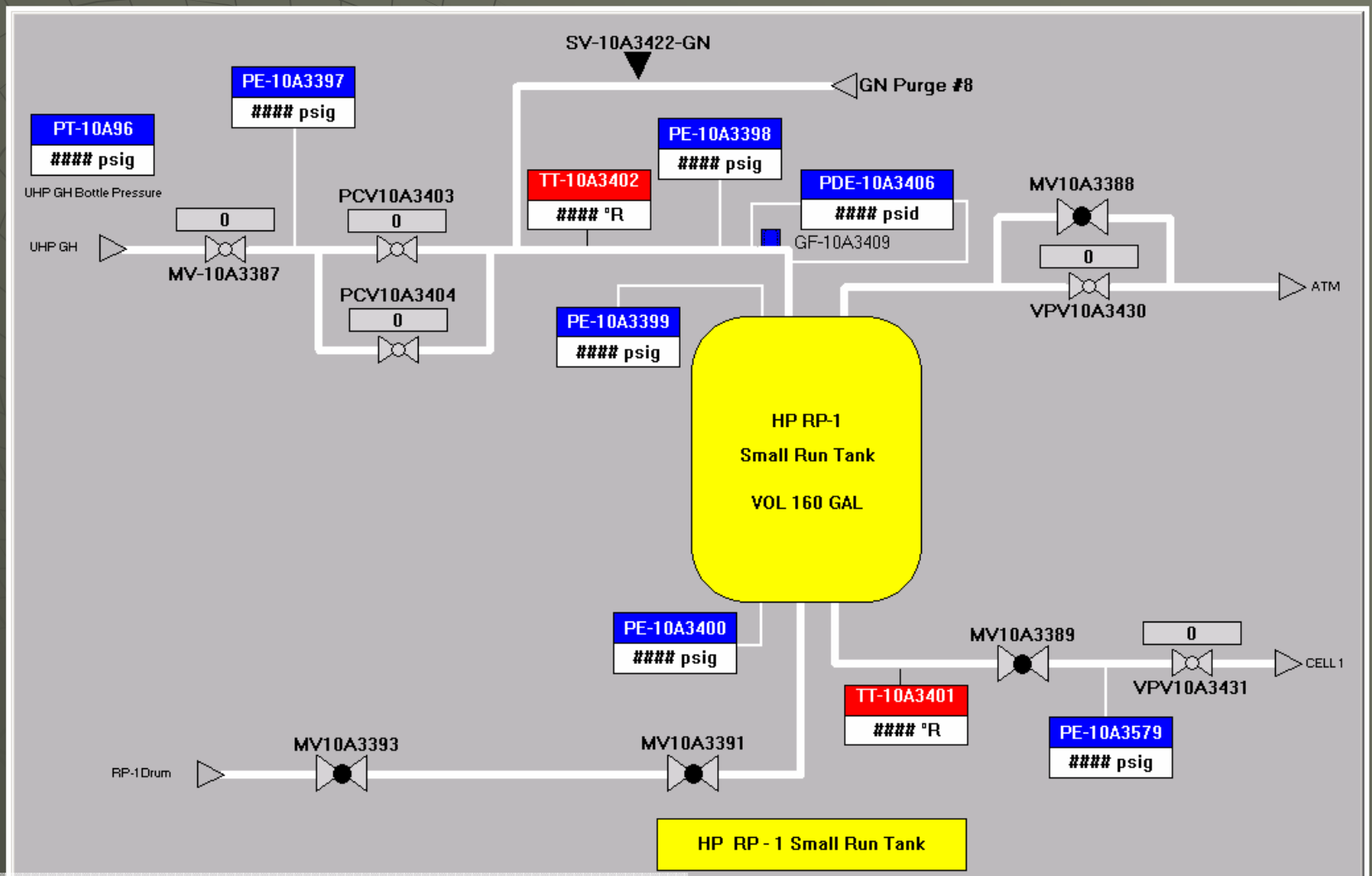
- A-Complex Redline System
- A-Complex Fire & Gas Leak Detect System
- B-Complex Redline System
- B-Complex Fire & Gas Leak Detect System in design
- E3 Redline System



Control Logix 5000 PLC

Test Control Center with Human Machine Interface (HMI) Screens

InTouch by Wonderware HMI



Data Acquisition & Control Systems Lab (DACS Lab)

