INSTRUMENTATION DEVELOPMENTS FOR VGOS AT YEBES OBSERVATORY

May 7th, 2025

13th TOW Meeting

MIT - Haystack Observatory (USA)

José A. López-Pérez
on behalf of Yebes Observatory staff

GOBIERNO DE ESPAÑA
MINISTERIO DE TRANSPORTES, MOVILIDAD Y AGENDA URBANA
INSTITUTO GEOGRÁFICO NACIONAL
YEBES
RAEGE
Red Atlántica de Estaciones Geodinámicas y Espaciales
Rede Atlântica de Estações Geodinâmicas e Espaciais

Introduction to Yebes Observatory, IGN-Spain

50th anniversary

Expertise

- 35+ years of expertise in receivers and LNAs developments.
- VLBI & SLR operations

National Role

- Key research facility of Spain's scientific infrastructure.
- **1st Spanish GGOS core site**

International Recognition

- Designated as IVS Technological Development Center since 2015.
- Collaborating with international partners in astronomy and geodesy.

Broadband Receiver Advancements

1

First Generation (S/X)

Legacy S/X receivers with limited bandwidth and slow antennas.

2

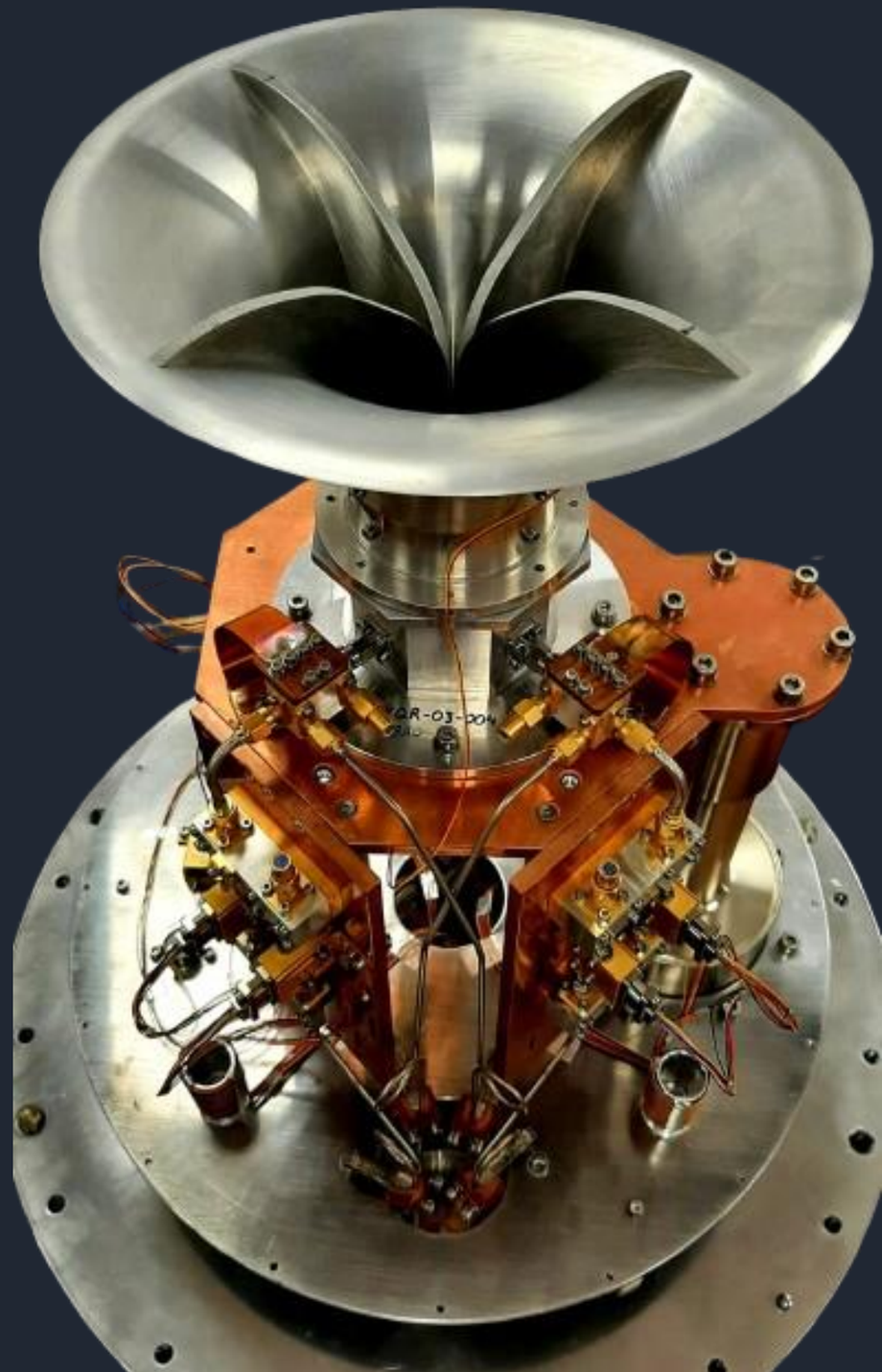
Current VGOS (2 – 14 GHz)

Wideband receivers with larger bandwidth, sampling and small high-speed antennas

3

Yebes Innovations for VGOS

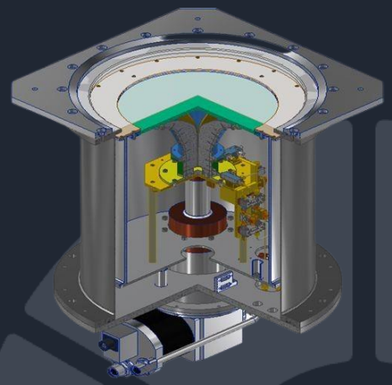
- Improved QRFH & dewar
- Cryo 30dB couplers
- Balanced LNAs
- FO CDMS
- PhaseCal equalizer
- HTS filters for RFI



Design Innovations

Cryogenic System

Compact dewar achieving 10K for critical components.



Feed Horn

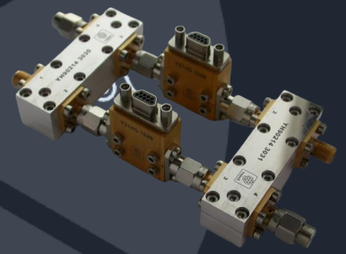
Quad-ridge design enabling octave bandwidth with good matching and phase center stability.

CDMS

Optimized CDMS using 5MHz fiber optic transceivers

Low-Noise Amplifiers

Custom-designed InP HEMT LNAs with noise temperatures below 4K.



HTS Filters

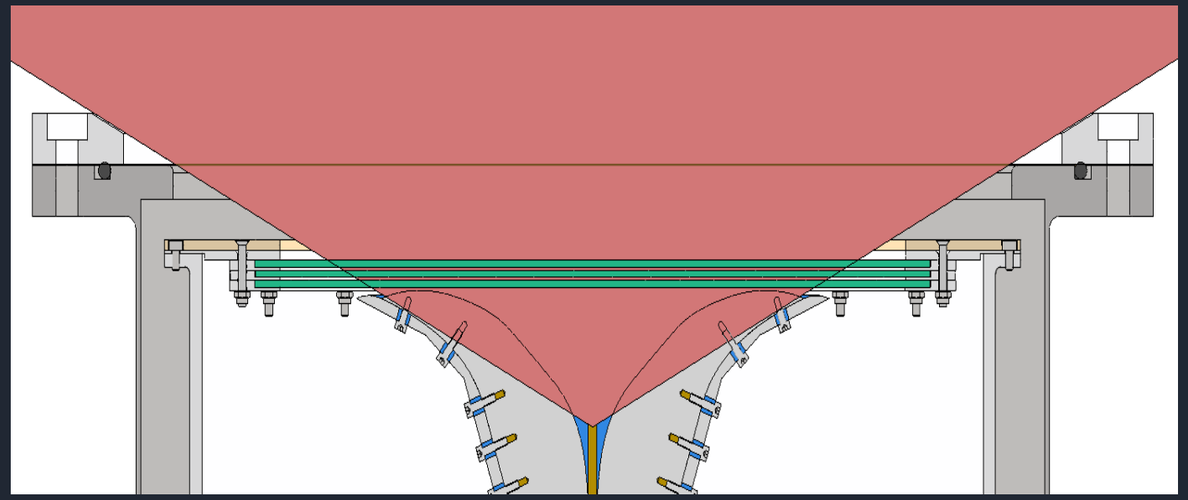
Advanced HTS filter implementation to eliminate RFI signals.

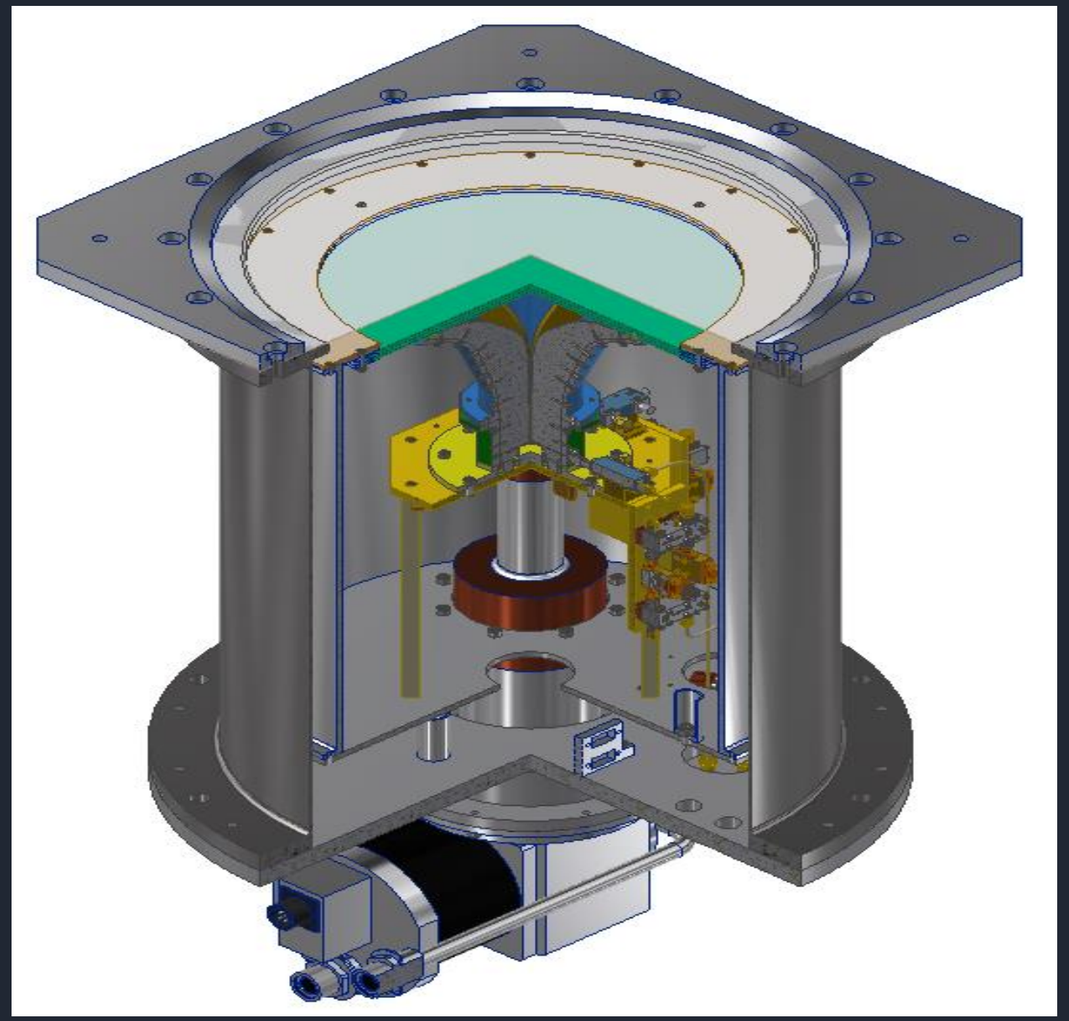
Calibration System

Equalized NoiseCal and PhaseCal injection via customized cryo coupler.

