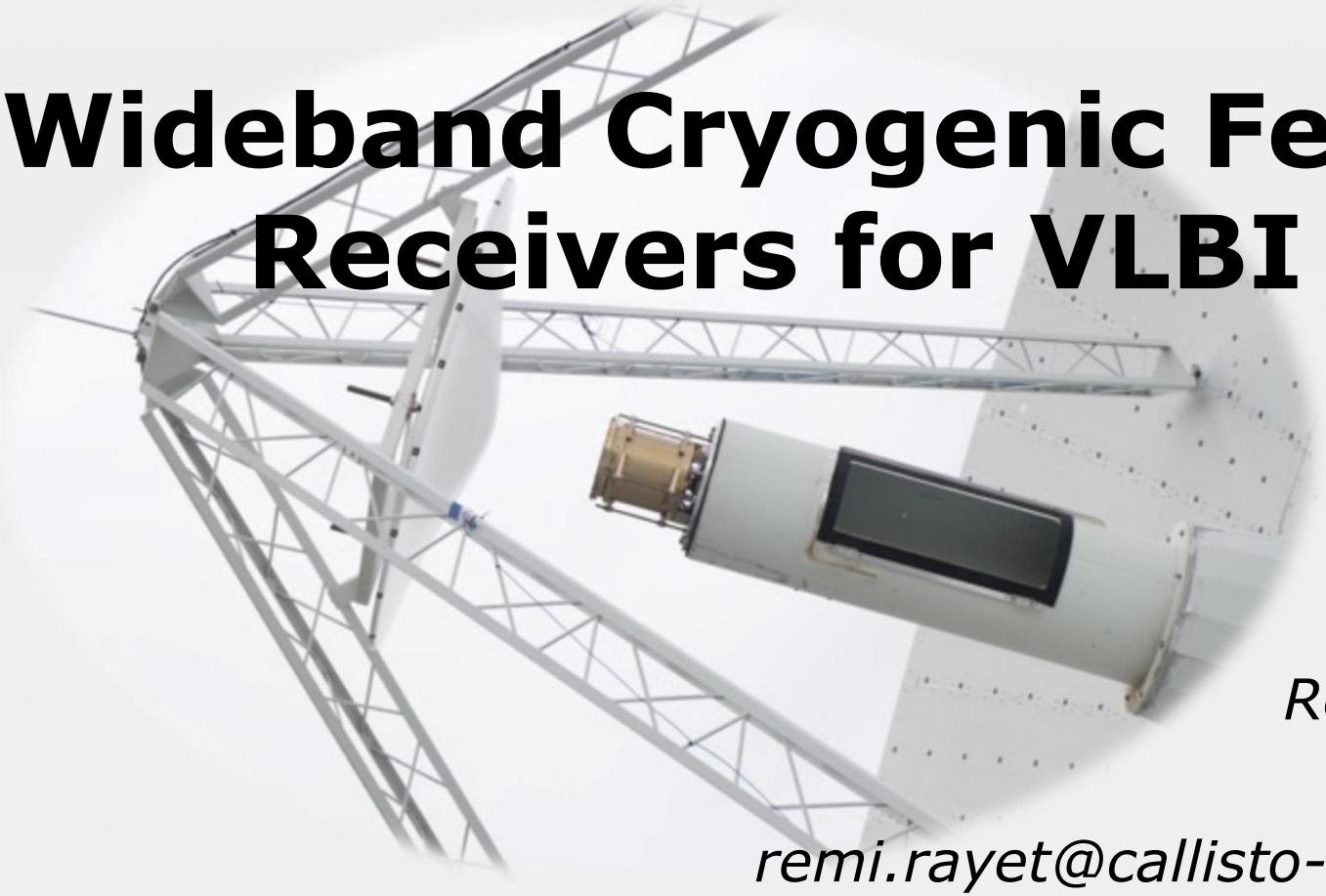
Callisto



Wideband Cryogenic Feed Receivers for VLBI

Rémi RAYET
Callisto
remi.rayet@callisto-space.com

Our experience:

> 20 years experience producing cryogenic LNAs

> 50 systems produced

Customers: ESA, ISRO, CNES, BKG, ZDS, etc…

VLBI developments:

Wideband (2.3—14GHz) cryogenic receiver optimized for VLBI applications (VGOS)

CalTech QRFH feed (Quad-Ridged Flared Horn)

Receiver in 2 models: Compact (NT<40K) and Ultra (NT<20K)

Compact Prototype tested on VLBI antenna in Hobart (TAS) (UTAS/AuScope) + 3 production units

Ultra Prototype being built – installation at BKG's Wettzell observatory by the end of 2017

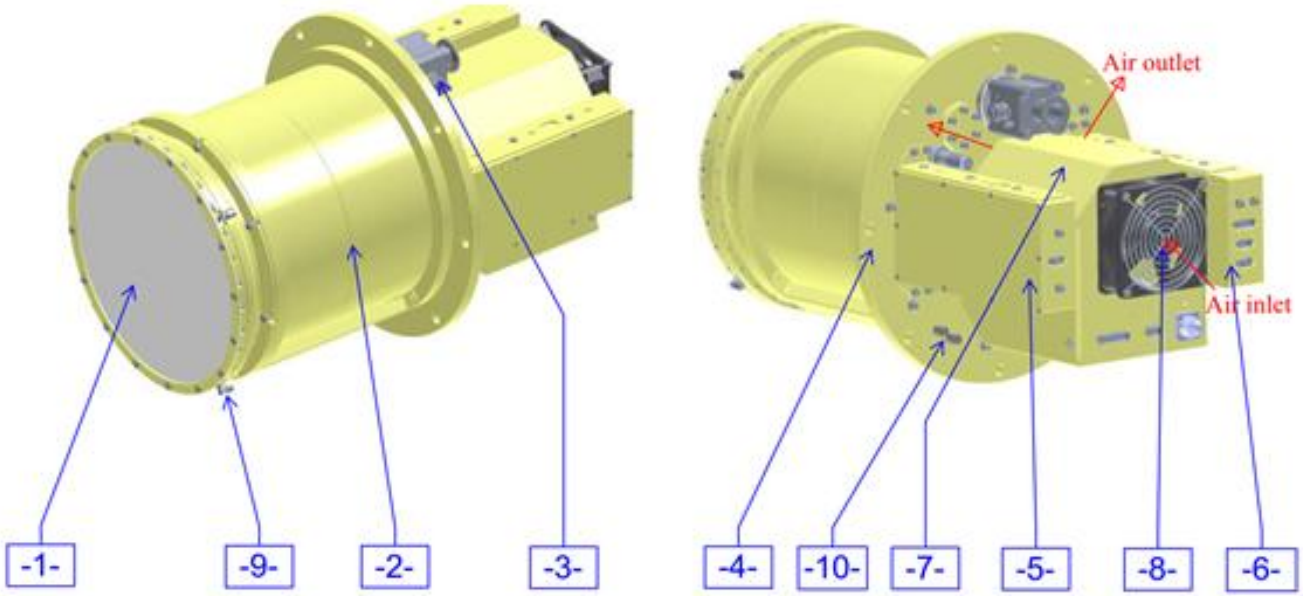


Figure 2-2: Receiver Mechanical Overview

1. Large RF vacuum window (RF Input) including radome
2. Sealed enclosure (receiver body with feed phase center marker line)
3. Vacuum valve
4. Base plate (with mechanical interface to antenna structure)
5. Post Box, with RF outputs (coaxial SMA connectors)
6. Calibration box (optional, for phase and noise calibration)
7. Vent box, with a fan providing air cooling to the cryocooler compressor and containing the cryocooler power controller
8. Air inlet port (source supplied by customer (AC for instance); see section 2.13.1.6
9. Coaxial SMA connector for Noise antenna probe (located inside the radome). This port is connected to the CalBox.
10. Pressurized dry air input and output ports for radome (pressurized dry air provided by customer)

Key features:

- **NT<40K**

(at Dewar window, excluding external noise contributions (Tsky, Tg, Tant).