Scott Jensen

DACS Lab

- The DACS Lab is a facility designed to provide an off-stand capability for developing data acquisition and control systems in support of testing.
  - Safe and controlled environment allows verification and development without impacting project schedules or compromising pre-existing test hardware, software, networks or configurations.
  - Useful in the identification and resolution of significant issues with equipment and configuration functionality prior to activation.
  - Servo valve control capability and personnel's expertise have been utilized to expedite mission critical valve integrity checks prior to field installation.
  - Helps to eliminate facility downtime and test delays.
  - Provides for hands-on training, qualifying spares, market evaluations, minor equipment repairs, and familiarization with data acquisition and controls equipment

DACS Lab

Stennis Space Center

DAS Station

Controls Station

Controls Checkout Cart

Sensor Workstation

Sensor Development

Wireless Sensor Development

Sensors Needed to Monitor Valve Health

High-Geared Ball Valves

- Torsional shaft strain
- Total valve cycles
- Cryogenic valve cycles
- Inlet temperature
- Outlet temperature
- Body temperature

Linearly Actuated Valves

- Linear bonnet strain
- Total linear travel
- Total directional changes
- Valve preload position
- Inlet temperature
- Outlet temperature
- Body temperature

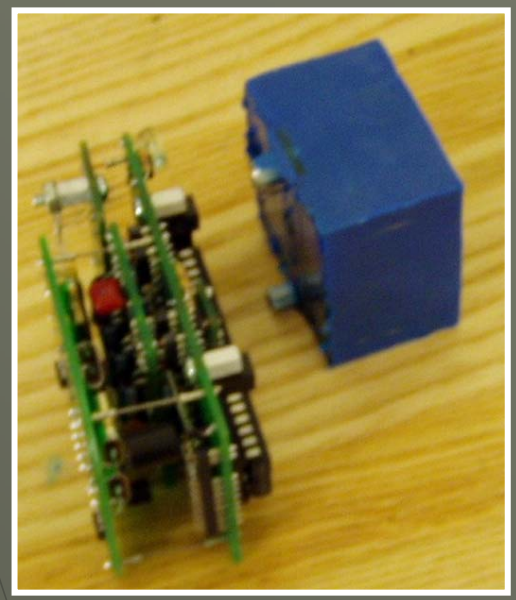
Wireless Sensor Development

Confined Locations

- **Sensor Size**
  - 2½ X 3 X 4 inch
- **Wireless**
  - 35 foot transmission radius
  - Added data security
  - 902-928 MHz band
  - Compliance with FFC
- **Battery powered**
  - Two battery packs with two 9 Volts supplies

Wireless Sensor Development

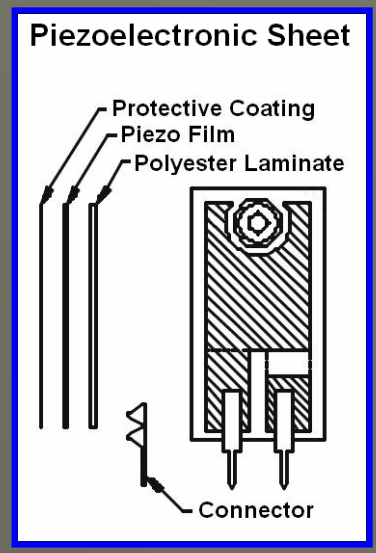
- **NEC Class I Division II B Hazardous Environment**
  - **Compliance with NEC article 501**
  - **Enclosed in Potting**
    - Blue-epoxy flame retardant 832FRB
    - M.G. Chemicals
  - **Internal temperature monitoring**
    - Shutdown 150° F
  - **No exposed arcing points**
  - **Limited operational power**
    - 9 Volts at 250 milliamp
  - **No exposed cavities**



