# ALMA Phase 1 Joint Receiver Work Program

# Version 1.0   2 October 1999

## 1. Introduction

The ALMA Phase 1 Joint Receiver Work Program describes the work program for NRAO and the European participants to be carried out in the receiver area (Joint WBS 4 and 5) during the design and development phase (Phase 1) of a large mm/submm array. The objective of the work program is to design components, develop technology and build prototypes of certain components for the ALMA receiver subsystem. It tries to avoid duplication, and to use the joint resources as efficiently as possible.

## 2. Receiver Team Organization

The overall technical direction of the effort will be focused in the joint receiver subsystem design group, consisting of five members from Europe and five members from the US (see 4.1). Its functions include:

- discuss, decide and carry out the joint receiver design at the system level,
- make sure that there is *one* receiver design,
- give the individual groups the framework to develop components (definition of modules and interfaces),
- define an appropriate test plan for components and systems, and
- in general take care of all questions related to the receiver at system level.

The European receiver team manager and his U.S. counterpart, the US receiver group Division Head will coordinate the work of this group.

## 3. Joint Phase 1 Work Breakdown Structure (WBS)

The design and development efforts for ALMA receivers (including LO) are organized according to the following joint phase 1 WBS:

4 Receiver Subsystem
- 4.1 Receiver Subsystem Design & Specification
- 4.2 SIS Junctions Production Study
- 4.3 SIS Mixers
  - 4.3.1 balanced, sideband separating SIS mixers
  - 4.3.2 submillimeter band SIS mixers
  - 4.3.3 moving backshort SIS mixers
- 4.4 Amplifiers
  - 4.4.1 HFET/MMIC
  - 4.4.2 IF amplifiers
    - 4.4.2.1 internal IF amplifiers

4.4.2.2 external IF amplifiers

4.5 Cryostat
- 4.5.1 Dewar
- 4.5.2 Cryocooler
- 4.5.3 Windows and IR filters
- 4.5.4 Prototype cryostat construction

4.6 Optics
- 4.6.1 Receiver optics
- 4.6.2 LO injection
- 4.6.3 Feed horn fabrication

4.7 Control & Test Electronics
- 4.7.1 bias and monitoring & control electronics
- 4.7.2 automatic testing

4.8 Calibration Equipment
- 4.8.1 Rx calibration system
- 4.8.2 183 GHz water vapor monitor system

4.9 Antenna Evaluation Receivers

5 Local Oscillator Subsystem
- 5.1 LO Subsystem Design & Specification
- 5.2 LO Reference
- 5.3 Multiplier Chain LO
- 5.4 Photonic LO

The deliverables of the design and development phase depend on the area, and range from reports to working prototypes. In the following, each work package is described in more detail, indicating the lead institution, the work package manager, participating institutions, scope of the work, and the deliverable(s). Nevertheless, the descriptions below necessarily represent a very abbreviated statement of the needed tasks, and some work packages may change depending on the chosen overall receiver subsystem baseline design. The work package managers, in close cooperation with the U.S. receiver and LO division heads and the European receiver team manager, will be responsible for formulating a detailed task description for their work package(s) and work out a detailed schedule with the indication of milestones. They are also responsible for ensuring that their part of the receiver effort is executed in a timely fashion, and will give regular progress reports to the European Team Manager and the responsible U.S. Division Head.

Appendix A gives an overview of the work packages, lead institutes, WP managers, and participating institutes.

## 4. Receiver Subsystem

### 4.1 Receiver Subsystem Design & Specification

This effort is centered in the Joint Receiver Design Group which consists of five U.S and five European members. Being a joint group effort, coordinated by the European Team Manager and U.S. Receiver Division Head, there is no lead institute.

