JOINT DESIGN AND DEVELOPMENT OF THE MMA-LSA

1999 February 21-23
NRAO—Tucson, Arizona

Draft Meeting Summary

MEETING ABSTRACT

The conclusions of this three day joint U.S.-European meeting may be summarized as a list of agreed principles to guide the design and development phase of the merged MMA-LSA project and some specific action items.

- The joint design and development program tasks should be part of a coherent, common effort. Parallel efforts done by the two groups on a single task are wasteful of resources and should be avoided;
- A joint procurement of two prototype 12-meter antennas, one procured by the U.S. group and one procured by the European group to common specifications, is the major goal of the joint design and development program. Contractor responses to the RFP will be assessed in common with a goal of procuring antennas of different designs from different vendors so that the largest range of technical options can be considered and price competition kept in the process through the prototype construction phase;
- The Project needs to develop a common scope of work for the design and development phase spelling out the tasks of each partner and the integration of those tasks in the program as a whole;
- The Project needs to develop a common set of procedures and interfaces;
- The joint Project needs a name and an acronym;
- The MMA Memo series should become the common memo series for the project reflective of the new project name. A mirror site for the Memo Series needs to be established in Europe;
- A joint operations study group is needed.

The next steps for the joint project planning include:

- Organizational workshops among the participating European institutions to meld the interests of each in a common effort and to identify the European Project Division Heads. These workshops will be followed by
- A workshop between the European and U.S. Project Managers and Division Heads to agree on the scope of work to be proposed to the Project management structure established under a MOU between the NSF and the participating ECC agencies.

MEETING REVIEW

1. Scientific and technical representatives of the U.S. Millimeter Array (MMA) project met with a counterpart group of representatives of the European Large Southern Array (LSA) project at the NRAO/MMA offices in Tucson. Approximately 40 people attended the meeting. A list of the attendees and their email addresses is attached as Appendix A. The meeting provided a forum for the two groups to exchange ideas at a working level that would form the basis for a joint Design and Development program for a common array to be created by the merger of the MMA and the LSA.

   The meeting began with a discussion of the scientific goals for the joint project as seen by both groups. There was common agreement on all the high level project goals and most of the detailed specifications. These goals are summarized in the report of the European SAC and in Chapter 1 of the MMA Project Book. The translation of the scientific objectives into a scope of work for the Design and Development phase of the MMA was outlined for the group in a series of short presentations by the MMA Division Heads. These presentations were meant to provide a background perspective for the efforts of the next two days in which the group would consider tasks that could be done by the European group that would be complementary to the U.S. group and would address common objectives.

   The following day began with a plenary session at which a charge was developed for each of six joint Working Groups. Those charges are outlined in Section 2 of this report below. The group spent the rest of that day in the Working Groups seeking to develop answers to the charge and seeking to establish ways that the European and U.S. groups could work collaboratively. On the morning of the third day of the meeting the European and U.S. groups met separately to discuss how their plans developed in the Working Groups fit together as a coherent plan that could be supported by their respective resources. Finally, in the afternoon of that day the European and U.S. groups met together to discuss how the separate U.S. and European plans fit together and how they could be supported by the collective resources. Plans were also identified by which the common US/European groups would function over the course of the design and development phase of the joint project.

   The meeting agenda is attached to this report as Appendix B.

2. Joint U.S-European Working Groups were defined for focussed discussions in six areas:
   - Science and System
   - Antennas
   - Software
   - Receivers
   - Backend Electronics (including Correlator)

- Site

The Plenary session of the whole was used to develop a charge to each of the joint working groups and a list of questions for each group to address. Those charges and questions are listed below by working group.

Science and System

- What is the role of the test interferometer?
- How do we verify instrument compatibility and confirm that one instrument is not interfering with others?
- What are the antenna accelerations needed to support fast-switch phase calibration and OTF observing?
- What is the process for establishing scientific requirements for the following:
  - Solar observing
  - Need for 30 GHz frequency band
  - Maximum data rate
  - Array operations
- Is a nutating subreflector needed on the antennas of the test interferometer? Is it needed on all array antennas?
- What is the range of elevations required of the antenna for scientific operations? Is over-the-top capability needed?
- How is the transition from system testing to system integration to be handled?
- Is simultaneous dual frequency observing a requirement?
- What is the location of the test interferometer?
- What are the polarization specifications for the receivers?
- What is the desired order of delivery for the various receiver frequency bands?
- What frequency band should be supported by the evaluation receivers (i.e. by the receivers to be used for antenna evaluation)?
- What is the scientific specification to be placed on the 1/f noise? Is it a function of receiver band?
- What are the requirements for instrumental reliability (i.e. up-time)?
- What are the array configurations with as many as 64 antennas?
- What is the process for arriving at all the interface specifications (e.g. voltages to be used etc)?

