Section 3:
Acceleration Measurement Systems

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Space Acceleration Measurement Systems (SAMS)

Project Manager

Presentation Agenda

- **Overview**
- **Carriers/Facilities Support Requirements**
- ***Space* Acceleration Measurement Systems (SAMS)**
  - Forerunners to Current Systems
    - High Frequency Generation I: SAMS
    - Low Frequency Generation I: OARE
  - Systems Currently Being Deployed
    - High Frequency Generation II: SAMS-II Elements
    - High Frequency Generation III: SAMS-FF Elements
    - Low Frequency Generation II: MAMS
- **Mission Operations**
  - On-Orbit & Ground
- **Future Development**
- **Acceleration Measurement Customers**

Overview

- **Initial Acceleration Measurement Systems**
  - High Frequency Data (Space Acceleration Measurement System)
  - Low Frequency Data (Orbital Acceleration Research Experiment)

- **International Space Station**
  - High/Low Frequency Accelerations
  - Need for Microgravity Acceleration Data
    - Microgravity Community (PIs, Mission & Project Scientists, PIMS)
    - ISS Vehicle Characterization
    - Information to ISS Crew
  - Measure, Process, Record, & Downlink Acceleration Data
  - Distribute Sensors Throughout ISS
  - Long ISS Mission Duration (Years) vs. Shuttle (~ Two Weeks)
  - Real Time Data Analysis Required
  - Data Acquisition and Parameter Control at PI Sites
  - Real Time Operations

Overview (continued)

- **Future Shuttle Missions, Sounding Rocket, KC-135, and other**
  - High/Low Frequency Accelerations
  - Microgravity Community (PI's, Mission & Project Scientists, PIMS)
  - Measure, Process, & Record Acceleration Data
  - Distribute Sensors Throughout Payload
  - Short Duration Missions
  - Data Analysis Required (Supplied by PIMS)
  - Data Acquisition and Parameter Control by PI's

Carriers/Facilities Support Requirements

- **Support Requirements for the International Space Station**
  - Based on PIMS-001, Experiment Support Requirements Document
  - Frequency Measure Range: Quasi-Steady to 300 Hz
  - Quasi-Steady Specification: component perpendicular to the orbital average acceleration vector must be < 0.2×10^{-6} g
  - Acceleration Magnitudes: 0.01 µg to 100 mg
  - Disturbance Triggers: 1 µg to 1 mg
  - Triaxial Sensor Close to Test Cell
  - Align One Sensor Axis with Test Section Axis
  - Onboard Recording of Data for Later Retrieval
  - Experiment Run Time: 1 msec to 1 hr
  - Experiment Process Time: 1 min to 100 days
  - Data Presentation Planned During Operations
    - Acceleration vs. time continuously with running averages
    - Acceleration vs. frequency continuously
    - Power Spectral Density (5 minute updates)

ISS Experiment Measurement Requirements

Experiment Type	Frequency Range	Measurement Level
Biotechnology	QS – 10 Hz	100 µg and above
Fluid Physics	QS – 300 Hz	1 µg to 1 mg
Combustion Science	QS – 50 Hz	10 µg and above
Fundamental Physics	QS – 180 Hz	0.1 µg and above
Material Science	QS – 300 Hz	0.01 µg and above

