7-9-99

REPORT OF THE MMA COST AUDIT COMMITTEE

July 9, 1999

****** NOT FOR GENERAL DISTRIBUTION ******

c: R. Bradley
C. Broadwell
G. Ediss
J. Effland
R. Escoffier
J. Greenberg
A. R. Kerr
D. Koller
S.-K. Pan
M. Pospieszalski
K. Saini
S. Srikanth
S. Thacker

7-9-99

SITE DEVELOPMENT (WBS 2)

Findings:

Mark Gordon presents a well developed and detailed site development cost estimate in MMA 199902-010 publication dated February 24, 1999. A supplement dated June 24, 1999 describes the changes to bring the estimate into agreement with Bob Brown's report "Construction Costs of the U.S. Reference Project" dated May, 1999. These changes primarily reflect the adjustments in the estimate developed by a Chilean Architectural/Engineering (A/E) firm required by scope changes (reduction in antenna pads from 145 to 130) and contingencies based on risk assessments consistent with other MMA WBS estimates. The Chilean firm selected to prepare the estimates is familiar with the region and is highly regarded by the mining industry in that area.

The recommended staffing appears appropriate except for the lack of supervisory and administrative people to provide oversight and quality assurance for construction contractors. Most of this effort could be accomplished by Title III services from the design A/E firm, however, some additional MMA staff should be on-site during construction. One person is currently included in the June estimate.

The two year construction period recommended by the Chilean A/E firm is appropriate for the project. Remote site construction should be accomplished in a single, continuous endeavor under one contract for efficiency and cost effectiveness.

The recently awarded contract to research alternatives to optimize the response to power surges caused by fast switching is commendable.

The major uncertainties affecting site development are: (1) which building and construction standards and codes will used; e.g., U.S., Chile, or European and (2) agreements to define land use, permits, customs requirements, taxes, etc.

Comments:

The amount and quality of the research accomplished in developing the site preparation estimate are impressive. The sole-source selection of a local A/E firm, familiar with the region and the type of construction involved was very appropriate. The response to each element of the charge to the panel is positive for WBS 2. Descoping the number of antenna pads from 145 to 130 resulted in significant cost savings. Other cost reduction possibilities are discussed in Gordon's cost estimate document.

Recommendations:

1. Need additional research on code selections; e.g., placement of electrical and fiber optic cables (duct banks, direct burial, overhead).

2. Early resolution of agreements with Chilean Government on land use.

3. Consider flexibility in management staffing offered by including some family housing at OSF.

4. Add staffing for Construction Quality Assurance on site (both MMA and local hire through Title III).

5. Consider providing facilities during construction to accommodate transition to operations; e.g., shops, test equipment, etc.

WBS 3.0 Antennas

Paul Swanson - recorder
Jacob Baars
Jacqueline Hewitt
Ray Blundell
Peter Napier – NRAO presenter

FINDINGS

The 36 antennas were costed by NRAO by three independent methods: parametric cost curves, estimates from manufacturers and a grass-roots, in-house design. There was good agreement between the manufacturers and in-house models. The parametric model was about 38 ~~30~~% lower. Costs were presented for the antennas, antenna transporter and personnel for contract monitoring, testing and installation in Chile

The antenna industry is large and well established. It should be possible to find a suitable company to manufacture the antennas. In fact NRAO has four bids in response to an industry solicitation. The bids have not been opened at the time of the cost review so the review board was not able to evaluate this information.

The presentations by NRAO gave the board a strong feeling that the technical feasibility was high and that several examples of antennas of this class are in use throughout the world.

COMMENTS

Written questions were submitted after the first presentation. The questions and answers by NRAO follow:

(1) Is there enough time for testing the prototype antennas before the production antennas need to be built? Answer: The schedule is optimistic, any delay in delivery of the prototypes would eat into the 1.5 years allocated for prototype testing and possibly delay the production antennas. The backup position would be to delay the start of the production antennas and produce more antennas per year.

(2) Are antenna fast switching and radiometry both necessary? Answer: Yes. The 183GHz radiometry may not work making fast switching necessary. The fast switching is a small cost increment in the total antenna cost.

(3) Will holography give surface accuracy measurements necessary for 700 GHz? Answer. Yes, it should work and has been demonstrated at other telescopes (SMT @ 38 GHz, SMA @ 92 GHz).

