Developments in test facility and data networking for the Altitude Test Stand at the John C. Stennis Space Center

A General Overview

Phillip W. Hebert

SSC Electrical Design Engineering (EA-31)

(228) 688-2995

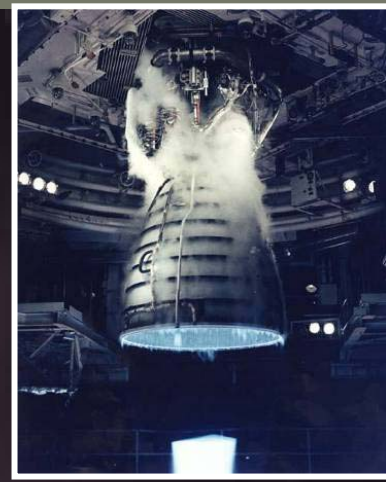
Phillip.W.Hebert@nasa.gov

Developments in test facility and data networking for the Altitude Test Stand at the John C. Stennis Space Center – A General Overview

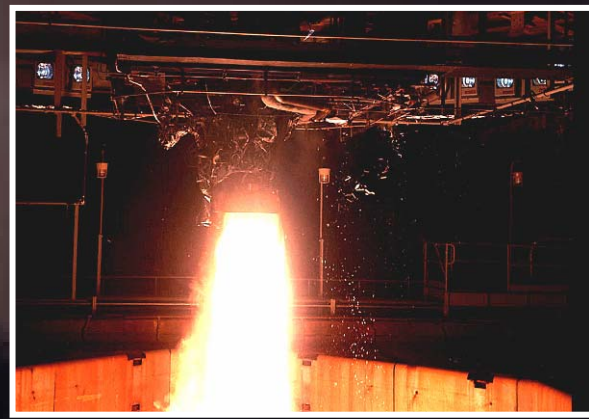
Stennis Space Center

Space Shuttle Main Engine Test
@ A2 Test Stand

RS-68 650 klbf
@ B1 Test Stand



Fastrac 60 klbf
@ B2 Test Stand



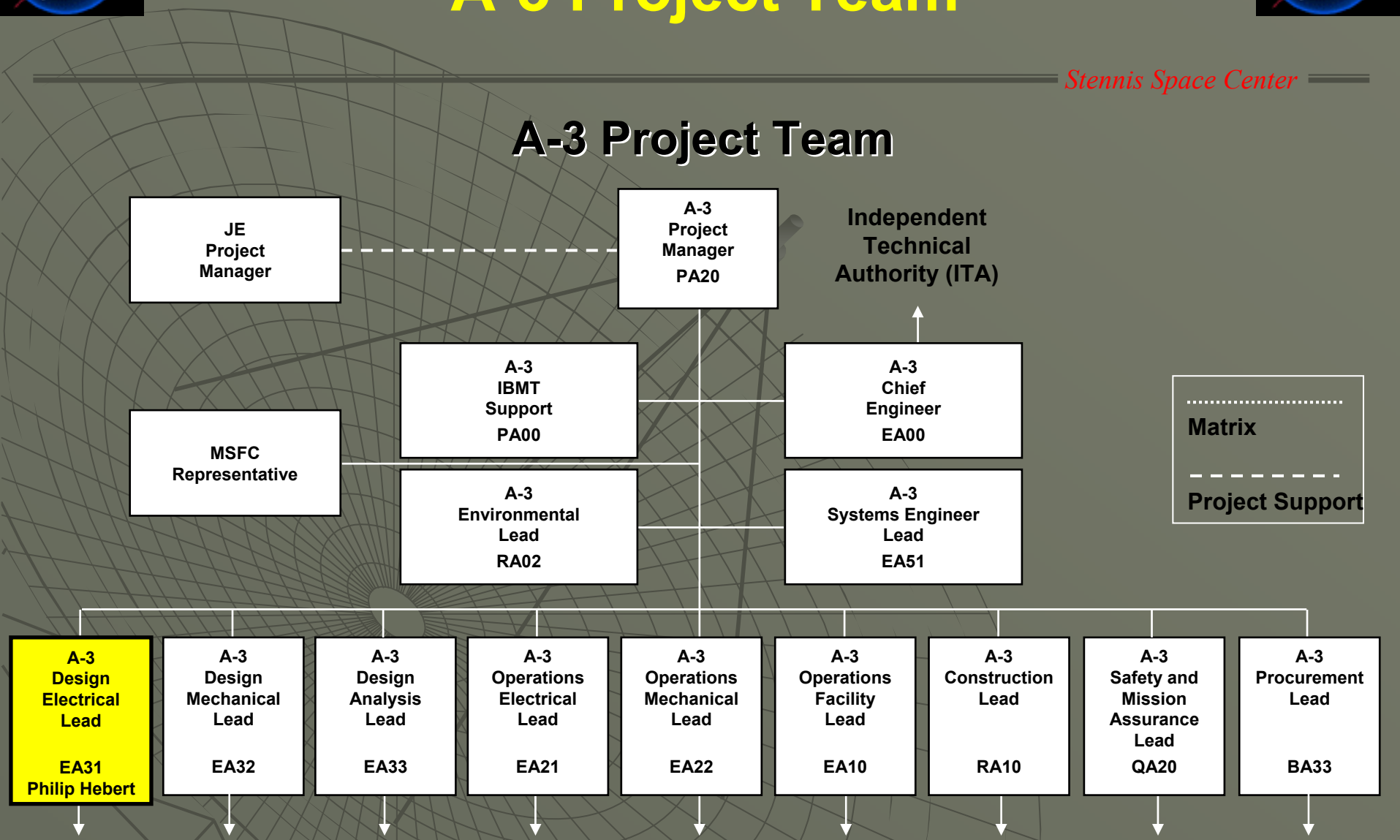
Developments in test facility and data networking for the Altitude Test Stand at the John C. Stennis Space Center – A General Overview

- 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
- Video Systems
- Network Architecture

A-3 Project Team



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

Stennis Space Center

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

SSC Test Facilities (continued)

E-Complex

Stennis Space Center

E-1
Cells 1, 2, 3

High Press., Full Scale
Engine Components

J-2X

E-2 Cell 2

Low Press. Mid-Scale
& Subscale, Stage

E-3
Cell 1

High Press. Small-Scale
Subscale

E-2
Cell 1

High Press.
Mid-Scale
& Subscale

J-2X

TGV

E-3
Cell 2

SSC Test Facilities (continued)

A-3

SSC Test Facilities (continued)

Stennis Space Center

RUN TANKS

DERRICK CRANE

SUPER STRUCUTRE

TEST CELL

TEST LEVEL

ENGINE TEST LOCATION

BLOCK OFF VALVE

1st STAGE EJECTOR

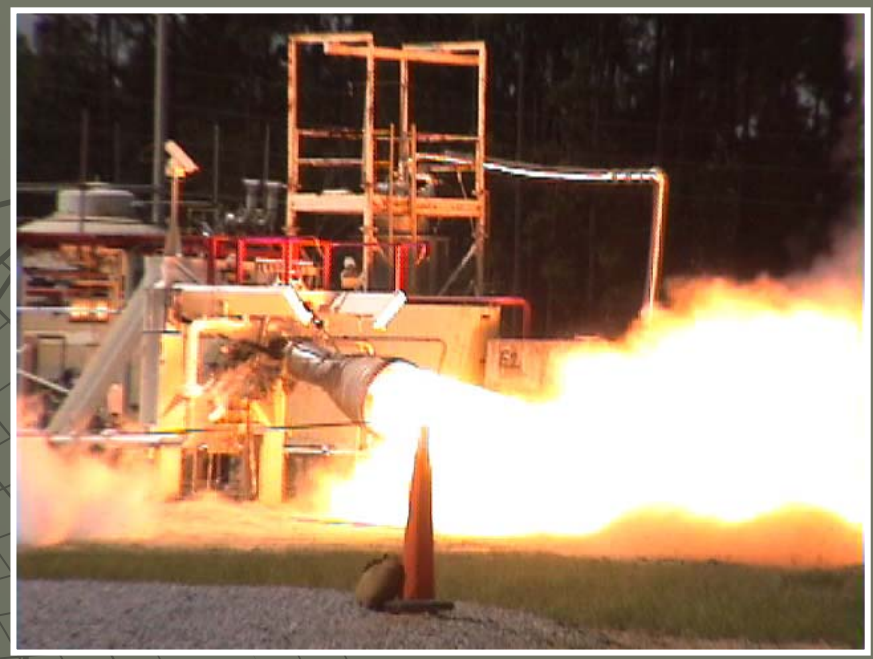
2nd STAGE EJECTOR

TOWER STRUCTURE

DIFFUSER

FOUNDATION

Typical Test Articles



LR-89

Integrated Powerhead Demonstrator

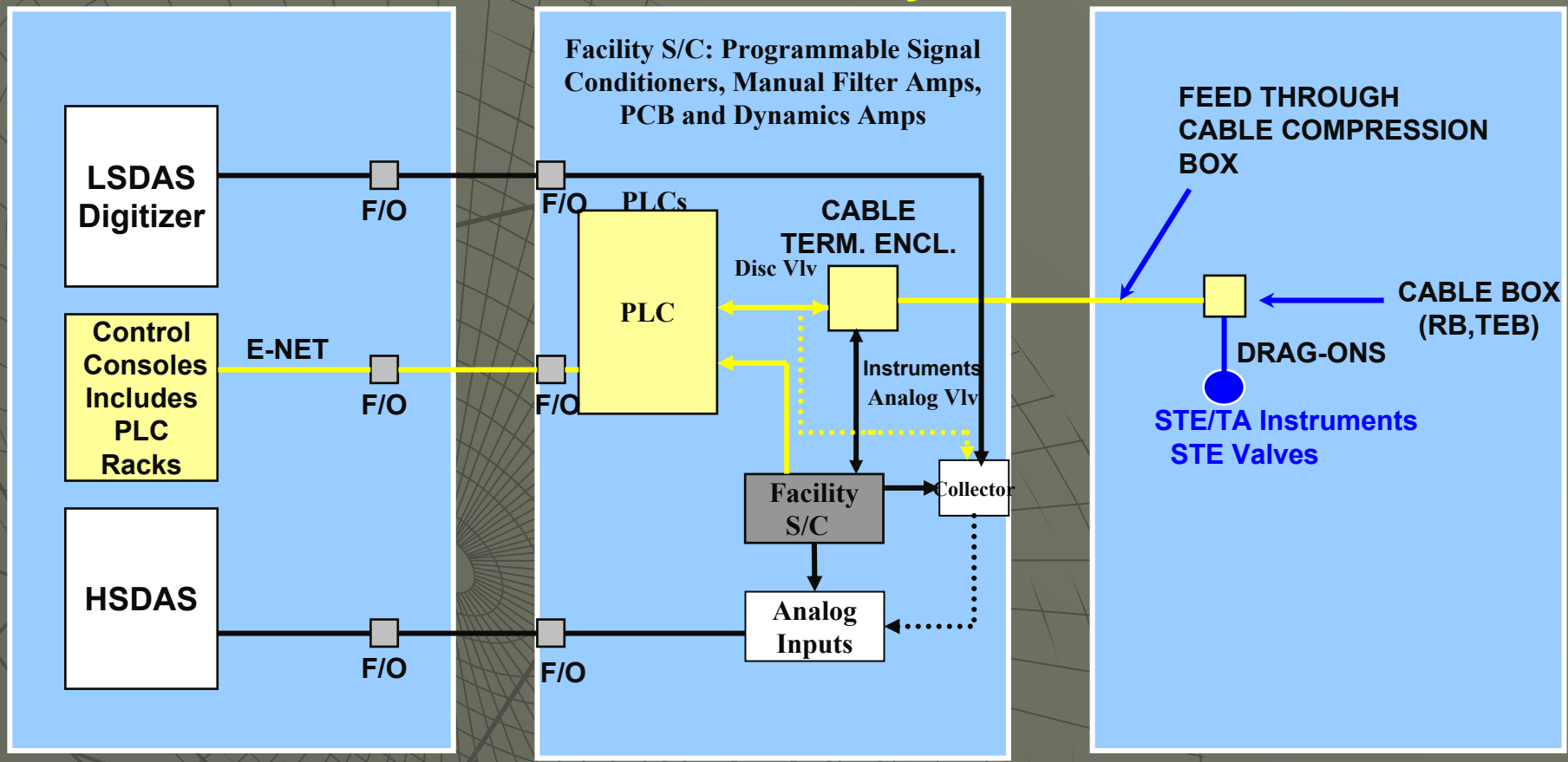
Test Facility Electrical Systems

- 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
- Aural Warning System
- Power Distribution System
- Uninterruptible Power System
- Video System
- Interconnecting Network

