The Compact, Adaptable Microwave Limb Sounder (CAMLS)

Developing the core system for next-generation Microwave Limb Sounders

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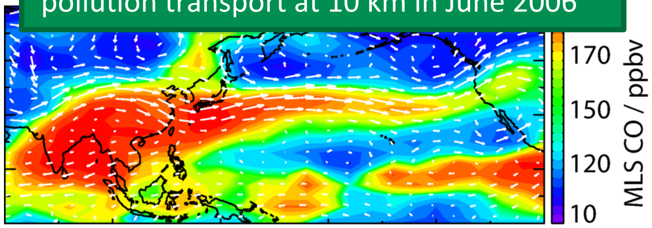
CAMLS Talk Outline

- Science motivation (3 slides)
- CAMLS goals
- System block diagram (1)
- Liquid cooled chassis (1)
- Front-end electronics (1)
- Cryostat and cooling performance (6)
- IF processor (2)
- Spectrometer (2)
- LO/Calibration Slice (2)
- Integration with the A-SMLS (1)
- Summary (1)

CAMLS science motivation – the "UT/LS"

- The CAMLS-family of instruments makes measurements needed to address key outstanding issues associated with the composition and structure of Earth's "upper troposphere and lower stratosphere" (UT/LS hereafter)
  - The ~10 km to ~20 km altitude region
- It is in this region where:
  - Water vapor (the strongest greenhouse gas) and ozone have sharp gradients, and where changes in their abundance strongly influence climate
  - Winds are fast and chemical lifetimes are long, promoting global transport of greenhouse gases and pollutants (see upper figure)
  - Climate (and chemistry-climate) models continue to poorly represent key processes and their impacts on water vapor, composition and clouds (see lower figure)

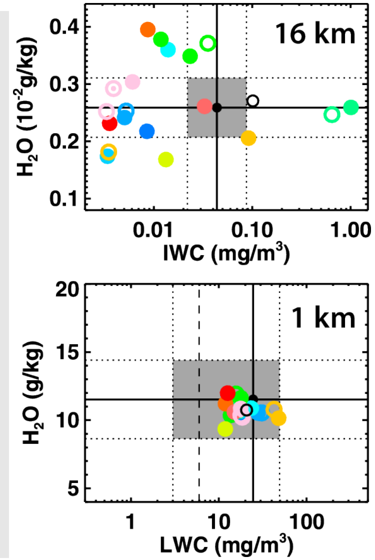
Aura MLS observations of long range CO pollution transport at 10 km in June 2006



Jiang et al., 2006, GRL

A-Train observations show climate models perform poorly in the upper troposphere (e.g., ~16 km, top panel) compared to the lower troposphere (e.g., ~1 km, bottom panel)

x-axes are cloud ice
y-axes are water vapor
Black points are observations
Grey shading denotes measurement uncertainty
Colored points are climate models
Top panel shows 16 km altitude observations from Aura MLS
Bottom panel shows 1 km altitude observations from AIRS & CloudSat



Jiang et al., 2012 JGR

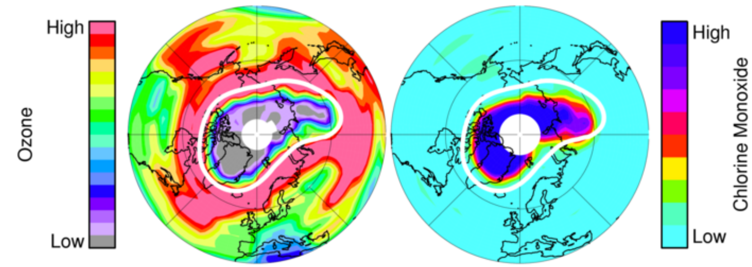
CAMLS science – issues in the stratosphere

- In the stratosphere itself (~15 – 50 km), high levels of atmospheric chlorine continue to destroy ozone

- Unexpected and incompletely explained changes in stratospheric humidity in the past decade have significantly affected surface temperature (e.g., masking 25% of expected warming during 2001–2010)

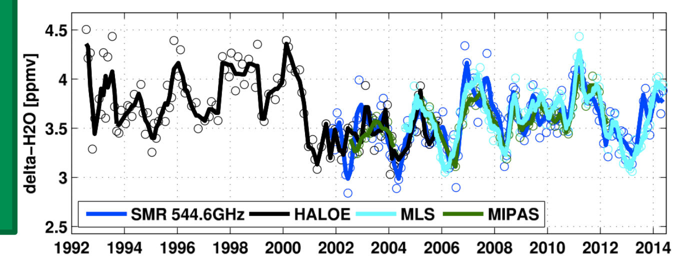
- Interest is growing in "geoengineering" approaches to tackling climate change, including injecting sulfate aerosols into the stratosphere, any study of which must be informed by observations

Aura MLS observations ozone (left) and chlorine monoxide (right) – the primary agent of ozone destruction – at ~20 km in March 2011, a period of unprecedented ozone loss in the northern hemisphere



Manney et al., 2011, Nature

Tropical water vapor at ~16 km from Aura MLS and other sensors, showing unexpected sudden declines in 2000 and 2012



Urban et al., 2014, EOS

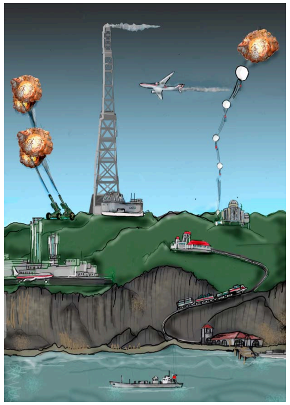
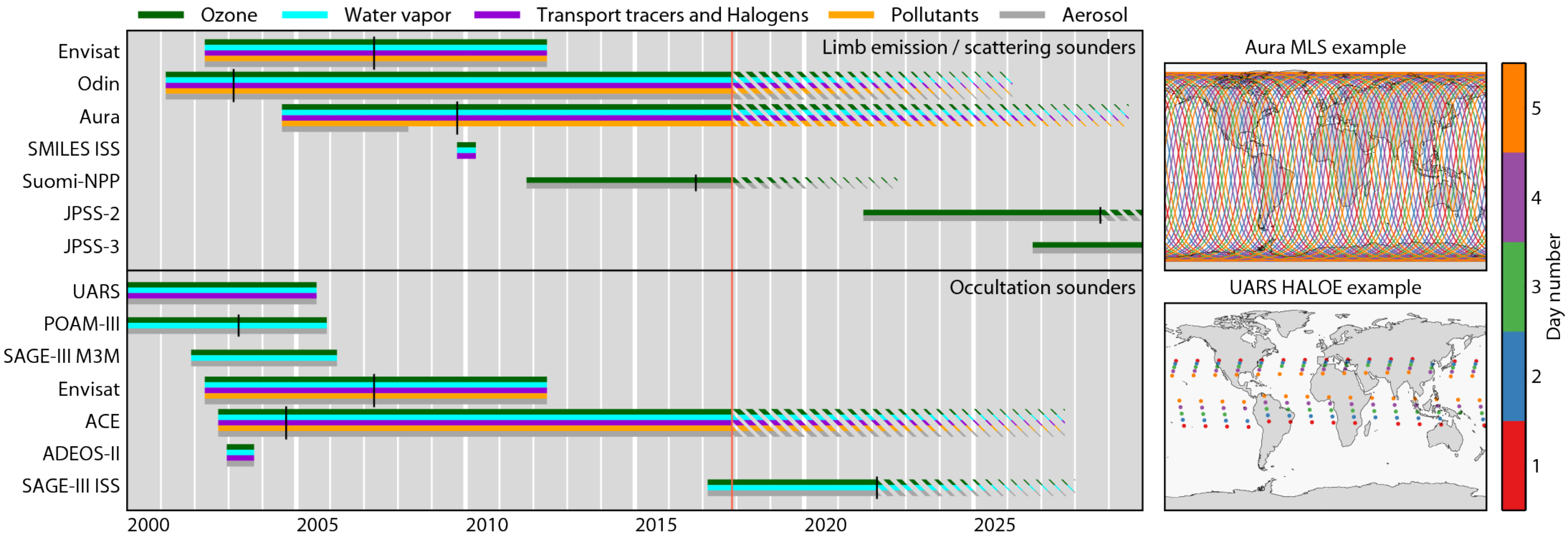


Illustration of various possible approaches to injecting sulfate aerosol into the stratosphere, in order to reduce surface heating

Robock, 2009, GRL

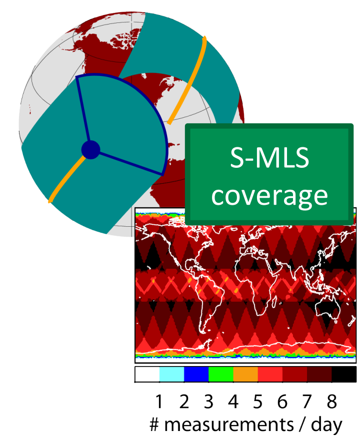
Past, current, and future UT/S measurements



- Timeline shows past, current, and future missions making UT/S measurements of
  Ozone (green): UV shield, greenhouse gas, and lower atmosphere pollutant
  Water vapor (cyan): Greenhouse gas
  Stratospheric tracers and halogens (purple): Essential to separating impacts of (and changes in) stratospheric chemistry from those of stratospheric dynamics
  Pollution tracers (orange): Tack world-wide transport of pollutants and greenhouse gases, and diagnose change in stratosphere / troposphere exchange
- Note the paucity of many such measurements in the coming decade

