First Report from the North American ALMA TECHNICAL ADVISORY COMMITTEE (ATAC)

Last revised 2003-01-10 (v.k1)

1 Introduction

In September 2002, a small advisory group was created, to perform an in-depth and end-to-end look at the technical progress of the ALMA construction, on the North American (NA) side. The committee is to report to the NRAO Director, who will feed findings back to the JAO and others, as appropriate. It is anticipated that our European partners may want to be involved in this review process too, but for expediency ATAC has been asked to commence its work immediately.

The main conclusions of this report are in sections **3** and **4**.

- Section 2 describes the **ATAC Organization and Methodology**
- Section 3, **The Overall State of the North American ALMA Project**, summarizes the main findings of ATAC.
- Section 4 outlines the **Major Recommendations** of ATAC.
- Section 5 gives detailed findings of ATAC in individual areas of the NA ALMA project.
- Section 6 summarizes the main **NA-Europe Dependencies** identified by ATAC.
- Section 7 is a **Glossary of Acronyms & Abbreviations** used in this document

Membership:

The committee will initially be chaired by Darrel Emerson and includes the following technical experts from within the NRAO: B. Clark, L. D'Addario, L. King, P. Napier, J. Payne, R. Sramek and A. R.Thompson. This will be a standing committee, but may or may not need to be active at all times.

Charge to the Committee:

To make an in-depth technical review of the North American side of ALMA, looking for potential problem areas, and for any areas that might not yet have received sufficient attention, or that might have "fallen through the cracks." The committee will make recommendations to the Director of the Observatory of possible solutions to any such problems found. The ATAC is not specifically asked to investigated budget issues; however, if an IPT leader brings up budget problems as an issue, then the committee will be prepared to make recommendations.

As part of the report, the ATAC should compile a list of the critical dependencies of the North American side of ALMA on European groups.

2 ATAC Organization and Methodology

For convenience and efficiency, ATAC divided the work amongst its members as follows; the sub-groups follow roughly, but not precisely, the IPT boundaries within the ALMA organizational structure.

- **The ALMA Chilean sites** (*D'Addario, Emerson, Napier, Sramek*)
- **The Antennas and Antenna Testing** (*D'Addario, Emerson, Napier, Payne, King*)
    - **Antenna Evaluation Group (AEG)** The Antenna Evaluation as such is included as part of the Antenna investigation group, although some ATF activities are part of the Systems investigation
- **Front Ends** (receivers, but excluding first local oscillator) (*D'Addario, Payne, Sramek, Thompson*)
- **Local Oscillators**, including mm-wave, photonics and backend LO systems (*D'Addario, Payne, Sramek, Thompson*)
- **Back End**, excluding correlator. (*D'Addario, Sramek, Thompson*)
- **Correlator** (*Clark, D'Addario, Sramek, Thompson*)
- **Computing** (*Clark, D'Addario*)
- **Systems Engineering & Integration** (*Clark, D'Addario, Emerson, Napier, Payne, Sramek, Thompson*)
    - **ATF** Excluding antenna testing, ATF activities at the VLA site, such as evaluating prototype ALMA electronics using the prototype antennas(s) and possibly an eventual prototype interferometer, are part of the Systems investigation
    - **Science**. Certain areas of the Science IPT, in particular calibration and antenna configurations, and in general whether science requirements have been thought through into the technical requirements and implications, will be covered together with the ATAC Systems Engineering & Integration investigations.

Although the main investigation in a given area was undertaken by the sub-groups, in all areas the reports have been reviewed by the entire ATAC. The conclusions presented here are to be considered to be from the entire ATAC membership.

The methodology of the committee has been to study existing documentation, and to interview the respective NA IPT leaders and other key individuals. Visits were made to the ATF at the VLA site to inspect the NA prototype antenna and the test facility there. The CDL was also visited in Charlottesville. As required, additional experts from inside or outside the NRAO may be invited to contribute to the process.

3 Overall State of the North American ALMA Project

3.1 General Comments

The technical design has developed in a “bottom-up” fashion on both sides of the Atlantic, and this fact has generated some problems particularly in the final stages of the design phase. The baseline plan is still not clearly defined in all areas, and the mechanisms for ensuring eventual compliance with a baseline plan are not yet effective.

3.2 Site

We found the preparations for the site work to be reasonably in hand. Our major findings concerned the lack of a clear plan for the operation and maintenance of the array.

3.3 Antennas

The NA prototype antenna contract with Vertex is overall in good shape. Although delivery is a year later than foreseen in the original contract, Vertex has made a substantial investment in meeting our requirements and we believe that they have produced a high quality design and prototype. Inevitably the design is complex and contains some untested innovations (especially non-isotropic structural elements); our biggest worry is how we will be able to test the design for any flaws prior to placing an order for production. The present test plan may not be sufficient, but we are unable to suggest a good alternative that would fit within the desired schedule.

3.4 Front End

The Front End is undoubtedly one of the most challenging parts of the ALMA project. The challenge is increased by the international nature of the effort. For example, delays are caused by European elements on which we are highly dependent, but which are out of our control. In NA, chip-level parts are not yet available as first prototypes; this includes SIS devices for Bands 3 and 6, and LO amplifier MMICs for all bands. Engineering manpower that might be assigned to FE tasks has been preoccupied with temporary instrumentation for the ATF.

3.5 Schedule

Other than the antenna, much of the NA effort is falling behind schedule. For all electronics from the IF (output of the Front End assembly) through the correlator, there is a goal for delivery as system-ready prototypes by 4Q2003. This will allow end-to-end laboratory testing and tests at the ATF on the prototype antennas. Unfortunately, the Front End assemblies are not included in this goal, and it appears to us that many of the other assemblies will not meet it. There are significant technical problems in the development of the laser synthesizers for the central first LO reference. Design of the second LO synthesizers is progressing slowly. Development of digitizers (a European task, at the University of Bordeaux) is proceeding very slowly. On the other hand, the prototype correlator (single baseline version) is one major element that will be ready ahead of the goal.

3.6 Communication

The project has been hampered by poor communication. Our interviews indicate that those who attend the regular meetings of IPT leaders consider that those meetings are ineffective. There is excessive secrecy in the project. Some delays are introduced by the JAO, which does not always give decisions in a timely fashion. The eventual dissemination of information from the JAO could be improved a great deal.

4 Major Recommendations

This is a summary of the most important recommendations from ATAC, collected from later subsections of this report.. Further details are given in the referenced places. There are several areas where the ATAC considers that project management has been inadequate, but this is outside the scope of ATAC's report.

- Being able to demonstrate "early science" on the array is important and the ATAC strongly supports this. However, if demonstrating early science results in electronics being built specifically for that purpose, then in the long term this is very counter-productive. (See recommendation 5.3-1.) The date set for "early science" should follow naturally from the construction schedule, rather than the construction schedule being tailored to fit an artificial deadline for "early science."

- With very high priority, produce an up-to-date system block diagram and the principal interface control documents. (See recommendation 5.8-1.)

- Re-establish an effective system engineering team by (see Footnote below)[1]:

  - Ensuring that the Systems IPT leader has extensive knowledge and understanding of the system level design. To the extent that his understanding is incomplete, he must have close, daily, contact with one or more experts who can fill in the gaps. (See recommendation 5.8-2, and also Footnote 1 below..)

  - Identifying a systems core group, being the minimum number of people who, among them, understand the hardware down to the component level, the software down to the task, ICD or tool component level, and the astronomical observing requirements and lore. (See recommendation 5.8-3.)

  - Providing the Systems IPT with the necessary support and authority from the JAO. (See recommendation 5.8-4.)

  - Drastically simplifying the document approval process. (Recommendation 5.8-5.)

- Establish a clear plan for maintenance of electronic devices, including the level of disassembly and replacement that will be done (a) at the high site; (b) at the OSF; (c) elsewhere. (See recommendations 5.1-1 and 5.1-2.)

- Develop a backup design for the first LO that can be implemented in a straightforward way, even if it implies performance worse than the current goals. (See recommendation 5.4-2.)

- Establish quantitative specifications for most software components, especially with respect to timing. The high level software design treats the telescope hardware as a minor peripheral and gives relatively little attention to its detailed control and monitoring. . This thinking needs to be reversed. (See recommendations 5.7-1 and 5.7-3.) A greater emphasis on this critical area at the current stage of project development is required.

5 Detailed Investigations

5.1 Chilean sites
5.2 Antenna
5.3 Front Ends
5.4 Local Oscillators
5.5 Back End

[1] During the preparation of this report, a new Systems IPT leader, Dick Sramek, took over the systems group. This is an excellent choice which has already begun to address some of the biggest concerns of the ATAC.

5.6 Correlator
5.7 Computing
5.8 Systems Engineering & Integration

5.1 Chilean Sites

2002-11-06

5.1.1 Introduction

This investigation is based mainly on attendance by some of the subcommittee members at the Infrastructure Requirements Review, held in Tucson 2002-Oct-22..24. In addition, Emerson and Napier interviewed Simon Radford on 2002-Oct-19; Radford is the Deputy Leader of the Site IPT (Jorg Eschwey of ESO is the IPT Leader). Finally, relevant sections of the ALMA Project Plan document (dated 2002-Oct-18) were examined.

5.1.2 Findings

The site work is considered to consist of all buildings, roads, power distribution, and similar infrastructure at the high Array Operations Site (AOS) and at the lower Operation Support Facility (OSF), along with all the antenna foundations. The cost is split 35% NA and 65% EU, and due to the funding profiles all of the facilities required by 2006 are NA responsibilities, whereas those required later are EU responsibilities. NA will build 127 of the 212 foundations and most of the other facilities at the AOS, while EU will build the remaining foundations and most of the OSF. Many practical issues regarding the division of work are not decided, including how similar but divided work (like foundations) will be coordinated if separate contracts are let.