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| **Work package managers:** | Wolfgang Wild and John Payne |
| **Group members:** | Victor Belitsky – OSO<br>Charles Cunningham – HIA<br>Brian Ellison – RAL<br>Rolf Guesten – MPIfR<br>James Lamb – OVRO<br>Bernard Lazareff – IRAM<br>John Payne – NRAO Tucson<br>Dick Plambeck - BIMA<br>John Webber – NRAO Charlottesville<br>Wolfgang Wild – NOVA/SRON |

**Scope of work:**

- overall technical direction of the joint receiver effort,
- responsible for a joint U.S./European receiver concept and overall receiver design,
- maintain an overview of all receiver design work,
- ensure compatibility between the various components and modules,
- act as interface to other ALMA groups,
- coordinate between all receiver subsystem groups, attempt to identify and resolve potential conflicts, and
- responsible for ensuring accurate and adequate generation of Interface Control Documents (ICDs) for all subsystems.

### 4.2 SIS Junctions Production Study

This work package is concerned with the large scale supply of SIS junctions for the production and operations phase of ALMA (phase 2 and beyond), but *not* with the supply of junctions for the prototype mixers built during phase 1. These junctions are the responsibility of the individual mixer groups.

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| **Lead institute:** | IRAM |
| **Work package manager:** | Karl Schuster |
| **Participating institutes:** | IRAM - Karl Schuster<br>SRON-DIMES - Teun Klapwijk<br>SRON-DIMES - J.R. Gao<br>KOSMA - Karl Jacobs<br>OSO - Sergey Kostonyok<br>NRAO – Tony Kerr, S.K. Pan |

**Scope of work:**

- Investigate present capability to produce SIS junctions in quantity, quality and uniformity as required for the ALMA receivers,
- identify necessary steps to achieve the required SIS junction production capability,
- investigate ways to test SIS junctions in large quantities,
- estimate cost and manpower requirements,
- estimate time scales, and
- develop scenarios for mass production and testing of SIS junctions throughout the lifetime of ALMA.

**Deliverable:**

Report, consisting of

- an evaluation of the present capabilities to produce SIS junctions for the ALMA receivers,
- a plan of how to build up the necessary production capability,
- a plan of how to organize the production phase, and
- an indication of the required investment and manpower including time scales.

### 4.3 SIS Mixers

The phase 1 effort for SIS mixers is divided into several work packages recognizing the amount of work, the most likely use of different technology in the mm and submm bands, and the need to pursue various approaches.

#### 4.3.1 Balanced, Sideband-separating SIS Mixers

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| **Lead institute:** | NRAO Charlottesville |
| **Work package manager:** | Tony Kerr |
| **Participating institutes:** | NRAO – John Webber, Tony Kerr, S.-K. Pan |

**Scope of work:**

For the frequency band 211 – 275 GHz:

- Design, fabricate and test prototypes of balanced, sideband-separating SIS mixers,
- fabricate a frequency module (dual linear polarization, RF in, LO in, IF out) to be used in a prototype receiver,
- integrate the prototype mixers into the frequency module, and
- investigate ways how to fabricate the large quantity of mixers required for ALMA.

**Deliverables:**

- Tested prototypes of balanced, sideband-separating SIS mixers in the band 211 – 275 GHz,
- a frequency module (dual linear polarization) for integration into a prototype receiver,
- test reports and documentation, and
- a plan of how to produce the chosen design in large quantities, including estimates of manpower and cost.

### 4.3.2 Submillimeter Band SIS Mixers

**Lead institute:** NOVA/SRON
**Work package manager:** Wolfgang Wild

**Participating institutes:** 275-370 GHz: OSO – Victor Belitsky
385-500 GHz: DEMIRM – Morvan Salez
602-720 GHz: NOVA/SRON – Wolfgang Wild

**Scope of work:**

For the frequency bands 275-370, 385-500, and 602-720 GHz:

- Investigate the feasibility and desirability of SSB mixers,
- design, fabricate and test a prototype SIS mixer in the respective band,
- fabricate a frequency module (dual linear polarization, RF in, LO in, IF out) for the indicated band to be used in a prototype receiver,
- integrate the prototype mixers into the frequency module, and
- investigate ways how to fabricate the large quantity of mixers required for ALMA.