The following comments were made during the review board deliberations in response to the specific charge made to the board:

- The antenna concept is sound and technically feasible.
- The schedule is consistent with the tasks to be performed. However, late delivery of the prototype could delay testing and require a compressed delivery schedule.
- The production schedule of eight antennas /year is feasible. Some manufacturers apparently wanted a faster schedule. The eight/year rate is based on the overall project needs so it seems unlikely that the antenna production could ever delay the rest of the project.
- The management structure is adequate for the job. Key people have been identified. The task leader, who has excellent credentials, is committed to .75 time, three more full-time people were named.
- The cost is probably somewhat conservative. The board felt there would be a high likelyhood of success within budget and schedule. The 27% reserve is adequate and can probably be reduced after a fixed-price contract is signed and the first production model is tested.
- There were no obvious options to save dollars, although it was felt that there should be some clever way to exploit the large numbers of identical components to be made.
- There were only two obvious descope options identified – reduce the number of antennas and/or reduce the size. It was strongly felt that the number of antennas should be reduced first since they could be restored later. If the antenna size was reduced it would be a permanent reduction. It was also recommended that a relaxation of surface figure <u>not</u> be a descope option.

RECOMMENDATIONS

There was only one recommendation by the review board. The first production antenna (#3) is the most problemmatic since it will likely be made by a different process than the extensively tested prototypes. There should be some additional testing process to determine if the first production antenna meets all of the specifications.

WBS4: Receivers

Findings

- The integration and test activities at the Tucson facility are pretty well thought out, although lots of hiring is needed, and we think the projected staffing level is low. A large labor force is available in the area for technicians, although the competition for labor may push up pay scales. There is a minimal staff in engineering at present.
- The production schedule seems optimistic but possible, both at Tucson and at the CDL.
- The SIS wafer suppliers at UVa and SUNY seem reasonably secure. While the present production rates are erratic, only one good wafer is needed for each band above 100 GHz, and so this does not represent a large burden on the suppliers.
- The majority of receiver work is on the receiver inserts at Tucson. This work is not overly dependent of actually receiving mixers from the CDL, and so the two groups do not need to synchronize their production plans. Testing of complete inserts is obviously dependent on receiving mixers and this task can not be permitted to fall too far behind, but sufficient schedule contingency is planned.
- The engineering staff at CDL seems very tight for all of the SIS design work, but may be adequate for the job. There is a total reliance on 2 key people, which seems a high risk.

Comments

- The 183 GHz water vapor radiometer needs a place in the focal plane; its only logical location is in the dewar as another insert. Eliminating one receiver band would permit this without other major disruption. There appears to be no space for the 22 GHz feed.
- Support for astronomy operations at the 12m is a longstanding obligation of the Tucson group, although much less of a burden as time goes on. If continued, even at a low level, this is likely to conflict with MMA development. Is a phase out of support practical?
- The required production rate of SIS mixers at the CDL is 3 times the highest rate achieved at present. While a major step up, this seems within the range that is achievable without major disruption.

- The cost of mixers averaged over the bands is about $48K each while for LO multipliers the cost is about $10K each. These parts are sufficiently similar in both machining difficulty and assembly that we would expect prices less than a factor of two apart. This does not provide a high level of confidence in the budget estimates, although the average may tend to work out. By comparison, the cost of HFET amplifiers seems exceptionally low at about $7K each, although this is an area where the CDL has considerable production experience and infrastructure. These costs should all be reviewed on a common basis of assumptions.
- One complete receiver band is required simply to cover a few GHz near 70 GHz. An HFET receiver could probably be built to cover 75-116 GHz with fully acceptable performance, and a complete band could then be saved with the sacrifice of only 8 GHz.

Recommendations

- The critical nature of the SIS design effort seems to require an additional experienced receiver engineer for the CDL.
- A second test dewar is needed at Tucson to keep up the production testing of receiver inserts, particularly if there are any production delays at the CDL.
- An extra test dewar set is needed at Chile as well, since receiver inserts will be sent to the site without integration into the full receiver dewar.
- A descope option to eliminate the 31-45 GHz band may help reduce a lot of engineering effort since it helps to fit all the parts within the dewar by eliminating a large feed horn. This band also has a complex (and unique) IF system although receiver itself is simple.
- The decision on whether to use HFET vs SIS receivers in 90-116 band should be made very soon. All of the data needed to make this choice would appear to be available without further testing. Since the decision is based upon the suitability of using the receivers for total power continuum measurements, a better (cost effective) alternative might be to dedicate a single antenna equipped with bolometers to the task.
- Eliminating 67-75 GHz, and redefining a new 75-116 GHz band using HFET's could eliminate one receiver in an apparently very cost effective descope.

