

LGWA Soundcheck E-Box Requirements, Design and Legacy from the Insight E-Box

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LGWA Soundcheck

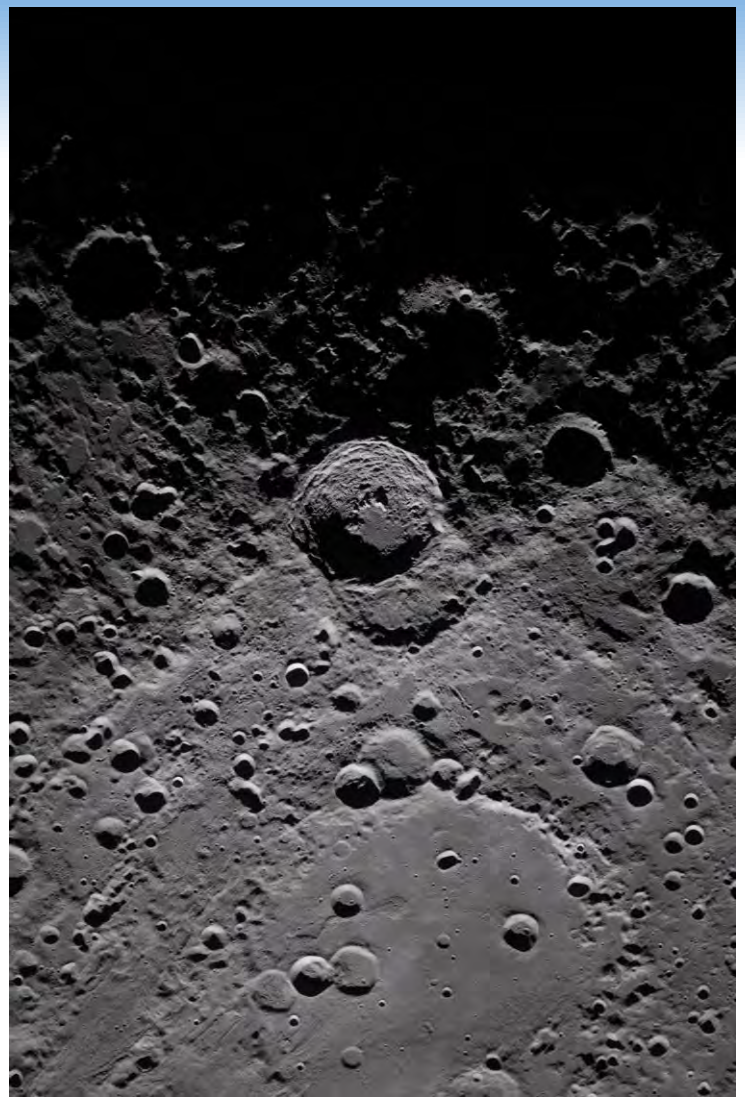
LGWA

LGWA Meeting 2026

ETH zürich

LGWA Soundcheck

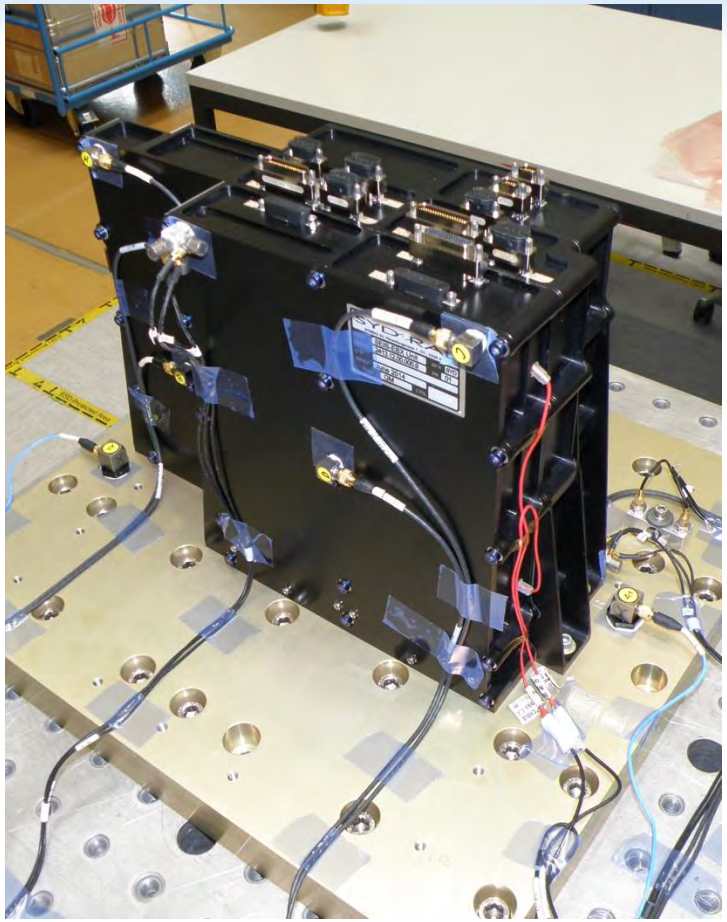
- **LGWA Soundcheck is the technological demonstrator for the Lunar Gravitational Waves Antenna (LGWA)**
  - long-term survival of quantum-limited sensors at ambient PSR temperatures
  - characterization of the seismic background from impacts and moonquakes inside a PSR
  - study of the Moon's internal structure at the south pole
  - first-ever long-duration, high-fidelity geophysical station inside a PSR
  - characterization of ice distribution and content in a PSR
  - Study of the plasma environment in a PSR
  - validate key exploration technologies (low noise, low power, low frequency, low temperature, high precision) for operation inside PSRs
- **Geophysical Sensors**
  - Accelerometer: Horizontal accelerometers, each with a mechanical structure out of Niobium known as a Watt's linkage. Readout laser interferometer homodyne system.
  - Magnetometer
  - Thermometer
- **Mission Profile**
  - Running in a PSR on the Moon for ~2 months (ambient temperature <100 K)
  - Power source on battery (battery and electronics in a warm box on the lander)
  - Seismic Station deployed on the PSR ground. Laser, electronics and battery pack on the lander in a "warm" box
  - Key performances for the sensors – 1 pm/$Hz^{1/2}$ between 0.1 – 1 Hz
  - Payload Power consumption < 25 W



PSR: permanently shadowed region

LGWA Soundcheck E-Box

- Electronic Box for LGWA Soundcheck
- Includes:
  - Acquisition front-end for the accelerometers, magnetometer and thermometers
  - High resolution / low noise digital to analog conversion
  - Digital processing of data and communication with the lander on-board computer
  - DC/DC power conversion and distribution to the instrument (conversion from primary lander power e.g. 28V to regulated power lines for the instrument)
  - Sensor feedback
  - Laser control (if not integrated in the laser module)