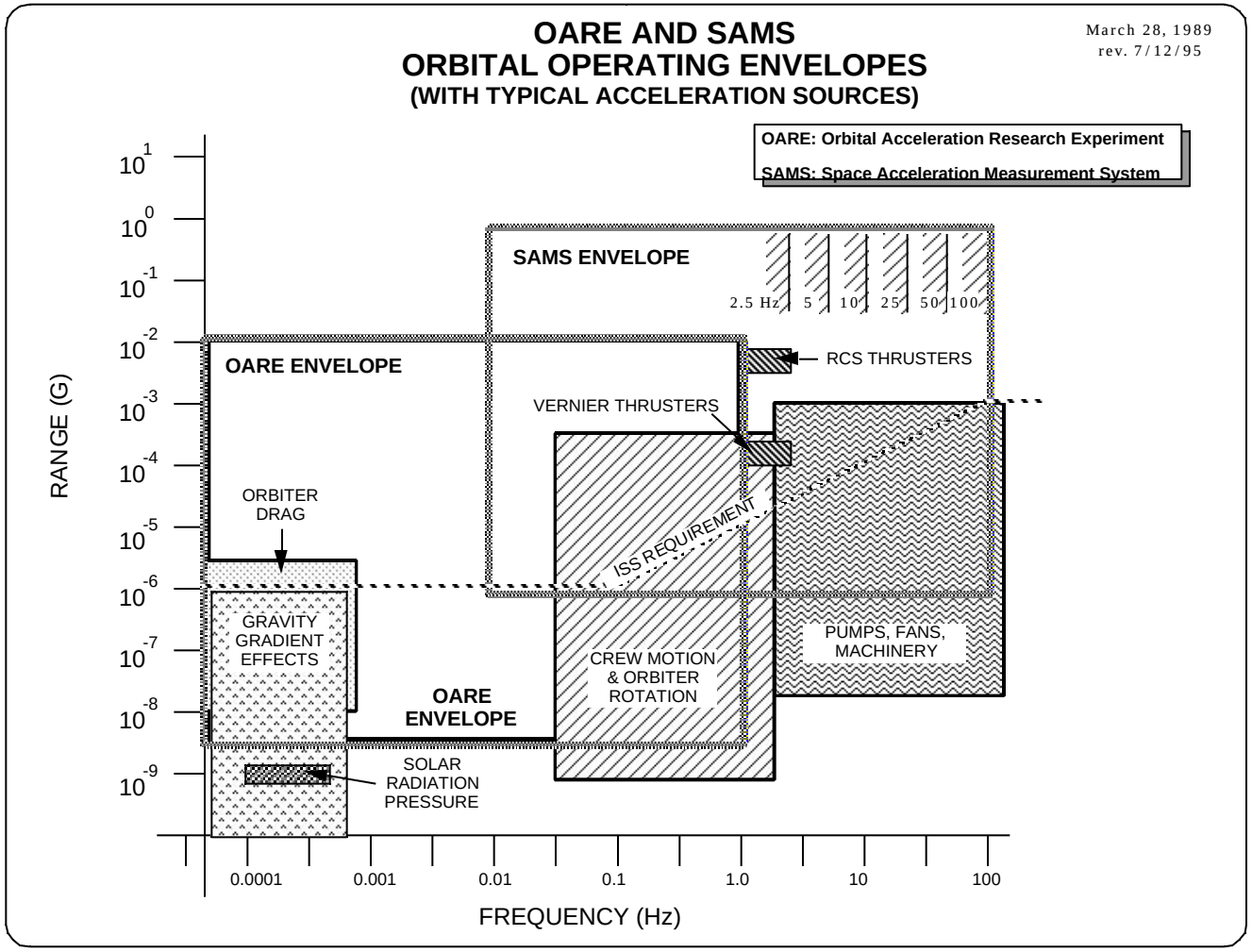
Carriers/Facilities Support Requirements (continued)

- **Future Shuttle Missions, Sounding Rocket, KC-135, and other**
  - Requirements compiled as customers are obtained
  - Frequency Measure Range: Quasi-Steady to 100 Hz
  - Acceleration Magnitudes: 0.01 µg to 100 mg
  - Configurable Modular Hardware and Service Package
  - Triaxial Sensor Close to Area of Interest
  - Align One Sensor Axis with Test Section Axis
  - Onboard Recording of Data for Later Retrieval
  - Support Short and Long Duration Activities
  - Experiment Process Time: 1 min to 100 days
  - Data Presentation Planned During Operations
    - Acceleration vs. time continuously with running averages
    - Acceleration vs. frequency continuously
    - Power Spectral Density (5 minute updates) (Shuttle only)