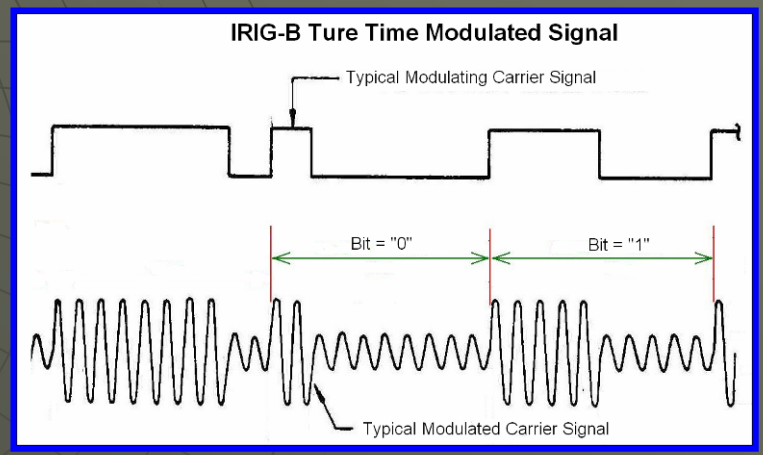
Wireless Sensor Development

Stennis Space Center

- **Power Conservative**
  - **One-Way Communications**
    Linx HP3 transmitter and receiver modules
  - **Microprocessor Sleep Mode**
  - **Piezoelectronic Wake-Up Circuitry**
    Measurement Specialties LDT series

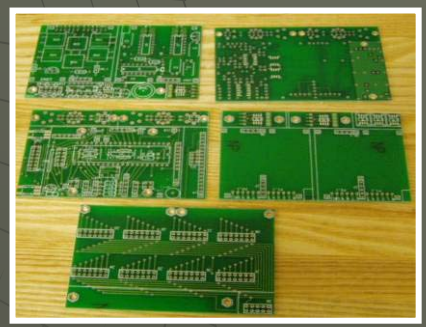


- **Accurate Data Synchronization**
  - **IRIG-B Timing Module**
    Facility correlation
  - **Communication Bus**
    Internal data correlation



Wireless Sensor Development

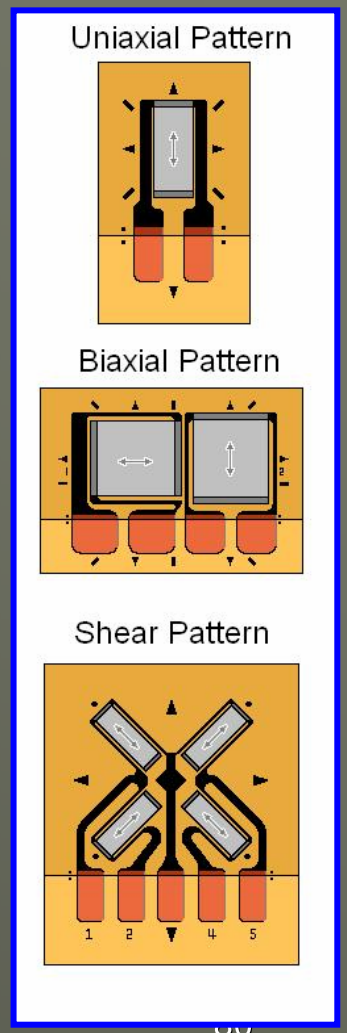
- **Automatic and Manual Data Access**
  - **Memory storage Network capable**
    - Compact flash card memory access
    - ARMA Design Inc.
  - **Network capable**
    - Ethernet broadcast I-7188E
    - ICS DataCom Inc.
- **Setup and Maintenance**
  - **Simple Human interface**
    - Switch and Indicator light
  - **On-board programmer interface**
    - Serial communications
    - Software updates



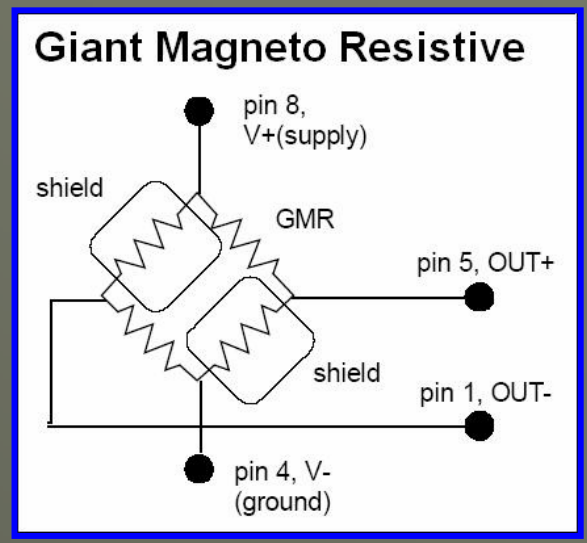
Wireless Sensor Development

- **The K-Type thermocouples sensor**
  (for inlet, outlet, and body temperature monitoring)
  - **Monolithic thermocouple amplifier from Analog Devices**
  - **Uses cold junction compensation**