Optimized dewar

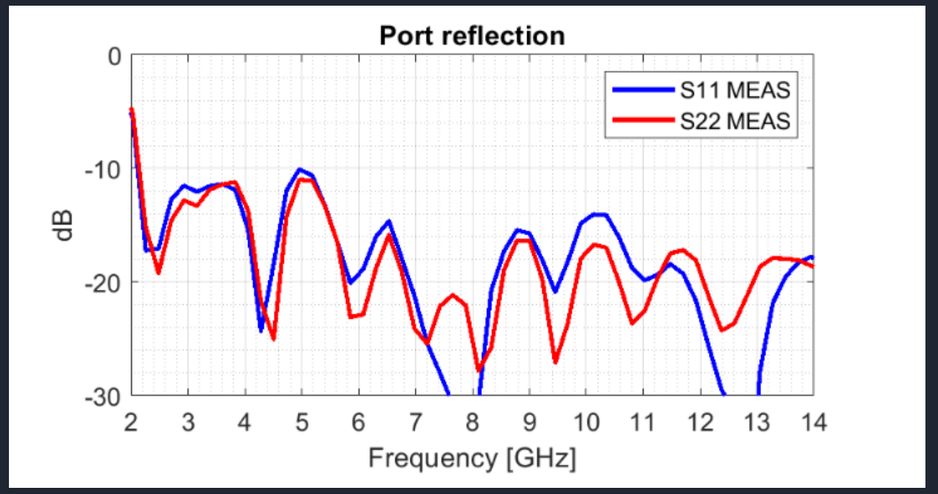
	1st gen.	2nd gen.
Vacuum window diameter	319 mm	335 mm
Feed distance to window	45 mm	37 mm
Clearance angle for feed	58º	65º
IR filter	Polystyrene	Polystyrene
Cryostat volume	59 L	49 L

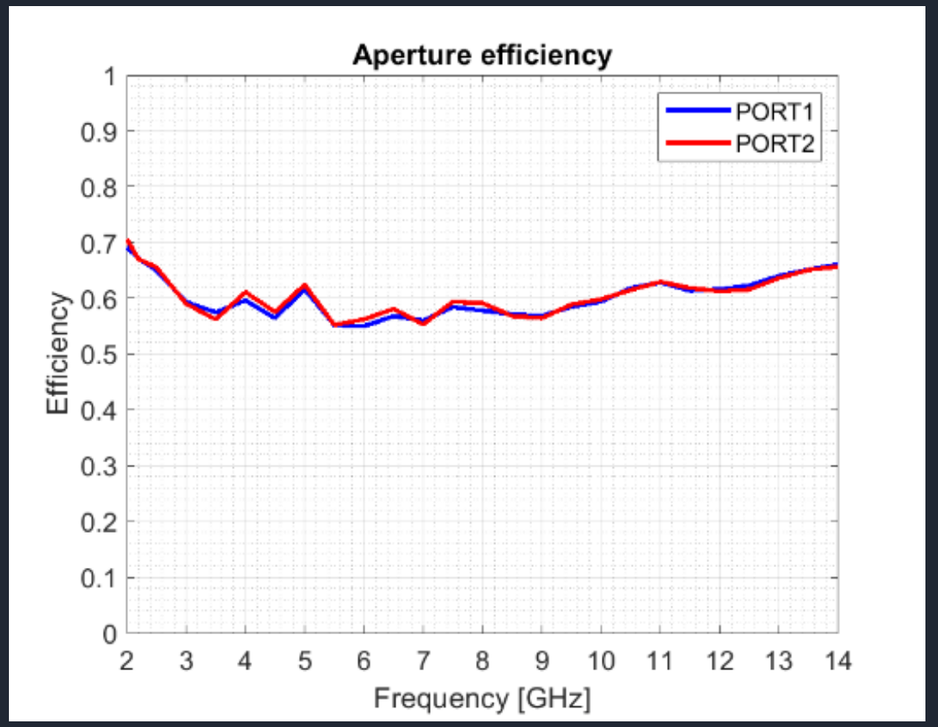




Improved QRFH

- YQR-03-00X Feed Horn
- Frequency range: 2.2-14 GHz
- Improved port reflection (return losses): Below -10dB across the whole bandwidth.
- Aperture efficiency in the 13.2m radio telescope: 60%





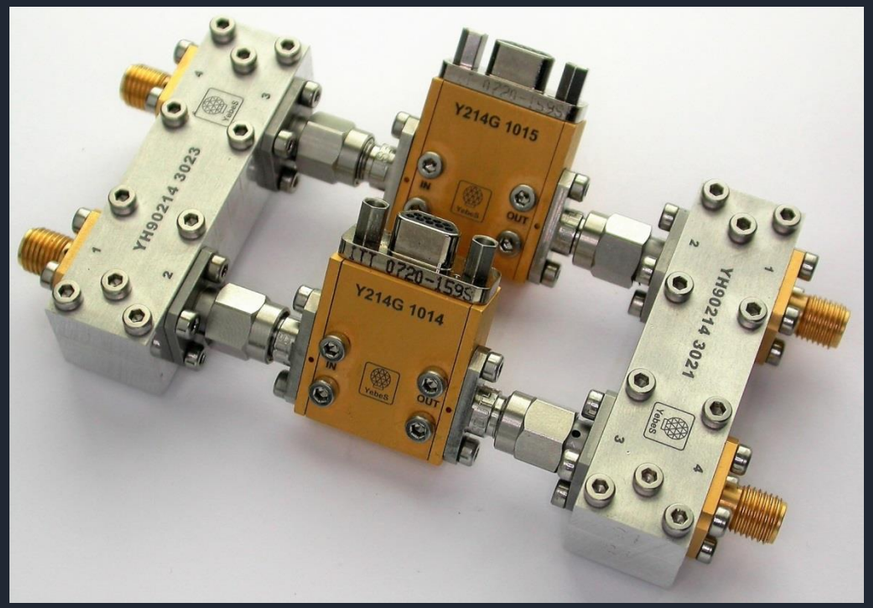
(IT-CDT-2020-26 https://icts-yebes.oan.es/reports/doc/IT-CDT-2020-26.pdf)

Cryogenic 30dB coupler

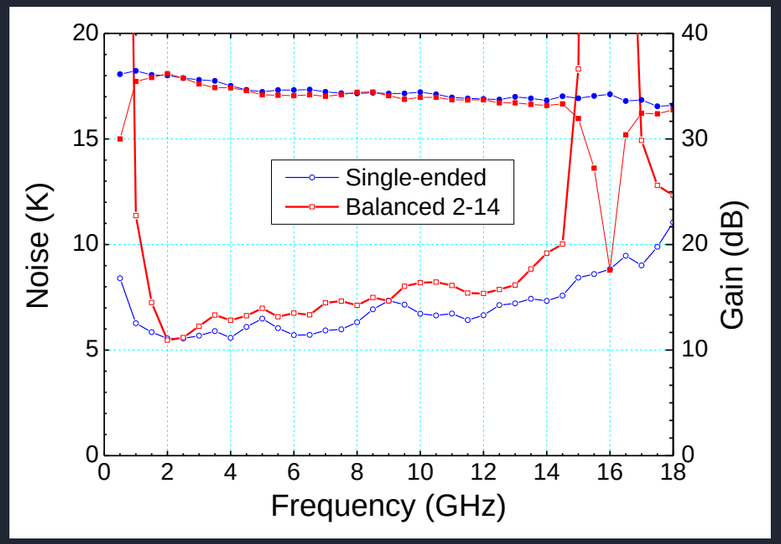
- Optimized in the range 3-14 GHz, usable down to 2 GHz.
- Specially designed to withstand thermal cycling and operate at cryo temps
- Port matching ≤ -20 dB
- Coupling = -29.2 ± 1 dB
- Insertion loss < 0.3 dB @ 14GHz & 15K
- Connectors contribution ≈ 2 x 0.1 dB
- Size: 21.3 x 14.5 x 17 mm
- Weight: 22 grams.
- Units available at 1k€

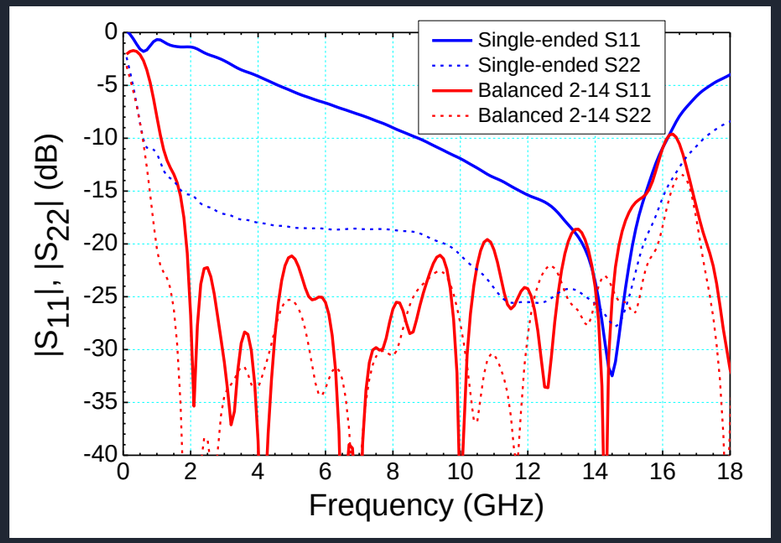
Balanced LNAs

- Using 3dB/90º hybrids
- Very low noise penalty
- Drastic improvement of input reflection
- Balanced versions for 2-14 GHz and 1.5-15.5 GHz available