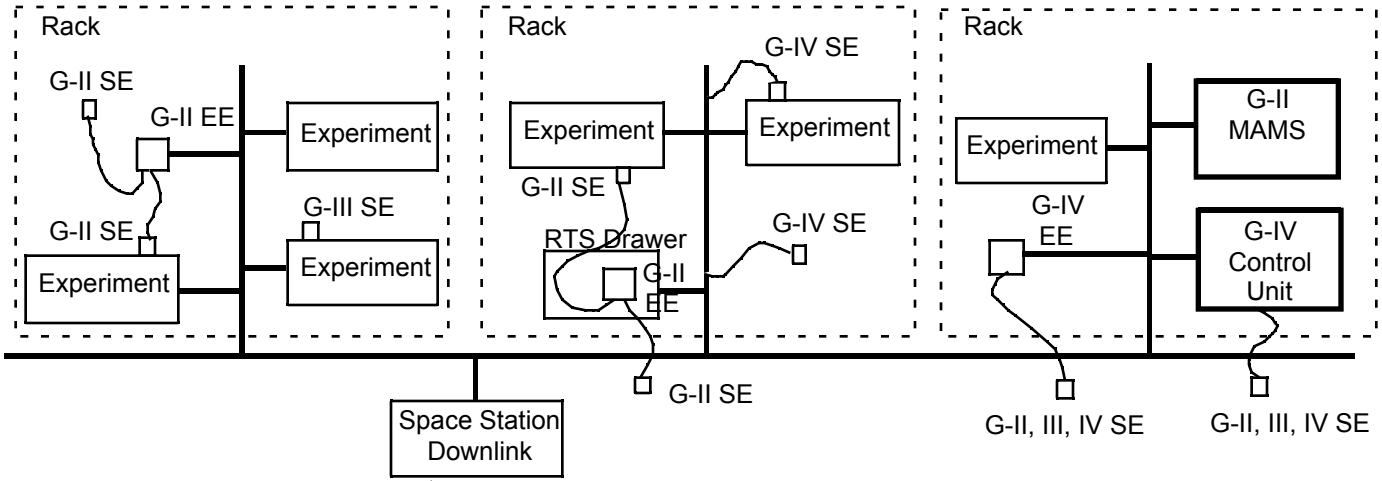
Early Shuttle Microgravity Measurements

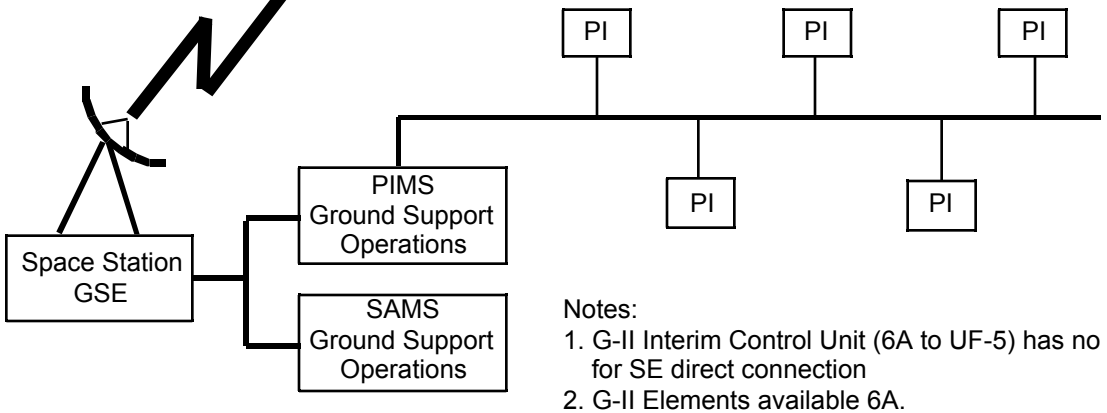
- **Microgravity Environment Description Handbook (NASA TM 107486)**
- **Acceleration Data Stored on Web Server**
- **NASA Glenn Systems**
  - Space Acceleration Measurement System (SAMS)
    - 20 Shuttle Flights, 7 Units (1991 to 1998)
    - Measured Acceleration Range: 0.01 to 100 Hz
  - Orbital Acceleration Research Experiment (OARE)
    - 8 Shuttle Flights, 1 Unit (1991 to 1997)
    - Measured Acceleration Range: DC to 1 Hz
- **Other Systems**
  - High Resolution Accelerometer Package (HiRAP)
  - 3-Dimensional Microgravity Accelerometer (3DMA)
  - Microgravity Measurement Device (MMD)
  - Quasi-Steady Acceleration Measurement (QSAM)
  - Microgravity Measurement Assembly (MMA)

Early System Capabilities (Generation I)



Deployment of SAMS Generation II Elements on ISS





Notes:
1. G-II Interim Control Unit (6A to UF-5) has no support for SE direct connection
2. G-II Elements available 6A.
3. G-III Elements available UF-1.
4. Control Unit available UF-5.

