

ALMA Front Ends

Atacama Large Millimeter Array

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ESO-Wide Review 13-17 February 2003



Location of the FE Sub-System



EWR 13-17 Feb 2003



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Summary Allocation European ALMA Phase 1 FE Work Elements

ALMA Project

Work Element Name	ALMA WBS	Responsible Organization	
Development of Cryostat	4.080.0660	Rutherford Appleton Laboratory / UK	
Development of Receiver Common Optics, RF Windows & IR Filters	4.090.0720	Inst. de RA Millimétrique / France	
Band 7 Cartridge Development	4.170.1007	Inst. de RA Millimétrique / France Onsala Space Observatory / Sweden	
Band 9 Cartridge Development	4.190.1009	NOVA – Space Research Organization Netherlands / Netherlands	
Water Vapour Radiometer Development	4.210.1011	Cambridge Astrophysics / UK Onsala Space Observatory / Sweden	



Summary Allocation European ALMA Phase 1 NA Work Elements

Work Element Name	ALMA WBS	Responsible Organization
Design, production of ATF Receivers	4.075.0054	National Radio Astronomy Observatory Tucson / USA
Development FE Cartridge Support Electronics	4.100.0782	National Radio Astronomy Observatory Tucson / USA
Band 3 Cartridge Development	4.130.1003	Herzberg Inst. of Astrophysics / Canada
Band 6 Cartridge Development	4.160.1006	National Radio Astronomy Observatory Charlottesville / USA
Develop, prototype 1 st Local Oscillator	4.258.1100	•National Radio Astronomy Observatory Tucson / USA



Cryostat – RAL (ALMA WBS: 4.080.0660)

ALMA Project

Summary Phase 1 Activities & <u>Results</u>

- Tasks:
 - Develop, prototype and test ALMA cryostat
- *Results*:
 - A development model cryostat has been built and is undergoing extensive testing
 - Performance of development model has been very encouraging:
 - '4 K' stages actually well below 3 Kelvin

Requirement: < 4 *K*

• Temperature stability 1,5 mK at '4 K' stage

Requirement: < 2 mK @ 1 min

• Cool down time approx. 28 hours

Requirement: < 36 *hours*







Common & Cartridge Optics- IRAM (ALMA WBS: 4.090.0720)

ALMA Project

Summary Phase 1 activities and results

- Tasks:
 - Develop optics (common, cartridge) design concept, design and prototype common components
- *Results*:
 - Detailed design common optics nearly completed
 - All critical interfaces have been documented
 - Full mechanical tolerance analysis of mirrors, lenses and support structures
 - Cartridge optics designs well advanced
 - Designs are complete for bands 1,2,4,6,and 7 and prototype cartridge optics are being made
 - Band 3 is being reanalyzed to obtain a better (compact / lighter) system using a phase corrected horn
 - Band 9 is designed, and awaits optics calculations from MRAO for evaluation
 - Design evaluation done by Gaussian beam analysis and actual prototype testing
- Freeze optics design Apr. '03 (Milestone: 4.090.8765)





RF Windows & IR Filters – IRAM (ALMA WBS: 4.090.0720)

ALMA Project

Summary Phase 1 activities and results

- Tasks:
 - Design and test RF windows and IR filters
- *Results*:
 - 3 design options for windows assessed: RF performance
 - 2 designs quartz based (QMC/NRAO)
 - 1 HDPE plastic based (IRAM)
 - Design solutions fulfill requirements Series production aspects investigated:
 - HDPE window production using injection molding technique
 - Identified companies for series production
 - Costing:
 - Quartz window: $\approx \in 750$ / window
 - HDPE window: ≈ € 400 / window
 - Jan. '03

Shipment of HDPE based windows and IR filters for cartridge test cryostats (4) and development model cryostat

• Freeze RF windows & IR filters in Apr. '03 (Milestone: 4.090.8770)

•Window type	•HDPE (IRAM)	•Quartz 1 (QMC)	•Quartz 2 (NRAO)
•Vacuum leak rate •[mbar liters/sec]	•7x10 ⁻⁷	$_{8}^{\bullet < 1 \times 10^{-}}$	$_{8}^{\bullet < 1 \times 10^{-}}$
•Band 3 T _n contribution •[Kelvin]	•1,0	•2,0	•t.b.m.
•Band 6 T _n contribution •[Kelvin]	•2,0	•2,5	•3,0
•Band 7 T _n contribution •[Kelvin]	•2,0	•3,0	•5,0
•Band 9 T _n contribution •[Kelvin]	•14	•4,0	•6,0



Band 7 Cartridge – IRAM (ALMA WBS: 4.170.1007)

