Overview of the Current ALMA Frontend and Its Future Developments

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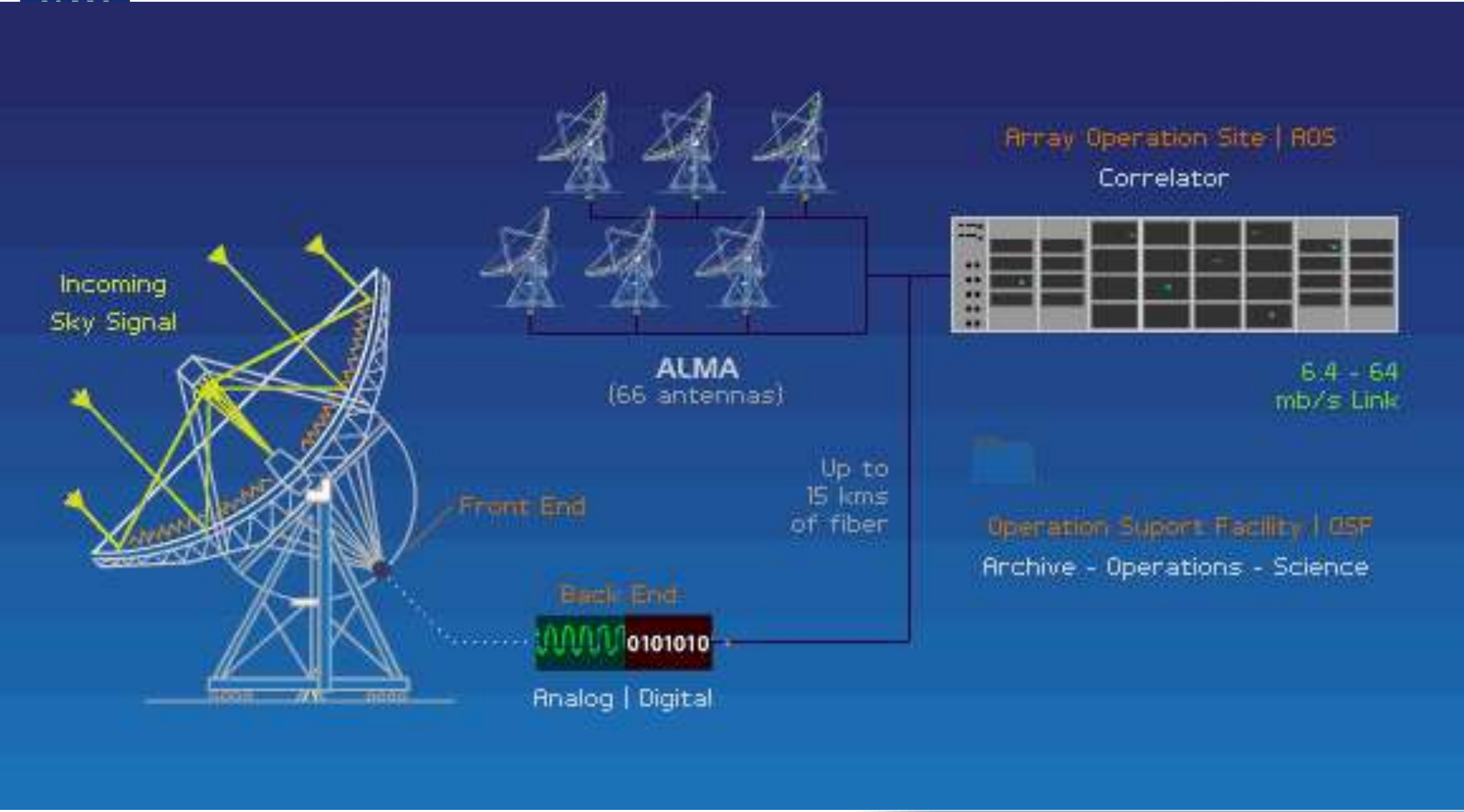
All the different parts have to work together !!



What is ALMA Front end?

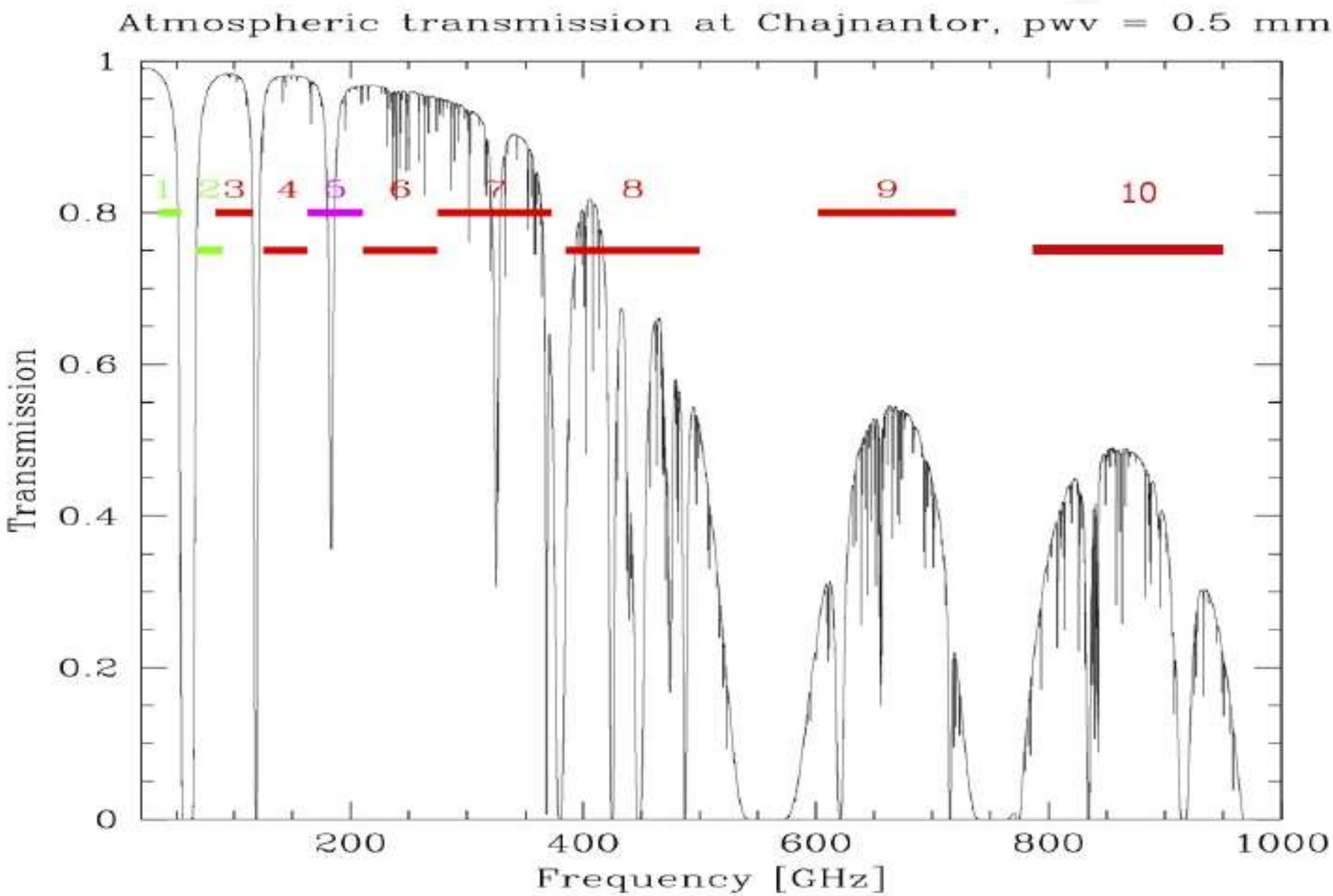
Antenna:
Receive radio wave from astronomical objects

Receiver (Front End):
Amplification and/or frequency down conversion

Correlator (Back End):
Detection
Spectral analysis
Correlation

ALMA ten receiver bands

- The receiver bands are shown in red superimposed on a zenith atmospheric transparency plot at the AOS for 0.5 mm of precipitable water vapor (PWV).

