The North America Array

Response to the Request for Information Part 2
Ground Concepts
Astro2010 Programs Subcommittee

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*Tables not included in page count requested from Astro2010 (see Appendix 8.2)
**Expansion to max. 6 pages for all enabling technologies per Astro2010 RFI#2 FAQ

Note that contrary to the FAQ posted at the Astro2010 website, we placed the Tables on separate pages following each section, rather than at the end of the document. This is intended to facilitate the reader in finding the relevant tables. The page counts without tables are listed in the second column of the TOC above, with the table page counts in parentheses.

1.1 Executive Summary

The scientific potential of the SKA is presented in the SKA Science Book (Carilli & Rawlings, eds. 2004, New Astronomy Reviews, 48, 979-1563). In the "high-frequency" range from 15-45 GHz the key science drivers require a radio interferometer with high sensitivity, high survey speed, and with baselines to 3000 kilometers or longer. Therefore, we propose the establishment of the North America Array (NAA) initiative, building upon the foundation and investment in the EVLA, VLBA and GBT network of radio telescopes, and harnessing the energy and expertise of the North American astronomical community, to prepare the case build and host the SKA-high.

In the 2010-2020 decade, we propose the following staged activities: (1) collaborations with SKA-mid precursors and pathfinding activities such as MeerKAT; (2) a SKA-high Technology Development Program (TDP-II) focusing on high-frequency low-cost antennas and systems, computing, and software readiness, and (3) the construction of a NAA Prototype Antenna Station (NAA-PAS) technology demonstrator covering at least the core frequencies 5-45 GHz. The NAA builds upon the the current SKA development efforts of the USSKA Consortium TDP-I, the international PrepSKA program, and various SKA pathfinder activities. Goals of these activities include developing a design and costing model for SKA-high in order to prepare a proposal to the next decadal review in 2019, and the building of a strong case for hosting the SKA-high in the U.S. for submission to the SKA-high site decision process in 2018-2020. We envision that beyond 2020 the SKA-high will be "grown" from the NAA, ultimately attaining the full capabilities of at least 10 times the sensitivity of the EVLA.

In this document, except where otherwise noted, the responses refer to the TDP-II and NAA-PAS projects to be proposed in the coming decade, including preparation for the SKA-high construction and operations proposal, but not to the ultimate SKA-high construction program itself. The cost as estimated in RFI#1 was FY09 $31,250K (excluding the MeerKAT collaboration), with considerable uncertainty in the PAS cost and the expectation that more personnel were needed (possibly contributed by partners). In this RFI#2 response we have refined the total cost to be FY09 $39,850K ($45,784K real-year assuming 2.7% inflation) with considerably more detail in the PAS work breakdown and costing, and including all needed personnel and management.

1.2 Science Overview

The NAA development and demonstrator projects proposed for the coming decade do not themselves have high-level science objectives as drivers. However, the SKA-high program does have a suite of Key Science Projects and goals that the NAA concept is geared towards enabling. The responses to the science overview questions refer to the SKA-high program. Note that since the SKA-high is proposed to start construction after 2020, and the new generation of centimeter and millimeter-wave instruments (ALMA and EVLA) have not yet entered full operations, these science cases are intended to represent obvious key science projects and to illustrate the observations that will drive the science requirements, and thus the technical development leading to SKA-high.

A description of the sensitivity calculations for EVLA and NAA is given in Appendix 8.1.

1. *Describe the measurements required to fulfill the scientific objectives expected to be achieved*

by your activity, providing up to four examples of the science this project is designed to address.

The SKA-high instrument will carry out a combination of large survey projects and General Observer programs, and will be a proposal-driven international observatory capable of a wide range of scientific studies, much like the VLA. The detailed science case for the array will be developed during the coming decade based on experience with our current and new generation of telescopes (ALMA, EVLA, GBT, enhanced VLBA, JWST, LST, etc.). We summarize four exemplary science programs taken from the original RFI#1:

- **Precision Astrometry for Distances, Motions, and Black Hole Masses** – ultra-high resolution imaging and microarcsecond astrometry of masers and megamasers to determine the local distance scale, local group motions, and black hole masses in active galactic nuclei. *Key measurements: maser and megamaser survey, sub-milliarcsecond scale imaging of masers , precision astrometry of masers, precision astrometry of continuum from weak AGN and compact objects in the Local Group and beyond.*
- **Imaging Galaxies in the Early Universe** – for redshifts $z>1.3$ the CO rotational lines are accessible in the centimeter-wave window below 50 GHz. The EVLA will be able to detect the most extreme gas-rich star-forming galaxies out to $z\sim5$, but the sensitivity of SKA-high is needed to image normal galaxies. These observations are complementary to those of ALMA, Herschel, JWST, and SKA-mid, and will complete our census of the dust, molecular, and atomic gas components of galaxies throughout cosmic time. *Key measurements: CO line galaxy search/survey, CO galaxy spectral imaging, galaxy continuum imaging.*
- **Protoplanetary and Protostellar Disks, Star Formation Regions** – probing deep into highly obscured star formation regions requires AU-scale imaging at centimeter wavelengths. High sensitivity on long baselines is needed to cover disk imaging at star formation sites through our galaxy (10 kpc), and also to image star cluster and cloud complexes to the nearest galaxy mergers (100 Mpc). Stellar objects (through maser, non-thermal active emission, or thermal photospheric detection) can be measured for astrometric motions and parallaxes. Centimeter-wave molecular lines are accessible for astrochemistry. *Key measurements: milliarcsecond scale disk continuum imaging, super star cluster continuum imaging, stellar object astrometry, molecular line imaging of star-forming regions.*
- **Transient and Periodic Phenomena: Supernovae, Gamma-Ray Bursts, Pulsars** – high sensitivity detection, imaging, and monitoring of supernovae photospheres and remnants, and of gamma-ray burst afterglows. Gated observations and astrometry of pulsars. *Key measurements: milliarcsecond scale SNe and GRB imaging, triggered transient detection and monitoring, pulsar astrometry.*

2. *Describe the technical implementation you have selected, and how it performs the required measurements.*

The NAA concept is to expand upon the North American radio astronomical observatory infrastructure in order to realize the SKA-high. The technical implementation under investigation by the TDP-II will be an interferometer array made up of "stations" ~20 of dishes of diameters in the range 9-15m. This is chosen to balance the field-of-view (larger for smaller dishes) and cost of correlation and post-processing (greater for a larger number of smaller dishes) given a total amount of collecting area. This implementation concept is chosen to build upon the design and development of the SKA-mid (TDP-I and PrepSKA) as well as to mesh with the existing infrastructure of the current arrays (in particular the EVLA) where appropriate.

3. *Of the required measurements, which are the most demanding? Why?*

The drivers for the instrumental capabilities are:

- Continuum imaging – imaging of continuum emission, primarily over a wide bandwidth to attain maximum sensitivity, to detect faint sources and to provide high-fidelity images of extended emission. Often requires a high ($>10^5$:1) dynamic range due to bright sources in or near the field-of-view of the target. Often also involves polarimetry, again at high fidelity and high dynamic range. There are two regimes of interest for science drivers: (1) *point source detection* – for the NAA, 8 GHz/pol bandwidth, a 9-hour observation reaches a rms level of 75 nJy; (2) *thermal continuum imaging* – sub-μJy rms sensitivity is needed to carry out imaging and astrometry of thermal objects beyond the solar neighborhood. In addition, imaging of parsec-scale star-forming regions at 100 Mpc distances requires resolution and sensitivity on milliarcsecond scales. See Appendix 8.1 for sensitivity calculations.
- Spectral line imaging – requires the sensitivity to detect redshifted CO (and other line) emission from the most distant sources. Targets are of galactic sizes (arcsecond scales), with sub-arcsecond resolution needed for kinematics and dynamics. Figure 1 of RFI#1 shows detectability for an extreme star-forming galaxy like Arp 220. NAA sensitivity is needed to image the low excitation CO lines at z=5 for less extreme examples such as M82 (~15 times fainter) and normal galaxies like the Milky Way (~100 times fainter) at nearer distances.
- High precision astrometry – requires the highest angular resolution and high instantaneous point-source sensitivity (at least 10x EVLA sensitivity on baselines to at least 3000 km). Implies high data transport rates from the furthest stations of the SKA-high array.
- Transient source detection and monitoring – requires the operational ability to trigger on external data (e.g. from a Gamma-ray, X-ray, optical/infrared, or wide-field radio detection, and to get on source in a short time interval.

4. *Present the performance requirements (e.g. spatial and spectral resolution, Strehl ratio, sensitivity, timing accuracy) and their relation to the science measurements.*

Key performance requirements are:

- Spatial (angular) resolution – key science measurements encompass an angular "dynamic range" of more than 6 orders of magnitude from arcminute scale imaging to microarcsecond scale astrometry. For simplicity, we break this into two key scales:
    - Arcsecond scale imaging – the scale of galaxies in the distant Universe. Diffuse Galactic emission requires arcminute scales using mosaicing of multiple pointings.
    - Milliarcsecond scale imaging – AU-scale emission regions in our galaxy and solar-system scale objects in more distant galaxies, non-thermal emission with extremely high brightness temperatures from masers, stars, and black hole accretion disks. At the sub-milliarcsecond level and at high (>100:1) signal-to-noise ratio, micorarcsecond astrometry is possible (see below).

  Note: a given angular scale θ range implies equivalent scales in the array baseline length B as a function of wavelength λ, roughly given by $\theta = B/\lambda$ in radians. Thus, for sub-mircoarcsecond resolution, baselines of 3000 km or longer are required.
- Frequency coverage – the SKA-high must cover at least the "core" science frequency range

from 5-45 GHz, necessitating multiple receiver systems on each antenna. We break the frequency range into two key bands:

  - 15-45 GHz – this is the most critical band, encompassing the redshifted CO lines, and providing the highest angular resolution.
  - 5-15 GHz – this is less important than the higher frequency band, but still important for maser studies, continuum imaging, and for pulsar observations (for steep-spectrum objects too faint at higher frequencies). Some performance reductions in this band are permissible. Note that this frequency range overlaps the prospective range of the SKA-mid (Cordes et al), providing opportunities for complementary observations (e.g. in the Northern Hemisphere).

  Note that in addition to performance specifications in our core range, we have the overall goals of extended frequency coverage from 1-50 GHz, to maximize overlap with EVLA and VLBA during the staged construction and to carry out auxiliary science in these bands. This extended coverage is not a driver and would be descoped if necessary.

- Spectral mode (bandwidth and resolution) – capabilities equivalent to that of the current EVLA are required (maximum bandwidth 8 GHz/polarization, resolution to 122 Hz when traded vs. bandwidth). For the NAA, 8-bit correlation is needed at the widest bandwidths (vs. 3-bit on EVLA), needed to accommodate high dynamic ranges. This has implications for data transmission rates on the long baselines and the required correlator capacity. The general spectral modes are *continuum* (generally wide-band, low spectral resolution) and *spectral line* (generally moderate to wide-band and moderate to high spectral resolution).
- Sensitivity – requires high point-source sensitivity for astrometry of faint objects, and high surface brightness sensitivity for imaging of distant thermal emission. This necessitates at least 10x EVLA collecting area, distributed over the entire range of baselines to at least 3000 km. For line sensitivity, this must be an increase in the A_{eff}/T_{sys} (primarily in collecting area as EVLA has state-of-the-art low system temperature receivers).
- Imaging Performance – there are two aspects of imaging performance to be considered:
  - Image fidelity – the ability to accurately reconstruct the brightness of the image in all polarizations. Requires optimizing the design of the array configuration to sample a wide range of baselines.
  - Dynamic range – the ability to image faint emission in the presence of brighter sources in (or outside) the field-of-view. This places requirements on the array baseline configuration and calibration purity and stability of the instrument.
- Astrometric performance – high-precision astrometry uses longest baselines at the highest frequencies for 100-400 μas resolution imaging. To reach 1-4 μas rms astrometric accuracy requires >100:1 signal-to-noise ratio and superb control of systematic errors from the instrument and from the troposphere/ionosphere.
- Timing accuracy – sub-millisecond pulsar timing at high frequencies in strongly dispersed regions (e.g. the Galactic center) is a science target. A gated (de-dispersed) mode (e.g. folding and gating by parts of a pulse period and integrating) is needed for pulsar astrometry.

5. *Present a brief flow down of science goals/requirements and explain why each instrument and the associated instrument performance are required.*

In this document, we refer to the two receiver bands as “instruments”. Note that the array can be operationally configured, including partitioning into simultaneous sub-arrays with different characteristics (e.g. the inner core and outer baselines observing different targets). The following table illustrates the “configuration” of the system needed for each science goal:

Science Objective	**Measurement**	**Performance Requirement**
1. Precision Astrometry for Distances, Motions, and Black Hole Masses	1(a). Sub-milliarcsecond scale maser imaging	Angular resolution: sub-milliarcsecond
		Frequency coverage: 15-45, 5-15 GHz
		Spectral mode: high resolution spectral line
		Sensitivity: high (point source)
		Imaging performance: high dynamic range
	1(b). Maser precision astrometry and monitoring program	As 1(a) above, *plus*:
		Astrometric performance: critical
	1(c). Maser line search and survey	As 1(a) above, *except*:
		Spectral mode: moderate to wide-band, moderate to high resolution spectral line
	1(d). Weak AGN and compact object astrometry	As 1(b) above, *except*:
		Spectral mode: wide-band continuum
2. Imaging Galaxies in the Early Universe	2(a). CO line search and survey	Angular resolution: arcsecond
		Frequency coverage: 15-45 GHz
		Spectral mode: moderate to wide-band, low to moderate resolution spectral line
		Sensitivity: high (extended source)
		Imaging performance: faint object detection
	2(b). Arcsecond scale CO spectral imaging	As 2(a) above, *except*:
		Imaging performance: high fidelity
	2(c). Galaxy continuum imaging	As 2(b) above, *except*:
		Spectral mode: wide-band continuum
		Imaging performance: high fidelity, high dynamic range
3. Protoplanetary and Protostellar Disks, and Star Forming Regions	3(a). Milliarcsecond scale disk continuum imaging	Angular resolution: 10 milliarcsecond
		Frequency coverage: 15-45 GHz
		Spectral mode: wide-band continuum
		Sensitivity: high (thermal, extended)
		Imaging performance: high-fidelity, high dynamic range
	3(b). Super star cluster continuum imaging	As 3(a) above, *except*:
		Angular resolution: 10 milliarcsecond to arcsecond (or larger)
	3(c). Stellar object astrometry	As 1(b) above, *except*:
		Spectral mode: wide-band continuum
	3(d). Molecular line imaging survey	As 2(a) above, *except*:
		Angular resolution: 10 milliarcsecond to arcsecond
4. Transient and Periodic Phenomena: Supernovae, Gamma-	4(a). Milliarcsecond scale GRB/SNe continuum imaging	Angular resolution: milliarcsecond
		Frequency coverage: 15-45 GHz, 5-15 GHz
		Spectral mode: wide-band continuum

Ray Bursts, Pulsars		Sensitivity: high (moderately extended)
		Imaging performance: faint source detection, moderate fidelity
	4(b). Transient source triggered detection and monitoring survey	As 4(a) above, *plus*:
		Transient source capability: triggering, detecting, monitoring
	4(c). Pulsar astrometry	As 1(b) above, *except (and plus)*:
		Frequency coverage: 5-15 GHz
		Spectral mode: wide-band continuum
		Timing: gated

6. *For each performance requirement, present as quantitatively as possible the sensitivity of your science goals to achieving the requirement. For example, if you fail to meet a key requirement, what will the impact be on achievement of your science objectives?*

   The sensitivity of SKA-high science goals to the key performance requirements are:

- Spatial resolution – performance and sensitivity on long baselines at the high frequencies must be achieved in order to carry out microarcsecond astrometry. Requires continental (3000 km or longer) baselines. Expansion to the longest VLBA baselines (e.g. Mauna Kea) would give baselines to 7500 km and thus even higher resolution.
- Frequency coverage – lowest noise wideband feed performance over 3:1 bandwidths needed for the 5-15 GHz and 15-45 GHz bands has not been proven, and is a key development target for TDP-II. Performance at the highest frequencies is the highest priority, and lower frequency sensitivity may be sacrificed. For example, if only 2.5:1 is possible (18-45 GHz), then a lower band from 6-18 GHz might be used (still covering the 6.7 GHz methanol maser line), or at 2:1 three bands could be used (approximately 24-45 GHz, 11-24 GHz, 5-11 GHz.
- Spectral bandwidth and resolution – descoping the bandwidth (<8 GHz/pol) reduces speed at which given observations can be made due to reduced instantaneous sensitivity or spectral coverage. Reducing bit depth (e.g. from 8 bits to 3 bits) increases sensitivity to RFI and reduces maximum dynamic range.
- Sensitivity –the main area in which the SKA-high improves over the capabilities of the EVLA and VLBA, and thus total collecting area is of primary importance. For extended objects, the baseline distribution of the array determines the sensitivity. If we adopt the formal SKA Memo 100 specifications for SKA-high (Phase III SKA), 50% of the antennas are within 5 km. We expect that for the final design, we will instead want 50% within 50 km (EVLA scales) to optimize sensitivity to thermal emission at milliarcsecond scale resolution.
- Imaging performance – a reduction in the number of stations will adversely impact the imaging performance, particularly in the image fidelity. Poor antenna station "beams" and phasing will reduce the dynamic range, making imaging of faint sources in the presence of bright emission difficult (and more computationally costly) or in extreme cases impossible.
- Astrometric performance – poor stability of station beams and inability to properly calibrate will severely limit the key astrometric science. Critical part of PAS testing with EVLA.
- Timing accuracy – sub-microsecond timing and a robust gated mode are necessary for pulsar astrometry. Post-correlation processing is outside the scope of the TDP-II and PAS.

2.0 Enabling Technology

Please update or provide information from the original RFI response describing new Enabling Technologies that must be developed for activity success. The committee assumes that Enabling Technology demonstrated by sub-unit demonstration models will be completed prior to Authorization to Proceed (ATP) or Preliminary Design Review by NSF. Technical Readiness of this demonstrated Enabling Technology at the full up unit level can occur after ATP during the Technical Implementation phase of the program. See the sections below. Please indicate any non-US technology required for activity success and what back up plans would be required if only US participation occurred.

1. *For any technologies that have not been demonstrated by sub-scale or full-scale models, please describe the rationale for the technical maturity, including the description of analysis or hardware development activities to date, and its associated technology maturation plan.*
2. *Describe the critical aspect of the enabling technology to your concept's success and the sensitivity of science performance if the technology is not realized.*
3. *Provide specific cost and schedule assumptions by year for all developmental activities before ATP and the specific efforts that allow the technology to be ready when required.*

For this part it is assumed "**Enabling Technologies"** is referring to areas where advanced R&D is required, there is significant development risk, and/or where non-commodity or experimental components are required and must be developed (either in-house, by a commercial entity or by an academic/research lab).

It does not include the technologies which can be implemented in the NAA Prototype Antenna Station with a high probability of success using commercial components or technologies that are available (or are widely expected to be available) at the time development starts. Because this is a development and demonstration project, we also briefly indicate areas where the TDP-II and PAS will be used to investigate Enabling Technologies for the SKA-high construction project.