Typical Test Facility Electrical System Layout

Stennis Space Center

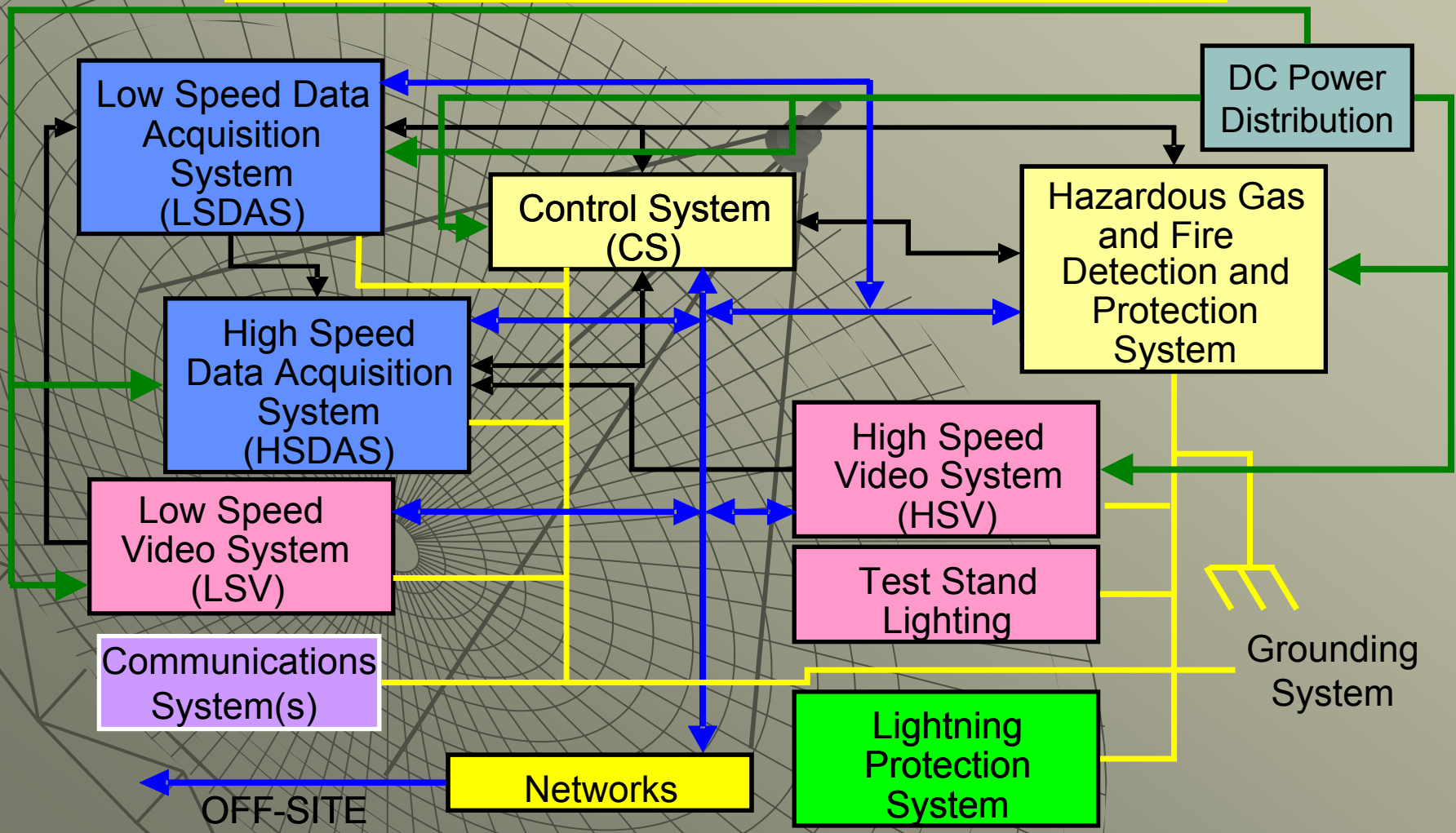
Historical Overview of Systems at SSC



Typical Test Facility Electrical System Layout

Stennis Space Center

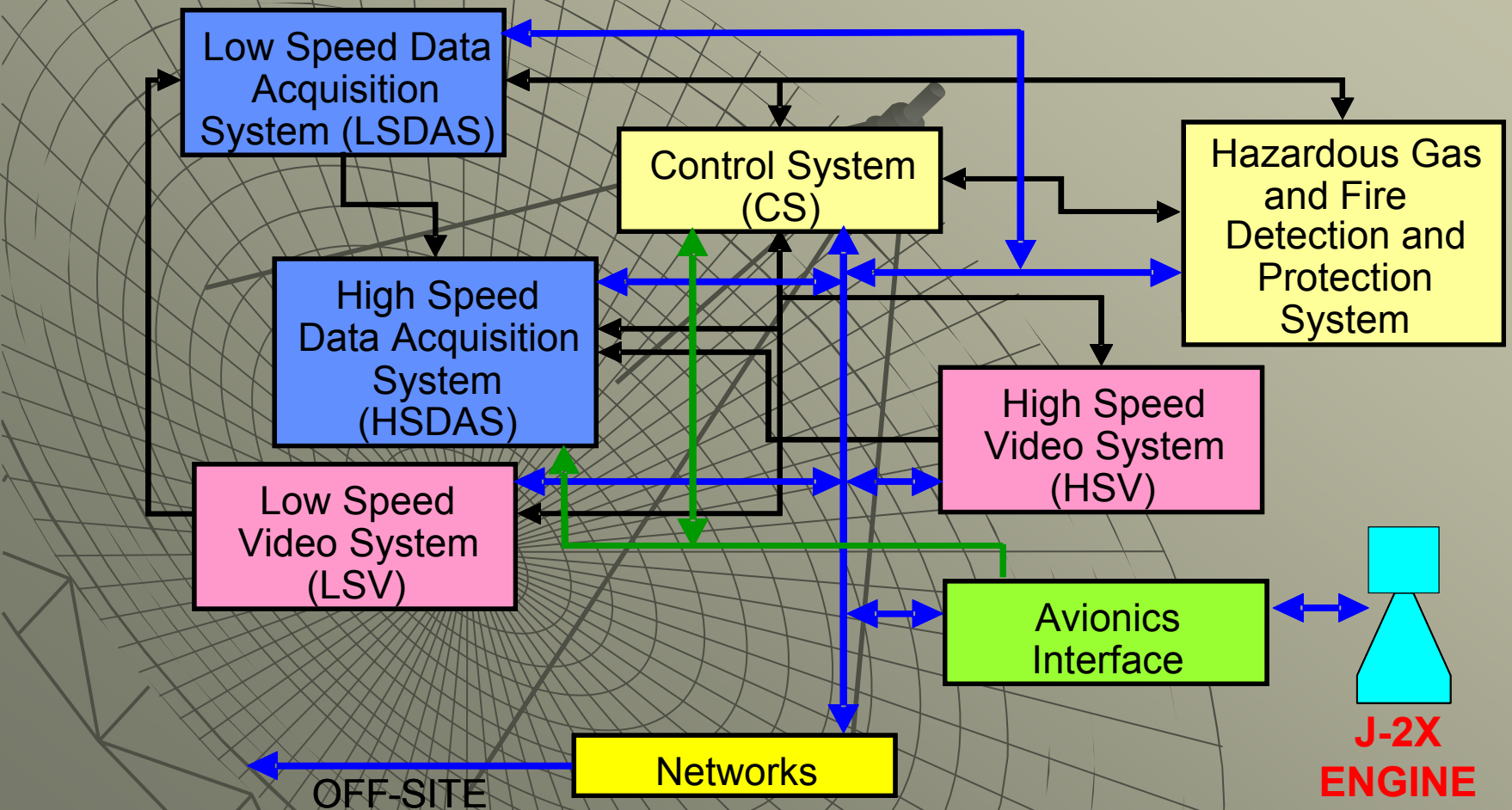
A-3 Test Stand Electrical Systems & Interactions



Typical Test Facility Electrical System Layout

Stennis Space Center

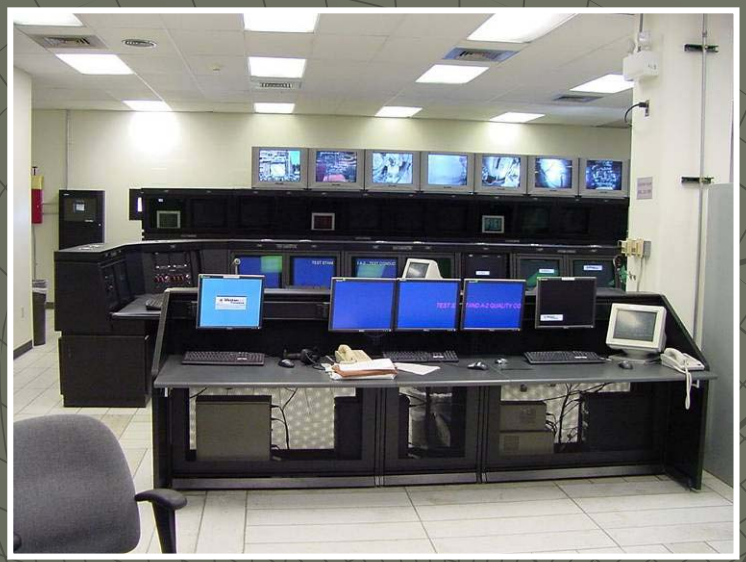
A-3 Test Stand Electrical Systems Software Data Flow & Interactions



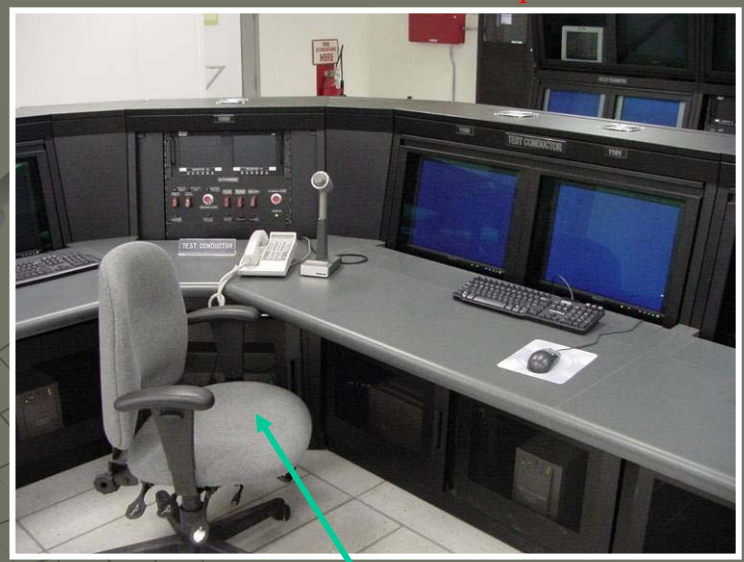
Test Control Centers –

Currently in Place

Stennis Space Center



A2 TCC



E2 TCC

Test Conductor's Station

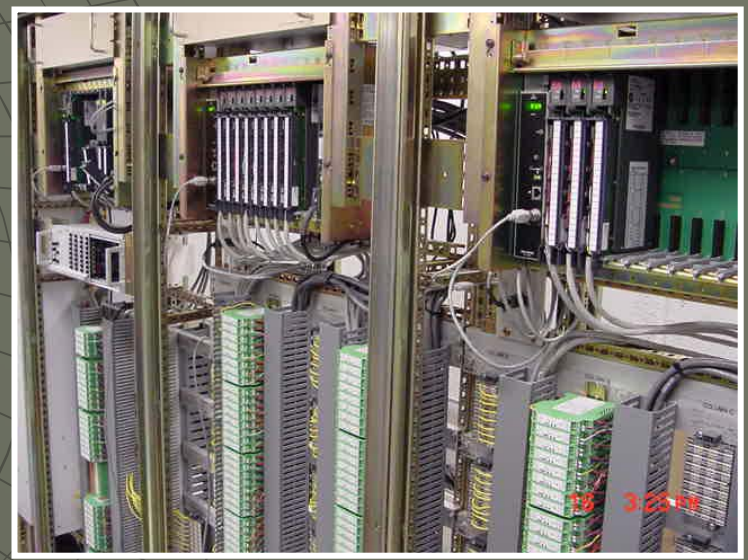
Signal Conditioning Buildings (SCB) –
Current Uses & Installations