Since the NA side will do the early work, we have control of the design and could pick up the later work if necessary (although funding it would be a problem).

A US architect has been hired to develop a master plan, but so far he has little to work with. The Requirements Review meeting was just the first step in figuring out how much work space is needed and how it should be arranged. So far the basic parameters of total building area at the AOS and OSF are unknown. The IPT leaders have been asked to fill out questionnaires about their needs, but these are just being tabulated.

All buildings are scheduled to be constructed in CY2004 and CY2005, including both the AOS (NA) and OSF (EU). This is just in time for delivery of the first construction antenna in 4Q05. Construction of antenna foundations is supposed to begin in 4Q03, even before the production antenna contract is signed.

It appears that Eschwey and Radford form a good team. Eschwey has relevant experience in managing large projects, but none in radio astronomy; whereas Radford has good insight into the technical needs of the telescope.

5.1.3 Points of Concern

- The antenna configuration is still not final. This is the responsibility of the Science IPT (see also section 5.8 of this report). Finalizing the inner 4 km part is the most urgent, since foundation construction must begin in 2003, but various design issues depend on the outer configuration as well.

- Documentation on the infrastructure design is needed with some urgency. There is risk that we will be attempting to outfit and test the first production antenna without adequate facilities.

- The operations plan (in the ALMA Project Plan) is inadequate. It is critical to understand how and where the complex hardware will be maintained, since this affects its design and it determines what facilities are needed at the AOS and OSF
- Although a firm decision seems to have been made to locate the correlator at the AOS (and we support that decision), there seems to be continued discussion of moving it to the OSF, leading to confusion and wasted effort.

- Some thought has been given to accommodating a "second generation correlator" (2GC). It must be installed and tested while the original correlator is still operating. It is clear that the correlator will eventually be upgraded, and provisions for it should be made now.

5.1.4 Recommendations

5.1-1. Establish a clear plan for maintenance of electronic devices, including the level of disassembly and replacement that will be done (a) at the high site; (b) at the OSF; (c) elsewhere. This must be done separately for each subsystem. Getting the boundary between (b) and (c) correct is crucial to ensuring that the OSF is properly sized and equipped. Roughly, we recommend that (a) be at the 'module' level, (b) at the 'component' level, and (c) at the 'subcomponent' level. Exact definitions are TBD and may vary by subsystem.

5.1-2. Subcomponent level maintenance should rely as much as possible on the organizations originally responsible for the corresponding design, rather than establishing a new repair center. For example, a failed SIS mixer should be sent back to its builder for repair. Eventually this may become impossible in some cases; only at that time should ALMA develop in-house facilities, and then only for the necessary special cases.

5.1-3. Technically it would be much more effective to locate the principle data archive and pipeline processing at the OSF, rather than in Santiago, as currently planned. Partial copies of the archive will be needed elsewhere, including in Santiago. We believe that the decision to locate the **principal** data archive and pipeline in Santiago should be reexamined.

5.1-4 Providing for an eventual “second generation” correlator (2GC) should assume that the 2GC will be smaller, and have lower power consumption and cost than the original; this is due to technology advances that have *already* occurred, with further improvements predictable from Moore’s Law. Thus, a simple solution is to make the correlator room at the AOS slightly oversize. The possibility of locating the 2GC at the OSF can be handled later by an addition to the original buildings or the construction of a new building.

5.2 Antenna Development and Testing

Information was obtained from the ALMA documentation, from interviews with the ALMA Antenna IPT leader (Jeff Kingsley) and the ALMA Antenna Evaluation Group (AEG) leader (Jeff Mangum) and from close inspection of the ALMA/US prototype antenna currently nearing completion by Vertex.

5.2.1 Background

Interview with Jeff Kinsley and antenna inspection (2002-Oct-16).
L. D'Addario, D. Emerson, P.Napier and J. Payne met with J. Kingsley at the VLA site and were given a detailed tour of the Vertex antenna. Discussion included the top-level antenna procurement plan for ALMA and antenna design issues. There was insufficient time at this meeting to cover topics related to antenna testing.

J. Kingsley stated that his principle areas of concern with respect to technical performance of the antenna are the adequacy of the reflector panel surface treatment and the maintenance of the surface figure in the face of changing elevation angle and environmental conditions.. Also, neither he nor Vertex are completely satisfied with the current design of the receiver cabin HVAC system.

In general the antenna tour gave the impression that the antenna has been well designed by an experienced company. A few areas of concern (see below) noted during the tour included the anti-solar-radiation surface treatment of the reflector panels and the complexity of the receiver cabin HVAC system.

The top-level milestone goals for the ALMA/US antenna procurement effort are[2]:

Accept antenna from Vertex:	Nov., 2002 (see footnote)
Issue RFQ to Vertex for 32 and 64 antennas with revised specs:	Nov., 2002 (see footnote)
JAO finalizes unified specification/ICDs for ALMA antenna	Apr., 2003
AEG preliminary report on performance of Vertex antenna	Jun., 2003 (see footnote)
Production contract with Vertex negotiated and ready to sign	Dec., 2003
First production antenna in Chile	Q4, 2005

The schedule for accepting the antenna is very tight and will require that no unexpected problems arise during the remaining commissioning tasks and acceptance tests. Specification changes expected to be implemented before the antenna goes into

[2] Since the first draft of this ATAC report was written, the antenna delivery date has slipped, which has an inevitable impact on other milestones. Antenna Acceptance is now (as of Dec 2002) set for January 19 2003, with the issuance of an RFQ to Vertex expected in January 2003. Some of the antenna tests are dependent on good observing weather, which is seasonal; production of the AEG preliminary report on performance is likely to be delayed because the good observing season in winter 2002/2003 may be missed.

production include: degradation in surface accuracy from 20 um on the prototype to 25 um on the production antenna (this will result in a reduction of collecting area by a factor 0.75 at 850 GHz), reduction in the capacity of the UPS, reduction in the electronics heat load in the receiver cabin, removal of the access platforms on the back of the antenna. These changes should bring the production cost of the antenna close to the budgeted cost.

In the discussions of detailed design considerations it was noted that in a number of areas, such as receiver cabin HVAC system, servo system and metrology system, Vertex has not yet provided documentation that explains the detailed design and principles of operation of these complex systems. As a result it is not possible for the ATAC to be sure that all specifications will be met, but the ATAC found no evidence indicating a problem with any specification.

Interview with Jeff Kinsley concerning Vertex antenna acceptance testing (2002-Oct-31). J. Kingsley's chief concern in the area of testing is that the tests currently planned, either Vertex acceptance tests or AEG tests, may not be adequate to completely guarantee that the antenna is meeting its surface accuracy specification. The Vertex acceptance tests will use digital photogrammetry to measure reflector surface shape and quadripod deformation at a number of elevation angles, but the accuracy of the measurements will not be sufficient to determine that the various components of the surface error budget are being achieved. The Finite Element Analysis (FEA) of the mount will be confirmed by pulling on the eye brackets at the top of the yoke arms with a load cell and then reading the deformations measured by the 5 inclinometers on the structure. The temperature sensors built into the reflector and mount will be used to verify that the temperature fields used in the FEA are correct. Measurement of the resonant frequencies of the antenna will provide further verification of the FEA. The primary method for acceptance testing of the pointing specification will be by using the NRAO supplied Optical Pointing Telescope (OPT) but this does not include any pointing errors due to primary reflector or quadripod deformation.

Interview with Jeff Mangum concerning AEG antenna testing (2002-Oct-31).
The chief concern of the AEG is their ability to measure the pointing performance of the telescope to the accuracy required. Whilst the surface accuracy measurement is difficult, the AEG is less concerned with this because other radio telescopes, some with CFRP reflector backup structures (BUS), have achieved the surface accuracy required by ALMA. The AEG is also concerned that the project decision to not use interferometry for antenna testing has made both pointing and surface accuracy tests more difficult. The slips in the antenna delivery schedule have reduced the amount of good winter weather for radiometric tests to a critical level. Finally, the AEG is concerned that communication needs to be improved between the AEG and some of the ALMA groups (e.g. software) responsible for providing antenna test capabilities.

The VLA site will not allow observations at sufficiently high frequency to confirm that the surface error specification is being met by a direct measurement of aperture efficiency. The AEG will use near-field holography to measure some components of the surface error budget. Elevation dependent deformations of the surface will be measured at a few points on the surface using a quadrant detector or five-degrees-of-freedom (5D) laser interferometer mounted on the BUS. Richard Hills has recently suggested that phase-recovery holography using astronomical sources may be useful for measuring elevation dependent effects but this has not yet been studied. Other possible approaches for measuring surface accuracy that have been considered, but are not being currently pursued, include use of a laser interferometer theodolite and laser ranging measurements based on the GBT metrology technology. The MPIFR APEX antenna, to be located on the ALMA site in Chile beginning in April, 2003, will have a reflector structure that is identical to the ALMA antenna. In principle the surface accuracy specification could be confirmed by making sub-millimeter wavelength aperture efficiency measurements on this telescope, but it seems unlikely that such measurements could be made on the timescale needed by ALMA.

Tests of the pointing and fast motion specifications will be made using the OPT and total power radiometric pointing with a nutator to remove atmospheric fluctuations. Accuracy of the radiometric measurements may be limited by residual atmospheric fluctuations, especially if the schedule forces some of the radiometric work into the poorer observing months, and by the length of time (1500 sec) that it will take for a pointing measurement.

The phase stability specification will be confirmed by direct measurement of the stability of the principle components of the antenna using a 5-degrees-of-freedom (5D) laser interferometer.

The overall impression of the ATAC is that the ALMA/US antenna group has done a good job of overseeing the design and implementation of an antenna with very difficult performance specifications. The following points should receive attention, but none of them are “show stoppers.”