Based on these criteria, we have identified the following areas of concern extracted from the three Technology Drivers presented in Section 4 of the original response to RFI#1, with an addition of the wide-band feed technology:

2.1 Receptor performance/cost-ratio

Low Cost Antenna Technology: Currently, the technology to build a high performance, 50 GHz capable, microwave antenna suitable for radio astronomy is very mature and widely available. However, the cost to build 1000+ of these antennas for an instrument the size of the SKA-high would render that project unrealizable in the current economic climate. For the NAA/SKA-high concept to be economically feasible, a design for a simple, reliable, very low cost, yet high performance antenna is absolutely essential. Antennas designed to be produced at a low cost, in thousand unit quantities, are currently being developed for various SKA Pathfinder arrays such as the ATA, MeerKAT and ASKAP projects. As built, these antennas are good to about 10-15 GHz and would likely not be suitable for the NAA/SKA-high instrument in which the sky frequency may extend up to 50 GHz. Parameters such as surface accuracy, structural stiffness and pointing accuracy become more critical as the top frequency goes up.

A major development effort is necessary to develop an antenna suitable for the NAA/SKA-high application. This effort will begin in TDP-II by looking at antenna technologies developed in TDP-I, PrepSKA, and the SKA Pathfinder arrays, and then expanding on those designs to increase high frequency performance while minimizing manufacturing costs. The resulting antenna design(s) will them be produced and installed in the NAA-PAS. Once installed, the antennas will be evaluated with both standard laboratory measurements and by using the antennas in astronomical observations.

Critical specifications include:

1) Surface accuracy
2) Optical performance
3) Spillover
4) Pointing accuracy
5) Structural stiffness under acceleration or high wind loads
6) Life expectancy / survivability
7) Maintainability / reliability
8) Lifetime operating cost

Some areas to be explored include:

1) Light weight, high strength composite materials & fabrication techniques
2) Spun reflectors
3) New manufacturing techniques
4) On-site manufacturing techniques
5) Low cost, high performance drive systems

To carry out this development, people with specialized expertise in antenna structures, composite materials and advanced manufacturing techniques will be required. This will likely involve close collaboration with private industry, other observatories and academic research laboratories.

Wideband Feed and Receivers: In addition to the antennas, wide-band feed technology is a key to reaching the performance and cost goals of the SKA-high project, and we add a discussion of it here (it was not included in the Technology Drivers of RFI#1). Radio Astronomy is unique in the area of radio and microwave technology applications in requiring feeds and receivers with both wide bandwidths and low system temperatures. Development work on receivers for SKA systems is already occurring throughout the community. EVLA is currently achieving 2:1 bandwidth ratios with high levels of performance, while the Allen Telescope Array (ATA) is achieving 20:1 ratios with much poorer performance. The challenge is to meet somewhere in the middle. Design and development of wideband (3:1 fractional bandwidth) feeds and polarizers are needed for meeting NAA frequency range goals at minimal cost without compromise in performance. Extensive design, prototyping and testing, both in the lab and on the NAA-PAS, is required to develop low cost high performance receivers for NAA/SKA-high. This may also mean going to linearly polarized receivers since the wideband phase shifters and ortho-mode transducers (OMT's) are two of the most difficult aspects of the design of wide bandwidth receivers. This, in turn, can have an impact on digital processing requirements either to convert signals to circular polarization digitally or for the more complex data calibration and software required for linearly polarized signals.

Critical feed & receiver specifications to be evaluated include (but are not limited to):

1) Noise temperature and sensitivity over the operating band
2) Gain flatness over the operating band
3) Phase stability
4) Repeatability of performance over multiple units
5) Cost per unit in large quantities
6) Pattern / beamwidth / sidelobe performance
7) Reliability / longevity / maintainability
8) Long term operating costs (particularly of any cryogenics)
9) Polarization purity & stability

The successful development of low cost, high performance receivers is essential to the success of NAA/SKA-high, and the NAA-PAS is an ideal platform for evaluating the performance of these receivers. New broadband receiver systems would likely utilize a number of technologies that need further development, including (but not limited to):

1) Monolithic Microwave Integrated Circuits (MMIC's)
2) New low cost Low Noise Amplifiers (LNA's)
3) New low cost cryogenics
4) Focal plane / multi-pixel arrays
5) New feed & polarizer designs

To carry out the development phase, expertise in the areas of electromagnetic feed, LNA, MMIC, and receiver system design, integration and testing will be employed. Considerable mechanical and manufacturing engineering will be required to determine how to build these receivers in large quantities at a low cost. While not critical in the relatively low quantities needed for NAA-PAS, it is absolutely essential to minimize the cost of these receivers for eventual use on the NAA/SKA-high instrument.

2.2 Data Transmission, Correlation, Computing Infrastructure

Digitization: Future Radio Astronomical instrumentation will depend heavily on the processing of signals in the digital domain. Challenging system performance specifications, as well as the scale and quantities of hardware to be built, require that the digitization of the RF signals be performed as close as possible to the RF receiver. To accomplish this, it is essential that very high speed (10-100 Gsps) digitization technology be developed and thoroughly tested. The radio astronomy community has a long history of being at the cutting edge of high speed digitizer technology and this project is no exception. The NRAO must work closely with the semiconductor industry, corporate research labs, academia and other projects to be sure such devices are developed and that they meet the requirements for Radio Astronomy. NRAO is already involved in collaborations with the South African SKA Project Office (SASPO), the Center for Astronomy Signal Processing and Electronics Research (CASPER) and Haystack Observatory to address various techniques and developments. Research and development of digital technology is also a specific goal in the collaboration between NRAO and SASPO on the South African MeerKAT Array. Digitizer and associated interface IC's (such as demultiplexers) must be developed and integrated into a radio telescope system. Extensive testing, both in a lab environment and on the NAA Prototype Antenna Station, is required to evaluate the suitability of the device(s) for use in the NAA/SKA-high system.

Critical specifications to evaluate include (but are not limited to):

1) Maximum sampling rate
2) Analog bandwidth (particularly if sampling in Nyquist zones other than the baseband)
3) Gain / phase response flatness
4) Jitter or phase noise
5) Temperature stability
6) Repeatability (or similarity) of performance across multiple devices
7) Power dissipation
8) Device production costs (particularly for applications in large arrays)
9) Accuracy of threshold levels
10) Aliasing / behavior at band edges (mostly effects anti-aliasing filters)

Projects involving the development of cutting edge semiconductor components of this type are usually successful but require substantial research and development and monetary investment. Multiple design/prototype/test iterations are common and must be provided for in project schedules and budgets. The successful development of these digitizers is absolutely essential to the final implementation of the NAA-PAS and an eventual NAA/SKA-high system.

Data Transmission: High speed digitizers produce extremely large quantities of data that must be efficiently transferred to the data processing hardware. In an array like the NAA/SKA-high instrument, this may involve moving many hundreds of gigabits per second of data from each antenna or station over large distances (1-3000 km) to a central data processing facility. In the EVLA and ALMA projects, this involved the development of 10 Gbps fiber optic links that transmit 120 Gbps total from each antenna. These data rates were beyond the state-of the art at the beginning of those projects. Development occurred concurrently with similar efforts in the multi-billion dollar telecommunications industry so commercial components and research materials were not readily available until relatively late in the design stage of the projects. In the end, both projects were able to utilize technology produced by the telecommunications industry, but that was modified or adapted by NRAO and/or the vendors to fit the unique requirements of radio astronomy.

High speed data transmission requirements for this project will result in a similar situation. The 100 Gbps class links required for this project and future arrays are expected to be in a research stage in telecommunications industry at the beginning of TDP-II. Development of this technology has a high probability of success due to the involvement of the telecommunications industry and the ever increasing worldwide demand for communications bandwidth. While 10 Gbps links designed for EVLA and ALMA could be used for NAA-PAS, it is completely essential to the successful development of an NAA/SKA-high system that reliable, low cost, long distance, 100 Gbps class communications links be developed and tested on the NAA-PAS. The eventual use of this technology will require close collaboration and involvement with the telecommunications industry.

2.3 Beam Forming, Data Processing, Software

Station Beam Forming: The use of stations of antennas combined into one or more “beams” on the sky that are then cross-correlated is on the critical path for an the SKA-high. With a significant fraction (as much as half) of the total collecting area on long baselines >50 km, transmission of and cross-correlation of wide-band data streams from over 500 individual antennas would be prohibitively expensive, as would maintenance of this number of individual sites. Therefore, the use of beam-forming technology is a key technology for the SKA program. For the NAA-PAS, we need only the capability of phasing the station array into a single beam to be correlated with the EVLA, and that is what is budgeted under Digital signals and processing (WBS 6.03.10). However, use of the PAS for development and testing of multi-beam forming technology would be a potential boon for the SKA-high program. We consider this to be an area where the international SKA partners could contribute to the NAA-PAS demonstrator program, as it is outside our baseline PAS budget presented here.

Software: There will be significant challenges in data processing, algorithms, and software needed to realize the ultimate science goals of the SKA-high. However, we do not foresee that significant new developments are needed beyond those included in the TDP-II which are needed to carry out the NAA-PAS project. For example, the PAS will be correlated with the EVLA as a single station (see Beamforming above). This is also an area where other partners or funding sources could be used to enhance the activities of the NAA beyond those budgeted here.

3.1 Optical Telescope or Antenna Array or Collector Array

Antenna and array design is part of the TDP-II phase of the project, and construction and testing of a station array is the goal of the PAS activity.

1. *Describe the characteristics and requirements of the optical telescope(s) or antenna(s) or collector(s) including all planned bands/wavelengths of operation and accuracy requirements (manufacture and alignment) of each surface. Include a description of the design and a summary of the estimated performance of the telescope(s) or antenna(s), number and size of optical segments or array elements, support structure(s), pointing requirements and methods and any unique aspects of the design. Describe telescopes or antennas with multiple reflective surfaces completely. Indicate why the specific geometry or implementation was chosen. Provide ray trace diagrams where appropriate. For arrays, state/describe if the array is reconfigurable. Please fill out the Telescope/Antenna Array Characteristics Table.*

See Table 3.1.1 below.

The baseline plan for the NAA Prototype Antenna Station (NAA-PAS) is to build 20 full sky AZ/EL mount antennas of a design developed in the TDP-II. The SKA-mid dish designs from TDP-I being considered have diameters in the range 9-15m, although the 6m ATA design will also be evaluated in TDP-II. The most likely optical configuration is an Offset Gregorian design with two 3:1 bandwidth feeds, one covering 5-15 GHz and the other 15-45 GHz. Surface and pointing accuracy specifications for the antennas will driven by the goal of an eventual 50 GHz top end frequency for NAA/SKA-high. The specific structural design of the antenna will be determined by a combination of the speed, acceleration and thermal stability necessary to meet the scientific specifications and the weather survivability requirements of the chosen site. The antenna drive system will likely be a traditional geared system driven by traditional servo motor technology. The method for selecting between the two RF feeds would involve the traditional techniques of moving either the feed or subreflector. The antennas will most likely be permanently mounted to a traditional cement foundation.

2. *Discuss the lifetime of the facility and any future upgrades. Outline plans for decommissioning when the activity is finished.*

The lifetime of the NAA-PAS facility depends on whether or not the PAS site is planned to be a permanent station in an eventual NAA/SKA-high telescope, or if it is simply a test facility. If it is not part of an eventual NAA/SKA-high system, the site's usefulness would likely end between 2020 and 2025 and would be decommissioned and the equipment removed at that time. In the (desirable) event that the SKA-high is constructed as the NAA, another scenario is that the NAA-PAS facility would become a part of the NAA/SKA-high system. In this case, the lifetime would become tied to the NAA-SKA-high telescope. That instrument would likely have a 20-30 year design lifetime after commissioning. This proposal assumes that this is a test facility only, and that any upgrading to become part of a longer-life science facility would be budgeted as part of that project.

3. *Provide a description and an overall assessment of the technical maturity of the critical components, polishing or fabrication techniques, alignment, actuators, and support structure.*

Provide a rationale and an assessment of the technical maturity of each key component or method (Off-the-shelf hardware, hardware demonstrated on other systems, extrapolation from demonstrated technology or implementations, requires new development of existing technology, requires new technology development). In particular, describe fully any required new technologies or developments or open implementation issues required for success.

The technology to build the type of antennas required for the NAA-PAS, and eventually NAA/SKA-high, is mature and exists today. The most important aspect of the antenna design efforts will actually be to minimize production and lifetime operations costs due to the large number of antennas (likely 1000+) that will be required for the NAA/SKA-high system. Producing a low cost antenna design is absolutely essential to eventually attaining an affordable NAA/SKA-high design. Work toward this goal is already occurring on the TDP-I project, PrepSKA, and in the various SKA-mid development efforts occurring around the world. Collaboration with commercial antenna vendors is already occurring and is critical to this process.

4. *For segmented telescopes or antenna arrays, describe in detail the individual segment or antenna element including the design (size, weight, surface requirements etc), type of construction, light-weighting technology required, fabrication techniques, investment required to produce large numbers (facility construction etc) and the support structure. Discuss alignment and pointing method knowledge and accuracy.*

Twenty 12-meter antennas will be installed. The antenna design will be produced as part of the TDP-II phase, and further refined for contracting at the start of the PAS phase. The design will be based upon antenna development carried out as part of the SKA-mid program, see the RFI#2 response of Cordes et al. for more details on the status of the antenna design.

5. *Describe all actuators including heritage, required actuator precision and associated range.*

There will be no active surfaces (e.g. segments). Focus and subreflector control will be actuated, as is standard in radio antenna designs. Antenna drive control and precision will have to meet more stringent specifications than those for the lower-frequency SKA-mid design, see answer to Q7 below.

6. *Identify and describe the three lowest technical maturity components, and explain how and when these components will be demonstrated in reduced-scale and/or full-scale hardware.*

Note that the purpose of the proposed NAA activities are in the design and demonstration of the relevant technologies. The lowest maturity antenna/array components at this time are:

a) SKA-mid antenna prototypes – the TDP-I and PrepSKA have not yet completed (scheduled for 2011-2012), although advanced designs are available (see Cordes et al. RFI#2 response). Thus, we do not know what will be delivered for the antenna evaluation part of TDP-II (and what compatibility concerns there will be). This will be mitigated by our involvement in the TDP-I/PrepSKA process.
b) 50-GHz capable NAA-PAS antenna – and there will be no design and prototype until the end of TDP-II in 2014-2015. Demonstration of this design is the primary goal of the PAS.
c) PAS beam-former and phasing system – will have to be developed during TDP-II and early in the PAS phase. Will base upon systems used in other arrays, such as ATA and EVLA.

Note that these are also described in the risks Q7 below.

7. *What are the three greatest risks to cost, schedule, and performance?*

From the standpoint of successful test operations as a technology demonstrator for SKA-high, the three primary technical risks for the Prototype Antenna Station antennas and array are:

a) Antenna Design – the PAS program is predicated upon TDP-II producing a viable 50 GHz antenna design (ideally including a prototype antenna) or concept that can be turned into a design that can be placed out for bid in the first year of the PAS. If this is not available, then extra time and cost will be required in the schedule. In the extreme case of no viable concept, then the PAS proposal would have to be delayed, and an antenna design and prototype program might have to be undertaken instead (e.g. a TDP-III).
b) Antenna Cost – we are proposing a station containing 20 antennas, at the cost presented in Section 6. If the true costs were higher (e.g. due to costs of steel, or to the design chosen) then either the cost of the PAS project would have to be increased or fewer antennas built. Note that for technology demonstration purposes (unlike for science) a reduced number of antennas in the station could be reduced with a corresponding reduction in the quality of the phased-array station beam, which impacts testing of station performance. We estimate that 16 antennas will still provide a robust station beam, a smaller number may not viable for the PAS goals.
c) Antenna station beamforming and operation – operation of an antenna cluster as a phased station with the EVLA, is a risk. Much testing of the receivers can be done in total-power single-antenna mode, but ultimately successful operation of the PAS will require stable phasing-up of the stations, which may incur schedule risk

8. *Describe the telescope/antenna construction and assembly methods. Indicate any unique construction and any special issues regarding the facility location. This may be included in Facility Construction section.*

The antennas will be constructed and assembled by the antenna contractors. Erection and outfitting will be carried out by the NAA engineers (see WBS). See Section 3.4 for more details on the facility construction and site.

9. *Address to the extent possible the specific accommodation of the instruments. In particular, identify any challenging or non-standard requirements (alignment and/or pointing considerations, thermal environment/temperature limits etc).*

No particular challenges for the VLA site. Blind pointing at the 1/10 "primary beam" FWHM level (6 arcseconds at 45 GHz for a 12-m antenna) or better is required. Fast-switching capability (slew and settle on a source a few degrees away in a few seconds) is also required.

10. *Describe any aspect of the design or implementation that requires non-US participation.*

During TDP-II we will be evaluating various antenna designs, including those from international SKA partners and pathfinders. To the extent possible, we will incorporate developments from the PrepSKA and SKA-mid programs, and also involve interested non-US SKA scientists and engineers in the NAA activities.

Table 3.1.1 – Telescope/Antenna Array Characteristics Table

Optical Telescope or Antenna Array	Value/ Summary, units
Main and Effective Aperture Size	Array diameter ~100 m
System Effective Focal Length	TBD for individual elements
Sizes of Array Elements or Segments	12m
Number of Array Elements or Segments	20
Total Collecting Area	2262m^2
Angular Resolution	14 arcsecond station beam at 45 GHz
Field of View (accessible area of sky)	Full Sky down to 10^o in elevation (~EVLA spec)
Wavelength range	1-50 GHz (goal) 5-45 GHz (spec)
Driving Wavelength for Surface Accuracy	50 GHz
Required Surface Accuracy	375um
Surface Coating Technique	TBD
Number of Mirrors or Reflecting Surfaces	1 (prime focus) or 2 (Cassegrain, offset Gregorian)
Size of each Optical Element and its Clear Aperture	9-12m primary reflector, ~1-2m secondary mirror
Mass of each Segment or Element *	~20 tons (e.g., 12m design)
Total Moving Mass *	~10 tons (e.g. 12m design)
Mass of each Optical Element *	TBD
Actuator Precision and Range	TBD
Type of mount used for pointing and allowed range	AZ/EL
Mass and Type of Material for Support Structure *	TBD
Optic Design (e.g., Cassegrain)	TBD

*Masses should be provided with and without contingency

3.2 Instrumentation

1. *Describe the proposed science instrumentation, and briefly state the rationale for its selection. Discuss the specifics of each instrument (Inst #1, Inst #2 etc) and how the instruments are used together. Indicate whether cryogens are required.*

For the purposes of the PAS, we consider the two proposed receivers to be the "instruments" with which the array is outfitted. These are:

5-15 GHz band receiver: 3:1 Bandwidth ratio, cryogenically cooled low-noise amplifier, circular or linear polarized microwave receiver to be designed as part of this project. Exact specifications, topology, construction and cryogenics configuration are unknown at this point, and our estimates are based upon EVLA X and Ku band designs. This is a lower-priority science band for SKA-high, but this is important for the NAA-PAS to allow interoperation with the EVLA during sub-optimal weather (particularly during the summer).