ALMA Project

Summary Phase 1 activities and results

- Tasks:
 - Develop Band 7 cartridge design concept, design and prototype critical Band 7 components
- *Results*:

Mixer development

- Focus on a 2SB, 4 8 GHz IF bandwidth, mixer solution
- DSB, 4 12 GHz IF bandwidth, mixer solution has been discarded
- Progress has been made to solve problem on obtaining a wideband matching at mixer IF output port
 - First design (black squares) shows large increase in noise temperature above 7 GHz
 - Second design (colored squares) shows more constant noise temperature over required IF (4 – 8 GHz)
 - A third, final design is in progress that should fulfill ALMA requirements:

< 57 K (80 % of full RF band) < 88 K (20 % of full RF band)





Band 7 Cartridge - IRAM (ALMA WBS: 4.170.1007)

- ALMA Project
- *Cartridge development*
 - Progress on cartridge development has been negatively affected by departure of S.Claude in mid-2002. A contract has been signed with a new engineer, effective 31 Mar. '03.
- Feed Horns
 - Horns for the Band 7 cartridge have been fabricated and tested (return loss, radiation diagram)
- Cartridge optics and 4K mechanical structure
 - Initial design for the 4K mechanical structure that supports the mirrors, grid, and mixer assemblies, had too much tolerance buildup
 - A second version of that structure is in an advanced stage of design. It has far fewer distinct parts than the first version enabling a more efficient series production





Band 7 Cartridge - OSO (ALMA WBS: 4.170.1007)

ALMA Project

Summary Phase 1 activities and results

- Tasks:
 - Develop Band 7 cartridge design concept, design and prototype critical Band 7 components
- *Results*:
 - 2SB mixer development (3 mm scale model)
 - Test cryostat and the mixer block are completed
 - 4-channel DC bias system and measurement setup are completed
 - The 2-channel IF system is completed and tested (amplitude misbalance is 0.2 dB, phase difference is ± 2.5 degree, T_{noise}<3K)
 - SIS mixer with 4 identical SIS junctions on substrate was produced, DC tested and mounted/bonded into the mixer block
 - The first RF test was done on 27 Dec. '02:
 - The concept of the mixer was proved
 - The LO distribution circuitry was proved working correct
 - Preliminary, SIS tuning circuitry works correct
 - The first noise temperature measurements should be completed during Jan. 2003





Band 9 Cartridge – NOVA/SRON (ALMA WBS: 4.190.1009)

Summary Phase 1 activities and results

- Develop Band 9 cartridge design concept, design and prototype critical Band 9 components
- SIS mixer design/measurements
 - RF coverage achieved
 Requirement: 602 720 GHz
 - Mixer DSB noise temperature of less then 150 K Requirement:
 - < 147 K (80 % of full RF band) < 224 K (20 % of full RF band)

- 4 10.5 GHz IF band coverage with isolator
 Requirement: 4 – 12 GHz
- Cartridge optics design concept completed
 - Performance demonstrated by Gaussian beam analysis
 - Tolerance analysis of optical components





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Band 9 Cartridge – NOVA/SRON (ALMA WBS: 4.190.1009)

ALMA Project

Summary Phase 1 activities and results

- *Mixer series production / Design for Manufacturing*
 - Two batch runs (6 pcs. + 14 pcs.) of mixer components by external commercial manufacturer
 - Waveguide back shorts
 - Diagonal horn antennas
 - Close mutual interaction with this company in the design process
 - Good tolerances statistics (y-axis units are μ m / compare with operating wavelength: $\approx 460 \mu$ m)





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Water Vapour Radiometer – CA/OSO (ALMA WBS: 4.210.1011)

ALMA Project

Summary Phase 1 activities and results

- Tasks:
 - Develop and test atmospheric delay calibration method, including the development of dedicated 183 GHz WVR
- *Results*:
 - FE Mixers have noise performance well within spec (2000 K) and with lower LO drive power than expected
 - All other RF & IF sub-system components now obtained & characterized
 - Filter BW Variations & insertion loss acceptable
 - IF component power & phase balance within spec
 - Power detector characteristics acceptable
 - Development of dual Phase-Locked LOs with computercontrolled DDS frequency reference completed
 - Chopper wheel system with high speed and efficiency constructed
 - Good control of phase demonstrated
 - Cold load using compact high-efficiency cooler built and tested
 - Good temperature control at ~120K indicated
 - Bench system testing commenced for Correlation WVR