5.2.2 Areas of Concern

- Reflector surface accuracy specification. The antenna BUS is a novel design not previously used for high performance antennas and must be thoroughly tested before committing to production. The FEA of the ALMA CFRP/aluminum honeycomb laminate BUS is significantly more complex than previous CFRP BUS analyses and requires more testing than Vertex has done to date. The critical test planned by the AEG is measurement of the deformation of a few points on the BUS surface using a quadrant detector and 5D laser interferometer to determine if the measured deformations confirm the FEA model. Since only a few points will be measured, one at a time under possibly varying environmental conditions, and the FEA has limited accuracy anyway, the interpretation of these data will be very difficult. There is a significant risk that even after these tests, there will not be sufficient confidence in the design to warrant going into production.

- Failure to implement interferometric tests, as originally intended, is a major limitation on our ability to evaluate the antenna and may cause the evaluation to fail. Interferometric holography would have allowed the surface to be measured over the necessary range of conditions, and interferometric pointing is far more accurate and more immune to atmospheric effects than radiometric pointing. It is understood that the lack of interferometry was forced on us by the lateness of the second antenna and necessary interferometric instrumentation.

- The schedules allowed for both Vertex acceptance and AEG testing are extremely tight. Any significant problems with antenna hardware or unexpected test results requiring redesign or repetition of tests will cause schedule slippage. The Vertex antenna is sufficiently sophisticated in design that such problems can be expected.

- Reflector panel surface treatment. Detailed inspection with a magnifying glass of the surfaces of various reflector panels suggested that either more than one surface treatment is being used or the results of the treatment is quite variable between panels. Also, the results of the solar diffusivity tests suggest that the attenuation of solar heating near the subreflector may be marginal.

- The HVAC system for the receiver cabin appears to be overly complex, is currently inadequately documented and is likely to be a maintenance headache.

- Although the servo simulations indicate that the antenna will meet its pointing and fast switching specifications, there is inadequate documentation explaining how the servo system works, including such major issues as how the fast-switching profiler works and how the metrology measurements are used to correct the pointing.

- The competitive nature of the US and European prototype antenna contracts and the resulting requirement for commercial confidentiality has had a noticeable negative impact on communication between the antenna group and other parts of the ALMA project and other parts of NRAO that have related experience. Communication between the AEG and other ALMA groups needs to be improved.

- Minor issues: The lightning protection cabling on the prototype antenna does not conform to the Vertex lightning design memo. Various non-metallic components on the outside of the antenna (e.g. rubber door fasteners, plastic vent covers) will probably not stand up to the extreme UV radiation of the Chilean site. The shroud for the inside of the quadripod legs, intended to reduce the scattered ground radiation reaching the receiver, has not yet been designed. These issues can easily be corrected for the production antennas.

- We are concerned that the plan for the antenna testing may have made unrealistic assumptions with regard to receiver performance. The 3mm receiver has been designed using HEMT amplifiers and, due to 1/f limitations may give a performance that is for from theoretical.

5.2.3 Recommendations

5.2-1 Develop additional tests to provide more confidence that the reflector is meeting all aspects of the surface accuracy specification. A test is needed that is sufficiently detailed to determine that the BUS is behaving linearly and without hysteresis and according to the FEA, under influence of gravity, thermal and wind loading. Possible tests could be based on a laser interferometer theodolite, the GBT laser ranging metrology, phase-recovery holography or interferometric holography. Also, work with the APEX group to see if their high frequency measurements can be done quickly enough to help ALMA.

5.2-2 Continue studying the reflector panel surface treatment issue to be sure that the treatment planned for the production antennas will be acceptable. Do a careful heating test on the prototype antenna to determine if the achieved solar diffusivity is adequate. Do a proper RF resistive loss test on a panel sample (the tests to date measure total reflective loss but do not determine how much of this loss is resistive).

5.2-3 Try very hard to make the receiver cabin HVAC system simpler on the production antennas.

5.2-4 Obtain full design and theory of operation documentation on those subsystems for which it is currently lacking, including the. HVAC system, servo, pointing metrology. This documentation will be required for commissioning and maintenance and will also be required if, as is currently planned, the European partner has to go to open bid for the Vertex antenna. The documentation should be obtained as a condition for final release of the contract payment retainage.

5.2-5 Review the current system for enforcing commercial confidentiality; as implemented at present, it is seriously hindering communication between the antenna, AEG and other groups within ALMA and NRAO.

5.3 Front Ends

2002-11-01

5.3.1 Introduction

This part of our investigation concerns the North American (NA) tasks of the Front End (FE) IPT. We discuss to some extent components of the local oscillator subsystem that are assigned to the Front End, but the LO is covered in more detail by a separate subcommittee.

The subcommittee's investigation consisted mainly of interviews with many individuals, including Charles Cunningham, Antonio Perfetto, and Wes Grammer (in Tucson around 2002-Sep-11); Tony Kerr, Eugene Lauria, Geoff Ediss, Eric Bryerton and Skip Thacker (in Charlottesville on 2002-Oct-04); and several others by telephone. Most of these interviews were in private, with only the subcommittee and one interviewee present. In addition, the subcommittee members attended the FE review meeting held in Charlottesville 2002-Oct-03..04.

A list of engineering staff working on the ALMA FE is given in Appendix FE-1, including all those at the NRAO and some key persons at other institutions, along with their current assignments as far as we can tell. Not included are some Tucson engineers who are now working full time on the ALMA Test Facility (ATF) electronics, but who are expected to be working on the FE in the future.

5.3.2 Findings

Roughly half of the major FE tasks are assigned to NA and the others to Europe, including:

Cryogenics, dewar, cartridge mechanical parts - EU (RAL - UK)
Optics design, all bands - EU (IRAM - France)
Band 3 cartridge - NA (HIA - Canada)
Band 6 cartridge - NA (NRAO - CHO)
Band 7 cartridge - EU
Band 9 cartridge - EU
LO drivers, all bands - NA (NRAO - CHO)
LO multipliers, all bands - NA (NRAO - CHO)
IF switch and back end interface - NA (NRAO - TUS)
Integrated FE assembly - NA (NRAO - TUS)

In addition, some critical parts (e.g., ortho-mode transducers (OMT) for bands 3 and 6, bias electronics for cold devices) and subsystems (monitor and control interfaces and firmware) are assigned to NRAO-TUS. For financial reasons there is a plan to have the IF Interface module produced in Spain, although design responsibility remains in NA.

This arrangement gives the NA side control over a great deal of the design. We are dependent on Europe for the dewar and cryogenics, but we have the capability of taking over that work if necessary. We are very dependent on European groups for SIS mixers for the high frequency bands; NRAO has never built SIS receivers above 300 GHz.

Although NA is also formally responsible for LO frequency multipliers, the actual plan is to purchase them commercially from Virginia Diodes, Inc. This is a sole source procurement of new and unproven devices from a small company, and thus a significant risk.

In addition, the NRAO is responsible for building all the electronics to support the ALMA Test Facility at the VLA, including two "evaluation" front ends. These have been built entirely in Tucson with no participation by the CDL or from Europe, and little of the design will be kept for the array FEs. This hardware is finally nearing completion, about two years behind the original schedule if it is delivered in 2003-Jan as now intended. There is not a clear plan for supporting it after delivery

Charles Cunningham has prepared a draft schedule for the FE tasks. This is heavily influenced by the desire for “early science” in 2007-October, to the extent of producing 8 prototype copies in parallel, all of which are likely to differ significantly from the eventual production FE assemblies to come later.

We have not investigated in detail the Band 3 Cartridge design that is being done at HIA (Victoria, BC). We know from discussions with S.K. Pan of the CDL that they will use Pan's design for the elementary mixer, and that tests of a single-mixer version have shown good performance over the specified band at the full IF bandwidth. SIS chips will be produced at University of Virginia (UVa) under a contract with HIA, independent of NRAO's contract with UVa for the Band 6 SIS chips. As far as we know, that contract is not yet in place. It does not seem completely clear to everyone that the receiver will use 2SB mixers scaled from the Band 6 design, with integrated IF amplifiers identical to those for Band 6 Another important component of the cartridge is the OMT. This is the responsibility of Wes Grammer in Tucson, and an initial production run of these has already been made. There is some talk of requiring Grammer to re-design the blocks to make packaging of the cartridge easier, but we see this as an unnecessary cause for delay.

The Band 6 Cartridge design, being done at the CDL, was examined more fully. The SIS mixer is a sideband separating type with waveguide hybrids and two single-ended mixer chips in one block. The favored design of a year ago was more integrated, with RF and LO hybrids on-chip; still earlier, an even more sophisticated approach with balanced mixers (4 elementary mixers altogether) was favored. This earlier approach has been abandoned because the SIS chip yield is insufficient. It is disappointing that the successful balanced design was dropped, since the present plan discards 99% of the LO power, and that the more complex sideband separating approach was retained, since its scientific value is questionable. The latest chip design is now being fabricated at UVa. If this is not completely successful, so that another iteration is required, then the schedule cannot be met. It is clear that SIS wafer/chip production is on the critical path for the whole receiver. (This is no doubt true of the European bands as well.) In NA, UVa is the only feasible foundry for these devices. Earlier this year, NRAO had a parallel contract with SUNY, but this was dropped for budgetary reasons and also because the technical competence of that group was being eroded. Another potential source is JPL, but they are expensive and they no longer have equipment to produce the Nb-NbO-Nb junctions that we need. In production, it is estimated that 9 UVa wafers are needed to get all the necessary chips, considering yield; the planned contract calls for 3 wafers per year for 3 years.

The cold IF amplifiers seem to be in good shape, under Gene Lauria. They will be made in separate blocks and bolted to the mixer block, with electrical connection by bond wires. A separate amplifier is used for each elementary mixer, with a passive IF hybrid following (COTS). Amplifiers will be tested separately and selected for phase and gain match before being mated to mixers. These amplifiers use discrete transistors, not MMICs. Existing MMIC designs (from JPL) give good performance but have excessive power dissipation for our 4K environment, and the best transistors (JPL's "cryo 3" wafer) are discrete. Gene has been in touch with SRON about using the same amplifiers with the Band 9 mixers, but there has been no interest from IRAM about Band 7. In production, a total of 256 amplifiers is needed to support Band 6 alone, and 280 are planned to allow for matching by selection.