15-45 GHz band receiver: 3:1 Bandwidth ratio, cryogenically cooled low-noise amplifier (LNA), circular or linear polarized microwave receiver to be designed as part of this project. Exact specifications, topology, construction and cryogenics configuration are unknown at this point, and our estimates are based upon EVLA K, Ka and Q-band designs. This is the primary high-frequency science receiver and good performance is critical for SKA-high in this band, and extremely important for PAS testing of the antenna and station performance at the highest frequencies.

Note: the receiver cryogenic systems use closed-cycle refrigerators, and thus there are no expendable cryogens required for operation.

2. *Indicate the technical maturity level of the major elements and the specific instrument maturity of the proposed instrumentation (for each specific Inst #1, Inst#2 etc), along with the rationale for the assessment (i.e. examples of heritage, existence of breadboards, prototypes, mass/volume and power comparisons to existing units, etc). Use the maturity designations: off-the-shelf hardware, hardware demonstrated on other systems, extrapolation from demonstrated technology or implementations, requires new development of existing technology, requires new technology development. For any instrument not demonstrated by a breadboard or engineering model in the operational environment, please describe the rationale for the rating, including the description of analysis or hardware development activities to date, and its associated technology maturation plan.*

- Antennas: requires new development based on existing technology
- Receivers (instruments 1 & 2): new development based on existing technology
- Cryogenics: off-the-shelf-hardware (EVLA systems) or new development based on existing technology (lower cost systems)
- Data transport: off-the-shelf hardware (10 Gbps links) or requires new development based on existing technology (100 Gbps links)
- Digital systems: requires new development based on existing technology
- Beam-forming: extrapolation from demonstrated technology or implementations
- Data-processing: extrapolation from demonstrated technology or implementations

Rationale: See answers to question 1 above and questions 3 and 10 below.

3. *In the area of instrumentation, what are the three primary technical issues or risks?*

From the standpoint of successful test operations as a technology demonstrator for SKA-high, the three primary technical risks for the receiver chain instrumentation of Prototype Antenna Station are:

a) Wide-band feed performance – although we do not require the highest performance for test operations with the PAS, a 3:1 bandwidth design and implementation may not be ready for the first few receivers. In this case, interim prototypes with lower bandwidths (e.g. 2:1 as in EVLA) may be used, and will need to be replaced later on. This should not impact the utility of early testing, as narrower bandwidths can be used.

b) Wide-band digitization and transmission – the boundary between the receivers as "instruments" and the common digital signal chain through to the EVLA is somewhat blurry, as the receivers must be able to produce data that can be correlated in order to function as an interferometer. Commissioning of the EVLA has shown that these digital systems can exhibit a number of "teething pains", and thus there is some schedule risk in bringing up these systems. There are several individual risk items related to the digitization and LO chain (see Section 5 below).

c) Low-cost receiver cryogenics – part of the PAS design will be demonstration of low-cost cryogenic technology, needed for the ultimate SKA-high array with a large number of antennas. The fallback for the PAS is to use higher-cost but reliable EVLA cryogenics..

4. *Fill in the entries in the Instrument Table. Provide a separate table for each Instrument (Inst #1, Inst #2 etc). As an example, a telescope could have four instruments, each having their own focal plane arrays. For RF antennas describe all up and down converters and instruments that combine/delay signals for calibration/phasing. Discuss all margins carried at the instrument level.*

See Table 3.2.1 (5-15 GHz band receiver) and Table 3.2.2 (15-45 GHz band receiver).

5. *Provide for each instrument what organization is responsible for the instrument and details of their past experience with similar instruments.*

NRAO will be responsible for development and construction of the receivers, feeds, digital systems, data transmission, cryogenic systems, and infrastructure. NRAO is in the process of finishing the EVLA and ALMA projects. These telescopes have provided the expertise to perform this new development. The antenna systems will be mostly developed by the TDP-I, PrepSKA, and SKA pathfinder (e.g. MeerKAT) teams. NRAO will evaluate these systems and will work with the teams to continue the development to produce an antenna that can operate at 50GHz.

6. *For the science instrumentation, describe any concept, feasibility, or definition studies already performed (to respond you may provide copies of concept study reports, technology implementation plans, etc).*

This development project will not produce a telescope that will be used for science.

7. *For instrument operations, provide a functional description of operational modes, and*

calibration schemes. This can be documented in the Operations Section. Describe the level of complexity associated with analyzing the data to achieve the scientific objectives of the investigation. Describe the types of data (e.g. bits, images) and provide an estimate of the total data volume.

The NAA-PAS will be integrated into the EVLA system for testing. The outputs from the beam formers and/or antennas will be optically transmitted to the EVLA WIDAR correlator. This will require the data format to be similar to the EVLA format. The 27 EVLA antennas will be used to determine the performance of the NAA-PAS.

EVLA operators will control the NAA-PAS. The data will be part of the WIDAR output which will be evaluated with the CASA software package.

8. *Describe the instrument control software, including an estimate of the number of lines of code.*

The EVLA monitor and control system is well developed and tested. The system is modular and was designed to handle more than 27 antennas. The addition of the TDP1 antennas and/or the NAA-PAS antennas to the present M&C system is possible but will require additional code.

9. *Describe any instrumentation or science implementation that requires non-US participation for activity success.*

The TDP-II activity is a US SKA Consortium activity, and does not require non-US participation in order to meet the minimal goals of a NAA PAS design. Note that it is expected that the international PrepSKA program does produce a prototype SKA-mid antenna to participate in the evaluation phase of TDP-II, and furthermore we hope that there will be further collaboration with the SKA program during the TDP-II activity. For the PAS, the schedule, WBS, and cost are for a fully self-contained demonstrator project that is in this baseline form a US-only funded activity. However, international participation would be welcome, e.g. to augment the PAS testing effort, and would be negotiated at the time of the NAA-PAS proposal in 2014-2015.

10. *Describe the heritage of the instruments and associated subsystems. Indicate items that are to be developed, as well as any existing hardware or design heritage.*

5-15 GHz and 15-45 GHz Low Noise Amplifiers: These will be standard NRAO-design HEMT amplifiers, designed for wide-band operation.

15-45 GHz Block Down-conversion: If a method of direct digitization at sky frequencies up to 45 GHz is determined to be unfeasible, block down-conversion of all or some portions of this bandwidth may be required. While the preference would be to avoid this, if required, this block would be a traditional analog down-converter.

Digital Synthesizer: If block down-conversion is deemed to be necessary, an LO source will be required. Due to recent advancements in high speed FPGAs and Digital to Analog converters, it is feasible that a low cost Direct Digital Synthesizer for microwave frequencies can be built that has suitable tuning capability, phase noise and spurious response characteristics for use as a radio astronomy LO source. This technology is under initial study at NRAO and being looked at for several applications. A fallback solution is also available and involves using the more expensive traditional PLL/ YIG Tuned Oscillator design currently used in the EVLA.

Signal Conditioning and filtering: Applied to both RF paths. This includes amplification and gain control to set appropriate input levels for the ADCs. It also includes all anti-aliasing filter requirements for the ADCs.

Analog to Digital Conversion: For the ADC, there are four design concepts currently under investigation:

1) A pass-band sampling technique expanding on the designs used for EVLA and ALMA. This would add a switched filter bank and Track & Hold amplifier in front of an ADC. This technique is currently under investigation at NRAO. ADCs and T&H amplifiers are currently available to support sampling of RF signals to between 25 and 30 GHz. The switched anti-aliasing filter bank is likely the most challenging and costly portion of this concept.
2) A Digitally Enhanced Sideband Separating Mixer combined with a high speed ADC. This technique is currently under investigation at NRAO and is described in the technology development whitepaper titled “Next Generation Radio Astronomy Receiver Systems” submitted to the ASTRO2010 Panel by Matt Morgan and Rick Fisher of NRAO.
3) Multiplexed lower speed ADCs. This is essentially the technique used by test equipment manufacturers for high speed oscilloscopes and similar products and can involve either single or multi-chip solutions. This technique presents problems in radio astronomy applications due to differences in precision timing and threshold levels between the devices. With some R&D work, these issues may not be insurmountable.
4) Direct digitization. This would require development of an ADC capable of a sampling clock rate of at least 30 GHz. This is extremely cutting edge technology. We are aware of several semiconductor companies researching solutions at this time. This would likely be the simplest and lowest cost solution in the long term but currently would represent the highest risk of the four approaches.

Note that we will be implementing 8-bit digitization in the NAA. This capability is available in the EVLA for “narrow” (<2 GHz) bandwidths, allowing testing of the PAS.

Optical Transmission: The tremendous amounts of data produced in these systems will require 100 Gbps class links for transmission of data for central processing. There are three concepts under investigation:

1) Hardware for 40-100 Gbps class links is under development by the telecommunications and fiber optics industries but has not been commercially deployed. Adaptation of this technology for radio astronomy would need to occur concurrently with industry development as was done for the 10 Gbps links in the EVLA and ALMA projects. This technology will likely still have data overhead, though we expect this to be less than 20% for the 10 Gbps links currently in use. The advantage of this technology is that eventually commodity components will be available and data streams may be easily tied into future commercial telecommunications networks for transmission over large distances.
2) Techniques using high speed logic and VCSEL lasers may be feasible. This technique is currently under investigation at NRAO and is also described in the technology

development whitepaper titled “Next Generation Radio Astronomy Receiver Systems” submitted to the ASTRO2010 Panel by Matt Morgan and Rick Fisher of NRAO. This system would be quite unique to radio astronomy and may well be the simplest and least costly approach. The only disadvantage is that this may not integrate well into commercial telecommunications networks – something that may eventually be a requirement for NAA/SKA-high.

3) Many copies of the 10 Gbps links currently used for EVLA and ALMA could also be utilized. This has the benefit of already tried & tested hardware. These links have 2 Gbps of overhead and would be expensive to produce in the quantities required for NAA-SKA-high. This may be useful for initial testing on the NAA-PAS and as an more costly fallback if higher capacity links do not materialize. It is not the preferred approach.

LO & Timing References: Clocks and timing signals required for ADC clocks, the Antenna Control Unit and the LO synthesizer will be distributed to the antenna over fiber using hardware similar to that used for EVLA and ALMA. This is largely based on low cost, commodity fiber optic components designed for Cable TV distribution. While already relatively inexpensive, engineering R&D work to further miniaturize and reduce the costs of this equipment is desirable.

Round Trip Phase Monitoring: To properly phase the array, the propagation delay in the LO fiber will need to be measured. The baseline plan is to use the designs for the EVLA round trip phase system which is already built, tested, and will meet the requirements for the NAA-PAS and NAA/SKA-high system. While already relatively inexpensive, engineering R&D work to further miniaturize and reduce the costs of this equipment is desirable.

Antenna Control Unit: To maintain low cost, it would be preferable to have a single Ethernet connected computer, located at the antenna, in control of the antenna drive system and all of the electronics.

Table 3.2.1 Instrument A (5-15 GHz band receiver)

Item	Value	Units
Type of instrument	Radio receiver	
Number of channels	64	channels
Spectral Range	5-15	GHz
Number and Type of Sensors	20 (1/antenna)	
Number of Pixels	1	
Pixel size	NA	microns
Pixel scale	NA	arcsec
Focal Plane Power and Thermal Requirements	NA	Watts
Temperature control range and accuracy	18 +/- 2	K
Size/dimensions (for each instrument)	TBD	
Instrument mass **without** contingency (CBE*)	TBD	kg
Instrument mass contingency	TBD	%
Instrument mass **with** contingency (CBE+Reserve)	TBD	kg
Instrument average power **without** contingency	TBD	Watts
Instrument average power contingency	TBD	%
Instrument average power **with** contingency	TBD	W
Instrument average science data rate^ **without** contingency	48 (see note)	Gbps
Instrument average science data^ rate contingency	0	%
Instrument average science data^ rate **with** contingency	48 (see note)	Gbps
Instrument Fields of View (if appropriate)	6-18	arcmin
Pointing requirements (knowledge)	18	arcsec
Pointing requirements (control)	18	arcsec
Pointing requirements (stability)	TBD	deg/sec

*CBE = Current Best Estimate.

^Instrument data rate defined as science data rate prior to processing

Note: The PAS will be correlated with the EVLA, which has a maximum bandwidth of 4 GHz (corresponding to 48 Gbps for 3-bit sampling, dual polarization) for all receiving bands in the 5-15 GHz range.

Table 3.2.2 Instrument B (15-45 GHz band receiver)

Item	Value	Units
Type of instrument	Radio receiver	
Number of channels	64	
Spectral Range	15-45	GHz
Number and Type of Sensors	20 (1/antenna)	
Number of Pixels	1	
Pixel size	NA	microns
Pixel scale	NA	arcsec
Focal Plane Power and Thermal Requirements	NA	Watts
Temperature control range and accuracy	18 +/- 2	K
Size/dimensions (for each instrument)	TBD	
Instrument mass **without** contingency (CBE*)	TBD	kg
Instrument mass contingency	TBD	%
Instrument mass **with** contingency (CBE+Reserve)	TBD	kg
Instrument average power **without** contingency	TBD	Watts
Instrument average power contingency	TBD	%
Instrument average power **with** contingency	TBD	W
Instrument average science data rate^ **without** contingency	96 (see note)	Gbps
Instrument average science data^ rate contingency	0	%
Instrument average science data^ rate **with** contingency	96 (see note)	Gbps
Instrument Fields of View (if appropriate)	2-6	arcmin
Pointing requirements (knowledge)	6	arcsec
Pointing requirements (control)	6	arcsec
Pointing requirements (stability)	TBD	deg/sec

*CBE = Current Best Estimate.
^Instrument data rate defined as science data rate prior to processing
Note: The PAS will be correlated with the EVLA, which has a maximum bandwidth of 8 GHz (corresponding to 96 Gbps for 3-bit sampling, dual polarization) for all bands in the 15-45 GHz range.

3.3 Observation Strategy

Please answer the following:

1. *Provide a brief descriptive overview of the observation strategy, field of view and pointing methodology and how it achieves the science requirements (e.g. if you need to cover the entire sky, how is it achieved?). Describe impact of weather/atmospheric conditions on operations mode, e.g. seeing-limited vs. AO-corrected observation time. Be specific on integration times and mapping timelines.*

For the coming decade, we are proposing only technology development and not an operational science instrument. Testing of the single-antenna system will be carried out largely using a combination of standard single-dish techniques (e.g., hot and cold loads) and interferometric techniques (e.g., scanning the antenna across a point source and measuring the cross-correlation with EVLA antennas whose pointing is held constant).

The test antenna station will most likely be located near the EVLA site, though it is possible that it might be sited remotely (e.g., next to the Pie Town VLBA station). The observation strategy for the test station will be for the individual antennas to track the same radio source, with antenna outputs combined coherently to mimic the effect of a single larger aperture. The combined signals will be digitized, transmitted to the EVLA correlator over an optical fiber, and processed there relative to EVLA antennas. Images will be constructed using standard interferometric techniques, and their quality measured using observables such as the image dynamic range and fidelity as a function of position in the field of view. Weather is expected to have little impact; when the troposphere is most active (e.g., summer days), tests may be restricted to the 5-15 GHz band.

2. *Describe scope of engineering activities and time (day or night) needed to maintain calibration and health of telescope/array and instruments (may be incorporated into Facility and Science Operations section).*

No science observations are planned for the technology development program, so all the time will be engineering time. Standard maintenance described in Facility and Science Operations below.

3. *Describe all software development and any science development required.*

No science development is required for the technology demonstration. The primary software development will be for the beam-forming that turns the collection of individual antennas into a "station." We expect that we will be able to adapt software being used for SKA pathfinders that will be creating such station beams well before our test station is developed in the second half of the next decade. Post-processing software for the image analysis described above will be the standard software used for the EVLA, VLBA, and ALMA. Small additions to the EVLA control software will be needed to account for the interface to the test station. We expect that the individual antennas in the test station will be procured along with basic control software for the antennas, so little additional control-software development will be required.

4. *Provide diagrams or drawings showing the observatory or antenna array with the instruments and other components labeled and a descriptive caption.*

See Block Diagram Tables 3.3.1 and 3.3.2 below.

5. *Indicate and describe methods chosen (coordinate systems, electronic versus mechanical) to point the telescope or array in two orthogonal axis.*

Because the individual antennas are expected to be approximately half the diameter of an EVLA antenna, the pointing requirements are correspondingly less rigorous. The general mechanism of pointing for the individual test antennas will be by specifying right ascension and declination, which will be converted into local azimuth and elevation coordinates in the control system.

The more significant effort will be required in the station beam-forming, since coherent combination of the individual antennas will be needed to synthesize the virtual station. This combination must account for varying path-length differences caused by the Earth's atmosphere, largely the troposphere at the higher frequencies. Two methods will be used: (1) phasing up the antennas on the radio source being observed, given sufficient signal/noise; and (2) periodically adjusting the antenna phases based on observation of a strong calibrator source at a small angular distance from the target source. Both of these techniques have been used for nearly 30 years with the VLA; they will require minor adaptations/transfer of software, but no new conceptual development. Hardware for the station phasing and beamforming will have to be constructed, including real-time control software. The antennas in a given station will be separated by possibly up to 100 m, and thus possible atmospheric variations over the station patch at high frequencies will have to be determined and compensated for. This is less important for the lower 5-15 GHz band and for more compact station designs.