**Deliverables:**

- Tested prototypes of SIS mixers in the bands 275-370, 385-500, and 602-720 GHz,
- a frequency module (dual linear polarization) for integration into a prototype receiver,
- test reports and documentation, and
- a plan of how to produce the chosen design in large quantities, including estimates of manpower and cost.

### 4.3.3 Moving Backshort SIS Mixers

**Lead institute:** IRAM
**Work package manager:** Bernard Lazareff

**Participating institutes:** IRAM – A. Karpov

**Scope of work:**

- Adapt a proven IRAM mixer design (single-ended, SSB tuned, moving backshort) to ALMA specs for the band 211-275 GHz,
- conduct endurance tests to validate reliability,
- fabricate a frequency module to be used in a prototype receiver,
- integrate the prototype mixers into the frequency module, and
- investigate ways how to fabricate the large quantity of mixers required for ALMA.

**Deliverables:**

- Tested prototype of a single-ended, SSB tuned, moving backshort SIS mixer in the band 211 – 275 GHz,
- a frequency module (dual linear polarization, RF in, LO in, IF out) for integration into a prototype receiver,
- a report describing the results of reliability tests, and
- a plan of how to produce the chosen design in large quantities, including estimates of manpower and cost.

## 4.4 Amplifiers

In the ALMA receiver subsystem, amplifiers may be used as frontend at millimeter wavelengths, and are needed as IF amplifiers.

### 4.4.1 HFET/MMIC amplifiers

**Lead institute:** NRAO Charlottesville
**Work package manager:** John Webber

**Participating institutes:** NRAO

**Scope of work:**

- Determine the performance of HFET receivers up to 116 GHz,
- compare performance with MMIC devices, and make a recommendation on their suitability for use in ALMA receivers,
- evaluate presently available devices,
- evaluate the suitability of present designs below 116 GHz for ALMA use,
- produce prototypes of any required new designs,
- produce amplifiers for use in a test/prototype receiver,
- integrate prototype amplifiers into a frequency module, and
- investigate ways how to fabricate the large quantity of HFET amplifiers required for ALMA.

**Deliverables:**

- Evaluation and test reports,
- prototypes of new designs,
- prototypes for use in a test/prototype receiver,
- a frequency module (dual linear polarization) for integration into the overall receiver system, and
- a plan of how to produce HFET or MMIC amplifiers in large quantities, including estimates of manpower and cost.

### 4.4.2 IF amplifiers

#### 4.4.2.1 Internal IF amplifiers

**Lead institute:** NRAO Charlottesville
**Work package manager:** Tony Kerr

**Participating institutes:** NRAO, Caltech

**Scope of work:**

- Investigate the feasibility of integration of an IF amplifier within the mixer,
- design, fabricate, and test prototypes of internal IF amplifiers,
- integrate prototype mixers with internal IF amplifiers into a frequency module, and
- investigate large scale production issues.

**Deliverables:**

- Prototype mixers with built-in IF amplifiers,
- frequency module with mixers and internal IF amplifiers,
- test reports and documentation, and
- a plan of how to produce the large quantities required for LAM receivers, including estimates of manpower and cost.

#### 4.4.2.2 External IF amplifiers

**Lead institute:** CAY
**Work package manager:** Alberto Barcia

**Participating institutes:** ETH Zuerich – Otte Homan

**Scope of work:**

- Optimize discrete devices (transistors) for cryogenic operation in the specified ALMA IF band,
- assess the feasibility of a hybrid technology approach for low noise amplifiers,

- design, fabricate and test a prototype IF amplifier for the specified IF band, and
- investigate ways how to fabricate the large quantity of amplifiers required for ALMA.

**Deliverables:**

- Tested prototypes of an IF amplifier, to be used in a prototype receiver, and
- a plan of how to produce the chosen design in large quantities, including estimates of manpower and cost.