High Frequency Generation II System: SAMS-II

- **Remote Triaxial Sensor (RTS) System**
  - Consists of one Electronics Enclosure and two Sensor Enclosure's
  - Acquires acceleration data
  - Performs initial processing of the acceleration data
  - Transmits the acceleration data to Control Unit
- **Interim Control Unit (ICU) Up to UF-5**
  - Stores acceleration data for later analysis
  - Provides control of the RTS systems
  - Provides acceleration data downlink capability
  - Facilitates display of acceleration data on crew laptops
- **Ground Operations Equipment (GOE)**
  - Acquires acceleration data from ISS downlink (SAMS/PIMS)
  - Stores acceleration data for later retrieval (PIMS)
  - Transmits acceleration data to PI sites for analysis (PIMS)

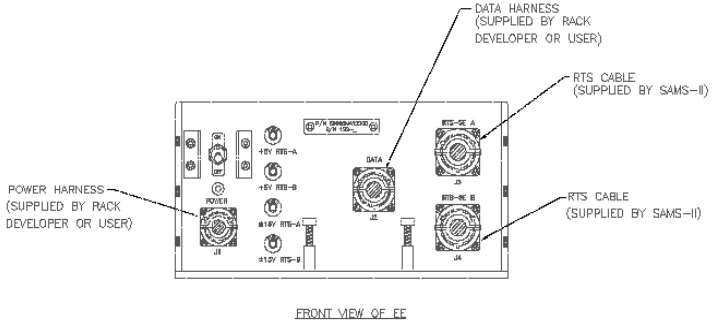
Initial High Frequency Generation II Deployment

- **Remote Triaxial Sensor (RTS) System**
  - Up to Ten RTS Electronics Enclosures (EE's)
  - Up to Two RTS Sensor Enclosures (SE's) per EE
- **One Control Unit (Interim Control Unit from UF-1 to UF-5)**
- **Utilization of ISS Payload Ethernet**
- **Ground Operations**
  - GRC Telescience Support Center (TSC)
  - PI Sites
- **Future Upgrades**

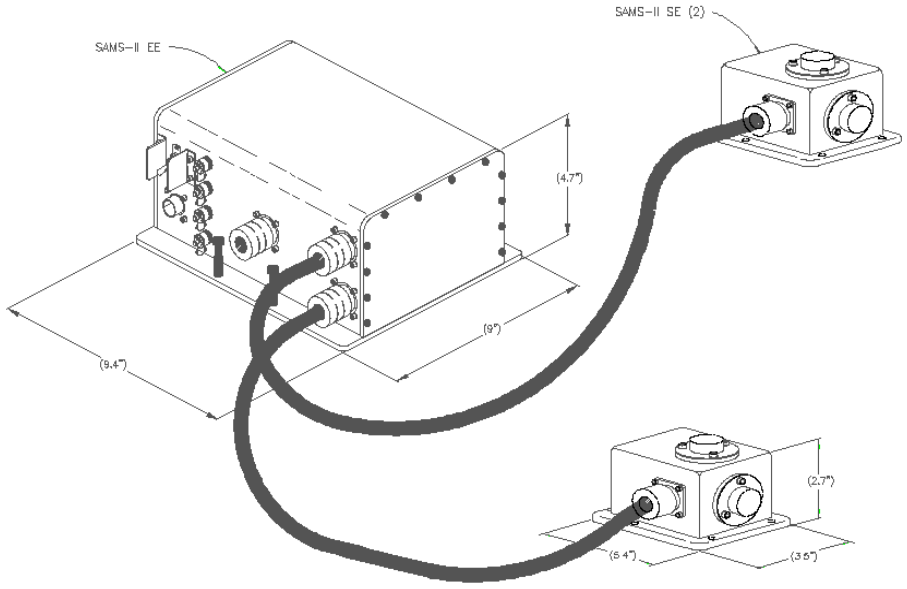
High Frequency Generation II: RTS Description

- **RTS Electronics Enclosure (EE)**
  - Located in EXPRESS or Facility Racks
  - Physical Properties: 9.1 in X 9.3 in. X 4.7 in. & 11.0 LB.
  - Up to Ten EE's for ISS modules
  - Receives Data from SE's
  - Performs Low Level Processing (Temp. Comp. & Axial Misalign.)
  - Transmits Processed Data to ICU/CU
- **RTS Sensor Enclosure (SE)**
  - Located near Microgravity Payloads
  - Physical Properties: 5.6 in X 4.0 in. X 3.5 in. & 2.5 LB.
  - Up to Two SE's per EE
  - Measures Acceleration Data

High Frequency Generation II: Remote Triaxial Sensor (RTS) System



EE – ELECTRONICS ENCLOSURE
SE – SENSOR ENCLOSURE



SAMS-II REMOTE TRIAXIAL SYSTEM (RTS)