Table 3.3.1 – Block Diagram of PAS Antenna System

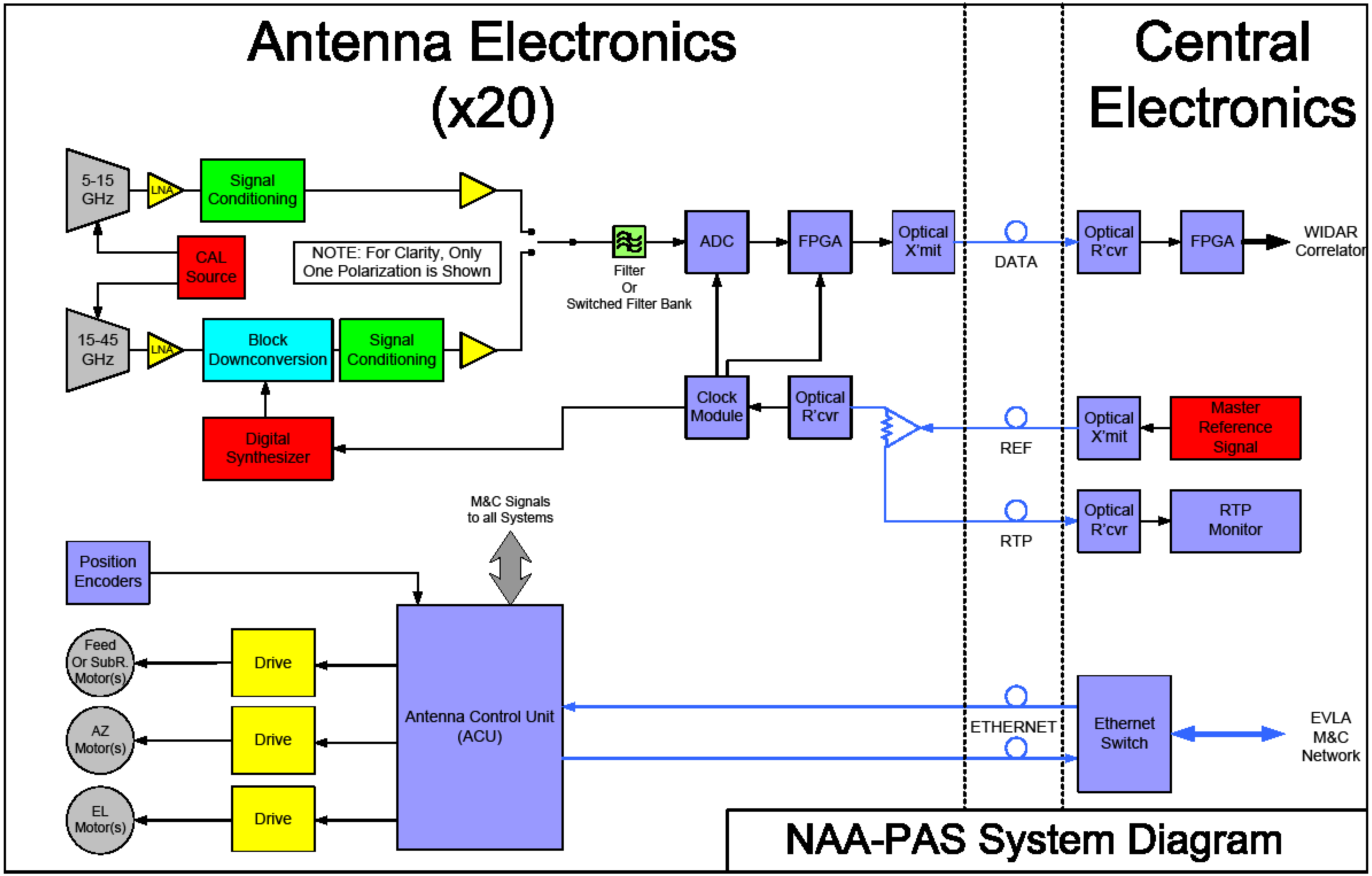
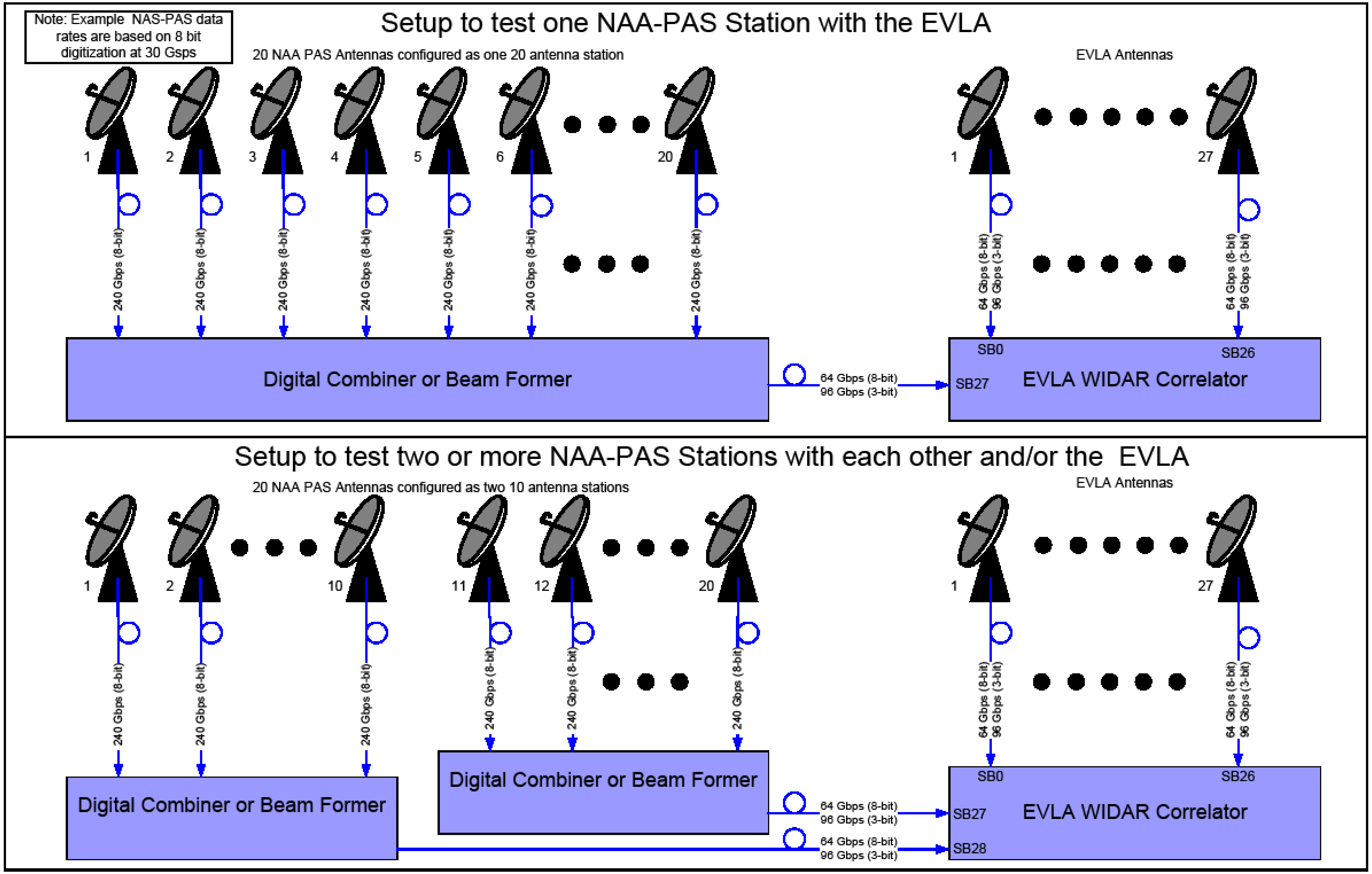


Table 3.3.2 – Block Diagram of PAS Array System



3.4 Facility Construction

This refers mostly to the PAS, although the prototype antenna produced during TDP-II will also occupy this facility.

1. *Describe the site and its location, including size, altitude, access, number of buildings, size of building(s) footprint and volume, existing infrastructure, power, internet, environmental considerations and logistics (proximity to major airport, housing and support for construction crews and facility staff etc.)*

The primary site will be the EVLA telescope site, at 2100 meters elevation in New Mexico. This site includes a central square mile owned by the National Science Foundation as well as rights of way along the three-armed VLA railroad. Sufficient infrastructure, commercial site power, buildings, and engineering staff are available to support the test facility. This site is strongly favored due to the shared logistics and simplicity of operation with the EVLA. Possible secondary sites include the inner VLBA stations (such as Pie Town) and developed LWA sites in New Mexico, and would allow for testing and science use of the PAS as a longer-baseline station. The site decision will be made at the end of the TDP-II phase.

2. *Provide electrical requirements for operations and discuss any significant aspects of these requirements on construction.*

Power requirements for an array of 15-20 dishes of 9-15 meters in diameter are relatively small compared to the present EVLA array of 27 dishes of 25 meters diameter (~20 kW per EVLA antenna). We estimate the PAS would require 150-200 kW (maximum during slewing, including the beam-former operation). VLA site commercial power would be sufficient for the PAS, and no primary generators would be required if sited in the EVLA core area, although additional transformers, conditioning and transmission infrastructure would be needed. A backup generator for PAS is desirable. There are no additional requirements for the EVLA correlator, which has 32 station inputs and therefore can accommodate either a test antenna or test station as the 28th antenna of the EVLA.

3. *For antenna arrays, provide specific infrastructure required such as concrete pad size, communications buildings etc for each element in the array. For telescope mirrors, describe infrastructure needed for mirror maintenance, e.g. coating facilities.*

Concrete pads will be required for each of the test antennas; since they will not be transported as the EVLA antennas are, they can be permanently fixed to the pads. We expect to locate them near one of the existing EVLA configuration arms, so that their combined input can be transmitted by using the existing fiber splice at an EVLA antenna pad. No additional maintenance facilities are required.

4. *Provide a brief descriptive overview of the facility construction plan (upgrades or new construction). Describe the various Civil Works packages indicating typical suppliers. Comment on key building construction and any unique aspects for critical components (temperature control, humidity etc).*

Design and construction of the concrete antenna pads at the EVLA site (or a VLBA site) would be performed by a combination of NRAO personnel, a construction contractor, and possibly the antenna vendor. There are no special design considerations. These pads will utilize standard construction techniques and be typical of foundations used worldwide for antennas of this size. All other work to connect into the site's existing electrical and communications infrastructure would be performed by site personnel and should require no external construction contracts.

5. *Describe any new and unique construction methods required for success.*

For a standard paneled antenna, no new construction methods are required. If the test antenna and the components of the later test station are constructed from composites, this will use technology that already is demonstrated via the current SKA development programs at the Herzberg Institute of Astrophysics (Canada) or the KAT-7 and MeerKAT arrays (South Africa).

6. *Describe the manner in which the General Contractor will interface with the Program Management and manage all subcontractors. Describe the type of contract expected to be implemented (fixed, cost plus etc).*

We expect a fixed-cost contract for procurement of antennas. The overall project will be managed by a program manager at NRAO. Work packages for standard civil works (e.g., antenna pads and electrical connections) will be carried out by NRAO personnel under the direction of this program manager. The actual testing of performance characteristics will be carried out by members of the USSKA Consortium (including NRAO scientific staff), under work packages negotiated with the NRAO Program Manager, and with specific deliverables and schedules.

4.0 Facility and Science Operations

1. *Provide a brief description of the facility operations. Be specific regarding manpower, number of staff required, 24 hour operation requirements, rates, resources required (electrical, coolants, water etc).*

The EVLA presently operates 24 hours a day, 362 days per year, so availability of power and other infrastructure (e.g., roads) is essentially guaranteed. Operation of the test antenna and test station initially will require a second operator, typically an engineer or scientist from the test team. Operations may be conducted from the EVLA site in early days, and from the Domenici Science Operations Center (DSOC) 50 miles away at later stages (presently connected via a 1 Gbit/s link). In late stages and beyond the end of the test phase, science operations with the EVLA would be incorporated into EVLA operations, and conducted by the on-duty EVLA operator.

2. *Identify any unusual constraints or special communications, tracking, or near real-time ground support requirements from other facilities.*

None

3. *Identify any unusual or especially challenging operational constraints (i.e. viewing or pointing requirements).*

None

4. *Provide a brief description of the science operations. Be specific regarding science manpower and rates, pre-observational planning, data processing/reduction required, coordination with other facilities. Provide cost estimates (cost section) for this effort including the funding for all scientists. Discuss observatory efficiency, e.g. the impact of maintenance and engineering and calibration time on fraction of science time availability.*

There will be no science operations in the critical path, only test operations. We anticipate that a significant amount of the testing will be carried out during regular EVLA maintenance times, but up to 5% of the annual EVLA observing time might be devoted to antenna station tests. At late stages in the testing, expert EVLA observers may be given the option to incorporate the NAA test station in their program and use its data to enhance their science return.

5. *Describe all development efforts and deployment plans associated with archiving data products (method, equipment and personnel required), calibrated data and products and archive maintenance over the lifetime of the facility.*

When the test station operates as part of the EVLA, it will simply be another element of the EVLA. As such, its data will be archived as part of the EVLA data set, with no additional requirements levied other than a minor amount of extra data storage capacity. Standalone operation of the PAS will produce much less data (typically only antenna total power data and monitor data). See answer to Q6 below.

6. *Describe science and data products in sufficient detail that thee costs presented in the Cost Section can be understood compared to the level of effort described in this section.*

The PAS test facility data will be archived with the EVLA data during combined operation, estimated to be ~5% of the time during the PAS project. The PAS for this purpose is equivalent to an additional antenna, or 7.5% ($28^2/27^2$) more data if used in addition to the full EVLA. There is no incremental cost if the PAS is used in place of one EVLA antenna input to the correlator (which is expected to be the case some fraction of the time). Antenna and system monitor data from the PAS will also be archived, but this is a negligible amount compared the cross-correlation data volume.

7. *Describe all required maintenance and provide maintenance costs in the Cost Section.*

For antenna and electronics maintenance, we expect each of the new prototype antenna systems in the station to require significantly less maintenance than a standard EVLA or VLBA antenna. This certainly must be the case for production antennas to make the SKA-high operationally viable, and the prototypes will be evaluated in this context as part of the PAS project. If science operation with the PAS were desired beyond the end of the demonstrator project, then maintenance of hardware and software would be required (not included in this budget).

8. *Please provide the total data volume for a typical day of observation.*

Test facility only. When used together with the EVLA, interferometric data involving the test station will simply be part of the EVLA data set. The exact data volumes depend upon the correlator mode (bandwidth/channels) and time resolution, but would amount to no more than a 7% increase over normal EVLA use in a given day if the PAS is located near the EVLA core. If located at a remote site, then the correlator would be run in a higher time/frequency resolution mode than normal, increasing this volume by perhaps a factor of 5 (e.g. for a Pie Town site).

9. *Please provide the archived data volume produced in a typical year of operation.*

For usage with EVLA no more than 5% of the time and a 7% increment in volume during cross-correlation, we estimate a 0.35% increment on the total volume averaged over the years of PAS operation. If the PAS is located outside the EVLA core, then this could be as high as a few percent increase on average.

10. *Describe the science and operations center for the activity if one is needed: will an existing center be expected to operate this activity? How many distinct investigations will use the facility? Will there be a guest observer program? Will investigators be funded directly by the activity?*

Not applicable for test observations covered by this proposal. In late stages, combined PAS-EVLA science observing will use the EVLA DSOC for combined operations, and will follow standard NRAO-wide proposal procedures.

11. *Be specific about whether development costs for implementing new or second-generation instruments are included in the reported operating costs.*

There are no second-generation developments planned as part of the PAS activity.

5.0 Programmatics and Schedule

The following items refer to both the TDP-II and NAA-PAS activities where applicable, or to the PAS only for construction and operations issues.

1. *Provide an organizational chart showing how key members and organizations will work together to implement the program. Include all key aspects of the concept including the management structure of the Construction General Contractor.*

See Table 5.1 (a) and (b) below for org charts of the TDP-II and PAS projects.

2. *Provide a table and a 5 by 5 risk chart of the top 8 risks to the program. Briefly describe how each of these risks will be mitigated and the impact if they are not. (See http://en.wikipedia.org/wiki/Risk_Matrix for a description of the risk chart, and http://www.dpmc.gov.au/implementation/images/risk_matrix.gif for an example.)*

See Tables 5.2 and 5.3 below.

3. *Provide an overall schedule from initial development activities, ATP, first light through all science operations that support the science discussed in the science section. Highlight key design reviews, the critical path and the development time for delivery required for each instrument, the telescope/antenna array, facility construction, development of ground and activity/science operations, calibration/alignment, system commissioning etc.*

See Table 5.4 below.

4. *Fill out the Key Phase Duration table indicating the length of time required (months).*

See Table 5.5 below.

5. *Fill out the Key Event Dates table indicating the dates (month/year) for the key development and operations milestones.*

See Table 5.6 below.

6. *Describe the management structure of the construction project, showing lines of reporting and authority. Who holds and controls the contingency? How are changes in specifications approved?*

The management structure will be similar to the EVLA project. The Project manager is responsible for the overall project. Once per year funds are allocated to the workgroups. The workgroups have a level 2 task leader that is responsible for that task and budget. The budgets and work progress is reviewed every 6 months. Workgroups external to NRAO will be managed similarly; this has worked well for the EVLA correlator constructed by partners at the Herzberg Institute of Astrophysics (HIA) in Canada.

The project office holds the contingency in a separate account. A change board consisting of the EVLA site director, the NAA-PAS project manager, the systems engineers, and the project scientist is responsible for approving contingency allocations. The change board receives written change board requests from the level 2 task leaders. These requests are to either obtain additional funds, return funds to the contingency account or to change the project specifications. A record of all changes is kept for the life of the project. This is system has worked well for the EVLA project , which is currently nearing the end of an 11-yr construction program within the budget specified in 2001.