## 4.5 Cryostat

### 4.5.1 Dewar

**Lead institute:** RAL/ATC
**Work package manager:** Brian Ellison

**Participating institutes:** ATC – William Duncan
IRAM – Bernard Lazareff
NRAO – John Payne

**Scope of work:**

- Mechanical, electrical and thermal design of the receiver dewar following the decided receiver baseline concept, and in close collaboration with the cryocooler, optics and mixer groups,
- mechanical design of the dewar and receiver mount to the telescope, including issues of exchanging receivers easily,
- investigate ways how to fabricate the large quantity of dewars required for ALMA.

**Deliverables:**

- Production drawings of the dewar and the mounts,
- reports on all of the above, and
- a plan of how to produce the chosen design in large quantities, including estimates of manpower and cost.

### 4.5.2 Cryocooler

**Lead institute:** RAL
**Work package manager:** Tom Bradshaw

**Participating institutes:** ATC – William Duncan
IRAM – Bernard Lazareff
NRAO – Larry D'Addario

**Scope of work:**

- Study different cryocooler options, taking into account both commercially available and in-house cryocoolers, and make a recommendation to the joint receiver design group,
- depending on the outcome of the study, and the decision of the joint receiver design group: procure or design and fabricate a prototype cryocooler,
- integrate the prototype cryocooler into the dewar and conduct extensive tests, and
- investigate ways how to obtain the cryocoolers in large quantities, including estimates of manpower and cost.

**Deliverables:**

- Tested prototype of a cryocooler, with demonstrated fulfillment of ALMA requirements,
- production drawings in case of in-house design,
- complete test reports, and
- a plan of how to obtain the chosen cryocooler in large quantities, including estimates of manpower and cost.

### 4.5.3 Windows and IR filters

**Lead institute:** ATC/RAL
**Work package manager:** William Duncan

**Participating institutes:** IRAM – Bernard Lazareff
NRAO – John Payne
RAL – Brian Ellison

**Scope of work:**

- study of electromagnetic, thermal and vacuum properties of suitable windows and IR filters,
- recommend solutions to the joint receiver design group, and
- investigate ways how to obtain the large quantities of components required for ALMA.

**Deliverables:**

- Prototype windows and IR filters,
- report on properties and test results, and
- a plan of how to obtain the components in the required quantities, including estimates of manpower and cost.

#### 4.5.4 Prototype cryostat construction

**Lead institutes:** TBD (one in US and one in Europe)
**Work package manager:** TBD

**Participating institutes:** NRAO – John Payne
IRAM – Bernard Lazareff
RAL – Brian Ellison

**Scope of work:**

- fabrication of a prototype dewar, following the production drawings from work package 4.5.1 (Dewar),
- integration of the prototype cryocooler and the dewar, and
- integration of existing components and modules into the prototype dewar,
- extensive tests (thermal, electrical, functional, reliability etc) of the system. Tests to include application of calculated thermal loads.

**Deliverables:**

- Two partially complete prototype production receivers, utilising all optical components and available receiver modules, one to be built in the U.S., and one to be built in Europe,
- complete receiver plans, ready for mass production,
- complete set of ICDs,
- test reports on the partially complete prototype production receivers.

### 4.6 Optics

#### 4.6.1 Receiver optics

**Lead institute:** IRAM
**Work package manager:** Bernard Lazareff

**Participating institutes:** MRAO – Stafford Withington
ATC – William Duncan
NRAO – James Lamb

**Scope of work:**

- Carry out a detailed design of the receiver optics, following the chosen receiver baseline concept,
- fabricate prototype optical components and system,
- carry out detailed measurements of the optical components and system, and

- investigate ways how to fabricate the large quantity of optical components required for ALMA.

**Deliverables:**

- Design drawings,
- a tested prototype optical system, for integration into a prototype receiver,
- reports on the results of tests and optical measurements, and
- a plan of how to produce the chosen design in large quantities, including estimates of manpower and cost.

### 4.6.2 LO Injection

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| **Lead institute:** | IRAM |
| **Work package manager:** | Matt Carter |
| **Participating institutes:** | OSO – Victor Belitsky<br>NRAO – James Lamb |

**Scope of work:**

- Study the options for LO injection for the various frequency bands,
- evaluate pro and cons of different schemes,
- investigate LO power considerations for alternate mixer designs, and
- propose LO injection schemes for the different frequency bands.