General Purpose Generation II RTS Capabilities

- Orthogonal acceleration measurements at two locations
- 24 Bit Resolution
- Single Gain
- Dynamic Range: 130 dB (0.1 µg to 1g)
- Selectable Frequency Ranges: 300, 200, 100, 50, 25 Hz
- Temperature measurement and acceleration data compensation

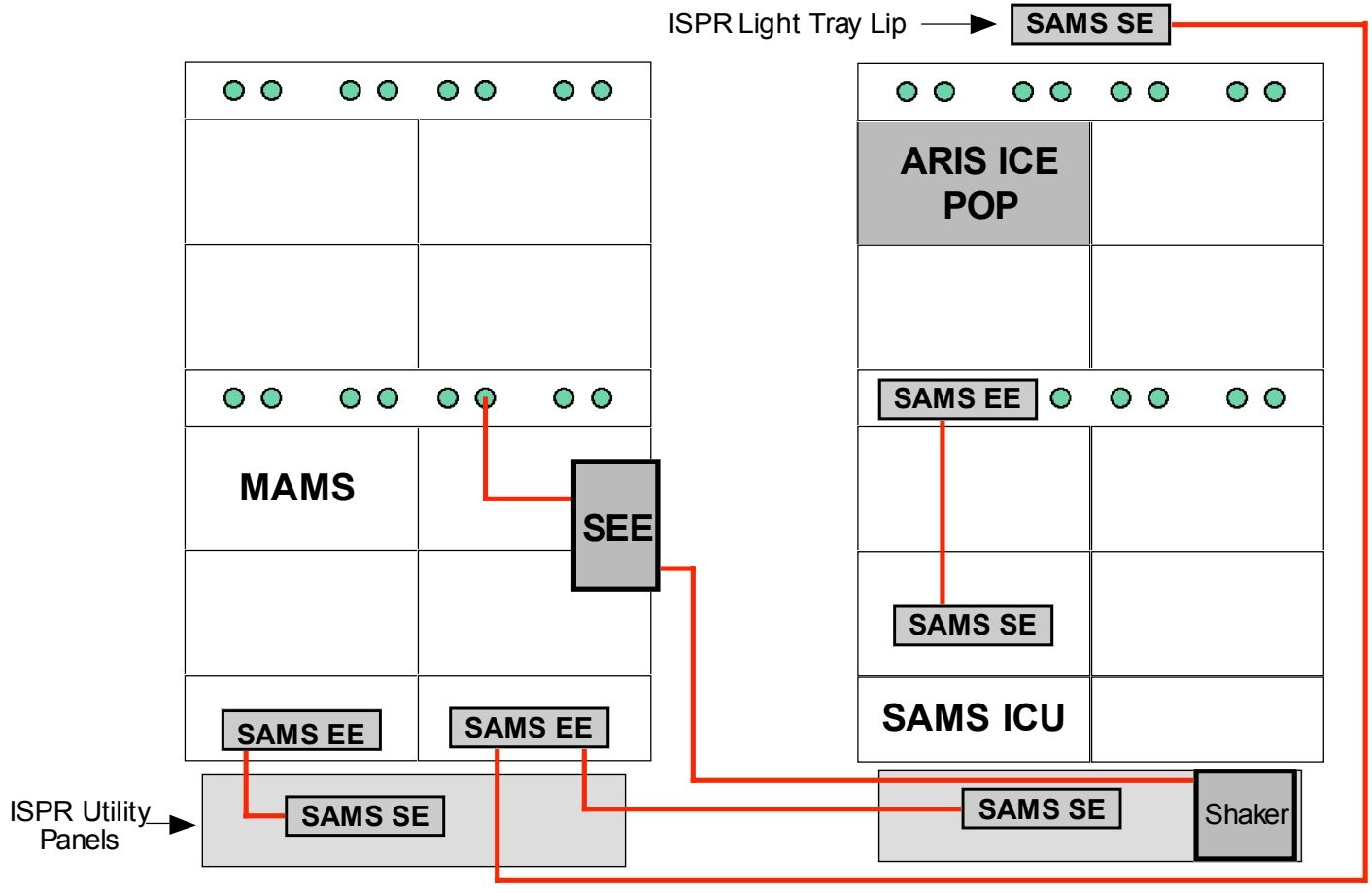
Generation II: Interim Control Unit (ICU)