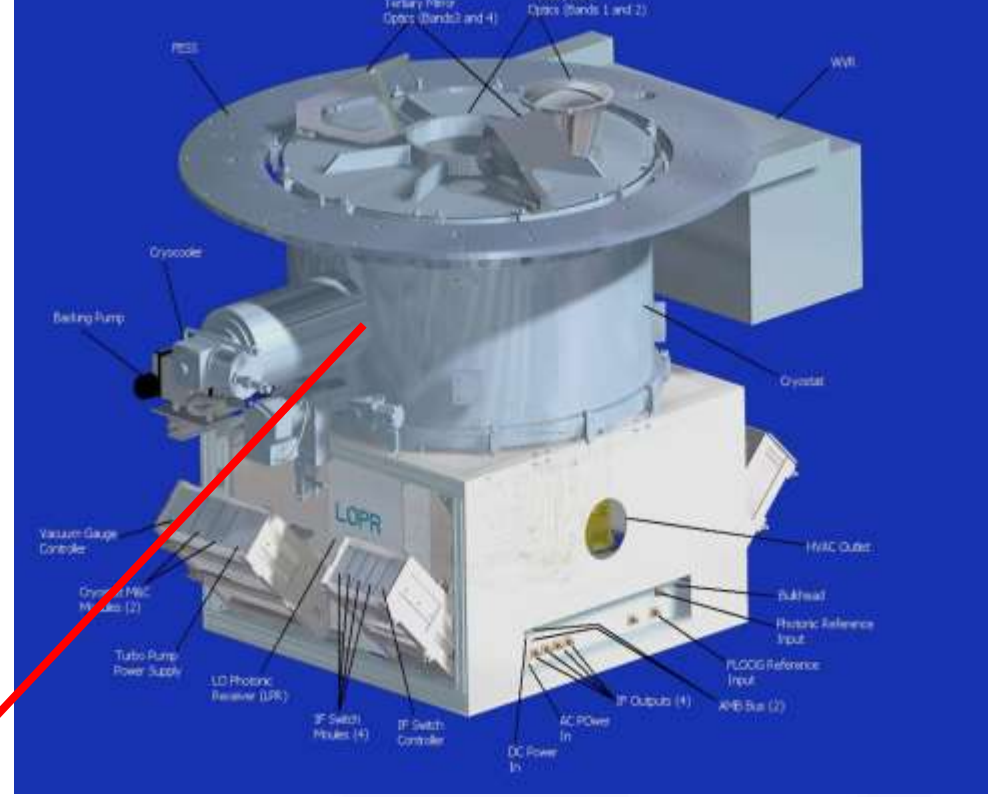


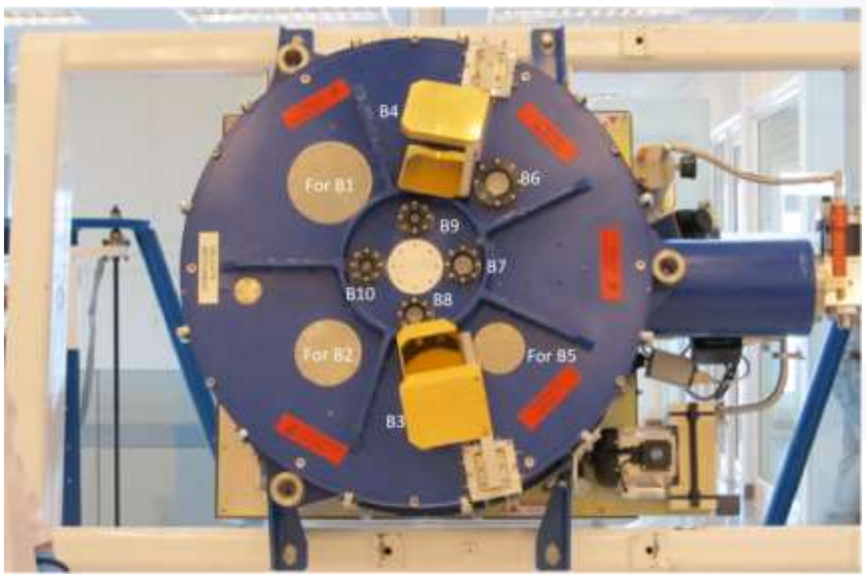
ALMA Receiver Cartridge Specifications

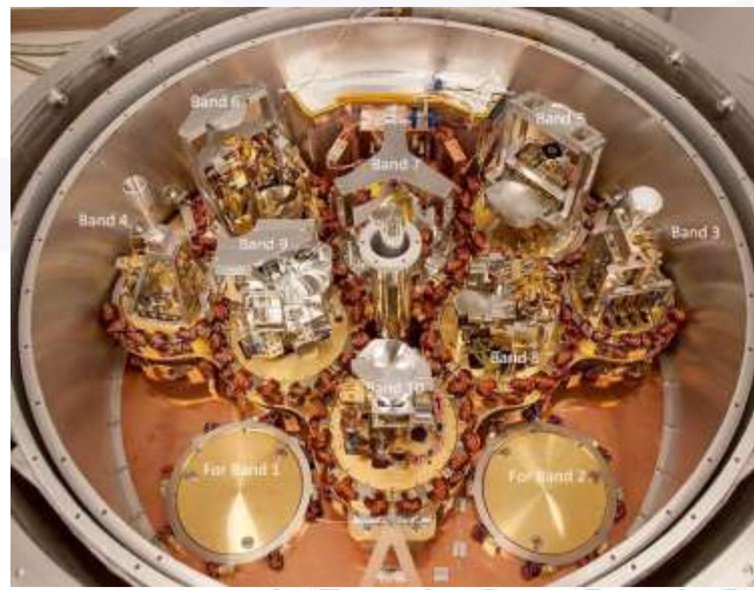
Band	Freq (GHz)	IF range (GHz)	Sideband Mode	Receiver Technology	Trx over 80% of band (K)	Trx at any frequency (K)	Responsible Organization
1	35–50	4–12	USB	HEMT	25	32	ASIAA
2	67–90	4–12	LSB	HEMT	30	47	TBD
3	84–116	4–8	2SB	SIS	< 39K at 104GHz	43	HIA
4	125–163	4–8	2SB	SIS	51	82	NAOJ
5	163–211	4–8	2SB	SIS	55	75	GARD NOVA
6	211–275	5–10	2SB	SIS	83	136	NRAO
7	275–373	4–8	2SB	SIS	147	219	IRAM
8	385–500	4–8	2SB	SIS	196	292	NAOJ
9	602–720	4–12	DSB	SIS	175	261	NOVA
10	787–950	4–12	DSB	SIS	230[2]	344	NAOJ

ALMA FE System

- The ALMA Front End system is a low-noise cryogenically-cooled 10-band receiver from 30 GHz to 950 GHz in one cryostat

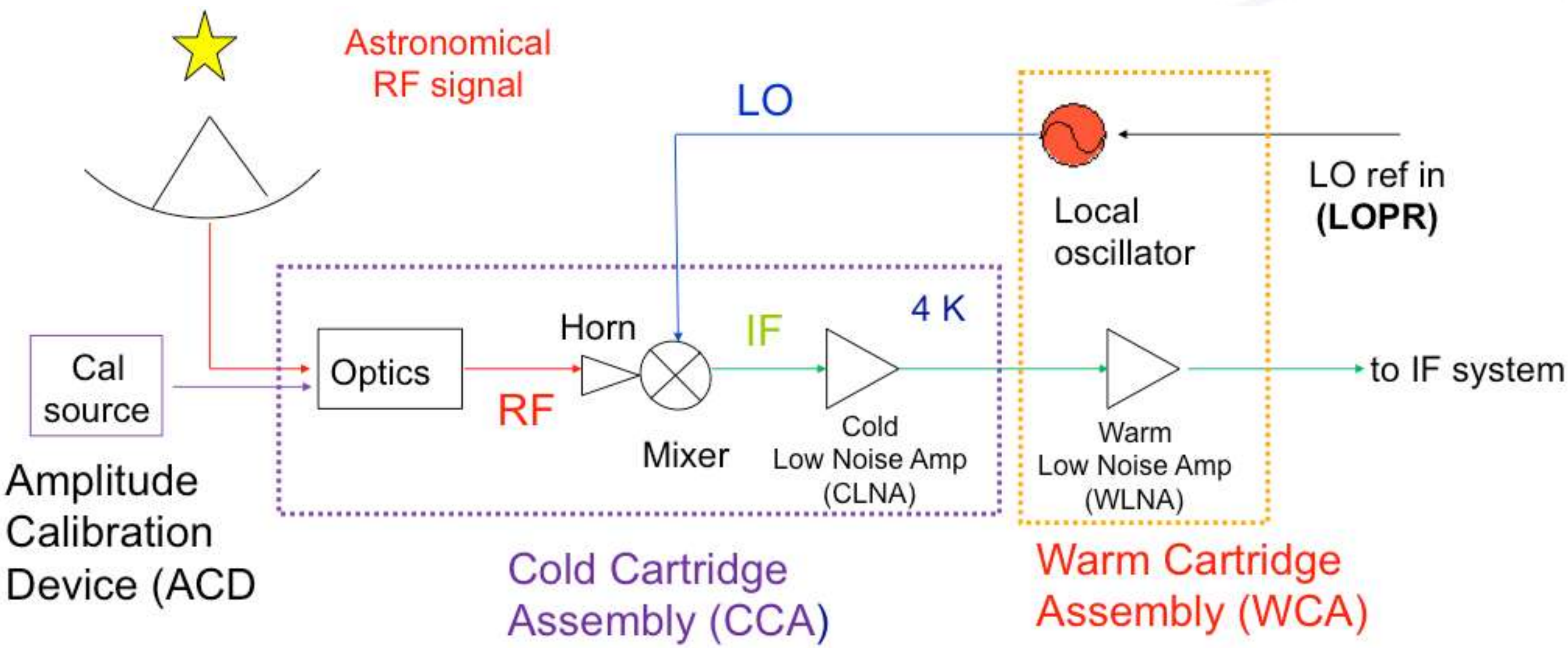






Block diagram of ALMA receiver

- Simplified block diagram of an ALMA receiver based on SIS mixers (bands 3–10)

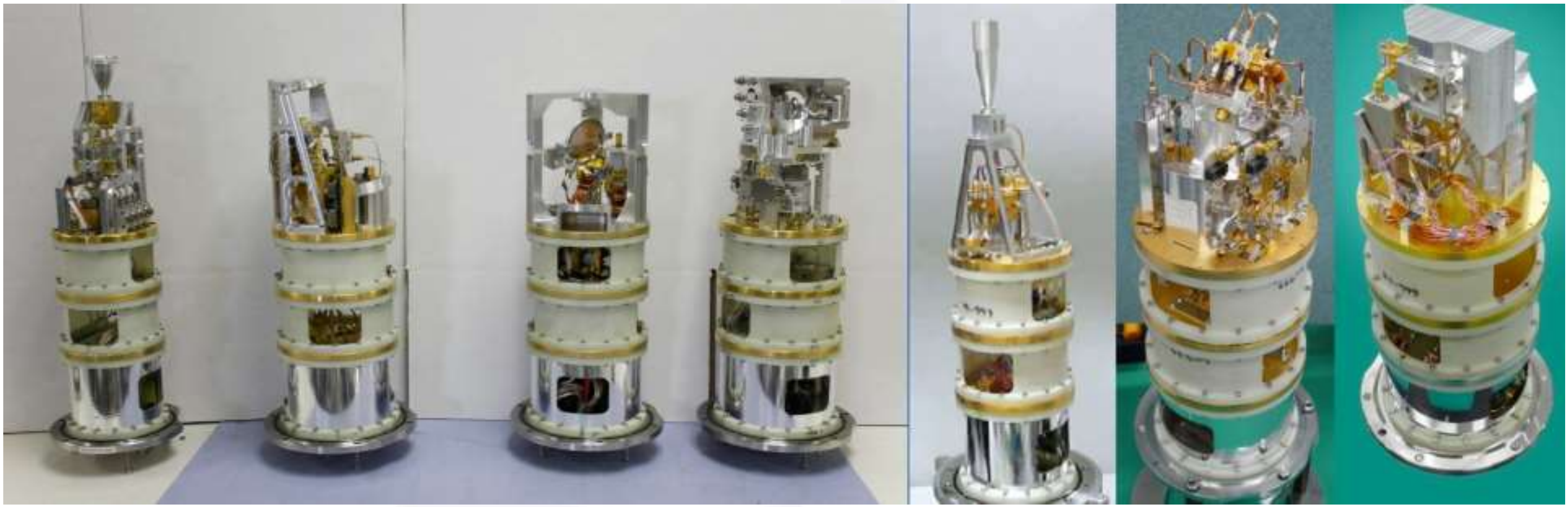


- Optics
- Mixer
- Local Oscillator (LO)
- Calibration source

- IF amplifier(s)
- Dewar and cryogenics
- Bias electronics
- Spectrometer(s)

