# Instrumentation Overview of the Space Environment Test Facilities at NASA GRC's Plum Brook Station

Richard K. Evans
Gerald M. Hill

**2015 IEEE International Conference on Wireless for Space and Extreme Environments**
December 16th, 2015

Presented by
**Richard K. Evans**
**(NASA Glenn Research Center)**

## ABSTRACT

Very large space environment test facilities present unique engineering challenges in the design of facility data systems. Data systems of this scale must be versatile enough to meet the wide range of data acquisition and measurement requirements from a diverse set of customers and test programs, but also must minimize design changes to maintain reliability and serviceability. This paper presents an overview of the common architecture and capabilities of the facility data acquisition systems available at two of the world's largest space environment test facilities located at the NASA Glenn Research Center's Plum Brook Station in Sandusky, Ohio; namely, the Space Propulsion Research Facility (commonly known as the B-2 facility) and the Space Power Facility (SPF). The common architecture of the data systems is presented along with details on system scalability and efficient measurement systems analysis and verification. The architecture highlights a modular design, which utilizes fully-remotely managed components, enabling the data systems to be highly configurable and support multiple test locations with a wide-range of measurement types and very large system channel counts.

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# Presentation Outline

- **Overview**
  - Plum Brook location and facilities
  - Summary of recent facility upgrades at Plum Brook
- **Plum Brook Facility DAS Design Drivers**
  - Goals
  - Challenges
  - Measurement Topology
  - Architecture
  - Specifications and Capabilities of shared assets
- **Overview of Plum Brook Data Systems**
  - B-2 Facility DAS
  - SPF Vibroacoustic Facilities DAS
  - SPF Thermal-Vacuum Chamber DAS

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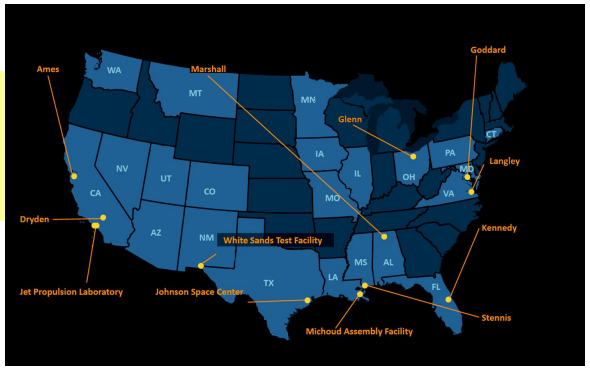


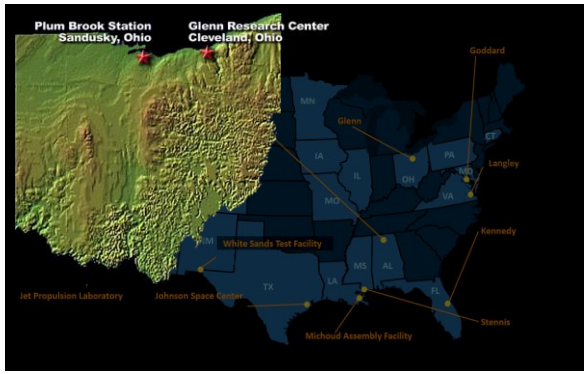


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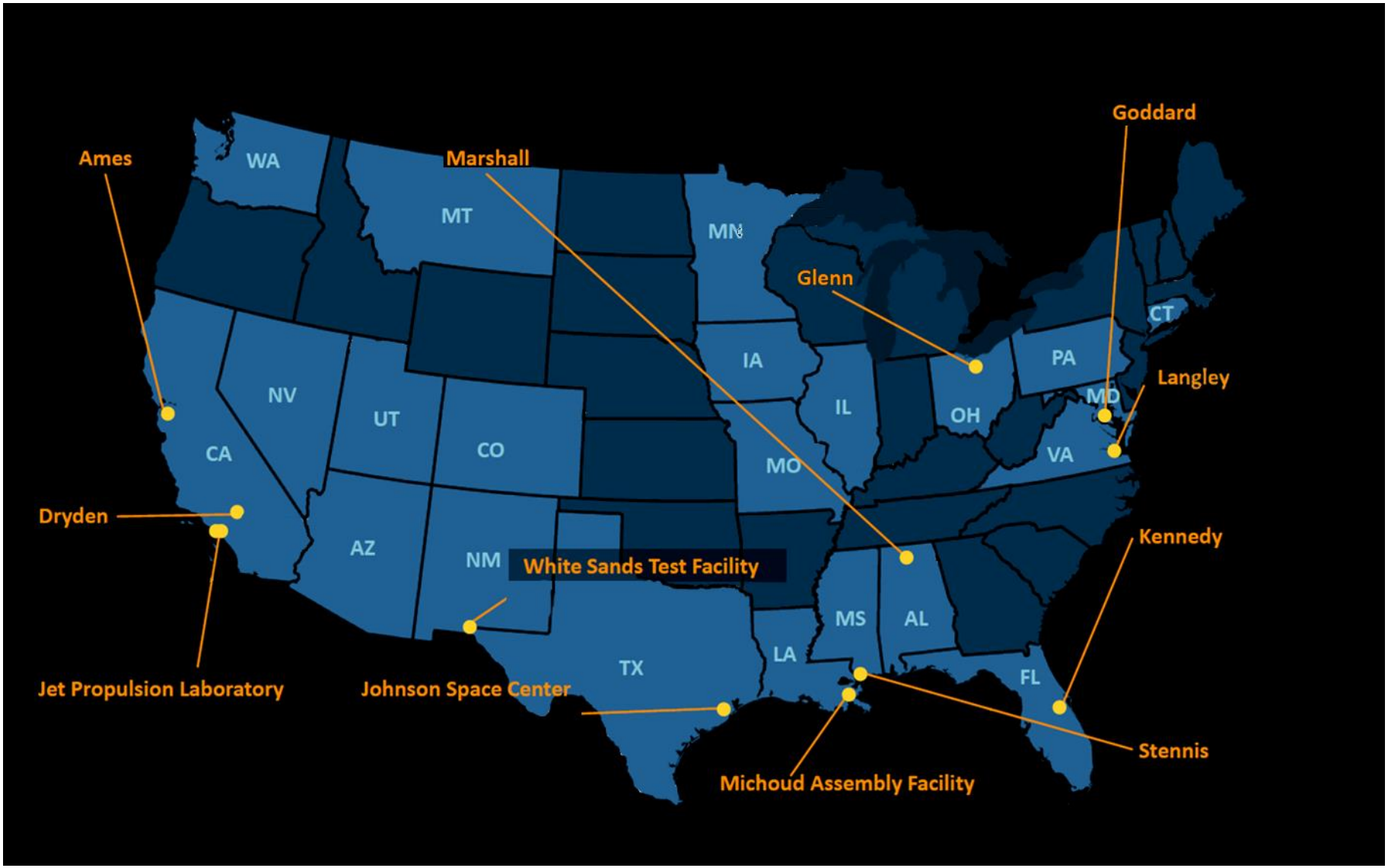

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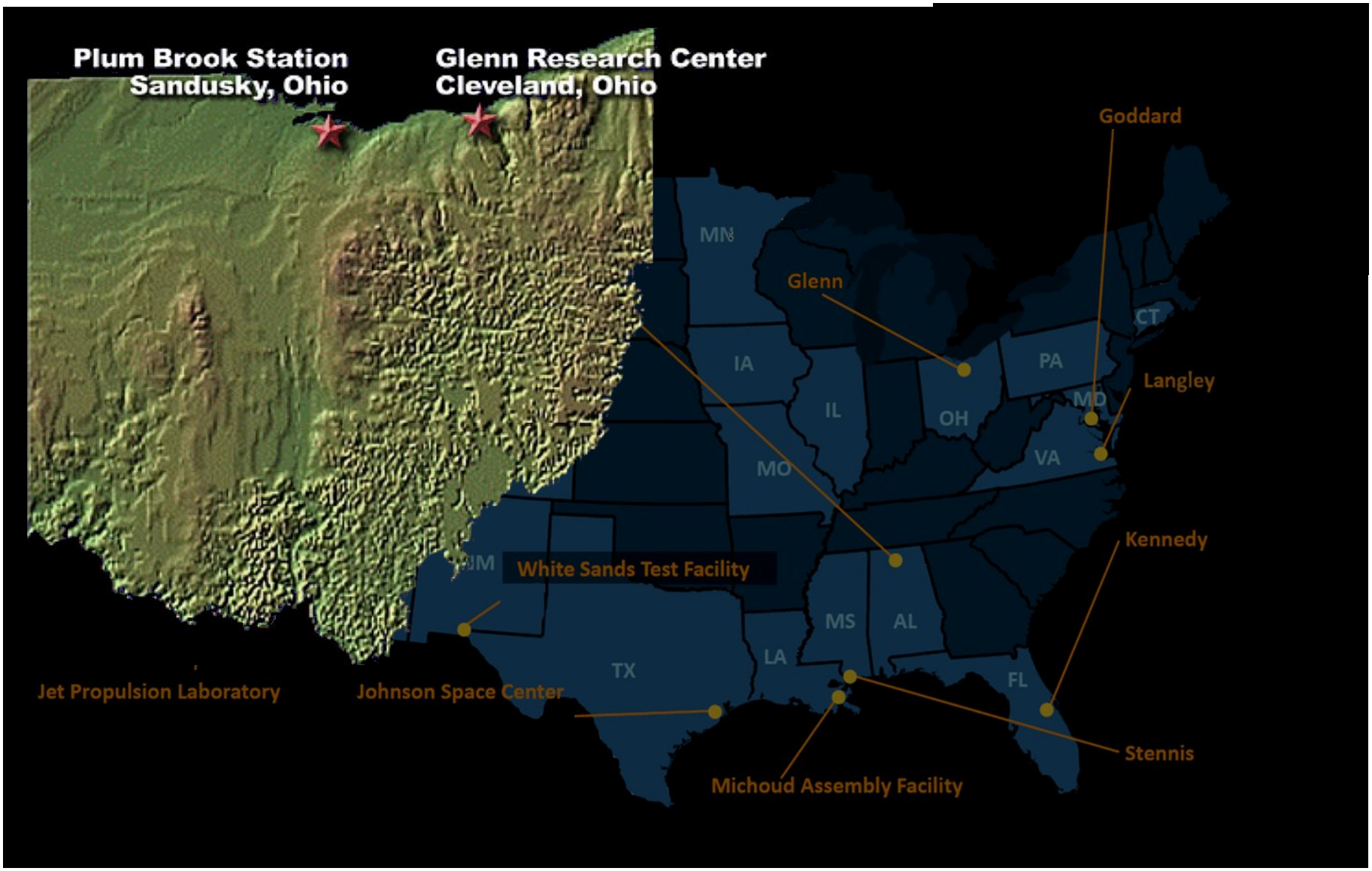

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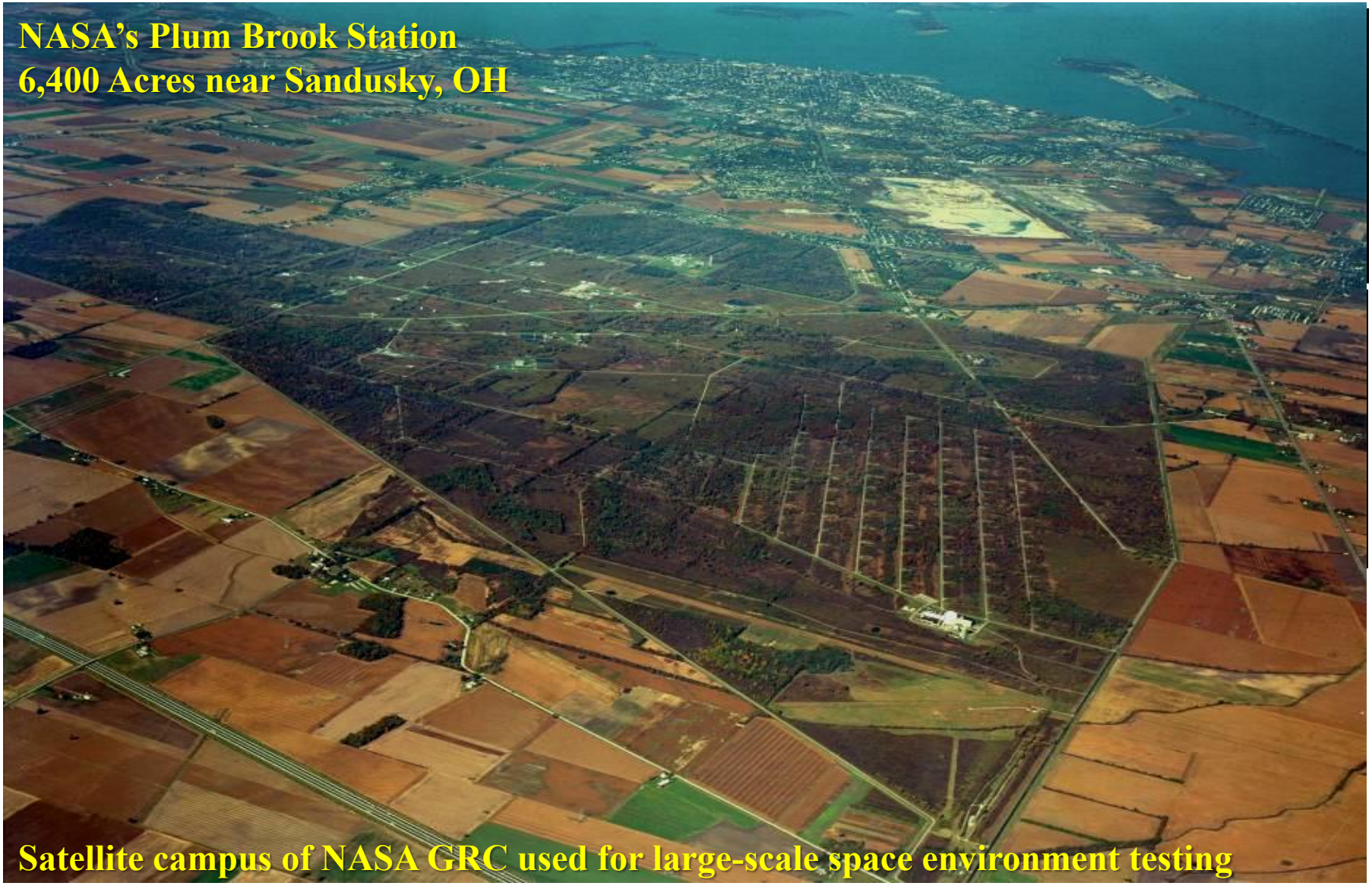
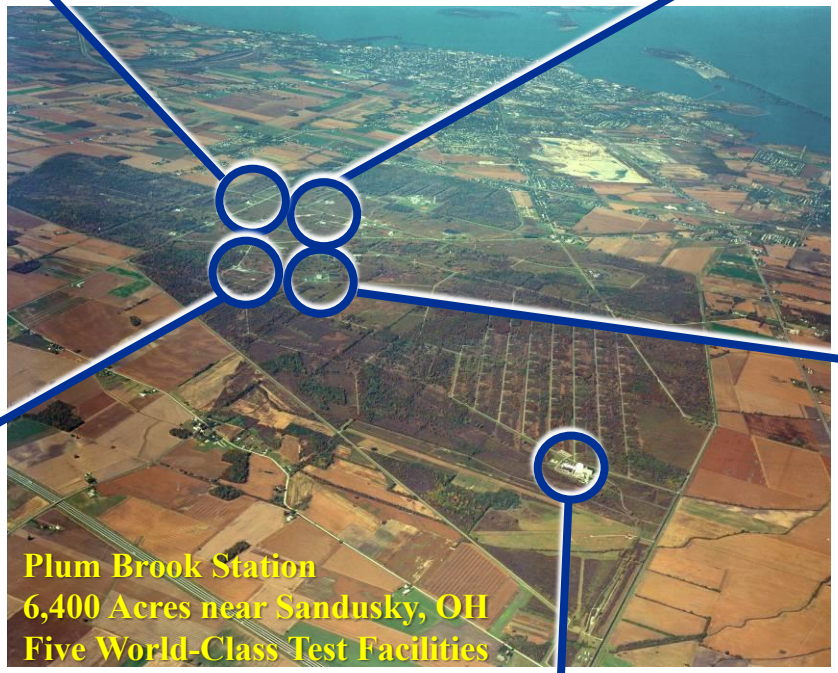


# Overview - NASA Plum Brook Station Test Sites


Large-Scale $LH_2$ Testing


High-Energy, High Risk
Cryogenics Systems Testing





Blow-Down, Non-Vitiated,
Free-Jet Wind Tunnel


High Altitude Engine Testing


Integrated Space Simulation Facility
* Thermal Vacuum Chamber
* Reverberant Acoustic Chamber
* 3 Axis Sine-Vibration Facility
* Reverberant EMI/EMC Chamber

# Overview – Recent Modernization Projects

## B-2 – Upper-Stage Engine/Spacecraft Research Facility

### ▪ B-2 Restorations (2006..2010) and 2011 to present day

Beginning in 2006, B-2 underwent a systematic, phased refurbishment program to revitalize all major facility subsystems and ancillary infrastructure equipment.

NASA's Space Operations Mission Directorate (SOMD) and Exploration Systems Mission Directorate (ESMD) have funded this activity, under the guidance of the Rocket Propulsion Test Management Board (RPTMB), a NASA Level II office responsible for maintaining the agency's chemical propulsion test capability.

To date this refurbishment includes the chamber and all vacuum systems, propellant and pressurant systems, control and data acquisition systems, and numerous facility support systems. Implementation efforts of additional facility capabilities are ongoing.

### ▪ About the Rocket Propulsion Test Program Office (the RPT)


The RPT provides the program management structure to:

- maintaining sufficient Agency capabilities without unnecessary duplication
  *Marshall (MSFC), Whitesands (WSTF), Stennis (SSC), and Glenn (GRC)*
- Making chemical propulsion test location assignments
- Managing the rocket propulsion test budget
- Advocates for testing and test planning
  - Provides program-to-program input for adequate test planning
  - ***Plans for future requirements not advocated by active programs***

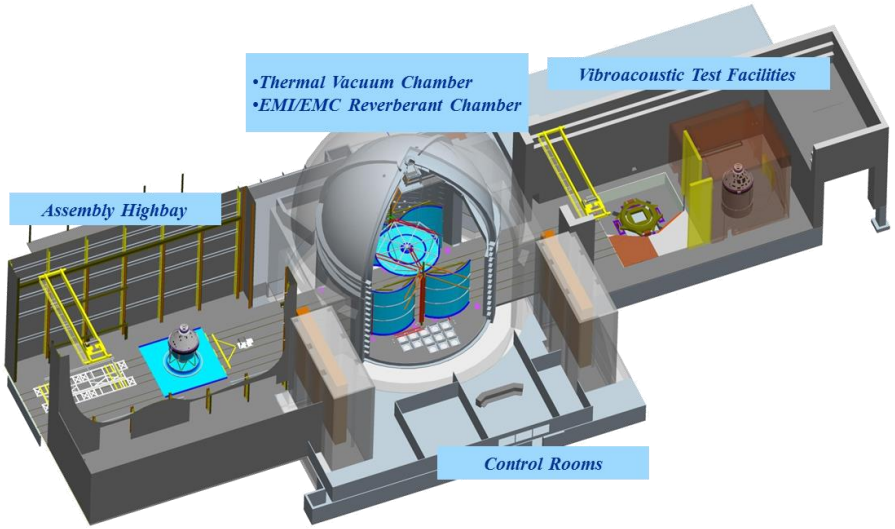
# Overview – Recent Modernization Projects

## SPF – Space Power Facility– Integrated Space Environment Test Chambers

- **SPF Vibroacoustic upgrade (2007..2011) and Current Test Programs**

In late 2007, NASA began a project to create single location where large-scale space environment testing could be performed. Leveraging the existing thermal-vacuum test chamber at the Space Power Facility (SPF), NASA began the work to add acoustic, vibration, modal, and EMI/EMC test capabilities at a comparable scale.

The major construction modifications to the facility were completed in 2011 and included the installation of a dedicated facility data acquisition system to support the new test capabilities as well as a replacement data system for the thermal-vacuum chamber. Since 2011 the facility has been engaged in extended commissioning goals, and a variety of integrated test programs and various test programs.




* Assembly Highbay
* Thermal Vacuum Chamber
* Reverberant EMI/EMC Chamber
* Mechanical Sine Vibration Facility
* Reverberant Acoustic Chamber

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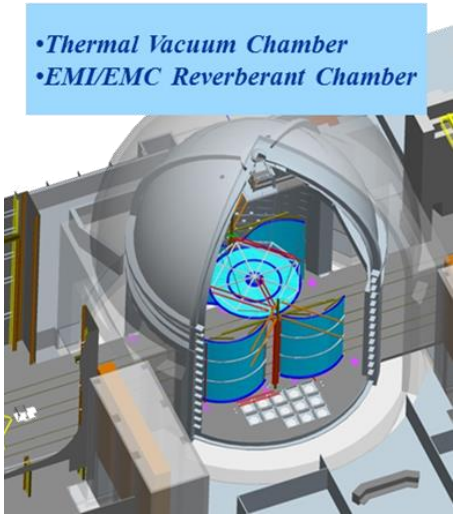


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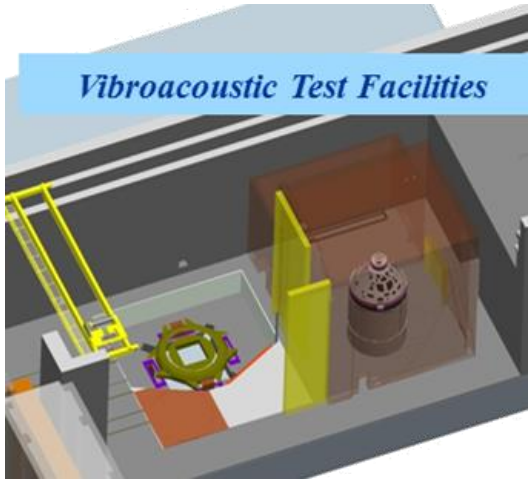


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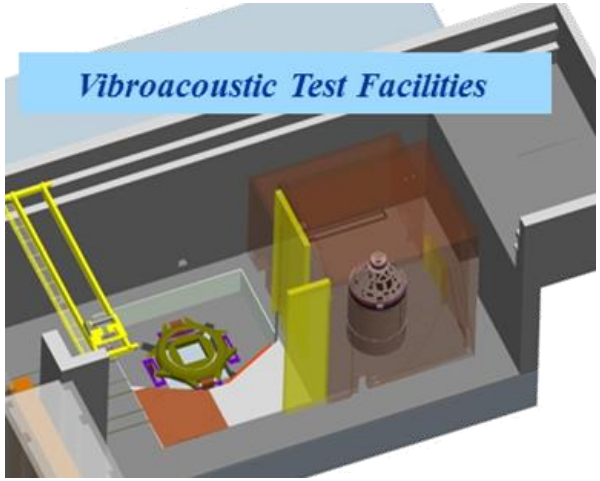


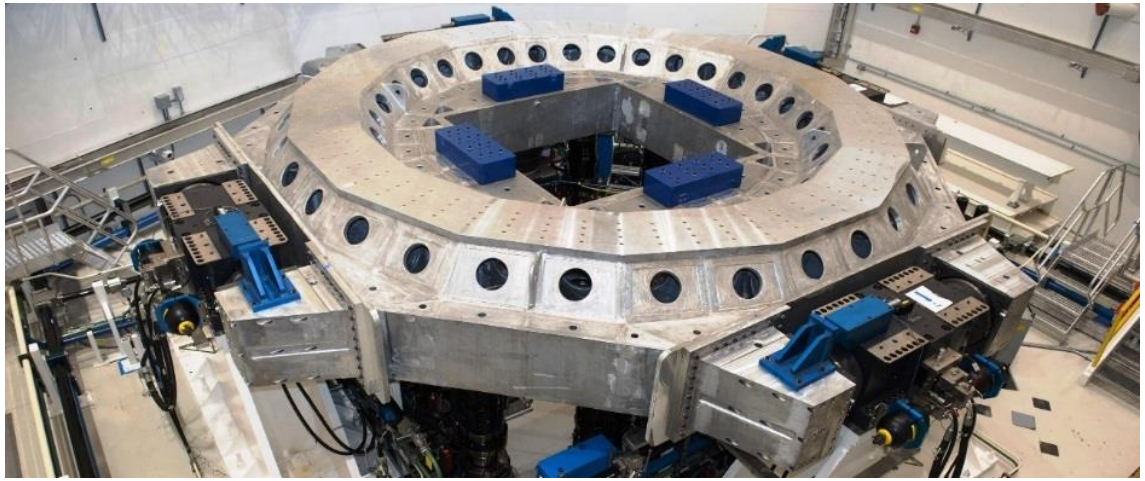

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# Design Approach for the New Data System

**Space/Aerospace mantra for reliability:**

**"Fly as you test and Test as you Fly"**

**Two kinds of tests for Large-scale integrated platforms:**

1. **Qualification Tests** (Qual. vehicle for planned Over-testing – does not fly)
2. **Acceptance Tests** (Flight vehicle for workmanship at standard levels)

**Due to budget and schedule constraints,**
**Large-scale integrated platform tests tend to be budgeted for**

**"One chance" to get the data**

**As a result…**

**Test Facility Data systems tend to be dealt with under "Napoleonic Law"**

**Data Systems are assumed to be "Guilty until proven Innocent"**

as opposed to British Common Law ("Innocent until proven guilty")

# Design Approach for the New Data System

## What would the IDEAL DAS solution look like?

- Commercial Off-The-Shelf (COTS)
  - Look for mature product lines from industry leading manufacturers
  - Maximize the use of open standards for both hardware and software
- Modular
  - Scalability
  - Upgradability
  - Easier to Troubleshoot, Check-out, Verify & Repair
- Electronically Configurable
  - Avoid Manual Knobs and Dials
  - Able to automate and back-up “SAVE/RESTORE” functions
  - Configurations included as part of the test record
  - Facilitates “Whole System” automation
- Highly Integrated Operation
  - Traceability is “built-in” to a fully integrated modular system
  - Borrowing the merits of the OSI 7-Layer model, Higher-Level Functions in a layered model allows some “transparency” in the system. (such as Ethernet and Fibre Channel) (i.e. – ability for upstream components to control and configure downstream devices)

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**~ Our Strategy ~**

These characteristics will result in a system that is:

- ✓ Easy to **Operate**
- ✓ Easy to **Maintain**
- ✓ Easy to **Upgrade**
- ✓ Easy to **Verify**

Our goal is to assure :

- ✓ **Highest Quality**
- ✓ **Highest Reliability**

# Design Approach for the New Data System

**What are some of the challenges in designing a permanent "facility" data system?**

- Wide variety of Data Rates and Measurement Bandwidths
- Wide variety of Measurement Types
- Distance Effects and Limitations
- Calibrating the system (and troubleshooting)

  ANSI/NCSLI Z540.3-2006 --- Requirements for the Calibration of Measuring and Test Equipment
- Synchronization and Timing of Data from Multiple Sources (IRIG)
- Future System Growth (Scaling-up when needed)
- Automated Software SAVE and RESTORE Functions
- Versatility (Every customer wants something different)
- Measurement Uncertainty Analysis (ISO "GUM")

  ANSI/NCSL Z540.2-1997 (R2007), U.S. Guide to the Expression of Uncertainty in Measurement