- The project should look into the use of MMIC amplifiers for all of the HFET bands. Wafers with all of the needed designs will go out for fabrication soon, and the cost to NRAO would be about the same for complete amplifiers on MMIC chips as for discrete HFET chips. There should be no loss in performance, and significant cost savings seem possible, given the much reduced complexity of MMIC amplifiers.
- A relaxed specification on receiver performance as it applies to the worst case of individual elements, will not hurt the overall array, as long as the averaged noise spec is met. This will greatly enhance the yield. This applies to specs on IF bandwidth, SSB/DSB operation and receiver noise temperatures. For early operations, almost any receiver performance may be accepted.

Local Oscillator

Findings

The local oscillator system for the MMA is based on similar systems in use at the VLA and at the 12 meter telescope at Kitt Peak. The central Hydrogen Maser frequency standard drives a series of frequency synthesizers to provide the needed reference frequencies which are then transmitted over optical fibers to the individual antennas. At each antenna, these reference frequencies are used by a synthesizer to generate four driver frequencies which are then used by individual driver-multiplier units to provide the nine local oscillator signals for the receiver front end mixers. The MMA local oscillator system extends the frequency range by a factor of two compared to the present 12 m system.

Comments

Conventional aspects of the design including the reference oscillators seem to be well in hand.

The cost estimates presented to the Committee appear to be adequate for a well managed project. However, by way of comparison, the unit cost of the high frequency multipliers of the local oscillator system appear to be at least a factor of two less than the unit cost of the mixers for these frequencies. Since the diodes are of similar difficulty to manufacture compared to the SIS mixers, it is difficult to understand this difference in estimated cost.

Given the difficulty of the design of the high frequency multipliers, a focused effort is needed to provide operational devices in time for the production of the local oscillator systems for the individual antenna.

The interfaces to other parts of the receiver system seem to be ill-defined. For example, multipliers for the LO will leave CDL component tested but not tested in the actual configuration that they will be used in the receiver modules.

The rf aspects of the local oscillator system are near the state of the art. As such, the availability of trainable engineers and technicians with sufficient technical expertise is a question. This may be a cost issue in terms of premium salaries.

Because of the difference in unit pricing noted above, there is a significant possible call on the contingency assigned to this category.

Recommendations

1. To avoid a potential major cost growth in the local oscillator system, especially in the high frequency bands, a full time person should be assigned to lead this development.

2. Establish agreed upon milestones to monitor progress on the development and production of the local oscillator system, especially the high frequency components.

3. Explore the use of outside consultants to assist in the development of the challenging high frequency multipliers.

IF

Findings

The design is straightforward and there is little technical risk.

Cost estimates are based primarily on commercial components such as amplifiers, mixers, filters. There is adequate contingency.

There is a plan to test IF electronics in a low-pressure chamber to ensure adequate thermal management.

Comments

Total-power stability is major concern; needs to be better that SIS receivers, which are likely to limit the stability.

Thermal noise is 2x10**-4 in 2 ms with 8 GHz bandwidth. The total power requirement for "on the fly" mapping is being studied. A few parts in 10**-5 in 10 minutes may be required; obtaining this stability may require temperature control of the electronics.

Recommendations

Need to measure receiver total-power stability in order to determine how stable IF electronics needs to be in order not to limit the overall performance.

FIBER OPTICS

Introduction:

There are three separate fiber optic subsystems in the U.S. Reference Project:

- Intermediate Frequency (IF) Data Channel,
- Local Oscillator (LO) Distribution System and,
- System Monitoring and Control.

Several important decisions, i.e. assumptions, have been made for the purpose of costing the Reference Project that may change for the as-built system. The most important of these decisions is that the IF system is digital and that the LO system is electronic, as opposed to a photonic alternative.

Dan Edmans presented a clear description of the three subsystems using diagrams which were provided to the committee previously.