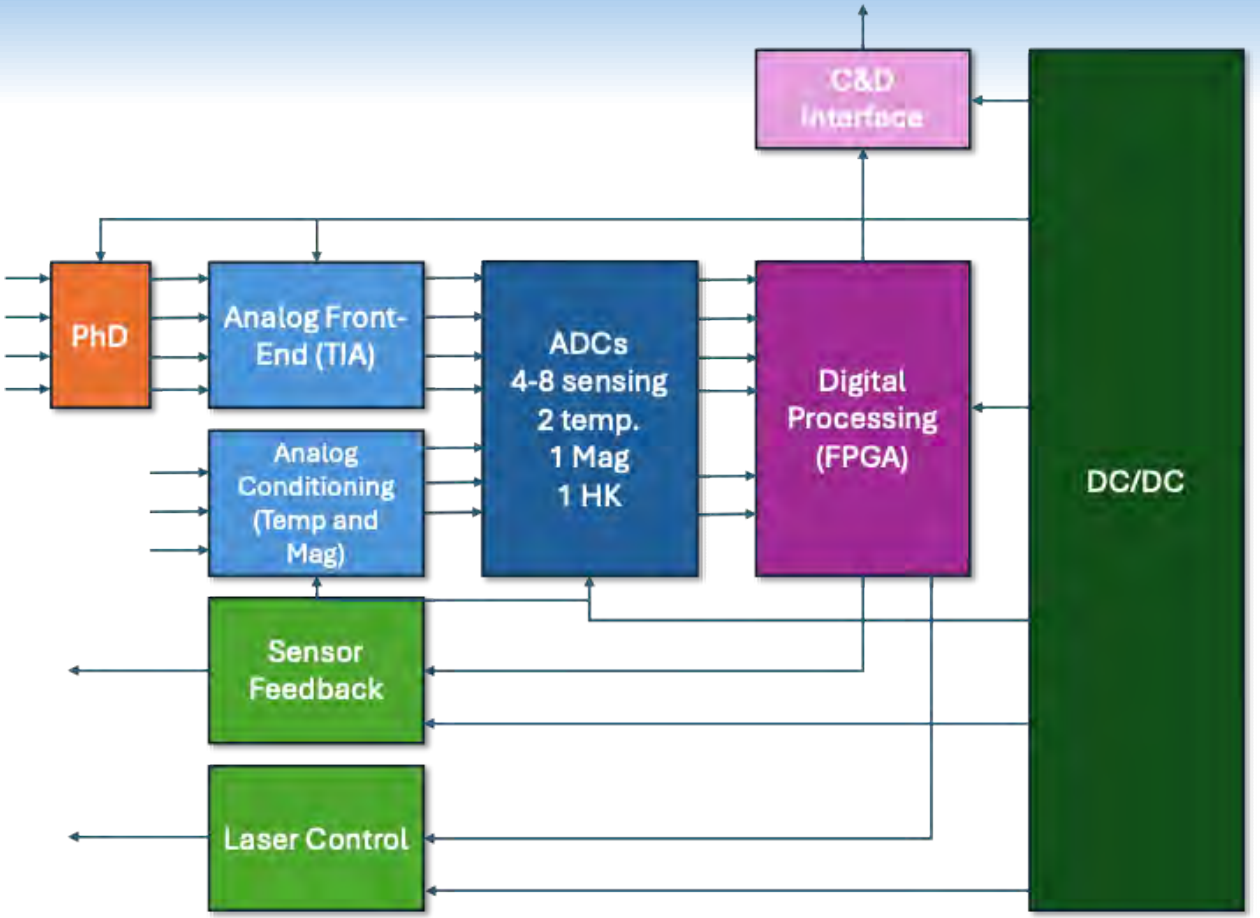


Insight E-Box QM at vibration testing

LGWA Soundcheck E-Box

Electronic Box for LGWA Soundcheck

- **Photodiode Module**
  - Two accelerometer sensors, homodyne interferometer readout system generating 4-8 sensing channel if balanced detection is considered
- **Analog Front-End TIA**
  - Low noise Transimpedance (I to V) amplification of the sensing signal
- **Analog conditioning**
  - Low noise conditioning of temperature sensors (e.g. TIA) and magnetometers
- **Sensor Feedback**
  - TBD Depending on the sensor scheme and needs. Provides analog feedback signal for actuating the sensor (e.g. keep the sensor centered)
- **Laser Control**
  - Provides analog signals to the laser module to control laser power and frequency (TBC possibly included in the laser module)
- **ADC conversion**
  - Provides analog to digital conversion for the science and housekeeping channels
  - 8 sensing channels ADC conversion
  - 2 temperature sensor channels ADC conversion
  - 1 magnetometer channel ADC conversion
  - HK channels ADC conversion
- **DC/DC power conversion** and distribution to the instrument (conversion from primary lander power e.g. 28V to regulated power lines for the instrument)
- **C&D communication** and data interface with the lander OBC

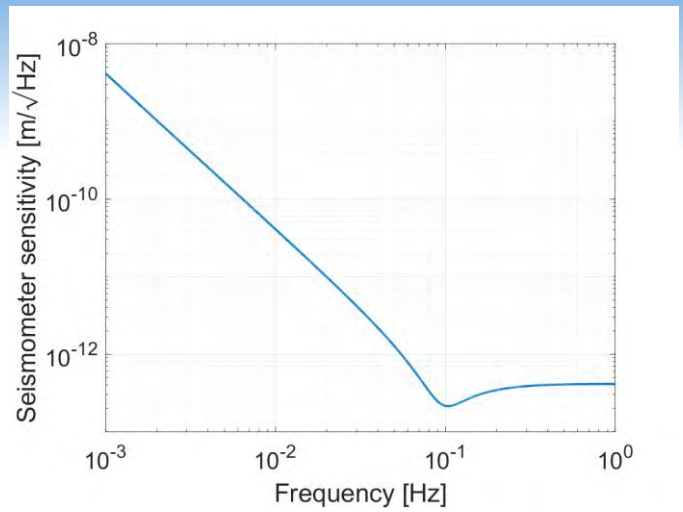


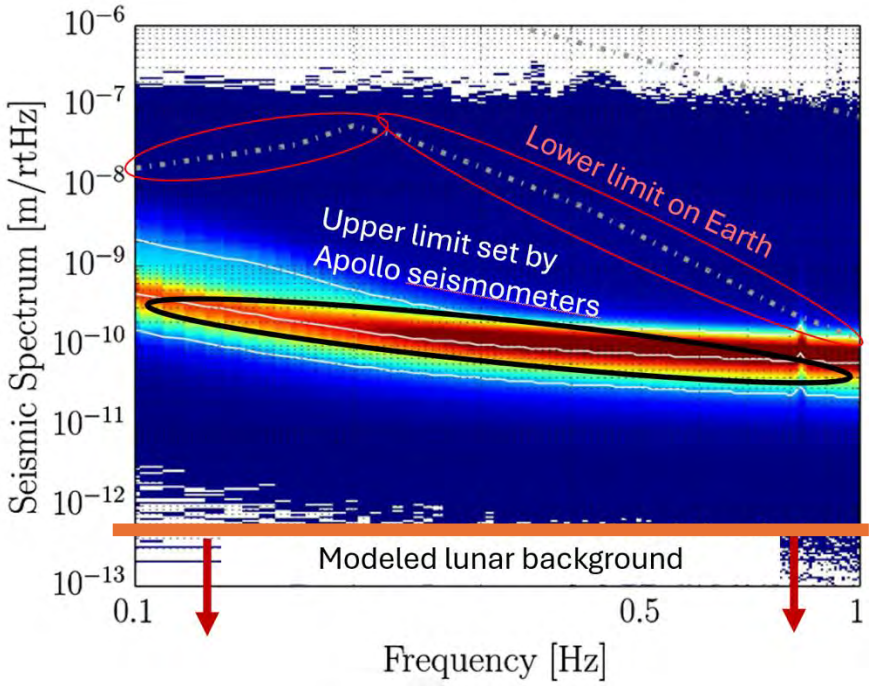
Block diagram of LGWA Soundcheck E-Box

LGWA Soundcheck E-Box – Performance Drivers

Performance Drivers for the LGWA Soundcheck E-Box

Item	Description
Bandwidth of acquisition system	[0.01 – 20] Hz
Displacement sensitivity of accelerometer channels	1 pm/Hz$^{1/2}$ Assumption converted to 1 μV/Hz$^{1/2}$
Dynamic Range	1-2 V
Radiation	TID ~ 1.9 krad (pessimistic assumption of deep space environment, 3 months, 1mm Aluminum)
Operations	Operations duration to be assumed 2-3 months
Power consumption	< 5 W





