10-2-99

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

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.

Work package managers: Wolfgang Wild and John Payne

Group members:

Victor Belitsky – OSO
Charles Cunningham – HIA
Brian Ellison – RAL
Rolf Guesten – MPIfR
James Lamb – OVRO
Bernard Lazareff – IRAM
John Payne – NRAO Tucson
Dick Plambeck - BIMA
John Webber – NRAO Charlottesville
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.

Lead institute: IRAM
Work package manager: Karl Schuster

Participating institutes:

IRAM - Karl Schuster
SRON-DIMES - Teun Klapwijk
SRON-DIMES - J.R. Gao
KOSMA - Karl Jacobs
OSO - Sergey Kostonyok
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

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

Lead institute:	IRAM
Work package manager:	Matt Carter
Participating institutes:	OSO – Victor Belitsky 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

Lead institute:	Arcetri
Work package manager:	Enzo Natale
Participating institutes:	IRAM – Matt Carter 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

Lead institute: NRAO Tucson
Work package manager: Graham Moorey

Participating institutes: IRAM – Bernard Lazareff
OSO – Victor Belitsky
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

Lead institute: MRAO
Work package manager: Stafford Withington

Participating institutes: OSO – Victor Belitsky
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

Lead institute: NRAO Tucson
Work package manager: Darrel Emerson

Participating institutes: IRAM – Bernard Lazareff
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.

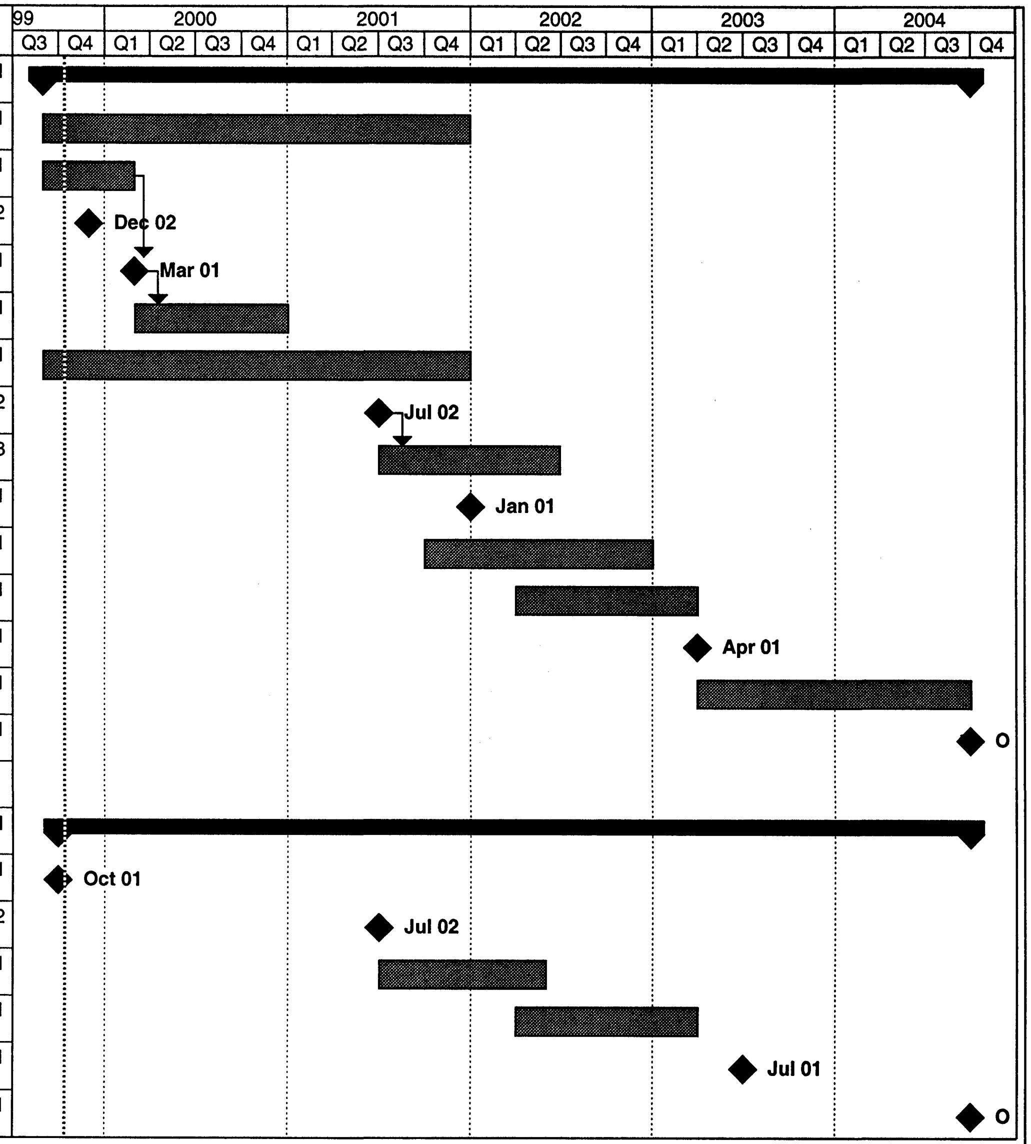
Deliverables:

- 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.

