End-to-End Assessment of SLS Artemis-1 Development Flight Instrumentation

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SLS Artemis-1 Overview

- **NASA's Artemis-1 will be the first integrated flight test of NASA's deep space exploration system (SLS)**
  - Non-crewed scientific mission
- **NASA intends to use Artemis-1 to verify vehicle flight dynamic models, including:**
  - Structural modes
  - Buffet/aeroacoustic environments
  - Pogo models
  - Random vibration environments
  - And more

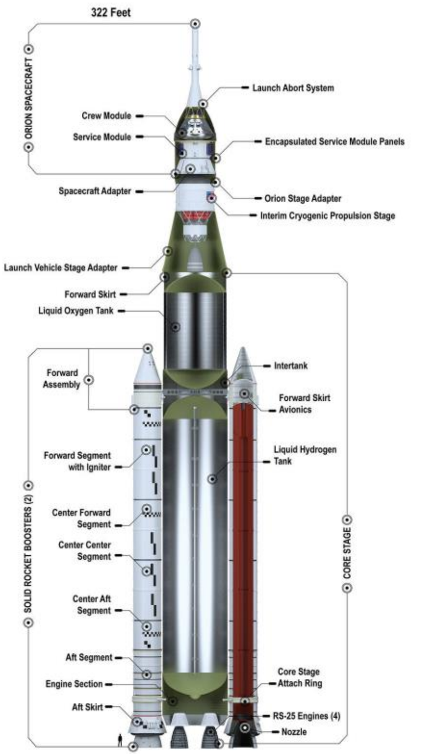
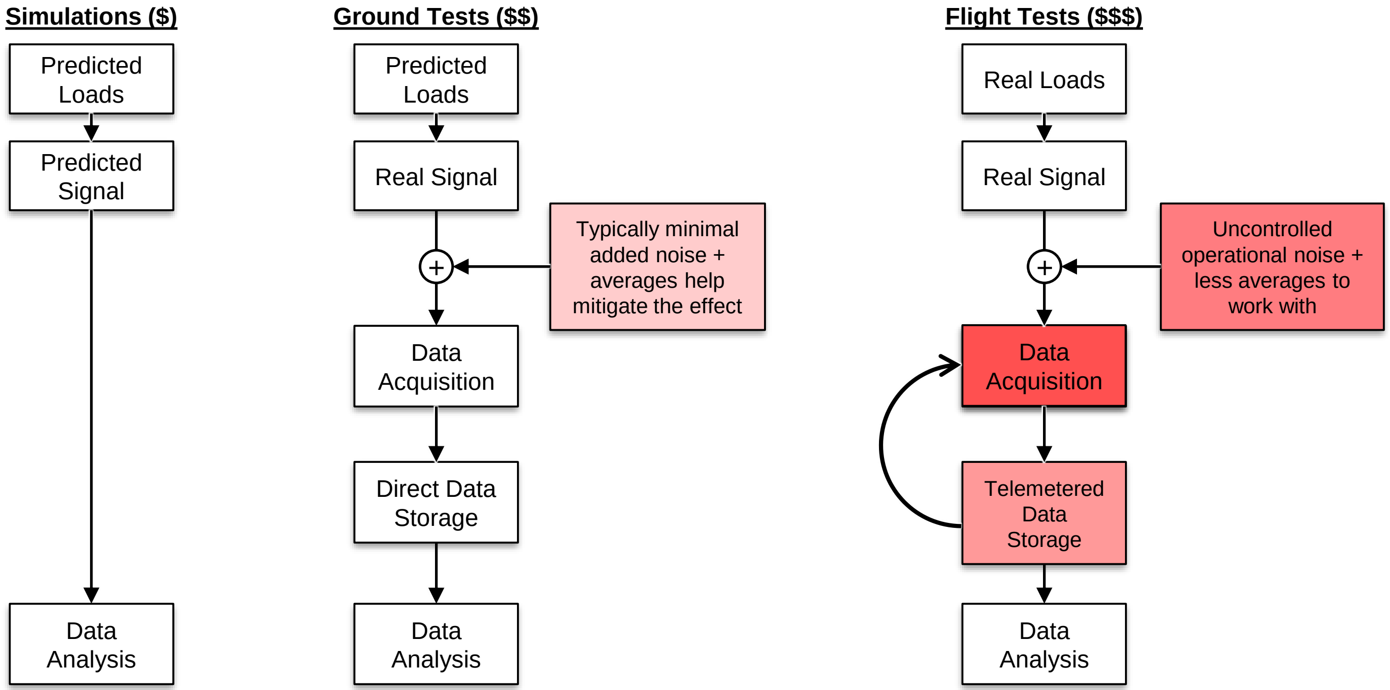