Stennis Space Center

E1 SCB Signal Conditioning Rack

E2 Cell 1 SCB 1 Controls Racks

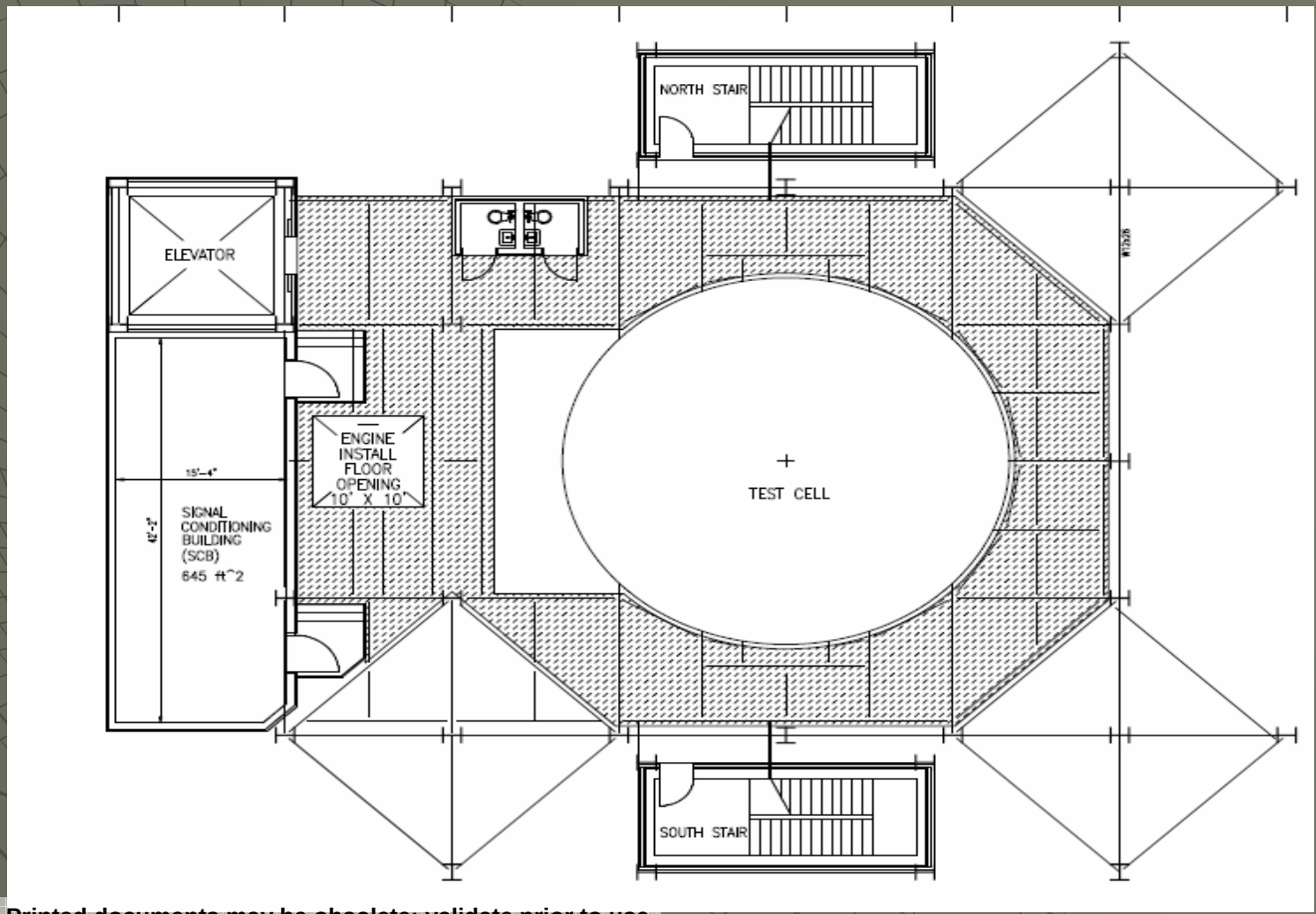
E2 SCB's 1 & 2



Signal Conditioning Buildings (SCB)

Stennis Space Center

A-3 Test Stand SCB Location



High Speed Data Acquisition Systems (HSDAS)

High Speed Data Acquisition System

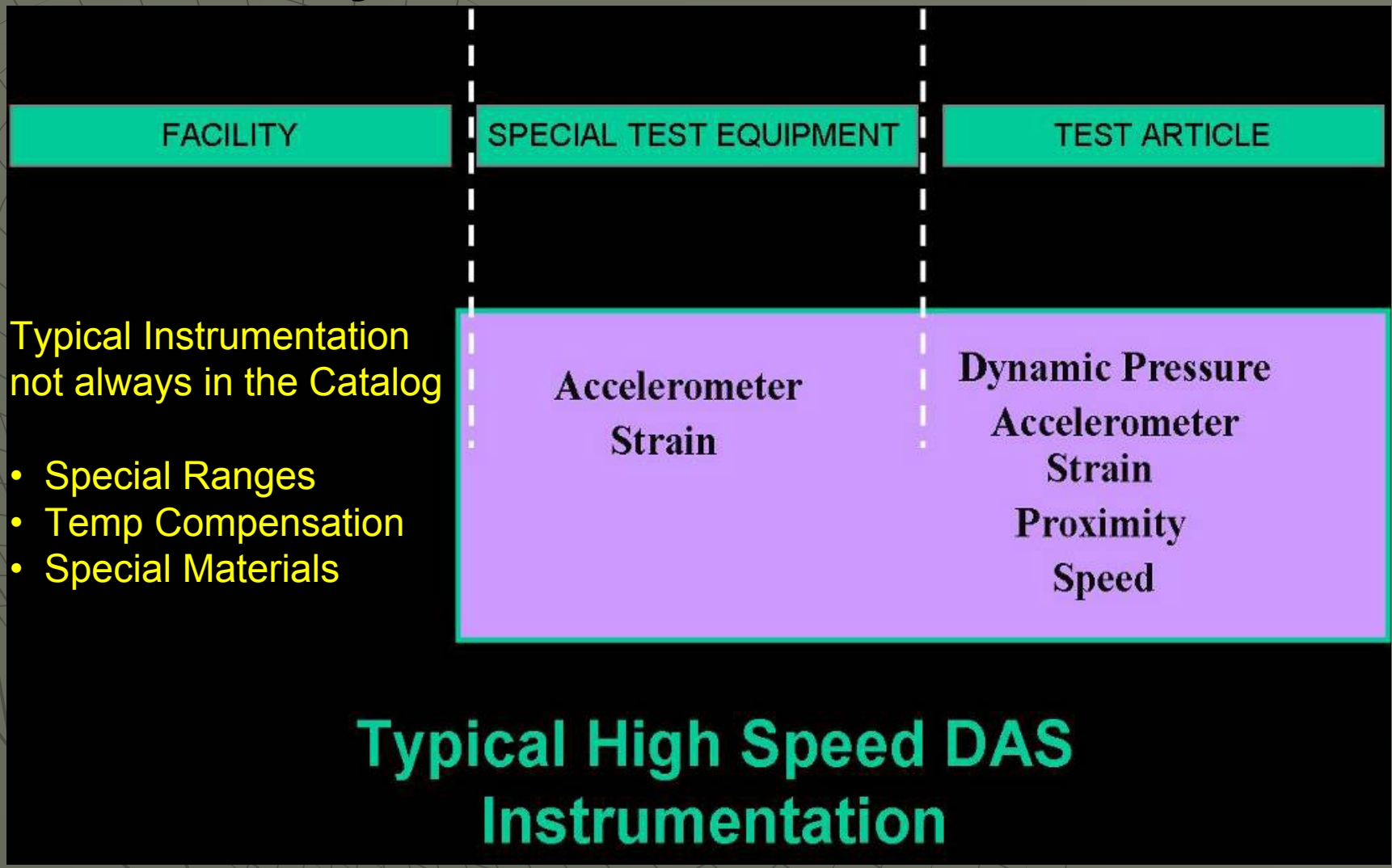
- The High Speed Data Acquisition System is used to record rocket engine or component data from a variety of dynamic sensors.
  - Sampling rates are normally an order of magnitude in sample rates compared to the Low Speed Data Acquisition System.
  - High speed data provides the Analyst with information 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.
  - The data is typically analyzed in the frequency domain.
  - Challenges to recording good high speed data include the environment (high temperatures, vibration, high flow, cryogenic temperatures, high pressure), proper cabling, appropriate sensor selection, and numerous other considerations.

High Speed Data Acquisition Systems

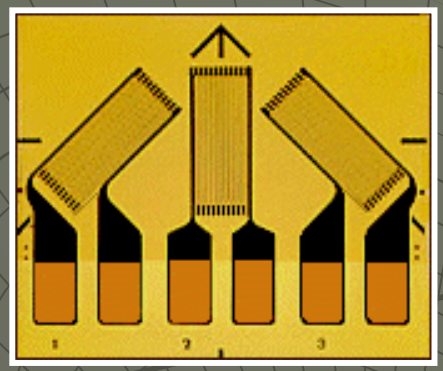
- DataMAX II (New to be used for A-3)- >= 200,000 Samples Per Second **(Binary & Decimal Sampling)**
  - AB Complex (RS-68, J-2X)
  - E Complex
  - Planned for use on A-3