- **Very compact**

L. 618 mm x ϕ. 311 mm

<30kg (all included! receiver, cold head, compressor, heat exchanger)

- **Very low power consumption**

(<440W, 20 times less than a conventional cryogenic receiver)

- **No maintenance**

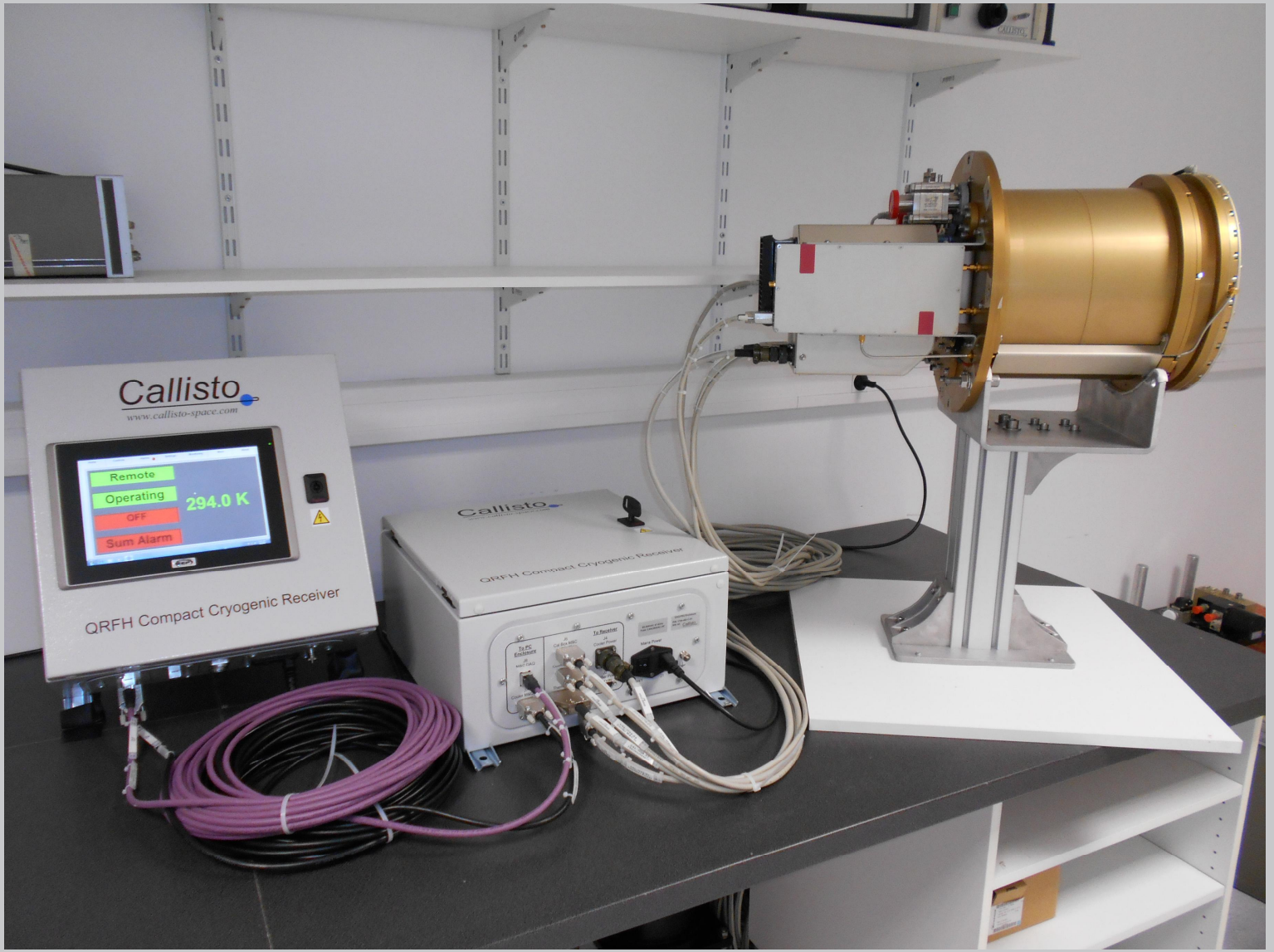
(on cryocooler for at least 5 years of continuous operation)

- Good for operations in remote locations
- Where energy cost is high (production + environmental impact)
- Where maintenance logistics is particularly complex and expensive

