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BAND 2+3 RECEIVER FOR ALMA

Status And Perspectives

Presented by Fabrizio Villa
INAF/IASF-Bologna
on behalf of
Band 2+3 Consortium



INAF



Cryowaves
è Bologna

Frequency bands of receivers: When it has all 10 bands incorporated, ALMA will measure signals from 8.6 mm to 0.32 mm. the following table shows the specifications of the bands astronomers will be able to use for their observations with ALMA (available from Cycle 5, in construction, and under development):

Band	Wavelength (mm)	Frequency (GHz)
1	8,6 – 6	35 – 50
2	4,6 – 3,3	65 – 90
3	3,6 – 2,6	84 – 116
4	2,4 – 1,8	125 – 163
5	1,8 – 1,4	163 – 211
6	1,4 – 1,1	211 – 275
7	1,1 – 0,8	275 – 373
8	0,8 – 0,6	385 – 500
9	0,5 – 0,4	602 – 720
10	0,4 – 0,3	787 – 950

During Cycle 0 and Cycle 1, the antennas were outfitted with four bands: Band 3, Band 6, Band 7, and Band 9. Two more were added in Cycle 2: Band 4 and Band 8. Band 10 was added in Cycle 3 and 4.

Band 2+3 Specifications (Change Request)

- Noise temperature Requirement concatenation of the Band 2 and Band 3
- Receiver noise T shall not exceed the values as follows:
 - 67-90 GHz RF frequency range:
 - $\leq 30\text{K}$ over 80% of the frequency range
 - $\leq 47\text{K}$ at any frequency within this RF range
 - 90-116 GHz RF frequency range:
 - $\leq 39\text{K}$ averaged over RF range 108-112 GHz
 - $\leq 43\text{K}$ over 100% of the RF range

The diagram illustrates the receiver architecture, divided into three main sections: Cold cartridge, Downconverter module, and Warm cartridge.

- Cold cartridge:** This section is enclosed in a blue box. It starts with a **Window** leading to an **IR filter**, followed by a **Feedhorn**. The signal then passes through an **OMT** (Orthomode Transducer) and is split into two paths, each containing a **Cryogenic LNA** (Low Noise Amplifier) and a circulator.
- Downconverter module:** This section is enclosed in a green dashed box. It receives signals from the Cold cartridge, labeled **Pol.0** and **Pol.1**, which pass through **WR-10** waveguide components. The module includes:
 - Pol.0 LO RF-hybrid** and **Pol.1 LO RF-hybrid** for local oscillator distribution.
 - Pol.0 IF-hybrid** for intermediate frequency processing.
 - Pol.0** and **LSB** (Lower Side Band) outputs.
 - Coax** (coaxial) connections for signal routing.
 - BP filter** (Band Pass filter) and **Coax** output for the Pol.0 path.
 - BP filter** and **Coax** output for the LSB path.
- Warm cartridge:** This section is enclosed in a yellow dashed box. It includes:
 - X6 active multiplier** and **WG BP filter** for signal processing.
 - Direct coupler** for signal routing.
 - PLL system** (Phase-Locked Loop) and **YIG assembly** (Yttrium Iron Garnet) for frequency control.
 - Power and control** block for system management.
 - Photomixer, or X6 multiplier** for optical or coaxial signal processing.
 - Optical (photomixer) or coaxial (multiplier)** output for the final signal.

Noise and power budget

<u>Noise budget</u>						
Component	Tphys (K)	Gain dB	Gain, line	Noise (K)	NET* (K)	% of Tsys
Window	300	-0.10	9.77E-01	6.99	6.99	19.20
110K Filter	110	-0.03	9.93E-01	0.76	0.78	2.14
15K Filter	15	0.00	1.00E+00	0.00	0.00	0.00
Feedhorn	15	-0.05	9.89E-01	0.17	0.18	0.49
OMT	15	-0.40	9.12E-01	1.45	1.51	4.15
1st LNA	15	35.00	3.16E+03	23.00	26.29	72.24
Waveguide	200	-5.00	3.16E-01	432.46	0.16	0.43
Warm LNA	300	20.00	1.00E+02	300.00	0.34	0.94
Mixer/IF hybrid	300	-13.00	5.01E-02	10000.00	0.11	0.31
1st IF LNA	300	15.00	3.16E+01	150.00	0.03	0.09
IF filter/att	300	-5.00	3.16E-01	648.68	0.00	0.01
2nd IF LNA	300	10.00	1.00E+01	300.00	0.01	0.02
Att	300	-4.10	3.89E-01	471.12	0.00	0.00
Total		52.32			36.39	



INAF/OAA-Arcetri

FH AND OMT DESIGN
AND MANUFACTURING
RF TESTS AND
ANALYSIS
SCIENCE

INAF/IAPS-Rome

CRYO CONTROL
SOFTWARE
OPTICS TEST BENCH

INAF/IRA-Bologna

RF ENGINEERING AND
INSTRUMENTATION

MW-UNIMI

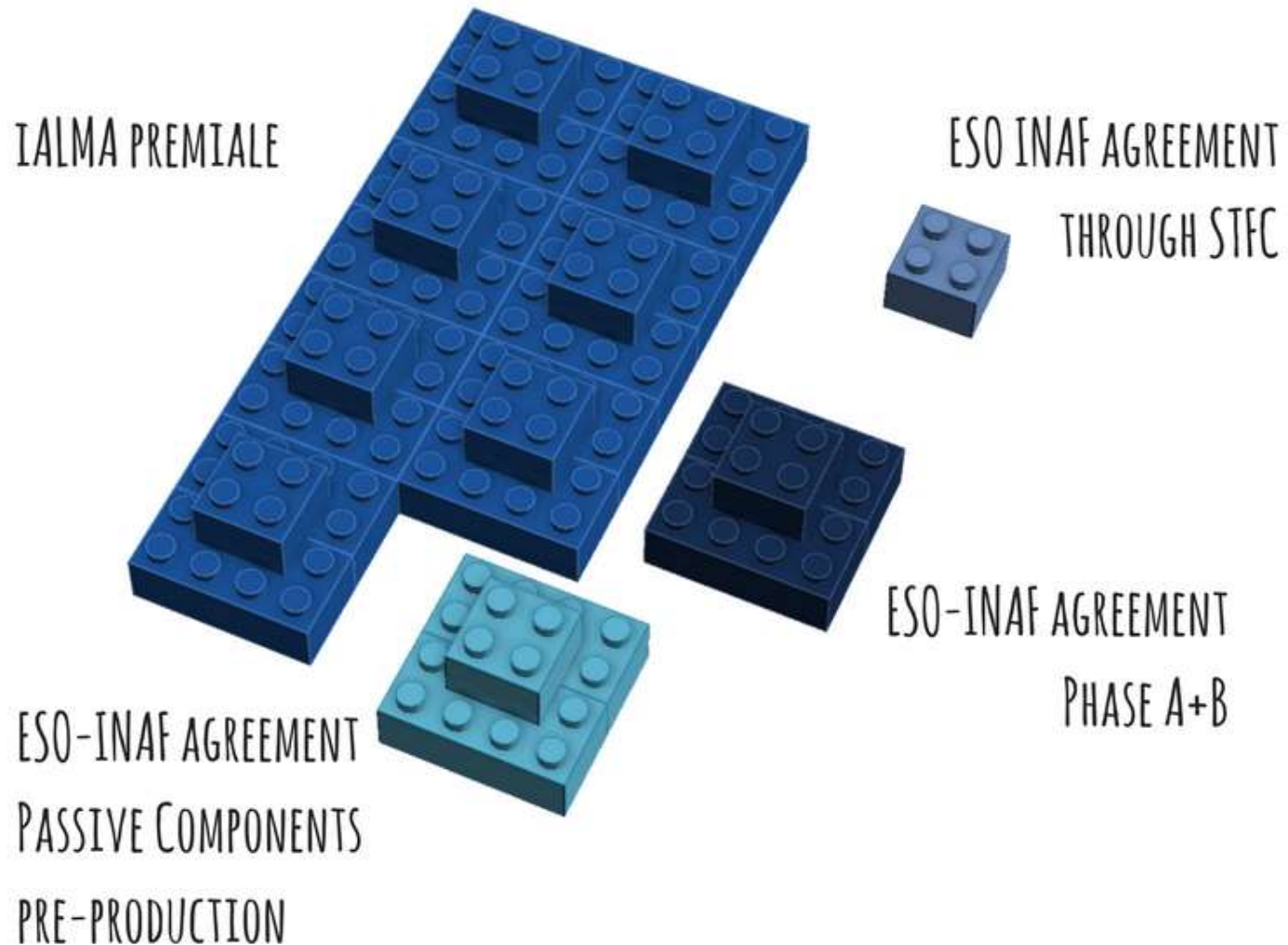
CCA MANUFACTURING

INAF/IASF-Bologna

SYSTEM DESIGN
SE + AIV
CRYOGENICS
WCA DEVELOPMENT
CALIBRATION
PROJECT CONTROL



Funding Profile for Italy



iALMA laboratories

INAF/OAA

- mm-wave test bench
 - VNA up to 116 GHz
- Anechoic chamber

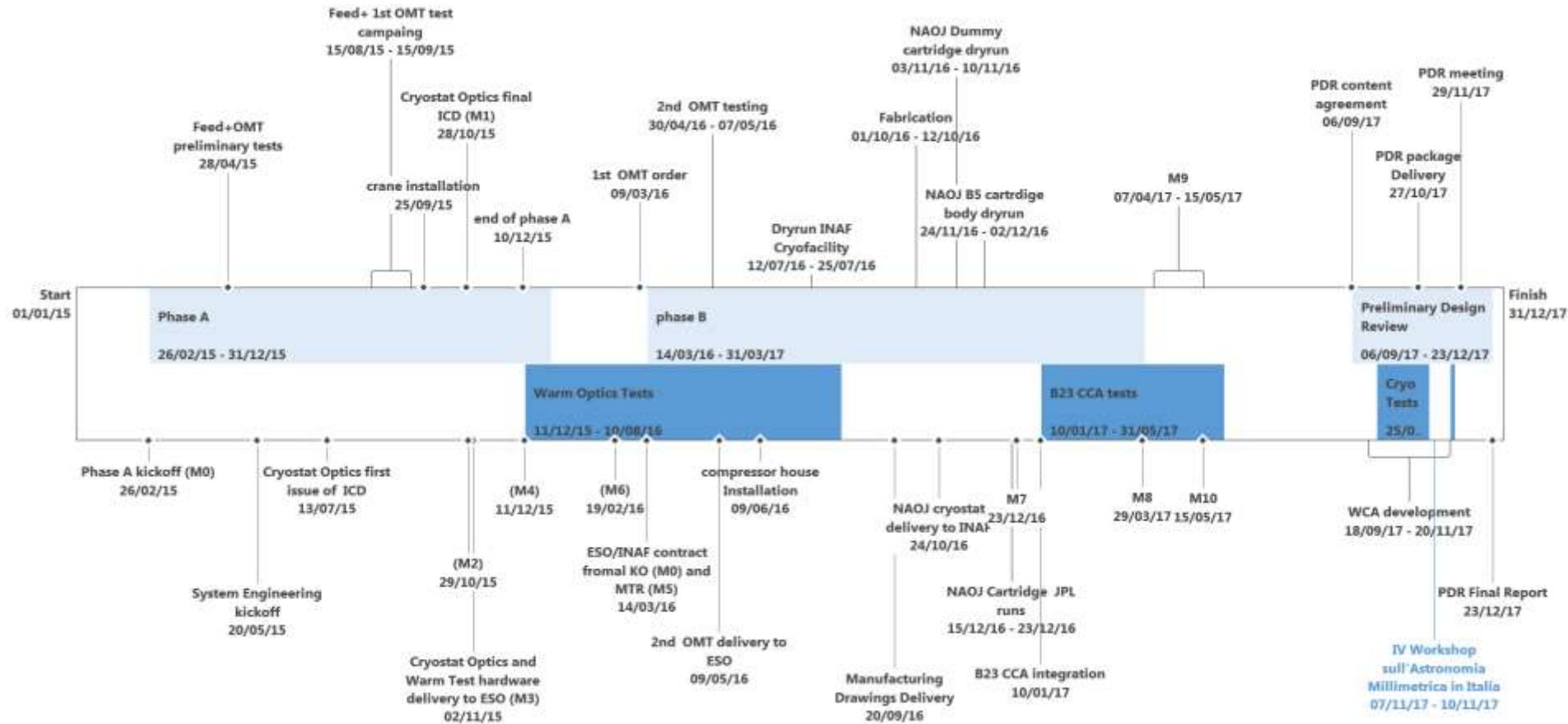


INAF/IASF-Bologna

- Cryofacilities for AIV
 - The 'blue barrel'
 - The 'big coffin'
 - The 1000Kg Crane
- RF inst.