Design of the rest of the Band 6 Cartridge is proceeding slowly, at the CDL. This is mainly a matter of mechanical and thermal design. The OMT is the responsibility of Wes Grammer in Tucson, who has the first test devices with good results although some re-design is needed to make their waveguide interfaces mechanically compatible with the mixers and the cartridge space. Prototypes are expected in 3Q03.

Design of the cold optics (mirrors and feed horn) is the responsibility of IRAM; the CDL is responsible for fabrication and testing. There are conflicting analyses of the optics from James Lamb (OVRO), Srikanth (CDL), and C. Tham (Cambridge). Lamb did the original design (ALMA Memo 362). The latest design is significantly different. We talked to Lamb before our visit to the CDL and his feeling was that the design has been modified for the wrong reasons. Greater understanding of the proposed design is needed in CV.

There are plans for large and complex test facilities at the CDL, and for this reason , a dedicatedtest setup for SIS mixer/preamps is needed. It is estimated that four cycles of mixer assembly, cooldown/test, warmup, disassembly will be needed before one good mixer is produced. A new, automated setup is planned at a cost of about $1M. A separate test facility for the completed cartridges is also planned at a similar cost.

5.3.3 Areas of Concern

Technical Issues

- Band 6 optics design is not understood at the CDL, and this creates an excessive dependency on Europe. It is reasonable to have one person responsible for the optics of all bands (Matt Carter at IRAM) so as to ensure consistency, but if the NRAO is responsible for the Band 6 performance then we must have full understanding of the design, the ability to check it, and the possibility of proposing changes if necessary.

- Test systems at the CDL are being overbuilt. The two levels of testing (mixer and cartridge) involve considerable duplication of hardware. Present plans call for construction of completely new equipment rather than re-use of existing facilities. Software for the test systems (and for existing test systems) is also overdone.

- The plan for SIS mixer manufacture seems unsuited to volume production. It allows for 75% failures, or 4 assembly attempts before one good mixer is obtained. Half of the failures are expected to be due to assembly errors and half due to bad chips. If the failure rate could be reduced to ~10%, testing at the mixer level could probably be skipped. We predict a production rate improvement of about 5x, and a corresponding cost decrease and schedule improvement.

- The mm/submm frequency multipliers from Virginia Diodes are not yet proven, especially for cryogenic operation. We have no backup plan if they have difficulties with performance or delivery. (See the LO subcommittee's report for more details.) Although NRAO is formally responsible for delivering the Band 7 and 9 multipliers to Europe, we cannot guarantee their performance and we have no facilities for testing them.

- The SIS chip fabrication foundry at UVa is a single-point of failure that constitutes some risk. Like most academic groups, they cannot provide guarantees of delivery, in contrast to commercial contractors. However, we see no viable alternative and we believe that UVa must be fully supported and well supervised in order minimize the risk.

- The "integration center" task in Tucson is not well specified. This is not surprising as the far more important job of actually designing the receiver has yet to be accomplished.

Management Issues

Although ATAC was not asked specifically to review ALMA management, some factors that are strictly management issues inevitably have a strong impact on the technical progress and development of the project. We think it worth mentioning the following points:

- We consider Charles Cunningham to be a good choice as the overall manager of the ALMA FE effort, but, like anyone in this position, he is having trouble keeping up with the work at many widely distributed sites while also satisfying demands from upper management for reports and reviews.

- The recently-developed schedule is not credible. Cunningham's Gantt chart does not show all the dependencies, and it shows no contingency. Task durations need realistic estimates. The Europeans have not yet agreed to it. Part of the problem is that estimates of time and cost of each task are too conservative, to the point of being padded with hidden contingency. (This is true throughout the project, not just in the Front Ends.)

- The schedule is driven by a desire for "early science" in 2007. This is not realistic. It will result in considerable waste because some designs will have to be re-done for production, and because about 8 systems will be built before any is fully tested, so all are likely to need rework. It would be far more efficient to build and test a smaller number of prototypes before beginning production, although still sufficient to support early interferometer testing. “Early science” is very important and a worthwhile goal, but should be matched to the schedule so as to avoid undue duplication and waste of effort, which in the long term will delay completion of the project.

5.3.4 Recommendations

5.3-1 Being able to demonstrate “early science” on the array is important; however, the schedule should be designed to lead to the final telescope (64 antennas) in a logical and efficient manner, so that the whole thing is finished and working correctly as soon as possible. The date set for “early science” should follow naturally from the construction schedule, rather than the construction schedule being tailored to fit an artificial deadline for “early science.” The ATAC believes that “early science” will be possible well before completion, and that a reasonable milestone can be set for it. But setting this milestone artificially and building the larger schedule around it makes the larger schedule inefficient and delays completion of the full telescope.

5.3-2 Make a serious effort to improve the manufacturing efficiency of SIS mixers by examining the process from a production viewpoint rather than as a research project. In the present plan, 88% of the chips end up being discarded and 75% of the assembled mixers fail when first tested. These rates must be drastically reduced.

5.3-3 Re-define the "deliverable" subassemblies so as to keep each one as simple as possible and reduce the number of separate integrations (assemblies that are delivered from one site to another). . One of us has analyzed the present plan and finds that it requires about 56 such integrations, whereas one possible re-organization would reduce this to about 40. Subassemblies should nevertheless be large enough so that they can be tested separately and so that their interfaces are clearly defined. In particular, the Warm Multiplier Assembly (WMA) should not be considered part of each cartridge (see also the LO subcommittee's report).

5.3-4 Allow band 7 and band 9 groups in Europe to purchase frequency multipliers directly from Virginia Diodes without going through NRAO. This avoids duplication of work. The CDL is not set up to test these devices, and need not be, whereas the European groups need to be. Delete the NRAO tasks associated with these multipliers. Allocate money accordingly. (The existing orders by NRAO for 2ea. band 7 triplers and 5ea. band 9 quintuplers should be completed but the devices should be sent directly to Europe for acceptance testing.)

Appendix FE-1: Front End Engineers and Their Current Assignments

Cunningham - IPT management
Perfetto - Tucson management (partly in back end IPT)
Freund - FE systems engineering

Kerr - SIS mixer design
Pan - SIS mixer design
Lauria - IF preamp design; mixer/preamp test facility development
Horner - Mixer/preamp fabrication
Ediss - cartridge layout and integration; optics (depends on IRAM)
Koller - cartridge test facility development
Effland - test automation software; schedule management

Bryerton - LO chain
Thacker - LO chain
Saini - Cold multipliers Part time on FE:

Grammer - OMT, bias, M&C
Shillue - photomixer (merely supervising RAL/E^2T)

Lichtenberger (UVa) - SIS device fabrication

Canada:

?(HIA) – band 3 cartridge and components

Europe:
Dewar and Cryogenics.
Band 7 Cartridge.
Band 9 Cartridge.
Optics for all bands.

5.4 Local Oscillators

5.4.1 Introduction

The Local Oscillator subsystem for ALMA consists of (a) components at the central equipment building for generation of timing reference signals over a wide range of frequencies; (b) transmission of the reference signals to each antenna over optical fiber, along with equipment for maintaining constant phase delay in the transmission; (c) components at the antenna for generating the three main LO signals so that they are coherent with the references; and (d) distribution of precise timing signals to other subsystems at the center and at each antenna (especially monitor/control and correlator).

The three LO signals used directly in the signal processing are: the first LO for the front end (29 to 948 GHz); the second LO to convert from IF to baseband (8 to 14 GHz); and the variable phase digitizer clock (4 GHz). We choose to treat the digitizer clock along with the digitizer in a separate section of this report.

For the first LO, the ALMA project has assigned responsibility for most of the antenna-based components to the Front End IPT and for most of the central and distribution components to the Back End IPT. We treat them together here.

The present schedule requires delivery of prototype modules for all parts of the LO subsystem by the end of 2003. Quantities sufficient for two antennas are planned, so as to allow laboratory integration of a pseudo-interferometer and later installation on the prototype antennas.

The material presented here includes input from:

The Front End review of 2002 Oct 01-02
LO workshop of 2002 Nov 19-20
Several Interviews on 2002 Oct 02 with Saini, Thacker, Bryerton
Several discussions with Shillue, on various dates.

5.4.2 Findings

5.4.2.0 General

Top-level specifications for the LO system are given in the Project Book, with the relevant section last edited in CY2000. There the overall phase noise and drift are derived from first principles for the most difficult case, band 9. This was done after allocating a substantial part of the error budget to uncorrected atmospheric fluctuations and to the antenna structure. The remaining budget for the electronics is very small (e.g., 2 deg of phase drift at 948 GHz). There is no agreement on a further allocation of the errors within the electronics (the Project Book contains only placeholders for this information), although it is logical to give most of it to the first LO and most of that to the 25 km (worst case) transmission path. There is a widespread feeling that the total allowed error is too stringent and not achievable by any method, but there is no agreement on what to do about this.

5.4.2.1 First LO

Important technical issues remain unresolved at all stages of the first LO, including:

1. Frequency multipliers at mm/submm wavelengths. The ability of Virginia Diodes to deliver triplers and quintuplers meeting the promised specifications is in doubt. Prototypes for bands 7 and 9, ordered early in 2002, are now 4 months late and are not expected for several months more due to fabrication failures. Prototypes for band 6 were delivered 3 months late; they do not to meet the efficiency specification, but nevertheless appear to be acceptable. There is no backup plan if Virginia Diodes cannot deliver adequate prototypes as well as production quantities. The NRAO is formally responsible for acceptance testing of all multipliers, but is not equipped for testing any except band 6.