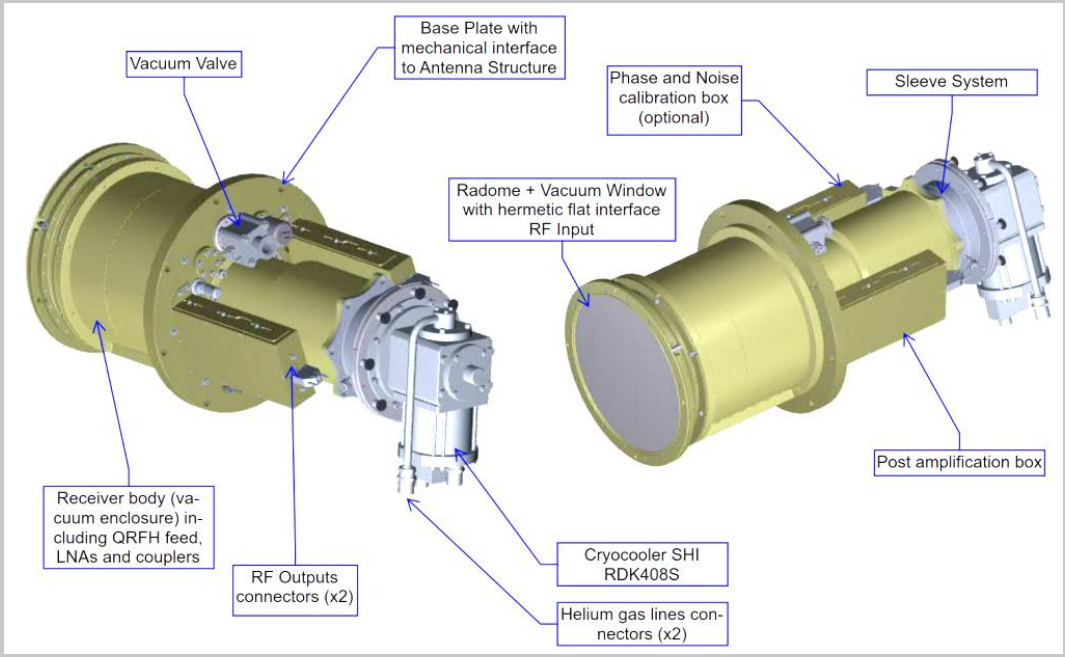
UTAS (Hobart-TAS) 12m VLBI Antenna

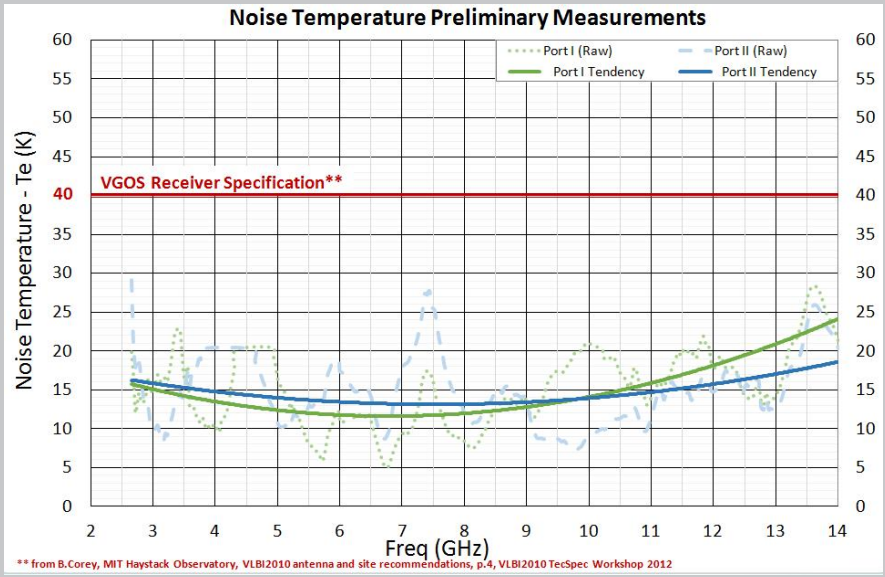
. Prototype tests on VLBI antenna

. Mostly issues with mechanical integration:
.. vibrations transfer to antenna structure,
.. optical alignment



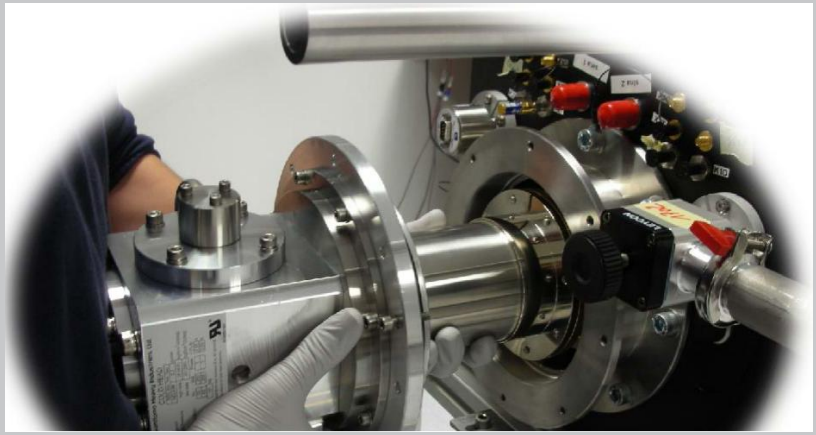
Ultra QRFH cryogenic receiver





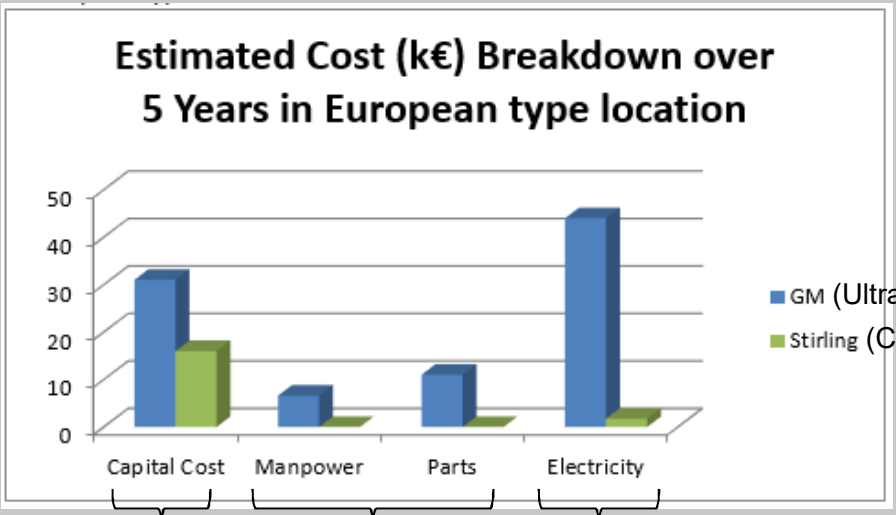
Key features:

- **NT<20K**
- **Simplified cold head service**
  - ✓ No need for receiver dismounting from the antenna
  - ✓ No receiver opening for dismounting full cold head
  - ✓ No need for receiver realignment after cold head service
  - ✓ Very fast cold head replacement by spare (<30 minutes when receiver at room temp.)
- Very best NT performance
- Users with no particular constraints on electrical consumption and regular maintenance



Cryogenic sub-system cost comparison

Coolers cost differences:



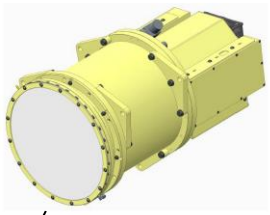
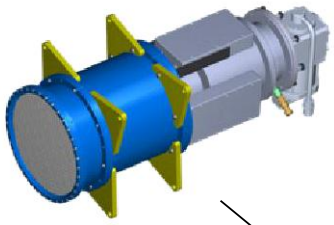
CryoSystem + support Equipment only

Maintenance

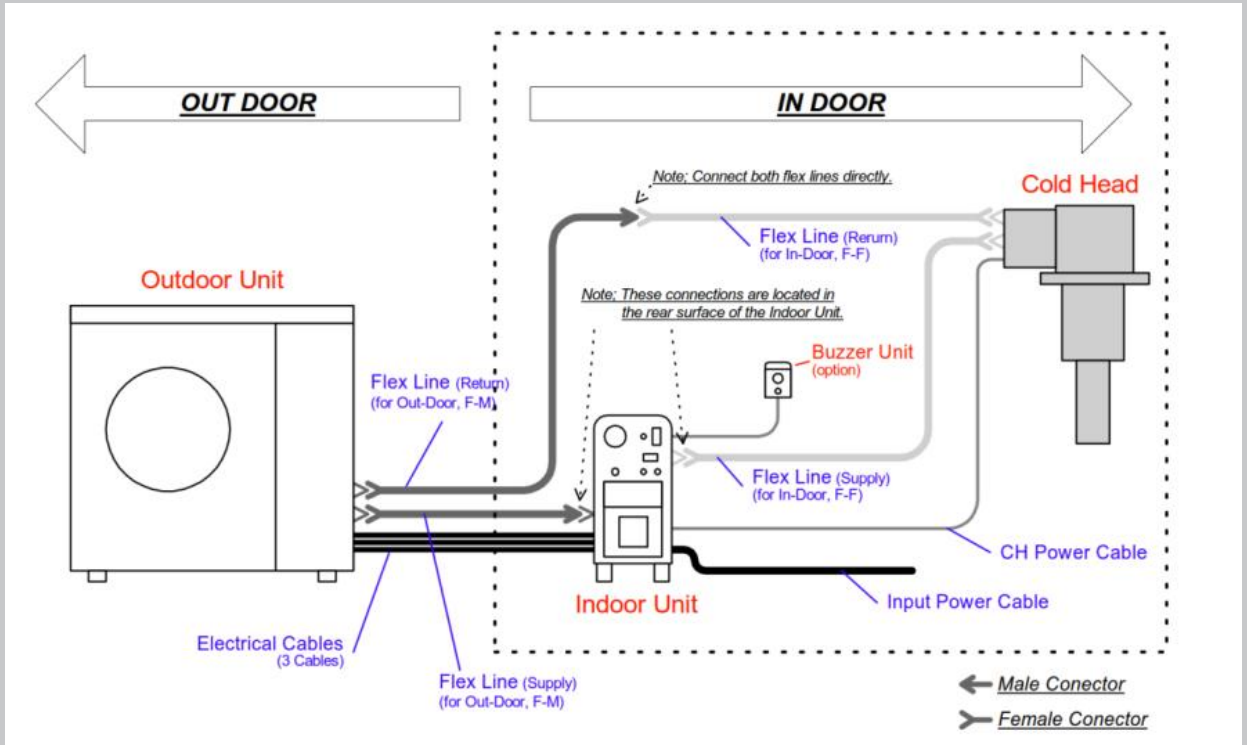
Operation (incl. support Equipment (water chiller, etc))