- **The strain instrumentation sensor**
  (for bonnet and torsional strain monitoring)
  - **Axial Strain by a Vishay precision quarter bridge**
  - **Biaxial Strain by a Vishay precision half bridge**
  - **Shear Strain by a Vishay precision full bridge**



Wireless Sensor Development



- **Limit switch sensor**

  (for monitoring number of cycle)

  - **6 magnetic reed switches**
  - **4 input with wake-up abilities**

- **Signal interface sensor**

  (for Linear Voltage Differential Transformer (LVDT) monitoring)

  - **4 to 20 milliamp current loop signal**

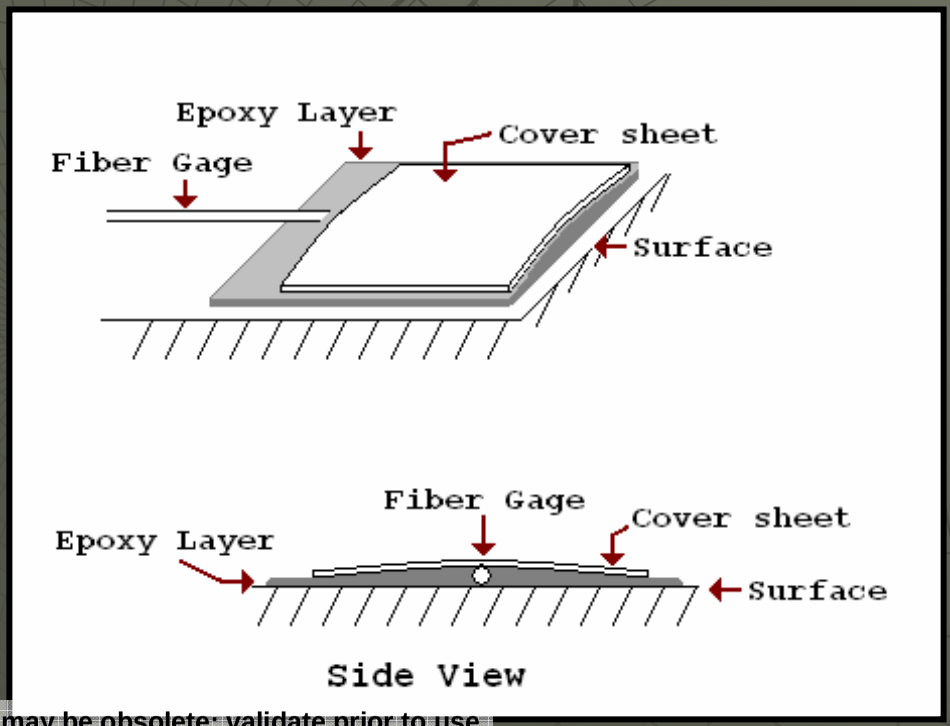
    Giant Magneto Resistive (GMR) from

    Unobtrusively monitors magnetic fields
  - **0 to 10 volts Direct Current (DC) signal**

    Basic voltage follower circuit

Cryogenic Sensor Development

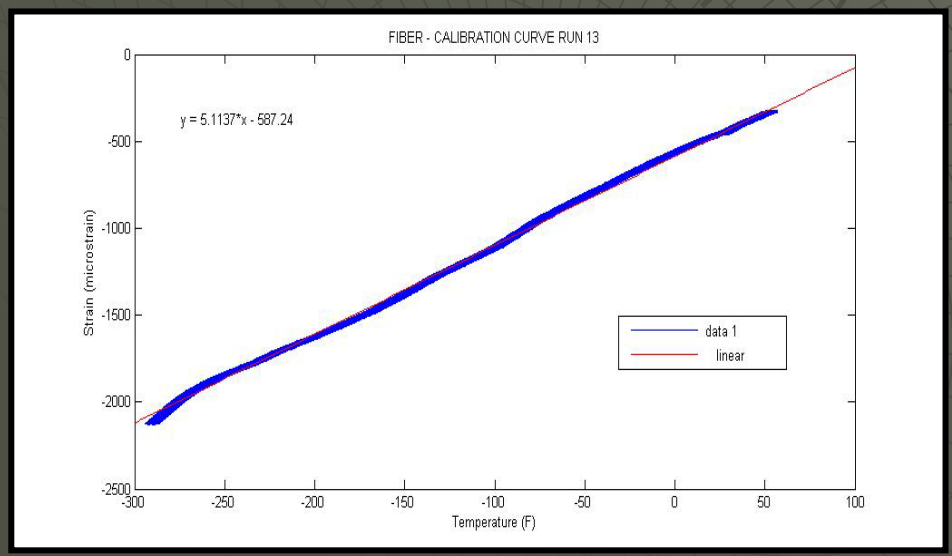
- Developed improved bonding techniques for strain gauges and thermocouples used in cryogenic service