Further background: In the present design, the final LO stage for band 4 and higher is a cryogenically operated multiplier. Sufficiently efficient tunerless multipliers covering the relatively wide ALMA bands did not exist before ALMA began, so this was a significant challenge. An in-house development effort was initiated at the NRAO in 1998 but it was abandoned in 2001 because of slow progress and the promise by a small company, Virginia Diodes, to produce the needed devices.

2. YTO/WMA assembly sideband noise problem. The present design involves an amplifier/multiplier chain starting from a YIG-tuned oscillator at 11.4-23.6 GHz. Phase noise and drift are limited by locking to the distributed reference at 27-142 GHz, and this appears to be under good control. But a power amplifier and higher-frequency multipliers are outside the PLL, and their phase stability remains a concern. More significantly, sideband noise (which increases the noise temperature of the mm/submm mixer) is a problem. Available components for the amplifiers and multipliers have noise temperatures that are too high, producing excess noise of tens to hundreds of K at band 6. This might be mitigated by careful design, addition of tunable filters, and selection of different components, but a satisfactory solution is not yet available. In addition, it is necessary to have fine adjustment of the LO power actually delivered to each SIS mixer. It is planned to accomplish this via bias changes to the last power amplifier, but this has not been tested and may exacerbate the sideband noise problem.

3. Reference generation: slave laser problem. The planned method for central synthesis of the first LO reference as the beat note between two lasers requires that one laser be tightly phase locked to the other. The locked, or slave, laser must be widely tunable but must also have a line width much smaller than its frequency modulation bandwidth. Lasers with the appropriate specifications have proved to be very difficult to obtain, even though the published literature has included examples of them for several years. Recent tests of a candidate commercial laser were not successful. Ideas exist for solutions using available lasers, but they have not yet been developed and the present schedule leaves little room for additional experimentation.

4. Reference transmission: master laser problem. The planned method for stabilizing the fiber transmission path length involves forming an optical interferometer over the entire fiber length at the master laser wavelength. This requires that the frequency of the master laser be unusually stable over a wide range of time scales. Techniques exist to build such lasers, but they are not off-the-shelf devices and we do not yet have a sufficiently stable laser on hand. Several companies have proposed to supply special lasers to the ALMA specification, so it is known that the requirements are feasible; but this is expensive and time consuming.

5. Reference transmission. It is possible, but not established, that transmission of a mm wavelength reference through long (>15 km) optical fiber may not be achieved with the accuracy desired for ALMA (~1 micron) because of second-order effects in the fiber itself, including dispersion, polarization, and non-reciprocity. For example, if polarization varies differently with fiber stress for the two optical wavelengths, then the beat note phase will vary. The magnitude of any such effects is presently unknown; the existing literature concentrates on data transmission applications, yielding only limited insight for our case. Both theoretical and experimental studies are needed to resolve this.

Achieving the prototype delivery milestone in one year will be very difficult under these circumstances.

The above discussion covers the so-called "baseline" design, also known as the high-frequency photonic reference approach. Alternatives to this approach are under discussion. One of these, the "hybrid photonic" approach, would substantially simplify the antenna-based part of the first LO, reducing construction costs and improving reliability and thereby reducing operating costs. However, its adoption would introduce additional unresolved technical issues.

Fallback approaches, which might involve a reduction of performance or added complexity but which would eliminate some of the technical risks, have also been suggested. These include: (a) reducing the highest distributed reference frequency to the microwave region and using a much higher multiplication factor at the antennas; and (b) distributing an optical-frequency comb for the first LO reference rather than just two carriers, with the desired pair of comb lines being selected at the antenna. Both of these allow eliminating the central slave lasers. Both preclude the hybrid approach, so adopting them involves forgoing those savings. Option (a) is certain to produce reduced performance, so it should not be pursued. The feasibility of option (b) requires further study.

5.4.2.2 Second LO

Four independent Second LO Synthesizer modules are needed at each antenna, one for each polarization pair of baseband channels. More development work for these modules needs to be done. The current design involves generating a comb of harmonics of 125 MHz up to 14 GHz, and locking a YTO in each synthesizer to one of these harmonics. The comb would be produced in a common module and distributed.

An ALMA engineer working on this task resigned in August 2000 and this task was taken over by a VLA LO engineer. The design work continued; a high frequency counter board was developed; the phase lock board and RF sections of the design were implemented; the on board microprocessor was coded and used to coarse tune the YIG oscillator leading. The module was assembled in the lab and successfully phase locked, but was out of spec for phase noise. This is attributed to the OmniYig oscillators which did not meet their phase noise spec.

Work on PLL loop bandwidth, the choice of phase detector and the YIG oscillator continued until February 2002, when this engineer had to stop work on this project to concentrate on the EVLA. Work continued on a slightly different design to meet EVLA specification. An ALMA engineer will be hired to finalize the ALMA design and carry it through production.

There are several outstanding technical risks. The comb generator design is critical, and simple approaches produce poor phase stability because of the large multiplication factor. A broad band distribution network for the comb is also needed, making reflection errors difficult to control. The choice of YIG oscillator and the comb distribution should be reviewed.

While the job is relatively straightforward in that no new technology is involved, considerable care is needed to achieve adequate stability and phase noise along with unambiguous phase reproducibility.

5.4.2.3 Timing

We usually discuss microwave signal timing in terms of phase and low-frequency signal timing more directly, but both are the same thing. In all cases, we are attempting to achieve synchronization among the widely distributed antennas. The timing of each of the three main LO signals has an ambiguity interval equal to its period, since one cycle is indistinguishable from another. For some purposes, much longer ambiguity intervals are needed. In particular, the first and second LOs will be partly generated by direct digital synthesizers (DDSs) with very fine resolution; to achieve unambiguous phase in the final LOs, the DDS timing must be accurate to a small fraction its reciprocal frequency and the ambiguity of this timing must be smaller than its reciprocal resolution. To achieve this, a low frequency timing reference with period 48 msec is distributed from the center. This must be received and distributed at the antenna with a precision of several nsec. The 48 msec signal is used within the DDSs to extend the ambiguity interval; further, arbitrarily large, extension is achieved by the monitor/control system provided that it can guarantee the receipt of a command within a known 48 msec interval.

Transmission of the precise timing reference from the center and its distribution within the antenna is part of the LO subsystem. Preliminary designs for this have been implemented for the ATF, but they are known to be inadequate for the array. So far, very little work is being done on an improved design. As with the second LO, this is relatively straightforward but tricky, and it requires an experienced engineer.

5.4.3 Points of Concern

Some of the items here are also discussed under "**Findings**" above.

- Specifications are very ambitious and may be impossible to achieve.

- We are dependent on a small, startup company for the high frequency multipliers. These are critical devices for which we have no alternative supplier nor any fallback plan.

- There is inadequate engineering expertise within NRAO to carry out designs of the second LO synthesizer and timing reference distribution.

5.4.4 Recommendations

5.4-1. Consider creating a separate division for all LO work, including fixed reference distribution, 2nd LO synthesizers, and all parts of the 1st LO. This would consolidate things that are now split between the Front End and Back End IPTs. Whether this would be the same "IPT" as the one that handles signal processing or a completely separate one is not important.

5.4-2. Develop a backup design for the first LO that can be implemented in a straightforward way, even if it implies performance worse than the current goals. The first LO "baseline" photonic reference design has numerous risks and unresolved technical issues, so this is an attempt to mitigate the risk. The backup design effort should be small and short term, on paper only, so as not to distract the engineering staff from the main development.

5.4-3. Maintain the small effort now being expended on an alternative design for the first LO. The rapid developments in photonic technology must not be ignored, even if they are not quite as rapid as we might like. It can now be predicted with confidence that, long before ALMA begins operation, a direct photonic LO (only a photomixer at the antenna) will be possible up to band 6 and that a "hybrid" photonic LO (photomixer + mm amplifier + multipliers) will be possible at all higher bands. Besides resulting in a simplification of the electronics out at the antenna, one important motivation for this is that it reduces the danger of self interference by removing high frequency oscillators and multipliers from the antenna. Most (but not all) of the problems associated with implementing this are also problems for the baseline design, so they are being addressed in the baseline development. In any event it is most important for future improvements in ALMA that steps are not taken today to preclude these developments.

5.4-4. To the extent that the mm/submm frequency multipliers for band 4 and above are purchased commercially (as now planned), let them be procured directly by those responsible for the corresponding FE cartridges. (See also the similar recommendation under Front Ends.) The LO group's deliverables for the 1st LO then end at a 70-142 GHz interface; this interface needs to be better defined. This LO hardware should be delivered to the FE integration center, not to the cartridge builders; it should not be considered part of the deliverable cartridge.

5.4-5. Augment the engineering manpower in Socorro with an experienced microwave engineer having knowledge of low noise oscillators and PLLs. (We note that the Back End IPT is already addressing this and that such a position is being advertised.) The existing personnel lack the experience to handle the design of the 2nd LO synthesizer (which is far behind schedule) or the subtle problems involved in the low-frequency reference distribution and DDS programming.

5.4-6. Do not pursue microwave frequency transmission of the first LO reference. It is not a technically viable alternative to the baseline.

5.4-7. Insist on delivery of true prototypes of each major assembly ASAP, even if late. Substitution of temporary “throw-away” versions is, in the long term, inefficient use of project resources.

5.5 Back End (excluding local oscillators)

The Back-End investigation is based on:
. A meeting on 2002-Oct-18 between Sramek, Thompson, D'Addario.
. Informal discussions with Socorro-based engineers, including Peereboom, Langley, and Long in 2002-Oct.
. A review of documents from the PDR of 2002-Apr.