High level CAMLS project goals

- The goal of the CAMLS IIP-2013 project is to develop state-of-the-art receiver/spectrometer technologies that can form the core of:
  - A “Continuity MLS” instrument to extend and augment the record from Aura MLS
  - A “Scanning MLS” that, using a cooled receiver and 2D scanning limb antenna (IIP-2010) can measure a wide swath with 50x50 km spatial resolution
- CAMLS uses a 340 GHz 2SB receiver to measure nearly all the species measured by Aura MLS over five spectral regions
- Digital spectrometers under development are to provide ~1.2 MHz spectral resolution across a ±20 GHz IF, avoiding the calibration challenges associated with individual discrete analog channels
- Overall a CAMLS-based “Continuity MLS” instrument can be accommodated within 20kg, 100W, 70cm antenna size, 0.01m³ electronics
  - Aura MLS was 350kg, 370W, 1.6m antenna, ~1m³ electronics
- CAMLS IIP project goal is to develop the receiver/spectrometer core for a 340 GHz instrument, integrate it with the “Airborne Scanning MLS” instrument developed in a prior IIP, and perform ER-2 test flights

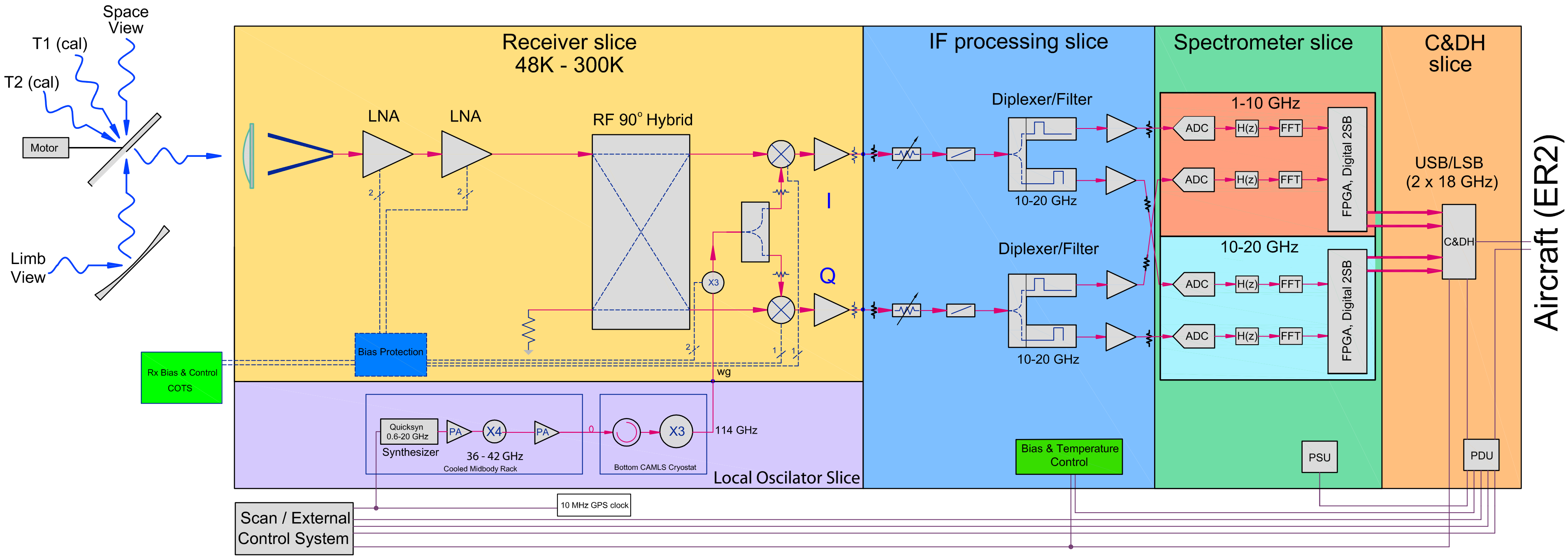


CAMLS measurements:
T/GPH, O_3, H_2O, CO, HNO_3, H_2CO, N_2O, ClO, HOCl, CH_3Cl, BrO, HO_2, CH_3CN, SO_2, Cloud ice, others…

CAMLS General Block Diagram

Compact Adaptable Microwave Limb Sounder

ASMLS



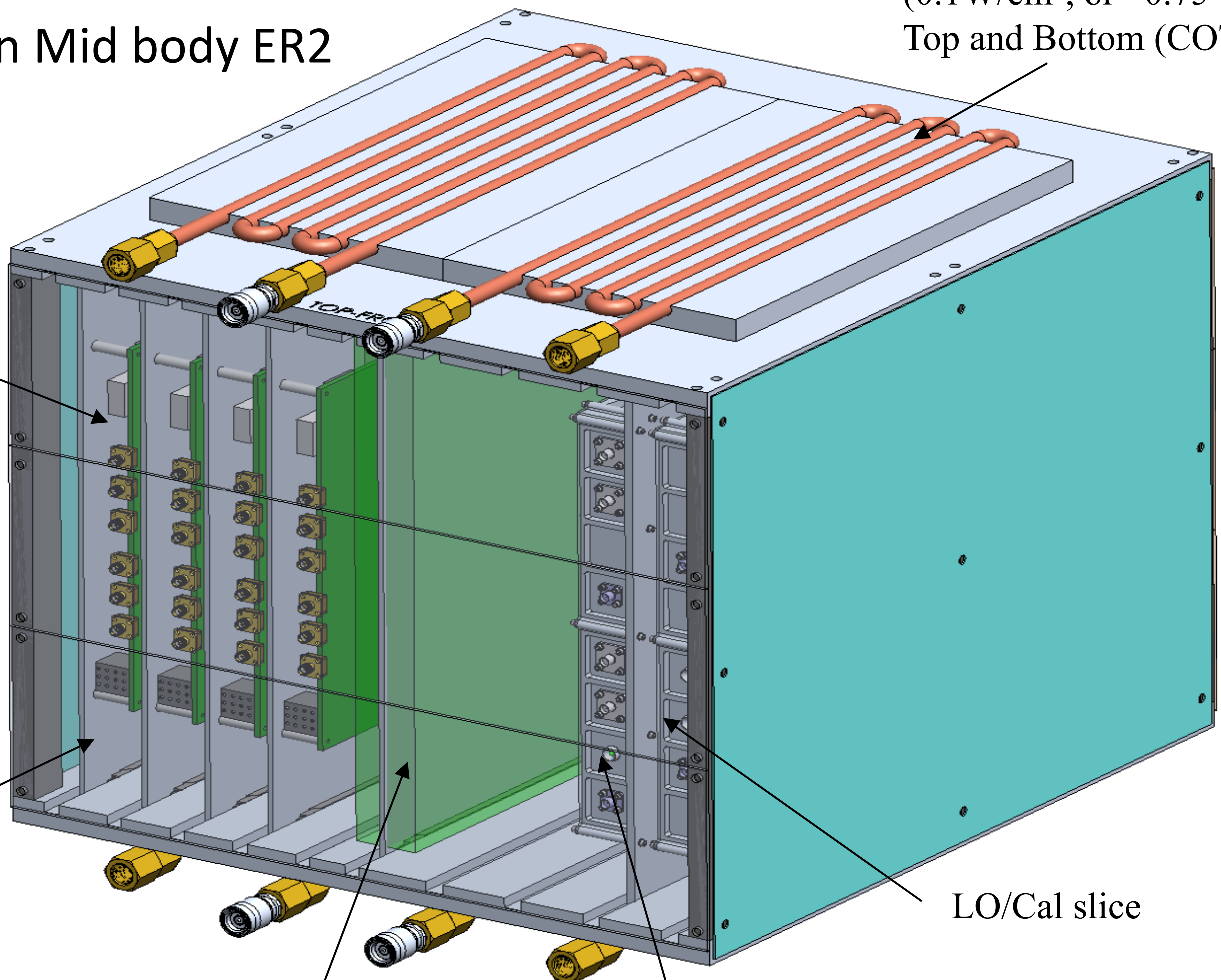
Legend:

- Receiver Slice
- IF Processor Slice
- Spectrometer Slice
- Local Oscillator Slice
- C&DH Slice

Liquid Cooled Chassis (Isometric View)

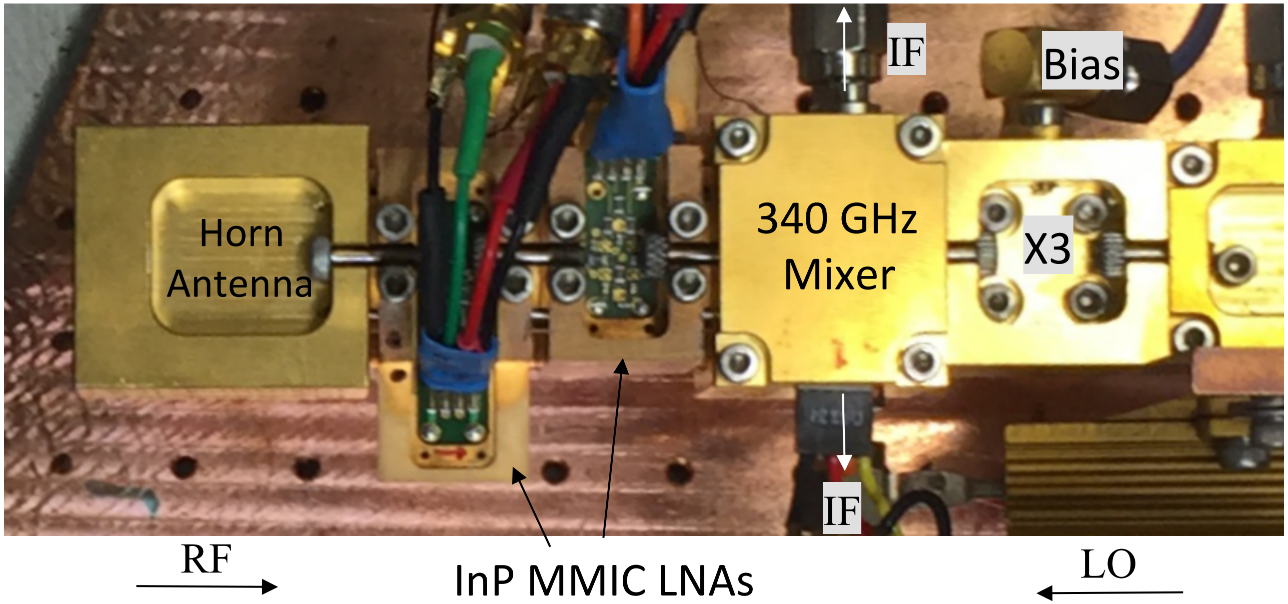
Compact Adaptable Microwave Limb Sounder