*Image from: https://www.nasa.gov/exploration/systems/sls/multimedia/block-1-70metric-ton-major-elements-illustration

Operational Flight Measurements

- **Flight data measurements offer greatest potential for system model characterization**
  - Accurate boundary conditions
  - Real loading
  - Accurate dynamic fuel conditions
  - Measure unpredicted events

Challenges with Flight Measurements

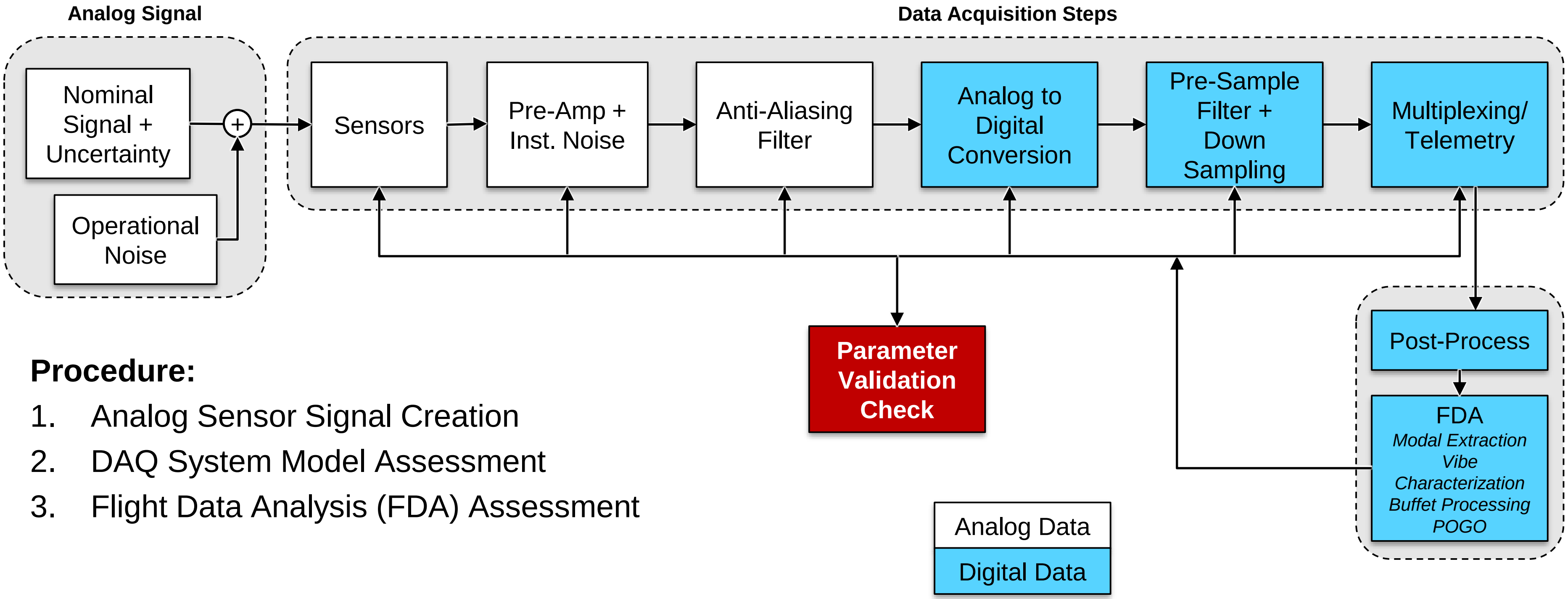


Investigation Overview

- **Objectives:**
  - Predict performance of Artemis-1 Development Flight Instrumentation (DFI) for Flight Test Objectives (FTO)
  - Pinpoint problem areas and recommend fixes
- **Multiple FTOs investigated**
  - Simulated data acquisition process
  - Performed mock Flight Data Analysis (FDA)