Coolers environmental impact:

	Ultra CryoLNA (GM)	Compact CryoLNA (Stirling)
Equivalent Carbon Footprint (oil consumption for electricity generation over 10 years : 893g(CO2-eq)/kW.he) [6])	**391 tons**	**15.6 tons**

Receiver Model:	Compact	Ultra
		

Ø



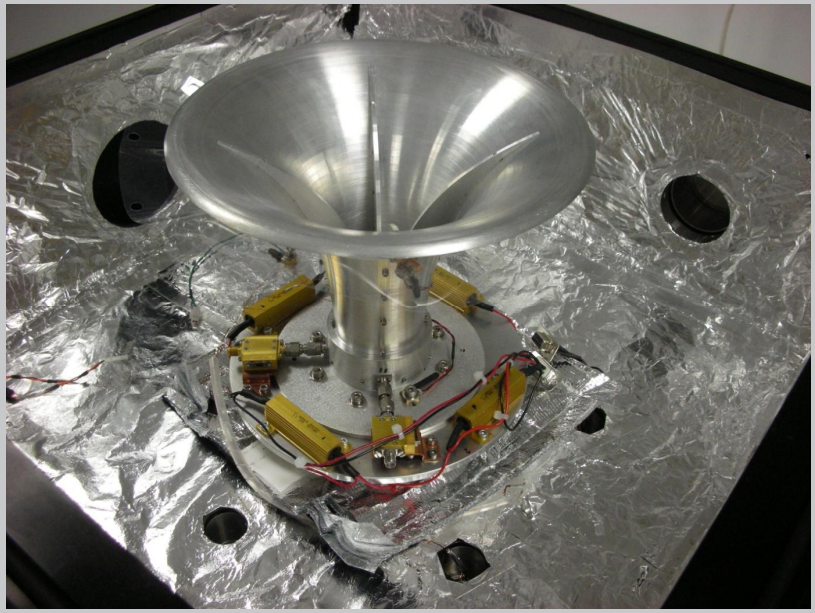
QRFH Feed

. “Quad-Ridged Flared Horn”, CalTech Design, wideband RF feed (2—14GHz)

. Compact, Aluminium design → good for cryogenic cooling

. Only 2 LNAs required

= complexity ↘, cost ↘, reliability ↗



. 2 linear polarizations outputs

. Standard feeds delivered by Callisto compatible with Patriot, Intertronic Solutions, MT Mechatronics and Vertex 12m telescopes

. Custom designs of QRFH feeds can adapt other frequency ranges, on-demand

. Unique, patented thermal insulation system for cryogenic RF receivers

. Solid thermal insulation

. ~~High vacuum~~

→ no need for high vacuum pumping before cooling!

→ only rough vacuum (~1mbar)

(simple scroll pump operating for few minutes,
no need of turbo pump)

. Compact Receiver:

→ sealed at factory

→ no vac. pump for cooldown

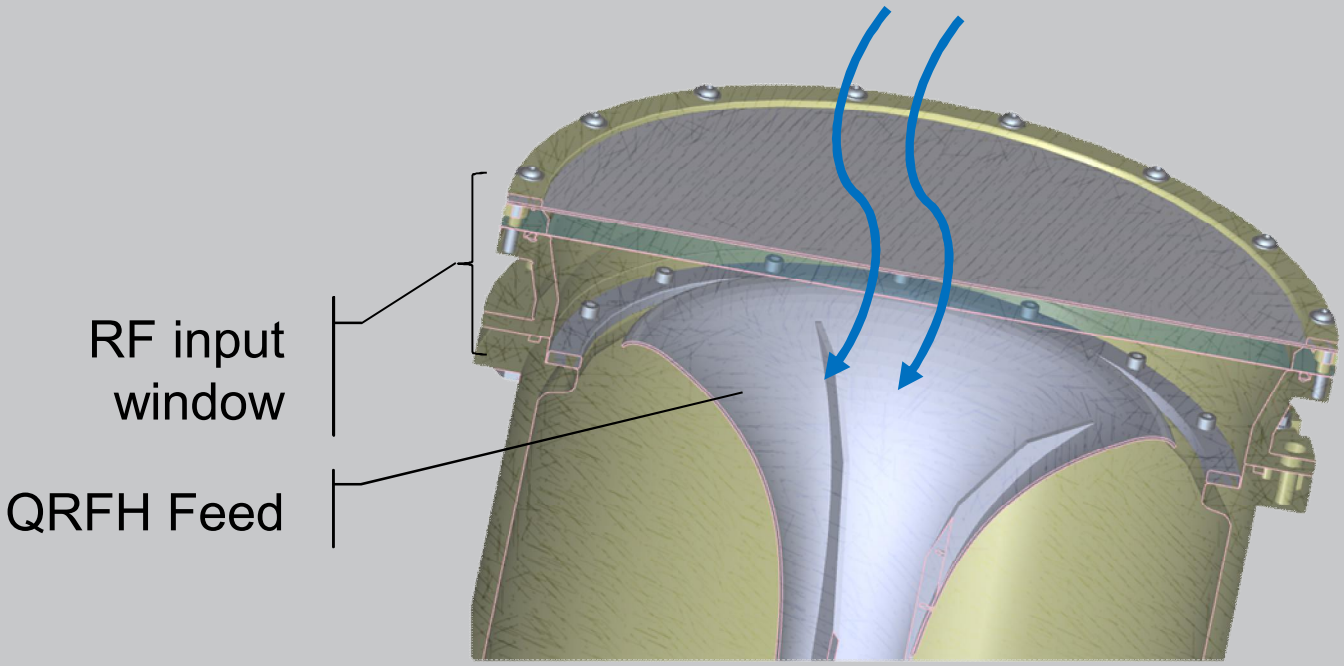
→ vacuum recycling for few minutes once a year or less often

. Ultra Receiver: → after cold head replacement for service

. Critical point: RF input window of the receiver

Must be at the same time:

→ Transparent + low loss RF 2—14GHz

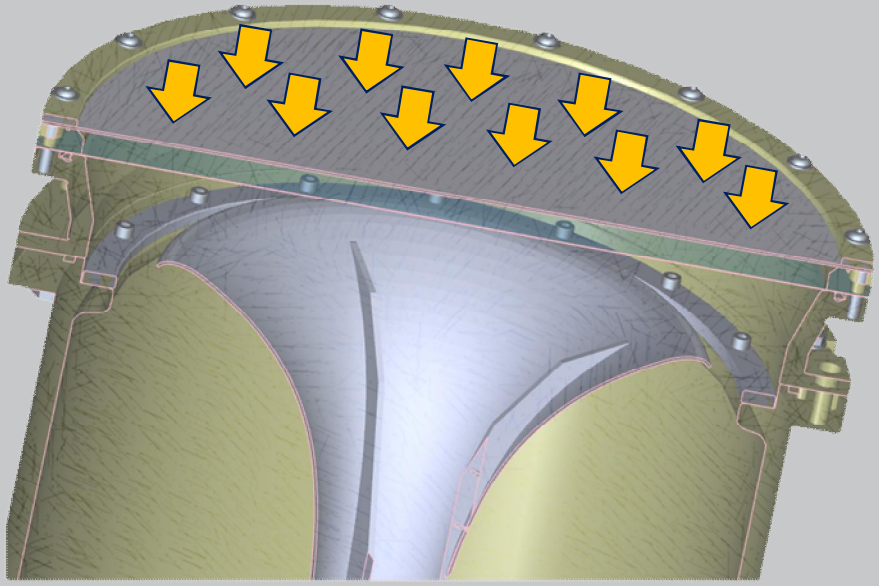


. Critical point: RF input window of the receiver

Must be at the same time:

→ Transparent + low loss RF 2—14GHz

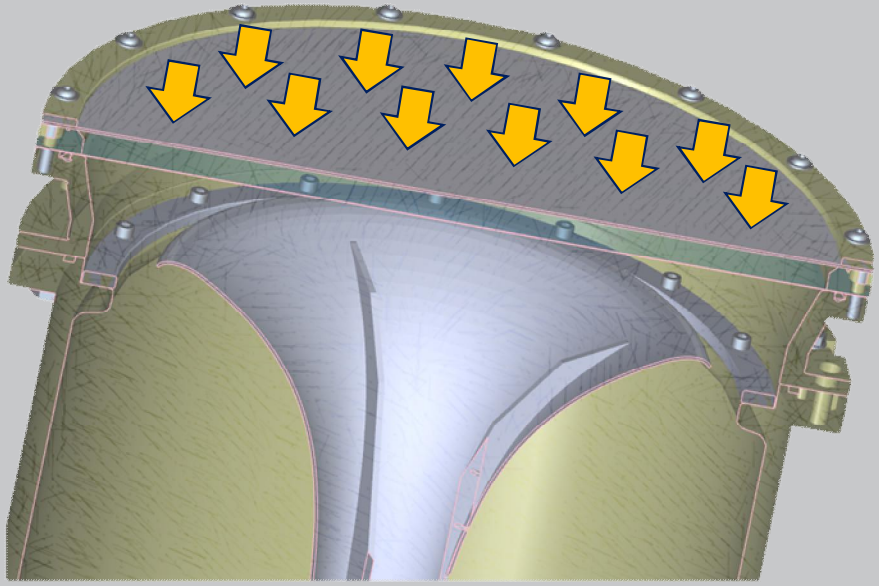
→ Robust to support large mechanical loads due to Atmospheric pressure (~700kg!)



. Critical point: RF input window of the receiver

Must be at the same time:

→ Transparent + low loss RF 2—14GHz
→ Robust to support large mechanical load due to Atmospheric pressure (~700kg!)

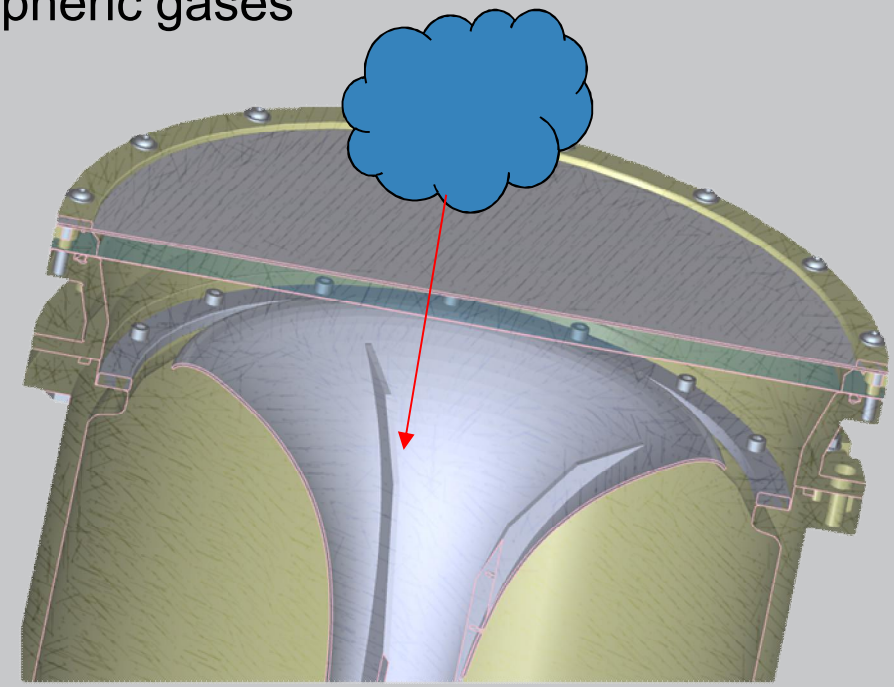


. Critical point: RF input window of the receiver

Must be at the same time:

→ Transparent + low loss RF 2—14GHz
→ Robust to support large mechanical load due to Atmospheric pressure (~700kg!)

→ Hermetic: isolate internal volume from atmospheric gases

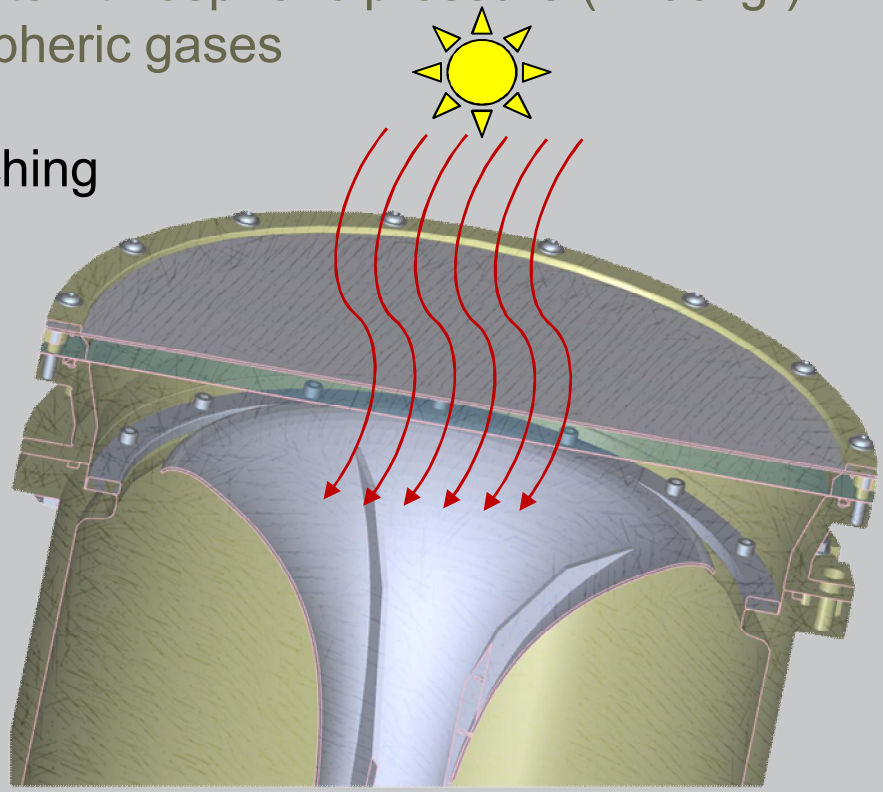


. Critical point: RF input window of the receiver

Must be at the same time:

→ Transparent + low loss RF 2—14GHz
→ Robust to support large mechanical load due to Atmospheric pressure (~700kg!)
→ Hermetic: isolate internal volume from atmospheric gases

→ Filter infrared heat loads to prevent from reaching the cryo parts

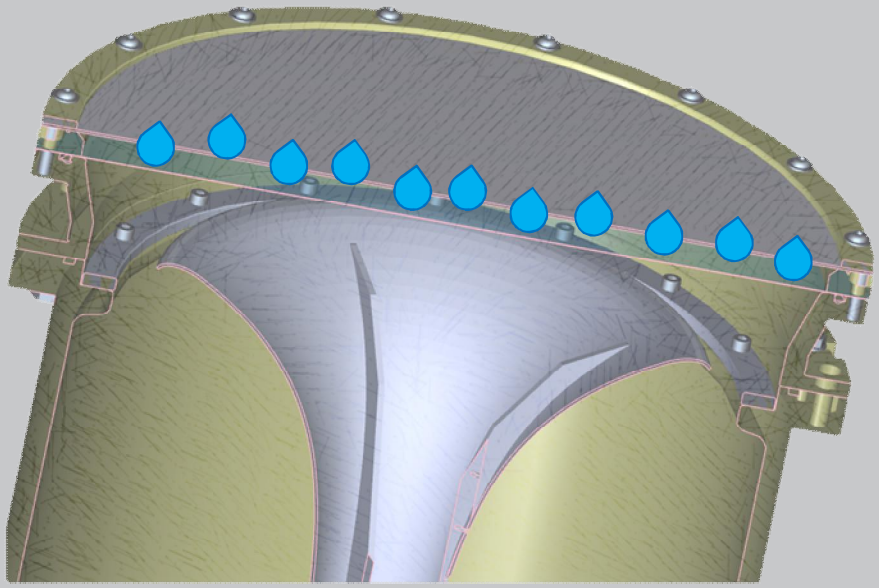


. Critical point: RF input window of the receiver

Must be at the same time:

→ Transparent + low loss RF 2—14GHz
→ Robust to support large mechanical load due to Atmospheric pressure (~700kg!)
→ Hermetic: isolate internal volume from atmospheric gases
→ Filter infrared heat loads to prevent from reaching the cryo parts

→ Prevent moisture condensation on window (RF attenuation)

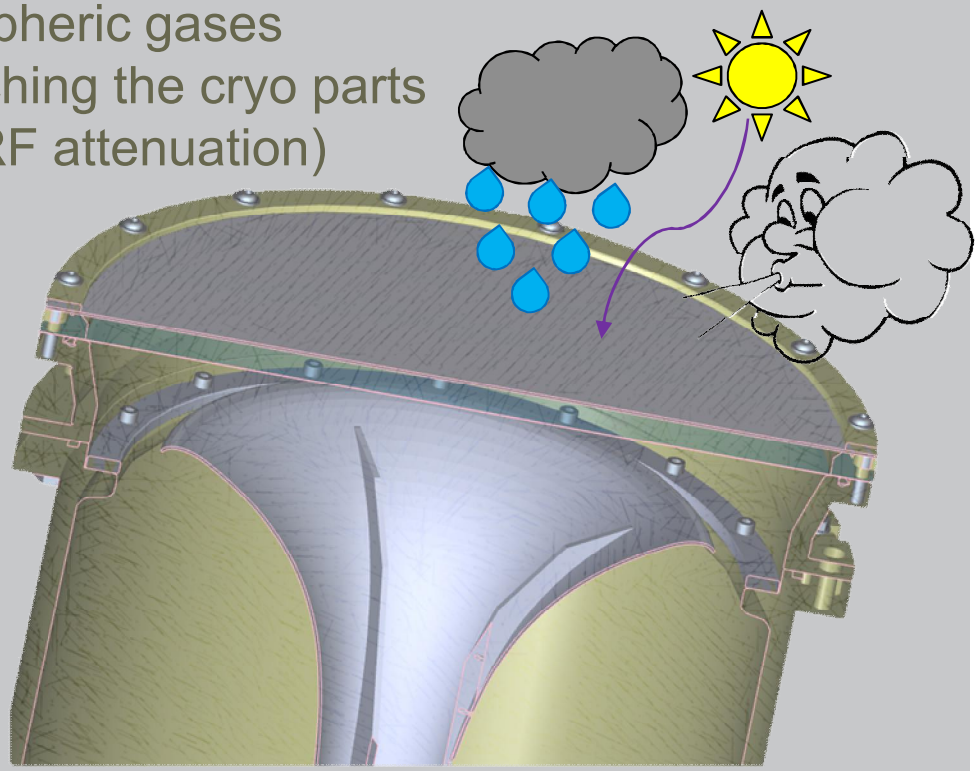


. Critical point: RF input window of the receiver

Must be at the same time:

→ Transparent + low loss RF 2—14GHz
→ Robust to support large mechanical load due to Atmospheric pressure (~700kg!)
→ Hermetic: isolate internal volume from atmospheric gases
→ Filter infrared heat loads to prevent from reaching the cryo parts
→ Prevent moisture condensation on window (RF attenuation)

→ Weather proof! (rain, wind, dust, hail, UV…)



. Critical point: RF input window of the receiver

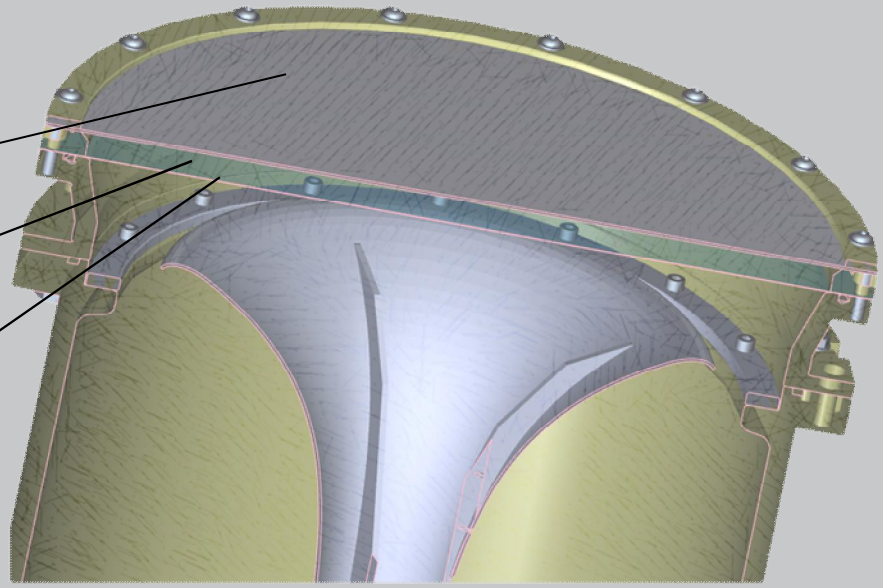
Must be at the same time:

→ Transparent + low loss RF 2—14GHz
→ Robust to support large mechanical load due to Atmospheric pressure (~700kg!)
→ Hermetic: isolate internal volume from atmospheric gases
→ Filter infrared heat loads to prevent from reaching the cryo parts
→ Prevent moisture condensation on window (RF attenuation)
→ Weather proof! (rain, wind, dust, hail, UV…)

Solution:

Two-layer window with:

- Radome
- Dry gas
- Polymeric vacuum window



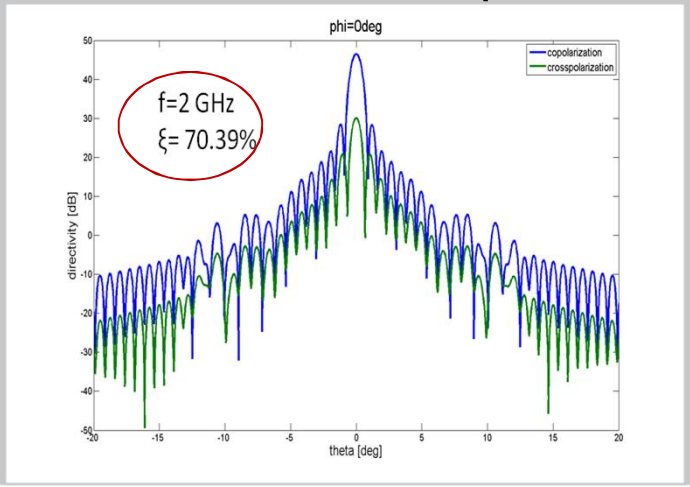
. Fundamental to design the input interface

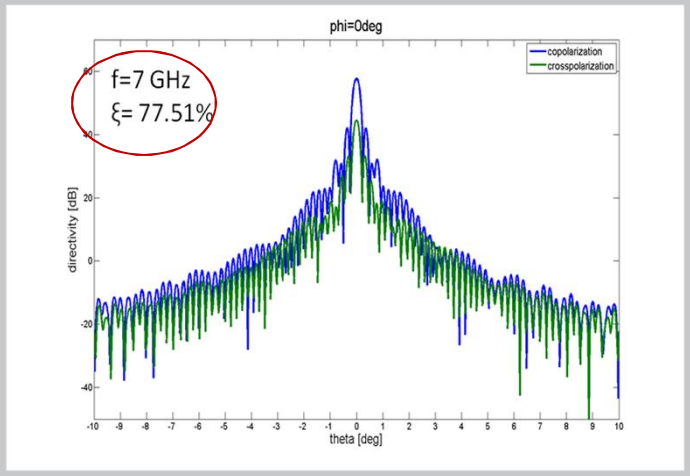
Engineering: . Internal dimensions of input interface
. Dimensions and materials of input window

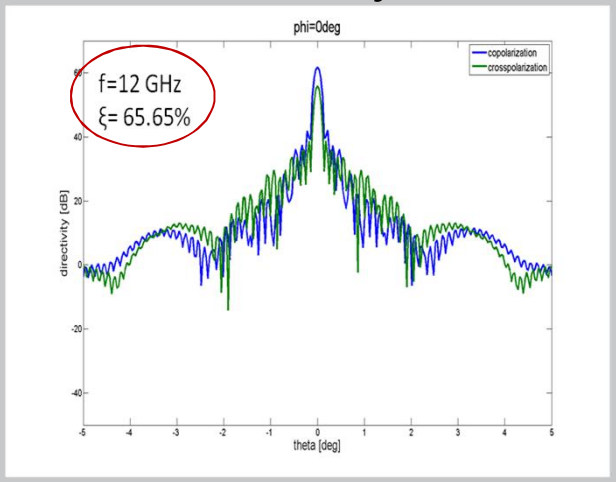
→ Minimal impact on QRFH radiation patterns
→ Best compromise thermal performance and mechanical robustness

→ 3DEM simulations of the QRFH receiver input interface → Radiation patterns

Radiation patterns → input for GRASP model of 12m Patriot antenna
→ Performance impact at antenna level: Co/Cross Polar + Antenna efficiency



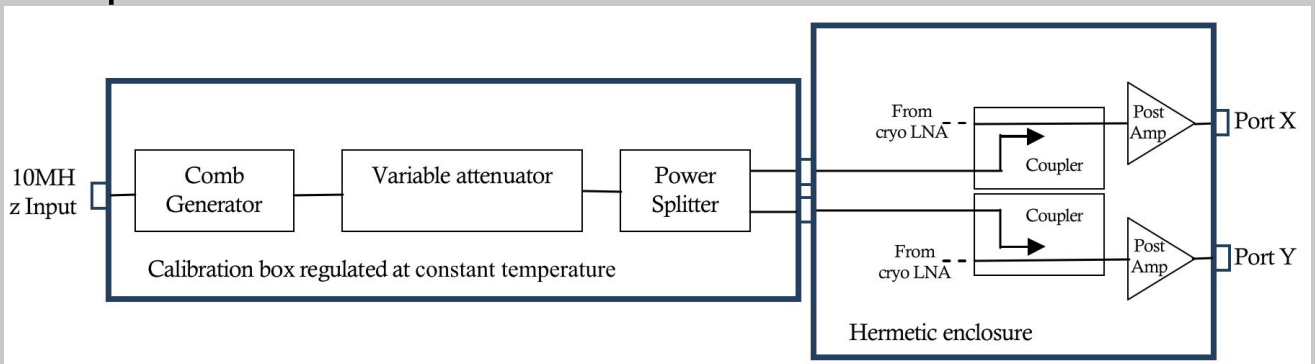


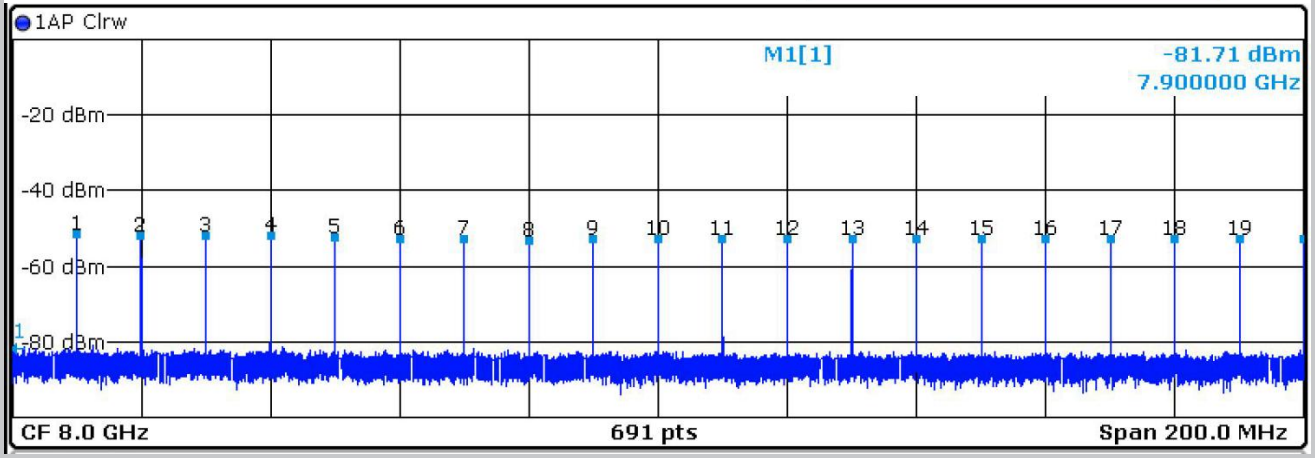


. Generate a comb spectrum signal up to 14GHz with spectral lines at 10MHz spacing