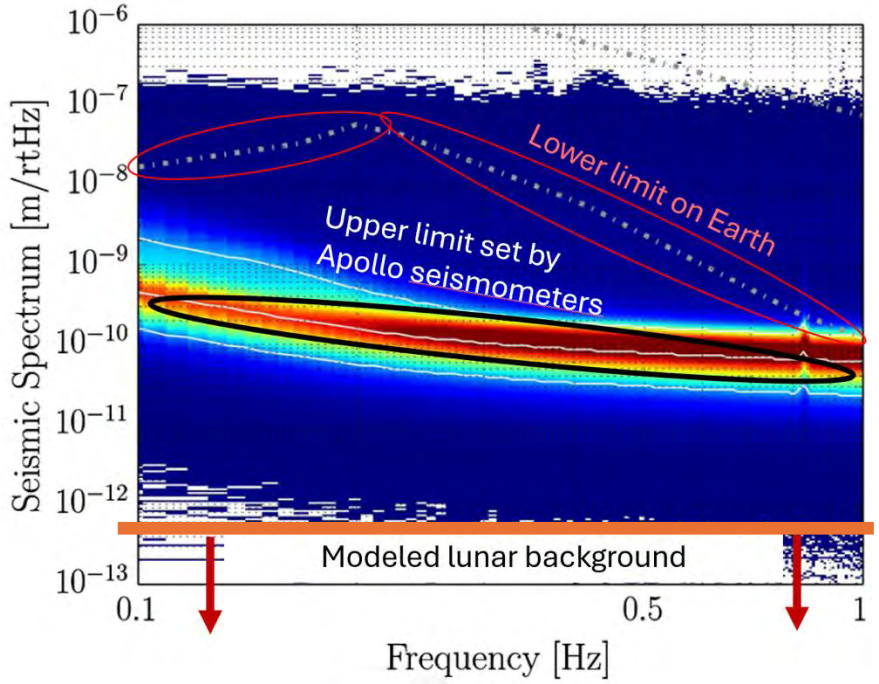
LGWA Soundcheck performance goal compared with Apollo seismometer results, expected Lunar noise background

LGWA Soundcheck E-Box – ADC Selection

ADC is a key element for the performances of the acquisition chain

ADC Requirements
- SNR > 121 dB
- Power Consumption per component < 30 mW
- Radiation TID tolerance > 2 krad
- Possibility to multiplex at least 2 inputs
- Power consumption of the ADC module < 160 mW

Dynamic range
Assuming a limit of 0.1 μV/Hz$^{1/2}$, fs = 1kHz provides ~121 dB



An example: ADS1282-SP

ADC from TI (31 bits, 19 effective)

Radiation tolerant: TID 50 krad

SNR = 128 dB at 1 kHz sampling

Power consumption ~ 25 mW

Two input multiplexing allows to halve the number of required components

Therefore with 128 dB we expect
ADC noise floor: 4.4e-8 V/Hz$^{1/2}$

LGWA Soundcheck E-Box – Voltage Reference

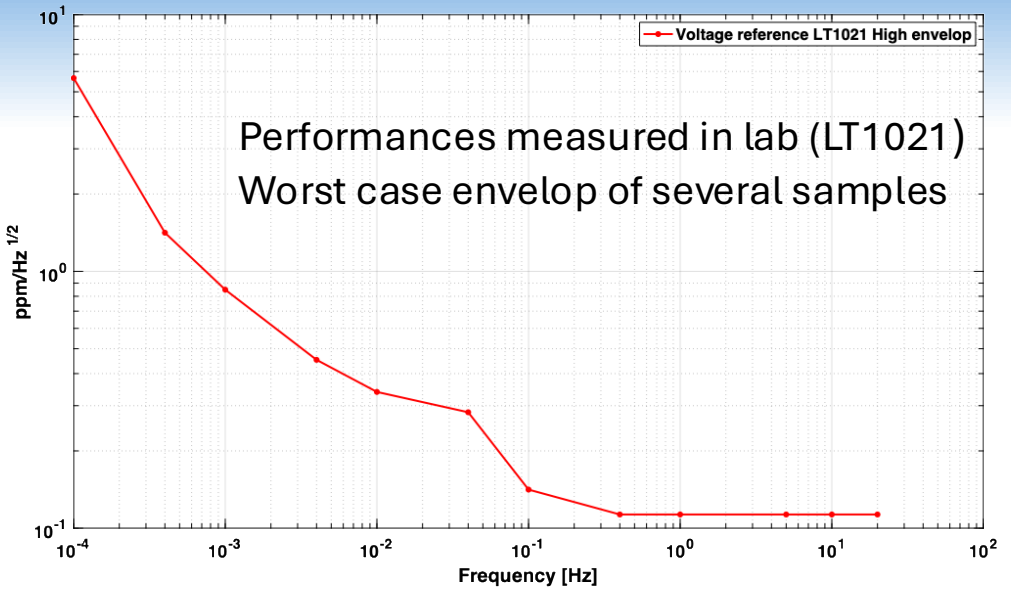
The voltage reference noise is a key source of sensing instability

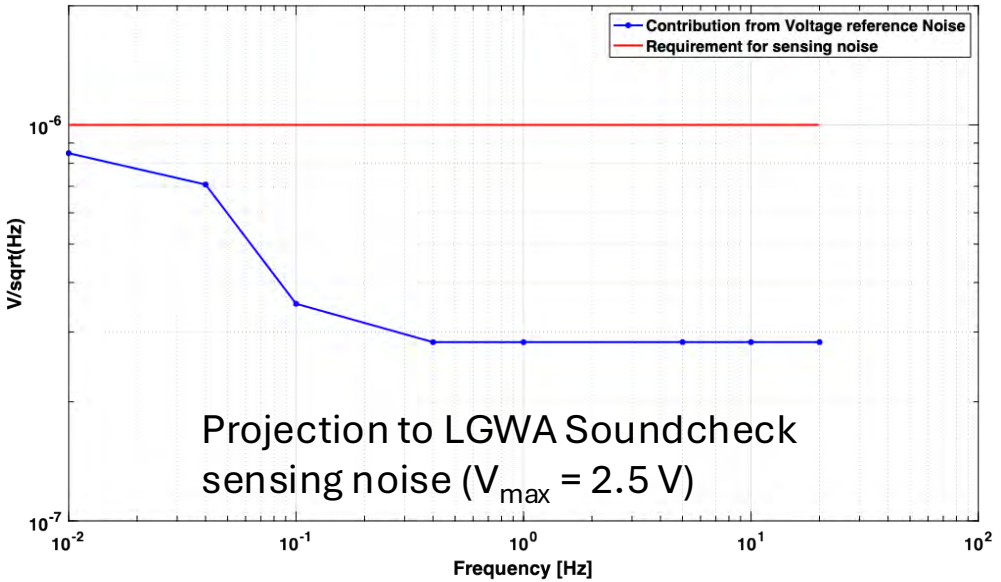
$$CODE = V_{IN} \times \frac{2^n}{V_{REF}}$$

Where V_{IN} is the input voltage, V_{REF} is the reference voltage and n is the ADC number of bits. Therefore, the fluctuations of the reference voltage affect directly the sampled code providing a gain error.

