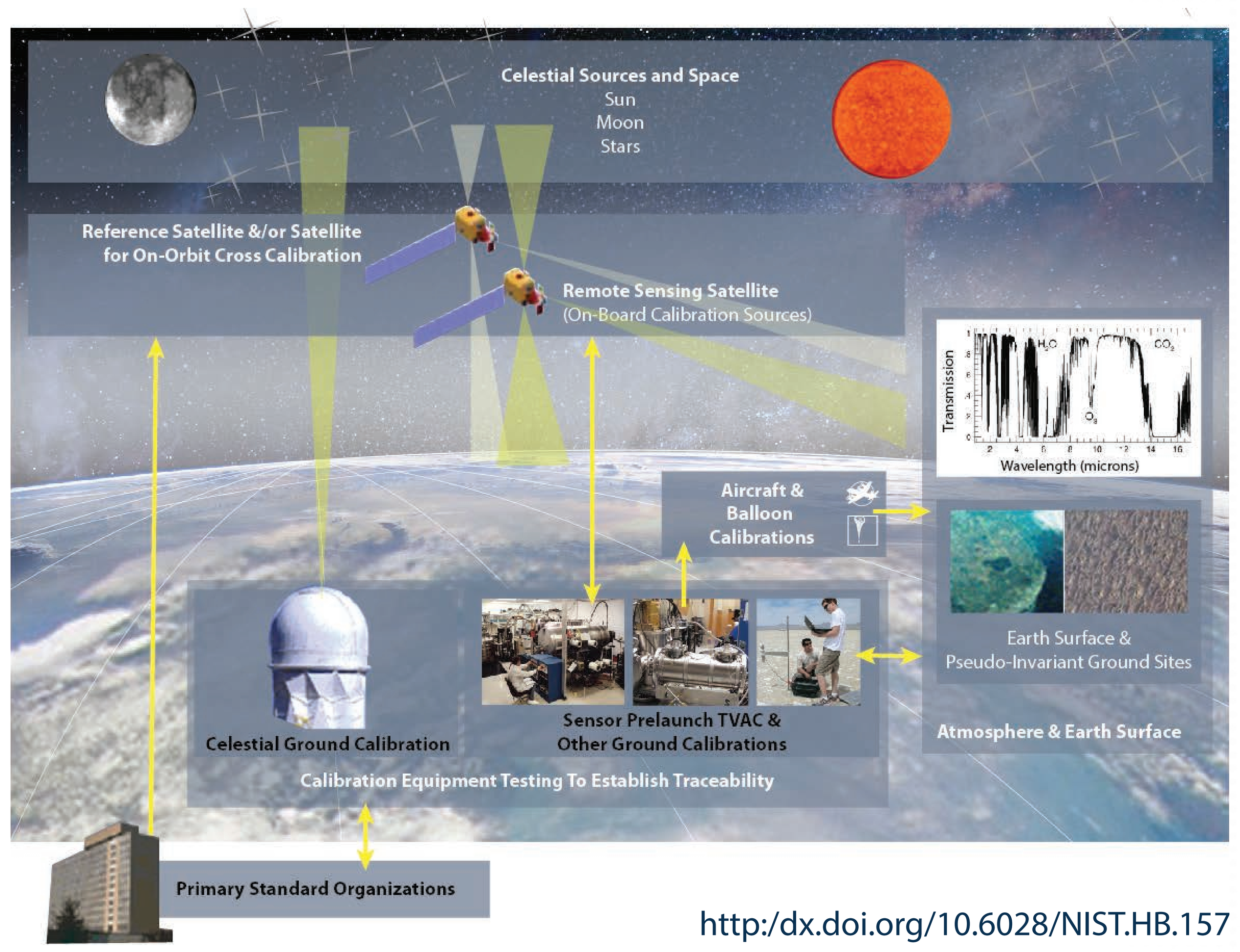
NIST Handbook 157

Guidelines for Radiometric Calibration of Electro-Optical Instruments for Remote Sensing