- **Housed in EXPRESS Rack ISIS Drawer**
- **Connected to the Payload Ethernet Network**
  - For Acquisition of Acceleration Data
  - For Downlink to SAMS-II Ground Operations Equipment (GOE)
  - Receipt of Uplink Commands
- **Interim Control Unit (ICU) Components (UF-1)**
  - ISS Laptop Computer (Portable Computer System - PCS)
  - Power Control Box
  - Limited Data Storage
- **Generation IV Control Unit (CU) Components (UF-5)**
  - High Level Data Processing Capability
  - Removable Media
  - Direct Connection of Sensor Enclosure (Generation II,III,IV)

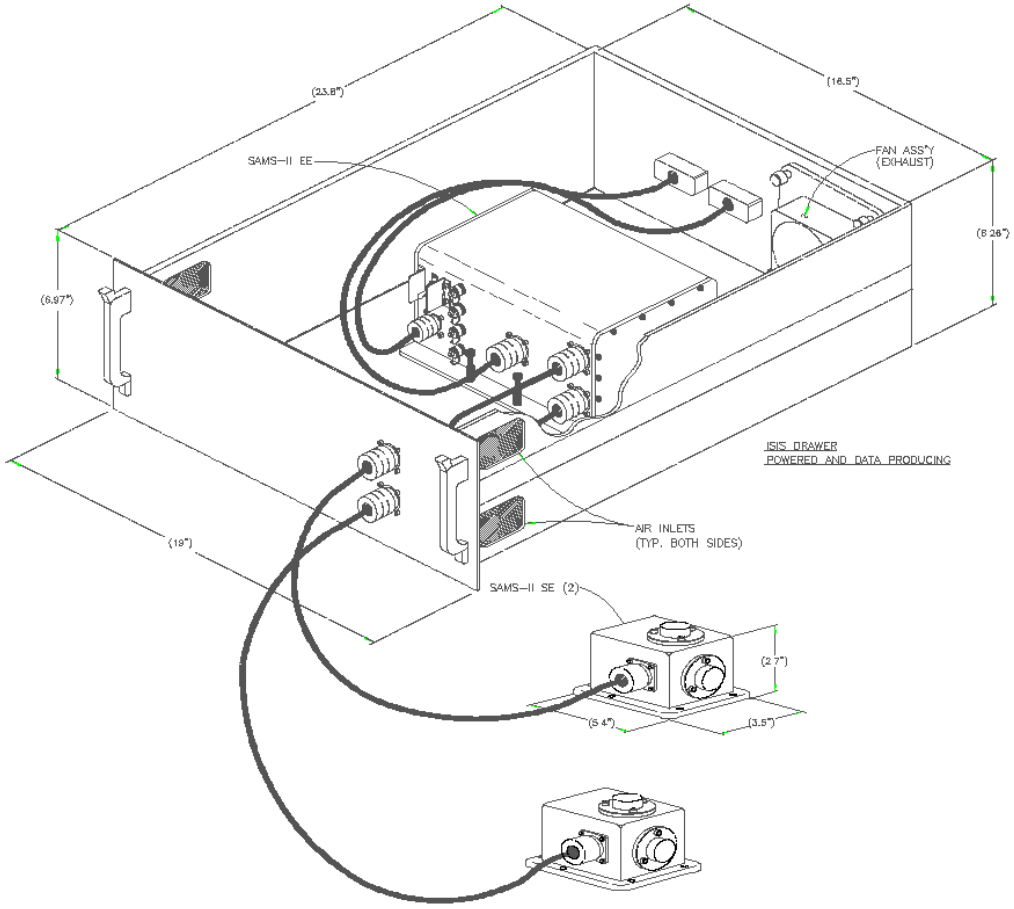
ARIS Initial Characterization Experiment

- **ARIS - Active Rack Isolation System (See Section 14)**
  - **Isolates Experiments from ISS Disturbances**
  - **Developed by Boeing for ISS Program**
- **ARIS ICE - ARIS Initial Characterization Experiment**
  - **Determines ARIS Performance Early in ISS Life**
  - **Utilizes Off-Rack Shaker and On-Rack & Off-Rack Accelerometers**
- **SAMS Support for ICE (UF-1 to UF-2)**
  - **On-Rack: One EE and One SE Dedicated to PCS Experiment**
  - **Off-Rack: Two EE's and Three SE's Dedicated to ARIS ICE**