Work Element Name ALMA WP Cryostat Design / Prototype 4.080 Cryostat / Pre-Production series 4 0 8 5 Windows/IR/Common optics Development 4.090 Common Optics / Pre-Production series 4.095 Windows & IR Filters / Pre-Production series 4.095 (Focal Plane) Calibration Unit Development 4.115 4.170 Band 7 Cartridge Design / Development Band 7 Cartridge / Pre-Production series 4.175 Band 9 Cartridge Design / Development 4.190 Band 9 Cartridge / Pre-Production series 4.195 Water Vapour Radiometer Development 4.210 Front End Test Station Replication 4.225

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ALMA Front Ends

Summary Allocation EU ALMA

Phase 2 FE Work Elements in 2003



ESO Phase 2 Call for Proposals / Front End Work Packages

ALMA Project

- Approval of European Phase 2 funding by ESO Council on 9 Jul. '02
- First Call for Proposal for EU Phase 2 work packages issued on 9 Aug. '02
- CfP included 6 FE work packages (binding proposals) for detailed development:
 - Cryostat Design/Prototype (ALMA WP: 4.080)
 - Windows/IR/Common optics Development (ALMA WP: 4.090)
 - (Focal Plane) Calibration Unit Development (ALMA WP: 4.115)
 - Band 7 Cartridge Design/Development (ALMA WP: 4.170)
 - Band 9 Cartridge Design/Development (ALMA WP: 4.190)
 - WVR Cartridge Design/Development (ALMA WP 4.210)
- Requested non-binding production oriented proposals for other EU FE Work Packages
- Proposal submission dead-line 11 Oct. '02



Submitted Phase 2 FE Work Packages

ALMA Project

- Received 8 binding proposals
 - 1 for each WP
 - Exception for WVR development and Band 7 cartridge development (2 proposals each)
- Each binding proposal was presented by bidder to a review panel on 4 6 Nov. '02
- Review panel consisted of 7 members, including 3 technical experts from outside the ALMA project
- The review panel made the following conclusions:
 - 7 proposals fulfilled the original CfP, 1 was non compliant
 - The review panel was impressed by the technical proposals and the experience demonstrated so far
- Approval to negotiate contracts for ALMA Phase 2 WPs expected at special ESO FC meeting in March '03



Cost Control (ALMA WBS: 4.075.0620)

ALMA Project

Work Package costs control

- In Jul. Aug. '02 a major reassessment of all European FE Work Packages was made
 - Total cost (incl. contingencies) of EU Front End IPT WPs:
 - Previous costing (2002-03-12): k\$_{Y2000} 59.055
 - Revised costing (2002-10-18): k\$_{Y2000} 60.043
 - Largest cost increase in:
 - Band 7 cartridge production (incl. NRE / excl. contingency): k\$ 7.304 → k\$ 9.738
 Previous costing was based on a DSB mixer approach not compliant with ALMA requirements. This has now been corrected with a 2SB mixer scheme.
- Phase II contracts made by ESO for European will be based on a fixed price policy
 - Regular programmatic control by ESO, including budget, for these contracts
 - ESO will be represented in Contract Award Committee (value > k€ 100, -) to be set up by the Contractor as part of the applicable tendering procedure
 - Design reviews will function as a tollgate for committing funds to next phase
 - Only in exceptional, unforeseen cases extra funding can be granted by the EU project manager to a contract from the contingency funds



Progress / Scope Control (ALMA WBS: 4.075.0620)

ALMA Project

Work Package progress control

- Extensive use of milestones to monitor progress:
 - Basis is formed by project milestones, Level 2, that are under direct control of the Joint ALMA Office
 - Each work package is linked to 1 .. 3 Level 2 milestones
 - Multiple Level 3 milestones derived for each WP, from project level milestones
 - Typically 10 Level 3 milestones per WP
 - Level 3 milestones are contractually binding
 - Often linked to payments
- Thorough design reviews:
 - New ALMA review procedures developed by System Engineering IPT

Scope control

- Detailed Statement of Work
 - Clear description of what/when should be done and what/when/where should be delivered
- Specification & Requirements
- Rigorous Configuration Control process

- Changes can only be made in a controlled way, approval by FE IPT and JAO required

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Phase 2: activities and milestones

• Jan. '03 – Apr. '03

Phase 2 of detailed testing/evaluation of development model cryostat:

- Long term vacuum integrity testing (including RF windows)
- Detailed, high accuracy temperature measurements
- Evaluation of improved cryo cooler (Sumitomo Mk IV, successor has been discontinued by manufacturer)

Cryostat Design / Prototype

& Pre-Production Series

• Jan. '03 – Apr. '03

Final design iteration to optimize design for series production and cost by simplifying the design and reduction of assembly time

• Jul. '03

Freeze dewar design (Milestone: 4.080.8720)