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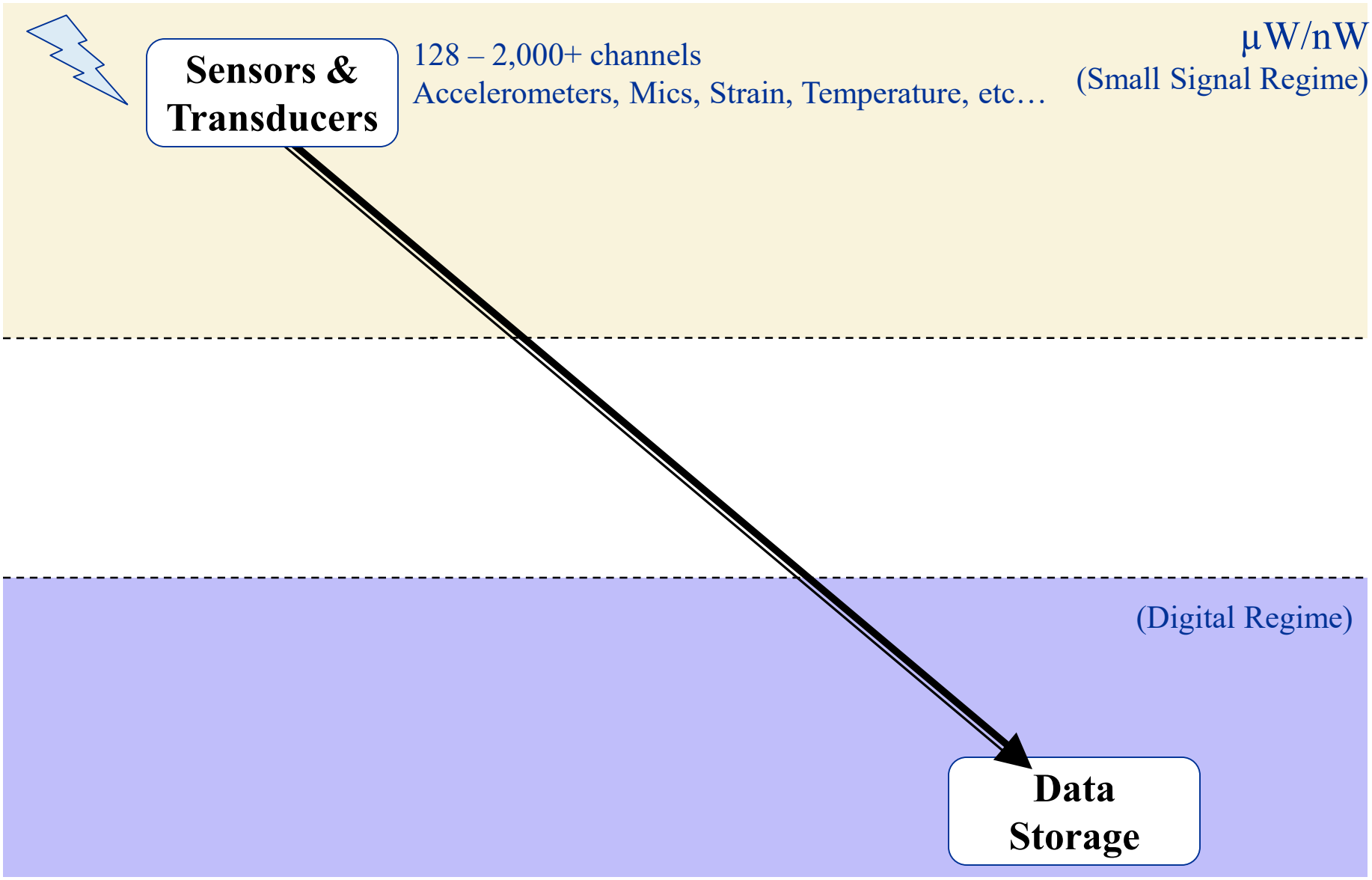
# Modular Distributed Measurement Topology



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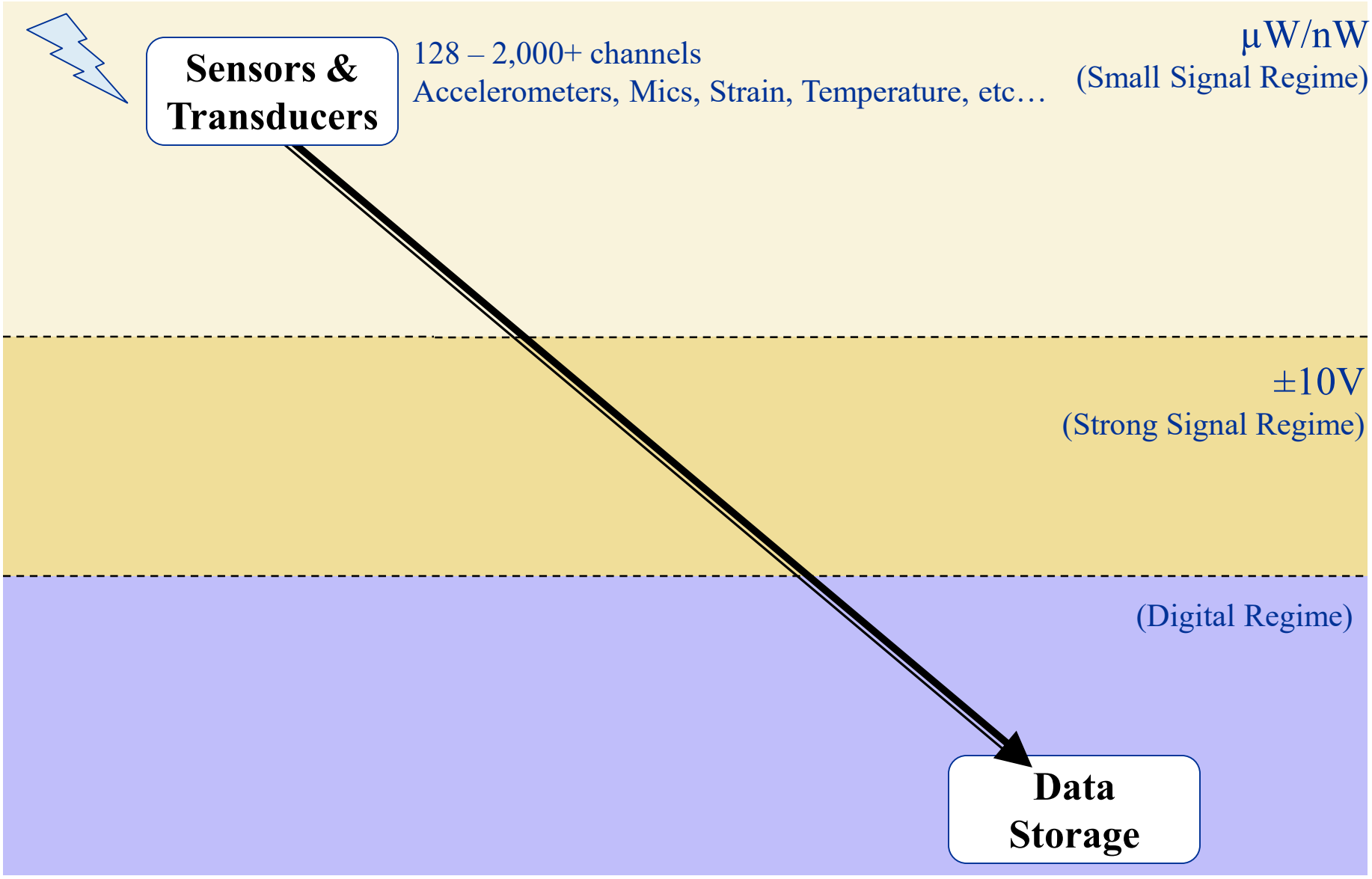

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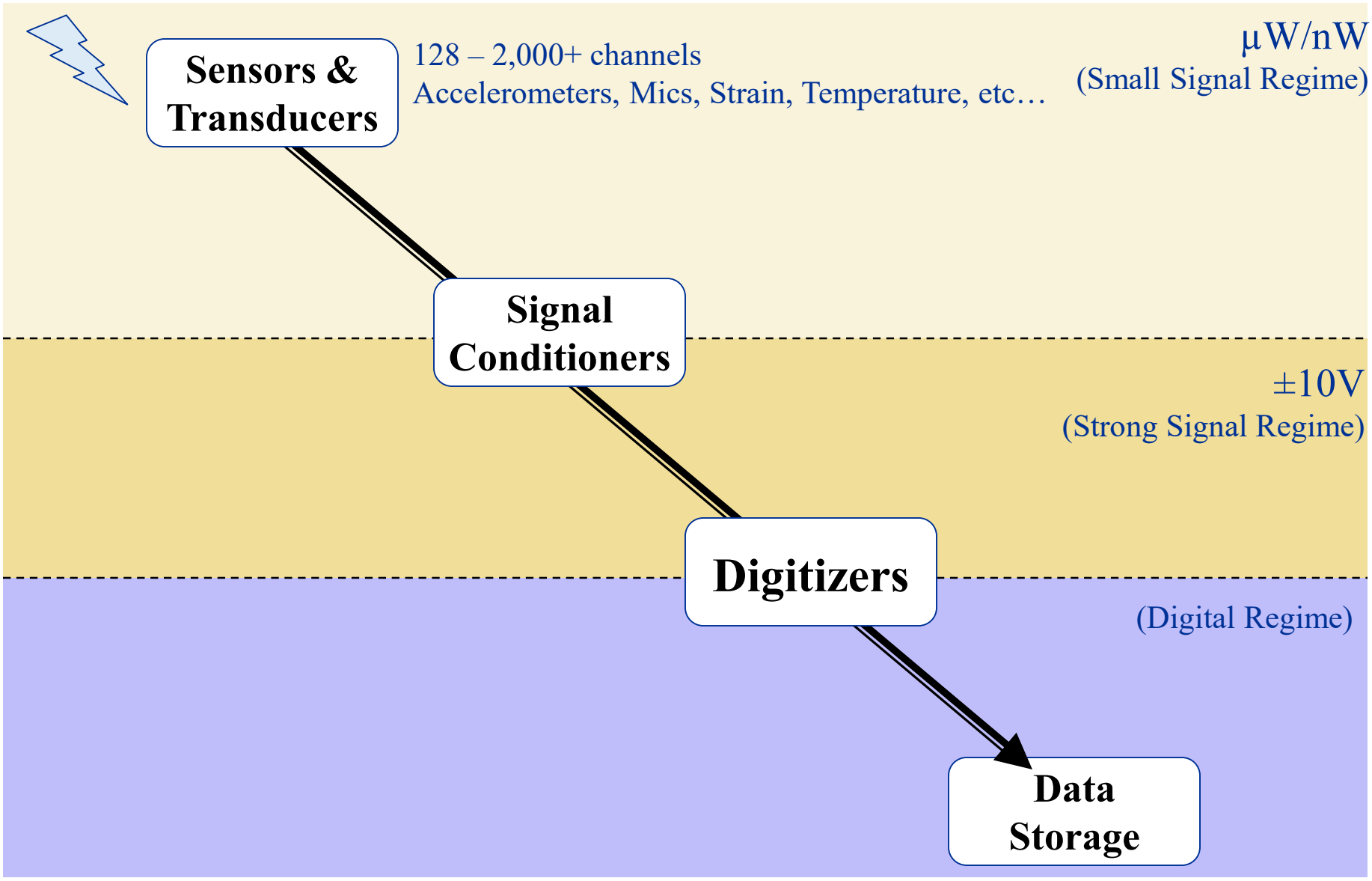

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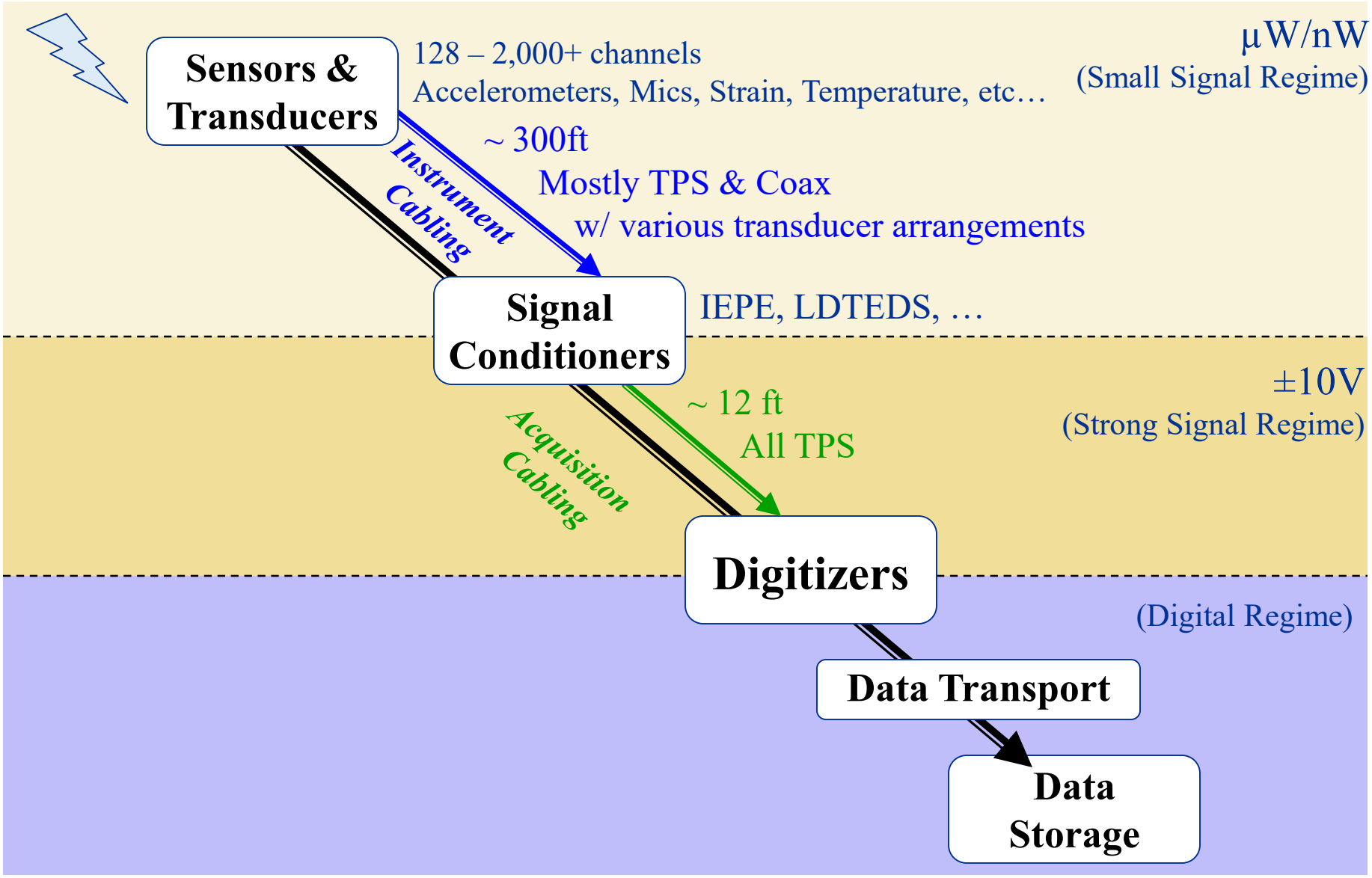

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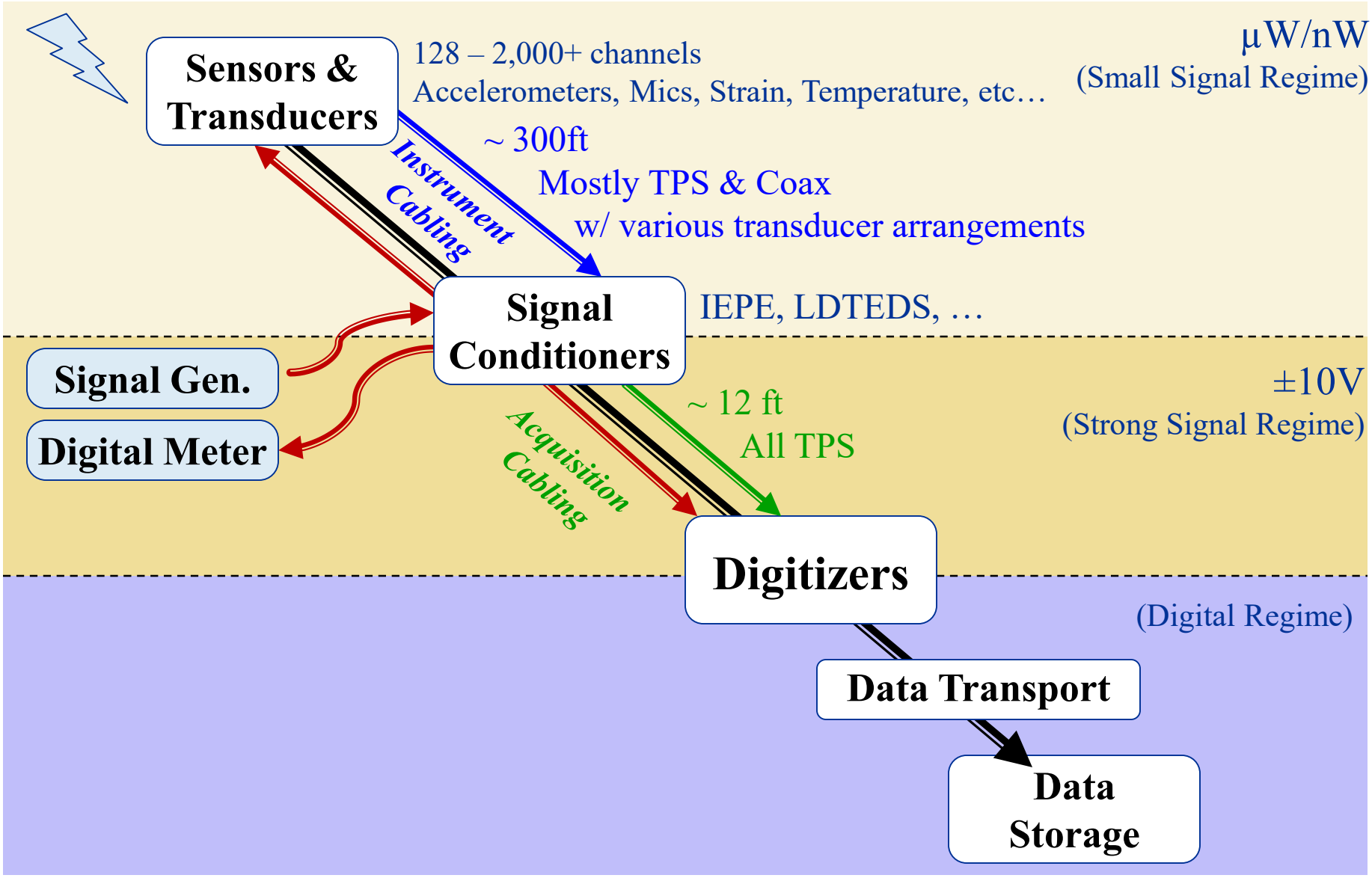

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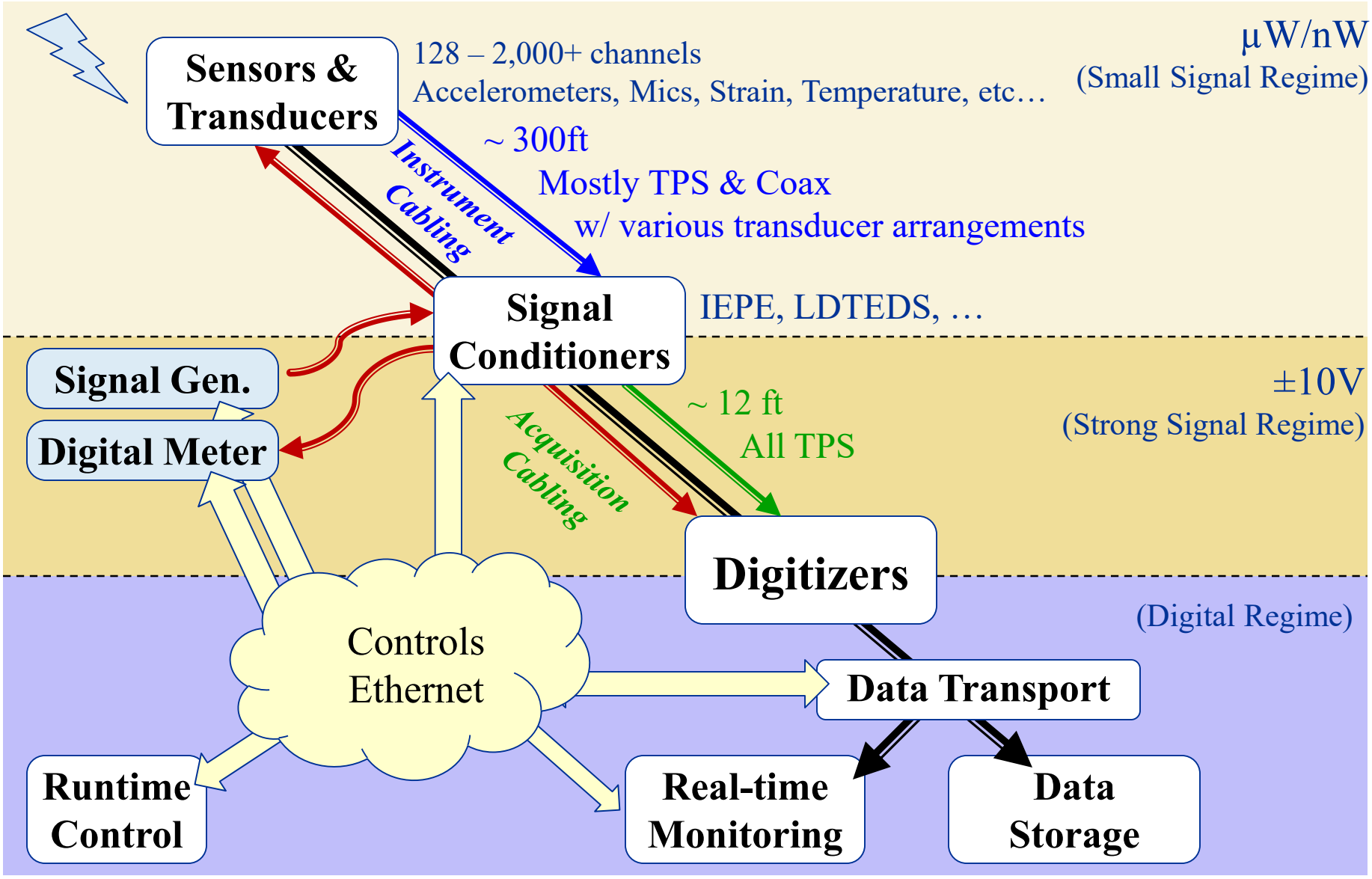

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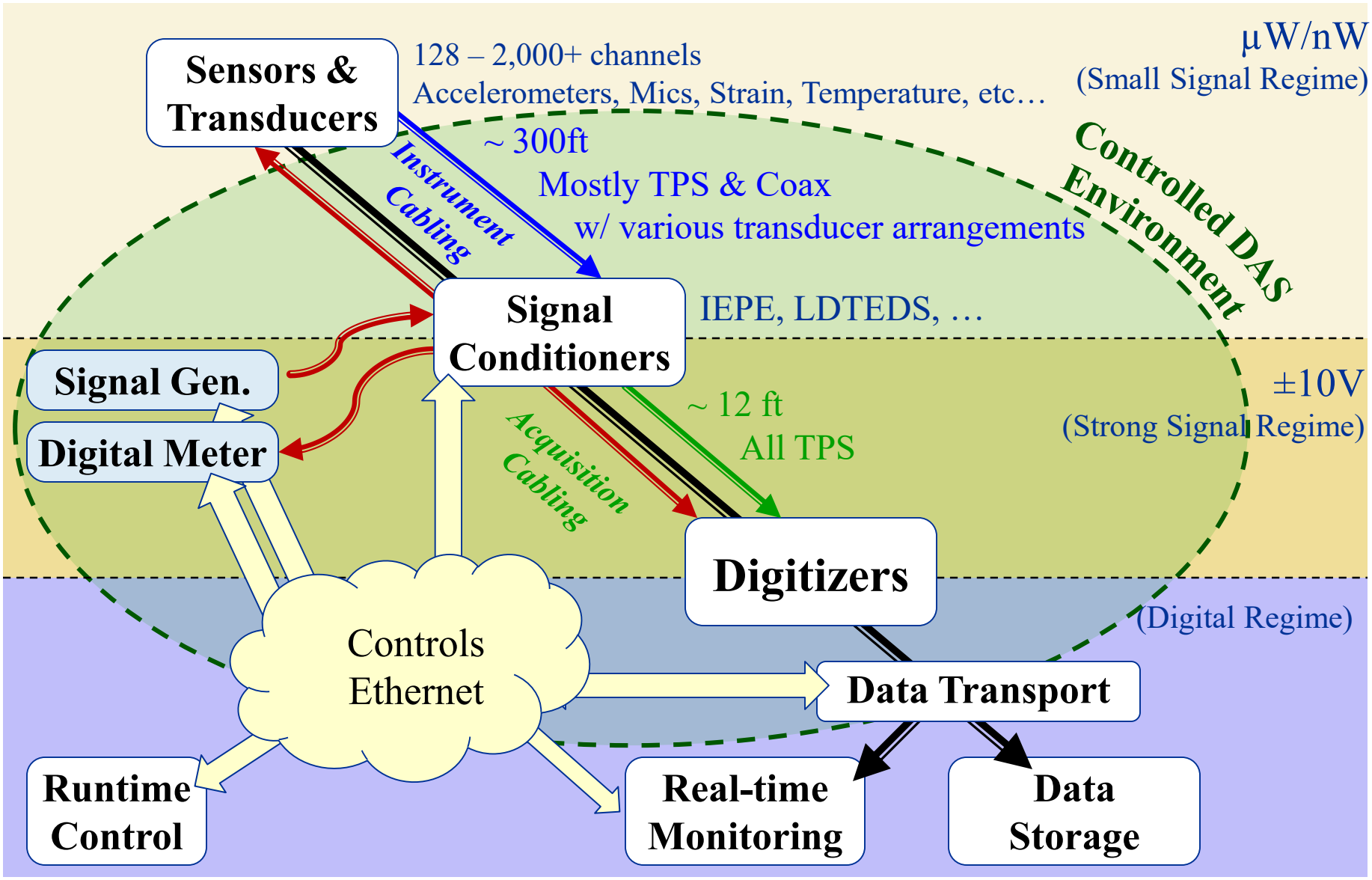

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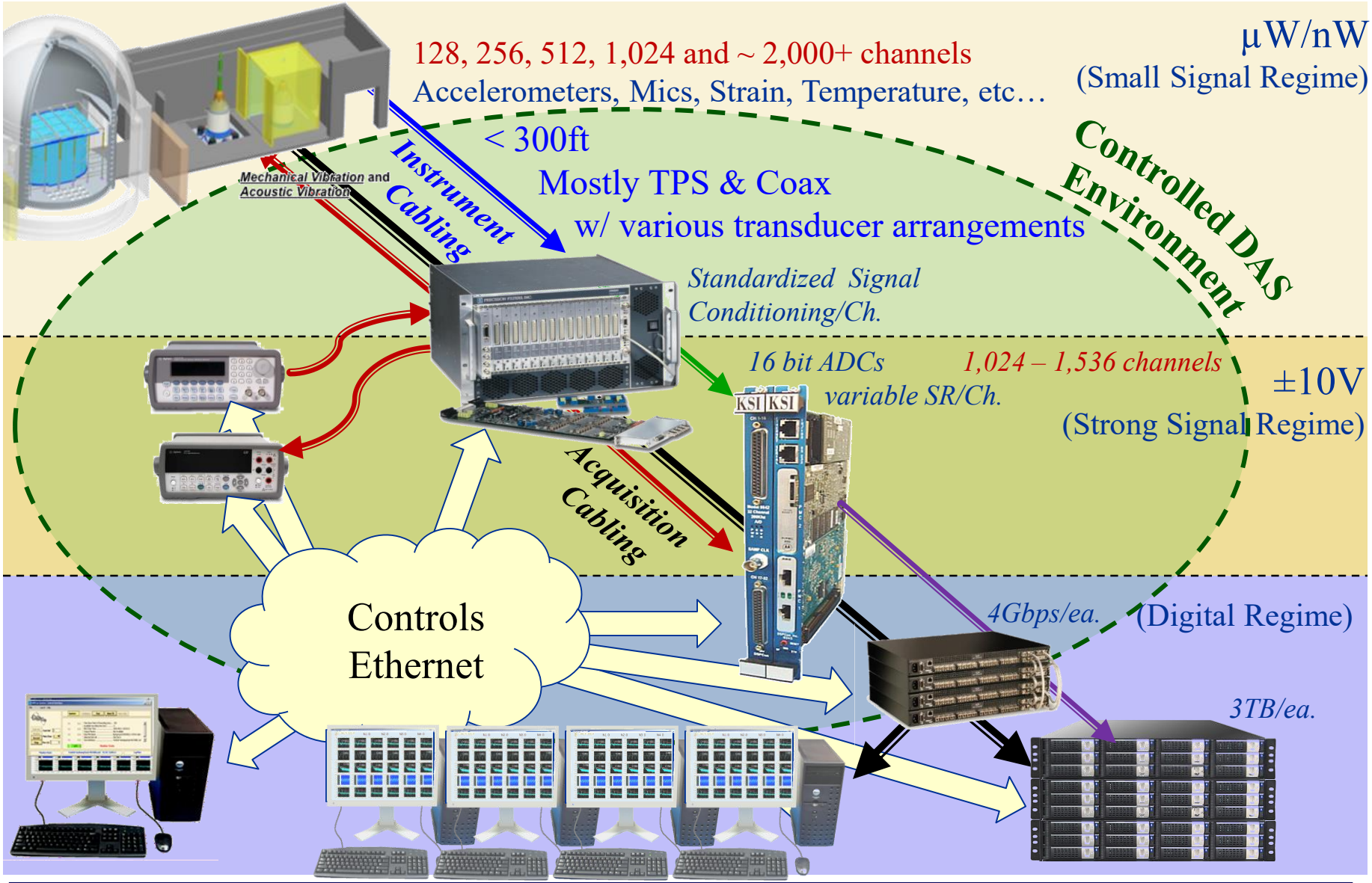