Timeline of the project



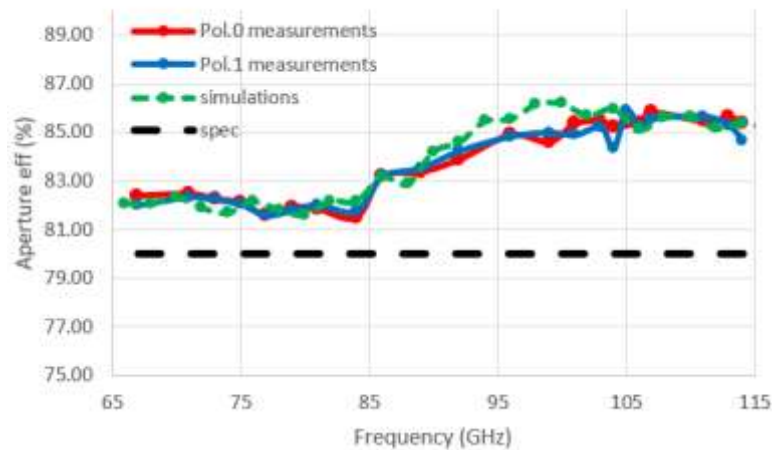
RE-IMAGING OPTICS

- **Reflective optics (cold and warm) were studied**
 - Truncation of the beam dominates
 - Warm mirror too large to be accommodated in the ALMA cryostat system
 - Vacuum window needed
- **Refractive optics chosen as baseline**
 - HDPE Fresnel (zoned) lens with Anti Reflection coating
 - Design by NAOJ/UdC manufactured by UdC
 - Silicon lens developed in 2017 with Anti Reflection coating (UdC) optimized for high permittivity
- **Catadioptric systems possible but not studied yet.**

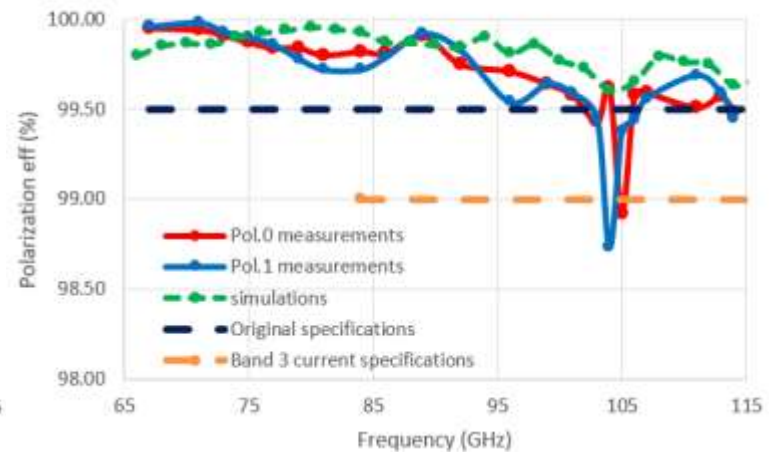
REFRACTIVE OPTICS (NAOJ, Udc, ESO) Lens for INAF



Aperture eff (%)



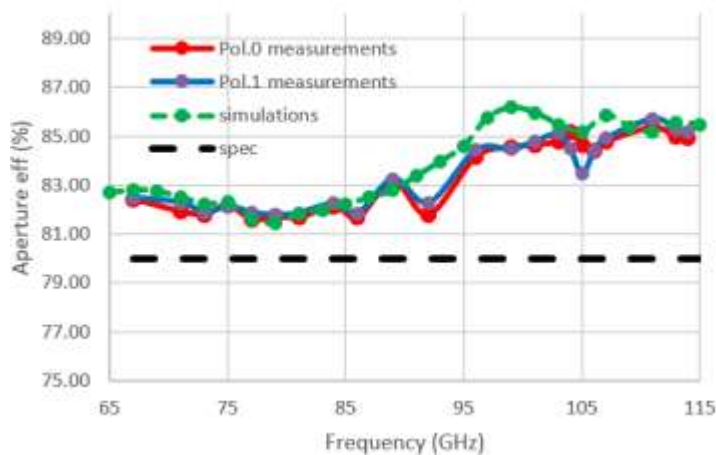
Polarization eff (%)



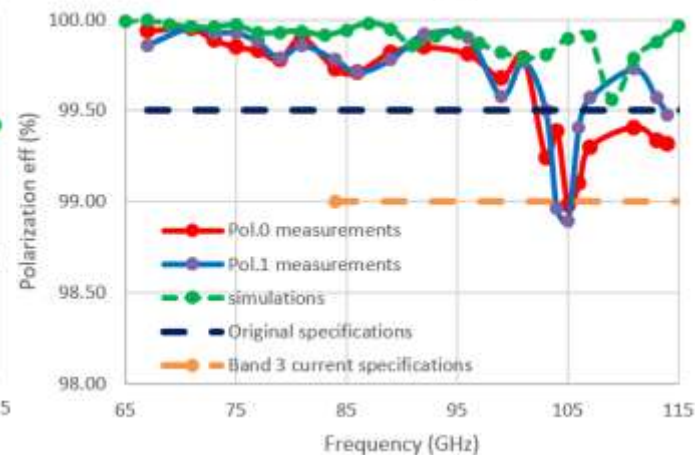
REFRACTIVE OPTICS (NAOJ, Udc, ESO) Lens for Udc



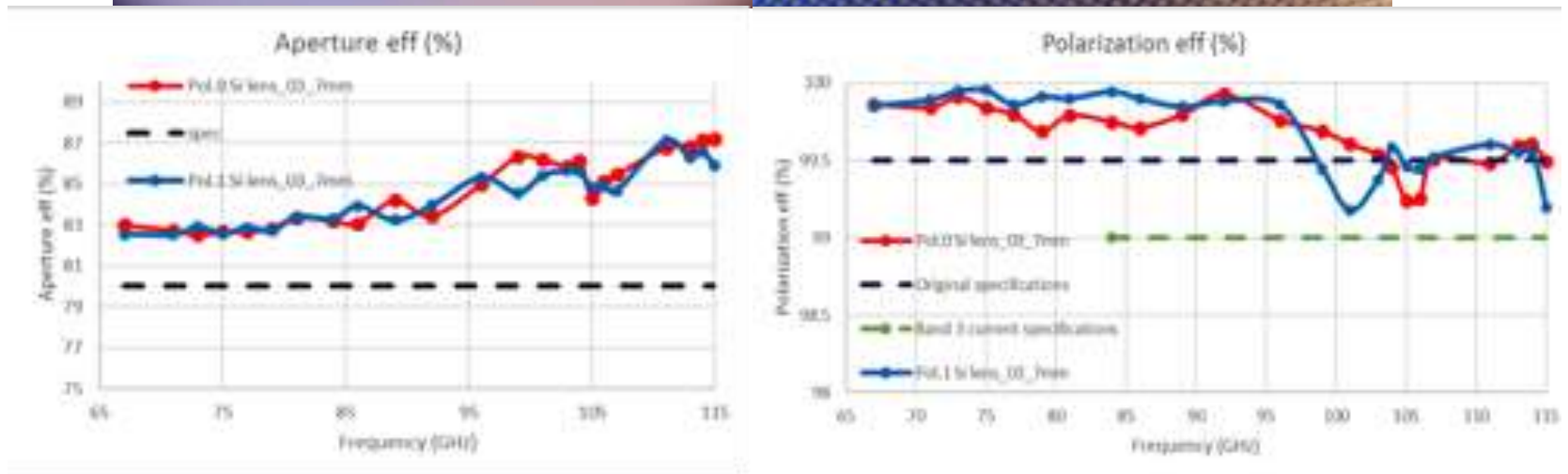
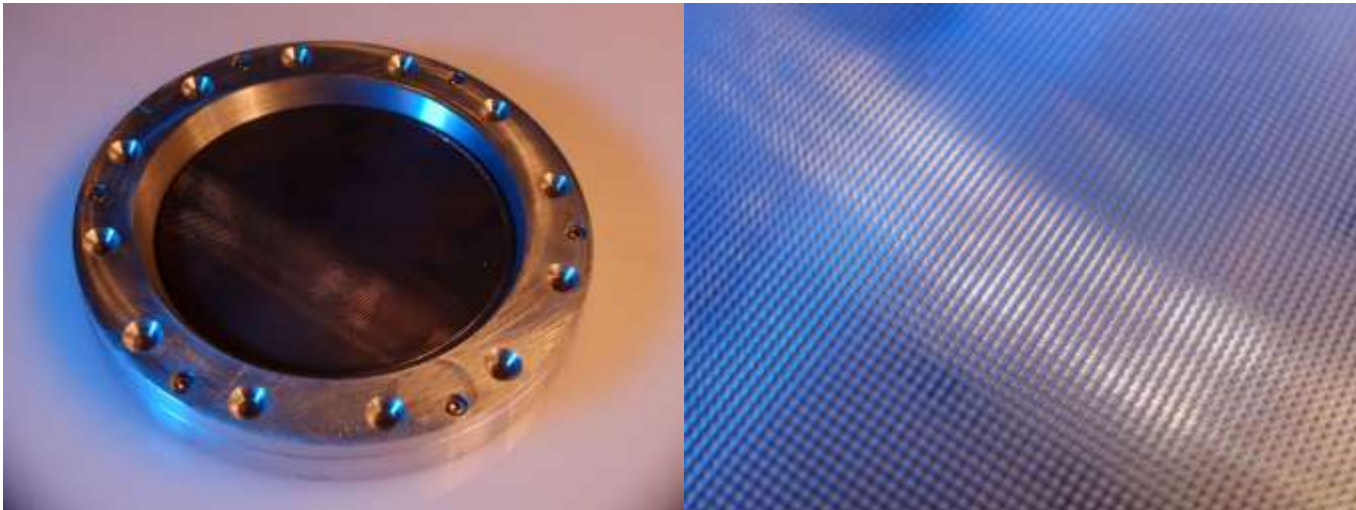
Aperture eff (%)



Polarization eff (%)