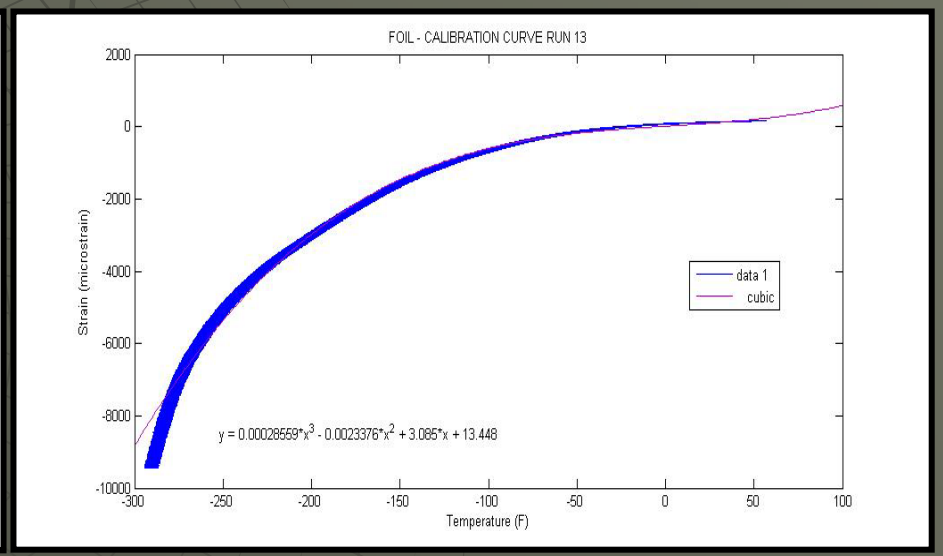
Cryogenic Sensor Development

- Developed calibration curves for foil and fiber optic strain gauges at cryogenic temperatures