Band	2-14 GHz
Tn	7.6 K
Gain	33.8 dB
IRL	-21 dB
ORL	-23 dB

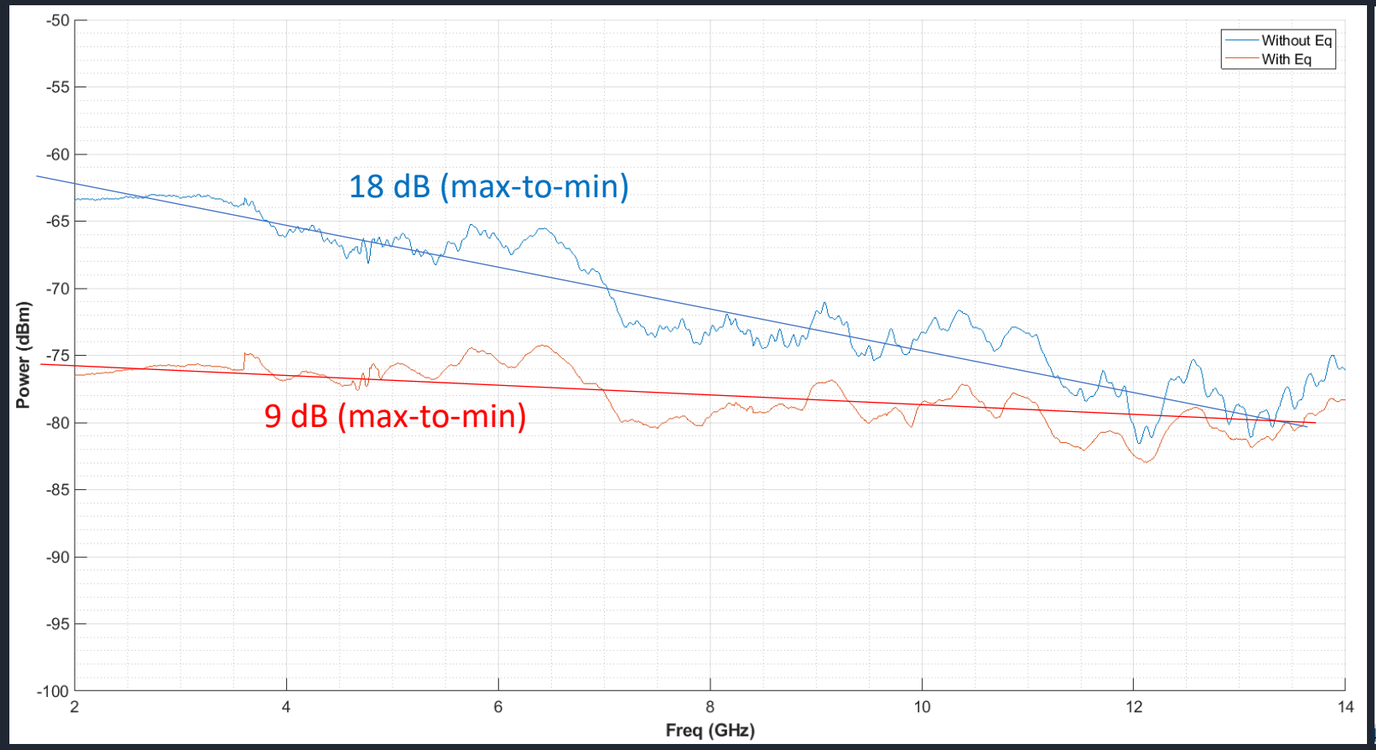


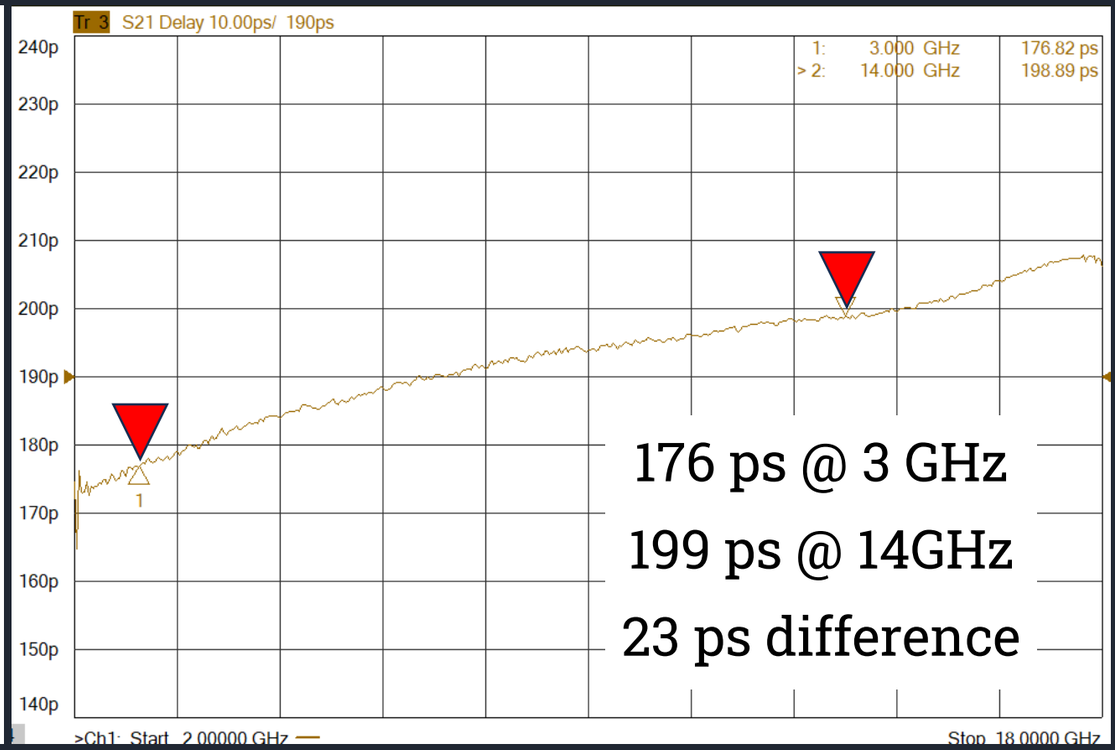


I. Malo-Gomez, J. D. Gallego-Puyol, C. Diez-Gonzalez, I. Lopez-Fernandez and C. Briso-Rodriguez, "**Cryogenic Hybrid Coupler for Ultra-Low-Noise Radio Astronomy Balanced Amplifiers**," in *IEEE TMTT*, Dec. 2009

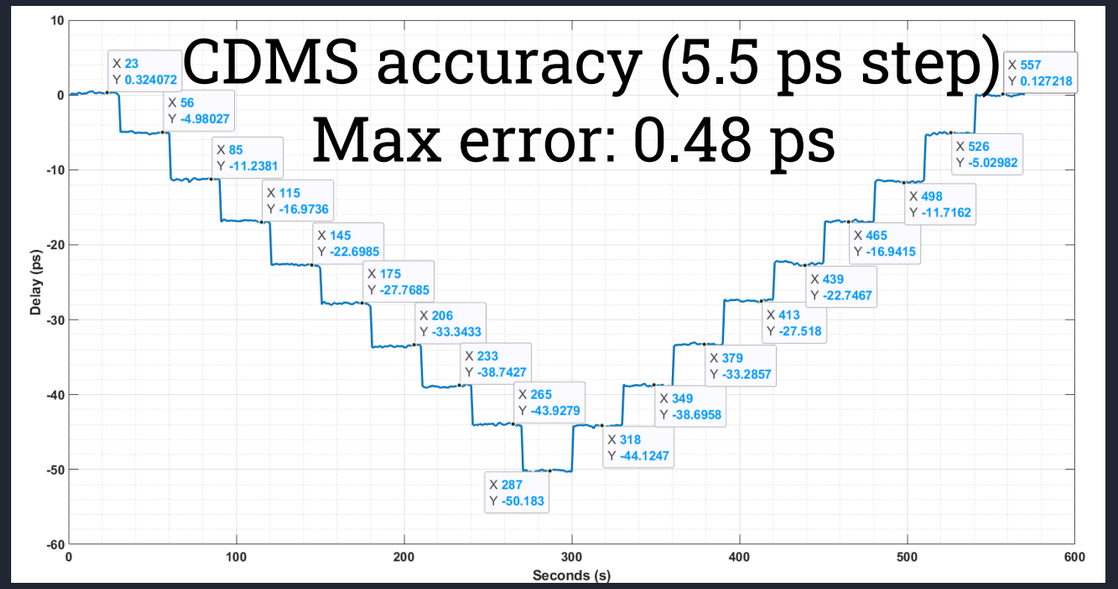
Equalized PhaseCal

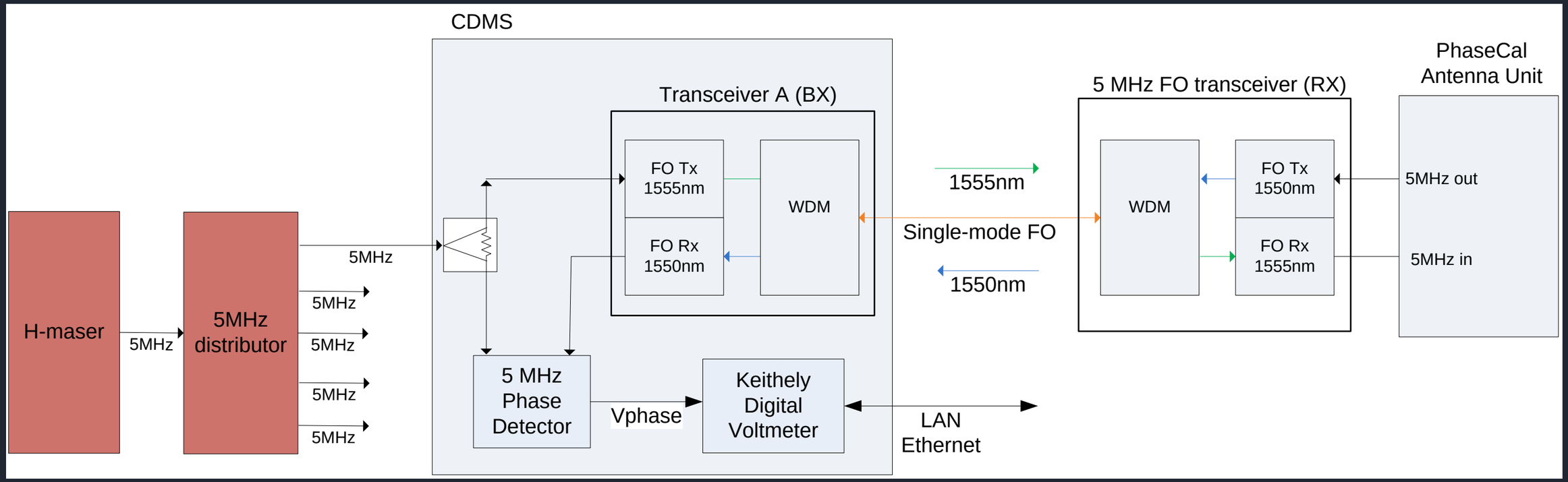
Equalized spectrum of tones





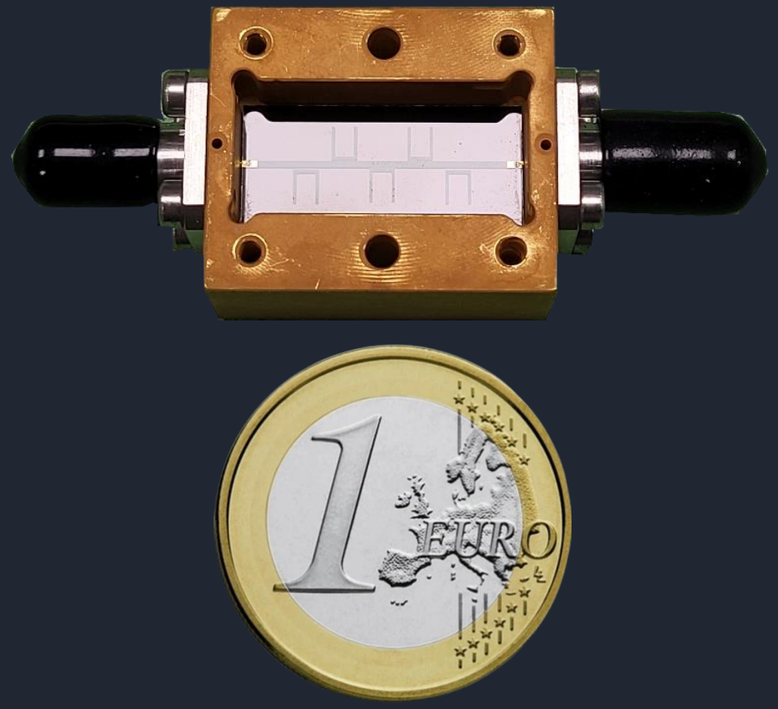
FO CDMS


CDMS accuracy (5.5 ps step)
Max error: 0.48 ps
Delay (ps)
Seconds (s)
X 23 Y 0.324072
X 56 Y -4.98027
X 85 Y -11.2381
X 115 Y -16.9736
X 145 Y -22.6985
X 175 Y -27.7685
X 206 Y -33.3433
X 233 Y -38.7427
X 265 Y -43.9279
X 287 Y -50.183
X 318 Y -44.1247
X 349 Y -38.6958
X 379 Y -33.2857
X 413 Y -27.518
X 439 Y -22.7467
X 465 Y -16.9415
X 498 Y -11.7162
X 526 Y -5.02982
X 557 Y 0.127218