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A Publication Background

- **Presents guidelines** on conducting a radiometric calibration of an electro-optical *(EO)* sensor for space-based remote sensing
- Intended as **a useful reference for planning and successfully carrying out a sensor calibration**
  - Managers, technical oversight personnel, scientists, and engineers
- Represents **lessons learned** by authors from academic institutions, US Government, and industry

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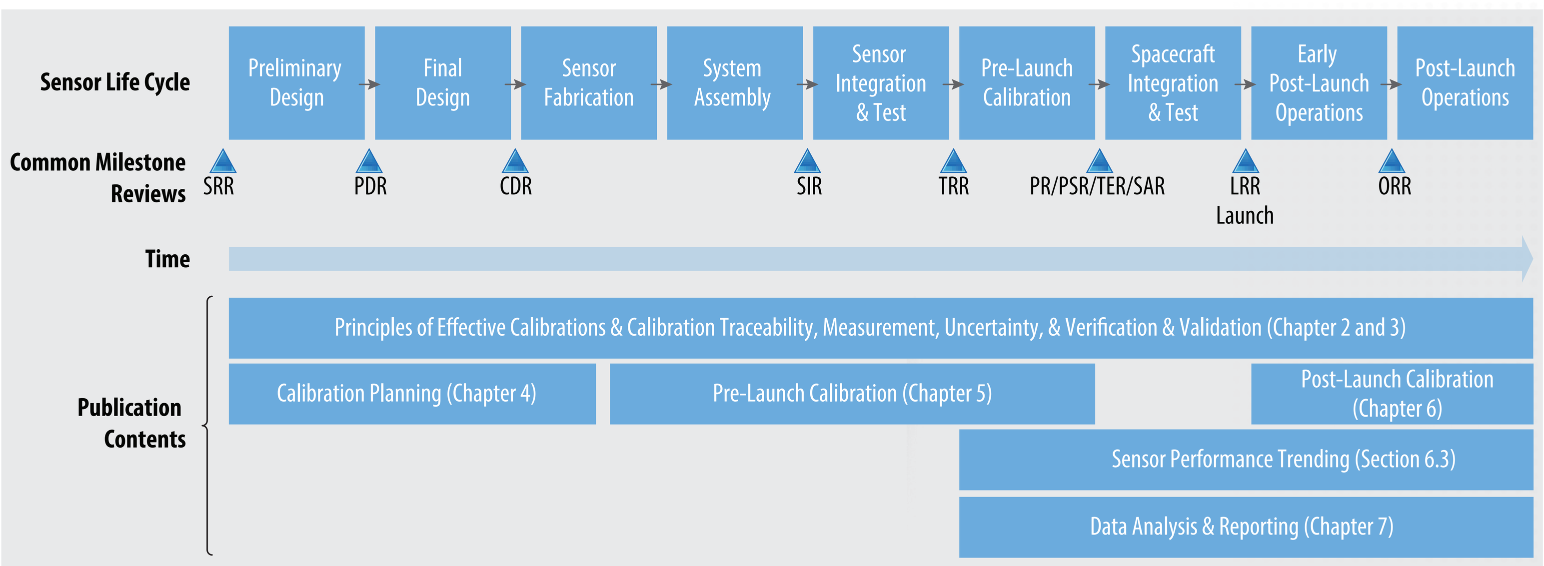
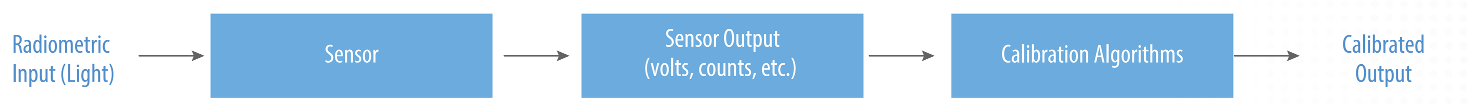
B Publication Content

- Contents address **calibration throughout the lifetime of the sensor**



C What Is Calibration and Why Is It Important?