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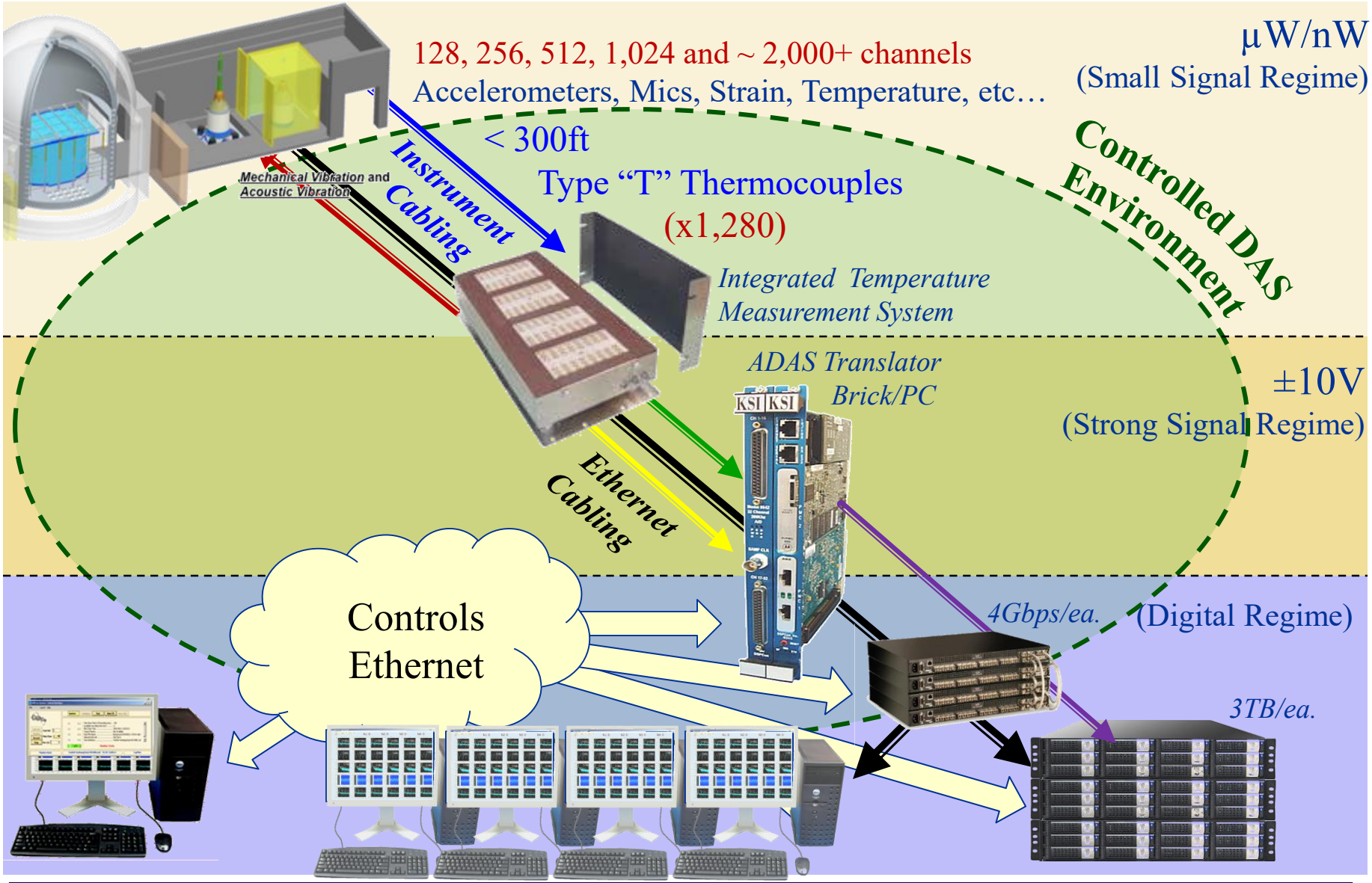
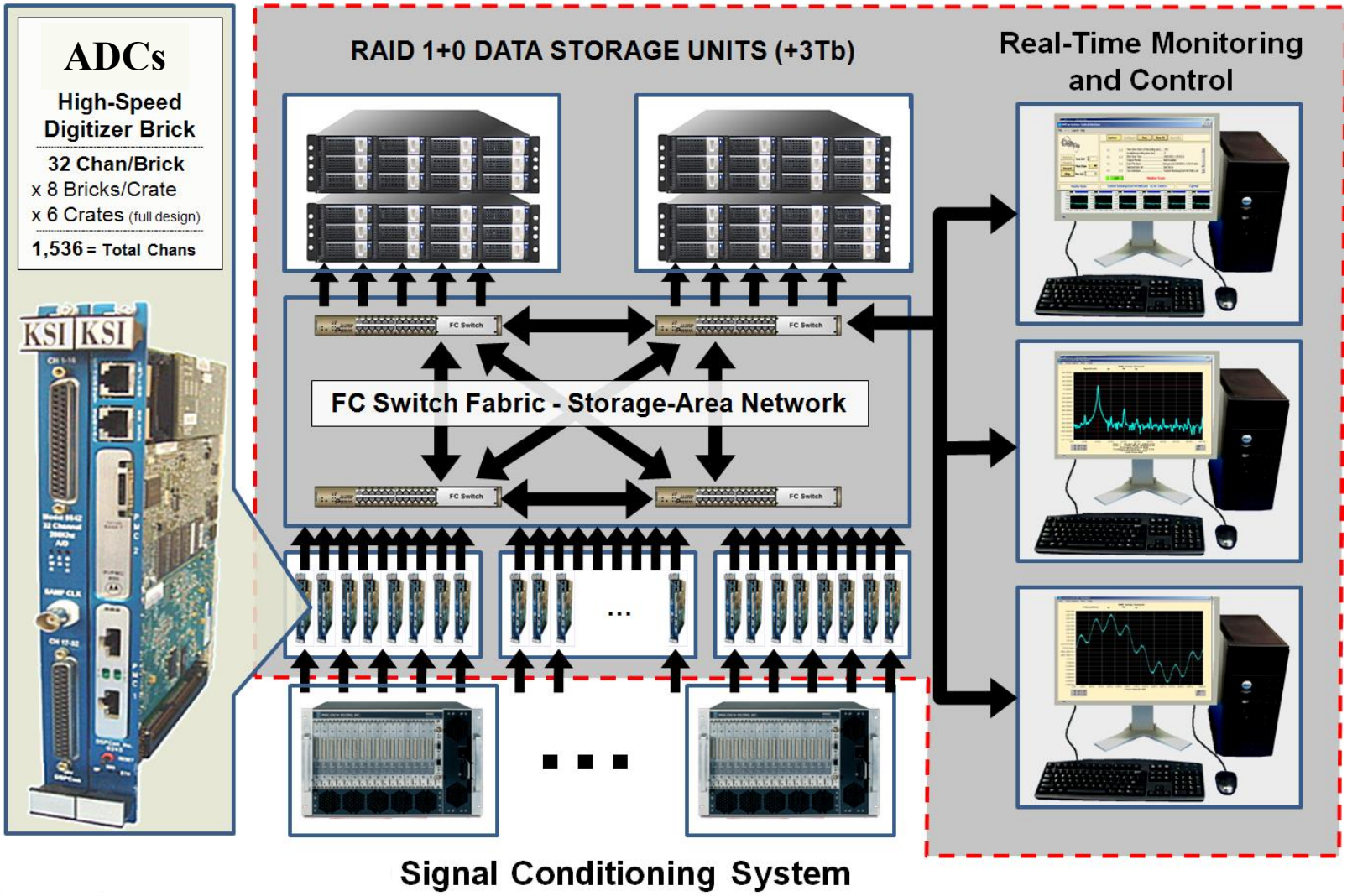


# Integrated FC-SAN for Distributed Scalability

## The completed system forms a Fibre-Channel Storage Area Network



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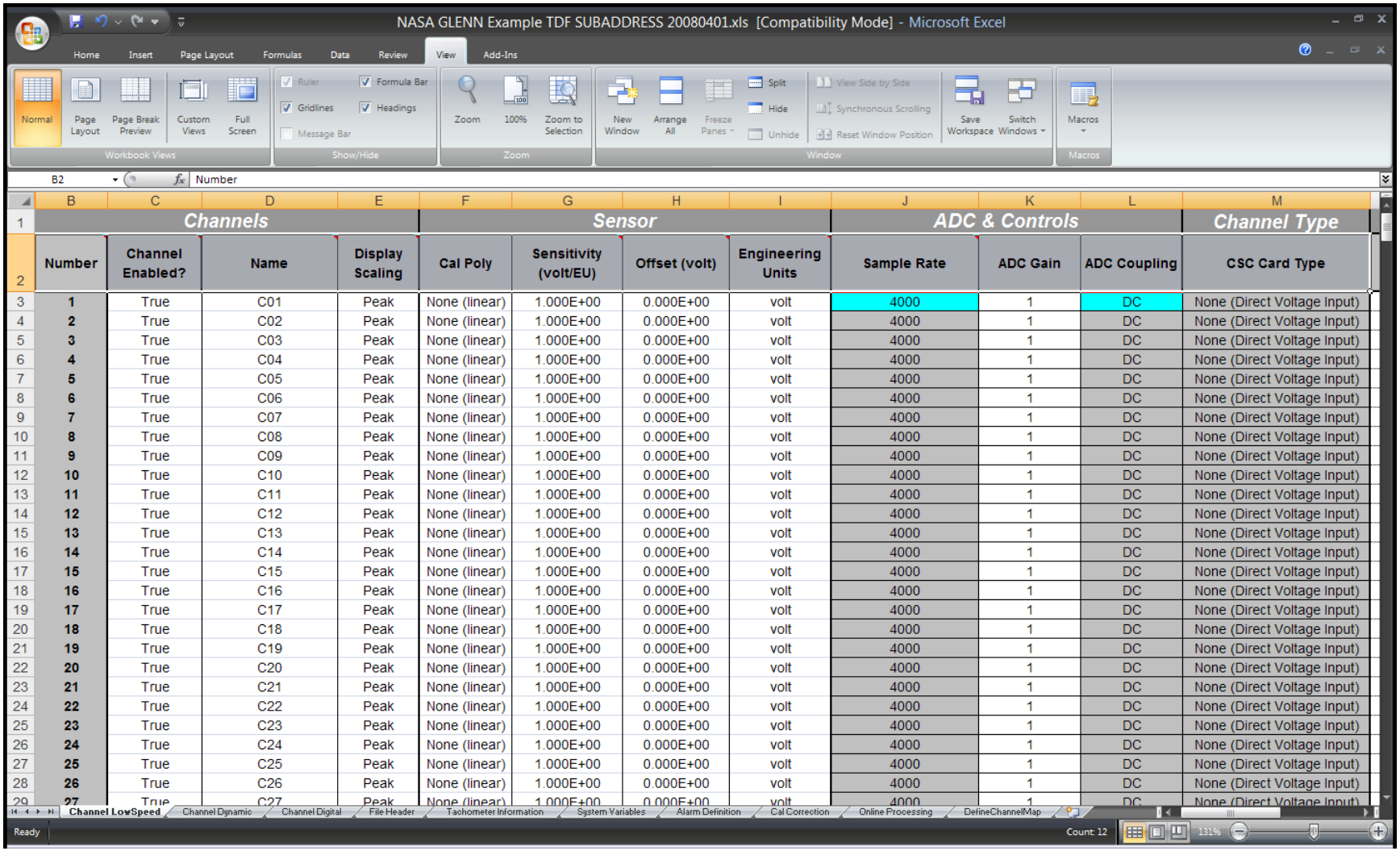
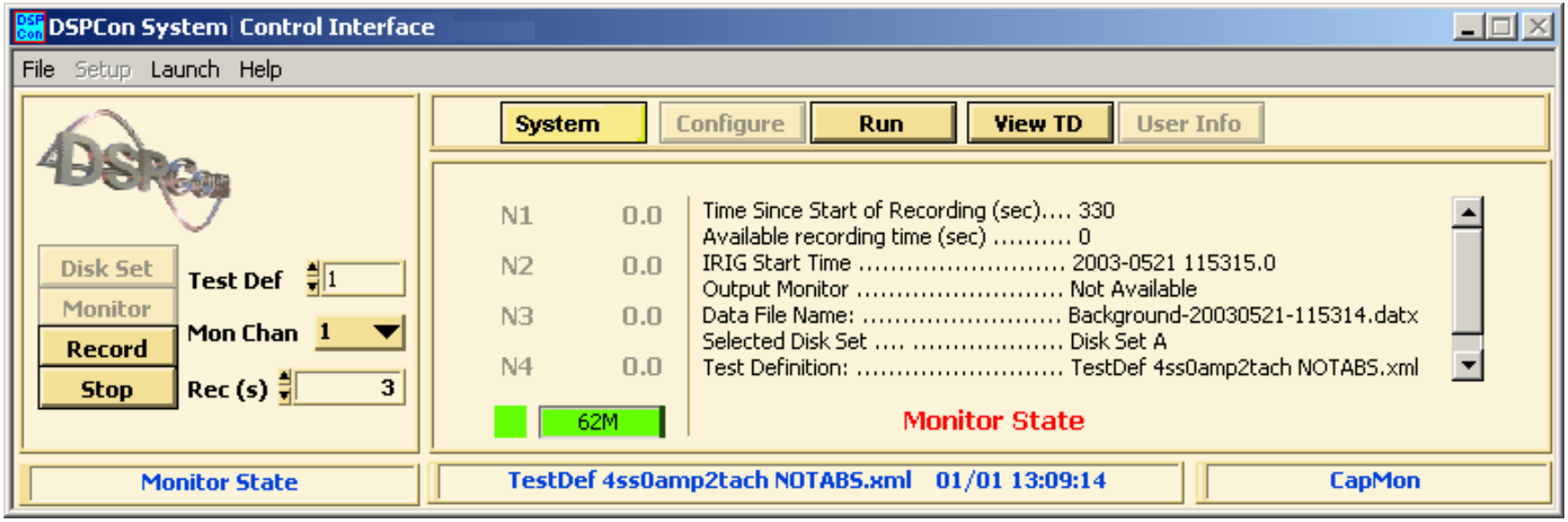
# DAS - Control and Real-Time Display

## System Configuration is done using a MS-Excel Spreadsheet



# DAS - Control and Real-Time Display

## System Operation is accomplished using a simple GUI Interface



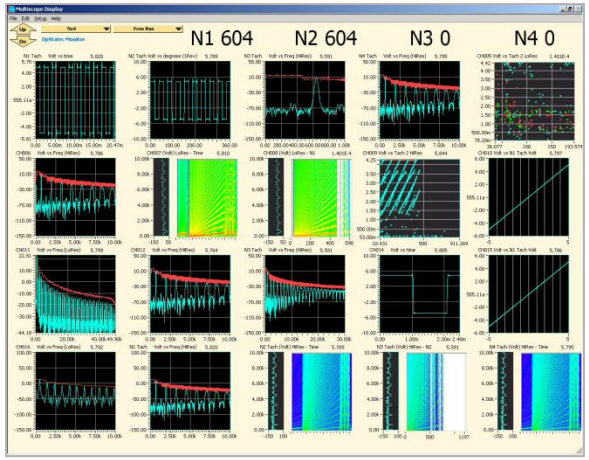

## Other Features:

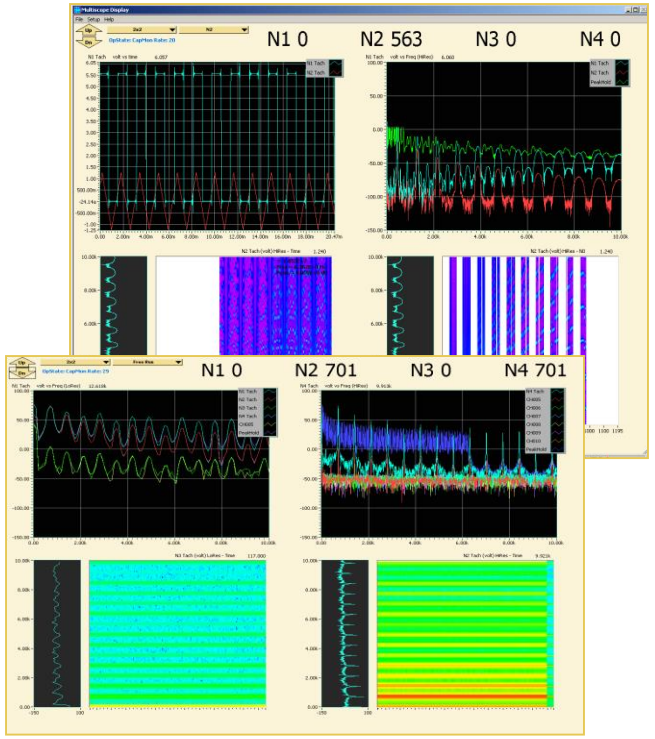
- ✓ Monitor Disk Usage
- ✓ Monitor System Health (Watchdog)
- ✓ Monitor Mode – Ability to Monitor without Acquiring until triggered (Monitor Mode will capture data prior to the event once triggered)

# DAS - Control and Real-Time Display

## Real-Time Display Capabilities

- ✓ Time Plots
- ✓ Frequency (FFT)
- ✓ $N^{th}$ Octave Plots
- ✓ Signal Transfer Functions
- ✓ many others in many different combinations and arrangements
- ✓ and on multiple "Data Monitoring" PCs

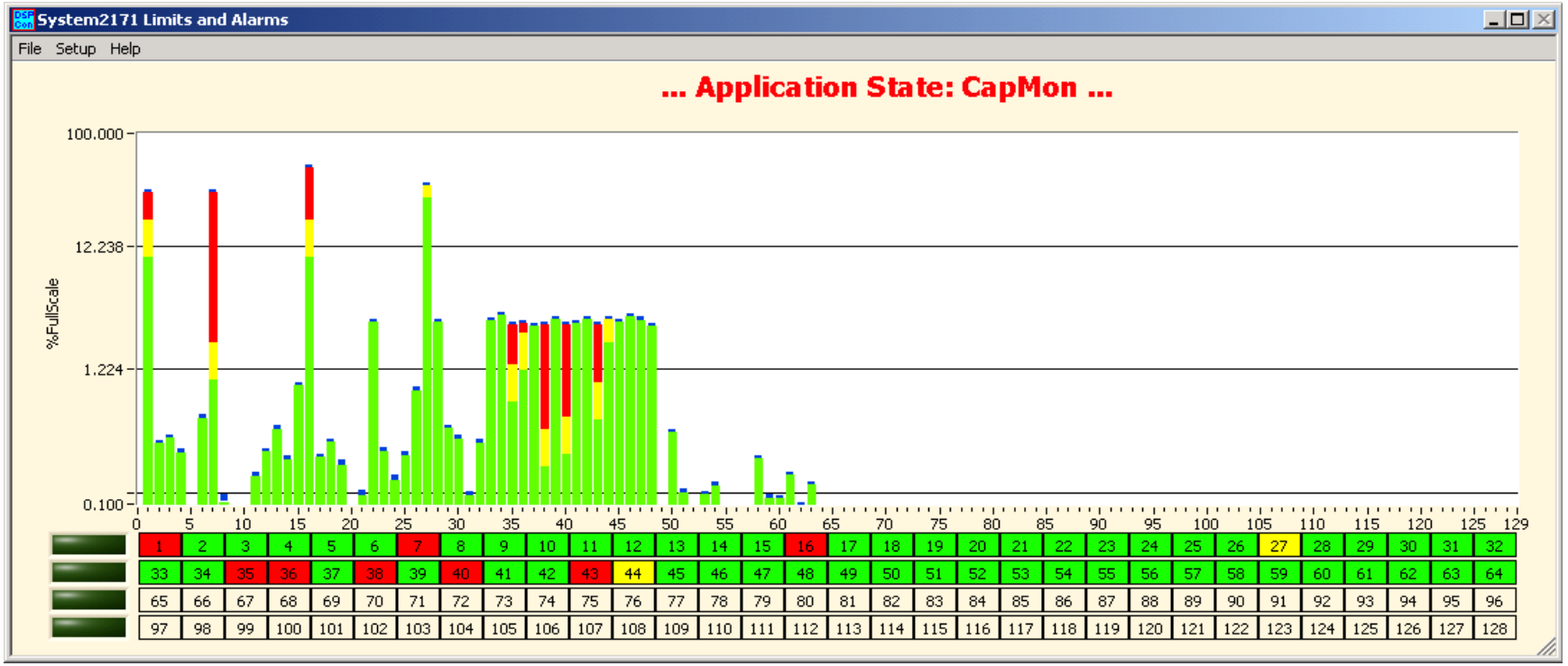



# DAS - Control and Real-Time Display

## Real-Time Display Types – **Limits & Alarms**

✓ Multiscope also allows for Real-time Monitoring of Alarm & Limits Settings for both Peak Amplitude for each Channel AND per Frequency/Per Channel



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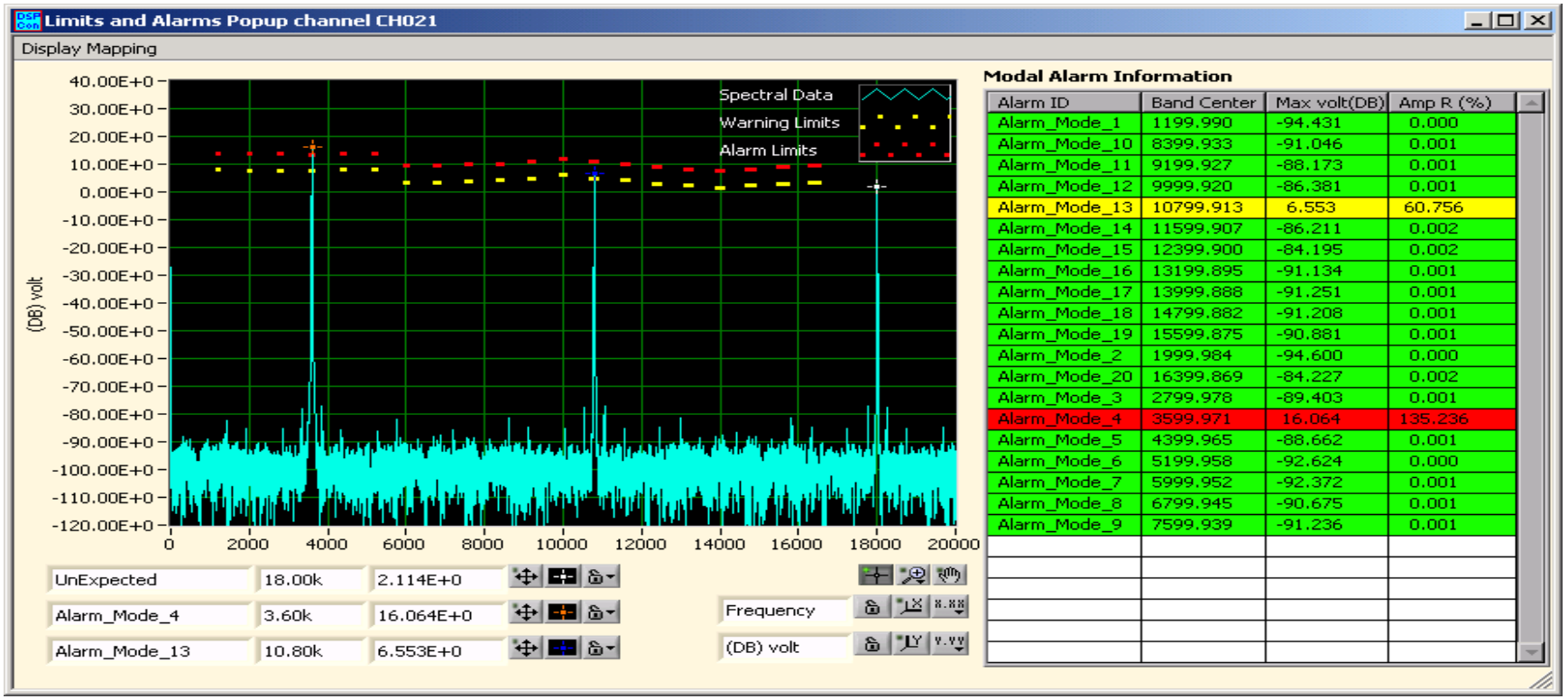


| Alarm ID | Band Center | Max volt(DB) | Amp R (%) |
|---|---|---|---|
| Alarm_Mode_1 | 1199.990 | -94.431 | 0.000 |
| Alarm_Mode_10 | 8399.933 | -91.046 | 0.001 |
| Alarm_Mode_11 | 9199.927 | -88.173 | 0.001 |
| Alarm_Mode_12 | 9999.920 | -86.381 | 0.001 |
| Alarm_Mode_13 | 10799.913 | 6.553 | 60.756 |
| Alarm_Mode_14 | 11599.907 | -86.211 | 0.002 |
| Alarm_Mode_15 | 12399.900 | -84.195 | 0.002 |
| Alarm_Mode_16 | 13199.895 | -91.134 | 0.001 |
| Alarm_Mode_17 | 13999.888 | -91.251 | 0.001 |
| Alarm_Mode_18 | 14799.882 | -91.208 | 0.001 |
| Alarm_Mode_19 | 15599.875 | -90.881 | 0.001 |
| Alarm_Mode_2 | 1999.984 | -94.600 | 0.000 |
| Alarm_Mode_20 | 16399.869 | -84.227 | 0.002 |
| Alarm_Mode_3 | 2799.978 | -89.403 | 0.001 |
| Alarm_Mode_4 | 3599.971 | 16.064 | 135.236 |
| Alarm_Mode_5 | 4399.965 | -88.662 | 0.001 |
| Alarm_Mode_6 | 5199.958 | -92.624 | 0.000 |
| Alarm_Mode_7 | 5999.952 | -92.372 | 0.001 |
| Alarm_Mode_8 | 6799.945 | -90.675 | 0.001 |
| Alarm_Mode_9 | 7599.939 | -91.236 | 0.001 |