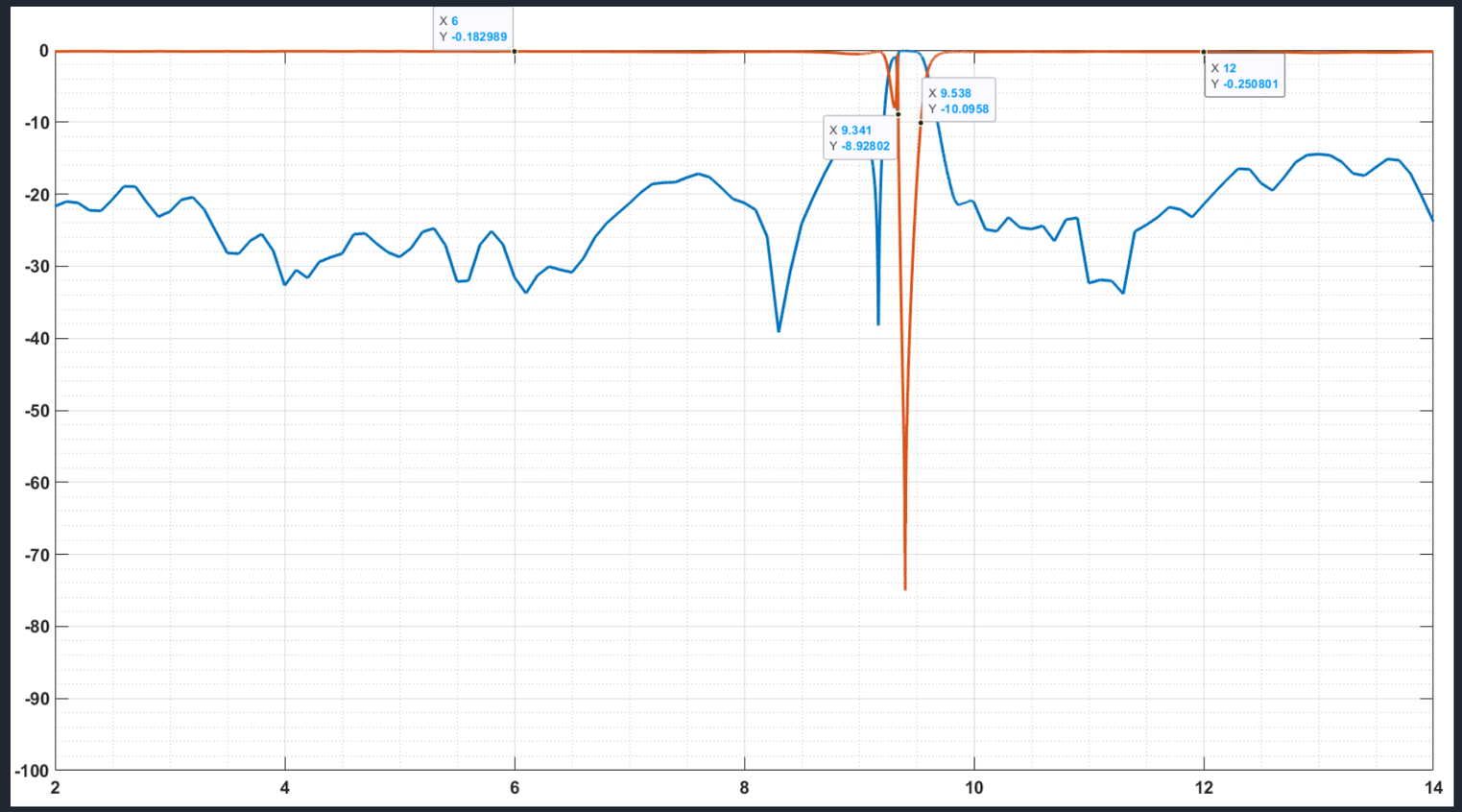

CDMS
Transceiver A (BX)
FO Tx 1555nm
FO Rx 1550nm
WDM
H-maser
5MHz
5MHz distributor
5MHz
5MHz
5MHz
5MHz
5MHz
5 MHz Phase Detector
Vphase
Keithely Digital Voltmeter
LAN Ethernet
1555nm
Single-mode FO
1550nm
5 MHz FO transceiver (RX)
WDM
FO Tx 1550nm
FO Rx 1555nm
PhaseCal Antenna Unit
5MHz out
5MHz in

HTS filters

HTS notch filter for SLR radar at 9.4 GHz



Measured performance @ 10K



See Pablo García-Carreño “Development of HTS filters at Yebes Observatory”, 9th IVTW-2024, Haystack Observatory

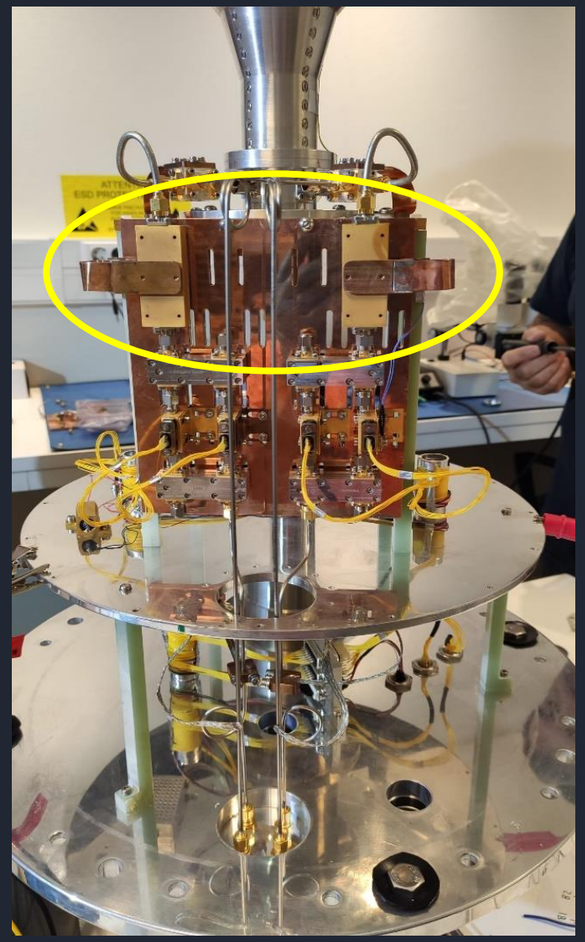
HTS filters

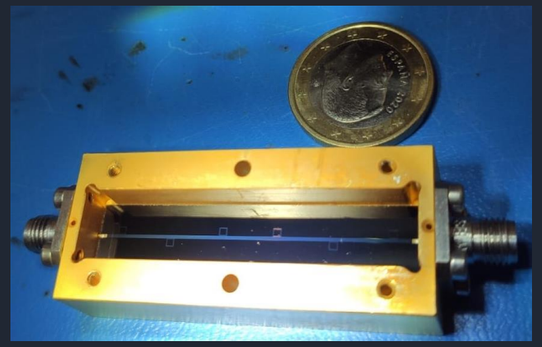
HTS notch filters for SD radar at 2.95 GHz

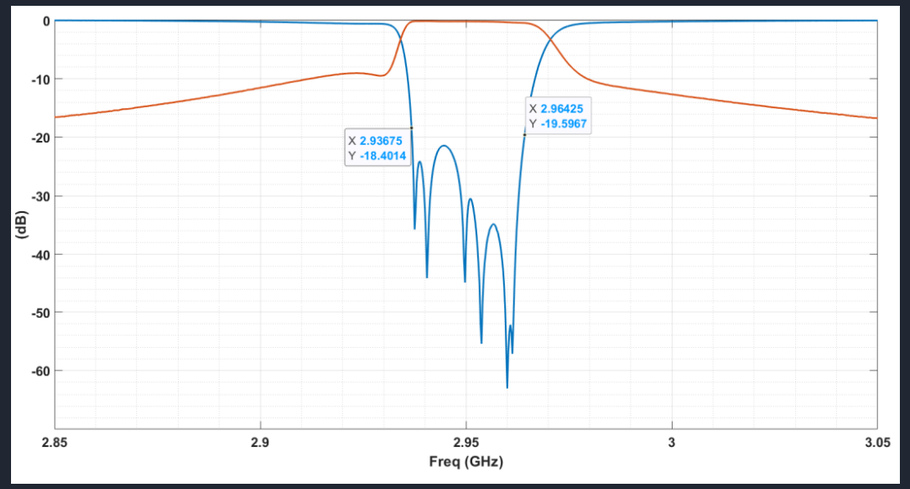
Upgraded VGOS receiver for RAEGE Santa Maria:

A high-power 2.95GHz radar caused receiver saturation in the VGOS band, leading to the design of HTS

- To reject the RFI.
- In front of the LNA to protect it.