Findings:

Edmans demonstrated a good understanding of the FO system requirements and alternative technologies for meeting the requirements. He has nearly ten years of relevant technical experience and is well qualified to lead the FO effort. We understood that detailed specifications for the interfaces of the FO system with other parts of the MMA system will not be available for, at least, another month. Nonetheless, Edmans has enough information on system requirements to block out the subsystems and choose among alternatives for implementation.

All three subsystems are to be designed at NRAO using commercial components (lasers, amplifiers, multiplexers, transmitters, and receivers). Estimated costs are based on current vendor prices with price projections based on historical experience with similar components. Edmans used particular components from his complete vendor files as examples to trace the derivation of costs used in the cost documents. It should be noted that the components to be used are developed for the highly competitive communications industry which will assure consistency of availability.

Technical risks for all three subsystems appear to be minimal. Cost risk is associated with the validity of the price models used to project future costs of components. Since there are multiple vendors for critical components the committee felt that the pricing models and contingencies appeared to be reasonable.

The LO system is less well defined than the IF system. Consequently, the technical risk for the LO system, although not high, is higher than that for the IF system. We understood that a decision to use the photonic LO system in the as-built system could, potentially, double the cost of the LO distribution system with respect to the cost estimated for the U. S. Reference Project.

Edmans felt that the planned level of support for the FO effort for duration of the reference project is adequate in terms of facilities and staff. We understood that present staffing is 1 ½ FTE, with the ½ person being a visitor until October 1999 and staffing planned for the construction period, FY '00 to FY '07, totals 31.8 engineering FTE years and 45 technician FTE years.

In conclusion, the committee was favorably impressed with Edmans' grasp of the system and its requirements, his organization of material and documentation, confidence, and enthusiasm. The feel that the FO system presents relatively low technical and cost risk as described for the U. S. Reference Project.

Recommendations:

The committee recommends that documentation of the interfaces for the FO system be completed in a timely manner.

The committee encourages the timely demonstration of a functioning LO design since the achievement of all the design requirements is critical to the success of the MMA.

The committee recommends that appropriate engineering resources be maintained to assure timely demonstration of the performance of the baseline LO distribution system.

Correlator

Introduction

The correlator system consists of three subsystems, which are referred to as separately-named items in the discussion below:

- Samplers – convert the analog IF signals to sampled and digitized replicas
- FIR filters – perform a digital filtering operation on the output of the samplers
- Correlator – performs the actual digital correlation operations

Findings

- The MMA correlator is being designed and constructed in two stages. The first stage is to build a test correlator based largely on the existing GBT correlator design. The final correlator is a further evolution of the basic design incorporating a new VLSI custom correlator chip, and scaled up to meet the demands of the full MMA system.
- The test correlator will sample an 800 MHz-bandwidth signal at 1.6 Gsamples/sec, which are multiplexed into 16 100-Mbit/sec subchannels for correlation. The test correlator is already well underway and is expected to be completed and tested by the end of 1999.
- The operational correlator will sample a 2 GHz bandwidth from each receiver of each antenna at 4 Gsamples/sec, which is then divided into 32 subchannels of 125 Msamples/sec before correlation. A new VLSI chip will be designed for this correlator, each chip to have 4096 lags operating at 125 MHz. NRAO looked into several options for chip design, including gate arrays as well as full-custom chips. Though a gate array can be designed that is functionally acceptable, the power dissipation of each such chip is expected to be ~9W, which significantly exceeds allowable dissipation in the final system, which must incorporate many thousands of these chips. A full-custom design based on a 0.25 um process, on the other hand, is expected to dissipate <2W, and is likely to operate at the lower target voltage of 2.5V.
- At least two sources of design for the new full-custom correlator chip were investigated. UVA has a chip design lab and is interested in the job, but would use 'canned' libraries for much of the design and might not have good continuity of design personnel (i.e. graduate students), judged to be a potential problem. The other possible source is to employ the personal consulting services of Mr. John Canaris (formerly of the NASA MRC chip design center at UNM and currently employed at Phillips). Mr. Canaris is probably the world's pre-eminent expert in correlator-chip design, having designed several chips in wide use today including the chip used in the GBT correlator. Discussions with Mr. Canaris suggest that first prototypes could be available for testing as early as 4Q 2000. NRAO will supply Mr. Canaris with the necessary equipment and hardware for design. Mr. Canaris would also subcontract with standard industry sources for fabrication, packaging and testing. Test vector generation will be jointly done with NRAO.