• Sep. '03

Assembly and first test of new build cryostat (pre-production model #1)

• Dec. '03

Completion of evaluation of pre-production model #1 cryostat

• Jan. '04 – Jul. '05

Delivery / acceptance pre-production series of 8 units

- Pre-production cryostat #1 delivery to and acceptance by NA FEIC (Milestone: 4.080.8730)
- Pre-production cryostat #8 delivery to and acceptance by NA FEIC (Milestone: 4.080.8735)



Common Optics, Windows & IR Filters & Pre-Production Series

ALMA Project

Phase 2: activities and milestones

• Jan. '03 – Apr. '03

Phase 2 of detailed testing/evaluation of development model cryostat:

- Complete evaluation RF windows & IR filters in collaboration with cryostat design group (RAL)
- Finalize assessment common / cartridge optics (EM-simulation, prototype)
- Apr. '03

Freeze common optics design (Milestone: 4.090.8765) Freeze windows & IR filter design (Milestone: 4.090.8770)

• Jan. '04 – Jul. '05

Delivery / acceptance pre-production series of 8 units

- Pre-production common optics #1 delivery to and acceptance by NA FEIC (Milestone:4.095.8775)
- Pre-production windows, IR filters #1 delivery to / acceptance by NA FEIC (Milestone:4.095.8780)
- Pre-production common optics #8 delivery to and acceptance by NA FEIC (Milestone:4.095.8785)
- Pre-production windows, IR filters #8 delivery to / acceptance by NA FEIC (Milestone:4.095.8790)



Focal Plan Calibration Unit Development

ALMA Project

Phase 2: activities and milestones

- This work package is shared with the ALMA Science IPT. The FE IPT is responsible for delivery of the appropriate hardware according to specifications as coming from the ALMA Calibration Working Group
- Jan. '03 Mar. '03

Test at IRAM 30 m radio telescope, Pico Veleta Observatory, to assess calibration principle

- Installation and implementation of development calibration unit: Jan. '03
- Two test periods scheduled for Feb. and Mar. '03
- Final test report Mar. '03
- *Jan. '03 Jun. '03* Microwave material tests
- *Jun. '04* Internal PDR
- Jul. '04 Dec. '04
 - Design, manufacture prototype calibrator



Band 7 Cartridge Design / Prototype & Pre-Production Series

ALMA Project

Phase 2: activities and milestones

- Jan. '03 Apr. '03
 Evaluation 2SB mixer 4 8 GHz completed

 Prototype cartridge assembly integration completed
- *May '03* Internal PDR
- *May '03 Sep. '03* Detailed design
 - Evaluation 2SB mixer type 2 junction completed
 - Evaluation 2SB mixer type 1 junction completed
 - Make SIS junction choice
- *Sep. '03 Mar. '04* Start-up pre-production series
- Mar. '04

Pre-production Band 7 cartridge lab qualification completed Internal Band 7 Cartridge CDR

• Oct. '04 – Jan. '06

Delivery / acceptance pre-production series of 8 units

- Pre-production Band 7 cartridge #1 delivery to and acceptance by NA FEIC (Milestone:4.175.8955)
- Pre-production Band 7 cartridge #8 delivery to and acceptance by NA FEIC (Milestone:4.175.8960)



Band 9 Cartridge Design / Prototype & Pre-Production Series

ALMA Project

Phase 2: activities and milestones

- *Jan. '03 Sep. '03* Finalize detailed design
 - Optics design
 - Cartridge mechanical design
 - Waveguide SIS mixer
- Oct. '03 Apr. '04

Start-up pre-production series

• Jun. '04

Pre-production Band 9 cartridge lab qualification completed Internal Band 9 Cartridge CDR

• Oct. '04 – Jan. '06

Delivery / acceptance pre-production series of 8 units

- Pre-production Band 9 cartridge #1 delivery to and acceptance by NA FEIC (Milestone:4.195.8965)
- Pre-production Band 9 cartridge #8 delivery to and acceptance by NA FEIC (Milestone:4.195.8970)



Water Vapour Radiometer Development

ALMA Project

Phase 2: activities and milestones

• Jan. '03 – May '03

Completion of original Phase 1 tasks (not funded from Phase 2 funds)

- Delivery of 1 Dicke switched and 1 correlator type WVR for lab testing
- Jun. '03 Jan. '04

Competitive lab testing of Dicke switched vs. correlator WVR Final design selection

• Feb. '04 – Aug. '04

Prepare 2 WVRs based on selected design for field tests

Prepare detailed test plan for ATF field tests in collaboration with ALMA Science IPT

Sep. '04
 2 Prototype WVRs delivered to and accepted by ATF (Milestone:4.210.8795)