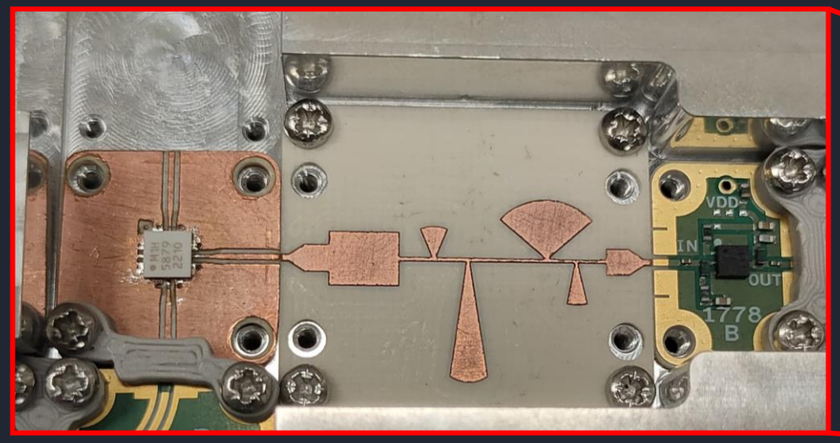


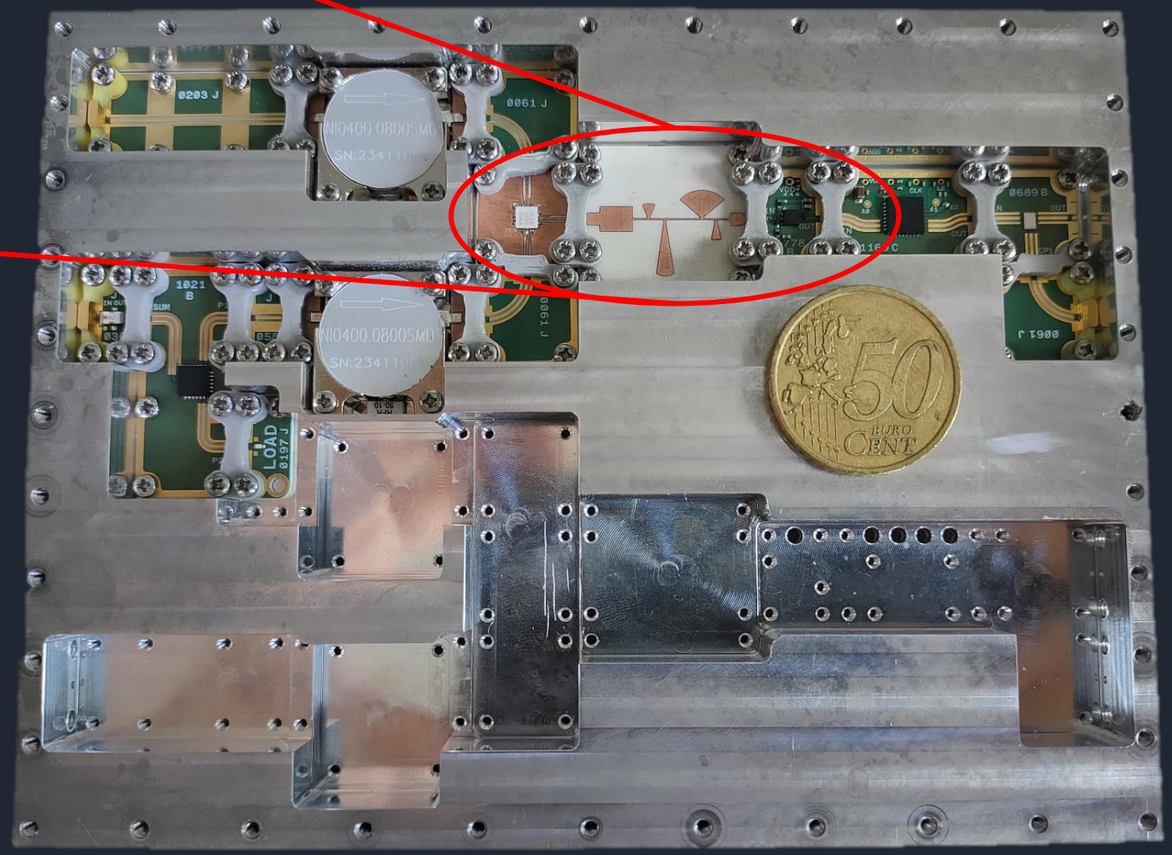




See Pablo García-Carreño “Development of HTS filters at Yebes Observatory”, 9th IVTW-2024, Haystack Observatory

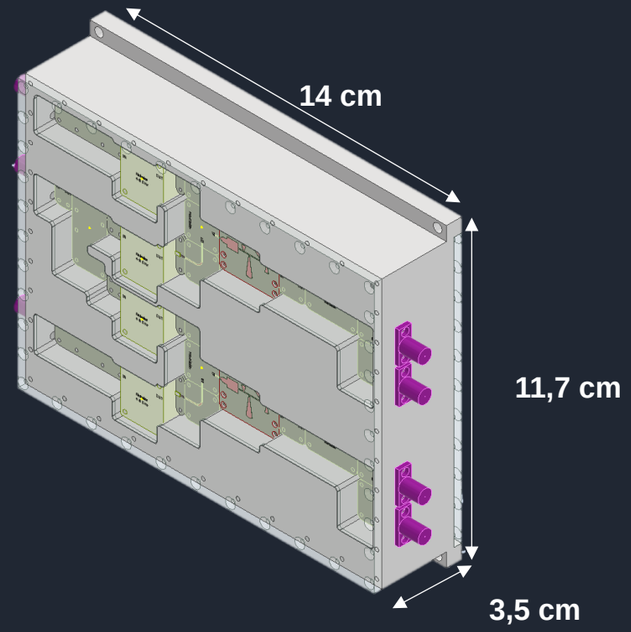
Compact down-converters

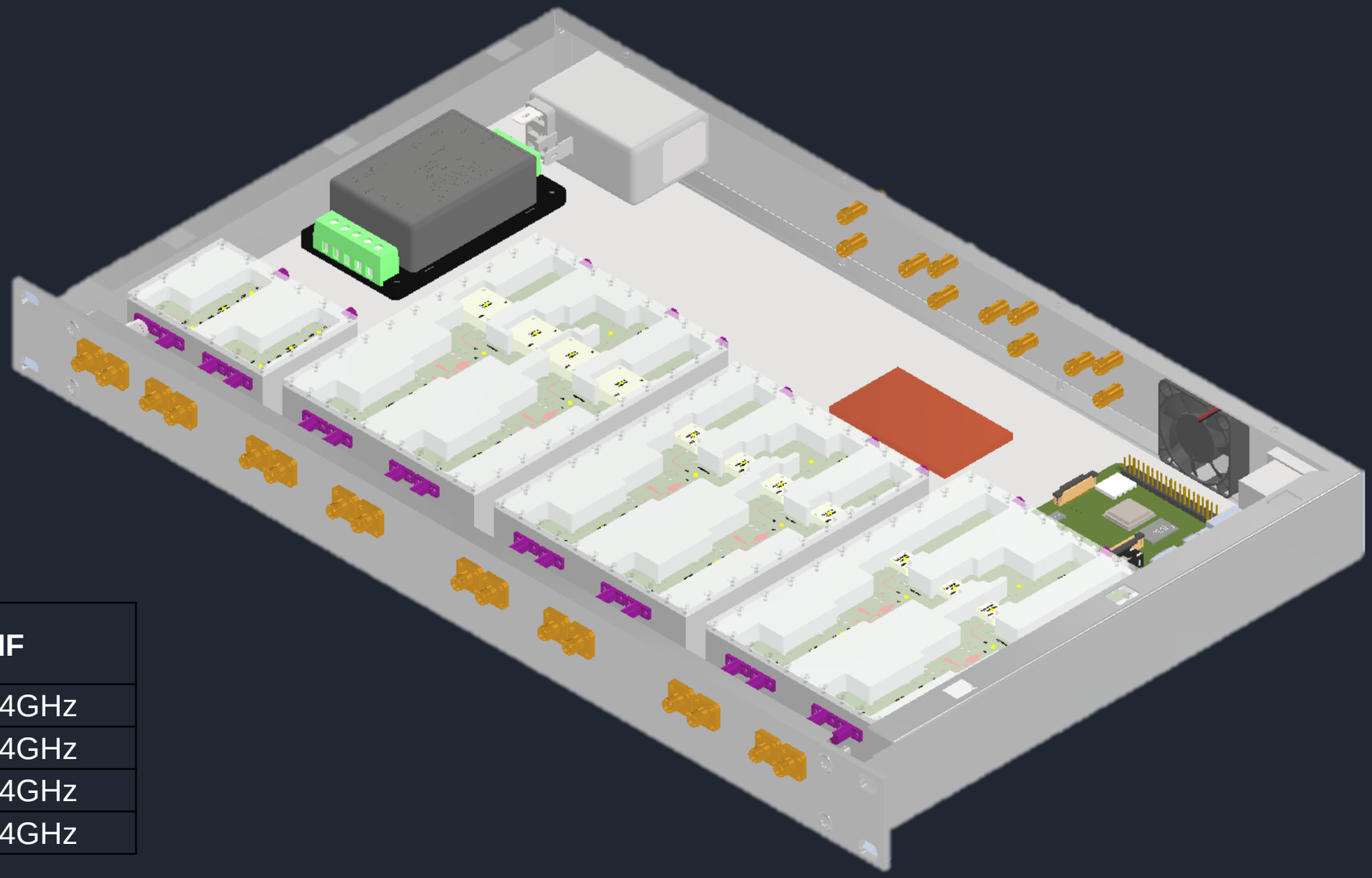




A new development centered on SMD components and microstrip circuits, involving either in-house designs manufactured in our workshops or components purchased from X-Microwave.

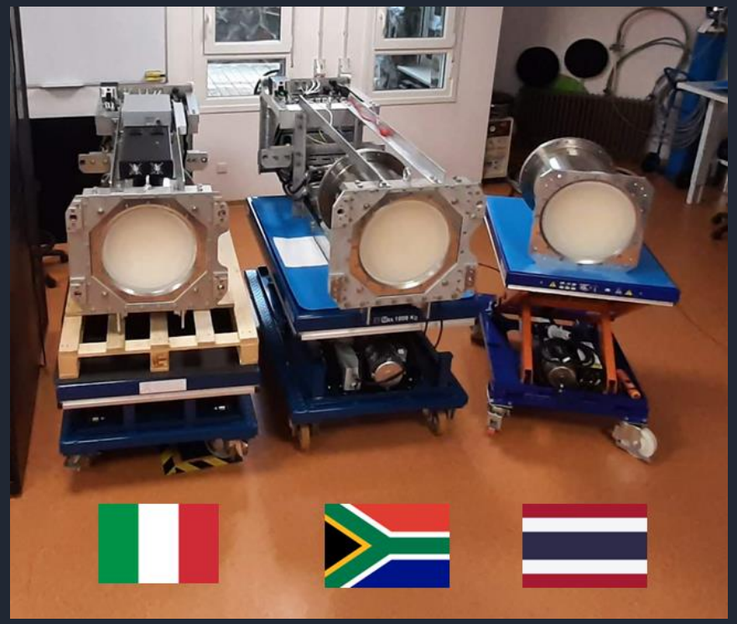
Compact down-converters

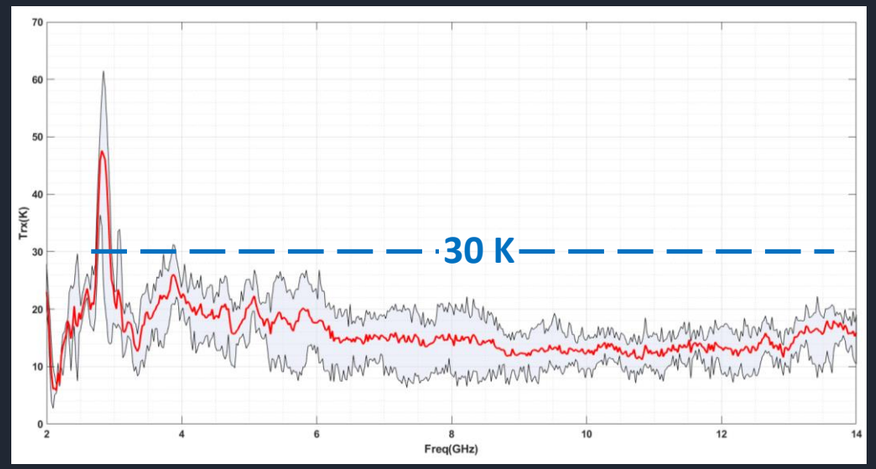




Frequency band	RF	IF
DC_A	DC-4 GHz	DC-4GHz
DC_B	4-8 GHz	DC-4GHz
DC_C	8-12 GHz	DC-4GHz
DC_D	12-16 GHz	DC-4GHz