- Calibration is the process of characterizing the parameters required to understand, describe, and quantify the performance of a sensor



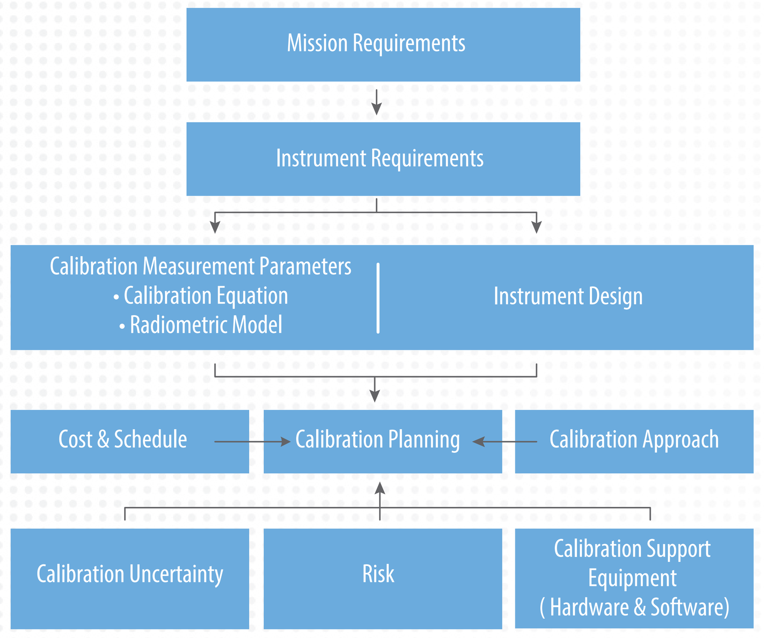
- Calibration characterizes interactions and dependencies between internal optical components
  - Example: Component level prediction versus system level measurement of Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) relative spectral response *(published in the International Journal of Remote Sensing)*

Component and system level spectral response differences were observed by as much as 23.5%

- Calibration discovers sensor specific performance dependencies
  - Example: Optical focus with changing sensor temperature

D Calibration Planning

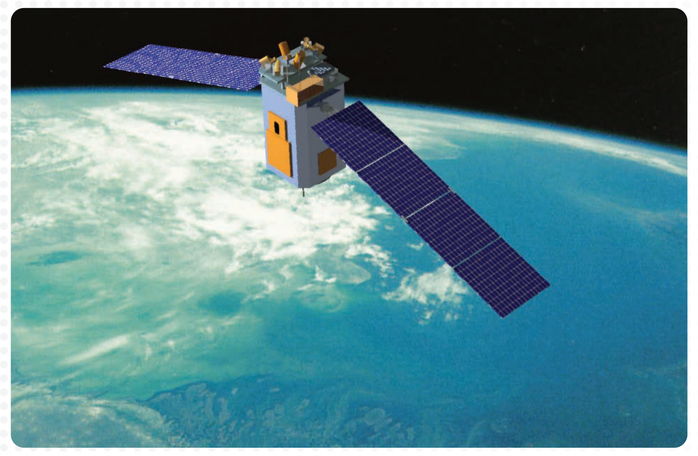
- Calibration is critical to the success of a mission
  - Unfortunately, it is often an afterthought in the development of a sensor
    - Lack of planning can lead to increased cost and schedule and inaccurate results
- Calibration considerations should begin during the sensor design phase
  - Promotes an optimum sensor calibration approach
  - Reduces costs and expenditures
  - Minimizes uncertainty
- Planning should address calibration throughout sensor lifetime