Typical High Speed Data Acquisition System Instrumentation

Stennis Space Center



Typical High Speed Data Acquisition System Instrumentation



Strain

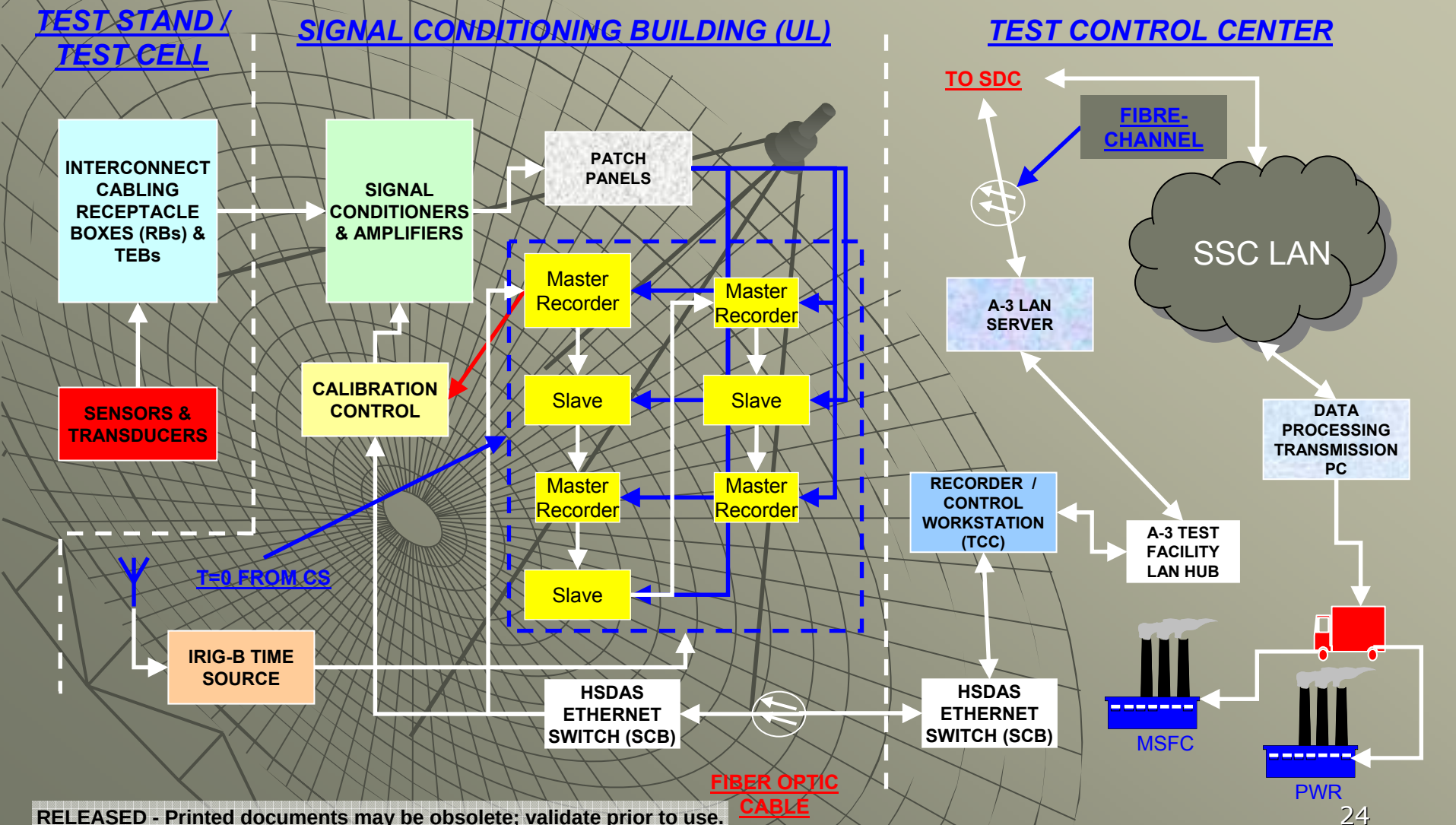
Dynamic Pressure

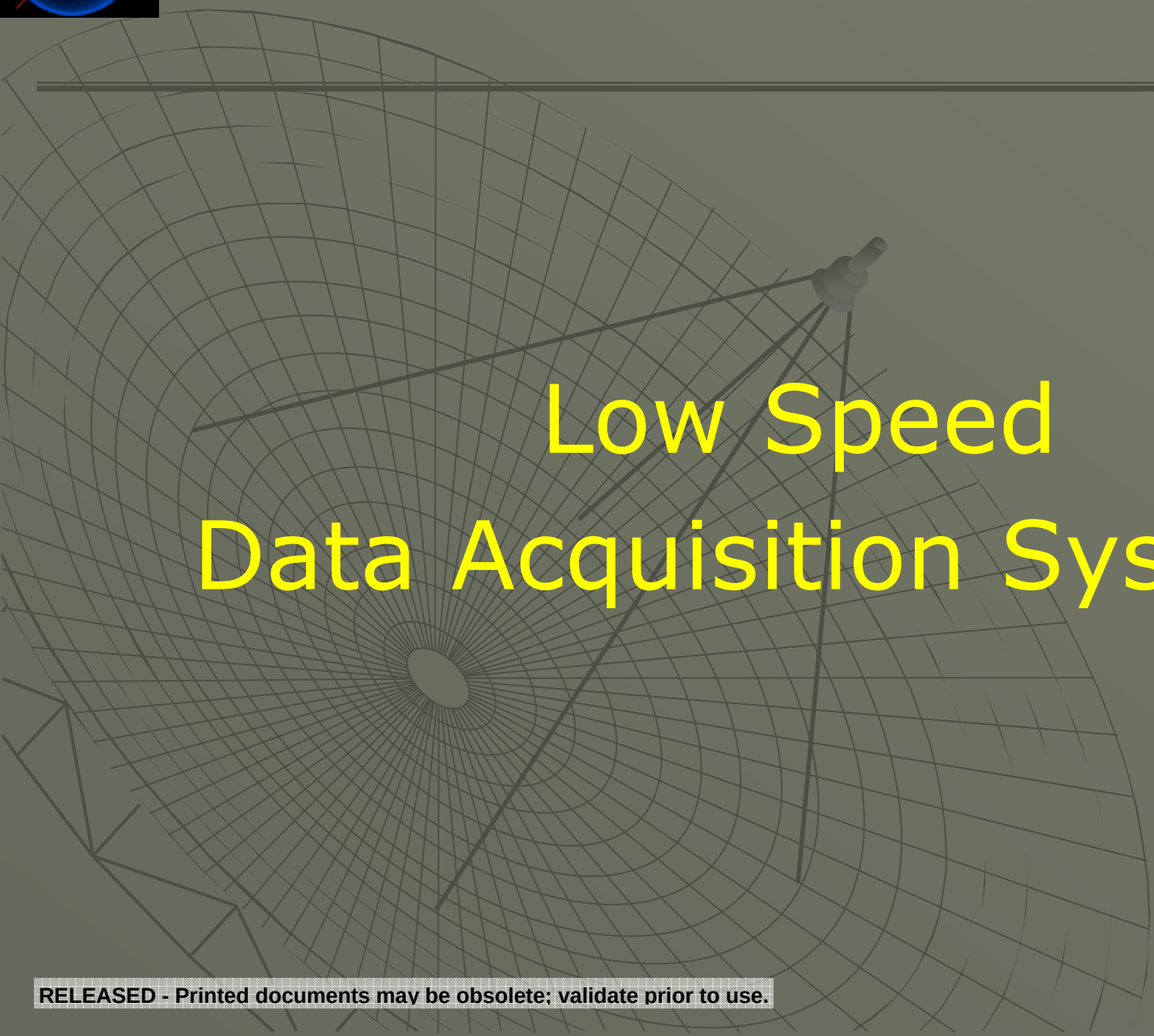
Speed

Accelerometer

Planned A-3 High Speed Data Acquisition System

Stennis Space Center





Low Speed Data Acquisition Systems

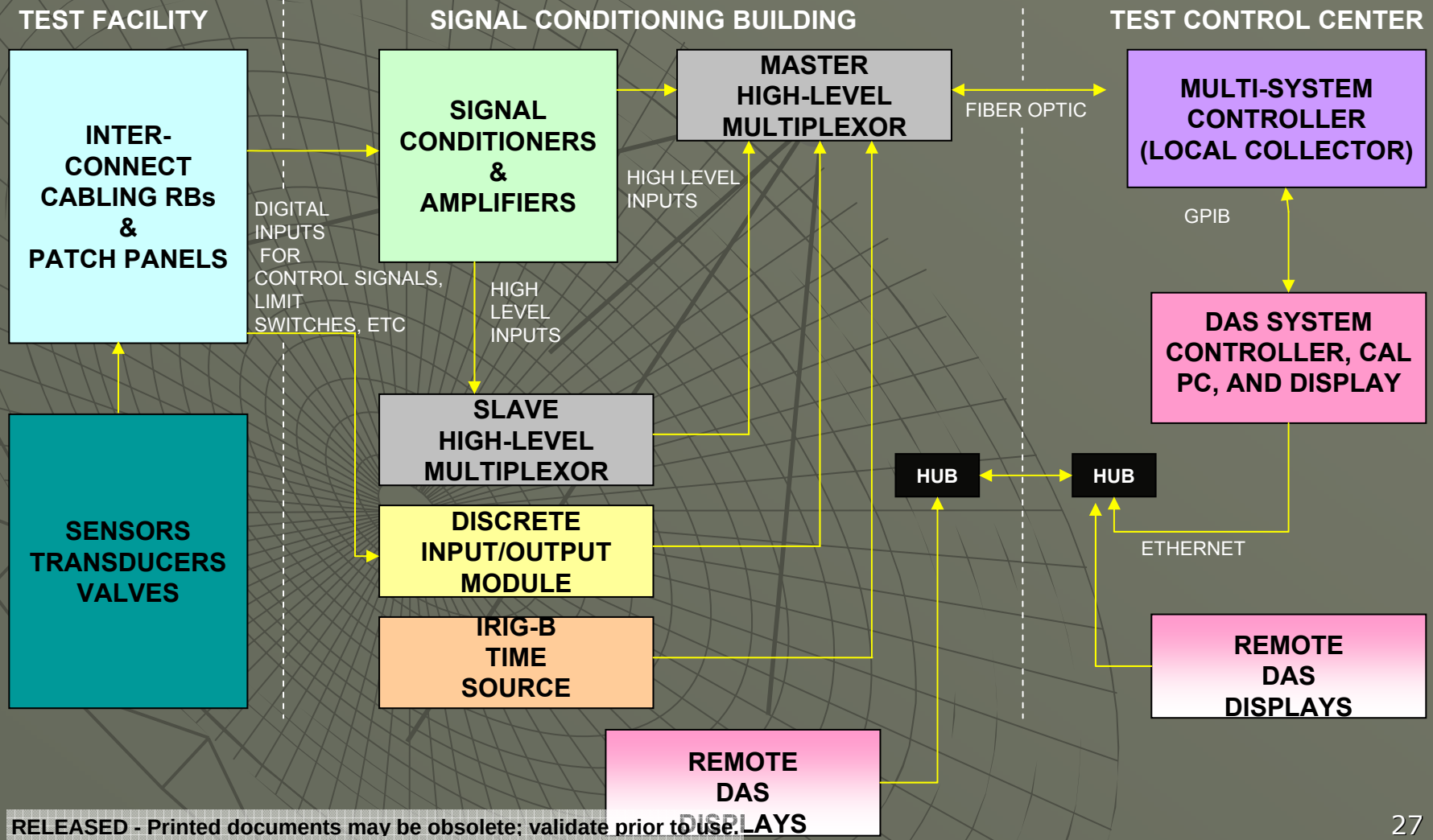
SSC's Low Speed Data Acquisition Systems

- Data acquisition, recording, real time display, data acquisition
  - **Data types:** Low frequency Analog Data, Discrete (event) Data, Pulse Data from flow meters and speed sensors
    - **E-Complex Digitizer** - ~ 200 samples per second or greater
    - **AB-Complex Digitizer** - ~ 200 samples per second or greater
    - **A-3 Test Stand** – ~ 200 samples per second or greater

E-Complex Low Speed Data Acquisition System Architecture

Stennis Space Center

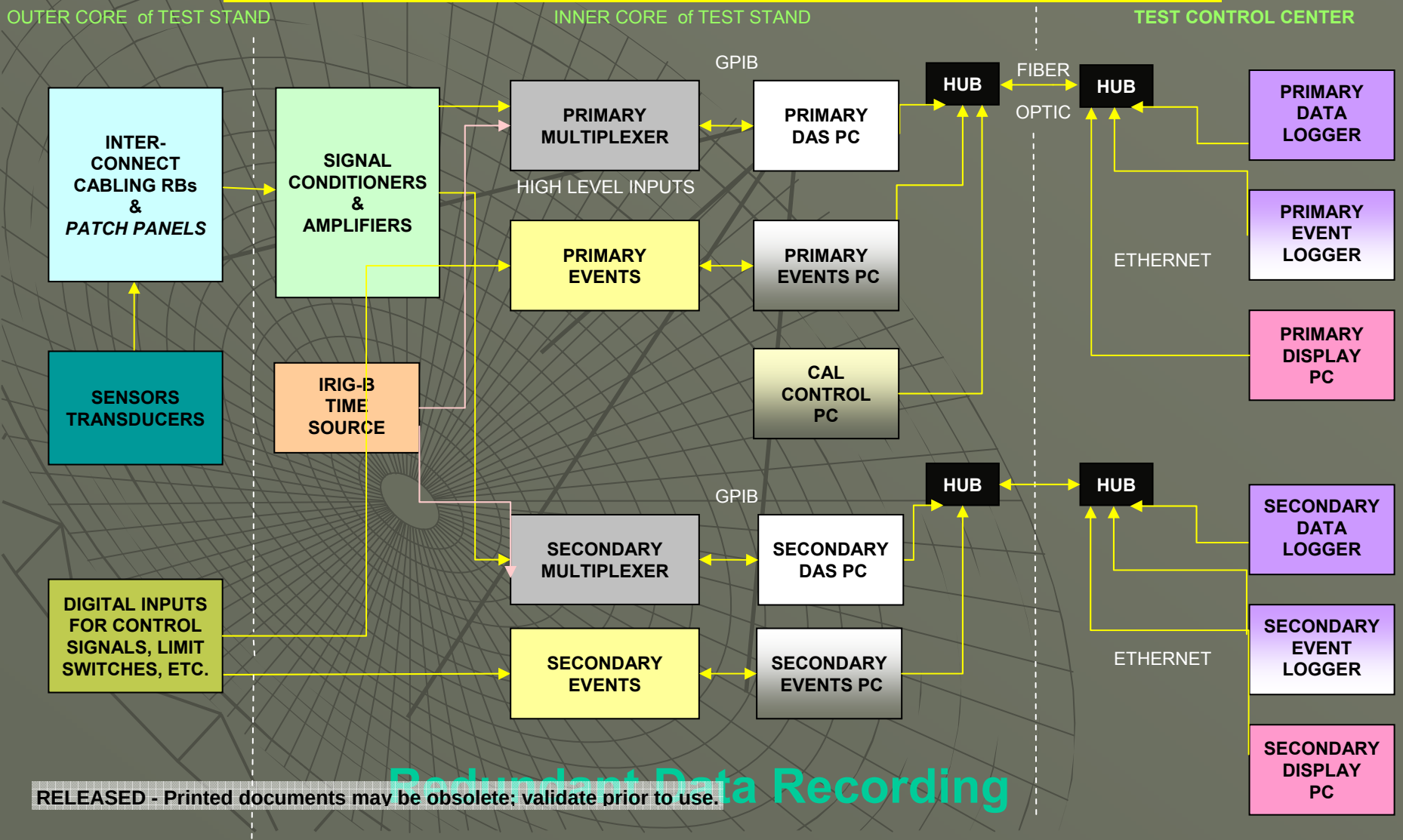
Historical Overview of LSDAS at SSC – E-Complex



AB-Complex Architecture
Low Speed Data Acquisition System

Stennis Space Center

Historical Overview of LSDAS at SSC – AB-Complex



Redundant Data Recording

AB-Complex Architecture
Low Speed Data Acquisition System

Historical Overview of LSDAS at SSC – AB-Complex

- The AB-Complex LSDAS consists of four test stand systems:
  - A1, A2, B1, B2 (B1/B2 one structure with two distinct sides)
    - Systems contain >= 500 analog input channels and >= 700 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

Stennis Space Center

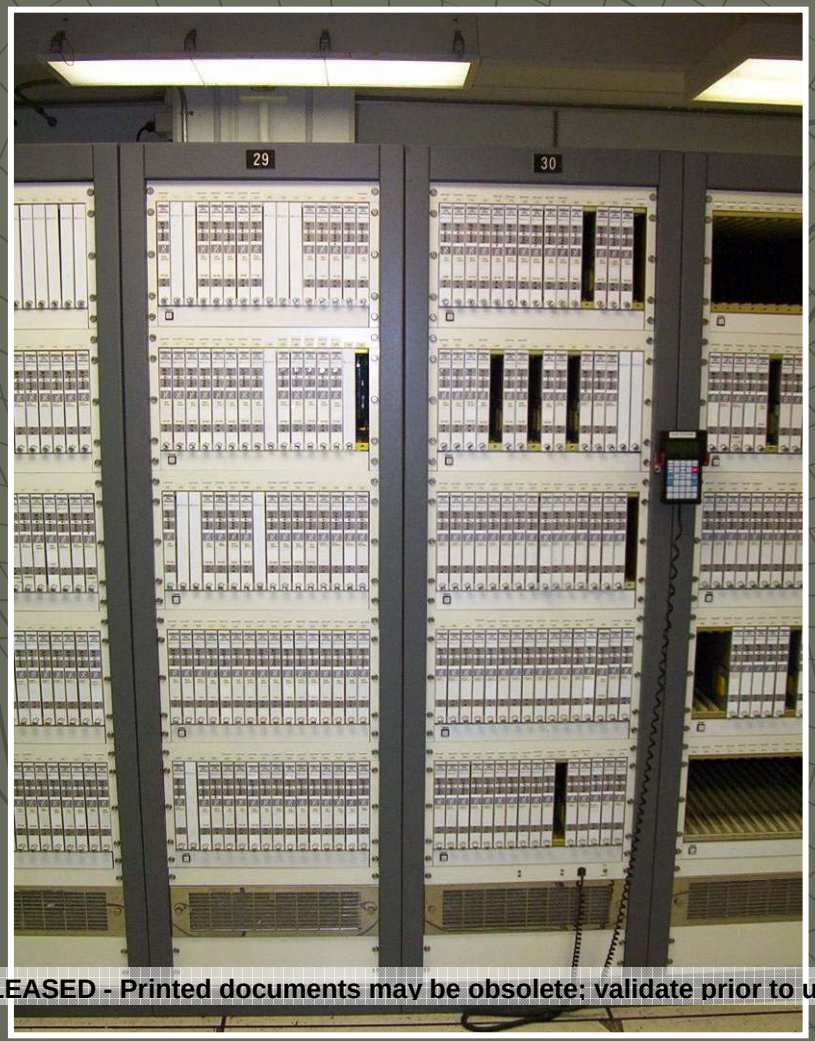
Historical Overview of LSDAS at SSC – AB-Complex