Table 5.1 (a) – TDP-II Org Charts

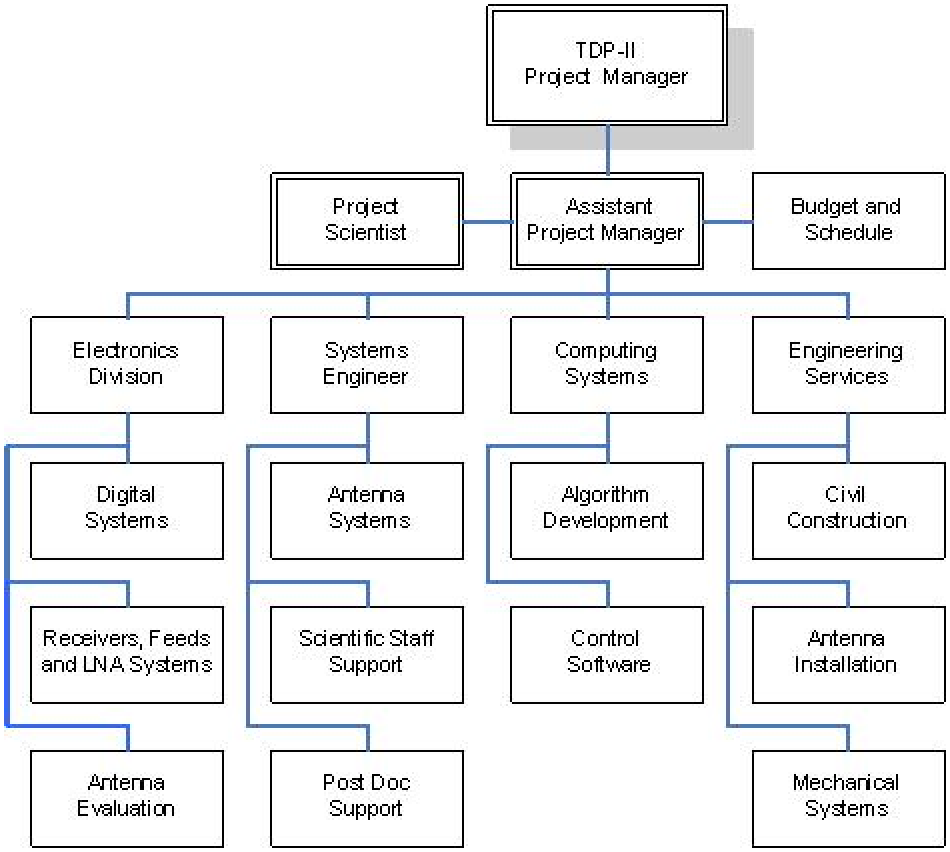


Table 5.1 (b) NAA-PAS org chart

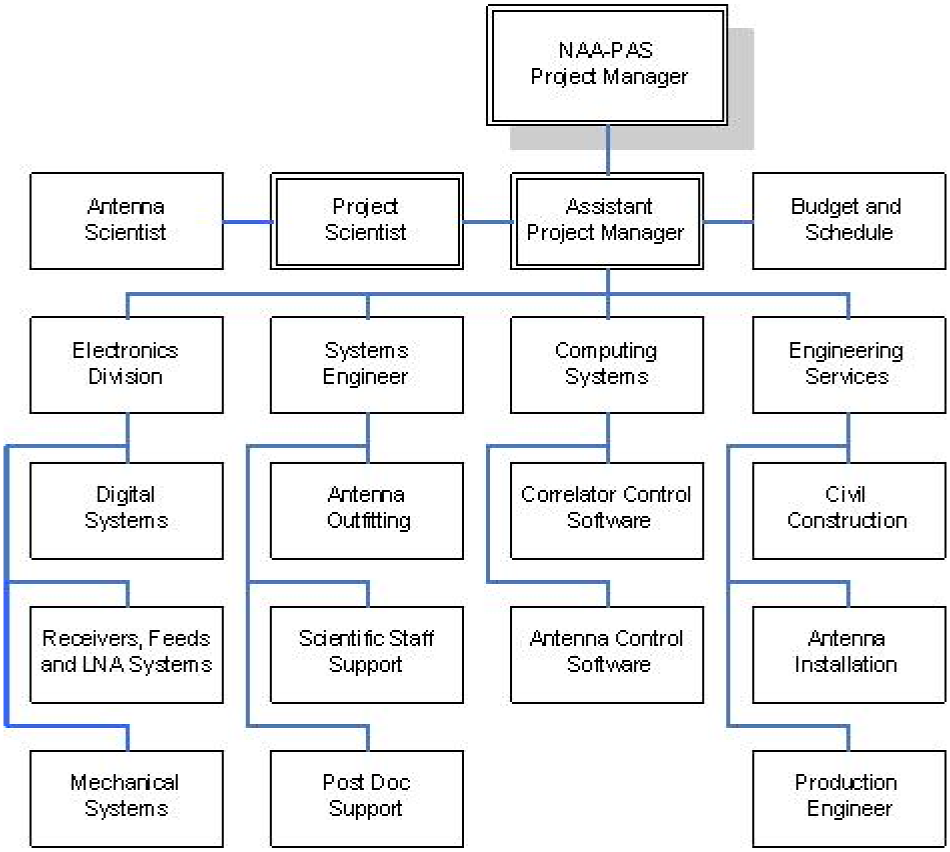
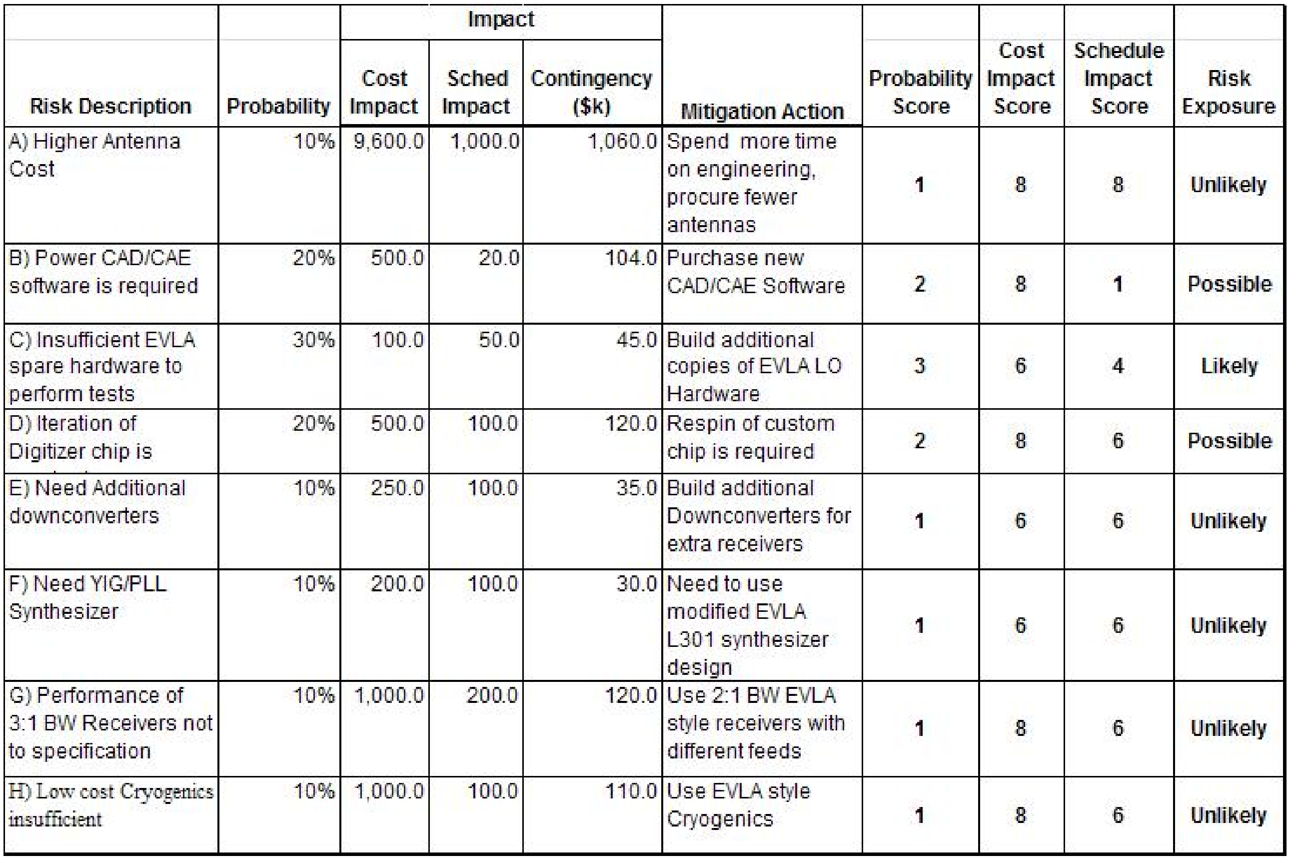


Table 5.2– Top 8 Program Risk Worksheet



Risk Description	Probability	Impact			Mitigation Action	Probability Score	Cost Impact Score	Schedule Impact Score	Risk Exposure
		Cost Impact	Sched Impact	Contingency ($k)					
A) Higher Antenna Cost	10%	9,600.0	1,000.0	1,060.0	Spend more time on engineering, procure fewer antennas	1	8	8	Unlikely
B) Power CAD/CAE software is required	20%	500.0	20.0	104.0	Purchase new CAD/CAE Software	2	8	1	Possible
C) Insufficient EVLA spare hardware to perform tests	30%	100.0	50.0	45.0	Build additional copies of EVLA LO Hardware	3	6	4	Likely
D) Iteration of Digitizer chip is	20%	500.0	100.0	120.0	Respin of custom chip is required	2	8	6	Possible
E) Need Additional downconverters	10%	250.0	100.0	35.0	Build additional Downconverters for extra receivers	1	6	6	Unlikely
F) Need YIG/PLL Synthesizer	10%	200.0	100.0	30.0	Need to use modified EVLA L301 synthesizer design	1	6	6	Unlikely
G) Performance of 3:1 BW Receivers not to specification	10%	1,000.0	200.0	120.0	Use 2:1 BW EVLA style receivers with different feeds	1	8	6	Unlikely
H) Low cost Cryogenics insufficient	10%	1,000.0	100.0	110.0	Use EVLA style Cryogenics	1	8	6	Unlikely

Table 5.3 – Top 8 Program Risks

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Severe
Almost Certain					
qLikely		C			
Possible			B, D		
Unlikely		E, F	G, H	A	
Rare					

Table 5.4 – Schedule

Schedule of key milestones on critical path for TDP-II and the NAA-PAS:

Project Task	**Start Date**	**End Date**
Delivery of TDP-1 Antenna(s) for TDP-2	Jan 2011	Jun 2012
Publish TDP-2 Test Results		Dec 2012
Conceptual PAS Antenna Design	Jan 2011	Dec 2014
Algorithm & Software Development	Jan 2012	Dec 2017
PAS Electronics System Design	Oct 2010	Feb 2015
CoDR		Dec 2013
PDR		June 2014
CDR		Feb 2015
Wideband Feeds and Receivers Design	Jan 2011	Jan 2015
CoDR		Jan 2012
PDR		Jan 2014
CDR		Jan 2015
Detailed PAS Antenna Design	Jan 2014	July 2016
PAS Civil Construction	Jan 2015	Dec 2018
PAS Receiver & Feed Production	Feb 2015	Dec 2017
First Article Delivery		Oct 2016
PAS Electronics Production	Feb 2015	Dec 2017
PAS Antenna Contract	July 2016	July 2018
First Article Delivery		June 2017
PAS Antenna First Light / Testing Begins		Oct 2017
Integration and Testing	Oct 2017	Oct 2019
PAS Operations and Maintenance	Jan 2016	Dec 2019

Table 5.5 – Key Phase Duration Table

Project Phase	**Duration (Months)**
Phase A – Conceptual Design	48
Phase B – Preliminary Design	12
Phase C – Detailed Design	12
Phase D – Integration & Test	24
Phase E – Primary (Test) Observations	12
Start of Phase B to end of PAS Construction	60
Start of Phase B to First Light/Signal Reception	46
Start of Phase B to Start of Test Observations	46
Start of Phase B to Delivery of Instrument #1	34
Start of Phase B to Delivery of Instrument #2	34
Project Total Funded Schedule Reserve	12

Table 5.6 – Key Event Dates

Project Phase	**Milestone Date**
Start of Phase A	Jan 2010
Start of Phase B	Jan 2014
Preliminary Design Review (PDR)	Jun 2014
Critical Design Review (CDR)	Feb 2015
Delivery of Instrument #1 (DoI-1)	Oct 2016
Delivery of Instrument #2 (DoI-2)	Oct 2016
Delivery of Instrument #n (DoI-n)	n/a
Date of End of Construction	Dec 2018
Date of First Light/Signal Reception	Oct 2017
(Test) Operational Readiness Date	Oct 2017
End of Operations	n/a

6.0 Cost

For the costing purposes, the salaries used assume the scales used at NRAO, even for activities that are likely to be done by non-NRAO partners (e.g. USSKA consortium participation in the TDP-II and the NAA-PAS). We have not included any contributed effort from the international SKA partners (e.g. the SKA Program Development Office, SPDO), and these would be negotiated and formalized at the time of the PAS proposal in 2014-2015.

The full costs are given in the WBS Section 9.1 and summarized in the Cost Table 6.1. The total cost of TDP-II plus NAA-PAS is FY09 $39,850K, which is higher than the FY09 $31,250 estimated in RFI#1 for these two activities. The difference is due to addition of extra management personnel, extra funding in TDP-II phase for antenna prototyping, and added personnel in the PAS phase for station construction and testing (left out of RFI#1 estimates and attributed to contributed effort in the previous document). This WBS and costing is more detailed and complete, and reflects the total projected cost of the project.

1. *Provide a detailed WBS structure (down to Level 3) indicating the basis of estimate for each entry supported by sub-level categories and Basis of Estimates (BOEs). If segmented mirrors or antenna arrays are utilized provide the specific cost reduction/learning metrics assumed and a detailed basis of estimate for the first three sets of units (define the number in a set). If there are a large number of segments or elements, provide cost details for the investment required for manufacturing facilities. Identify all contingency/reserves and provide rationale as to why the stated contingency is adequate.*

See WBS attached as Section 9.1 of this document.

2. *Indicate total reserve held and controlled by the Program Manager and the methodology for allocating reserves. How are telescope/antenna, instruments and facility specification and change orders managed within these reserves? Who has final approval of specification changes?*

The Project manager is responsible for the overall project. Once per year funds are allocated to the workgroups. The workgroups have a level 2 task leader that is responsible for that task and budget. The budgets and work progress is reviewed every 6 months.

See Section 5.0 answer to Q6 for a description of contingency and the change board.

3. *For the basis of estimate, include manpower and rates assumed for each key phase (program management/systems engineering/quality assurance, telescope/antenna manufacture and assembly, facility construction, instrument integration, testing/checkout and alignment and facility operations).*

The attached spread sheets are costed by major activity and include program management, systems engineering, telescope/antenna manufacture and assembly, facility construction of the test antennas, instrument integration, testing/checkout and alignment and facility operations. The salaries are categorized into one of five levels, and include 32.5% benefits. In FY09 dollars:

Labor Rates in $K dollars:

Grade	Annual Cost
1	164.920
2	109.946
3	73.298
4	48.865
5	32.577

4. *Provide manpower estimates and cost by year/Phase for all expected scientists that will be involved. Assume a 5-year science operations phase following initial checkout operations.*

The WBS spreadsheet labeled 6.03 shows that the Project scientist is funded for 9 years. The algorithm scientist is funded for 6 years. The antenna engineer is funded for 5 years at the PhD level. There are 14 years of Post Docs funded. There are no science operation planned as part of this proposal, these scientists are those participating in the TDP-II development and PAS testing.

5. *If a foreign organization(s) is assumed to be a partner or a major contributor, provide an estimate by year and Phase for the breakdown between US and Foreign contributions. This should be separate, but consistent with Total Concept Cost Funding Table*

Although we anticipate an international collaboration, there are no funds allocated in the cost tables. See introductory paragraph to this section.

6. *Provide a description and cost of what will be performed during the preliminary analysis phase by year. Also include total length of the preliminary analysis phase in months and total preliminary analysis estimated costs. (Generally speaking, publication of the preliminary plan with costing data marks the completion of the preliminary analysis phase).*

The project is divided into two phases, the TDP-II phase and the NAA Prototype Antenna Station phase. The TDP-II phase will last about 5 years, which will develop a preliminary plan for the PAS. The NAA-PAS phase will also last about 5 years. At this point, a preliminary plan for the NAA as a SKA-high proposal will be developed.

The TDP-II activity is a US SKA Consortium activity, and does not require non-US participation in order to meet the minimal goals of a NAA PAS design. Note that it is expected that the international PrepSKA program does produce a prototype SKA-mid antenna to participate in the evaluation phase of TDP-II, and furthermore we hope that there will be further collaboration with the SKA program during the TDP-II activity. The development task will cost about $18.3M (in 2009 dollars).

The baseline plan for the NAA Prototype Antenna Station (NAA-PAS) is to build twenty full sky AZ/EL mount antennas of a design developed in the TDP-II. The SKA-mid dish designs from TDP-I being considered have diameters in the range 9-15m, although the 6m ATA design will also be evaluated in TDP-II. The most likely optical configuration is an Offset Gregorian design with two 3:1 bandwidth feeds, one covering 5-15 GHz and the other 15-45 GHz. Surface and pointing accuracy specifications for the antennas will driven by the goal of an eventual 50 GHz top end frequency for NAA/SKA-high. The specific structural design of the antenna will be determined by a combination of the speed, acceleration and thermal stability necessary to meet the scientific specifications and the weather survivability requirements of the chosen site. The antenna drive system will likely be a traditional geared system driven by traditional servo motor technology. The the PAS, the schedule, WBS, and cost are for a fully self-contained demonstrator project that is in this baseline form a US-only funded activity. However, international participation would be welcome, e.g. to reduce the US cost or to augment the PAS testing effort, and would be negotiated at the time of the NAA-PAS proposal in 2014-2015. We estimate that the PAS task will cost $21.5M, see cost data sheet 6.03.20 (in 2009 dollars).

7. *Please fill out the top level Concept Cost Funding Profile table assuming that the activity is totally funded by NSF or DOE and all significant work is performed in the US. The WBS provided with all cost should be separate from this table with sufficient detail at lower WBS levels.*

The total cost of the project was determined assuming the activity was totally funded by NSF. See Table 6.1 below.

8. *For those partnering with foreign or other organizations (including private institutions or foundations), provide a second Concept Cost Funding Profile table and indicate the total activity costs clearly indicating the assumed NSF or DOE and contributed costs.*

Although we anticipate an international collaboration there are no funds allocated in the cost tables.

9. *Describe how you calculated the contingency in the construction budget – a simple, overall percentage or on the basis of assigned risk. For the latter, how was risk assessed?*

A Risk data sheet was developed for each WBS element. In each area the multiple risks were identified. The full impact of the risk on the project cost and schedule in $K dollars was estimated. A probability was determined and multiplied by the total cost to obtain the required contingency. These contingency dollars were added to the cost data sheets in the years we believe the risk will be mitigated. The top risks were given in the risk summary Table 5.2. The full risk register is attached as Section 9.2.

Table 6.1 – TOTAL ACTIVITY COST FUNDING PROFILE TEMPLATE – US-Federal Only

(FY costs[1] in 2009 Dollars)

WBS	Item	Prior	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
	Cost													2009 $K
6.03.05	Concept Study and Antenna Evaluation	0.0	3.0	1219.5	552.8	287.1	529.8	0.0	0.0	0.0	0.0	0.0	0.0	2,592
6.03.01	Project Management	0.0	341.5	415.4	302.9	216.6	216.6	326.5	375.4	395.4	336.5	216.6	0.0	3,143
6.03.14	Instrument A 5-15 GHz Feed and Receiver	0.0	0.0	40.3	410.6	135.6	135.6	153.5	153.5	98.5	0.0	0.0	0.0	1,128
6.03.14	Instrument B 15-45 GHz Feed and Receiver	0.0	0.0	33.0	336.0	111.0	111.0	125.6	125.6	80.6	0.0	0.0	0.0	923
6.03.20	Telescope-Prototype Station and Facilities	0.0	0.0	0.0	0.0	0.0	0.0	1163.5	14493.5	2820.8	1047.5	479.5	0.0	20,005
6.03.10	Ground Data system - Digital signals	0.0	247.4	967.3	1167.3	976.5	571.5	461.5	356.5	109.9	109.9	0.0	0.0	4,968
6.03.12	Ground Data system - LO systems and M&C	0.0	0.0	0.0	0.0	346.6	346.6	309.9	173.3	0.0	0.0	0.0	0.0	1,176
6.03.15	Software Development	0.0	0.0	0.0	183.2	329.8	366.5	293.2	256.5	219.9	0.0	0.0	0.0	1,649
6.03.11	Operations and Maintenance	0.0	0.0	0.0	0.0	0.0	0.0	0.0	335.2	514.3	567.6	461.8	0.0	1,879
all	Reserves - Contingency	0.0	0.0	65.0	170.5	144.0	322.5	161.0	1478.0	45.0	0.0	0.0	0.0	2,386
	Total Cost per year	0.0	591.9	2740.5	3123.4	2547.2	2600.1	2994.9	17747.6	4284.6	2061.6	1157.8	0.0	39,850

FY costs[1] in Real Year Dollars, Totals in Real Year)

WBS	Item	Prior	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
	Cost													Real $K
6.03.05	Concept Study and Antenna Evaluation	0.0	3.0	1252.5	583.1	311.0	589.4	0.0	0.0	0.0	0.0	0.0	0.0	2,739
6.03.01	Project Management	0.0	341.5	426.6	319.5	234.6	240.9	373.0	440.4	476.4	416.5	275.3	0.0	3,545
6.03.14	Instrument A 5-15 GHz Feed and Receiver	0.0	0.0	41.4	433.1	146.9	150.9	175.4	180.2	118.7	0.0	0.0	0.0	1,247
6.03.14	Instrument B 15-45 GHz Feed and Receiver	0.0	0.0	33.9	354.4	120.2	123.4	143.5	147.4	97.2	0.0	0.0	0.0	1,020
6.03.20	Telescope-Prototype Station and Facilities	0.0	0.0	0.0	0.0	0.0	0.0	1329.3	17005.7	3399.2	1296.4	609.4	0.0	23,640
6.03.10	Ground Data system - Digital signals	0.0	247.4	993.4	1231.2	1057.7	635.8	527.3	418.3	132.5	136.1	0.0	0.0	5,380
6.03.12	Ground Data system - LO systems and M&C	0.0	0.0	0.0	0.0	375.4	385.6	354.1	203.3	0.0	0.0	0.0	0.0	1,318
6.03.15	Software Development	0.0	0.0	0.0	193.3	357.3	407.7	335.0	301.0	265.0	0.0	0.0	0.0	1,859
6.03.11	Wideband Feeds and Recievers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	393.3	619.8	702.5	586.9	0.0	2,302
all	Reserves - Contingency	0.0	0.0	66.8	179.8	156.0	358.8	183.9	1734.2	54.2	0.0	0.0	0.0	2,734
	Total Cost per year	0.0	591.9	2814.5	3294.4	2759.1	2892.5	3421.6	20823.9	5163.0	2551.4	1471.5	0.0	45,784

TOTAL ACTIVITY COST FUNDING PROFILE TEMPLATE – With Partner Contributions ("Partner" defined as any non-federal funding source)

(FY costs[1] in Real Year Dollars, Totals in Real Year and 2009 Dollars)

NOTE: no partner contributions required for given budget – see previous table.