Calibration Planning Trade Space

E Calibration Success Example

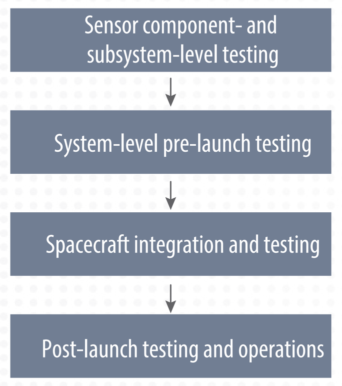
- **SABER**
  - 10-channel radiometer spans range of wavelengths from 1.27 to 17 µm
  - Launched December 7, 2001
  - Still on orbit collecting data
- **Calibration planning began early in the sensor design**[1]
  - Coordinated with science, instrument, and calibration teams
  - Iterated on calibration approach *(strawman plan formulated)*
  - Updated sensor design capability to support calibration
  - Drafted uncertainty budget and tracked throughout the development process
  - Performed comprehensive ground calibration before launch
- **Both pre- and post-launch calibrations were used to minimize uncertainty**[2]



[1] Tansock et al., SABER Ground Calibration, IJRS, 2003; [2] Tansock et al., "An Update of the SABER Calibration," 2006

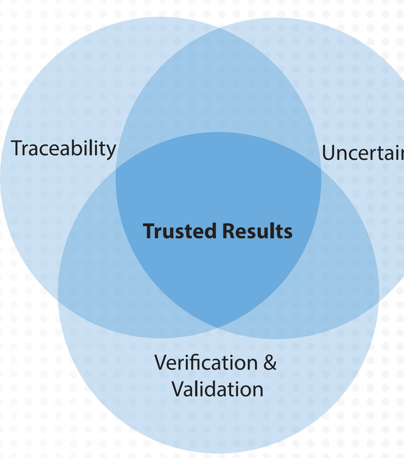
F Calibration Planning Should Begin During the Sensor Design Phase

- **Beginning calibration planning in the early stages of sensor design:**
  - Promotes an optimum sensor calibration approach
  - Reduces costs and expenditures
  - Minimizes uncertainty for the intended application
- **Experienced calibration personnel must be involved throughout the sensor's development phase to optimize calibration efforts**
- Planning should address **calibration throughout the lifetime of the sensor**
  - Data management and analysis should be considered in the planning process
    - Today's sensors produce large amounts of data



G Calibration Measurements Should be Traceable to Standards

- Sensor must provide **measurements that can be trusted**
- Three properties work together to provide confidence in sensor data
  - **Traceability**
    - Traceability is the ability to track a measurement to a known standard unit within a given uncertainty
  - **Measurement uncertainty**
    - Defines an interval that is likely to enclose the true value of a quantity *(see JCGM 200:2012, 2.26)*
  - **Verification and validation** *(V&V)*
    - V&V ensures that the instrument operates as designed and produces relevant data by proven processes and standards



G Tradeoffs Must be Made When Planning and Implementing a Calibration

- When performing calibration, there is always a tradeoff between what is ideal, what is desired, and what is strictly required
  - Sensor programs have limited funding, which can affect the scope of the calibration effort
    - Reducing the scope of pre-launch calibration efforts may impart additional requirements for post-launch calibration, where options for collecting particular data sets are either limited or unavailable
  - Knowledgeable experts should be involved to identify trades among available budget, schedule, and impact to sensor performance/mission objectives

H System-Level Testing Provides the Best Representation of Sensor Performance

- Component-level testing **may not** be adequate to represent a full system-level calibration
  - Components may behave differently than expected once assembled into an EO sensor
  - Characterizing the interactions and dependencies between the optical and electronic components:
    - Provides information on how the integrated system operates
    - Enables systematic errors to be discovered, evaluated, and resolved before flight
  - **System-level calibration can be visualized as the quality control aspect of system design and testing** *(Wyatt 1991)*