- Fully populated analog box
  - >= 200 analog input channels
- Fully populated discrete box
  - >= 400 digital input channels

AB-Complex Architecture
Low Speed Data Acquisition System

Stennis Space Center

Historical Overview of LSDAS at SSC – AB-Complex

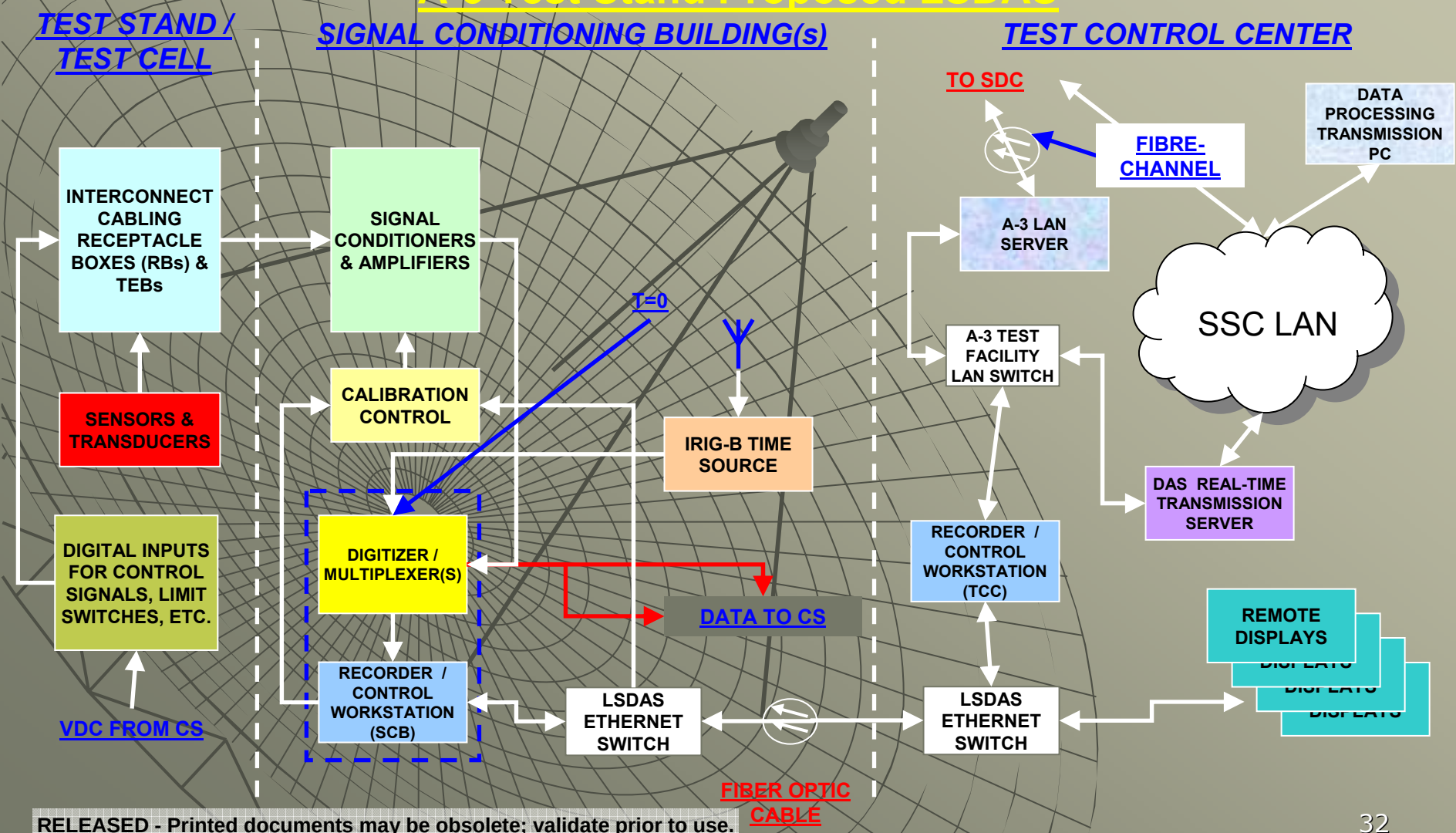


- Model 8300
  - **Programmable**
    - Gain, filter, excitation
  - **Automated calibration**
    - Voltage Insertion
    - Shunt
    - Rcal
  - **Various Mode Cards**
    - Strain Gauge
    - Full Bridge , Half Bridge
    - RTD
    - Thermocouple
  - **Measurements**
    - Strain Gauges
    - Pressure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

Proposed A-3 Low Speed Data Acquisition System Architecture

Stennis Space Center

A-3 Test Stand Proposed LSDAS



Low Speed Data Acquisition System Software

Software:

- Existing functionality
  - All of the E-Complex Low Speed DAS software is developed in LabVIEW
    - LSDAS Operational and Control Software
    - Display Screens
    - Calibration Software
    - Measurement System Analysis (MSA's)
    - "Near" real-time data transmissions
- Proposed for A-3
  - Currently considering option of having vendor provided software or Pratt-Whitney Rocketdyne developed Stennis Data Acquisition (SDAS) software for the following functions:
    - LSDAS Operational and Control Software
    - "Near" real-time data transmissions
    - Display Screens
    - Calibration Software
  - The Measurement System Analysis (MSA's) function is planned to be developed in-house by NASA Engineering & Sciences Directorate (E&SD).

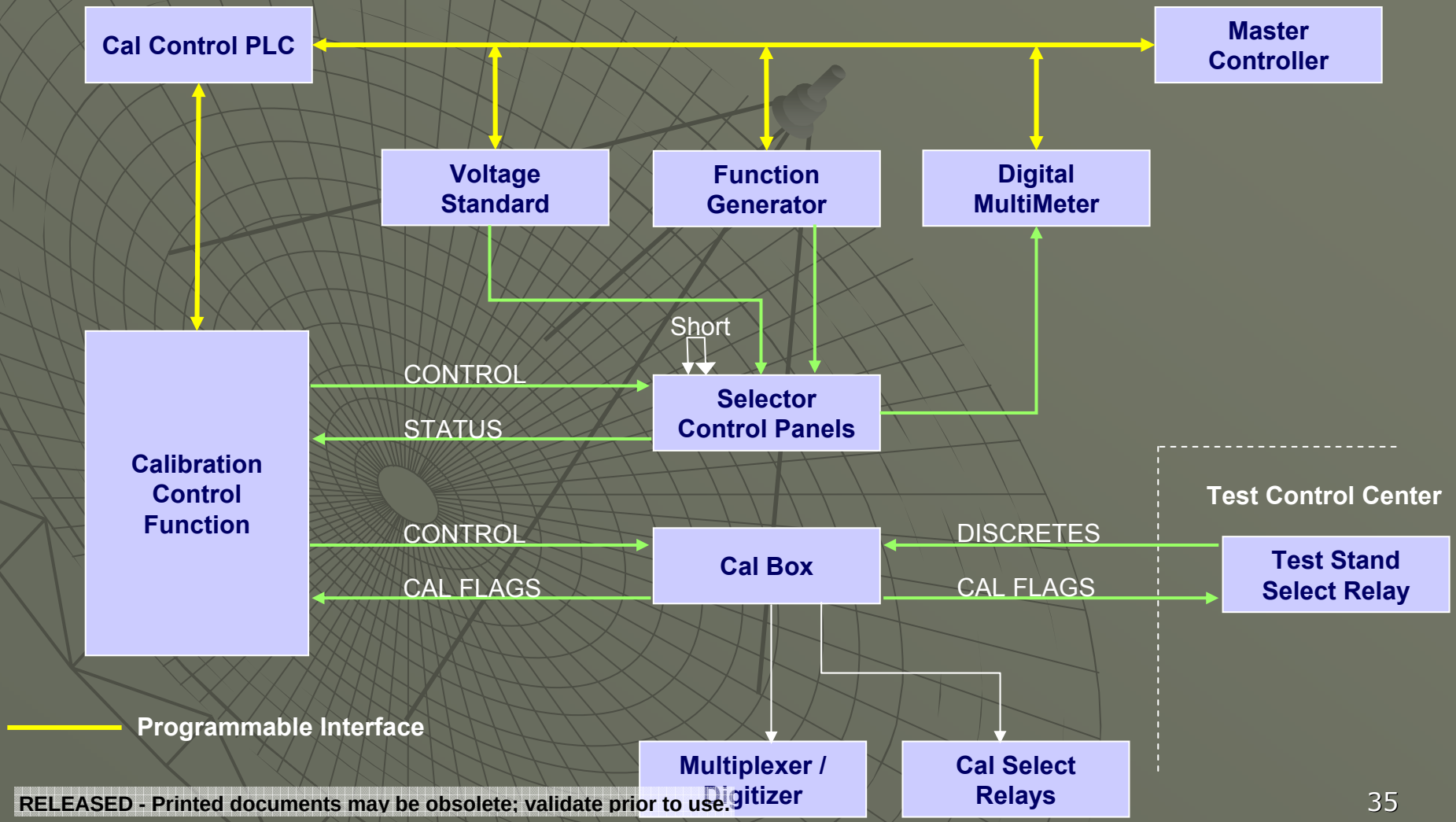
AB-Complex Architecture
Low Speed Data Acquisition System

Software

- Data Acquisition and Real-time Display
  - 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 and methodology 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.

Low Speed Data Acquisition System – Calibration Control

Calibration Control

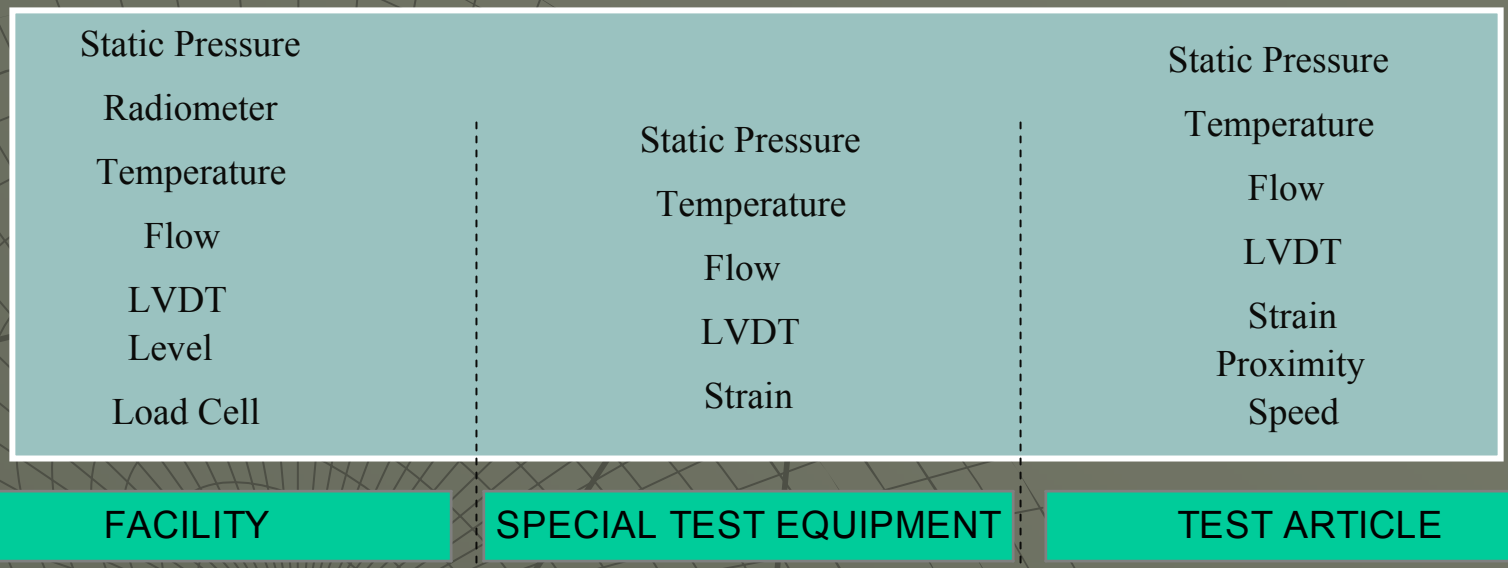


AB-Complex Architecture
Low Speed Data acquisition System

Calibration Software

- Provides computer controlled setups and calibration of the Signal Conditioners.
- Signal Conditioning Setup
  - Select gain, filter
  - Setup and adjustment of individual signal conditioners and amplifiers
  - Calibration
  - 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

Typical Low Speed Data Acquisition System Instrumentation



- **Standard Instrumentation - Not always in the Catalog**
  - Special Ranges (Cryogenics, Hundreds of Degrees F)
  - Special temperature compensation circuits
  - Special Materials
  - Extremely High Pressures
  - Vacuum pressure transducers – Specific to the A-3 Test Stand

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

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 – New term Programmable Automation Controllers (PAC).
  - 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
  - Blue-line 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 timed relays
  - For the A-3 Test Stand, proper control of the Chemical Steam Generator (CSG) system is also required.