Latest VGOS receivers





VGOS NARIT

- Dewar + Frontend integrated, tested and shipped by Dec. 2023.
- NARIT is developing the room-temperature electronics

VGOS HartRAO - SARAO

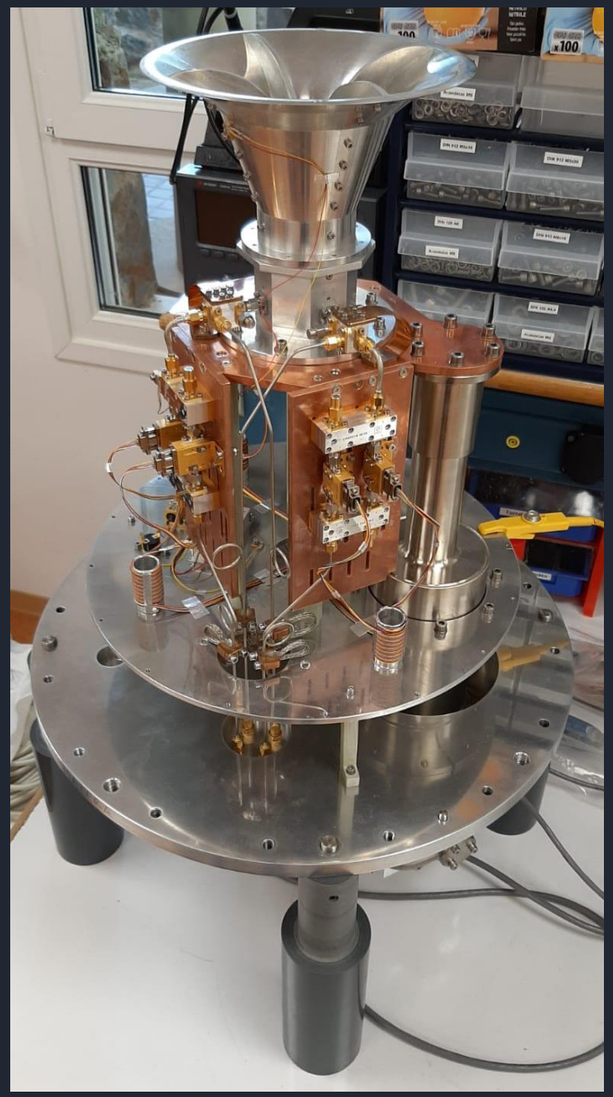
- Full receiver (except backends) integrated, tested, shipped
- Installed in collaboration with HartRAO in 12-23 Feb. 2024
- Currently under tests to join the VGOS core network

VGOS ASI - Matera

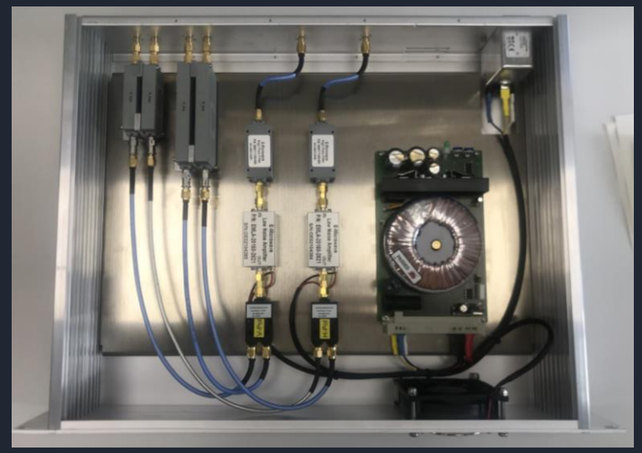
- Full receiver (incl. backends) integrated, tested, shipped
- Installed in collaboration with OHB/eGEOS in 2-12 Apr. 2024
- Currently under tests to join the VGOS core network

Receiver construction

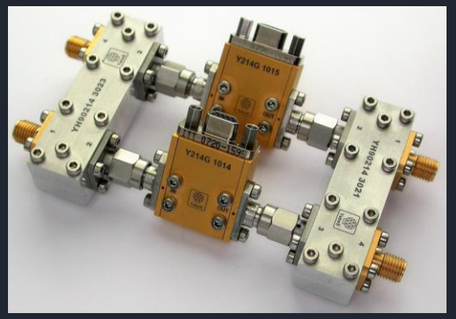
Cooled frontend



FPA: Preamp

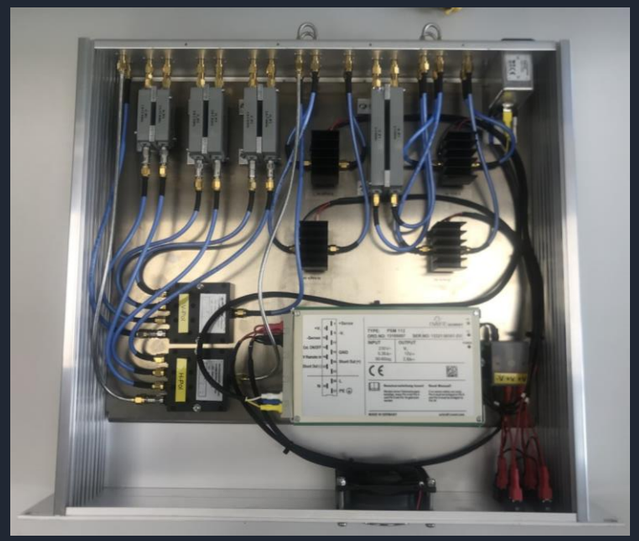


LNAs



Cryo couplers

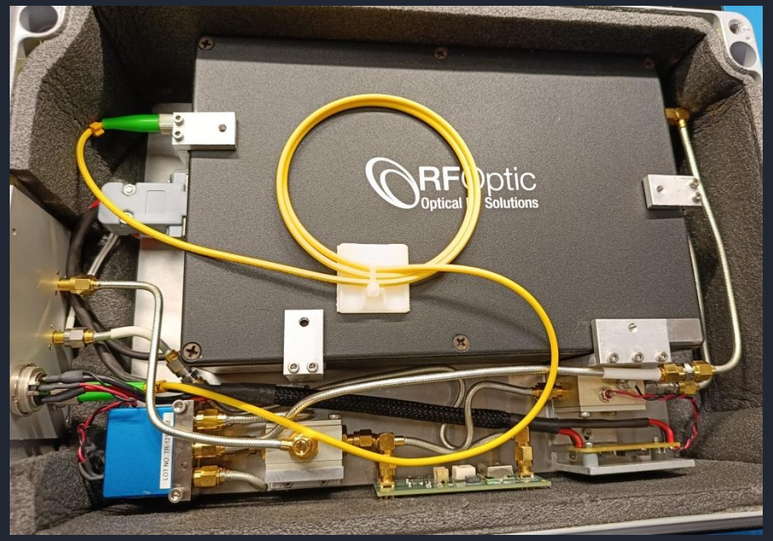
BSCU: Filter bank



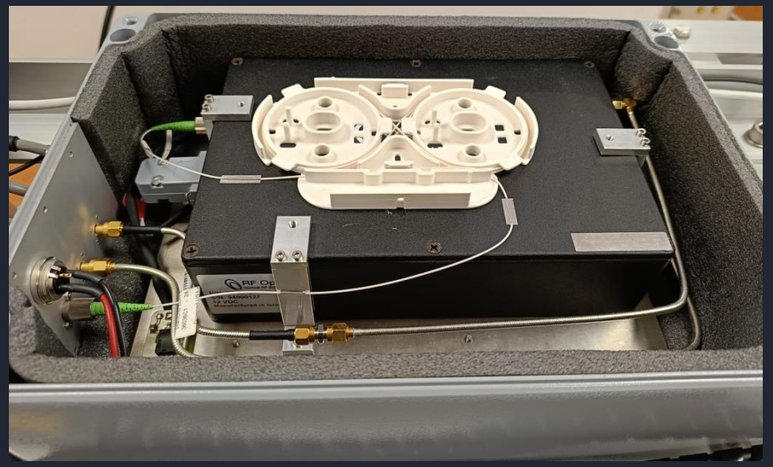
PhaseCal+NoiseCal

Receiver construction

CDMS GU



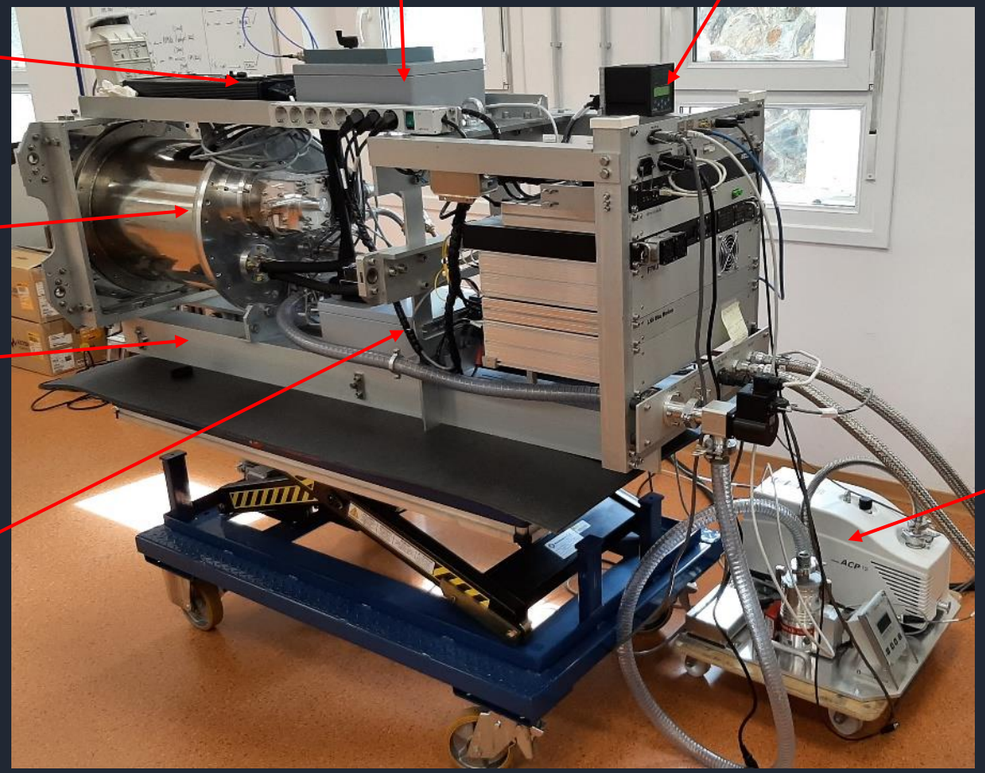
CDMS AU

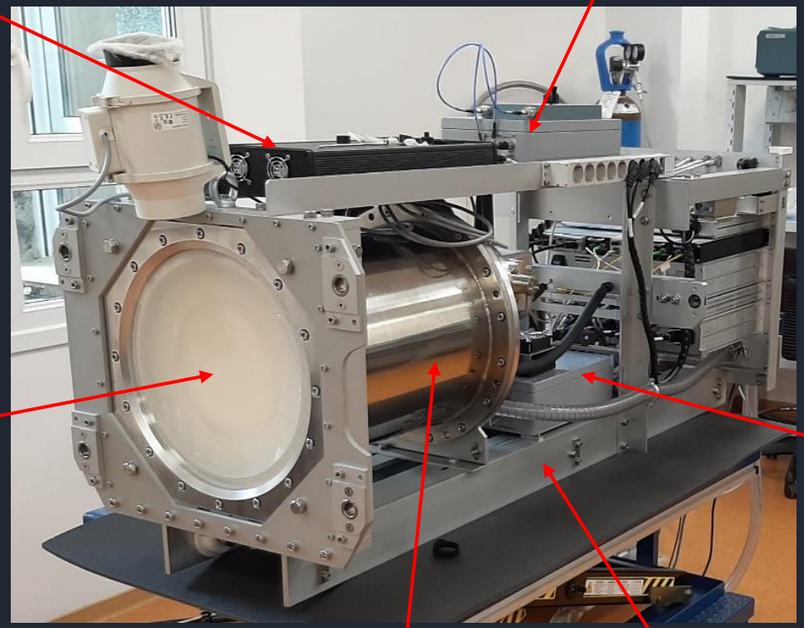


LNAs Biasing Unit

Trolley

Receiver integration





Rx interface plate

Interface plate (connectors and FO)