An example from LISA and LISA Pathfinder FEE

RH1021
Very stable: 5 ppm/K





LGWA Soundcheck E-Box – Voltage Reference Alternatives

Part	Manufacturer	Temperature drift max [ppm/C]	Voltage noise	power consumption [mW]	Qualified Part
RH1021	Analog Devices	5	120 nV/Sqr(Hz) @1kH	>= 50	Y
ADR435	Analog Devices	3	115 nV/Sqr(Hz) @1kH	14.4	Y
REF50XX Enhanced-grade	Texas Instruments	2.5	75 nV/Sqr(Hz) @1kH	>= 30	N REF5025 tested at CERN of for TID 25 krad arXiv:2603.04129v1
REF5025MDTEP	Texas Instruments	5		>= 30	N HiRel Enhanced Product EF5025 tested at CERN of for TID 25 krad arXiv:2603.04129v1
ISL71090SEH25	Renesas	10	50 nV/Sqr(Hz) @1kH	>= 50	Y

Interesting alternatives to the RH1021 can be identified
e.g. ADR435 and REF50

LGWA Soundcheck E-Box – Temperature Stability Requirement

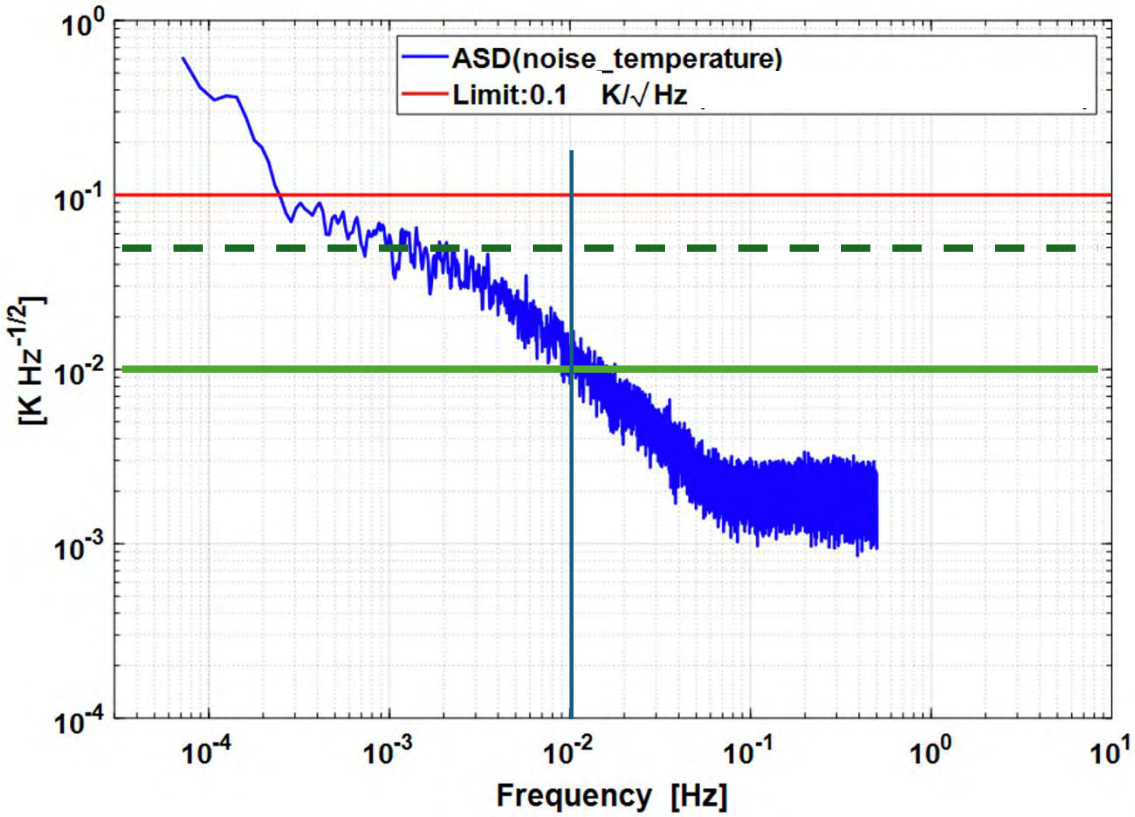
- **Considering 5 ppm/K for the voltage reference**
- We need to stay below the sensing noise limit
- Assuming 2.5 V range

T fluctuation @ 0.01 Hz	Sensing Noise ppm/Hz$^{1/2}$	Sensing Noise uV/Hz$^{1/2}$
1 K/sqrt(Hz)	5	12.5
0.1 K/sqrt(Hz)	0.5	1.25
0.05 K/sqrt(Hz)	0.25	0.625
0.01 K/sqrt(Hz)	0.05	0.125

The thermal stability of the platform to enable E-Box performances should be better than 0.05 K/Hz$^{1/2}$ @ 0.01 Hz (ideally 0.01 K/Hz$^{1/2}$)

Not impossible to obtain e.g. obtained in laboratory without very special measures (basement room)

Laboratory Measurement



LGWA Soundcheck E-Box – Temperature Stability Requirement

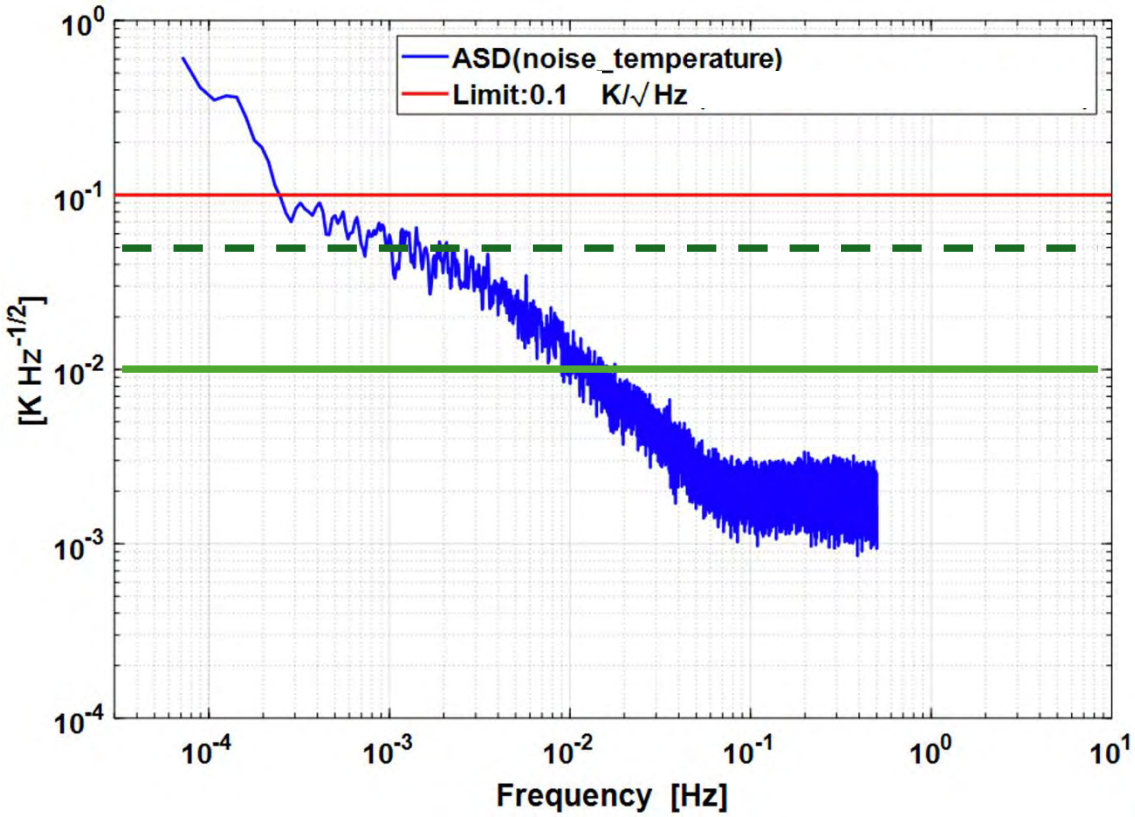
- **Considering 2.5 ppm/K for the voltage reference**
- We need to stay below the sensing noise limit
- Assuming 2.5 V range