FTO	Sensors				
	Low Freq Accels	High Freq Accels	Internal Pressure	External Pressure	External Mics
Modal Extraction	X				
Vibration Characterization		X			
POGO	X		X		
Aero/Buffet				X	X

DFI Simulation Overview

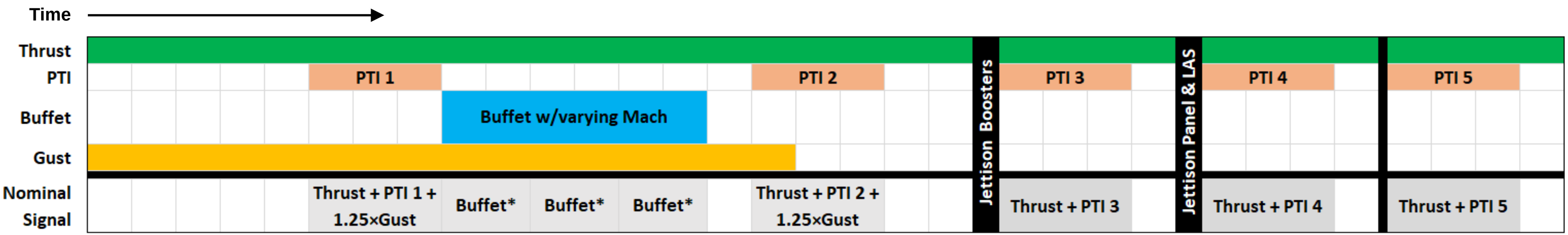


Procedure:

1. Analog Sensor Signal Creation
2. DAQ System Model Assessment
3. Flight Data Analysis (FDA) Assessment

Nominal Signal Predictions

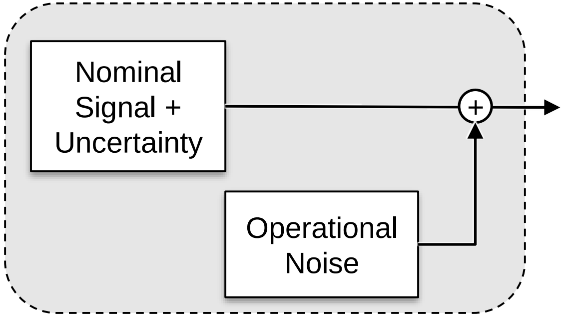
- **Nominal signals = portion of signal we want to measure**
- **Signal predictions unique based on FTO:**
  - Low frequency accelerometers: recovered signals from CLA transient analysis
  - High frequency accelerometers: predicted vibration environments
  - Buffet pressure sensors and aeroacoustic microphones: signals from full scale wind tunnel data
  - Pogo pressure and acceleration: derived from state-space matrices