Antenna

- Principal WG task is to refine the RFP for the prototype antenna.
- How will the Joint US-European procurement for the prototype antenna be handled?
- What is the cost and complexity of achieving a capability for solar observing?
- What is the desired location of the test interferometer?
- What is the cost and complexity of achieving a capability for fast switch phase calibration?

- How best is the number of antennas, US+European antennas, expressed in the RFP?
- What specifications for the wind statistics are needed by the antenna contractors?

Receivers (including LO)

- What is the role of photonics development in the project?
- How are photonic techniques to be assessed relative to microwave approaches (for the local oscillator, round-trip phase measurement etc)?
- How can the receiver work be divided between the U.S. and European groups?
- What is the cost and complexity of achieving a simultaneous dual frequency observing capability?
- What is the cost and complexity of achieving a capability to observe the sun?
- What is the cost and complexity of including observing capability in the 30 GHz band?
- What are the desired receiver polarization specifications?
- What is the optimum receiver and dewar configuration?
- What is the schedule for producing the various frequency bands, both for the evaluation receiver and for the array prototype receivers?
- Should the SIS mixers be SSB?
- What are the issues to be considered in preparation for mass production of the receivers?
- Is the radiometric phase calibration receiver a dedicated receiver or is it the science receiver?
- How do we separate the polarizations? Do we use waveguide devices, OMTs, or should this be done optically using grids? What, in each case, is the price to be paid in additional system noise or bandwidth?
- What 1/f noise floor can presently be achieved with SIS receivers that include a HFET IF stage and what can be achieved by fundamental HFET amplifiers?
- What engineering tradeoffs between receiver reliability and performance are feasible?
- What are the plans for testing and evaluation of the very large number of receivers needed? Plans should include tests of the devices (i.e. mixers, amplifiers and multipliers) and the integrated receiver modules.

Software

- What are the software goals for the project and what are the timescales involved in achieving these goals?
- What plans can be made to divide the software tasks between the U.S. and European groups?
- How do we assess the compatibility of software written for testing purposes (testing of the antennas, initial correlator, evaluation receivers etc) with software written for the final array and its instrumentation?

- What is the process by which we arrive at software standards?
- What are the lifetime goals for the software?
- What is the communications bandwidth required between the array site (or the OSF at San Pedro) and the U.S. and Europe for purposes of remote software development and debug?
- How is a common development software platform to be defined?

Backend Electronics (including Correlator)

- What is the process by which we may choose between analog or digital transmission of the IF?
- What is the process by which we may choose between analog or digital bandwidth selection and conversion to baseband?
- What is the role for parallel correlator developments to be done on present generation and next generation correlators?
- Should the round trip instrumental phase correction be done using optical or microwave techniques?

Site and Site Development

- What are the plans for developing and testing the 183 GHz radiometric phase correction technique?
- What soil sampling on-site do we need (for specification of the antenna foundations) and what is the plan to get these data?
- What assurance would we like from the Chilean government regarding the potential risk on-site from landmines?
- What is the process for determining the array configurations, including the ~10 km configuration, and for layout of those configurations on the site topography?
- What is the process by which the location of the OSF is to be established?
- How should safety issues be handled and coordinated between the U.S. and European groups?
- Can the existing wind data be analyzed in time for inclusion in the RFP for the prototype antenna? How can we establish the wind statistics on the very short timescales of interest to antenna manufacturers (i.e. sampling rates up to 10 Hz)?
- What are the plans for determining other site environmental parameters (e.g. snowfall and ice loading)?
- What steps should be taken to ensure the site maintains free of RFI? What steps should be taken to protect dark skies at the site for future optical telescopes? More generally, what is the process by which standards are set for limiting ‘pollution’ of the site?
- What is the planning for an environmental assessment of the site?
- How do we assess the impact of the 5000m environment on the performance of the electronic equipment we intend to place on-site?