Fiber Optic Strain Gauge Curve



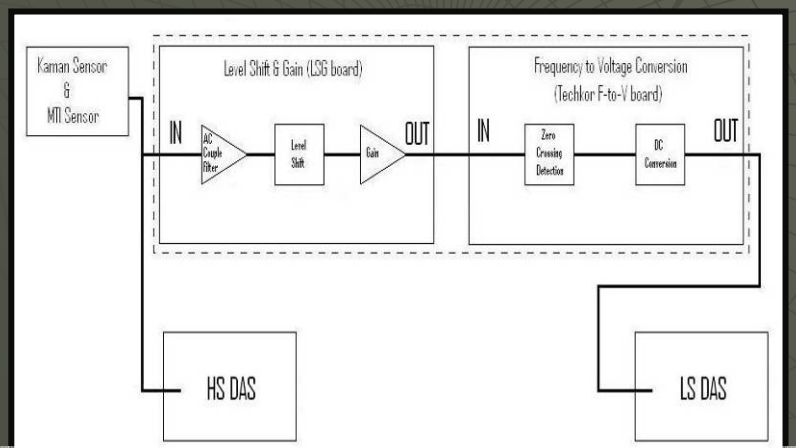
Foil Strain Gauge Curve



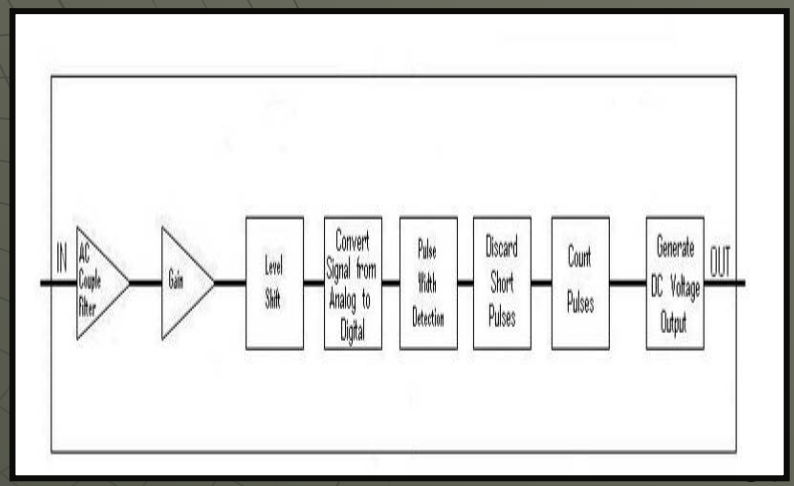
Speed Sensor Signal Conditioning Development

- Developed a frequency to voltage converter for determining rotational speed of turbopumps during rocket engine testing - improved the response to complex waveforms recorded from speed sensors

Existing Speed Detection Logic

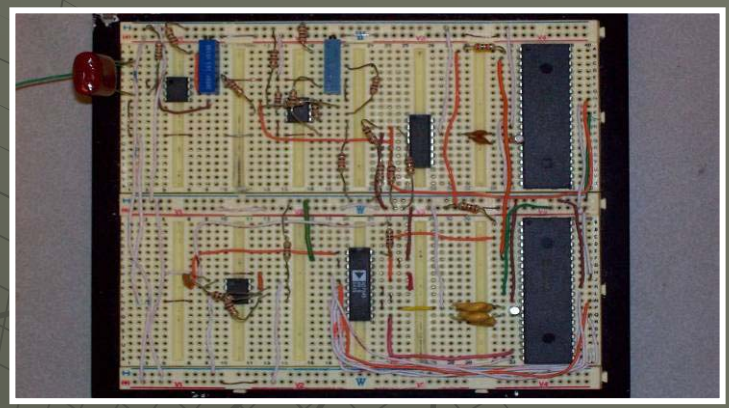


Experimental Speed Detection Logic

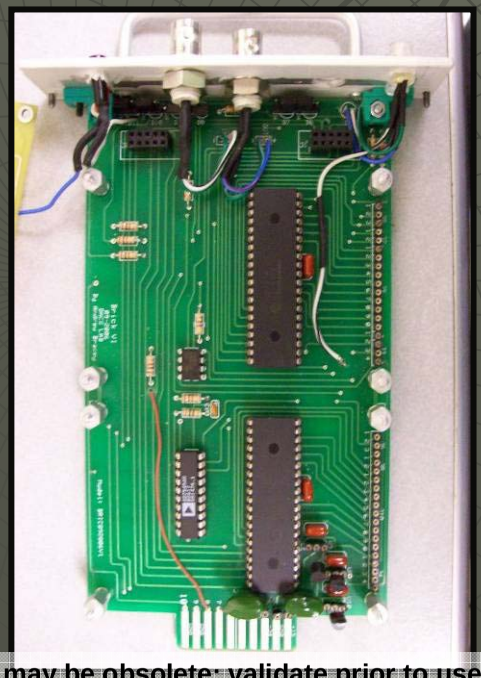


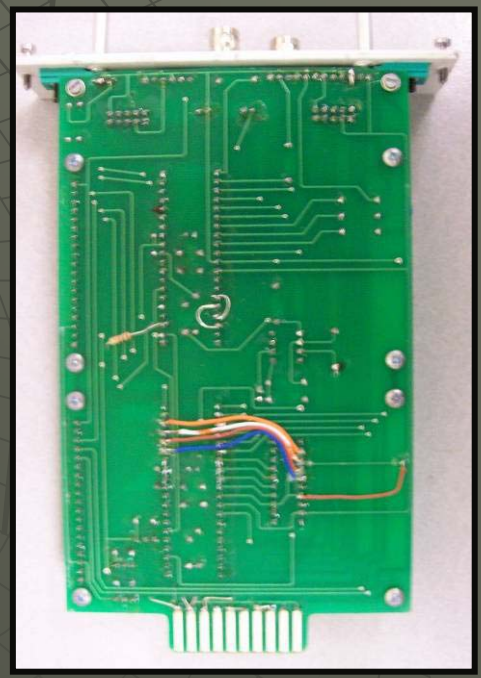
Speed Sensor Signal Conditioning Development