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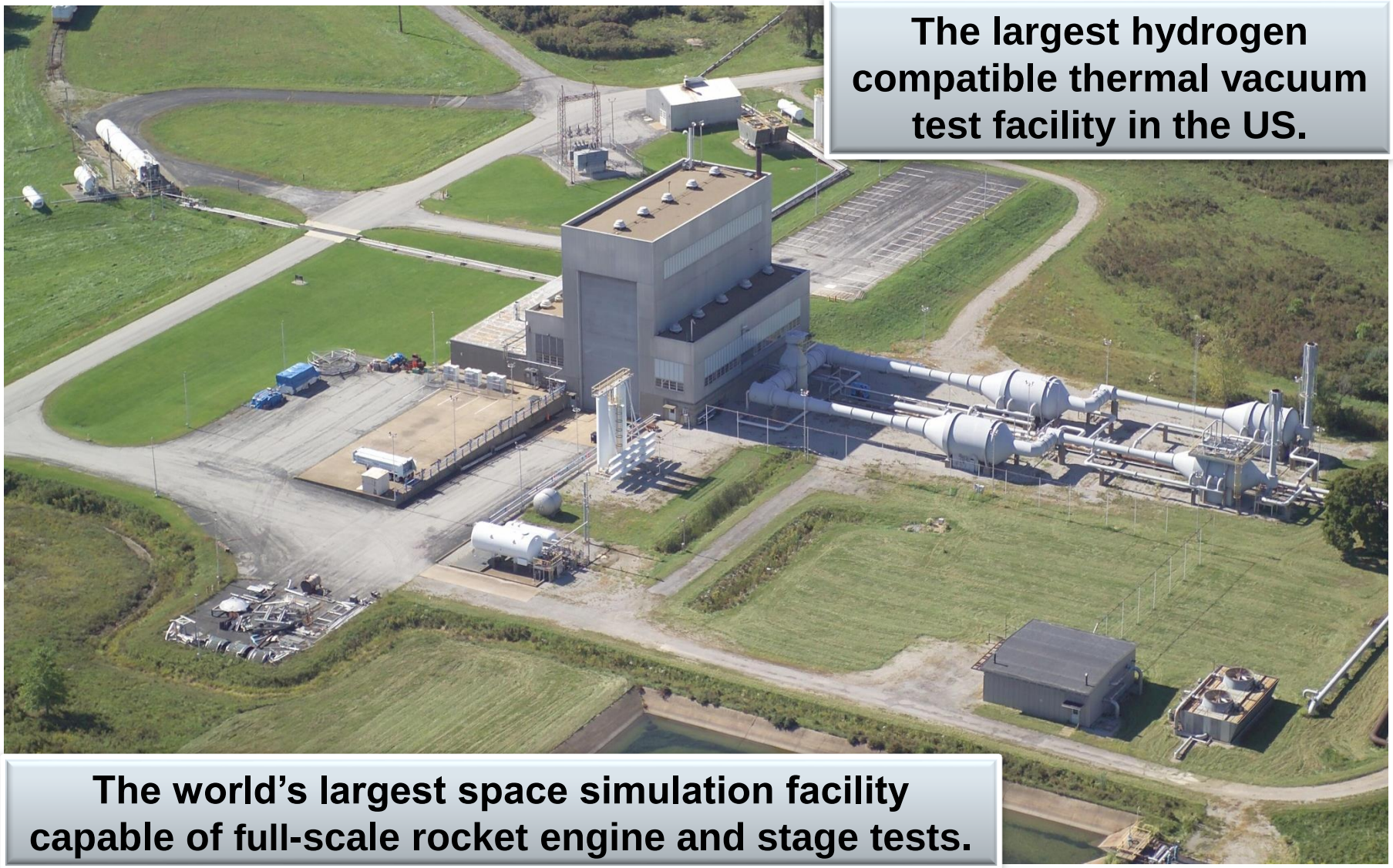
**Ideal for High Altitude Engine Testing**

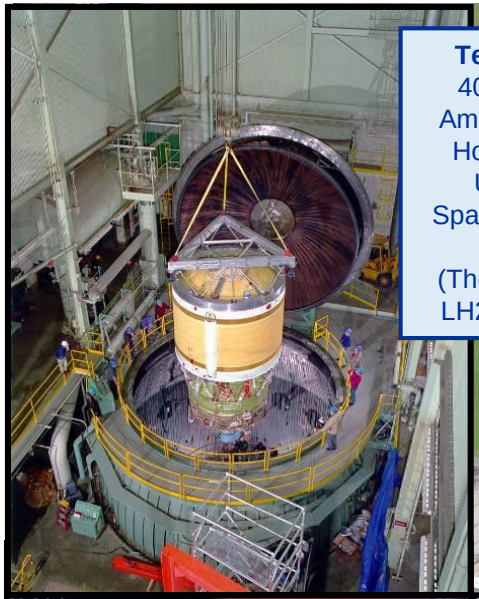
# B-2 Facility – Upper-stage Thermal-Vac Chamber (33ft dia. x 55ft high)



**The largest hydrogen compatible thermal vacuum test facility in the US.**

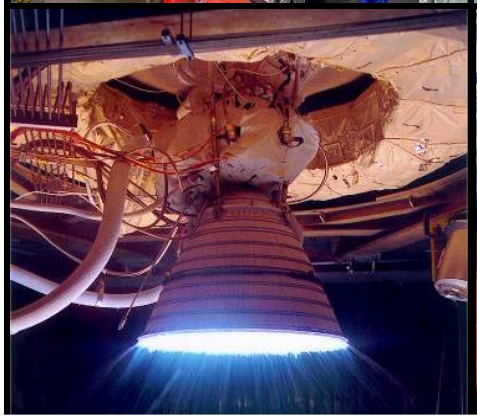
**The world's largest space simulation facility capable of full-scale rocket engine and stage tests.**

# B-2 Facility – Upper-stage Thermal-Vac Chamber (33ft dia. x 55ft high)

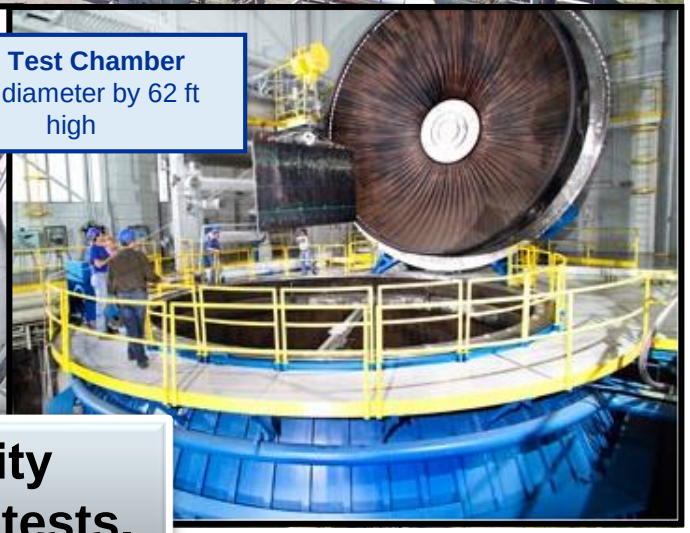


**Test Stand B-2**
400 Klbf Thrust
Ambient to 130 Kft
Hot-Fire Testing
Up to 900Kft
Space Environment
Simulation
(Thermal Vacuum)
LH2/LOX/RP/CH4

**The largest hydrogen compatible thermal vacuum test facility in the US.**



**B-2 Test Chamber**
32 ft diameter by 62 ft high

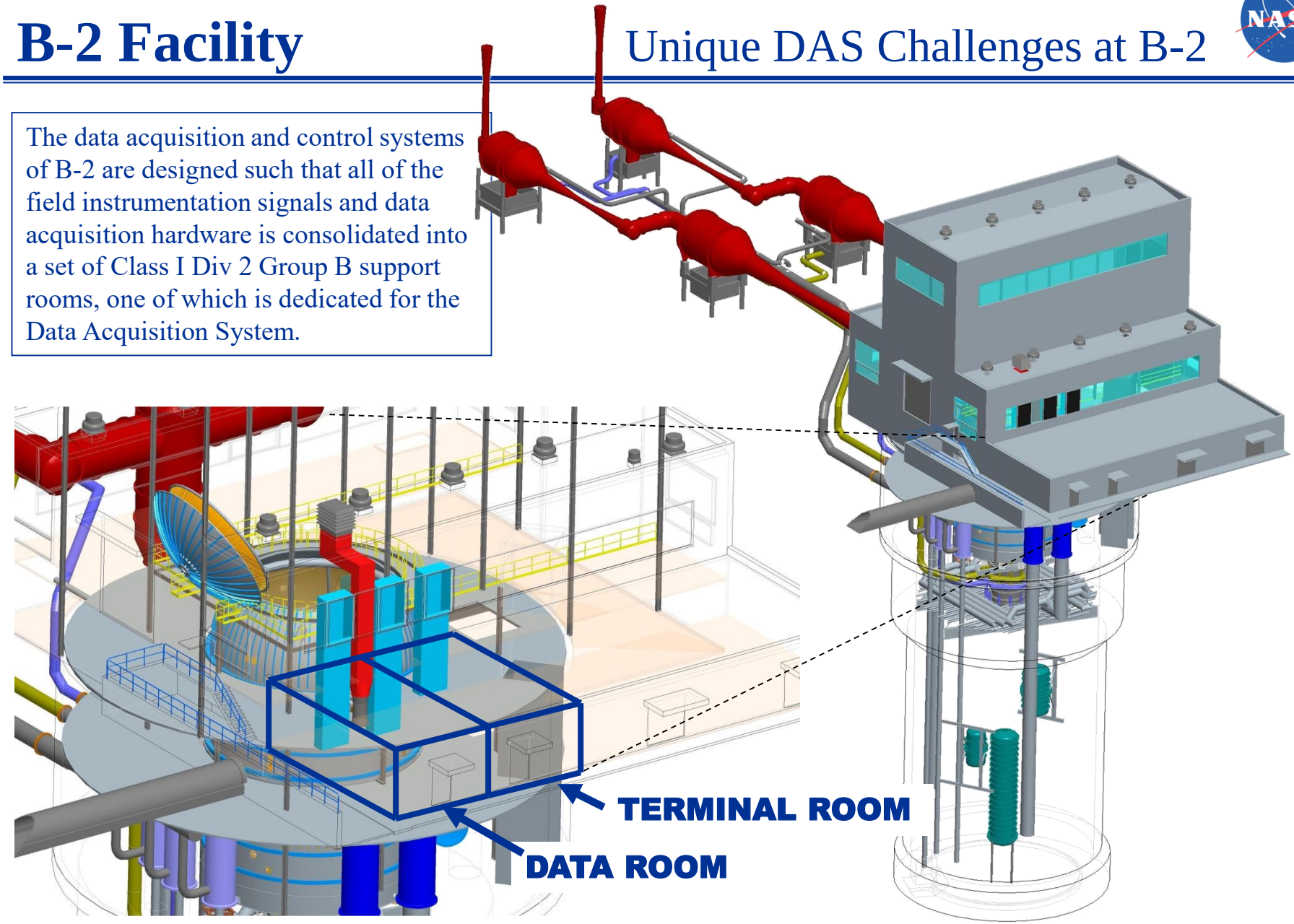


**The world's largest space simulation facility capable of full-scale rocket engine and stage tests.**

# B-2 Facility

## Unique DAS Challenges at B-2

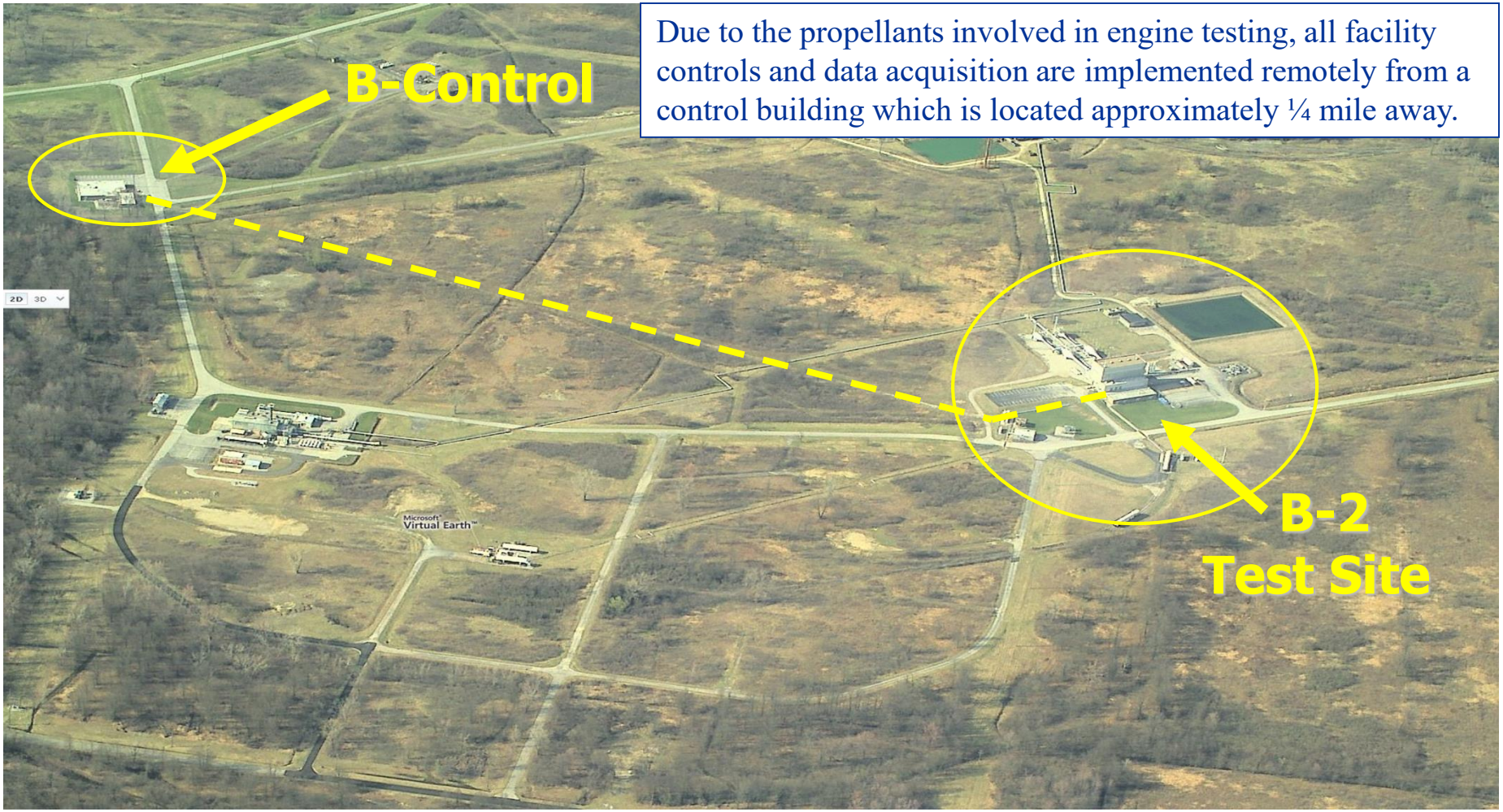
The data acquisition and control systems of B-2 are designed such that all of the field instrumentation signals and data acquisition hardware is consolidated into a set of Class I Div 2 Group B support rooms, one of which is dedicated for the Data Acquisition System.



# B-2 Facility

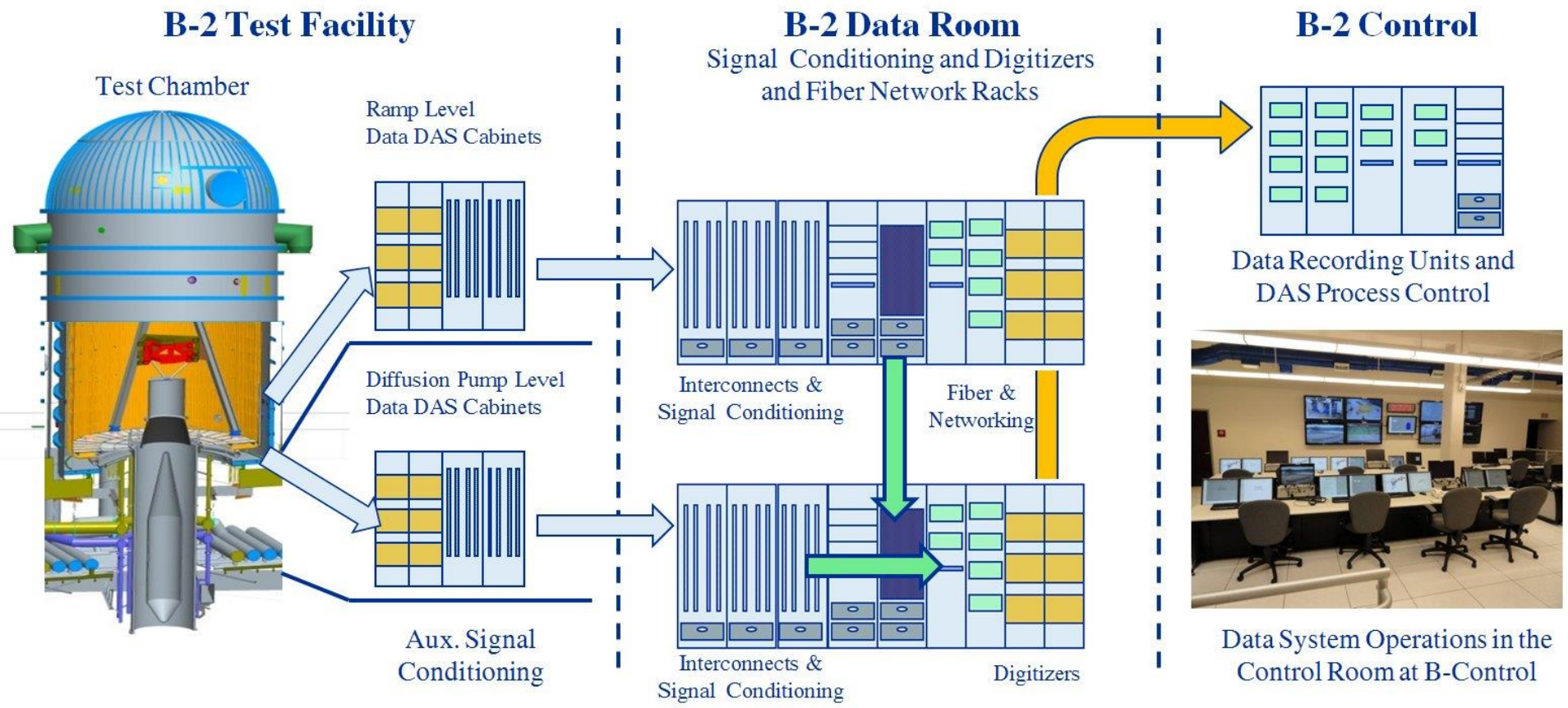
## Unique DAS Challenges at B-2

Due to the propellants involved in engine testing, all facility controls and data acquisition are implemented remotely from a control building which is located approximately ¼ mile away.



# B-2 Facility

## DAS Signal Flow



# B-2 Facility – Dedicated Data Room

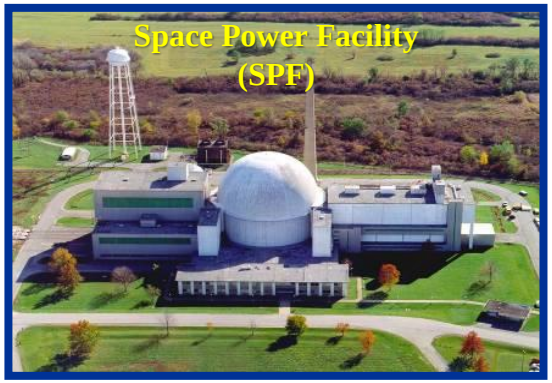
# B-2 Facility DAS – Summary


**Designed for High Altitude Engine Testing**

| Instrument Cabling to Test Chamber | | Quantities |
|---|---|---|
| 1 | Single Pair, Twisted-Pair Shielded | >1,700 Ch. 1PR TPS |
| 2 | Four-Wire, Twisted-Pair Shielded | 312 Ch. of 4C / Ch. |
| 3 | Impedance Matched Coaxial | ~64 Ch. |
| | | |
| **Signal Conditioning Equipment** | | |
| 4 | Constant-Voltage Bridge Conditioners | 76 Ch. |
| 5 | Constant-Current Bridge Conditioners | 32 Ch. |
| 6 | ICP/IEPE Conditioners | 48 Ch. |
| 7 | Charge-Type Amplifiers | |
| 8 | Filter/Amplifier Signal Conditioners | 160 Ch. |
| 9 | Frequency-to-Voltage | 28 Ch. |
| 10 | Direct Voltage Inputs | 600+ (see ADCs) |
| 11 | UTR Thermocouple Conditioners | <tbd> |
| | | |
| **Digitizing Equipment (ADCs)** | | |
| 12 | High-Speed Digitizers (110 kHz MBW/Ch.) | 32 Ch. - 256 Ch. |
| 13 | Low-Speed Digitizers (1 kHz MBW/Ch.) | 576 Ch. |
| 14 | Discrete Channel Acquisition | 32 Ch. |
| | | |
| **Data Storage** | | |
| 15 | RAID 1+0 redundant fail-over storage | 2.5 – 3 Terabytes |
| | | |
| **Control, Monitoring and Post-Processing** | | |
| 16 | Dedicated Control Computers | 2 |
| 17 | Dedicated Monitoring Computers | 4 |
| 18 | Dedicated Post-Processing Computer | 1 |
| | | |
| **Other Notable System Elements** | | |
| 19 | IRIG-B Distribution | All |
| 20 | LTO-3 Tape Archival System | All |

# Presentation Outline

- **Overview**
  - Plum Brook location and facilities
  - Summary of recent facility upgrades at Plum Brook
- **Plum Brook Facility DAS Design Drivers**
  - Goals
  - Challenges
  - Measurement Topology
  - Architecture
  - Specifications and Capabilities of shared assets
- **Overview of Plum Brook Data Systems**
  - B-2 Facility DAS
  - SPF Vibroacoustic Facilities DAS
  - SPF Thermal-Vacuum Chamber DAS



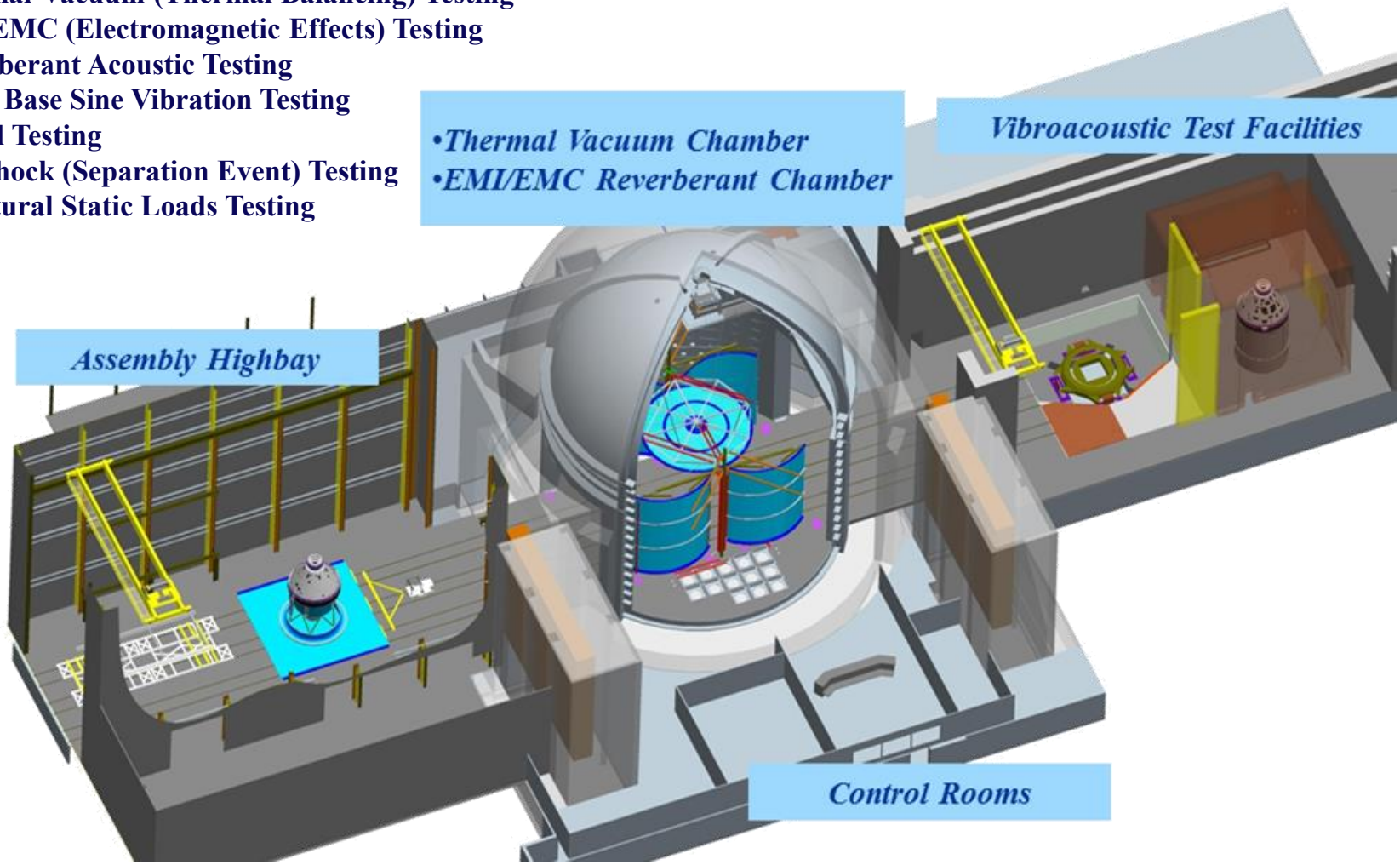

**Designed for High Altitude Engine Testing**

# Space Power Facility (SPF)

# Space Power Facility (SPF)

## Space Environment Testing under "one roof"

- Upper Stage (Payload) fairing separation Testing
- Thermal-Vacuum (Thermal Balancing) Testing
- EMI/EMC (Electromagnetic Effects) Testing
- Reverberant Acoustic Testing
- 3-axis Base Sine Vibration Testing
- Modal Testing
- Pyroshock (Separation Event) Testing
- Structural Static Loads Testing



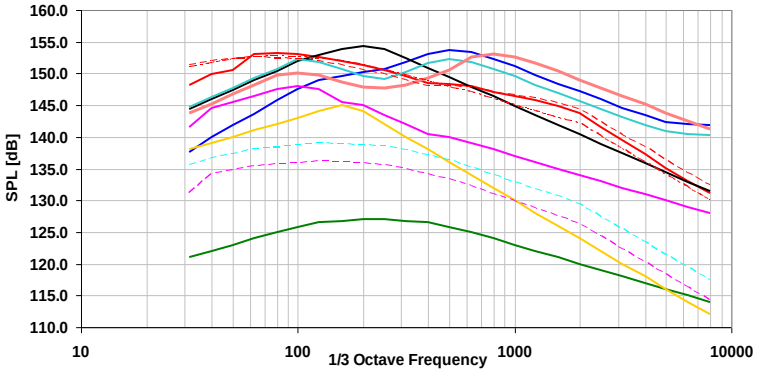
# Space Power Facility – Acoustic Facility

## SPF – Reverberant Acoustic Test Facility

# Space Power Facility – Acoustic Facility

## SPF – Reverberant Acoustic Test Facility

- ~101,000 $ft^3$ chamber volume
- ~ 37ft (w) x 47ft (d) x 57ft (h)
- ~ 163dB OASPL (Overall Sound Pressure Level)
- 20k Hz Measurement Bandwidth




### DAS Measurements Channels to RATF

- 800 - IEPE accels and/or microphones
- 40 - IEPE/charge conditioners
- 184 - 4-arm strain gauge conditioners

# Space Power Facility – Vibration Facility

## SPF - Mechanical Vibration Facility (MVF)

- 3-axis servo-hydraulic shaker
- Ring design for Orion ~18ft dia.
- Sized for 75,000 lb test articles
- ~4 million lb seismic mass
- 5 -150 Hz Sine Vib.
  - 1.25 g Vert.
  - 1.0 g Lateral

**Data System**

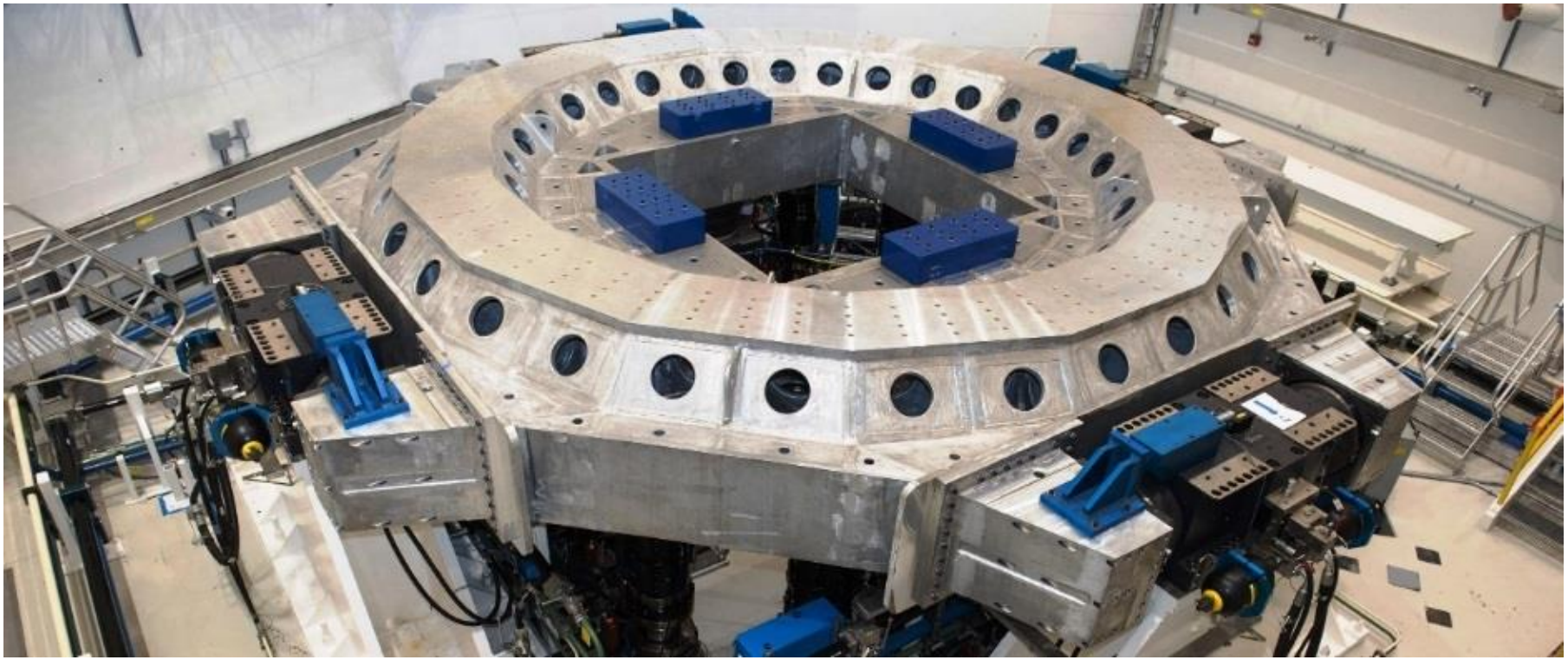
**Measurements Channels to MVF**

- 800 - IEPE Accel. conditioners
- 40 - IEPE/Charge conditioners
- 184 - 4-arm Strain gauges