ALMA Current Receiver Cartridges

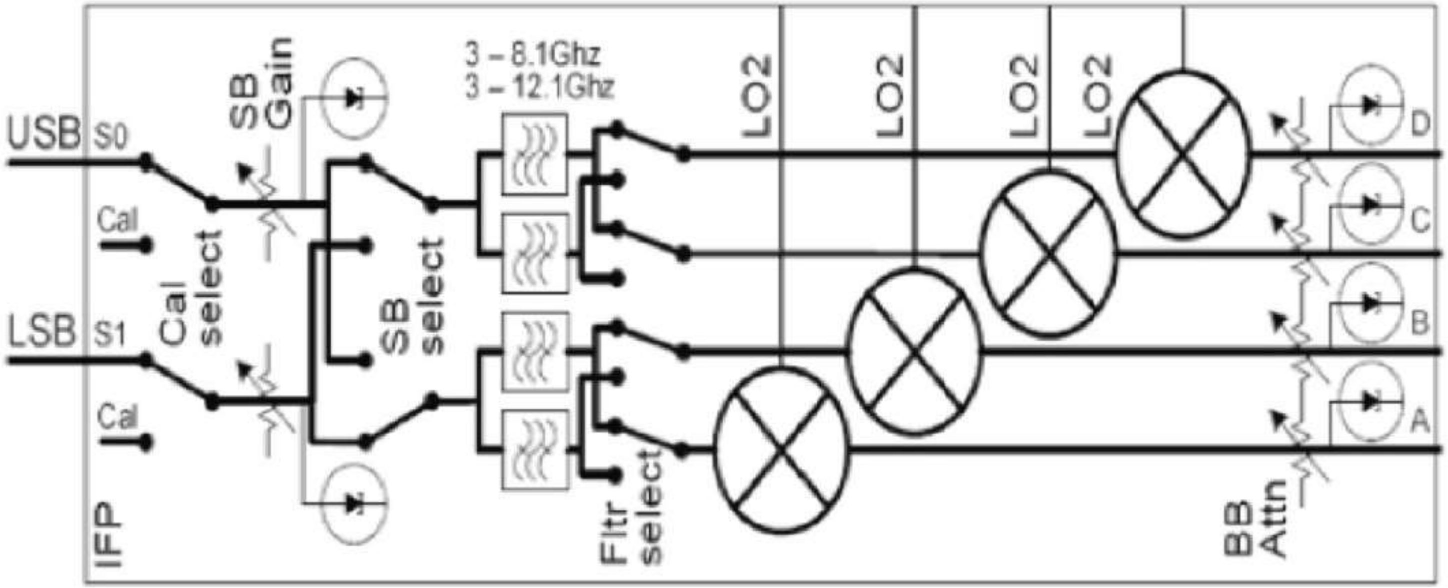
- The ALMA construction project initially defined seven bands: Band 3, 4, 6, 7, 8, 9 and 10 as high priority.
- The corresponding receivers were developed and built by different groups within the ALMA Project.



Band 3 HIA | Band 6 NRAO | Band 7 IRAM | Band 9 NOVA | Band 4 NAOJ | Band 8 NAOJ | Band 10 NAOJ

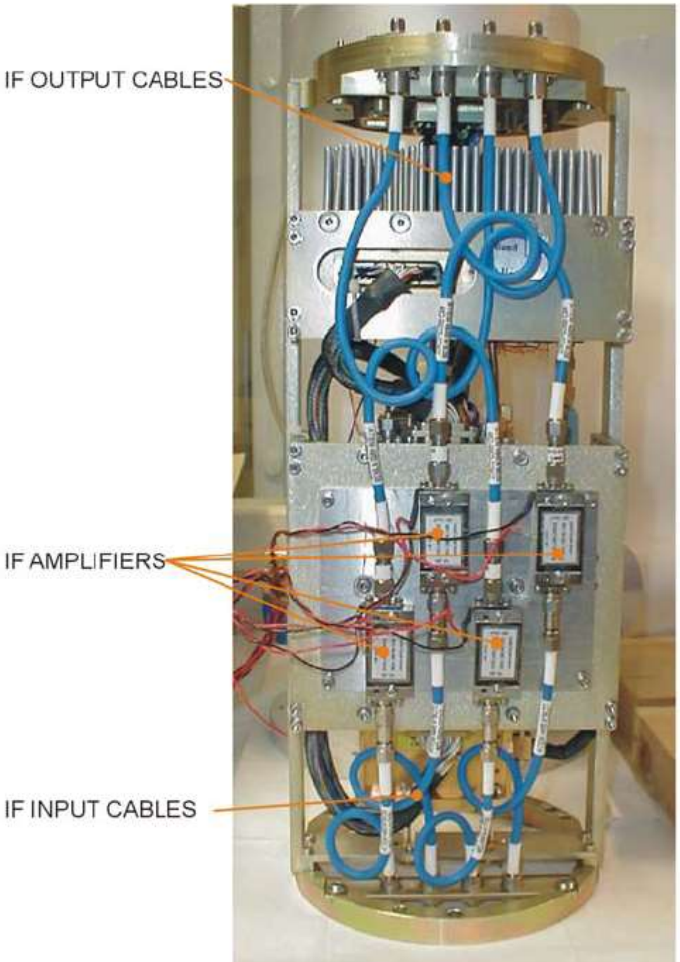
Intermediate Frequency System

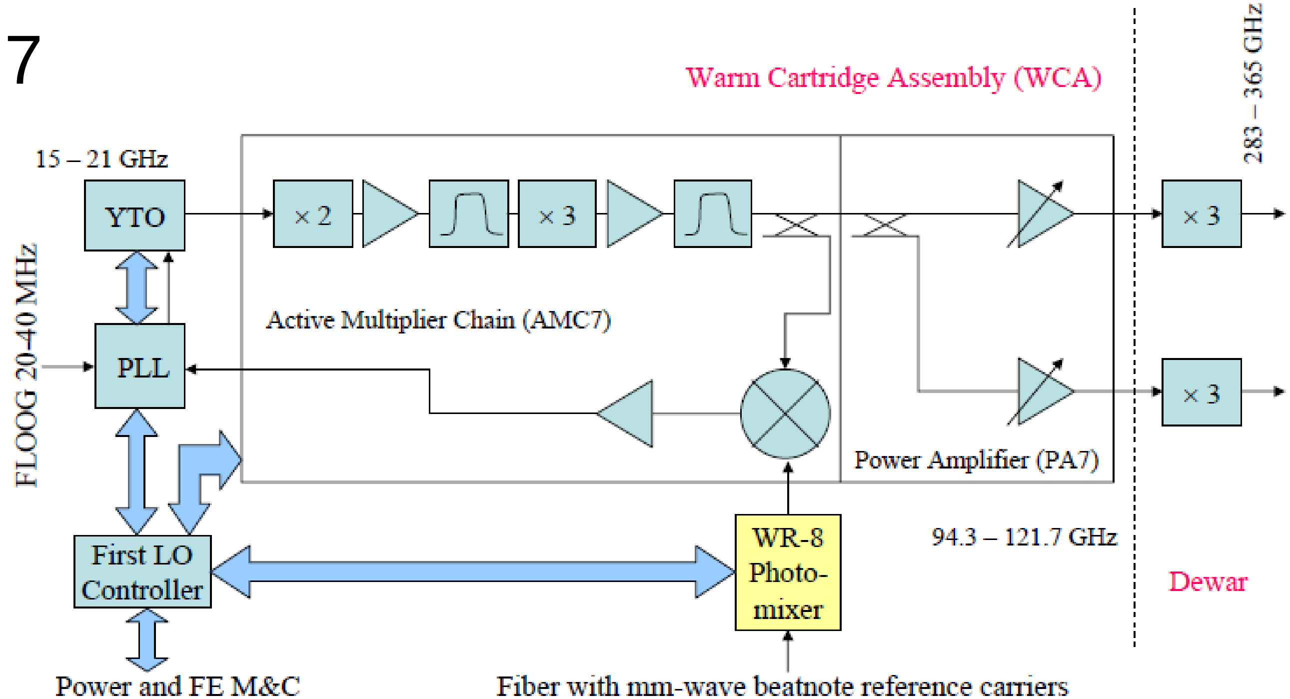
- Block diagram of one polarization channel of the ALMA IF Processor (IFP).
- The IFP has two IF inputs (at left), and feeds 4 IF outputs to the digitizers (to the right of the diagram).