T fluctuation @ 0.01 Hz	Sensing Noise ppm/Hz$^{1/2}$	Sensing Noise uV/Hz$^{1/2}$
1 K/sqrt(Hz)	2.5	6.25
0.1 K/sqrt(Hz)	0.25	0.625
0.05 K/sqrt(Hz)	0.125	0.313
0.01 K/sqrt(Hz)	0.025	0.063

The thermal stability of the platform to enable E-Box performances should be better than 0.1 K/Hz$^{1/2}$ @ 0.01 Hz (ideally 0.05 K/Hz$^{1/2}$)

Not impossible to obtain e.g. obtained in laboratory without very special measures (basement room)

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ISL71090SEH25	Renesas	10	50 nV/Sqr(Hz) @1kH	>= 50	Y

A voltage reference with 2.5 ppm/C is advantageous with respect to a 5 ppm/C

- Higher probability of meeting sensing noise requirements
- Relaxed requirements on thermal stability of the platform
- **Testing in Laboratory for low frequency performances are critical for the selection process**

LGWA Soundcheck E-Box – Technical Budgets

Item	Description	Comment
Power Consumption	Expected to be < 5 W for nominal science operations	Legacy from insight is 4 W nominal + 4.3 W extra for the leveling motors and controller The main source is expected to be the FPGA, Analog Front-End, DC/DC and ADC
Mass	Expected < 5 Kg	Can be optimized during the design phase. Wall thickness etc…
Dimensions	Allocation 300x300x80 mm	Can be adapted on the basis of the allocated volume on the lander

Legacy from Insight

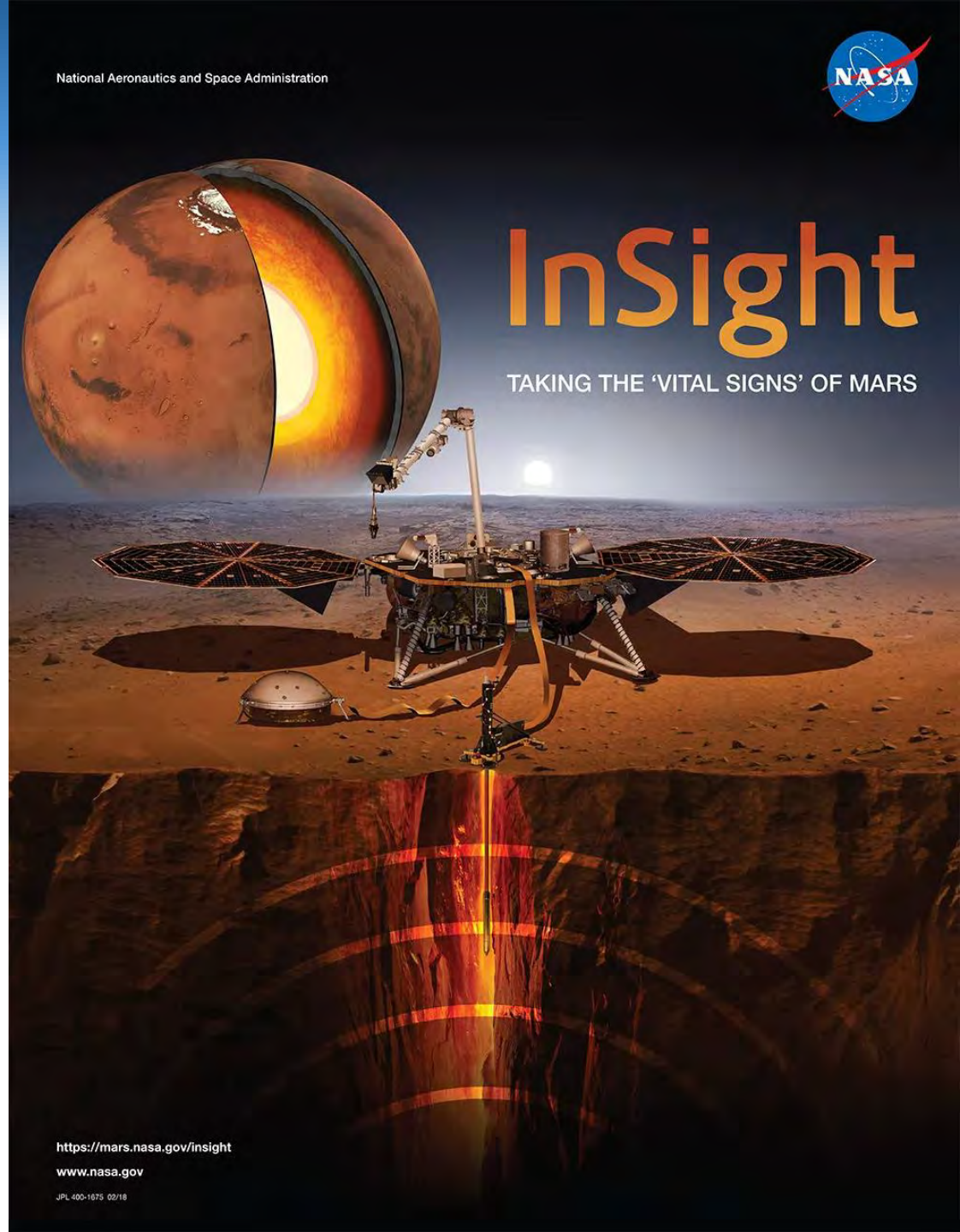
Detected First Quake on Another Planet
InSight made the first-ever detection of quakes on the Red Planet. Its onboard seismometer measured over 1,300 seismic events, and over 50 of them had signals that were clear enough for the team to derive information about their location on Mars.

Shed Light on Three Mars Layers
InSight gathered new information about Mars' three major layers – crust, mantle, and core. The crust beneath InSight is about 25 to 40 km thick, comprising three internal layers. Mars' core is molten and considerably larger than expected, about 1,800 km in radius.