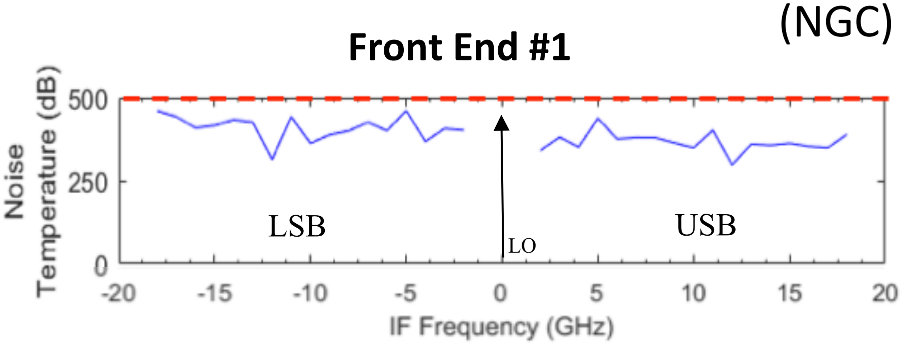
- Up to 7 'slices'
- To be mounted in Mid body ER2

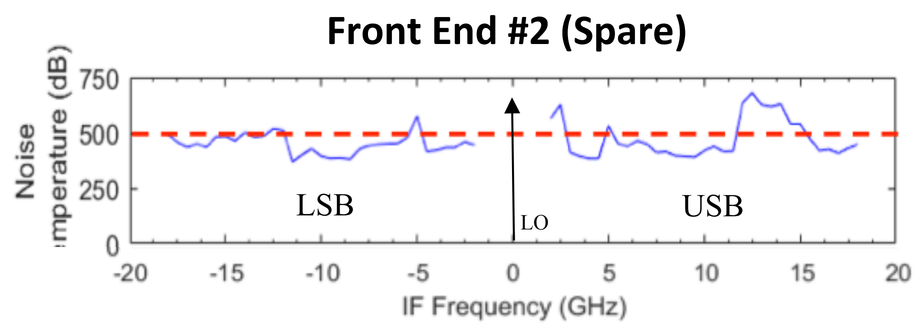


ESTO Earth Science Technology Office

Front-End Single Channel ($T_{ambient}$ = 55K)

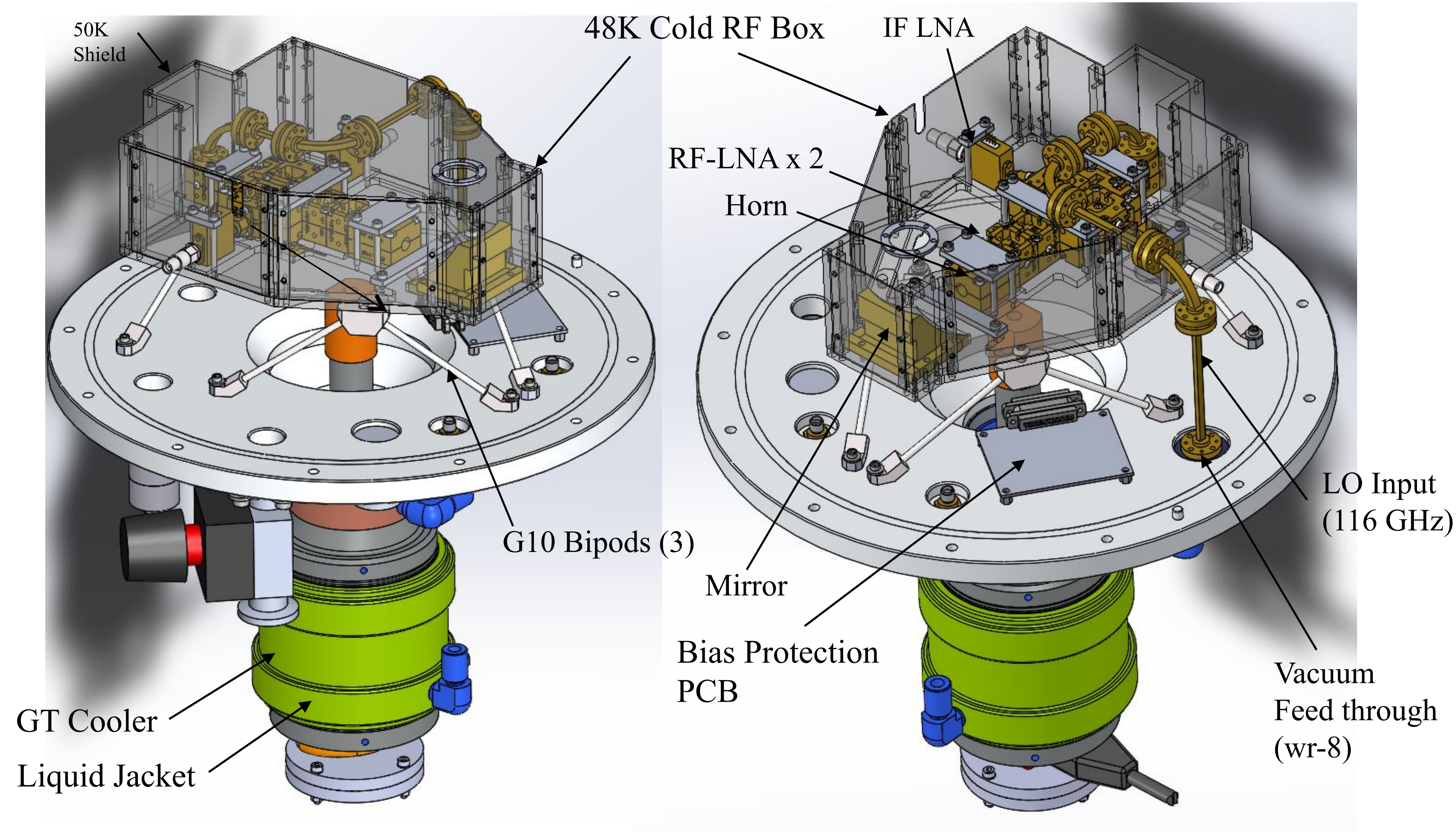






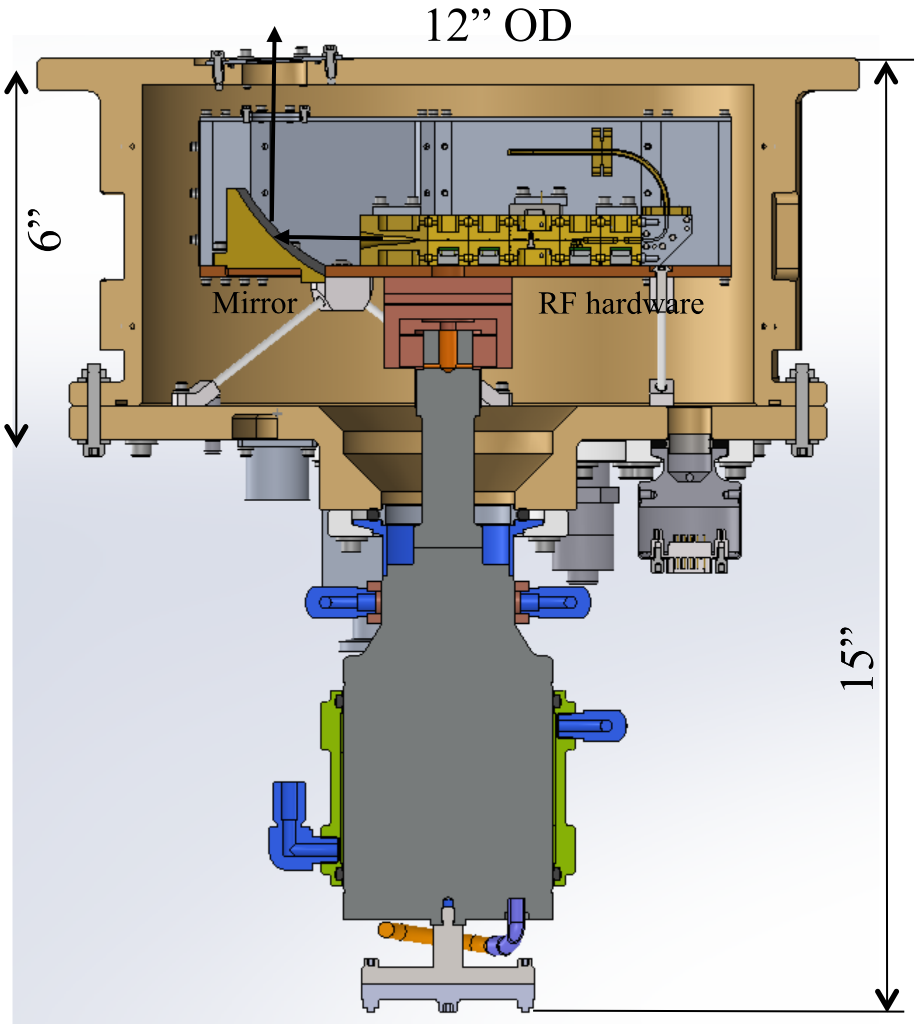
- **Goal of 500 K noise temperature met in RFE #1**
- **Sensitivity should improve when integrated with Intermediate Frequency LNAs**