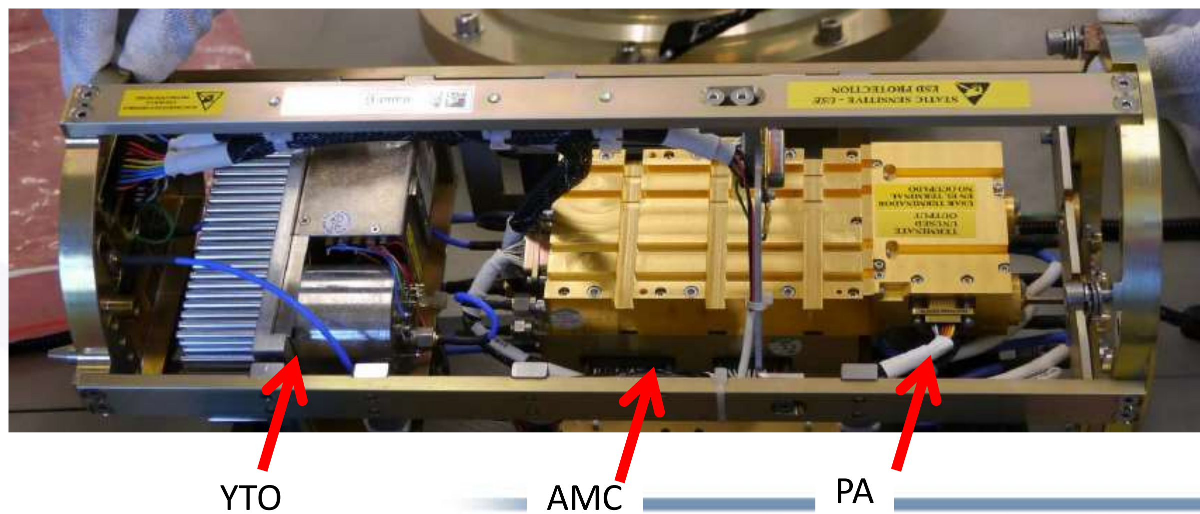


Local Oscillator Systems

- Example: Band 7

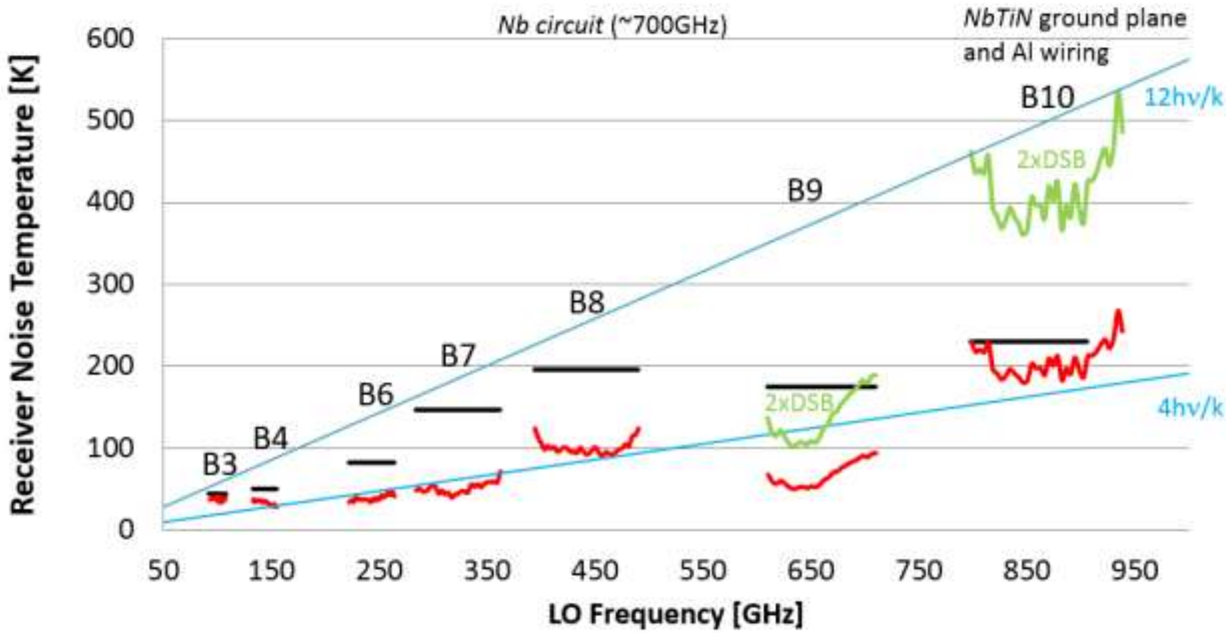




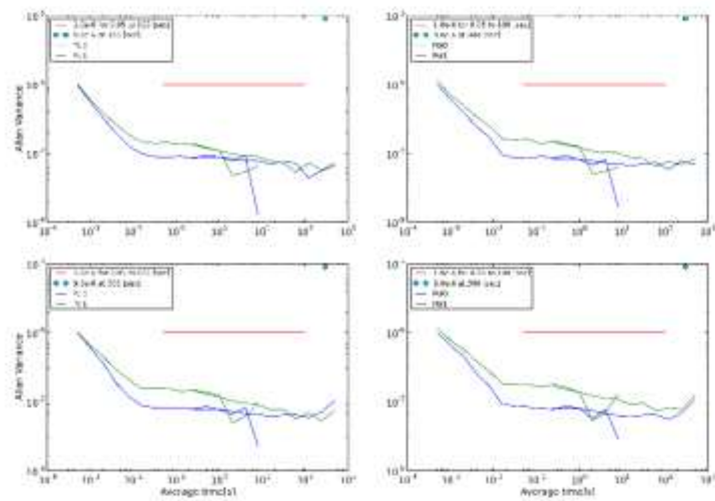


Receiver performances

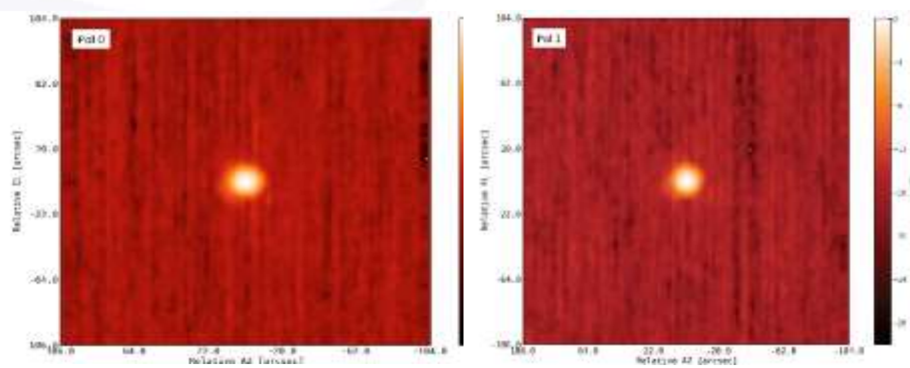
Measure receiver noise temperatures on an ALMA antenna (B3-B8: SSB, B9 & B10: DSB)

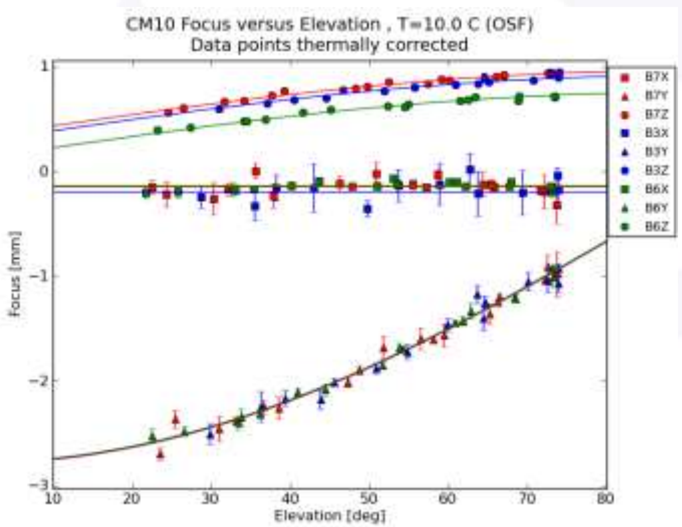


Total power Stabilities (Band 10)



Band 10 Beam-maps of Mars with an EA12-m antenna at 806 GHz for Polarization 0 (left) and Polarization 1 (right).





Focus curve for ACA 7-m antenna as a function of elevation :

X axis. Triangles: Y axis. Circles: Z axis. Red: B7. Green: B6. Blue: B3

ALMA Frontend Future Developments

ALMA Development Program

ALMA has already produced many impressive and scientifically compelling results as the largest mm/submm interferometer in the world. ALMA still has some scientific weak points, mainly due to limited FOV, bandwidth, and spatial resolution. upgrades and developments are essential.

<u>ASAC Recommendations for ALMA 2030</u>

- Finish the Scope of ALMA (B1, B2, and B5 receivers, VLB capability)

<u>Recommended development paths (ASAC)</u>

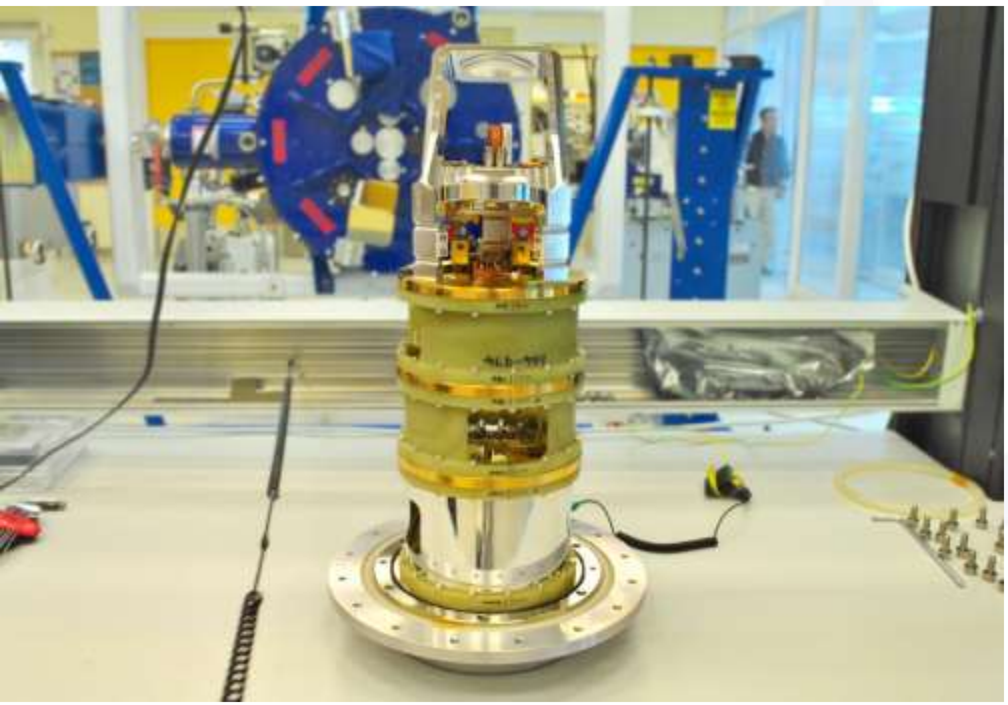
1) implementation of larger bandwidths and better sensitivity receivers
2) realization of longer baselines
3) improvements in the wide field mapping capabilities
4) Increasing wide field mapping speed: enabling efficient mapping

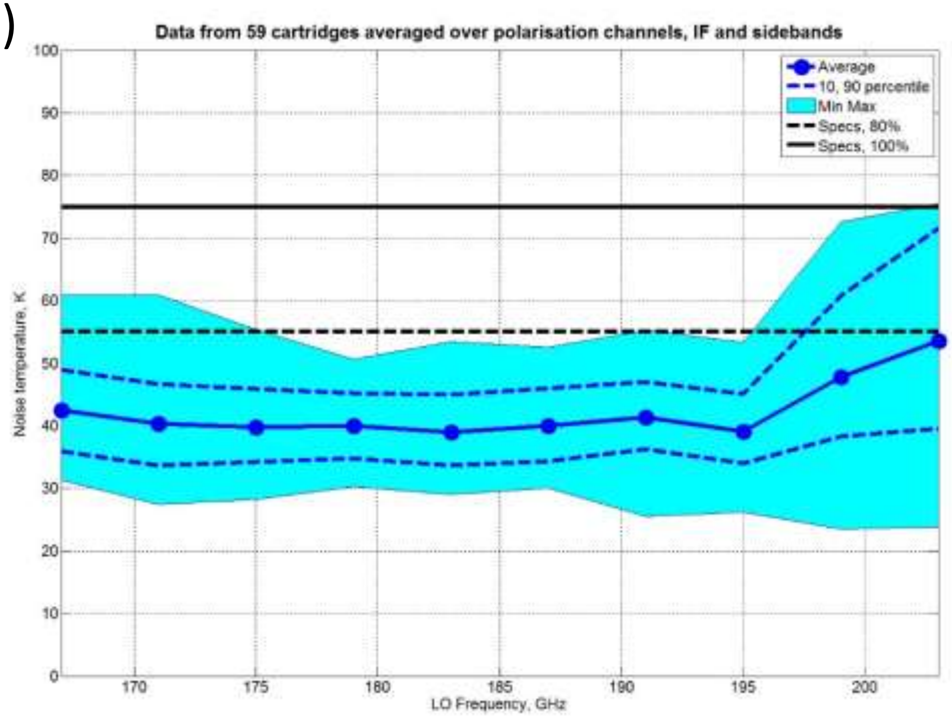
<u>Development program consists of:</u>

- Execution of *short term* (few – 5 year) projects
- Planning and initial studies for *longer term* (10 – 20 years) developments that are essential for future upgrades