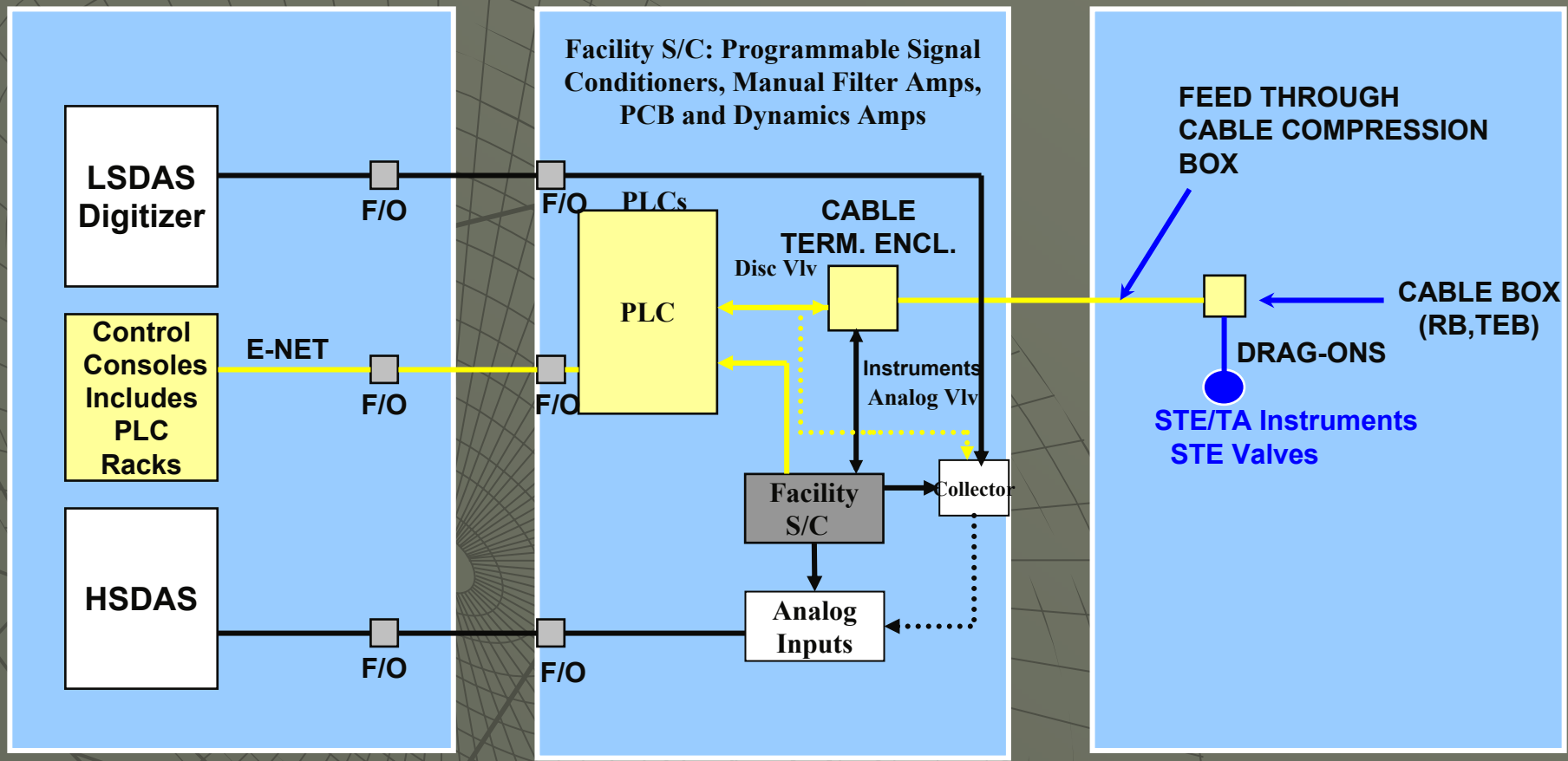
A-3 Test Stand Control System

- Seven PLC functions:
  - Facility Control
  - CSG Control
  - CSG Control Backup
  - Blue-Line and Redline Monitoring & Test Sequence Control
  - Fire and Hazardous Gas Detection
  - Dock – Propellant Transfer
  - Calibration Control
- Generic Ladder Logic is envisioned
  - System is configured entirely through Excel or Database
  - Excel tables and/or Database can be configured in advance and downloaded on test day.
  - Excel tables and/or Database can be archived for historical reference

E1 Control System Layout

Stennis Space Center

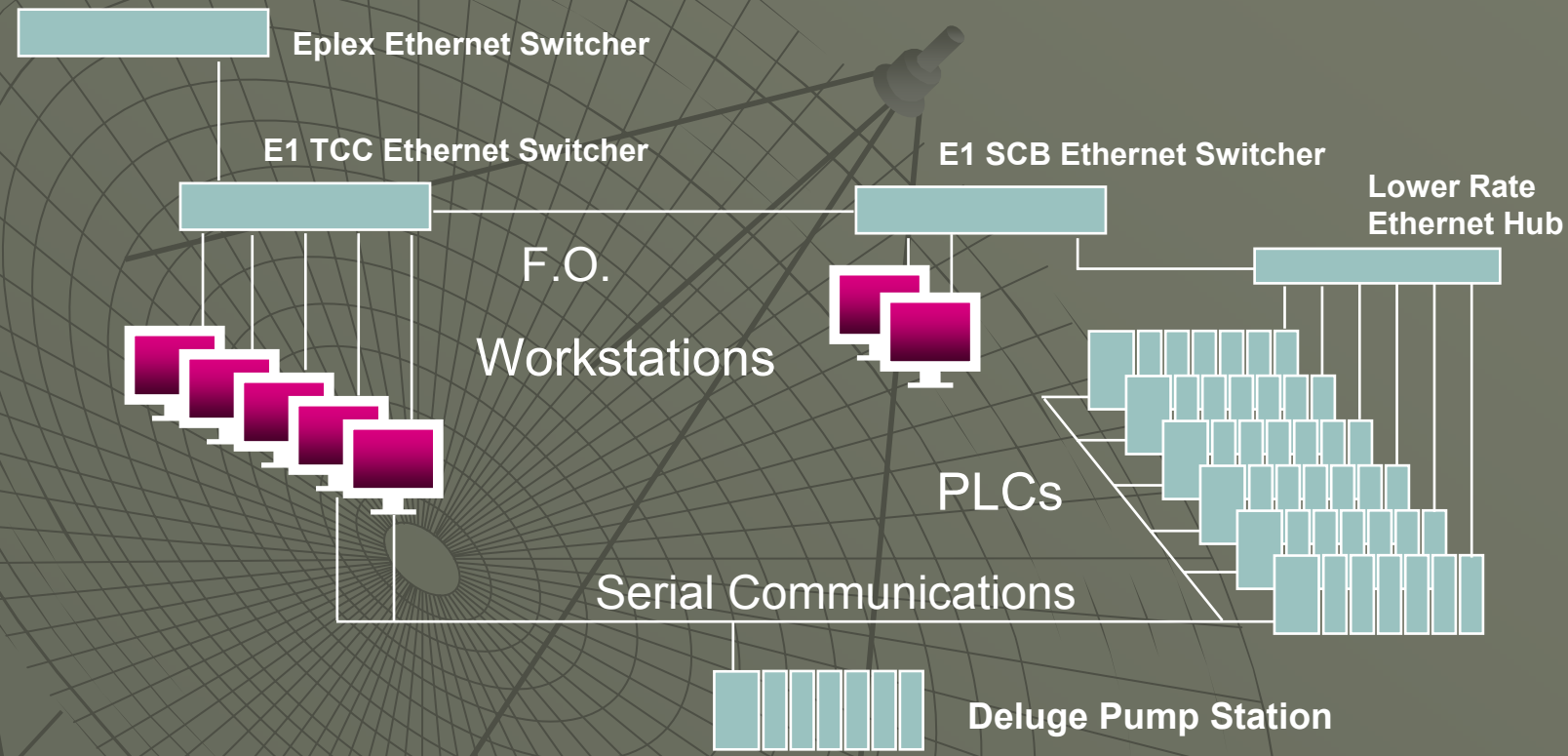
Historical Overview of Controls System at SSC – E1