5.5.1 Introduction

The ALMA "Back End" is here understood to include the signal processing electronics from the IF (4-12 GHz) outputs of the front end assembly to the digital inputs of the correlator. Administratively, this is all the responsibility of the Back End IPT, but this IPT is also responsible for many components of the local oscillator subsystem. We have chosen to cover all of the local oscillator in a separate section of this report, so the present section considers only the signal processing chain just delineated. Specifically, it includes the downconverter modules at the antennas that convert from IF to baseband (2-4 GHz) and provide total power detection; the digitizers and their clock generators; and the data transmission system (DTS) for transmitting the digitized signals to the correlator over optical fiber. The DTS includes digital formatting electronics, photonic transmitters and a wavelength division multiplexer at each antenna; optical fiber cables; and fiber management, optical switches, photonic receivers, and data de-formatting at the central equipment building.

Various modules are at the margins of other subsystems, and could arguably have been included elsewhere. The second LO synthesizers are closely associated with the downconverters, but because of the technologies involved we have chosen to consider them with the other LO components. The digitizer clock is logically the third LO, but we have included it here as part of the digitizer subsystem. The DTS receivers and de-formatters are physically installed in the correlator rackes, but we include them here rather than as part of the correlator.

Overall design responsibility for the Back End subsystem is in North America at the NRAO, but some of the components are European tasks. These are the photonic parts of the DTS (transmitters, receivers, optical cable, optical amplifiers, optical switches), assigned to Jodrell Bank; the digitizers, assigned to University of Bordeaux; and the digitizer clock, assigned to IRAM. The remaining components are being developed by an engineering team in Socorro. They consist of the Downconverters, DTS Transmitters and the DTS Receivers. The DTS modules include integration of the photonic parts, mostly commercial, selected by Jodrell Bank.

5.5.2 Findings

Downconverters
The downconverter development has been proceeding slowly for several years, partly as a result of turnover in personnel. It was originally conceived as a single plug-in module, of which two would be required per antenna (one for each polarization, servicing two IF inputs and four baseband outputs). Each such downconverter has now expanded to three modules, one for the IF circuitry (filters, switches) and mixers, a second for baseband circuitry (more switches and filters, variable attenuators, and total power detectors), and the third for monitor and control interfaces. An engineer is assigned to each part, even though the original concept was expected to be handled by one engineer.

There should be an attempt at greater integration to save production costs.

Digitizers
The digitizer development is an important European task, and is on the critical path; unfortunately, it is progressing slowly and is late. The digitizer clock plan is unorthodox.

Digital Transmission System (DTS)
The DTS transmitters and receivers being built by NRAO are now in good shape, after some false starts and difficulties with components.

The DTS photonics (EU) is reported to be in good shape; and NRAO staff seem satisfied with the coordination with Jodrell Bank. As this is primarily a European responsibility, it has not been directly investigated by ATAC.

5.5.3 Points of Concern

.There is a danger of RFI (radio frequency interference) being generated in the receiver cabin from high speed electronics, which could interfere with observations. This is not an insuperable problem, but does need to be taken into account.

- The DTS is perhaps overly complex.
- Unreasonable choices of fabrication techniques in downconverter
- Overly stringent "requirements" have been adopted for the downconverter (1% linearity, phase invariance of gain).
- The digitizer development is too slow, with poor architectural choices and no fallback or alternative. Strong EU dependency.
- The digitizer clock plan is unorthodox and needs careful review.

5.5.4 Recommendations

5.5-1. Get a knowledgeable engineer to review the work on the baseband section of the downconverter. The cost effectiveness of the implementation currently being pursued is questionable, especially considering that progress has been very slow. Specifically, the attempts to build phase-invariant step attenuators out of discrete components are unnecessary; commercial devices should be used. The attempt to build all filters as printed structures may or may not be reasonable, so a careful review is needed. The use of silver-plated traces on special substrates is also questionable, especially in view of the high cost. In any case, a firm deadline for delivering a prototype module must be set, along with reasonable earlier deadlines.

5.5-2. Develop a backup plan for obtaining prototype digitizers, and perhaps for production digitizers. Note that this task is assigned to Europe, it has insufficient visibility to the US-based IPT Leader, and it appears to be behind schedule. Failure to deliver a prototype (including the digitizer proper, the required demultiplexer, and the clock generator) by late 2003 will delay the planned integrated lab tests; although this date is promised, it may be too optimistic. A temporary substitute should be investigated.

5.6 Correlator

5.6.1 Introduction

The correlator development and construction takes place in Charlottesville, at the CDL, under the guidance of Ray Escoffier. Ray and other staff at the CDL were interviewed.

Two critical dates for the correlator shown in the program plan are Sept. 30, 2003 for delivery of the two-antenna prototype to the VLA site, and Sept 30, 2004 for the delivery of the first quadrant.

5.6.2 Findings

Development up to this point has been concentrated on the boards that are required, of which the principal ones are as follows.

1) A board that receives the fiber signal from an antenna and distributes the data in 125 Mbit/s streams. This is being designed and made in Socorro.

2) Filter board with FIR digital filters.

3) Station Board. Includes memory chips for the delays.

4) Correlator board.

5) Long-term accumulator board. Provides data averaging and also control functions for correlator board.

- **Filter Board** A possible remaining problem concerns power dissipation of the tap-weight multiplier FPGAs, of which there are eight on each board. The power dissipation per chip is 4W, which Ray believes is too high to allow adequate cooling. A proposed solution is to replace these FPGAs with ASICs, which would use the same package size and pin connections but would omit the circuitry that provides the programming capability: that is the programmable interconnections of gates would become hard-wired. Ray estimates that the power dissipation could be reduced by a factor of 2 to 4. Getting such ASICs produced is straightforward, but it is necessary to be sure that the configuration of gates is correct since reprogramming would not be possible. In addition to the digital filters, the board contains delay circuitry that allows fine adjustment in steps of 1/16 of the sample interval. A prototype filter board was tested satisfactorily, except for the power dissipation. A test report, dated Dec. 4 2000, has been written. The test board incorporates all the functions of the final board except for a chip to allow readout of the board serial number by the monitor and control system. It is planned that the filter boards for the two-element prototype correlator will use the FPGAs, and conversion to ASICs will be made after testing of the prototype in two-element observing.

- **Station Board** The station board contains the main delay RAM chips. These provide time delay that is variable in steps of 32 sample intervals, and the finer delay is implemented on the filter board. Re-ordering of the samples in the input streams as required for the correlator board also occurs on the station card. A prototype station board has been built and satisfactorily tested. The test report is dated April 1 2001.

- **Correlator Board** The correlator board contains the correlator ASICs, approximately 200 of which have been received from the manufacturer. Although each of these chips had been tested by the manufacturer before shipping, approximately five failed when tested at NRAO. These were returned to the manufacturer, who found that they could be made to fail if their temperature was increased. It was also found that chips failing at NRAO could be made to pass the tests by cooling. It is necessary that the testing by the manufacturer should reliably indicate chips that are satisfactory for the NRAO application, since for the main correlator construction NRAO will not have the capacity to test all chips received before they are installed on the boards. The chips are supplied in a 240-pin, surface-mount, package and to replace a chip requires special equipment that is not available in NRAO-Charlottesville. Thus boards would have to be sent back to the board-assembly house or to NRAO-Tucson. Ray points out that there is nothing unusual about the correlator ASICs that should make them difficult to test, and believes that the testing problem can be worked out. The acceptance rate of these chips by the manufacturer is approximately 80%, and the power consumption is about 1.5W compared with the goal of 2W, so in these respects the chips are very satisfactory. Testing of a prototype correlator board is in progress

- **Long-Term Accumulator Board** The long-term accumulator board provides averaging of the output data from the correlator. Testing of a prototype board is progressing and no problems are anticipated. The board contains the capability of switching the input data between different binning registers at intervals of 16 msec. This has been envisaged as necessary to enable beam switching by subreflector wobbling, and possibly could also be used for sideband separation by quadrature phase switching.

- **Other Boards** The correlator will also require a further data-averaging board, although this is not needed for the two-antenna prototype. Other boards include a station control board and power supply boards. The latter provide 1.3 and 3.3 V from 48 V DC input.

Other issues:

- **Correlator for a Compact Array** The possible addition to ALMA of a compact array would require additional correlator capacity. Ray says that it is now too late to redesign the correlator to accommodate more than 64 antennas. However, it may not be necessary to cross-correlate the antennas of a compact array with those of the main array. It would be easy to make a second correlator for up to 32 antennas using the same boards as for the main correlator. The only change would be redesign of the motherboards to avoid having empty slots take up rack space
- **Software** Two software people, Jim Pisano and J. Perez, both located in Charlottesville, are currently developing software for the correlator. A third person is expected to join them. Ray estimates that the software effort is running about six months behind the hardware, but believes that the overall effort will achieve the required dates for the two-antenna prototype and the first quadrant in the program plan

5.6.3 Points of Concern

There are no major points of concern. The issue of power dissipation (see **Filter Board** above) needs to be watched, but viable alternatives have already been lined up, should they become necessary. Plans for possible extension to incorporate a **Compact Array** have already been thought through. As is so often the case in major hardware projects like this, the **software effort** appears to be running about 6 months behind the hardware, but this is not presently a cause for concern.

5.6.4 Recommendations

The ATAC finds that this effort is going well, so we have no major recommendations. We do have a few minor concerns, detailed elsewhere in our report. One minor recommendation follows.

5.6-1. Reconsider the plan to hire a third software person as a member of the correlator team. This seems to be overstaffing, perhaps because the correlator software is overspecified; therefore, the requirements for this software should be re-analyzed. (Formally, this recommendation applies to the Computing IPT, since all three software persons report to that IPT even though they actually work with the Correlator group.)

5.7 Computing

5.7.1 Introduction

The intent of the ALMA software system is that it be a unified system which provides the interface to the instrument at every step along the path from an initial idea, through an observing proposal, preparation of the observing plan, collection of the data, production of final images, and to some extent, interpretation of the images. The observer will have little contact with the actual ALMA hardware; he will regard the instrument as a matter of dealing with its software.