Ongoing ALMA Frontend Receiver Project: Band 5 (163-211 GHz)

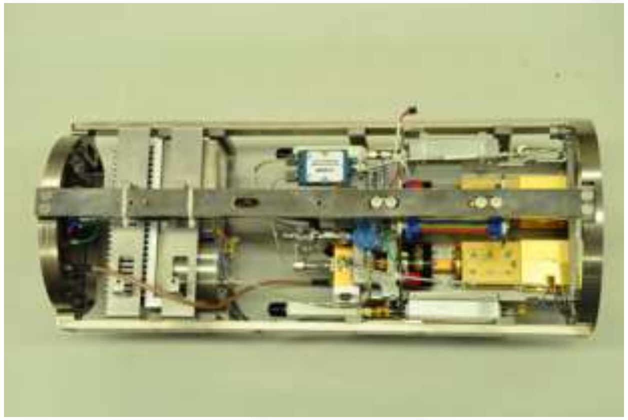
- EU project
- Built by a consortium of GARD and NOVA (cold cartridge) and NRAO (warm cartridge)
- Noise specifications improved and LO tuning range extended.
- SV results and data released (Humphreys et al.)
- Offered in Cycle 5



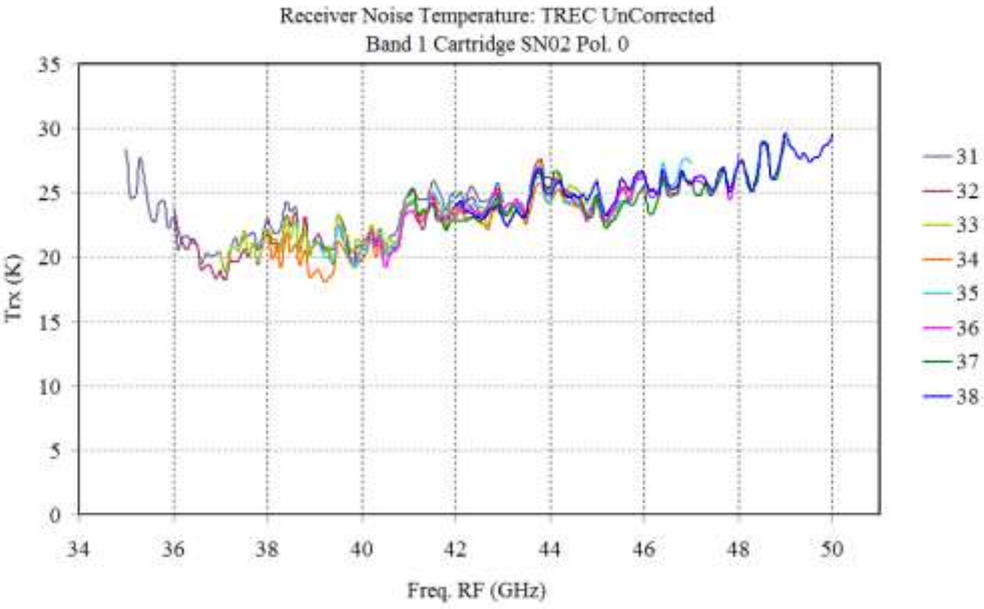


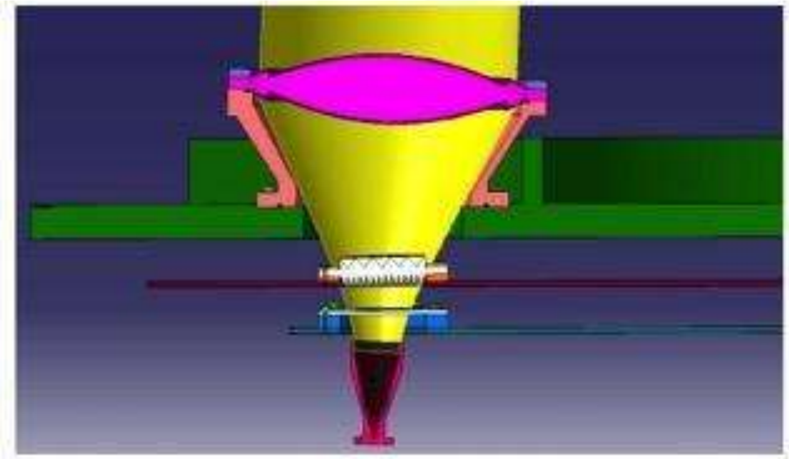
Ongoing ALMA Frontend Receiver Project: Band 1 (35-50 GHz)

- EA project (lead: ASIAA, Collaboration: NAOJ, U of Chile, NRAO, HIA)
- CDR and project review were held on Jan 19-20, 2016 at ASIAA in Taiwan
- Band 1 LO Critical Design and Manufacture Review (CDMR) was done with success on December 12th 2016.
- Manufacturing Readiness Review will be held in 2017.

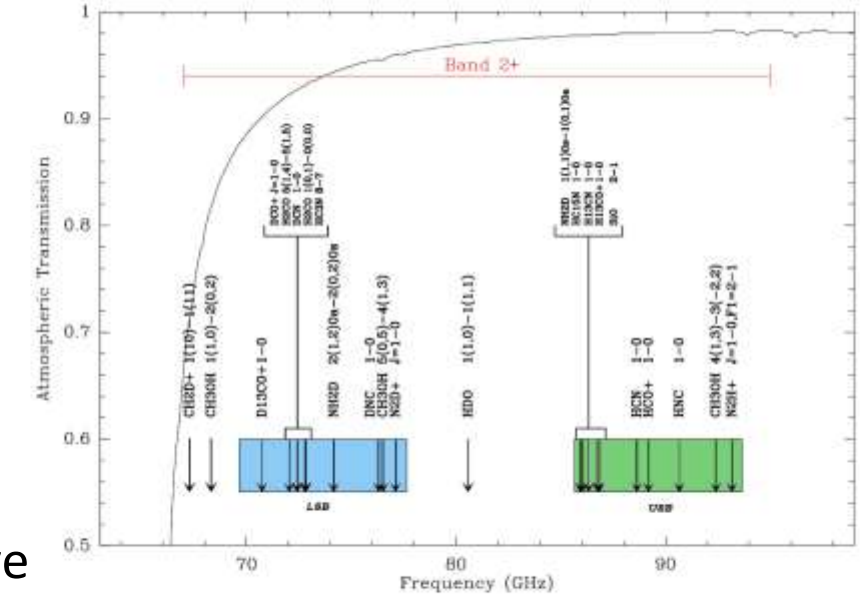


Noise temperature < 28.0 K for 35.5 – 48.5 GHz (> 80% Bandwidth)
Noise Temperature < 30.0 K for full band (specification < 32 K)





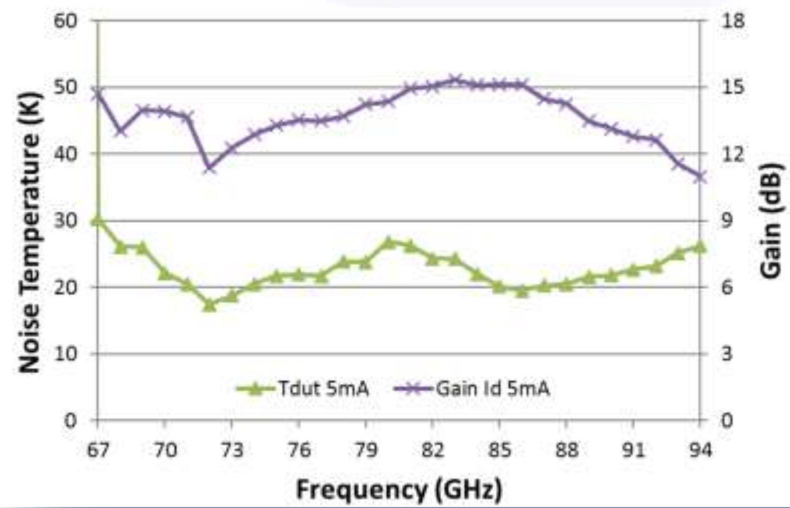
NA Frontend related Developments/Studies



- Receiver
  - ALMA Band 2+ (NRAO and NAOJ):
    - Passed PDR May
    - *Currently suspended*
  - B3 upgrade to deliver improved Total Powe stability

More info. - J13-4: SUSTAINING SUBMILLIMETER SCIENCE: NEW DEVELOPMENT this conference

B2+ CRAL LNA performance (Kangaslahti et al. 2017)



- Correlator Upgrade

More info. - J2-1 UPGRADE TO THE 64-ANTENNA ALMA CORRELATOR

- ALMA Phasing Project

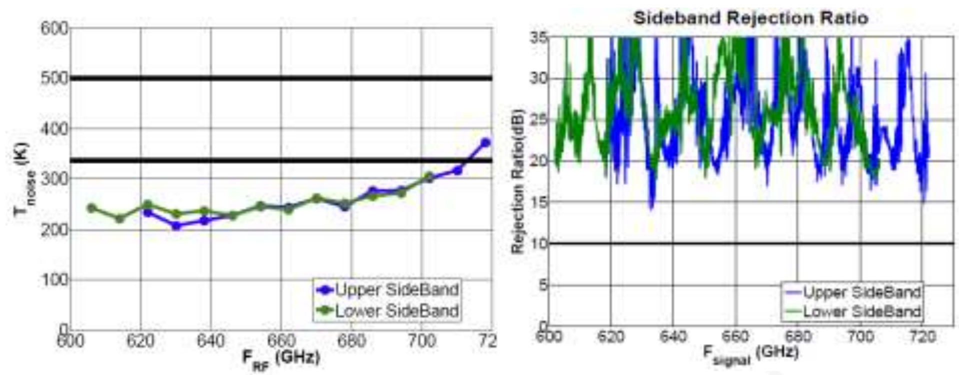
More info. - J26-1:MILLIMETER VLBI WITH PHASED ALMA