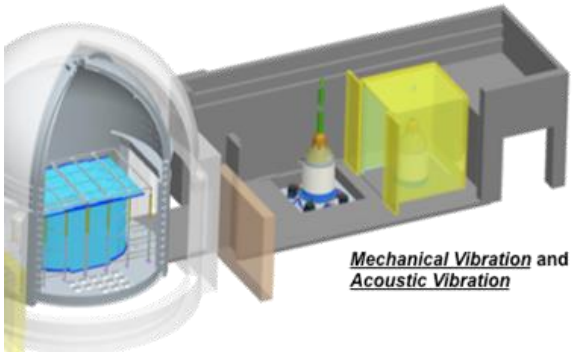
# Space Power Facility – Vibration Facility

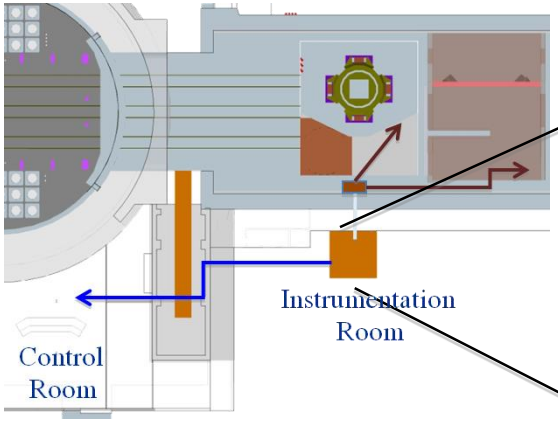
## SPF - Mechanical Vibration Facility (MVF)

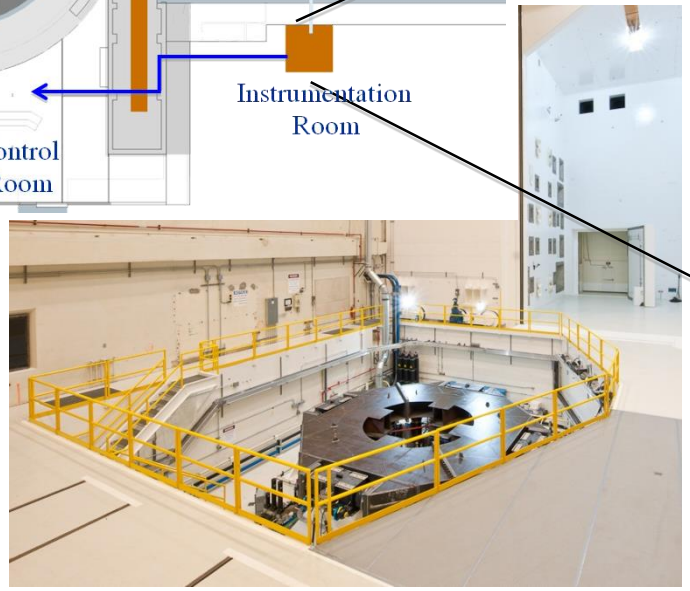
- 3-axis servo-hydraulic shaker
- Ring design for Orion ~18ft dia. → Flat table option via "ring head expander"
- Sized for 75,000 lb test articles reduced test article max weight to ~50,000 lbs



# SPF - FDAS - Instrument (Data) Room



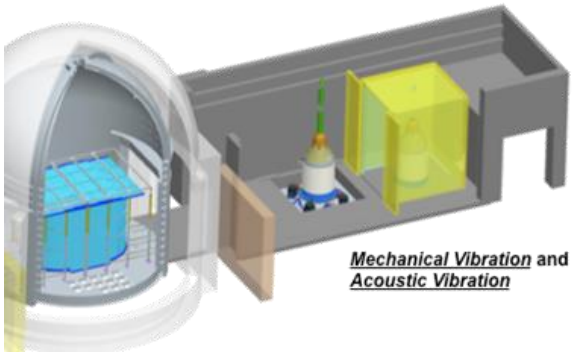



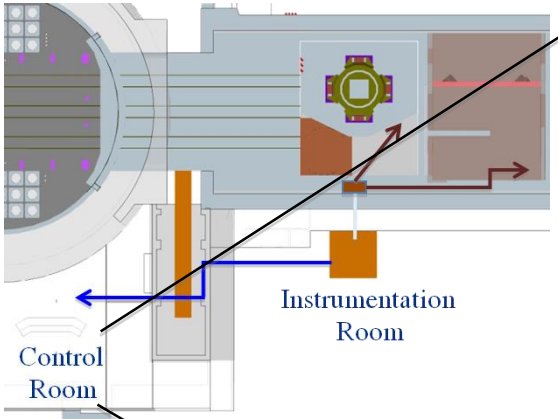
The 1,024 (1,536) Measurement Channels of the HSDAS can be “switched” between the three test locations within a 24 hours period at the “Interface Panel” in the VTC High-bay.

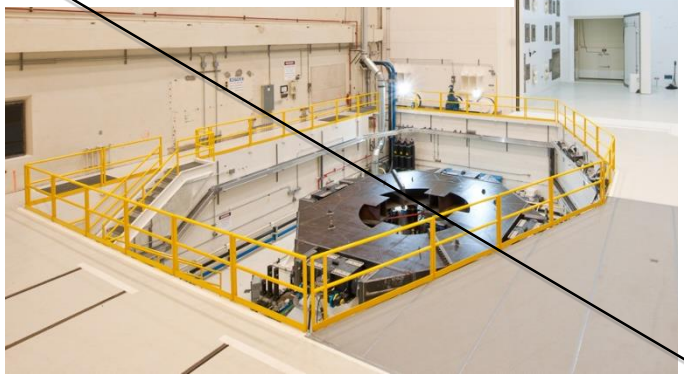

From the Interface Panel in the VTC High-Bay area, all 1,024 (1,536) Channels are routed through the wall and into the HSDAS Instrument Room. The Instrument Room houses all of the Signal Conditioning and Digitizing Hardware

# SPF - FDAS – Integrated Control Room




The 1,024 (1,536) Measurement Channels of the HSDAS can be “switched” between the three test locations within a 24 hours period at the “Interface Panel” in the VTC High-bay.



# SPF Vibroacoustic FDAS – Summary

Designed for Large-Scale Environment Testing

| Instrument Cabling to the MVF table and RATF chambers | | Num. of Channels |
|---|---|---|
| 1 | Single Pair, Twisted-Pair Shielded | >1,700 Ch. TPS |
| 2 | Impedance Matched Coaxial to/from ACS | 64 Ch. |
| 3 | Impedance Matched Coaxial to/from VCS | 64 Ch. |
| | | |
| **Signal Conditioning Equipment** | | |
| 4 | ICP/IEPE Conditioners | 800 Ch. |
| 5 | Constant-Voltage Bridge Conditioners | 160 Ch. |
| 6 | Direct Voltage Inputs from ACS/VCS | 64 Ch. |
| 7 | Buffered Voltage Outputs to ACS/VCS | 64 Ch. |
| | | |
| **Digitizing Equipment (ADCs)** | | |
| 8 | High-Speed Digitizers (20 kHz MBW/50 kHz SR) | 1024 Ch. |
| | | |
| **Data Storage** | | |
| 9 | RAID 1+0 redundant fail-over storage | 3 Terabytes total |
| | | |
| **Control, Monitoring and Post-Processing** | | |
| 10 | Dedicated Control Computers | 1 |
| 11 | Dedicated Monitoring Computers | 3 |
| 12 | Dedicated Post-Processing Computer | 1 |
| | | |
| **Other Notable System Elements** | | |
| 13 | IRIG-B Distribution | All |
| 14 | LTO-3 Tape Archive | All |

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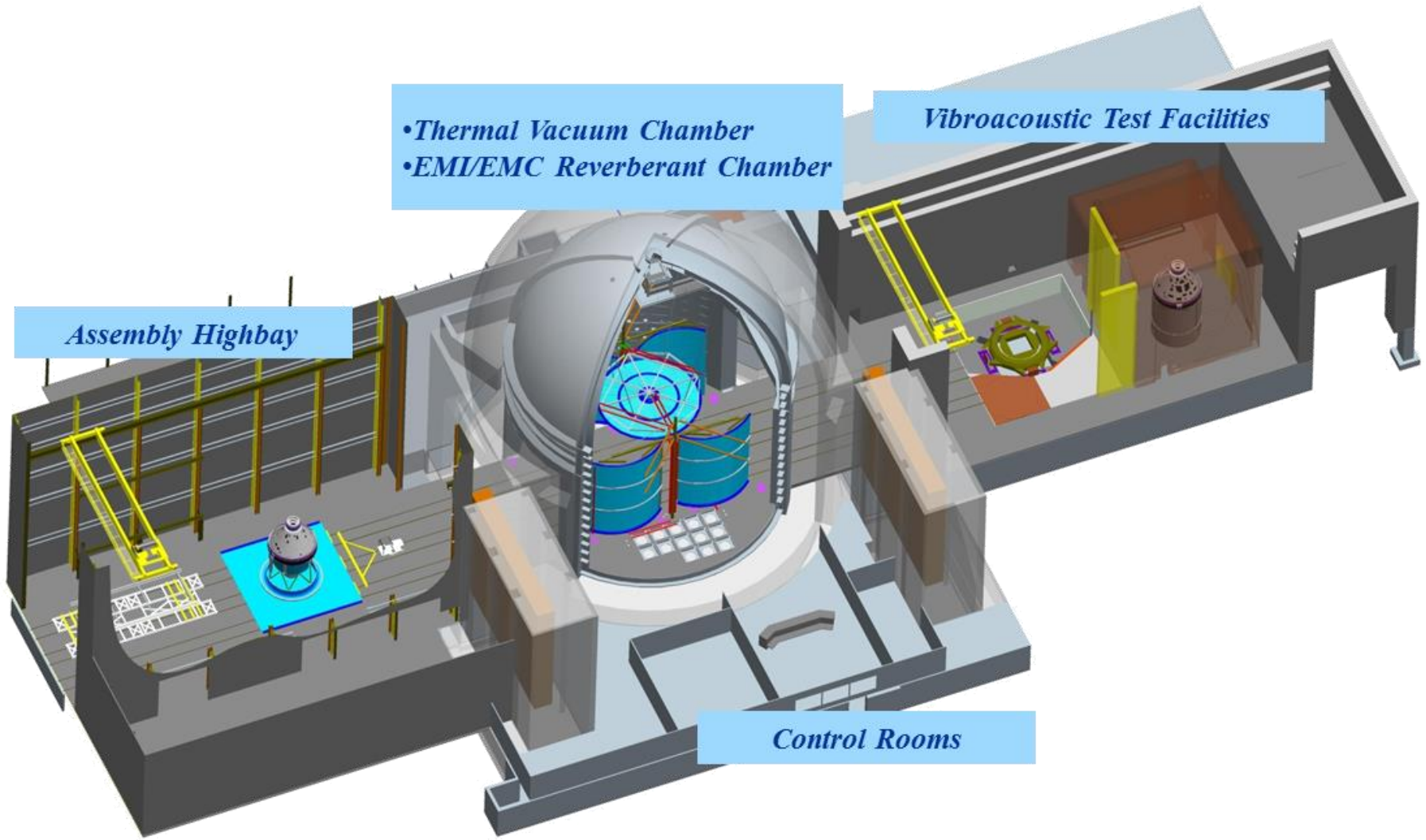
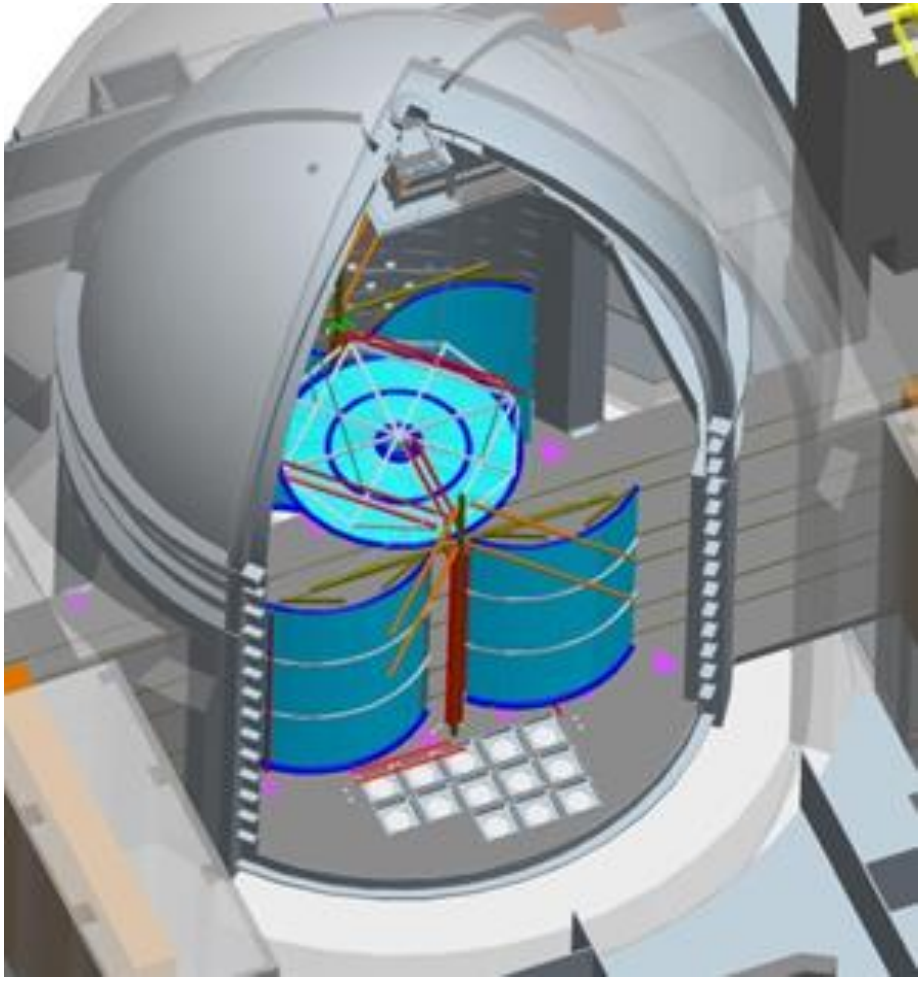
  - B-2 Facility DAS
  - SPF Vibroacoustic Facilities DAS
  - SPF Thermal-Vacuum Chamber DAS

**Designed for Large-Scale Environment Testing**

# Space Power Facility (SPF)



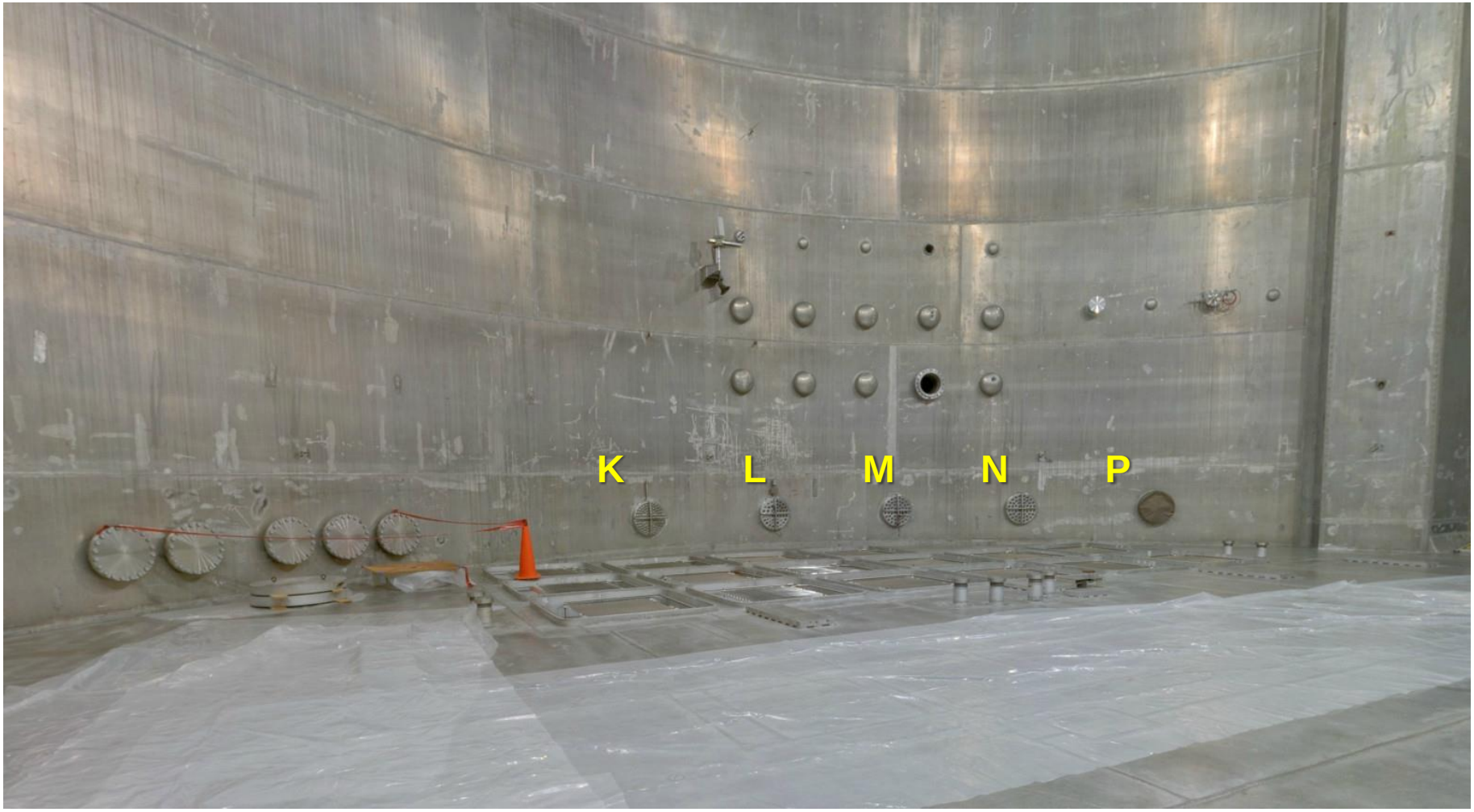
# SPF Thermal-Vacuum – Chamber Description



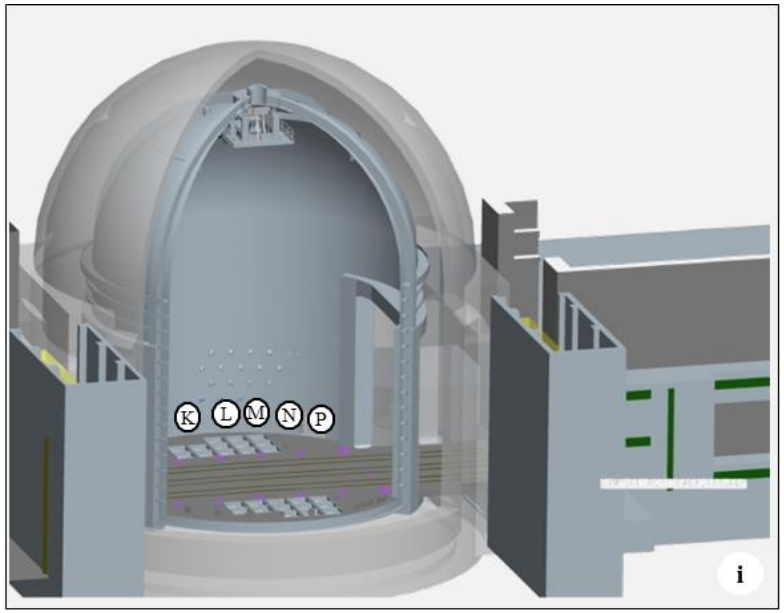

**Thermal-Vacuum Tests Require "Low-Speed" DAS**

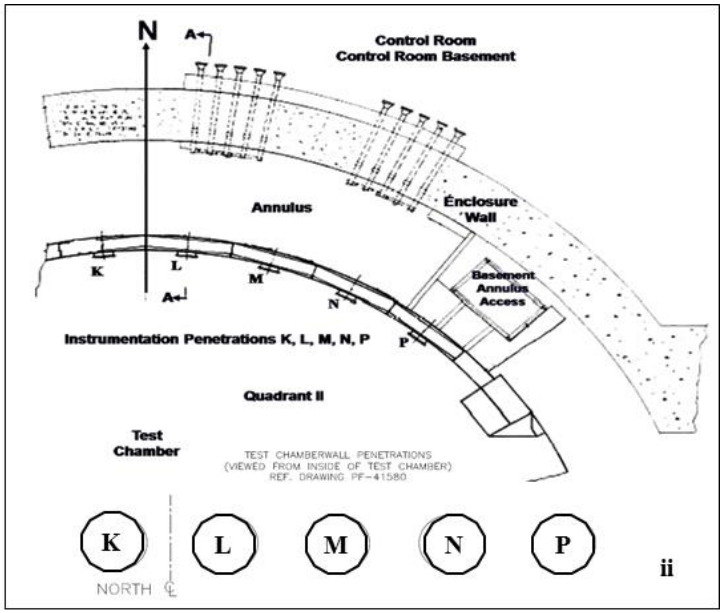
**Altitude Performance Tests Require "High-Speed" DAS**

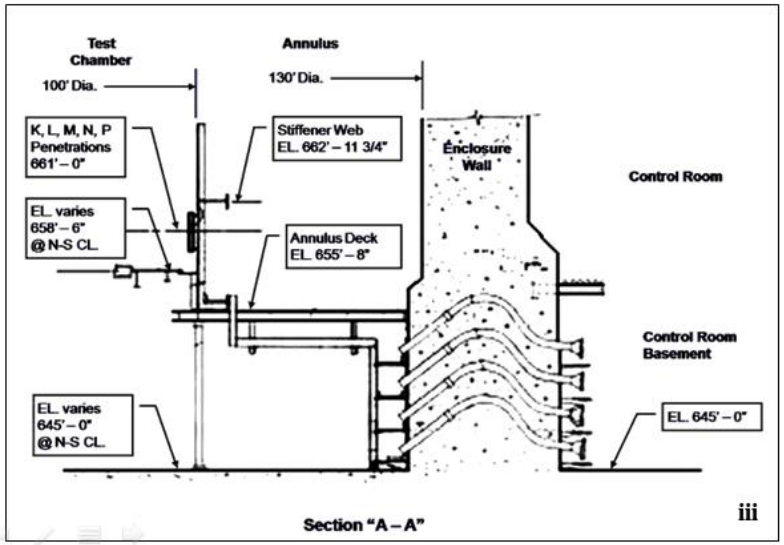
# SPF Thermal-Vacuum – Chamber Connections