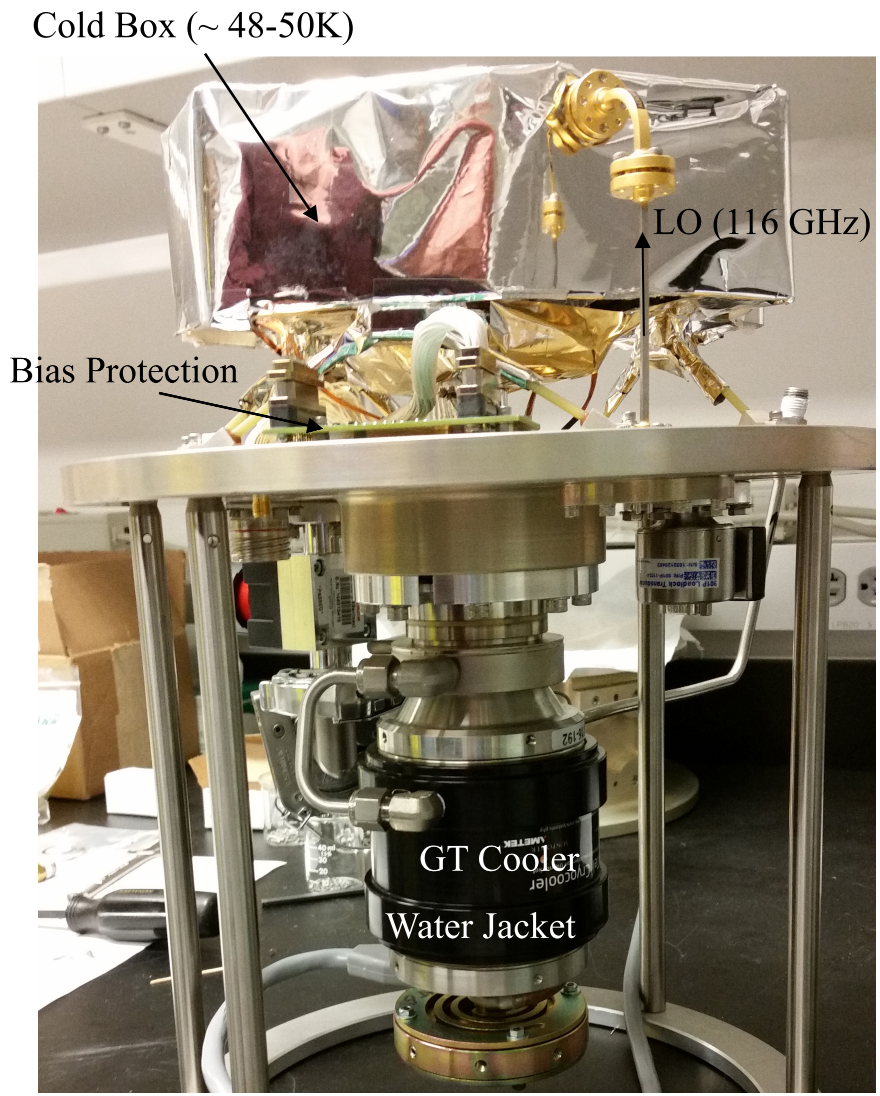
CAMLS Cryostat 48K RF Box (Design)



CAMLS Cryostat: Cross- and Side View

Compact Adaptable Microwave Limb Sounder