EU Frontend related Developments/Studies

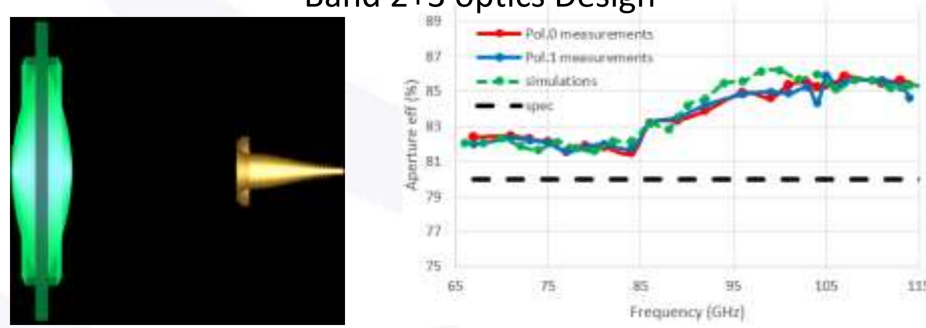
- SIS Junction Development (GARD, V. Belitsky)
- Band 2+3 (ESO, INAF, UManc, NAOJ, RAL, UChile): PDR will be held in Nov 2017
  - Passive Optical Components (lens, feed-horn, OMT)
  - InP MMIC LNAs for ALMA Band 2+3
  - Band 2+3 Prototype (internal; ongoing)
- Digitization and Digital Signal Processing (U. Bordeaux, A. Baudry,)

  More info. - J2-4: DIGITIZATION AND DIGITAL FILTERING FOR 16 GHZ ON-SKY BANDWIDTH ANALYSIS WITH ALMA
- Digital ALMA Front End
  - Digital sideband separation (NOVA, Chile Univ.)
- 2SB upgrade for Band 9 (NOVA, A. Baryshev)
  - Implementation Plan for 2SB, 4-12GHz IF upgrade

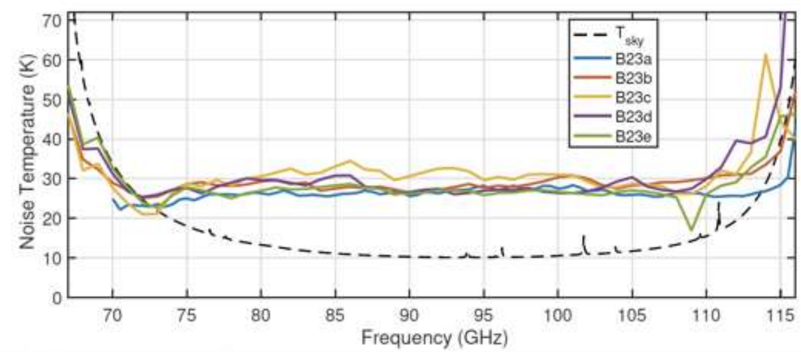
Band 9 2SB achieved performance



Band 2+3 optics Design



B2+3 LNA performance (Cuadro-Calle et al. 2017)

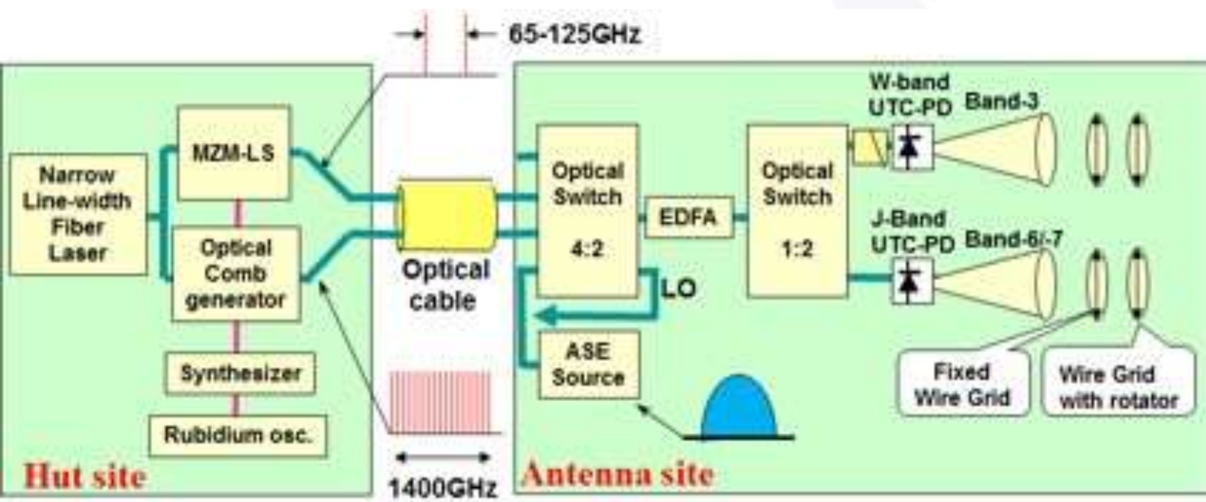


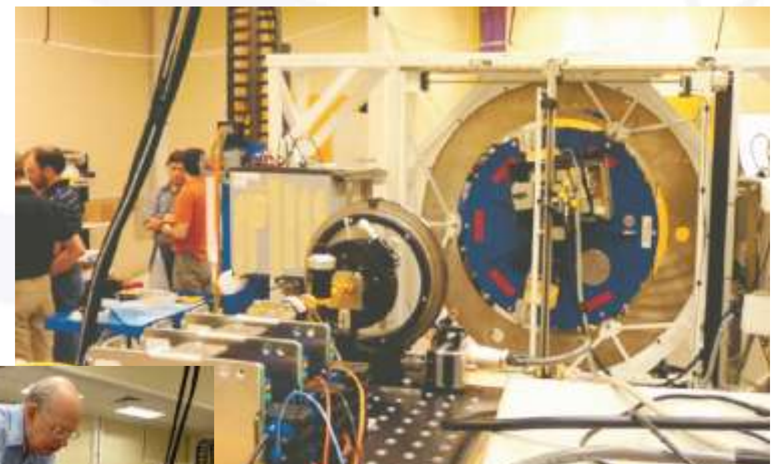
EA Frontend related Developments/Studies

- Studies & Small Projects
  - ALMA Calibration Source
    - Calibration at bands 3,6,7
  - High Critical Current Density (Jc) SIS Junction Device Development (including Wideband RF/IF and THz devices)
  - GPU Spectrometer for ACA Total Power array (with KASI)
    - Supplements the ACA correlator
- ASTE development project (but extendable to ALMA)
  - Multi-beam receiver (with KASI)

Photonic Reference Signal and Artificial Calibration Source

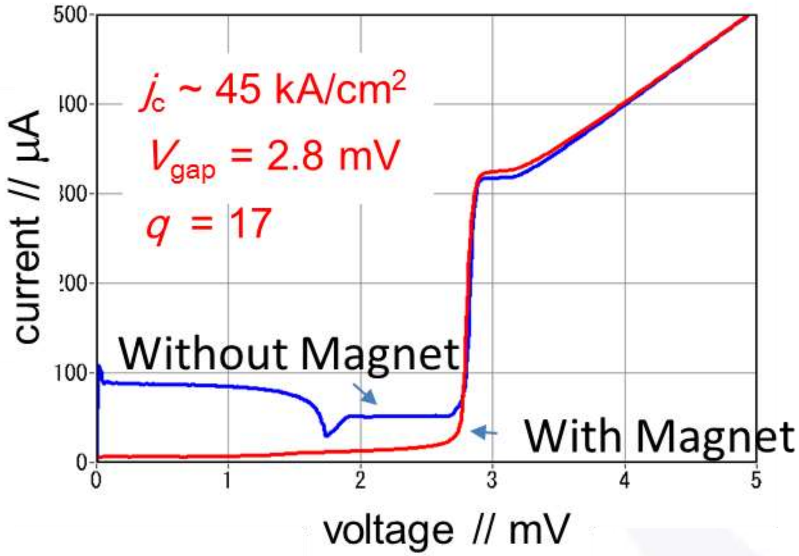
- For a longer baseline such as ALMA Extended Array (~300 km), there is a need for the photonic highly-stable signal generation and distribution system.
- A photonic millimeter-wave generator and a photonic transmission signal phase stabilizer has been developed by H. Kiuchi in collaboration with NICT.
- An Artificial Calibration Source (ACS) for ALMA antennas in collaboration with JAO.
- The ACS with Band 3 frequency range has been delivered to JAO. This ACS for Band 6 and 7 is ongoing and will be delivered to JAO by 2018.

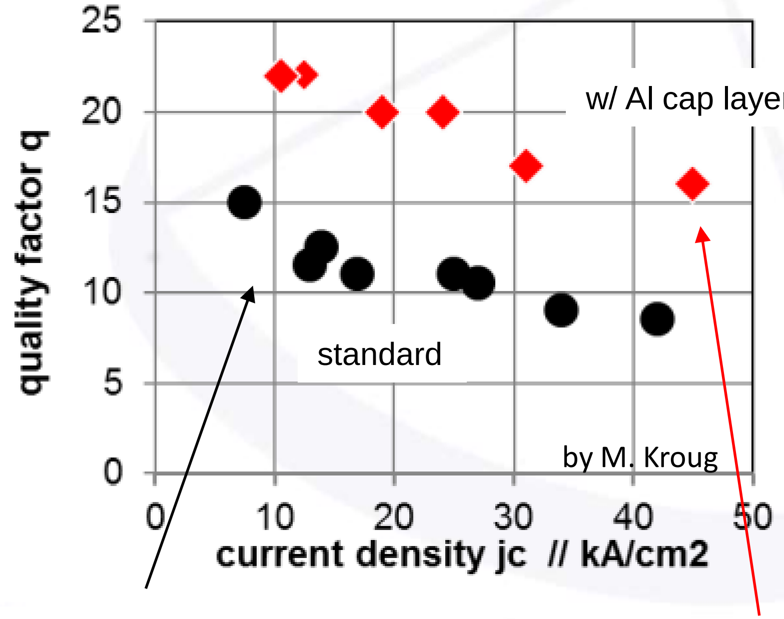




ACS acceptance at OSF

High Critical Current Density (J_c) Nb Junction at NAOJ





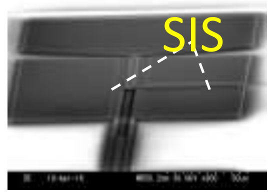
◆Conventional
Nb/Al/AlOx/Nb
(Band 4, 8, 10)