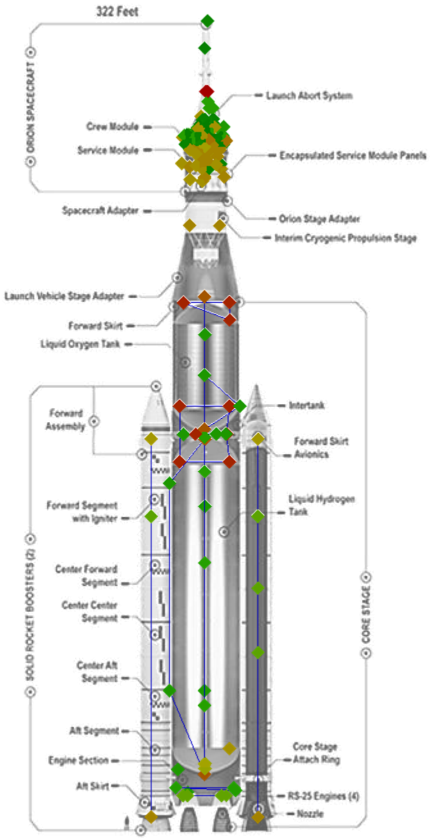


Operational Noise Estimation

- **Aero-acoustics assumed to be largest contributor to unwanted sensor noise**
  - NASA had assessed max predicted environments (MPE) based on wind tunnel data and aeroacoustic models
  - MPEs defined as PSDs by zone and/or component throughout SLS
- **Mapped MPE levels to each individual sensor to approximate operational noise environments**
  - Synthesized transients from operational noise PSDs