Item	Prior	FY2010	FY2011	...	FY2023	Total (Real Yr.)	Total (FY 2009)
Cost							
Concept Study							
Project Management/Systems Engineering							
Instrument A							
Instrument B							
Instrument n							
Telescope							
Optics/Antenna							
Facilities							
Ground Data System/Software Development							
Operations							
Reserves							
Other (specify)							
Total Cost	$	$	$	$	$	$	$

Contributions							
Concept Study							
Project Management/Systems Engineering							
Instrument A							
Instrument B							
Instrument n							
Telescope							
Optics/Antenna							
Facilities							
Ground Data System/Software Development							
Operations							
Reserves							
Other (specify)							
Total Contributions	$	$	$	$	$	$	$
					Total Activity Cost		$

7.0 Changes Since Previous NRC Recommendation

The report *Astronomy and Astrophysics in the New Millennium* (AANM) made two primary recommendations that are of relevance to the North America Array (NAA). First, the Expanded Very Large Array (EVLA) was recommended as a major initiative ($140M FY00 dollars), while the Square Kilometre Array (SKA) technology development was recommended as a moderate initiative ($22M FY00 dollars). Parts of both programs have been executed, which has an impact on the landscape for the North America Array.

The recommended EVLA program contained two major stages. Quoting from AANM (page 126): "The first stage of the expansion will replace instruments, computers, and software and install wideband fiber-optics data links. In the second stage, up to eight new antennas will be sited within 250 km of the VLA and connected via fiber-optics links." The first stage of EVLA is well on the way to completion in 2012, on the initial budget proposed to NSF in 2001, while the second stage has not been funded.

The funded portion of the EVLA project essentially makes use of all the bandwidth between 1 and 50 GHz (up to 8 GHz simultaneously), thus reaching the sensitivity limit available with a fixed collecting area. Toward the high-frequency end of this bandwidth range, we expect the EVLA to produce noteworthy science accomplishments in the coming decade in the areas of star formation (e.g., probing the ionized gas at frequencies near 30 GHz) and galaxy formation (e.g., imaging redshifted CO in distant galaxies). However, such science goals, particularly in the spectral-line domain where added bandwidth does not increase the sensitivity, will remain handicapped by insufficient sensitivity. For example, only the most extreme star-forming galaxies, especially those that are gravitationally lensed, will have CO emission strong enough to be imaged by EVLA at sub-arcsecond resolution. The follow-on to the exciting EVLA science to be produced in the coming decade must be a significant increase in sensitivity, as promised by the NAA.

The second stage of EVLA was aimed at imaging thermal sources (e.g., star-formation regions) at resolution of a few milliarcseconds. However, its scientific promise was handicapped by marginal sensitivity on the long baselines. The NAA would increase the long-baseline sensitivity dramatically by placing considerably more collecting area (roughly a factor of 5, compared to EVLA stage 2) on the baselines between a few kilometers and a few hundred kilometers.

The potential of the NAA to produce considerably more sensitivity per unit cost is predicated on the development of antennas with much lower cost per unit area than the 25m antennas of the VLA and the Very Long Baseline Array. Since the AANM report, there have been significant efforts to develop such antennas for new arrays and for the Square Kilometre Array Program. Examples include the 6m antennas of the Allen Telescope Array, the 12m antennas under test for NASA's Deep Space Network Array, and the composite 12m antennas for the Karoo Array Telescope in South Africa. These antenna concepts raise the possibility for the North America Array to be affordable in the decade following 2020.

A primary goal of the SKA Technology Development Project (TDP), the other relevant recommendation of AANM, was the production of the low-cost antennas referred to above. However, in the decade since 2000, the focus of the SKA has shifted toward a goal at lower frequencies, the socalled “SKA-mid”. (See Cordes et al. Astro2010 submission from the US SKA Consortium for further information.) Thus, the focus on receptor development throughout the world has been almost entirely on low-cost antennas that operate up to a few gigahertz (perhaps as high as 10 GHz) in frequency. The first step of NAA technology development program for the coming decade is intended to leverage this effort by extending the capability of such antennas up to the atmospheric cutoff at 50 GHz.

Since the AANM report, two sites have been “short-listed” for the SKA, centered in southern Africa and western Australia. However, there is a growing realization around the world that these relatively low-altitude sites, which were optimized for the lowest radio-frequency interference, do not have the best tropospheric conditions for deep imaging at frequencies of a few gigahertz and above. Thus it is highly likely that the NAA we envision could in fact become the realization of “SKA-high”, at a different site from the lower frequency components of the SKA. Testing a prototype antenna station with the EVLA is thus a natural step to the construction of SKA-high centered at the same location as the EVLA.

In closing, we note that the instruments recommended by AANM (notably EVLA, JWST, and the completion of ALMA) will produce revolutionary science in planet, star, and galaxy formation in the 2010-2020 decade. In the latter half of the decade, it will become clear that the increased collecting area of SKA-high will be needed at frequencies of 10-50 GHz in order to probe sensitively the obscured regions in which the most important action takes place. Preparing the technology groundwork for the NAA is a critical step if this additional sensitivity is to be made available in the 2020-2030 decade.

Appendix 8.1 – NAA Sensitivity

Here we summarize some assumptions used for the calculation of NAA sensitivity, for the numbers given in Section 1.

We focused our discussion in Section 1 by framing the science in terms of fiducial observations that drive the design specifications of the SKA-high and thus the development of the NAA: point-source observations (sensivity and resolution), thermal continuum source observations (sensitivity at a given resolution), line observations (sensitivity at a given angular and frequency resolution), and precision astrometry (resolution and signal-to-noise ratio). We often refer to the EVLA as a benchmark for collecting area and sensitivity. For our purposes the EVLA has a ratio of effective collecting area to system temperature A_{eff}/T_{sys} = 159 m^2/K (27 antennas of 25m diameter, with 48% aperture efficiency and T_{sys} = 40K at 26 GHz), and thus we assume a NAA with 10 times EVLA sensitivity to have a A_{eff}/T_{sys} figure of merit of 1600 m^2/K around 26 GHz.

Point source sensitivity – the rms sensitivity level determined by the total collecting area (or collecting area on baselines less than the scale on which the source becomes resolved). We estimate the NAA will have the sensitivity given by:

$$\sigma_{\mathrm{lim}} \approx 0.075\,\mu\mathrm{Jy}\left(\frac{1600\,\mathrm{m}^2/\mathrm{K}}{\mathrm{A}_{\mathrm{eff}}/\mathrm{T}_{\mathrm{sys}}}\right)\left(\frac{8\,\mathrm{GHz}}{\Delta\nu}\right)^{1/2}\left(\frac{9\,\mathrm{hrs}}{\mathrm{t}}\right)^{1/2}$$

For the NAA, in 8 GHz/pol bandwidth, a 9-hour observation reaches a rms level of 75 nJy.

Thermal continuum imaging sensitivity – the Rayleigh-Jeans flux density observed from a blackbody with effective temperature T and solid angle W is given by:

$$S \approx 0.65\,\mu\mathrm{Jy}\left(\frac{T}{1000\,\mathrm{K}}\right)\left(\frac{\nu}{30\,\mathrm{GHz}}\right)^{2}\left(\frac{\Omega}{1\,\mathrm{mas}^2}\right)$$

with the Solar disk subtending 5 mas at a distance of 1 pc. Optically-thin emission has the equivalent temperature reduced by the optical depth. Some emission, such as that from dust, has an additional emissivity factor, usually a power-law with frequency. Detection and imaging of thermal sources beyond the solar neighborhood requires sensitivites below the micro-Jansky level.

Appendix 8.2 – Guidelines from Astro2010 Panel

Purpose

The Committee on Astro2010 has completed an initial evaluation to responses for the first Request for Information sent out by letter in early April 2009. More detailed information is now required to further evaluate the technical implementation and cost of your concept.

The panel requests that teams respond to the following questions as completely as possible.

We also request that you please ensure that any written responses or diagrams that you include do not include ITAR-controlled information. The NRC will consider your response as public information and available to the public, if requested.

Responding to the RFI#2

The Committee on Astro2010 asks that responses to this RFI be submitted no later than 11:59 PM, Eastern Time, on ***Monday July 27th***. Submissions should be made via e-mail to ***astro2010@nas.edu***, with a subject line of "RFI#2 Ground Response". All formatting guidelines should be consistent with the original RFI response, except the page counts. For the page restrictions below, the requested tables in this RFI should be on separate pages from other text and they do not count in the page limitations.

The committee will allow up to six (6) pages for a combination of an Executive Overview and/or a Science Overview which can be restated using material from the original response. It is important to note that technical implementation and cost review teams may or may not look at your original response.

The committee would like to focus on the Technical Implementation of your concept including the Optical Telescope or Antenna Array or Collector Array, Instrumentation, Observation Strategy and Facility Construction. Up to twelve (12) pages are allowed for this section to answer the specific questions below as well as to explain your concept. This RFI requests that the Instrumentation be broken into separate Instruments (Inst#1, Inst#2 etc.). Each instrument should be adequately described indicating which instruments are required at early or first light/signal reception and which ones may be added later as upgrades. Discuss all instrumentation for active optics, adaptive optics, guiding, alignment, phasing/calibration and proper pointing performance. An additional two (2) pages will be allowed for each additional instrument to allow for proper discussion of instrument heritage and other important aspects of the design and implementation.

Three (3) pages will be allowed for specific required technical development for Enabling Technologies that may be required. It is very important in the Enabling Technology and Technology Implementation sections to identify all technologies and units that are immature and the plan, including cost and schedule required, for all units to be demonstrated by sub-scale or full scale models prior to the commencement of the Critical Design Review (CDR).

Three (3) pages will be allowed for Facility and Science Operations.

Five (5) pages will be allowed for Programmatics and Schedule. The committee understands that it may be difficult to provide accurate organizational charts for concepts that may start several years from now. However, the committee asks that you provide an organizational chart that bests represents how you want the committee to evaluate your concept. In particular, if you wish to use foreign organizations as a partner or for significant contributions, their assumed involvement must be stated in this and the cost sections.

The cost section will have an unlimited page allocation, but the committee asks for each respondent to be reasonable and provide detailed justification or basis of estimate for any grass roots or independent assessments and to provide all data requested in the tables (cost and technical) below.

Summary of RFI Page Allocations

RFI Section	Page Allocation
Executive Summary & Science Overview	6 pages
Technical Implementation	12 pages*
Enabling Technology	3 pages
Facility and Science Operations	3 pages
Programmatics & Schedule	5 pages
Cost Section	Unlimited
Changes since Previous NRC Recommendation (if applicable)	4 pages

*Can increase by 2 pages for each extra instrument

Activities ranked in the 2000 "Astronomy and Astrophysics in the New Millennium" survey should provide up to four (4) additional pages describing the changes in the activity science goals, technical implementation, and/or estimated cost since AANM. We need to hear your explanation of changes that significantly affect the scientific return, the activity risk, and/or estimated cost of the activity, and the reasons for them.

NAA Cost Data Sheet

Last Saved: 07/28/09

Note: All monetary amounts are listed in $K 39849.6

Task Name: NAA
WBS Number: 6.03 **Acct #** 2920.XXXX.LM020

Name/Estimator: S Durand Phone: 505-835-7435
Basis of Estimate: Version Date: 15-Dec-08

Assigned Risk Factors:
Technical (1,2,3,4,6,8,10,15)
Cost (1,2,3,4,6,8,10,15)
Schedule (2,4,8)

Multipliers for Contingency:
Technical Multiplier: (2,4)
Cost Multiplier: (1,2)
Calc. Contingency.: 0.0%

	M&S	**Labor**	**NAA Totals**		
			M&S	**Labor**	
% Complete	0.0%	0.0%			
Budget	23944.0	15905.6	23944.0	0.0	Total Budget
PV					
Actual					
Earned Value	0.0	0.0	23944.0	0.0	Remaining $
SV	0.0	0.0	**SPI** #DIV/0!		
CV	0.0	0.0	**CPI** #DIV/0!		
	As of June 30, 2007		<1.0 = overrun		

Task Description: This WBS element
(Text for the WBS dictionary)

PLEASE NOTE:
THIS WORK SHEET SUMMARIZES AL OTHER WORKSHEETS IN THIS WBS CATEGORY.
DO NOT CHANGE OR DELETE ANY DATA ON THIS PAGE. ALSO, SEE NOTE BELOW.

Labor:

In Person Months

Employee Name	**SG**	**Job Desc**	**SS**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total FTE's**
Project Manager	1		ES	0.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	0.0	10.0
Assistant Manager	2		ES	0.0	12.0	12.0	3.0	0.0	0.0	12.0	12.0	12.0	12.0	0.0	0.0	6.3
Budget and Scheduler	3		ES	0.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	5.0
Project Scientist	1		ES	0.0	0.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	0.0	9.0
Scientist A	2		ES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	12.0	12.0	12.0	0.0	4.0
Scientist B	2		ES	0.0	0.0	0.0	0.0	0.0	0.0	12.0	12.0	12.0	12.0	12.0	0.0	5.0
Systems Engineer	2		ES	0.0	3.0	12.0	12.0	12.0	12.0	6.0	12.0	12.0	12.0	12.0	0.0	8.8
Engineer A	3		ES	0.0	0.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	0.0	9.0
Engineer B	3		ES	0.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	0.0	10.0
Engineer C	3		ES	0.0	0.0	0.0	0.0	12.0	12.0	12.0	12.0	12.0	12.0	0.0	0.0	6.0
Senior Digital Engineer	2		ES	0.0	0.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	0.0	0.0	8.0
Production Engineer	2		ES	0.0	0.0	0.0	0.0	0.0	0.0	12.0	12.0	12.0	12.0	0.0	0.0	4.0
Algorithm Scientist	2		ES	0.0	0.0	0.0	12.0	12.0	12.0	12.0	12.0	12.0	0.0	0.0	0.0	6.0
Algorithm Programmer	2		ES	0.0	0.0	0.0	0.0	8.0	12.0	12.0	12.0	12.0	0.0	0.0	0.0	4.7
Fiber Technician	3		ES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	12.0	12.0	0.0	0.0	3.0
Operator	4		ES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	6.0	6.0	6.0	0.0	2.0
HVAC Technician	3		ES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	12.0	12.0	0.0	0.0	3.0
Antenna Engineer	1		ES	0.0	0.0	0.0	0.0	0.0	12.0	12.0	12.0	12.0	12.0	0.0	0.0	5.0
Electrician	3		ES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	12.0	12.0	0.0	0.0	3.0
Technician A	3		ES	0.0	0.0	0.0	12.0	12.0	12.0	12.0	12.0	12.0	0.0	0.0	0.0	6.0
Technician B	3		ES	0.0	0.0	0.0	0.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	0.0	7.0
Technician C	3		ES	0.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	0.0	0.0	0.0	8.0
Technician D	3		ES	0.0	0.0	12.0	12.0	0.0	0.0	12.0	12.0	12.0	12.0	12.0	0.0	7.0
Technician E	4		ES	0.0	0.0	12.0	12.0	12.0	0.0	12.0	12.0	12.0	12.0	12.0	0.0	8.0
Post Doc A	3		ES	0.0	0.0	0.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	0.0	0.0	7.0
Post Doc B	3		ES	0.0	0.0	0.0	12.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
Post Doc C	3		ES	0.0	12.0	12.0	12.0	12.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0
Engineering Student A	5		ES	0.0	0.0	0.0	0.0	0.0	0.0	12.0	12.0	12.0	0.0	0.0	0.0	3.0
Engineering Student B	5		ES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	12.0	12.0	0.0	0.0	3.0
Buyer	4		ES	0.0	0.0	12.0	12.0	0.0	0.0	0.0	12.0	12.0	0.0	0.0	0.0	4.0
Labor Totals ($K):				0.0	558.9	1160.5	1407.9	1478.2	1557.6	1913.9	2404.6	2404.6	1956.6	1062.8	0.0	15905.6
TOTAL FTEs:				0.0	5.8	12.5	15.8	16.2	15.5	20.0	27.0	27.0	21.0	11.0	0.0	171.7
TOTAL EV FTEs:				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Off Budget FTEs:				0.0	5.8	12.5	15.8	16.2	15.5	20.0	27.0	27.0	21.0	11.0	0.0	171.7
TOTAL EV LABOR ($k):				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Materials:

In $K

	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	
Material Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
	0.0	30.0	50.0	70.0	60.0	60.0	460.0	160.0	30.0	20.0	10.0	0.0	950.0
	0.0	0.0	540.0	350.0	450.0	450.0	450.0	750.0	600.0	80.0	80.0	0.0	3750.0
	0.0	0.0	200.0	100.0	100.0	0.0	0.0	200.0	0.0	0.0	0.0	0.0	600.0
	0.0	0.0	100.0	300.0	200.0	0.0	0.0	400.0	300.0	0.0	0.0	0.0	1300.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	250.0	0.0	0.0	0.0	0.0	250.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	3.0	25.0	25.0	15.0	10.0	10.0	5.0	5.0	5.0	5.0	0.0	108.0
Materials Total ($K):	**0.0**	**33.0**	**915.0**	**845.0**	**825.0**	**520.0**	**920.0**	1765.0	935.0	105.0	95.0	0.0	6958.0

Contracts (Committed):

	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	
Contract Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
	0.0	0.0	600.0	200.0	100.0	0.0	0.0	2500.0	900.0	0.0	0.0	0.0	4300.0
	0.0	0.0	0.0	500.0	0.0	200.0	0.0	9600.0	0.0	0.0	0.0	0.0	10300.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Contracts Total ($K):	**0.0**	**0.0**	**600.0**	**700.0**	**100.0**	**200.0**	**0.0**	12100.0	900.0	0.0	0.0	0.0	14600.0

Contingency	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total Cost**
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2386.0
Cost:	0.0	0.0	65.0	170.5	144.0	322.5	161.0	1478.0	45.0	0.0	0.0	0.0	

NAA Cost Data Sheet

Last Save(07/28/09

Note: All monetary amounts are listed in $K 3247.3

Task Name: Project Management
WBS Number: 6.03.01 **Acct #**

Name/Estimator: S Durand
Phone: 505-835-7435
Basis of Estimate:
Version Date: 27-Jul-09

Assigned Risk Factors:
Technical
Cost
Schedule

Multipliers for Contingency:
Technical Multiplier:
Cost Multiplier:
Calc. Contingency.: $104K

	M&S	Labor	NAA Totals M&S	NAA Totals Labor	
% Complete	0.0%	0.0%			
Budget	349.0	2898.3	349.0	0.0	Total Budget
PV					
Actual					
Earned Value	0.0	0.0	349.0	0.0	Remaining $
SV	0.0	0.0	**SPI** #DIV/0!		
CV	0.0	0.0	**CPI** #DIV/0!		