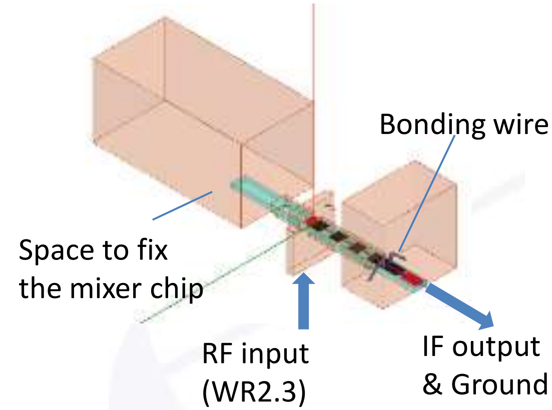
◆ Nb/Al/AlNx/Nb
High Jc + moderate quality factor

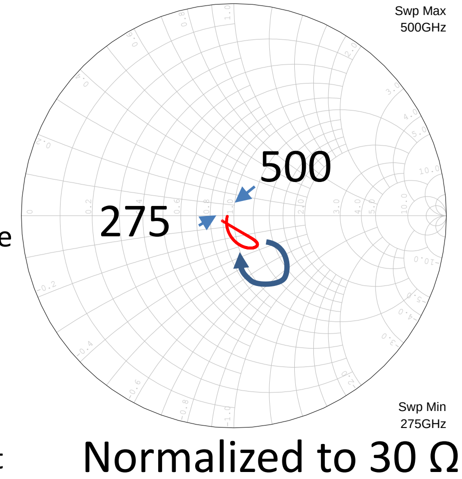
◆ Nb/Al/AlNx/Al/Nb
High Jc + low leakage

Ultra wideband RF receiver

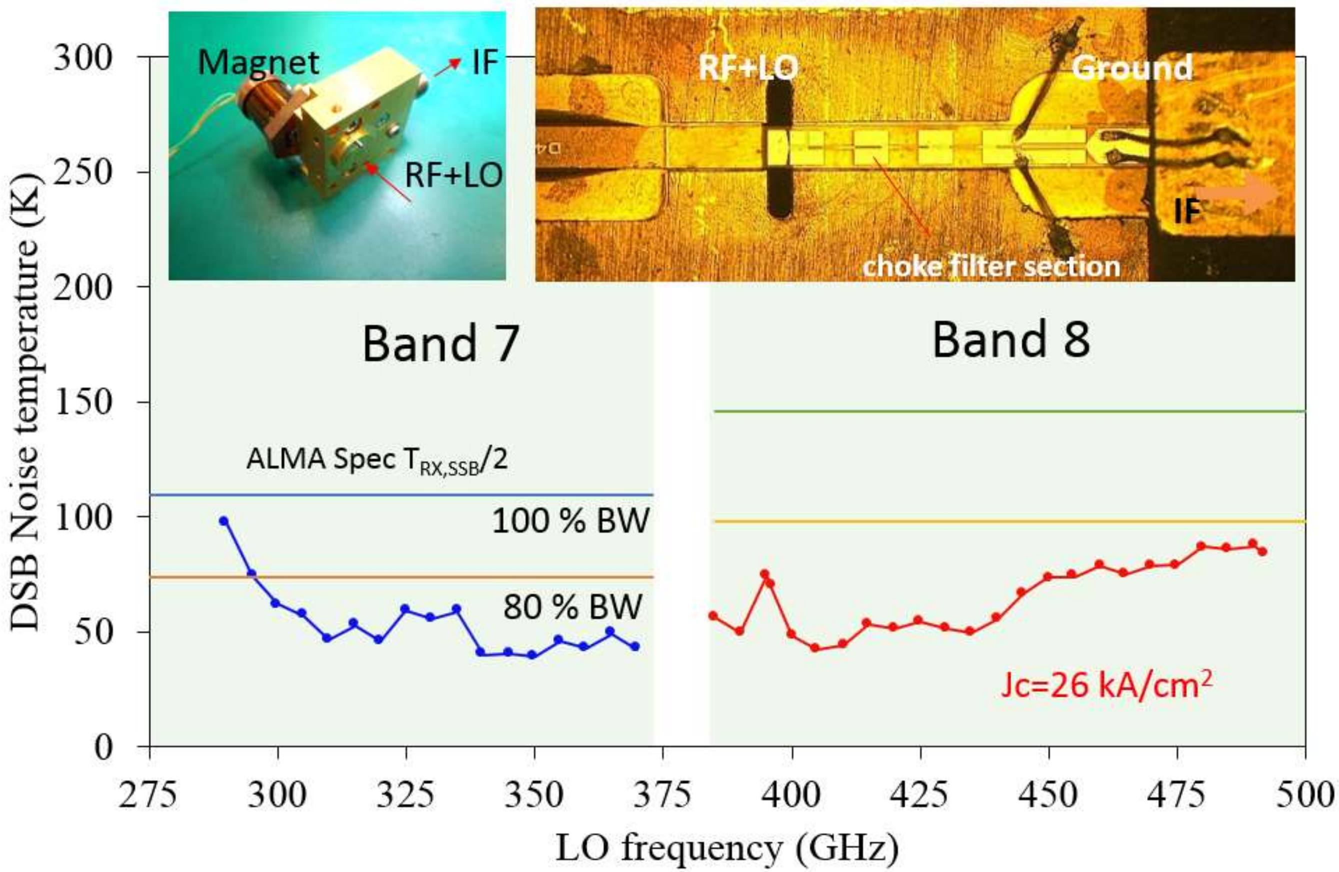
Thanks to
High Jc SIS Junction



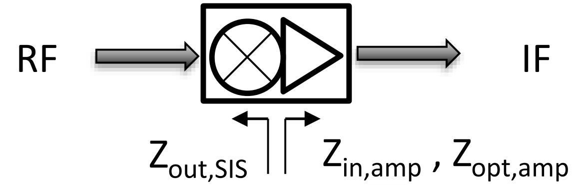




Low noise and wideband "RF" performance was demonstrated.



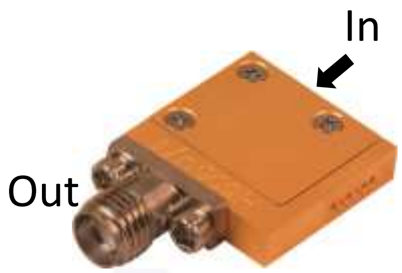
- Not optimization yet in terms of design.
- Need to be investigated for the receiver with high Jc junctions



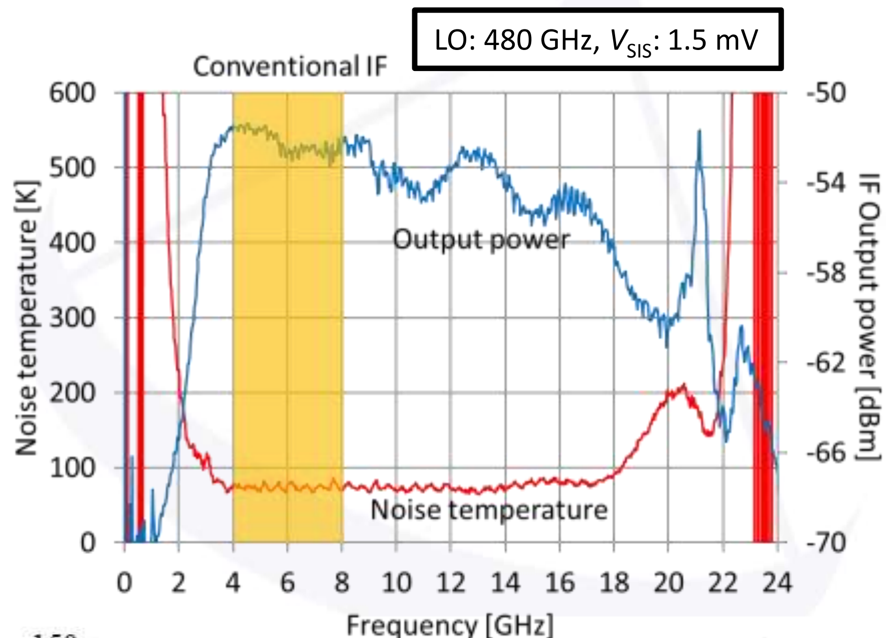
Ultra wideband IF receiver

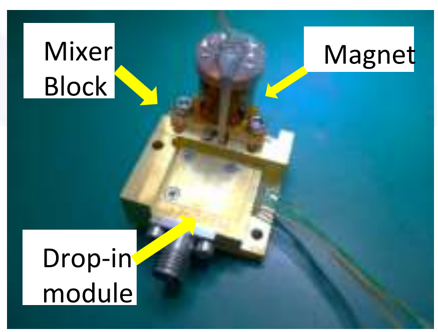
Thanks to High Jc SIS Junction

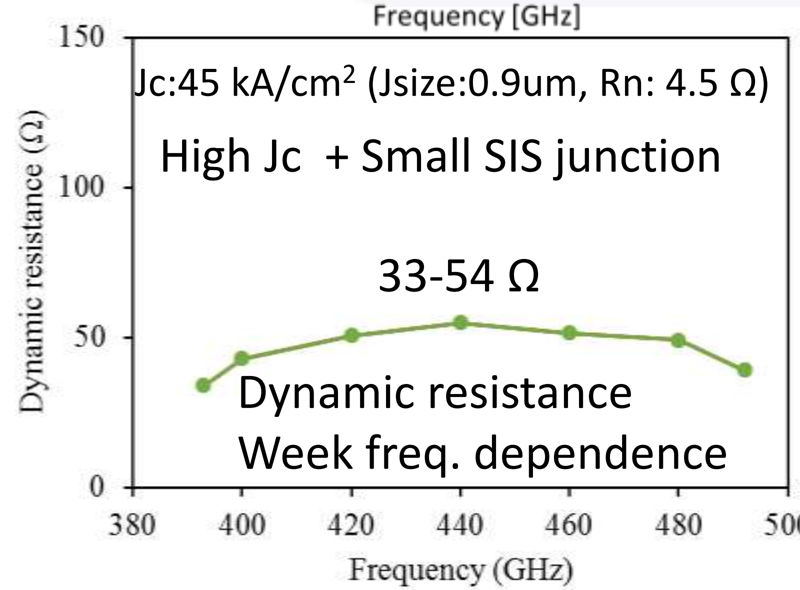
- Ultra wideband receiver
  - Low noise and wideband "**IF**" performance have been demonstrated
  - High Jc and small size SIS junction allows to keep almost constant SIS dynamic resistance and achieved good impedance matching entire Band 8 RF bands