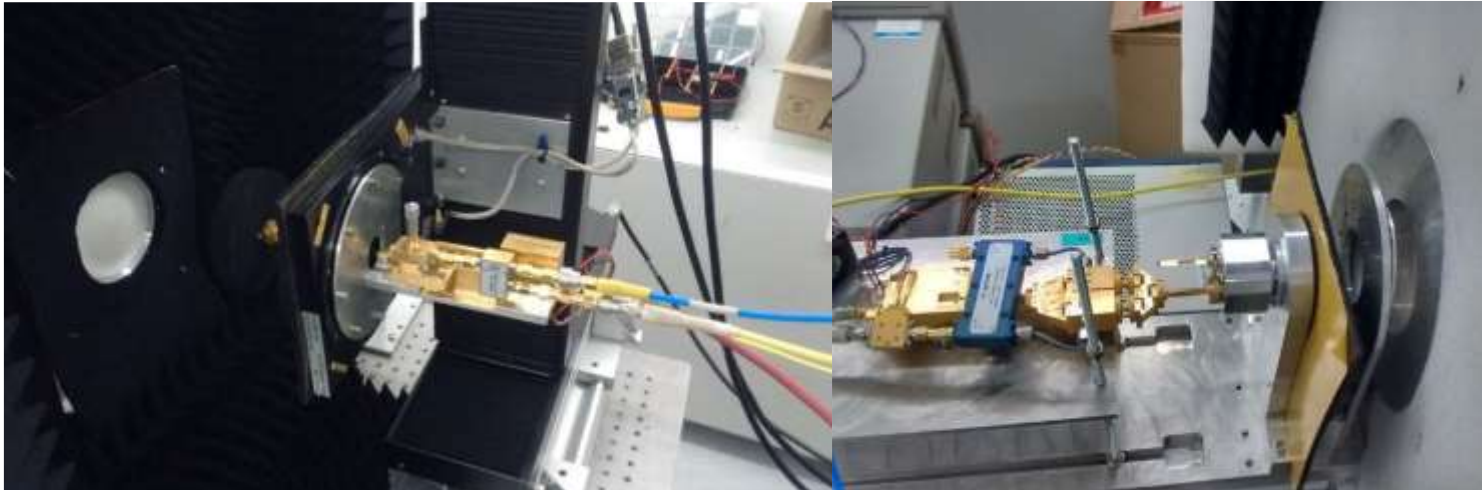


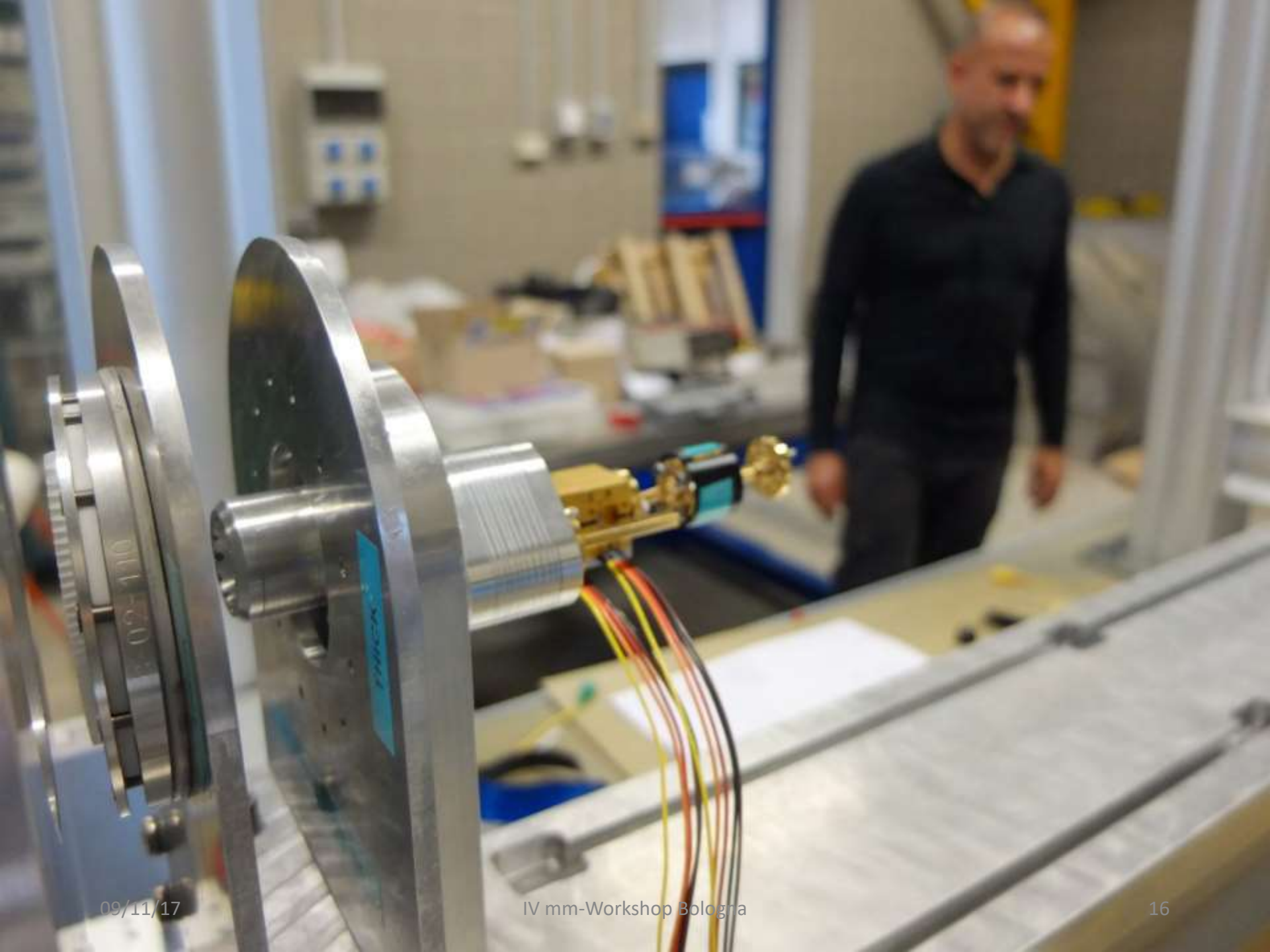
REFRACTIVE OPTICS (Silicon) (Udc, ESO)



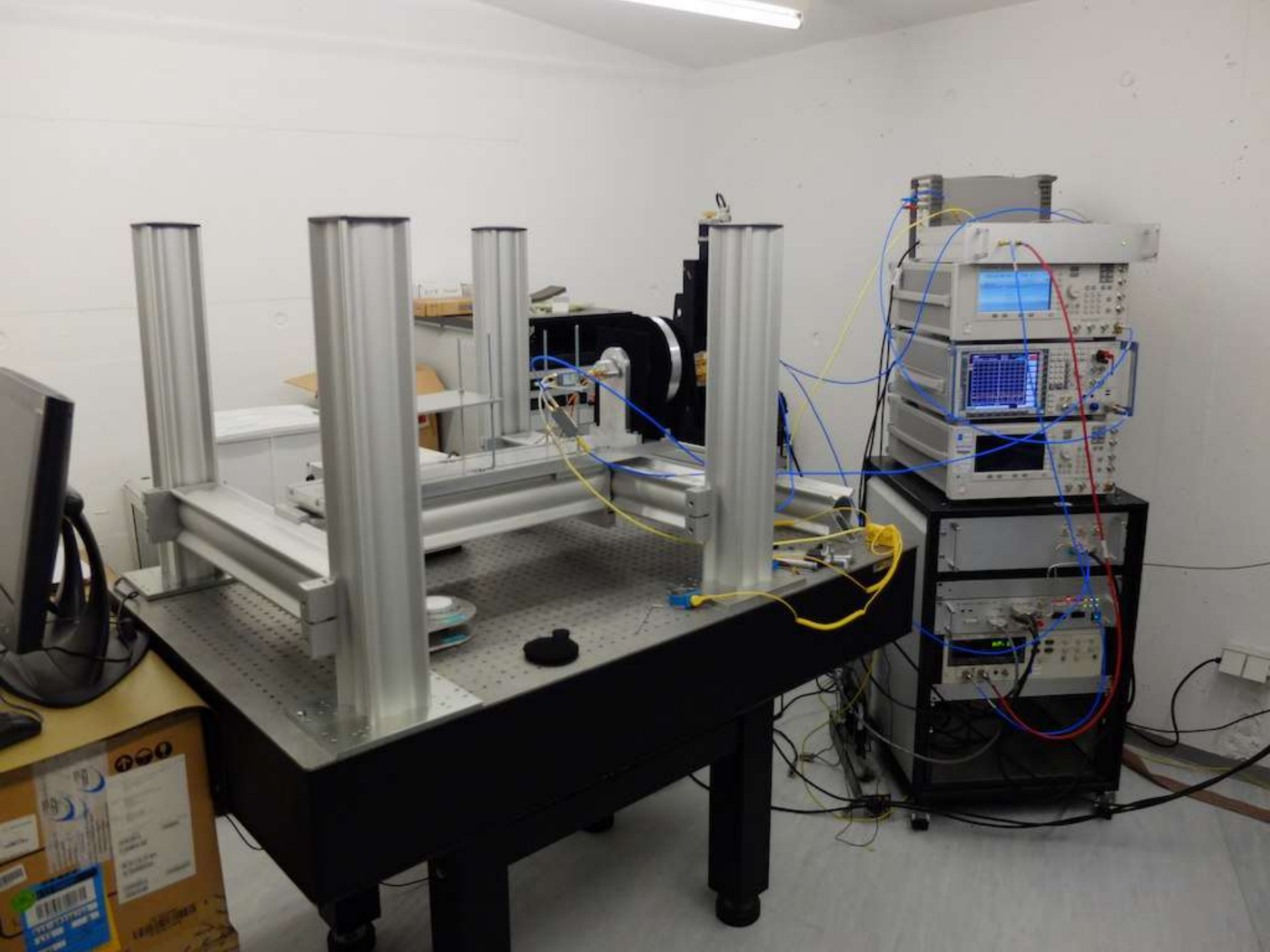
Optical Efficiency meas.

- Performed @ ESO at room temperature
- Near-field beam measurement system 67-115 GHz

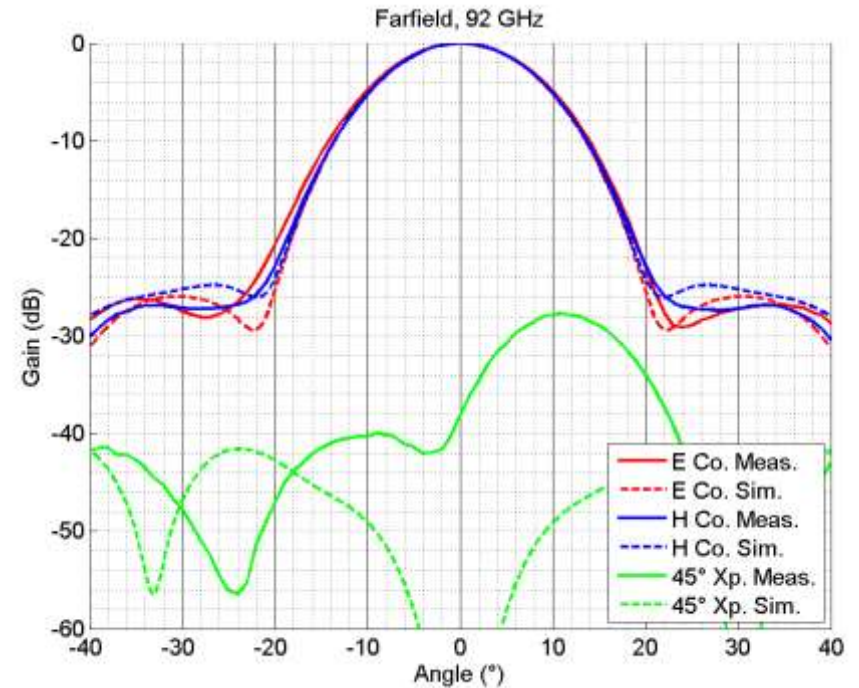
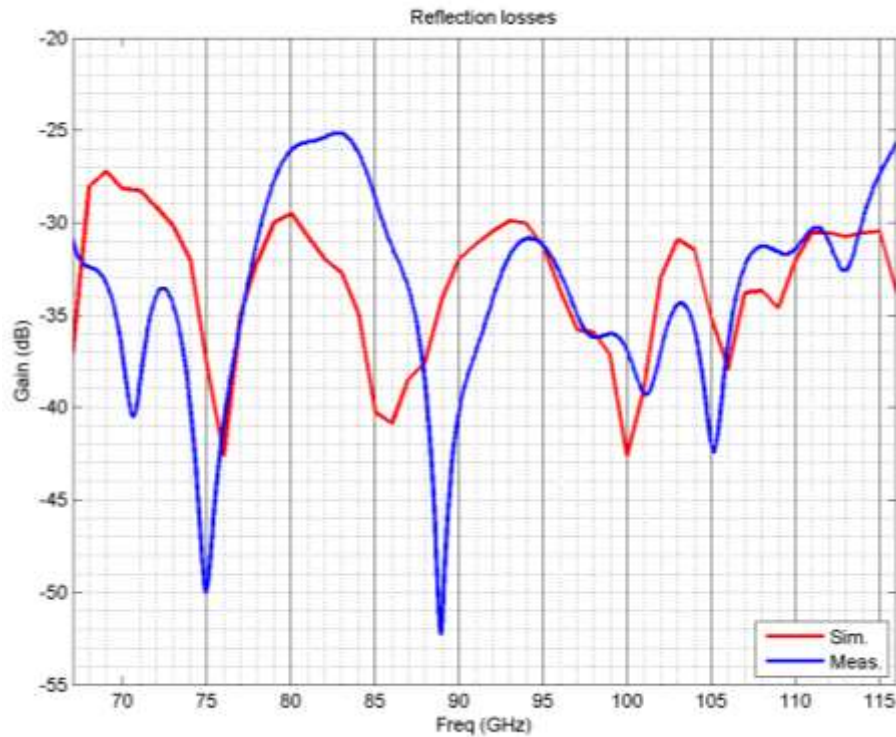