. Lines are derived from an input reference frequency signal provided by the user

. Use couplers placed after the cryogenic LNAs inside the enclosure (for compact)
→ reduced impact on critical NT





Comb generator output with +10dBm 10MHz input @8GHz

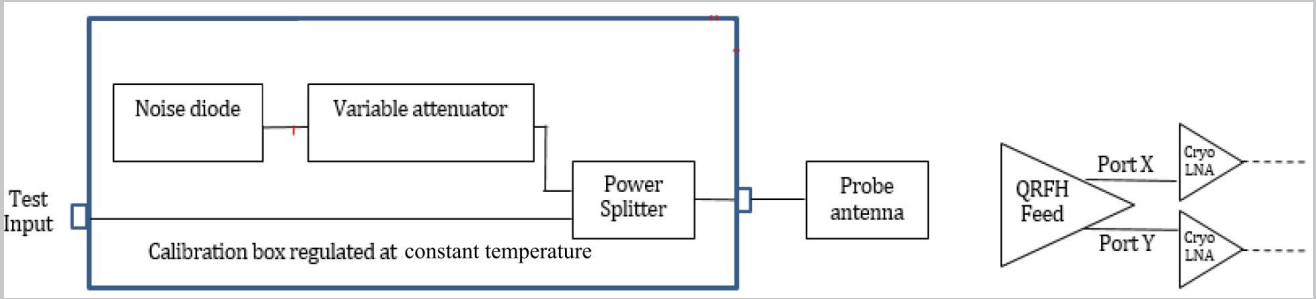
incl. Thermal stabilisation

. Inject two levels of noise in the QRFH receiver in order to do a noise measurement using the Y-factor method

. Noise generated by Noise diode

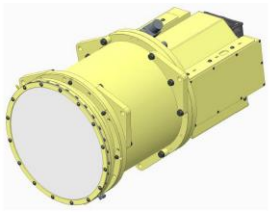
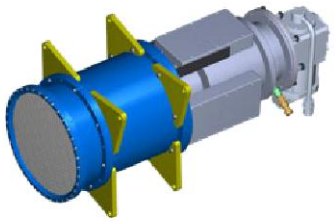
. Level of noise set using a variable attenuator

. Compact receiver: Probe antenna designed to optimize the coupling with the QRFH feed while being integrated within the large vacuum window and under the protection of the radome



incl. Thermal stabilisation

Summary

Receiver Model:	Compact	Ultra
		
Frequency Band	2-14GHz	
Noise Temperature (at receiver input flange)	**<40K**	**<20K**
Gain	>33dB	
Other RF features	. Phase & Noise calibration (standard or optional)	
Operation Type	Continuous	
Cryocooler type	Stirling	Gifford-McMahon (GM)
Receiver Dimensions	L. 612 mm x φ. 311 mm	L. <1 m x φ. 311 mm
Receiver Weight	<25kg (all included:receiver, cryocooler, compressor, heat exchanger)	<50kg (includes receiver, cryocooler, sleeve system); exludes compressor, gas lines, heat exchanger)
Mean time **between services**	**No Service required**	10,000 hours (~14 months)
Mean time **to failure (MTTF)**	200,000 hours	Non Specified
Power Consumption (max)	**400W**	8000W
Unique Features	**No vacuum pump** required for operations (not required for cooldown)	**Sleeve system**: cold head removal for service without dismounting receiver from the antenna
Monitoring & Control	Drawer + Software (running on industrial PC) for local and remote M&C	
Other Options	Installation support, training course, warranty extension	

Compact:

- Good for operations in remote locations
- Where energy cost is high (production + environmental impact)
- Where maintenance logistics is particularly complex and expensive

Ultra:

- Very best NT performance
- Users with no particular constraints on electrical consumption and regular maintenance

Thank You!

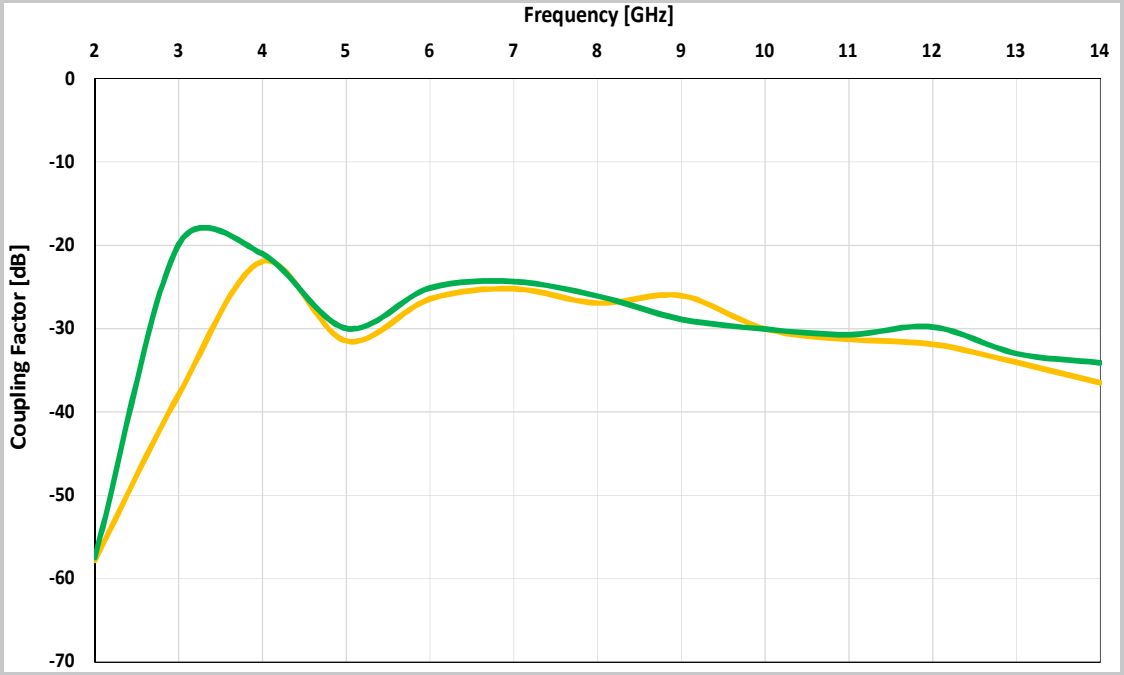
. Also used to optimize coupling noise injection antenna probe vs QRFH

→ Wideband patch antenna (included in receiver window, protected by radome)

Included in HFSS model:

Optimised position of the antenna probe → min. coupling:

-35 dB = 2.5--14 GHz and 3.2--14 GHz for the two QRFH input ports



Phase and Noise Calibration option

. VLBI relies on accurate measurement of phase and delay

. Calibration signals can be used to measure, and hence correct for, instrument time and frequency variations of phase and delay

. Both receivers have CalBox

. Contains components for phase and noise calibration of the QRFH and LNAs RF path

. CalBox has solid thermal insulation + temperature control
→ thermal stability of RF components

. CalBox fits on base plate of receiver