ARIS Initial Characterization Experiment Layout



RTS-EE in ISIS Drawer for ARIS ICE



CONCEPT FOR SAMS–II RTS FOR ISIS DRAWER

Low Frequency Generation II: Specifications (MAMS)

- **MAMS contains a Miniature Electro-Static Accelerometer (MESA) which has a resolution of 3 x 10^{-9} g.**
  - **The MESA consists of an electro-statically suspended, beryllium, cylindrical proof-mass which is kept centered within an outer "cage" through the use of forcing electrodes.**
  - **The forcing voltage required to keep the cylinder centered is proportional to the acceleration of the outer cage.**
- **MAMS contains a Bias Calibration Table Assembly (BCTA) which allows for the measurement of the sensor bias.**
  - **Sensor bias arises from electro-static charge build-up and temperature gradients on the beryllium cylinder proof-mass.**
  - **Correcting MAMS acceleration data for bias results in an expected accuracy of approximately 50 x 10^{-9} g.**
- **MAMS Frequency Range: DC to 1 Hz.**

Generation III System: SAMS-FF

- The modular SAMS-FF hardware package includes three different types of sensors, a control and data acquisition module, data storage devices, and ground support equipment interfaces.
- The three different types of tri-axial sensors combine to measure both high and low frequency accelerations and the roll rate of the spacecraft.
- Smaller, lighter, more flexible, and more power efficient than its predecessors
- Standard interface for "stand-alone" acceleration sensor head operation - connect to any computer serial port
- Choice of data storage mediums (flash memory, hard disk, etc.)
- Real-time data access when a telemetry downlink is available
- Custom system configurations for special needs (such as additional sensor heads) easily accommodated
- Post-mission data processing available through the PI Microgravity Services data-analysis team

Generation III SE: Tri-axial Sensor Head (TSH)

- Allied Signal QA 3000 sensors
- Sensor output signal conditioning and filtering
- Adjustable frequency bandwidth, 0-200 Hz (under software control); can be changed during operation
- 24-bit Delta-Sigma analog-to-digital conversion for low noise and large dynamic range
- Over sampling rate at 3.8 to 1
- Full-scale range:
  - up to ~78 milli-g (for operation, at gain of 16)
  - up to 1.25 g (for ground calibration, at gain of 1)
- Sensor temperature measured on each individual axis
- RMS-to-DC measurements --- abbreviated sensor data
- RMS measurement at 600 Hz bandwidth and 0.1g full-scale with minimum crest factor of 5
- Digital signal output(RS-422): low noise, small cables (DB-9 connector)
- Can be used stand alone with a standard RS-422 interface and ±15V power supply
- Only 1.6 W power consumption (±15VDC)
- Compact, light enclosure: 2.9" x 2.9" x 2.8"

Generation III: Fiber Optic Gyro (FOG)

- **Designed to measure roll rate - data will tell how well the spacecraft stabilizes in orbit and the refinement of the satellite onboard control system pointing capability.**

  Some features:

  - **Fiber optical gyroscope with no moving parts**
  - **Low scale factor and bias**
  - **Random walk at 1 deg/hour on any axis**
  - **Low frequency acceleration data can be derived**
  - **Record of available onboard stabilization signals**
  - **Interface electronics in separate package.**

- **Planned deployment on Sounding Rocket and Shuttle.**

Generation III: Specifications

- Acceleration Sensitivity: 10 ng, 0-2 Hz (MSS); 0.6 µg, 0-10 Hz (TSH)
- Acceleration Bandwidth: 0-200 Hz (TSH) Software selectable during operation
- Acceleration Range: ±1.25 g (TSH)
- Number of high freq. sensor enclosures (TSH): 1, 2, 3 or more
- TSH cable length (max): 20 m
- Roll-Rate Sensitivity: 0.1 arc sec
- Roll-Rate Bandwidth: 190 deg/sec
- Data Storage flash(solid state) or hard drive
- Synchronization Options: IRIG-B, GPS, 8-bit digital control and status interface
- Downlink Interface: RS-232 or 422
- Operator intervention: Not Required
- Power Consumption: 1.6-50 W depending on configuration
- Size of CDU (main unit): approximately 5.3" x 5.3" x 5"