- The FIR filter board design appears to be well-advanced and adequate. The FIR filter provides a 128-tap filter at the 1 GHz output bandwidth, with more taps at smaller bandwidths.
- The development of the 4 Gsample/sec sampler is proceeding more slowly than the rest of the project. This sampler is required to have at least 3 bits/sample (preferably 4) and must meet extremely stringent specifications imposed by high-quality interferometry. Only a preliminary specification exists and one person at Tucson is devoting an unknown amount of time to this item.
- The total correlator system is expected to dissipate as much as 30 kW of power. The expectation is that a forced-air ambient-temperature cooling system (~-2C) in Chile will be sufficient for cooling, though active refrigeration may have to be considered if power consumption is significantly greater.
- The various interfaces both to and from the correlator, as well as inside the correlator, are fairly well define, though not complete.

Comments

- The correlator design appears to be entirely adequate for the tasks required of it .
- The correlator cost is credible, apart from the potential significant uncertainties in design costs of the full-custom correlator chip.
- The proposed schedule is realistic provided the correlator chip is available.
- The functional specification of the new correlator chip design appears to be mature and well thought out.
- The cost and schedule for the development of the new correlator chip is heavily dependent on the availability of Mr. Canaris. Should Mr. Canaris not be available as anticipated, both the cost and schedule for the chip development are likely to be heavily affected. If it becomes necessary, for example, to contract with industry for the design, the development cost could balloon to many times the current projected costs.
- The FIR filter design is mature and well advanced and appears to be adequate to meet the necessary requirements.
- The lack of focus on sampler development is somewhat worrisome. Adequate commercial samplers are not known to be available and development costs are really unknown. Status of the current sampler development at Tucson is not known and there is little indication that management is concerned about this situation. Projected costs for samplers may be significantly low.

Recommendations

- The sampler development must be given much higher priority and adequate resources assigned. Budget estimates must be carefully re-examined.
- A realistic correlator-chip development and production cost/schedule utilizing standard commercial services should be developed so that the extent of cost/schedule impacts costs is known should the services of Mr. Canaris not be available.

Computing (WBS #9)

Findings:

We find that the plans for the control software are based on previous experience and the budget for this software seems well planned and of low risk. The scheduling and image pipeline software seems well planned and costed based on the stated assumptions but the development of this software is of higher risk than the control software.

We find that the MMA Project relies on the AIPS++ Project heavily for data reduction software.

We find that the pipeline and archiving plans and budgets are based on parameters that have not been recently addressed in a scientific context.

Comments:

The data rate from the correlator into the archive, currently specified as 1MB/sec, needs to be re-addressed from scientific requirements.

The expressed Project goal of producing images from a pipeline as the usual product of observing needs to be re-addressed from scientific requirements and the parameters of the goal quantified. What quality of images? What percentage of the observations need to result in images from the pipeline?

Recommendations:

The committee recommends that the MMA Project create a Computing Requirements Document that reflects a concerted effort to contact and understand scientific and user requirements for data, images, operations and other computing capabilities. The RD should be maintained as a living document.

The committee recommends that a Computing Plan be formulated and maintained, based on the RD and embodying the mission of the computing project , the organization, staffing, budgets, schedules, milestones and computing products. The hardware and software products needed are part of this plan.

The committee recommends that there ~~must~~ be a formal commitment by NRAO management of sufficient resources from the AIPS++ project to the MMA project to meet the scientific requirements.

CALIBRATION and IMAGING

Findings:

Fast slewing is needed to overcome 1/f noise for the single dish continuum measurements using raster ("on the fly" mapping) scanning of the dish and for atmospheric calibration at the shortest wavelengths. Studies indicate that antenna slew rate is high enough that a nutating subreflector should not be needed.

The single dish total power performance is only critical for continuum imaging. There should be no problem with spectral line imaging.

A 183 GHz 64 channel WVR is included (and is budgeted) within the dewar to provide simultaneous WVR measurements with a beam within 10 arcminutes of the observing beam. Exact frequencies/details are not yet decided.

The 25 micron antenna specification was based upon image quality requirements at 1 mm and hence the decision to include submillimeter wavelengths did not impact the antenna specifications.

There is currently no plan for conventional vane calibration but can easily be added.

Comments:

The technical feasibility and schedule are fine and cost estimates are well developed with adequate contingency.

If a nutating subreflector is needed like those on other existing antennas. This should only cost 50k$ per antenna and is within the contingency.