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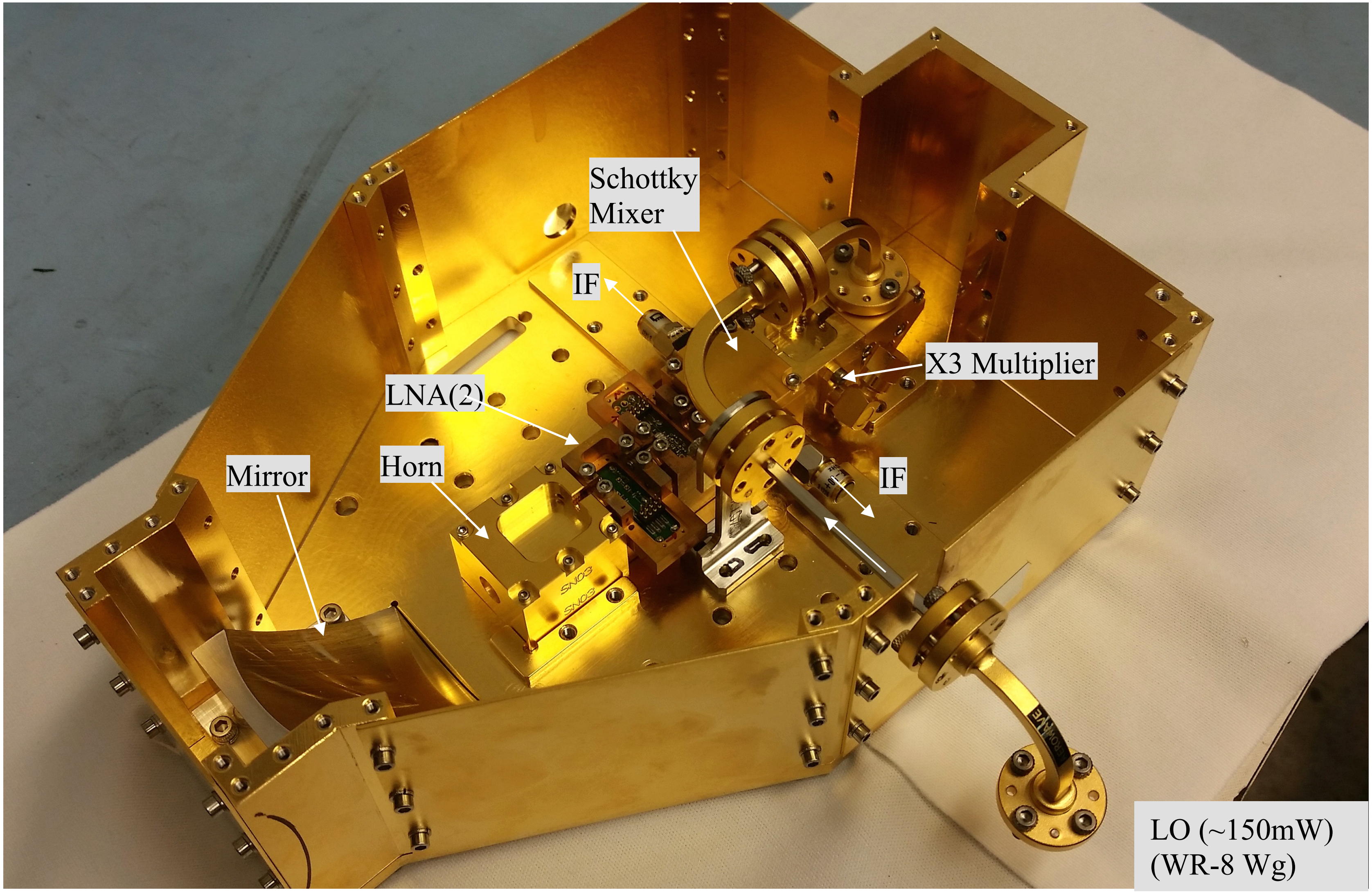
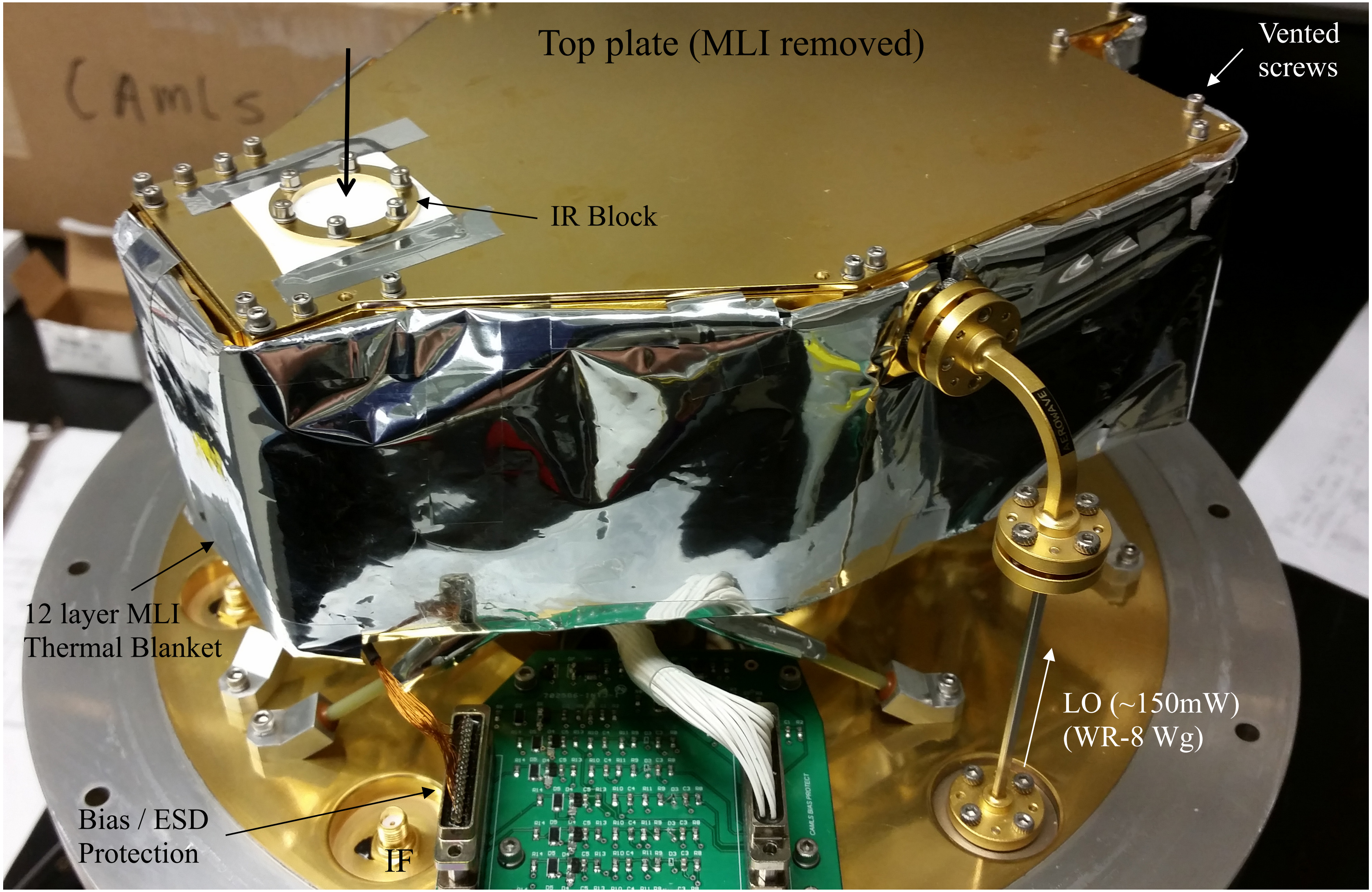
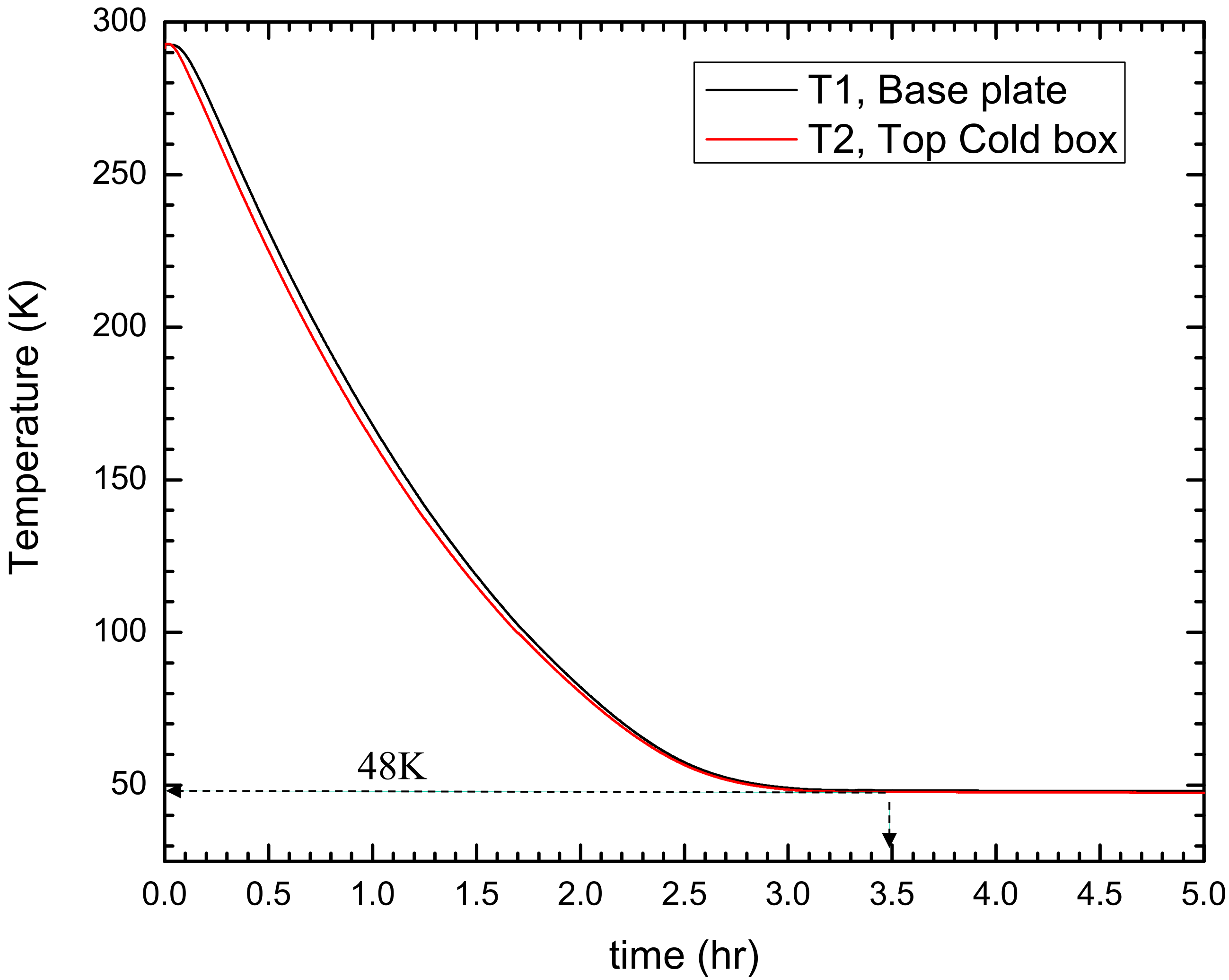
CAMLS RF Hardware in Cold Box