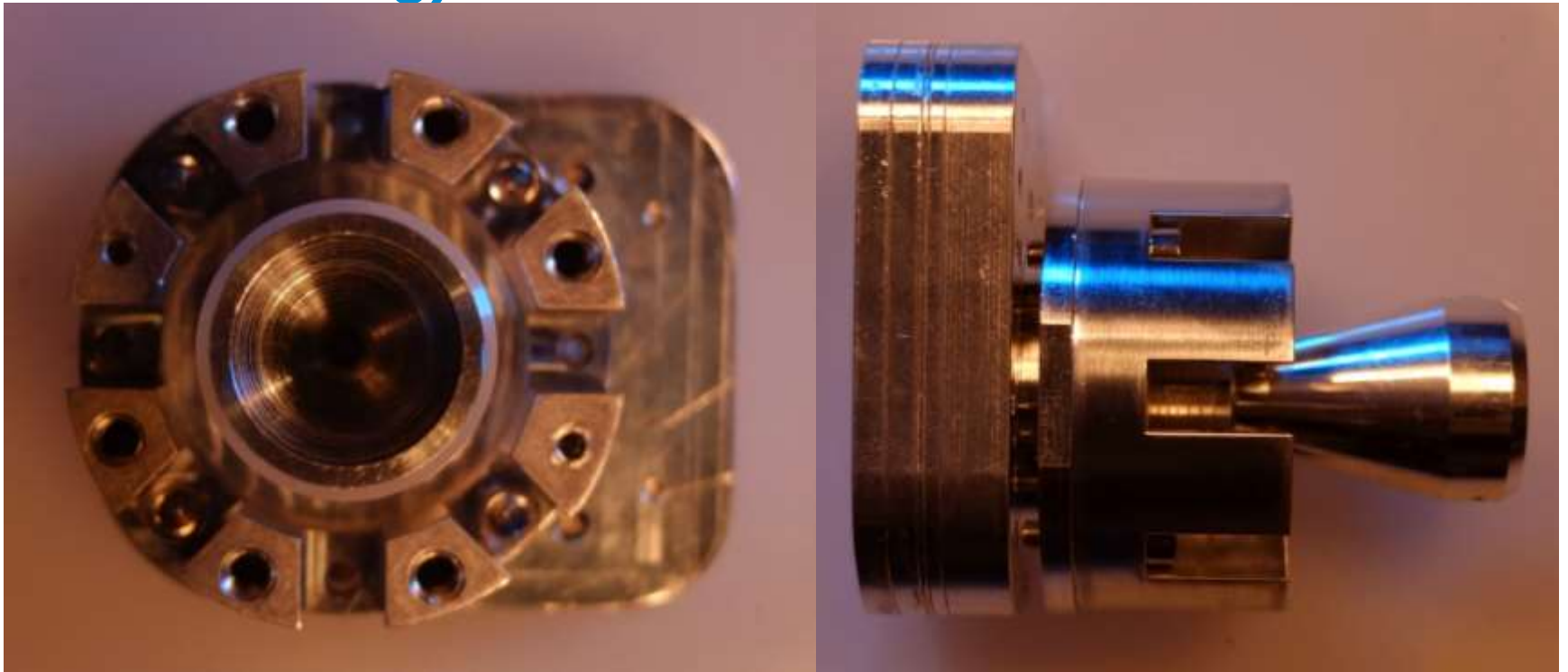


Corrugated Feed Horn (UdC)



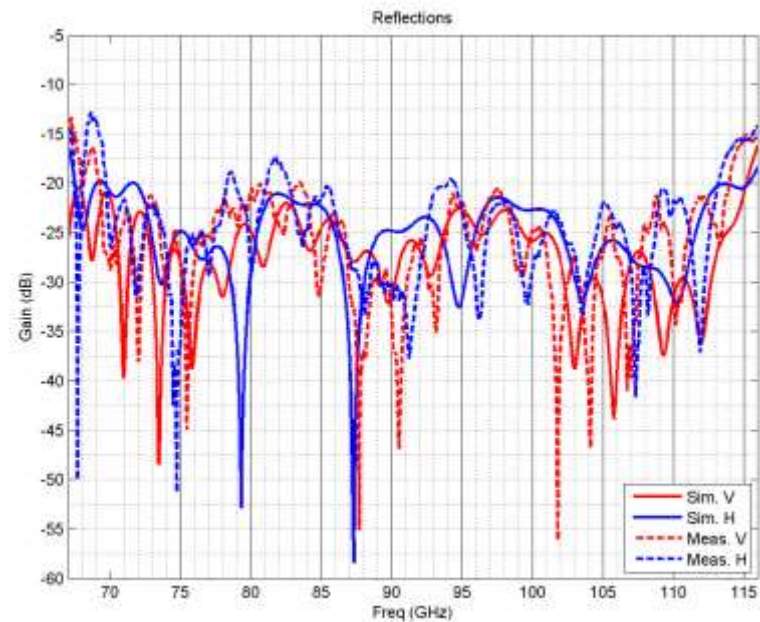
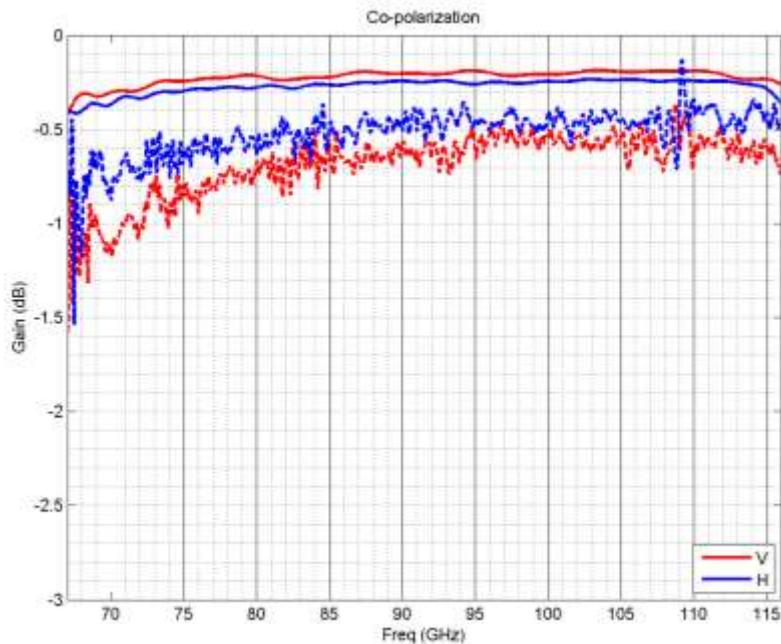
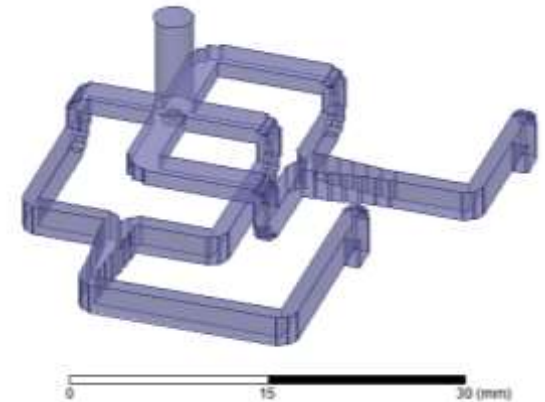
Corrugated Feed Horn (UdC) + OMT (UdC)

- UdC design and fabrication (Direct machining)

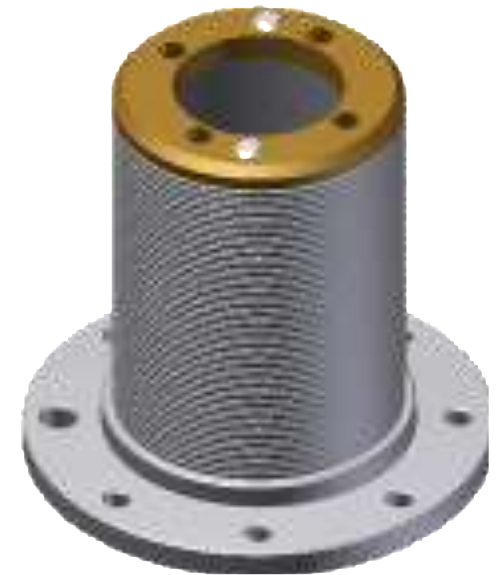
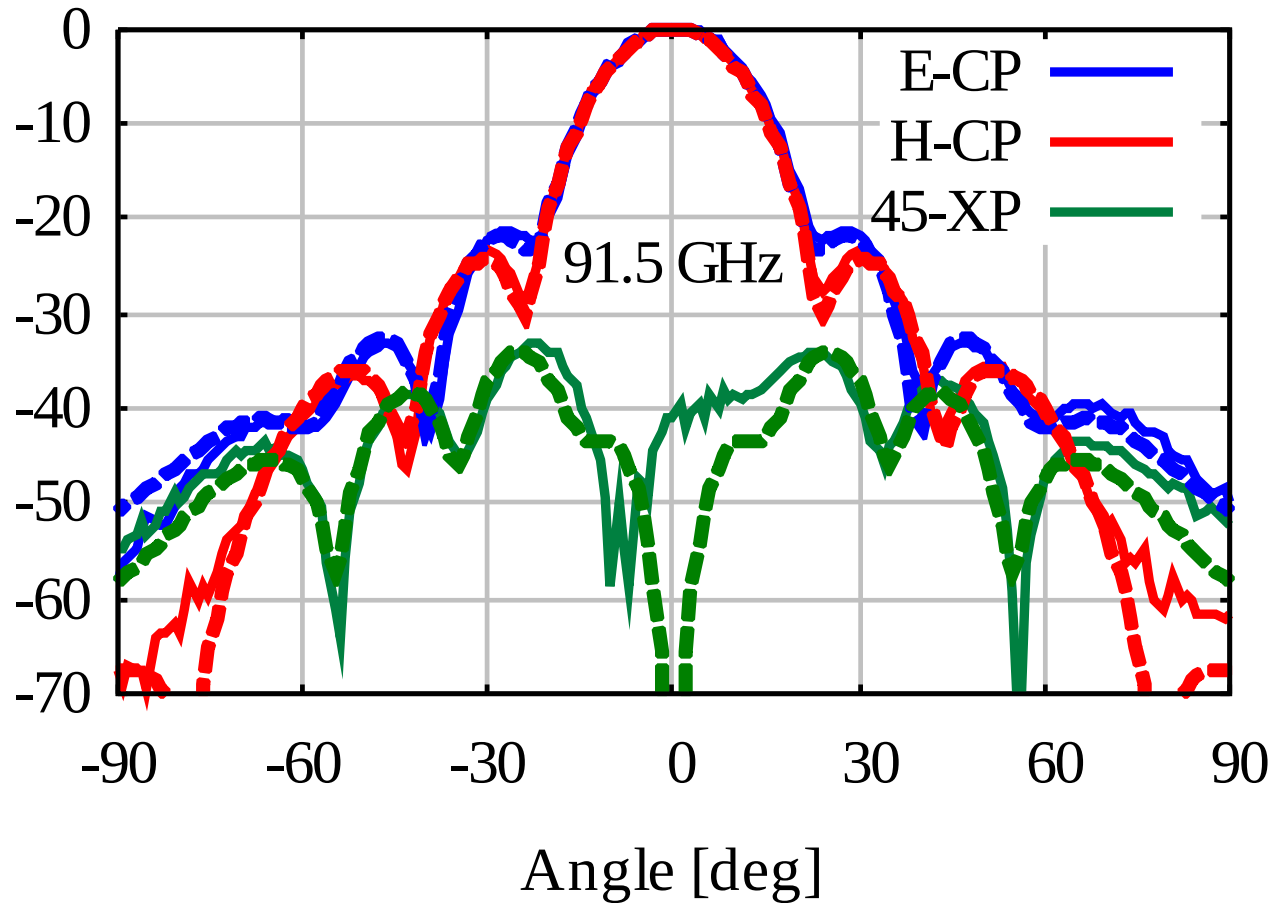


OMT (UdC)

The band 2+3 UdC OMT is based on a turnstile junction architecture

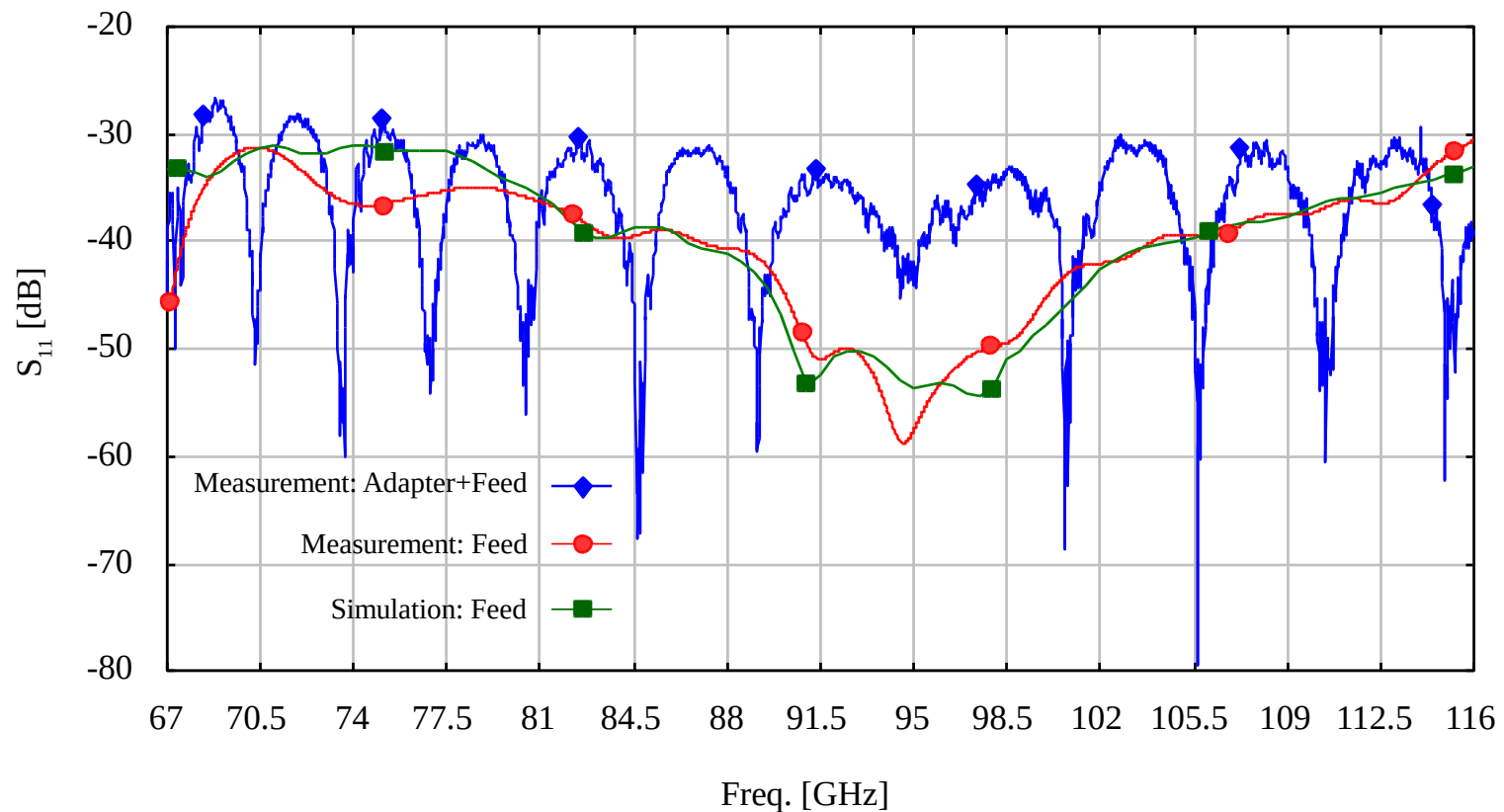


Corrugated horn (INAF/OAA)