ID	ℹ	Task Name	Duration	Start	Finish
1		**RX master schedule**	**1328 days**	**1999-09-01**	**2004-10-01**
2		Phase 1 D&D	609 days	1999-09-01	2001-12-31
3		Conceptual design	131 days	1999-09-01	2000-03-01
4		Conceptual rx design meeting	0 days	1999-12-02	1999-12-02
5		CoDR: choose baseline concept	0 days	2000-03-01	2000-03-01
6		Detailed rx system design	218 days	2000-03-02	2001-01-01
7		Component D&D	609 days	1999-09-01	2001-12-31
8		Cryostat CDR	0 days	2001-07-02	2001-07-02
9		Prototype cryostat construction	260 days	2001-07-02	2002-06-28
10		Preproduction design review	0 days	2002-01-01	2002-01-01
11		Prototype rx integration & test	328 days	2001-10-01	2003-01-01
12		Prepare production	262 days	2002-04-01	2003-04-01
13		Start rx production	0 days	2003-04-01	2003-04-01
14		Rx production	394 days	2003-04-01	2004-10-01
15		First rx on site	0 days	2004-10-01	2004-10-01
16					
17		**Antennas**	**1305 days**	**1999-10-01**	**2004-10-01**
18		prototype contract	0 days	1999-10-01	1999-10-01
19		1st antenna VLA	0 days	2001-07-02	2001-07-02
20		Antenna evaluation	240 days	2001-07-02	2002-05-31
21		Interferometer testing VLA	262 days	2002-04-01	2003-04-01
22		Start antenna production	0 days	2003-07-01	2003-07-01
23		1st antenna in Chile	0 days	2004-10-01	2004-10-01



Project: Master schedule
Date: 1999-10-12

Task		Summary		Rolled Up Progress	
Split		Rolled Up Task		External Tasks	
Progress		Rolled Up Split		Project Summary	
Milestone	◆	Rolled Up Milestone	◇		

ALMA Phase 1 Joint Receiver Work Program - Overview

Version 1.0 2 October 1999

No.	Work package	Lead by	WP manager	Participating institutions
4.1	Rx Subsystem design & spec		W. Wild and J. Payne	NRAO Tuc, NRAO CV, NOVA/SRON, IRAM RAL, MPIfR, OSO, HIA, OVRO, BIMA
4.2	SIS Junctions production study	IRAM	K. Schuster	IRAM, SRON-DIMES, KOSMA, OSO, NRAO
4.3	SIS mixers			
4.3.1	balanced, sideb-sep.	NRAO CV	A. Kerr	NRAO
4.3.2	submm bands	NOVA/SRON	W. Wild	NOVA/SRON, OSO, NRAO, DEMIRM
4.3.3	moving backshort	IRAM	B. Lazareff	IRAM
4.4	Amplifiers			
4.4.1	HFET/MMIC	NRAO CV	J. Webber	NRAO
4.4.2	IF amplifiers			
4.4.2.1	internal IF amplifiers	NRAO CV	J. Webber or S. Weinreb	NRAO
4.4.2.2	external IF amplifiers	CAY	A. Barcia	ETH, CAY
4.5	cryostat			
4.5.1	dewar	RAL/ATC	B. Ellison	RAL, ATC, IRAM, NRAO
4.5.2	cryocooler	RAL	T. Bradshaw	RAL, ATC, NRAO, IRAM
4.5.3	windows and IR filters	ATC/RAL	W. Duncan	ATC, RAL, IRAM, NRAO
4.5.4	prototype cryostat construction	US/Europe	TBD	NRAO, IRAM, RAL
4.6	optics			
4.6.1	receiver optics	IRAM	B. Lazareff	IRAM, MRAO, NRAO
4.6.2	LO injection	IRAM	M. Carter	IRAM, OSO, NRAO
4.6.3	feed horn fabrication	Arcetri	E. Natale	Arcetri, IRAM, MRAO
4.7	control & test electronics			
4.7.1	bias and monitor & control elec	NRAO Tuc	G. Moorey	NRAO, OSO, IRAM, ALMA software group
4.7.2	automatic testing	MRAO	S. Withington	OSO, MRAO, NRAO
4.8	Calibration equipment			
4.8.1	Rx calibration system	NRAO	D. Emerson	IRAM, NRAO, MRAO
4.8.2	183 GHz water vapor monitor	MRAO	R. Hills	MRAO, OSO, RAL
4.9	Antenna evaluation receivers	NRAO Tuc	G. Moorey	NRAO
5	Local oscillator subsystem			
5.1	LO subsystem design & spec	NRAO Socorro	D. Sramek	NRAO, RAL, MPIfR
5.2	LO reference	NRAO Tuc	B. Shillue	NRAO, RAL
5.3	multiplier chain LO	NRAO CV	J. Webber	NRAO
5.4	photonic LO	NRAO Tuc	J. Payne	NRAO, MPIfR/KOSMA, RAL