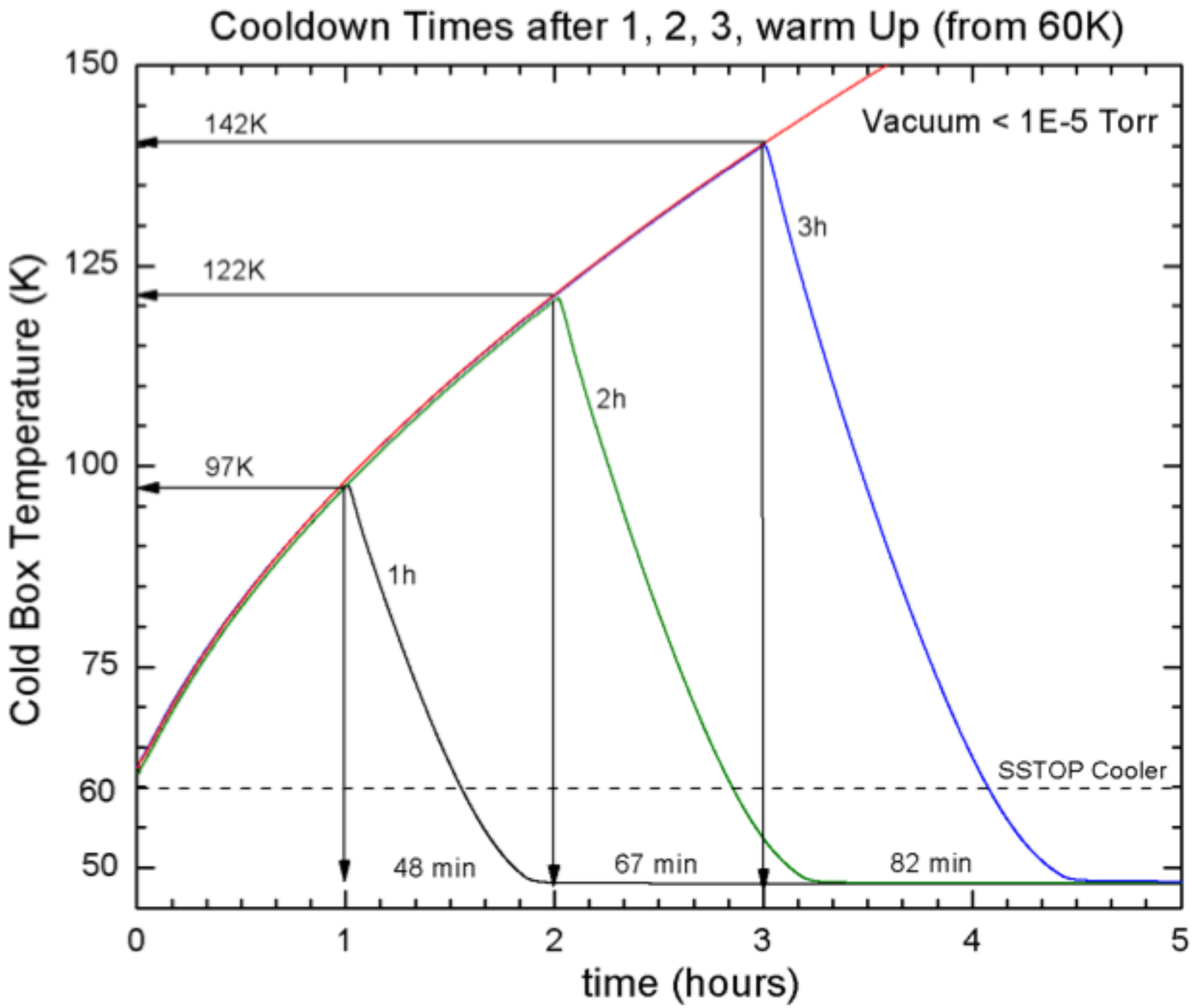
Cryostat Bias Protection and 116 GHz LO



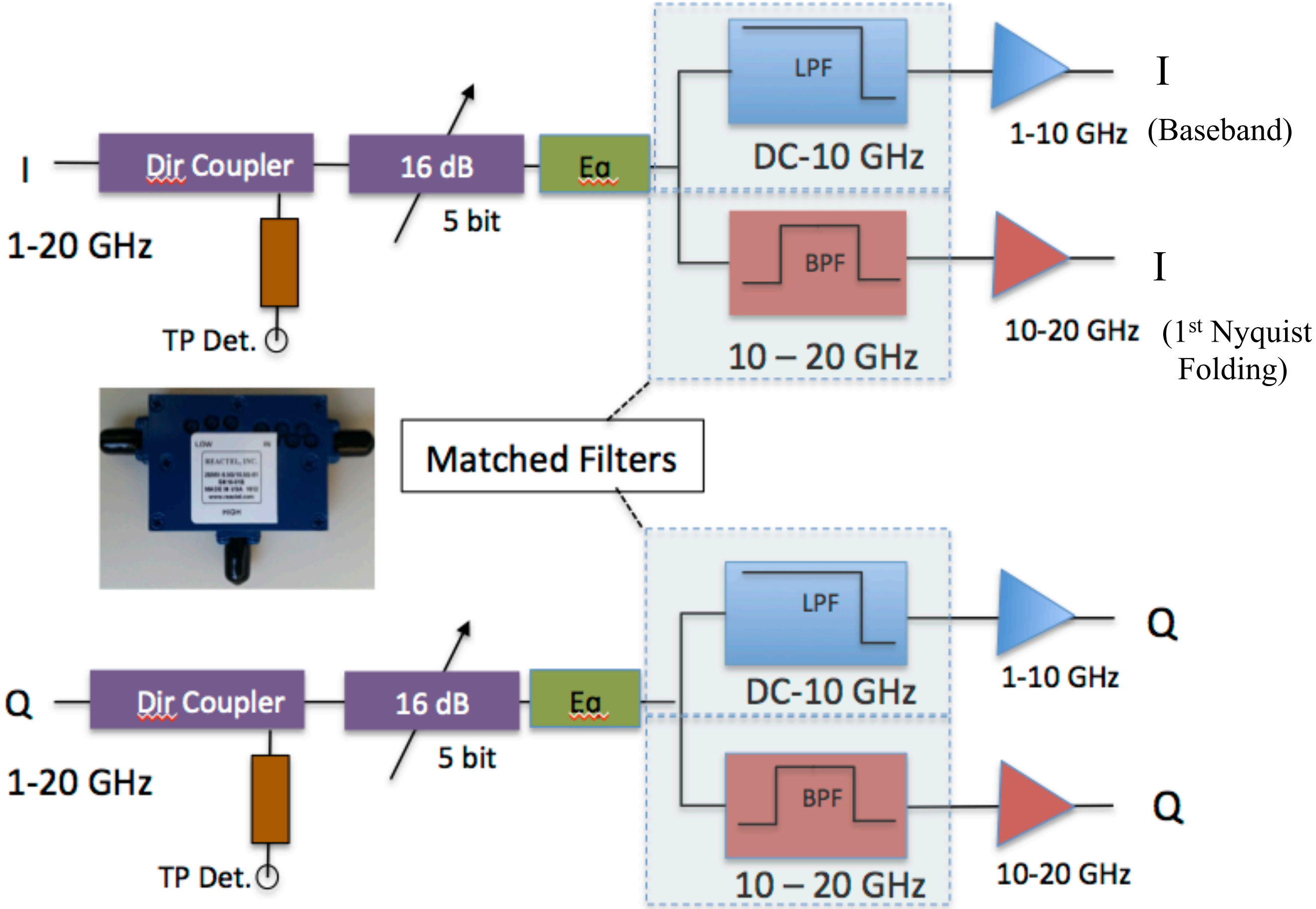
CAMLS Cooling Performance



CAMLS Cooling Performance

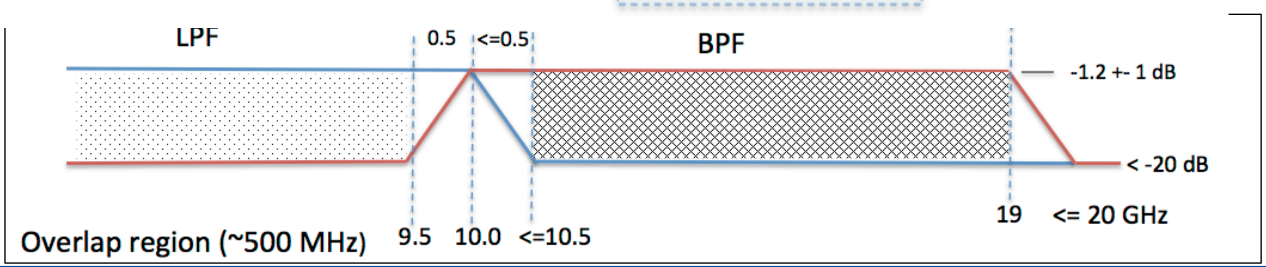


IF Processor Slice (Layout)



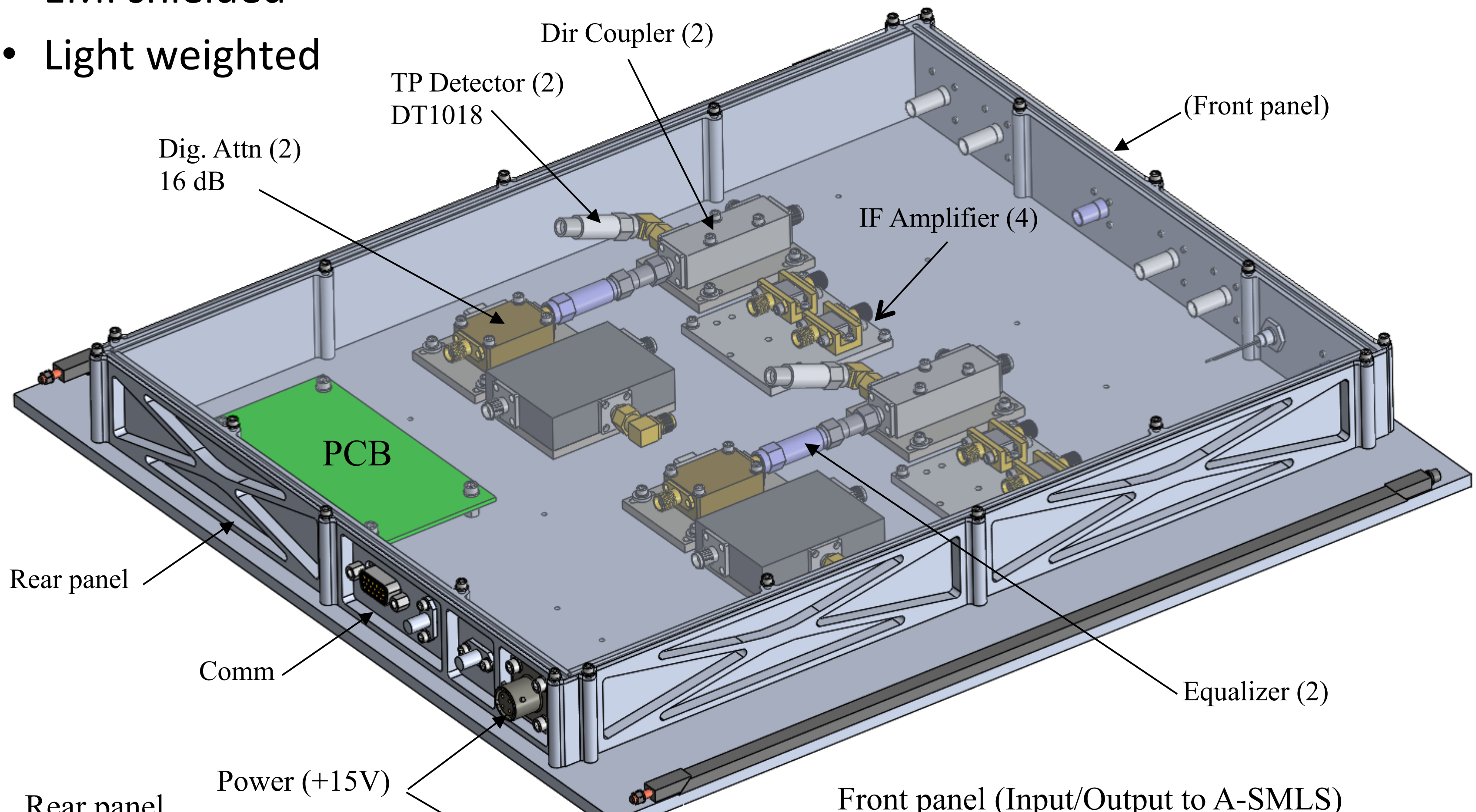
Parameters	Value
F_0 (-3dB)	10.0 GHz
Insertion Loss	1.2 dB
Ripple	< 1 dB
LPF Passband	DC – 9.5 GHz
BPF Passband	10 .5– 20 GHz
Stopband Atten	40 dB
-20 dB LPF	DC - 10.5 GHz
-20 dB BPF	9.5 - 20.5 GHz
Connectors	SMA
Qty: 2*	Ampl. Matched

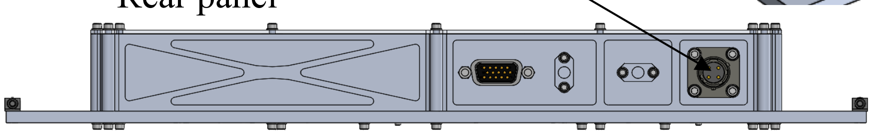
*Reactel Inc.

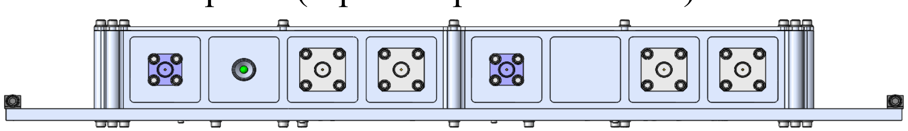


IF Processor Slice (Physical Implementation)