**Deliverables:**

- Report

### 4.6.3 Feed Horn Fabrication

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| **Lead institute:** | Arcetri |
| **Work package manager:** | Enzo Natale |
| **Participating institutes:** | IRAM – Matt Carter<br>MRAO – Stafford Withington |

**Scope of work:**

- Get the detailed optical design from the responsible work package manager,
- design feed horns for mixers in close collaboration with the optics and mixer groups,
- fabricate and test prototypes, and
- assess mass production aspects.

**Deliverables:**

- Prototypes of feed horns at t.b.d. frequencies, and
- a plan of how to produce the chosen design in large quantities, including estimates of manpower and cost.

## 4.7 Control & Test Electronics

### 4.7.1 Bias and monitoring & control electronics

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| **Lead institute:** | NRAO Tucson |
| **Work package manager:** | Graham Moorey |
| **Participating institutes:** | IRAM – Bernard Lazareff<br>OSO – Victor Belitsky<br>ALMA software group |

**Scope of work:**

- Design, fabricate and test bias electronics for SIS mixers, amplifiers, and magnets,
- design, fabricate and test monitoring and control electronics for a prototype receiver system,
- specify the interfaces to the receiver system and to the monitor and control software,
- demonstrate remote and automatic receiver tuning and monitoring on a test/prototype receiver,
- coordinate with software and systems groups,
- investigate ways how to fabricate the large quantities required for ALMA.

**Deliverables:**

- Tested prototypes of bias circuit and monitor and control modules, to be used in a test/prototype receiver,
- provide accurate and adequate Interface Control Documents (ICDs), and
- a plan of how to produce the chosen design in large quantities, including estimates of manpower and cost.

### 4.7.2 Automatic testing

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| **Lead institute:** | MRAO |
| **Work package manager:** | Stafford Withington |
| **Participating institutes:** | OSO – Victor Belitsky<br>NRAO – John Payne, John Webber |

**Scope of work:**

- Establish procedures to characterize automatically a complete receiver system,
- design a system for automatic testing. This includes:
  - automatic tuning throughout the receiver frequency range,
  - measurement of noise performance and gain and phase stability throughout range, and
  - automatic measurement of feed patterns, amplitude and phase.

**Deliverables:**

- Description of procedures to characterize a complete receiver system,
- demonstration of these procedures on existing and/or test/prototype receivers,
- detailed designs and plans, and
- test and measurements reports.

## 4.8 Calibration equipment

### 4.8.1 Receiver calibration system

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| **Lead institute:** | NRAO Tucson |
| **Work package manager:** | Darrel Emerson |
| **Participating institutes:** | IRAM – Bernard Lazareff<br>MRAO – Richard Hills, John Richer |

**Scope of work:**

- Study amplitude and phase calibration requirements and its implications on and interactions with the receiver design, in close cooperation with science and system groups,
- design, fabricate and test a phase and amplitude receiver calibration system, and
- investigate ways how to fabricate the large quantities required for ALMA.

**Deliverables:**

- Report about amplitude and phase calibration and its technical implementation,
- a tested prototype calibration system to be used in a prototype receiver, and
- a plan of how to produce the chosen design in large quantities, including estimates of manpower and cost.

### 4.8.2 183 GHz water vapor monitor system

**Lead institute:** MRAO

**Work package manager:** Richard Hills

**Participating institutes:**
NRAO – Simon Radford
OSO – Victor Belitsky
RAL – Brian Ellison

**Scope of work:**

- Study the requirements for a 183 GHz water vapor monitor system,
- develop the technical concept of a water vapor monitor system (consisting of a 183 GHz frontend, a dedicated backend, and software) for phase correction,
- design, fabricate and test a 183 GHz cooled Schottky mixer to be used in a prototype receiver,
- fabricate a frequency module (dual linear polarization, RF in, LO in, IF out) for 183 GHz to be used in a prototype receiver,
- integrate the prototype mixers into the frequency modules,
- design, fabricate and test a dedicated backend for the water vapor monitor, and
- investigate ways how to fabricate the large quantity required for ALMA, including man power and cost estimates.