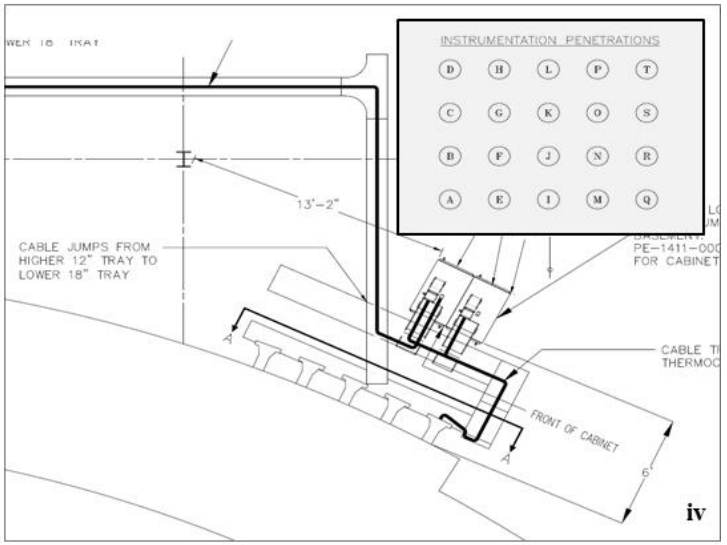


# SPF Thermal-Vacuum – Annulus Feedthroughs



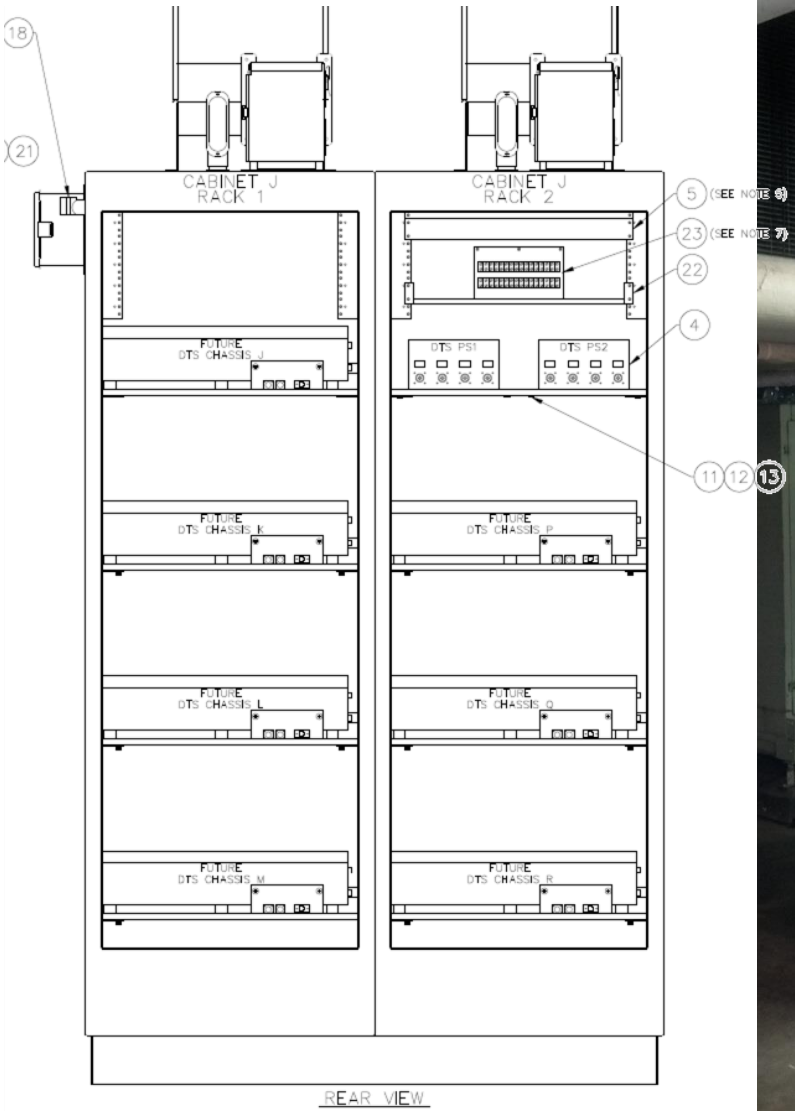



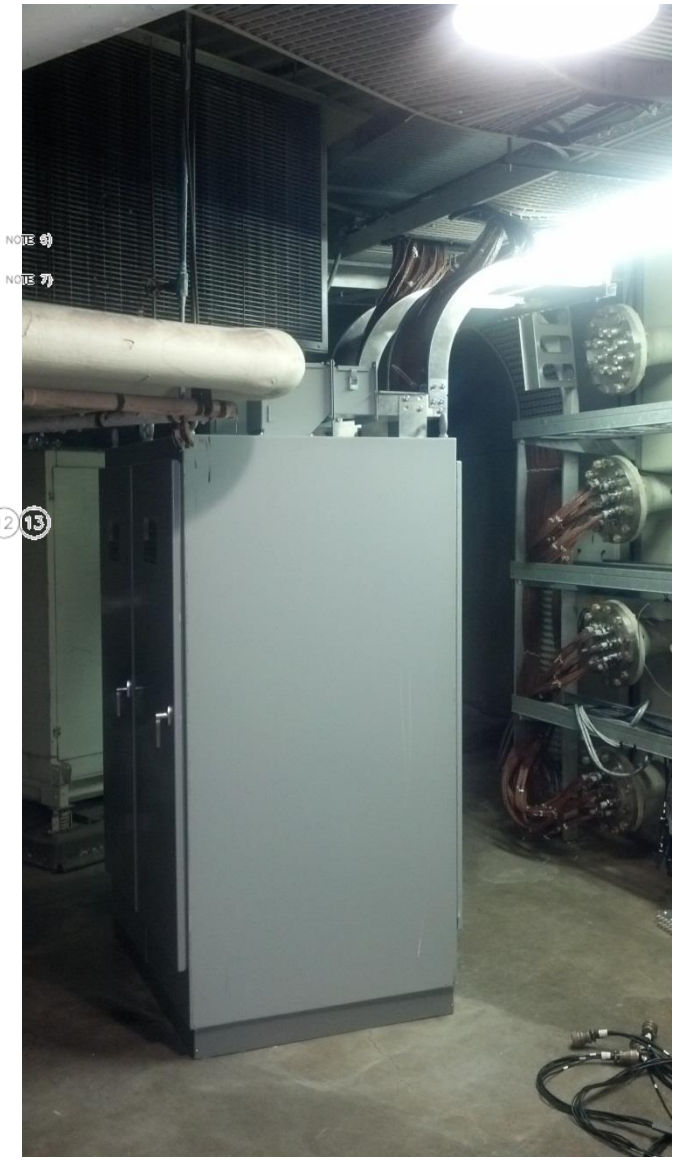



# SPF Thermal-Vacuum – Outside Connections

# SPF Thermal-Vacuum – Outside Connections

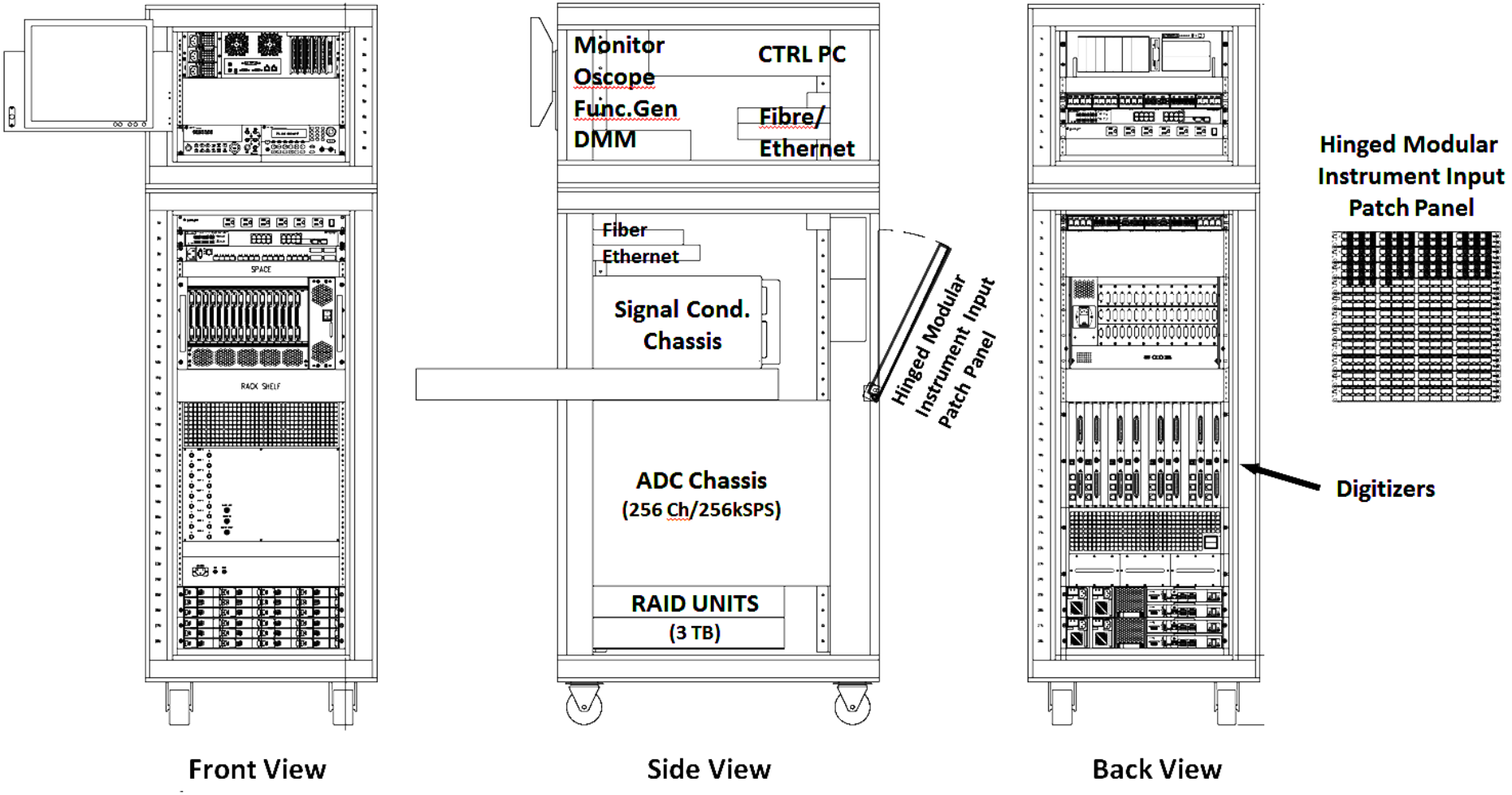
# SPF Thermal-Vacuum Temperature DAS Racks



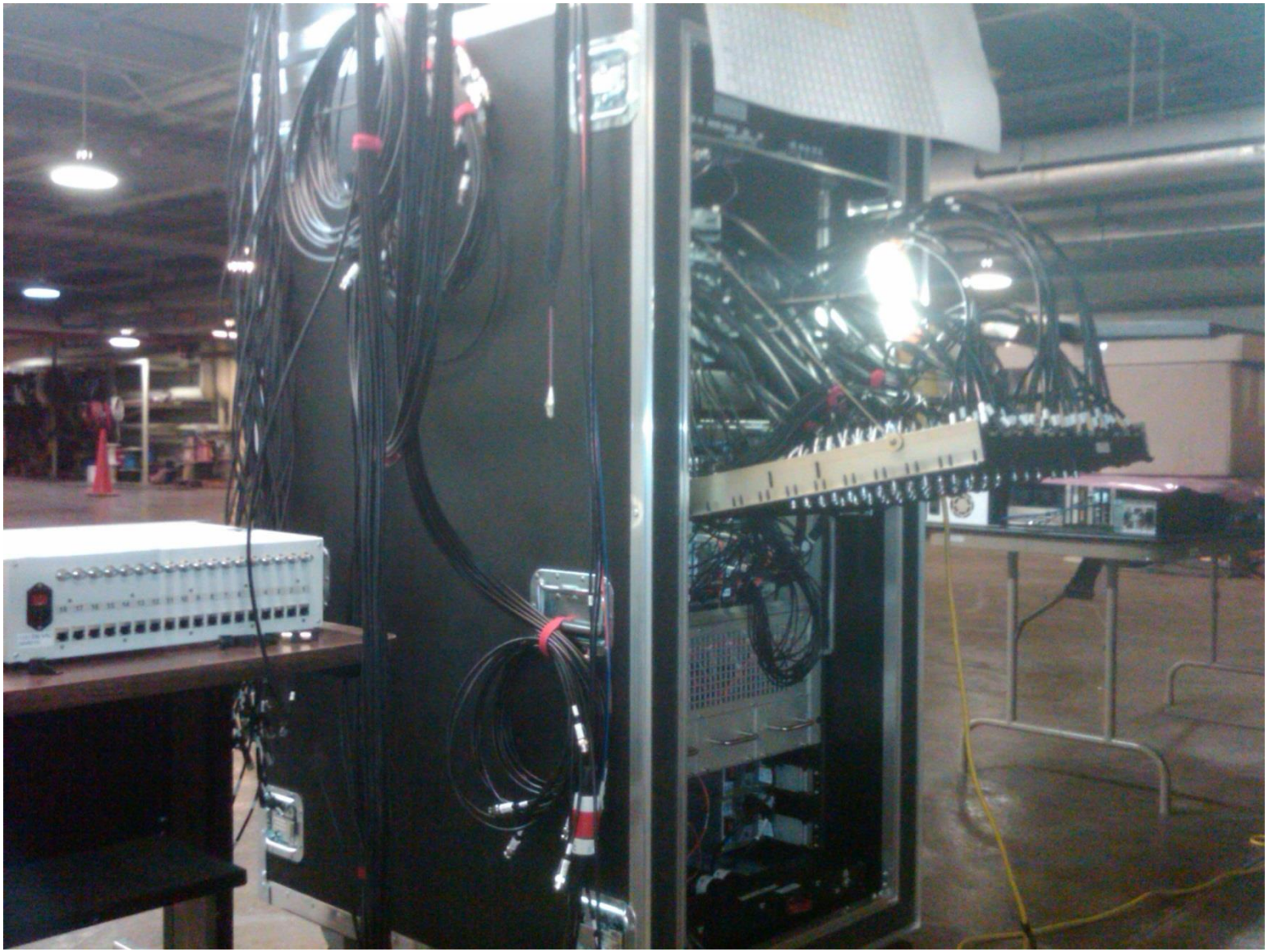
# SPF Thermal-Vacuum – Mobile DAS Layout

## (High-Speed/Dynamic, 256 Channels, 256 kSPS)

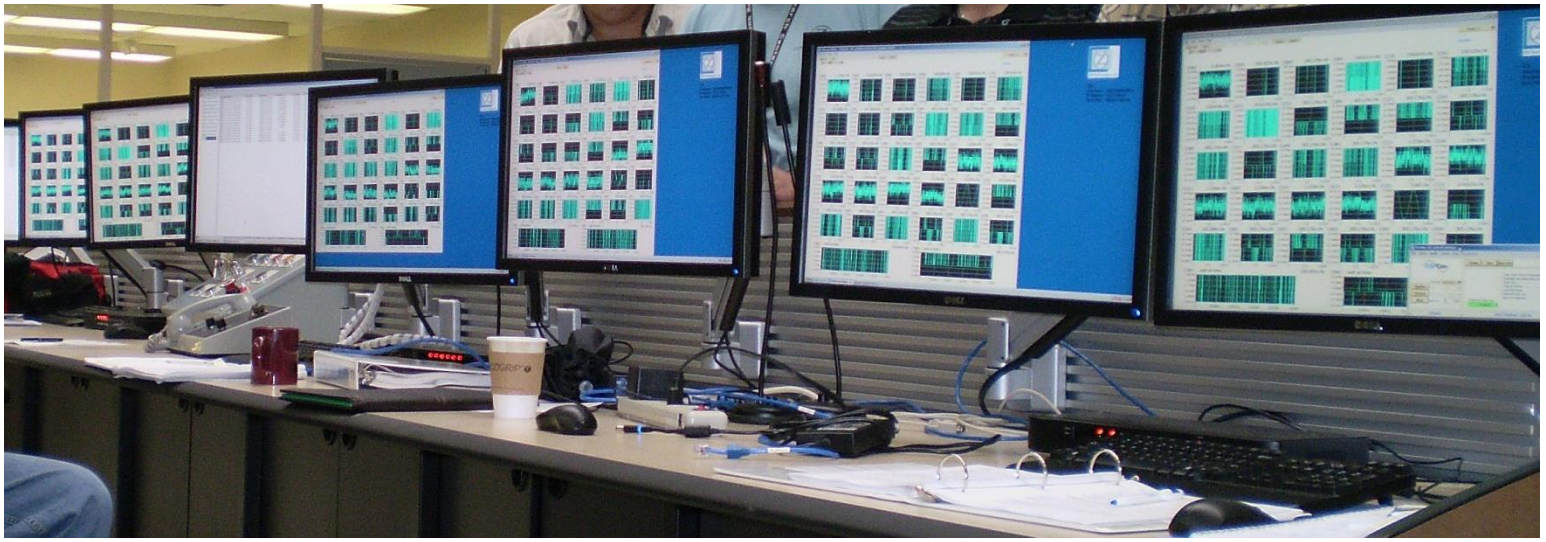


# SPF Thermal-Vacuum MDAS – Front View

# SPF Thermal-Vacuum MDAS – Rear View



# SPF Thermal-Vacuum MDAS – Control



# SPF Thermal-Vacuum MDAS – Summary

Designed for Large-Scale Environment Testing


| Instrument Cabling in the Vacuum Chamber Annulus | | Num. of Channels |
|---|---|---|
| 1 | Single Pair, Twisted-Pair Shielded | 324 Ch. 1PR TPS |
| 2 | Four-Wire, Twisted-Pair Shielded | 288 Ch. 4C/Ch. |
| 3 | Impedance Matched Coaxial | 126 Ch. BNC |
| 4 | Type-T Thermocouple Instrumentation Wire | 512 Ch. - 1,280 Ch. |
| | | |
| **Signal Conditioning Equipment** | | |
| 5 | ICP/IEPE Conditioners | 64 Ch. * |
| 6 | Constant-Voltage Bridge Conditioners | 48 Ch. † |
| 7 | Charge-Type Conditioners | 24 Ch. † |
| 8 | Direct Voltage Inputs | 120 Ch. |
| 9 | Buffered Voltage Follower Outputs | As needed† |
| 10 | Thermocouple Signal Conditioning | |
| | | |
| **Digitizing Equipment (ADCs)** | | |
| 11 | High-Speed Digitizers (100 kHz MBW/256 kHz SR) | 256 Ch.* |
| 11a | Low-Speed Digitizers/Data-Translators (10Hz SR) | 512 Ch. - 1,280 Ch. |
| **Data Storage** | | |
| 12 | RAID 1+0 redundant fail-over storage | 3 Terabytes total |
| | | |
| **Control, Monitoring and Post-Processing** | | |
| 13 | Dedicated Control Computers | 1 |
| 14 | Dedicated Monitoring Computers | 4* |
| 15 | Dedicated Post-Processing Computer | 1* |
| | | |
| **Other Notable System Elements** | | |
| 16 | IRIG-B Distribution | All |
| 17 | LTO-3 Tape Archive | All* |


***Thank you.***

# *Backup Charts*

# DAS - Signal Conditioning

A Modular, COTS, Fully Remote-Controllable Signal Conditioning Platform has been selected. This system supports all major transducer types and provides unprecedented remote control and monitoring capabilities.

**Current Signal Conditioning System:**

- Multiple "Card-Cage" Chassis for Signal Conditioning
  ("n" crates x 16 cards/crate @ 4, 8, and 16 Ch/Card = 512 – 1,536 Channels)

# DAS - Signal Conditioning

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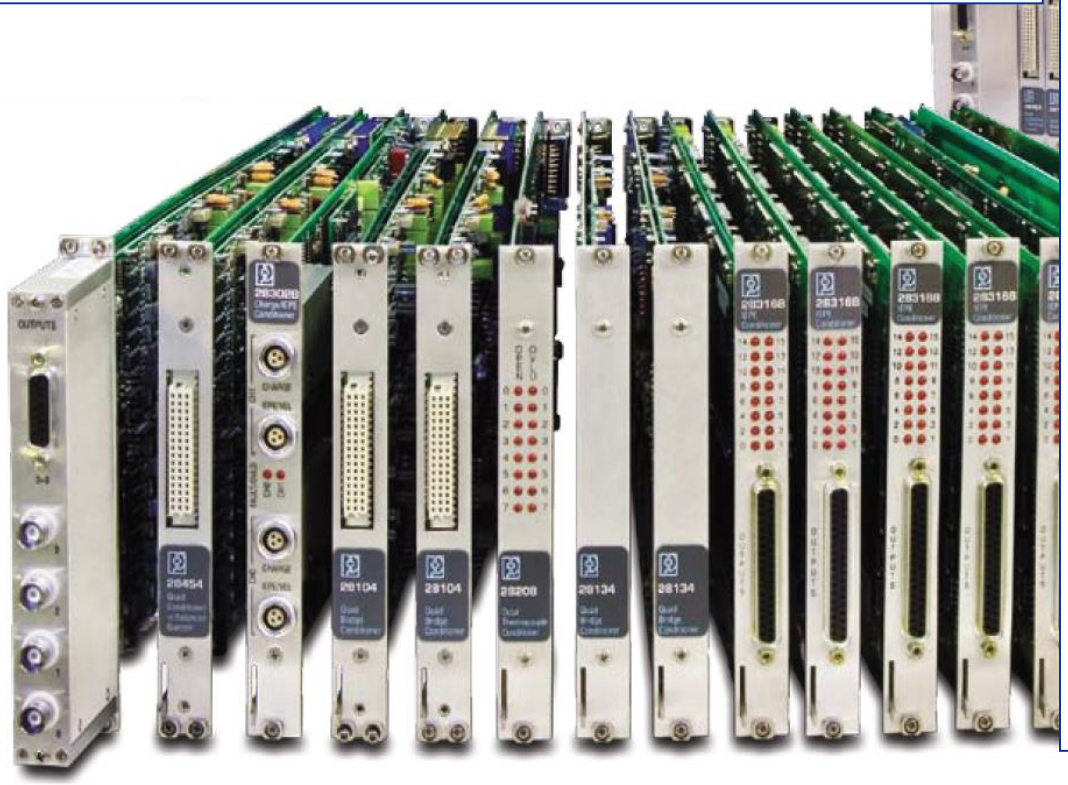
**Current Signal Conditioning System:**

- Multiple "Card-Cage" Chassis for Signal Conditioning
  ("n" crates x 16 cards/crate @ 4, 8, and 16 Ch/Card = 512 – 1,536 Channels)



**Current Signal Conditioning System supports the following measurement types:**

- Voltage Bridge Conditioners
  (42 cards @ 4 ch/card = 168 channels)
- Constant Current Conditioners
  (12 cards @ 4 ch/card = 48 channels )
- Voltage Amplifier/Filter
  (25 cards @ 8 ch/card = 200 channels)
- IEPE/ICP Accels/Microphones
  (50 cards @ 16 ch/card = 800 channels)
- Charge/Voltage Accelerometers
  ( 6 cards @ 4 ch/card = 24 channels )
- Frequency to Voltage Converters
  ( 8 cards @ 4 ch/card = 32 channels )

# DAS – ADCs (Digitizers)

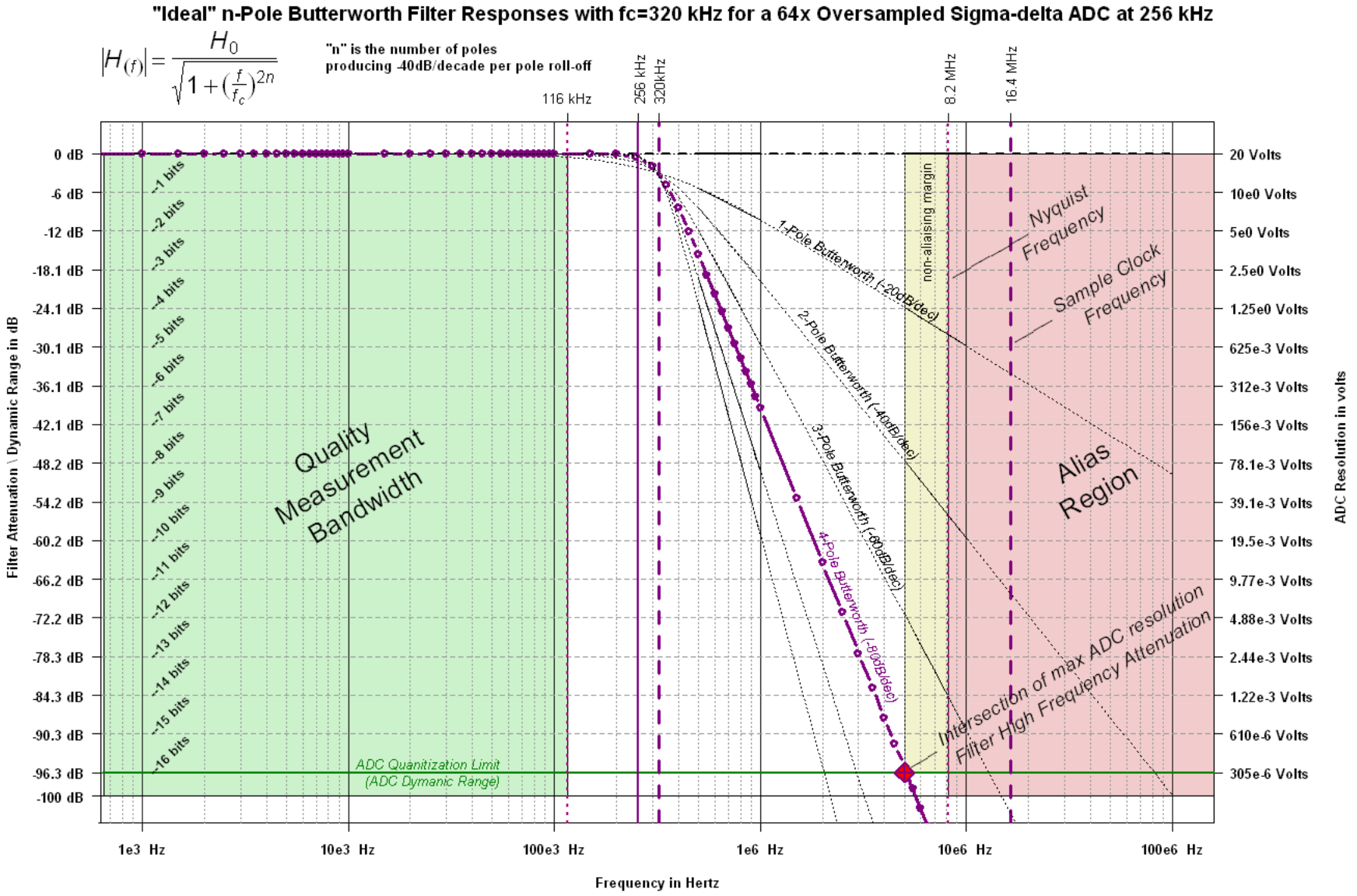
## VME-based Digitizer Modules ("Bricks")

High-Speed and Low-Speed ADCs

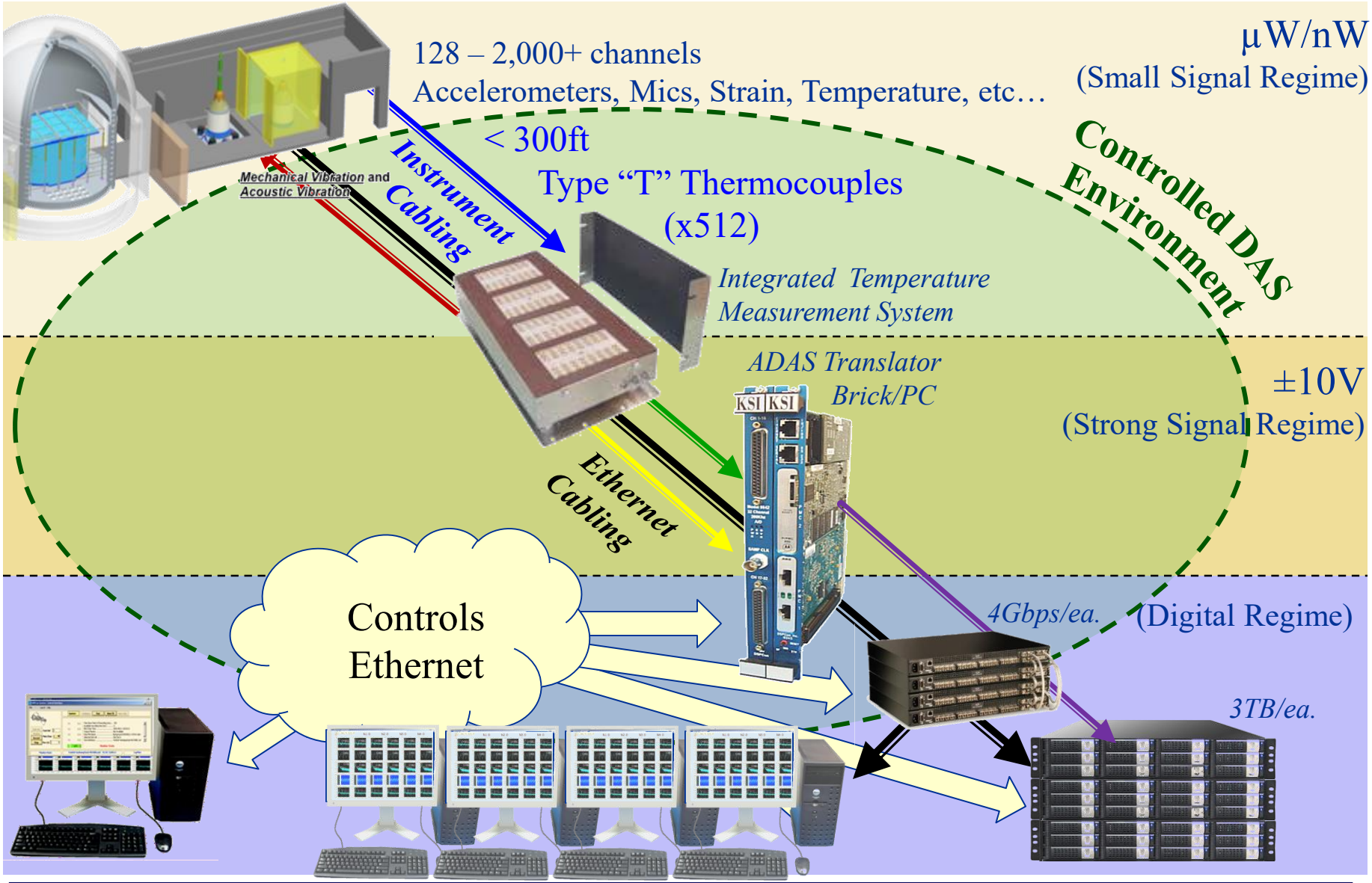
6 x Low-Speed Bricks
32 x High-Speed Bricks and
1 x Discrete Inputs Brick


- Low-Speed Bricks → 96 Channels/Board
- High-Speed Brick (and Discrete) → 32 Channels/Board
- 6 Low-Speed Bricks → 576 channels @ 100 Hz-5kHz SR
- 32 High-Speed Bricks → 1,024 channels @ 5kHz - 256 kHz SR
- 1 Discrete Brick → 32 channels @ 5kHz - 256 kHz SR
- Auxiliary Data Translator for accepting external data sources.
- Simultaneous sampling on all channels
- 16-bit resolution with ~90 dB signal-to-noise
- Integrated linear-phase, anti-alias filters (>100dB Alias rejection)
- Differential inputs (+/- 10V)
- Programmable gains of 1, 10, 100 & 1,000
- On-board DSP and FPGA