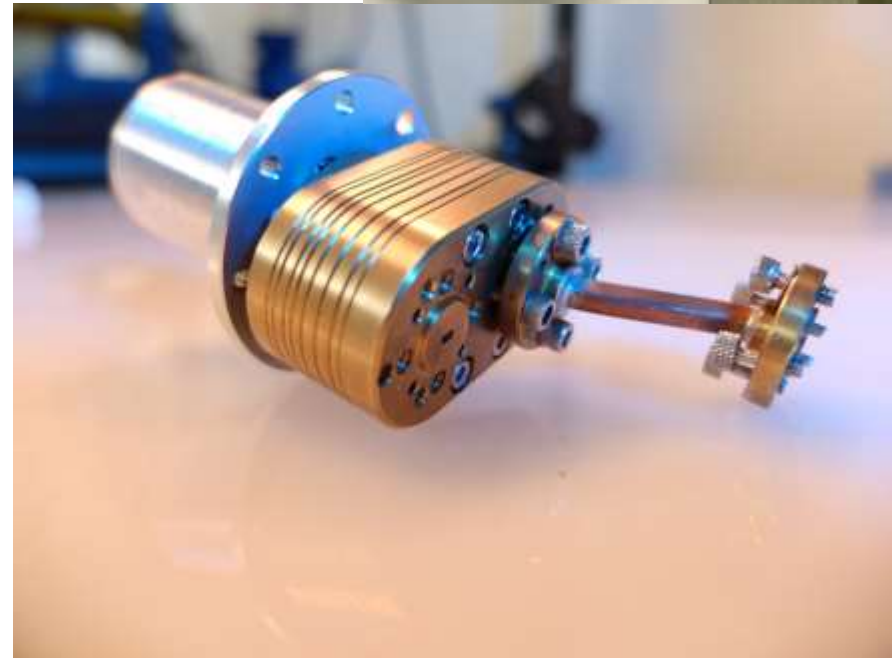
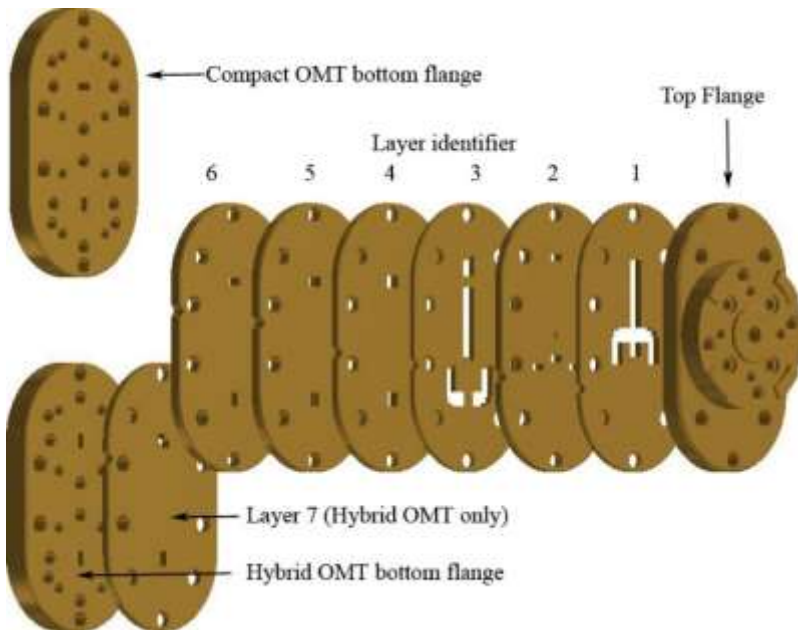
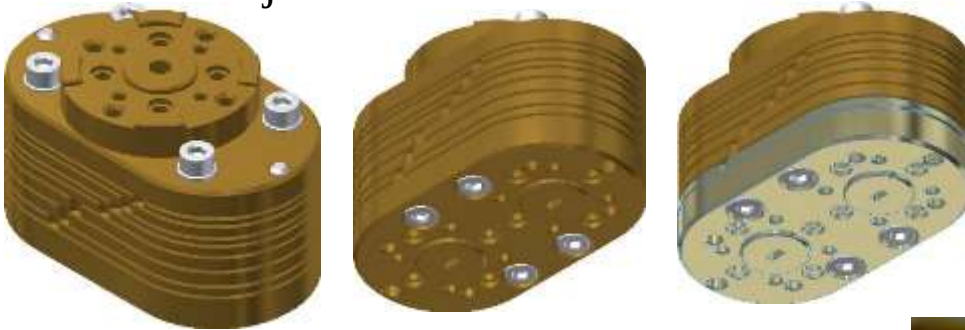
Corrugated horn (INAF/OAA)

- Platelet technique

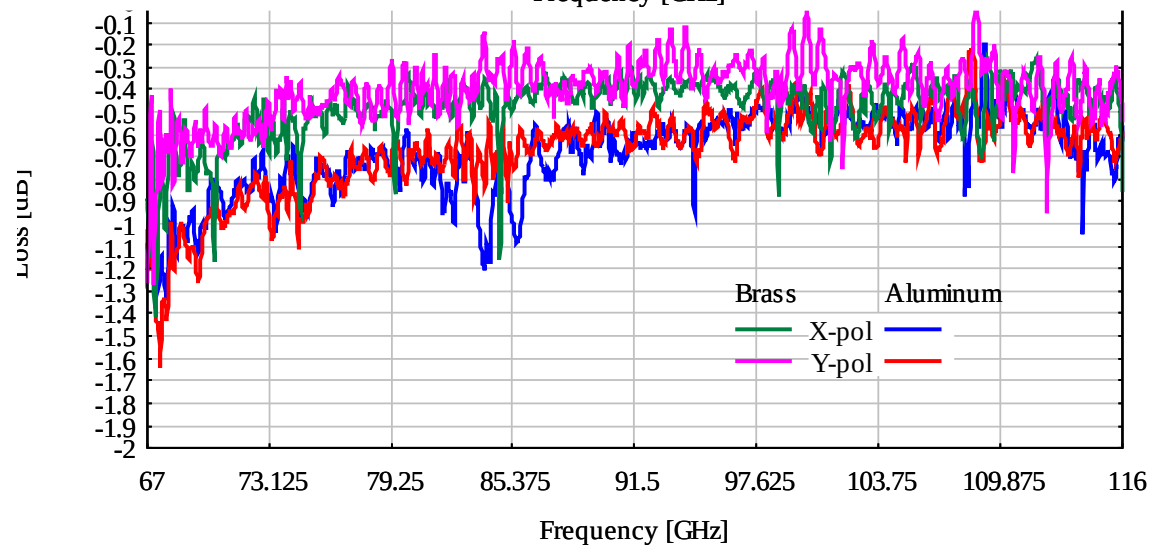
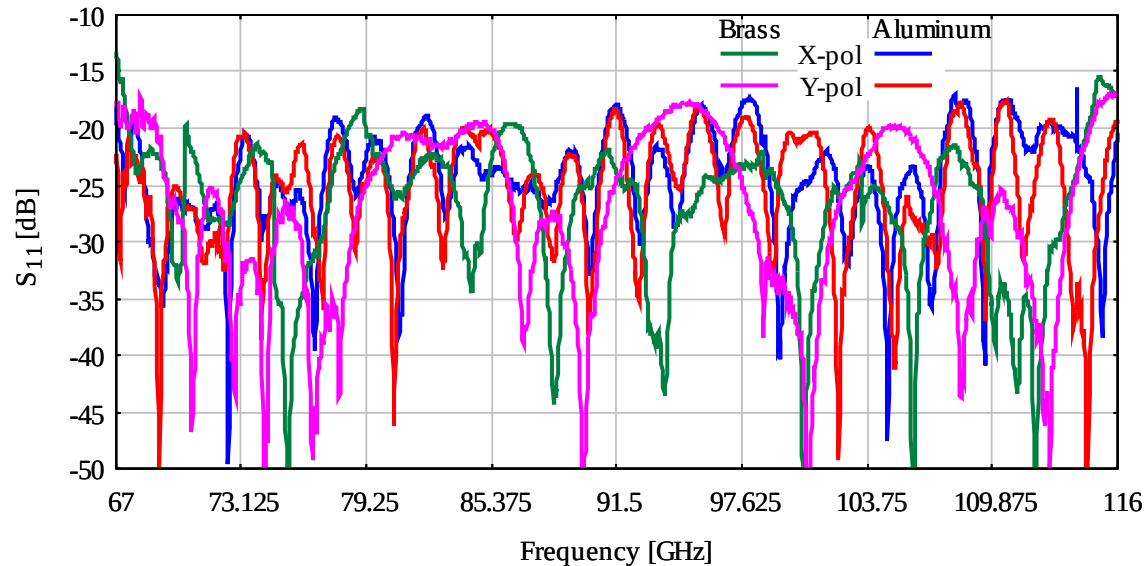


OMT (INAF/OAA)

Two OMTs have been designed at INAF based on turnstile junctions.

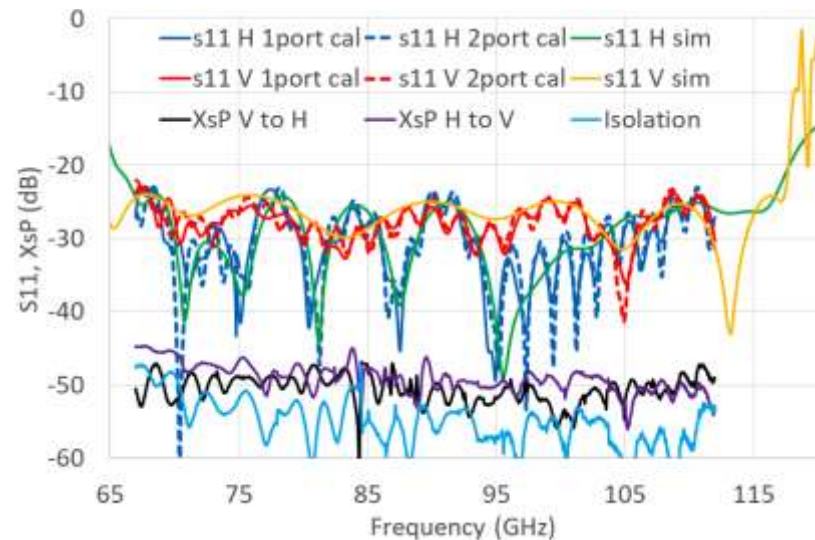
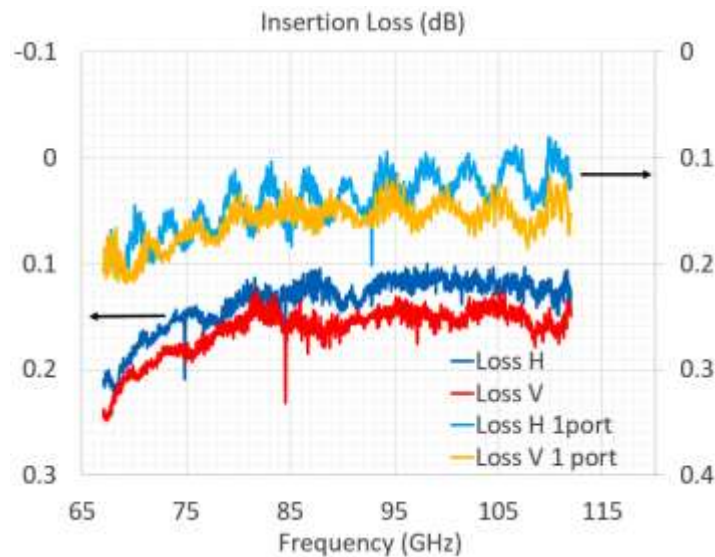
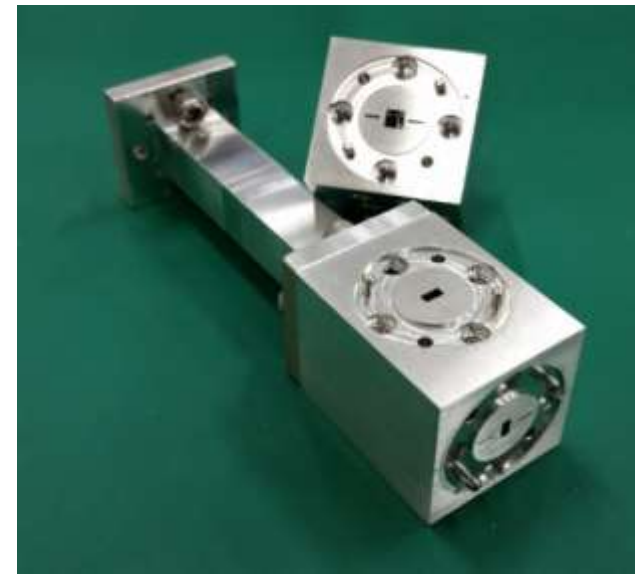
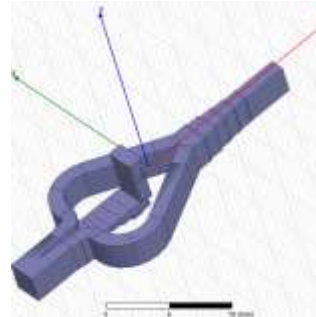