- EMI shielded
- Light weighted

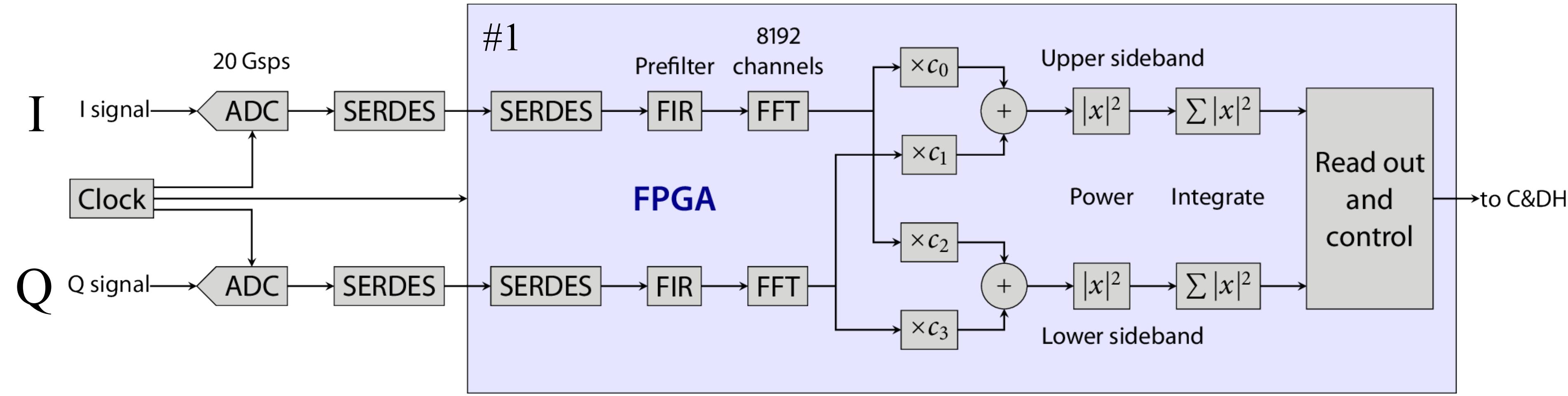




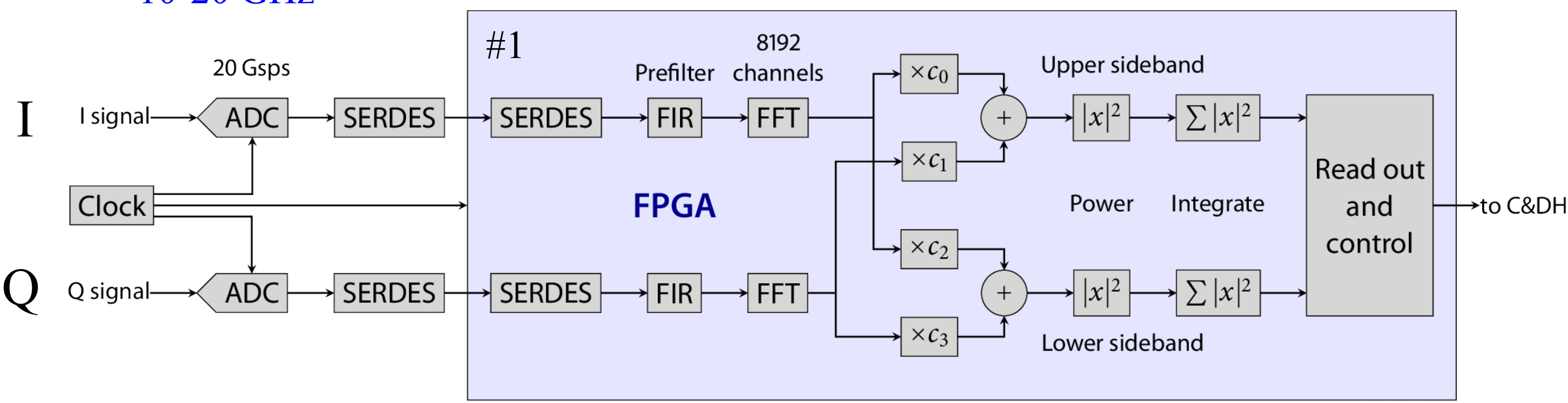


Spectrometer overview – Functional diagram

1 – 10 GHz



10-20 GHz

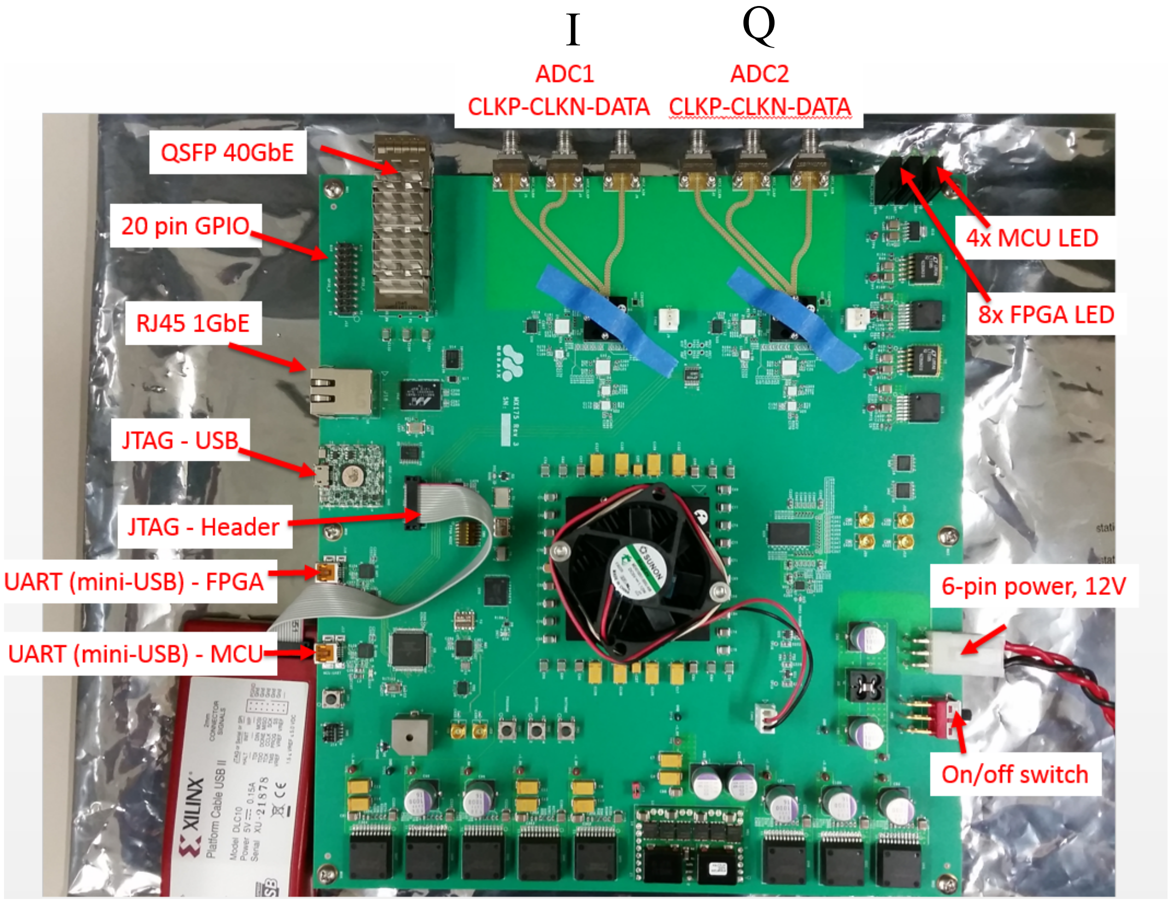


FPGA Spectrometers – MX175v3

Compact Adaptable Microwave Limb Sounder

Status:

- Issue with understanding ADC interface. This needs to be resolved before a ‘flight’ board with proper interface to the liquid cooled chassis can be finalized and procured.
- Very similar FPGA spectrometer software has been developed and in use at OVRO (28 nm Virtex 7)