I Both Pre- and Post-Launch Calibrations are Critical to Mission Success

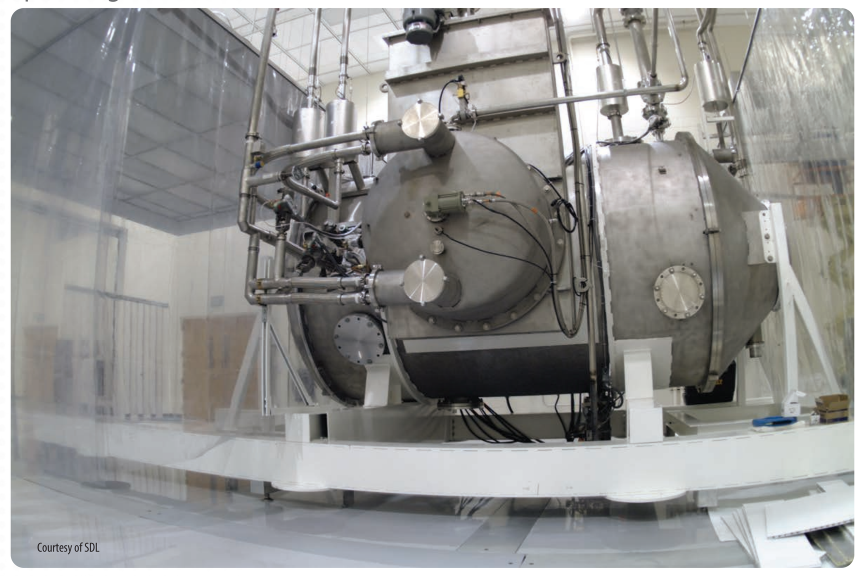
- Pre-launch calibration, or ground calibration, provides the capability to perform tests in a controlled environment with known sources that cannot be duplicated on orbit
  - Can discover and resolve anomalies prior to launch
- Post-launch testing, or on-orbit calibration, has the advantage of being performed under true flight conditions rather than simulated flight-like conditions
- Hubble Space Telescope *(Example)*
  - Component-level testing was performed prelaunch
    - Decision was to proceed without performing sensor-level validation on the ground prior to launch
  - A serious focus problem was identified on orbit
    - "The Hubble Space Telescope Optical Systems Failure Report" *(NASA-TM-103443, November 1990)*
  - This anomaly could have been identified during pre-launch system level calibration, potentially saving millions of program dollars

J Environmental Conditions for Pre-Launch Calibration

When conducting pre-launch calibration, it is best to follow the axiom "test as you fly" or "test like you fly" *(Datla et al., 2011; Russell 2008)*

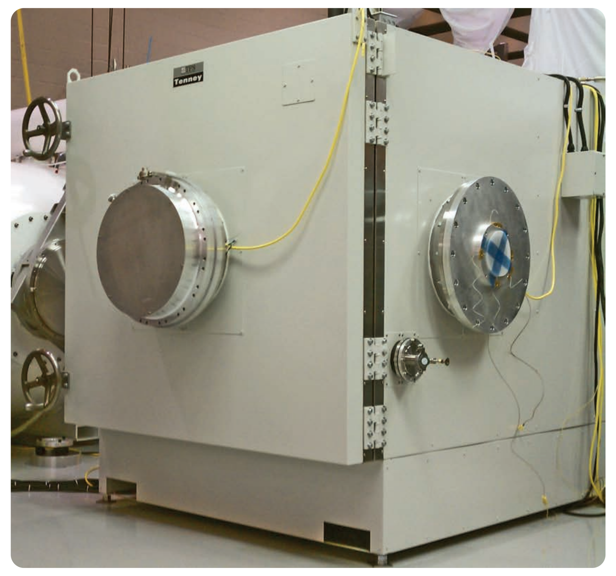
- Instruments should be calibrated under the same environmental conditions as expected during operation

Space Flight Sensor



TVAC chamber to simulate the space environment
Cryogenic operating pressure: ~10^{-7} Torr
LN_2 shroud provides low background

Airborne or Aircraft Sensor



Altitude simulation: (0 to 100,000 ft.)
Temperatures: -60°C to 125°C
Pressure: Ambient to ~10 Torr

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