OMT (INAF/OAA)

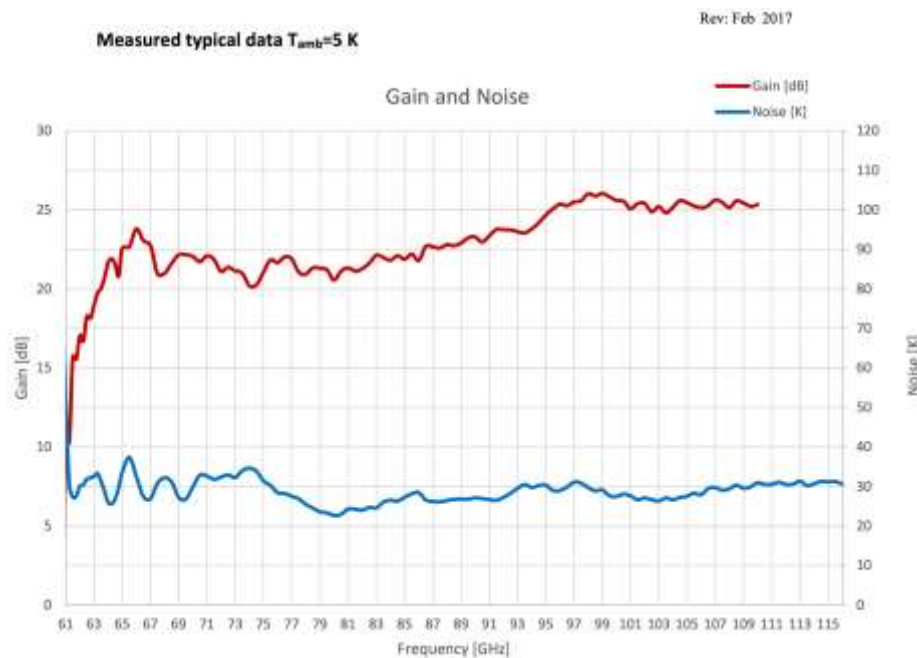


OMT (NAOJ)

The NAOJ OMT design is based on a standard Boifot junction modified for wideband performance



Low Noise Amplifiers (Low Noise Factory)



LNF-LNC65_115WA



FEATURES

- RF bandwidth: 65-115 GHz
- Noise Temperature: 28 K typical
- Noise Figure: 0.40 dB typical
- Gain: 23 dB
- DC-power: $V_d=1.00\text{ V}$, $I_d=7\text{ mA}$
- One gate and one drain supply only
- RF-connectors: WR10, UG387/U
- DC-connector: 9-pin female Nano-D

DESCRIPTION

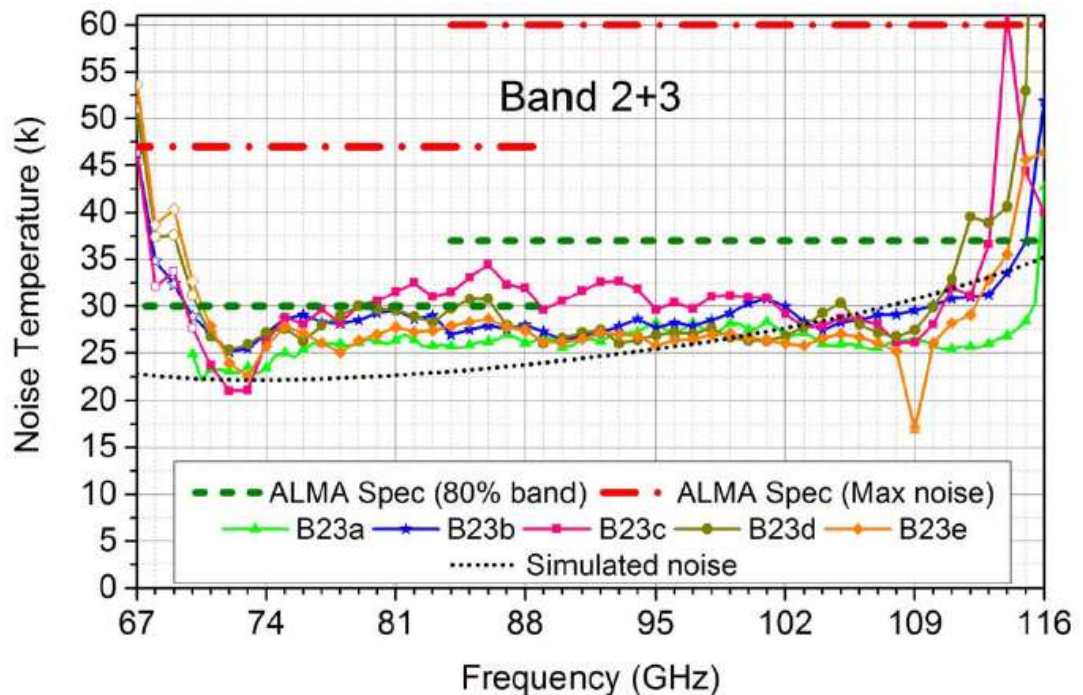
LNF-LNC65_115WA is an ultra-low noise cryogenic amplifier operating in the 65-115 GHz frequency range. The LNA is packaged in a waveguide module using industry standard WR10 and Nano-D connectors.

The lightweight gold plated aluminum module measures 14.92*24.00*20.75 mm excluding the connectors. MMIC technology ensures reliable and repeatable unit-to-unit result.

Low Noise Amplifiers

Univ. of Manchester

“The best LNAs reported here show a noise temperature less than 250 K from 72 to 104 GHz at room temperature, and less than 28 K from 70 to 110 GHz at cryogenic ambient temperature of 20 K. To the best knowledge of the authors, this is the lowest wideband noise ever published in the 70–110 GHz frequency range, typically designated as W-band.”



D. Cuadrado-Calle *et al.*, "Broadband MMIC LNAs for ALMA Band 2+3 With Noise Temperature Below 28 K," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 65, no. 5, pp. 1589-1597, May 2017.

Cold Cartridge AIV

- **INAF/IASF-Bologna decided to manage the manufacturing, integration and test on cryowaves lab with the support of**
 - ESO
 - INAF/OAA
 - Mechanical Workshop @ UNIMI
- **The activity started on 20 Sept. 2016 and optimization and tests are on-going facing the Preliminary Design Review (end of Nov. 2017)**
 - Several configuration testes, with different receiver layout (amplifiers, isolators) and down-converter breadboard

Cold Cartridge AIV

- GARD (Univ. of Chalmers) provided mechanical design and thermal analysis of the CCA (4 variants)



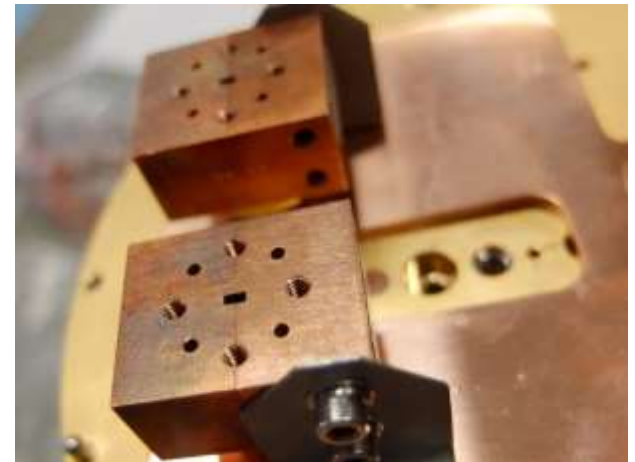
Cold Cartridge AIV

- Manufacturing of the CCA structure a the Mechanical Workshop @ UNIMI



Cold Cartridge AIV

- PMS s.r.l and Aerowave inc for WG components



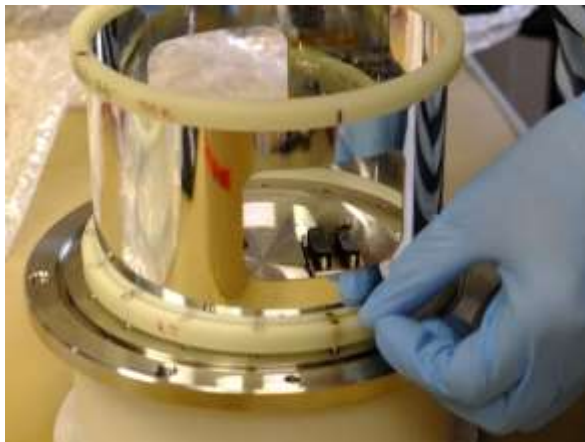
Cold Cartridge AIV

- INAF/OAA measured all the WG components from 67 to 116 GHz



Cold Cartridge AIV

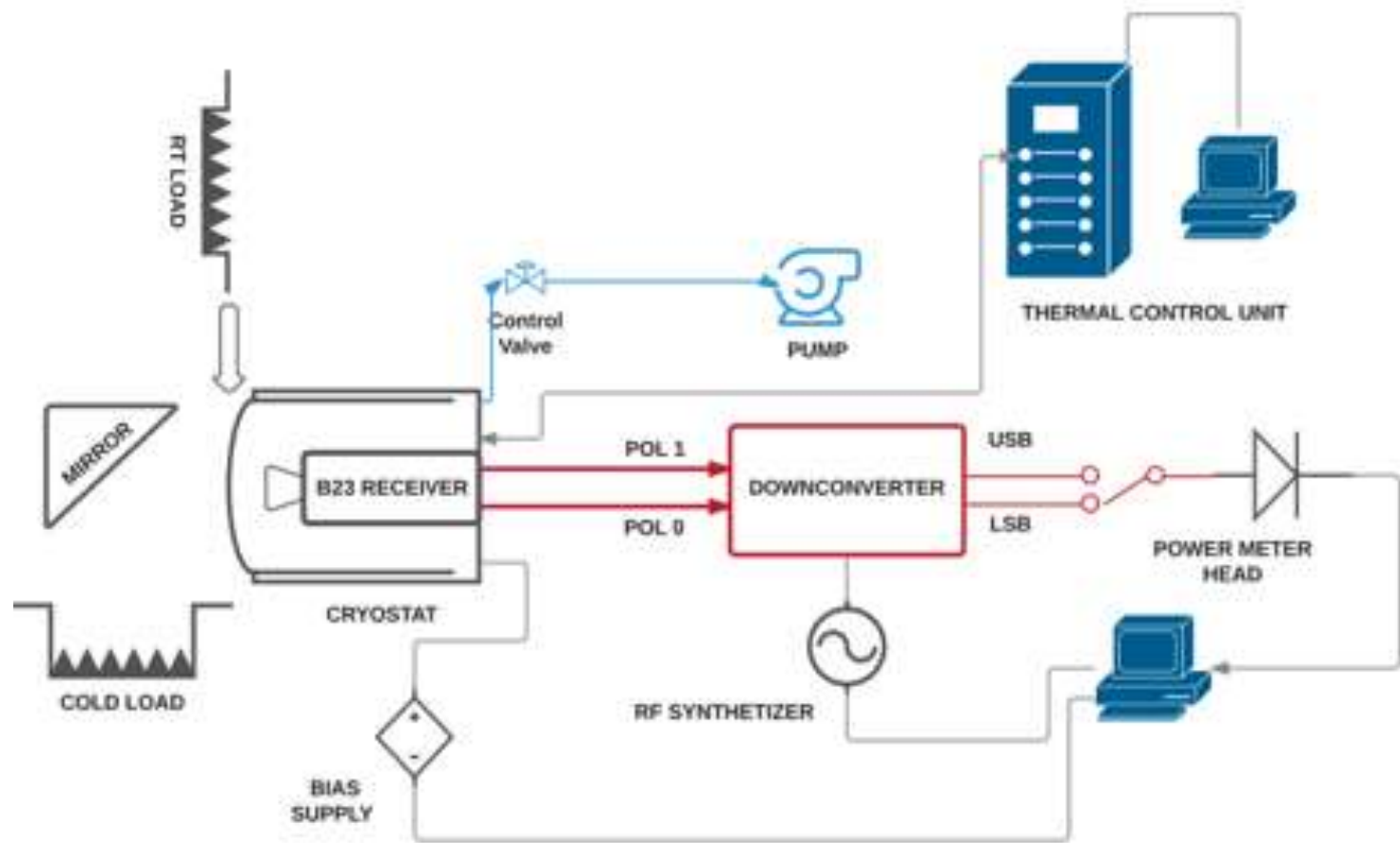
- ESO provided the ALMA test Cryostat, Down-Converter breadboard and manpower for tests
- Integration and Calibration performed at INAF/IASF-Bologna (Crywaves lab)