5.7.2 Findings

The software system to accomplish this is a large and ambitious project, comparable in size and scope to AIPS or AIPS++. It therefore shares in the risk that accompanies all large software projects. It is being managed with tools currently common for large software projects. A requirements document has been constructed, upon the basis of which progress can be measured. The software has been divided as much as possible along natural lines of minimum interaction, and assigned to different programming teams. The management structure has been maintained with a common oversight to determine if the various pieces fit together, rather than trusting to a "contracts" system of prespecifying all interfaces. Perhaps all that can be done to manage the team is being done.

5.7.3 Points of Concern

With a project this size, it seems unlikely that a useful and flexible set of software satisfying the ambitious requirements can be completed on the timescale required.

The software system of most immediate concern is the real-time software for controlling and monitoring the array. This element is unique in that it must be produced soon, and that its shortcomings must be minimal. This is the basis upon which the rest of the software system rests. The first ALMA antenna is now upon us, and must be operated now. It is very advantageous, though not absolutely required, that the software should be an early implementation of something that can grow into the eventual array control software. The software group recognizes this importance, and, realizing the short timescale required has recruited additional programmers for this early implementation.

The choices for technologies are reasonable and defensible. The CAN bus chosen as the antenna field bus can be made to perform everything required of it. (The Ethernet field bus chosen for the EVLA project is driven by a desire to distribute the intelligence of the system to a lower level; the pros and cons of doing so can be argued.) A real-time system in the antenna (vxWorks) drives the field bus, a sensible choice given the nature of the chosen field bus. The higher level system is intended to be python, communicating with a C++ system via CORBA. This is, again, a reasonable and common choice, although a python/Java combination is currently more fashionable.

The real-time system has an additional requirement that is not common to the rest of the software system. Once the system comes into use, modifying it, and testing the modifications, becomes a much more difficult process, because often the instrument must be taken out of astronomical use to test the modifications, and because an error in the installed software can cause irretrievable data loss. Therefore flexibility, to minimize required future changes, should be emphasized especially in the real-time system. To the extent possible, the real-time software should support whatever the hardware is capable of doing. Unlike the rest of the software system, the real-time software should be regarded as being the servant of the hardware, not of the user. We think that the unified approach being taken in the software system may not be recognizing this special requirement of the real-time system.

5.7.4 Recommendations

5.7-1. Establish quantitative specifications for most software components, rather than the vague qualitative descriptions now used, especially with respect to timing. Identify hard real-time components.

5.7-2. In filling open positions, attempt to hire people with true real-time programming experience. Such people are rare, and since the ALMA senior software people are generally inexperienced in this area it is difficult for them to evaluate applicants adequately.

5.7-3. The high level software design treats the telescope hardware as a minor peripheral and gives relatively little attention to its detailed control and monitoring. . This thinking needs to be reversed. If the telescope control and monitoring does not work well at an early date, it would be disastrous. Failures and delays in other areas can be detoured or delayed. A greater emphasis on this critical area at the current stage of project development is required.

5.7-4. As a consequence of the above, the most difficult parts of the control system design have not yet been considered. These include the operation of the array as separate subarrays and the operation in a phased-array mode for VLBI. Such things are extremely difficult to implement as add-ons, so they need to be part of the initial design.

5.8 Systems Engineering & Integration[3]

Information was obtained from the ALMA documentation, by interviews with Peter Gray (NA Systems IPT Leader) and Al Wootten (NA Science IPT Leader), and conversations with other IPT leaders and members of the ALMA project.

5.8.1 Background

Interview with Peter Gray

Peter Gray has been leader of the ALMA Systems IPT since January 2002. The deputy leader is Jaap Baars (interim only). Peter has concentrated on putting a documentation system in place, with help from Gie Han Tan (Europe) and Stacy Oliver. Although the basic documentation system is now in place, obtaining content for the documentation system has been disappointingly slow.

Peter outlined his concept of "system engineering." It is:

1. Looking after project support admin tasks
2. Worrying about system level technical issues
3. Setting standards for the project
4. The highest level ICDs

The state of ICDs is very bad; in effect, they only exist for computing and for the antenna. There are not yet any Level 1 ICDs between the major subsystems in place.

Especially in the last year, the ALMA Systems Group has lost manpower on both sides of the Atlantic, to the point of becoming technically dysfunctional. There are open engineer positions.

There is no-one in the Systems group who knows the whole system technically from end to end. It is Peter Gray's view that this may not be possible for one person, but perhaps a group of as many as 6 engineers together could collectively be sufficiently knowledgeable. (In past NRAO projects, not more than 2 or 3 individuals together have been enough.) Even worse, there exists at present no complete block diagram of the ALMA system.

Peter Gray gives as the major problems:
In the short term, that the whole project management is up in the air. Systems Engineering needs strong backing from top-level project management, but it's not

[3] During the preparation of this report, the announcement appeared of the new Systems IPT leader, Dick Sramek. This is an excellent choice and already begins to address some of the ATAC concerns, but it is important to appreciate the magnitude of the problem now facing Dick.

receiving this. ICDs need to be produced. The Change Control Board doesn't work, and doesn't even respond to urgent requests. There is a huge backlog of material that needs attention: administrative, standards, documentation, staffing & ICDs.

In the Long term: ALMA is a large project with an aggressive schedule and many challenges. The geographical separation, and the mass production that will be required, makes the project different from others attempted by the participating institutions.

Peter Gray sees the basic solution is for top level project management to give the support and recognition to Systems Engineering.

When asked about systems integration responsibilities – i.e. getting things to work together – Peter said that issue hasn't been addressed at all; this should be the duty of Systems Integration, quite distinct from Systems Engineering.

Interview with Al Wootten

Al Wootten is Deputy Leader of the Science IPT; the Leader is Ewine van Dishoek. Responsibilities of that group include defining the antenna configuration for Chajnantor, and defining the necessary calibration schemes.

Al expressed very strong concerns that IPT leaders were not communicating with each other. Several examples were given; the regular teleconference meetings of all IPT leaders were not successful in encouraging communication between the different leaders.

There is a configuration group, led by John Conway at Onsala Space Observatory . This has made very good progress defining antenna positions for configurations out to 4 km, with just position tolerances still to be defined.

The calibration group is led by Bryan Butler. Their ASAC-defined goal for amplitude calibration (1% at millimeter wavelengths, 3% at sub-mm) is extremely aggressive. Many issues, including that of the importance of gain compression, have not yet been agreed upon; this issue requires knowledge both of the astronomical requirements, and of the engineering understanding of the detailed hardware nitty-gritty. Overall, progress has been relatively slow, with a need for much better communication.

As with the Systems interview, we frequently heard of the difficulty getting decisions back from the Joint ALMA Office (JAO).

Definition of Systems Tasks in ALMA

There are varying definitions and understanding of the terms "systems engineering" and "systems integration," but we understand clearly that there are several tasks within ALMA that might reasonably be expected to be carried out by the Systems IPT. These include:

(a) Design of the telescope at the system level, which includes defining the characteristics of the whole signal path, separating the design into subsystems, establishing the major technical specifications, ensuring that the system built will be maintainable, and ensuring that the scientific objectives can be met.
(b) Overseeing and monitoring the detailed design to ensure that it conforms to the system level design and that the specifications will be met. This includes, but is not limited to, establishing clear interfaces between subsystems or components, especially those that span groups.
(c) Establishing and maintaining administrative procedures for control of the design, including approval of initial designs and changes, and making sure that the design is well documented and that the documentation is available to everyone who needs it.
(d) Assembling and installing the subsystems so as to create the complete telescope, and then conducting tests to verify that the specifications are being met. (This is sometimes called "integration.")

5.8.2 Points of Concern of ATAC

General

As of October 2002, there is no functioning technical systems engineering in the ALMA project, in spite of the fact that an effective Systems group is so essential for the success of the whole project[4]. The perception is that this has been allowed to happen because the top ALMA management has little understanding for the magnitude of engineering accomplishment needed for ALMA to be technically successful.

With respect to the four facets of systems engineering that we have outlined above:

We find that a reasonable beginning was accomplished on task (a) (system design) with the Systems PDR (2000 Feb) and with the drafting and review of the Project Book (late 2000), but that since then the effort has been inadequate. That existing documentation has not been kept up-to-date with this as the design has developed, so that today there is no reasonably complete, up-to-date block diagram.

Task (b) (design supervision) has not received adequate attention. Many design decisions and design changes have been made by individual engineers, with little review of the system level consequences. Formal interface definitions, even at the highest level, are mostly non-existent.

For the past year, most of the effort of the Systems IPT has been focused on task (c) (documentation). A reasonable software system for organizing and archiving electronic documents has been selected and installed; however, the top ALMA management has

[4] See footnote 3 at the start of section 5.8; during the preparation of this report, some important changes, beginning to address this problem, have already been put into effect.

imposed a cumbersome and unworkable set of rules and procedures. For example, the document approval procedure itself is described in a 17-page document, and even this document is not yet approved; it was submitted on August 15, but its own procedures require that it be reviewed by 15 people and then approved by 4 others before it is official. This causes a huge delay, so much so that today hardly any official documents exist. At the opposite extreme, unofficial or "IPT level" documents can be created and distributed with no approval at all, yet they contain the details of the actual design. Many engineering documents are being held by individuals in their own PCs or other inaccessible places, rather than in the central archive..

The present leadership seems to think that if revision control over official documents is maintained, then control over the design is maintained. But the present system allows the design to diverge from the documents due to the lack of effort in task (b).

The project has not yet progressed to the point where task (d) (integration) is needed. Some thought has been given to how this will be done in Chile beginning around 2006, with several engineers and technicians reporting to the Systems IPT assisted by experts from the other IPTs and by scientists for astronomical testing. However, a great deal is needed before that, including end-to-end integrating and testing of the prototype electronics, first in the laboratory and then on the prototype antennas at the ATF. Planning for this has not yet taken place.

