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

Space Shuttle Main Engine Test @ A2 Test Stand

RS-68 650 klbf @ B1 Test Stand

Fastrac 60 klbf @ B2 Test Stand

Released - Printed documents may be obsolete; validate prior to use.
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

RELEASED - Printed documents may be obsolete; validate prior to use.
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
Design & Analysis Division

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

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SSC Test Facilities

AB-Complex

A-1  Full Scale Engine Devt. & Cert
J-2X

A-2  SSME

B-1/B-2  Full Scale Engine/Stage Devt. & Cert
RS-68/ARES

Components
…Engines
… Stages

RELEASED - Printed documents may be obsolete; validate prior to use.
Stennis Space Center

Test Facility Layout

Test Control Center

Signal Conditioning Bldg

Test Article

Tustin LSDAS

Control Consoles Includes PLC Racks

Racal HSDAS

Facility S/C: PSC 9355, MFA 70A, PCB 481A and Dynamics 6163 Amps

PLCs

A-B SLC 500 & Control Logix

CABLE TERM. ENCL.

Disc Vlv

Instruments Analog Vlv

Facility S/C

Racal

Tustin

FEED THROUGH CABLE COMPRESSION BOX

CABLE BOX (RB)

DRAG-ONS

STE/TA Instruments STE Valves

RELEASED - Printed documents may be obsolete; validate prior to use.
Signal Conditioning Buildings (SCB)

E2 Cell 1
SCB 1
Controls
Racks

E1 SCB
Signal Conditioning Rack
Typical Test Articles

Integrated Powerhead Demonstrator

LR-89

Released - Printed documents may be obsolete; validate prior to use.
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

RELEASED - Printed documents may be obsolete; validate prior to use.
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)

- **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

*NOTE: This System is being replaced.*

RELEASED - Printed documents may be obsolete; validate prior to use.
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

F/O

RELEASED - Printed documents may be obsolete; validate prior to use.
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

RELEASED - Printed documents may be obsolete; validate prior to use.
MIDDAS HSDAS

128 Channel MIDDAS System

MIDDAS in Standalone Configuration

RELEASED - Printed documents may be obsolete; validate prior to use.
DataMAX II HSDAS

- 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

SCB

Recorder 32
Recorder 32
Recorder 32
Recorder 32

TCC

F/O

Mirror PC

Mirror PC

Redundant Data Storage

RELEASED - Printed documents may be obsolete; validate prior to use.
DataMAX II
Planned for B2 Test Complex

Stennis Space Center

Gigabit Gear

DataMAX Playback

Test Facility

DataMAX Recorders

192 Channels

RELEASED - Printed documents may be obsolete; validate prior to use.
DataMAX II
Planned for B2 Test Complex

- KVM
- Gigabit Gear
- USB HDD’s
- Rack PC
- DataMAX Remotes
- Flat screen
- Keyboard
- Mouse

Test Control Center

RELEASED - Printed documents may be obsolete; validate prior to use.
Typical High Speed Data Acquisition System Instrumentation

Typical Instrumentation not always in the Catalog

- Special Ranges
- Temp Compensation
- Special Materials

FACILITY
SPECIAL TEST EQUIPMENT
TEST ARTICLE

Accelerometer
Strain

Dynamic Pressure
Accelerometer
Strain
Proximity
Speed

Typical High Speed DAS Instrumentation

RELEASED - Printed documents may be obsolete; validate prior to use.
Typical High Speed Data Acquisition
System Instrumentation

Strain

Dynamic Pressure

Speed

Accelerometer

RELEASED - Printed documents may be obsolete; validate prior to use.
E-Complex High Speed Data Processing System

Stennis Space Center

Printer
HP 9000N

Parallel

RACAL Storeplex Playback Unit

Processor HP J6750
Operating HP-UX
Application PV-Wave

Processor HP J6750
Operating HP-UX
Application PV-Wave

Printer HP 9000N

Internet (Secure FTP)

SCSI II

SCSI II

RELEASED - Printed documents may be obsolete; validate prior to use.
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

RELEASED - Printed documents may be obsolete; validate prior to use.
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

RELEASED - Printed documents may be obsolete; validate prior to use.
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

RELEASED - Printed documents may be obsolete; validate prior to use.
E-Complex
Low Speed Data Acquisition System

Calibration Bus

Test Control Center
- GPIB Bus Extender
- System Controller (PC)
- Tustin CCIS

Signal Conditioning Building
- GPIB Bus Extender
- Programmable Signal Conditioner
- Voltage Standard
- Function Generator
- Programmable Relay
- Programmable Relay
- Manual Filter Amplifier

GPIB Cable
Fiber Cable
Multi-conductor Cable

RELEASED - Printed documents may be obsolete; validate prior to use.
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
**E-Complex**