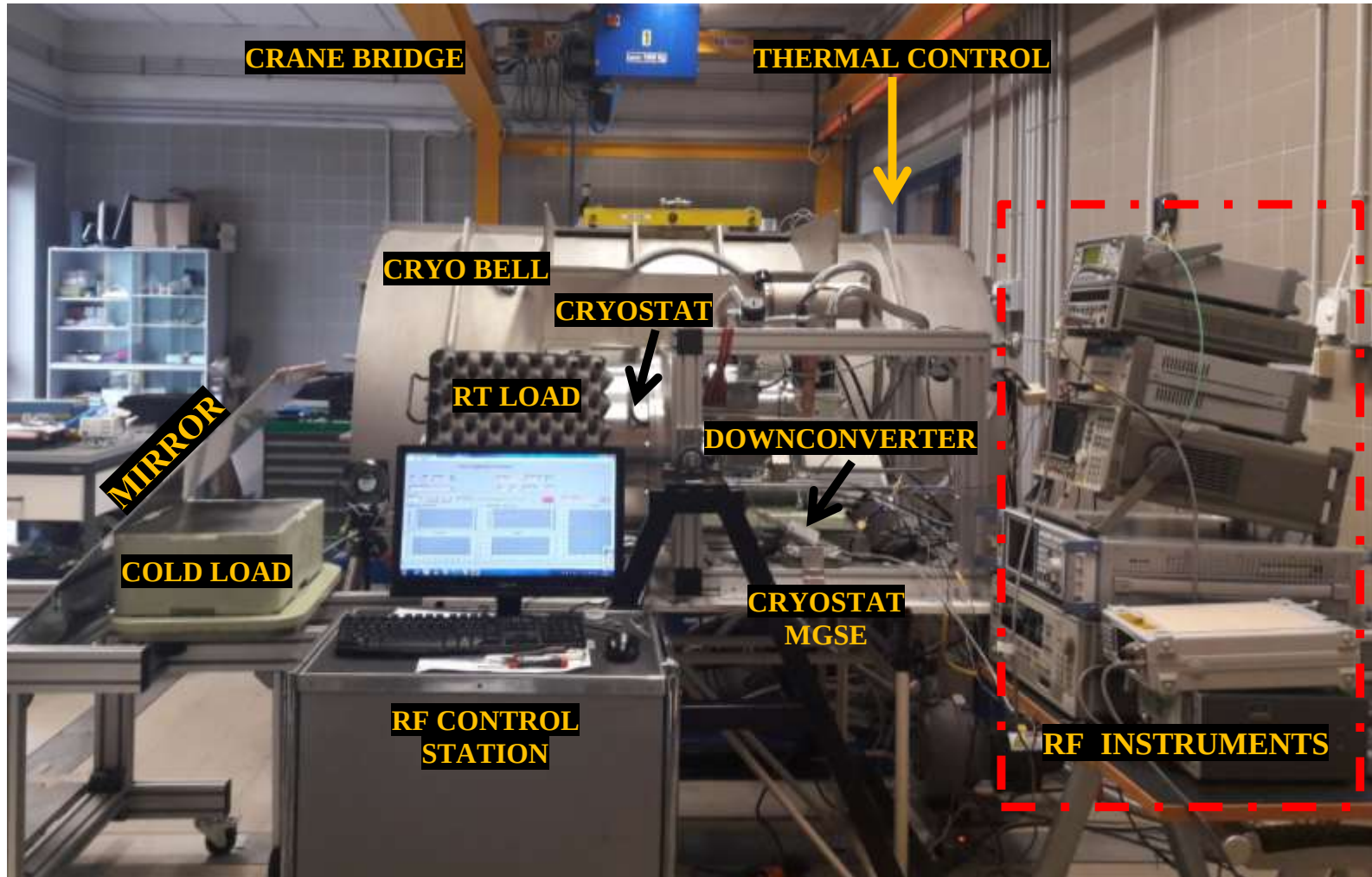
Cryogenic noise meas.

- **Overall qualification of the CCA**
 - Temperatures level and stability, interfaces, mechanics
 - Functional tests vs cooldown/warmup
 - Vacuum qualification (lens)
- **LNA bias optimization**
 - Tuning of amplifiers
- **Performance Tests**
 - Noise (Y-factor) over the whole bandwidth
 - Spurious signals
 - Amplitude Stability (Allan variance)