As of June 30, 2007 <1.0 = overrun

Task Description: System engineering and project management will be handled by the Socorro Operations This includes the MeerKAT support and conceptual design
700+330=1030
(Text for the WBS dictiona

Labor: **In Person Months**

Employee Name	**SG**	**Job Desc**	**SS**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total FTE's**
Project Manager	1		ES		12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0		10.0
Assistant Manager	2		ES		12.0	12.0	3.0			12.0	12.0	12.0	12.0			6.3
Budget and Scheduler	3		ES		6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0		5.0
Project Scientist	1		ES													0.0
Scientist A	2		ES													0.0
Scientist B	2		ES													0.0
Systems Engineer	2		ES													0.0
Engineer A	3		ES													0.0
Engineer B	3		ES													0.0
Engineer C	3		ES													0.0
Senior Digital Engineer	2		ES													0.0
Production Engineer	2		ES													0.0
Algorithm Scientist	2		ES													0.0
Algorithm Programmer	2		ES													0.0
Fiber Technician	3		ES													0.0
Operator	4		ES													0.0
HVAC Technician	3		ES													0.0
Antenna Engineer	1		ES													0.0
Electrician	3		ES													0.0
Technician A	3		ES													0.0
Technician B	3		ES													0.0
Technician C	3		ES													0.0
Technician D	3		ES													0.0
Technician E	4		ES													0.0
Post Doc A	3		ES													0.0
Post Doc B	3		ES													0.0
Post Doc C	3		ES													0.0
Engineering Student A	5		ES													0.0
Engineering Student B	5		ES													0.0
Buyer	4		ES			12.0	12.0				12.0	12.0				4.0
Labor Totals ($K):				**0.0**	**311.5**	**360.4**	**277.9**	**201.6**	**201.6**	**311.5**	360.4	360.4	311.5	201.6	0.0	2898.3
TOTAL FTEs:				**0.0**	**2.5**	**3.5**	**2.8**	**1.5**	**1.5**	**2.5**	3.5	3.5	2.5	1.5	0.0	25.3
TOTAL EV FTEs:				**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
Off Budget FTEs:				**0.0**	**2.5**	**3.5**	**2.8**	**1.5**	**1.5**	**2.5**	3.5	3.5	2.5	1.5	0.0	25.3
TOTAL EV LABOR ($k):				**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0

Materials: **In $K**

	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	
Material Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
R&D, expendables, mgmt tools		30.0	50.0	20.0	10.0	10.0	10.0	10.0	30.0	20.0	10.0		200.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
Travel			5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0		45.0
Materials Total ($K):	**0.0**	**30.0**	**55.0**	**25.0**	**15.0**	**15.0**	**15.0**	15.0	35.0	25.0	15.0	0.0	245.0

Contracts (Committed):

	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	
Contract Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
													0.0
													0.0
													0.0
													0.0
													0.0
Contracts Total ($K):	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0

Contingency	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total Cost**
													104.0
Cost:	0.0	0.0	30.0	30.0	44.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

NAA Cost Data Sheet

Last Saved: 07/28/09

Note: All monetary amounts are listed in $K 2667.8

Task Name: Concept Study and Antenna Evaluation
WBS Number: 6.03.05 **Acct #**

Name/Estimator: S Durand
Phone: 505-835-7435
Basis of Estimate:
Version Date: 27-Jul-09

Assigned Risk Factors:
Technical
Cost
Schedule

Multipliers for Contingency:
Technical Multiplier:
Cost Multiplier:
Calc. Contingency.: $75.5K

	M&S	Labor			
			NAA Totals		
% Complete	0.0%	0.0%	**M&S**	**Labor**	
Budget	1238.5	1429.3	1238.5	0.0	Total Budget
PV					
Actual					
Earned Value	0.0	0.0	1238.5	0.0	Remaining $
SV	0.0	0.0	**SPI**	#DIV/0!	
CV	0.0	0.0	**CPI**	#DIV/0!	
	As of June 30, 2007		<1.0 = overrun		

Task Description: Test and Evaluate TDP1 and prototype antennas. 2320+330=2650
(Text for the WBS dictionary)

Labor: **In Person Months**

Employee Name	SG	Job Desc	SS	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total FTE's
Project Manager	1		ES													0.0
Assistant Manager	2		ES													0.0
Budget and Scheduler	3		ES													0.0
Project Scientist	1		ES			12.0	12.0	12.0	12.0							4.0
Scientist A	2		ES													0.0
Scientist B	2		ES													0.0
Systems Engineer	2		ES			9.0	9.0									1.5
Engineer A	3		ES													0.0
Engineer B	3		ES													0.0
Engineer C	3		ES													0.0
Senior Digital Engineer	2		ES													0.0
Production Engineer	2		ES													0.0
Algorithm Scientist	2		ES													0.0
Algorithm Programmer	2		ES													0.0
Fiber Technician	3		ES													0.0
Operator	4		ES													0.0
HVAC Technician	3		ES													0.0
Antenna Engineer	1		ES						12.0							1.0
Electrician	3		ES													0.0
Technician A	3		ES													0.0
Technician B	3		ES													0.0
Technician C	3		ES													0.0
Technician D	3		ES			12.0	12.0									2.0
Technician E	4		ES			12.0	12.0	12.0								3.0
Post Doc A	3		ES													0.0
Post Doc B	3		ES				12.0	12.0								2.0
Post Doc C	3		ES													0.0
Engineering Student A	5		ES													0.0
Engineering Student B	5		ES													0.0
Buyer	4		ES													0.0
Labor Totals ($K):				0.0	0.0	369.5	442.8	287.1	329.8	0.0	0.0	0.0	0.0	0.0	0.0	1429.3
TOTAL FTEs:				0.0	0.0	3.8	4.8	3.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5
TOTAL EV FTEs:				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Off Budget FTEs:				0.0	0.0	3.8	4.8	3.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5
TOTAL EV LABOR ($k):				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Materials: **In $K**

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Material Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
													0.0
Temporary LO/IF, DTS,			440.0	100.0									540.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
Travel		3.0	10.0	10.0									23.0
Materials Total ($K):	0.0	3.0	450.0	110.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	563.0

Contracts (Committed):

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Contract Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
A&E Contract			400.0										400.0
Antenna Manufacturer Partners						200.0							200.0
													0.0
													0.0
													0.0
Contracts Total ($K):	0.0	0.0	400.0	0.0	0.0	200.0	0.0	0.0	0.0	0.0	0.0	0.0	600.0

Contingency	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	**Total Cost**
													75.5
Cost:	0.0	0.0	35.0	40.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

NAA Cost Data Sheet

Last Saved: 07/28/09

Note: All monetary amounts are listed in $K 5230.5

Task Name: Digital signals and processing
WBS Number: 6.03.10 **Acct #**

Name/Estimator: S Durand
Basis of Estimate:

Phone: 505-835-7435
Version Date: 27-Jul-09

Assigned Risk Factors:
Technical
Cost
Schedule

Multipliers for Contingency:
Technical Multiplier:
Cost Multiplier:
Calc. Contingency.: $262.5K

	M&S	Labor	NAA Totals M&S	NAA Totals Labor	
% Complete	0.0%	0.0%			
Budget	2802.5	2428.0	2802.5	0.0	Total Budget
PV					
Actual					
Earned Value	0.0	0.0	2802.5	0.0	Remaining $
SV	0.0	0.0	**SPI** #DIV/0!		
CV	0.0	0.0	**CPI** #DIV/0!		

As of June 30, 2007 <1.0 = overrun

Task Description: Data transmission and Digital signal processing - samplers 3280+2190=5470
(Text for the WBS dictionary)

Labor: **In Person Months**

Employee Name	SG	Job Desc	SS	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total FTE's
Project Manager	1		ES													0.0
Assistant Manager	2		ES													0.0
Budget and Scheduler	3		ES													0.0
Project Scientist	1		ES													0.0
Scientist A	2		ES													0.0
Scientist B	2		ES													0.0
Systems Engineer	2		ES		3.0	3.0	3.0	12.0	12.0							2.8
Engineer A	3		ES													0.0
Engineer B	3		ES		12.0	12.0	12.0	12.0	12.0	12.0	12.0					7.0
Engineer C	3		ES													0.0
Senior Digital Engineer	2		ES			12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0			8.0
Production Engineer	2		ES													0.0
Algorithm Scientist	2		ES													0.0
Algorithm Programmer	2		ES													0.0
Fiber Technician	3		ES													0.0
Operator	4		ES													0.0
HVAC Technician	3		ES													0.0
Antenna Engineer	1		ES													0.0
Electrician	3		ES													0.0
Technician A	3		ES													0.0
Technician B	3		ES													0.0
Technician C	3		ES		12.0	12.0	12.0	12.0	12.0	12.0	12.0					7.0
Technician D	3		ES													0.0
Technician E	4		ES													0.0
Post Doc A	3		ES													0.0
Post Doc B	3		ES													0.0
Post Doc C	3		ES		12.0	12.0	12.0									3.0
Engineering Student A	5		ES													0.0
Engineering Student B	5		ES													0.0
Buyer	4		ES													0.0
Labor Totals ($K):				0.0	247.4	357.3	357.3	366.5	366.5	256.5	256.5	109.9	109.9	0.0	0.0	2428.0
TOTAL FTEs:				0.0	3.3	4.3	4.3	4.0	4.0	3.0	3.0	1.0	1.0	0.0	0.0	27.8
TOTAL EV FTEs:				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Off Budget FTEs:				0.0	3.3	4.3	4.3	4.0	4.0	3.0	3.0	1.0	1.0	0.0	0.0	27.8
TOTAL EV LABOR ($k):				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Materials: **In $K**

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Material Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
													0.0
Hardware			100.0	200.0	300.0	200.0	200.0	100.0					1100.0
Software tools			200.0	100.0									300.0
Samplers and PC boards			100.0	300.0	200.0								600.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
Travel			10.0	10.0	10.0	5.0	5.0						40.0
Materials Total ($K):	0.0	0.0	410.0	610.0	510.0	205.0	205.0	100.0	0.0	0.0	0.0	0.0	2040.0

Contracts (Committed):

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Contract Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
Unviversity and industry			200.0	200.0	100.0								500.0
													0.0
													0.0
													0.0
													0.0
Contracts Total ($K):	0.0	0.0	200.0	200.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	500.0

Contingency	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	**Total Cost**
													262.5
Cost:	0.0	0.0	0.0	100.0	100.0	62.5	0.0	0.0	0.0	0.0	0.0	0.0	

NAA Cost Data Sheet Last Saved: 07/28/09 Note: All monetary amounts are listed in $K 1923.9

Task Name: Operations and Maintenance
WBS Number: 6.03.11 **Acct #**

Name/Estimator: S Durand Phone: 505-835-7435
Basis of Estimate: Version Date: 27-Jul-09

Assigned Risk Factors:
Technical
Cost
Schedule

Multipliers for Contingency:
Technical Multiplier:
Cost Multiplier:
Calc. Contingency.: $45K

	M&S	Labor		NAA Totals	
% Complete	0.0%	0.0%	**M&S**	**Labor**	
Budget	405.0	1518.9	405.0	0.0	Total Budget
PV					
Actual					
Earned Value	0.0	0.0	405.0	0.0	Remaining $
SV	0.0	0.0	**SPI**	#DIV/0!	
CV	0.0	0.0	**CPI**	#DIV/0!	

As of June 30, 2007 <1.0 = overrun

Task Description: Operations and Mauintenance
(Text for the WBS dictionary)

Labor: **In Person Months**

Employee Name	SG	Job Desc	SS	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total FTE's
Project Manager	1		ES													0.0
Assistant Manager	2		ES													0.0
Budget and Scheduler	3		ES													0.0
Project Scientist	1		ES													0.0
Scientist A	2		ES								12.0	12.0	12.0	12.0		4.0
Scientist B	2		ES													0.0
Systems Engineer	2		ES								3.0	3.0	3.0	3.0		1.0
Engineer A	3		ES										12.0	12.0		2.0
Engineer B	3		ES									12.0	12.0	12.0		3.0
Engineer C	3		ES													0.0
Senior Digital Engineer	2		ES													0.0
Production Engineer	2		ES													0.0
Algorithm Scientist	2		ES													0.0
Algorithm Programmer	2		ES													0.0
Fiber Technician	3		ES													0.0
Operator	4		ES								6.0	6.0	6.0	6.0		2.0
HVAC Technician	3		ES													0.0
Antenna Engineer	1		ES													0.0
Electrician	3		ES													0.0
Technician A	3		ES													0.0
Technician B	3		ES								6.0	12.0	12.0	12.0		3.5
Technician C	3		ES													0.0
Technician D	3		ES													0.0
Technician E	4		ES													0.0
Post Doc A	3		ES								6.0	12.0	12.0			2.5
Post Doc B	3		ES													0.0
Post Doc C	3		ES													0.0
Engineering Student A	5		ES													0.0
Engineering Student B	5		ES									12.0	12.0			2.0
Buyer	4		ES													0.0
Labor Totals ($K):				**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	235.2	414.3	487.6	381.8	0.0	1518.9
TOTAL FTEs:				**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	2.8	5.8	6.8	4.8	0.0	20.0
TOTAL EV FTEs:				**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
Off Budget FTEs:				**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	2.8	5.8	6.8	4.8	0.0	20.0
TOTAL EV LABOR ($k):				**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0

Materials: **In $K**

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Material Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
													0.0
Parts and supplies								100.0	100.0	80.0	80.0		360.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
Materials Total ($K):	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	100.0	100.0	80.0	80.0	0.0	360.0

Contracts (Committed):

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Contract Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
													0.0
													0.0
													0.0
													0.0
													0.0
Contracts Total ($K):	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0

Contingency	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total Cost**
													45.0
Cost:	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.0	0.0	0.0	0.0	

NAA Cost Data Sheet

Last Saved: 07/28/09

Note: All monetary amounts are listed in $K 1297.4

Task Name: LO systems and Montior & Control
WBS Number: 6.03.12 **Acct #**

Name/Estimator: S Durand
Phone: 505-835-7435
Basis of Estimate:
Version Date: 27-Jul-09

Assigned Risk Factors:
Technical
Cost
Schedule

Multipliers for Contingency:
Technical Multiplier:
Cost Multiplier:
Calc. Contingency.: $121K

	M&S	Labor	NAA Totals M&S	NAA Totals Labor	
% Complete	0.0%	0.0%			
Budget	821.0	476.4	821.0	0.0	Total Budget
PV					
Actual					
Earned Value	0.0	0.0	821.0	0.0	Remaining $
SV	0.0	0.0	**SPI**	#DIV/0!	
CV	0.0	0.0	**CPI**	#DIV/0!	

As of June 30, 2007 <1.0 = overrun

Task Description: Montior and Control 1360
(Text for the WBS dictionary)

Labor: **In Person Months**

Employee Name	**SG**	**Job Desc**	**SS**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total FTE's**
Project Manager	1		ES													0.0
Assistant Manager	2		ES													0.0
Budget and Scheduler	3		ES													0.0
Project Scientist	1		ES													0.0
Scientist A	2		ES													0.0
Scientist B	2		ES													0.0
Systems Engineer	2		ES													0.0
Engineer A	3		ES													0.0
Engineer B	3		ES													0.0
Engineer C	3		ES					12.0	12.0	6.0	6.0					3.0
Senior Digital Engineer	2		ES													0.0
Production Engineer	2		ES													0.0
Algorithm Scientist	2		ES													0.0
Algorithm Programmer	2		ES													0.0
Fiber Technician	3		ES													0.0
Operator	4		ES													0.0
HVAC Technician	3		ES													0.0
Antenna Engineer	1		ES													0.0
Electrician	3		ES													0.0
Technician A	3		ES													0.0
Technician B	3		ES					12.0	12.0	12.0	6.0					3.5
Technician C	3		ES													0.0
Technician D	3		ES													0.0
Technician E	4		ES													0.0
Post Doc A	3		ES													0.0
Post Doc B	3		ES													0.0
Post Doc C	3		ES													0.0
Engineering Student A	5		ES													0.0
Engineering Student B	5		ES													0.0
Buyer	4		ES													0.0
Labor Totals ($K):				0.0	0.0	0.0	0.0	146.6	146.6	109.9	73.3	0.0	0.0	0.0	0.0	476.4
TOTAL FTEs:				0.0	0.0	0.0	0.0	2.0	2.0	1.5	1.0	0.0	0.0	0.0	0.0	6.5
TOTAL EV FTEs:				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Off Budget FTEs:				0.0	0.0	0.0	0.0	2.0	2.0	1.5	1.0	0.0	0.0	0.0	0.0	6.5
TOTAL EV LABOR ($k):				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Materials: **In $K**

	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	
Material Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
													0.0
Hardware					100.0	200.0	200.0	100.0					600.0
Software tools					100.0								100.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
Travel													0.0
Materials Total ($K):	**0.0**	**0.0**	**0.0**	**0.0**	**200.0**	**200.0**	**200.0**	100.0	0.0	0.0	0.0	0.0	700.0

Contracts (Committed):

	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	
Contract Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
													0.0
													0.0
													0.0
													0.0
													0.0
Contracts Total ($K):	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0

Contingency	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total Cost**
													121.0
Cost:	0.0	0.0	0.0	0.0	0.0	60.0	61.0	0.0	0.0	0.0	0.0	0.0	

NAA Cost Data Sheet Last Saved: 07/28/09 Note: All monetary amounts are listed in $K 2350.6

Task Name:	Wideband Feeds and Recievers		
WBS Number:	6.03.14	**Acct #**	
Name/Estimator:	S Durand	Phone:	505-835-7435
Basis of Estimate:		Version Date:	27-Jul-09
Assigned Risk Factors:		**Multipliers for Contingency:**	
Technical		Technical Multiplier:	
Cost		Cost Multiplier:	
Schedule		Calc. Contingency.:	$300K

	M&S	**Labor**		**NAA Totals**	
% Complete	0.0%	0.0%	**M&S**	**Labor**	
Budget	1300.0	1050.6	1300.0	0.0	Total Budget
PV					
Actual					
Earned Value	0.0	0.0	1300.0	0.0	Remaining $
SV	0.0	0.0	**SPI**	#DIV/0!	
CV	0.0	0.0	**CPI**	#DIV/0!	
	As of June 30, 2007			<1.0 = overrun	

Task Description: Wideband Feeds and Recievers 2320
(Text for the WBS dictionary)