Felt Meteoroid Impacts, Leading to Icy Discovery
The onboard seismometer detected a magnitude 4 marsquake in 2021 that was caused by a meteoroid strike. Later NASA's Mars Reconnaissance Orbiter found that the impact had churned up a layer of water ice buried underground closer to the Martian equator than anything discovered previously

Found Magnetic 'Ghosts' from an Old Field
The magnetometer allowed to measure the remnant of the ancient global magnetic field in magnetized rocks below the surface

Atmosphere and Weather Data
InSight collected the most comprehensive weather data of any mission sent to the surface of Mars



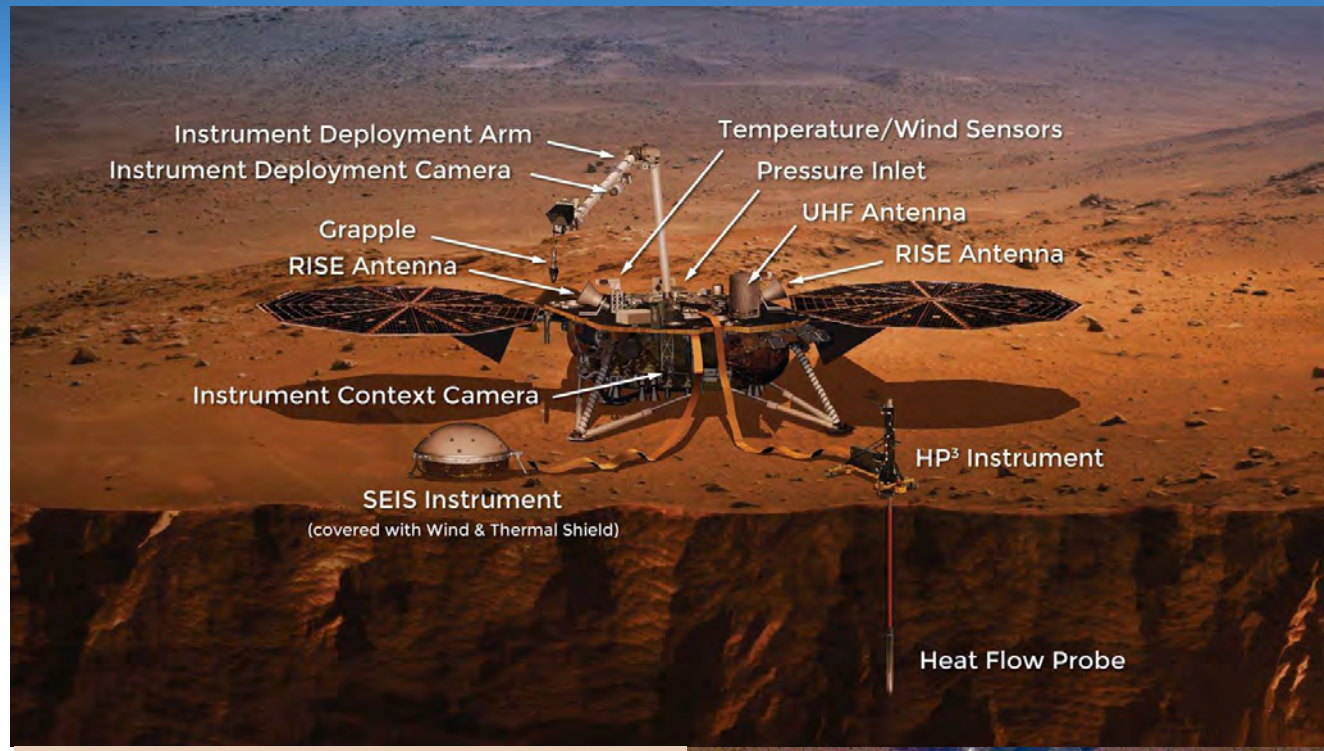
Legacy from Insight

The InSight lander was equipped with three instruments:

- **Seismic experiment for interior structure (SEIS)**: Consisting of a very broadband (VBB) and one short-period (SP) seismometer, each with three components. SEIS was the main scientific payload consisting of three main parts:
  - the sensor assembly, which was placed on the ground by the InSight's robotic arm
  - the electronics box (E-Box), which was located in the temperature-controlled lander compartment, and
  - the tether connecting the SA to the E-Box.

- **HP^3**: Heat Flow and Physical Properties Package

- **RISE**: Rotation and Interior Structure Experiment (radio science experiment onboard InSight Mars lander, precisely tracked the location of the lander to determine just how much Mars' north pole wobbles as it orbits the Sun)

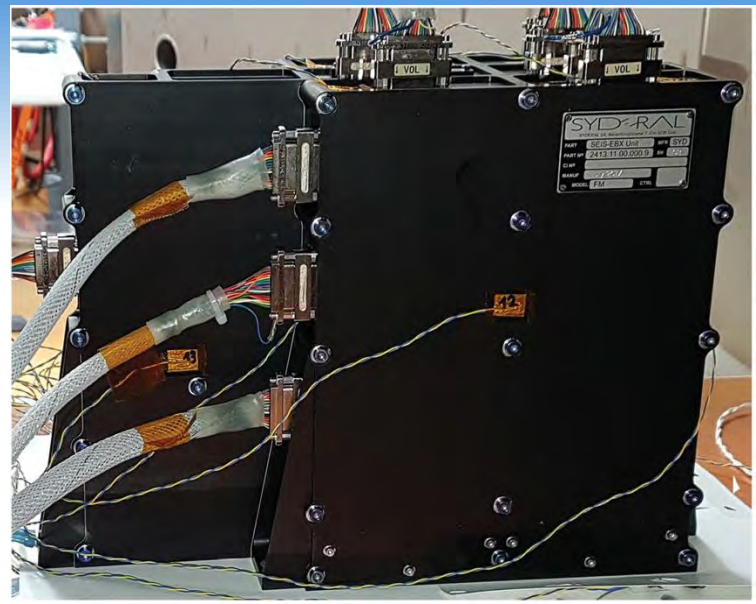






Insight SEIS E-Box

E-Box flight model in preparation for the thermal test

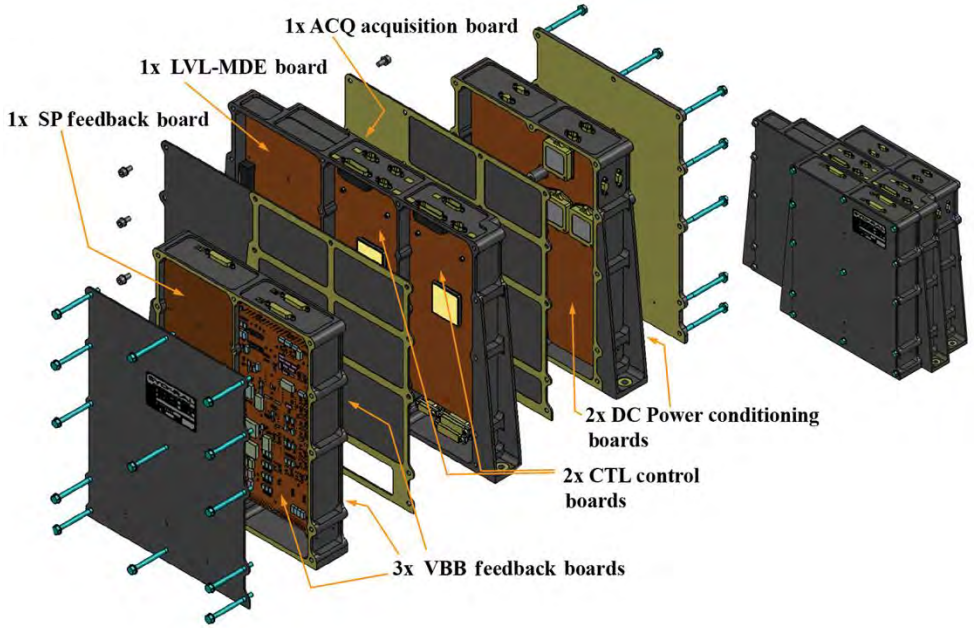


The E-Box comprises all SEIS electronics, except the VBB proximity electronics, some electronics inside the SP sensors, and the high-precision tiltmeter front-end electronics mounted on the LVL.

The E-Box was located in the lander's electronics compartment, which is heated to prevent temperatures to fall below −35°C.