Planning

There does not seem to be a clear plan for how the Alma Test Facility (ATF) at the VLA will be used for testing of electronic systems, after completion of the antenna tests. This plan is important and needs to be agreed on by the whole project.

The schedule for the final calibration plan is so late that there is risk that some design and funding decisions already taken by the IPTs will have to be reopened. The date for the final calibration plan must not slip beyond the present milestone of June 2003.

Communication

The lack of responsiveness from the JAO is a cause for concern. There needs to be more transparency in how decisions are made. At the very least there should be a publicly available list of pending decisions, with target dates for making the decision. Key decisions have to pass through the JAO, but we are not confident that anyone in that office is capable of understanding the engineering issues in decisions being put before them – decisions, if they are made at all, may be judged purely on cost. It is important that the project should not be slowed down by this type of paperwork.

Members of the ATAC were surprised by the apparent level of secrecy within the project. We came across several cases where those nominally responsible for certain sub-systems were unaware of decisions taken by the JAO relating directly to their part of the project, and apparently were not themselves involved in the decision process. Examples include approval of a configuration report that had not been seen by the Deputy Leader of the Science IPT, and a decision to locate the data archive and processing pipeline in Santiago without consulting or informing the Leader of the Computing IPT.

5.8.3 Recommendations

5.8-1 **With very high priority, produce an up-to-date system block diagram and the principal interface control documents.**

5.8-2 It is vital to ensure that the Systems IPT leader has extensive knowledge and understanding of the system level design. To the extent that his understanding is incomplete, he must have close, daily, contact with one or more experts who can fill in the gaps.

5.8-3 Efforts should be made to recruit into the Systems group competent engineers with proven experience in radio astronomy systems. There should be identified a systems core group, being the minimum number of people who, between them, understand the hardware down to the component level, the software down to the task, ICD or tool component level, and the astronomical observing requirements and lore. This group should be charged with guaranteeing that the instrument meets the astronomical needs. Note that this core group is quite distinct from the IPT leaders, having responsibility for understanding and defining technical goals, not for managing the effort.

5.8-4 The responsibilities of the Systems group need to be clarified The core systems group should be given the power on its own to approve changes to the basic system and to ICDs, up to some maximum budgetary impact and within schedule constraints. The Systems group needs to be given the necessary support and authority from the JAO. There is the feeling that the JAO does not understand the technical difficulties – even the technical issues – involved in the ALMA project.

5.8-5 The document approval process must be drastically simplified. Presently, the personal approvals of both the Project Manager and Project Director are required for every official document and every design change; this requirement should be eliminated. Decisions made and decisions pending should be openly published within the project, so that people know what the baseline plan actually is

5.8-6 Communication between different IPT leaders, and to and from the JAO, needs to be improved enormously.

5.8-7 Designs must be documented in detail. The Systems group should provide guidelines to IPTs on how to do this. All engineering documents should become official, but in many cases, approval by one person (the originator's supervisor) should be sufficient.

5.8-8 Systems must take responsibility for ensuring that the detailed implementation complies with the system level design. At present there is no provision for this whatsoever. The present convention where IPT products only have to conform at their interfaces is inadequate for this purpose. Systems must be able to investigate design details and insist on changes if needed to meet performance goals or to conform to higher level design.

5.8-9 Plans need to be agreed on how the ATF will be used beyond antenna testing, and in detail how the system integration at Chajnantor will be implemented. Ideally, the same people ought to be involved in the outfitting and testing of the two element interferometer system at the ATF in New Mexico, as will be involved in outfitting the antennas in Chile and testing the electronics at the OSF in Chile.

5.8-10 The telescope calibration plan should be completed with some urgency. It needs to be made official and widely publicized. Although there may be some controversy about the optimum approach, we need a clear "baseline" plan for calibration, just as we do for the hardware design.

5.8.4 Postscript

An important part of this ATAC review is the technical end-to-end overview of the entire project. This should start with the system block diagram; since there **is** currently no up-to-date system block diagram, this important part of ATAC's charge cannot yet be fulfilled. ***Is is very important that this part of ATAC's work be addressed as soon as the up-to-date system block diagram does become available***.

6 NA-Europe Dependencies

In principle, the ALMA project is split 50:50 between Europe and North America. In some cases, this is just a question of scale or of number – e.g. the antennas – but in other cases some critical components or sub-systems are being developed and constructed just on one side of the Atlantic.

Critical components or sub-systems being developed only in Europe:

- Many (half) of the ALMA **receiver band cartridges** are intended to be provided from Europe. The EU cartridges are for the highest frequency bands, and so technically most demanding, with higher risk of late delivery.

- The **cryogenics and dewars** are being provided by EU. This particular development work seems to be in good shape, but in case of difficulty NA could easily take over the work – NRAO has much experience in this area, and had already invested some time in cryogenics development for ALMA before the responsibility was handed over to EU. NRAO alone has the experience in closed cycle 4K systems married to SIS receivers, so if necessary NRAO could easily take over this responsibility.

- The **digitizer** is being developed in Europe. This is a most critical component, without which the array cannot function. Each antenna needs 8 digitizers. This particular sub-system is already behind schedule; it might be as well for NA to investigate alternatives, or at least have some contingency plan prepared. NRAO could undertake the development if necessary, with some inevitable delay in overall project schedules.

- **Mm-wave interferometry expertise**. Within ALMA, although the US has enormous cm-wave interferometer experience, most of the millimeter interferometer experience lies with our European partners, in particular with IRAM. In NA, the mm interferometry experience lies mostly with the universities or other government research organizations (OVRO, BIMA and the SMA). The NA contingency plan may simply be to call on our NA colleagues currently outside of the ALMA project, should any development seriously limit the European contribution in this area.

7 Glossary of Acronyms and Abbreviations used in this document

2GC	2nd Generation Correlator
2SB	Dual sideband, where upper and lower **SSB** signals may be available simultaneously from a receiver. Not to be confused with **DSB**
AEG	Antenna Evaluation Group
ALMA	Atacama Large Millimeter Array
AOS	Array Operations Site (i.e. the high Chajnantor site in Chile)
APEX	Atacama Pathfinder Experiment (MPIfR antenna in Chile)
ASAC	Alma Science Advisory Committee
ASIAA	Academia Sinica Institute of Astronomy & Astrophysics of Taiwan
ASIC	Application Specific Integrate Circuit
ATAC	Alma Technical Advisory Committee
ATF	Alma Test Facility (i.e. at the VLA site in New Mexico)
Band #	See definition of ALMA frequency bands in the table below
BIMA	Berkeley Illinois Maryland Association (operating the Hat Creek array)
BUS	Backup Structure
C++	An object oriented programming language
CCB	Change Control Board
CDL	Central Development Laboratory (at NRAO headquarters, Charlottesville)
CDR	Critical Design Review
CORBA	"Common Object Request Broker Architecture", an emerging open distributed object computing infrastructure.
COTS	Commercial off the shelf
CV or **CHO**	Charlottesville
CY2000	Calendar Year 2000 (e.g.)
DDS	Direct Digital Synthesis
DSB	Double sideband; upper and lower sidebands are not separated
DTS	Digital Transmission System
EE	Electrical Engineer
EU	Europe
EVLA	The Expanded Very Large Array project
FE	Front End (i.e. receiver front end)
FEA	Finite Element Analysis
FPGA	Field Programmable Gate Array
GBT	Green Bank Telescope
HEMT	High Electron Mobility Transistor
HIA	Herzberg Institute of Astrophysics (Canada)
HVAC	Heating, Ventilation & Air Conditioning
ICD	Interface Control Document
IF	Intermediate Frequency
IPT	Integrated Product Team
IRAM	Institute for Radio Astronomy in Millimetre-waves (Grenoble)

JAO	Joint ALMA Office
JPL	Jet Propulsion Laboratory
LO	Local Oscillator
M&C	Monitor and Control
MMIC	Monolithic Microwave Integrated Circuit
MPIfR	Max Planck Institut fhr Radioastronomie (Bonn)
NA	North America(n)
NRAO	National Radio Astronomy Observatory
OMT	Orthomode Transducer (separates orthogonal polarization signals)
OPT	Optical Pointing Telescope
OSF	Operations Support Facility (i.e. the lower Chajnantor site)
OVRO	Owens Valley Radio Interferometer (operated by Caltech)
PDR	Preliminary Design Review
PLL	Phase Locked Loop
Q4 or **4Q** etc.	4^{th} quarter of the year
RAL	Rutherford Appleton Laboratory (UK)
RAM	Random Access Memory
RF	Radio Frequency
RFI	Radio Frequency Interference
RFQ	Request for Quotes
RSC	Regional Support Center
SIS	Semiconductor-Insulator-Semiconductor
SAO	Smithsonian Astrophysical Observatory
SMA	Sub-Millimeter Array (a collaboration between the SAO & ASIAA)
SOC	Socorro
SRON	Space Research Organization, Netherlands
SSB	Single sideband; the receiver responds only to one sideband, not both
SUNY	State University of New York
TBD	To be defined
TUS or **TUC**	Tucson
UPS	Uninterruptible Power Supply
UV	Ultraviolet
UVa	University of Virginia
VLA	Very Large Array
VLBI	Very Long Baseline Interferometry
VLBA	Very Long Baseline Array
WMA	Warm Multiplier Assembly
YIG	Yttrium Iron Garnet (a crystal with high Q characteristics)
YTO	YIG Tuned Oscillator

ALMA Frequency Bands

Band #	GHz	
1	31.3 – 45	
2	67 – 90	
3	84 – 116	(recently revised from 89-116 GHz)
4	125 – 163	
5	163 – 211	
6	211 – 275	
7	275 – 370	
8	385 – 500	
9	602 – 720	
10	797 – 950	