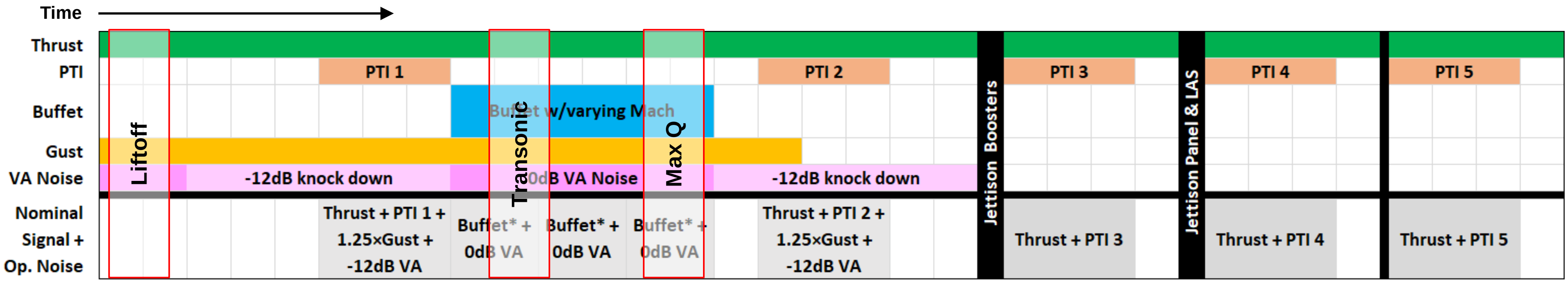
Analog Sensor Signal



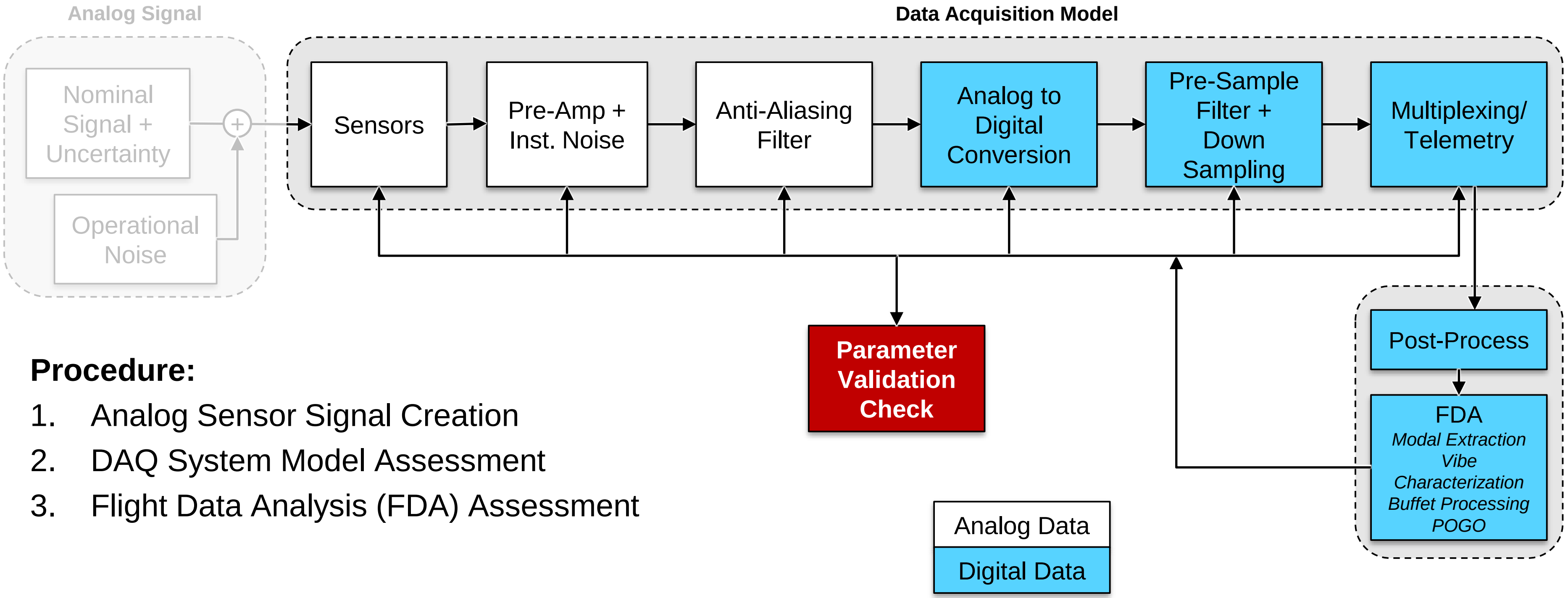


Addition of Operational Noise

- **MPE operational noise environments added to nominal signal throughout ascent**
  - 0dB levels applied for liftoff, transonic, and Max Q
  - -12dB knock down applied for quiescent stages of ascent
    - SP-8050 Saturn I and STS flight data used to estimate knock down



DFI Simulation Overview



Procedure:

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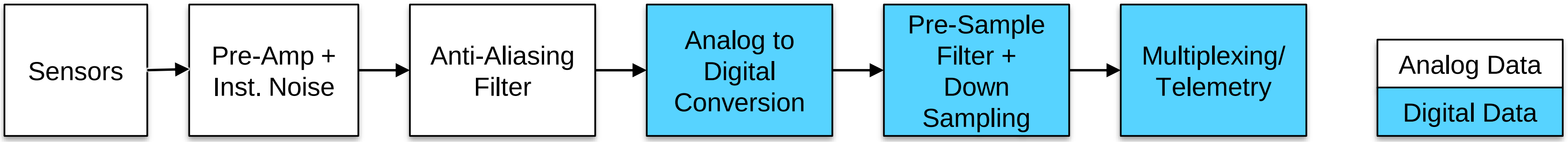
Consolidated Data Acquisition Settings

- **Data acquisition parameters consolidated from NASA branches and contractors for each sensor in DFI system**
  - Sensor settings
    - Sensor ranges, resolution, and coupling
  - Data acquisition cards
    - Filter settings, gains, word size, sampling frequency
  - Telemetry system
    - Time synchronization variation between acquisition systems
- **Computationally modeled each step in DAQ chain**