**Low Speed Data Acquisition System**

**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

---

**RELEASED** - Printed documents may be obsolete; validate prior to use.
E-Complex
Low Speed Data Acquisition System

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

RELEASED - Printed documents may be obsolete; validate prior to use.
E-Complex
Low Speed Data Acquisition System

Software

- Calibration Software

Main Page

Single Channel Operations

RELEASED - Printed documents may be obsolete; validate prior to use.
E-Complex
Low speed Data Acquisition System

Software

- Calibration Software

Channel Diagnostics

Report
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
# E-Complex

## Low Speed Data Acquisition System

Software

- Measurement System Analysis Software

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### Measurement System Analysis

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RELEASED - Printed documents may be obsolete; validate prior to use.
E-Complex
Low Speed Data Acquisition System

Software
- Measurement System Analysis Software

RELEASED - Printed documents may be obsolete; validate prior to use.
AB-Complex Architecture
Low Speed Data Acquisition System

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

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AB-Complex Architecture

Low Speed data acquisition System

Calibration Control

- Test Control Center
- Test Stand Select Relay
- Engine Events
- Cal Flags
- PreSys MUX
- PreSys Events
- Annadex Cal Relays

- Cal Control PC
- Analogic ANDS5400
- Or Neff 470
- GPIB Cable

- Preston 8300 Master Controller
- Digital MultiMeter
- Function Generator
- Selector Control Panels
- Voltage Standard

RELEASED - Printed documents may be obsolete; validate prior to use.
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
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

RELEASED - Printed documents may be obsolete; validate prior to use.
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

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<th>FACILITY</th>
<th>SPECIAL TEST EQUIPMENT</th>
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<td>Speed</td>
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<tr>
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</table>

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

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Typical Low Speed Data Acquisition
System Instrumentation

Pressure
- Transmitter
- Delta P

Temperature
- Thermocouples
- RTD’s

Flow
- Pressure
- Transmitter
- Venturi Flowmeter

Strain
- Strain Gauges
- Turbine Flowmeter

Speed
- Speed Probe

RELEASED - Printed documents may be obsolete; validate prior to use.
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

Facility S/C: PSC 9355, MFA 70A, PCB 481A and Dynamics 6163 Amps

- Tustin LSDAS
- Racal HSDAS
- Control Consoles Includes PLC Racks

PLCs
- A-B SLC 500
- & Control Logix

CABLE TERM. ENCL.
- Disc Vlv
- Instruments Analog Vlv

Facility S/C
- Tustin
- Racal

FEED THROUGH CABLE COMPRESSION BOX
- DRAG-ONS (RB, TEB)
- STE/TA Instruments STE Valves

CABLE BOX

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E1 PLC Network Design

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Eplex 100BaseT Switcher
E1 TCC 100BaseT Switcher
100Mb F.O.
Workstations
PLCs
DH-485
Deluge Pump Station
10BaseT Hub
E1 SCB 100BaseT Switcher

Control Room

SCB

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Typical E1 SLC Programmable Logic Controller (PLC) Installation

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

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

- **SLC-505 & I/O**
- **Parallel Cable**
- **Discrete Handshaking**
- **SLC I/O CARDS**

**Advantage:** Fast Throughput
- Multiple Processors

**Disadvantages:**
- Only three racks of I/O per processor
- Parallel cables are short

*Stennis Space Center*

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

PLC

I/O Cards
A/B/E2 PLC Architecture

Advantages: One Processor
   Much larger I/O count
   Longer distances

Disadvantages:
   Throughput slowed by serial communications

PLC-5/80 & I/O
Remote I/O
Controlnet
Remote I/O
Controlnet
Remote I/O
Controlnet
Remote I/O
Controlnet
Remote I/O

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**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
Test Control Center with Human Machine Interface (HMI) Screens

Hard Wired Controls

Controls HMI

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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.
### Sensors Needed to Monitor Valve Health

<table>
<thead>
<tr>
<th>High-Geared Ball Valves</th>
<th>Linearly Actuated Valves</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Torsional shaft strain</td>
<td>➢ Linear bonnet strain</td>
</tr>
<tr>
<td>➢ Total valve cycles</td>
<td>➢ Total linear travel</td>
</tr>
<tr>
<td>➢ Cryogenic valve cycles</td>
<td>➢ Total directional changes</td>
</tr>
<tr>
<td>➢ Inlet temperature</td>
<td>➢ Valve preload position</td>
</tr>
<tr>
<td>➢ Outlet temperature</td>
<td>➢ Inlet temperature</td>
</tr>
<tr>
<td>➢ Body temperature</td>
<td>➢ Outlet temperature</td>
</tr>
<tr>
<td></td>
<td>➢ Body temperature</td>
</tr>
</tbody>
</table>
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

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Wireless Sensor Development

- **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

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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

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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.
Speed Sensor Signal Conditioning Development

Breadboard

Populated Board (top)

Populated Board (bottom)

Released - Printed documents may be obsolete; validate prior to use.
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