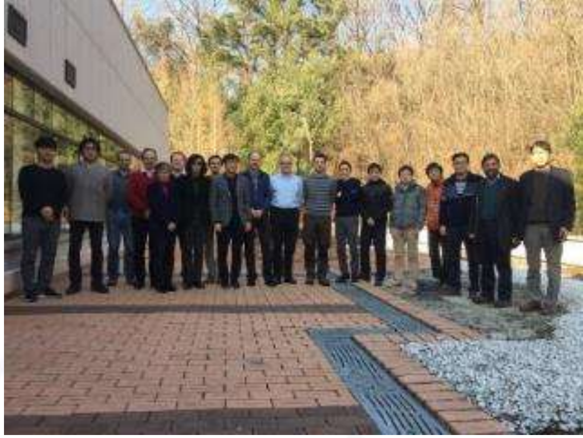
Low noise factory (Sweden)
3-21 GHz drop-in module



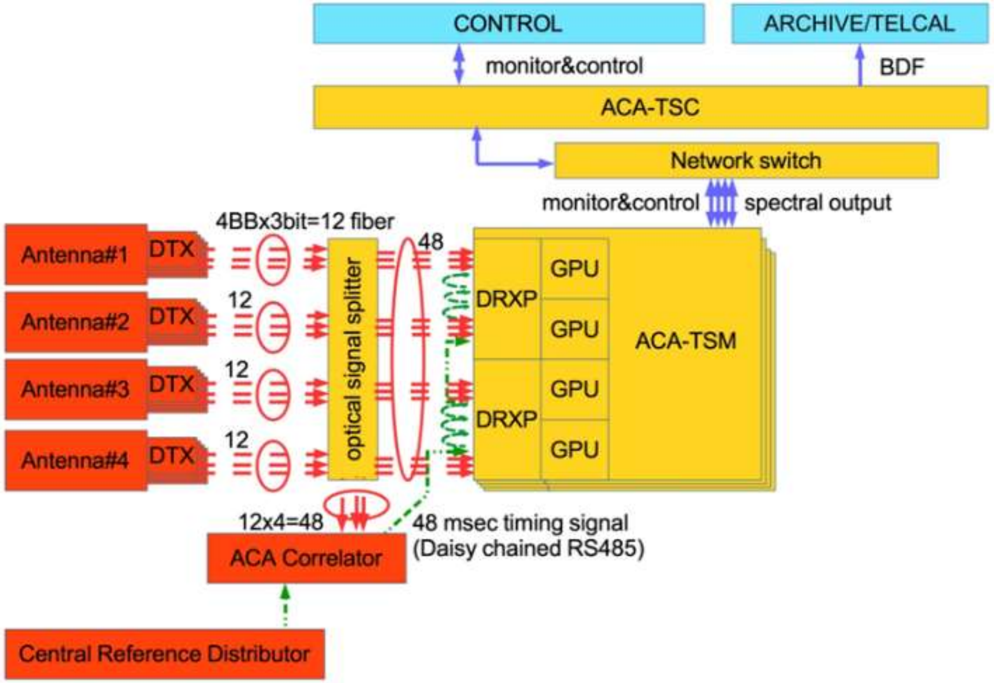




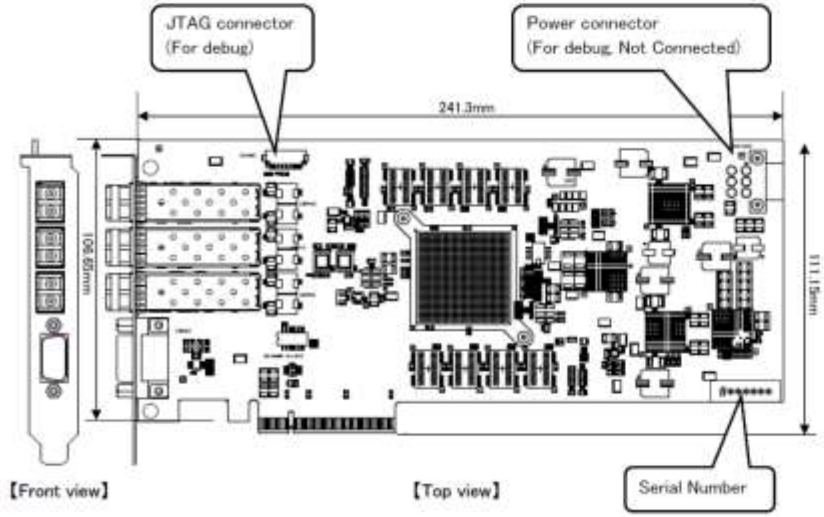
ACA Spectrometer



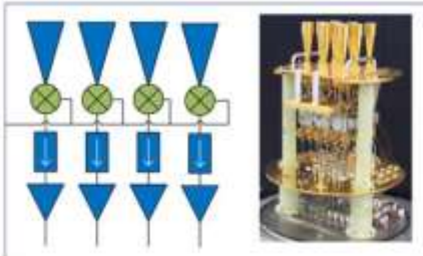
- PDR on Feb 20-22, 2017 (KASI, Korea)
  - ✓ Successfully passed
- ASAC review on the scientific/technical justification (Mar 16-17, 2017)
  - ✓ ASAC recommends that the TP spectrometer project is carried out.
- ALMA Board meeting on Apr 19-21, 2017
  - ✓ The Board decided to kick off the written procedure for all the Approvals

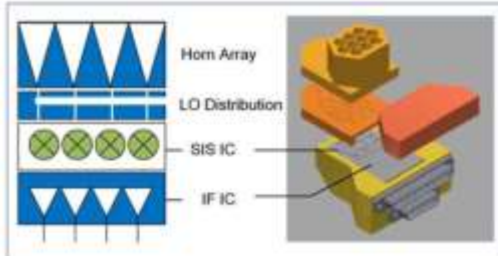


DRXP
(data acquisition card based on PCI-E bus)

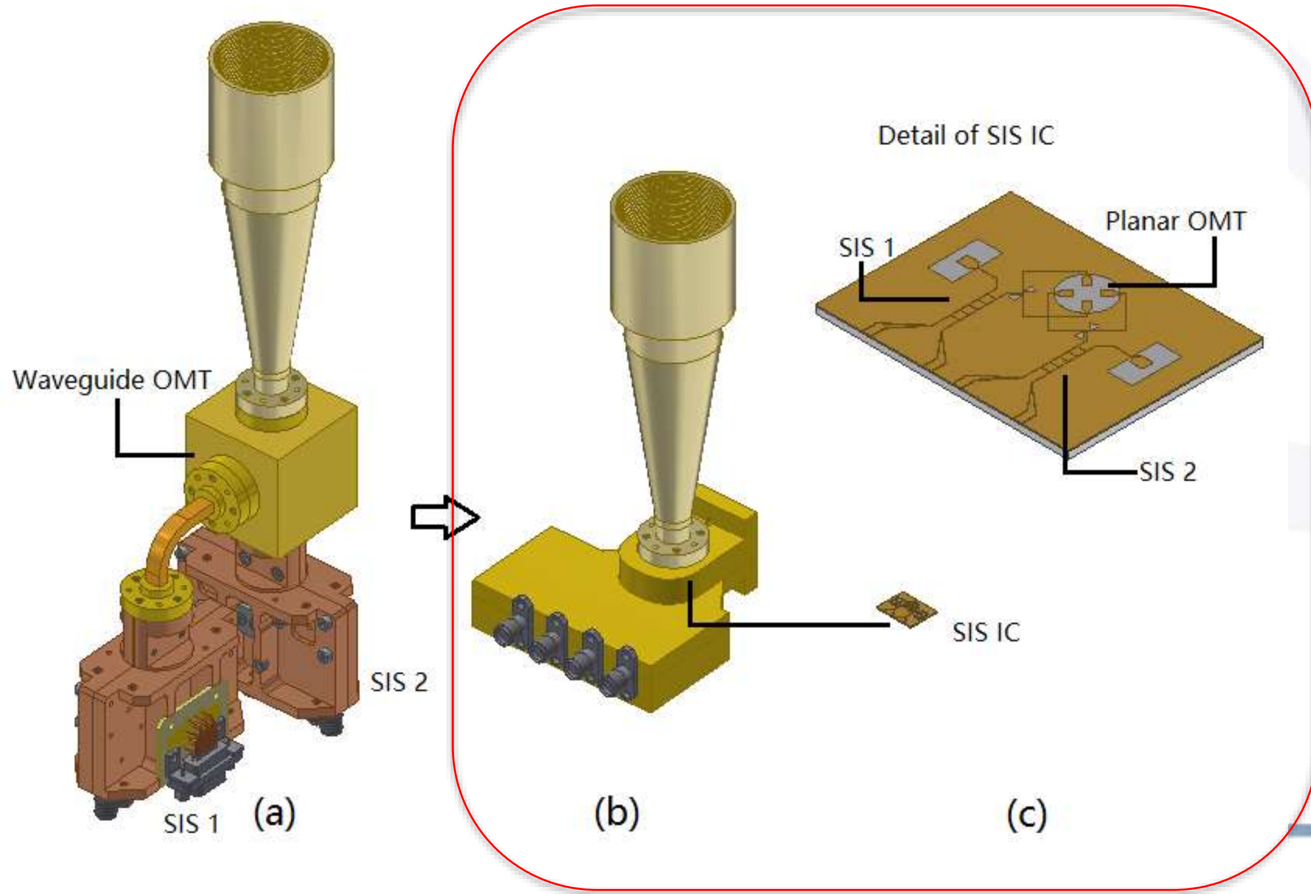


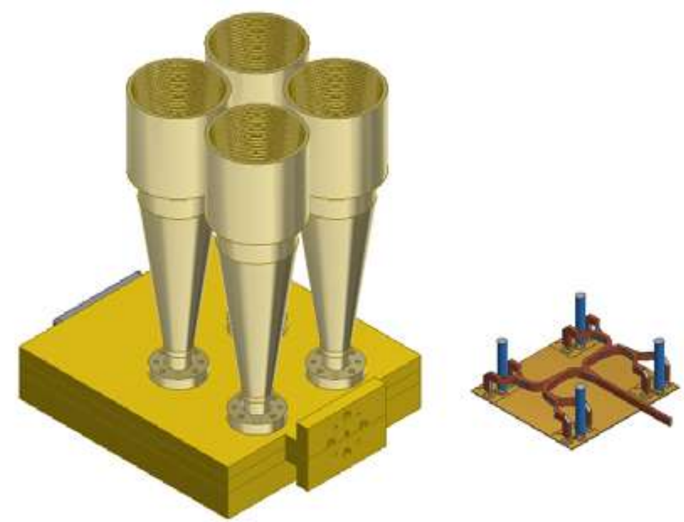
NAOJ Multi Beam Receiver Initial Study





The goal of NAOJ: From the conventional way (left) to a new way (right).





The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of ESO (representing its members states), NSF (USA) and NINS (Japan), together with NRC (Canada), NSC and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under the cooperative agreement by Associated Universities Inc. We than all those who have contributed to making the ALMA project possible.