E1 PLC Network Design

Stennis Space Center

Historical Overview of Controls System at SSC – E1



Typical E1 SLC Programmable Logic Controller (PLC) Installation

Historical Overview of Controls System at SSC – E1

E1 PLC Cabinet

- Dedicated STE PLC for Cell 2

DO AI

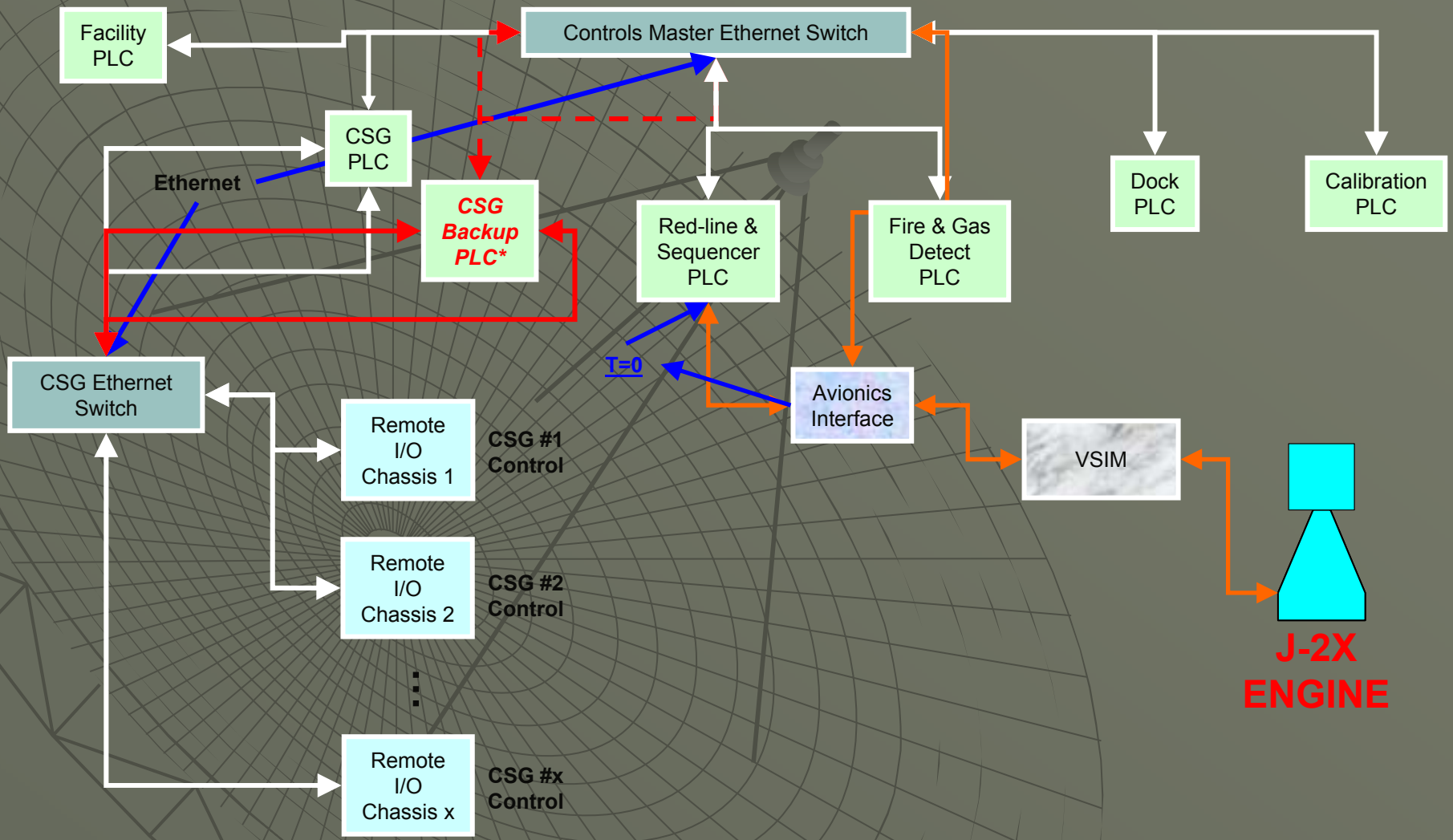
AO DI

- Shared Display PLC~

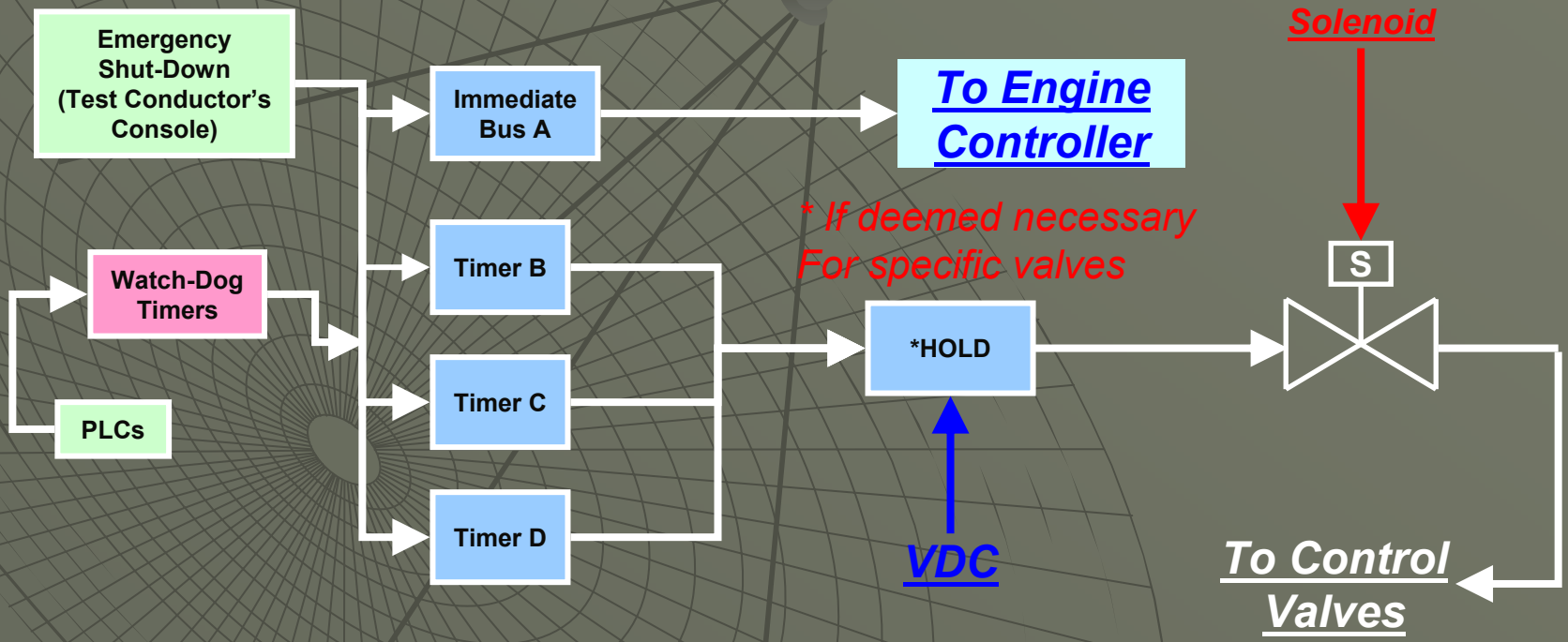
AI

DI

Proposed A-3 Control System Architecture



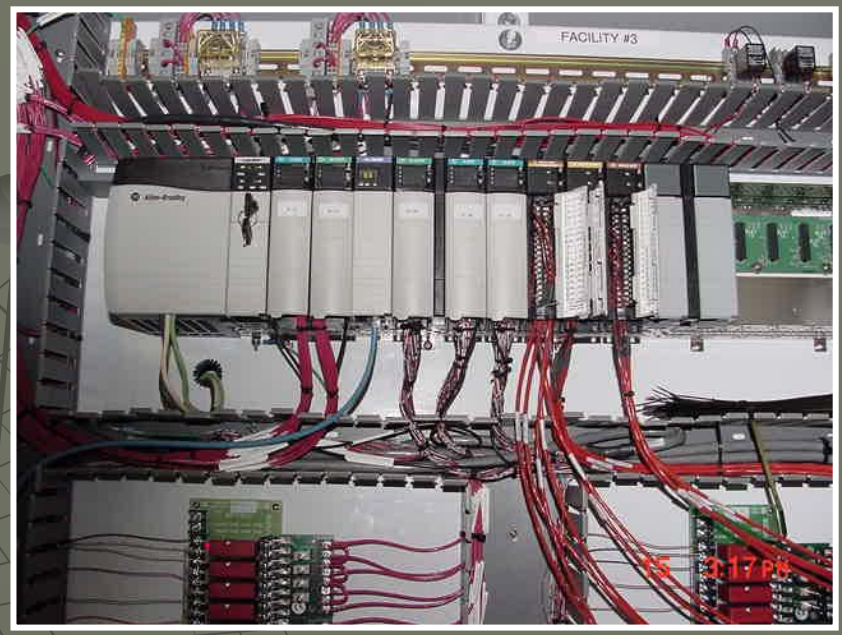
Proposed A-3 Control System Architecture



SSC PLC Architecture Changes

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

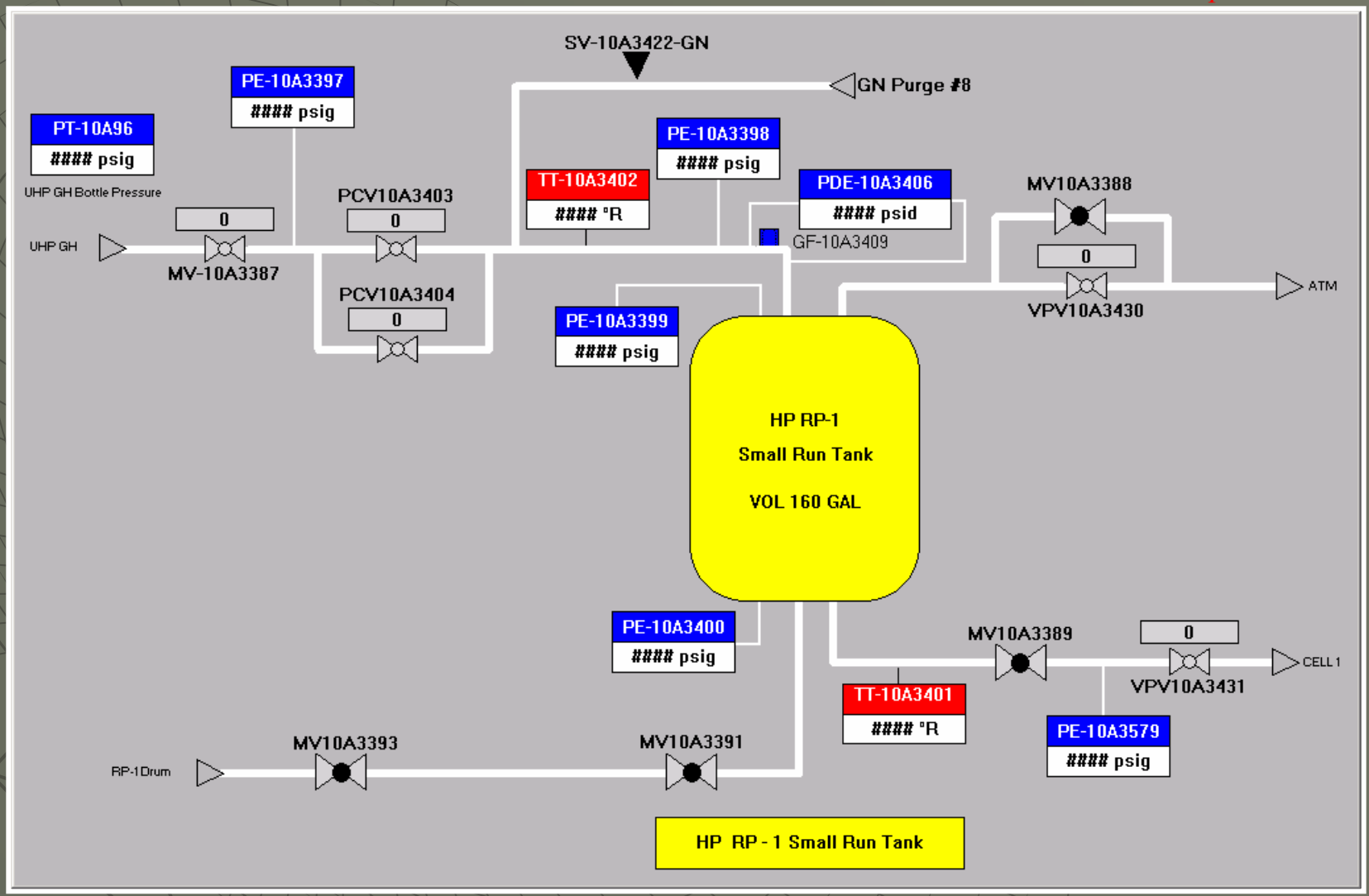
- A-Complex Redline System
- A-Complex Fire & Gas Leak Detect System
- B-Complex Redline System
- B-Complex Fire & Gas Leak Detect System in design
- E3 Redline System