3. Summary Recommendations and Answers from the Working Groups

Science and System

- Array Specifications. The number of antennas should target 7000 square meters, or 64 12m diameter antennas. The antennas should be deployed in configurations ranging from a compact array, closely spaced (15-16 m) to a large array encompassing 10 to perhaps 20 km in diameter. Action: Investigation of the optimum pattern for the array should be iterated by the U.S. and European groups. The process of identification of specific antenna locations to be done jointly.
- Antenna Acceleration Rate. If the acceleration rate specification can be met at reasonable cost nutating secondaries may not be necessary in the production run of antennas. Holdaway modeled the noise in total power maps made with an antenna in an unpublished memo. Action: The Cambridge group will test the theoretical predictions on the JCMT.

  Specifications for on-the-fly (OTF) mapping along with fast switch phase calibration contribute to the specifications for antenna acceleration. The rate is determined such that the interferometric instrumental noise is not limited by atmospheric contributions, and neither should 1/f noise dominate. Specifications for these quantities appear in the MMA Project Book.
- Capability at 30 GHz. Scientific specifications for the 30 GHz band were established when the MMA concept was 40 antennas of 8 meters diameter. Action: The scientific need for the 30 GHz band should be assessed now that the array consists of 12m diameter antennas. A committee of astronomers should be established for this task.
- Receiver Bandwidth. Concern was expressed that the desire for wide frequency coverage from the receivers may lead to degraded receiver noise figures. Action: Tests and comparisons of wideband receivers versus optimized (but still tunerless) receivers of narrow band design should be a task for the receiver group.
- Receiver Polarization. Linear polarization is preferred for all receiver bands with a capability to insert quarter wave plates to provide circular polarization at a few frequencies to be defined. Action: Science group to determine the frequencies for which circular polarization capability is required. Action: Systems group to determine the effect on the system design of the circular polarization capability.
- Receiver Bands. The receiver bands in the MMA Project Book are endorsed by the group. Action: The initial antennas on the Chile site, either the prototype antennas or the first of the production antennas, should have receiver capability in the 650 GHz band.
- Receiver Tuning. Receiver tuning and receiver selection needs to be achieved in the time it takes to move the primary mirror from source to calibrator in a fast switching cycle. Action: Issue for consideration by software and correlator groups.
- Simultaneous Dual Frequency Observation. Not necessary for science observing. Action: None.
- Over the Top Capability. Over the top is not a science imperative but may be useful for calibrating the antenna. Action: None.

- Data Rate. A specification of the maximum sustained data rate has not been established. Action: Science group to consider this question and make a recommendation.
- Science Goals. The joint science group recommends (1) that interim scientific operation of the array as it comes to life with only a few antennas should be a primary goal of the project; and (2) that no actions should be taken to design out the ability of the array to operate in the 200 micron atmospheric window at some time in the future.
- Advisory Committee. The joint project should have a joint science advisory committee that evolves from the present U.S. MAC and the European SAC.
- Outreach. The joint project should have a single memo series to evolve from the present MMA Memo series and a mirror site in Europe.
- Project Name. The joint project needs a uniquely identifiable name and an acronym.

Antenna

- Role of the Test Interferometer. The test interferometer is to permit a thorough evaluation of the prototype antennas so that we develop the confidence needed to place the order for the production antennas. In addition, the test interferometer will serve as an engineering facility for system integration: as each new piece of prototype hardware is developed it will be tested for compatibility and non-interference on the test interferometer. The array software will first control the test interferometer and feedback on this real-world software application will be solicited from the software science advisory group. Action: A joint system integration group needs to be established to define carefully all the evaluation and integration tasks to be conducted with the test interferometer. Action: Both sides will use their best efforts to bring the two prototype antennas to a common location to form the test interferometer.
- Location of the Test Interferometer. Neither side regards it as desirable to take the prototype antennas to the Chile site. The issues involved in qualifying one or both of the prototype antennas for quantity production are too complex to attempt in a remote, high altitude location. Action: Both sides agree to use their best efforts to bring the two prototype antennas together at the VLA site. Action: The U.S. will prepare the VLA site for the antennas and make available to the joint evaluation team office space, laboratory space, and housing on-site.
- Duration of the Test Interferometer. The test interferometer should continue to function for the purposes noted above until the time that the first production antennas arrive on site. Action: This plan should be reassessed by the system group at the time that the contract for the production antennas is placed. Action: The system group should bear in mind the desire of the science group to have a functioning interim facility in Chile as soon as possible. Action: Project management should build into the timeline recognition that the site environment may produce requirements for re-design of some antenna components; these requirements will not be known until the time that antennas are in Chile on-site.