**Deliverables:**

- Report describing the concept of a water vapor monitoring system,
- a prototype of water vapor monitoring system consisting of phase correction procedures, a dedicated backend, and a 183 GHz frequency module,
- a tested prototype of a 183 GHz cooled Schottky frequency module, and
- a plan of how to produce the system in large quantities, including estimates of manpower and cost.

### 4.9 Antenna evaluation receivers

**Lead institute:** NRAO Tucson
**Work package manager:** Graham Moorey

**Participating institutes:** NRAO

**Scope of work:**

- Design, construction, and test of two complete receiver systems for the evaluation of two prototype antennas, containing the following bands: 30 – 40 GHz, 89 – 116 GHz HFET, 89 – 116 GHz SIS, and 211 – 275 GHz SIS.

**Deliverables:**

- Two complete and tested receiver systems.

## 5 Local Oscillator Subsystem

### 5.1 LO Subsystem Design & Specification

**Lead institute:** NRAO Socorro
**Work package manager:** Dick Sramek

**Participating institutes:** RAL – Brian Ellison
MPIfR – Rolf Guesten

**Scope of work:**

- Specify all reference frequencies needed for ALMA,
- design circuitry, and
- construct and test prototypes.

**Deliverables:**

- Tested prototype systems,
- complete documentation and test reports.

### 5.2 LO Reference

**Lead institute:** NRAO Tucson
**Work package manager:** Bill Shillue

**Participating institutes:** RAL – Brian Ellison
MPIfR – Rolf Guesten

**Scope of work:**

- Design and develop a photonic LO reference system delivering frequencies in the 100 GHz range.

**Deliverables:**

- Photonic LO reference system to be used at the interferometer test array,
- complete documentation and test reports.

### 5.3 Multiplier Chain LO

**Lead institute:** NRAO Charlottesville

**Work package manager:** John Webber

**Participating institutes:** RAL – Brian Ellison

**Scope of work:**

- design, fabrication and test of tunerless multipliers to provide LO power for the different frequency channels of ALMA receivers,
- fabrication and test of a prototype multiplier LO,
- demonstrate suitability of multiplier LO to pump SIS mixers, and
- investigate ways how to fabricate the large quantity of mixers required for ALMA

**Deliverables:**

- tested prototypes of tunerless multipliers,
- complete LO chain for use in a test receiver, and
- a plan of how to produce the chosen design in large quantities, including estimates of manpower and cost.

### 5.4 Photonic LO

**Lead institute:** NRAO Tucson
**Work package manager:** John Payne

**Participating institutes:** MPIfR/KOSMA – Rolf Guesten
RAL – Brian Ellison

**Scope of work:**

- Demonstration of purity of LO signal, satisfactory noise performance of the photonic system,
- demonstration of round trip phase correction,
- prototype of NRAO "Option II" concept,
- continued efforts to obtain high frequency photodetectors with suitable power output, with a view to implementation of the NRAO "Option III", and
- investigate ways how to obtain the quantities of components required for ALMA.

**Deliverables:**

- Working prototype system to demonstrate Option II (photonic reference system), and if possible also Option III (full photonic system), and
- reports on all the above, with recommendations on which options to adopt.

## 6. Schedule of the Joint Phase 1 Receiver Work Program

The overall schedule for the phase 1 (and beyond) receiver effort is shown in Figure 1. It is driven by the arrival of the first production antenna on the site in Q4/2004. Various receiver concepts will be presented and discussed at a conceptual receiver design meeting to be held on 2/3 December 1999, and the receiver baseline design will be chosen at a conceptual design review in March 2000. Time scales for component and module design and development and dates for design reviews depend on the individual module. The phase 1 D&D ends at the latest end of 2001. Prototype cryostat construction will start mid 2001, and integrate available components and modules as much as possible before the end of 2001.