Overview of the Current ALMA Frontend and Its Future Developments

Shin’ichiro Asayama
Nicholas D. Whyborn
All the different parts have to work together!!
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

<table>
<thead>
<tr>
<th>Band</th>
<th>Freq (GHz)</th>
<th>IF range (GHz)</th>
<th>Sideband Mode</th>
<th>Receiver Technology</th>
<th>Trx over 80% of band (K)</th>
<th>Trx at any frequency (K)</th>
<th>Responsible Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35–50</td>
<td>4–12</td>
<td>USB</td>
<td>HEMT</td>
<td>25</td>
<td>32</td>
<td>ASIAA</td>
</tr>
<tr>
<td>2</td>
<td>67–90</td>
<td>4–12</td>
<td>LSB</td>
<td>HEMT</td>
<td>30</td>
<td>47</td>
<td>TBD</td>
</tr>
<tr>
<td>3</td>
<td>84–116</td>
<td>4–8</td>
<td>2SB</td>
<td>SIS</td>
<td>&lt; 39K at 104GHz</td>
<td>43</td>
<td>HIA</td>
</tr>
<tr>
<td>4</td>
<td>125–163</td>
<td>4–8</td>
<td>2SB</td>
<td>SIS</td>
<td>51</td>
<td>82</td>
<td>NAOJ</td>
</tr>
<tr>
<td>5</td>
<td>163–211</td>
<td>4–8</td>
<td>2SB</td>
<td>SIS</td>
<td>55</td>
<td>75</td>
<td>GARD NOVA</td>
</tr>
<tr>
<td>6</td>
<td>211–275</td>
<td>5–10</td>
<td>2SB</td>
<td>SIS</td>
<td>83</td>
<td>136</td>
<td>NRAO</td>
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<tr>
<td>7</td>
<td>275–373</td>
<td>4–8</td>
<td>2SB</td>
<td>SIS</td>
<td>147</td>
<td>219</td>
<td>IRAM</td>
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<tr>
<td>8</td>
<td>385–500</td>
<td>4–8</td>
<td>2SB</td>
<td>SIS</td>
<td>196</td>
<td>292</td>
<td>NAOJ</td>
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<tr>
<td>9</td>
<td>602–720</td>
<td>4–12</td>
<td>DSB</td>
<td>SIS</td>
<td>175</td>
<td>261</td>
<td>NOVA</td>
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<tr>
<td>10</td>
<td>787–950</td>
<td>4–12</td>
<td>DSB</td>
<td>SIS</td>
<td>230²</td>
<td>344</td>
<td>NAOJ</td>
</tr>
</tbody>
</table>
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 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.
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

- YTO
- AMC
- PA

15 - 21 GHz

First LO Controller

Power and FE M&C

Fiber with mm-wave beatnote reference carriers

Warm Cartridge Assembly (WCA)

Active Multiplier Chain (AMC7)

Power Amplifier (PA7)

94.3 - 121.7 GHz

Dewar

IF OUTPUT CABLES

IF AMPLIFIERS

IF INPUT CABLES
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:
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.

ASAC Recommendations for ALMA 2030

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

Recommended development paths (ASAC)

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

Development program consists of:

- 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.

Appendix A. Noise Temperature, Output Power and Spectrum 
S/N 02 cold cartridge Test Result

Test Condition: LO ... full band (specification < 32 K)

Note: CLNA 1st, 2nd stage drain current reduced to optimize the noise performance.

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 Power stability

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

• 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
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

$J_c \sim 45 \text{kA/cm}^2$

$V_{\text{gap}} = 2.8 \text{ mV}$

$q = 17$

Without Magnet

With Magnet

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

◆ Nb/Al/AlNx/Nb
  High $J_c$ + moderate quality factor

◆ Nb/Al/AlNx/Al/Nb
  High $J_c$ + low leakage

In Search of our Cosmic Origins
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.
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

**Conventional IF**

- **LO:** 480 GHz, **V_{SIS}** 1.5 mV

**High Jc + Small SIS junction**

- **Jc:** 45 kA/cm² (Jsize: 0.9um, Rn: 4.5 Ω)
- **Dynamic resistance**:
  - 33-54 Ω
  - Week freq. dependence
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)
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.