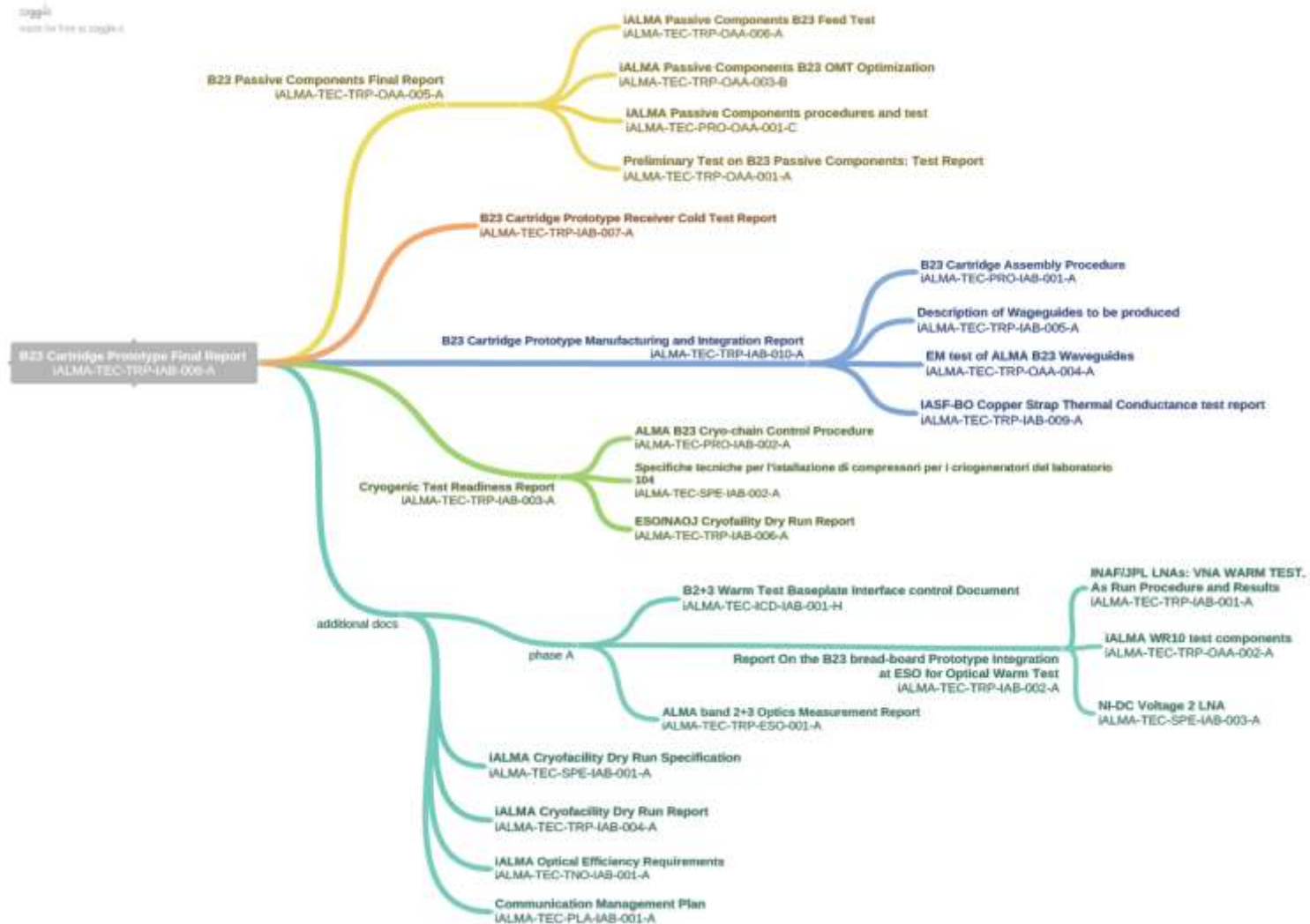
Cryogenic noise meas. setup



Cryogenic noise meas. setup

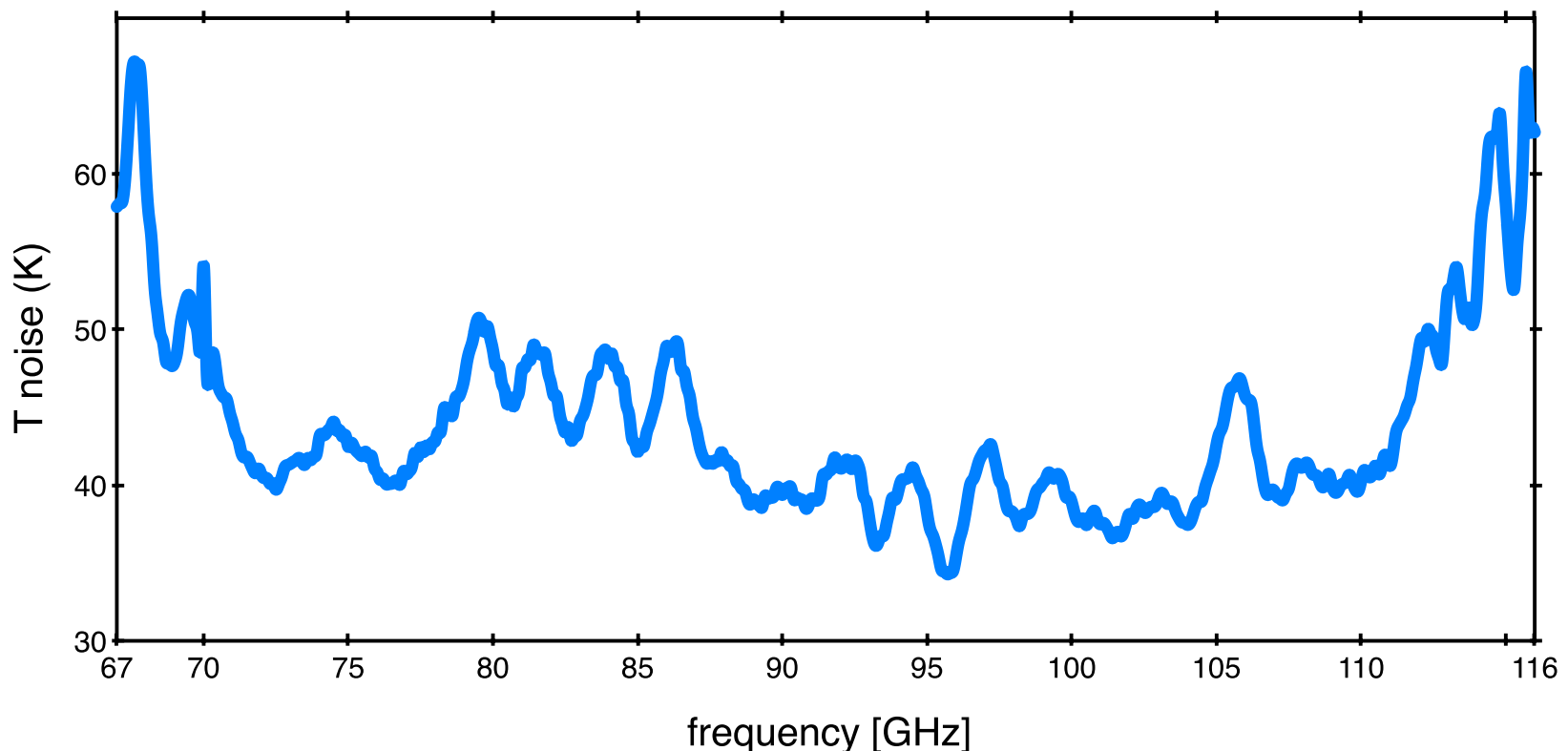


ESO/INAF Document tree



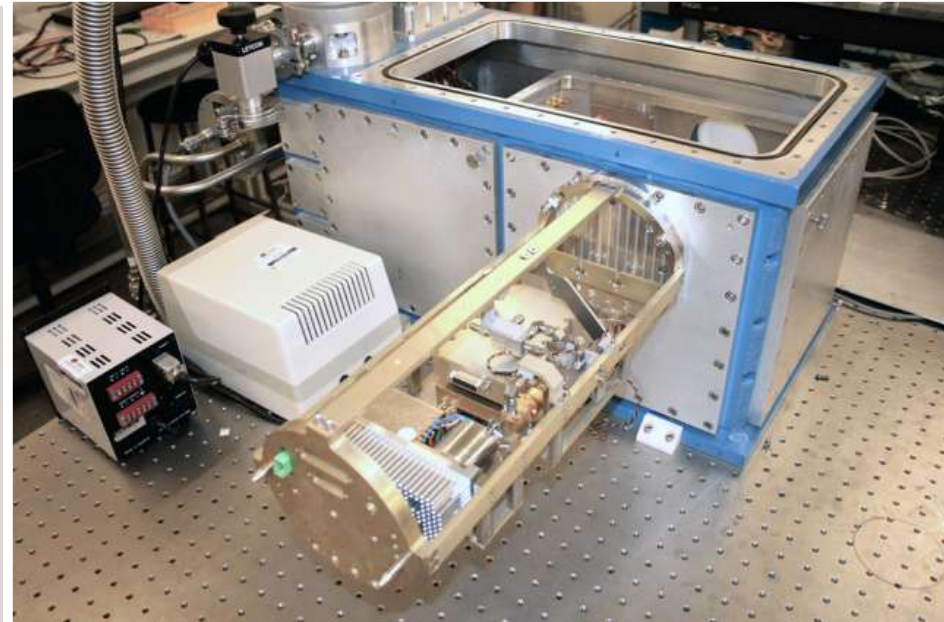
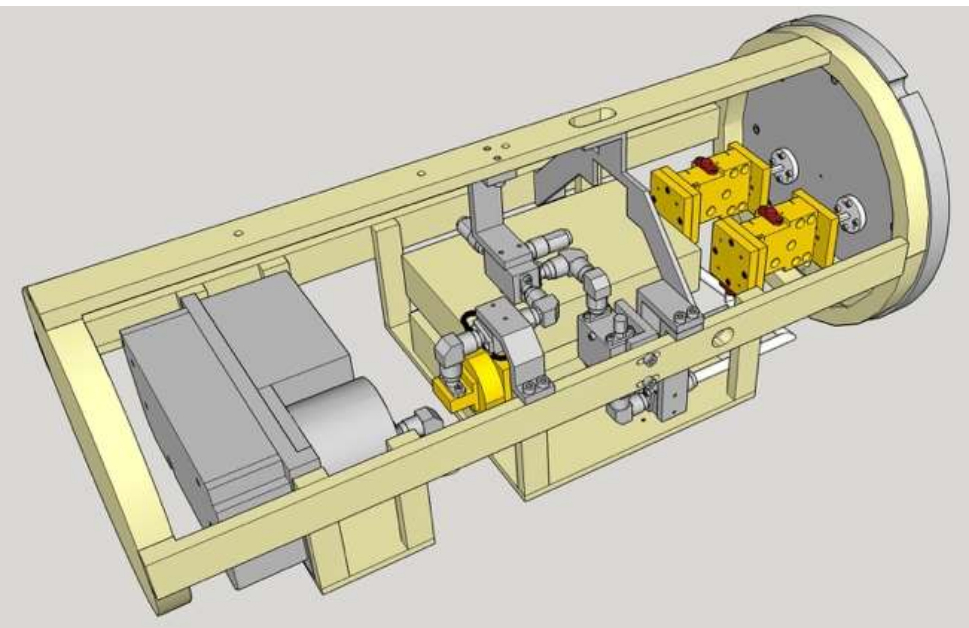
Noise Temperature meas. April 2017

- Starting point for Cartridge Prototype optimization (on-going)



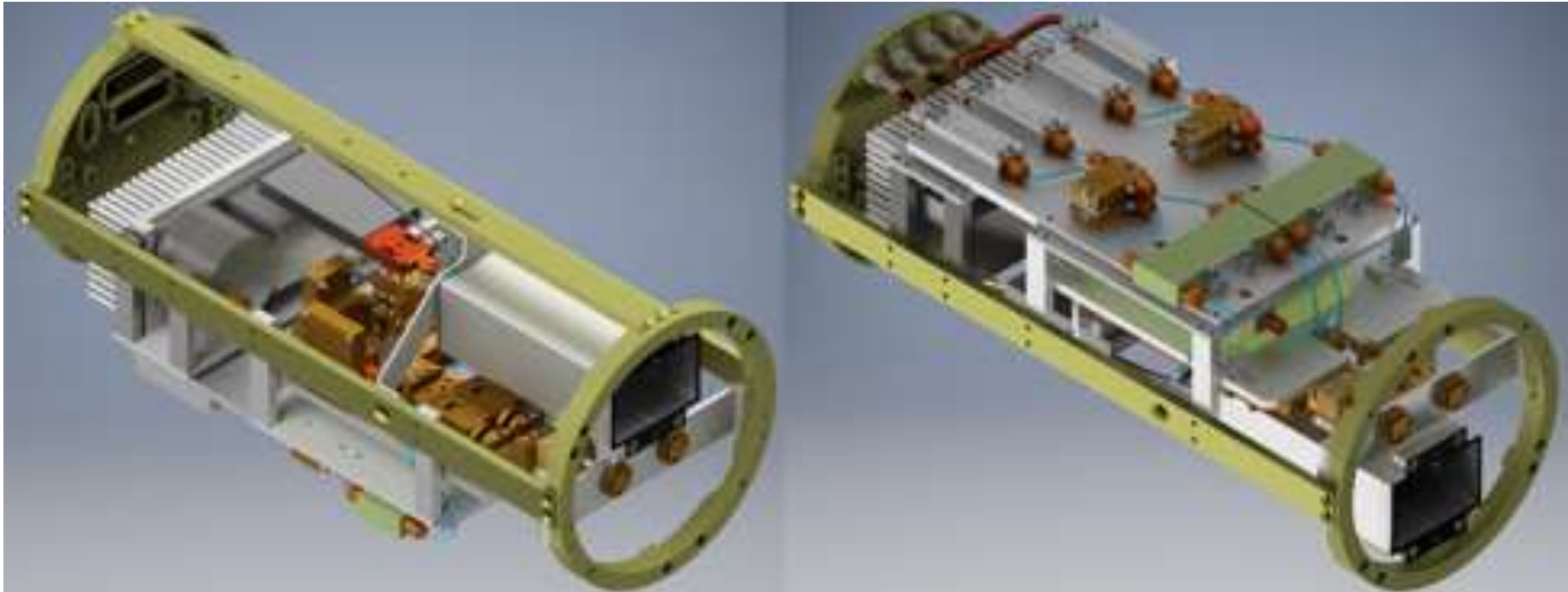
Warm Cartridge Assembly

- R.A.L started to develop a WCA specifically for Band 2+3 system according to ALMA specs

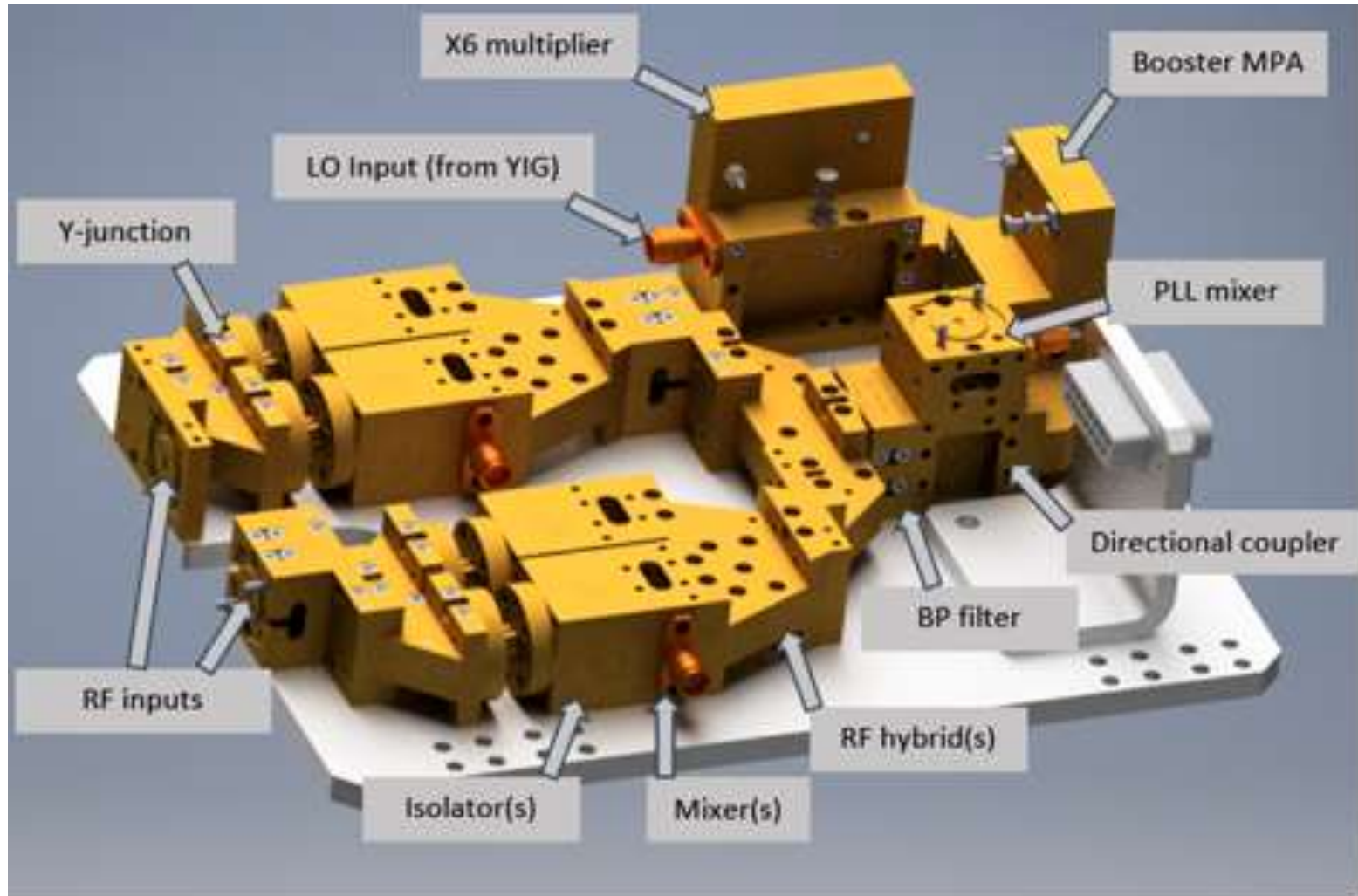


Warm Cartridge Assembly

- ESO, Radiometer Physics GmbH, INAF/IASF-Bologna started to produce a prototype of the WCA based on Band 5 hardware



Down Converter Unit (ESO, Radiometer Physics GmbH)



Next Step for INAF Study funded by ESO

**B23 passive components
for ALMA receivers**

**Technical and
Management proposal**

9 August 2016

Optimization and Production Engineering of **BAND 2+3 PASSIVE COMPONENTS** for **ALMA** Receivers

A proposal to
CFP/ESO/16/11115/OSZ for the Advanced Study for Upgrades of
the Atacama Large Millimeter/Submillimeter Array (ALMA)

Content of the study

- **Goal to reach the required level of maturity to face the production of B23 passive components on the basis of the activities already performed in Italy.**
 - Optimize the performances and processes
 - Reduce risks and costs
 - Solve criticalities of performance and technology
- **Build a pre-series of components to face the production for Band 2+3 Passive Components**
 - Identify possible providers
 - Assess the capability from design to qualification to face the mass production

Thanks to

- All the Band 2+3 consortium
- Most of the material has been taken from the PDR datapack under evaluation in these days



Atacama
Large
Millimeter
Array

Band 2+3 Receiver PDR Design and Test Report

FEND-40.02.02.00-0049-A-DSN

Version: A

Status: Released

2017-10-27

Flickr album for pictures

<https://www.flickr.com/photos/gilas69/sets/72157677037620172>