- Acceleration Spec. The antenna acceleration specification is driven by OTF observing, not fast switch phase calibration. Action: OTF acceleration spec should be reviewed by the Science and System group.
- Solar Observing. The specification for the antenna to be capable of observing the sun is not to enable astronomical observations of the sun per se, but rather it is to eliminate the operational necessity to worry about the position of the sun in the sky relative to the position of the source of interest. The spec is achieved by anodizing the surface panels with a chemical etch—very low cost, no complexity. Action: none.
- Wind specification. Potential antenna vendors have indicated an interest in having data on the site wind spectrum on timescales comparable with the expected lowest resonant frequency of the antenna structure, i.e. 6-10 Hz. Existing wind data is inadequate as it is taken with a propeller-driven anemometer that smoothes the measurement interval out to frequencies of 0.3 Hz or even smaller values. Action: Site group to analyze existing wind statistics and report them in a form that can be made available to antenna vendors. Action: Site group to make plans to measure wind statistics with a hot wire anemometer at frequencies as high as 10 Hz; it is desirable to make measurements simultaneously over a range of heights to 12m above the ground perhaps by mounting several anemometers on a mast.
- Test Interferometer Site. For the purpose of the 12-18 month program of antenna evaluation leading to procurement of the production run of antennas, it is most desirable if both the U.S. and the European prototype antennas are delivered to the VLA site and connected as an interferometer. Testing would be by a joint US-European group of scientists, engineers and programmers. Action: Antenna group to retain the VLA site as the delivery point for both prototype antennas.
- Joint Antenna Procurement. There is enormous advantage to the Project for the procurement of the two prototype antennas to be done in concert by the U.S. and European groups. The bids received by vendors should be assessed by a joint U.S.-European assessment team, but done this way there is a need for strict confidentiality so that the technical ideas in the proposal from each vendor remain proprietary. Action: Antenna group to draft guidelines for the assessment team.

Receivers

- Organization. There is a strong desire from both the U.S. and the European sides to form a joint receiver working group that addresses a common set of assigned objectives. Competitive, overlapping, work by the two groups designed solely to select a *winner* are to be avoided. Action: This desire is to be communicated to the Project Management.
- Receiver Design. Recommend that the receivers be built as modular inserts to a common cryogenic dewar. Design and prototype of receiver modules can be divided by frequency band among the participating institutions. Action: Management to negotiate a division of design and development tasks involved in building the receiver modules.

- 30 GHz Capability. The 30 GHz band receiver is not planned for the 4K dewar at the cassegrain focus. Instead 30 GHz, if required, would be accessed via a flip-in mirror. Action: Science group to establish the requirement for a 30 GHz scientific capability.
- Simultaneous Dual Frequency. The planned cassegrain optics has all the receivers in the focal plane each offset from the optical axis and hence each pointing to a different point on the sky. Receiver selection is done by re-pointing the antenna. To change this design philosopy would require an entire re-design of the antenna optics and use of dichroics and additional, noise-adding, reflections. Action: Recommend that simultaneous, dual frequency observing be removed from the science requirements.
- Mixer Operating Temperature. The suggestion that SIS mixers, particularly at submillimeter wavelengths, have substantially lower noise temperature when they are operated at temperatures below 4 K needs to be quantified. Action: Receiver group to assess this suggestion quantitatively either through direct measurement or by discussions with groups who have made such measurements. Action: Receiver group to recommend operating temperature for joint array SIS mixers.
- Design Interfaces. For geographically separate receiver development groups to work to common goals requires that standards and interfaces be defined. Action: System Engineering group to develop a plan for the dewar design and for definition of receiver modules and their interface specifications (e.g. electrical and mechanical connections etc).
- Total Power Capability. There is concern over the 1/f noise in wideband HFET amplifiers, either HFETs used at the signal frequency or used as SIS IF amplifiers. This concern refers to continuum total power observations. Action: Receiver group to assess the magnitude of the problem through suitable models and tests and make a recommendation for ameliorative measures to be incorporated in the final array receiver system.
- Photonic Local Oscillator. The photonic system has great potential to simplify the LO system and to reduce cost. Many areas still require development, especially the high frequency photodetectors. Action: Receiver group to solicit interest in development among European institutes.