# Signal Digitization, Alias Rejection

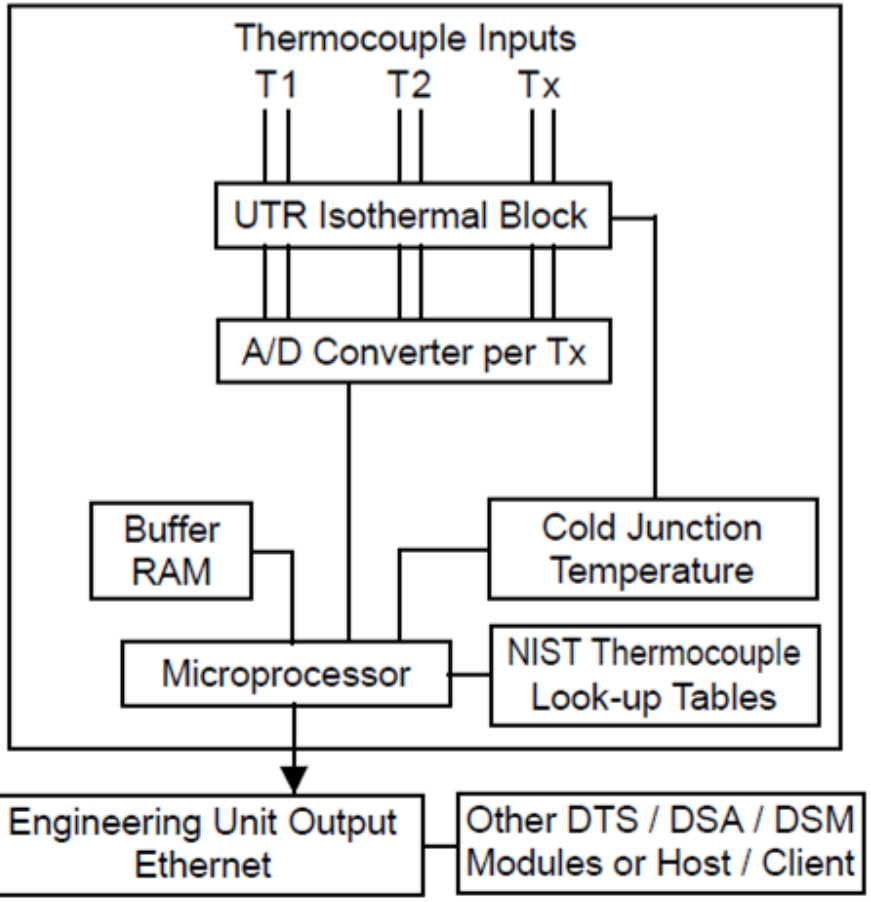


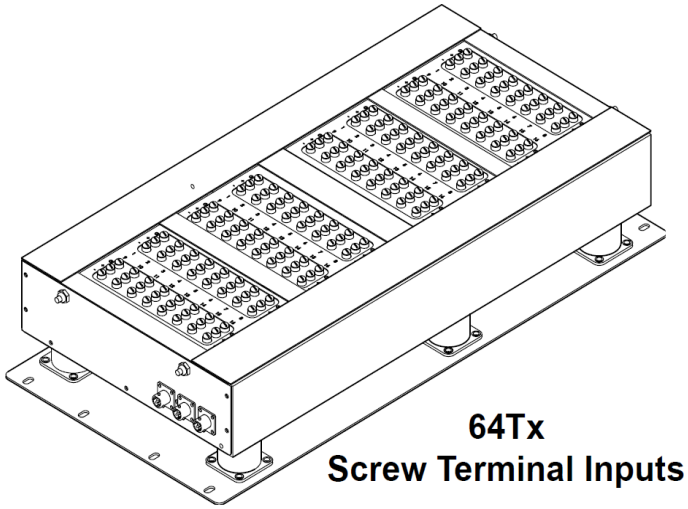
# Modular Distributed Measurement Topology



# SPF Thermal-Vacuum – Temperature Data

## (Low-Speed, 512 Channels)



**64Tx**
**Screw Terminal Inputs**

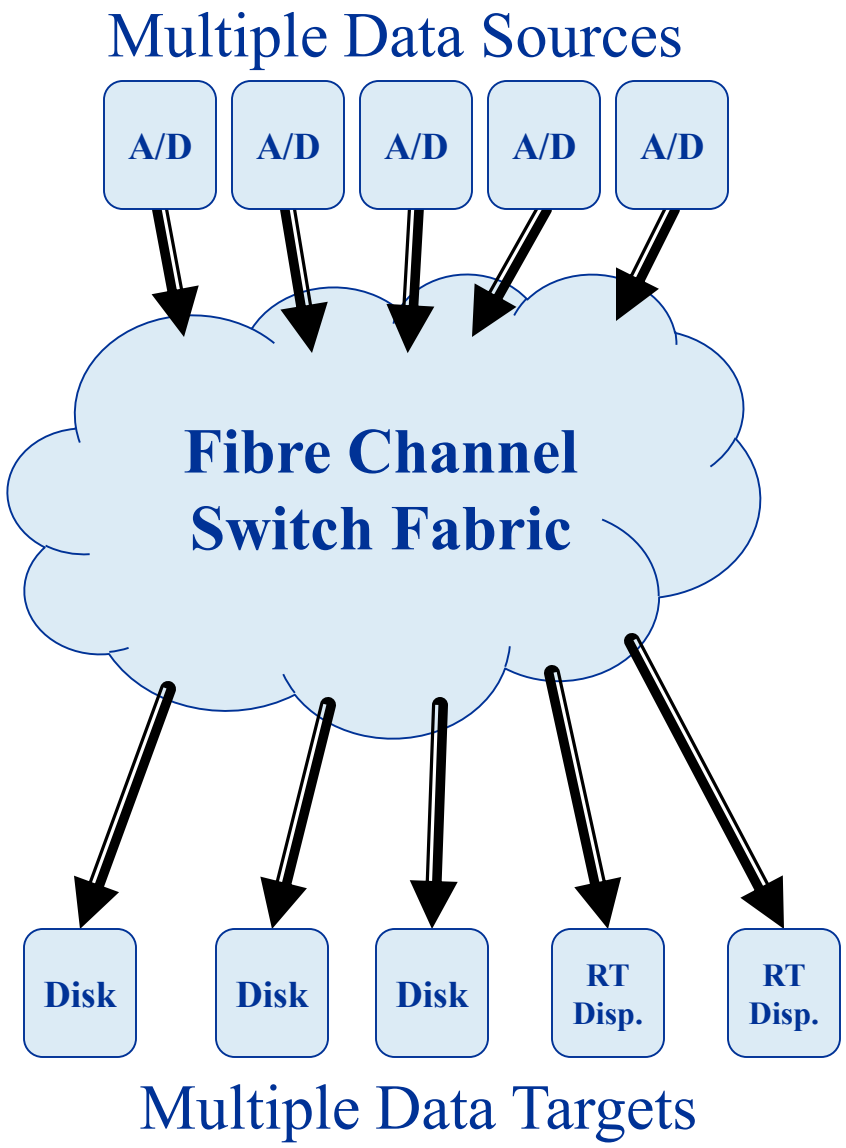
### Features

- Accepts type E, J, K, N, R, S, T, and B
- Engineering Unit output, °C, °F, °R, or K
- Ethernet TCP/IP protocol "network ready"
- 10 samples/channel/second
- 50 - 60 Hz noise rejection
- Open thermocouple test
- 1000 Vdc input isolation
- LabView® driver and OPC server
- 16, 32, and 64 channel

# DAS - Data Transport using an FC-Switch Fabric

## Benefits of a Fibre-Channel Switch Fabric

- Performance to over 4 Gbits/second.
- Delivers sustained Transfer Bandwidth of ≈ 97 Mbytes/Sec for file transfers.
- Support for long distances up to 10 Km.
- Support for multiple simultaneous protocols.
- Allows for shared storage.
- Provides a scalable network.
- Robust data integrity and reliability
- Fast data access and backup.

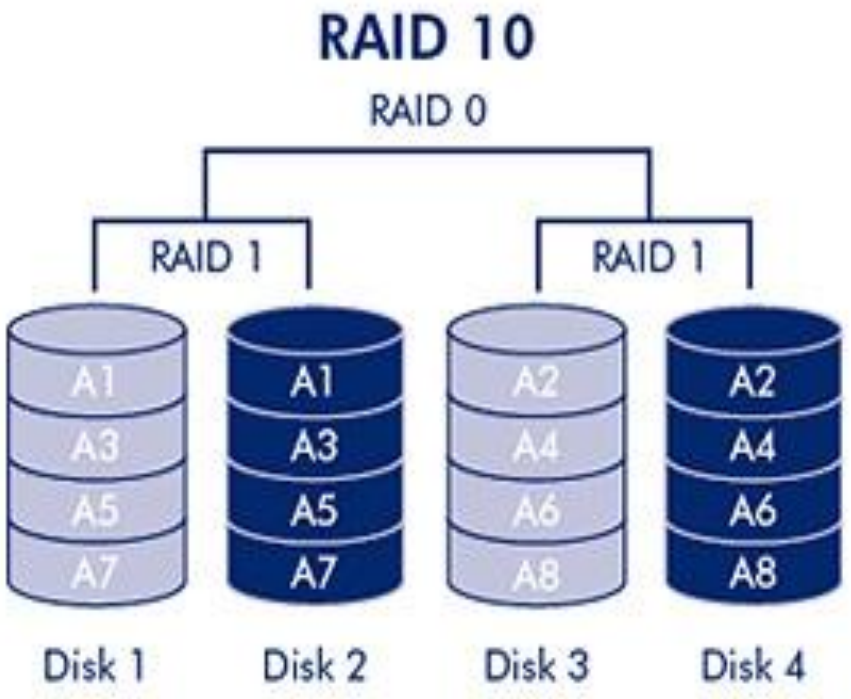


# DAS - Data Storage

## > 3TB of RAID 1+0 are provided for the Data System to record to

Total Storage Size =
{Aggregate Data Rate}
× {required test duration}

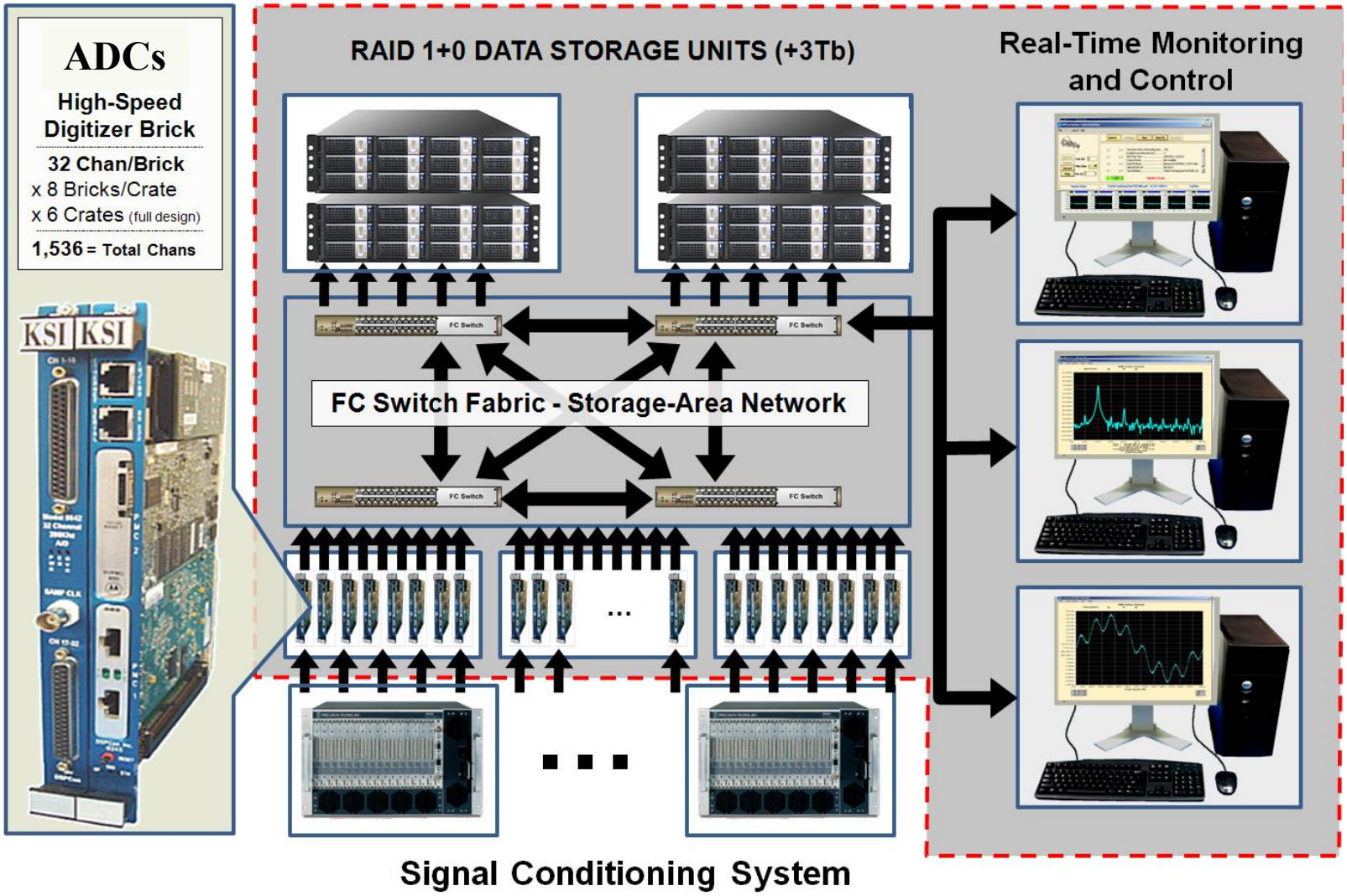
> 3 Terabytes ≈
{153.6 Mbytes/sec}
× {8 hours × 3,600 seconds/hour}




RAID 1+0 provides the best combination of data-recording bandwidth and disk-failure protection.

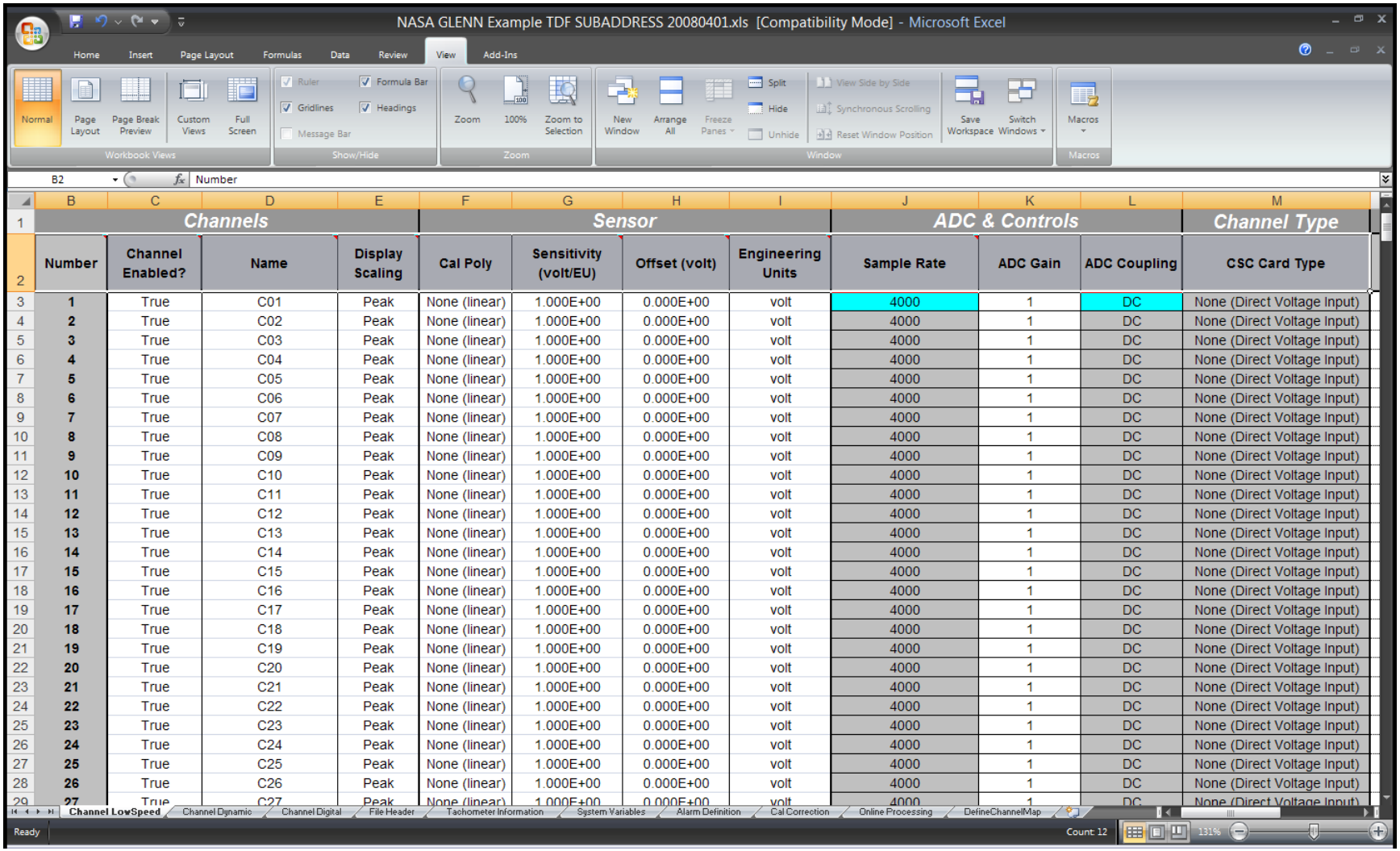
# Integrated FC-SAN for Distributed Scalability

## The completed system forms a Fibre-Channel Storage Area Network



# DAS - Control and Real-Time Display

## System Configuration is done using a MS-Excel Spreadsheet

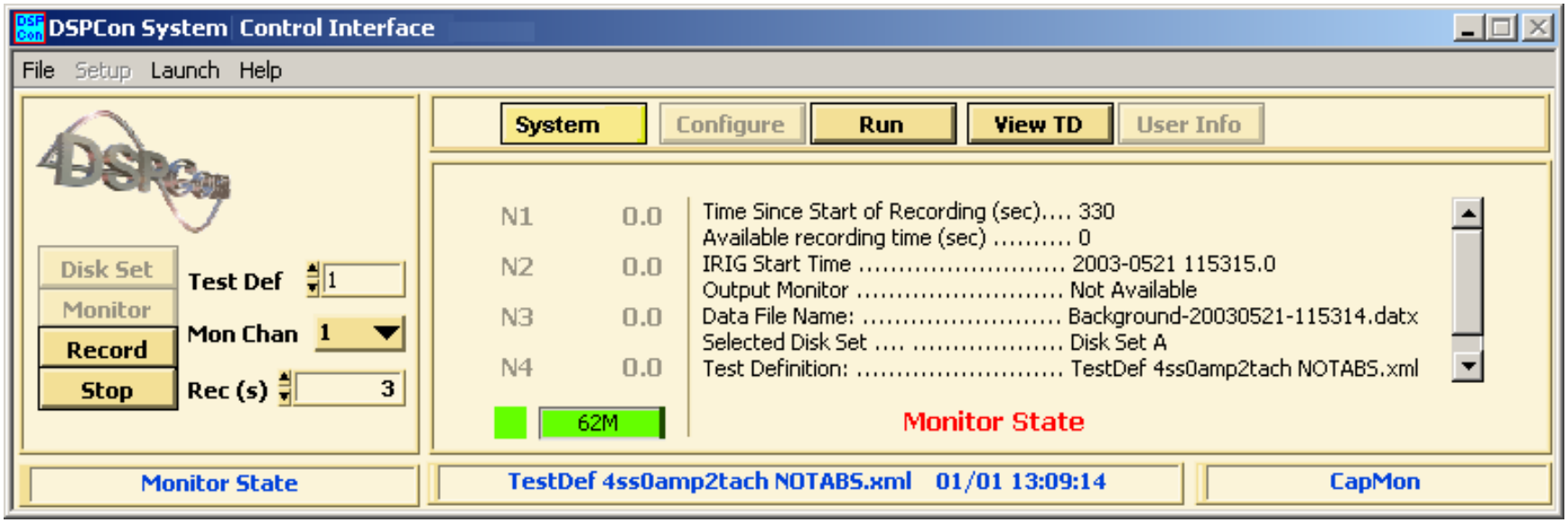


NASA GLENN Example TDF SUBADDRESS 20080401.xls [Compatibility Mode] - Microsoft Excel

| | Channels | | | | Sensor | | | | ADC & Controls | | | Channel Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Channel Enabled? | Name | Display Scaling | Cal Poly | Sensitivity (volt/EU) | Offset (volt) | Engineering Units | Sample Rate | ADC Gain | ADC Coupling | CSC Card Type |
| 3 | 1 | True | C01 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 4 | 2 | True | C02 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 5 | 3 | True | C03 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 6 | 4 | True | C04 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 7 | 5 | True | C05 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 8 | 6 | True | C06 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 9 | 7 | True | C07 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 10 | 8 | True | C08 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 11 | 9 | True | C09 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 12 | 10 | True | C10 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 13 | 11 | True | C11 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 14 | 12 | True | C12 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 15 | 13 | True | C13 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 16 | 14 | True | C14 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 17 | 15 | True | C15 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 18 | 16 | True | C16 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 19 | 17 | True | C17 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 20 | 18 | True | C18 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 21 | 19 | True | C19 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 22 | 20 | True | C20 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 23 | 21 | True | C21 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 24 | 22 | True | C22 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 25 | 23 | True | C23 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 26 | 24 | True | C24 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 27 | 25 | True | C25 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 28 | 26 | True | C26 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |
| 29 | 27 | True | C27 | Peak | None (linear) | 1.000E+00 | 0.000E+00 | volt | 4000 | 1 | DC | None (Direct Voltage Input) |

# DAS - Control and Real-Time Display

## System Operation is accomplished using a simple GUI Interface




## Other Features:

- ✓ Monitor Disk Usage
- ✓ Monitor System Health (Watchdog)
- ✓ Monitor Mode – Ability to Monitor without Acquiring until triggered (Monitor Mode will capture data prior to the event once triggered)

# DAS - Control and Real-Time Display

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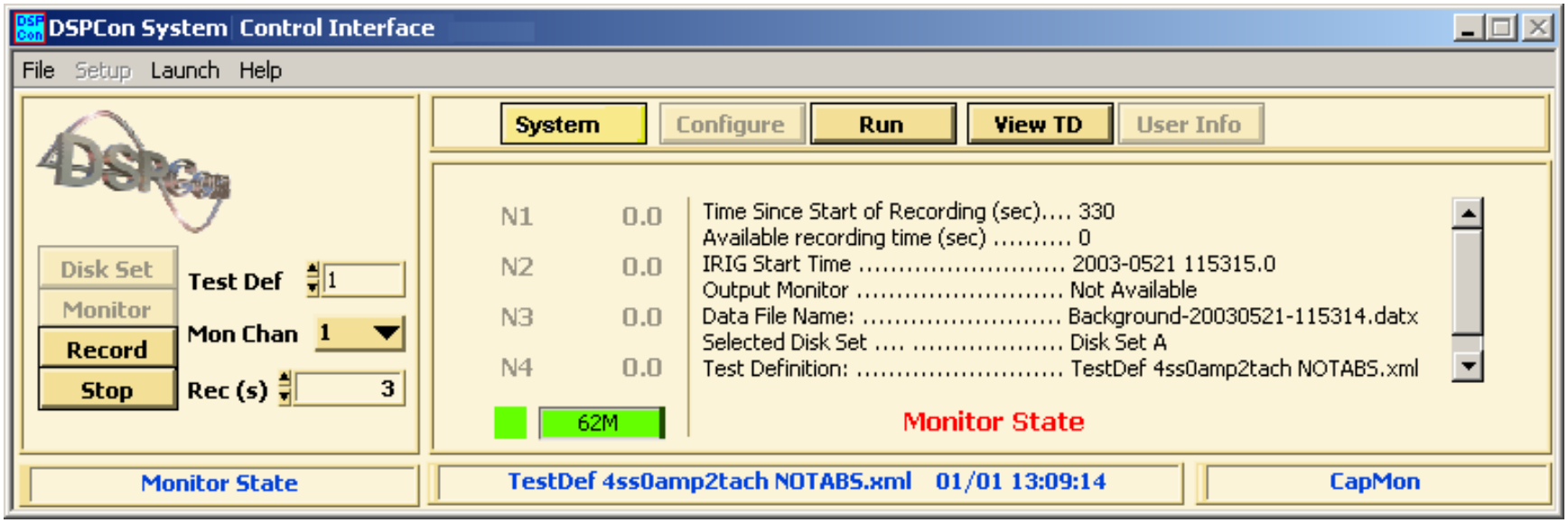


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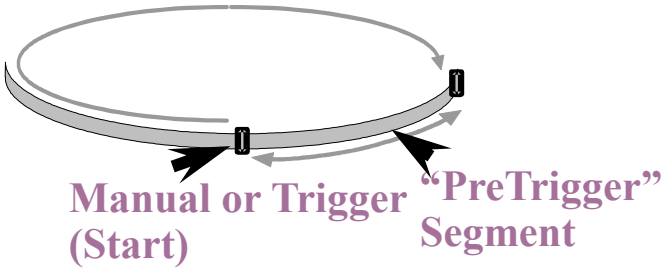
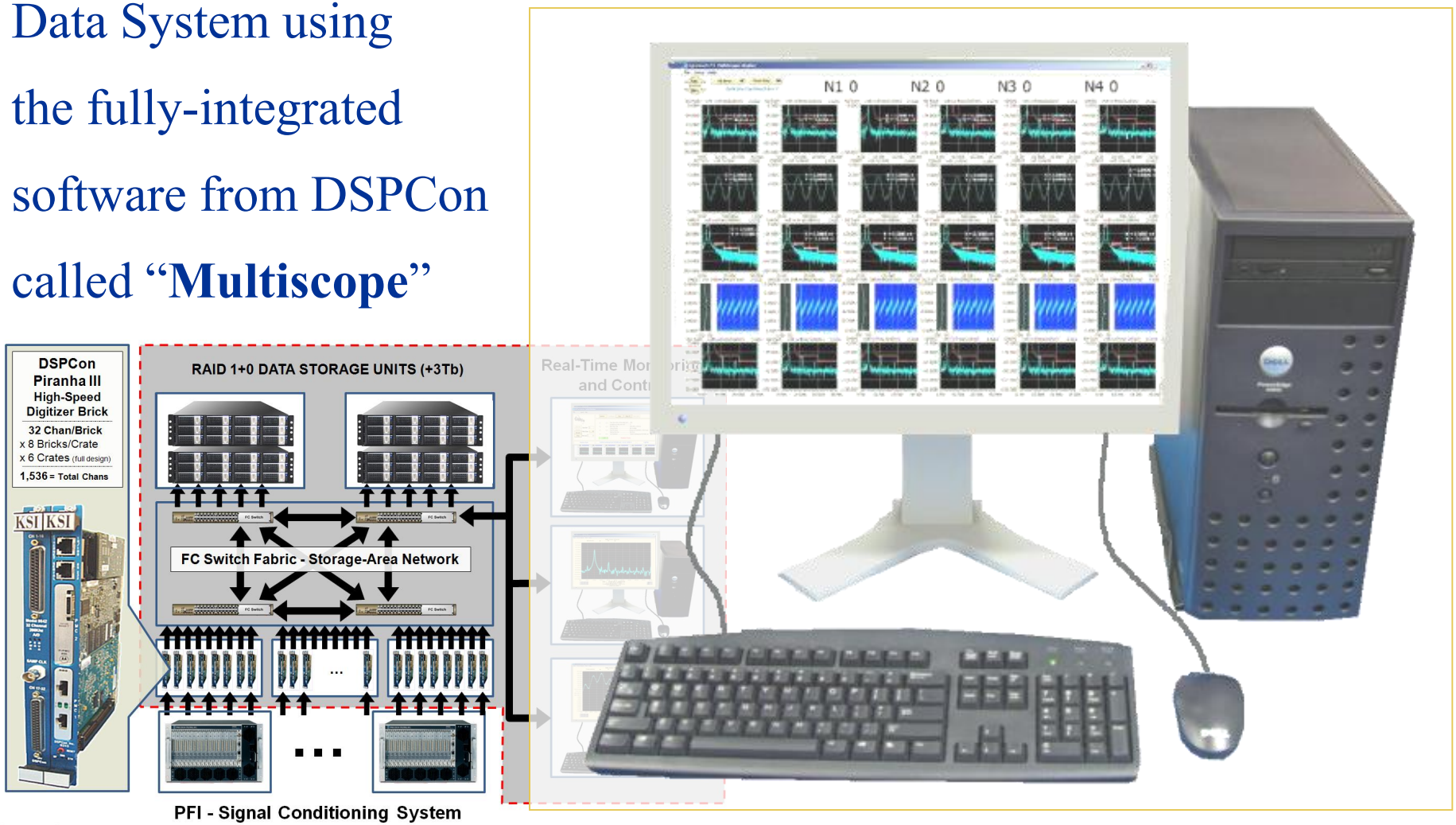



- ✓ Monitor Mode – Ability to Monitor without Acquiring until triggered (Monitor Mode can capture data prior to the event once triggered)