Ethernet-controlled socket strip

80Hz FO link transceiver

RFoF link transmitters

FPA module

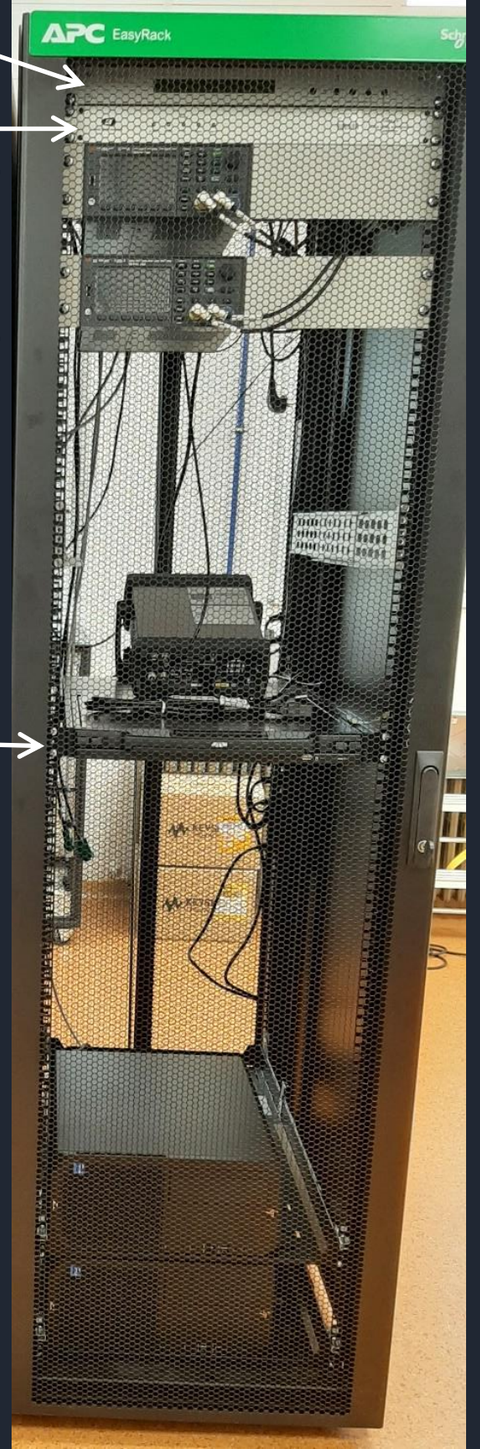
LNA Bias module

CVCU

Cryo & Vacuum interface plate

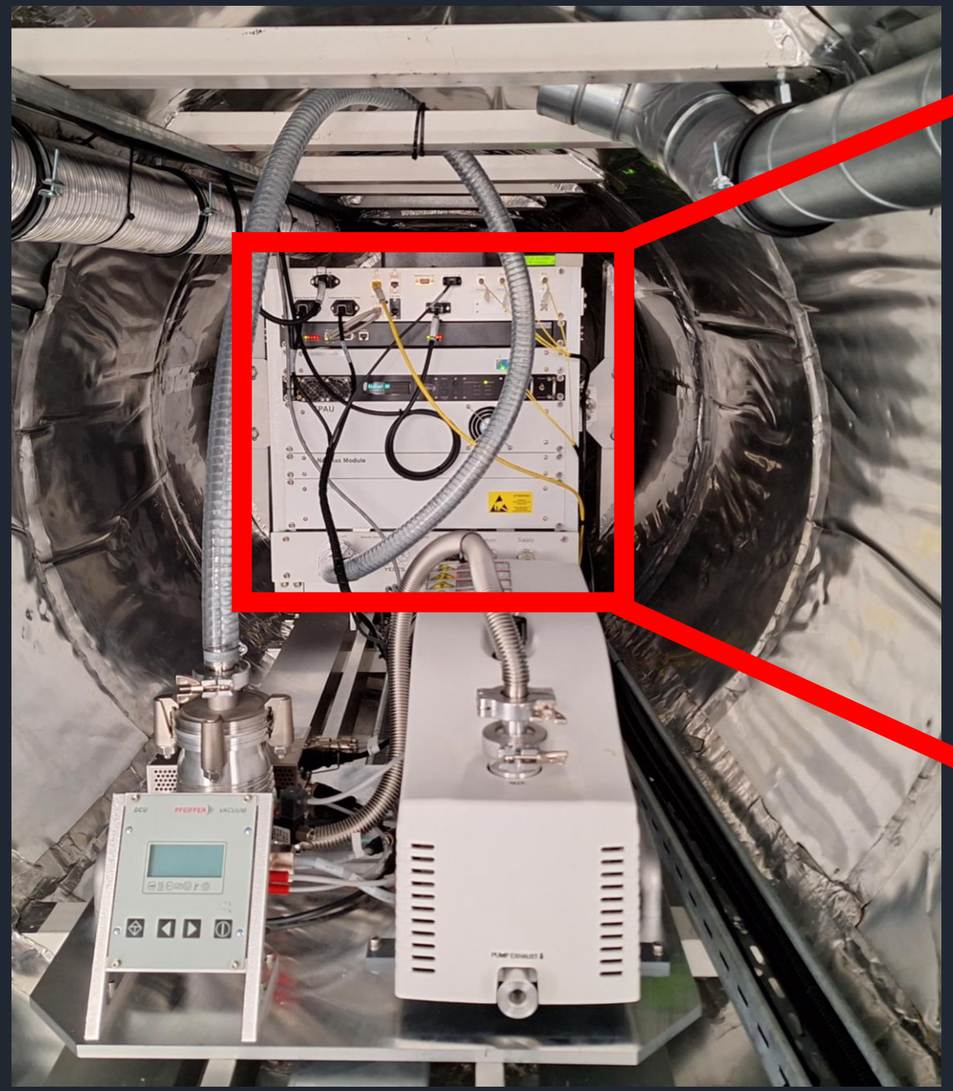
Backends and T&F cabinets

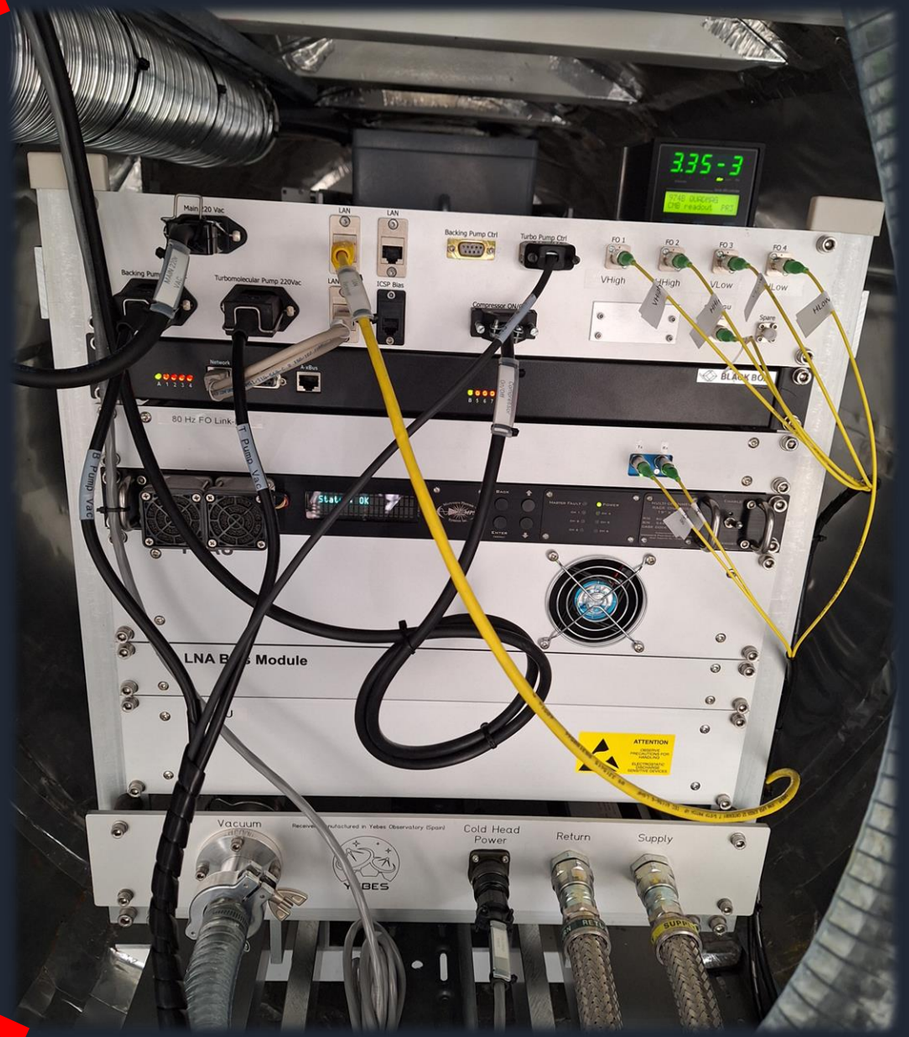
2 x 19”/42U racks



Receiver installation: April 3rd, 2024

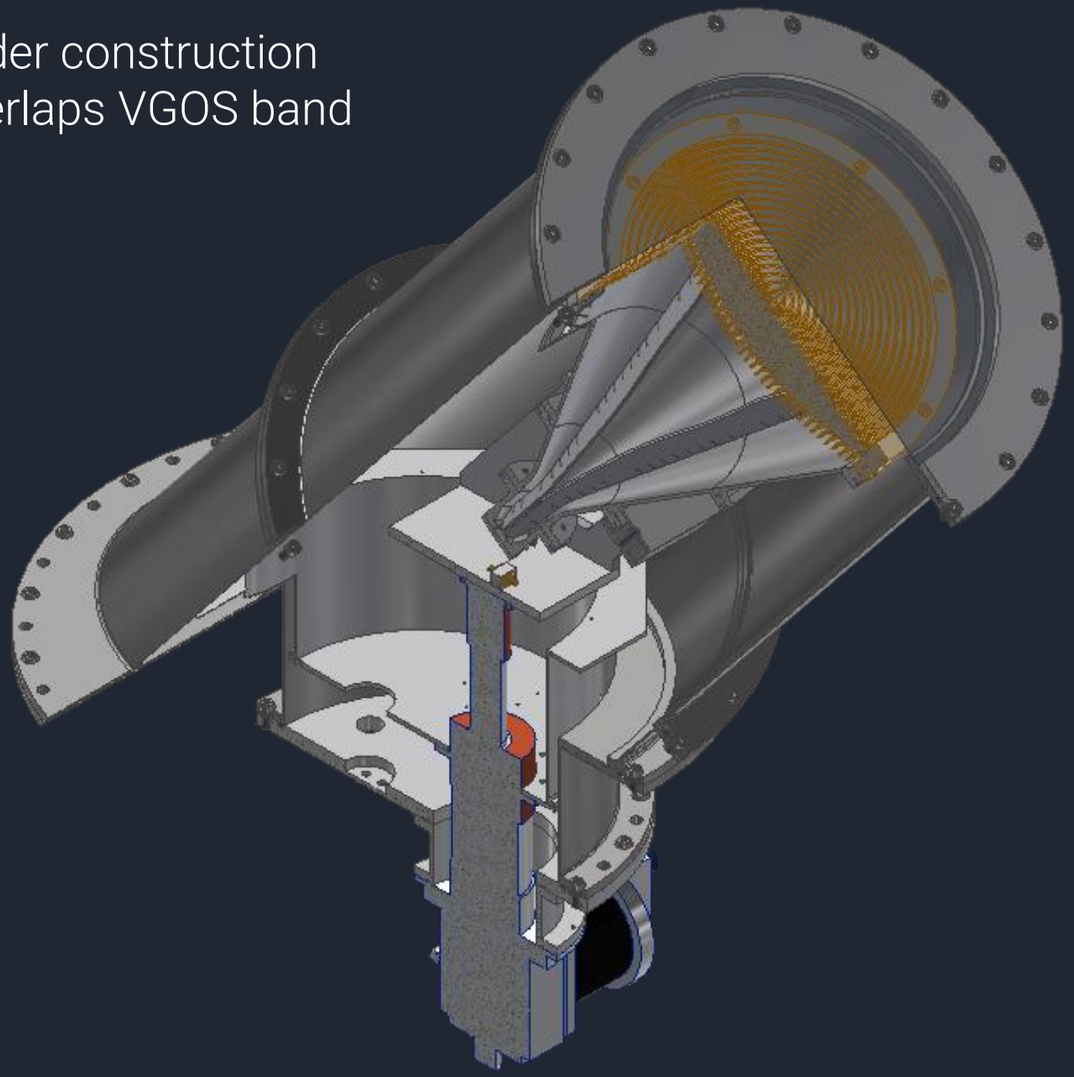
Receiver installation





YNART 4-18 GHz receiver for 40-m telescope

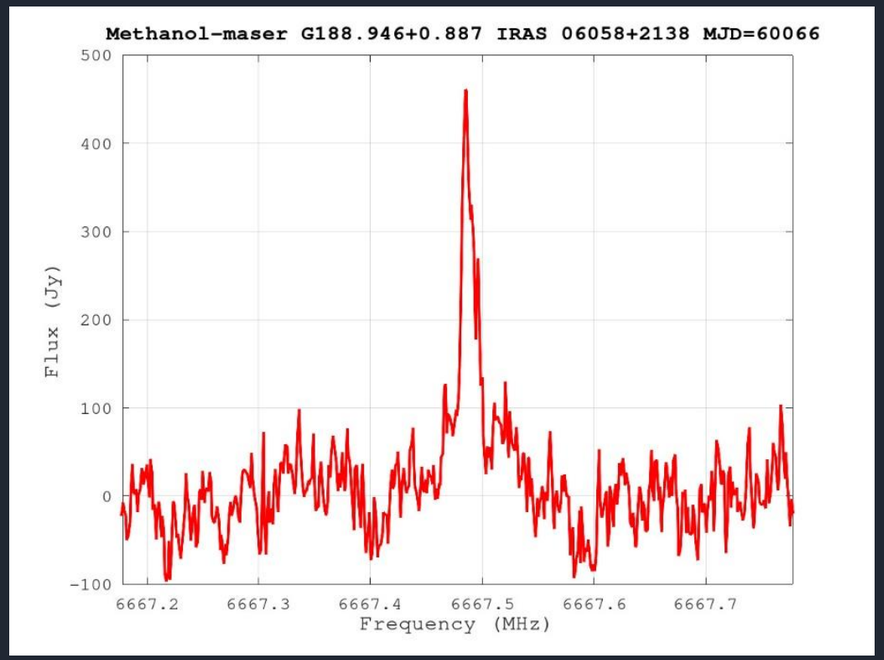
- Under construction
- Overlaps VGOS band



Science cases: astro-VLBI and methanol masers

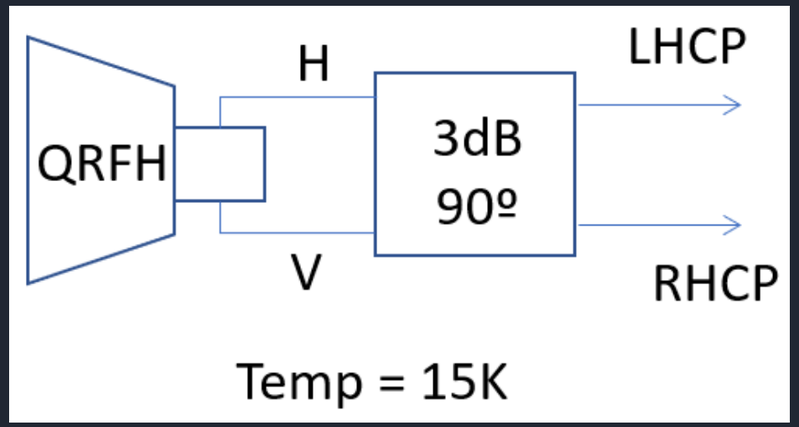
Specifications:

- Operating band: 4 – 18 GHz
- Trx < 20 K
- Dual linear polarization
- Noisecal and phasecal inyection



Linear-to-circular hardware converter

- Adding a cryogenic 3dB/90º hybrid circuit, circular polarizations can be easily obtained by hardware