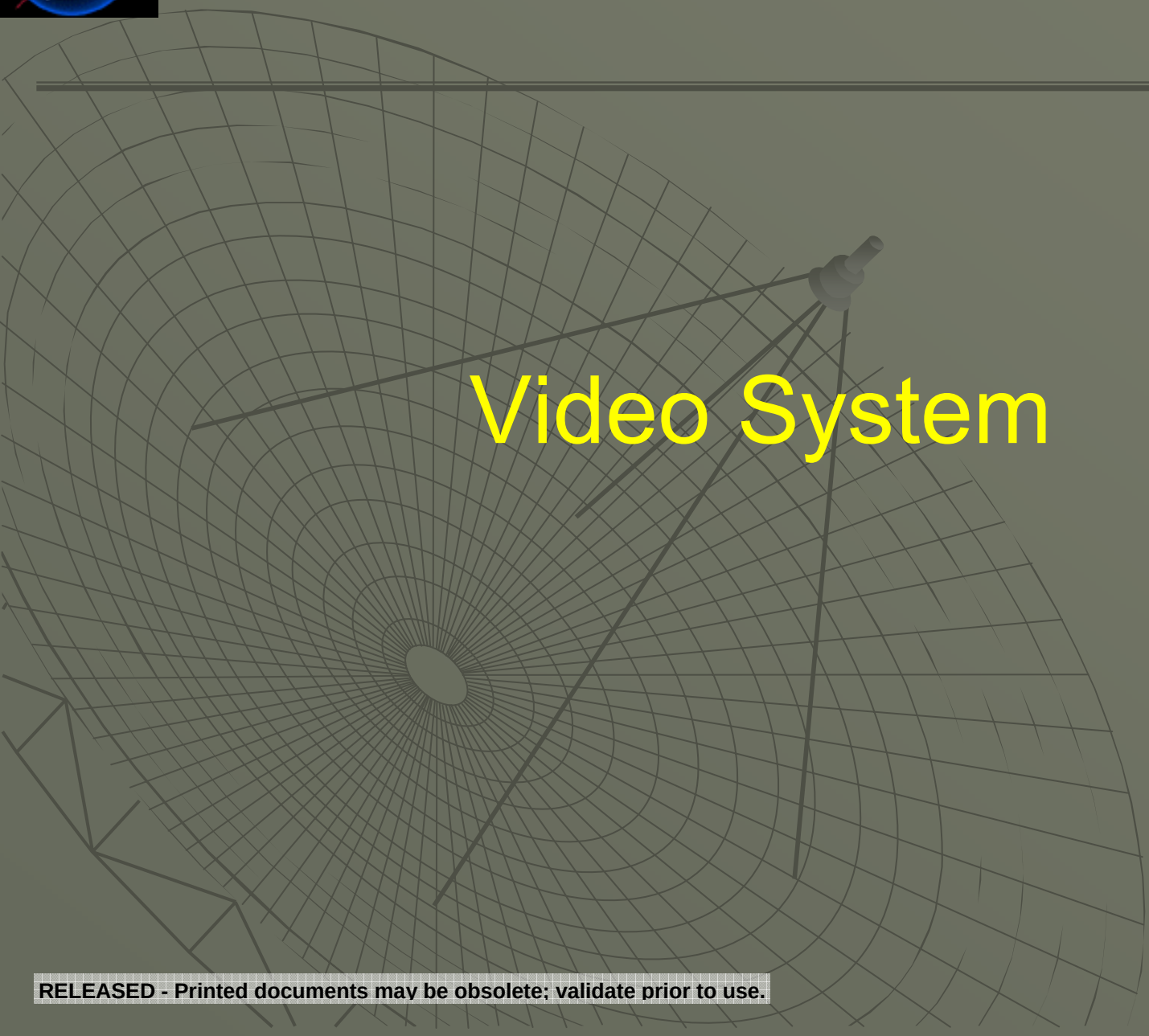
Modernized PLC

Test Control Center with Graphical User Interface (GUI) Screens

InTouch by Wonderware GUI



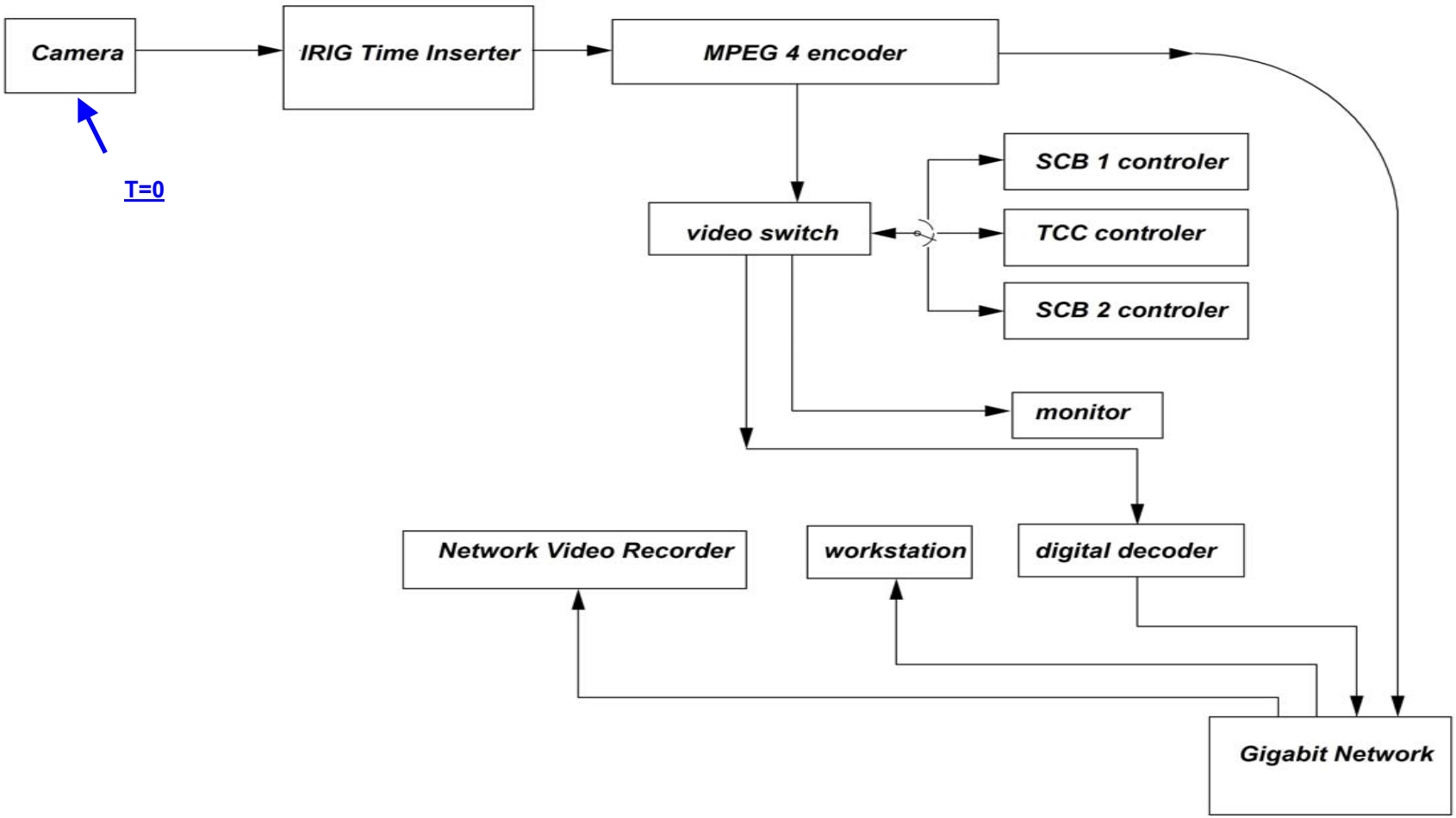
Video System



A-3 Test Stand Video System

- The A-3 Video System is envisioned to be a digital media video recording system. To this date at SSC, video recording system has been based upon a system that records to video tapes.
  - **A-3 TEST STAND VIDEO REQUIREMENTS:**
    - Must record digital data to either hard drive or DVD.
    - Low Speed frame rate of ~30 frames per second (fps). High Speed frame rate of ~200 fps or greater.
    - Recording time of >= steam generation time plus margin, minimum for both Low and High-Speed Video Systems.
    - Recording must be remote from the camera.
    - Cameras and/or enclosures must operate at expected vacuum pressures.
    - Must digitally stream real time Low Speed test video off-site.
    - Must support Infrared (IR) video.

A-3 Test Stand Video System



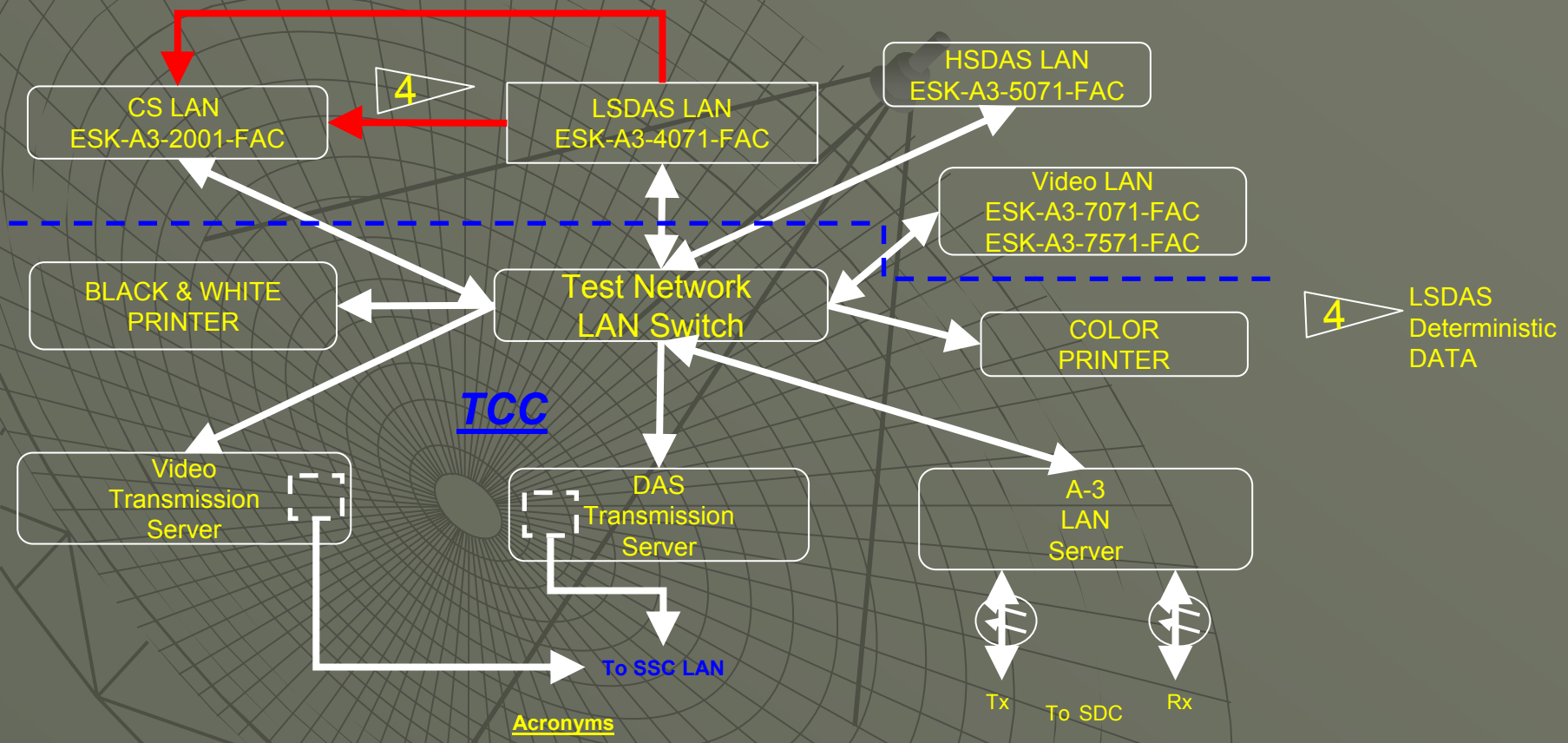
A-3 Test Facility Network Architecture

A-3 Network Architecture Description

- The A-3 Network System is designed to provide overall network connectivity between all of the sub-networks required for the A-3 Electrical Systems.
  - **A-3 TEST STAND NETWORK REQUIREMENTS:**
    - Test data network must be physically isolated from facility data network.
    - Transmission of “near” real-time data and video must use outgoing only physical connections.
    - Provide method of transmitting post-test data outside of Test Facility network.
    - Provide a means of digitally transmitting “deterministic” LSDAS data to the Control System.

A-3 Network Architecture Block Diagram

A-3 Test Facility LAN

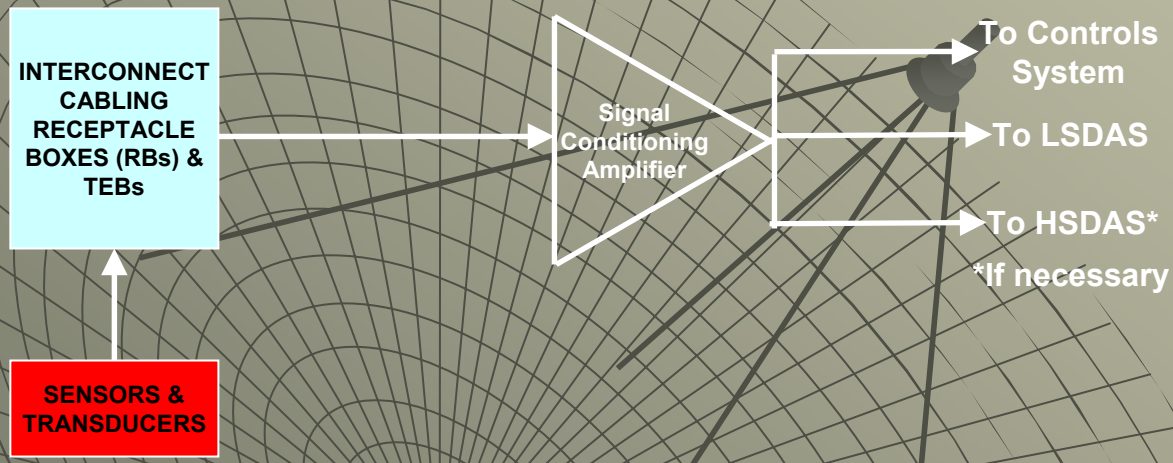


Acronyms

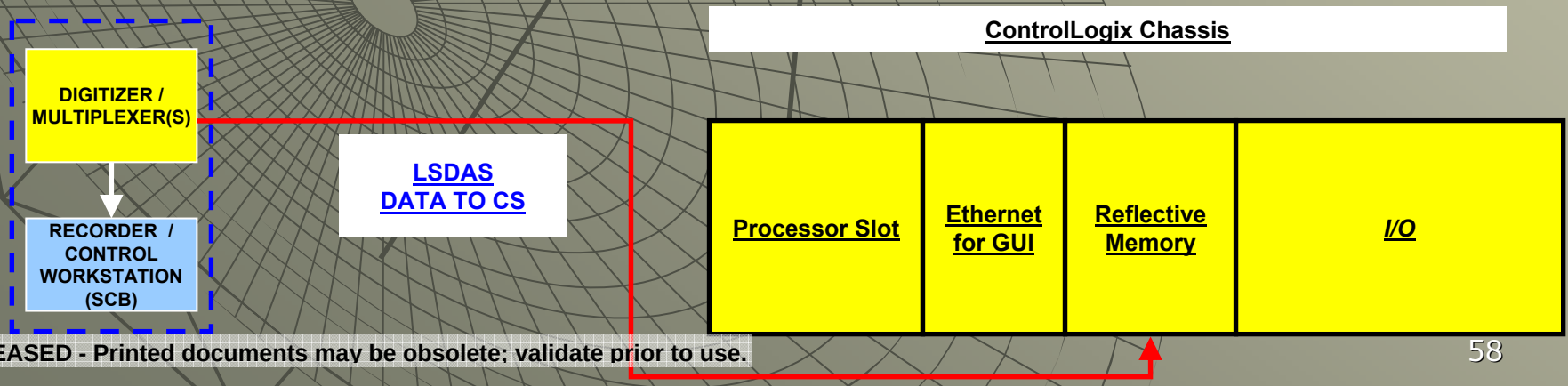
CS	Control System	SDC	Stennis Data Center
LSDAS	Low Speed Data Acquisition System	SSC	Stennis Space Center
HSDAS	High Speed Data Acquisition System	Tx	Transmit
			Receive
LAN	Local Access Network	TCC	Test Control Center

A-3 Network Architecture Block Diagram

Typical Control System Type Inputs



Networked Control System Connection



A-3 Network Architecture Block Diagram

- Advantages of network connectivity:
  - **Reduced Input modules to the controller:**
    - Reduce costs of acquiring unnecessary analog input modules
    - Reduce costs of wiring channels to the CS
    - Reduce effort of programming required for analog inputs
    - Reduce schedule by not requiring additional wiring, programming, and activation time.
    - Reduce space required to house CS channels
  - **Reduced potential failure points with less hardware**
  - **Potentially increased scan speed with fewer modules to query**
  - **Data consistent between LSDAS and Controls Systems**

- Disadvantages of network connectivity:
  - **Lack of comparison of measurements between systems (Controls vs. DAS)**
  - **Reduced independence of Controls operations.**
  - **Controls blindness if DAS fails**

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 high pressure regimes
- A-3 Test Stand Development is equally challenging with respect to accommodating vacuum environment, operation of a CSG system, and a large quantity of data system and control channels to determine proper engine performance as well as Test Stand operation.
- SSC is currently in the process of providing modernized DAS, Control Systems, Video, and network systems for the A-3 Test Stand to overcome these challenges.