Software

- Joint Organization. There is a strong desire of both the U.S. and European groups to form a single project software group with the two groups working together. Action: Guideline for Project Management.
- Scientific Guidance. There is a need for scientists to be actively involved providing operational and functional specifications for the software system. The scientists will also review plans and critique progress through use of prototype software subsystems. Action: Science group to identify a joint U.S.-European Software Scientific Advisory Committee (S^2AC) and provide the membership of that group to the Project Management.
- Division of the Software Effort. Recommendation is that the software be organized as a set of subsystems. Each subsystem to become the responsibility of a single participating institution. Action: Common software group to be set up and charged

with the responsibility to recommend a division of the software task into subsystems of a size suitable for a single institution to handle. A process to establish interface specifications among the subsystems, and to assure compliance with them, must also be planned.

- Software for Antenna and Interferometer Tests. Goal is to develop using common software and the common software organization the software needed for support of the prototype antenna testing and for the test interferometer. Action: Software group to decide by summer 1999 whether this goal is attainable.
- Remote Software Development. In order to expect to develop the software needed in Chile from institutions located in the U.S. and Europe will require a communications bandwidth to the site and the OSF of approximately 1 Mb/s. Action: Site group to establish a plan to realize this bandwidth.

Backend Electronics (including Correlator)

- Parallel Correlator Studies. It is regarded as desirable that the U.S. group continue with its plan to provide a correlator for the test interferometer and the initial phase of a correlator for the Chile site that is capable of accommodating the first subset of antennas that arrive on site (32?). Simultaneously the European group will initiate studies for an advanced concept correlator designed from the outset to handle the entire joint array. In approximately the year 2003 a decision is made whether to expand the U.S. correlator to the needs of the entire array or to shift all resources to the advanced concept correlator design. Action: Need to develop the joint tasking, schedule and milestones to support the parallel studies.
- FIR Filter. The digital approach using a finite impulse response (FIR) filter to select the bandwidth and convert to baseband is the recommended approach. However simulations should be done to verify that the filter accurately preserves phase. There is also concern over whether the sampler running at 4 GHz will have sufficient stability. Action: Simulations and prototype tests needed to confirm the FIR and sampler performance.
- IF Transmission. The IF transmission system is one part of a larger cost and performance tradeoff. The FIR filter has the potential to permit sampling at the antenna and hence adoption of the FIR strongly favors digital transmission. Action: The joint system and backend electronics groups need to agree on a complete system diagram so that the effects of tradeoffs can be assessed. The goal is to accomplish this task in the next 12 months.

Site and Site Development

- Radiometric Phase Correction. The comparison of the site testing interferometer phase and the total power difference of the two183 GHz radiometers will provide one assessment of the viability of this technique for phase correction on the Chajnantor site. Action: European group to make a best effort to analyze and interpret these data as they are acquired over the next months.

- Paired Interferometer Analysis. The two interferometers located side-by-side on the Chajnantor site but pointed at two geostationary satellites at different elevation angles has the potential to provide information on the height above the ground of the turbulent layer. Action: The U.S. group will make a best effort to analyze and interpret these data as they are acquired over the next months.
- Soil Properties. An analysis of the mechanical bearing strength of the soil on-site is needed for design of the antenna foundations and for the design of the road system. Action: The site group will recommend a plan to obtain the soil data either by contracting for services or by acquiring data from the pipeline company GasAtacama.
- Array Configurations. In order to lay out the conceptual array configurations on the actual site topography will require accurate positional information. Action: The site group to make plans for use of a differential GPS system for use when establishing the configurations on site.
- Safety and Security. A set of safety concerns and rules needs to be established. Action: The joint site group to determine the Chilean standards and produce a plan for the array that is consistent with those standards.
- Radio Interference. Action: Site group to inquire through Chilean officials and others as to what measures may be available to protect the site from harmful sources of RFI.
- OSF Location. Action: Joint site group to identify a subgroup to locate one or more possible sites for the OSF and produce a recommendation for the favored location.
- Communication Between the Array Site and the OSF. Action: Site group to establish a subgroup to plan for optical fiber communications over the ~50 km between the OSF and the array site.