Labor: **In Person Months**

Employee Name	SG	Job Desc	SS	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total FTE's
Project Manager	1		ES													0.0
Assistant Manager	2		ES													0.0
Budget and Scheduler	3		ES													0.0
Project Scientist	1		ES													0.0
Scientist A	2		ES													0.0
Scientist B	2		ES													0.0
Systems Engineer	2		ES													0.0
Engineer A	3		ES			12.0	12.0	12.0	12.0	12.0	12.0	12.0				7.0
Engineer B	3		ES													0.0
Engineer C	3		ES													0.0
Senior Digital Engineer	2		ES													0.0
Production Engineer	2		ES													0.0
Algorithm Scientist	2		ES													0.0
Algorithm Programmer	2		ES													0.0
Fiber Technician	3		ES													0.0
Operator	4		ES													0.0
HVAC Technician	3		ES													0.0
Antenna Engineer	1		ES													0.0
Electrician	3		ES													0.0
Technician A	3		ES				12.0	12.0	12.0	12.0	12.0	12.0				6.0
Technician B	3		ES													0.0
Technician C	3		ES													0.0
Technician D	3		ES													0.0
Technician E	4		ES													0.0
Post Doc A	3		ES													0.0
Post Doc B	3		ES													0.0
Post Doc C	3		ES													0.0
Engineering Student A	5		ES							12.0	12.0	12.0				3.0
Engineering Student B	5		ES													0.0
Buyer	4		ES													0.0
Labor Totals ($K):				**0.0**	**0.0**	**73.3**	**146.6**	**146.6**	**146.6**	**179.2**	179.2	179.2	0.0	0.0	0.0	1050.6
TOTAL FTEs:				**0.0**	**0.0**	**1.0**	**2.0**	**2.0**	**2.0**	**3.0**	3.0	3.0	0.0	0.0	0.0	16.0
TOTAL EV FTEs:				**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
Off Budget FTEs:				**0.0**	**0.0**	**1.0**	**2.0**	**2.0**	**2.0**	**3.0**	3.0	3.0	0.0	0.0	0.0	16.0
TOTAL EV LABOR ($k):				**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0

Materials: **In $K**

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Material Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
Receiver prototype A				50.0	50.0	50.0	50.0	50.0					250.0
Receiver prototype B				50.0	50.0	50.0	50.0	50.0					250.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
Materials Total ($K):	**0.0**	**0.0**	**0.0**	**100.0**	**100.0**	**100.0**	**100.0**	100.0	0.0	0.0	0.0	0.0	500.0

Contracts (Committed):

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Contract Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
													0.0
Subcontracts				500.0									500.0
													0.0
													0.0
													0.0
Contracts Total ($K):	**0.0**	**0.0**	**0.0**	**500.0**	**0.0**	**0.0**	**0.0**	0.0	0.0	0.0	0.0	0.0	500.0

Contingency	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	**Total Cost**
													300.0
Cost:	0.0	0.0	0.0	0.0	0.0	200.0	100.0	0.0	0.0	0.0	0.0	0.0	

NAA Cost Data Sheet

Last Saved: 07/28/09

Note: All monetary amounts are listed in $K 1649.2

Task Name: Algorithms and Computation and Software
WBS Number: 6.03.15 **Acct #**

Name/Estimator: S Durand Phone: 505-835-7435
Basis of Estimate: Version Date: 27-Jul-09

Assigned Risk Factors:
Technical
Cost
Schedule

Multipliers for Contingency:
Technical Multiplier:
Cost Multiplier:
Calc. Contingency.: 0

	M&S	Labor	M&S	Labor	
			NAA Totals		
% Complete	0.0%	0.0%	**M&S**	**Labor**	
Budget	0.0	1649.2	0.0	0.0	Total Budget
PV					
Actual					
Earned Value	0.0	0.0	0.0	0.0	Remaining $
SV	0.0	0.0	**SPI**	#DIV/0!	
CV	0.0	0.0	**CPI**	#DIV/0!	

As of June 30, 2007 <1.0 = overrun

Task Description: Algorithms and Computation and Software 1650
(Text for the WBS dictionary)

Labor: **In Person Months**

Employee Name	SG	Job Desc	SS	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total FTE's
Project Manager	1		ES													0.0
Assistant Manager	2		ES													0.0
Budget and Scheduler	3		ES													0.0
Project Scientist	1		ES													0.0
Scientist A	2		ES													0.0
Scientist B	2		ES													0.0
Systems Engineer	2		ES													0.0
Engineer A	3		ES													0.0
Engineer B	3		ES													0.0
Engineer C	3		ES													0.0
Senior Digital Engineer	2		ES													0.0
Production Engineer	2		ES													0.0
Algorithm Scientist	2		ES				12.0	12.0	12.0	12.0	12.0	12.0				6.0
Algorithm Programmer	2		ES					8.0	12.0	12.0	12.0	12.0				4.7
Fiber Technician	3		ES													0.0
Operator	4		ES													0.0
HVAC Technician	3		ES													0.0
Antenna Engineer	1		ES													0.0
Electrician	3		ES													0.0
Technician A	3		ES													0.0
Technician B	3		ES													0.0
Technician C	3		ES													0.0
Technician D	3		ES													0.0
Technician E	4		ES													0.0
Post Doc A	3		ES				12.0	12.0	12.0	12.0	6.0					4.5
Post Doc B	3		ES													0.0
Post Doc C	3		ES					12.0	12.0							2.0
Engineering Student A	5		ES													0.0
Engineering Student B	5		ES													0.0
Buyer	4		ES													0.0
Labor Totals ($K):				0.0	0.0	0.0	183.2	329.8	366.5	293.2	256.5	219.9	0.0	0.0	0.0	1649.2
TOTAL FTEs:				0.0	0.0	0.0	2.0	3.7	4.0	3.0	2.5	2.0	0.0	0.0	0.0	17.2
TOTAL EV FTEs:				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Off Budget FTEs:				0.0	0.0	0.0	2.0	3.7	4.0	3.0	2.5	2.0	0.0	0.0	0.0	17.2
TOTAL EV LABOR ($k):				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Materials: **In $K**

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Material Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
Materials Total ($K):	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Contracts (Committed):

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Contract Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
													0.0
													0.0
													0.0
													0.0
													0.0
Contracts Total ($K):	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Contingency		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	**Total Cost**
Sub total	0.00													0.0
Cost:		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

NAA Cost Data Sheet

Last Saved: 07/28/09

Note: All monetary amounts are listed in $K 21482.9

Task Name: Prototype Antenna Station
WBS Number: 6.03.20 **Acct #**

Name/Estimator: S Durand
Basis of Estimate: TDP
Phone: 505-835-7435
Version Date: 27-Jul-09

Assigned Risk Factors:
Technical
Cost
Schedule

Multipliers for Contingency:
Technical Multiplier:
Cost Multiplier:
Calc. Contingency.: $1478K

	M&S	Labor	NAA Totals M&S	NAA Totals Labor	
% Complete	0.0%	0.0%			
Budget	17028.0	4454.9	17028.0	0.0	Total Budget
PV					
Actual					
Earned Value	0.0	0.0	17028.0	0.0	Remaining $
SV	0.0	0.0	**SPI** #DIV/0!		
CV	0.0	0.0	**CPI** #DIV/0!		
As of June 30, 2007			<1.0 = overrun		

Task Description: Prototype Antenna Station at the VLA. Includes testing and modifications. 20 installed antennas, fiber connections to WIDAR, Completed in 2019 17800
(Text for the WBS dictionary)

Labor: **In Person Months**

Employee Name	SG	Job Desc	SS	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total FTE's
Project Manager	1		ES													0.0
Assistant Manager	2		ES													0.0
Budget and Scheduler	3		ES													0.0
Project Scientist	1		ES							12.0	12.0	12.0	12.0	12.0		5.0
Scientist A	2		ES													0.0
Scientist B	2		ES							12.0	12.0	12.0	12.0	12.0		5.0
Systems Engineer	2		ES							6.0	9.0	9.0	9.0	9.0		3.5
Engineer A	3		ES													0.0
Engineer B	3		ES													0.0
Engineer C	3		ES							6.0	6.0	12.0	12.0			3.0
Senior Digital Engineer	2		ES													0.0
Production Engineer	2		ES							12.0	12.0	12.0	12.0			4.0
Algorithm Scientist	2		ES													0.0
Algorithm Programmer	2		ES													0.0
Fiber Technician	3		ES								12.0	12.0	12.0			3.0
Operator	4		ES													0.0
HVAC Technician	3		ES								12.0	12.0	12.0			3.0
Antenna Engineer	1		ES							12.0	12.0	12.0	12.0			4.0
Electrician	3		ES								12.0	12.0	12.0			3.0
Technician A	3		ES													0.0
Technician B	3		ES													0.0
Technician C	3		ES									12.0				1.0
Technician D	3		ES							12.0	12.0	12.0	12.0	12.0		5.0
Technician E	4		ES							12.0	12.0	12.0	12.0	12.0		5.0
Post Doc A	3		ES													0.0
Post Doc B	3		ES													0.0
Post Doc C	3		ES													0.0
Engineering Student A	5		ES													0.0
Engineering Student B	5		ES								12.0					1.0
Buyer	4		ES													0.0
Labor Totals ($K):				0.0	0.0	0.0	0.0	0.0	0.0	763.5	1043.5	1120.8	1047.5	479.5	0.0	4454.9
TOTAL FTEs:				0.0	0.0	0.0	0.0	0.0	0.0	7.0	11.3	11.8	10.8	4.8	0.0	45.5
TOTAL EV FTEs:				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Off Budget FTEs:				0.0	0.0	0.0	0.0	0.0	0.0	7.0	11.3	11.8	10.8	4.8	0.0	45.5
TOTAL EV LABOR ($k):				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Materials: **In $K**

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Material Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
Receivers and feeds							400.0	100.0					500.0
DTS								400.0	500.0				900.0
Servo and CRYO								200.0					200.0
LO								400.0	300.0				700.0
													0.0
Site Power Upgrde								250.0					250.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
													0.0
Materials Total ($K):	0.0	0.0	0.0	0.0	0.0	0.0	400.0	1350.0	800.0	0.0	0.0	0.0	2550.0

Contracts (Committed):

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Contract Description:	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	**Total Cost**
A&E Contractor $150K/foundation plus Power								2500.0	900.0				3400.0
Antenna Contractor								9600.0					9600.0
													0.0
													0.0
													0.0
Contracts Total ($K):	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12100.0	900.0	0.0	0.0	0.0	######

Contingency	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	**Total Cost**
													1478.0
Cost:	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1478.0	0.0	0.0	0.0	0.0	

Project Management
RISK ESTIMATES

Risk ID#	WBS	Owner	Risk Description	Trigger	Probability	Impact				Action	Probability Score	Cost Impact Score	Schedule Impact Score	Risk Exposure
						Cost Impact	Sched Impact	Contingency ($k)	Remarks					
1	6.03.01		More Power CAD/CAE software is required	Present CAD/CAE software not up to task	20%	500.0	20.0	104.0		Purchase new CAD/CAE Software	**2**	**8**	**1**	**Medium**
				Totals	**20%**	**500.0**	**20.0**	**104.0**						

Conceptual Design and Antenna Evaluation
RISK ESTIMATES

Risk ID#	WBS	Owner	Risk Description	Trigger	Probability	Impact				Action	Probability Score	Cost Impact Score	Schedule Impact Score	Risk Exposure
						Cost Impact	Sched Impact	Contingency ($k)	Remarks					
1	6.03.05		Insufficeint EVLA spare hardware to perform tests	More than 2 antennas are submitted for evaluation	30%	100.0	50.0	45.0		Build addition copies of EVLA LO Hardware	**3**	**6**	**4**	**High**
2	6.03.05		Antennas don't have comon pad interface	An antenna design is submitted for evaluation after the pads are constructed that has a different pad interface	20%	50.0	10.0	12.0		Pad Adapter must be designed and fabricated	**2**	**4**	**1**	**Medium**
3	6.03.05		Antennas don't have a common electrical power requirement	Antennas don't have a common electrical power requirement	30%	20.0	5.0	7.5		Specify, purchase and install transformer.	**3**	**1**	**1**	**Low**
4	6.03.05		NAA-PAS System Design	System Design fails to meet requiremtns	10%	10.0	100.0	11.0		Redo system Design	**1**	**1**	**6**	**Low**
				Totals	**22%**	**180.0**	**165.0**	**75.5**						

Digital Development
RISK ESTIMATES

						Impact								
Risk ID#	**WBS**	**Owner**	**Risk Description**	**Trigger**	**Probability**	**Cost Impact**	**Sched Impact**	**Contingency ($k)**	**Remarks**	**Action**	**Probability Score**	**Cost Impact Score**	**Schedule Impact Score**	**Risk Exposure**
1	6.03.10		Must Use 10 Gbps links	100 Gbps class linls unsucessful	10%	100.0	50.0	15.0	Development cost	Utilize more expensive EVLA/ALMA 10 Gbps hardware	**1**	**6**	**4**	**Medium**
2	6.03.10		DTS PCB Iteration	Respin of a major DTS PCB is required	50%	50.0	25.0	37.5		Respin major PCB	**4**	**4**	**1**	**Medium**
3	6.03.10		2nd DTS PCB Iteration	Respin of a second major DTS PCB is required	25%	50.0	25.0	18.8		Respin major PCB	**3**	**4**	**1**	**Medium**
4	6.03.10		3rd DTS PCB Iteration	Respin of a third major DTS PCB is required	10%	50.0	25.0	7.5		Respin major PCB	**1**	**4**	**1**	**Low**
5	6.03.10		Iteration of Digitizer chip is required	1'st prototype of a custom digitizer chip fails	20%	500.0	100.0	120.0		Respin of custom chip is required	**2**	**8**	**6**	**Medium**
6	6.03.10		Digitizer PCB Iteration	Respin of a major Digitizer PCB is required	50%	50.0	25.0	37.5		Respin major PCB	**4**	**4**	**1**	**Medium**
1	6.03.10		2nd Digitizer PCB Iteration	Respin of a 2nd major Digitizer PCB is required	25%	50.0	25.0	18.8		Respin major PCB	**3**	**4**	**1**	**Medium**
8	6.03.10		3rd Digitizer PCB Iteration	Respin of a 3rd major Digitizer PCB is required	10%	50.0	25.0	7.5		Respin major PCB	**1**	**4**	**1**	**Low**
				Totals	**22%**	**900.0**	**300.0**	**262.5**						

Operations
RISK ESTIMATES

Risk ID#	WBS	Owner	Risk Description	Trigger	Probability	Impact				Action	Probability Score	Cost Impact Score	Schedule Impact Score	Risk Exposure
						Cost Impact	Sched Impact	Contingency ($k)	Remarks					
1	6.03.11		Unknow maintenance costs	Antenas cost more to maintain than anticipated	20%	150.0	75.0	45.0		Additional materials and/or labor are required	**2**	**6**	**4**	**Medium**
				Totals	**20%**	**150.0**	**75.0**	**45.0**						

LO and MC System
RISK ESTIMATES

Risk ID#	WBS	Owner	Risk Description	Trigger	Probability	Impact Cost Impact	Sched Impact	Contingency ($k)	Remarks	Action	Probability Score	Cost Impact Score	Schedule Impact Score	Risk Exposure
1	6.03.12		Antenna M&C Computer	If it is determined that a computer separate from the ACU is needed to run antenna electronics	20%	20.0	10.0	6.0	Development cost	Separate computing hardware must be procured for this function	**2**	**1**	**1**	**Low**
2	6.03.12		Need YIG/PLL Synthesizer	Digital Synthesizer development unsucessful	10%	200.0	100.0	30.0	Development cost	Need to use modified EVLA L301 synthesizer design	**1**	**6**	**6**	**Medium**
3	6.03.12		Need Additional downconverters	3:1 BW receiver development fails causing switch to 2:1 BW designs	10%	250.0	100.0	35.0		Build additional Downconverters for extra receivers	**1**	**6**	**6**	**Medium**
4	6.03.12		Integrated LO Design respin	Respin of integrated LO hardware design is required	10%	200.0	100.0	30.0		Respin LO hardware design	**1**	**6**	**6**	**Medium**
5	6.03.12		EVLA LO Design required	Integrated LO development fails	10%	100.0	100.0	20.0		Need to adapt more expensive EVLA designs	**1**	**6**	**6**	**Medium**
				Totals	**10%**	**770.0**	**410.0**	**121.0**						

Front End Development
RISK ESTIMATES

Risk ID#	WBS	Owner	Risk Description	Trigger	Probability	Impact Cost Impact	Sched Impact	Contingency ($k)	Remarks	Action	Probability Score	Cost Impact Score	Schedule Impact Score	Risk Exposure
1	6.03.14		2:1 BW Receivers	3:1 BW feed/receiver development is unsuccessful	10%	1,000.0	300.0	130.0	Development cost	Use 2:1 BW EVLA style receivers with different feeds	**1**	**8**	**8**	**Medium**
2	6.03.14		Cryogenics	Low Cost Cryogenics development unsucessful	10%	1,000.0	300.0	130.0	Development Costs	Use EVLA style Cryogenics	**1**	**8**	**8**	**Medium**
3	6.03.14		LNA Design Iteration	1'st LNA design prototype fails	10%	300.0	100.0	40.0		Respin LNA Design	**1**	**8**	**6**	**Medium**
				Totals	**10%**	**2,300.0**	**700.0**	**300.0**						

Software
RISK ESTIMATES

Risk ID#	WBS	Owner	Risk Description	Trigger	Probability	Impact Cost Impact	Impact Sched Impact	Impact Contingency ($k)	Impact Remarks	Action	Probability Score	Cost Impact Score	Schedule Impact Score	Risk Exposure
1	6.03.15				0%	0.0	0.0	0.0			1	1	1	Low
				Totals	#DIV/0!	0.0	0.0	0.0						

Prototype Antenna Station
RISK ESTIMATES

Risk ID#	WBS	Owner	Risk Description	Trigger	Probability	Impact				Action	Probability Score	Cost Impact Score	Schedule Impact Score	Risk Exposure
						Cost Impact	Sched Impact	Contingency ($k)	Remarks					
1	6.03.20		Higher Antenna Cost	Antenas cannot be built to project spec for $600K per unit	10%	9,600.0	1,000.0	1,060.0	Cost is for engineering redesign	Double Antenna Cost - reduce antenna quantity to 10	**1**	**8**	**8**	**Medium**
2	6.03.20		Need YIG/PLL Synthesizer	Digital Synthesizer development unsuccessful	10%	200.0	100.0	30.0	Production costs	Need to use modified EVLA L301 synthesizer design	**1**	**6**	**6**	**Medium**
3	6.03.20		2:1 BW Receivers	3:1 BW feed/receiver development is unsuccessful	10%	1,000.0	200.0	120.0	Production costs	Use 2:1 BW EVLA style receivers with different feeds	**1**	**8**	**6**	**Medium**
4	6.03.20		Antenna M&C Computer	If it is determined that a computer separate from the ACU is needed to run antenna electronics	20%	40.0	25.0	13.0	Production costs	Separate computing hardware must be procured for this function	**2**	**1**	**1**	**Low**
5	6.03.20		Must Use 10 Gbps links	100 Gbps class linls unsuccessful	10%	1,000.0	200.0	120.0	Production costs	Utilize more expensive EVLA/ALMA 10 Gbps hardware	**1**	**8**	**6**	**Low**
5	6.03.20		EVLA LO Design required	Integrated LO development fails	10%	200.0	50.0	25.0	Production costs	Utilize more expensive EVLA hardware	**1**	**6**	**4**	**Low**
6	6.03.20		Cryogenics	Low Cost Cryogenics development unsuccessful	10%	1,000.0	100.0	110.0	Production Costs	Use EVLA style Cryogenics	**1**	**8**	**6**	**Medium**
				Totals	**10%**	**13,040.0**	**1,675.0**	**1,478.0**						