High Frequency Acceleration Measurement Systems Comparison

	SAMS	SAMS Upgrade	SAMS-FF	SAMS-II ICU	SAMS-II CU
Vehicle	Shuttle / Mir	Shuttle	Sounding Rocket, Free Flyer, Shuttle, or ISS	ISS	ISS
Concept Development	1987	1995	1996	1996	1994
First Flight	1991	1997	1997	2000	2002
No. of Flights	20 + Mir	2 + 3 more planned	1 + HOST mission (others planned)	Three years in ISS	Seven years in ISS
Sensors Heads	3 per unit	3 per unit	3 per unit	~ 10	~ 20
Frequency Range	Fixed @ 2.5, 5, 10, 25, 50, or 100 Hz	Fixed @ 2.5, 5, 10, 25, 50, or 100 Hz	Selectable in real time up to 200 Hz	Selectable in real time up to 400 Hz	Selectable in real time up to 400 Hz
Low Frequency Capability	Post Mission with OARE data	Post Mission with OARE data	MESA Sensor Subsystem	Real Time with MAMS	Real Time with MAMS
Sensor Distance from Unit	20 ft.	50 ft.	Limited only by RS-422 and / or power drop	Limited only by Ethernet	Limited only by Ethernet
Digital Conversion Location	In Main Unit	In Main Unit	In Sensor Head	In Sensor Head	In Sensor Head
Crew Display	Only for MPESS (1996)	Only for MPESS (1997)	GSE Laptop Display	Onboard Display via Crew Laptops	Integral Onboard Display on CU
Storage Devices	Optical Drives (200 MB per disk)	Hard Drives (2.1 GB per drive)	Configurable (Flash or Hard Drive)	PCS Laptop with Hard Drive	Magneto-Optical & Hard Drive
Data Collected	~ 2 GB per mission	~ 2 GB per mission	Mission dependent	~ 50 GB per inc.	~ 130 GB per inc.
Role Rate Sensor	No	No	Yes, Fiber Optic Gyroscope	No	No
Real Time Processing	Post Flight	Post Flight	Possible in future	Low Level	High Level (DSP)

ISS Initial Mission Operations On-Orbit

- Pre-mission installation of EE's and some SE's planned
- Ability to perform on-orbit EE replacement limited by accessibility within payload rack
- Installation or movement of additional SE's
- No RTS open box maintenance
- Set-up of ISS PCS laptop and associated cables in ICU
- Two removable laptop hard drives for onboard data collection
- ICU laptop can be exchanged for another ISS PCS laptop
- Selective acceleration displays available to the crew on ISS PCS laptops via Payload Ethernet

ISS Initial Mission Operations on Ground

- **SAMS Operations at GRC Telescience Support Center .**
  - Control SE, EE, or ICU on/off modes and SE frequency ranges
  - Communicate maintenance operations to the crew
  - Screen all PI commanding operations
  - Limit operations staff by utilizing selected programmed routines
- **PI Sites**
  - Communication links with GRC TSC via World Wide Web
  - Ability to selectively view PIMS acceleration data displays
  - Command SE frequency range, data start and stop times, and limited data recording (Fully implemented with Generation IV Control Unit)
- **PIMS Operations**
  - Control MAMS on/off modes.
  - Process SAMS data, provide data analyses for PI's, characterize ISS environment, and identify ISS disturbances.

Future Development

- Develop and deploy Generation IV Control Unit with increased processing capability and interfaces.
- SE and EE Size Reduction (Generation IV)
  - Generation III Packaging Improvements Utilized
  - Sensor Miniaturization Technology Considered
  - Universal Serial Port and Ethernet capabilities for SE's
- Software Modifications to support communication of other Acceleration Systems with Control Unit (MAMS)
- Package Acceleration System for External Facility on JEM Porch
- Identification of Disturbance Signatures on User Displays

Current Customers for SAMS

- **PI Measurement Services (PIMS)**
- **ISS Customers**
  - ARIS EXPRESS Racks (Eight Racks Planned)
  - Physics of Colloidal Spheres (PCS) Experiment for UF-1
  - ARIS ICE for UF-1
  - Combustion Integrated Rack (CIR) for UF-3
  - Material Science Facility
  - BioTechnology Facility (BTF)
  - Fluids Integrated Rack (FIR) for UF-5
  - Microgravity Science Glovebox (MSG)
  - Low Temperature Microgravity Physics Facility (LTMPF)
- **Shuttle**
  - STS-107 Payloads
  - STS-117 Payloads
- **Sounding Rocket**
  - Terrier Orion Characterization
  - SAL
- **KC-135 (6 flights planned FY2000)**