The project feasibility is very good. There is very little technical risk at 1mm and longer wavelengths. Even if WVR phase calibration works poorly there will still be a large amount of time at which observations can be made at 1mm. At 230 GHz the atmospheric phase noise is less than 1 radian on a 1.6 km baseline for 43 percent of the time.

Recommendations:

1] Analyze and summarize satellite phasemonitor and WVR data from the site in order to decide on the details of the 183 GHz WVR.

2] Need early tests of the total power stability using the first antenna at to VLA site to decide the possible need for a nutating subreflector.

3] Need to add a conventional vane calibrator for system temperature measurement and engineering tests in addition to the hot/cold calibrator at subreflector. This addition should not add significantly to the cost.

4] Need better plan for calibration imaging activities during pre-operations.

REPORT OF THE COMMITTEE ON SYSTEM ENGINEERING AND SYSTEM INTEGRATION

Members:

Goldsmith
Peoples
Snavely
Stiening
Tenerelli

Introduction:

In the task definition for the committee system engineering and system integration were considered as a single function. The committee, however, consider these to be separate and will consider them so in the discussion that follows. We view system engineering as a management tool and system integration as a task.

Findings:

The scope of the system engineering function in the WBS is 1 ½ FTE. The leader has responsibilities elsewhere and devotes only one-half of his time to the task.

The primary function of the systems engineer is to assemble and manage technical specification documents, error trees, and interface control documents. It should be emphasized that the systems engineer does not generate the information in these documents but rather collects and organizes the information for the benefit of the management of the project.

At this time the technical specification documents and error tree, and flowdown to the subsystems, are incomplete. In particular, the interface control document for the antenna is incomplete. Other interface control documents are in a very preliminary state. At this time specifications are traceable to project memos, and not to an integrated error tree.

The scope of the system integration task the assembly, installation, and testing of project project hardware. This task is to be carried out at sites in the U.S. and in Chile.

The plan for integration and testing is based on prior NRAO experience with similar projects. The MMA project intends to carry out the U.S. portion of this function at existing NRAO sites. The systems integration group plans to supply four FTEs at these sites. Additional staff will be provided as needed by the project groups responsible for the hardware.

The plan for system integration in Chile parallels that for the U.S.

The project has not provided a plan or cost estimate for the implementation of a laboratory infrastructure in Chile that is a necessary element for system integration in Chile.

Comments:

It was clear to the committee that project management understands the need for the systems engineering function as described above. The committee was pleased to find that the necessary information is readily available within NRAO for implementation of this function. The staff presently performing this function have multiple responsibilities. Staffing needs to be increased to provide the level of effort necessary for the function.

The committee was pleased with the depth of the understanding of the scope of the system integration task. We do not anticipate that the project will have any difficulty in preparing more complete installation and testing plans. The NRAO has ample prior experience in the installation and testing of similar equipment.

We feel that the plan for integration and testing at U. S. facilities is adequate and that the similar plan for Chile is also adequate provided that the infrastructure and staffing in Chile is available at the time it is needed.

Recommendations:

The project should separate the system engineering and system integration functions.

The project should hire a full-time, professional systems engineer and support this function with appropriate staff.

The project should develop a top-level project requirements document in a timely manner. The requirements for all systems should be traceable to this document.

The project should develop a verification and testing plan for each system, and each division leader should identify an individual to carry out this function.

An implementation plan for site technical and support infrastructure for Chile should be developed during the D & D phase of the project.

ADMINISTRATION

Sanders, Roth, Goldsmith, Robertson, Peoples

Findings:

The MMA Project presented two documents to the review panel describing the construction cost and schedule of the US Reference Project. These include a listing of the project Work Breakdown Structure (WBS), the project schedule, and a summary of the cost estimate, as well as a volume including a one page detail sheet for each costed WBS element. The summary cost for MMA is $343 million for construction, with $25.9 million for the D&D phase, totaling $368.5 million. This cost is increased from the May 1999 cost estimate by design choices and by an alternate study of contingencies.

MMA management described the evolution of the project's scope and cost estimate from the original 1990 proposal. The original proposal was based upon 40 8-meter antennas, covering 3 millimeter bands, and sited at Socorro. Site studies, site characterization, and physics opportunities have led to a much more powerful array concept. Now sited at the very superior site in Chile, with 9 bands covering into the submillimeter region, the current reference design includes 36 10-meter antennas. The current cost estimate is based upon a more systematic use of estimating techniques typical of large projects in the early stage of development. This has led to a substantial increase in the cost estimate.