- Degradation of LNA noise by 1-3 Kelvin
- Concept already tested in EVN-BRAND 1.5-15.5 GHz receiver

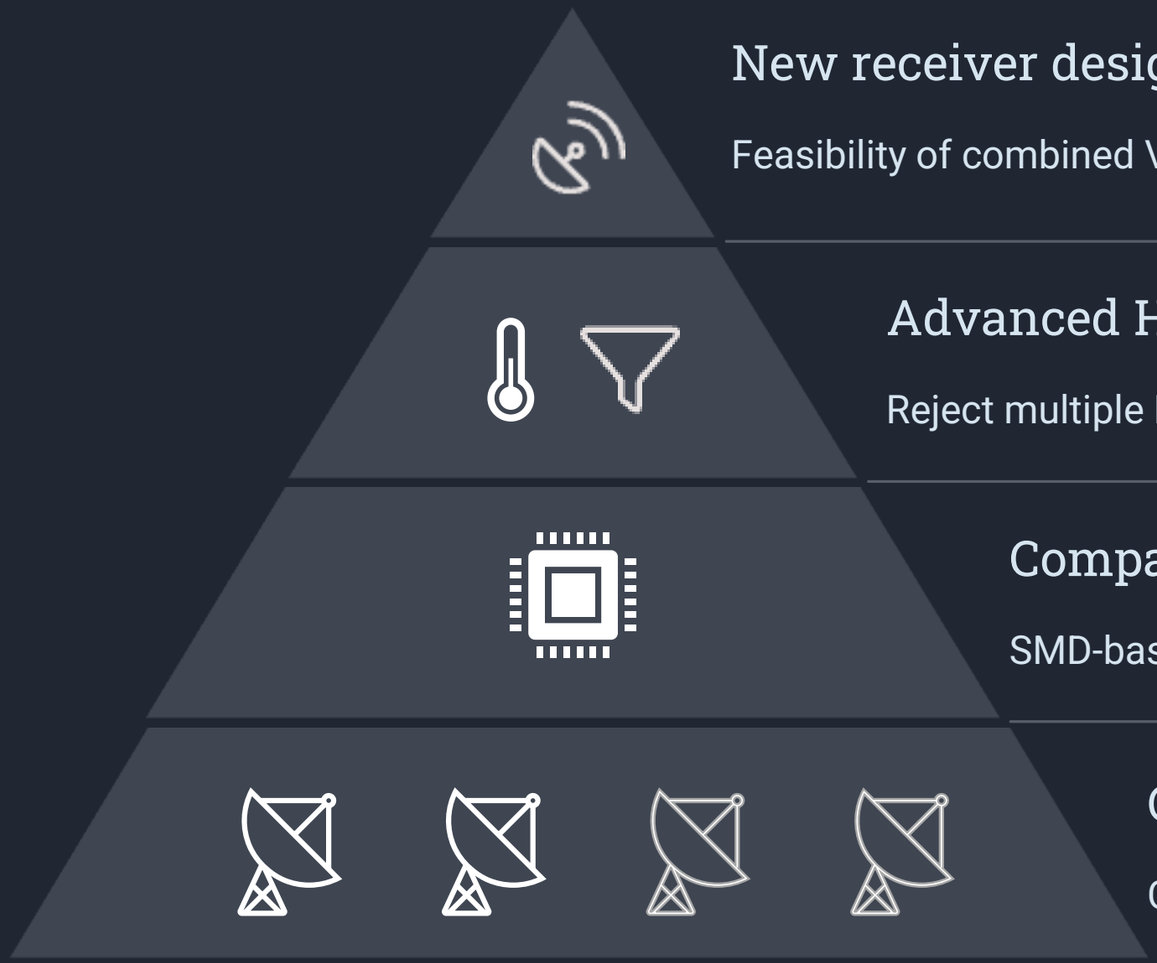


O. García-Pérez, F. Tercero, I. Malo, J. A. López-Pérez: "**Linear to circular polarization conversion using microwave hybrids for VGOS (2-14 GHz)** ", CDT Technical Report 2018-13.

I. Malo-Gómez, J. D. Gallego-Puyol, C. Díez-González, et al., "**Cryogenic hybrid coupler for ultra-low-noise radio astronomy balanced amplifiers**," *IEEE Trans. Microw. Theory Tech.*, vol. 57, pp. 3239-3245, Nov. 2009.

Yebes receivers around the world

Future Works



New receiver designs

Feasibility of combined VGOS + 22GHz WVR

Advanced HTS filtering

Reject multiple RFIs with a single filter

Compact Down-converters

SMD-based components

Complete RAEGE network

Gran Canaria + Flores stations

Thank you for your attention

Remember: “Talent win games, but teamwork win championships”

(Michael Jordan)