# DAS - Control and Real-Time Display

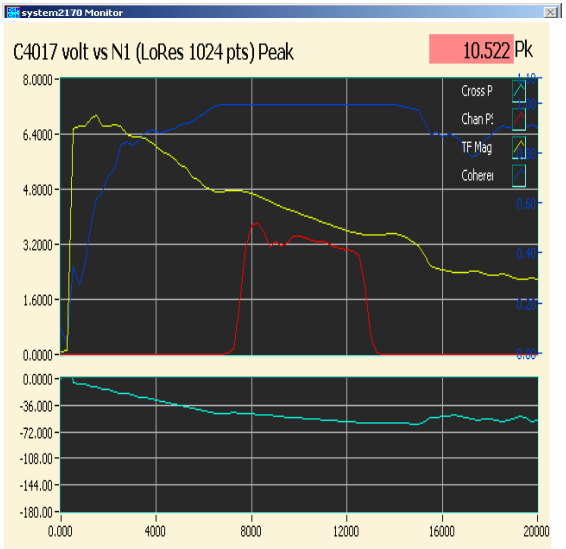
(Pseudo) Real-Time (< 1 sec.) Data Display is provided by the Data System using the fully-integrated software from DSPCon called "**Multiscope**"



# DAS - Control and Real-Time Display

## Real-Time Display Types

- ✓ Time Plots
- ✓ Frequency (FFT)
- ✓ N$^{th}$ Octave Plots
- ✓ Signal Transfer Functions
- ✓ many others…

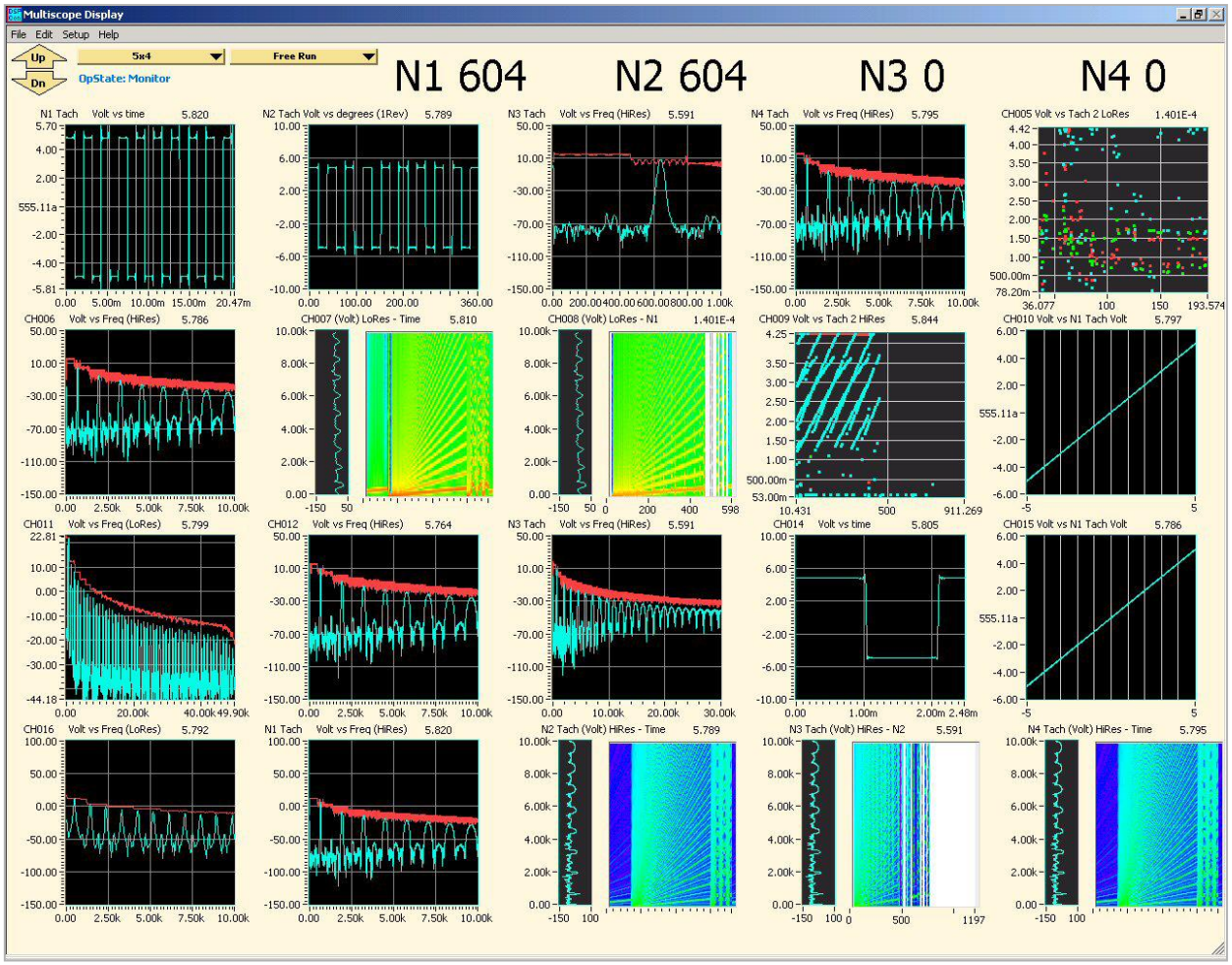



| Plot Types | Description |
|---|---|
| Time Plots | Amplitude Versus Time |
| Spectral Plots | Amplitude Versus Frequency (Low and High Resolution) |
| Nth Octave Plots | Amplitude versus Log Frequency |
| Track Order Plots | Track order plots display spectral responses with a fixed or variable bandwidth that are harmonic orders of shaft speed.<br>Display RMS, minimum, or maximum spectral values. |
| ZMod Plots | ZMod plots show the user how spectral values change over time as shaft speed changes. |
| Lissajous | Lissajous shows the time domain correlation between two signals. The reference signal values are plotted on the x axis. The second signal is plotted on the y axis. |
| Bode Plots | Bode plots show the spectral amplitude and phase response at the shaft speed's fundamental harmonic. |
| 1 Revolution | 1 Revolution plots show the time response that spans a single shaft revolution (for rotating machinery applications). |
| Campbell | Display types:<br>1. Shaft speed - Campbell Shaft speed shows an icon that is proportional to spectral amplitude centered at the spectral frequency (y axis) and shaft speed (x axis).<br>2. Time – Campbell Time shows an icon that is proportional to spectral amplitude centered at the spectral frequency (y axis) and time (x axis).<br>3. Reference channel – Campbell Reference Channel shows an icon that is proportional to spectral amplitude centered at the spectral frequency (y axis) and rms value of the reference channel. |
| Strip Chart Plots | Strip chart (RMS, Min, Max) show an envelope of the channel response over time; updates are every 2048 samples. Strip Charts can be plotted to show the shaft speed over time; updates are every processed frame. |
| Waterfall Plots | Waterfall plots allow users to see how x and y values (representing frequency response) change as a function of time or shaft speed. |
| Transfer Function | This scope renders the transfer function, coherence, and/or cross spectral magnitude and phase response of a channel against a reference channel. |

# DAS - Control and Real-Time Display

## Real-Time Display Capabilities

- ✓ Time Plots
- ✓ Frequency (FFT)
- ✓ $N^{th}$ Octave Plots
- ✓ Signal Transfer Functions
- ✓ many others in many different combinations and arrangements
- ✓ and on multiple "Data Monitoring" PCs



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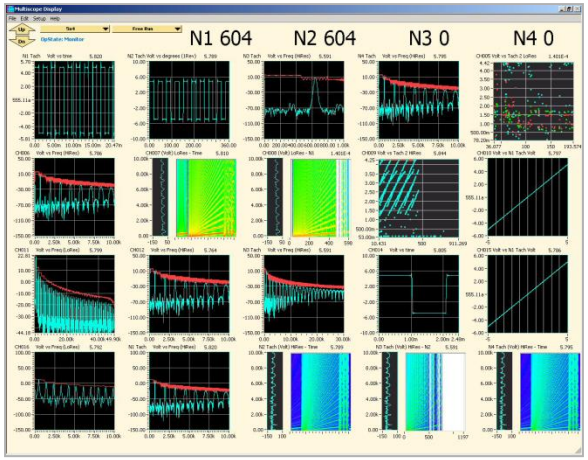
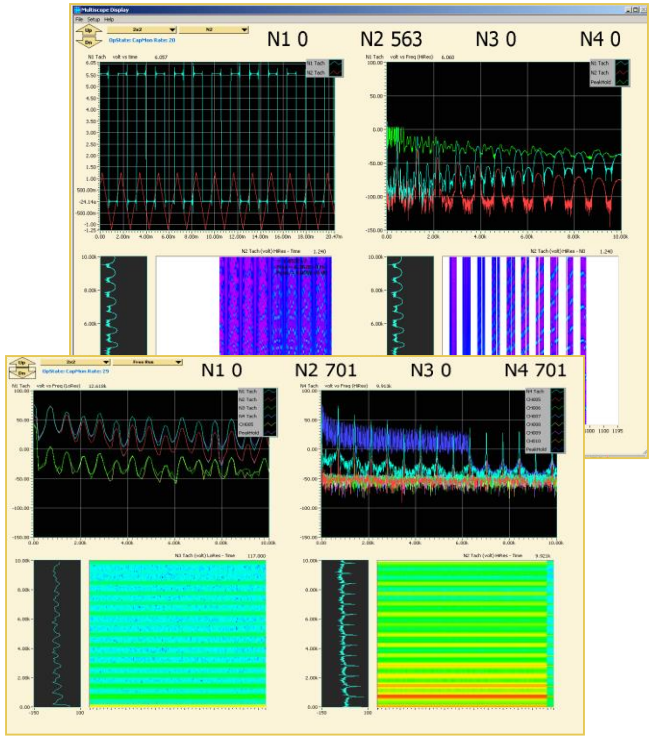
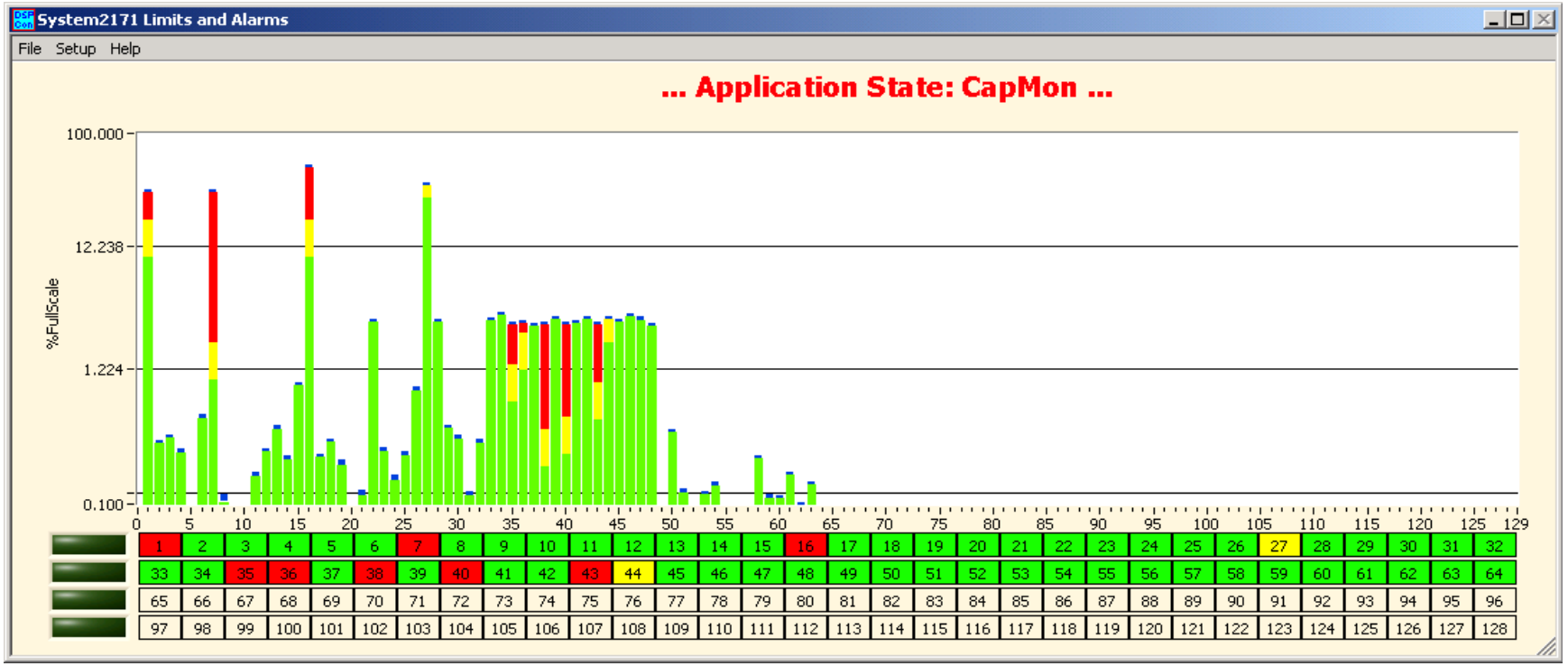



# DAS - Control and Real-Time Display

## Real-Time Display Types – **Limits & Alarms**

✓ Multiscope also allows for Real-time Monitoring of Alarm & Limits Settings for both Peak Amplitude for each Channel AND per Frequency/Per Channel



# DAS - Control and Real-Time Display

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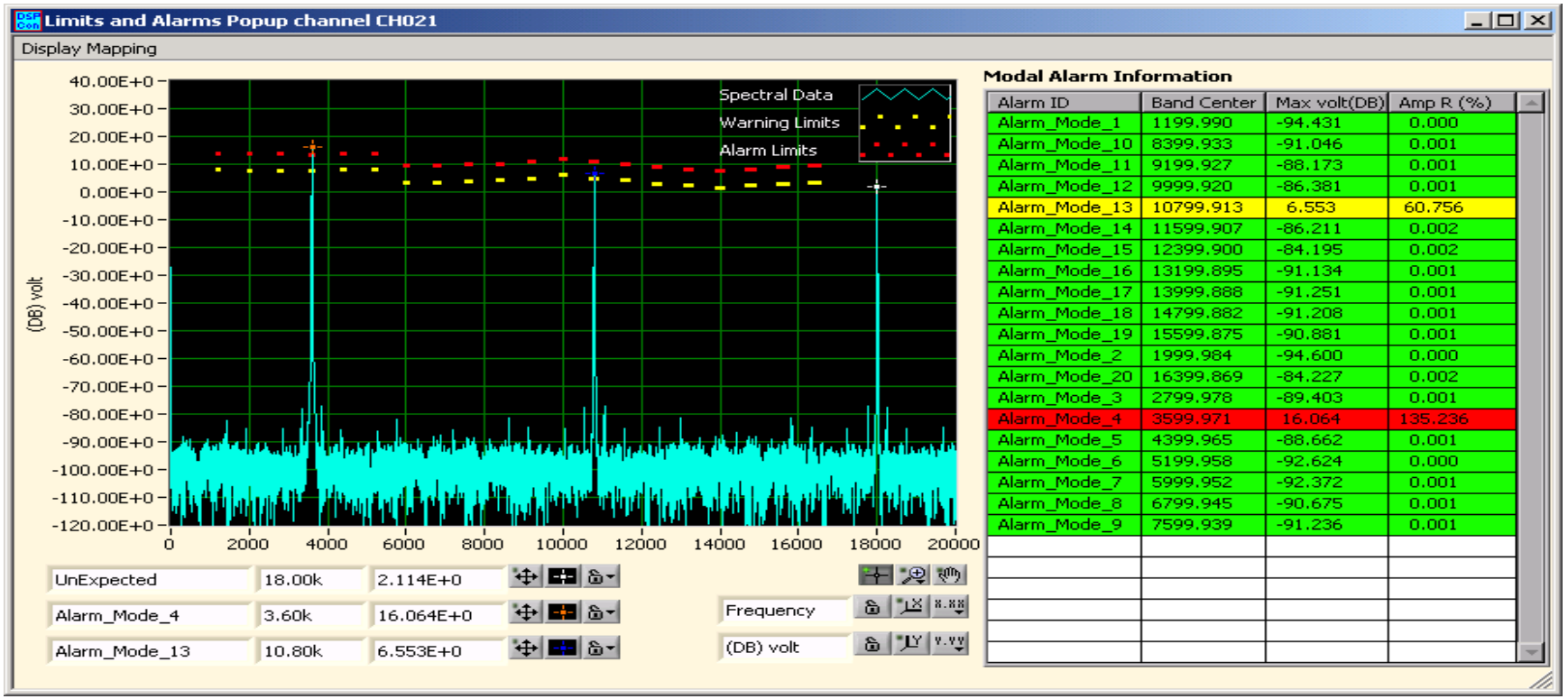



| Alarm ID | Band Center | Max volt(DB) | Amp R (%) |
|---|---|---|---|
| Alarm_Mode_1 | 1199.990 | -94.431 | 0.000 |
| Alarm_Mode_10 | 8399.933 | -91.046 | 0.001 |
| Alarm_Mode_11 | 9199.927 | -88.173 | 0.001 |
| Alarm_Mode_12 | 9999.920 | -86.381 | 0.001 |
| Alarm_Mode_13 | 10799.913 | 6.553 | 60.756 |
| Alarm_Mode_14 | 11599.907 | -86.211 | 0.002 |
| Alarm_Mode_15 | 12399.900 | -84.195 | 0.002 |
| Alarm_Mode_16 | 13199.895 | -91.134 | 0.001 |
| Alarm_Mode_17 | 13999.888 | -91.251 | 0.001 |
| Alarm_Mode_18 | 14799.882 | -91.208 | 0.001 |
| Alarm_Mode_19 | 15599.875 | -90.881 | 0.001 |
| Alarm_Mode_2 | 1999.984 | -94.600 | 0.000 |
| Alarm_Mode_20 | 16399.869 | -84.227 | 0.002 |
| Alarm_Mode_3 | 2799.978 | -89.403 | 0.001 |
| Alarm_Mode_4 | 3599.971 | 16.064 | 135.236 |
| Alarm_Mode_5 | 4399.965 | -88.662 | 0.001 |
| Alarm_Mode_6 | 5199.958 | -92.624 | 0.000 |
| Alarm_Mode_7 | 5999.952 | -92.372 | 0.001 |
| Alarm_Mode_8 | 6799.945 | -90.675 | 0.001 |
| Alarm_Mode_9 | 7599.939 | -91.236 | 0.001 |

# RPT Backup Charts

# RPT Functions and Duties

- *The Rocket Propulsion Test Program Office (RPT) provides the program management structure necessary for:*
  - *Accomplishing chemical rocket propulsion testing by maintaining sufficient Agency capabilities without unnecessary duplication*
  - *Making chemical propulsion test location assignments utilizing the Rocket Propulsion Test Management Board (RPTMB) or National Rocket Propulsion Test Alliance (NRPTA)*
  - *Managing the rocket propulsion test budget*
  - *Advocates for testing and test planning*

# RPT Functions and Duties

## Maintaining Agency Capabilities

- *RPT Maintains Appropriate Rocket Propulsion Test Capabilities By:*
  - *Funding a core capability*
  - *Establishing a core capability based on Agency requirements*
    - *5-year strategic analysis and planning tool 2008*
    - *RPT "Right Size" study 2011*
    - *RPT "Right Size" update 2015*
    - *Continuous evaluation of requirements and readiness*
  - *Working with outside parties for maintenance and modernization*
    - *Inside NASA (FED, Recap, SLS)*
    - *Outside NASA (DoD, Boeing, Aerojet-Rocketdyne)*

# RPT Functions and Duties

## Rocket Propulsion Test Assignments

- *RPT Makes Rocket Propulsion Test Assignments and Approves Alternate Uses of RPT Facilities*
  - *Primarily uses the RPTMB*
    - *RPT Program Manager – Chair*
    - *GRC/PBS – Member*
    - *MSFC – Member*
    - *SSC – Member*
    - *WSTF – Member*
    - *KSC, WFF, NESC – Associate Members*
  - *Uses the NRPTA as appropriate*
    - *RPTMB members*
    - *DoD members*
      - *Air Force Arnold Engineering Test Complex (AEDC)*
      - *Air Force Research Lab (AFRL)*
      - *Naval Air Warfare Center (NAWC)*
      - *Redstone Test Center (RTC)*
      - *Test Resource Management Center (TRMC)*

# RPT Functions and Duties

## Managing The Rocket Propulsion Test Budget

- *RPT Manages HEO's Rocket Propulsion Test Budget*
  - *Enables test capabilities at RPT Centers*
    - *Facilities and skills*
    - *Test stands and support systems*
  - *Charters Maintenance & Modernization projects*
    - *Focused on attacking risks*
    - *Emphasis on safety and supporting future Agency requirements*
    - *Historically $3M - $6M per year*
    - *40+ year old systems often need significant overhauls due to wear and obsolescence*
    - *Segment most affected by budget cuts*
  - *Provides Direct Agency Influence On Infrastructure Levels*
    - *Helps control Center independent capability development*

# RPT Functions and Duties

## Test and Test Planning Advocate

- *RPT Advocates For Test Issues*
  - *Provides program-to-program input for adequate test planning*
    - *Adequate time for build-up*
    - *Facility selections based on both Agency and Program requirements*
    - *Offers options in complexity, cost, and schedule for customer program trades*
  - *Plans for future requirements not advocated by active programs*
    - *Active programs may not be concerned about follow-on requirements*
    - *RPT must consider both current and future requirements*

# RPT Relationship With DoD

- RPT participates in a partnership with the Department of Defense to look at the nation's propulsion test infrastructure

- The partnership is codified through a Memorandum of Understanding signed by the Under Secretary of Defense for Acquisition, Technology and Logistics and the NASA Administrator and is called the National Rocket Propulsion Test Alliance (NRPTA), which was established in 1998.

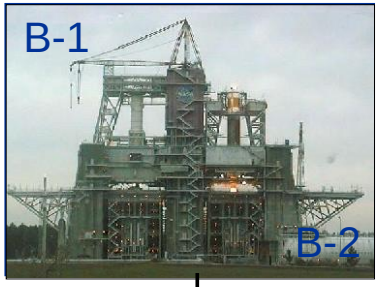
- NRPTA includes representatives from:
  - Air Force Arnold Engineering Test Complex (AEDC)
  - Air Force Research Lab (AFRL)
  - Naval Air Warfare Center (NAWC)
  - Redstone Test Center (RTC)
  - Test Resource Management Center (TRMC) (Under Secretary's Office)

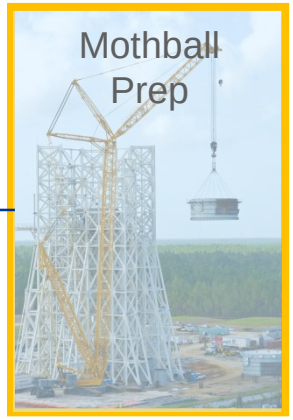
- RPTMB provides Directives / NRPTA provides Recommendations

# SSC Test Capability

**A-1 Test Stand**
**Max Thrust (Klbf)**
1,100 (designed)
650 (current)
**Altitude (Kft)**
Ambient
**Propellants**
LOX/LH2

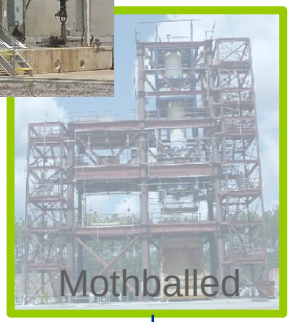
**A-1 Test Stand**
**Max Thrust (Klbf)**
1,100 (designed)
650 (current)
**Altitude (Kft)**
65
**Propellants**
LOX/LH2




**E-1 Test Facility Cells 1-3**
**Max Thrust (Klbf)**
1000
**Altitude (Kft)**
Ambient
**Propellants**
LOX/LH2/RP

**E-2 Test Facility Cell 1**
**Max Thrust (Klbf)**
100
**Altitude (Kft)**
Ambient
**Propellants**
LOX/LH2/RP




**B-1 Test Stand**
**Max Thrust (Klbf)**
11,000 (designed)
750 (current)
**Altitude (Kft)**
Ambient
**Propellants**
LOX/LH2

**B-2 Test Stand**
**Max Thrust (Klbf)**
11,100 (designed)
7,000 (current)
**Altitude (Kft)**
Ambient
**Propellants**
LOX/LH2

**A-3 Test Stand**
**Max Thrust (Klbf)**
900 (designed)
300+ (altitude)
**Altitude (Kft)**
100 (designed)
**Propellants**
LOX/LH2

**E-2 Test Facility Cell 2**
**Max Thrust (Klbf)**
150
**Altitude (Kft)**
Ambient
**Propellants**
LOX/RP

**E-3 Test Facility Cell 2**
**Max Thrust (Klbf)**
25
**Altitude (Kft)**
Ambient
**Propellants**
LOX/H202/CH4/RP

**E-3 Test Facility Cell 1**
**Max Thrust (Klbf)**
60
**Altitude (Kft)**
Ambient
**Propellants**
LOX/H2O2/RP

# MSFC Test Capability

**Test Stand 115**
7.5 Klbf Thrust
Ambient
LOX/LH2/CH4/RP


**Test Stand 500**
Variable up to 40K Thrust
Ambient
LOX/LH2/CH4

**Test Stand 116**
60 Klbf Thrust
Ambient
LOX/LH2/CH4/RP

**SPTA**
500 Klbf Thrust
Ambient
Solids

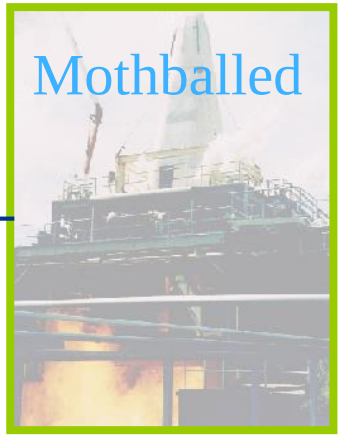

**Test Stand 4670**
900 Klbf Thrust
Ambient
LOX/LH2/RP

# WSTF Test Capability

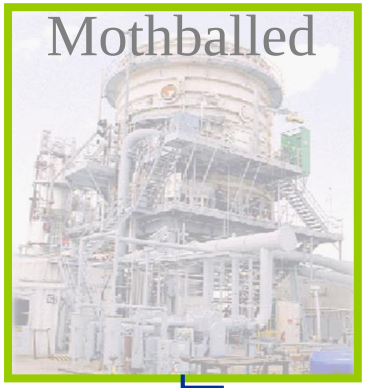
**Test Stand 301**
25 Klbf Thust
Ambient
N204/Hydrazines

**Test Stand 401**
25 Klbf Thrust
120 Kft Altitude
LH2/LOX/CH4/RP
N204/Hydrazines

**Test Stand 402**
60 Klbf Thrust
Ambient
Portable Tankage



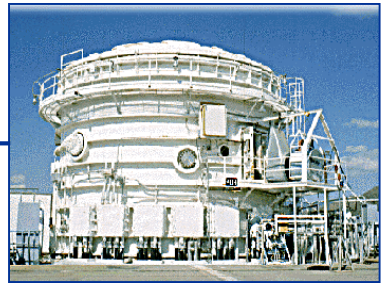





**Test Stand 303**
1 Klbf Thrust
120 Kft Altitude
N2H4

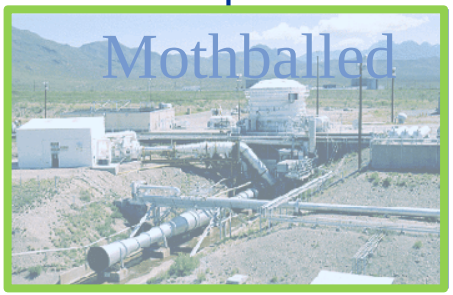
**Test Stand 302**
1 Klbf Thrust
120 Kft Altitude
N2H4

**Test Stand 403**
25 Klbf Thrust
120 Kft Altitude
N204/Hydrazines



**Test Stand 328**
25 Klbf Thrust
Ambient
N204/Hydrazines

**Test Stand 405**
25 Klbf Thrust
120 Kft Altitude
N204/Hydrazines/Solids




**Test Stand 406**
1 Klbf Thrust
120 Kft Altitude
N2O4/Hydrazines

# GRC-PBS Test Capability

**Test Stand B-2**
400 Klbf Thrust
Ambient to 130 Kft
Hot-Fire Testing
Up to 900Kft
Space Environment
Simulation
(Thermal Vacuum)
LH2/LOX/RP/CH4

**B-2 Test Chamber**
32 ft diameter by 62 ft
high

**B-2**
Thermal Vacuum test
capability available in
for testing in 2011

**B-2**
Propulsion system testing
capability currently being
refurbished