Given the short duration of the D&D phase, and the available budget, some D&D activities will be completed in the early phases of the construction project.

MMA management described the plan for staffing the construction project relative to the existing staff in NRAO. It was acknowledged that the large size of the MMA Project burdens the NRAO staff and impacts ongoing NRAO activities. It was further acknowledged that some critical skills are in short supply. The MMA plan includes some redirection of existing staff, some curtailment of ongoing activities and some hiring of new staff.

A plan was presented for staffing and organizing the top level management team of MMA, and for the redefinition of some of these job assignments.

Comments:

The WBS, schedule and cost estimate for MMA construction, as presented, is a good start on a framework for further development of the MMA Project. The WBS should be edited to support "rollup" of subsystem costs. The format for collecting the basis of estimate is sound.

The methodology for estimating risks and identifying contingency funds is a useful technique and encourages detailed attention to risks. It can support the judgements that must be made by experienced project leaders.

The cost estimate of $368.5 million (FY1999$ including $26 million for the D&D phase) appears to be conservative. As the project design is further developed, it should be possible to identify cost reductions through design and production efficiencies, and value engineering.

In order to establish the scientific capability of MMA, antenna systems must be turned over to an operating entity as they are completed. Thus, the operating costs of the MMA system will commence as the final years of the construction are carried out. The project should clearly identify the early costs required to establish the operational capability of the observatory in Chile and to accept responsibility for operating the progressively larger array of antennas through the first large-scale scientific operations. The construction costs, and these early operations costs represent the total cost of the project.

It is essential that project and subsystem scope be fixed, through timely decisions on technical options, through resistance to potential improvements once baselines are established, and through consistent and firm management to the baseline.

The team must commit to designing and building to the agreed upon cost and schedule.

Project management tools and controls must be rapidly brought to completion and used throughout the project, by all subsystems. Refining the cost estimate and schedule must be continued vigorously.

There do not appear to be any technical, cost or schedule showstoppers in the reference project, and risks can be managed by acceptable compromises.

The reference project schedule appears to be plausible. Options to shorten some production durations, such as antenna production, should be considered with a view to reducing project costs. Critical paths should be clearly identified and brought under the focus of project management. Some critical paths, such as SIS mixer production, should be examined for possible increments in staff and support, or examined for potential fallbacks, such as phased implementation of late system components.

The review committee continues to be concerned by the staffing requirements needed to successfully execute the MMA program. Building a robust staff to execute the project must be a very high priority. This should include vigorous recruitment outside the existing, experienced NRAO staff. Efforts to fill open positions should be pursued with urgency. Critical skill positions should be filled at market rates despite existing compensation schedules. Maximize industrial participation in fabrication activities in order to reduce the in-house staff requirements.

Unifying the MMA project team across the several NRAO sites, and redirecting dedicated and experienced staff from the operation of existing NRAO instruments to a highly paced, deliverable-oriented construction project will be a challenge. This unification requires sharing goals in addition to developing a coherent flowdown of requirements and attention to interfaces and system tradeoffs that is widely understood. The MMA project is an overarching goal for the NRAO with great scientific promise.

Recommendations:

1. Define and fill the top project management roles with additional experienced staff. Complete recruitment of an experienced project manager. The definition, roles and responsibilities of the Project Director, Project Manager, System Engineer, Integration/Installation Manager, Project Scientist, and Antenna Task Leader must be made more definite and the persons occupying these roles must carry out these specific roles as full time assignments. These positions must be supported by adequate staff. There must be sufficient attention to defining the baseline, measuring performance, defining and controlling specifications, defining and controlling interfaces, testing and acceptance, definition and adherence to scientific requirements, and management and surveillance of contractor activity.

2. Refine and fully develop the WBS, integrated resource-loaded schedule and cost estimate. Seek design efficiencies and exploit opportunities for cost reductions. Establish the total project cost including the construction cost, and the cost of early operations up to first large-scale scientific operation.

3. Complete the staffing plan to explicitly identify all of the staffing required to execute MMA construction.

4. Advance the Project Book to the maturity required so that it can be used as as a definitive statement of the MMA configuration. Put the MMA configuration under strict configuration control.