The E-Box includes

- The acquisition board with electronics for analog to digital conversion
- The LVL-MDE board (controller of the levelling system)
- The SP sensor feedback board
- The VBB sensors feedback board
- The DC power conditioning board
- The Control board (digital processing and interface with the lender command and data interface)



P. Zweifel et al, Bulletin of the Seismological Society of America, Volume 111 Number 6 December 2021

Insight SEIS E-Box Acquisition Chain

The acquisition chain consists of the conditioning electronics (amplifier and filter), the ADC, and a finite impulse response (FIR) filter.

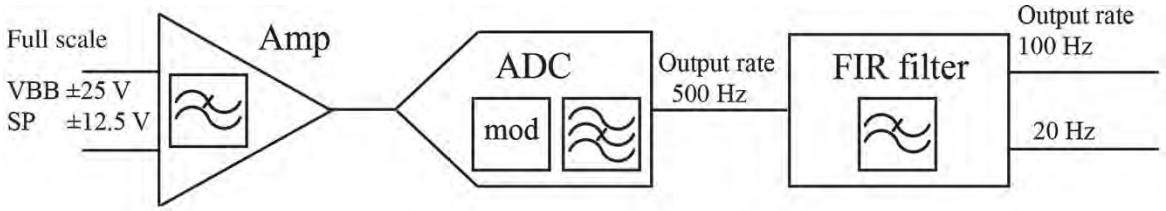
The conditioning electronics in front of the ADC scales the seismic signals from the sensor full-scale range (FSR) to the input voltage range of the ADC.

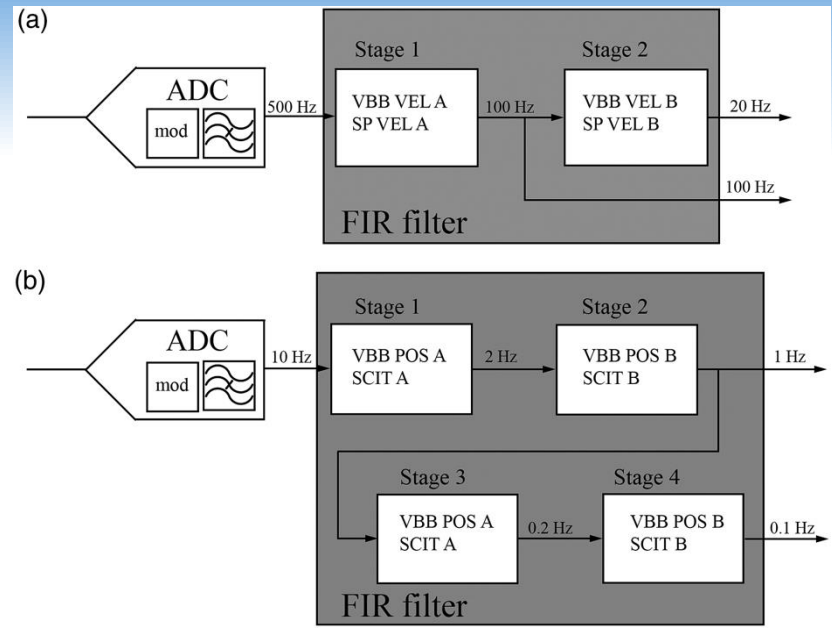
The performance required a dynamic range of 130 dB in amplitude (i.e. at least 24-bit ADC).

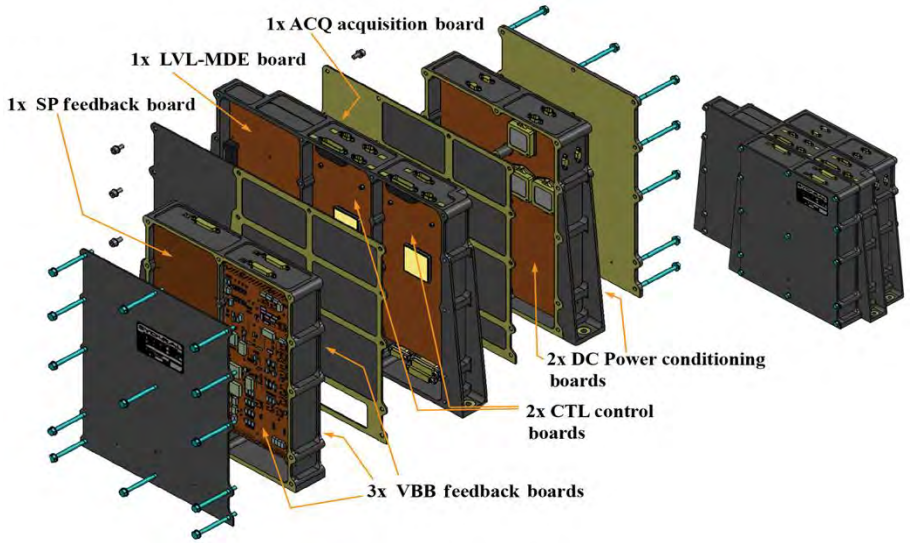
At the time the InSight development began in 2012 it was challenging to find a component with such performances and capable to sustain radiation. The 24-bit sigma-delta ADC AD7712 was finally selected for SEIS due to its robustness with respect to radiation and its availability in military quality (extended temperature range and ceramic packaging).

The ADC converts the signals with an input sampling rate of 32 kHz. The on-chip third-order sinc-in-time filter (sinc3) is followed by a decimation by a factor of 64 for the velocity channels and by a factor of 3200 for the position channels.

The corresponding ADC output rates are thus 500 Hz for VBB and SP velocity, and 10 Hz for VBB position.







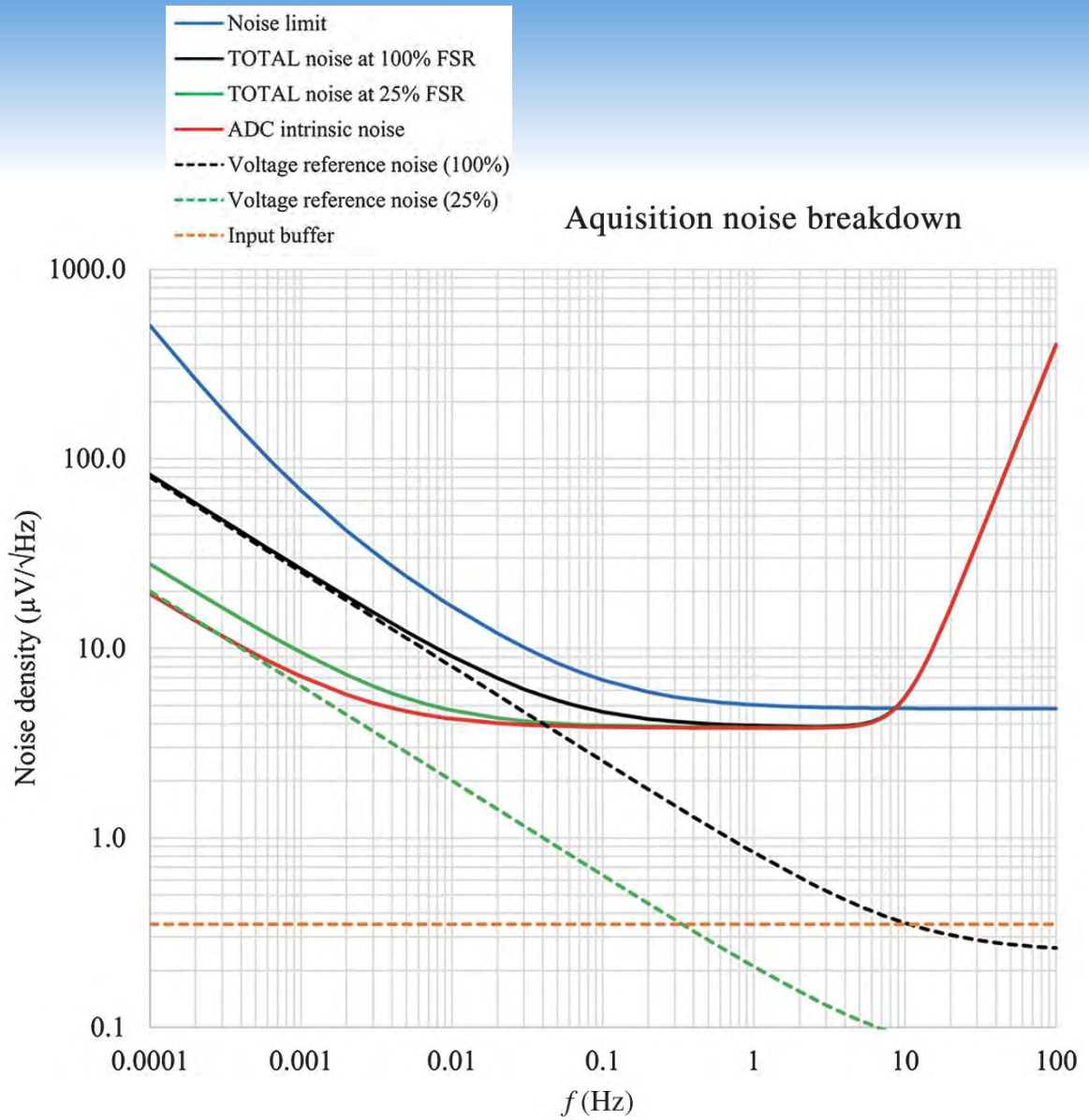
Insight SEIS E-Box Acquisition Chain Performances