Breadboard



Populated Board (top)



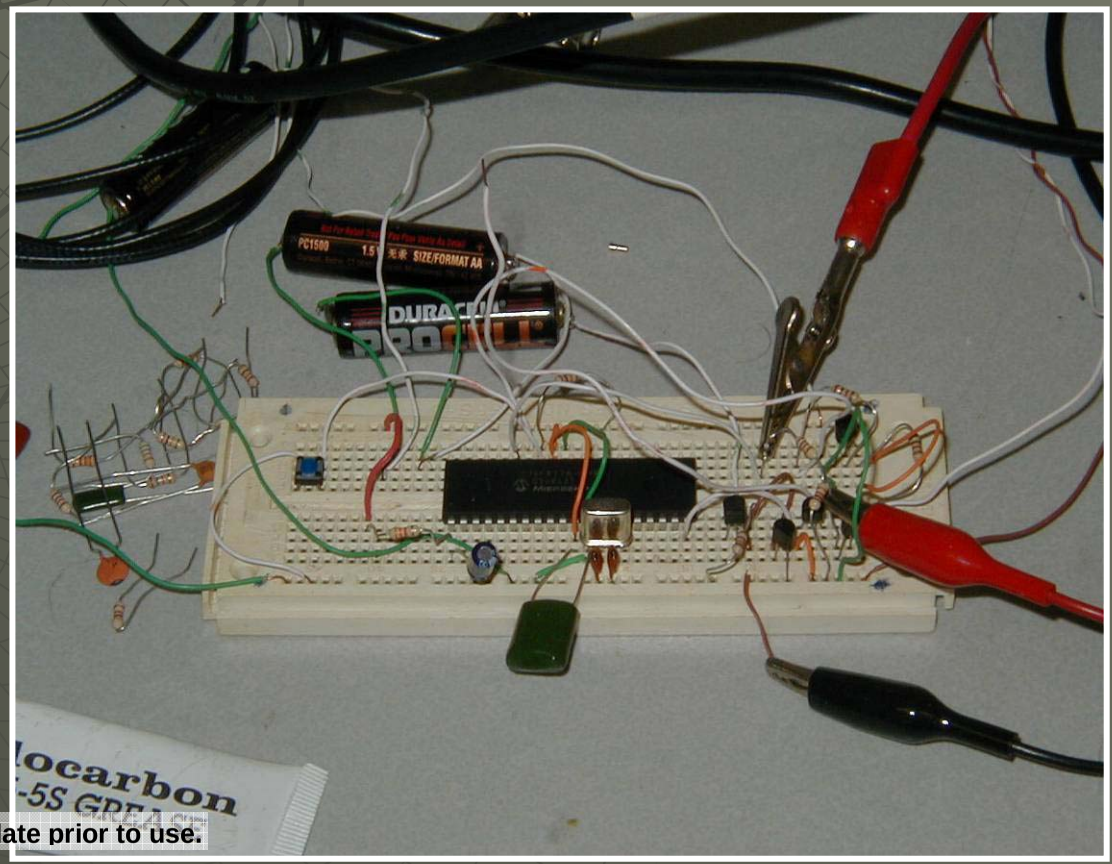


Populated Board (bottom)

Piezoelectric Sensor Health

- Developing the techniques to evaluate the health of piezoelectronic sensors

Breadboard of Piezoelectric Sensor Tester



Summary

- NASA/SSC's Mission in Rocket Propulsion Testing Is to Acquire Test Performance Data for Verification, Validation and Qualification of Propulsion Systems Hardware
  - Accurate
  - Reliable
  - Comprehensive
  - Timely
- Data Acquisition in a Rocket Propulsion Test Environment Is Challenging
  - Severe Temporal Transient Dynamic Environments
  - Large Thermal Gradients
  - Vacuum to 15 ksi pressure regimes
- SSC Has Developed and Employs DAS, Control Systems and Robust Instrumentation that Effectively Satisfies these Challenges