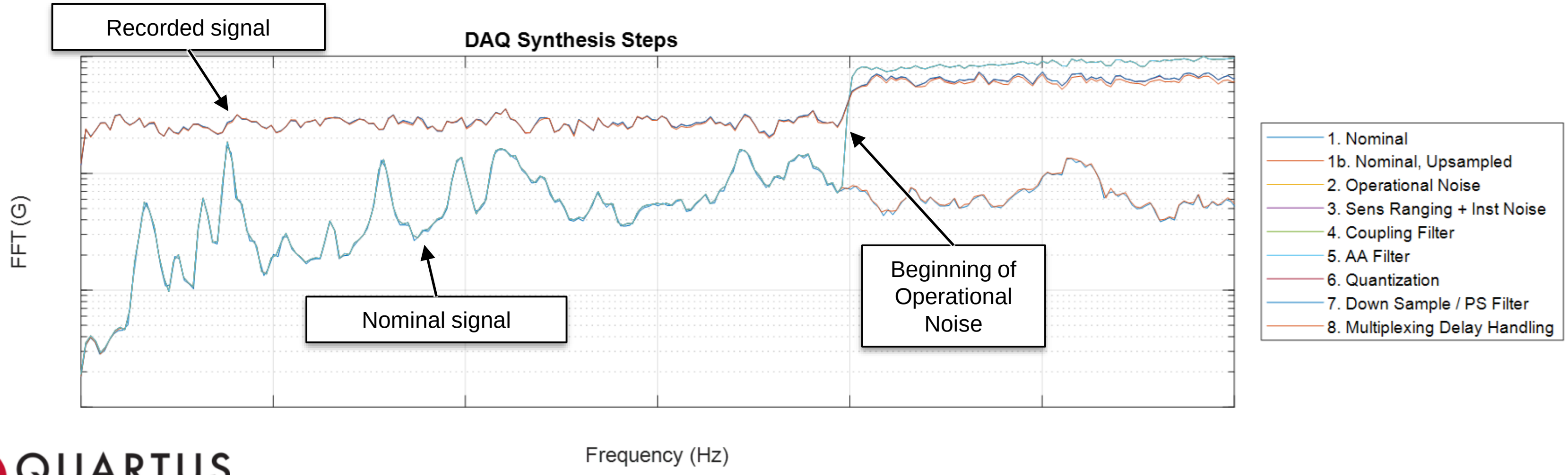


Critical Parameters to Data Quality

- **Multiple parameters deemed critical to signal quality throughout investigation**
  - Clipping: sensor range, anti-aliasing filter, and digital range (set by analog gain)
  - Resolution: gain, word size (dynamic range/bit resolution)
  - Phase distortion: pre-sample filter settings
- **How do you fix the data acquisition parameters if signal is compromised?**
  - Recommended fixes depend on source of corruption and FTO

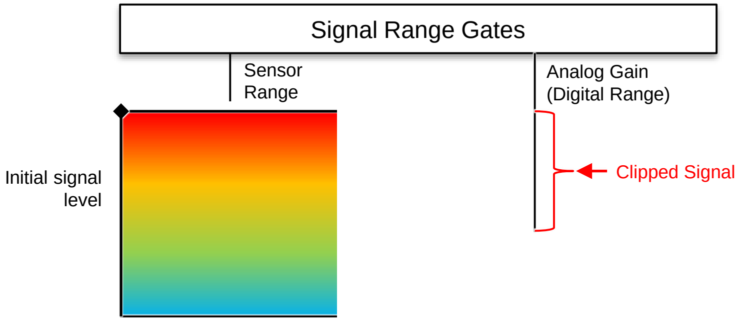
Effect of Signal Clipping

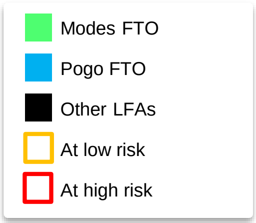
- **Clipping leads to loss in spectral fidelity**
- **Clipping prediction requires complete understanding of:**
  - All operational environments
  - All range and filter settings

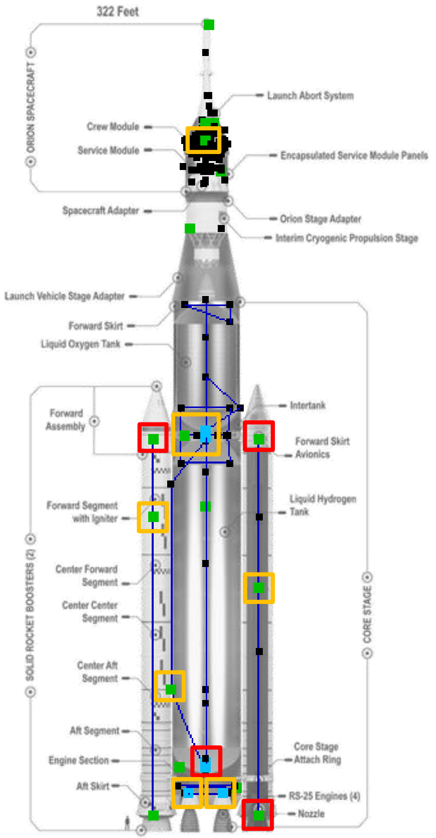


SLS Clipping Check

- **Clipping of sensors assessed for each FTO**
  - Used 3σ of stochastic MPE levels
  - Compared peak to each sensor and digital range
- **At risk sensors require unique solutions**
  - Multiple options for fixing the problem
  - Best solution depends on the intended use of the data
    - Better to sacrifice resolution or bandwidth?
    - Increasing digital range -> decrease in digital resolution