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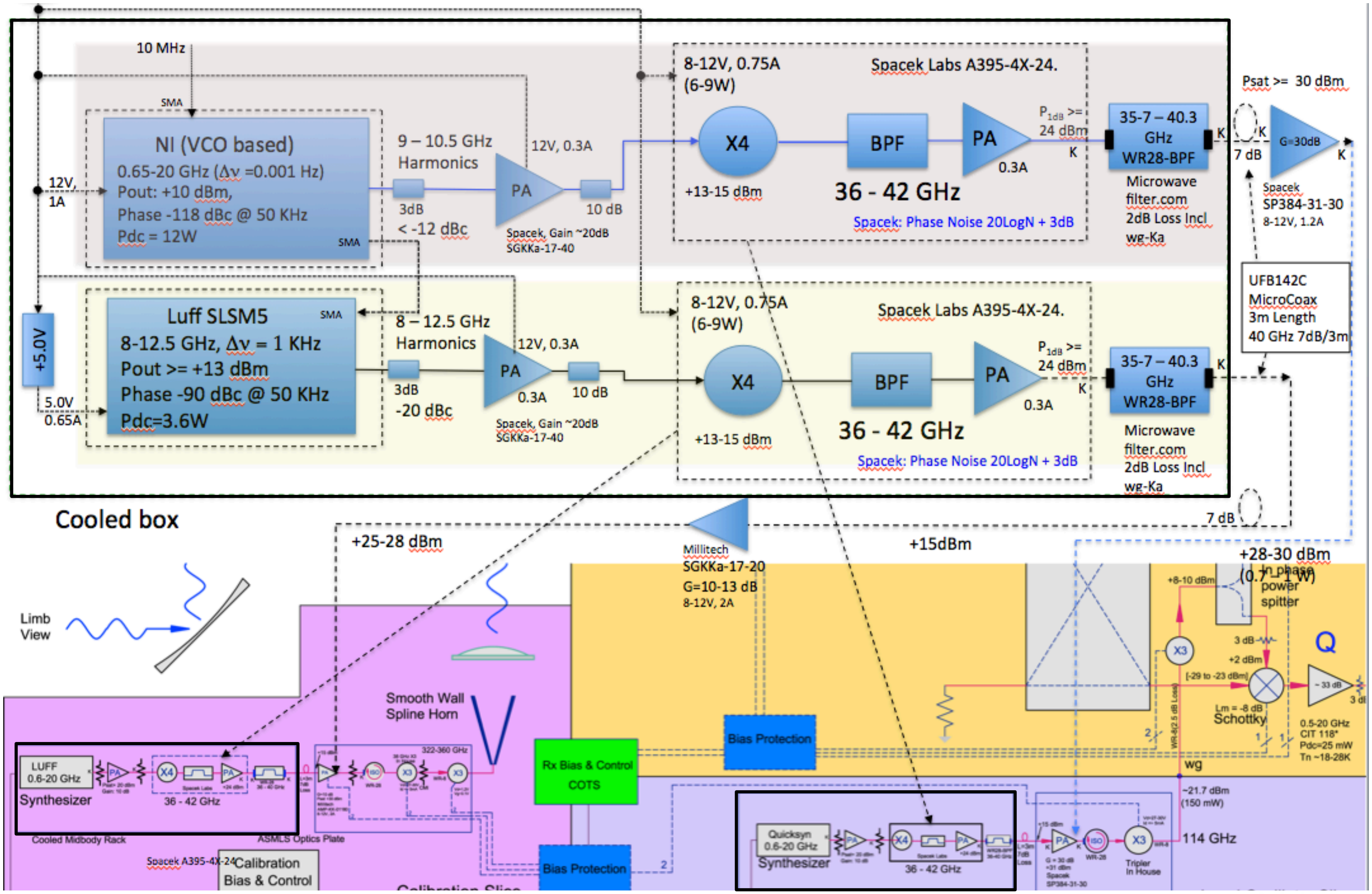
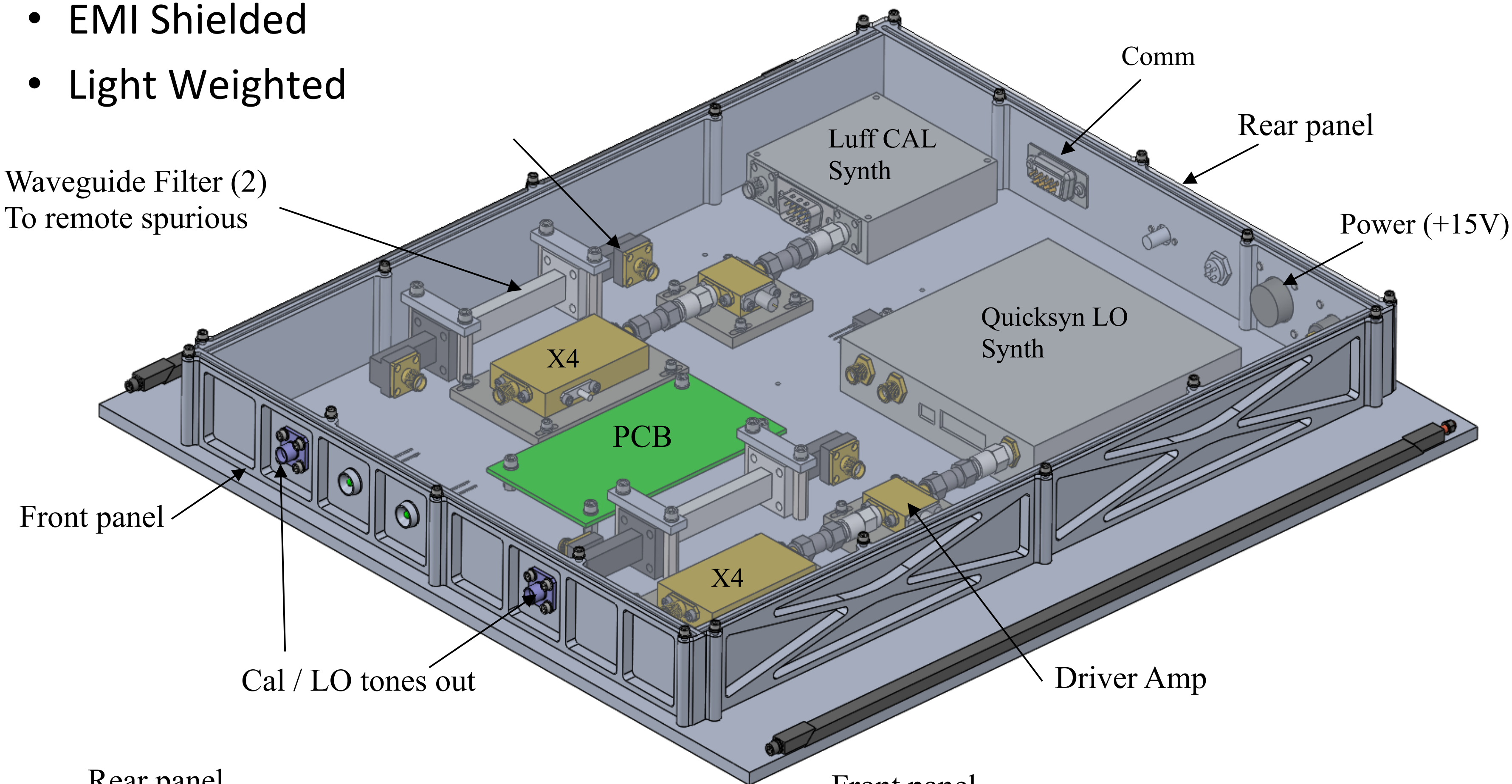
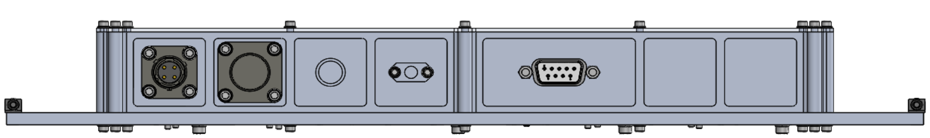
LO/CAL Slice (Diagram)

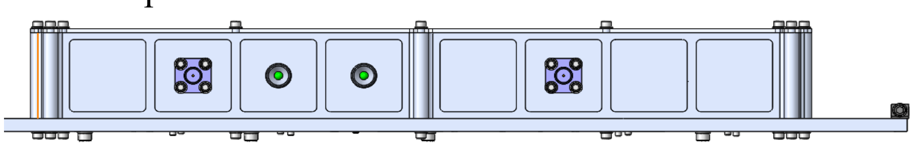


LO/CAL Slice (Physical Implementation)

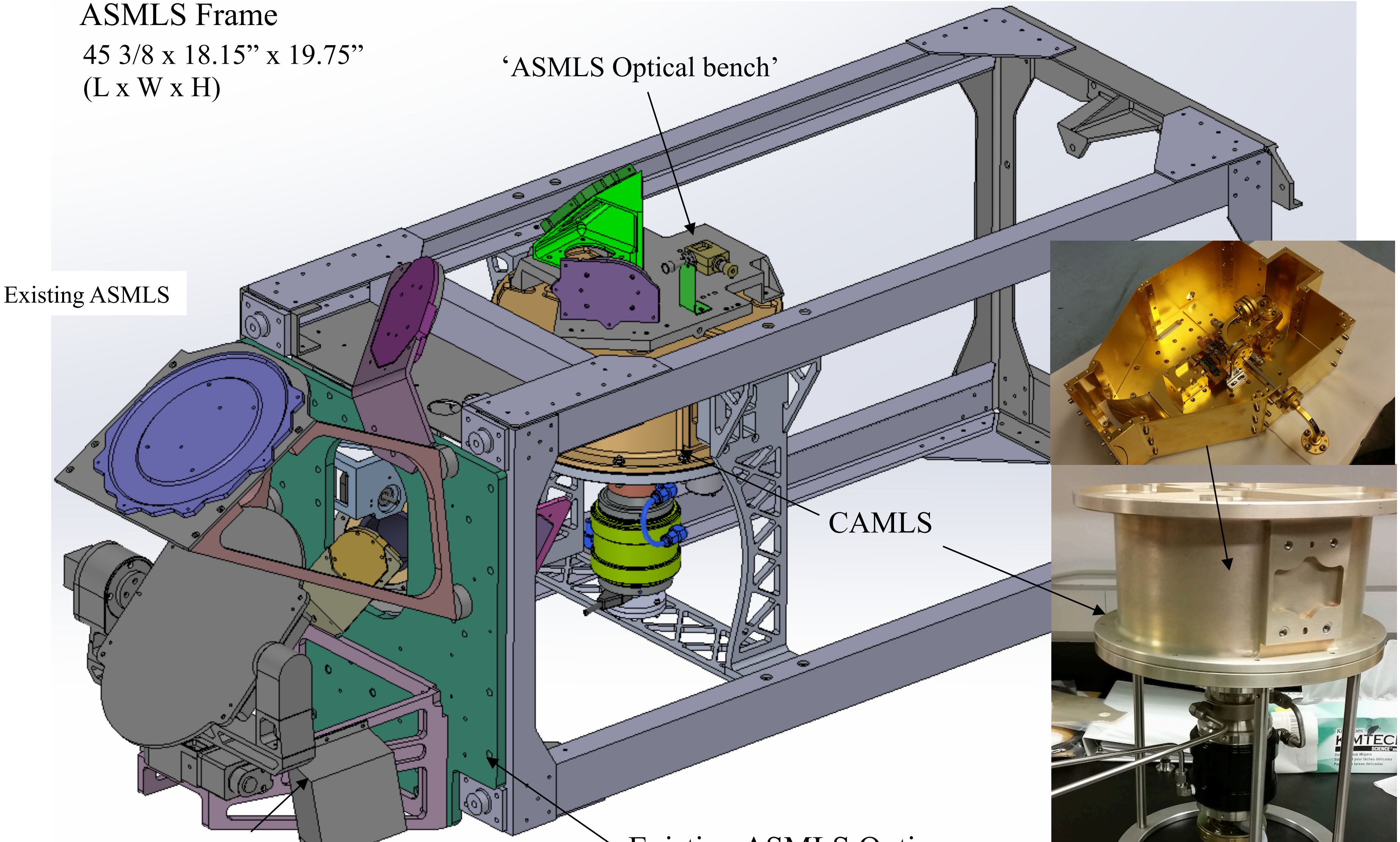
- EMI Shielded
- Light Weighted







CAMLS vs. ASMLS



Conclusion

- The CAMLS project is making good progress but a little behind schedule
- CAMLS 340 GHz Receiver Front End is complete and tested
  - Integration into the cryostat is underway
- CAMLS FPGA spectrometer is still under testing
- Main work in coming months is assembly and testing of complete CAMLS system and installation in A-SMLS instrument, e.g. AIV.
- Planning test flights in January 2018
  - Flying with Canadian colleagues developing a new Near IR limb sounder, targeting water vapor (one of the CAMLS target molecules)