The acquisition noise is a result of the amplifier noise of the signal conditioning, the intrinsic noise of the ADC, and the voltage reference noise.

The ADC intrinsic noise of 3.8 $\mu V/Hz^{1/2}$ is flat (white) down to 10 mHz, below which the 1/f noise becomes visible.

Above about 8 Hz, the ADC sigma-delta quantization noise starts to dominate over the white noise floor.

The acquisition noise level at low frequencies (<100 mHz) depends on the input signal amplitude, because the voltage reference noise is proportionally scaled with the acquired signal. In the figure the contribution of the voltage reference noise is calculated for 25% and 100% of the FSR.

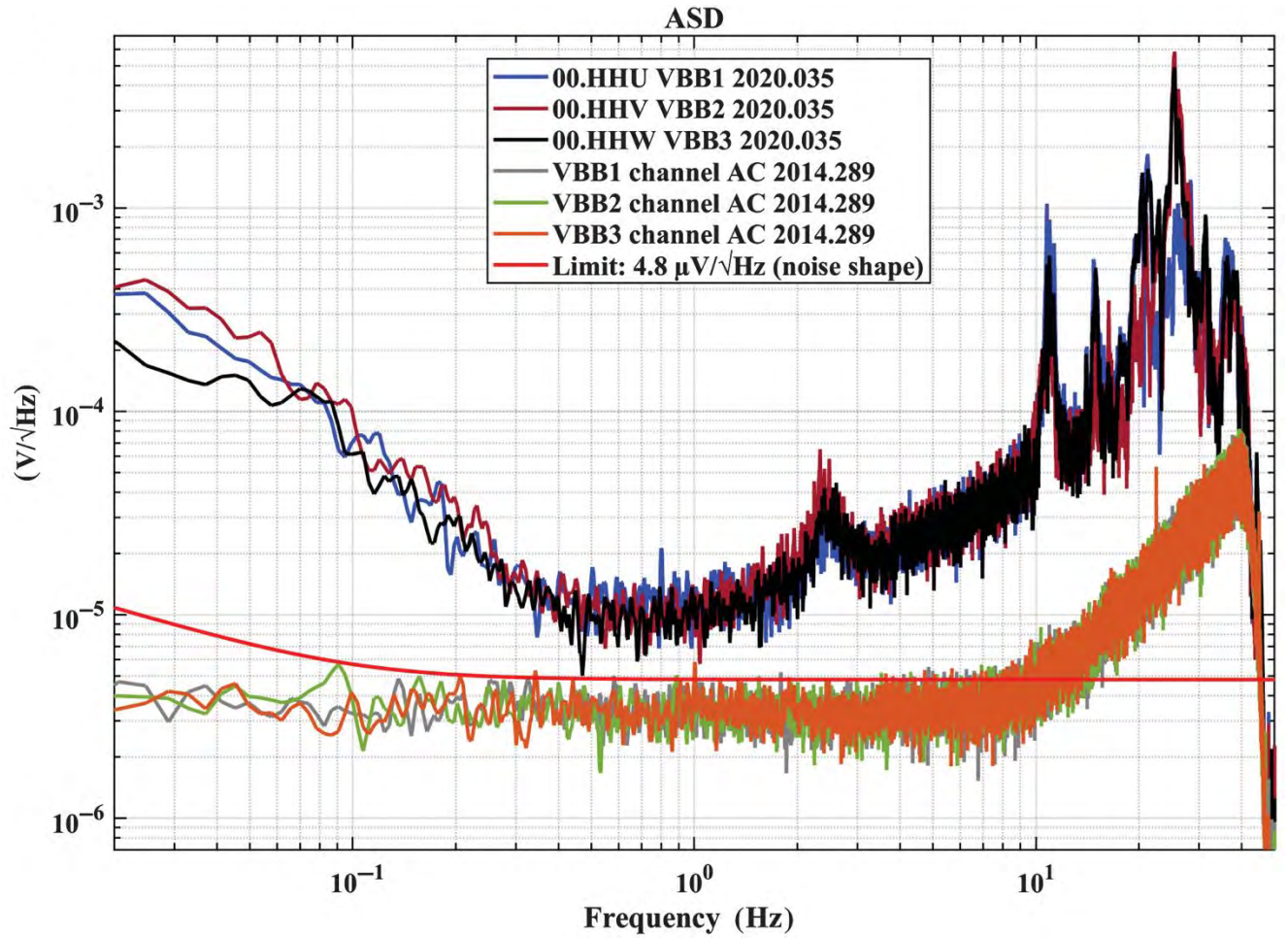


Insight SEIS E-Box Acquisition Chain Performances

We compare the electrical noise of the acquisition channels obtained during the electrical tests with the seismic noise recorded during a very quiet period on Mars.

Results recorded during the electronics tests before integration of the sensor feedback are reported as AC 2014.289. They present the noise floor of the E-Box acquisition system

VBB velocity channels recorded with a sampling rate of 100 Hz. The Mars data were acquired on 4 February 2020 at 17:52 for 15 min (between 21:00 and 22:00 on Sol 423—an extremely quiet time with minimal wind noise)



P. Zweifel et al, Bulletin of the Seismological Society of America, Volume 111 Number 6 December 2021

Summary and Concluding Remarks LGWA Soundcheck E-Box

- ADC performances (noise floor and quantization noise) expected to fulfill requirements
- Voltage reference is a dominating noise source at low frequency but available components allow to meet requirements
- Required temperature stability is considered achievable
- Power consumption, mass, volume expectations are based on legacy from Insight E-Box and marginally in-line with mission needs
- E-Box can inherit a lot from Insight and LISA Pathfinder but new mission requirements imply new challenges
- Early prototyping and testing for critical functions is essential (e.g. voltage reference and ADC)