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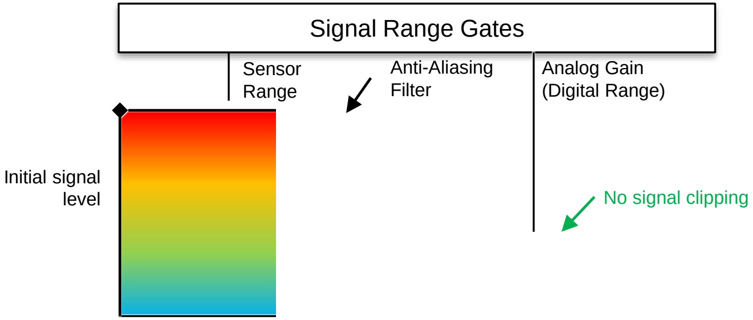
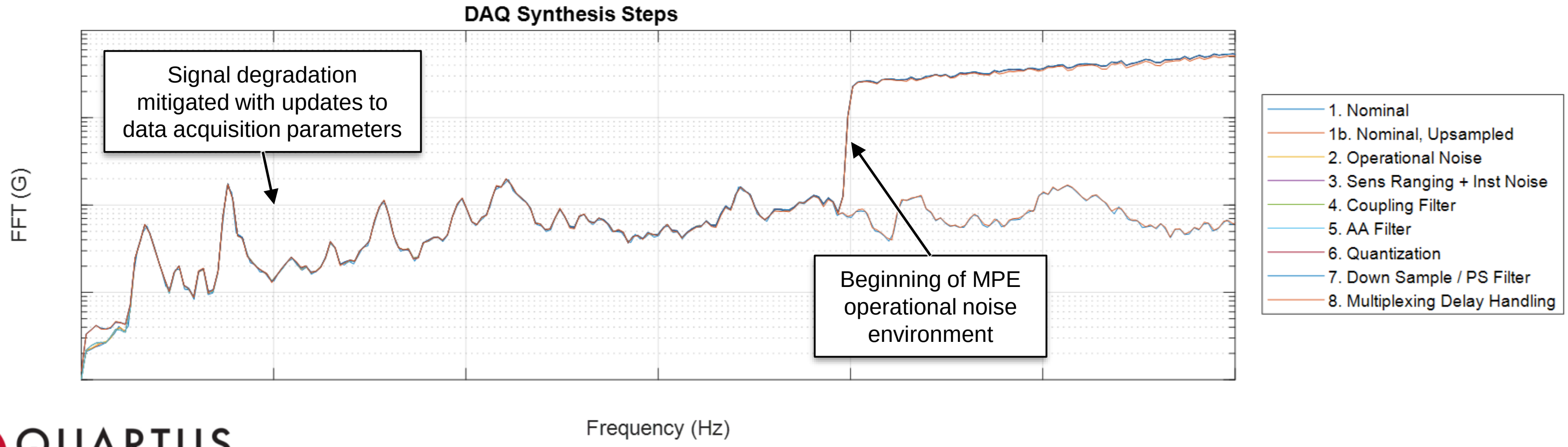
System Performance Improvement

- **Updates to anti-aliasing filter could rectify data corruption**
  - FTO success relies on high resolution at low frequencies
  - Can sacrifice high frequency content without affecting FTO





Conclusion

- **Flight measurements on launch vehicles:**
  - Have many advantages over ground based tests
  - Also come with unique challenges
    - Typically only get one opportunity to get the desired data
    - Unavoidable operational noise
    - Less robust storage which limits fidelity of data acquired
- **End-to-end assessment is important tool to guide data acquisition design and mitigate data corruption risks**
  - Necessary to find solutions that both mitigate data pollution while still accomplishing the test objective
  - If done before design of DAQ system, can save lots of headache down the road

Questions?